Asynchronous evolution of the Indian and East Asian Summer Monsoon indicated by Holocene moisture patterns in monsoonal central Asia

Yongbo Wang[1,2,*] , Xingqi Liu[3], Ulrike Herzschuh[1,2]

(*contact: Yongbo.Wang@awi.de)

1, Alfred Wegener Institute for Polar and Marine Research, Research Union Potsdam, 14473 Potsdam, Germany

2, Department of Geoscience, University of Potsdam, 14469 Potsdam, Germany

3, Nanjing Institute of Geography & Limnology, Chinese Academy of Sciences, 210008 Nanjing, China

0. Abstract

The numerical meta-analysis of 92 proxy records (72 sites) of moisture change confirms earlier findings that the dominant trends of climatic evolution in monsoonal central Asia since the Last Glacial roughly parallel changes in Northern Hemisphere summer insolation. i.e. the period following the Last Glacial Maximum was characterized by dry and cold conditions until 15 cal. kyr BP, followed by a warm, wet period coincident with the Bølling/Allerød warm period and terminated by a cold, dry reversal during the Younger Dryas period. After an abrupt increase at the start of the Holocene, warm and wet conditions prevailed until ca. 4 cal. kyr BP when moisture levels and temperatures started to decrease.

Ordination of moisture records reveals strong spatial heterogeneity in moisture evolution during the last 10 cal. kyr. We assign such phenomena to strengthened Hadley Circulation centered over the Tibetan Plateau during the early Holocene which resulted in subsidence in the East Asian monsoonal regions leading to relatively dry conditions.

1. Data collection and synthesis

To ensure sufficient data quality, all records included in our analyses were required to meet the following criteria:

1) Indicative of moisture/ temperature change.
2) Continuous for at least 4000 years since 18 cal. kyr BP.
3) Reliable chronology
4) Sufficient resolution

40 pollen and 52 non-pollen based moisture records from 72 sites were collected.

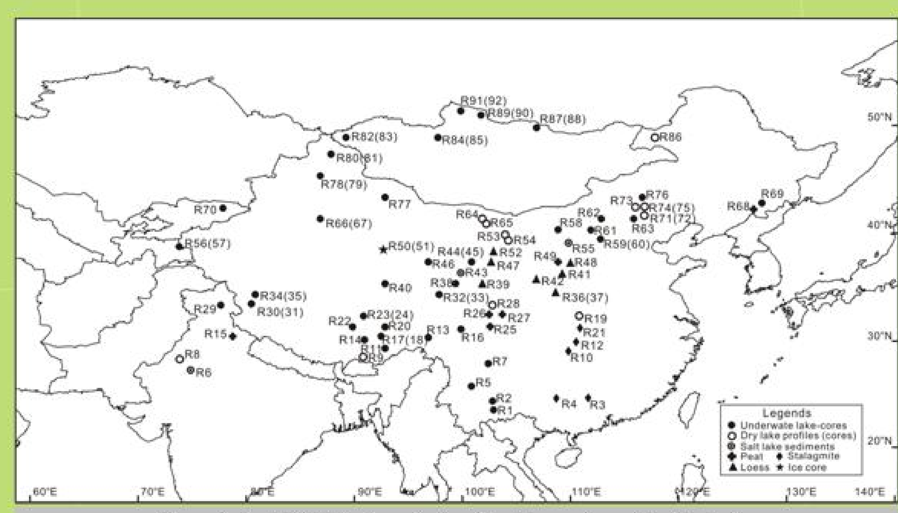

Figure 1 Spatial distribution of palaeoclimatic records used in this study

We translated the moisture (temperature) signals from the separate studies into a moisture (warmth) index of a five-part scale (-2, -1, 0, +1, +2): the lowest value (-2) indicates the driest (coldest) intervals for each site since 18 cal. kyr BP while the maximum (+2) indicates the wettest (warmest) periods, (0) indicates that climatic conditions were similar to present.

2. Temporal moisture patterns since 18 cal. kyr BP

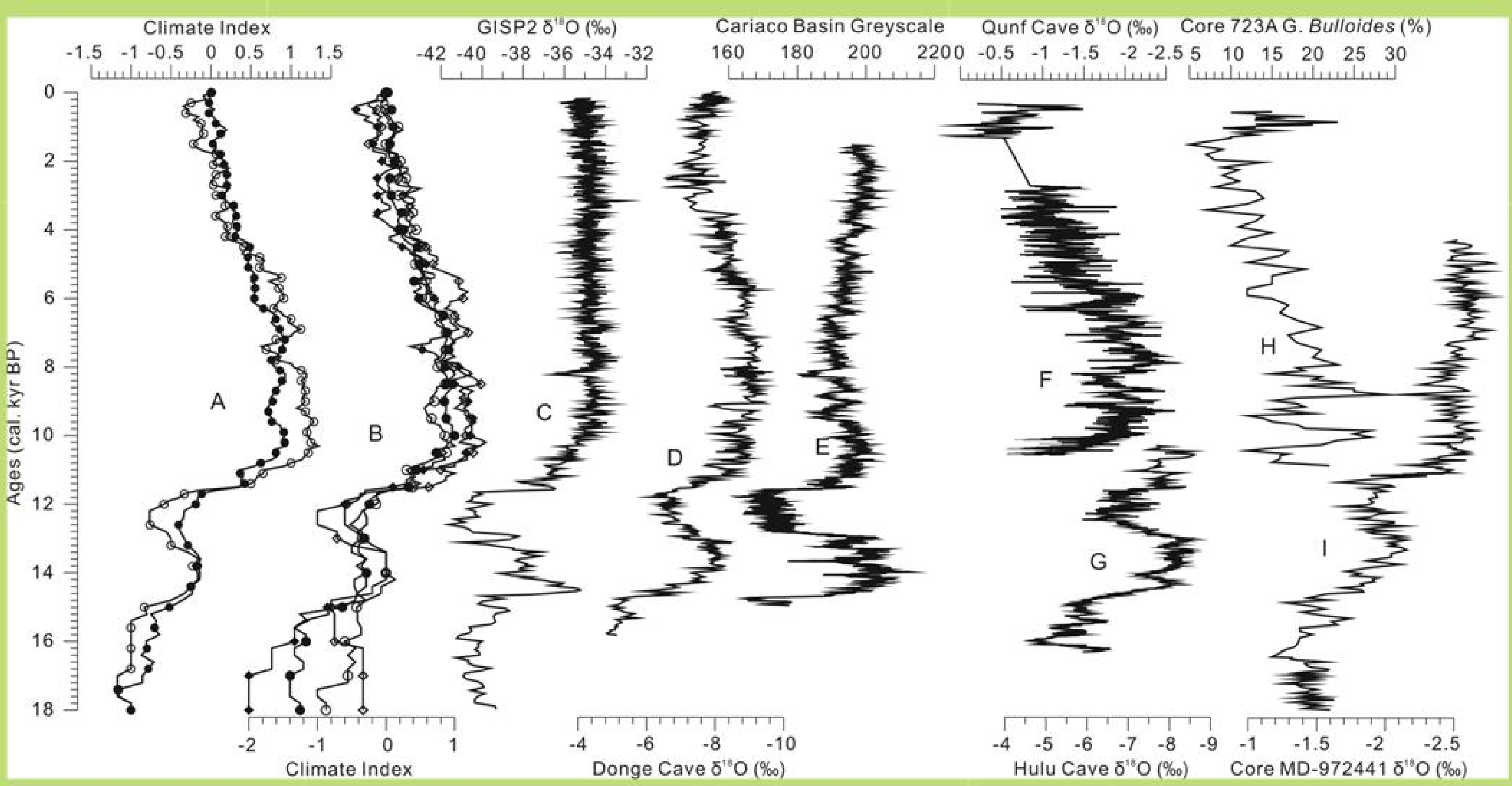

Figure 2 Synthesized Holocene climate indices in Central Asia (A, B) and comparison with selected palaeoclimatic proxy records (C - I). (A) Mean moisture (solid circles) and warmth (hollow circles) indices based on all synthesized records; (B) Mean climate indices based on pollen (moisture, solid circles; warmth, solid diamonds) and non-pollen records (moisture, hollow circles; warmth, hollow diamonds);

Despite a scarcity of available data for periods prior to 15 cal. kyr BP, mostly dry and cold conditions prevailed. Thereafter, a relatively wet and warm period which lasted for ~2000 years (synchronous with the Bølling/Allerød period in the north Atlantic region) was followed by a 1500-yr dry, cold phase, probably reflecting the Younger Dryas event. At the beginning of Holocene, both moisture levels and temperatures increased abruptly reaching a maximum at around 10 cal. kyr BP. The Holocene Optimum lasted until 8 cal. kyr BP followed by a trend towards drier and colder conditions, which prevailed until the latter part of the Holocene.

3. Spatial moisture patterns since 18 cal. kyr BP

The mapping of moisture indices reveals regional differences. Whilst maximum moisture conditions are concentrated in southwest China during early to mid-Holocene, records from Mongolia, Inner Mongolia and Xinjiang indicate moderately dry conditions

The period between 7 and 4 cal. kyr BP is still warm and wet on average but is characterized by a clear southeast-northwest moisture gradient which is different from the early Holocene wet phase.

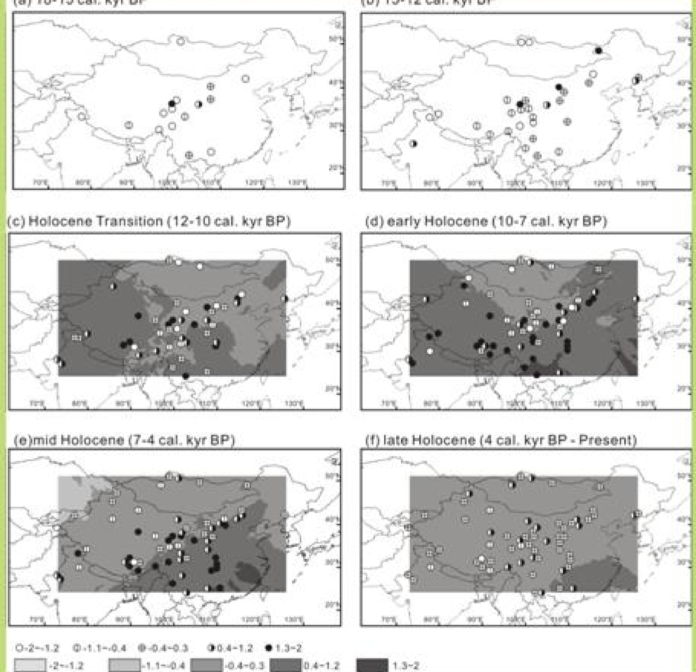

Figure 3 Spatial distribution of moisture indices from Central Asia for defined time periods (symbols indicate the values for each site during certain periods while the gray bands present the interpolated zones through Kriging model).

4. PCA axes scores (1)

The axes scores from PCA performed on the combined pollen and non-pollen data sets of the last 10 cal. kyrs are shown in Fig. 4. The first axis (PC1) shows relatively high values until 7 cal. kyr BP, then decreases gradually over the following 3000 year. After this, for the last 4000 years, values remain stable.

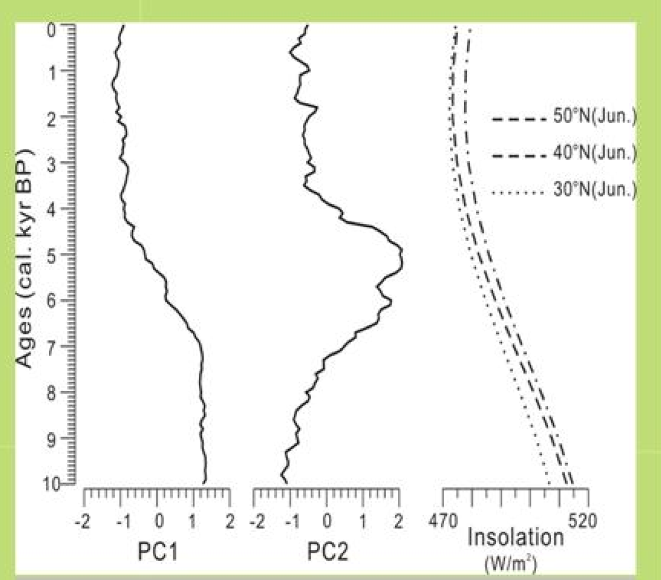

Figure 4 Temporal pattern of results after ordination analysis for the last 10 cal. kyr BP together with Northern Hemisphere solar insolation changes in June at 30°N, 40°N and 50°N

Compared to the relatively steady PC1, the second axis (PC2) shows more fluctuations. Following a gentle increase over 3500 years, PC2 reaches a maximum at about 5000 cal. yr BP which lasts for 2000 years, then decreases sharply to negative values in less than 1000 years. Values slightly fluctuated during the last period, illustrating a different temporal pattern from PC1.

5. PCA axes scores (2)

The two PCA axes also show distinctive spatial patterns (Fig 5). The PC1 decreases stepwise from south to north i.e. from the highest values in northern India and southwestern China, to the lowest values in Mongolia. PC2, in contrast, shows a more continuous decrease from southeast to northwest

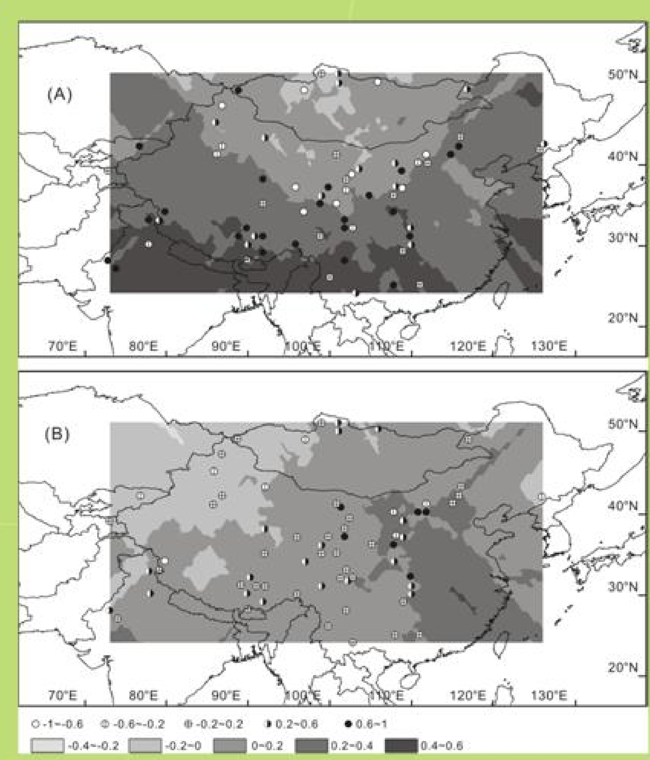

Figure 5 Spatial distribution of results after ordination analysis based on moisture indices from 72 sites as: (A) PC1, (B) PC2. Symbols indicate values for each site whilst colored bands represent interpolated zones through the Kriging model.

Hence, the regions influenced by the two Asian Summer Monsoon sub-systems evolved in notably different ways during the first half of the Holocene.

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Nanjing Institute Of Geography & Limnology

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