TEMPERATURE PROXY RECORDS COVERING THE LAST TWO MILLENNIA: A TABULAR AND VISUAL OVERVIEW

BY
FREDRIK CHARPENTIER LJUNGQVIST

Department of History, Stockholm University, Sweden

Ljungqvist, F.C., 2009: Temperature proxy records covering the last two millennia: a tabular and visual overview. *Geogr. Ann.*, 91 A (1): 11–29.

ABSTRACT. Proxy data are our only source of knowledge of temperature variability in the period prior to instrumental temperature measurements. Until recently, very few quantitative palaeotemperature records extended back a millennium or more, but the number is now increasing. Here, the first systematic survey is presented, with graphic representations, of most quantitative temperature proxy data records covering the last two millennia that have been published in the peer-reviewed literature. In total, 71 series are presented together with basic essential information on each record. This overview will hopefully assist future palaeoclimatic research by facilitating an orientation among available palaeotemperature records and thus reduce the risk of missing less well-known proxy series. The records show an amplitude between maximum and minimum temperatures during the past two millennia on centennial timescales ranging from *c*. 0.5 to 4°C and averaging *c*. 1.5–2°C for both high and low latitudes, although these variations are not always occurring synchronous. Both the Medieval Warm Period, the Little Ice Age and the 20th century warming are clearly visible in most records, whereas the Roman Warm Period and the Dark Age Cold Period are less clearly discernible.

Key words: palaeoclimatic records, temperature proxy data, climate variability, temperature reconstructions.

Introduction

The instrumental temperature record is unfortunately too short to assess whether the observed 20th century global warming falls outside the range of the natural variability of the last one or two millennia in either magnitude or rate (IPCC 2007; NRC 2006). In order to place the recent climate change in the context of natural, long-term variability of the climate system, and thus better be able to estimate the contribution of natural versus anthropogenic forcing, information on climate variability for the period prior to the instrumental temperature measurements must be drawn from proxy-based temperature reconstructions. Proxy data with sensitivity to temperature variations can be extracted from various natural recorders of climate variability such as corals, fossil pollen, ice cores, lake and ocean sediments, speleothems, and tree ring width and density, as well as from historical records. A good introduction to different types of climate proxy data and proxy-based temperature reconstructions is given in, for example, Bradley (1999).

There exists no such thing as a perfect palaeoclimate record, which without problem can be converted to a temperature record, since all proxy data contain 'noise', e.g. information not related to the climate. Futhermore, different types of palaeoclimate records reflect climate variability on various timescales with different degrees of accuracy and can have anything from annual resolution (e.g. tree rings) to multi-decadal to centennial resolution (e.g. fossil pollen). Only proxy records that can provide a quantitative estimate of past temperatures are really useful when placing the recent warming in a long-term perspective.

A number of attempts have been made in recent years to reconstruct global or hemispheric mean temperatures for the last one to two millennia with the help of different sets of proxy data (e.g. Briffa 2000; Cook *et al*. 2004; Crowley and Lowery 2000; D'Arrigo *et al*. 2006; Esper *et al*. 2002; Hegerl *et al*. 2007; Jones *et al*. 1998; Jones and Mann 2004; Juckes *et al*. 2007; Loehle 2007; Mann *et al*. 1999, 2008; Mann and Jones 2003; Moberg *et al*. 2005; Osborn and Briffa 2006). The amplitude of the reconstructed temperature variability in the pre-industrial period differs considerably due to the use of different proxy data collections and different methodological approaches. All reconstruction efforts have furthermore been hampered by the relative scarcity of quantitative palaeoclimate records extending back a millennium or more as well as by the dominance of proxy records from high latitudes among the millennia-long series. Another difficulty in placing the recent warming in a longer perspective has been that many longer proxy records end sometime during the 20th century and, hence, before the 'extreme' warming of the past few decades.

For a more comprehensive discussion concerning the problems with palaeotemperature reconstructions, we refer to IPCC (2007), Juckes *et al*. (2007) and NRC (2006) and the literature cited there.

The present overview

The number of long quantitative temperature proxy data records from different parts of the world is growing. With such an increase follows a greater risk of missing interesting records out of pure ignorance of their existence. A systematic survey of the available temperature proxy records is therefore of value. So far, however, no such survey of the available records has ever been published. It is hence with the intention of assisting future palaeoclimatological research that this tabular and visual overview of quantitative temperature proxy data records has been written.

Most of the records that, to our knowledge, have been published in the peer-reviewed literature with at least centennial sample resolution covering the last two millennia are presented here: all in all 71 records. Only such records that have been proved to quantitatively reflect a statistically significant temperature signal, and where the proxy values have been calibrated to temperature, have been included in this overview. This rule has, however, been departed from if a record has been included as a temperature proxy in the northern hemispheric respectively global temperature multi-proxy reconstructions by Moberg *et al*. (2005) and Mann *et al*. (2008). Twelve records used here are therefore not, in its proper sense, temperature indicators: Record 29 from Dongge Cave, south China (Wang *et al*. 2005); record 30 from the Arabian Sea (Moberg *et al*. 2005); record 31 from Socotra Island, Indian Ocean (Burns *et al*. 2003); record 35 from Agassiz Ice Cap, northern Canada (Fisher *et al*. 1995); records 53, 55–56 from Indian Garden, Methuselah Walk, and White Mountain, southwest USA (Moberg *et al*. 2005); record 59 from Punta Laguna, Yucatan, Mexico (Curtis *et al*. 1996); record 60 from Lake Chichancanab, Yucatan, Mexico (Hodell *et al*. 2005); record 62 from Nicoa Cave, Nicoya, Costa Rica (Mann *et al*. 2008); record 64 from Lake Pallcacocha, Ecuador (Moy *et al*. 2002); record 65 from western Argentina (Mann *et al*. 2008). Record 19 from Galicia, northwest Spain (Martínez-Cortizas *et al*. 1999), is a temperature index and not a proper temperature record and as such shows relative and not absolute temperature variations.

Data from some published quantitative temperature proxy records have unfortunately, despite efforts, been impossible to obtain and have consequently been omitted from this overview: the Finnish Lapland tree ring width record by Helama *et al*. (2002); the Czech Republic merged borehole temperature record by Bodri and Čermák (1997); the Tagus River Estuary fossil and sediment record by Abrantes *et al*. (2005); the Sierra Nevada tree ring width record by Scuderi (1993); the Santa Barbara Basin seafloor sediment record by Bemis *et al*. (1998); the south Chile tree ring width record by Lara and Villalba (1993); the Yakushima Island $\delta^{13}C$ tree record by Kitagawa and Matsumoto (1995).

Tabular representations

Essential information on each record is given in Table 1: (1) name of the record and geographical location; (2) exact latitude and longitude; (3) type of proxy; (4) sample resolution; (5) season bias; and (6) reference to the original publication where the record first appeared. The proxy records are presented in Table 1 in a strict geographical order, continent by continent from north to south, and have thus not been organized in accordance with any criteria such as type of proxy or sample resolution. The geographic location of each record is shown on the map in Fig. 1. More detailed information about a specific record, may be found in the reference given for that record. When a record has been published with various sample resolutions, reference is always given to the publication with the highest resolution.

The different records have been classified into ten types of proxies: (1) borehole temperature records (either from inland ice-sheets or boreholes drilled into the Earth crust); (2) chemical records (e.g. atmospheric metal deposition); (3) historical documentary data; (4) isotopic analysis from ice-cores or lake/river sediments or seafloor sediments; (5) lake/river fossils and sediments records (e.g. diatom and chironomid data); (6) fossil pollen records; (7) seafloor sediment records; (8) speleothem isotopic records; (9) tree ring width or maximum latewood density records; (10) varved thickness sediment records.

Graphical representations

Each record is plotted graphically in Fig. 2 (1–71). All records with a sample resolution less than annu-

Table 1. Two-millennia long temperature proxy records

Proxy location	Latitude	Longitude	Proxy type*	Sample resolution	Season	Reference
Europe						
1. Dalmutladdo, N Fennoscandia	69°10'N	20°43'E	Po	Multi-decadal to centennial	Summer	Bjune *et al*. 2004
2. Lake Toskaljavri, N Fennoscandia	69°02'N	21°47'E	Po	Multi-decadal to centennial	Summer	Seppä and Birks 2002
3. Lake Toskaljavri, N Fennoscandia	69°02'N	21°47'E	Lf	Multi-decadal to centennial	Summer	Seppä *et al*. 2002
4. Lake Tsuolbmajavri, N Fennoscandia	68°41'N	22°05'E	Lf	Multi-decadal to centennial	Summer	Korhola *et al*. 2000
5. Lake Tsuolbmajavri, N Fennoscandia	68°41'N	22°05'E	Po	Multi-decadal to centennial	Summer	Seppä and Birks 2001
6. Abisko Valley, N Fennoscandia	68°21'N	18°49'E	Po	Multi-decadal to centennial	Summer	Larocque and Halla 2004
7. Torneträsk, N Fennoscandia	68°13'N	19°43'E	T	Annual	Summer	Grudd *et al*. 2002
8. Lake Sjuodjijaure, N Fennoscandia	67°22'N	18°04'E	Po + Lf	Multi- centennial	Summer	Rosén *et al*. 2003
9. Søylegrotta, N Fennoscandia	66°33'N	13°55'E	Sp	Multi-decadal	Annual	Lauritzen and Lundberg 1999
10. North Iceland Shelf	66°33'N	17°42'W	Sd	Multi-decadal	Summer	Jiang *et al*. 2005
11. North Iceland Shelf	66°33'N	17°42'W	Sd	Multi-decadal	Winter	Jiang *et al*. 2005
12. Off N Iceland	66°30'N	19°30'W	Sd	2–5 years	Summer	Sicre *et al*. 2008
13. Stora Viðarvatn, Iceland	66°23'N	15°08'W	Lf	Multi-decadal to centennial	Summer	Axford *et al*. 2008
14. Jämtland, C Sweden	63°10'N	13°30'E	T	Annual	Summer	Linderholm and Gunnarson 2005
15. Lake Spåime, C Sweden	63°07'N	12°19'W	Lf	Multi-decadal to centennial	Summer	Hammarlund *et al*. 2004
16. Lake Laihalampi, S Finland	61°29'N	26°04'E	Po	Multi-decadal to centennial	Annual	Heikkilä and Seppä 2003
17. Lake Flarken, C Sweden	58°33'N	13°40'E	Po	Multi-decadal to centennial	Annual	Seppä *et al*. 2005
18. Spannagel Cave, C Alps	47°05'N	11°40'E	Sp	1–10 years	Annual	Mangini *et al*. 2005
19. Penido Vello, Galicia, NW Spain	43°32'N	7°34'W	Ch	Multi-decadal	Annual	Martínez-Cortizas *et al*. 1999

Table 1. Continued

Asia						
20. Taimyr peninsula, N Siberia	70°30'N–73°00'N	105°E	T	Annual	Summer	Naurzbaev *et al*. 2002
21. Yamal, NW Siberia	66°92'N	69°17'E	T	Annual	Summer	Hantemirov and Shiyatov 2002
22. Yamal, NW Siberia	66°92'N	69°17'E	T	Annual	Summer	Briffa 2000
23. Solongotyn Davaa, Mongolia	48°3'N	98°93'E	T	Annual	Summer	D'Arrigo *et al*. 2001
24. E China	27°N–40°N	107°E–120°E	D	30 years	Winter	Ge *et al*. 2003
25. Shihua Cave, Beijing, China	39°54'N	116°23'E	Sp	Annual	Summer	Tan *et al*. 2003
26. Lake Qinghai, Tibetan Plateau	37°N	100°E	Lf	Multi-decadal to centennial	Annual	Liu *et al*. 2006
27. NW North Pacific Ocean	34°95'N	128°88'E	Sd	Multi-decadal to centennial	Annual	Kim *et al*. 2004
28. Northern Okinawa Trough, East China Sea	29°13'N	128°53'E	Sd	Multi-decadal to centennial	Annual	Fengming *et al*. 2008
29. Dongge Cave, S China	25°28'N	108°08'E	Sp	Annual to decadal	Annual	Wang *et al*. 2005
30. Arabian Sea	18°25'N	57°58'E	Sd	Multi-decadal to centennial	Summer and winter	Moberg *et al*. 2005
31. Socotra Island, Indian Ocean	12°29'N	53°54'E	Sp	Annual to decadal	Annual	Burns *et al*. 2003
32. W tropical Pacific Ocean	6°30'N	125°83'E	Sd	Multi-decadal	Annual	Stott *et al*. 2004
33. W tropical Pacific Ocean	5°18'S	133°26'E	Sd	Multi-decadal	Annual	Stott *et al*. 2004
North America						
34. Lower Murray Lake, N Canada	81°21'N	69°32'W	V	Annual	Summer	Cook *et al*. 2008
35. Agassiz Ice Cap, N Canada	80°70'N	73°10'W	Is	25 years	Annual	Fisher *et al*. 1995
36. Agassiz Ice Cap, N Canada	80°70'N	73°10'W	Is	20 years	Annual	Vinther *et al*. 2008
37. Devon Ice Cap, N Canada	75°33'N	89°W	Is	5 years	Annual	Fisher *et al*. 1983
38. NorthGRIP, N Greenland	75°10'N	42°32'W	Is	20 years	Annual	Vinther *et al*. 2006
39. GRIP, C Greenland	72°58'N	37°63'W	B	Multi-decadal to centennial	Annual	Dahl-Jensen *et al*. 1998
40. GRIP, C Greenland	72°58'N	37°63'W	Is	20 years	Annual	Johnsen *et al*. 2001
41. GISP2, C Greenland	72°58'N	38°45'W	Is	Decadal	Annual	Grootes and Stuiver 1997

Table 1. Continued

42. GISP2, C Greenland	72°58'N	38°45'W	Is	Multi-decadal	Annual	Alley 2000
43. Victoria Island, NW Canada	71°34'N	113°78'W	Po	Multi-decadal to centennial	Summer	Peros and Gajewski 2008
44. Renland, E Greenland	71°3'N	26°7'W	Is	20 years	Annual	Vinther *et al*. 2008
45. Boothia Peninsula, N Canada	69°54'N	95°42'W	Po	Multi-decadal to centennial	Summer	Zabenskiea and Gajewski 2007
46. Blue Lake, N Alaska	68°08'N	150°46'W	V	Annual	Summer	Bird *et al*. 2008
47. Dye-3, S Greenland	65°19'N	49°83'W	B	Multi-decadal to centennial	Annual	Dahl-Jensen *et al*. 1998
48. Dye-3, S Greenland	65°19'N	49°83'W	Is	20 years	Annual	Vinther *et al*. 2006
49. Northwest Territories, N Canada	63°11'N	109°07'W	Lf	Multi-decadal to centennial	Summer	MacDonald *et al*. 2008
50. Farewell Lake, C Alaska	62°55'N	153°63'W	Lf + Is	Multi-decadal to centennial	Summer	Hu *et al*. 2001
51. Hallet Lake, S Alaska	61°49'N	146°24'W	Lf	Decadal	Summer	McKay *et al*. 2008
52. Conroy Lake, NE USA	46°17'N	67°53'W	Po	Multi-decadal	Summer	Gajewski 1988
53. Indian Garden, SW USA	39°08'N	115°43'W	T	Annual	Summer	Moberg *et al*. 2005
54. Chesapeake Bay, E USA	38°89'N	76°40'W	Sd	Multi-decadal	Spring	Cronin *et al*. 2003
55. Methuselah Walk, SW USA	37°43'N	118°1'W	T	Annual	Summer	Moberg *et al*. 2005
56. White Mountain, SW USA	37°42'N	118°17'W	T	Annual	Summer	Moberg *et al*. 2005
57. S Colorado Plateau, SW USA	35°20'N	111°40'W	T	Annual	Summer	Salzer and Kipfmueller 2005
58. Bermuda Rise, Sargasso Sea	32°17'N	64°50'W	Is	Multi-decadal to centennial	Annual	Keigwin 1996
59. Punta Laguna, Yucatan, Mexico	20°63'N	87°50'W	Is	Decadal	Annual	Curtis *et al*. 1996
60. Lake Chichancanab, Yucatan, Mexico	19°8'N	88°9'W	Is	Decadal	Annual	Hodell *et al*. 2005
61. NE Caribbean Sea	17°88'N	66°60'W	Is	Multi-decadal to centennial	Annual	Nyberg *et al*. 2002
62. Nicoa Cave, Nicoya, Costa Rica	10°2'N	85°3'W	Sp	Annual to decadal	Annual	Mann *et al*. 2008

Table 1. Continued

South America						
63. Cariaco Basin, Venezuelan Coast	10°42'N	64°56'W	Sd	Multi-decadal to centennial	Annual	Goñi *et al*. 2004
64. Lake Pallcacocha, Ecuador	2°76'N	79°23'W	Lf	Annual	Annual	Moy *et al*. 2002
65. W. Argentina	41°25'S	71°9'W	T	Annual	Summer	Mann *et al*. 2008
Africa						
66. Subtropical Atlantic off W Africa	20°45'N	18°35'W	Sd	Multi-decadal to centennial	Annual	deMenocal *et al*. 2000
67. Makapansgat Valley, S Africa	24°54'S	29°25'E	Sp	5–10 years	Annual	Holmgren *et al*. 2001
68. SE South Atlantic	25°30'S	13°16'E	Sd	Multi-decadal to centennial	Annual	Farmer *et al*. 2005
Australia/New Zealand						
69. Mt. Read, W Tasmania	42°52'S	146°50'E	T	Annual	Summer	Cook *et al*. 2000
Antarctica						
70. Law Dome, E Antarctica	66°73'S	112°83'E	B	Multi-decadal to centennial	Annual	Dahl-Jensen *et al*. 1999
71. Dome C, E Antarctica	76°06'S	123°21'E	Is	Decadal	Annual	Jouzel *et al*. 2001

*B, borehole; Ch, chemical; D, documentary; Is, isotopic analysis; Lf, lake/river fossils and sediments; Po, fossil pollen; Sd, sea-floor sediments; Sp, speleothem isotopic analysis; T, tree ring width or maximum latewood density; V, varved thickness sediments

al have been linearly interpolated to annual resolution before being plotted graphically. Although most records show quantitative temperature variations in degrees Celsius, some records are presented as unit standard deviation (σ). The period prior to AD 1, in the case of records extending still further back, has been excluded in the graphic presentations.

Some of the records plotted graphically constitute the arithmetic mean of several different records from the same site. Record 6 from Abisko Valley, northern Fennoscandia (Larocque and Halla 2004), is the arithmetic mean from three different pollen lake cores in the region. Another northern Fennoscandia record, record 8 from Lake Sjuodjijaure (Rosén *et al*. 2003), is the arithmetic mean from the temperature interpretation of three different variables: diatom, chironomid, and pollen. Record 31, from Socotra Island in the Indian Ocean (Burns *et al*. 2003), consists of the arithmetic mean of one δ^{13}C and one δ^{18}O record. Three records from Latin America constitute the arithmetic mean from several data series: record 59 from Punta Laguna, Yucatan, Mexico (Curtis *et al*. 1996), consists of the arithmetic mean of two δ^{13}C and two δ^{18}O records; record 60 from Lake Chichancanab, Yucatan, Mexico (Hodell *et al*. 2005), consists of one calcium carbonate and one δ^{18}O record; record 62 from Nicoa Cave, Nicoya, Costa Rica (Mann *et al*. 2008), consists of the arithmetic mean of one δ^{13}C and one δ^{18}O record. In cases when the data series consists of temperature values, the arithmetic mean of temperature values has simply been calculated. The records have otherwise first been normalized to have zero mean and unit standard deviation before an arithmetic mean value in unit standard deviation has been calculated.

Concluding remarks

Although this survey should be seen merely as a tabular and visual overview of available temperature proxy records, some concluding remarks can be made about the records included in this survey

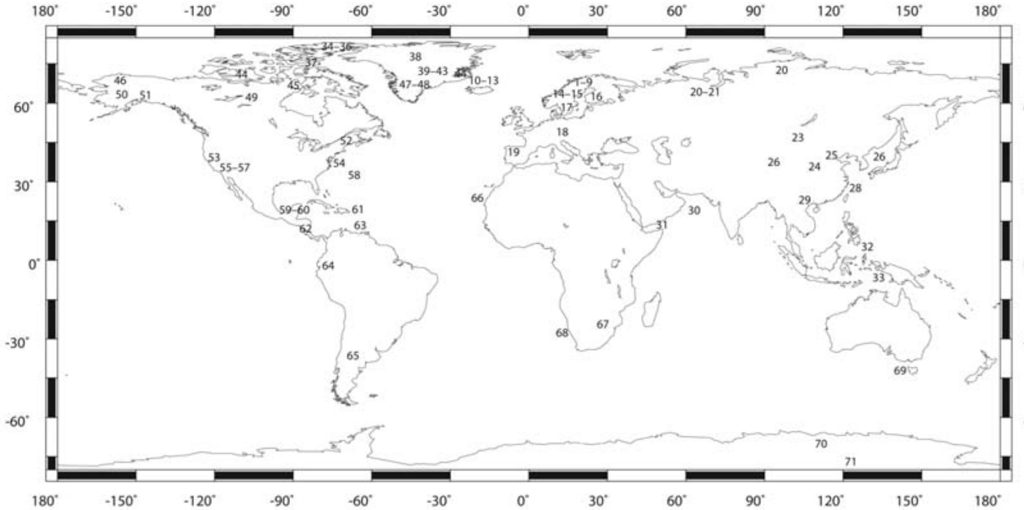


Fig. 1. Locations of the proxy records presented in Table 1

and the climate picture they represent. First, it is appropriate to point out that concern about the accuracy of some records included here can be raised. The Grudd *et al.* (2002) tree ring width record used here shows a much smaller amplitude in the long-term variability, and a considerably colder climate *c.* AD 900–1100, than the new Torneträsk maximum latewood density record AD 500–2004 by Grudd (2008). Doubts can also be raised if the very pronounced 20th century warming in the Yamal, northwest Siberia, tree ring width record by Briffa (2000) is actually reflecting such a strong temperature increase since other circum-Arctic tree dendroclimatological records, especially the nearby Polar Urals record (Esper *et al.* 2002), show a much less pronounced 20th century warming. The Dye-3 borehole temperature and ice-core isotopic records must be considered very uncertain for the more recent centuries because of the problematic ice-flow conditions at this drilling site; the magnitude of the mid-20th century warming is very likely artificially high (B. Vinther, personal communication). It should also be mentioned that the Makapansgat Valley speleothem isotopic record by Holmgren *et al.* (2001) is published as a preliminary temperature reconstruction and no definitive temperature reconstruction has yet been published (K. Holmgren, personal communication).

It is a heterogeneous picture of the temperature development that appears in the different records for the last two millennia. Some general trends are, however, visible in most of the records and five more or less distinct climate episodes can be distinguished. The end of the Roman Warm Period, an episode not much discussed in the literature but usually assumed to have occurred from *c.* 300 BC to AD 300, is visible in many, but far from all, of the records. The supposed Dark Age Cold Period, insufficiently discussed in the literature but usually reported to have occurred sometime between *c.* AD 300 and *c.* AD 800, is also visible in a considerable number of the records. In many of the records included in this overview, two different 'Dark Age Cold Periods' are discernible with warmer conditions between them: a cold period *c.* AD 400 and another *c.* AD 800. The much discussed Medieval Warm Period (Broecker 2001; Esper and Frank 2008; Hughes and Diaz 1994), usually supposed to have occurred *c.* AD 800–1300, is clearly visible in most of the records and is the most pronounced warming episode in the majority of the records during the last two millennia. The likewise much discussed Little Ice Age (Grove 1988; Matthews and Briffa 2005) in the time interval *c.* AD 1300–1900 is also clearly visible in most of the records where it represents the coldest and longest cold period. The 20th century warming (IPCC 2007) is apparent to different extents in most, but far from all, records. Late 20th century temperatures are in some of the records the highest for the last two millennia, although more

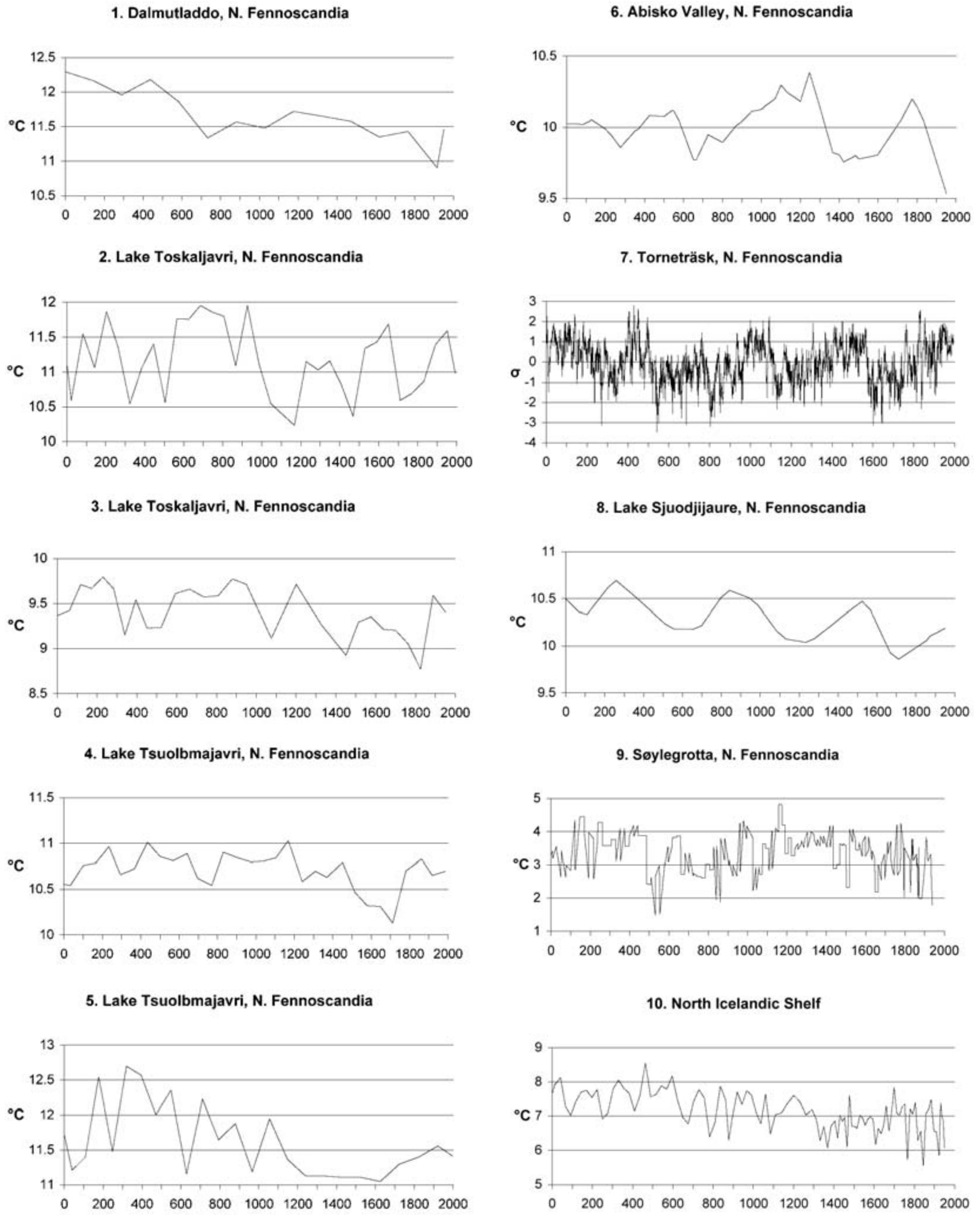
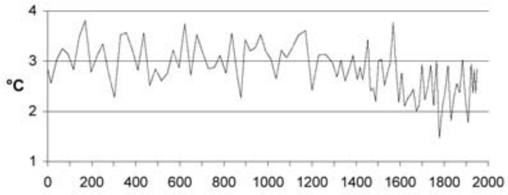
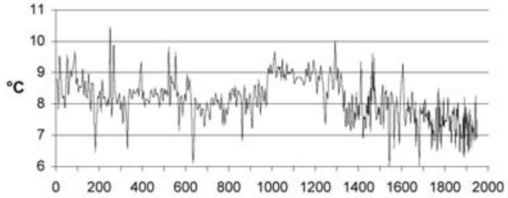


Fig. 2.1–71. Graphical representations of the 71 proxy records presented in Table 1

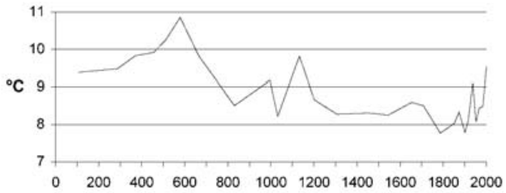
11. North Icelandic Shelf



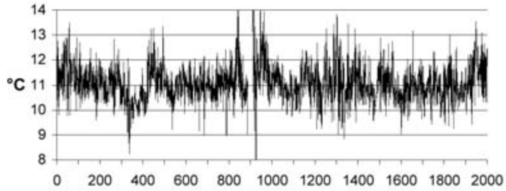
12. Off N. Iceland



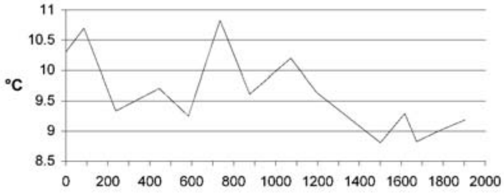
13. Stora Viðarvatn, Iceland



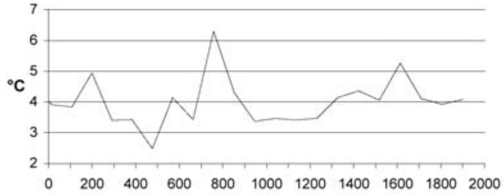
14. Jämtland, C. Sweden



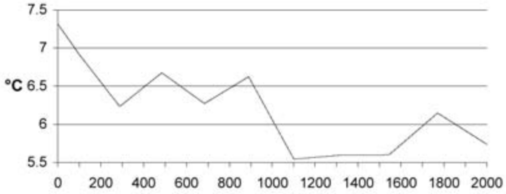
15. Lake Spåmine, C. Sweden



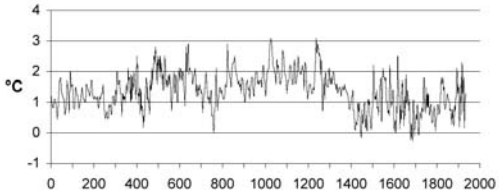
16. Lake Laihalampi, S. Finland



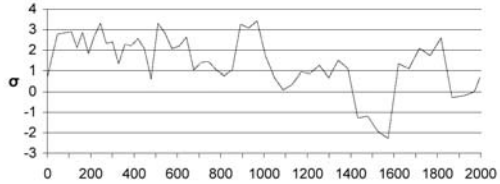
17. Lake Flarken, C. Sweden



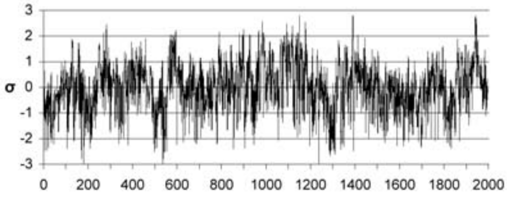
18. Spannagel Cave, C. Alps



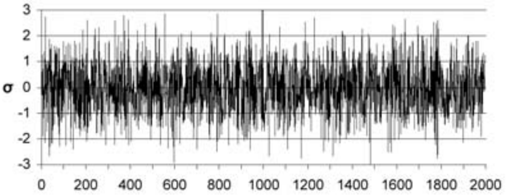
19. Penido Vello, Galicia, NW. Spain



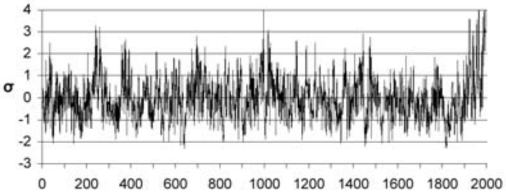
20. Taimyr peninsula, N. Siberia



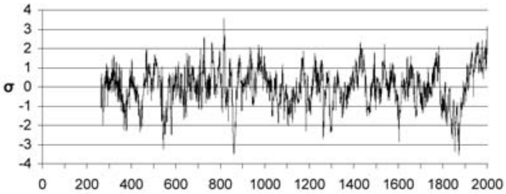
21. Yamal, NW. Siberia



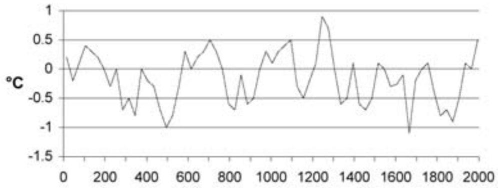
22. Yamal, NW. Siberia



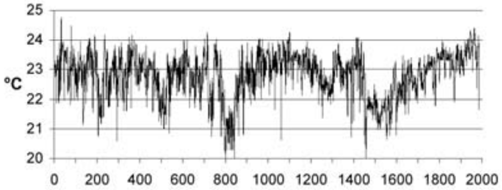
23. Solongotyn Davaa, Mongolia



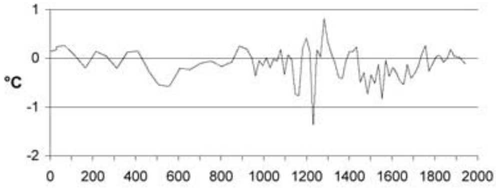
24. E. China



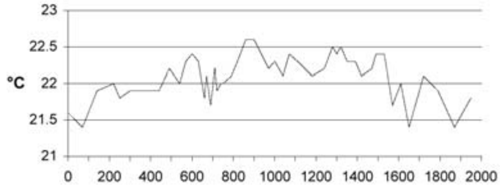
25. Beijing, China



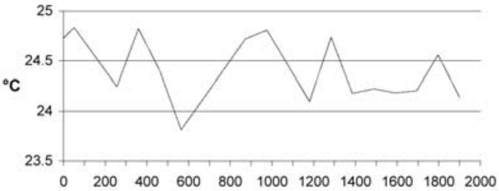
26. Lake Qinghai, Tibetan Plateau



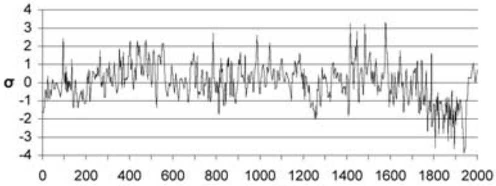
27. NE. North Pacific Ocean



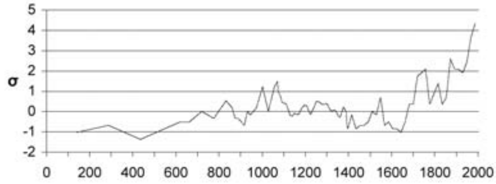
28. Northern Okinawa Trough, East China Sea



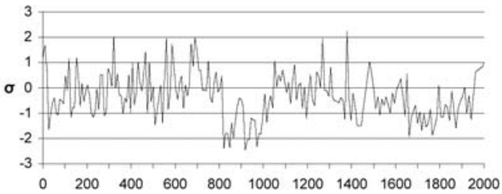
29. Dongge, China



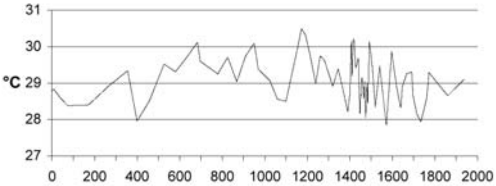
30. Arabian Sea



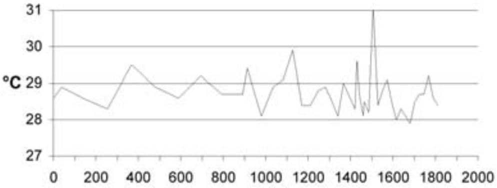
31. Socotra Island



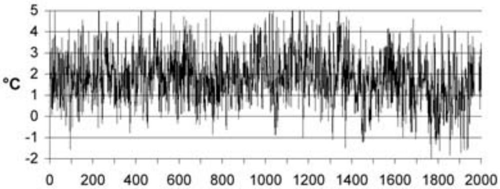
32. W. tropical Pacific Ocean



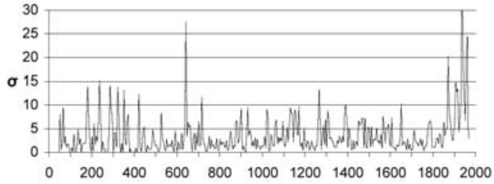
33. W. tropical Pacific Ocean



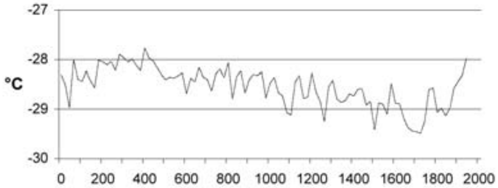
34. Lower Murray Lake, N. Canada



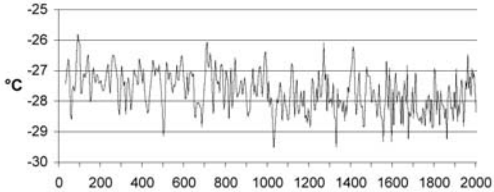
35. Agassiz Ice Cap, N. Canada



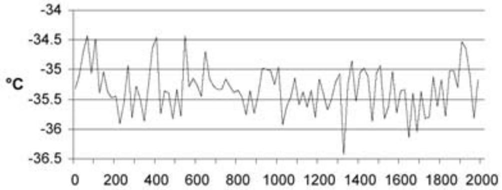
36. Agassiz Ice Cap, N. Canada



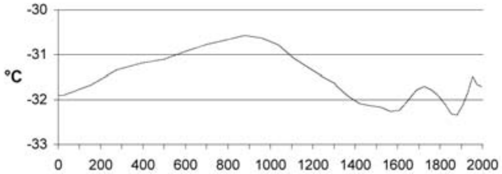
37. Devon Ice Cap, N. Canada



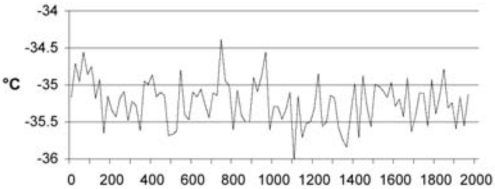
38. NorthGRIP, N. Greenland

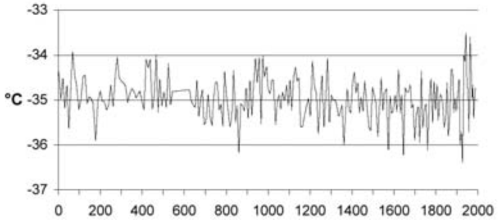


39. GRIP, C. Greenland

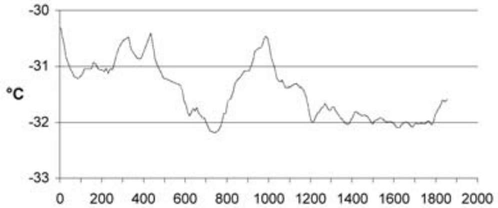


40. GRIP, C. Greenland

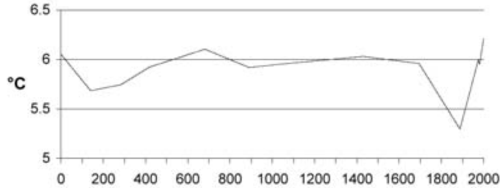




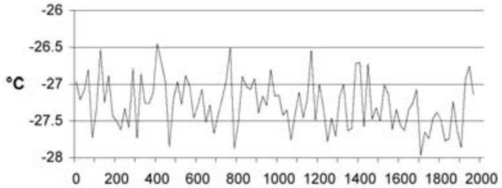
41. GISP2, C. Greenland



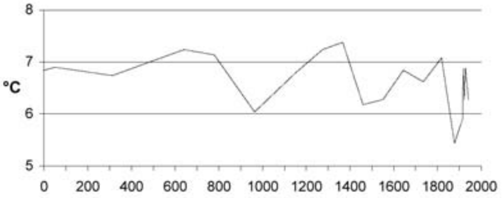
42. GISP2, C. Greenland



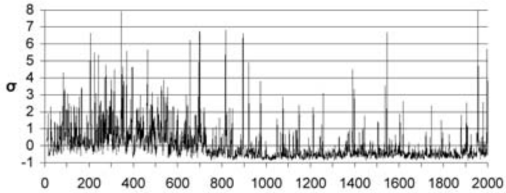
43. Victoria Island, NW. Canada



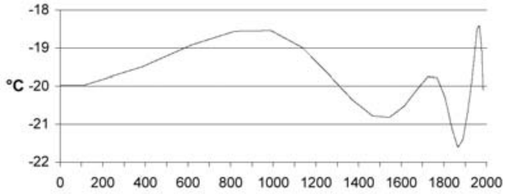
44. Renland, E. Greenland



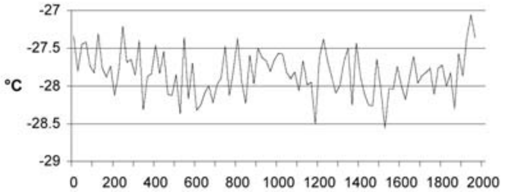
45. Boothia Peninsula, N. Canada



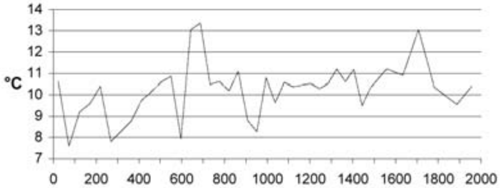
46. Blue Lake, N. Alaska



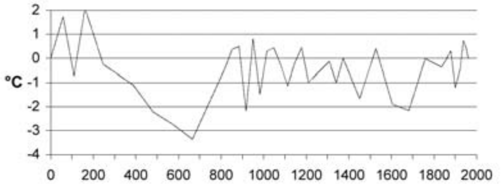
47. Dye-3, S. Greenland



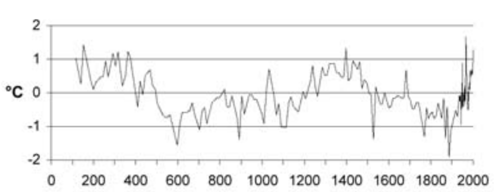
48. Dye-3, S. Greenland

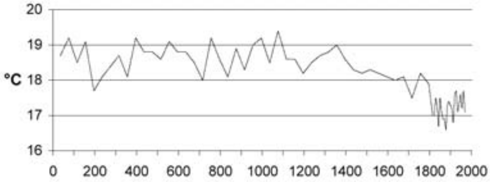


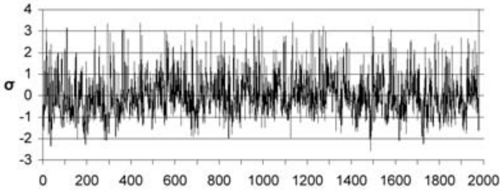
49. Northwest Territories, N. Canada

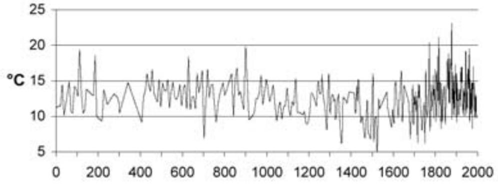


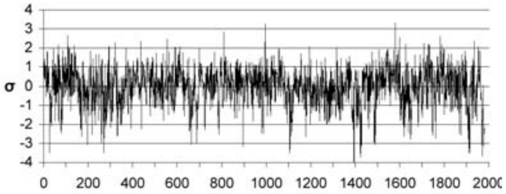
50. Farewell Lake, C. Alaska

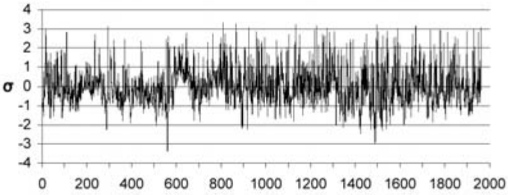

51. Hallet Lake, S. Alaska

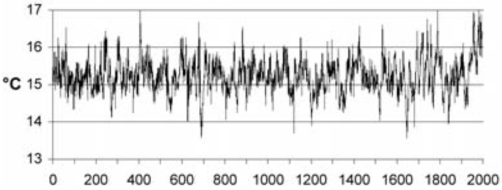

52. Conroy Lake, NE. USA

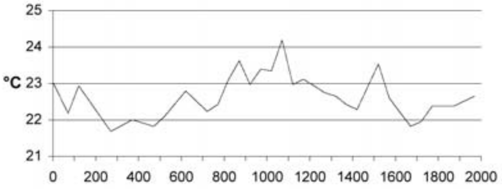

53. Indian Garden, SW. USA

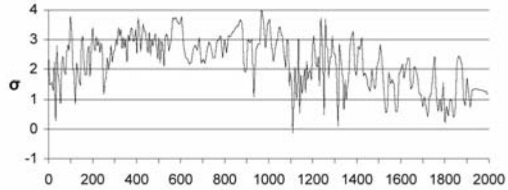

54. Chesapeake Bay, E. USA

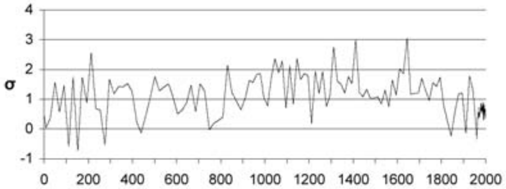

55. Methuselah Walk, SW. USA


56. White Mountain, SW. USA

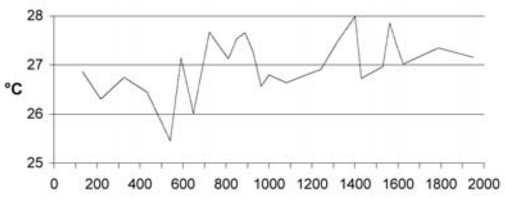

57. S. Colorado Plateau, SW. USA


58. Bermuda Rise, Sargasso Sea

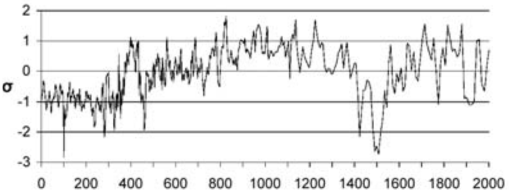

59. Punta Laguna, Yucatan, Mexico


60. Lake Chichancanab, Yucatan, Mexico

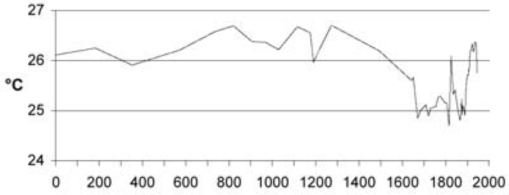
61. NE. Caribbean Sea



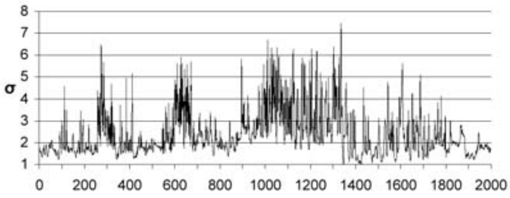
62. Nicoa Cave, Nicoya, Costa Rica



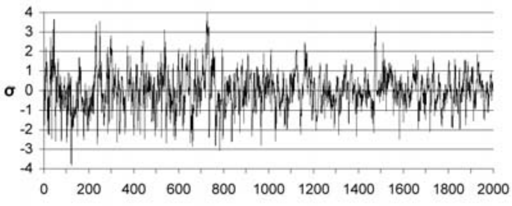
63. Cariaco Basin, Venezuelan Coast



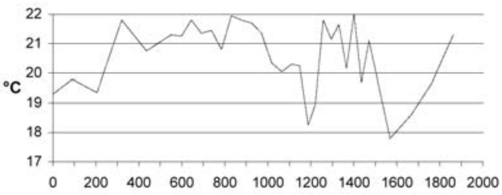
64. Lake Pallcacocha, Ecuador



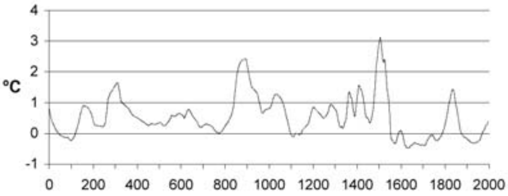
65. W. Argentina



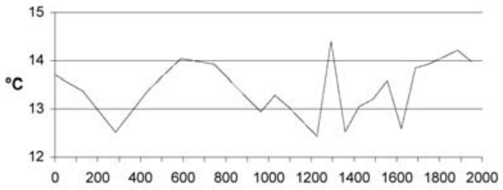
66. Subtropical Atlantic off W. Africa



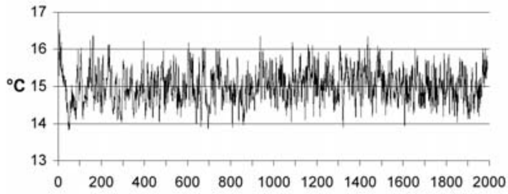
67. Makapansgat Valley, S. Africa



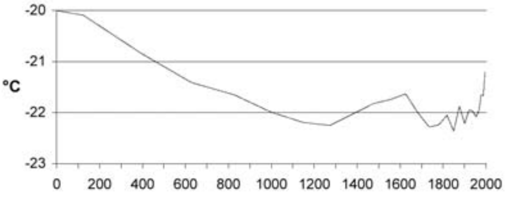
68. SE. South Atlantic

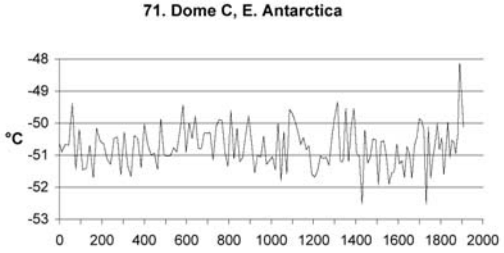


69. Mt. Read, W. Tasmania



70. Law Dome, Antarctica




71. Dome C, E. Antarctica

records seem to show peak medieval temperatures exceeding the modern temperatures.

The Roman Warm Period and Dark Age Cold Period are much less clearly discernible and seem to show a more heterogeneous pattern than the Medieval Warm Period, the Little Ice Age and the 20th century warming. In the records from the circum-North Atlantic region (including Europe, Greenland and the North American eastern seaboard), the Medieval Warm Period and the Little Ice Age are perhaps most clearly revealed but these climate episodes are also very distinctly shown in the records from China and Alaska. Thus, the Medieval Warm Period and the Little Ice Age seem to have been as much a circum-North Pacific phenomenon as a circum-North Atlantic phenomenon. In fact, evidence of the Medieval Warm Period and the Little Ice Age is to be seen in places all around the world, such as the tropical Pacific Ocean, Central America, the Caribbean Sea, Ecuador and South Africa. The period around *c*. AD 1000 seems, in many of the records, to have been the warmest in the past two millennia, whereas the 16th and 17th centuries seem to have been the coldest. In some records the 19th century is also a very cold century.

The amplitude between maximum and minimum temperatures during the past two millennia on centennial timescales in the different records is ranging from *c*. 0.5 to 4°C and averaging *c*. 1.5–2°C. However, the different records do not, as discussed above, necessarily show an exact chronological consistency in the timing of the warm and cold episodes. The 20th century warming is generally most pronounced in the higher latitudes, in agreement with the instrumental record. Nonetheless, a surprising feature is – when considering the entire two millennia period – that the range of centennial temperature variability is virtually the same in high and low latitudes. The records hence do not support the presumption that it is evident that long-term temperature variability increases with latitude.

Discussion

A quite clear cyclical climatic pattern on centennial timescales between warm and cold periods appears in some of the records, with both a Roman Warm Period, a Dark Age Cold Period, a Medieval Warm Period, a Little Ice Age and the 20th century warming discernible. This is especially true for: (1) record 7 from Torneträsk, northern Fennoscandia, by Grudd *et al*. (2002); (2) record 12 from northern Iceland by Sicre *et al*. (2008); (3) record 14 from Jämtland, central Sweden, by Linderholm and Gunnarson (2005); (4) record 18 from Spannagel Cave, Central Alps, by Mangini *et al*. (2005); (5) record 19 from Galicia, northwest Spain, by Martínez-Cortizas *et al*. (1999); (6) records 24–26 from China and Tibet by Ge *et al*. (2003), Tan *et al*. (2003), and Liu *et al*. (2006) respectively; (7) the Greenland isotopic ice-core records 38, 40–42, 44 and 48 by Vinther *et al*. (2006), Johnsen *et al*. (2001), Grootes and Stuiver (1997), Alley (2000), Vinther *et al*. (2008), Vinther *et al*. (2006) respectively; (8) record 50 from Lake Farewell, central Alaska, by Hu *et al*. (2001); (9) record 58 from Bermuda Rise, Sargasso Sea, by Keigwin (1996).

Generally, the pollen, sediment and speleothem isotopic records show a greater amplitude of long-term variability than the tree ring width records. The Medieval Warm Period and the Little Ice Age are, for example, more pronounced in the former records. This cannot merely be a consequence of the fact that the tree ring width records reflect only summer temperatures (i.e. growth) since many of the other records (such as diatom and chironomid data and fossil pollen records) also reflect only summer temperatures. It is an important task for further research to look more closely into the different pictures of long-term climatic variability that are expressed by different kinds of proxy records. Only two of the records in this overview primarily reflect a winter temperature signal and just one reflects a spring temperature signal, while 32 records reflect a summer temperature signal. Although 36 records reflect an annual temperature signal there is a considerable bias towards summer temperature variability in the records. New records, reflecting winter, spring or autumn temperature variability, would therefore be of value.

It can also be concluded that the geographical distribution of the available temperature records for the last two millennia is still very uneven with a strong concentration to the circum-North Atlantic region and East Asia, as shown in Fig. 1. The coverage for the southern hemisphere is still very sparse. Records are also lacking for the interior of the continents of Asia and North and South America as well as from, for example, the Sahara. Nevertheless, considerable progress has been made in the last few years. A far greater number of records are available now than at the time the IPCC (2007) report was written. An urgent task would therefore be to use the new data to update existing global and hemispheric multi-proxy temperature reconstructions.

Access to data

Data have been made available from the World Data Center for Paleoclimatology, 325 Broadway, Boulder, Colorado, Unites States.
website: http://www.ncdc.noaa.gov/paleo/paleo.html.
E-mail: paleo@noaa.gov.

Acknowledgements

I would like to express my gratitude to several scholars who provided me with non-archived, and thus not publically availably, proxy data: Dr Anne E. Bjune, Bjerknes Centre for Climate Research, University of Bergen; Dr Fengming Chang, Institute of Oceanology, Chinese Academy of Sciences, Professor Antonio Martínez Cortizas, Departamento dae Edafología y Química Agrícola, Universidad de Santiago de Compostela; Professor Konrad Gajewski, Laboratory for Paleoclimatology and Climatology, University of Ottawa; Associate Professor Miguel A. Goñi, College of Oceanic and Atmospheric Sciences, Oregon State University; Dr Björn Gunnarson, Department of Physical Geography and Quaternary Geology, Stockholm University; Professor Dan Hammarlund, Department of Geology, Lund University; Professor Karin Holmgren, Department of Physical Geography and Quaternary Geology, Stockholm University; Professor Feng Sheng Hu, Department of Plant Biology, University of Illinois; Dr Zhonghui Liu, Department of Geology and Geophysics, Yale University; PhD student Nicholas McKay, Department of Geosciences, University of Arizona; Dr Peter Rosén, Department of Ecology and Environmental Science, Umeå University; Dr Marie-Alexandrine Sicre, Laboratoire des Sciences du Climat et de l'Environnement.

Fredrik Charpentier Ljungqvist, *Department of History, Stockholm University, SE-106 91 Stockholm, Sweden.*
E-mail: fredrik.c.l@historia.su.se

References

Abrantes, F., Lebreiro, S., Rodrigues, T., Gil, I., Bartels-Jónsdóttir, H., Oliveira, P., Kissel, C. and Grimalt, J.O., 2005: Shallow-marine sediment cores record climate variability and earthquake activity off Lisbon (Portugal) for the last 2000 years. *Quaternary Science Reviews*, 24: 2477–2494.

Alley, R.B., 2000: The Younger Dryas cold interval as viewed from Central Greenland. *Quaternary Science Reviews*, 19: 213–226.

Axford, Y., Geirsdóttir, A., Miller, G.H. and Langdon, P.G., 2008: Climate of the Little Ice Age and the past 2000 years in northeast Iceland inferred from chironomids and other lake sediment proxies. *Journal of Paleolimnology*: in press.

Bemis, B.E., Spero, H.J., Bijma, J, and Lea, D.W., 1998: Reevaluation of the oxygen isotopic composition of planktonic foraminifera: Experimental results and revised paleotemperature equations. *Paleoceanography*, 13: 150–160.

Bird, B.W., Abbott, M.B., Finney, B.P. and Kutchko, B., 2008: A 2000 year varve-based climate record from the central Brooks Range, Alaska. *Journal of Paleolimnology*: in press.

Bjune, A., Birks, H.J.B. and Seppä, H., 2004: Holocene vegetation and climate history on a continental-oceanic transect in northern Fennoscandia based on pollen and plant macrofossils. *Boreas*, 33: 211–223.

Bodri, L. and Čermák, V., 1997: Climate changes of the last two millennia inferred from borehole temperatures: results from the Czech Republic – Part II. *Global and Planetary Change*, 14: 163–173.

Bradley, R.S., 1999: Paleoclimatology: Reconstructing Climates of the Quaternary. Academic Press: San Diego, CA. 613 p.

Briffa, K.R., 2000: Annual climate variability in the Holocene: interpreting the message of ancient trees. *Quaternary Science Reviews*, 19: 87–105.

Broecker, W.S., 2001: Was the Medieval Warm Period global? *Science*, 291: 1497–1499.

Burns, S.J., Fleitmann, D., Matter, A., Kramers, J. and Al-Subbary, A.A., 2003: Indian Ocean climate and an absolute chronology over Dansgaard/Oeschger Events 9 to 13. *Science*, 301: 1365–1367.

Cook, E.R., Buckley, B.M., D'Arrigo, R.D. and Peterson, M.J., 2000: Warm-season temperatures since 1600 BC reconstructed from Tasmanian tree rings and their relationship to large-scale sea surface temperature anomalies. *Climate Dynamics*, 16: 79–91.

Cook, E.R., Esper, J. and D'Arrigo, R.D., 2004: Extra-tropical Northern Hemisphere land temperature variability over the past 1000 years. *Quaternary Science Reviews*, 23: 2063–2074.

Cook, T.L., Bradley, R.S., Stoner, J.S. and Francus, P., 2008: Five thousand years of sediment transfer in a high arctic watershed recorded in annually laminated sediments from Lower Murray Lake, Ellesmere Island, Nunavut, Canada. *Journal of Paleolimnology*: in press.

Cronin, T.M., Dwyer, G.S., Kamiya, T., Schwede, S. and Wil-

lard, D.A. 2003: Medieval Warm Period, Little Ice Age and 20th century temperature variability from Chesapeake Bay. *Global and Planetary Change*, 36: 17–29.

Crowley, T.J. and Lowery, T., 2000: How warm was the Medieval Warm Period? A comment on "man-made versus natural climate change". *Ambio*, 29: 51–54.

Curtis, J.H., Hodell, D.A. and Brenner, M., 1996: Climate variability on the Yucatan Peninsula (Mexico) during the past 3500 yr, and implications for Maya cultural evolution. *Quaternary Research*, 46: 37–47.

Dahl-Jensen, D., Mosegaard, K., Gundestrup, N., Clow, G.D., Johnsen, S.J., Hansen, A.W. and Balling, N., 1998: Past temperatures directly from the Greenland Ice Sheet. *Science*, 282: 268–271.

Dahl-Jensen, D., Morgan, V.I. and Elcheikh, A., 1999: Monte Carlo inverse modelling of the Law Dome (Antarctica) temperature profile. *Annals of Glaciology*, 29: 145–150.

D'Arrigo, R., Jacoby, G., Frank, D., Pederson, N., Cook, E., Buckley, B., Nachin, B., Mijiddorj, R. and Dugarjav, C., 2001: 1738 years of Mongolian temperature variability inferred from a tree-ring width chronology of Siberian pine. *Geophysical Research Letters*, 28: 543–546.

D'Arrigo, R., Wilson, R. and Jacoby, G., 2006: On the long-term context for late 20th century warming. *Journal of Geophysical Research*, 111: D3, D03103.

deMenocal, P., Ortiz, J., Guilderson, T. and Sarnthein, M., 2000: Coherent high- and low-latitude climate variability during the Holocene Warm Period. *Science*, 288: 2198–2202.

Esper, J. and Frank, D.C., 2008: IPCC on heterogeneous Medieval Warm Period. *Climatic Change*, in press.

Esper, J., Cook, E.R. and Schweingruber, F.H., 2002: Low-frequency signals in long tree-ring chronologies for reconstructing past temperature variability. *Science*, 295: 2250–2253.

Farmer, E.C., deMenocal, P.B. and Marchitto, T.M., 2005: Holocene and deglacial ocean temperature variability in the Benguela upwelling region: Implications for low-latitude atmospheric circulation. *Paleoceanography*, 20: PA2018.

Fengming, C., Tiegang, L., Lihua, Z. and Jun, Y., 2008: A Holocene paleotemperature record based on radiolaria from the northern Okinawa Trough (East China Sea). *Quaternary International*, 183: 115–122.

Fisher, D.A., Koerner, R.M., Paterson, W.S.B., Dansgaard, W., Gundestrup, N. and Reeh, N., 1983: Effect of wind scouring on climatic records from icecore oxygen isotope profiles. *Nature*, 301: 205–209.

Fisher, D.A., Koerner, R.M. and Reeh, N., 1995: Holocene climatic records from Agassiz Ice Cap, Ellesmere Island, NWT, Canada. *The Holocene*, 5: 19–24.

Gajewski, K., 1988: Late Holocene climate changes in eastern North America estimated from pollen data. *Quaternary Research*, 29: 255–262.

Ge, Q., Zheng, J., Fang, X., Man, Z., Zhang, X., Zhang, P. and Wang, W.-C., 2003: Winter half-year temperature reconstruction for the middle and lower reaches of the Yellow River and Yangtze River, China, during the past 2000 years. *The Holocene*, 13: 933–940.

Goñi, M.A., Woodworth, M.P., Aceves, H.L., Thunell, R.C., Tappa, E., Black, D., Müller-Karger, F., Astor, Y. and Varela, R., 2004: Generation, transport, and preservation of the alkenone-based $U_{37}^{K'}$ sea surface temperature index in the water column and sediments of the Cariaco Basin (Venezuela). *Global Biogeochemical Cycles*, 18: 10.1029/2003GB002132.

Grootes, P.M. and Stuiver, M., 1997: Oxygen 18/16 variability in Greenland snow and ice with 10^3 to 10^5-year time resolution. *Journal of Geophysical Research*, 102: 26455–26470.

Grove, J.M., 1988: The Little Ice Age. Methuen. London. 498 p.

Grudd, H., 2008: Torneträsk tree-ring width and density AD 500–2004: a test of climatic sensitivity and a new 1500-year reconstruction of north Fennoscandian summers. *Climate Dynamics*, 31: 843–857.

Grudd, H., Briffa, K.R., Karlén, W., Bartholin, T.S., Jones, P.D. and Kromer, B., 2002: A 7400-year tree-ring chronology in northern Swedish Lapland: natural climatic variability expressed on annual to millennial timescales. *The Holocene*, 12: 657–665.

Hammarlund D., Velle G., Wolfe B.B., Edwards T.W.D., Barnekow L., Bergman J., Holmgren S., Lamme S., Snowball I., Wohlfarth B. and Possnert G., 2004: Palaeolimnological and sedimentary responses to Holocene forest retreat in the Scandes Mountains, west-central Sweden. *The Holocene*, 14: 862–876.

Hantemirov, R.M. and Shiyatov, S.G., 2002: A continuous multimillennial ring-width chronology in Yamal, northwestern Siberia. *The Holocene*, 12: 717–726.

Hegerl, G., Crowley, T., Allen, M., Hyde, W., Pollack, H., Smerdon, J. and Zorita, E., 2007: Detection of human influence on a new, validated, 1500 year temperature reconstruction. *Journal of Climate*, 20: 650–666.

Heikkilä, M. and Seppä, H., 2003: A 11,000 yr palaeotemperature reconstruction from the southern boreal zone in Finland. *Quaternary Science Reviews*, 22: 541–554.

Helama, S., Lindholm, M., Timonen, M., Meriläinen, J. and Eronen, M., 2002: The supra-long Scots pine tree-ring record for Finnish Lapland: Part 2, interannual to centennial variability in summer temperatures for 7500 years. *The Holocene*, 12: 681–687.

Hodell, D.A., Brenner, M. and Curtis, J.H., 2005: Terminal Classic drought in the northern Maya Lowlands inferred from multiple sediment cores in Lake Chichancanab (Mexico). *Quaternary Science Reviews*, 24: 1413–1427.

Holmgren, K., Tyson, P.D., Moberg, A. and Svanered, O., 2001: A preliminary 3000-year regional temperature reconstruction for South Africa. *South African Journal of Science*, 97: 1–3.

Hu, F.S., Ito, E., Brown, T.A., Curry, B.B. and Engstrom, D.R., 2001: Pronounced climatic variations in Alaska during the last two millennia. *Proceedings of the National Academy of Sciences, USA*, 98: 10552–10556.

Hughes, M.K. and Diaz, H.F., 1994: Was there a 'medieval warm period', and if so, where and when? *Climatic Change*, 26, 109–142.

IPCC, 2007: Climate Change 2007: The physical science basis. Contribution of working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change (edited by: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L.). Cambridge University Press. Cambridge and New York. 996 p.

Jiang, J., Eiriksson, M., Schultz, K.L., Knudsen, K.-L. and Seidenkrantz, M.S., 2005: Evidence for solar forcing of sea surface temperature on the North Icelandic Shelf during the late Holocene. *Geology*, 33: 73–76.

Johnsen, S.J., Dahl-Jensen, D., Gundestrup, N., Steffensen, J.P., Clausen, H.B., Miller, H., Masson-Delmotte, V., Sveinbjörnsdottir, A.E. and White, J., 2001: Oxygen isotope and palaeotemperature records from six Greenland ice-core stations: Camp Century, Dye-3, GRIP, GISP2, Renland and NorthGRIP. *Journal of Quaternary Science*, 16: 299–307.

Jones, P.D. and Mann, M.E., 2004: Climate over past millennia. *Reviews of Geophysics*, 42: RG2002.

Jones, P.D., Briffa, K.R., Barnett, T.P. and Tett, S.F.B., 1998: High-resolution palaeoclimatic records for the last millennium: interpretation, integration and comparison with General Circulation Model control-run temperatures. *The Holocene*, 8: 455–471.

Jouzel, J., Masson, V., Cattani, O., Falourd, S., Stievenard M., Stenni, B., Longinelli, A., Johnsen, S.J., Steffensen, J.P., Petit, J.R., Schwander, J., Souchez, R. and Barkov, N.I., 2001: A new 27 ky high resolution East Antarctic climate record. *Geophysical Research Letters*, 28: 3199–3202.

Juckes, M.N., Allen, M.R., Briffa, K.R., Esper, J., Hegerl, G.C., Moberg, A., Osborn, T.J. and Weber, S.L., 2007: Millennial temperature reconstruction intercomparison and evaluation. *Climate of the Past*, 3: 591–609.

Keigwin, L.D., 1996: The Little Ice Age and Medieval Warm Period in the Sargasso Sea. *Science*, 274: 1504–1008.

Kim, J.-H., Rimbu, N., Lreorenz, S.J., Lohmann, G., Schneider, R., Nam, S.-I., Schouten, S., Sirocko, F. and Rühlemann, C., 2004: North Pacific and North Atlantic sea-surface temperature variability during the Holocene. *Quaternary Science Reviews*, 23: 2141–2154.

Kitagawa, H. and Matsumoto, E., 1995: Climatic implications of δ^{13}C variations in a Japanese cedar (*Cryptomeria japonica*) during the last two millenia. *Geophysical Research Letters* 22: 2155–2158.

Korhola, A., Weckström, J., Holmström, L. and Erästö, P.A., 2000: A quantitative Holocene climatic record from diatoms in northern Fennoscandia. *Quaternary Research*, 54: 284–294.

Lara, A. and Villalba, R., 1993: A 3620-year temperature record from *Fitzroya cupressoides* tree rings in Southern South America. *Science*, 260: 1104–1106.

Larocque, I. and Halla, R.I., 2004: Holocene temperature estimates and chironomid community composition in the Abisko Valley, northern Sweden. *Quaternary Science Reviews*, 23: 2453–2465.

Lauritzen, S.-E. and Lundberg, J., 1999: Calibration of the speleothem delta function: an absolute temperature record for the Holocene in northern Norway. *The Holocene*, 9: 659–669.

Linderholm, H.W. and Gunnarson, B.E., 2005: Summer temperature variability in central Scandinavia during the last 3600 years. *Geografiska Annaler*, 87A: 231–241.

Liu, Z., Henderson, A.C.G. and Huang, Y., 2006: Alkenone-based reconstruction of late-Holocene surface temperature and salinity changes in Lake Qinghai, China. *Geophysical Research Letters*, 33: 10.1029/2006GL026151.

Loehle, C., 2007: A 2000-year global temperature reconstruction based on non-treering proxies. *Energy & Environment*, 18: 1049–1058.

MacDonald, G.M., Porinchu, D.F., Rolland, N., Kremenetsky, K.V. and Kaufman, D.S., 2008: Paleolimnological evidence of the response of the central Canadian treeline zone to radiative forcing and hemispheric patterns of temperature change over the past 2000 years. *Journal of Paleolimnology*: in press.

McKay, N.P., Kaufman, D.S. and Michelutti, N., 2008: Biogenic silica concentration as a high-resolution, quantitative temperature proxy at Hallet Lake, south-central Alaska. *Geophysical Research Letters*, 35: 10.1029/2007GL032876.

Mangini, A., Spötl, C. and Verdes, P., 2005: Reconstruction of temperature in the Central Alps during the past 2000 yr from a δ^{18}O stalagmite record. *Earth and Planetary Science Letters*, 235: 741–751.

Mann, M.E. and Jones, P.D., 2003: Global surface temperatures over the past two millennia. *Geophysical Research Letters*, 30: 1820.

Mann, M.E., Bradley, R.S. and Hughes, M.K., 1999: Northern hemisphere temperatures during the past millennium: inferences, uncertainties, and limitations. *Geophysical Research Letters*, 26: 759–762.

Mann, M.E., Zhang, Z., Hughes, M.K., Bradley, R.S., Miller, S.K., Rutherford, S. and Ni, F., 2008: Proxy-based reconstructions of hemispheric and global surface temperature variations over the past two millennia. *Proceedings of the National Academy of Sciences, USA*, 105: 13252–13257.

Martínez-Cortizas, A., Pontevedra-Pombal, X., García-Rodeja, E., Novóa-Muñoz, J.C. and Shotyk, W., 1999: Mercury in a Spanish peat bog: Archive of climate change and atmospheric metal deposition. *Science*, 284: 939–942.

Matthews, J.A. and Briffa, K.R., 2005: The 'Little Ice Age': Re-evaluation of an evolving concept. *Geografiska Annaler*, 87A: 17–36.

Moberg, A., Sonechkln, D.M., Holmgren, K., Datsenko, N.M. and Karlén, W., 2005: Highly variable Northern Hemisphere temperatures reconstructed from low- and high-resolution proxy data. *Nature*, 433: 613–617.

Moy, C.M., Seltzer, G.O., Rodbell, D.T. and Anderson, D.M., 2002: Variability of El Niño/Southern Oscillation activity at millennial timescales during the Holocene epoch. *Nature*, 420: 162–165.

Naurzbaev, M.M., Vaganov, E.A., Sidorova, O.V. and Schweingruber, F.H., 2002: Summer temperatures in eastern Taimyr inferred from a 2427-year late-Holocene tree-ring chronology and earlier floating series. *The Holocene*, 12: 727–736.

NRC (National Research Council), 2006: Surface temperature reconstructions for the last 2000 years. National Academies Press. Washington, DC. 196 p.

Nyberg, J., Malmgren, B.A., Kuijpers, A. and Winter, A., 2002: A centennial-scale variability of tropical North Atlantic surface hydrography during the late Holocene. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 183: 25–41.

Osborn, T.J. and Briffa, K.R., 2006: The spatial extent of 20th-century warmth in the context of the past 1200 years. *Science*, 311: 841–844.

Peros, M.C. and Gajewski, K., 2008: Holocene climate and vegetation change on Victoria Island, western Canadian Arctic. *Quaternary Science Reviews*, 27: 235–249.

Rosén, P., Segerström, U., Eriksson, L. and Renberg I., 2003: Do diatom, chironomid, and pollen records consistently infer Holocene July air temperatures? A comparison using sediment cores from four alpine lakes in Northern Sweden. *Arctic, Antarctic and Alpine Research*, 35: 279–290.

Salzer, M.W. and Kipfmueller, K.F., 2005: Reconstructed temperature and precipitation on a millennial timescale from tree-rings in the Southern Colorado Plateau, U.S.A. *Climatic Change*, 70: 465–487.

Scuderi, L.A., 1993: A 2000-year tree ring record of annual temperatures in the Sierra Nevada Mountains. *Science*, 259: 1433–1436.

Seppä, H. and Birks, H.J.B., 2001: July mean temperature and annual precipitation trends during the Holocene in the Fennoscandian tree-line area: pollen-based climate reconstructions. *The Holocene*, 11: 527–537.

Seppä, H. and Birks, H.J.B., 2002: Holocene climate reconstructions from the Fennoscandian tree-line area based on pollen data from Toskaljavri. *Quaternary Research*, 57: 191–199.

Seppä, H., Nyman, M., Korhola, A. and Weckström, J., 2002: Changes of treelines and alpine vegetation in relation to post-glacial climate dynamics in northern Fennoscandia based on pollen and chironomid records. *Journal of Quaternary Science*, 17: 287–301.

Seppä, H., Hammarlund, D. and Antonsson, K., 2005: Low-frequency and high-frequency changes in temperature and effective humidity during the Holocene in south-central Sweden: implications for atmospheric and oceanic forcings of climate. *Climate Dynamics*, 25: 285–297.

Sicre, M.-A., Jacob, J., Ezat, U., Rousse, S., Kissel, C., Yiou, P., Eiríksson, J., Knudsen, K.L., Jansen, E. and Turon, J.-L., 2008: Decadal variability of sea surface temperatures off North Iceland over the last 2000 years. *Earth and Planetary Science Letters*, 268: 137–142.

Stott, L.D., Cannariato, K.G., Thunell, R., Haug, G.H., Koutavas, A. and Lund, S., 2004: Decline of surface temperature and salinity in the western tropical Pacific Ocean in the Holocene epoch. *Nature*, 431: 56–59.

Tan, M., Liu, T., Hou, J., Qin, X., Zhang, H. and Li, T., 2003: Cyclic rapid warming on centennial-scale revealed by a 2650-year stalagmite record of warm season temperature. *Geophysical Research Letters*, 30: 1617.

Vinther, B.M., Clausen, H.B., Johnsen, S.J., Rasmussen, S.O., Andersen, K.K., Buchardt, S.L., Dahl-Jensen, D., Seierstad, I.K., Siggaard-Andersen, M.-L., Steffensen, J.P., Svensson, A., Olsen, J. and Heinemeier, J., 2006: A synchronized dating of three Greenland ice cores throughout the Holocene. *Journal of Geophysical Research*, 111: D13102.

Vinther, B.M., Clausen, H.B., Fisher, D.A., Koerner, R.M., Johnsen, S.J., Andersen, K.K., Dahl-Jensen, D., Rasmussen, S.O., Steffensen, J.P. and Svensson, A.M., 2008: Synchronizing ice cores from the Renland and Agassiz ice caps to the Greenland Ice Core Chronology. *Journal of Geophysical Research*, 113: D08115.

Wang, Y. Cheng, H., Edwards, R.L., He, Y., Kong, X., An, Z., Wu, J., Kelly, M.J., Dykoski, C.A. and Li, X., 2005: The Holocene Asian monsoon: Links to solar changes and North Atlantic climate. *Science*, 308: 854–857.

Zabenskiea, S. and Gajewski, K., 2007: Post-Glacial climatic change on Boothia Peninsula, Nunavut, Canada. *Quaternary Research*, 68: 261–270.

Manuscript received Oct. 2008, revised and accepted Nov. 2008.