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Editorial

Holocene climate variability in arid Asia: Nature and mechanisms

Abstract

The papers in this special issue are derived from a selection of presentations given at the RACHAD workshop titled "Pattern of Holocene Climate Change in Central Asia: Data Synthesis" held at Lanzhou University, People's Republic of China, from 25th to 27th July 2006. RACHAD is INQUA Palaeoclimate Commission (PALCOMM) Project (#0502), concerned with 'rapid climate change in Central Asia's drylands', and the 2006 workshop was its fourth gathering. The RACHAD project was established in 2000 and has been led by Prof Fahu Chen from Lanzhou University. RACHAD's initial objectives were to stimulate the reconstruction of Holocene climatic and environmental changes in arid Central Asia at high resolution, to intensify international research collaboration, and to develop and refine techniques for environmental reconstruction and dating.

1. Introduction

The drylands of Central Asia occupy a climatic transition zone between the Asian monsoons and westerly airflow. As a result of this location, the region is sensitive to changes in climate on timescales of decades to millennia and longer. The area is topographically diverse, consisting of the northern part of the vast Tibetan Plateau at about 4000 m above sea level, the basins and mountain ranges that lie to the north of the Tibetan Plateau, the southern edge of the Mongolian Plateau, and the western extremity of the Loess Plateau (Fig. 1). The area has a rich archaeological record that can be used to investigate human cultural evolution within the region, especially the colonization of climatically harsh upland regions and the development of agriculture. Although most of the region is sparsely populated today, parts of Central Asia are undergoing economic development at an unprecedented rate. This growth has contributed to a number of significant environmental problems, such as land degradation and water shortage. Understanding past changes in climate and environment are essential for sustainable development in this region in the future.

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Forty-four delegates from China, the USA, Germany, the UK, Norway, Japan, and Australia attended the RACHAD 2006 meeting, with the aims of synthesizing information about patterns of Holocene climate change in arid Central Asia, identifying forcing factors, discussing possible ways of integrating proxy data with model output, and identifying future research needs. The resulting volume presented here consists of original research and syntheses loosely grouped into two themes, namely late glacial and Holocene climate, and late Holocene climate.

2. Climate change during the late glacial and Holocene

Five papers deal wholly or largely with the late glacial–Holocene interval. Zhao et al. (2008) investigate large spatial-scale changes in vegetation in China's drylands by summarizing pollen data from 30 sites across the region. Although all of the sites show evidence for increasing aridity over the past 5000 calendar years, the earlier part of the Holocene shows regional diversity. Over the northern part of the Tibetan Plateau and eastern Inner Mongolia, for example, early and mid-Holocene vegetation indicates wetter conditions associated with enhanced summer monsoon precipitation, whereas in the north-western part

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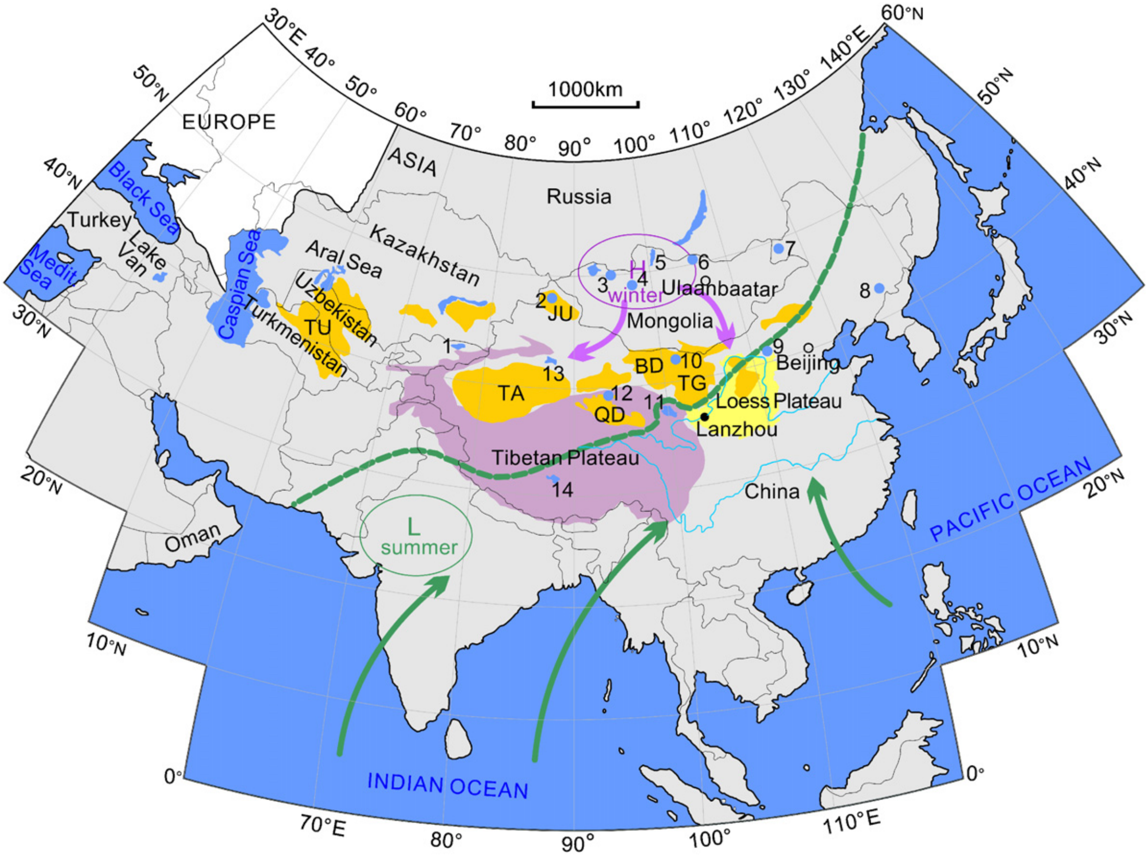

Fig. 1. Map of arid Central Asia and adjacent regions. Dashed line shows the approximate extent of summer monsoon precipitation. Solid lines indicate surface airflow during summer and winter associated with areas of high (H) and low (L) pressure. Numbered sites are as follows: 1. Issyk-Kul; 2. Wulun Lake; 3. Bayan Nuur; 4. Telmen Lake; 5. Hovsgol Nuur; 6. Gun Nuur; 7. Hulun Nuur; 8. Sihailongwan; 9. Daihai Lake; 10. Juyanze; 11. Qinghai Lake; 12. Sugan Lake; 13. Bosten Lake; 14. Selin Co. TU = Turkestan Desert; JU = Junggar Basin; TA = Tarim Basin; QD = Qaidam Basin; BD = Badain Jaran Desert; TG = Tenger Desert.

of the loess plateau and western Inner Mongolia/Xinjiang, the early Holocene was dry. The wider messages of this work are twofold. First, there is, unsurprisingly perhaps, asynchrony in Holocene climate over this vast region. Second, there are dangers in extrapolating the results from single sites to the wider region. However, the authors do warn that some, but by no means all, of the asynchrony observed may be an artefact of imprecise chronologies. Moreover, they argue that the contribution of human activity to the vegetation histories is uncertain.

Yang et al. (2008) continue the theme of regional synthesis by bringing together data from 11 lake sites across arid Central Asia, from Lake Van, Turkey in the west to Hulun Nuur, Inner Mongolia in the east. They produce time series of lake-status assessments of the individual sites, generally for 200-year timeslices. The lake-status determinations, which are based on multiple-proxy evidence, provide an indication of effective moisture. Their results show that the early Holocene was generally arid and that there was a shift to wetter conditions during the mid Holocene, followed by progressive desiccation.

Huang et al. (2008) examine the Holocene evolution of Bosten Hu, China's largest freshwater lake, situated on the southern slope of the Tien Shan Mountains in Xinjiang. This site-specific study lends support to the synthesis of Wünnemann et al. (2007) and Chen et al. (2008). Because of marked aridity, there was no water body in the basin during the late glacial and early Holocene, as shown by the presence of a thick aeolian sand unit and absence of pollen grains. A lake became established around 8000 calendar years BP although conditions remained fairly dry until 6000 calendar years BP, after which time effective moisture increased. The authors maintain that this mid- to late Holocene wet phase at this site cannot be explained by enhanced monsoons—other records from the monsoon domain indicate that monsoon rainfall was diminishing during this period as a result of weakened summer insolation forcing—but must instead relate to strengthened westerly storm tracks.

In a further site-specific study, Hartmann and Wünnemann (2008) describe a Holocene record from eastern Juyanze Lake. This is a palaeolake site located in arid Northwest China, north of the Badain Jaran sand desert. The authors present multi-proxy evidence to show that there has been a complex development of the lake throughout the Holocene. During the earliest Holocene, a fluctuating freshwater lake occupied the basin, indicating wet conditions with peaks in local surface runoff, although this time of increased effective moisture was interrupted by several dry phases. A marked drought possibly coinciding with the early Holocene cooling event occurred around 8000 calendar years BP and was followed by a prominent dry period from 7500 to 5400 calendar years BP. A wetter phase from 5400 to 4000 calendar years BP, marking a Holocene climatic optimum, preceded progressive drying and finally desiccation of the basin. The authors propose that the complex changes at this site reflect interplay between monsoon rainfall and westerly storms.

Moving further to the east, Sun et al. (2008) describe a late glacial to Holocene lake-level reconstruction from Lake Dahai, which lies to the northeast of the Loess Plateau in north central China. The lake-level curve, which mirrors changes in effective precipitation, is typical of a lake within the summer monsoon domain. It shows fluctuating effective precipitation during the late glacial stage, with a prominent dry event coinciding with the Younger Dryas interval. The early Holocene was mainly wet, but with a drought apparently coinciding with the 8200-year cooling event, followed by a trend towards drying after about 3000 calendar years BP.

Zou et al. (2008) focus on Holocene vegetation changes in the western part of the Chinese Loess Plateau. The change from desert steppe, typical of the late glacial, to forest and forest steppe in the early Holocene indicates wet conditions, whereas variable but generally drying climate after about 4000 calendar years BP is suggested by a return to steppe vegetation.

3. Late Holocene climate change

Six papers in this set cover the late Holocene, typically the last one to two millennia. Yang et al. (2008) provides a synthesis of ice-core, tree-ring, and lake-sediment records coupled with information from historical documents and glacier fluctuations to provide an environmental history of arid Central Asia for the past 2000 years. Most striking was the dry Medieval Warm Period, which spanned from the 9th to 12th centuries AD, and the Little Ice Age, which lasted from the 15th to the 18th centuries.

Boomer et al. (2008) summarize our understanding of fluctuations in the water level of the Aral Sea over the past 2000 years. The Aral Sea lies in the western part of arid Central Asia and is a particularly important site owing to the absence of any summer monsoon precipitation. It therefore should preserve a record of changes in the westerlies. Four major low stands of the lake during the past 2000 years, 0–400 AD, 900–1350 AD, 1500–1650 AD, and 1800 AD–present, indicate major dry periods that are also seen in nearby tree-ring records (Naurzbaev and Vaganov, 2000).

Holmes et al. (2008) synthesize data for the past 2000 years from western China. They show that patterns of change across this large region have been complex, echoing the patterns seen in the earlier parts of the Holocene and reported in a number of papers within the present volume. Despite this variability, late 20th century warming seems unprecedented, at least for the past two millennia, and it is clear that this warming has been greatest at higher altitude. Recent droughts, however, have been no more severe than earlier dry intervals.

Chu et al. (2008) take an unusual approach to examine a major environmental issue in contemporary China—dust storms. They produce a dust record for north-eastern China from the minerogenic fraction of Maar Lake sediments. Their 1400-year sequence agrees well with dust records from Tibetan Plateau ice cores and shows a number of periods of increased dust fall, most notably during the Medieval Warm Period and over the past 200 years.

Zhang et al. (2008) present an 850-year ostracod trace element from Sugan Lake, a medium-sized saline lake on the northern edge of the Tibetan Plateau in the Qaidam Basin. Variations in ostracod-shell Sr/Ca ratios reflect salinity for part of the record, but only when aragonite is not being formed within the lake water. During times of aragonite formation, Sr behaves highly non-conservatively with respect to salinity. During times of no aragonite formation, the Sr/Ca ratio of ostracods appears to provide a good proxy for salinity and agrees well with oxygen-isotope values of ostracod shells from the same sediments (Holmes et al., 2007). Their study shows that it is important to understand modern lake water chemistry and sediment mineralogy before interpreting ostracod geochemical records.

Henderson and Holmes (2008) provide a critical evaluation of records from Lake Qingahi that cover the past 1000 years. Lake Qinghai, which lies on the north-eastern margin of the Tibetan Plateau, is China's largest natural lake and has been the focus of numerous palaeolimnological studies. However, Henderson and Holmes warn that many previous studies lack sound chronologies, making it difficult to compare their data with results from other areas. Moreover, some of the proxy data may be open to alternative interpretations. For those datasets that do have well-supported interpretation, the results suggest that Lake Qinghai does not record a simple story of changing monsoon strength, but is rather a function of complex interplay between monsoon precipitation and the westerlies.

The paper of Sato (2008) is the sole contribution concerned with climate modeling, yet it has major implications for all of the other papers in this volume since it addresses the question of why aridity arises in this region. The Tibetan Plateau is an imposing topographical feature; with a mean altitude of around 4000 m above sea level and an area of some 2,000,000 km^2, it has long been known to have a significant effect on hemispheric climate. Sato uses a regional climate model (RCM) to investigate the meteorological and climatological effects of the Tibetan Plateau and other mountain ranges of Central Asia. His study looks specifically at the occurrence of aridity over northern and western China and the development of rain belts extending eastwards over Korea and Japan. Results show that during winter, aridity over northern China and Mongolia is associated with dynamical forcing of the atmosphere by the Tibetan Plateau during summer. Strong thermal forcing by the Plateau causes atmospheric subsidence in the area of the major deserts.

4. Concluding remarks

Despite the growth in our understanding of late glacial and Holocene climate in arid Central Asia, further work is needed. First, the overall density of study sites across the region is low, leading to difficulties in the identification of regional patterns. Further studies focused on climatically sensitive areas are needed. Second, some individual studies suffer from poorly defined age models. The exceptions to this are the annually resolved archives, such as tree rings, ice cores, and laminated lake sediments as well as documentary records. Further work should be directed at improving the chronologies wherever these are deficient, although the challenges that this task poses are often considerable. Third, it is necessary to update methodologies for environmental reconstruction in order to better understand the process–response system. Further efforts to develop transfer functions for individual biological and geochemical proxies, such as those of Mischke et al. (2007) for ostracods, Yang et al. (2003) for diatoms, Herzschuh et al. (2003) for pollen, Zhang et al. (2007) for chironomids, and Liu et al. (2006) for biomarkers, are needed. Calibration of individual proxy records by comparison with instrumental climate data (e.g. Henderson et al., 2003), China's rich documentary data (e.g. Yang et al., 2008), or inter-archive comparisons (e.g. Holmes et al., 2007) are also important.

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