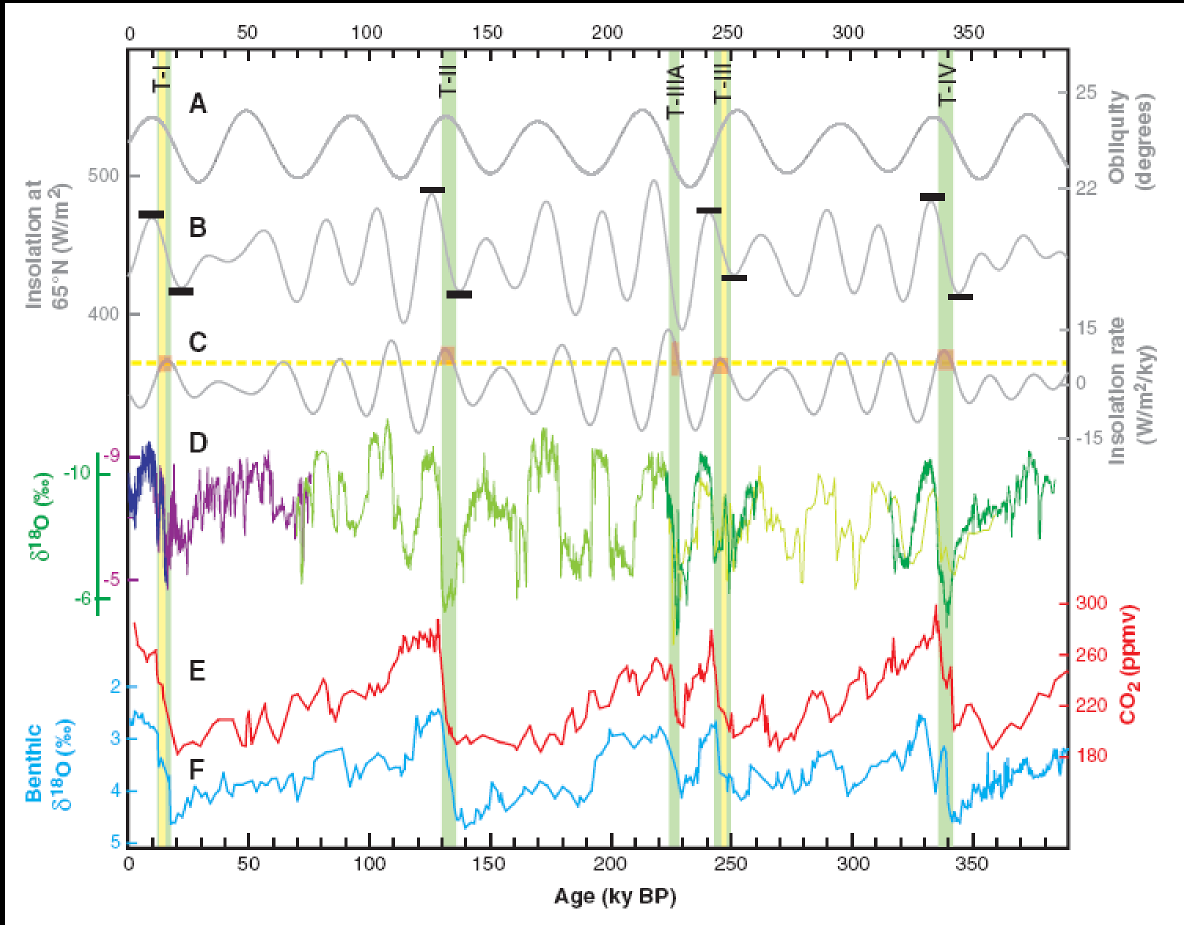
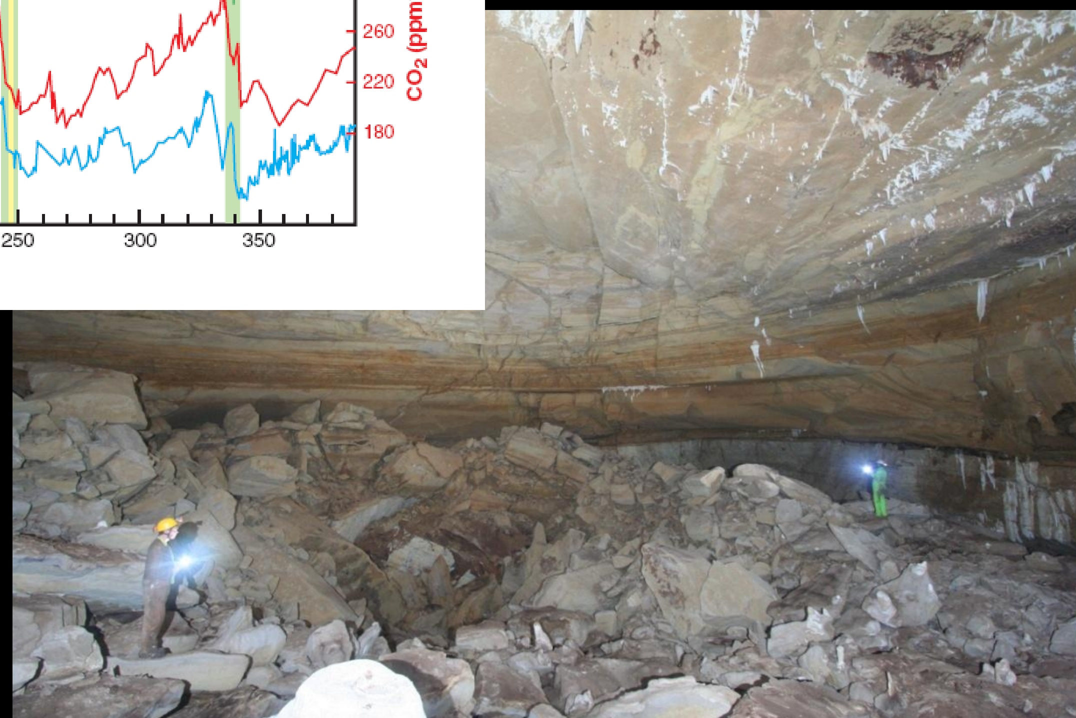
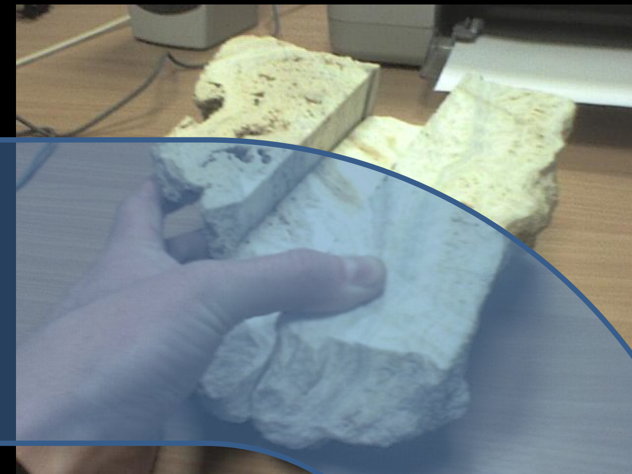


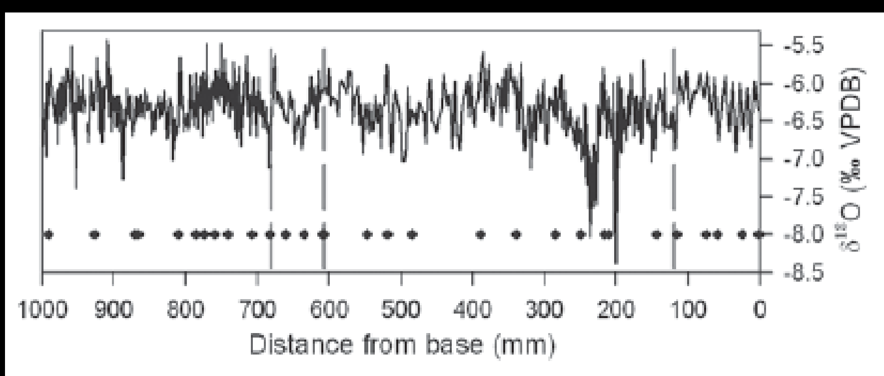
Stalagmites and paleoclimate

Cheng, H. et al., 2009, Ice Age Terminations. Science, 326, 248-



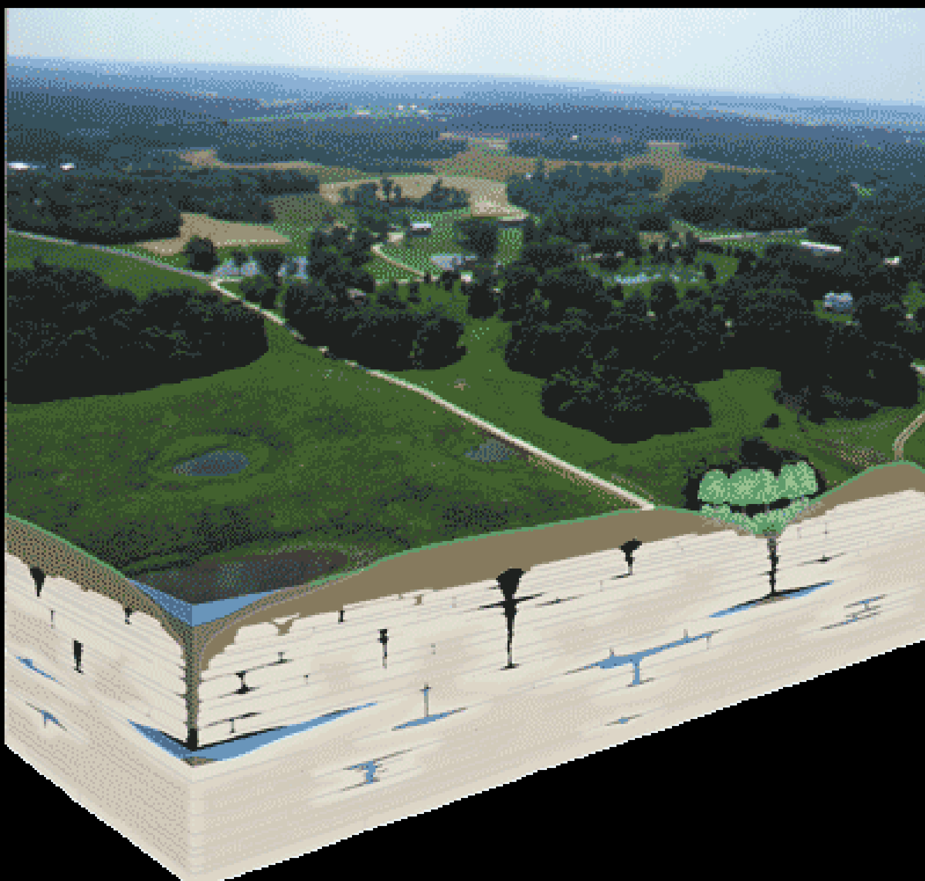
Andy Baker
a.baker@unsw.edu.au

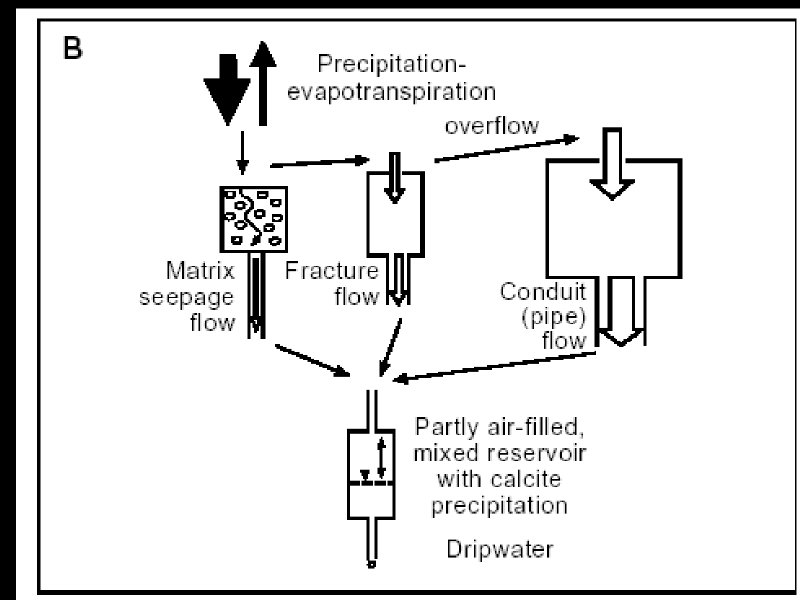




Dominguez-Villar, D., Fairchild, I.J., Baker, A., Wang, X-F, Edwards, R.L. and Cheng, H., 2009. Oxygen isotope precipitation anomaly in the North Atlantic region during the 8.2 ka event. Geology, 37, 1095-1098.

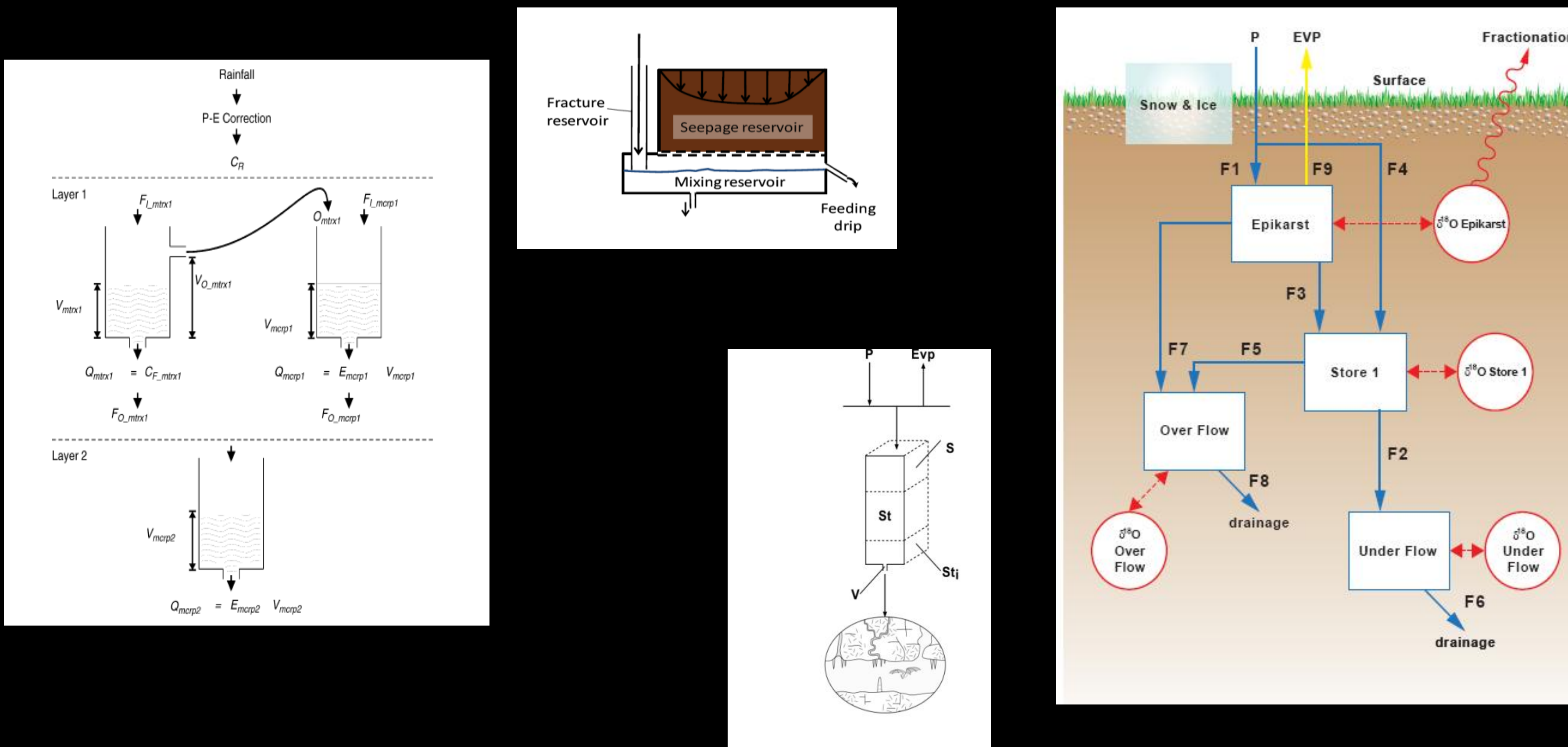
1. Understanding how water moves from the surface to a cave





Fairchild, I.J., Tuckwell, G.W., Baker, A. and Tooth, A.F., 2006. Modelling of dripwater hydrology and hydrogeochemistry in a weakly karstified aquifer (Bath, UK): implications for climate change studies. *Journal of Hydrology,* 321, 213-231

Conceptual hydrological models of stalagmite drip water geochemistry. (a) Two-layer soil-epikarst model for Mg, Sr, Ca fluxes (Fairchild, Baker et al 2006) (b) Single reservoir with overflow feed model for $\delta^{18}O$ and p_{CO_2} (Baker et al. 2010). (c) Single reservoir model with underflow feed for $\delta^{18}O$ Baker and Bradley (2010) and (d) lumped parameter $\delta^{18}O$ model of Bradley, Baker et al (in press).

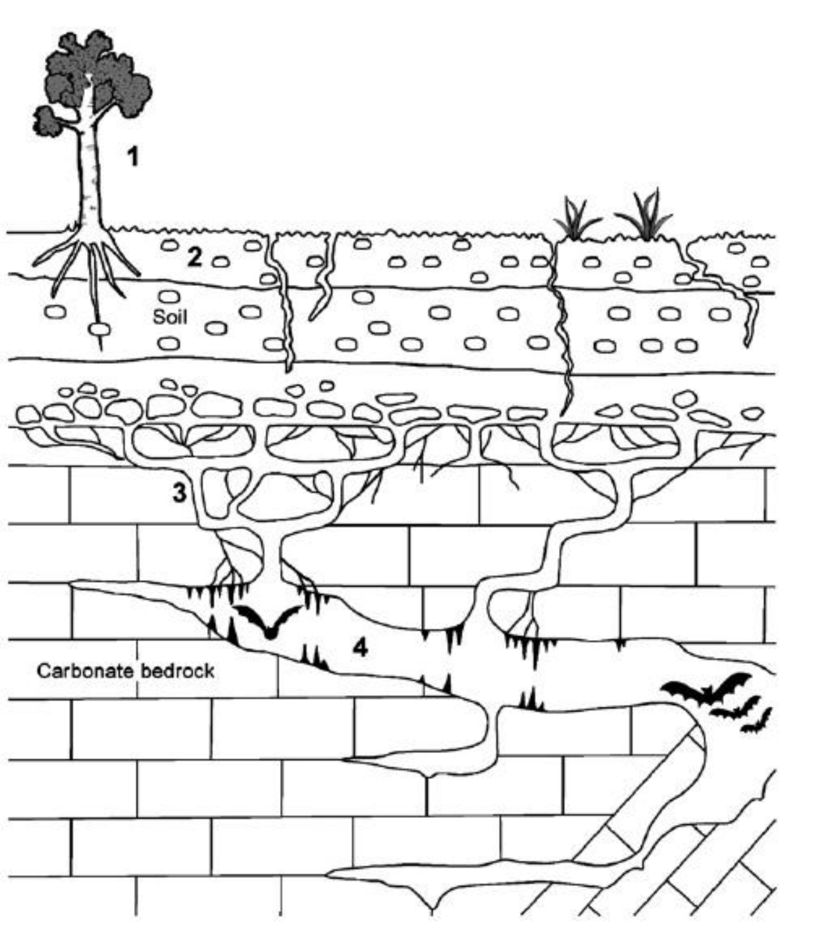


2. Tracers of water movement from the surface to a cave

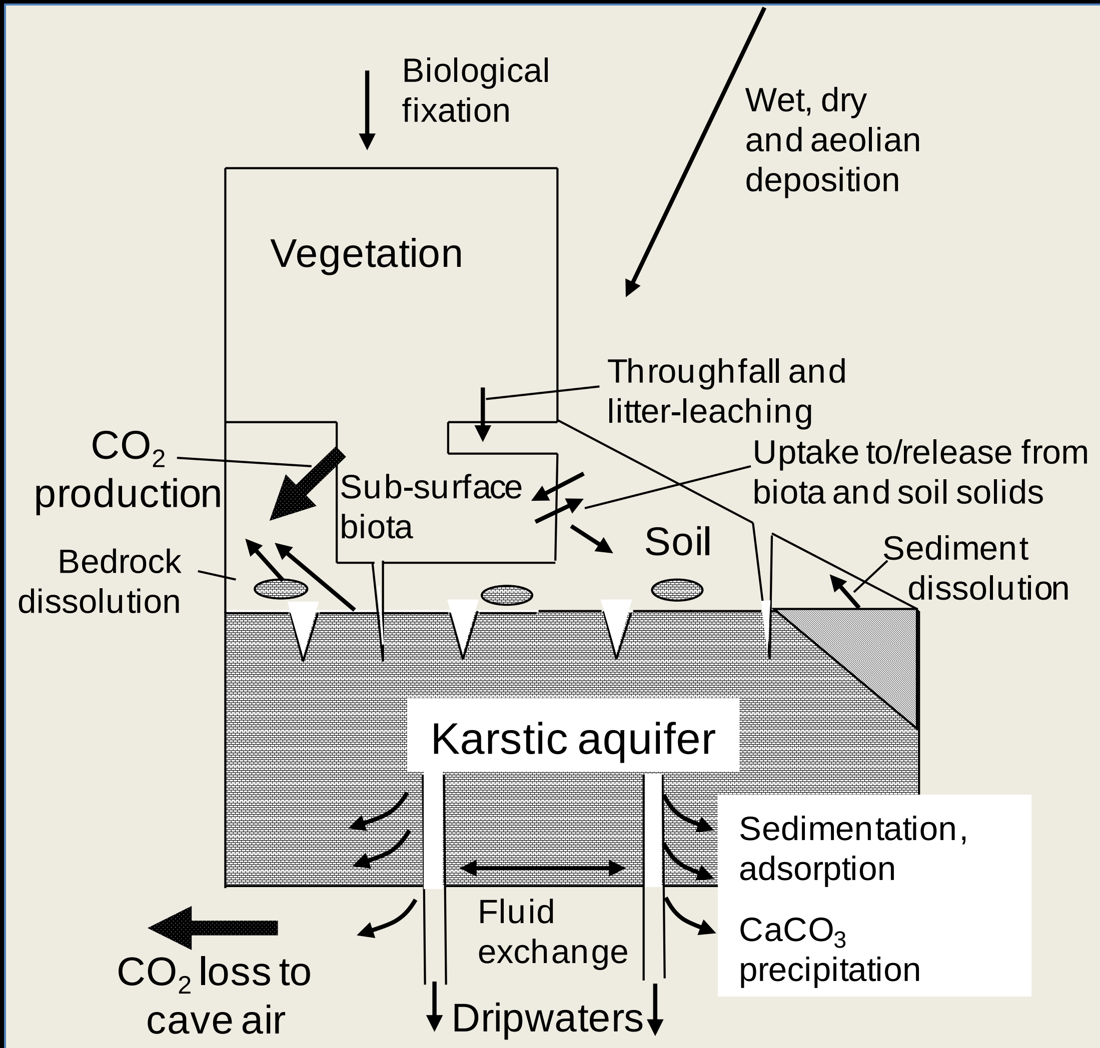
So, rainwater will reach a cave, often with complex choice of flow paths.

What climate and environmental signals will it carry?

1. From the atmosphere
2. From the soil and vegetation
3. From the geology
4. From the cave



Picture drawn by Kevin Burkhill, Cartography, Birmingham



Schematic diagram of the sources of elements and processes involved in their transport to caves. Arrows indicate element fluxes as particulates, colloids or solutes in aqueous solutions (Fairchild and Treble, 2009). Stalagmites preserve archives of these processes.

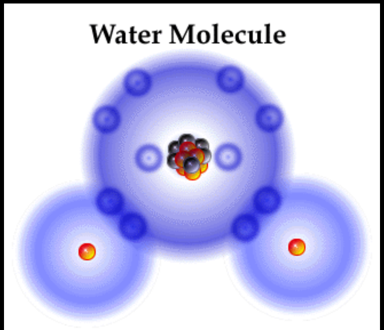
Rainfall (H_2O)

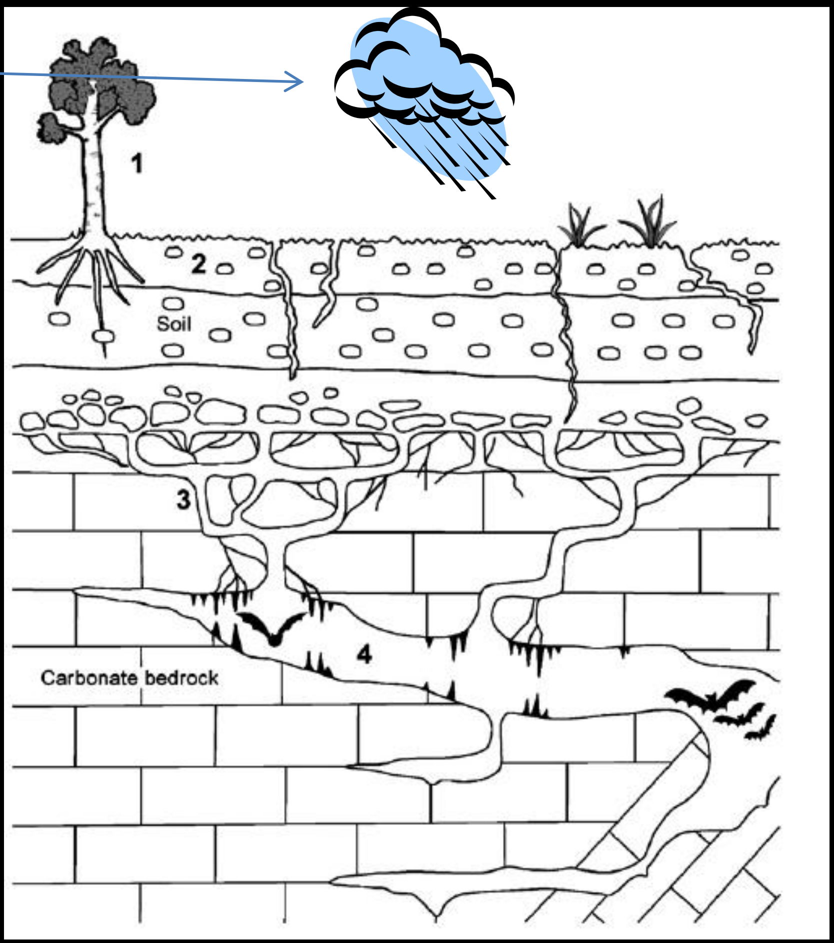
Most useful are oxygen isotopes.

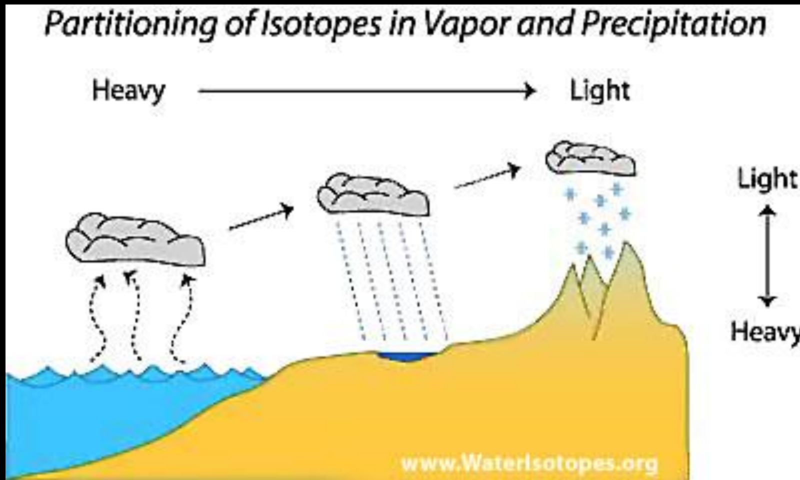
^{16}O and ^{18}O

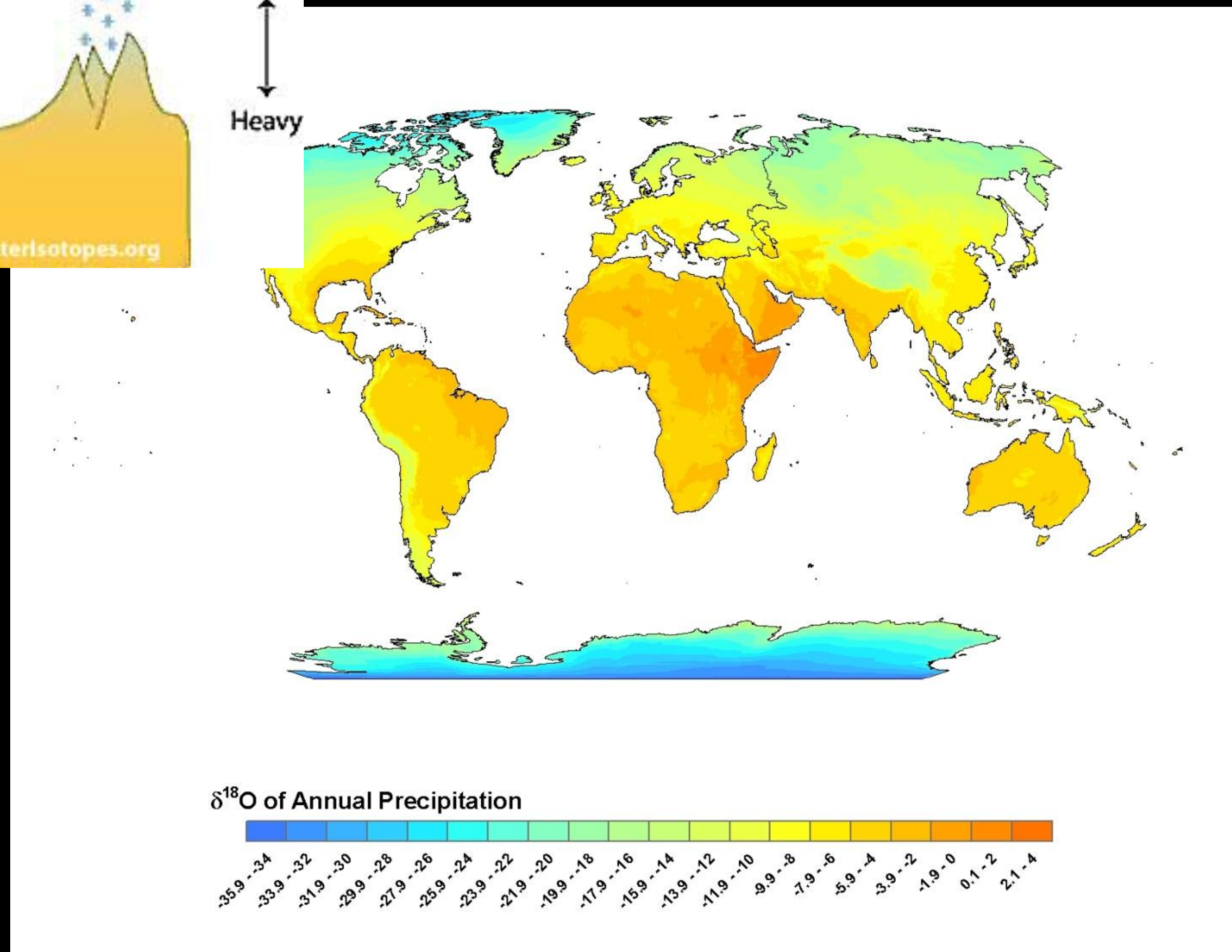
Vary geographically (with latitude, with altitude, with source region) and with time (within event, seasonally, between years)

Relative amounts of each isotope can provide information of rainfall amount and source

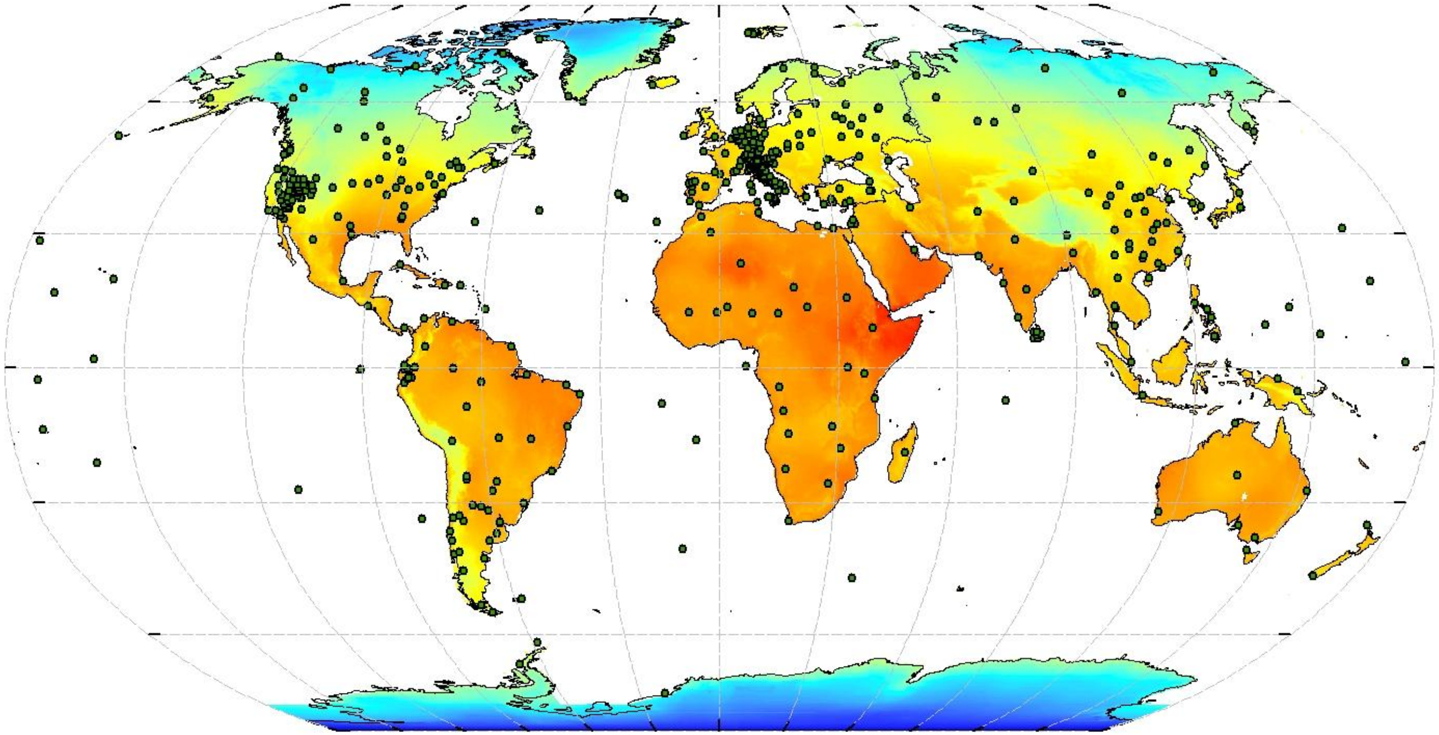








Bowen G. J. and Revenaugh J. (2003) Interpolating the isotopic composition of modern meteoric precipitation. *Water Resources Research* **39**(10), 1299



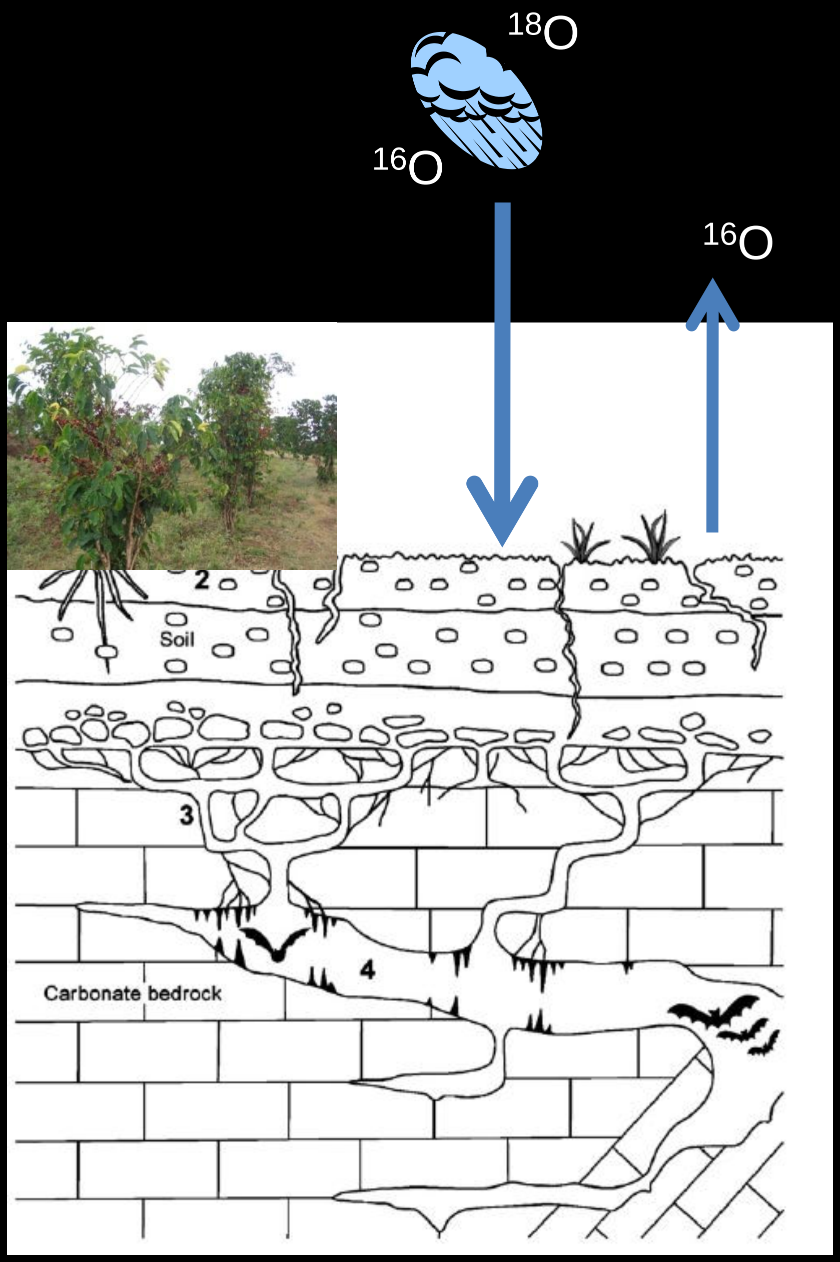
Rainfall interacts with soil and vegetation

Water can be stored as soil water.

Water can be lost and fractionated by evaporation.

Soils are rich in carbon dioxide produced from microbial respiration. This is dissolved into the water.

Soil and vegetation biomarkers are transported by the water



Soil water reaches the limestone.

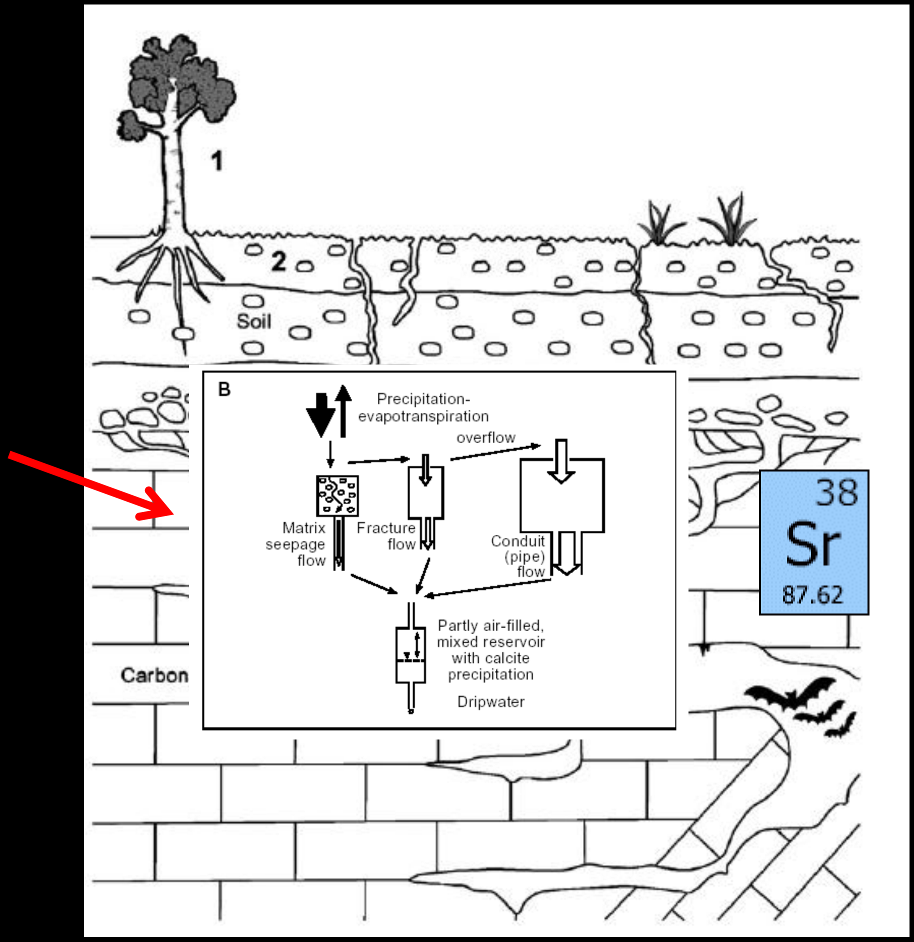
Limestone is dissolved and the water enters the ground water.

Mixing of ground water of different flow paths

Mixing of water isotope tracer.

Loss and degradation of the biomarker tracer.

Addition of geological tracers such as Mg and Sr.

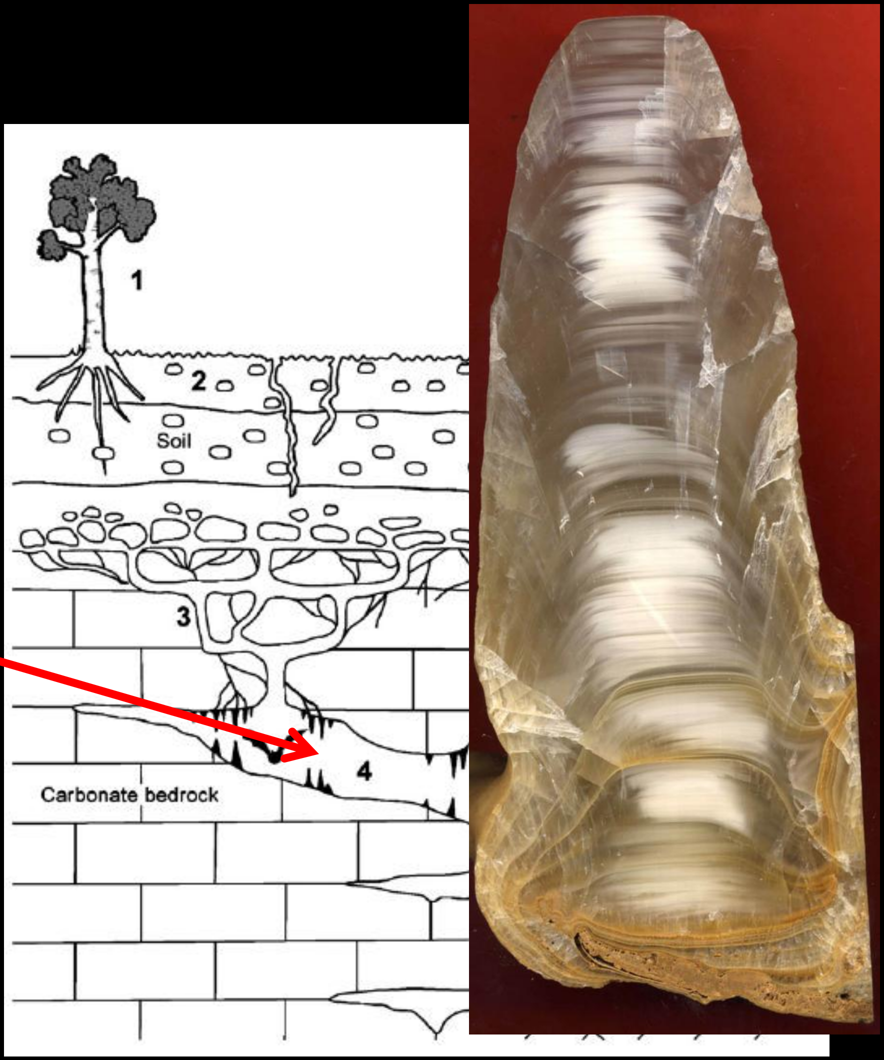


Water reaches the cave

The CO_2 dissolved in the water degasses, and stalagmites and stalactites are formed.

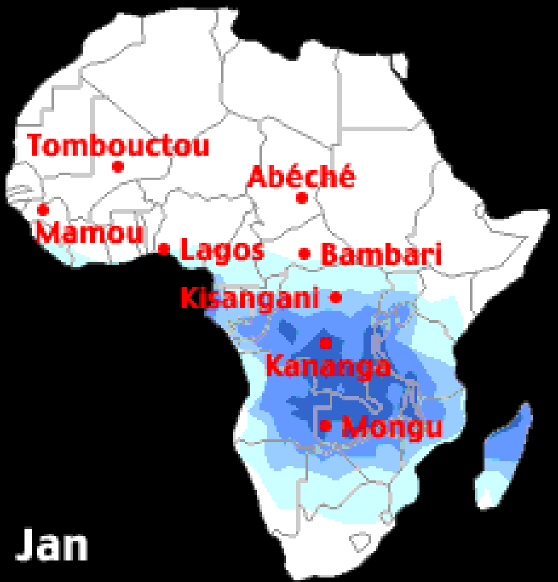
Water isotopes might fractionate if this process is rapid. The isotopes are preserved in the speleothem ($CaCO_3$).

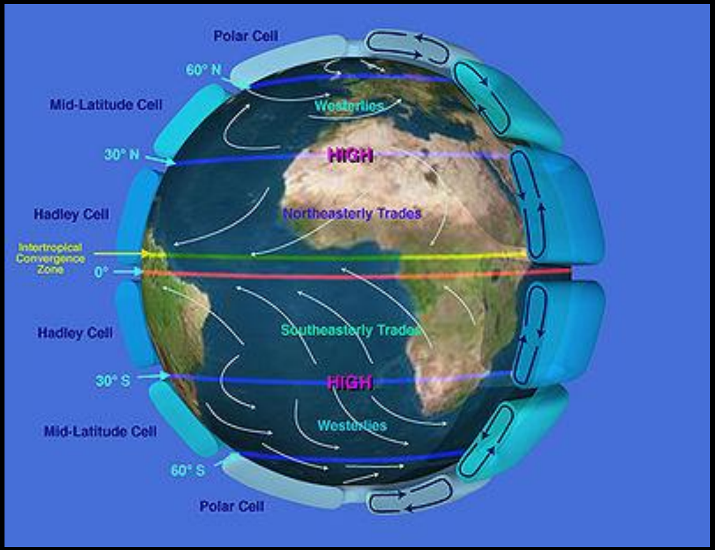
Biomarkers and geological tracers are also preserved in the speleothem. Again, some changes will occur during speleothem formation.



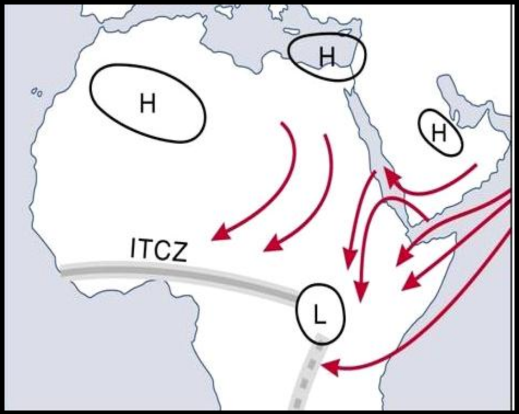
3. Ethiopian Climate Variability

Climatology   (text book version)

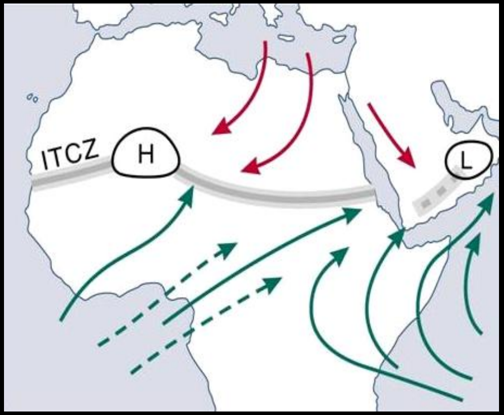




N Hemisphere winter



N Hemisphere summer



Climatology and socio-economics

Drought and subsequent famine in Ethiopia is due to 'spring rains' failure in the north and low and variable rainfall in the south.

Poverty and subsistence farming is the cause of famine (GDP $700; 39% below poverty line). Irrigation was rare until recently, a large amount of the population is dependent on the success of the small rains for germination of the annual crop, as much as it is on the regularity of the big rains.

Overpopulation is also an issue – rapid population growth (74 M people, growing at 2.23%, life expectancy 55 yrs). Plus global rising costs of food purchase.

We need to understand how rainfall variability is related to large-scale climate processes. There is a periodicity in rainfall amount and seasonality – is it predictable and how will it change with anthropogenic global warming?

Ethiopian Caves

Eight years of field monitoring (1-3 trips per year, 5 caves):

major element water hydrochemistry, rain and drip water stable isotopes, cave climate (data loggers)

Cave exploration – several new caves

Stalagmite sampling – almost all stalagmites contain continuous visible annual growth lamina.

Asrat, A., Baker, A., Leng, M.J., Gunn, J. and Umer, M., 2008. Environmental monitoring in the Mechara caves, SE Ethiopia: implications for speleothem paleoclimate studies. Int. J. Speleo. 37, 207-220

Bero Caves

Bero-1 Stalagmite

Bero Cave, SE Ethiopia

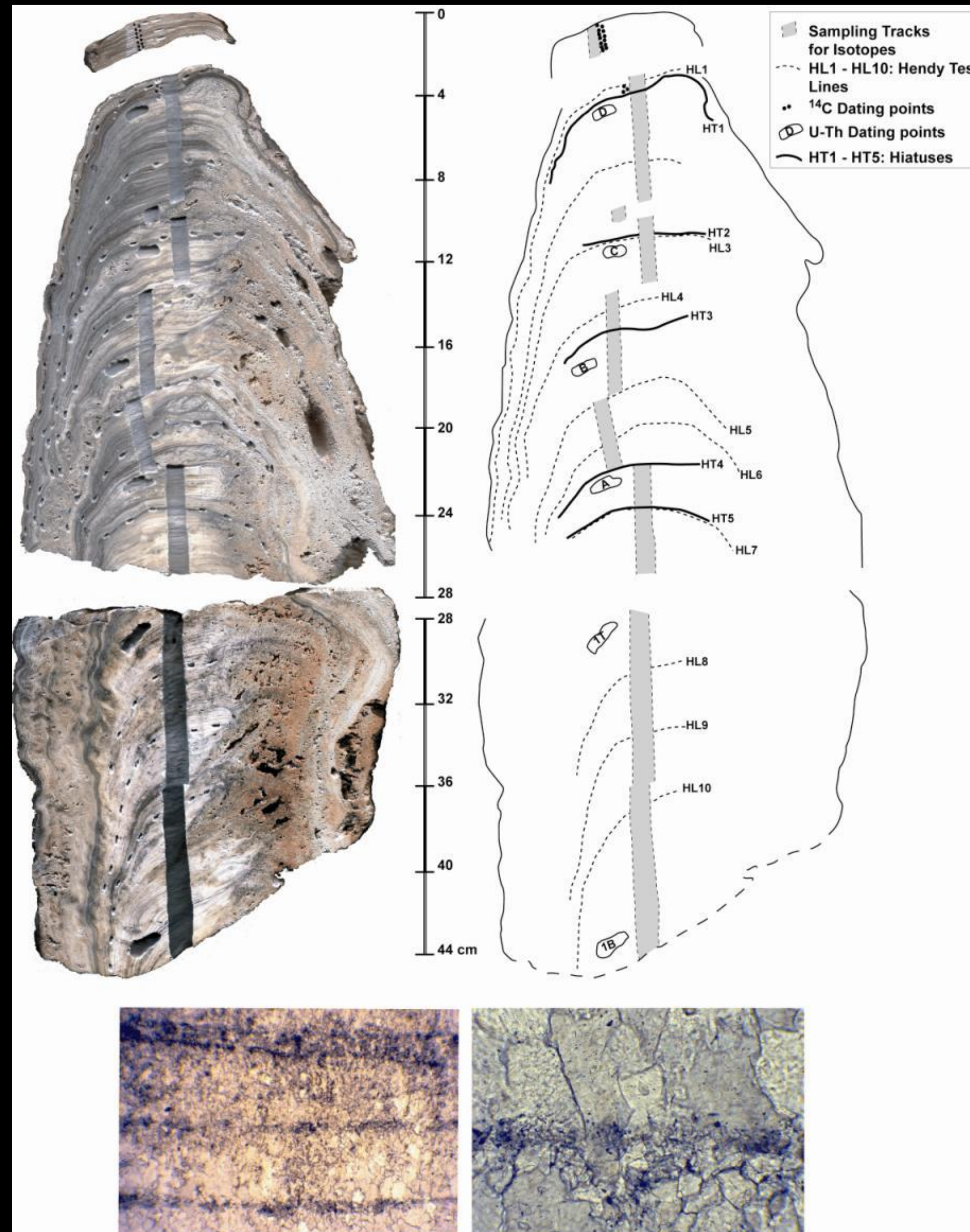
Sampled in 2005 and actively dripping.

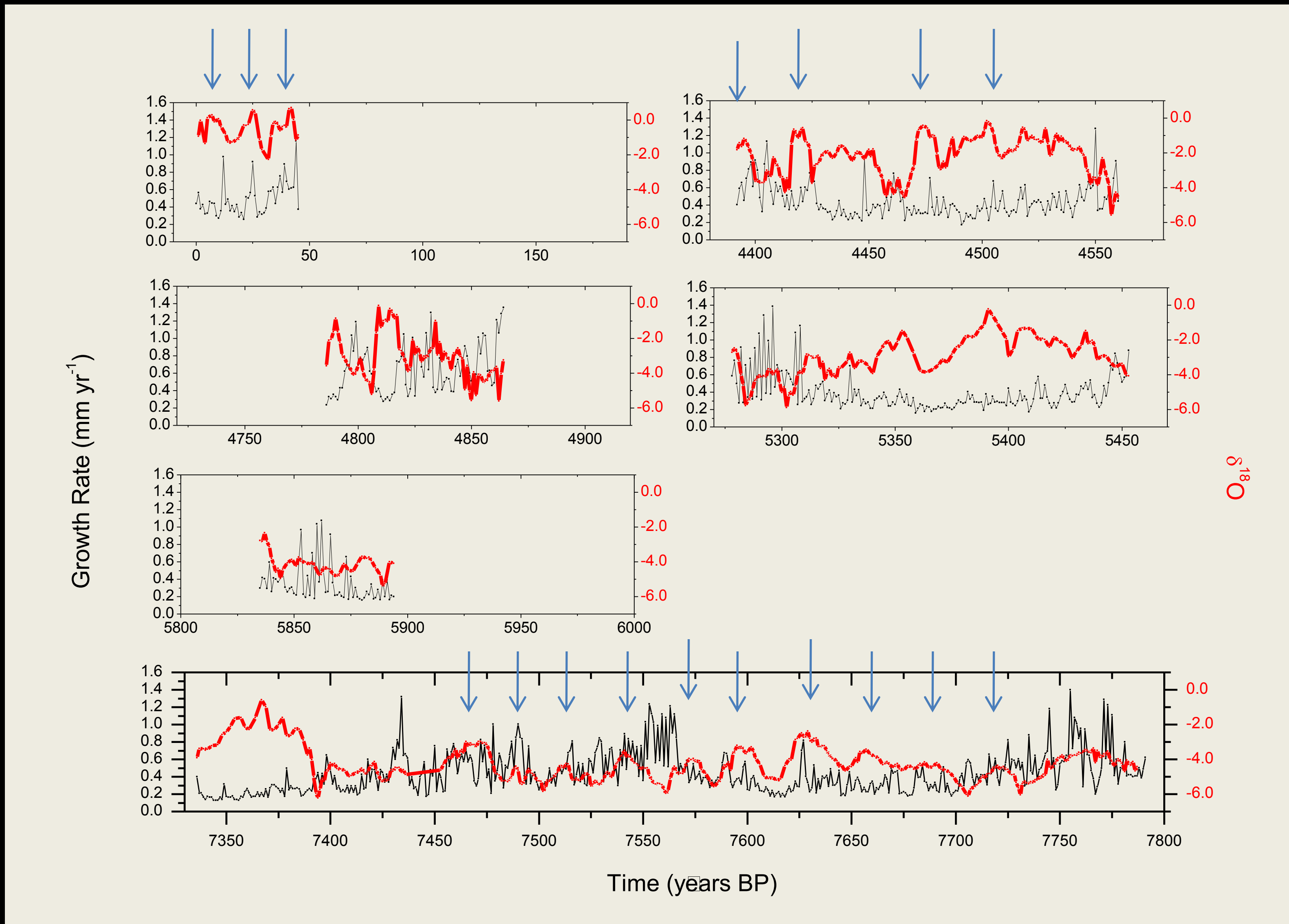
Continuous annual laminae

Growth phases of ~100-600 yrs and long hiatuses

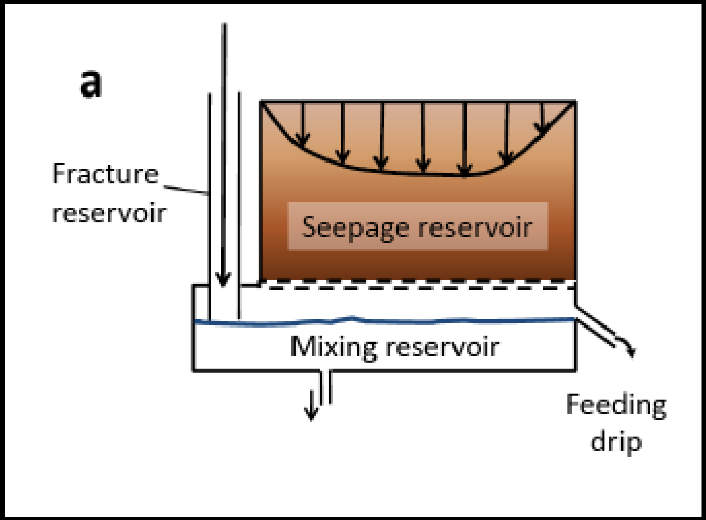
Several U-Th and radiocarbon analyses

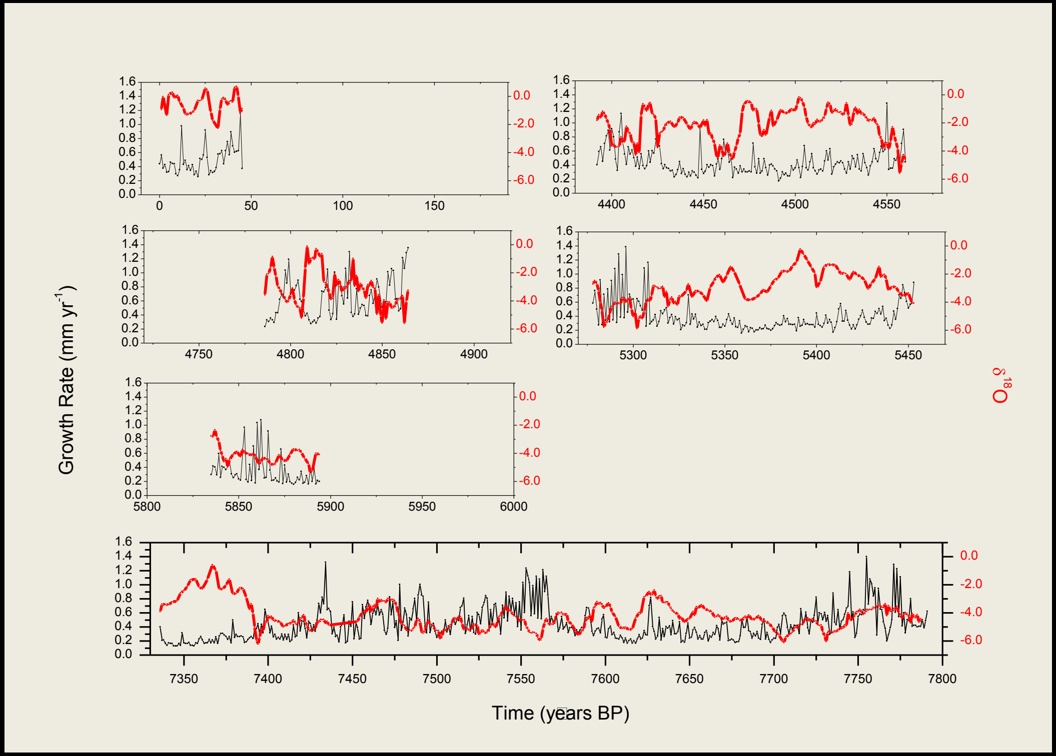
~Annual-biennial samples drilled for ^{18}O.





^{18}O (thick red line) and annual growth rate (thin line). Notice the clear decadal periodicity in the isotope record. What it is recording?

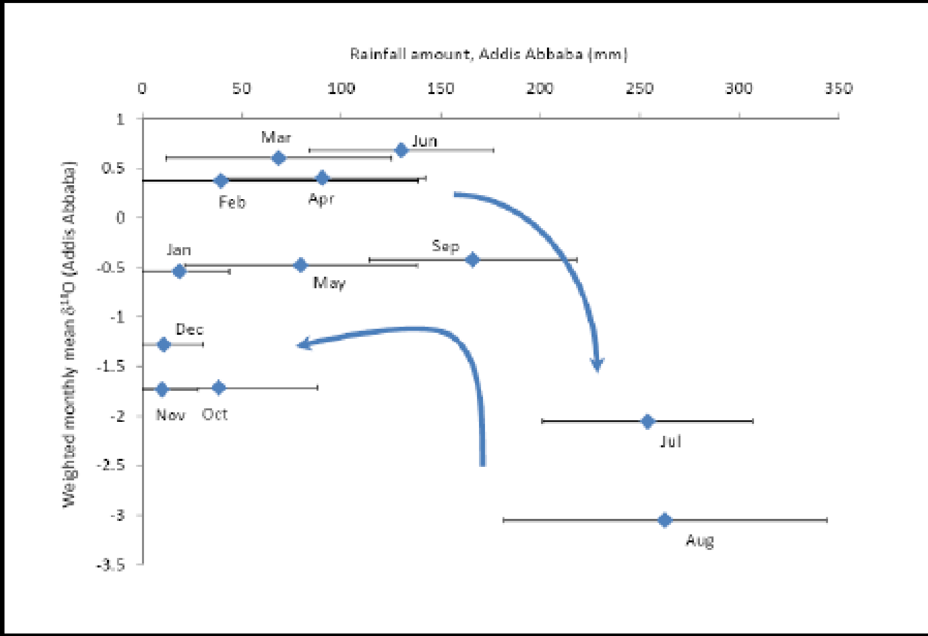


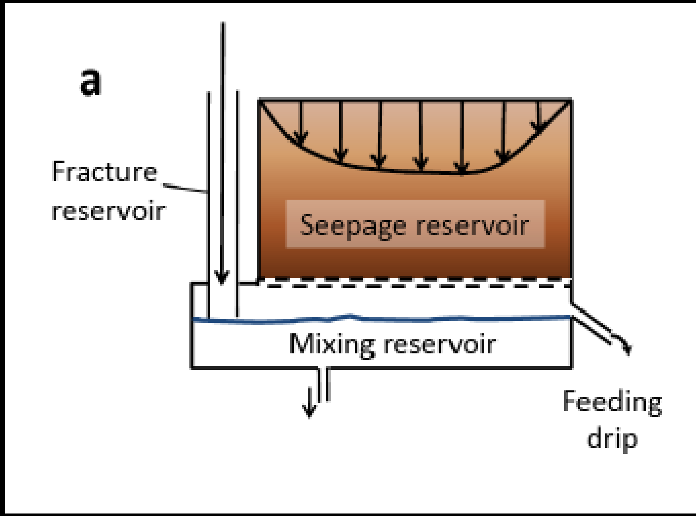


Oxygen isotope data very smooth and predictable. Suggests that the water has been stored for some time.

Growth rate more ‘spikey’. Suggests that there is some sort of non-linear response.

Combine the two – the stalagmite is being fed by a storage overflow...





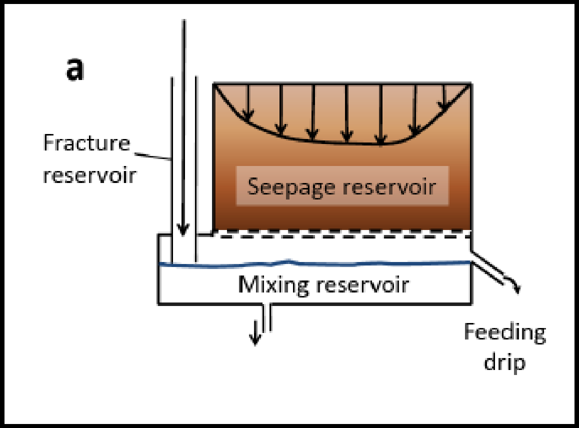
We ran a hydrological model to understand the ^{18}O record.

Input data: isotope and climate data from Addis Ababa.

Model: reservoir model with fracture flow bypass. Model 'spun-up' using rainfall ^{18}O for 1986-1989.

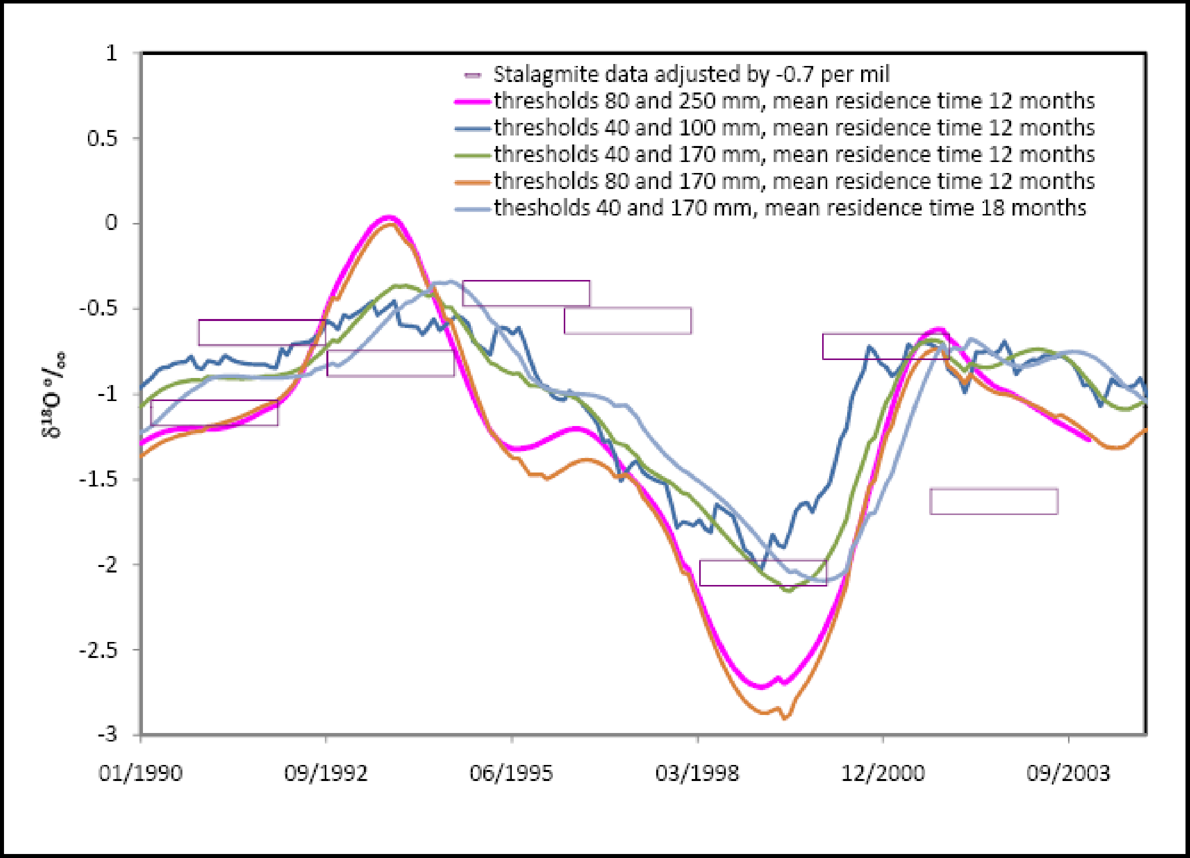
Output: scenarios for drip water $\delta^{18}O$ from 1990 – 2005.

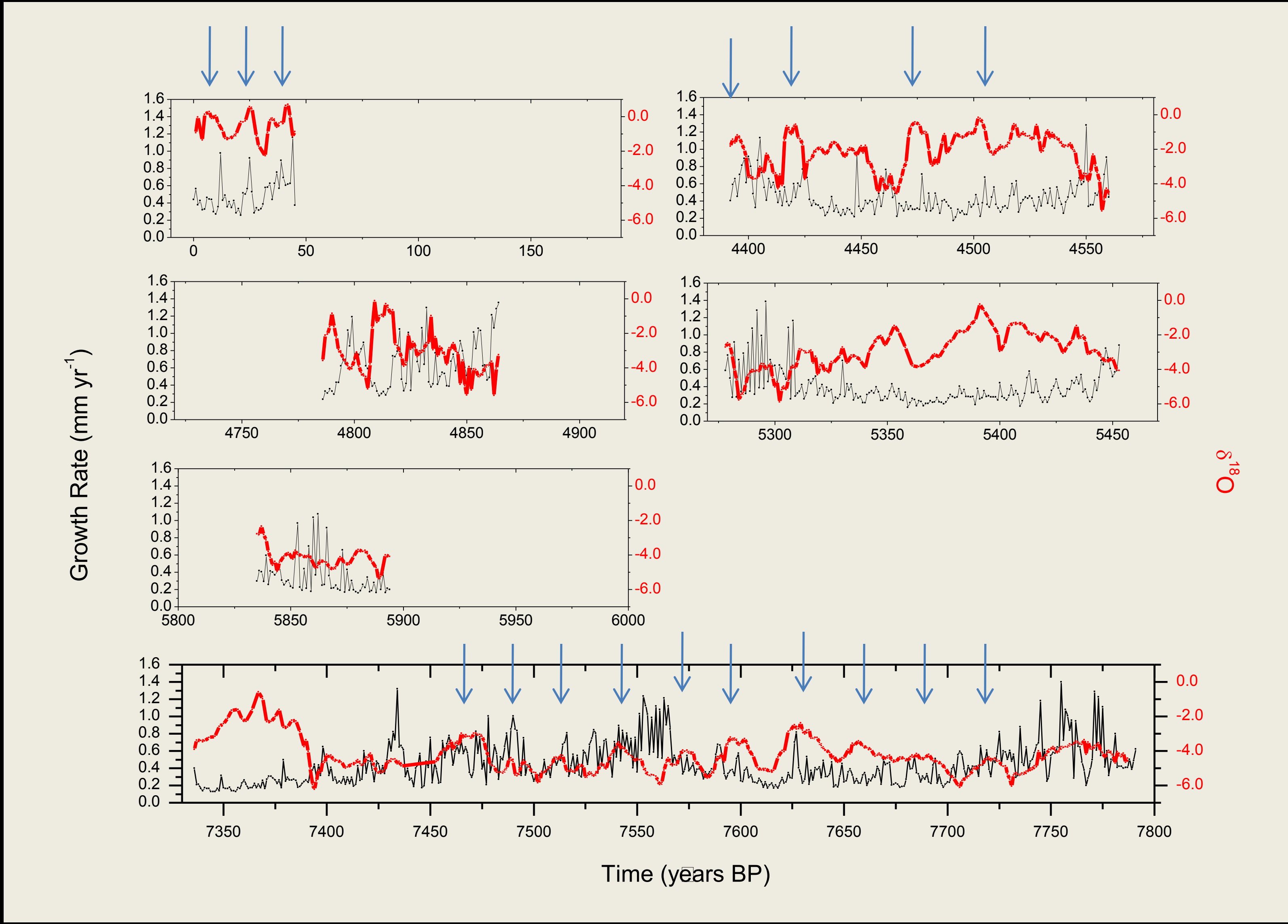
Baker, A., Asrat, A., Fairchild, I.J., Jex, C.N., Leng, M.J., Thomas, L., Widmann, M., Dong, B., van Calsteren, P., and Bryant, C. Decadal-scale Holocene rainfall variability recorded in an Ethiopian stalagmite. The Holocene, in press.



Varying the model parameters confirms that the stalagmite is responding to rainfall amount and seasonality.

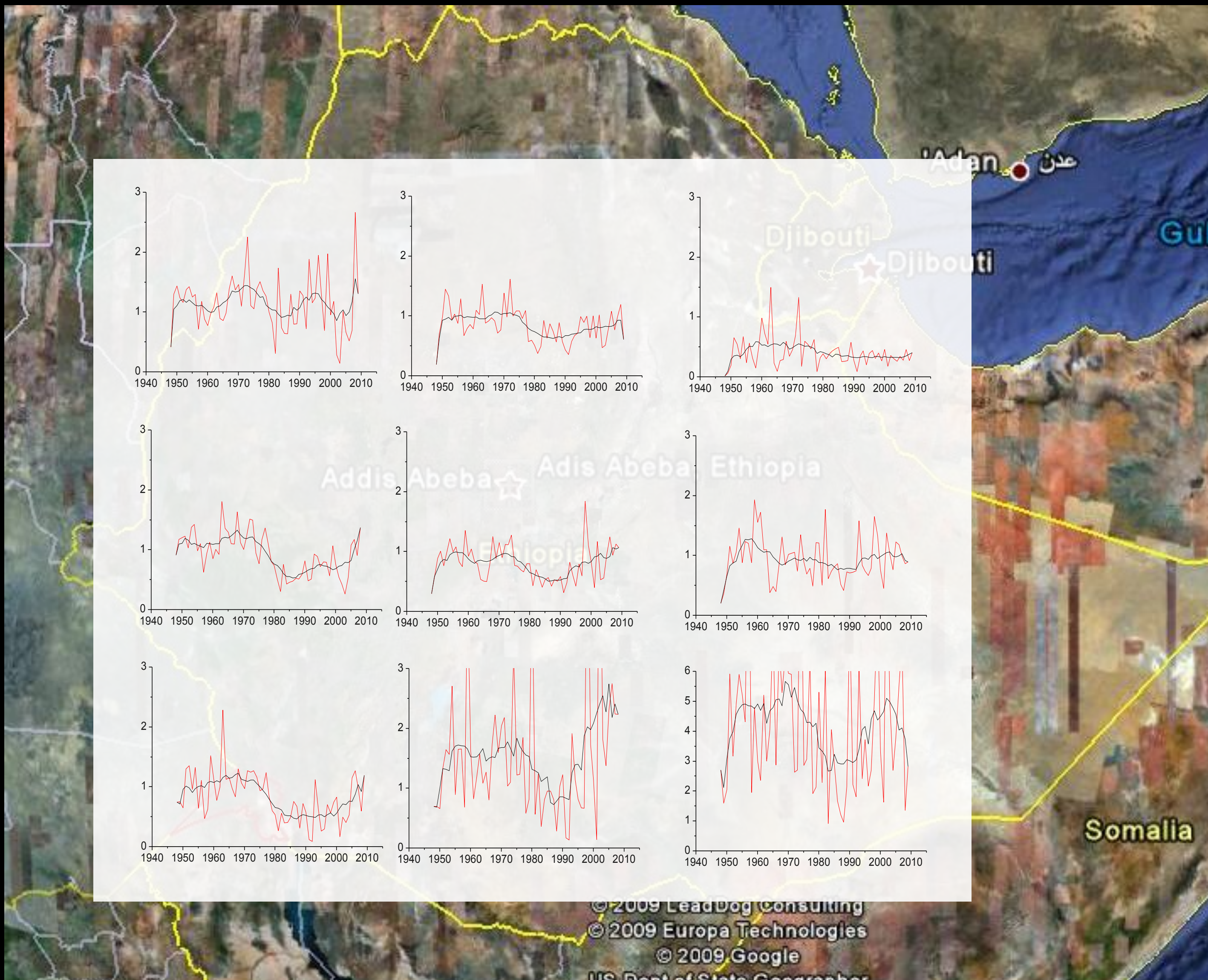
Note the negative isotope shift in the 1997-99 spring rains failure





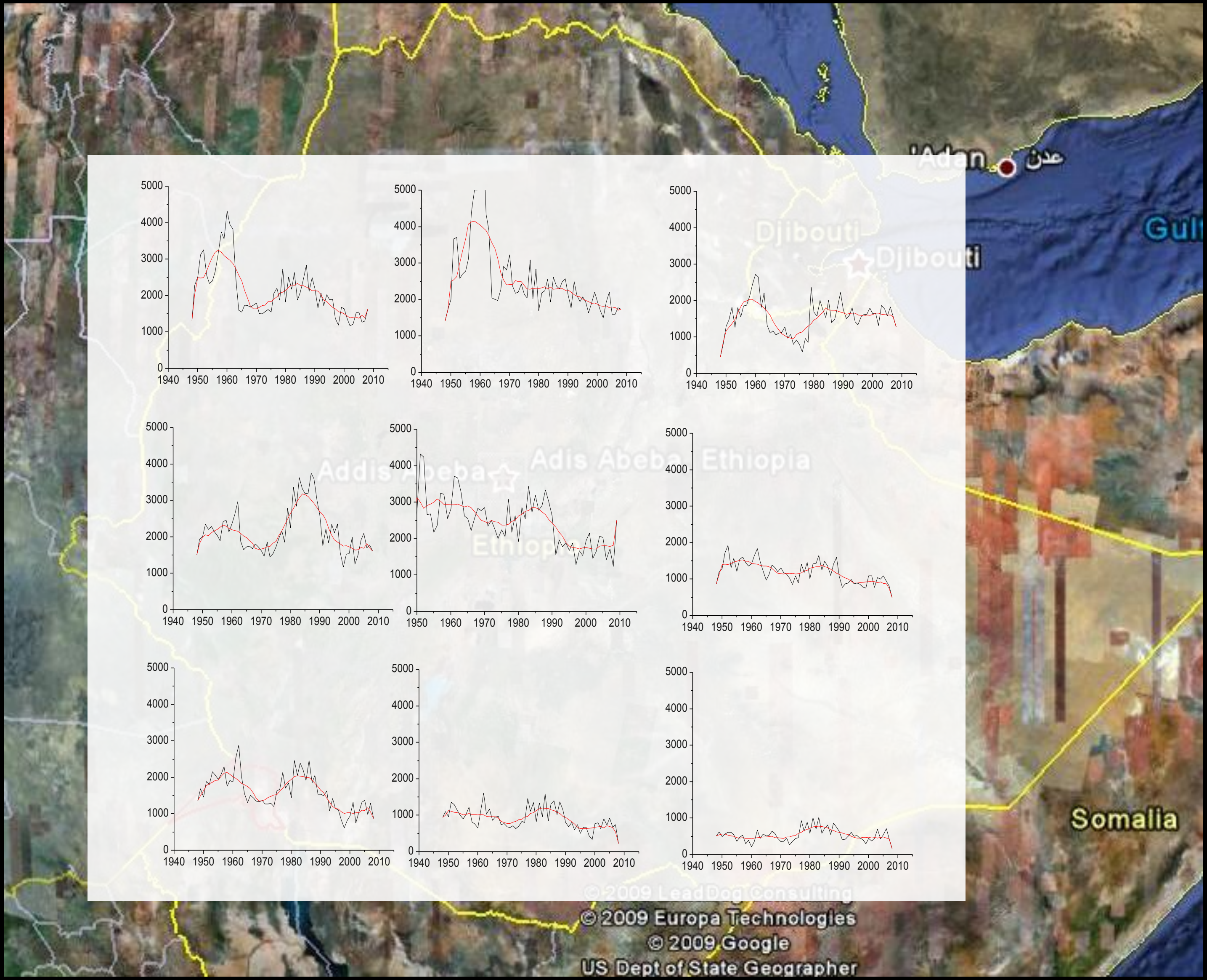
Oxygen isotopes are recording decadal variations in total rainfall amount and seasonality.

Rainfall Variability 1948 - 2009



Ratio of Spring (April, May) to Summer (July, August) rainfall

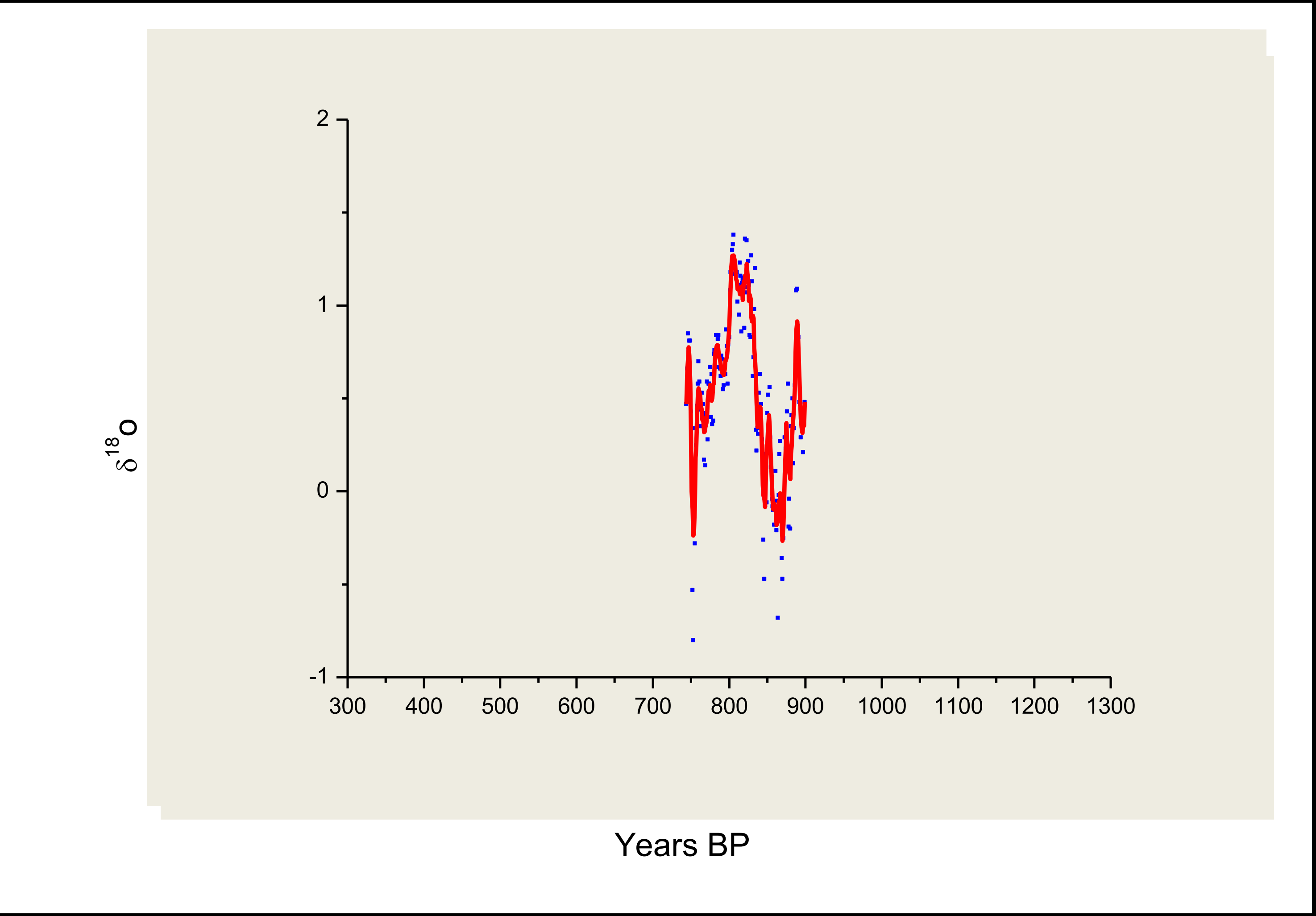
Data: 1948-2009; NCEP/NCAR reanalysis (3° x 3° grid, 33-42E, 3-12N) – treat with caution!



Total annual rainfall

Data: 1948-2008; NCEP/NCAR reanalysis – treat absolute values with extreme caution!

Six stalagmites and the last 10000 years from Ethiopia…



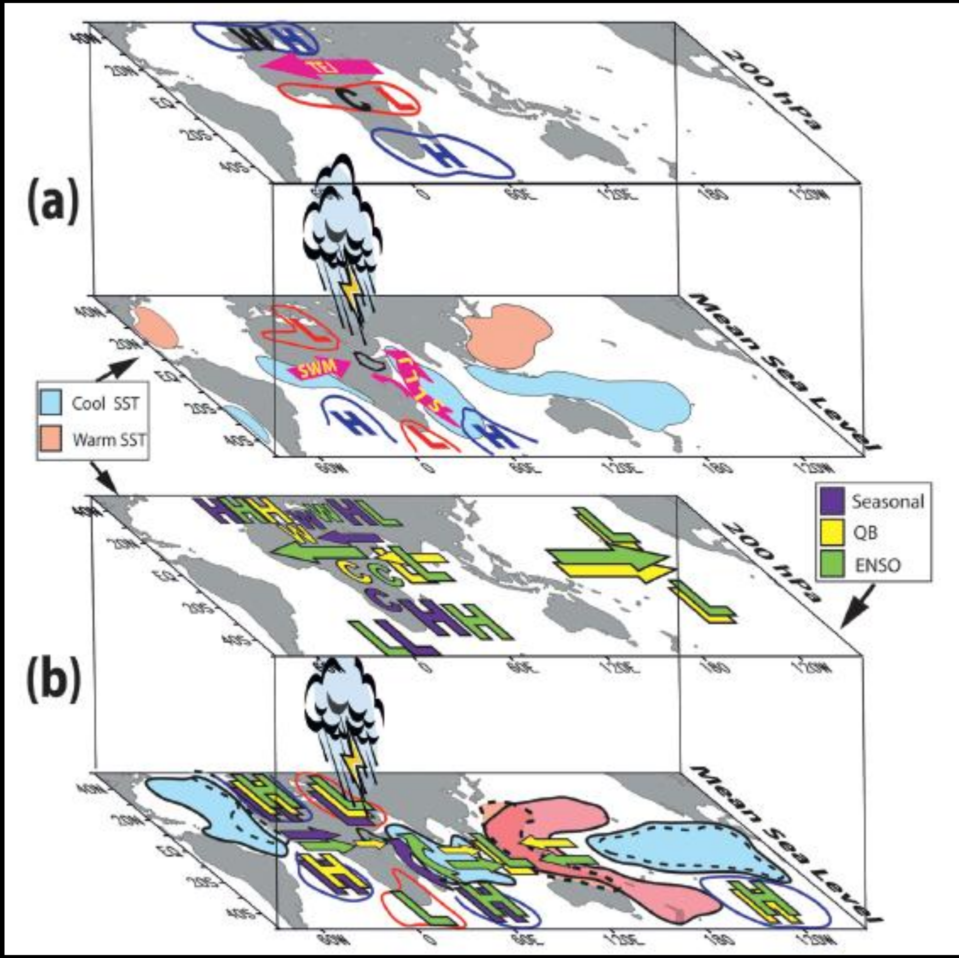
…a persistent decadal variability in rainfall seasonality and amount

Conclusions

•Persistent multidecadal variability in rainfall seasonality and /or amount in Ethiopia

•Likely cause is semi-regular failures in spring rains and/or enhanced summer rains.

•Variability likely driven by variations in sea surface temperatures (ENSO, IOD) which effects strength of summer monsoon rains.



Segele, Z.T., Lamb, P.J. and Leslie, L. M., 2009. Seasonal-to-interannual variability of Ethiopia / Horn of Africa monsoon Part I… Journal of Climate, 22, 3396-3421.

Future Research?

- Ethiopia: need to provide independent (GCM) evidence of forcing behind a ~20 yr periodicity in East African rainfall. Collaboration with CCRC, UNSW.

- New long term strategic development of paleoclimate stalagmite record(s) in SE Australia, with focus on timing of groundwater recharge.

- 'Super Science' funded groundwater and climate monitoring facility at Wellington, UNSW.

www.connectedwaters.unsw.edu.au
www.groundwater.com.au

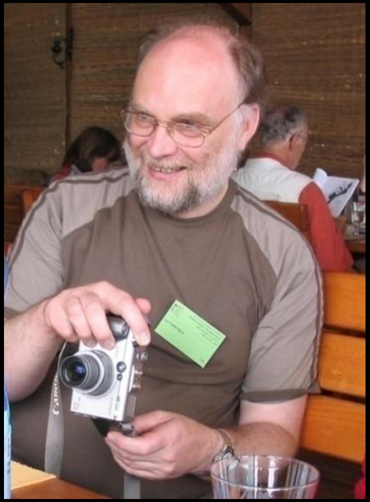
With thanks to:
All expedition and science team members, UK NERC and Royal Society and UN START for funding, UK NIGL and OU-USF laboratories, and the people of Oromo, Ethiopia.

Prof Mohammed Umer

Dr Asfawossen Asrat

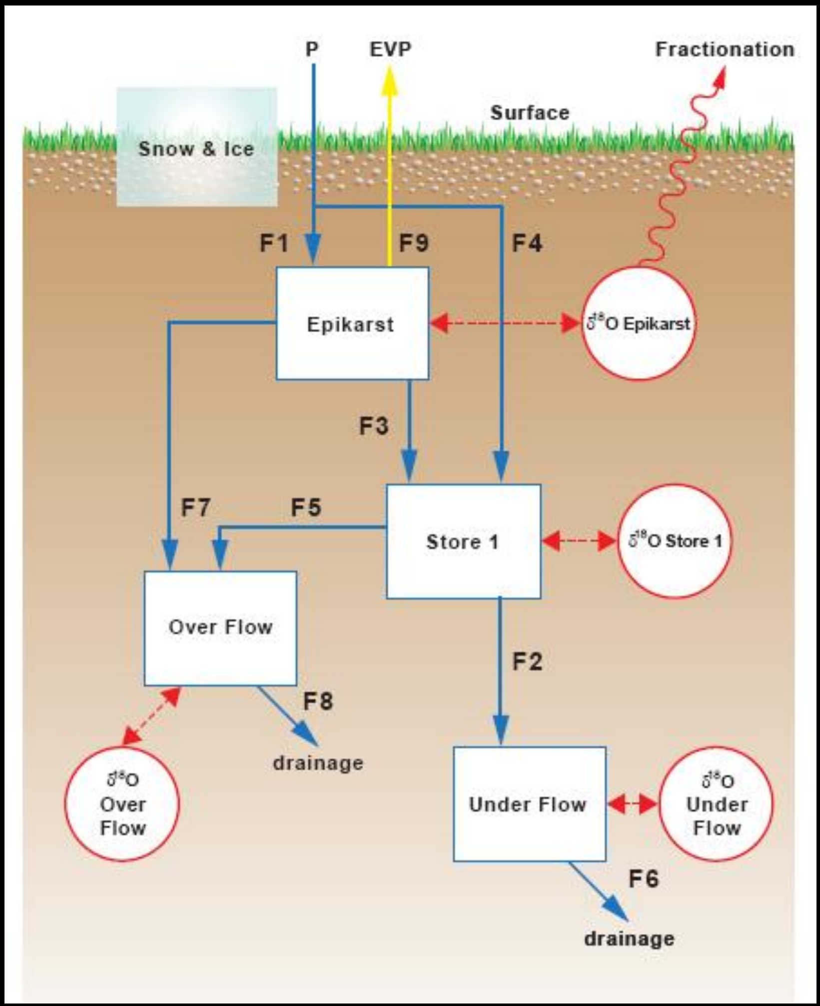
Prof John Gunn

Dr Cath Jex



Prof Ian Fairchild

Thank You!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EVP
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Surface
Snow & Ice
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F9
F4
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δ18O Store 1
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F2
F8
drainage
δ18O Over Flow
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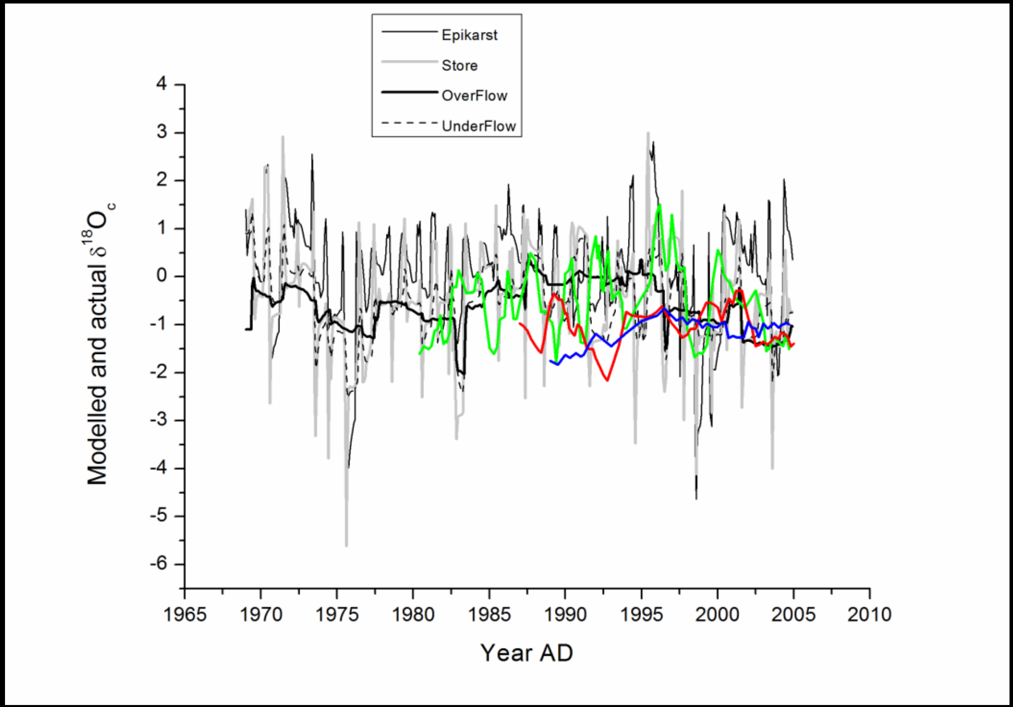
δ18O Under Flow
F6
drainage


Epikarst
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Modelled and actual δ18Oc
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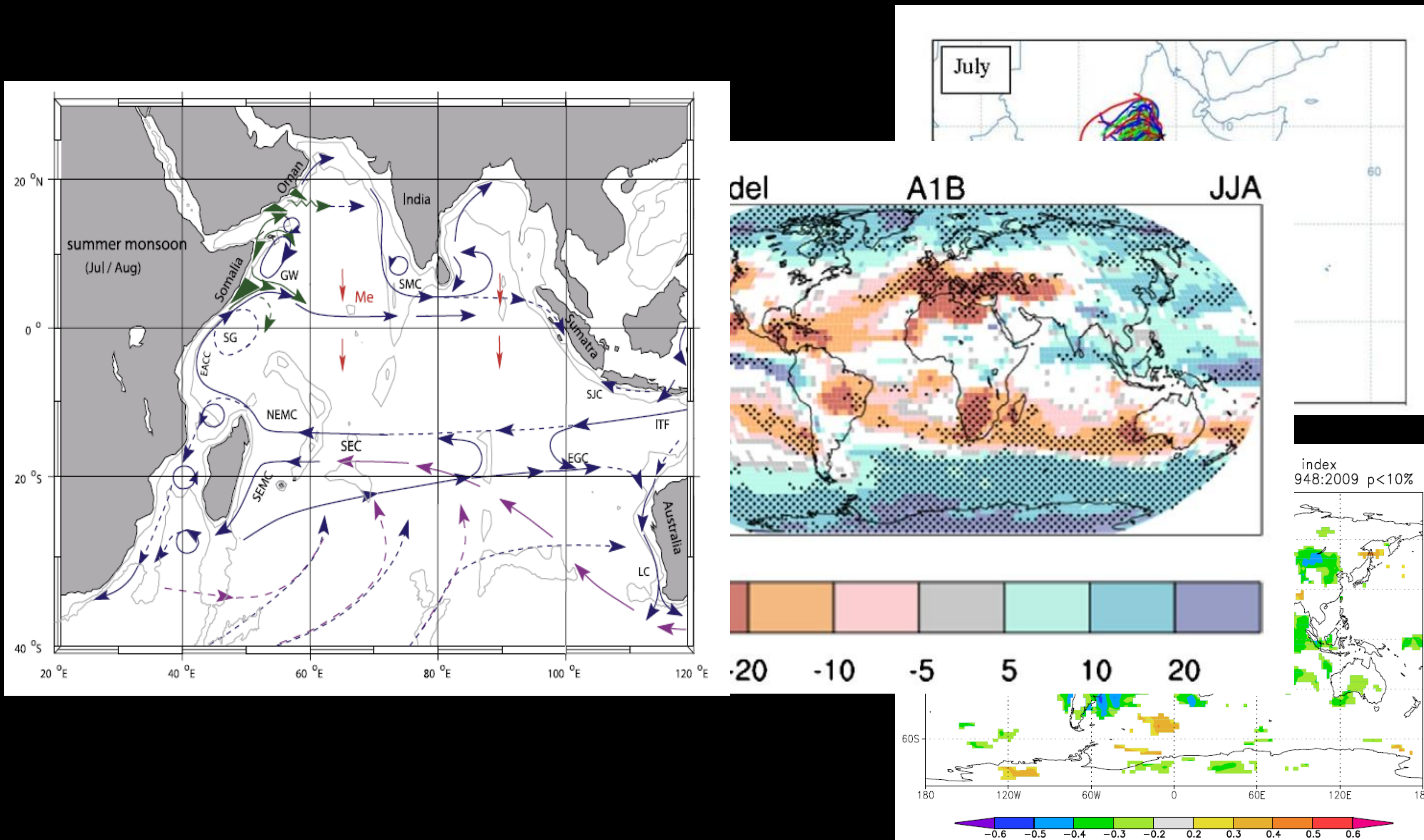
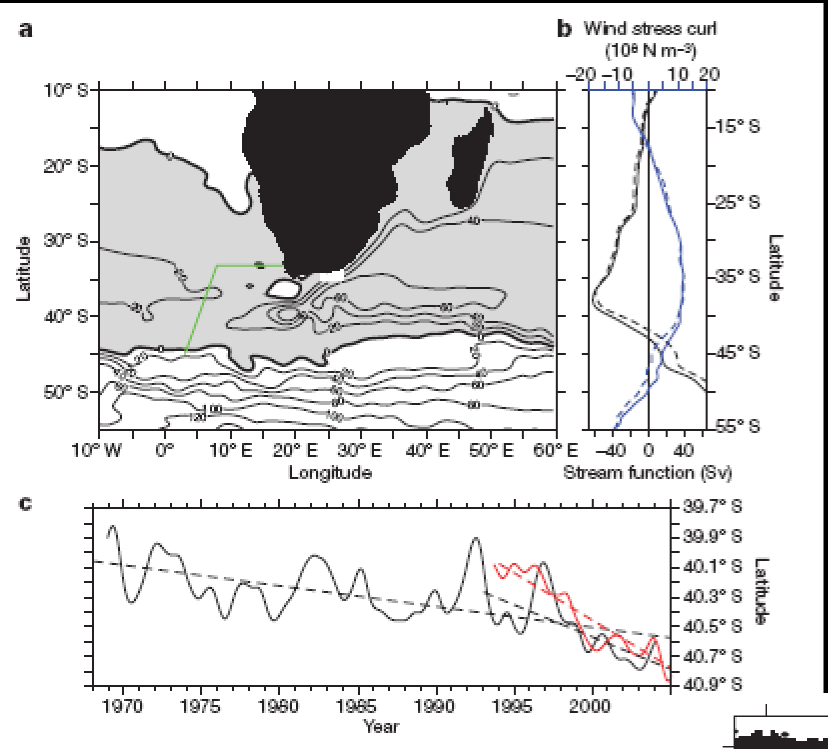
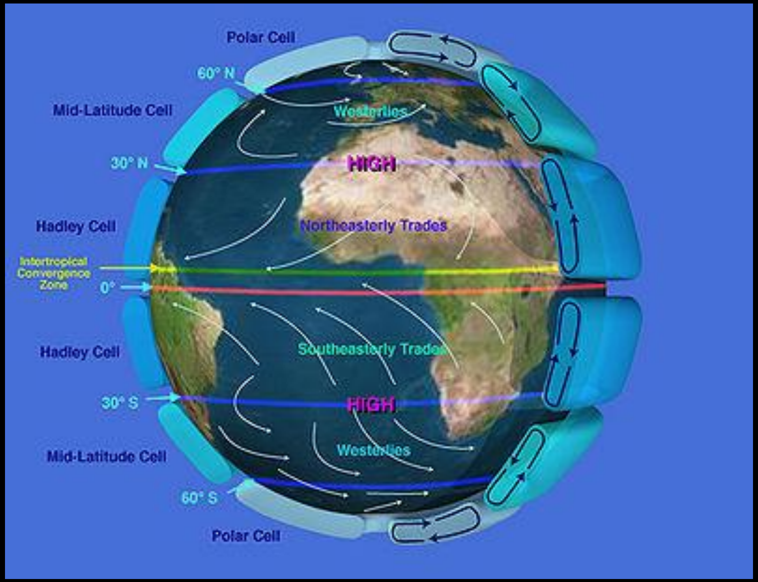
Rainfall in Ethiopia: the future?

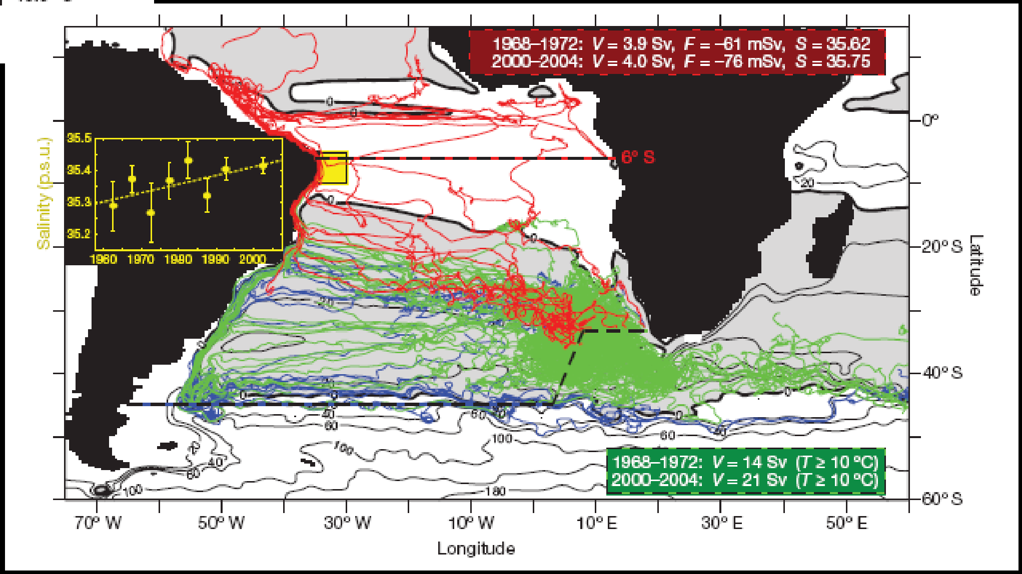


Janicot, S., 2009. A Comparison of Indian and African monsoon variability at different time scales. Comptes Rendus Geoscience, 341, 575-590.

Schott, F.A., Xie, S-P. and McCleary Jr, J.P., 2009. Indian Ocean circulation and variability. Rev. Geophys, RG000245

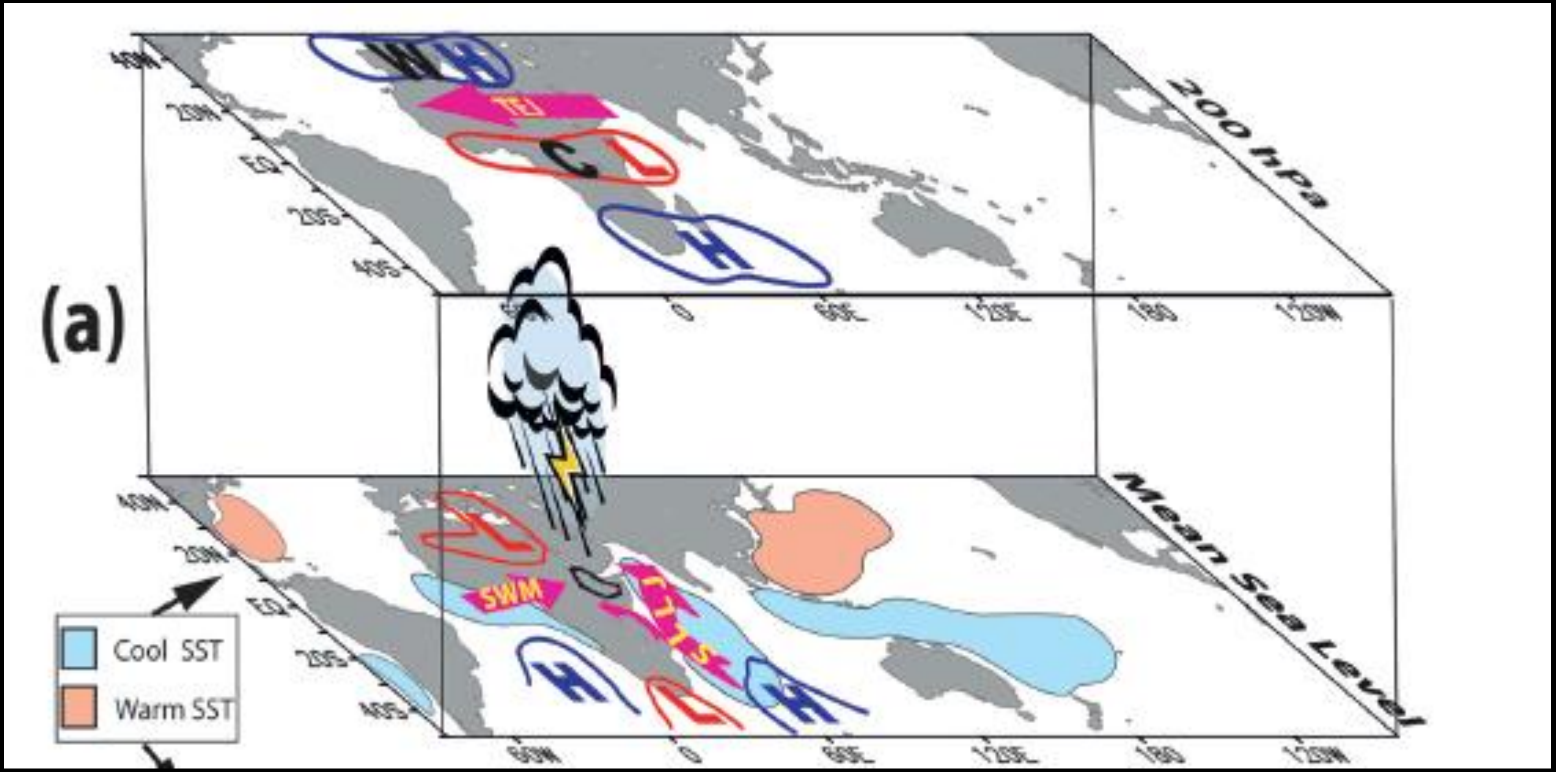




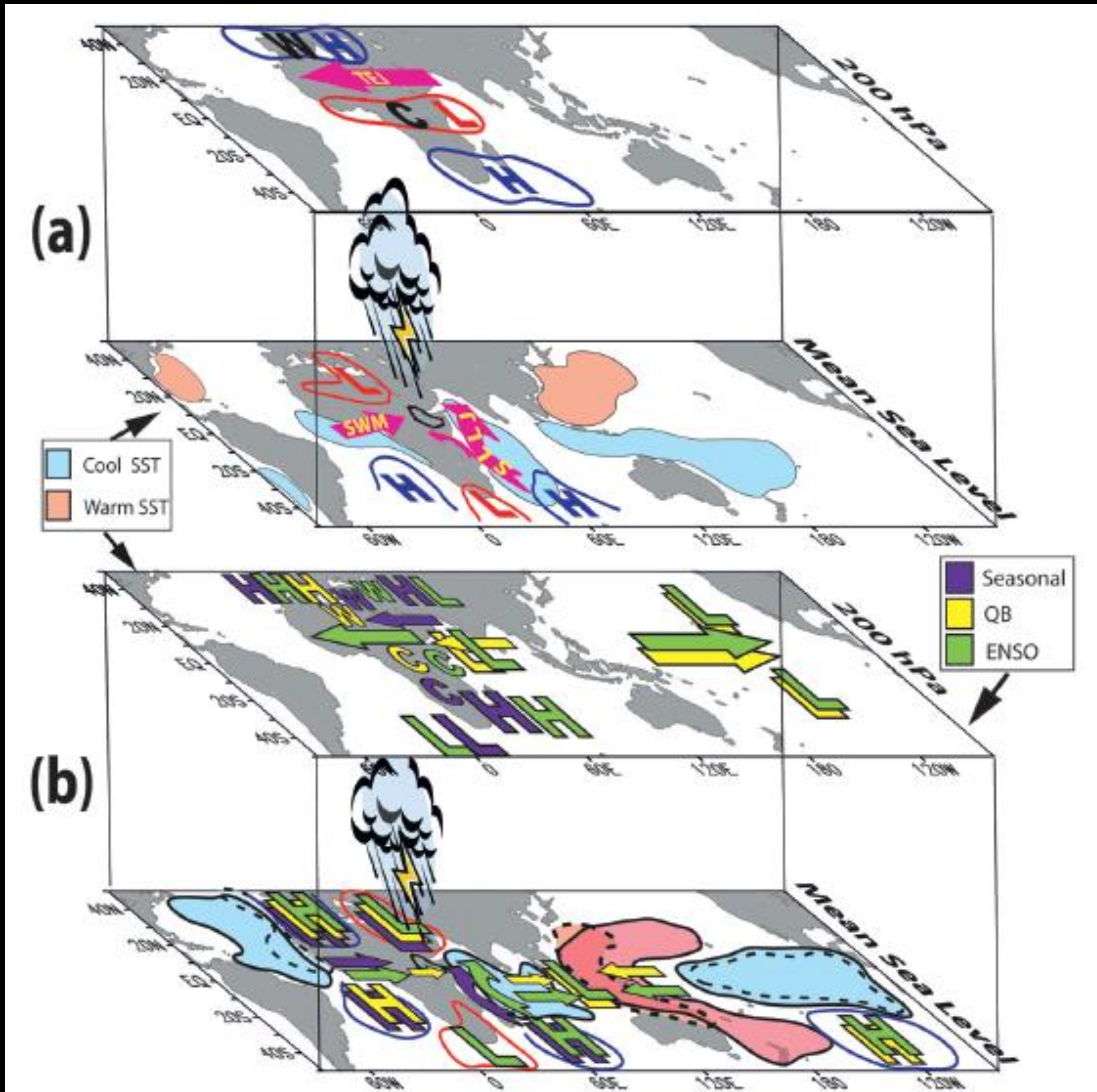


Biastoch, A., Boning, C.W., Schwarzkopf, F.U., Lutjeharms, J.R.E., 2009. Increase in Agulhas leakage due to poleward shift of Southern Hemisphere westerlies. Nature, 462, 495-

The East African Monsoon



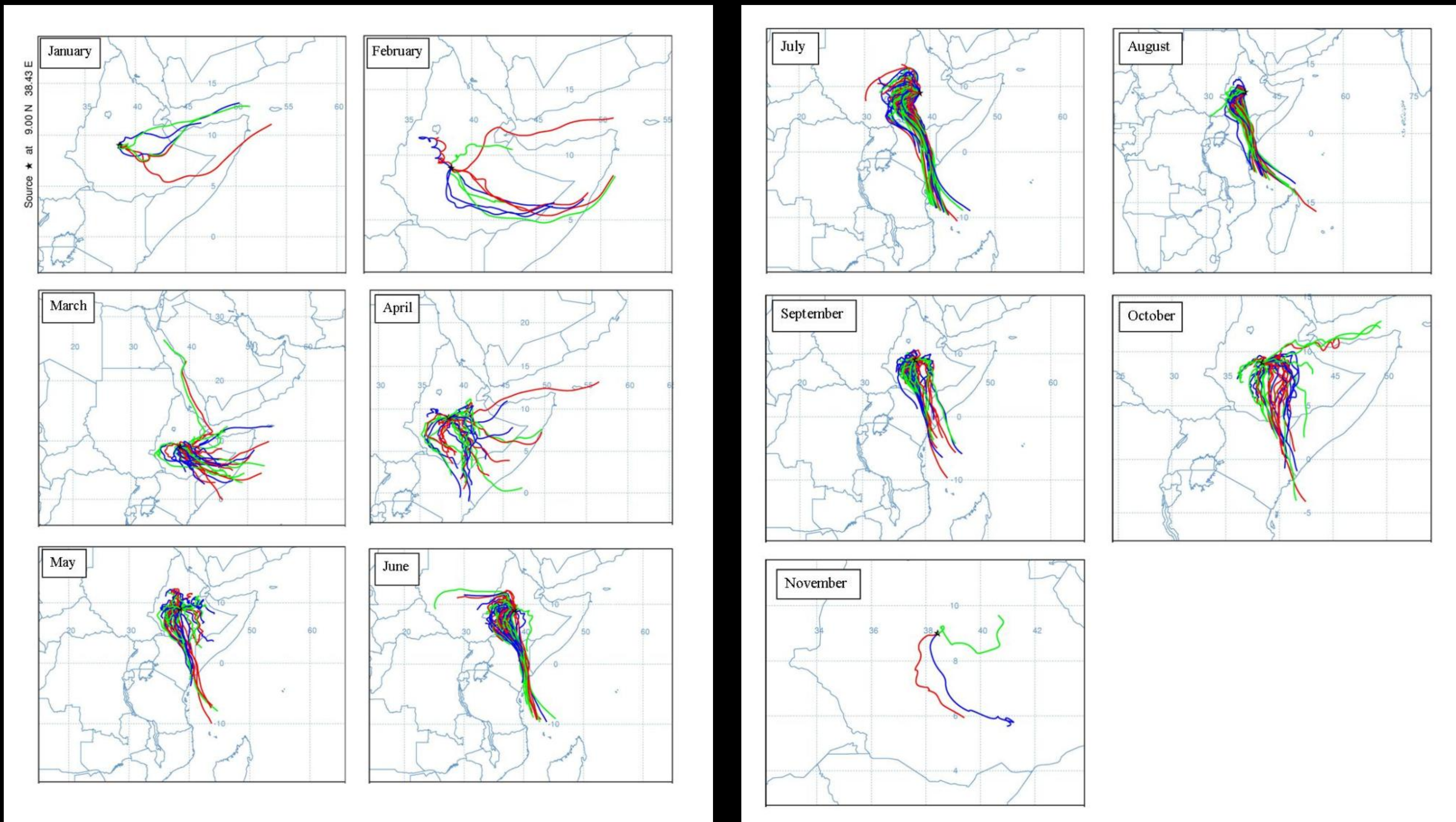
Segele, Z.T., Lamb, P.J. and Leslie, L. M., 2009. Seasonal-to-interannual variability of Ethiopia / Horn of Africa monsoon Part I… Journal of Climate, 22, 3396-3421.



Summer rainfall: processes on an annual (top) and seasonal to multiannual timescale

Segele, Z.T et al., 2009. J. Clim, 22, 3396-

HYSPLITT: Addis Ababa Rainfall Back Trajectories



May, E., Baker, A, Eden, J. and Asrat, A. Back trajectory and source region analysis of Addis Ababa rainfall. Int. J. Climatology, submitted