Clim. Past, 5, 707–711, 2009
www.clim-past.net/5/707/2009/

Climate of the Past

Preface

Climate change: from the geological past to the uncertain future – a symposium honouring André Berger

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André Berger – many of us have heard of or met this lively figure of the climate scientific community in person. In May 2008 a workshop was organised in Louvain-la-Neuve, Belgium, for the occasion of his "official" retirement – of course André will never retire: he was recently awarded an Advanced Research Grant by the European Research Council too pursue his research. More than one hundred scientists were present with a spectrum ranging from friends since the beginnings of modern climate research to current PhD students. A huge concentration of talents, a healthy mix of generation and nationality; a wonderful testimony to a professor about whom the youngest of us can only suspect the breadth of his commitment to the scientific community and public education, the depth of his scientific insight and his faith into what mankind can accomplish.

The present special issue includes 17 papers presented during the workshop. Here, the generation mix is present again: while three authors are recipients of the Milankovitch medal (initiated by André) of the EGU, one author is the PhD student of a former PhD student of a former PhD student of André. All authors share a common point: the work they present somehow relies on the impulse given by André Berger to climate and palaeoclimate science throughout his career, either through his contribution to the astronomical theories of palaeoclimates, his vision of the multidisciplinary character of palaeoclimate and climate sciences, the promotion of climate modelling, or his action as a leader at the service of the scientific community as a whole.

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Milankovitch theory and Berger cycles

The idea about the influence of Earth's orbital parameters on climate dates back to the nineteenth century mostly with J. A. Adhémar (1860) in France, J. Herschel and J. Murphy (1876) in Great Britain, J. Croll (1875) in Scotland, L. Pilgrim (1904) in Germany as pioneers of the *astronomical theory of palaeoclimate* (cf. Berger, 1988 for a historical account). It is usually referred though as *Milankovitch theory (1941)* because of the large contribution of Milutin Milankovitch, a Serbian engineer and mathematician. He was indeed the first to complete a full astronomical theory of the Pleistocene ice ages, using computations of the orbital elements by Le Verrier (1855) and Stockwell (1873) to estimate changes in the energy balance of the Earth and the resulting climate variations, and give quantitative support to the view that ice ages are caused by changes in Earth's orbit.

However, the theory remained the Milankovitch hypothesis in the literature until the mid-1970s when Hays, Imbrie and Shackleton (1976) published their now classical "pacemaker" paper. They analysed a number of marine records and found spectral power concentrated near periods of 100, 42, 23 thousand years (kyr) and, in two records, 19 kyr. At that time there was reason to think that orbital variations, with periods near 40 kyr (obliquity, "tilt" of earth's axis) and 23 kyr (precession) could influence climate change. There was however no reason to expect that the period of 19 kyr could also dominate precession.

Published by Copernicus Publications on behalf of the European Geosciences Union.

Fig. 1. About 110 scientists were present to honour André Berger in May 2008 at a symposium entitled "Climate change: from the geological past to the uncertain future – a tribute to André Berger" in Louvain-la-Neuve, Belgium.

By the mid-seventies the secular variations of the orbital elements of the principal planets were known with a reasonably high accuracy, notably due to the works of Brouwer and van Woerkom (1950), Sharaf and Boutnikova (1967) , Anolik et al. (1969) and Bretagnon (1974) who based themselves on the foundations laid by J. L. Lagrange (1781), U. Leverrier (1855), J. Stockwell (1873), and G. Hill (1897). However most of the time they were expressed in a sideral framework, that is, with respect to the stars and not with respect to the seasons. Investigators interested in the problem of ice ages, such as L. Pilgrim (1904), M. Milankovitch (1941) and, later, Sharaf et al. (1967) and A. Vernekar (1972) computed time-series of elements expressed relative to the vernal equinox and the ecliptic plane, hence more relevant for climatic theories. However, the characteristic periods of these elements were not known, and there was no extensive assessment of their accuracy. In particular, there was nothing like a "double" precession peak in the orbital frequencies known at the time.

This is where André Berger comes into play. During his PhD thesis (Berger, 1973) he first delivered an up-to-date numerical solution for obliquity and the longitude of perihelion relative to the equinox (Berger 1976b), based on the solutions of Bretagnon (1974) for the planetary system, and Sharaf and Budnikova (1967) for the luni-solar precession. He next compared the accuracy of this solution with those previously available (Berger, 1977a). The breakthrough was then his finding of an analytical expression for the *climatic* astronomical elements, under the form a sum of sines and cosines (Berger 1978b). In this way, the periods characterising them could be listed in tables for the first time, and insolation could be computed at very little numerical cost. This very patient and obstinate work yielded the demonstration that the spectrum of climatic precession is dominated by three periods of 19, 22 and 24 kyr, that of obliquity, by a period 41 kyr, and that of eccentricity has periods of 400 kyr, 125 kyr and 96 kyr (the Berger periods). The origin of the 19 and 23 kyr peaks in the Hays et al. spectra was thus elucidated (Berger, 1977b). According to John Imbrie, this result constituted the most delicate proof that orbital elements have a sizable effect on the slow evolution of climate (Imbrie and Imbrie, 1979). Berger's solution, named BER78, was later used by Shackleton et al. (1990) to correct the then-adopted age of the Brunhes-Matuyama magnetic reversals, soon confirmed by radiometric methods.

After this milestone, Berger and coworkers also delivered a trigonomical expansion of the orbital elements valid for several million years (Berger and Loutre, 1991) built up from a numerical solution of the planetary system (Laskar, 1988). They explored the astronomical origins of the 100-kyr cycles, as well as the frequency and amplitude modulations of the astronomical parameters and their instability (Berger and Loutre, 1990, Berger et al., 1998, 2005; Mélice et al., 2001). Berger was also the first to introduce and compute the long-term variations of daily, monthly and seasonal insolation and demonstrated the large amplitude of daily insolation changes (Berger, 1976a), which is now used in all climate models. His prediction in the early 1990s about the shortening of astronomical periods back in remote times (Berger et al., 1989, 1992) has been confirmed by palaeoclimate data of Cretaceous ages, and constitutes thus an important validation and development of the Milankovitch theory for Pre-Quaternary climates.

EMICS before their time

Berger's scientific carrier is also highlighted by his very first efforts in the 1980s to develop what might be considered today as the first Earth system model of intermediate complexity (which he called at that time a 2.5D model), even if the phrase *EMIC* would be coined much later by Martin Claussen in 2000 and popularized in Claussen et al. (2002). The *LLN-2D* model included simplified ice-sheet, atmosphere and even ocean mixed-layer dynamics, and proved to be able to reproduce the transient response of the climate system to the astronomical forcing over the last glacial-interglacial cycle (Berger et al., 1990; Gallée et al., 1991). This approach has now been recognized as a key to understand long-term climate variations and constitutes another important contribution to the development of astronomical theories of palaeoclimates. In the recent years, together with his team, he has been applying these lines of knowledge to understand the behaviour of the Earth's climate system at key time intervals, such as the climate during the marine isotope stages (MIS) 11 (Loutre and Berger, 2003), MIS-13 (Yin et al., 2008), the Holocene (Crucifix et al., 2002; Bertrand et al., 2002) and the future (Berger and Loutre, 2002; Berger et al., 2003). These results are not only important for our theoretical understanding of past climates, but they are also of huge value for climate prediction. Indeed, when in the 1970's the succession of glacial and interglacial episodes became correctly dated, palaeoclimatologists shared the opinion that the present interglacial would last about 10 000 years just like the previous ones. The statement is not without political implications: why should one care about greenhouse-gas emissions if our destiny is to dive into glaciation? By developing the concept of insolation analogues (Berger, 1979) and promoting climate dynamics modelling André Berger substantiated the paradigm according to which glacial inception is not expected to happen for several tens of thousands of years, even in absence of human intervention (Berger and Loutre, 2002).

Towards data-model comparison

A decisive step in the study of the climate of the last millennium was the first International Workshop on Dendroclimatology in 1974. It was organised by the Laboratory of Tree-Ring Research of Tucson, and in particular H. Fritts, the pioneer of this discipline. This workshop with André Berger as participant and contributor was the start of an impressive network of tree-ring data and of the International Tree-Ring DataBase (ITRDB). The foundation of the ITRDB meant that most of the active practitioners around the world shared a minimum set of criteria for the development and recording of dendroclimatic data. This database laid the foundation for the famous millennial climate reconstructions by Mann et al. (1998) and many others in their wake.

André Berger was convinced of the robustness of the techniques developed by the Tucson's school and came back enthusiastic to Belgium. "Collect proxy data, share them with colleagues and work in an interdisciplinary way: this is the way to go" he said. This moment marks the beginning of collaborations between climatologists and palaeoecologists in Belgium, France and Italy (at least). The enterprise demanded the development of quantitative methods to deal with tree-ring data, a task he assigned to himself with success: significant progress was achieved when the Climate Research Unit in Norwich (1980) organised a second workshop (specifically with Moroccan cedar data: Berger et al., 1979; Munaut et al., 1979). The reference book published after this workshop proved that the team built by André Berger had reached visibility (Guiot et al., 1982a, b).

His vision was contagious and, with the book edited by Flohn and Fantechi (1984), he appeared to be one of those who inspired the environmental research program of the European Union (Berger et al., 1984): Several EU- and NATO-funded projects, schools and workshops (launched or simply supported by André) gathered continental palaeoclimatologists, palaeoceanographers, glaciologists and climate modellers to better understand the climate mechanisms governing the last climatic cycle, e.g. EPOCH project (1988–1992), the Palaeoclimate Modelling Intercomparison Project (PMIP), which is still active today, and other summer schools (Duplessy et al., 1991, 1994)

Teaching new generations

Berger also contributed significantly to the training of research scientists and students, stimulated a multi- and interdisciplinary approach to Earth system problems, and fostered international collaborations in order to strengthen the relationships between geophysics, geochemistry and geosciences in general. Today, many senior climatologists remember well the "Erice" summer school that he organised in 1980, and where he gathered the most famous scientists of a period where global change was not yet that trendy: R. Barry, B. Bolin, W. Broecker, W. Dansgaard, J. C. Duplessy, H. Flohn, H. Fritts, W. Gates, M. Ghil, K. Hasselmann, W. Kellog, G. Kukla, J. Imbrie, N. Shackleton, J. Smagorinsky. One product of this school is a reference book edited by Berger (1981). For sure this summer school gave the motivation and scientific bases to several climatologists today active in the Intergovernmental Panel on Climatic Change (K. Briffa, J. Guiot, A. Henderson-Sellers, M. Hughes, P. Huybrechts, J. Jouzel, H. Oerlemans, J. P. van Ypersele). Later, his book for a wider audience (Berger, 1992) inspired generations of French-speaking climate students.

André Berger continued to promote geosciences (Berger et al., 1984, 1989, 2005) and became the president of the European Geophysics Society (EGS). He set the merging of EGS and the European Union of Geosciences (EUG), which resulted in the foundations of the present European Geosciences Union (EGU), of which he is the honorary president.

At last, a tribute to André Berger would not be complete without mentioning his profound commitment to the civil society. We all know that there is no point in being a skilful and esteemed scientist if you do not somehow communicate your passion and knowledge. André always put this into practice. Early in the eighties he warned policy-makers and the media about the urgency of climate change and its implications for the development of the society, especially regarding energy choices. Still nowadays he devotes a large amount of his time sharing his vision of climate and human society to the public. It is therefore no surprise that besides the recognition he gained among his peers, André Berger became a known and respected figure in Belgium and well beyond.

Acknowledgements. The present special issue was supported by the EGU in recognition of the exceptional services of André Berger. The meeting held 26–29 May 2008 in Louvain-la-Neuve was co-funded by the Belgian Agency for Radioactive Waste and Enriched Fossil materials, the IGBP Past Global Changes (PAGES) programme, the Belgian National Fund of Scientific Research, the Belgian Federal Science Policy Office, the French Institut National des Sciences de l'Univers, the French Commissariat à l'Énergie atomique, the Vinçotte company and the Science Faculty of the Université catholique de Louvain.

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