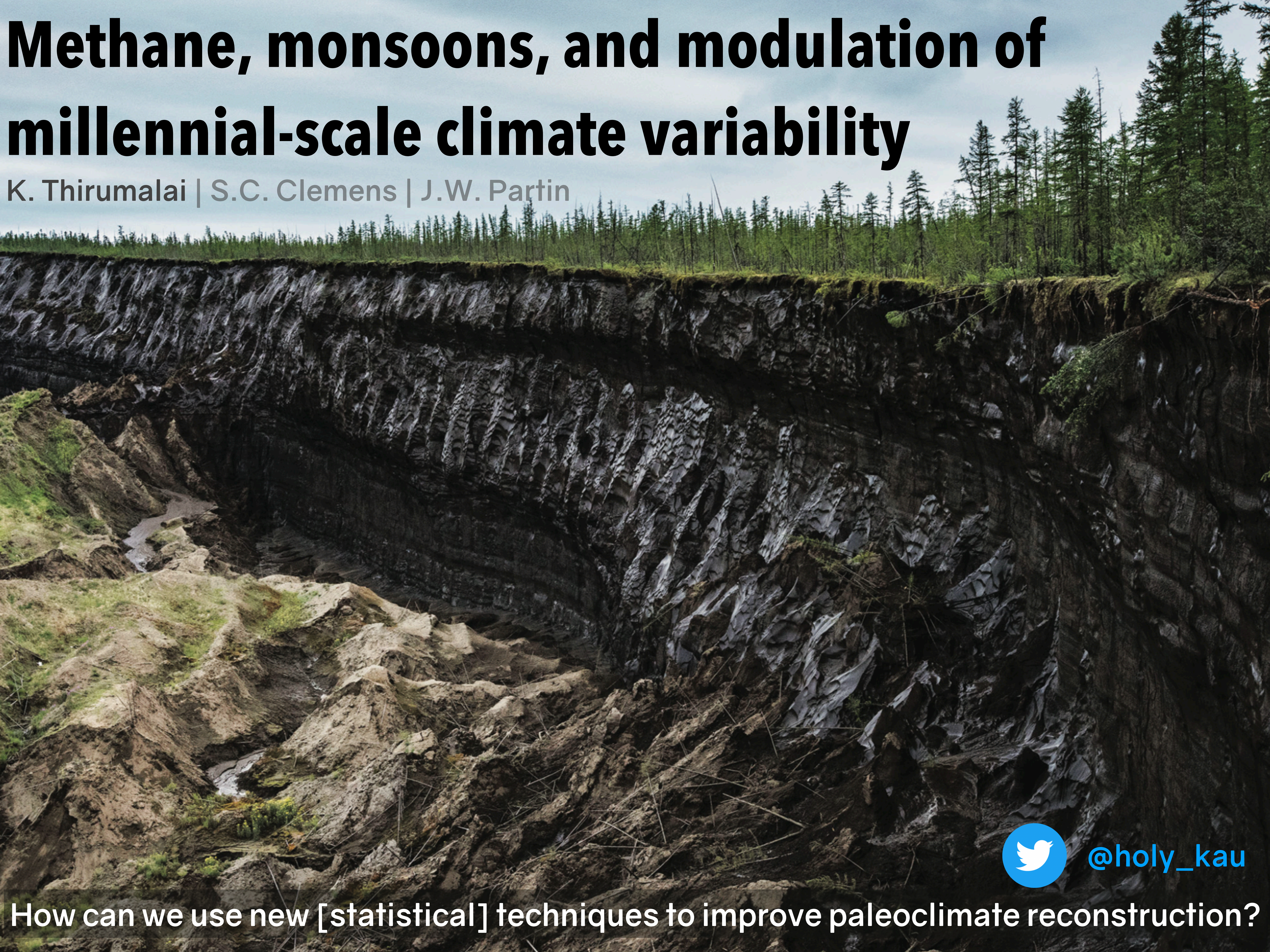
Methane, monsoons, and modulation of millennial-scale climate variability

K. Thirumalai | S.C. Clemens | J.W. Partin



@holy_kau

How can we use new [statistical] techniques to improve paleoclimate reconstruction?

Uncertainties in future methane budget

The Batagaika crater in eastern Russia was formed when land began to sink in the 1960s owing to thawing permafrost.

32 | NATURE | VOL 569 | 2 MAY 2019

Permafrost collapse is accelerating carbon release

The sudden collapse of thawing soils in the Arctic might double the warming from greenhouse gases released from tundra, warn **Merritt R. Turetsky** and colleagues.

Spatial: thaw lakes, collapse, & wetland emissions

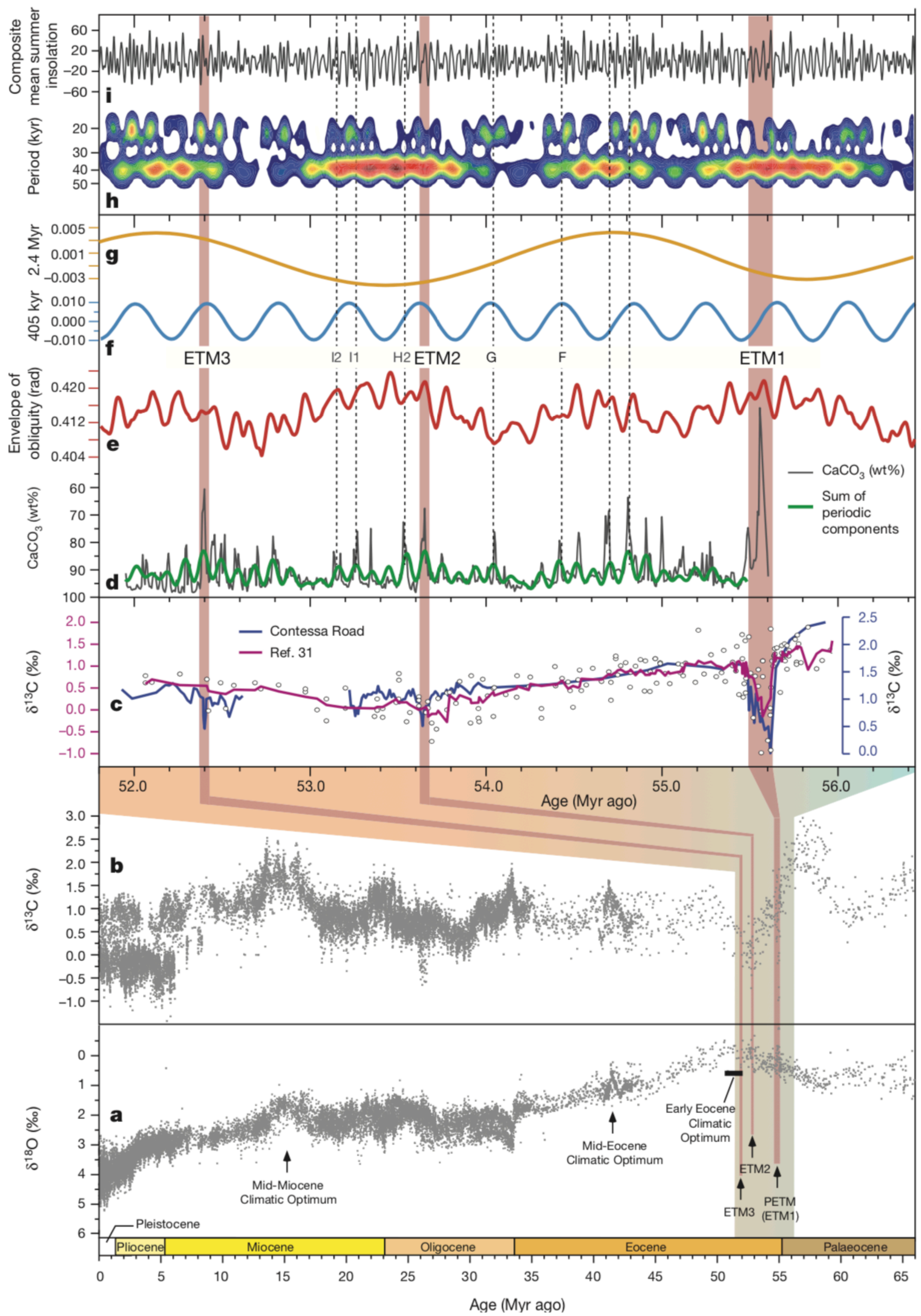
Temporal: abrupt emissions

Uncertain interactions with hydrology

Structural questions regarding changing background conditions

Past extreme warming events linked to massive carbon release from thawing permafrost

Robert M. DeConto[1], Simone Galeotti[2], Mark Pagani[3], David Tracy[1], Kevin Schaefer[4], Tingjun Zhang[4,7], David Pollard[5] & David J. Beerling[6]



Statistical analyses of Contessa Road $\delta^{13}C$ and $CaCO_3$ record to find relationship between envelope of obliquity, eccentricity, and hyperthermals - proposed to be associated with methane release

Past extreme warming events linked to massive carbon release from thawing permafrost

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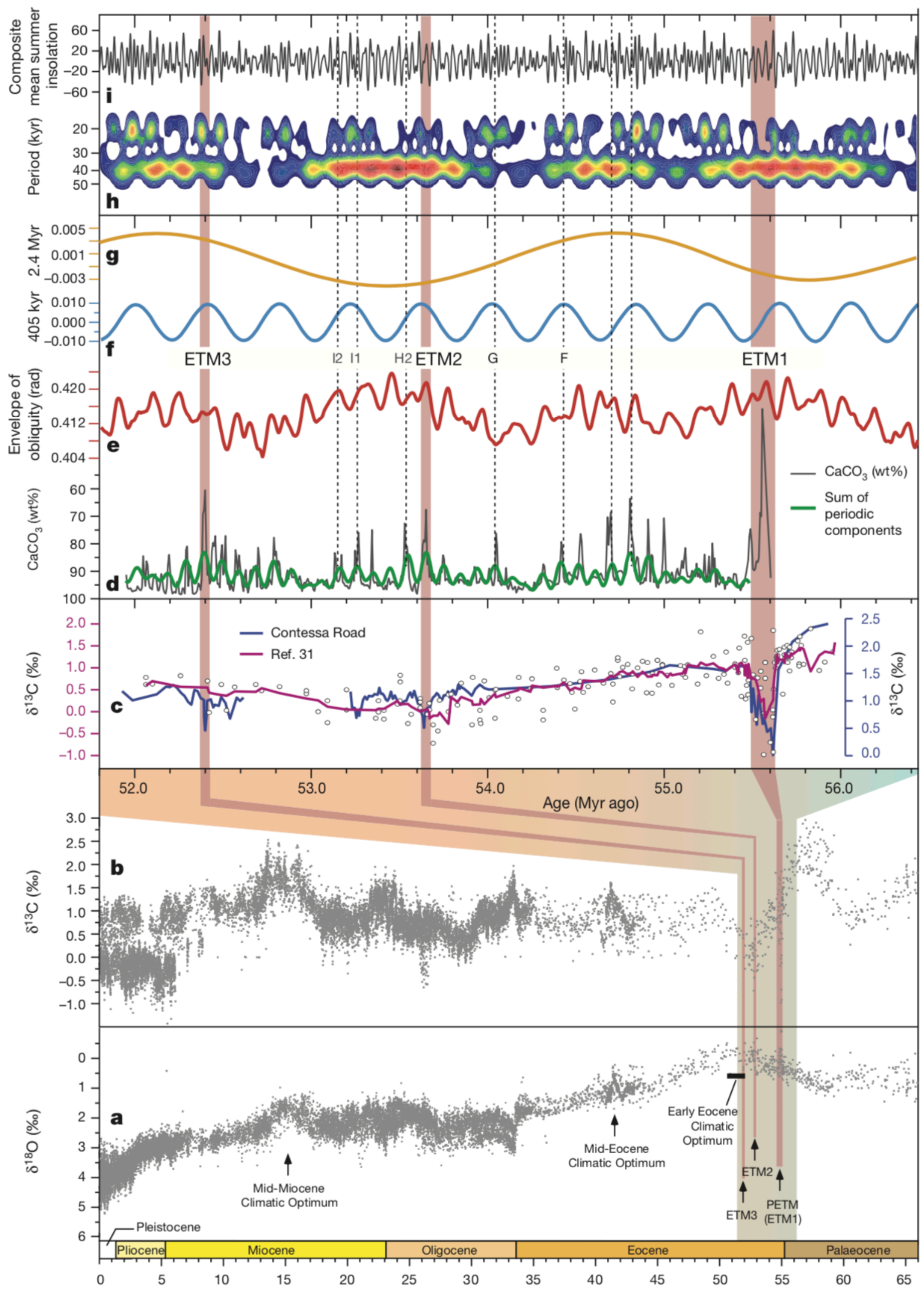

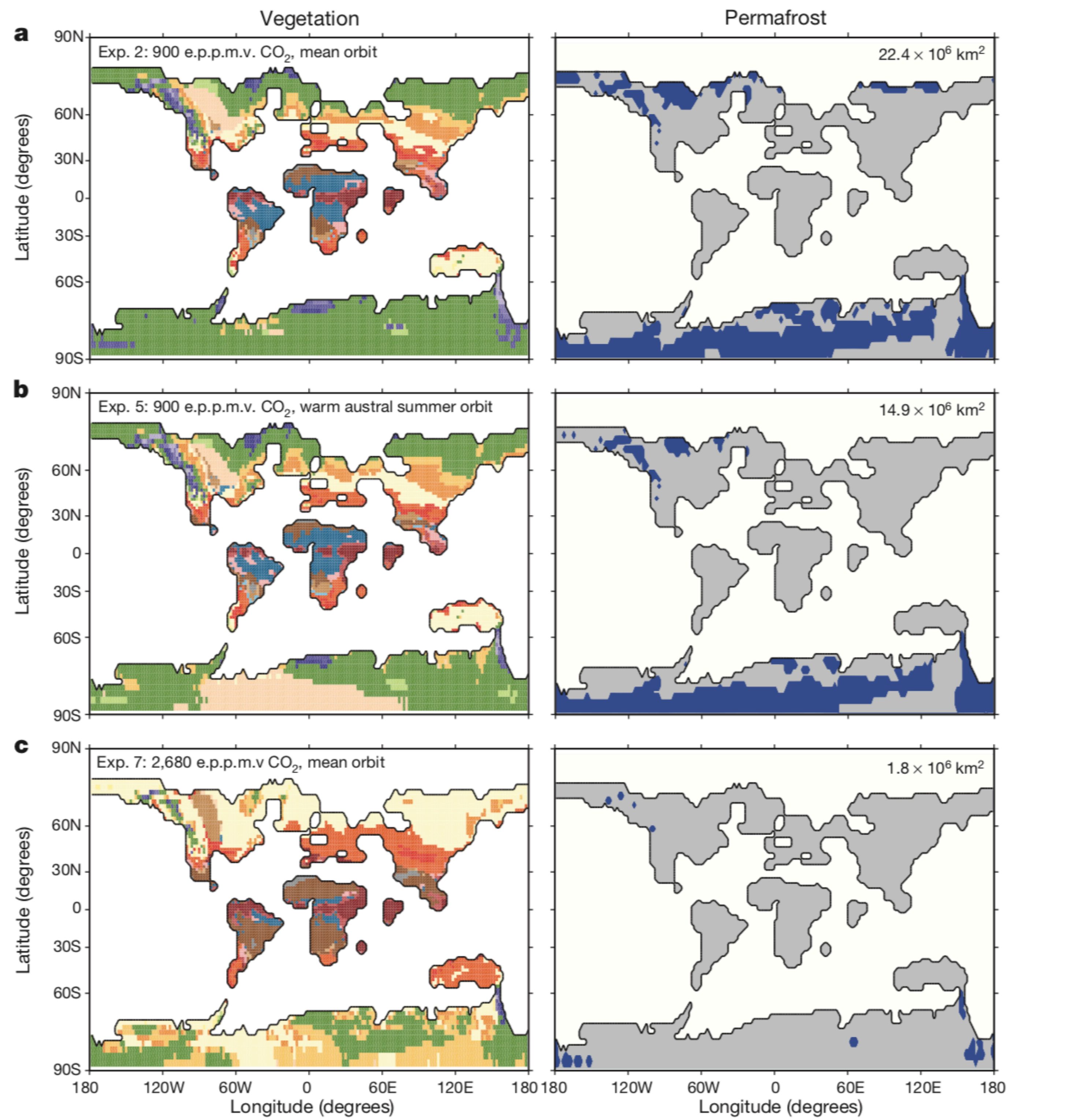

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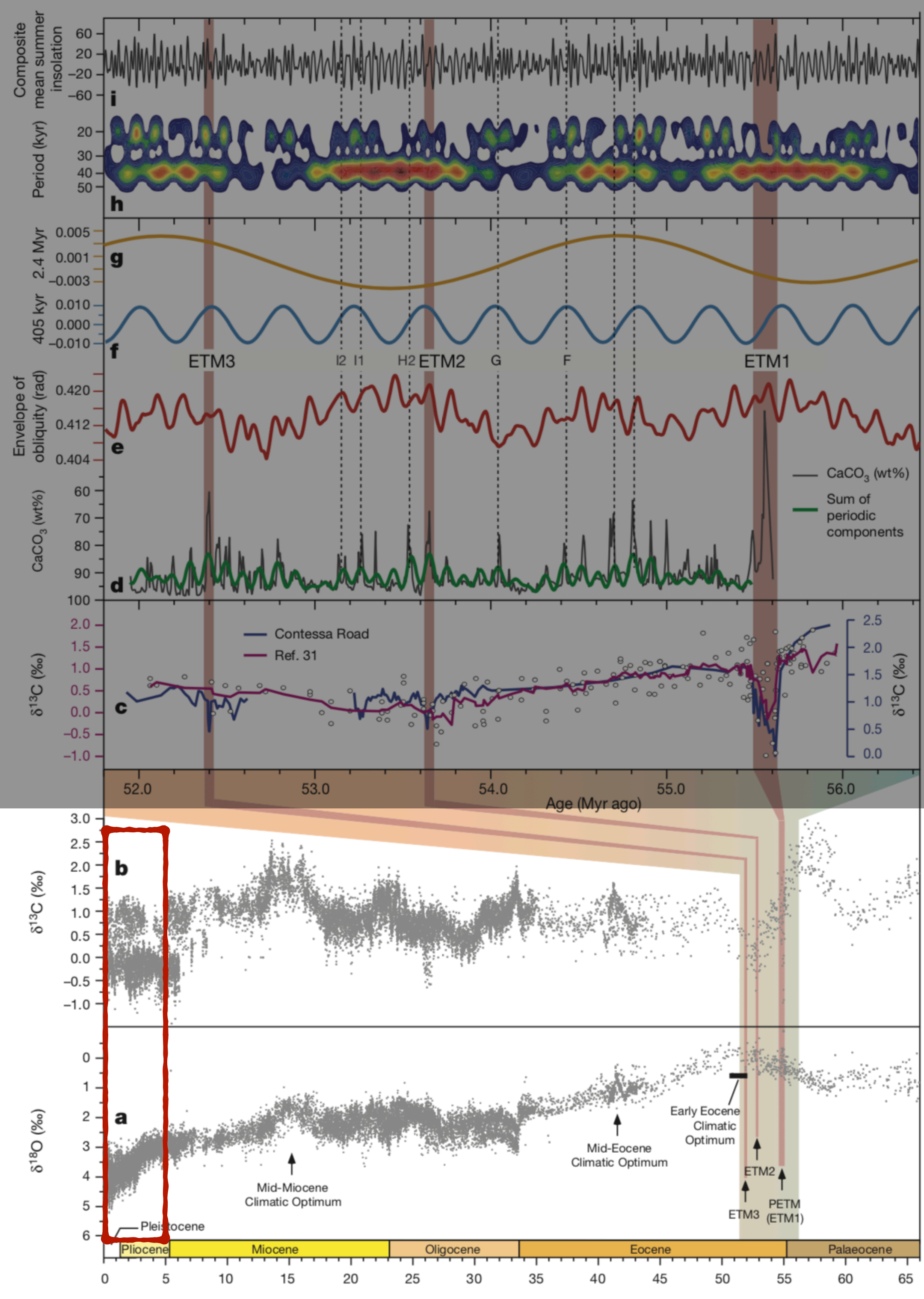
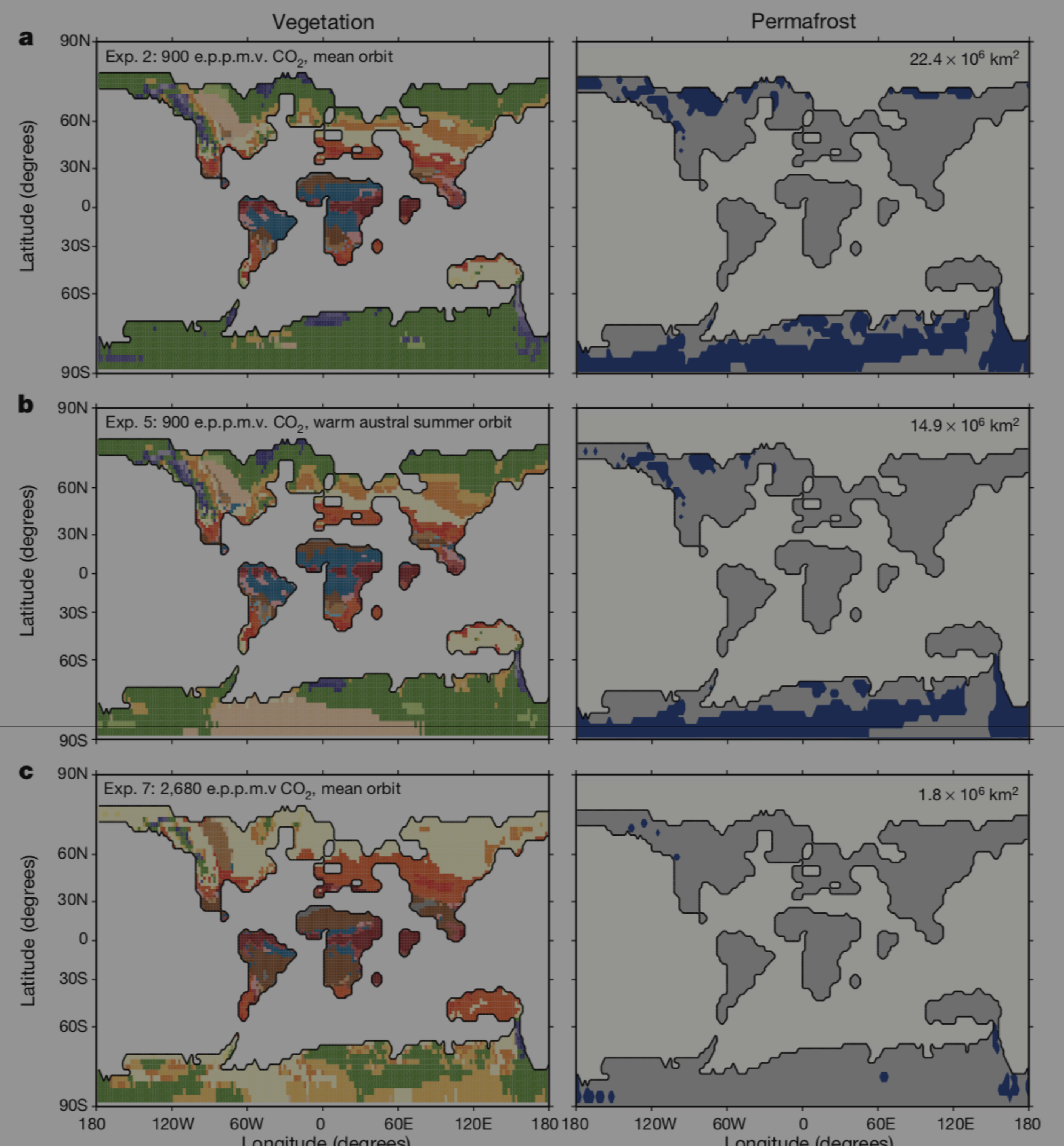




NATURE · VOL 345 · 10 MAY 1990 **ARTICLES**

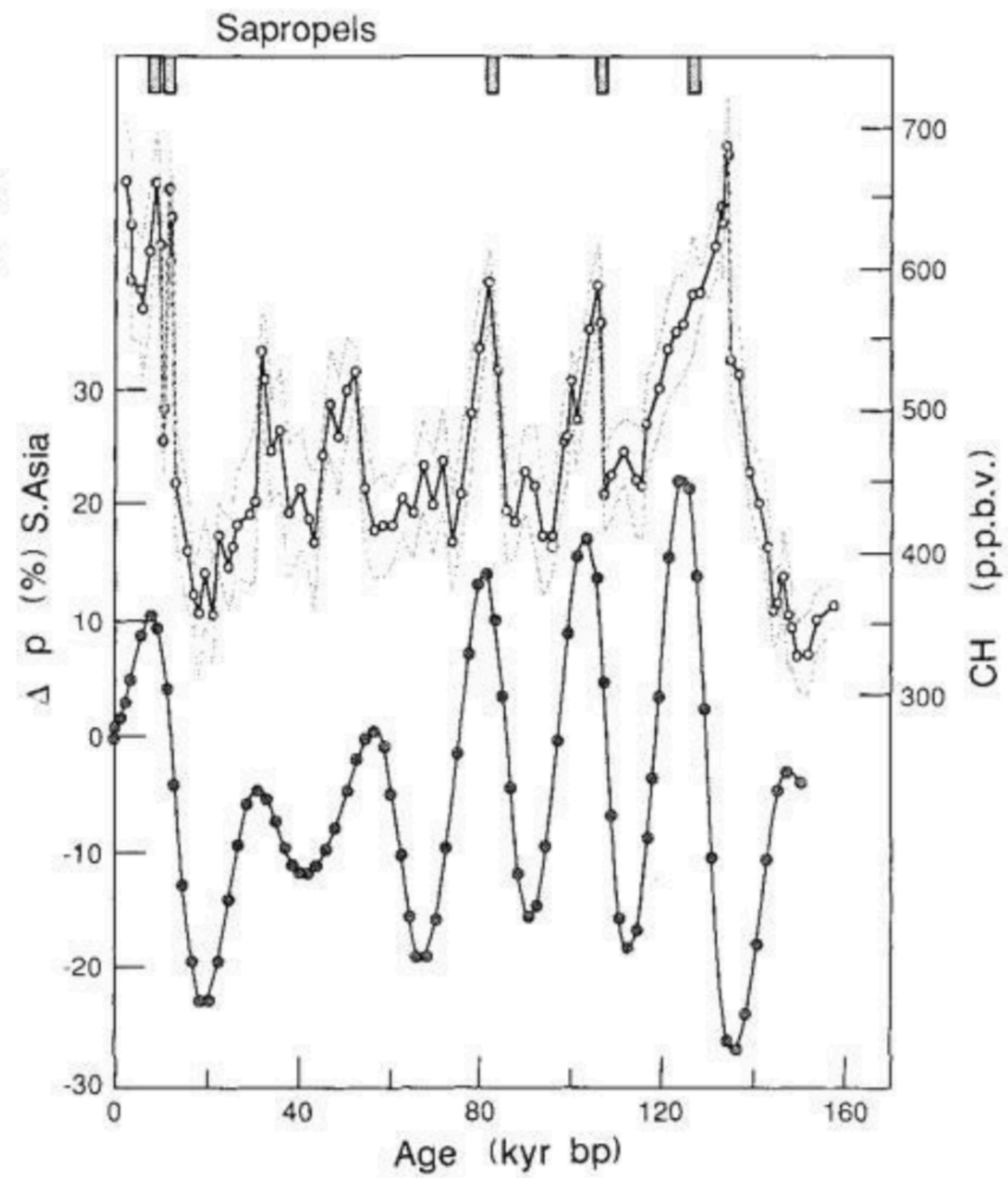
Ice-core record of atmospheric methane over the past 160,000 years

J. Chappellaz*, J. M. Barnola*, D. Raynaud*, Y. S. Korotkevich† & C. Lorius*

* Laboratoire de Glaciologie et Géophysique de l'Environnement, BP 96, 38402 St Martin d'Hères Cedex, France
† Arctic and Antarctic Research Institute, Beringa Street 38, 199226 Leningrad, USSR

We therefore propose that the monsoon circulation could have had a principal role in controlling palaeomethane concentration through variations of low-latitude wetland areas.

Chappellaz and others favored tropical precipitation control on methane over ice age cycles as opposed to high-latitude driver.



NATURE · VOL 345 · 10 MAY 1990 ARTICLES

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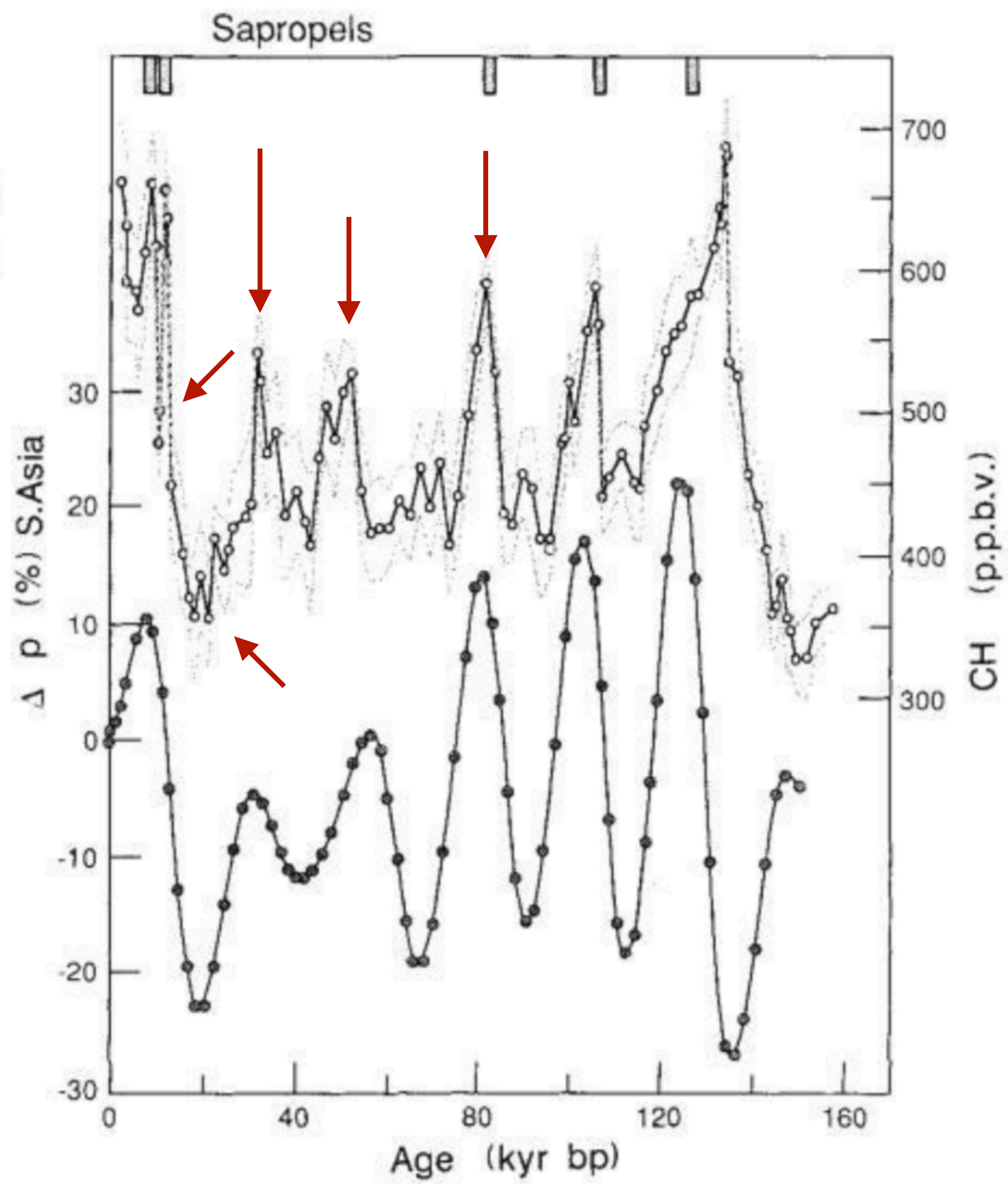


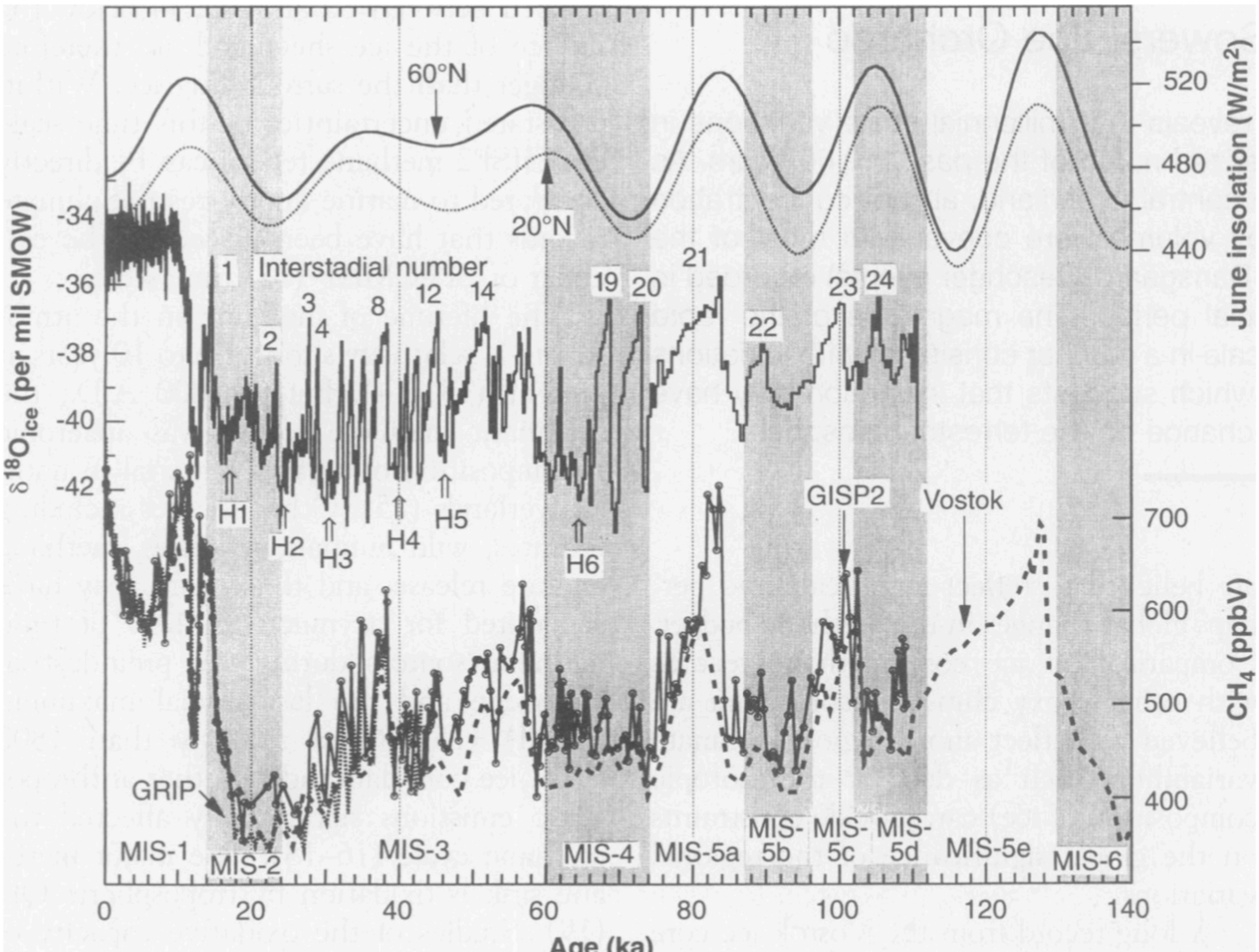
Chappellaz and others favored tropical precipitation control on methane over ice age cycles as opposed to high-latitude driver.

They also found evidence for millennial-scale variability including DO cycles... Heinrich events prior to the association with Heinrich events (e.g., Broecker et al. '92)

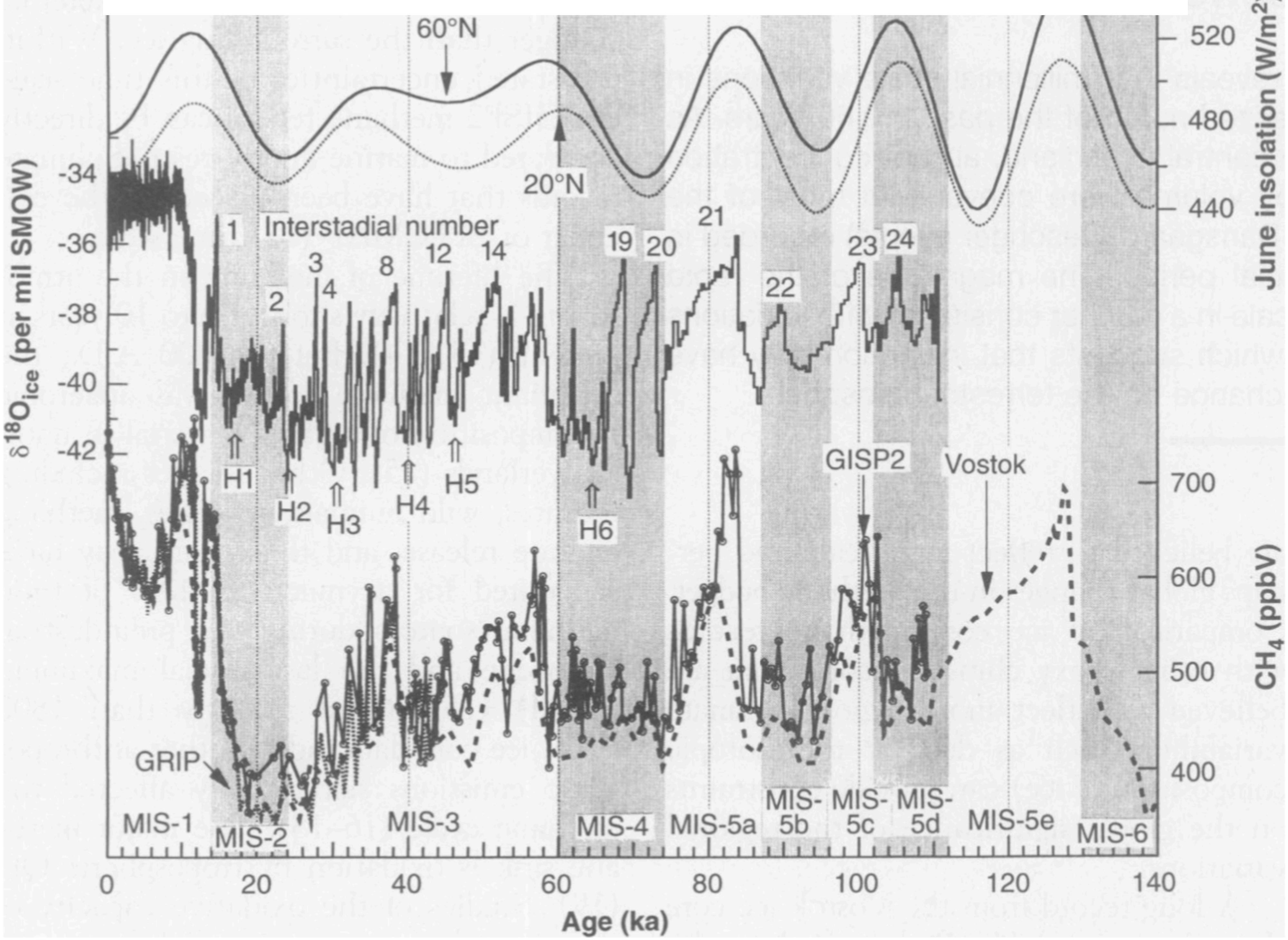
SCIENCE • VOL. 273 • 23 AUGUST 1996

Rapid Variations in Atmospheric Methane Concentration During the Past 110,000 Years

Edward J. Brook, Todd Sowers, Joe Orchardo

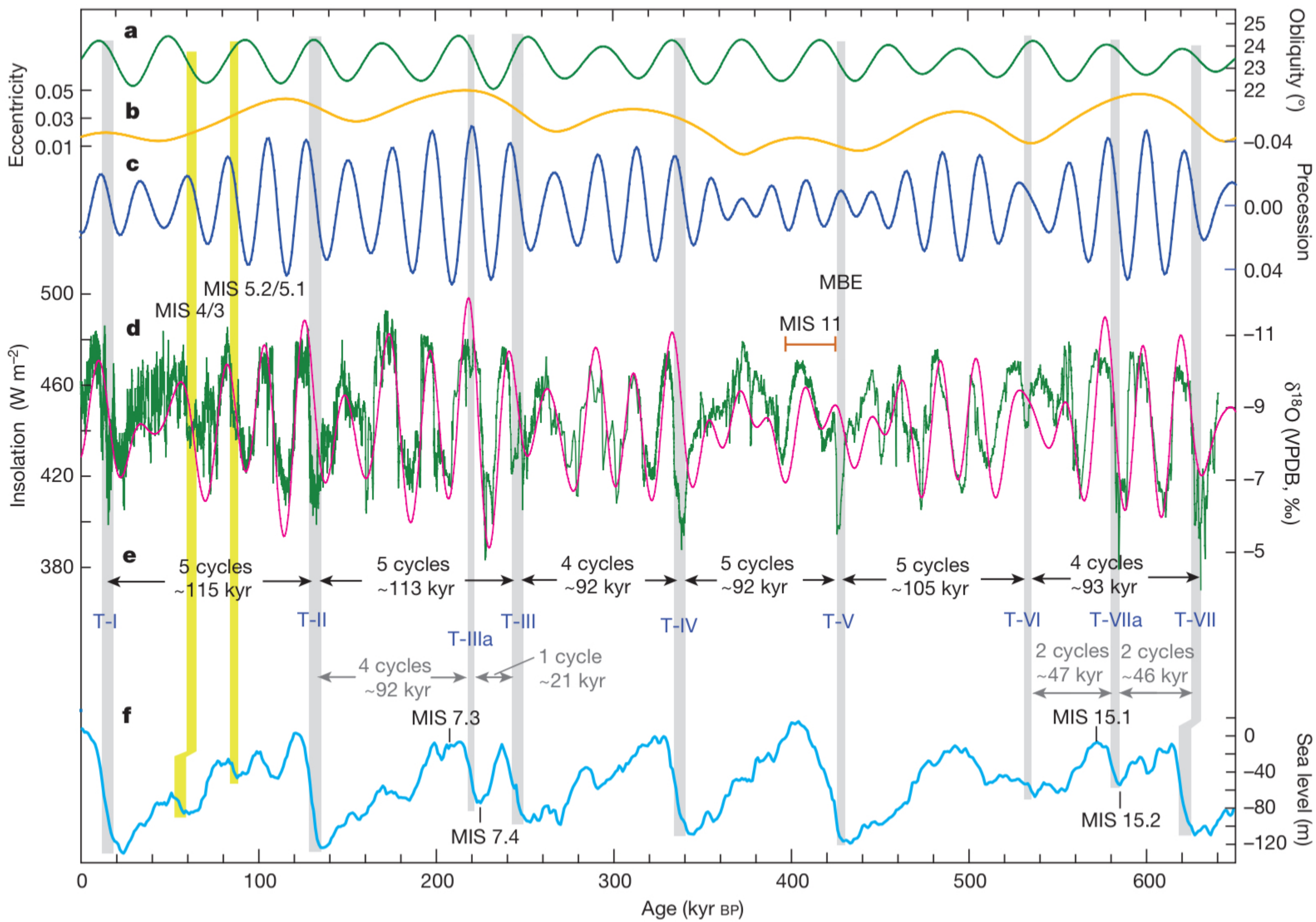


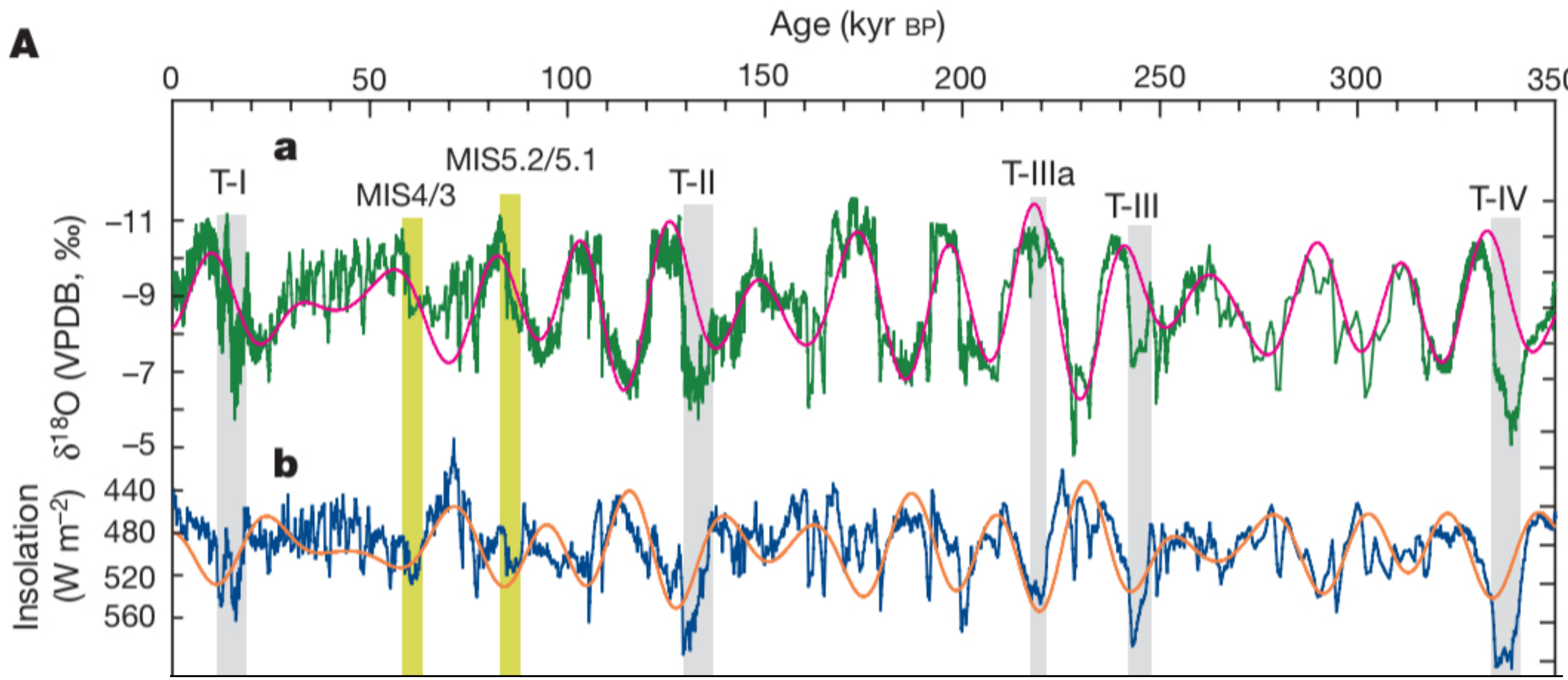
A methane record from the GISP2 ice core reveals that millennial-scale variations in atmospheric methane concentration characterized much of the past 110,00 years. As previously observed in a shorter record from central Greenland, abrupt concentration shifts of about 50 to 300 parts per billion by volume were coeval with most of the interstadial warming events (better known as Dansgaard-Oeschger events) recorded in the GISP2 ice core throughout the last glacial period. The magnitude of the rapid concentration shifts varied on a longer time scale in a manner consistent with variations in Northern Hemisphere summer insolation, which suggests that insolation may have modulated the effects of interstadial climate change on the terrestrial biosphere.

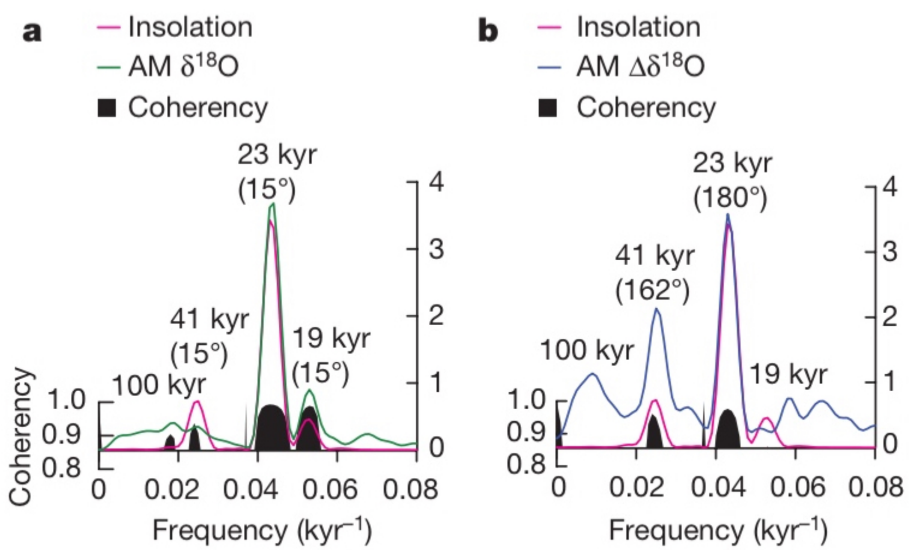


The Asian monsoon over the past 640,000 years and ice age terminations

Hai Cheng[1,2], R. Lawrence Edwards[2], Ashish Sinha[3], Christoph Spötl[4], Liang Yi[5], Shitao Chen[6], Megan Kelly[2], Gayatri Kathayat[1], Xianfeng Wang[7], Xianglei Li[1], Xinggong Kong[6], Yongjin Wang[6], Youfeng Ning[1] & Haiwei Zhang[1]

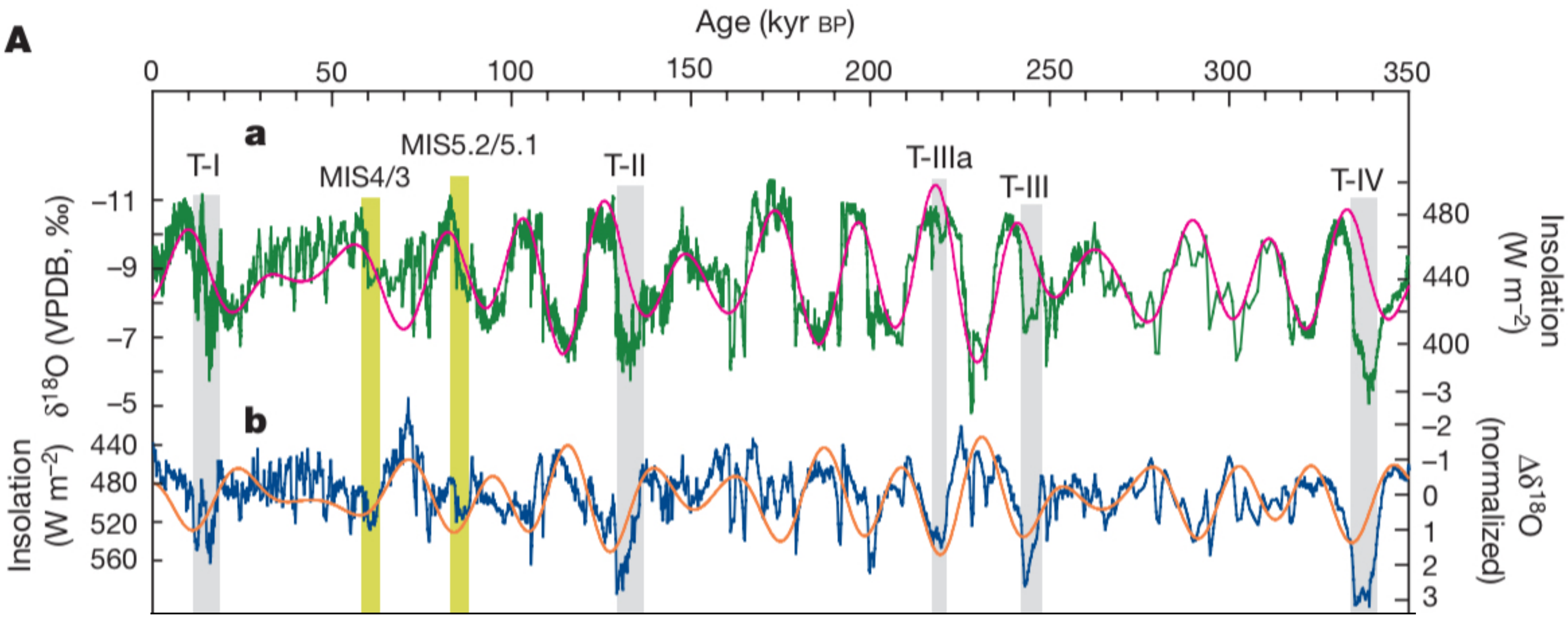


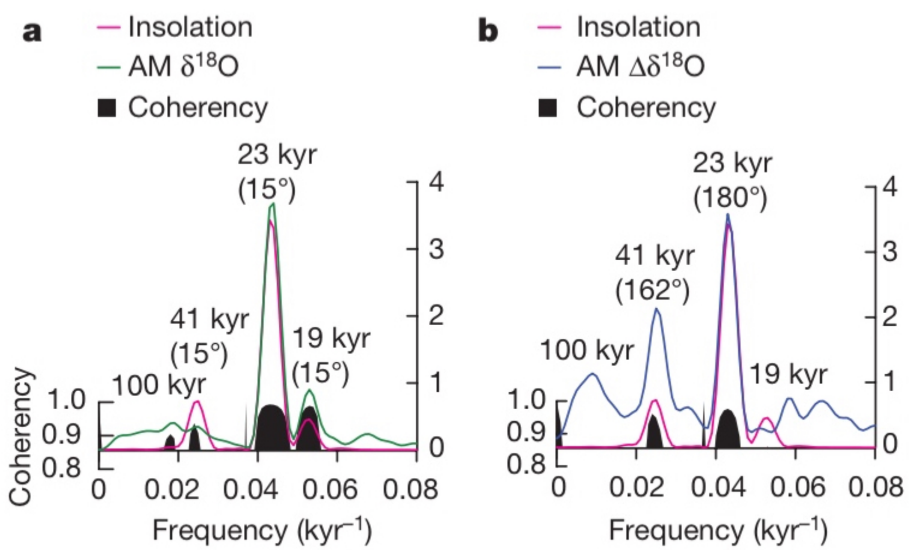




Pacemaker of millennial-scale events

A





Pacemaker of millennial-scale events

Oxygen isotope records from Chinese caves characterize changes in both the Asian monsoon and global climate. Here, using our new speleothem data, we extend the Chinese record to cover the full uranium/thorium dating range, that is, the past 640,000 years. The record's length and temporal precision allow us to test the idea that insolation changes caused by the Earth's precession drove the terminations of each of the last seven ice ages as well as the millennia-long intervals of reduced monsoon rainfall associated with each of the terminations. On the basis of our record's timing, the terminations are separated by four or five precession cycles, supporting the idea that the '100,000-year' ice age cycle is an average of discrete numbers of precession cycles. Furthermore, the suborbital component of monsoon rainfall variability exhibits power in both the precession and obliquity bands, and is nearly in anti-phase with summer boreal insolation. These observations indicate that insolation, in part, sets the pace of the occurrence of millennial-scale events, including those associated with terminations and 'unfinished terminations'.

30 JUNE 2016 | VOL 534 | NATURE | 641

The Asian monsoon over the past 640,000 years and ice age terminations

Hai Cheng[1,2], R. Lawrence Edwards[2], Ashish Sinha[3], Christoph Spötl[4], Liang Yi[5], Shitao Chen[6], Megan Kelly[2], Gayatri Kathayat[1], Xianfeng Wang[7], Xianglei Li[1], Xinggong Kong[6], Yongjin Wang[6], Youfeng Ning[1] & Haiwei Zhang[1]

anti-phased with obliquity. Thus, insolation modulates the suborbital component of AM variability, but in the opposite sense from the more direct control of orbital-scale variability of the AM. We take these observations to indicate that high NHSI, whether in the precession or obliquity bands, favours the disintegration of the northern ice sheets and the release of ice and meltwater into the North Atlantic. This signal

Antarctic and global climate history viewed from ice cores

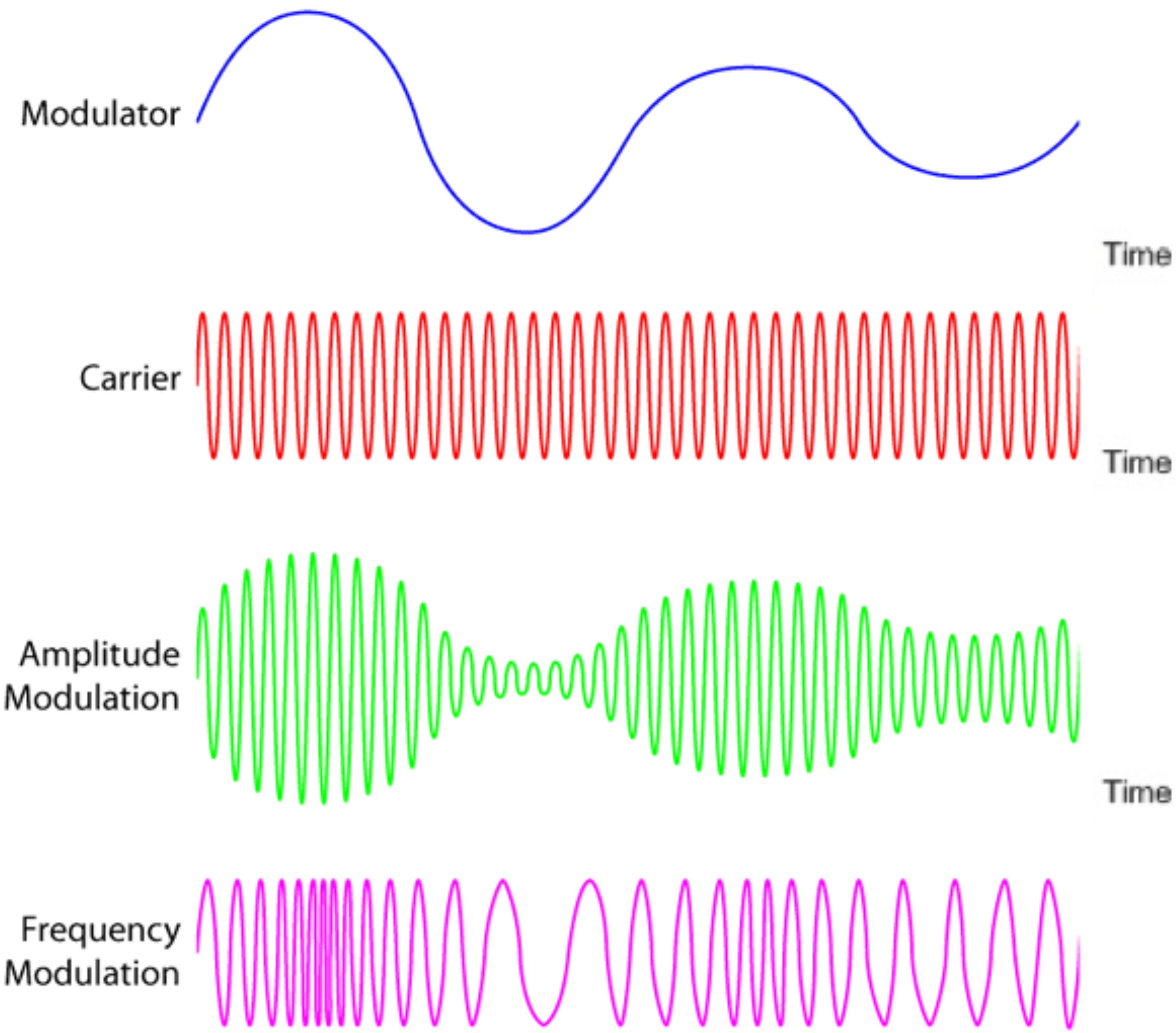
Edward J. Brook[1]* & Christo Buizert[1]

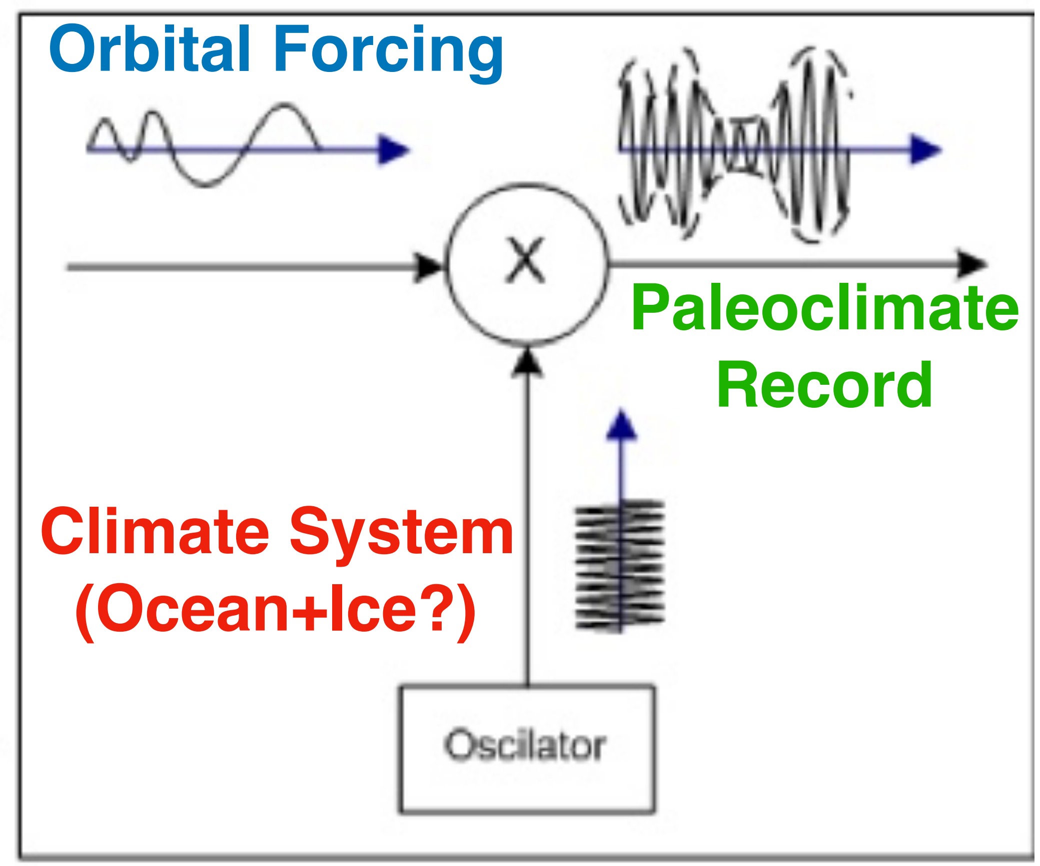
200 | NATURE | VOL 558 | 14 JUNE 2018

On millennial timescales, CH_4 is tightly coupled to Dansgaard–Oeschger events (see section 'The close view: millennial-scale variability'), although the response appears to be modulated by insolation[50]

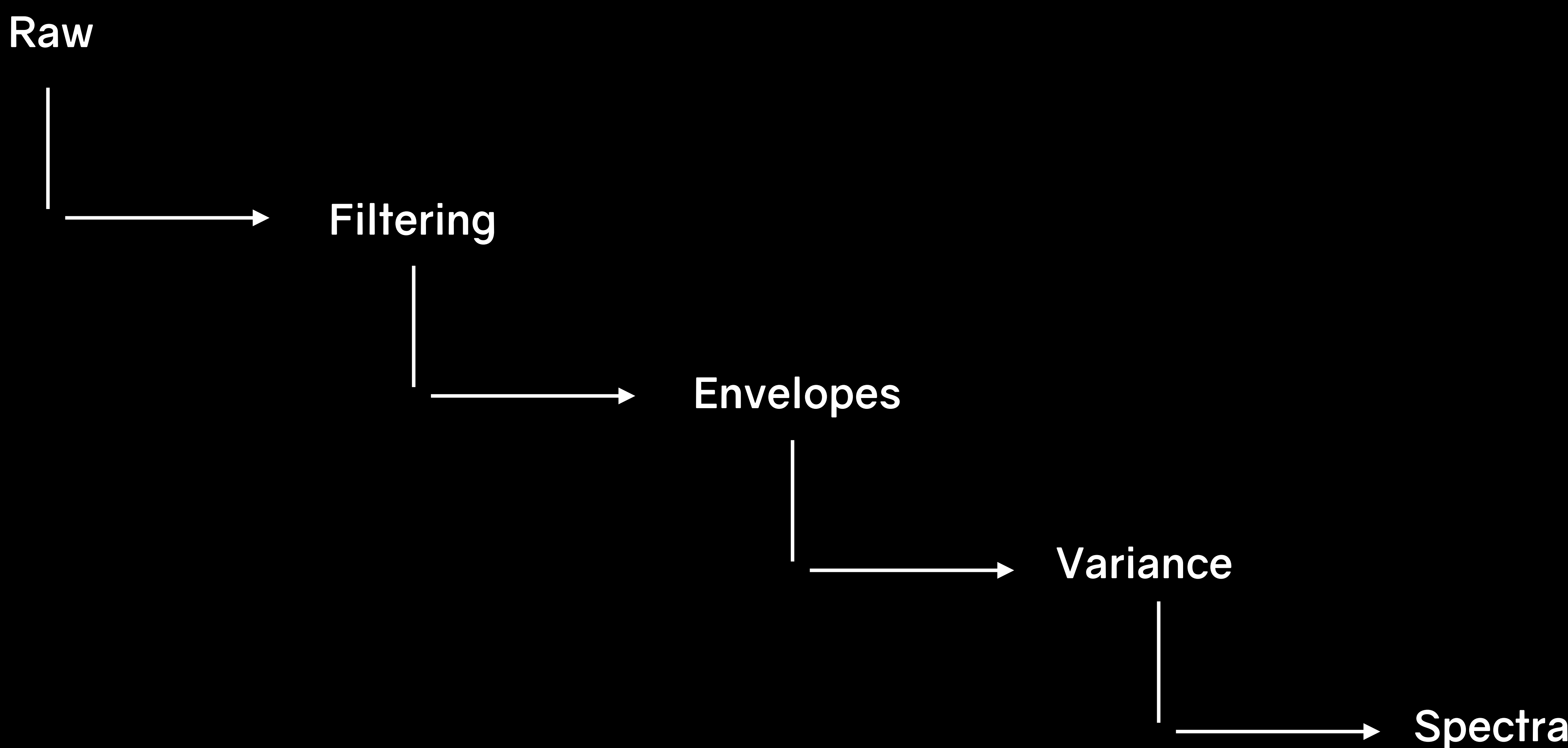
the GISP2 ice core throughout the last glacial period. The magnitude of the rapid concentration shifts varied on a longer time scale in a manner consistent with variations in Northern Hemisphere summer insolation, which suggests that insolation may have modulated the effects of interstadial climate change on the terrestrial biosphere.

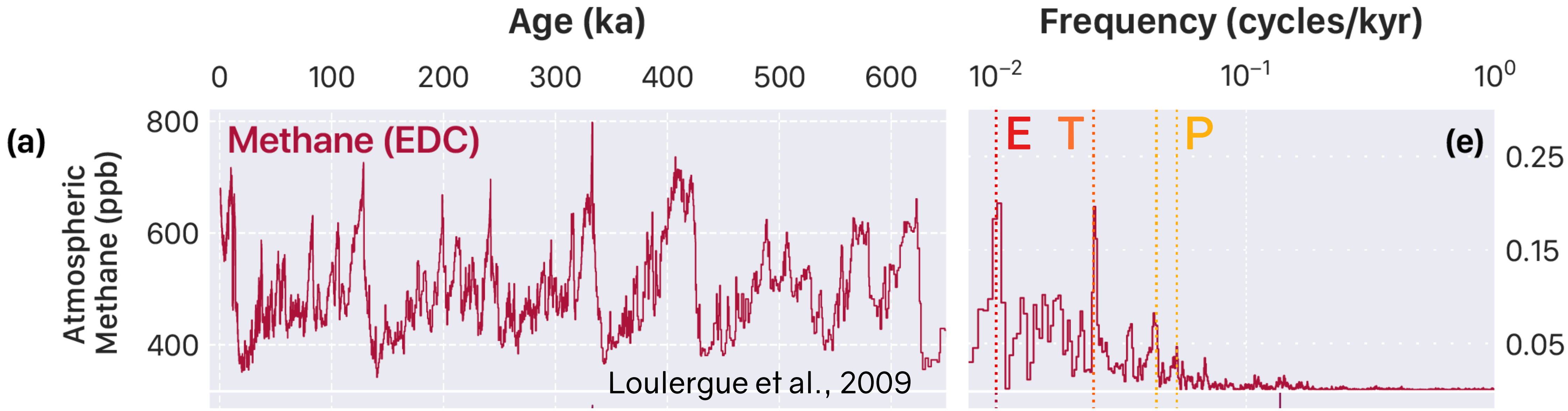
What is modulation?

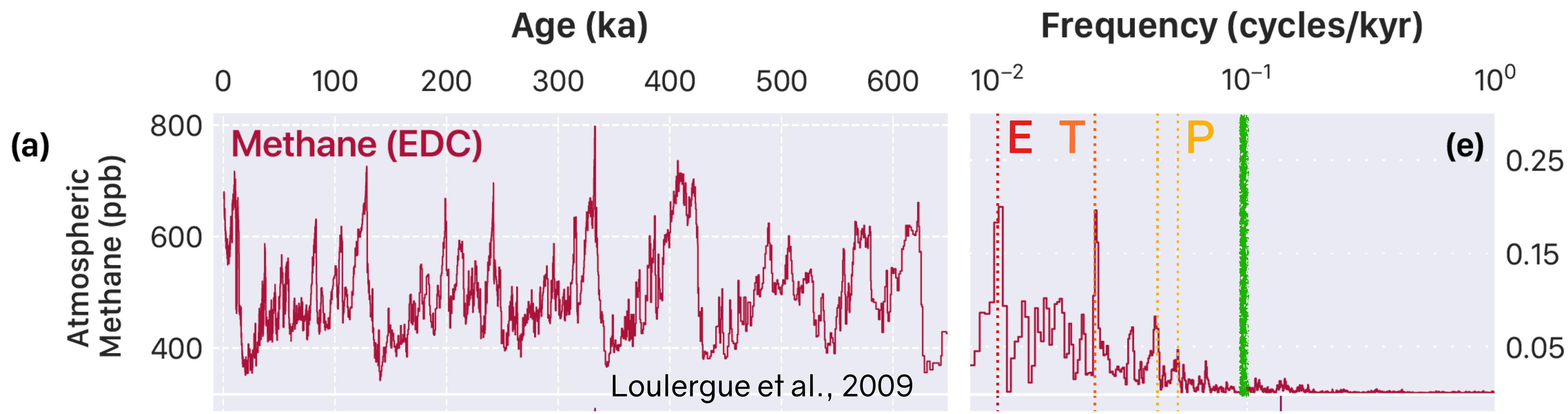




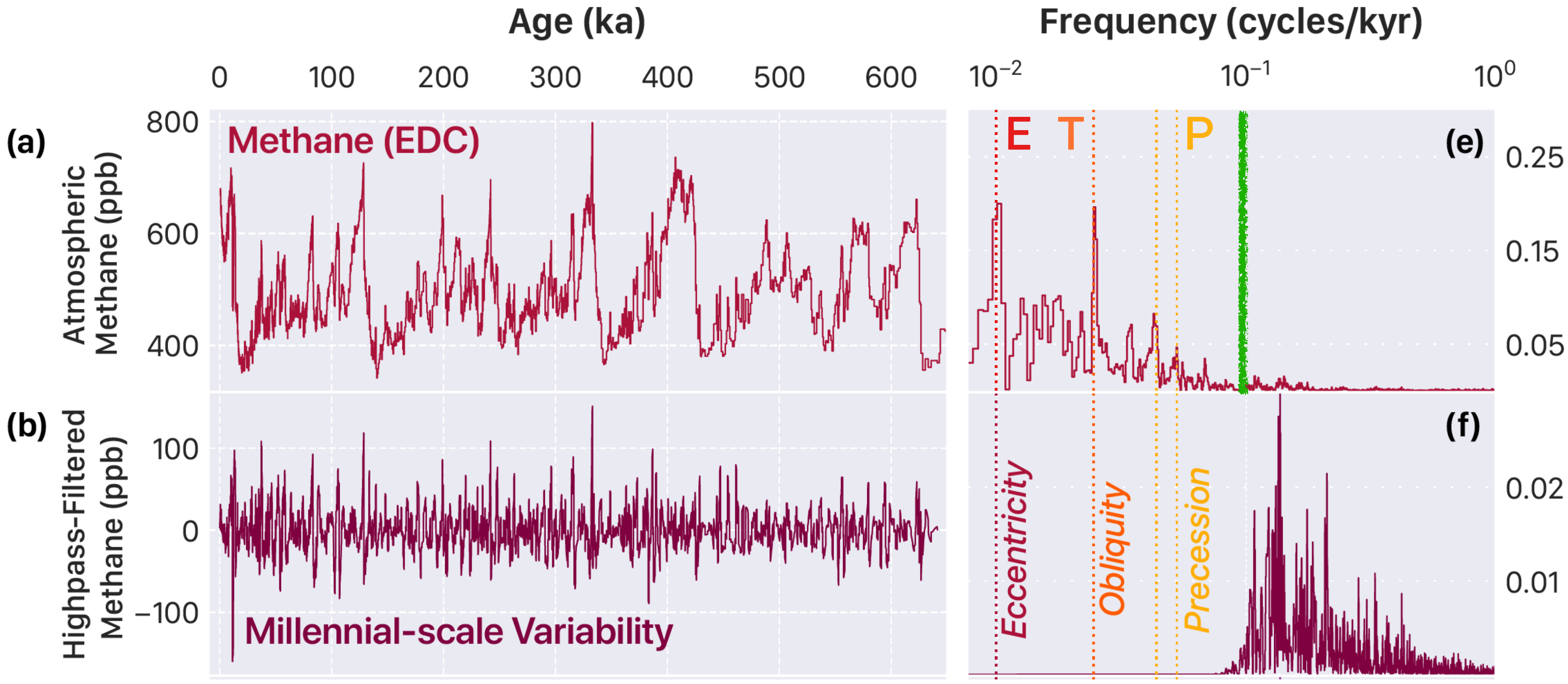
Recipe: signal processing approach



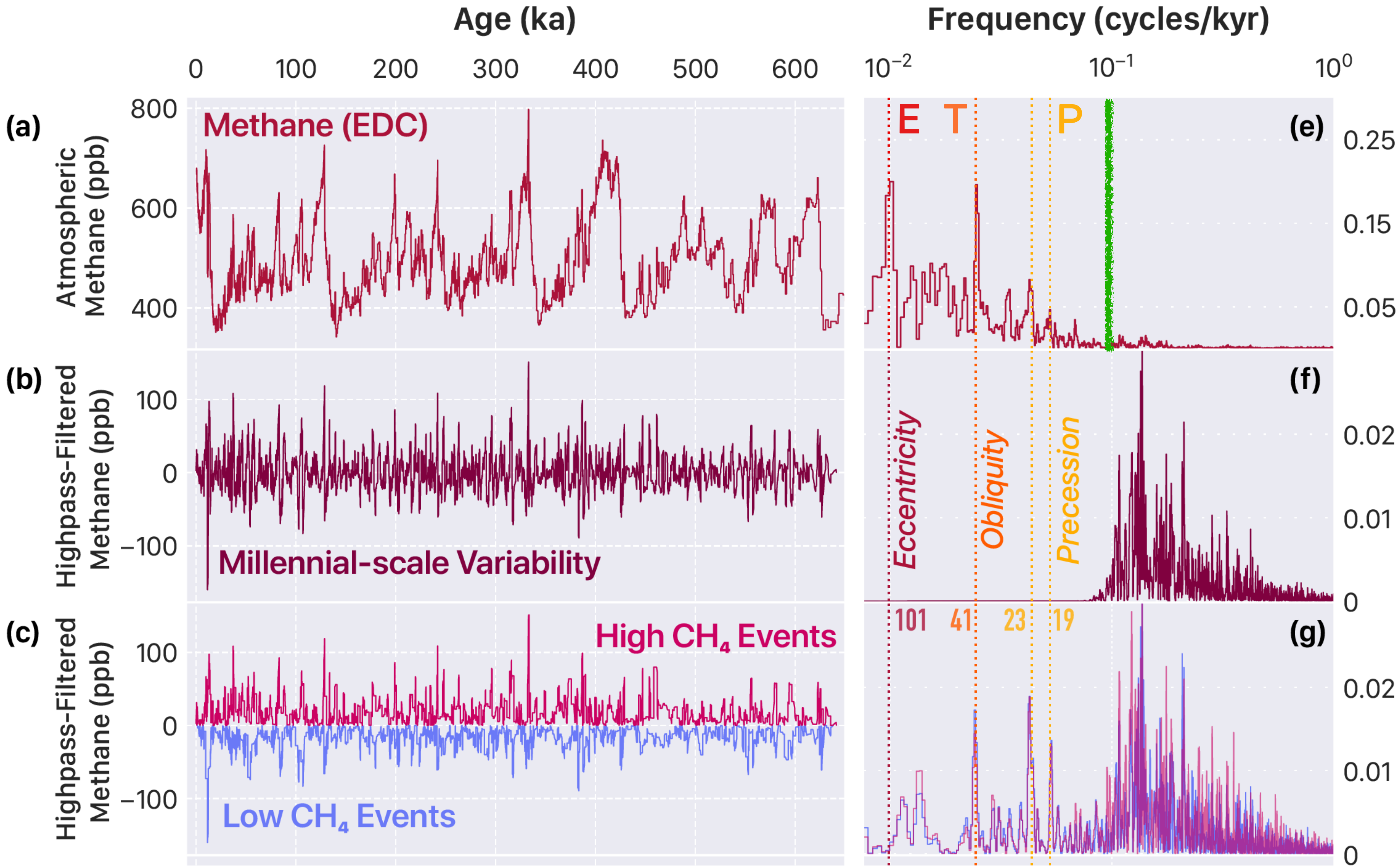

Age (ka)
0
100
200
300
400
500
600
Frequency (cycles/kyr)
10^{-2}
10^{-1}
10^{0}
(a)
Atmospheric Methane (ppb)
800
600
400
Methane (EDC)
Loulergue et al., 2009
E
T
P
(e)
0.25
0.15
0.05



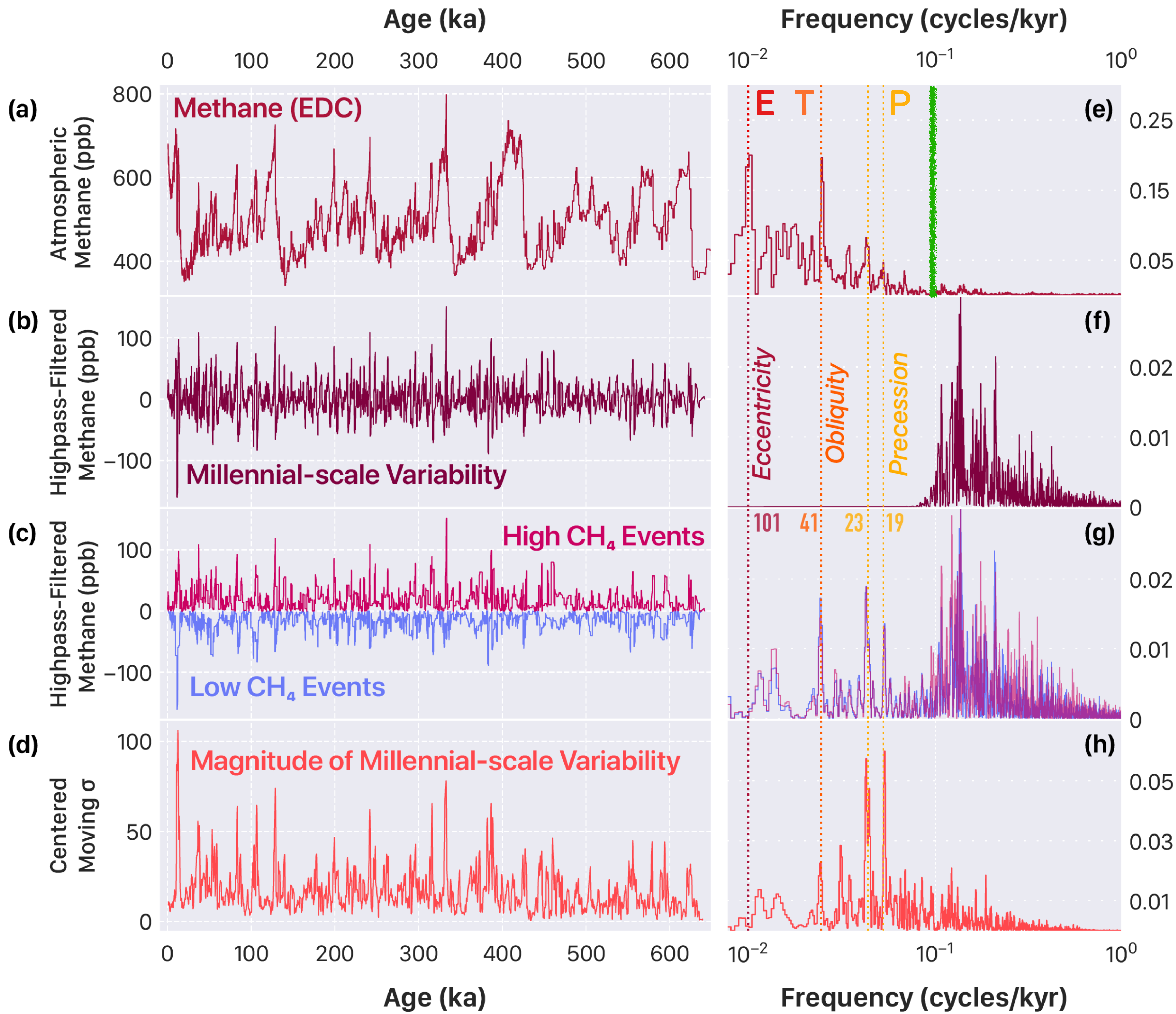
Age (ka)
Frequency (cycles/kyr)
0
100
200
300
400
500
600
10^{-2}
10^{-1}
10^{0}
(a)
800
600
400
Atmospheric Methane (ppb)
Methane (EDC)
Loulergue et al., 2009
E
T
P
(e)
0.25
0.15
0.05



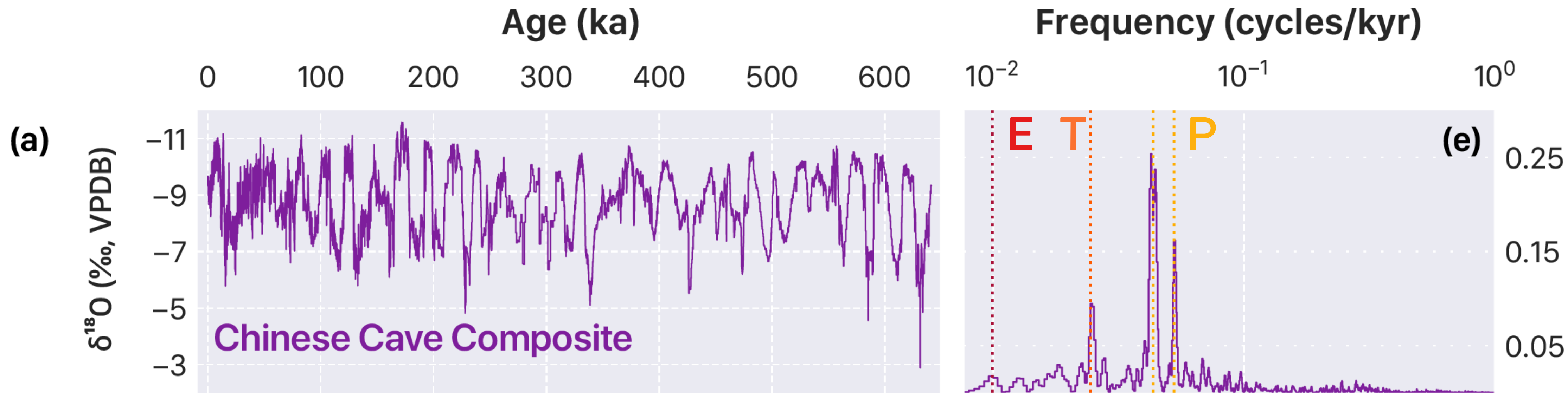
Age (ka)
Frequency (cycles/kyr)
0
100
200
300
400
500
600
10^{-2}
10^{-1}
10^{0}
(a)
Atmospheric Methane (ppb)
800
600
400
Methane (EDC)
E
T
P
(e)
0.25
0.15
0.05
(b)
Highpass-Filtered Methane (ppb)
100
0
−100
Millennial-scale Variability
(f)
0.02
0.01
Eccentricity
Obliquity
Precession

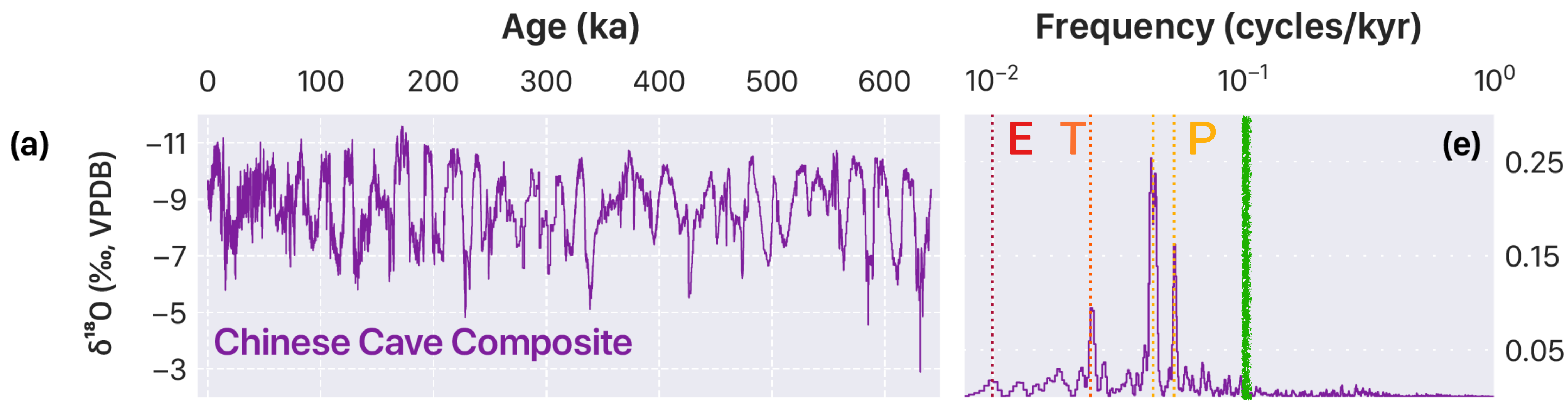


Age (ka)
Frequency (cycles/kyr)
(a)
(b)
(c)
(e)
(f)
(g)
Methane (EDC)
Atmospheric Methane (ppb)
Highpass-Filtered Methane (ppb)
Millennial-scale Variability
High CH4 Events
Low CH4 Events
E
T
P
Eccentricity
Obliquity
Precession
101
41
23
19

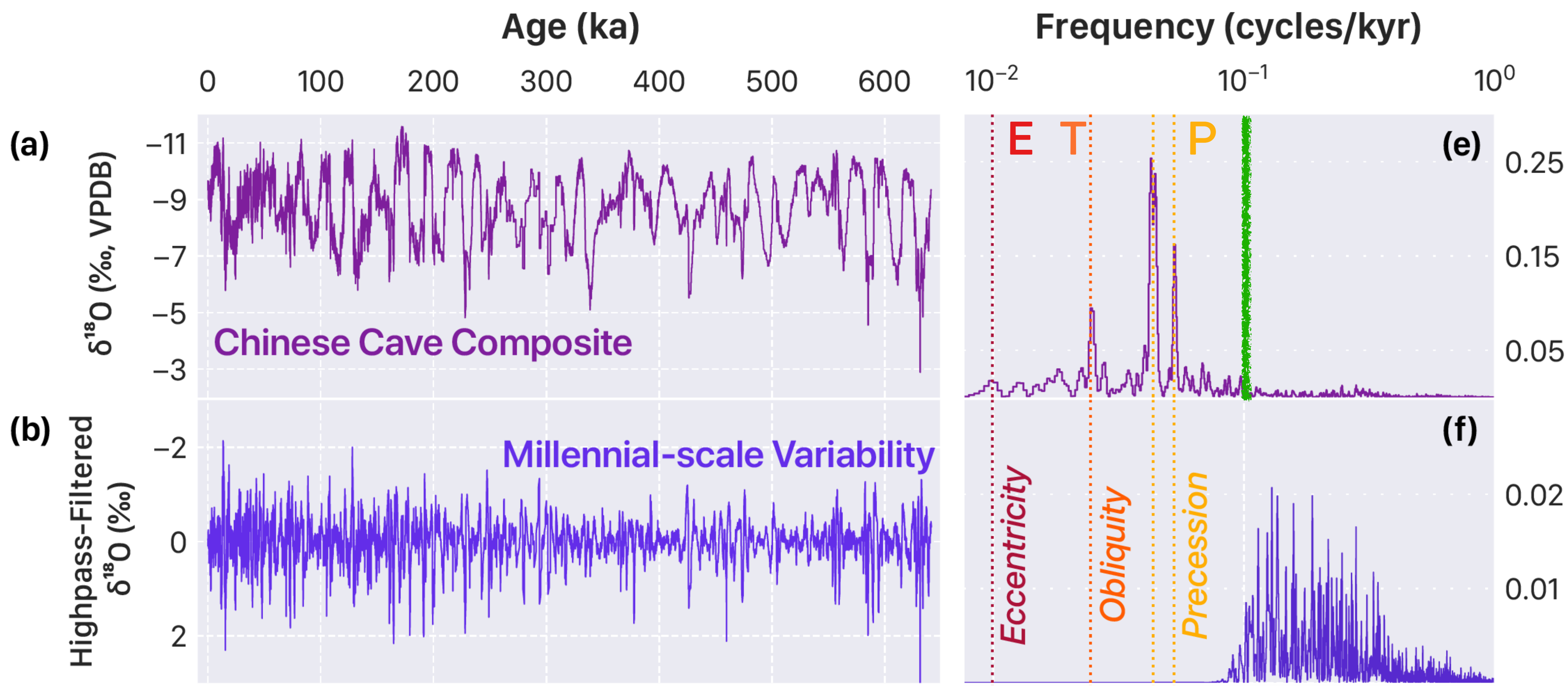


Age (ka)
Frequency (cycles/kyr)
(a)
Atmospheric Methane (ppb)
Methane (EDC)
E
T
P
(e)
(b)
Highpass-Filtered Methane (ppb)
Millennial-scale Variability
(f)
Eccentricity
Obliquity
Precession
101
41
23
19
(c)
High CH_4 Events
Low CH_4 Events
(g)
(d)
Centered Moving σ
Magnitude of Millennial-scale Variability
(h)

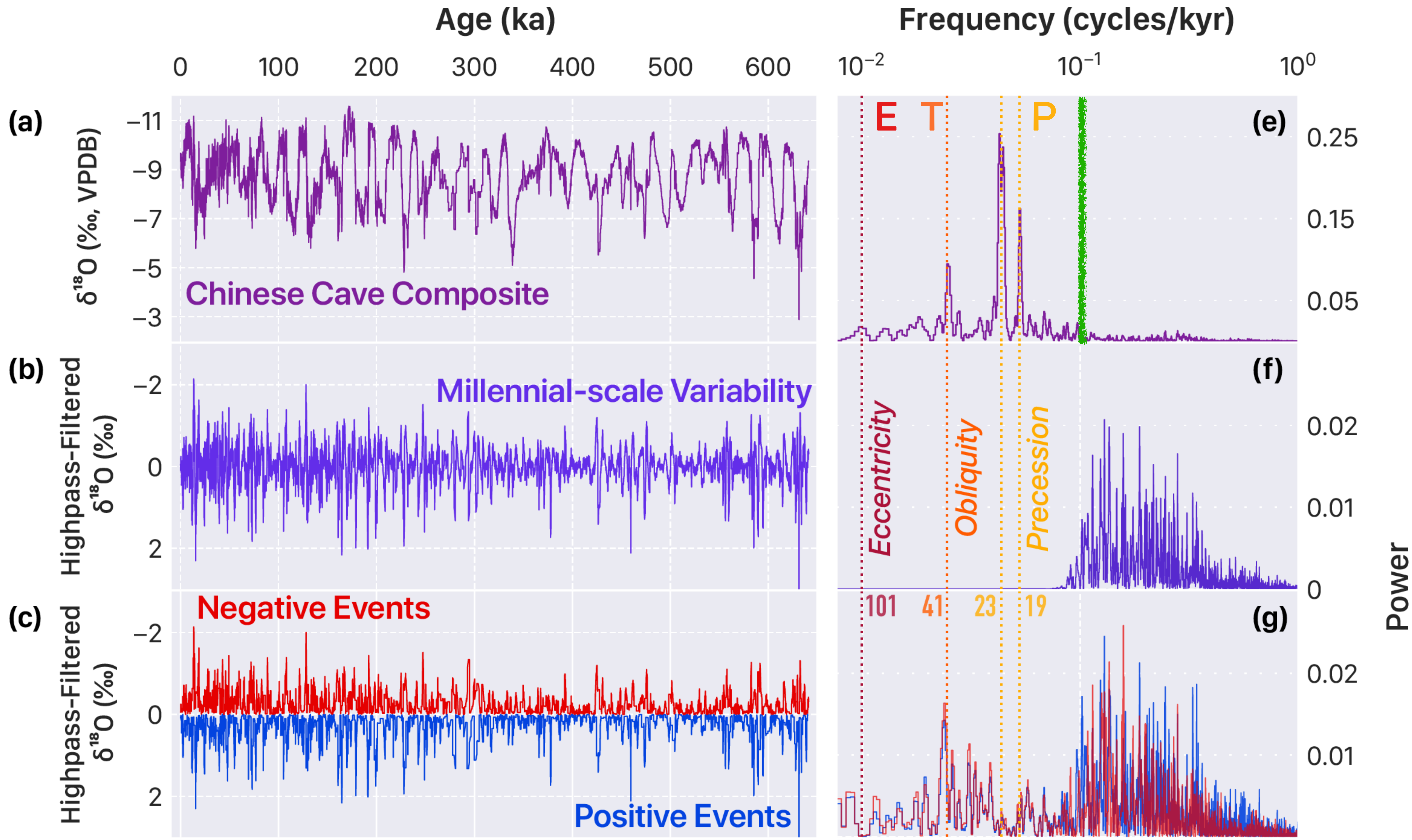

Age (ka)
0
100
200
300
400
500
600
Frequency (cycles/kyr)
10−2
10−1
100
(a)
δ18O (‰, VPDB)
−11
−9
−7
−5
−3
Chinese Cave Composite
E
T
P
(e)
0.25
0.15
0.05



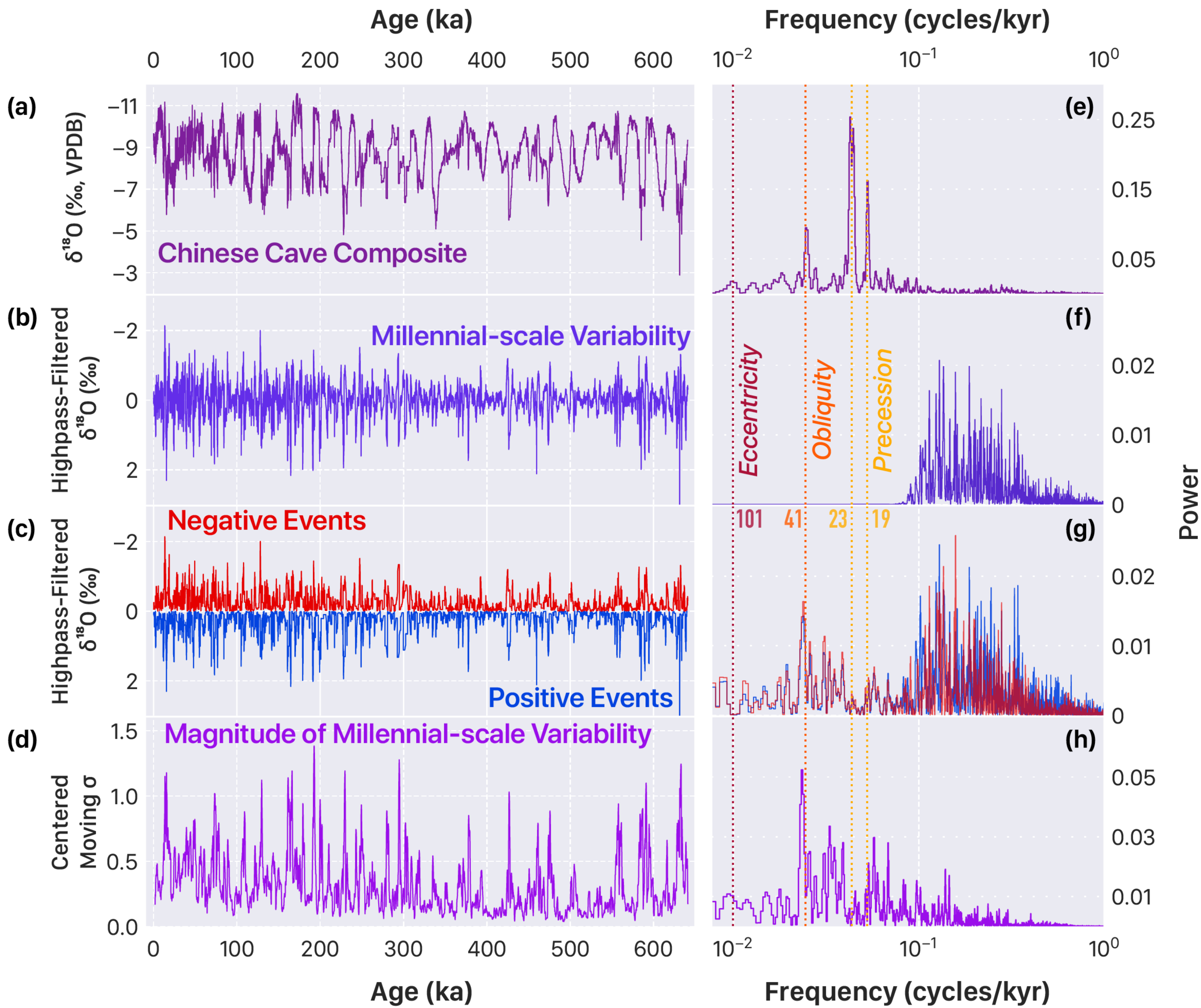
Age (ka)
0
100
200
300
400
500
600
(a)
δ¹⁸O (‰, VPDB)
−11
−9
−7
−5
−3
Chinese Cave Composite
Frequency (cycles/kyr)
10^−2
10^−1
10^0
E
T
P
(e)
0.25
0.15
0.05

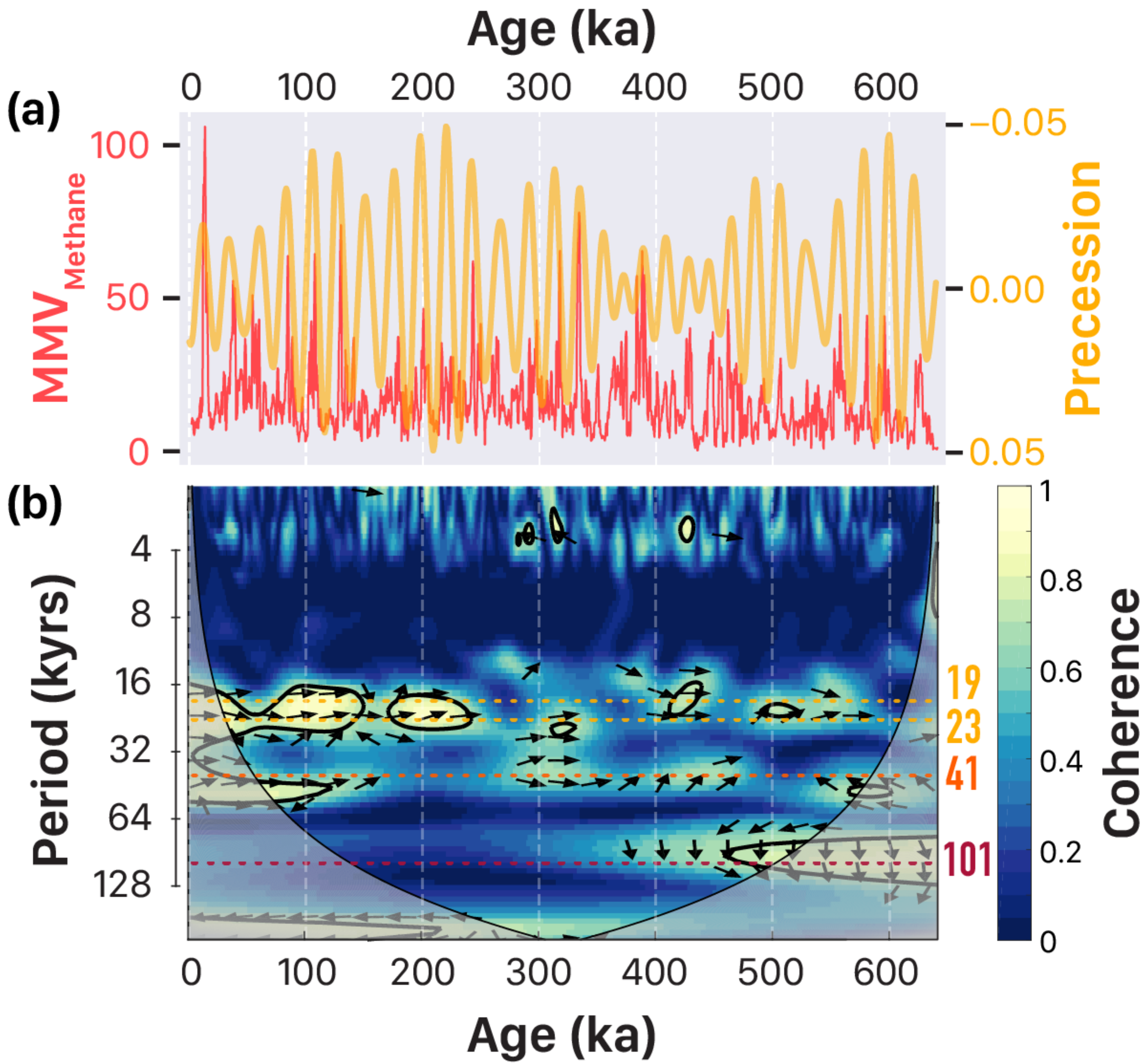


Age (ka)
0
100
200
300
400
500
600
Frequency (cycles/kyr)
10−2
10−1
10⁰
(a)
δ18O (‰, VPDB)
−11
−9
−7
−5
−3
Chinese Cave Composite
(b)
Highpass-Filtered
δ18O (‰)
−2
0
2
Millennial-scale Variability
E
T
P
(e)
0.25
0.15
0.05
(f)
0.02
0.01
Eccentricity
Obliquity
Precession

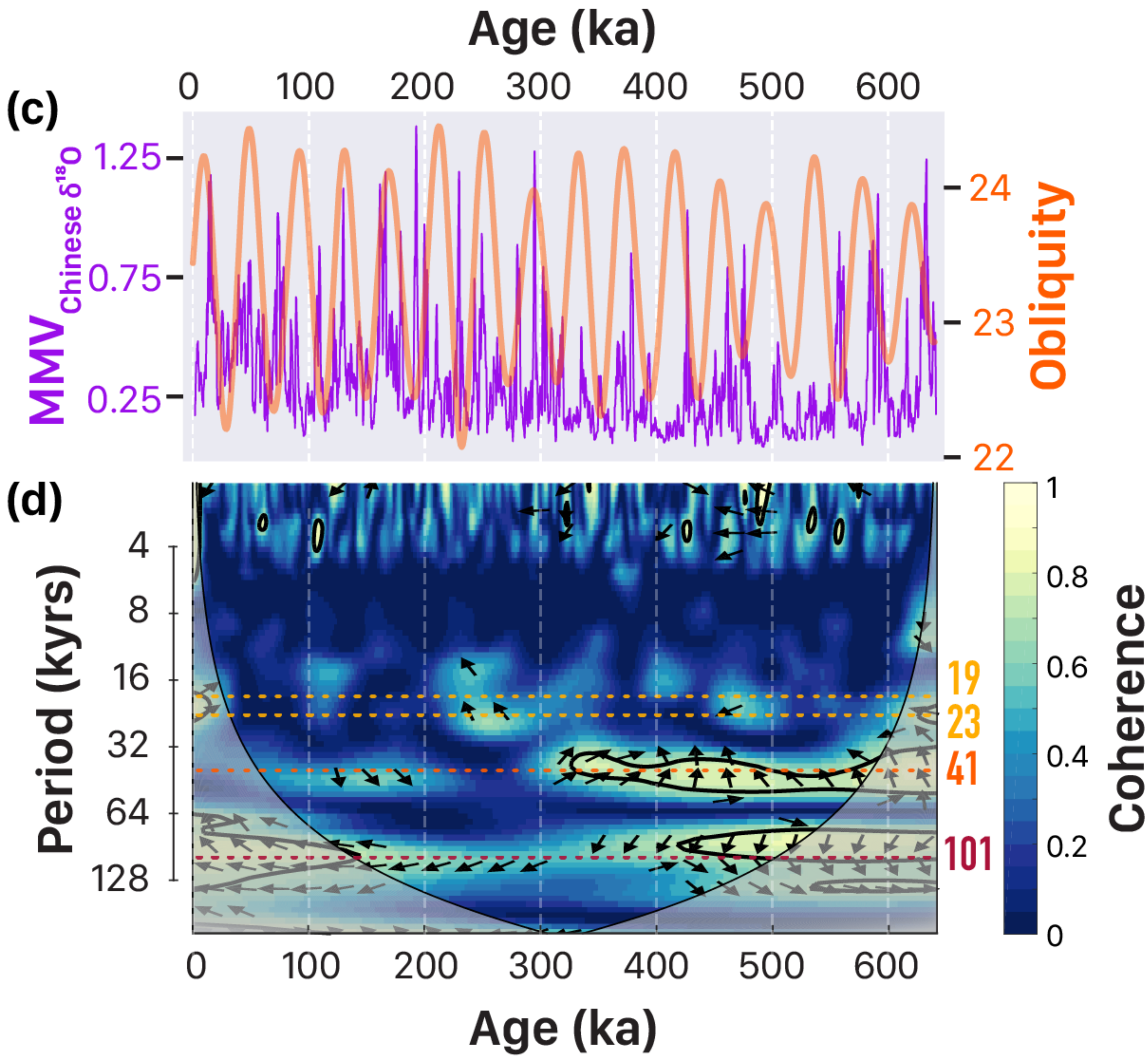


Age (ka)
0
100
200
300
400
500
600
Frequency (cycles/kyr)
10^{-2}
10^{-1}
10^{0}
(a)
δ18O (‰, VPDB)
−11
−9
−7
−5
−3
Chinese Cave Composite
(b)
Highpass-Filtered δ18O (‰)
−2
0
2
Millennial-scale Variability
(c)
Highpass-Filtered δ18O (‰)
−2
0
2
Negative Events
Positive Events
E
T
P
(e)
(f)
(g)
0.25
0.15
0.05
0.02
0.01
0
0.02
0.01
Power
Eccentricity
Obliquity
Precession
101
41
23
19

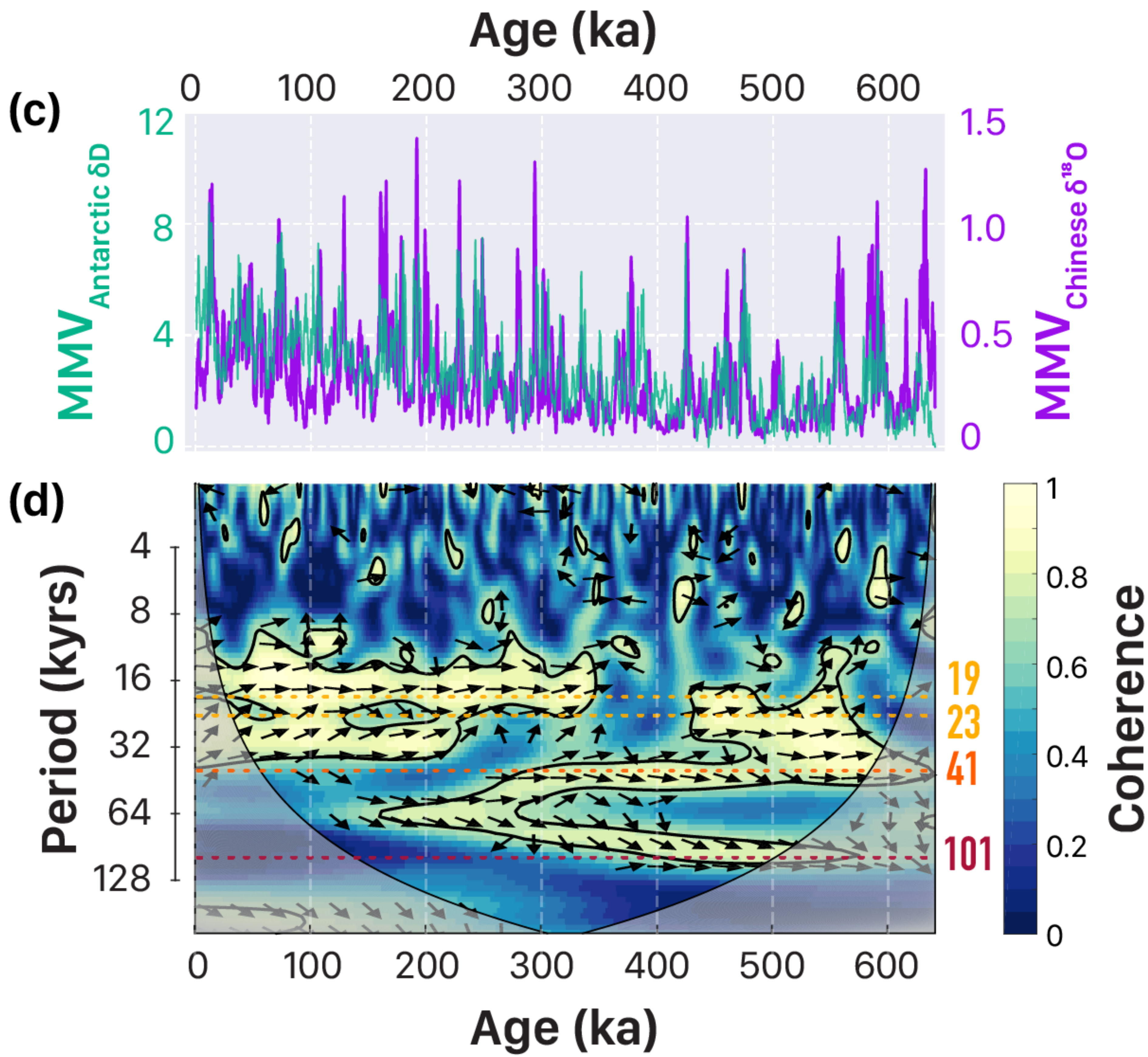

Age (ka)
Frequency (cycles/kyr)
(a)
δ18O (‰, VPDB)
Chinese Cave Composite
(e)
(b)
Highpass-Filtered δ18O (‰)
Millennial-scale Variability
(f)
Eccentricity
Obliquity
Precession
101
41
23
19
(c)
Negative Events
Positive Events
(g)
(d)
Centered Moving σ
Magnitude of Millennial-scale Variability
(h)
Power



Age (ka)
(a)
0
100
200
300
400
500
600
100
50
0
MMV_Methane
−0.05
0.00
0.05
Precession
(b)
4
8
16
32
64
128
Period (kyrs)
19
23
41
101
1
0.8
0.6
0.4
0.2
0
Coherence
Age (ka)



Age (ka)
0
100
200
300
400
500
600
(c)
$MMV_{Chinese\ \delta^{18}O}$
1.25
0.75
0.25
Obliquity
24
23
22
(d)
Period (kyrs)
4
8
16
32
64
128
19
23
41
101
Coherence
1
0.8
0.6
0.4
0.2
0
Age (ka)



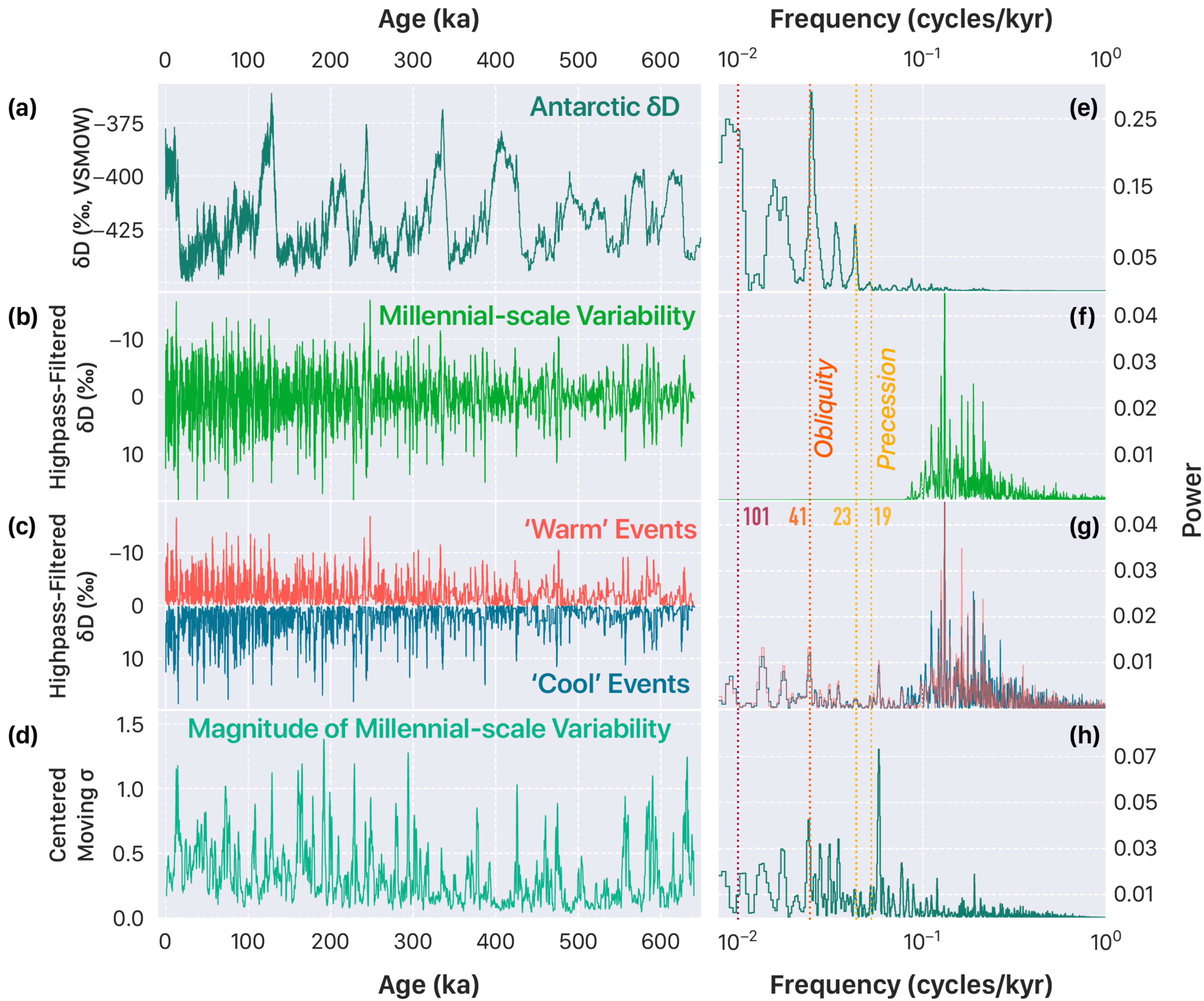
Age (ka)
0
100
200
300
400
500
600
(c)
12
8
4
0
MMV Antarctic δD
1.5
1.0
0.5
0
MMV Chinese δ18O
(d)
4
8
16
32
64
128
Period (kyrs)
19
23
41
101
1
0.8
0.6
0.4
0.2
0
Coherence
Age (ka)

Summary

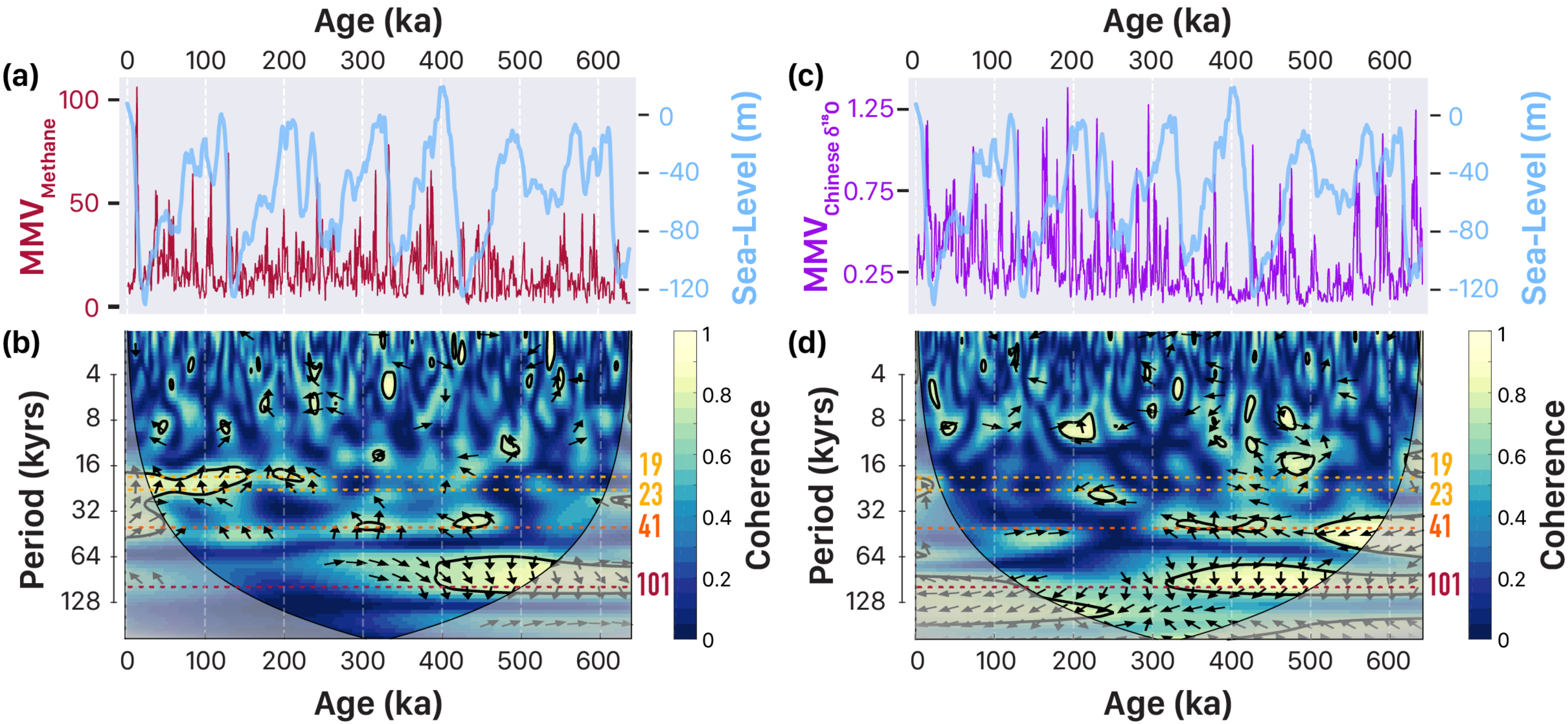
- Strong evidence for millennial-scale activity in methane modulated by insolation - particularly precession
- If taken at face value, Chinese $\delta^{18}O$ record of East Asian monsoon intensity not modulated by insolation
- Does the decoupling imply a high-latitude source of methane for abrupt climate change events?
- Monsoons seem to be modulated by processes internal to the climate system

Open Questions

- Can we constrain sources of methane in Pleistocene?
- How do uncertainties in Chinese speleothem $\delta^{18}O$ shift this interpretation?
- Could modulation paradigm be applied to other time periods?
- How can we explain increasing trend of millennial-scale activity?



Age (ka)
Frequency (cycles/kyr)
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
Antarctic δD
δD (‰, VSMOW)
Millennial-scale Variability
Highpass-Filtered δD (‰)
'Warm' Events
'Cool' Events
Magnitude of Millennial-scale Variability
Centered Moving σ
Obliquity
Precession
101
41
23
19
Power



Age (ka)
(a)
MMV$_{Methane}$
Sea-Level (m)
(b)
Period (kyrs)
Coherence
19
23
41
101
Age (ka)
(c)
MMV$_{Chinese\ \delta^{18}O}$
Sea-Level (m)
(d)
Period (kyrs)
Coherence
19
23
41
101

PERGAMON

Quaternary Science Reviews 22 (2003) 141–155

QSR

A methane-based time scale for Vostok ice

William F. Ruddiman[a,*], Maureen E. Raymo[b]

[a] Department of Environmental Sciences, University of Virginia, Clark Hall, Charlottesville, VA22903, USA
[b] Department of Earth Sciences, Boston University, Boston, MA 02215, USA

Received 7 February 2002; accepted 21 May 2002

Ruddiman and Raymo proposed that methane should follow precession because monsoons ought to follow precession (Kutzbach's idea)