

Climate and groundwater recharge: the story from Australian caves



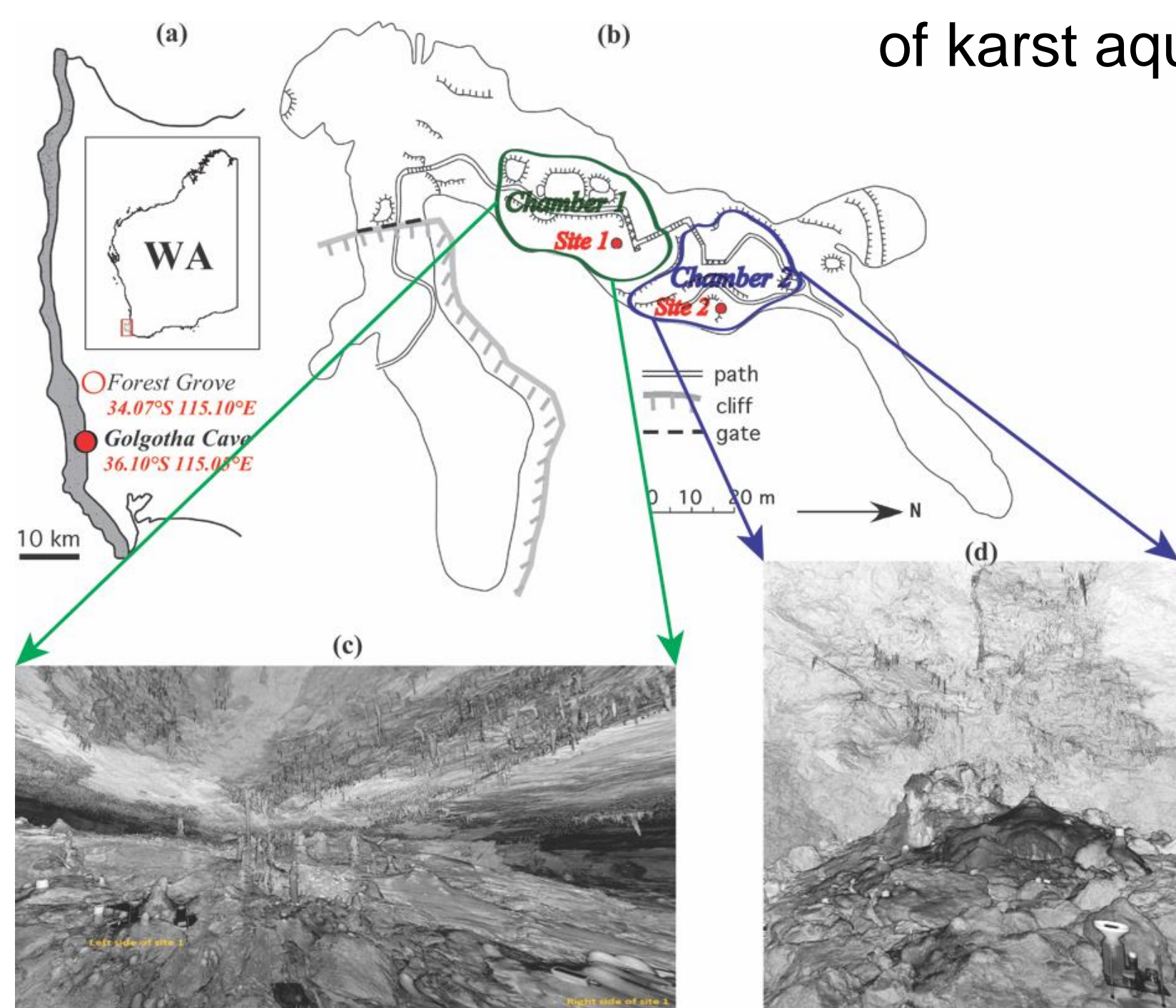
Andy Baker, Pauline Treble, Monika Markowska, Martin Andersen, Zhangyong Wang, Kashif Mahmud, Mark Cuthbert, Katie Coleborn and the Kempsey Speleological Society



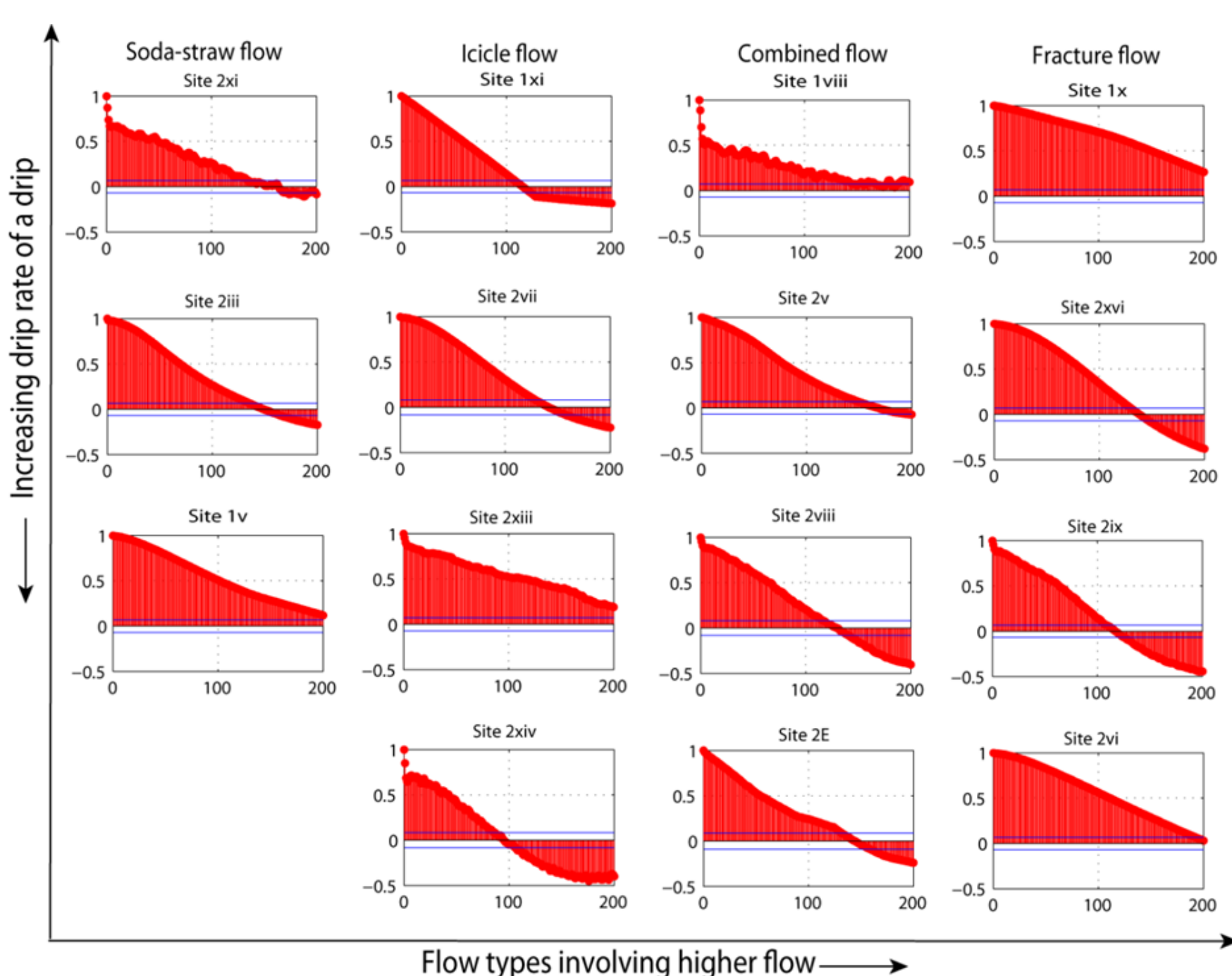
Caves provide direct access into the unsaturated zone. Direct observation of groundwater recharge can be used to compliment data from the saturated zone (boreholes) and models. The heterogeneity of recharge in karst aquifers can be directly observed and quantified. Speleothems preserve a record of groundwater recharge that can extend back for hundreds of thousands of years, providing a long-term view on the timing and processes of groundwater recharge in Australia.

Recharge Monitoring Network

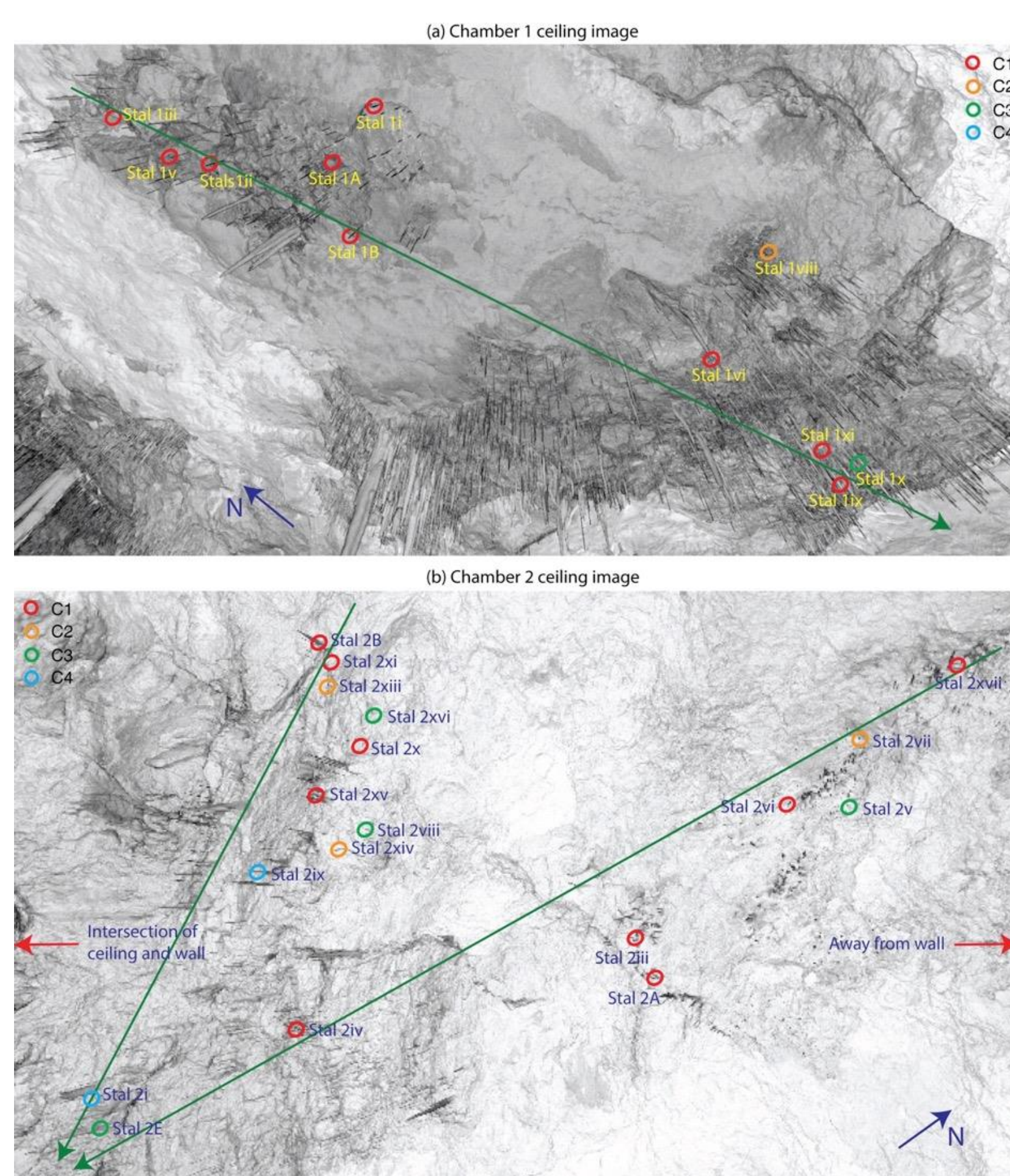
We have hundreds of loggers measuring recharge in the unsaturated zone of karst aquifers across Australia. We present results from two locations.



In South-West Western Australia (a), we are monitoring deep infiltration at two locations in Golgotha Cave at depths of 32.33 m (Site 1) and 40.24 m (Site 2). (c) Site 1 LiDAR image and (d) Site 2 LiDAR image (Mahmud et al 2015; 2016; 2017).

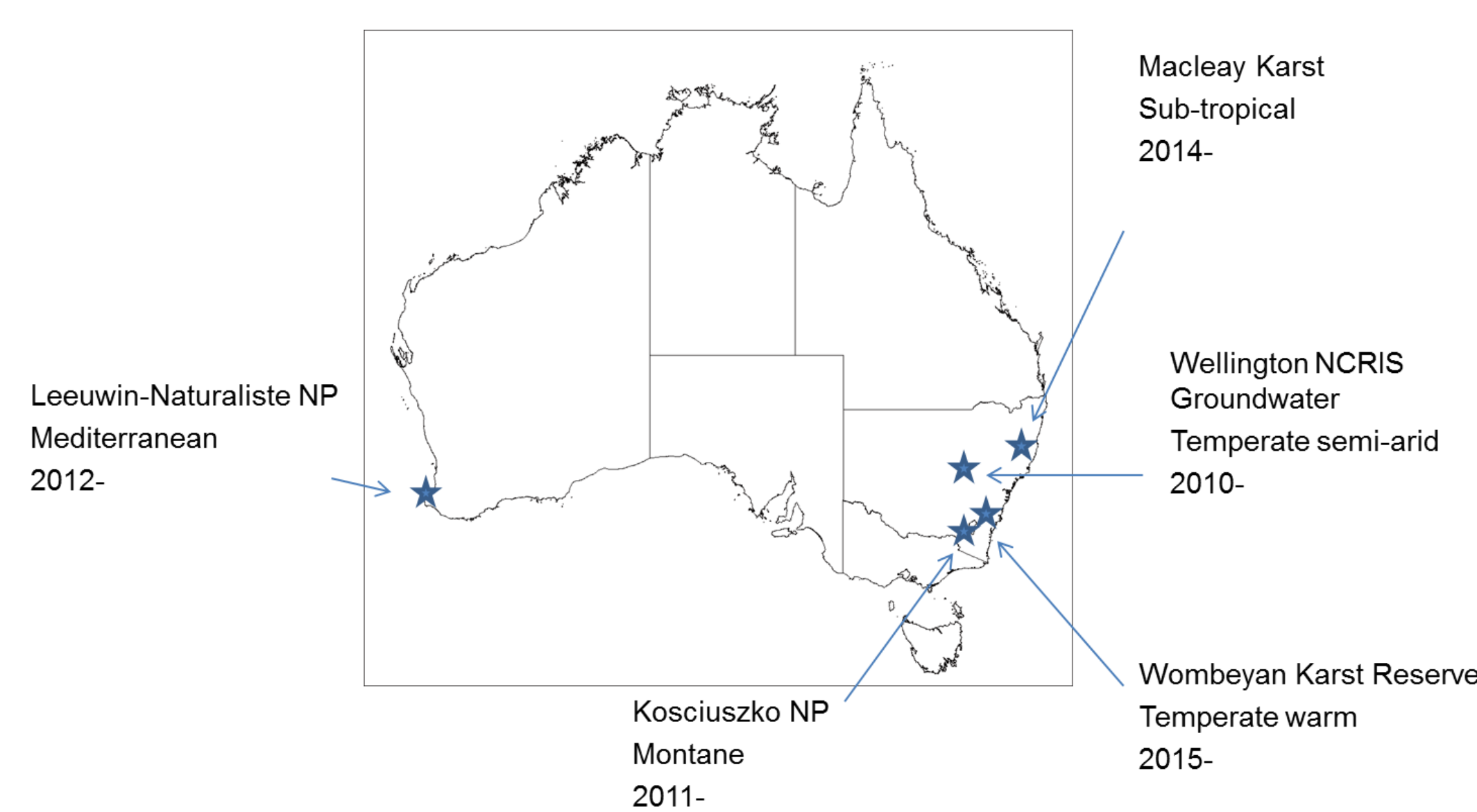


The Tamala Limestone is typical of Quaternary aeolianites found around Australia's coastal fringe. The limestone retains primary porosity, which is reflected in the >100 day temporal autocorrelation in drip rates (Mahmud et al 2017).

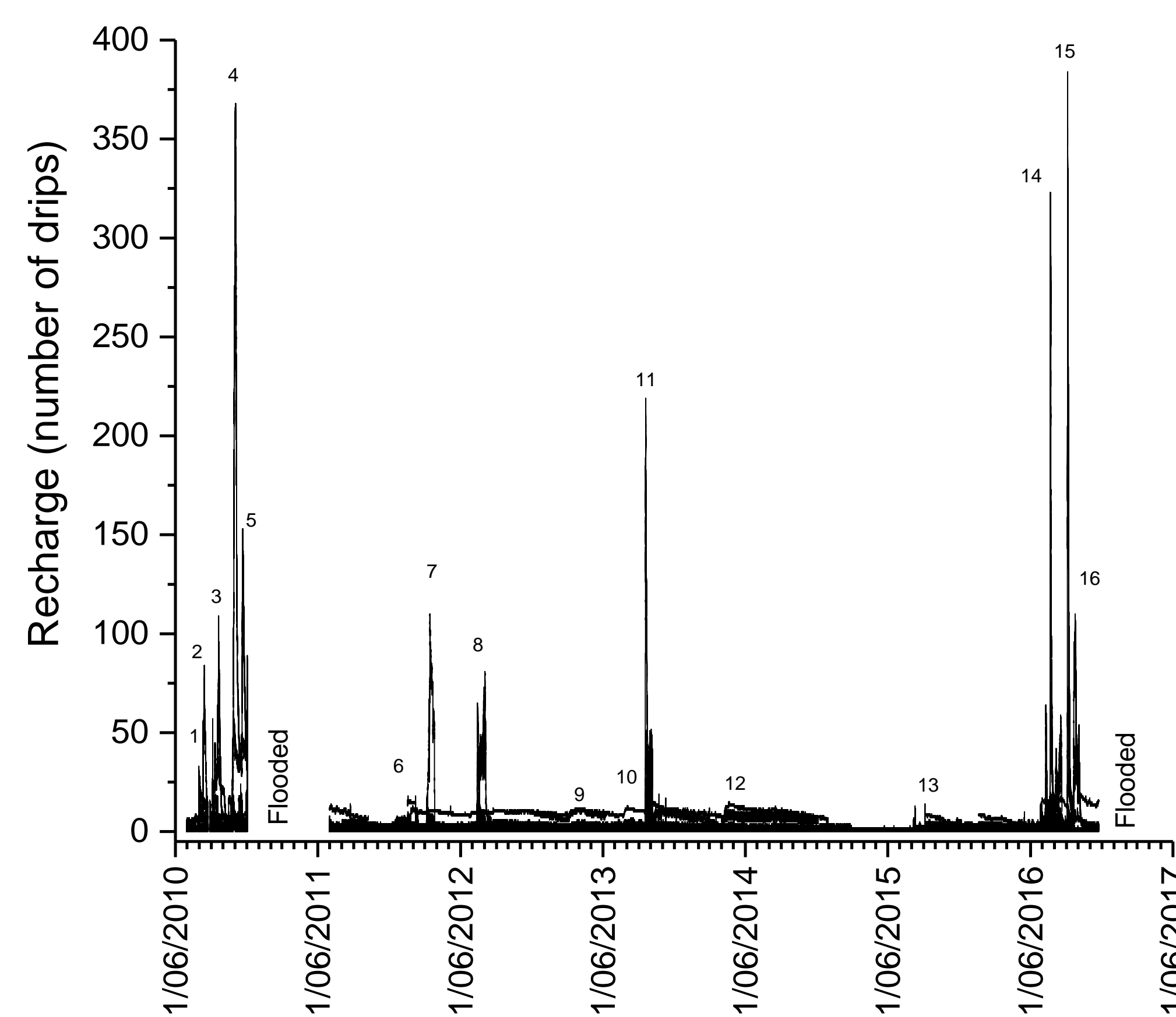


Infiltration characteristics can be used to cluster the drip sites into four types (C1 to C4). Heterogeneity in deep infiltration is related to both fracturing and ceiling elevation. The blue arrows in both figures show the geographic orientation and the green arrows represent the approximate transects throughout the chambers from higher to lower ceiling elevation.

Mahmud, K., et al. 2015. Estimation of deep infiltration in unsaturated limestone environments using cave LiDAR and drip count data. *Hydrological Earth Syst. Sci.*, 20, 3559-373
 Mahmud, K. et al. 2016. Terrestrial LiDAR survey and morphological analysis to identify infiltration properties in the Tamala Limestone, Western Australia. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 8, 4871-4881
 Mahmud, K. et al., 2017. Hydrological characterization of cave drip waters in a porous limestone: Golgotha Cave, Western Australia. *Hydrological Earth Syst. Sci. Discuss.*, doi.org/10.5194/hess-2017-127.

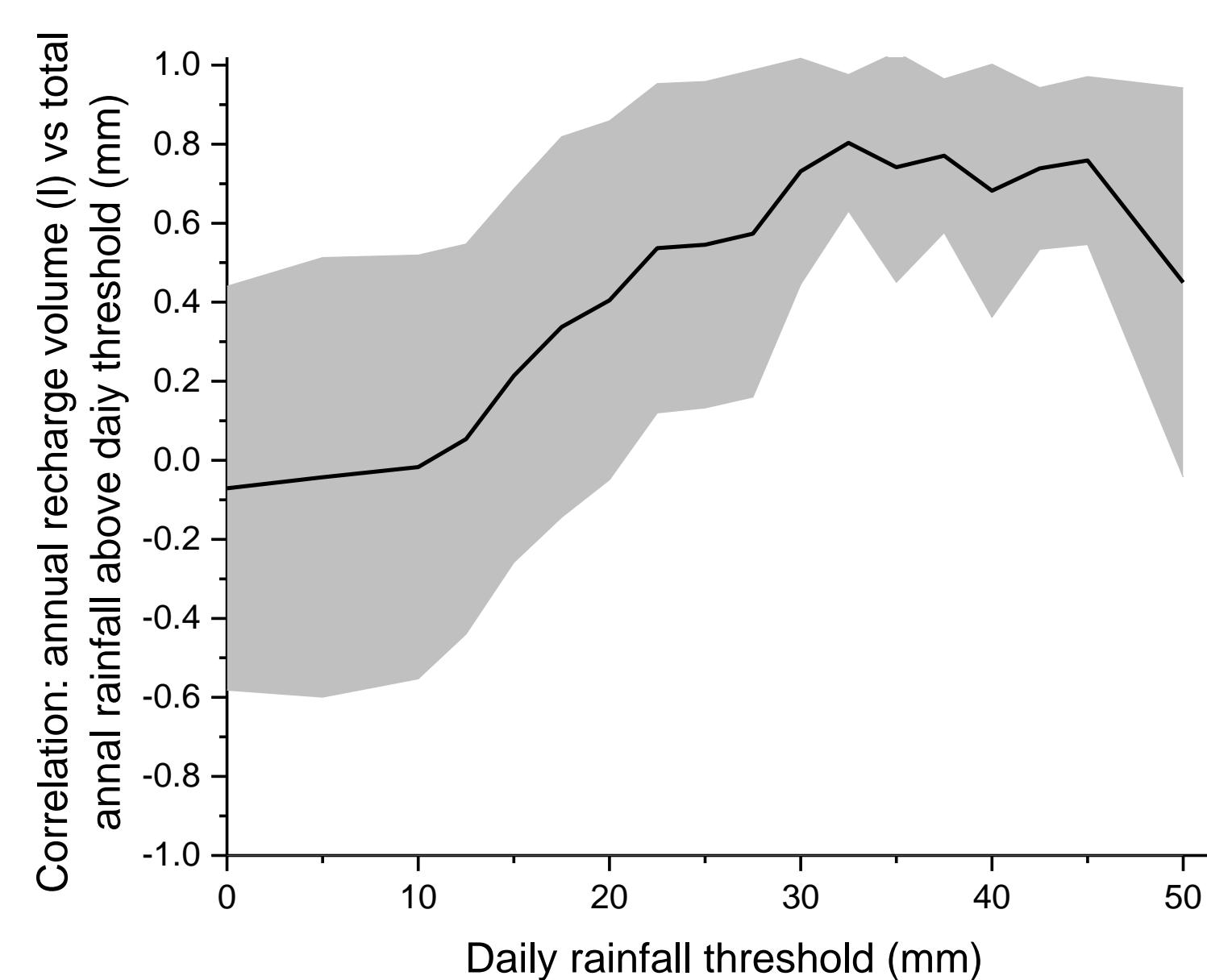


Our longest monitoring record is from Wellington Caves, in the Central-west NSW. This temperate semi-arid region has an average of 619 mm rainfall and 1825 mm evaporation a year. At this site we now have seven years of deep infiltration data.



Cave drip water monitoring data demonstrate that 16 rainfall recharge events have occurred at this location over 6.5 years.

For drip sites with reliable continuous data (n=8), we compared the total annual infiltration volume in litres to the total annual rainfall above a specific daily rainfall threshold (in mm). The graph below shows that the highest correlation is with 30-40 mm daily rainfall (black line = mean of all drip sites, grey line = sd between drip sites).



At Wellington, NSW, we observe on average 2.5 rainfall recharge events per year. The number of rainfall recharge events varies considerably between years.

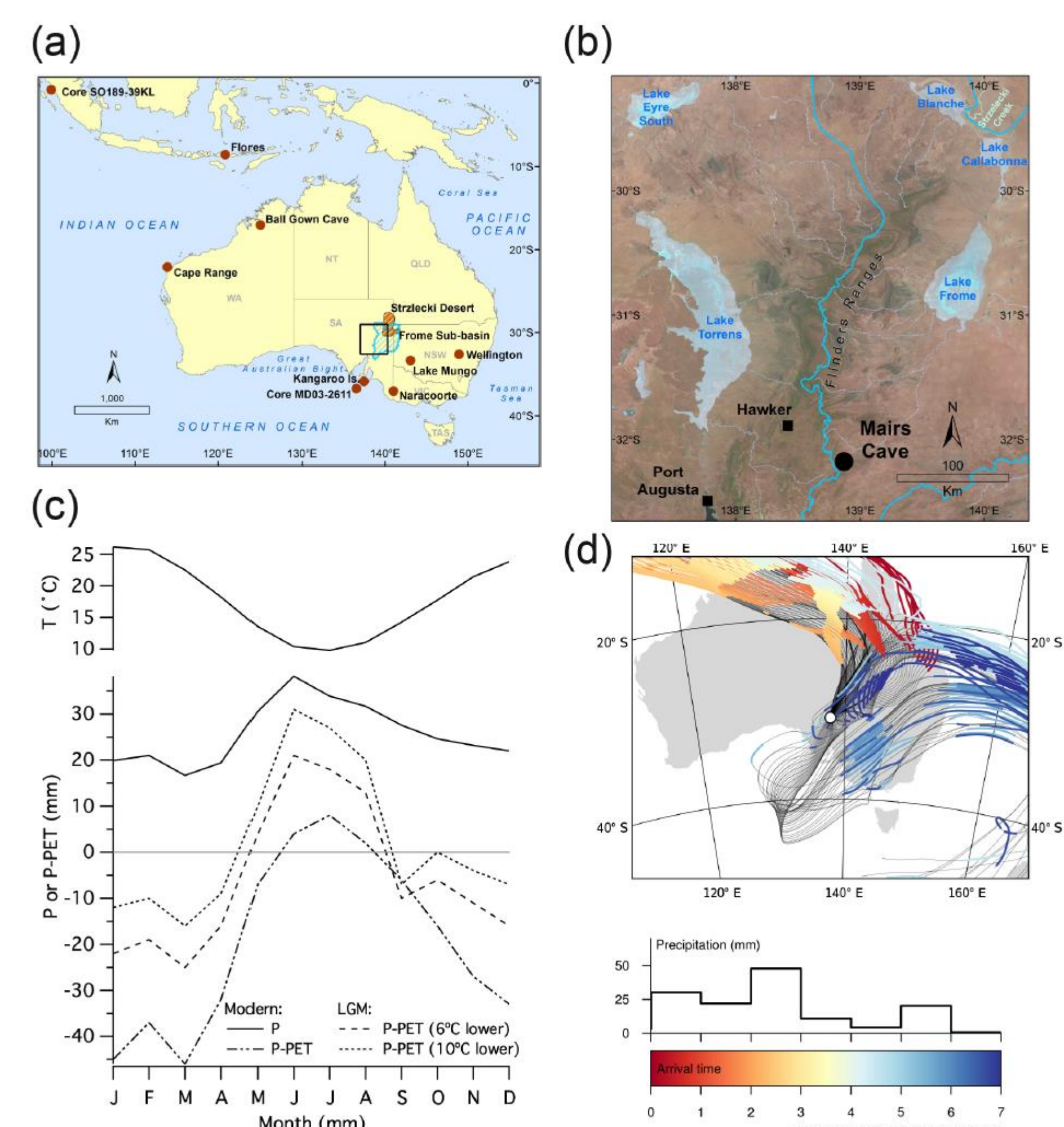
Annual infiltration volume correlates with annual total rainfall over >30 mm daily rain days. The latter result agrees with the national rainfall recharge modelling study of Barron et al. (2012).

Over time, our drip water time-series get longer, and we will repeat these analyses for the other sites in our long-term monitoring network, and we will extend this analysis.

Our cave observatory system helps improve our understanding of the rainfall recharge process and provides a baseline monitoring network during this period of climate change.

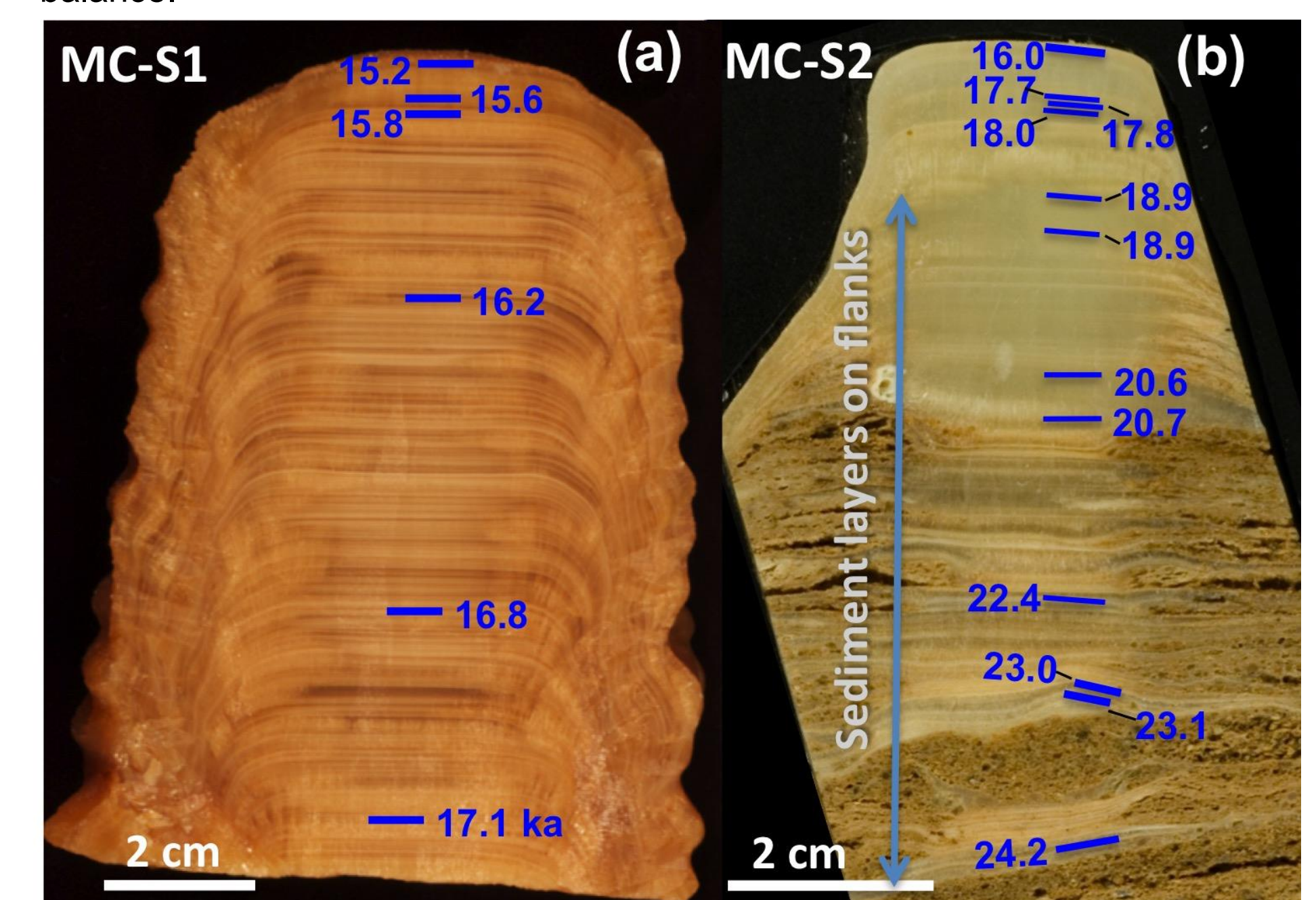
Barron, O.V. et al. 2012. Climatic controls on diffuse groundwater recharge across Australia. *Hydrology and Earth Systems Science*, 16, 4557-4570.

Past Recharge

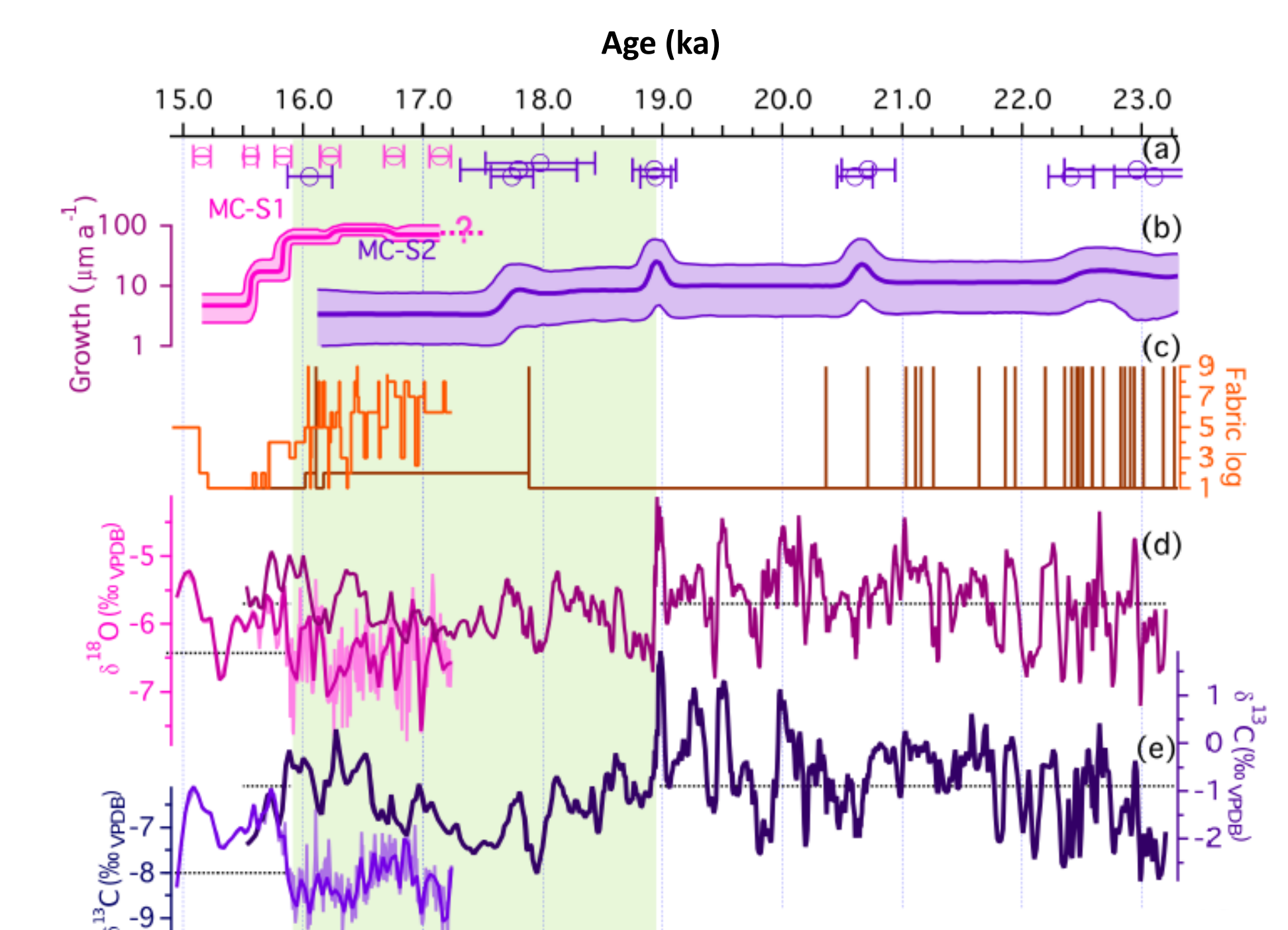


The Flinders Ranges (a) are in the semi-arid drylands. Mairs Cave (b) rarely receives infiltration today, as evapotranspiration exceeds rainfall for most of the year (c). Speleothem growth in the cave today is therefore rare.

A record breaking rainfall event occurred in 1974 (d), where moisture was sourced from the north and east of Australia. In the Last Glacial Maximum, cooler global temperatures decreased evaporation (c) and changed the water balance.



Two stalagmites from Mairs Cave have been precisely dated and were precipitated from 23,000 to 15,000 years ago, the Last Glacial Maximum. Recharge to Mairs Cave is interpreted from the activation of stalagmite growth, physical flood layering in one sample, and oxygen and carbon isotope minima.



Recharge occurs in the Last Glacial Maximum and deglaciation, from 23-15 ka. Periods of relatively low recharge are indicated by ^{18}O and ^{13}C enrichment (e.g. 23-19 ka), argued to be driven by evaporation of shallow soil/epikarst water. Reduced recharge is also indicated by a shift to slower-growing, more compact calcite (e.g. 16-15 ka). The wettest phase is shown in green.

Treble, P.C. et al 2017 Hydroclimate of the Last Glacial Maximum and deglaciation in southern Australia's arid margin interpreted from speleothem records (23-15ka) *Clim. Past*, 13, 667-687.