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Cold Periods During the Last Millennium

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ABSTRACT

Studies of temperature change during the last millennium in China and in other regions of the globe were reviewed. Cold periods were identified for East Asia, USSR, Europe, North America, Polar Region and Southern Hemisphere. Most of them were grouped into the same time intervals: first half of 12th, second half of 13th, second half of 15th, 17th and 19th century. Temperatures in the last two cold periods were 0.5°C-1.0°C lower than the average of the 20th century. The first three cold periods were less cold and less uniform in geographical distribution and in temporal variations. Therefore, the first three cold periods may be regarded as the transition from the Medieval Warm Period to the Little Ice Age. Long-term variations of solar activity and volcanism were compared with the changes of temperatures. The second to the fourth cold periods seem to relate to the Wolf, Spörer, and Maunder Minima of solar activity. The intensification of explosive volcano eruptions in early 15th and 17th century may also have contributed to the occurrence of the third and fourth cold periods. However, only a slight increase of volcanism and a weak decrease in solar activity in the early 19th century can hardly fully intepret the severe cold period throughout the 19th century. Perhaps neither one nor both of the aforementioned factors can be responsible for all of the five cold periods identified during the last millennium. It is suggested that the changes in cryosphere, biosphere and the oceans may interact with the atmosphere, controlling (together with the external factors) the occurrence of the cold periods. Of course, anthropogenic factors should also be considered, especially for the last one and a half centuries. Finally, factor or factors other than those aforementioned, such as changes in orbital parameters, may also take part in regulation of the climate for the last millennium.

(Key words: Historical records, Paleoclimate, Temperature, China)

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1. INTRODUCTION

Recently, climatic change during the last millennium was studied with greater and greater interest, because it is important not only for examining the mechanism and causes of natural variability of the climate in the past, but also for detection of the greenhouse effect at the present time and for prediction of climatic change in the future. Most notably, an International Symposium on the Little Ice Age climate was held at Tokyo, Japan 25-27 September 1991 and a Workshop on the Medieval Warm Period was convened at Tucson, the U.S. 5-8 November, 1991. Meanwhile, a series of papers has been published in the last decade. Present paper aims at reviewing recent research works, comprising the state of the art in reconstruction of the palaeo-climate, solar activity and volcanism, and finally providing a schematic picture of the temperature changes, especially the cold periods within the last millennium, and a preliminary interpretation of the latter.

2. COLD PERIODS SINCE A.D. 1000

East Asia: Curves in Figure 1 show the temperature changes in East Asia. The curve (d) was reproduced from the famous paper of Chu (1973). Curve (e) shows the 50-year running mean temperature anomalies in China referred to the average of the period from the 1880s-1970s. Horizontal lines correspond to the average of the last millennium (Wang 1991). Both the curves (d) and (e) were reconstructed on the basis of documentary records. However curve (e) was found from the average of four seasons, whereas curve (d) has a bias towards winter time, so shows a bigger amplitude than (e). Figure 1f was based on oxygen isotopes in an ice core from the Dunde ice cap in the Qinghai-Tibetan Plateau (Thompson *et al.* 1989). Good parallelism between curves (e) and (f) demonstrated the reliability of the reconstruction based on documentary records. The two curves of Japan (Figure 1b and 1c) show some resemblance to China, but the cold period in 19th century seems stronger than that in China. Figure 1a indicates that the cold periods over the Himalayas occurred in the 13th, 15th, and 18th to 19th century. It is generally in accordance with that in China and in Japan. Finally, five cold periods over East Asia are schematically shown on the bottom of Figure 1 with blank or shaded checks, which represent the cold and severe cold periods respectively. (The former or latter has an anomaly about -0.5° or -0.5°C to -1.0°C.)

USSR: Klimanov (1992) has carried out a comprehensive review of studies on climate change in the former USSR. Various proxy data were applied in the analysis: glacier fluctuations, lake level changes, documentary records, dendrochronological records, pollen data, lichenometry data and isotopic carbon data. The area examined started in the west from Estonia (26°E) and ended in eastern Siberia (125°E). Great geographical coverage of the study ensures the representativeness of the result. Because of limitations of space in this paper, only four curves are shown (Figure 2). The cold periods synthesized are shown on the bottom of Figure 2 as in Figure 1.

Europe: A lot of papers have been contributed to the study on the climate change in historical time over Europe. Two curves are given in Figure 3; one was the classical temperature series of central England, which is based on both instrumental observations and documentary records (Lamb 1977), another is the schematic presentation of fluctuations of the Grosser Aletsch Glacier (Holzhauser and Zumbuhl 1988). Pfister (1992) has compared the latter with the results of the study based on documentary records. Very good accordance was found. Four cold periods are outlined at the bottom of Figure 3.

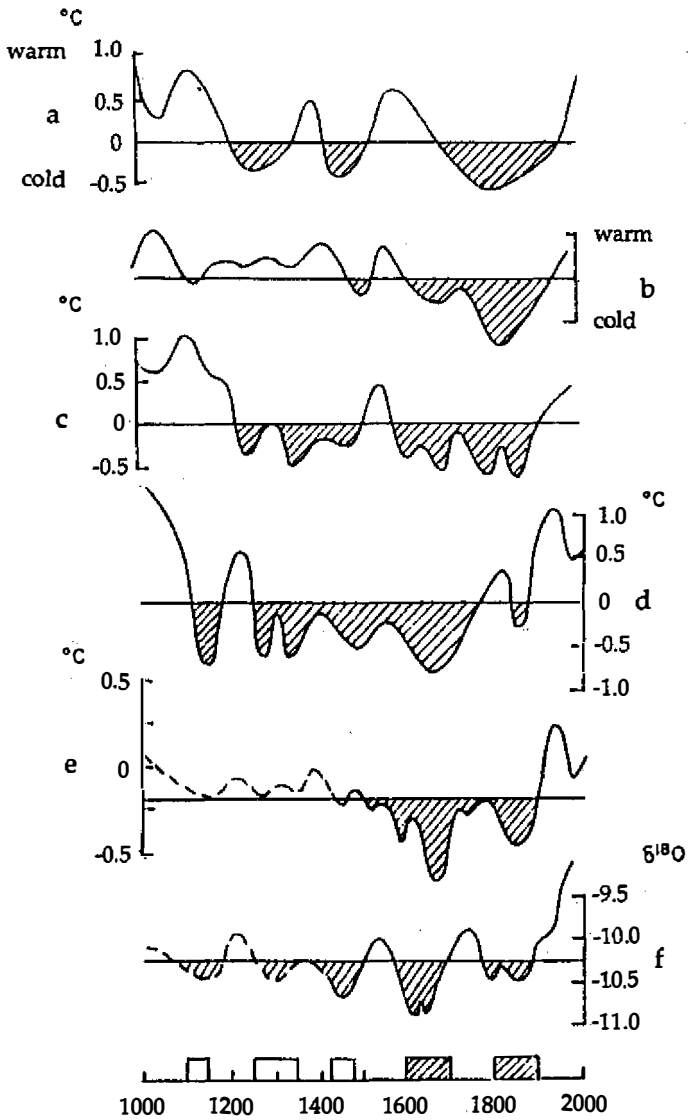

Fig. 1. Temperature changes in East Asia. (a. Kalakunlum Himalaya, glacier (Rothlisberger 1986); b. Japan, documentary records (Tagami 1992); c. Japan, documentary records (Takahasi 1980); d. China, documentary records (Chu 1973); e. East China, documentary records (Wang 1991); f. West China, ice core $\delta^{18}O$ (Thompson *et al.* 1989))

North America: Scuderi (1987) has correlated the tree-ring indices of California with glacier fluctuations. Six cold periods were found. The first two in the 13th and 14th centuries were called "early Matthes," the name of the author who invented the terminology of the Little Ice Age. The last four cold periods were concentrated between A.D. 1450 and 1850 (Figure 4a). Another tree-ring series of California is shown in Figure 4c (LaMarche 1974). The narrowing of the tree-ring widths in the middle of the 13th century, from the middle to

late 15th century and in the 17th and early 19th century were synchronous in both curves of the tree-ring series. However, a study on pollen data of north western Lower Michigan (Bernabo 1981) shows somewhat different characteristics to the tree-ring data (Figure 4b). It shows a prolonged cold period between A.D. 1450 and 1850. The discrepancy may depend on the poor time resolution of pollen data. This notwithstanding, most of the troughs in Figure 4b are in accordance with that in Figure 4c. Six generally common cold periods were identified for North America and shown at the bottom of Figure 4.

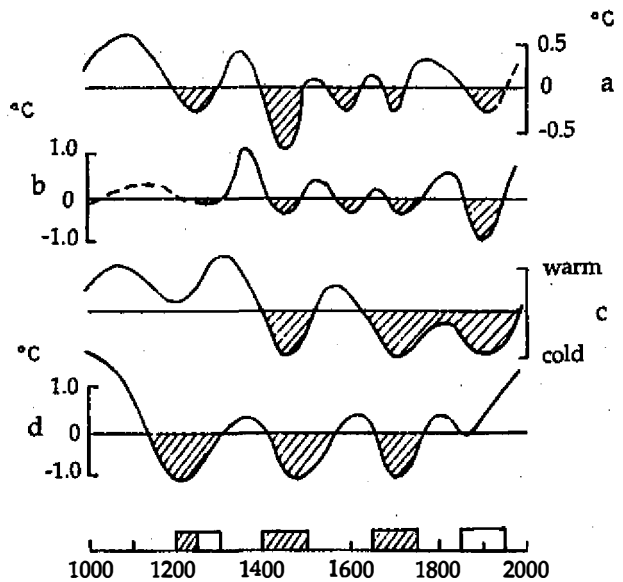

Fig. 2. Temperature changes in the former USSR. (a. West former USSR, documentary records (Voronov 1990); b. Central former USSR, documentary records (Lykhov 1988); c. Alps, glacier (Rothlisberger 1986); d. Estonia, pollen (Klimanov *et al.* 1985))

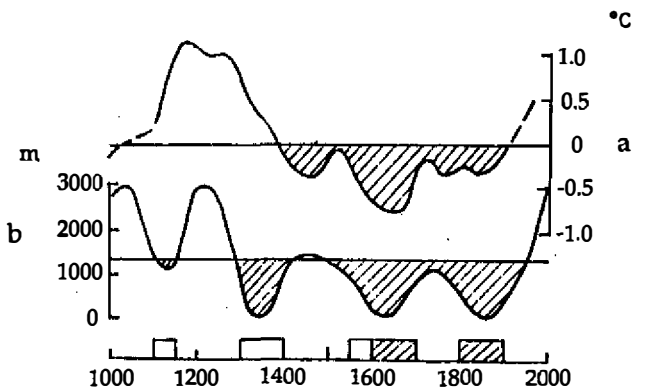

Fig. 3. Temperature changes in Europe. (a. Central England, documentary and observational data (Lamb 1977); b. Central Europe, glacier (Holzhauser and Zumbuhl 1988))

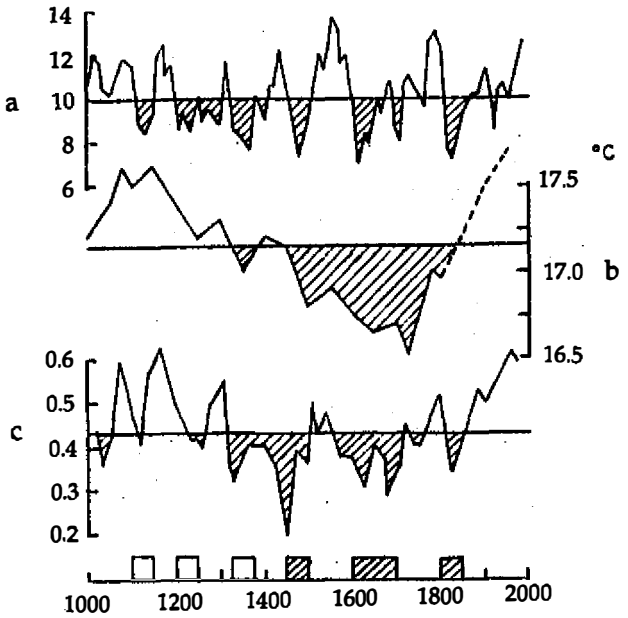

Fig. 4. Temperature changes in North America. (a. California, tree-ring (Scuderi 1987); b. Marion lake, pollen (Bernabo 1981); c. California, tree-ring (LaMarche 1974))

Polar Region: Temperature data were very scarce in Polar Regions. Fortunately, data of sea ice and of oxygen isotopes in ice cores supplied the gaps. Ice cores from Devon Island (Patterson *et al.* 1977) and from Greenland (Robin 1983) provide a quantitative measure of the temperature changes (Figure 5). Temperature series reconstructed from tree-ring data (Briffa 1992) and from sea-ice records (Bryson 1974) present evidences for the occurrence of cold periods in the 12th to 13th and 17th to 19th centuries. The cold period in the second half of the 15th century was unstable and relatively weak in the two latter curves.

Southern Africa: Until very recent time, climate change during the last millennium in Southern Africa was rarely known. Tyson and Lindsay (1992) have reviewed studies on oxygen isotope analysis of cave speleothems and mollusk remains in shell middens, on the foraminifera of inshore marine deposits, palynological and micromammalian fossils, and on tree-ring data. However, one can hardly find any characteristics which are common to the Northern Hemisphere. A prolonged cold period was found from A.D. 1300 to 1650, and since 1650 temperature generally increased. That is contrary to the trend found elsewhere on the globe. Another group of proxy temperature series showed that the 11th, 14th and 18th centuries were colder than the others. However, these centuries were relatively warmer in the Northern Hemisphere. Does this discrepancy depend on the regionality of the climate change, or on the difference of data sources? This has yet to be understood.

Other Regions of the Southern Hemisphere: Despite the significant discrepancy found between temperature changes in Southern Africa and in the Northern Hemisphere, a series of temperature reconstructions for other regions of the Southern Hemisphere showed good

accordance with the Northern Hemisphere. For example, Thompson *et al.* (1986) demonstrated close correlation between decadal temperature anomalies in the Northern Hemisphere (which were reconstructed by Groveman and Landsberg 1979), and the oxygen isotope record of an ice core from Quelccaya Ice Cap, Peru. Figure 6 shows three series of oxygen isotope and one of a temperature reconstruction for New Zealand based on stalagmite anomaly measurements (Wilson *et al.* 1979). The cold periods are summarized and schematically shown at the bottom of Figure 6. It confirms the general contemporaneity of cold periods in the Northern Hemisphere and in some areas of the Southern Hemisphere.

New evidence on temperature changes during the last millennium are being found all the time. Therefore, the results outlined above should be considered as preliminary, and will be improved with more data sources.

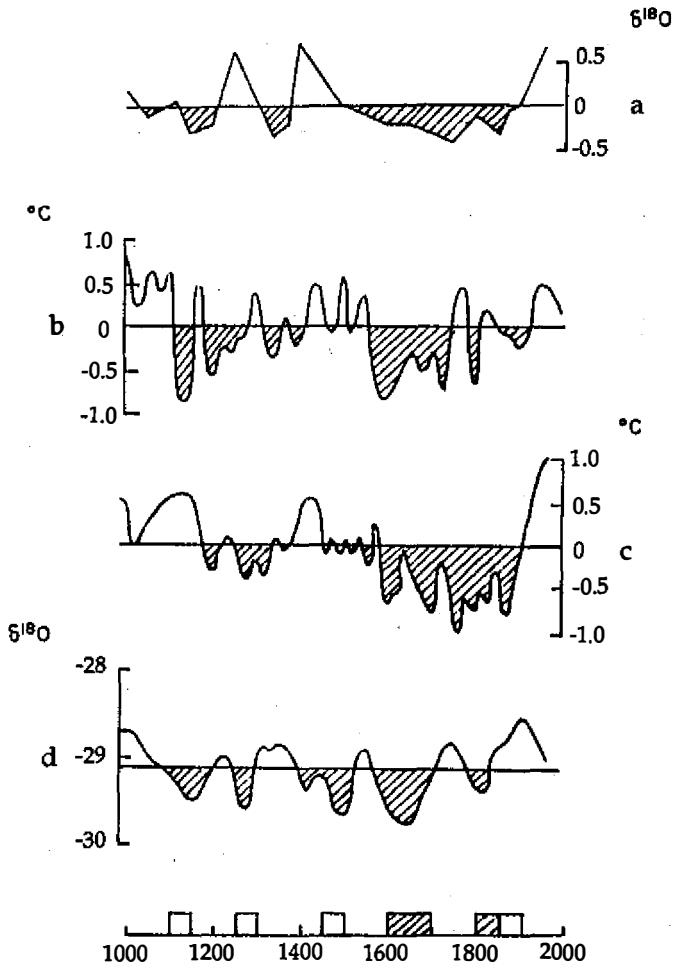

Fig. 5. Temperature changes in Polar Region. (a. Devon Island, ice core δ^{18}C (Patterson *et al.* 1977); b. Northern Fennoscandia, tree-ring (Briffa 1992); c. Iceland, documentary records (Bryson 1974); d. Greenland, ice core δ^{18}O (Robin 1983))

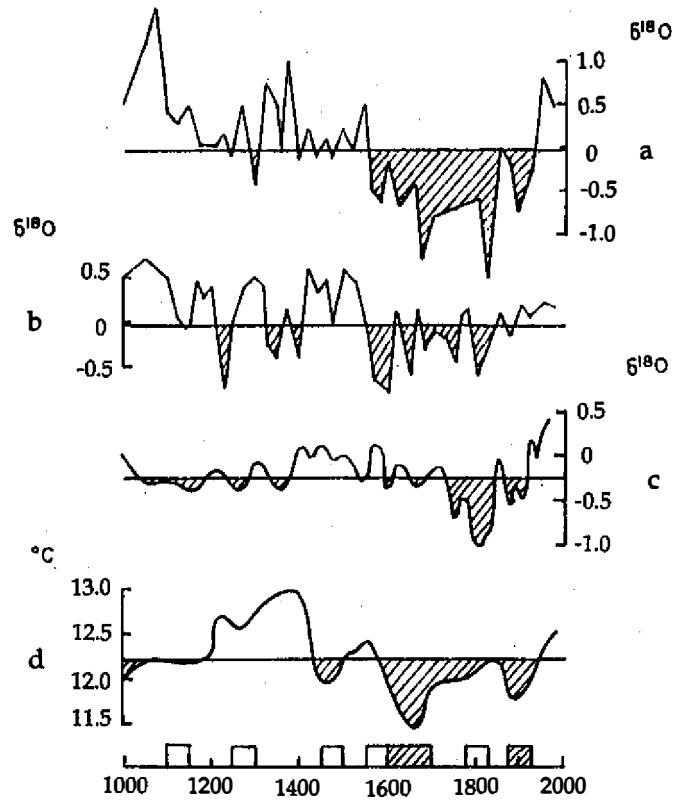

Fig. 6. Temperature changes in the Southern Hemisphere except Southern Africa. (a. Peru, ice core $\delta^{18}O$ (Mosley-Thompson *et al.* 1990); b. Antarctica, South Pole Station, ice core $\delta^{18}O$ (Mosley-Thompson *et al.* 1990); c. Antarctica, Low Dome ice core $\delta^{18}O$ (Morgan 1985); d. New Zealand, stalagmite (Wilson *et al.* 1979))

3. THE "LITTLE ICE AGE", SOLAR ACTIVITY AND VOLCANISM

The cold periods identified for East Asia, USSR, Europe, North America, Polar Region and the Southern Hemisphere are reproduced in Figure 7. However, Southern Africa showed quite different cold periods, so those were not included in Figure 7. Five cold periods were synthesized for the globe; the first half of 12th, second half of 13th, second half of 15th, 17th and 19th centuries. The first three cold periods were relatively weak, with temperature anomalies probably less than -0.5°C compared to the average of the last millennium. The last two cold periods are characterized by severe climate, and temperature anomalies may have varied between -0.5°C to -1.0°C. Lamb (1977) had suggested that the "Little Ice Age" lasted from A.D. 1550 to 1850. However, the climate deterioration began much earlier, after the "Medieval Warm Period" (A.D. 900-1300) so some authors suggested that the "Little Ice Age" was started by the end of Middle Ages at around A.D. 1250 (Porter 1986). Considering that the first three cold periods identified above were relatively weak, and the timing of them varies significantly from region to region, they could be regarded as the precursor of, or the transition to, the "Little Ice Age," rather than a stage of it.

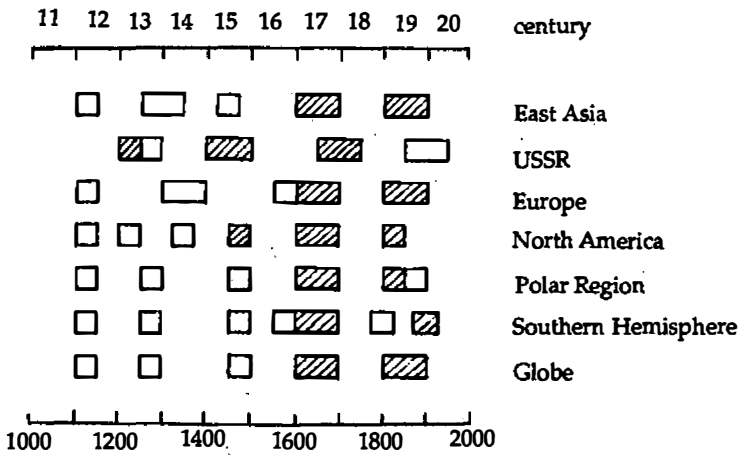

Fig. 7. Schema of the occurrence of cold periods during the last millenium, blank or shaded checks show the cold or severely cold periods.

The planetary scale of the cold periods during the last millennium suggests that they were controlled by the same scale of forcing factor or factors, for example, solar activity and volcanism. Figure 8a and Figure 8b outline the solar activity during the last millennium. The former was based mainly on documentary records of sunspots observed by the naked eyes (Schove 1955). The latter came from quantitative carbon isotope data (Stuiver and Quay 1980). Both of them show very similar secular changes, including the famous Wolf, Spörer, and Maunder Minima. Figure 8c shows volcanism detected from the acidity of an ice core from the Greenland Ice Cap (Porter 1986). The cold periods identified above are shown on the bottom of Figure 8 for comparison. The second cold period in 13th, the third one in 15th and the fourth one in 17th century were more or less concomitant with the minima of solar activity. The two maxima of volcanism (scale of ordinate is reversed downward) seem also to contribute to the occurrence of the third and fourth cold periods. However, the first cold period is difficult to interpret either from the record of solar activity or from the volcanism. A weak minimum of solar activity was found in the 11th rather than in the 12th century. The maximum of volcanism in the 12th century was too weak to be responsible for the cold period. The fifth cold period in the 19th century can hardly be attributed to the weak minimum of solar activity and maximum of volcanism in the early 19th century, for the last cold period was quite severe, and was the coldest period for the last millennium in some area. So, neither just solar activity nor volcanism, nor both of them, can account for all of the five cold periods during the last millennium.

It is suggested that factor or factors other than those above mentioned have taken part in regulation of the earth climate. First of all, internal interaction between the components of early climate system may be considered. The cryosphere, biosphere and the oceans may actively react to climatic change and significantly modulate the latter on different time scales. Secondly, other external factors may also be important in interpreting climatic changes during the last millennium. For example, recently Loutre *et al.* (1992) emphasized the role of the the earth's orbital parameters in modulation of the climate on the decadal to century time scale. Finally, the cold periods identified above seem also to need modification, and the average temperature should be found with greater accuracy with improved numbers of data sources. Then, the climatic change during the last millennium can be interpreted on a new basis.

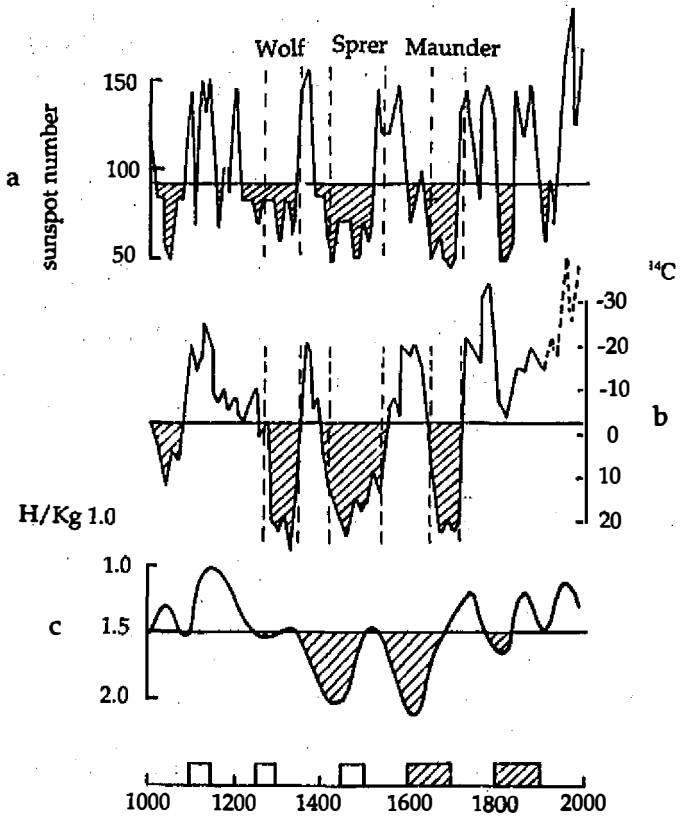

Fig. 8. Solar activity and volcanism for the last millennium. (a. Solar activity and volcanism for the last millenium (Schove 1955, observations updated); b. ^{14}C production rate (ΔQ_M) (Stuiver and Quay 1980); c. Greenland Ice Sheet acidity (Porter 1986))

REFERENCES

Bernabo, J. C., 1981: Quantitative estimates of temperature changes over the last 2700 years in Michigan based on pollen data. *Quat. Res.*, **15**, 143-159.

Briffa, K. R., 1992: Dendroclimatological reconstructions in Northern Fennoscandia. In: T. Mikami (Ed.), Proc. Int'l Symposium on the Little Ice Age Climate. Tokyo Metropolitan University, 25-27 September 1991, 5-10.

Bryson, R. A., 1974: A perspective on climatic change. *Science*, **184**, 753-760.

Chu K., 1973: A preliminary study on the climatic change during the last 5000 years in China. *Scientia Sinica (B)*, **16**, 226-256.

Groveman, B. S., and H. E. Landsberg, 1979: Reconstruction of the Northern Hemisphere temperature, 1579-1880. University of Maryland, Department of Meteorology, Publ. No. 79, 181-182.

Hammer, C. U., H. B. Clausen, and W. Dansgaard, 1980: Greenland ice sheet evidence of post-glacial volcanism and its climatic impact. *Nature*, **288**, 230-235.

Holzhauser, H., and H. Zumbuhl, 1988: Alpine glaciers in the Little Ice Age. *Die Alpine*, **64/3**, 130-322 (in German).

Klimanov, V. A., 1992: Climatic changes in Little Ice Age on the Plains of the USSR. In: T. Mikami (Ed.), Proc. Int'l Symposium on the Little Ice Age Climate. Tokyo Metropolitan University, 25-27 September 1991, 58-64.

LaMarche, V. C., Jr., 1974: Paleoclimatic inferences from long tree-ring records. *Science*, **183**, 1043-1048.

Lamb, H. H., 1977: Climate, Present, Past and Future. Methuen, London, p.835.

Loutre, M. F., A. Berger, P. Bretagnon, and P-L. Blanc, 1992: Astronomical frequencies for climate research at the decadal to century time scale. *Climate Dynamics*, **7**, 181-194.

Morgan, V. I., 1985: An oxygen isotope-climatic record from the Law Dome, Antartica. *Climatic Change*, **7**, 415-426.

Mosley-Thompson, E., L. G. Thompson, P. M. Grootes, and N. Gundestrup, 1990: Little Ice Age (Neoglacial) paleoenvironmental conditions at Siple Station, Antarctica. *Ann. Glaciology*, **14**, 199-204.

Patterson, W. S. B., R. M. Koerner, D. Fisher, S. J. Johnsen, H. B. Clausen, W. Dansgaard, P. Bucher, and H. Oeschger, 1977: An oxygen-isotope climatic record from the Devon Island Ice Cap, Arctic Canada. *Nature*, **266**, 508-511.

Pfister, C., 1992: Five centuries of Little Ice Age climate in western Europe. In: T. Mikami (Ed.), Proc. Int'l Symposium on the Little Ice Age Climate, Tokyo Metropolitan University, 25-27 September 1991, 208-213.

Porter, S. C., 1986: Pattern and forcing of Northern Hemisphere glacier variations during the last millennium. *Quat. Res.*, **26**, 27-48.

Robin, G. deQ., 1983: The Climate Record in Polar Ice Sheets. In: G. deQ. Robin (Ed.), Cambridge University Press, p.101.

Schove, D. J., 1955: The sunspot cycle, 649 B.C. to A.D. 2000. *J. Geophys. Res.*, **60**, 127-146.

Scuderi, L. A., 1987: Glacier variations in the Sierra Nevada, California, as related to a 1200-year tree-ring chronology. *Quat. Res.*, **27**, 220-231.

Stuiver, M., and P. D. Quay, 1980: Changes in atmospheric carbon-14 attributed to a variable sun. *Science*, **207**, 11-19.

Thompson, L. G., E. Mosley-Thompson, W. Dansgaard, and P. M. Grootes, 1986: The Little Ice Age as recorded in the stratigraphy of the tropical Quelccaya Ice Cap. *Science*, **234**, 361-364.

Tyson, P. D., and J. A. Lindsay, 1992: The Little Ice Age in Southern Africa. In: T. Mikami (Ed.), Proc. Int'l Symposium on the Little Ice Age Climate, Tokyo Metropolitan University, 25-27 September 1991, 18-32.

Wang, S. W., 1991: Reconstruction of palaeo-temperature series in China from the 1380's to the 1980's. *Wurzburger Geographishe Arbeiten*, **80**, 1-19.

Wilson, A. T., C. H. Hendy, and C. P. Reynolds, 1979: Short-term climatic change and New Zealand temperatures during the last millennium. *Nature*, **279**, 315-317.