The higher climate sensitivity during glacial inceptions in multi-millennial CCSM4 simulations

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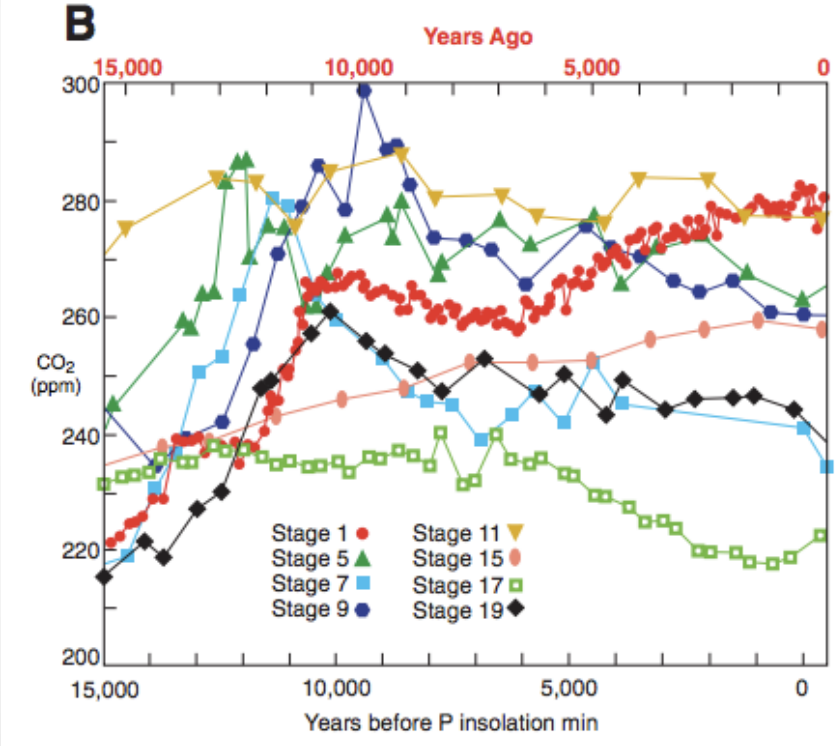
Outline

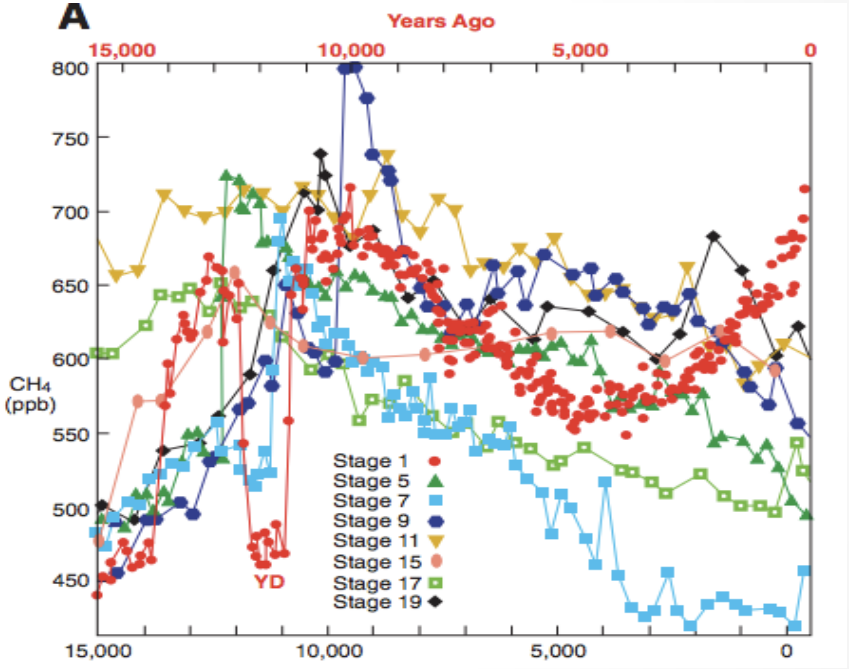
- Early agriculture deferred the glacial inception around pre-industrial (1850 AD)
- Enhanced climate sensitivity during glacial inceptions

Trend reversal within the Holocene

CO_2

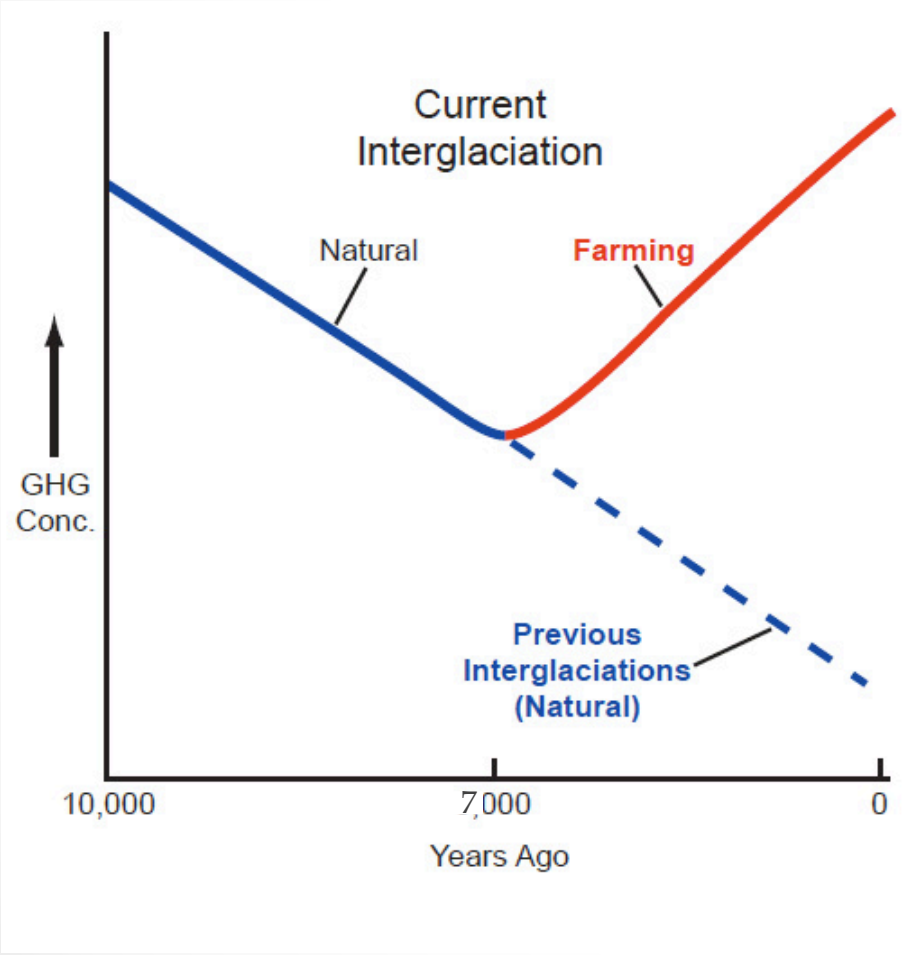


CH_4



- Ruddiman et al. 2011

Early Anthropogenic Hypothesis



285ppm PI with farming

245ppm "Natural PI"

Ruddiman 2003

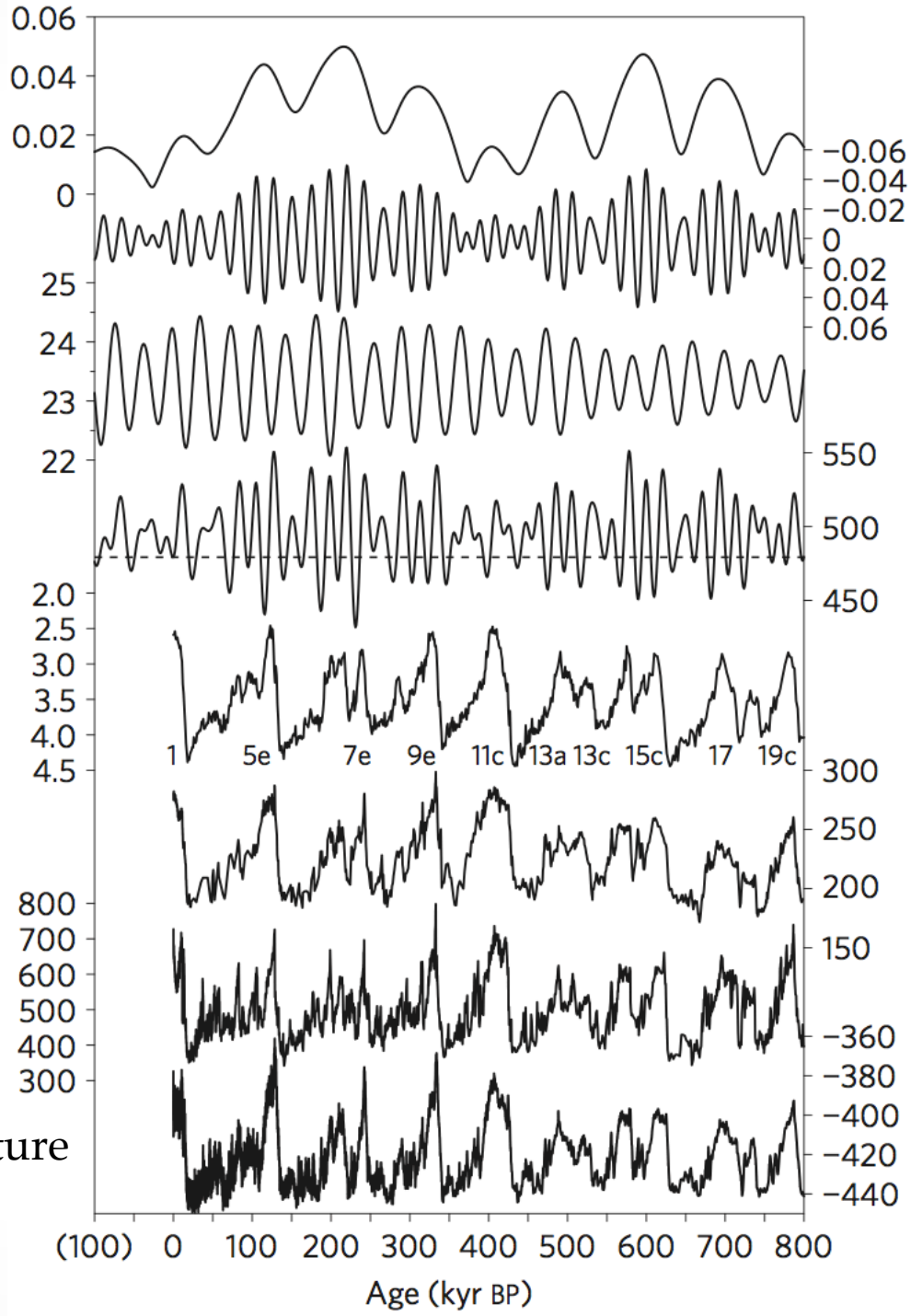
http://www.realclimate.org/index.php/archives/2011/04/an-emerging-view-on-early-land-use/

Should glacial inception have occurred at pre-industrial (1850 AD)

without the carbon emissions from early agriculture?

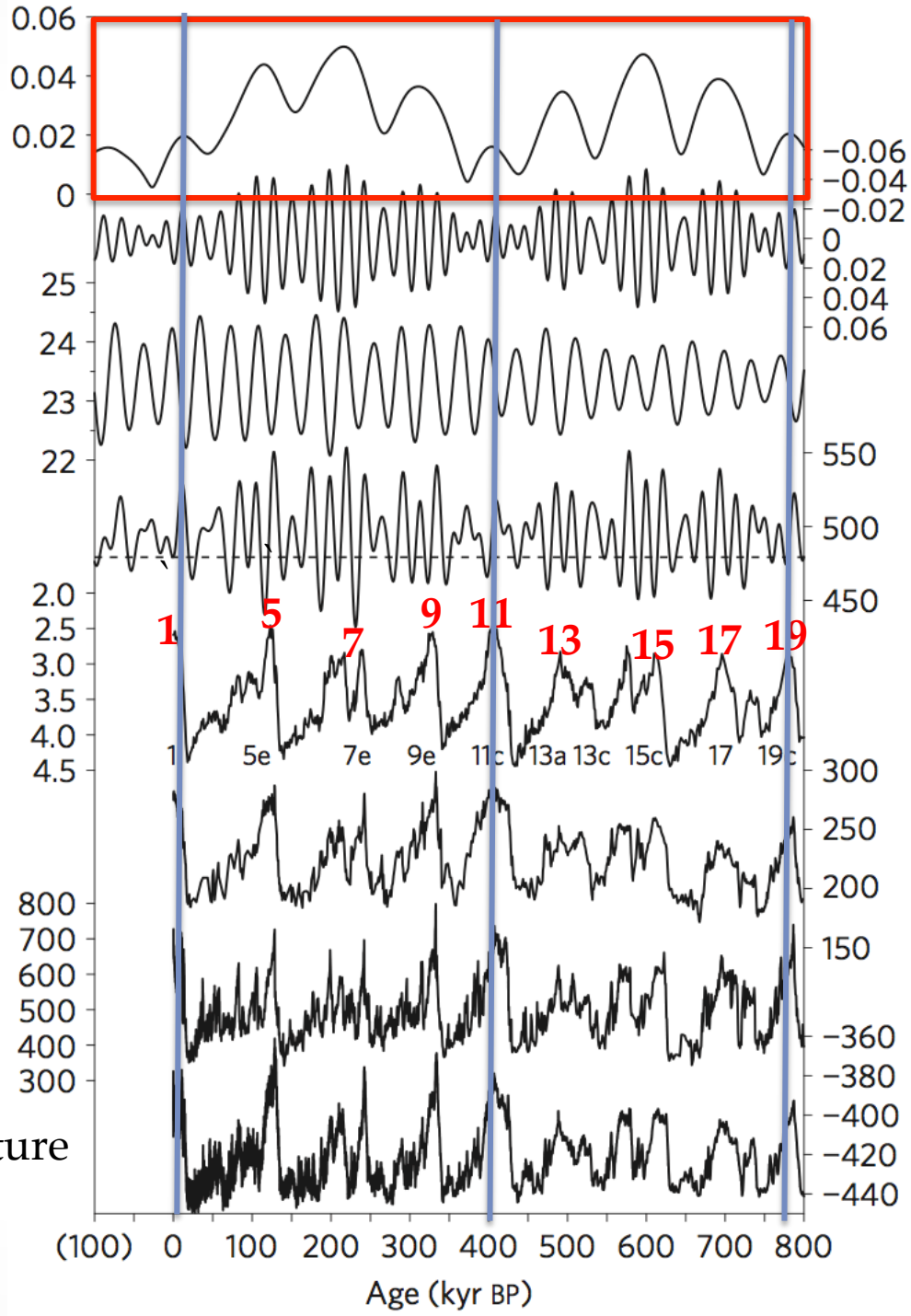
Orbital parameters and GHG of last 8 interglacials and glacial inceptions

(Tzedakis et al. 2012)



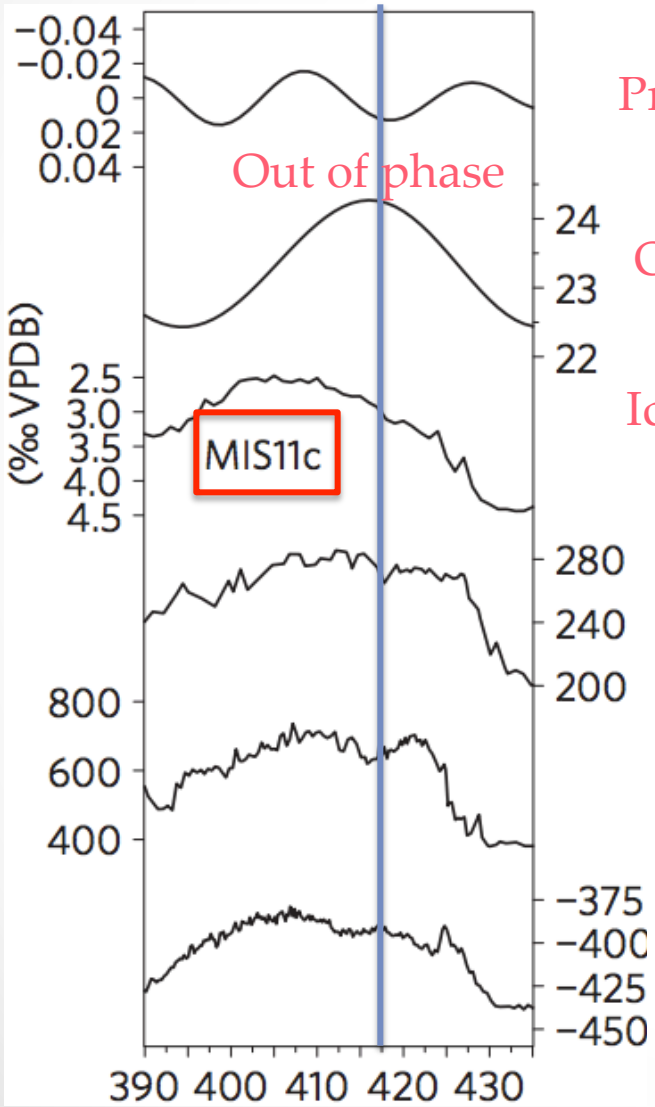
Best Analogs based on eccentricity:
Stage 11 and Stage 19

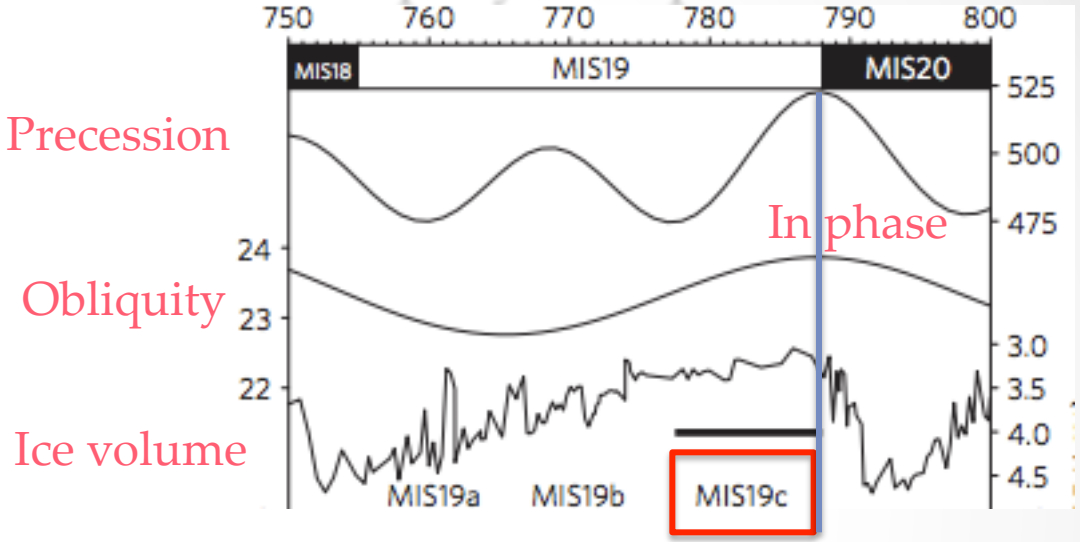
(Tzedakis et al. 2012)



Stage 11 Vs. Stage 19

Based on phasing between obliquity and precession





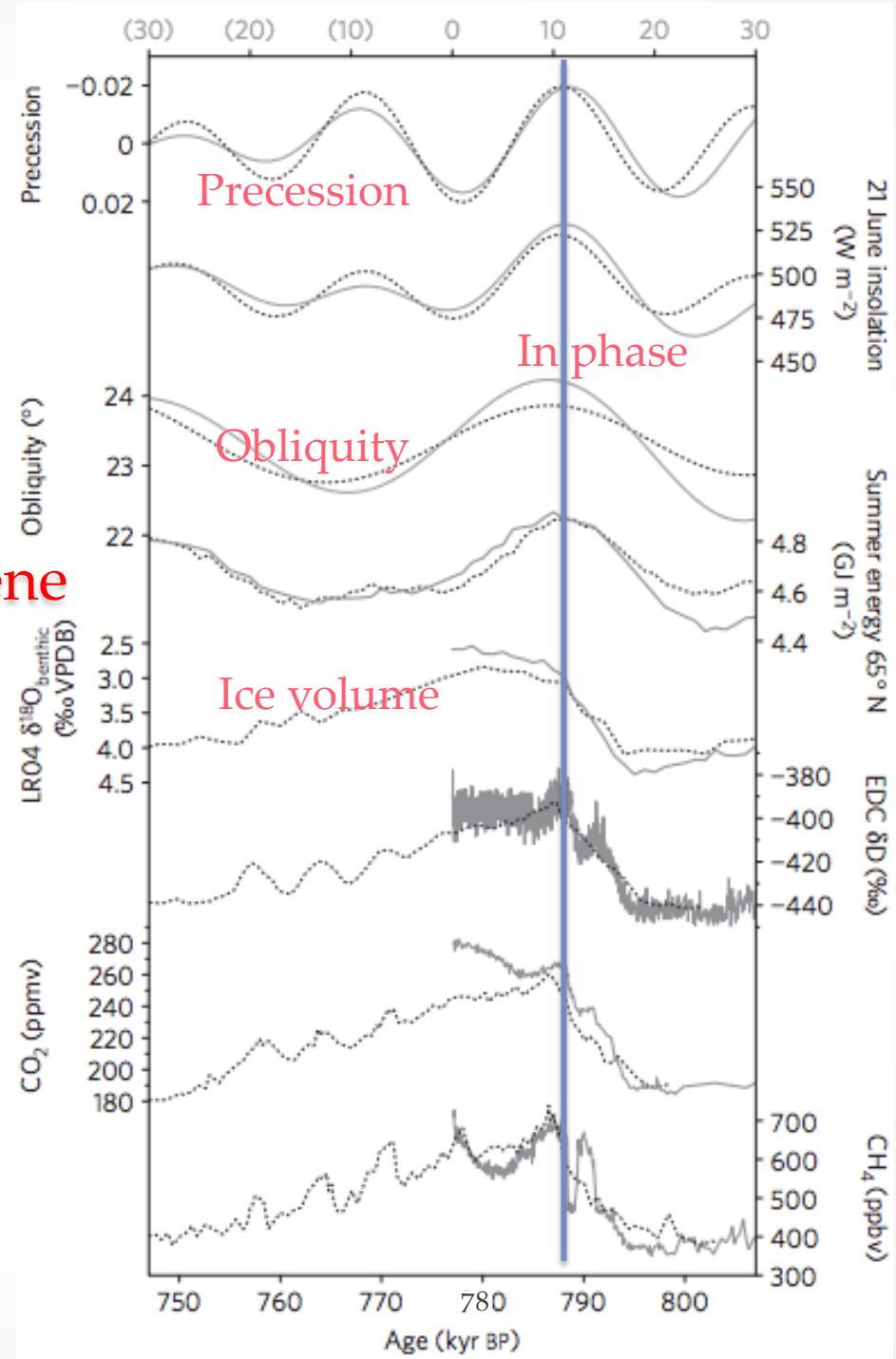
(Tzedakis et al. 2012)

Holocene ——
Stage 19 -------

Stage 19
Best analog of Holocene

1) Low eccentricity
2) In-phase between
Obliquity and precession

- (Tzedakis et al. 2012)



Climatic forcing
(GHG and orbital parameters)

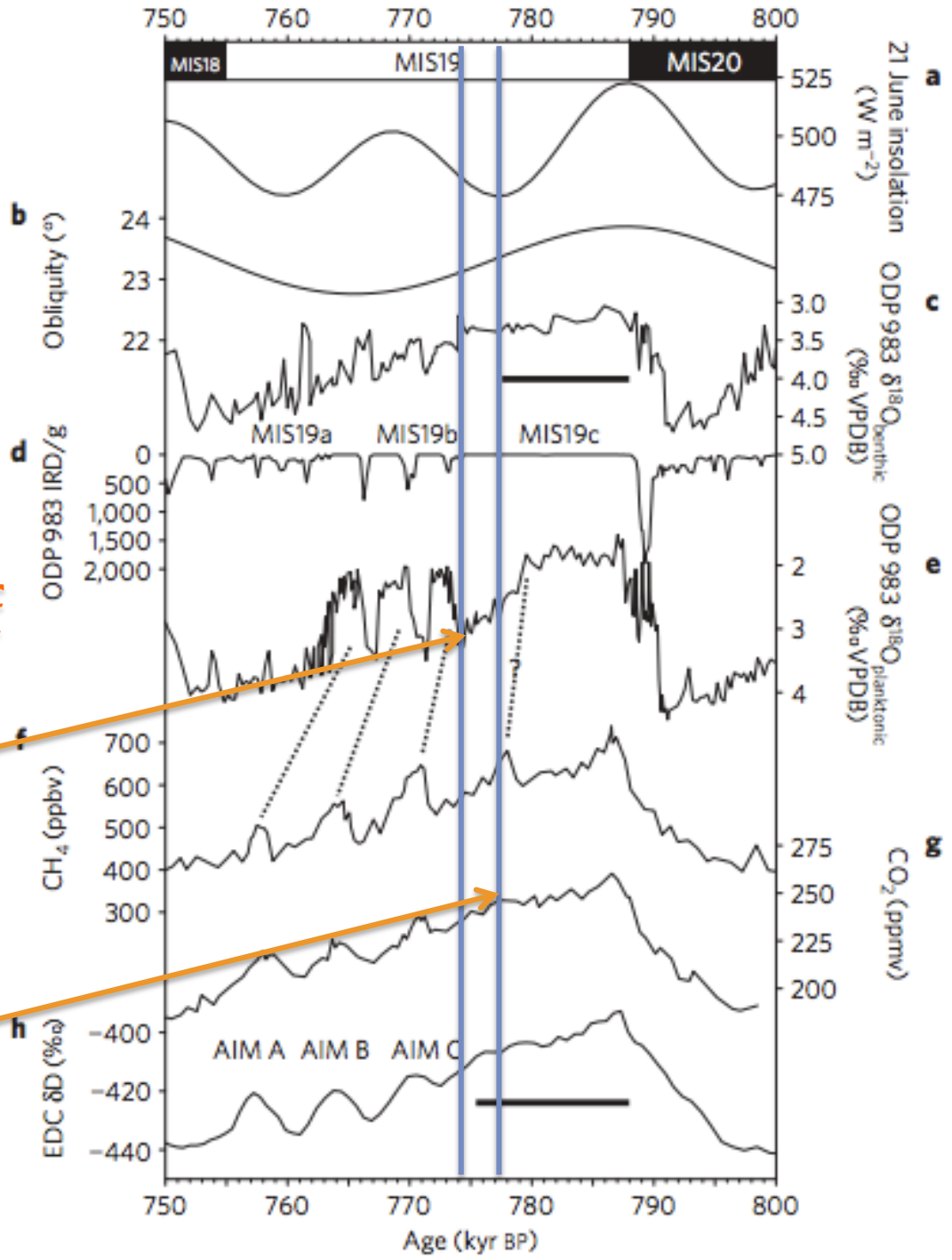
at the glacial inception of the stage 19

Timing of Glacial inception at stage 19

3 kyr before the onset of the millennial events

Timing: 777 kyr BP

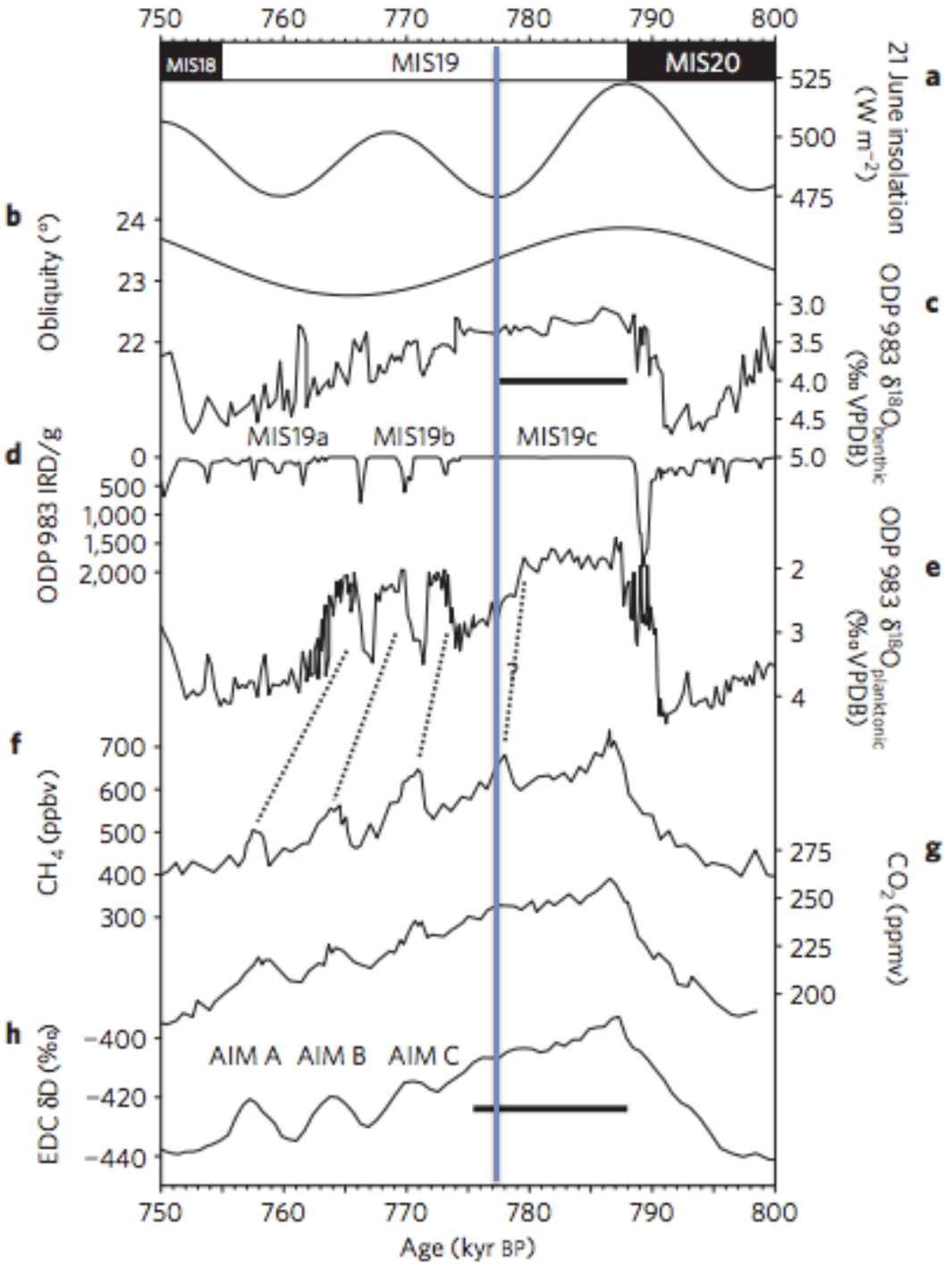
- (Tzedakis et al. 2012)



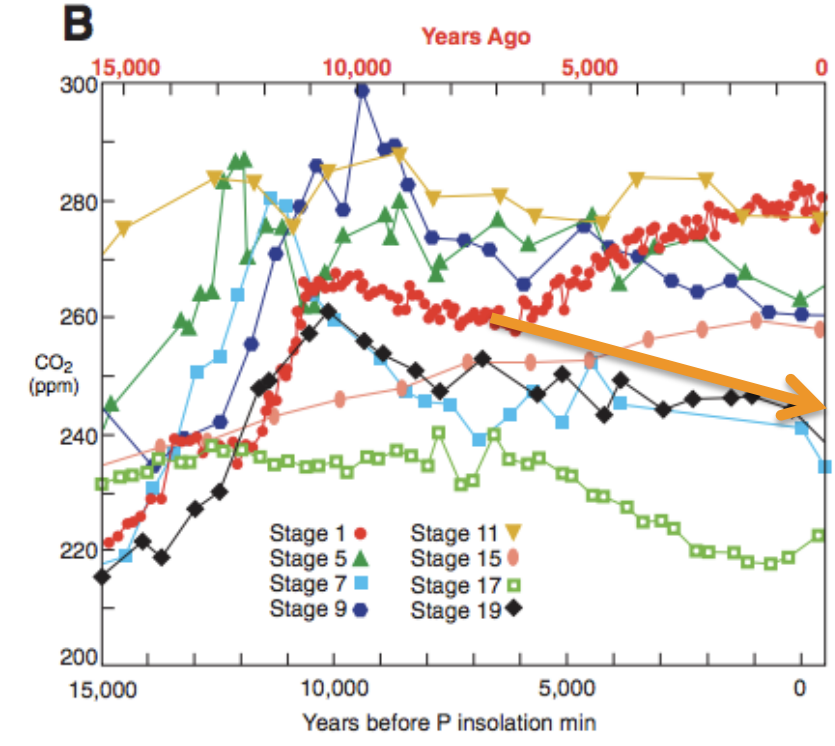
GHGs and orbital parameters at 777 ka

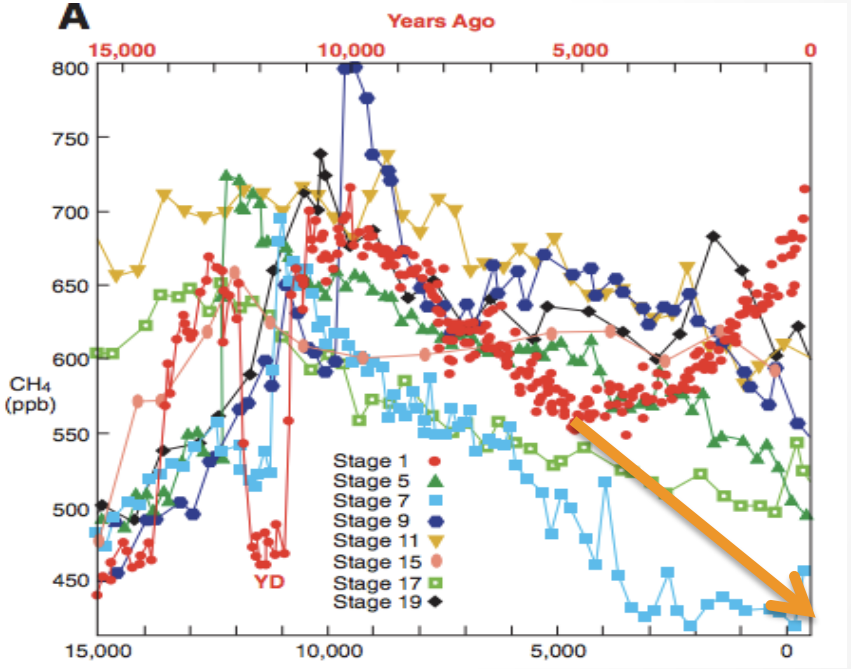
GHGs	
CO_2	245 ppm
CH_4	631 ppb
N_2O	270 ppb

Orbital parameters	
Eccentricity	0.023
Obliquity	23.3°
Precession	108.9°



GHGs at pre-industrial without carbon emissions from early agriculture





CO_2: 245ppm

CH_4: 445ppb

- Vavrus et al. 2008, Ruddiman et al. 2011

GHGs and orbital parameters at PI with no anthropogenic forcing ("natural PI")

GHGs	
CO_2	245 ppm
CH_4	445 ppb
N_2O	270 ppb

Orbital parameters	
Eccentricity	0.017
Obliquity	23.4°
Precession	102.7°

Radiative forcing from the lower GHGs is -1.05 W/m^2 compared to the CCSM4 control run

"Similar" climatic forcing at

Stage-19 glacial inception and "natural PI"

GHGs

	Stage 19 glacial inception	Natural PI
CO_2	245 ppm	245 ppm
CH_4	631 ppb	445 ppb
N_2O	270 ppb	270 ppb

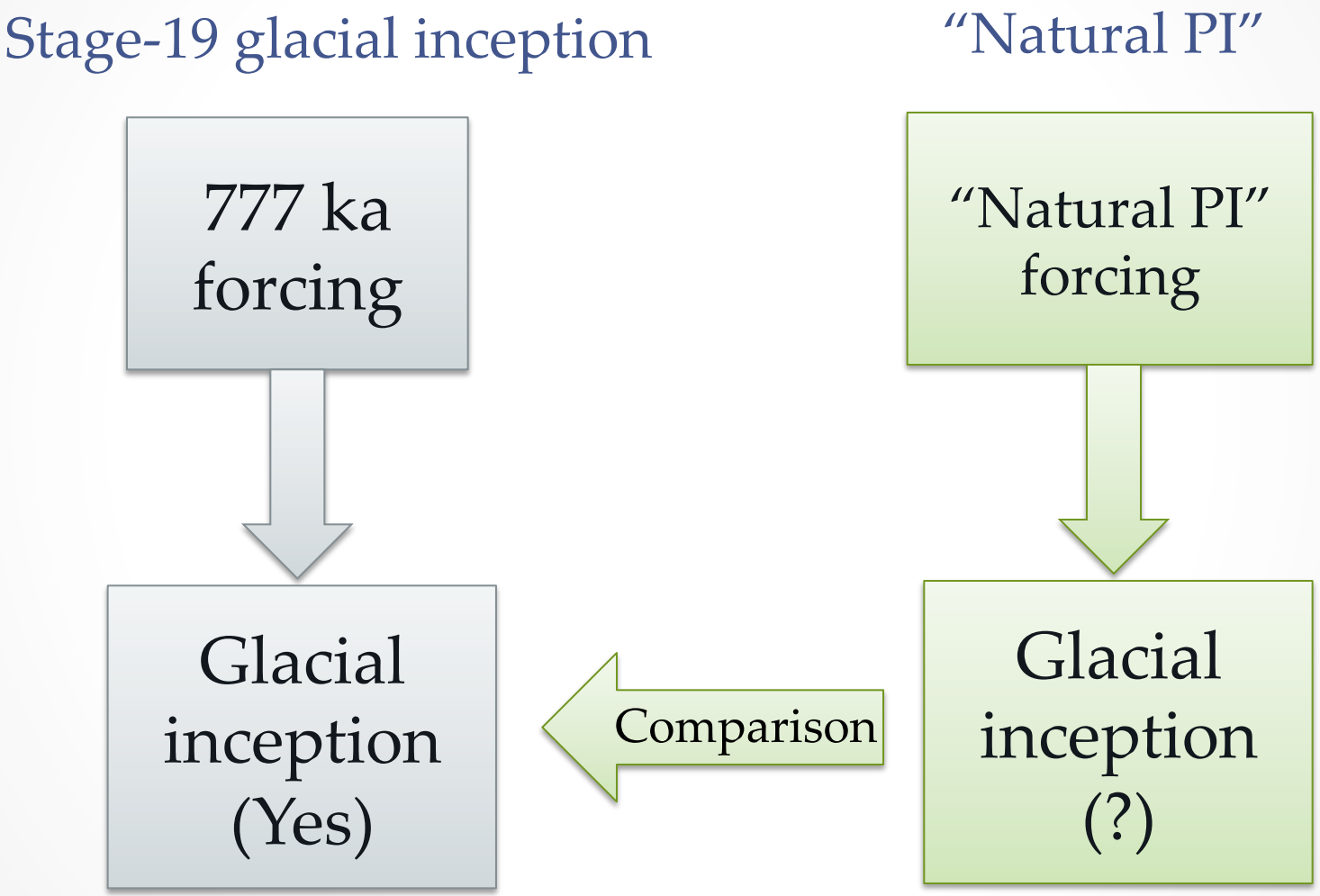
Orbital parameters

	Stage 19 glacial inception	Natural PI
Eccentricity	0.023	0.017
Obliquity	23.3°	23.4°
Precession	108.9°	102.7°

Radiative forcing from CH4 difference: 0.13 W/m^2

Eccentricity varies between 0 and 0.05
Precession: longitude of the perihelion varies between 0 and 360°

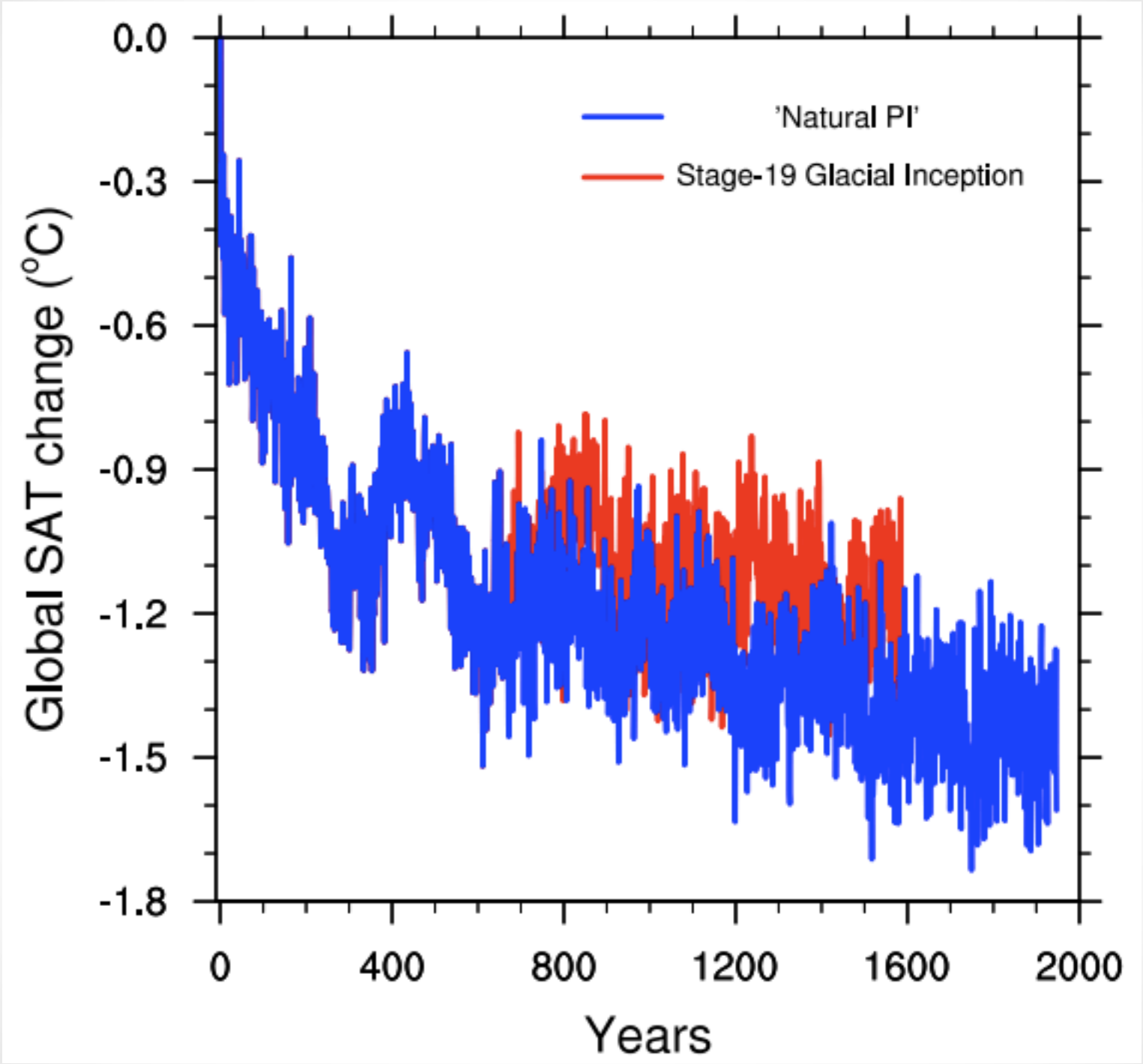
Experiment design

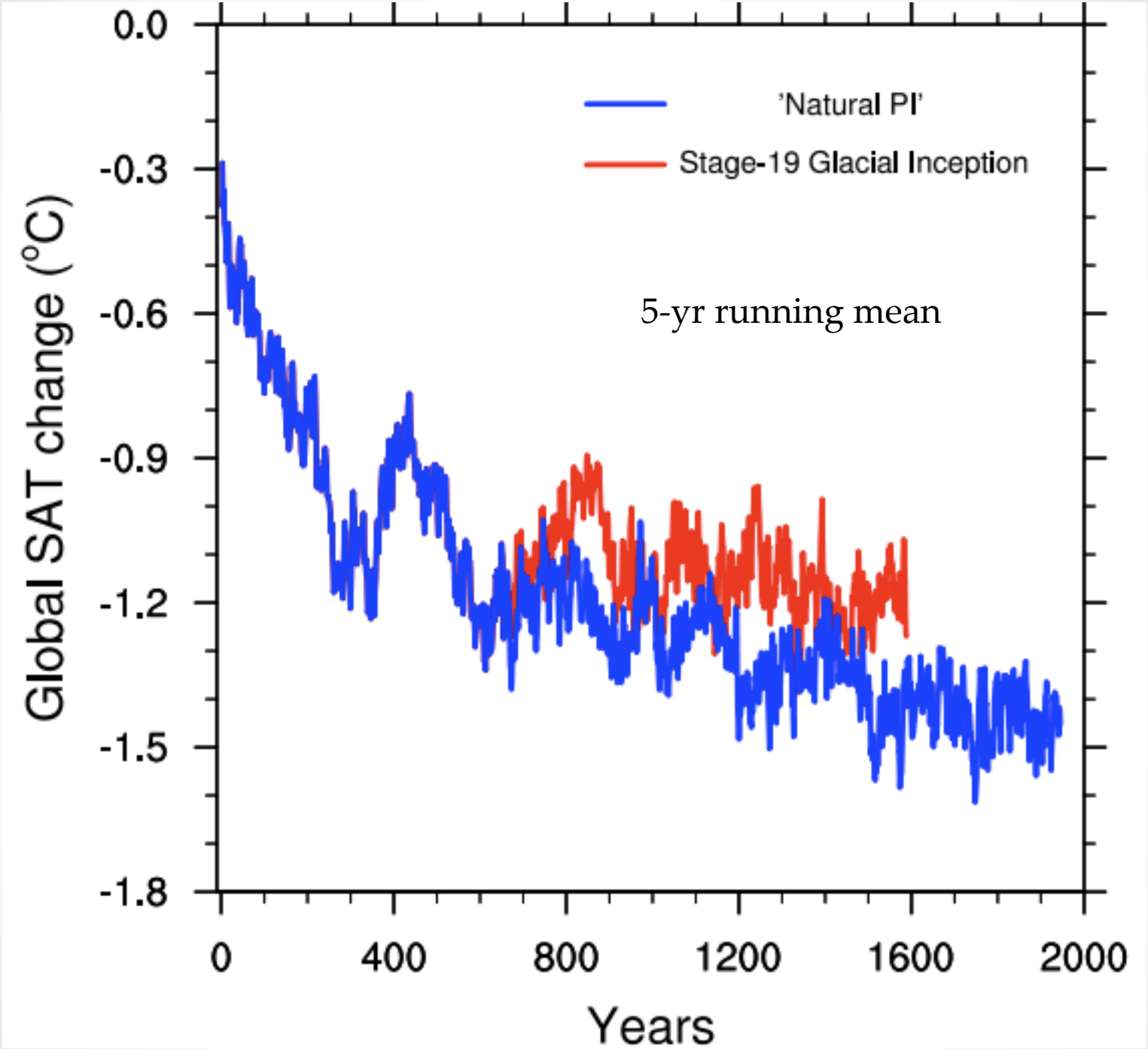


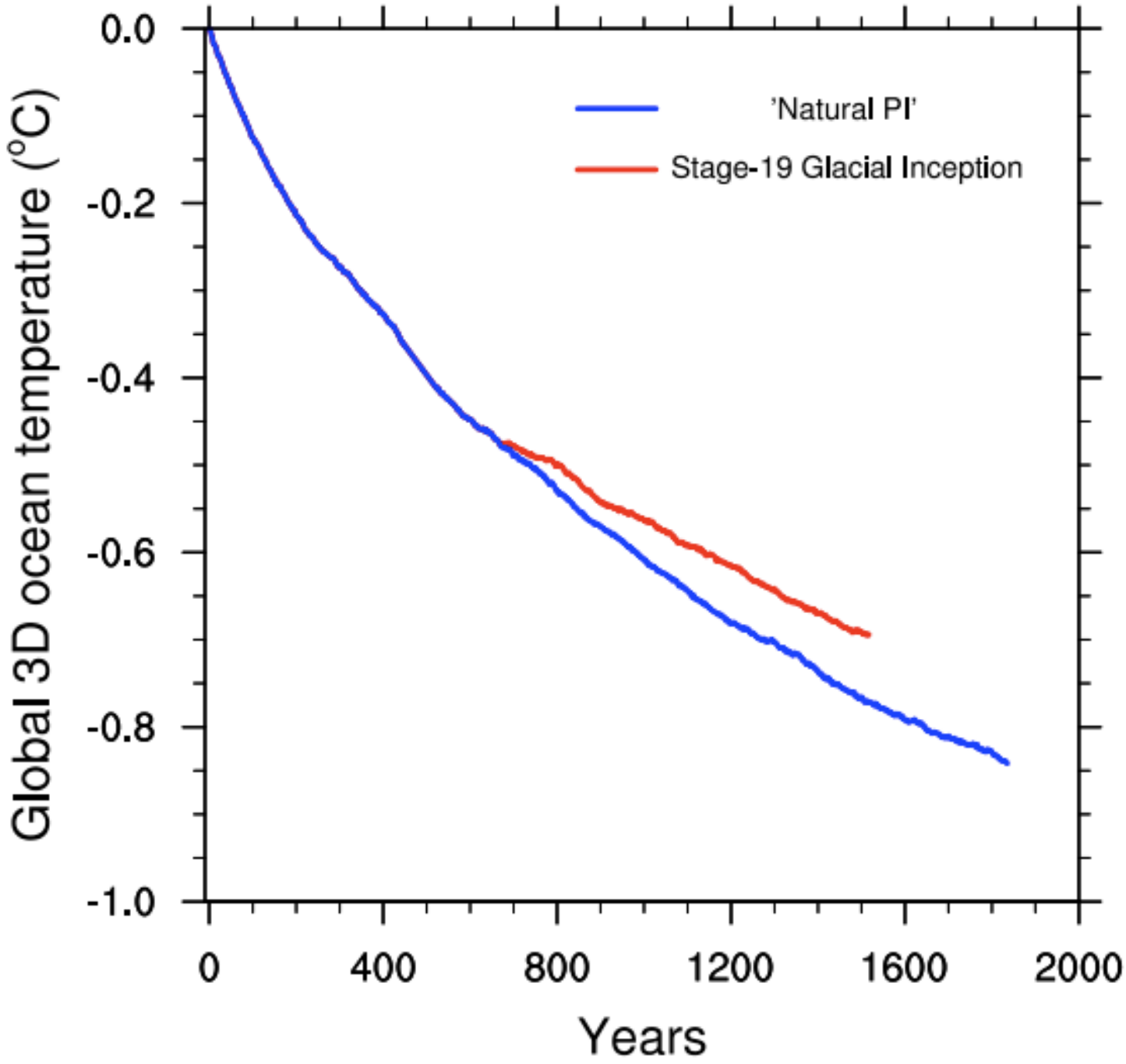
Experiment design

1-degree fully coupled CCSM4 simulations

EXP	Initialization	Run length
"Natural PI"	Year 1300 of NCAR CCSM4 control run	1950 years
Stage-19 Glacial Inception	Year 670 of "Nature PI" run	920 years


0.0
-0.3
-0.6
-0.9
-1.2
-1.5
-1.8
Global SAT change (°C)
'Natural PI'
Stage-19 Glacial Inception
0
400
800
1200
1600
2000
Years

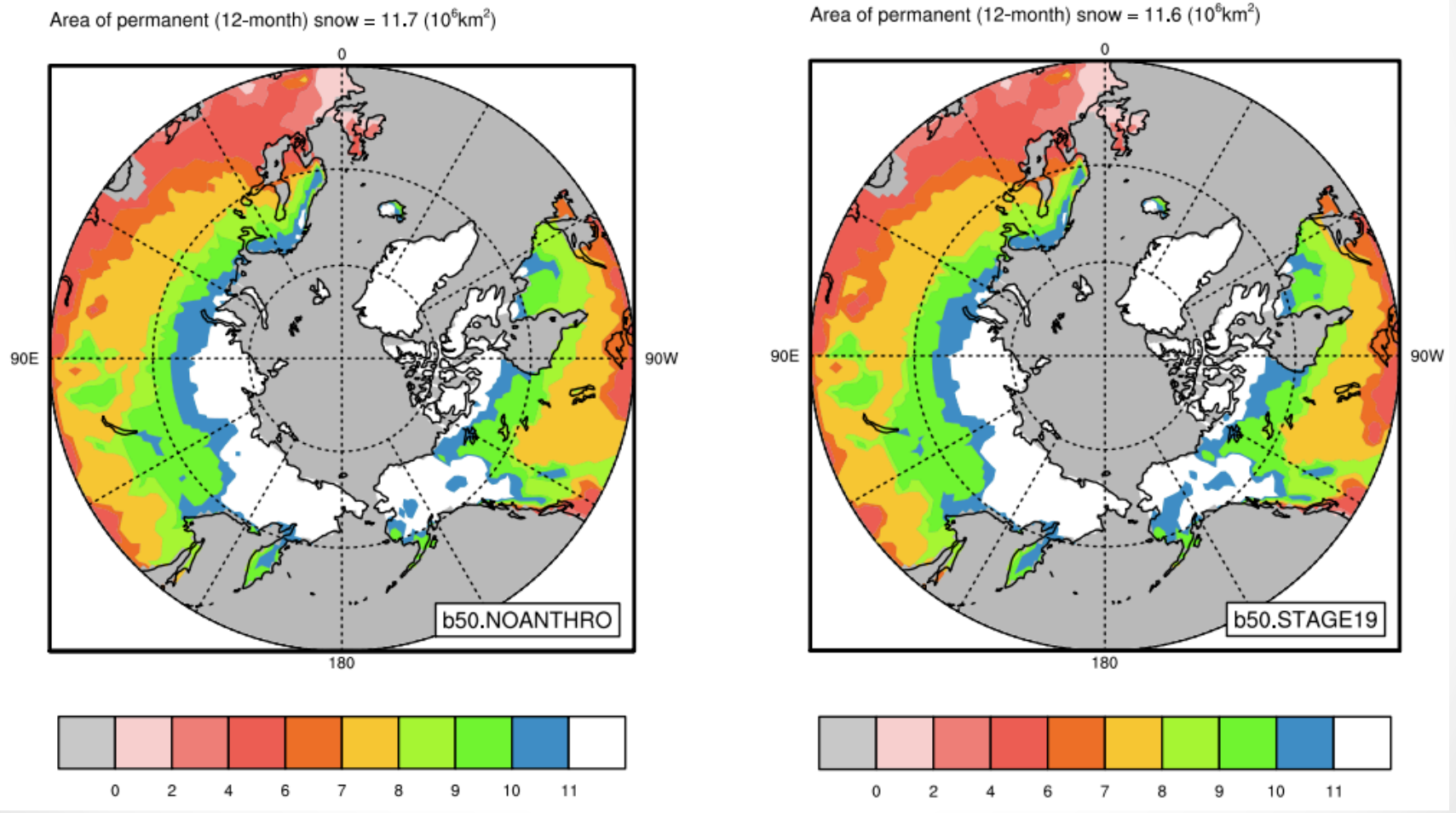

0.0
-0.3
-0.6
-0.9
-1.2
-1.5
-1.8
Global SAT change (°C)
'Natural PI'
Stage-19 Glacial Inception
5-yr running mean
0
400
800
1200
1600
2000
Years


0.0
-0.2
-0.4
-0.6
-0.8
-1.0
Global 3D ocean temperature (°C)
'Natural PI'
Stage-19 Glacial Inception
0
400
800
1200
1600
2000
Years

Permanent snow cover

"Natural PI"
11.7 million km^2

Stage 19 Glacial inception:
11.6 million km^2



Months of Snow Cover

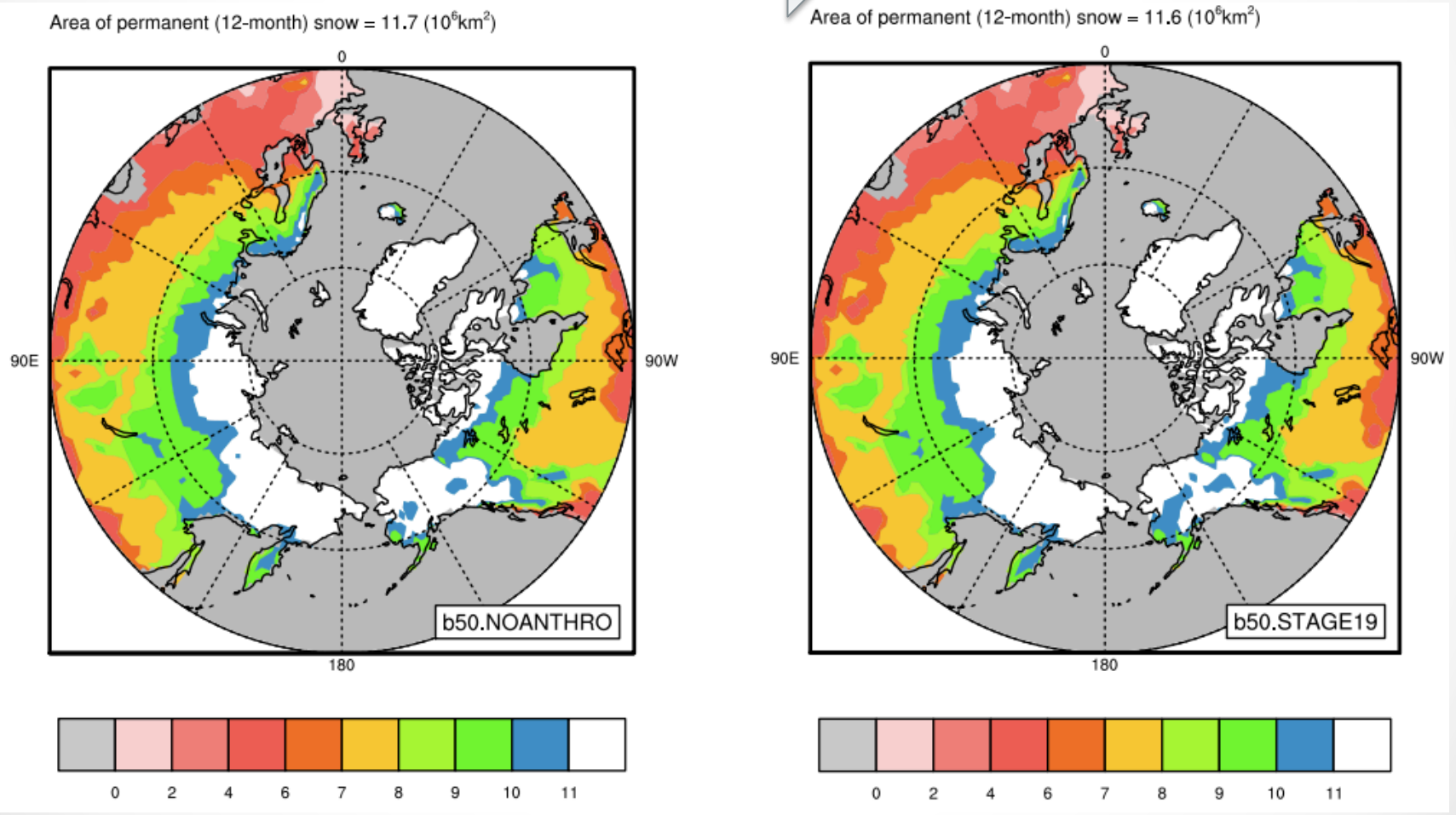
Glacial inception? (Yes)

Permanent snow cover

"Natural PI"
11.7 million km^2

Comparison

Stage-19 glacial inception:
11.6 million km^2

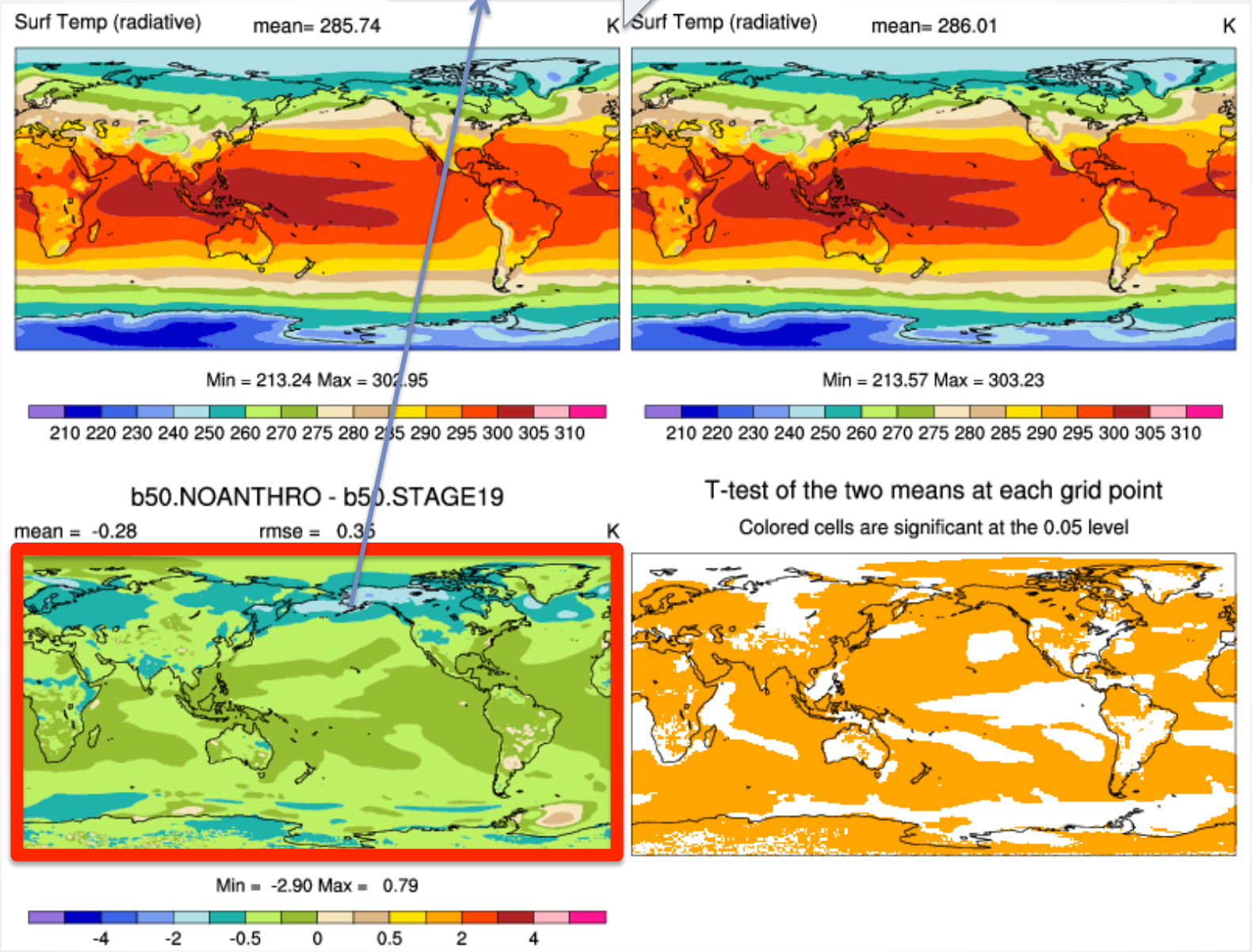


Months of Snow Cover

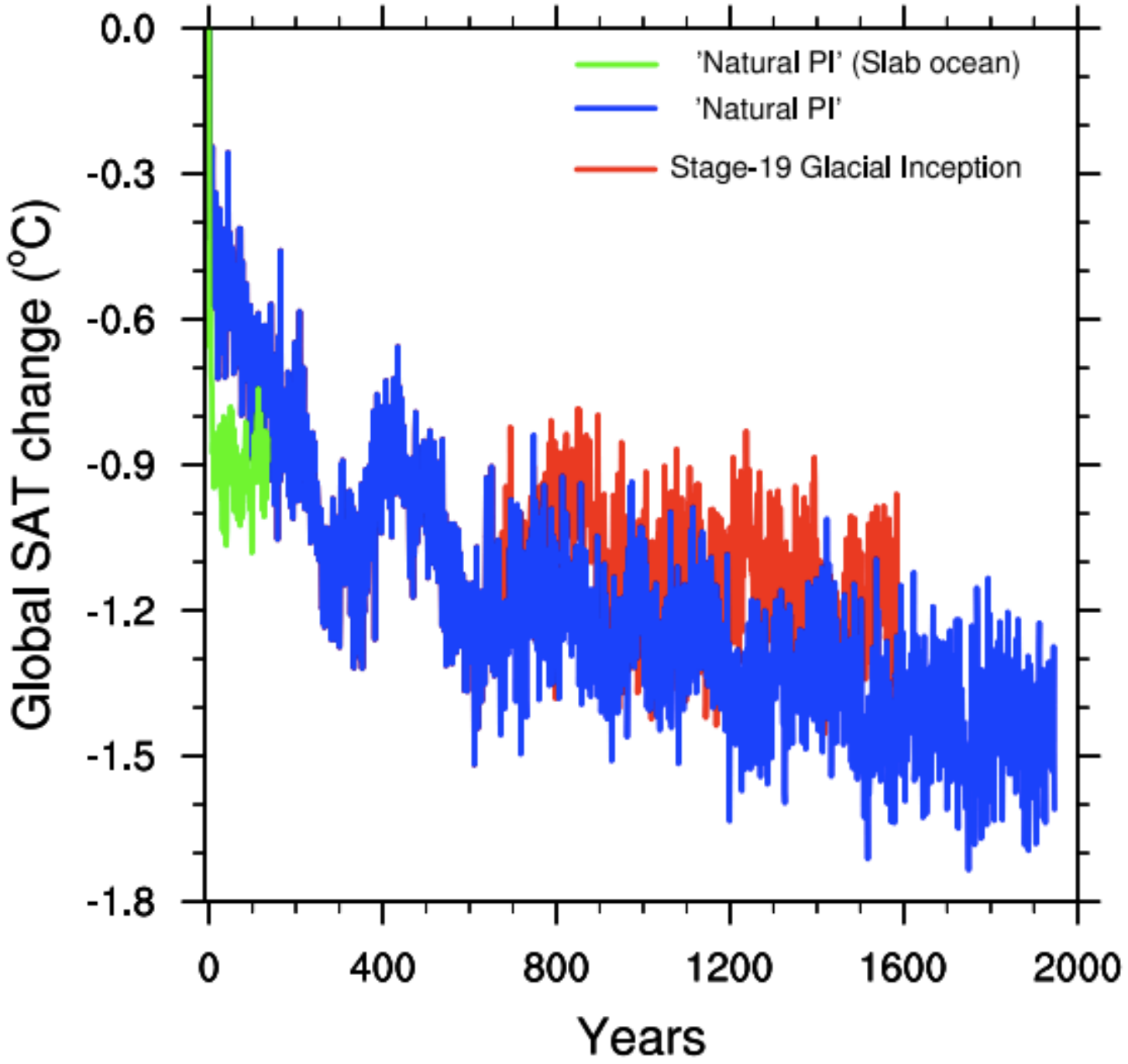
"Natural PI"

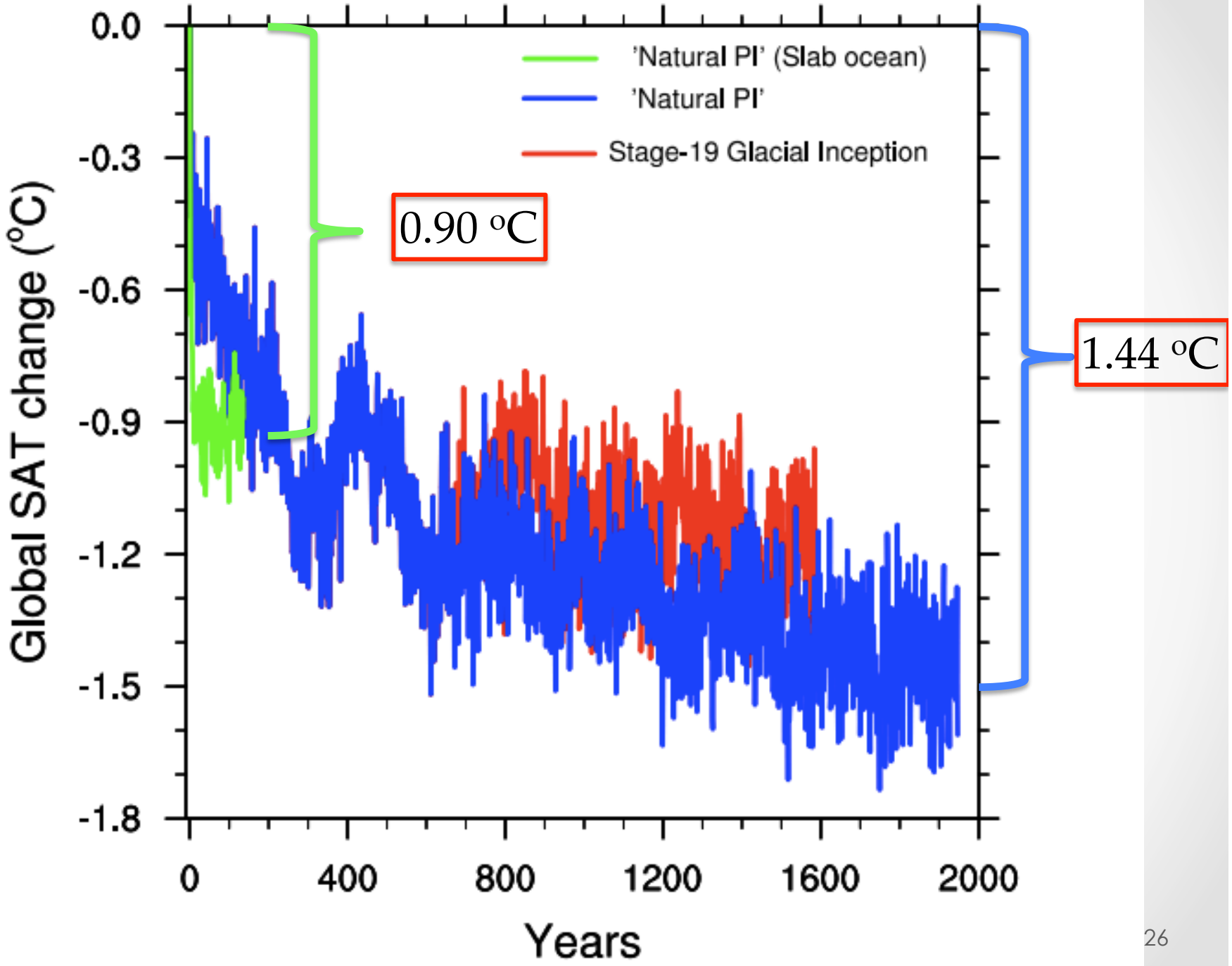
0.28 °C colder

Stage-19 glacial inception



Higher climate sensitivity during glacial inceptions


'Natural PI' (Slab ocean)
'Natural PI'
Stage-19 Glacial Inception
Global SAT change (°C)
0.0
-0.3
-0.6
-0.9
-1.2
-1.5
-1.8
0
400
800
1200
1600
2000
Years


'Natural PI' (Slab ocean)
'Natural PI'
Stage-19 Glacial Inception
0.90 °C
1.44 °C
Global SAT change (°C)
0.0
-0.3
-0.6
-0.9
-1.2
-1.5
-1.8
0
400
800
1200
1600
2000
Years

Higher climate sensitivity in fully-coupled simulations

$\Delta T/\Delta F^{*}\Delta F_{2xco2}$

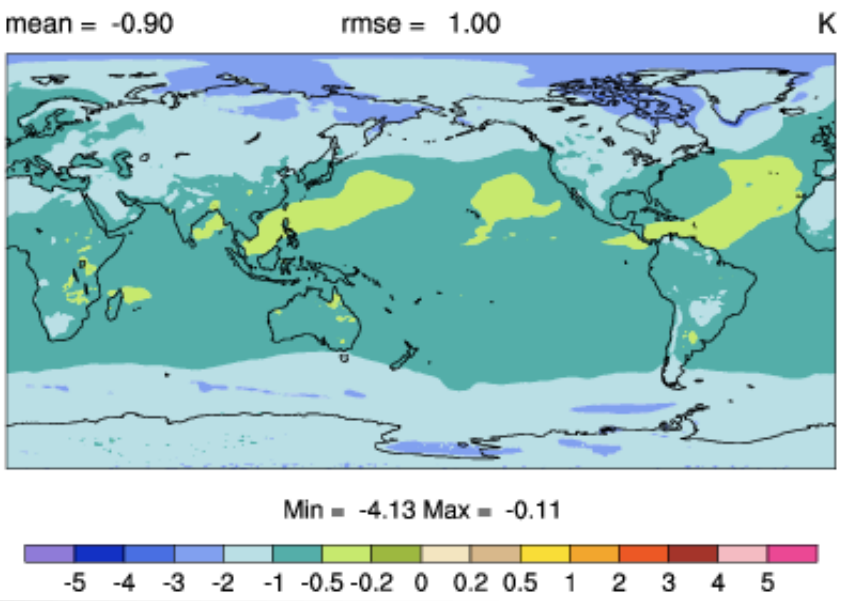
= (0.90)/(1.05)*3.7
= **3.2 K**

Consistent with **3.2 K** in
slab ocean runs in Bitz et al. (2012)

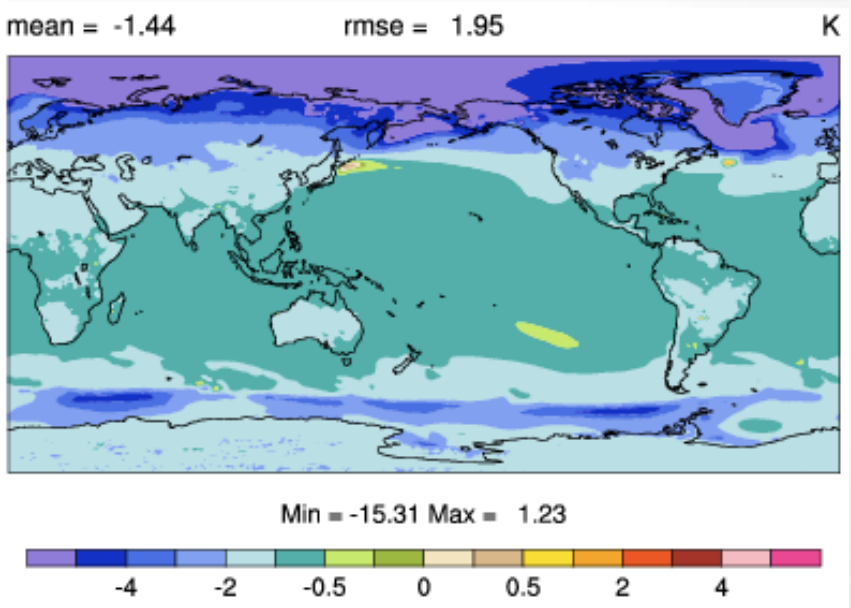
$\Delta T/\Delta F^{*}\Delta F_{2xco2}$

= (1.44)/(1.05)*3.7
= **5.1 K**

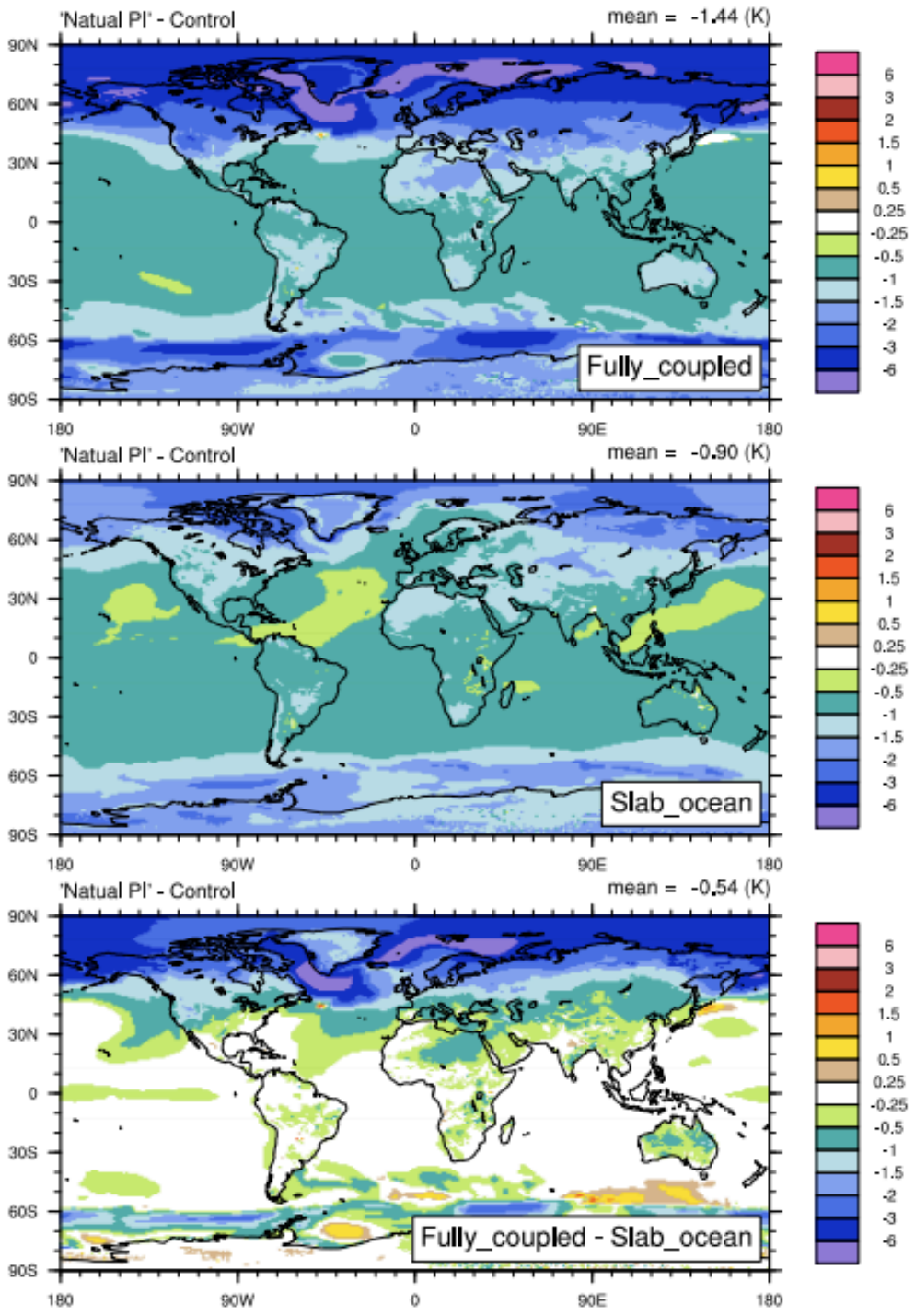
Brady et al. (2013) found **4.2 K** in fully coupled LGMCO_2 run



Slab ocean run



Fully-coupled run



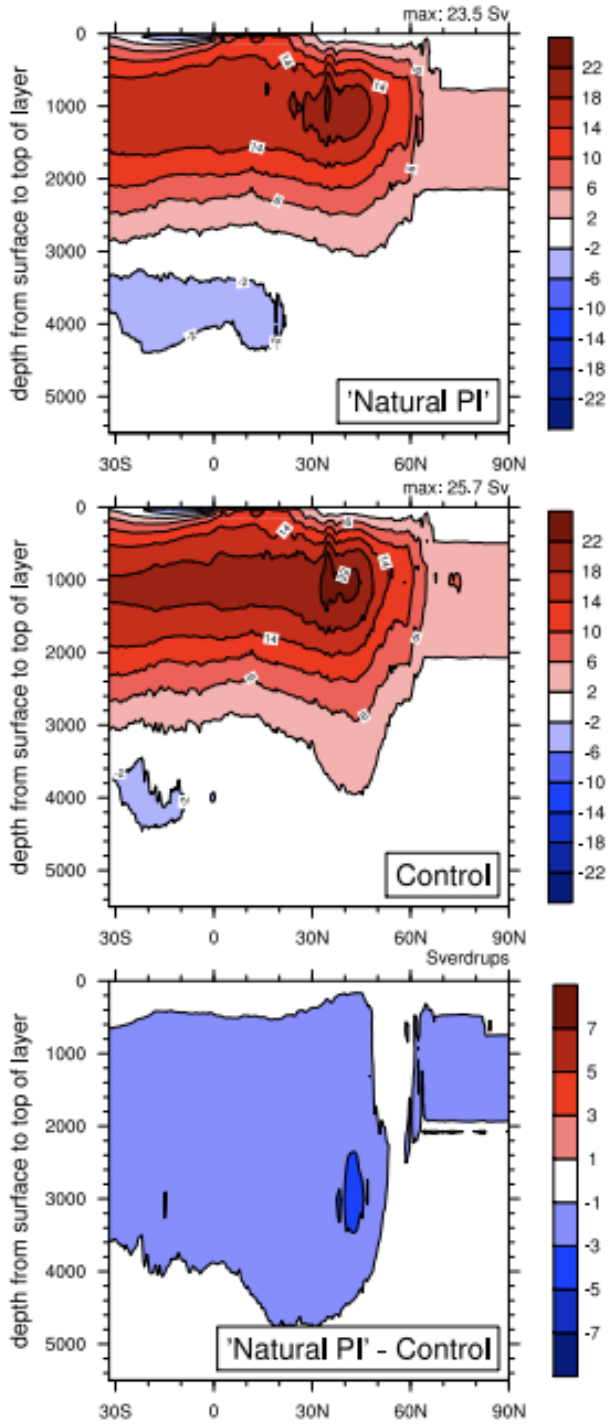
Global cooling at glacial inception

Fully-coupled simulation

Slab-ocean simulation

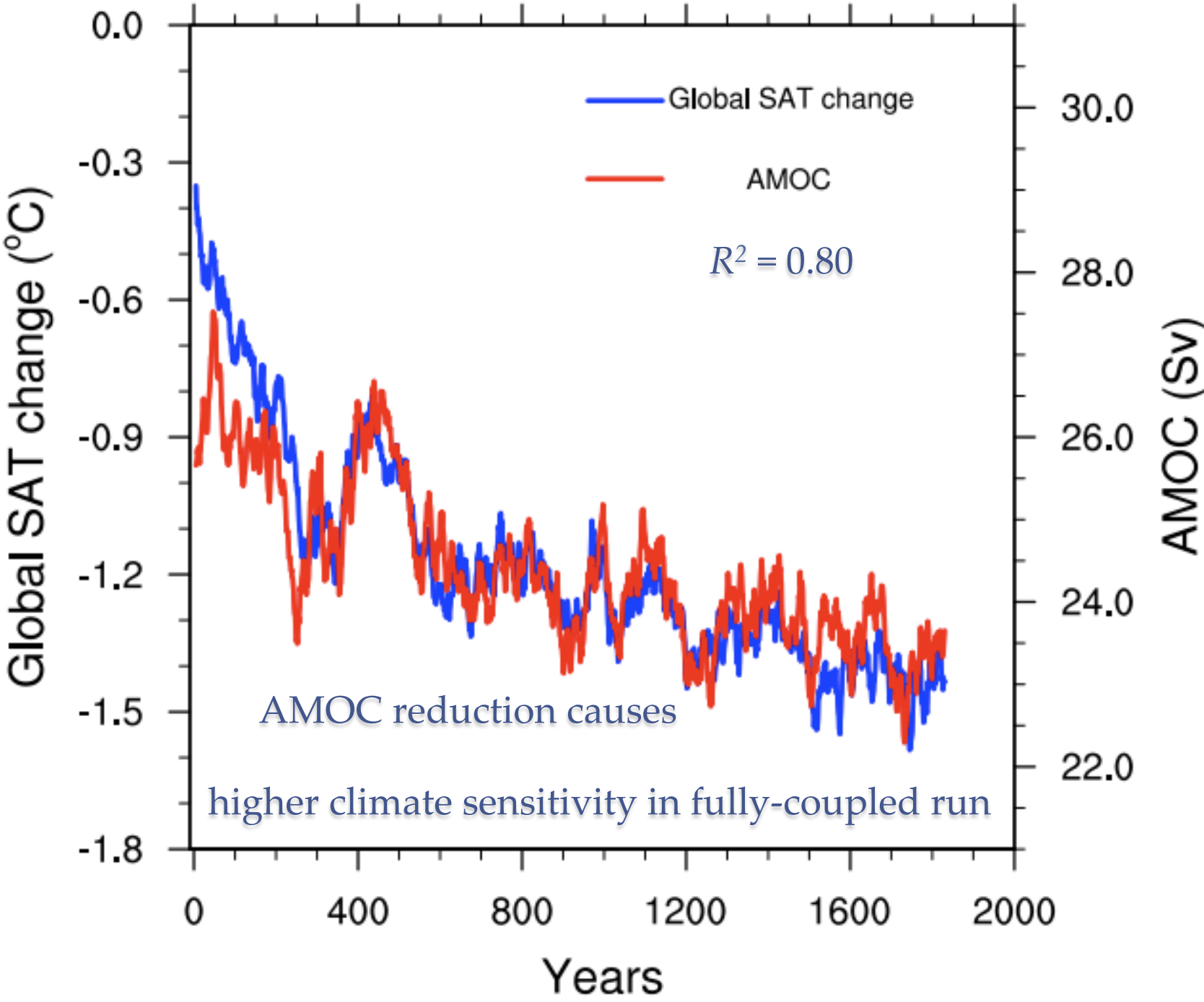
Extra cooling in fully-coupled run in Northern Hemisphere high latitudes, especially in Labrador Sea and Nordic Sea.

Fully_coupled – Slab_ocean



AMOC reduction causes

extra cooling in fully-coupled run


Global SAT change
AMOC
$R^2 = 0.80$
AMOC reduction causes
higher climate sensitivity in fully-coupled run
Global SAT change (°C)
AMOC (Sv)
Years
0.0
-0.3
-0.6
-0.9
-1.2
-1.5
-1.8
30.0
28.0
26.0
24.0
22.0
0
400
800
1200
1600
2000

Conclusions

Without the carbon emissions from the early agriculture, the climatic forcing (GHGs and orbital parameters) should have caused similar glacial inception at 1850 AD as the stage-19 glacial inception.

During glacial inceptions, the climate sensitivity is higher due to the reduction of the AMOC.