Orbital to Millennial Scale Variability in the Southeast Asian Monsoon Since the Last Glacial Period

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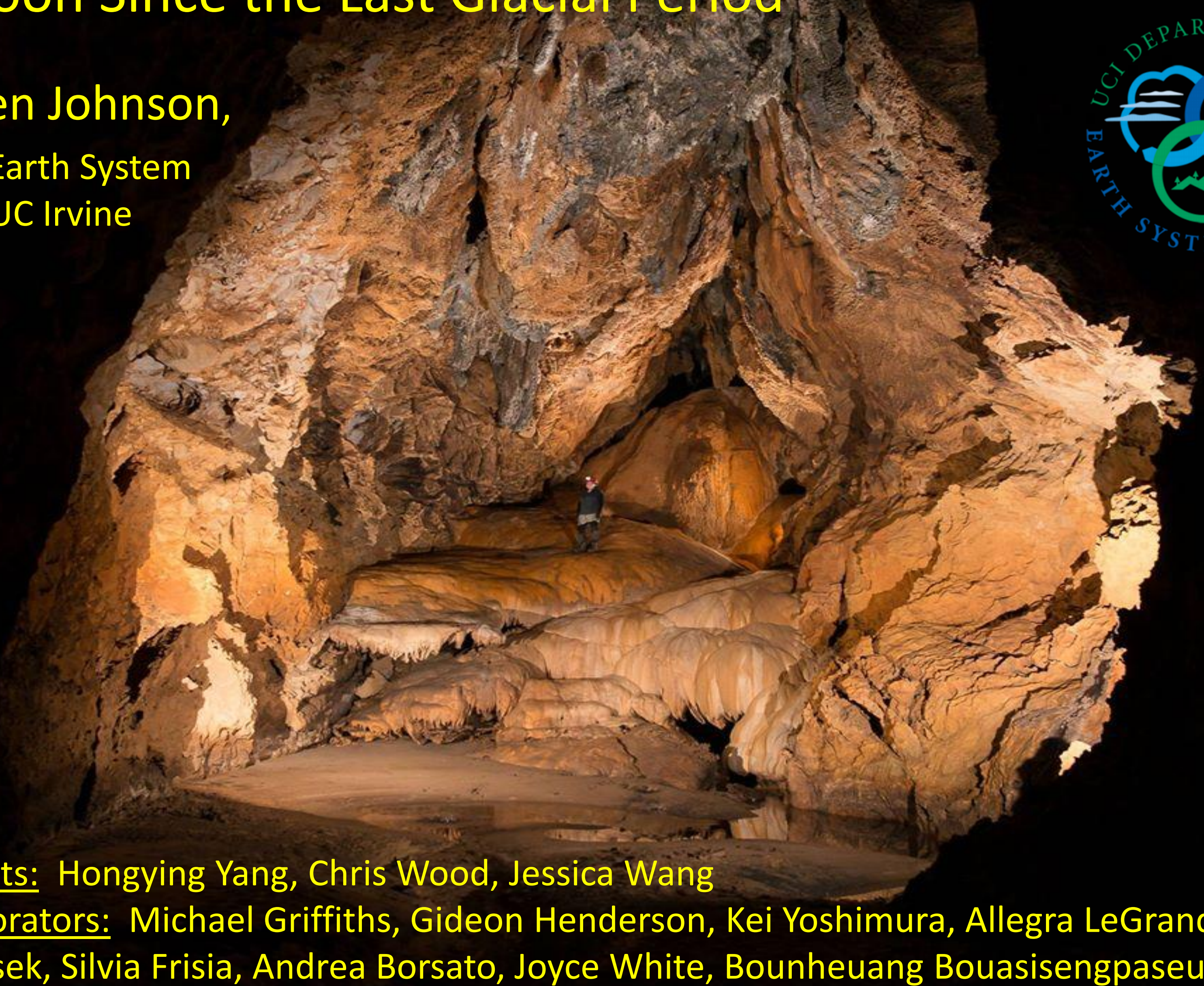

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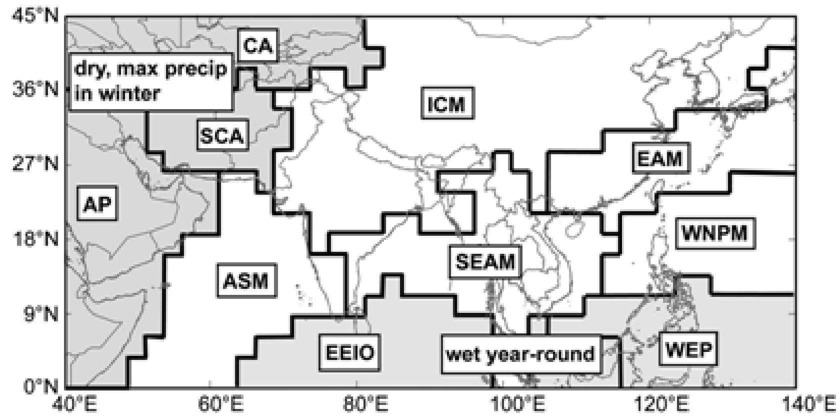
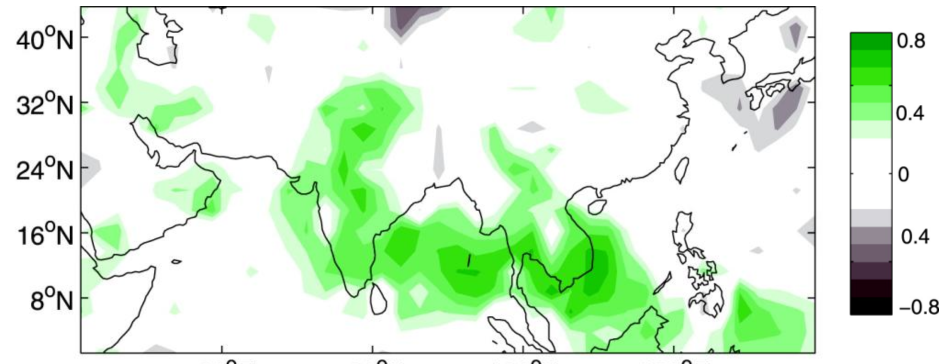
The Southeast Asian Monsoon (SEAM)

- Analyses of instrumental data show pronounced spatial variability in regional precipitation patterns in the Asian monsoon region
  - Precipitation in the SEAM region shows more coherent variations.
  - SEAM precipitation is not strongly correlated with precipitation over East Asia, but shows a stronger correlation with India.
- The SEAM region sits in a key region, at the interface between the East Asian and Indian monsoon domains.
  - How does the SEAM vary on orbital and millennial timescales?





Southeast Asian monsoon (2a)

Conroy and Overpeck, 2011

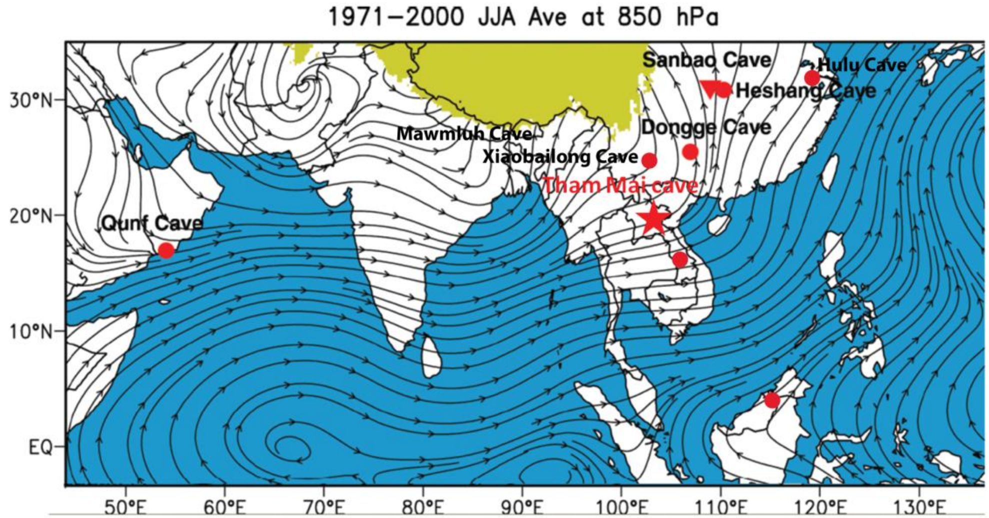
Study Site: Tham Mai Cave, Laos

•Tham Mai Cave (N20°45.24’, E102°39.09’; elevation 360 m)

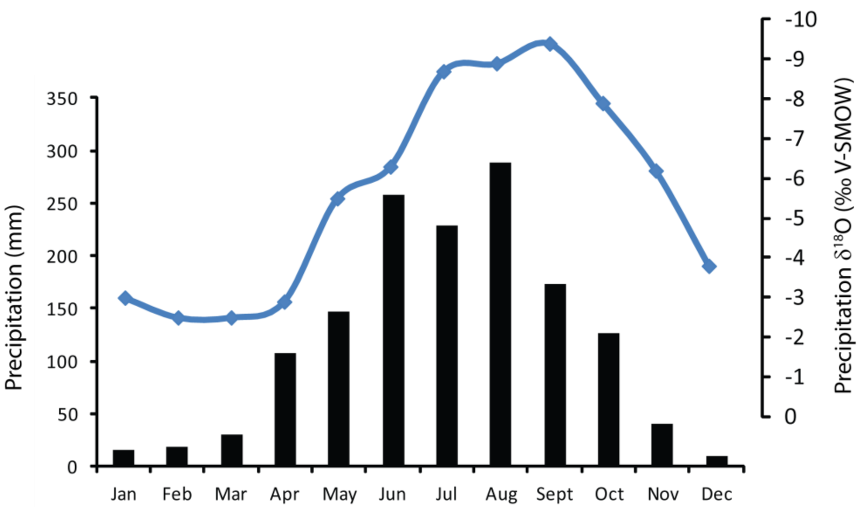
•~80% of annual rainfall occurs during summer monsoon season (May to September)

•Precipitation $\delta^{18}O$ exhibits a seasonal cycle similar to other Asian monsoon regions

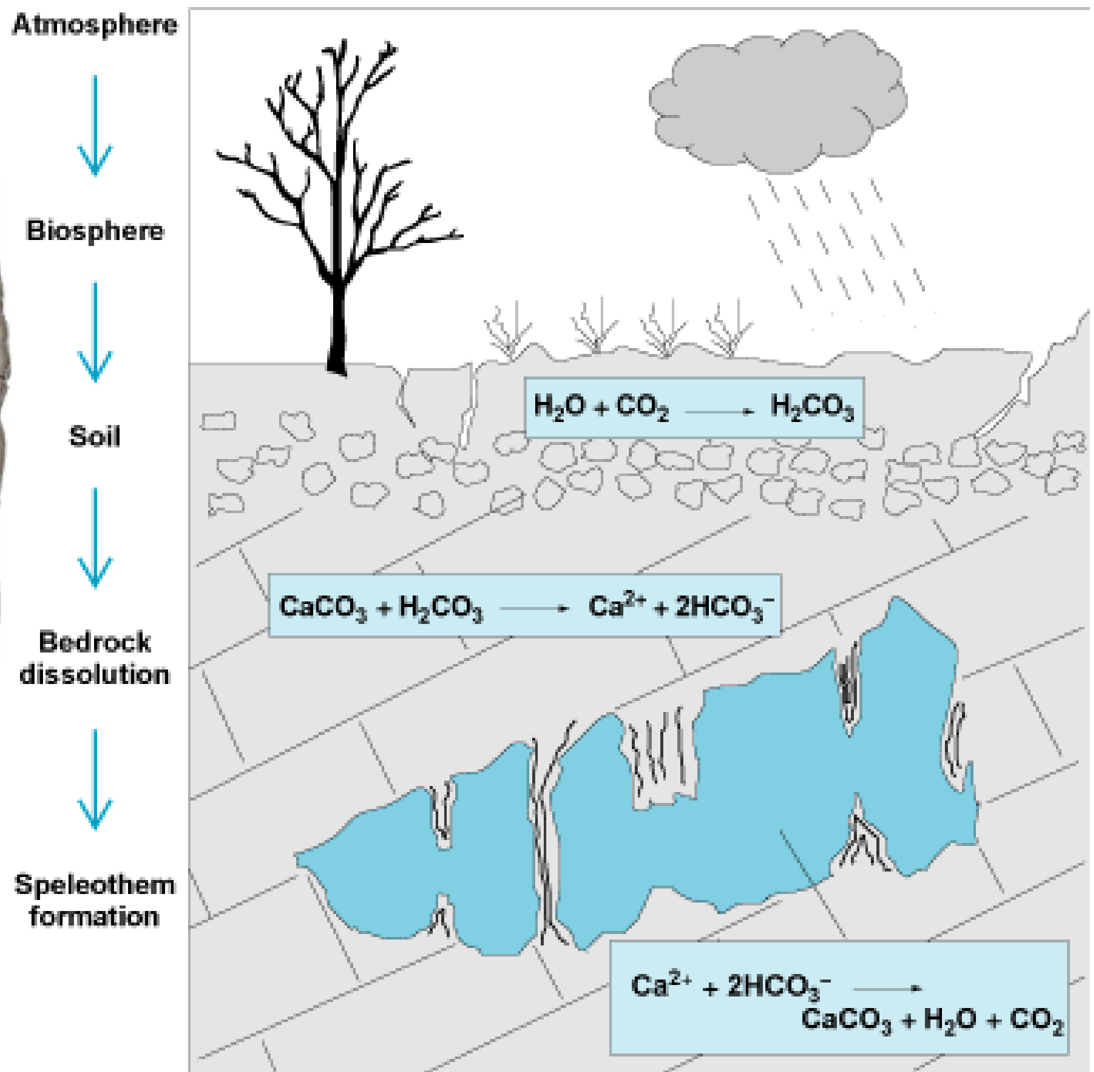
- •Most negative values during Aug-Sept.



Modified from Dong et al., 2010



Paleoclimate records from speleothems



- Growth layers can be precisely dated with U-Th method
- The ratio of $^{18}O/^{16}O$ ($\delta^{18}O$) in local precipitation is sensitive to climate and is recorded in the speleothem $CaCO_3$
- $^{13}C/^{12}C$ ($\delta^{13}C$)and trace element composition (e.g. Mg/Ca) reflect vegetation/soil processes, water-rock interaction, and degassing history

Fairchild et al., 2006

Processes affecting speleothem $\delta^{18}O$

$$\delta^{18}O = \left\{ \frac{\left({}^{18}O/{}^{16}O\right)_{Sam.} - \left({}^{18}O/{}^{16}O\right)_{Std.}}{\left({}^{18}O/{}^{16}O\right)_{Std.}} \right\} \times 10^3$$

- Assuming equilibrium deposition:

$\delta^{18}O_{calcite} = f\ [\delta^{18}O_{water}, \text{Cave T} (\cong \text{MAT})]$

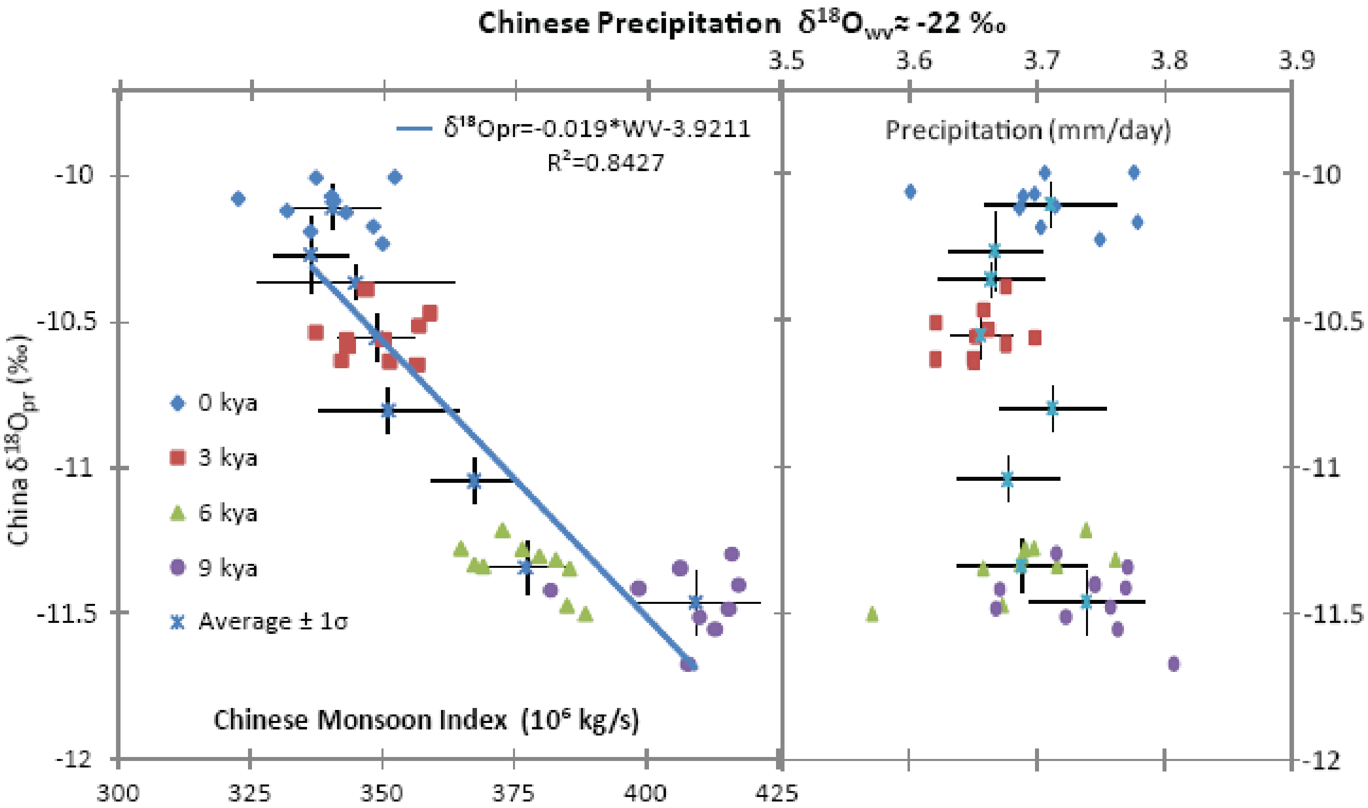
Measured

$d\delta^{18}O/dT = -0.23$ ‰ /°C

Accounts for most of variability

(precipitation $\delta^{18}O$ + hydrology + (fractionation/kinetics?)

Isotope enabled GCM simulations can help investigate mechanisms

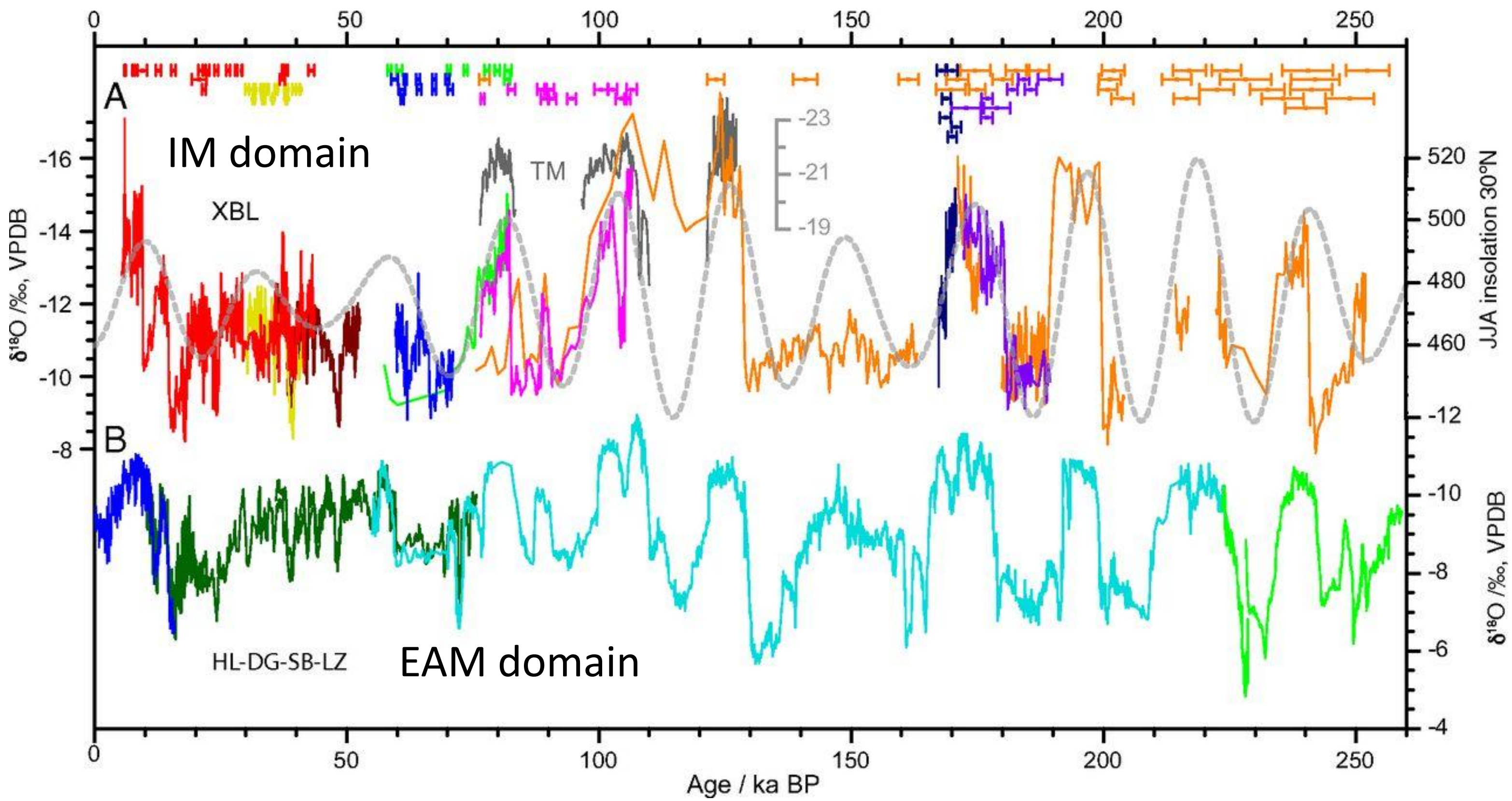


Orbital scale $\delta^{18}O$ changes in East Asian speleothems reflect monsoon intensity, but not local rainfall

LeGrande and Schmidt, 2009

East Asian-Indian monsoon variability since 250 ka

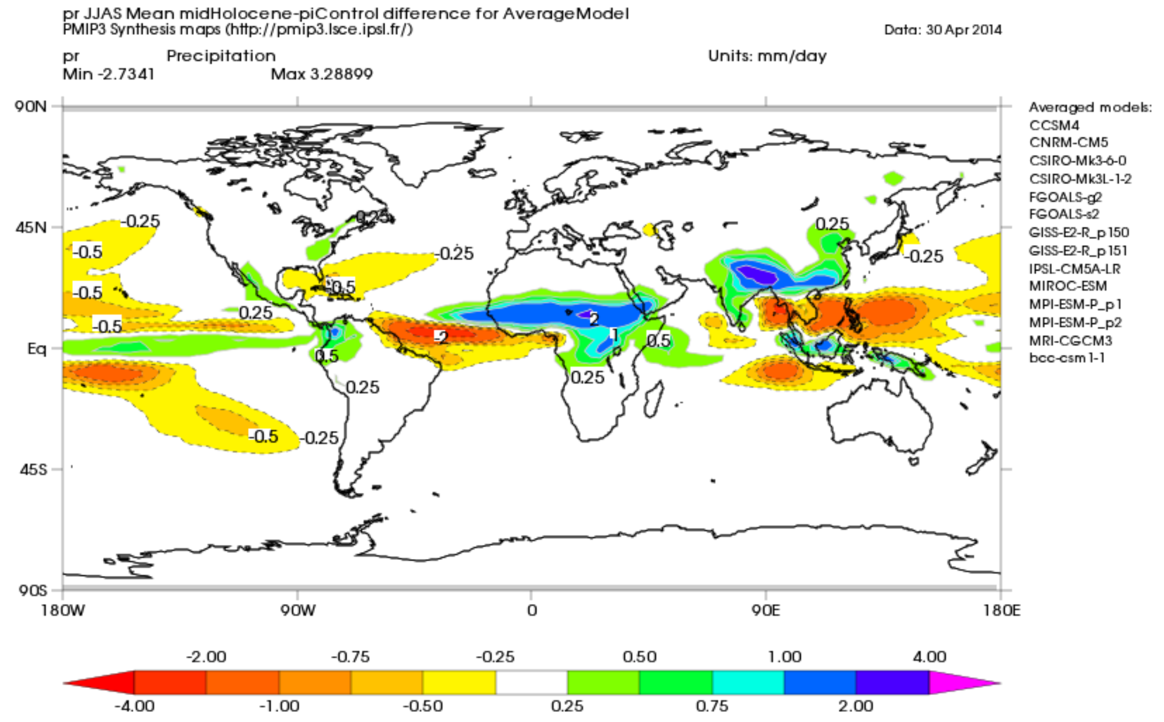
- Speleothem $\delta^{18}O$ in EAM region is best interpreted as a proxy for monsoon intensity, with negative values associated with enhanced southerly monsoon winds and increased rainfall in N. China. (Liu et al., 2014).
- A recent record from SW China (Xiaobailong Cave) is interpreted in terms of Indian Monsoon intensity



Cai et al., 2015

Mid-Holocene (6k) model results

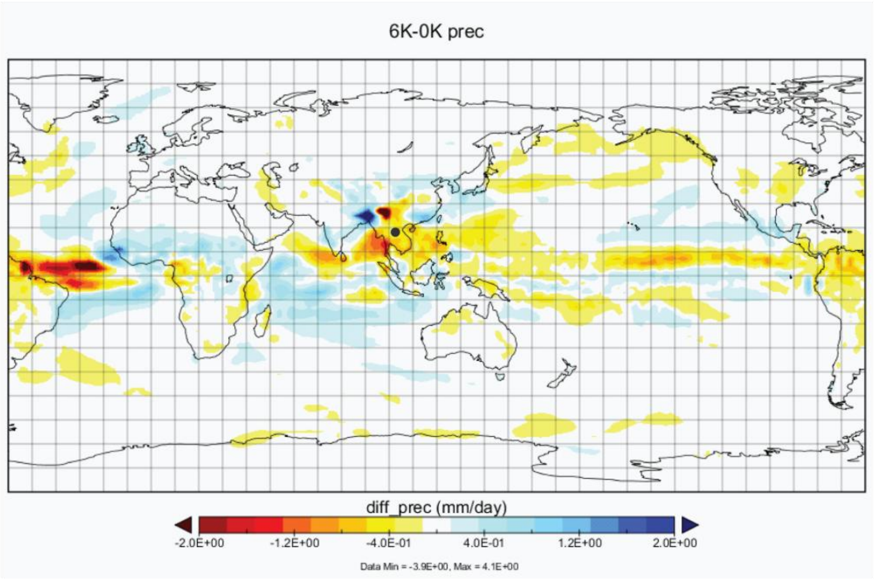
- PMIP2/PMIP3 models show reduced summer precipitation in SEAM region
  - Insolation forced response differs from IM and EAM regions
  - What do isotope enabled models & proxy data show?

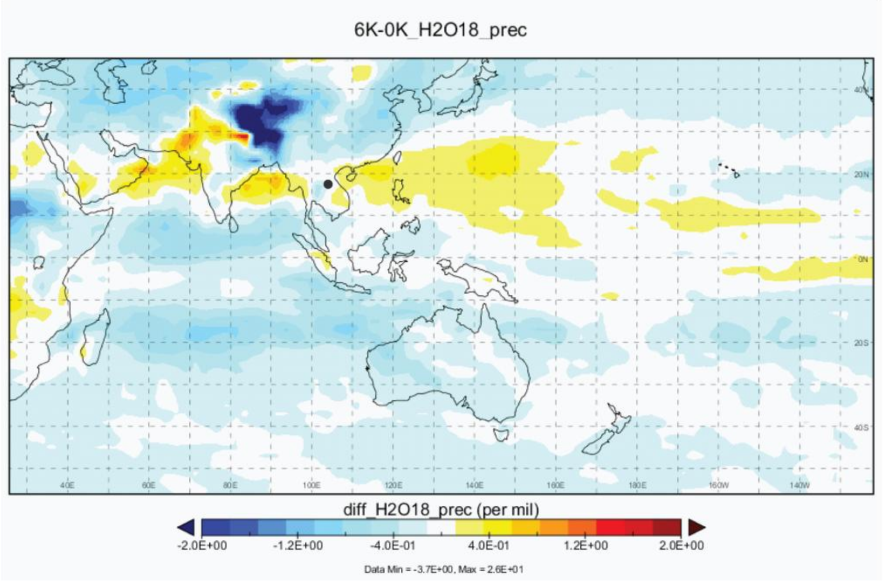


https://pmip3.lsce.ipsl.fr/

Mid-Holocene (6k) model results

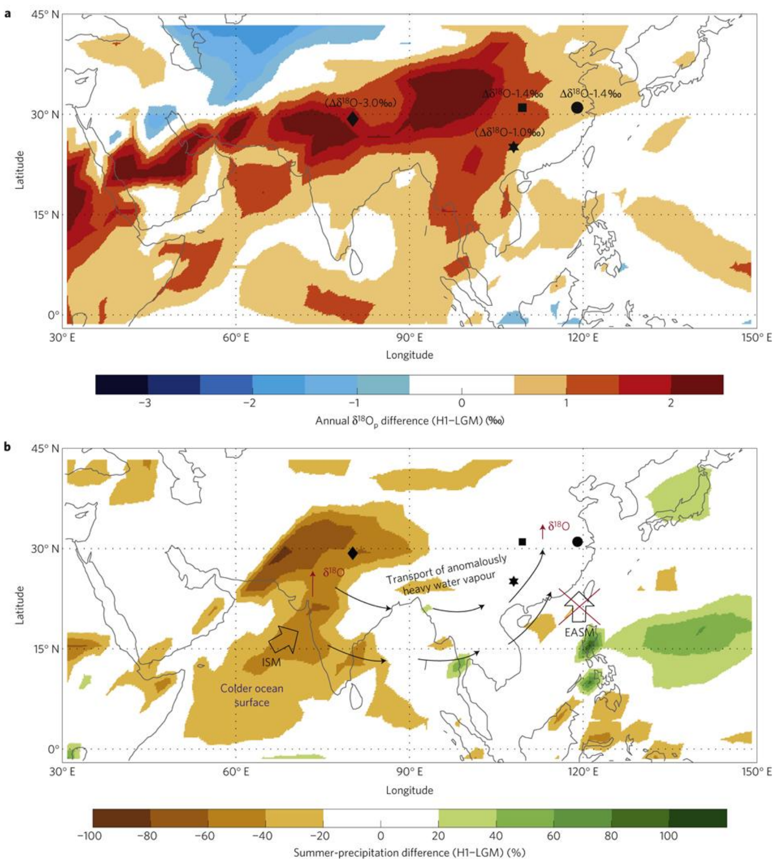
- GISS Model E2-R shows a negative $\delta^{18}O_p$ signal at 6 ka, despite modeled regional precipitation decrease.

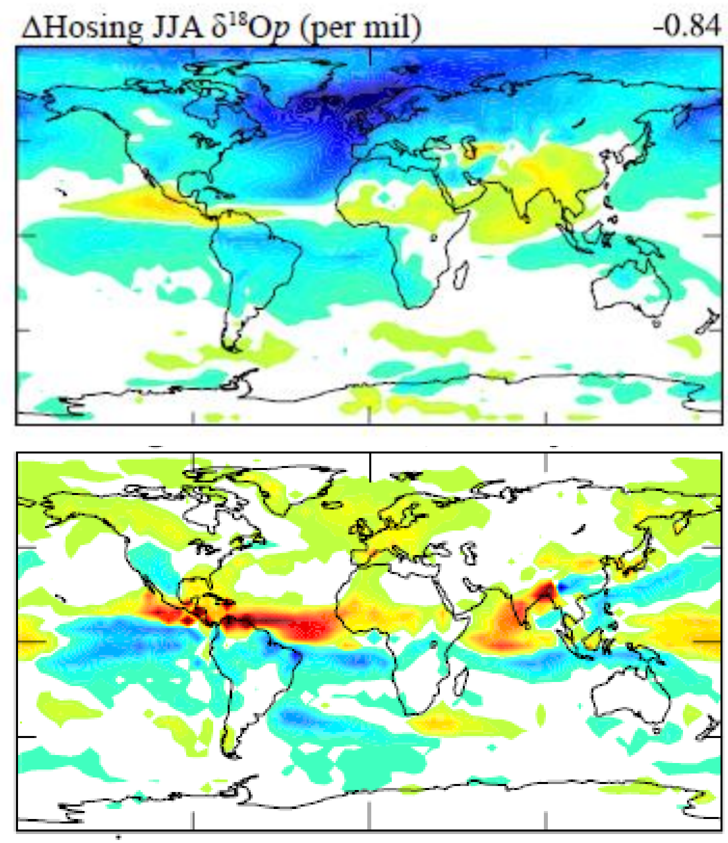




Models suggest similar response to Heinrich events

- Precipitation δ^{18}O increases, but no significant change in precipitation amount.

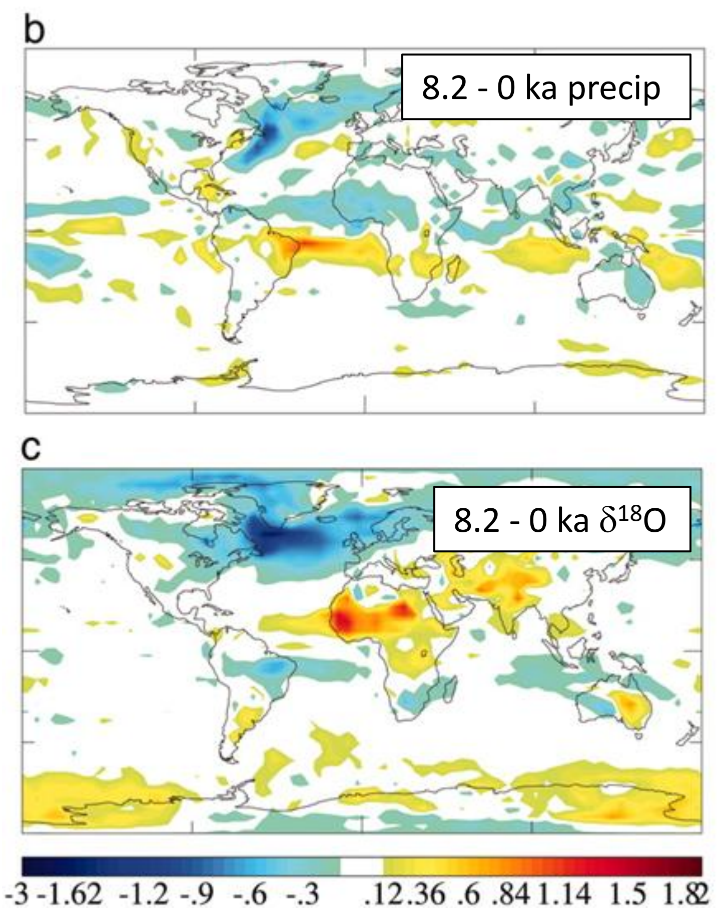




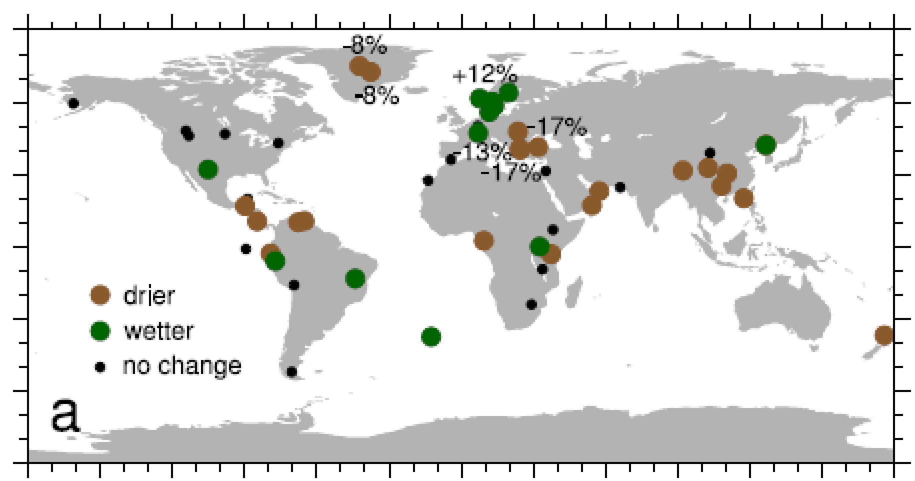
Pausata et al., 2011

Lewis et al., 2010

Models suggest similar response to Heinrich events…and 8.2 ka event

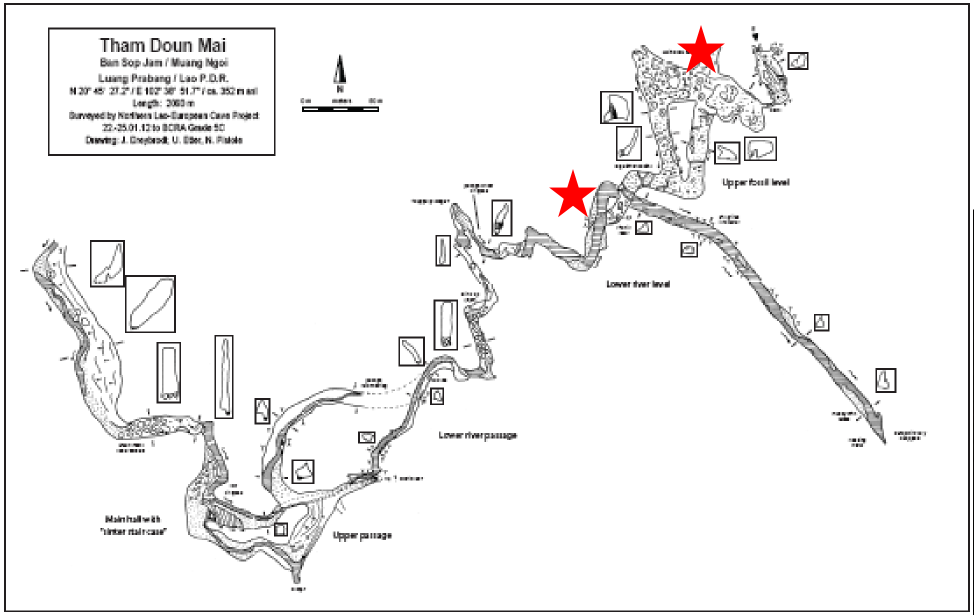


- Precipitation $\delta^{18}O$ increases, but no significant change in precipitation amount.
- A recent proxy synthesis shows dry conditions across EAM region, but no data for SEAM region.

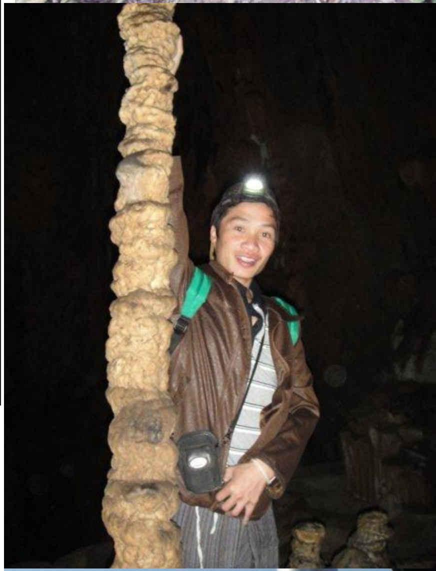


LeGrande et al., 2006; Morrill et al., 2013

Tham Mai Cave, Laos

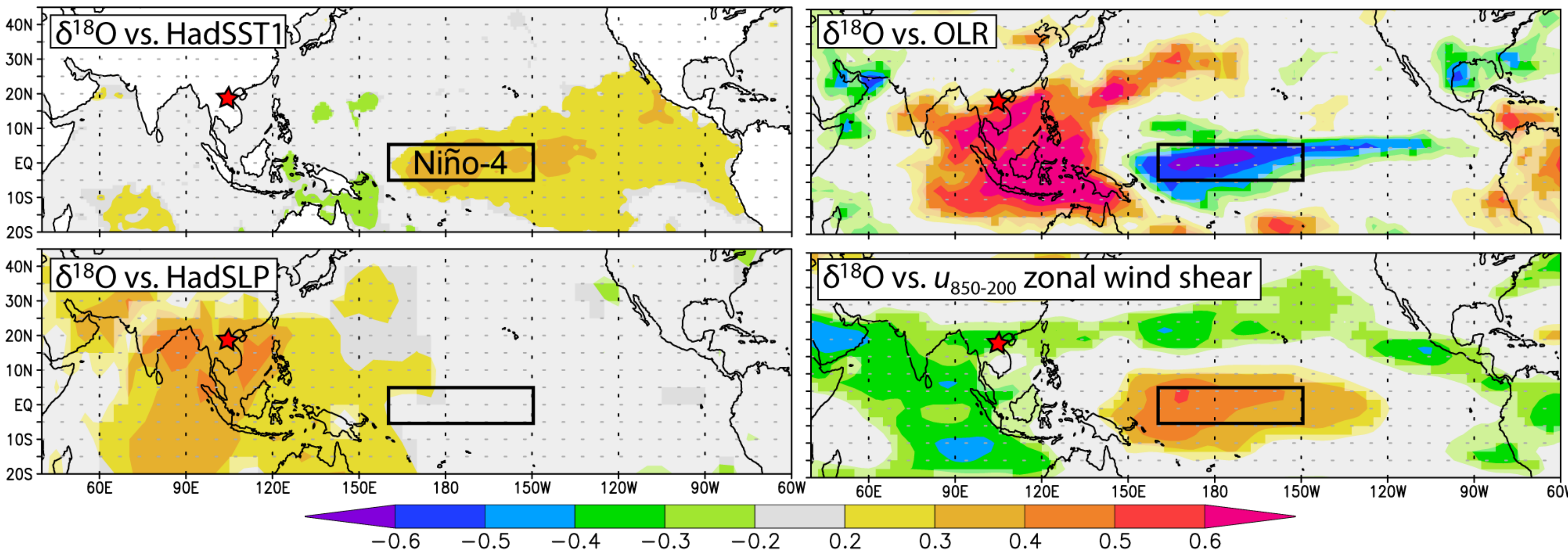


- >2 km of cave passage with numerous actively growing stalagmites
- Ongoing monitoring work –
  - Drip rate, drip water $\delta^{18}O$, trace elements (TEs) , and DIC $\delta^{13}C$ and ^{14}C
  - Precipitation amount and $\delta^{18}O$
  - Modern calcite (isotopes and TEs)
  - Cave air pCO_2
  - Soil and soil CO2 (TEs, $\delta^{13}C$ and ^{14}C)



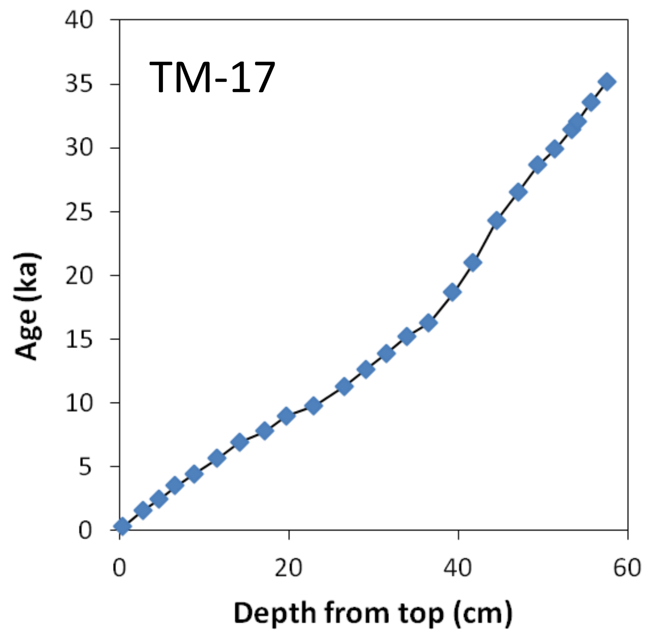
Modern controls on precipitation δ^{18}O

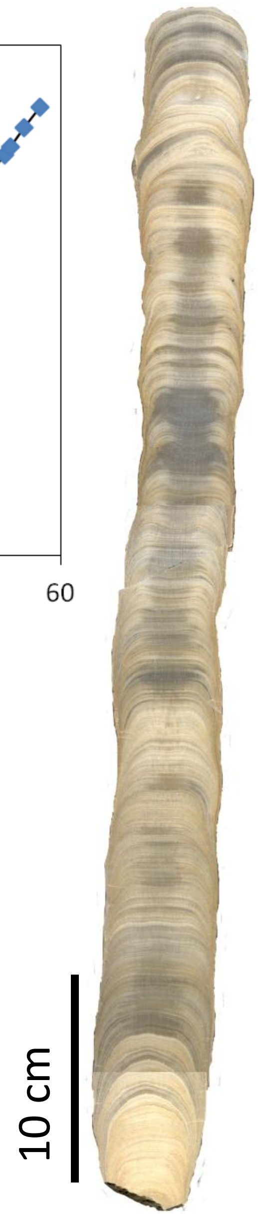
Spatial correlations of modeled δ$^{18}O_p$ (IsoGSM) and instrumental climate data

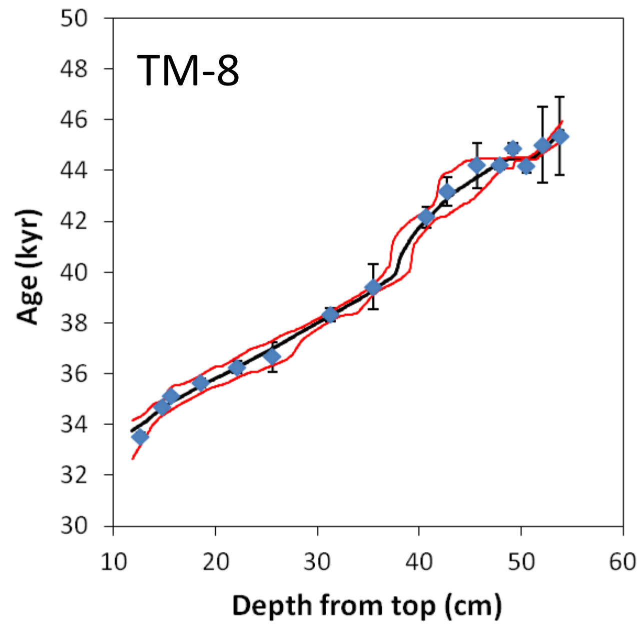


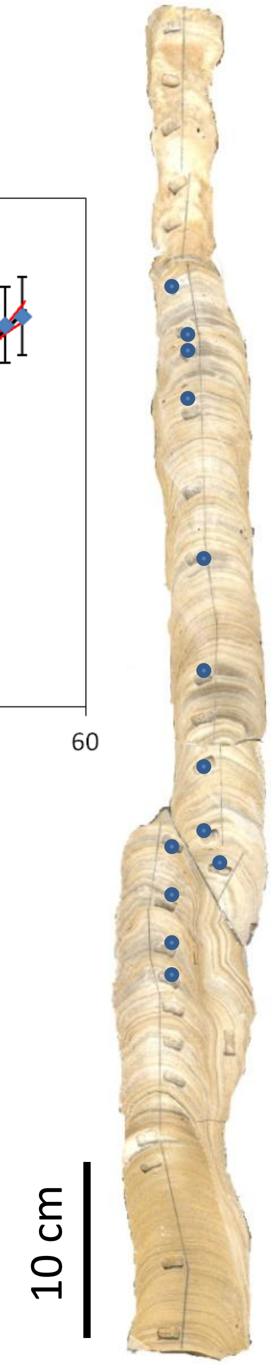
- Inter-annual δ$^{18}O_p$ variability reflects ENSO/Walker circulation, convection over the Indo-Pacific warm pool, and Indian monsoon intensity.
- No significant correlation is seen between δ$^{18}O_p$ and local precipitation amount.

Speleothem samples and age models





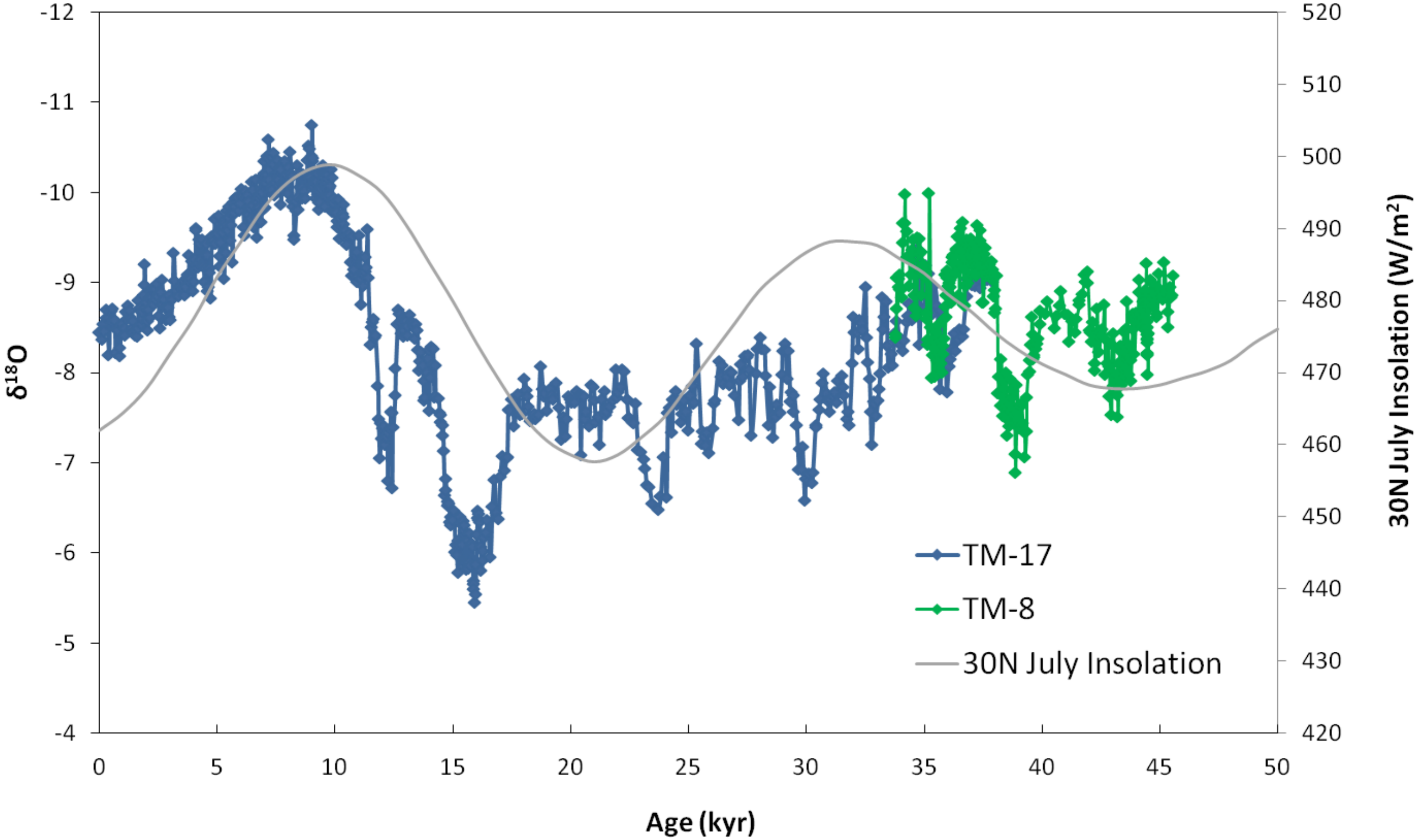




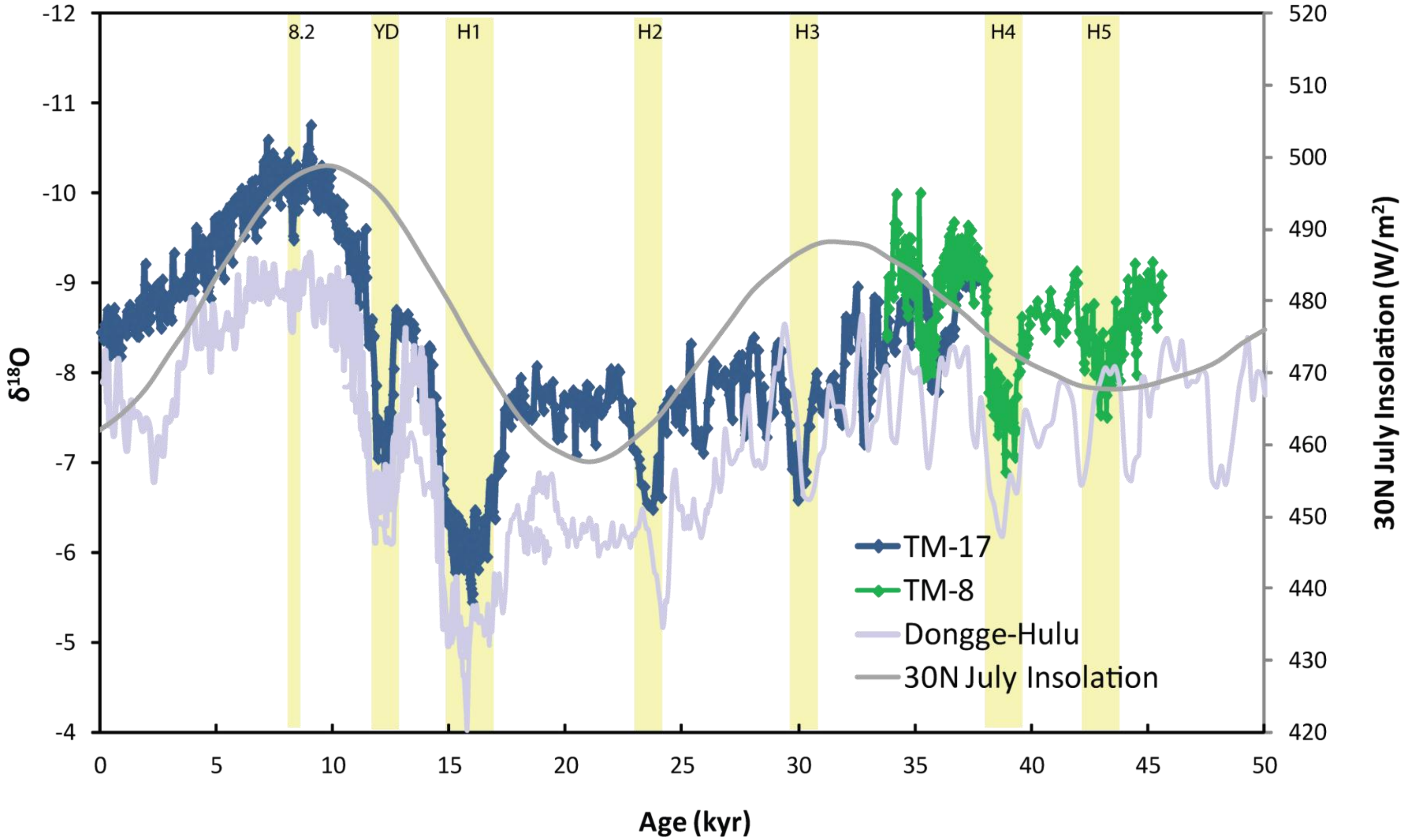
- Actively forming when collected in 2013
- Average growth rate ≈ 20 μm/year
- Microsampled at 500 μm resolution for stable isotope and trace element analysis

- Previously broken stalagmite, collected in 2010
- Average growth rate ≈ 70 μm/year
- Microsampled at 500 μm resolution for stable isotope and trace element analysis

Preliminary $\delta^{18}O$ record



Preliminary $\delta^{18}O$ record



•Tham Mai speleothem $\delta^{18}O$ looks very similar to other speleothem records from the broad Asian monsoon region and shows millennial scale shifts linked to high-latitude climate.

•What can other proxies (e.g. $\delta^{13}C$, trace elements) tell us about SEAM rainfall?

Speleothem $\delta^{13}C$ and trace element variations

$\delta^{13}C$

- Prior calcite precipitation
- Soil respiration
- Closed vs. open system dissolution
- C3:C4 vegetation

Trace elements (TE)

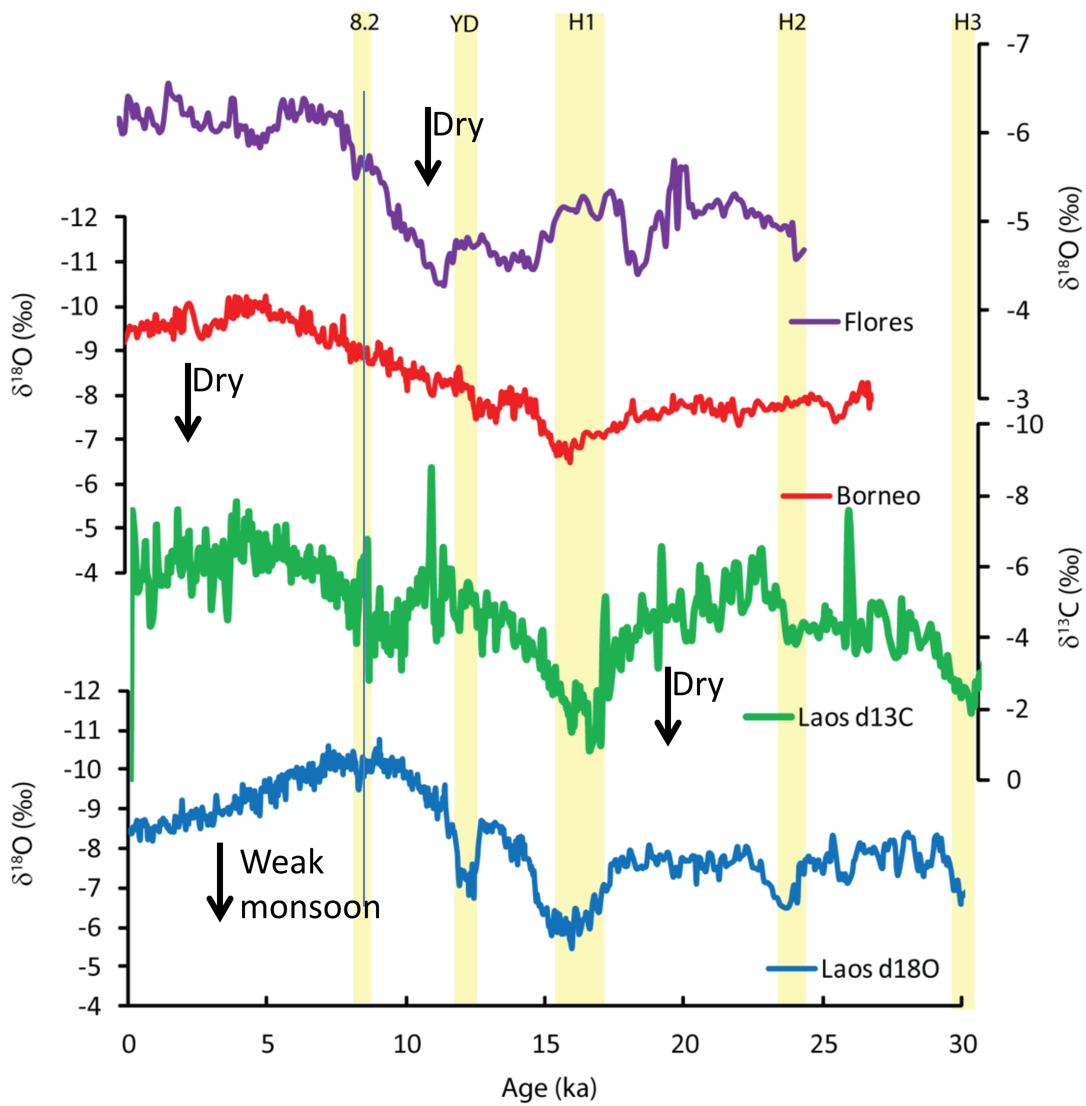
- Elements controlled by D <<1:
    - Prior calcite precipitation
    - Calcite precipitation efficiency
- Temperature (Mg/Ca)
- Growth rate (Sr/Ca)

- Oxygen isotopes are primarily useful for reconstructing synoptic to mesoscale climate whereas $\delta^{13}C$ and trace elements may primarily reflect local climate and hydrology.
- Cave monitoring studies can help determine proxy controls & uncertainty.
- $\delta^{13}C$ reflects multiple complex processes, but in general, higher $\delta^{13}C$ values reflect drier conditions.

Johnson et al., 2006; Fairchild et al., 2006; Tremaine et al., 2013; Oster et al., 2012, etc.

Preliminary $\delta^{13}C$ record

- TM-17 $\delta^{13}C$ may reflect local water balance
- Suggests dry conditions in Laos during Heinrich Events
  - HS1 is driest period of last 30 kyr
- Interestingly, shows no change during Younger Dryas and suggests wet conditions during 8.2 ka event
- $\delta^{13}C$ suggests that early to mid Holocene was dry and that wettest conditions in Holocene occurred ~4 ka, then decreased slightly towards present.
  - Consistent with 6 ka models and Borneo $\delta^{18}O$ record (Partin et al., 2007; Carolin et al., 2013)
- Anti-phase precipitation response to Heinrich events is evident through comparison with Flores record (Griffiths et al., 2009; Ayliffe et al., 2013), but Y. Dryas, 8.2 event, and Holocene trend are more complicated.



Conclusions

- Models suggest that SEAM precipitation during the Mid-Holocene decreased relative to modern, while $\delta^{18}O_p$ also decreased, reflecting strong AM and increased “pre-fractionation” upstream.
  - New speleothem $\delta^{18}O$ records from Tham Mai cave, Laos are broadly similar to other AM records on orbital to millennial timescales.
  - New speleothem $\delta^{13}C$ records suggest that the mid-Holocene was dry, and that precipitation increased towards maximum value ~4 ka.
- Models suggest that SEAM precipitation $\delta^{18}O$ should increase in response to Heinrich events and the 8.2 ka event.
  - New speleothem $\delta^{18}O$ records support this.
  - New speleothem $\delta^{13}C$ records indicate decreased precipitation in Laos during Heinrich events, no change during the Younger Dryas, and increased precipitation during the 8.2 ka event.
- Future work will focus on trace element analysis to provide additional information on local SEAM water balance.


Thank you!
Any questions?