Modelling the Climates of the Earth

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This white paper contribution deals with the following working groups:
WG1.3: Limits and evolution of life on Earth and beyond
WG1.4: Extreme environmental events and punctuated evolution
WG1.5: Paleo-ecosystems: biodiversity and biogeography
WG3.1: Extreme and/or rapid climatic events
WG3.2: High latitude regions and stability of ice sheets
WG3.3: Rates and amplitudes of sea level change
WG3.4: Ocean-atmosphere circulation dynamics
WG3.5: From greenhouse to icehouse worlds
WG4.4: Fluid flow, heat flow and hydrothermal systems
WG4.7: Tectonic-climate interactions
WG5.4: Ocean acidification: past and future

Depending on the question raised, modellers built different climate model to quantify plausible scenarios. In this short summary of our activity, we investigate a very large spectrum in terms of periods of Earth History (from Snowball Earth to future ice sheet melting) using mostly either model of intermediate complexity (CLIMBER) or General Circulation Model (IPSL or FOAM). These models are, depending of the application coupled with carbon models developed at LMTG [1] on Ice Sheet Models developed at LGGE [GRISLI and GREMLINS, 2].
The underlying questions are to understand climate changes in the past and to establish scenarios providing results consistent with data and many of them are based on ODP. The different examples are briefly summarized but all the associated works from LSCE/LMTG/LGGE are cited to enable the readers to have the complete information.

- Neoproterozoic Glaciation

Global glaciation of the Earth as first depicted by Joseph L. Kirschvink [3] and investigated in details by Paul F. Hoffman [4] provide an explanation for most of the isotopic evidences, cape carbonates and BIF reappearance which occurred at this period . Nevertheless no explanation was provided to understand why such an event was made possible.
Yannick Donnadieu et al [5], thanks to an EMIC coupled with a carbon model (COMBINE) [1] demonstrated that tectonics and silicate weathering play a major role to drastically decrease the CO2 in the atmosphere. The Neoproterozoic glaciation occured when most of the continent was spread out over the tropical band which is the most favourable condition to trap large quantify of CO2 through weathering [6]. Moreover, we also show that the initial idea of Joseph L. Kirschvink: a CO2 increase in the atmosphere due to the quasi absence of weathering (sink)

during snow ball episodes was actually too simple. First as shown by Raymond T. Pierrehumbert, [7] because the thermal inversion implies much larger value of CO2 and second because the carbon cycle was not restricted to atmosphere [8; 9]. More generally, the carbon cycle was more complex during snow ball Earth and after, than initially depicted [10]. Therefore Climate – CO2 relationships were completely revisited from the onset of a snowball glaciation to its collapse [5 to 10].

- Palaeozoic and Mesozoic Climate – Tectonics – CO2 relationship

Following the building of GEOCLIM, Yannick Donnadieu and Yves Goddéris have tried to decipher the role of continental drifting on the Palaeozoic and Mesozoic climate evolution. Indeed, although long-term CO2 models already existed based on the Berner's approach, nobody knew the role of paleogeography on the CO2 because the previous models did use very simple climate model that could hardly simulate hydrological cycles changes between a supercontinent and a more dispersed continental world such as the Cretaceous one. We have published some papers [11] on the Mesozoic long-term climatic evolution emphasizing that the CO2 drastically drops at the end of the Triassic because of a fast northward drift of Pangea. The dispersed Cretaceous world leaves us with a mixed feeling. Indeed, in the latest version of GEOCLIM (accounting for the effect of land plant on the climate and on the weathering), we find CO2 levels between 600 and 1200 ppm for the Cretaceous that appear high but clearly still not enough high to reproduce the SST patterns.
We are now working on building a Palaeozoic CO2 curve using the same method but focusing on the specific impact of the appearance of land plants during the Devonian. We have also an in progress paper focusing on the cold snap events of the late Jurassic Early Creatceous (such as the Callovian -Oxfordian cooling event).

- Cenozoic glaciations

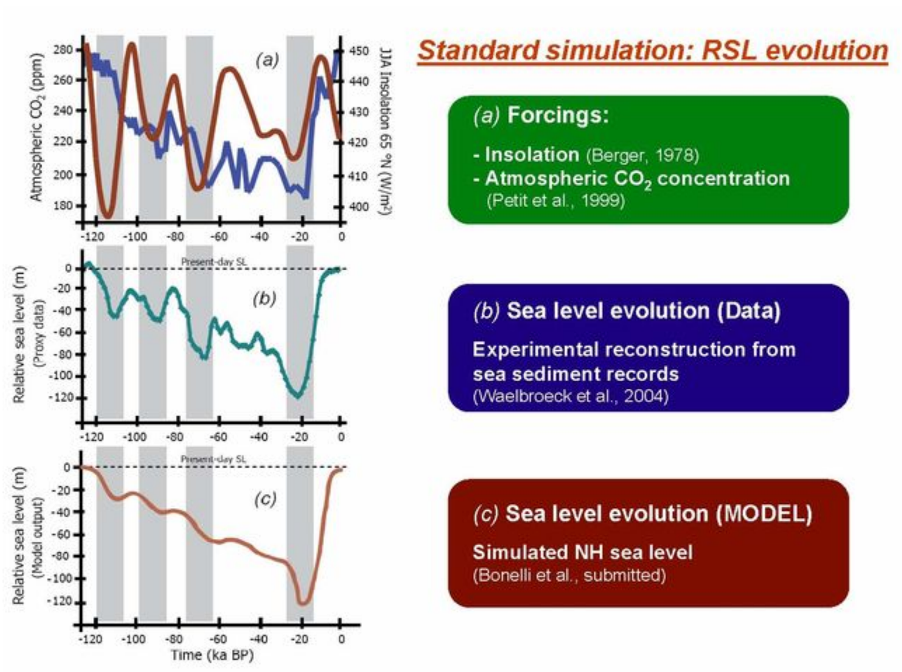
During Cenozoic, globally the pCO2 decrease and both tectonics and orogenesis play an important role [Andean Uplift 12; African Uplift 13].
It appears that this decrease drives the major glaciations: Antarctica [14] and Greenland [15].
We used an EMIC coupled with an Ice Sheet Model to infer and quantify the Drake Passage and the insolation roles compared to the CO2 decrease [16]. The simulated threshold in CO2 is very consistent with the value from Mark Pagani [17].
Similarly, we also investigate the CO2 threshold for Greenland glaciations which is also consistent with pCO2 reconstruction at the onset of Greenland Glaciation.

- Quaternary

In this part, we also used an EMIC coupled with an ice sheet model, but in stead of using equilibrium simulations, we perform transient simulations from Last Interglacial 126Ky BP to Present Day.

These simulations [18] show an onset of the Laurentide Ice Sheet at 115Ky and of the Fennoscandian Ice Sheet at 75Ky consistent with data. Moreover, the sea level evolution is in good agreement with data [19 and Figure].

Since the low frequency sea level evolution (orbital) is correctly reproduced, it is interesting to explore different future scenarii of CO2 emission to investigate the response of Climate Ice Sheet system. In a recent study [20], we explored the conditions of Greenland melting and showed that for value higher than 2500GT of cumulated carbon, the same coupled model (CLIMBER / ISM) which has produced the glacial interglacial cycle depicted above predict an irreversible melting of Greenland Ice Sheet.



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