# Interpreting water isotope records without an iso-climate model?

David S. Battisti
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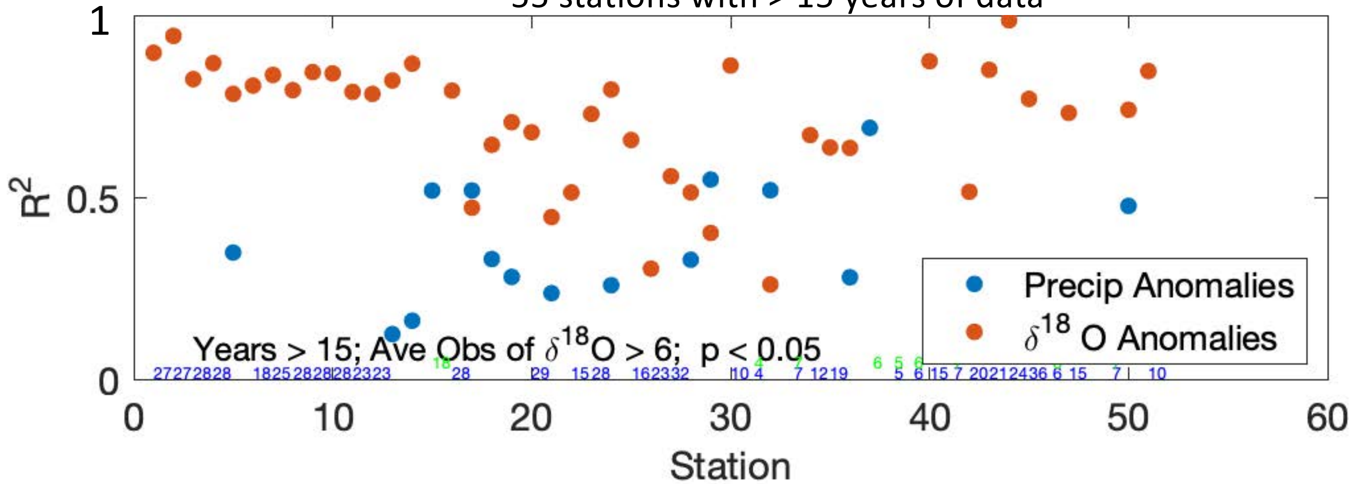
1. Where do water isotopes inform on *in situ* local climate?
2. How have they been used to inform water cycle history and processes? Examples
3. Additional applications of water isotopes in climate
4. Future challenges/advances

# What controls the variability in annually averaged precipitation weighted $\delta^{18}O_p$ today?

~ 55 stations with > 15 years of data



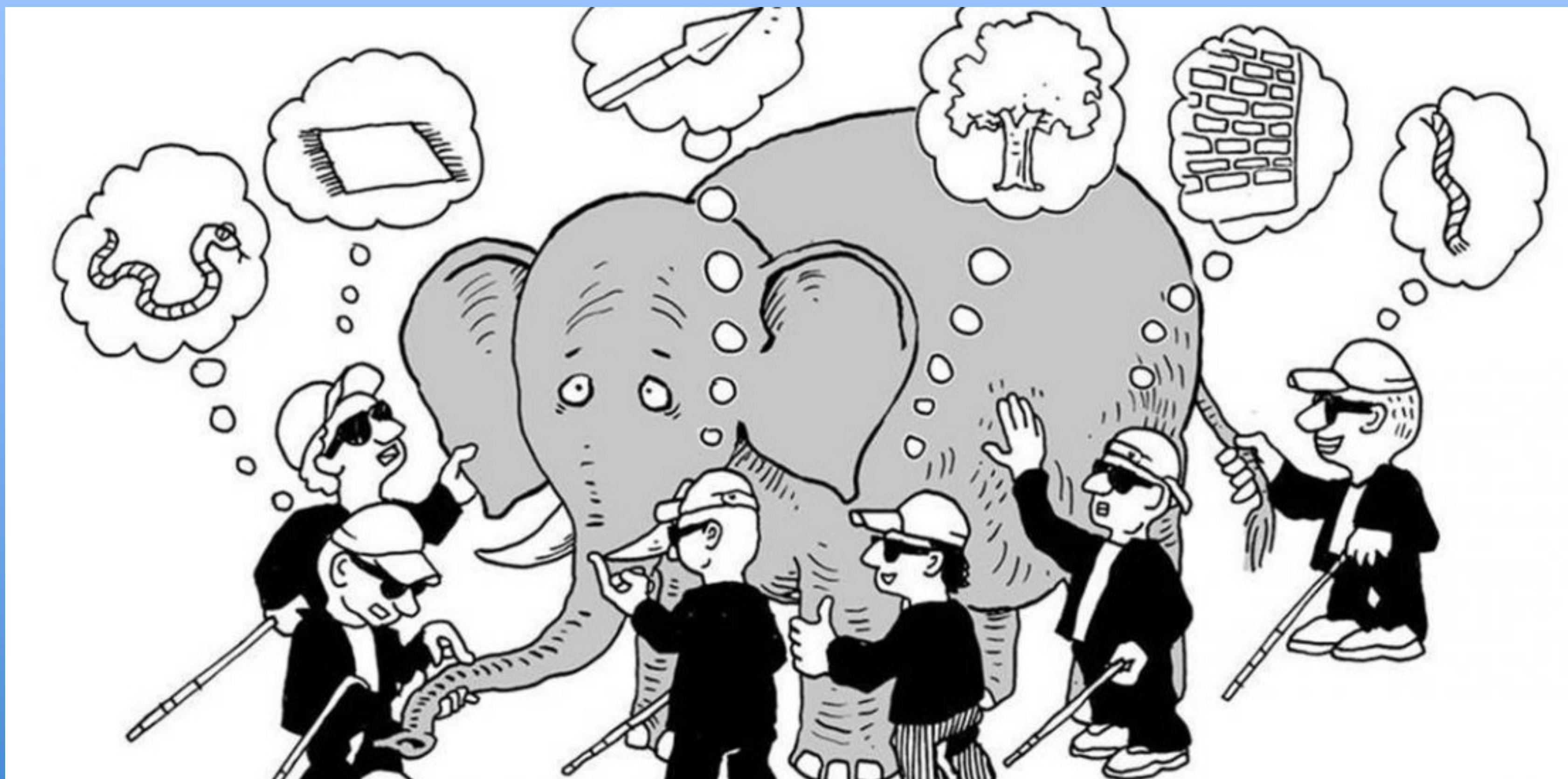

(calculations done in 2011)

$r^2$ ($\delta^{18}O_p$, Precip) ≈ 0 – 0.3 $r^2$ ($\delta^{18}O_p$, $\delta^{18}O$) ≈ 0.6 – 0.9

Variability in $\delta^{18}O_p$ is mainly determined by changes in the isotopic composition of the condensing vapor (i.e., changes in the pathway and past history of vapor that is condensing) and *not* the amount of precipitation. **Why?**

*Precipitation is regional and depends on water vapor convergence, but water vapor is distributed globally by winds*

# Interpreting water isotope records without an iso-climate model?



# Interpreting water isotope records without an iso-climate model?

# Climate models w/ water isotopes can inform climate history and processes

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# Climate models w/ water isotopes can inform climate history and processes

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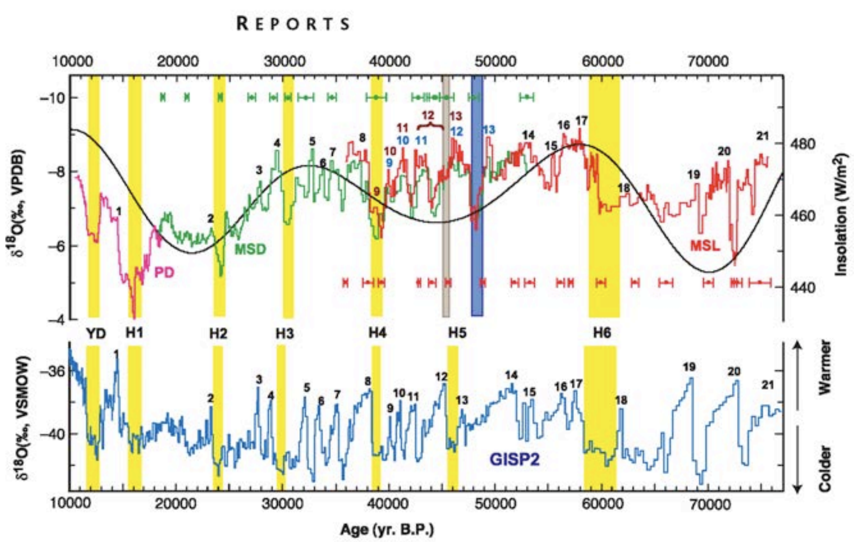
1. Where do water isotopes inform on *in situ* local climate?
2. How have they been used to inform water cycle history and processes? Examples
   - Heinrich events & Dansgaard-Oeshcger (D-O) cycles and the South Asian monsoon
   - Precession Cycles & Monsoon dynamics

# Heinrich events , D-O cycles and the China Caves

- During the last Ice Age, episodic large abrupt changes in the sea ice extent in the Nordic Seas due to:
  - Heinrich events (abrupt discharges of ice and freshwater into the N. Atlantic)
  - Warm phases of Dansgaard-Oeshcger (D-O) cycles (abrupt *reduction* in sea ice in the N. Atlantic)
- These events are registered in $\delta^{18}O$ of Chinese Stalagmites
  - More sea ice ← → heavier $\delta^{18}O$

Interpretation?
heavier $\delta^{18}O$ = in situ drying ?




Hulu

Greenland GISP2

Wang et al 2001

## What happens when you increase sea ice extent in the N. Atlantic in a climate model?

Large decrease in temperature & in the strength of the southeast Asian monsoon

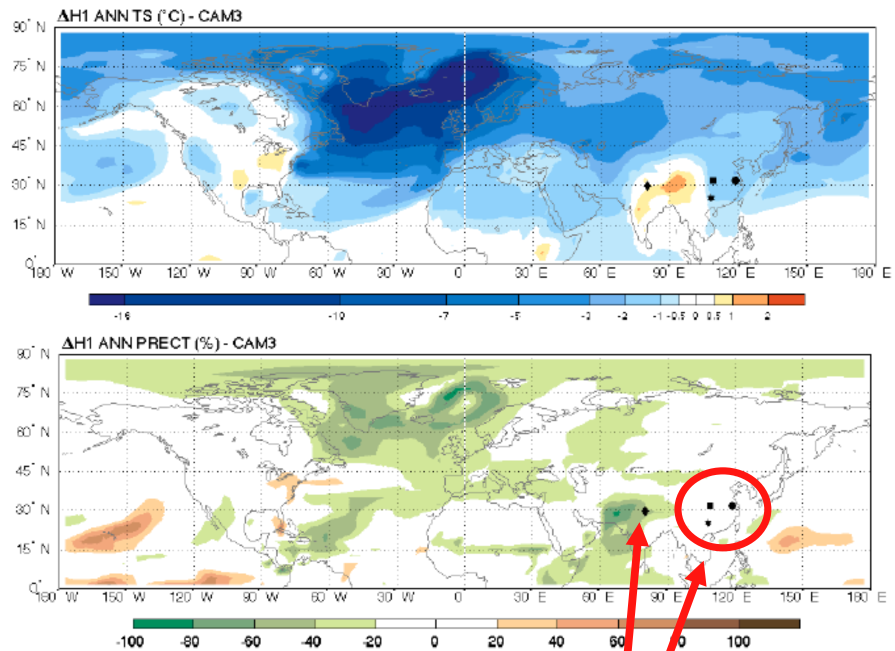



Figure 1: Annual anomalies with respect to LGM at H1 for surface temperature (top), and precipitation in percentage (bottom). Markers indicate the location of the following caves: Hulu (bullet), Songjia (square), Dongge (star), Timta (diamond).

Annual Temp change

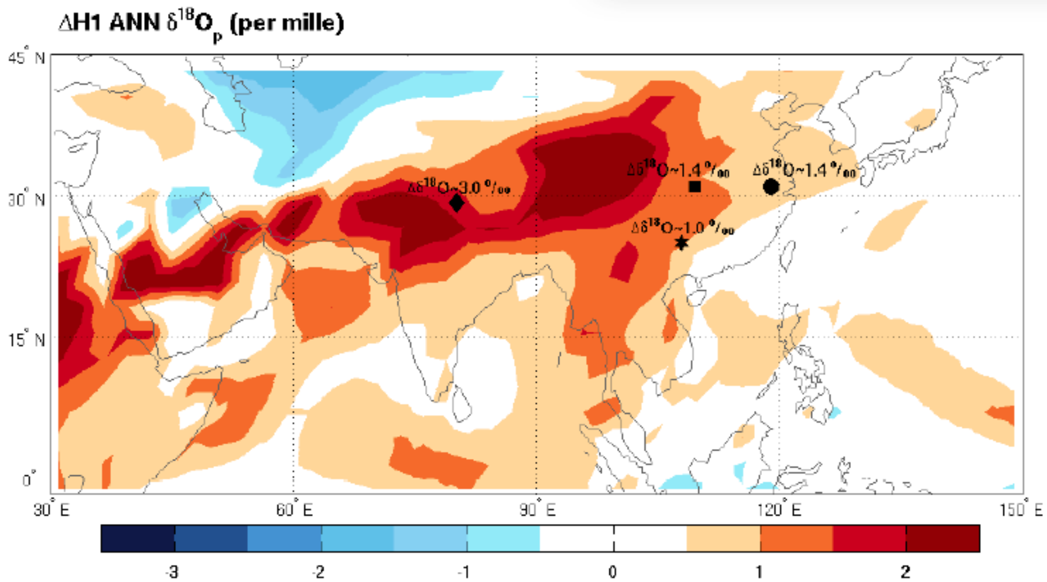
Annual Precip change

Cave Sites in China and Tibet

Pausata et al 2011

What happens when you increase sea ice extent in the N. Atlantic in a climate model?

Change in precip weighted $\delta^{18}O$




An abrupt increase in sea ice causes an abrupt increase in $\delta^{18}O_p$ consistent with the proxy data with *no change in the precipitation over China. How?*

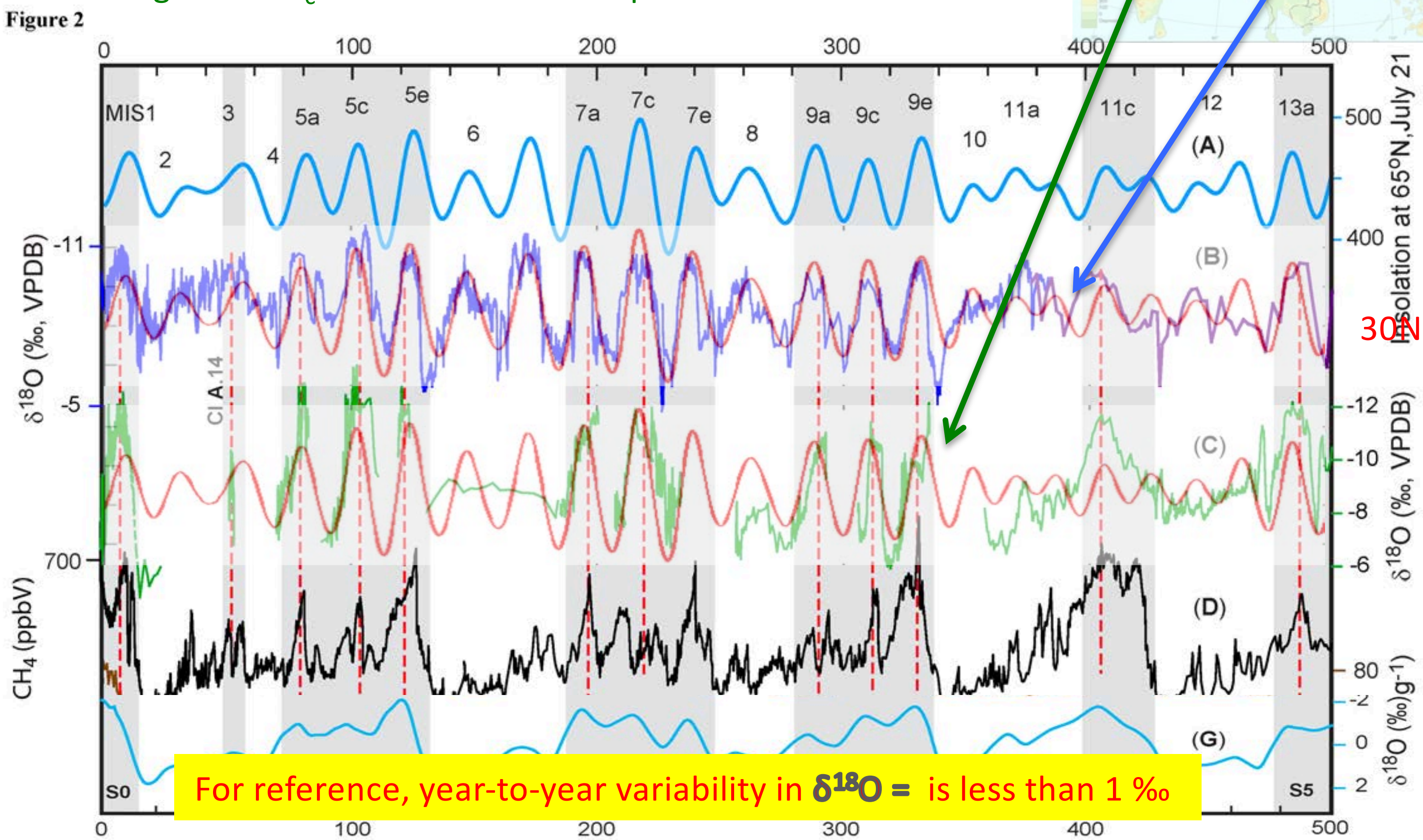
Reduced fractionation due to a weaker *Indian* monsoon in colder climate

Nb: Water isotopes in Greenland ice cores and Nordic Sea sediment cores contributed greatly to the leading theory for Dansgaard-Oeshcger cycles

Pausata et al 2011

# Precessional Forcing of Speleothem $\delta^{18}O_c$


Change in $\delta^{18}O_c$ are 3-4 ‰ or so on precessional time scales



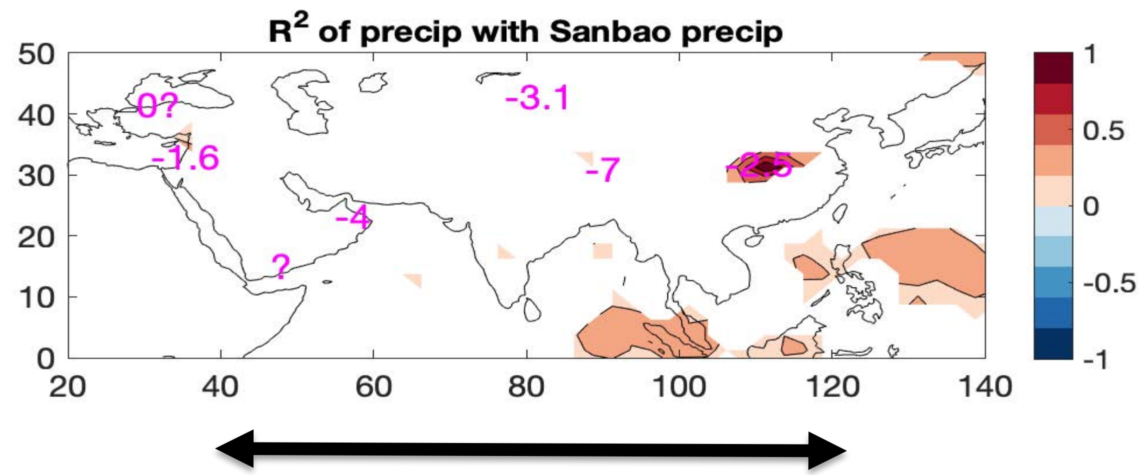

Age uncertainty +/- 3K at 300Kyr BP

Cheng et al 2013

# Summary: Amplitude of Precessional swings in Stalagmite $\delta^{18}O_c$ in caves from Arabia to China

Difference between high and low NH summer (JJA) Insolation

**Caves**
Peqiin
Soreq
Hoti
Kesang
Tianmen
Sanbao



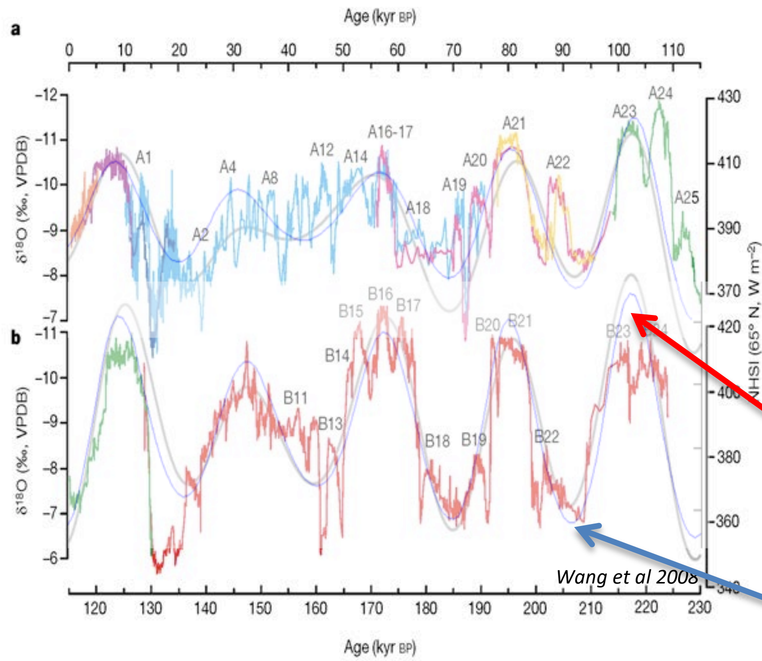

6000 km

A *large*-scale pattern of *large* changes in $\delta^{18}O_c$! How?

Refs: Bar-Matthews et al 2003; Fleitmann et al 2003; Cai et al 2010, 2012; Wang et al 2008

# *Precessional Cycles*

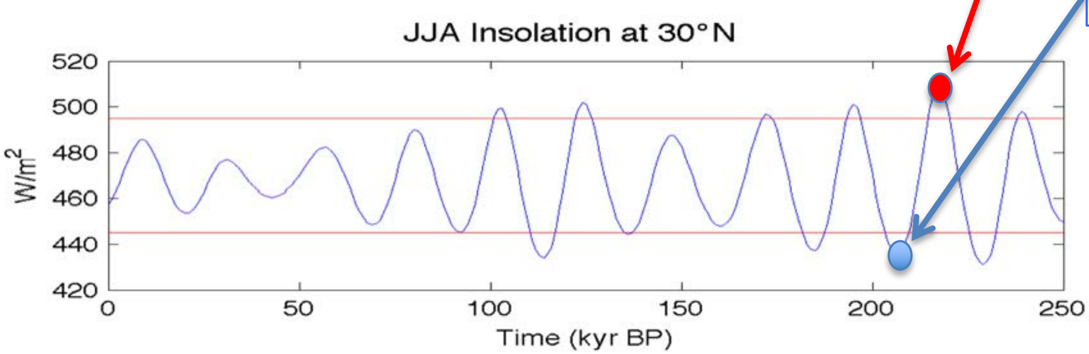
Insolation at 30N (JJA)
Insolation at 65N (July 21)




Change in $\delta^{18}O_c$ are 3 to 4 ‰ on orbital time scales

218kyr (High)

207kyr (Low)



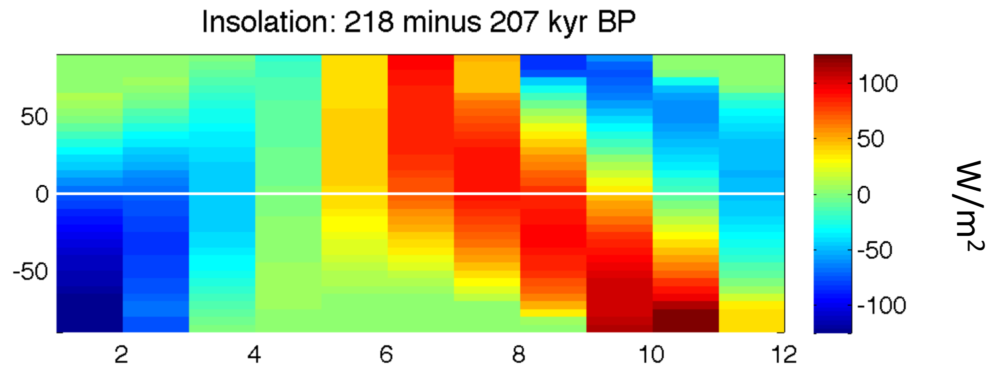
# Experiments with ECHAM4.6

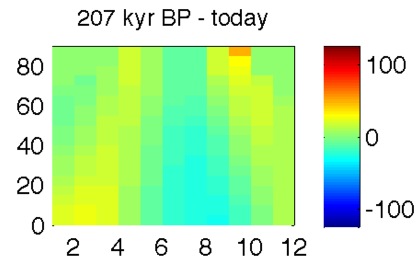
- ECHAM Atmospheric GCM
  - T42 horizontal resolution (2.8°)
  - Coupled to a slab ocean with SST adjusted to ~ modern day values when forced by modern day insolation, greenhouse gases and boundary conditions
    - q-flux added slab to mimic modern day ocean ocean heat transport and adjust for biases in surface energy flux
  - Isotope module included
- Two core Experiments
  - 218K insolation (High)
  - 207K insolation (Low)
  - Modern day geometry, orography & greenhouse gas concentration

Battisti et al: Coherent pan-Asian climatic and isotopic response to orbital forcing of tropical insolation. *JGR Atmospheres* 2014

# The change in forcing

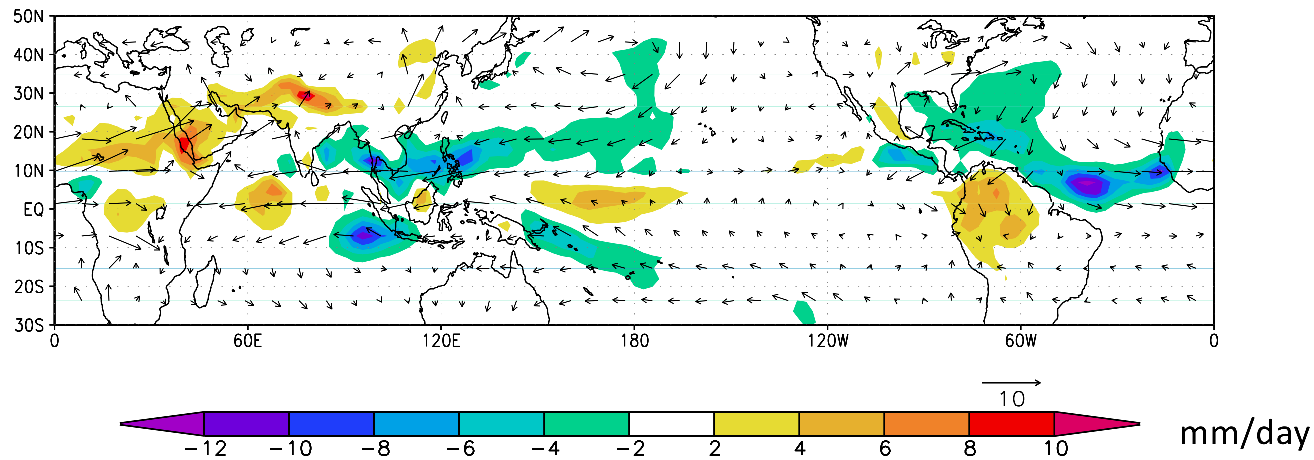
## High minus Low NH summer insolation




- Not surprisingly, the simulated NH climate in the "Low Forcing" at 207kyr BP is similar to the modern climate

# Change in Precipitation and 850 hPa Winds
# JJA (218 minus 207 kyr)

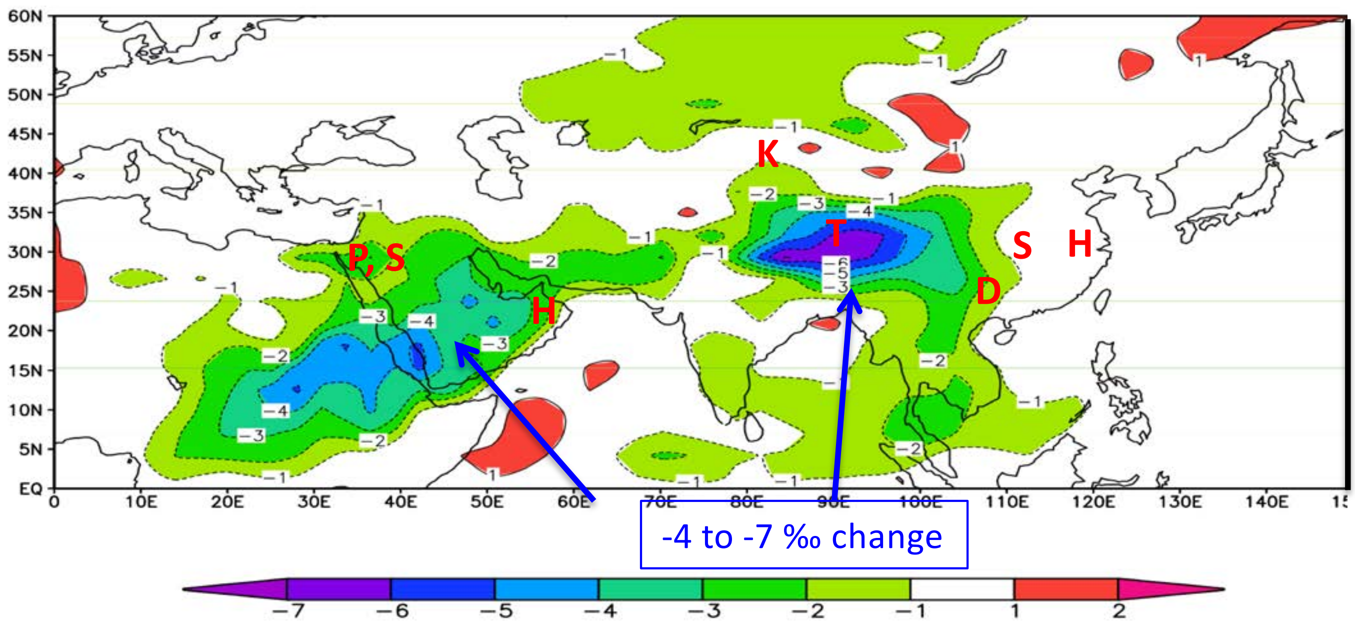



**For "high" summer insolation**

- Heavy rainfall from the Sahel to Arabia to Northern India
- Less over SE Asia
- More over China (~40%)
- Green Sahara?
- Collapse of Atlantic ITCZ/Trades (supported by $N^{15}$ in sediment)

Battisti et al 2014

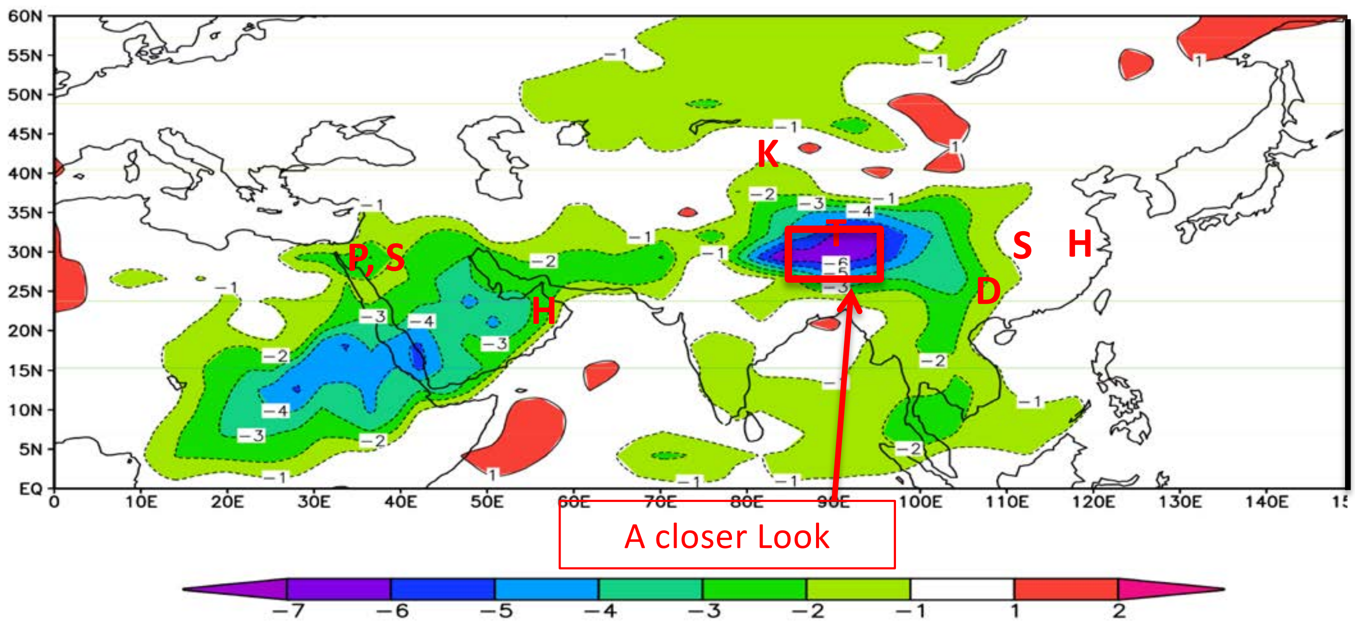
# Change in Precipitation weighted $\delta^{18}O$




- The model produces precessional changes of 5 to 7 ‰ over the eastern Tibetan plateau
  - Mainly due changes in the $\delta^{18}O$ of imported vapor due to non-local changes in climate in summer
- 3 to 4 ‰ change over Arabia and N. India
  - Due to change in summer vapor transport and local amount effect

Battisti et al 2014

# Change in Precipitation weighted δ$^{18}$O

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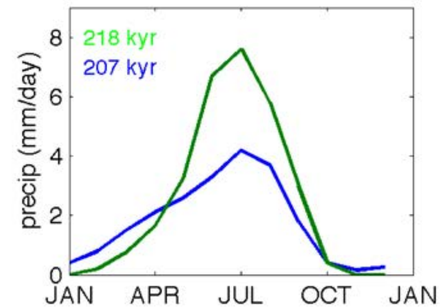
Battisti et al 2014

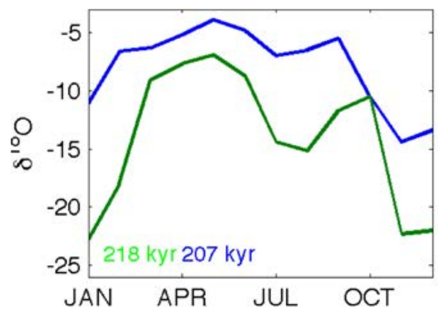
# Change in Precipitation weighted $\delta^{18}O$

| | 218 Minus 207 |
|---|---|
| **Annual Precip** | +38 % |
| Summer precip | +77 % |
| Winter precip | -24 % |
| **Precip wt $\delta^{18}O$** | -5.5 ‰ |

Tibet

(26-32N, 85-95E)



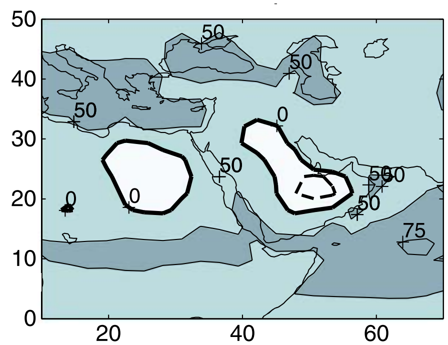

More precip, but …

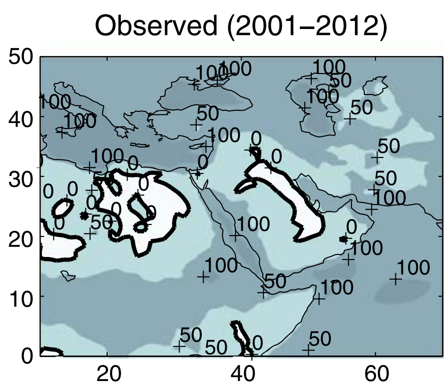
*Lighter $\delta^{18}O_p$ is mainly due to lighter vapor imported to Tibet*

Battisti et al 2014

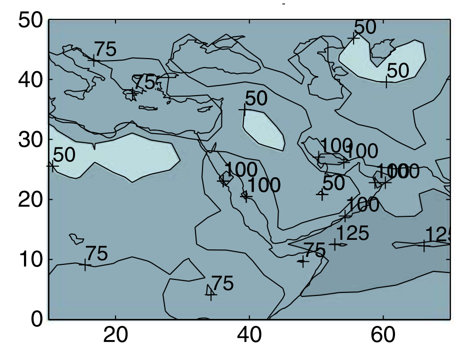
# Net Summer Radiation at the Top of the Atmosphere

207 kyr BP (like today)






218 kyr

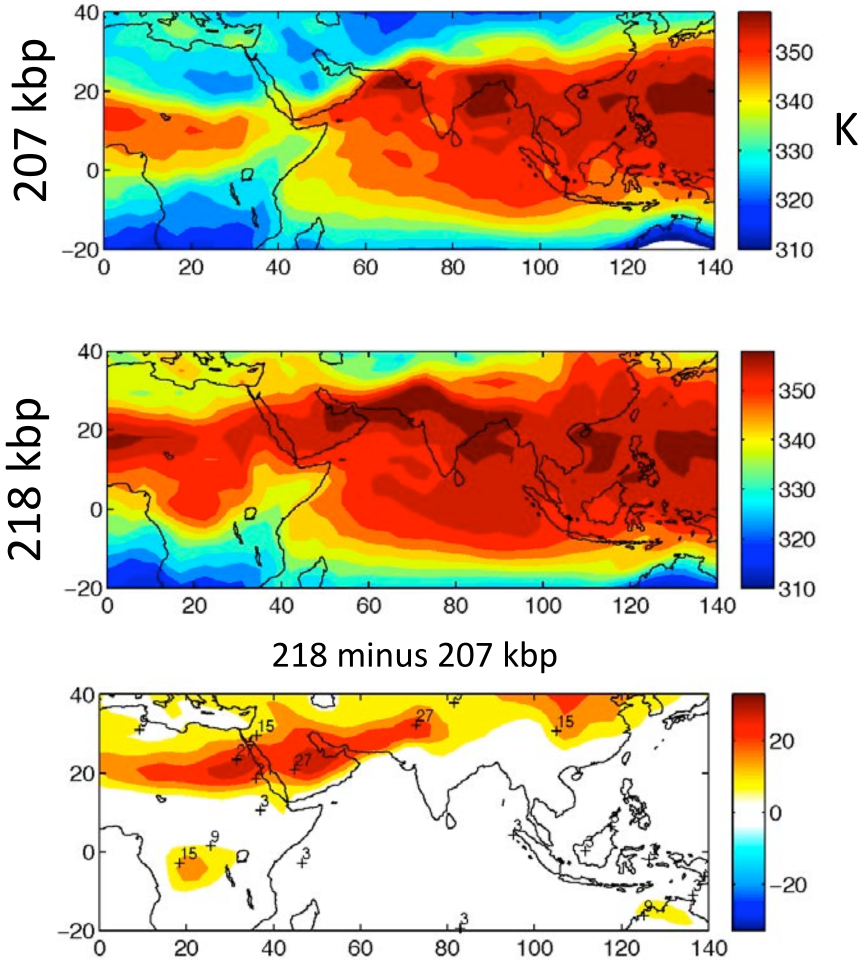


- With sufficiently high summer insolation, there is a fundamental transition to entirely different climate state!

Battisti et al 2014

# The new view of monsoons: its about near surface energy, not temperature

(Privé and Plumb 2007; Boos and Kwang 2010, Bordoni and Schneider 2010; Molnar et al 2010; Geen et al 2019)




Battisti et al 2014

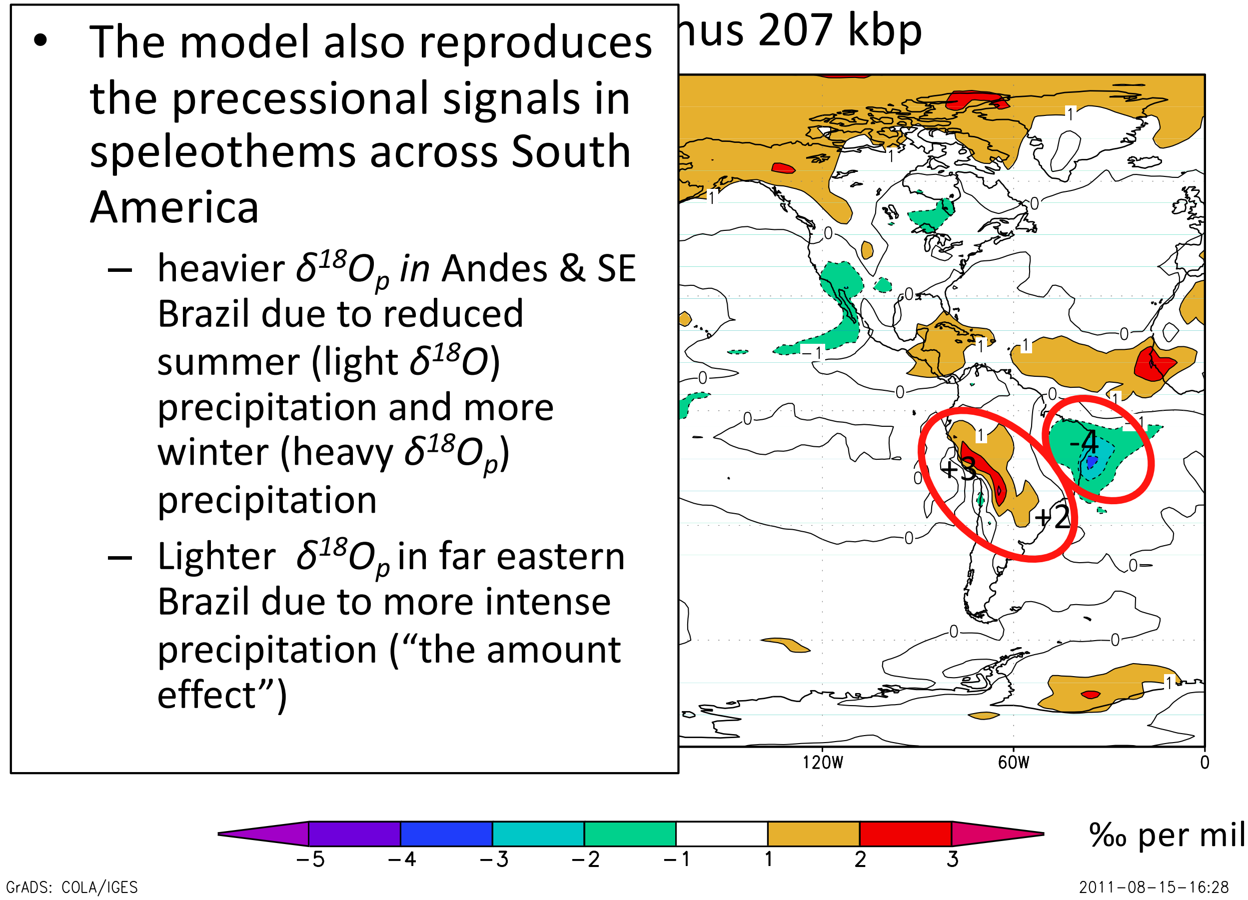
Precipitation is centered over maximum $\Theta_e$ → over oceans in low NH summer insolation (e.g., today)

Precipitation is centered over land in high insolation (a textbook monsoon)

* MSE and $\Theta_e$ are functionally equivalent

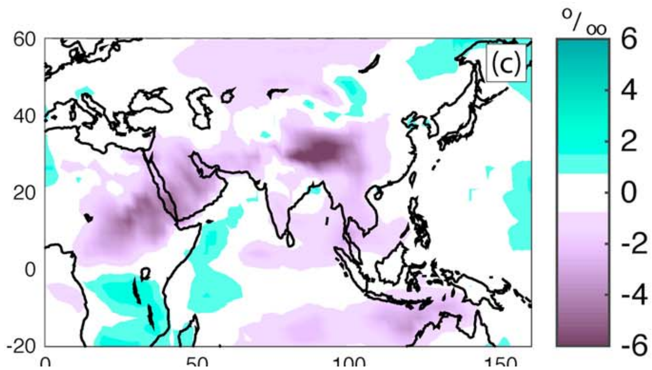
# Precessional Cycle in South America: Precip weighted $\delta^{18}O$

- The model also reproduces the precessional signals in speleothems across South America
  - heavier $\delta^{18}O_p$ *in* Andes & SE Brazil due to reduced summer (light $\delta^{18}O$) precipitation and more winter (heavy $\delta^{18}O_p$) precipitation
  - Lighter $\delta^{18}O_p$ in far eastern Brazil due to more intense precipitation ("the amount effect")



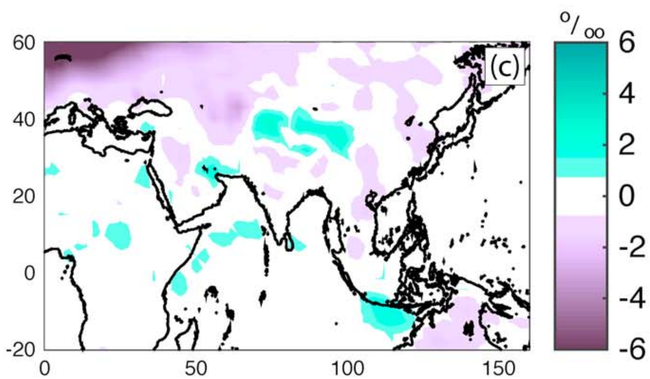

Liu and Battisti 2015

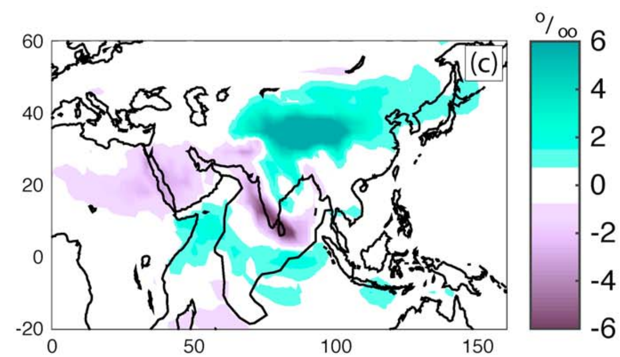
Precession



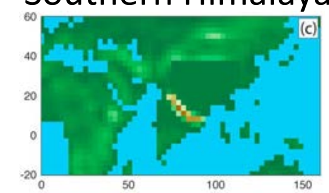

*Change in $\delta^{18}O_p$ : Experiment - today*

LGM minus today

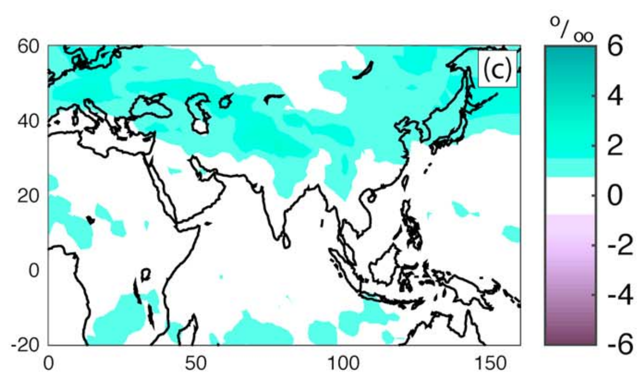


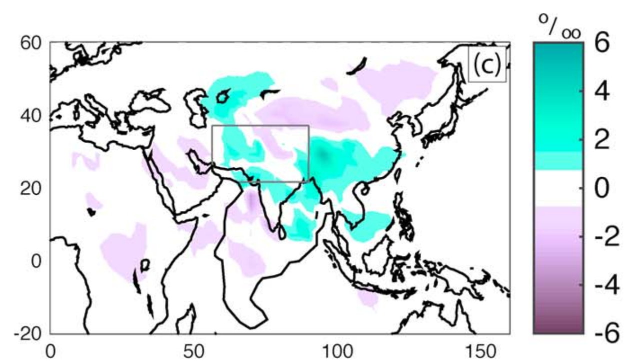




Southern Himalaya

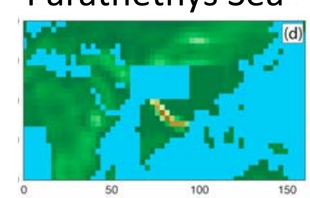



2 x $CO_2$




Parathethys Sea




Roe et al 2016

# 3. Additional applications of water isotopes in climate

- Not promising
  - Paleothermometry

- Promising
  - ENSO in the past: need sub-annual coral records and ***vastly*** improved coupled atmosphere-ocean models (which are isotopically enabled)
    - E.g., models with good modern ENSOs show ENSO is reduced in the mid-Holocene by 20-40% (see references in Roberts et al 2014).

## 4. Future challenges/advances

- Better understanding of processes important for setting mid- and upper- tropospheric water vapor distribution (climate sensitivity)
- Better quantification of re-evaporation of falling rain (relative humidity)
- Better understanding of the relationship between soil moisture, evapotranspiration and surface shortwave radiation in summertime (changing temperature extremes)

# Summary

- Water isotopes ($\delta^{18}O$) *rarely inform on local climate conditions*
  - Precipitation is local; water vapor is distributed by winds. Hence, changes in fractionation in precipitation centers are registered downwind and on continental scales via vapor transport.
  - Hence, you can only safely interpret isotope records with a climate model and, collectively, the records can be used to inform on climate processes
- Models show that Heinrich events, D-O cycles and precessional changes in insolation affect the location and intensity of the Asian monsoon and thus the isotopic composition of the *vapor* that condenses and precipitates throughout central Asia and over China
  - For each of these phenomenon, there is good agreement between modelled precipitation weighted $\delta^{18}O$ *and that recorded in stalagmites through the globe. This gives support to the new ideas on monsoon dynamics and is strong support for the leading theory of D-O cycles.*