



UCL

Université
catholique
de Louvain

Institut d'Astronomie et de Géophysique G. Lemaître

Chemin du Cyclotron, 2

1348 Louvain-la-Neuve

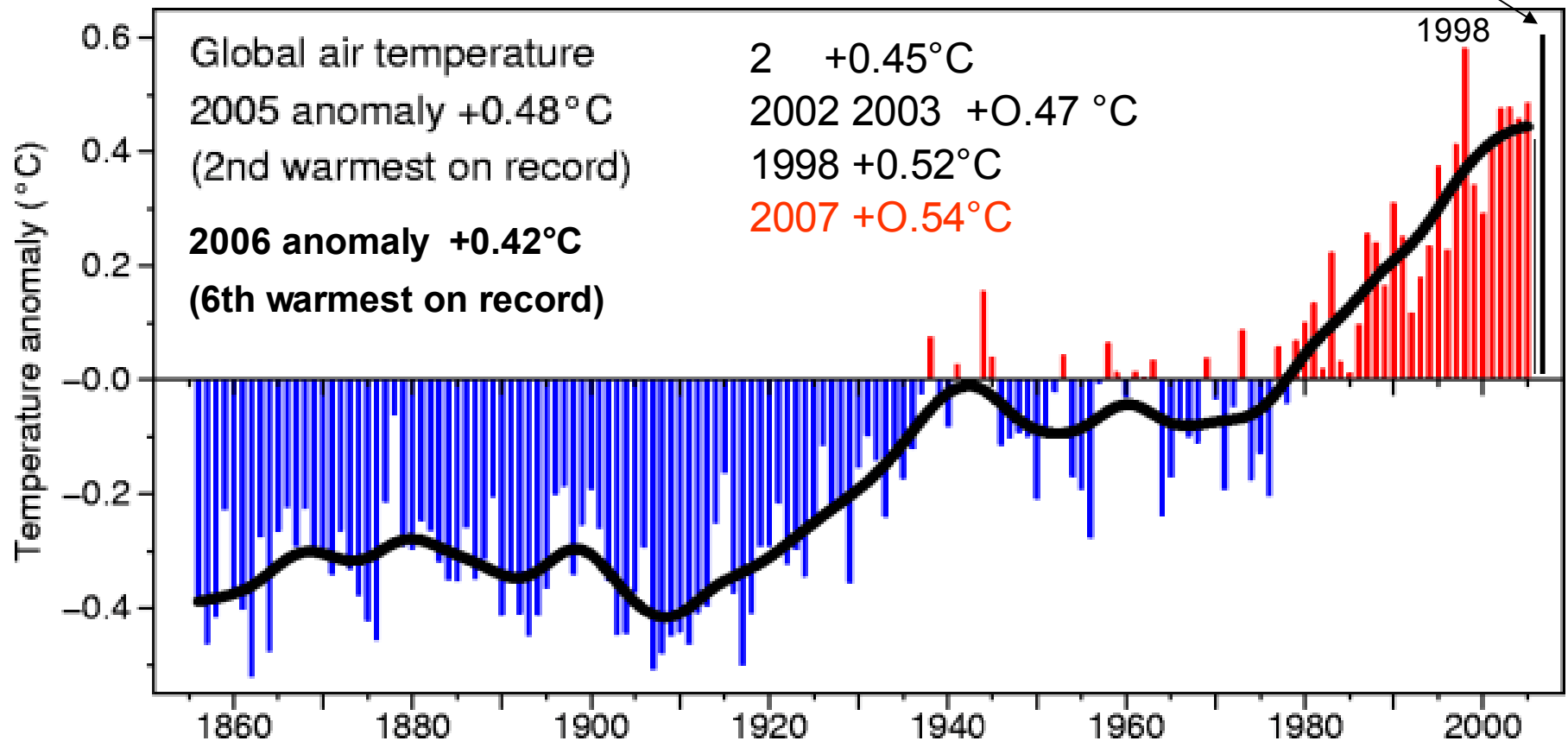
LE CLIMAT DES PROCHAINS MILLÉNAIRES

A. Berger

**Département des Sciences de la Vie et de la Terre , École
Normale Supérieure de Lyon, le 10 janvier 2007**

EST-IL POSSIBLE QUE LES
ACTIVITES HUMAINES
INFLUENCENT
L'EVOLUTION NATURELLE
DU CLIMAT AUSSI A
L'ECHELLE GEOLOGIQUE ?

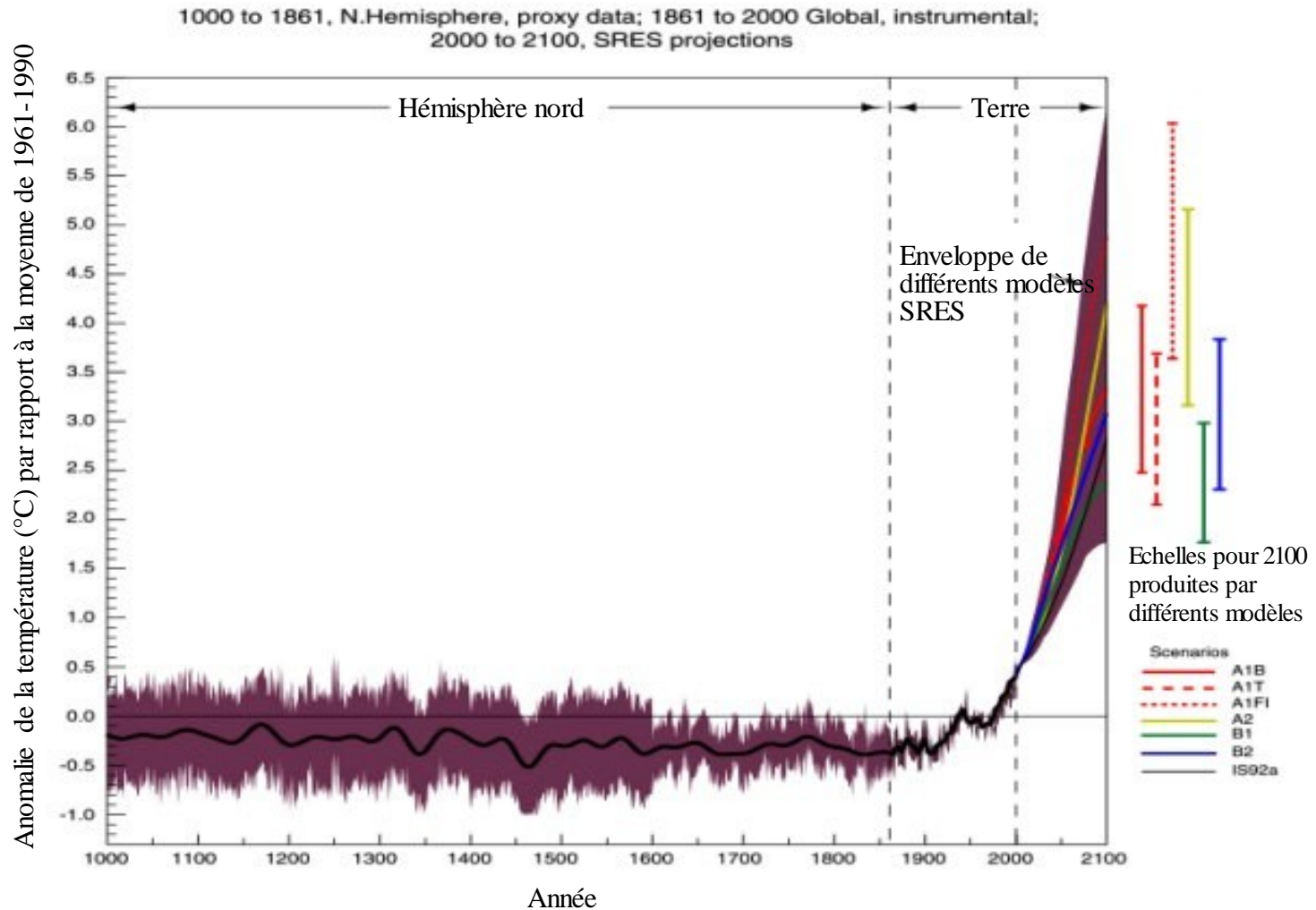
JONES-FOLLAND prediction for 2007
(January 4 2007)

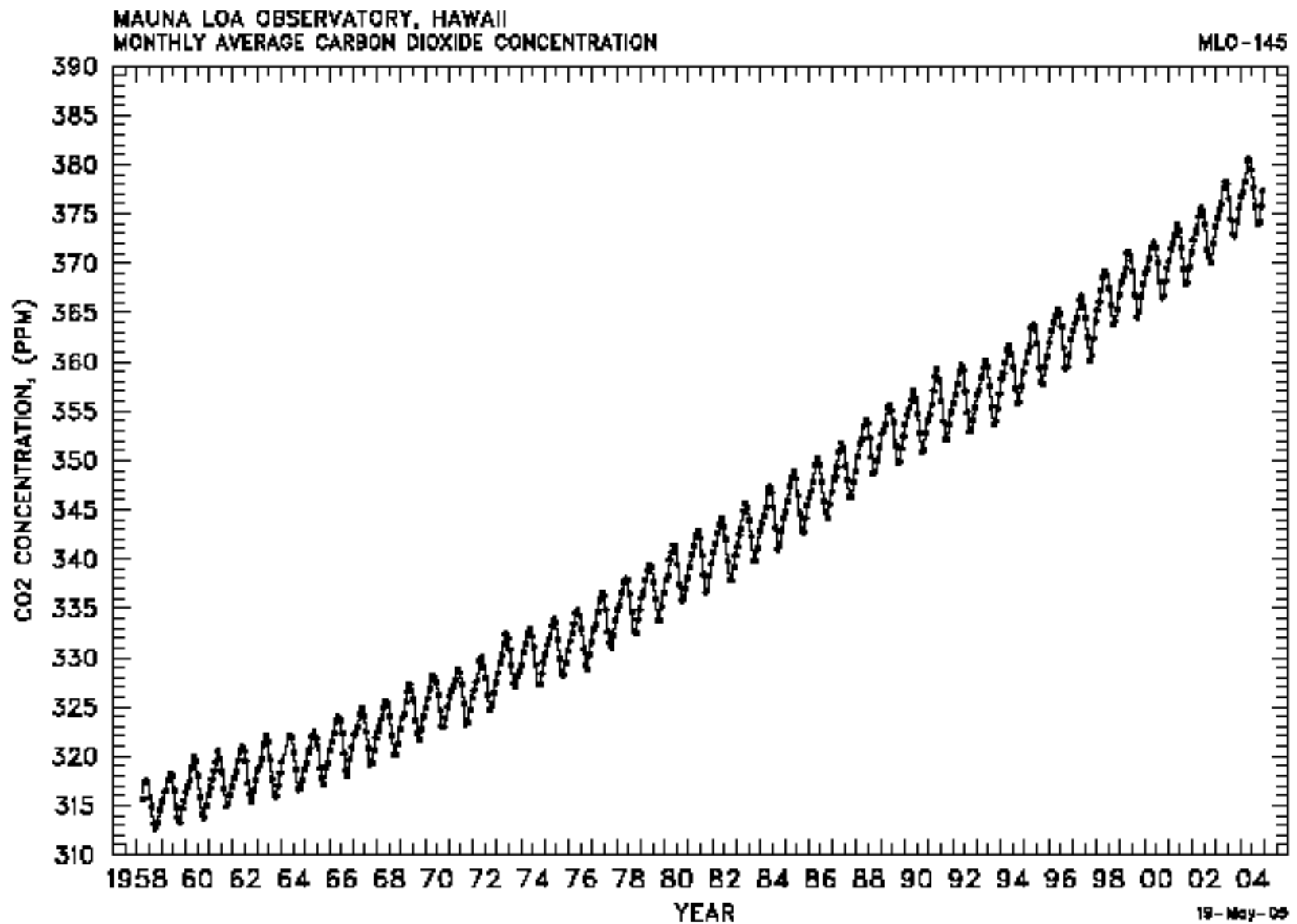


Climatic Research Unit, UEA, 2006

SURFACE AIR TEMPERATURE

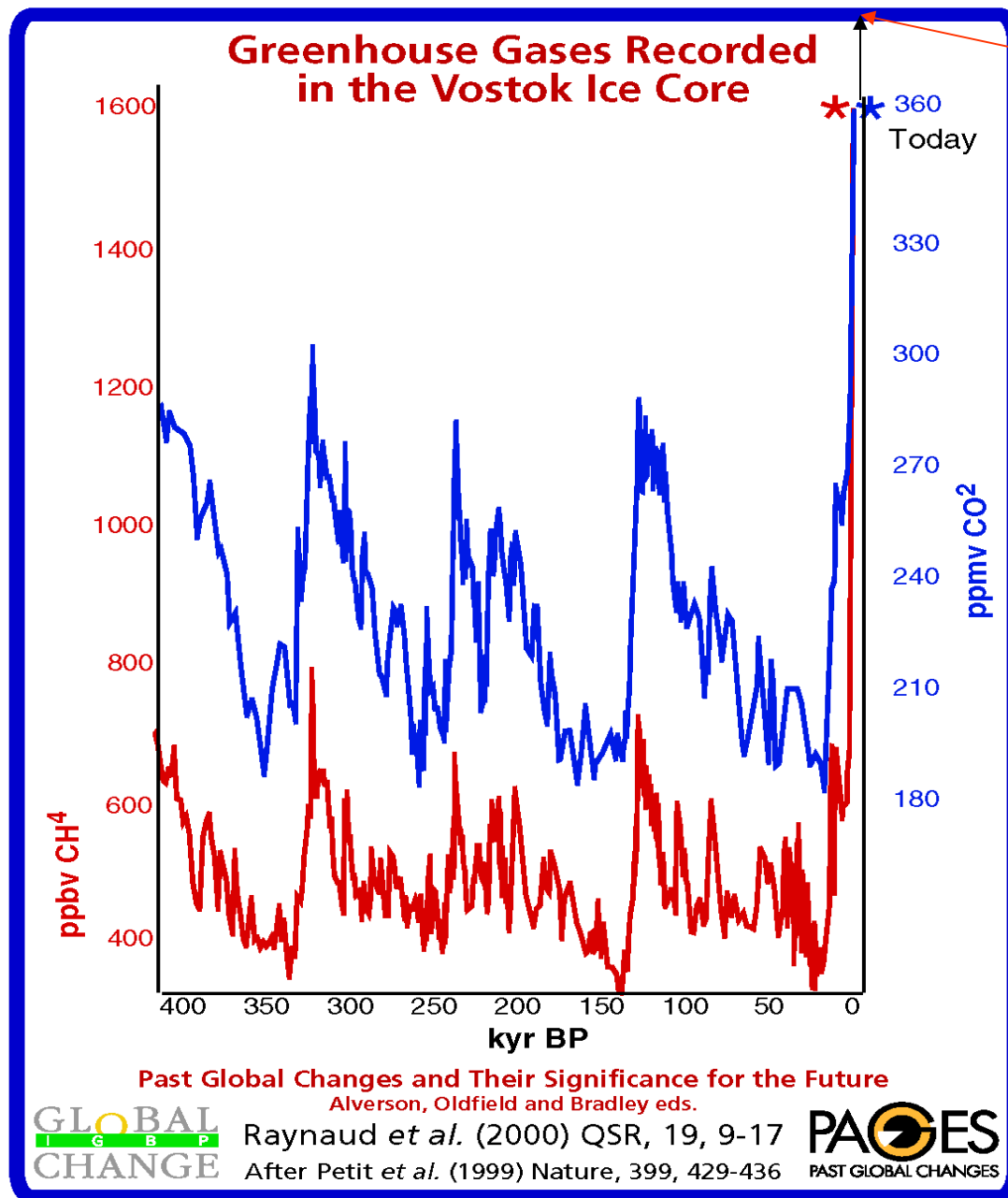
From 1000 to 2100 A.D.





Keeling C.D. and Whorf T.P., Trends-CDIAC, 2005

En 2003 :
465 ppmv CO_{2eq}



377.5 en 2004
375.6 en 2003
en 1995

accroissement

2000-01 : 1.5

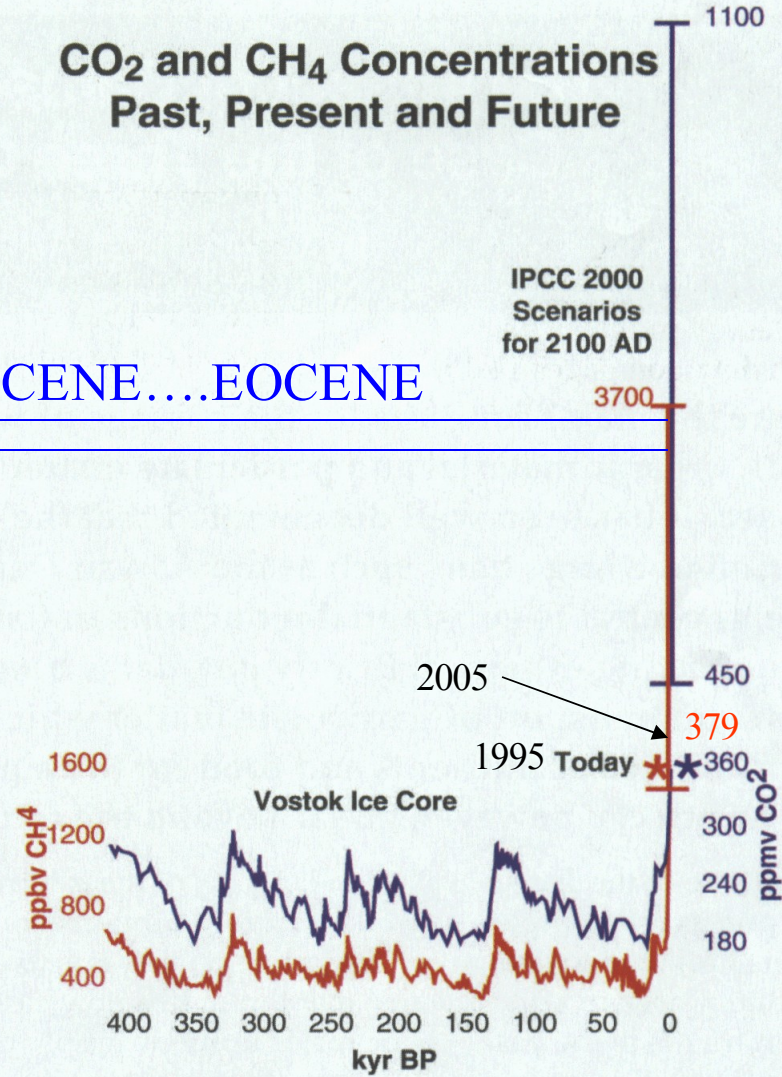
2001-02 : 2.0

2002-03 : 2.5

CO₂ and CH₄ Concentrations Past, Present and Future

MIOCENE....EOCENE

IPCC 2000
Scenarios
for 2100 AD

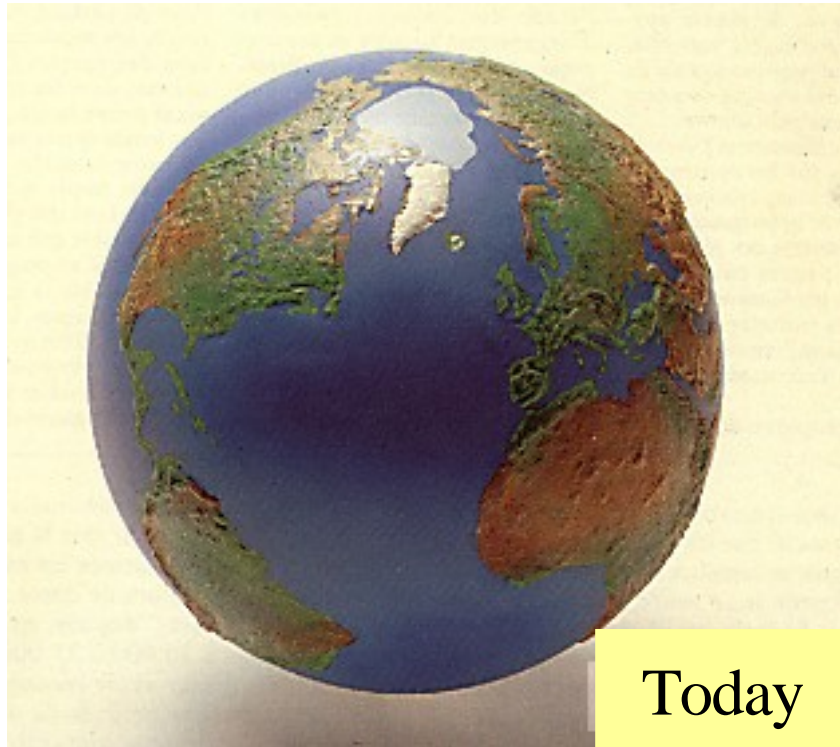


EN CONSÉQUENCE, NOUS
DEVONS ANALYSER LE
PASSÉ POUR ÉLARGIR LE
SPECTRE DES SITUATIONS
CLIMATIQUES QUI SONT
DISPONIBLES EN **GRAND**
DÉTAIL POUR LE **DERNIER**
SIÈCLE, MAIS AVEC UNE
PAUVRE DIVERSITÉ

QUE NOUS
APPREND LE
PASSE ?

CHANGEMENTS
LENTS ET RAPIDES

Last Glacial Maximum 21kyr BP



Pre-industrial CO₂ = 280 ppmv

2000 AD CO₂ = 370 ppmv

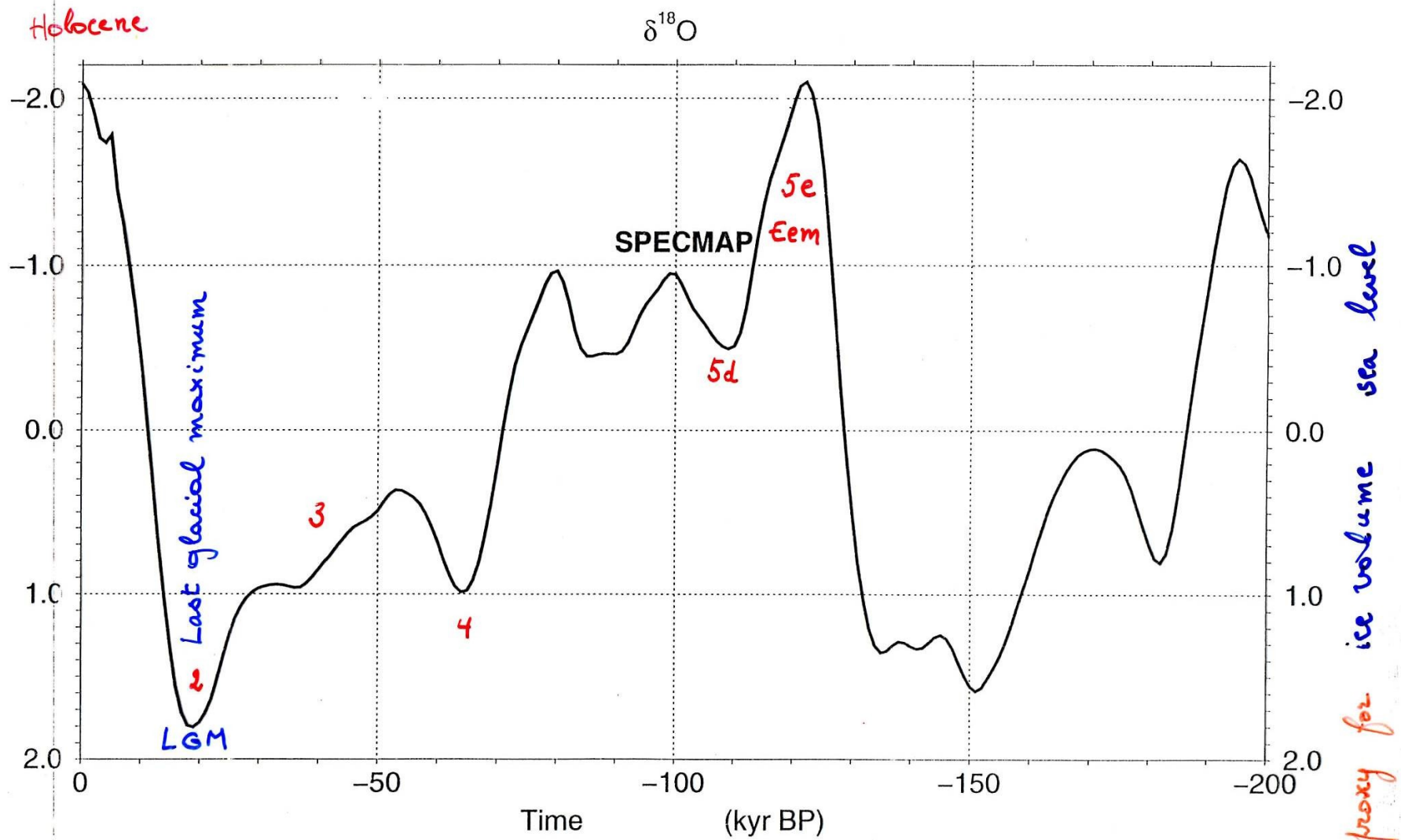


$\Delta T = -5^{\circ}\text{C}$

$\Delta \text{sea level} = -130\text{m}$

$\Delta \text{ice volume} = +52 \cdot 10^6 \text{km}^3$

CO₂ = 200 ppmv

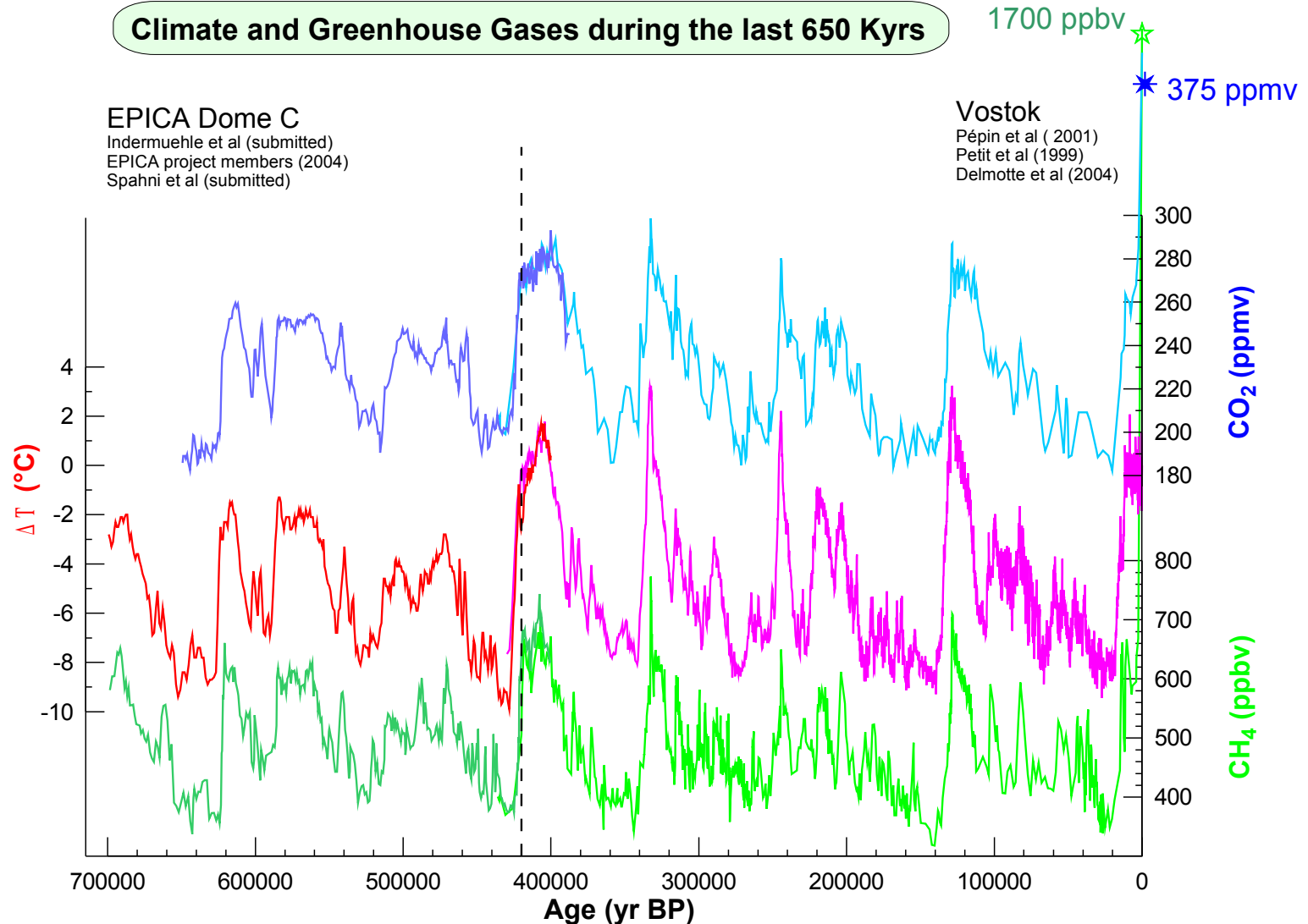


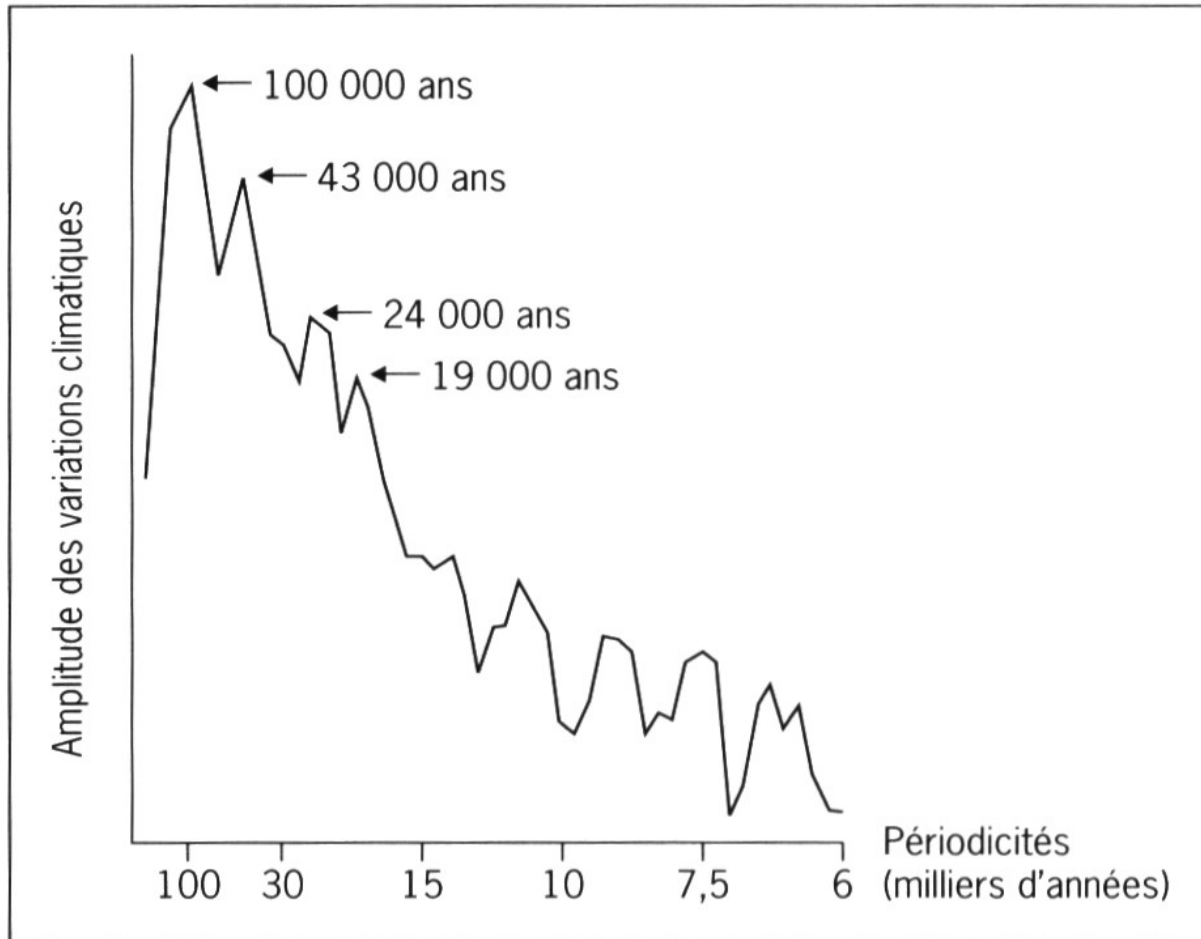
Last Glacial Maximum
relative to present day

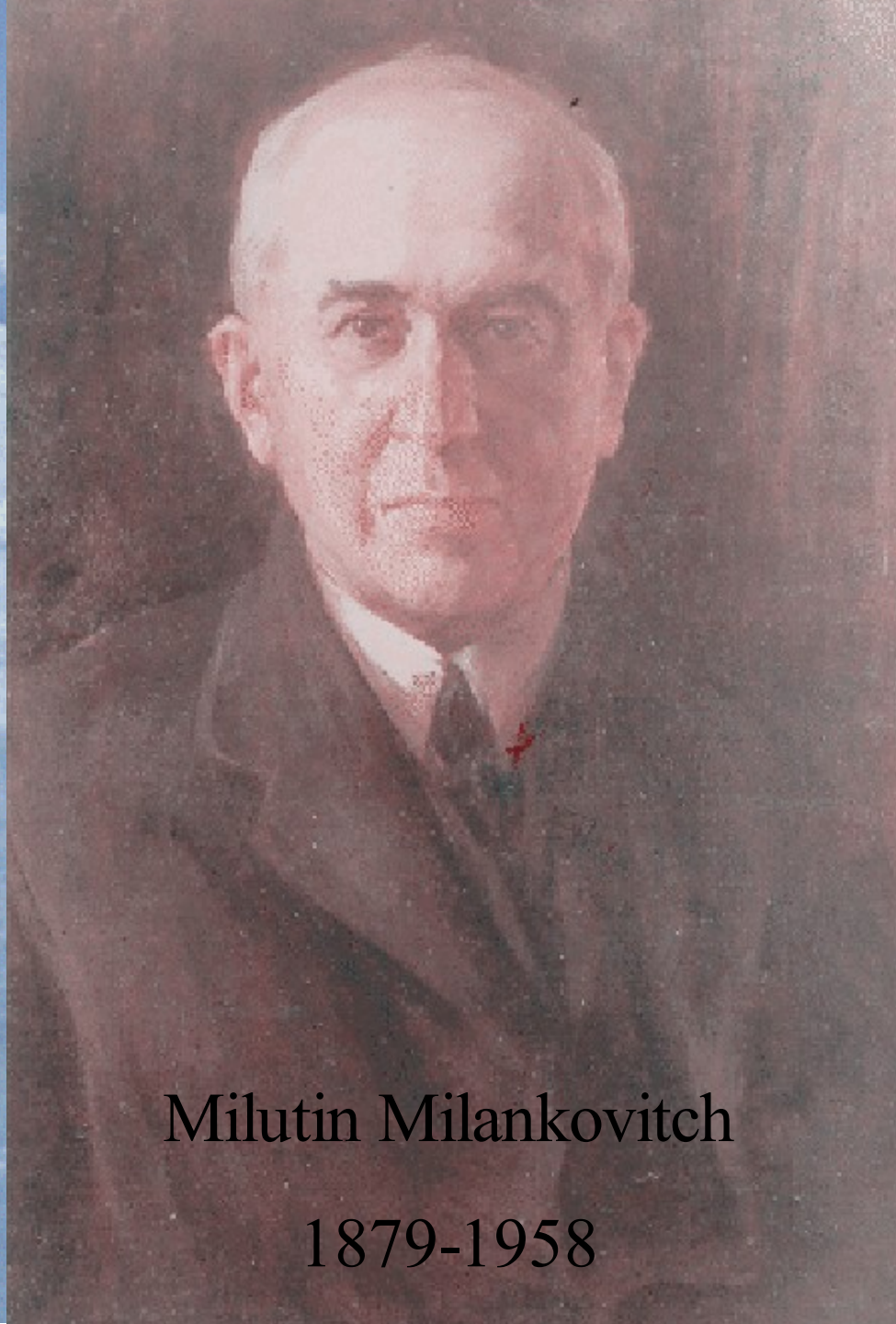
Δ ice volume = + 40 - 50 10^6 km^3
 Δ sea level = - 100 - 120 m
 Δ temperature = - 5°C

EPICA : CO₂, TEMPERATURE and CH₄

Climate and Greenhouse Gases during the last 650 Kyr







Milutin Milankovitch

1879-1958

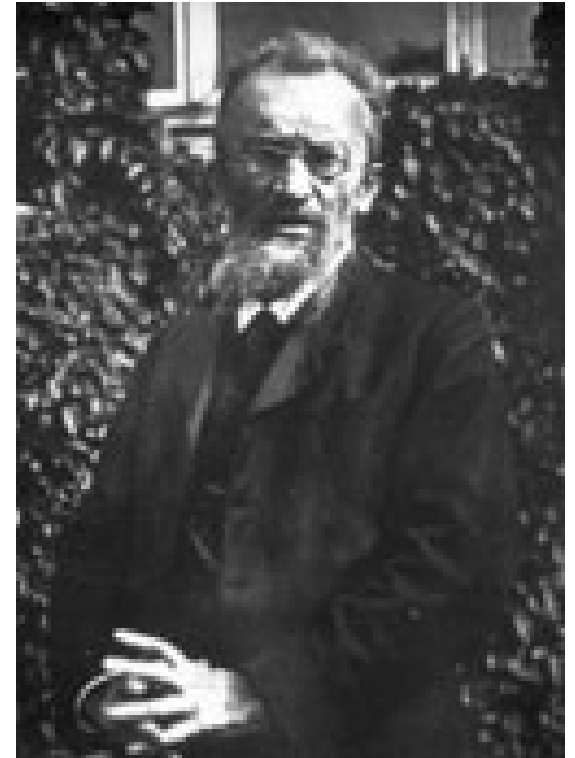
(Paja Jovanovic, 1943)



Milutin Milankovitch



Alfred Wegener

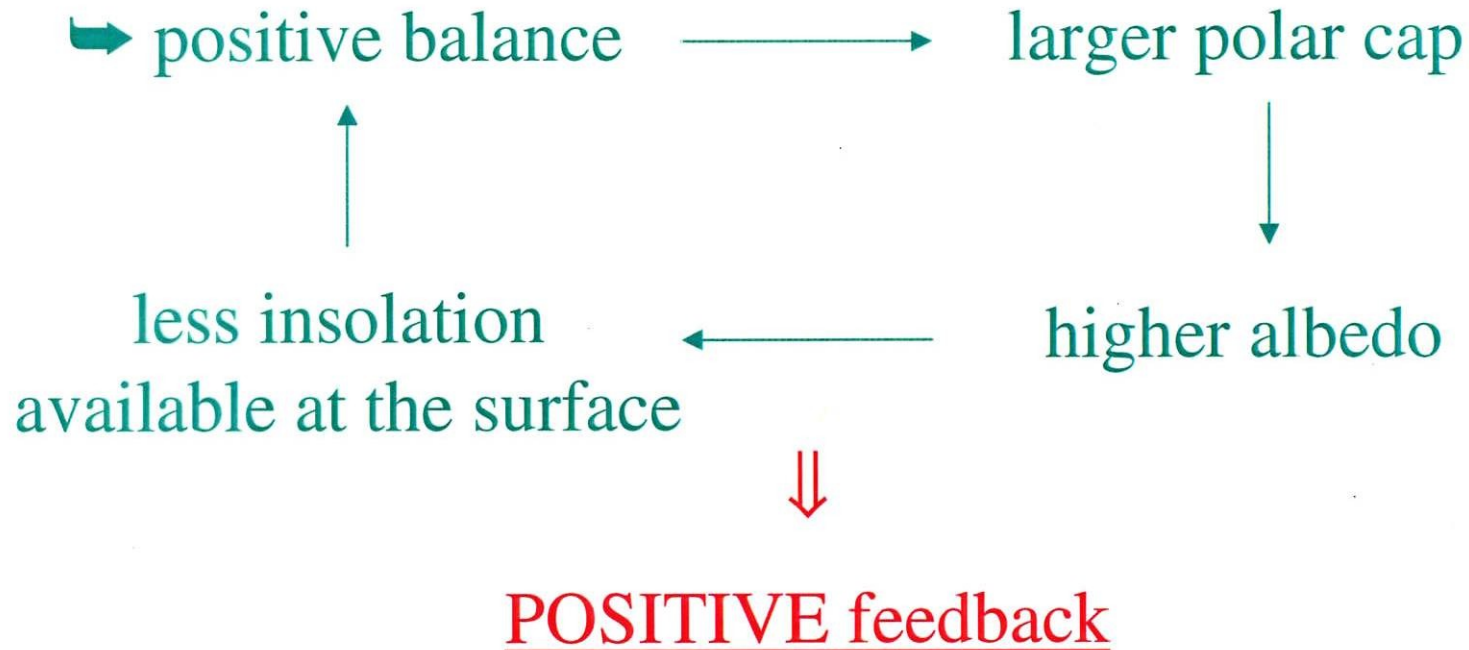


Vladimir Köppen

MILANKOVITCH

FOR GLACIAL :

Snow accumulated during winter does not melt in summer.



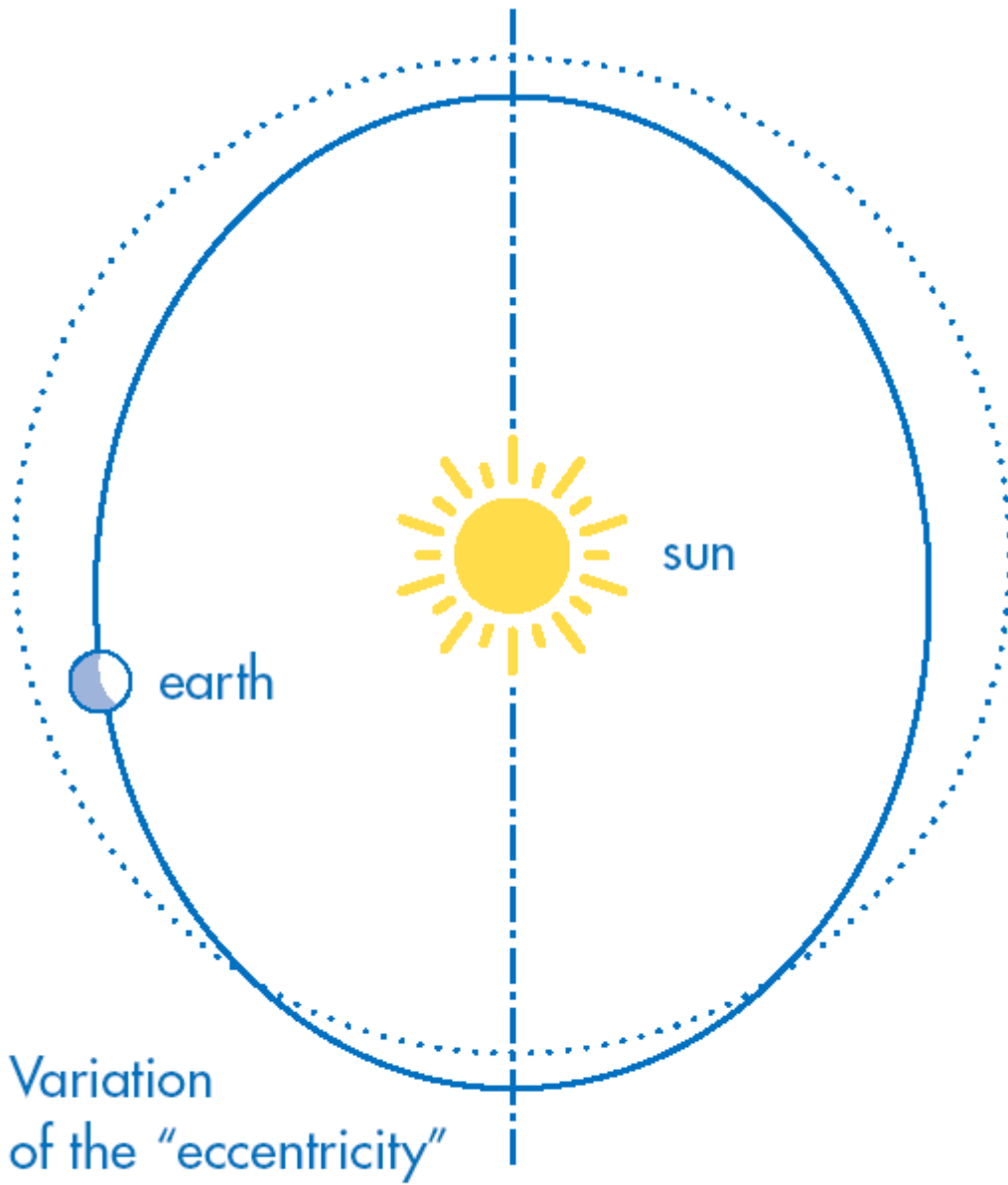
1. SOLUTION ASTRONOMIQUE

2. MATHEMATIQUE INSOLATION

3. MODELISER LE PASSE

4. MODELISER LE FUTUR

**5. L'IMPACT DE L'HOMME A
L'ECHELLE ASTRONOMIQUE**



$$(R_a - R_p)/a = 2e$$

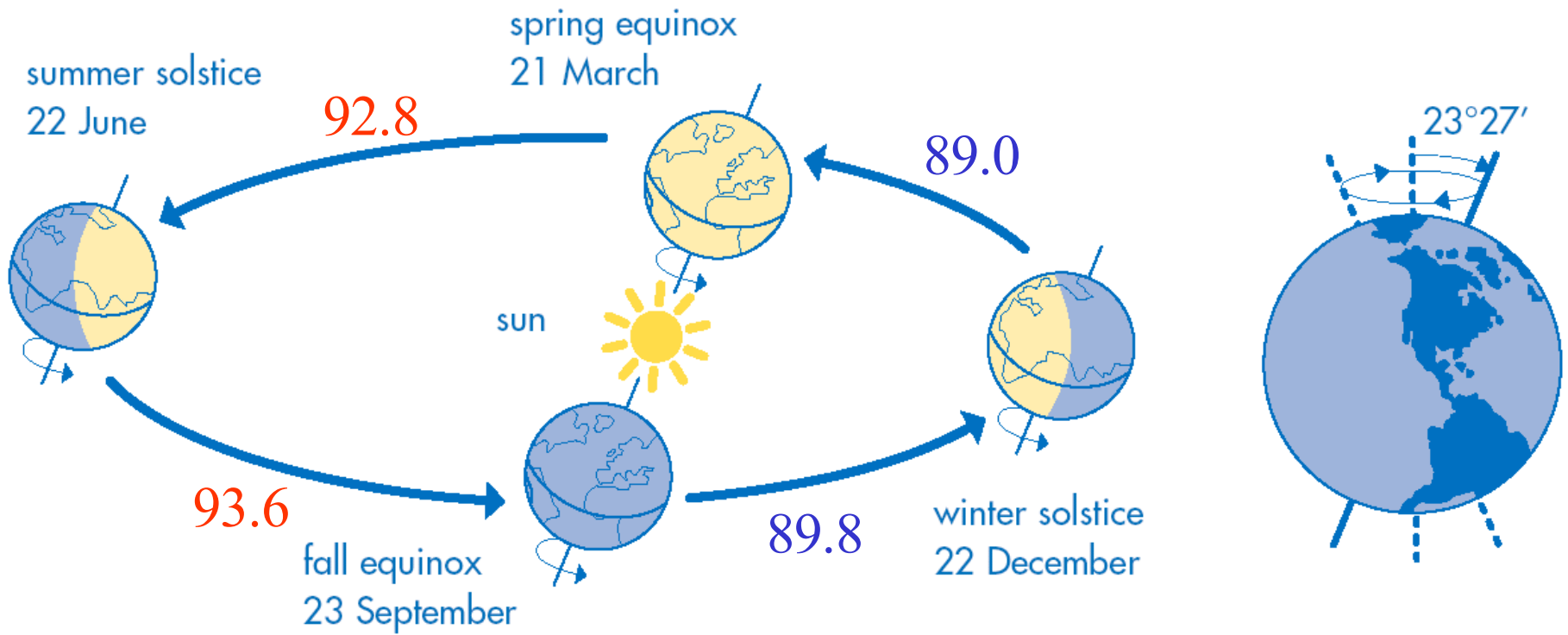
$$(E_p - E_a)/E = 4e$$

$$e_{\max} = 0.07$$

which leads to

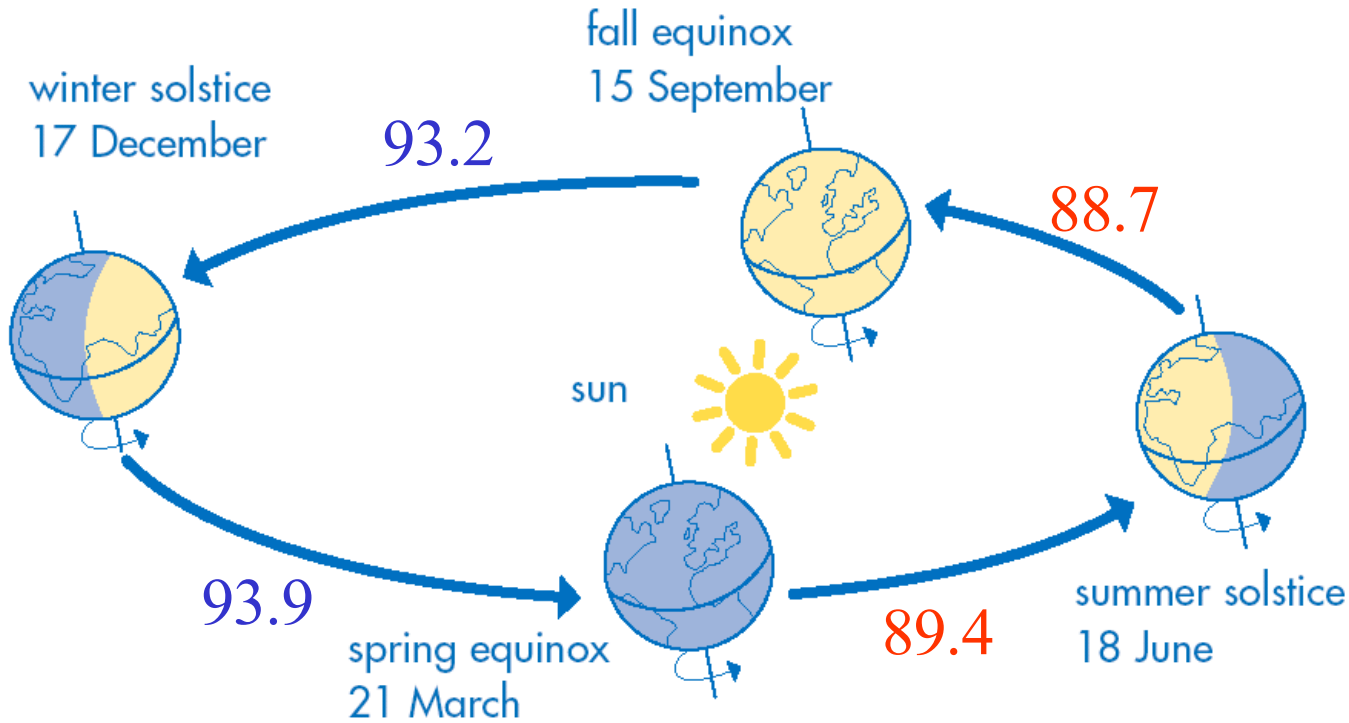
$$(dE/E)_{\max} = 28 \%$$

Today



ORBIT-O-LATSIS,2001

11 000 year's ago



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

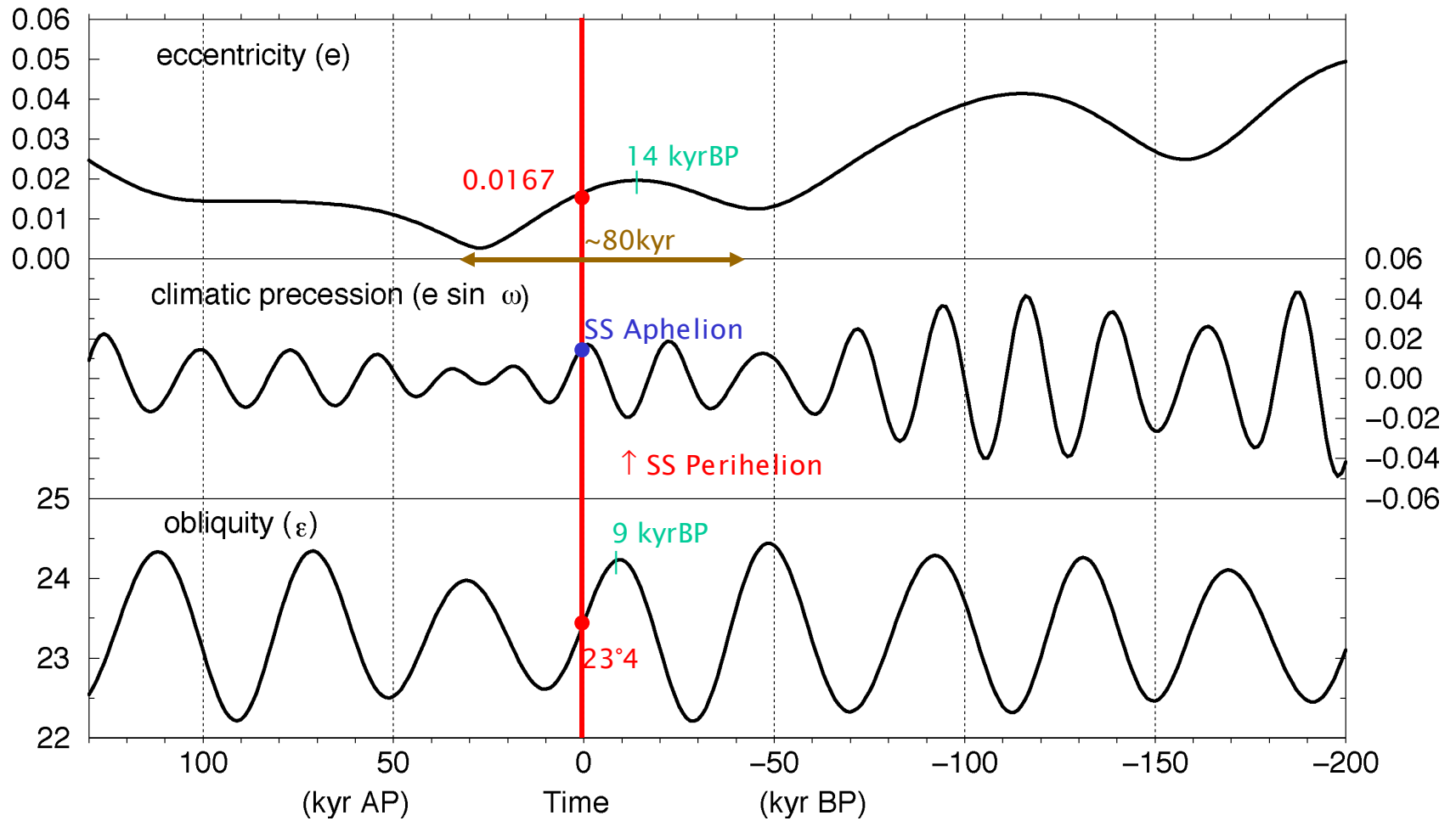
OBLIQUITY

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

BER78



ϵ large

SS Perihelion ($\bar{\omega}=270^\circ$; $e \sin \bar{\omega}$ min)

High insolation
 Lat. MAX
 NH in summer

Δ lat in summer

Δ season in high lat NH

MAX

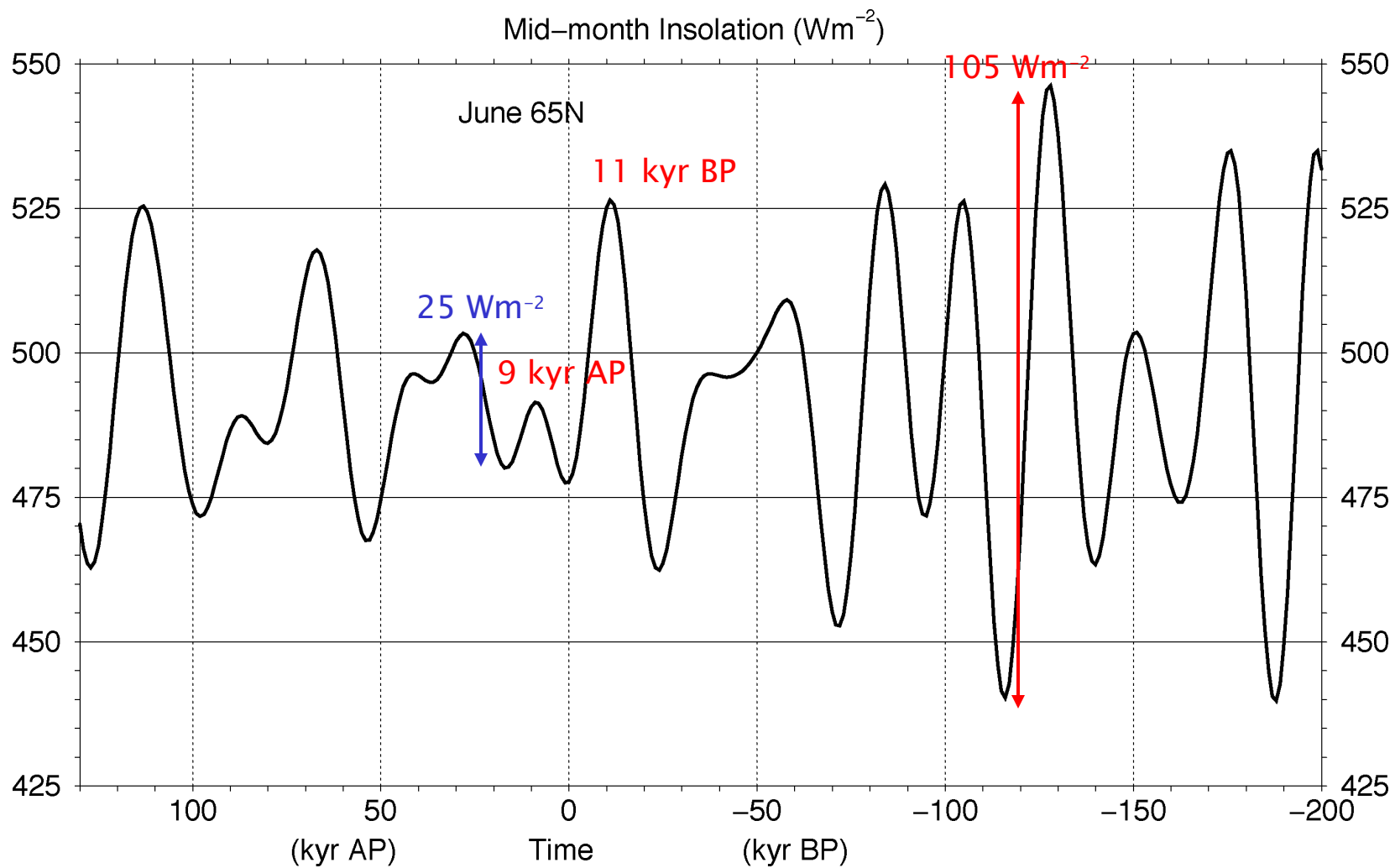
1. SOLUTION ASTRONOMIQUE

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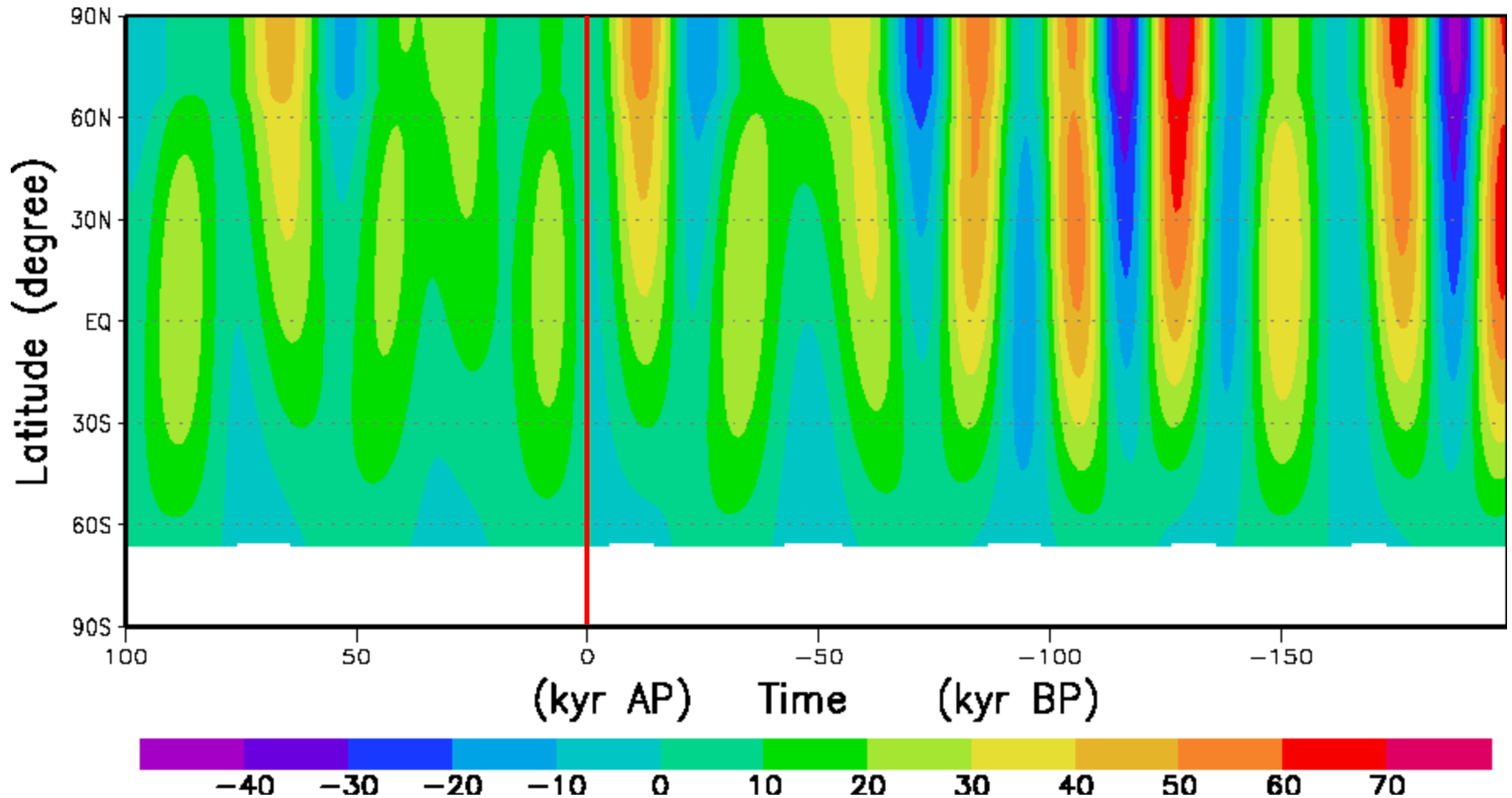
4. MODELISER LE FUTUR

**5. L'IMPACT DE L'HOMME A
L'ECHELLE ASTRONOMIQUE**



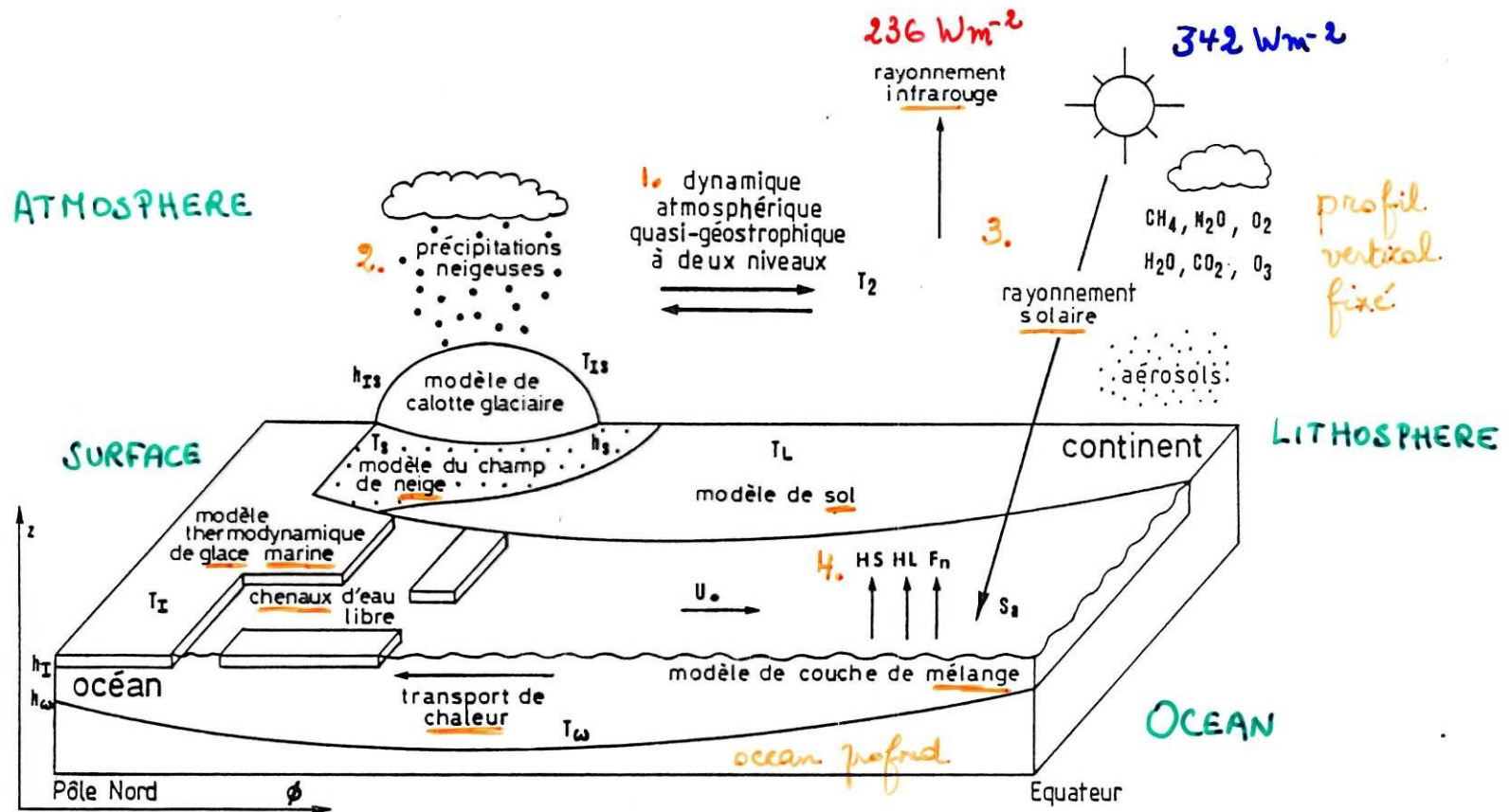
24h mean irradiance (Wm^{-2})

Mid-month June



- 1. SOLUTION ASTRONOMIQUE**
- 2. MATHEMATIQUE INSOLATION**
- 3. MODELISER LE PASSE**
- 4. MODELISER LE FUTUR**
- 5. L'IMPACT DE L'HOMME A
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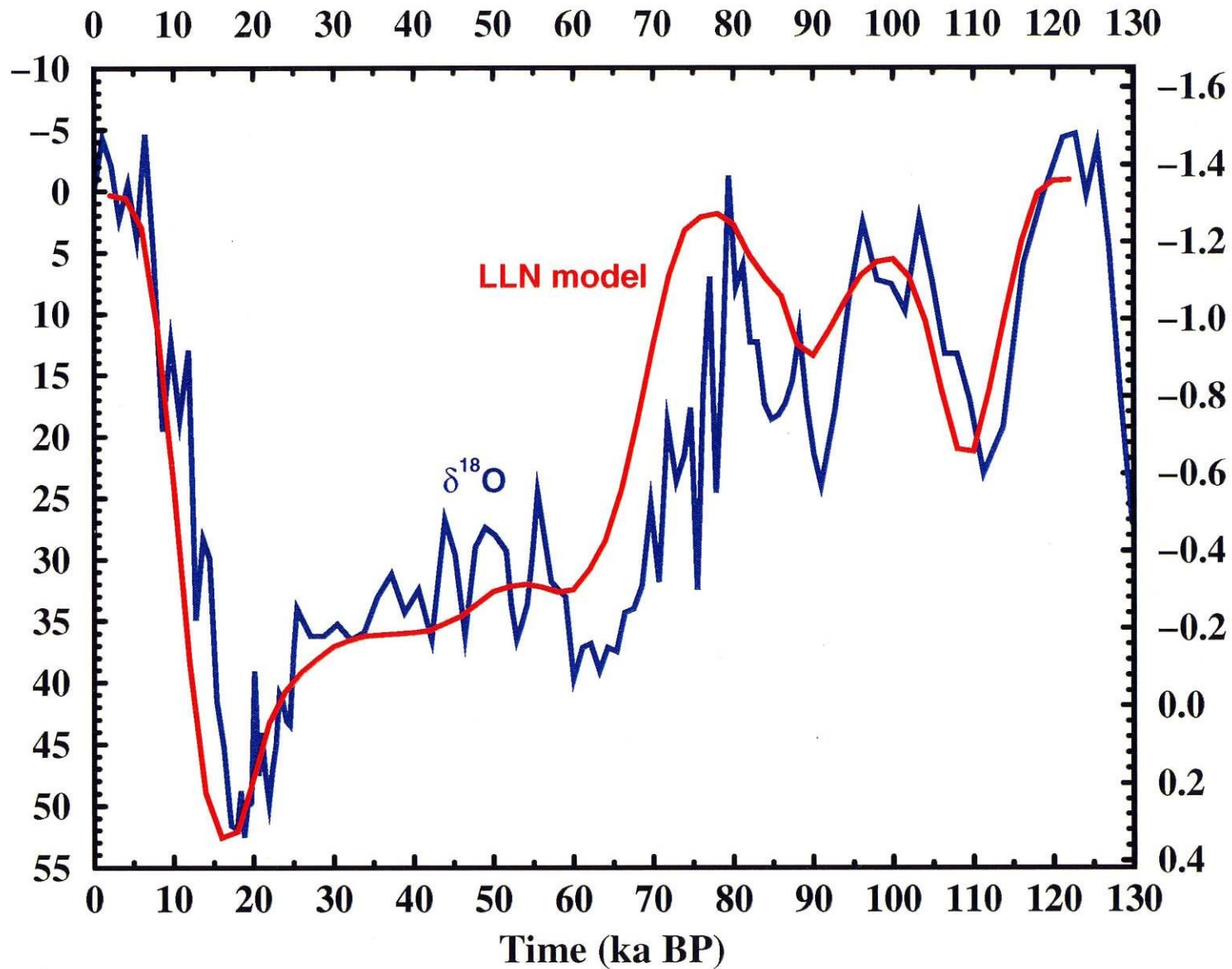
MODELE 2.5-D LLN



Gallée et al. JGR 1991 96

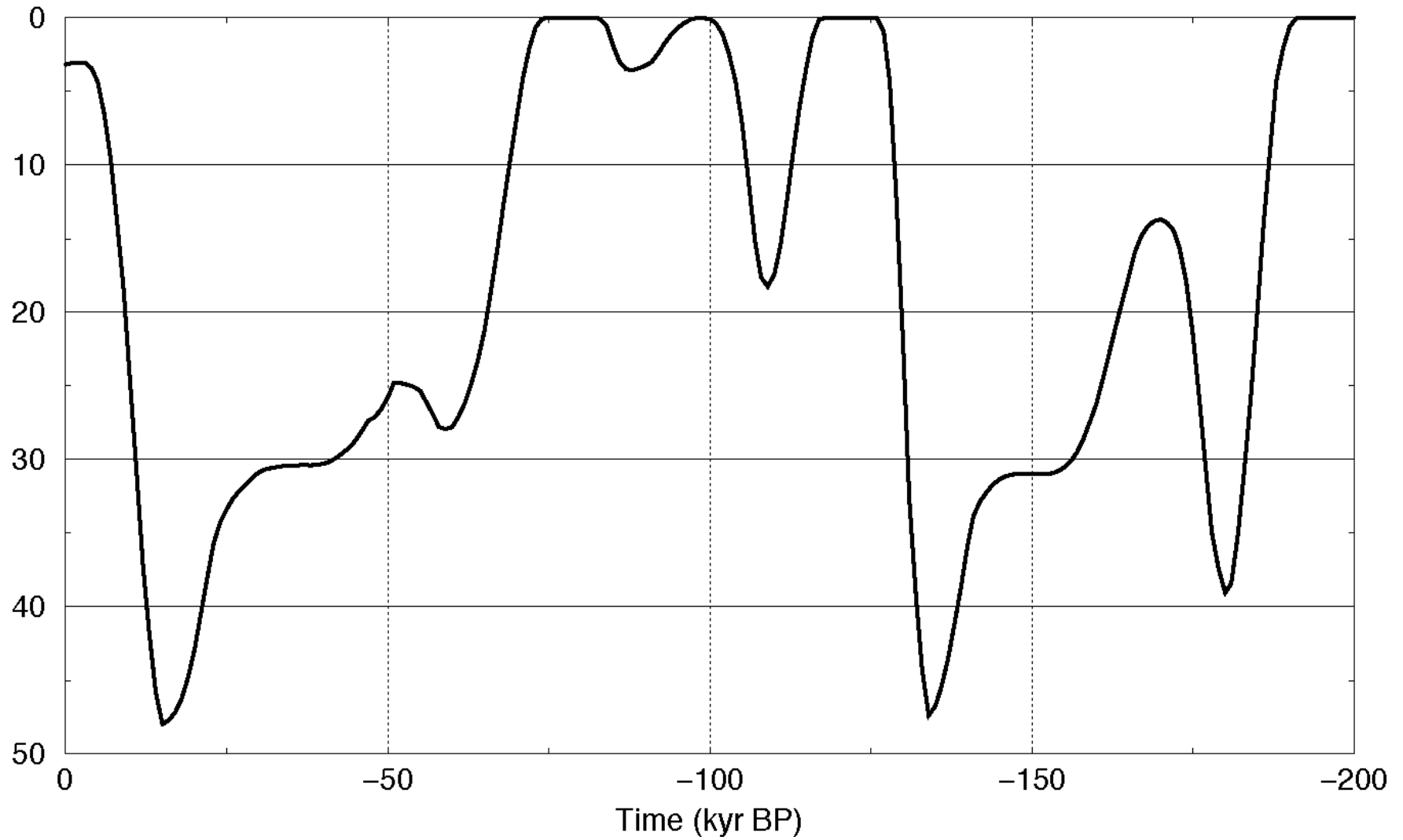
13139-13161

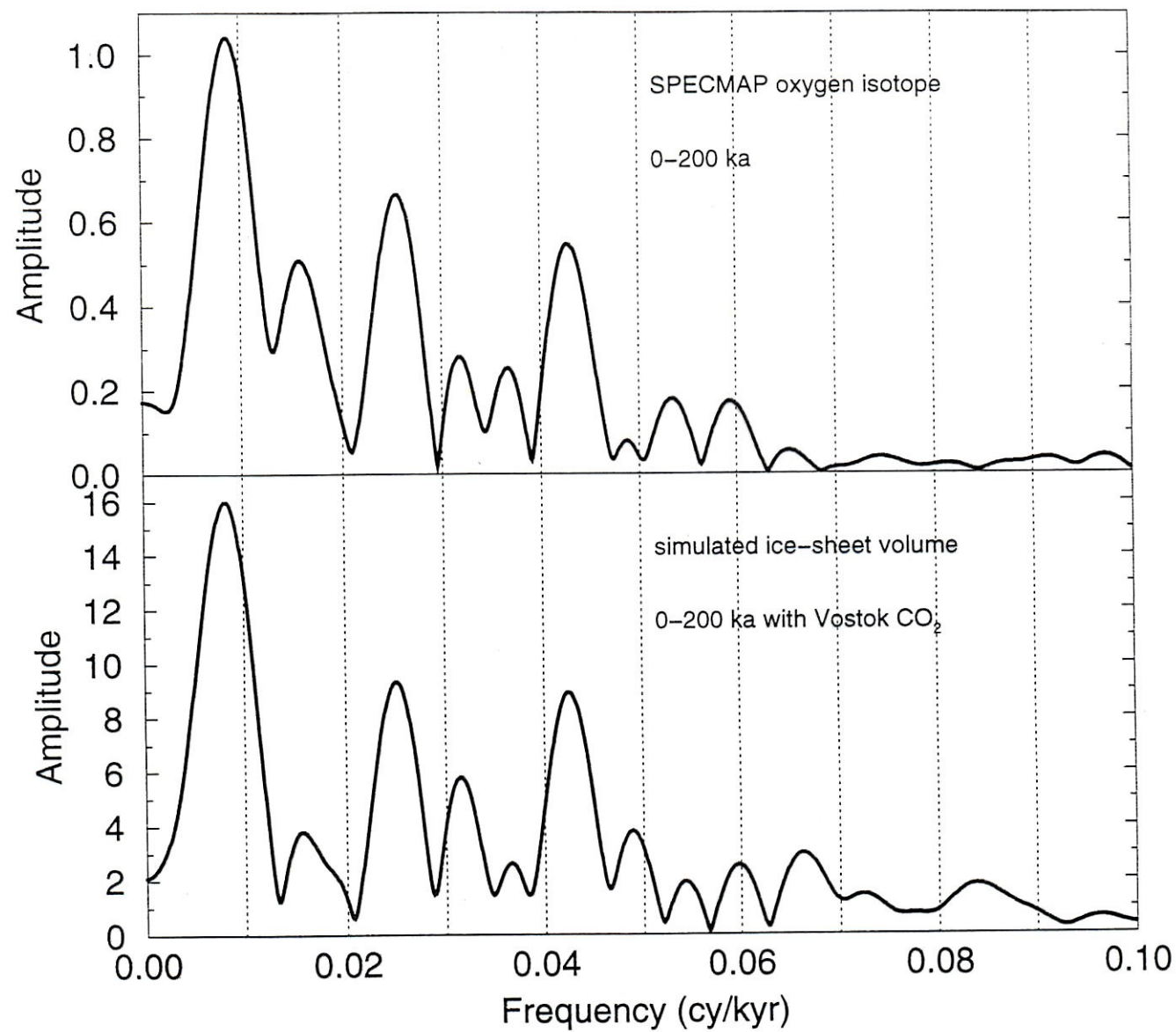
Deviation from present day₃
continental ice volume (10⁶ km³)
(Gallee *et al.*, 1991; 1992)



Core MD85-668 δ¹⁸O (per mil) to PDB
(Shackleton *et al.*, 1993)

Northern Hemisphere ice volume (10^6 km^3)

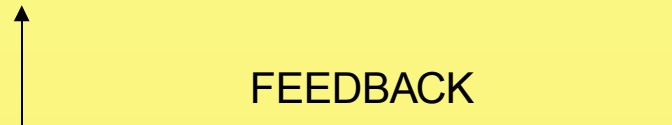




AT GEOLOGICAL TIME SCALE

FORCING : SOLAR IRRADIATION

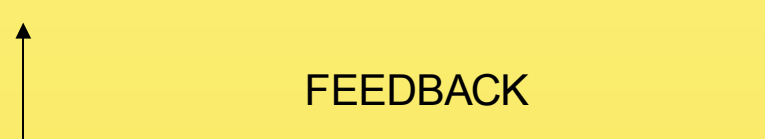
RESPONSE : CHANGE IN CLIMATE → IN BIOGEOCHEMICAL CYCLES



AT PRESENT-DAY HUMAN TIME SCALE

FORCING: SOLAR IRRADIATION + GREENHOUSE GASES ...

RESPONSE : CHANGE IN CLIMATE → IN BIOGEOCHEMICAL CYCLES



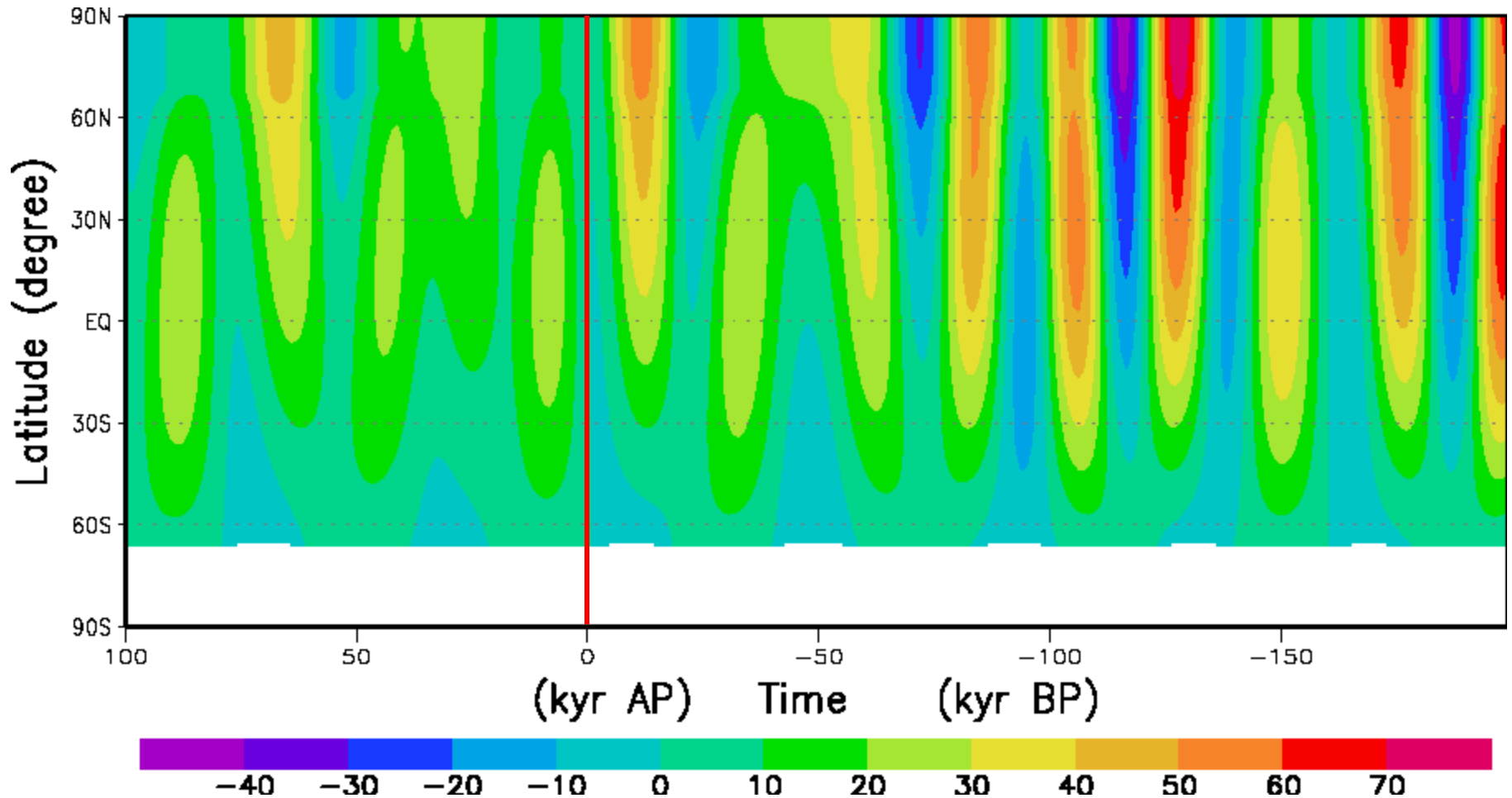
QUEL POURRAIT ÊTRE
NOTRE CLIMAT A
L'ÉCHELLE
GÉOLOGIQUE SANS
INTERVENTION
HUMAINE ?

- 1. SOLUTION ASTRONOMIQUE**
- 2. MATHEMATIQUE INSOLATION**
- 3. MODELISER LE PASSE**
- 4. MODELISER LE FUTUR**
- 5. L'IMPACT DE L'HOMME A
L'ECHELLE ASTRONOMIQUE**

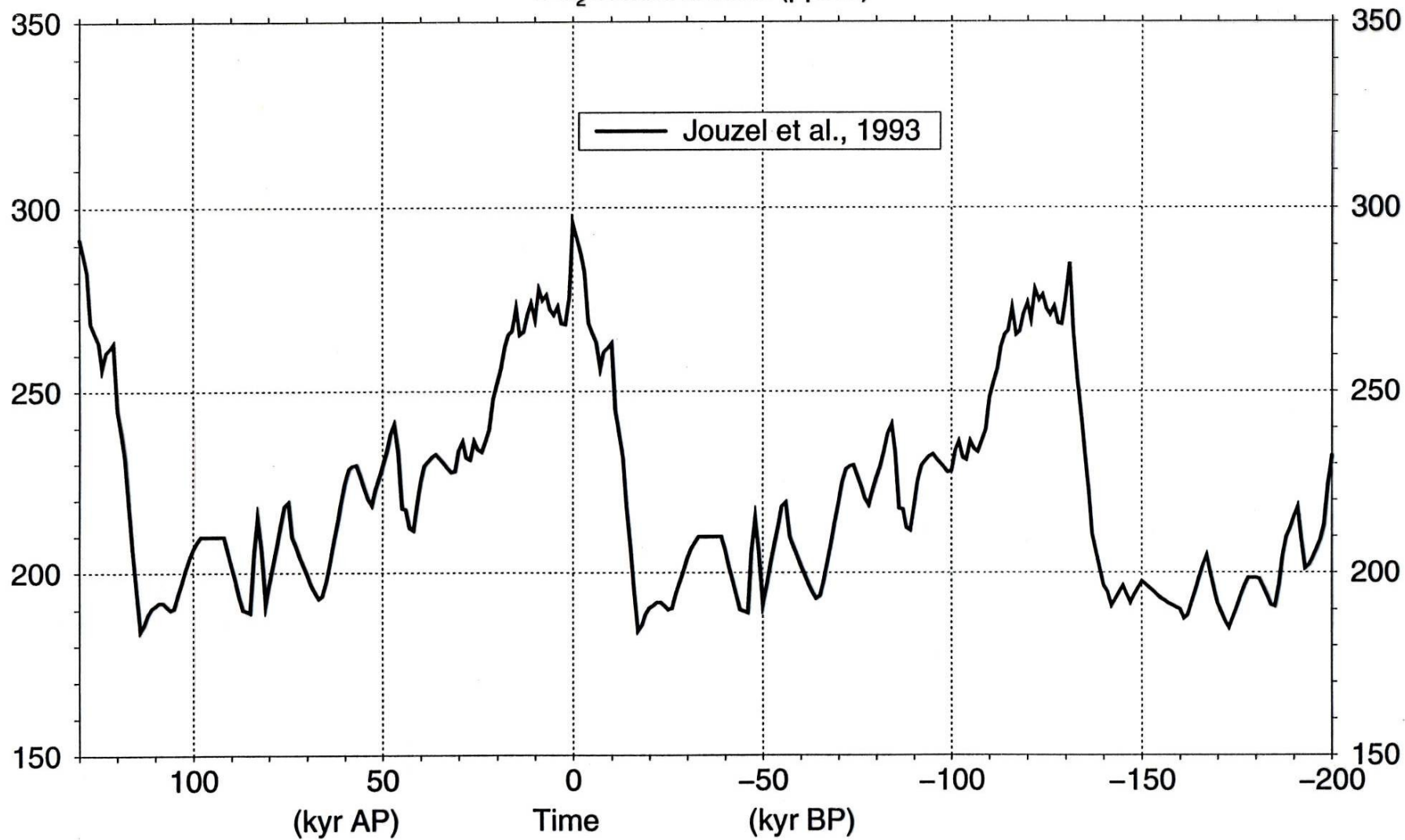
**Forçage astronomique
exceptionnel au cours
des 50.000 prochaines
années**

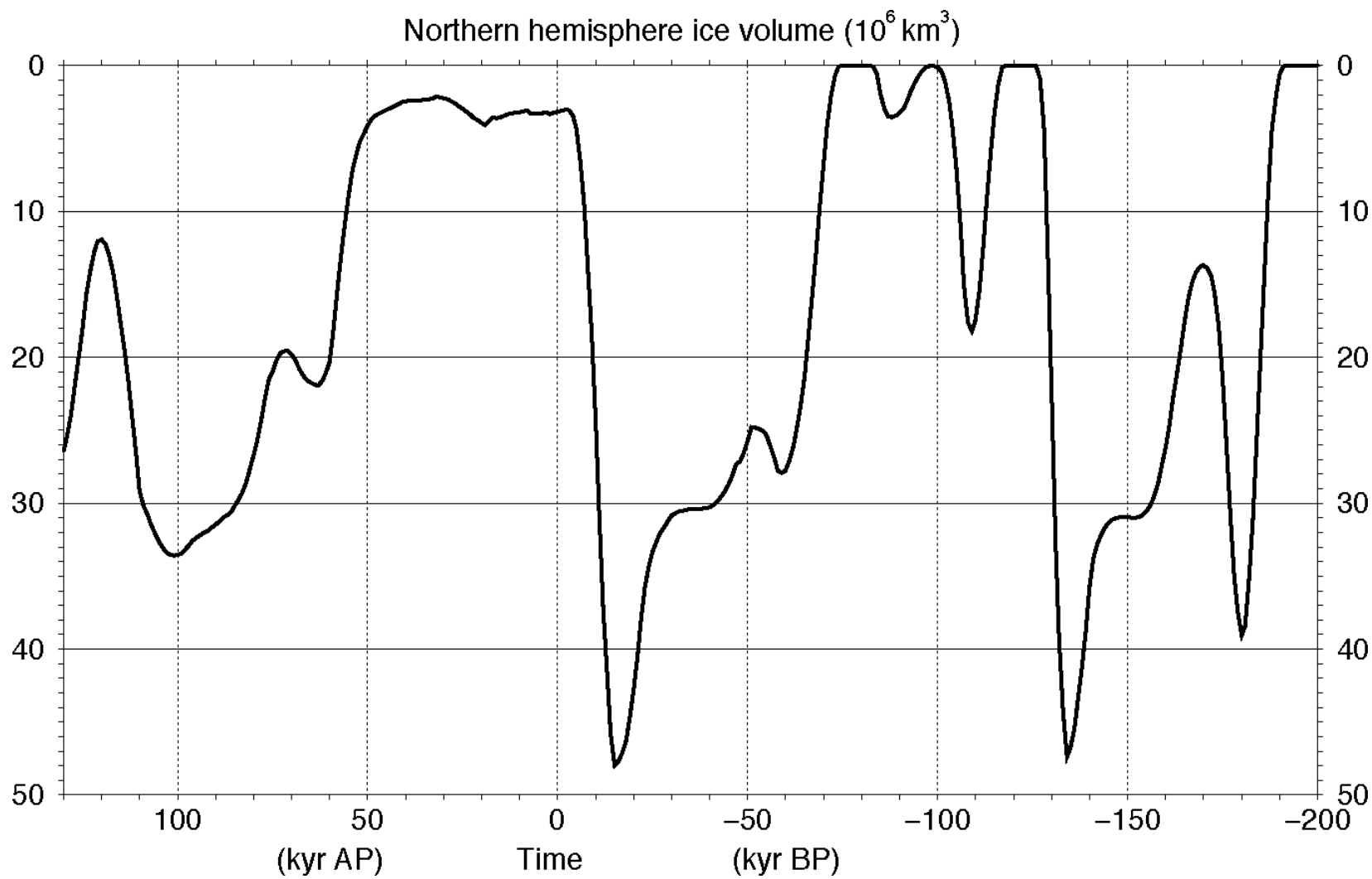
24h mean irradiance (Wm^{-2})

Mid-month June



CO₂ concentration (ppmv)

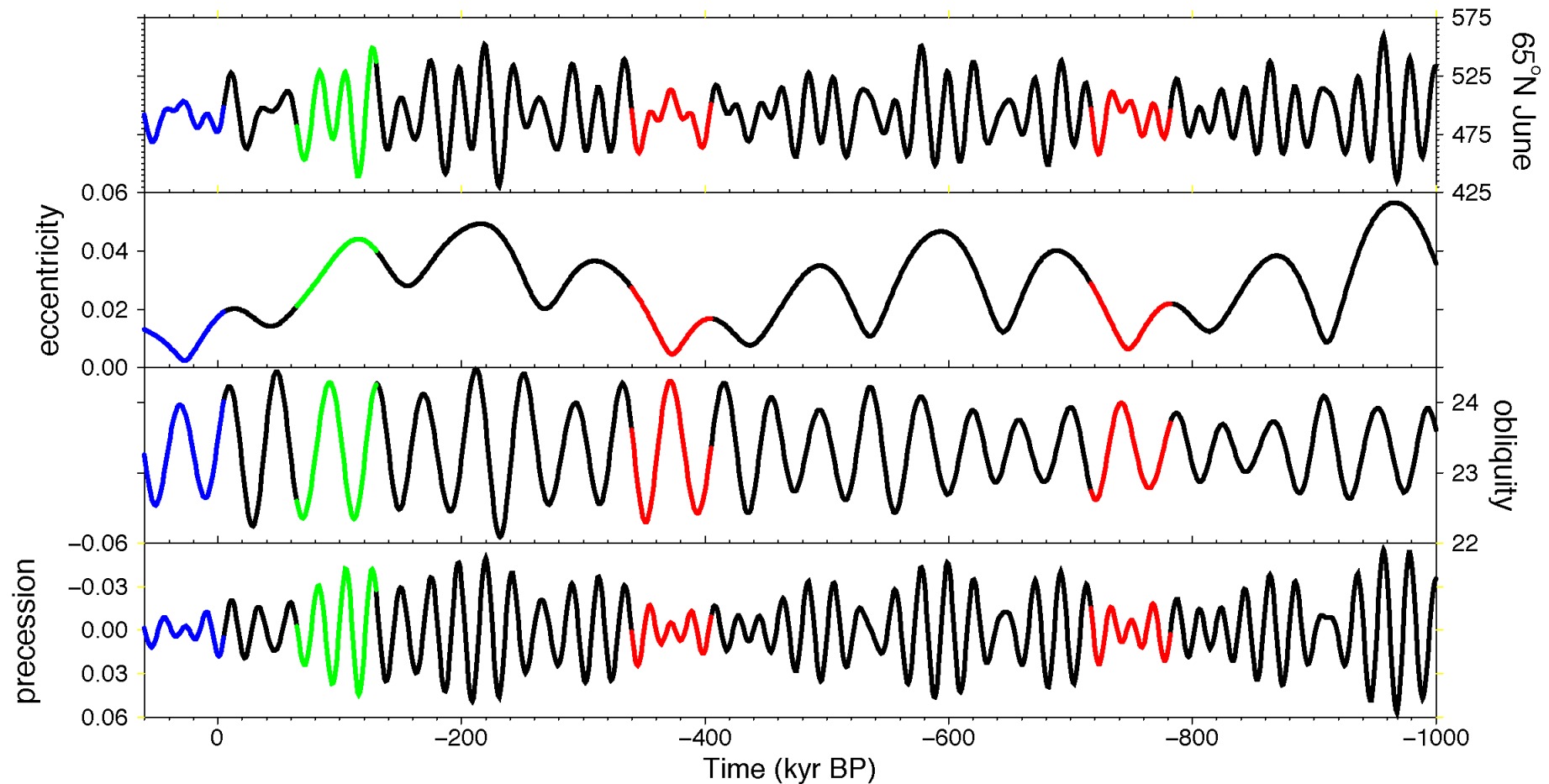




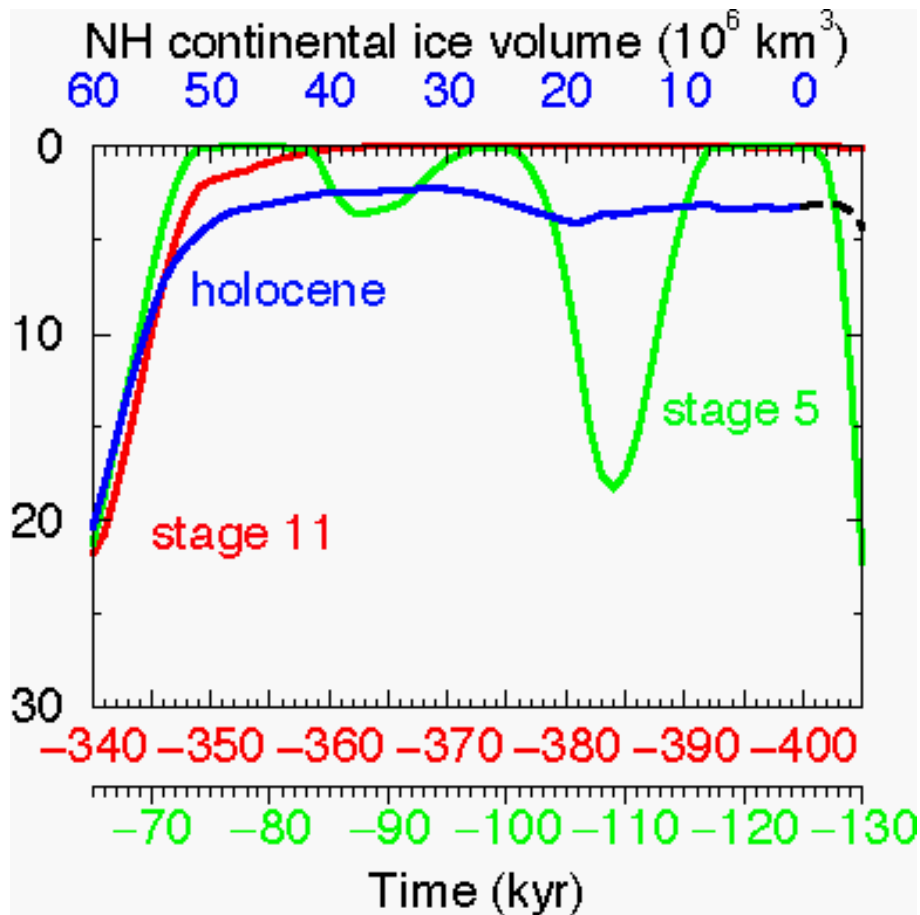
STAGE 11 / STAGE 1

and its Future

Orbital parameters : an analogue for the future

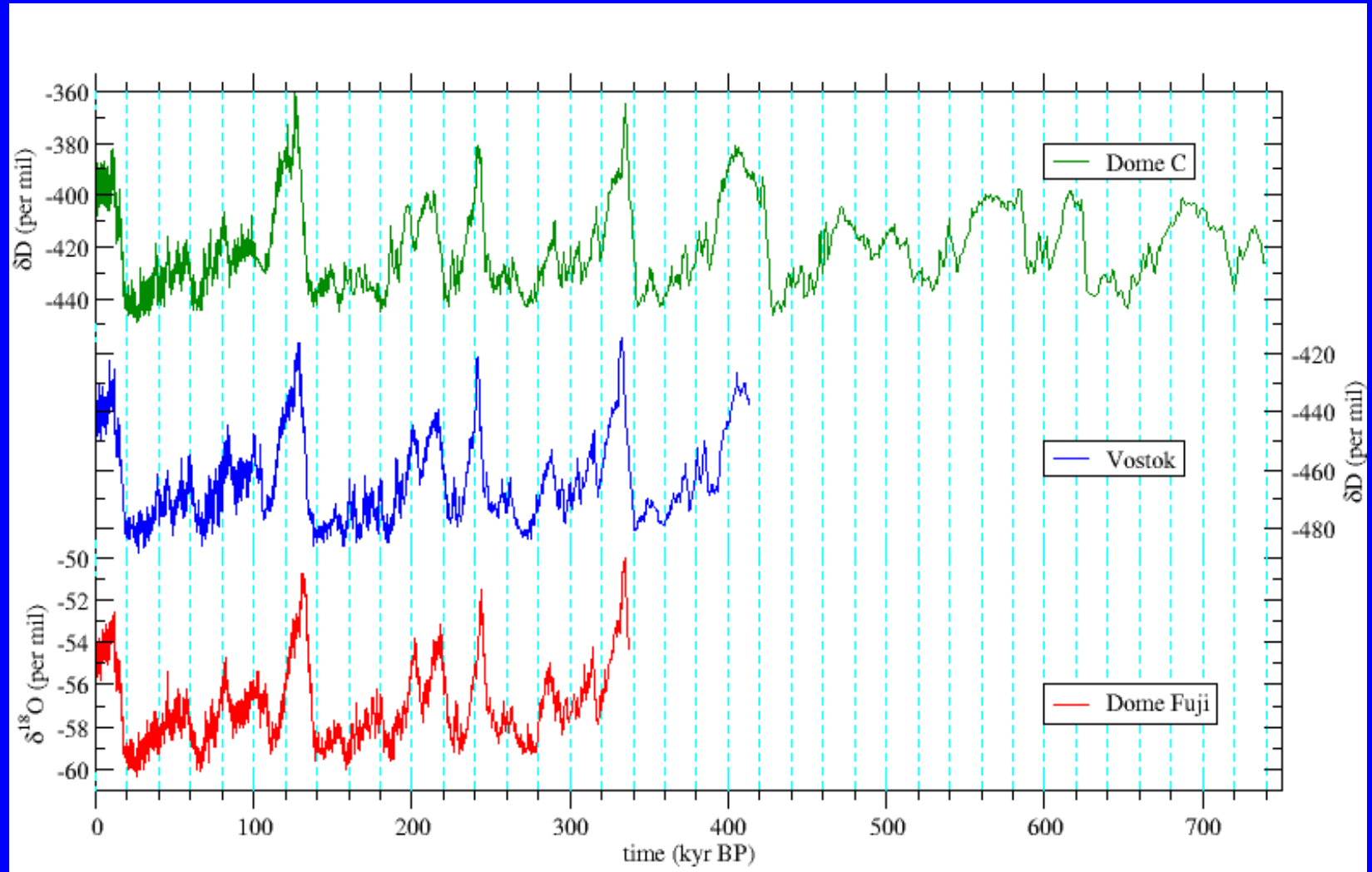


MIS11 : an analogue for the future



$\text{CO}_2 = \text{Vostok}$

Archives of climate in Antarctica



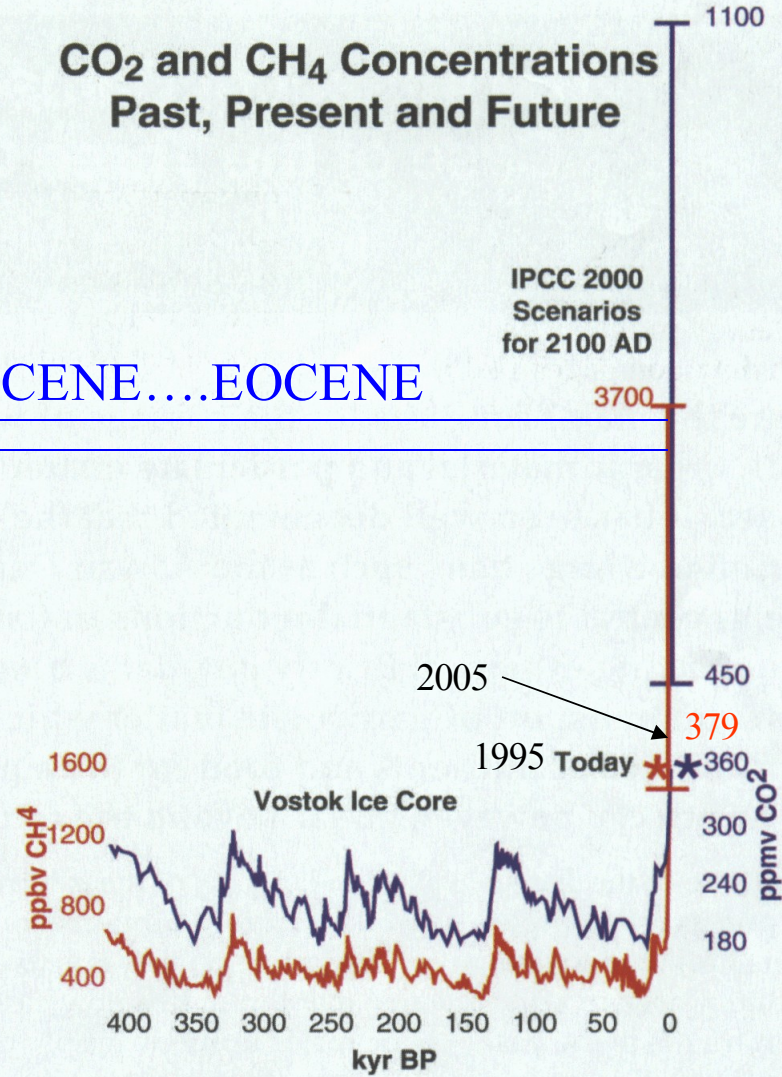
QUEL POURAIT ÊTRE
NOTRE CLIMAT A
L'ÉCHELLE
GÉOLOGIQUE SOUS
L'EMPRISE DES
ACTIVITÉS HUMAINES

- 1. SOLUTION ASTRONOMIQUE**
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L'ECHELLE ASTRONOMIQUE**

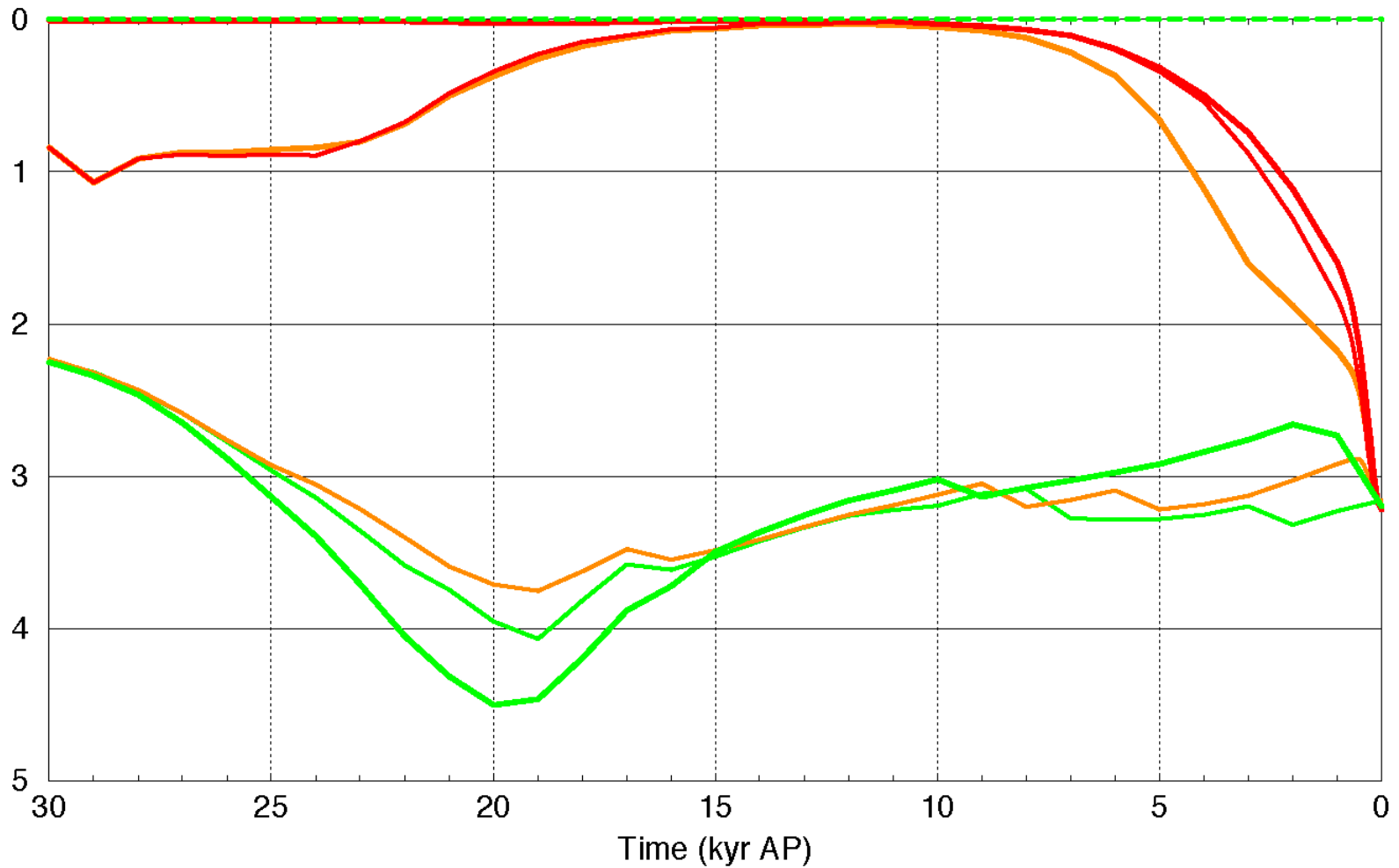
CO₂ and CH₄ Concentrations Past, Present and Future

MIOCENE....EOCENE

IPCC 2000
Scenarios
for 2100 AD



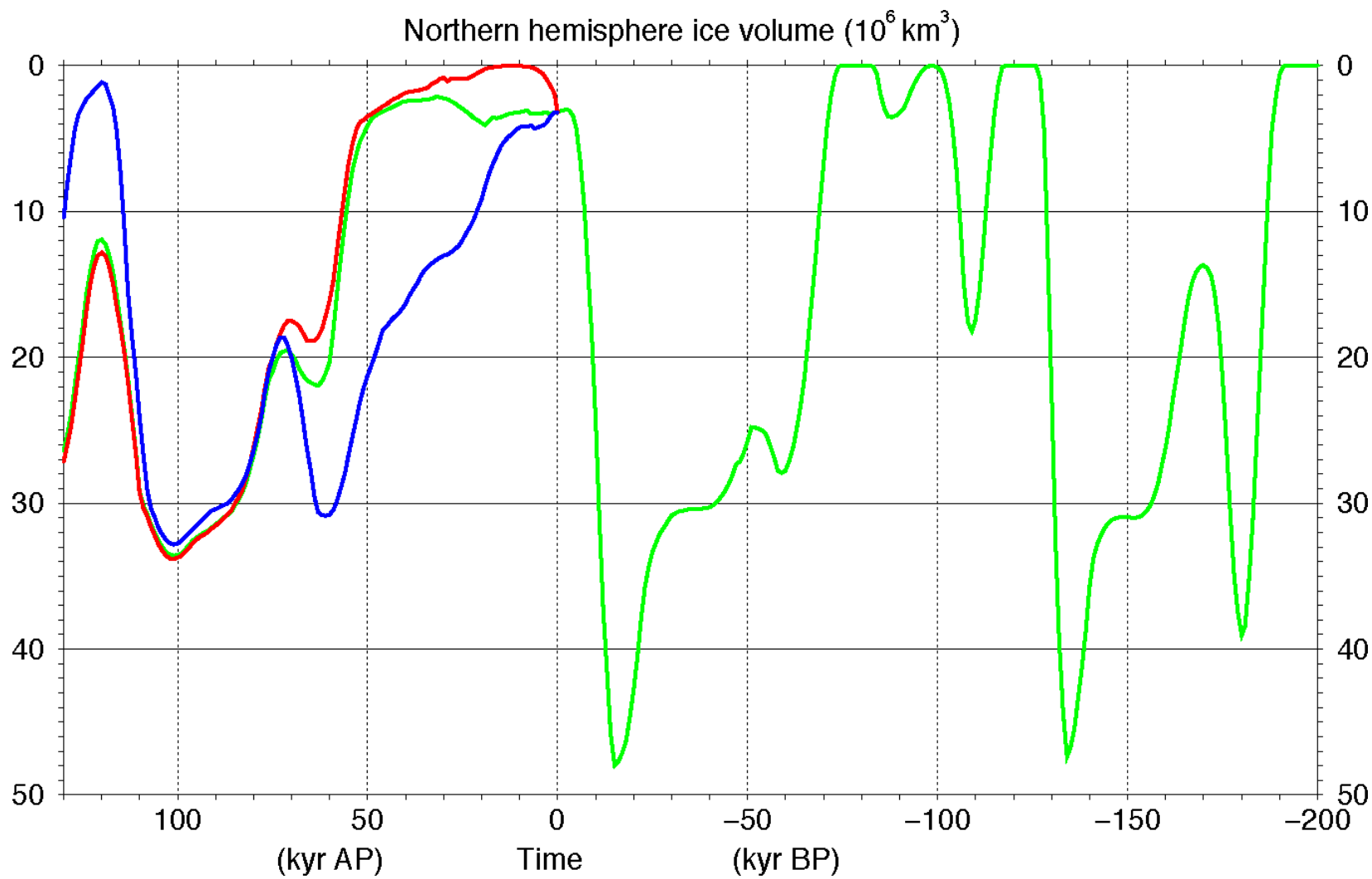
Northern Hemisphere ice volume (10^6 km^3)



thin line - initial conditions from run -200 - 0

thick line - initial conditions from run -122 - 0

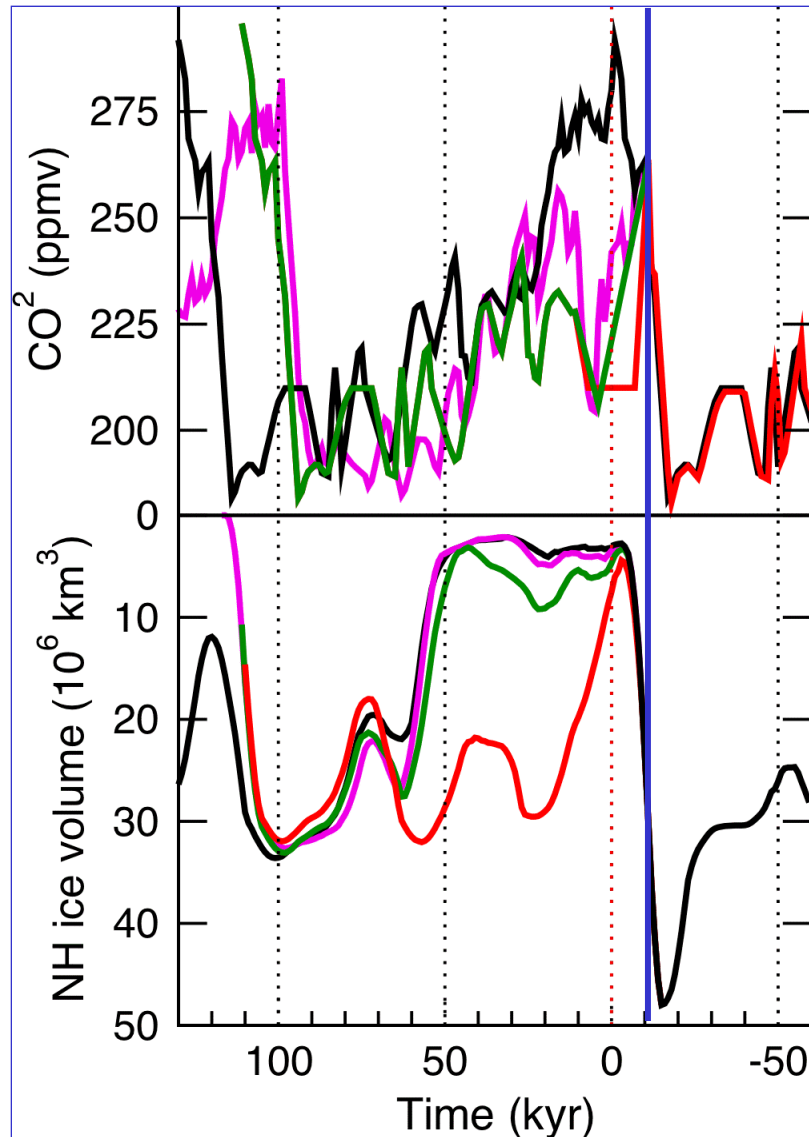
- 550 (M06)
- 750 (M07)
- Jouzel et al., 1983 (B52)
- Jouzel et al., 1983 - initial volume = 0 (B43)
- 550 (M10)
- 750 (M11)
- Jouzel et al., 1983 (B40)



The anthropogenic greenhouse era began thousands of years ago

W.F. Ruddiman, climatic changes, 2004.

Human impact in the past



SCENARI - 52 to + 130 kyr

CO₂

black VOSTOCK 131 kyr BP shift to 0

purple MIS 7 shift to 11 kyr BP

green VOSTOCK younger by 20 kyr

red green but decrease more rapid

CONCLUSIONS

NOUS VIVONS UNE
EPOQUE
EXCEPTIONNELLE

**1. LE FORCAGE PRINCIPAL
(ASTR) A L'ECHELLE DE
MILLIERS D'ANNEES
N'ALLANT PLUS VARIER AU
COURS DES MILLIERS
D'ANNEES A VENIR,
L'IMPORTANCE DES AUTRES
(GES) S'EN TROUVE
LARGEMENT ACCRUE**

**2. L'ENTREE EN GLACIATION
NE PEUT PLUS SERVIR
D'EXCUSE AUX EMISSIONS DE
GES. AU**

**CONTRAIRE, LE RG POURRAIT
ETRE A L'ORIGINE D'UN
REFROIDISSEMENT DU NORD
DE L'ATLANTIQUE NORD DU A
UN AFFAIBLISSEMENT DU
GULF STREAM**

2200 A.D.

