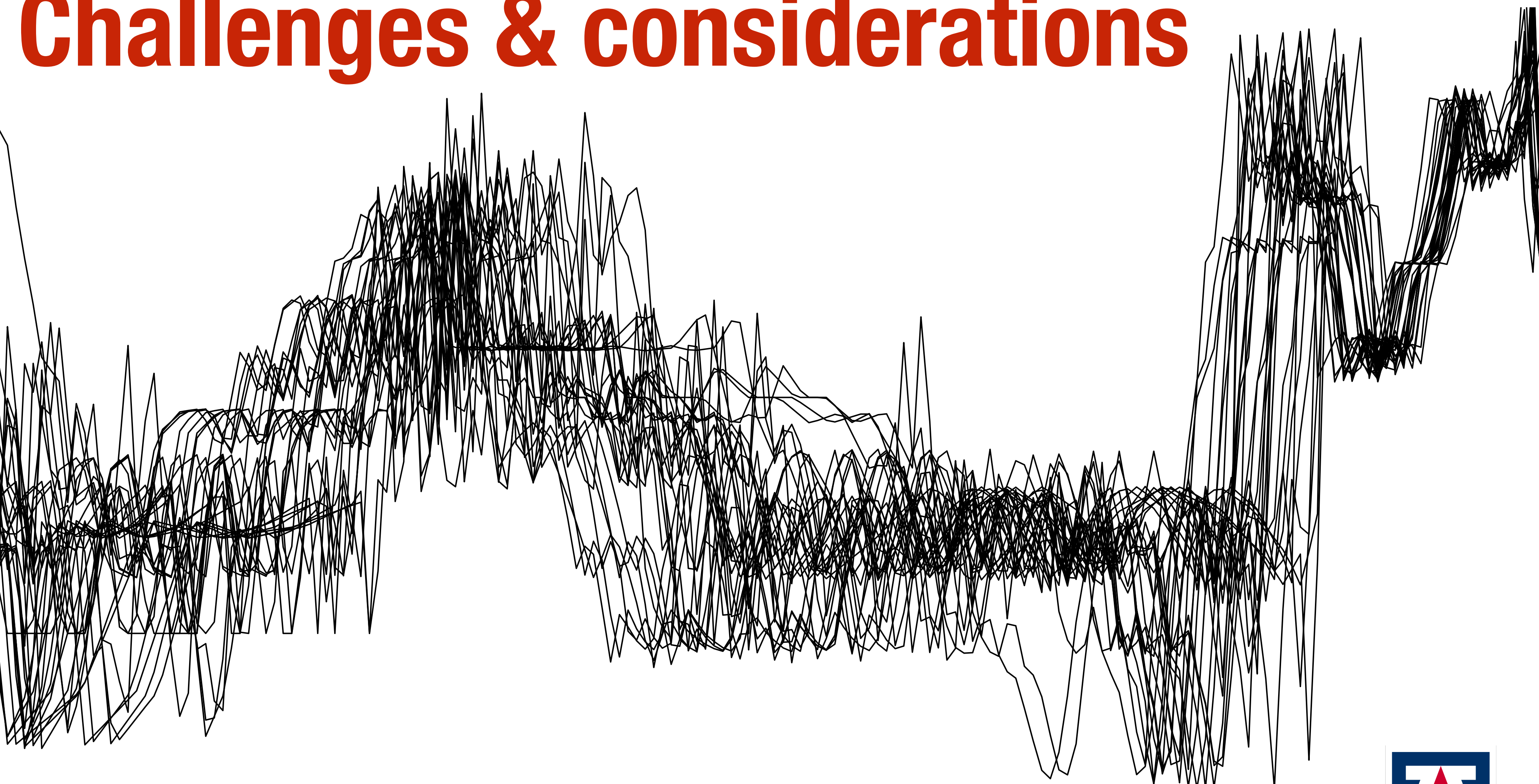
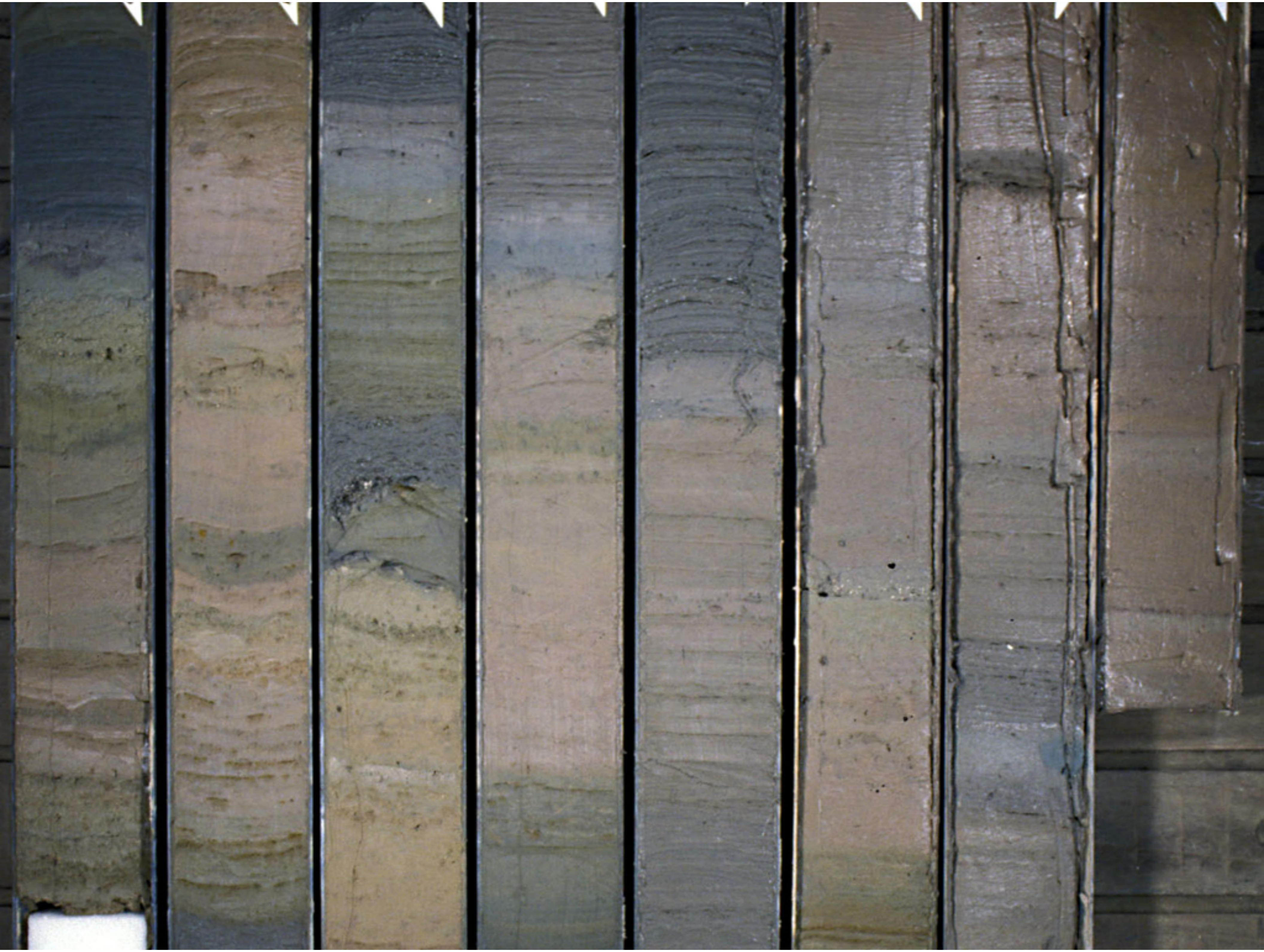
Interpreting past hydroclimate variability from sedimentary records: Challenges & considerations

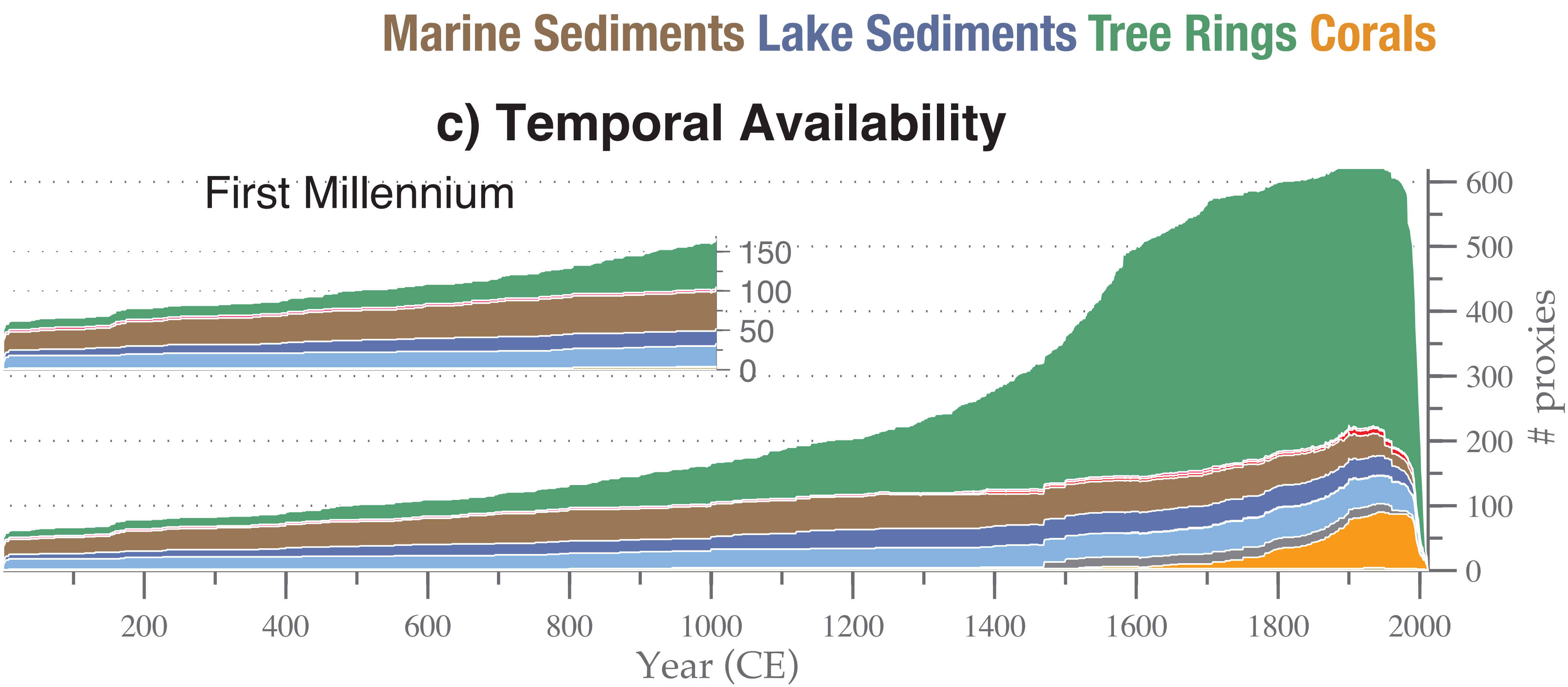


Jessica Tierney

The University of Arizona



The farther back in time you go, the more important sediments become.



PAGES2K, 2016, Scientific Data, in prep

Some nice features of sediment archives

- Long, continuous records
- Multiple sensors and proxies can be measured

Sedimentary Observations (Proxies) with hydroclimate information

- Oxygen isotopes ($\delta^{18}O$) on foraminifera (marine)
- Lake levels
- Things sensitive to lake levels (Mg/Ca of minerals, $\delta^{18}O$ of authigenic carbonate).
- δD of leaf waxes
- Runoff indicators (Ti concentration, varves)
- Microfossil assemblages (pollen, diatoms)

Some challenging features of sediment archives

- Age uncertainty is usually large
- Bioturbation mixes signals
- The archive itself adds red noise (e.g. lakes).

Interpreting sedimentary archives: an overview

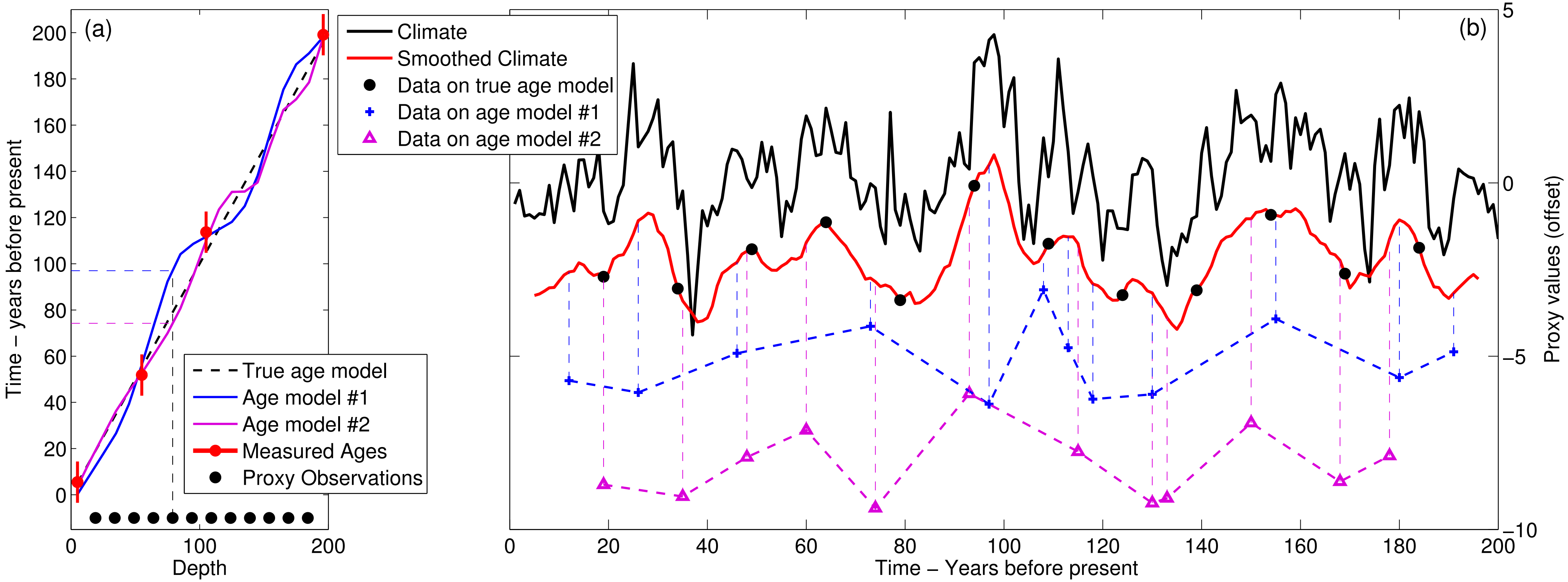


Figure made by Martin Tingley

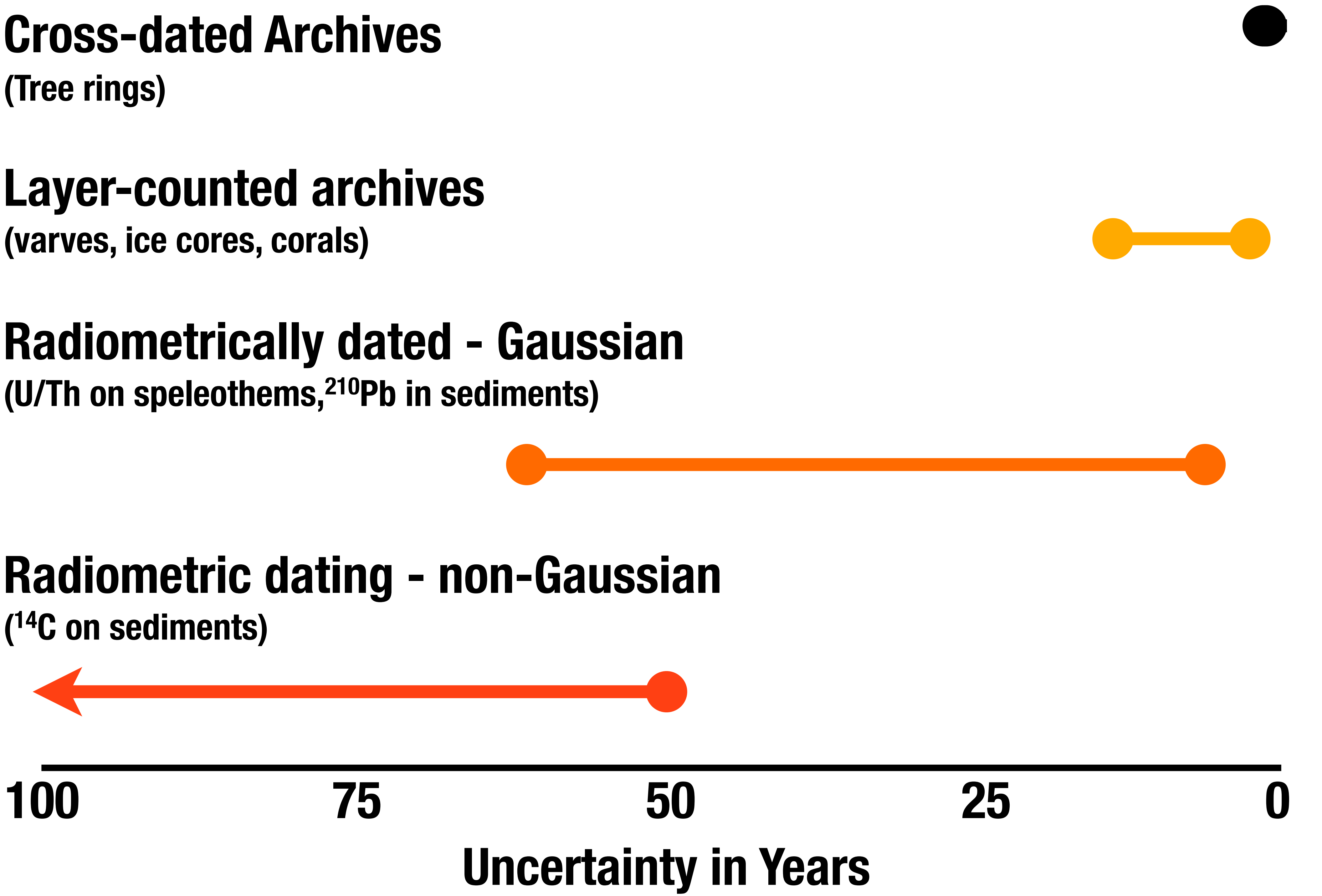
Proper interpretation of hydroclimate data from sediments requires:

- Proxy (observation) forward model(s)
- An archive model to account for smoothing/reddening
- A way to deal with age uncertainty

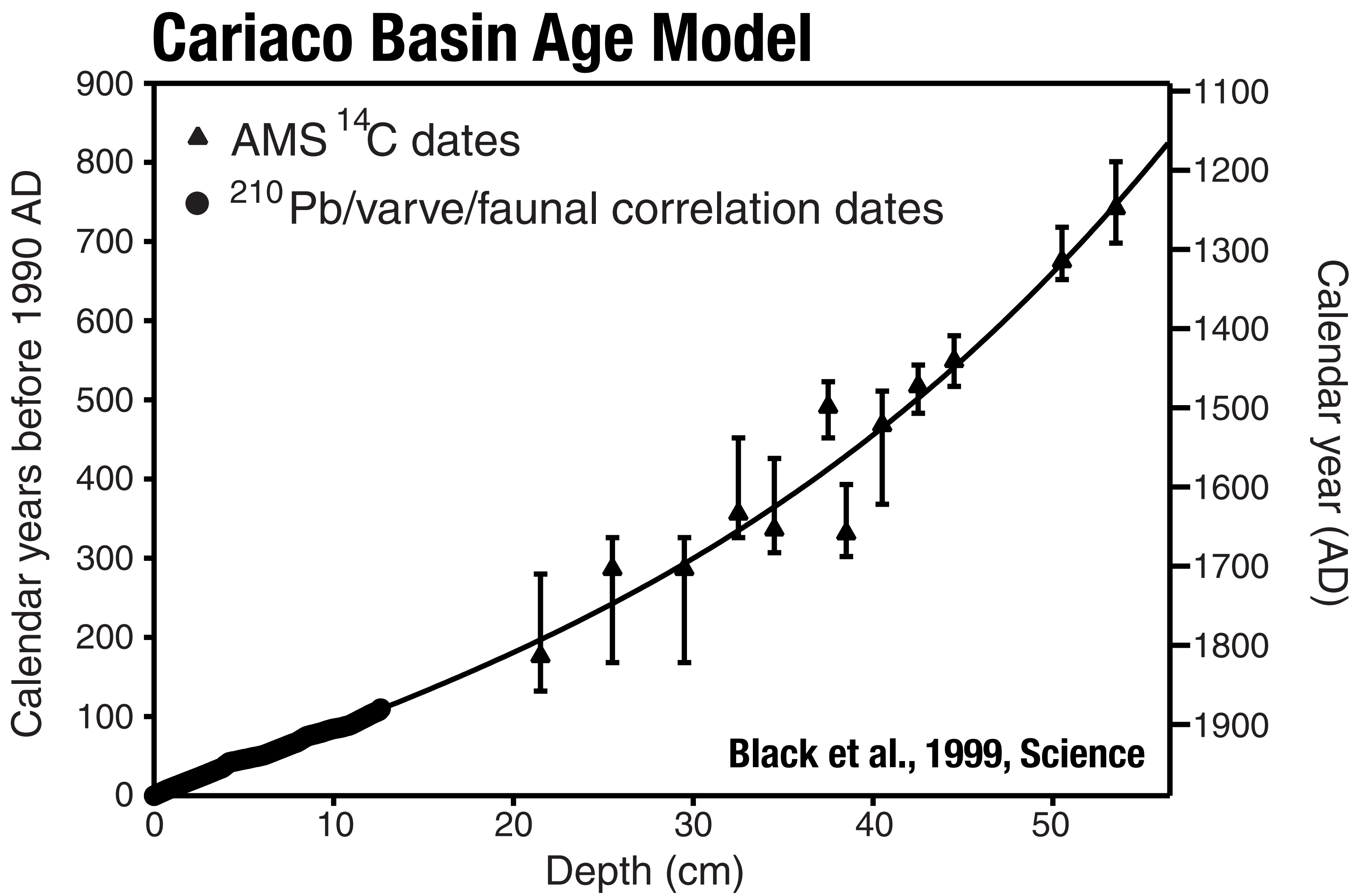
Archive issues:

Age Uncertainty

The time uncertainty continuum

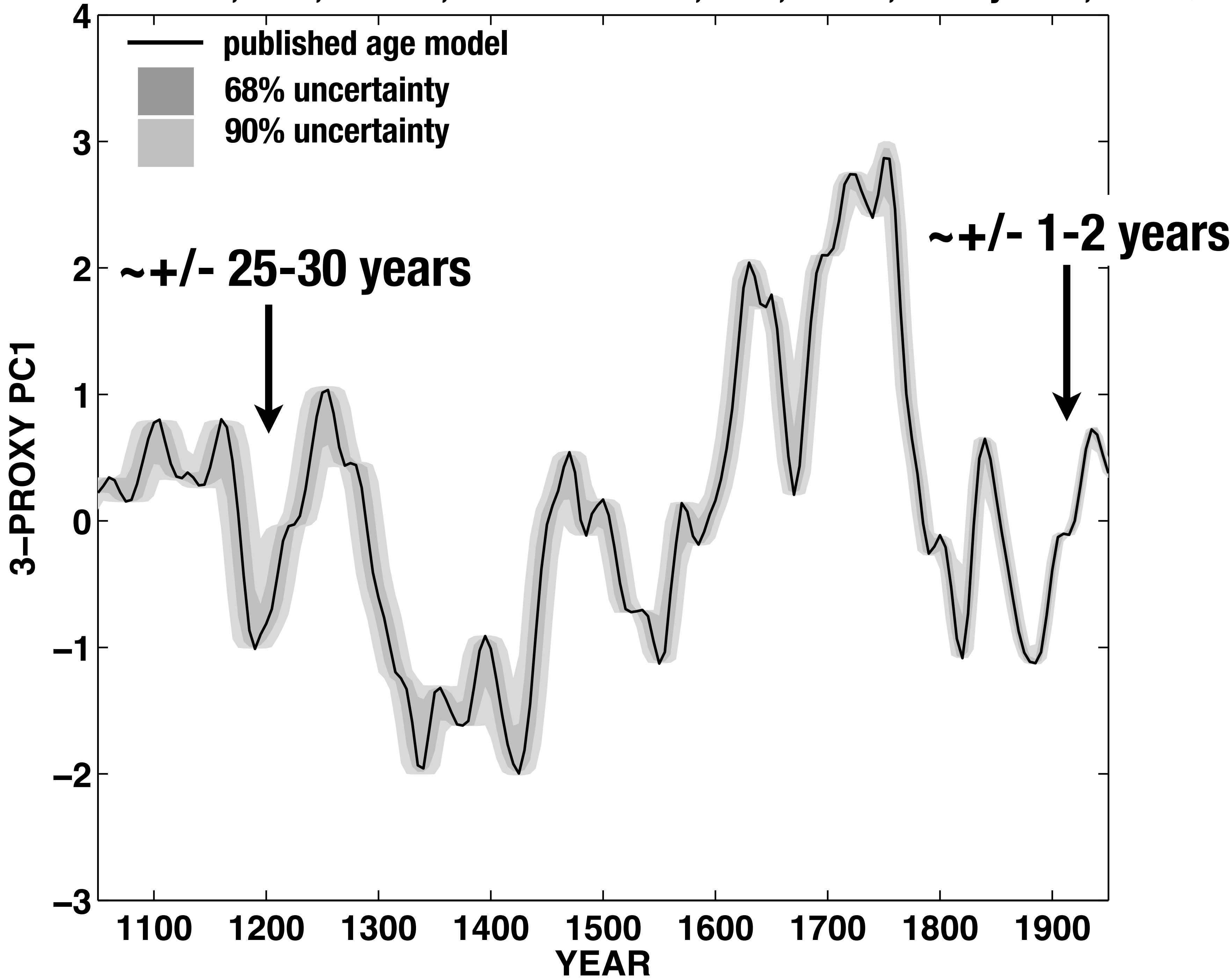


Annually resolved ≠ time certain



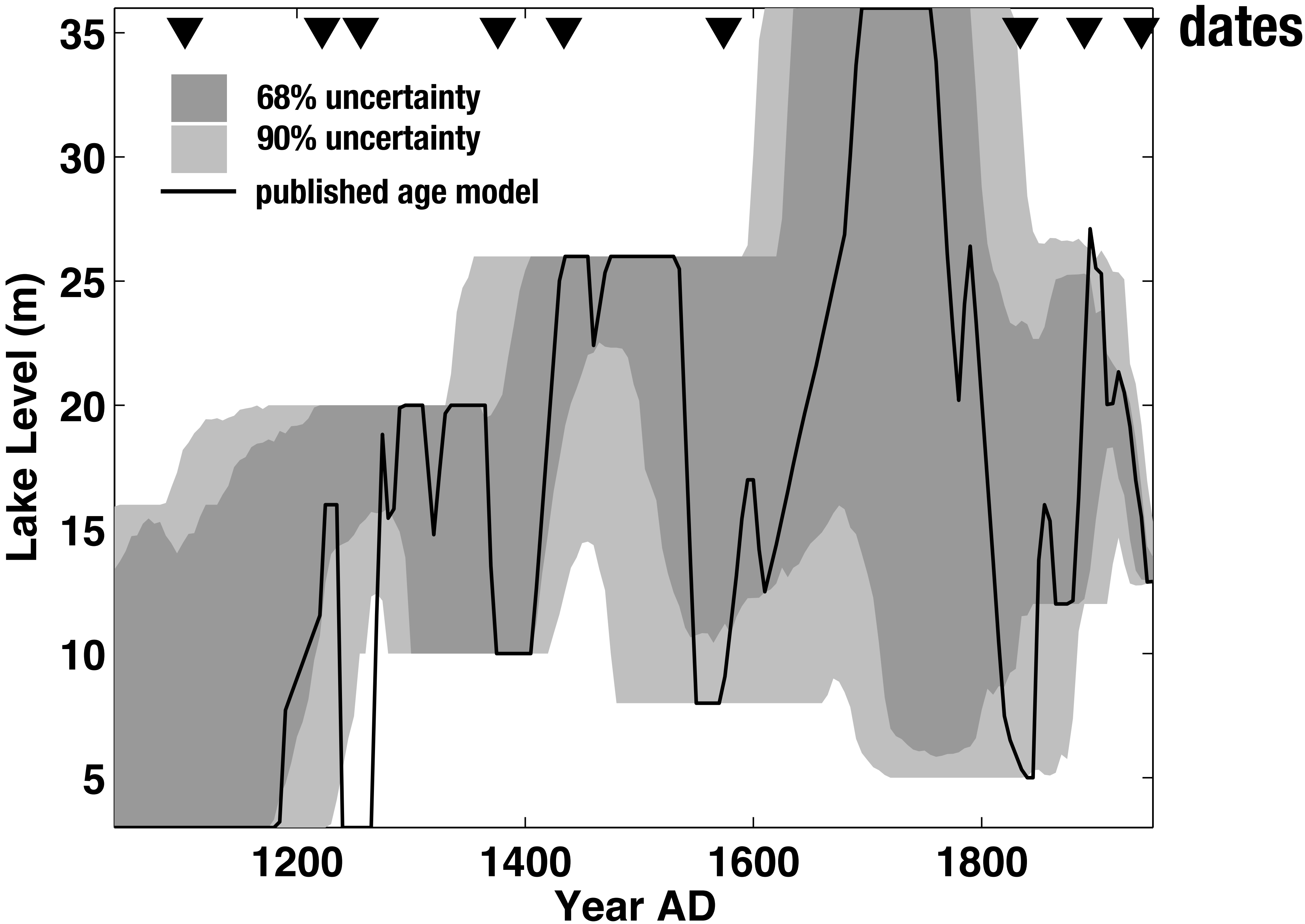
LAKE CHALLA, KENYA (VARVE-COUNTED)

Wolff et al., 2011, Science; Verschuren et al., 2009, Nature, Tierney et al., 2011 QSR



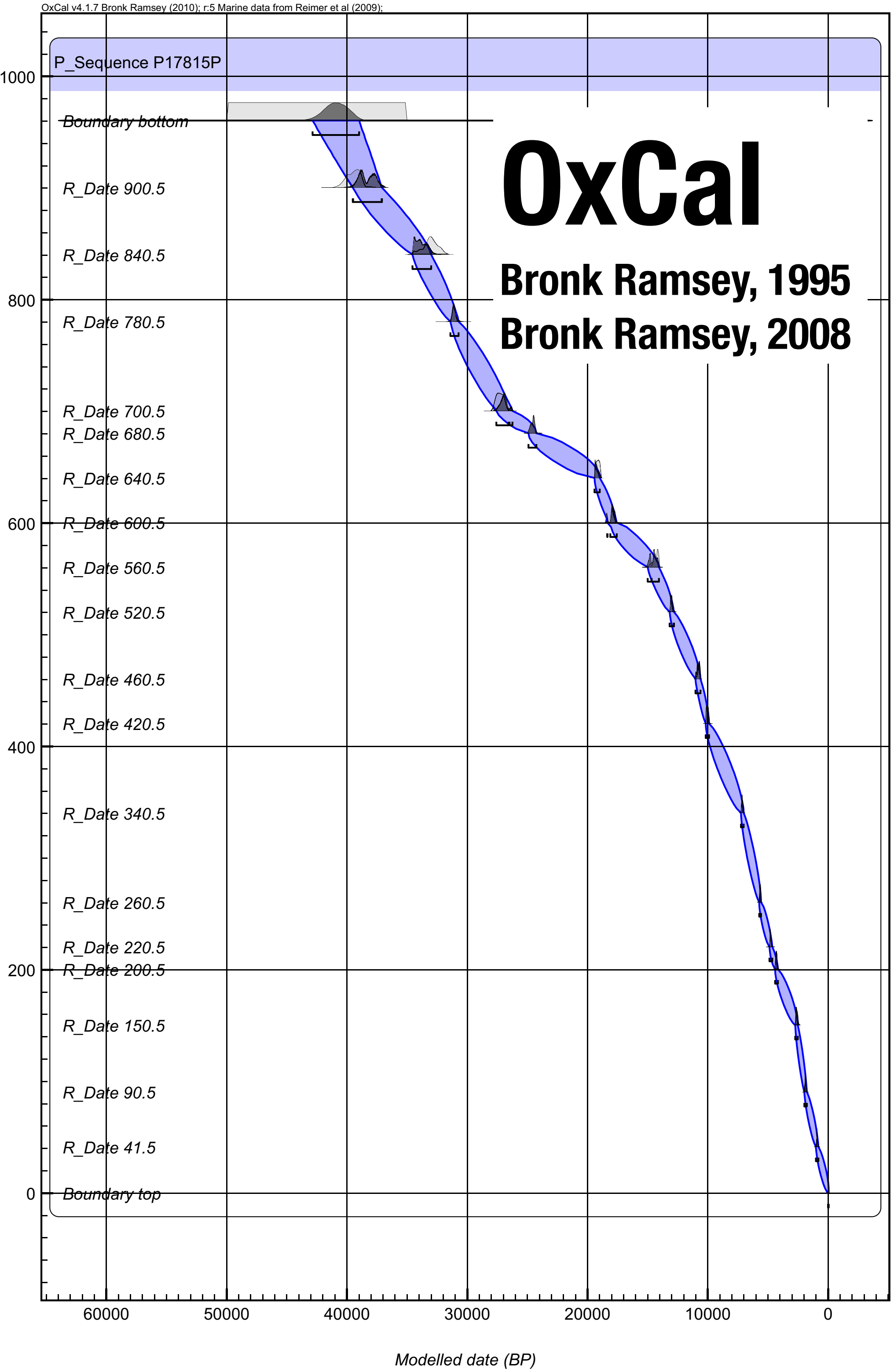
LAKE NAIVASHA, KENYA (^{14}C DATED)

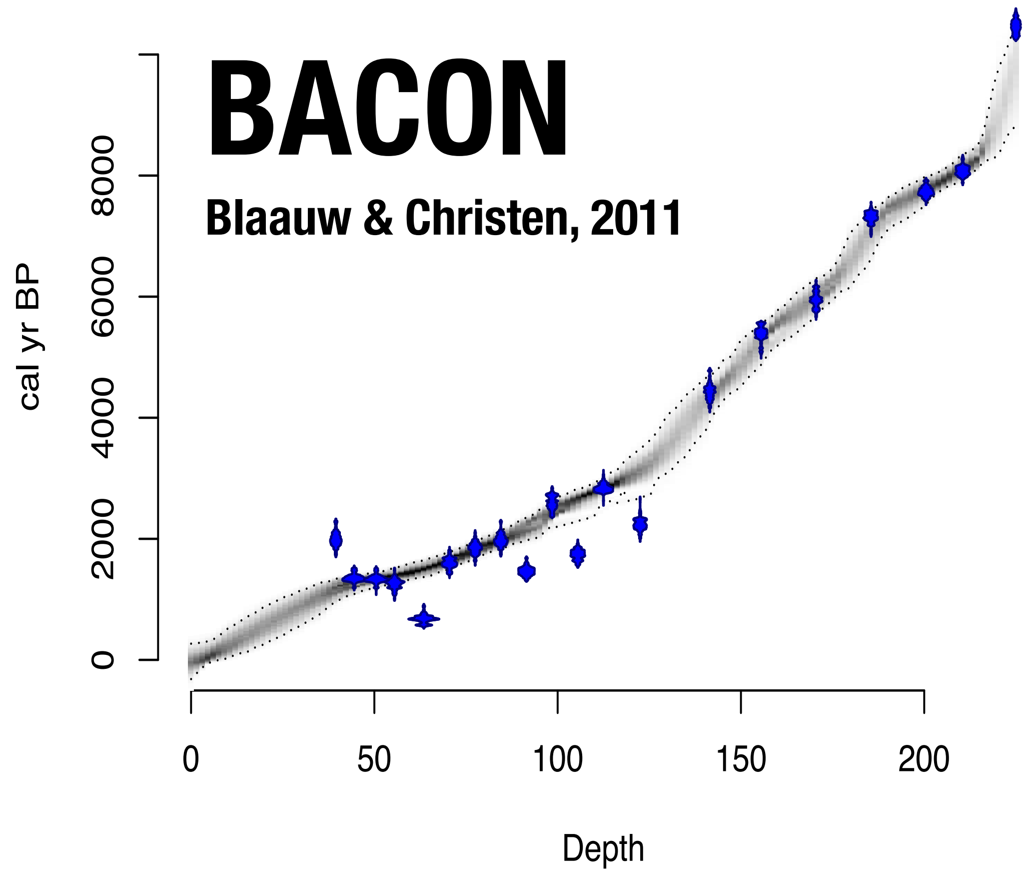
Verschuren et al., 2000, Nature



Age Modeling Techniques

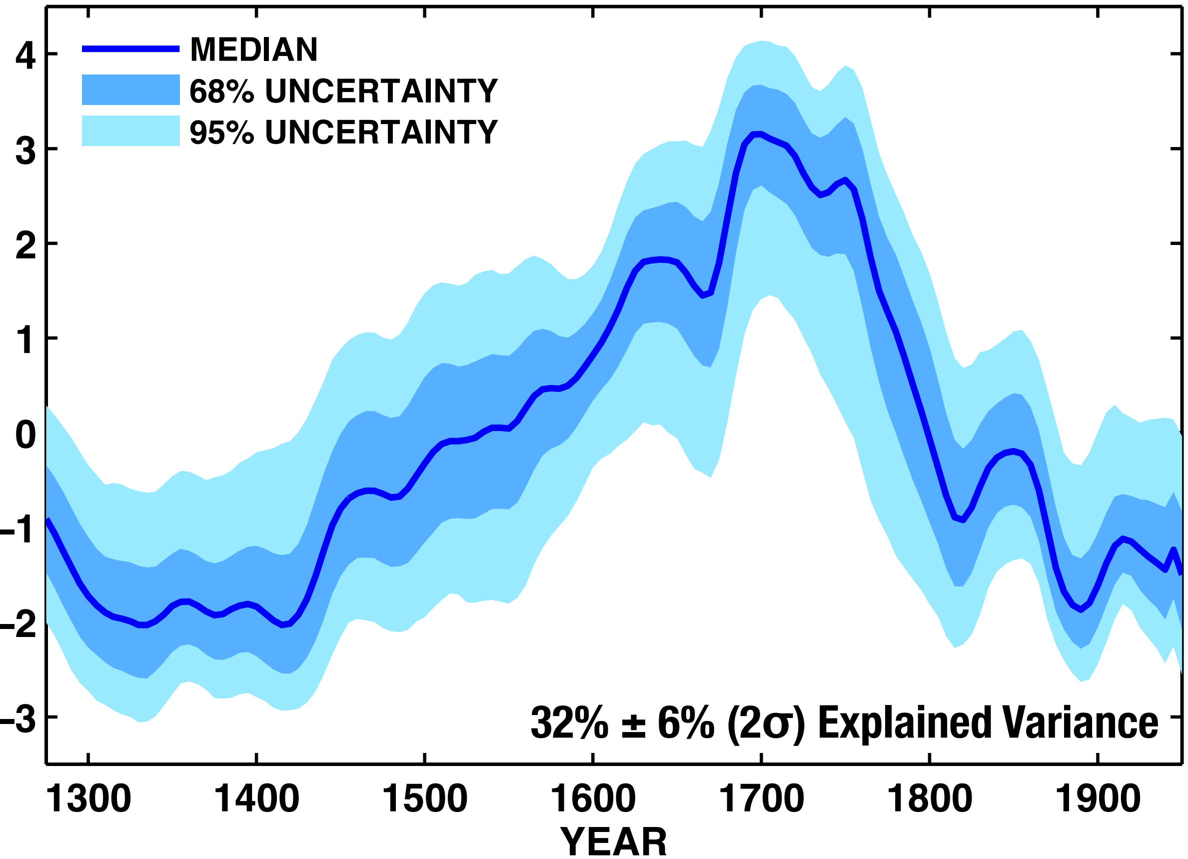
Simplest approach uses MC iteration and the constraint of superposition. More complex approaches make assumptions about the sedimentation process





Monte Carlo EOF

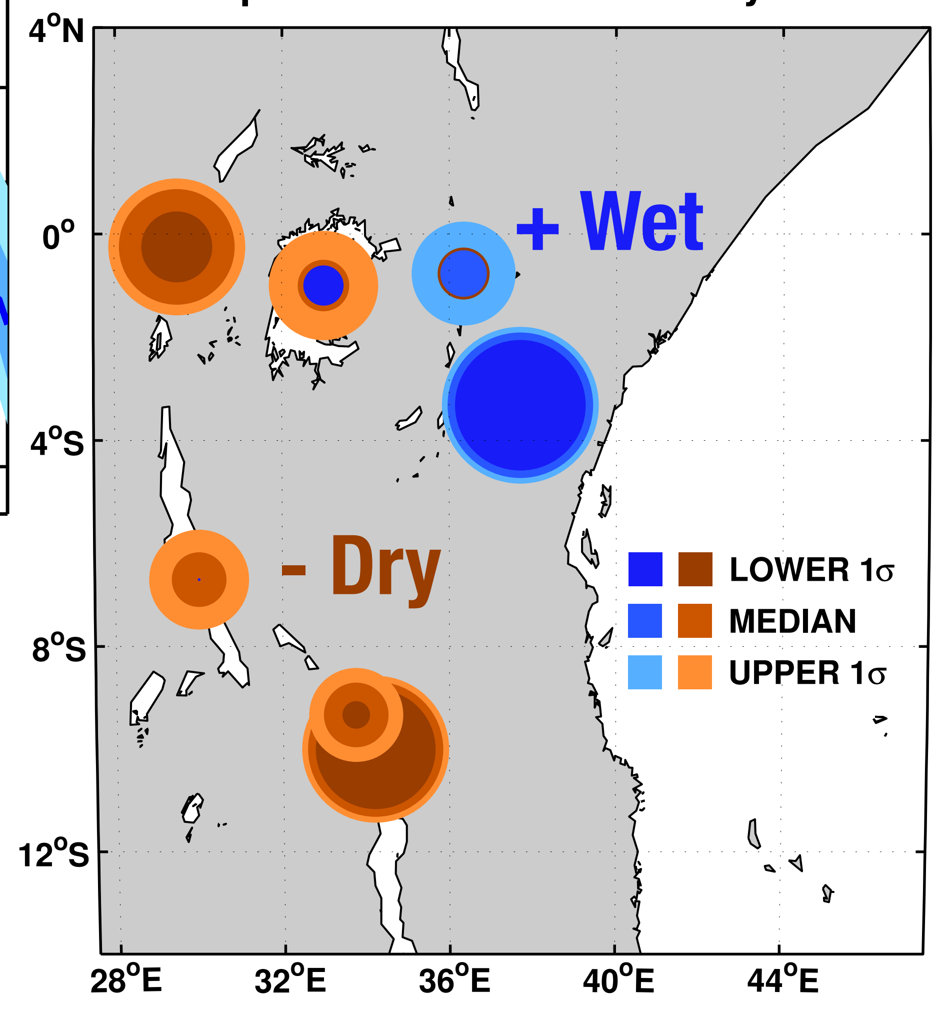
East Africa MCEOF1; 10,000 simulations



EOF1 Loadings

sizes of circles represents loading value

colors represent median and uncertainty bounds

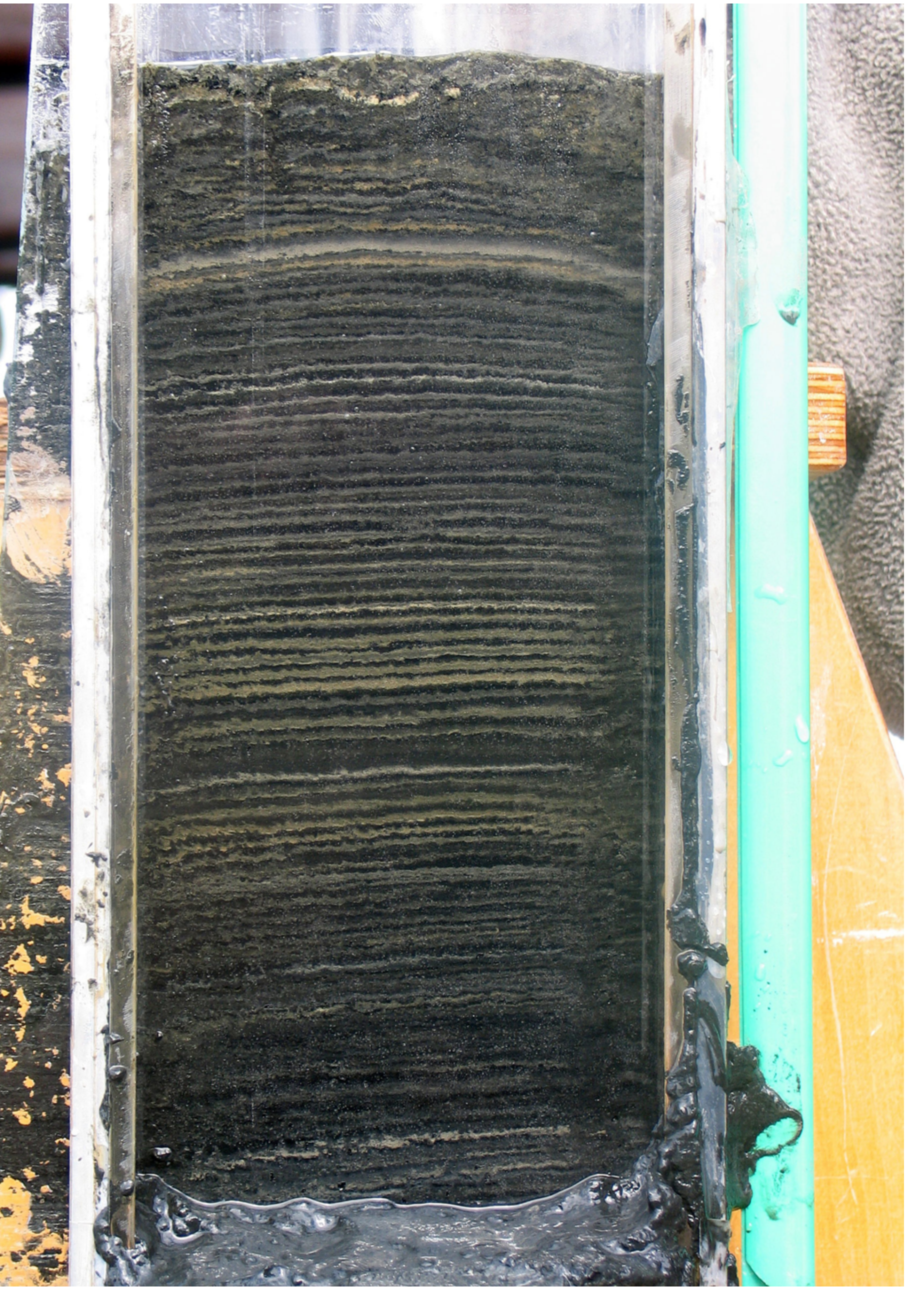


Tierney, Smerdon, Anchukaitis & Seager

Nature, 2013

Archive issues:
Bioturbation

Unless you have this:



You need to account for bioturbation!

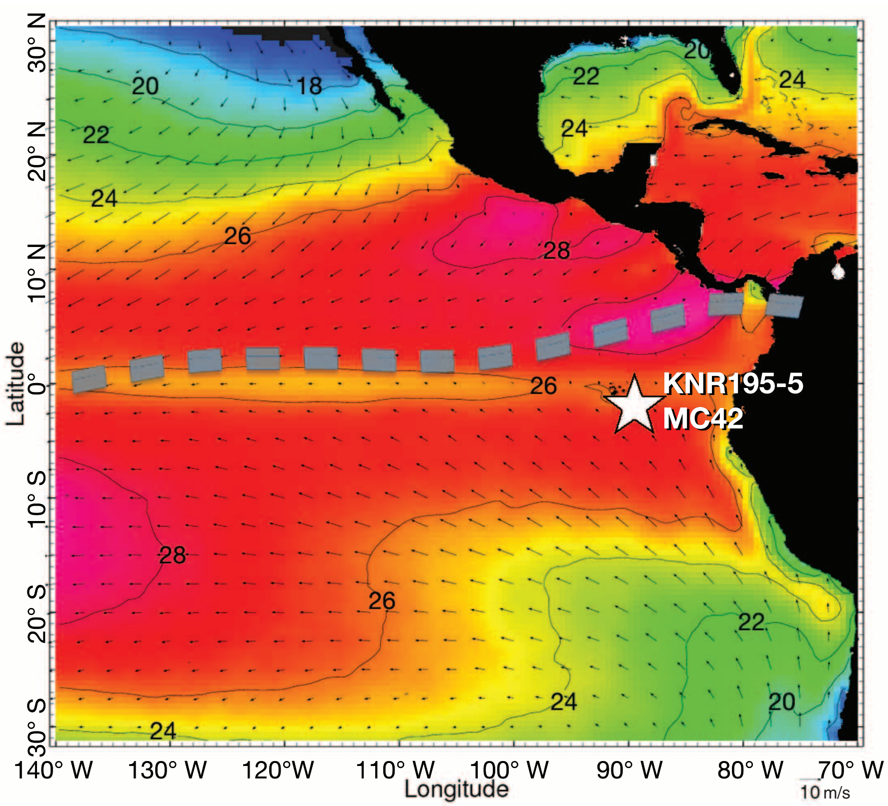
Example

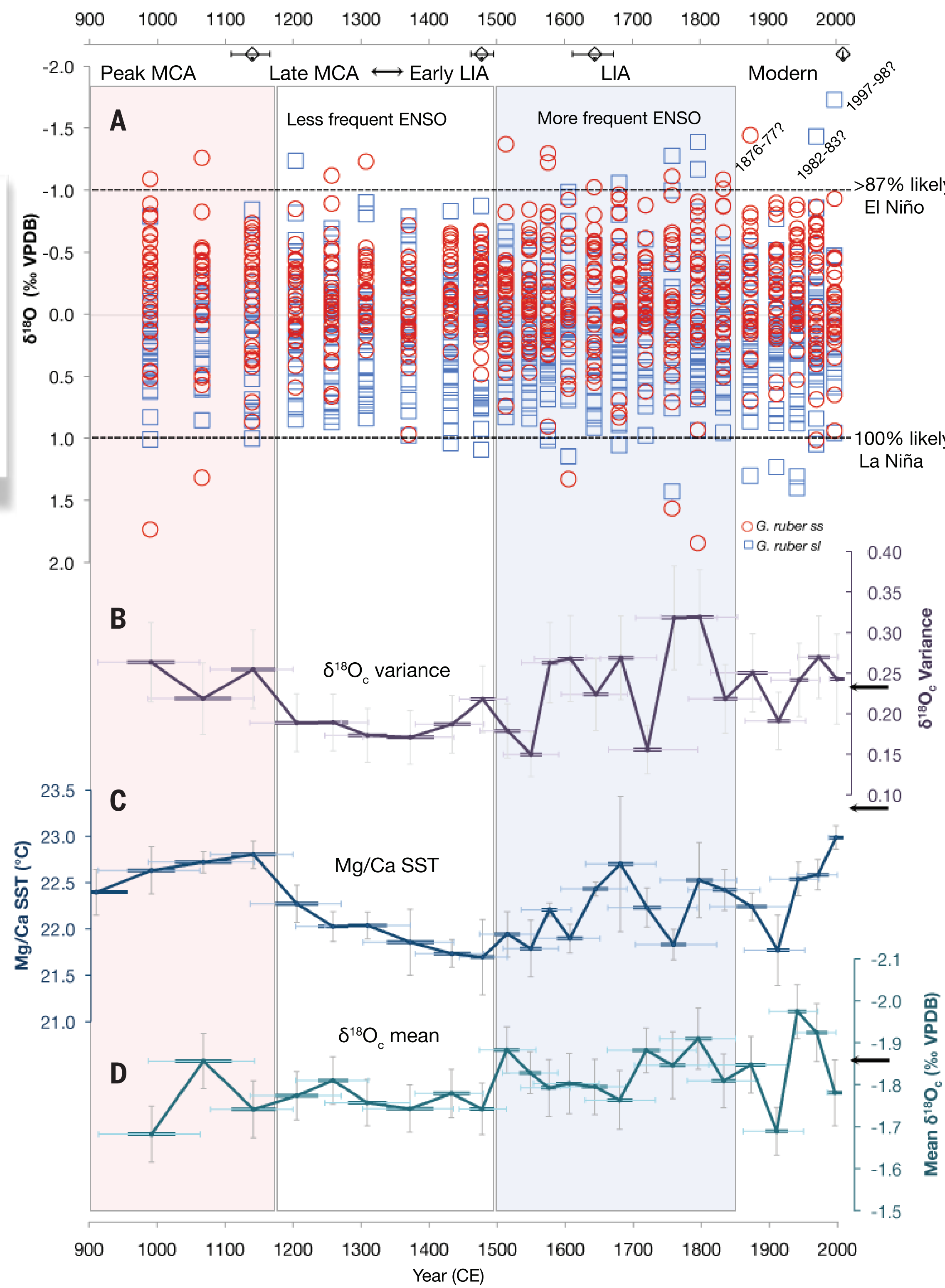
PALEOCEANOGRAPHY

Dynamical excitation of the tropical Pacific Ocean and ENSO variability by Little Ice Age cooling

Gerald T. Rustic,[1,2*†] Athanasios Koutavas,[1,2,3]
Thomas M. Marchitto,[4] Braddock K. Linsley[3]

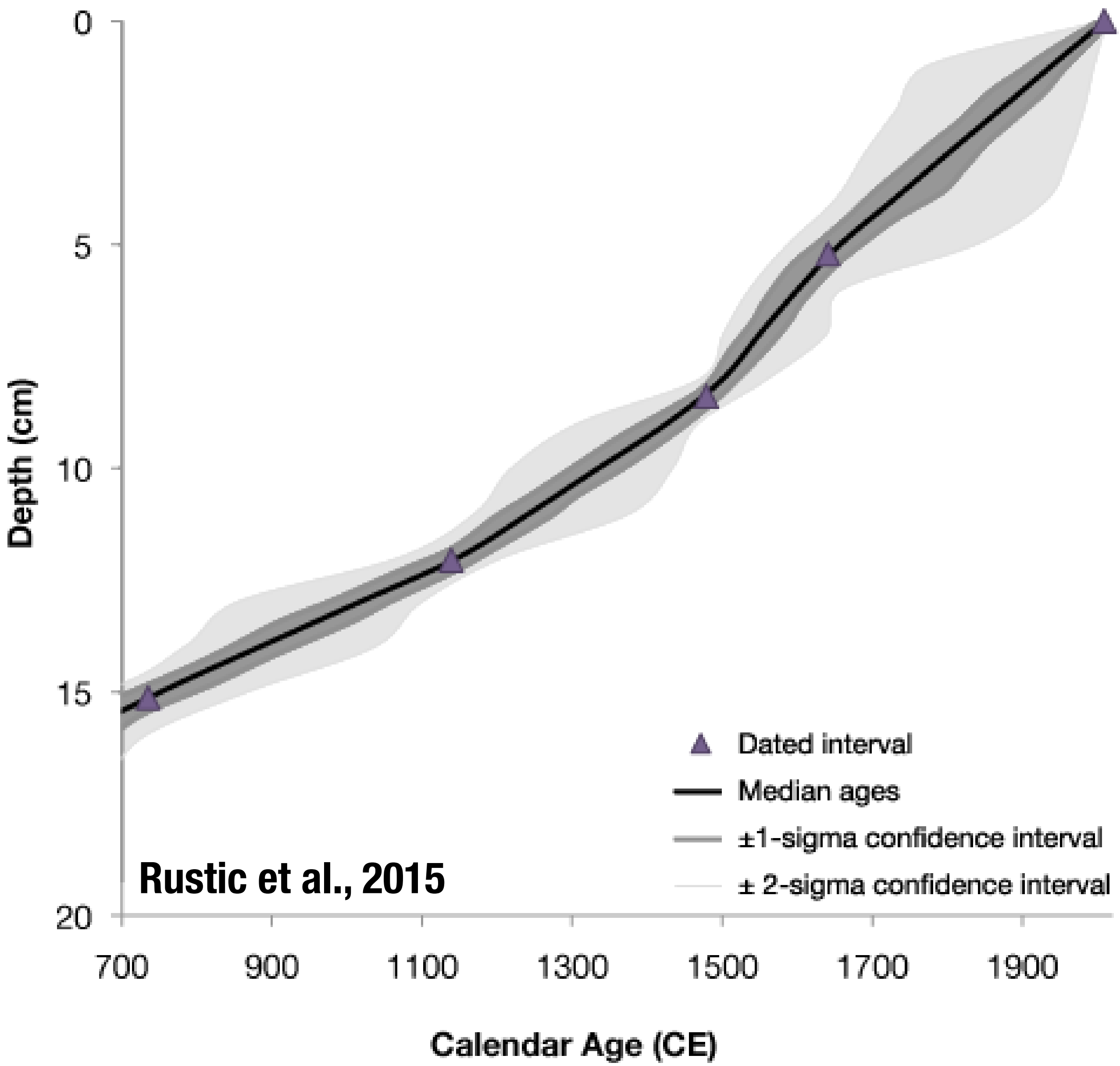
Rustic et al., 2015



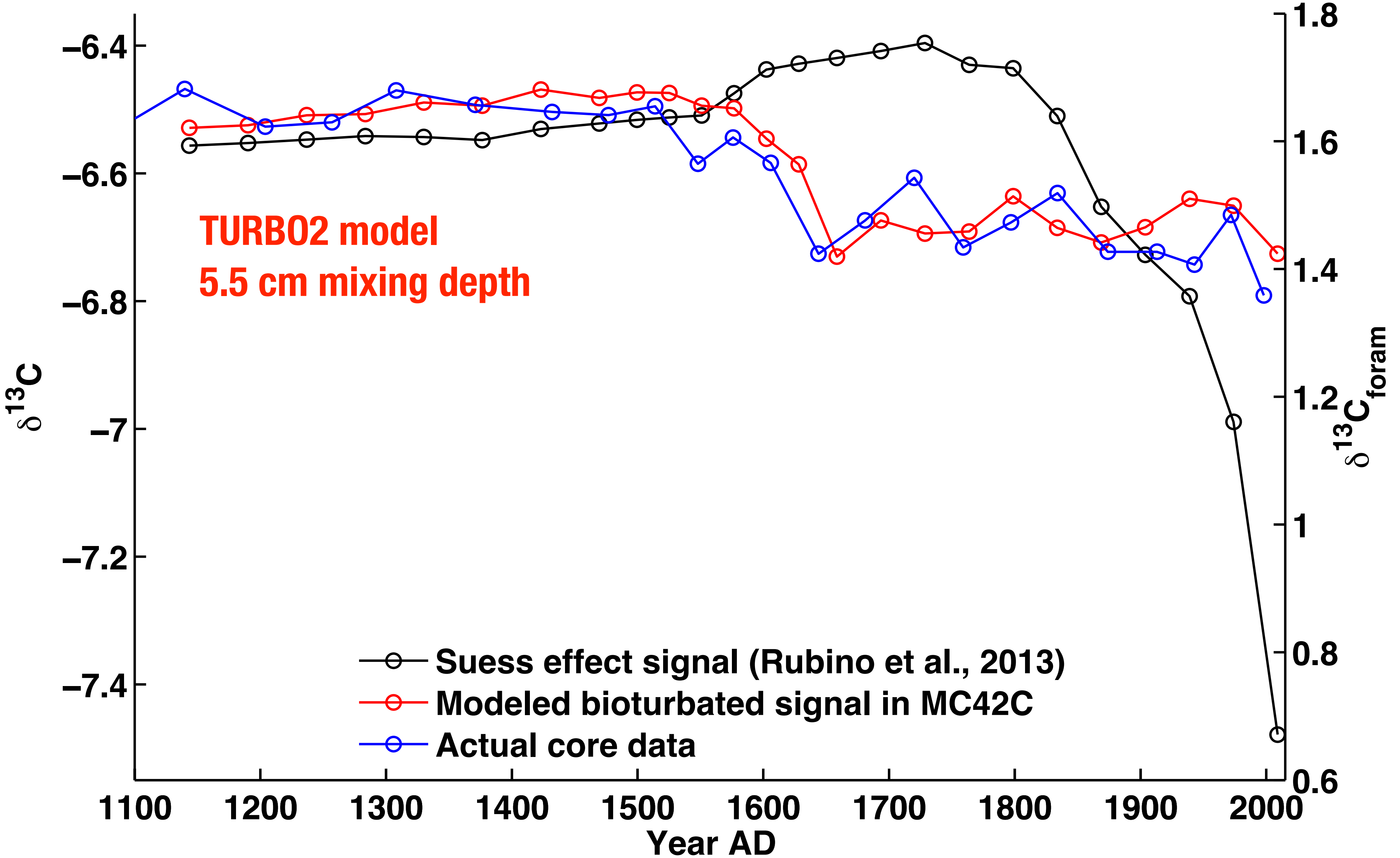


The Problem:

Record is only ca. 15 cm long, and is not laminated.



Using the Suess effect to assess bioturbation



Bioturbation models

Typically modeled as an impulse response function that describes instantaneous mixing of initial deposition in the "bioturbation layer" (H).

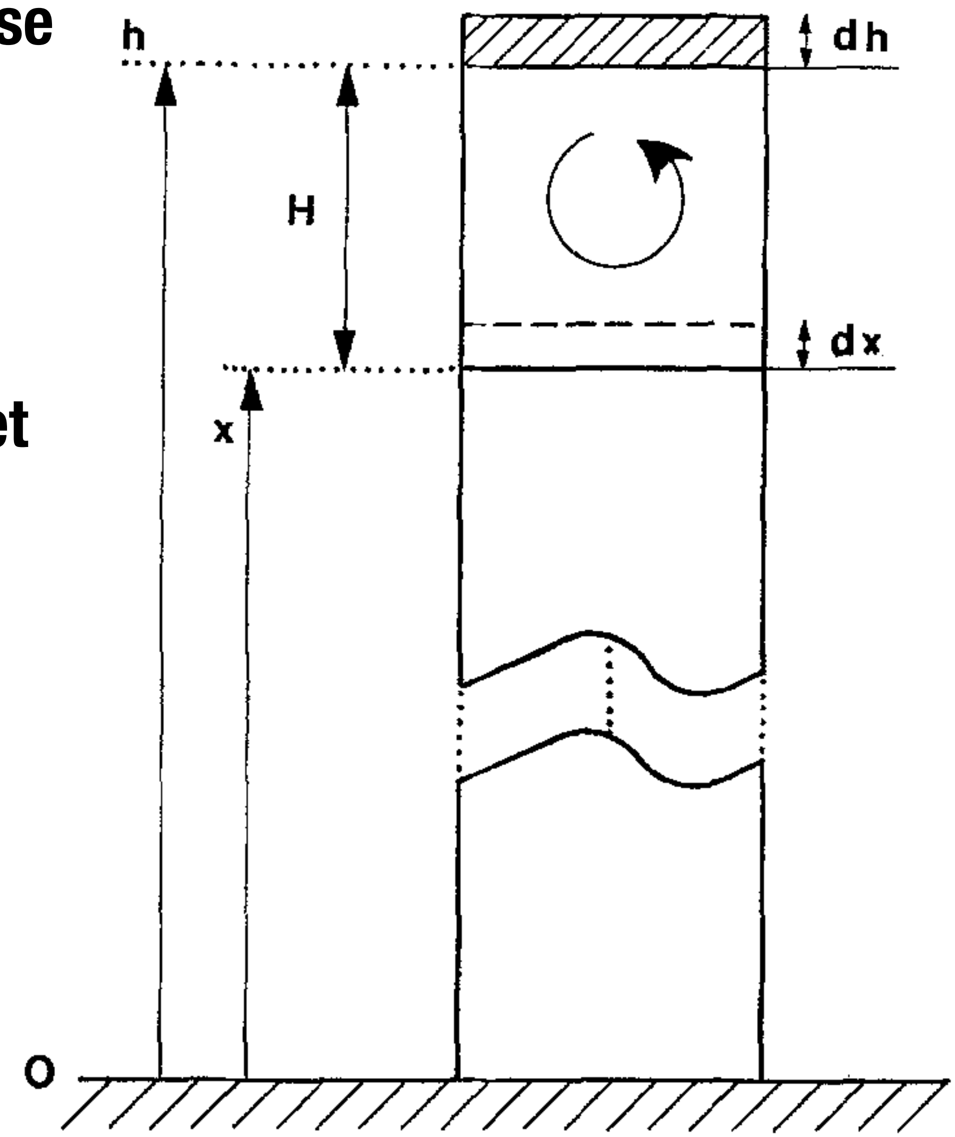
e.g., Berger and Heath (1968) and Bard et al., (1987) model:

$$dC/dt = 1/H * (C_{dh} - C_H)$$

or, the diffusion model of Guinasso and Schink, 1975, JGR:

$$dC/dt = D\ d^2C/dx^2 - v*dc/dx$$

where D is diffusivity and v is sed rate.



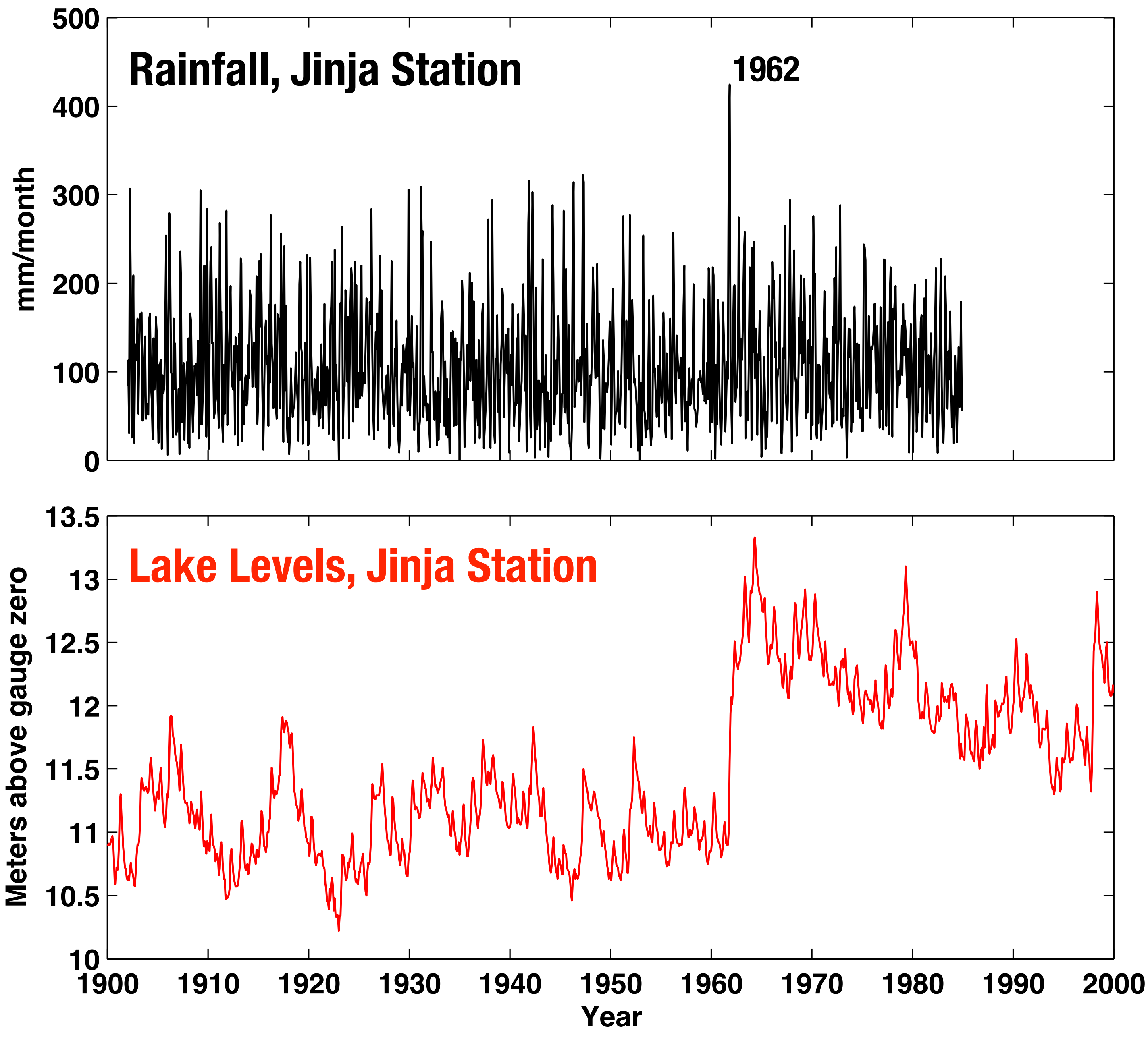
Bard et al., 1987, Clim. Dyn.

Archive issues:

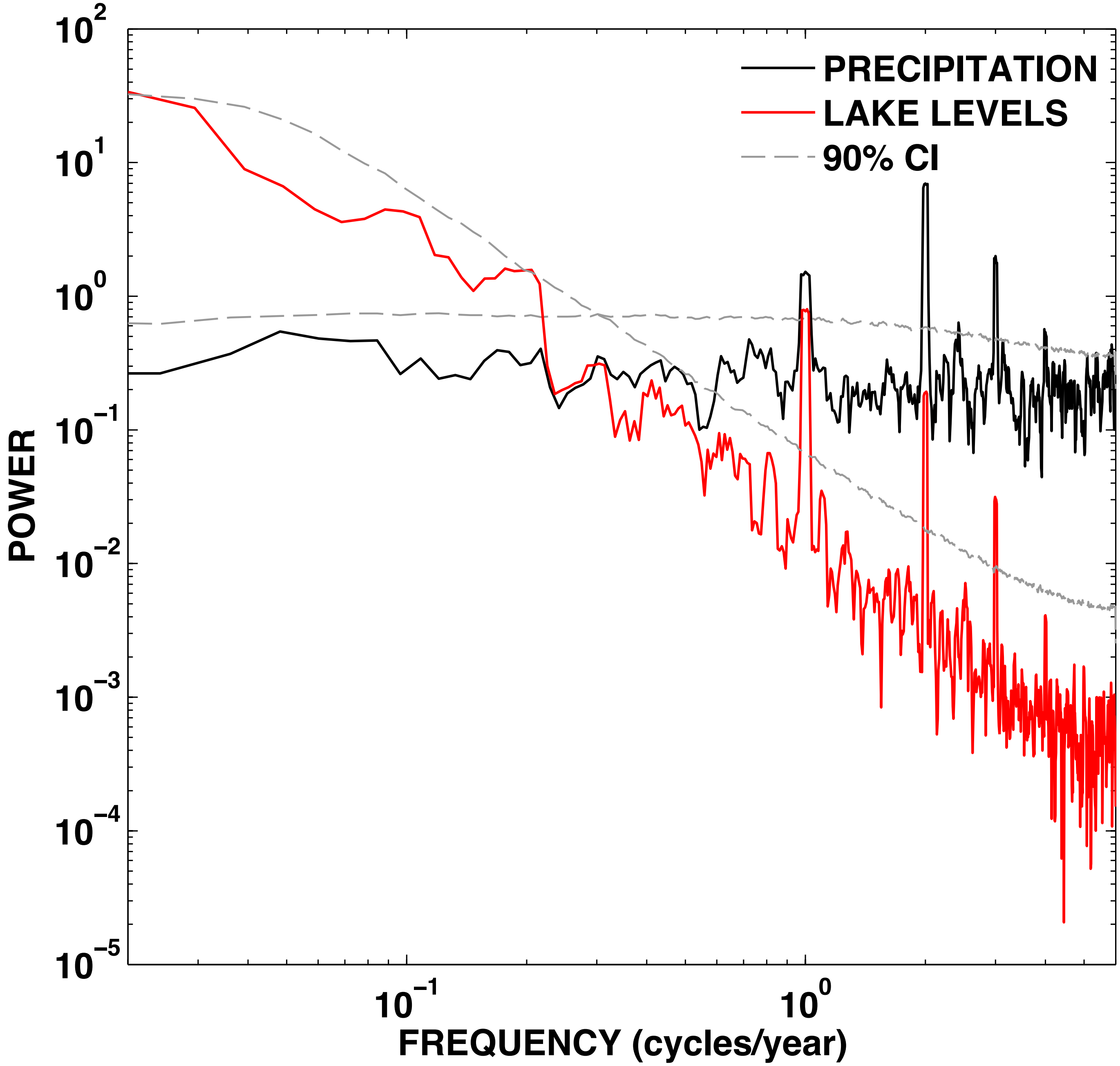
Reddening of the signal

(lake level proxies)

Example: Lake Victoria



Spectral comparison



Ways forward

- Ad-hoc approach: only use/interpret lowest frequencies (drawbacks: qualitative only, plus archive creates low frequency, so is this variability even “real”?)
- Better idea: start forward modeling sedimentary records from climate models.

Envisioning a hierarchical model for sediments

Level 1: Spatiotemporal process model

$$SST_{t+1} - \mu = \alpha \cdot (SST_t - \mu) + \epsilon_t$$
$$\epsilon_t \sim \mathcal{N}(0, \Sigma)$$
$$\Sigma_{i,j} = \sigma^2 exp(-\phi |x_i - x_j|)$$

$$logit(U_{37}^{K'})|SST = \alpha + \beta \cdot SST + \epsilon,$$
$$\epsilon \sim \mathcal{N}(0, \tau^2) \text{ IID.}$$

Level 2: Proxy forward model, can be updated to account for age model uncertainty (Werner & Tingley, 2015, Clim. Past)

$$logit(U_{37}^{K'})|\mathcal{T}, SST = \alpha + \beta \cdot \Lambda^{\mathcal{T}} \cdot SST + \epsilon,$$
$$\epsilon \sim \mathcal{N}(0, \tau^2) \text{ IID.}$$

Level 3: Archive model (bioturbation or other sedimentary features)

$$U_{37obs}^{K'}|U_{37}^{K'} = \sum_{t_n} U_{37t_1+t_n}^{K'} \cdot g(t_n) + \epsilon(t_1),$$
$$\epsilon(t_1) \sim \mathcal{N}(0, \tau^2) \text{ IID.}$$

Shameless Plug:

Awesome Postdoctoral position available in my lab!

- **Part of the "Data Assimilation for Deep Time" Project. We're doing DA from the LGM to present…and also for the PETM!**
- **Looking for someone with good quant skills, and expertise in paleoclimate/climate dynamics/climate modeling.**