AMOS

Australian Meteorological & Oceanographic Society

Book of Abstracts

AMOS 18th National Conference

Connections in the Climate System

UNSW, 31 Jan - 3 Feb 2012

AMOS 18th Annual Conference
Connections in the Climate System

31st January – 3rd February 2012

General Information, Programme and Abstracts Handbook

Conference Convener
Jason Evans

AMOS Annual Conference 2012
Connections in the Climate System
Connections between * physical components of the system * time scales * spatial scales * biophysical & socio-economic systems
University of New South Wales , 31 Jan to 3 Feb 2012

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Front cover image of Sydney Harbour Bridge by Christopher Chan (www.christopher-chan.com)

Welcome

AMOS Annual Conference 2012
Connections in the Climate System
John Niland Scientia Building, UNSW, Sydney

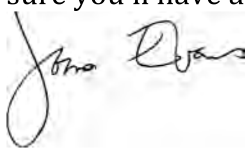
Welcome to the 2012 Australian Meteorology and Oceanography Society Annual Conference. The guiding theme for AMOS 2012 is Connections in the Climate System. The conference will explore connections between physical components of the system, time scales, spatial scales as well as biophysical and socio-economic systems. With so many interesting problems existing across traditional disciplinary boundaries it seems timely to focus on the connections between them for a moment.

During this 3.5 day conference more than 180 oral presentations and 150 poster presentations will be made across 3 general and 15 special sessions. The conference theme, Connections in the Climate System, is represented in the wide array of special sessions covering topics including: Hydroclimate of the Murray-Darling Basin; Natural Hazards, Fire weather and Tsunamis; covering regions from the Tropical Pacific to the Southern Ocean; looking into the past Climate of the last 2000 years; and into the future with a session on Renewable Energy, amongst many others.

Each day of the conference begins with talks by our plenary speakers which will cover various topics: ocean observations (Dr Susan Wijffels, CSIRO), palaeoclimate (Prof. Tim Bralower, Penn State, USA), climate change detection and attribution (Dr. Nathan Gillet, CCCMA, Canada), remote sensing of the global hydrological cycle (Prof. Chris Kummerow, Colorado State, USA), and atmospheric dynamics (Prof. Paul O'Gorman, MIT, USA). Plenary talks will also be given by the recently awarded Uwe Radok winner for best PhD Thesis in 2010 – Dr Jan Zika who will present a new perspective on ocean circulation, and the Priestley medal winner – Dr Lisa Alexander who will be discussing observational products for the analysis of temperature and precipitation extremes. There should be something for everyone.

I would like to thank our sponsors. Foremost our gold sponsor the ARC Centre of Excellence for Climate System Science who made it possible to bring so many great plenary speakers to the conference. Our silver sponsors: the NSW Office of Environment and Heritage; the Murray-Darling Basin Authority and the Bureau of Meteorology. And our bronze sponsor CSIRO. The generosity of these organisations allows us to organise a conference everyone can enjoy. I also want to thank everyone on the local organising committee and the program committee. The work they have done really makes the conference successful and I could not have put the conference together without them.

Sydney is one of the world's best cities (according to my personal survey!) so I hope you get the chance to explore while you're here. The harbour is a beautiful setting for a city and you'll have the chance for some wonderful harbour views at the conference dinner at Luna Park. There are some great beaches, fantastic eateries and bars, and for a little culture there is an array of museums, art galleries and of course the Opera House. Whatever your preference, I'm sure you'll have a good time at the conference and in Sydney.



Jason Evans   Convener, AMOS 2012

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Bronze Sponsor

CSIRO

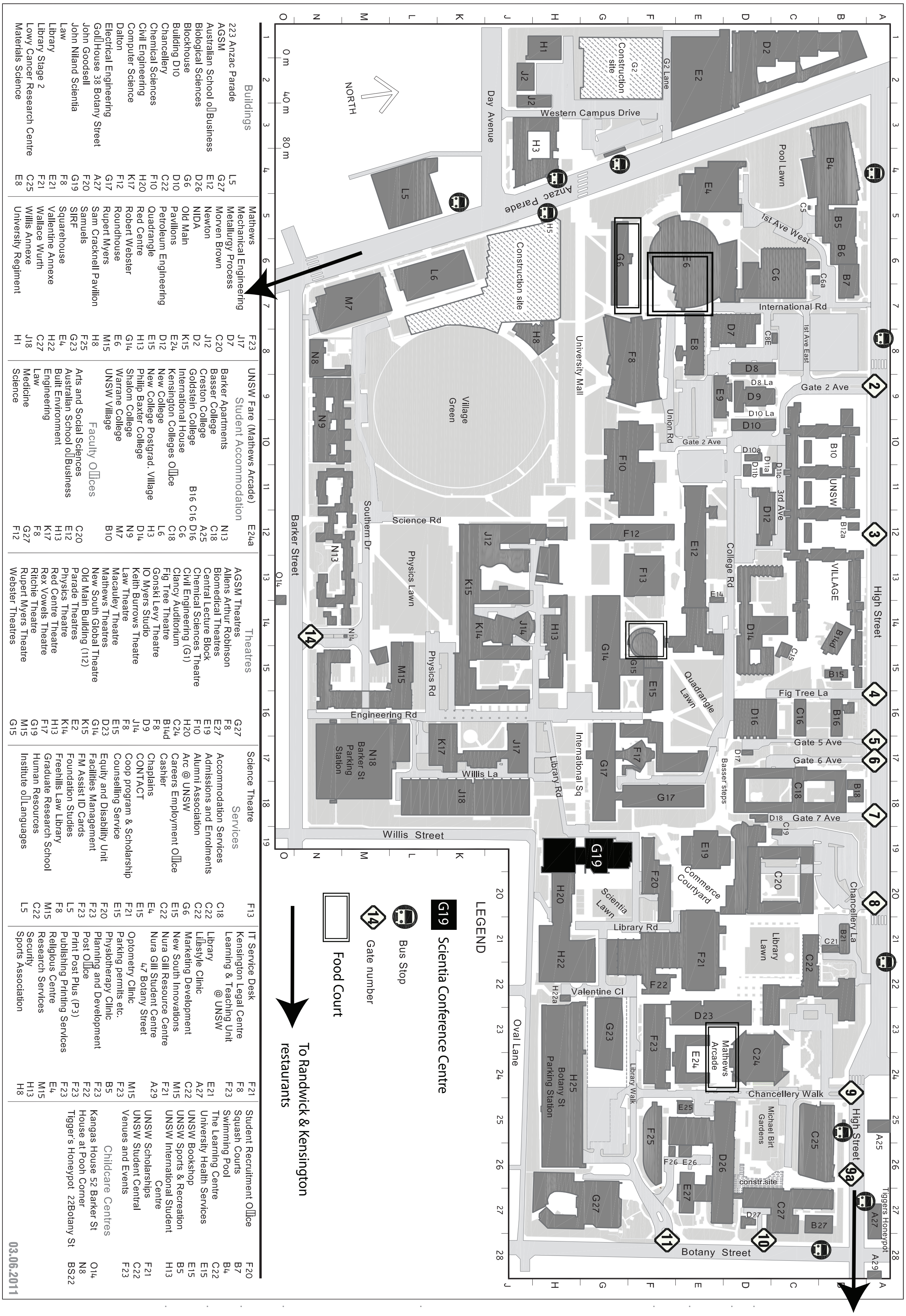
General Information

Scientia Conference Centre

Getting there on foot:
Enter through Gate 11, Botany St, continue past multi-level parking station into Library Road, turn left, turn right, and proceed to The John Niland Scientia Building main entrance. From Anzac Parade and public transport; walk 800m up the magnificent University Mall. The John Niland Scientia Building is directly in front of you.

Parking:
Enter through Gate 11, Botany St. Park in multi-level parking station. Parking charges apply on weekdays. Upon exiting vehicle, proceed out of the carpark at the western end and follow small hill down to The John Niland Scientia Building main entrance.

John Niland Scientia Building


LEGEND
G19 Scientia Conference Centre
Bus Stop
Gate number
Food Court
To Randwick & Kensington restaurants
NORTH
0 m 40 m 80 m
High Street
Anzac Parade
Botany Street
Barker Street
Willis Street
Oval Lane
Day Avenue
Western Campus Drive
University Mall
Library Rd
College Rd
Union Rd
Engineering Rd
Physics Rd
Science Rd
Southern Dr
International Rd
International Sq
Valentine Cl
Chancellery Walk
Library Walk
Village Green
Physics Lawn
Quadrangle Lawn
Library Lawn
Pool Lawn
Scientia Lawn
Commerce Courtyard
Michael Birt Gardens
Construction site
N18 Barker St Parking Station
H25 Botany St Parking Station
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Buildings
223 Anzac Parade L5
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Morven Brown C20
Newton J12
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Quadrangle E15
Red Centre H13
Robert Webster G14
Roundhouse E6
Rupert Myers M15
Sam Cracknell Pavilion H8
Samuels F25
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Childcare Centres
Kangas House 52 Barker St O14
House at Pooh Corner N8
Tigger's Honeypot 22Botany St BS22
03.06.2011

Dinner Information

The AMOS 2012 Conference Dinner will be taking place at 7pm on Wednesday, 1 February 2012 at historic Luna Park on Sydney Harbour's foreshore.

The evening will commence with pre-dinner drinks, which will be served next to the Ferris Wheel (weather permitting). Dinner tickets include admission to the Wheel, which will be available for our exclusive use.

The dinner itself will be served in the heritage-listed Crystal Ballroom, which enjoys panoramic views over the Harbour. Enjoy a sumptuous three-course meal, complete with unlimited soft drinks, beer and wine.

None other than HG Nelson himself will be the after-dinner speaker. In his own unique style, he will share with us his take on the climate change issue including his experiences as a presenter of the "Steaming Toad".

How to get to and from the conference dinner

The conference dinner will take place on the evening of Wednesday 1 February 2012 at Luna Park. The venue is located adjacent to the northern end of the Sydney Harbour Bridge, and can easily be reached by ferry, bus, train, taxi or even by foot.

Pre-dinner drinks will be served from 7pm to 8pm, either next to the Ferris Wheel (if the weather is fine) or in the Crystal Ballroom (if the weather is wet).

The dinner itself will take place in the Crystal Ballroom from 8pm to 11pm.

The cheapest and most scenic way to get from the conference venue to the dinner is to take a bus from UNSW to Circular Quay, then to take the ferry from Circular Quay to Luna Park. If the weather is fine, walking over the Sydney Harbour Bridge instead is highly recommended.

Getting from UNSW to Circular Quay

By bus

Bus routes 392, 394, L94, 396, 397 and 399 travel along Anzac Parade (at the western edge of the UNSW campus) and terminate at Circular Quay. The following buses arrive at Circular Quay between 6pm and 7pm:

Route	Anzac Parade Stand B	Circular Quay
397	5.35pm	6.03pm
396	5.40pm	6.08pm
L94	5.45pm	6.08pm
392	5.50pm	6.18pm
399	5.55pm	6.23pm
394	6.00pm	6.28pm
397	6.05pm	6.33pm

396	6.10pm	6.38pm
394	6.15pm	6.43pm
392	6.20pm	6.48pm
399	6.25pm	6.53pm
397	6.30pm	6.58pm

*** PLEASE NOTE THAT TICKETS FOR THESE SERVICES MUST BE PURCHASED BEFORE YOU BOARD. ***

A single “MyBus 2” ticket is required, which costs $3.50 for adults and $1.70 for concessionals.

Tickets can be purchased on the UNSW campus at Arc@UNSW shops, as well as at most convenience stores and service stations.

By taxi

A taxi from UNSW to Circular Quay should cost around $25-30.
A taxi from UNSW direct to Luna Park should cost around $40-45.

Getting between Circular Quay and Luna Park

By ferry

It takes six or seven minutes to travel from Circular Quay to Luna Park. The ferry ride is very scenic and passes beneath the Sydney Harbour Bridge. The terminal at Milsons Point/Luna Park is located just metres from the Ferris Wheel (the fine-weather venue for pre-dinner drinks) and only 100m from the Crystal Ballroom (the wet-weather venue for pre-dinner drinks, as well as the venue for the dinner itself).

Pre-dinner drinks will be served from 7pm to 8pm. The following ferries arrive at Luna Park between 6.30pm and 8pm:

Route	Circular Quay Wharf 5	Milsons Point/Luna Park
Darling Harbour	6.25pm	6.32pm
Darling Harbour	6.55pm	7.02pm
Darling Harbour	7.25pm	7.31pm

The dinner will finish at 11pm. The following ferries depart Luna Park after 10.30pm:

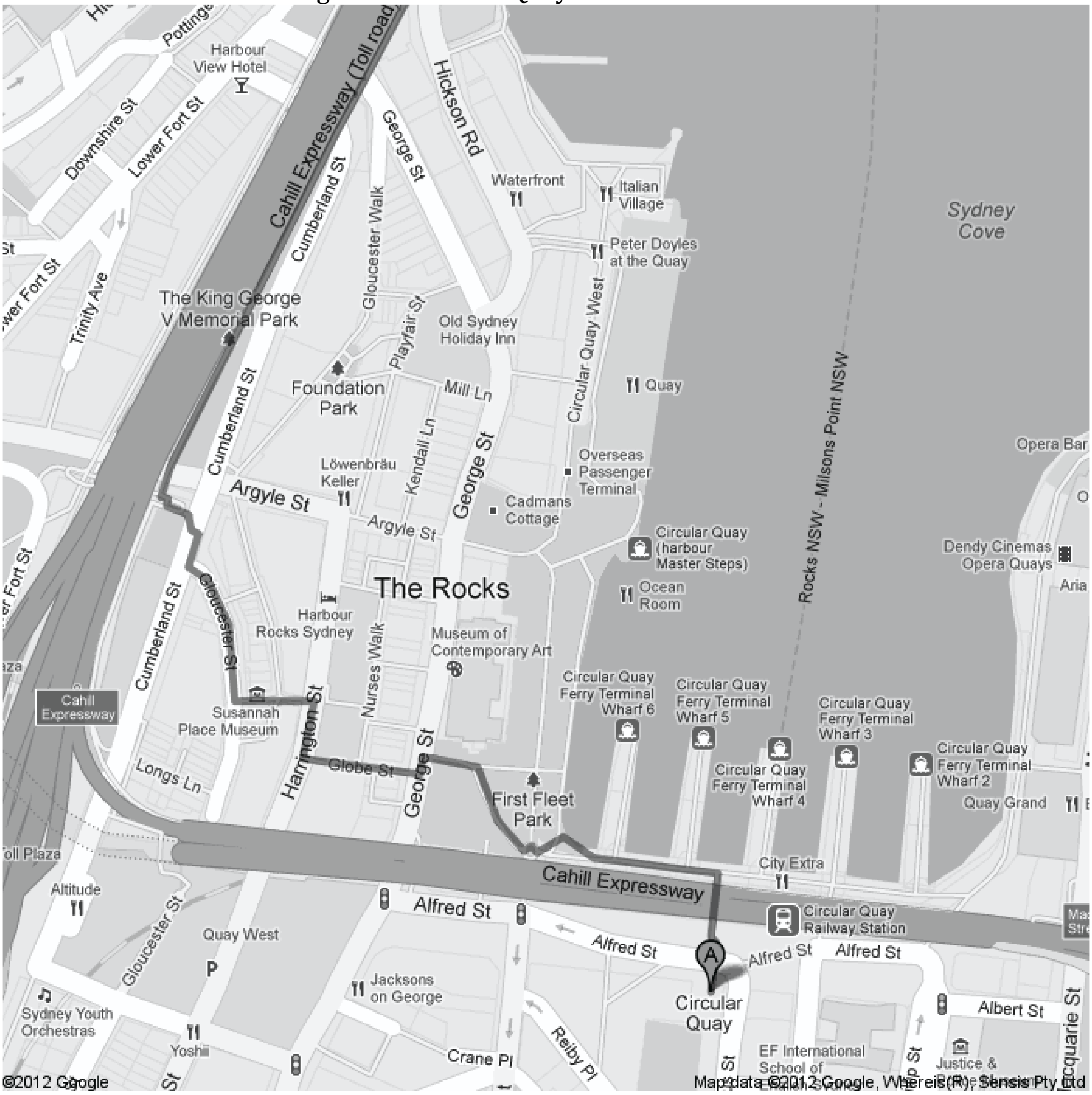
Route	Milsons Point/Luna Park	Circular Quay Wharf 4
Darling Harbour	10.39pm	10.46pm
Darling Harbour	11.14pm	11.20pm
Darling Harbour	11.41pm	11.47pm

A return “MyFerry 1” ticket is required, which costs $11.20 for adults and $5.60 for concessionals. For one-way travel only, a single “MyFerry 1” ticket costs $5.60 for adults and $2.80 for concessionals. Tickets can be purchased at Circular Quay and at any other ticket outlets.

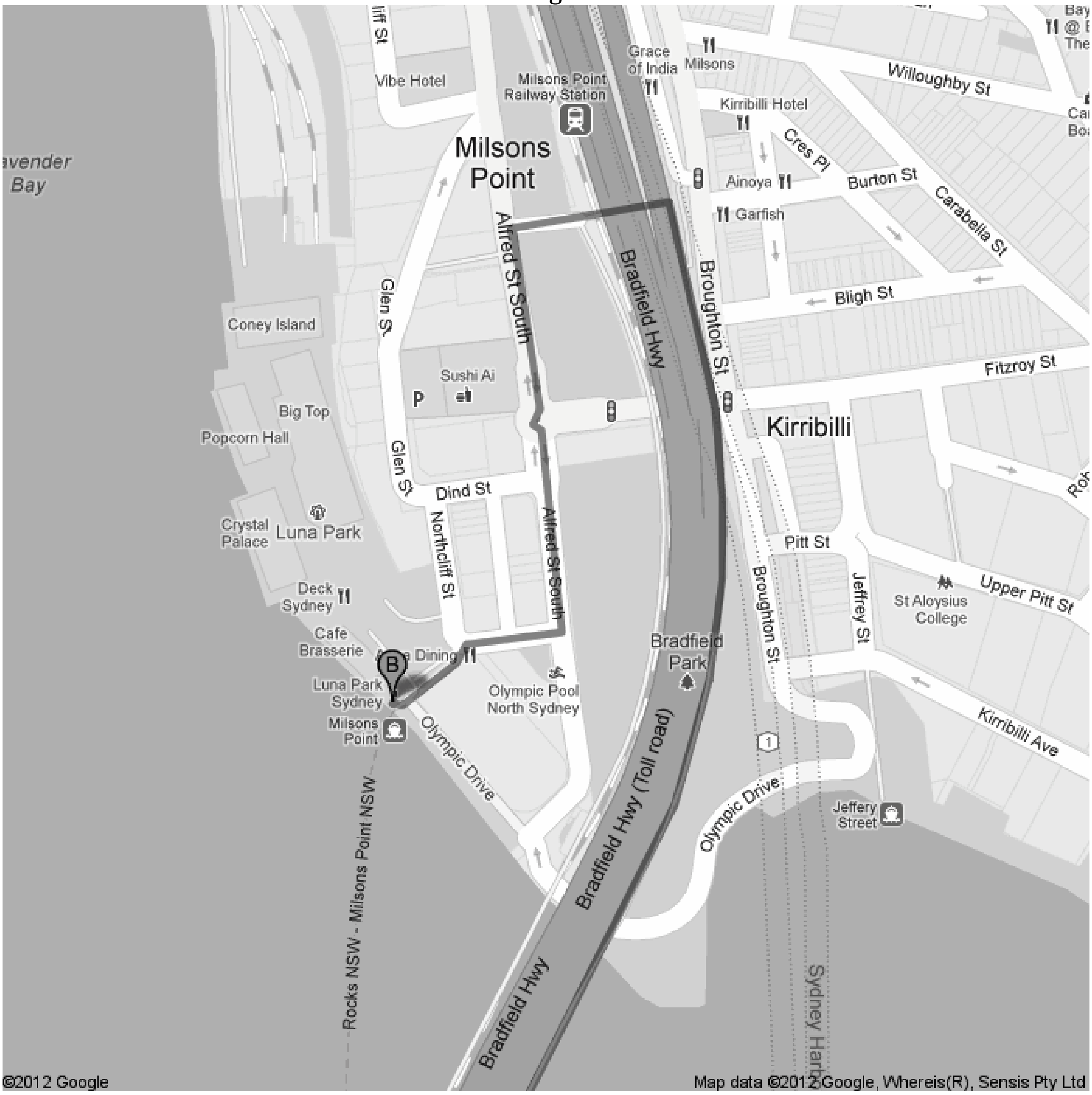
By foot

The walk from Circular Quay to Luna Park via the Sydney Harbour Bridge is 2.7km, and takes only 30-40 minutes. This option is highly recommended if it is a fine evening.

To access the Harbour Bridge from Circular Quay:



And to access Luna Park from the Harbour Bridge



Getting from Circular Quay to Coogee

Many of the conference participants are staying in Coogee, which can be reached from Circular Quay by bus or taxi.

By bus

Bus routes 373 and 374 travel from Circular Quay to Coogee. The following buses depart Circular Quay at or after 11pm:

Route	Circular Quay Stand D	Coogee Beach
373	11.00pm	11.34pm
373	11.20pm	11.54pm
374	11.23pm	11.57pm
373	11.45pm	12.19am
374	12.08am	12.42am
373	12.15am	12.49am
373	12.40am	1.12am
373	1.30am	1.57am
373	2.30am	2.57am
373	3.30am	3.57am

A single "MyBus 3" ticket is required, which costs $4.50 for adults and $2.20 for concessionals. Tickets for these services can be purchased aboard the bus.

By taxi

A taxi from Circular Quay to Coogee should cost around $30-35.

A taxi from Luna Park direct to Coogee should cost around $40-45.

Quick Program Guide

Tuesday 31 January			
8:40	Welcome		
9:00	Plenary – Susan Wijffels		
9:45	Plenary – Jan Zika		
10:30	Morning tea		
11:00	2. General Ocean	6. Downscaling	7. Eastern seaboard
12:30	Lunch 1pm: CMIP5 @ NCI		
1:30	2. General Ocean	5. CMIP5	18. MDB
2:45	afternoon tea		
	Posters: 2. General ocean, 5. CMIP5, 6. Downscaling, 7. Eastern seaboard, 8. Fire weather, 18. MDB		
4:15	2. General Ocean	5. CMIP5	8. Fire weather
5:30	Welcome reception		
7:30	End		

Wednesday 1 February			
9:00	Plenary – Lisa Alexander		
9:45	Plenary – Paul o'Gorman		
10:30	Morning tea		
11:00	1. General Atmosphere	12. Southern ocean	15. Tropical Pacific
12:30	Lunch – AMOS AGM		
1:30	1. General Atmosphere	12. Southern ocean	4. Boundary currents
2:45	afternoon tea		
3:15	1. General Atmosphere	11. Renewable energy	4. Boundary currents
4:30	Posters: 1. General atmosphere, 4. Boundary currents, 11. Renewable energy, 12. Southern ocean, 15. Tropical Pacific		
6:00	End		
7:00	Conference Dinner – Luna Park		

Thursday 2 February				Friday 3 February			
9:00	Plenary – Nathan Gillet			9:00	Plenary – Chris Kummerow		
9:45	Plenary – Tim Bralower			9:45	3. General Climate	9. Land-atmosphere	17. Waves
10:30	Morning tea			11:00	Morning tea		
11:00	3. General Climate	1. General Atmosphere	15. Tropical Pacific	11:30	3. General Climate	9. Land-atmosphere	16. Tsunamis
12:30	Lunch			1:00	End		
1:30	3. General Climate	14. Past climate	13. Storm tracks				
2:45	afternoon tea						
3:15	3. General Climate	14. Past climate	10. Natural hazards				
4:30	Posters: 3. General climate, 9. Land-atmosphere, 10. Natural hazards, 13. Storm tracks, 14. Past climate, 16. Tsunamis, 17. Waves						
6:00	End						
6:30	Student BBQ – Coogee beach						
7:30	Fellows Dinner - Montpelier Public House						

Program – Oral Presentations

		Leighton Hall	Ritchie Theatre	Tyree Room	Galleries
Tuesday 31 Jan	8:40	Opening for AMOS 2012			
	9:00	Plenary: Susan Wijffels – A Decade of Argo: Achievements and Future Outlook			
	9:45	Plenary: Jan Zika – The Ocean: A contour-wise view			
Morning tea	**10:30**				
Tuesday 1		**2. General Ocean Session** Chair: Katrin Meissner	**6. Downscaling climate projections** Chair: Jack Katzfey	**7. Eastern Seaboard Extreme Weather, Climate and impacts in the coastal zone** Chair: Milton Speer	
	11:00	Invited: The Global Ocean Circulation on both Eddy-Resolving and Millennial Scales. Eric van Sebille	Downscaling Climate Projections for Application to Regional Biodiversity Research Michael Grose	Eastern Seaboard Climate Hazard Tool – MATCHES Felicity Gamble	
	11:15	Insights into the Effects of Turbulent Mixing on the Overturning Circulation Ross Griffiths	Evaluation of High-Resolution Regional Climate Simulations over Islands in the South Pacific: Results for Future Climates Jack Katzfey	Climatological Influences on Rainfall on the Eastern Seaboard of Australia, and the Impact of East Coast Lows. Acacia Pepler	
	11:30	A Computationally-efficient approximate for of Neutral Density for use with ocean models Trevor J McDougall	Exploring the added value of projections of climate extremes from the CCAM regional climate model. Sarah Perkins	Will East Coast Lows be more likely in a warmer world? Andrew Dowdy	
	11:45	The oceanic response of anomalous surface contributions Veronique Lago	Explaining Differences Between GCM-derived Wheat Yield Projections for New South Wales: Implications for Climate Change Impact Assessments Ian Macadam	Extreme rainfall variability on the eastern seaboard of Australia Agata Imielska	
	12:00	Evaluating the Numerical	Modeling High Impact Weather and Climate:	Multi-decadal variability of flood risk	

		Weather Prediction Air-Sea Fluxes over the Global Ocean for ACCESS-G Eric Schulz	The Tropical Cyclone Experience James Done	along the eastern seaboard of Australia Anthony Kiem	
	12:15	Input From Surface Buoyancy and Wind Forcing to the Ocean Energy Budget Juan A. Saenz	Regional Climate Simulations for Australia using the weatherathome Citizen Science Experiment David Karoly	Synoptic Drivers and Secular Shifts in Extreme Wave Climate in South-Eastern Australia Ian Goodwin	
Lunch	**12:30**		**1:00 Special topic:** Using NCI to access and analyse CMIP5 data Ben Evans		
Tuesday 2		**2. General Ocean Session** Chair: Steven Siems	**5. CMIP5 Modelling Project: Model evaluation, data analysis and projections** Chair: Jozef Syktus	**18. Hydroclimate of the Murray-Darling Basin** Chair: Jai Vaze	
	13:30	The Vertical Transport of Tracers in the Ocean: a Pump Driven by Submesoscale Structures Isabella Rosso	A dummies' guide to accessing and understanding the CSIRO-Mk3.6.0 CMIP5 data archive Stacey Dravitzki	Invited: What future for water. Why climate science matters Jason Alexandra	
	13:45	Biological Productivity Teleconnections Mediated by Long-Range Nutrient Transport Mark Holzer	Invited: Projected and Historic Changes in Circulation and Rainfall in the Australian Region Simulated by CSIRO-Mk3.6 under Different Forcing Assumptions Leon Rotstayn	Projections of Future Water Availability for the Murray-Darling Basin David Post	
	14:00	The Mysterious Case of the Missing 14C: A Palaeo-oceanographic Investigation Willem Huiskamp	Invited: ACCESS: The Australian Coupled Climate Model for IPCC AR5 and CMIP5 Daohua Bi	South Eastern Australia Rainfall in relation to the Mean Meridional Circulation Bertrand Timbal	
	14:15	Sudden Increase in Antarctic Sea Ice: Fact or Artifact? (and was 2011 a Record Low for Arctic Sea Ice?) James Screen		Impact of the Choice of Downscaling Methods on Future Runoff Projections for South-eastern Australia Jin Teng	
	14:30	Mesoscale circulation of the Southeast Indian Ocean Gary Brassington	Climate extremes in Australia during the 20th and 21st centuries: Impacts of various radiative forcing factors Kenneth Wong	Impact of Climate Entity Choices on Statistical Downscaling and Modelled Runoff Yang Wang	
Coffee	**14:45**				

					Poster session: 2. General Ocean, 5. CMIP5, 6. Downscaling, 7. Eastern seaboard, 8. Fire weather, 18. MDB
Tuesday 3		**2. General Ocean Session** Chair: Andy Hogg	**5. CMIP5 Modelling Project: Model evaluation, data analysis and projections** Chair: Tony Hirst	**8. Fire weather and risk** Chair: Todd Lane	
	16:15	Impact of the Madden-Julian Oscillation in the Indian Ocean and its remote influence on the western Australian coast Andrew Marshall	Climate change projections in Australian region using CMIP5 simulations with CSIRO Mk3.6 climate model Jozef Syktus	Investigating the Fire Channelling Phenomenon using the WRF Model Colin Simpson	
	16:30	Remote Effects of Localized Upwelling in a Shelf-Break Canyon Jochen Kaempf	Simulation of El Niño–Southern Oscillation in the Australian Community Climate and Earth System Simulator (ACCESS) Harun Rashid	Localized enhancements in fire danger during the ‘Black Saturday’ fires Chermelle Engel	
	16:45	Tidal Mixing: Barotropic versus Baroclinic Robin Robertson	Forming and distributing the ACCESS CMIP5 archive Peter Uhe	WRF can simulate recent fire weather in southeast Australia Hamish Clarke	
	17:00	The Contribution to Tidal Asymmetry by Different Combinations of Tidal Constituents Dehai Song	CMIP5 and AR5: An update Tom Beer	Assessing Bushfire Risk Under Warming Climate Scenarios Using Regional Climate Model Projections in Tasmania Michael Grose	
	17:15	Tides and Sound: The Inside Story on Internal Waves and Acoustics James Cooper	Constraining regional climate projections with observed recent change Jonas Bhend	A research framework for assessing the spatio-temporal dynamics of bushfires Nic Gellie	
	17:30	Ice-breaker.			
	20:00	End			

		Leighton Hall	Ritchie Theatre	Tyree Room	Galleries
Wednesday 1 Feb	9:00	Plenary: Lisa Alexander – The CLIMDEX project: Creation of long-term global gridded products for the analysis of temperature and precipitation extremes			
	9:45	Plenary: Paul O'Gorman - Changing atmospheric circulations, precipitation patterns, and connections to the broader climate system			
Morning tea	**10:30**				
Wednesday 1		**1. General Atmosphere Session** Chair: Peter Steinle	**12. Southern Ocean Processes** Chair:Peter Strutton	**15. Tropical Pacific Climate Variability and Projections** Chair: Jaclyn Brown	
	11:00	Invited: BoM Representative	Identifying the Causes of Model Errors in Southern Ocean Clouds: A Regime-Oriented Approach Applied to the ACCESS Model Christian Jakob	Invited: The Changing Face of El Niño Michael J. McPhaden	
	11:15		Sea Ice Variability and Trends in the Weddell Sea: A Comprehensive View of the Relationships between Sea Ice and its Driving Mechanisms over the last 30 Years Ruediger Gerdes		
	11:30	Climate and Weather Culturomics for Fun and Profit Neville Nicholls	Tracing Dense Circumpolar Deep Water in the South Pacific using Potential Vorticity and 3He Stephanie M. Downes	Interannual Variations of Wind Stress and Sea Surface Temperature in the Eastern Equatorial Pacific Xuebin Zhang	
	11:45	Recent Developments in the Bureau of Meteorology's ACCESS NWP Suite Chris Tingwell	Reconciling Lagrangian and Eulerian Estimates of Eddy Diffusivities Andreas Klocker	The El Nino Southern Oscillation Pattern Non-linearity Dietmar Dommenget	

	12:00	Controlling overestimation in ensemble Kalman filters Georg Gottwald	Interannual shifts of the dynamical regime of the Southern Ocean in response to climatic modes Clothilde Langlais	ENSO impacts on Pacific Islands' climate and the atmospheric dynamics that bring them about Brad Murphy	
	12:15	Use of Doppler Radar for Numerical Weather Prediction Susan Rennie	The Paradox of Southern Ocean Upwelling in amplifying and delaying the onset of Ocean Acidification Ben McNeil	The Walker circulation, tropical cyclones, and global warming Scott Power	
Lunch	**12:30**				
Wednesday 2		**1. General Atmosphere Session** Chair: Joe Kidston	**12. Southern Ocean Processes** Chair: Zanna Chase	**4. Boundary currents, eddies, and continental shelf processes** Chair: Moninya Roughan	
	13:30	High Resolution Operational Forecast for Heat Load Management of Feedlot Cattle in Australia Andrew Wiebe	First Steps Towards Determination of the Southern Ocean Air-Sea Heat Exchange: Evaluating Flux Datasets using the SOFS Mooring Simon Josey	Marine downscaling of a future climate scenario for Australian boundary currents Chaojiao Sun	
	13:45	The Adelaide Urban Heat Island: Spatial and temporal aspects Caecilia Ewenz	On the non-Equivalent Barotropic Structure of the Antarctic Circumpolar Current Helen Phillips	Spatio-temporal Variability of sporadic Upwelling events over the east Australian continental margin for the last decade. Vincent Rossi	
	14:00	Idealised Simulations of Turbulence Near Thunderstorms Dragana Zovko Rajak	Interplay between the zonal momentum balance and overturning in the Southern Ocean Adele K. Morrison	The Leeuwin Current: The Role of Mixing and Advection in Topographic Trapping and Shelfbreak Intensification of a Density-Driven Flow Jessica Benthuysen	
	14:15	The Role of Nonlinear Processes in the Generation of Gravity Waves by Convective Clouds Michael Reeder	A New Conceptual Model for the Antarctic Circumpolar Current (and the Global Ocean Overturning) Andy Hogg	The 2011 Marine Heat Wave off Western Australia Ming Feng	
	14:30	Numerical study on the formation of Typhoon Ketsana (2003) in the western North Pacific Guoping Zhang	The role of Southern Ocean gateways in controlling global climate Matthew England	Interaction between the Leeuwin Current and continental shelf along the Rottnest shelf and Perth Canyon Charitha Pattiaratchi	
Coffee	**14:45**				

Wednesday 3		**1. General Atmosphere Session** Chair: Michael Reeder	**11. Renewable Energy – the effects of weather and climate on integrating renewables into our energy industry** Chair: Merlinde Kay	**4. Boundary currents, eddies, and continental shelf processes** Chair: Ming Feng	
	15:15	Probability of Precipitation Medium Term (1-7 days) Forecasting for Australia. Shaun Cooper	The Impact of Cloud Events on Simulated Photovoltaic Arrays Nicholas A. Engerer	Interaction of eddies with the western boundary Andrew Kiss	
	15:30	Precipitation Case Studies Of Synoptic Weather Regimes In South Eastern Queensland, Australia Louise Wilson	Wind speed trends and climate change - implications for wind energy Annette L. Hirsch	Anatomy of a Flooding Warm-Core Eddy Helen Macdonald	
	15:45	Warm-season frontal precipitation and its moisture sources Todd Lane	An Optimised Network Renewable Energy System for Australia Roger Dargaville	An Eddy Census of Southeast Australia: The Abundance and Distribution of Eddies and their Role in Supporting Primary Production Jason Everett	
	16:00	Investigating the Relationship between Large-Scale and Convective States in the Tropics Laura Davies	Synoptic Influences on Large-Scale Renewable Energy Output for Australia. Robert Huva	Observing and Modelling the East Australian Current and its Eddies using IMOS data and Bluelink models David Griffin	
	16:15	The dynamics of subtropical anticyclones Juliane Schwendike	Wind Farm Siting to Improve Wind Contribution in a High Penetration Renewable Electricity System Ben Elliston	Physical variability on the shelf off NSW Australia: new insights from the NSW Integrated Marine Observing System. Amandine Schaeffer	
	16:30				Poster session: 1. General Atmosphere, 4. Boundary currents, 11. Renewable energy, 12. Southern Ocean, 15. Tropical Pacific
	18:00	End			
	19:00	Conference Dinner – Luna Park			

		Leighton Hall	Ritchie Theatre	Tyree Room	Galleries
Thursday 2 Feb	9:00	Plenary: Nathan Gillett - What can observed climate change tell us about the future?			
	9:45	Plenary: Tim Bralower – The Anatomy of an Ancient Global Warming Event			
Morning tea	**10:30**				
Thursday 1		**3. General Climate Session** Chair: Caroline Ummenhofer	**1. General Atmosphere Session** Chair: Jatin Kala	**15. Tropical Pacific Climate Variability and Projections** Chair: Alex Sen Gupta	
	11:00	Invited: Droughts are bigger in Texas too: global climate in 2011 Blair Trewin	A New Look at the Interconnections between Precipitation Drivers over Australia Penelope Maher	Influences of the tropical Indian and Atlantic Oceans on the Predictability of ENSO Claudia Frauen	
	11:15	The 'Big Dry' and other synchronous dry spells across the Southern Hemisphere Danialle Verdon-Kidd	Intra-Seasonal Prediction of Remote Drivers of Australian Climate Variability using POAMA-2 Andrew Marshall	An asymmetry in the IOD and ENSO teleconnection pathway Peter van Rensch	
	11:30	Performance of the CMIP3 models in representing the precipitation teleconnection to Australia and its asymmetry Evan Weller	Tropical tropopause layer processes driving of short-lived substance concentrations Robyn Schofield	The effect of the South Pacific Convergence Zone on the termination of El Niño events and the meridional asymmetry of ENSO Shayne McGregor	
	11:45	The Impact of Climate Change on Interannual Modes of Variability of Southern Hemisphere Atmospheric Circulation in CMIP3 Models Simon Grainger	Characterisation of Aerosols over Australia and New Zealand and Effects on Surface UV Radiation Franklin Mills	The response of the SPCZ to enhanced climate change: a multi-model case study Simon Borlace	
	12:00	Regime Dependent Changes in Monsoon Precipitation over Tropical Australia and the Wider Region Aurel Moise	Transient Anticyclones and the Role of Rossby Wave Breaking in Heatwaves over Southern Australia Teresa Parker	Potential Changes in Monsoon Onset/Intensity in the Australia-Asian Region Derived from IPCC AR4 Models Huqiang Zhang	

	12:15	Australian Climate Modulated by the Indian Ocean Basin-Wide Warming Andrea Taschetto	Fronts and Precipitation in Observations and Climate Models Jennifer Catto	The South Pacific Convergence Zone in Coupled Model Simulations of 20th Century and Future Climate Josephine Brown	
Lunch	**12:30**				
Thursday 2		**3. General Climate Session** Chair: Neville Nicholls	**14. The climate of the last 2,000 years: Bridging the gap between the past and the future** Chair: Steven Phipps	**13. Storm Track Variability and Changes** Chair: Joe Kidston	
	13:30	A Comparison of Classification Methods for Identifying Relationships between the Southern Annular Mode and the Australian Hydroclimate Carly Tozer	Invited: How Well do Climate Models Perform? Evaluation using Palaeoclimate Data Sandy Harrison	Invited: Understanding future changes in the Southern Hemisphere extratropical circulation using perturbation experiments Julie Arblaster	
	13:45	The Link Between ENSO and North Australian SSTs Jennifer Cato			
	14:00	Do we really know the cause of the recent southeast Australian autumn rainfall reduction? Tim Cowan	Evidence of rapid late 20th century warming from an Australasian temperature reconstruction spanning the last millennium Joelle Gergis	Changes and Projections in the Annual Cycle of Southern Hemisphere Baroclinicity for Storm Formation Carsten Frederiksen	
	14:15	A Simple Climate Model for Conceptual Understanding of the Physics of Climate Change Dietmar Dommenget	Analogue based methodology for multi-proxy reconstruction of Southern Hemisphere atmospheric circulation patterns during the Medieval Climate Anomaly Stuart Browning	Attribution and projections of changes in southern hemisphere storm tracks Meelis Zidikheri	
	14:30	Exploring trends and low-frequency variability in rainfall extremes based on Ensemble Empirical Mode Decomposition (EEMD) Doerte Jakob	Utilising palaeoclimate reconstructions of the Interdecadal Pacific Oscillation to inform hydroclimatic risk in Australia Danielle Verdon-Kidd	Interactions Between the Hadley Cell and the Eddy-Driven Jet Joseph Kidston	
Coffee	**14:45**				

Thursday 3		**3. General Climate Session** Chair: Tim Cowan	**14. The climate of the last 2,000 years: Bridging the gap between the past and the future** Chair: Joelle Gergis	**10. Natural Hazards** Chair: Sandra Schuster & Bob Cechet	
	15:15	The IPCC Special Report “Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation” Neville Nichols	“Karst”ing Back in Time: Expanding the Applicability of Palaeo Information for Hydroclimatic Reconstructions Michelle Ho	Cluster analysis of tropical cyclone tracks in the Southern Hemisphere Hamish Ramsay	
	15:30	When did Anthropogenic Climate Change Commence and what is its Impact on Global Tropical Cyclones? Greg Holland	Quantifying Seasonal-scale Changes in El Niño-Southern Oscillation for the Past Millennia Helen McGregor	Australia National Wind Risk Assessment (NWRA): Quantifying wind hazard and risk under current and future climate Bob Cechet	
	15:45	Trends and uncertainties in gridded global data sets of observed climate extreme indices Markus Donat	Refining speleothem based proxy interpretations, utilizing the CSIRO Mk3L climate system model Catherine Jex	A Climatology of Australian Severe Thunderstorm Environments 1989-2011 John T. Allen	
	16:00	To little ado about nothing in 21st century rainfall projections Scott Power	Famine, Pestilence and Flagellation: What Can We Learn from the Climate of the Last 2,000 Years? Steven J. Phipps	Victorian communities impacted by record rainfall and widespread flooding in January 2011 Belinda Campbell	
	16:15	Remote influence of the tropical Atlantic on the variability and trend in North West Australia summer rainfall Yun Li	Insights on Australian and Southern hemisphere climate and variability over the last 2000 years from the high resolution Law Dome Antarctic ice core Mark Curran	The Dynamics of Volcanic Ash Clouds in a Cross-wind Peter G Baines	
	16:30				Poster session: 3. General Climate, 9. Land-atmosphere, 10. Natural Hazards, 13. Storm tracks, 14. Past climate, 16. Tsunamis, 17.Waves
	18:00	End			
	19:00	Students BBQ – Coogee Beach Fellow Dinner – Montpelier Public House			

		Leighton Hall	Ritchie Theatre	Tyree Room	Galleries
Friday 3 Feb	9:00	Plenary: Chris Kummerow - The Evolution of Spaceborne Precipitation Sensors and Retrievals – The Impact of A-priori Information			
Friday 1		**3. General Climate Session** Chair: Dietmar Dommenget	**9. Modelling and observation of land surface and atmosphere interactions: recent advances and future changes** Chair: Rachel Law	**17. Wind-Generated Waves and their Role in Large-Scale Air-Sea Interactions** Chair: Diana Greenslade	
	9:45	An extended high-quality daily temperature data set for Australia Blair Trewin	Benchmarking land surface models: standardisation of evaluation or a quantification of a priori expectations? Gab Abramowitz	Invited: Long Term Oceanic Trends in Wind Speed and Wave Height I.R. Young	
	10:00	High-quality Monthly Upper-air Temperature and Humidity Datasets for Australia Branislava Jovanovic	Simulation of the Land Surface During the Recent Australian Drought: Impact of Groundwater and Forcing Data Mark Decker	Connection Between Time Scales: Turbulence, Waves, Weather, Climate Alex Babanin	
	10:15	Identifying daily Rainfall Entities from high resolution Gridded data Morwenna Griffiths	Application of CABLE to regional climate simulations over Australia Marcus Thatcher	Projected change in global wave climate for future climate scenarios Mark Hemer	
	10:30	Consistency of observed and simulated changes in temperature, precipitation, and sea level pressure Jonas Bhend	Evaluation of Energy and Water Cycles in CABLE and Model Sensitivity to Key Parameters Huqiang Zhang	Is the surface wind asymmetry in a tropical cyclone affected by the waves? Jeff Kepert	
	10:45	The Indo-Australian Monsoon of the Last 25 ka: A Continuous Stalagmite Record from Sulawesi, Indonesia Claire Krause	Continuous Monitoring of Mixing Depth with Radon–222 and Lidar Alan Griffiths	Recent and future changes in wave climate in the Pacific Region Tom Durrant	
Morning tea	**11:00**				

Friday 2		3. General Climate Session Chair: Blair Trewin	9. Modelling and observation of land surface and atmosphere interactions: recent advances and future changes Chair: Luigi Renzullo	16. Tsunamis and their Impact Chair: Chari Pattiaratchi	
	11:30	Modelling Insights into Deuterium Excess in Water Vapour as an Indicator of Oceanic Source Conditions Sophie Lewis	ACCESS and the Carbon Cycle Lauren Stevens	Invited: Progress towards a Global Tsunami Warning System Vasily Titov	
	11:45	Millennial-scale Oscillations of the Inter-Tropical Convergence Zone over the last 50kyr as seen from the Flores Speleothem Paleo-Monsoon Record Nick Scroxton	Exploring the Uncertainty of the Soil Carbon Processes Parameterization in the CABLE model J-F Exbrayat	On the gulf between effective tsunami warning systems and meaningful disaster risk reduction Dale Dominey-Howes	
	12:00	Dynamical balance between assimilating temperature and salinity impact on seasonal forecast skill in a coupled model Mei Zhao	Development of an Ensemble-Adjoint Optimization Approach to derive Uncertainties in Net Carbon Fluxes Tilo Ziehn	Developing Tsunami Inundation Models for Emergency Response Planning Sean Garber	
	12:15	The Diagnosis of ENSO events in an Operational Setting Felicity Gamble	Simulated impacts of land cover change on temperature extremes from the LUCID intercomparison study Francia Avila	Validation of Tsunami Warning Thresholds using Inundation Modelling Burak Uslu	
	12:30	POAMA2 Precipitation Verification over 50 Hindcast Years Guomin Wang	Improving land cover and surface biophysical property assessment in support of the Australian Water Resources Assessment system Juan Guerschman	Tsunamis: All tsunamis are not generated by earthquakes and not all earthquakes generate tsunamis James Goff	
	12:45	Barriers to the wider application of climate projections Andrew Herron	Quantifying Spatial Variability in Mean wind speed and Momentum Transfer within a Model Vegetation Canopy Margi Bohm	The Effect of Bathymetric Features on Tsunami Propagation in the Great Barrier Reef region Arthur Simanjuntak	
	13:00	End			

Program – Poster Presentations

Tuesday 31 Jan		
Poster #	**Title of Abstract**	**Presenting Author**
02	**General Oceanography**	
02-01	Ocean Mixing in Shallow Water off South East Queensland and a Potential Link with Deep Water Oceanographic Processes: Analysis of in-situ and Ocean Reanalysis Data	Daijiro Kobashi
02-02	A New Toolbox for Oceanographic data Quality Control and NetCDF formatting	Guillaume Galibert
02-03	Oceans of data: the Australian Ocean Data Network	Roger Proctor
02-04	Ocean Model, Analysis and Prediction System version 2 (OceanMAPSv2)	Gary Brassington
02-05	What dynamics does Argo observe in the Tasman Sea?	Gary Brassington
02-06	Three Dimensional Hydrodynamics in Darwin Harbour, Northern Territory	Li Li
02-07	Finding a proxy for Wind Stress over the Coastal Ocean off Sydney	Julie Wood
02-08	Development of an Environmental Performance Indicator Framework to Evaluate an Environmental Management System for Shoalwater Bay Training Area, Queensland, Australia	Wen Wu
02-09	Aspects of tides and mean sea level variability in Victoria	Heeyoon Park
02-10	The Seasonal Cycle of Sea Level around Australia	Sarath Wijeratne
05	**CMIP5 Modelling Project: Model evaluation, data analysis and projections**	
05-01	Climate sensitivity of the CSIRO-Mk3.6 Model	Stacey Dravitzki
05-02	Bias correction of CSIRO Mk3.6 model output for Australia	Carlo Hamalainen
05-03	Projections of drought during the 21st Century using data from CMIP5 simulations with CSIRO Mk3.6 climate model	Jozef Syktus
05-04	Heat Stress in a Warming World: Projections of wet-bulb globe temperature during the 21st Century using data from CMIP5 simulations with CSIRO Mk3.6 climate model	Jozef Syktus
05-05	Impacts of changes in radiative forcings on the large scale circulation in the Southern Hemisphere during the 20th and 21st centuries	Kenneth Wong
05-06	Decadal variability of ENSO and the IOD in ACCESS simulations	Arnold Sullivan
05-07	Sensitivity of modeled precipitation to different cloud and condensation schemes	Annette L. Hirsch
05-08	Analysis on Annual and Decadal Variability in the Climate Indices of Surface Temperature derived from the ACCESS Simulations	Frank Drost
05-09	A Sea-Ice Sensitivity Study with the ACCESS/AusCOM Model	Petteri Uotila

06	Downscaling climate projections	
06-01	Climate change impacts on the Australian dairy sector: An integrated analysis	Don Gunasekera
06-02	Global 60 km simulations with CCAM over the tropics	Kim Nguyen
06-03	Corrections to Analogue Statistical Downscaling Climate Series	Yang Wang
06-04	Regional climate modeling for the agricultural region of southwest Western Australia using the Weather Research and Forecasting Model	Jatin Kala
06-05	The Impact of Anthropogenic Climate Change-Induced Storminess Changes on Extreme Sea Levels over Southern Australia	Frank Colberg
06-06	A method for dynamically downscaling future urban climate for Australian cities	Marcus Thatcher

07	Eastern Seaboard Extreme Weather, Climate and impacts in the coastal zone	
07-01	An energetics signature of Southern Hemisphere explosive cyclones	Mitchell Black
07-02	LRET Global Networking to Improve Prediction of Extreme Marine Events	Chris Chambers
07-03	Extreme Precipitation and East Coast Low Events: The Impact of Physical Parametrization	James Gilmore
07-04	East Australian Cut-off Lows, a New Asymmetric Model	Mohammad Olfateh
07-05	Impact of the El Nino Southern Oscillation, Indian Ocean Dipole, and Southern Annular Mode on daily to sub-daily rainfall characteristics in East Australia	Agus Santoso
07-06	Meteorological Overview of Three Eastern Seaboard Flash Floods	Milton Speer
07-07	How natural climate variability influences storm surge and related coastal flooding	Heather Stevens
07-08	Eastern Seaboard Climate Change Initiative – East Coast Lows: Program Road Map from Research Investigation to User Application	Peter Smith
07-09	Evaluate the Potential Economic Benefits from Weather and Ocean Related Information to Beach Users in Australian East Coastal Areas	Fan Zhang

08	Fire weather and risk	
08-01	Simulation of the processes underlying sudden Drying Events and their implications for Fire Danger	Rachel Badlan
08-02	Modelling the fire weather of Black Saturday	Robert Fawcett
08-03	Idealised numerical modelling of bushfire plumes	William Thurston

18	Hydroclimate of the Murray-Darling Basin	
18-01	Some Influences on Rainfall and Run-off in selected South Eastern Australian Catchment Areas	Morwenna Griffiths
18-02	A preliminary look at the hydroclimate of Southeastern Australia in the next generation of Australian Global Circulation Model simulations	David Kent

Wednesday 1 Feb		
Poster #	**Title of Abstract**	**Presenting Author**
01	**General Atmospheric Science**	
01-01	Analyses of Inversions and Stability in the Surface Layer using High Resolution Sonde Data and Sigma theta Observations	Warwick Grace
01-02	Non-linear and Non-stationary Influences of Geomagnetic Activity on the Winter North Atlantic Oscillation	Yun Li
01-03	Validation of TRMM Daily Precipitation Estimates of TC Rainfall using PACRAIN data	Yingjun Chen
01-04	High-Resolution Simulations of a Springtime Precipitation Event in the Australian Alps	Campbell D Watson
01-05	Recreational Storm Chasing in the United States Great Plains	Nicholas A. Engerer
01-06	Determining statistical uncertainties associated with observing convective overshoots in the TTL using TWP-ICE WRF simulations	Muhammad Hassim
01-07	Secondary Eyewall Formation and Eyewall Replacement Cycles in Hurricane Simulations: Effect of Unbalanced Forces	Xingbao Wang
01-08	Assessing the importance of the Australian Radiosonde Network to Numerical Weather Prediction Systems.	Elaine Miles
01-09	Error Amplification and Predictability of Heavy Precipitation Events in Cloud-Resolving ACCESS Model	Xingbao Wang
01-10	Python-based plotting for ACCESS NWP forecasts	Ivor Blockley
01-11	The Bureau of Meteorology's Next Generation High Resolution NWP Systems	Peter Steinle
01-12	The effects of ENSO on high impact weather in Queensland	Andrew King
01-13	An observational study on the rainfall distribution of landfalling tropical cyclones in the northwestern Australian region	Yubin Li
01-14	Reduced stochastic climate models for data assimilation	Georg Gottwald
01-15	A Statistical Model of the Large-Scale Distribution of Tropical Convection	Jackson Tan
01-16	Verification of WRF Upper-air Variables for Quantitative Precipitation Forecast of Snowy Mountain Region	Jingru Dai
01-17	Observations of Orographic Snow Cloud Formation, Supercooled Liquid Water Content and Precipitation of a Cyclonic Weather System Moving over the Snowy Mountains	Luke Osburn
01-18	Triangles in the Sky: 'Striated Delta' Clouds and Associated Inertia-Gravity Wave Dynamics	Adam Morgan
01-19	Identification of Synoptic Weather Patterns Affecting Rainfall Distribution Over Major Australian Cities.	Bhupendra Raut
01-20	Recent global trends in atmospheric fronts	Gareth Berry
01-21	Observation and Simulation of the Gravity Waves Generated by Convection during TWP-ICE	Nguyen Chi Mai
01-22	Application of Limited-Area Domain high-order Spectral Filter to Regional map projections	Ja-Rin Park
01-23	Slippery Thermals and the Cumulus Entrainment Paradox	Daniel Hernández-

		Deckers

04	**Boundary currents, eddies, and continental shelf processes**	
04-01	Australia's Integrated Marine Observing System – monitoring major boundary currents and inter-basin flows	Tim Moltmann
04-02	The First Three Years of NSW-IMOS Mooring Deployments	Bradley Morris
04-03	Comparison of Coastal Sea Level in OceanMAPS to Tide Gauges	Andy Taylor
04-04	Using High-Resolution Ocean Timeseries Data to give context to Long Term Hydrographic Sampling off Port Hacking, NSW, Australia.	Moninya Roughan
04-05	Entrain, Retain and Nurture: the fisheries oceanography potential of submesoscale eddies of western boundary currents	Iain Suthers

11	**Renewable Energy – the effects of weather and climate on integrating renewables into our energy industry**	
11-01	The Potential for TAPM to be used as a Wind Energy Forecasting Tool	Patrick Wong

12	**Southern Ocean Processes**	
12-01	A Climatology of the Low-Elevation Clouds over the Southern Ocean using a merged A-Train data product (the DARDAR MASK)	Steven Siems
12-02	Three-dimensional distribution of clouds around the Southern Hemisphere extratropical cyclones	Pallavi Govekar
12-03	Wind Shear and the Southern Ocean Buffer Layer	Luke Hande
12-04	Critical Concerns and Latitudes: Tidal Effects on Ice Shelves of the Amundsen Sea	Robin Robertson
12-05	Recent Progress on the Tracer Contour Inverse Method	Sjoerd Groeskamp
12-06	Rapid Variability of Oceanic Jets Driven by Eddy-Topography Interaction, with Application to the Southern Ocean Frontal Variability	Chris Chapman
12-07	Physical and Biological Response of the Southern Ocean to the Southern Annular Mode: 1997 to 2011	Pete Strutton
12-08	Biogenic Flux along the Southern Chilean Margin over the Past 30,000 Years: Implications for Southern Ocean Processes	Zanna Chase

15	**Tropical Pacific Climate Variability and Projections**	
15-01	Model Biases in the Western Tropical Pacific, Improvements from CMIP5, and Implications for Projections.	Jaclyn N. Brown
15-02	An updated assessment of land-based temperature and rainfall trends across the island nations of the western Pacific	Belinda Campbell
15-03	Sensitivity of the Southern Hemisphere Climate to Changing ENSO Conditions	Laura M. Ciasto
15-04	Managing climate variability in agriculture: predicting the onset of the north Australian wet season	Wasyl Drosdowsky

15-05	Application of the ENSO Unified Oscillator theory to an ocean-only model	Felicity Graham
15-06	Providing Climate Projections for Individual Pacific Island Nations: Challenges, Progress and Future Directions	Damien Irving
15-07	Evaluation of Air-Sea Flux Algorithms Performance in Ocean-Atmospheric Coupled Model to Improve Climatic Simulation of Tropical Pacific SST Variability	Yimin Ma
15-08	"Climate Change in the Pacific: Scientific Assessment and New Research"	Scott Power
15-09	Sensitivity of Oceanic Carbon Uptake to Permanently Changed Equatorial Surface Wind Stress	Nina N. Ridder
15-10	Impact of Indo-Pacific feedback interactions on ENSO dynamics diagnosed using ensemble climate simulations	Agus Santoso
15-11	Projected Wind Driven Changes to the Tropical Pacific	Alexander Sen Gupta
15-12	Analysis of Historical Climate Extremes in the Pacific Region using New and Existing Indices.	Kirien Whan
15-13	Convection related model bias and its impact on tropical weather simulation	Hongyan Zhu

Thursday 2 Feb

Poster #	Title of Abstract	Presenting Author
03	**General Climate Science**	
03-01	Modelling and understanding the causes of increased rainfall in Northwestern Australia	Duncan Ackerley
03-02	Recent observed changes in snow depth and snow cover duration in the Australian Alps	Jonas Bhend
03-03	Analysis of historical observations narrows uncertainty range for temperature projections	David Karoly
03-04	ENSO-related SST Changes Amplify the Radiative Impact of Indonesian Biomass Burning Aerosols	Alena Chrastansky
03-05	Towards the development of long term winter records for the Snowy Mountains	Clem Davis
03-06	The Simulation of Rainfall Regimes for Adelaide, Melbourne, Sydney and Brisbane using WRF	Lorenzo de la Fuente
03-07	Prescribed versus Time-varying Ozone in an Ensemble of AMIP Simulations	Frank Drost
03-08	Patterns of Sea Surface Temperature and Sea Level Pressure With Teleconnections to Rainfall in South-West Western Australia	Fiona Evans
03-09	Multi-week Rainfall Predictions from POAMA – Part One	Grant Beard
03-10	Multi-week Rainfall Predictions from POAMA - Part 2	Catherine Ganter
03-11	A Land of Flooding Rains and Drought: Australian Climate in 2011	Catherine Ganter
03-12	A Model for Runs of Extremes in a Daily Variable	Warwick Grace
03-13	Impact of the Indian Ocean High Pressure System On Winter Precipitation over Western and Southwestern Australia	M J Iqbal
03-14	Developing a high-quality rainfall dataset for Western Australia – the effects of infilling and disaggregating daily rainfall	Doerte Jakob
03-15	Ororgaphic Flows and Climate of the Antarctic Peninsula	Amelie Kirchgaessner

03-16	Assessing the influence of the Tropospheric Biennial Oscillation on Asian-Australian Monsoon predictability	Yue Li
03-17	Study of SPI Drought Index and Reconstruction of Precipitation Data using Dendroclimatology science	Monfared Najafi
03-18	The Indian Ocean Dipole in a warming climate	Benjamin Ng
03-19	Changes in the Hadley circulation and its implication for sub-tropical climate	Hanh Nguyen
03-20	Spatial Patterns of Changes in Temperature Extremes across Southeast Australia	Acacia Pepler
03-21	Key Meteorological Factors Contributing to Severe Frost in Winter Crops in Southeastern Australia	Mike Pook
03-22	Aerosol Regional Dimming and its Impact on Rainfall in S.E. Australia	Keith Potts
03-23	Half-Century Air Temperature Change Above Antarctica	James Screen
03-24	Drought Assesment Over Northern Oromia Of Ethiopia	Asaminew Teshome
03-25	Progress towards simulating tropospheric chemistry using UKCA and the ACCESS climate model	Marcus Thatcher
03-26	Influence of time of observation on temperatures in Australia	Blair Trewin
03-27	Multi-decadal Modulation of the El Niño-Indian Monsoon Relationship by Indian Ocean Variability	Caroline Ummenhofer
03-28	The Extreme Wet Season of 2010/11 in Western Australia	Patrick Ward
03-29	Projections for Australian Temperature and Rainfall Emerging from Observed Trends	Ian Watterson
03-30	Southeastern Australian Temperature Variations 1860–1910	Linden Ashcroft

09	**Modelling and observation of land surface and atmosphere interactions: recent advances and future changes**	
09-01	Daily Surface Solar Radiation Estimation Using Neural Network Technique based on Climatological Data	Bahram Bakhtiari
09-02	The Australian community land surface model (CABLE): present status and future development	Ying-Ping Wang
09-03	Using Atmospheric Carbon Dioxide Measurements to Assess Carbon Fluxes Produced by CABLE	Rachel Law
09-04	Offline CABLE in Multiple-processor Mode: Structure, Datasets and Performance	Bernard C Pak
09-05	Parameterization improvements in online version of the Community Atmosphere Biosphere Land Exchange model.	E.A. Kowalczyk
09-06	Modelling the diurnal cycle in ACCESS NWP	Vaughan Barras
09-07	Modeling Surface Radiation Under a Changing Climate	Michael R Grose
09-08	A Wind Tunnel Analysis of Momentum Adjustment Across a Forest Edge with detailed Spatial Resolution	Stuart Nulty

10	**Natural Hazards**	
10-01	Tropical Cyclone Wind Hazard for the Western Pacific	Nicholas Summons

10-02	Assessment of the Consistency of Gust Wind Speed Measurements	L.A. Sanabria
10-03	Adaptation actions and human security in Bangladesh: an analysis of disaster resilient response mechanisms in the context of coastal hazards	Edris Alam
10-04	Developing climatologies of heat stress for Western Australia	Agata Imielska
10-05	Influence of Ocean and Rainfall on the Intensity of Tropical Cyclones	Nicolas Jourdain

13	Storm Track Variability and Changes	
13-01	To what extent are cyclones associated with climate anomalies in high northern latitudes?	Irina Rudeva
13-02	Changes in Southern Hemisphere Jet-streams and Weather Systems	Stacey Osbrough
13-03	Objective methods of frontal recognition – a case study in south western Australia	Kevin Keay
13-04	Using a Self-Organising Map to capture the range of current and future weather systems	Pandora Hope
13-05	An asymmetry within the IOD and ENSO teleconnection pathway to southeast Australian rainfall	Wenju Cai

14	The climate of the last 2,000 years: Bridging the gap between the past and the future	
14-01	A modern analog analysis of out-of-phase pattern between North and South East Asian summer monsoon during the recent 1000 years	Fei Ma
14-02	Interpreting Past Climate Using Southwest Australian Speleothems	Pauline Treble
14-03	Understanding Hydrological Flow in Karst to Improve Paleoclimate Modelling of Speleothems in SE Australia.	Monika Markowska

16	Tsunamis and their Impact	
16-01	Modelling tsunami induced shelf and bay oscillations in Western Australia	Charitha Pattiaratchi
16-02	Holocene Sedimentary Record of Gradual, Catastrophic and Human Influenced Environmental Changes at Moawhitu Wetland, D'Urville Island, New Zealand.	Jessica Cope
16-03	Holocene evolution of four South Coast sites and implications for understanding Australian tsunami risk	Claire Courtney
16-04	Tsunamis in the northeastern Indian Ocean with a particular focus on the Bay of Bengal region – a review	Edris Alam

17	Wind-Generated Waves and their Role in Large-Scale Air-Sea Interactions	
17-01	Wind-generated Long-period Waves in the Southern Ocean Observed by Satellite Laser Altimetry	John Heinrichs
17-02	A three-dimensional, wave-current coupled, sediment transport model for POM	Xiao Hua Wang

Plenary Presentations

A DECADE OF ARGO: ACHIEVEMENTS AND FUTURE OUTLOOK

Susan Wijffels[1], Dean Roemmich[2] and Paul Durack[3]
[1]*CSIRO Wealth from Oceans Flagship, Hobart Tas*
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When first mooted in the late 1990's, the idea of deploying an array of thousands of real-time reporting deep profiling ocean floats spread evenly across the global oceans was considered extremely ambitious by many, and simply preposterous by some. A decade later, the Argo project has largely achieved the goal of sustaining an array of over 3000 active floats delivering high quality temperature and salinity profiles from depths of around 2000m to the surface every 10 days. This data stream has revolutionised our ability to characterise and track subsurface ocean processes across the globe, in particular delivering first order information from poorly sampled regions such as the Southern Hemisphere and winter oceans. In this talk we will describe the status of Argo, its current challenges and possible future evolution. We will also touch on some of the new science based on Argo, including what Argo is telling us about longterm changes in the oceans, and how this relates to the changing global water cycle, sea level and energy budgets.

THE OCEAN: A CONTOUR-WISE VIEW

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A new perspective on ocean circulation is presented. The ocean is sliced along contours of constant temperature and salinity. Flow across such contours is that which influences global budgets of heat and fresh water and, ultimately, the climate system. In such a coordinate, the role of turbulence and air-sea fluxes are distilled and adiabatic flows and fluctuations are removed.

Observed distributions of heat and salt in the interior North Atlantic and Southern Ocean are used to relate large scale flows to rates of mixing. A general tool is then developed for estimating the ocean circulation and mixing purely from mean hydrographic observations; the tracer-contour inverse method. The method relates geostrophic flow across contours of constant tracer to rates of mixing and combines the 3 classical inverse methods of physical oceanography into one framework.

Finally, the fully global circulation of a climate model is considered from a contour-wise or 'thermohaline' perspective. The entire ocean is sliced into iso-volumes of constant temperature and salinity. Averaging the flow in this coordinate is proposed as a robust quantification of the Ocean's Thermohaline Circulation. Only in this coordinate is the globally interconnected and conveyor-like nature of the Thermohaline Circulation revealed.

THE CLIMDEX PROJECT: CREATION OF LONG-TERM GLOBAL GRIDDED PRODUCTS FOR THE ANALYSIS OF TEMPERATURE AND PRECIPITATION EXTREMES

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The CCl/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI) has developed a suite of indices derived from daily temperature and precipitation data with a primary focus on extreme events. These indices have been calculated at station locations using quality controlled data from international daily datasets e.g. daily Global Historical Climatology Network (GHCN-Daily) and the European Climate Assessment (ECA&D), with data sparse regions of the globe supplemented with data from targeted regional workshops. In order to account for the uneven global distribution of stations and in order to easily compare with the output from climate models, these indices were gridded onto a 3.75 longitude x 2.5 latitude grid to create the dataset HadEX. While HadEX made significant advances to our understanding of global changes in temperature and precipitation extremes and allowed evaluation of modelled extremes for the first time using state-of-the-art global climate models, it still suffers from a lack of coverage over large areas (particularly for precipitation extremes), only covers the period 1951-2003 and does not contain the measures of uncertainty required to fully assess the trends and variability in extremes.

This presentation will introduce the “next generation” of global gridded extremes products (the CLIMDEX project) which aim to improve our understanding of the variability of extremes, enhance detection and attribution studies and provide the highest quality observations for model evaluation. Advances over previous datasets include longer-term data availability, delivery via a web interface including near-real time updates, and an assessment of the uncertainty in the gridded products.

CHANGING ATMOSPHERIC CIRCULATIONS, PRECIPITATION PATTERNS, AND CONNECTIONS TO THE BROADER CLIMATE SYSTEM

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Surface winds and precipitation are a primary means by which atmospheric dynamical processes affect the ocean and land surface. Changes in atmospheric circulations and precipitation are associated with diverse impacts such as changes in the ocean circulation, in soil erosion and landslide hazards, and in cloud radiative forcing. In addition to reviewing some of the major challenges in understanding how climate change affects atmospheric circulations and precipitation patterns, I will focus on two specific research questions: the extent to which observations and models constrain the rate of intensification of precipitation extremes with warming, and the extent to which we currently understand controls on the position and intensity of the extratropical storm tracks.

WHAT CAN OBSERVED CLIMATE CHANGE TELL US ABOUT THE FUTURE?

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Projections of future climate change, vital for assessments of future climate impacts and planning of mitigation measures, are usually derived directly from an ad-hoc range of climate model simulations. These projections typically have large uncertainties, which are dependent on the particular climate models used to derive the projections. However, if for example a particular model tends to underestimate historical greenhouse-gas induced warming, it will also tend to predict weaker future warming. Observations of past climate change may therefore be used to constrain projections of future warming, by scaling future warming rates up or down based on a comparison of past simulated warming with observed warming. Scaling factors on the responses to each forcing may be derived using a detection and attribution analysis to compare simulated historical climate change with observed climate change. This talk will begin by reviewing recent developments in the detection and attribution of changes in temperature and other variables, and go on to discuss the use of such results to constrain projections of future climate change.

THE ANATOMY OF AN ANCIENT GLOBAL WARMING EVENT

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The Paleocene-Eocene thermal maximum (PETM) at 55 million years before present is arguably the best ancient analog of modern climate change. The event involved more than 5oC of warming in 10-15 thousand years, fueled by the input of more than 2000 Gt of carbon into the atmosphere. The PETM was associated with the largest deep-sea mass extinction event in the last 93 million years and remarkable diversification of life in the surface ocean and on land.

The abruptness of the onset of the PETM results in the major changes being recorded in centimetres to decimetres of slowly deposited deep-sea sediments. Compounding this problem is the fact that the addition of large quantities of carbon caused dramatic shoaling of the lysocline and calcite compensation depth in the ocean, resulting in pervasive chemical erosion of key sedimentary sections.

In my presentation, I will provide an overview of the effect of abrupt PETM warming and resulting change in ocean circulation on vital plankton groups at the base of the marine food chain. In addition, I will demonstrate how the most complete deep-sea record recovered at Ocean Drilling Program Site 690 in the Weddell Sea, allows us to track the progression of physical (warming), chemical (input of carbon, ocean acidification, increase in continental weathering), and biological changes (extinction, diversification, migration) at the onset of the PETM. In particular, I will attempt to separate the effects of deep-sea dissolution from surface ocean acidification.

THE EVOLUTION OF SPACEBORNE PRECIPITATION SENSORS AND RETRIEVALS – THE IMPACT OF A-PRIORI INFORMATION

Christian Kummerow
Colorado State University

Satellite precipitation retrievals are fundamentally underconstrained requiring either implicit or explicit a-prior information to constrain the solutions. The earliest approaches relied almost exclusively on infra-red observations with empirical relationships to convert cloud top temperature to rainfall rates. Results were not very encouraging as cold, non-precipitating clouds often contaminated the rainfall signatures. Advances were made with the advent of passive microwave observations. Algorithms using Special Sensor Microwave/Imager data were able to exploit emission and scattering indices related to large liquid and ice particles in the storm to the underlying precipitation rates. The first precipitation radar in space arrived with the TRMM mission. It allowed for detailed vertical profiling but the single frequency radar still requires significant assumptions about the potential drop size distribution as well as cloud inhomogeneities below the 4 km resolution of the radar. TRMM also ushered in an era of active/passive microwave retrievals and the challenges as well as opportunities that the synergy afforded. Progress was originally quite slow as a-priori information had to be recast before algorithms could exploit information from both sensors. These developments, however, paved the way for the Global Precipitation Mission, now scheduled for mid 2013. Its core satellite carries a dual frequency radar and state of the art microwave radiometer. This combination of sensors, and the accompanying multi-sensor algorithm will provide a benchmark for global rainfall properties. In the retrieval sense, these observations are also being prepared to serve as the a-priori database of precipitating cloud structures to be used in a Bayesian framework that a much larger number of available passive microwave sensors can exploit to provide a unified, 3 hourly rainfall product. This use of a-priori databases and Bayesian algorithms can also be compared to cloud structures derived through data assimilation schemes. This talk will conclude by comparing retrieved cloud profile information that makes use of the observed a-priori database to cloud profiles determined by ECMWF 'first guess' and 'analysis' for an oceanic convective system observed by SSMI. Differences, where they exist, are likely attributable to the cloud parameterizations used by ECMWF.

Abstracts

Stream 1. General Atmospheric Science

Conveners: Barry Hanstrum, Stephen Lellyet, Steven Sherwood, Peter Steinle.

Oral Presentations

CLIMATE AND WEATHER CULTUROMICS FOR FUN AND PROFIT

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Atmospheric scientists have, in the past, used changes in word frequency in various types of documents to infer variations in changes in climate or weather (eg., Nicholls, 1988; Nicholls, 2011). Such studies have been time-consuming and problematic. The recent digitization by Google Books of millions of books, and the development of software that allows the rapid calculation of multi-century changes in the relative frequency of usage of specific words or phrases in these books (Michel et al., 2010; http://books.google.com/ngrams), provides an opportunity for improved linguistic meteorological archaeology. The large Google Books corpus reduces concerns in earlier work that the lack of comprehensiveness, or subjectivity on the part of the person analyzing the data, could bias results. I will use the Google Books corpus and the ngrams software to show examples of how changes in the relative frequency of usage of meteorological terms such as "fog" can reflect changes in linguistic preferences, cultural and geographic focus, technology, urbanization and industrialization, and possibly even variations and changes in climate or the human and societal adaptation to these. Separation of these various potential influences on the relative changes in usage is a challenge, and great fun.

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RECENT DEVELOPMENTS IN THE BUREAU OF METEOROLOGY'S ACCESS NWP SUITE

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The Australian Community Climate and Earth System Simulator (ACCESS) provides the Australian Bureau of Meteorology with a suite of Numerical Weather Prediction (NWP) systems that incorporate data assimilation and forecast model components developed by the UK Met Office and adapted for local use by the Centre for Australian Weather and Climate Research (CAWCR).

The ACCESS global, regional and national systems feature 4D-VAR assimilation of conventional and remotely sensed data including satellite data not available previously to Bureau NWP systems; e.g. radiance data from the infrared sounder AIRS. The Met Office Unified Model provides the ACCESS forecasts. As well as generating its own forecasts, each ACCESS system provides the nesting conditions for the next higher resolution ACCESS system.

The original operational implementation of the ACCESS NWP suite represented a one-for-one replacement of the components of the Bureau's previous NWP suite and, as such, has provided a significant improvement in forecast skill. CAWCR has recently completed a significant upgrade of the ACCESS system with the intention of providing NWP forecast skill comparable to that of leading NWP centres. The upgrade features a rationalisation of the different ACCESS NWP configurations and a significant increase in their horizontal and vertical resolution.

Another major aspect of this upgrade is the increased use of satellite data, with significant new observation sources in the form of hyperspectral IR data from the IASI instrument, and GPS-RO data. There are also improvements to the calculation of satellite radiance bias corrections.

Here we will give an overview of the ACCESS systems, discuss the recent upgrade and show results indicating the improvements in forecast skill that will result.

CONTROLLING OVERESTIMATION IN ENSEMBLE KALMAN FILTERS

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We consider the problem of an ensemble Kalman filter when only partial observations are available. For small ensemble sizes this leads to an overestimation of the error covariances. We show that by incorporating climatic information of the unobserved variables the variance can be controlled and superior analysis skill is obtained. We then employ this Variance Controlling Kalman Filter to control model error when the model is allowed to be void of stabilizing artificial numerical viscosity.

Part of this work has been published in *Monthly Weather Review* **139** (2011), 2650-2667.

USE OF DOPPLER RADAR FOR NUMERICAL WEATHER PREDICTION

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Doppler radar measures the radial velocity, i.e. the velocity component parallel to the radar beam, of airborne backscatter targets such as precipitation and insects. These observations, which are a proxy for the wind velocity, have high spatial and temporal frequency and are useful for observing and forecasting severe weather. Australia's weather radar network includes Doppler capability in most capital cities and a few regional areas. The Australian Bureau of Meteorology (BoM) is working towards better utilizing these observations for numerical weather prediction (NWP).

The BoM runs the Australian Community Climate Earth-System Simulator (ACCESS) model to forecast weather. To produce a best estimate of the atmospheric state for the model initial conditions, data assimilation is used. This involves combining observations with a modelled short-range forecast (or background). The resulting analysis forms the initial conditions for the subsequent forecast. When running high-resolution models with limited area domains, the background may be provided by a lower-resolution model. Therefore data assimilation can introduce high-resolution weather features into the domain to reduce the spin-up time.

Australia has a sparse observation network. For the smallest model domains, radar can provide a large proportion of the observations. These have a spatial and temporal resolution superior to that of many other observation types. Before assimilation, the radial winds undergo extensive processing to remove erroneous echo, and reduce the observation density and correlations. Radial velocities have been assimilated into the ACCESS-City models that cover Australian capital cities. Test cases include a range of weather events. The radial velocity observations induce small changes to the initial conditions that can adjust where and when precipitation occurs, which can be critical for forecasting severe weather.

HIGH RESOLUTION OPERATIONAL FORECAST FOR HEAT LOAD MANAGEMENT OF FEEDLOT CATTLE IN AUSTRALIA

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The Australian beef cattle industry has an estimated economic worth of 7.9 billion dollars a year and is Australia's largest agricultural exporter. The need to maintain the health of feedlot cattle has significant economic and moral implications. A key concern of animal health is heat stress, with prolonged periods having the potential to cause of a significant number of cattle deaths. To manage the climatic effects on feedlot cattle, a weather forecasting system was developed by the authors to warn cattle feedlot operators of impending adverse weather conditions that could lead to heat stress for feedlot cattle.

A high resolution numerical weather prediction (NWP) model was run from October 2010 to March 2011 for the Australian continent. The hourly heat load index (HLI) and accumulated heat load unit (AHLU) was calculated from model output for feedlot locations across Australia. The model (Weather Research and Forecasting – Advanced Research and Weather (WRF-ARW) model version 3.1.1) was initialized daily from the Global Forecasting System (GFS) at a resolution of 27 kilometres (km) for the Austral-Asian region, with three 9 km nests representing the spatial distribution of registered feedlots.

Model performance was assessed for the meteorological variables that are used in the calculation of hourly HLI and AHLU values. The predictions have been assessed against 91 automatic weather station observations operated by the Bureau of Meteorology that coincide with feedlot locations. It was found that the model performs well out to 3 days. Predictions of relative humidity showed the largest root mean squared error (RMSE) across all sites, which are believed to be due to the model's characterisation of in the Australian land surface.

The movement of warm and moist tropical air masses to southern parts of the continent for extended periods of time likely resulted in prolonged periods of high HLI and AHLU. The synoptic patterns exhibited during these events indicate that fluctuations in the position of the monsoon trough and the interaction of Tropical Cyclones along the eastern and western coasts of northern Australia can modulate the flow of tropical air masses to southern parts of the continent and play a significant role in the development of heat load events. Further study is required to understand the interactions between the movement of tropical air masses, their variability at intra-seasonal timescales and influence on heat load events in Australia.

THE ADELAIDE URBAN HEAT ISLAND: SPATIAL AND TEMPORAL ASPECTS

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Increasing urbanisation requires accounting for the anthropogenic urban heat island (UHI) effect by urban planning. Urban areas produce a major portion of the world's greenhouse gas (GHG) emissions. Mitigation of the UHI effect is achieved through green areas, open spaces and parklands. Adelaide provides a unique setting for studying the effect of parklands on the UHI. The Central Business District (CBD), 2km square, is surrounded by a 500m wide parkland-strip, covered with grass and sparse trees. These parklands can mitigate the UHI. The work reported here is an attempt to quantify their effect.

The study used a network of low-cost temperature sensors to evaluate the spatial and temporal structure of the thermal climate. 41 sensors, deployed in CBD, parklands and suburbs, run since June 2010. Traverses in 2011, measuring atmospheric parameters, achieved a greater temporal and spatial resolution.

Quantifying the UHI under different synoptic conditions has shown the average intensity of the nocturnal UHI in winter 2010 was approximately 3 to 4^{o}C with a maximum intensity of 9^{o}C. The nocturnal UHI was most pronounced during clear and calm conditions. The rural landscape cooled faster and more than the urban area. The UHI intensity shows a minimum difference mid-day to early afternoon and a maximum six to eight hours after sunset. The parklands surrounding the CBD had an air temperature comparable to the rural site, namely cooler than the CBD. The parklands appear to play an ameliorating role in limiting the magnitude of the nocturnal UHI by exchanging warmer and cooler air between regions.

The traverses revealed that the shallow Torrens River valley, which separates the CBD from the adjacent urban area, had a significantly lower temperature than in the CBD and adjacent urban regions. Thermal contour maps showing the extent, strength, and temporal evolution of the UHI will be presented.

IDEALISED SIMULATIONS OF TURBULENCE NEAR THUNDERSTORMS

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Atmospheric turbulence is a significant hazard to the aviation industry because it can cause injuries, damage to aircraft as well as financial losses. A number of recent studies have been conducted in order to explain the mechanisms that are responsible for convectively induced turbulence (CIT), which can occur within the cloud as well as in the clear air regions surrounding the cloud. The majority of these studies were focused on above cloud turbulence, however, relatively little is known about the mechanisms that generate turbulence around thunderstorms. This type of turbulence, also known as near-cloud turbulence, is of particular interest because it is much more difficult to avoid than turbulence within clouds since it is invisible and undetectable using standard hazard methods (e.g. on-board and ground-based radars).

This study examines turbulence generation by organised convection (viz. supercells) using three-dimensional (3D) simulations conducted with the Weather Research and Forecasting model. Results from several high-resolution idealised simulations will be shown, with a focus on the role of 3D cloud-induced flow perturbations on turbulence generation and their sensitivity to different background flow conditions like wind shear. The simulation results show regions of turbulence that extend more than 100 km away from the active deep convection (i.e. regions with high radar reflectivity). These turbulent regions are related to strong upper-level storm outflow and the associated enhanced vertical shear. Simulations also show localised modulation of the outflow jet by small-scale gravity waves (~ 4 km wavelength) that contribute to further destabilisation and susceptibility to turbulence. The results of these simulations and their implications for turbulence avoidance by aircraft will be discussed.

THE ROLE OF NONLINEAR PROCESSES IN THE GENERATION OF GRAVITY WAVES BY CONVECTIVE CLOUDS

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Convective clouds generate gravity waves and these waves are known to have important influences on the momentum budget of the middle atmosphere. Significant advances in our understanding of the wave generation process and the resultant spectrum have been achieved in the last decade using theory, models, and observations. One outcome of this understanding has been the development of a number of new parameterizations of the source spectrum of convectively generated gravity waves for use in general circulation models. These source parameterizations are ultimately based on the linear response to imposed diabatic heating. However, previous studies have shown that nonlinearities within convective clouds play an important role in defining the wave spectrum. In this study, we focus our attention on the characteristics and dynamics of these nonlinearities. In particular, a set of idealized linear and nonlinear models forced by an imposed diabatic heat source are used to explore the role of nonlinearities in the wave generation process. These simulations clearly show that the nonlinearities play the key role in the production of gravity waves that have frequencies close to the Brunt-Väisälä frequency. They also demonstrate that the fully nonlinear wave spectrum is reproduced using a weakly nonlinear source formulation. The implications for these results for improving gravity wave source parameterizations will also be discussed.

NUMERICAL STUDY ON THE FORMATION OF TYPHOON KETSANA (2003) IN THE WESTERN NORTH PACIFIC

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Lu et al. (2011) simulated the formation of Typhoon Ketsana (2011) in the western North Pacific using the Advanced Research version of the Weather, Research and Forecasting (WRF) model (ARW) developed by the U.S. National Center for Atmospheric Research. In particular, the

mesoscale dynamics associated with the generation of mesoscale convective vortices (MCVs) and the roles of mesoscale convective systems (MCSs) during the formation process were investigated. Lu et al. concluded that with the successive occurrence of MCSs, midlevel average relative vorticity was strengthened through generation of MCVs via mechanisms such as vertical stretching and eddy fluxes. Through sensitivity experiments to modify the vertical humidity profile in each MCS, it was found that the development of a MCS depends substantially on that of the prior ones through remoistening of the midtroposphere, and thus leading to different scenarios of system intensification during the typhoon formation.

This study further analyzes the formation mechanisms of this typhoon case by examining the warm core formation process and contribution from the convective-scale vertical hot towers (VHTs). For the warm core generation, it was identified in the ARW simulations that every MCS was associated with strong mid- to upper-level heating as typically found in stratiform clouds. However, how these heating associated with the MCSs lead to the warm core when the tropical cyclone forms was not extensively discussed in previous studies, and will be one of the key questions to answer. On the other hand, scale separation showed that the activity of the VHT-type vortices correlated well with the development of the MCSs. These VHTs have large values of positive relative vorticity induced by intense low-level convergence. A quantitative comparison between the relative contributions from these VHTs and the MCSs to the typhoon formation will be performed, and mechanisms by which the VHTs can get organized to form the system-scale surface vortex will be identified.

PROBABILITY OF PRECIPITATION MEDIUM TERM (1-7 DAYS) FORECASTING FOR AUSTRALIA.

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Guidance for Probability of Precipitation (PoP) forecasts issued by the Australian Bureau of Meteorology is produced by the Gridded Operational Consensus Forecasting System (GOCF) using forecasts of rainfall amount from a Poor Man's Ensemble (PME) of Numerical Weather Prediction (NWP) output from a number of international centres.

In the present GOCF system the PoP is forecast using the proportion of ensemble members that predict rainfall exceeding a given threshold, calibrated using historical data. At least several months of data is required to obtain a stable calibration. An alternative approach currently being implemented is to use the Quantitative Precipitation Forecast (QPF) as the predictor and to develop statistical relationships between PoP and QPF based on historical data.

The probability of receiving precipitation greater than a given threshold is found to increase with an increasing QPF. Following the work of Sloughter et al., a statistical model has been developed consisting of a logistic equation to predict the probability of rain >0.2 mm and a Gamma function for the probability density function of rainfall amount given rain above that threshold. The parameters of these functions are fitted to historical data. This method produces reliable and skillful PoP forecasts and allows a range of extra statistics to be easily produced. Furthermore, it requires a much smaller amount of historical data than the calibrated model counting method.

Different climatic regions (eg the topics and Tasmania) will likely need different calibration co-efficients. An approach that automatically selects calibration regions based on past forecasts/observations relationships has been developed.

The prediction methodology and the approach used to select calibration regions will be outlined, and verification statistics on the performance of the system will be presented.

Sloughter, J.M., A. Raftery, T. Gneiting, and C. Fraley, *Probabilisitic Quantitative Precipitation Forecasting Using Bayesian Model Averaging*, Monthly Weather Review, 2007, 135, 3209-3320.

PRECIPITATION CASE STUDIES OF SYNOPTIC WEATHER REGIMES IN SOUTH EASTERN QUEENSLAND, AUSTRALIA

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The present study uses kmeans cluster analysis of soundings from Brisbane Airport to determine 8 synoptic regimes associated with rain and no-rain days in south-eastern Queensland. The region of interest is the land area east of 151°E and lying between 29°S and 26°S. The terrain rises rapidly from the coast to the ridges of the Great Dividing Range, with a maximum elevation of about 1000 m in the south of the region. The terrain tends to confine the rainfall to the coast, with the monthly rainfall decreasing to the west of the ridges around 152°E.

Four of the regimes are associated with moist conditions each account for about 15-20% of the mean total annual rainfall. These regimes preferentially occur during the summer and are characterized by high onshore moisture flux. The four dry regimes are characterized by southerly moisture flux and generally occur throughout the year. These regimes combined account for less than 25% of the mean total annual rainfall but more than 60% of the days in a year.

Case studies for each of the four moist regimes were investigated using the Weather Research and Forecasting (WRF) model. Model data was validated using in situ observations and radar observations. Precipitation initiation mechanisms and dynamics are discussed.

WARM-SEASON FRONTAL PRECIPITATION AND ITS MOISTURE SOURCES

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A large proportion of warm season precipitation in southeast Australia is derived from cold frontal systems. The synoptic-scale flow associated with these fronts is responsible for notable moisture advection that, along with the frontal ascent, is an important ingredient in the formation and amount of precipitation. Indeed, the most common precipitation bearing systems are those whose analyzed cold front extends into the tropical regions. These fronts, sometimes referred to as 'interacting fronts', are said to tap into the tropical moisture reservoir, with the synoptic flow creating a pathway for tropical moisture to reach the midlatitudes. But where does this moisture actually come from? Answering this question is crucial to establish the physical link between the precipitation in southeast Australia and the known large-scale drivers of variability, many of which manifest as tropical circulation anomalies. Moreover, recent work has shown that warm-season precipitation in southeast Australia shows a weaker relationship to the common large-scale drivers of variability than during other periods of the year. Therefore, there is a need to better understand the processes underlying these warm-season events.

Simulations using the Weather Research and Forecasting (WRF) model of two warm-season precipitation events are considered. To expose the moisture transport processes a suite of (online) passive scalars are also included. These scalars demonstrate the importance of the Coral Sea in providing the moisture that eventually falls as precipitation in southeast Australia. In particular, the pre-frontal flow leads to moistening of the eastern states, preconditioning the environment for the front's arrival. The results also demonstrate that the tropical regions directly to the north and northwest of Australia play only a secondary role in providing moisture to the southeast.

INVESTIGATING THE RELATIONSHIP BETWEEN LARGE-SCALE AND CONVECTIVE STATES IN THE TROPICS

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One of the challenges when developing numerical weather and climate models is improving convective parameterisations. The difficultly arises in determining how to represent the small-scale, sub-grid convection as a function of the large-scale atmosphere.

The lack of concurrent observations of large-scale and small-scale states over a sufficient periods of time to obtain robust statistics is a limiting factor when determining the relationships required in convective parameterisations.

A new data set is presented that uses a hybrid approach to combine reanalysis data with rainfall observations to determine the large-scale atmospheric state for 3 wet seasons over Darwin, Australia. The small-scale convective state is derived for the same time period from radar data using a variety of techniques including objective identification of cells. Analysis of these two data sets provides a fuller picture of the relationships that exist between convection and the large-scale atmosphere. We are able to test some assumptions made in convective parameterisations, determine how stochastic relationships are and probe where stronger relationships may exist.

THE DYNAMICS OF SUBTROPICAL ANTICYCLONES

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The aim of this study is to better understand the dynamics of subtropical anticyclones in the Australian region as rainfall in the winter and heatwaves and bushfires in the summer are very strongly connected to the strength and position of the anticyclones. Climatologies of some of the important dynamical properties of subtropical anticyclones are calculated from the ERA Interim reanalyses and compared in detail to AMIP-style ACCESS model runs to assess the accuracy of the model.

Among the important quantities calculated is the psi vector, which is a generalized vector streamfunction defined in such a way as to objectively decompose three-dimensional divergent circulations into two circulations projected onto zonal and meridional vertical planes. The psi vector provides a way of distinguishing between meridional circulations, which might be thought of as local a Hadley circulations and a local circulation associated with SAM, and zonal circulations, which can be identified with the localized heating of the continent. An important point here is that the local Hadley and SAM circulations are not defined by zonal averaging and, therefore avoid conflating the local heating effects with remote heating (convection associated with the Asian monsoon and ozone-related heating at high southern latitudes). Moreover, after defining the divergent circulation in terms of the psi vector, the omega equation separates into component equations for the zonal and meridional circulations. The component forcing terms provide a way of identifying the physical processes responsible for the divergent circulations, and hence, the subtropical anticyclones themselves.

A NEW LOOK AT THE INTERCONNECTIONS BETWEEN PRECIPITATION DRIVERS OVER AUSTRALIA

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El Niño – Southern Oscillation (ENSO) is the dominant large – scale precipitation driver over Australia. Other contributing drivers include the Southern Annular Mode (SAM), Indian Ocean Dipole (IOD), blocking (BLK), subtropical ridge (STR) and subtropical jet stream (STJ). Previous studies have primarily focused on a single driver in isolation, however Risbey et al. 2009 identified the leading driver in each grid cell over Australia. While this work provides insight into the lead driver, it does not describe how the drivers interact.

In our investigation of the interconnections between precipitation drivers over Australia, we have implemented partial correlations (PC). Linear chain graphs of partial correlations between precipitation, ENSO, SAM, IOD, BLK, the strength and position of both the STR and STJ were investigated for the winter months of June, July and August. Precipitation data from the Australia Water Availability Project (AWAP) was used together with NCAR Reanalysis data for MSLP, zonal wind, geopotential height and SST.

Two regions of interest were identified, south Western Australia (SWA) (115-120°E, 30-35°S) and southern Victoria and Tasmania (VIC/TAS) (138-150°E, 35-45°S). Preliminary results indicate that in both of these regions the dominate correlation is between the latitude of the STR and precipitation, where more precipitation occurs when the STR is poleward, which is contradictory to expectations. Notable indirect influences include the link between strong STR and STJ events with La Niña, as well as strong STR with negative SAM events. The STR is stronger when in its equatorward position, however this is not true for the STJ whose position and latitude are not correlated. An interesting missing link is between the latitude of the STJ and STR, which are generally assumed to be related.

Further analysis was conducted and the interconnections from the reanalysis investigation were compared to those found from CMIP3 model runs.

Risbey, J. S., M. J. Pook, P. C. Mclntosh, M. C. Wheeler, and H. H. Hendon, 2009: On the remote drivers of rainfall variability in Australia. Mon. Wea. Rev., 137, 3233–3253, DOI: 10.1175/2009MWR2861.1

INTRA-SEASONAL PREDICTION OF REMOTE DRIVERS OF AUSTRALIAN CLIMATE VARIABILITY USING POAMA-2

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We assess the ability of the Predictive Ocean Atmosphere Model for Australia version 2 (POAMA-2) to represent remote drivers of intra-seasonal climate variability over Australia using an 18-year, 33-member ensemble hindcast dataset. POAMA-2 is the new generation of the Bureau of Meteorology's coupled ocean-atmosphere climate model and data assimilation system. The model includes enhancements to the ensemble generation and initialisation strategy, provided by a novel pseudo-coupled data assimilation system, specifically designed for forecasting at the intra-seasonal timescale. Our analyses primarily focus on the simulation and prediction of weekly rainfall anomalies in association with three key climate drivers: the Madden-Julian Oscillation (MJO), the Southern Annular Mode (SAM), and blocking in the Australian region.

POAMA-2 is shown to simulate well the weekly-mean rainfall variation associated with the evolution of the MJO over the tropical Indo-Pacific. Weekly rainfall anomalies associated with the SAM and blocking are also simulated reasonably well over the Australian region. Skilful prediction is achieved out to about 3 weeks for the MJO index and 2 weeks for the SAM and blocking indices, with POAMA-2 outperforming its predecessor POAMA-1.5 in its ability to predict all 3 climate drivers. These results translate to enhanced predictability of rainfall in weeks 2 and 3 over much of the tropical Indo-Pacific when the MJO is present in the initial conditions compared to when the MJO is not present in the initial conditions, and over parts of the Australian continent for the other climate drivers.

TROPICAL TROPOPAUSE LAYER PROCESSES DRIVING SHORT-LIVED SUBSTANCE CONCENTRATIONS

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The properties of the tropical tropopause layer have changed in recent decades, e.g. increases in greenhouse gases (GHGs), and associated changes in dynamics, have cooled the tropical tropopause layer thereby decreasing *in situ* water vapour and partially offsetting surface climate warming. From 1984 to 2005, ozone in the tropical tropopause layer declined, affecting radiative forcing in the tropical tropopause layer region. Water vapour in the tropical tropopause layer modulates much of the chemistry that affects ozone, sulfur and halogen compounds. As a result, understanding water vapour transport through the tropical tropopause layer, its chemical interactions with trace species, and associated aerosol and cloud formation, is a prerequisite to understanding the processing of sulfur and short-lived substances in the tropical tropopause layer.

Here, we compare models of increasing complexity for their description of the dehydration processes through the tropical tropopause layer including convective influence. The effect of the temperature perturbations due to gravity waves is included. Convective detrainment into the Lagrangian advected airmasses using ERA-Interim detrainment rates is also considered. The accuracy of this representation of convective influence is explored using archived ERA-Interim detrainment rates compared to cloud resolving convective models. The seasonality of the stratospheric water vapour at 400 K is reproduced and the sensitivity to convectively delivered sulfur and other short-lived species is discussed.

CHARACTERISATION OF AEROSOLS OVER AUSTRALIA AND NEW ZEALAND AND EFFECTS ON SURFACE UV RADIATION

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Aerosols play a key role in the radiation balance of the earth-atmosphere system, can play a significant role in atmospheric chemistry through heterogeneous reaction, and can have significant localised impacts on respiratory health. Through scattering and absorbing solar ultraviolet (UV) radiation, they can affect health indirectly by altering UV exposure and affect the availability of solar energy.

This study characterised aerosols at several sites in Australia and New Zealand using ground-based observations. Five aerosol classes were identified, including one class of bushfire smoke. Of the sites studied, Darwin had the greatest aerosol concentrations as well as the most distinct seasonal trends. In particular, aerosol concentrations over Darwin were found to increase as the bushfire season intensifies.

The optical properties of “standard” aerosol types used in many radiative transfer models are based on northern hemisphere measurements. Coincident aerosol optical depth measurements and UV spectra collected at Darwin provide an opportunity to compare the UV to visible optical properties of the aerosols observed over Darwin with those of the “standard” northern hemisphere aerosols types.

Potential long-term health effects due to reductions in surface UV radiation at these sites were investigated using radiative transfer modelling, with the results expressed in terms of the effective sun protection factor (SPF). The modelled effective SPF due to aerosols is less than 1.12 – 1.3 on 95% of days at all sites using a range of northern hemisphere aerosol types. The highest estimate using the tropospheric aerosol type in the measurement period is 1.25, which occurred at Darwin. The long-term averaged impacts on UV exposure and health are likely to be very small compared to typical lifestyle factors, such as the amount of time spent outdoors and the use of sunscreen and sun-protective clothing.

TRANSIENT ANTICYCLONES AND THE ROLE OF ROSSBY WAVE BREAKING IN HEATWAVES OVER SOUTHERN AUSTRALIA

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Strong transient anticyclones are a common feature of severe weather conditions in summer over the southern parts of Australia, directing hot dry air from the continental interior toward the coastal regions. It is hypothesised that heat waves in this region are associated with propagating Rossby waves, which grow in amplitude and eventually overturn. The resulting stirring in the atmosphere generates a low level anticyclone over southern Australia, as well as an upper level trough.

Using ERA-Interim data from 1989-2009, together with the Australian Bureau of Meteorology’s High Quality Temperature Dataset, the development and characteristic dynamics of the large-scale atmospheric processes surrounding heatwave events over several centres in southern Australia is examined. The link between these events and rainfall in the northeastern parts of the continent is discussed, as well as the geographical and dynamical sources of the Rossby waves.

FRONTS AND PRECIPITATION IN OBSERVATIONS AND CLIMATE

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Atmospheric fronts are important for the day-to-day variability of weather in the midlatitudes, particularly during winter when extratropical storm-tracks are at their maximum intensity. Fronts are often associated with heavy rain, and strongly affect the local space-time distribution of rainfall. Although global climate models should be expected to represent the baroclinic systems within which the fronts are embedded, the fronts themselves and precipitation processes within them are of much smaller scale. As a consequence, models with the typical horizontal resolution of contemporary climate models do not necessarily accurately capture these features.

A recently developed objective front identification method applied to reanalysis data will be combined with a daily global rainfall data set to investigate how precipitation around the globe is associated with atmospheric fronts. The study will cover extratropical frontal features associated with mid-latitude baroclinic systems, sub-tropical "fronts" such as the South Pacific Convergence Zone (SPCZ), and various frontal features over the Australian region. Having established the observed distribution of fronts and their role in producing precipitation, the occurrence of fronts and the associated precipitation is then evaluated in a state-

of-the-art climate model, the Australian Community Climate and Earth System Simulator (ACCESS). The evaluation will highlight issues in the model in locating frontal features correctly, as well as identifying the within-front rainfall distribution, thereby providing a methodology for the evaluation of models in a process-oriented fashion.This is the abstract text. It should be in style “AbstractText” (Times New Roman 11 point, justified, 12pt space before each paragraph). A space is automatically inserted before each paragraph. Don’t use a tab to indent paragraphs.

Poster Presentations

1.1. ANALYSES OF INVERSIONS AND STABILITY IN THE SURFACE LAYER USING HIGH RESOLUTION SONDE DATA AND SIGMA THETA OBSERVATIONS

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The connection of the earth’s surface to the troposphere is modulated by the stability in the surface layer, the lower part of the boundary layer.

One measure of stability in the surface layer is the presence and strength of associated inversions. We have used 10 years of Bureau of Meteorology high-resolution sonde data from several sites to analyse the presence and diurnal evolution of surface level inversions. A characterisation of the surface layer inversions is presented in terms of their climatology and also in terms of easily obtained surface temperatures – the minimum, maximum and current temperatures.

Another measure of stability in the surface layer is the quantity, sigma theta, which is the standard deviation of the wind direction. Though not widely used by the Bureau, this quantity is recorded at all Bureau AWS (Automatic Weather Stations). Analyses of sigma theta are summarised and related to the presence and strength of surface layer inversions.

The motivation for these investigations is to assist agricultural operators in identifying meteorological conditions where it is safe or unsafe to spray pesticides including herbicides.

1.2. NON-LINEAR AND NON-STATIONARY INFLUENCES OF GEOMAGNETIC ACTIVITY ON THE WINTER NORTH ATLANTIC OSCILLATION

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The relationship between the geomagnetic aa index and the winter North Atlantic Oscillation (NAO) has previously been found to be non-stationary, being weakly negative during the early 20th century and significantly positive since the1970s. The study reported here applies a statistical method called the Generalised Additive Modelling (GAM) to elucidate the underlying physical reasons.

We find that the relationship between *aa* index and the NAO during the Northern Hemispheric winter is generally non-linear and can be described by a concave shape with a negative relation for small to medium *aa* and a positive relation for medium to large *aa*. The non-stationary character of the *aa*-NAO relationship may be ascribed to two factors. Firstly, it is modulated by the multi-decadal variation of solar activity. This solar modulation is indicated by significant change points of the trends of solar indices around the beginning of solar cycle 14, 20 and 22 (i.e. ~1902/1903, ~1962/1963, and ~1995/1996). Coherent changes of the trend in the winter time NAO followed the solar trend changes a few years later. Secondly, the *aa*-NAO relationship is dominated by the *aa* data from the declining phase of even-numbered solar cycles, implying that the 27-day recurrent solar wind streams may be responsible for the observed *aa*-NAO relationship. It is possible that an increase of long-duration recurrent solar wind streams from high latitude coronal holes during solar cycles 20 and 22 may partially account for the significant positive *aa*-NAO relationship during the last 30 years of the 20th century.

1.3. VALIDATION OF TRMM DAILY PRECIPITATION ESTIMATES OF TC RAINFALL USING PACRAIN DATA

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Since its launch in 1997, Tropical Rainfall Measuring Mission (TRMM) precipitation products have been widely used in tropical cyclone (TC) rainfall studies. As satellite data are indirect estimates of rainfall, it is important to evaluate their accuracy and expected error characteristics. Previous validation studies were mainly made over land, with no TRMM validation studies of TC rainfall having been done over the ocean before.

This study is to validate TRMM daily precipitation estimates of TC rainfall using the Comprehensive Pacific Rainfall Database (PACRAIN) of 24h rain gauge observations. The evaluation is done on both atoll sites, which represent open ocean conditions and coastal sites and islands, which may be influenced by the topography, so that we can compare TRMM's performances for different terrain. The results show that TRMM 3B42 has reasonable skill at detecting TC rains. The performance on atoll sites (over ocean) is better than on coastal sites (over land), and it is better able to estimate the intensity of the TC heavy rains on atoll sites. This gives users more confidence to use TRMM data to analyse TC rainfall over the ocean. TRMM 3B42 is less impressive at coastal sites where it underestimates TC heavy rains, suggesting that TRMM is not able to detect orographic enhancement during TC landfall.

1.4. HIGH-RESOLUTION SIMULATIONS OF A SPRINGTIME PRECIPITATION EVENT IN THE AUSTRALIAN ALPS

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A significant challenge today is the prediction of orographic precipitation in regions of complex terrain. Operational numerical weather prediction models simulate the atmosphere using grid scales of order 10 km, and while for many synoptic weather systems these scales are small enough to capture many important physical processes, they are still too large to properly simulate cloud processes and precipitation. Small-scale detail in topography is also not adequately captured. Forecasts of precipitation over mountainous regions (such as SE Australia) therefore tend to be overly smooth and featureless, failing to capture the important spatial variability that is present in the observations.

The Weather Research and Forecasting (WRF) Model V3.3 is used to simulate a springtime precipitation event in the Australian Alps using an inner domain with 1.1 km grid spacing. The event was characterized by the passage of a relatively short-lived pre-frontal event with orographically induced precipitation, followed by a more prominent orographically enhanced frontal system. The upstream flow conditions that characterize these events are considered in the context of known flow regimes, and the relationship between terrain geometry and the spatial patterns of precipitation is examined. Finally, an ensemble of upstream conditions for this event is constructed to examine the sensitivity of Alpine precipitation.

1.5. RECREATIONAL TORNADO CHASING IN THE UNITED STATES GREAT PLAINS

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During the past decade, the act of 'storm chasing' has become a recreational activity. Once largely reserved for dedicated atmospheric scientists and the occasional ill-placed local citizen, storm chasing has become more accessible due the spread of mobile broadband internet. It is now possible to receive continuous streams of weather data while on the road, making the pursuit of severe storm events much easier than ever before. Such advancements have led to the commercialization of footage of destructive weather, and the creation of television shows such as 'Storm Chasers', which have spurred dramatic growth in amateur participation and public interest in the activity.

Amongst the wide variety of weather events pursed by storm chasers, the tornado remains the most elusive of such events. Generally short in duration and small in scale, placing ones self in a safe place to observe, document and escape a tornado takes a great deal of skill and experience. But how do amateur storm chasers forecast, target, pursue and document tornadic supercells? What does the act of 'tornado chasing' entail?

A review of the forecast resources, navigation materials, software products and real time data streams used in the pursuit of tornadic storms in the U.S. Great Plains will be covered. In addition to the technical aspects of chasing, the 'real' side of tornado chasing will be discussed, with topics ranging from the true dangers behind the activity to what storm chasers do when the weather is nice. Ethical questions will be briefly discussed and personal accounts will be shared.

1.6. DETERMINING STATISTICAL UNCERTAINTIES ASSOCIATED WITH OBSERVING CONVECTIVE OVERSHOOTS IN THE TTL USING TWP-ICE WRF SIMULATIONS

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Appropriate measurements of deep convection penetrating the Tropical Tropopause Layer (TTL) are important as they help to constrain the degree of influence that such convection has on the humidity of the region. With its high time-resolution, ground-based radar can potentially quantify the statistics of overshoots reaching into the TTL, including its frequency of occurrence, areal coverage and depth. Such statistics are important as they can be used to help estimate the total amount of water transported into the TTL by these convective overshoots. However, the veracity of these statistics is affected by systematic biases associated with limitations of the radar platform itself (e.g. the effects of radar beam geometry) and its imposed scanning strategy. At present, it is still unclear how these inherent uncertainties are quantified in the bulk statistics derived from gridded radar products, despite them being used often.

In this study, statistical uncertainties of convective overshoots in the TTL are assessed using an abridged observing system simulation experiment approach. Simulated cloud populations during the Tropical Warm Pool-International Cloud Experiment are sampled using an algorithm designed to mimic the volumetric scanning strategy and observational constraints of the C-POL radar near Darwin. Bulk statistics from these synthetic radar observations are compared with those derived from model 'truth' (i.e., absolute reflectivities that would be measured if there was no signal attenuation and gaps in coverage) in order to assess the statistical errors due to these constraints. The spread of these uncertainties are determined and measurement biases in the TTL are found to be related to both vertical smearing (due to beam geometry) and insufficient sampling (due to vertical gaps between adjacent beams). Implications for total water transport in convective overshoots will be discussed.

1.7. SECONDARY EYEWALL FORMATION AND EYEWALL REPLACEMENT CYCLES IN HURRICANE SIMULATIONS: EFFECT OF UNBALANCED FORCES

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Secondary Eyewall Formation (SEF) and Eyewall Replacement Cycles (ERC) are successfully simulated with Mesoscale Model (MM5) at high resolution (0.67 km). The simulated hurricane is initialized from a weak synthetic vortex representing a tropical disturbance in a quiescent environment. After 12 hour spin-up and 48 hour rapid intensification, the vortex reaches category 4 intensity with azimuthal mean tangential wind of 62 ms^{-1} and minimum sea level pressure of 938 hPa. Then the hurricane reaches the stage of relative slow evolution. The minimum sea level pressure slowly decreases. The clouds in the eyewall become more tighten. At about 78 hour, the convective clouds in 50-70 km radius are organized into a ring. The formation of secondary tangential wind maximum coincides with this outer cloud ring indicates that a SEF has occurred. The secondary eyewall then propagates inward and amplifies its tangential wind. The inner eyewall weakens and is eventually replaced by the outer eyewall. This is one typical ERC, which repeats five times during the simulation from 72-h to 237-h with quasi-period of 33-h.

Model diagnostics reveal that the radial unbalanced force (sum of pressure gradient, centrifugal, Coriolis and surface friction forces in the radial direction, UBF hereafter) near the primary eyewall plays a crucial role in SEF. Positive UBF occurs inside the radius of maximum tangential wind (RMW), and negative UBF occurs outside the RMW. As a dynamic response of radial momentum equation to this unbalanced force, a secondary maximum convergence zone (SMCZ) of radial flow in the boundary layer is generated outside the negative UBF zone at around 50 km radius. In the moist, conditionally-unstable atmosphere, the vertical updraft at the boundary layer top of SMCZ triggers the moist convections systematically, which results in SEF in SMCZ.

1.8. ASSESSING THE IMPORTANCE OF THE AUSTRALIAN RADIOSONDE NETWORK TO NUMERICAL WEATHER PREDICTION SYSTEMS.

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Previous studies have attempted to quantify the effect of the Australian radiosonde network, however recent major advances in both Numerical Weather Prediction (NWP) modelling and remote sensing systems require this problem be revisited as up-to-date information is essential for observational network planning and assessment.

An assessment is presented on the impact of Australia's radiosonde network and aircraft meteorological data relay (AMDAR) observations to short and medium range forecasts generated by the Australian Community Climate Earth-System Simulator (ACCESS) NWP system over global, regional and Australian domains. Observing System Experiments (OSEs) were conducted over the period March 22 2010 – June 30 2010 when additional 12Z radiosonde flights were temporarily scheduled at twenty–four stations over the Australian mainland.

We discuss the impact of sustained additional observations over this period on both analyses and forecasts at a variety of scales, using both observations and analyses as reference data sets. These experiments show positive mid-range forecast impacts from inclusion of extra radiosonde data considered over the full depth even though the sonde releases only go from once a day to twice daily.

1.9. ERROR AMPLIFICATION AND PREDICTABILITY OF HEAVY PRECIPITATION EVENTS IN CLOUD-RESOLVING ACCESS MODEL

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In this study, the dynamics associated with the growth and propagation of initial uncertainties is investigated by means of a real-case study with high-resolution (1.5 km) cloud resolving ACCESS model integrations. The considered case is Brisbane/ Toowoomba flood which happened in January 10th 2011, involving convection and heavy precipitation. To assess the predictability of the flood, vastly different initial perturbations are compared, while some of the simulations use identical lateral boundary conditions to mimic a perfectly predictable synoptic-scale flow, the others use different lateral boundary conditions to mimic the error from synoptic-scale flow.

Analysis shows that the precipitation fields will be quite different from each other along with the time integration, although the initial perturbations are small. The differences of precipitation cells inside the large precipitation band could be more than 100 mm/day. Analysis also shows that the error growth can quickly (~1 h after initialization) develop far away from the location of initial perturbations. This rapid radiation of the initial uncertainties throughout the computational domain is due to both sound and gravity waves, and their speed has been modified by the model numerics. This result reveals that the triggering and/or growth of perturbations over regions of convective instability are important error amplification mechanisms. The growth of the uncertainties is then limited by saturation effects, which in turn are controlled by the larger-scale atmospheric environment.

From a practical point of view, the combined effects of rapid propagation, fast amplification, and inherent nonlinearities of moist physics may cause severe difficulties for convective scale ensemble prediction system (EPS) and data assimilation.

1.10. PYTHON-BASED PLOTTING FOR ACCESS NWP FORECASTS

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A range of new weather forecast charts have been provided to the public based on the Bureau's operational numerical weather prediction systems. These charts were released in 2009, coinciding with the ACCESS versions of the Bureau's NWP systems becoming operational. The current version of the displays is based on proprietary software from the ECMWF. A new version of these forecast charts has been developed using freely available software based on python and the associated library matplotlib. The new versions have the same appearance as the operational displays, but are more adaptable and open-ended. With the new software, the chart plotting would be straightforward for others to employ who may be interested in producing similar types of plots.

1.11. THE BUREAU OF METEOROLOGY'S NEXT GENERATION HIGH RESOLUTION NWP SYSTEMS

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As part of the Australian Government's Strategic Radar Enhancement Project, a new generation of high resolution numerical weather prediction (NWP) systems is currently being developed. Based on the Australian Community Climate and Earth-System Simulator (ACCESS) system, these models endeavour to provide improved forecasts of convective events via the assimilation of rainfall, Doppler radar winds as well as the standard observations available to larger scale NWP models to drive high resolution (1.5km) forecast models. This talk will provide an update on the development of these systems with particular emphasis on the Queensland floods of January 2011 and an extended trial over Sydney during spring 2011.

1.12. THE EFFECTS OF ENSO ON HIGH IMPACT WEATHER IN QUEENSLAND

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The study focuses on the teleconnection between the El Niño-Southern Oscillation (ENSO) and high impact weather (tropical cyclones and heavy precipitation) in the north-east of Australia. ENSO is found to significantly shift location of tropical cyclogenesis and tracking in the south-west Pacific, such that in La

Niña seasons tropical cyclones form nearer to, and more frequently track across, Queensland. This observed south-westward shift in cyclone genesis and tracks is captured, to some extent, by a high-resolution atmosphere-only model. The physical mechanisms related to the ENSO-tropical cyclone teleconnection in observations and the model are examined, however firm conclusions could not be made.

Observational data is used to show that heavy precipitation events are significantly more frequent in La Niña years across most of Queensland, particularly in austral spring. Whilst previous studies have found an asymmetric ENSO-rainfall teleconnection in parts of Queensland (where the magnitude of La Niña events has a stronger effect on total rainfall than the magnitude of El Niño events) a similar asymmetric relationship involving heavy rainfall is not observed. The Interdecadal Pacific Oscillation (IPO) is found to have a modulating effect on the ENSO-heavy precipitation teleconnection with more frequent heavy-rain events during the La Niña-like IPO negative phase.

1.13. AN OBSERVATIONAL STUDY ON THE RAINFALL DISTRIBUTION OF LANDFALLING TROPICAL CYCLONES IN THE NORTHWESTERN AUSTRALIAN REGION

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This study attempts to identify the physical processes associated with the land-sea differences during tropical cyclone (TC) landfall through the analyses of data from five TCs during the 2005/06 to 2009/2010 seasons that made landfall along the northwestern coast of Australia based on available rain gauge data, satellite IR brightness temperature and radar-estimated rain rate. Whereas the distributions of deep convection do not show much asymmetry for the five TCs as seen in satellite IR brightness temperatures, the radar-estimated rainfall clearly reveals that most of the rainfall associated with the TCs are concentrated on either the front-right or rear-right quadrant during landfall with respect to landfall direction. That is, most rainfall occurred on the offshore-flow side of the TCs.

Potential mechanisms responsible for this observed asymmetry in rainfall distribution are discussed. These include the deep-tropospheric vertical wind shear that is observed to change to more westerly especially right after landfall and more northerly during landfall for these five TCs. These changes in shear are attributed to increased mid-to-upper-level westerlies and mid-to-low-level southerlies. Another influence from land is the reduced surface moisture flux, but the effect through modifying the convective stability within the environment may not be local and sometimes can be advected to more inland or at the offshore flow location by the TC circulation. The low-level environment of the five northwestern Australian TCs mostly remain convectively unstable during landfall, and thus the effect of reduced moisture flux is not apparent. However, in the case of TC Glenda, a layer of low-level stable air is believed to affect the resulted rainfall distribution. These observational results reveal the necessity to further investigate these mechanisms through numerical simulations.

1.14. REDUCED STOCHASTIC CLIMATE MODELS FOR DATA ASSIMILATION

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We consider a deterministic multiscale toy model in which a chaotic fast subsystem triggers rare transitions between slow metastable regimes, akin to weather or climate regimes in the context of climate dynamics. Using homogenization techniques we derive a reduced stochastic model as a stochastic parametrization model for the slow dynamics only. We show that the stochastic reduced model can outperform the full deterministic model as forecast model in an ensemble data assimilation procedure, in particular in the realistic setting when observations are only available for the slow variables. We relate the observation intervals for which skill improvement can be obtained to the time scales of the system. We then set out to explain why stochastic climate models produce superior skill in an ensemble setting. The improvement in skill is due to the finite size of the ensemble, and we show that there is no skill improvement in very large ensembles or when the forecast variance is artificially and unreasonable inflated. We corroborate this with numerical simulations.

1.15. A STATISTICAL MODEL OF THE LARGE-SCALE DISTRIBUTION OF TROPICAL CONVECTION

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The large-scale atmospheric conditions associated with global tropical cloud regimes derived from the International Satellite Cloud Climatology Project (ISCCP) are examined. The cloud regimes are constructed using cluster analysis, statistically independent of any atmospheric variables, on 23 years of ISCCP D1 data between 35°N and 35°S. 19-year composite-analyses with the European Centre for Medium-Range Weather Forecasts Re-analysis (ERA-Interim) data are used to characterise the thermodynamic stability, water content and dynamics of the environment in each regime. Convective regimes are generally wetter, warmer and are associated with large-scale upward motion, while cumulus and stratocumulus regimes are identified with opposite conditions. However, there are regimes that straddle between the two extremes. One regime, suggestive of congestus cumulus, possesses convective attributes but resides in a cooler and more stable atmosphere. Another regime, largely composed of thin cirrus, is generally devoid of deep convection but has properties akin to convective regimes.

The atmospheric properties of the regimes are exploited as the basis for a stochastic model of the large-scale distribution of convection over the tropical oceans. Using simple rules, a field of cloud regimes is evolved according to known atmospheric variables and its fidelity assessed through comparisons with observed regime statistics. The stochastic model can be used as a representation of tropical convection in simple models or as a stochastic constraint in the representation of convection in general circulation models.

1.16. VERIFICATION OF WRF UPPER-AIR VARIABLES FOR QUANTITATIVE PRECIPITATION FORECAST OF SNOWY MOUNTAIN REGION

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Quantitative precipitation forecast (QPF) and estimation (QPE) are important for water management and planning, especially over a water catchment area such as the Snowy Mountain Region. A method of statistical downscaling is explored in which the surface precipitation is adjusted based upon daily weather patterns (Bellone et al. 2000). Here, 20 years of nearby upper air soundings were classified by a K-mean cluster analysis with four rainfall regimes were identified.

The quantitative rainfall forecast skill of upper air sounding data is found to be robust for immediate adjustments (QPE) but decreases quickly with time (QPF). For the Snowy region the downscaling demonstrates skill up to 48 hours. As the local (Wagga Wagga) soundings are only available at 00UTC, this approach is of limited value for QPF. An alternative approach will be using simulated sounding forecasts instead of observations. The model forecasts of upper air variables such as pressure and relative humidity generally outperform forecasts of precipitation. WRF (Weather Research Forecasting) model sounding output will be verified with observation for up to three days ahead. The frequency of clusters from WRF output also will be inspected with the original clusters to check whether it can obtain similar rainfall regimes.

1.17. OBSERVATIONS OF OROGRAPHIC SNOW CLOUD FORMATION, SUPERCOOLED LIQUID WATER CONTENT AND PRECIPITATION OF A CYCLONIC WEATHER SYSTEM MOVING OVER THE SNOWY MOUNTAINS

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MODIS observations have indicated that large quantities of supercool water exist in orographic clouds flowing over the Snowy Mountains, furthermore, accurate quantification of this supercool water will allow for more accurate modeling of such cloud formations. This paper will present the observations from a case study, primarily using data gathered by ground based radiometers installed both at Cabramurra and Blue Cow Mountain. This case study will form the basis for building a greater climatology for the region.

The radiometer at Cabramurra is a Radiometrics MP3000A and utilises multiple channels and includes measurements for supercooled liquid water, liquid water and both cloud top and base temperatures and heights, while the measurements from Blue Cow are restricted to liquid water and water vapour paths. Additionally sonde releases from both Khancoban Dam and Wagga Wagga during the event were also analysed.

Cloud top height ranged from between 4000-6000m during the event while cloud base height was initially at 4000m at 4am on 25th September and continued to decrease until it was below the radiometer at Cabramurra which is at a height of 1481m at 16:00 on the 25th September. The descent of the cloud base coincided with the 0 degree isotherm level also descending below the radiometer and consequently at this time the cloud above the radiometer consisted entirely of ice and supercooled liquid water. The 0 degree isotherm height ascended above the radiometer at about 07:00 on the 27th of September which was a few hours before the system had passed over the mountains and the termination of the study period.

1.18. TRIANGLES IN THE SKY: 'STRIATED DELTA' CLOUDS AND ASSOCIATED INERTIA-GRAVITY WAVE DYNAMICS

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'Striated Delta' cloud formations frequently indicate upper tropospheric inertia-gravity wave activity coincident with rapid extratropical cyclogenesis (Feren, 1995). Large-amplitude inertia-gravity waves are able to propagate energy and momentum vertically throughout the atmosphere, and transfer it to the mean flow through breaking or attenuation processes.

The specific dynamical mechanisms remain poorly understood, although it is hypothesised that strong parcel accelerations within the upper jet stream exit region are responsible for the generation of inertia-gravity waves. Convective activity is also preferred in the vicinity of the poleward jet-exit, and this is thought to modulate inertia-gravity wavelengths in this region.

Presented here is continuing research into upper-tropospheric inertia-gravity wave dynamics in the context of rapid extratropical cyclogenesis. Twenty-eight 'Striated Delta' cases are identified in MTSAT-1R satellite imagery over the Australia/New Zealand region during the period May to September 2009. A climatology is compiled using both the ECMWF ERA-Interim and ECMWF YOTC datasets. Climatology composites show various diagnostics symptomatic of inertia-gravity wave activity to be clearly observed in the upper jet-exit region, confirming the background synoptic and dynamical conditions requisite for inertia-gravity wave emission.

A selected 'Striated Delta' case is simulated in high resolution in the Weather Research and Forecasting (WRF) Model, and the wave dynamics investigated further.

Feren, G., 1995: The "Striated Delta" Cloud System – A satellite imagery precursor to major cyclogenesis in the Eastern Australian-Western Tasman Sea region. *Wea. Forecasting,* **10**, 286-309.

1.19. IDENTIFICATION OF SYNOPTIC WEATHER PATTERNS AFFECTING RAINFALL DISTRIBUTION OVER MAJOR AUSTRALIAN CITIES.

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Daily gridded rainfall accumulation data for 1989-2009 provided by Australian Water Availability Project (AWAP) is used to separate dry and rainy days over four Australian cities, namely Melbourne, Sydney, Brisbane and Adelaide. K-means cluster identification method is used to classify rainy days in to five clusters and synoptic pressure patterns are examined for each cluster type. Rainfall distribution is found to be highly uneven and changes with synoptic pattern even over a city scale area. Dry days are mainly characterized by the presence of either a high-pressure contour or a ridge over or near the city.

Over Melbourne, ~85% of the rainy days are associated with Westerly winds and ~10% are associated with Northerly winds. North-westerly winds can be observed for ~5% of rainy days. Large Rainfall accumulation is mostly along the windward side of the local hills and mountains. Presence of Northward extending trough or closed pressure contour over the region enhances the rainfall. In addition, Northerly component of winds produced more rainfall over the Northern parts of the city than southern parts and the Westerly winds produced more rainfall along Eastern mountainous region.

Such classification of weather pattern and their relationship with rainfall distribution at city-scale domain is useful for forecasting applications. This exercise is performed for all the four cities.

1.20. RECENT GLOBAL TRENDS IN ATMOSPHERIC FRONTS

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An automated, objective method is used to identify atmospheric fronts in four independent reanalysis datasets for the period 1989-2009 and to calculate changes in their frequency. The analysis highlights several coherent regions of statistically significant change in the frequency of fronts. The front frequency in the North Atlantic storm track has decreased by about 10-20%, whereas changes observed over the Southern Ocean are relatively small. In the subtropical Pacific the front frequency has increased significantly, which is consistent with an expansion of the dry subtropics. The sensitivity of these trends to the detection method is tested and the results are found to be robust. The results provide a concise summary of the recent changes in a major component of synoptic weather conditions, providing a benchmark for climate models as well as an additional tool for interpreting climate change predictions.

1.21. OBSERVATION AND SIMULATION OF THE GRAVITY WAVES GENERATED BY CONVECTION DURING TWP-ICE

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Using a combination of detailed numerical simulation and observations, we investigate gravity waves generated by convection during the Tropical Warm Pool International Cloud Experiment (TWP-ICE). The key results are that: (i) large-amplitude, low-frequency inertia-gravity waves and a 3-to-4-day wave are detected in the radiosonde data in the lower stratosphere; (ii) the high frequency gravity wave activity were modulated with a 3-to-4-day period during the suppressed monsoon period; (iii) the gravity wave activity shows a diurnal variation, which is strongest during the monsoon break; (iv) at low rain rates, the wave activity increases with increasing rain rate, whereas at higher rain rates the wave activity is independent of the rain rate. These findings are useful for the validation of the model's representation of the high-frequency gravity waves generated by convection. Furthermore, the best estimates of the wave spectrum, combined from both observations and simulations, can be used for further studies on the impacts of these high-frequency gravity waves on other processes such as cirrus formation, and hence, the radiative processes.

1.22. APPLICATION OF LIMITED-AREA DOMAIN HIGH-ORDER SPECTRAL FILTER TO REGIONAL MAP PROJECTIONS

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This study is to apply the high-order spectral filter with the regional map projections to time-stepping procedure of the regional model to remove poorly resolved kinematic features, which have wavelengths of 2-4 times the grid interval. The limited-area domain spectral filter consists of the elliptic equation with high-order spherical Laplacian operator calculated by harmonic or biharmonic terms using the operator splitting method (Park et al, 2011). The filter provides a sharp cutoff filtering by controlling the order of Laplacian operator and can decompose the wave scales selectively. To show its performance in the selective removal of

small-scale noises, which appear prominently in vertical velocity field, it was applied to the time-step procedure in weather research and forecasting (WRF) model. The performance of the filter with Mercator map projection was evaluated through tropical cyclone (TC) track and intensity prediction using the TC initialization scheme, named SABV (Kwon and Cheong, 2010). The simulation result using the spectral filter is compared with that of diffusion scheme provided in the model for the same purpose. The use of the limited domain spectral filter improved the performance of TC predictions, especially in TC track prediction. The result of the filter for Lambert conformal map projection will be also discussed.

References

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Park, J.-R., H.-B. Cheong, and H.-G. Kang, 2011: High-order spectral filter for the spherical-surface limited area. Mon. Wea., Rev., 139, 1256-1278.

1.23. SLIPPERY THERMALS AND THE CUMULUS ENTRAINMENT PARADOX

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In existing theories of cumulus clouds, ascent is strongly damped by friction, particularly when high entrainment rates are present. However, simple calculations show that an air parcel can rise through the troposphere even with a very high entrainment rate throughout (e.g., $(2\ \text{km})^{-1}$) if it is “slippery”, but not otherwise. Here we show that direct computation of entrainment and momentum flux in cloud-resolving simulations support the idea that deep convective parcels strongly entrain without this leading to significant drag. Such “slippery” thermals provide a better match regarding important features where current convection schemes tend to fail, like the mid-level moisture dependence and condensed water amounts. Although more detailed work needs to be done in this direction, this simple idea may be useful for improving parameterizations of deep convection in climate models, in particular because it conceives highly-entraining parcels without the drag commonly associated to them.

Stream 2. General Oceanography

Conveners: Andy Hogg, Katrin Meissner, Steven Siems.

Oral Presentations

THE GLOBAL OCEAN CIRCULATION ON BOTH EDDY-RESOLVING AND MILLENNIAL SCALES

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The global ocean circulation, in particular the overturning circulation, operates on time scales of decades to millennia. Assessing the pathways of water parcels around the globe, and the connection between the different basins, is only viable on such long time scales using low-resolution ocean models. However, the ocean circulation is in many regions eddy-rich, and these eddies are not resolved in coarse-resolution models.

Recently, we have developed a novel technique to account for the impacts of eddies on the long time scale evolution of watermass trajectories, by using a statistical representation of the Lagrangian flow in an eddy-resolving ocean model. The high-resolution model is filled with virtual particles, which are then advected for a relatively short time. From these millions of short trajectories, it is possible to construct a matrix that gives the probability of moving from any one grid cell to any other. This probability matrix can then be used to form so-called super-trajectories (essentially short trajectories tied together in a Monte-Carlo process) of any desired length.

We will show how these super-trajectories can be used to trace out the global overturning circulation in an eddy-resolving model. We will discuss how mesoscale eddies affect the global circulation and how the Southern Ocean plays a key role in the global overturning circulation by acting as a distributor between the different basins. Finally, we will give an estimate of the amount of time it takes a water parcel to complete an 'overturning loop' via the North Atlantic conveyor.

INSIGHTS INTO THE EFFECTS OF TURBULENT MIXING ON THE OVERTURNING CIRCULATION

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Turbulent mixing is thought to influence the ocean meridional overturning circulation (MOC), however a detailed physical understanding of the coupling between mixing and the MOC is yet to emerge. This coupling is examined through idealized laboratory experiments with a convective overturning driven by an applied salt flux at the surface. Additional mechanical mixing was imposed using horizontal rods that are yo-yoed continuously through the water column. The resulting density stratification and overturning rate were, for large rod velocities, found to be consistent with an existing theoretical model. The overturning rate increased with increasing mixing rates. The total diffusivity is parameterized and it is found that for weak (or no) externally imposed stirring the convection itself maintained an apparent background vertical diffusivity

that is 100 times larger than the molecular level, outweighing the externally forced mixing. Insights into relevant mechanisms governing ocean mixing and stratification will be discussed.

A COMPUTATIONALLY-EFFICIENT APPROXIMATE FOR OF NEUTRAL DENSITY FOR USE WITH OCEAN MODELS

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In order to accurately distinguish between vertical mixing and the much larger lateral mixing achieved by mesoscale eddies, it is necessary to be able to analyse ocean data along surfaces that are everywhere accurate approximations to neutral tangent planes. There are now several different methods available to form such approximate neutral surfaces, but none of them are sufficiently computationally efficient to be used in a forward ocean model in real time. The work described here addresses this need for computational efficiency. The way the algorithm was constructed and its accuracy will be described.

THE OCEANIC RESPONSE OF ANOMALOUS SURFACE CONTRIBUTIONS

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Observed changes in the climate over the past few decades are reflected on the ocean. The anomalies are transmitted to the oceans through the changes in the various forcings exerted. Changes in the physical properties are observed not only at the surface, but also carried into the deeper layers of the ocean (Dickson et al., 2002; Curry, Dickson and Yashayaev, 2003; Durack and Wijffels, 2010). Notably, Durack and Wijffels (2010) compared the spatial salinity pattern enhancement to infer changes within evaporation minus precipitation pattern. They found that the surface salinity spatial pattern in the ocean has amplified by a factor two, but in an idealised experiment with solely evaporation minus precipitation implicitly amplified, the surface salinity pattern is only amplified by 80% (Durack and Wijffels, personal communication). This raises questions of the role of changes in individual surface fluxes on the subsurface properties of the ocean. Using the Australian Climate Ocean Model (AusCOM) (Roberts et al., 2007), different surface boundary conditions are individually enhanced to assess their role on the anomaly at the surface and its propagation into the ocean interior over a 50 years period. The decomposition of the boundary condition perturbations allows a spatio-temporal understanding of the propagation of climate variability anomalies into the ocean interior. Changes in the ocean interior from a enhanced atmospheric temperature field will be presented.

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EVALUATING THE NUMERICAL WEATHER PREDICTION AIR-SEA FLUXES OVER THE GLOBAL OCEAN FOR ACCESS-G

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The Australian Bureau of Meteorology has been providing operational ocean forecasts since 2007. The ocean model is forced by the atmosphere represented by the ACCESS-G Numerical Weather Prediction (NWP) system. The performance of the ocean model is linked to the quality of the surface fluxes provided by NWP and used to generate forecasts, and it is important to be able to separate the effects of deficiencies in ocean model physics from atmospheric forcing.

Here we use a sparse array of global moored buoys: the OceanSITES climate flux reference stations, to evaluate the performance of ACCESS-G forecasts out to 10-day lead time for heat and mass fluxes.

INPUT FROM SURFACE BUOYANCY AND WIND FORCING TO THE OCEAN ENERGY BUDGET

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We evaluate the roles of buoyancy and mechanical forcings on the energy budget and on the dynamics of the overturning circulation. We use an idealised, pole to pole ocean with a zonally reconnecting sill in the south. Heat fluxes and wind stresses representative of global climatology are used to define a reference configuration that is spun up to steady state.

Scenarios with differing heat fluxes or wind stresses are also simulated; energy fluxes from buoyancy forcing and wind forcing into the ocean are calculated for each scenario and compared with those from the reference run. Buoyancy forcing and wind variations are each found to have significant effects on energy fluxes into the system, total kinetic and available potential energy, overturning circulation, and on the zonal transport through the sill. Moreover, the two energy sources are coupled, in that variation in buoyancy forcing alters the energy fluxes from wind stress (and vice versa)

THE VERTICAL TRANSPORT OF TRACERS IN THE OCEAN: A PUMP DRIVEN BY SUBMESOSCALE STRUCTURES

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The upper ocean can be considered as a vehicle for the exchange of gases between air and the deep ocean. Furthermore, for the transport of nutrients through the mixed layer occurs via a combination of biogeochemical and physical pumps; both of these mechanisms play a fundamental role in the carbon cycle.

In the surface layer phytoplankton convert carbon dioxide into organic compounds using nutrients and light, a process called photosynthetic reaction. Nutrients, which are depleted at the surface, can be transported in to the mixed layer by vertical motion; recently, it has been discovered that this vertical transport is more often associated with submesoscale fronts of O(10) km (rather than inside mesoscale structures, of O(100) km, like eddies). At the submesoscale front, rates of O(100) m day^{-1} can emerge, particularly high compared to values of 10 m day^{-1} found at the mesoscales [Lèvy et al. (2001)]. At this fine scale, the vertical transport of nutrients is highly effective, upwelling waters from the depth rich of nutrients and downwelling depleted waters from the surface.

This fine-scale vertical transport mechanism has recently become of great interest, though is not completely understood. We investigate the dynamics and the transport of tracers at the fine scales by running numerical simulations, using a non-hydrostatic model at a very high resolution (1 km). We analyze the distribution of a passive tracer released in the model and study how the submesoscale structures govern the net rates of upwelling.

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BIOLOGICAL PRODUCTIVITY TELECONNECTIONS MEDIATED BY LONG-RANGE NUTRIENT TRANSPORT

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We use a data-assimilated ocean biogeochemical model and Green-function techniques to track both phosphate and dissolved organic phosphorous (DOP) backward to the places and times of last biological utilization and forward to the places and times of next biological uptake as phosphate. The fraction of phosphorous last utilized over region A and the fraction whose next uptake occurs over region B are then combined into the A-to-B path densities of (i) remineralized phosphate and of (ii) DOP that is converted to phosphate en route. By binning the paths according to the time between last and next biological utilization, the path density allows us to quantify the nutrient flow rates with which biological production in region A fuels production in region B. The nutrient pathways will be contrasted with those of water itself to highlight the role of particulate transport, DOP to phosphate conversion, and biological utilization in shaping the ocean's nutrient transport pathways. Implications of the phosphate transport for the biological carbon pump will be examined.

THE MYSTERIOUS CASE OF THE MISSING 14C: A PALAEO-OCEANOGRAPHIC INVESTIGATION

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The `Mystery Interval' as defined by Denton et al. (2006) is characterised by an anomalously large decline in atmospheric delta carbon 14 (^{14}C) synchronous with an increase in atmospheric CO_2 spanning 17.5 - 14.5 kyr BP. This study is a palaeo-oceanographic investigation of the delta ^{14}C excursion. Broecker and Barker (2007) suggest the existence of a deep ocean ^{14}C deficient reservoir that was vertically stabilised and isolated from large scale circulation in the ocean such that much of the ^{14}C it contained decayed away. The ventilation of this water mass could explain the 190 +- 10 permil drop in atmospheric delta ^{14}C synchronous with an increase in atmospheric CO_2 . This study uses the UVic Earth System Climate Model to investigate two possible mechanisms for the stabilisation and subsequent ventilation of such an old, carbon rich reservoir, namely the weakening of North Atlantic meridional overturning due to fresh water influx and latitudinal shifts in Southern Hemisphere Westerlies (SHW). Ultimately the strength of Atlantic overturning is seen to be the dominant mechanism in ventilating deep water while shifting of SHW results in a rearranging of deep ocean carbon largely between the Atlantic and Pacific basins.

Broecker, W. and Barker, S. (2007) A 190‰ drop in atmosphere's Δ14C during the "Mystery Interval" (17.5 to 14.5 kyr) *Earth and Planetary Science Letters 256 (2007) 90–99*

Denton, G. H., Broecker, W. S. and Alley, R. B. (2006) The Mystery Interval 17.5 to 14.5 kyrs *Pages News., 13(2), 14–16*

SUDDEN INCREASE IN ANTARCTIC SEA ICE: FACT OR ARTIFACT? (AND WAS 2011 A RECORD LOW FOR ARCTIC SEA ICE?)

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Three sea ice data sets commonly used for climate research display a large and abrupt increase in Antarctic sea ice area (SIA) in recent years. This unprecedented change of SIA is diagnosed to be primarily caused by an apparent sudden increase in sea ice concentrations within the ice pack, especially in the area of the most-concentrated ice (greater than 95% concentration). A series of alternative satellite-derived records do not display any abnormal sudden SIA changes, but do reveal substantial discrepancies between different satellite sensors and sea ice algorithms. SIA values derived from the Advanced Microwave Scanning Radiometer for the Earth Observing System (AMSRE) are consistently greater than those derived from the Special Sensor Microwave Imager (SSMI), as are those derived using the NASA-Team 2 (NT2) algorithm compared to the original NT algorithm. A switch in source data from the SSMI to AMSRE, and in data processing from the NT to NT2 algorithm, in mid-2009 explains most of the SIA increase in all three affected data sets. If uncorrected for, the discontinuity artificially exaggerates the winter Antarctic SIA increase (1979-2010) by more than a factor of two and the spring trend by almost a factor of four.

In recent months, there has been hot debate in the media and scientific community as to whether 2011 was the lowest Arctic sea ice extent on record. This talk will show that the precise ranking of recent sea ice minima depends on the sea ice algorithm used. Based on the ASI algorithm, the 2011 Arctic sea ice was the lowest on record. Based on the NT2 algorithm, 2011 fell a close second (behind 2007). Nevertheless, the long-term melting of Arctic sea ice continues apace.

MESOSCALE CIRCULATION OF THE SOUTHEAST INDIAN OCEAN

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The time mean ocean circulation for the southeast Indian Ocean (SEIO) is analyzed using a colorwheel to reveal an “arterial-like” structure. Although quasi-zonal, the mean circulation in this region is distinctly more complex than previously presented in recent literature. The mean flow is derived from eddy-resolving BLUELink ocean reanalysis (BRAN2.1) of the past 14 years. The ocean state is constrained through data assimilation with observed sea level anomaly, sea surface temperature and *in-situ* profiles. Geostrophic currents derived from the reanalyzed mean dynamic topography are validated against two other MDT analyses to show a comparable arterial structure and distribution of scales. In particular, the broad scale eastward flow is regularly interspersed by narrow bands of the near westward flow. Meridional sections from the ocean reanalysis reveal a net eastward transport in the surface layer and a net westward flow at mid-depth. The seasonality of the surface layer flow in the SEIO appears to have increased (decreased) eastward mean transport that coincide with seasons of stronger (weaker) Leeuwin Current (LC). Such seasonal patterns are minimal at mid-depth (250-1000 m). At the deeper layer (1000-3500 m) alternating eastward and westward features are comparable in both magnitude and width with greater “Arterial” nature. We also note a deep pole-ward flowing shelf transport in the deeper layer. There is a specific orientation of reanalysis currents near bathymetry indicating they are on average influenced by and interacting with the bathymetry.

IMPACT OF THE MADDEN-JULIAN OSCILLATION IN THE INDIAN OCEAN AND ITS REMOTE INFLUENCE ON THE WESTERN AUSTRALIAN COAST

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We assess the evolution of the Madden Julian Oscillation (MJO) in the Indian Ocean using reanalyses from the POAMA Ensemble Ocean Data Assimilation System (PEODAS) and explore the remote influence of the MJO on the western Australian coast using observations of sea level at Fremantle.

A 30-90d equatorial wave signal appears in the surface and sub-surface equatorial Indian Ocean analysis of PEODAS in association with the MJO. Downwelling (upwelling) Kelvin waves and Ekman convergence (divergence) are driven by the active (suppressed) phases of the MJO as illustrated by composite anomalies in equatorial Indian Ocean heat content, 20°C isotherm depth, surface current and SST anomalies. Locally-forced oceanic Rossby waves also appear as a strong signal in response to the MJO in the central Indian Ocean. When eastward-propagating downwelling Kelvin waves reach the Indonesian boundary, a coastally-trapped component propagates southeast along the Indonesian coastline, delivering high heat content north of the northwest Australian shelf. During the November-April months, MJO easterlies south of the equator give rise to southward Ekman transport of these heat content anomalies onto the northwest Australian shelf.

This influence of the MJO on the northwest shelf is carried down the Western Australian coast as a coastally trapped wave, as evidenced by a coherent fluctuation of sea level at Fremantle and thus a strengthening of the Leeuwin Current, with high sea level at Fremantle occurring after development of high heat content

anomalies on the northwest shelf. The amplitude of the MJO signal in Fremantle sea level is ±4cm, which is comparable to the interannual variations driven by El Niño.

REMOTE EFFECTS OF LOCALISED UPWELLING IN A SHELF-BREAK CANYON

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Process-oriented modelling is employed to study localised canyon-induced flow and density disturbances along the shelf break on distances of ~100 km downstream from the shelf-break canyon. Findings show that, in the first instance, the canyon upwelling process creates a standing barotropic topographic Rossby wave downstream of the canyon. Localized upwelling occurs in the shelf-break canyon, but also in multiple onshore excursions of this Rossby wave. Interaction between sheared coastal geostrophic flow, created by an undulating coastline, such as a headland, and the Rossby wave, created by canyon upwelling, can trigger farther onshore movement of the upwelled water. This process, promoting the formation of a stationary coastal upwelling centre, is related to a merger of process-individual relative vorticity zones on the shelf, such that the upwelling flow can be retained in a shallower environment despite the initial water-column squeeze it experienced during the canyon-upwelling phase. This "inheritance" of ambient relative vorticity, not described before, it postulated as an important component of coastal upwelling dynamics.

TIDAL MIXING: BAROTROPIC VERSUS BAROCLINIC

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Tides have been estimated to contribute about 1 TW of energy to ocean mixing. The mixing energy originates from interactions of the baroclinic tides with topography generating baroclinic tides. Presently, this tidal mixing is being included in ocean circulation models using parameterizations. Mixing estimates from the models will only be as good as the performance of the mixing parameterization and with a wide variety of mixing parameterizations, it is desirable to know which ones perform best. In this study, the performances of ten different vertical mixing schemes were evaluated against observational data.

In order to evaluate vertical tidal mixing in the current version Regional Ocean Model System (ROMS), the combined tides for four constituents, M_2, S_2, K_1, and O_1, were modeled over Fieberling Guyot using different vertical mixing parameterizations. Although estimates for the major axes of the tidal ellipses were similar between all vertical mixing schemes, diffusivities varied widely between parameterizations. Most of the parameterizations generated spectra consistent with the Garrett-Munk observational spectra for baroclinic tides. In the velocity fields, the greatest differences between the different parameterizations occurred at high frequencies. There was a strong correlation between schemes with high diffusivities and less energy in the velocities at high frequencies. Although there was no definitive best performer, several parameterizations could be eliminated based on comparison of the vertical diffusivity estimates with observations, resulting in a few top performers. These existing mixing schemes primarily generate barotropic tidal mixing. A new mixing scheme based on Polzin's work was implemented to generate baroclinic tidal mixing. This is an update of a previous study, necessitated by major changes in ROMS during the last 8 years and a new vertical mixing scheme.

THE CONTRIBUTION TO TIDAL ASYMMETRY BY DIFFERENT COMBINATIONS OF TIDAL CONSTITUENTS

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We provide a general framework for identifying the constituents responsible for asymmetry in any tidal time series, by extending and generalizing the skewness-based approach of *Nidzieko* (2010) to include any number of tidal constituents. We show that this statistic has two features which greatly simplify the attribution of asymmetry to particular constituents: 1) only combinations of two or three constituents can contribute to skewness, regardless of how many constituents are significant in the time series; and 2) of those combinations, only the few meeting the frequency conditions $2\omega_1 = \omega_2$ or $\omega_1 + \omega_2 = \omega_3$ will give rise to long-term mean asymmetry. It is therefore relatively easy to identify every such combination, even when many constituents are present. We then go on to show how the relative contribution of each such combination can be measured and compared, based on the amplitudes, frequencies and relative phases of the constituents. We also show that there is an upper bound to the skewness generated by any such combination. The metrics are applied to data from 335 worldwide sea level stations and from a global ocean tidal model based on TOPEX/Poseidon altimetry. Global maps are made of the patterns of tidal skewness. We identify the combinations of astronomical tides that dominate skewness in different tidal regimes and geographic locations, and explain the dependence of skewness on tidal form number.

Nidzieko, N. J. (2010), Tidal asymmetry in estuaries with mixed semidiurnal/diurnal tides, *J. Geophys. Res.*, *115*, C08006, doi: 10.1029/2009JC005864.

TIDES AND SOUND: THE INSIDE STORY ON INTERNAL WAVES AND ACOUSTICS

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Sound propagates further in the ocean than other radiated energy, and is a very important tool for ocean operations. The earliest usage of underwater acoustics is reported to be in the 15th century when Leonardo da Vinci made the observation “If you cause your ship to stop, and place the head of a long tube in the water and place the outer extremity to your ear, you will hear ships at a great distance from you”. The same idea was used during WWI with the simple addition of second tube in order to gain sense of directionality. From these humble beginnings sound has become vital in the oceans for; communication, navigation, imaging, bathymetry, data collection and warfare. Sound propagation changes with small variations in the temperature, salinity and pressure fields. These perturbations can come from many sources including internal tides.

This study investigates the specific effects of internal tides on acoustic propagation in the Indonesian seas. By utilizing acoustic ray tracing software and model results; the effects of internal tides on acoustic propagation were shown to strengthen and deteriorate a sound channel, leading to variations in ray paths and transmission losses. These effects were discovered to be strongly depth dependent, which impacts the potential applications of the study. This study opens the door on the shadowy world of internal tides and its effects on acoustics. Whilst still in the early stages of the study, it has produced tantalizing results, unlocking the gate to a myriad of future research possibilities.

Poster Presentations

2.1. OCEAN MIXING IN SHALLOW WATER OFF SOUTH EAST QUEENSLAND AND A POTENTIAL LINK WITH DEEP WATER OCEANOGRAPHIC PROCESSES: ANALYSIS OF *IN-SITU* AND OCEAN REANALYSIS DATA

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Ocean mixing has significant implications for critical issues on coastal environment such as water quality and marine ecosystems. Turbid bottom water, high energy bottom currents and potential upwelling events in shallow water off the Gold Coast have been reported and the facts suggest that ocean mixing may be prevalent and play an important role in the phenomena, but has not been quantitatively understood. In order to have solid understanding of ocean mixing in shallow water and its potential physical mechanisms, we analysed a 17-month *in-situ* data measured in 20 m of water off the Gold Coast between June 2007 and October 2008, and ocean reanalysis outputs from CSIRO (BRAN2). It is a part of our efforts to quantify salient oceanographic processes of shallow water for SEQ comprehensively.

Results from *in-situ* data indicate that during severe storms, surface waves are high enough to re-suspend bottom sediments and caused mixing near the bottom. Results of sequential temperature profiles show large amplitudes of temperature fluctuation in the Austral summer/fall with the largest in April. Such temperature fluctuations are often a sign of internal waves and accompany strong vertical mixing. However, the *in-situ* data suggests that vertical mixing does not seems to have been significant during the period, but instead became more significant sometime later as corroborated by temperature shear and negative buoyancy frequency. This period coincides with northwestward currents driven by meandering of the East Australian Current (EAC) and intrusion of cyclonic eddy moving southward based on the BRAN2 outputs, which may potentially have driven mixing and upwelling during the period. The above facts suggest a strong influence of localised and regional physical processes including the EAC in ocean mixing in shallow water for the SEQ coast. More detailed data analysis is ongoing and will be presented at the conference.

2.2. A NEW TOOLBOX FOR OCEANOGRAPHIC DATA QUALITY CONTROL AND NETCDF FORMATTING

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We introduce a new Toolbox for converting oceanographic data files into pre-processed and quality controlled (QC) NetCDF files. The toolbox is written in MATLAB and Java with a graphical user interface and was developed by the Australian National Mooring Network supported through the Integrated Marine Observing System (IMOS) eMarine Information Infrastructure.

The toolbox can read data files from a wide range of sensors and platforms including CTDs (Seabird, FSI, RBR), pressure and temperature loggers (Aquatec, RBR), multi-sensor instruments (WET Labs WQM, YSI 6 series) and ADCPs (Teledyne RDI, Nortek). Metadata from a deployment database can also be critically integrated into these data files.

Time series, profiling, and underway data can be displayed, as well as metadata following the IMOS NetCDF template for global attributes and variable attributes

(http://imos.org.au/fileadmin/user_upload/shared/emii/IMOS_netCDF_usermanual_v1.2.pdf).

Three working groups have recently been formed to define proper QC procedures for different kinds of instruments (CTDs, ADCPs and bio-optical sensors). These sets of standard IMOS QC procedures will then be implemented in the toolbox so that consistent QC'd data will be available through the IMOS portal (http://imos.aodn.org.au/webportal/).

Quantitative QC and logical set based systems are presently under development to streamline issues associated with the QC of long term data records such as sensor drift, step functions, inter-observer bias, biological data with high rates of change, and introducing a sensor quality management.

The IMOS moorings data toolbox is freely available in a standalone Windows executable with its source code. Using the source code within Matlab (R2010b recommended) enables the user to make modifications, be platform independent, and feedback new additions.

More documentation and downloads can be found at http://code.google.com/p/imos-toolbox/ .

2.3. OCEANS OF DATA: THE AUSTRALIAN OCEAN DATA NETWORK

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The Australian Integrated Marine Observing System (IMOS, www.imos.org.au) is a research infrastructure project to establish an enduring marine observing system for Australian oceanic waters and shelf seas (in total, 4% of the world's oceans). Marine data and information are the main products and data management is therefore a central element to the project's success. A single integrative framework for data and information management has been developed which allows discovery and access of the data by scientists, managers and the public, based on standards and interoperability. All data is freely available.

This information infrastructure has been further developed to form the Australian Ocean Data Network (AODN, www.aodn.org.au) which is rapidly becoming the 'one-stop-shop' for marine data in Australia. New features have recently been added to data discovery and visualisation which moves the AODN closer towards providing full integration of multi-disciplinary marine data.

2.4. OCEAN MODEL, ANALYSIS AND PREDICTION SYSTEM VERSION 2 (OCEANMAPSV2)

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This paper presents an overview of the features and performance of the Ocean Model, Analysis and Prediction System version 2. OceanMAPS is the Bureau of Meteorology's operational ocean forecast system. OceanMAPS has been in continuous operation since 2007 and underpins a service to the Royal Australian Navy. In 2011, the system was upgraded to OceanMAPS version 2. This upgraded system was developed through a follow-on BLUElink-2 project, an Australian Government partnership project of the Bureau of Meteorology, CSIRO and the Royal Australian Navy. The OceanMAPSv2 includes enhancements to the ocean model, assimilation system, initialisation and other components. In addition, the forecast cycle has been upgraded from a twice per week forecast to a daily forecast. The daily forecasts has been achieved through the implementation of four independent forecast cycles. Each forecast cycle has a four day repeat cycle and are time-lagged relative to each other over four days. The four day repeat cycle is a similar strategy to that adopted in OceanMAPSv1 which reflects the period taken for a complete orbit of the Jason-class altimeters, 9.9 days. The four cycles share a common observing system and hindcast atmospheric fluxes but are otherwise independent. Perturbations accumulate from the changes in the observations assimilated, observation errors assigned due to the age penalty in the ensemble OI system and atmospheric forecast fluxes. The design provides a multi-cycle lagged ensemble which is exploited to provide an estimate of forecast uncertainty.

http://www.bom.gov.au/oceanography/forecasts

2.5. WHAT DYNAMICS DOES ARGO OBSERVE IN THE TASMAN SEA?

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The Tasman Sea is composed of numerous eddies and fronts some of which originate from the East Australian Current separation and subsequent interactions. A description of the circulation in the Tasman Sea in not complete without an adequate representation of the mesoscale dynamics. Although satellite altimetry can provide us with a description of the location of eddies through the surface anomalies this quantity represents only an integral of the specific volume changes within the water column and does not provide the vertical distribution of the specific volume anomalies. In complement to altimetry, the Argo autonomous profiling floats provide approximately vertical profile observations of the ocean state although at greatly reduced spatial sampling. As Argo is autonomous the position of the float is strongly influenced by the circulation encountered during its cycling pattern. In this paper we are interested in the question, what ocean and dynamics does an Argo float observe in the Tasman Sea? It is well known that the surface circulations of ocean eddies are relatively stable, forming closed material surfaces that limit the exchange of water masses with the surrounding environment. Numerous observations from drifting buoys, when deployed within an eddy, can persist for months completing multiple orbits around the eddy. Whilst drifting buoys deployed outside eddies can pass many eddies without being entrained. Does a similar thing occur for Argo and if so what does that mean for its representativeness of the Tasman Sea ocean state? We compare the available

record of Argo with analysis products of altimetry to estimate how frequently an Argo float profiles anticyclonic eddies, cyclonic eddies and fronts and discuss the results.

2.6. THREE DIMENSIONAL HYDRODYNAMICS IN DARWIN HARBOUR, NORTHERN TERRITORY

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An unstructured mesh is constructed to accurately present the bathymetry of tidal flats, mangrove area and the geometry of the arms in Darwin Harbour. The three dimensional Finite Volume Coastal Ocean Model (FVCOM) is used to simulate the hydrodynamics of the Harbour. The model is calibrated and agreed well with observed water surface elevation and current velocity. Results indicate that the hydrodynamics of the Harbour are complex and driven mainly by tides. Wind and river input play a small role on the hydrodynamics. The M2 tide is prevalent with amplitude of 1.7 m and peak current speed of more than 3.0 ms-1 occurring at the surface level of the Middle Arm. Numerical experiments indicate that the wetting-drying process plays a key role in the simulation of tides in the estuarine system. Without the wetting-drying process, the M2 and M4 tidal currents drop dramatically. The tidal flats, Harbour water depth and the shallow water tides at the open boundary have positive contributions to the tidal asymmetry. The detailed hydrodynamic information of the Harbour provided can be used to support the sediment transport research in future work.

2.7. FINDING A PROXY FOR WIND STRESS OVER THE COASTAL OCEAN OFF SYDNEY

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Forcing by the wind influences oceanographic processes such as upwelling. Ideally, wind measurements should be obtained from a site close to where oceanographic data has been collected. In general, this is not possible and wind information is usually provided by reanalysis products or from nearby on-shore locations, however it is often difficult to quantify how representative these products are of oceanic winds.

We compared wind stress, derived from data measured over a 5 year period (2001 to 2005) from an oceanographic mooring, located offshore from Bondi (Sydney), with the NCEP and Blended Sea Wind reanalysis products and with wind stress calculated from observations from six land based sites. The objective of the study was to determine the data sets that can best act as a proxy for the wind stress over the ocean off Sydney.

The linear correlations for u and v were higher between the offshore and land based sites (>0.8) than between the offshore site and the reanalysis products (0.44 to 0.54). Spectral analysis revealed that the reanalysis products were unable to capture features with periods of less than 2 days while the land-based sites were able to capture these features.

Isothermal uplift was observed when the offshore site was subjected to wind stresses of 0.1 Nm^{-2} (equivalent to wind stress of 0.036 – 0.040 Nm^{-2} at the land based sites). Calculations of vertical velocities in the ocean shows that using land based winds were consistent with the calculated vertical velocity from the offshore observations and matched the vertical movement of the isotherms.

This study shows that land based sites indicate the wind speed and direction over the coastal ocean more accurately than reanalysis products in this region. Furthermore, wind stress data from specific land based sites can be used to accurately calculate vertical movement of isotherms.

2.8. DEVELOPMENT OF AN ENVIRONMENTAL PERFORMANCE INDICATOR FRAMEWORK TO EVALUATE AN ENVIRONMENTAL MANAGEMENT SYSTEM FOR SHOALWATER BAY TRAINING AREA, QUEENSLAND, AUSTRALIA

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The integration of environmental management into military training activities has become a growing concern for the military sector internationally. There is also an increasing research interest in EMS evaluation worldwide. An Environmental Performance Indicator (EPI) framework is considered to be an effective means for environmental management planning and assessment. Yet, there is a scarcity of research evidence of its use for the military sector. As one of the largest landowners in Australia, the Australian Defence Force (ADF) is extremely mindful of its duty as an environmental manager. It has an Environmental Management System (EMS) in place to assist military environmental management. The Shoalwater Bay Training Area (SWBTA) is one of the most significant military training and environmental protection areas in Australia. Based on reviewing the EMS evaluation and indicator framework development initiatives, this paper introduces the ISO 14031 Environmental Performance Evaluation (EPE) approach and develops an Environmental Performance Indicator framework - the SWBTA-APISR (A=Activity indicator; P=Pressure indicator; I=Impact indicator; S=State indicator; R=Response indicator) to estimate how effective the EMS is as a tool for maintaining the sustainable environmental management of military training activities. The innovative features of this framework are described. This paper uses the military activities conducted within the Talisman Saber (TS) exercise as a case study of the ADF's activities within SWBTA. This case study assists in developing an environmental reporting framework to examine the effectiveness of the ADF's EMS. It is expected that the combination of the EMS and the EPE through a specific EPI framework for the SWBTA, will provide a systematic evaluation of the ADF's EMS implementation and its environmental management performance in the area.

2.9. ASPECTS OF TIDES AND MEAN SEA LEVEL VARIABILITY IN VICTORIA

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The tide along the Victorian coast is dominated by the M_2 constituent, which has a Bass Strait maximum on the western coast of Wilsons Promontory, and is of greatest amplitude in Western Port Bay and Corner Inlet. In this talk we present new observations of the Corner Inlet resonance, which occurs in an embayment characterized by deep channels similar to those occurring in Western Port Bay.

We also discuss the evolution of the tidal regime using monthly mean tide gauge data which indicate that between about 1985 and 1995 a gradual shift in datum occurred at Stony Point and Point Lonsdale which appears unlikely to be due to oceanographic or instrumental causes, and is therefore of tectonic origin (Park

et al 2011). Geophysical evidence of raised shore platforms in Port Phillip Bay, and of its periodic closure to Bass Strait (Holdgate et al 2011) are consistent with this interpretation, as also is the emergence of the bathymetry of Western Port Bay and Corner Inlet.

References

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Park, H., Bye, J.A.T. and Hughes, R.L. 2011 On the largest tides and the cause of mean sea- level fall in Victoria Proc. Roy. Soc. Victoria (in press)

2.10. THE SEASONAL CYCLE OF SEA LEVEL AROUND AUSTRALIA

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The seasonal cycle of sea level (SCSL) around Australia has been investigated using monthly mean sea level (MMSL) datasets from satellite altimetry, tide gauges and a barotropic hydrodynamic model for the period 2000 to 2010. The model is based on the DHI-Mike21 and the domain was configured to capture the seasonal meteorological forcing over Australian waters. Water levels derived from TPX07.2 global tidal model were used to drive the open boundaries. Atmospheric forcing fields are obtained from the NOAA-NCEP reanalysis. The modelled barotropic annual amplitude has been compared with other model (e.g. ECCO) and satellite (e.g. GRACE) based estimations. The SCSL associated with the baroclinic signal was estimated by subtracting the modelled barotropic component from the altimeter and tide gauge datasets. The baroclinic signal was then compared with steric heights derived from temperature and salinity climatology (WOA-09). The modelled and altimeter datasets have been combined to map the distribution of the barotropic and baroclinic MMSL and SCSL around Australia.

The annual amplitude of SCSL exceeds 0.3 m in the Gulf of Carpentaria and peaks in January. In this region the barotropic signal accounts for more than 90% of variability. A significant barotropic SCSL with amplitude ~0.1 m occurs along the eastern end of the Great Australian Bight and peaks in August. A modelled volume flux analysis revealed that strong southward net advective transport occurs on the continental shelf region along western and southern Australia during April to June. A steric component associated with fluxes dominates the annual amplitude along continental shelf regions on the western and southern Australian coast with amplitude up to ~0.15 m and peaks in April and June, respectively. Analysis further reveals that the annual steric amplitude and its phase speed is determined by the strength of the barotropic signal at Northern Part of Australia. However, the propagating steric signal is weak along the eastern coast of Australia.

Stream 3. General Climate Science

Conveners: Matthew McCabe, Andy Pitman, Michael Roderick

Oral Presentations

DROUGHTS ARE BIGGER IN TEXAS TOO: GLOBAL CLIMATE IN 2011

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Global temperatures for January-August were approximately 0.42°C above the 1961-90 normal. These January-August temperatures are tracking 11th highest on record, near the average for the last decade, although they are well short of the record annual anomaly (+0.53°C) set in 2010. Global temperatures are typically cooler than the long-term trend when a La Niña is in place at the start of the year, as in 2011, but 2011 has been substantially warmer than the previous strong La Niña year, 2008.

Strong La Niña conditions were established at the start of the year, weakening during the first half of 2011 before showing signs of redevelopment later in the year. Many of the most significant anomalies in 2011 were associated with this event. These included severe and damaging floods in January and February in eastern Australia and southern Africa, and persistent drought in east Africa and the southern United States.

The east African drought, which caused severe local famine, was triggered by the failure of the usual wet seasons in both late 2010 and early 2011, over a relatively small region focused on northern Kenya, western Somalia and southern Ethiopia, where seasonal rainfall approached or broke post-1950 record lows. The American drought was most intense in Texas, which experienced January-August rainfall 30% below the previous record and 60% below normal, as well as its hottest summer on record.

Pakistan suffered severe flooding during the summer monsoon for the second year in succession, although the most abnormal rains were in the southern part of the country in 2011, rather than the north as in 2010. Other regions to experience major flooding in 2011 included Japan, coastal Brazil, and the north-eastern and central United States.

Arctic minimum sea ice volume in 2011 was the lowest on record, and minimum extent ranked second lowest, just short of the 2007 record. This continues the recent strong downward trend in Arctic sea ice volume and coverage.

THE 'BIG DRY' AND OTHER SYNCHRONOUS DRY SPELLS ACROSS THE SOUTHERN HEMISPHERE

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South-eastern Australia (SEA) experienced a step change to a dry climate from the mid-1990s until 2010 (i.e. the Big Dry) that resulted in a marked reduction in rainfall and runoff. In 2010, a strong La Niña and warm sea surface temperatures off north-western Australia resulted in a reasonably wet year, providing relief from the extended drought. However, it is not yet understood if the protracted dry conditions experienced during the Big Dry should be considered as the new climate (a significantly drier climate than what has been experienced over the last 100 years), or if the Big Dry was just a temporary shift, and perhaps the wet 2010 represents the beginning of a shift away from a dry climate state. It has been suggested that the recent drought in SEA is similar to the extended dry spell that began in the mid 1970's in southwest Western Australia (SWWA). However, the timing with respect to both the start of the decreasing rainfall trend and the season where the majority of reduction has been observed is not consistent. A review of the literature revealed an apparent connection between precipitation in SWWA, East Antarctica, Southern Africa and New Zealand. This presentation demonstrates that a step change in climate, similar to that observed in the mid-1970's in SWWA, occurred for other continental regions in the Southern Hemisphere and that the mid 1990's climate shift in SEA is likely related to the 1970's climate shift. Further we demonstrate that this synchronicity is not an isolated event. For example an extended dry epoch occurred during the late 1800's through to the early 1900's (known as the Federation Drought in Australia) across much of the continental Southern Hemisphere. The likely climate driving mechanisms that have resulted in this hydroclimatic synchronicity are also discussed.

PERFORMANCE OF THE CMIP3 MODELS IN REPRESENTING THE PRECIPITATION TELECONNECTION TO AUSTRALIA AND ITS ASYMMETRY

Evan Weller, Wenju Cai and Tim Cowan

Recent research on the teleconnection pathway of the tropical Indian Ocean (TIO) to the extratropics and its impact over Australia have shown that there is a good relationship between future rainfall trends and the amplitude of present-day Indian Ocean Dipole (IOD) events. Further, a positive skewness exists in its present-day climate. That is, positive IOD events tend to grow to greater amplitude than negative IODs and the impacts are better able to manifest out of stochastic noise than those associated with negative IOD events, and thus are more effective in triggering convective anomalies over the TIO resulting in Rossby wavetrain formation and downstream impacts over Australia. Here we demonstrate that although climate models simulate a positive skewness over the TIO and a well established teleconnection pathway into the extratropics, they do not simulate the observed downstream positive skewness in Australian rainfall. Further, the relationship of Australian future rainfall trends and the TIO teleconnection weakens when the IOD is separated into its positive and negative phases.

THE IMPACT OF CLIMATE CHANGE ON INTERANNUAL MODES OF VARIABILITY OF SOUTHERN HEMISPHERE ATMOSPHERIC CIRCULATION IN CMIP3 MODELS

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The seasonal mean atmospheric circulation is affected by processes with time scales from less than seasonal to interannual or longer. It is therefore useful to conceptualise the seasonal mean as consisting of intraseasonal and slowly-varying (longer than a season) components. Based on this model, an Analysis of Variance method has been developed to separate the interannual variability of the seasonal mean into terms related to these components. For ensembles of model realisations, the slow component can be further thought of as consisting of components related to slowly-varying internal dynamics and external forcings. Coherent patterns, or modes, of variability of each component are then estimated by eigenvalue decomposition of the corresponding covariance matrix.

The method is applied to monthly mean Southern Hemisphere 500hPa geopotential height from Coupled General Circulation Models from the Coupled Model Intercomparison Project Phase 3 (CMIP3). An ensemble was formed using realisations from 7 CMIP3 models that have been found to reproduce well the 20th century modes of variability (Grainger et al., 2011). In 21st century climate change scenarios, it is found that the largest change is in the slow-externally forced component, related to the atmospheric response to changes in external radiative forcings, including greenhouse gases. The structure of the dominant slow-external mode changes from annular in the 20th century to a uniform response, and the variability associated with the mode increases with projected greenhouse gas concentration. In contrast, there are only small changes in the variability associated with the leading two modes of the slow-internal component, related to the Southern Annular Mode and the atmospheric response to the El Niño-Southern Oscillation respectively, and no change in their structure. No clear differences between the 20th and 21st centuries are found for the modes of the intraseasonal component.

Grainger, S., Frederiksen, C. S. and Zheng, X. 2011. Interannual modes of variability of Southern Hemisphere atmospheric circulation in CMIP3 models. Part I: Assessment. Submitted to *Theor. Appl. Climatol.*.

REGIME DEPENDENT CHANGES IN MONSOON PRECIPITATION OVER TROPICAL AUSTRALIA AND THE WIDER REGION

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The Australian monsoon is a fundamental component of Southern Hemisphere summer circulation, and dominates rainfall distributions over northern Australia and adjacent regions. Changes to the Australian monsoon over the coming century could have profound consequences for these regions, .affecting industries, agriculture, eco systems, human life, etc through changes in total rainfall, frequency and distribution of extreme rainfall and temperature events. We have reported earlier on projected changes in the Australian monsoon as simulated by CMIP3 coupled climate models (Moise and Colman, 2010), in which we found inconclusive results on changes in Australia's wet season rainfall. In this presentation, we provide results on changes in the strength of simulated convection associated with Australia's monsoon rainfall in order to decrease the uncertainty in rainfall projections using alternative analysis tools. We will also assess the changes in these convective regimes under enhanced greenhouse conditions with the view of a more dynamical understanding of projected changes in monsoon rainfall over Australia and the wider region.

AUSTRALIAN CLIMATE MODULATED BY THE INDIAN OCEAN BASIN-WIDE WARMING

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In this study we investigate the indirect effect of El Niño events onto Australian climate via the Indian Ocean basin-wide warming (IOBW). The Indian Ocean generally exhibits warm sea surface temperature anomalies (SSTA) during and after the peak of El Niño events. In particular, the IOBW appears as the leading pattern of the tropical Indian Ocean SSTA during austral summer and autumn. We use observations and numerical experiments with an atmospheric general circulation model to assess the role of the Indian Ocean relative to the Pacific onto Australian rainfall and circulation. Results suggest that the IOBW enhances and prolongs the El Niño-related anomalous conditions over Australia through austral autumn. The mechanisms by which the indirect effect of El Niño impact Australia are discussed.

More information about this research can found at
http://web.science.unsw.edu.au/~andrea/papers/Taschetto_etal_2011.pdf

Reference: Taschetto, A. S., A. Sen Gupta, H. H. Hendon, C. C. Ummenhofer and M. H. England. 2011. The contribution of Indian Ocean sea surface temperature anomalies on Australian summer rainfall during El Niño events. *Journal of Climate*, 24(14):3734-3747.

A COMPARISON OF CLASSIFICATION METHODS FOR IDENTIFYING RELATIONSHIPS BETWEEN THE SOUTHERN ANNULAR MODE AND THE AUSTRALIAN HYDROCLIMATE

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Recent research has shown that the Southern Annular Mode (SAM) plays a role in modulating the climate in southern Australia, however, there is debate over both the magnitude and seasonality of this affect. The disagreement may be due to the way in which the SAM-rainfall relationship has previously been analysed, with past studies focusing on using correlations to classify the seasonal relationship between SAM and rainfall. Correlations, which describe linear relationships, may not provide a complete picture of the inherently non-linear relationship between SAM and Australian hydroclimatology. This study demonstrates an alternative method of assessing SAM impacts via the use of threshold SAM index values to stratify corresponding rainfall amounts into negative, neutral and positive SAM episodes. A key issue with this method however is the selection of the threshold value. This study investigates whether the relationship between SAM index and rainfall in southern Australia varies significantly according to threshold value, and has the ultimate aim of determining whether the threshold method can offer new insights into the relationship between SAM and rainfall in southern Australia.

THE LINK BETWEEN ENSO AND NORTH AUSTRALIAN SSTS

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Interannual variations in the sea surface temperature (SST) to the North of Australia are strongly linked to variations in Australian climate such as winter rainfall, or tropical cyclone numbers. The North Australian SST is also closely linked to ENSO and Tropical Pacific SSTs, with the relationship exhibiting a strong seasonal cycle. Credible predictions of future Australian climate change therefore depend on climate models being able to represent ENSO and its connection to North Australian SSTs.

Observational datasets of SST are used to further investigate links between the Nino3.4 index and a North Australian SST index, as well as the temporal evolution of North Australian SSTs during ENSO events. During Austral autumn, the correlation between Nino3.4 SST and North Australian SST is positive, while in Austral spring the correlation is negative. During El Nino events, the North Australian SST anomalies become negative in the Austral spring preceding the development of the positive Nino3.4 SST anomalies.

The coupled models participating in the CMIP3 project and assessed in the IPCC AR4 are then evaluated in terms of this temporal evolution of Nino3.4 SST and the relationship to North Australian SSTs for the 20th century simulations. Some of the models perform very well, while some do not capture the seasonal cycle of correlations at all. The models that do capture the observed link between the two regions can be used to understand the physical mechanisms by which this link exists. This is the abstract text. It should be in style "AbstractText" (Times New Roman 11 point, justified, 12pt space before each paragraph). A space is automatically inserted before each paragraph. Don't use a tab to indent paragraphs.

DO WE REALLY KNOW THE CAUSE OF THE RECENT SOUTHEAST AUSTRALIAN AUTUMN RAINFALL REDUCTION?

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Since the 1950s, annual rainfall over coastal eastern Australia has decreased by as much as 20-30% with some of the largest reductions occurring across southeast Australia (SEA). This region's rainfall is influenced by both tropical and extratropical climate drivers. From around the 1980s SEA has experienced a maximum decline of around 40% during the austral autumn season (March-May), coinciding with an extended drought period known as the "Big Dry". Although much work has progressed the understanding of the seasonal SEA rainfall variability, the exact causes and associated mechanisms for the autumn reduction still remain elusive. This is because known drivers such as the Southern Annular Mode (SAM), the Indian Ocean Dipole (IOD) and El Niño-Southern Oscillation (ENSO) either do not operate or exhibit weak teleconnections in this season. As such, a new mechanism for SEA autumn rainfall variability is described, and the reasons for the significant reduction are hypothesized. A strong collapse in the relationship between the locally defined subtropical ridge intensity (STRI) and position (STRP) during autumn in recent decades corresponds to a strengthening in the influence of the post-monsoonal winds (easterlies) from north of Australia, with a strong post-1980 coherence with both the STRI and SEA rainfall. A poleward extension of the early northern dry-season in April and May effectively replaces a "wet" climate in SEA with a "drier" climate from northern latitudes, representing a climate shift that has contributed to the autumn rainfall reduction. Associated with this is a poleward shift of the dominant process controlling SEA autumn rainfall. The combined effect of the expanding tropics, an earlier reversal of the summer monsoon, and a poleward shift of the extratropical ocean over the past few decades have all contributed to the unprecedented decline in autumn rainfall across SEA.

A SIMPLE CLIMATE MODEL FOR CONCEPTUAL UNDERSTANDING OF THE PHYSICS OF CLIMATE CHANGE

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The future climate change projections of the IPCC AR4 are based on GCM simulations, which give a distinct global warming pattern, with an arctic winter amplification, an equilibrium land sea contrast and an inter-hemispheric warming gradient. While these simulations are the most important tool of the IPCC predictions, the conceptual understanding of these predicted structures of climate change are very difficult to reach if only based on these highly complex GCM simulations.

In this study presented here we will introduce a very simple gridded globally resolved energy balance model based on strongly simplified physical processes, which is capable of simulating the main characteristics of global warming. The model shall give a bridge between the 1-dimensional energy balance models and the fully coupled 4-dimensional complex GCMs. It runs on standard PC computers computing globally resolved climate simulation with 2yrs per second or 100,000yrs per day.

The simple model's climate sensitivity and the spatial structure of the warming pattern is within the uncertainties of the IPCC AR4 models simulations. It is capable of simulating the arctic winter amplification, the equilibrium land sea contrast and the inter-hemispheric warming gradient with good agreement to the IPCC AR4 models in amplitude and structure. The results suggest, that the spatial pattern and amplitude of climate sensitivity is a result of very simple physical processes under the given climate mean state. The presentation will discuss the feedbacks and processes causing these structures, as estimated from the deconstruction of the simple model.

EXPLORING TRENDS AND LOW-FREQUENCY VARIABILITY IN RAINFALL EXTREMES BASED ON ENSEMBLE EMPIRICAL MODE DECOMPOSITION (EEMD)

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Our current understanding indicates that climate change is likely to lead to an increase in rainfall in already wet regions and a drying trend in dry regions. Low-frequency variability in Australian rainfall is dominated by a number of drivers acting on different spatial and temporal scales (Risbey et al 2009), and may be of similar magnitude to the underlying long-term trends.

Empirical Mode Decomposition (EMD) is a statistical technique that can be used to decompose a time series into a set of inherent oscillations, referred to as *Intrinsic Mode Functions* (IMF), and a *Residue,* which can be interpreted as an underlying trend (Huang and Shen 2005). This technique is suitable for the analysis of non-linear and non-stationary processes and may therefore be better suited to analysing long-term variability in rainfall (and rainfall extremes) than traditional spectral analysis techniques.

EMD has been used in the past to analyse hydrological time series for Australia (McMahon et al 2008). This work adds to existing studies in two ways:

Firstly, it makes use of an approach termed *Ensemble Empirical Mode Decomposition* (EEMD) which allows assessing the statistical significance of IMF and Residue, and therefore distinguishing between 'signal' and 'noise', and

Secondly, by extending the analysis to series of extremes (annual maxima and peaks-over-threshold).

The technique was applied to time series of annual, monthly and daily rainfall totals and extremes series (annual maxima and peaks-over-threshold) at daily and sub-daily durations for five stations in eastern Australia for which suitably long records at sub-daily resolutions were available. Results indicate a link between low-frequency variability and long-term trend for time series of daily, monthly and annual totals on one hand; and annual maxima and peaks-over-threshold series on the other.

References

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McMahon, T.A., Kiem, A.S., Peel, M.C., Jordan, P.W., and Pegram, G.S.. (2008): A new approach to stochastically generating six-monthly rainfall sequences based on Empirical Mode Decomposition. Journal of Hydrometeorology, 9, 1377-1389.

Risbey, J. S., Pook, M. J., McIntosh, P. C., Wheeler, M. C. and Hendon, H. H. (2009), On the remote drivers of rainfall variability in Australia, Monthly Weather Review, 137, 3233 – 3253.

THE IPCC SPECIAL REPORT "MANAGING THE RISKS OF EXTREME EVENTS AND DISASTERS TO ADVANCE CLIMATE CHANGE ADAPTATION"

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In April 2009, the Intergovernmental Panel on Climate Change (IPCC) decided to, in collaboration with the International Strategy for Disaster Reduction (ISDR) prepare a special report reviewing the scientific literature on how weather and climate extremes may have been changing and may change in the future, and the relevance of such changes to disaster risk reduction and climate change adaptation. The report, known as SREX, will be presented to an IPCC Plenary session for approval 14-18 November 2011. In this presentation I will discuss the structure and contents of the SREX, focusing on Chapter 3 (of which I was a Coordinating Lead Author): "Changes in climate extremes and their impacts on the natural physical environment". I will discuss who wrote the chapter, how it was structured and written, the review process, and the main findings (including differences between SREX's conclusions and those of the IPCC Fourth Assessment of 2007). I will also discuss the relevance of SREX to disaster risk reduction.

WHEN DID ANTHROPOGENIC CLIMATE CHANGE COMMENCE AND WHAT IS ITS IMPACT ON GLOBAL TROPICAL CYCLONES?

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A number of studies have assumed that anthropogenic climate change has occurred as a quasi-linear warming trend from around the turn of the 20th century and related this to potential changes in other parameters, such as tropical cyclone frequency. However, we shall argue, using a comparison of Global Climate Model (GCM) simulations with and without anthropogenic forcing (following Meehl et al 2004) that the net anthropogenic forcing was indistinguishable from natural variability until the late 20th century. A sharp change to a marked quasi-linear warming began around 1960 and this warming became distinct from the annual variability by ~1975. This change has been associated in previous studies with reductions in emissions of sulfate aerosols, which counteracted the warming component due to greenhouse gases before 1960 and further discussion on this will be provided.

Taking this result as a basis, we then discuss the implications for impacts on tropical cyclones globally. There is a major advantage in this shorter period in that many issues with data reliability are largely removed. Further, there are good reanalysis products available for use in statistical downscaling of cyclone activity. Both of these data will be utilized to show the relative anthropogenic signatures on tropical cyclone activity in each of the main ocean basins. Particular emphasis will be given to the relationship with events in the Australian region.

TRENDS AND UNCERTAINTIES IN GRIDDED GLOBAL DATA SETS OF OBSERVED CLIMATE EXTREME INDICES

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This study reports on the production and analysis of new global gridded data sets of extreme climate indices. These data sets are derived from daily in situ observations of temperature and precipitation and are used to examine changes in climate extremes since the mid 20th century. Inherent to the production of these data sets are not only the uncertainties related to the observations themselves (e.g. instrumental errors, errors of representivity, inhomogeneities introduced through station relocation, different regional observing practices) but also uncertainties related to methodological choices made ('parametric' uncertainties) as well as the fundamental assumptions made within a methodological framework ('structural' uncertainties).

This analysis investigates the spread of possible results with regard to the trends in observed climate extremes when considering a number of data sets, all of them assuming reasonable choices regarding the inherent uncertainties. This allows us to quantify the uncertainties regarding changes in climate extremes during recent decades on global and regional scales, and to enhance our state of knowledge regarding the robustness climate change observations.

TO LITTLE ADO ABOUT NOTHING IN 21ST CENTURY RAINFALL PROJECTIONS

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Under global warming increases in precipitation are very likely at high latitudes and near major tropical convergence zones in some seasons, while decreases are likely in many subtropical land areas. In many other areas there is no consensus among models on the sign of the projected change. This is often assumed to indicate that precipitation projections in these regions are highly uncertain. Large uncertainty is a very undesirable situation because it impedes the ability of the scientific community to provide guidance on future climate in the affected regions. This, in turn, limits the ability of decision-makers in the wider community to optimise their mitigation and adaptation plans.

However, the absence of a consensus on the sign of change will tend to occur even if the models agree that an externally forced change in a particular area is either absent or small compared with internal variability. We examine this possibility using 21st century precipitation projections under the SRES A1B scenario using 24 WCRP/CMIP3 climate models. We show that in areas with no consensus on the sign of projected change there are extensive sub-regions where the projected change is *very likely* (i.e. probability > 0.90) to be small or absent. "Small" here is defined either as small relative to the size of the interannual variability during the late 20th century or small relative to late 20th century average precipitation. Such regions also tend to correspond to regions where there is a consensus among the models that the changes are either small or absent. This highlights that "agreement on the sign of a projected change amongst models" is not the same thing as "agreement amongst models", and that the distinction is important.

We recommend that in future, greater emphasis be given to identifying where models agree that projected changes in precipitation or other variables (or in important phenomena), are either small or possibly absent.

Power, S.B., F. Delage, R. Colman and A,. Moise, 2010: Consensus on 21st century rainfall projections in climate models more widespread than previously thought. *J. Climate*, submitted.

REMOTE INFLUENCE OF THE TROPICAL ATLANTIC ON THE VARIABILITY AND TREND IN NORTH WEST AUSTRALIA SUMMER RAINFALL

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Rainfall in North West Australia (NWA) has been increasing over the past decades, occurring mainly in austral summer season (December-March). A range of factors such as decreased land albedo in Australia and increasing anthropogenic aerosols in Northern Hemisphere, identified using simulations from climate models, have been implicated in this wetting trend. However, the impact of land albedo and aerosols on Australian rainfall remains unclear. In addition, previous studies showed that dominant sea surface temperature (SST) signals in the Pacific-Indian Ocean including El Niño-Southern Oscillation (ENSO), ENSO-Modoki and the Indian Ocean dipole mode have no significant impact on the NWA rainfall trend. The present study proposes another viewpoint on the remote influence of tropical Atlantic atmospheric vertical motion on the observed rainfall variability and trend in NWA.

It is found that, with the atmospheric ascent instigated by the warming of SST over the tropical Atlantic, a Rossby wave train is emanating southeastward from off the west coast of subtropical South America to mid latitudes of the South Atlantic Ocean. It then travels eastward embedded in the westerly jet waveguide over the South Atlantic and South Indian Oceans. The eastward-propagated Rossby wave induces an anticyclonic anomaly in the upper troposphere over Australia, which is at the exit of the westerly jet waveguide. This leads to an in-situ upper-tropospheric divergence, ascending motion and a lower-tropospheric convergence, and the associated increase in rainfall in NWA. Thus, the increasing trend in atmospheric upward motion induced by the warming trend of SST in the tropical Atlantic may partially explain the observed rainfall trend in NWA.

AN EXTENDED HIGH-QUALITY DAILY TEMPERATURE DATA SET FOR AUSTRALIA

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A new homogenised temperature data set for Australia at the daily timescale has been developed by the Bureau of Meteorology. This data set extends from 1910 to the present and includes data from 112 locations, with nearly all locations having at least 50 years of data and 60 of them extending through the full post-1910 period.

The new data set draws on large amounts of daily data that have only been digitised in recent years. This allows daily coverage to be extended to the full post-1910 period, whereas previously there was only very limited daily coverage prior to 1957. The new data set also includes some new locations which were not in the previous daily data set, particularly in Western Australia.

The data have been homogenised at the daily timescale, using a combination of statistical methods and metadata. The technique used for homogeneity adjustment involves a percentile-matching algorithm, allowing different adjustments to be made to different parts of the frequency distribution. This is important for homogenising extremes since the impact of some inhomogeneities on extremes differs substantially from their impact on means. All adjustments and amendments made to the data have been comprehensively documented.

The new data set will allow more robust analyses of changes and variability in Australian temperature over the last 100 years, in particular allowing analyses of century-scale changes in extremes for the first time. It is due to be released in early 2012.

HIGH-QUALITY MONTHLY UPPER-AIR TEMPERATURE AND HUMIDITY DATASETS FOR AUSTRALIA

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It is known that discontinuities in climatological time-series can be caused by a range of factors. For surface data these are mostly station moves and changes in the types of instruments used or their exposure. For upper-air data these factors are predominantly related to changes in the types of sondes and observing practices. It is important to develop homogenous series that are adjusted in points of discontinuity, with the aim of gaining greater confidence in obtained trends. Such efforts were previously made for global upper-air data by several authors.

Here we will present on-going work related to the development of the homogeneous upper-air temperature and humidity datasets of 26 stations, produced in order to analyse trends in these variables over Australia. Datasets are based on 23UTC soundings for the standard levels of 850, 700, 500, 400, 300, 200, 150 100 and 50 hPa. Most records start from 1958. Necessary adjustments of the time-series were determined using historical metadata and an objective statistical test. As a reference series for the temperature at the two lowest levels (850 and 700 hPa), high-quality surface mean temperature data series were used. For temperature at higher levels, as well as for relative humidity at all levels, an attempt will be made to find an appropriate way to create reliable reference series.

IDENTIFYING DAILY RAINFALL ENTITIES FROM HIGH RESOLUTION GRIDDED DATA

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Rainfall bearing systems are usually recognized based on synoptic tracking tools, and using meteorological variables other than rainfall. In this work we use the Bureau of Meteorology daily gridded rainfall data at 5km resolution over the entire Australian continent which was formed as part of the Australian Water Availability Project (AWAP). This data is used to identify “rainfall entities” and to form a climatology of these systems. This novel and challenging approach has a lot of potential since it tracks directly the surface variable that matters most (ie rainfall). The AWAP data set runs from 1900, thus we are able to generate a very long climatology of daily rainfall systems across Australia – much longer than using mean sea level pressure.

The challenge is to define a set of rules to identify the rainfall entities. As part of the development of the methods, choices were made regarding thresholds, how to deal with missing data, and how far apart discrete entities could be to be joined together. Several methods were investigated, either using simple empirical thresholds or more advanced interpolation techniques (e.g. Fast Fourier transforms). We will review some of the key technical aspects of the method chosen to define the rainfall entities.

With a set methodology, a 110 year climatological dataset was formed. Rainfall entities are defined by their size, intensity and the position of their centre (weighted by rainfall intensity). Seasonality, inter-annual variability and long-term trends are evaluated for all these characteristics.

Two examples are provided to illustrate the potential of this dataset for climatological analysis:

- an investigation of the characteristics of the South Eastern Australian prolonged drought from 1997 to 2009, and

- an application to identify East Coast Low events.

CONSISTENCY OF OBSERVED AND SIMULATED CHANGES IN TEMPERATURE, PRECIPITATION, AND SEA LEVEL PRESSURE

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Our confidence in regional climate projections depends strongly on how well the current models are able to represent recent observed changes. Recent research has identified inconsistencies between simulated and observed warming in western Europe and drying in south-eastern Australia. A globally comprehensive analysis, however, is not available so far. Based on various observational data sets and simulations from the CMIP3 archive, we assess whether the identified inconsistencies between observed and simulated changes are globally significant and whether we can identify coherent spatial patterns of inconsistencies across models.

We find coherent areas of inconsistency between observed and simulated warming over the oceans in a large number of models. Although there are inconsistencies between observed and simulated warming over land, no coherent patterns across models are identified. Due to the low signal-to-noise ratio of precipitation changes, large observational uncertainties, and inter-model differences, we find no pattern of inconsistencies between simulated and observed precipitation changes at the grid-box level shared by the majority of models despite sometimes considerable inconsistencies between observed and simulated changes for individual models. Finally, we identify tropical regions in which the observed increase in sea level pressure is underestimated by the models. The same applies to increases over mid-latitude oceans and decreases in high-latitude sea level pressure. Due to the larger variability in extra-tropical regions, however, the underestimation of simulated sea level pressure change is less often significant.

Our globally comprehensive analysis of the inconsistencies between observed and simulated changes indicates that the CMIP3 models likely share common deficiencies, mainly in regions that attract little attention for regional climate projections. Follow up research is thus needed to find out to what extent limitations in simulating recent change in regions (far) away from the target areas limits our confidence in regional projections.

THE INDO-AUSTRALIAN MONSOON OF THE LAST 25 KA: A CONTINUOUS STALAGMITE RECORD FROM SULAWESI, INDONESIA

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A number of prominent records of the Asian Monsoon over the last 100 ka have been published for the Northern Hemisphere (see e.g. Wang et al., 2001, Dykoski et al., 2005, Partin et al., 2007), however, there remains a large gap in our understanding of the southern counterpart of the Asian Monsoon, referred to here as the Indo-Australian Monsoon. Here we will present a continuous $\delta^{18}O$ paleo-monsoon record from southwest Sulawesi, Indonesia, spanning the period 25 ka to present. This site is in a key location to document changes in Austral-summer monsoon rainfall, as well as tracking north-south migrations of the inter-tropical convergence zone since the last glacial maximum. This new record documents a strong intensification of the Indo-Australian monsoon through the deglaciation that lags the warming of tropical sea surface temperatures and also documents isotopic changes associated with the flooding of the Sunda Shelf. Millennial-scale variability in this new record also allows for an examination of how northern hemisphere climate events propagate through the tropics and into the southern hemisphere.

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MODELLING INSIGHTS INTO DEUTERIUM EXCESS IN WATER VAPOUR AS AN INDICATOR OF OCEANIC SOURCE CONDITIONS

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Stable water isotopes (δD and $\delta^{18}O$) from polar ice cores are often used as local temperature (Tsite) proxies in palaeoclimate reconstructions. The deuterium excess signal is a second order isotopic parameter recording conditions in the oceanic source region, including sea surface temperatures (Tsource). Studies combining both water isotopes and deuterium excess have estimated past changes in Tsite and Tsource. These records indicate dynamic past changes in the atmospheric water cycle, including significant variability in the location of moisture sources to high-latitudes around the Last Glacial Maximum (LGM).

Field observations constraining the fundamental relationship between deuterium excess in water vapour and oceanic surface conditions are, however, limited. We aim to improve the estimate of this observed relationship through multiple simulations of past and present climate using the Goddard Institute of Space Studies ModelE-R, a fully coupled atmosphere-ocean general circulation model equipped with water isotope tracers. In addition, we incorporate a novel suite of vapour source distribution tracers to assess the skill of deuterium excess as a proxy for Tsource variability during a variety of climate changes.

We simulate mean climate conditions during various time slices and compare to results palaeo-reconstructions from Greenland and Antarctica. We find that the drivers of variability in water isotopes and deuterium excess over these regions are complex and dynamic, and linked to changes in large-scale changes in atmospheric circulation, water vapour transport and mixing, together with changes occurring in the vapour source region. This study demonstrates the utility of integrated model-data comparisons in constraining isotope-climate relationships and for interpreting variability in water isotope records.

MILLENNIAL-SCALE OSCILLATIONS OF THE INTER-TROPICAL CONVERGENCE ZONE OVER THE LAST 50KYR AS SEEN FROM THE FLORES SPELEOTHEM PALEO-MONSOON RECORD

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Tropical speleothem $\delta^{18}O$ has been shown to act as a paleo-rain gauge, recording a combination of the source and amount of rainfall falling over karst areas. Over the maritime continent of Indonesia much is known about the variability in the seasonal fluctuations of the Inter-Tropical Convergence Zone (ITCZ) into the northern hemisphere, known as the East Asian Monsoon (*Wang et al. 2008*). The strength of the monsoon on millennial and greater timescales is believed to be controlled largely through variations in sensible heating of the Asian landmass due to changing solar irradiance over orbital cycles. This pulling effect of the changing differential land-sea heating shifts the mean ITCZ position. If the ITCZ is pulled northwards by the strength of the East-Asian Monsoon then there must be profound effects on its southern-hemisphere counterpart, the Indo-Australian monsoon. As yet, little is known about the paleo-strength of this part of the monsoon system.

The tropical speleothem record from Flores is an emerging record of the Indo-Australian monsoon that will help provide new insight into latitudinal changes in the ITCZ. Here we extend the record, previously published (*Griffiths et al. 2009*) through Marine Isotope Stage (MIS) 1 (0-12kyr BP) and submitted (*Ayliffe et al. 2011, in prep*) through MIS 2 (12-24kyr BP) back through to 50kyr BP. Our initial results show that the Flores Paleo-monsoon record is anti-correlated with the acclaimed Hulu-Dongge record (*Wang et al. 2008*) from eastern China on millennial timescales. The degree of difference between the Flores and Hulu-Dongge record may provide a past proxy as to the mean location of the ITCZ.

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DYNAMICAL BALANCE BETWEEN ASSIMILATING TEMPERATURE AND SALINITY IMPACT ON SEASONAL FORECAST SKILL IN A COUPLED MODEL

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We assess the impact of improved ocean initial conditions for predicting ENSO and IOD using the Bureau of Meteorology's POAMA coupled model for the period 1982-2006. The new ocean initial conditions are provided by an ensemble-based analysis system that assimilates subsurface temperatures and salinity and which is a clear improvement over the previous optimal interpolation system which used static error covariances and was univariate (temperature only).

Hindcasts using ocean initial conditions from the multi-variate ensemble analysis system have better skill at predicting sea surface temperature (SST) variations associated with ENSO, and this increased skill is derived from better dynamical balance between temperature and salinity and larger interannual variability of the surface salinity throughout the tropical Pacific in the initial condition, i.e., a more realistic mean state and interannual variability of salinity. Also, those subsurface improvement regions have less influenced by the model bias and provide the long "effective memory" to the SST variations associated with ENSO.

However, improved ocean initial conditions do not translate into improved skill for predicting the IOD. Improved skill at predicting subsurface temperature variations is demonstrated south of the equator in the Indian Ocean unlike the Pacific along the equator, presumably associated with slow westward propagating Rossby waves, but skill for near-equatorial subsurface temperature variations associated with the IOD skill drops off quickly with forecast lead time in both cases. Results suggest that potential predictability of IOD is much smaller than for ENSO due to the shorter memory within the subsurface.

THE DIAGNOSIS OF ENSO EVENTS IN AN OPERATIONAL SETTING

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The irregular cyclic phenomenon of the equatorial Pacific known as the El Niño-Southern Oscillation (ENSO) phenomenon can have a disruptive and sometimes devastating effect on worldwide weather patterns, especially in the countries bordering the Pacific. Timing between events varies, though events typically occur on a 2-7 year cycle. Furthermore, characteristics such as duration and strength can vary from event to event.

The relationship between ENSO and climate worldwide has made it a priority of international modelling efforts to predict event occurrence, as early warning of an event can allow some degree of preparation and management of the associated risks such as drought and flooding. Likewise, early surety that an event is underway can allow more certain forward planning, eg. for the agricultural industry. However, the pressure for early diagnosis of an event may lead to an increase in 'false alarms', which would lead to decreased reliance of the public on subsequent such declarations.

In this study we examine a number of commonly used ENSO indices for their ability to diagnose ENSO events with few false alarms, i.e. the frequency of which events are diagnosed are compared with the actual frequency of event occurrence. We examine the separate skill for both El Niño (EN) and La Niña (LN) events and also the timing of the diagnosis.

We found that indices using a combination of variables, such as the Multivariate ENSO Index (MEI) and the

5VAR index generally gave the fewest false alarms whilst diagnosing the most number of EN and LN events in a timely manner. This was followed closely by the Niño-4 and Niño-3.4 SST indices with results showing that using the standard deviation rather than a set threshold tends to identify events earlier. The benefits of the 5VAR and Niño SST indices above the MEI are that they are easier to compute and are also available on a weekly basis. A method of diagnosing ENSO events may include combinations of these indices at the levels and averaging periods discussed in the paper.

POAMA2 PRECIPITATION VERIFICATION OVER 50 HINDCAST YEARS

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POAMA (Predictive Ocean Atmosphere Model for Australia) is an intra-seasonal to inter-annual climate prediction system based on coupled ocean and atmosphere general circulation models. The most recent version POAMA2 has become operational since early 2011. The major upgrades in POAMA2 include a new ocean initialization scheme (PEODAS) and multi-model approach with larger ensembles (30 members) and longer hindcasts (50 years, 1960-2009).

In this talk an introduction of the new POAMA2 system will be presented. Main focus will be on global precipitation verification at seasonal time scales. As there is no precipitation verification dataset available during the early hindcast period of 1960-1978 and over the global oceans, a surrogate dataset derived from two reanalyses (ERA-40 of ECMWF and Twentieth Century Reanalysis V2 of NOAA) has been developed.

Results show POAMA2 has comparable predictive skill over the early hindcast period compared to more recent decades.

BARRIERS TO THE WIDER APPLICATION OF CLIMATE PROJECTIONS

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Engineers and scientists use climate projection information to provide insight into potential future conditions. Applications of this include undertaking water resource assessments and determining future runoff from catchments. Traditionally this results in time series information being adjusted using baseline periods to factor series. However, this approach is very simplistic. There are inherent assumptions such as the stationarity of time series and that factoring is applicable across sub-annual and decadal timescales. Isn't the answer then to apply the more rigorous techniques developed by climate scientists to overcome these limitations? While this sounds great in theory, there are barriers in actually applying this. Communicating how climate change adjusted series were created to those not in the climate science industry can be difficult, determining which projection is best for specific applications and understanding that the application of climate projections often will not produce a single answer or time series. This paper will use case studies to demonstrate examples of typical climate projection methods used water resource assessments and discuss the limitations for the application of more complex climate projections. These limitations include data availability, complexity and accuracy of water resource models and rainfall runoff models and the end purpose of the climate projections in the context of their hydrologic applications.

Poster Presentations

3.1. MODELLING AND UNDERSTANDING THE CAUSES OF INCREASED RAINFALL IN NORTHWESTERN AUSTRALIA

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Various studies have shown that December – February rainfall has increased significantly over the last sixty years in Northwestern Australia (NWA). However, there is little consensus on the underlying causes of this rainfall trend and General Circulation Models (GCMs) struggle to capture the processes that lead to rainfall generation in NWA, making an assessment of the potential drivers of the observed trend difficult.

The work presented here assesses the capability of a GCM, in this case a version of the Hadley Centre Global Environmental Model (HadGEM), to represent NWA rainfall characteristics for December – February relative to the available observational and reanalysis data. If the model adequately represents the processes governing NWA rainfall generation then perturbation experiments can be undertaken to understand the likely forcing mechanism(s) that may be causing the observed trend.

3.2. RECENT OBSERVED CHANGES IN SNOW DEPTH AND SNOW COVER DURATION IN THE AUSTRALIAN ALPS

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We examine the influence of climatic drivers on changes in snow depth and snow cover duration in the Australian Alps over the past decades using a suite of empirical models. We use snow depth measurements from four sites in the Snowy Mountains and the Victorian Alps and compare these with monthly averaged temperature and precipitation observations. The decrease in maximum snow depth and earlier termination of the snow season identified in earlier work continues in the first decade of the twenty-first century. We find that the observed warming from June to September explains about two thirds of the recent decline in maximum snow depth, and the changes in precipitation account for roughly one third. Warming is even more dominant in explaining changes in earlier termination of the snow season, with changes in precipitation explaining a negligible fraction of the observed earlier termination of the snow season. We furthermore identify a consistent trend towards an earlier onset of the snow season which is smaller in magnitude than the trend in the end of the snow season. Neither monthly temperature nor precipitation provide a satisfactory explanation of the variability in the onset of the snow season. We conclude that especially ablation and thus the end of the snow season in the Australian Alps is highly sensitive to changes in temperature and thus to global warming. Further research is needed, however, to assess whether the observed changes can be attributed to anthropogenic influences.

3.3. ANALYSIS OF HISTORICAL OBSERVATIONS NARROWS UNCERTAINTY RANGE FOR TEMPERATURE PROJECTIONS

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The 2007 IPCC Fourth Assessment Report provides an estimate for the future global-mean temperature increase as likely to be 1.1°C to 6.4°C by 2100 (relative to 1990). This wide range reflects uncertainties in both future emissions and the response of the combined climate system. However, this result is not particularly helpful for policy and planning purposes, especially in the absence of probabilities.

This research investigates the sources of uncertainty associated with such projections, taking into account interactions between the climate system, the carbon cycle and aerosols. A reduced complexity Earth System Model was selected as an appropriate tool for this work.

To investigate setting the model's climate system and carbon cycle parameters, the contribution of each of the parameters to the overall uncertainty was assessed first. The climate sensitivity and ocean vertical diffusivity account for most of the climate system uncertainty, along with a combined aerosol forcing uncertainty parameter. The model's carbon cycle parameters are also important, since they have the strongest influence on carbon dioxide concentrations, but also impact on temperature projections.

The most significant parameters were assigned prior probability distributions, which were then combined with twentieth-century historical climate and carbon cycle observations using a Monte Carlo Metropolis-Hastings algorithm. This produced posterior distributions for the key model parameters.

The posterior parameter distributions enabled probabilistic temperature and CO_2 concentration projections to be made. These show reduced uncertainty ranges for future warming projections, with increased lower bounds for warming due to SRES A1FI emissions as compared to the results reported in the IPCC Fourth Assessment Report. The upper bound for the likely range is also considerably reduced. For this emission scenario, relative to pre-industrial, there is a 50% probability of global warming exceeding 2°C by 2045, with a 60% probability of exceeding 4°C by 2100.

3.4. ENSO-RELATED SST CHANGES AMPLIFY THE RADIATIVE IMPACT OF INDONESIAN BIOMASS BURNING AEROSOLS

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El Niño-related droughts promote fire activity in Indonesia and often go along with anomalously high biomass burning aerosol burdens in equatorial Asia that regionally change the radiation budget. As ENSO-related SST variations alter atmospheric circulation, it is likely that decreased rainfall rates during El Niño influence aerosol removal and thus control the amount and distribution of aerosols in the atmosphere. In this talk we show how ENSO-related SST variations amplify the radiative impact of Indonesian biomass burning aerosols. The results are based on CSIRO Mk3.6 Global Climate Model simulations using El Niño (1997) and La Niña (2000) fire emissions from the Global Fire Emissions Database (GFED). The direct aerosol impact through scattering and absorption of solar radiation and the indirect effect through changed cloud properties are addressed separately.

3.5. TOWARDS THE DEVELOPMENT OF LONG TERM WINTER RECORDS FOR THE SNOWY MOUNTAINS

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Alpine regions are extremely sensitive to climate change in the impact on plants and animals as well as on human activity. Small changes in temperature and precipitation can have large impacts on the ability of ecosystems to survive while changes in snow cover could have enormous ramifications on human activity such as the ski industry. It is therefore highly important to try to develop a long term data set on climate and snow depth in order to examine whether any signal of climate change is in fact occurring in these regions.

This paper provides a method for developing long term winter records of temperature, rainfall and snow depth data sets from available climate information in the Kosiuzsko National Park region and what we can infer from these data sets regarding possible historical records.

The inference from the derived winter snow depth data set indicates that although extreme heavy snow events may not have changed over the period of record, the early record did not appear to have as many poor snow years. Snow seasons around the turn of the 20th Century appear to have been more regular with maximum winter snow depths being considerably higher than measured in recent decades. This reduction in snow depths would tend to support the expected impacts on the Australian Alpine region of global warming as indicated from computer climate modelling and highlight the possible impacts on the ecosystems and human activity that may occur in this sensitive climatic region.

3.6. THE SIMULATION OF RAINFALL REGIMES FOR ADELAIDE, MELBOURNE, SYDNEY AND BRISBANE USING WRF

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The characteristic rainfall patterns for Adelaide, Melbourne, Sydney and Brisbane are determined from a k-means cluster analysis of the Australian Water Availability Project (AWAP) rainfall fields, and the synoptic pattern corresponding to each rainfall pattern is calculated using the ERA-Interim 1.5 degree horizontal resolution reanalyses. These combined rainfall and synoptic patterns within a 21 by 21 degree region drawn from the most climatologically representative clusters are designated rainfall regimes. Using initial and boundary conditions from the ERA-I reanalyses, the Weather Research and Forecasting model (WRF) is used to simulate the daily accumulated rainfall for 2000-2005 centred on Adelaide, Melbourne, Sydney and Brisbane. Analyses of the WRF simulations are done on the 0.15 degree horizontal resolution inner domain. Rainfall regimes are calculated from the WRF simulations and verified against those determined from AWAP and ERA-I reanalyses.

3.7. PRESCRIBED VERSUS TIME-VARYING OZONE IN AN ENSEMBLE OF AMIP SIMULATIONS

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The AR5 climate simulations will include time-varying ozone fields, either prescribed or determined interactively. Using the Australian ACCESS climate model, we investigate how the inclusion of time-varying ozone in the model impacts various aspects of our climate, in particular that of the Southern Hemisphere, differently then using solely climatological ozone.

We have run several climate simulations covering the period 1978-2008 with climatological ozone and several climate simulations with time-varying ozone. All other forcings remained identical for both sets of simulations. Differences in simulated climatology between the ensemble means of both sets of simulations that exceed the 90 percentile significance level can be attributed to the inclusion of time-varying ozone in the model.

3.8. PATTERNS OF SEA SURFACE TEMPERATURE AND SEA LEVEL PRESSURE WITH TELECONNECTIONS TO RAINFALL IN SOUTH-WEST WESTERN AUSTRALIA

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Climate change projections indicate that south-west Western Australia (SWWA) is likely to experience a drying climate with declining growing season rainfall and rising temperatures. However, seasonal variability will remain the dominant driver of adaptation at the farm level. Forecasts of seasonal rainfall made at managerially relevant times of year should enable farmers to modify farm management to maximize returns in good seasons and minimize losses in bad seasons. Current use of seasonal forecasts is limited by perceived low levels of skill and limited availability of long-lead forecasts at appropriate times of year.

To forecast rainfall using statistical models, we need to identify drivers that can be used to predict rainfall in the future. Risbey *et al.* (2009) identified large-scale remote drivers of variability of Australian rainfall that vary slowly and modulate rainfall via their links to synoptic processes affecting rainfall. They considered the El Niño – Southern Oscillation phenomenon, the Indian Ocean Dipole, the Southern Annular Mode, the Madden-Julian Oscillation and atmospheric blocking, which was used as a proxy for the influence of the long-wave circulation in the Southern Hemisphere. However, correlating these drivers and future SWWA rainfall shows their use to be limited for seasonal forecasting in this region.

We compare the use of principal components and partial least squares (PLS) regression to derive patterns of global sea surface temperature and sea level pressure using monthly data and normalized data from all years and all months. Because partial least squares regression uses future rainfall data to derive the patterns, we use cross-validation to assess the stability of the derived PLS predictors. We identify patterns with the most use for forecasting in SWWA, and discuss their teleconnections to SWWA rainfall.

The patterns are used as predictors in a statistical seasonal forecast system, with forecasts and methodology available online at http://www.agric.wa.gov.au/forecast.

Risbey, J.S., Pook, M.J., Fiedler, P.C., Wheeler, M.C. and Hendon, H.H. (2009). On the remote drivers of rainfall variability in Australia. *Monthly Weather Review*, 137, 3233-3253.

3.9. MULTI-WEEK RAINFALL PREDICTIONS FROM POAMA – PART ONE

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Following the work of Hudson et al in CAWCR, POAMA1.5 hindcast rainfall data were analysed in terms of the potential to provide rainfall outlooks at multi-week time scales. The project has received funding from the Managing Climate Variability Program (MCV) under the auspices of the Grains Research and

Development Corporation (GRDC). This funding source reflects the desire of stakeholders, particularly those in agriculture, for forecasts of rain for periods which bridge the gap between weather forecasts and seasonal outlooks.

The work to date has consisted of two main facets: 1. how accurate or skilful is POAMA in predicting rain at these time scales?; and 2. what different forms of output do stakeholders find most appealing?

The POAMA1.5 hindcast data span the years 1980 to 2006 inclusive (27 years). Ten-member ensembles, initiated at three-hour intervals prior to the first of each month, provided both ensemble mean data and individual member data; the latter giving an estimate of spread in the forecast.

Ensemble mean rainfall data were aggregated into weekly, fortnightly and four-weekly blocks. Given that POAMA's "climate" is different from the observed, it was necessary to calibrate model data to more closely reflect reality. Initially a bias correction was used, in which POAMA's predicted rainfall was converted to a fraction of POAMA's mean, which was then multiplied by the observed mean. The second was a more complex "inflation of variance (IOV)" technique, in which the variability in the POAMA output is calibrated to reflect the observed variability.

Using Bias, Mean Absolute Error (MAE) and the Mean Square Skill Score (MSSS) as measures of skill, the IOV method was clearly better.

The MCV Climate "Champions" were sent an online survey seeking response and reaction to a number of different presentation formats of POAMA prediction: ensemble mean rainfall total, totals expressed as a percentage of the climate average for the whole month, ensemble extremes (maximum & minimum) shown as total and monthly percentage, the ensemble mean number of days with rain $\geq$ 1.0mm, and the chance that rainfall will exceed various thresholds (5mm, 10mm, 15mm, 25mm, 50mm and 100mm).

3.10. MULTI-WEEK RAINFALL PREDICTIONS FROM POAMA – PART 2

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As part of the *Multi-week Climate Outlook Products for Australia* project, funded by Grains Research and Development Corporation (GRDC) Managing Climate Variability (MCV) R&D program, the feasibility of using a coupled ocean-atmosphere dynamical model to forecast multi-week time periods was explored. The first phase of the project explored the potential for operational rainfall outlooks using POAMA1.5, a coupled ocean-atmosphere dynamical model run at the Bureau of Meteorology.

Multi-week Rainfall Predictions from POAMA – Part 1 details the calibration process of the POAMA1.5 hindcast rainfall data. Model data is attuned to the model world, rather than the real world, making a degree of calibration necessary for the raw data to more closely reflect reality. *Part 2* details the verification process of these calibrated hindcasts.

Two methods of calibration were employed. The first was a simple bias correction, while the second a more complex variance inflation method ("inflation of variance", IOV). These two methods were also compared alongside the raw POAMA output. Besides simple rainfall totals, number of rain days and chance of exceeding a given threshold were also assessed.

The calibration was applied on a finer grid than the coarse POAMA grid. Both calibration methods improved the rainfall distribution in relation to geographical features, e.g., increased rainfall across elevated areas.

Bias, Mean Absolute Error (MAE) and the Mean Square Skill Score (MSSS) were used as measures of skill for totals and rain days. Upon inspection of the results, and aggregation across the whole of Australia, the bias correction actually lowered the skill of the original raw forecast, while the IOV method showed improvement on the raw forecast. Seasonality also plays a part in the skill of the forecast, with the lowest skill during the austral summer. Dynamical models tend to forecast too many days with very light rain, and despite using a threshold of 1mm, results still showed a bias towards too many rain days.

3.11. A LAND OF FLOODING RAINS AND DROUGHT: AUSTRALIAN CLIMATE IN 2011

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Australian mean temperatures for January-August were 0.29ºC below the 1961-1990 normal, on course to be the first below average value since 2001. They are currently tracking as equal 14th coolest of 62 years of record. The year of 2011 is not likely to set a temperature record; years beginning with a La Niña in place tend to be cooler than usual, but with a warming trend in the record, this most recent period is warmer than other similar La Niña periods.

2011 arrived with a bang, with flooding rife across eastern Australia, the result of the strong La Niña conditions that became established in mid-2010. Eastern Queensland and northern Victoria were particularly badly affected. With an Australia-wide mean rainfall of 406mm, the January to March period was the second wettest in the 112 years of record (420mm in 1974 the record). The 2010-11 summer was the wettest on record for Victoria, and ranked in the top ten wettest summers in every state except Tasmania.

The La Niña declined into a neutral ENSO state during the austral autumn. From April to August, Australian rainfall anomalies resembled those that had prevailed for much of the ten years prior to the strong La Niña, namely, dry conditions across southeastern and southwestern Australia, and seasonally dry conditions through most of the tropics. A result of the prolific rain from the La Niña, abundant vegetation growth in central Australia dried and ignited, causing some of the most widespread grass and scrub fires across the region since 1974.

By September, there were signs of a redevelopment of La Niña.

3.12. A MODEL FOR RUNS OF EXTREMES IN A DAILY VARIABLE

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Quantifying the likelihood of runs of extremes of daily quantities of a meteorological nature such as temperature, evaporation, sunshine and wind can be accomplished using a model with two free parameters. The runs of extremes could be heat waves, cold spells, periods of high evaporation, low sunshine, etc. Extremes are regarded here as quantities exceeding any arbitrary threshold defined in terms of ranking percentile, eg, 90th or 99th. The model has the property of symmetry and so extremes may also be regarded as those observations below given percentiles, such as the 10th or first.

Essentially, the model is intended to answer the question, "What is the likelihood of a run of x days with daily quantity exceeding (or, alternatively, not reaching) a threshold of y?"

Two physical properties that many meteorological quantities have in common are a degree of daily persistence and seasonality. Daily quantities such as temperature, evaporation, sunshine, rainfall and wind are modelled using a stochastic seasonal autoregressive representation incorporating daily persistence and seasonality.

The daily persistence and seasonality may be calculated beforehand or they can be regarded as two free parameters to be determined by fitting the model to the data.

One advantage of this method to the probability of rare events is that a sizable fraction of the data is used to determine the two parameters – not just the rare events. With reasonable caution, it is possible to determine the probability of events which have not been recorded in the database.

3.13. IMPACT OF THE INDIAN OCEAN HIGH PRESSURE SYSTEM ON WINTER PRECIPITATION OVER WESTERN AND SOUTHWESTERN AUSTRALIA

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Previous studies have linked ongoing winter drought in southwest Western Australia (SWWA) to changes in local, as well as large area, sea level pressure. Because the area of SWWA occupies only a few grid points of a typical global climate model (GCM), it is difficult to infer the possible role of global climate change in the drought in SWWA. Since the Indian Ocean High is a robust and large scale feature of atmospheric general circulation, it is simulated qualitatively in all GCMs. A quantitative comparison of the simulated past changes in its pressure and position in a GCM with those found in reanalysis data can be used to verify its suitability in projecting future changes in winter rainfall in southwest Western Australia. This paper examines the linkages between changes in the Indian Ocean High and rainfall in SWWA, as well as a larger section of Western Australia. By introducing objective indices for area weighted pressure, the area weighted latitude and longitude positions of the High, this analysis shows that winter rainfall in a large section of Western Australia and in SWWA is significantly correlated with longitudinal displacement of the Indian Ocean High. Rainfall in SWWA is also correlated with the area averaged pressure of the High. A regression model of May to August rainfall in SWWA using the pressure and longitude of the Indian Ocean High as independent variables explains 52 percent of the rainfall variance during 1951-2008.

3.14. DEVELOPING A HIGH-QUALITY RAINFALL DATASET FOR WESTERN AUSTRALIA – THE EFFECTS OF INFILLING AND DISAGGREGATING DAILY RAINFALL

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The current 'gold standard' for daily rainfall data for Australia is the high-quality rainfall dataset developed by Lavery et al (1992). Recently, this data set was extended to allow more detailed analyses of observed rainfall trends in Western Australia. The resulting network of 157 high-quality daily sites (Marinelli et al 2011, submitted) has improved the coverage over the state, especially for the two regions of interest: the southwest where a sharp decline in winter rainfall with accompanying drop in inflows to reservoirs has been observed and the north of Western Australia where rainfall during the monsoon season has increased.

As part of the quality control in developing this dataset, the homogeneity of the 157 daily rainfall series has been assessed using the software RHtest (Wang and Feng, 2010) and automated procedures were applied to flag suspicious data (Siriwardena and Seed, 2009). The automated checks where followed by manual assessments. These were required to identify whether values flagged as suspicious were indeed wrong or just unusual when compared with nearby stations.

While records for sites in the newly defined high-quality daily rainfall network are generally very complete, it might still be desirable to process the raw data to a) infill missing data and b) disaggregate rainfall accumulated over a number of days. Here we will discuss the performance of techniques for infilling and disaggregating daily rainfall data proposed by Siriwardena and Seed (2010) for Western Australia. Error statistics are used to describe the performance depending on season and region. Particular attention is being paid to values below 1 mm and the highest daily totals. Information of this type will be used to develop guidance about the suitability of the resulting series for further analysis like detecting trends in the number of wet days, extreme value analysis or trends in extremes.

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3.15. OROGRAPHIC FLOWS ACROSS THE ANTARCTIC PENINSULA

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Over the past 50 years the Antarctic Peninsula (AP) is one of the most rapidly warming regions on the planet, with the strongest warming rate occurring in winter along the west coast of the Peninsula. In summer, the largest temperature increase is observed over the northern part of the east coast. During summer the temperature on both sides of the Peninsula is correlated with the circumpolar westerlies, expressed in the Southern Annular Mode (SAM). The suggestion is that the stronger westerlies interact with the orographic barrier formed by the Peninsula, resulting in Föhn events on the lee side in the area of the Larsen Ice Shelf.

During the field season 2010/11 three Automatic Weather Stations (AWS) were deployed along a transect across the AP, soundings of the vertical structure of the atmosphere were performed on both sides of the Peninsula, and aircraft measurements were carried out during periods of westerly winds to study this phenomenon.

Since their deployment early in 2011 the data transmitted back by the AWSs have revealed several Föhn events that vary in their extent across the Larsen Ice Shelf. This contribution will present data received from the AWSs, characterize the Föhn events captured, and put them into a greater spatial and temporal context using high resolution runs with the Weather Research and Forecasting model WRF.

3.16. ASSESSING THE INFLUENCE OF THE TROPOSPHERIC BIENNIAL OSCILLATION ON ASIAN-AUSTRALIAN MONSOON PREDICTABILITY

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The Asian-Australian monsoon affects the economies of many countries and the livelihoods of millions of people in the monsoon regions. Significant year-to-year variability that exists in this system makes rainfall prediction difficult and may lead to hardship. Previous studies have reported a biennial tendency in this system, such that a strong/weak Asian monsoon is followed by a strong/weak Australian monsoon, namely the Tropospheric Biennial Oscillation (TBO).

In this study, the All-Indian monthly rainfall data and the Australian rainfall data from the Australian Water Availability Project (AWAP) have been used to investigate the TBO during the period 1900-2008, and to assess how useful this biennial tendency is for predicting monsoon anomalies. We develop a number of indices relating to the biennial signal and use Monte Carlo technique to quantify its predictability. In addition, we used lagged correlations between the monsoon rainfall and the Indian and Pacific sea surface temperature (SST) anomalies to identify when this relationship is strongest.

Results have identified a biennial signal in these indices, indicating that the TBO is not a random signal. However, we are only improving our predictive capability by 6% from no predictability.

3.17. STUDY AND RECONSTRUCTION OF SPI DROUGHT INDEX USING DENDROCLIMATOLOGY SCIENCE

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One of the ongoing debates in the global climate change involves the prediction of more droughts, longer droughts, and droughts of greater intensity. Common to all types of drought is the fact that they originate from a deficiency of precipitation that result in water shortage for some activity or for some group. Various drought indices have been developed to quantify drought status. The SPI is the most commonly used index. However, the SPI has limitations, it is calculated based on precipitation limited data, as are many other drought indices.. Dendroclimatology science provides access to long-term climate data which are the prerequisites for many climatological studies. This knowledge offers the possibility of reconstructing the past climate data taking into account the relationship between climatic variables and tree rings. This research was carried out to analyze Alder and Beech tree rings in Asalem-Khakhal forest (Iran) using increment borer cored samples and operation of cross dating relationship between the width of the tree rings and the limited precipitation data has been extracted. The results indicate that Alder trees are sensitive to drought but more resistant to pluvial, whereas the Beech trees are sensitive to pluvial and more resistant to drought than Alder. Since the climate elements have the same influence intensity on the tree growth process, it is irrelevant to investigate the relashionship between only one element with the tree rings and it is therefore necessary to use a climate index. Based on the results and the correlation coefficients between Alder tree rings and the SPI drought index, reconstruction was carried out to obtain the index values for years with missing data.

3.18. THE INDIAN OCEAN DIPOLE IN A WARMING CLIMATE

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It has been shown that a 19-model averaged Indian Ocean Dipole (IOD) index produces an upward trend towards more positive IOD events (Cai et al., 2009). While climate change is increasing the occurrences of positive IOD events, the precise cause is unknown. How much does a basin-wide warming in the tropical Indian Ocean contribute to this trend and what are the processes that cause models to show a projected increase or decrease in IOD events? Using climate models from phase 3 of the World Climate Research Programme's Coupled Model Intercomparison Project (WCRP CMIP3), SRES scenarios A1B and A2 are analysed to examine the behavior of the IOD in the mid-late 21st century. For the A2 scenarios, many of the models display a trend towards more positive IOD events in the mid-late 21st century with warming in the tropical Indian Ocean contributing significantly to this behavior. This is particularly noticeable for models where the IOD is projected onto the global warming signal such that the tropical western Indian Ocean warms at a greater rate than the eastern Indian Ocean. The mechanism for this will be discussed.

Cai, W. A. Sullivan, and T. Cowan (2009), Climate change contributes to more frequent consecutive positive Indian Ocean Dipole events, *Geophys. Res. Lett., 36,* L23704, doi:10.1029/2009GL040163.

3.19. CHANGES IN THE HADLEY CIRCULATION AND ITS IMPLICATION FOR SUB-TROPICAL CLIMATE

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Changes in the large scale general circulation of the atmosphere are examined across seven sets of reanalyses The use of a large number of existing dataset ensures an appropriate sampling of the errors in the global observing system and its assimilation by the models producing the climate mean state. The analysis presented here focused on the "post satellite era" from 1979-2009 since it is well recognised that the global observing systems have markedly improved since late 1970's. Global extent and intensity of the Hadley Cells (HCs) have been characterized by computing the zonal mean meridional streamfunction.

It is found that the HCs have been expanding at the rate of about 0.5o per decade at each hemisphere. This expansion has been very robust in the Southern Hemisphere amongst all the reanalyses. The expansion is largest during the summer and autumn. The analysis shows that there is no clear signal in terms of HC intensification or weakening. Theoretically, the expansion would be expected to be in conjunction with the weakening of the cells. However most of the datasets presented here hint at a small intensification in conjunction with the widening.

A key part of this analysis is to relate variability in the HC and the surface signature of the descending branch: the sub-tropical ridge (STR). An important finding is that the expansion of the HC is associated with the poleward shift of the STR as well as the observed intensification of the STR.

These results were obtained using zonal averages over the entire southern hemisphere. Further work, focusing on changes in the HC at the longitudes of the Australian continent is underway. This is likely to be crucial to better understand the recent period of lower rainfall observed across southern Australia.

3.20. SPATIAL PATTERNS OF CHANGES IN TEMPERATURE EXTREMES ACROSS SOUTHEAST AUSTRALIA

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Several studies have investigated trends in temperature extremes across Australia during recent years; however, such studies typically use station data. In this poster, we use the daily Australian Water Availability Project gridded temperature data to investigate trends in extreme maximum and minimum temperatures across NSW and Victoria during the 1911-2010 and 1961-2010 periods. In particular, an area with an increase in frost days is identified in southern NSW and Victoria, despite increasing minimum temperatures. The poster also briefly examines the relationship between extreme temperatures and ENSO, with hot days more common during summers following El Niño years, particularly in northern NSW and coastal areas.

3.21. KEY METEOROLOGICAL FACTORS CONTRIBUTING TO SEVERE FROST IN WINTER CROPS IN SOUTHEASTERN AUSTRALIA

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Winter cereal crops are particularly vulnerable to frost damage in the reproductive phases of their growth. Maximum vulnerability to frost tends to occur in late winter and early spring, the time of year when daytime temperatures are ideal for growth and night-time screen temperatures can readily fall below 2°C, the threshold adopted here for a frost. Damage from frost can beset wine grapes and fruit trees at the same time of year. The meteorological conditions associated with frost events in southeastern Australia have been examined by reference to NCEP/NCAR reanalysis data and synoptic observations from the Bureau of Meteorology for the critical August to October period each year from 1956 to 2010.

Each of the frost events examined supports theory and forecasting practice for Australia that the main ingredients for a frost in the region are relatively clear skies, light winds and low relative humidity in an air mass of polar maritime origin. These conditions usually occur when rapid anticyclogenesis takes place after a cold front crosses and introduces cold, dry air from high southern latitudes.

The synoptic situation prior to and during frost events has a critical bearing on the severity of the event. In particular, anticyclones centred to the south and west of the region provide a favourable environment for the subsequent radiative cooling which gives rise to freezing temperatures overnight. When the minimum temperature is less than or equal to -2°C (a severe frost) these synoptic conditions are met on at least 80% of occasions. Additionally, this investigation has identified the descent of dry air in the southerly airstream as a critical factor in the development of stable atmospheric conditions and one which also makes a major contribution to the transparency of the atmosphere to outgoing long-wave radiation.

3.22. AEROSOL REGIONAL DIMMING AND ITS IMPACT ON RAINFALL IN S.E. AUSTRALIA

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The IPCC AR4 identified aerosols as the forcing agent likely to have the greatest effect on hydrologic cycles and large scale atmospheric circulation systems. Using aerosol data from the NASA Nimbus 7, Earth Probe

and Terra satellites this paper demonstrates a direct link between the continental scale, anthropogenic, aerosol plume over S.E. Asia (the South East Asian Plume ("SEAP")) in the southern Spring (Sep, Oct and Nov) and rainfall in S.E. Australia. The increasing extent and intensity of the SEAP is driven by the increase in population in S.E. Asia which trebled from 1950 to 2010 (UN figures) and is expected to increase by a further 25% by 2050. Hence historic droughts in S.E. Australia could not have been caused by the SEAP.

The major natural source of aerosols in the SEAP Area (10S to 10N and 90 to 160E) is volcanic eruptions. This area is the most volcanically active region in the World with 20% of the recorded eruptions occurring in this area since 1500 (Global Volcanism Program data). I show a direct connection between the volume of tephra ejected by volcanoes in the SEAP Area and drought in S.E. Australia over the period 1891 to 2009.

Further since drought in S.E. Australia correlates with ENSO and Indian Ocean Dipole events I show that the level of tephra in the SEAP Area also correlates with ENSO and IOD events thus demonstrating that volcanic aerosols in the SEAP Area must have been the historic cause of ENSO and IOD events as no other interpretation is logically possible.

Finally the cause of the recent drought in S.E. Australia is shown to be the significant increase in the frequency and intensity of the anthropogenic SEAP allied with a major increase in volcanic activity in the SEAP Area in the last decade.

3.23. HALF-CENTURY AIR TEMPERATURE CHANGE ABOVE ANTARCTICA

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This talk provides a synthesis of observed 50-year (1961-2010) seasonal air temperature trends above Antarctica, revealing the vertical profile of Antarctic temperature change from the surface to the stratosphere. Statistically significant temperatures trends have occurred aloft over the past half-century, characterized by tropospheric warming and stratospheric cooling. Tropospheric warming is found in all seasons, indicating that it is not solely the winter phenomenon revealed previously. In contrast, the stratospheric cooling has been manifest primarily in austral spring and summer. Three of the latest atmospheric reanalyses are used to construct simple statistical models relating pan-Antarctic temperature changes to observed trends at eight locations. The statistical models explain a large proportion of the temporal variance of temperature above Antarctica, and the reconstructed trends are in close agreement with observed trends at five independent validation sites. The best statistical model is identified and then used to create the first spatial reconstructions of pan-Antarctic upper-air temperature trends. These reconstructions strongly suggest that both the tropospheric warming and the stratospheric cooling have occurred above the entire continent, although their magnitudes vary regionally. The causes of the tropospheric warming remain unclear; however, unlike *surface* temperature change, it is unrelated to a shift in the Southern Annular Mode. Possible wintertime increases in polar stratospheric clouds are insufficient to explain the year-round tropospheric warming. The stratospheric cooling appears to be primarily related to ozone depletion.

3.24. DROUGHT ASSESMENT OVER NORTHERN OROMIA OF ETHIOPIA

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The economy of Ethiopia mainly depends on rain fed agriculture, which is highly sensitive to seasonal and inter annual variations of rainfall. Adequate amount of rainfall is reacquired every year to year for agricultural production and for drinking water. Therefore, the distribution of seasonal rainfall in space and time is critical to the country's economy. Drought has great influence on the socio-economic aspect and livelihood of the rural population .this study mainly focuses on the Climate Change of Northern oromia in connection with different agricultural products.

The investigation mainly focuses on the drought which occurs over northern oromia during the period of 1961-2003.Rainfall data from Ethiopian meteorological Agency will be used to determine the characteristics or intensity of drought.

3.25. PROGRESS TOWARDS SIMULATING TROPOSPHERIC CHEMISTRY USING UKCA AND THE ACCESS CLIMATE MODEL

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The UK Chemistry and Aerosols (UKCA) module of the ACCESS Earth Systems Model is used to model various reactive chemical gases and aerosol species (i.e., non-CO2), as well as the radiative feedbacks with the coupled climate system. In this presentation, we outline current progress and future plans for developing the tropospheric chemistry component of UKCA. Preliminary results demonstrate the model sensitivity to changes in surface emissions when running ACCESS with prescribed sea-surface temperatures (i.e., not coupled with an ocean model). We also discuss the simulated sensitivity of the climate to radiative feedbacks with methane. Observations from the AGAGE and CSIRO surface networks are used to evaluate the model, as well as comparing the simulations with reanalysis products. We also discuss progress with atmospheric nudging schemes and improved emission datasets.

3.26. INFLUENCE OF TIME OF OBSERVATION ON TEMPERATURES IN AUSTRALIA

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Daily maximum and minimum temperatures in Australia are measured for the 24 hours ending at 0900 local time. This practice has been in general use since 1964. Several other observation time periods have been in use at some locations at various times in history, including midnight-midnight (standard at Bureau-staffed stations between 1932 and 1963), the 24 hours ending at 0000 UTC (for minima) and 1200 UTC (for maxima), and minima for the period from 1500 to 0900 local time. The introduction of daylight saving time has also introduced an effective one-hour shift in observation times during summer in some states since the early 1970s.

Systematic differences between these observation days were investigated using recent one-minute data from 32 stations, mostly covering the period 2003-2009.

The most substantial differences found were between temperatures for observation periods ending at 0900 and midnight. Mean minimum temperatures were lower for a midnight observation day at all 32 stations tested, with a mean difference across the stations tested of 0.25°C. The differences are smallest (near 0.1°C) at most northern Australian stations, and largest near southern coasts, reaching 0.66°C at Mount Gambier and 0.55°C at Eucla. The impact on extremes is stronger still, with a mean difference of 0.58°C for the highest minimum temperature of the month, and a 22% reduction in the number of days with minima above the 90th percentile. The impact on maximum temperatures is negligible.

These results suggest a potential inhomogeneity in Australian mean minimum temperature in 1964, although the network-wide impact is substantially smaller than 0.25°C as only a small proportion of stations used a midnight-midnight day. It is estimated that the overall impact on Australian mean minimum temperatures is between 0.05°C and 0.08°C.

Other observation days tested show minimal differences (0.03°C or less) with the current 0900 standard. In particular, using standard time rather than local time during daylight savings periods has an impact of only 0.01°C on minimum temperatures and no impact on maxima.

3.27. MULTI-DECADAL MODULATION OF THE EL NIÑO-INDIAN MONSOON RELATIONSHIP BY INDIAN OCEAN VARIABILITY

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The role of leading modes of Indo-Pacific climate variability is investigated for modulating the strength of the Indian summer monsoon during the period 1877-2006. In particular, the effect of Indian Ocean conditions on the relationship between the El Niño-Southern Oscillation (ENSO) and the Indian monsoon is explored. Using an extended classification for ENSO and Indian Ocean Dipole (IOD) events for the past 130 years and reanalyses, we have expanded previous interannual work to show that variations in Indian Ocean conditions modulate the ENSO-Indian monsoon relationship also on decadal timescales.

El Niño events are frequently accompanied by a significantly reduced Indian monsoon and widespread drought conditions due to anomalous subsidence associated with a shift in the descending branch of the zonal Walker circulation. However, for El Niño events that co-occur with positive IOD (pIOD) events, Indian Ocean conditions act to counter El Niño's drought-inducing subsidence by enhancing moisture convergence over the Indian subcontinent, with an average monsoon season resulting.

Decadal modulation of the frequency of independent and combined El Niño and pIOD events are consistent with a strengthened El Niño-Indian monsoon relationship observed at the start of the 20th Century and the apparent recent weakening of the El Niño-Indian monsoon relationship.

http://iopscience.iop.org/1748-9326/6/3/034006

3.28. THE EXTREME WET SEASON OF 2010/11 IN WESTERN AUSTRALIA

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The wet season of 2010/11 was a season of extreme rainfall in northern WA. Rainfall across the whole of WA was the 2nd highest on record for the October to April period (comparable records commenced in 1900), only behind the equally remarkable 1999/2000 season, and many sites across northern WA observed their highest wet season rainfall totals on record.

Numerous extreme rainfall and flooding events occurred across WA during the season. Extreme rainfall was observed in the Kimberley during January 2011 where Kuri Bay recorded a monthly total of 1540.4 mm, the highest monthly rainfall total ever recorded in WA. In the Gascoyne, significant flooding was observed on a number of occasions, particularly in mid-December 2010 when the Gascoyne River recorded its highest peak level on record before instrument failure and Carnarvon recorded its wettest day in 128 years of record. Flash flooding was observed in Warburton (Interior) and Nungarin (Central Wheat Belt) in February 2011, whilst extensive flooding occurred in the east Kimberley during March as the result of unprecedented rainfall in the first half of the month. Seven tropical cyclones were observed in the WA region, and several maintained tropical cyclone intensity south of 25 °S, in part due to very warm waters extending further south than normal, most significantly Tropical Cyclone Bianca in January 2011.

The very wet conditions observed in northern WA over the 2010/11 wet season was primarily due to a very active monsoon over the north of the state for much of the season, with consistent falls across each of the summer months a result of one of the strongest La Nina's on record. This presentation will provide details on where these significant events fit in the WA climate record.

3.29. PROJECTIONS FOR AUSTRALIAN TEMPERATURE AND RAINFALL EMERGING FROM OBSERVED TRENDS

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'Climate Change in Australia' (2007) provided probabilistic projections of change to local temperature and rainfall that incorporated the range of sensitivities to global warming simulated by CMIP3 models. However, the changes were relative to an idealised base climate for 1980-99, disregarding observed trends and variability. We develop a theory that represents projections for decadal means as time series that emerge from the observed series.

The CMIP3 sensitivities are first combined with an extended global warming series to depict change relative to an unforced base climate at 1900. Matching these series to the mean of the full observational record allows a representation of absolute values of the quantities, including the base climate itself. A Bayesian theory can be applied to combine the model-based sensitivity with that estimated from observations. For central Victoria and the central Murray-Darling Basin the two estimates appear compatible, and series using the modified sensitivities are generated. For rainfall in Southwest Australia and the Darwin region, however, the observed trends are outside the model range for greenhouse gas forcing, and a change due to other forcings is invoked. The uncertainty at each time can be expanded to allow for decadal variability. Finally, the observed series is linked to the values for the future.

The approach provides probabilistic estimates for near-term decadal means. For example, the Victorian temperature for the coming decade has a probability of 0.5 of being even higher than the record value of the past decade. Rainfall is unlikely to be as low as it was then, but has a probability of 0.7 of being lower than the average for the rather moist 1961-1990 period. It is hoped that the projections can be refined further by using near-term simulations from CMIP5 to improve the representation of the effects of ocean state anomalies and the various forcings.

3.30. SOUTHEASTERN AUSTRALIAN TEMPERATURE VARIATIONS 1860–1910

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Annual and seasonal temperature variations across southeastern (SE) Australia during 1860–1910 are examined for the first time, using a newly developed observational dataset. This provides an additional 50 years of important temperature information across Australia's most highly populated region.

Long-term monthly mean maximum and minimum temperatures from 38 locations across SE Australia were obtained from the Bureau of Meteorology observational network. Stations were combined if necessary to provide continuous records to the present day. Detailed homogenisation was undertaken using metadata from station history files and iterative statistical tests.

The homogenisation process was unable to reconcile the large positive temperature trend present in the data after 1950, but produced a greatly improved dataset when data for 1860–1950 were examined on their own.

In particular, the impact of the systematic change from Glaisher temperature screens to Stevenson screens at the beginning of the 20^{th} century appears to have been removed.

Interannual variations of SE Australian area-average temperature from this dataset are highly correlated with those from equivalent stations in the high-quality temperature network currently used for Australian research for the period after 1910. The new dataset was also compared to historical documentary accounts and a paleaoclimate temperature reconstruction.

Significant correlations were found between the Southern Oscillation Index and temperature, showing an out-of-phase relationship with maximum temperature and in-phase relationship with minimum temperature. Preliminary results suggest a stronger relationship in the late 19^{th} century and a weaker relationship in the early 20^{th} century. The coherence between these variables and rainfall from 1860–1910 was also examined. Finally, a combination of the new dataset and the annual high-quality record allows for analysis of longer-term variations of SE Australian temperature over 1860–2009. Additional historical data may make it possible to extend this temperature record for SE Australia to as early as 1826.

Stream 4. Boundary Currents

Conveners: Ming Feng, Chari Pattiaratchi, Moninya Roughan

Oral Presentations

MARINE DOWNSCALING OF A FUTURE CLIMATE SCENARIO FOR AUSTRALIAN BOUNDARY CURRENTS

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Ocean boundary currents are poorly represented in existing coupled climate models, partly because of their insufficient resolution to resolve narrow jets. Therefore there is limited confidence in the simulated response of boundary currents to climate change by climate models. To address this issue, we use the eddy-resolving Ocean Forecasting Australia Model (OFAM), forced with bias-corrected output in the 2060s under SRES A1B from the CSIRO Mk3.5 climate model, to provide downscaled regional ocean projections. Mk3.5 captures a number of robust changes common to most climate models and are consistent with observed changes, including the weakening of the equatorial Pacific zonal wind stress and strengthening of the wind stress curl in the Southern Pacific, important for driving the boundary currents around Australia.

The 1990s climate is downscaled using air-sea fluxes from the ERA40 reanalysis. The current speed, seasonality, and volume transports of the Australian boundary currents show much greater fidelity to the observations in the downscaled model. Between the 1990s and the 2060s, the downscaling with the OFAM model simulates a 15% reduction in the LC transport, a 20% decrease in the ITF transport, a 12% increase in the EAC core transport, and a 35% increase in the EAC extension. The projected changes by the downscaling model are consistent with observed trends over the past several decades, and with changes in wind-driven circulation derived from Sverdrup dynamics. Although the direction of change projected from downscaling are usually in agreement with Mk3.5, there are important regional details and differences that will impact response of ecosystems to climate change.

SPATIO-TEMPORAL VARIABILITY OF SPORADIC UPWELLING EVENTS OVER THE EAST AUSTRALIAN CONTINENTAL MARGIN FOR THE LAST DECADE.

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Boundary currents around Australia, namely the East Australian Current along the east coast and the Leeuwin current along the west/south coast of the continent, are quite unique since they both flow poleward. Although the large scale wind patterns are almost all-year long upwelling favourable over Western Australia, the Leeuwin current forced by an along-shore pressure gradient globally overcomes the offshore Ekman drift, thus preventing persistent upwelling. On the east coast, trade winds are generally upwelling defavourable, but the intrusions of the East Australian Current on the narrow shelf have been related to topographic upwelling events. Despite these contrasted situations, localised upwelling events have been documented on both coasts.

This study presents the first extensive analysis of sporadic upwelling phenomenon over Australian continental margins for a 15 years period (1995-2010). Based on long-time series of remotely sensed data such as scatterometry, altimetry and SST, upwelling indexes have been developed to account for wind-driven events (based on Ekman transport) but also for current-driven events (based on a composite index). The temporal evolution of these indexes is studied to understand the seasonal and inter-annual variability of upwelling events over Australian continental margins. The numbers of coastal events and their duration have been recorded and their long-term trends are compared to large scale climatic/oceanographic indexes such as the Southern Oscillation Index or Nino indexes. Spatially, some preferential areas reveal high occurrence of localised upwelling. Ship-based and moorings in-situ data are used to validate our remote sensed approach and to estimate the biological responses associated with these events. Although not being a persistent feature of Australian margins, sporadic upwelling phenomenon play a key role on shelf productivity by significantly promoting biological activity.

THE LEEUWIN CURRENT: THE ROLE OF MIXING AND ADVECTION IN TOPOGRAPHIC TRAPPING AND SHELFBREAK INTENSIFICATION OF A DENSITY-DRIVEN FLOW

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The Leeuwin Current is a poleward eastern boundary current that is shelfbreak intensified. A suite of numerical experiments is used to investigate the role of buoyancy forcing of this current over shelf-slope topography. The buoyancy forcing is composed of a meridional density gradient distributed over an upper layer depth, which balances a zonal geostrophic flow. The intersection of this upper layer with the slope supports a poleward current by topographic trapping of Rossby waves. The position of the upper layer's intersection sets the offshore width of the current. Key processes, including mixing and advection, modify the current's speed, transport, and spatial structure. Vertical diffusion thickens the upper layer, strengthening the poleward current. Horizontal viscosity modifies the current width over which the zonal flow converges and hence controls the jet speed. Poleward density advection forms a cross-shelf density front, intensifying the poleward flow near the surface. Offshore advection by bottom frictional flow can contribute to the jet's frontal position near the shelf break. The simulations also reveal cases in which an equatorward flow exists at depth, similar to a Leeuwin Undercurrent.

THE 2011 MARINE HEAT WAVE OFF WESTERN AUSTRALIA

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During the austral summer of 2010/2011, a record strength of the Leeuwin Current off the Western Australia coast was associated with one of the strongest La Niña events. The event was accompanied by the highest sea surface temperatures off southwestern Australia, with temperature anomalies > 3°C in February-March 2011. This unprecedented warming event, or the "marine heat wave", had some dramatic consequences for the fish and marine invertebrates along the continental shelf.

In this study, a good set of temperature records from monitoring sites along most Western Australian coast and offshore islands, the Integrated Marine Observing System (IMOS) moorings, as well as satellite observations are used to document the growth and decay of the "marine heat wave" off the coast during the La Niña event. Strong Leeuwin Current transport brings anomalous heat southward from the austral spring, and a surge in Leeuwin Current transport accompanied with a rather calm weather condition caused the peak temperature anomalies up to 5°C from 27 February to 4 March 2011.

In the large-scale context, the long term temperature rising trend off the coast and a multi-decadal strengthening trend of the Leeuwin Current are further discussed.

INTERACTION BETWEEN THE LEEUWIN CURRENT AND CONTINENTAL SHELF ALONG THE ROTTNEST SHELF AND PERTH CANYON

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The use of High-Frequency radar for measuring surface currents on continental shelves has been well established through development for over 30 years. The West Australian Integrated Marine Observing System (WAIMOS) has access to two HF Radar systems are operated by the Australian Coastal Ocean radar Network (ACORN): a WERA phased array system with shore stations located at Leighton Beach and Guilderton and a CODAR Seasonde beam-forming system with shore stations located at Seabird and Cervantes. These systems cover the coastal region from Cape Peron to Jurien Bay, extending up to 150 km offshore. The systems provide hourly values of surface currents on a regular grid with spacing of 4-6km. The WERA data have been analysed in detail to provide time-series consisting over 10,000 to provide information on seasonal variability and the interaction between the two major current systems: the Leeuwin and Capes currents with the latter present mainly during the summer months. The surface currents measured by the HF Radar together with coincident sea surface temperature images indicated the presence of several eddies, particularly within the Perth canyon. Here, a topographically trapped eddy was observed many times and appears to be a quasi-permanent feature. However this eddy migrates to the north and south of the canyon which leads to either upwelling or downwelling at the head of the canyon which was confirmed by a current mooring at the 200m contour. The presence of the eddy confirmed previous numerical modelling of the region which also predicted the presence of the eddy within the canyon. The surface currents also revealed the rapid changes in the current system through the passage of a continental shelf wave generated by Tropical Cyclone Bianca in January 2011.

INTERACTION OF EDDIES WITH THE WESTERN BOUNDARY

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Western boundaries have recently been proposed as a site of significant mesoscale eddy kinetic energy dissipation in the oceans (Zhai, Johnson & Marshall, 2010). I will present some recent work on the behaviour of eddies when they interact with a western boundary and western boundary current. This will highlight the importance of the lateral boundary condition (no-slip, partial-slip or free-slip) in determining the longshore eddy propagation. I will also show that this dependence has important consequences for the structure of the mean flow (particularly the presence and extent of a retroflection in the separation region) and also on the eddy terms in the mean momentum and potential vorticity balances. Interaction of propagating eddies with the mean current may also give a systematic bias in the location of eddy kinetic energy dissipation, depending on the sign of the eddy vorticity.

Reference:

Zhai, Johnson & Marshall (2010) *Nature Geosci*, 3(9):608–612.

ANATOMY OF A FLOODING WARM-CORE EDDY

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Warm-Core Eddies (WCE), a common feature of western boundary systems, can play an important role in marine ecosystems. One such WCE formed from a retroflection of the East Australian Current (EAC) in late 2008. To investigate this eddy, an approximately 3 km resolution version of the Regional Ocean Modelling System (ROMS) is configured for the coast off south-east Australia. This model is used to produce ocean state estimates coinciding with the formation of this WCE in 2008. Datasets from recent cruises and deployments contain temperature and salinity data from this eddy and are used to assess the model. Particle paths, a variety of tracers, and streamlines are used to investigate the structure and evolution of the eddy. The eddy becomes flooded with EAC waters which flush out some of the original eddy. The remainder of the original core is pushed down 10-90 m. Water is expelled from the eddy between 300 m and 100 m depth and upwells up the side of the eddy. There is also uplift in the EAC waters as water is drawn up to replace the flooding water. This flooding is self perpetuating as temperature gradients created during the flooding then drive the flooding process.

AN EDDY CENSUS OF SOUTHEAST AUSTRALIA: THE ABUNDANCE AND DISTRIBUTION OF EDDIES AND THEIR ROLE IN SUPPORTING PRIMARY PRODUCTION

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Satellite altimetry provides opportunities to identify and track mesoscale oceanic features such as eddies on large temporal and spatial scales. Chelton et al. (2011) use sixteen years of global sea-surface height fields to automatically identify and track approximately 1.15 million individual eddy observations. This study examines the approximately 18,500 eddies which were identified off southeast (SE) Australia. The results of this study are consistent with the global analysis of eddy distribution (Chelton et al. 2011). Off SE Australia, there is a slight preference for cyclonic eddies, however larger and longer-lived eddies are preferentially anti-cyclonic.

An avenue of eddies is identified along the continental slope between Smokey Cape (31 deg. S) and Eden (35 deg. S), with the highest abundances just south of Sydney. This study attempts to link the occurrence of eddies with indicators of biological productivity such as remotely-sensed ocean-colour and fisheries landings. Climatology anomalies for sea-surface temperature and ocean-colour are identified at the centre of the eddies. Yearly and seasonal trends for SE Australian eddies will also be discussed.

Chelton, D. B., M. G. Schlax, and R. M. Samelson, (2011) Global observations of non- linear mesoscale eddies, Progress In Oceanography, 91 (2), 167-216, doi: 49 10.1016/j.pocean.2011.01.002

OBSERVING AND MODELLING THE EAST AUSTRALIAN CURRENT AND ITS EDDIES USING IMOS DATA AND BLUELINK MODELS.

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The East Australian Current (EAC) is Australia's most energetic boundary current, carrying tropical waters from central Queensland as far south as Tasmania. It flows as an intense, relatively stable jet from Fraser Island to central New South Wales where its path is highly variable on a day-to-day basis. Observing, modeling and understanding this most salient of Australia's ocean features has challenged oceanographers for decades. In this talk we will discuss some of the *in-situ* and satellite observations of the EAC that have been made or processed by IMOS and use them to assess the hindcasting and forecasting systems developed in the Bluelink project. The state of the EAC at the time of the conference will be described, drawing on the real-time analysis published at http://imos.aodn.org.au/oceancurrent/index.htm as well as the Bluelink Relocatable Ocean Atmosphere Model (ROAM).

PHYSICAL VARIABILITY ON THE SHELF OFF NSW AUSTRALIA: NEW INSIGHTS FROM THE NSW INTEGRATED MARINE OBSERVING SYSTEM.

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Within the framework of the Australian Integrated Marine Observation System, several moorings have been deployed along the NSW shelf. In particular, upstream of the EAC separation point at Coffs Harbour and off Sydney, mooring arrays have been continuously monitoring physical parameters including temperature and current velocities through the water column since 2009. Over 12 months of these concomitant datasets have been assessed, relative to remote sensing SST, SSH derived geostrophic velocities and wind observations. These unprecedented, high-resolution data are analyzed in order to identify the dominant shelf dynamics.

The shelf circulation at 30^{o}S is primarily dominated by the poleward East Australian Current variability. This strong boundary current intrudes onto the continental shelf in autumn, associated with warm, nutrient-poor water, but also drives some intense current-driven upwellings, with measurements revealing sudden cooling of the bottom temperature by up to 4 degrees.

In contrast downstream of the separation point meso scale eddies and wind stress play a role in the uplift and suppression of isotherms to a greater extent, resulting in a significant bio-geochemical response, as identified from in situ observations. In particular, the encroachment of a cold core sub-mesoscale eddy on the shelf has been captured, leading to an unusual northward flow reaching 0.4m/s and sub-surface temperature anomalies in excess of -8 degrees.

Poster Presentations

4.1. AUSTRALIA'S INTEGRATED MARINE OBSERVING SYSTEM – MONITORING MAJOR BOUNDARY CURRENTS AND INTER-BASIN FLOWS

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Australia's Integrated Marine Observing System (IMOS) was established in 2007 under the National Collaborative Research Infrastructure Strategy (NCRIS), and extended under the Education Investment Fund (EIF) in 2009. It has successfully deployed a range of observing equipment in the oceans around Australia, making all of the data freely and openly available through the IMOS Ocean Portal (http://imos.aodn.org.au/webportal) for the benefit of Australian marine and ocean-climate science as a whole.

IMOS is guided by a National Science and Implementation Plan that has been developed collaboratively with the open-ocean 'Bluewater and Climate' Node, and the five regional Nodes covering Australia's coastal oceans i.e. NSW-IMOS, QIMOS, WAIMOS, SAIMOS and TasIMOS.

The National Science Plan addresses five major research themes i.e.

1. Multi-decadal ocean change,
2. Climate variability and weather extremes
3. Major boundary currents and interbasin flows
4. Continental shelf processes, and
5. Ecosystem responses (productivity, abundance and distribution).

In this talk, an overview of IMOS activities in monitoring major boundary currents and interbasin flows will be provided, outlining research questions to be addressed and the observing strategy being implemented. Monitoring boundary currents remains a major challenge. IMOS takes an integrated approach; drawing on the strengths of the XBT network as the global backbone of the boundary current observing system, deep mooring arrays for direct monitoring of full depth transports and gliders; all of which are underpinned by satellite altimetry.

Recent deployments in the Indonesian Throughflow will be highlighted, covering Timor Passage and Ombai Strait. Deployments in the East Australian Current off Brisbane, planned for first quarter 2012, will also be explained. Both deepwater moorings are connected to a shelf array, to support research into the interaction of boundary currents with continental shelf processes.

4.2. THE FIRST THREE YEARS OF NSW-IMOS MOORING DEPLOYMENTS

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The NSW node (NSW-IMOS) of the national Integrated Marine Observing System (IMOS) has collected data from the shelf along the NSW coast since June 2008. The mooring array consists of three shore normal transects across the shelf in the north at Coffs Harbour, off Sydney and in the south at Narooma. The data collected allow the observation of temperature, current and biogeochemical variations, both spatially and temporally, on the NSW continental shelf.

All moorings record temperature, and water pressure at selected depths, through the water column at eight metre intervals every five minutes. At the Sydney and Coffs Harbour moorings these data are complimented with current measurements through the water column from upward looking bottom mounted ADCPs recording every five minutes. Further to this, Water Quality Monitors (WQM) are installed 20m below the surface on one mooring off Sydney and the mooring adjacent to the IMOS National Reference Station (NRS) at Port Hacking (both in 100m water depth) to collect biogeochemical data every fifteen minutes.

The moorings are serviced nominally every six to eight weeks with the Sydney mooring operations undertaken by a subcontractor to NSW-IMOS (Oceanographic Field Services). The Narooma moorings are managed by UNSW/SIMS which includes instrument setup and maintenance, logistical management and deployment and recovery of the moorings at sea. Recently the mooring operations of the Coffs Harbour transect was taken over from Manly Hydraulics Laboratory as the capability and capacity of the UNSW/SIMS moorings group continues to expand. All data from the moorings are managed by UNSW/SIMS which involves processing, quality control and delivery to the IMOS database. Data recovery over the three years of mooring deployments to date has been good overall with return rates, apart from unforseen circumstances such as instrument failure, generally above 90%.

4.3. COMPARISON OF COASTAL SEA LEVEL IN OCEANMAPS TO TIDE GAUGES

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This paper compares operational OceanMAPS output to sea level observations from Australian coastal tide gauges. Emphasis is given to the latest operational version of OceanMAPS. Preprocessing rationale and methodology are presented in some detail along with statistical results. It is asserted that quantification of OceanMAPS skill at representing a non-tidal component of observed coastal sea level is relevant to the ongoing development of routine coastal sea level forecast products.

OceanMAPS is the Bureau of Meteorology's mesoscale ocean circulation forecast system. Version 1 (OMv1) of the system was maintained operationally by the Bureau from 2007-2011. Whilst ostensibly designed for resolving blue water eddy-scale non-tidal circulation, evaluations of OMv1 sea level anomaly have shown the system to have location dependant skill within the coastal zone. A major upgrade to Version 2 (OMv2) in late 2011 encompassed a variety of changes; of particular relevance to this work is the re-designed daily forecast cycle schedule and the storage of higher frequency surface outputs. Statistical evaluations of OMv2 include treatment of the output as a multi-cycle lagged ensemble. It is emphasized that neither OMv1 nor

OMv2 include tidal or barometric pressure forcing, such that the quantity under evaluation is a sub-component of the total observed signal. The relative magnitude of this sub-component to the total sea level varies considerably along the vast Australian coastline. One unique characteristic of OceanMAPS compared with other coastal models is that it includes the whole of Australia and therefore has the ability to forecast remotely generated coastally trapped waves around the coast. Further, being operational on a daily schedule it provides routine monitoring for extremes in coastal sea level from which other models might be nested and downscaled. Preliminary results from a regional nested ocean model with explicit representation of tides and atmospheric pressure forcing will be briefly presented.

4.4. USING HIGH-RESOLUTION OCEAN TIMESERIES DATA TO GIVE CONTEXT TO LONG TERM HYDROGRAPHIC SAMPLING OFF PORT HACKING, NSW, AUSTRALIA.

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Through the development of the NSW node of the Australian Integrated Marine Observing System (NSW-IMOS), a mooring array consisting of 4 locations has been deployed off the coast of Sydney, Australia, providing more than 2 years of timeseries data on the Sydney shelf. Parameters measured include velocity and temperature, salinity, fluorescence, dissolved oxygen and turbidity at 5-15min resolution.

This moored timeseries data complements the more than 70 years (since 1942) of physical sampling at the Port Hacking (Sydney, Australia) sites, in 50m and 100m water depths, by providing spatial and temporal context. In this paper we investigate the relationship between the monthly vertical CTD profiles and the high temporal resolution moored timeseries, specifically the sub-monthly variability in the data from the moored instruments.

For the first time we have a timeseries of optical signals at two sites which can be used to give spatial and temporal context to the monthly biogeochemical and phytoplankton record from the physical samples. We assess the significance of sub monthly variability relative to the seasonal and annual signals.

4.5. ENTRAIN, RETAIN AND NURTURE: THE FISHERIES OCEANOGRAPHY POTENTIAL OF SUBMESOSCALE EDDIES OF WESTERN BOUNDARY CURRENTS

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Submesoscale cyclonic cold-core eddies are a characteristic of the frontal edge of boundary currents. These small (<80 km) and short-lived (<14 d) eddies are not well resolved by standard altimetry and oceanographic models, but are evident in MODIS imagery and the trajectory of ocean gliders. Bakun (2006) proposes three processes for the successful recruitment of fishes by ocean eddies (enrichment, entrainment and retention; Bakun 2006). We re-examine this hypothesis at the separation zone of the East Australian Current (EAC, 30-34 degr. S), where a large size range of eddies is generated, adjacent to a narrow continental shelf. Shelf waters <~100 m isobath are particularly enriched in chlorophyll, and shelf waters are also enriched in ichthyoplankton. These waters have the potential to be entrained in coastal eddies by strengthening and shear of the EAC associated with a narrowing of the shelf off Smoky Cape (31 degr. S).

We describe 4 small cyclonic eddies in the separation zone using ship, MODIS and ocean glider observations to demonstrate the entrainment of enriched shelf waters, and the relative retention of these waters compared to their source on the shelf. Particle size frequency distributions of zooplankton from an optical plankton counter, and the age and growth of larval fish in these eddies, provide evidence of retention and nurturing for 10-15 d compared to their source waters on the shelf. These small eddies decay and release juvenile fish which are capable of migration back to the coast. The parallels with studies from the Kuroshio, Gulf Stream and California Current are discussed.

Bakun A. (2006) Fronts and eddies as key structures in the habitat of marine fish larvae: opportunity, adaptive response and competitive advantage. In Recent Advances in the Study of Fish Eggs and Larvae, M.P. Olivar and J.J. Govoni (eds.) SCIENTIA MARINA 70S2: 105-122.

Stream 5. CMIP5 Modelling Project: Model evaluation

Conveners: Gab Abramowitz, Tony Hirst, Jozef Syktus

Oral Presentations

A DUMMIES' GUIDE TO ACCESSING AND UNDERSTANDING THE CSIRO-MK3.6.0 CMIP5 DATA ARCHIVE

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Recently the team behind the CSIRO-Mk3.6.0 Atmosphere Ocean General Circulation Model (AOGCM) completed its submission of requested data to the Coupled Model Intercomparison Project phase 5 (CMIP5). This joint team, consisting of the Queensland Climate Change Centre of Excellence and the Commonwealth Scientific and Industrial Research Organisation (CSIRO), decided in 2009 to perform the necessary work to enable an entry with this improved version of the CSIRO-Mk3.5 model (Rotstayn, 2010). A summary of the modelling and technical strategy as well as achievements is given in Collier et al (2011).

The data now resides on the Earth System Grid (ESG), a network of Gateways and Data Nodes spread across the Earth and accessible to any registered user. However, it remains a complex and large volume of data to examine.

In this presentation a comprehensive summary of the contents of the archive will be provided, including an explanation of why certain CMIP5 parameters are missing. Both the strong features of the submission and some potential limitations will be noted.

Collier, M.A., Jeffrey, S. and L.D. Rotstayn (2011). The latest Australian CMIP climate model submission. BAMOS, October 2011, in press.

Rotstayn, L.D., Collier, M.A., Dix, M.R., Feng, Y., Gordon, H.B., O'Farrell, S.P., Smith, I.N. and J.I. Syktus (2010). Improved Simulation of Australian Climate and ENSO-related rainfall variability in a global climate model with an interactive aerosol treatment. Int. J. Climatol. 30: 1067-1088. doi: 10.1002/joc.1952.

PROJECTED AND HISTORIC CHANGES IN CIRCULATION AND RAINFALL IN THE AUSTRALIAN REGION SIMULATED BY CSIRO-MK3.6 UNDER DIFFERENT FORCING ASSUMPTIONS

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CSIRO-Mk3.6 is the most recent version of the CSIRO Global Climate Model (GCM), which can be traced back to the two-layer model developed by Hal Gordon some 30 years ago (Gordon, 1981). It differs from its recent predecessors (Mk3.0 and Mk3.5) by inclusion of an interactive aerosol scheme, which treats sulfate, dust, sea salt and carbonaceous aerosol. It also includes an updated radiation scheme and other changes to the atmospheric physics package. Mk3.6 was described and evaluated by Rotstayn et al. (2010), whose assessment of the model's simulation of Australian climate was generally favourable.

CSIRO-Mk3.6 has been used to perform an extensive suite of simulations for CMIP5. The Mk3.6 submission is a collaborative effort between CSIRO and the Queensland Climate Change Centre of Excellence (QCCCE). As well as the core simulations, a number of targeted, attribution-focused experiments have been performed. These 10-member ensembles are designed to cleanly separate the climatic impacts of individual forcing agents such as long-lived greenhouse gases (GHGs), anthropogenic aerosols, ozone and natural forcing.

In this talk, simulated changes in circulation and rainfall in the Australian region will be discussed. In CSIRO-Mk3.6, 21st Century projections (which are dominated by GHG forcing) show a strong decrease of rainfall over most of Australia. Historical (1850 – 2005) simulations that include all forcing agents do not show widespread, statistically significant rainfall trends over Australia in the ensemble mean. However, an historical ensemble forced only by changes in GHGs does show significant rainfall decreases, similar in character to those in the future projections. Other single-forcing runs are used to provide insight into these differences: According to Mk3.6, anthropogenic aerosols and other forcing agents may have "masked" some of the effects of increasing GHGs on regional circulation and rainfall. The attribution-focused experiments in CMIP5 should provide a valuable opportunity to compare these effects across a range of models.

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Rotstayn, L. D., M. A. Collier, M. R. Dix, Y. Feng, H. B. Gordon, S. P. O'Farrell, I. N. Smith, and J. Syktus, 2010: Improved simulation of Australian climate and ENSO-related rainfall variability in a global climate model with an interactive aerosol treatment. Int. J. Climatol., 30, 1067–1088. doi:10.1002/joc.1952.

ACCESS: THE AUSTRALIAN COUPLED CLIMATE MODEL FOR IPCC AR5 AND CMIP5

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The Australian Community Climate and Earth System Simulator (ACCESS) will provide Australia with the next generation capability for weather prediction and climate/climate change simulations. The ACCESS coupled model is built by coupling the UK Met Office atmospheric model UM (Unified Model), and other sub-models as required, to the Australian Climate Ocean Model (AusCOM), an IPCC class coupled ocean-sea ice model consisting of the GFDL MOM4p1 ocean model and the LANL CICE4.1 sea ice model, under the PRISM OASIS3 coupling framework.

The ACCESS coupled model was successfully assembled in mid-2009 and has been fully functional since early 2010. Over the past 2 years, significant progress has been made so that recent ACCESS century-length simulations surpass in realism those from the preceding CSIRO Mk3 model delivered to IPCC Assessment Report 4 (AR4), over a range of skill scores. Scientists from the Center for Australian Weather and Climate Research (CAWCR) have been performing detailed testing to further improve the ACCESS coupled model performance for the final AR5 version.

This presentation provides our preliminary analyses of the recent ACCESS simulations of world climate, especially the world ocean climate, for assessing the suitability of this model to contribute to the Coupled Model Inter-comparison Project phase 5 (CMIP5) and IPCC AR5. The assessment criteria include the size of regional biases and global drift of sea surface temperature and salinity; ocean interior changes; ENSO and its influence on Australian rainfall; polar region sea ice extent and seasonality; world ocean meridional overturning circulations; Antarctic Circumpolar Current, and the overall skills in simulating a set of key climatic fields, etc.

CLIMATE EXTREMES IN AUSTRALIA DURING THE 20TH AND 21ST CENTURIES: IMPACTS OF VARIOUS RADIATIVE FORCING FACTORS

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Studies have shown that climate change will result in more extreme weather in many parts of the globe. Analysis of observed climate records at a global scale has shown a general trend of statistically significant increases in the frequency of warm days and nights and a decrease in the frequency of cold days and cold nights. In many regions, the frequency of dry days has increased resulting in more droughts. However, it is unclear to what degree these changes in radiative forcing due to an increased concentration of greenhouse gases; changed aerosol loading and ozone depletion, have contributed to observed trends in climate extremes in the Australian region.

Several attribution experiments have been performed using the CMIP5 experimental design to evaluate the impacts of various radiative forcings on climate extremes in Australia. These experiments were performed using climate simulations with the CSIRO Mk3.6 coupled climate model and include ensembles of simulations with all forcings, natural forcings (no anthropogenic effects), pre-industrial aerosols and un-depleted ozone for the 1850–2012 period. Climate extreme indices developed by the Australian Bureau of Meteorology are computed from the simulated daily data in these experiments. These include a number of indices based on daily temperatures such as warm spell duration, hot days and warm nights, and daily rainfall such as rainfall intensity, heavy precipitation days and consecutive dry days.

Trends in the climate extreme indices were computed from these model simulations. The presentation will describe the result of analyses quantifying the relative contribution of various radiative forcing factors to the changes in extreme indices in Australia for the 1971–2005 period. In addition, climate change projection experiments based on Representative Concentration Pathways (RCPs), namely RCP4.5, RCP8.5, RCP2.6 and RCP6.0, have been used to compute projected changes in extreme indices during the 21st century. These changes will also be presented.

CLIMATE CHANGE PROJECTIONS IN AUSTRALIAN REGION USING CMIP5 SIMULATIONS WITH CSIRO MK3.6 CLIMATE

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Major international climate modeling groups are contributing climate simulations towards a set of coordinated climate model simulations to the Coupled Model Intercomparison Project phase 5 (CMIP5). A new generation of emission scenarios developed by the research community (Moss *et. al*., 2010) are used to conduct those climate model simulations. The CMIP5 experimental protocol provides four emission scenarios based on the Representative Concentration Pathways (RCPs), which are identified with their amounts of net radiative forcing input into Earth's climate system at the end of 21st Century. They include following scenarios:
(a) A "no policy" RCP8.5 W/m^2;
(b) Two "stabilization" RCP6 W/m^2 and RCP4.5 W/m^2;
(c) A "peak and decline" RCP2.6 W/m^2.

The CSIRO Mk3.6 climate model has been used to contribute climate change simulations to the CMIP5 data portal (http://pcmdi3.llnl.gov/esgcet/home.htm). In this presentation a results from a selected simulations with CSIRO Mk3.6 model will be presented with focus on historical and future climates. MK3.6 climate model data was used in analysis consisting of 10-member ensemble for each of the following:

- Historical climate for the period 1851-2005
- Future climates (RCP8.5, RCP6.0, RCP4.5 and RCP2.6) for the period 2006-2115
- Future climates (extension of RCP8.5 and RCP4.5 to 2300) with 3 members each.

This presentation will describe results from the above simulations with a focus on projected climate change in the Australian region during the 21st Century and selected results from climate simulations extended to 2300. Climate change projections for surface temperature, mean sea level pressure, surface wind and precipitation for various time slices during the 21st Century in the Australian region and at a global scale will be presented. The presentation will also focus on large-scale circulation changes and associated changes in the global hydrological cycle.

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SIMULATION OF EL NIÑO–SOUTHERN OSCILLATION IN THE AUSTRALIAN COMMUNITY CLIMATE AND EARTH SYSTEM SIMULATOR (ACCESS)

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The Australian Community Climate and Earth System Simulator (ACCESS) is a coupled modelling system developed at the Centre for Australian Weather and Climate Research (CAWCR), with contributions from the participating Australian universities. An important objective for developing the ACCESS model has been to take part in the CMIP5 project. The atmosphere component of this coupled model is based on the UK Met Office Unified Model (MetUM). The ocean and sea-ice components, forming the Australian Climate Ocean Model (AusCOM), comprise the NOAA/GFDL MOM4p1 ocean model and the LANL CICE4.1 community sea-ice model, respectively. These component models of the ACCESS are coupled through the OASIS (version 3.2.5) flux coupler developed at the CERFACS. An important local contribution is the use of the CABLE land surface model in some versions of this coupled model.

In this presentation we describe the performance of the ACCESS model in simulating the El Niño–Southern Oscillation (ENSO) phenomenon and tropical climate variability using multi-century simulations. ENSO is the most important mode of interannual climate variability; therefore, the realistic simulation of this phenomenon is a key indicator of the efficacy of a climate model in simulating global climate variability. This is also important for the Australian region, as ENSO is a major driver of climate variability in this region. Here we examine some important characteristics of the simulated ENSO and compare them with available observations. Among other things, we examine the spatial structures of ENSO, phase-locking to the annual cycle, time scales, and ENSO evolutions. The ENSO teleconnections with surface air temperatures, precipitation, and atmospheric circulations are also investigated. In addition to the effectiveness, the major deficiencies in the ENSO simulation by the ACCESS model will be identified and some possible mechanisms for these deficiencies will be discussed.

FORMING AND DISTRIBUTING THE ACCESS CMIP5 ARCHIVE

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An important component of the submission of the ACCESS model to the Coupled Model Intercomparison Project Phase 5 (CMIP5) is publishing a comprehensive set of the CMIP5 requested data and ensuring the data meets the stringent CMIP5 format and quality requirements. CMIP5 specifies a standard for model output, where each parameter is stored in a single netCDF file and includes additional metadata. The CMIP5 data set includes parameters from each modeling realm, and different sampling frequencies. This is required to make analysis of the data as straightforward as possible.

The ACCESS Post Processor (APP) uses the Climate Model Output Rewriter tool (CMOR2) from PCMDI to convert the ACCESS model output into CMIP5 formatted data. The APP has been developed to automate the production of CMIP5 data, using a data base that contains information about each of the requested parameters for any experiment. Parameters are processed via a wrapper tool which selects entries in the data base then processes them through the APP. The data base approach allows simple and flexible user control of the processing and can be extended to produce additional parameters for other studies.

The APP is also able to produce parameters that are indirectly calculated from ACCESS diagnostics, such as the atmospheric mass content of aerosols or the meridional mass overturning circulation. These derivations are defined in configuration files and can use external functions. The APP system may be run for incomplete experiments, allowing the diagnostics to be used for evaluation of the model during development. This will be demonstrated for a specific variable. Additional steps have been performed to ensure the quality of the dataset and to enable the dataset to appear on the Earth System Grid (ESG). The processing of data from new ACCESS simulations is underway and their ESG publishing status will be presented.

CMIP5 AND AR5: AN UPDATE

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CMIP5 (Coupled Model Intercomparison Project) is a WCRP project that involves 20 sinternational climate modelling groups, which hopes to address scientific questions from the IPCC Fourth Assessment Report (AR4) in time for evaluation in the Fifth Assessment Report (AR5, scheduled for publication in late 2013).

Because sufficient time needs to be available for scientists to access the CMIP5 data that they intend to analyse, analyse it, document the results and then submit them for publication, the timely provision of CMIP5 data has become a concern. Within Australia, three issues have become immediate priority concerns:

1. Downloading and storing CMIP5 data from the international nodes that store it and making it available in Australia;

2. Software for downloading and processing of CMIP5 data;

3. AR5 project requirements.

The NCI has provided 0.5 PB of disk storage space. Data is being moved from the overseas nodes to Australia, but there appears to be less data available than was expected. As at August 2011, the Australian contribution of CSIRO Mk3.6 data is the largest data set available.

Once data has been archived, researchers and analysts need to be able to get at the data and do their science. Generally, this means accessing data (potentially non-trivial sized subsets of the whole archive) directly on a processing machine and, ideally, avoiding the movement of large amounts of data. The intent is to accomplish this with software tools that are available to users.

The Centre for Australian Weather and Climate Research (CAWCR) is liaising with NCI and the University user community to facilitate researchers and assist them to meet the AR5 and CMIP5 requirements.

CONSTRAINING REGIONAL CLIMATE PROJECTIONS WITH OBSERVED RECENT CHANGE

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A wealth of different methods have been proposed to calibrate regional projections with observed recent change. Most of these methods, however, adopt a perfect-model approach in that they assume that the multi-model ensemble is centered about the real climate (or real climate change). In contrast, we allow for model errors common to all climate models in our approach. These shared model biases are by design under-constrained in that we cannot infer their characteristics from the model ensemble. Therefore, we explore different assumptions on shared model biases.

We find that for variables with high signal-to-noise ratio of externally forced changes such as temperature, shared model biases can have a large impact on future projections. In most regions, however, the simulated warming is consistent with observed warming and thus shared model biases play a minor role - assuming that future and past shared model biases are correlated. For variables with low signal-to-noise ratio of externally forced changes such as precipitation, recent observed trends offer little guidance to constrain projections and shared model biases are generally small compared to internal variability.

Poster Presentations

5.1. CLIMATE SENSITIVITY OF THE CSIRO-MK3.6 MODEL

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Traditionally the climate sensitivity of a GCM model has been determined through a ‘q-flux’ technique using an atmospheric GCM coupled to an ocean mixed-layer model (e.g., Wilson and Mitchell, 1987). This technique requires stabilization before the sensitivity can be calculated. Fully coupled models used in the CMIP5 project do not stabilize as fast as ocean mixed-layer models used in the ‘q-flux’ technique, and the latter is not included in the CMIP5 protocol. An alternative method is that of Gregory et al. (2004), which uses linear regression applied to the changes in net radiative forcing and temperature to calculate the sensitivity using the first 20 years of a model run with an abrupt change in CO_2 forcing. This new method also provides a way to estimate the total amount of warming that would be expected once the model has stabilized without having to run the coupled model to stabilization.

Previously climate sensitivity calculations have been based on a doubling of CO_2 but as this experiment is not a core CMIP5 experiment it is more appropriate to use the core “abrupt4xCO2” experiment. The method described by Gregory et al (2004) has been applied to this experiment from the CSIRO-Mk3.6 CMIP5 submission to calculate sensitivity. This method produced a climate sensitivity of $1.24 \pm 0.32 W/m^2/K$, with the quadrupling of CO_2, which resulted in an initial net downward radiative forcing of 7.45 ± 0.89 W/m^2. This method approximates that the temperature difference will eventually stabilize at 6.0K above the initial conditions (1850 in this case).

The modeling team has also performed an additional non-CMIP5 experiment that provides the required information to conduct the traditional q-flux climate sensitivity test. This talk will compare the climate sensitivity calculated using both methods, as well as the sensitivity of other CMIP5 models that are available.

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5.2. BIAS CORRECTION OF CSIRO MK3.6 MODEL OUTPUT FOR AUSTRALIA

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Global climate models (GCMs) such as the CSIRO Mk3.6 model produce output on a coarse grid, and are known to contain biases in some variables, for example overestimating rainfall during summer over the Australian region. We use the multi-ensemble bias correction method developed by Dosio and Paruolo (2011) which uses transfer functions based on the cumulative distribution functions (CDFs) of observational and model output.

We apply the technique to two daily rainfall datasets: CSIRO Mk3.6 (CMIP5 historical) and downscaled high-resolution CCAM data (also derived from the CMIP5 historical run of the CSIRO Mk3.6 model). We use a long control run of 1960-1990 and then apply the method to the decade 1995-2004 for validation. We find that the bias corrected data gives significantly better estimates for continental mean rainfall, and the Kolmogorov-Smirnov test indicates that the corrected data has a much closer distribution to the observed rainfall. The range of annual bias is also reduced. The ensemble-averaged results of bias corrected output give results that are closer to the expected values.

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5.3. PROJECTIONS OF DROUGHT DURING THE 21ST CENTURY USING DATA FROM CMIP5 SIMULATIONS WITH CSIRO MK3.6 CLIMATE MODEL

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Major international climate modeling groups are contributing climate simulations towards a set of coordinated climate model simulations to the Coupled Model Intercomparison Project phase 5 (CMIP5). A new generation of emission scenarios developed by the research community (Moss *et. al*., 2010) are used to conduct those climate model simulations. The CMIP5 experimental protocol provides four emission scenarios based on the Representative Concentration Pathways (RCPs), which are identified with their amounts of net radiative forcing input into Earth's climate system at the end of 21st Century. They include following scenarios:

(d) A "no policy" RCP8.5 W/m^2;
(e) Two "stabilization" RCP6 W/m^2 and RCP4.5 W/m^2;
(f) A "peak and decline" RCP2.6 W/m^2.

The CSIRO Mk3.6 climate model has been used to contribute climate change simulations to the CMIP5 data portal (http://pcmdi3.llnl.gov/esgcet/home.htm). In this presentation a results from a selected simulations with CSIRO Mk3.6 model will be presented with focus on historical and future climates. MK3.6 climate model data was used in analysis consisting of 10-member ensemble for each of the following:

- Historical climate for the period 1851-2005
- Future climates (RCP8.5, RCP6.0, RCP4.5 and RCP2.6) for the period 2006-2115

Results from the above simulations were used to undertake analysis of projected changes in the distribution of meteorological droughts during the 21st Century. This presentation will describe results of analysis on projected changes in the frequency and intensity of meteorological droughts using the Standardized Precipitation Index (SPI). Analysis of projected changes in the occurrence of extremely dry and wet conditions for four Representative Concentration Pathways at a global scale will be presented with a focus on the areas with robust changes leading to increased frequency of droughts (sub-tropics) and wet conditions (mid-to high latitudes). This presentation will also show projected changes in drought under 2^{o}C and 4^{o}C of global warming in the Australian region. The presentation will conclude by addressing the role of dynamical changes in atmospheric circulation, including the role of aerosols and greenhouse gases as a driver of increased aridity in subtropics.

5.4. HEAT STRESS IN A WARMING WORLD: PROJECTIONS OF WET-BULB GLOBE TEMPERATURE DURING THE 21ST CENTURY USING DATA FROM CMIP5 SIMULATIONS WITH CSIRO MK3.6 CLIMATE MODEL

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Major international climate modeling groups are contributing climate simulations towards a set of coordinated climate model simulations to the Coupled Model Intercomparison Project phase 5 (CMIP5). A new generation of emission scenarios developed by the research community (Moss *et. al*., 2010) are used to conduct those climate model simulations. The CMIP5 experimental protocol provides four emission scenarios based on the Representative Concentration Pathways (RCPs), which are identified with their amounts of net radiative forcing input into Earth's climate system at the end of 21st Century. They include following scenarios:

(g) A "no policy" RCP8.5 W/m^2;
(h) Two "stabilization" RCP6 W/m^2 and RCP4.5 W/m^2;
(i) A "peak and decline" RCP2.6 W/m^2.

The CSIRO Mk3.6 climate model has been used to contribute climate change simulations to the CMIP5 data portal (http://pcmdi3.llnl.gov/esgcet/home.htm). In this presentation a results from a selected simulations with CSIRO Mk3.6 model will be presented with focus on historical and future climates. MK3.6 climate model data was used in analysis consisting of 10-member ensemble for each of the following:

- Historical climate for the period 1851-2005;
- Future climates (RCP8.5, RCP6.0, RCP4.5 and RCP2.6) for the period 2006-2115

Projected changes in thermal comfort using the wet-bulb globe temperature (WBGT) are calculated using daily screen level mean temperature and relative humidity from CSIRO Mk3.6 climate model simulations. This presentation will describe results of analysis on the projected change in the thermal comfort by examining the changes in the rates of threshold exceedance corresponding to the five threshold categories determined by the WBGT as described in ISO 7243 (Hot Environments - Estimation of the Heat Stress on Working Man, Based on the WBGT Index). Regional and seasonal variations in projected changes in WBGT will be examined. Projected changes in thermal comfort under 2^{o}C and 4^{o}C of global warming in Australian region will be presented.

5.5. IMPACTS OF CHANGES IN RADIATIVE FORCINGS ON THE LARGE SCALE CIRCULATION IN THE SOUTHERN HEMISPHERE DURING THE 20TH AND 21ST CENTURIES

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Studies have shown that there have been significant changes in the Southern Hemisphere large-scale circulation during the second part of the 20th Century. The studies show a general trend of increasing atmospheric mean sea level pressure (MSLP) at mid-latitudes, with a corresponding decrease in the Antarctic region. These changes are accompanied by the marked strengthening of the circumpolar westerlies in both the stratosphere and troposphere resulting in a southward shift of storm tracks. This observed southward shift of extra-tropical cyclones are the dominant weather systems impacting the precipitation in the southern part of the Australian continent during the winter months. This shift has been proposed as one of the main factor contributing to a substantial decline in rainfall in this region during the second half of the 20th Century.

Several attribution experiments have been performed using the CMIP5 experimental design to evaluate the impact of various radiative forcing factors on the changes in the Southern Hemisphere large-scale circulation. These experiments were performed using the CSIRO Mk3.6 coupled climate model and included ensemble of simulations with all forcings, natural forcings (no anthropogenic effects), pre-industrial aerosols loading and un-depleted ozone for the 1850–2012 period.

The results of analyses assessing the impact of various forcing factors on the changes in MSLP and changes in the storm track intensity and location will be presented. The impact of these changes on the climate of South-West Western Australia and South-East Australia will be discussed. In addition, climate change projection experiments based on Representative Concentration Pathways (RCPs), namely RCP4.5, RCP8.5, RCP2.6 and RCP6.0, have been used to compute projected changes in storm tracks during the 21st century. These changes will also be presented.

5.6. DECADAL VARIABILITY OF ENSO AND THE IOD IN ACCESS SIMULATIONS

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Simulations of individual global climate drivers in the Australian Community Climate and Earth-System Simulator (ACCESS) model associated with two different type of land surface schemes: a) the UK Met Office Unified Model (MetUM) with CSIRO Atmosphere Biosphere Land Exchange (CABLE); b) the UM with Met Office Surface Exchange Scheme (MOSES) have been examined. Those climate drivers are also examined in the global climate models from the Third Coupled Model Inter-comparison Project (CMIP3) for model comparison.

According to the Watterson (1996) M-Skill score test, a model performance measurement, ACCESS has an average score of 0.67 for global, quite comparable with the ECMWF interim reanalysis data of the period 1989-present at 0.68. In ACCESS the El Niño-Southern Oscillation (ENSO) amplitude compares well with observations, however, the coherence of monthly data of ENSO and the Indian Ocean Dipole (IOD) events is much weaker than observations.

We assess the relationship between decadal signals in the Pacific and Indian Oceans from the SST anomaly and the northern hemisphere subtropical high pressure anomaly, and the major climatic modes affecting Australian climate in these models.

These analyses are carried out to address several important issues: a) the possibility of decadal signals from the North Pacific subtropical gyre (NPGO) forcing ENSO and the IOD events; b) the possible impact of decadal signals of the IOD on ENSO events; c) and whether there are differences in the decadal signals when separate land surface schemes are used in the ACCESS experiments.

The preliminary results show that the NPGO decadal signals positively project onto the ENSO and the IOD, however the signals have a negative impact on the IOD in the case with CABLE. The relationship between decadal ENSO and the IOD signals is different in the CABLE and MOSESII versions of ACCESS experiments, and it is far different to the observed. However, the NPGO influence is associated with a spurious oceanic teleconnection near the equator, whereby ENSO signals are predominantly projected only through traditional ENSO. Other model features will also be discussed.

5.7. SENSITIVITY OF MODELED PRECIPITATION TO DIFFERENT CLOUD AND CONDENSATION SCHEMES

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The simulation of present day precipitation in General Circulation Models (GCMs), particularly for the tropics, has been a persistent problem in modeling the global climate system. In preparation for CMIP5, we evaluate precipitation from single realizations of the HadGEM2 and HadGEM3 atmospheric models against two observational datasets (CMAP and AWAP) over the common period, 1979 to 1998 for the Australian region. Two different cloud and condensation schemes were implemented, including the Smith (1990) scheme and a newer prognostic cloud and condensation scheme, PC2 (Wilson et al. 2008). Five different simulations were evaluated to distinguish whether differences in model performance were a result of: Unified Model code, HadGEM atmospheric model version, cloud and condensation scheme or the vertical resolution.

Our results show that model biases exceeded 4 mm day^{-1} for the tropics were present in all simulations, extending to northern Australia in DJF and MAM. Comparisons between the simulations and CMAP revealed that the implementation of PC2 reduced these biases and that they were reduced further by additional amendments in the radiation, convection and boundary layer schemes in going from the HadGEM2-A to HadGEM3-A.

Our analysis was extended to evaluate whether the different configurations produced significant improvements in the simulation of the inter-annual variability of precipitation for the region. The various model improvements showed no significant change in model performance in simulating the temporal variability, with lower correlations (~0.3) than those observed between the CMAP and AWAP (~0.9) observational datasets. Due to the high temporal variability of precipitation for the region, these low correlations were not unexpected.

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5.8. ANALYSIS ON ANNUAL AND DECADAL VARIABILITY IN THE CLIMATE INDICES OF SURFACE TEMPERATURE DERIVED FROM THE ACCESS SIMULATIONS

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Analysis of simulated variability in the climate indices can aid in evaluating the performance of climate models as they are not 'tuned' to the indices. Therefore the indices give independent information on a model's performance. This presentation will evaluate the differences in the variability in the climate indices for simulations using the MOSES versus the CABLE landscheme in the ACCESS model.

Simulated variability in the indices in the ACCESS simulations is compared to both variability in three different observational datasets (GISS, NCDC and HadCRUT3v) and simulated variability in the control simulations of 9 different CMIP3 models. The ACCESS simulations were analysed over 75 years and there were 109 120year long control simulations.

The main differences between the MOSES and CABLE simulations are for the Land_Ocean contrast and for the Seasonal Cycle where the annual variability in CABLE is much lower (~30%) then in the observations whereas those in MOSES fit the observations quite well. These differences can be completely ascribed to the different responses during the Northern Hemisphere winter (NH_djf) where the variability in CABLE is only about 65% of that in the observations.

Comparing the annual variability in the indices of the MOSES and CABLE simulations against those in the CMIP3 control simulations, except for SUMMER and WINTER, they all lay within the range of values found for the CMIP3 control simulations. In that sense, the indices analysis indicates that for reason of comparison with other models, there is no real preference for MOSES or CABLE.

5.9. A SEA-ICE SENSITIVITY STUDY WITH THE ACCESS/AUSCOM MODEL

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The sensitivity of the global sea-ice distribution in the Australian Climate Ocean Model (AusCOM) to a range of parameter values related to sea ice physics was explored. The sea-ice component of AusCOM is the U.S. Los Alamos National Laboratory Sea Ice Model (CICE) and the ocean component is the NOAA/GFDL MOM4p1 model. We aimed to determine optimal sets of parameter values to produce as realistic a global sea-ice distribution as possible. A small number of sets of optimal parameter values was selected based on the closest match between the model and the observed or observationally constrained model climatologies. These optimal sets have been used to improve the representation of sea ice in the CMIP5 experiments utilising the Australian Community Climate and Earth-System Simulator (ACCESS).

The sea-ice distribution shows a similar degree of sensitivity to parameters determining ice-ocean stress, mechanical redistribution, oceanic heat and surface albedo. Accordingly, AusCOM can be effectively tuned to produce realistic sea ice by parameters internal to the sea-ice model. The sensitivity of ice volume is stronger than that of ice area indicating that the internal ice model parameters mostly influence the ice thickness. The sea ice area has significantly weaker sensitivity to the sea-ice model parameters considered, particularly in winter. Then, the evolution of sea ice is dominated by external factors, such as location of land, and atmospheric and oceanic forcing. The performance of the ocean model is crucial in producing a realistic sea-ice cover, especially in the Southern Ocean.

Stream 6. Downscaling climate projections

Convener: Jack Katzfey

Oral Presentations

DOWNSCALING CLIMATE PROJECTIONS FOR APPLICATION TO REGIONAL BIODIVERSITY RESEARCH

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Climate model projections are a useful tool for understanding some likely effects of an enhanced greenhouse effect, and generating plausible scenarios of climate change into the future. However, the coarse scale of global climate models (GCMs) means that they do not produce the regional detail desired by many applied studies. Also, since climate model projections follow hypothetical scenarios and feature large ranges and uncertainties, care must be taken in applying them in detailed applied analysis of complex systems, as is required in biodiversity research.

Downscaling GCM model simulations to the regional scale is a useful first step in the analysis of biodiversity responses to climate change. In this study we use a set of six dynamically downscaled GCM projections created using the regional climate model Conformal Cubic Atmospheric Model (CCAM) by the Climate Futures for Tasmania project. These simulations are at 0.1 ° lat/lon resolution, and produce output that is usable at the sub-daily scale.

We outline a framework and examples of how these model outputs inform analysis in a broad spectrum of fields relevant to biodiversity conservation, using the midlands region of Tasmania as an example. The approach features multiple scales and a flow from quantitative into qualitative research, to enable the application of climate change projections to diverse fields such as terrestrial bioregionalisation, freshwater ecology, wildlife distributions and fire ecology, as well as economic, social and institutional impacts. We build locally-relevant future impact scenarios, where the physical climate change scenario informs a set of future impact scenarios that account for the spectrum of issues at the study site, and also account for the wider regional context. In this way, the full value of regional climate projection scenarios are more fully realized into analysis of impacts at the regional scale.

EVALUATION OF HIGH-RESOLUTION REGIONAL CLIMATE SIMULATIONS OVER ISLANDS IN THE SOUTH PACIFIC: RESULTS FOR FUTURE CLIMATES

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Because the relatively coarse resolutions of the GCMs (typically around 200 km) do not resolve the Pacific Islands, climate change studies of this area require techniques such as dynamical downscaling to better capture detailed topography and land use and produce more realistic projections of future climate.

In this study, conducted as part of the Pacific Climate Change Science Program (PCCSP), six downscaled climate projections at 60 km horizontal resolution for the whole globe were produced for the period 1961-2099 using the Conformal Cubic Atmospheric Model (CCAM) with the IPCC SRES A2 scenario and bias correction of sea-surface temperatures. Three of these simulations were further downscaled to 8 km resolution using a stretched-grid version of CCAM for the periods 1980-2000, 2046-2065 and 2080-2099. Projections were for seven Pacific Island nations: Papua New Guinea, Samoa, Solomon Islands, Fiji, Federated States of Micronesia, Vanuatu, and East Timor.

Verification of temperature and precipitation data against gridded observations and satellite data shows that the high-resolution 8 km simulations are able to capture the main topographically forced climate features of the current climate, such as greater rainfall on the upwind side of mountains in Fiji, as well as realistic seasonal distributions of temperature and rainfall. Since model grid-point data is more detailed than gridded observations, further validation was through comparison of model results with station observations and calculation of probability density function at various locations.

Better representation of current climate at high resolution increases confidence in climate change projections, including greater warming over land relative to the surrounding oceans. The effect of the local topography on the climate change signal was more complex, with changes in both amounts and frequency distributions of temperature and precipitation. These results strongly suggest that care must be taken when applying coarse-scale GCM climate change projections to regions of significant topography.

EXPLORING THE ADDED VALUE OF PROJECTIONS OF CLIMATE EXTREMES FROM THE CCAM REGIONAL CLIMATE MODEL.

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In dynamical downscaling, large-scale climate information from a Global Climate Model (GCM) is used as input to a finer resolution atmospheric model. This allows atmospheric processes to be simulated with greater detail, possibly resulting in an improved representation of weather events (particularly extremes). Because of the higher resolution and greater ability to provide sub-regional detail, dynamically downscaled projections are often favored by impacts and adaption groups over those arising from GCMs. This talk explores the ‘added value’ that dynamical downscaling provides in comparison to the host GCM, with a focus on climate extremes.

This study focuses on dynamical downscaling simulations from the CSIRO Conformal Cubic Atmosphere Model (CCAM) over the Australian region. CCAM has been forced by five different CMIP3 GCMs, using bias-corrected sea-surface temperatures (SST), and a mixed-layer ocean (MLO) at 0.5x0.5 resolution. Projections of climate extremes are calculated for daily precipitation, and maximum and minimum temperature for the current (1981-2000) and future (SRES-A2 scenario) climate, for each CCAM and GCM simulation. Evaluation of CCAM against the current climate, as well as CCAM projections of the future climate are compared to the corresponding host GCMs to determine if any extra information is provided at a higher resolution. This assessment is performed at the continental scale, as well as selected sub-regions. The results of this study may help determine regions where dynamical downscaling is most useful, as well as regions where raw projections from GCMs may suffice. Further research may focus on identifying the physical mechanisms within CCAM (and other high resolution dynamical models) that provide the 'added value'.

EXPLAINING DIFFERENCES BETWEEN GCM-DERIVED WHEAT YIELD PROJECTIONS FOR NEW SOUTH WALES: IMPLICATIONS FOR CLIMATE CHANGE IMPACT ASSESSMENTS

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A common finding of climate change impact assessments that use downscaled output from simulations of multiple General Circulation Models (GCMs) is that different GCMs yield different impact projections. This presentation uses the case study of future wheat yields for New South Wales (NSW), Australia to illustrate how differences in downscaled climate projections can combine with the sensitivities of an impact model to lead to differences in impact projections. The APSIM agricultural model is used to simulate wheat yields for the 2059-2098 period for a selection of sites in NSW. APSIM simulations are performed forced with climate data downscaled from simulations of 18 different GCMs. Monthly gridded output of the GCMs is spatially interpolated to the analysis sites, bias-corrected using a quantile-mapping method and then disaggregated to the daily data required by the APSIM model using a weather generator. Although all of the GCM simulations are forced with the same scenario for greenhouse gas and sulphate aerosol emissions, total wheat yields for the 2059-2098 period show substantial differences between the 18 different GCM-forced APSIM simulations. These yield differences are related to differences in the downscaled, bias-corrected GCM climate output. Implications for the selection of GCMs and downscaling and bias-correction methods in climate change impact assessments are discussed.

MODELING HIGH IMPACT WEATHER AND CLIMATE: THE TROPICAL CYCLONE EXPERIENCE

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The societal impact of a weather event increases with the rarity of the event yet our current ability to model extreme events is limited by not only rarity but also by the fidelity of current approaches and a lack of understanding of the underlying physical processes. This challenging conflict is driving fresh approaches to assess high impact weather and climate. We explore and document recent lessons learned and suggest a

number of best practices in modeling high impact weather and climate using the case of tropical cyclones as an illustrative example. Through examples using the Nested Regional Climate Model to downscale large-scale climate data the need to treat bias in the driving data is illustrated and important model sensitivities are highlighted. The notion of sufficient model fidelity is introduced together with the added value in combining dynamical and statistical assessments to fill out the parent distribution of high impact parameters and adequately sample the rare events on the tail of the distribution. Finally, combinations of weather and climate modeling with impact modeling are presented that enable direct regional impact assessments relevant to societal and industry planning and adaptation activities. This experience serves as guidance to determine priorities for the development of next generation modeling systems.

REGIONAL CLIMATE SIMULATIONS FOR AUSTRALIA USING THE WEATHERATHOME CITIZEN SCIENCE EXPERIMENT

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Global climate model simulations of regional climate variability and change are limited by the spatial resolution of the models that can be run with available high performance computer resources and by uncertainties in the representation of key physical processes in the models. Higher resolution climate simulations are possible using regional models nested within global models. Some of the limitations associated with the representation of physical processes can be assessed by considering the results from a number of different regional climate models.

We outline the plans and preliminary results for a new very large ensemble of regional climate model simulations for Australia that will be produced through the weatherathome experiment. This uses the HadRM3P regional model with 50km horizontal resolution, nested within the HadAM3P global model. Simulations are run on a vast network of individual computers provided by volunteer participants, who donate free time on their personal computers. A large number of different versions of the global and regional models are used to simulate the period from 1960 to 2010 using observed changes in sea surface temperatures, sea ice, atmospheric greenhouse gases and aerosols.

Regional simulations for Europe, western US and southern Africa are already being run in the weatherathome experiment, with more than 300,000 model years of simulations completed since the launch in November 2010. Daily data for a number of surface weather variables are available from these simulations, making them well suited for assessing the impacts of climate variability and change on daily extremes.

A new region, using the Australasian CORDEX domain, is being added to weatherathome and will be launched in 2012. Preliminary results for Australia from the global model simulations run as part of weatherathome will be presented, evaluating the performance of the global model in the Australian region.

For more information, see http://climateprediction.net/weatherathome

Poster Presentations

6.1. CLIMATE CHANGE IMPACTS ON THE AUSTRALIAN DAIRY SECTOR: AN INTEGRATED ANALYSIS

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In this study, we analyse the socio-economic implications of climate change driven pressures on the pasture-based dairy sector in Australia. Our focus is on the climate change impacts over the coming decades which relate to the A1FI emissions pathway scenario. In particular, we analyse the impact of changes in key climate variables such as temperature and rainfall on perennial pasture growth and hence on stocking rates and dairy sector output in key dairy producing regions in Southeastern Australia.

We use an integrated assessment framework in this study. It has two main components, a 'climate-biophysical response' framework and an 'economy-wide socio-economic' analytical framework. Within the climate-biophysical response framework we use a biophysical model, namely the DairyMod model with inputs of changes in climate variables for the CSIRO Mark 3 global circulation model from the OzClim database. The climate-biophysical response framework enables us to quantify the potential impacts of climate change on pasture growth, and dry matter yields, pasture intake by dairy stock, and hence on dairy stocking rates and the milk output under the A1FI scenario in the key dairy producing regions in Southeastern Australia. Changes in stocking rates and dairy output estimates from the climate-biophysical response framework are then used in the economy-wide socio-economic analytical framework, namely the NIAM (National Integrated Assessment Model) to quantify the Australian dairy sector trade and economic implications.

Our analysis illustrates the usefulness of an integrated analytical framework which combines climate, biophysical, and socio-economic variables and their interactions in assessing the potential impacts of future climate scenarios in a more holistic manner.

6.2. GLOBAL 60 KM SIMULATIONS WITH CCAM OVER THE TROPICS

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A partnership between CSIRO and the Bureau of Meteorology

A six-member ensemble of 60 km resolution global atmospheric simulations has been performed for studying future climate scenarios of Pacific island nations. The simulations were undertaken using the CSIRO Conformal Cubic Atmospheric Model (CCAM), driven by bias corrected Sea Surface Temperatures (SSTs) provided by six Coupled Model Intercomparison Project phase 3 Global Climate Models (GCMs) for the period 1971 to 2100. This work focuses on the representation of the current climate in the tropical region, a region where the "cold tongue" problem is apparent in all host GCMs. The SST bias-correction and the fine horizontal resolution employed in the CCAM simulations produce a significant improvement over the host GCMs in the rainfall patterns for the transient seasons March-April-May and September-October-November, and a moderate improvement for December-January-February and June-July-August. CCAM also simulates improved rainfall patterns over the South Pacific Convergence Zone. The performance of other tropical features, such as El Niño Southern Oscillation and the Walker circulation, is also evaluated. Future projection of large scale circulation and rainfall will be discussed.

6.3. CORRECTIONS TO ANALOGUE STATISTICAL DOWNSCALING CLIMATE SERIES

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The Australian Bureau of Meteorology's Statistical Downscaling Model (BoM-SDM) is based on the analogue technique, where local scale climate series are reconstructed from the large scale circulation patterns simulated by global climate models. Currently, the BoM-SDM is able to provide high resolution, gridded projections of rainfall, maximum and minimum temperatures for the entire Australian continent.

An inherent issue associated of any statistical downscaling method is that they tend to underestimate observed variance. This issue is particularly critical for rainfall, because average rainfall is predominantly influenced by the heavy rain days. Thus, an underestimation of the variance results in an underestimation of the average. To address this problem, a heuristic correction (inflation) factor was developed based on the weather station observations and it was shown to be reasonably effective for rainfall[1]. Recently, the inflation scheme has been further developed for both rainfall and temperature that takes into account regional and seasonal variability. For rainfall, the inflation factor is based on the fact that the daily rainfall distribution closely follows a gamma probability distribution function. The variance underestimation of reconstructed temperature series are also corrected that better account for temperature extremes. As the BoM-SDM has evolved from site specific applications to a gridded dataset, so to has necessity to develop gridded inflation factors.

These recent developments have shown positive results. Nevertheless, there are still several aspects open for possible future improvements. Persistent underestimation of temperature variance, rainfall variance and means not corrected together result in relatively high computational cost. These problems are partially due to the fact that the current methodology is based on the optimization of a domain of discrete values. Future developments aim to optimize the factors in a continuous domain, as well as maximize corrections to the variance and means simultaneously at relatively cost-effective and computationally efficient manner.

References

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6.4. REGIONAL CLIMATE MODELING FOR THE AGRICULTURAL REGION OF SOUTHWEST WESTERN AUSTRALIA USING THE WEATHER RESEARCH AND FORECASTING MODEL

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The southwest of Western Australia (SWWA) is a region of significant cereal production, with the main crops being winter grown wheat and barley. The most important factors influencing wheat growth and production are temperature extremes and precipitation, and hence, it is critical to have an understanding of how these environmental factors have changed in the past, and how they are likely to change in the future.

The use of Regional Climate Models (RCMs) such as the Weather Research and Forecasting (WRF) model, Advanced Research WRF (WRF-ARW) (Skamarock et al. 2008), allow for such assessments to be carried out. However, RCMs such as WRF-ARW can be set-up in a wide variety of configurations, which can lead to different results and hence, it is critical to carefully evaluate the model for specific applications (e.g. Bukovsky and Karoly 2009). We will present results from a sensitivity analysis of WRF-ARW3.3 to different input data and physics options on a yearly time-scale by evaluating the simulations against gridded observations of maximum and minimum temperatures, and precipitation. It will be shown that the choice of radiation scheme can have a large influence on simulated maximum and minimum temperatures, whereas the convective and micro-physics schemes have a stronger influence on precipitation. Preliminary results will also be presented from a climatological analysis of SWWA carried out by using WRF-ARW3.3 to dynamically downscale the 2.5 by 2.5 degree National Center for Atmospheric Research / National Center for Environmental Prediction re-analysis product.

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6.5. THE IMPACT OF ANTHROPOGENIC CLIMATE CHANGE-INDUCED STORMINESS CHANGES ON EXTREME SEA LEVELS OVER SOUTHERN AUSTRALIA

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This study investigates anthropogenic climate change induced changes in storminess on extreme sea levels for southern Australia and Tasmania by means of hydrodynamic ocean modelling. Two regionally downscalled CMIP3 climate models and one GCM have been used to force a hydrodynamical model of the ocean for current and future climates, respectively. Ocean model results indicated a robust response across the range of atmospheric forcing for future climates of a reduction of about 1-10cm along Australian's southcoast, Tasmania and Bass Strait. However, results also suggest a strong seasonality in the response with a tendency of reduced extreme sea levels to occur along the southcoast, Bass Strait and Tasmania in austral autumn but possible raised mean sea levels over Tasmania in austral winter. Changes in maximum sea levels reflect changes in atmospheric conditions. Reduced maximum sea levels in austral summer and spring are associated with enhanced easterly winds near the southcoast and reduced westerlies over the Southern Ocean. In austral winter enhanced westerlies lead to enhanced sea levels over Tasmania and reduced maximum windspeeds along Australia's south-coast further reducing sea levels there. The magnitudes of the projected changes in sea levels due to altered circulation patterns are within 10 cm of current climate extreme sea levels, which suggests that projected sea level rise will dominate future changes to extreme sea levels.

6.6. A METHOD FOR DYNAMICALLY DOWNSCALING FUTURE URBAN CLIMATE FOR AUSTRALIAN CITIES

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We describe a technique for dynamically downscaling a four member ensemble of General Circulation Models (GCMs) to explore the consequences of future global warming scenarios on the Australian urban climate. We evaluate the climate for Brisbane and Melbourne after downscaling to 3 km resolution from NCEP reanalyses (i.e., as an idealized GCM), four CMIP3 GCMs for 1991-2000 and the same GCMs for

2086-2095 under the A2 SRES emission scenario. The GCMs were downscaled using a combination of the Conformal Cubic Atmospheric Model (CCAM) and The Air Pollution Model (TAPM), with an urban parameterization based on the Town Energy Budget (TEB) approach that has been optimized for Australian cities. The downscaled simulations produced realistic urban 2-m air temperature and 10-m wind speed climatologies, despite the use of generic urban parameters and biases inherited from the GCMs. Future climate simulations suggest a non-trivial increase in extreme temperatures which may have implications for urban planning, energy consumption and health.

Stream 7. Eastern Seaboard Extreme Weather

Conveners: Aaron Coutts-Smith, Ian Goodwin

Oral Presentations

EASTERN SEABOARD CLIMATE HAZARD TOOL - MATCHES

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With a significant proportion of the New South Wales and southern Queensland population and infrastructure concentrated in the corridor between the coast and the tablelands, knowledge of the highly variable weather systems that cause significant impacts in this region is vital. The Bureau of Meteorology (BoM), in partnership with the NSW Office of Environment and Heritage under the Eastern Seaboard Climate Change Initiative, has developed the Eastern Seaboard Climate Hazard Tool. The tool identifies significant rainfall/wind/wave/water-level events on the Eastern Seaboard according to user specified thresholds while simultaneously displaying east coast low (ECL) tracks. This allows easy analysis of the relationship between the movement and location of an ECL and where its impacts are subsequently felt.

The tool draws on the BoM's rainfall and wind datasets and Manly Hydraulics Laboratory's wave height and water-level datasets, which are displayed graphically for each event, and available for download. An objective analysis is used to identify ECL tracks using the NCEP MSLP reanalysis with each track providing a link to the associated AWAP gridded rainfall map.

The Eastern Seaboard Climate Hazard Tool will be accessible publicly through the BoM website, initially via a 'registered-users page', and will provide users across a range of sectors with the ability to create and assess their own climatic risk profiles. The Authors would like to acknowledge the funding providing by the NSW Environmental Trust.

CLIMATOLOGICAL INFLUENCES ON RAINFALL ON THE EASTERN SEABOARD OF AUSTRALIA, AND THE IMPACT OF EAST COAST LOWS.

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The Eastern Seaboard (ESB) of Australia is a known climatic anomaly, with major climatic influences such as the El Niño-Southern Oscillation having substantially weaker correlations with rainfall in this region than elsewhere in eastern Australia. While a variety of factors could potentially contribute to these weak rainfall correlations three are particularly prominent. These factors are 1) proximity to the Tasman Sea and its maritime influence, 2) the presence of the Great Dividing Range and its likely influence on rainfall derived from easterly wind flow, and 3) the occurrence of East Coast Lows (ECLs), strong low pressure systems that are responsible for a large proportion of significant rainfall events on the coast. In this paper, we investigate how much of this anomalous correlation pattern can be attributed to ECLs.

Using the NSW Maritime Low Database (Speer et al. 2009), days between 1970 and 2006 can be classified as either "ECL" or "non-ECL". Using this simple classification the daily Australian Water Availability Project (AWAP) gridded rainfall dataset is separated into ECL rain days and non-ECL rain days. This is then used to investigate the spatial behaviour of correlations between both ECL and non-ECL related rainfall with key climate indices such as NINO3.4.

The climate indices investigated had little to no influence on ECL-related rainfall. By excluding this component, we observed a slight strengthening of relationships between climate indices such as NINO3.4 and non-ECL rainfall. This suggests ECLs can be considered a contributor to the anomalous rainfall patterns on the ESB. However, ECLs do not fully explain the unusual rainfall correlations in this region and this suggests other factors are influencing rainfall along the ESB.

References:

Speer, M. S., Wiles, P., and Pepler, A. 2009. Low Pressure Systems off New South Wales coast and associated hazardous weather: establishment of a database. *Aust. Met. Mag., 58,* 29-39

WILL EAST COAST LOWS BE MORE LIKELY IN A WARMER WORLD?

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East Coast Lows often have severe consequences such as flooding and damaging winds and seas, as well as beneficial consequences such as being responsible for heavy rainfall events that contribute significantly to total rainfall and runoff. Recent studies have shown that the development of most major events is associated with the movement of a high amplitude upper-tropospheric trough system over eastern Australia (*1*), and that large-scale upper tropospheric diagnostics can be constructed that provide a good indication of the occurrence of east-coast cyclogenesis (*2*).

Here, we present the application of an upper-tropospheric diagnostic method to global climate model (GCM) data. The diagnostics provide a fairly reliable indication of the risk of formation of East Coast Lows. The diagnostics rely on thresholds which are resolution dependent. In a first step, the diagnostic is applied to a number of reanalyses with different resolutions to gain an insight into appropriate threshold values. Based on this, the diagnostic is applied to GCMs and its applicability is assessed. Temporal and spatial variability of the diagnostic is also examined for each GCM to assess diagnostic performance.

Applying the diagnostic to both simulations of present and future climates provides an insight on how the risk of occurrence of East Coast Lows will be influenced by climate change.

As part of the climatological analysis, the relationship between large-scale climate drivers (such as the Subtropical Ridge, Southern Annular Mode, El Niño-Southern Oscillation, East Australian Current, etc.) and the risk of occurrences of East Coast Lows is examined.

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EXTREME RAINFALL VARIABILITY ON THE EASTERN SEABOARD OF AUSTRALIA

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The Eastern Seaboard of Australia (ESB) is a different climatological entity to the rest of eastern Australia. Major climate drivers such as the El Niño – Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) are not the dominant drivers of climate in this region (Timbal 2010). Recent research has suggested that extreme rainfall along the ESB may be strongly influenced by East Coast Lows (ECLs). The aim of this research was to investigate extreme rainfall along the ESB annually as well as for the winter and summer months (defined as May to October and November to April respectively). ECLs occur mostly during the winter half of the year and results show that winter extreme rainfall variability in the ESB is unusually high compared to summer and annual extremes.

Extreme rainfall was defined as the daily rainfall total of 1% Probability of exceedance (Pe) – equivalent to 1 in 100 year Average Recurrence Interval (ARI). This was calculated using the Generalised Extreme Value (GEV) theory using gridded rainfall data originally developed as part of the Australian Water Availability Project (AWAP). Station data from the Bureau of Meteorology's observation network were also used to calculate 1% Pe and for intercomparison between gridded and observed values. An assessment of the viability of using the GEV technique on gridded and station values will also be presented.

Station density is sufficient across the ESB (Jones et al. 2009) however, as expected, gridded data underestimated the corresponding extreme station values. Grids in the northern half of the domain tended to underestimate station values by a greater proportion than those in the south. Although there are reliability issues stemming from potential station errors the gridded data and the GEV technique provide a good spatial representation of extreme rainfall variability along the ESB.

The work presented here is a part of the Eastern Seaboard Climate Change Initiative (ESCCI) East Coast Low project.

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MULTI-DECADAL VARIABILITY OF FLOOD RISK ALONG THE EASTERN SEABOARD OF AUSTRALIA

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Previous work has established that the risk of climate related emergencies (e.g. floods, droughts, bushfires etc.) in Australia, and many other parts of the world, is non-stationary. That is, the chance of an extreme climatic event occurring is not the same from one year to the next and is in fact dependent on the state of the various climate phenomena that are responsible for Australia's hydroclimatic variability. The previous work demonstrated how, on average for New South Wales, the probability of a flood occurring that is equal in magnitude to the '1 in 100 year flood' is about five times greater during La Niña event compared to all other years and twelve times greater during a La Niña event that occurs during the negative phase of the Inter-decadal Pacific Oscillation. This work has recently been extended to focus specifically on eastern seaboard catchments where it has been found that the non-stationarity of flood risk is even further enhanced when compared to the non-coastal catchments. Also investigated is whether this non-stationarity of flood risk is due to non-stationarity of antecedent conditions or non-stationarity of extreme daily and sub-daily rainfall events with the finding being that both are important. This is contrary to recent studies that claim there is no evidence of non-stationarity in extreme daily and sub-daily rainfall across Australia. The implications of these results are significant given the large populations and infrastructure investment along the eastern seaboard and also timely given current updates to Engineers Australia's "Australian Rainfall and Runoff: A Guide to Flood Estimation", the de facto standard for flood estimation in Australia.

SYNOPTIC DRIVERS AND SECULAR SHIFTS IN EXTREME WAVE CLIMATE IN SOUTH-EASTERN AUSTRALIA

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Extreme maritime weather includes Anticylone Intensifications (AI) and East Coast Cyclones (ECC also known as East Coast Lows, ECL's). ECC are complex weather systems that form off the east coast of Australia and/or travel parallel to the coast of Australia from south-east Queensland to Victoria. The hazards associated with AI and ECC events include storm beach erosion, marine inundation, coastal lowland flooding, and persistently high relative sea-level anomalies. Along the South-Eastern Australian coastline, there is a strong latitudinal gradient in coastal risk due to storm wave climate for each AI and ECC synoptic type. The level of risk is affected by storm duration, intensity, and sequencing, in addition to the distinctive regional coastal, estuarine and shoreface geomorphology. To develop an improved understanding of the latitudinal gradient in storm wave climate and subsequent coastal impacts, we classified the AI and ECC storms into 8 synoptic types using NCEP-NCAR Reanalyses, and the 20th Century V2 reanalysis. We present the regional variability in extreme wave climate (significant wave height, maximum wave height, wave direction and period, storm duration, total wave power) for each synoptic type as recorded by 9 Waverider buoys along the New South Wales and South-East Queensland coast. Regional coastal behaviour

(recession and progradation phases) and shoreface sand supply on annual to decadal time scales was found to be driven by the modal storm wave climate for each ECC synoptic type.

We demonstrate that AIs and ECCs are associated with secular shifts in the major hemispheric modes of extratropical climate variability and the ENSO phenomenon. The storm magnitude appears to be greatest when clusters of events occur during transition months between ENSO states, or during abrupt shifts in climate, such as the transition between the phases of the Interdecadal Pacific Oscillation (IPO); for example the 1890's, 1950-56, 1971-76, and more recently 2007-2011 periods. Hence, there is some predictability for both forecasting and hindcasting storm wave climate and defining the present and future ECC hazard with respect to climate change predictions.

Poster Presentations

7.1. AN ENERGETICS SIGNATURE OF SOUTHERN HEMISPHERE EXPLOSIVE CYCLONES

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Cyclonic systems experiencing explosive development (ED), also known as meteorological 'bombs', are characterised by a reduction of central pressure at the rate of 24 hPa in 24 hours, relative to 60 degrees of latitude. Explosive cyclones are of concern to regions of Australia, New Zealand and South America as general features associated with these systems include destructive winds, flooding rains and coastal storm surges.

This study presents the first analysis of the Lorenz energetics associated with Southern Hemisphere explosive cyclones. A traditional and compact way to study the energetics of the atmosphere is adopted, whereby the kinetic and available potential energies are partitioned into zonal and eddy components. Energy budgets are calculated for climatologies of explosive cyclones within two regions, the Southwest Pacific and the South Atlantic.

Marked environmental changes in the Lorenz energy cycle are observed surrounding the period of ED. A peak in the conversion of zonal available potential energy to zonal kinetic energy precedes ED, maximized between 350 and 550 hPa. Sharp maxima in the baroclinic conversion terms closely follow ED at similar vertical levels, indicating the growth of eddy kinetic energy at the expense of available potential energy. These results suggest that the environment played an important role during the process of ED.

Analysis of the Lorenz energetics suggests that a robust signature can be attributed to this class of cyclones regardless of geographical location or time of occurrence. This result opens new avenues of exploration in both climatology and climate prediction of explosive cyclone development.

7.2. LRET GLOBAL NETWORKING TO IMPROVE PREDICTION OF EXTREME MARINE EVENTS

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Marine transportation, oil and gas exploration and exploitation, and the development of coastal infrastructure all depend on the prediction of extreme marine events. For example, efficient marine transportation depends on accurate short-term (1 to 3 days) forecasts of marine winds and surface waves; safe operation of oil and gas operations requires forecasts of extreme currents with the potential to significantly damage offshore platforms; and coastal communities located in low lying areas are dependent on accurate forecasts of storm surges to mitigate the effect of flooding. There is growing evidence that extreme marine events are becoming more likely in some regions, and that the problem is likely to increase over the next century. To address some of these problems the Lloyd's Register Educational Trust has funded a proposal to establish an international network of researchers from Canada, Australia, the U.K. and Brazil to (a) improve short-term forecasts of extreme marine events, and (b) estimate the frequency of extreme marine events over coming decades with realistic measures of uncertainty. The network will develop new models and statistical methodologies, train graduate students and postdoctoral fellows, and present the results in a way that is useful for scientists, users and the general public. We will outline the goals of the network as well as those of the Australian node.

7.3. EXTREME PRECIPITATION AND EAST COAST LOW EVENTS: THE IMPACT OF PHYSICAL PARAMETRIZATION

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On the eastern seaboard, East coast lows (ECLs) can lead to very high rainfall totals in short time periods. We investigate the underlying physics of this observation by examining the impact of different physics parameterizations on extreme precipitation in ECLs. A number of ECLs are simulated with the Weather Research and Forecasting model, and we focus on the strongest simulated event here: the 2007 Newcastle ECL. We examine the sensitivity of precipitation extremes to microphysical schemes, radiation schemes, boundary and surface layer physics, and cumulus parameterizations. We show how the cumulus parameterization, and to a lesser extent the boundary layer, can have a significant impact on the most extreme precipitation accumulations on the sub-daily time scale. Extreme accumulations on daily and longer time scales are less sensitive to the choice of physical parameterization. The most likely explanation for this behaviour involves changes in moisture transport when different cumulus parameterizations and boundary layer schemes are employed.

7.4. EAST AUSTRALIAN CUT-OFF LOWS, A NEW ASYMMETRIC MODEL

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The parametric pressure and wind field models of Tropical Cyclones (TCs) have been extensively applied in hazard engineering applications. There are a broad range of parametric models available, among them the Holland model (Holland, 1980) obtaining the greatest acceptance. Those parametric models have a common property of symmetrical pressure and wind fields. The asymmetry in TCs may result from system forward

speed or friction. An important cause of asymmetry is also existence of a high pressure system adjacent to the TC, known as east Australian cut-off lows (Holland et al., 1987) or east coast lows. Since this asymmetry affect the pressure and wind field pattern significantly, modeling of these cut-off lows using the parametric symmetrical models result in underestimation (or overestimation) of the pressure gradient force and as the result the wind speed on the side of the high pressure system (or the opposite side). For TC Roger as an example of an asymmetric TC, symmetric models underestimate maximum wind by about 30%. Additionally, the parameters of the symmetric models are not capable to represent properties of asymmetric TCs.

A new asymmetric pressure field parametric model is proposed, following Holland (1980) by manipulating the radius of maximum wind $R_{\max}$ and the pressure deficit Δp by two periodic functions in cylindrical coordination. The new function can model all levels of asymmetry and shows a good fitting result to different east coast cut-off lows. The gradient wind field of this asymmetric model is derived numerically and is estimated by a simplified function which deviates from symmetric wind field. The estimated asymmetric wind field is also in agreement with measurement from different cut-off lows. This new asymmetric wind field is capable to model the high winds on the side of high pressure system resulted from the higher pressure gradients. The new parameters in this model can also represent the TC properties considering the TC's degree of asymmetry.

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Holland, G.J., Lynch, A.H. and Leslie, L.M., 1987. Australian east-coast cyclones. Part I: Synoptic overview and case study. Monthly Weather Review, 115(12): 3024-3036.

7.5. IMPACT OF THE EL NIÑO SOUTHERN OSCILLATION, INDIAN OCEAN DIPOLE, AND SOUTHERN ANNULAR MODE ON DAILY TO SUB-DAILY RAINFALL CHARACTERISTICS IN EAST AUSTRALIA

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The relationship between seasonal aggregate rainfall and large scale climate modes, particularly the El Niño Southern Oscillation (ENSO), has been the subject of a significant and on-going research effort. Despite this, relatively little is known about how the character of individual rainfall events varies as a function of each of these climate modes. This study investigates the change in rainfall occurrence, intensity, and storm inter-event time at both daily and sub-daily timescales in eastern Australia, as a function of indices for ENSO, the Indian Ocean Dipole (IOD), and the Southern Annular Mode (SAM). Results using both the daily and sub-daily rainfall datasets detrended over the long record period of 1920-1999 consistently show that in general it is the occurrence of rainfall events, rather than the average intensity of rainfall during the events, which is most strongly influenced by each of the climate modes. This is shown to be apparently associated with changes to the time between wet spells. Furthermore, it is found that despite the recent attention in the research literature on other climate modes, over the long run ENSO remains the leading driver of rainfall variability over East Australia, particularly further inland during the winter and spring seasons. These results have important implications for how we manage our water resources, as well as how we incorporate the effects of large-scale climate modes in rainfall models to best simulate interannual and longer-scale variability.

7.6. METEOROLOGICAL OVERVIEW OF THREE EASTERN SEABOARD FLASH FLOODS

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There are several factors that contribute to flash flooding and its severity. They include: antecedent soil moisture conditions; the steepness of catchments; the extent to which catchments are urbanized; and, the rainfall rate. Even relatively low rates of short duration rainfall, when combined with the other factors can result in flash flooding. Compared to southern and western Australia the eastern seaboard is subject to particularly high rainfall rates over short durations. Flash floods are usually defined to occur within six hours of the causative rainfall. On the eastern seaboard they result from rain systems that source copious amounts of moisture from the adjacent warm East Australian Current.

For vulnerable locations such as Coffs Harbour, New South Wales with the steep topography of the Coffs Harbour Creek catchment adjacent to the coast, there have been three recent short duration rainfall events within 13 years that have produced severe flash floods. One of the events to be discussed produced the most severe flash flooding recorded at Coffs Harbour. This was a detailed case study among five flood rain events since the 1970s that have affected the New South Wales north coast (http://web.science.unsw.edu.au/~mss/Coffs-Harbour_IJC2000.pdf).There are many different ways meteorologically of producing heavy rain. It will be shown that there are similarities in addition to subtle differences between the three events by comparing the synoptic and mesoscale processes involved. A key issue, which will be discussed, arises from attempting to assign common atmospheric circulation features of the events to large scale climate drivers. The climate drivers of most relevance to the eastern seaboard are the interdecadal Pacific oscillation (IPO), southern annular mode (SAM) and ENSO (http://web.science.unsw.edu.au/~mss/eastcoast-climate-drivers.pdf).

7.7. HOW NATURAL CLIMATE VARIABILITY INFLUENCES STORM SURGE AND RELATED COASTAL FLOODING

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Coastal flooding widespread damage to property and lives. It can be caused by both heavy rainfall and/or storm surge, which is a a raise in ocean levels due to low atmospheric pressure and persistent winds.

Currently most coastal planners use a 100 year Average Reoccurrence Interval (ARI) storm surge estimate as an acceptable level of risk. This risk estimate informs planning controls such as floor heights and is also a base for calculating future sea level rise hazard areas.

The ARIs are calculated based on the assumption of a 'stationarity' climate – that is, the assumed chance of an extreme event occurring is the same from one time period (season, year, decade) to another. However, recent research has shown that the Average Return Interval (ARI) of climatic events such as rainfall, streamflow, drought and floods may be significantly under or over estimated depending on the climate state.

Previous studies have focused on the non-stationarity of coastal flooding as a result of heavy rainfall, however the results presented here demonstrate that similar inter-annual to multi-decadal variability in the risk of coastal flooding due to storm surge inundation also exists – and that this compounds the risks and impacts associated with rainfall induced coastal flooding.

This research will help improve our understanding of flood and inundation risk in the coastal zone and will be valuable for anyone dealing with urban and coastal management. The better we understand our historical and current sea level fluctuations, and what drives them, the better our coastal planning and management will be into the future.

7.8. EASTERN SEABOARD CLIMATE CHANGE INITIATIVE – EAST COAST LOWS: PROGRAM ROAD MAP FROM RESEARCH INVESTIGATION TO USER APPLICATION.

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The Eastern Seaboard Climate Change Initiative (ESCCI) is a cooperative research consortium formed to address information and knowledge gaps in climate change and variability on the Australian east coast, ranges and inshore marine environment. ESCCI's first research agenda in the climate systems theme is the East Coast Lows (ECL) Program developed by the Bureau of Meteorology, Office of Environment & Heritage, and climate science researchers at the Universities of New South Wales, Macquarie and Newcastle. The influence of major drivers on ECL formation and severity are poorly understood but may be dramatically affected by climate change. The ECL program has initiated five projects to investigate the ECL regime and their manifestation under climate change scenarios:

Project 1: ECL Hazard Tool - This tool builds on and integrates existing datasets linking historical ECL events with information on their impacts (e.g. location and intensity of heavy rainfall, severe winds and extreme waves). The database currently contains all severe storm data (including ECLs) from 1961-2009, and the map-based web interface allows users to search, query, retrieve and analyse events.

Project 2: Projections of future ECL frequency along the NSW coast – This project identifies the risk factors for ECL formation and applies them to existing (dynamic downscaling) climate models. Simulations (36) have been completed for two week intervals of seven ECL events, including the 2007 "Pasha Bulker" storm.

Project 3: Establish the long-term (1000 years) natural variability and probability assessment of ECL's – This project produces a climate pattern time-series using climate data to define climate variability in extreme storms over the past 1000 years

Project 4: Coastal System Response and Probabilistic Risk Assessment of Extreme East Coast Low Sequences – This project defines regionally distinct impacts for the NSW coastal zone for a range of storm intensities. The project forms the basis for the regional identification of coastal and estuarine vulnerability to extreme ECL events.

Project 5: The Influence of ECL on the Water Security of Coastal NSW – This study aims to better understand the hydrologic importance of ECL for water supply to major storages, and how water security will change if future climate change alters the frequency, magnitude and geographic extent of these weather systems.

7.9. EVALUATE THE POTENTIAL ECONOMIC BENEFITS FROM WEATHER AND OCEAN RELATED INFORMATION TO BEACH USERS IN AUSTRALIAN EAST COASTAL AREAS

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The overall objective of this study is to estimate the potential economic benefits from improved weather and ocean related forecast information to beach users in Australian East Coastal Areas. More specifically, it firstly attempted to learn the relationship between daily beach visitation densities in Gold Coast and Sydney and various weather and marine forecast information. The long term daily beach density changes corresponding to distinct weather and ocean forecast information are significant indicators to show visitors' demand of forecast information to plan their trips to the beaches in Australia. Secondly, the current forecast accuracy about weather and ocean information related to Gold Coast and Sydney areas will be examined to explain the forecast efficiency. Finally, the potential economic benefits from improved forecast information will be estimated through the simulations of beach visitor number changes to more accurate meteorological and oceanic forecast information. There are certain kinds of weather and ocean conditions that are preferred by most beach visitors, the tourists to Gold Coast and Sydney beaches with more accurate forecast information can make better decisions about the time of their trips to enjoy the beaches. On the one hand increase their enjoyment to beaches in good weather and ocean conditions and on the other hand decrease their trips under unpleasant weather and ocean conditions.

Stream 8. Fire Weather and Risk

Conveners: Todd Lane, Michael Reeder

Oral Presentations

INVESTIGATING THE FIRE CHANNELLING PHENOMENON USING THE WRF MODEL

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Observations of major fires have revealed a number of instances of atypical fire propagation, which occur in connection with steep, lee-facing slopes under conditions of extreme fire weather. Characteristics of the atypical spread include: rapid lateral propagation of the flank; downwind extension of the flaming zone; and the upwind edge of the flaming zone constrained by a major break in topographic slope. Instances of such atypical spread have been referred to as *fire channelling* events (Sharples et al. 2011).

Research has indicated that the fire channelling phenomenon results from the interaction between a fire and a lee-rotor. Some of the firebrands circulated within the rotor are incorporated into the synoptic flow above the rotor and are deposited downwind where they ignite spot fires that grow and coalesce, thereby explaining the extensive flaming zones associated with fire channelling events. Less clear, however, is the mechanism driving the lateral spread, which proceeds across the lee-slope in a direction perpendicular to the synoptic winds. Based on the available evidence it is possible to rule out a number of prospective mechanisms such as vertical momentum transport associated with directional wind shear. Combustion tunnel experiments have also indicated that the lateral spread only requires the presence of a fire and a lee rotor.

To better understand the physical mechanism driving the lateral spread, and the complex dynamics underlying the fire channelling phenomenon more generally, the WRF model is being implemented at the landscape scale to conduct a number of idealised simulations. Initial simulations involve an idealised triangular ridge with the effect of fire represented as a surface heat flux emanating from the lee slope. The simulations will investigate the effects of stratification in the atmosphere and will ultimately incorporate actual terrain data. The presentation reports on progress with this work.

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LOCALIZED ENHANCEMENTS IN FIRE DANGER DURING THE 'BLACK SATURDAY' FIRES

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On Saturday 7 February 2009 a series of fire complexes occurred over the state of Victoria. The fires caused more than 150 fatalities, the destruction of more than 2000 residences, and decimated a number of townships. The meteorological conditions on 7 February for the region were categorized as the worst fire weather conditions on record. Specifically, the maximum temperature exceeded 45 C (113 F) and gusty surface winds were sustained at 15 m/s (30 knots) for most of the day. These conditions were followed by the passage of a strong cold front in the late afternoon / early evening. In addition to these broad scale meteorological conditions, numerous mesoscale atmospheric processes contributed to localized enhancement in fire danger in the vicinity of many of the fires; these phenomena may have contributed to the extraordinary nature of some of the fires occurring that day. This study documents these localized processes using a combination of surface observations and a very high-resolution numerical weather prediction (NWP) model with a horizontal resolution of 500 m.

The observations and model forecast identify many notable phenomena of relevance to fire danger that persist throughout the day. These include enhanced down-slope surface winds and organized boundary layer horizontal convective rolls (HCRs). The HCRs are responsible for significant spatial variability in surface winds and forest fire danger index (FFDI). The model forecast elucidates the complex interaction between the cold front and the terrain, including the large variability in the timing and direction of the cool change. Finally, two nocturnal bores are identified that propagate ahead of the cool change; such bores have the potential to cause rapid, yet unexpected, changes to fire danger. In addition to documenting these important phenomena, the model forecast demonstrates the future capabilities of operational NWP that could be utilized for improved fire weather guidance.

WRF CAN SIMULATE RECENT FIRE WEATHER IN SOUTHEAST AUSTRALIA

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The climate of southeast Australia has been simulated using the Weather Research and Forecasting (WRF) model. WRF was implemented using both a 10 km and 50 km horizontal grid and run for 25 years from 1985-2009. The National Oceanic and Atmospheric Administration Centers for Environmental Prediction (NCEP) / National Centre for Atmospheric Research (NCAR) reanalysis supplied the lateral boundary conditions. The model simulated climate was evaluated against station-based observations of the McArthur Forest Fire Danger Index (FFDI), an index used to predict the likelihood of putting out any fires which may occur. WRF was evaluated at daily, monthly and seasonal timescales against measures of average and extreme FFDI, as well as variability in FFDI. WRF showed skill in simulating the main features of the FFDI distribution and their spatiotemporal variation. Biases in the model simulated climate were biggest at the uppermost values of the FFDI distribution e.g. days above 50. Increasing the resolution from 50 km to 10 km improved the performance of the simulations in most cases, although often only marginally. The skill shown by WRF in simulating regional climate in southeast Australia suggests it is suitable for use in downscaling projections from global climate models for this part of the world, provided that known biases in simulating extreme values are taken into account.

ASSESSING BUSHFIRE RISK UNDER WARMING CLIMATE SCENARIOS USING REGIONAL CLIMATE MODEL PROJECTIONS IN TASMANIA

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Long-term changes to the climate affect the incidence of weather conditions suitable for bushfires as well as the growth and dry matter accumulation that contribute to fuel loads. Estimating the changes to fire danger with a changing climate is an essential task for the long-term planning of bushfire response. Our best tools for projecting changes to the climate system are climate models, however the coarse scale of global climate models (GCMs) does not show the regional detail of changes. In this study, we use output from the dynamical regional climate model (RCM) named conformal cubic atmospheric model (CCAM) to examine the simulation of Tasmanian fire weather.

The finer spatial resolution of the RCM simulations gives enhanced simulation of several aspects of bushfire weather compared to GCMs. The RCM produces a realistic simulation of one atmospheric pattern associated with elevated fire danger in southeast Australia including Tasmania. The RCM also reproduced some important spatial and temporal patterns of McArthur 5 forest fire danger index (FFDI) over Tasmania at multiple scales. The temporal pattern at time scales from 3-hourly to annual, and the spatial pattern of accumulated FFDI, count of days FFDI>25 and maximum FFDI compare well to observations.

The RCM simulations can also provide additional information for analysis of the other important aspect of bushfire risk, that of fuels. This project uses a flexible framework to examine fuels, from quantitative methods and models through to a scenario approach for the widest aspects of change. Basic changes to fuel dryness are calculated using the standard drought factors for the McArthur system, and changes to fuel biomass are estimated using biophysical modeling. To examine more fundamental changes to fuel structure and bioclimatic zones, a scenario approach is used. Initial examples and the framework for further investigation are discussed.

A RESEARCH FRAMEWORK FOR ASSESSING THE SPATIO-TEMPORAL DYNAMICS OF BUSHFIRES

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This presentation outlines an approach for assessing the spatial and temporal dynamics of bushfire behaviour using three separate and dynamic components: 1) available fuel energy; 2) fire spread and spotting pattern; and 3) energy release. This framework has been developed to address major shortcomings of the fire danger

rating systems, particularly the Forest Fire Danger Index (FFDI), arising out of the fire behaviour reconstruction studies of the Victorian Black Saturday fires of 2009. Although the FFDI functions well for the 'conventional' fire conditions for which it was designed, it fails to perform under extreme fire behaviour scenarios.

The proposed system would go beyond the limitations of the FFDI by integrating static and dynamic landscape fuel arrangements, terrain, fire weather and atmospheric conditions. The first component of the system addresses available fuel energy by determining the effective heat content and fuel load of each component (live and dead) of the fuel structure rather than just for the dead fine fuels. New advances in BOM spatio–temporal climate and weather datasets mean that landscape scale moisture estimates can be modelled using remotely sensed solar radiation data at fortnightly, daily and hourly intervals.

The fire spread pattern component of the system would address the way in which the available fuel energy across a fire landscape interacts with local fire weather and atmospheric conditions to drive various fire propagation mechanisms like convective fire spread, mass short distance spotting and coalescence, and fingering of individual runs. Information to feed this component of the approach would come from analysis of past fire reconstruction studies and historical climate information, as well as more detailed fire intelligence.

The final energy release component is meant to capture the variability of convection column and spotting dynamics. Energy from large bushfires is not released uniformly, and is poorly understood given the difficulty with measuring fire behaviour parameters under these conditions. Analysis of integrated radar and video imagery following large fire events will help unravel the complex wave of pulsing energy and spotting events across space and time.

This approach to understanding bushfire risk combines multiple large scale research projects into a modular system that addresses the complexities of fire behaviour across a range of possible fire scenarios in both space and time. Such a research framework could improve estimates of bushfire hazard, fire dynamics, and application of vegetation–fuel management, fire preparedness and response, as well as fire advice to the community.

Poster Presentations

8.1. SIMULATION OF THE PROCESSES UNDERLYING SUDDEN DRYING EVENTS AND THEIR IMPLICATIONS FOR FIRE DANGER

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Observations have identified the existence of 'sudden drying events' downstream of significant terrain. These events are characterized by rapid increases in surface temperature and wind speed, along with a decrease in water vapour mixing ratio. Drying events also cause an increase in fire danger, as measured by the Forest Fire Danger Index (FFDI). This study examines two such events to determine the underlying processes. High-resolution numerical modelling using the Weather Research and Forecasting (WRF) model was conducted, with particular emphasis on the role of nonhydrostatic processes that were unable to be considered in previous work on these processes.

The first event occurred in December 2001 in the Latrobe Valley Victoria and the second occurred in May 2007 at East Sale, Victoria in 2007. For the Latrobe Valley case, the model simulations illustrated that the drying event was the result of a regime transition associated with the deepening of the mixed layer accompanying daytime heating. Subsequently, a nonlinear gravity wave caused mixing of warm and dry air from aloft to the surface layer. Simulation of the East Sale event highlighted the presence of enhanced downslope flow, consistent with the observed drying event. In this case, trapped mountain waves are also identified, which induce mesoscale variations in FFDI and produce a spatial and temporal localization of the drying conditions. The implications of these processes for fire danger and future numerical weather prediction will be discussed.

8.2. MODELLING THE FIRE WEATHER OF BLACK SATURDAY

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This presentation will describe preliminary results for a very high resolution numerical weather prediction (NWP) simulation of the Victorian fire weather of Black Saturday, 7 February 2009. The simulation will be performed using the Australian Community Climate Earth Simulation System (ACCESS), and will involve a sequence of nested limited area model (LAM) runs embedded in the ACCESS global model run.

This work forms part of a project, funded by the Bushfire Cooperative Research Centre, which aims to produce very high resolution simulations of significant recent fire events, so as to (i) better understand the meteorology of those events (in the first instance, Black Saturday) and (ii) support the research of other Bushfire CRC project components by providing relevant meteorological data. Intended downstream applications of these results include inputs to fire intensity and spread models, fire decision support tools, understanding and predicting smoke dispersion, and understanding and predicting small-scale weather variability relevant to fire behaviour.

8.3. IDEALISED NUMERICAL MODELLING OF BUSHFIRE PLUMES

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The lofting of firebrands from bushfires into a background flow leads to spotting downwind of the fire front. Firebrands can travel a considerable distance under suitable conditions, so lofting and spotting make a significant contribution to the spread of fires. A thorough knowledge of the potential for lofting from a fire is therefore desirable in order to accurately predict the fire's rate of spread and coverage.

The potential for the lofting of firebrands is determined by interaction between the atmospheric boundary layer, topography and the fire convective column. Here we use high resolution, idealised numerical simulations to investigate the behaviour of bushfire plumes, with reference to the potential for vertical transport of firebrands. In particular, we explore the sensitivity of the updraft to the background thermodynamic and wind profiles, fire intensity and external sources of vorticity.

Stream 9. Modelling and Observation of Land Surface and Atmosphere Interactions: Recent Advances and Future Changes

Conveners: Rachel Law, Luigi Renzullo, Christoph Rudiger, Albert van Dijk

Oral Presentations

BENCHMARKING LAND SURFACE MODELS: STANDARDISATION OF EVALUATION OR A QUANTIFICATION OF *A PRIORI* EXPECTATIONS?

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Several recent initiatives both nationally and internationally aim to transition land surface model evaluation from an idiosyncratic, ad-hoc procedure to one that is standardised within a mutually agreed framework, and typically describe the new paradigm as "benchmarking". This talk briefly discusses whether the standardisation of existing evaluation procedures, while undoubtedly critical, can answer the question of how well we should expect a land surface model to perform. The bulk of the talk will be spent introducing the Protocol for the Analysis of Land Surface models (PALS) web application (pals.unsw.edu.au) and specifically how it attempts to incorporate both of these definitions of benchmarking.

SIMULATION OF THE LAND SURFACE DURING THE RECENT AUSTRALIAN DROUGHT: IMPACT OF GROUNDWATER AND FORCING DATA

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The impact of groundwater and precipitation forcing on offline simulations of the land surface during the recent multi-year Australian drought are investigated using the Community Land Model Version 4. Interpolated precipitation measurements from the Australian Water Availability Project (AWAP), the Modern Era Retrospective Reanalysis (MERRA), Tropical Rainfall Measurement Mission (TRMM) satellite measurements, and the Global Land Data Assimilation (GLDAS) forcing data set are compared and combined using different techniques to construct multiple forcing data sets. It is found that the soil moisture profile is drastically changed through surface-groundwater interactions independent of the forcing data. The impact of groundwater on soil moisture variability varies depending on the forcing data chosen due to the different characteristics of the precipitation forcing. The surface-groundwater interactions and choice of

forcing data has very little effect on soil moisture memory (defined through auto-correlation). All simulations show much higher near surface soil moisture memory than satellite derived soil moisture estimates and don't reproduce the spatial patterns of satellite observed total soil moisture memory. Observed changes in green vegetation fraction and vegetation optical depth are used as proxies for the simulated transpiration. While surface-groundwater coupling increases the correspondence between transpiration and green vegetation fraction in South Eastern Australia the impact of groundwater interactions on the correspondence with vegetation optical depth changes with the forcing data utilized.

APPLICATION OF CABLE TO REGIONAL CLIMATE SIMULATIONS OVER AUSTRALIA

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We simulate the regional climate over Australia using the CABLE land-surface scheme coupled to the Conformal Cubic Atmospheric Model (CCAM). Although the preliminary results presented in this talk are based on downscaling NCEP reanalyses, the methodology is intended to predict future regional climate scenarios when downscaling an ensemble of General Circulation Models. The Australia climate was simulated at 60 km resolution from 1971-2000 with no perturbation of the atmosphere below the boundary layer, including no lateral boundary conditions as CCAM employs a variable resolution global grid. The results suggest that CABLE performs reasonably well for such regional climate experiments. Specifically, for this configuration of CABLE we found minimum temperature biases are reduced when compared to CCAM’s original land-surface scheme, although maximum temperature biases are found to increase. However, the results are sensitive to the input land-use parameter datasets and the methodology used to calculate the 2-m air temperature diagnostics under tall canopies. These issues may then need to be considered when using CABLE for regional climate modeling applications.

EVALUATION OF ENERGY AND WATER CYCLES IN CABLE AND MODEL SENSITIVITY TO KEY PARAMETERS

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In this study, we focus on exploring the skill of ACCESS land model CABLE in simulating energy and water cycles and their interactions at different temporal and spatial scales. At first, we force the model with three-hourly 10-yr meteorological forcing data from the Global Soil Wetness Project (GSWP) and compare the global terrestrial energy and water budgets and the composition of evapotranspiration in the model against the GSWP multi-model climatology (GSWP_mmc). Results are also compared with evaporation from other global land data assimilation products and runoff data from observations. Then extensive sensitivity experiments are conducted to explore key parameters/processes governing energy and water cycles in the model and how the model performs in simulating rainfall-runoff relationship under different vegetation and soil conditions. At interannual and decadal time scales, we have further conducted 50-yr model offline experiments using another set of global six-hourly forcing data to assess the model-simulated trends in runoff and evapotranspiration against some observed results over selected regions, including factors contributing to the rapid runoff decline in southwest of Western Australia.

CONTINUOUS MONITORING OF MIXING DEPTH WITH RADON–222 AND LIDAR

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We report on the development of a combined approach using both lidar and radon-222 measurements to obtain a near-continuous record of mixing depth which can, in turn, be used to assist in the interpretation of simultaneous trace gas measurements.

Interactions between the land surface and the atmosphere above are moderated by the strength and depth of mixing in the lower atmosphere which ranges diurnally between several meters at night to over one kilometer during the day. Elastic backscatter lidar can be used to measure the depth of mixing during the day, i.e. the height of the planetary boundary layer (PBL), by employing the change in aerosol concentration, and hence lidar signal, at the boundary between the PBL and the free atmosphere. These measurements are only possible when the mixing depth is large.

A complimentary approach, based on radon measurements, works well from the time turbulence decays in the afternoon through till mid morning when mixing depths are too small to be observed using lidar. Radon-222 is chemically inert and is released from the surface at a relatively constant rate and as such is a natural passive tracer. Since it is radioactive, with a half-life of 3.8 days, it does not accumulate in the atmosphere. At horizontally homogeneous inland sites, vertical mixing is the main process affecting near-surface concentration. An estimate can therefore be obtained of an "equivalent mixing depth" from time-series of radon concentration measurements, which can themselves be obtained with robust and low-maintenance instrumentation.

Using two measurement techniques sidesteps the limitations of each to make a combined dataset a useful component of field studies which seek to understand the exchanges of trace gases between the land surface and atmosphere.

ACCESS AND THE CARBON CYCLE

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Modelling the carbon cycle in global climate models is one component of the Coupled Model Intercomparison Project (CMIP5) which is a contribution to the IPCC Fifth Assessment Report (AR5). There are two types of climate simulations involving carbon described in CMIP5. The first type, Representative Concentration Pathways (RCP), use prescribed atmospheric CO_2 concentration and carbon fluxes from land and ocean are simulated, dependent on this atmospheric CO_2 and the associated climate. The second type, emissions-driven, has prescribed anthropogenic carbon fluxes and atmospheric CO_2 evolves based on these fluxes and those simulated by land and ocean carbon schemes. Cases are run with and without coupling to climate. These simulations are important because there is considerable carbon-climate feedback uncertainty in a warming climate, including how the carbon storage capacity of the terrestrial biosphere will change and how this will respond to limitations in the soil nutrients, nitrogen and phosphorus, in addition to environmental constraints such as water, light and temperature.

The Australian Community Climate and Earth System Simulator (ACCESS) initiative is in the process of including a fully interactive carbon cycle. The Carnegie-Ames-Stanford Approach with Carbon, Nitrogen and Phosphorus (CASA-CNP) is a global biogeochemical model and has been coupled to the land surface model, CABLE, in ACCESS. CASA-CNP estimates carbon, nitrogen and phosphorus pool sizes and the major fluxes between plant, litter and soil pools, such as respiration.

We have begun to calibrate and test the carbon-only component of the ACCESS/CABLE/CASA-CNP model, initially running atmosphere only simulations. This presentation will outline some of the challenges of coupling and calibrating CASA-CNP in ACCESS, as well as showing progress towards diagnosing land carbon fluxes for the CMIP5 RCP simulations.

EXPLORING THE UNCERTAINTY OF THE SOIL CARBON PROCESSES PARAMETERIZATION IN THE CABLE MODEL

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Land surface models like CABLE are used to investigate the climate feedback on soil carbon fluxes and storages. Large uncertainties remain in the description of soil processes within model structures. For example, heterogeneities in the way soil moisture and soil temperature control the heterotrophic respiration exist between models.

In order to address the influence of the parameterization on the model simulation, we implemented different soil moisture and soil temperature functions into the CABLE source code. Corresponding equations were inherited from previously published model studies. Each possible combination of controlling functions was then used to model soil processes at different FLUXNET sites under heterogeneous vegetation, soil and climatic conditions without further modifications in the CABLE model structure. Differences between net ecosystem exchange, heterotrophic respiration and soil carbon storages simulated by each combination were then analyzed.

Probability density functions of modelled heterotrophic respiration rates show large variations at the same site depending on the chosen controlling functions. These first results encourage us to further extend the analysis to other soil carbon controlling factors (e.g. nutrient availability). Addressing these uncertainties is primordial in order to assess the effectiveness of soils as potential carbon sinks.

DEVELOPMENT OF AN ENSEMBLE-ADJOINT OPTIMIZATION APPROACH TO DERIVE UNCERTAINTIES IN NET CARBON FLUXES

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Accurate modelling of the carbon cycle strongly depends on the parametrization of its underlying processes. The Carbon Cycle Data Assimilation System (CCDAS) [1] can be used as an estimator algorithm to derive posterior parameter values and uncertainties for the Biosphere Energy Transfer and Hydrology scheme (BETHY) [2]. However, the simultaneous optimization of all process parameters can be quite challenging, due to the complexity and non-linearity of the BETHY model. Therefore, we propose a new overall concept, which combines ensemble runs and the adjoint optimization approach of CCDAS in order to derive the probability density function (PDF) for posterior soil carbon parameters and the net carbon flux at the global scale. In this way, we optimize only those parameters within CCDAS, which can be constrained best by atmospheric carbon dioxide data. The prior uncertainties of the remaining parameters are included in a consistent way through ensemble runs. The final PDF for the optimized parameters and the net carbon flux are then derived by superimposing the individual PDFs for each ensemble member. We find that the optimization with CCDAS converges much faster, due to the smaller number of processes involved. Moreover, it is more likely that we find the global minimum in the reduced parameter space.

For future applications the proposed concept also allows the inclusion of posterior uncertainties for the remaining, yet unconstrained photosynthesis parameters. The work of [3] has demonstrated how to constrain the parameters of the Farquhar photosynthesis model using an extensive set of plant traits and therefore provide a way on how to derive the posterior PDF for the photosynthesis parameters. Those results could be used within the same ensemble-adjoint optimization framework, but in this case all parameters would be constrained by observations.

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SIMULATED IMPACTS OF LAND COVER CHANGE ON TEMPERATURE EXTREMES FROM THE LUCID INTERCOMPARISON STUDY

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Preliminary results from a climate model, coupled to a sophisticated land surface scheme, indicate that many extremes indices related to temperature are significantly affected by land use induced land cover change (LULCC). Compared to the impact of doubling atmospheric carbon dioxide (CO_2), some indices are systematically affected by LULCC in the same direction as increasing CO_2 while for other indices, LULCC opposes the impact of increasing CO_2. In some regions, the scale of the LULCC forcing is of a magnitude similar to the impact of CO_2 alone. This suggests that assumptions that anthropogenically-induced changes in temperature extremes can be approximated by increasing greenhouse gases alone are flawed, as LULCC may regionally mask or amplify the impact of increasing CO_2 on climate extremes. Using results from the "Land-Use and Climate, IDentification of robust impacts" (LUCID) project, we determine whether these LULCC-induced changes in temperature extremes are common across several climate models using different land surface schemes implementing the same LULCC and identify the common mechanisms which result in changes in the extremes.

IMPROVING LAND COVER AND SURFACE BIOPHYSICAL PROPERTY ASSESSMENT IN SUPPORT OF THE AUSTRALIAN WATER RESOURCES ASSESSMENT SYSTEM

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The Australian Water Resources Assessment (AWRA) System will provide the Bureau of Meteorology the tools needed to perform annual assessments of the water balance continentally. The AWRA landscape model (AWRA-L) (Van Dijk 2010) simulates the water and energy fluxes on a daily time step. The current configuration in AWRA-L includes two main land cover types, or hydrological response units (HRUs) which occupy each grid-cell (~5 km) in a certain proportion: tall, deep-rooted vegetation and short, shallow-rooted vegetation. This study presents results of firstly, an assessment, intercomparison and evaluation against observations (from airborne Lidar) of two alternative sources of land cover information to represent the proportions of deep and shallow-rooted vegetation and secondly, an empirical method to resolve the relative contribution of each land cover type into the albedo, greenness and leaf area index observed by the MODIS sensor in mixed pixels. The two sources of land cover information showed important differences between them in many parts of Australia with consequences for the performance of AWRA-L. The "unmixing" of the biophysical properties of the two HRUs provides a spatially explicit estimate of the most relevant properties which is also dynamic. This information will be assimilated into AWRA-L and the improvement in streamflow predictions will be assessed.

QUANTIFYING SPATIAL VARIABILITY IN MEAN WIND SPEED AND MOMENTUM TRANSFER WITHIN A MODEL VEGETATION CANOPY

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Reliable estimates of hydrological, energy and carbon cycles under different climate scenarios rely on both modelling and observations. Flux stations provide continuous, long-term measurements of land-atmosphere exchange. A global network, FluxNet, includes 21 towers in Australia and New Zealand (OzFlux). When coupled with numerical modelling, their data provide avenues to understand the interacting hydrological, energy and carbon cycles and atmospheric processes more generally.

It is critical that tower measurements are representative of their biome so that local anomalies in turbulent flow and fluxes must be avoided. Turbulent mixing ensures measurements taken well above the canopy are representative of the region around the tower. However, closer to and within tall vegetation, mixing is often insufficient to smooth out spatial variations imposed on the flow by the canopy elements so tower location becomes important.

It is difficult and expensive to undertake spatial heterogeneity studies under field conditions. Consequently, we investigated the within-canopy flow in very great detail using a wind tunnel model that accurately mimics a tall vegetation canopy (Raupach et al., 1986). Using Laser Doppler Velocimetry, we were able to resolve mean wind and turbulence characteristics in 3D and to study the relationships between 84 vertical profiles and their spatial average. The experiment suggests that the influence of wakes from 'tree' elements within the canopy extends well downstream, resulting in significant spatial heterogeneity in the turbulence statistics. In different regions of the space around a typical element, we observed four characteristic wind profile shapes. These were spatially correlated and may reflect different turbulent processes. These results provide useful insights for the analysis of within-canopy eddy-covariance measurements and the siting of future flux towers. They also provide uncertainty estimates when point measurements are used to estimate flux storage terms as part of hydrological, energy and carbon balance calculations.

Raupach, M.R., Coppin, P.A. and Legg, B.J., 1986. Experiments on scalar dispersion within a model plant canopy. Part I: The turbulence structure. Boundary Layer Meteorol., 35: 21-52.

Poster Presentations

9.1. DAILY SURFACE SOLAR RADIATION ESTIMATION USING NEURAL NETWORK TECHNIQUE BASED ON CLIMATOLOGICAL DATA

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Most agrometeorologic and hydrometeorologic models use climatic inputs such as temperature, relative humidity, solar radiation and precipitation. In Kerman (southeast of Iran), few automatic weather stations can monitor incoming solar radiation. Hence, surface incoming solar radiation must be estimated from other climatological data. Artificial neural network (ANN) is an effective tool to model nonlinear systems and require fewer inputs. The objective of this study was to test an artificial neural network for estimating the daily solar radiation as a function of daily mean air temperature, daily precipitation, daily maximum and minimum air temperature, relative humidity, sunshine duration and extraterrestrial radiation (seven different models MQ_1 to MQ_7) in semi-arid climate of Kerman. The multilayer feed-forward preceptron types were trained to estimate daily solar radiation as a function of meteorological data. The data used in the network training were obtained from a historical series (2000–2002) of daily climatic data collected in the synoptic weather station of Kerman. It is assumed that time-series model could be effective in one step forward prediction of solar radiation values. After fitting of different models with different time steps (6-1 delay steps), it is showed that ANN model with 3 time–delay step is the best model. The results obtained from the tree models MQ_5 (with extraterrestrial radiation, daily maximum and minimum air temperature, sunshine duration and relative humidity), MQ_6 (with extraterrestrial radiation, sunshine duration and relative humidity) and MQ_7 (with extraterrestrial radiation, daily mean air temperature and sunshine duration) have been acceptable comparing to model MQ_3 (with extraterrestrial radiation, daily minimum air temperature, relative humidity, sunshine duration, and 3 time–delay step solar radiation). RMSE and R for the comparison between observed and estimated daily solar radiation for the tested data using the proposed ANN model (MQ_3) are 1.98 MJ $m^{-2}d^{-1}$ and 0.91, respectively.

9.2. THE AUSTRALIAN COMMUNITY LAND SURFACE MODEL (CABLE): PRESENT STATUS AND FUTURE DEVELOPMENT

Ying-Ping Wang[1], Eva Kowalczyk[1], Jhan Srbinovsky, Bernard Pak[1], Rachel Law[1], and Lauren Stevens[1], Qian Zhang[2], Huqiang Zhang[3], Marcus Thatcher[1], Gab Abramowitz[4]

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CABLE is the Australian community land surface model for studying biophysical and biogeochemical interactions between the land surface and atmosphere. Over the last five years, we have significantly improved and developed the model, and coupled the model to a number of atmospheric models and developed a benchmarking framework. Major model improvement includes a better energy and mass conservation, improved responses to seasonal drought and representation of land surface heterogeneity. Major components added to CABLE are: ecosystem biogeochemistry, interactive leaf area and prognostic maximal leaf photosynthetic rate, land use and land use change, and a lake scheme. The model has been evaluated against various observations and model-data products for surface fluxes, major basin runoff, biogeochemical pools and responses to environmental perturbations. In this talk we will present some key results from each of those three activities and highlight the strength and weakness of this model, as compared other major global land surface models. A plan is being developed how to use the PALS (pals.unsw.edu.au) to benchmark different versions of CABLE or CABLE and other global land surface models against different datasets. Finally we will discuss how the developers and users of CABLE can work together to develop a better model using the benchmarking framework.

9.3. USING ATMOSPHERIC CARBON DIOXIDE MEASUREMENTS TO ASSESS CARBON FLUXES PRODUCED BY CABLE

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The Community Atmosphere Biosphere Land Exchange (CABLE) model simulates carbon uptake by photosynthesis. When coupled to CASA-CNP, carbon pools and respiration fluxes are also simulated. As part of the Australian Community Climate and Earth System Simulator (ACCESS) these carbon fluxes can be used to simulate the biospheric component of atmospheric carbon dioxide concentrations. Atmospheric CO_2 is measured at a number of sites across the globe, either with in-situ instruments (usually reporting hourly concentrations) or through flask sampling (typically with weekly frequency). These measurements are valuable for assessing the carbon fluxes produced by land surface models because, under well-mixed meteorological conditions, they can integrate the impact of carbon fluxes over large regions. This is especially true of sites that are remote from land regions; the mean seasonal cycle of CO_2 at remote sites in the northern hemisphere is dominated by biospheric CO_2 exchange and is commonly used for assessing model-generated carbon fluxes. In the southern hemisphere, seasonal cycles are smaller and harder to interpret. Consequently, to assess the carbon fluxes from Australia, it is necessary to use in-situ records, such as that from Cape Grim, NW Tasmania. Hourly CO_2 concentrations show episodes of high or low CO_2 when air has passed over SE Australia before arriving at Cape Grim.

We will present an evaluation of CABLE carbon fluxes in ACCESS using both seasonal cycles of atmospheric CO_2 and synoptic variability. We will discuss the challenges of sampling the model output to be most comparable to the observations, particularly for coastal sites.

9.4. OFFLINE CABLE IN MULTIPLE-PROCESSOR MODE: STRUCTURE, DATASETS AND PERFORMANCE

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We have developed a stand-alone version (offline) of the Australian community land surface model (CABLE). This version makes use of the multiple processors on high-performance computers, and is about 12 times as fast as the single processor version for running globally at 1^{o} by 1^{o} spatial resolution. In this talk, I will describe the availability of the codes, the new code structure in the repository, input datasets for running globally offline, some sample results and the datasets available for model benchmarking. With the improved computation of this version of CABLE, we will discuss possible future applications, such as parameter estimation, model-data fusion, ensemble simulations and regional/continental studies at finer scales.

9.5. PARAMETERIZATION IMPROVEMENTS IN ONLINE VERSION OF THE COMMUNITY ATMOSPHERE BIOSPHERE LAND EXCHANGE MODEL.

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2Plant Functional Biology and Climate Change Cluster, University of Technology, Sydney

The Community Atmosphere Biosphere Land Exchange (CABLE) model has been coupled to the UK MetOffice atmospheric Model (UM). AMIP style simulations of the present day climate with UM/CABLE revealed a number of temperature and moisture biases in comparison with ERA-Interim reanalysis and Fluxnet observations. A series of improvements and additional parameterizations were implemented in CABLE to minimise the biases and produce a plausible climate. The improvements were related to polar region hydrology and reducing canopy water stress in dry seasons.

The snow model was extended to allow for liquid precipitation to percolate through or refreeze in the snow pack layers. The heat exchange between advected soil moisture and the soil was included. The rate of percolation of water through the soil was adjusted to allow a more realistic fresh water influx into the North Atlantic. The water stress function used by the canopy for extraction of soil water was modified to be less dependent on root distribution to allow soil water uptake from the lower layers in the dry season. The model was extended to include hydraulic redistribution of soil moisture which allows for the moistening of upper soil during the dry season and for more efficient uptake of soil water during wet season in areas of tropical forest.

The presentation will show the latest results from a global AMIP-style 20 year simulation of UM/CABLE. We compare the simulated temperature, rainfall and energy fluxes with ERA-Interim reanalysis and Fluxnet observations at different time scales globally and for selected locations.

9.6. MODELLING THE DIURNAL CYCLE IN ACCESS NWP

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The diurnal cycle is a feature that is poorly represented in General Circulation Models. This is, in part, due to the difficulty in modelling the stable nocturnal boundary layer. Recently, Bureau of Meteorology forecasters have noted discontinuities in the ACCESS calculation of screen-level temperature and moisture during the evening transition period under conditions of low wind speed. Under these conditions, the appropriateness of the scaling parameters used in the derivation of screen-level diagnostics is called into question. We applied a number of practical alternatives to the modelling of these scenarios in ACCESS NWP operational forecasts involving the restriction of the scalar interpolation coefficent at a critical Richardson Number and friction velocity threshold. The impact and validity of these approaches will be presented and future directions of model development in this area will be discussed.

9.7. MODELING SURFACE RADIATION UNDER A CHANGING CLIMATE

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Many key landscape processes for human land use and natural ecosystems are regulated by surface climatic conditions, including an important influence from incoming shortwave radiation. Surface radiation has a key influence on landscape ecosystems through effects on surface thermal regimes, photosynthesis and evapo-transpiration, which in turn affects soil water. The radiation environment varies on all spatial and temporal scales, from site to landscape. Incoming shortwave radiation is a key component of the global radiation budget in climate models and is examined in studies of the climate system. However, gauging the impact of changes to the climate on surface radiation at a scale relevant to landscape processes is not commonly done, and requires new methods and focus.

For much of the Australian continent, surface radiation can be readily and accurately modeled to fine scales as a function of time of year, latitude, and a broad estimate of atmospheric attenuation. However in rugged terrain, surface radiation is significantly modified by surface slope, aspect, and topographic shading (a stark example is deep ravines). Here we examine the local radiation environment in Tasmania and the Australian Alps, where topography effects are important. The Solar Radiation Attributes program (SRAD) uses a digital elevation model (DEM) and a set of ancillary climatic and environmental parameters to estimate topographically modified surface radiation. We present a set of regional climate model outputs run at 10-20 km resolution coupled directly to the SRAD system with a 250 m DEM to describe changes to the local radiation environment under projected climate change scenarios. This process illustrates the effect of projected climate change on radiation at the surface, where many landscapes processes occur. We propose this method as a useful tool to account for local attributes and improve understanding of climate change impacts at a scale meaningful for natural ecosystems.

9.8. A WIND TUNNEL ANALYSIS OF MOMENTUM ADJUSTMENT ACROSS A FOREST EDGE WITH DETAILED SPATIAL RESOLUTION

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Windstorms cause major damage to forests. E.g., in 2004-2005, Sweden sustained windthrow damage of 75 million m^3, equivalent to a normal annual harvest[1]. Windthrow is related to tree location relative to a forest edge so quantification of wind flow adjustment to changes in roughness is economically important. More generally, data on internal boundary layer adjustment in landscapes with complex land cover provide insights on the interpretation of flux tower measurements and into the parameterisation of surface exchange processes in such landscapes. It is difficult and expensive to undertake these studies under field conditions. Consequently, we investigated flow adjustment using a well characterised wind tunnel model that mimics a tall vegetation canopy (Raupach et al., 1986). Mean wind and turbulent characteristics were measured using 3D Laser Doppler Velocimetry at high spatial resolution across the interface from a short 'grass' surface to a tall 'forest' model canopy.

The mean wind speed begins to adjust to the roughness change slightly upwind of the canopy edge with rapid adjustment occurring immediately downwind of the transition. Above 1.5 canopy heights (z=1.5h) turbulent mixing smooths out variations in mean wind and turbulence profiles related to individual canopy elements. Within and immediately above the canopy, the profiles reflect their spatial location relative to these elements. Within a wake-like zone behind each element, adjustment is rapid as the mean momentum is removed by pressure forces across each element and wake patterns show little variation with distance downwind of the forest edge. In contrast, within the non-wake zones the adjustment takes longer as mean streamwise momentum is mixed laterally by turbulence. The profile of mean wind speed does not fully develop its characteristic inflection point until 5h downwind of the edge and full adjustment of within-canopy profiles of momentum flux does not occur until well downwind of 5h.

Raupach, M.R., Coppin, P.A. and Legg, B.J., 1986. Experiments on scalar dispersion within a model plant canopy. Part I: The turbulence structure. Boundary Layer Meteorol., 35: 21-52.

[1]UNECE/FAO Forest Products Annual Market Review, 2004-2005.

http://books.google.com.au/books?id=T92FZIPK3-0C&pg=PA9&lpg=PA8&ots=M4AFyBuwUX&dq=forestry+industry+europe+windthrow#v=onepage&q&f=false

Stream 10. Natural Hazards

Conveners: Bob Cechet, Sandra Schuster

Oral Presentations

CLUSTER ANALYSIS OF TROPICAL CYCLONE TRACKS IN THE SOUTHERN HEMISPHERE

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A probabilistic clustering method is used to describe various aspects of tropical cyclone (TC) tracks in the Southern Hemisphere, for the period 1969-2008. A total of 7 clusters are examined: three in the South Indian Ocean, three in the Australian Region, and one in the South Pacific Ocean. Large-scale environmental variables related to TC genesis in each cluster are explored, including sea surface temperature, low-level relative vorticity, deep-layer vertical wind shear, outgoing longwave radiation, El Niño-Southern Oscillation (ENSO) and the Madden-Julian Oscillation (MJO). Composite maps, constructed 2 days prior to genesis, show some of these to be significant precursors to TC formation – most prominently, westerly wind anomalies equatorward of the main development regions. Clusters are also evaluated with respect to their genesis location, seasonality, mean peak intensity, track duration, landfall location, and intensity at landfall. ENSO is found to play a significant role in modulating annual frequency and mean genesis location in three of the seven clusters (two in the South Indian Ocean and one in the Pacific). The ENSO-modulating effect on genesis frequency is caused primarily by changes in low-level zonal flow between the equator and 10°S, and associated relative vorticity changes in the main development regions. ENSO also has a significant effect on mean genesis location in three clusters, with TCs forming further equatorward (poleward) during El Niño (La Niña) in addition to large shifts in mean longitude. The MJO has a strong influence on TC genesis in all clusters, though the amount modulation is found to be sensitive to the definition of the MJO.

AUSTRALIA NATIONAL WIND RISK ASSESSMENT (NWRA): QUANTIFYING WIND HAZARD AND RISK UNDER CURRENT AND FUTURE CLIMATE

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The National Wind Risk Assessment (NWRA), a collaborative study between Geoscience Australia and the Dept. Climate Change and Energy Efficiency, has developed a computational framework to evaluate both the wind hazard and risk due to severe wind gusts (based on modelling techniques and application of the National Exposure Information System; NEXIS). A combination of tropical cyclone, synoptic and thunderstorm wind hazard estimates is used to provide a revised estimate of severe wind hazard across

Australia. This hazard modelling utilises both current-climate information and also simulations forced by IPCC SRES climate change scenarios, which are employed to determine how wind hazard will be influenced by climate change.

Results from the current climate regional wind hazard assessment are compared with the hazard based on the existing understanding as specified in the Australian/New Zealand Wind Loading Standard (AS/NZS 1170.2, 2011). Regions were mapped where the design wind speed depicted in AS/NZS 1170.2 is significantly lower than the hazard analysis provided by this study. Regions requiring more immediate attention regarding the development of adaptation options are discussed in the context of the minimum design standards in the building code regulations.

A national assessment of localised wind speed modifiers including topography, terrain and the built environment (shielding), has also been undertaken to inform the local wind speed hazard that causes damage to structures. Wind speed modifiers are incorporated through a statistical modification of the regional wind speed. We report on an assessment of severe impact and wind risk to residential houses across the Australian continent (quantified in terms of annualised loss). In addressing future climate scenarios of regional severe wind hazard, we consider the changing nature of severe wind risk focusing on the Southeast Queensland and Tasmanian regions and illustrate where the wind loading standard becomes inadequate at a specified future time.

A CLIMATOLOGY OF AUSTRALIAN SEVERE THUNDERSTORM ENVIRONMENTS 1989-2011

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Severe thunderstorms present a frequent and significant threat to property and life in Australia during the spring and summer. However, these relatively infrequent events are poorly understood in their frequency and occurrence over the continent resulting from a lack of in situ observations. With the influence of a warming climate, there is an increasing need to not only understand thunderstorms as they have occurred in the past over Australia, but also to assess the future potential for severe thunderstorms and their impacts.

To establish the environmental conditions that are associated with severe thunderstorms in Australia, a proximity climatology of known severe thunderstorm environments has been produced for 2003-2010. This was first produced using high resolution MesoLAPS forecast profiles to develop covariate discriminants that identify the increased probability of an environment to produce severe thunderstorms (Allen et al. 2011). Convective variables were then derived from soundings produced using 1.5 degree ERA-Interim reanalysis data. The MesoLAPS discriminants have been used to evaluate the application of the ERA-Interim to analyzing thunderstorm environments. The covariates use a combination of ingredients describing instability (MLCAPE) and potential for organized severe convection (deep-layer wind shear). These discriminants have been used to produce a climatology of environments favourable to the development of severe thunderstorms over the period 1989-2011 from this reanalysis. This climatology represents the first analysis of its kind for the occurrence of severe thunderstorm environments over Australia.

The inter-annual variations in the spatial distribution of convective environments over Australia are analyzed, with particular focus on the influence of the El Niño-Southern Oscillation on the occurrence of severe thunderstorm environments. A case study of the high population of severe weather reports in the

2005/2006 warm season is considered in the context of the distribution of favourable environments and its impact on the reporting of severe thunderstorm phenomena.

Allen, J.T., Karoly, D.J. and Mills, G. 2011: A severe thunderstorm climatology for Australia and associated thunderstorm environments. *Aust. Meteor. Ocean. Jour*. **In Press.**

VICTORIAN COMMUNITIES IMPACTED BY RECORD RAINFALL AND WIDESPREAD FLOODING IN JANUARY 2011

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Victoria experienced phenomenal climate events, severe weather and major flooding in the six months from September 2010 to February 2011. This paper aims to explain the extraordinary nature of the January 2011 rain event in Victoria by providing a climatological and hydrological context for the record breaking conditions and large-scale damage.

In Victoria, 2010 was the first year of above average rainfall state-wide since 1996 and the fifth wettest year on record. The extreme rainfall events of 2010/2011 were driven by record warm sea surface temperatures north of Australia, a negative Indian Ocean Dipole mode event and one of the strongest La Niña events observed.

The January 2011 event was a result of a tropical intrusion in which persistent low pressure systems were associated with extremely high tropical moisture levels. The event of 9-15 January 2011 was one of the most extreme rainfall events recorded in northwestern Victoria, with most of central, western and northern Victoria recording rainfall equivalent to that normally expected from an entire summer. State-wide rainfall for 12-14 January was the largest ever three-day total and several stations with over 100 years of record observed their highest daily and monthly rainfall for any time of year.

Multiple monitoring sites observed their highest ever river levels, some breaking records of more than 70 years, and most catchments in western Victoria experienced major flooding. Of the 330 flood warnings issued for the event, 172 were in the Major Flood Warning category.

Widespread flooding across western Victoria caused extensive damage, impacting over 100 towns and more than 7500 people. The prolonged wet and humid conditions also brought significant health hazards to Victoria, such as mosquito borne diseases which had not been seen on such a large scale for several decades.

THE DYNAMICS OF VOLCANIC ASH CLOUDS IN A CROSS-WIND

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Volcanic ash clouds are a prominent threat to air traffic and aircraft safety, in most regions of the world. They are produced by volcanic eruptions that eject buoyant material that rises as a plume and then spreads at an equilibrium level, or levels. Sedimentation occurs due to fall-out of solid material from these clouds, and most of our information about pre-historic eruptions comes from geological analysis of these sediments. Existing models of ash cloud formation are based on intrusive gravity current dynamics, and are axisymmetric about the source, assuming no wind. The presence of crosswind changes this picture completely, and a model of this behaviour is presented here. The resulting cloud becomes much thicker near the source, and in the far field assumes a wedge-shaped form with the wedge angle dependent on the strength of the cross-wind and the strength of the volcanic source. There are applications to prediction of cloud movement and the geological analysis of sediments.

Poster Presentations

10.1. TROPICAL CYCLONE WIND HAZARD FOR THE WESTERN PACIFIC

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Tropical cyclones pose a significant threat to islands in the tropical western Pacific. The extreme winds from these severe storms can cause extensive damage to housing, infrastructure and food production, as well as loss of life. As part of the Pacific Climate Change Science Program (PCCSP), Geoscience Australia assessed the wind hazard posed by tropical cyclones for 14 islands in the western Pacific and East Timor. The wind hazard was assessed for both the current climate and for the future climate under the A2 SRES emission scenario.

Wind hazard maps were generated using Geoscience Australia's Tropical Cyclone Risk Model (TCRM) that applies a statistical-parametric process to estimate return period wind speeds. To obtain a robust estimate of wind hazard from a short historical track record, TCRM produces several thousand years worth of tracks that are statistically similar to the input track dataset. The model then applies a parametric wind profile to these tracks and fits a Generalized Extreme Value (GEV) distribution to the maximum wind speeds at each location. To estimate how the hazard may change in the future, tracks of Tropical Cyclone-Like Vortices (TCLVs) detected in dynamically downscaled global climate model are used as input into TCRM. This process is performed for four downscaled global climate models for two twenty year periods centered on 1990 and 2090.

This study provides the first detailed assessment of the wind hazard for this region, despite these countries being highly exposed and vulnerable to the severe storms. The hazard climate projections should be treated with caution because of known deficiencies in the global climate models and poor agreement between the hazard projections produced from the four climate models. However, keeping these limitations in mind, the results suggest that the wind hazard will decrease north of latitude 20ºS in the South Pacific by 2090.

10.2. ASSESSMENT OF THE CONSISTENCY OF GUST WIND SPEED MEASUREMENTS

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A study of the consistency of gust wind speed records from two types of recording instruments has been undertaken. The study examined the Bureau of Meteorology's (BoM) wind speed records in order to establish the existence of bias between coincident records obtained by the old pressure-tube Dines anemometers and the records obtained by the new cup anemometers.

This study was an important step towards assessing the quality and consistency of gust wind speed records that form the basis of the Australian Standards/NZ Standards for design of buildings for wind actions

(AS/NZS 1170.2:2011 and AS 4055:2006). The Building Code of Australia (BCA) requires that buildings in Australia meet the specifications described in the two standards.

BoM has been recording peak gust wind speed observations in the Australian region for over 70 years. The Australia/New Zealand Wind Actions Standard as well as the wind engineering community in general rely on these peak gust wind speed observations to determine wind loads on buildings and infrastructure. In the mid-1980s BoM commenced a program to replace the aging Dines anemometers with Synchrotac and Almos cup anemometers. During the anemometer replacement procedure, many localities had both types of anemometers recording extreme events. This allowed us to compare severe wind recordings of both instruments to assess the consistency of the recordings. The results show that the Dines anemometer measures higher gust wind speeds than the 3-cup anemometer when the same wind gust is considered. The bias varies with the wind speed and ranges from 5 to 17%. This paper presents the methodology and main outcomes from the assessment of coincident measurements of gust wind speed.

10.3. ADAPTATION ACTIONS AND HUMAN SECURITY IN BANGLADESH: AN ANALYSIS OF DISASTER RESILIENT RESPONSE MECHANISMS IN THE CONTEXT OF COASTAL HAZARDS

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Coastal hazards are considered as the greatest threats to human life and security in many countries in the world. It is known that frequent natural hazards coupled with climate change are triggering complex development challenges in many developing countries. In Bangladesh rapid population growth and a slow economic growth rate have forced a substantial part of the ever-increasing vulnerable population to settle in natural hazard prone unsecured locations. For example, offshore islands such as Sandwip, Kutubdia and Hatiya in the Bay of Bengal are subjected to frequent tropical cyclones (e.g., cyclone 1991, cyclone 1997, Sidr 2007 and Aliya 2009). Local communities in these remote islands are also severely affected by coastal erosion. To live in the changing environment, the coastal people are continuously applying adaptation strategies. Adaptation means adjustment of survival strategies in response to coastal hazards, to reduce vulnerability or enhance resilience. In this context, the present research is an attempt to identify what sort of adaptation strategies the hazard affected coastal communities are adopting and will continue to adopt for their future life and livelihood. To understand community led adaptation strategies through the eyes of the affected people, qualitative data (i.e. participant observation, focus group discussions, semi structured interviews and archival research) have been collected from the rural communities who are surviving in the hazardous coastal and island areas of Bangladesh. The findings suggest that hazards affected people actively interact with changing disaster situations through their self instinct coping mechanisms and survival strategies. It is also explored how with no social security schemes and appropriate mitigation measures, frequent disasters have posed a constant threat to the basis of livelihoods and settlement leading to deterioration of the general standard of living, quality of their environment and consequently to increases in human insecurity for coastal Bangladesh.

10.4. DEVELOPING CLIMATOLOGIES OF HEAT STRESS FOR WESTERN EXTREME RAINFALL VARIABILITY ON THE EASTERN SEABOARD OF AUSTRALIA

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Sustained very high temperatures over a number of days can severely impact human health (e.g. deCastro et al. 2011). Given that the last decade (2001-2010) was the warmest on record for Australia (0.52°C above the 1961-1990 average), heat stress is an increasing threat to Australian communities. The aim of our work is therefore to provide the information required by decision-makers.

A set of three indices based on maximum daily temperatures has been developed for an objective analysis of heat stress for Australia (Nairn et al. 2009). These indices allow quantifying:

a) significance of heat stress in climatological context (exceedance of 95th percentile over a three-day period),

b) an acclimatisation component (based on two three-day periods with a lag of 30 days), and

c) a heat factor (the combined effect of these two measures).

Work is currently underway to develop sector-relevant information on heat stress based on gridded temperature data originally developed as part of the Australian Water Availability Project (AWAP). In the first stage, we are providing information on both averages and the range of conditions encountered across regions of Western Australia, with particular emphasis on extremes. On the basis of these assessments we will be able to provide guidance on which regions are most likely affected and at what time of the year. Temporal trends are explored on the basis of both gridded and station data.

The reliability of our assessments will be affected by the network density of stations available for developing gridded temperature data (Jones et al 2009). Relevant supporting information is provided for users to assess the confidence in these assessments based on period and region. The effects of relative humidity and wind speed as used in the calculation of apparent temperature are outside the scope of our current analysis. We would like to acknowledge that this work is supported by funding from the Indian Ocean Climate Initiative (IOCI).

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10.5. INFLUENCE OF OCEAN AND RAINFALL ON THE INTENSITY OF TROPICAL CYCLONES

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Operational Tropical Cyclone (TC) intensity forecasts have been improved since the inclusion of the upper ocean properties in forecasting systems. Indeed, regions of high upper ocean heat content (OHC) tend to be favorable for the development of intense TCs. The use of the OHC is empirical, the latter usually being computed between the surface and the 26ºC isotherm. Based on energetic considerations, a cooling inhibition index (CI) has been developed to take the entire ocean vertical profile into account. Forecasting skills of the TC induced cooling are improved when using CI instead of the OHC.

The same energetic considerations can be used to assess the ocean mixing inhibition due to heavy rainfall that often occur in TCs. An ocean reanalysis and satellite products of SST and precipitation are used to estimate the impact of this mixing inhibition by rain on the TC induced cooling. A linear theory is then developed to analyze the various influence of rain among the different basins.

Stream 11. Renewable Energy – the Effects of Weather and Climate on Integrating Renewables into our Energy Industry

Conveners: Roger Dargaville, Merlinde Kay

Oral Presentations

THE IMPACT OF CLOUD EVENTS ON SIMULATED PHOTOVOLTAIC ARRAYS

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Using solar radiation observations from the Oklahoma Mesonet, the performance of simulated rooftop sized (2-3 kW) photovoltaic arrays under a variety of meteorological conditions is investigated using the translation system outlined in Engerer 20111.

The Oklahoma Mesonet represents the world's largest long-term network of solar radiation sensors, consisting of over 115 Li-Cor pyranometers that cover the 182,000 km2 area of the state with an average station spacing of <40km and have reported five-minute averages of global horizontal irradiance since 1994.

This extraordinary dataset provides a unique opportunity to investigate the potential impact of a wide variety of cloud events on the solar radiation resource, and, furthermore, through the application of the translation system of Engerer 2011, solar energy generation. This presentation will compare and contrast the power generation of simulated photovoltaic arrays under clear sky, broken sky and overcast conditions occurring in the U.S. Southern Great Plains region, in an attempt to quantify the impact of various cloud events on solar energy generation.

1Engerer, Nicholas A. Simulating Photovoltaic Array Performance Using Radiation Observations from the Oklahoma Mesonet. M.S. Thesis. School of Meteorology, University of Oklahoma, 2011.

WIND SPEED TRENDS AND CLIMATE CHANGE - IMPLICATIONS FOR WIND ENERGY

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Linear trends in near-surface wind speed have been documented in the peer-reviewed literature at many locations across the world. There has been limited research articulating why these trends are observed or whether they will continue under future climate change. A recent study for Australia revealed conflicting wind speed trends for the 2 m and 10 m observations.

The susceptibility of wind speed observations to the land surface conditions, particularly the positioning of instrumentation in the vicinity of domestic structures or vegetation and changes in instrumentation, has had some impact on surface wind speed observations limiting their suitability for long-term trend analysis. With these limitations in mind, we have used the CSIRO Conformal-Cubic Atmospheric Model to understand why particular wind speed trends are observed over the period 1979 to 2009 for Australia. A series of perturbed numerical experiments have been run to examine how the trends change as a result of changes in the large scale circulation or land surface characteristics. This has been extended to consider how wind speed trends will evolve under climate change.

We discuss the implications of current trends on wind energy by analyzing whether these factors have a substantial influence on modeled hub-height wind speeds. It is hypothesized that the decreasing trends observed in the 2 m observations are a result of vegetation growth and urbanization near observational sites. The 10 m observations are more likely to be influenced by changes in the large scale circulation as the effect of the surface roughness has a diminishing influence on wind speed with increasing height above ground level.

AN OPTIMISED NETWORK RENEWABLE ENERGY SYSTEM FOR AUSTRALIA

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As the penetration of renewable energy increases, a key question to ask is what is the ideal combination of the various technologies available. Technologies include generators such as wind turbines, solar photovoltaic panels, concentrating solar thermal, hydropower, coal or gas with capture and storage or geothermal, while demand side technologies include smart meters and time-of-day pricing, smart appliances and electrical vehicle fleets. The penetration of different technologies will impact on the cost of transmission and distribution, and the effect on energy prices, both wholesale and retail need to be considered.

We will present a prototype energy system model for Australia that uses NWP output to take into account the effect of short-term variability in weather on both supply from wind and solar power and also on demand. The model performs a network optimization to find the best mix and the geographic locations for wind and solar farms that maximize the resource quality, minimize the transmission costs while minimizing the need for fossil fuel powered backup.

Model results suggest that wind power will dominate the optimal solution, with hydro and gas fired backup, mainly because of the inability of solar power to meet the high overnight demand. However, if the current high overnight demand can be shifted to daytime, through removal of off-peak incentives and modifications to large-scale industrial processes, then solar power can be a more attractive option due to its load-following characteristics. On the other hand, the addition of medium (hours) to long-term (hours) storage either in batteries, molten salt or pumped hydro storage can shift the balance in favour of wind power through the dampening the variability. These results need to be viewed with caution as the economic impacts on the spot market have not yet been considered.

SYNOPTIC INFLUENCES ON LARGE-SCALE RENEWABLE ENERGY OUTPUT FOR AUSTRALIA.

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With increasing installation of renewable energy technologies across Australia the question as to whether or not technologies such as wind and solar are able to provide stable and reliable energy at large amounts of uptake is quickly becoming a question that needs addressing. To date, most of the research (often undertaken by the wind/solar farm operators themselves) has focused on the local conditions that affect single wind farms or solar stations. Yet the processes in the atmosphere that drive variability on the large-scale are quite different from those that drive the small scale and will determine the optimal mix and geographical placement of wind and solar farms to meet Australia's electrical energy needs. The current study uses the European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis data, ERA-Interim, for the period 1989-2009 to investigate the variability of the wind and solar fields over the Australian region. Various statistical techniques, including the Self Organising Map and Singular Value Decomposition, are applied to the raw wind and solar fields as well as to each fields' potential power output. The results identify specific spatial and temporal co-variances between the wind and solar fields and identify certain synoptic classes that are more (and less) favorable to large-scale energy production in the Australian region.

WIND FARM SITING TO IMPROVE WIND CONTRIBUTION IN A HIGH PENETRATION RENEWABLE ELECTRICITY SYSTEM

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The lead author has been investigating high penetration renewable electricity systems within the five states covered by the Australian National Electricity Market (NEM), and has identified low "reliable available capacity" from wind farms in the NEM. This is related to poor wind power availability during some high demand periods, which becomes an impediment to a more significant contribution from wind power. Most of the existing 2,000 MW of wind power in the NEM is located in South Australia, Victoria, and Tasmania, predominantly in the same wind regime. Hence, aggregate wind farm output can drop to very low levels. Increasing the reliable available capacity of wind generation can be achieved by using a fleet of more geographically diverse wind farms, sited in different and, potentially, less profitable wind regimes. This is in agreement with a smaller study carried out for Australia in 2003 (Davy and Coppin, 2003). Diversifying wind sites will reduce the requirement for more costly dispatchable generation of a high capacity.

Across the NEM coverage area, aggregate wind power has also been found to have weak correlation with aggregate electricity demand. In an electricity supply system with a high proportion of wind generation and limited storage options (eg. pumped storage hydro), the contribution of wind can be significantly improved if wind generation coincides with demand.

We report on the use of The Air Pollution Model (TAPM) software package to generate synthetic wind data for the year 2010 and the application of search techniques to find a set of sites within the NEM that produces the highest reliable available capacity. Sites are also assessed for their correlation with electricity demand, as this is likely to influence the proportion of wind capacity installed in different locations.

References

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Poster Presentations

11.1. THE POTENTIAL FOR TAPM TO BE USED AS A WIND ENERGY FORECASTING TOOL

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A greater proportion of the world's power generation is coming from wind energy. The available wind resource and the availability of that resource both play a crucial role in designing the supporting infrastructure needed for wind energy to be integrated within a nation's electricity market. Therefore, having the ability to predict when wind energy will be available to supply electricity to the consumer will facilitate the integration of wind energy into power systems.

This work assesses the potential of a mesoscale model called The Air Pollution Model (TAPM) to generate forecasts specifically for wind energy purposes. The case study for this assessment focuses on Studland Bay, stage 3 of the Woolnorth wind farm situated in Tasmania. TAPM is able to produce forecasts with user defined resolutions as small as 100m without the need for existing local wind data and only minimal computational resources to generate these forecasts.

Forecast simulations were run over a 15 month period and compared with recorded data from the wind farm site. Results presented will show the effect of varying the different input parameters on the accuracy of the forecast for different wind speed ranges. Different verification techniques were applied to analyse TAPM's ability to forecast the wind resource, specific meteorological systems and wind energy generation. Recent results show TAPM consistently under-predicts in all wind speed ranges, with larger forecast errors recorded for meteorological systems such as large high pressure systems and cold fronts.

Stream 12. Southern Ocean Processes

Conveners: Zanna Chase, Peter Strutton

Oral Presentations

IDENTIFYING THE CAUSES OF MODEL ERRORS IN SOUTHERN OCEAN CLOUDS: A REGIME-ORIENTED APPROACH APPLIED TO THE ACCESS MODEL

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The representation of clouds in weather and climate models remains one of the biggest challenges in atmospheric modelling. Clouds and the processes that generate and maintain them act on scales much smaller that model grid-boxes, requiring their inclusion into models by means of parametrization. In-situ cloud observations are sparse and much of our knowledge on the global distribution of clouds and their characteristics relies on satellite observations. Recent studies have highlighted the Southern Ocean as a region with particularly large and persistent errors in the radiative energy budget at the surface with errors common to almost all climate models. Models also show large errors in Sea Surface Temperatures in the same region. Both errors imply a potentially poor representation of Southern Ocean Clouds.

In previous work (Haynes et al., 2011) we have identified the key regimes of Southern Ocean cloudiness by combining observations from the International Satellite Cloud Climatology Project (ISCCP) and the recent CloudsSat and CALIPSO satellites using a regime identification technique previously developed for tropical clouds. In this presentation we will apply this regime identification methodology to the ACCESS model to demonstrate that the model errors over the Southern Ocean are largely caused in a small subset of the observed regimes. We demonstrate that the large model errors south of 55^{o}S are due to an inability of the model to simulate the key cloud regime in that region. We also show that the apparently small errors north of 55^{o}S are the result of large compensating errors in the model, highlighting "hidden" model problems and demonstrating the power of the diagnostic technique.

Reference

Haynes, J. M., C. Jakob, W. B. Rossow, G. Tselioudis, J. Brown, 2011: Major characteristics of Southern Ocean cloud regimes and their effects on the energy budget J. Clim., accepted 20 March 2011 .

SEA ICE VARIABILITY AND TRENDS IN THE WEDDELL SEA: A COMPREHENSIVE VIEW OF THE RELATIONSHIPS BETWEEN SEA ICE AND ITS DRIVING MECHANISMS OVER THE LAST 30 YEARS

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Sea ice concentration (SIC), the fraction of sea ice coverage per unit area, shows distinct regional trends and variability in the Weddell Sea. The magnitude and origin of local trends in sea ice coverage were 181avour181181 using the bootstrap algorithm SIC data from the National Snow and Ice data Center (NSIDC) for the period 1979 through 2006. SIC was compared with surface air temperatures (SAT) and wind speed obtained from the National Center for Environmental Predictions/ National Center for Atmospheric Research (NCEP/NCAR) to estimate the impact that these atmospheric parameters might have on SIC.

Generally, the observed variability of SIC at the Antarctic Peninsula is negatively related to changes in SAT and wind speed with local correlation coefficients of as much as -0.7. For the other parts of the Weddell Sea, the correlation between SIC and wind speeds is rather low. Additionally, the correlation between SIC and SAT is positive in the central Weddell Sea, which is somewhat counterintuitive. Furthermore, the correlations between SIC and atmospheric patterns such as the Southern Annular Mode (SAM) and the El Niño Southern Oscillation (ENSO) are rather low and not robust throughout the year.

To gain further insight into the relevant processes, we use results from ocean-sea ice hindcasts obtained for the Weddell Sea with the Finitie Element Sea Ice Ocean Model (FESOM).

TRACING DENSE CIRCUMPOLAR DEEP WATER IN THE SOUTH PACIFIC USING POTENTIAL VORTICITY AND ^{3}HE

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Using potential vorticity and other tracers we identify the pathways of the densest form of Circumpolar Deep Water in the South Pacific. We focus on the quasi-conservative potential vorticity signals associated with four major dynamical processes occurring in the vicinity of the Pacific-Antarctic Ridge: (1) the strong flow of the Antarctic Circumpolar Current (ACC); (2) eddy stirring; (3) upwelling of southward flowing Deep Waters, and (4) heat and stratification changes induced by hydrothermal vents.

It is found that the Lower Circumpolar Deep Water carries a potential vorticity minima signal (i.e., weak stratification) south of the ACC as it climbs the mid-ocean ridge crest. Interaction with the ridge and eddy stirring results in a large displacement of the signal southward along rising isopycnal surfaces. Using ^{3}He

released from the hydrothermal vents and the potential vorticity signals, we trace the influence of volcanic activity on Circumpolar Deep Water across the South Pacific along the ACC path to Drake Passage. This densest Circumpolar Deep Water also flows along the eastern flank of the Ross Gyre, reaching the Antarctic Slope in places, and contributes via entrainment to the formation of Antarctic Bottom Water. Finally, we show that the magnitude and location of the potential vorticity signals have endured over the last two decades, and that they are unique to the South Pacific region.

RECONCILING LAGRANGIAN AND EULERIAN ESTIMATES OF EDDY DIFFUSIVITIES

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Geostrophic eddies are a key mechanism for mixing tracers such as heat or carbon across the Southern Ocean. There is an ongoing debate on the magnitude of eddy mixing in the Southern Ocean. Estimates based on the dispersion of Lagrangian floats have found that eddy mixing is largest in the core of the Antarctic Circumpolar Current, whereas estimates based on satellite-derived surface geostrophic velocities showed a suppression in the core of the Antarctic Circumpolar Current and enhancement on its northern flank.

In this study we use a three-dimensional velocity field derived from satellite measurements of sea surface height together with equivalent-barotropic scaling arguments in the vertical to compare estimates estimates of eddy mixing from tracer release experiments and Lagrangian floats. We find the the two estimates converge if enough floats are deployed and the tracer is sampled at sufficient resolution. Eddy mixing is indeed suppressed in the core of the Antarctic Circumpolar Current from the surface down to 1500m, while it is enhanced on its flanks and at depth. Previous discrepancies found in the literature are the result of poor Lagrangian statistics, rather than any fundamental difference in the various approaches.

These results are then discussed in the context of the Diapycnal and Isopycnal Mixing Experiment in the Southern Ocean (DIMES). A major goal of DIMES is to estimate eddy mixing through releases of an anthropogenic tracer and 150 isopycnal RAFOS floats. Based on our numerical results, we will discuss how to analyze the data in order to obtain statistically robust estimates of eddy mixing. In particular we will focus on diagnostics for the lateral and vertical structure of eddy mixing which represent a key uncertainty in parameterizations of the effects of eddies in coarse-resolution ocean models used in climate studies.

INTERANNUAL SHIFTS OF THE DYNAMICAL REGIME OF THE SOUTHERN OCEAN IN RESPONSE TO CLIMATIC MODES

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Understanding the dynamical regimes of the Southern Ocean and their variations is critical to predicting future climate changes. As stable zonal jets of the Antarctic Circumpolar current (ACC) act as barriers to meridional transport, unsteady jet behavior contributes to poleward heat flux to balance the heat lost by the ocean to the atmosphere at high southern latitudes. The mesoscale activity plays then a central role in the thermal balance in the SO. Its relationship with climatic modes could then impact on the thermal content and heat transport in the SO.

Because of conflicting theories, the different mechanisms which set the regimes of the Southern Ocean are under debate. This paper assesses the interannual relationship between wind forcing (including wind stress and wind stress curl), the mesoscale eddy field and the Antarctic Circumpolar Current (ACC) transport. We use a global eddy-permitting model integrated over two decades and show that during this period the Southern Ocean oscillates between different dynamical regimes on interannual timescale: an “eddy saturation” like regime and an “acceleration” like regime. Depending on the local wind stress curl in the Western South Atlantic, the enhanced input of energy from strengthened wind can be either released through mesoscale activity (eddy saturation regime) or used to accelerate the mean flow (wind curl acceleration regime). While the Southern Annular Mode (SAM) describes the strength of the circumpolar zonal wind stress, the local wind stress curl appears to be controlled by the relationship between the two climatic mode SAM and ENSO (El Nino Southern Oscillation).

THE PARADOX OF SOUTHERN OCEAN UPWELLING IN AMPLIFYING AND DELAYING THE ONSET OF OCEAN ACIDIFICATION

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Antarctic coastal waters have an abundance of marine organisms that secrete the mineral aragonite for growth and survival. Increasing oceanic anthropogenic CO_2 uptake will push these waters to a point whereby aragonite will start to geochemically corrode, with direct consequences for the Antarctic ecosystem. Although upwelling of naturally corrosive waters seemingly amplifies the onset of these conditions in the Southern Ocean, I show here through data and application of regional biogeochemical model that upwelling also delays the onset of ocean acidification by pushing surface waters further out of equilibrium with the atmosphere. I discuss these implications for Southern Ocean acidification.

FIRST STEPS TOWARDS DETERMINATION OF THE SOUTHERN OCEAN AIR-SEA HEAT EXCHANGE: EVALUATING FLUX DATASETS USING THE SOFS MOORING

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Air-sea heat exchange in the Southern Ocean is a poorly determined variable that is critical for a better understanding of ocean-atmosphere dynamics in this region and its role within the wider climate system. Here, we present a first step towards accurate more determination of the Southern Ocean net air-sea heat flux, and its components, using measurements from the Integrated Marine Observing System (IMOS) Southern Ocean Flux Station (SOFS) Mooring to evaluate a range of air-sea flux datasets. The mooring was deployed at 46.75 ^{o}S, 142 ^{o}E from March 2010-March 2011 and collected high quality flux measurements throughout this period. These measurements have been used to evaluate fluxes from the NCEP/NCAR reanalysis. The two main terms are the latent heat loss and the shortwave gain. NCEP/NCAR persistently overestimates the amount of latent heat loss from the ocean by greater than 20 Wm^{-2} in the monthly mean. For the shortwave, NCEP/NCAR underestimates the amount of heat gained by up to 30 Wm^{-2} with the largest differences in the Austral summer. The combination of excess latent heat loss and insufficient shortwave gain results in monthly mean net heat flux values from NCEP/NCAR that are typically 20-40 Wm^{-2} smaller than SOFS from October 2010 though February 2011. Thus, the NCEP/NCAR heat exchange fields are significantly biased and further results will be presented on the underlying mechanisms responsible for these biases. In addition, we will show results of an ongoing evaluation of the Woods Hole Oceanographic Institution OAFLUX dataset and the Bureau of Meteorology operational global numerical weather prediction model ACCESS-G. Finally, the results will be put in the context of the wider air-sea heat exchange field for the Southern Ocean.

ON THE NON-EQUIVALENT BAROTROPIC STRUCTURE OF THE ANTARCTIC CIRCUMPOLAR CURRENT

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The Antarctic Circumpolar Current (ACC) has been traditionally considered an "equivalent barotropic" current, where the direction of flow does not change with depth. This paradigm for the ACC's behaviour was proposed by Killworth (1992) on observing the high correlation between eastward velocities at different depths in a 6-year mean of the FRAM simulation. High vertical coherence of horizontal velocity is also seen in direct current meter measurements. The equivalent barotropic idea motivated simplified models of the ACC, and allowed the development of Gravest Empirical Mode (GEM) climatologies of the Southern Ocean. However, if we allow no rotation of the flow with depth, then vertical motion is confined to be small or non-existent, and important dynamical interactions achieved by vertical modes higher than the barotropic and first baroclinic are ignored. The equivalent-barotropic idea has proven very insightful but there is much more to the story of the ACC.

Strong rotation of horizontal velocity vectors with depth is clearly seen in new high-vertical-resolution direct measurements of ACC velocity profiles from EM-APEX floats at the northern Kerguelen Plateau. Rotation with depth is particularly enhanced in profiles around a large cyclonic meander to the northeast of Kerguelen. Vertical velocities estimated from the conservation of mass equation are large (up to 100 m/day).

We describe the distribution of flow rotation and diagnosed vertical velocity across the northern Kerguelen Plateau, and examine their variability in the context of curvature of the flow, slope of the density field, and location of the ACC fronts. Recent work (Zika et al 2011) suggests that the eddy contribution to the Meridional Overturning Circulation (MOC) is achieved by transient (standing) eddies contributing the vertical (meridional) exchange. We endeavour to examine our observational snapshot of an ACC eddy in the context of this idea inspired by an eddy-resolving numerical model.

Killworth, P. D., An equivalent-barotropic mode in the Fine Resolution Antarctic Model, J. Phys. Oceanogr., 22, 1379–1387, 1992.

Zika, J. D. et al., Cancellation of the Deacon Cell by Vertical Eddy Fluxes, J. Phys. Oceanogr., submitted, 2011.

INTERPLAY BETWEEN THE ZONAL MOMENTUM BALANCE AND OVERTURNING IN THE SOUTHERN OCEAN

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Understanding the response of the Southern Ocean overturning circulation to changes in wind stress is pivotal to projecting the future of the Southern Ocean CO_2 sink and developing theories of glacial-interglacial outgassing. Wind stress is thought to drive both the zonal Antarctic Circumpolar Current (ACC) and the meridional overturning, yet high resolution models indicate that mesoscale eddies reduce the sensitivity of the circulations to wind stress changes. The mechanisms by which the eddy field limits the response of the circulation, and the link between the sensitivity of the ACC and the sensitivity of the overturning remain unclear. We apply a layer-wise momentum balance analysis in an isopycnal framework to a suite of simulations with resolution varying from coarse to 1/16° eddy resolving in an idealised domain. We find that the responses of the ACC and overturning circulation to wind stress perturbations, and the extent to which they are linked, depend upon both the eddy field and the timescale being considered.

A NEW CONCEPTUAL MODEL FOR THE ANTARCTIC CIRCUMPOLAR CURRENT (AND THE GLOBAL OCEAN OVERTURNING)

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The Antarctic Circumpolar Current (ACC) is the strongest ocean current on the planet, yet there is no real consensus on the factors that control its transport or sensitivity to change.

We will outline a new conceptual model for the ACC, including predictions for the relative influence of surface buoyancy forcing and wind stress forcing upon the current. As a by-product, the model also yields scaling predictions for the strength of the ocean overturning circulation in both hemispheres.

The model is tested against an idealised, eddy-permitting simulation of an Atlantic-sized ocean basin. The simulations both support model scaling and provide additional evidence for the coupled nature of surface wind and buoyancy forcing in governing the global ocean overturning and the ACC.

THE ROLE OF SOUTHERN OCEAN GATEWAYS IN CONTROLLING GLOBAL CLIMATE

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The role of Southern Ocean gateways in controlling regional and global climate is examined in a set of coupled ocean-atmosphere-ice experiments. This involves exploring model simulations employing different geometries in the Drake Passage gap and also in the Tasman Seaway. A profound climate response to the opening of a Drake Passage is obtained, with significant cooling over Antarctica once a Southern Ocean gateway is established. This is mainly due to a large reduction in poleward heat transport in response to changes in the ocean overturning circulation; in particular, the modern day ocean geometry admits only limited abyssal water-mass formation around Antarctica, despite this region having by far the densest of all global surface waters. The depth of the Southern Ocean gateway also plays a critical role in controlling the scale of the response; with North Atlantic Deep Water only overturning at modern-day formation rates once a sufficiently deep Southern Ocean gateway exists.

Other parameters that affect the climate sensitivity to Southern Ocean gateway changes include the rate of poleward atmospheric moisture transport in the Southern Hemisphere, and also the concentration of greenhouse gases in the atmosphere. We find in particular that when atmospheric CO2 concentrations are high, there is a much greater sensitivity of Antarctic temperatures to Southern Ocean gateway changes. For high enough levels of atmospheric CO_2, the conditions for Antarctic ice-sheet formation are only reached once a deep Southern Ocean gateway has been established. The presence of a Drake Passage gap inhibits a return to warmer and more Eocene-like Antarctic and deep ocean conditions, even under enhanced atmospheric greenhouse gas concentrations. This could have significant implications for Antarctic climate change at the Eocene/ Oligocene boundary.

For relevant papers and further information, go to http://web.science.unsw.edu.au/~matthew/

Poster Presentations

12.1. A CLIMATOLOGY OF THE LOW-ELEVATION CLOUDS OVER THE SOUTHERN OCEAN USING A MERGED A-TRAIN DATA PRODUCT (THE DARDAR MASK)

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Trenberth and Fasullo (2010) observed, "disproportionately large biases exist in both the reanalysis and global coupled models" over the Southern Ocean (SO), which are "directly linked to the simulation of clouds in this region." Moreover they found a "remarkably strong relationship between the projected changes in clouds/climate and the simulated current-day cloud error."

A four-year (2006-2009) climatology of the thermodynamic phase of the clouds over the SO (40-65°S, 100-160°E) has been constructed with the A-Train merged data product, DARDAR_MASK. Low-elevation clouds (cloud-tops below 1km) with very little seasonal cycle dominate this climatology. Such clouds are problematic for the DARDAR_MASK due to its dependence on the Cloud Profiling Radar (CPR) of CloudSat, which is unable to distinguish returns from the lowest kilometer due to the bright surface. It is further limited as these clouds are predominantly in the temperature from freezing to -20° C, where the thermodynamic phase can only be observed at cloud-top by the CALIOP lidar on CALIPSO.

A cloud-top phase climatology comparison has been made between CALIPSO, the DARDAR_MASK and MODIS. All products highlight the extensive presence of supercooled liquid water over the SO, particularly during summer. The DARDAR_MASK recorded substantially more ice at cloud-top as well as mixed phase in the low-elevation cloud tops. It was further observed that the lidar signal from CALIPSO was sensitive to the overlying cirrus, and this effect similarly filtered through to the DARDAR_MASK.

Moving beyond the cloud-top, the DARDAR_MASK finds ice to be dominant at heights greater than 1km. Below this height, the uncertain class is dominant as there is no CPR signal and the lidar signal is commonly attenuated.

This study further highlights the enormous challenge that remains in better defining the energy and water budget over the SO.

12.2. THREE DIMENSIONAL DISTRIBUTION OF CLOUDS AROUND SOUTHERN HEMISPHERE EXTRATROPICAL CYCLONES

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The organization and, for the first time, the three dimensional structure of clouds associated with the Southern Hemisphere extratropical cyclones are studied using active observations from the CLOUDSAT and CALIPSO satellites. First, a composite cyclone is constructed from more than 800 individual cases using the cyclone centre as the composite reference point. It is shown that the three-dimensional cloud distribution around the composite cyclone captures well known features of conceptual models of extratropical cyclones with thick high top clouds in the frontal region and low clouds of varying depth behind the system.

Composites mean fields of mean sea level pressure, vertical motion, potential temperature and relative humidity are superposed on the composite three-dimensional cloud structure to better understand the relationship of clouds with the dynamical properties of extratropical cyclones. Cold air sinking to the west of the cyclone centre gives rise to low top clouds in that region while warm rising air to the east of the cyclone centre is associated with deep frontal clouds. The region of divergence is characterized by the absence of thick and high clouds. Further, cyclones are partitioned and compared according to their intensity and different stages of life cycle.

The methodology used here illuminates the relationship between dynamical and cloud processes in full three dimensions around cyclones and will also provide the foundation for an in-depth evaluation of climate models' ability in simulating the cloud and dynamical structures of the Southern Hemisphere extratropical cyclones.

12.3. WIND SHEAR AND THE SOUTHERN OCEAN BUFFER LAYER

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The Southern Ocean is a remote area, with the overlying atmosphere being unique and largely ignored by the meteorology community. There is a growing body of evidence that suggests the clouds over the Southern Ocean are poorly understood, and poorly represented in climate models[2]. The focus of this study is on the structure and dynamics of the lower atmosphere over the Southern Ocean.

Sounding data from Macquarie Island were analysed to determine the thermodynamic structure of the boundary layer, and statistics for cloud amount, cloud vertical structure and wind shear at cloud interfaces. The mean and variance of a number of thermodynamic variables was computed and compared to ECMWF ERA-Interim re-analysis data. ERA underestimated temperature over all levels by up to 3 degrees, compared to the soundings, and significantly underestimates wind shear over all levels.

High resolution soundings from were used to determine the structure of the lower atmosphere over Macquarie Island. It was found that the well mixed boundary layer extends up to approximately 800 m, and an additional 'Buffer Layer', defined by wind shear, occurs in about 30% of soundings, extending up to 1700 m. Interestingly, Ekman Spirals are observed in a significant number of the high resolution soundings. These results were compared to two years of model level data from the ERA-Interim re-analysis. It is found that the higher resolution re-analysis does not capture the boundary layer/buffer layer structure, and Ekman Spirals are not observed with the same frequency.

[2] Simulation of Present-Day and Twenty-First-Century Energy Budgets of the Southern Oceans. K. E. Trenberth, J. T. Fasullo, JOURNAL OF CLIMATE, VOL 23, DOI: 10.1175/2009JCLI3152.1

12.4. CRITICAL CONCERNS AND LATITUDES: TIDAL EFFECTS ON ICE SHELVES OF THE AMUNDSEN SEA

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Ice shelves in the Amundsen Sea are melting orders of magnitude faster than other Antarctic ice shelves and the melting is ocean driven. The circulation in the ocean cavity below the ice shelf is primarily density driven and controlled by the topography of the cavity; however, tides play a role in the circulation and their role can be quite complex. To examine the role of tides in the circulation under the ice shelves Amundsen Sea, the Regional Ocean Model System (ROMS) was used to simulate circulation and mixing for the individual ice shelves and for the entire sea.

Tidal influence varied widely and was highly dependent on the position of the M_2 semidiurnal critical latitude with respect to the ice shelf front and/or grounding line. Ice shelves located equatorward of the critical latitude experienced an increase in melting of 3 m/yr attributable to tides compared to those poleward of the critical latitude. Mean currents had the capacity to shift the critical latitude by up to 5^o essentially modifying it to an effective critical latitude, further complicating the dynamics. Along with the increase in melting, there was a corresponding increase in the baroclinicity of the velocity fields and an increase in mixing for ice shelves equatorward of the critical latitude or effective critical latitude when a mean circulation was present. This has implications for other ice shelves near the critical latitude, including the Larsen C and ice shelves of the Antarctic peninsula.

12.5. RECENT PROGRESS ON THE TRACER CONTOUR INVERSE METHOD

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To understand the Meridional Overturning Circulation (MOC), a detailed global understanding of the diffusive and advective processes that contribute to the modification of water masses and the MOC is needed. The vertical mixing coefficient, D, and along-isopycnal mixing coefficient, K, is thought to strongly control the MOC and climate sensitivity.

Inverse methods are tools used to diagnose the ocean circulation from hydrographic data. Inverse box models simultaneously solve a set of equations for various unknowns, including reference level velocities and diapycnal fluxes of properties or the vertical mixing coefficient D. Box inversions are always underdetermined, and the final solution often depends sensitively on the choice of reference level. Inverse models have so far, been unable to resolve the spatial structure of D and K.

Zika et al (2010) has establish a overdetermined Tracer-Contour Inverse Method (TCIM) that is less sensitive to error than existing methods and has the potential to resolve the magnitude and vertical distribution of D, K, and the geostrophic flow directly from hydrographic data. In the TCIM, a geostrophic stream function is defined that is related on isopycnals by tracer contours (of absolute Salinity and conservative temperature) and by the thermal wind relationship in the vertical, and include volume and tracer conservation constraints.

Recent progress on the TCIM now allow for multiple 'communicating' boxes. This, and replacing K with simply the isopycnal heat flux (from which K can be determined), is expected to increase accuracy of the TCIM and finally allow for a 'global inversion' resulting in a global spatial distribution of K, D and the geostrophic flow.

References

Zika JD, McDougall TJ, Sloyan BM (2010) A tracer-contour in- verse method for estimating ocean circulation and mixing. Journal of Physical Oceanography 40(1):26–47

12.6. RAPID VARIABILITY OF OCEANIC JETS DRIVEN BY EDDY-TOPOGRAPHY INTERACTION, WITH APPLICATION TO THE SOUTHERN OCEAN FRONTAL VARIABILITY

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The general circulation of the Southern Ocean is composed of a series of strong, eastwards jets, or ‘fronts’. These jets are transient, undergoing changes in both strength and latitudinal position. However, these jets show a particular, quasi-stable feature: they are `pinned’ to large, subsurface topographic features. For example, jets may deviate from a purely zonal path to detour around a sub-surface plateau. In these regions, jets show little of the time variability observed in regions without such topography. Similar features have been observed in other ocean basins.

However, recent observations have indicated strong variability of jets in the vicinity of these features. Two (or more) jets that pass near the same topographic feature display anti-correlated 190avour190190g, where one jet will increase in strength at the expense of others. This variability can manifest itself in dramatic ways, with a particular jet changing ``preference” for a topographic feature. A jet that previously skirted a plateau to the north, can very rapidly shift to skirt the plateau to the south. Shifts in the latitudinal position of jets of more than 10° have been observed.

We will present a theory explaining this 190avour190190g, built on the results of an idealized numerical model. This theory is an extension of the dynamical theory of annual modes, used to explain the vacillation of jets in the mid-latitude atmosphere (giving rise to the Southern Annular Mode phenomena). We posit that it is the interaction of turbulent eddies and topographically driven flow in the abyssal layers that explains the observed variation in mean currents observed at the surface and middle layers. The feedback of eddy – mean flow will also be discussed.

12.7. PHYSICAL AND BIOLOGICAL RESPONSE OF THE SOUTHERN OCEAN TO THE SOUTHERN ANNULAR MODE: 1997 TO 2011

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The Southern Annular Mode (SAM) is the dominant mode of climate variability in the southern hemisphere. In recent decades, its mostly positive phase has been associated with a strengthening and southerly migration of the westerly winds over the Southern Ocean. These winds drive the large-scale overturning circulation and therefore modulate vertical fluxes of nutrients and dissolved inorganic carbon, which fuel Southern Ocean productivity. The satellite ocean color data record is now long enough (1997 to present) to document circumpolar and regional trends in surface ocean productivity, in response to the SAM. This presentation documents interannual and spatial variability in sea surface temperature, winds, mixed layer depths and surface chlorophyll as a function of the SAM. While this presentation is focused on physics and productivity, the ultimate goal of this work is to understand the air-sea carbon dioxide flux for the Southern Ocean, and develop a predictive capability for the future.

12.8. BIOGENIC FLUX ALONG THE SOUTHERN CHILEAN MARGIN OVER THE PAST 30,000 YEARS: IMPLICATIONS FOR SOUTHERN OCEAN PROCESSES

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Biogenic particle flux was reconstructed using the Thorium-230 normalisation technique at two sites on the southern Chile margin. ODP Site 1233 at 41°S, 838 m depth is at the southern limit of the Peru-Chile upwelling system, where the northern extent of the Antarctic Circumpolar Current (ACC) impinges on the South American continent. ODP Site 1234, at 36°S, 1014 m depth, is located within the core of the coastal upwelling system. At 41°S, maximum organic carbon, opal and carbonate fluxes over the last 30 ka occurred during the last glacial period (26-20 ka). At 36°S, the pattern is very similar, except a second, larger maximum in organic carbon flux is observed during the late Holocene (~5 ka), withiout an accompanying peak in opal flux. These reconstructed fluxes at 36°S and 41°S fit within a larger latitudinal pattern of a poleward increase in the magnitude of opal flux during the glacial period. A similar gradient is observed in the magnitude of lithogenic flux.

The pattern of reconstructed productivity is consistent with several mechanisms, including: i) a more northerly position of the ACC during the last glacial period, bringing the core of high-nutrient waters to 41°S; ii) enhanced supply of Si from the Southern Ocean, as proposed by the Silicic Acid Leakage Hypothesis. And iii) enhanced macro or micro-nutrient delivery from land, driven by glaciation in the south. The pattern of reconstructed productivity also confirms that the less reducing conditions during the glacial interval, inferred from authigenic metal accumulation, were driven by increased ventilation by Antarctic Intermediate Water, rather than by increases in local productivity.

Stream 13. Storm Track Variability and Changes

Convener: Joe Kidston

Oral Presentations

UNDERSTANDING FUTURE CHANGES IN THE SOUTHERN HEMISPHERE EXTRATROPICAL CIRCULATION USING PERTURBATION EXPERIMENTS

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Future anthropogenic climate change in the extratropics of the Southern Hemisphere is likely to be driven by two opposing effects, stratospheric ozone recovery and increasing greenhouse gases. Poleward shifts in the extratropical storm tracks and positive trends in the Southern Annular Mode (SAM) are projected in almost all climate models under increasing CO_2. Ozone recovery, on the other hand, is expected to lead to a reversal in the SAM response in austral summer. The relative importance of each forcing to summer projections of the SAM varies across model experiments, with multimodel analyses suggesting close to equal contributions from both, although there is a large range across the models in the magnitude of their SAM response. To what extent this range is due to processes in the tropics or the extratropics in the models is examined with perturbation experiments in those regions. We contrast the response of two models – the National Center for Atmospheric Research Community Atmospheric Model Version 4 (NCAR CAM4) and the Australian Community Climate and Earth System Science (ACCESS) model – to perturbations in sea surface temperatures and atmospheric heating, finding the models to be quite different in their responses. Understanding the mechanisms behind projected changes, and the sensitivity to changes in those mechanisms, is essential to increasing our confidence in predictions of future climate change.

CHANGES AND PROJECTIONS IN THE ANNUAL CYCLE OF SOUTHERN HEMISPHERE BAROCLINICITY FOR STORM FORMATION

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Recent studies have shown that over the last sixty years, there have been dramatic changes in the properties of mid-latitude winter storms which have impacted on southern Australian winter rainfall. In particular, there have been large reductions and negative trends in rainfall over this period, associated with similar reductions in the growth rates of storm track modes and a preference for some storms to develop further south of the

Australian continent. These changes in the properties of mid-latitude storms have been shown to be associated with major shifts in the Southern Hemisphere winter circulation over this period. In particular, there have been significant negative trends in the baroclinic instability of the mid-latitude atmospheric circulation resulting in a reduction in storm formation at these latitudes, while increases in baroclinicity further poleward has led to increased storm development.

In this paper, we consider the observed changes in baroclinicity of the Southern Hemisphere circulation in all months. We employ the Phillips criterion as a useful diagnostic of storm development related to baroclinic instability. The relationship between changes in the Phillips criterion and implied hemispheric changes in storm formation and rainfall in all months during the twentieth century is discussed. We find that there are significant negative trends in baroclinicity at mid-latitudes in all months which imply a reduction in storm formation and rainfall at these latitudes. Further poleward, we find significant positive trends associated with increased cyclogenesis and rainfall, in all months.

Projected changes in baroclinicity in SRESA1B and SRESA2 scenarios for the period 2001 to 2099 show similar patterns of negative and positive trends in the mid-latitudes and high latitudes to those observed and simulated in the twentieth century. Consistent with this result, the projections show hemispheric reductions in rainfall in a band between 10S and 40S and increases further south.

ATTRIBUTION AND PROJECTIONS OF CHANGES IN SOUTHERN HEMISPHERE STORM TRACKS

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Attributing the causes of observed climate change to a variety of physical and dynamical processes is a problem of great contemporary significance in climate science. In the southern hemisphere there have been dramatic changes in the circulation and associated storm tracks during the second half of the 20th century, particularly in the winter and autumn. Understanding the extent to which these changes are due to internal variability and the extent to which a systematic shift in the climate and rainfall is occurring due to increasing anthropogenic greenhouse gases is of major scientific and policy concern.

In this study, a new method is developed and applied for attributing changes in climate states by calculating the anomalous forcing functions responsible for these changes. The method is motivated by recent advances in the statistical dynamics of climate states. We apply the method to climates obtained from the statistics of direct numerical simulations of atmospheric circulations during the second half of the 20th century. The anomalous forcing functions responsible for dramatic changes in the southern hemisphere climate, including changes to storm tracks, since the mid-1970s are calculated using the new method. We demonstrate that the forcing functions obtained by this method are in very good agreement with the forcing functions used in simulations of observed climate states during the 20th century. The anomalous forcing functions are consistent with a superposition of global and localised heating patterns. The implications of our results are discussed.

In climate change projections a major issue is again disentanglement of the causes of inter-annual and decadal variability and anthropogenic climate change. Here we consider projected changes and trends in circulation and storm tacks in different emissions scenarios using results from general circulation models. We elucidate the roles of anthropogenic forcing and internal variability. We find that increases in anthropogenic greenhouse gas concentration under the emissions scenarios can lead to further large changes

in southern hemisphere circulation, with reductions in winter storm formation and rainfall over southern Australia, by the middle and end of the 21st century.

INTERACTION BETWEEN THE HADLEY CELL AND THE EDDY-DRIVEN JET

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The dynamical interaction between the Hadley cell and the mid-latitude eddy-driven jet is investigated using an idealised moist primitive equation model with grey radiation. Recent studies have shown that in the real atmosphere and in GCMs, the unforced variability of these two features are correlated only in the Southern Hemisphere during summer. Here we show that the degree of interaction is determined by the time-mean separation between the two features, and moreover whether there are one or two upper level jet streams. When the eddy-driven jet is well separated from the thermally-driven jet, the correlation disappears. When the two jets are coincident, the two features move in tandem.

When the two jets are in a correlated state, the changes in the thermally-driven jet precede those of the eddy-driven jet. Moreover, when the jets are separated and independent, the eddy dynamics controlling the edge of the Haddley cell do not appear to alter. The picture that arises is of the Hadley cell variability being relatively insensitive to the mean-state, and when the two features happen to be close together, the eddy-driven is affected by Hadley cell variability.

Poster Presentations

13.1. TO WHAT EXTENT ARE CYCLONES ASSOCIATED WITH CLIMATE ANOMALIES IN HIGH NORTHERN LATITUDES?

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Extratropical cyclones are known to be important factors in determining weather and climate. In this study we focused on the role of cyclones in the latest climate anomalies in Arctic region. September 2007 and 2011 have shown dramatic reduction in Arctic sea ice extent (SIE). Screen et al. (2011) found strong relationships between the extreme year-to-year changes in September sea ice extent (SIE) and the number of cyclones in the preceding late spring and early summer. The September 2011 sea ice extent almost broke the lowest record set in 2007; this extreme year presents us with the opportunity to test our hypotheses on independent data.

For the analyses of cyclone activity we applied a tracking algorithm developed in the University of Melbourne. In this study we used the MERRA reanalysis SLP for the identification and tracking of synoptic features. MERRA is much more comparable to the station data than the previous generations reanalyses and is more reliable for research in high latitudes.

The findings reinforce the previous suggestions that perennial Arctic sea ice anomalies are closely associated with the synoptic activity in the Arctic basin during the preceding months. In contrast to earlier research we found that there is no relationship between late spring cyclone characteristic and the minimum of SIE during the melting season. The strongest associations have been found between the SIE and the mean size of the storms propagating in the Arctic, while their depth and total number are of less importance.

Screen, J. A., I. Simmonds, and K. Keay (2011), Dramatic interannual changes of perennial Arctic sea ice linked to abnormal summer storm activity, *J. Geophys. Res.*, **116**, D15105, doi:10.1029/2011JD015847.

13.2. CHANGES IN SOUTHERN HEMISPHERE JET-STREAMS AND WEATHER SYSTEMS

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During the last sixty years there have been large changes in the seasonal cycle of Southern Hemisphere circulation, jet-streams and reductions in rainfall particularly in the southern Australian region. Here we examine the corresponding changes in dynamical modes of variability during the annual cycle focusing on the mid-latitude storm track modes. We also discuss and 195avour195 more briefly changes in other modes including onset of blocking modes and northwest cloud-band disturbances during southern winter. We employ a global two-level primitive equation instability-model and here we examine changes, during the periods 1949-1968, 1975-1994 and 1997-2006, in atmospheric modes of variability growing on 195avour195195g195 observed three-dimensional basic states in the four seasons.

We relate the reduction in the rainfall in the southwest of Western Australia since the mid-1970s and in South-eastern Australia since the mid-1990s to changes in growth rate and structures of leading storm track and blocking modes. We find that cyclogenesis modes growing on the subtropical jet have significantly reduced growth rates in the latter periods. As well there is a reduction of the intensity of the subtropical storm track and increase in the polar storm track particularly in autumn and spring. On the other hand during winter there is a significant increase in the growth rate of northwest cloud-band modes and that cross Australia.

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13.3. OBJECTIVE METHODS OF FRONTAL RECOGNITION – A CASE STUDY IN SOUTH WESTERN AUSTRALIA

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The early focus of the objective identification of fronts was weather forecasting applications (Hewson, 1998). Recently, two objective methods that can be applied to reanalyses and climate model outputs have been developed for use in climate studies (Berry et al, 2011; Simmonds et al., 2011). It is instructive to explore the value of a comparative set of related techniques in climatological studies.

In Australia the southern coastal regions are all impacted by frontal systems stemming from the westerlies. In the southwest of Western Australia (SWWA), these types of systems bring a large proportion of high rainfall events to the region (Pook et al., 2011). SWWA is also sensitive to spatial shifts in the extent of frontal systems as fronts only impact significantly up to about 400km inland. Thus SWWA serves as an excellent location to examine the ability to objectively capture frontal systems and examine their changing climatology through time, both historical and for future scenarios. Fronts were identified within a region spanning 25°S-40°S, 105°E-125°E.

The five different methods considered in this study employ a range of measures to capture the front. Two identify specific fronts, one identifies regions where a front is likely to form and two identify key patterns that match frontal characteristics in the region (Hope et al., 2006). A baseline series of fronts were identified using Bureau of Meteorology's daily weather charts where fronts are manually drawn following a synoptician's guidelines and information from satellites and models. Each rain day during June and July over 1979-2006 for each method was analysed. The different methods did not necessarily identify a front on the same day. This result highlights that different methods have different strengths and possibly can be applied to different research questions about how fronts change over time.

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13.4. USING A SELF-ORGANISING MAP TO CAPTURE THE RANGE OF CURRENT AND FUTURE WEATHER SYSTEMS

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Australia's south-west is highly sensitive to spatial shifts in the storms that bring rainfall to the region. This sensitivity is demonstrated by the seasonal transition from summer, when few storms impact upon the region, to winter when the rainfall has historically been reliable and plentiful. In the late 1960s the south-west experienced a downturn in rainfall, with further drying since 2000 and its driest year on record in 2010. The types, number and rain-bearing properties of the weather systems that impact the region vary through time and illustrate the rainfall changes well. In the late 1960s there was a significant decline in the daily occurrence of deep low-pressure systems (Hope et al., 2006) and since 2000 there has been a marked increase in the daily occurrence of high pressure systems (Hope and Ganter, 2010). These changes imply different forcing behind the two periods of decline, with the latter more closely aligned with the fingerprint of greenhouse-gas induced warming.

Future projections show a strong rainfall decline in the south-west. However, it can be expected that the future global climate will not necessarily resemble a direct analogue from the past. In order to explore the range of weather systems associated with the projected rainfall decrease the full range of future systems must be considered. A new technique using a large self-organising map (SOM) (Skific et al., 2009) incorporates information from the future climate itself into the production of the range of synoptic types. Thus it may be that the weather systems in the current climate will be represented by one part of the SOM while the climate of the future might be characterised by a range of different types. The full range of weather types encompassing both current and future conditions will be presented and the shifts through time will be discussed.

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13.5. AN ASYMMETRY WITHIN THE IOD AND ENSO TELECONNECTION PATHWAY TO SOUTHEAST AUSTRALIAN RAINFALL

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The climatic impact from El Niño-Southern Oscillation (ENSO) on southeast Australia in austral spring (September to November) has been shown to be conducted via the tropical Indian Ocean (TIO) (Cai et al. (2011). This study was undertaken assuming linearity between the positive and negative phases of ENSO and the Indian Ocean Dipole (IOD). However, it is shown that a strong asymmetry exists within this teleconnection depending on the phase of the ENSO and the IOD. The asymmetry is mainly driven through the IOD, where a greater convection anomaly and wavetrain response occurs during positive IOD (pIOD) events than during negative IOD (nIOD) events. This is linked with an asymmetry in the ENSO-IOD relationship, with El Niño-pIOD events being far more coherent than La Niña-nIOD events. The inherent positive skewness of the IOD helps drive this "impact asymmetry," mainly due to the sea surface temperature (SST) skewness towards negative anomalies in the east IOD (IODE) pole. A greater decrease in convection is observed for negative SST anomalies in the IODE region when compared to an increase in convection associated with similar positive SST anomalies. This result suggests there is a greater damping on the negative SST anomalies and implies the skewness occurs in spite of the greater damping, rather than due to its breakdown, which is at odds with previous studies. This impact asymmetry could provide a reason for the reduction in spring rainfall over southeast Australia during the 2000s. Increased occurrences of El Niño and pIOD events during this time, provides a greater reduction in rainfall than the lack of large rainfall events due to fewer nIOD events.

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Stream 14. The Climate of the Last 2,000 Years: Bridging the Gap Between the Past and the Future

Conveners: Joelle Gergis, Helen McGregor, Steven Phipps

Oral Presentations

HOW WELL DO CIMATE MODELS PERFORM? EVALUATION USING PALAEOCLIMATE DATA

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Evaluation against observed changes in the geologic past provides an opportunity to evaluate how well models that are used to project future climates reproduce large climate changes. Three palaeoclimate simulations are included in the current round of the Coupled Modelling Intercomparison Project (CMIP5) and evaluation of these simulations will feed into the next Intergovernmental Panel on Climate Change (IPCC) Assessment exercise. These three simulations are for the Last Glacial Maximum (21,000 years ago), the Mid-Holocene (6000 years ago) and the Last Millennium (850-1850 AD). The Palaeoclimate Modelling Intercomparison Project (PMIP) has assembled benchmark data sets, including quantitative climate reconstructions, and data on carbon cycle and land-surface hydrology, for palaeo-evaluation. Model evaluations using these data show that whereas current models are able to reproduce first-order patterns of climate change, they still underestimate the magnitude of changes in many regions and represent land-surface feedbacks inadequately.

EVIDENCE OF RAPID LATE 20TH CENTURY WARMING FROM AN AUSTRALASIAN TEMPERATURE RECONSTRUCTION SPANNING THE LAST MILLENNIUM

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We present the first multi-proxy warm season (September–February) temperature reconstruction for the combined land and oceanic region of Australasia (0ºS–50ºS, 110ºE–180ºE). We perform an ensemble

Principal Component Reconstruction (PCR) using 28 temperature proxies from the region. The proxy network yielded a correlation coefficient of r= 0.83 with the HadCRUT3v SONDJF spatial mean temperature over 1921–1990 period; explaining 69% of inter-annual variance in the calibration interval.

Applying eight stringent reconstruction 'reliability' metrics identified the post A.D. 1430 as the highest quality section of the reconstruction, but also revealed a skilful reconstruction is possible over the A.D. 1000–2001 period, with reduced reliability due to fewer, but internally well-replicated records available between A.D. 1000–1429.

The reconstruction provides evidence of 'Medieval Climate Anomaly' warming in Australasia around A.D. 1240–1330, somewhat later than maximum medieval warmth described from many Northern Hemisphere regions. From the results presented here, the average temperature anomaly in the Australasian region for the warmest 30-year medieval period, A.D. 1238–1267, is 0.09°C (±0.19°C) below 1961–1990 levels.

Following the medieval warmth until the early 1300s, a cooling trend led to a temperature anomaly of 0.43°C (±0.18°C) below 1961–1990 levels, during the height of the 'Little Ice Age' between A.D. 1830–1859. Warming in the region began after the coolest period in the reconstruction (1837–1841), with a continuous temperature increase observed post-1950.

The role of solar, volcanic, anthropogenic and ocean–atmosphere forcing are assessed using CSIRO Mk3L model simulations and independent palaeoclimate records. From the ensemble presented here, there are no other warm periods in the last millennium that match or exceed the post-1950 warming observed in the Australasian region.

ANALOGUE BASED METHODOLOGY FOR MULTI-PROXY RECONSTRUCTION OF SOUTHERN HEMISPHERE ATMOSPHERIC CIRCULATION PATTERNS DURING THE MEDIEVAL CLIMATE ANOMALY

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Paleoclimate records spanning the past 2000 years are now available for many key southern hemisphere locations. The challenge for paleoclimate research is to synthesis this data into quantitative climatic reconstructions that are coherent across multiple lines of evidence. We present a quantitative methodology that is ideal for synthesising data from multiple paloeclimate records. The method is based on identifying modern analogues to conditions recorded at each proxy site. Many proxy paloeclimate records present evidence of persistent conditions such as multi-decadal droughts that lie outside the range of variability seen in the modern record. Therefore modern analogues at this time scale do not exist. However, by searching for analogues at the event scale it is possible to find individual events that conform to the signals recorded across multiple proxy sites. The assumption is that similar conditions have persisted over longer time scales in the past resulting in the anomalous signals preserved within the paleoclimate record. This method is used to reconstruct southern hemisphere paleoclimate for key time-slices during the Medieval Climate Anomaly (MCA). Utilising the NCEP-NCAR 200avour200200g we identify individual days in the modern record that conform the signal recorded at each proxy site (eg, wet/dry or hot/cold etc). Multiple records are then combined to identify those days that best satisfy conditions across multiple proxy records for each time-slice. It is then possible to produce a spatial reconstruction for any variable, such as atmospheric circulation and SSTA. The key advantage of this method is that it is essentially a qualitative method that allows each proxy record signal to be individually assessed for consistency with multiple signals from other proxy records. The ability to reconstruct multiple variables such as pressure, temperature and SSTA means that this method is ideal for evaluation of GCM simulations.

UTILISING PALAEOCLIMATE RECONSTRUCTIONS OF THE INTERDECADAL PACIFIC OSCILLATION TO INFORM HYDROCLIMATIC RISK IN AUSTRALIA

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Previous research has highlighted the significant role that the Interdecadal Pacific Oscillation (IPO) plays in modulating hydroclimatic variability on a decadal to multi-decadal scale in Australia. However, due to the slowly varying nature of the IPO, the instrumental record captures only two full cycles, leading to uncertainty around the true historical behaviour of this phenomena (i.e. how persistent are these cycles?). In an attempt to overcome this issue, a number of reconstructed IPO time series have been developed based on palaeoclimate records (dating as far back as 1000AD). This study compares a number of IPO proxies to update a previously developed persistence model of the IPO based on the length of time between phase shifts. The IPO persistence model is then used to generate synthetic (stochastic) rainfall and streamflow series for southeast Queensland (QLD) by exploiting the historical relationship between instrumental rainfall/streamflow and IPO variability. The model is tested against a local coral based proxy record of rainfall (dating back to 1639) for southeast QLD to demonstrate that the simple IPO persistence model can capture pre-instrumental rainfall and streamflow variability. Importantly, the model may be applied in the absence of local palaeoclimate records to any region where there is a strong IPO signal. It is also shown that there is significant scope for the methodology to be further developed by including palaeoclimate information on other large-scale climate modes that are known to influence Australian climate (e.g. the Southern Annular Mode and the Indian Ocean Dipole).

"KARST"ING BACK IN TIME: EXPANDING THE APPLICABILITY OF PALAEO INFORMATION FOR HYDROCLIMATIC RECONSTRUCTIONS

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A dilemma facing many in the field of hydroclimatology in Australia is the ability to adequately assess long term decadal and interdecadal hydroclimatic risk, given the relatively short instrumental records available. Recent advances in the collection and analysis of palaeo information has enabled insights to be gained into historical environmental events and processes prior to the availability of instrumental records, enabling greater understanding of long-term environmental behaviors and associated hydroclimatic risks. In particular, the use of palaeo proxies derived using speleothems from karst formations and tree ring analysis has yielded high resolution records (i.e. annual and seasonal) suitable for use in hydroclimatic assessments. However, there is a relative lack of palaeo information in many areas where such insights and long term data are crucial, such as the Murray-Darling Basin (MDB). There is an immediate need for improved understanding into the long term variability of water availability in the MDB given the social, economic and environmental importance of the region. This paper explores relationships between rainfall outside the MDB and rainfall inside the MDB, in order to identify key locations that may be used to inform pre-instrumental MDB hydroclimatic reconstructions. Importantly, this work pinpoints locations where existing palaeo

information is most useful. Furthermore, this work also identifies regions where the future collection and interpretation of palaeo records will be of greatest value in expanding long term knowledge of MDB hydroclimatology.

We present the results of a high-resolution study of lake sediments from two sites in western Victoria, reconstructing climate variability over the past 1500 years. Fossil diatom samples were taken from the sediment cores at an average of approximately 5 years per sample. Diatoms are highly sensitive to changes in water chemistry and a diatom-conductivity transfer function was used to reconstruct variation in lake-water conductivity, a proxy for effective moisture in closed system lakes such as crater lakes. The reconstruction indicates distinct periods of contrasting climates. Both lakes record evidence of an extreme and protracted drought centered around AD 750, which was far more severe than any subsequent drought. A 600 year period (ca. AD 900 – 1500) of highly variable climate follows, with high amplitude fluctuations in effective moisture. Thereafter, a period of positive moisture balance is evident (ca. AD 1500 – 1850) with a marked reduction in the amplitude of variability. A shift towards a drier climate is evident after ca. 1850. Comparisons with proxy records of large-scale climate drivers suggest that ENSO and the Indian Ocean dipole are the key sources of observed variability.

The results indicate that climate extremes faced by Europeans have been of a markedly lower amplitude than what has occurred in the past, with far more extreme droughts and floods evident in the extended climate history of western Victoria.

QUANTIFYING SEASONAL-SCALE CHANGES IN EL NIÑO-SOUTHERN OSCILLATION FOR THE PAST MILLENNIA

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The El Niño-Southern Oscillation (ENSO) is the greatest source of interannual climate variability, yet model forecasts of the response of this system to global warming are inconsistent. The brevity of the instrumental record and lack of detailed knowledge of ENSO under different background states contribute to the uncertainty.

Here we present a sequence of *Porites* coral microatoll $\delta^{18}O$ records from Kiritimati (Christmas) Island in the central equatorial Pacific showing ENSO variability during discrete "windows" spaced between 1500 and 6000 years ago (mid- to late Holocene), when background climate conditions were different due to changes in the Earth's orbit around the sun.

Our sequence includes a 175-year monthly-resolved microatoll $\delta^{18}O$ record showing ENSO variability 4,300 thousand years ago. The record shows a 60% reduction in the ENSO variance, a stronger annual cycle that persisted for the full 175 years of the record, and limited low frequency (multi-decadal) modulation of the ENSO signal. El Niño events were 'damped' during their June-December growth phase, but still phase-locked to the seasonal cycle. La Niña events were reduced and together ENSO seasonal phasing was likely similar to that observed during the weak ENSO period of the 1920-1950s.

Further, results from corals aged between 1,500 and 2,000 years ago also show reduced ENSO, as well as changes in the contribution of the annual cycle, El Niño and La Niña events to the overall coral $\delta^{18}O$ signal.

Our results show fundamental metrics on the seasonal characteristics of ENSO during the altered background conditions of the mid- to late Holocene. The results suggest that Holocene ENSO responded to changes in orbital forcing and that there was limited, unforced variability. This may have implications for ENSO under future global warming conditions.

REFINING SPELEOTHEM BASED PROXY INTERPRETATIONS, UTILIZING THE CSIRO MK3L CLIMATE SYSTEM MODEL

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Long, annually-resolved proxy records provide insights into climate variability and change on centennial timescales and longer. However, interpretation of these records involves making the assumption of stationarity in the relationship between proxies and larger-scale climatic variables. Climate modelling can be used to test this assumption. Here, a speleothem from northeast Turkey is used to reconstruct past changes in cool-season (autumn-winter) precipitation. We then attempt to interpret these changes in terms of the large-scale atmospheric circulation. At this study site, the cool season represents the time of year during which ground water is recharged, and understanding the controls on precipitation at this time of year is thus of great importance for managing future water resources.

A verified instrumental calibration of annually-resolved δ18O of a stalagmite from Akçakale Cave yields a record of precipitation in October-January (ONDJ) from AD ~1500 to 2004. The relationship between modern ONDJ precipitation at the study site and the large-scale atmospheric circulation is explored using the ERA-40 reanalysis. We find a strong correlation with pressure fields in Western Russia, and in particular at heights that describe the North Sea-Caspian Pattern (NCP).

We then test the stability of these relationships using the CSIRO Mk3L climate system model. In a 1000-year control simulation, we find similar correlations between precipitation at the study site and 500mb geopotential height to those found in the reanalysis. These correlations are found to be robust under natural and anthropogenic forcings. However, there is considerable variability in the nature and strength of the teleconnections on decadal and centennial timescales, which arises from a complex interplay between different modes of variability. A key feature of the reconstructed record is a period of anomalously lower reconstructed rainfall at AD 1540-1560. Here we discuss whether this can be interpreted in terms of NCP state and/or strength.

FAMINE, PESTILENCE AND FLAGELLATION: WHAT CAN WE LEARN FROM THE CLIMATE OF THE LAST 2,000 YEARS?

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The last 2,000 years provides a valuable opportunity to study the sensitivity of the climate system and to evaluate the models that are used to simulate future climate states. Proxy-based reconstructions are available that have both high temporal resolution and widespread geographical coverage. The boundary conditions on the climate system over this period are also reasonably well constrained.

Here, the CSIRO Mk3L climate system model is used to simulate the global climate of the last 2,000 years. Different combinations of natural and anthropogenic forcings are applied, including changes in the Earth's orbital parameters, solar irradiance, volcanic emissions and anthropogenic greenhouse gases. Two different volcanic reconstructions are assessed.

When all the natural and anthropogenic forcings are applied, the model is broadly able to reproduce changes in hemispheric-mean temperature over the last 2,000 years, including both the Mediaeval Climate Anomaly and the Little Ice Age. Peak pre-industrial warmth occurs between 800 and 1150 CE, followed by a cooling trend that persists until the early 19th century. The subsequent anthropogenic warming causes temperatures to exceed pre-industrial levels by the late 20th century.

Volcanic eruptions are found to be a more important climatic driver than changes in solar irradiance, giving rise to both the relative warmth of the Mediaeval Climate Anomaly and the cool conditions of the Little Ice Age. However, of all the natural forcings on the climate system over this period, volcanic emissions are arguably the least well constrained. The two available reconstructions differ considerably in terms of both the magnitudes and dates of individual eruptions, and neither reconstruction extends further back in time than 500 CE. In order to unlock the secrets of the last 2,000 years, and learn all that it can tell us about the future, a critical challenge is therefore to develop better reconstructions of past volcanic activity.

INSIGHTS ON AUSTRALIAN AND SOUTHERN HEMISPHERE CLIMATE AND VARIABILITY OVER THE LAST 2000 YEARS FROM THE HIGH RESOLUTION LAW DOME ANTARCTIC ICE CORE.

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One of the knowledge gaps highlighted in IPCC AR4 was that Southern Hemisphere climate reconstructions are limited by sparcity and quantity of well resolved paleoclimate records over the last 2000 years. Climate information from the Australian Law Dome ice core (near Casey station) has been extended over this 2000 year period, to better than annual resolution. The record has been dated to +- 4years at -18 CE using annual layer counting. This has been used to date and assess sulphate fluxes for the major volcanic eruptions during this time period (Plummer et al.). The stable isotopes have been used to produce a temperature record at the site (Moy et al.), and snow accumulation measurements have been used as a proxy for rainfall in SWWA over the last 700 years (van Ommen and Morgan, 2010), now extended over 2000 years. Variations in the seasonal concentrations of sea salts have been linked to ENSO variability and teleconnections to Australian rainfall (and temperature?) patterns. The history of sea ice extent will be explored through the use of proxies from methanesulphonic acid and a fraction of the sea salt signal (Curran et al.). We will present these proxies with an emphasis on those climate records most relevant to the Southern hemisphere, particularly Australia.

Poster Presentations

14.1. A MODERN ANALOG ANALYSIS OF OUT-OF-PHASE PATTERN BETWEEN NORTH AND SOUTH EAST ASIAN SUMMER MONSOON DURING THE RECENT 1000 YEARS

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During Mediaeval Warm Period, North and South Asian Summer Monsoon region (NEASM/SEASM) have an out-of-phase pattern in precipitation. By 205avour205205g the NCEP reanalysis data of recent 63 years (1948-2010), the present research identifies a shift in moisture index from wet to dry for NEASM around 1977, while it's the opposite for SEASM around the year 1986. Both local subsident/uplift abnormal and larger scale circulations contribute to this dipole system.

The index for vertical motion (omega) in the EAM region reveals the abnormal ascent in the south and descent in the north after the year 1977. Anomalies in zonal index (uwind/vwind), pressure index (geo-potential height), vertical index (omega) and ENSO index (SST) implies a larger scale atmospheric circulation system that contributes to the dipole. The ocean surface cooling around 1978 near Philippine Sea, which was correlated with ENSO events, is the triggering factor of the whole process. The convection anomaly of NWP affects the ascent in Indian Summer Monsoon region (ISM). The tele-connection with the Mediterranean/Aral Sea via the Rossby wave transports the anomaly to the west. An enhanced Asian Jet then transmits the PV anomaly from the west back to NEASM, which contributed to its less-than-normal precipitation. The SEASM, on the other hand, is affected mostly by the abnormal meridional wind originated from the SST anomaly in Philippine Sea. This anomaly also blocks the wind southward, which provided abnomaly abundant water 205avour. In all, the combination of local subsidence and larger-circulation patterns explains the dipole pattern of NEASM and SEASM that emerged on the decadal scale in WMP. This mechanism also serves as an effective way for explaining the precipitation anomalies at centennial and hundred- to- thousand year scales.

14.2. INTERPRETING PAST CLIMATE USING SOUTHWEST AUSTRALIAN SPELEOTHEMS

Treble, P.C.[1], Azcurra, C.[2], Baker, A.[2], Bradley, C.[3], Wood, A.[4],Fischer, M.J.[1,3]Fairchild, I.J.[3], Hellstrom, J.C.[5] & Gagan, M.K.[6]
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There is an identified need to extend our baseline climate information beyond the relatively short duration of instrumental records in Australia. An improved knowledge of natural rainfall variability would assist in our understanding of climate change. SW Australia (SWWA) is one region that has been identified as having a changing climate since the 1970s.

Speleothems (cave stalagmites) are an effective archive of past climate variability and caves from the coastal region of SWWA are being studied for paleoclimate records. The modern speleothem record from this region has been assessed and shown to record the post-1970s rainfall decrease (Treble et al., 2003; 2005; Fischer and Treble, 2008). The extension of the speleothem record is currently underway, however, a long-term cave monitoring program was also deemed necessary to separate the climatic from non-climatic signals i.e. to reduce uncertainty when interpreting these records.

This presentation outlines what we have learnt about the possible hydrological modification of the climate signal in speleothems. In particular, we present results from a five-year long monitoring study of rainfall and cave drip water O isotopes ($\delta^{18}O$) from Golgotha Cave, SWWA. From this study, we have been able to characterize the probable flow paths feeding stalagmites in our monitored cave. These flow paths range from slow diffuse flow of isotopically-averaged rainfall to preferential routing of high-magnitude, ^{18}O-depleted, events along fast flow routes into the cave. Hence, we offer a possible explanation for why paleoclimate records from coeval speleothems in our cave may differ. Our study suggests that this disagreement may simply be due to different flow paths resulting in a bias towards the preservation of high or low magnitude rainfall events.

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14.3. UNDERSTANDING HYDROLOGICAL FLOW IN KARST TO IMPROVE PALEOCLIMATE MODELLING OF SPELEOTHEMS IN SE AUSTRALIA.

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Paleoclimate studies are an important tool to aid our current knowledge and understanding of past climatic conditions. This in turn can be used to make informed predictions about future climate change and improve natural resource management. In the last decade, paleoclimate research using speleothems has increased. Methods have been established and it has been demonstrated that they may be applied to successfully reconstruct paleoclimate records from stalagmites (Tan *et. Al*., 2003; Treble *et. Al*., 2003; Trouvet *et. Al*., 2009; Jex *et. Al*., 2011).

A key parameter in the successful reconstruction of speleothem-based paleoclimate archives is the understanding of the karst hydrology influencing drip water that leads to calcite deposition (Baldini *et. Al*., 2006). The typically non-linear relationship between surface recharge and drip water response is highly complex and not yet fully understood (Baker and Brunson, 2003). For example McDonald *et. Al.* (2007) demonstrated that drips which responded simultaneously to recharge events still exhibited different delivery mechanisms and in turn exhibited discharge responses.

To improve speleothems as a climate proxy, long term cave monitoring in two hydrologically different field sites in SE Australia (Wellington and Yarrangobilly caves) is being conducted. Drip water hydrology over a variety of flow regimes was characterised using over 30 drip water loggers. Distinct flow regimes and spatial variability were observed, indicating that drip waters experienced a wide variety of flow paths. It was evident that even over small spatial variations; surface to groundwater connectivity was considerably heterogeneous.

To enhance the drip water study, a novel application was introduced to the cave monitoring program which used micro-temperature loggers to monitor heat signals in drip waters. This study is still in its infancy but has the potential to enhance current monitoring programs and produce greater information regarding flow regimes in speleothem formation.

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Stream 15. Tropical Pacific Climate Variability and Projections

Conveners: Jaclyn Brown, Josephine Brown, Alex Sen Gupta

Oral Presentations

THE CHANGING FACE OF EL NIÑO

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Over the past 30 years, a new type of El Niño has emerged with its largest warming concentrated in the central Pacific. These "central Pacific" (CP) El Niños, also referred to as "dateline", "modoki", or "warm pool" El Niños, can have different climatic impacts than more traditional El Niños, which have their largest warming in the eastern Pacific. Understanding the differences in evolution, dynamics, and predictability for these two types of El Niño is not only a challenging scientific problem but also important for practical applications. This presentation will make use of detailed observations over the past 30 years to examine the distinguishing features of CP El Niños vs eastern Pacific (EP) El Niños. It will also address the question of whether the trend towards more frequent occurrence of CP El Niños can be attributed global warming.

INTERANNUAL VARIATIONS OF WIND STRESS AND SEA SURFACE TEMPERATURE IN THE EASTERN EQUATORIAL PACIFIC

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The evolution of sea surface temperature (SST) over the eastern equatorial Pacific (EEP) in response to remote wind forcing in the western and central equatorial Pacific is of central importance to the El Niño-Southern Oscillation (ENSO) phenomenon. Because the remote wind forcing plays a dominant role in ENSO-related SST variations in the EEP, the local wind forcing in the EEP and associated physical processes were often neglected. However, local wind forcing may also vary interannually and thus have impacts on individual ENSO events. The impact of local wind stress on SST variations during ENSO events is examined here with both empirical analysis and numerical 208avour208208g.

Empirical analysis indicates that a zonal wind stress anomaly of 0.01 N m^{-2} leads to approximately a 1°C SST anomaly over the Niño-3 region. It is later verified by a numerical sensitivity test based on a general circulation model. A novel heat balance analysis for the upper 50 m of the Niño-3 region is further

designed to investigate the oceanographic processes underlying interannual EEP SST variations. Especially, the decomposition of vertical advection indicates that the mean seasonal advection of anomalous temperature difference (the so-called thermocline feedback) dominates and is highly correlated with 20°C isotherm depth variations which are mainly forced by the remote wind forcing. Temperature advection by anomalous vertical velocity (the Ekman feedback), which is highly correlated with local wind forcing, is smaller with an amplitude about 40% on average of remotely forced vertical heat advection.

In conclusion, the local wind forcing, while not dominant, significantly affects ENSO SST variations in the EEP.

THE EL NINO SOUTHERN OSCILLATION PATTERN NON-LINEARITY

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The El Nino and La Nina events are generally described by a fixed pattern evolving over time, but in the recent literature it has been noted that individual ENSO events have different patterns. In particular a new type of ENSO mode has been coined, named El Nino Modoki or Central Pacific El Nino, which is assumed to be independent of the canonical El Nino.

On the other hand it has also been noted the ENSO event have a positive skewness with extreme El Nino being more like than extreme La Nina events. This skewness is not only in the amplitude, but also in the shape of extreme El Nino and La Nina events, with later being more in the central Pacific and the first being more in the east Pacific.

The analysis of observations and model simulation presented here will illustrate that the El Nino Modoki or Central Pacific El Nino are part of the ENSO non-linearity (skewness) that leads to different a spatial pattern of ENSO events depending on the strength and sign of the event. Strong El Nino and weak La Ninas events tend to be shifted to the eastern Pacific and weak El Nino and strong La Nina events tend be shifted to the central Pacific and have are more wider meridional extent. It will be illustrated that these differences are related to non-linearities in atmospheric feedbacks.

ENSO IMPACTS ON PACIFIC ISLANDS' CLIMATE AND THE ATMOSPHERIC DYNAMICS THAT BRING THEM ABOUT

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The Pacific Australia Climate Change Science and Adaptation Planning Program (PACCSAP) has collaborated with the National Meteorological Services (or equivalent agency) in the 14 partner countries in the Pacific region and East Timor to produce detailed descriptions of the mean climate, observed seasonal and inter-annual climate variability and climate trends in each country. This research has demonstrated that interannual climate variability across the region is dominated by ENSO. For climate variables such as rainfall, the phase of ENSO can produce a response at a single site from an 80% decrease to a 250% decrease in annual rainfall.

This presentation will summarise the main impacts of ENSO events on the climate of each partner country. Both "Cold Tongue ENSO" (wherein the largest changes in sea surface temperatures are in the eastern Pacific Ocean) and "Warm Pool ENSO" (wherein the largest SST changes are in the central and western

Pacific) events will be considered and the differences in the impacts of these two types of ENSO will be assessed. The mechanisms and teleconnections through which ENSO events affect the climate of the region will be presented, such as shifts in rainfall patterns associated with the South Pacific Convergence Zone, changes to local ocean temperatures, and changes in trade winds and associated moisture transport. Local-scale influences that result in variations in ENSO impacts within each country, such as the exposure to prevailing trade winds, will also be discussed.

THE WALKER CIRCULATION, TROPICAL CYCLONES, AND GLOBAL WARMING

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The Walker Circulation (WC) is one of the world's most prominent and important atmospheric systems. The WC weakened during the 20th century, reaching record low levels in recent decades. This weakening is thought to be partly due to global warming and partly due to internally generated natural variability. There is, however, no consensus in the literature on the relative contribution of external forcing and natural variability to the observed weakening of the WC. Here we examine changes in the strength of the WC in both the observations and in WCRP/CMIP3 climate model simulations for the 20th and 21st centuries. The analysis we will present leads us to conclude that: (i) both external forcing and internally generated variability contributed to the observed weakening of the WC over the 20th century and (ii) external forcing accounts for approximately 50% +/- 20% of the observed weakening, with internally generated climate variability making up the rest.

We then examine changes in the Southern Oscillation Index (SOI), an index that is often used to track and predict changes in both the El Niño-Southern Oscillation (ENSO), and the WC. During El Niño, for example, the WC weakens and the SOI tends to be negative. In stark contrast to expectations the SOI increases in response to global warming during the 21st century integrations, even though the WC weakens. The reasons for and implications of this stark contrast between the character of ENSO-driven natural variability and anthropogenically-forced climate change will be discussed.

Finally, we describe and use a new data base (Callaghan and Power, Climate Dynamics, 2010) of severe land-falling tropical cyclones (TCs) for eastern Australia derived from numerous historical sources that has taken many years to develop. It allows us to document changes in TC activity over much longer periods than has been done previously for the Southern Hemisphere. Land-fall numbers are well-simulated as a Poisson process. They occurred almost twice as often in La Niña years as they did in El Niño years, and multiple land-falls only occurred during La Niña years. Decadal variability in ENSO drives some of the decadal variability in land-fall numbers. Other links between decadal variability in land-falls and climate variability in the Pacific more broadly will be examined. The number of severe TCs making land-fall over eastern Australia declined from about 0.45 TCs/yr in the early 1870s to about 0.17 TCs/yr in recent times ($p=0.1$ only). This decline can be partially explained by a weakening of the Walker Circulation, and a natural shift towards a more El Niño-dominated era.

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INFLUENCES OF THE TROPICAL INDIAN AND ATLANTIC OCEANS ON THE PREDICTABILITY OF ENSO

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The El Niño Southern Oscillation (ENSO) is the leading mode of interannual tropical variability and it is the only predictable mode of variability on interannual time scales. Recent studies suggest that the tropical Indian and Atlantic Oceans influence the dynamics of ENSO and possibly the predictability of ENSO. In this study we examine the effects of the tropical Indian and Atlantic Oceans on the dynamics and predictability of ENSO in a hybrid coupled model consisting of a full complexity atmospheric general circulation model coupled to a linear 2-dimensional ENSO recharge oscillator ocean model in the tropical Pacific. We find a strong dynamical effect of the tropical Indian Ocean onto ENSO that is consistent with previous studies. We further find in perfect model forecast simulations that the initial conditions of both the tropical Indian and Atlantic Oceans have a significant impact on the predictability skill at lead times of about 6 months. Interestingly we find that the initial conditions of the tropical Atlantic Ocean have a stronger impact on the predictability skill than those of the tropical Indian Ocean, despite the fact that the coupling to the tropical Atlantic has almost no effect on the dynamical parameters of the ENSO mode.

AN ASYMMETRY IN THE IOD AND ENSO TELECONNECTION PATHWAY

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Recent research has shown that the climatic impact from El Niño-Southern Oscillation (ENSO) on southeast Australia in austral spring (September to November) is conducted via the tropical Indian Ocean (TIO). However, it is not clear whether this impact pathway is symmetric about the positive and negative phases of ENSO and the Indian Ocean Dipole (IOD). It is shown that a strong asymmetry does exist: a greater convection anomaly and wavetrain response occurs during positive IOD (pIOD) events than during negative IOD (nIOD) events. El Niño-pIOD events are far more coherent than La Nin˜a-nIOD events, and thus are more effective in triggering convective anomalies over the TIO resulting in Rossby wavetrain formation. This "impact asymmetry" is consistent with a positive skewness of the IOD (indicative of a greater amplitude of pIOD events), due principally to a negative skewness of sea surface temperature (SST) anomalies in the east IOD (IODE) pole. Negative SST anomalies in the IODE region exhibit a greater decrease in convection compared to an increase in convection associated with similar positive SST anomalies, suggesting a greater damping on the negative SST anomalies. Thus, the skewness occurs in spite of the greater damping, rather than due to its breakdown as suggested by previous studies. The presence of such an impact asymmetry provides an explanation for much of the reduction in spring rainfall over southeast Australia during the 2000s, and suggests that the increased occurrences of El Nin˜o and pIOD events over the past decade play a major role in the rainfall 2 reduction, more so than the lack of nIOD events.

THE EFFECT OF THE SOUTH PACIFIC CONVERGENCE ZONE ON THE TERMINATION OF EL NIÑO EVENTS AND THE MERIDIONAL ASYMMETRY OF ENSO

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The westerly wind response to an El Niño event shifts southward during boreal winter and early spring, such that the maximum zonal wind is centred about 5-7 degrees south of the equator. The resulting meridional asymmetry, along with a related seasonal weakening of wind anomalies on the equator are key elements in the termination of strong El Niño events. Using an intermediate complexity atmosphere model it is demonstrated that these features result from a weakening of the climatological wind speeds south of the equator. The reduced climatological wind speeds, which are associated with the seasonal intensification of the South Pacific Convergence Zone (SPCZ), lead to anomalous boundary layer Ekman pumping and a reduced surface momentum damping of the combined boundary layer/lower troposphere surface wind response to El Niño. This allows the maximum anomalous zonal wind speed to shift south of the equator. Therefore, the development of a realistic climatological SPCZ in DJF/MAM is one of the key factors in the seasonal termination of strong El Ni\~no events. Furthermore, using a linear shallow water ocean model it is demonstrated that this southward wind shift plays a prominent role in changing zonal mean equatorial heat content and is solely responsible for establishing the meridional asymmetry of thermocline depth in the turnaround (recharge/discharge) phase of ENSO. This result calls into question the role of ocean memory due to Rossby wave dynamics in terminating El Niño events.

THE RESPONSE OF THE SPCZ TO ENHANCED CLIMATE CHANGE: A MULTI-MODEL CASE STUDY

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The South Pacific Convergence Zone (SPCZ) is a band of enhanced convective precipitation, high cloudiness and low level convergence that extends from the west Pacific warm pool south-eastward toward French Polynesia. It has been shown that variations in the position of the SPCZ are highly correlated with the El Niño-Southern Oscillation. Considering the precipitation gradient associated with the SPCZ is strong small variations in the position of the SPCZ will most likely result in significant variations in precipitation in the region. During El Niño years the SPCZ has been observed to shift equatorward relative to its mean climatological position, whilst during La Niña years the SPCZ shifts south-west. The interannual response of the SPCZ, however, is not always symmetric. During strong El Niño years, such as the austral summers of 1982/83, 1991/92, and 1997/98, the SPCZ becomes essentially zonal due to the eastward movement of the west Pacific warm pool past a threshold longitude. The region south of the SPCZ is known to 212avour tropical cyclogenesis, and the large displacement during asymmetric years brings tropical cyclones to French Polynesia, not accustomed to such occurrences. We employ global coupled ocean-atmosphere models used for the Fourth Assessment Report of the Intergovernmental Panel on Climate Change to examine their simulation of such events and to investigate the interannual variability of the SPCZ. In particular, we identify climate models that are able to produce asymmetric events in a realistic manner and use multi-model statistics to investigate the response of such events to human-induced global warming. This talk will present the results and the associated long-term rainfall and temperature change patterns.

POTENTIAL CHANGES IN MONSOON ONSET/INTENSITY IN THE AUSTRALIA-ASIAN REGION DERIVED FROM IPCC AR4 MODELS

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In this study, seasonal variations in both atmospheric precipitable water and wind conditions are used in defining monsoon onset/retreat. Combining these two large-scale variables from ERA-40 reanalysis daily data, we show it gives satisfactory monsoon onset/retreat dates, their detailed spatial patterns as well as interannual variations in the Asian and tropical Australian regions. Then, we use the method to investigate some detailed aspects of monsoon activities from current global climate models which show some skills in reproducing these large-scale variables. In this analysis, we have applied the method to the majority of IPCC AR4 models, using daily data from their three sets of experiments: 20C3m for current climate and A1B and A2 for two future emission scenarios. At first, we examine whether fundamental mean monsoon climate can be captured by the models. We further calculate the model-simulated changes in atmospheric moisture and wind conditions in the monsoon region, including changes in their mean climatologies, seasonality and their spatial distributions. Then, we assess how the monsoon onset/retreat, duration and intensity are simulated by these models under current climate and their potential changes in future. Uncertainty in the model results will also be assessed.

THE SOUTH PACIFIC CONVERGENCE ZONE IN COUPLED MODEL SIMULATIONS OF 20TH CENTURY AND FUTURE CLIMATE

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The South Pacific Convergence Zone (SPCZ) consists of a band of intense rainfall, convection and cloudiness extending from near New Guinea in a southeast direction to the subtropics (around 30°S, 120°W). The SPCZ is most intense and well defined in the austral summer (December to February), and varies on a range of time scales from synoptic to inter-annual and decadal. The ability of 24 CMIP3 coupled climate models to simulate the SPCZ is evaluated based on 20th century climate simulations carried out for the Intergovernmental Panel on Climate Change Fourth Assessment Report. The majority of models simulate an SPCZ with an overly zonal orientation, rather than extending in a diagonal band into the southeast Pacific as observed (Brown et al. 2011).

Projections of changes in the position and intensity of the SPCZ are produced for simulations of the 21st century climate under the SRES A2 emission scenario using a subset of 16 CMIP3 models (Brown et al., *in press*). Changes in the SPCZ position are examined using a linear fit to the band of maximum precipitation and using a "pattern matching" technique (Moise and Delage, 2011). Both techniques find no consistent shift in the slope or mean latitude of the austral summer SPCZ. However, many models simulate a westward shift in the eastern edge of the SPCZ in austral summer, with reduced precipitation to the east of around 150°W. The westward contraction of the SPCZ is associated with a strengthening of the trade winds in the southeast Pacific and an increased zonal sea surface temperature gradient across the South Pacific. The majority of models simulate an increase in the area of the SPCZ and in mean and maximum precipitation within the SPCZ, consistent with enhanced tropical moisture convergence in a warmer climate.

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Poster Presentations

15.1. MODEL BIASES IN THE WESTERN TROPICAL PACIFIC, IMPROVEMENTS FROM CMIP5, AND IMPLICATIONS FOR PROJECTIONS.

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Regional climate projections in the Pacific region are potentially sensitive to a range of existing model biases. We examine the implications of coupled model biases on regional climate projections in the tropical western Pacific in CMIP3 and preliminary results from CMIP5. We focus on how the model biases have been reduced (or not) in the new CMIP5 archive. Model biases appear in simulations of El Niño Southern Oscillation, the location and movement of the South Pacific Convergence Zone, rainfall patterns, and the mean state of the ocean-atmosphere system including the cold tongue bias and erroneous location of the edge of the warm pool. These limitations are examined by comparing the 20th Century runs with observations. We discuss the implications of these biases for making climate projections using model output and processes to work around them.

15.2. AN UPDATED ASSESSMENT OF LAND-BASED TEMPERATURE AND RAINFALL TRENDS ACROSS THE ISLAND NATIONS OF THE WESTERN PACIFIC

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As part of the Pacific Climate Change Science Program, homogeneous long-run station records for rainfall and temperature have been produced for the island countries of the western Pacific. Station records have undergone homogeneity assessment and adjustment where appropriate to produce reliable analyses of rainfall and temperature trends and variations.

The homogeneous temperature records indicate that mean temperatures have increased at all available Pacific Island stations over 1961-2010, with rates ranging from +0.04 to +0.33ºC/decade and averaging +0.16°C/decade across the network. The strongest warming trends are found in Papua New Guinea and French Polynesia. None of the updated homogeneous records show cooling over the past 70, 50 or 30 years.

The long-term rainfall trends are less spatially and temporally coherent than those evident in air temperature records as a result of high variability. The updated analyses are consistent with previous studies in indicating a general increase in rainfall totals north-east of the South Pacific Convergence Zone (SPCZ) over the past 50 years, with declines mostly observed to the southwest. This pattern of change is reflected in both wet and dry seasons and is consistent with a northeast movement of the SPCZ since the middle of the 20th Century.

Unlike changes in temperature, which are dominated by background global warming, the lack of a sustained trend in rainfall suggests that shifts in rainfall patterns in the Pacific region continue to be significantly influenced by natural climate variability.

15.3. SENSITIVITY OF THE SOUTHERN HEMISPHERE CLIMATE TO CHANGING ENSO CONDITIONS

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The El Niño Southern Oscillation (ENSO) has significant impacts on the global climate system, but the extent to which these global teleconnections are sensitive to the strength and location of the anomalous warming in the tropical Pacific basin is still largely unexplored. In this study, we compare the response of the extratropical Southern Hemisphere (SH) climate to the following two manifestations of ENSO: 1) canonical or "traditional" El Niño, characterized by anomalous warming centered in the eastern tropical Pacific and 2) El Niño Modoki, characterized by anomalous warming centered in the eastern Pacific, flanked by cooling to its east and west. Observational analysis reveals that during the austral cold season (June-September), a similar wave train pattern in the atmospheric circulation arises in response to both canonical and Modoki El Niño events. However, during the warm season (November-February), the SH atmospheric circulation response differs between the canonical and Modoki El Niño events. Under canonical ENSO conditions, the SH atmospheric circulation exhibits a more zonally symmetric structure that arises from the statistically significant relationship with the leading mode of extratropical atmospheric circulation, the Southern Annular Mode (SAM). During El Niño Modoki events, the teleconnections to the SH atmosphere and ocean have weakened significantly, no longer exhibiting a strong link to variability in the SAM. An atmospheric GCM is then used to examine the sensitivity of the SH climate response to the strength and location of warming in the tropical Pacific basin.

15.4. MANAGING CLIMATE VARIABILITY IN AGRICULTURE: PREDICTING THE ONSET OF THE NORTH AUSTRALIAN WET SEASON

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In this project sponsored by the Managing Climate Variability research and development program, we aim to provide skilful forecasts of the onset of the north Australian wet season. We define wet season onset to occur when a threshold rainfall accumulation of 50 mm is reached from 1st September. This amount has been shown to be useful for many agricultural applications as this is about the amount of rainfall that is required to generate new plant growth after the usually dry winter. For the cattle grazing industry, for example, the date at which 50 mm of rainfall is reached approximately marks the time that cattle are able to start gaining weight. The mean onset date by this definition occurs first around Darwin in the north and Cairns in the east in late October. The mean onset is progressively later for locations further inland away from these locations, generally occurring before 1st December for locations north/east of 18°S/145°E and later for locations further south/west. However, there is significant interannual variability in the onset, and skilful predictions of this can be very valuable. Here we show the great potential of the Predictive Ocean-Atmosphere Model for Australia (POAMA) version 2, run operationally at the Bureau of Meteorology, for making probabilistic predictions of onset, derived from its multi-member ensemble. Using hindcasts from 1960 to 2009 we find that the model is able to skilfully predict the onset, despite a generally dry bias, with the "percent correct" exceeding 70% over about a third of the Northern Territory. Much of the variability in onset is related to the El Nino-Southern Oscillation with early/late onsets usually occurring in La Nina/El Nino years, but other factors, such as ocean temperatures around northern Australia, are also found to be important.

15.5. APPLICATION OF THE ENSO UNIFIED OSCILLATOR THEORY TO AN OCEAN-ONLY MODEL

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El Niño-Southern Oscillation (ENSO) is a climate phenomenon resulting from ocean-atmosphere interactions in the tropical Pacific. Positive and negative feedbacks that arise from this coupling cause the system to oscillate on interannual timescales. Despite considerable progress in our understanding of ENSO over the last few decades, there remains uncertainty involved in predicting and explaining changes in ENSO characteristics. Conceptual models of ENSO, based on different negative feedbacks, are valuable in understanding ENSO and its oscillatory nature.

Recently, Wang (2001) derived the Unified Oscillator (UO) conceptual model of ENSO from the dynamics and thermodynamics of the coupled ocean-atmosphere system. When certain assumptions and simplifications are made, this conceptual model reduces to different oscillator models, namely the delayed oscillator, the recharge-discharge oscillator, the western Pacific oscillator and the advective-reflective oscillator.

There are six key parameters in the UO, which correspond to the positive and negative feedbacks that drive the oscillatory nature of the coupled ocean-atmosphere system in the Pacific. Here, we analyse the temporal variation of these parameters using the Geophysical Fluid Dynamics Laboratory (GFDL) Modular Ocean Model version 4 (MOM4). The effect of the 1976-77 regime shift on the magnitude and variation of these parameters, the effect of different parameter values on the leading ENSO modes (or "flavours") and the importance of the eastern and western equatorial Pacific in defining the model's parameters are considered.

Wang, C., 2001: A Unified Oscillator Model for the El Niño-Southern Oscillation. J. Climate, 14, 98-115.

15.6. PROVIDING CLIMATE PROJECTIONS FOR INDIVIDUAL PACIFIC ISLAND NATIONS: CHALLENGES, PROGRESS AND FUTURE DIRECTIONS

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As part of the recent Pacific Climate Change Science Program (PCCSP), an extensive assessment of both the present climate and projected future climate was undertaken for 14 Pacific island nations and East Timor. The assessment focused on a range of climatic variables including temperature (ocean and atmosphere), rainfall, sea level, ocean acidity and tropical cyclone activity, which involved the analysis of observational data, output from CMIP3 global climate model simulations and results arising from various dynamical and statistical downscaling techniques. A number of products were developed for disseminating the outcomes of this research to decision makers and the wider community, the centrepiece of which was a series of 10-15 page summary documents for each country (see http://www.cawcr.gov.au/projects/ PCCSP/index.html).

A major challenge in the development of these summary documents, particularly with respect to the provision of climate projections, was finding a balance between the needs of decision makers and the desire of the scientific community to adequately convey the associated uncertainties and limitations of the science. The synthesis of multiple sources of projection information (e.g. projections arising from both global climate models and downscaling techniques) also provided unique challenges. This presentation will discuss the approaches used in the PCCSP to overcome these challenges, including the development of a user-appropriate system for assigning a scientific level of confidence to each projection. An emphasis was placed on presenting the full range of plausible future climates, in order to facilitate robust decision making. Future directions for the development of updated PCCSP partner country projections (based primarily on CMIP5 output) will also be discussed. These include the possible use of pattern scaling techniques to obtain information about a broader range of future scenarios, statistical methods for separating out natural climate variability from model output, and methods for improving the integration of projections across multiple climate variables and modeling approaches.

15.7. EVALUATION OF AIR-SEA FLUX ALGORITHMS PERFORMANCE IN OCEAN-ATMOSPHERIC COUPLED MODEL TO IMPROVE CLIMATIC SIMULATION OF TROPICAL PACIFIC SST VARIABILITY.

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Algorithms for parameterisations of momentum, sensible heat and moisture flux at the air-sea interface are evaluated in the ACCESS ocean-atmospheric coupled model. New algorithms based on recently published field experimental results demonstrate improved performance in reproducing the mean global SST distributions compared with existing algorithms.

The problematic SST cool tongue in the equatorial Pacific is reduced with the new algorithms. Tests on Nino 3 and 3.4 indices show sensitivity of ENSO frequency simulations to the different algorithms. The physical mechanisms responsible for the different tropical Pacific SST simulation results are discussed with reference to the flux parameterisations in coupled models.

15.8. CLIMATE CHANGE IN THE PACIFIC: SCIENTIFIC ASSESSMENT AND NEW RESEARCH

S. Power, K. Hennessy, G. Cambers, J. Rischbieth, S. Baldwin, Jaclyn N. Brown, Dean Collins, Robert Colman, D. Irving, J. Katzfey, P. Kokic, B. Murphy, D. Abbs, John Church, Francois P. Delage, A. Sen Gupta, D. Jones, S. McGree, M. Hopkins, A. Moise, S. Perkins, A. Schiller, B. Tilbrook, Xuebin Zhang (Pacific Climate Change Science Program), M. Vaiimene, D. Maihia, N. Bates (Cook Islands) , T. Terencio, F. Moniz, S. da Silva (East Timor), D. Aranug, J. Berdon, E. Skilling (Federated States of Micronesia), A. Waqaicelua, A. Daphne, B. Prakash, V. Vuniyayawa, R. Kumar (Fiji), U. Toorua, T. Tetabo, R. Abeta, N. Teuatabo (Kiribati), R. White, L. Jacklick, N. Lobwij (Marshall Islands), A. Kaierua, F. Teimitsi, D. Audoa (Nauru), R. Misiepo, A. Misikea, F. Pihigia Talagi (Niue), M. Ngemaes, D. Ngirengkoi, G. Sisior (Palau), K, Inape, M. Virobo (Papua New Guinea), F. Lagomauitumua, S. K. Seuseu , T. Faasaoina (Samoa), D. Hiriasia, L. Tahani (Solomon Islands), O. Fa'anunu, M. Lakai (Tonga), H. Vavae, K. Epu (Tuvalu), S. Kaniaha, P. Malsale (Vanuatu), on behalf of all PCCSP staff and others who contributed to the report or its production.

A 600 page, two volume scientific report called "*Climate Change in the Pacific: Scientific Assessment and New Research*" was recently released as part of the Pacific Climate Change Science Program (PCCSP). This report draws on research conducted around the world, including PCCSP research. The PCCSP was a major research program aimed at helping 14 developing island countries in the Pacific (Cook Islands, Federated States of Micronesia, Fiji, Kiribati, Marshall Islands, Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu) and East Timor gain a better understanding of how climate has changed in the past and how it may change in the future. The PCCSP ran to the end of December 2011 and has now been superseded by the Pacific Australia Climate Change Science and Adaptation Program (PACCSAP).

Volume One describes the climate and oceanography in and around the Pacific Ocean (25°S-20°N and 120°E-150°W), the main factors influencing climate and oceanography in the region, observed trends, our ability to simulate Pacific climate and projections of future Pacific climate based on new analyses of WCRP/CMIP3 models and dynamical downscaling. Projections are provided for temperature, rainfall, extreme events, (including tropical cyclones, extreme hot days and heavy rainfall days), sea-surface temperature, ocean acidification, and sea-level rise for three future 20-year periods centred on 2030, 2055 and 2090, and for three different scenarios of future greenhouse gas and aerosol emissions: B1 (low), A1B (medium) and A2 (high). The report also describes uncertainties associated with the projections – including those on regional scales – and concludes with recommendations to further improve understanding of the climate system in the region.

Individual climate change reports for each of the 15 participating countries are presented in the second volume. Each of the country reports in *Volume 2* has four main sections: (1) seasonal cycles, (2) climate variability, (3) observed annual trends, and (4) projections for atmospheric and oceanic variables.

A brief outline of the report and some of its main findings will be described.

15.9. SENSITIVITY OF OCEANIC CARBON UPTAKE TO PERMANENTLY CHANGED EQUATORIAL SURFACE WIND STRESS

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This study aims to analyse the sensitivity of the ocean's carbon uptake and storage characteristics to the strength of the surface equatorial wind stress. For this a global climate model of intermediate complexity (UVic ESCM v2.9) is forced using seven different scenarios with wind climatologies based on NCAR reanalysis data. The suite of scenarios consists of one control experiment which uses the unchanged NCAR surface wind stress and six experiments perturbed by a surface wind stress reduction or intensification by 10%, 20% and 30% in the equatorial region between 30°S and 30°N. All other forcing is kept identical across the seven experiments.

Initial results suggest that the applied changes in surface wind stress cause significant alterations in ocean circulation that lead to major modifications in the behaviour of the solubility and the biological carbon pumps. The response of the global ocean carbon cycle differs strongly between the reduced surface wind stress scenarios and those with enhanced wind forcing. While the system seems to react in an almost linear manner to the enhancement of equatorial wind stress exhibiting a progressive decrease in total DIC, the response to a reduction is more complex, with a slight increase in total DIC for the 10% and 20% reduction cases and a slight decrease in total DIC for the 30% reduction case. The study presented here analyses this behaviour in detail and identifies the main drivers of this change in the carbon cycle response. This provides insight into the processes that govern the ocean carbon cycle and furthermore offers indications about the evolution of the global carbon cycle under climate change, which could have a high impact on the equatorial surface wind stress.

15.10. IMPACT OF INDO-PACIFIC FEEDBACK INTERACTIONS ON ENSO DYNAMICS DIAGNOSED USING ENSEMBLE CLIMATE SIMULATIONS

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The impact of Indo-Pacific climate feedback on the dynamics of El Niño Southern Oscillation (ENSO) is investigated using an ensemble set of Indian Ocean decoupling experiments, utilising a millennial integration of a coupled climate model. It is found that eliminating air-sea coupling over the Indian Ocean results in stronger ENSO variability with various degrees of amplification across the experiments. This is accompanied by a shift in the underlying ENSO dynamics toward a more prominent thermocline mode that stems from stronger air-sea coupling in the equatorial Pacific. The stronger coupling results from weaker western Pacific zonal wind anomalies that generally act as a negative feedback on ENSO. This is shown to be consistent with the absence of Indian Ocean basin-wide mode (IOBM) in the decoupled runs.

The decoupling experiments reveal that the net effect of the Indian Ocean in the control simulation is a damping on ENSO. The degree of this damping appears to be negatively correlated to the coherence between ENSO and Indian Ocean Dipole (IOD). Such relationship arises from the tendency in the model to simulate more prevalent IOBM anomalies that coincide with ENSO growth during epochs when ENSO and IOD co-occur less frequently. It is demonstrated using AGCM experiments that, in contrast to the damping effect of IOBM, the IOD does not interrupt ENSO growth. This study thus suggests that the net negative feedback by the Indian Ocean on ENSO is weaker (stronger) during epochs of stronger (weaker) ENSO-IOD coherence, with an impact on ENSO dynamics. This study demonstrates that Indo-Pacific feedback and ENSO dynamics are linked, and thus supports the notion that the Indian Ocean should be viewed as an integral part of ENSO dynamics.

15.11. PROJECTED WIND DRIVEN CHANGES TO THE TROPICAL PACIFIC

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The Equatorial Undercurrent (EUC) is a fast subsurface jet spanning the Pacific Basin. It supplies the eastern equatorial Pacific with the dissolved iron that allows high levels of biological productivity. On interannual timescales a strong relationship exists, in both observations and models, between the strength of the EUC and the equatorial Trade winds. Weaker winds, associated with El Nino, drive a weaker current. However, climate projections suggest both an overall reduction in the strength of the equatorial trade winds and an increase in the EUC strength in the western and central Pacific. We demonstrate that this apparent discrepancy can be explained by examining the relative importance of equatorial and off-equatorial wind changes associated with interannual variability and anthropogenic climate change. Using a shallow water model we show that the projected changes can be explained as a linear response to the wind changes alone (i.e. without recourse to buoyancy changes). While the changes in the equatorial winds bear some resemblance on the two timescales, the off-equatorial response is quite distinct and the processes driving the wind change patterns are very different.

15.12. ANALYSIS OF HISTORICAL CLIMATE EXTREMES IN THE PACIFIC REGION USING NEW AND EXISTING INDICES.

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Small island states in the Pacific Ocean are amongst the most vulnerable nations to climate variability and climate change. The high vulnerability of these nations means that understanding climate variability and change is essential while the remoteness of the islands and lack of historical data has made the task challenging.

Current climate variability must be well understood so that the impacts of future climate change, particularly those related to climate extremes, may be assessed. To this end, the Pacific-Australia Climate Change Science and Adaptation Planning Program (PACCSAP) is addressing this issue for Pacific Island nations.

As part of the PACCSAP, this research has focused on enhancing tools for analysis of historical climate extremes in 15 Pacific Island Countries and East Timor. This research utilised indices of climate extremes which were developed by the WMO Expert Team on Climate Change Detection and Indices (ET-CCDI). Indices describing climate extremes were calculated and analysed using the RClimDex software, with the software extension incorporating the novel ET-CCDI indices. Data was collected for partner countries from various sources and quality controlled. The results of the analysis of daily temperature and precipitation data are presented here. In this way the current research fits in to an existing global framework, building on an international effort to improve understanding of climate variability and trends and includes the latest in a series of workshops dedicated to building our understanding of climate extremes and capacity building in regional areas. New sector specific indices, developed by the Expert Team on Climate Risk and Sector-specific Climate Indices (ET-CRSCI) were also analysed. The addition of new climate indices reflected a shift to the end users of climate services. The new indices are focused on the on-ground needs of specific sectors such as the health and agricultural industries.

Acknowledgment

The research discussed in this paper was conducted with the support of the Pacific-Australia Climate Change Science and Adaptation Planning Program, which is supported by the Australia Agency for International Development (AusAID), in collaboration with the Department of Climate Change and Energy Efficiency.

15.13. CONVECTION RELATED MODEL BIAS AND ITS IMPACT ON TROPICAL WEATHER SIMULATION

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Convection behavior in UM 7.8 has been investigated. This work shows that in UM the following features of convection are not well represented:

1) There is still convection occurring in the relatively dry environment, and convection is persistent, but lack of organization.

2) The model fails to produce the pre-moistening by shallow convection before intensive rainfall events.

3) The deep convection is not efficient to moisten the troposphere.

The impact of these model bias on MJO, the tropical rainfall climatology and tropical cyclone simulation are discussed. Model simulation has been improved by changing convection trigger and increasing entrainment rate.

Stream 16. Tsunamis and their Impact

Conveners: Dale Dominey-Howes, James Goff, Diana Greenslade, Chari Pattiaratchi

Oral Presentations

PROGRESS TOWARDS A GLOBAL TSUNAMI WARNING SYSTEM

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The need for a global tsunami warning system was clearly evident after the 26 December 2004 Indian Ocean tsunami *(1)*. As a first step towards this goal, UNESCO's Intergovernmental Oceanographic Commission (IOC) coordinated the expansion of the existing Tsunami Warning System (TWS). The TWS in the Indian Ocean envisioned a modeling tool to transfer expertise among the Indian Ocean nations. NOAA's Center for Tsunami Research (NCTR) developed the Community Model Interface for Tsunamis (ComMIT) to meet this goal. ComMIT distribution sessions in the Indian Ocean and other regions have trained more than two hundred scientists in basic tsunami science and modeling and resulted first generation inundation maps for many tsunami-prone shorelines *(2)*.

On 11 March 2011 at 05:46:23 (UTC), a magnitude 9.0 earthquake, the fourth largest since 1900, occurred off the northeastern Tiheiyou coast of Japan. The Tohoku earthquake generated a devastating local tsunami that caused over 20,000 deaths. Warnings were issued throughout the Pacific and the resulting tsunami disrupted maritime activities ocean-wide and caused significant damage in two California harbors. Actions taken during the Tohoku tsunami illustrated how the ComMIT technology, or some version of it, could be adapted in to a global tsunami warning operations. The distributed tsunami forecast system technology, use and results will be presented.

ON THE GULF BETWEEN EFFECTIVE TSUNAMI WARNING SYSTEMS AND MEANINGFUL DISASTER RISK REDUCTION

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The Pacific Ocean has had a Tsunami Early Warning System (TEWS), the PTWS for nearly five decades. After the 2004 Indian Ocean tsunami disaster, organizations and governments in partnership with the UNESCO-IOC have worked to establish several additional regional TEWSs including the Australian Tsunami Warning System or ATWS.

The rapid establishment of operational TEWSs is a credit to those scientists who have worked tirelessly since 2004 and are a necessary component of effective disaster risk reduction efforts. The operational capacity of the ATWS has been demonstrated successfully several times following the generation of tsunamis broadly within our region (e.g., July 15, 2009 Tasman Sea tsunami). By successful, I mean that the system has accurately and quickly detected a tsunamigenic earthquake, located its source, depth and magnitude, identified precomputed tsunami wave height forecasts and travel time estimates and disseminated warning and advice messages via appropriate www and media outlets.

Not-with-standing the operational effectiveness of the ATWS, members of the public still ventured down to watch and even swim into the arriving tsunami. This social process was notably observed following the February 201o Chile tsunami along the beaches of Sydney. To date Australia has been lucky because no significant tsunami has affected our shores since the implementation of the ATWS. If the general public continues to behave as it has done on previous occasions, then despite the best efforts of government scientists and engineers to develop and deploy the ATWS, it will fail and meaningful disaster risk reduction will not occur.

This talk will explore these issues in greater depth.

DEVELOPING TSUNAMI INUNDATION MODELS FOR EMERGENCY RESPONSE PLANNING

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With increasing awareness and understanding of the risks associated with tsunami, government and emergency service providers are looking to better understand tsunami risk within their jurisdictions. One such effort is the New South Wales (NSW) tsunami hazard risk assessment, established by the NSW Department of Environment, Climate Change and Water (DECCW) and the NSW State Emergency Service (SES). Phase 2 of this assessment included investigations of potential tsunami inundation at five NSW coastal sites identified as being relatively vulnerable low-lying coastal communities. Of specific interest was the likely inundation extent and hazard (velocity x depth) from tsunami events to enable future consideration of tsunami impacts in coastal zone management and planning, as well as to assist in the development of tsunami emergency planning, response and community education.

Inundation modelling was completed using Delft3D hydrodynamic models making use of a specialised advection scheme for flooding that is able to describe the rapidly varying and super-critical flows observed during tsunami inundation events. Of particular importance to the study was the verification of the modelling approach to international benchmark standards, as well as to local historical records. Furthermore, an efficient model setup that adequately characterises the foreshore area was established and rigorously tested.

Tsunamigenic databases developed by the Bureau of Meteorology (BoM – T2 database) and GeoScience Australia (GA – Tsu-DAT) were utilised and scenarios from these used as boundary conditions to shelf scale Delft3D inundation models. These databases provided tsunami signals at inshore locations from a range of possible source zones that allowed consideration of events at a number of risk (recurrence) levels.

This paper will discuss the lessons learnt in developing a modelling methodology for assessing tsunami inundation and to comprehensively investigate this risk along the NSW coast.

VALIDATION OF TSUNAMI WARNING THRESHOLDS USING INUNDATION MODELLING

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Tsunami warnings issued by the Joint Australian Tsunami Warning Centre (JATWC) are derived from a database (T2) consisting of more than two thousand pre-computed tsunami scenarios. Following every potential earthquake a warning is issued for each coastal zone with three different levels of threat: marine, land or no threat. The decision is based on the wave amplitudes at the offshore locations of the relevant T2 scenario within the coastal zones. Threshold amplitude values have been derived through analysis of observed impacts for recent events. Given that historical records are available for a very short time period and no observations for which a land threat would have been issued for Australia exist, it has been difficult to determine the appropriate threshold for a land threat and this is currently set at a relatively conservative value. A recent study for NSW investigated possible mega earthquakes from known subduction zones and computed predicted inundation distances. These are used for the further evaluation of the land threat threshold values for the JATWC tsunami warnings. Inundation results of tsunamis from Puysegur, New Hebrides, Kermadec, Tonga and South Chile are used for verifying the threshold values at Swansea, Manly, Botany Bay, Wollongong (Port Kembla) and Merimbula.

TSUNAMIS: ALL TSUNAMIS ARE NOT GENERATED BY EARTHQUAKES AND NOT ALL EARTHQUAKES GENERATE TSUNAMIS

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We often hear that the 2004 Indian Ocean Tsunami was larger than expected as were the 2011 Tōhoku and 2009 South Pacific events. Quite rightly it is acknowledged by seismologists that these “caught them out” and indeed there is still much to learn about the geophysical complexities of earthquake-generated tsunamis.

On the other hand though, many of the same researchers appear capable of producing numerous probabilistic tsunami hazard assessments (PTHAs) that apparently show the hazard for a place, region or country. Most PTHAs though are based upon extrapolation from historical events and essentially, best professional guesses about how bad fault rupture sources might be.

This is wrong in so many ways, not the least of which are:

a) Numerous recent large tsunamis have been larger than expected so the ability to produce reasonable PTHAs is suspect.

b) All tsunamis are not generated by earthquakes and not all earthquakes generate tsunamis.

The first point largely comes down to history. Extrapolating from historical events essentially ignores prehistory and, not surprisingly, in most cases palaeotsunamis are larger than their historic counterparts. So why not include them? Indeed, in the wake of the 2011 Tōhoku event, Japanese authorities recognised the urgent need to consider the palaeotsunami record in order to better understand their tsunami hazard. A PTHA without palaeotsunami data serves little purpose.

The second point is to a certain extent fundamental to understanding tsunamis. We fail to consider other potential sources at our peril – or rather at the peril of others. PTHAs rarely do more than pay lip service to non-earthquake sources. Tsunami scientists ("tsunamologists") study tsunamis, seismologists study earthquakes; seismology contributes to tsunamology, and tsunamology contributes to seismology. In the absence of a comprehensive tsunamological perspective, tsunami hazard assessments of any kind fail to appreciate the full extent of the hazard.

THE EFFECT OF BATHYMETRIC FEATURES ON TSUNAMI PROPAGATION IN THE GREAT BARRIER REEF REGION

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Tsunami warnings for the Australian coast are based on a database of pre-computed scenarios called T2. In the event of a tsunamigenic earthquake, the level of warning is determined by selecting the closest matching scenario and evaluating the modelled tsunami amplitude near the Australian coast

The Great Barrier Reef (GBR) region imposes a large range of scales and types of underwater formations, some of which are poorly resolved by the 4 arcmin computational grid size of T2. Expected types of formations include ridges and troughs, submarine islands and channels, and small scale irregularities with relevant scales ranging up to 30 km. While it is generally given that a higher resolution would achieve a more accurate simulation, we address two practical questions concerning the typical scales of tsunamis and types of obstacles in the GBR: (1) What is the minimum resolution to adequately simulate the effect of an obstacle of a particular type and size? (2) For this obstacle, which of these are more limiting: (a) bathymetry resolution, or (b) wave resolution ? These questions are useful in nested modeling, where the choice of domain boundaries and grid size needs to take into account the dominant bathymetry features.

We classify bathymetry features of the GBR into different classes of obstacles, each characterised by a typical scale and expected wave-bathymetry effect. For each class, we run nested simulations using high resolution bathymetry and analyse the results using simple analytical solutions and scaling analysis. The results are discussed in terms of different types of bathymetric effects on waves, including reflection and transmission, wave guiding and multiple scattering.

Poster Presentations

16.1. MODELLING TSUNAMI INDUCED SHELF AND BAY OSCILLATIONS IN WESTERN AUSTRALIA.

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The coastline of Western Australia (WA) experiences both seismic tsunamis originating from the Java/Sumatra region and meteorological tsunamis ('meteo-tsunamis') generated through the Proudman resonance phenomenon due to travelling atmospheric pressure jumps, particularly during the summer months. High frequency sea level oscillations and currents induced by these events have been investigated using observations and hydrodynamic models. The predicted sea levels and currents were subjected to spectral analyses to determine the temporal and spatial oscillation behaviour along the coastline and within the continental shelf region. The results show that both type of events enhanced existing natural period shelf and bay oscillations. The spectral energy distribution maps for the entire WA shelf region have been produced by analysing predicted sea levels. The fundamental mode of shelf resonance period ranges ~ 1.5 to 4 hrs along the coastline of WA in relation to shelf width variation, with nodal line (minimum energy) located along ~250 m depth contour line. These energy distribution maps allow us to identify the nodal and anti-nodal points (and lines) of shelf and bay oscillation in WA continental shelf. The results revealed that superimposition of shelf, bay resonance causes to temporal and spatial irregular sea level oscillations along the coastline. The high risk coastal regions and relatively low risk locations within the shelf region during tsunami events may be identified using the resonance spectral energy distribution maps.

16.2. HOLOCENE SEDIMENTARY RECORD OF GRADUAL, CATASTROPHIC AND HUMAN INFLUENCED ENVIRONMENTAL CHANGES AT MOAWHITU WETLAND, D'URVILLE ISLAND, NEW ZEALAND.

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Active tectonism, sea level fluctuation and human arrival have moulded the present day physical environment of New Zealand. Coastal wetlands are recognised archives of Holocene environmental changes. By applying sedimentological, geochemical and chronological techniques to coastal wetlands, natural and anthropogenic changes can be observed. Moawhitu Wetland, located on D'Urville Island, New Zealand, is home to a Maori oral tradition that describes a giant wave destroying a community in the 15th century. Little geological work has been carried out to investigate the evidence of the event and no studies have researched the palaeoenvironmental history of the area. This research was therefore aimed at reconstructing the Holocene environmental record at Moawhitu Wetland to determine if there was evidence of severe changes to the landscape as described in Maori oral traditions.

Three sedimentary sequences from Moawhitu Wetland were used to reconstruct a 7500 year record that incorporated gradual, catastrophic and human influenced changes. The record was established by using multiple sedimentary proxies (grainsize, organic matter content, geochemistry and mineralogy) at three different sites that were temporally aligned with dating techniques (14C and 210Pb) . Barrier formation, lake and wetland formation, erosion, human influences and a tsunami ~3000-3300 yr BP were identified in the sedimentary record. These changes were applied to a broader spatial context from which inferences of sea level rise, regional faulting and potential climate change were drawn. The central west coast of New Zealand has undergone an array of short and long term environmental changes throughout the Holocene and can be identified as an area susceptible to potential tsunami events.

16.3. HOLOCENE EVOLUTION OF FOUR SOUTH COAST SITES AND IMPLICATIONS FOR UNDERSTANDING AUSTRALIAN TSUNAMI RISK

Claire Courtney

The 2004 Indian Ocean tsunami resulted in a marked increase in concern regarding regions previously considered low risk of tsunami inundation. The southeast coast of Australia has a record suggesting low tsunami risk, with only 47 small tsunamis striking since European arrival. However, the controversial megatsunami hypothesis suggests patterns of massive inundation of the east Australian coast. Given the extreme vulnerability of the NSW coastline due to population concentration and the reliance on boulder deposit evidence, there is a need to provide thorough re-evaluation of the Australian tsunami risk.

This re-examination has led to research at four back-beach locations on the south coast of New South Wales, located close to sites reported to contain evidence of megatsunami inundation. Analysis of stratigraphy, sediments, geochemistry and microfossils, plus an extensive radiocarbon chronology of these sites allows for a full reconstruction of the Holocene environments. This success highlights the importance of using multi-proxy diagnostic techniques in investigating potential tsunami inundation sites with relatively short historical records. In the case of NSW, no evidence of Holocene tsunamis has been identified, casting serious doubt on the existing understanding of tsunami risk on the NSW coast and the diagnostic criteria used for identifying tsunami deposits.

16.4. TSUNAMIS IN THE NORTHEASTERN INDIAN OCEAN WITH A PARTICULAR FOCUS ON THE BAY OF BENGAL REGION – A REVIEW

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The 2004 Indian Ocean Tsunami (IOT) challenged assumptions about the level of risk in the region. Debate exists about the hypothesis that the northern Bay of Bengal may be capable of generating large tsunamis similar to the 2004 IOT. To test this hypothesis, we document tsunamis in the northeastern Indian Ocean. Using multiple sources, we identify 135 purported tsunamis. After completing a process of validity assessment, we categorised 31 definite, 27 probable, 51 doubtful tsunamis and 20 events that only caused a seiche or disturbance in an inland river. Six of the purported events were identified as either cyclones or earthquakes without any associated tsunamis. The oldest event is dated to 38000 BC. Global tsunami databases and Cummins (2007) indicate that an event occurred on the 2nd April 1762 along the Arakan Coast, generated a megatsunami and flooded the northern Bay of Bengal. In contrast to global tsunami databases and Cummins (2007), local Bangladesh (LB) archives and documents in the Indian Record Office at the British Library (BL) report only land subsidence on the banks of the Meghna, Karnaphuli and Halda rivers and along the coast of the Bay of Bengal with subsequent inundation of the subsided areas from the adjacent rivers or sea. In addition, the BL and LB have also reported soil liquefaction, land-uplift, and human casualties and injuries in Chittagong, Bangladesh. An analysis of the reported areas provided by the LB and BL sources is currently in progress following field investigations in Chittagong. Statistical analysis of tsunami data suggests that the occurrence of a tsunami affecting the coasts of Bangladesh and Myanmar is around 1% in any given year. We recognise that this is an incomplete tsunami dataset and recommend further 'deep' archival research coupled with regional palaeotsunami studies to gain a sophisticated understanding of the hazard.

Reference:

Cummins, P.R., 2007. The potential for giant tsunamigenic earthquakes in the northern Bay of Bengal. Nature, 449: 75-78.

Stream 17. Wind-Generated Waves and their Role in Large-Scale Air-Sea Interactions

Conveners: Alex Babanin, Mark Hemer, Ian Young

Oral Presentations

LONG TERM OCEANIC TRENDS IN WIND SPEED AND WAVE HEIGHT

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Long term global data sets are now becoming available for oceanic parameters such as wind speed and wave height. These data sets provide an opportunity to assess whether the global ocean wind and wave climate is changing. This paper will review data from: altimeter and SSM/I satellite platforms, buoy observations, micro-seismic observations and global wave model reanalysis predictions. All data sources suggest that there is a statistically significant global trend towards increasing wind speed and wave height. The data also suggests that extreme conditions are increasing at a faster rate than the mean, indicating the there is a tendency towards more storm or more intense storms, or both.

CONNECTION BETWEEN TIME SCALES: TURBULENCE, WAVES, WEATHER, CLIMATE

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It is rapidly becoming clear that many both small- and large-scale geophysical processes are essentially coupled with the surface waves. The waves are generated by the atmospheric winds, but in turn they determine the surface roughness for these winds, and this roughness evolves as the waves develop. The evolving waves moderate or even define fluxes of energy and momentum across the ocean interface, as well as gas and humidity exchanges, and these fluxes influence both the atmosphere above and the ocean below. In this paper, role of the waves in producing turbulence, unrelated to wave breaking, will be discussed. Such turbulence is depth-distributed at the scale of wavelength, it affects the upper-ocean mixing and thus produces feedback to the large-scale processes, from weather to climate. In order to account for the wave-turbulence effects, large-scale air-sea interaction models need to be coupled with wave models.

PROJECTED CHANGE IN GLOBAL WAVE CLIMATE FOR FUTURE CLIMATE SCENARIOS

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Surface wind-waves are a key driver within the coastal zone, but up until recently only little attention was given to how the global wind-wave climate might respond to projected future changes in climate.

The CSIRO cubic conformal atmospheric model has dynamically down-scaled a select few CMIP-3 global climate models, to a resolution of approximately 60km globally. Three-hourly surface 10-m winds from the high resolution CCAM runs are used to force the WaveWatchIII spectral wave model for two 30-yr periods which represent a present (1979-2009) and future (2070-2099) time-slice respectively. These runs are repeated for two CCAM ensemble members (downscaled CSIRO Mk3.5 GCM, and downscaled ECHAM5 GCM), for the SRES A2 emission scenario, to allow measure of uncertainty within modeled wave conditions under climate model forcing.

Wave properties from the control period (1979-2009) are compared with the ECMWF ERA-Interim reanalysis for verification. Broad features of the global wave climate are qualitatively well reproduced by the climate model forced wave fields.

Comparing wave climate derived from future time-slice (2070-2099) with wave climate derived from the present time-slice (1979-2009) suggests projected changes in global wave climate. A southern contraction of the Southern Ocean extra-tropical storm belt leads to projected changes in wave climate throughout the global ocean.

Projected changes in wave conditions are compared within the context of an international community ensemble of wave climate projections established through the Coordinated Ocean Wave Climate Projections (COWCLIP) project, to assess robustness of projected changes.

IS THE SURFACE WIND ASYMMETRY IN A TROPICAL CYCLONE AFFECTED BY THE WAVES?

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Observations and theory show that, while the wind field of a tropical cyclone is reasonably symmetric, the wave field beneath is very much less so. This strong wave field asymmetry is expected to lead to a significant asymmetry in the surface drag coefficient, which will in turn contribute to the wind asymmetry. Other sources of wind asymmetry include environmental wind shear and the storm motion. This study uses an idealised model of the tropical cyclone boundary layer to diagnose the relative contribution of drag coefficient asymmetries to the wind asymmetry, and to provide a preliminary assessment of the relative importance of parameterising this process in tropical cyclone models.

RECENT AND FUTURE CHANGES IN WAVE CLIMATE IN THE PACIFIC REGION

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Many Pacific Islands are vulnerable to impacts of waves through coastal inundation, coastal and beach erosion, wave driven lagoon circulation, disturbances to reef habitats etc. On steep continental shelves like Pacific island coral atolls, surface waves are the dominant contributor to coastal sea-level extremes via wave set-up.

A recent review of the availability of modelled and observed wave data in the Pacific region noted the need for a high-quality multi-decadal wave climate data set. The absence of high temporal resolution spectral wave data was noted, with existing hindcast products assessed as being of inadequate spatial and temporal resolution in general. Wave hindcast resolution has historically been limited by the resolution of available winds. The recently completed National Centers for Environmental Prediction's (NCEP) Climate Forecast System Reanalysis (CFSR) surface winds now provide a consistent product at 0.5°, hourly resolution over the past 30 years, providing a valuable source of forcing for wave hindcasting.

As part of the Pacific-Australia Climate Change Science and Adaptation Program (PACCSAP) , work has recently begun examining recent, existing and projected future ocean wave conditions with a focus on the Pacific region. This project aims to deliver a 0.5° 30-yr (1979-2009) global wave hindcast, as well as a number of wave climate projection runs, produced using various CMIP5 wind forcing data. An important aspect of the hindcast is that it will be capable of providing wave boundary conditions for nested, high spatial resolution models for Country/Island scale studies, to support coastal and nearshore hazard assessments.

This talk will present an overview of the project as a whole, and discuss some initial verification results of both the CFSR winds, and one or more wave model hindcasts forced by these winds.

Poster Presentations

17.1. WIND-GENERATED LONG-PERIOD WAVES IN THE SOUTHERN OCEAN OBSERVED BY SATELLITE LASER ALTIMETRY

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Ocean waves with periods greater than several seconds and wavelengths greater than a few kilometers frequently cause damage to coastal areas and have been implicated in the breakup of floating ice shelves. The Geosciences Laser Altimetry System (GLAS) aboard the ICESat-1 satellite produces surface elevation measurements with a vertical precision of a few centimeters and spatial resolution of 172 meters and is thus an ideal instrument for studying the origin, propagation, and characteristics of long-period ocean waves. This paper describes ICESat-1 observations of such waves in the Weddell and Ross Seas and off the New Zealand coast that correspond with in situ data and are associated with storm events hundreds or thousands of kilometers away. Observed wave behavior includes propagation of the waves hundreds of kilometers into floating sea ice and shoaling as the waves encountered shallow bottom topography. The characteristics of some of the waves, including wavelengths of 70-100 km and amplitudes of 1-2 m in the open ocean, correspond with theoretical predictions of waves that deposit maximum energy into floating ice shelves.

17.2. A THREE-DIMENSIONAL, WAVE-CURRENT COUPLED, SEDIMENT TRANSPORT MODEL FOR POM

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In the high-energy environment of coastal seas and estuaries, strong sediment resuspension/deposition events are driven by surface waves, tides, winds and buoyancy driven currents. In recent years, A POM based three-dimensional, wave-current coupled, sediment transport model has been developed by the University of New South Wales. This talk presents several examples of the model applications to study sediment dynamics in the environments where forcings such as waves, tides, and winds are equally important to affect sediment fluxes and distributions. Firstly, the sediment transport model coupled to the Adriatic Sea general circulation model and a third generation wave model SWAN was implemented in the Adriatic Sea to study the dynamics of the sediment transport and resuspension in the northern Adriatic Sea (Italy). The sediment distributions and fluxes under various forcing conditions such as the Po River plume, the Bora and Scirocco wind stress and the surface waves were studied by process oriented as well as realistic numerical simulations. Secondly, the sediment transport model was used to explore the effect of suspended sediment-induced stratification in the bottom boundary layer (BBL). The model uses a re-parameterized bottom drag coefficient C_d that incorporates a linear stability function of flux Richardson number R_f. The study has shown that the sediment induced stratification in the BBL reduces the vertical eddy viscosity and bottom shear stress in comparison with the model prediction in a neutrally stratified BBL. In response to these apparent reductions, the tidal current shear is increased and sediments are abnormally concentrated within a thin wall layer that is overlain by a thicker layer with much smaller concentration. The formation of this fluid-mud layer near the seabed has led to a significant reduction in the total sediment transport. This study contributes to the understanding of formations of tidal flats along the coasts of turbid seas and estuaries. Finally, the ecological and socio-economic impact of resuspended sediments in the turbid estuaries and seas such as Australia and China was also studied. For example, the green tide (macroalgal bloom) which occurred in the 2008 Olympic sailing venue in Qingdao, China, attracted international media coverage. This presentation will show that the algae bloom event was primarily caused by a reduction in the Yellow Sea turbidity. The study also showed the direct economic loss associated with the algae clean up was more than 600 million RMB (AU$120 million).

Stream 18. Hydroclimate of the Murray-Darling Basin

Convener: David Post

Oral Presentations

WHAT FUTURE FOR WATER? WHY CLIMATE SCIENCE MATTERS.

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DAVID.POST@CSIRO.AU PROJECTIONS OF FUTURE WATER AVAILABILITY FOR THE MURRAY-DARLING BASIN

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The majority of global climate model simulations indicate that south-eastern Australia (including the Murray-Darling Basin) will, on average, be drier in the future, particularly across the far south of the region. This is consistent with the expected changes in the large scale atmospheric and oceanic drivers of rainfall in this region in a warmer world. Although the average rainfall and streamflow in south-eastern Australia are projected to decline, extreme rainfall events are likely to be more intense because warmer temperatures will provide stronger convection and an increased capacity for moisture to be held in the air. These higher intensity storms will increase flood risks, cause greater storm and sewer runoff in urban areas, and increase erosion and nutrient delivery to waterways, particularly during high-runoff events following dry periods.

This presentation will discuss the projected changes in future average annual rainfall and runoff modelled using future climate series downscaled from global climate model projections, focusing on the impacts of a 1°C global warming. The wet, median and dry estimates show the range of projected change representing the uncertainty. Averaged across the northern half of the region (north of 33°S), the median estimate is a decline in average annual rainfall of 3% (range of –12% to +4%) and decline in runoff of 10% (range of –30% to +14%). Averaged across the southern half of the region (south of 33°S) the median reductions in rainfall and runoff tend to be larger and are more consistent across the vast majority of projections, with a median decline in average annual rainfall of 4% (range of –9% to 0%) and decline in runoff of 12% (range of –24% to –1%).

SOUTH EASTERN AUSTRALIA RAINFALL IN RELATION TO THE MEAN MERIDIONAL CIRCULATION

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South eastern Australia (SEA) experienced during 1997-2009 its worst extended period of low rainfall since the instrumental record begin in the 1860's. In this presentation we will review the key internal drivers of SEA rainfall interannual variability and argue that while they all combined to produce the very wet spring-summer during 2010/11 and are useful to explain some of the observed decadal variability in SEA rainfall, they do not account for the persistent deficit during 1997 to 2009 and which has recommenced in 2011. In particular, 70% of that annual rainfall deficiency has occurred between April and July, when the main internal modes of variability have limited impact on SEA.

The long-term rainfall deficit can be explained in term of changes in the mean meridional circulation (MMC), which from the perspective of the atmospheric general circulation acts to transfer excessive heat from the Tropics to higher latitudes. In response to global warming, the meridional extent of the Tropical portion of the MMC (i.e. the Hadley circulation) is expected to widen. We will show estimates of a widening of the Hadley Cells diagnosed from re-analyses as well as independent measurement of the edge of the tropical tropopause from radiosondes. It will be shown that in the southern hemisphere, the extent of the MMC relates to the strength of the Subtropical Ridge (STR), thereby acting at Australian longitudes as a barrier to rain-bearing systems affecting SEA. Climate model simulations of the last 50 years can reproduce some of these observed changes, although not necessarily the full magnitude, providing anthropogenic external forcings are used. The climate model simulations, together with the analysis of the observed behavior of the internal modes of climate variability suggest that it is unlikely that the recent epoch of low rainfall is solely due to natural factors such as variation in natural forcings (e.g. volcanoes and solar activity) or internal variability (e.g. El Niño and the Southern Annular Mode), but rather is a consequence of human alteration of the climate.

Reference:

Timbal, B., and H. Hendon (2011), The role of tropical modes of variability in recent rainfall deficits across the Murray-Darling Basin, Water Resour. Res., 47, W00G09, doi:10.1029/2010WR009834: http://www.agu.org/journals/wr/wr1109/2010WR009834/

CHOICE OF DOWNSCALING METHODS FOR HYDROLOGICAL MODELLING

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Downscaling methods are increasingly being used to transfer coarse resolution climate projections from general circulation models (GCMs) to obtain catchment-scale climate series to drive hydrological models. Empirical scaling, statistical downscaling and dynamic downscaling are generally used to assess climate change impact on water resources.

The empirical scaling method perturbs the observed rainfall (and other climate variables) time series, informed by GCM simulations, to obtain future rainfall series. It can be used to reflect changes in the means as well as the daily rainfall distribution. The method is simple and robust and is therefore suitable for modelling over large regions with many GCMs and global warming scenarios. The statistical downscaling method relates synoptic predictors to local-scale predictands. The relationships are then used to downscale the GCM outputs to obtain future catchment-scale rainfall. The use of the statistical downscaling method is more laborious due to calibration and rainfall interpolation. However it can capture potential changes in a fuller range of rainfall characteristics and is therefore suitable for detailed hydrological studies over smaller regions. The dynamic downscaling model is a fine-scale climate model which attempts to represent the topography, vegetation and weather patterns. The dynamic downscaling model produces gridded daily rainfall directly (which may require bias correction for direct input to hydrological models) but needs longer computer run times.

This study shows the use of four downscaling models for hydrological modelling across south-eastern Australia. The models are an empirical daily scaling model, an analogue downscaling model, the non-homogeneous hidden Markov model (NHMM) in a gridded application, and the Weather Research and Forecasting (WRF) model. We compare the range of future runoff projections (means and other runoff characteristics) modelled using the different downscaling models and GCMs. Based on the results, the relative advantages and limitations of the downscaling models for hydrological applications are discussed.

IMPACT OF CLIMATE ENTITY CHOICES ON STATISTICAL DOWNSCALING AND MODELLED RUNOFF

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The Australian Bureau of Meteorology's Statistical Downscaling Model (BoM-SDM) is employed to provide fine scale (0.05 degree resolution) daily rainfall data, for both historical (1961-200) and future (2046-2065) periods. The downscaled rainfall data are used to drive hydrological models to estimate surface runoff. The study area is in the southeast Australia. It includes the entire Murray-Darling Basin and the Southeast Coast drainage divisions, which covers about 20% of the entire continent.

The SDM is applicable to the entire Australia continent, which is divided into ten climate entities (regions). The model builds the reconstructed daily series independently for each combination of region, season and predictand. For larger areas that span across more than one climate entity, we naturally have the choice of either combining the results from multiple entities or using a single main entity to represent the entire area. There are valid arguments for both of the methods, which need to be justified by comparing the final outputs to the observed values. This applies to the area of interest in this study. The study area can be represented by either combining the three climate entities, south east coast, south east Australia and Murray-Darling basin, or using a single south east Australia entity, which is considered to be the dominant climate entity for this area.

Here we show how the reconstructed rainfall series changes with the choices of representing climate entities. The boundary smoothing is studied for the multiple climate entity approach. The surface runoff is modelled using the rainfall series downscaled from these two different approaches. The validity of the two approaches and the hydrological model sensitivity to these input series are also discussed.

Poster Presentations

18.1. SOME INFLUENCES ON RAINFALL AND RUN-OFF IN SELECTED SOUTH EASTERN AUSTRALIAN CATCHMENT AREAS

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There has been an observed deficit in rainfall across Victoria from 1996-2009 which has been investigated in detail as part of the South Eastern Australia Climate Initiative. This deficit led to a very pronounced reduction in the inflow in the water catchments across most of the region. A wet 2010 has restored water levels in most catchments of south eastern Australia. Despite record rainfall across most of Australia (such as the entire Murray-Darling Basin) leading to above average run-off for the Murray River and most catchments north of the Great Dividing Range; below average run-off was recorded south of the divide (i.e. Melbourne Water catchment area).

In this study we focus on the rainfall-runoff relationship on both sides of the Great Dividing Range. Two well observed and natural catchments were chosen: the Eildon catchment on the north side of the divide and the Melbourne Water catchments on the south side. First, long-term relationships between rainfall in these two catchments and known modes of variability affecting South Eastern Australia are investigated with a focus on the differences between the two sides of the Divide. It is shown that while tropical modes of variability have a marked signature on the run-off on catchments on both sides of the Divide (but more pronounced on the northern side), it does not explain the consistently below average run-off since 1997. Alongside remote tropical influences, the role of the regional sub-tropical ridge (intensity and position) is shown to affect rainfall in these two areas on inter-annual and decadal time-scales and is more likely to explain the deficit since 1997. In addition the role that rising temperature may be playing in the rainfall run-off relationship is investigated on both sides of the Divide.

18.2. A PRELIMINARY LOOK AT THE HYDROCLIMATE OF SOUTHEASTERN AUSTRALIA IN THE NEXT GENERATION OF AUSTRALIAN GLOBAL CIRCULATION MODEL SIMULATIONS

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Australian researchers will contribute global circulation model (GCM) simulations to the next major global model inter-comparison project, the fifth phase of the Coupled Model Intercomparison Project (CMIP5). We examine the performance of two Australian contributions, ACCESS and CSIRO Mk3.6, in the simulation of the hydroclimate of south-eastern Australia and its broad scale drivers compared to earlier model simulations. In particular, we examine the representation of rainfall, temperature, the Australian Sub-tropical ridge and the rainfall-ENSO relationship.

In addition to model evaluation, we endeavor to quantify the variability inherent in the ten member CSIRO Mk3.6 ensemble and how this compares to our prior understanding of inter-model variability.

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