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High-resolution analysis of upper Miocene lake deposits: Evidence for the influence of Gleissberg-band solar forcing

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ABSTRACT

A high-resolution multi-proxy analysis was conducted on a 1.5-m-long core of Tortonian age (~10.5 Ma; Late Miocene) from Austria (Europe). The lake sediments were studied with a 1-cm resolution to detect all small-scale variations based on palynomorphs (pollen and dinoflagellate cysts), ostracod abundance, geochemistry (carbon and sulfur) and geophysics (magnetic susceptibility and natural gamma radiation). Based on an already established age model for a longer interval of the same core, this sequence can be limited to approx. two millennia of Late Miocene time with a resolution of ~13.7 years per sample. The previous study documented the presence of solar forcing, which was verified within various proxies on this 1.5-m core by a combination of REDFIT spectra and Gaussian filters. Significant repetitive signals ranged in two discrete intervals corresponding roughly to 55–82 and 110–123 years, fitting well within the lower and upper Gleissberg cycle ranges.

Based on these results, the environmental changes along the 2000-year Late Miocene sequence are discussed. No major ecological turnovers are expected in this very short interval. Nonetheless, even within this brief time span, dinoflagellates document rapid changes between oligotrophic and eutrophic conditions, which are frequently coupled with lake stratification and dysoxic bottom waters. These phases prevented ostracods and molluscs from settling and promoted the activity of sulfur bacteria. The pollen record indicates rather stable wetland vegetation with a forested hinterland. Shifts in the pollen spectra can be mainly attributed to variations in transport mechanisms. These are represented by a few phases of fluvial input but mainly by changes in wind intensity and probably also wind direction. Such influence is most likely caused by solar cycles, leading to a change in source area for the input into the lake.

Furthermore, these solar-induced variations seem to be modulated by longer solar cycles. The filtered data display comparable patterns and modulations, which seem to be forced by the 1000-year and 1500-year cycles. The 1000-year cycle modulated especially the lake surface proxies, whereas the 1500-year cycle is mainly reflected in hinterland proxies, indicating strong influence on transport mechanisms.

1. Introduction

Reliable documentations of high-frequency climate behavior, such as fluctuations in temperature or rainfall, reach back several hundred years only (Charvátová, 2000; Versteegh, 2005). This is clearly too short to allow convincing interpretations of the natural variations of climatic systems. Thus, high-resolution archives from the geological record may serve as additional sources of information. Especially in Holocene records, resolutions on decadal scales are abundant. Many of these suggest repetitive climate shifts strikingly similar to known variances of solar activity (e.g. Patterson et al., 2004; Solanki et al., 2004; Versteegh, 2005; Gray et al., 2010). Typically, the 11-year Schwabe-cycle, the 22-year Hale-cycle, the 50–80-year lower Gleissberg cycle, the 90–120-year upper Gleissberg cycle, the ~210-year Suess/deVries cycle, and the 2200–2300-year Hallstatt cycle – along with the unnamed 500- and 1000-year cycles – are thought to have influenced the Holocene climate records (see Kern et al., 2012a for extensive discussion and references). Next to the famous radioactive isotope records of the Arctic and Antarctic ice cores (Stuiver and Braziunas, 1989, 1993; Beer et al., 1990, 2000; Damon and Sonett, 1991; Solanki et al., 2004), terrestrial and marine records document the presence of the influence of solar cycles around the globe. An early key discipline to discuss such external forcing was dendrochronology, where measurements of ^{14}C radioactive isotopes and the thickness of the tree rings mirror significant solar-related periodicities (Rigozo et al., 2002, 2008; Muscheler et al., 2004; Raspopov et al., 2004, 2008). Nevertheless, non-laminated lacustrine and marine sequences also revealed repetitive signals with comparable frequencies. This includes studies on isotopes (e.g. Cini Castagnoli et al., 2005;

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Taricco et al., 2009), pollen (Di Rita, 2011), nannoplankton (Incarbona et al., 2010) and multi-proxy-data sets (Garcin et al., 2006). Still, aside from the better understood 11-year sunspot-cycle and the 22-year Hale-cycle, the origin of other cyclic variations in the sun's emitted energy remains unsolved (Versteegh, 2005). The sun's spin rate and rotation as well as the strength of solar winds are being discussed as explanations for longer-term variations, but the studies are inconclusive (Tsiropoula, 2003). Nevertheless, all of the proposed longer solar cycles have been documented globally from various geochemical and sedimentological archives (Sonett and Suess, 1984; Raspopov et al., 2004). The expression and modulation of these cycles vary strongly in their local imprint (Hoyt and Schatten, 1997, 1998) and different responses on both hemispheres to the same cycle have also been noted (Li et al., 2001; Claud et al., 2008). This documents that the detection of the signals in the geochemical and sedimentological archives is comparatively easy while their explanation is not.

Comparable studies for the Miocene are scarce. Whereas the overall Neogene climatic history is well studied (e.g. Utescher et al., 2000, 2009; Zachos et al., 2001), small-scale shifts and short periods encompassing few thousands of years are usually unresolved. Recently, however, several high-resolution studies were conducted on Late Miocene sediments of Lake Pannon (Harzhauser et al., 2008; Gross et al., 2011; Paulissen and Luthi, 2011; Kern et al., 2012a,b). All detected high-frequency fluctuations of the paleo-environment of that lake on a decadal scale. By using longer records, Gross et al. (2011) and Kern et al. (2012a) documented various repetitive patterns, which were linked to known periods of solar cycles. In addition, Kern et al. (2012a) showed how different proxies, such as magnetic susceptibility, natural gamma radiation and total abundance of ostracods, reflect the various cyclicities in individual intensities (Fig. 1). Periodicities of 50–80 (lower Gleissberg), 90–120 (upper Gleissberg), ~208 (deVries/Suess), 500, 1000, 1500 and 2300 years were described. All represent well-known solar cycles, except the 1500-year periodicity. Although the latter is well known from the Holocene, it seems to be de-coupled from solar forcing and is therefore labeled as an “Earth-system-immanent-cycle” (Bard and Frank, 2006; Debret et al., 2007, 2009). Importantly, the impact of this cycle on the sedimentation in the ancient Lake Pannon was one of the most prominent (Kern et al., 2012a, Fig. 1). No causal link between these observed changes in environmental conditions, as expressed by the proxy data and the suggested solar forcing, has been forwarded. To better elucidate the interaction between the environment, the climate and the presumed solar cycles, we conducted a further study based on the data presented in Kern et al. (2012a) and new data on pollen, dinoflagellates, molluscs, total carbon (TC), total organic carbon (TOC), and total sulfur (TS).

These proxy-data provide information on the vegetation surrounding the lake (pollen), climate (pollen), surface water productivity (dinoflagellates), lake bottom conditions and on the overall sediment input

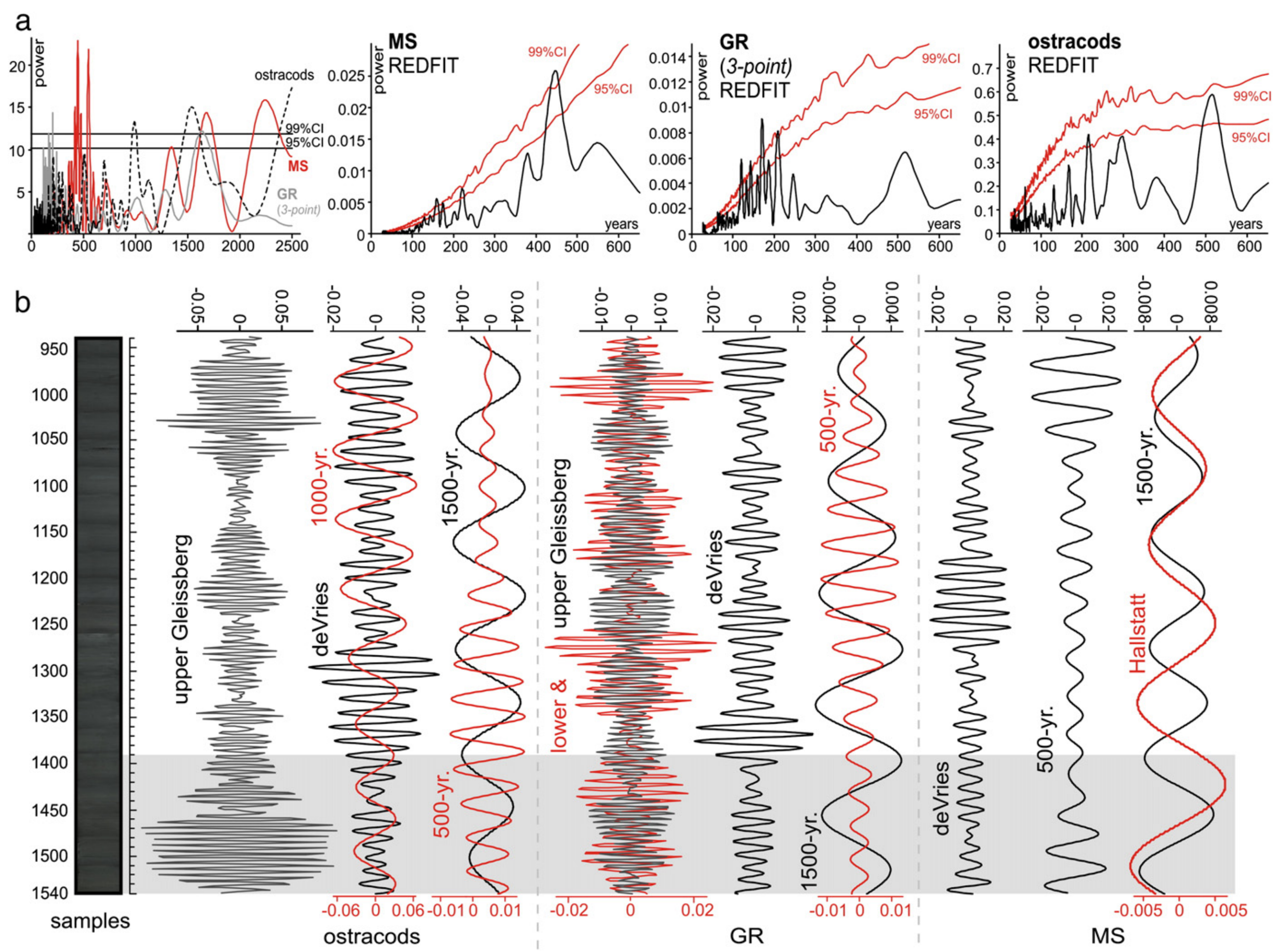

Fig. 1. A summary of the assumed solar cycles in the 6-m-long Hennersdorf core from Kern et al. (2012a). (a) Combined Lomb–Scargle periodograms of MS (magnetic susceptibility; red), GR (natural gamma radiation; gray) and the total abundance of ostracods (dashed) and REDFIT spectra. (b) Filtered records based on dominant frequencies as revealed by spectral analysis (modified from Kern et al., 2012a). Each filtered curve is labeled with the corresponding solar cycle (lower Gleissberg, upper Gleissberg, deVries, 500-year, 1000-year, Hallstatt cycle as well as the 1500-year cycle of unknown origin). The shaded area indicates the herein analyzed interval.