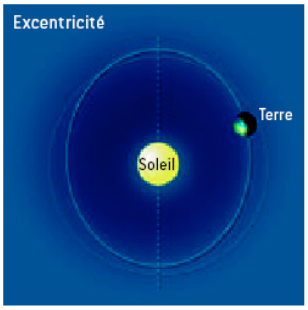
SOFIE School – Beijing May 2014

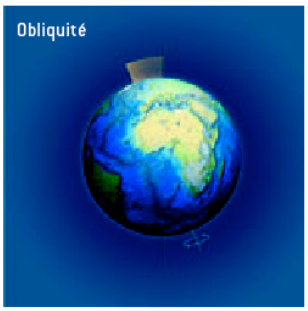
L. Bopp Practical Modelling Workshop

Glacial-Interglacial cycles : Insights from a conceptual model

Introduction :

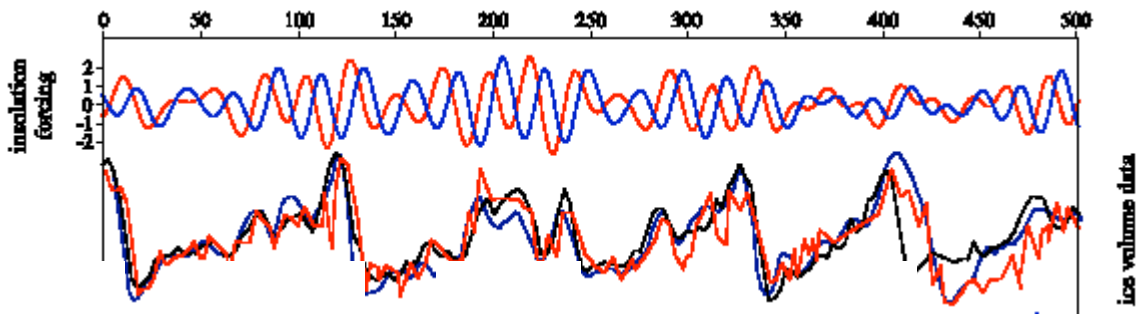
Milankovitch theory : Northern Summer Insolation, driven by astronomical parameters (precession, obliquity and excentricity), is the key driver of the interglacial-glacial cycles (astronomical theory of quaternary climate).





Periodicity of those processes
Precession : 26000 yrs
Obliquity : 41 000 yrs
Precession : 100 000 and 400 000 yrs

Observations :



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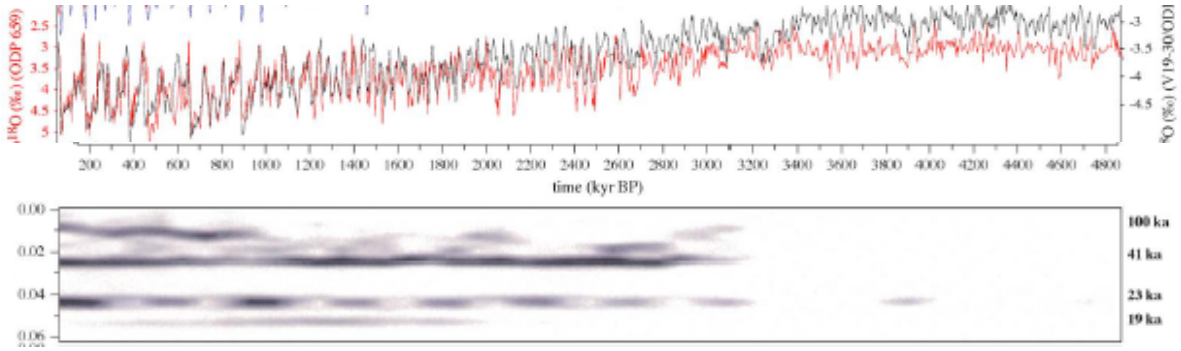
Open questions :

100 000 yr cycle ?

Relation between insolation and ice volume not so clear ? Where are the non-linearities ?
Role and explanation of atmospheric CO2 variations ?
Changes in the main frequency over the last millions years ?



Another theory to explain glacial-interglacial cycles of CO2 and climate

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Earth and Planetary Science Letters 227 (2004) 263–271

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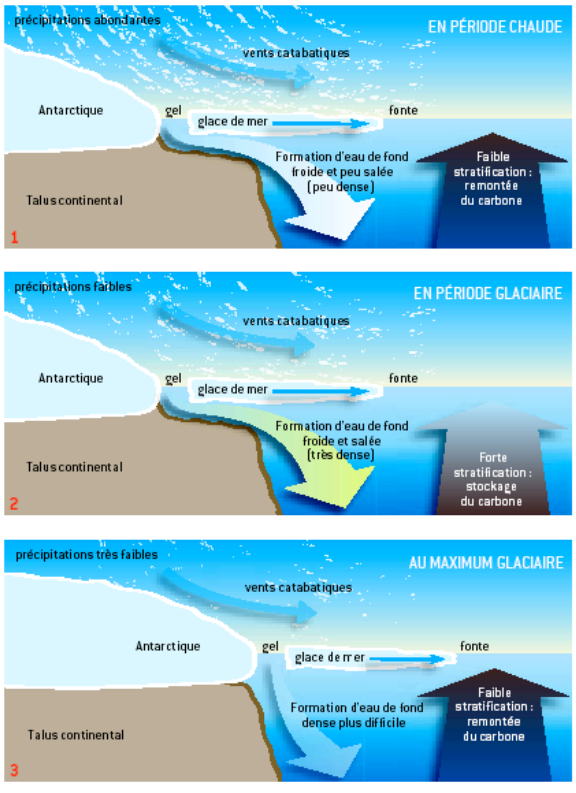
The Antarctic ice sheet and the triggering of deglaciations

Didier Paillard[a,*], Frédéric Parrenin[b,1]



Interglacial :
- Formation of fresh and cool water.
- Little stratification.
- CO2 escapes.

Glacial :
- Less precipitation, more seaice
- Formation of very salty and cool water.
- Strong stratification.
- CO2 stays in the deep ocean.

Glacial Maximum:
- Antarctic Ice cap everywhere over the shelf
- Formation of deep water is difficult.
- Little stratification.
- CO2 escapes.

How do we test this theory ?
By a conceptual Model and its mathematical formulation

A mathematical expression of this conceptual model follows. We need three variables: global ice volume V forced both by Northern Hemisphere summer insolation and atmospheric pCO_2; extent of Antarctic ice sheet A forced by sea level changes (i.e., by V); and atmospheric CO_2 C linked primarily to deep-water state «glacial» or «interglacial». The oceanic switch is forced by the «salty bottom waters formation efficiency» parameter:

$$F = aV - bA - cI_{60} + d$$

which increases with V and decreases with A. a, b, c, and d are constant coefficients. Indeed, F should increase when global climate cools (through V) and decrease when continental shelf areas are reduced (through A). I_{60} is the daily insolation (60°S, 21st February) inasmuch as a reduced sea-ice extent during late Austral summer could affect the Southern Ocean heat budget, and consequently, warm the regional climate, thus affecting F. Coefficient c is typically very small. When F is negative, the ocean is in "interglacial" mode and reciprocally. The model equations are:

$$dV/dt = (V_R - V)/\tau_V$$

$$dA/dt = (V - A)/\tau_A$$

$$dC/dt = (C_R - C)/\tau_C$$

with $V_R = -xC - yI_{65} + z$ (i.e., ice volume is driven by insolation and CO_2); $C_R = \alpha I_{65} - \beta V + \gamma H(-F) + \delta$ (i.e., CO_2 is driven by some precessional forcing, here I_{65}, by global climate V and by deep ocean stratification); H is the Heaviside function ($H=1$ if $F<0$; $H=0$ otherwise); I_{65}=insolation 65°N, 21st June; τ_V, τ_A, and τ_C are time constants; x, y, z, α, β, γ, and δ are constants. Contribution of Antarctica to V is neglected. V is limited by a minimum zero value. This system is linear, except for the discontinuity represented by $H(-F)$, which reflects either a non-linearity in the carbon cycle, or more probably, a nonlinearity of the interactions between deep stratification, bottom water formation, and thermohaline

3 questions :

- Is this simple conceptual model able to catch the main features of the glacial-interglacial cycles when forced by insolation ?
- Is this simple model able to catch the changes in frequencies over the last 5 millions years ?
- "What if" question : If we add a massive amount of carbon in the atmosphere, when does this simple model predict the next glaciation ?