



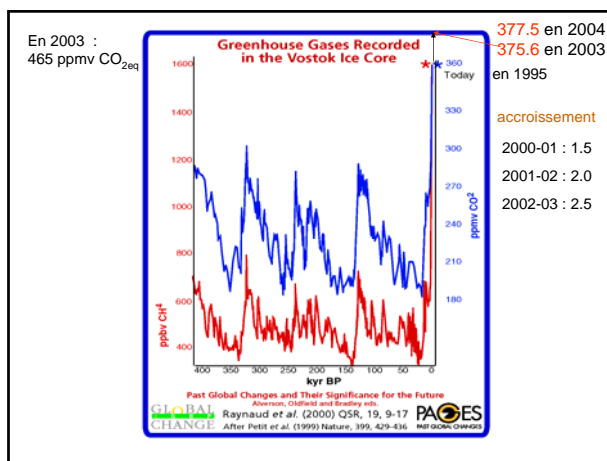
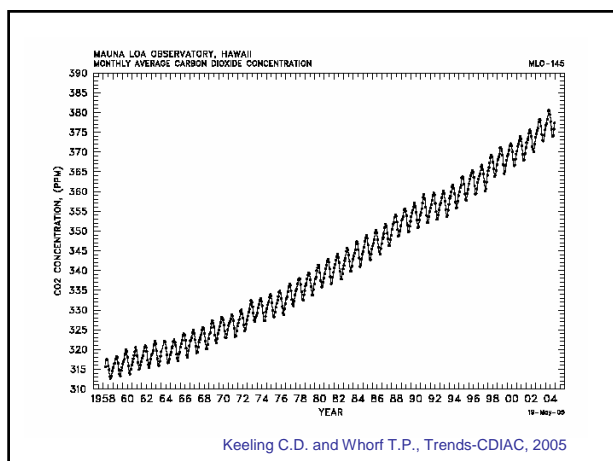
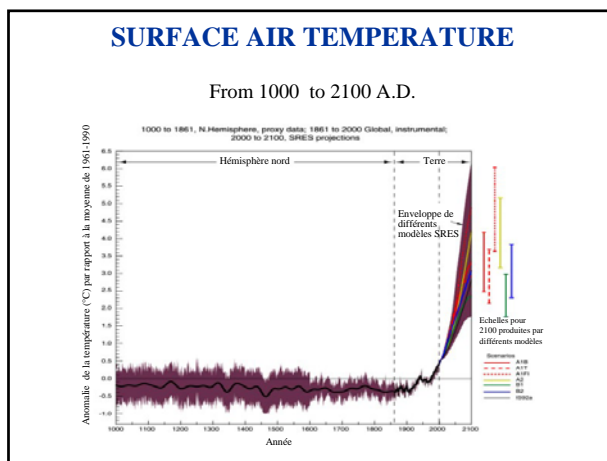
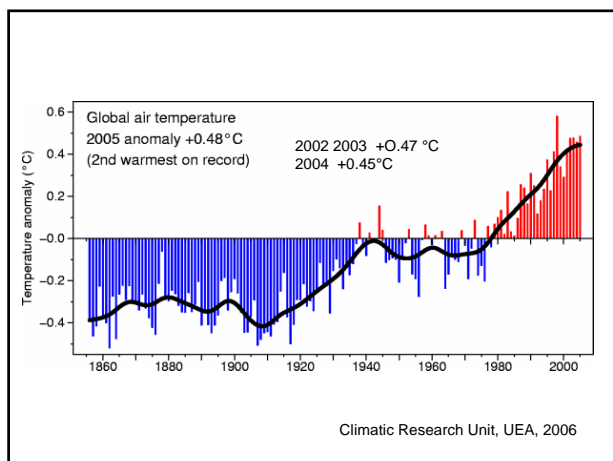
Institut d'Astronomie et de Géophysique G. Lemaître
Chemin du Cyclotron, 2
1348 Louvain-la-Neuve

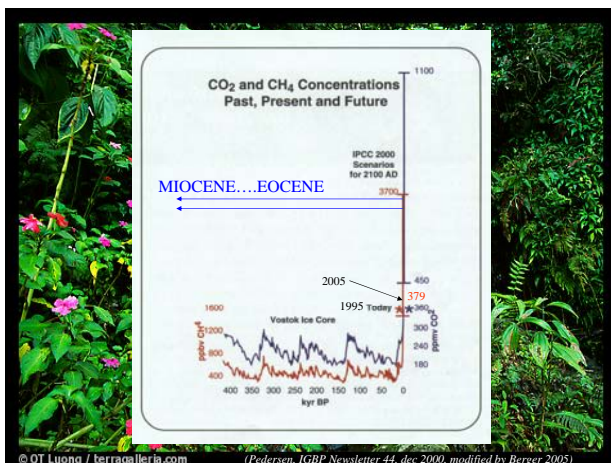
LE CLIMAT DES PROCHAINS MILLÉNAIRES

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'ÉVOLUTION NATURELLE
DU CLIMAT AUSSI A
L'ÉCHELLE **GÉOLOGIQUE** ?

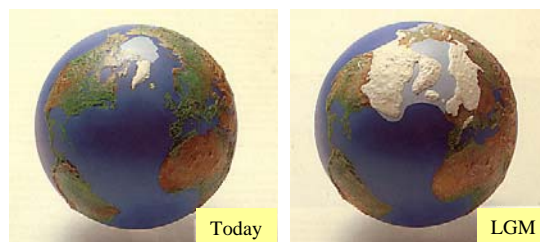




EN CONSÉQUENCE, NOUS DEVONS ANALYSER LE **PASSÉ** POUR ÉLARGIR LE **SPECTRE** DES SITUATIONS CLIMATIQUES QUI SONT DISPONIBLES EN **GRAND DÉTAIL** POUR LE **DERNIER SIÈCLE**, MAIS AVEC UNE **PAUVRE DIVERSITÉ**

QUE NOUS APPREND LE PASSE ?
CHANGEMENTS LENTS ET RAPIDES

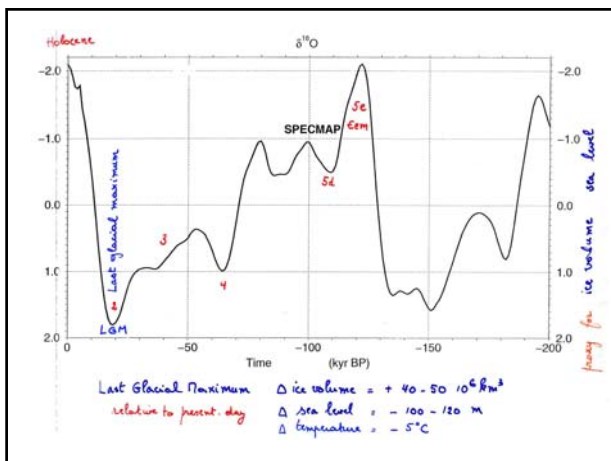
Last Glacial Maximum 21kyr BP



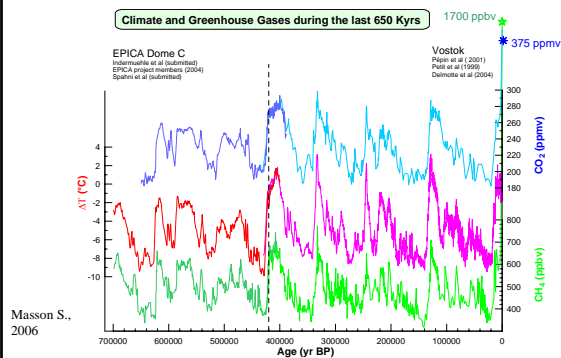
Pre-industrial CO₂ = 280 ppmv
2000 AD CO₂ = 370 ppmv

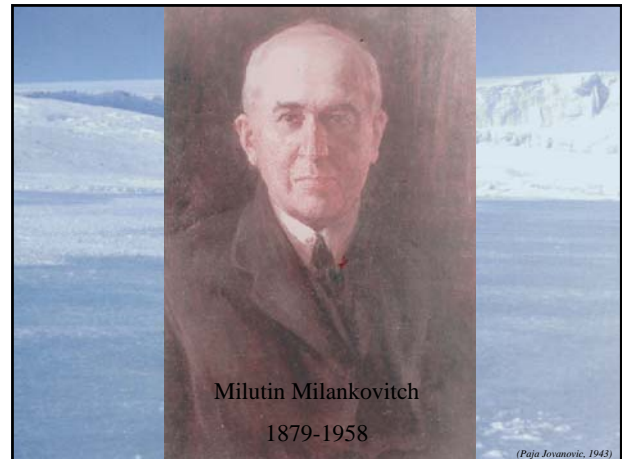
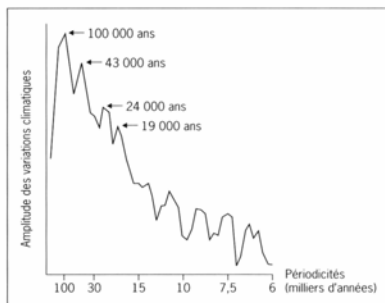
ΔT = -5°C
Sea level = -130m
Ice volume = +52 10⁶ km³
CO₂ = 200 ppmv

(Joussame, 1993)



EPICA : CO₂, TEMPERATURE and CH₄





Milutin Milankovitch



Alfred Wegener

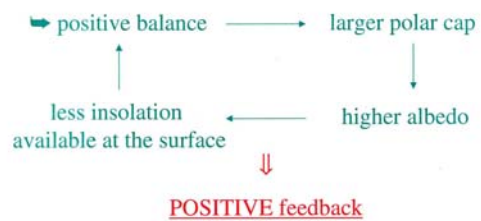


Vladimir Köppen

MILANKOVITCH

FOR GLACIAL :

Snow accumulated during winter does not melt in summer.



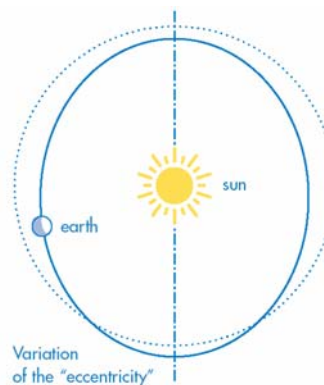
1. SOLUTION ASTRONOMIQUE

2. MATHEMATIQUE INSOLATION

3. MODELISER LE PASSE

4. MODELISER LE FUTUR

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



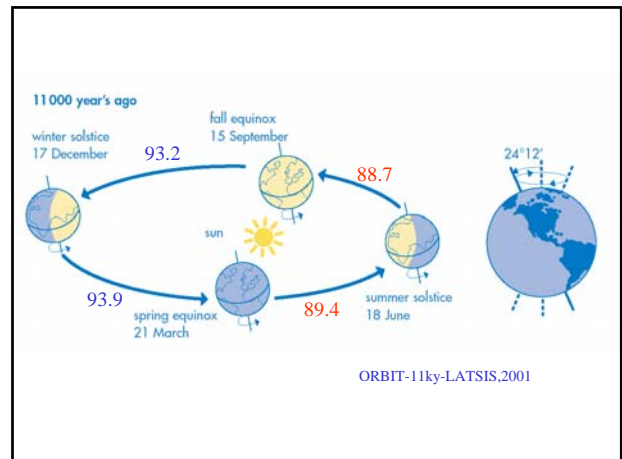
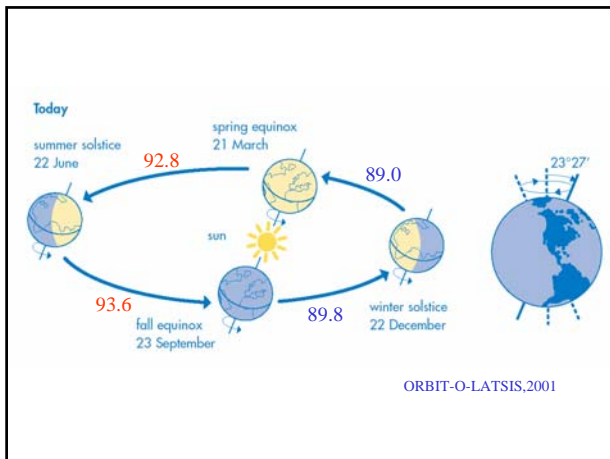
$$(R_a - R_p)/a = 2e$$

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

$$e_{\max} = 0.07$$

which leads to

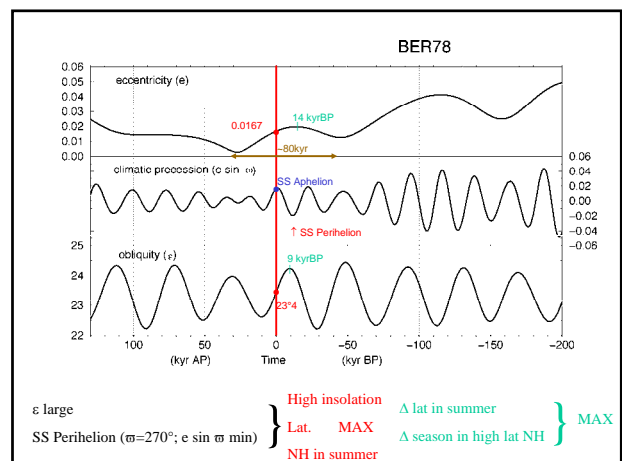
$$(dE/E)_{\max} = 28 \%$$



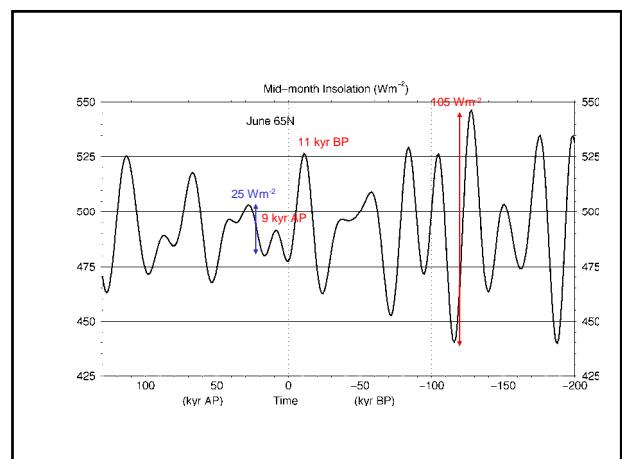
PERIODS ASSOCIATED TO THE MAIN TERMS

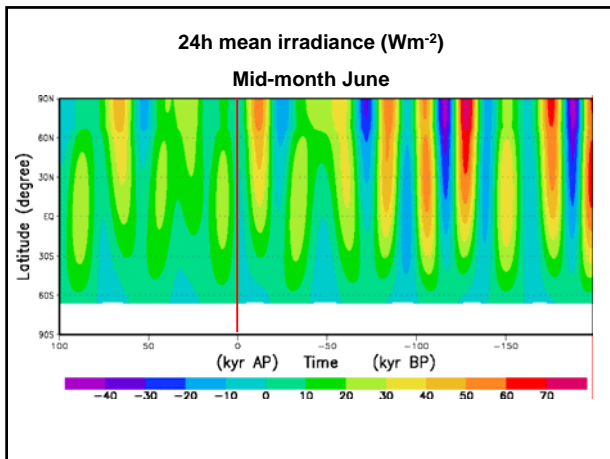
IN THE ANALYTICAL EXPANSIONS OF

PRECESSION			OBLIQUITY			ECCENTRICITY		
N	Ampl.	Period (years)	N	Ampl. (")	Period (years)	N	Ampl.	Period (years)
1.	0.0186080	23716	1.	-2462.22	41000	1.	0.011029	412885
2.	0.0162752	22428	2.	-857.32	39730	2.	-0.008733	94945
3.	-0.0130066	18976	3.	-629.32	53615	3.	-0.007493	123297
4.	0.0098883	19155	4.	-414.28	40521	4.	0.006724	99590
			5.	-311.76	28910	5.	0.005812	131248
						6.	-0.004701	2305441

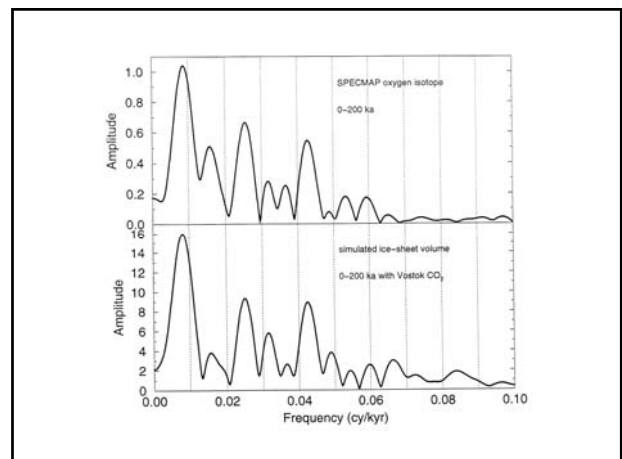
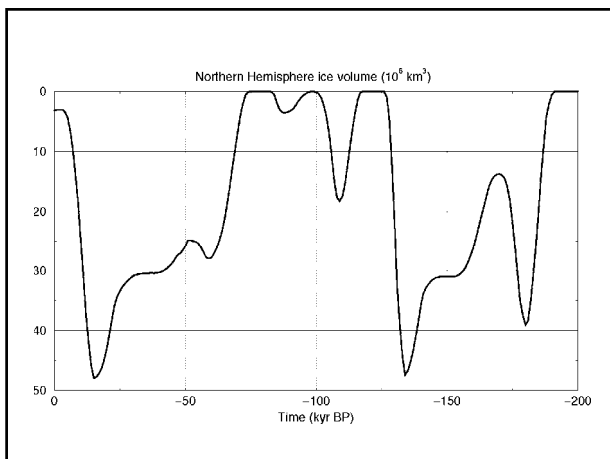
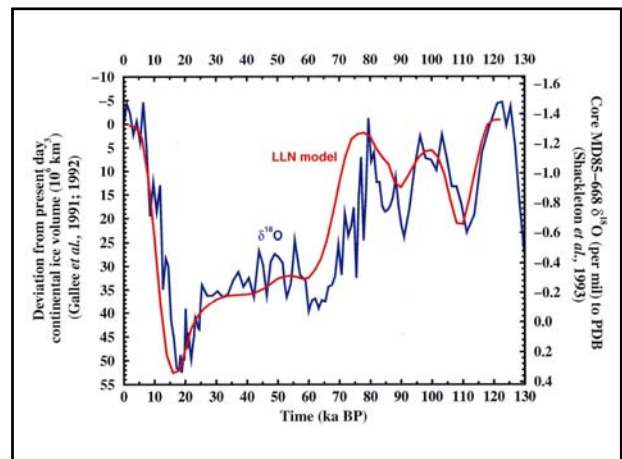
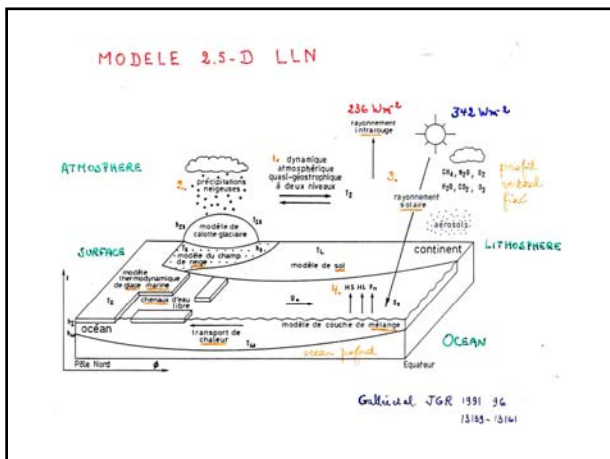


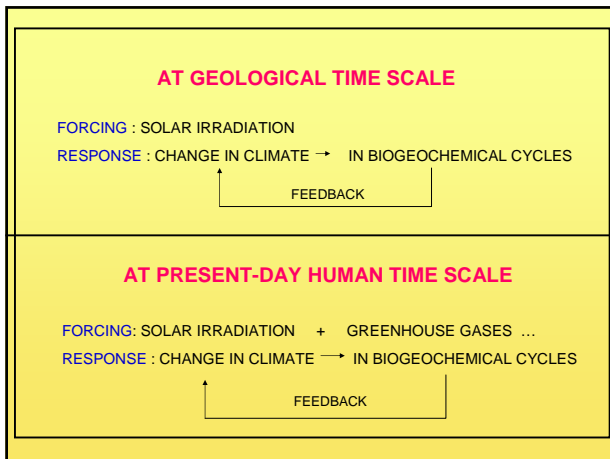
1. SOLUTION ASTRONOMIQUE
2. MATHEMATIQUE INSOLATION
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4. MODELISER LE FUTUR
5. L'IMPACT DE L'HOMME A L'ECHELLE ASTRONOMIQUE





1. SOLUTION ASTRONOMIQUE
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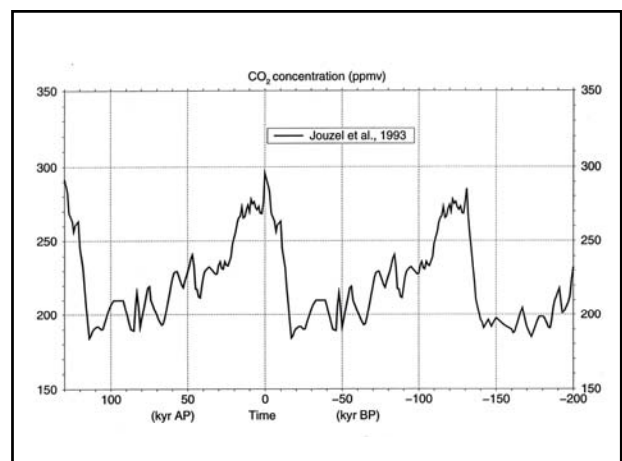
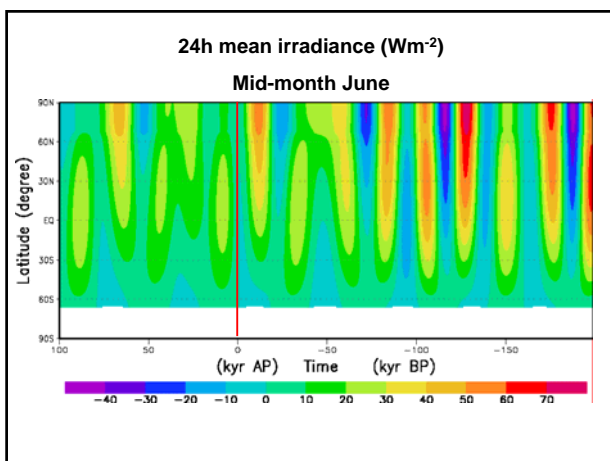


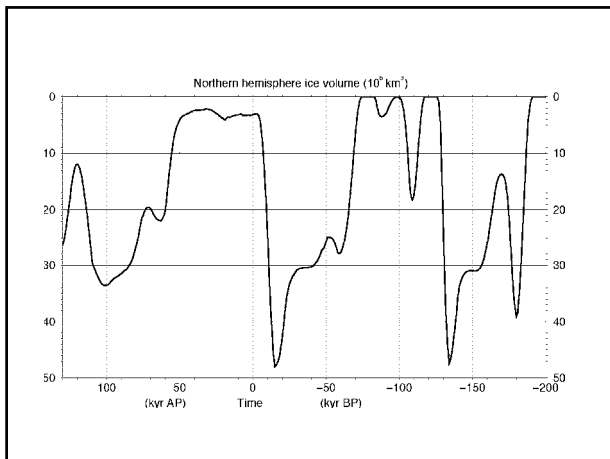


QUEL POURRAIT ÊTRE
NOTRE CLIMAT A
L'ÉCHELLE
GÉOLOGIQUE SANS
INTERVENTION
HUMAINE ?

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

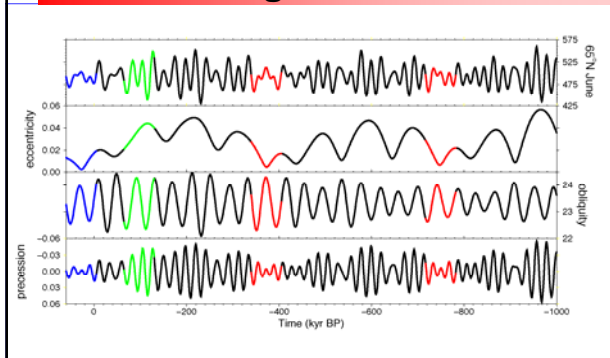
**Forçage astronomique
exceptionnel au cours
des 50.000 prochaines
années**



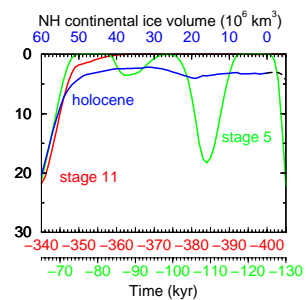


STAGE 11 / STAGE 1 and its Future

Orbital parameters : an analogue for the future

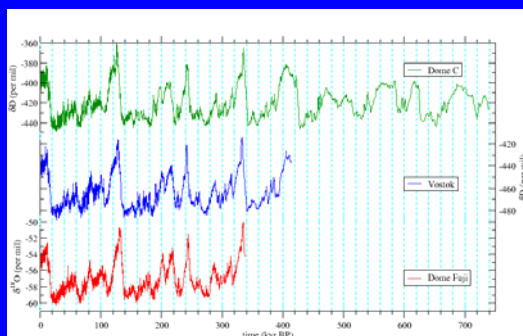


MIS11 : an analogue for the future



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

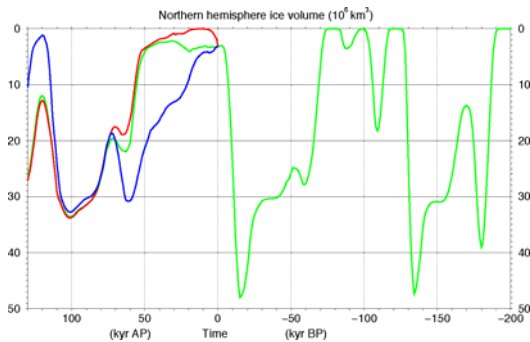
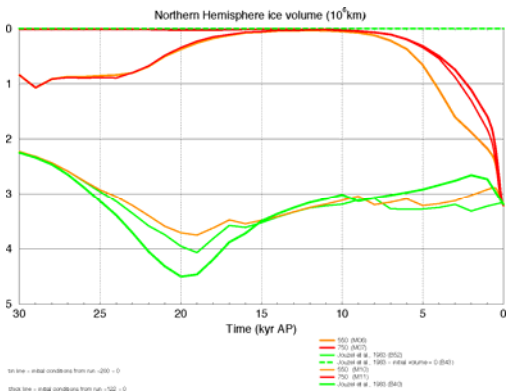
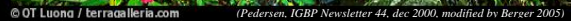
Archives of climate in Antarctica



EPICA community members, Nature, 2004

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

- ## 5.L'IMPACT DE L'HOMME A L'ECHELLE ASTRONOMIQUE



The anthropogenic greenhouse era began thousands of years ago

W.F. Ruddiman, climatic changes, 2004.



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

Is our interglacial going to be exceptionally long? XV^{èmes} rencontres de Blois, 23-28 May 2004

Tongji University, Shanghai, 14-18 August 2005

A. Berger and M.F. Loutre

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

