Hyperthermals – rapid and extreme global warming in our geological past

The strength of methane hydrate feedbacks (aka 'Burps of Death') during the PETM :: Implications for our future hyperthermal?

Andy Ridgwell

University of California – Riverside
University of Bristol


vs.


Outline

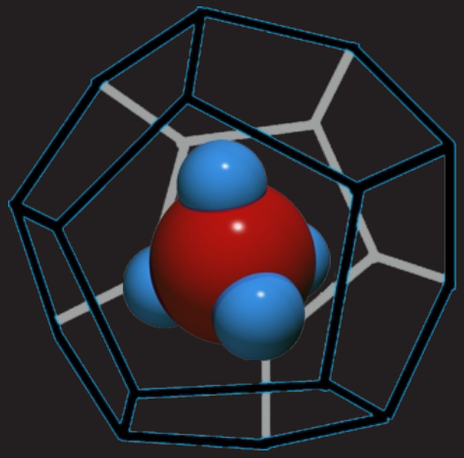
Methane hydrates 101.

Potential methane hydrate feedbacks on climate during Paleogene hyperthermals.

Did methane hydrates play a role (in the PETM)?
#1 – a forward modelling approach.

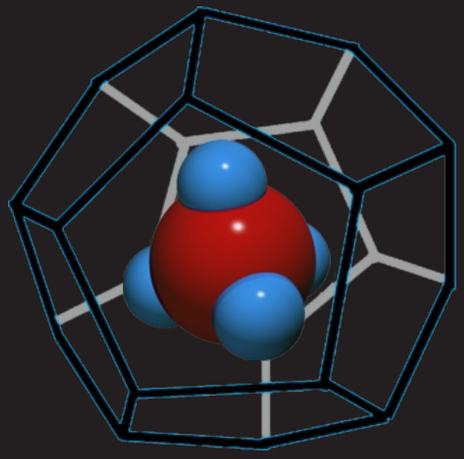
Did methane hydrates play a role (in the PETM)?
#2 – an inverse modelling approach.

Conclusions and implications for the PETM as a useful future 'analogue'.

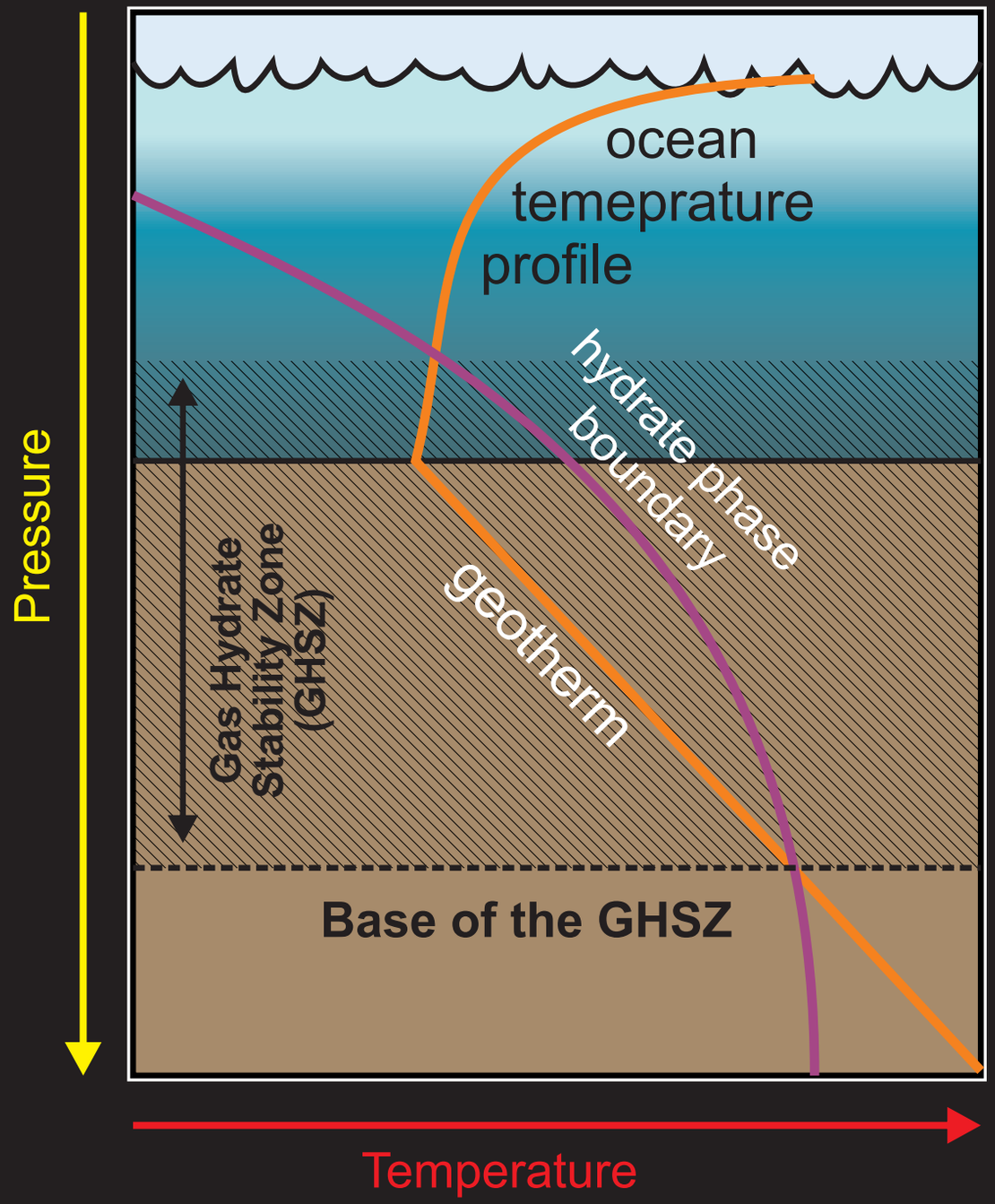


Outline

Methane hydrates 101.	*(anon)*
Potential methane hydrate feedbacks on climate during Paleogene hyperthermals.	*Dan Lunt, Appy Sluijs, James Zachos, Stephen Hunter, Alan Haywood.*
Did methane hydrates play a role (in the PETM)? #1 – a forward modelling approach.	*Mark Maslin, Ron Kahana, Daniela Schmidt.*
Did methane hydrates play a role (in the PETM)? #2 – an inverse modelling approach.	*Marcus Gutjahr, Gavin Foster, Philip Sexton, Paul Pearson*
Conclusions and implications for the PETM as a useful future 'analogue'.	*(anon)*



Climate fedback with methane hydrates



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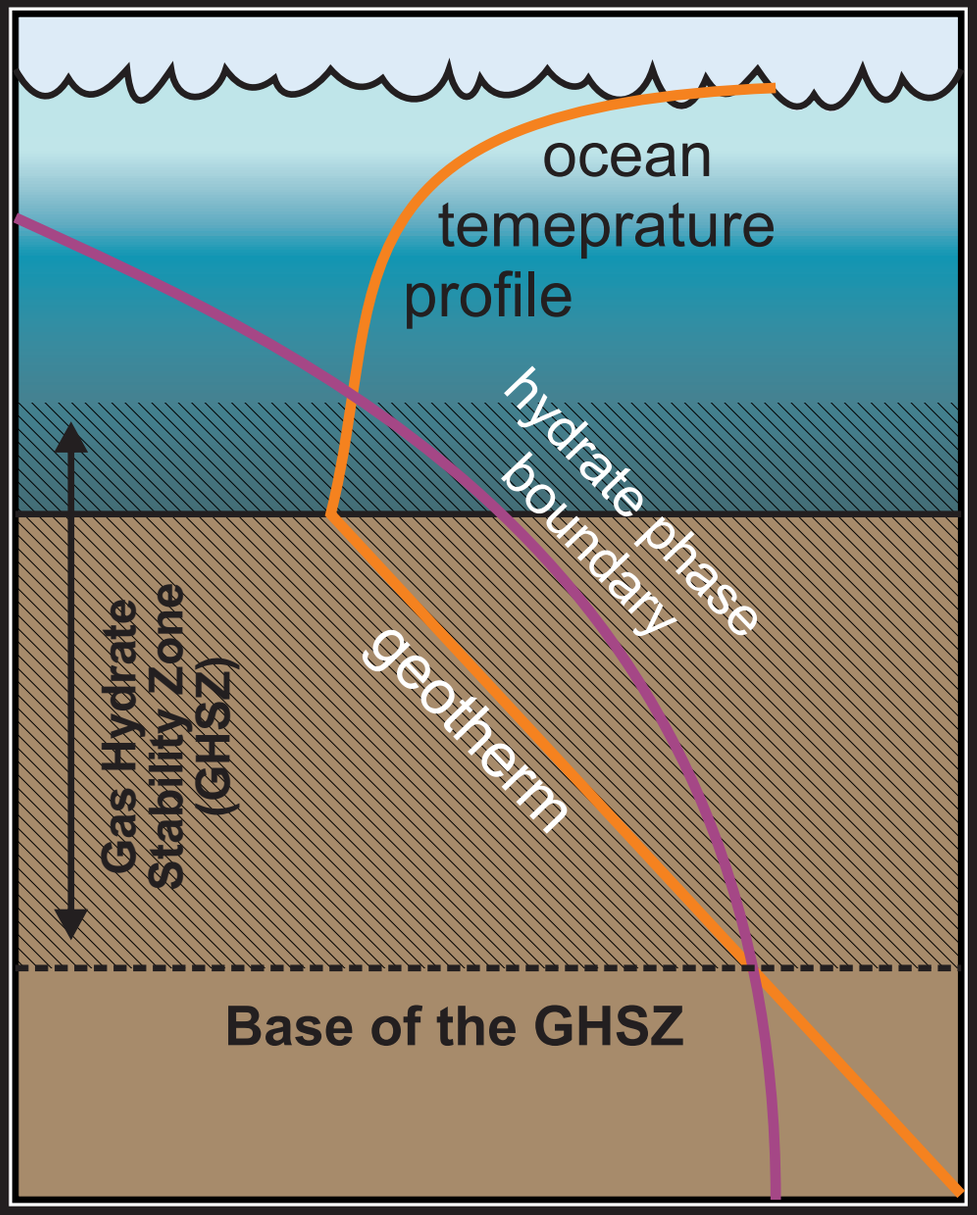

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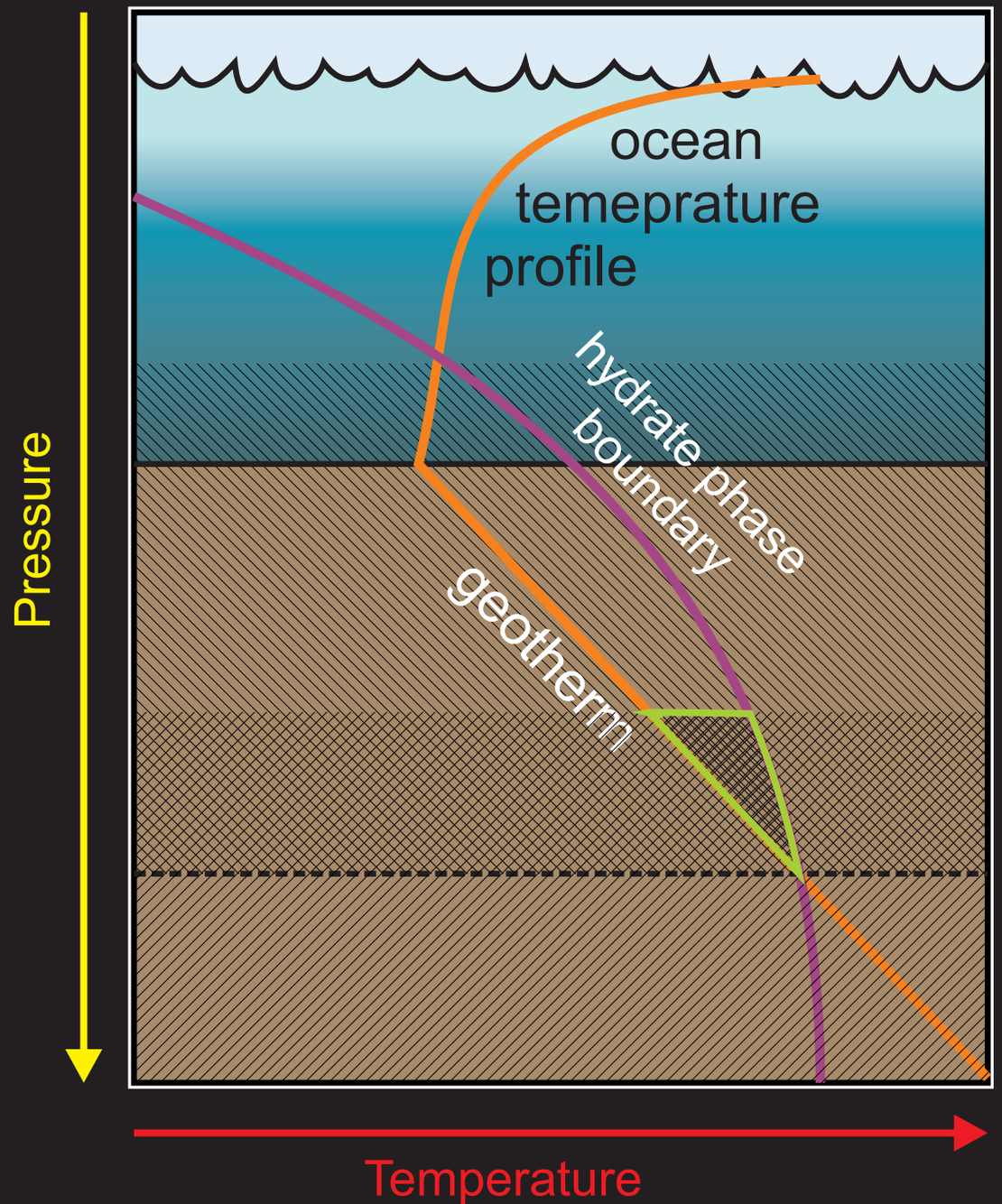
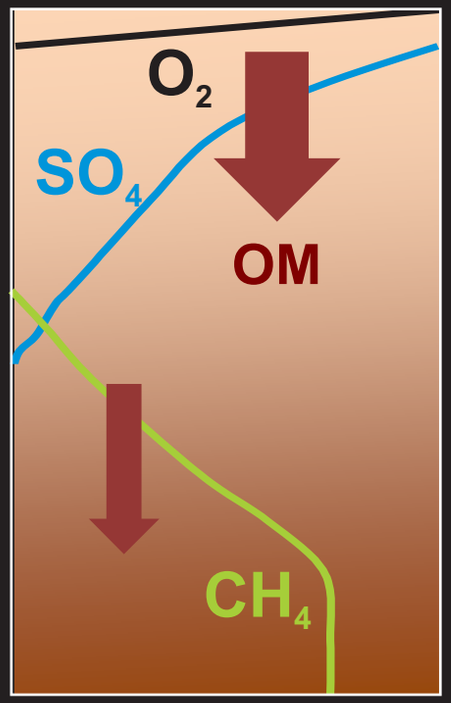
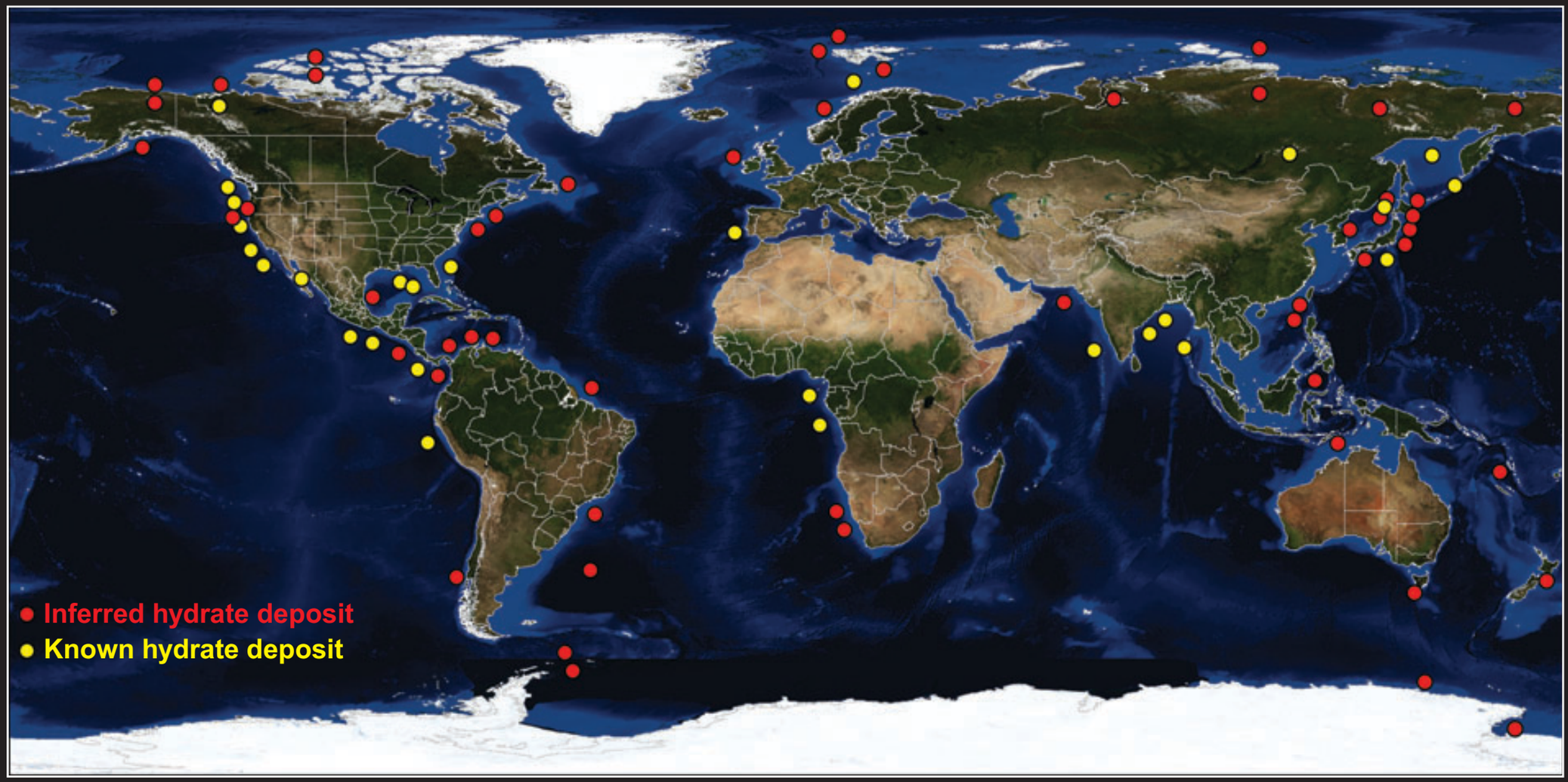


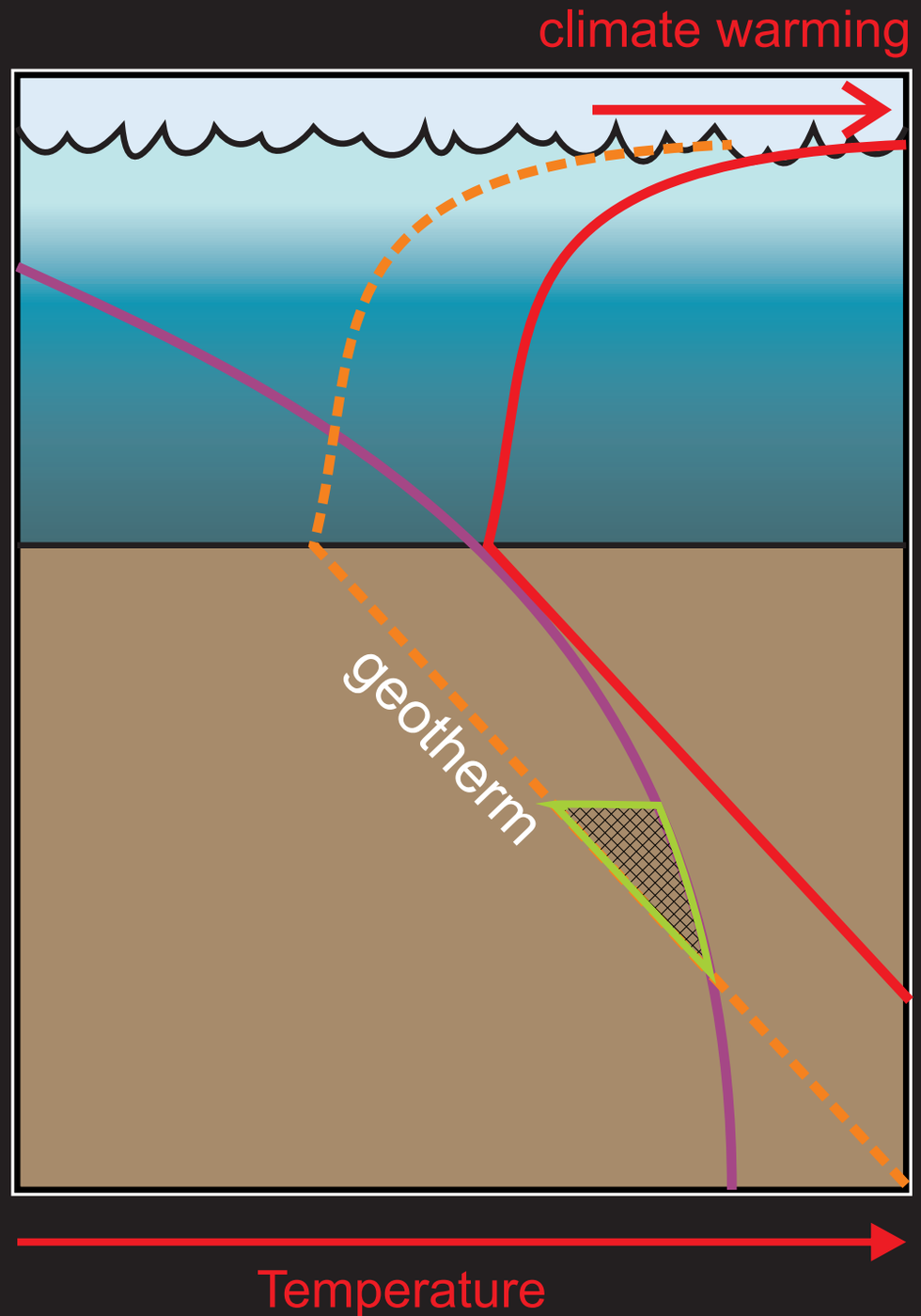


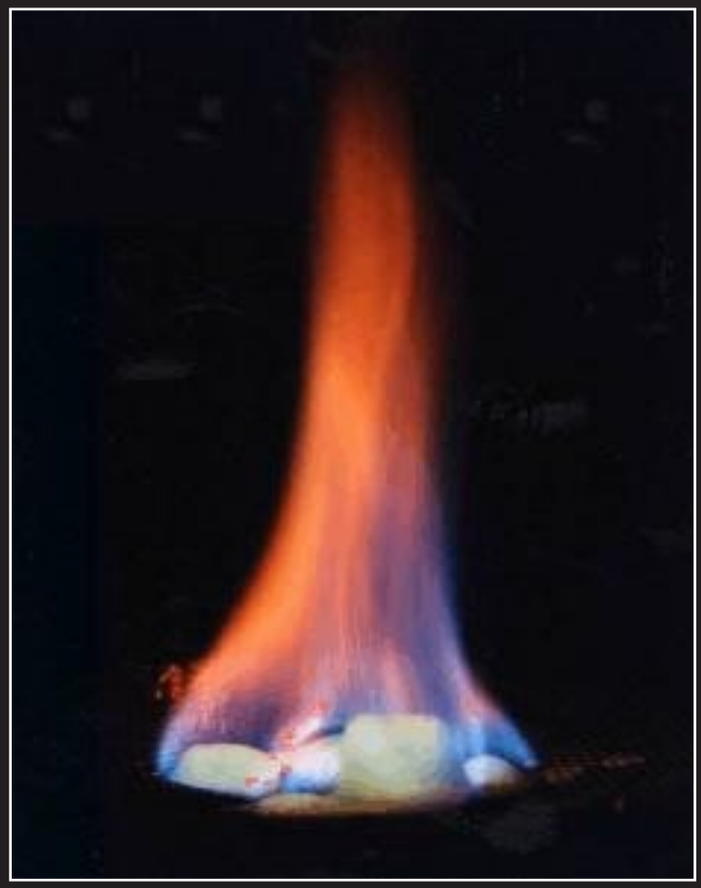
Climate fedback with methane hydrates



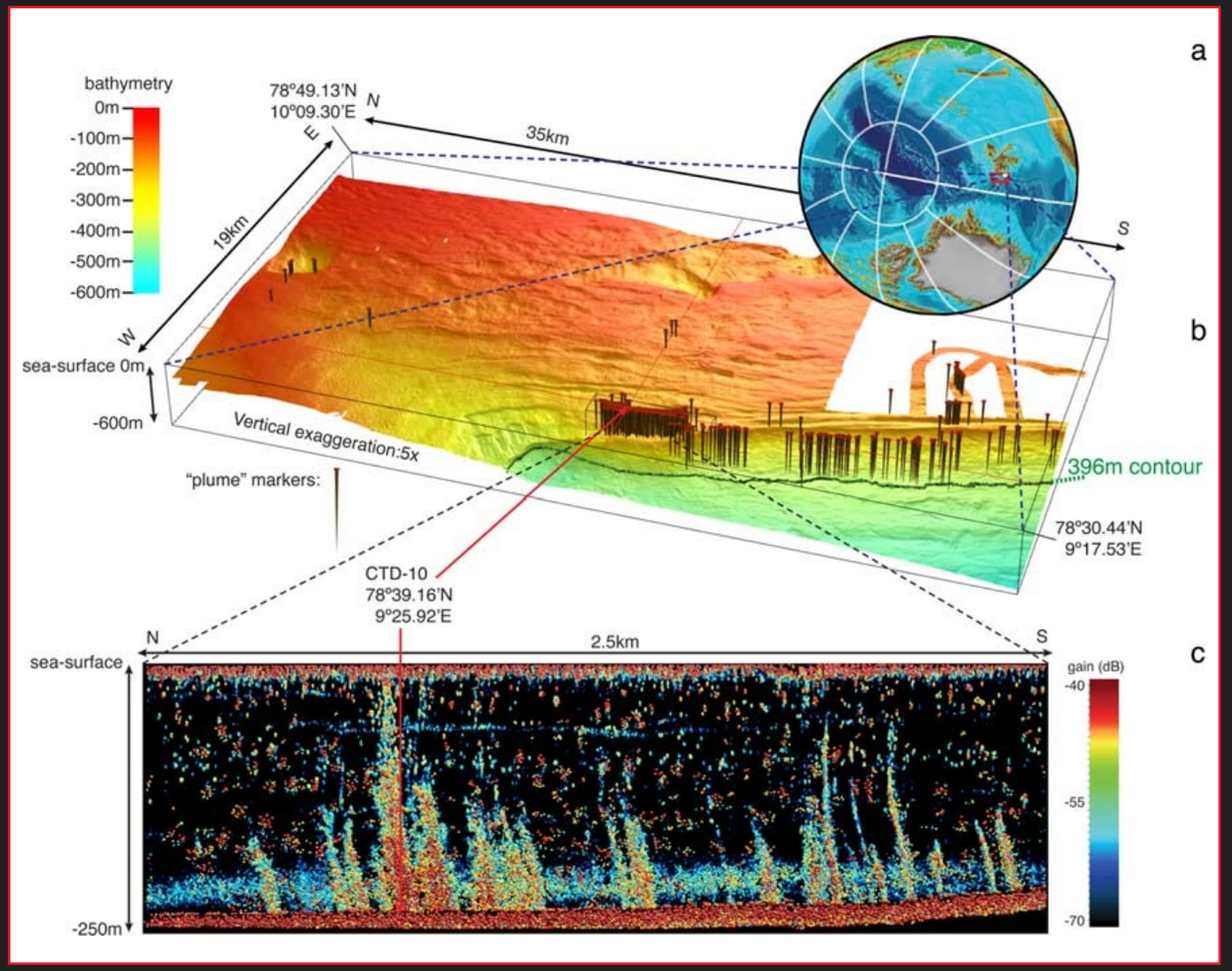
Hester and Brewer [2008]

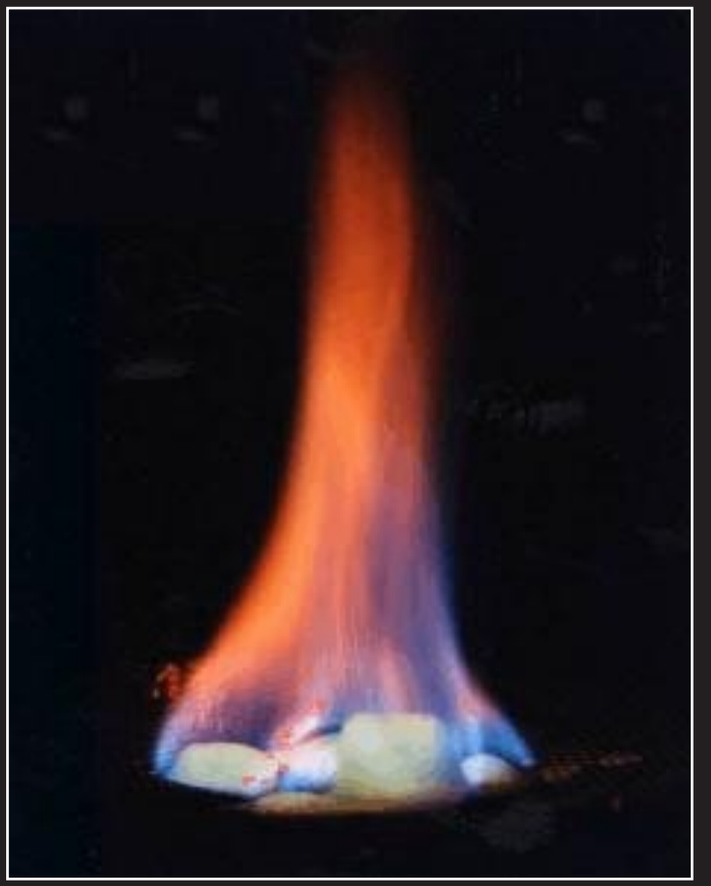
Climate fedback with methane hydrates





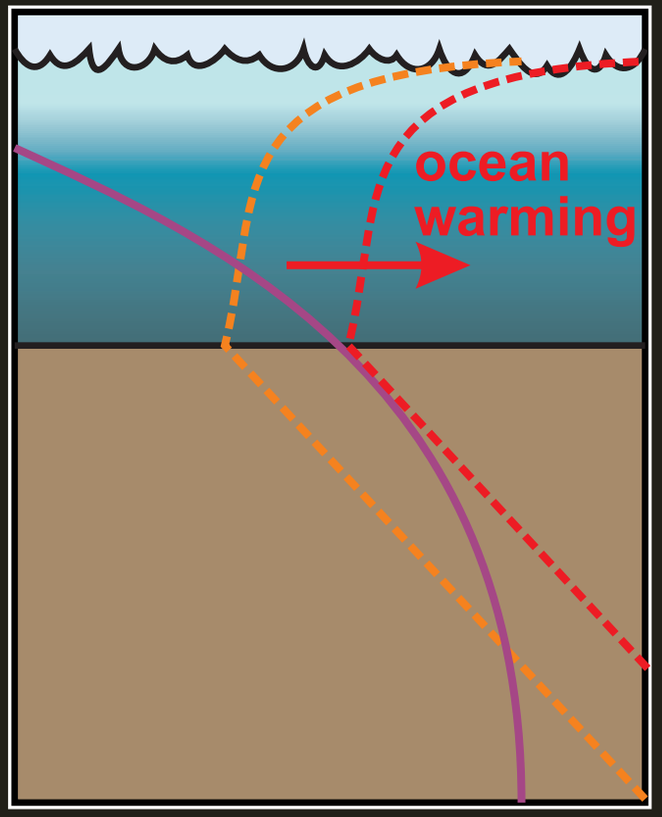
Climate fedback with methane hydrates

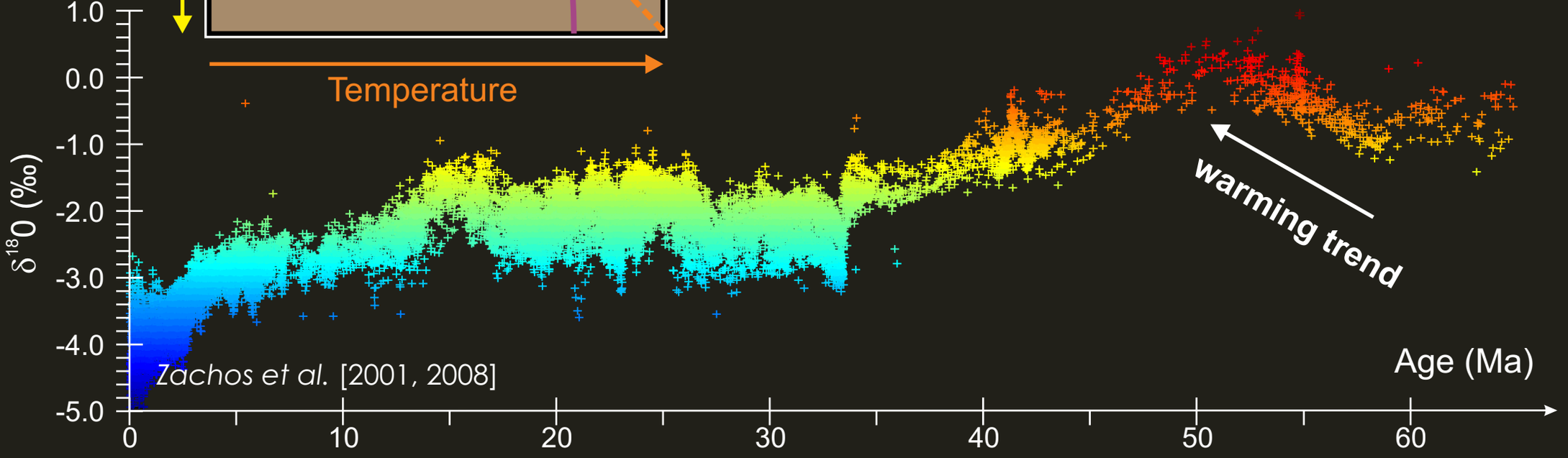




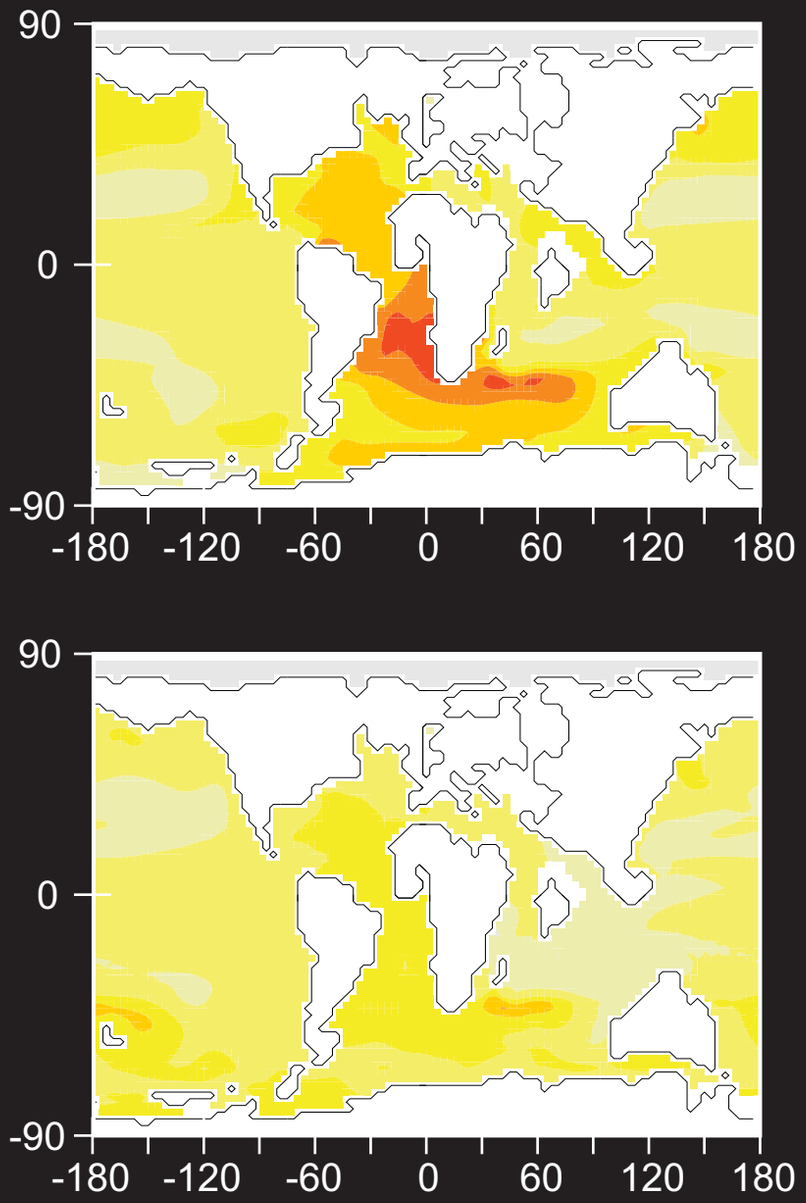
Westbrook et al. [2009]

Climate fedback with methane hydrates





Climate fedback with methane hydrates



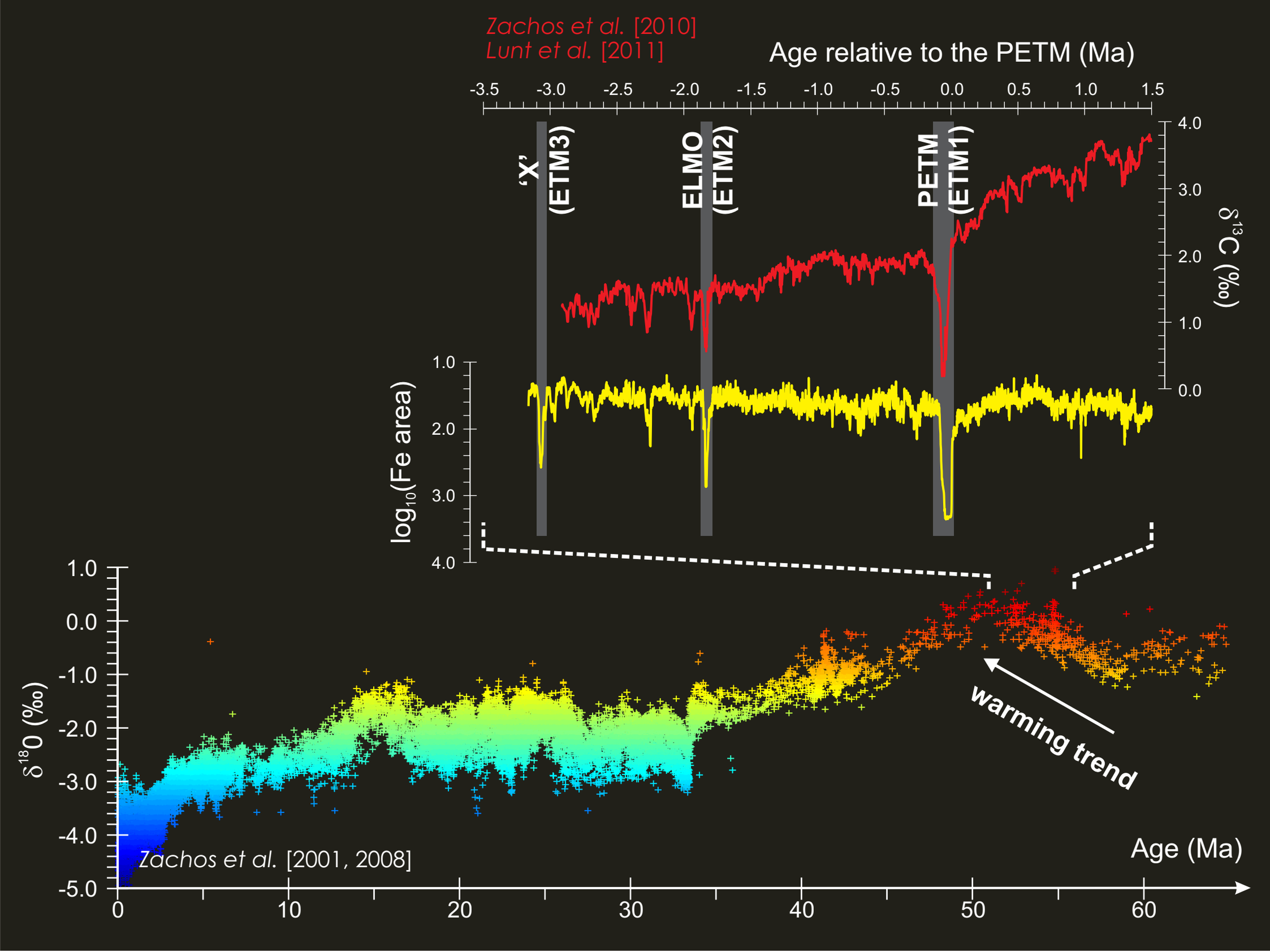
$\times 1CO_2 \rightarrow \times 4CO_2$

(normalized to a CO_2 doubling)

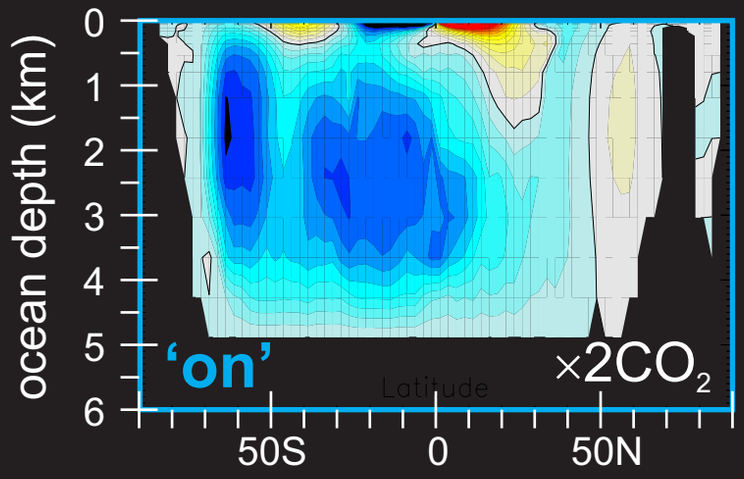
intermediate water depth warming

$\times 1CO_2 \rightarrow \times 2CO_2$

Lunt et al. [2010]


Zachos et al. [2010]
Lunt et al. [2011]
Age relative to the PETM (Ma)
-3.5
-3.0
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
'X' (ETM3)
ELMO (ETM2)
PETM (ETM1)
4.0
3.0
2.0
1.0
0.0
δ13C (‰)
log10(Fe area)
1.0
2.0
3.0
4.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
δ18O (‰)
warming trend
Zachos et al. [2001, 2008]
Age (Ma)
0
10
20
30
40
50
60

increasing CO_2 and radiative forcing

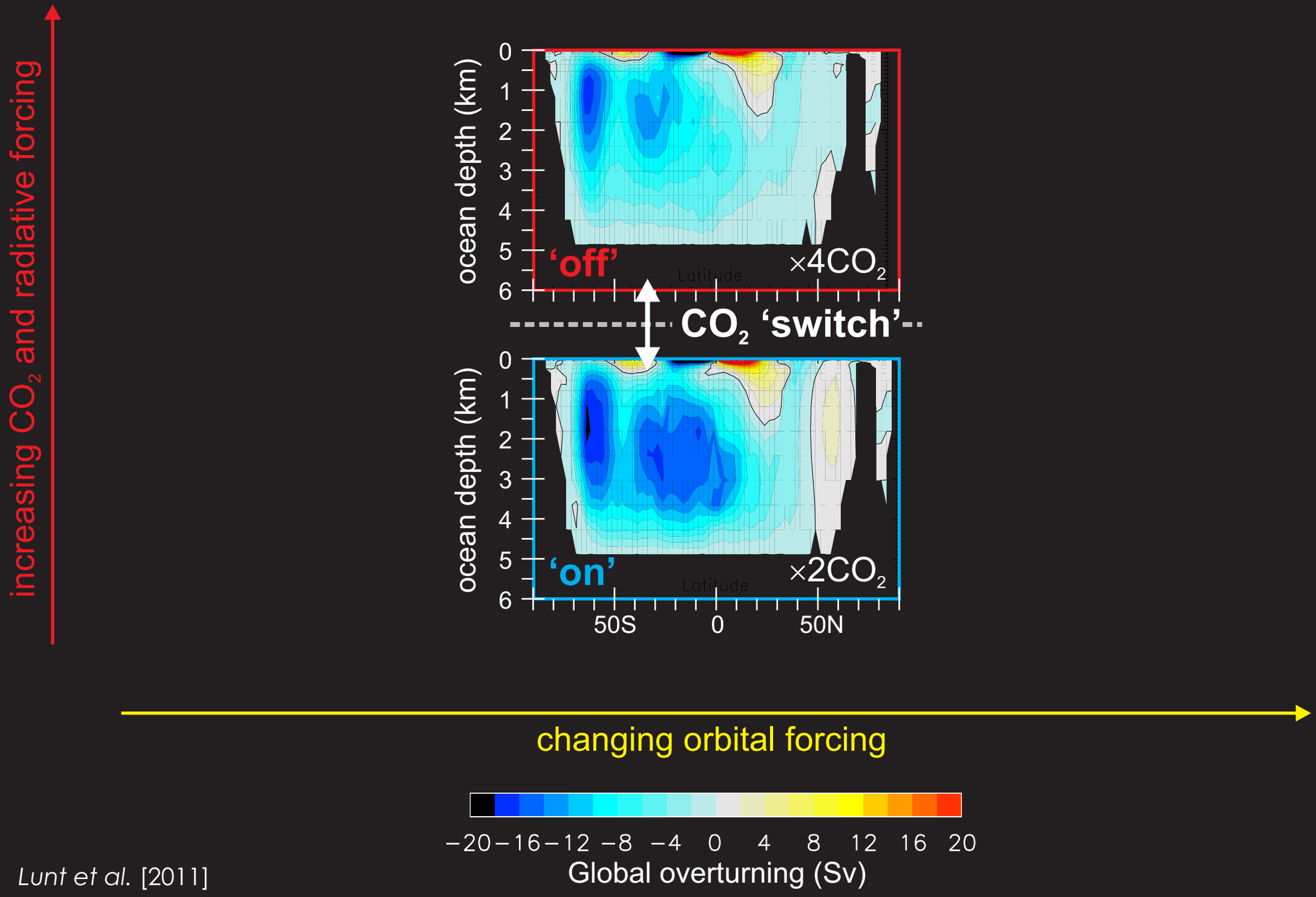


changing orbital forcing

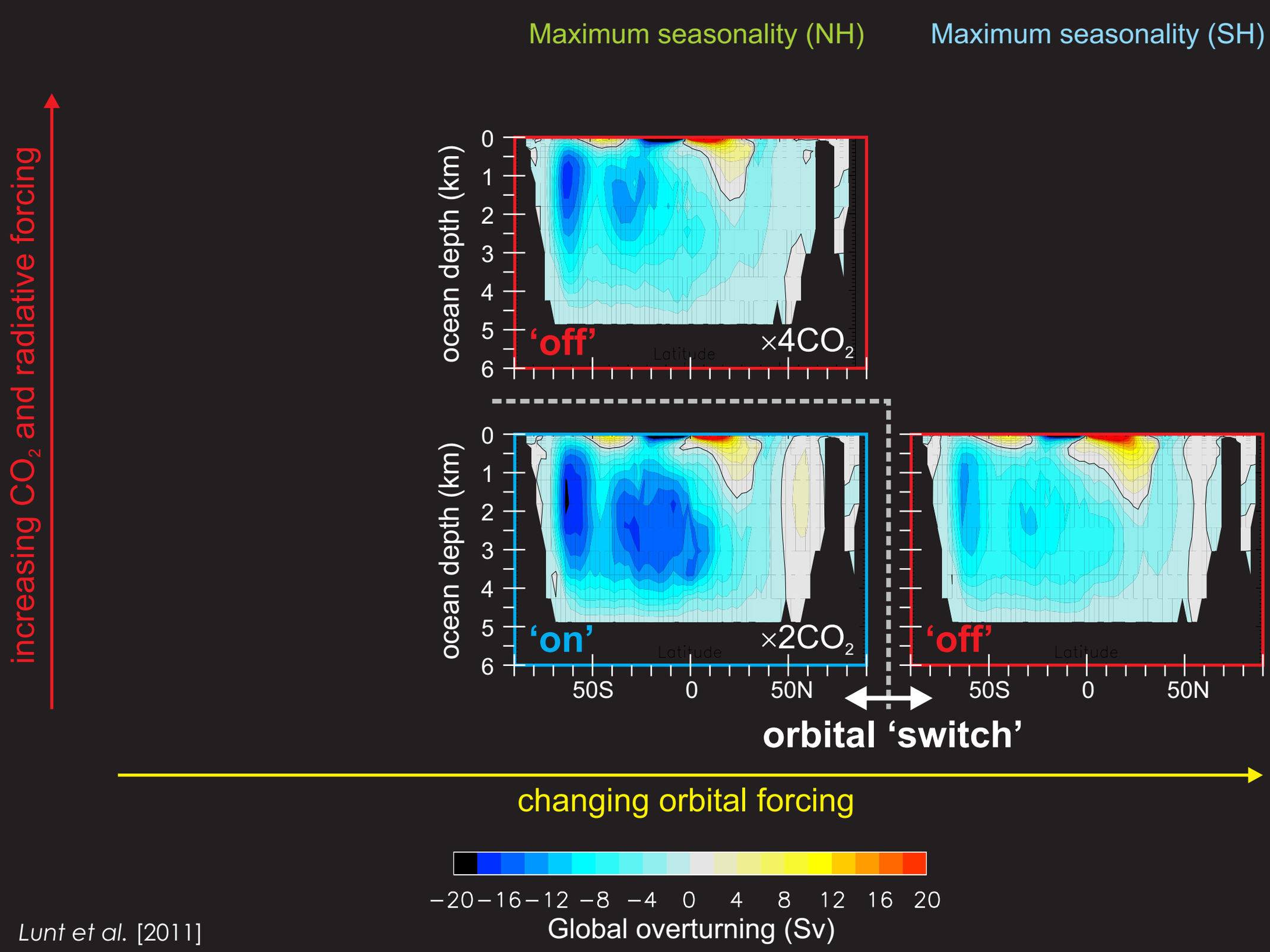
−20 −16 −12 −8 −4 0 4 8 12 16 20

Global overturning (Sv)

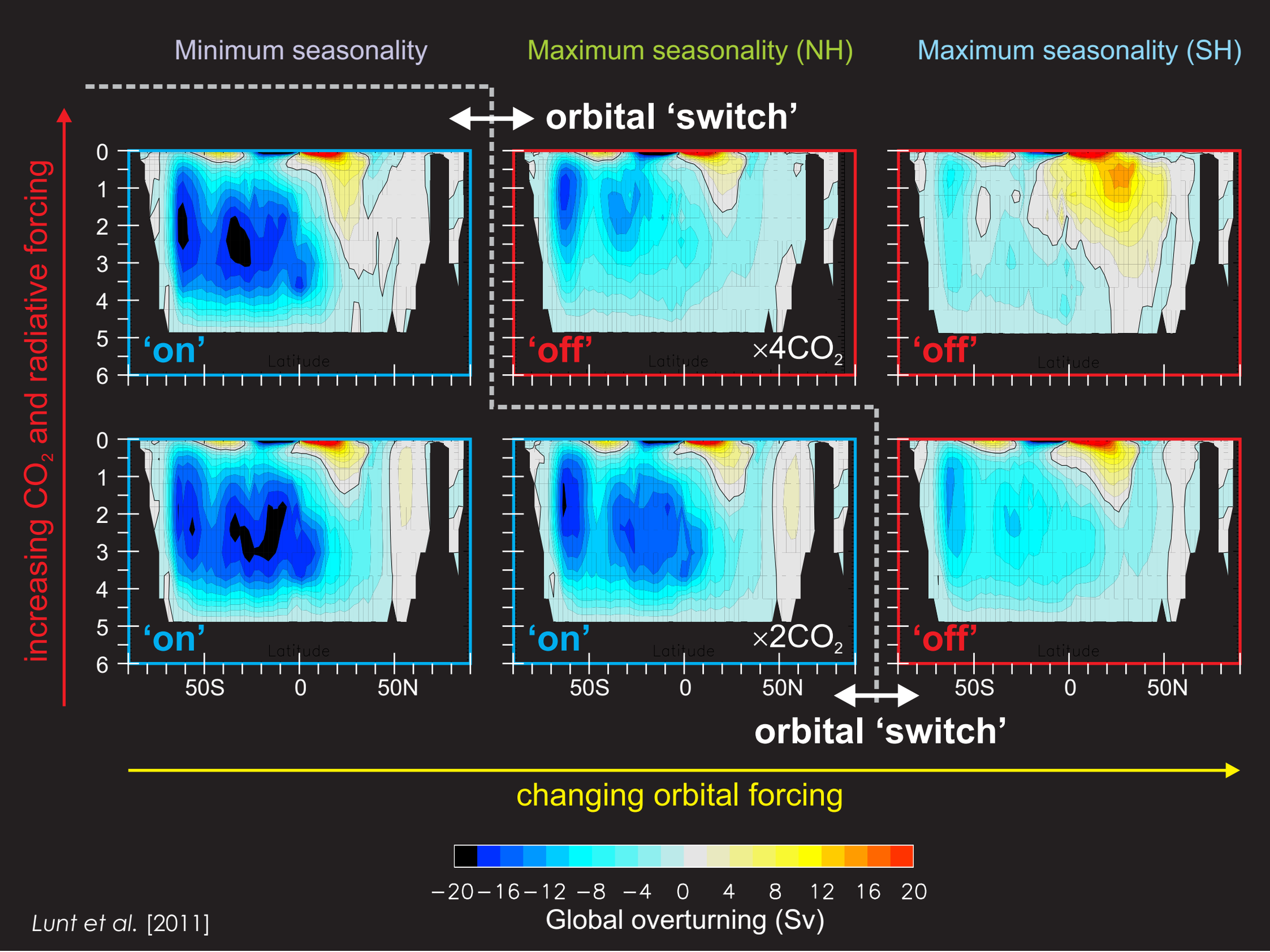
Lunt et al. [2011]



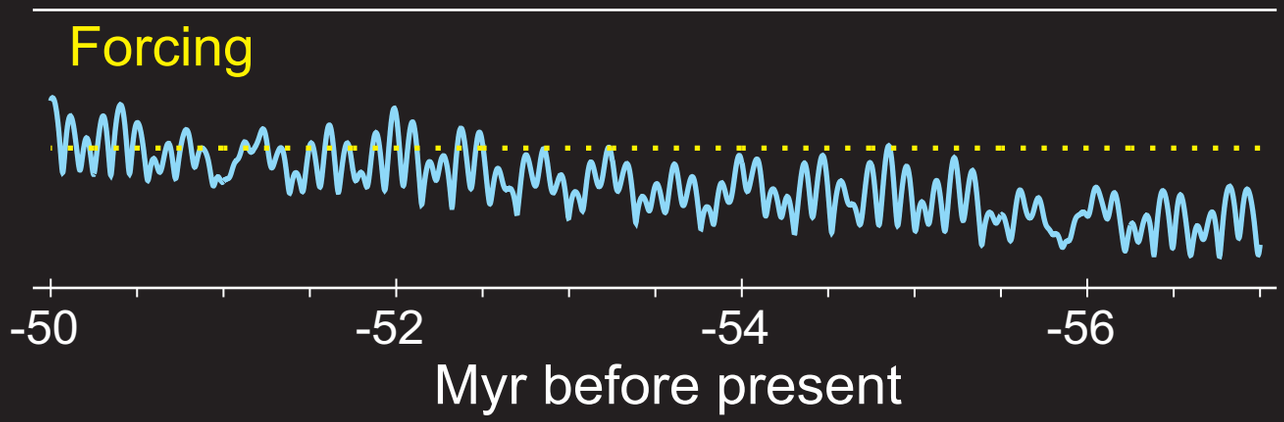
Lunt et al. [2011]



Lunt et al. [2011]



Lunt et al. [2011]



Orbital pacing of methane hydrate destabilisation during the Palaeogene?

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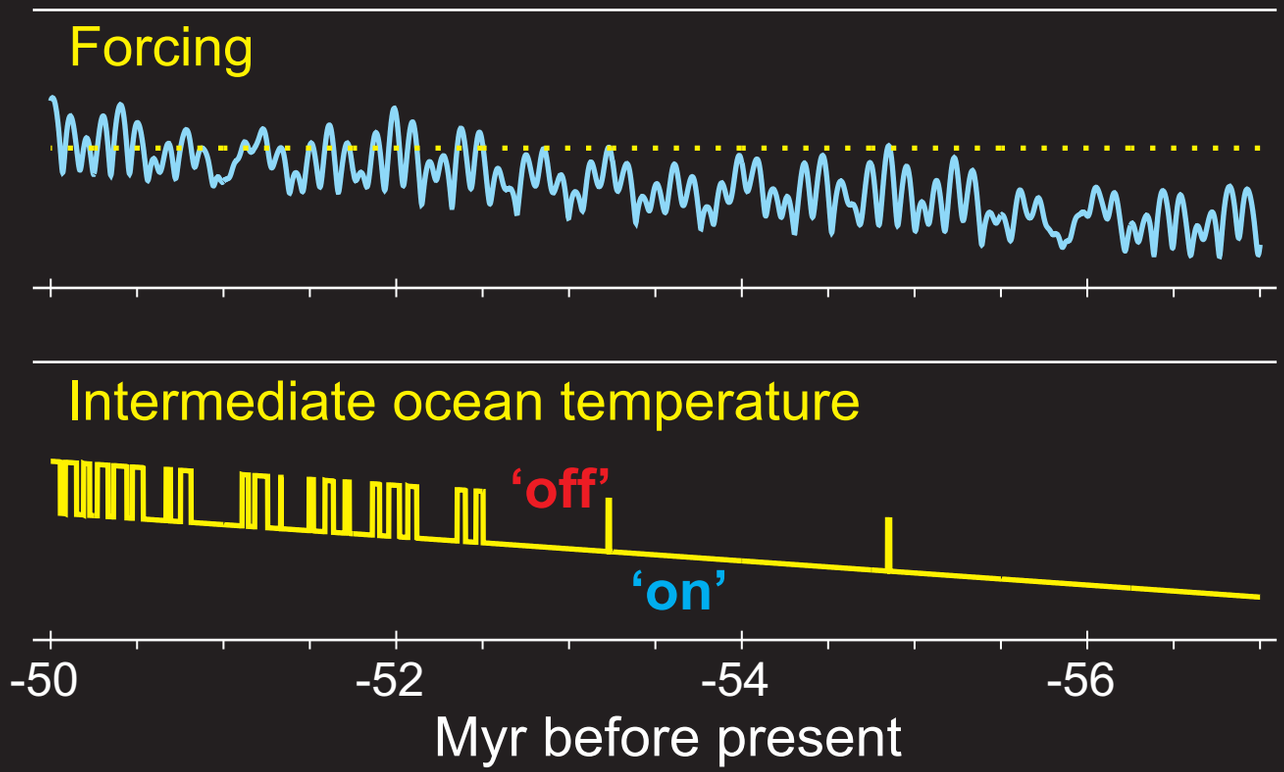
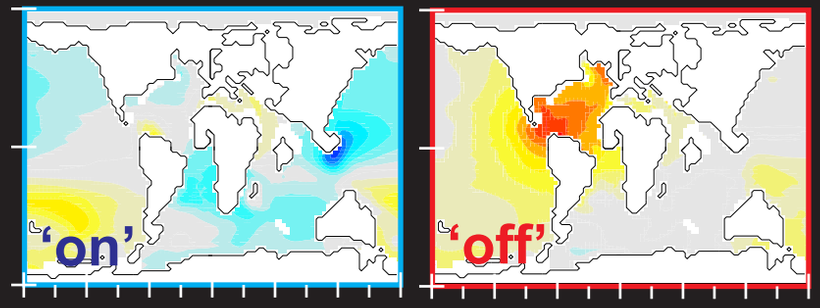
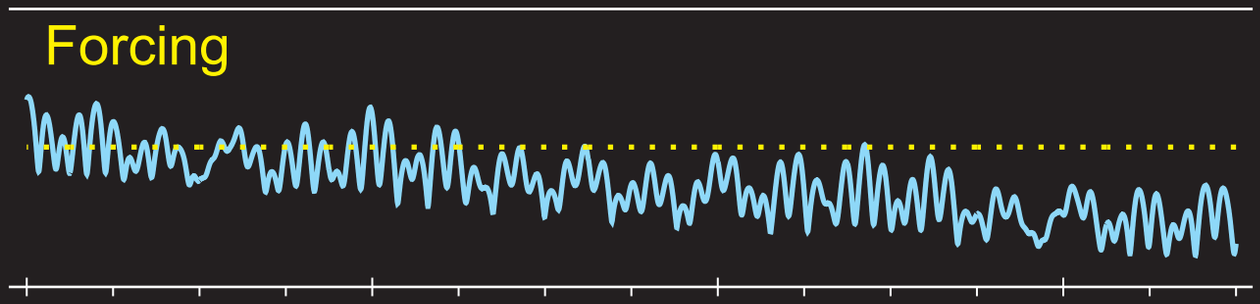
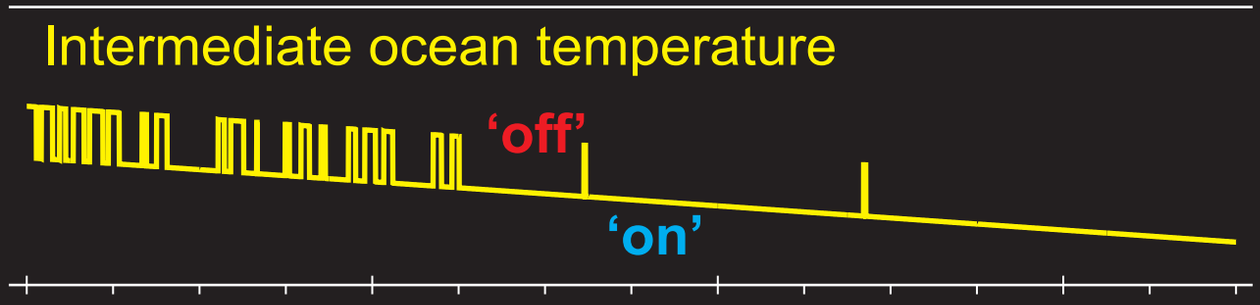
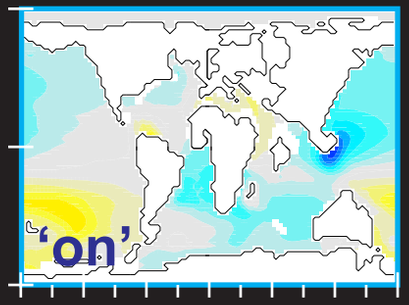


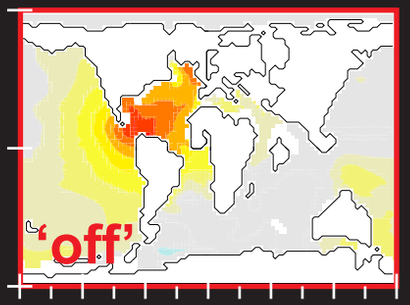


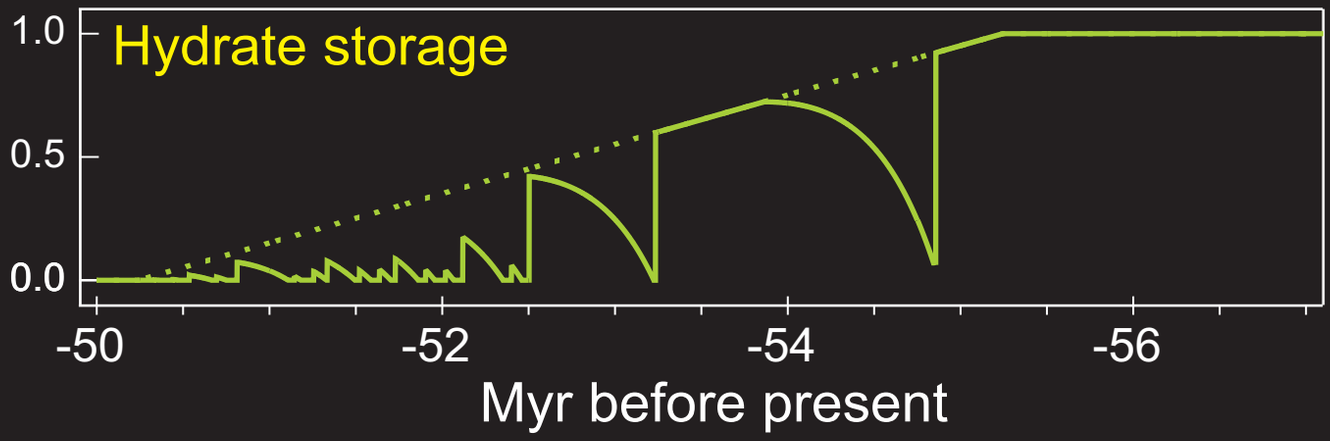
Orbital pacing of methane hydrate destabilisation during the Palaeogene?



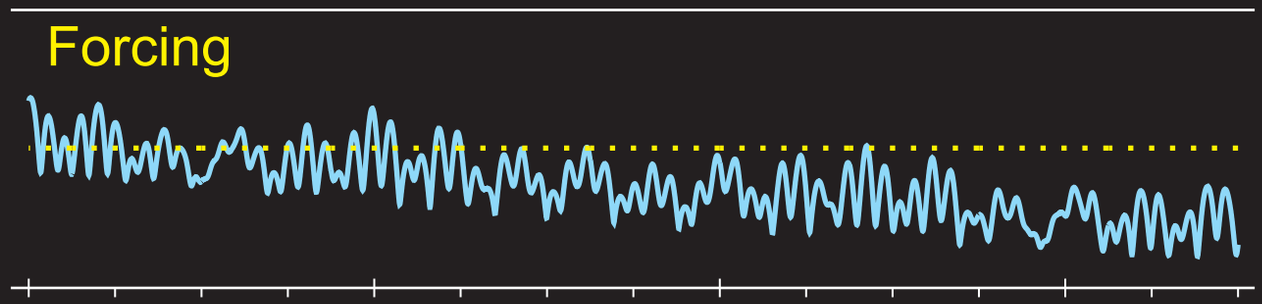


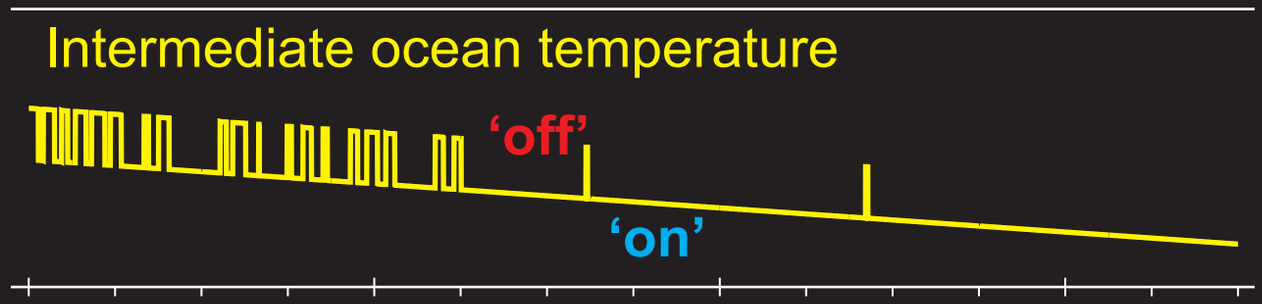


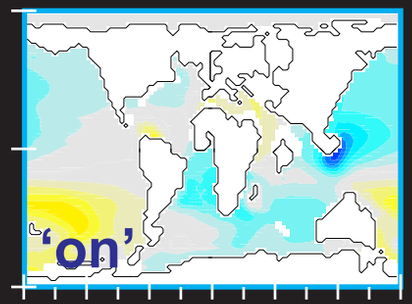


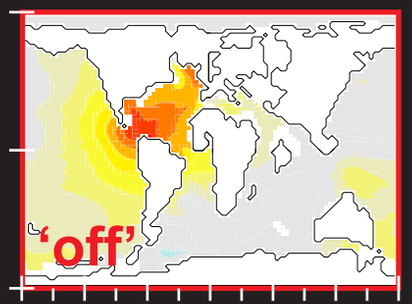


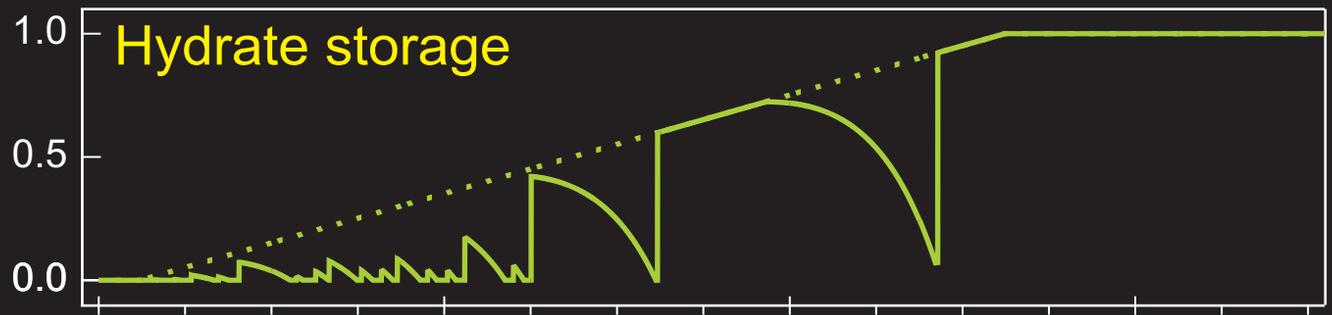
Orbital pacing of methane hydrate destabilisation during the Palaeogene?

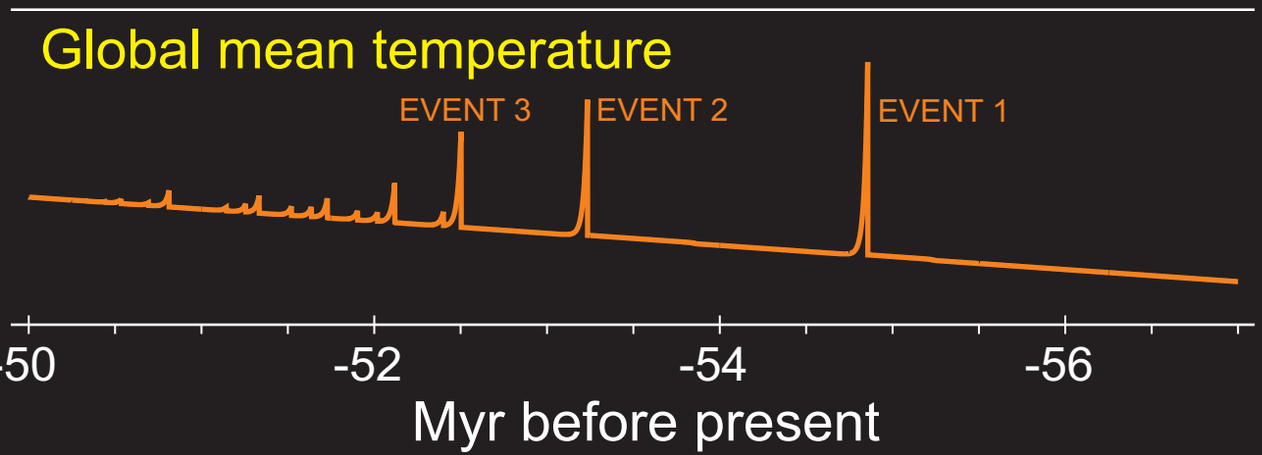












Climate fedback with methane hydrates

biological productivity

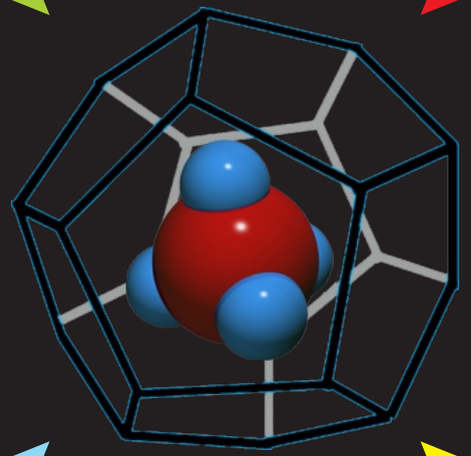
climate and ocean circulation

greenhouse gas forcing

ocean $[O_2]$

sedimentary organic matter burial flux

bottom-water temperature

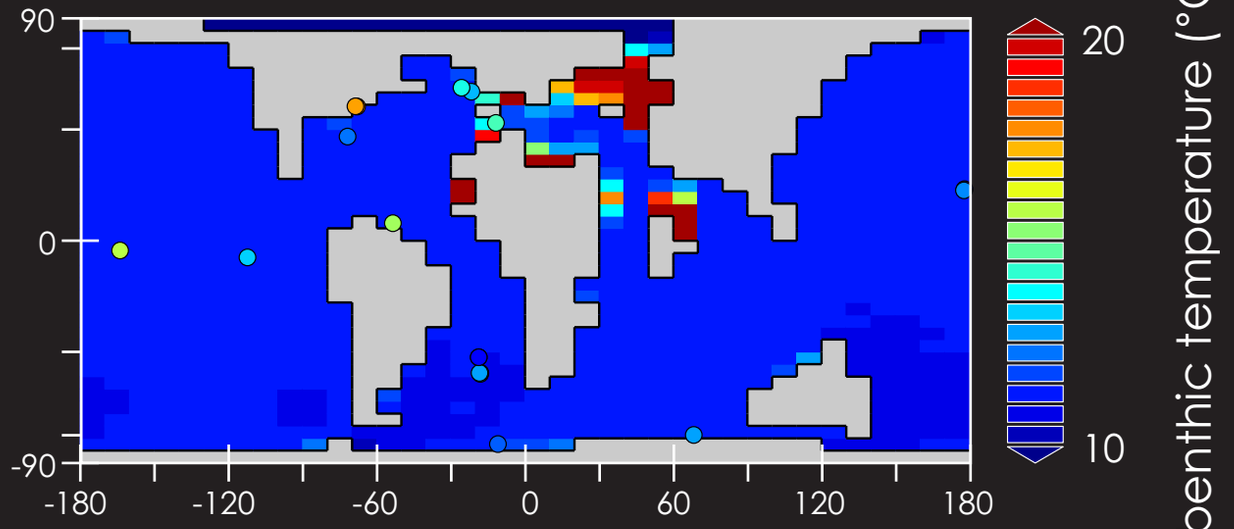


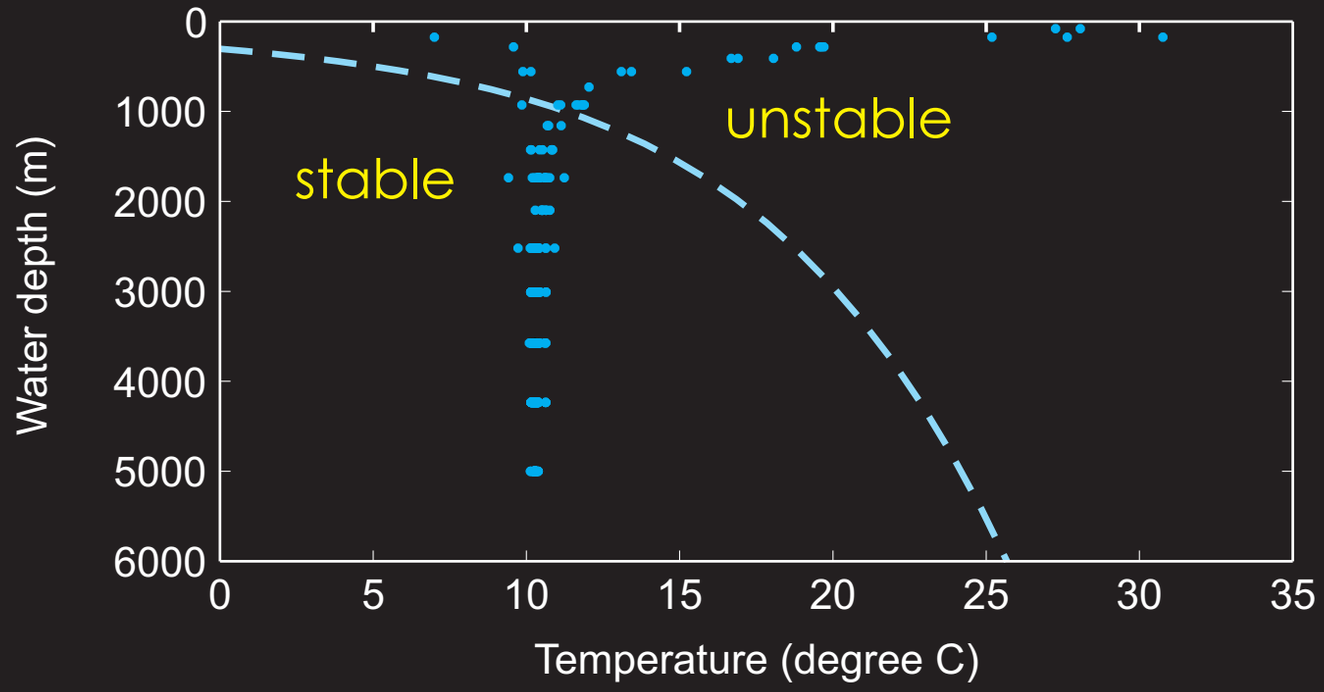
paleo topography

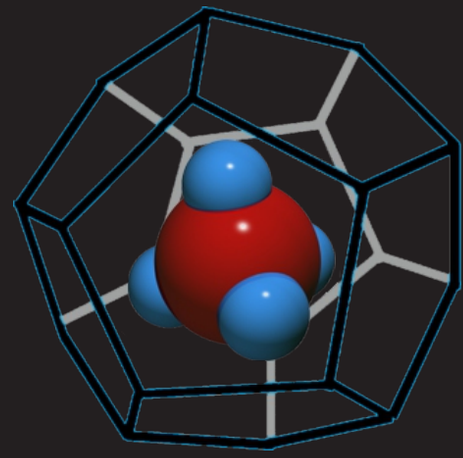
pressure

active/passive margin
bulk sedimentation rate
geothermal gradient
organic matter degradability

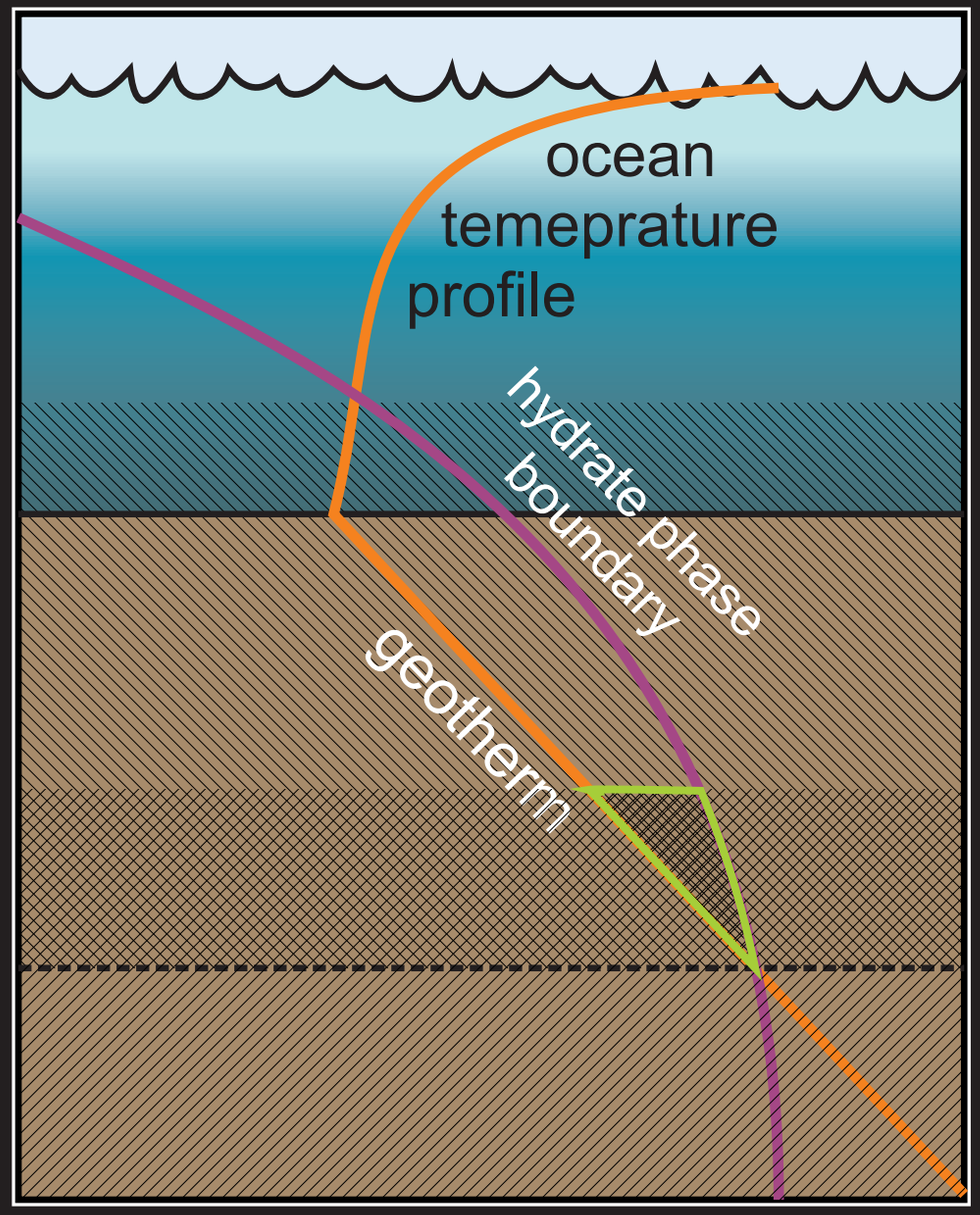
Climate fedback with methane hydrates

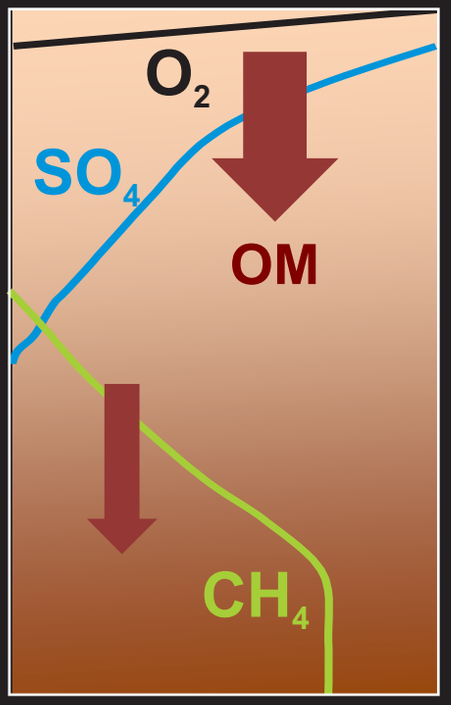


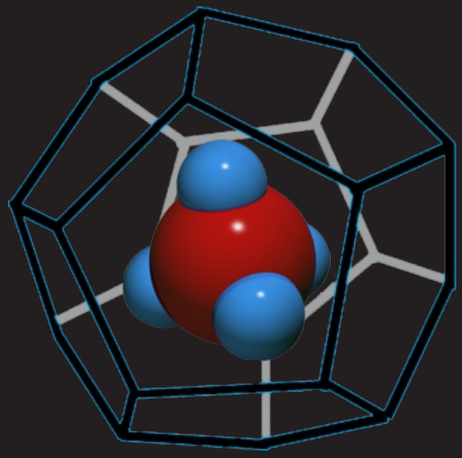




Climate fedback with methane hydrates







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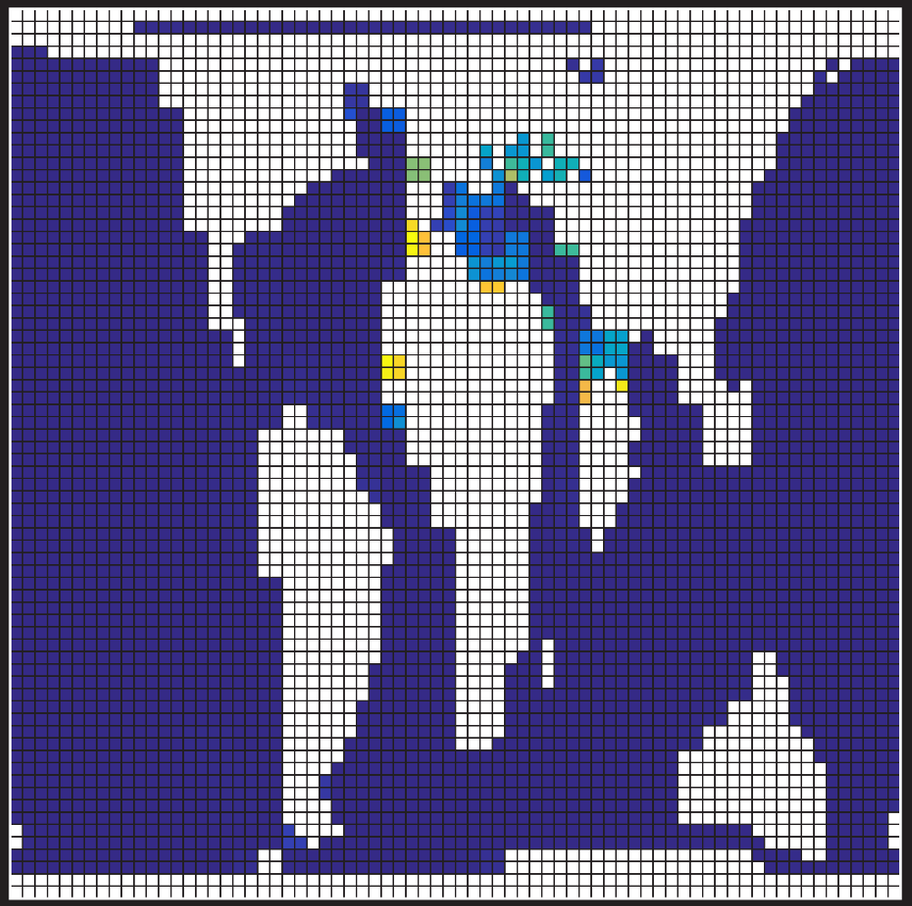

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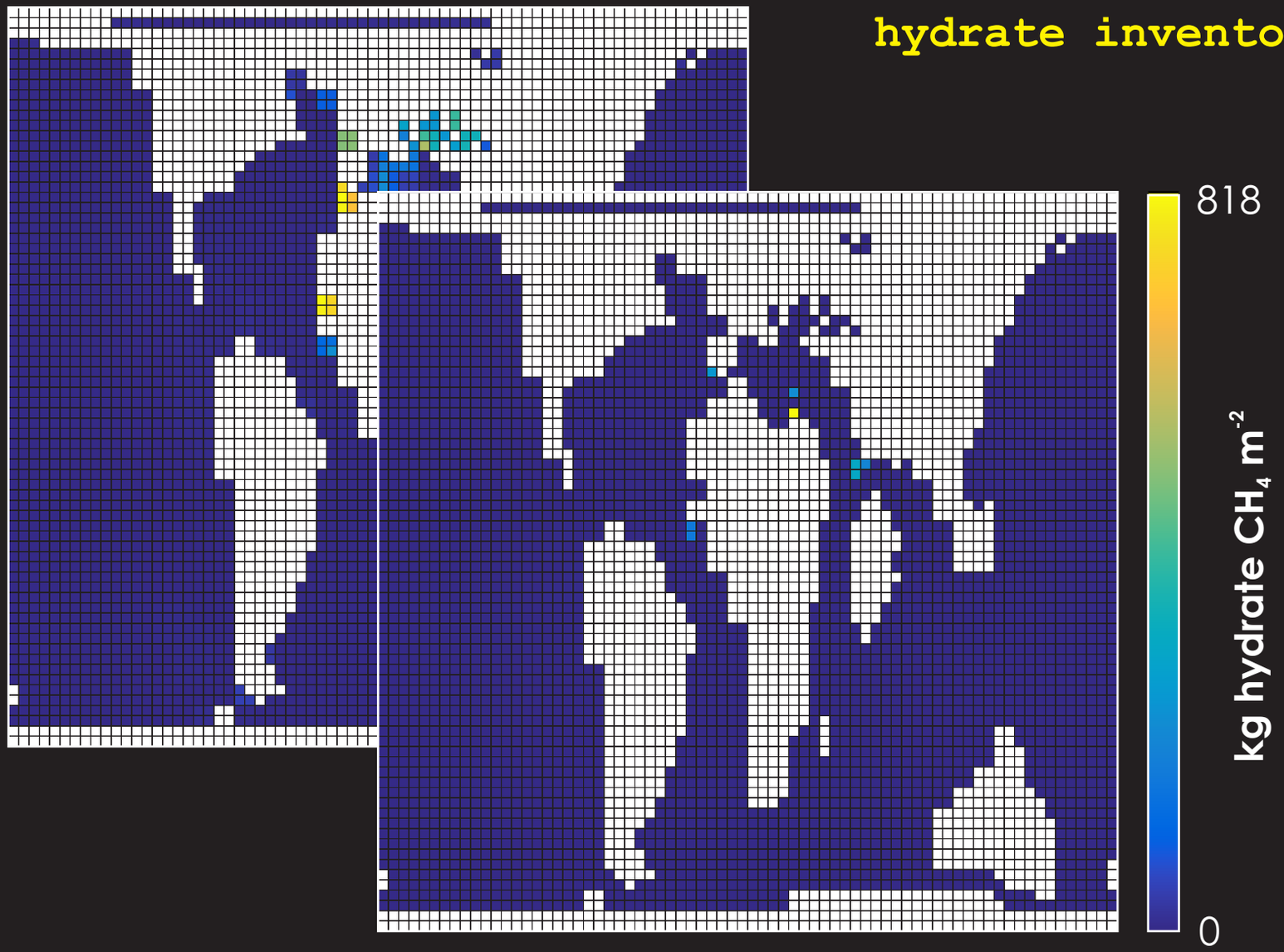

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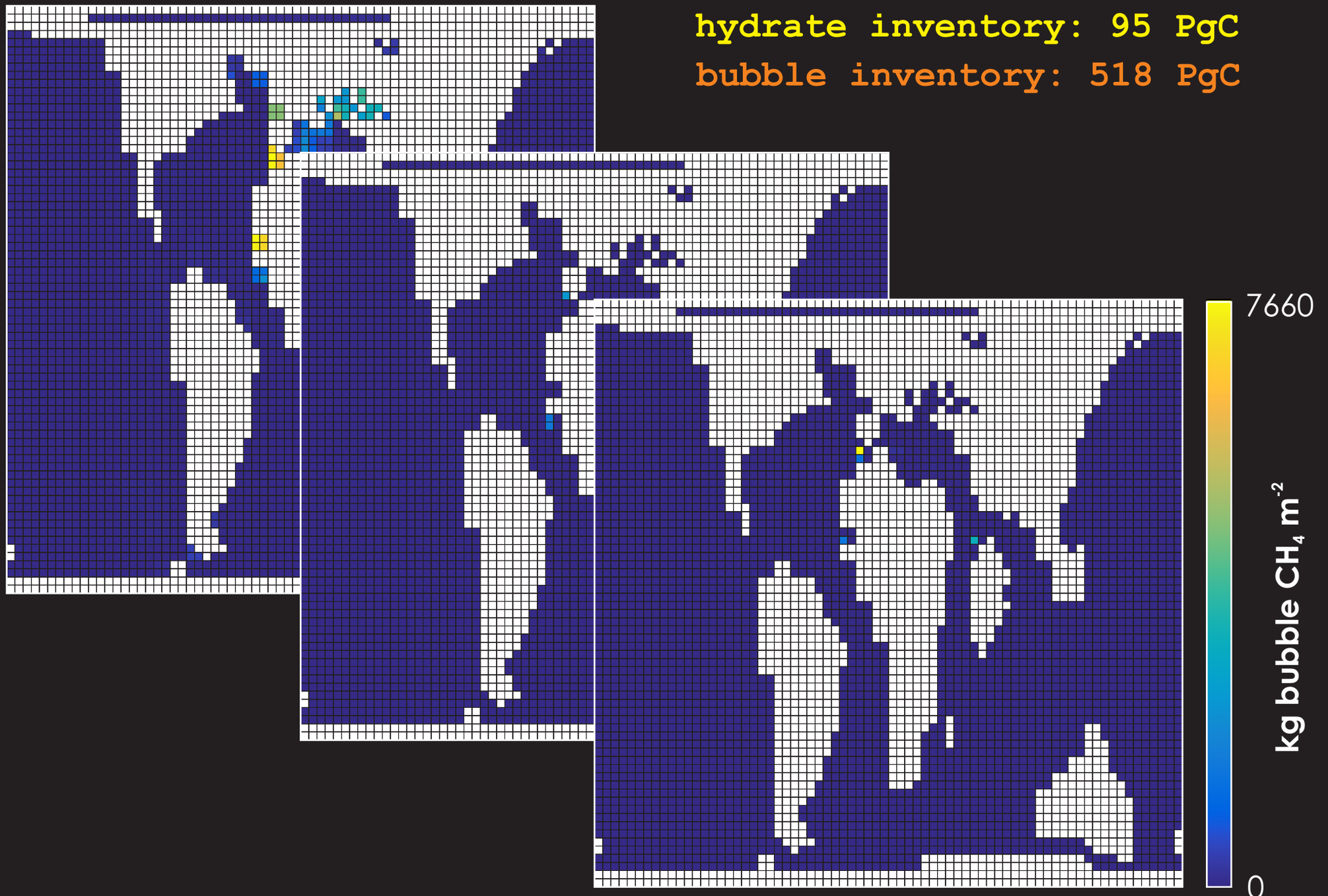
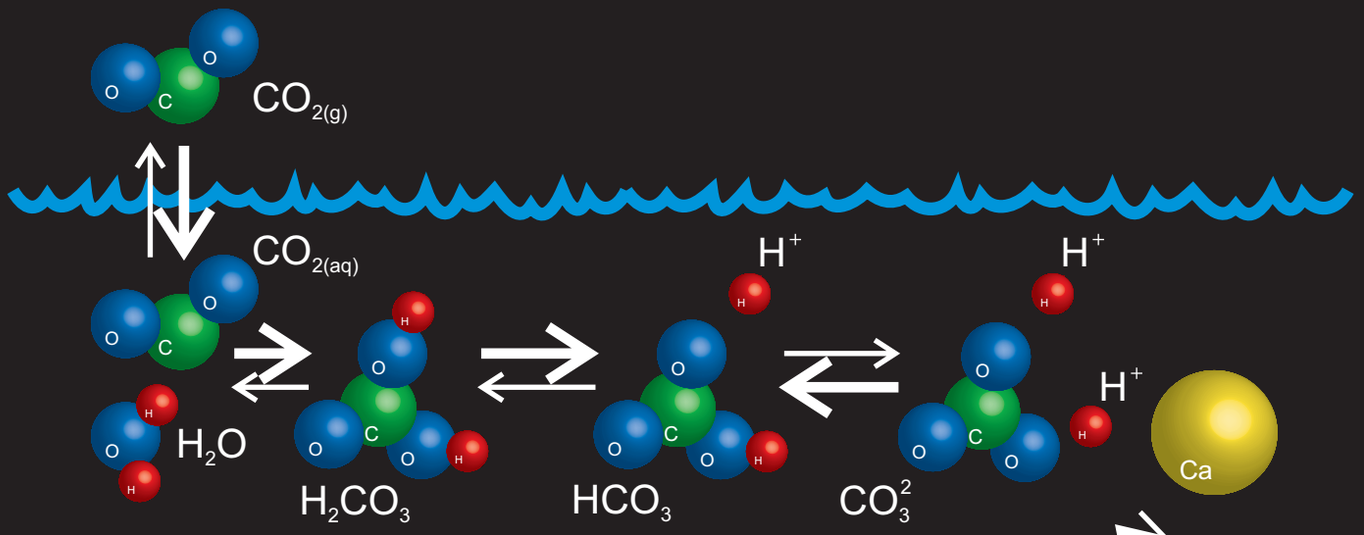
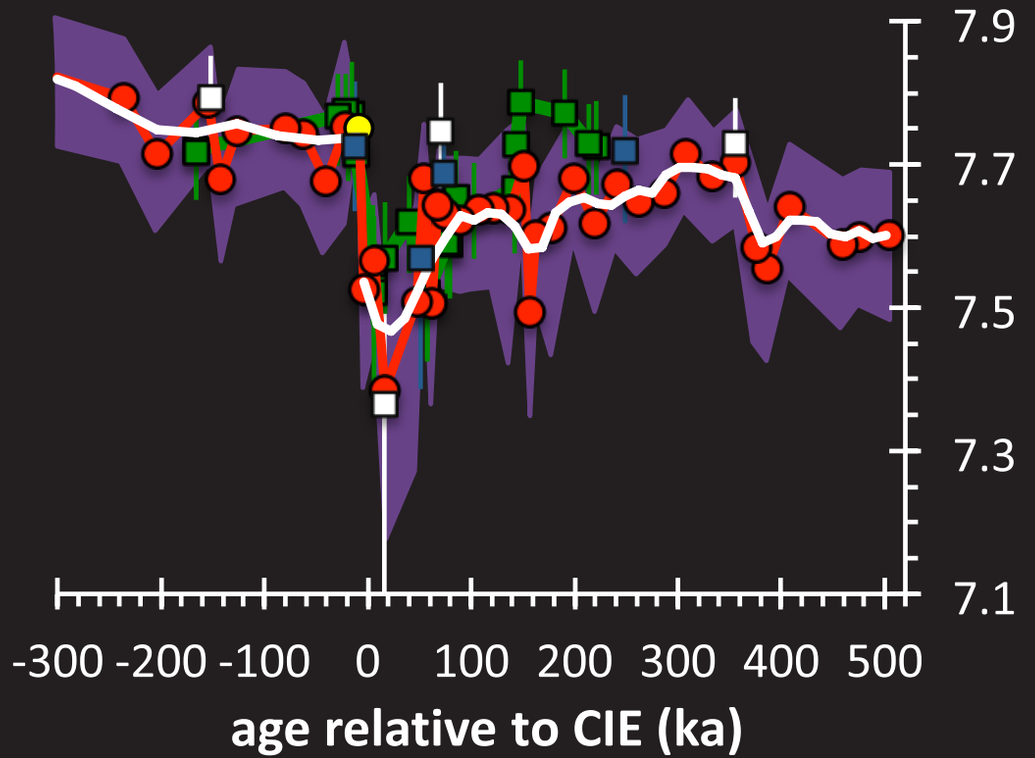
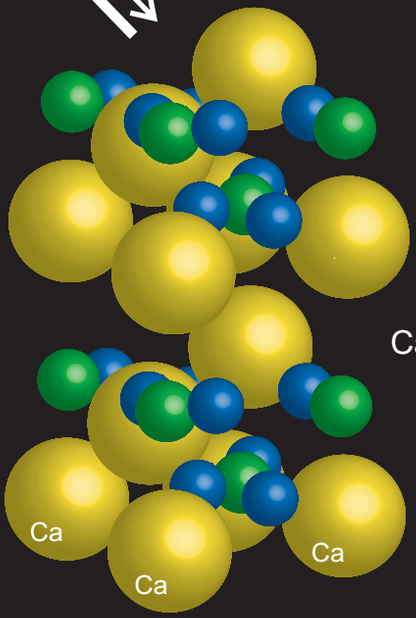


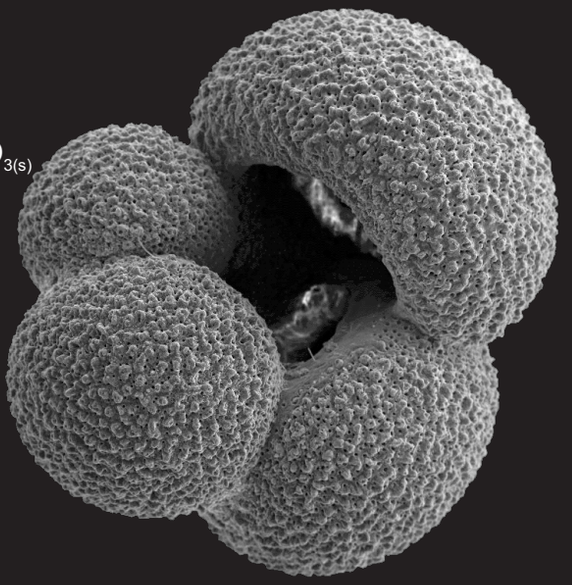
Climate fedback with methane hydrates – inverse modelling



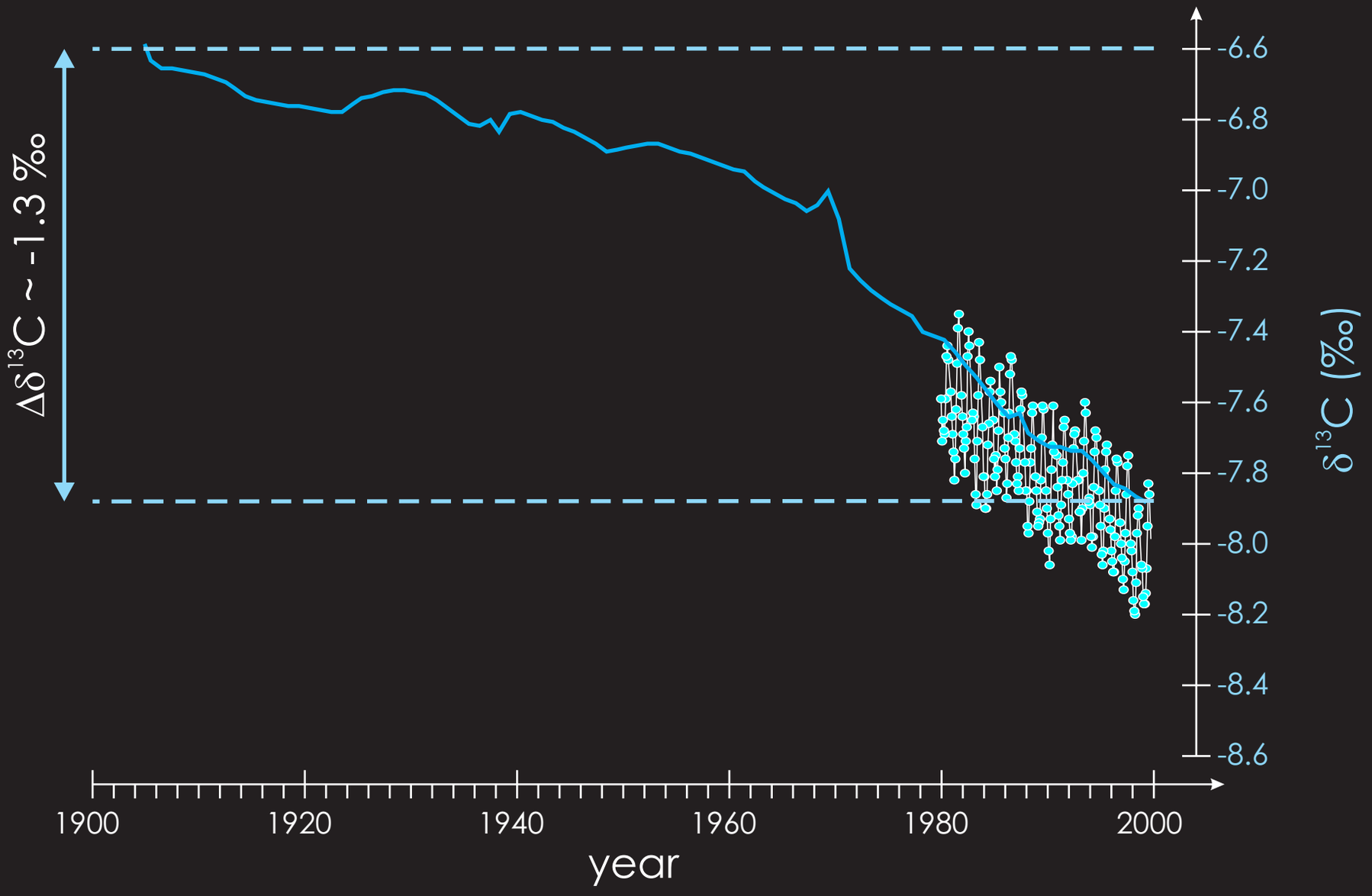




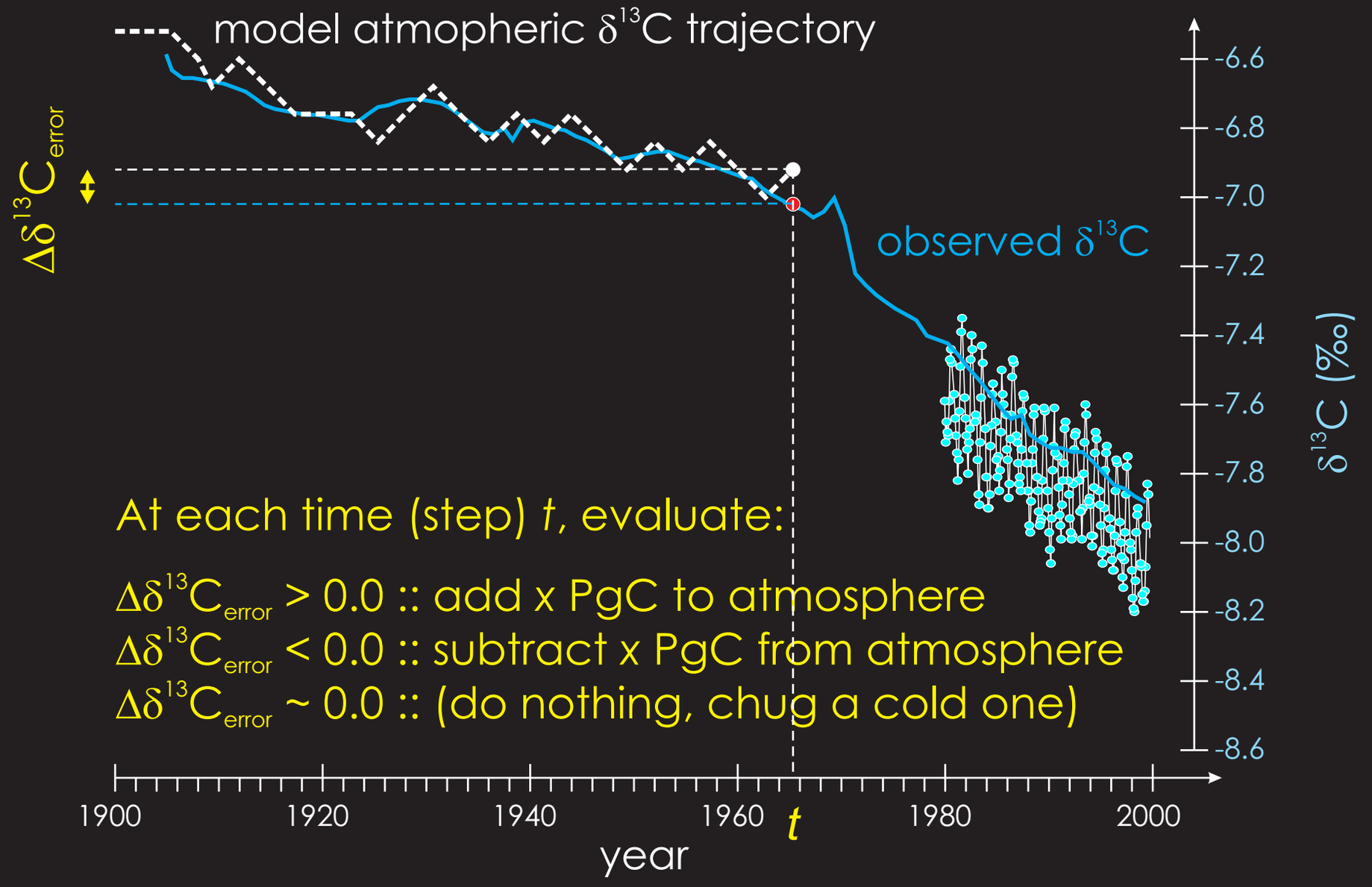
$CaCO_{3(s)}$



Methods


$\Delta\delta^{13}C \sim -1.3$ ‰
-6.6
-6.8
-7.0
-7.2
-7.4
-7.6
-7.8
-8.0
-8.2
-8.4
-8.6
$\delta^{13}C$ (‰)
1900
1920
1940
1960
1980
2000
year

Methods


model atmopheric δ13C trajectory
observed δ13C
Δδ13Cerror
δ13C (‰)
-6.6
-6.8
-7.0
-7.2
-7.4
-7.6
-7.8
-8.0
-8.2
-8.4
-8.6
1900
1920
1940
1960
1980
2000
t
year
At each time (step) t, evaluate:
Δδ13Cerror > 0.0 :: add x PgC to atmosphere
Δδ13Cerror < 0.0 :: subtract x PgC from atmosphere
Δδ13Cerror ~ 0.0 :: (do nothing, chug a cold one)

Methods

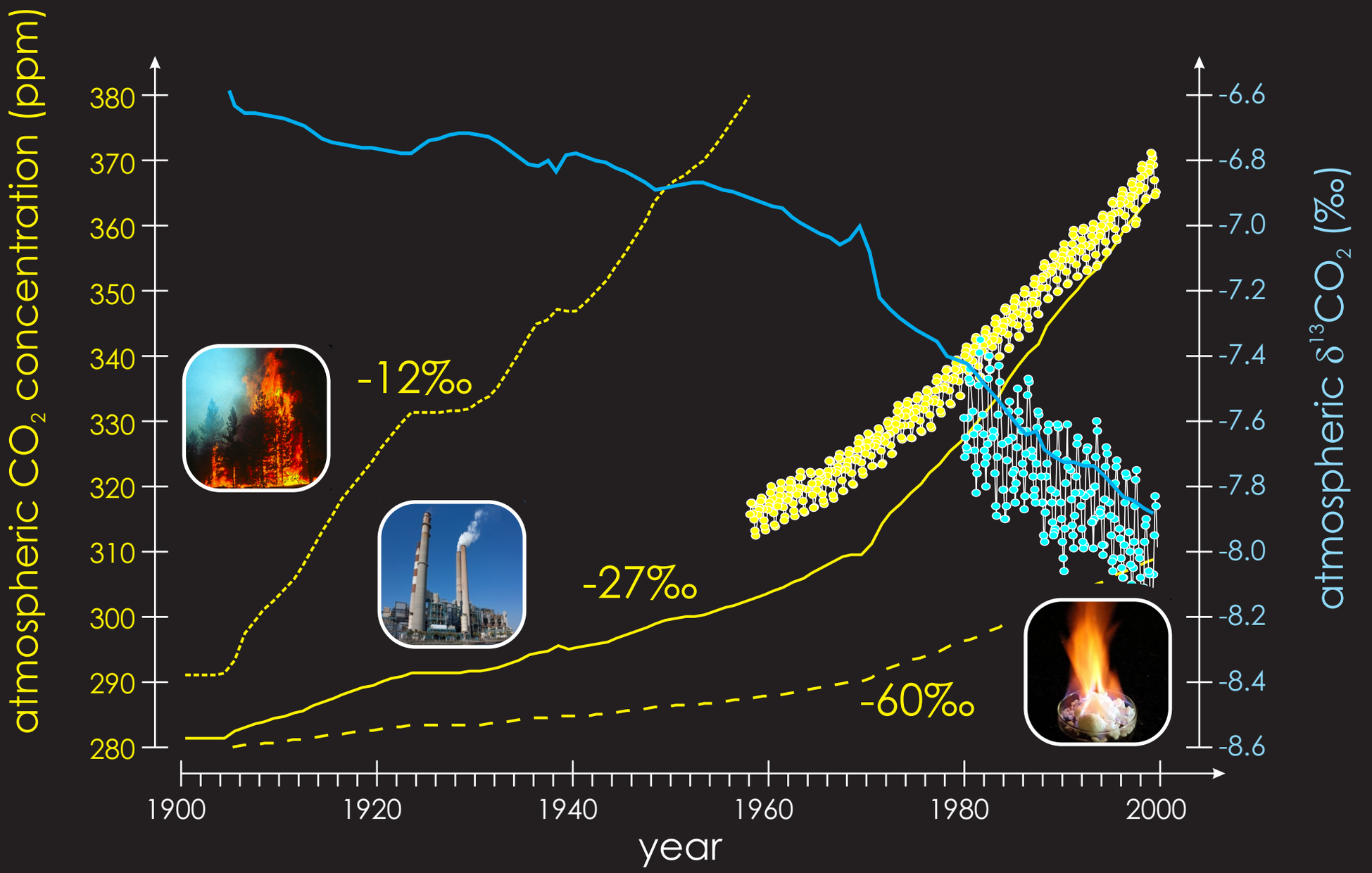
-6.6
-6.8
-7.0
-7.2
-7.4
-7.6
-7.8
-8.0
-8.2
-8.4
-8.6

$\delta^{13}C$ (‰)

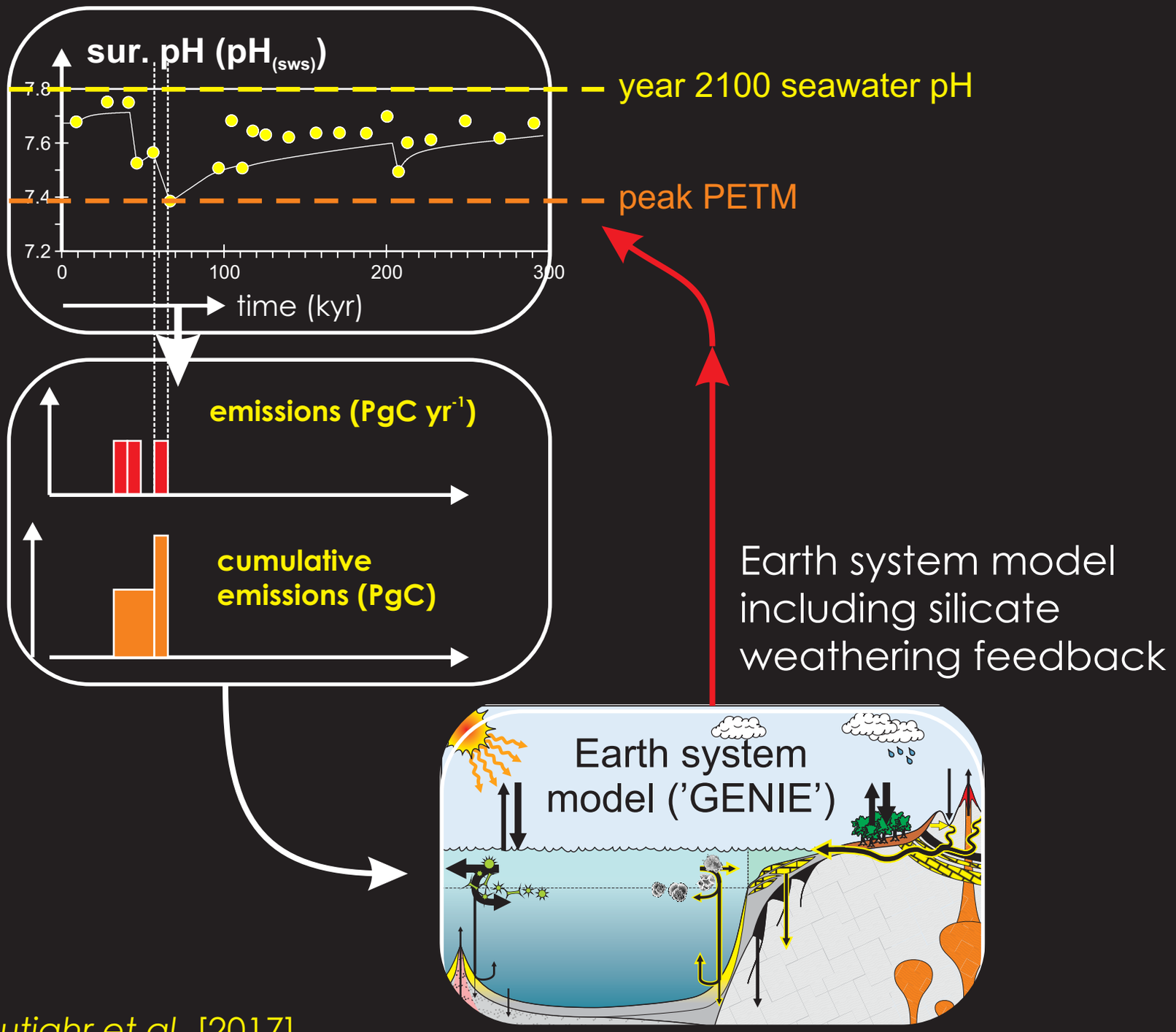
1900
1920
1940
1960
1980
2000

year

Methods

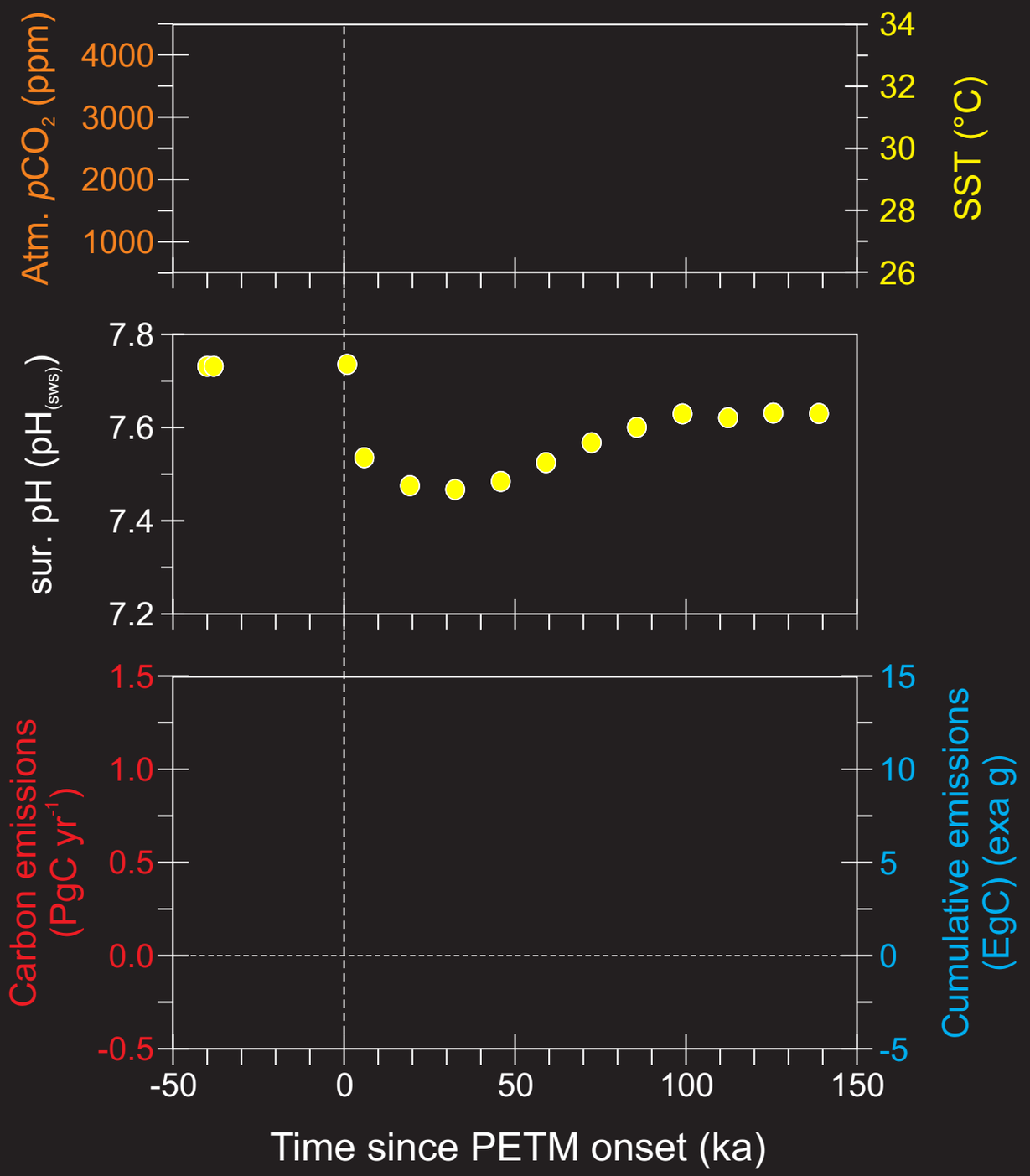

atmospheric CO_2 concentration (ppm)
380
370
360
350
340
330
320
310
300
290
280
-12‰
-27‰
-60‰
atmospheric $\delta^{13}CO_2$ (‰)
-6.6
-6.8
-7.0
-7.2
-7.4
-7.6
-7.8
-8.0
-8.2
-8.4
-8.6
1900
1920
1940
1960
1980
2000
year

Assimilating surface ocean pH change (only)

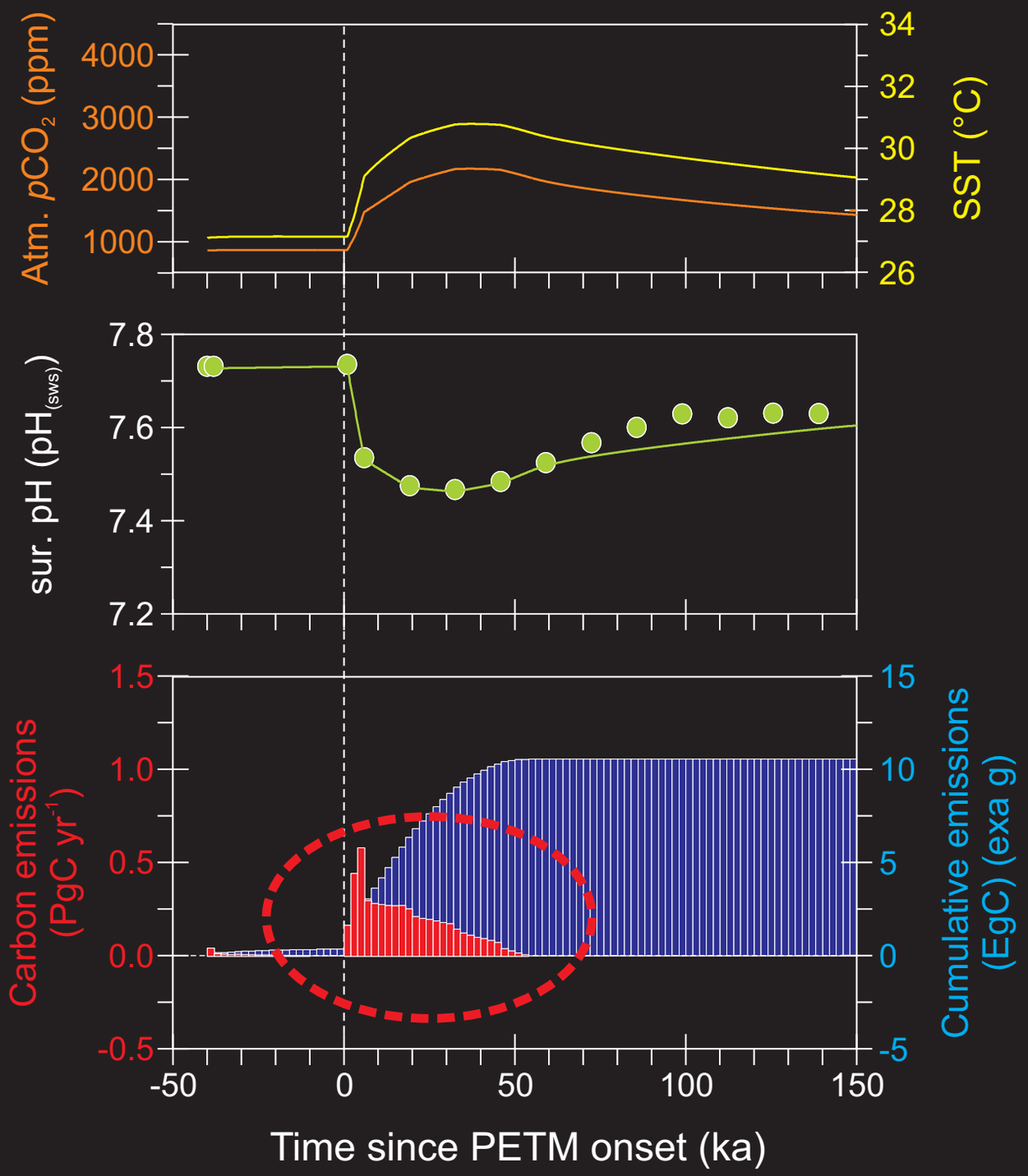


Gutjahr et al. [2017]

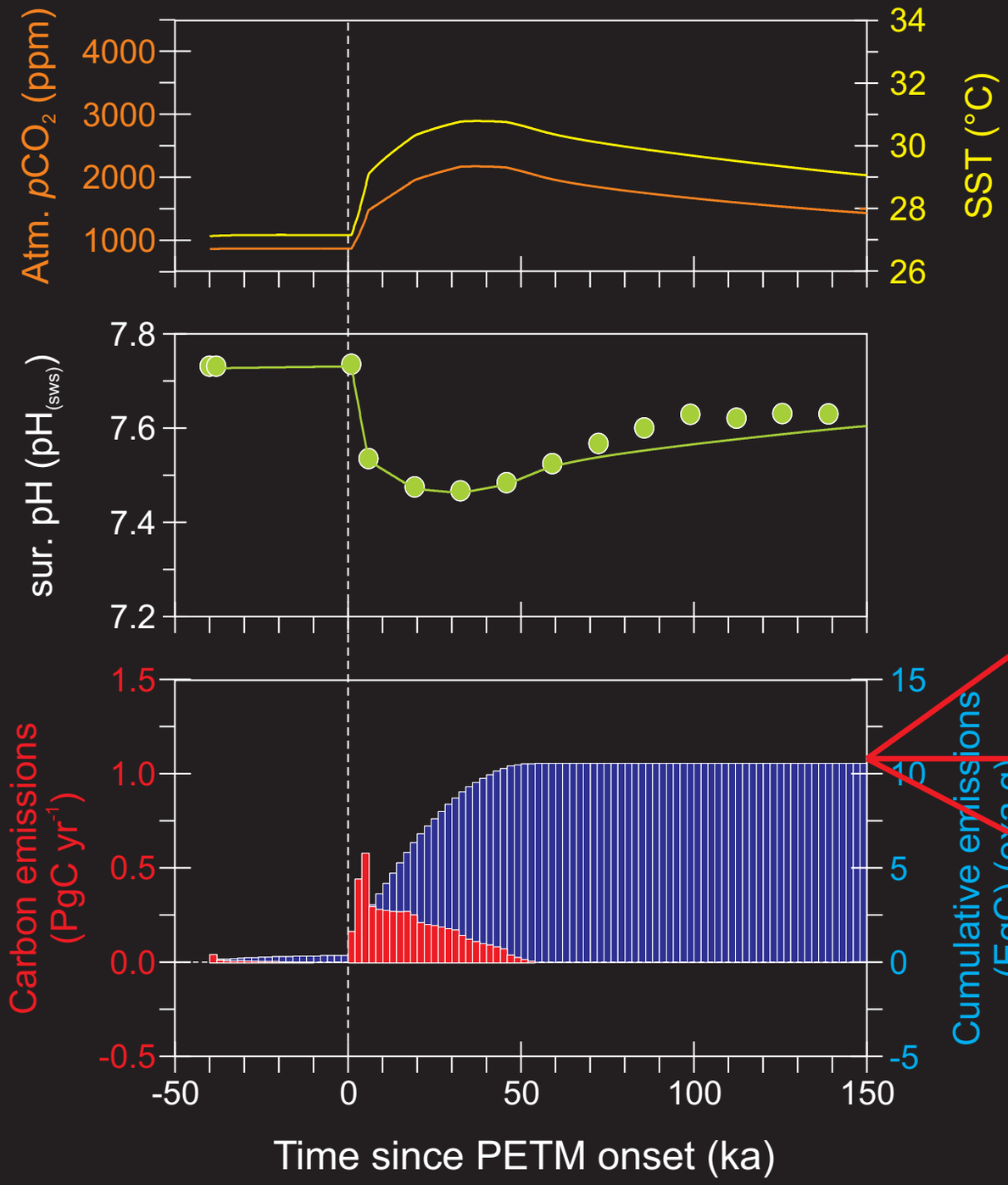
Assimilating surface ocean pH change (only)



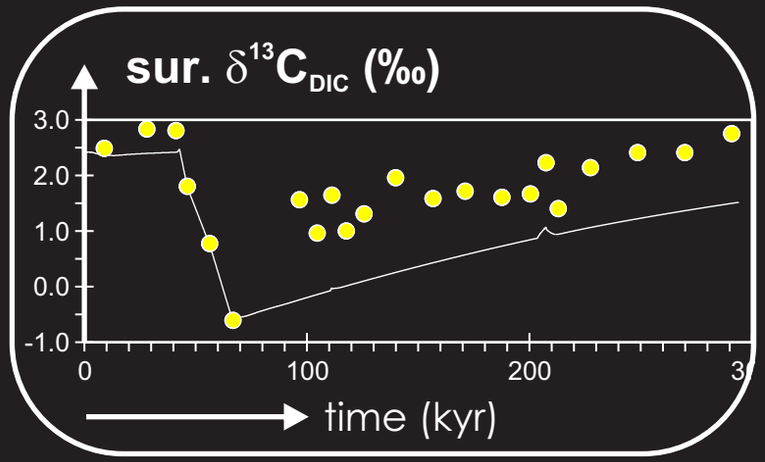
Assimilating surface ocean pH change (only)



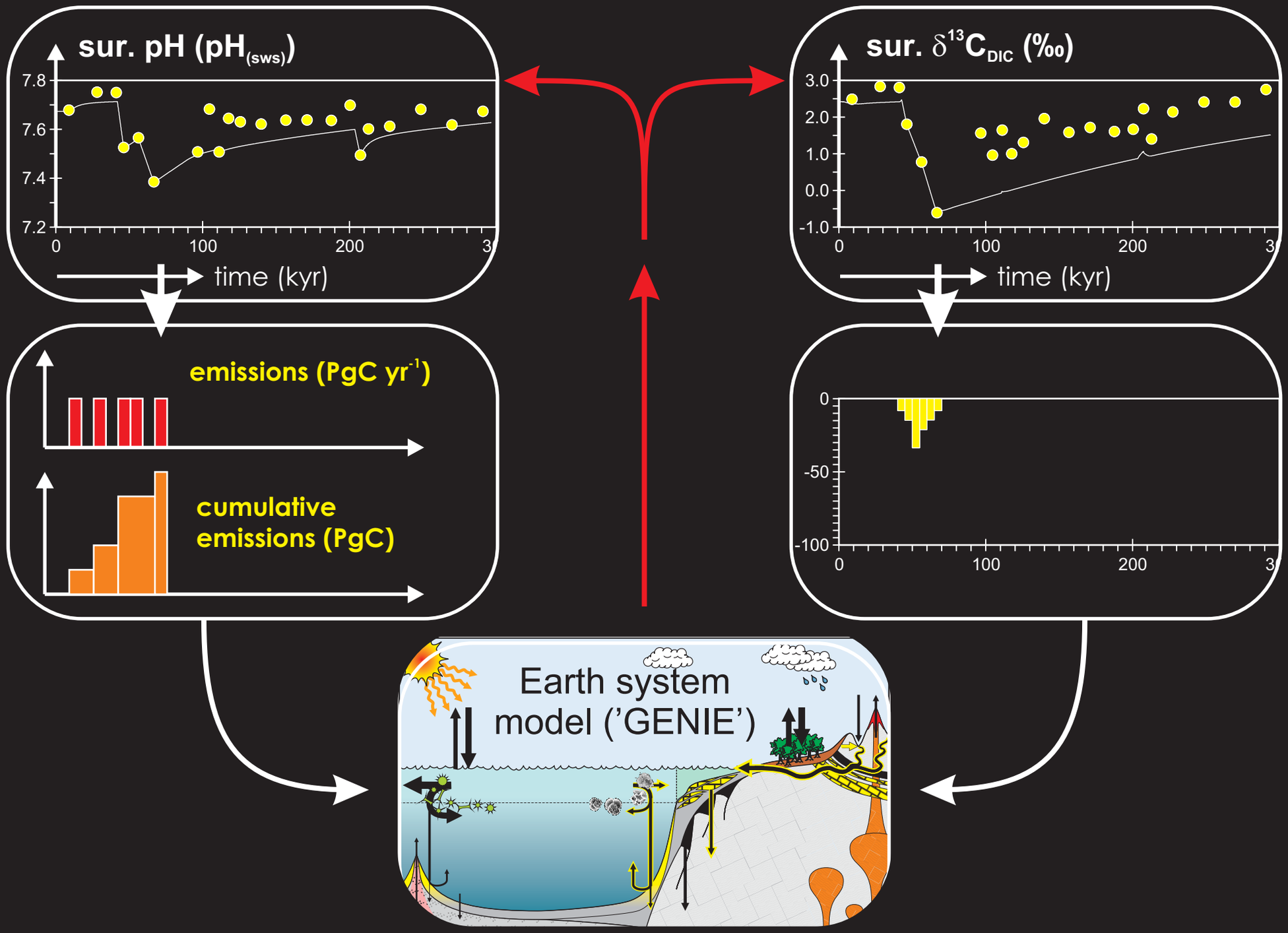
Assimilating surface ocean pH change (only)



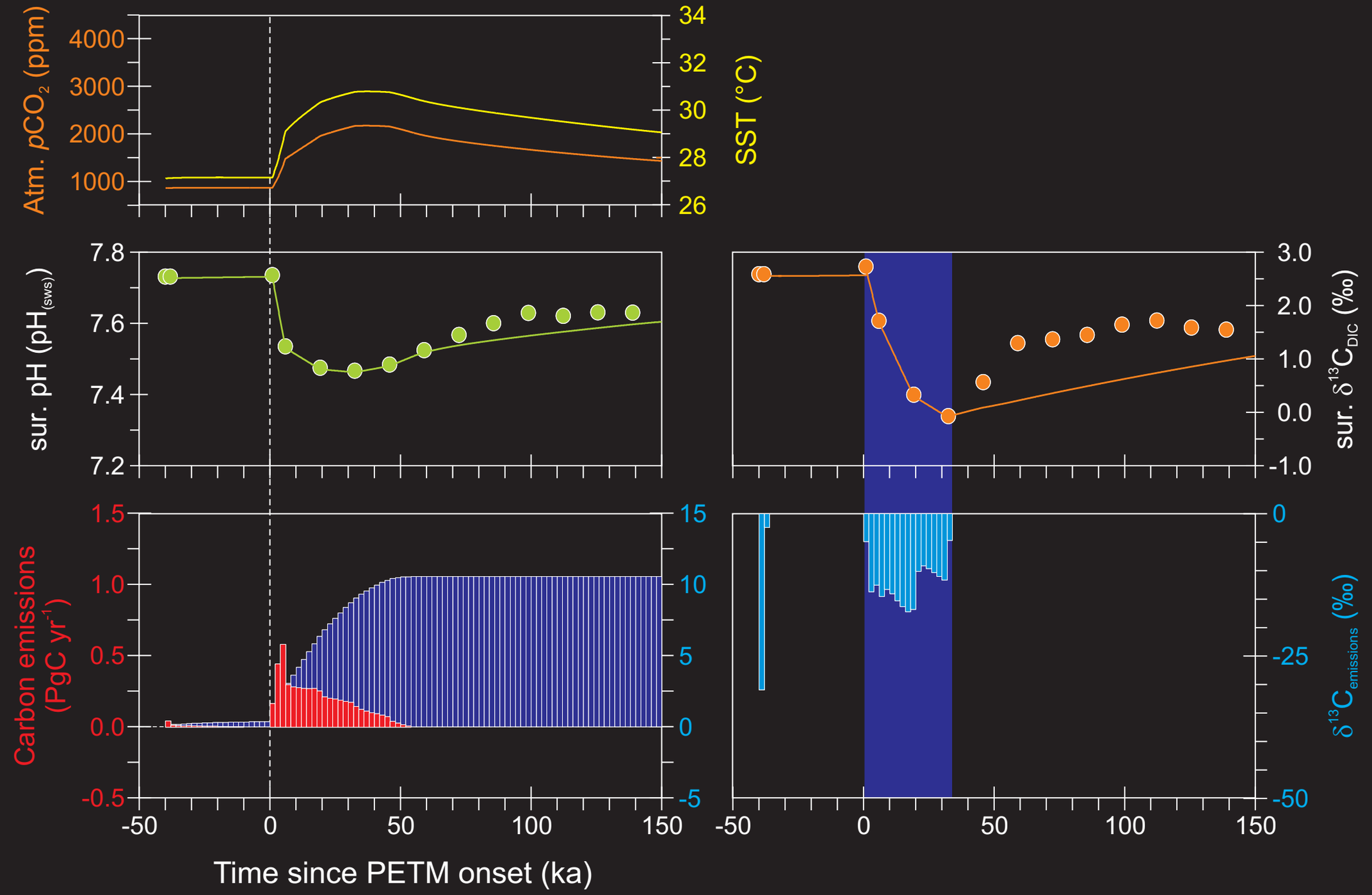
Assimilating surface ocean pH and $\delta^{13}C$



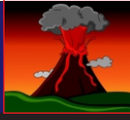
Assimilating surface ocean pH and $\delta^{13}C$



Assimilating surface ocean pH and $\delta^{13}C$



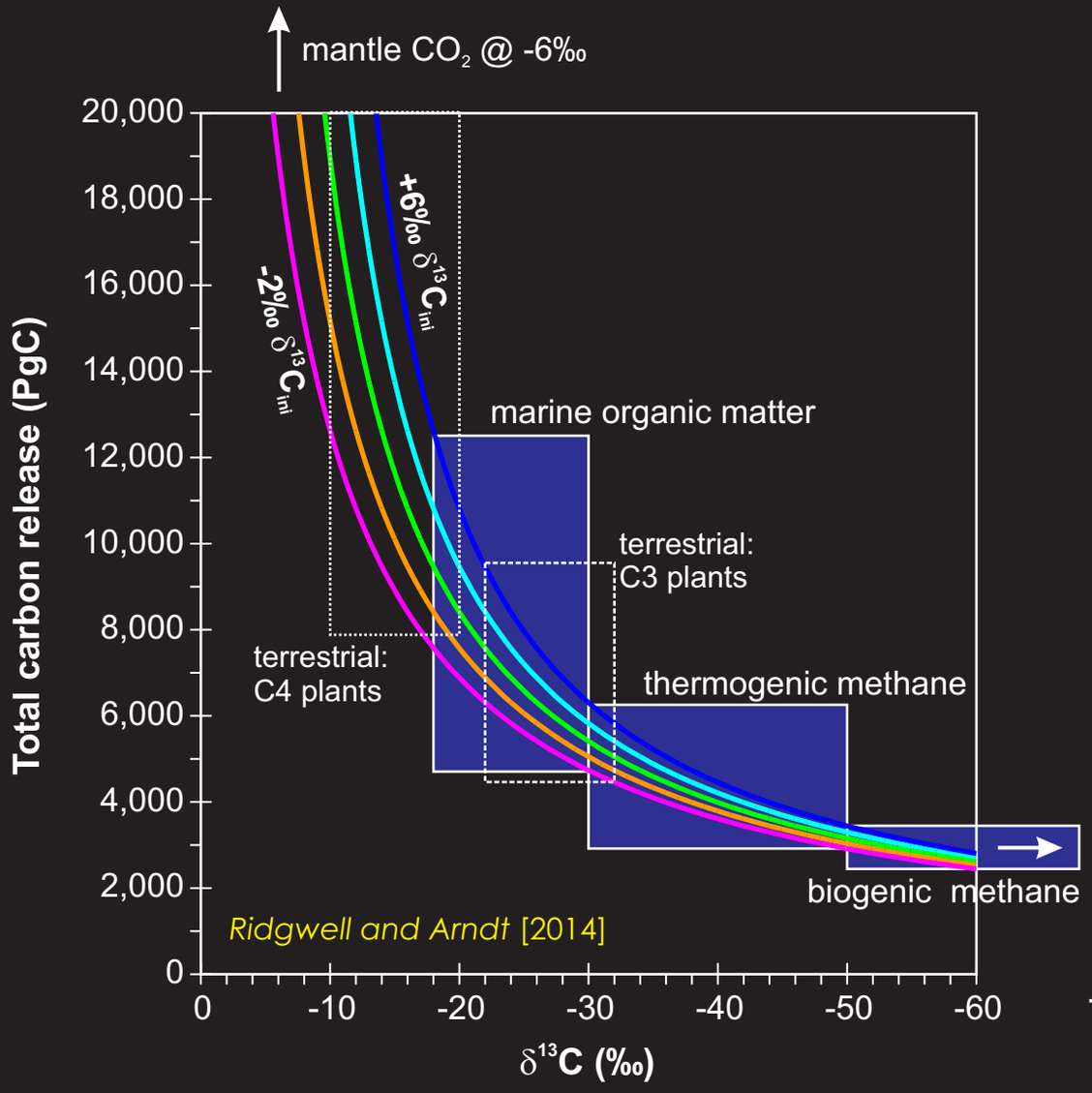
Assimilating surface ocean pH and $\delta^{13}C$

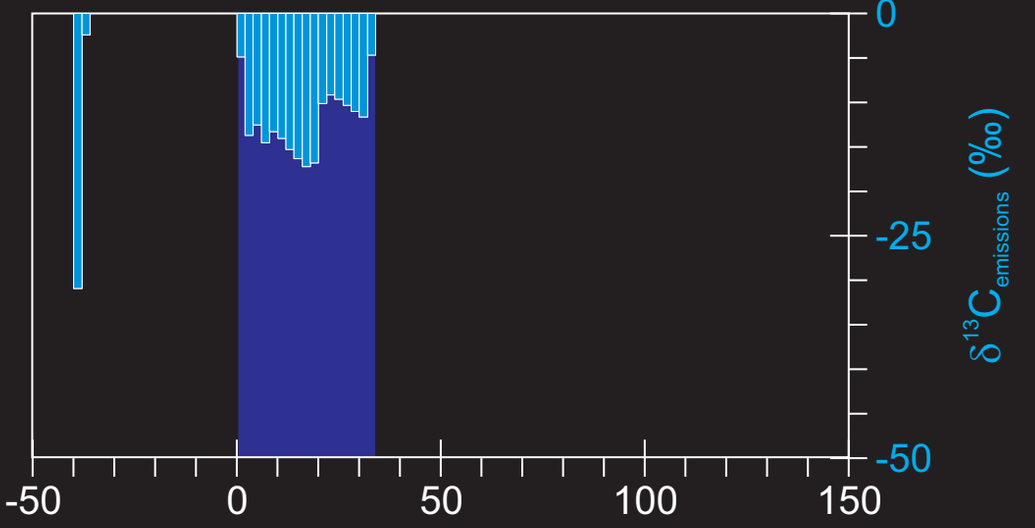


+

OR

+



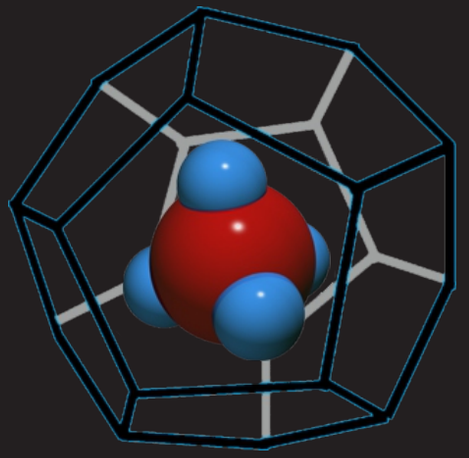


Conclusions

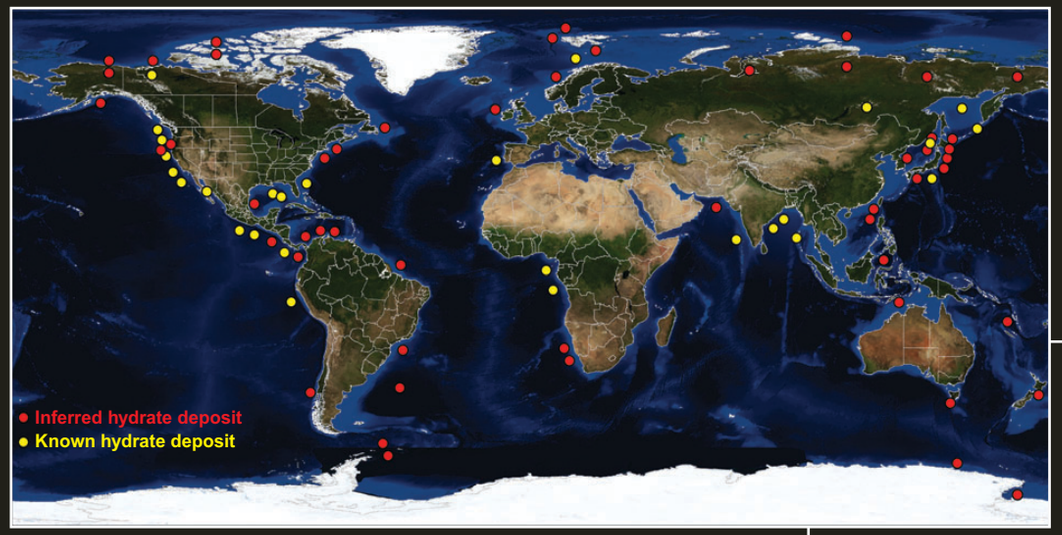
10,000-12,000 PgC was emitted over the PETM as a whole, with a mean isotopic signature of -11 to -17 per mil. This is largely independent of the assumed onset time-scale.

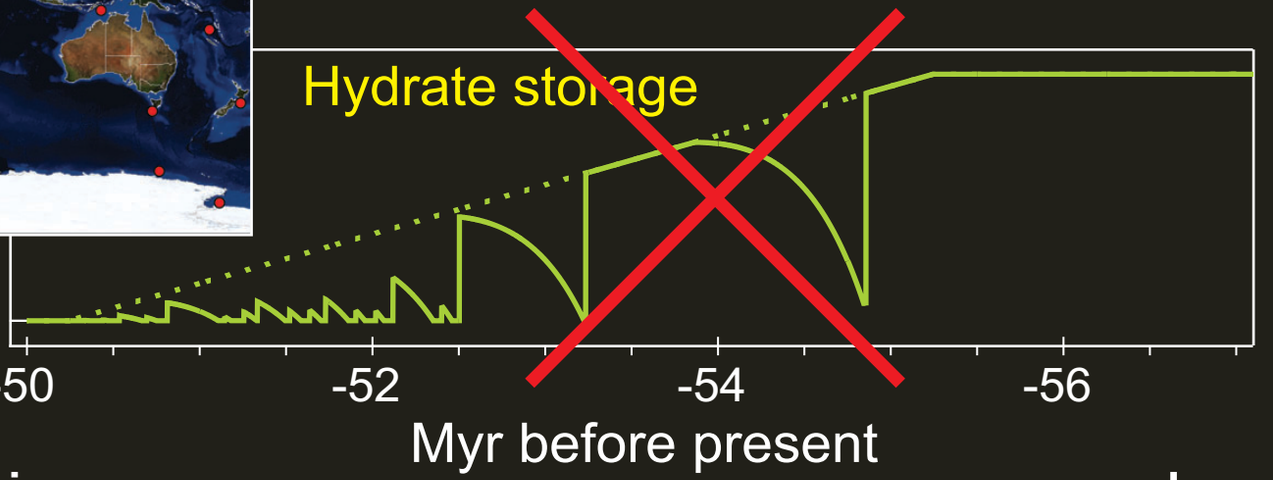
This can be explained entirely by volcanism + volcanic-related processes (e.g. thermogenic methane), or volcanism in combination with sufficial carbon cycle feedbacks.

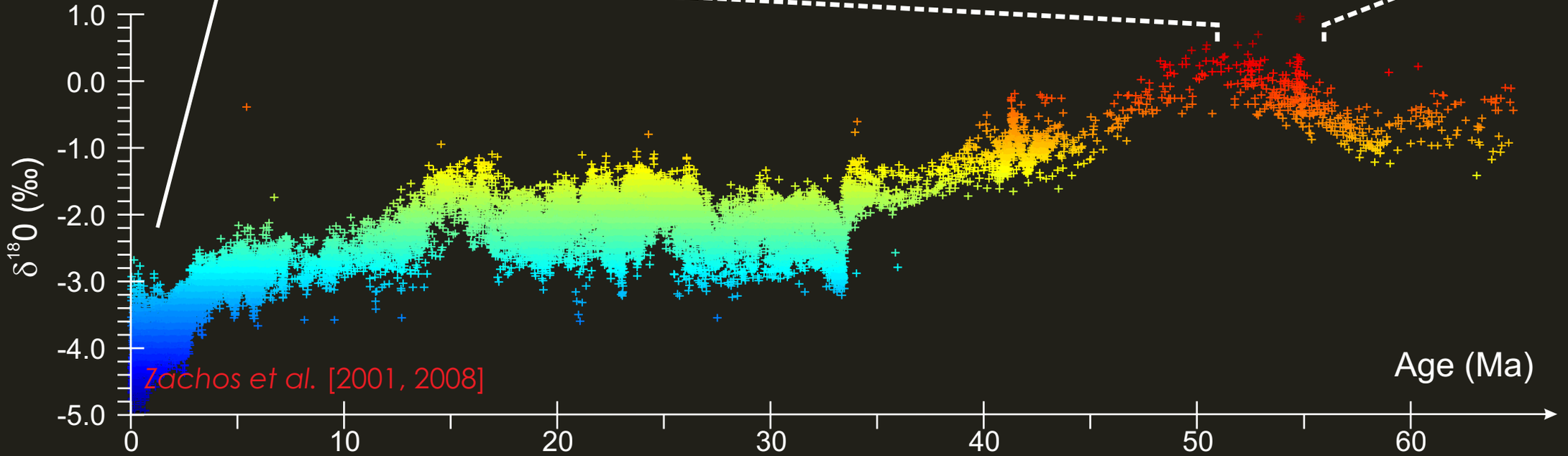
A 'perfect' record could be assimilated in models to derive a time-resolved reconstruction of carbon emissions, and their specific sources (and potentially de-convolving 'triggers' and feedbacks).



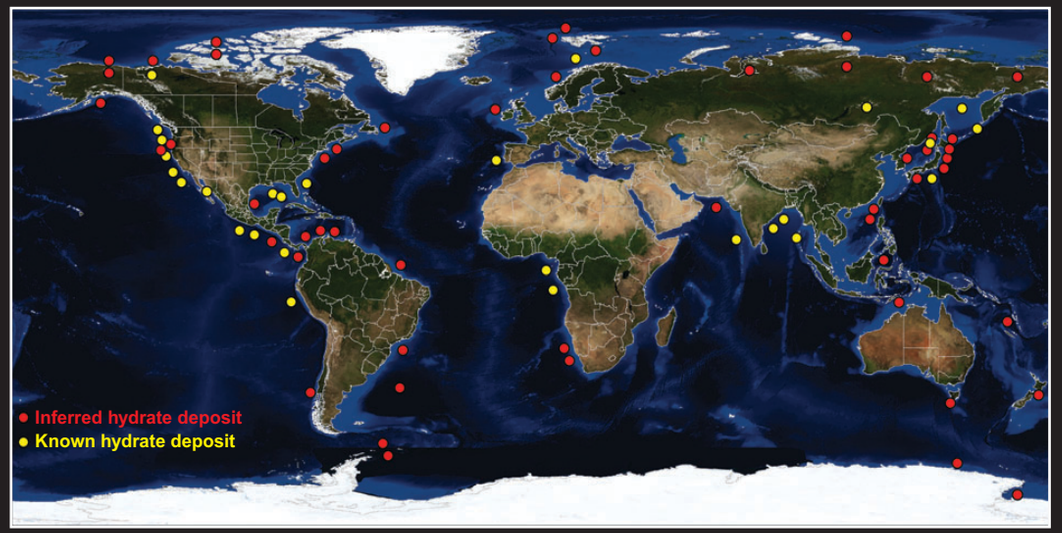
Conclusions

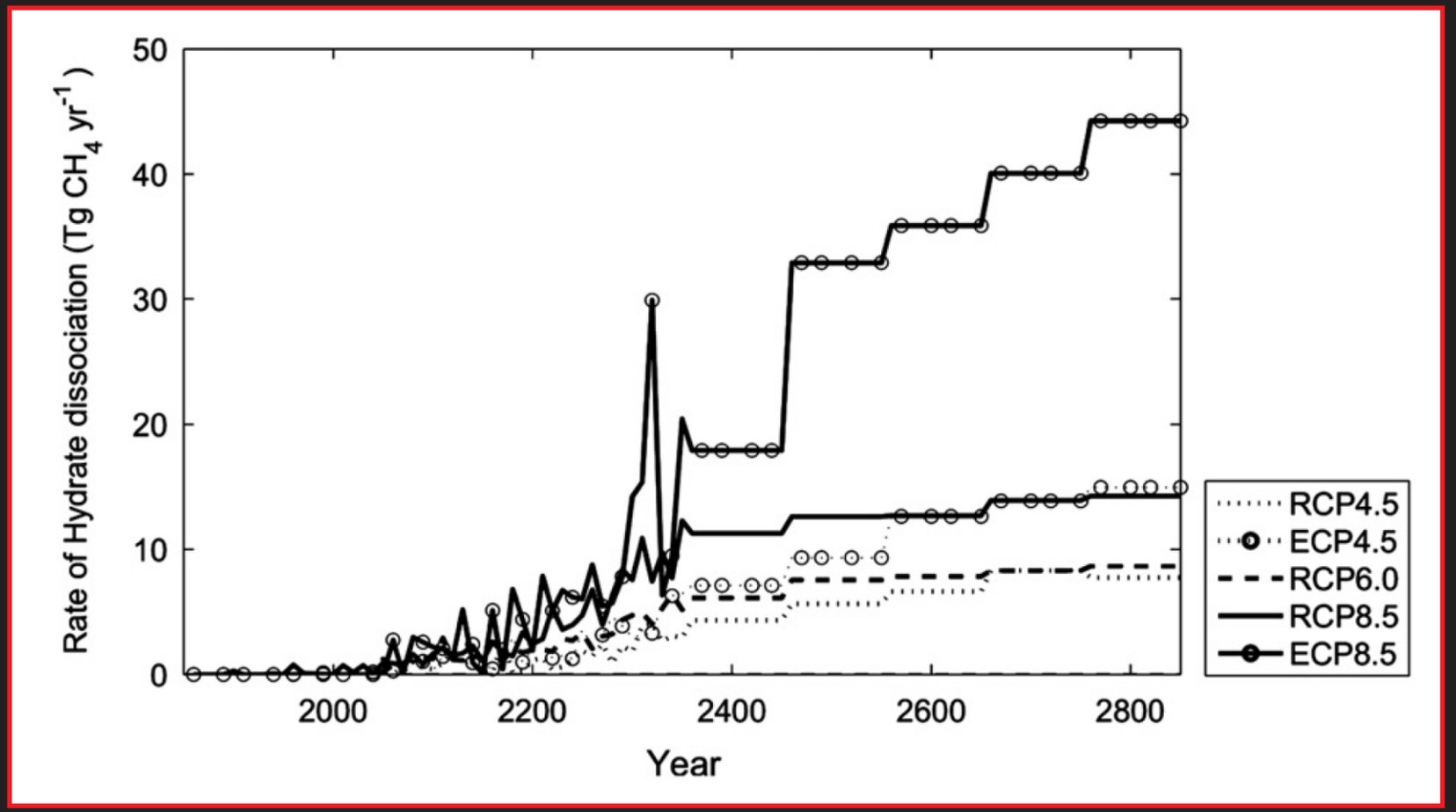






Conclusions





Hunter et al. [2013]

Thanks to:

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Mark Maslin, Ron Kahana, Daniela Schmidt.

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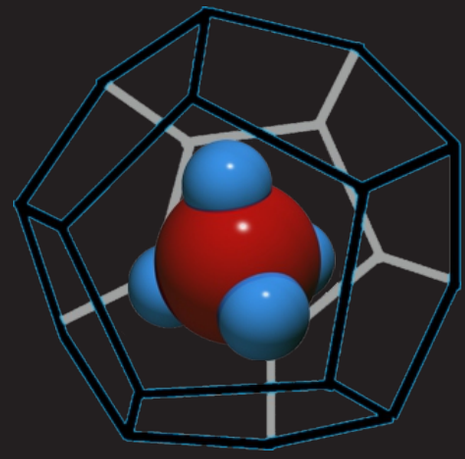
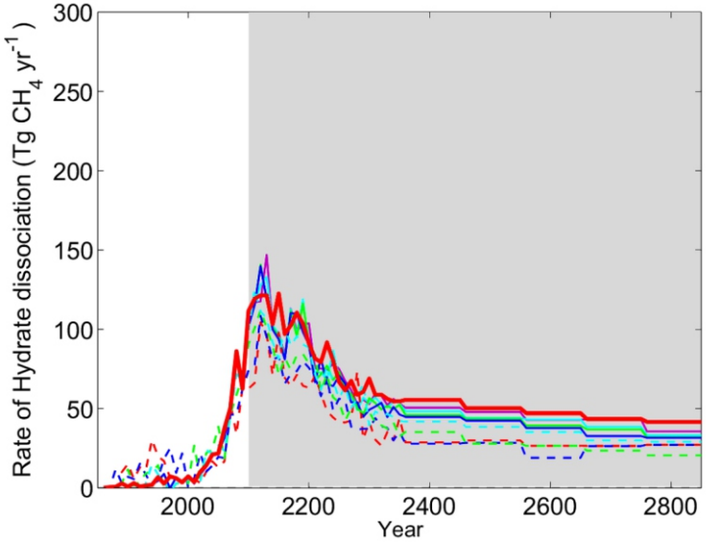
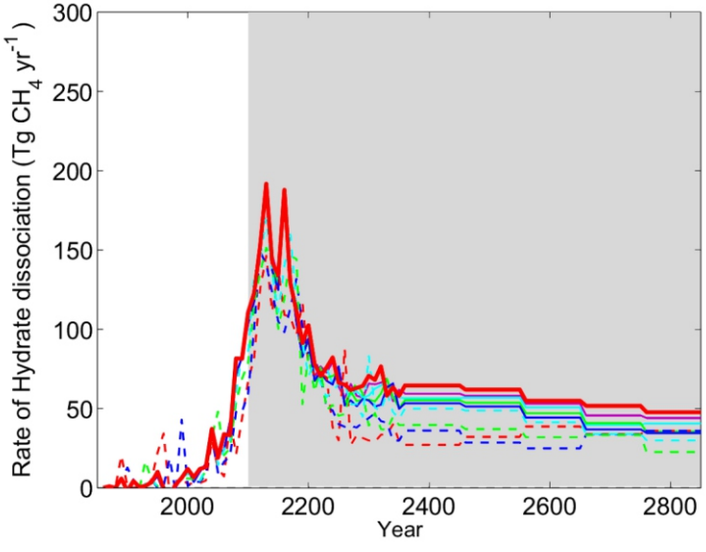
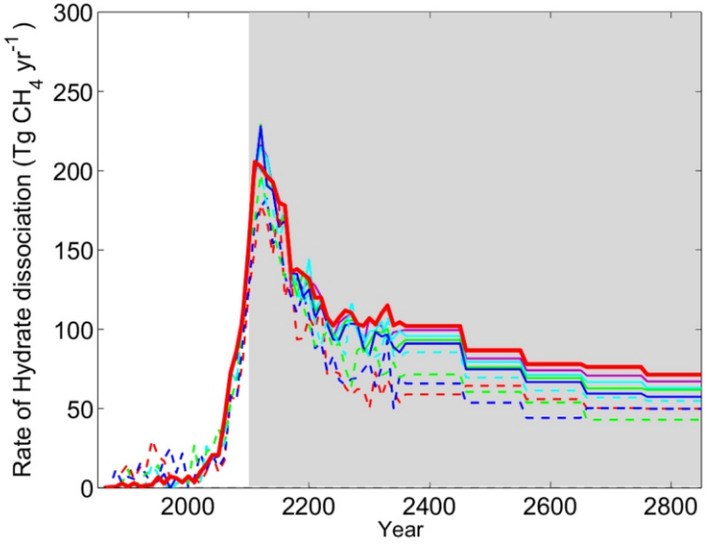




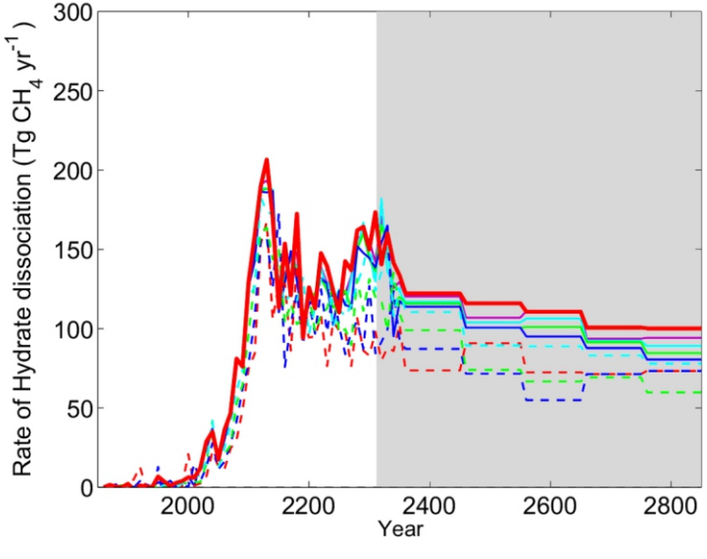
(a) RCP 4.5

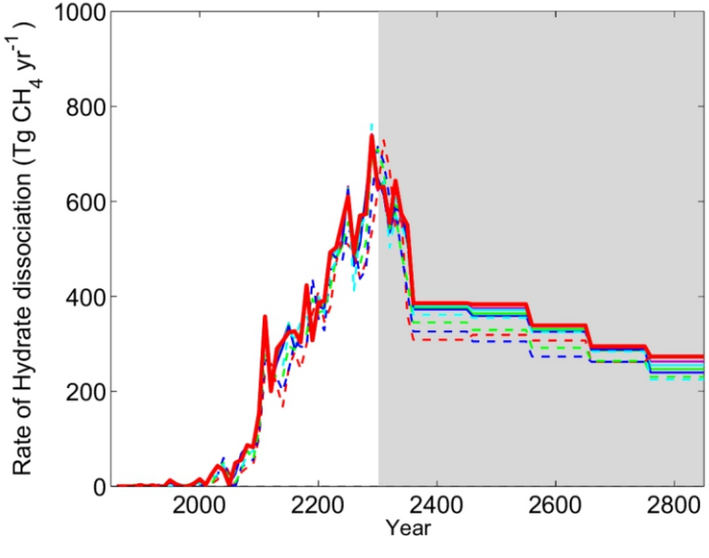


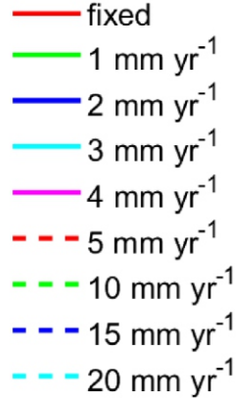
(b) RCP 6.0



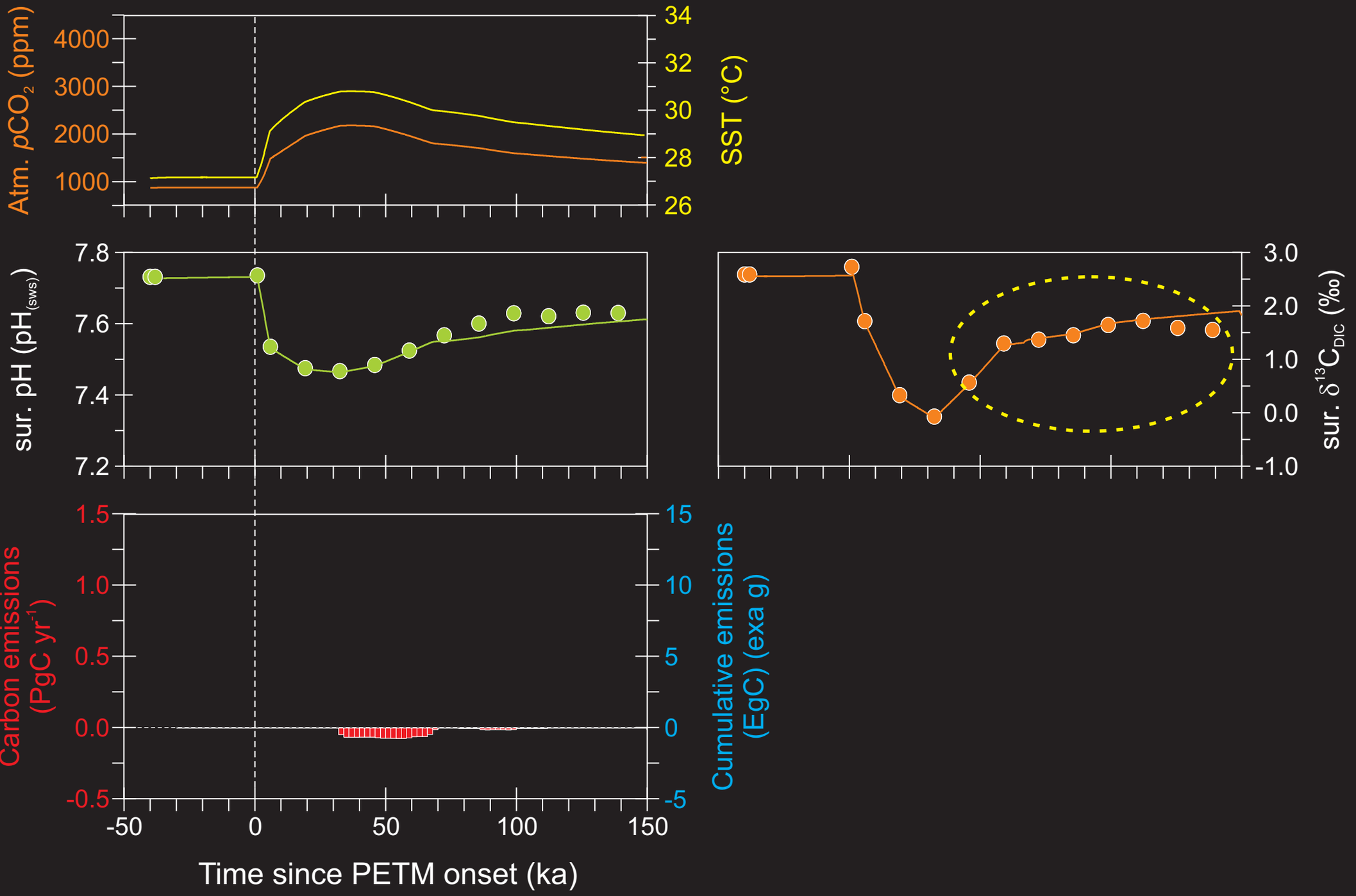
(c) RCP 8.5



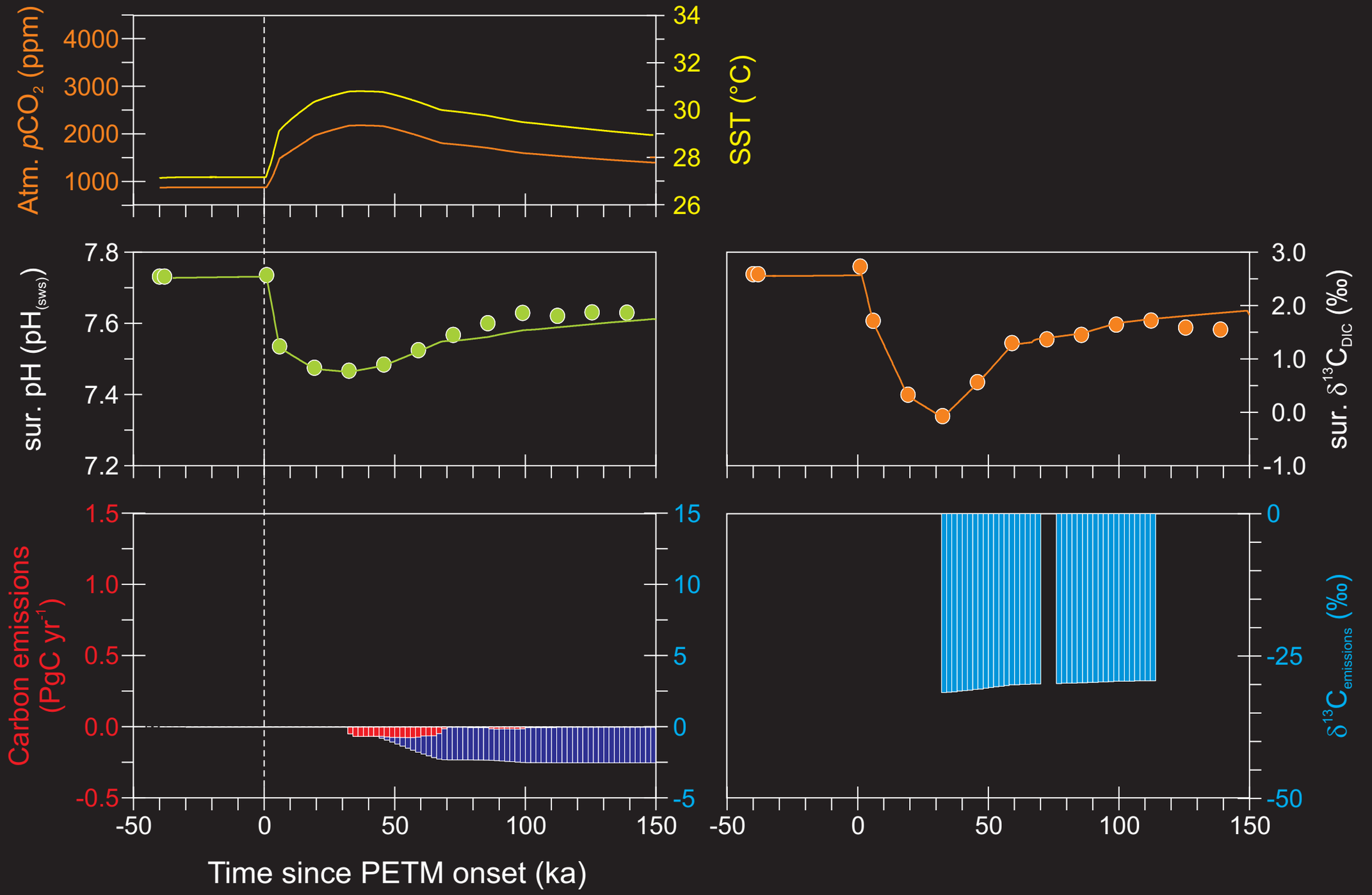




Assimilating surface ocean pH and $\delta^{13}C$



Assimilating surface ocean pH and $\delta^{13}C$



Osmium isotope records

radiogenic Os

granitic weathering: $^{187/188}$Os=1.4

basaltic weathering: $^{187/188}$Os=0.12

hydrothermal:
$^{187/188}$Os=0.12

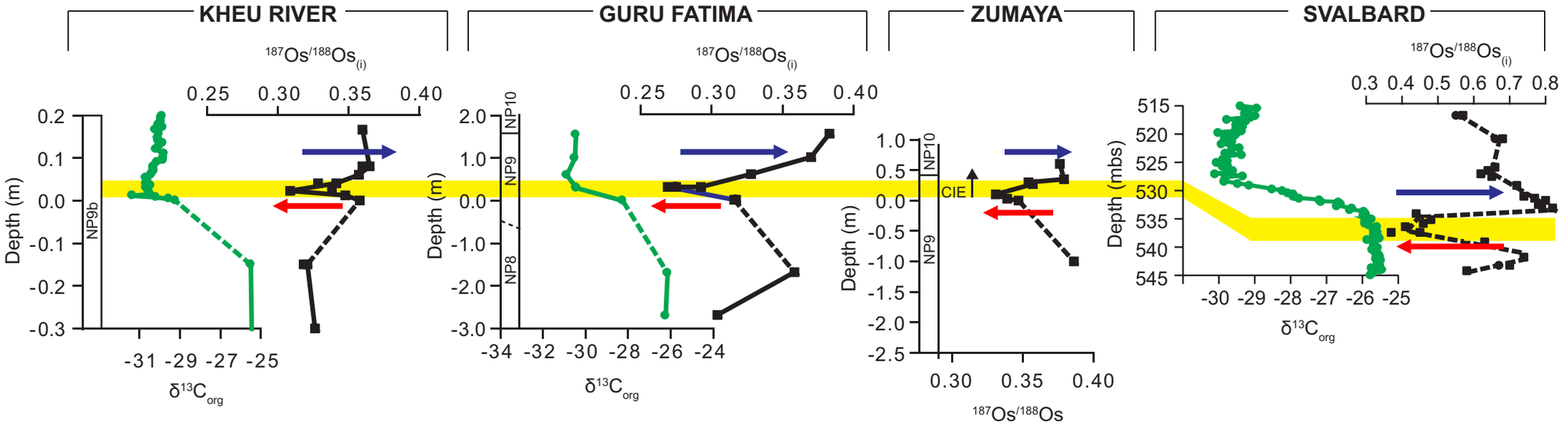
seawater:
$^{187/188}$Os~0.35

burial with
organic matter

un-radiogenic Os

un-radiogenic Os

Osmium isotope records



time

radiogenic Os

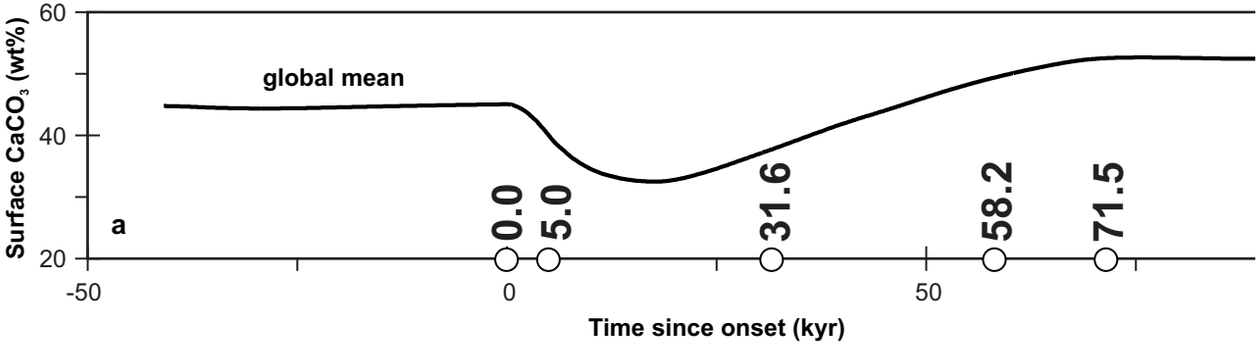
un-radiogenic Os

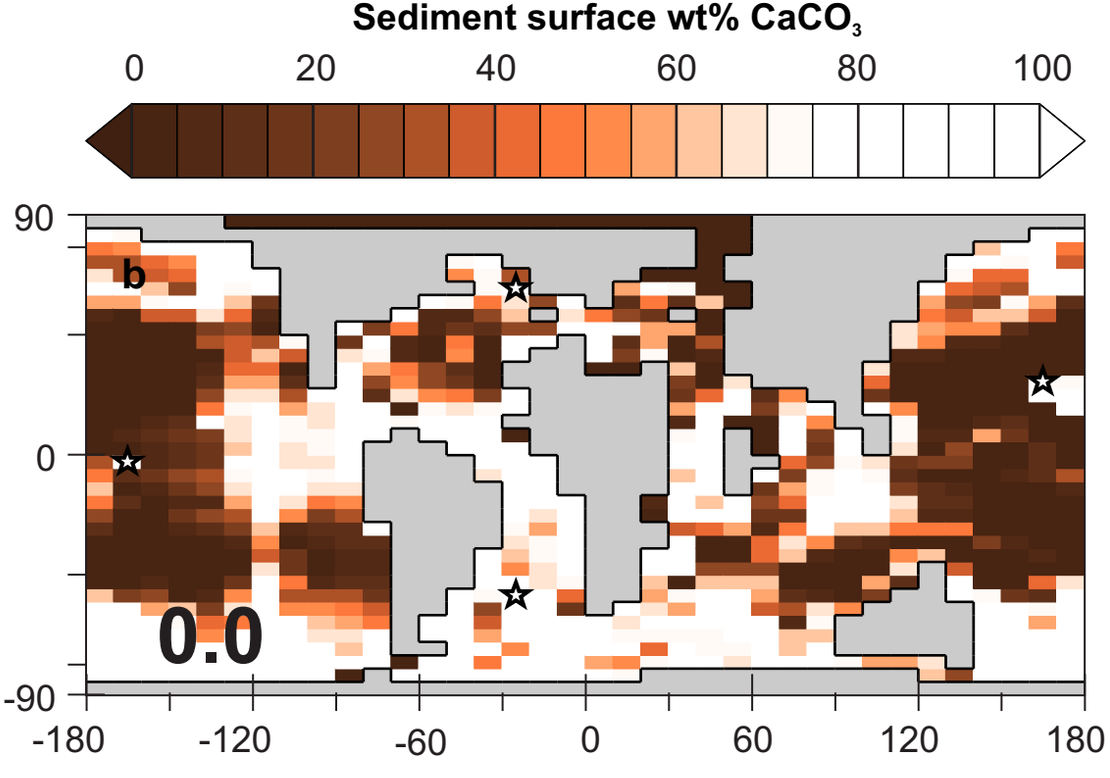
PETM recovery characterized by long-lasting shift to radiogenic Os. Consistent with enhanced granitic weathering (silicate weathering feedback).
(Also, expulsion of fluids form organic rich sediments.)

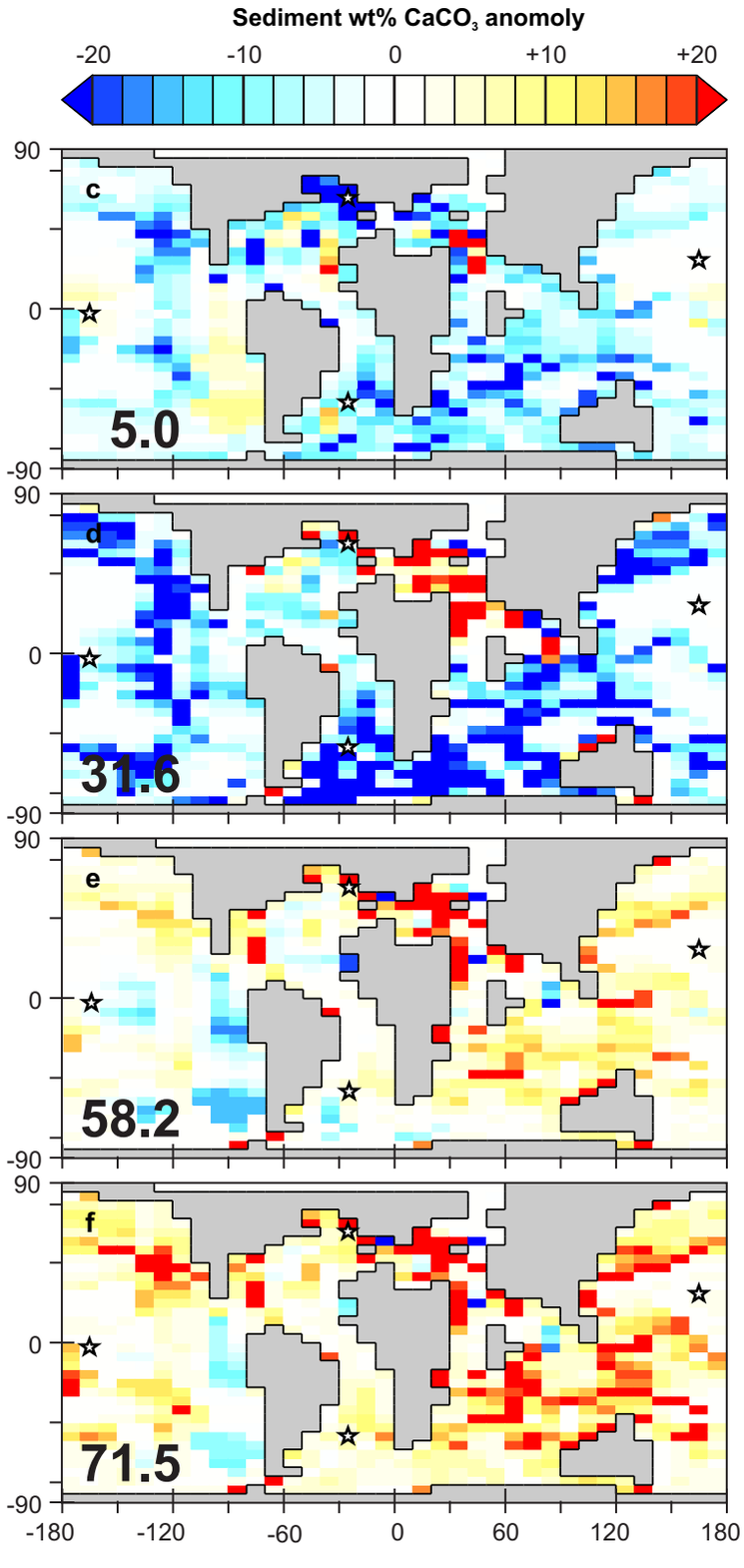
Strong transient decline in $^{187/188}Os$.
Enhanced unradiogenic input from volcanism.
(Also, extraterrestrial ...)

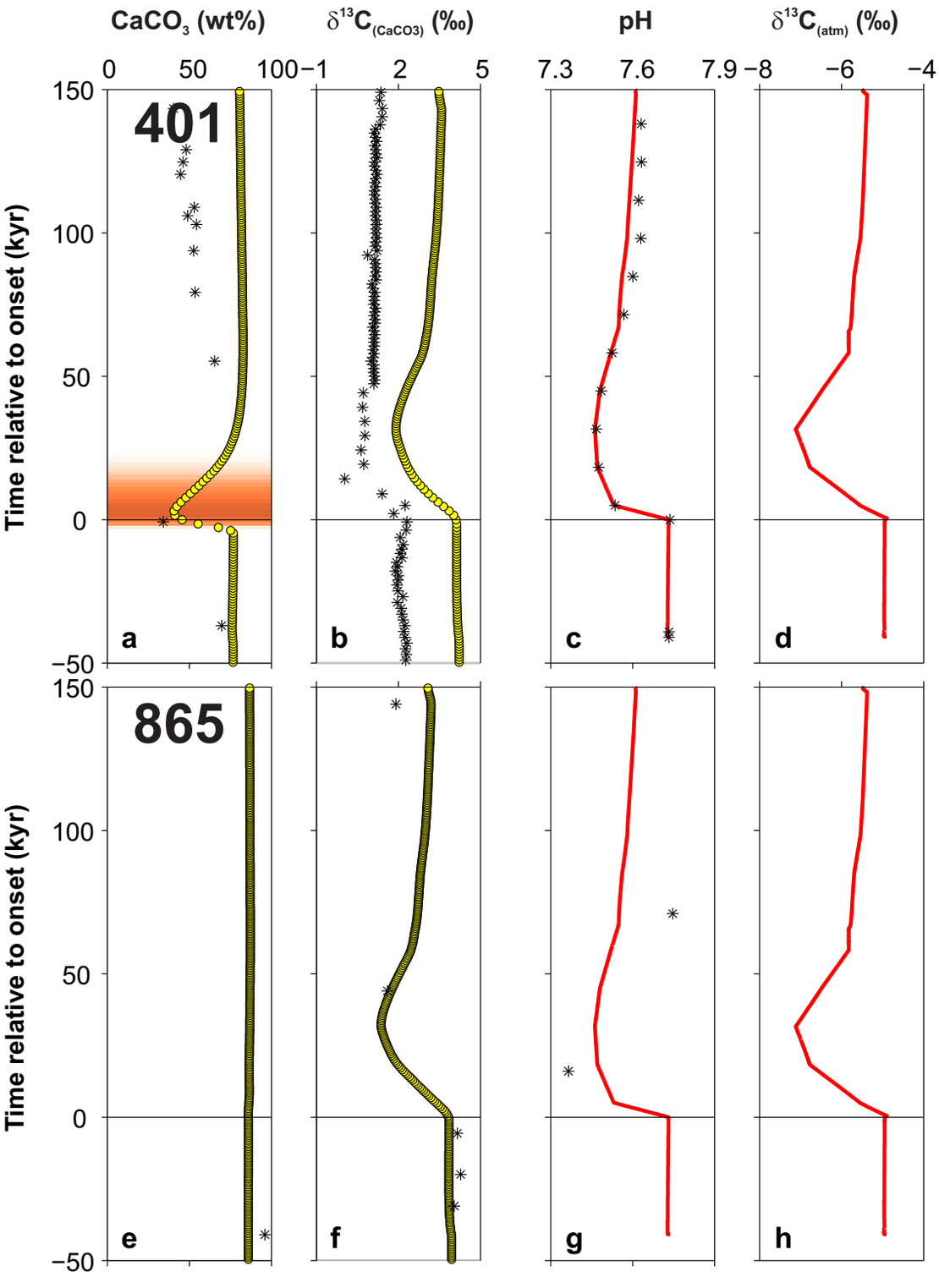
Dickson et al. [2015] (*Palaeogeography, Palaeoclimatology, Palaeoecology* **438**)
(also see: *Wieczorek et al.* [2013] (*GCA* **119**))

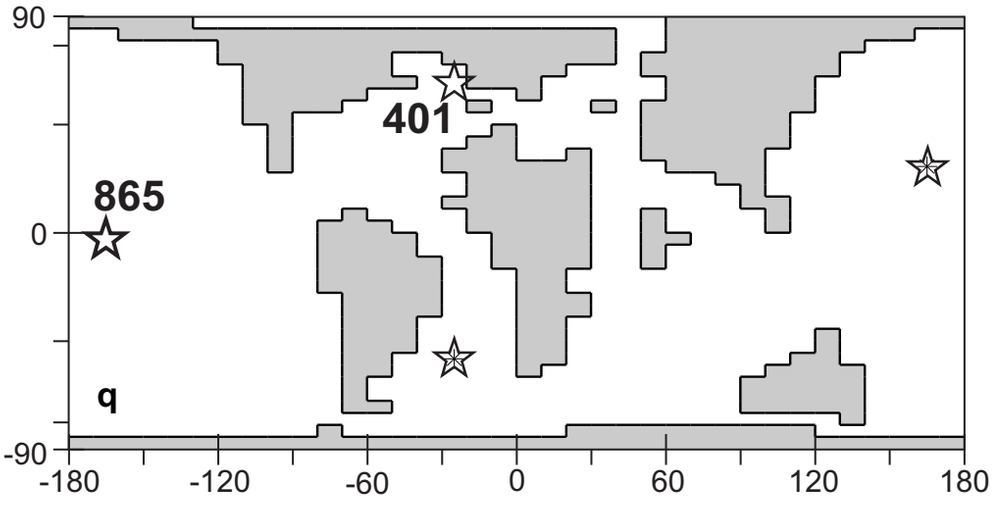
Deep-sea (modelled) carbonate response

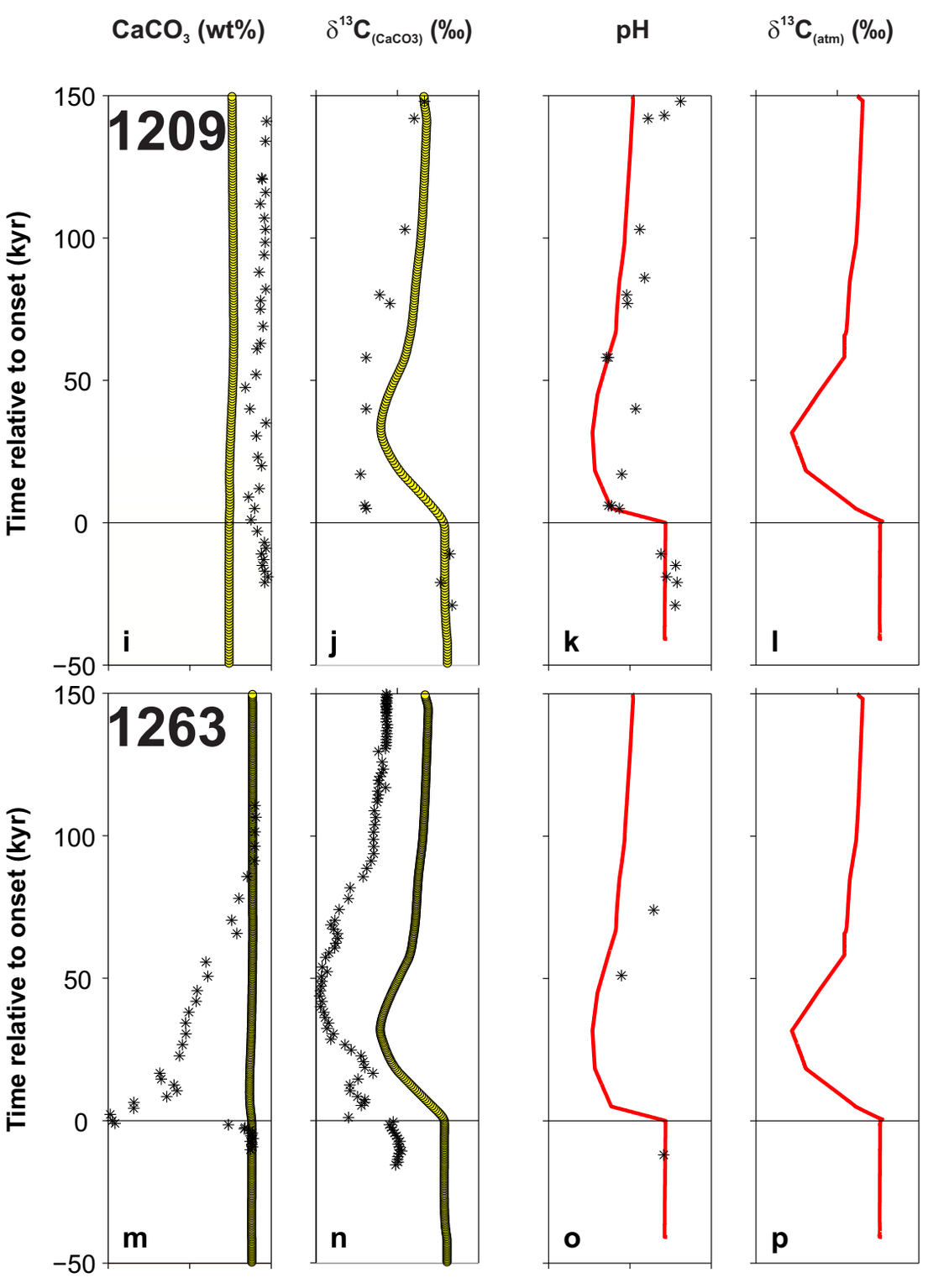


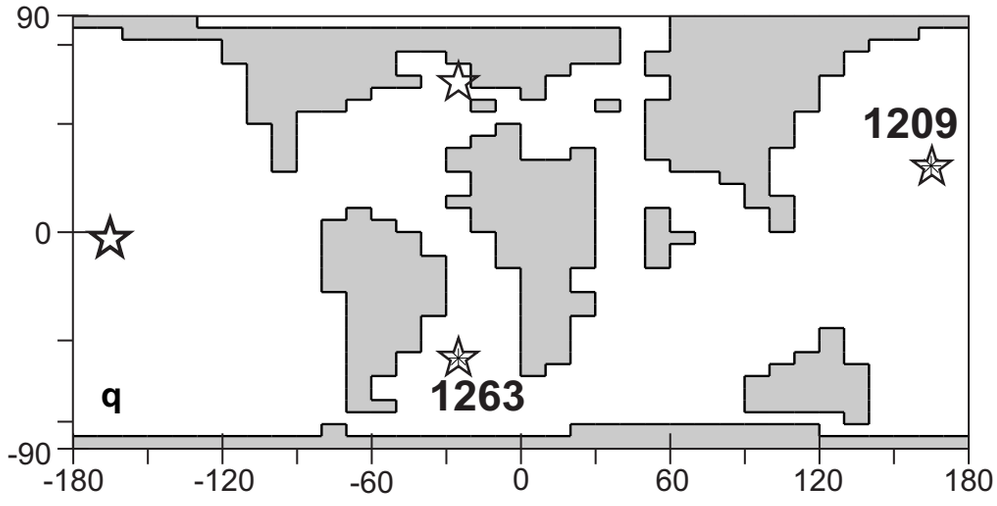





CaCO3 (wt%)
δ13C(CaCO3) (‰)
pH
δ13C(atm) (‰)
0
50
100
−1
2
5
7.3
7.6
7.9
−8
−6
−4
150
100
50
0
−50
Time relative to onset (kyr)
401
865
a
b
c
d
e
f
g
h

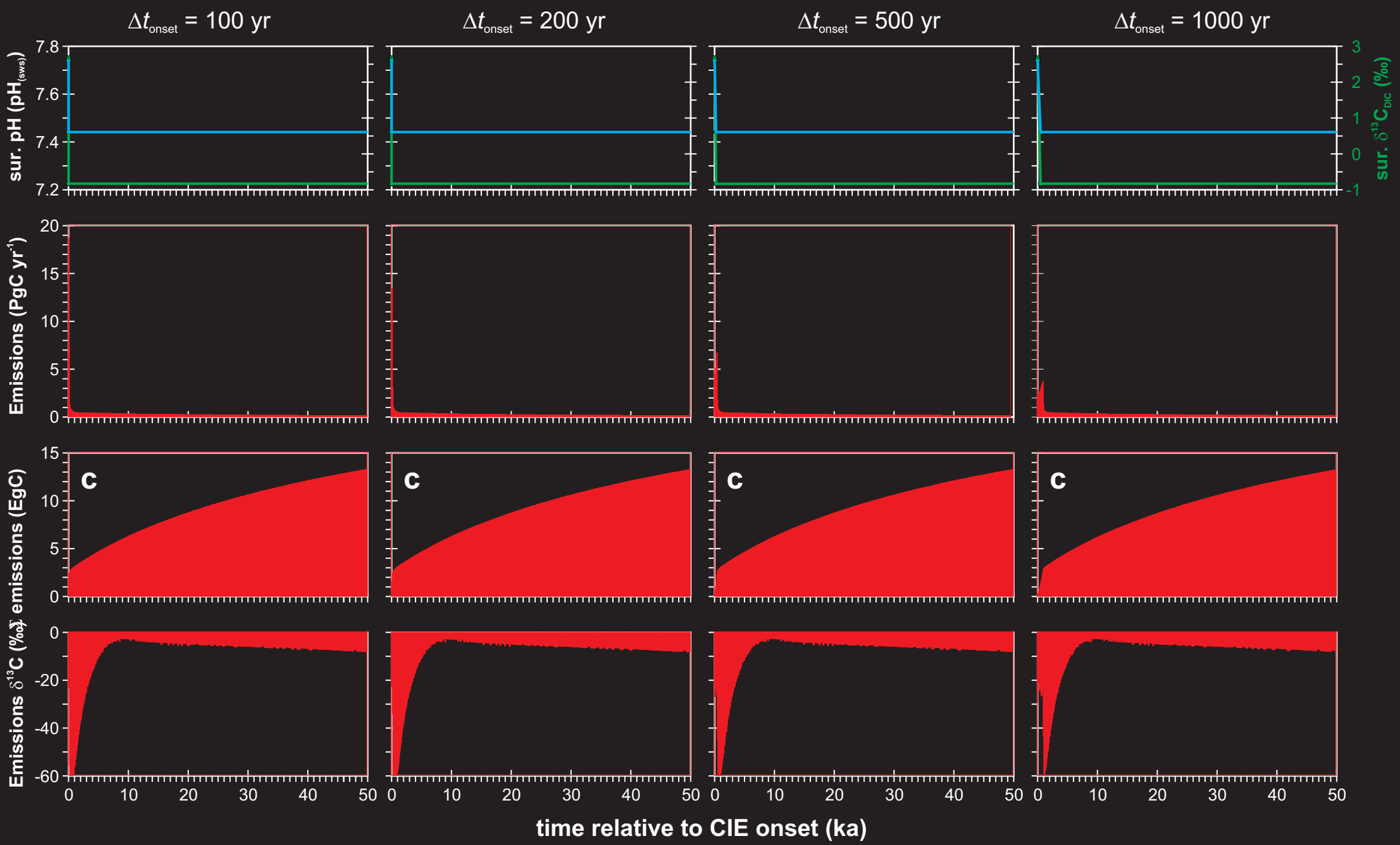

90
0
-90
-180
-120
-60
0
60
120
180
401
865
q


CaCO3 (wt%)
δ13C(CaCO3) (‰)
pH
δ13C(atm) (‰)
1209
1263
Time relative to onset (kyr)
150
100
50
0
−50
i
j
k
l
m
n
o
p


90
0
-90
-180
-120
-60
0
60
120
180
1209
1263
q

Sensitivity of total carbon release to onset time-scale

Assumed excursion on-set: 100 - 1,000 yr



Sensitivity of total carbon release to onset time-scale

Assumed excursion on-set: 2,000 - 20,000 yr