# Diatom-based inference of variations in the strength of Asian winter monsoon winds between 17,500 and 6000 calendar years B.P.

Luo Wang,[1] Houyuan Lu,[1] Jiaqi Liu,[1] Zhaoyan Gu,[1] Jens Mingram,[2] Guoqiang Chu,[1] Jingjing Li,[3] Patrick Rioual,[1] Jörg F. W. Negendank,[2] Jingtai Han,[1] and Tungsheng Liu[1,4]

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[1] We present a continuous record of fossil diatoms from Huguang Maar Lake (HML) in southeastern China, spanning the time interval 17,500 to 6000 calendar years (cal years) B.P. The seasonal change in relative abundance of the dominant diatom taxa, *Aulacoseira* and *Cyclotella* species, can be used as a proxy of the strength of winter monsoon winds (WMW), which is supported by the results of a sediment trap experiment in HML and by an extensive review of the literature on the autoecologies of these species. In the sediment, high *C. stelligera* abundance and high-diatom concentration, which indicate warm conditions and low wind-driven turbulence of the water column, characterize an interval equivalent to the Greenland Interstadial 1. This is followed by an interval with low-diatom concentration and with assemblages dominated by *Aulacoseira* species, which suggests high wind-driven turbulence and therefore strong WMW. This interval corresponds with the Greenland Stadial 1. During the early and middle Holocene, another two episodes with strong WMW are evident from the data between 10,000 and 8500 and between 7000 and 6000 cal years B.P. The diatom record implies that strong winter monsoon episodes not only occurred during the last glacial-Holocene transition but also during the Holocene "thermal maximum."

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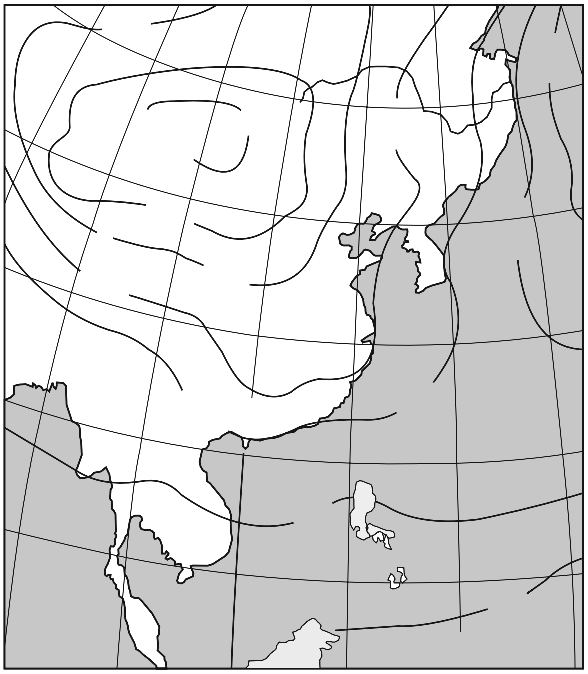
## 1. Introduction

[2] The Asian-Australian monsoon is an important component of the Earth's climate system that influences the societal and economic activity of roughly half the world's population. The Asian monsoon consists of summer monsoon and winter monsoon. The summer monsoon transport moisture and heat northward from the north of Australia across the Warm Pool to northern China. The winter monsoon is characterized by cold, dry Siberian airflowing southward across eastern China, ultimately contributing to the Australian summer monsoon [*An*, 2000]. In addition, the Asian monsoon may affect climate globally, through interactions with ENSO [*Z. Y. Liu et al.*, 2000]. Recently, several studies focused on the relationship between the Asian winter monsoon and El Nino [*Wang et al.*, 2000; *W. Zhou et al.*, 2007]. Archives such as cave deposits have been used successfully to reconstruct changes in the past strength of the rain-bearing East Asian summer monsoon. Such records show that on a millennial scale the monsoon is controlled by changes in oceanic and atmospheric circulation patterns in addition to those forced by solar changes [*Wang et al.*, 2001; *Yuan et al.*, 2004; *Dykoski et al.*, 2005]. However, in most high-resolution studies, reconstruction of the winter monsoon is rarely offered because of the lack of suitable proxie records, especially during the Holocene. Therefore, there is a clear need to develop high-resolution-independent proxies records suitable for the reconstruction of the strength of winter monsoon winds.

[3] The high-resolution records of Huguang Maar Lake (HML) represent a potential archive to investigate past changes in the intensity of the Asian monsoon. In recent years, several studies tried to reconstruct the Asian monsoon from this site [*J. Q. Liu et al.*, 2000; *Chu et al.*, 2002; *Fuhrmann et al.*, 2003; *Mingram et al.*, 2004; *Liu et al.*, 2005; *Wang et al.*, 2007; *Yancheva et al.*, 2007]. So far, however, only titanium (Ti) content has been used as a proxy record of past variations in WMW [*Yancheva et al.*, 2007]. *H. Y. Zhou et al.* [2007], however, have argued that instead of being transported by winds, as proposed by *Yancheva et al.* [2007], Ti is likely to have come mainly from the catchment of HML and so that the Ti content may be more related to the hydrology of the lake than to the strength of the WMW.

[4] Diatoms are unicellular algae and are used extensively in palaeoecological studies because they are excellent indicators of past environmental conditions [*Battarbee et al.*, 2001]. Diatoms have been widely used as proxy indicators to reconstruct Holocene climate variability



[*Smol and Cumming*, 2000; *Mackay et al.*, 2003b]. The majority of recent studies use quantitative multivariate techniques to reconstruct past climatic variables either directly, such as surface water temperature [*Pienitz et al.*, 1995; *Vyverman and Sabbe*, 1995; *Rosén et al.*, 2000; *Bigler et al.*, 2002] and air temperature [*Korhola et al.*, 2000], or indirectly by reconstructing, for example, salinity [*Fritz et al.*, 1991; *Laird et al.*, 1996; *Gasse et al.*, 1997; *Verschuren et al.*, 2000; *Yang et al.*, 2004], DOC [*Pienitz et al.*, 1999], and conductivity [*Davies et al.*, 2002]. Furthermore, numerous studies on lake systems have shown that seasonal changes in the composition, production and diversity of diatom assemblages are related to variations of limnological variables such as the duration and timing of ice cover, the stability of the water column thermal stratification usually in summer and the turbulence of the water column because of strong wind in winter, and snow thickness [*Pilskaln and Johnson*, 1991; *Weyhenmeyer et al.*, 1999; *Lotter and Bigler*, 2000; *Mackay et al.*, 2003a; *Tolotti et al.*, 2007]. So far only a few studies have used such relationships for interpreting sedimentary diatom sequences. Among the most remarkable ones are studies focused on recent global warming [*Smol et al.*, 2005; *Rühland et al.*, 2008], shifts in ITCZ [*Pilskaln and Johnson*, 1991] and the African monsoon [*Stager et al.*, 2003].

[5] Here we use seasonal changes in diatom composition from the HML as a proxy for tracking changes in the intensity of WMW. Our data (sediment trap experiments,

meteorological and lake hydrology physical data) suggest that, over the time interval 17,500 to 6000 calendar years (cal years) B.P., shifts in the relative abundances of the dominant diatom taxa in this lake (heavily silicified, meroplanktonic, species of *Aulacoseira* against small euplanktonic *Cyclotella* species) are mainly controlled by changes in seasonal windiness.

[6] The HML (21°9′N, 110°17′E, Figure 1) is located in Guangdong province, near the South China Sea coast. This lake is very sensitive to hydrological and atmospheric cycles, because it is situated in a zone with seasonal climate, influenced by both the Asian summer and winter monsoons (Figures 1a and 1b). The mean annual temperature in Zhanjiang (15 km from the HML) is 23.1°C and the mean annual precipitation is 1440 mm (Figure 2a). The natural vegetation is that of a tropical semievergreen seasonal rain forest [*Zheng and Lei*, 1999]. The areas of the lake and its catchment are 2.3 $km^2$ and 3.5 $km^2$, respectively. The lake has no surface inflow or outflow. It has a maximum depth of 22 m, and is warm monomictic, being stratified from March to October. Human impact on the lake is small as only two small temples, built during the Sui (between A.D. 581 and 618) and Song dynasties (between A.D. 960 and 1200), are located within the catchment of HML. Moreover, agricultural activities have been stopped since the year 2000, when

limiting resources among each other and with other algae [*Tilman et al.*, 1982].

[19] In our sediment trap, *A. granulata* and *C. stelligera* are the main species. The water column temperature (Figure 2b) and the diatom assemblages found in sediment trap samples from the HML support previous findings on the ecology of *Aulacoseira* species and *C. stelligera*. In August, *C. stelligera* dominates the trap samples, but in October, the relative abundance of *C. stelligera* decreased and that of *A. granulata* significantly increased.

[20] It is well established that the stability of thermal stratification in lakes is greatly affected by wind speed. In particular, when wind speed exceeds a threshold of roughly 3 m $s^{-1}$, Langmuir cells circulation can develop, which has a strong effect on the vertical distribution in the epilimnion of nonmotile planktonic organisms such as diatoms [*Reynolds*, 2006].

[21] The meteorological data for the Zhanjiang area in 2007 show that in November the daily mean wind speed often exceeded 3 m $s^{-1}$ (70% of the daily mean), and in October the daily mean wind speed often exceeded 3 m $s^{-1}$ (54% of the daily mean). In contrast in August the daily mean wind speed seldom exceeds 3 m $s^{-1}$ (26% of the daily mean) (Figure 2c). Over the whole period covered by the meteorological data (1954–2007), there is still a significant difference between the daily mean wind speed of winter months (December, January, and February) and summer months (June, July, and August), although it is less pronounced (58 and 35% exceeding 3 m $s^{-1}$, respectively). The data suggests that *C. stelligera* dominates during summer because of well-developed lake thermal stratification and decreases with increasing wind strength, while *A. granulata* has opposite requirements (Figure 2c). Therefore, these data suggest that wind speed is an important factor in the mixing regime of this lake and is consistent with the diatom shifts recorded in the trap, indicating that relative abundance of *A. granulata* and *C. stelligera* is a good indicator of WMW and thermal stratification.

## 4.2. Interpretation of the Diatom Sequence

[22] DAZ 1b and 2, covering 16,800–14,400 cal years B.P., is most likely equivalent to the cold period defined in the Greenland ice core $\delta^{18}$O record as Greenland Stadial (GS) 2a [*Lowe et al.*, 2008]. *A. granulata*, and *A. ambigua* dominate (Figure 3). In zone 4a (between 13,400 and 11,000 cal years B.P.), that includes the GS 1 cold period [*Lowe et al.*, 2008] (still widely referred to as the Younger Dryas), the relative abundance of *A. granulata* in the sediments is high, while that of *C. stelligera* is low. Therefore, these diatom data indicate that the WMW was strong during the GS 2a and GS 1cold periods.

[23] In contrast, during 14,400 and 13,400 cal years B.P. (DAZ3), equivalent to the warm Greenland Interstadial (GI) 1 (widely known as the Bølling Allerød), and between 11,000 and 10,000 cal years B.P. (DAZ 4b), an interval equivalent to the Preboreal [*Lowe et al.*, 2008], the relative abundance of *C. stelligera* in the sediments is high, while that of *A. granulata* is low and *A. ambigua* disappear (Figure 3). The diatom data from these zone suggested that strength of WMW was reduced during these warm periods.

[24] Following GS 1, another two intervals with relatively strong WMW occurred between 10,000 to 8500 and between 7000 to 6000 cal years B.P., as evident from the curve of *A. granulata* abundance (Figure 3). Although we cannot quantify how strong the WMW were during these two intervals, high relative abundances of *A. granulata* suggest that the WMW was quite strong.

[25] As indicated by the zonation, the most significant shift in diatom composition occurred at about 14, 400 cal years B.P. with *A. ambigua* and *C. radiosa* disappearing from the assemblages as *A. granulata* and *C. stelligera* become the dominant species. *A. ambigua* has similar ecological requirements to *A. granulata*, as these species often cooccur [*Bradbury*, 1975]. However, by contrast with *A. ambigua* that is commonly found in temperate and high-latitude regions [e.g., *Siver and Kling*, 1997; *Trifonova and Genkal*, 2001; *Kauppila et al.*, 2002], *A. granulata* is considered as a thermophilic diatom [*Shear et al.*, 1976; *Poulícková*, 1993]. *A. granulata* is often found in tropical and subtropical lakes [e.g., *Levis*, 1978; *Kilham et al.*, 1986; *Torgan et al.*, 2002; *Davies et al.*, 2004] while in the temperate regions its occurrences are restricted to the warm season [e.g., *Stoermer and Ladewski*, 1976; *Simola et al.*, 1990; *Poulícková*, 1993]. *C. radiosa*, like *A. ambigua*, is also a species commonly found in lakes of the temperate and northern regions, where it blooms preferentially during the spring and autumn circulation periods [e.g., *Kiss and Padisák*, 1990; *Chu et al.*, 2005; *Kienel et al.*, 2005]. *C. stelligera*, unlike *C. radiosa*, is frequently reported in tropical lakes [*Bradbury*, 2000; *Dam et al.*, 2001]. This suggests that the temperature during the interval 17500 and 15,000 cal years B.P., which was dominated by *C. radiosa* and *A. ambigua*, was colder than the following period. The Mg/Ca and alkenones (UK37) records from the tropical South China Sea also show that the temperature of sea surface during the Greenland Stadial (GS) 2a was colder than in the following period, including GI1, GS1 and the Holocene [*Steinke et al.*, 2008].

[26] An alternative interpretation for the variations in diatom relative abundance observed in the HML sediment sequence would be to consider changes in precipitation instead of the WMW. It is generally assumed that increased precipitation during summer could bring more nutrients to the lake from its surrounding catchment because of increased runoff and groundwater supply. Such catchment-mediated process would favor the development of *A. granulata*, which is an eutrophic species [*Kilham and Kilham*, 1975], instead of *Cyclotella*, which is considered as oligotrophic species. However, our trap data show that the dominant diatom species is not *A. granulata* but *C. stelligera* in summer. This indicates that the physical process, especially windiness and its effect on the stability of the water column in the case of HML, is likely to be more important here for explaining the dynamic shifts between these two diatoms than changes in nutrient concentrations. Indeed, *Aulacoseira* taxa are thickly silicified and form filamentous colonies which make them relatively heavy and more likely to sink out of the photic zone as stratification develops unless turbulent conditions help them to remain in suspension [*Kilham et al.*, 1996; *Pannard et al.*, 2008]. On the other hand, *Cyclotella* species such as *C. stelligera* are small-sized diatoms that do not form colonies and have therefore much lower sinking rates compared with *Aulacoseira* which allow them to remain in suspension in the lake column

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climates, before 14.400 cal y [redacted]
*Aulacoseira* species (*granulata* [redacted]
and S/G ratio is low while Ti [redacted]
(Figure 4). Pollen analysis from this sa [redacted]
our interpretation of the diatom resu [redacted]
[redacted] btropical and temperate trees were do [redacted]
[redacted] icating a relatively cool climate. In [redacted]
[redacted] reboreal, tropical evergreen trees [redacted]
[redacted] 7].

benefit the development of *A. granulata* [*Miyajima et al.*, 1994] while being detrimental to taxa adapted to a more stable water column such as *C. stelligera*.

[29] Between 7000 to 6000 years B.P., the abundance of *A. granulata*, the S/G ratio and high percentages of benthic species all suggest that WMW was strong. This is consistent with the Ti and $\chi$ records (Figure 4). In the paleosol records of northern China, the sparsity of $^{14}C$ dates for this time interval also suggests that the interval was characterized by severe dry events [*Guo et al.*, 2000]. Lake geomorphological and lithological evidence from the Alashan Plateau indicates strong lake desiccation during the mid-Holocene around 5000 to 7000 cal years B.P. [*Chen et al.*, 2003]. We should also consider that a stronger winter monsoon might not have been the only cause of the dry events recorded in North China. These events may have been caused by lower precipitation (weaker summer monsoon), or a combination of both a strengthening of the winter monsoon and a weakening of the summer monsoon.

Kiss, K. T., and J. Padisák (1990), Species succession in the Thalassiosiraceae: Quantitative studies in the Large, shallow lake Balaton, Hungary, in *Proceedings of the* 10th *International Diatom Symposium*, *Joensuu, Finland 1988*, edited by H. Simola, pp. 481–490, Koeltz Sci., Koenigstein, Germany.

Korhola, A., J. Weckstrom, L. Holmstrom, and P. Erasto (2000), A quantitative Holocene climatic record from diatoms in northern Fennoscandia, *Quat. Res.*, *54*, 284–294, doi:10.1006/qres.2000.2153.

Krammer, K., and H. Lange-Bertalot (1991), *Bacillariophyceae*, *Süsswasserflora Mitteleur. Ser.*, vol. 2, Spektrum Akade. Verlag, Berlin.

Kutzbach, J. E. (1981), Monsoon climate of the early Holocene: Climate experiment with the Earth's orbital parmeters for 9000 years ago, *Science*, *214*, 59–61, doi:10.1126/science.214.4516.59.

Laird, K. R., S. C. Fritz, K. A. Maasch, and B. F. Cumming (1996), Greater drought intensity and frequency before AD 1200 in the Northern Great Plains, USA, *Nature*, *384*, 552–554, doi:10.1038/384552a0.

Levis, W. M. (1978), Dynamics and succession of the phytoplankton in a tropical lake: Lake Lanao, Philippines, *J. Ecol.*, *66*(66), 849–880.

Liu, J. Q., H. Y. Lu, J. Negendank, J. Mingram, X. J. Luo, W. Y. Wang, and G. Q. Chu (2000), Periodicity of Holocene climatic variations in the Huguangyan Maar Lake, *Chin. Sci. Bull.*, *45*(18), 1712–1717, doi:10.1007/BF02898993.

Liu, Q., Z. Y. Gu, J. Q. Liu, H. T. You, H. Y. Lu, G. Q. Chu, and X. L. Qi (2005), Bulk organic carbon isotopic record of Huguangyan maar lake, southeastern China and its paleoclimatic and paleoenvironmental significance since 62 kaBP (in Chinese with English abstract), *Mar. Geol. Quat. Geol.*, *25*(2), 115–126.

Liu, Z. Y., J. Kutzbach, and L. X. Wu (2000), Modeling climate shift of El Nino variability in the Holocene, *Geophys. Res. Lett.*, *27*(15), 2265–2268, doi:10.1029/2000GL011452.

Lotter, A. F., and C. Bigler (2000), Do diatoms in the Swiss Alps reflect the length of ice-cover?, *Aquat. Sci.*, *62*, 125–141, doi:10.1007/s000270050002.

Lowe, J. J., S. O. Rasmussen, S. Bjorck, W. Z. Hoek, J. P. Steffensen, M. J. C. Walker, Z. C. Yu, and I. Grp (2008), Synchronisation of palaeoenvironmental events in the North Atlantic region during the Last Termination: A revised protocol recommended by the INTIMATE group, *Quat. Sci. Rev.*, *27*(1–2), 6–17, doi:10.1016/j.quascirev.2007.09.016.

Mackay, A. W., R. W. Battarbee, R. J. Flower, N. G. Granin, D. H. Jewson, D. B. Ryves, and M. Sturm (2003a), Assessing the potential for developing internal diatom-based transfer functions for Lake Baikal, *Limnol. Oceanogr.*, *48*(3), 1183–1192.

Mackay, A. W., V. J. Jones, and R. W. Battarbee (2003b), Approaches to Holocene climate reconstruction using diatoms, in *Global Change in The Holocene*, edited by A. W. Machay et al., pp. 294–309, Arnold, London.

Mayewski, P. A., et al. (2004), Holocene climate variability, *Quat. Res.*, *62*(3), 243–255, doi:10.1016/j.yqres.2004.07.001.

Mingram, J., G. Schettler, N. R. Nowaczyk, X. Luo, H. Y. Lu, J. Q. Liu, and J. F. W. Negendank (2004), The Huguang maar lake-a high-resolution record of palaeoenvironmental and palaeoclimatic changes over the last 78,000 years from South China, *Quat. Int.*, *122*, 85–107, doi:10.1016/j.quaint.2004.02.001.

Mingram, J., F. W. Negendank, A. Brauer, D. Berger, A. Hendrich, M. Köhler, and H. Usinger (2007), Long cores from small lakes-recovering up to 100 m long lake sediment sequences with a high-precision rod-operated piston corer (Usinger-corer), *J. Paleolimnol.*, *37*, 517–528, doi:10.1007/s10933-006-9035-4.

Miyajima, T., M. Nakanishi, S. Nakano, and Y. Tezuka (1994), An autumnal bloom of the diatom Melosira granulata in a shallow eutrophic lake: Physical and chemical constraints on its population dynamics, *Arch. Hydobiol.*, *130*(2), 143–162.

Pannard, A., M. Bormans, and Y. Lagadeuc (2008), Phytoplankton species turnover controlled by physical forcing at different time scales, *Can. J. Fish. Aquat. Sci.*, *65*, 47–60, doi:10.1139/F07-149.

Petrova, N. A. (1986), Seasonality of Melosira-plankton of the great northern lakes, *Hydrobiologia*, *138*, 65–73, doi:10.1007/BF00027232.

Pienitz, R., J. P. Smol, and H. J. B. Birks (1995), Assessment of freshwater diatoms as quantitative indicators of past climatic change in the Yukon and Northwest Territories, Canada, *J. Paleolimnol.*, *13*, 21–49, doi:10.1007/BF00678109.

Pienitz, R., J. P. Smol, and G. M. MacDonald (1999), Paleolimnological reconstruction of Holocene climatic trends from two boreal tree line lakes, Northwest Territories, Canada, *Arct. Antarct. Alp. Res.*, *31*(1), 82–93, doi:10.2307/1552625.

Pilskaln, C. H., and T. C. Johnson (1991), Seasonal signals in Lake Malawi sediments, *Limnol. Oceanogr.*, *36*(3), 544–557.

Poulícková, A. (1993), Ecological study of seasonal maxima of centric diatoms, *Algol. Stud.*, *68*, 85–106.

Reynolds, C. (2006), *Ecology of Phytoplankton*, 535 pp., Cambridge Univ. Press, New York.

Rosén, P., R. Hall, T. Korsman, and I. Renberg (2000), Diatom transfer-functions for quantifying past air temperature, pH and total organic carbon concentration from lakes in northern Sweden, *J. Paleolimnol.*, *24*(2), 109–123, doi:10.1023/A:1008128014721.

Rühland, K., A. Priesnitz, and J. P. Smol (2003), Paleolimnological evidence from diatoms for recent environmental changes in 50 Lakes across Canadian Arctic Treeline, *Arct. Antarct. Alp. Res.*, *35*, 110–123, doi:10.1657/1523-0430(2003)035[0110:PEFDFR]2.0.CO;2.

Rühland, K., A. M. Paterson, and J. P. Smol (2008), Hemispheric-scale patterns of climate-related shifts in planktonic diatoms from North American and European lakes, *Global Change Biol.*, *14*, 1–15.

Saros, J. E., S. J. Interlandi, A. P. Wolfe, and D. R. Engstrom (2003), Recent changes in the diatom community structure of lakes in the Beartooth Mountain Range, USA, *Arct. Antarct. Alp. Res.*, *35*(1), 18–23, doi:10.1657/1523-0430(2003)035[0018:RCITDC]2.0.CO;2.

Schelske, C. L., H. J. Carrick, and F. J. Aldridge (1995), Can wind-induced resuspension of meroplankton affect phytoplankton dynamics?, *J. N. Am. Benthol. Soc.*, *14*(4), 616–630, doi:10.2307/1467545.

Shear, H., C. Nalewajko, and H. M. Bacchus (1976), Some aspects of the ecology of Melosira ssp. in Ontario lakes, *Hydorbiologia*, *50*, 173–176.

Simola, H., I. Hanski, and M. Liukkonean (1990), Stratigraphy, species richness and seasonal dynamics of plankton diatoms during 418 years in Lake Lovojärvi, *Ann. Bot. Fenn.*, *27*, 241–259.

Siver, P. A., and H. Kling (1997), Morphological observations of Aulacoseira using scanning electron microscopy, *Can. J. Bot.*, *27*, 241–259.

Smol, J. P., and B. F. Cumming (2000), Tracking long-term changes in climate using algal indicators in lake sediments, *J. Phycol.*, *36*, 986–1011, doi:10.1046/j.1529-8817.2000.00049.x.

Smol, J. P., et al. (2005), Climate-driven regime shifts in the biological communities of arctic lakes, *Proc. Natl. Acad. Sci. U.S.A.*, *102*(12), 4392–4402.

Sorvari, S., A. Korhola, and R. Thompson (2002), Lake diatom response to recent arctic warming in Finnish Lapland, *Global Change Biol.*, *8*, 171–181, doi:10.1046/j.1365-2486.2002.00463.x.

Stager, J. C., B. F. Cumming, and L. D. Meeker (2003), A 10,000-year high-resolution diatom record from Pilkington Bay, Lake Victoria, east Africa, *Quat. Res.*, *59*(2), 172–181, doi:10.1016/S0033-5894(03)00008-5.

Steinke, S., M. Kienast, J. Groeneveld, L. C. Lin, M. T. Chen, and R. Rendle-bühring (2008), Proxy dependence of the temporal pattern of deglacial warming in th tropical South China Sea: Toward resolving seasonality, *Quat. Sci. Rev.*, *27*, 688–700, doi:10.1016/j.quascirev.2007.12.003.

Stoermer, E. F., and T. B. Ladewski (1976), Apparent optimal temperatures for the occurrence of some common phytoplankton species in southern Lake Michigan, report, 49 pp., Univ. of Mich., Ann Arbor, Mich.

Talling, J. F. (1957), Photosynthetic characteristics of some freshwater plankton diatoms in relation to underwater radiation, *New Phytol.*, *56*, 345–356.

Tilman, D., S. S. Kilham, and P. Kilham (1982), Phytoplankton community ecology: The role of limiting nutrients, *Annu. Rev. Ecol. Syst.*, *13*, 349–372, doi:10.1146/annurev.es.13.110182.002025.

Tolotti, M., F. Corradini, A. Boscaini, and D. Calliari (2007), Weather-driven ecology of planktonic diatoms in Lake Tovel (Trentino, Italy), *Hydrobiologia*, *578*, 147–156, doi:10.1007/s10750-006-0441-4.

Torgan, L. C., J. G. Tundisi, and L. F. H. Niencheski (2002), Seasonal variation of planktonic diatoms in Patos Lagoon, Southern Brazil, in *Proceedings of the 1*5th *International Diatom Symposium*, *Perth, Australia*, edited by J. John, pp. 459–470, Gantner Verlag, Ruggell, Liechtenstein.

Trifonova, I., and S. I. Genkal (2001), Species of the genus *Aulacoseira* Thwaites in lakes and rivers of north-western Russia-distribution and ecology, in *Proceedings of the 1*6th *International Diatom Symposium*, *Athens and Aegean Islands*, edited by A. Economou-Amilli, pp. 315–322, Univ. of Athens, Athens.

Verschuren, D., K. R. Laird, and B. F. Cumming (2000), Rainfall and drought in equatorial east Africa during the past 1100 years, *Nature*, *403*, 410–414, doi:10.1038/35000179.

Vyverman, W., and K. Sabbe (1995), Diatom-temperature transfer-functions based on the altitudinal zonation of diatom assemblages in Papua-New-Guinea: A possible tool in the reconstruction of regional paleoclimatic changes, *J. Paleolimnol.*, *13*(1), 65–77, doi:10.1007/BF00678111.

Wang, B., R. G. Wu, and X. H. Fu (2000), Pacific-East Asian teleconnection: How does ENSO affect East Asian climate?, *J. Clim.*, *13*(9), 1517–1536, doi:10.1175/1520-0442(2000)013<1517:PEATHD>2.0.CO;2.

Wang, S. Y., H. Y. Lu, J. Q. Liu, and J. F. W. Negendank (2007), The early Holocene optimum inferred from a high-resolution pollen record of Huguangyan Maar Lake in southern China, *Chin. Sci. Bull.*, *52*(20), 2829–2836, doi:10.1007/s11434-007-0419-2.

Wang, Y. J., H. Cheng, R. L. Edwards, Z. S. An, J. Y. Wu, C.-C. Shen, and J. A. Dorale (2001), A high-resolution absolute-dated late Pleistocene monsoon record from Hulu Cave, China, *Science*, *294*, 2345–2348, doi:10.1126/science.1064618.

Wang, Y. J., H. Cheng, R. L. Edwards, Y. Q. He, X. G. Kong, Z. S. An, J. Y. Wu, M. J. Kelly, C. A. Dykoski, and X. D. Li (2005), The Holocene Asian monsoon: Links to solar changes and North Atlantic climate, *Science*, *308*, 854–857, doi:10.1126/science.1106296.

Wetzel, R. G., and G. E. Likens (2000), *Limnological Analysis*, 3rd ed., 429 pp., Springer-Verlag, New York.

Weyhenmeyer, G. A., T. Blenckner, and K. Pettersson (1999), Changes of the plankton spring outburst related to the North Atlantic Oscillation, *Limnol. Oceanogr.*, *44*(7), 1788–1792.

Yancheva, G., N. R. Nowaczyk, J. Mingram, P. Dulski, G. Schettler, F. W. Negendank, J. Q. Liu, D. M. Sigman, L. C. Peterson, and G. H. Haug (2007), Influence of the intertropical convergence zone on the East Asian monsoon, *Nature*, *445*, 74–77, doi:10.1038/nature05431.

Yang, X. D., S. M. Wang, C. Kamenik, J. Shen, L. P. Zhu, and S. H. Li (2004), Diatom assemblages and quantitative reconstruction for paleosalinity from a sediment core of Chencuo Lake, southern Tibet, *Sci. China Ser. D*, *47*(6), 522–528.

Yuan, D. X., et al. (2004), Timing, duration, and transitions of the last interglacial asian monsoon, *Science*, *304*, 575–578, doi:10.1126/science.1091220.

Zheng, Z., and Z.-Q. Lei (1999), A 400,000 year record of vegetational and climatic changes from a volcanic basin, Leizhou Peninsula, southern China, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, *145*, 339–362, doi:10.1016/S0031-0182(98)00107-2.

Zhou, H. Y., H. Z. Guan, and B. Q. Chi (2007), Record of winter monsoon strength, *Nature*, *450*, E10–E11, doi:10.1038/nature06408.

Zhou, W., X. Wang, T. J. Zhou, and J. C. L. Chan (2007), Interdecadal variability of the relationship between the East Asian winter monsoon and ENSO, *Meteorol. Atmos. Phys.*, *98*(3–4), 283–293, doi:10.1007/s00703-007-0263-6.

G. Chu, Z. Gu, J. Han, J. Liu, H. Lu, P. Rioual, and L. Wang, Key Laboratory of Cenozoic Geology and Environment, Institute of Geology and Geophysics, Chinese Academy of Sciences, 52 Sanlihe Road, 100864 Beijing, China. (wangluo@mail.igcas.ac.cn)

J. Li, School of Geosciences and Resources, China University of Geosciences, Xuanyuan Road 29, 100083 Beijing, China.

J. Mingram and J. F. W. Negendank, GeoForschungsZentrum, Telegrafenberg, D-14473 Potsdam, Germany.