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Quaternary glaciations : from observations to theories (Milankovic Medal Lecture)

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Since the mid-nineteenth century, the idea that climate may change through time has been substantiated by the observation of past glacial periods. During this time, two alternative views of glaciations have dominated the scientific debates : astronomical theories and geochemical ones involving changes in greenhouse gas concentrations. In the last decades, the validity of the Milankovitch theory has been clearly demonstrated, though several problems have been pointed out, most notably the difficulty to explain the 100-kyr cycles in simple versions of this theory. Besides, changes in atmospheric CO_2 concentration have been documented, and they appear tightly linked to glaciation cycles. A central question of Quaternary Climate Sciences is therefore to understand the respective roles of the astronomical and geochemical changes, and how they can be dynamically combined in order to explain paleoclimatic observations.
After some historical background, I will address this question from the viewpoint of conceptual models. I will highlight their predictive power and their limitations. Most importantly, these models are helping us to formulate hypotheses in order to unravel the required dynamical structure of the astronomical-glaciological-geochemical-climatical problem. I will discuss in some details how the model of Paillard (1998) leads naturally to the counter-intuitive idea that full glaciations should trigger oceanic CO_2 degassing and thus to the model of Paillard and Parrenin (2004), by using the underlying mechanism of brine rejection during sea ice formation around Antarctica. Then I will present results from a more complex model (CLIMBER-2) that validate this mechanism through the comparison of simulated and observed paleoclimatic tracer distributions of 13C and 14C (Bouttes et al., 2011; Mariotti et al. 2013). The model simulation of the last deglaciation (Bouttes et al., 2012) predicts that, when brine formation is stopped, atmospheric CO_2 and Antarctic temperatures should start rising together at the exact same time. This fact has now been confirmed from Antarctic ice core analysis (Parrenin et al, 2013). It seems therefore that we are getting closer to a full synthesis of the astronomical and geochemical theories of Quaternary Climate.

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