Paleoclimate perspectives on the Afro-Asian monsoon

Jessica E. Tierney[1,2]

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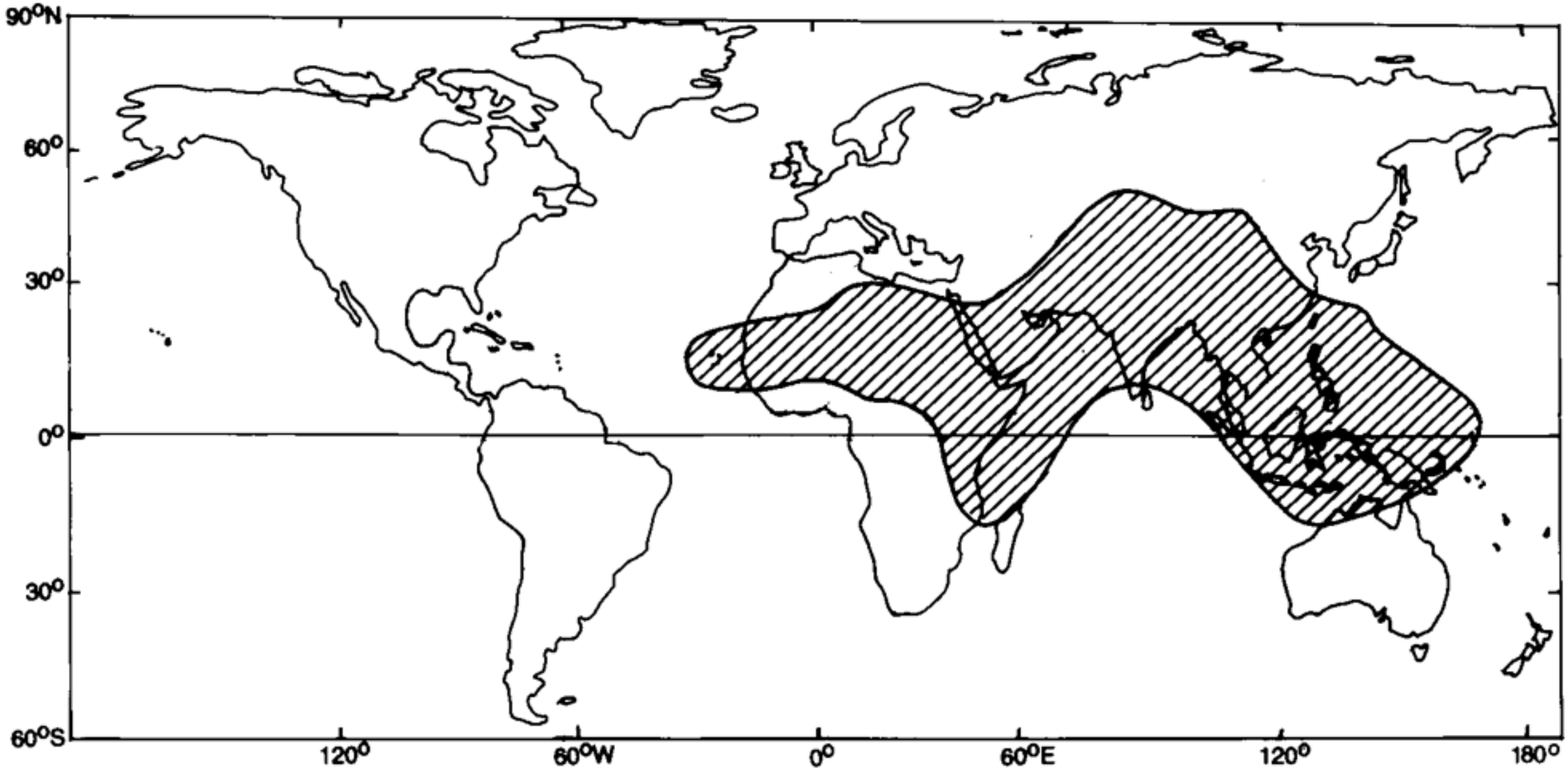
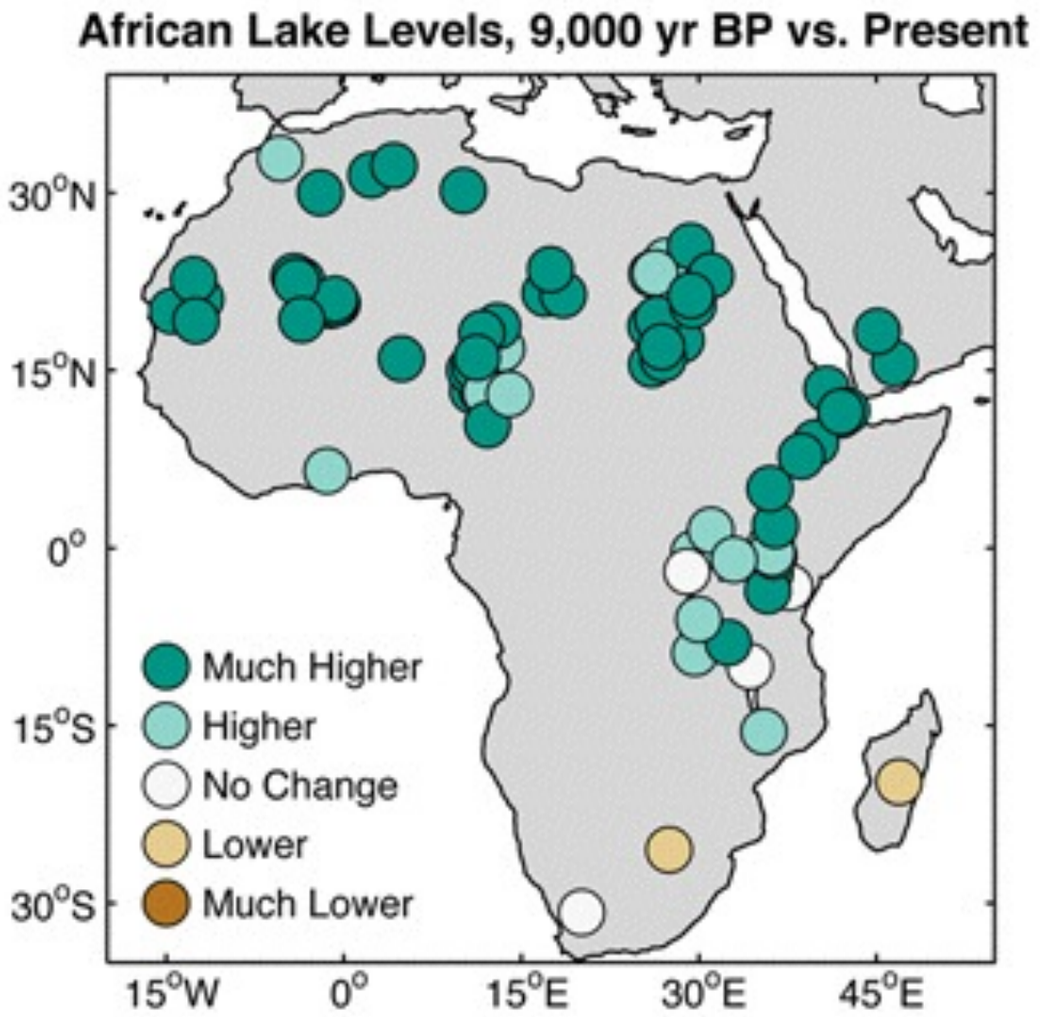
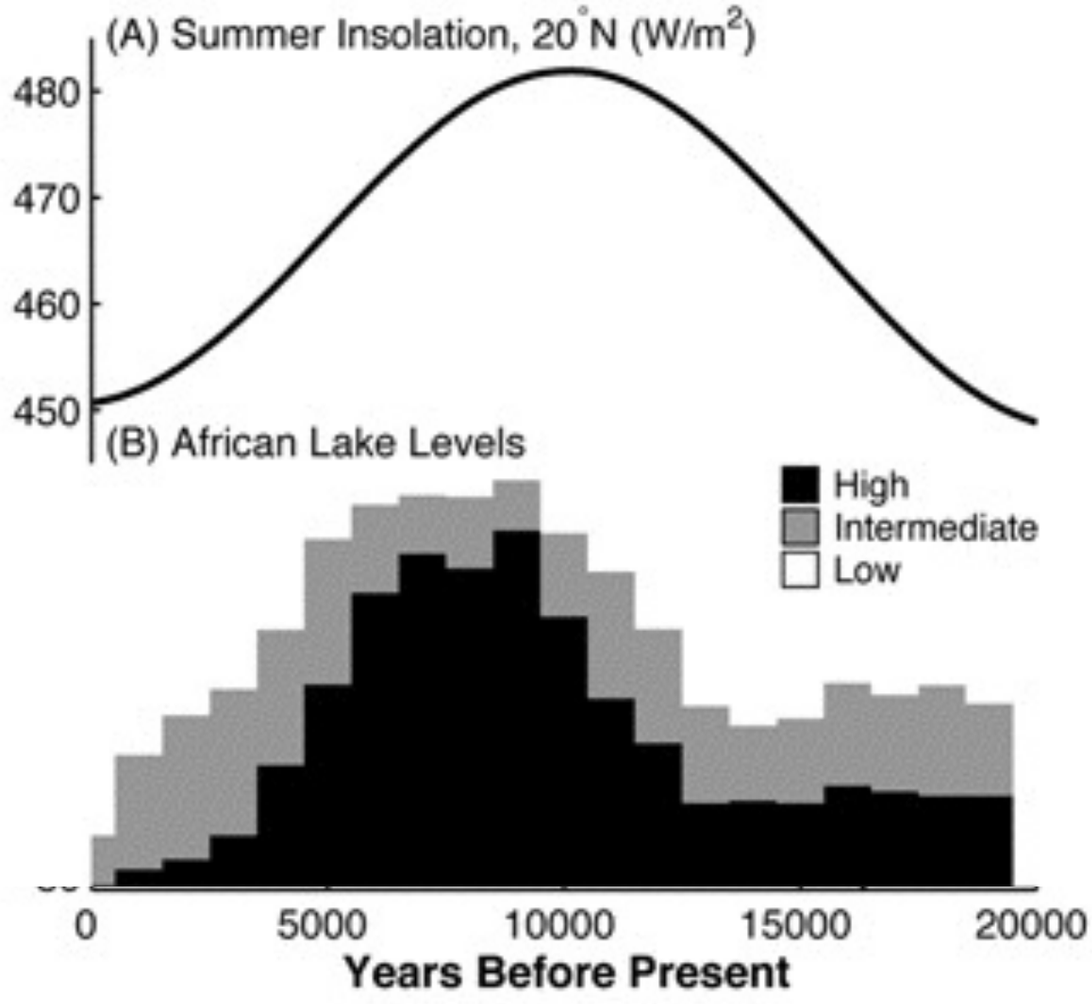

90°N
60°
30°
0°
30°
60°S
120°
60°W
0°
60°E
120°
180°

Road Map

- **Response of the monsoon to orbital and glacial forcing: a quick trip through recent history**
- **Response of the monsoon to millennial-scale events: exploring Heinrich Event 1.**
- **Abrupt shifts in the monsoon driven by gradual forcing: what we know and what we don't know.**

The Beginning.

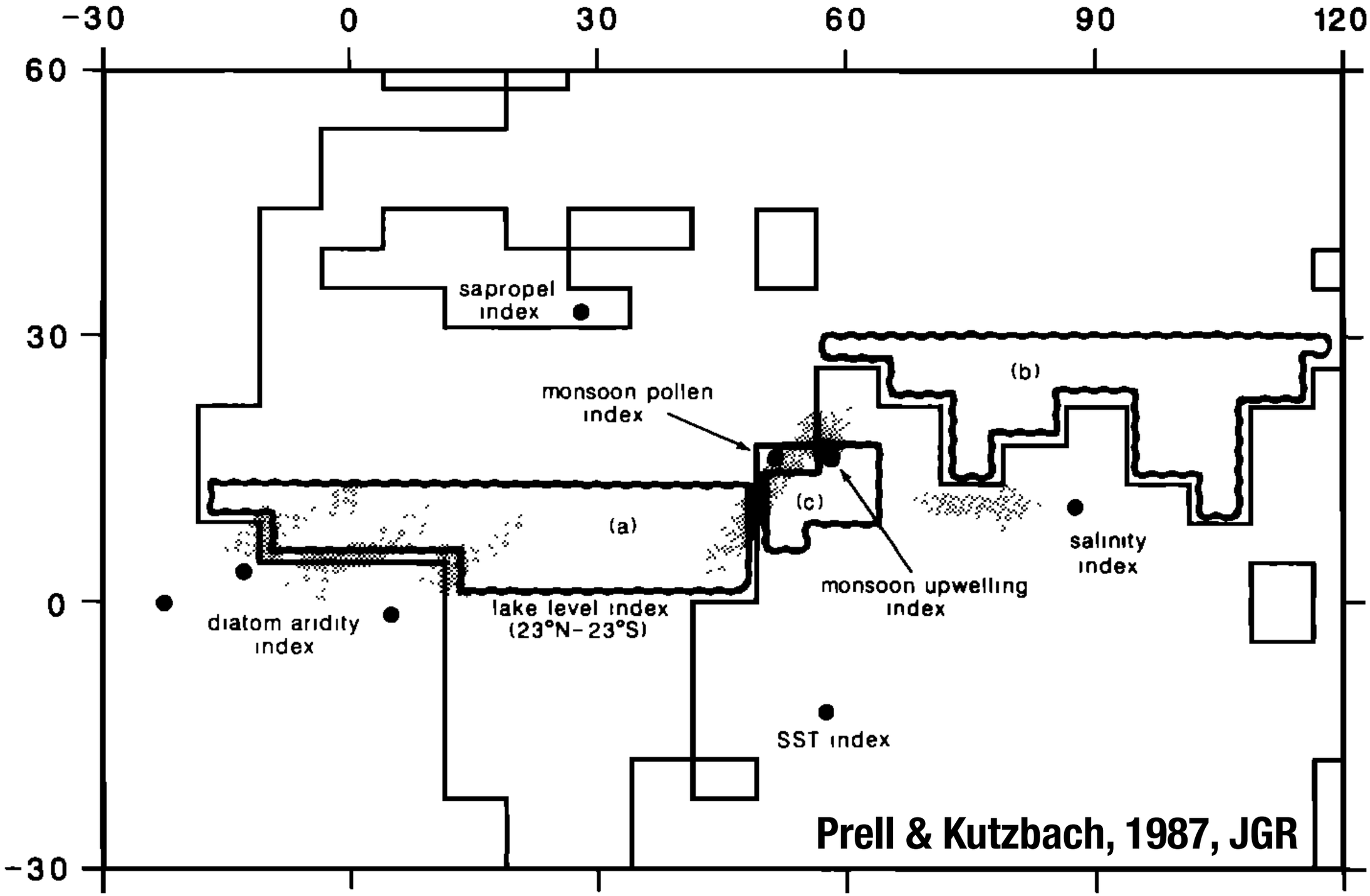


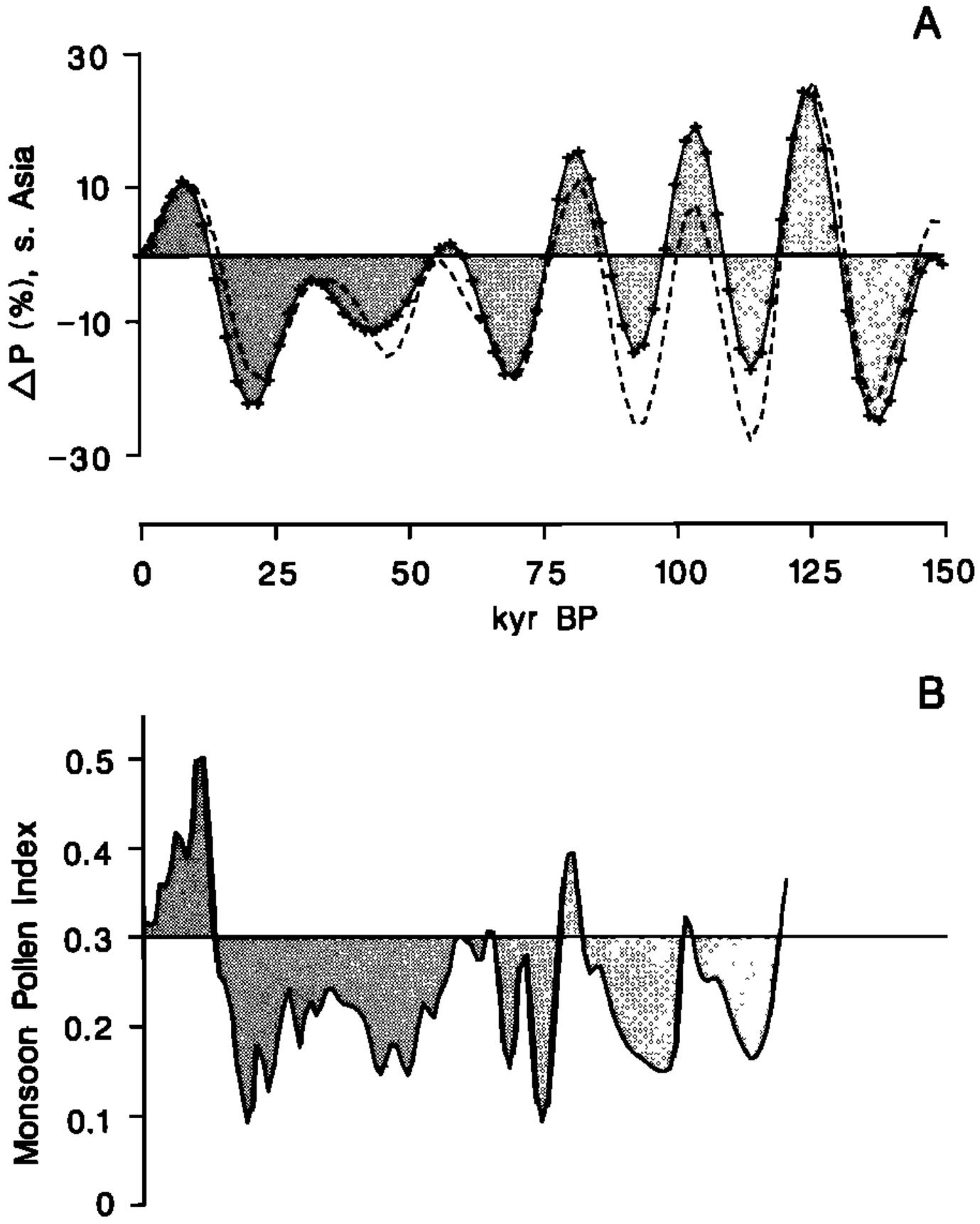


Monsoon Climate of the Early Holocene: Climate Experiment with the Earth's Orbital Parameters for 9000 Years Ago

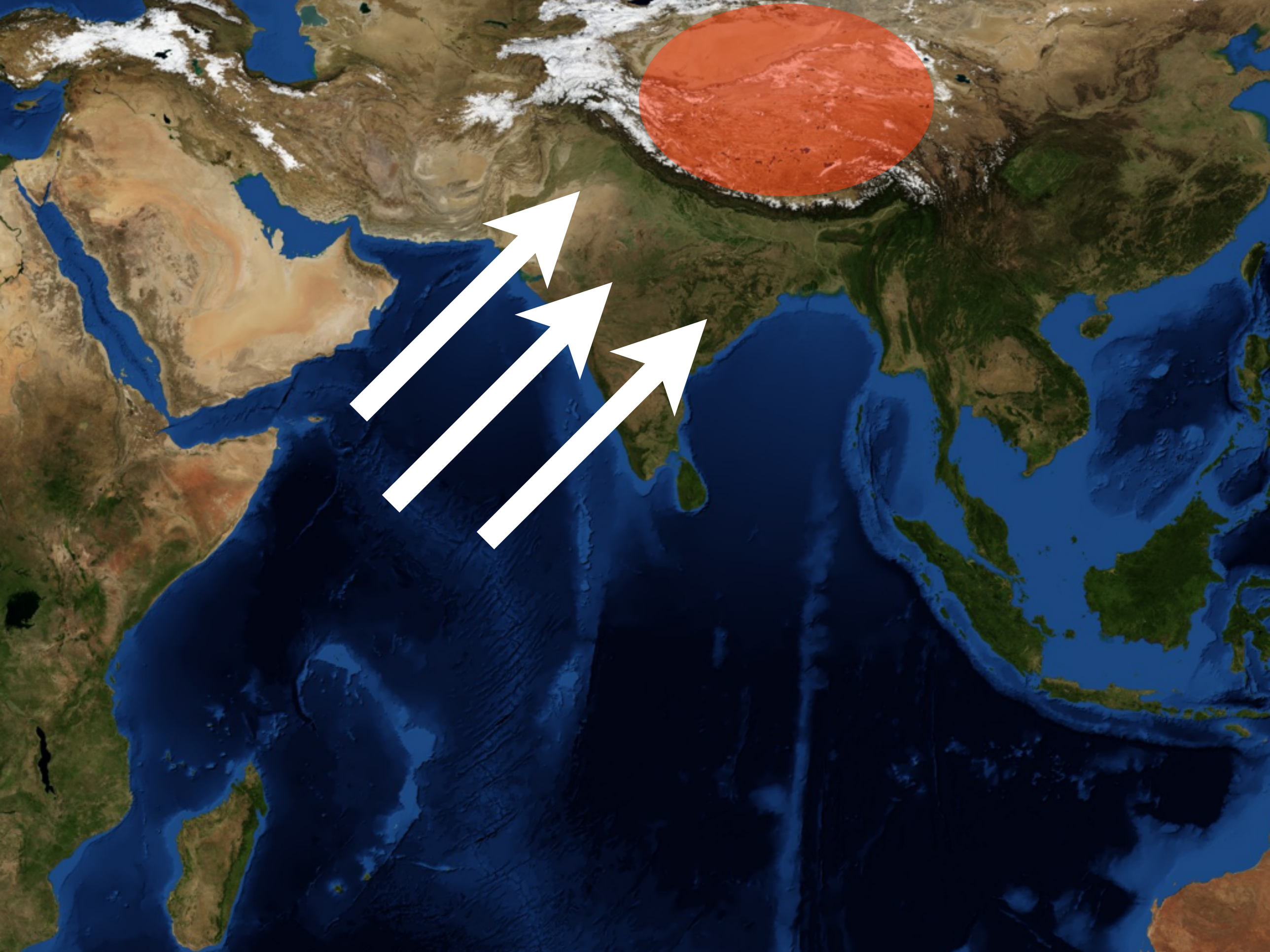
Abstract. *Values for the precession and obliquity of the earth 9000 years ago indicate that the global average solar radiation for July 9000 years ago was 7 percent greater than at present. When the estimated solar radiation values are used in a low-resolution climate model, the model simulates an intensified continent-scale monsoon circulation. This result agrees with paleoclimatic evidence from Africa, Arabia, and India that monsoon rains were stronger between 10,000 and 5000 years ago than they are today.*

Kutzbach, 1981, Science


-30
0
30
60
90
120
60
30
0
-30
sapropel index
monsoon pollen index
(b)
(c)
(a)
salinity index
monsoon upwelling index
diatom aridity index
lake level index (23°N-23°S)
SST index
Prell & Kutzbach, 1987, JGR



Prell & Kutzbach, 1987, JGR



The plot thickens.

ARTICLES

Forcing mechanisms of the Indian Ocean monsoon

Steven Clemens*, Warren Prell*, David Murray*, Graham Shimmield† & Graham Weedon‡

* Geological Sciences, Brown University, Providence, Rhode Island 02912-1846, USA
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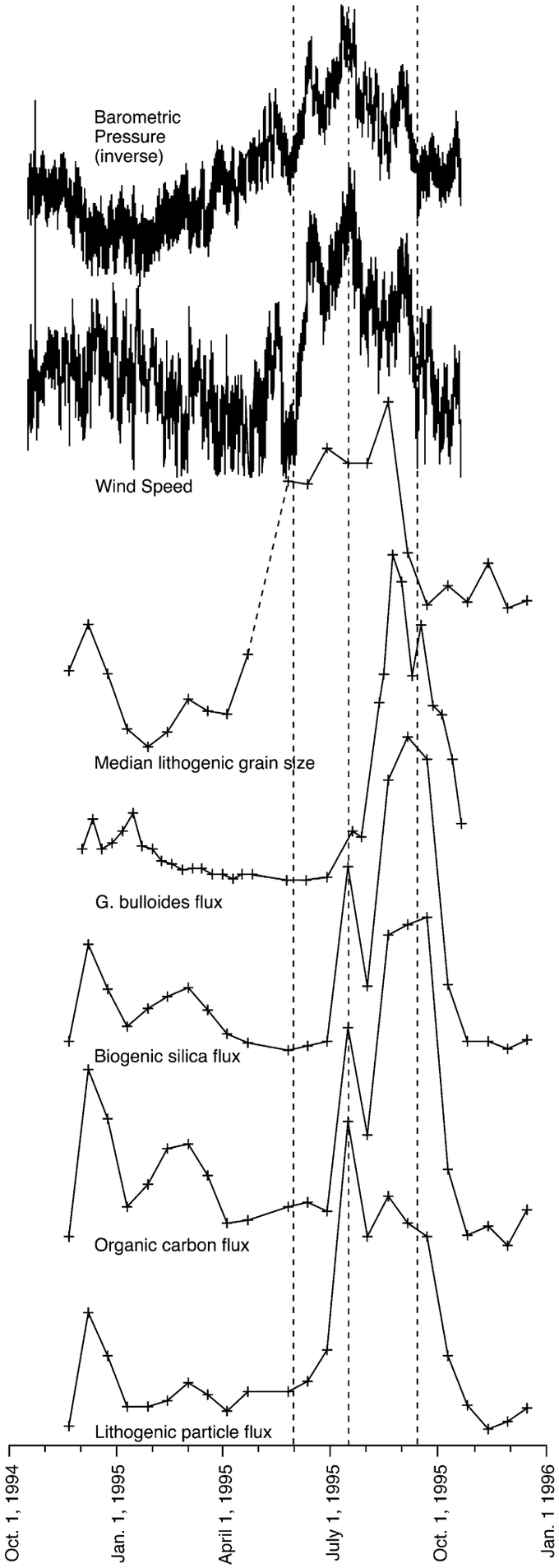
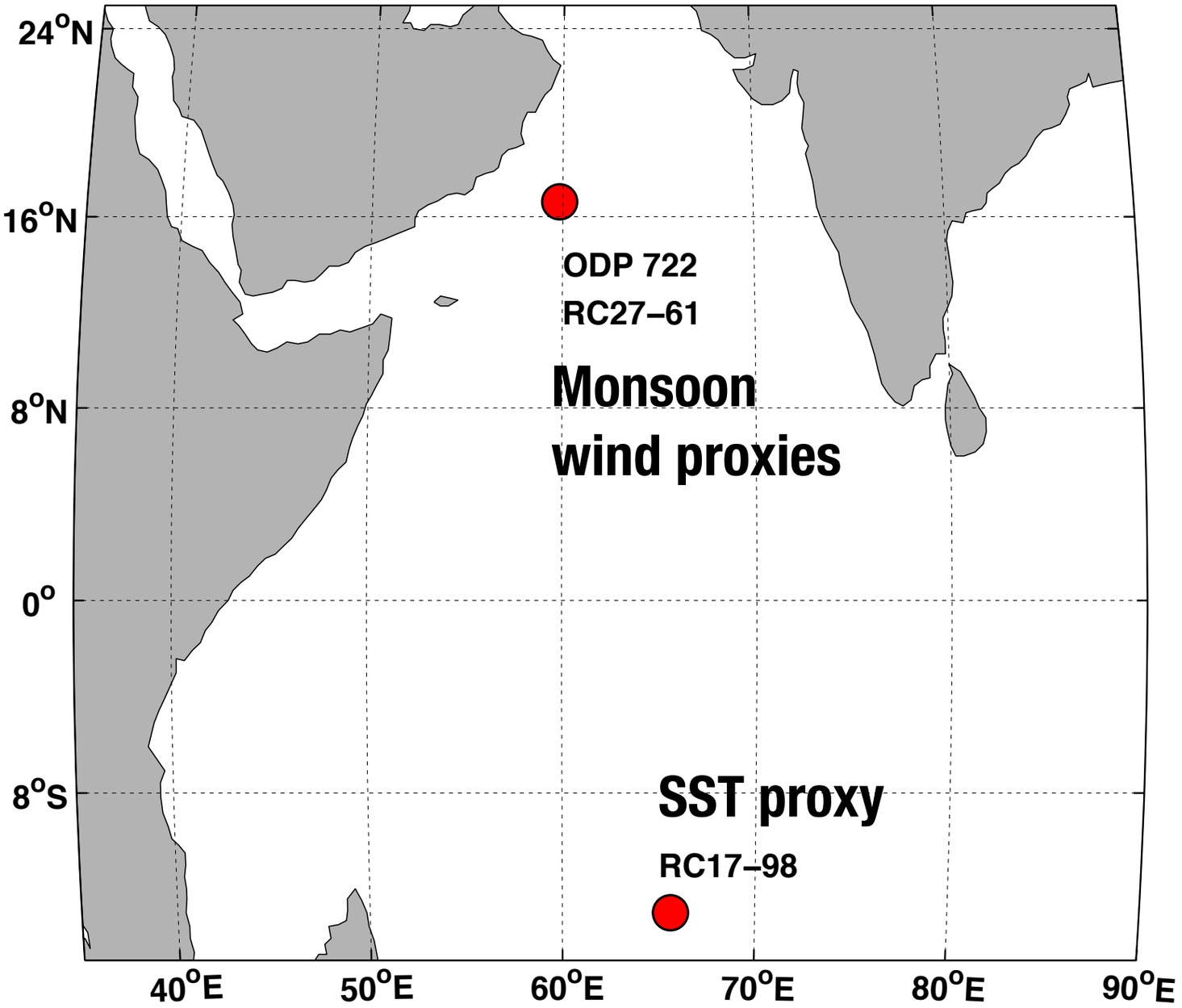
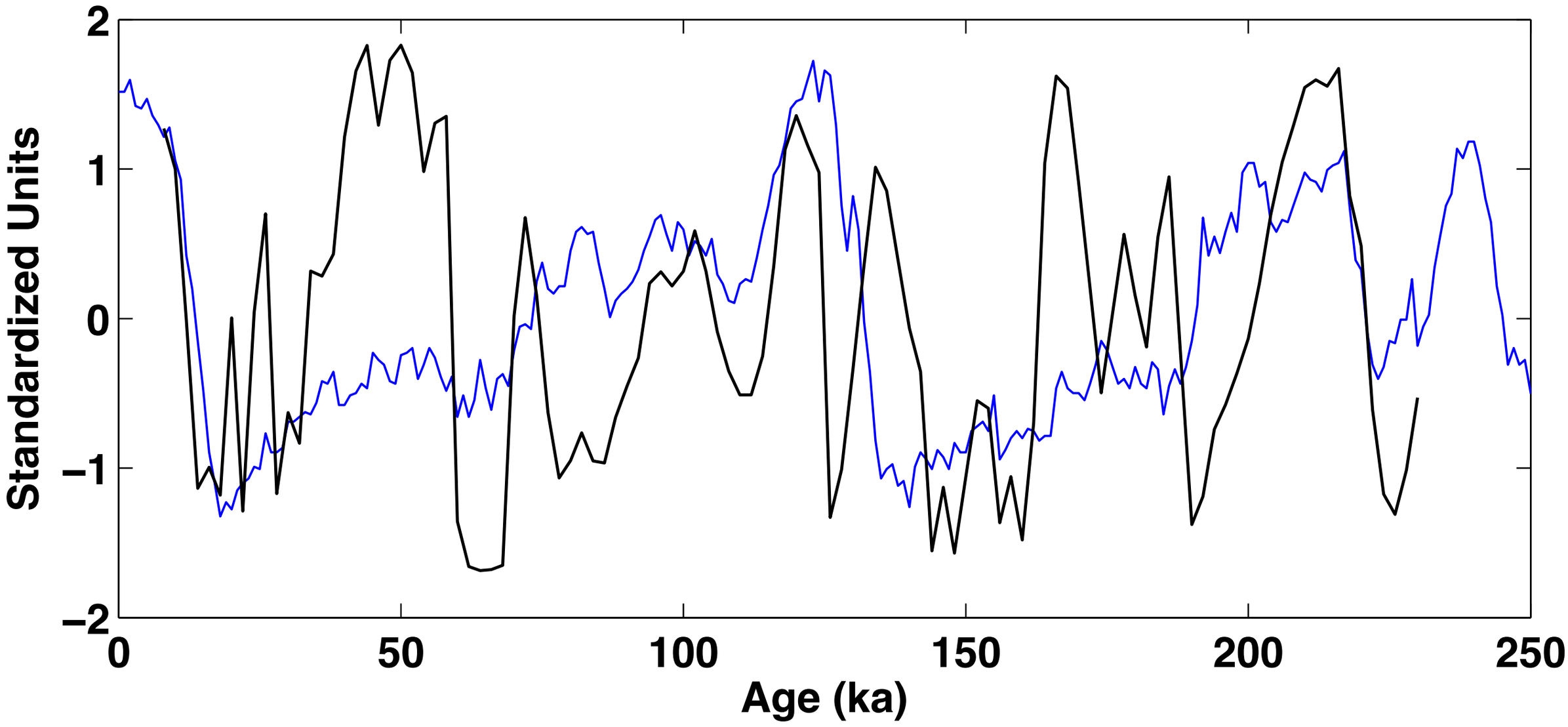
‡ Earth Sciences, Cambridge University, Downing Street, Cambridge CB2 3EQ, UK

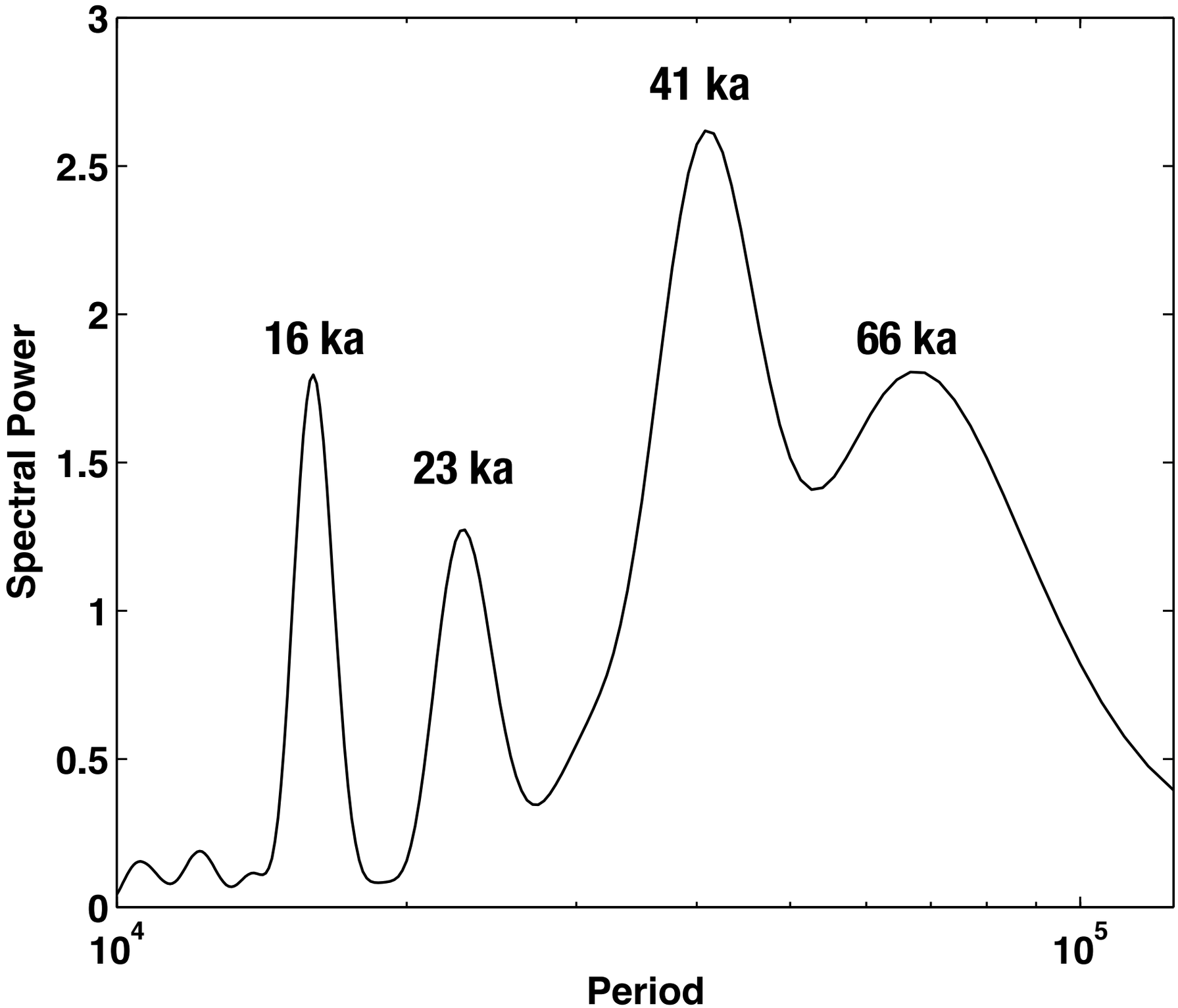




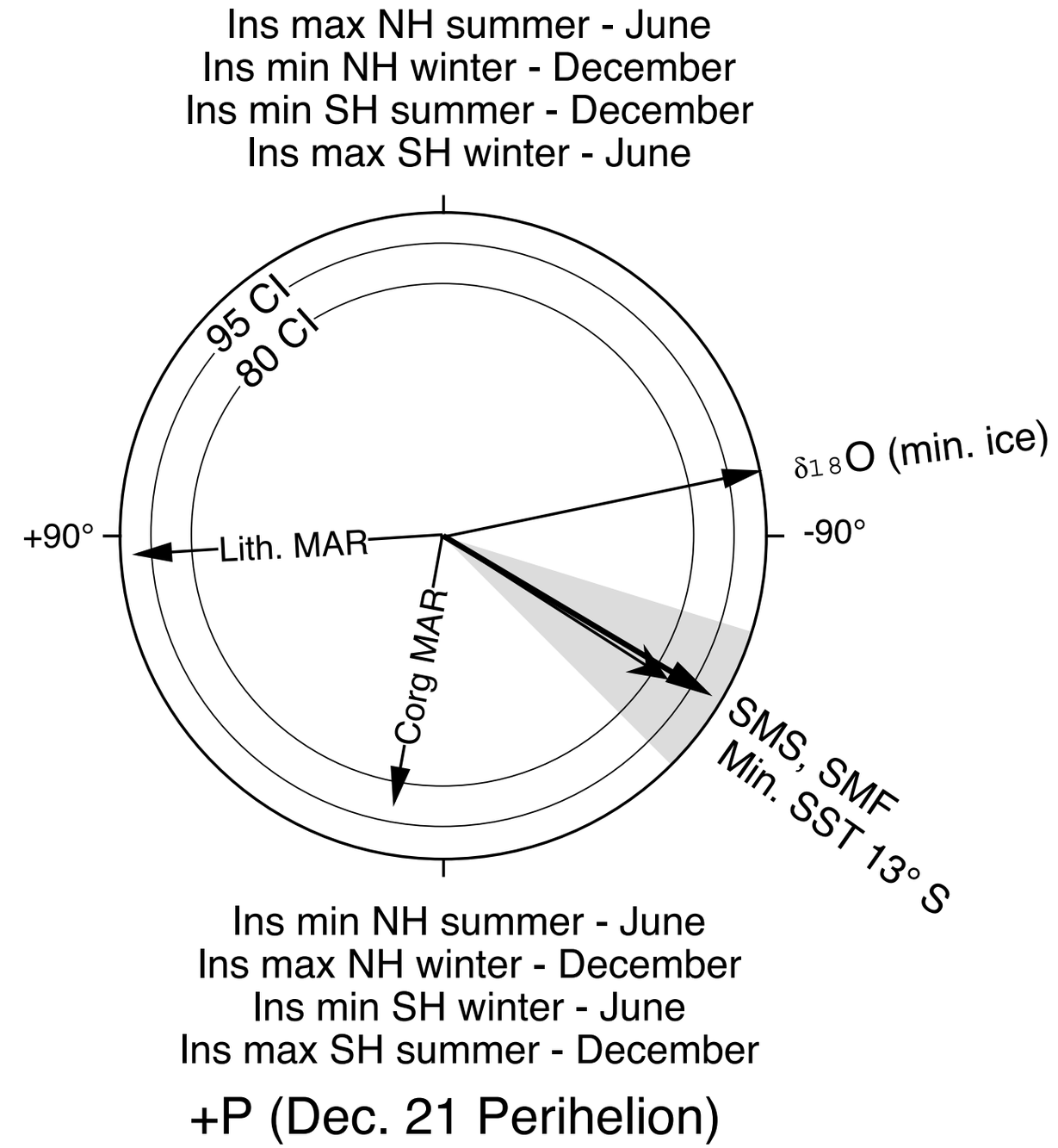
Clemens et al., 1991, Nature
Clemens & Prell, 2003, Marine Geology



Clemens et al., 1991, Nature
Clemens & Prell, 2003, Marine Geology


3
2.5
2
1.5
1
0.5
0
Spectral Power
16 ka
23 ka
41 ka
66 ka
10^4
10^5
Period

-P (June 21 Perihelion)
23-kyr cycle



+P (Dec. 21 Perihelion)

Clemens et al., 1991, Nature

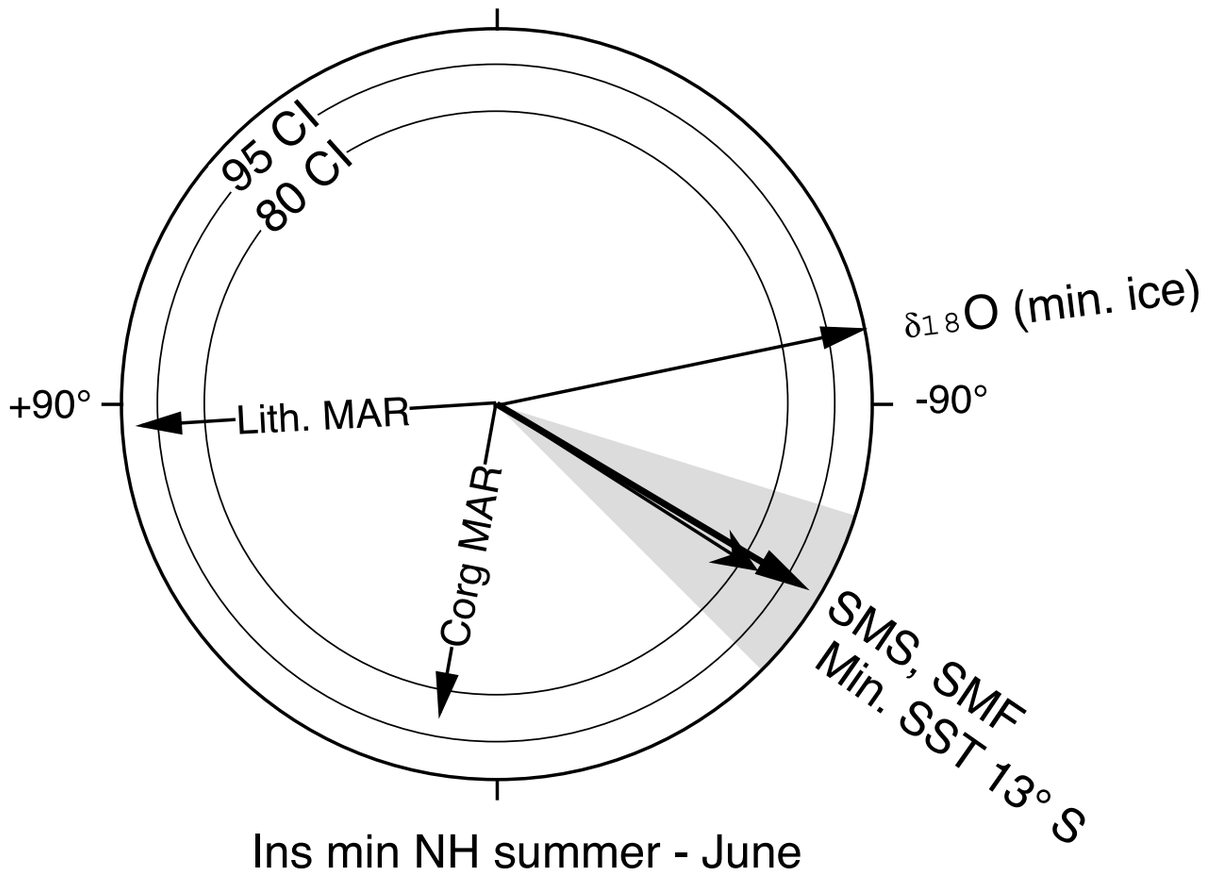
Clemens & Prell, 2003, Marine Geology

P_{max}, O_{max}

DJA
(SH Winter)

-P (June 21 Perihelion)
23-kyr cycle

Ins max NH summer - June
Ins min NH winter - December
Ins min SH summer - December
Ins max SH winter - June

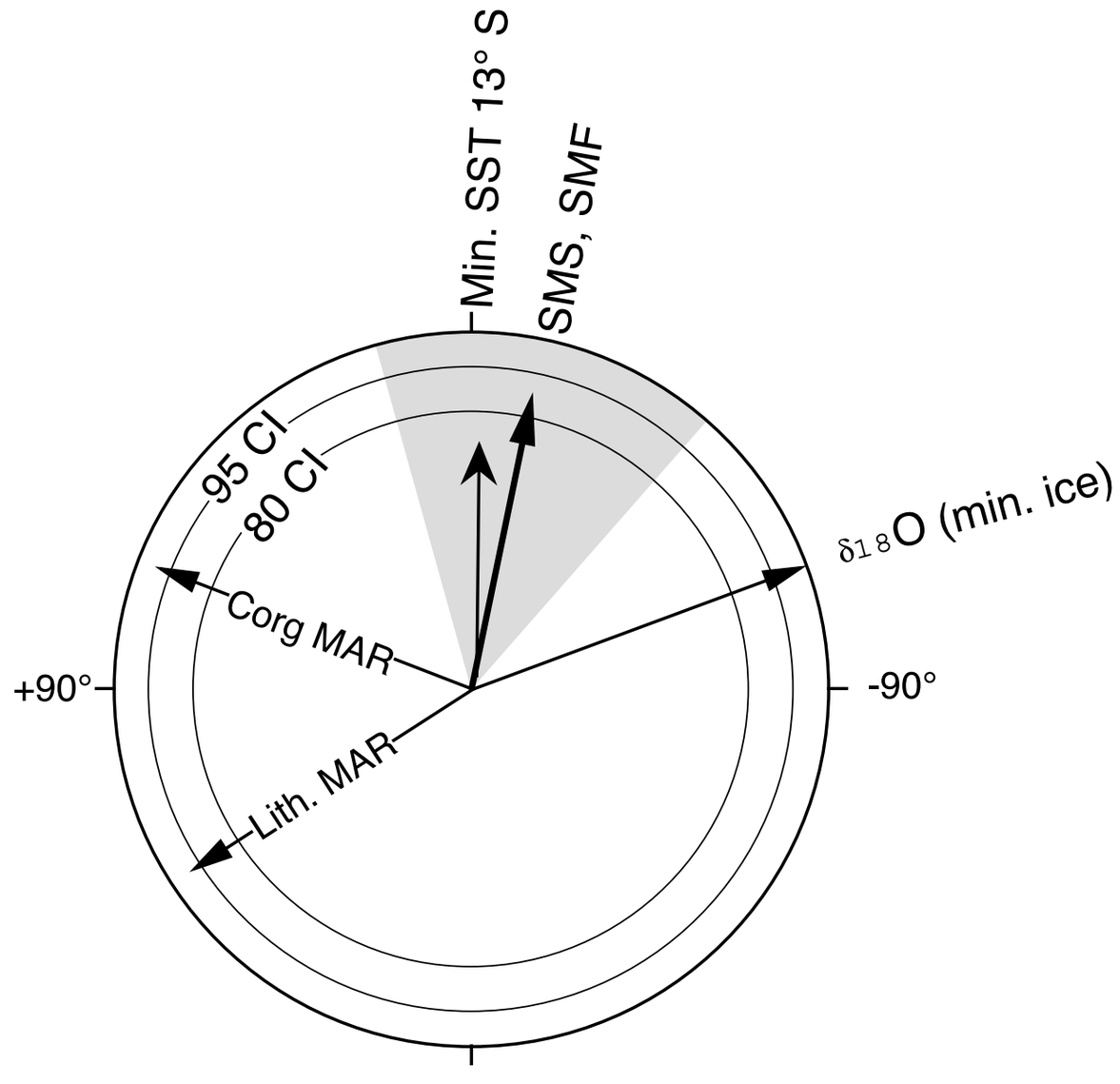


Ins min NH summer - June
Ins max NH winter - December
Ins min SH winter - June
Ins max SH summer - December

+P (Dec. 21 Perihelion)

Obliquity
41-kyr cycle

Ins max NH summer - June
Ins min NH winter - December
Ins max SH summer - December
Ins min SH winter - June

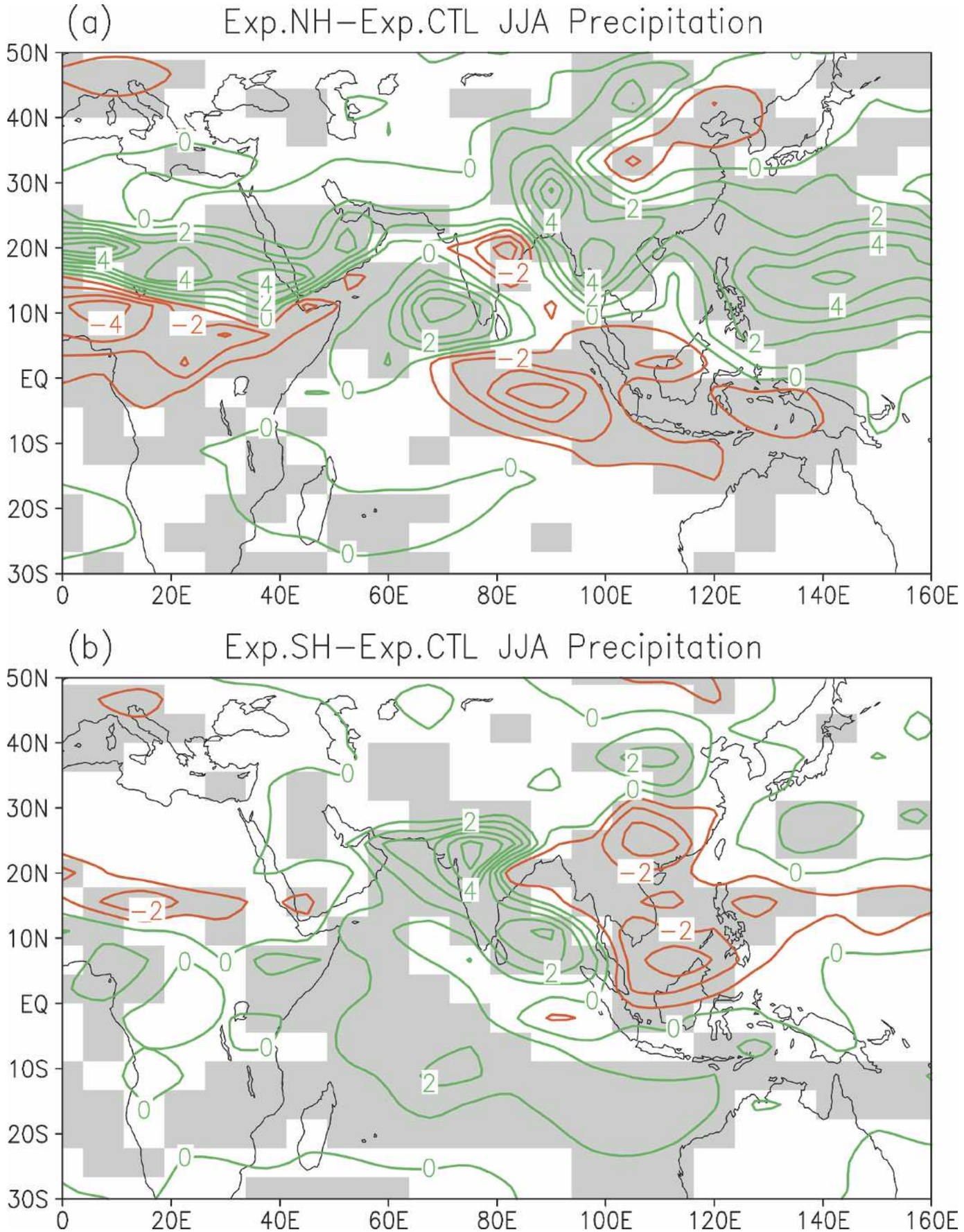


Ins min NH summer - June
Ins max NH winter - December
Ins min SH summer - December
Ins max SH winter - June

Clemens et al., 1991, Nature
Clemens & Prell, 2003, Marine Geology

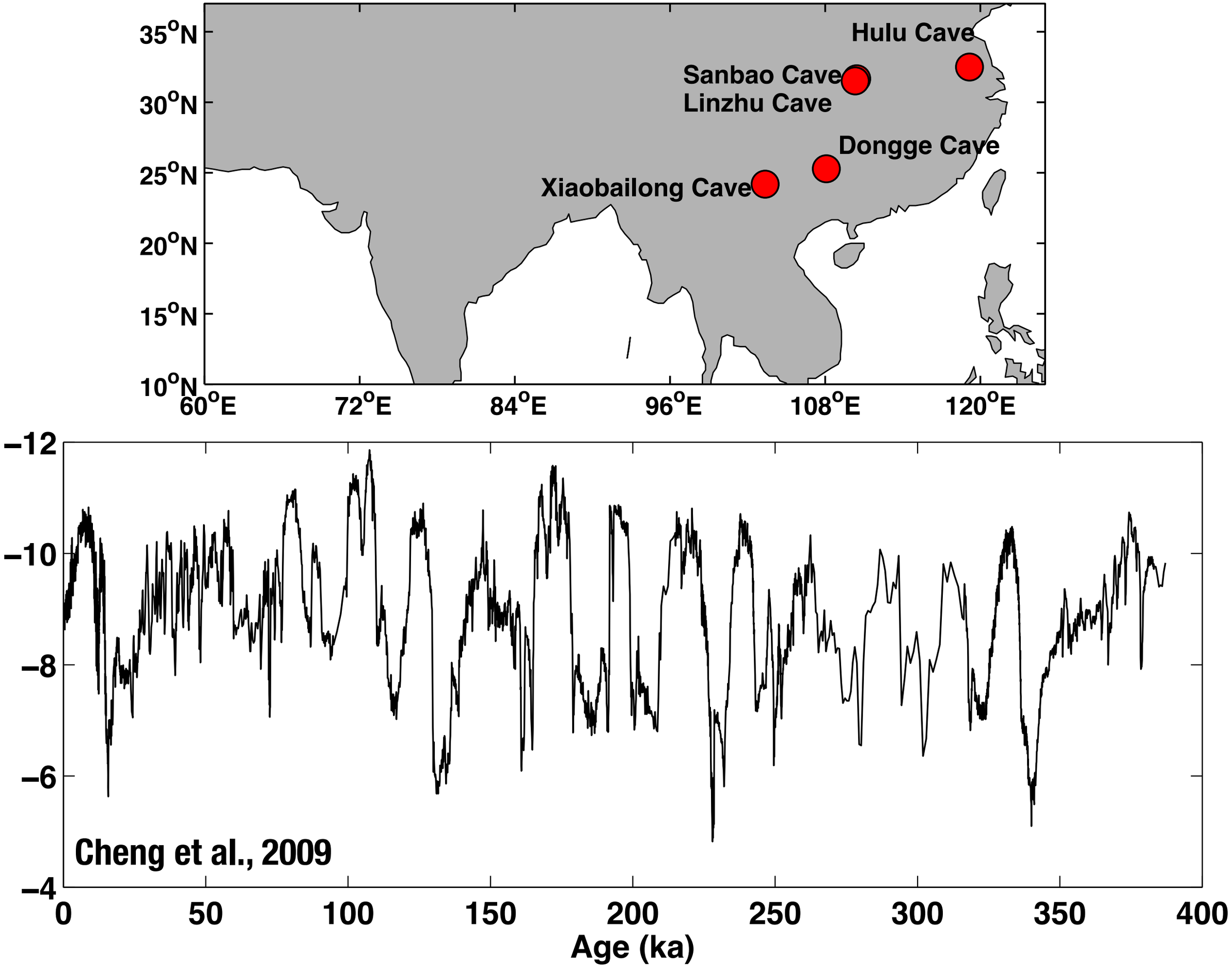
+ NH Summer Insolation

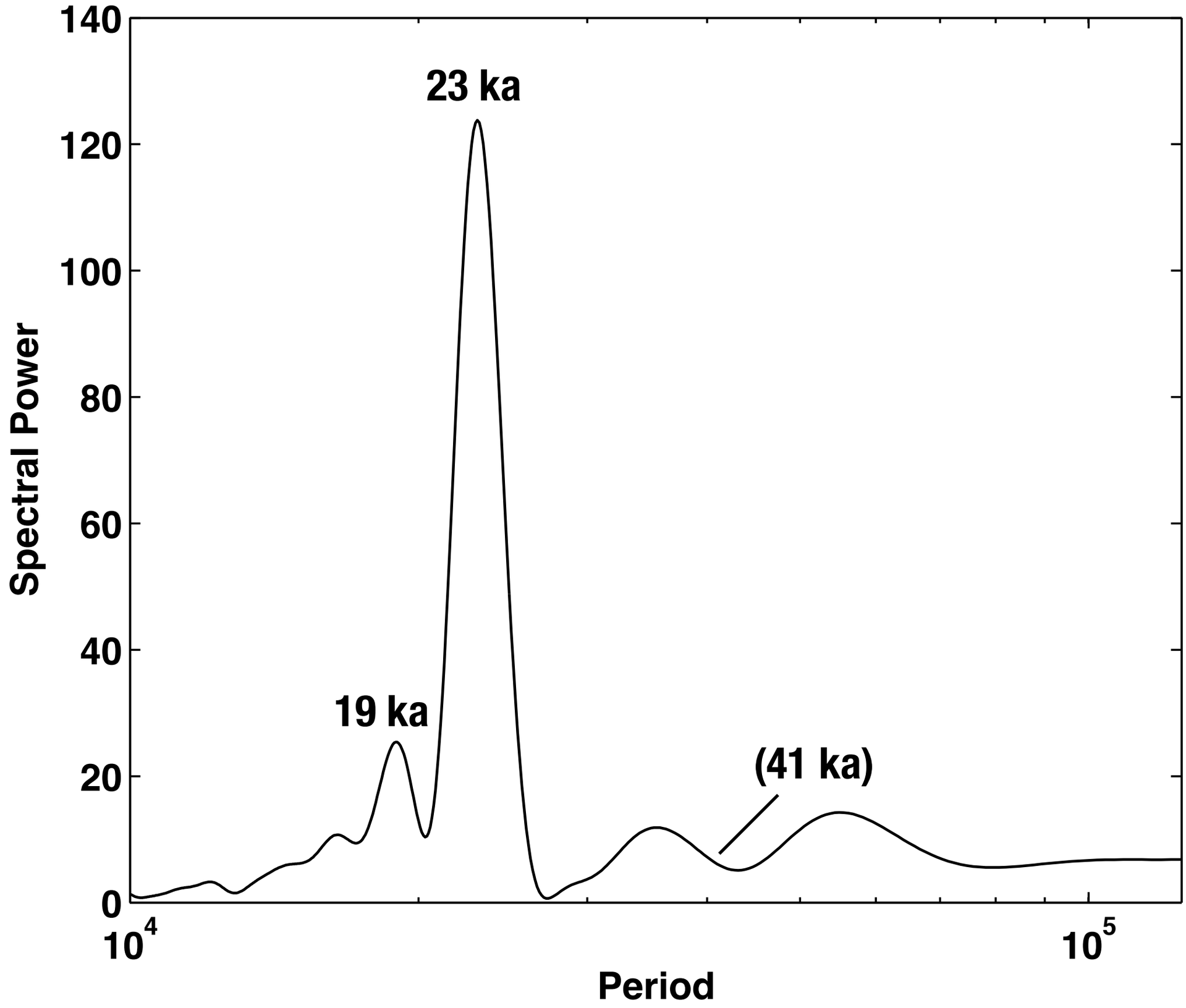
+ SH Summer Insolation

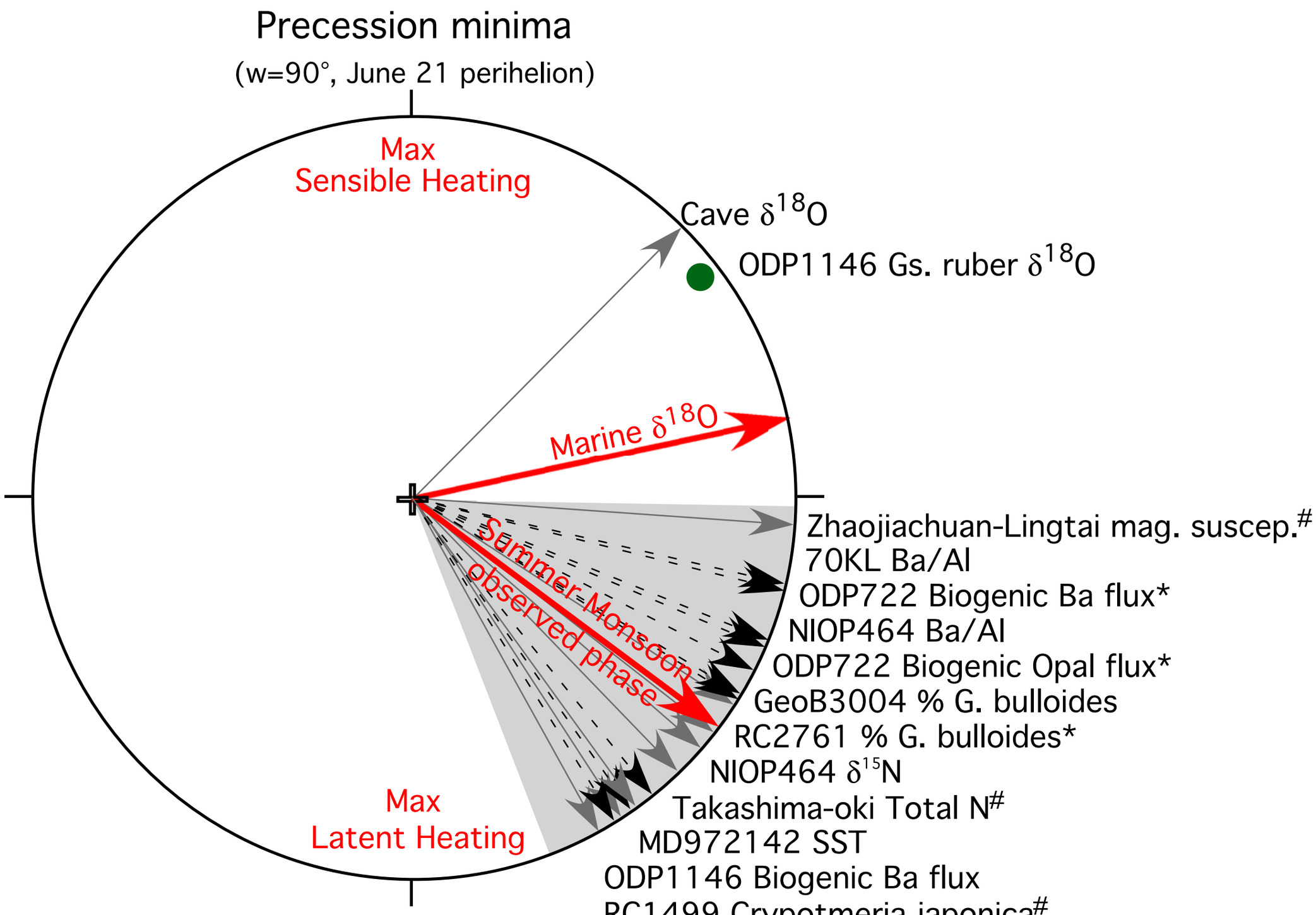


Liu et al., 2006, J. Clim.

Along come the speleothems.


35°N
30°N
25°N
20°N
15°N
10°N
60°E
72°E
84°E
96°E
108°E
120°E
Hulu Cave
Sanbao Cave
Linzhu Cave
Dongge Cave
Xiaobailong Cave
−12
−10
−8
−6
−4
δ18O
Cheng et al., 2009
0
50
100
150
200
250
300
350
400
Age (ka)

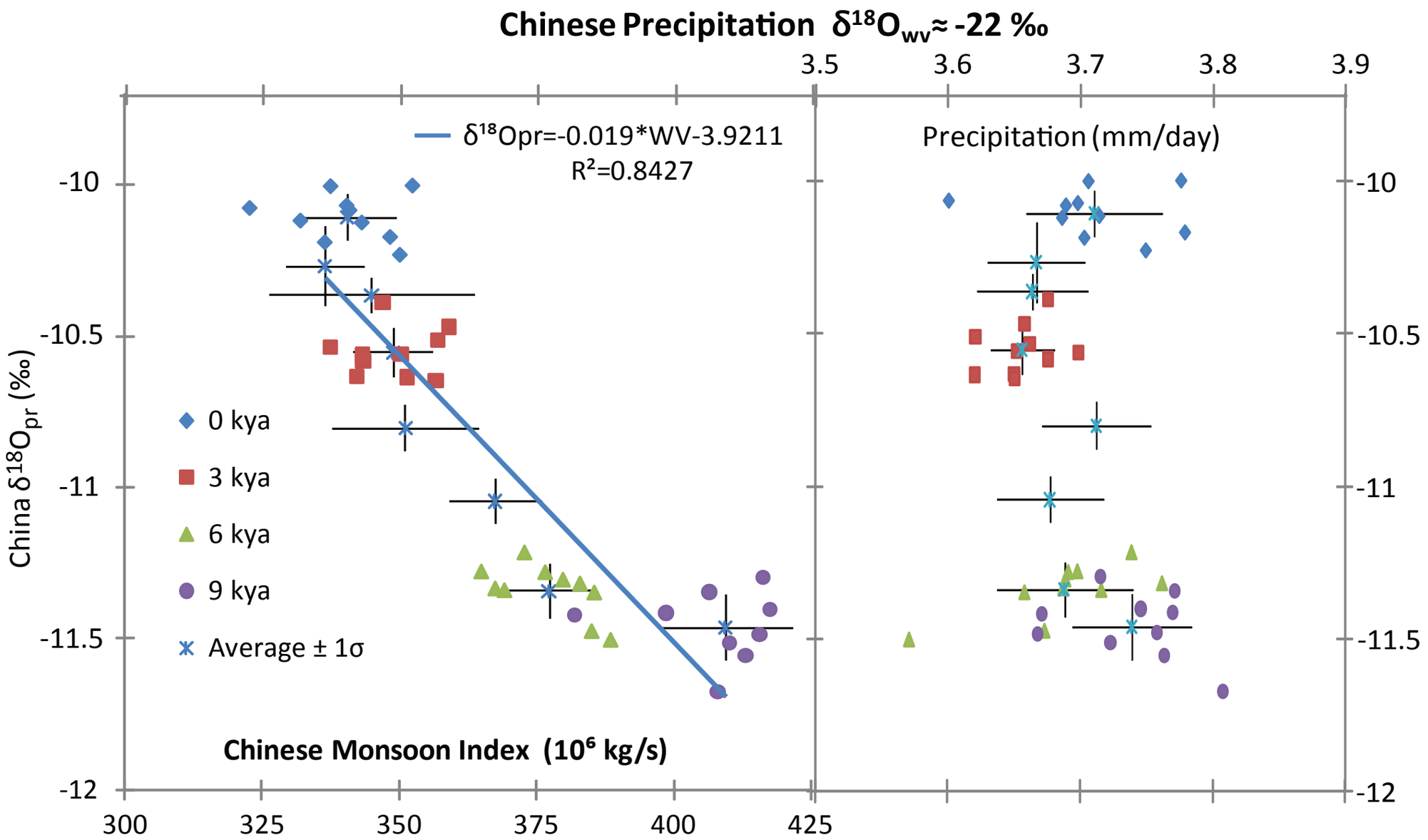

140
120
100
80
60
40
20
0
Spectral Power
23 ka
19 ka
(41 ka)
10^4
10^5
Period



Clemens et al., 2010, Paleoceanography

Interpreting speleothem $\delta^{18}O$.

$\delta^{18}O_{cave} \neq$ local rainfall



LeGrande & Schmidt, 2009, Clim. Past. Simulations with GISS E-R.

see also:

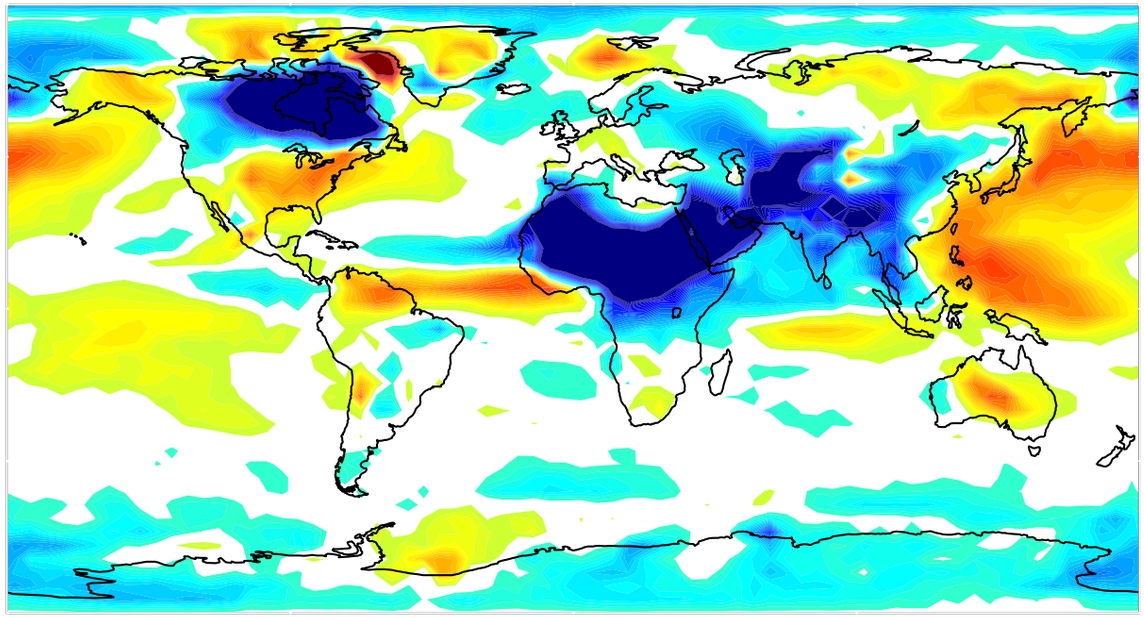
Pausata et al., 2011, Nat. Geosci.

Maher & Thompson, 2012, JQR

Liu et al., 2014, QSR

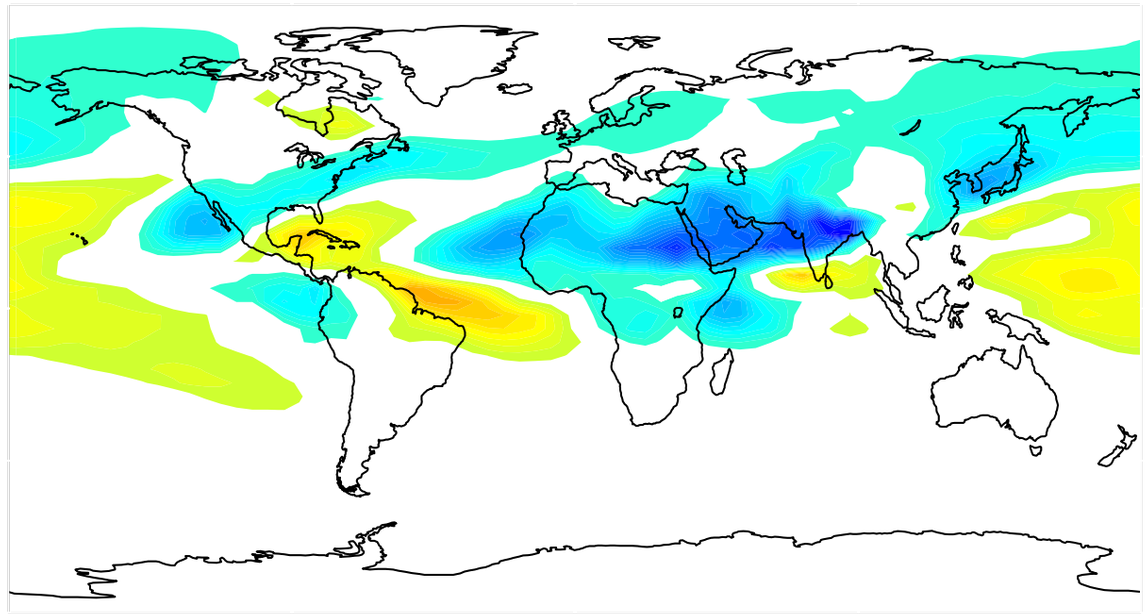
Battisti et al., 2014, JGR

Δ JJA $\delta^{18}O_{pr}$ (permil) −0.21



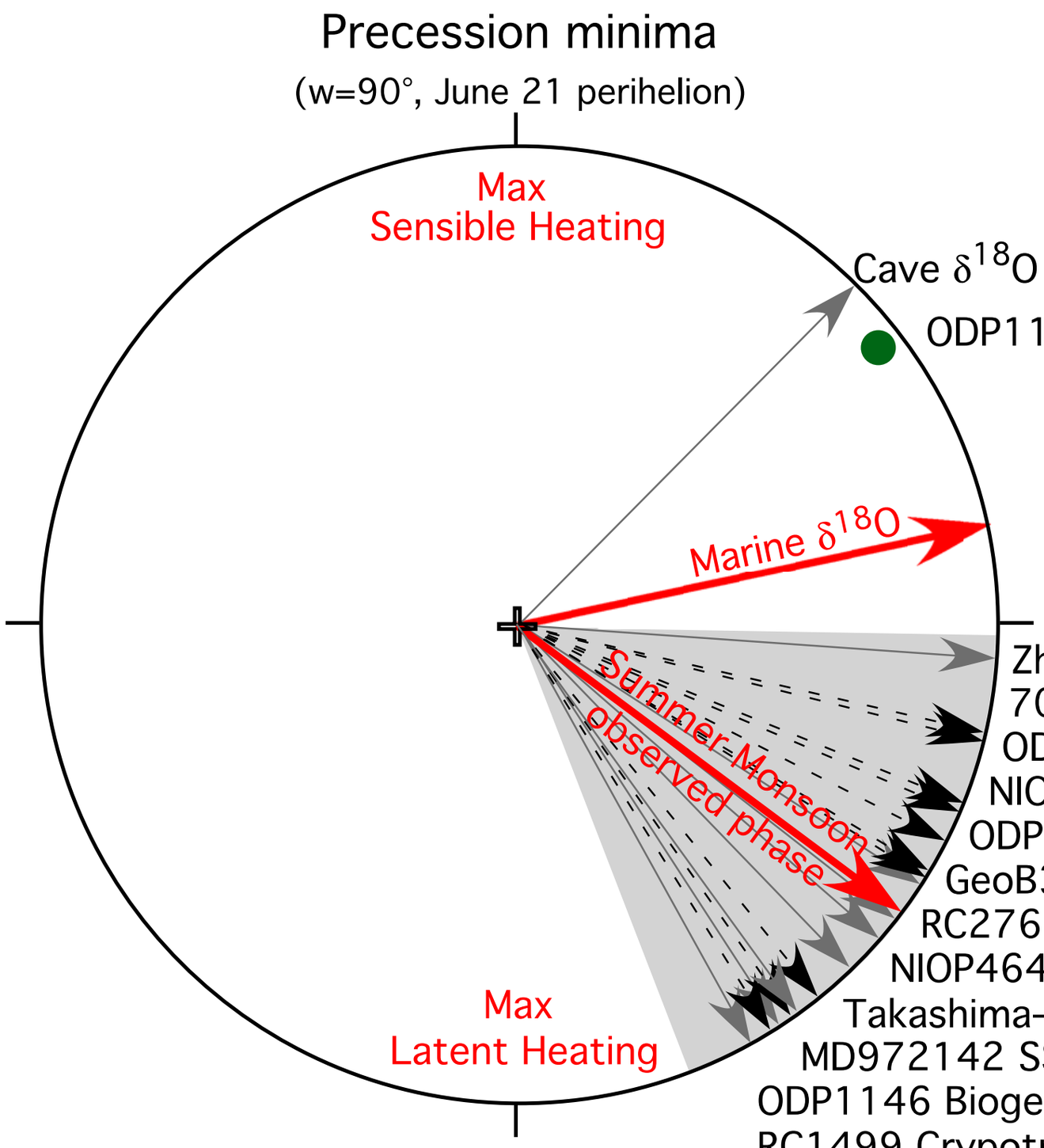
−10.7 −2.3 −1.7 −1.1 −.6 −.2 .2 .5 .8 1 1.3 1.7 2 2.3 2.7 5.4

Δ JJA Prec (mm/day) 0.06



−3.5 −2.4 −1.8 −1.2 −.7 −.3 .2 .5 .8 1 1.3 1.7 2 2.3 2.7 5.4

LeGrande & Schmidt, 2009. 9 ka - 0 ka. GISS ModelE-R.



Monsoon "strength" proxy

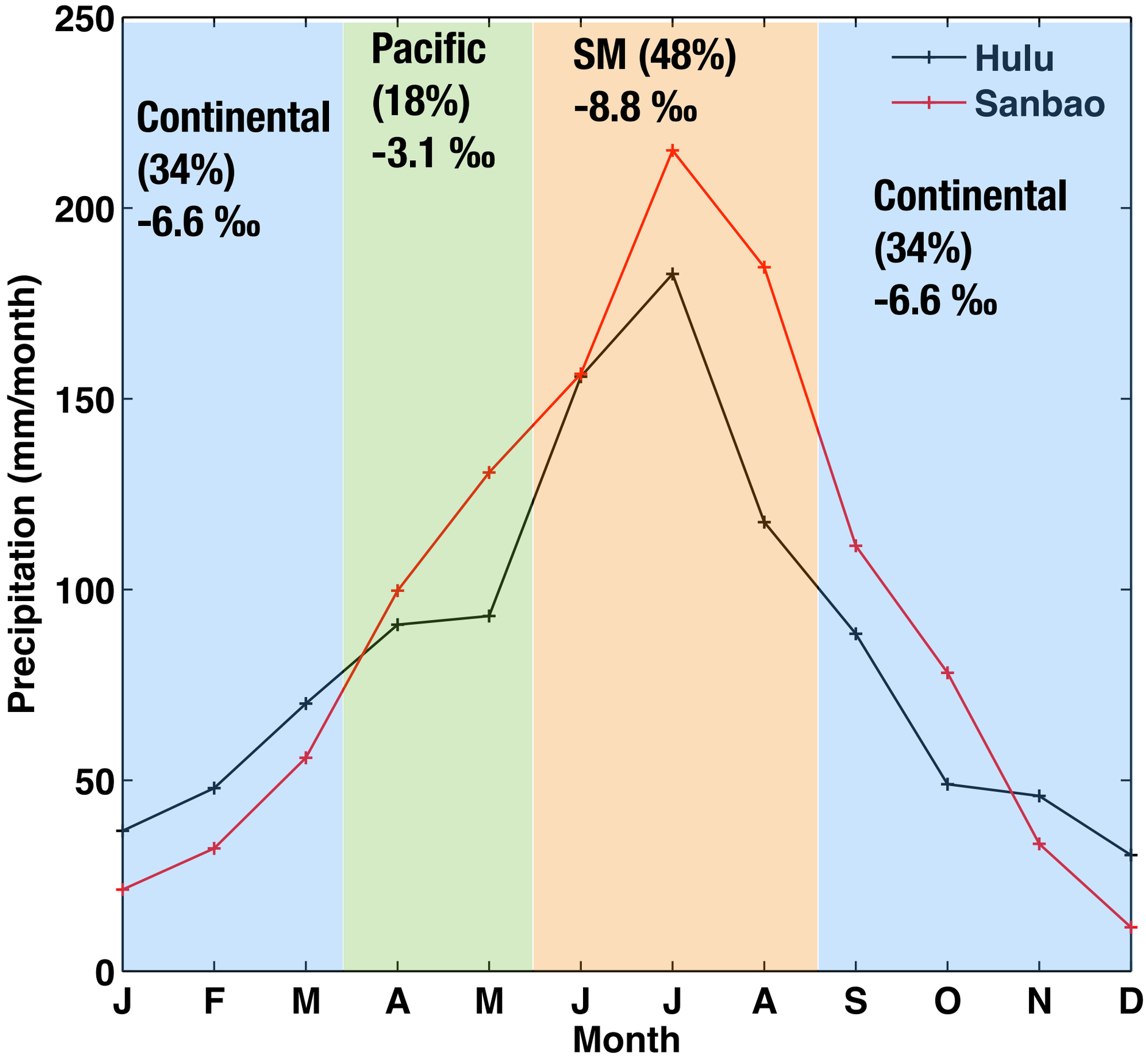
Cave $\delta^{18}O$

ODP1146 Gs. ruber $\delta^{18}O$

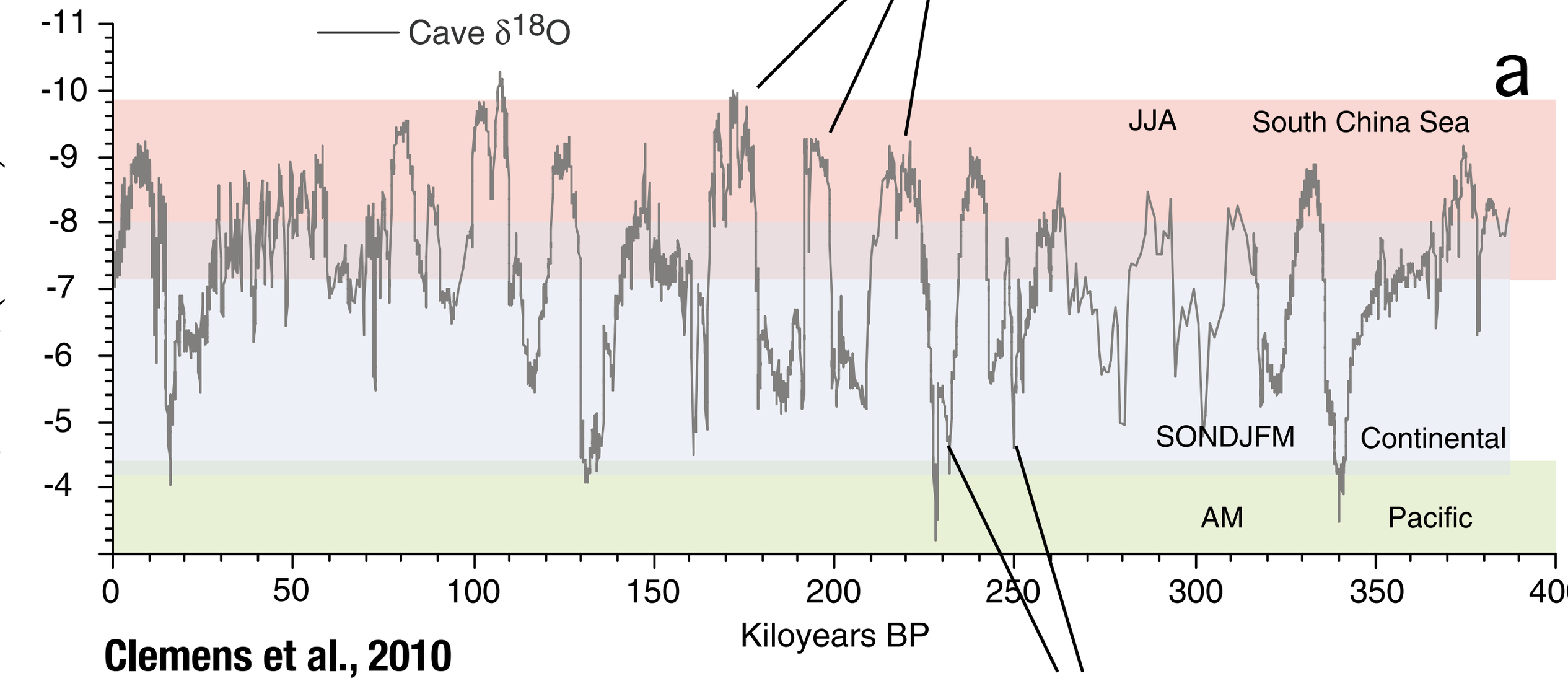
Wind proxies

Zhaojiachuan-Lingtai mag. suscep.#
70KL Ba/Al
ODP722 Biogenic Ba flux*
NIOP464 Ba/Al
ODP722 Biogenic Opal flux*
GeoB3004 % G. bulloides
RC2761 % G. bulloides*
NIOP464 $\delta^{15}N$
Takashima-oki Total N#
MD972142 SST
ODP1146 Biogenic Ba flux
RC1499 Crypotmeria japonica#
RC2761 $\delta^{15}N$*
ODP1145 Ba/Al
NIOP464 G. bulloides
Takashima-oki Total C#
RC2761 Lithic grain size*#
MD012421 Crypotmeria japonica#

Clemens et al., 2010, Paleoceanography

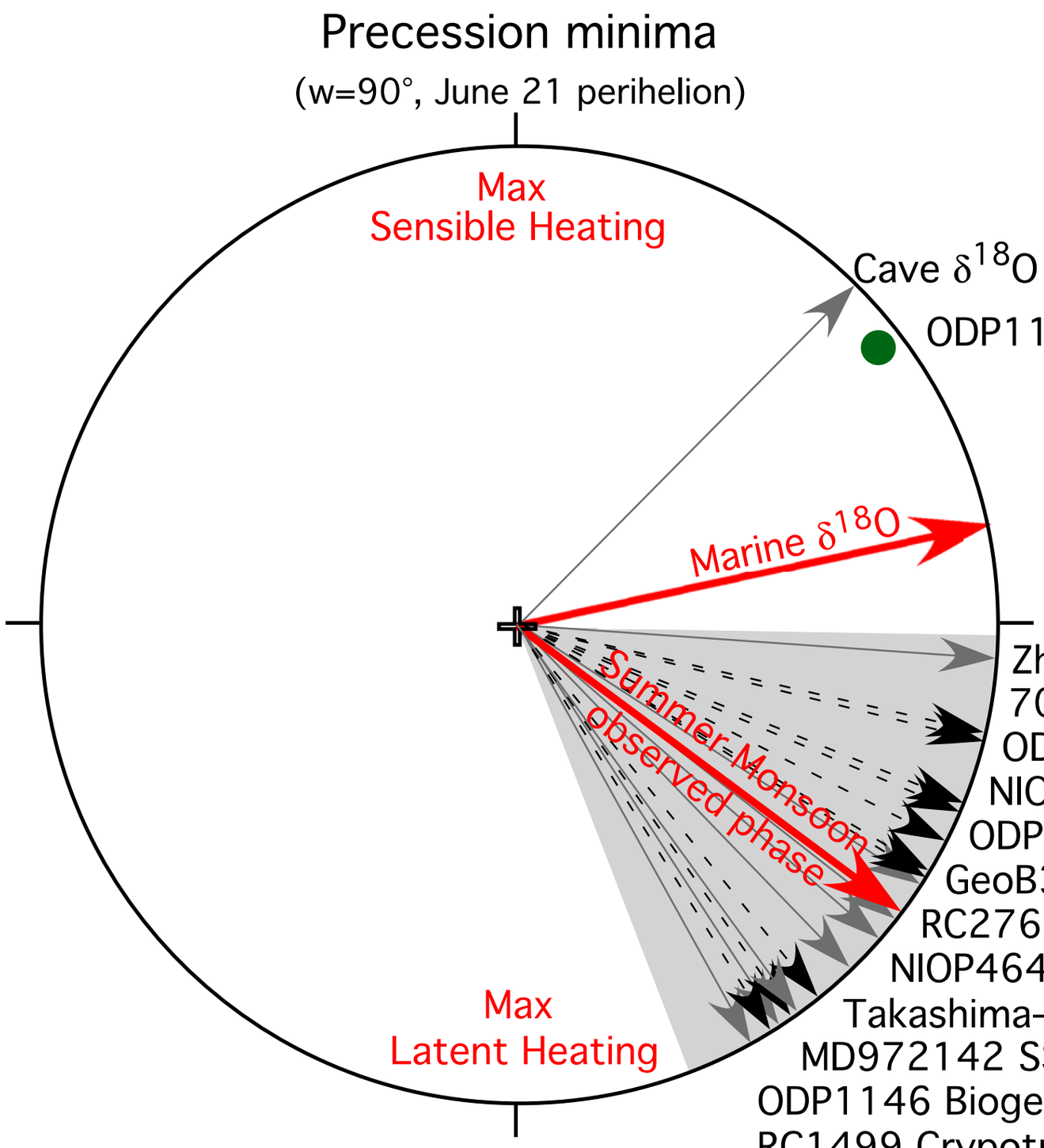

Continental
(34%)
-6.6 ‰
Pacific
(18%)
-3.1 ‰
SM (48%)
-8.8 ‰
Continental
(34%)
-6.6 ‰
Hulu
Sanbao
Precipitation (mm/month)
250
200
150
100
50
0
J
F
M
A
M
J
J
A
S
O
N
D
Month

More light SM rain
(and lighter winter rain due to cool T)?



Clemens et al., 2010

More continental/Pacific rain?



Monsoon "strength" proxy

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MD972142 SST
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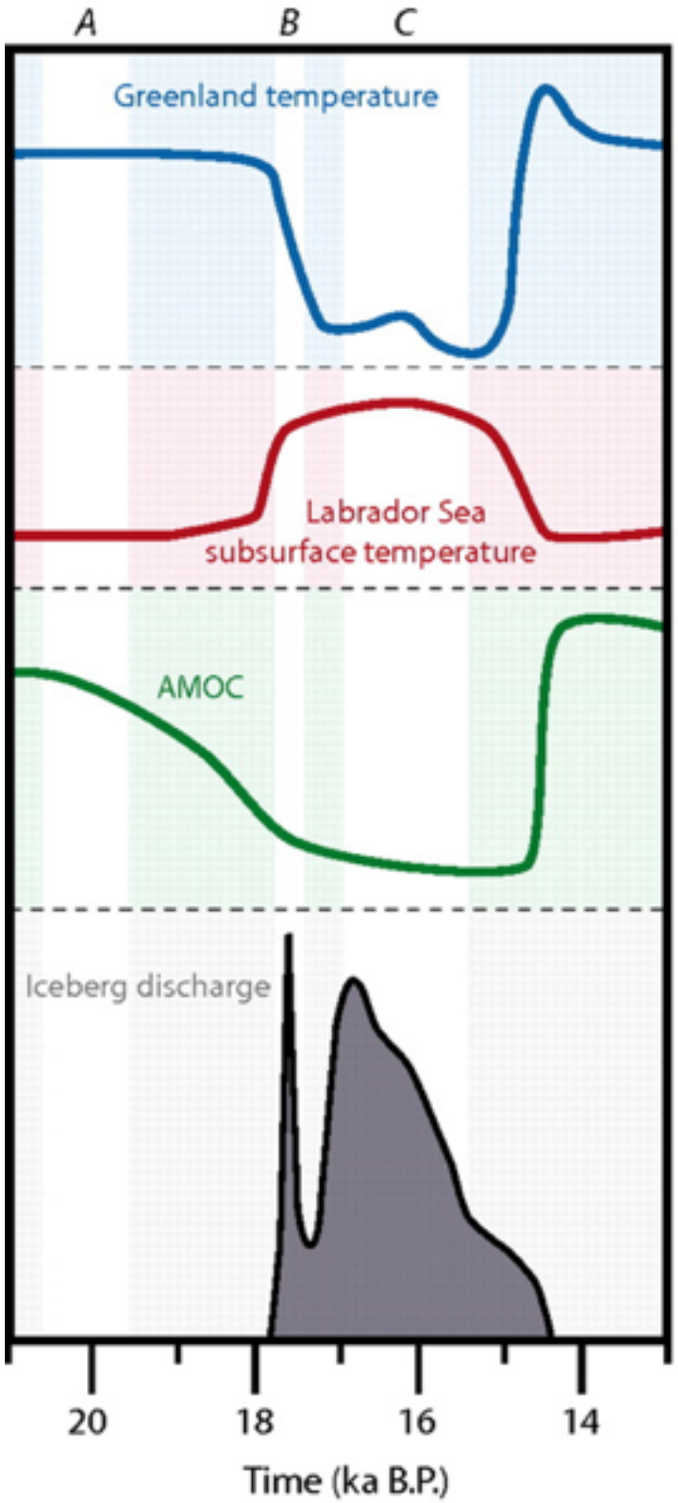
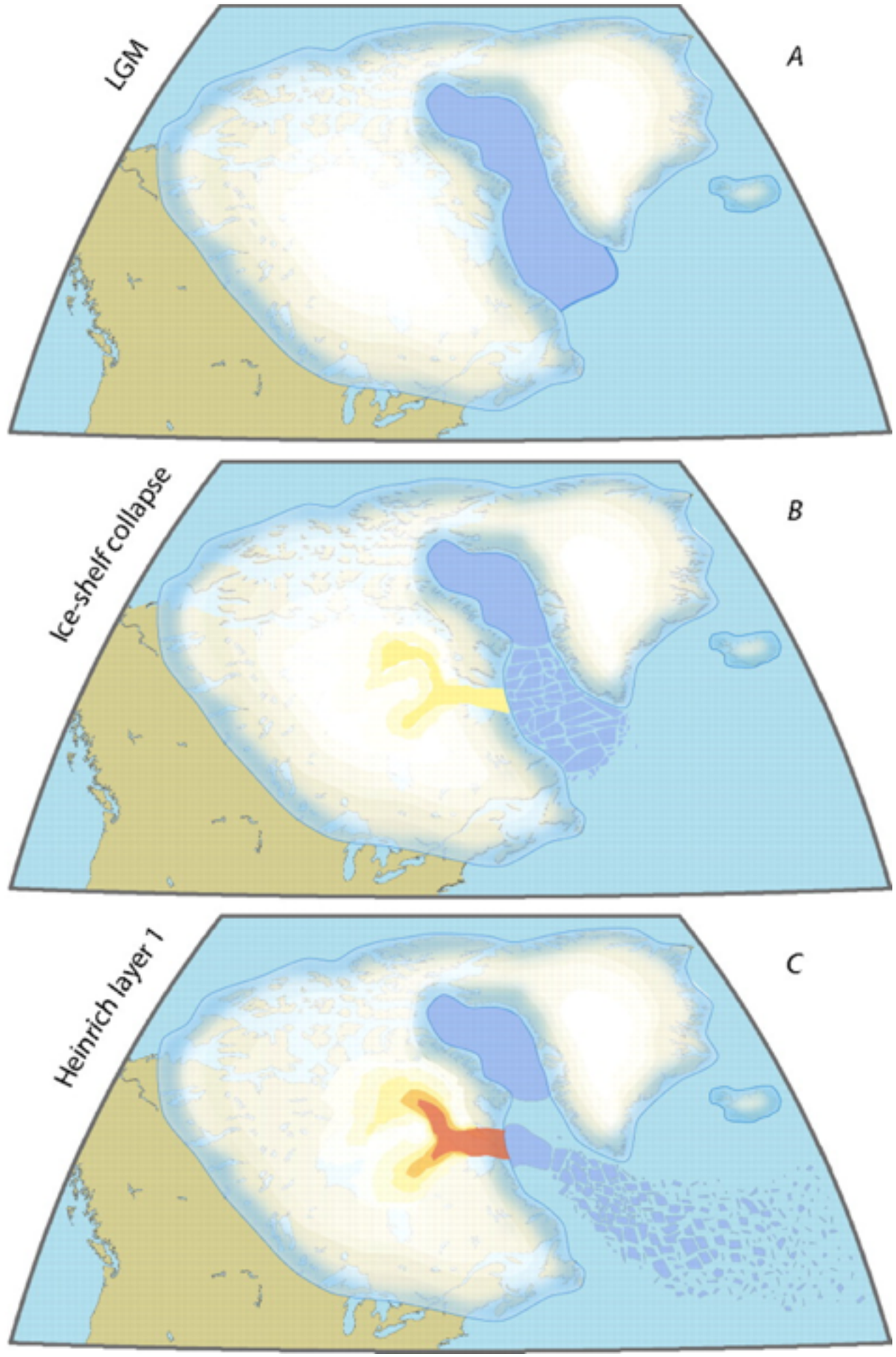
RC2761 $\delta^{15}N$*
ODP1145 Ba/Al
NIOP464 G. bulloides
Takashima-oki Total C#
RC2761 Lithic grain size*#
MD012421 Crypotmeria japonica#

Clemens et al., 2010, Paleoceanography

Millennial-Scale Climate Change.



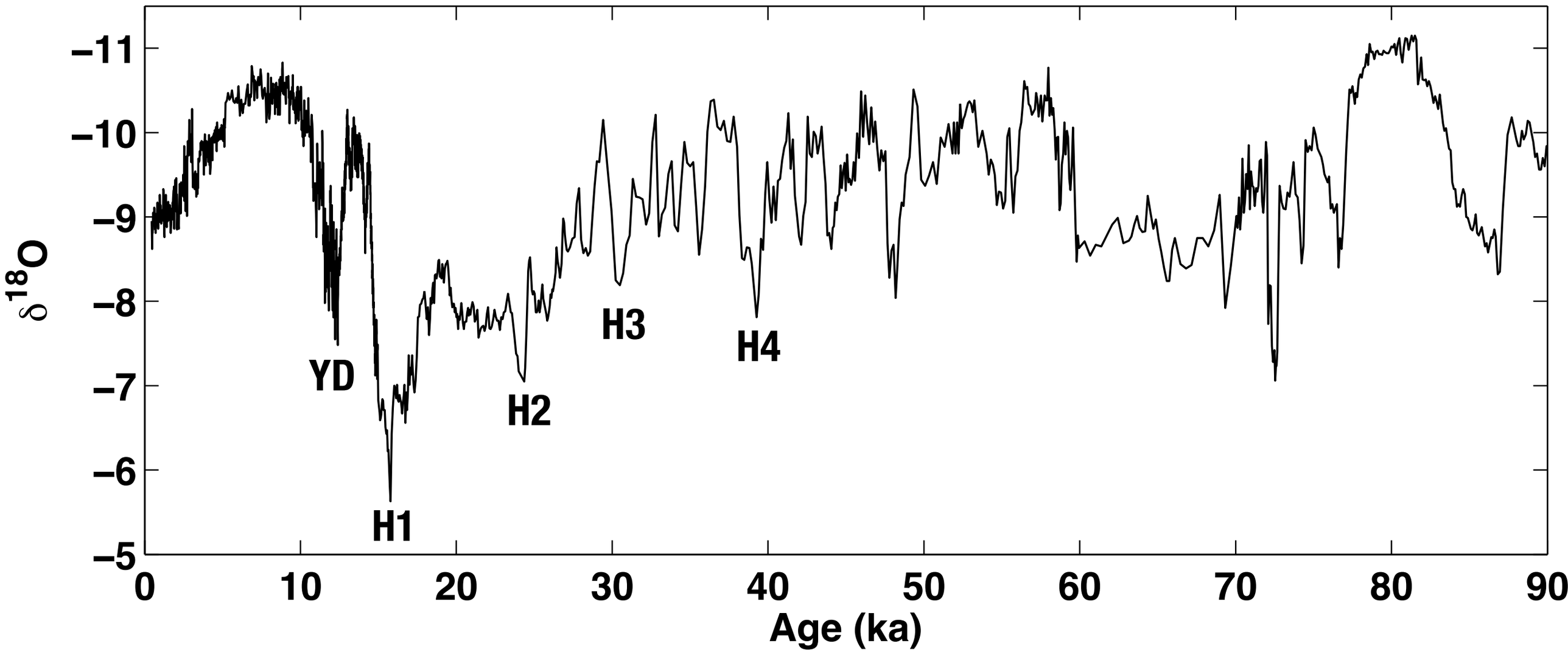


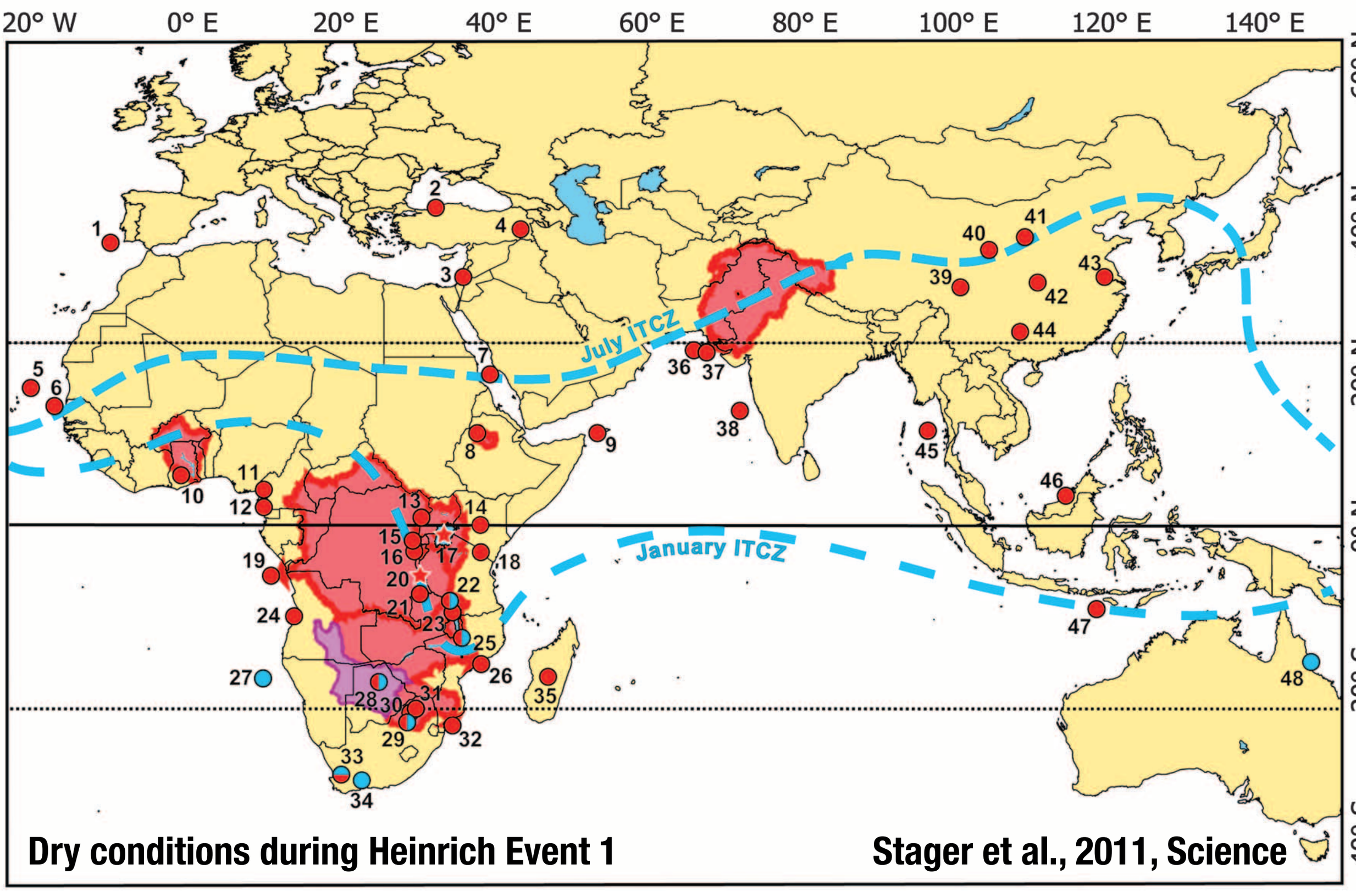
Alvarez-Solas & Ramstein, 2011, PNAS

90N
60N
30N
EQ
30S
60S
180
120W
60W
0
60E
120E
180
−4.0 −3.0 −2.0 −1.5 −1.0 −0.5 0.5 1.0 1.5 2.0 3.0 4.0
Temperature (K)

Chiang & Friedman, 2012, Ann. Rev. Earth Planet Sci.

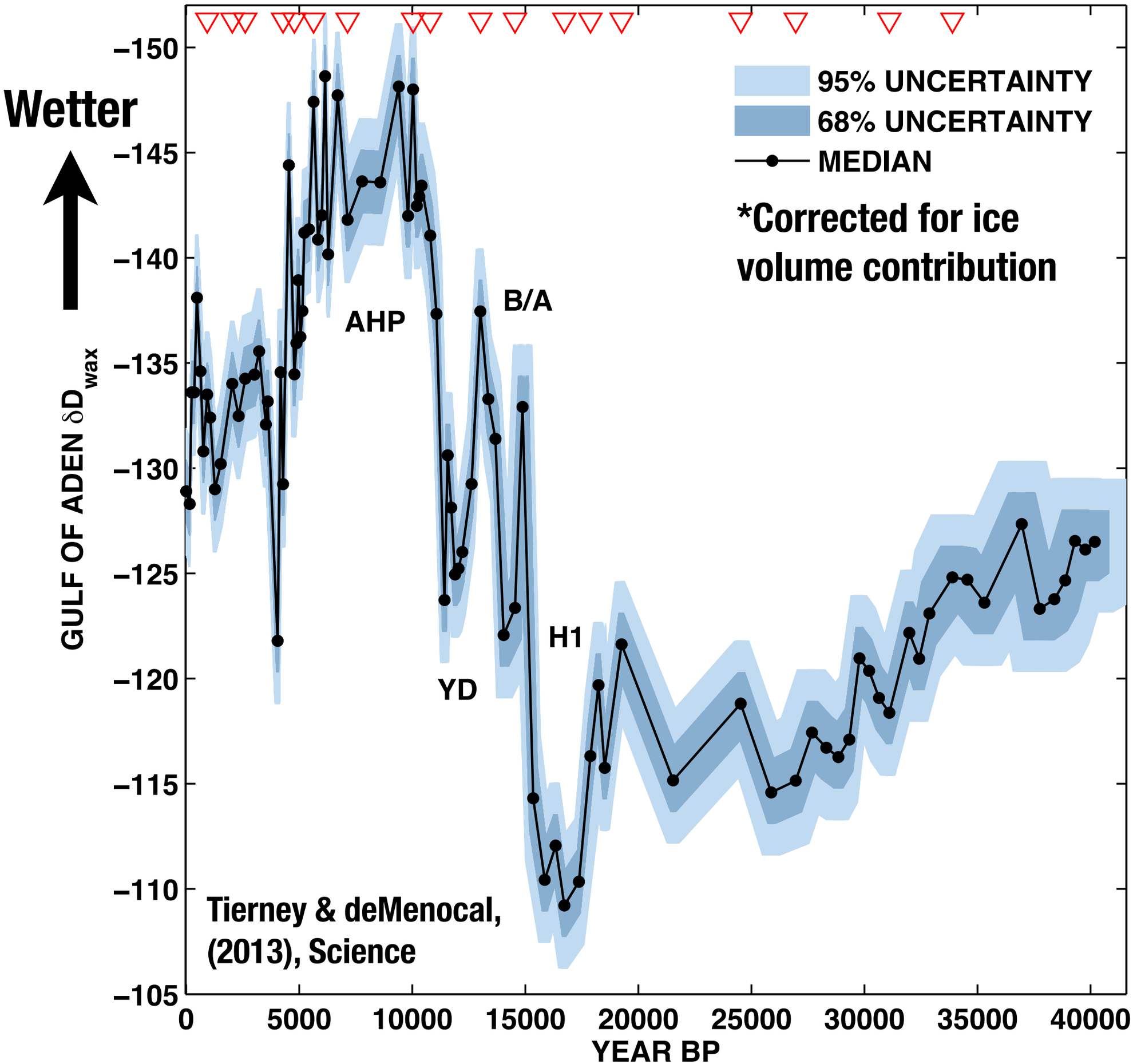
North Atlantic cooling = weaker monsoon



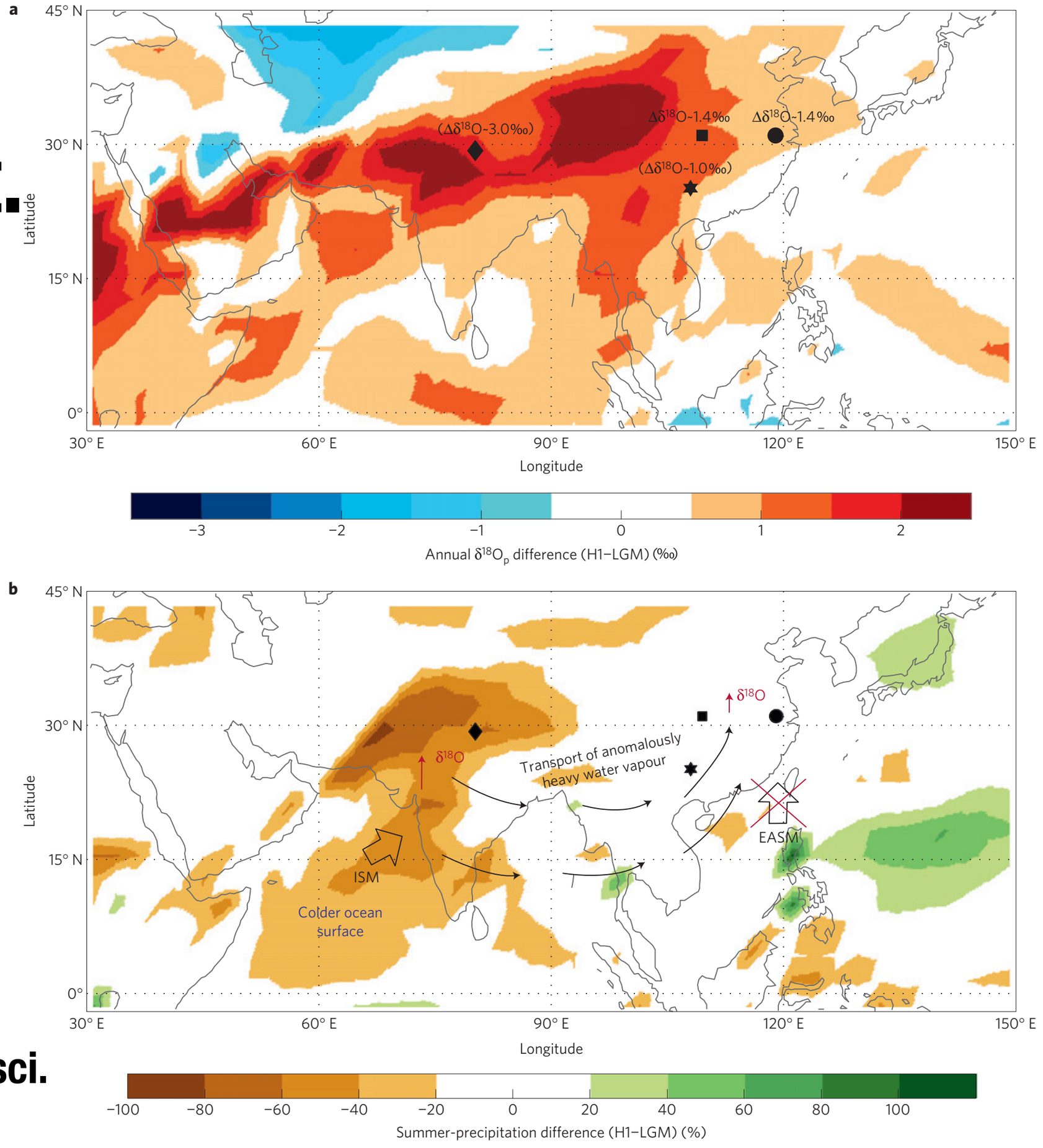


Dry conditions during Heinrich Event 1

Stager et al., 2011, Science

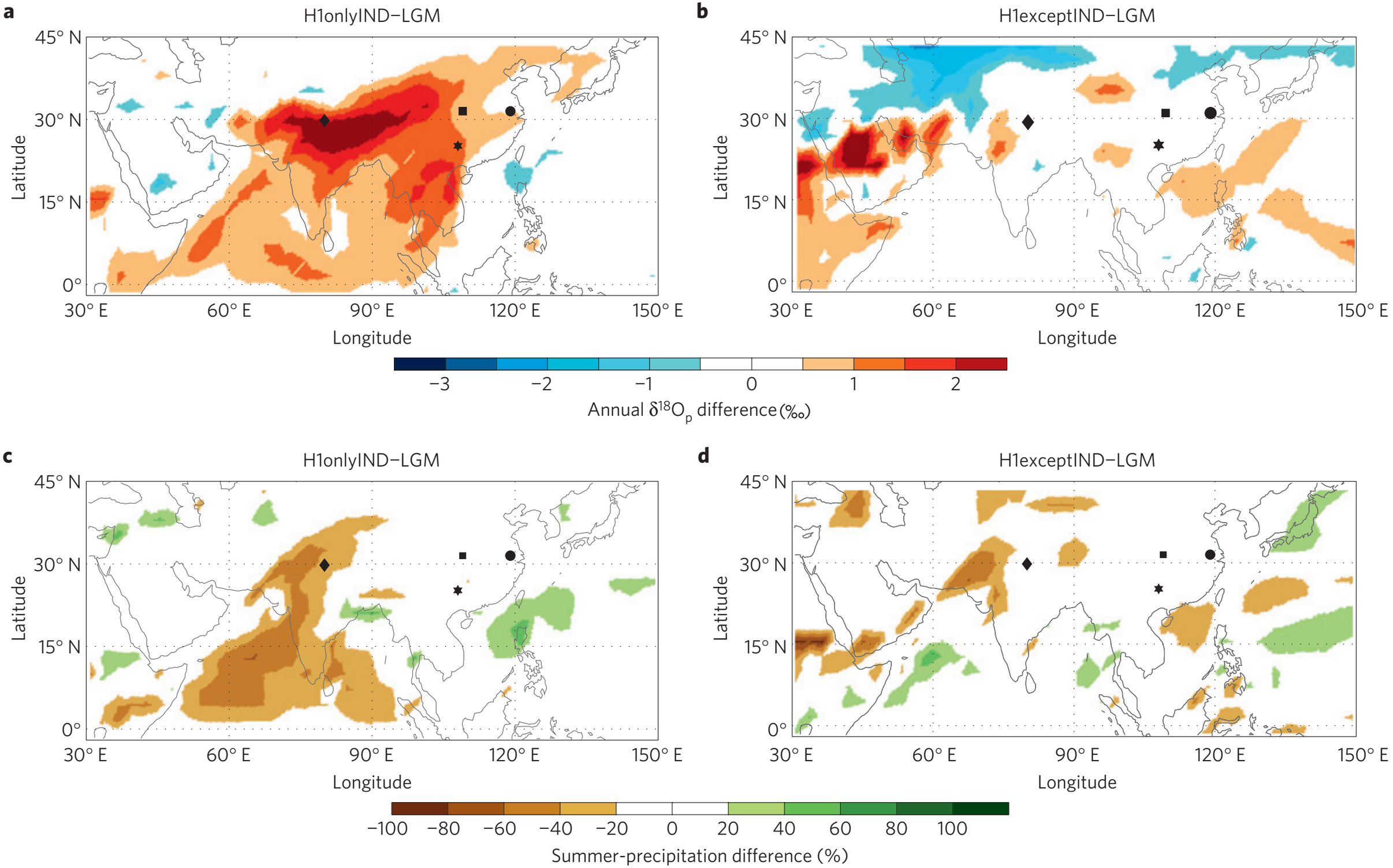

Wetter
GULF OF ADEN δD_{wax}
−150
−145
−140
−135
−130
−125
−120
−115
−110
−105
0
5000
10000
15000
20000
25000
30000
35000
40000
YEAR BP
AHP
B/A
YD
H1
95% UNCERTAINTY
68% UNCERTAINTY
MEDIAN
*Corrected for ice volume contribution
Tierney & deMenocal, (2013), Science

A Simulated Heinrich Event.



Pausata et al., 2011, Nat. Geosci.
CAM3 with isotopes.

Cold IO drives Monsoon Failure.

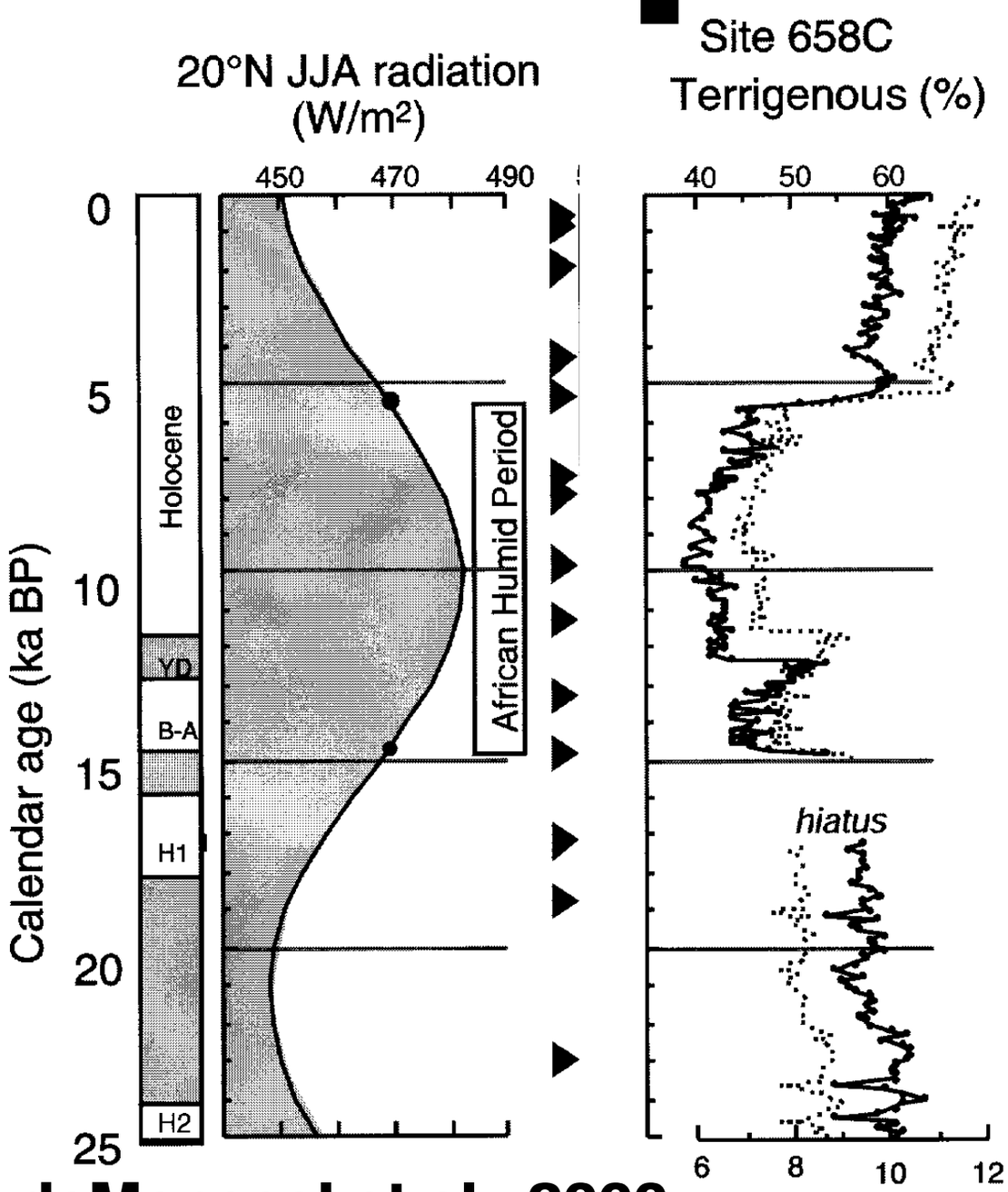


Pausata et al., 2011, Nat. Geosci.

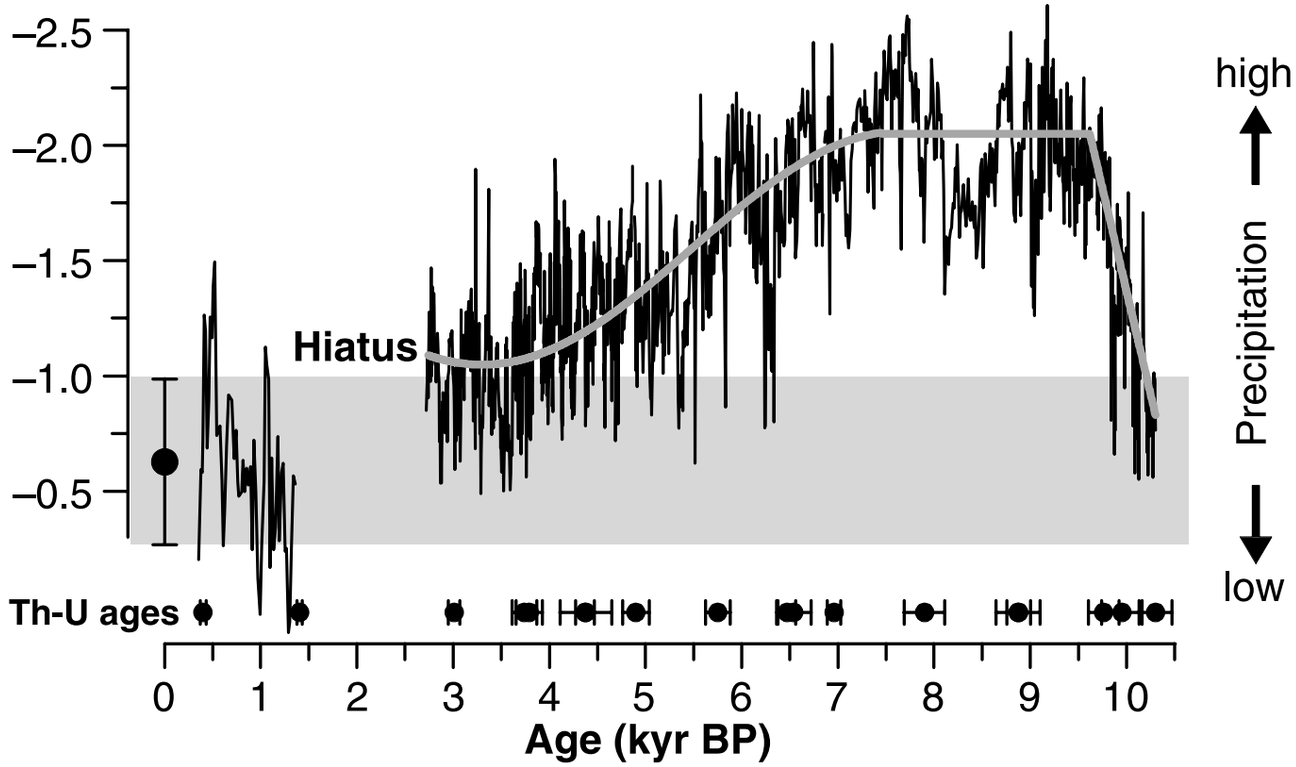
Abrupt changes in the monsoon.

African Humid Period Termination:

Abrupt or Gradual?



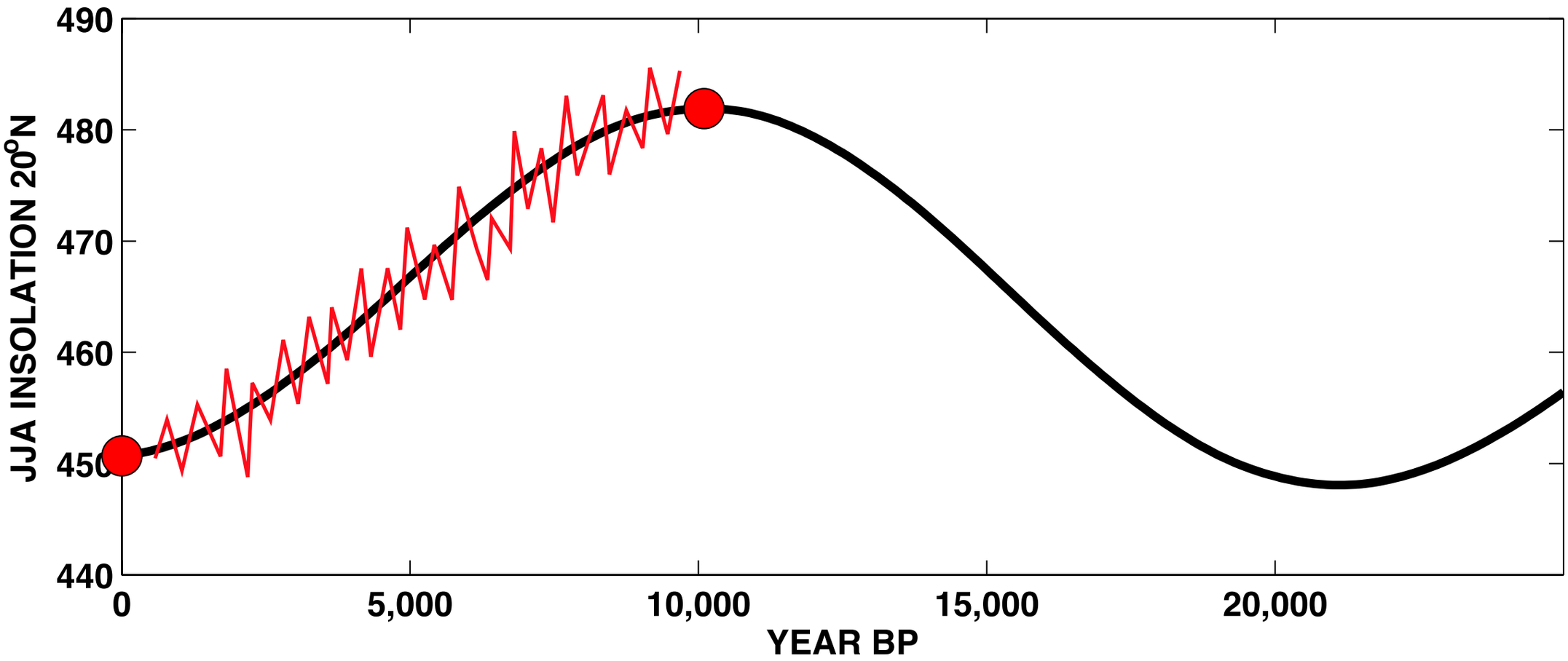
deMenocal et al., 2000
McGee et al., 2013
(western Sahara)

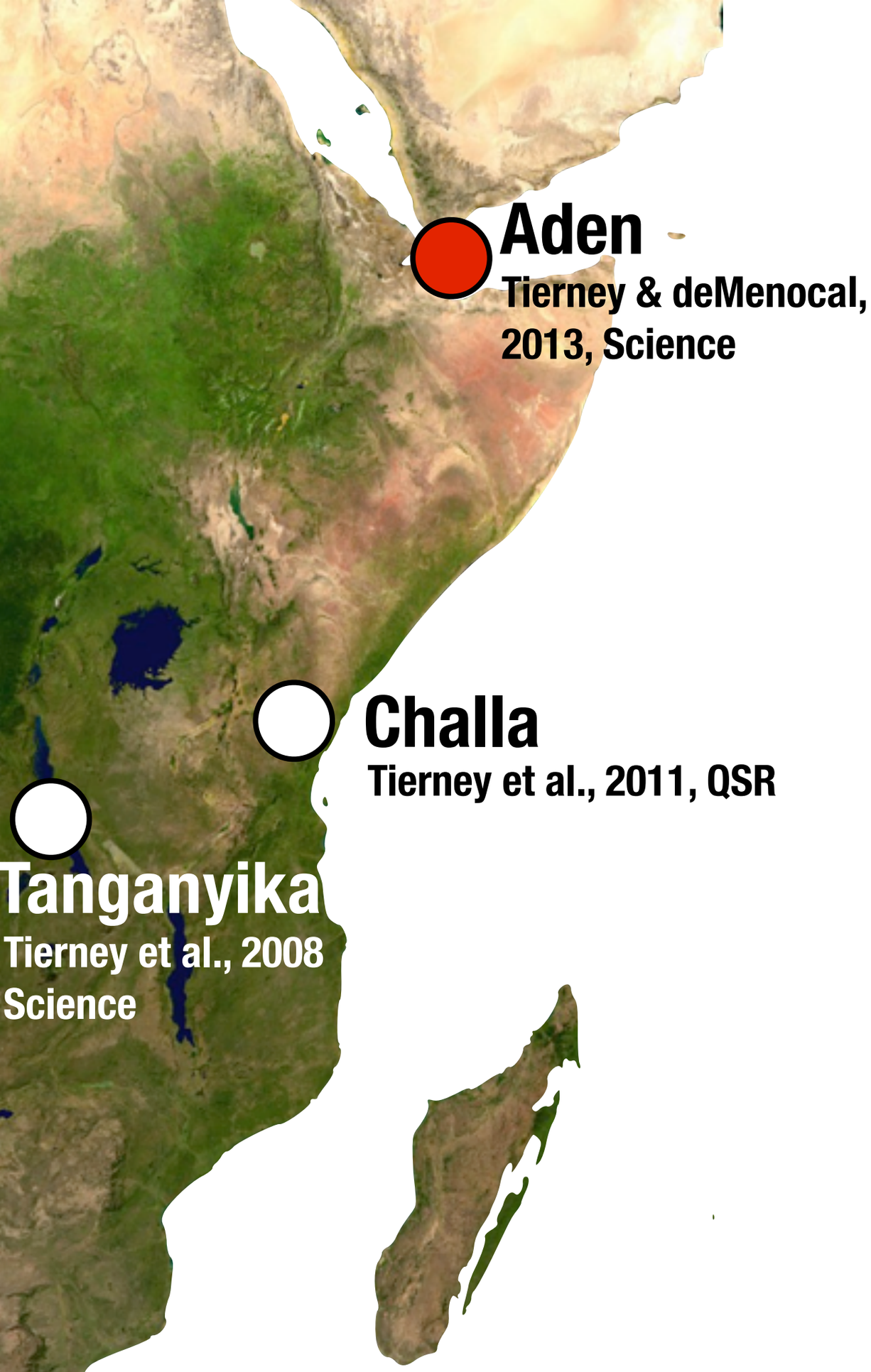


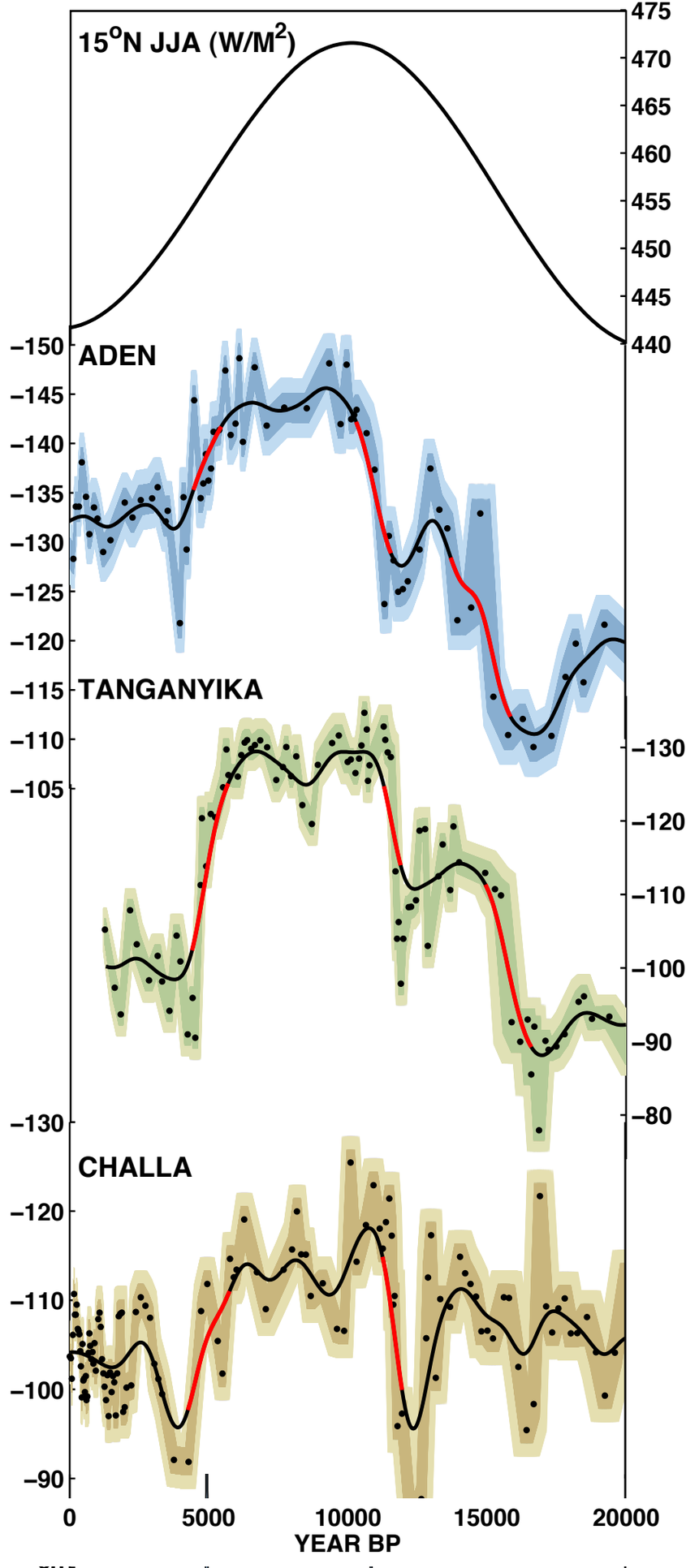
Fleitmann et al., 2003
Kröpelin et al., 2008
(eastern Sahara/Arabian Peninsula)

H_0:

"The duration of the termination of the AHP is indistinguishable from the duration of the change in orbital forcing; i.e., 10,000 years"

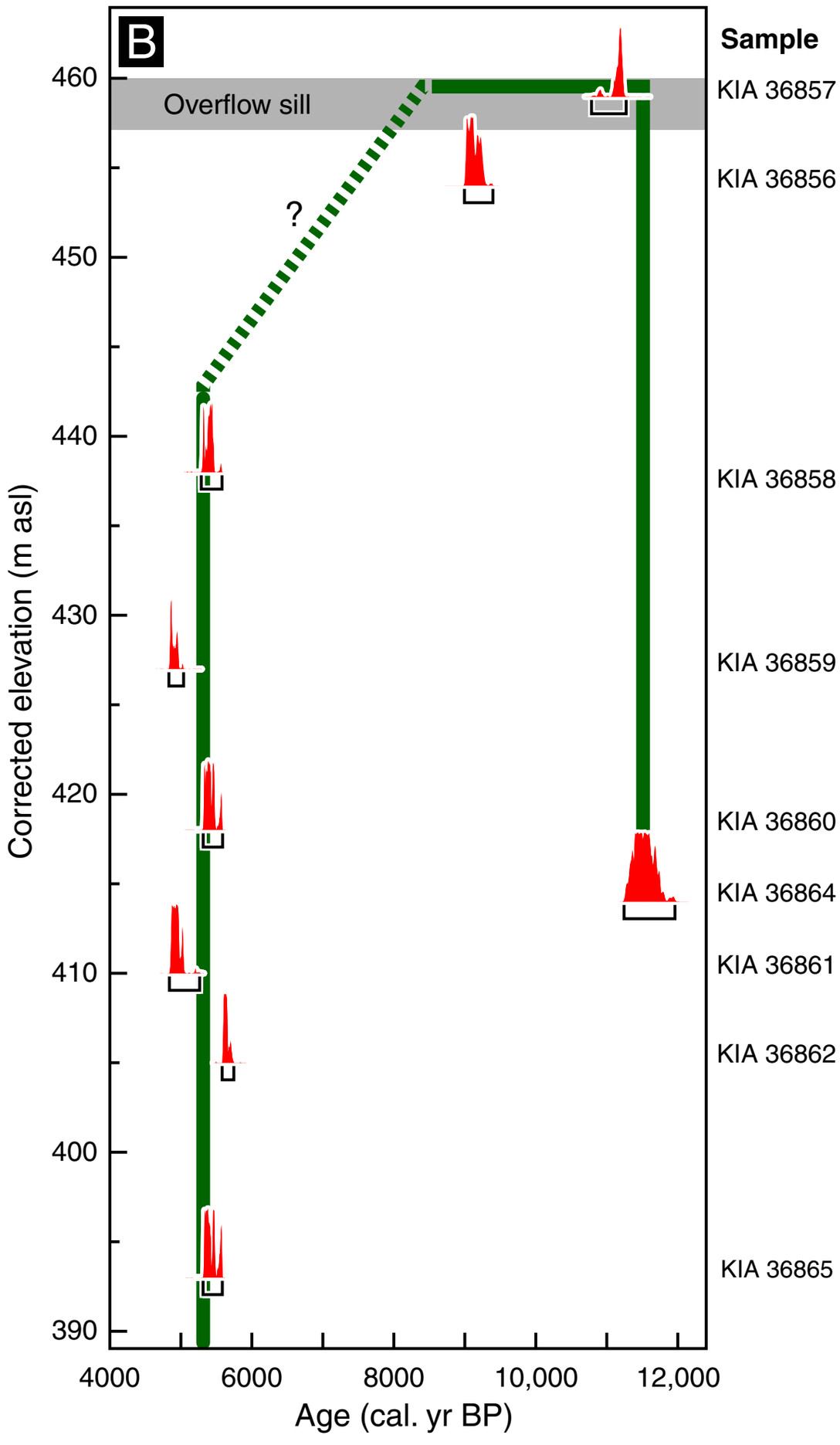



Aden
Tierney & deMenocal,
2013, Science
Challa
Tierney et al., 2011, QSR
Tanganyika
Tierney et al., 2008
Science


15°N JJA (W/M²)
ADEN
TANGANYIKA
CHALLA
YEAR BP
0
5000
10000
15000
20000
475
470
465
460
455
450
445
440
−150
−145
−140
−135
−130
−125
−120
−115
−110
−105
−100
−90
−80

Lake Turkana Shorelines

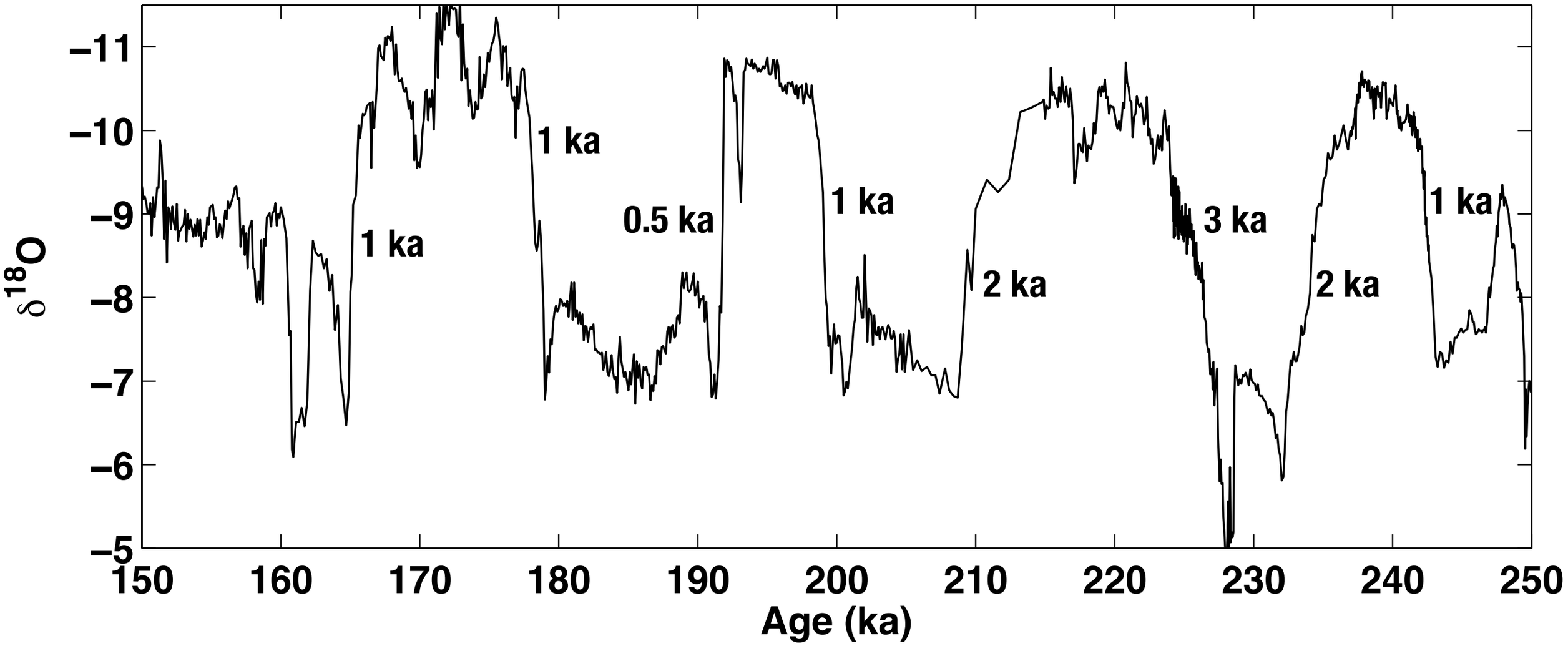
Garcin et al., 2012, EPSL



Estimated duration of AHP termination

GC27 2400
GC37 900
GC49 1600
GC68 600
400 P178-15P
400 Turkana
300 Challa
700 Tanganyika

Monsoon Asia too.



Mechanisms of abrupt change

Summary

- **Precessional forcing dominates monsoon behavior (but there are outstanding issues relating the phase + mechanisms)**
- **Cooling in the North Atlantic drives monsoon failure, via atm response to cooling of the western Indian Ocean.**
- **Transitions from strong to weak monsoon states tend to be abrupt. Why?**

Thanks.

Thanks also to Francesco S. R. Pausata and Peter B. deMenocal for their contributions

jesst@email.arizona.edu

http://www.whoi.edu/tierney