Stalagmite records of abrupt climate change in the tropical Pacific

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West Pacific Warm Pool: the global heat engine

- Intense convection driven by Walker and Hadley circulations
- Significant seasonal (monsoon) and interannual (ENSO) variability
- Evolution of large-scale atmospheric circulation patterns under changing boundary conditions?
What was the sequence of events during the last deglaciation?

How are the two hemispheres linked climatically?

What caused the abrupt climate change events?

How was the tropical Pacific involved?
1) East Asian monsoon tracks Greenland abrupt climate change events.
2) Large hydrological anomaly during Heinrich 1 event (16ka).
3) Monsoon variability tied to insolation.
Tropical Pacific Marine Sediment Cores

→ early warming reminiscent of Antarctica

→ coarse resolution and poor dating make abrupt climate changes difficult to detect

→ hint of Younger Dryas in hydrology, but not temperature

→ Heinrich 1 strong cooling in eastern Pacific (Kienast et al., 2006)

Rosenthal et al., 2003
How has Warm Pool climate evolved since the Last Glacial Maximum?

Stalagmites as climate archives: 
absolutely-dated (±1%) with U/Th 
high-resolution (sub-decadal sampling) 
records of terrestrial precipitation
Research goal: resolve abrupt climate changes in Warm Pool precipitation since the Last Glacial Maximum

Approach:

1) identify accessible site and conduct fieldwork

2) date stalagmites with U/Th, target time intervals of interest

3) calibrate paleo-precip proxy (oxygen isotopes, $\delta^{18}O$) w/ on-site monitoring program

4) perform multiple reconstructions (reproducibility)

5) compare with other paleo-records, forcing histories to build mechanistic insights
Rainfall at Gunung Mulu National Park, Malaysian Borneo

- Seasonal variability low, always under ITCZ
- Intraseasonal variations important

Cobb et al., 2007
Dai and Wigley, 2000

- interannual variability large (±50% for DJF)
- very sensitive to ENSO variability
Jayapura, Indonesia

Rainfall and $\delta^{18}$O of rainfall: the tropical “amount effect”

- empirical negative correlation between rainfall and the $\delta^{18}$O of rainfall (Dansgaard, 1964; Rozanski, 1993)

nearest long-term rainfall $\delta^{18}$O measurements
On-site monitoring program: climate controls on local rainfall $\delta^{18}O$

- strong seasonal cycle in rainfall $\delta^{18}O$ (despite lack of rainfall seasonality)

- seasonally-varying moisture trajectories fractionate vapor $\delta^{18}O$

- hint of ENSO-related response during 2005/06 La Niña event (more rain=lighter $\delta^{18}O$)

- drip $\delta^{18}O$ is muted version of rainfall $\delta^{18}O$

Cobb et al., 2007
Speleothem Formation

1. rain
2. soil = high pCO$_2$
3. dissolve CaCO$_3$
4. degas CO$_2$
5. precipitate CaCO$_3$

→ assumption is that rainfall $\delta^{18}$O is recorded in stalagmite $\delta^{18}$O

→ complex flow regimes, kinetic fractionation can obscure climate-related signals

→ strategy: search for common signals observed in multiple stalagmite $\delta^{18}$O records

Rainwater and dripwater monitoring program
Growth rates (1-100μm/yr) easily allow for decadal to centennial resolution.

Low U (0.1-1ppm), low 234U (-100‰) and high 232Th (1ppb) make U/Th dating challenging. Use MC-ICPMS.

Many stals cover desired interval (LGM to present); allow for REPRODUCIBILITY
BA04 492mm
SCH02 296mm
SSC01 483mm
Excellent reproducibility of stalagmite $\delta^{18}$O records back to 27kbyp

- Climatic interpretation supported
- Many dates needed; numerous hiatuses uncovered
- Slow-growing portions discounted for climate interpretation due to possible unresolved hiatuses

Partin et al., 2007
WPWP rainfall $\delta^{18}$O during the LGM

Observed:
-1.3‰ shift in stalagmite $\delta^{18}$O from LGM to present

Contributions:
- ice volume $\delta^{18}$O = -1.0‰
- 2-3.5°C warming = -0.4 to -0.7‰
- local seawater $\delta^{18}$O = ?

KEY: effect of Sunda Shelf on ocean-atmosphere system unconstrained

Oppo et al., 2003
Abrupt climate change events during the deglaciation

- largest excursion a drying event that started ~20kypb and terminated ~16kybp (Heinrich 1 event)

- later deglacial records look like Antarctica (northern-most signal of Antarctic Cold Reversal?; no Younger Dryas)

Partin et al., 2007
What’s so special about H1?

Observed shut-down of Atlantic meridional overturning circulation (McManus et al., 2004)

...which pushes ITCZs southward and decreases West Pacific Warm Pool precip by changing Walker circulation (Zhang and Delworth, 2005)
Tropical Pacific was involved in H1: trigger or amplifier, or both?

North Atlantic H1:
- begins 17kybp
- ends 14.7 kybp

- observed drying in Borneo precedes NA Heinrich expression, MOC shutdown
  *and* it recovers before the NA recovers from H1

- other tropical Pacific records show similar results, but are less well-dated

- did the tropical Pacific force a shutdown of the MOC, and dictate its recovery?

Kienast et al., 2006
WPWP convection sensitive to spring/fall precessional insolation

→ China convection linked to JJA (Dykoski et al., 2005)

→ Brazil convection linked to DJF (Cruz et al., 2005)

→ If north-to-south march of ITCZ over Holocene, then perhaps a spring/fall sensitivity makes sense?

→ Or does the zonal structure of tropical Pacific convection respond to insolation forcing (Clement et al., 1999)
Global methane budget also linked to spring/fall insolation

- Atmospheric methane shows mid-Holocene low

- Modern ENSO does perturb global methane budget (Dlugokencky et al., 2001)

- Need AGCM coupled to global methane model to investigate how changes in precip patterns affect methane budget

Chappellaz et al., 1997; Koutavas et al., 2002
Conclusions

Malaysian stalagmites provide reproducible $\delta^{18}$O signals, favoring a climatic interpretation.

WPWP convection sensitive to some, but not all, abrupt climate change events.

Malaysia hydrology changes lead the North Atlantic into and out of the Heinrich 1 abrupt climate change event – driver?

Holocene trends driven by spring/fall insolation, match CH$_4$ records.

Future Work

Monthly stalagmite $\delta^{18}$O data for last millennia (D. Lund)

New proxies in stalagmites (organic biomarkers, charcoal layers?)

Coarse-resolution for last million years (N. Meckler)