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Interhemispheric anti-phasing of orbitally driven monsoon intensity: Implications for ice-volume forcing in the high latitudes

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ABSTRACT

The influence of precession on the redistribution of insolation on the top of the atmosphere predicts that climate change in the low latitudes is out of phase between the hemispheres. We test this prediction by the most direct approach, the analysis of terrestrial climate records, as they provide direct information on regional changes in the atmosphere. A review of evidence from absolutely-dated climate records shows that precession drives an interhemispheric anti-phasing of monsoon intensity. Maxima of boreal monsoon intensity are opposed by minima of austral monsoon intensity and *vice versa*.

The interhemispheric anti-phasing of monsoon intensity implies that low-to-high latitude climate gradients are asymmetric between the hemispheres; periods with maximum boreal monsoon intensity steepen the gradient in the NH but flatten it in the SH and *vice versa*. These precession driven changes are superimposed on obliquity's influence on meridional climate gradients; high obliquity causes flat gradients and low obliquity steep gradients.

We propose the hypothesis that orbitally driven changes of low-to-high latitude climate gradients drive ice-volume changes in the high latitudes. To test the hypothesis we quantify a proxy for the climate gradients and predict ice-volume forcing in the NH and SH during the last 120 ka. Then we use the contributions of both hemispheres to predict global ice-volume forcing. The comparison with records related to global ice volume verifies our ice-volume hypothesis. Therefore, ice-volume changes can be predicted for the NH and SH separately.

1. Introduction

The prevalent interpretation of Milankovitch's theory that summer insolation in the high northern latitudes drives Earth's ice-ages is more and more in conflict with evidence from absolutely-dated records (e.g. Winograd et al., 1992, 1997, 2006; Gallup et al., 2002; Henderson et al., 2006; Peltier and Fairbanks, 2006; Drysdale et al., 2009). A less well-known but the central conclusion of Milankovitch's theory is that the influence of precession is focused on the low latitudes and drives summer insolation changes which are opposed; i.e., those in the tropics of the SH are mirror-inverted to those in the tropics of the NH, whereas the influence of obliquity is especially strong in the high latitudes and drives summer insolation changes in the high latitudes which are in phase between the hemispheres (Milankovitch, 1941: p. 607 ff.). Since it is long known that surface temperatures are strongly influenced by local insolation Milankovitch's conclusion predicts that precession drives summer temperature changes in the low latitudes that are out of phase between the hemispheres (compare Kutzbach, 1981; McIntyre et al., 1989; Partridge et al., 1997; Ruddiman, 2008).

Because insolation data refer to the top of the atmosphere the most direct approach to test the influence of precession is to analyze changes in the atmosphere rather than in the ocean. Terrestrial climate records are well suited for this direct approach since they offer information on regional temperature and humidity changes in the atmosphere (Baker et al., 2001; Wang et al., 2001; Müller and Kukla, 2004; Cruz et al., 2005, 2006). The much larger heat capacity of the ocean, in contrast, is likely to mask the influence of local insolation changes on sea surface temperatures (Bard et al., 1997). Moreover, if precession drives climate changes that are out of phase between the hemispheres then this effect is cancelled out in globally integrated climate proxies such as ocean $\delta^{18}O$ or sea level (Raymo et al., 2006).

The test of the prediction given by Milankovitch's conclusion about the influence of precession requires evidence from climate records which (i) are well constrained by independent

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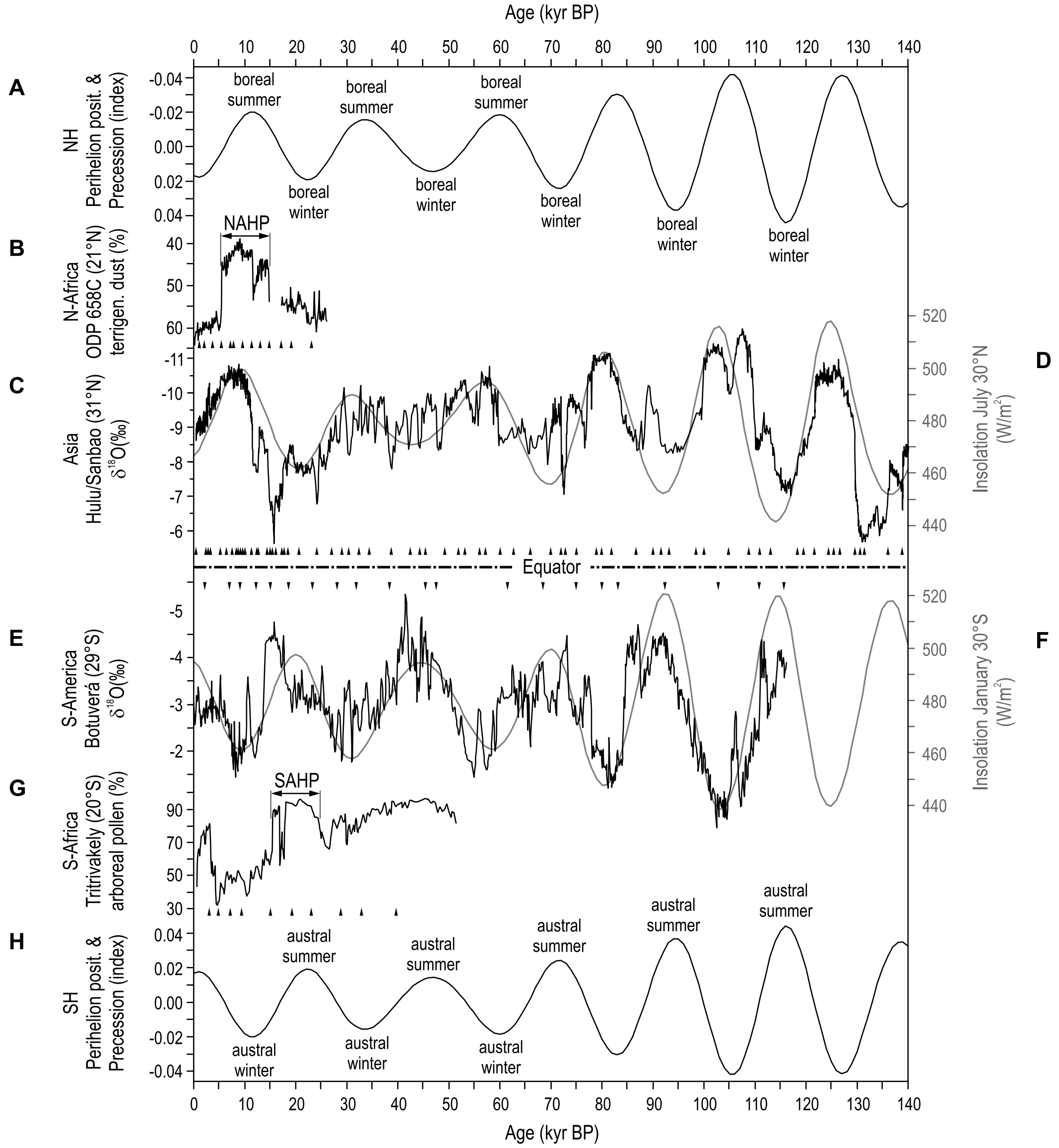

Fig. 1. Interhemispheric anti-phasing of precession driven climate change in the low latitudes documented in terrestrial/terrigenous records from Asia, Africa, and America. (A) Precession and perihelion position in the NH (Berger and Loutre, 1991). (B) Terrigenous dust record of ODP Site 658C off Mauritania (deMenocal et al., 2000), NAHP = North African Humid Period. (C) Chinese speleothem δ^{18}O-record composed of Hulu and Sanbao cave records (Wang et al., 2001, 2008a). (D) July 21st insolation at 30°N (Berger and Loutre, 1991). (E) Brazilian speleothem δ^{18}O-record of Botuverá cave (Cruz et al., 2005). (F) January 21st insolation at 30°S (Berger and Loutre, 1991). (G) Tritrivakely pollen record, Madagascar (Gasse and Van Campo, 1998), SAHP = South African Humid Period. (H) Precession and perihelion position in the SH (Berger and Loutre, 1991). Triangles next to records mark position of absolute age control points.

chronologies, (ii) are continuous over an interval sufficiently long to reflect changes on orbital timescales, (iii) are located in the low latitudes of the NH and SH, and (iv) provide direct information on changes in the atmosphere. Climate records which provide clear seasonal information such as on summer temperature changes would be ideal for the test since precession moves the position of perihelion through the annual cycle; hence precession exerts a strong influence on seasonality. We recognize that it is difficult and would be risky to assign the variability documented in paleo-climate records to a distinct season as they rather reflect an unknown mixture of summer and winter changes. Furthermore, the test requires a focus on changes on orbital timescales. The superimposed short-term variability triggered by system internal oscillations such as multiple and abrupt reorganizations in ocean circulation should not deflect from changes on orbital timescales.

2. Evidence from records in the low latitudes of the NH

In the low latitudes of the NH, the speleothem δ^{18}O-records from Hulu and Sanbao cave, SE-China, document precisely dated changes of East Asian monsoon intensity (Wang et al. 2001, 2008a). The composed record (Fig. 1C) shows that the strength of East Asian monsoon is on orbital timescales in phase with local summer insolation (Fig. 1D). The absolutely-dated terrigenous dust record of Site 658C (21°N, 19°W) off Mauritania documents changes of humidity and vegetation density in the Sahara (deMenocal et al., 2000). The dust record (Fig. 1B) shows that the timing of the North African Humid Period (NAHP) was congruent to the early Holocene maximum of monsoon intensity in China (Fig. 1C). Therefore, the evidence of terrestrial/terrigenous records from Asia and Africa supports earlier findings that the intensity of monsoonal circulation in the NH low latitudes is in phase with precession controlled summer insolation intensity change in