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High latitude Eurasian paleoenvironments: introduction and synthesis

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Abstract

This special issue developed partly from the open PAGES conference held in Moscow in May 2002. The dominant theme of the present collection of articles is the Late Pleistocene and Holocene paleoenvironmental history of Northern Eurasia-from the White to the Black Sea and from the Estonia to the Kurile Islands.

Here, we briefly summarize the available paleorecords from the FSU territory covering the last 1500 years. A number of records allow one to distinguish the climatic pattern of the 9th–13th centuries from earlier and later colder conditions in the Kola peninsula, Urals, Taymir, Russian Plain, Caucasus and East Siberia. The 10–12th centuries were also slightly warmer in the Far East (Kurile Islands). The warming of the 14th century in several regions, including the Russian plain, Altai and Central Asia, was at least as intense as the earlier one at ca. 1 kyr before present or even warmer. The available data for this time period remain controversial in the arid area of Central Asia. Records from the Caspian Sea area suggest moderate temperature and relatively high humidity in the first half of the millenium, whereas in the Tien Shan mountains, the beginning of the millenium seems to have been warm and dry. Various line of evidence suggest a climatic deterioration in the second half of the last millenium throughout the FSU, including the European part, Siberia, the Caucasus,the mountains of the Central Asia, the Far East and the Arctic archipelagoes.

Keywords: Former Soviet Union; Northern Eurasia; Late Pleistocene; Holocene; Last Millenium; paleoclimate; Little Ice Age; Medieval Warm Period

1. PAGES in Moscow

PAGES is an international scientific program promoting international and interdisciplinary cooperation in paleoenvironmental research. The first open PAGES conference within the vast territory of the former Soviet Union was held in Moscow in May 2002. This event brought together more than 100 local paleoenvironmental researchers from Bellarussia, Estonia, Georgia, Kyrgyzstan, Russia, Ukraine and Uzbekistan. Another 30 scientists from 18 additional countries, including the PAGES Scientific Steering Committee, were also in attendance. The meeting provided a unique opportunity for paleo-researchers from a diverse set of sub-disciplines, the majority of whom had never met each other before, to strengthen their community, to interact, and to showcase their work for the international community. Although the primary benefits of the meeting were

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almost certainly community building and the fostering of new scientific ideas and collaborations, we hope that the present collection of selected papers, as a secondary output of the meeting, will continue and support this effort to promulgate the wealth of paleoenvironmental archives and active paleoenvironmental researchers, in high latitude Eurasia.

The dominant theme of the present collection of articles is the Late Pleistocene and Holocene paleoenvironmental history of Northern Eurasia—from the White to the Black Sea and from Estonia to the Kurile Islands (Fig. 1). A broad variety of environmental archives, such as tree-rings marine and lake sediments, and proxies, such as pollen, diatoms and stable isotopes are employed. Although this issue, and the conference from which it arose, cannot possibly represent the entire spectrum of paleoenvironmental research in the Former Soviet Union, they do provide a glimpse at the vast range of past accomplishments and future possibilities. Given the wide-ranging scope of the special issue drawing out a main set of conclusions is a formidable task. Nonetheless, we seek, in this introduction to provide a synthesis and provide at least a flavor of the much richer, more detailed, contributions to follow.

2. General climatic trends of the last few millennia

Over the past decade, understanding of hemispheric to global scale climatic evolution of the last millennium has improved dramatically. This progress has been due primarily to the advent of annually resolved time series calibrated against instrumental meteorological data. In particular, the degree and extent of, as well as plausible forcing mechanisms for, events such as the Medieval Warm Period (MWP) and the Little Ice Age (LIA) are coming increasingly into focus (Hughes and Diaz, 1994; Bradley and Jones, 1992; Grove, 1988; Grove and Switsur, 1994; Mann et al., 1998; Esper et al., 2002; Olgivie and Jonsson, 2001; Bradley et al., 2003). The once accepted tenet of a globally ‘warm’ MWP around AD 900–1250 followed by a global LIA cooling from around AD 1250–1850 has been replaced by a much more detailed mosaic of climatic variations occurring at different times in different parts of the world. Furthermore, considerable debate remains as to fundamental questions relevant to detecting and attributing anthropogenic climate change, such as whether recent decades have been warmer than the MWP or not. In order to make progress, it has become necessary to clearly identify how various proxy cli-

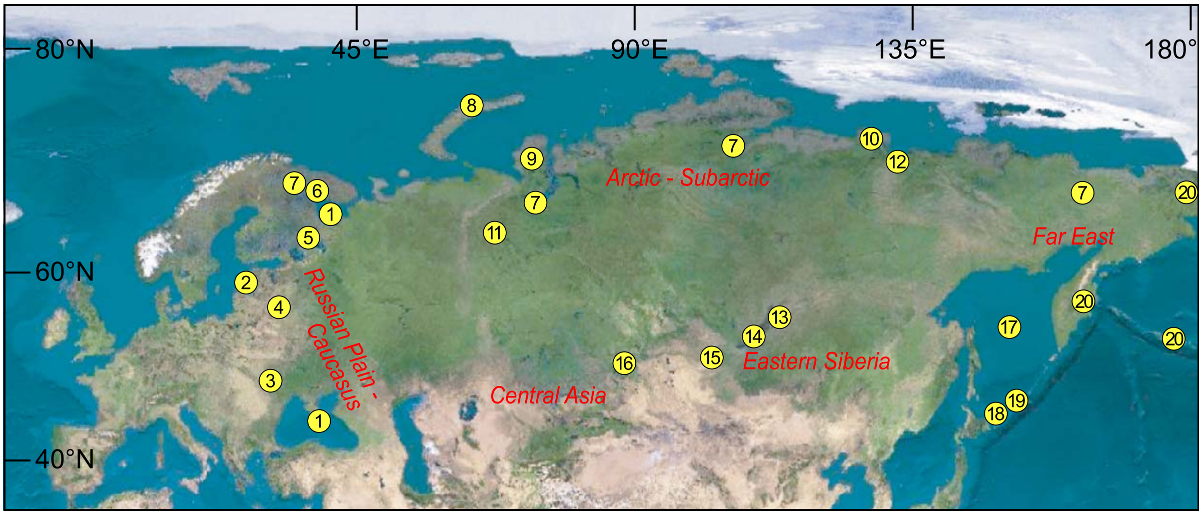

Fig. 1. Map of northern Eurasia. The locations corresponding to the papers in this special issue are indicated by the yellow dots. (1) Kaplin and Selivanov, (2) Poska et al., (3) Huhmann et al., (4) Makhnach et al., (5) Kozlov and Kisternaya, (6) Kremenetski et al., (7) Raspopov et al., (8) Murdmaa et al., (9) Hantemirov et al., (10) Bobrov et al., (11) Agafonov et al., (12) Andreev et al., (13) Osipov, (14) Karabanov et al., (15) Fedotov et al., (16) Blyakharchuk et al., (17) Gorbarenko et al., (18) Jacoby et al., (19) Razjigaeva et al., (20) Savinetsky et al. The regions discussed in this synthesis and introduction are labeled in red.

mate records are influenced by an enormous range of effects, including, for example, seasonality, time resolution, differential preservation of long-term versus short-term signals, and statistical methods of quantification and smoothing.

A primary goal of ongoing and future research into climate variability of the past millennium will certainly be the elucidation of the myriad temporal and regional details, including identification of hemispheric and long-term trends, but also regional signals and high-frequency variations. Such regional reconstructions will allow the LIA and MWP to be understood in a global context and in the perspective of the entirety of the warm climatic background state that has existed since the last glaciation. Here we attempt to provide a synopsis of information that would allow one such reconstruction by briefly summarizing the available paleorecords from the FSU territory covering the last 1500 years. The MWP has been well described based on a number of proxies in Western Europe and numerous studies have sought to investigate how far to the east (as well as to the north and south) it can be traced. The Little Ice Age is well documented throughout the FSU, mostly in tree-ring records (Shiyatov, 1986, 2003; Vaganov et al., 1996; Hantemirov and Shiyatov, 2002), glacier variations (Solomina, 1999) and documentary evidence (Borisenkov, 1988; Krenke and Chernavskaya, 2002). Therefore, we consider here only the most prominent markers of the LIA. We discuss both high- and low-resolution data, but only records with decent chronological control, though this approach strongly limits the available data set. We have broken the discussion into five regions: The Arctic and Sub-Arctic, The Russian Plain and Caucasus, Central Asia, Eastern Siberia, and The far East (Fig. 1). Following a brief overview of climatic history of these regions over the last millennium, we discuss the potential errors and biases of the methods employed to produce these histories and conclude with some general conclusions of the climatic changes over the entire region.

3. The Arctic and Sub-arctic

Recent tree-ring studies along the northern tree line, including both wood macrofossils and dendrochronology, have provided a detailed Holocene chronology of climatic changes in this area. On the Kola Peninsula, warm conditions from about 600 to 1200 AD is clearly documented by the presence of wood macrofossils found beyond the present, temperature controlled, upper tree limit (Fig. 2A, Hiller et al., 2001; Kremenetski et al., this issue). Various proxies suggest that this period was characterized both by relatively warm summers and low precipitation, as compared to modern conditions, throughout the year. In the Polar Urals, the upper timberline was above its modern position from the 9th to 13th centuries (Fig. 2C, Shiyatov, 1986, 2003). At the end of the 13th century, a degradation of larch forests began and lasted until the early 20th century. Climate in Yamal during the period AD 800–1400 was generally favorable for woody vegetation at the northern tree limit (Hantemirov and Shiyatov, 2002) (Fig. 2F).

Long, summer temperature sensitive tree-ring width chronologies from the Urals (Fig. 2D, Briffa et al., 1995), Yamal (Fig. 2G, Hantemirov and Shiyatov, 2002), Taymir (Fig. 2H, Naurzbaev and Vaganov, 2000) and Indigirka lowlands (Fig. 2I, Sidorova et al., 2003) all indicate cold summers in the early 19th, late 17th, early 16th, and 13th centuries, and warmer conditions in the late 6th, 10th and 20th centuries. The curves G, H and I (Fig. 2) are in fairly good agreement, though several peaks in the Polar Urals tree-ring curve are shifted in comparison with the others. Numerous shorter records including 25 tree-ring maximum density chronologies along the northern tree limit (Schweingruber and Briffa, 1996) clearly show the short, intense coolings around AD 1700 and in 1880s, and a long cooling in the first half of the 19th century, as well as a density decrease since the 1950–1960s. This very comprehensive study demonstrates, however, that none of these events was common to all chronologies from 42–152°E.

Additional proxy records from the Russian Arctic and Sub-Arctic, for example from ice cores, glacial landforms, borehole temperatures, marine and lacustrine sediments and pollen spectra, though potentially useful for the climatic reconstructions, are at present either less reliable or available only in lower resolution.

Ice cores have been obtained during the period from 1978 to 1999 from the Vavilova Ice cap (Oktyabr'skoy revoliutsii Island, Severnaya Zemlya), Akademii Nauk Ice Cap (Komsomolets Island, Severnaya Zemlia) and Vetreny Ice Cap (Graham Bell, FZL). They provide

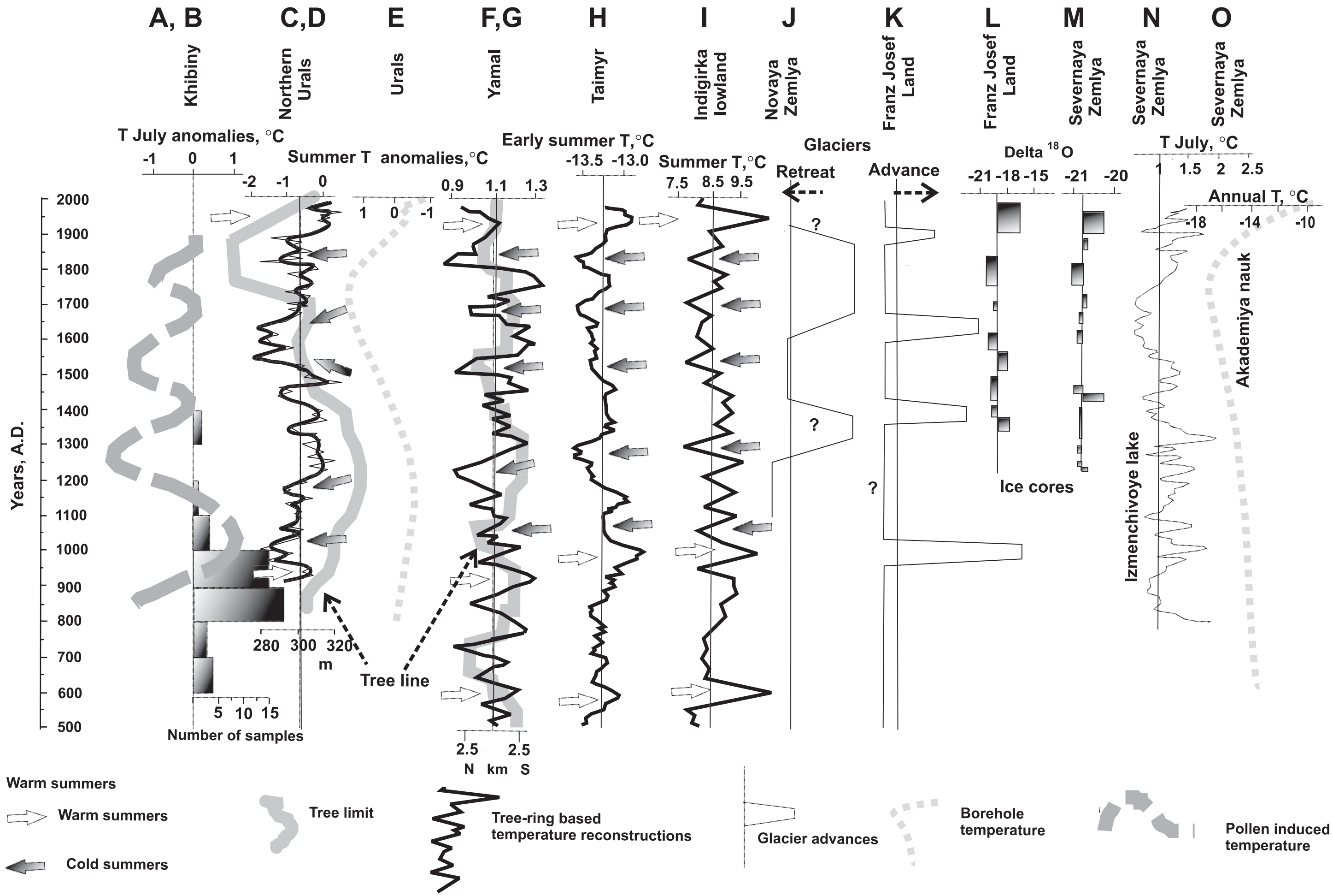

Fig. 2. Climatic proxy records from the Russian Arctic and Sub-Arctic. (A) Khibiny Mountains. Distribution of wood macrofossils from the upper tree limit (Hiller et al., 2001). (B) Khibiny Mountains. July temperature reconstructed from pollen analyses (Klimanov, 1997). (C) Northern Urals. Tree-ring based summer temperature anomalies (Briffa et al., 1995). (D) Northern Urals. Upper tree limit fluctuations (Shiyatov, 2003). (E) Urals. Annual mean temperature reconstructed from borehole measurements (Demezhko et al., 2003). (F) Yamal. Tree-ring based summer temperature. (G) Yamal. Northern tree limit variations (Hantemirov and Shiyatov, 2002). (H) Taymir. Tree-ring based summer temperature (Naurzbaev et al., 2002). (I) Indigirka lowlands. Tree-ring based summer temperature (Sidorova et al., 2003). (J) Novaya Zemlya glacier variations (Zeeberg and Forman, 2001; Murdmaa et al., this issue). (K) Franz Josef Land glacier variations (Lubinsky et al., 1999). (L) Franz Josef Land. Generalized oxygen isotope variations (Henderson, 2002, generalized). (M) Severnaya Zemlya. Generalized oxygen isotope variations (Henderson, 2002, generalized). (N) Severnaya Zemlya. July temperature derived from the annual sediment layer thickness in Lake Izmenchivoye (Bolshyanov and Makeev, 1995). (O) Severnaya Zemlya. Annual temperature reconstructed by the borehole measurements (Nagornov et al., 2001).

isotopically inferred annual temperature estimates for the last millennia, though the chronology of these data is still very contradictory due to the possible melting of annual ice layers. Recently Henderson (2002) revised the data and suggested a new chronology starting at AD 1200. Four data series from the Severnaya Zemlya and one from the Franz Josef Land all indicate a prominent warming since AD 1900 as well as colder conditions around AD 1800 and in the 17th century. Earlier variations are less consistent among the different records (Henderson, 2002, Fig. 2L, M).

Lacustrine deposits in the Birranga, Putorana and Polar Urals have been studied using the varvometric, pollen and diatom analyses (Bolshyanov and Makeev, 1995; Pavlov et al., 2002). According to these authors, the thickness of the sediment layers correlates positively with the air temperature. The authors did not find evidence supporting synchronous regional climatic fluctuations over the last 500 years, however, the lack of correspondence between their records may be due to poor chronological control. One of the best varve chronologies, from Izmenchivoye lake in Severnaya Zemlia (Fig. 2N) records warm periods in the 10th–11th, late 12th–mid 14th, late 15th–early 16th and 19th–20th centuries; cold phases are recorded in the 9th, late 11th–early 12th, mid 14th–mid 15th, and mid 16th–early 19th centuries.

The chronology of glacier variations in the Russian Arctic is poorly studied. The most comprehensive work is that of Lubinsky et al. (1999) who obtained numerous ^{14}C dates documenting four glacier advances in Franz Josef Land (Fig. 2K). One occurred in the 14th century and roughly coincides with the advance in the Novaya Zemlia (Fig. 2J) (Zeeberg and Forman, 2001; Murdmaa et al., 2003). High-resolution marine sediments from the Russkaya Gavan’ (Novaya Zemlya) indicate warm conditions in the 12th century and glacier advances in the 14th century and after about AD 1600 (Murdmaa et al., 2003) (Fig. 2J). The comparison of these records with isotopically inferred temperature from the GISP-2 ice core suggests that the glacier advance in the 14th century was most probably triggered by increased precipitation, whereas the more prominent advances in the 17th century may be in response to colder temperatures. According to regional tree-ring records (Fig. 2A–E), all of these glacier advances roughly coincide with warm conditions. Thus, it remains an issue of debate as to whether temperature or moisture supply was the more dominant control, especially taking into consideration the rather long response time of Arctic glaciers and ice caps. For example, the glacier advance of the beginning of the 20th century precedes regional warming, whereas the most prominent advance in the Franz Josef Land, ca. 1 ky, occurred in the middle of a period of regional warming documented by most other proxies. It is of interest to note, that the period AD 995–1015, the coldest in the last four millennia in the Yamal Peninsula, occurred in the mid of a generally warm period lasting from AD 700 to 1400 (Hantemirov and Shiyatov, 2002). Such a short, but intense, cooling might provide an explanation for the otherwise difficult to explain glacier advance. It is clear that more and better quality data will be required in order to fully constrain the timing of glaciological events in this region and understand their climatic forcing.

Inversions of direct temperature measurements in boreholes in the Arctic are available from Severnaya Zemlya (Fig. 2O) and Franz Josef Land (Nagornov et al., 2001). In general, the temperature changes recorded at Windy Dome (Franz Joseph Land) resemble the Academia Nauk Ice Cap (Severnaya Zemlya) records with the exception of the last 30–40 years when a strong cooling is indicated by the Franz Jozef Land borehole data. Unfortunately, the chronological control of these records is poor. Demezhko et al. (2003) reconstructed surface temperature using 47 boreholes from the Urals (Fig. 2E). Unlike the Severnaya Zemlya reconstruction, this one clearly captures the warm period between AD 800 and 1400. The Urals borehole temperature reconstruction is in good agreement with tree-line variations in the Northern Urals (Shiyatov, 2003).

Several pollen-based reconstructions of July, January and annual mean temperature and precipitation are available in the Sub-Arctic area. The July temperature reconstruction from Khibiny (Klimanov, 1997), for example, is shown in Fig. 2A. However, the use of palynology in the Arctic and Sub-arctic is limited by very poor local pollen production.

Despite the fact that numerous proxy records are available from the Russian Arctic and Sub-arctic a robust, quantitative regional reconstruction is not available. However, the general tendency of climatic change over the last two millennia can be described.

The 9th–14th centuries were relatively warm, though at least two colder periods probably occurred in the 11th and 13th centuries. The 15th–early 20th centuries were generally cold. Subsequent warming is recorded with almost all proxies, although tree rings register an apparent, probably false, summer cooling subsequent to the 1960s in many places (Briffa et al., 1998), a result that is at odds with instrumental records.

4. The Russian plain

This is the most densely populated and most thoroughly studied area in the greater region of the FSU. Instrumental meteorological records in the region extend back to the mid 18th century and can be used to calibrate climatic proxies. Sporadic written historical data are available for the entirety of the last millennium, though they are systematically available only since the beginning of the 12th century. Natural archives consist of tree rings (primarily 200–300 year-long time series), laminated sediments and numerous pollen records, though many of the latter suffer from poor chronological control.

Palinological records indicate a clear boundary in the vegetation history of the central and northern Russian Plain around AD 1000. At that time, coniferous forests were largely replaced by birch, pine and herbal communities (Khotinsky, 1977). Whether this ecosystem shift was in response to climatic or anthropogenic forcing remains unclear. Based on numerous pollen spectra and statistical analyses Klimanov (1997) has suggested that at ca. AD 1000 summer temperature was higher than present by 0.5 °C in the southern Russian plain and by 1.5–2.0 °C in the north (Figs. 3 and 4).

Chernavskaya (1996) investigated 11 chronologically controlled sections calibrated against more than 100 modern pollen spectra from all over the Russian plain. Pollen from broad-live trees is the best indicator of temperature changes in these regions. According to these data, the maximum warmth occurred in the 9th–10th centuries in the west and in 10th–11th centuries in the east. Some spectra indicate a cooling in the middle of the 12th century and especially in the late 12th–early 13th centuries, when the temperature decreased by 2–3 °C. Colder conditions also occurred in the late 17th and 18th centuries and two warm periods are recorded in 16th and second half of the 18th centuries.

According to historical data (Borisenkov and Pasetsky, 1988; Klige et al., 1998) (Fig. 3B), annual temperature varied relatively synchronously in the western, southwestern, northwestern and central regions of the Russian plain. The late 12th and late 14th centuries were the warmest within the period from the 12th to 19th centuries, whereas the early 15th and the entire 19th centuries were the coldest.

Regional variability in precipitation over the Russian Plain during the last millennium is more substantial than for temperature (Fig. 3D). According to pollen analyses, precipitation anomalies around 1 ky were positive in the regions to the north of the 50 °N and negative to the south of this latitude (Klimanov, 1997). Zolotokrilin et al. (1986), using historical data, generally support this conclusion. However Krenke and Chernavskaya (2002), who analyzed more than 600 written records of hydrologically significant climatic phenomena over the Russian plain, suggest that during the generally warm period from AD 970–1380 the contribution of droughts to the total of extremes was higher than from AD 1381 to 1850 over the entire plain. Remarkably, the absolute number of records indicating drought conditions is higher for the early period, despite the much lower number of total records. Archeological data from sites located near Smolensk, Pskov, and Moscow (i.e. to the north of the 50 °N) show that lake levels and spring floods were lower in the early part of the millennium compared to the 16th–19th centuries (Krenke and Chernavskaya, 2002). Two long varve series (Fig. 3E, F) (Schostakovich, 1934) located at the very North and South of the region, respectively, show some similarity in their long-term variability.

In conclusion, there are several different lines of evidence suggesting that the climate of the Russian plain was relatively warm from the 11th to 14th centuries, with the exception of the late 12th–early 13th centuries, and colder from the 15th to 19th centuries, except for a warm intervals in the first half of the 16th century. The more severe climate in the

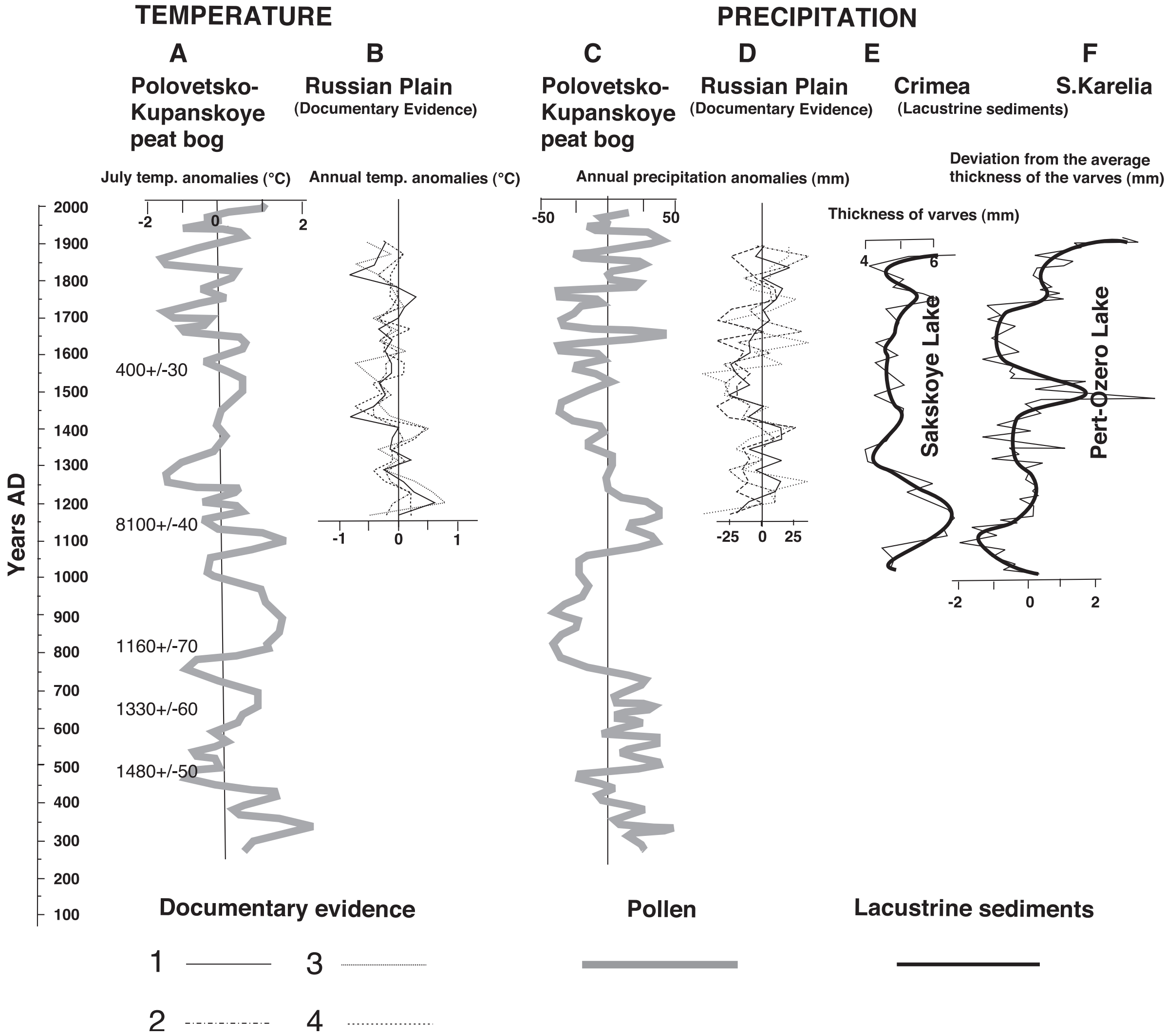

Fig. 3. Temperature and precipitation variations on the Russian Plain. (A) Polovetsko–Kupanskoye peat bog. July temperature anomalies reconstructed using pollen analysis (Klimanov et al., 1995). (B) Russian plain. Annual temperature anomalies (30-year averages) from written historical records (Borisenkov and Pasetsky, 1988; Klige et al., 1998). (C) Polovetsko–Kupanskoye peat bog. Annual precipitation anomalies reconstructed using pollen data (Klimanov et al., 1995). (D) Annual precipitation anomalies from written historical records (30-year averages) (Borisenkov and Pasetsky, 1988; Klige et al., 1998). (E) Pert-ozero Lake, Karelia. Thickness of annual sediment layers. (Schostakovich, 1934, cited by Klige et al., 1998). (F) Sakskoye Lake, Crimea. Thickness of annual layers. (Schostakovich, 1934, cited by Klige et al., 1998).

15th–19th centuries may have been due to a prevailing meridional type of atmospheric circulation.

5. The Caucasus

Archeological data and one ^{14}C date from a buried soil horizon (AD 610–980), pollen analysis and reduced glacier sizes indicate relatively warm climate around the end of the first to the beginning of the second millennium AD in the Central Caucasus. However, the chronological control of data in this region remains poor. Lichenometry moraine dating indicates that the first glacier advances, which are the most prominent of the millennium, occurred in the mid 13th century. This was most

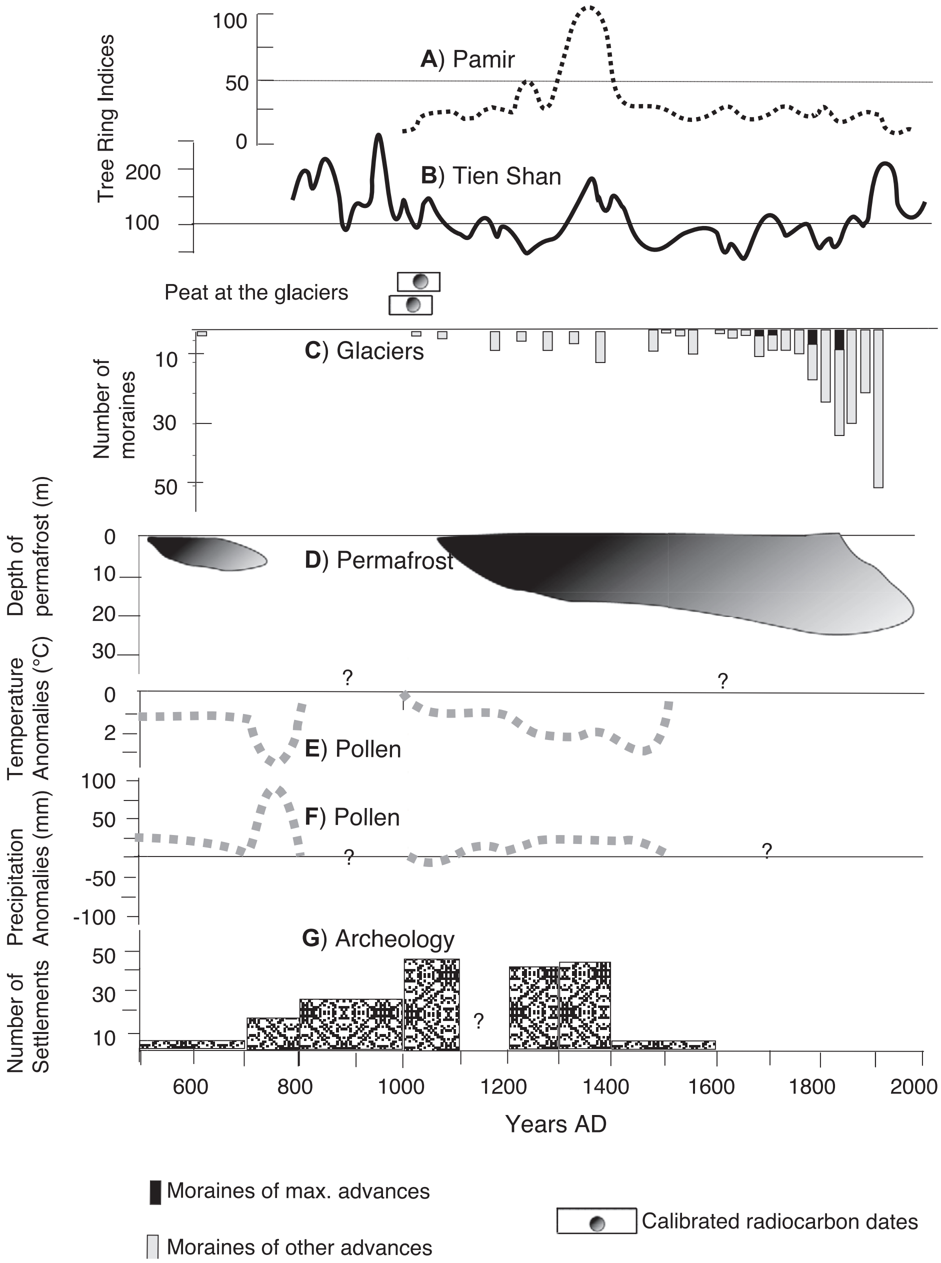

Fig. 4. Climatic proxies for the Central Asia and Caspian region. (A) Tree-ring width, Pamir-Alay (Mukhamedshin, 1977). (B) Tree-ring width, Tien Shan (Esper et al., 2002). (C) Number of moraines in the Tien Shan Mountains dated by lichenometry (Solomina, 1999). (D) Permafrost depth distribution in Zailiisky Alatau, Tien Shan (Marchenko, 2003). (E) Pollen inferred mean annual temperature, peat bog at the lower reaches of the River Uzboi, in the Caspian Sea region (Abramova and Varuchenko, 1989). (F) Same as E, but annual precipitation. (G) Number of settlements in the Dakhistan oasis (Turkmeno–Khorosanskiye Mountains) (Varuchenko, 1985).

probably the first interruption of an extended previous warm period. The timing of numerous glacier advances in the Caucasus during the 14th–19th centuries corroborates well with those in the European Alps to the extent that dating is available. Numerous pollen data indicate relatively cold conditions during the second half of the millennium (Serebryanny et al., 1984; Solomina, 1999).

6. Central Asia and the Caspian region

Historical descriptions and archeological data from Central Asia and the Caspian region indicate that climate was less continental at the end of the first and beginning of second millennium AD. Masson (1948), who analyzed primarily Arabic historical sources, reported that the 10th century was particularly "mild": grapes were cultivated in the Talas valley, palms grew between the Vakhsh and Piandzh valleys and cypress were widespread near Samarkand. Unfortunately, investigation of historical documents has not been continued since Masson's seminal work in this region.

The Dakhistan oasis in the Turkmeno–Khorosanskiye Mountains existed in the desert from the 9th–16th century, whereas from the 5th–8th centuries, and after the end of the 16th century, it was dry and able to support only a very sparse population (Fig. 4G) (Varuchenko et al., 1987). According to pollen and radiocarbon analysis of deposits along the lower reaches of the River Uzboi, in the Caspian region, between the 7th and the 15th centuries, mean annual temperature was 0.5–2.5 °C lower and annual precipitation 25–100 mm higher than at present (Varuschenko, 1984; Abramova and Varuchenko, 1989; Abramova, 1994) (Fig. 4E, F).

The Tien Shan glaciers experienced numerous advances during the 17th–19th centuries (Fig. 4C); the glaciers were smaller than at present in the early part of the millennium (Solomina, 1999). Several radiocarbon dates in the Tien Shan and Pamir Alay Mountains suggest that peat was forming very close to the end of the reduced glaciers at ca. 1000 BP (Solomina, 1999). A soil horizon was formed on the lateral moraine of the Abramova glacier at 986 ± 115 BP, indicating an interruption of glacier activity (Zech et al., 2000). Reconstructed permafrost depth distribution (Fig. 4D) and ground temperature variations (Marchenko, 2003), though of much lower resolution, agree quite well with the glaciological data as well as with tree-ring width from the Pamirs (Mukhamedshin, 1977) (Fig. 4A) and Tien Shan upper tree limit (Esper et al., 2002) (Fig. 4B). Esper et al. (2002) demonstrated that in the Tien Shan and Karakorum, the tree-ring width was generally high from AD 618 to 1139 and low from AD 1140 to 1874. The reconstructed temperature anomalies compared to present ranged from -0.2 to $+0.2$ °C over the last millennium in this region. The first half of the 17th century was the coldest time.

In the Tien Shan Mountains, numerous archeological and radiocarbon data point to lake Issyk-Kul having fallen about 5–7 m below its present level from approximately the 9th–16th century (Shnitnikov, 1980) (Fig. 5D). Chatyr-Kel Lake was low in the 11th and 16th centuries (Shnitnikov, 1980) (Fig. 5C). Regression of Lake Balkhash occurred around 1200–800 years BP, whereas a transgression is documented ca. 300 years BP (Khrustalev and Chernousov, 1992) (Fig. 5E). Shalkar lake level (Fig. 5F) was high from the 8th to 12th centuries and low in the 13th and 14th centuries. It reached the highest position at the end of the 16th century (Schnitnikov, 1985).

The level of the Aral (Fig. 5B) and Caspian Seas (Fig. 5A) is partly controlled by non-climatic factors, such as wandering of the two big rivers Amu-Darya and Syr-Darya, making climatic interpretation of these data difficult. The level of the Aral Sea depends on climatic conditions in the Pamirs and Tien Shan, where these rivers have their sources, whereas the Caspian is largely controlled by runoff from the Volga, which has its source in the temperate zone of the Russian plain. Thus, one should expect substantial differences in their level variations. Despite this fact, there is some similarity in these records since the 9th century, for example, low stands in the 13th and end of the 16th centuries are evident in both records (Klige et al., 1998).

In conclusion, most data indicate a milder, less continental climate with more precipitation approximately from the 9th to 12th centuries. Cold conditions dominated from the 13th to 19th centuries, though interrupted by a brief warm period

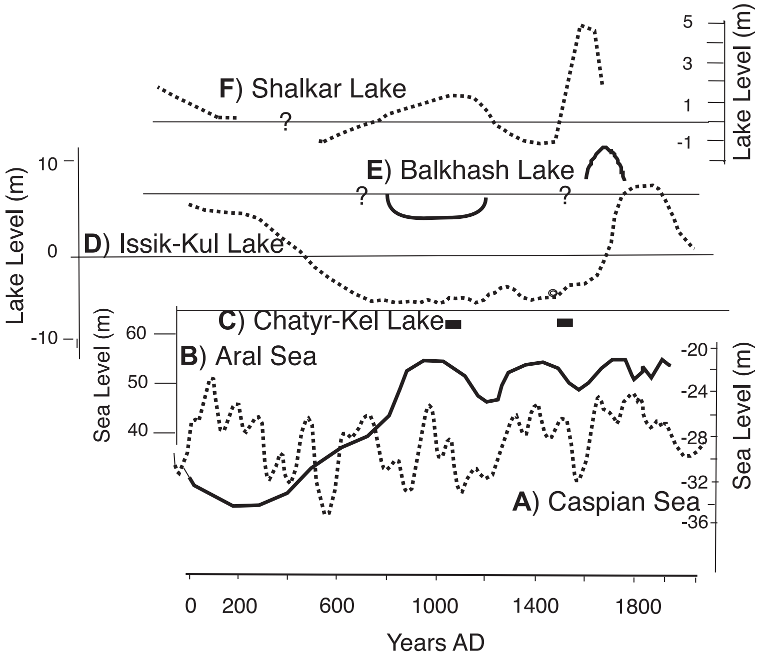

Fig. 5. Sea and lake level variations in Central Asia. (A) Caspian Sea (Klige et al., 1998). (B) Aral Sea (Klige et al., 1998). (C) Chatyr-kel, Tien Shan Mountains (Shnitnikov, 1980). (D) Issyk-Kul, Tien Shan Mountains (Shnitnikov, 1980). (E) Balkhash Tien Shan Mountains (Khrustalev and Chernousov, 1992). (F) Shalkar lake, Kazakhstan (Schnitnikov, 1985).

from the end of the 14th–early 15th century. The coldest conditions were probably in the 17th and 19th centuries, when glaciers advanced several times, lake level was high, and permafrost depth increased.

7. Eastern and Southern Siberia

Although this area is enormous, we consider it as a single region primarily due to the fact that paleoclimatic information of high resolution is so sparse. The stratigraphy of moraine-dam lake sediments in the Altai Mountains has revealed dry and warm periods at ca. 540 ± 25 years BP, and between 830 ± 50 and 1140 ± 30 years BP (Ivanovsky et al., 1982) (Fig. 6C). Butvilovsky (1993) defined periods of decreased river runoff in the Altai at 1205 ± 30 and 540 ± 25 years BP. A decrease in the continentality of climate around 850 years BP has been suggested based on pollen analyses in the Western Sayan Mountains (Savina, 1986) (Fig. 6G) and in the area near Lake Baikal around 900 years BP (Vorob'eva and Goriunova, 1994) (Fig. 6H). Buried soils indicate two regressions of Chany Lake around 1035 ± 40–1180 ± 50 and 820 ± 120 years BP (Zikina and Orlova, 2000). A buried soil horizon in the Suntar-Khayata Mountains dated to 660 ± 90 years BP (Fig. 6K) provides evidence for a relatively warm climate in this extremely cold area (Nekrasov et al., 1973). An extended warm period at 420 ± 50 years BP is documented by ^{14}C dates from tree remnants above the modern, temperature-controlled treeline.

Glacial moraines in the Altai Mountains have been dated by ^{14}C, tree-rings and lichenometry. The most numerous and prominent advances of the last millennium occurred from the 17th to early 20th centuries. The dates for the moraines of the 11th–14th centuries are mostly from fragments of lateral moraines partly buried by later advances and are less certain (Fig. 6B) (Solomina, 1999).

Tree-ring-based temperature reconstructions in the Altai Mountains suggest that the longest and deepest June–July cooling occurred from the late 18th–mid 19th centuries (Ovchinnikov, 2002) (Fig. 6A). The

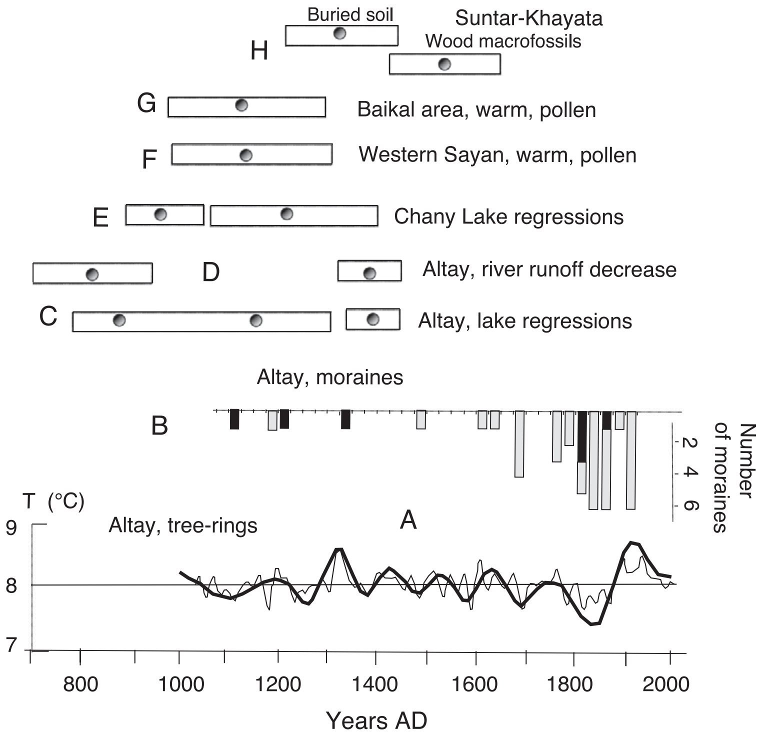

Fig. 6. Siberian climatic proxies. (A) Tree-ring-based reconstruction of June–July temperature in the Altay Mountains (Ovchinnikov, 2002). (B) Number of moraines in the Altai Mountains dated by lichenometry (Solomina, 1999). (C) Lake regressions in the Altai Mountains inferred from moraine-dam lake sediments in the Dzhazator valley (Ivanovsky et al., 1982). (D) period of decreased river runoff in the Altai Mountains (Butvilovsky, 1993). (E) Chany Lake regressions identified from buried soil dates (Butvilovsky, 1993; Zikina and Orlova, 2000). (F) Warm period in the Western Sayan Mountains identified by pollen analyses (Savina, 1986). (G) Warm period in the Baikal area identified by pollen analyses (Vorob'eva and Goriunova, 1994). (H) Warm period in the Suntar-Khayata Mountains identified by a buried soil horizon and ^{14}C dating of tree remnants found above the modern upper tree limit (Nekrasov et al., 1973).

cooling of the late 17th–early 18th centuries was less prominent. The 14th and 20th centuries were the warmest of the entire record. The 11th–13th centuries look surprisingly cool in this reconstruction, a result that disagrees with the pollen and glacier evidence discussed above. There are several possible explanations for this disagreement, including low sample density in the beginning of the chronology, or reaction of the trees to possible drought conditions at the beginning of the millennium suggested by the lake levels.

In conclusion, two periods of warmer and drier climate can be roughly identified in this huge area as having occurred from the 9th to 11th centuries and in the 14th century. The 15th–19th centuries were clearly cold and the 20th century has seen a return to warm conditions.

8. The Far East

A cold period between 1700 and 1300 years BP has been documented for Kunashir and Iturup Islands, in the Kurile Island chain, by diatom, pollen and sedimentological analysis and ^{14}C dating (Fig. 7A). A moderate warming and sea level rise occurred ca. 1060 $\pm$60 BP on Iturup Island (Fig. 7A) (Razjigaeva et al., 2002, this issue). The warming resulted in an interruption in dune deposition and formation of a soil horizon on Kunashir Island (Fig. 7A) between AD 810 and 1260. This warming correlates with one that occurred between 1300 and 700 year BP on the Japanese Islands (Korotky et al., 2000). The subsequent cooling and sea regression has been attributed to the Little Ice Age.

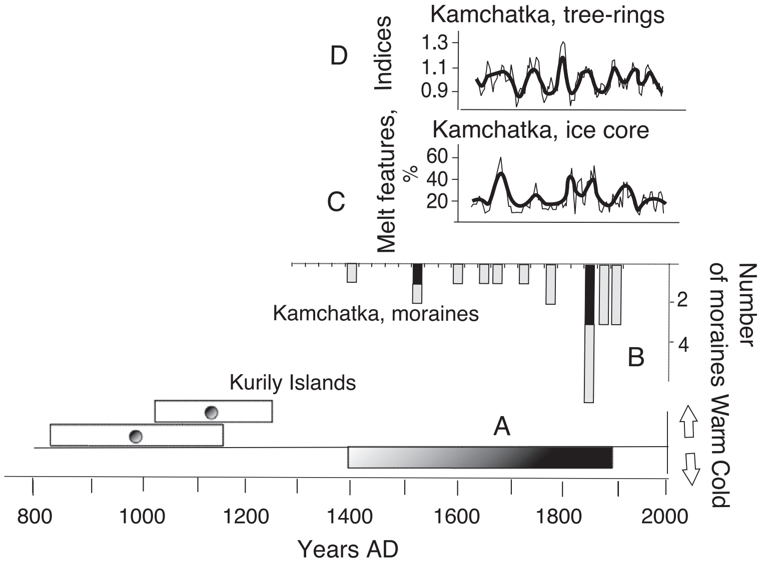

Fig. 7. Far East climatic proxies. (A) Kunashir and Iturup Islands (Kurile Islands) qualitative indications of warmings and coolings from diatom, pollen and sedimentological analysis (Razjigaeva et al., 2002). (B) Number of moraines in Kamchatka dated by lichenometry (Solomina, 1999). (C) Melt features in the Ushkovsky ice core, Kamchatka (Shiraiwa et al., 1997). (D) Warm season temperature on the Kamchatka Peninsula reconstructed based on tree-ring analyses (Solomina, 1999).

The dates of glacier advances during the last two millennia in Kamchatka are constrained by tephrochronology and lichenometry. Tephrachronology indicates that the first set of advances occurred earlier than 1000–1700 years BP (Braitseva et al., 1968); the more recent advances occurred from the 14th to early 20th century (Fig. 7B). The timing of glacier variations of the last millennium in Kamchatka correlates well with those in Alaska (Luckman and Villalba, 2001; Solomina and Calkin, 2003).

Summer temperature reconstructions from tree-ring analyses are available for the last 300–400 years for Kunashir Island (Jacoby et al., 2003) and the Kamchatka peninsula (Solomina, 1999) (Fig. 7D). No chronology longer than 400 years exists in the area. Ice core data from the Ushkovsky glacier provide a 500-year climatic record (Shiraiwa et al., 1997). The melt feature percentage from this core (Fig. 7C) is in good agreement with the tree-ring based temperature reconstruction (Fig. 7D). The snow accumulation record from an ice core from Mt. Logan, Canada covering the past 300 years has been shown to provide a robust record of large scale decadal scale variability in the North Pacific region, including the Pacific Decadal Oscillation (Moore et al., 2001, 2002). These data show a strong increase in moisture transport to the site of the ice core, associated with strengthening of the Pacific North America pattern and thus colder conditions in the central North Pacific Ocean, has been occurring over the past 150 years.

In conclusion, there is some evidence suggesting moderately warm conditions in the North Pacific region from the end of the first to the beginning of the second millennium. A subsequent cooling after the 14th century is better documented. However, new, longer and high-resolution data are necessary in order to better constrain these climatic events.

9. Conclusions

Various proxy records are available to contribute to regional reconstructions of climatic variability over the last few millennia in the FSU, especially the Sub-Arctic and the Russian plain. Although the southern and eastern regions are less well studied, the potential to obtain high-resolution records from tree-rings, lake sediments, pollen, boreholes and speleothems certainly exists. Presently available data allows only rather general climatic trends over the last 1.5 millennia to be described for most regions in this huge and diverse territory. This limitation is not just due to lack of data, but also problems interpreting available records. The primary difficulties are poor chronological control, unclear or mixed climatic signals embedded in the proxy records and the lack of preservation of either long-term or short term variations in a given record.

In general, no single proxy provides an ideal record of past climatic changes. To some degree, multiple proxy reconstructions allow compensation for individual proxy limitations. Several recent successful combinations of different proxies in the FSU should be mentioned here. Klimenko et al. (2001) demonstrated very good agreement between pollen-derived temperature records with the both instrumental and historical data for summer temperature since AD 1750 (Fig. 8). Sidorova et al. (2003) compared new chronologies from eastern Taymir and the Indigirka lowlands with high-resolution pollen data and ^{18}O variations from GISP2 and found rather good covariance in both cases. Knorre (2001) demonstrated a correlation between tree-ring width and growth of mosses and shrubs. Demezhko et al. (2003) found good agreement between tree line dynamics and borehole temperature changes in the Urals. Although these multiproxy studies are a step in the right direction, a comprehensive, quantitative, multiproxy climatic reconstruction for the past millennium has yet to be performed for any of the regions we discuss in this paper.

Although paleoclimatic data from the first millennium AD are very sparse, a number of records allow one to distinguish the climatic pattern of the 9th–13th centuries from earlier and later colder conditions in the Kola Peninsula, Urals, Taymir, Russian Plain, Caucasus and East Siberia. The 10th–12th centuries were also slightly warmer in the Far East (Kurile Islands). In some places, the climate remained relatively warm until the 14th century, though in most regions, cooling began in the 13th century. Tree rings and pollen data suggest that conditions were also relatively warm in the Arctic from the 9th–13th centuries, however, a prominent glacier advance occurred about 1000 years ago in Franz Josef Land, which requires further explanation. The available data for this time period remain controversial in the arid area of Central Asia. Records from the Caspian Sea area suggest moderate temperature and relatively high humidity in the first half of the millennium, whereas in the Tien Shan Mountains, the beginning of the millennium seems to have been warm and dry.

The spatial pattern of temperature anomalies ca, 1 ky ago is similar to the earlier mid-Holocene "optimum" with the magnitude of positive temperature anomalies decreasing from north to south in the Arctic and temperate zone and a transition to negative anomalies in the arid subtropical zone (Klima-

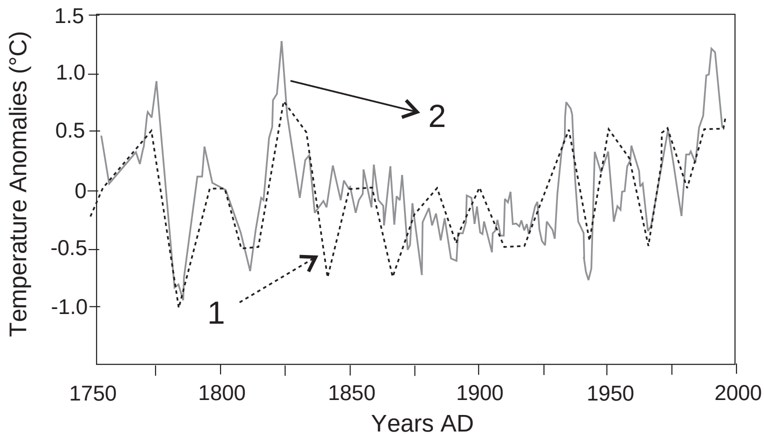

Fig. 8. Comparison between deviations of (1) average annual temperature derived from pollen data and (2) 7-year moving average of combined instrumental temperature records from Riga, St. Petersburg and Moscow meteorological stations (Klimenko et al., 2001).

nov, 1997, Klimenko, 2001, Fig. 9a). However, the pattern of temperature anomalies for the MWP is substantially different from those for the warm period from 1966–1995 (Sereeze et al., 2000) (Fig. 9b). In contrast to the meridional pattern of the MWP, the temperature anomaly maxima for the modern period are centered in Novaya Zemlia/Northern Urals, Central Asia, with the exception of the Tien Shan, and near Lake Baikal.

It is of interest that the warming of the 14th century in several regions, including the Russian plain, Altai and Central Asia, was at least as intense as the earlier one at ca. 1 ky before present or even warmer. Various lines of evidence suggest a climatic deterioration in the second half of the last millennium throughout the FSU, including the European part, Siberia, the Caucasus, the mountains of the Central Asia, the Far East and the Arctic archipelagoes. In general, this agrees well with the conclusion of Meeker and Mayewski (2002) that the primary mode of atmospheric circulation over Northern Eurasia may have changed between AD 1400 and 1450. Such a circulation change might provide a plausible explanation for the footprint of the MWP and LIA throughout the Eurasian North.

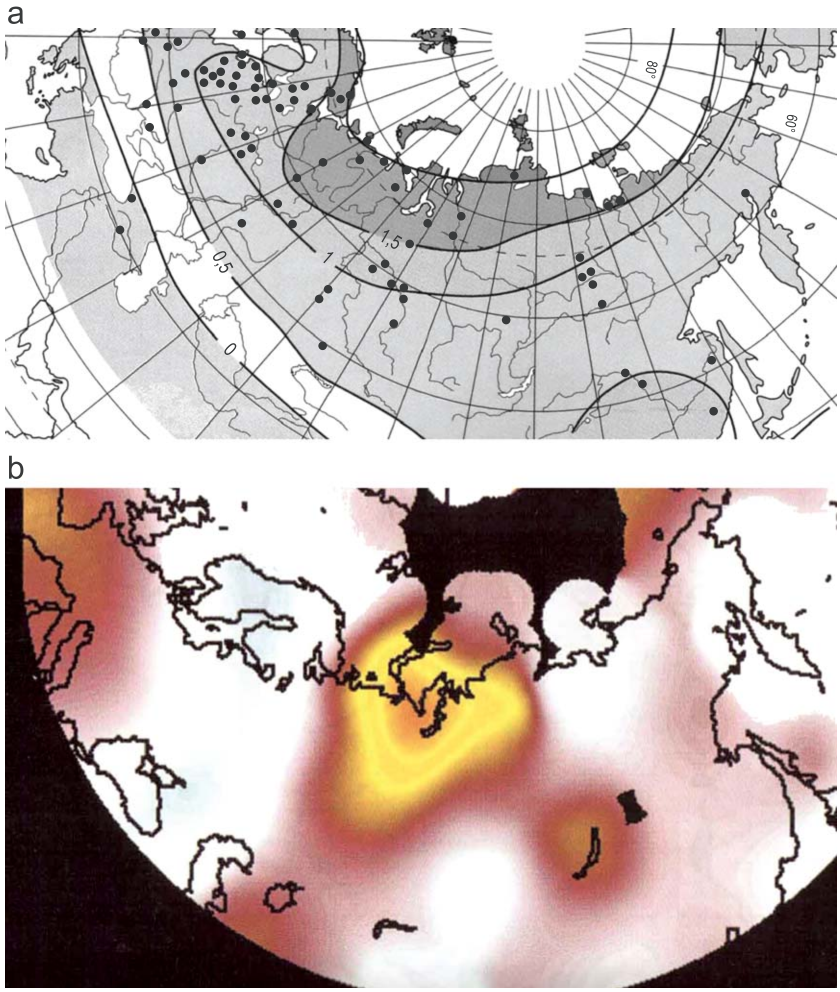

Fig. 9. Summer temperature anomalies in Northern Eurasia. (a) During the Medieval Warm Period reconstructed using various climatic proxies (Klimenko et al., 2001). (b) During the warm period from 1966–1995 according to instrumental records (Sereeze et al., 2000).

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