Article ID: 1673-1719 (2006) Suppl. 1-0073-04

Studies on the Chronology of Millennial Time Scale Climate Oscillations in the Holocene

Wang Shaowu, Zhu Jinhong

Department of Atmospheric Science, School of Physics, Peking University, Beijing 100871, China

Abstract: Ten high-resolution time series of climate proxy data of the Holocene were synthesized. Comparison of the chronologies of cold events in the North Atlantic with which of monsoon failures in the Asian-African monsoon region shows great identity. All together nine cold events in the Holocene are identified with the weak monsoon events, while the monsoon rainfall decreased.

Key words: Holocene; millennial scale climate oscillation; chronology

Introduction

Extensive examination of Younger Drays (YD) event marks the development of studies on the millennial scale climate oscillations. The YD occurred between 12.5−11.5 ka BP (calendar years). The amplitude of temperature change in the YD ranged about 3/4 of that in glacial-interglacial cycle, sometime reached 7−8℃. Lower temperature persisted about 1 ka during the YD, and then recovered abruptly. The lowering and recovering of temperature were completed usually within a few decades, and even in less than ten years in extreme cases. It means that the time scale of the recovering is only less than 1% of the length of cold period, so the YD event is regarded as an abrupt change. Latter studies confirmed the predominance of the millennial scale climate oscillations of 1.47 ka in the glacial age, which was named the Dansgaard/Oeschger Oscillations (D/O Oscillations) to memory the authors who first revealed the oscillations.

However, it has been considered that the climate in the Holocene was benign and steady, for no significant millennial scale oscillation was found, according to the ice core data over the Greenland. O'Brien *et al.* [1] at first indicated that variations of concentrations of sea salt and terrestrial dusts manifested the occurrence of a series of cold events in 0−0.6ka BP, 5.0−6.1ka BP, 7.8−8.8 ka BP and before 11.3 ka BP in the Holocene. Recently, high-resolution proxy palaeoclimate data demonstrate the instability of climate in the Holocene, and a series of cold events over the North Atlantic and monsoon failures over the Asian-African monsoon region are identified.

Present paper aims at synthesizing the recent evidences of the chronology of cold events and monsoon failures. Of course, the amplitude of temperature or precipitation variations associated with the millennial scale oscillation in the Holocene was much less than that in the YD event. It has been found that the temperature range in the events of 8.2 ka BP and Little Ice Age (LIA) was only 1/3 and 1/5 of that in the YD event, respectively. Therefore, terminology "millennial scale oscillation" is used instead of abrupt climate change in present paper.

1 Cold events over the North Atlantic

Millennial scale climate oscillations are manifested well over the North Atlantic. Bond *et al*. [2] analyzed two cores of sediment over the North Atlantic, VM28-14 (64°47′N, 29°34′W) and VM29-191 (54°16′N, 16°47′W). The former is located between southeast Greenland and Iceland, 1855 m of depth. The latter is located in the west of Ireland, 2370 m of depth. Sedimentation rate is greater than 10 cm/ka. Subsamples are taken at intervals of 0.5−1.0 cm, corresponding to a time resolution of 50−100 years. Three proxies are used to identify the episodes of ice-rafting (cold events): 1) concentration of lithic grains, defined as the number of grains with diameters greater than 150 μm in 1g weight of core; 2) fresh volcanic glass, which comes from Iceland or Jan Mayen; and 3) hematite-stained grains, mostly quartz and feldspar, that come from sedimentary

Received: January 27, 2006; revised: March 17, 2006
Corresponding to Wang Shaowu (E-mail: swwang@pku.edu.cn)

Table 1 Relevant ages for nine cold events over the North Atlantic (Series No.1−3), weak monsoon events (Series No. 4−9) and strong monsoon events (Series No. 10) in the Holocene

Series number	Series name	Relevant ages for nine cold events / ka BP								
		0	1	2	3	4	5	6	7	8
1	VM29-191 [2]		1.4	2.8	4.3	5.9	8.2	9.5	10.3	11.1
2	VM28-14 [2]		1.4	2.7	4.1	5.8	8.0	9.4	10.4	
3	NEAP-15K [3]	0.4	1.4	2.8	4.2	5.2				
4	SCS monsoon [4]	0.3	1.2	3.1	4.3	6.0	8.3	9.5		
5	SW monsoon1 [5]		1.8	3.0	4.0	5.8	8.2	9.4		
6	SW monsoon2 [6]	0.3	1.4	3.4	4.4	5.8	8.2	9.6	10.4	
7	African monsoon [7]	0.5	1.9	3.0	4.6	6.0	8.0		10.2	11.8
8	Monsoon over Plateau [8]	0.3	1.5	2.8	4.4	5.9	8.2	9.5	10.2	11.3
9	Indian monsoon [9]	0.3	1.5	2.8	4.1	5.9	8.3	9.5	10.4	11.2
10	Asian monsoon [10]	0.3	1.5	2.8	4.3	5.9	8.4	9.7	10.4	11.4

deposits containing red beds.

These lithic/petrologic events demonstrate that ice-rafting episodes occurred also during the Holocene. Age differences of lithic/petrologic maximal between the two sites are within the 2σ of calendar age error, hence, the events can not be local in origin. No. 1 and No. 2 in Table 1 show the chronology of ice-rafted debris (IRD) events, namely of the cold events over the North Atlantic in the two sites.

Bianchi *et al*. [3] examined the cold events by using kasten core NEAP-15K (56° 22′ N, 27° 49′ W) recovered from 2848 m depth near the crest of Gardar drift in the south Iceland Basin. In this area Holocene sedimentation rate varied between 20−150 cm/ka. The core contains a 450 cm long Holocene sediment record with a mean time resolution of 90 years. It provides climate information nearly during the last 10 ka. The site of the core is under the influence of Iceland- Scotland Overflow Water (ISOW), the flow of which is an important component of the thermohaline circulation (THC). The mean grain size of the 10−63 μm terrigenous silt fraction is investigated, which is a parameter that varies independently of sediment supply in current-sorted and deposited muds and for which higher values represent relatively greater near-bottom flow speeds and warmer climate over Europe. Reverse is true when the values are lower. No. 3 in Table 1 shows calendar ages of five cold events, where the LIA was numbered as 0 event, for the eight cold events from 1.4 to 11.1 ka BP was numbered by 1 to 8, respectively. The cold event in the time interval of 7.5−10.0 ka BP in the series of Bainchi *et al*. [3] was omitted in Table 1 for the correlation of ISOW to the climate in this time interval seems different from that before 7.5 ka BP.

Besides, cold events in 11.3 ka BP and 8.2 ka BP were also found according to the δ^{18}O of ice core in Greenland (GISP2), but cold events in the mid- and late Holocene were insignificant. This is probably the reason why the millennial scale climate oscillations were not acknowledged earlier than they were.

2 Monsoon failures

A series of high-resolution proxy climate data were published in the recent decade from the middle of 1990s to the present. They manifested well the events above-mentioned of monsoon failures in the Asian- African monsoon region. Wang *et al*. [4] presented a new time series of sea surface salinity (SSS), which was reconstructed from hemipelagic sediments at the continental margin of South China, about 400 km southeast of Hong Kong for the last 10 ka. Gravity core 17940 (20° 07′ N, 117° 23′ E, 1727 m water depth, 13.30 m long) was obtained on SONNE cruise 95. Sedimentation rates of 40−85 cm /ka and a δ^{18}O sampling interval of 1−2 cm provided a time resolution of 15−25 years over the last 10 ka. The series of SSS was found by subtracting the impact of SST from the δ^{18}O value. Enhanced precipitation and fluvial runoff in South China lead to an enlarged plume of low SSS, therefore, the high SSS means monsoon failure. The series of SSS show clearly a distinct peak in 8.25 ka BP, and other minor peaks give the ages of monsoon failures in middle and late Holocene, as shown in No.4 South China Sea monsoon in Table 1.

Overpeck *et al*. [5] synthesized 26 items of proxy palaeo-climate series related to rainfall variations from east Africa via Arabian Peninsular to the northern India, and compared the results to the records of marine sediments from the Oman margin over the Arabian Sea. It is found that the southwest summer monsoon was weaker during the last glacial period than the present, and then strengthened during the last deglaciation. The monsoon intensity was strong in the period from 9.5 to 5.5 ka BP, wherein a series of events of monsoon failures were embedded, some of them lasted a few hundred years. No.5 in Table 1 gives the ages of the events identified according to original figures of Overpeck *et al.* [5]

Gupta *et al.* [6] examined the variations of Asian southwest monsoon by using the records of planktonic foraminifera (*globigerina bulloides*, later as GB, unit: %) in Oman margin. The series covers 10877 calendar years by sampling cores from Ocean Drilling Program (ODP) site 723, Hole A at 18° 03′ N, 57° 36′ E with water depth 807.8 m. The average age interval per sub-sample is about 133 years (ranging from 53 to 166 years). Cooling of the sea surface associated with coastal and open ocean upwelling promotes the blooming of distinct fauna and flora, therefore, the decreases of GB (%) indicate the monsoon failures. Advantages of this proxy are: 1) its unique association with the summer monsoon for GB has a subpolar habitat and would be absent in the tropics except for wind-driven upwelling; 2) linear correlation with the surface cooling due to upwelling, apparently unbiased by other influences, and 3) strong sensitivity to wind speed and the intensity of monsoon. It is found that the summer monsoon was strong during 8−12 ka BP and gradually weakened from 8 ka BP to 1.5 ka BP, showing a close relation to the variations of July solar radiation at 65° N. Millennial scale climate oscillations manifested well when the trend of the climate was removed from the origional series. No.6 in Table 1 shows the chronology of the southwest monsoon failures.

de Menocal *et al.* [7] investigated low-latitude climate variability during the Holocene, and demonstrated that high- and low-latitude climates were coupled by quantifying past SST variations preserved in a well-dated, high-accumulation-rate sediment core off West Africa. ODP Hole 658C was cored off Cap Blanc, Mauritania (20° 45′ N, 18° 35′ W, 2263 m water depth). Sediment accumulation rates are 22 cm/ka average. The core was sub-sampled at 2 cm intervals, which is equivalent to a 50−100 years time resolution. The core of 4 m long provides climate information for the last 24 ka. Warm and cold season SST estimates were calculated from the census counts of the foraminiferal assemblage. The reconstructed SST variations demonstrate that the Holocene interval at subtropical Atlantic was punctuated by a series of millennial scale cold events, which infer the strengthening of the trade, namely the weakening of the monsoon. No.7 in Table 1 outlines the age of the events.

Zhou *et al.* [8] examined the peat record of Zoigê Plateau (32° 48′ N, 102° 32′ E), with an altitude of 3505 m. The profile cored has a depth of 4.5 m, and consists of brown to dark brown acid peat with a large amount of undecomposed plant residues from just above the 4m level. The core, which covers about 13 ka, was sub-sampled at 1cm intervals, it is relative to a time resolution of 10−30 years. The percentage of organic carbon can be considered indirectly as the indicators of vegetation cover and biomass, reflecting the intensity of monsoon precipitation. The color of the sediment bears a close relationship to the sedimentation environment. There were 9 climatic events, which can correlate with ice rafting events from the North Atlantic. The first in 12.8 ka BP may relate to the YD event. However, Zhou *et al.* [8] indicated that some cold-dry events, for example, in 3.7, 6.4, 6.8 and 8.9 ka BP, are also found in the series except the 9 events mentioned above. They might reflect the local or regional characters in environmental variations. No. 8 in Table 1 shows the ages of the events.

Hong *et al.* [9−10] analyzed the proxy record of the East Asian summer monsoon (EAM) and Indian Ocean summer monsoon (ISM) from the $\delta^{13}C$ data of the plant cellulose of the peat bog in Hani of Northeast China (42° 13′ N, 126° 31′ E) and in Hongyuan of the Tibetan Plateau (32° 46′ N, 102° 30′ E). The Hani peat bog is at an altitude of 900 m. The core of about 8 m was sub-sampled at intervals of 1cm, equivalent to a mean time resolution of 20 years. The Hongyuan peat bog is at an altitude of 3466 m. The core with a length of 4.95 m was sub-sampled at intervals of 1cm corresponding to a mean time resolution of 30 years. In the period before ca. 5.0 ka BP, the intensity of EAM tended to gradually weaken while the intensity of ISM tended to gradually strengthen, and then the EAM gradually strengthened while the ISM weakened. The maximum intensity of ISM was found in ca. 6.0 ka BP, while the minimum intensity of EAM appeared in 5.0−6.0 ka BP. Millennial scale oscillations showed close correspondence to the IRD events at high northern latitudes. The ISM was weaker while the EAM was stronger in the IRD events (No.9 and No.10 in Table 1).

3 Discussion

The high-resolution proxy climate series reveal the occurrence of millennial scale oscillations in the Holocene. Present paper aims at the examination of the chronology of the cold events over the North Atlantic and the monsoon failures in the Asian-African monsoon region. The results show that the nine cold events in the Holocene were accompanied by the monsoon failures. It is an important mode in the variations of palaeo-climate.

The climatic meaning of IRD events is very clear and accurate. However, the interpretations of precipitation variations need to be further confirmed with observations. For example, Wang *et al.* [4] examined the variations of the East Asian summer monsoon using the sediment in the South China Sea. However, modern observations indicated that the East Asian summer monsoon correlates best to the variations of precipitation in North China. Weak correlation between monsoon index and precipitation in South China may relate to the activity of ITCZ, but not to the monsoon directly. The relationship between ISM and the precipitation over the Plateau remains to be confirmed with more observations, and uncertainty might occur in the deduction of the climate conditions of the events outlined in Table 1.

Besides, Maslin *et al.* [11] studied the variations of rainfall over the Amazon Basin by using four indices. These series show some distinct dry periods in the times when cold events occurred over the North Atlantic, although they do not demonstrate regular millennial scale oscillations as in IRD events or in some monsoon records. For example, severe droughts were found in 3.0 ka BP in the sediment of ODP-1002, and in 7.5−8.5 ka BP in the sediment of ODP-942. Variations of lake level of Junin show the occurrence of dry periods in 1.2, 2.0, 3.2, 4.0, 4.8, 6.2, and 7.5 ka BP. As Maslin *et al.* [11] indicated that great discrepancies occurred between the series, so they are not included in Table 1.

Of course, the chronology as shown in Table 1 needs to be improved with updated records, and new data sources should be further exploited.

References

[1] O'Brien S R, Mayswski P A, Meeker L D, *et al*. Complexity of Holocene climate as reconstructed from a Greenland ice core [J]. Science, 1995, 270: 1962−1964.

[2] Bond G, Showers W, Cheseby M, *et al*. A pervasive millennial-scale cycle in North Atlantic Holocene and glacial climates [J]. Science, 1997, 278: 1257−1266.

[3] Bianchi G G, McCave I N. Holocene periodicity in North Atlantic climate and deep-ocean flow south of Iceland [J]. Nature, 1999, 397: 515−517.

[4] Wang L, Sarnthein M, Erlenkenser H, *et al*. Holocene variations in Asian monsoon moisture: A bidecadal sediment record from the South China Sea [J]. Geophy. Res. Lett., 1999, 26 (18): 2889−2892.

[5] Overpeck J, Anderson D, Trumbore S, *et al.* The southwest Indian monsoon over the last 18000 years [J]. Climate Dynamics, 1996, 12: 213−225.

[6] Gupta A K, Anderson D M, Overpeck J T. Abrupt changes in the Asian southwest monsoon during the Holocene and their links to the North Atlantic Ocean [J]. Nature, 2003, 421: 354−357.

[7] de Menocal P, Ortiz J, Guilderson T, *et al*. Coherent high- and low-latitude climate variability during the Holocene warm period [J]. Science, 2000, 288: 2198−2202.

[8] Zhou Weijian, Lu Xuefeng, Wu Zhengkun, *et al*. Peat record reflecting Holocene climatic change in the Zoigê Plateau and AMS radiocarbon dating [J]. Chinese Science Bulletin, 2002, 47 (1): 66−70.

[9] Hong Y T, Hong B, Lin Q H, *et al*. Correlation between Indian Ocean summer monsoon and North Atlantic climate during the Holocene [J]. Earth Planet Sci. Lett., 2003, 211: 371−380.

[10] Hong Y T, Hong B, Lin Q H, *et al*. Inverse phase oscillations between the East Asian and Indian Ocean summer monsoons during the last 12000 years and paleo-El Niño [J]. Earth Planet Sci. Lett., 2005, 231: 337−346.

[11] Maslin M, Pike J, Stickley C, *et al.* Evidence of Holocene climate variability in marine sediments [C] // Mackecy A, Battarbee R, Birks J, *et al*. Global Change in the Holocene. London: Arnoed, 2003: 185−209.