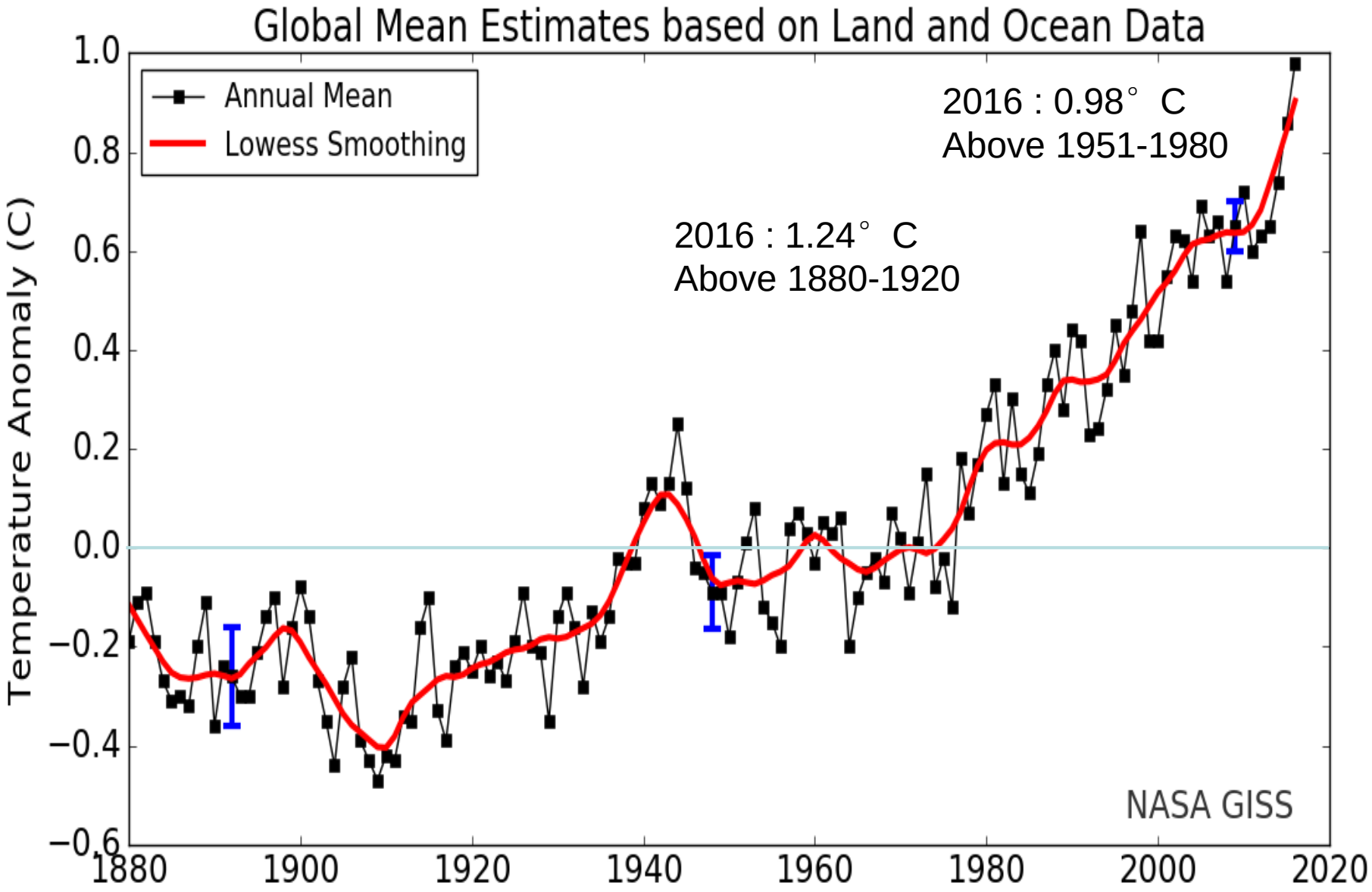
Georges Lemaître Center for Earth and Climate Research
Formerly Institute of Astronomy and Geophysics George Lemaître
Place L. Pasteur, 3
1348 Louvain-la-Neuve

Past Climates, a key for the future

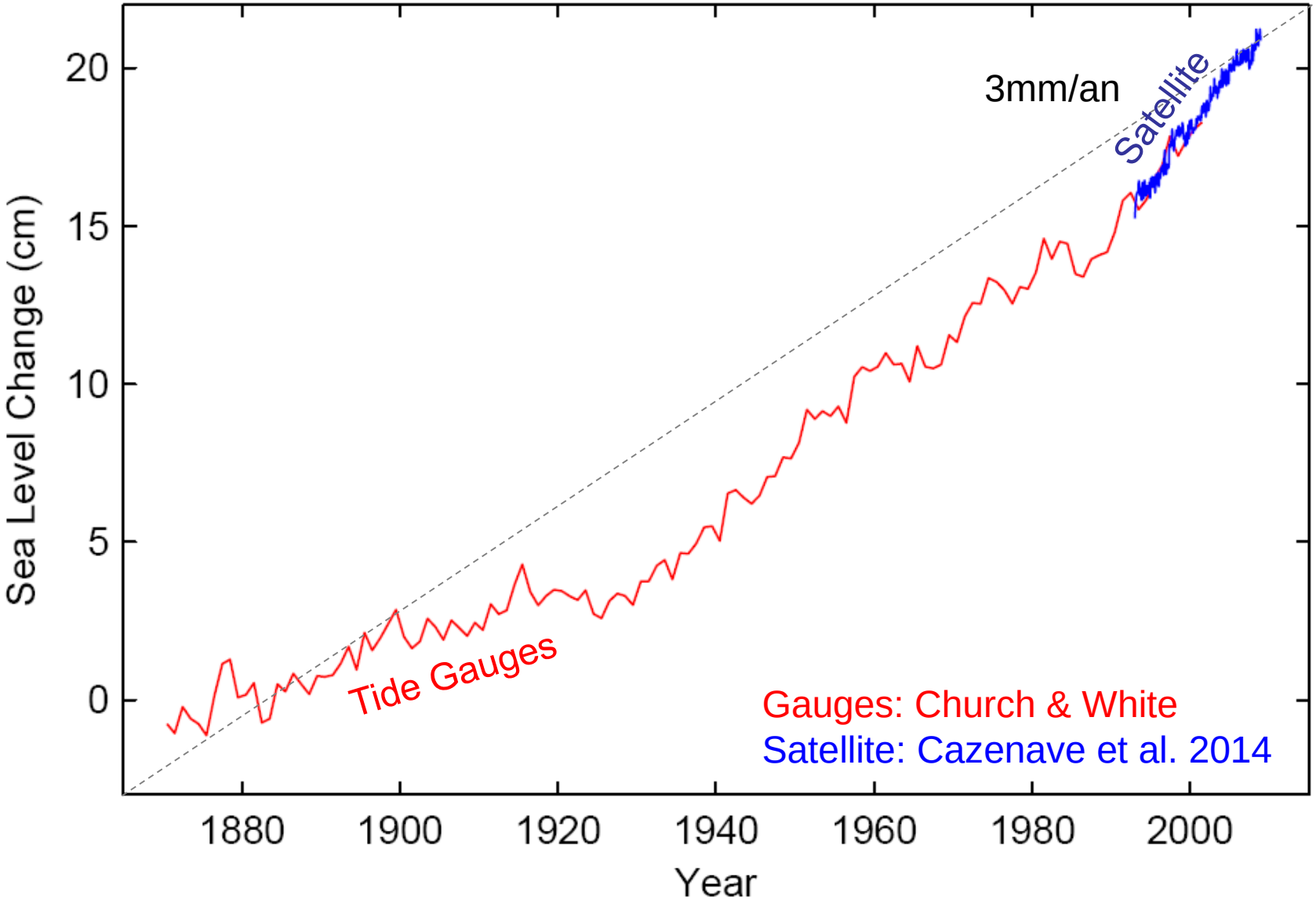
André Berger and Qiuzhen Yin

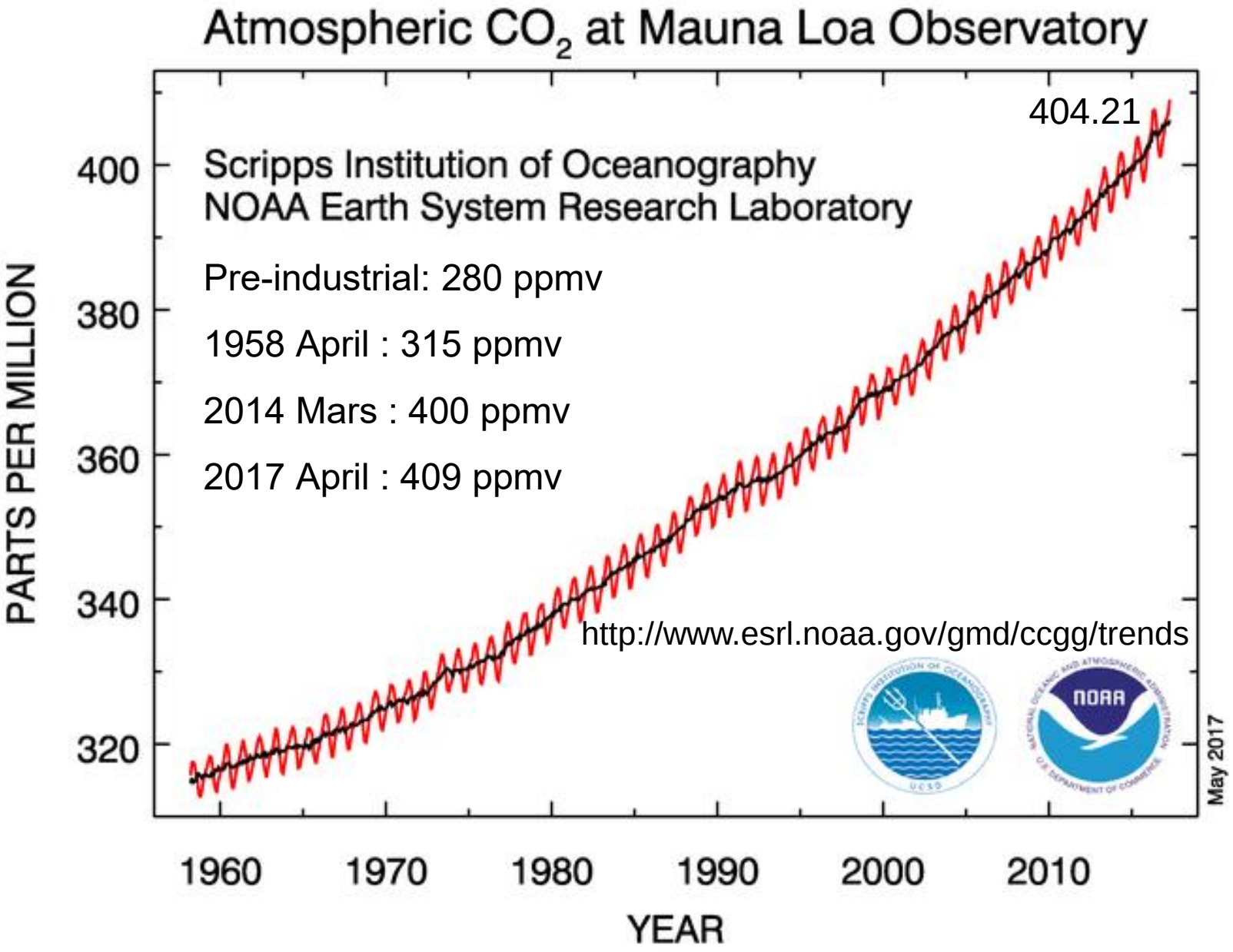
Invited lecture, Geosciences Information for Teachers, European Geosciences Union, Cape Town 30 August-1 September 2017.

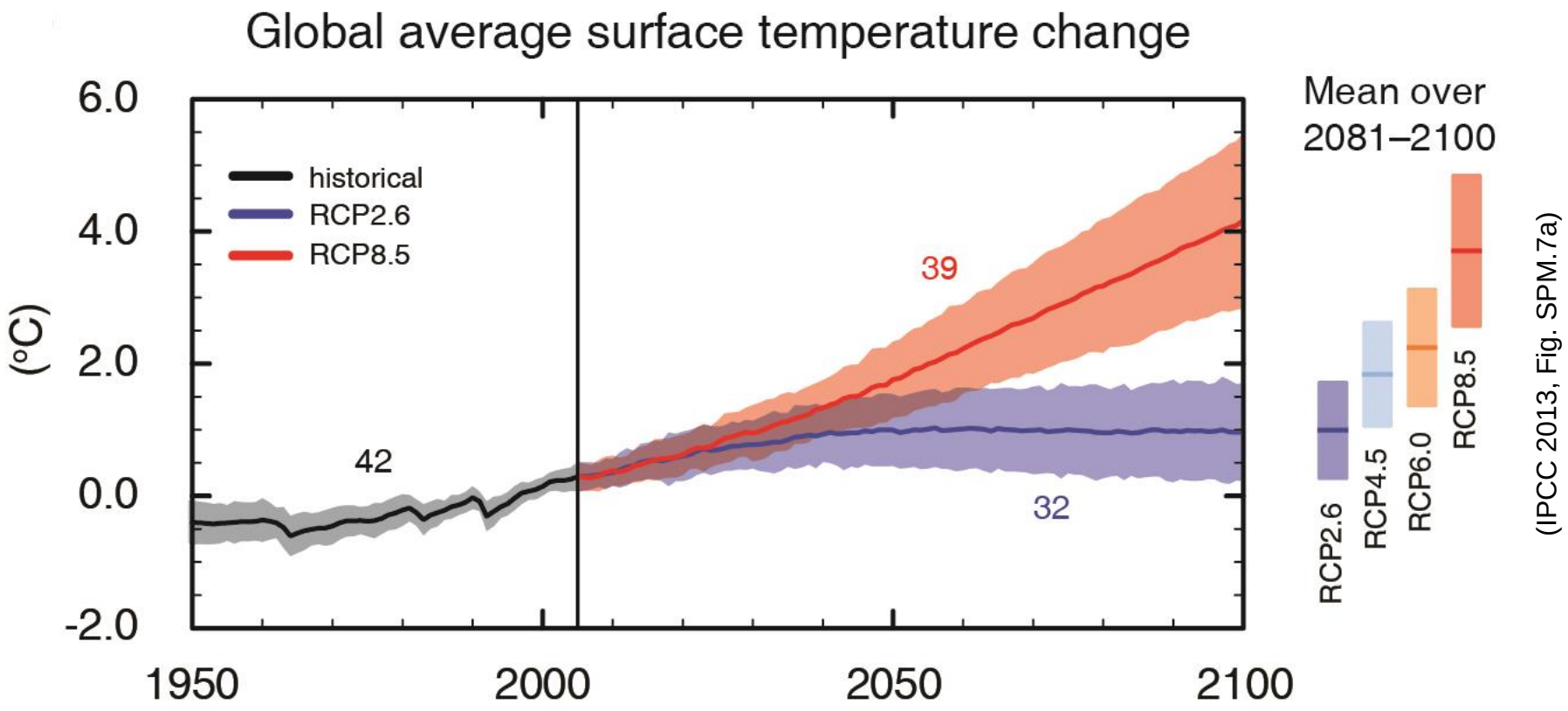


https://data.giss.nasa.gov/gistemp/graphs/

Sea Level Rise



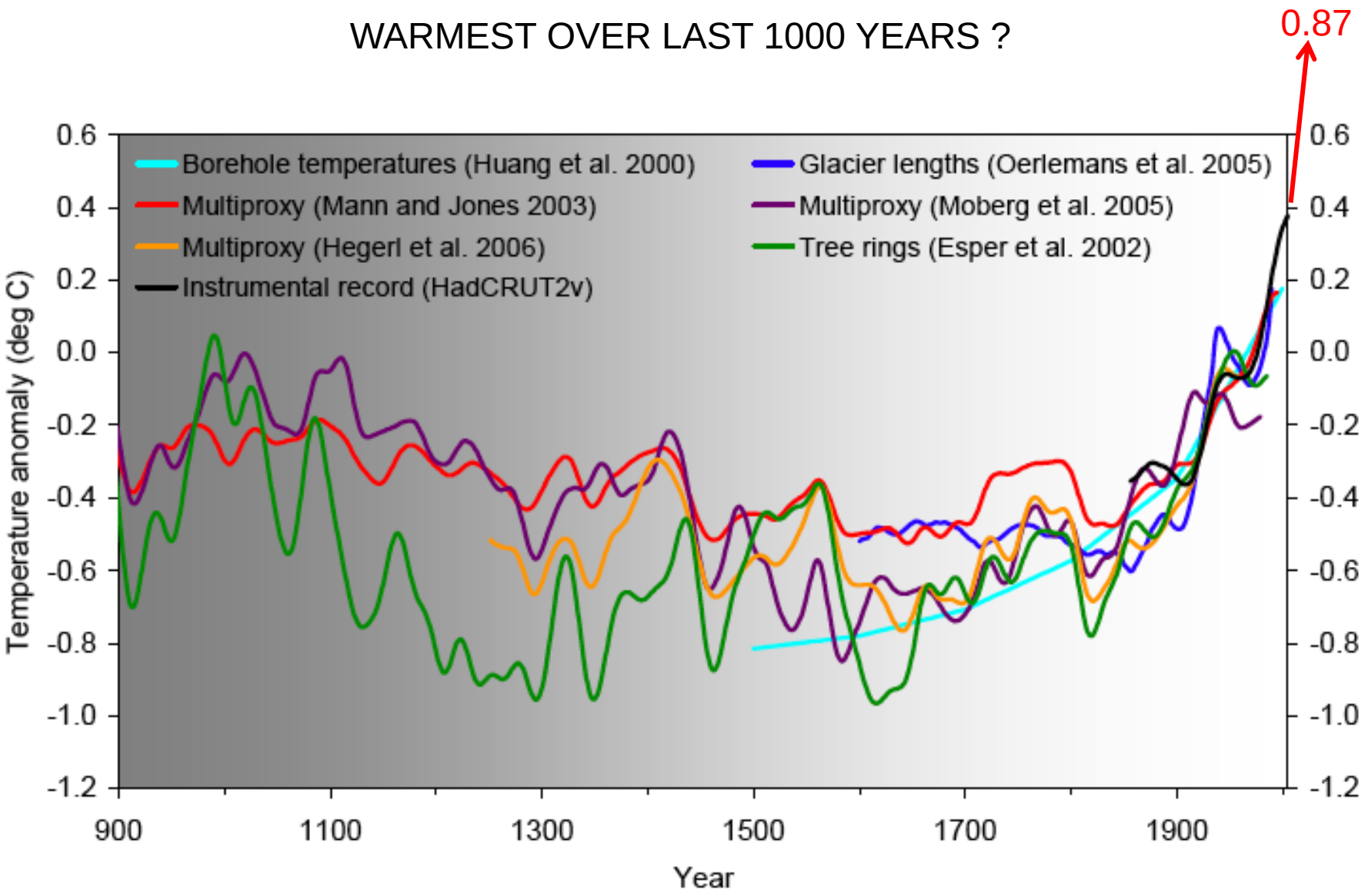

Atmospheric CO_2 at Mauna Loa Observatory
404.21
Scripps Institution of Oceanography
NOAA Earth System Research Laboratory
Pre-industrial: 280 ppmv
1958 April : 315 ppmv
2014 Mars : 400 ppmv
2017 April : 409 ppmv
http://www.esrl.noaa.gov/gmd/ccgg/trends
PARTS PER MILLION
400
380
360
340
320
1960
1970
1980
1990
2000
2010
YEAR
May 2017



Global surface temperature change for the end of the 21st century is *likely* to exceed 1.5°C relative to 1850 for all scenarios

Stocker et al., 2013; IPCC

WARMEST OVER LAST 1000 YEARS ?



WHAT DO WE LEARN FROM PAST CLIMATE CHANGES ?

Last Glacial Maximum 21kyr BP

Pre-industrial CO_2 = 280 ppmv

2000 AD CO_2 = 370 ppmv

2015 AD CO_2 = 400 ppmv

ΔT=-5°C

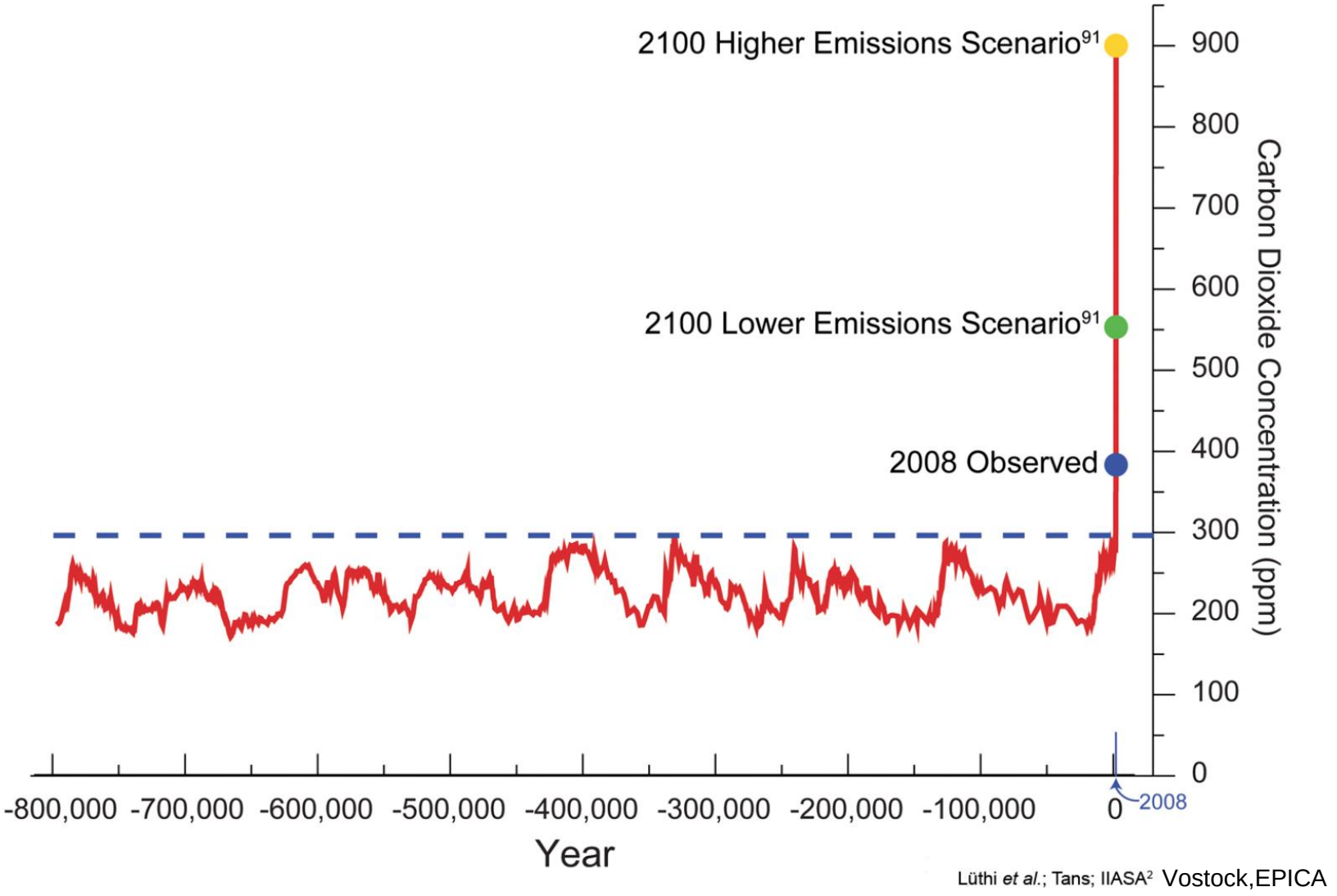
Δsea level = –130m

Δice volume = +52 $10^6 km^3$

CO_2 = 200 ppmv

(Joussaume, 1993)

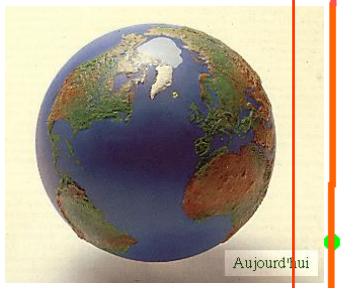
Atmospheric CO_2 over the last 800000 years

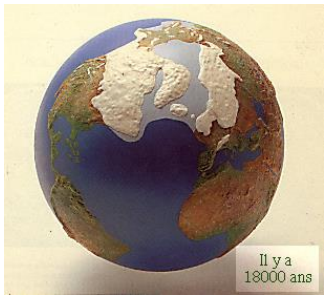


U.S. Global Change Research Program:Lüthi *et al.*; Tans; IIASA

ATMOSPHERIC CO_2 CONCENTRATION

Last Glacial Maximum to Present





Taylor Dome
Byrd Station
Siple Station
Mauna Loa

100 ppmv

100 ppmv

CO_2 (ppmv)

360
340
320
300
280
260
240
220
200
180

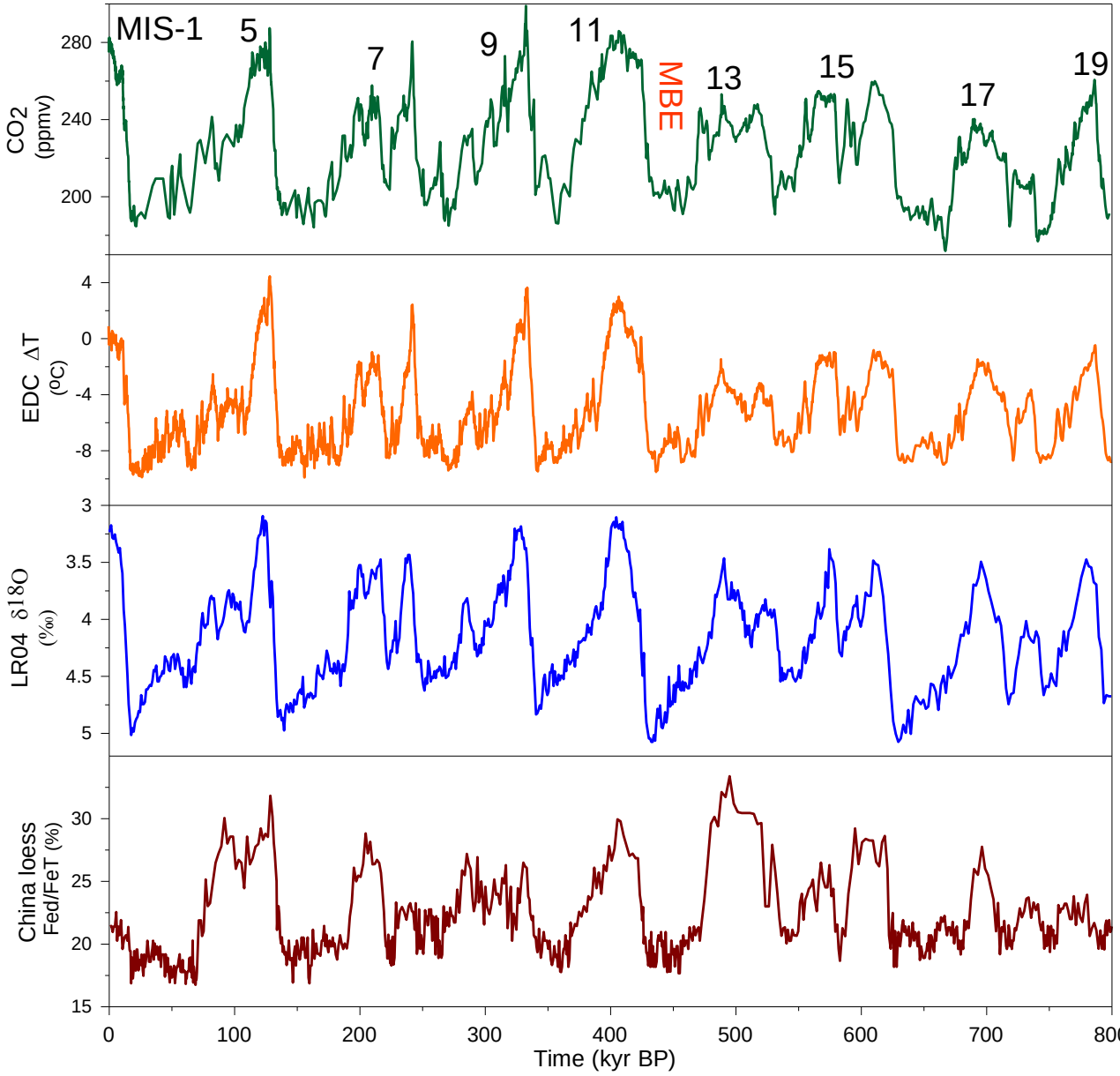
60000
50000
40000
30000
20000
10000
0

age (yr BP)

Ref. : PAGES and Joussaume,1993

http://www.climate;unibe.ch/gallery_co2.html

Interglacial diversity in time and space



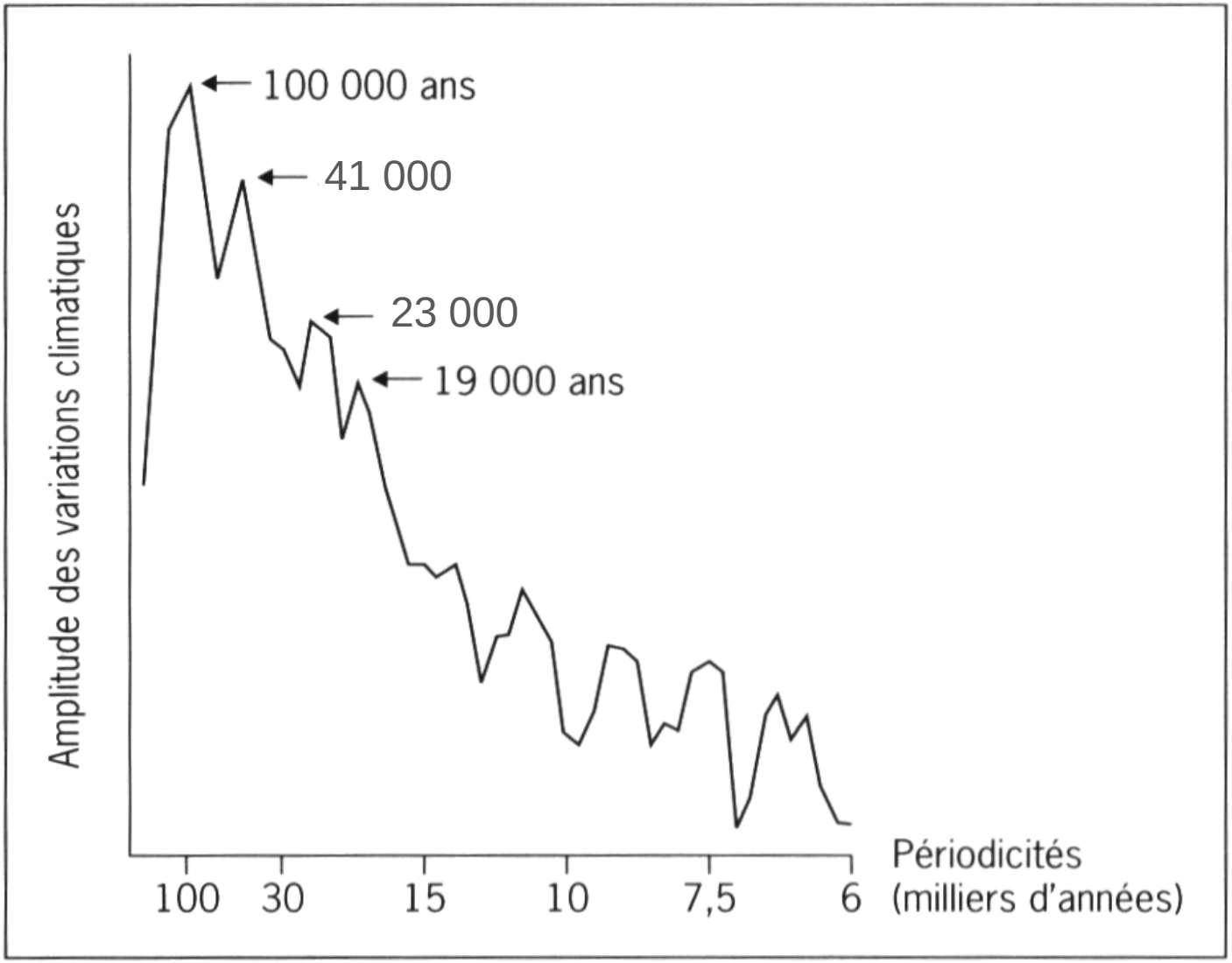
CO2 Concentration
Loulergue et al., 2008

Antarctica temperature
Jouzel et al., 2007

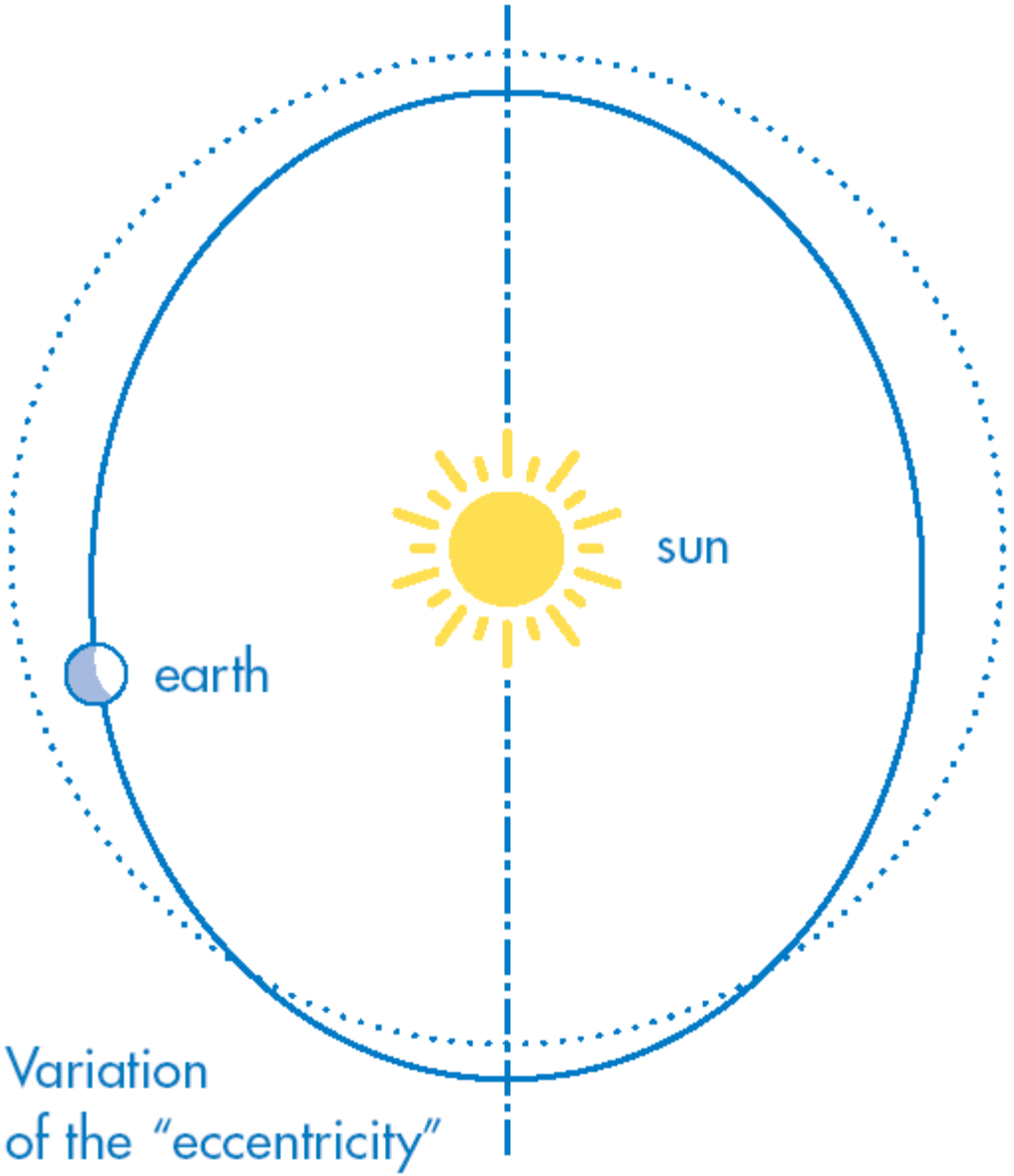
Global ice volume /deep-sea temperature
Lisiecki and Raymo, 2005

East Asian summer monsoon
Guo et al., 2009

Yin and Berger, 2012



Hays, Imbrie, Shackleton, 1976; Berger, 1977



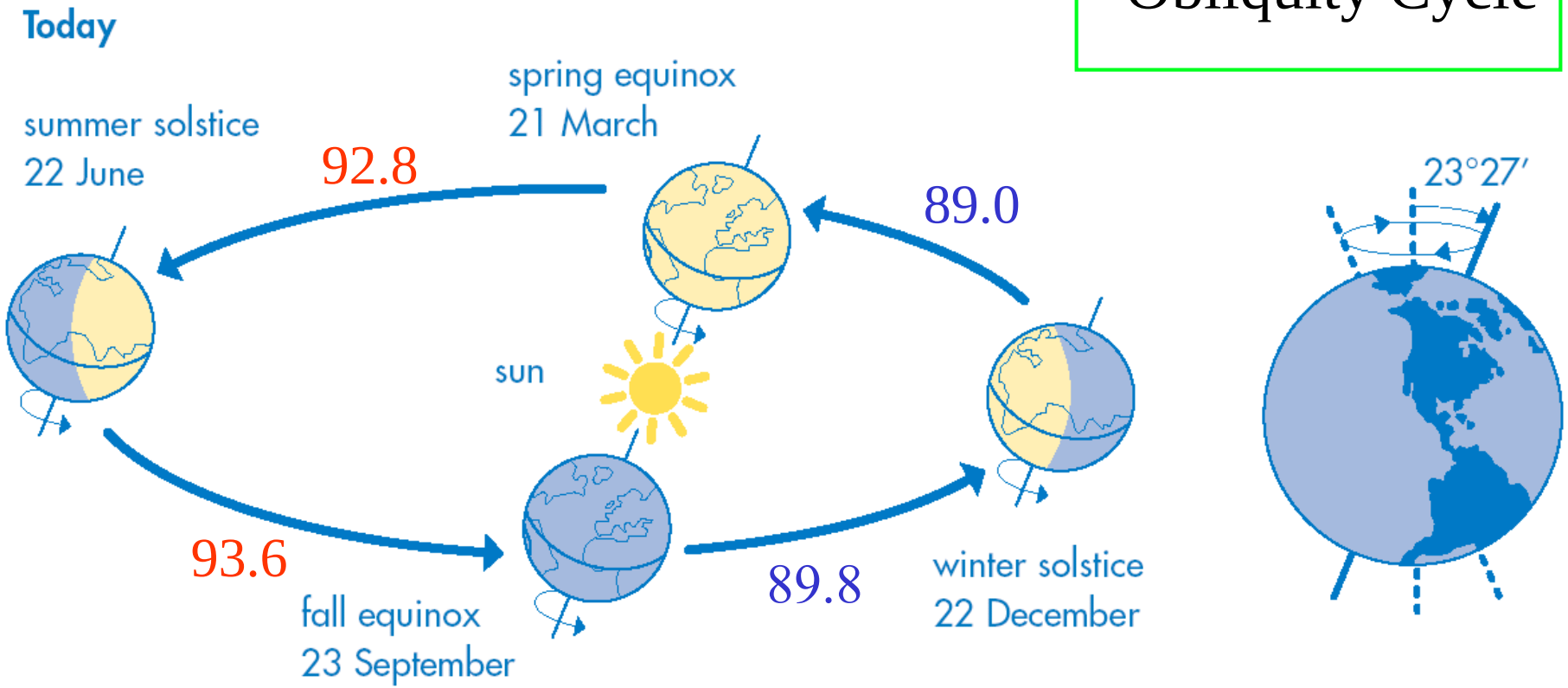
- 100 kyr and
- 400 kyr

Eccentricity Cycle

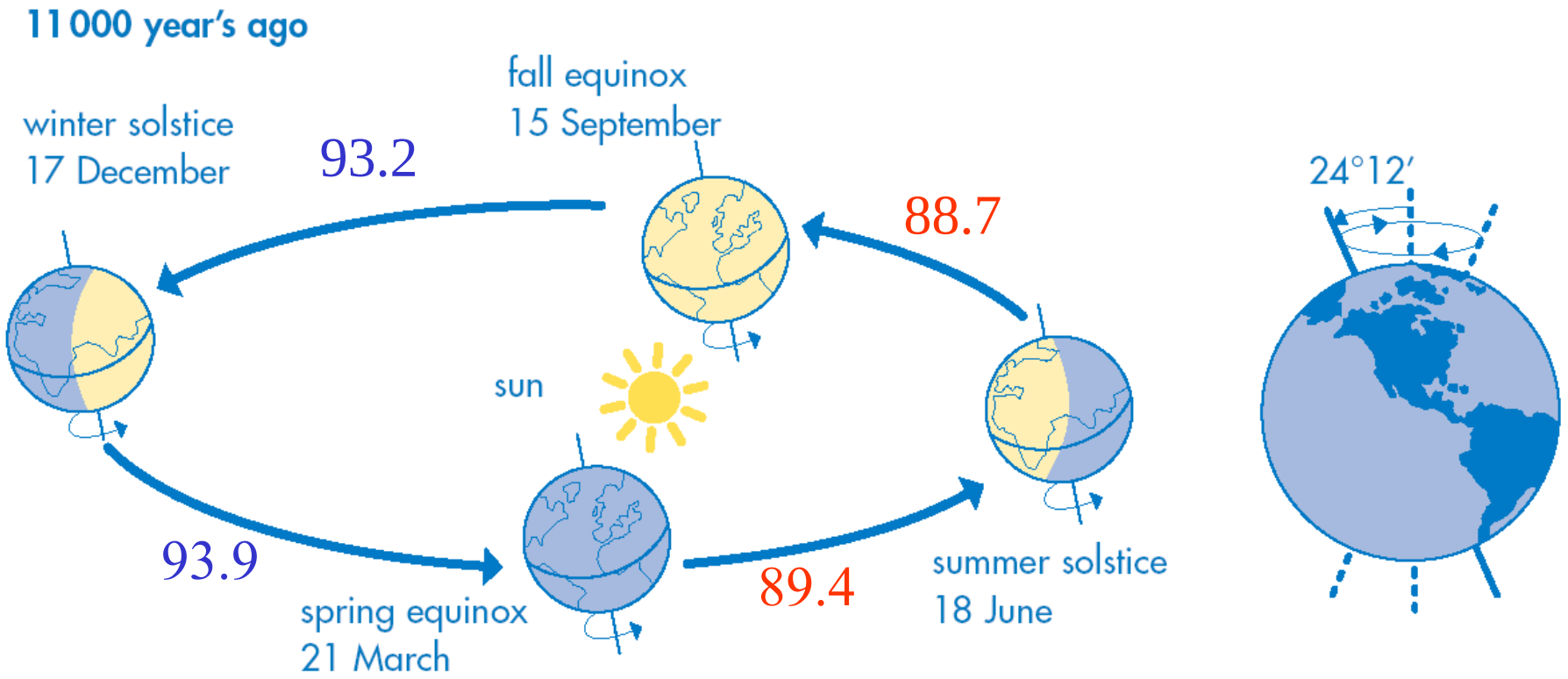
Berger, 1988 (Rev Geophys); Berger, ORBIT-ECC-LATSIS,2001

The 21 kyr (23 and 19) Precession Cycle

The 41 kyr Obliquity Cycle



Berger, 1988 (Rev Geophys); Berger, ORBIT-O-LATSIS,2001



Berger, 1988 (Rev Geophys); Berger, ORBIT-11ky, LATSIS, 2001

PERIODS ASSOCIATED TO THE MAIN TERMS

IN THE ANALYTICAL EXPANSIONS OF

PRECESSION

N	Ampl.	Period (years)
1.	0.0186080	23716
2.	0.0162752	22428
3.	–0.0130066	18976
4.	0.0098883	19155

OBLIQUITY

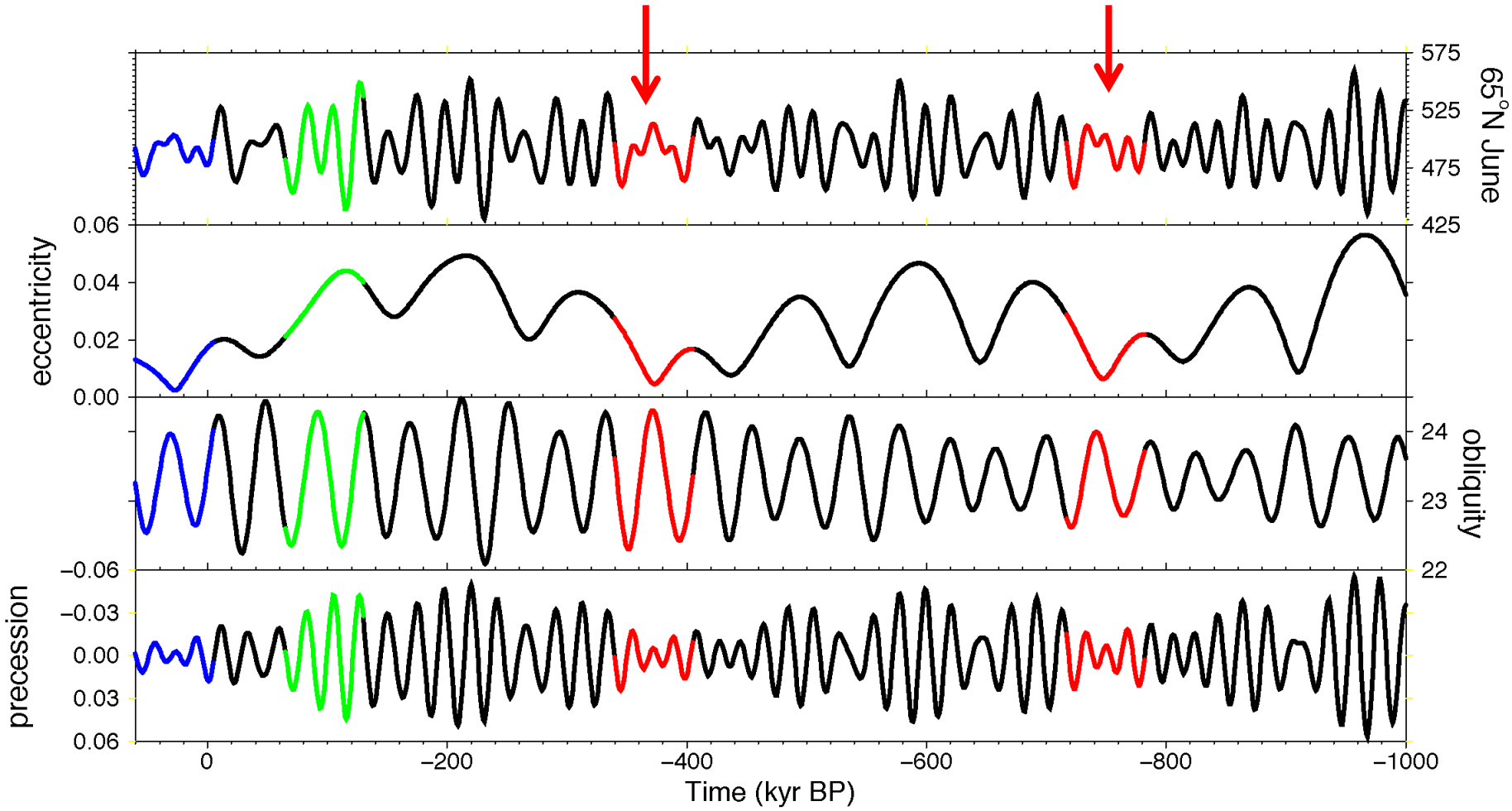
N	Ampl. (")	Period (years)
1.	–2462.22	41000
2.	–857.32	39730
3.	–629.32	53615
4.	–414.28	40521
5.	–311.76	28910

ECCENTRICITY

N	Ampl.	Period (years)
1.	0.011029	412885
2.	–0.008733	94945
3.	–0.007493	123297
4.	0.006724	99590
5.	0.005812	131248
6.	–0.004701	2305441

Berger, 1978. J. Atmos. Sc.

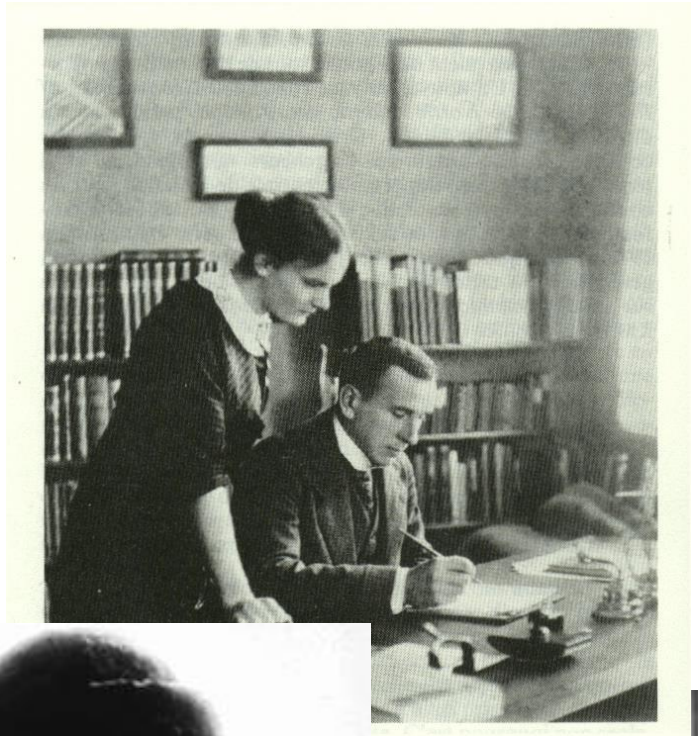
Astronomical parameters : an analogue for the future



Berger, 1978; Berger et al., 2003

Berger, 2012; in Climate Change, Berger et al. (eds)

Milutin Milankovitch
28 May 1879-12 December 1958

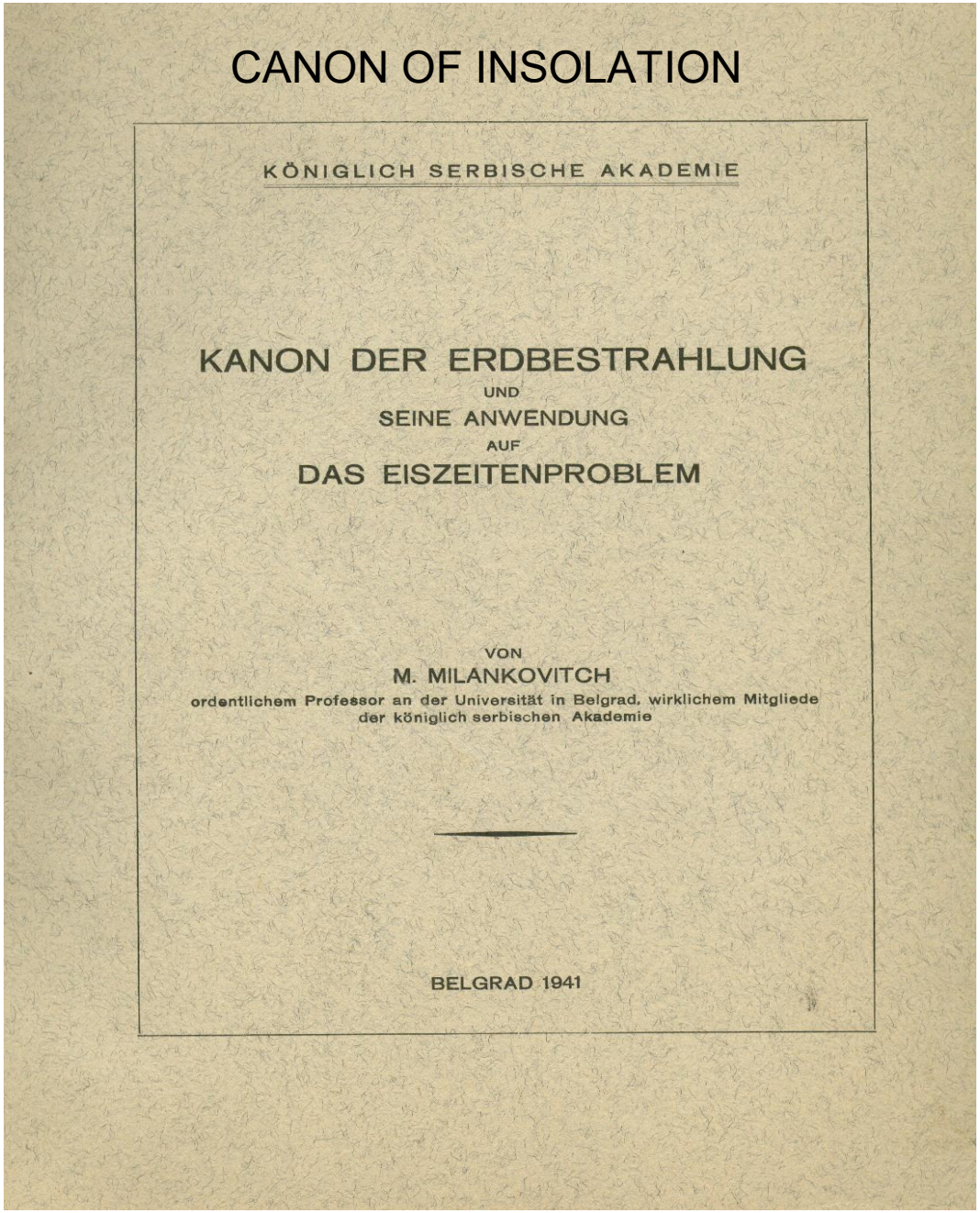


Elsa Köppen
1913

1 November 1880-November 1930

7 October 1846-22 June 1940

CANON OF INSOLATION



KÖNIGLICH SERBISCHE AKADEMIE

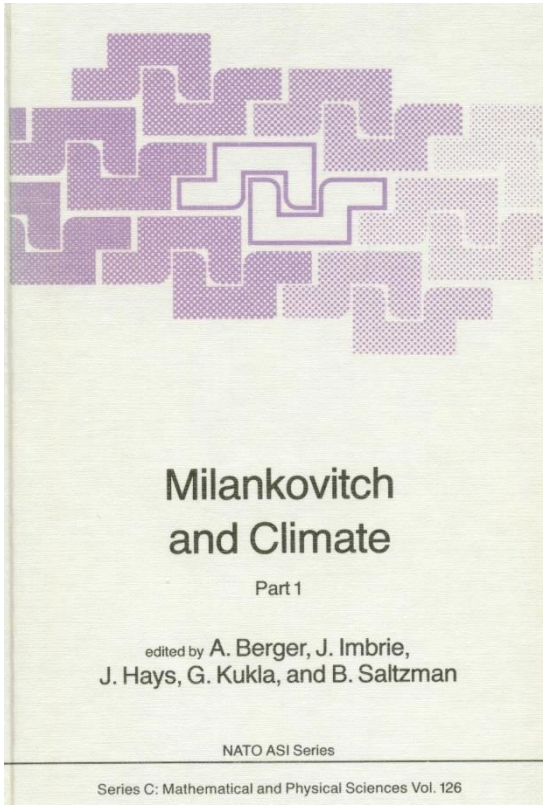
KANON DER ERDBESTRAHLUNG
UND
SEINE ANWENDUNG
AUF
DAS EISZEITENPROBLEM

VON
M. MILANKOVITCH
ordentlichem Professor an der Universität in Belgrad, wirklichem Mitgliede
der königlich serbischen Akademie

BELGRAD 1941

Milutin Milanković
1879 - 1958

European Geophysical
Society, 1995



Milankovitch
and Climate

Part 1

edited by A. Berger, J. Imbrie,
J. Hays, G. Kukla, and B. Saltzman

NATO ASI Series

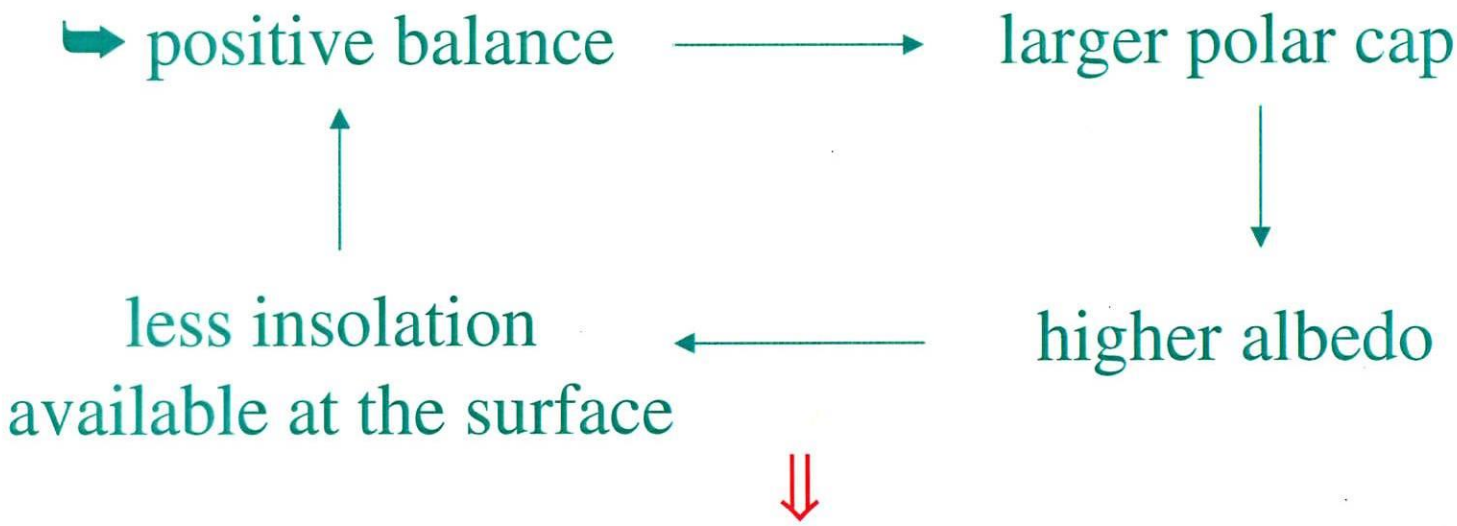
Series C: Mathematical and Physical Sciences Vol. 126

1982-1984

MURPHY - MILANKOVITCH

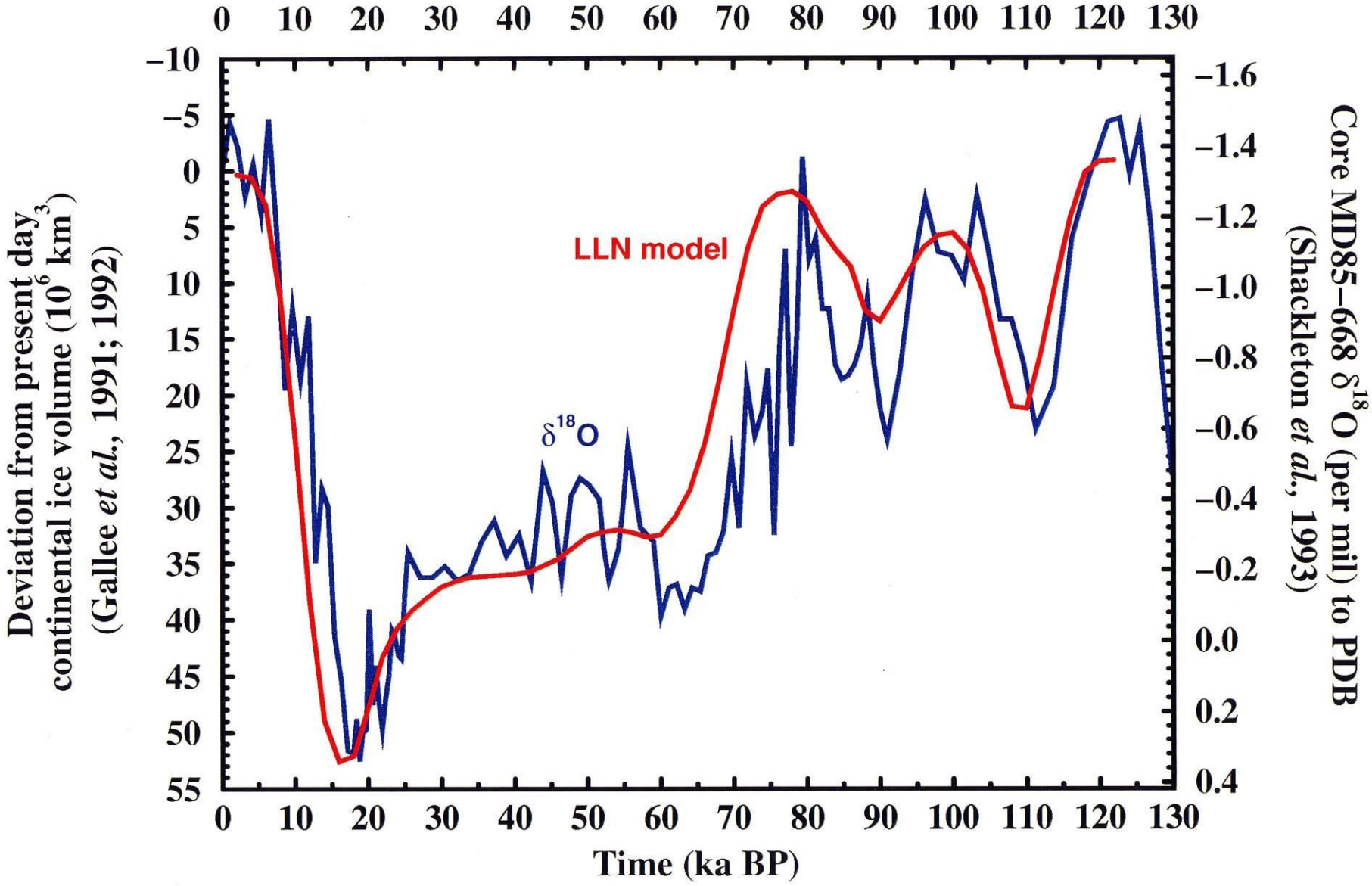
FOR GLACIAL : Cool summer in NH

Snow accumulated during winter does not melt in summer.



⇓

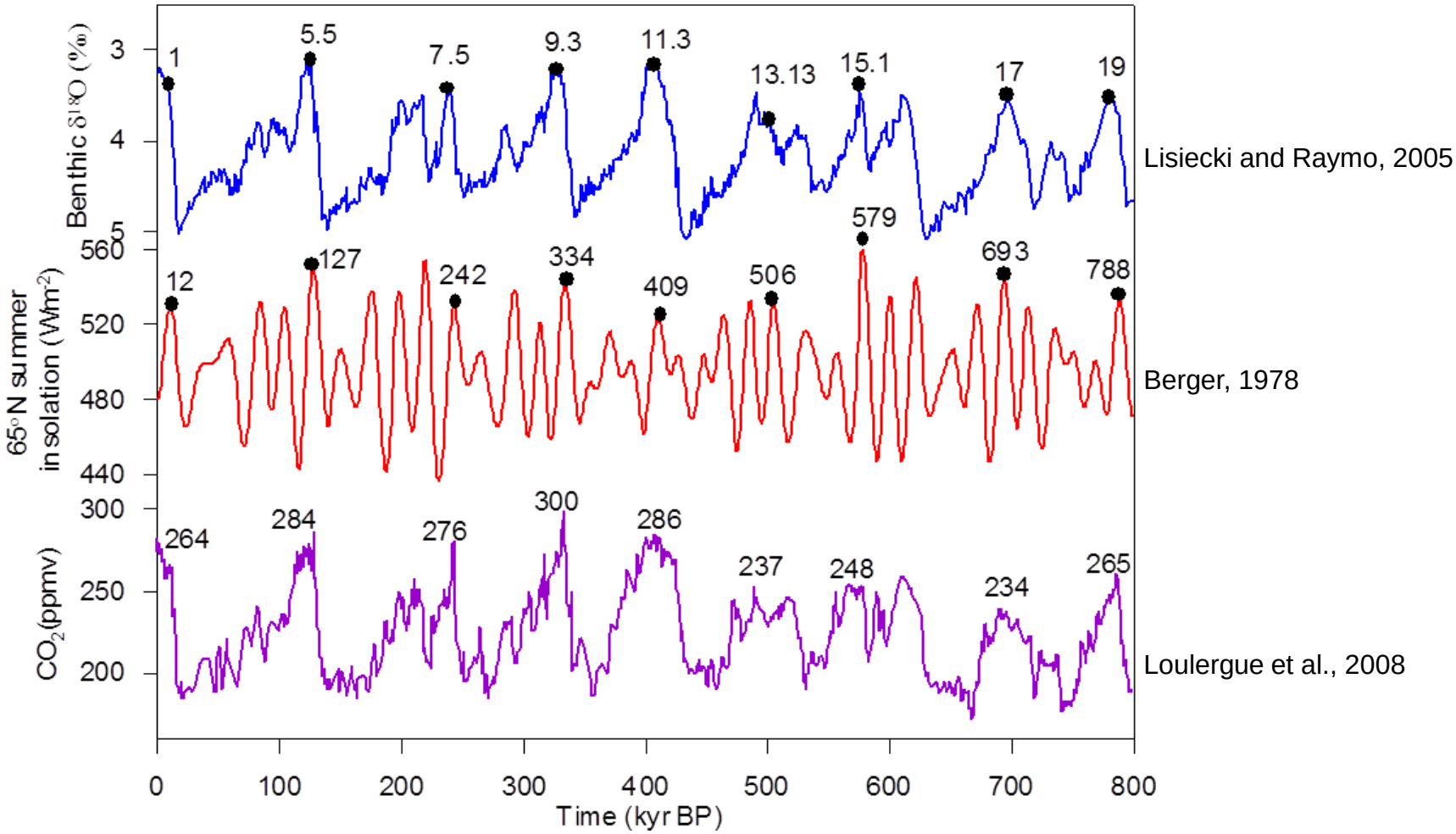
POSITIVE feedback



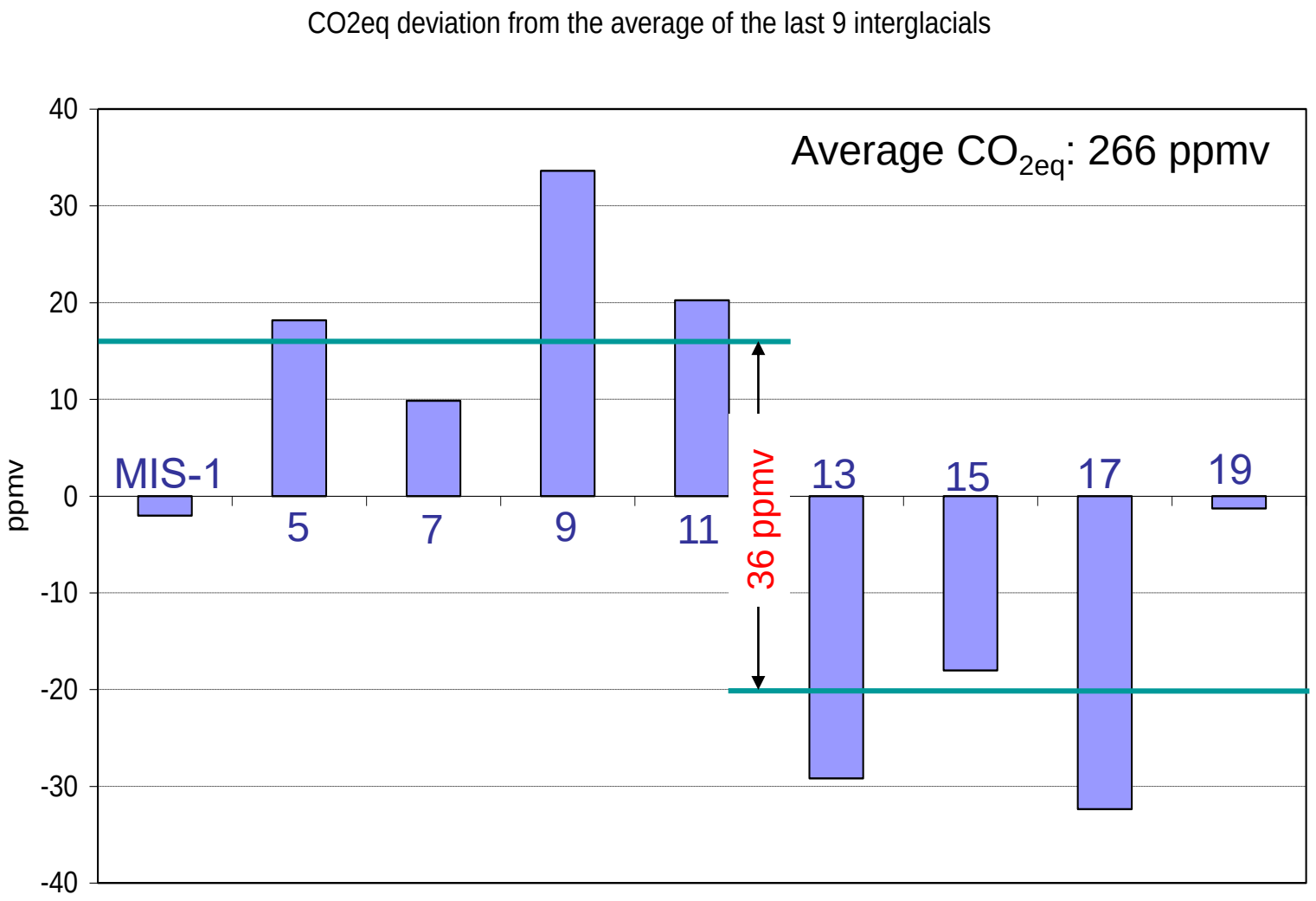
2-D LLN model; Gallée et al., 1992, 1993

Snapshot simulations

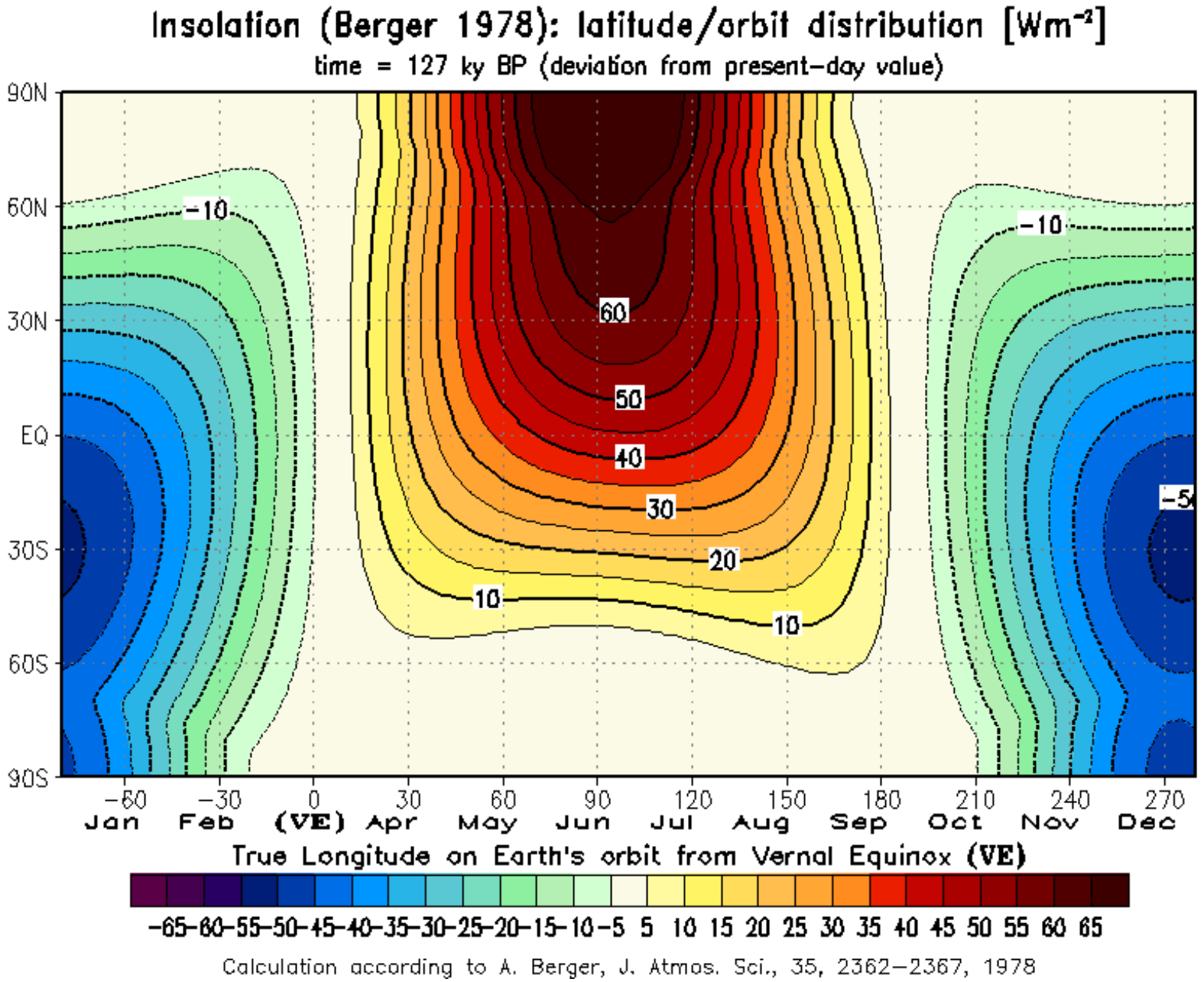
Insolation choice : dates of NH summer occurs at perihelion.



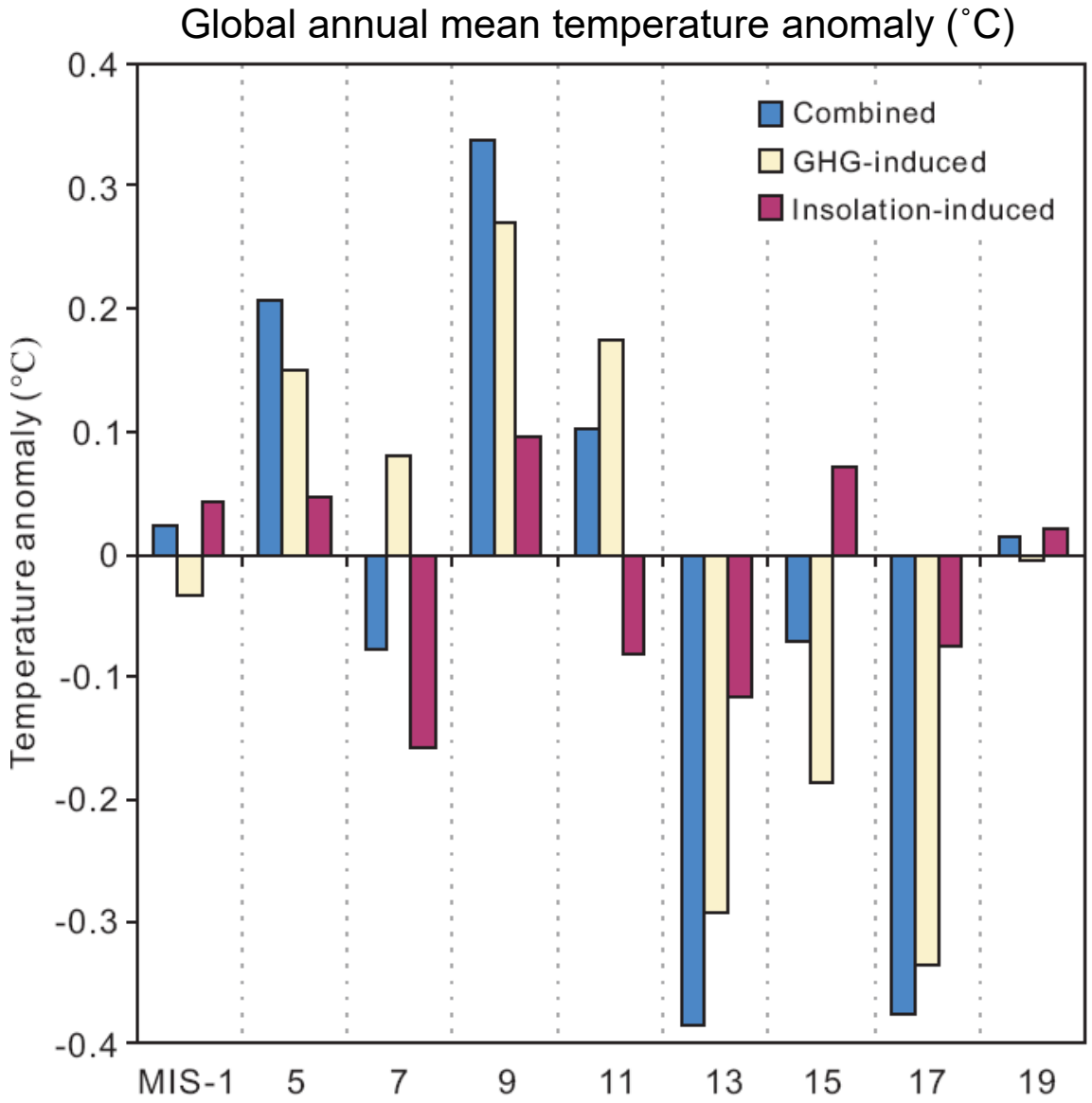
28 snapshot experiments (LOVECLIM) for 9 interglacials are performed for using factor separation method. (Yin and Berger, 2010)



Yin and Berger, 2012

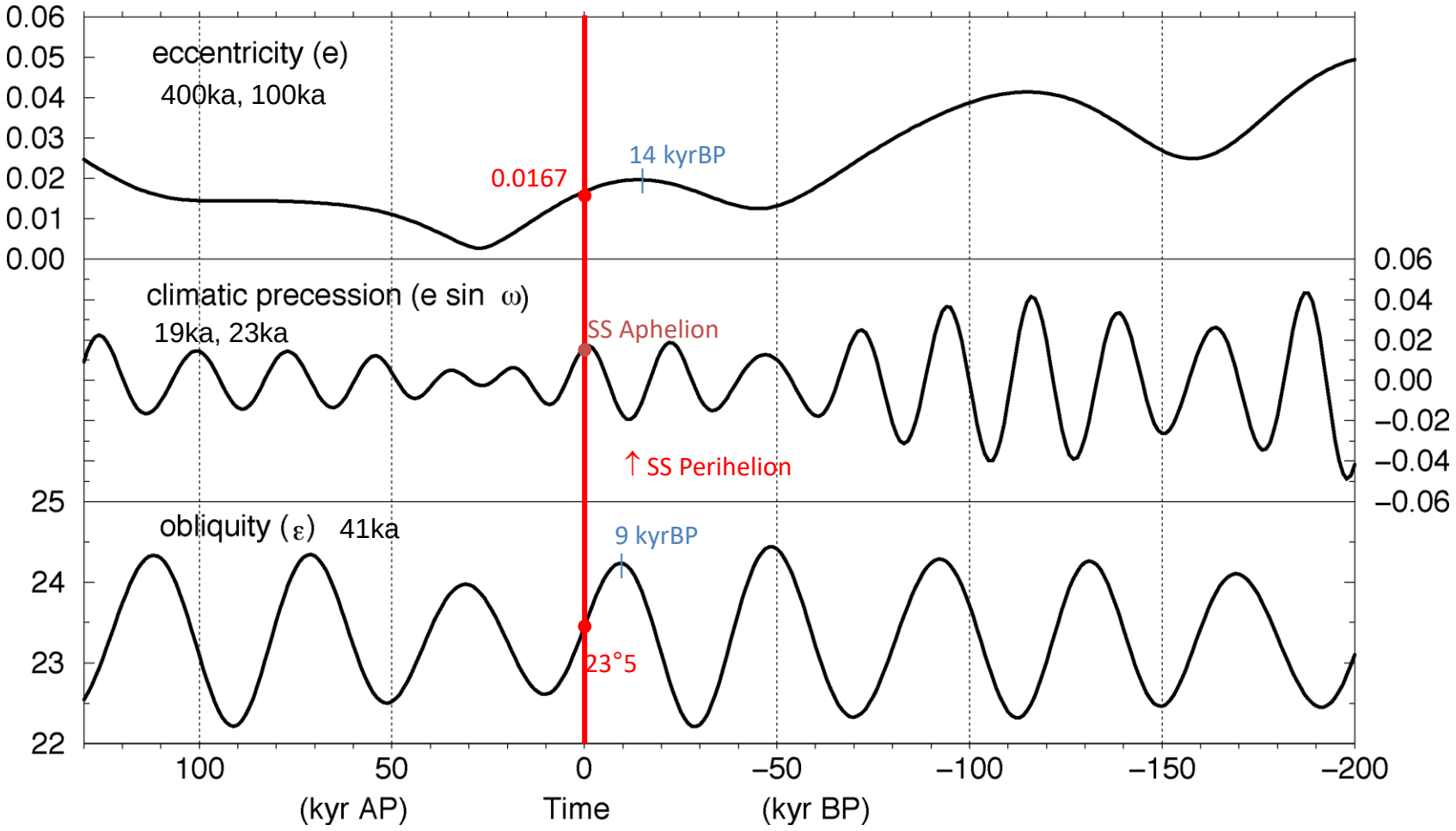

Insolation (Berger 1978): latitude/orbit distribution [Wm⁻²]
time = 127 ky BP (deviation from present-day value)
90N
60N
30N
EQ
30S
60S
90S
-10
60
50
40
30
20
10
-60 -30 0 30 60 90 120 150 180 210 240 270
Jan Feb (VE) Apr May Jun Jul Aug Sep Oct Nov Dec
True Longitude on Earth's orbit from Vernal Equinox (VE)
-65 -60 -55 -50 -45 -40 -35 -30 -25 -20 -15 -10 -5 5 10 15 20 25 30 35 40 45 50 55 60 65
Calculation according to A. Berger, J. Atmos. Sci., 35, 2362-2367, 1978

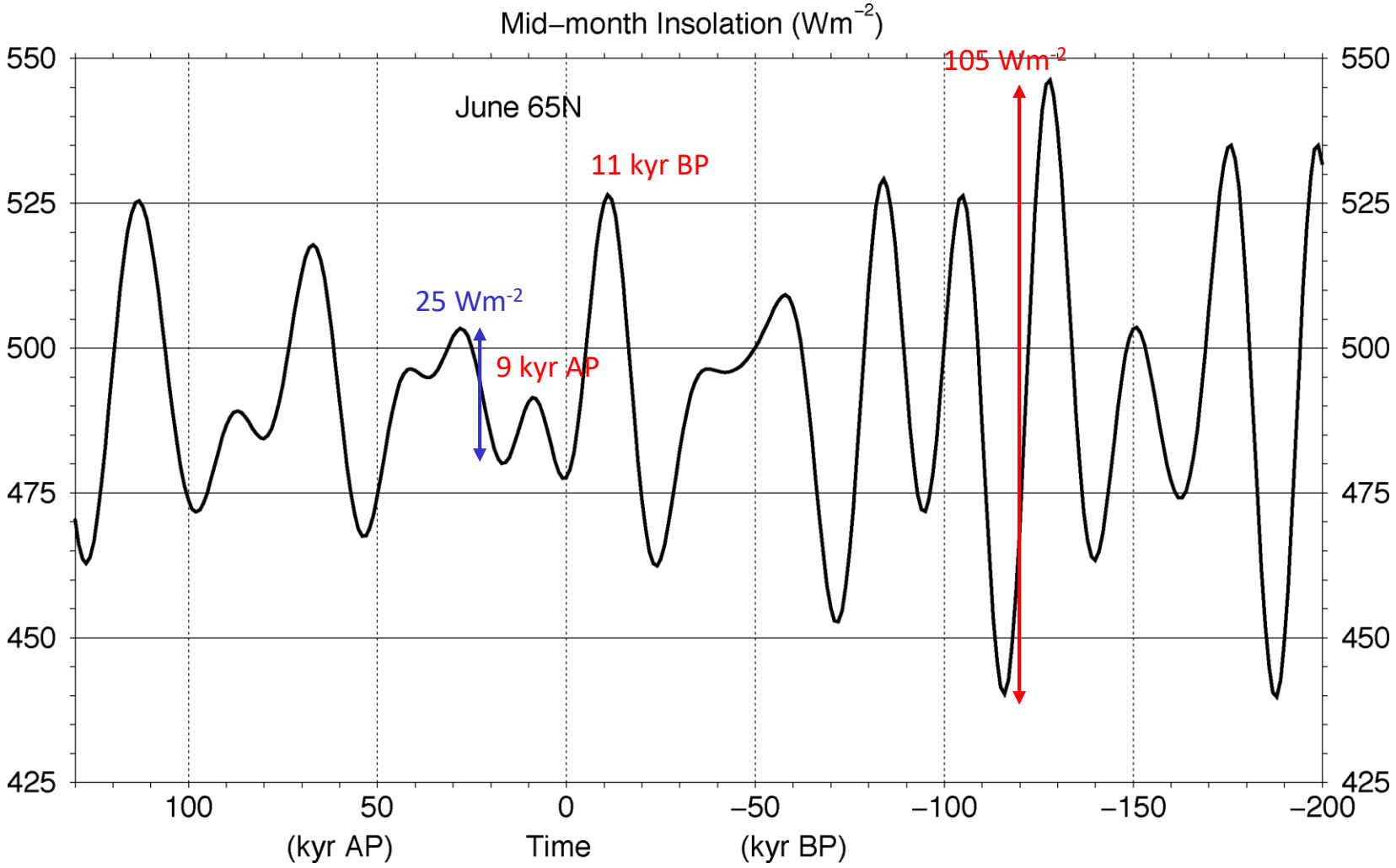
Relative importance of CO_2 and insolation on the warmth intensity is different from one interglacial to another.



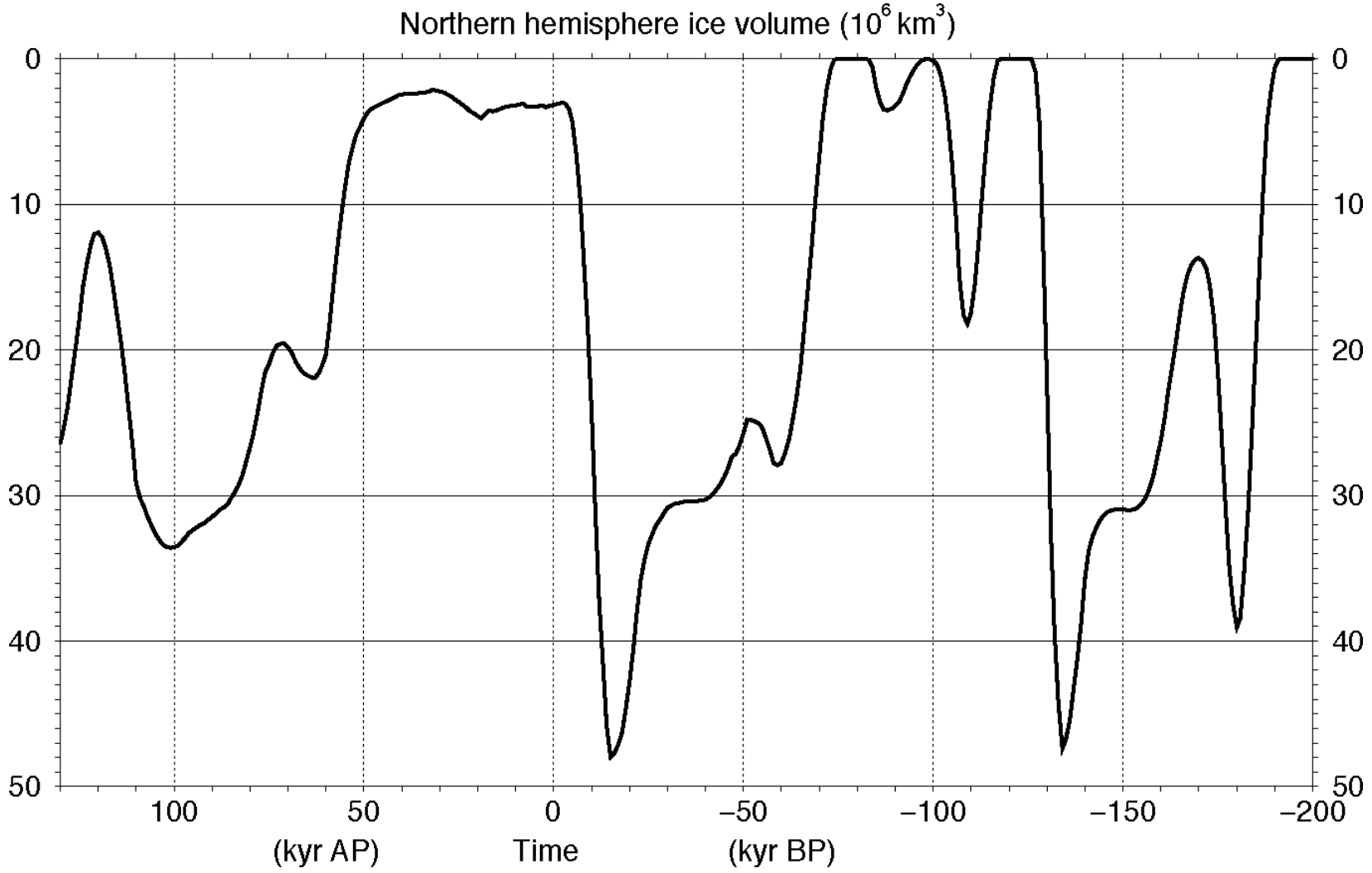
Yin and Berger, 2012, Climate Dynamics

Berger (1978)


eccentricity (e)
400ka, 100ka
0.0167
14 kyrBP
climatic precession (e sin ω)
19ka, 23ka
SS Aphelion
↑ SS Perihelion
obliquity (ε) 41ka
9 kyrBP
23°5
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0.06
0.04
0.02
0.00
−0.02
−0.04
−0.06
25
24
23
22
100
50
0
−50
−100
−150
−200
(kyr AP)
Time
(kyr BP)

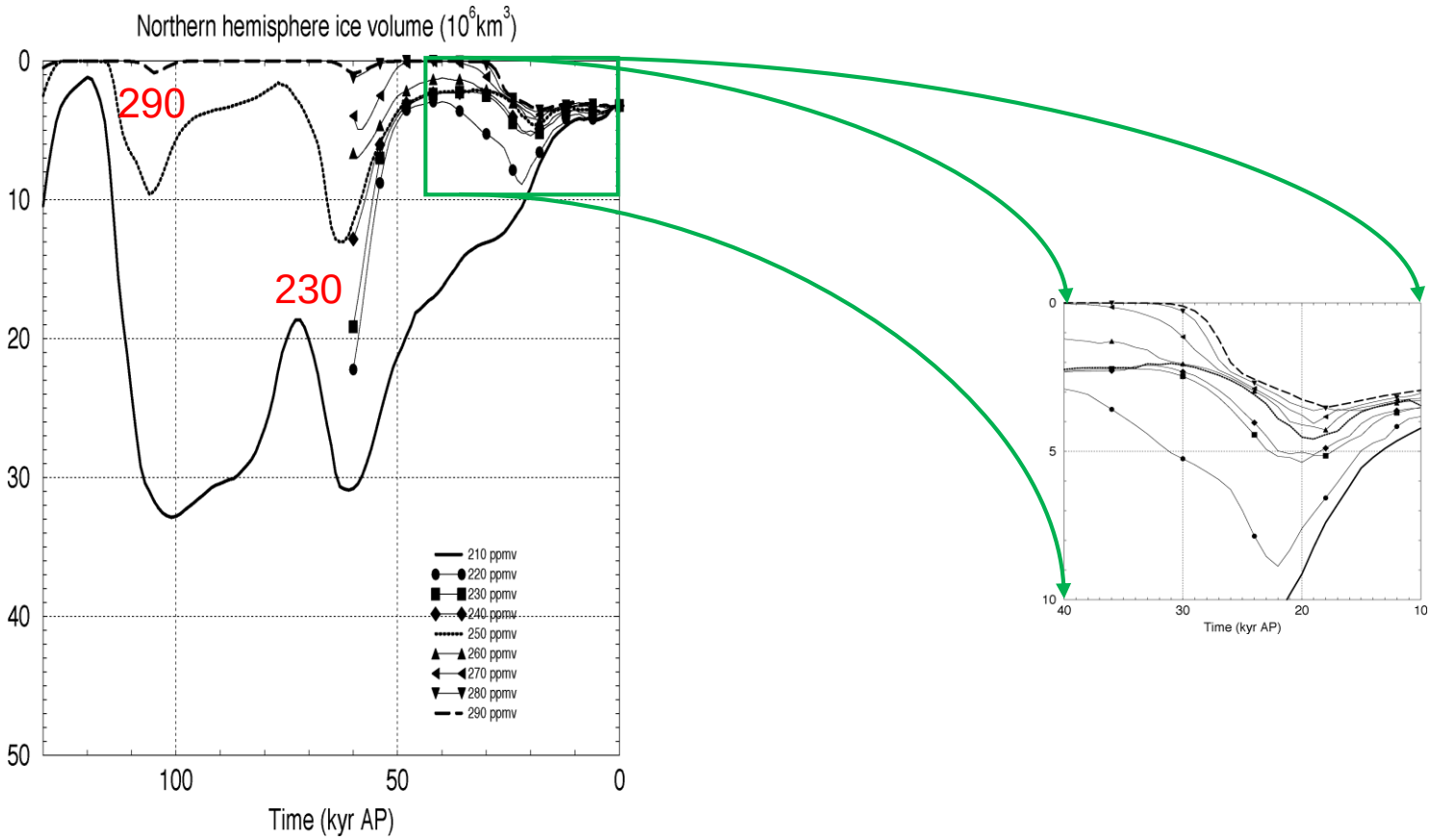

Mid–month Insolation (Wm^{-2})
June 65N
105 Wm^{-2}
11 kyr BP
25 Wm^{-2}
9 kyr AP
550
525
500
475
450
425
100
50
0
–50
–100
–150
–200
(kyr AP)
Time
(kyr BP)

Berger, 1978



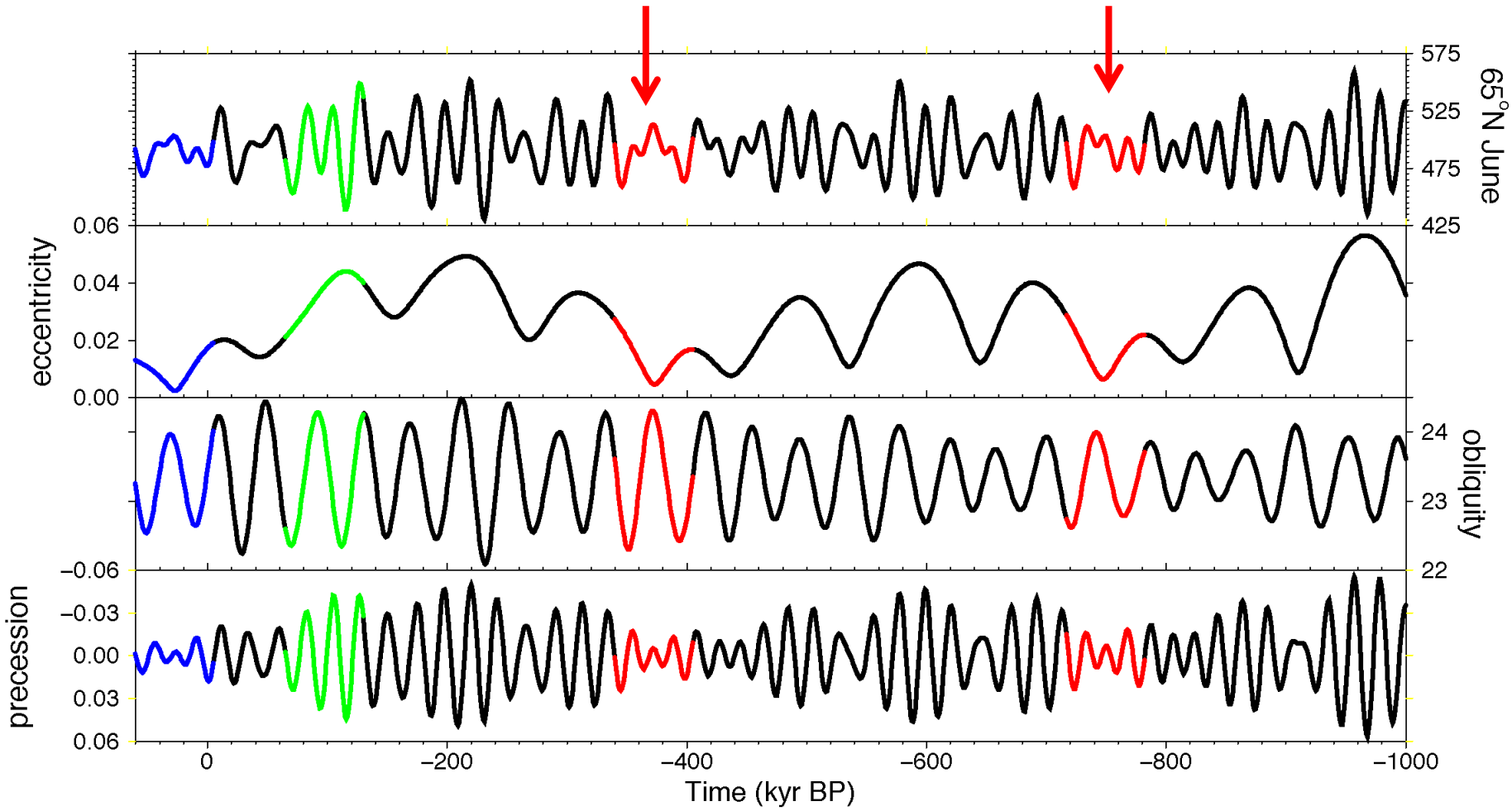
Berger et al., Ambio 1997, Science 2002, Surveys in Geophysics, 2003

Future climate under constant CO_2 scenarios



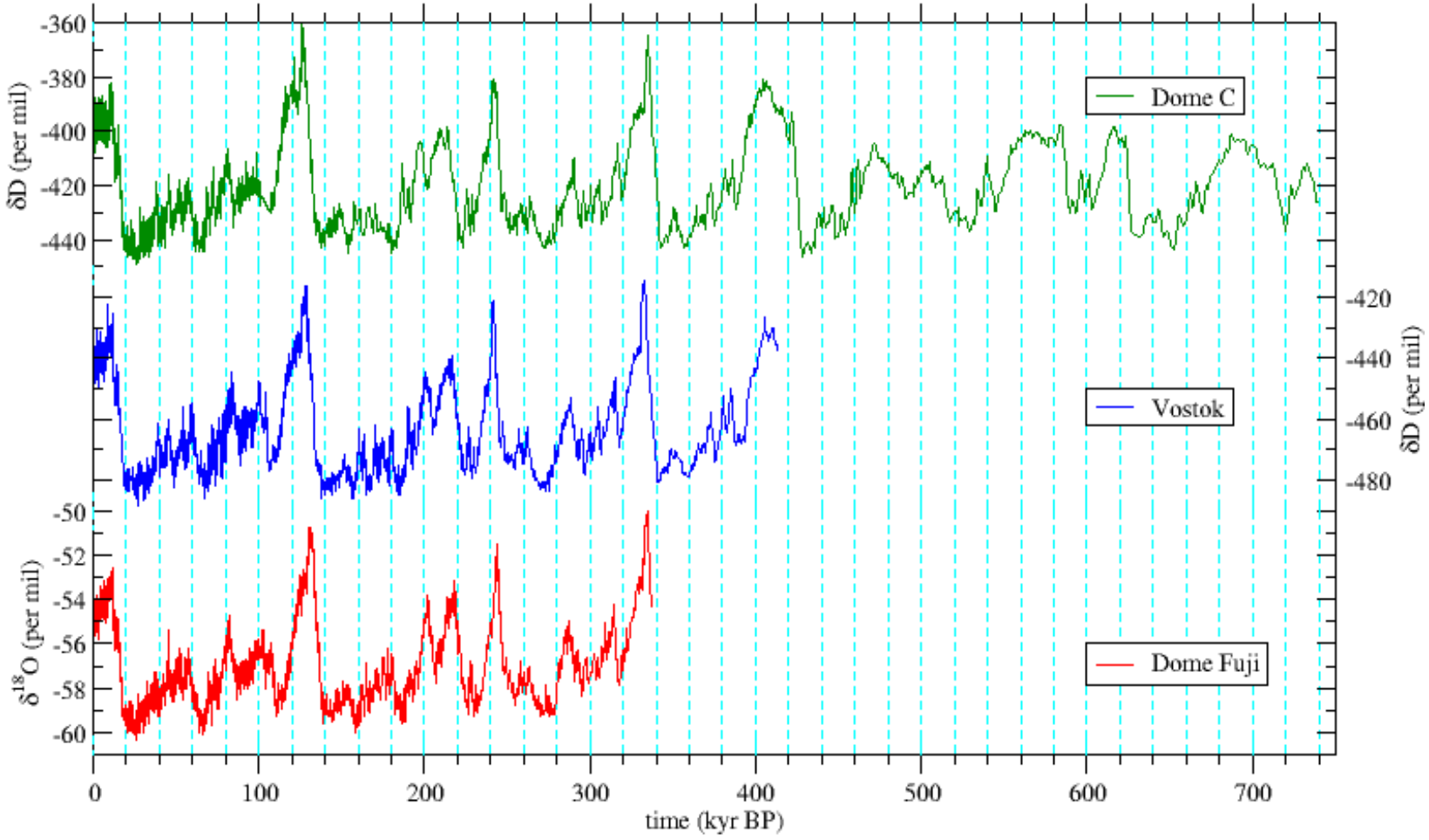
Loutre and Berger, Climatic Change, 2000

Astronomical parameters : an analogue for the future

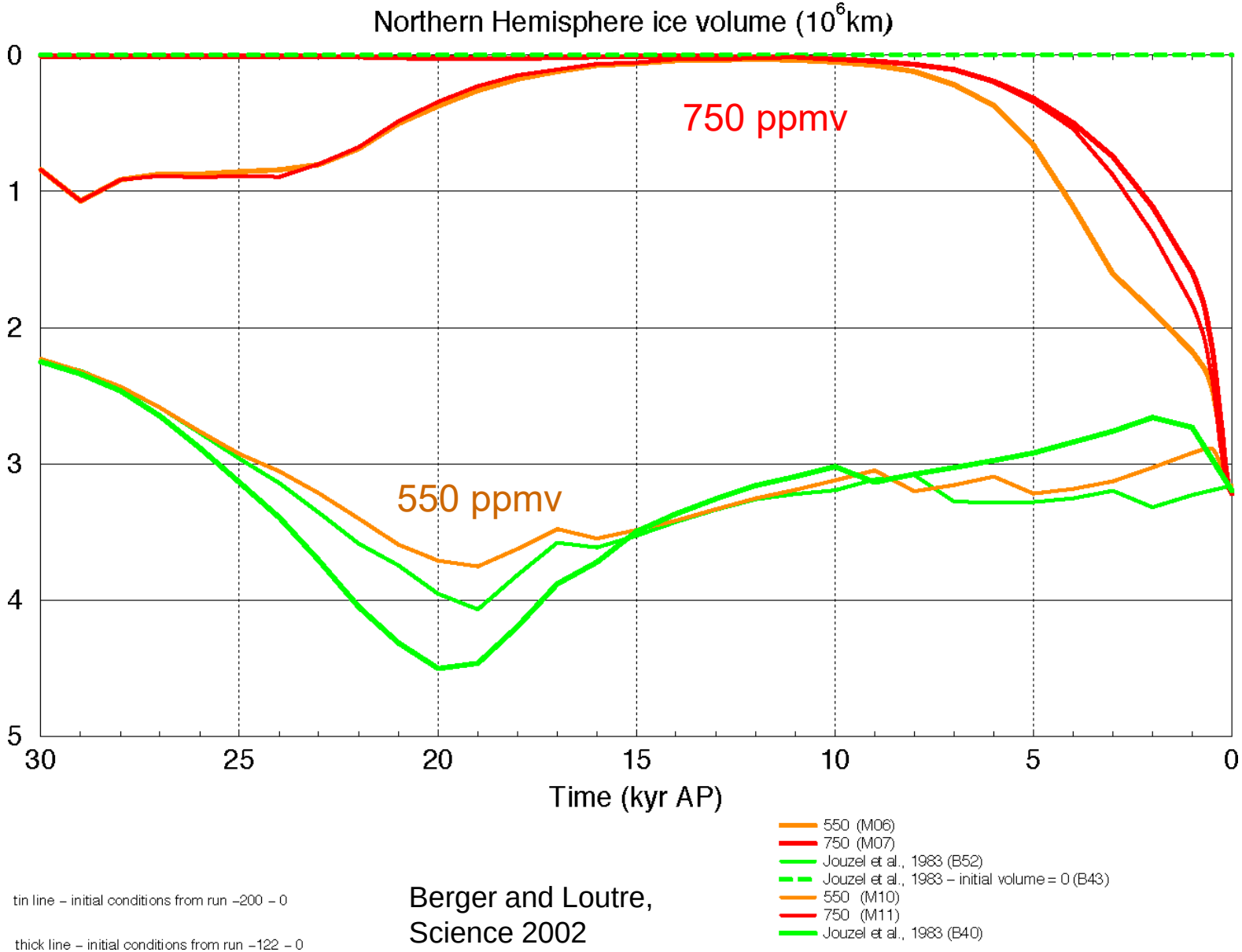


Berger, 1978

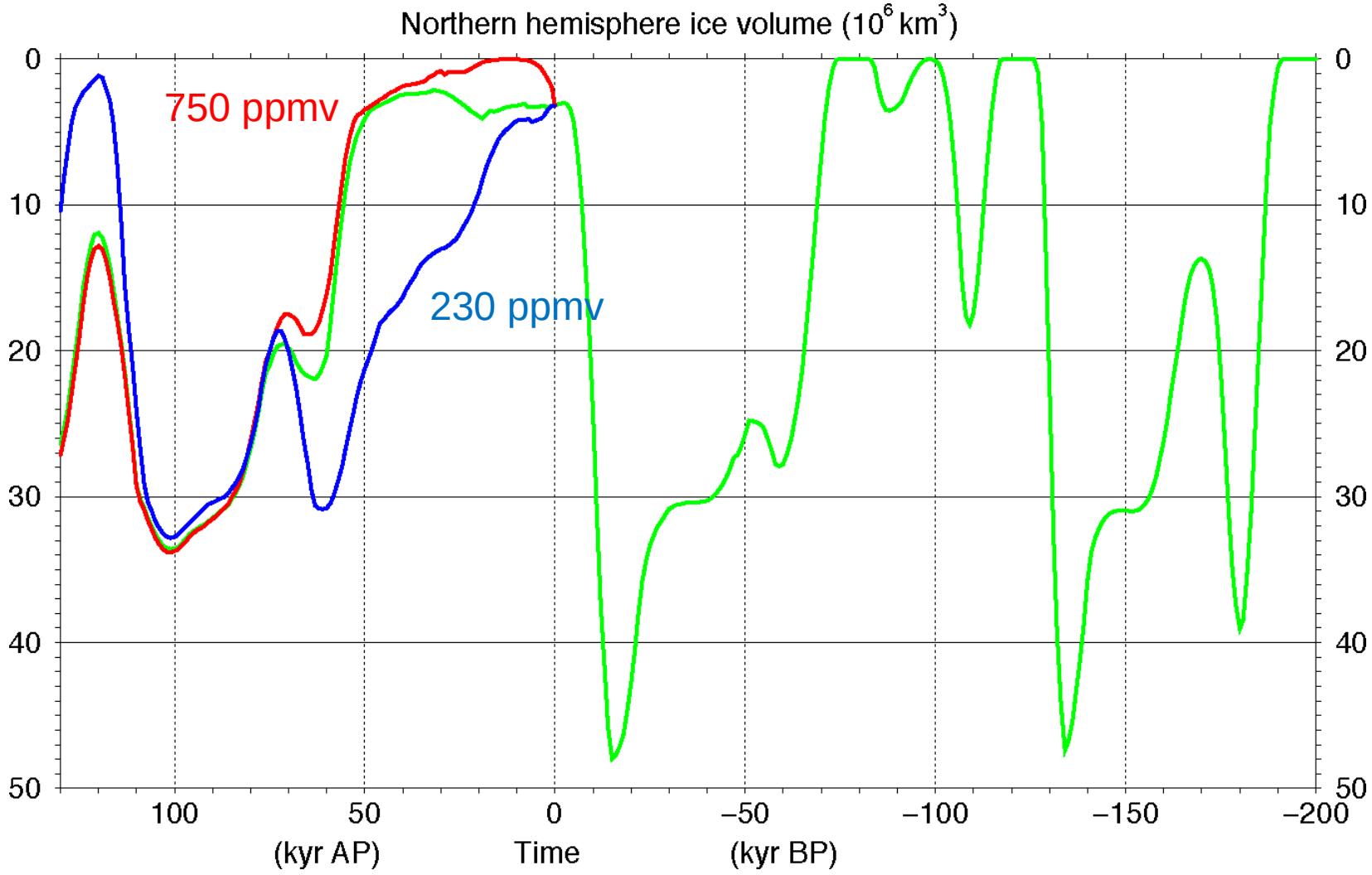
Archives of climate in Antarctica



EPICA community members, Nature, 2004



Berger and Loutre,
Science 2002



Berger and Loutre, 2002

CONCLUSIONS

WE ARE LIVING EXCEPTIONAL TIMES

1. BECAUSE THE MAIN FORCING AT THE THOUSANDS OF YEARS TIME SCALE WILL NOT VARY ANYMORE, THE OTHER FORCINGS (GHG) WILL HAVE AN EVEN STONGER INFLUENCE

2. ENTERING AN ICE AGE IS NOT ANYMORE AN EXCUSE FOR ALLOWING GHG RELEASE. ON THE CONTRARY, THE RESULTING GW MIGHT CAUSE AN EARLIER COOLING IN NNA DUE TO A WEAKER ENERGY TRANSPORT BY THE GULF STREAM