Jeffrey S. Dean David M. Meko Thomas W. Swetnam
Editors

TREE RINGS, ENVIRONMENT AND HUMANITY

Proceedings of the International Conference, Tucson, Arizona,
17–21 May 1994

RADIOCARBON
Department of Geosciences
The University of Arizona
4717 E. Ft. Lowell Road
Tucson, Arizona 85712 USA

Library of Congress Cataloging-in-Publication Data

Tree rings, environment, and humanity : proceedings of the
international conference : Tucson, Arizona, 17-21 May 1994 / [edited
by] Jeffrey S. Dean, David M. Meko, Thomas W. Swetnam.
p. cm.
"International Conference on Tree-Rings, Environment, and
Humanity--Processes and Relationships"--Pref.
Includes bibliographical references (p.).
ISBN 0-9638314-2-9 (pbk.)
1. Dendrochronology--Congresses. 2. Tree-rings--Congresses.
3. Dendroclimatology--Congresses. 4. Climatic changes--Congresses.
5. Trees--Ecology--Congresses. 6. Man--Influence on nature--Congresses. I. Dean, Jeffrey S., 1939- . II. Meko, David M.,
1950- . III. Swetnam, Thomas W. IV. International Conference on
Tree-Rings, Environment, and Humanity: Processes and Relationships
(1994 : Tucson, Ariz.)
QK477.2.A6T74 1996
582.16--dc20 96-25331

Printed and bound by Cushing-Malloy, Inc., Ann Arbor, Michigan in the United States of America.

ISBN 0-9638314-2-9 *RADIOCARBON,* The University of Arizona, Tucson, Arizona USA

SUMMER TEMPERATURE VARIATIONS RECONSTRUCTED BY TREE-RING DATA AT THE POLAR TIMBERLINE IN SIBERIA

S. G. SHIYATOV,[1] V. S. MAZEPA,[1] E. A. VAGANOV[2] and F. H. SCHWEINGRUBER[3]

ABSTRACT. This paper discusses preliminary results of a dendroclimatic study in the subarctic regions of Siberia and the Far East, along a transect 4500 km long. Ring-width chronologies were developed using living coniferous trees. The chronologies range from 227 to 612 yr in length and most contain a very strong climatic signal, mainly of June and July temperatures of the growth year. A similar variability of index values within large areas (up to 800 km) along the transect was observed. The territory studied was divided into four dendroclimatic regions using threshold values of the coefficients of correlation (>0.4) between chronologies and synchronization of growth indices (>68%) and by comparison with the spatial variations of the first eigenvector of growth indices. Seven types and fifteen subtypes of growth index changes along the transect in separate calendar years were determined. Variability of reconstructed summer temperatures is very high (year-by-year range is up to 5.0–6.3°C). There is no evidence of increasing trend in tree growth during the last few decades that could be connected with anthropogenic climatic changes in summer months.

INTRODUCTION

Reconstruction and analysis of climatic changes at high latitudes for the last millennium are of great importance as climatic conditions, especially the thermal regime in these regions, are most variable and sensitive to various forcing functions (Rubinshtein and Polozova 1966; Budyko 1980). Climatic reconstruction by tree-ring data is of special interest, as trees growing at the polar timberline are very sensitive to temperature changes and can attain considerable age (up to 800–900 yr) (Jacoby and D'Arrigo 1989; Schweingruber, Briffa and Jones, 1991; Graybill and Shiyatov 1992; Archambault and Bergeron 1992). This study is part of the circumpolar dendroclimatic project (CDP) which has been carried out recently on the initiative of Dr. F. H. Schweingruber. The main goals of the CDP are: 1) development of a basic chronology network from old living trees growing at the northern limit; 2) assessment of the main climatic factors which influence tree radial growth; 3) development of statistical and simulation models of tree growth; 4) reconstruction of climatic conditions for the last 300–700 yr; 5) analysis of peculiarities in the chronology network and evaluation of the possible effect of anthropogenic factors on regional and global climatic changes. Preliminary results of dendroclimatic studies along a subarctic transect 4500 km long (from the Polar Ural Mountains in the west to the upper reaches of the Maly Anuy River in the east) are presented in this paper.

SITE DESCRIPTION

Old living trees of *Larix sibirica* Ldb., *Larix gmelini* Pilger, *Larix cajanderi* Mayr, *Picea obovata* Ldb. and *Pinus sylvestris* L. were collected by the Russian-Swiss expedition in 1991 and 1992. The locations of the study sites are shown in Figure 1. The average distance between sampling sites is about 200 km. We collected increment cores from the northernmost forest islands, as well as from large forest massifs located 200–400 km to the south of the polar timberline. In the territory located to the east of the Lena River (*ca.* 120°E) we also collected wood samples from 80 sites up to 1100 km distant from the Arctic Ocean.

[1]Institute of Plant and Animal Ecology of the Ural Division of the Russian Academy of Sciences, Ekaterinburg 620219 Russia
[2]Institute of Forest of the Siberian Division of the Russian Academy of Sciences, Krasnoyarsk 660036 Russia
[3]Swiss Federal Institute for Forest, Snow and Landscape Research, CH–8903, Birmensdorf, Switzerland

Tree Rings, Environment and Humanity, edited by
J. S. Dean, D. M. Meko and T. W. Swetnam. RADIOCARBON *1996, pp. 61–70*

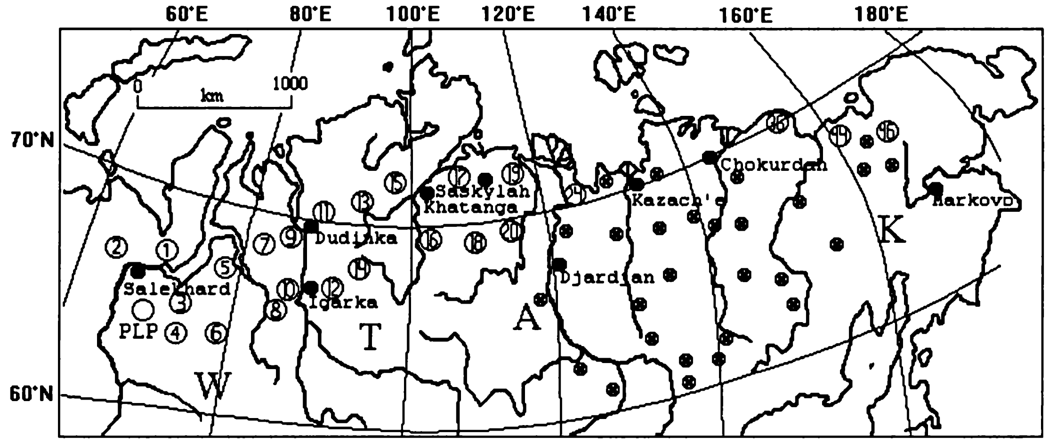

Fig. 1. Map of the locations and numerical codes of tree-ring chronologies and meteorological stations. ① = locations of sampled and developed chronologies, ⊗ = locations of sampled sites, ● = locations of meteorological stations

Tree-ring chronologies of larch are most suitable for climatic reconstruction because of the species' biological and ecological peculiarities: longevity, light requirements, lack of long-lived needles, capacity of maximum use of ambient heat, growth on permafrost, resistance to fires, frosts, winds and other unfavorable environmental factors, and the presence of distinct growth layers in the wood.

To increase the amount of information available for analysis, densitometric and cell chronologies will be developed later. In this paper we have analyzed 29 ring-width chronologies only (Table 1). The ring-width chronologies are longest and contain low-frequency variability in larger degree. (The oldest trees that we sampled usually had trunk rot.) The length of these chronologies varies from 227 yr (series 4) to 612 yr (series 24). The oldest trees were found in areas with extremely continental climates (the lower reaches of the Lena, Indigirka and Kolyma Rivers), and in areas located 200–300 km to the south of the polar timberline. The main problem that appeared during tree-ring chronology development for sites in high-latitude areas in Siberia was detecting the exact locations of missing rings. In many individual chronologies, especially in larch, up to 5–10% of rings were missing.

Only a few meteorological stations in the north of Siberia have kept records since before 1930. The longest records are available from Salekhard station (since 1883). Others have shorter common periods of observation, with many gaps. Climate data used are monthly air temperature for 9 stations (Fig. 1, Table 2) which were compiled from different sources (Bradley *et al.* 1985; Laboratory files, Institute of Plant and Animal Ecology, Ekaterinburg) and compared with adjacent stations. Missing data were estimated using simple regression with appropriate temperature records.

METHODS

All cores were mounted and sanded. Ring widths were measured to the nearest 0.01 mm and then all cores were crossdated using plots of individual ring-width series. All segments of cores that had been assigned calendar years inconsistent with corresponding ones of other cores were visually rechecked and either corrected or eliminated from further analysis.

TABLE 1. Tree-Ring Chronology Collections (listed west to east)

Series no.	Location	Lat. N	Long. E	Elevation (m)	Species*	Trees sampled	Common interval (AD)	Mean sensitivity
1	Khadyta-Yakha River	67°12′	69°50′	40	L.s.	21	1628–1990	0.37
1A	Longot-Yugan River	66°49′	69°17′	20	P.o.	12	1710–1990	0.22
1B	Yakhady-Yakha River	67°25′	70°58′	25	L.s.	23	1573–1991	0.39
2	Sob River	66°55′	65°46′	120	L.s.	19	1563–1992	0.45
PLP	Sukhoy Poluy River	65°18′	69°41′	35	P.s.	23	1595–1992	0.22
3	Lower Nadym River	66°13′	71°40′	20	P.o.	12	1720–1990	0.21
4	Kheigi-Yakha River	65°30′	72°39′	100	L.s.	18	1764–1990	0.27
5	Khadutte River	67°28′	76°46′	20	L.s.	17	1561–1990	0.41
6	Tab-Yakha River	67°07′	77°50′	20	L.s.	11	1745–1990	0.32
7	Indiga River	68°08′	79°46′	30	L.s.	14	1592–1990	0.39
8L	Mangazeya	66°40′	82°20′	50	L.s.	35	1624–1990	0.27
8P	Mangazeya	66°40′	82°20′	50	P.o.	24	1675–1990	0.19
9	Malaya Kheta River	69°07′	84°30′	50	L.s.	20	1606–1990	0.40
10	Solyonaya River	68°07′	85°03′	50	L.s.	18	1553–1990	0.42
11	Ikon River	70°31′	89°30′	70	L.s.	18	1615–1990	0.41
12L	Kulyumbe River	67°58′	88°55′	150	L.s.	30	1517–1990	0.37
12P	Kulyumbe River	67°58′	88°55′	150	P.o.	12	1617–1991	0.23
13	Bolshaya Kamenka River	71°20′	93°50′	70	L.g.	12	1540–1990	0.44
14	Ayakly River	69°32′	97°32′	400	L.g.	18	1517–1990	0.43
15	Novaya River (Ary-Mas)	72°27′	101°45′	10	L.g.	26	1514–1990	0.48
16	Kotuykan River	70°30′	104°15′	75	L.g.	22	1412–1990	0.40
17	Popigay River	71°54′	111°02′	25	L.g.	22	1570–1990	0.44
18	Bolshaya Kuonamka River	69°46′	112°49′	60	L.g.	17	1400–1990	0.35
19	Ary–Ongorbut River	71°42′	118°35′	80	L.g.	25	1600–1990	0.41
20	Olenek River	69°47′	119°07′	210	L.g.	20	1398–1990	0.33
24	Neleger River	71°13′	127°26′	40	L.c.	18	1380–1991	0.43
36	Alazeya River	69°17′	154°46′	50	L.c.	15	1412–1991	0.43
44	Vymey River	68°48′	163°03′	300	L.c.	21	1468–1991	0.35
46	Maly Aniuy River	67°28′	167°40′	450	L.c.	14	1420–1991	0.36

**Larix sibirica* (L.s.), *Pinus sylvestris* (P.s.), *Picea obovata* (P.o.), *Larix gmelini* (L.g.), *Larix cajanderi* (L.c.)

Low-frequency trends in growth related to age and other nonclimatic sources were modeled by fitting splines to each individual series using the TREND computer program developed by Rimer (1992). Sometimes, when an unexpected disturbance pulse in ring-width sequences occurred, the fitted curve was corrected manually within the computer program. When developing the mean chronology for each site, we used the GNRL computer program (Mazepa 1982). This program estimates mean index values from a mixture of normal distributions for each calendar year. The magnitude of autoregression was assessed by calculating autocorrelation functions. Time-series techniques were used to model and transform each mean chronology to a residual one which is statistically equivalent to white noise (Guiot 1986). We also used multiple regression techniques (Fritts 1976) to estimate the relationship between growth indices and the climatic parameter, which was monthly temperature data from the most proximate meteorological station. Response functions have been calculated for the majority of sites studied. All responses described here include 12 weights associated with variables of monthly mean temperature. We also transformed the chronology network to their principal components (PCs). This set of PCs was then reduced by discarding a number of high-order components representing relatively unimportant modes of variance in the tree-ring data set. We inspected maps representing the first three eigenvectors (orthogonal and unrotated) of growth indices from all sites throughout the transect studied. Finally, we reconstructed mean June–July temperature for separate sites for four areas of the Subarctic using mean chronologies that accounted for the greatest percent of variance reduced in a univariate regression equation. Only for chronology 1B was a calibration subperiod verified on an independent time interval, due to the presence of a long (>100 yr) temperature record. For the other three chronologies, we did not verify the calibration because of short (<57 yr) temperature records. Nevertheless, visual comparisons of plots between actual and reconstructed average June–July temperature series were performed. The simple regression coefficient estimated for whole period of time was used in the final reconstruction equation.

TABLE 2. Names and Locations of the Meteorological Stations Used

WMO No.	Station name	Lat. (N)	Long. (E)	Common interval (AD)
2012333000	Salekhard	66°31′	66°36′	1883–1990
2012307400	Dudinka	69°24′	86°05′	1934–1990
2012327400	Igarka	67°28′	86°16′	1930–1990
2012089100	Khatanga	72°00′	102°10′	1933–1990
Lab file	Saskylah	72°00′	114°00′	1937–1990
2012414300	Djardjan	68°44′	124°00′	1936–1989
Lab file	Kazachye	70°47′	138°08′	1935–1991
2012194600	Chokurdah	70°40′	147°52′	1946–1991
2012555100	Markovo	64°41′	170°25′	1928–1989

RESULTS AND DISCUSSION

The highest values of correlation (up to 0.7–0.8) and synchronization (up to 80–85%) were observed within neighboring sites; the distance between them was no more than 200–300 km. There is a rather high similarity (correlation coefficient 0.4–0.6; synchronization coefficient 70–80%) between sites up to 600–800 km distant. At greater distances, similarity between chronologies completely disappeared and crossdating was impossible. The highest similarity between the chronologies developed is for larch species. Between larch and spruce chronologies, correlation and synchronization values are smaller (up to 0.48 and 78%) and such similarity exists mainly between neighboring sites. The highest values of correlation and synchronization are observed among chronologies developed for flat regions of the West-Siberian Plain, located 400–600 km to the south of the Arctic Ocean seashore. In mountain regions (the Putorana Plateau and Anuy-Chukot Highland) and in flat regions located near the seashores, the similarity between tree-ring chronologies essentially decreases. For example, chronologies developed for coastal areas (series 17, 19 and 24) do not have high correlation and synchronization with neighboring chronologies developed for areas 400–500 km distant from seashores (series 16, 18 and 20). This is probably connected with rather large differences in climate between these areas. The coastal regions are largely influenced by air masses which form over the Arctic Ocean, especially in summer months.

Setting threshold values (correlation coefficient 0.4, synchronization coefficient 68%), we divided the subarctic transect into four sectors in which crossdating between chronologies was evident (Fig. 1). (From our experience the synchronization coefficient should be no less than 66% to crossdate.) The first stage in our analysis was to inspect the similarity among the chronologies. As a result, the Siberian and Far East Subarctic could be divided into the following four dendroclimatic regions: (W) West Siberia (from the Polar Ural Mountains to the lower reaches of the Taz River); (T) Taimyr (from the lower reaches of the Taz River to the lower reaches of the Khatanga River); (A) Anabar (from the lower reaches of the Khatanga River to the lower reaches of the Lena River); (K) Kolyma (in the lower reaches of the Yana, Indigirka and Kolyma Rivers). The reality of these dendroclimatic regions is confirmed by mapping the first eigenvector of the tree-ring data set. The percent variance accounted for by the first eigenvector is extremely high in larch chronologies (up to 36%). This indicates that there is a single common factor that influences tree growth in subarctic regions. The first three and, hence, most important eigenvectors out of 29 account for approximately 70% of variance.

The developed ring-width chronologies have a strong climatic signal. This is evidenced by the presence of high values of the mean sensitivity coefficient (from 0.27 to 0.48 in larch chronologies and from 0.19 to 0.23 in spruce and pine chronologies). Chronologies from eastern sectors of the transect (Anabar and Kolyma dendroclimatic regions) have higher sensitivity on average; they are also longer on average (Table 1). Low-order autocorrelations were recognized (between 0.16 and 0.27). The order of the pooled autoregressive model that was used for prewhitening shows similar variation within the chronology network. It is estimated as an AR(2). Only in two cases did we choose an AR(4) model.

Figure 2 presents 14 plots of response functions for larch chronologies developed for the northernmost sites of the study area. Vertical bars delimiting the 95% confidence limits are used to indicate significance. It can be inferred from these response functions that the main contribution to the variability of the chronologies developed for the western part of the study area derives from air temperatures during July and, to a lesser degree, June of the current growth year (Fig. 2, series 1B, 2, 5, 7, 9, 11, 13, 15 and 17). In most continental regions, the June temperatures are more important for tree growth than are July temperatures (series 19, 24 and 36). There is no evident tendency of response to summer temperatures in the easternmost chronologies (series 44 and 46). At present we do not have a clear explanation of this fact. However, the mountainous regions located to the east of the Kolyma River are affected by air masses that are formed over the Okhotsk and Bering Seas. All response weights with high values are positive.

Figure 3 shows reconstructed June–July temperature variation from AD 1690 to 1990 for the western part of the West-Siberian Plain (series 1B), the lower reaches of the Enisei River (series 9), the south part of the Taimyr Peninsula (series 13) and the Kolyma Lowland (series 36). Of course, these reconstructions do not represent regional climate but account for the greatest percentage of variance reduced in a simple regression equation. All series show both very high interannual and low-frequency variability of air temperatures in summer months. During the last 300 yr, the range of annual changes of June–July temperatures varied from 5.0° to 6.3°C; the range of low-frequency changes was from 1.6° to 2.4°C. The greatest temperature variability was in the northern regions of the West-Siberian Plain. This finding agrees with conclusions made by Rubinshtein and Polozova (1966), who analyzed temperature changes using instrumental meteorological observations. They concluded that the north of the West-Siberian Plain, and the area of the Kara and Barents Seas are the regions with the highest temperature variability over the Northern Hemisphere. Figure 4 shows low-frequency fluctuations of growth indices in various regions of the Siberian and Far East Subarctic. As a whole, long-term fluctuations of indices within large territories coincide. For example, at the end of the seventeenth century and the beginning of the 18th century a very cold period was observed in the central part of the transect (from the Taz River in the west to the Lena River in the east). In the north of the West-Siberian Plain very low summer temperatures occurred in the 1820s and 1830s. Low-frequency fluctuations in the western and central parts of the transect are often in antiphase in comparison with fluctuations in the eastern part of the transect (Fig. 3 and 4).

We analyzed annual variability of growth index values of larch species growing in the northernmost forest islands and massifs from 1650 to 1990. Along the subarctic transect 14 chronologies were selected (# 2, 1B, 5, 7, 9, 11, 13, 15, 17, 19, 24, 36, 44 and 46). We identified 7 types and 15 subtypes of growth changes along the transect, bearing in mind that within the transect four dendroclimatic regions with similar variability in tree growth were determined (Table 3). The proposed classification is based on the shape or sign of index value changes between the neighboring

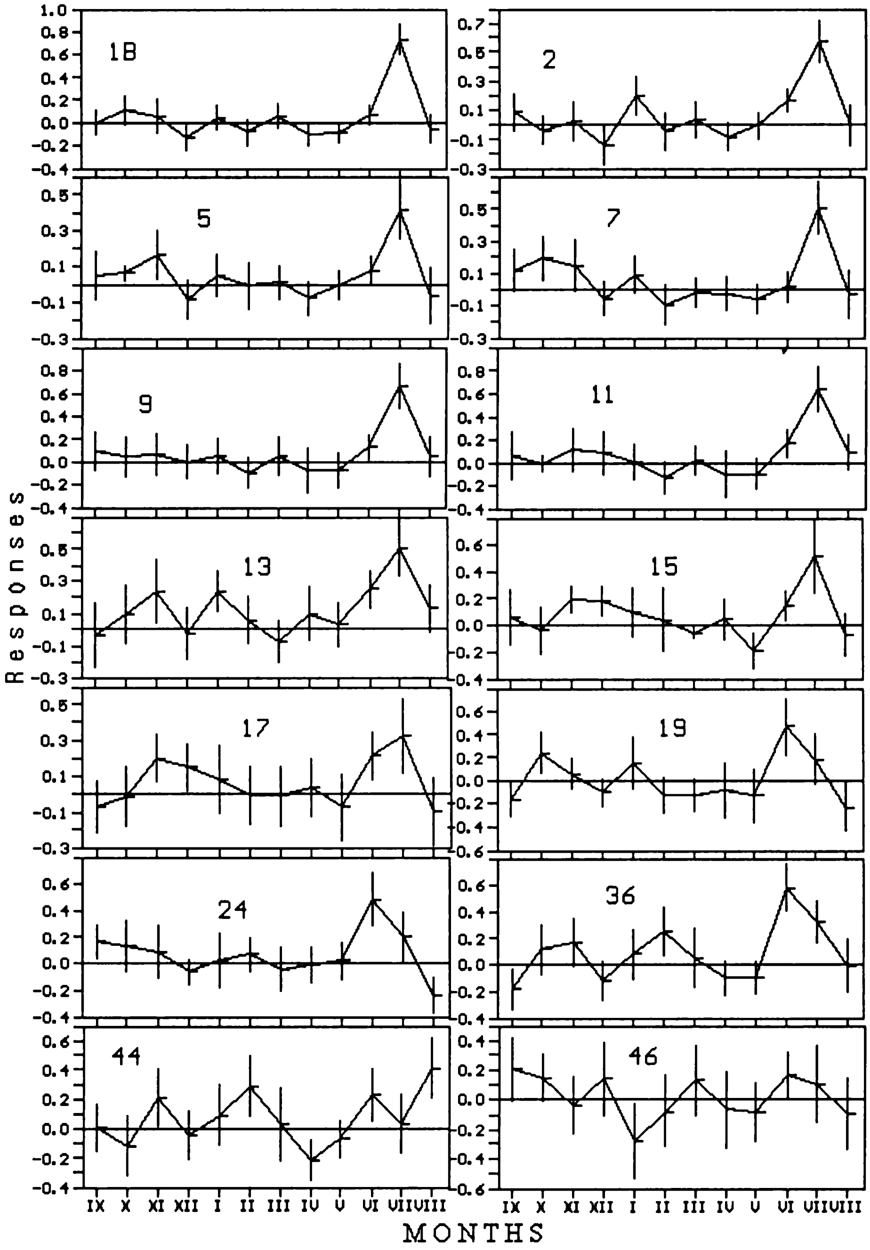

Fig. 2. Response functions for ring-width indices on air temperature from proximate meteorological stations

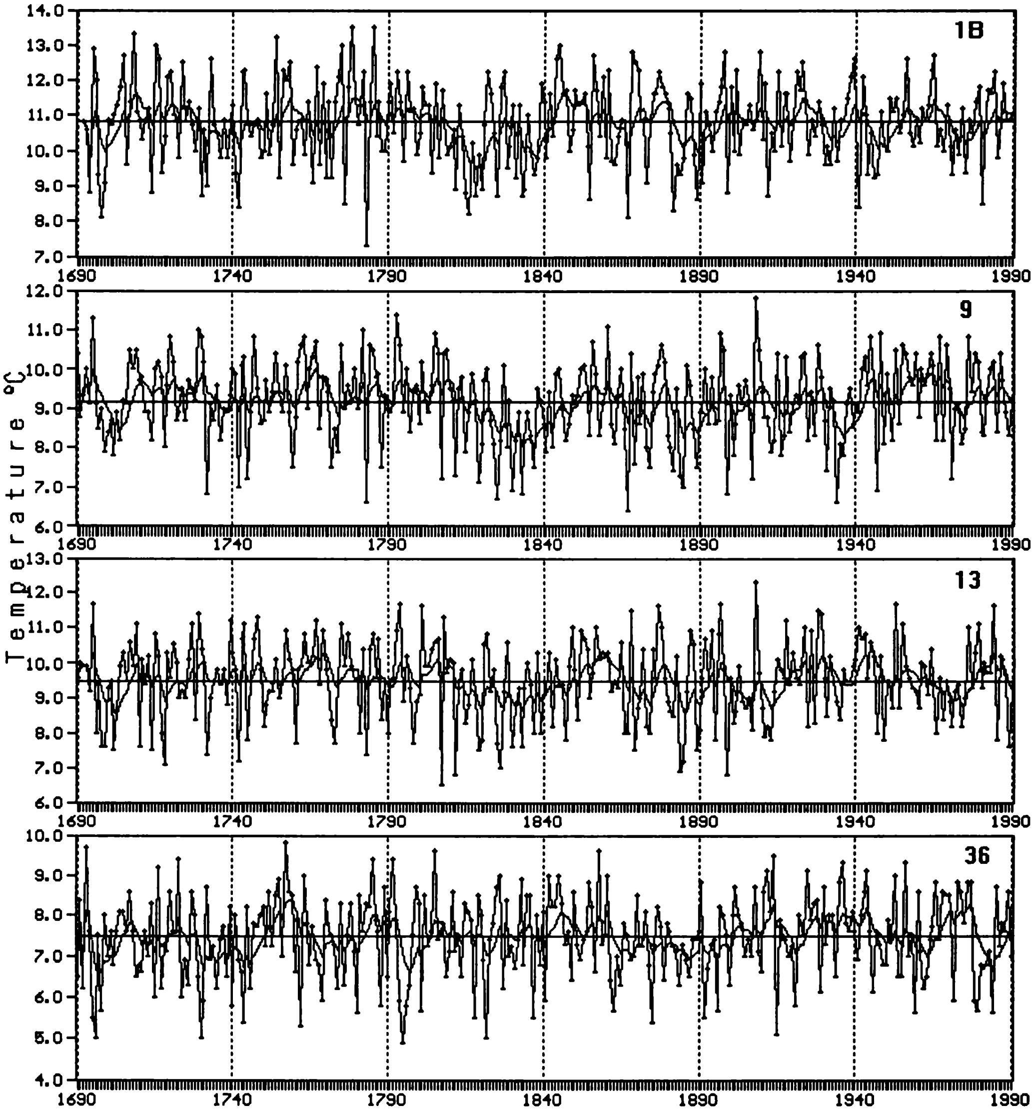

Fig. 3. Reconstructed average June–July temperature from prewhitened tree-ring series for the different regions (series 1B, 9, 13, 36), listed west to east

dendroclimatic regions (positive, negative and zero), not on the value of the index. The distribution of calendar years for various types and subtypes of tree growth changes along the transect is presented in Table 4. The frequency of years with growth change types 1, 2, 5 and 6 is the same (17–19%). Types 3, 4 and 7 occur less frequently (9, 8 and 11%, respectively). The rarest cases are: index values below the average along the whole transect (7C subtype, 1%) and high index values at the western end (6B subtype, 1%).

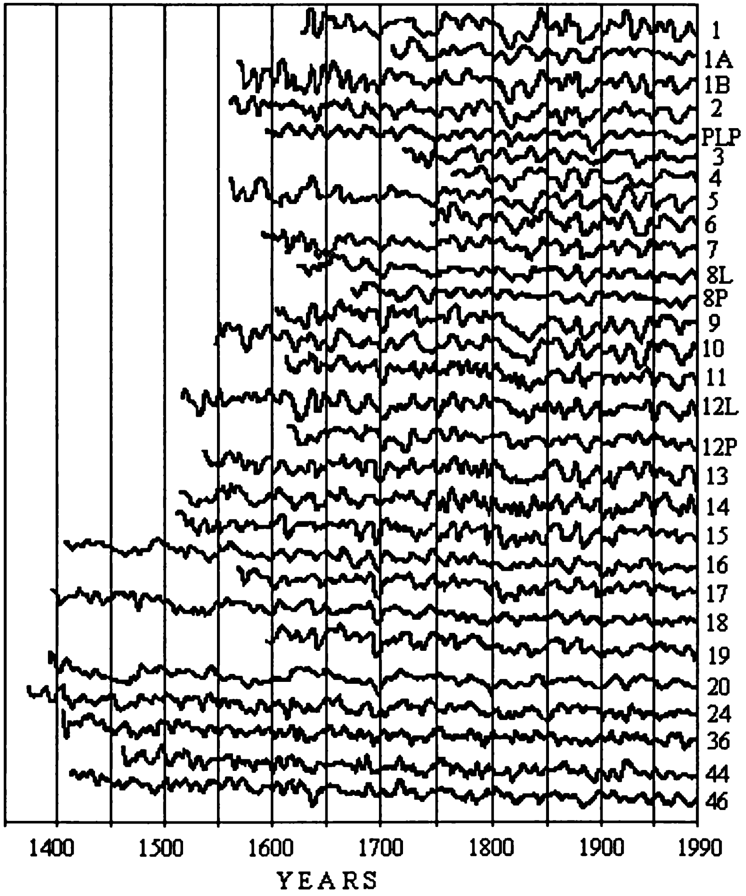

Fig. 4. Smoothed (spline >10 yr) tree-ring chronology collections, listed west to east

TABLE 3. Types of Tree-Growth Changes During the Same Calendar Year in Different Dendroclimatic Regions*

Type	West-Siberian (W)	Taimyr (T)	Anabar (A)	Kolyma (K)
1A	–	+	+	–
1B	–	–	+	–
1C	–	+	–	–
2A	+	–	–	+
2B	+	+	–	+
2C	+	–	+	+
3	–	+	–	+
4	+	–	+	–
5A	–	–	+	+
5B	–	–	–	+
5C	–	+	+	+
6A	+	+	–	–
6B	+	–	–	–
6C	+	+	+	–
7A	+	+	+	+
7B	mean	mean	mean	mean
7C	–	–	–	–

*See text for explanation of +, –, and mean

TABLE 4. Calendar Years of Various Types of Tree Growth Changes within the Transect from 1650 to 1990

Type of changes	Calendar years	No. of years	Percent
1A	1652 1661 1665 1667 1668 1673 1679 1680 1686 1687 1688 1711 1729 1730 1736 1743 1747 1765 1768 1769 1776 1777 1784 1787 1806 1810 1817 1854 1862 1865 1868 1872 1883 1894 1908 1919 1932 1945 1946 1948 1955 1961 1967 1986 1969 1979	46	13
1B	1676 1706 1713 1727 1738 1746 1860 1934 1940	9	3
1C	1808 1861 1887 1910 1920 1950	6	2
1A–1C		61	18
2A	1653 1658 1660 1670 1685 1702 1703 1718 1728 1733 1791 1792 1800 1807 1826 1830 1832 1837 1839 1845 1847 1869 1871 1890 1904 1906 1911 1913 1925 1927 1985 1989	32	9
2B	1675 1696 1754 1762 1771 1773 1813 1842 1844 1853 1866 1870 1886 1898 1900 1943	16	5
2C	1720 1745 1760 1781 1798 1840 1902 1907 1916 1931 1935 1952 1966 1974	14	4
2A–2C		62	18
3	1663 1669 1674 1678 1690 1692 1698 1731 1741 1775 1770 1799 1804 1805 1811 1814 1818 1821 1838 1863 1905 1912 1928 1929 1941 1944 1953 1976 1977 1980	30	9
4	1654 1657 1659 1672 1704 1705 1719 1725 1737 1744 1774 1788 1790 1802 1803 1824 1846 1850 1874 1880 1881 1895 1896 1917 1938 1988 1990	27	8
5A	1651 1655 1677 1683 1691 1693 1714 1734 1742 1750 1752 1772 1783 1789 1812 1816 1820 1828 1831 1834 1835 1836 1841 1843 1855 1867 1882 1884 1885 1888 1891 1899 1901 1914 1936 1960 1968 1970 1975	39	11
5B	1682 1684 1697 1699 1701 1723 1732 1759 1815 1819 1825 1833 1858 1873 1889 1947 1971 1973	18	5
5C	1666 1689 1694 1739 1748 1749 1763 1864 1930	9	3
5A–5C		66	19
6A	1662 1671 1681 1695 1708 1709 1710 1715 1735 1740 1751 1756 1775 1779 1786 1793 1801 1809 1823 1827 1848 1849 1851 1878 1897 1909 1921 1924 1962 1963 1965 1972 1978 1987	34	10
6B	1656 1778 1923	3	1
6C	1724 1726 1764 1767 1780 1782 1794 1795 1796 1822 1852 1856 1857 1875 1879 1892 1915 1918 1926 1957 1959 1984	22	6
6A–6C		59	17
7A	1650 1664 1716 1721 1757 1785 1877 1922 1933 1942 1956 1964	12	4
7B	1707 1712 1717 1722 1753 1758 1761 1766 1797 1829 1859 1876 1903 1937 1939 1951 1958 1981 1982 1983	20	6
7C	1700 1893 1949 1954	4	1
7A–7C		36	11
Total		341	100

CONCLUSION

The subarctic regions of Siberia and the Far East show great prospects for climatic reconstruction using tree-ring data, as there are old living trees and a great amount of subfossil wood. Tree-ring chronologies from this region contain a strong climatic signal. These regions are essential for understanding climatic changes and for verifying regional and global climatic models.

Similar climate-dependent tree growth over large areas (at distances up to 800 km) was observed, and the study territory (the subarctic transect from the Polar Ural Mountains to the Chukot Peninsula) can be divided into four dendroclimatic regions, West Siberia, Taimyr, Anabar and Kolyma. The main limiting factor for tree growth in the subarctic regions of Siberia is June–July temperatures. In the most continental regions June temperatures are more important for the radial growth of trees, but in the more humid western regions June temperatures influence tree growth to a lesser degree than do July temperatures. There is very high interannual and low-frequency variability of reconstructed summer temperatures in subarctic regions (the ranges are up to 5.0–6.3°C and 1.6–2.4°C, respectively). The rarest cases were when either low or high index values were observed along the whole transect (1–2%). The most common cases were found when tree growth was dissimilar in various dendroclimatic regions.

The whole transect provides no evidence for an increasing trend in tree growth during the last few decades that could be connected with anthropogenic climatic changes in summer months. Moreover, from the middle of the 1960s to the middle of the 1970s a significant decrease was observed in tree growth and air temperatures in many subarctic regions. Apparently, at present natural factors influence climatic changes to a greater degree than anthropogenic ones.

REFERENCES

Archambault, S. and Bergeron, Y. 1992 Discovery of a living 900 year-old Northern White Cedar, *Thuja occidentalis*, in northwestern Quebec. *Canadian Field-Naturalist* 106(2): 192–195.

Bradley, R. S., Kelly, P. M., Jones, P. D., Goodess, C. M. and Diaz, H. F. 1985 A climatic data bank for northern hemisphere land areas, 1851–1980. TR017, DOE/EV/10739–2, Carbon Dioxide Research Division, U. S. Department of Energy, Washington, D.C.

Budyko, M. I. 1980 *Climate in the Past and Future.* Leningrad, Gydrometeoizdat: 350 p. (in Russian).

Fritts, H. C. 1976 *Tree Rings and Climate.* New York, Academic Press: 567 p.

Graybill, D. A. and Shiyatov, S. G. 1992 Dendroclimatic evidence from the northern Soviet Union. In Bradley, R. S. and Jones, P. D., eds., *Climate since AD 1500.* London and New York, Routledge: 393–414.

Guiot, J. 1986 ARMA techniques for modeling tree-ring response to climate and for reconstructing variations of paleoclimates. *Ecological Modeling* 33: 149–171.

Jacoby, G. C. and D'Arrigo, R. 1989 Reconstructed Northern Hemisphere annual temperature since 1671 based on high-latitude tree-ring data from North America. *Climatic Change* 14: 39–59.

Mazepa, V. S. 1982 Method of computing annual growth indices for a generalized dendroclimatological series. *Soviet Journal of Ecology* 13: 172–177.

Rimer, T. 1982 *TREND. User's Guide for Personal Computers.* Germany, University of Gottingen: 35 p.

Rubinshtein, E. S and Polozova, L. G. 1966 *The Recent Climatic Change.* Leningrad, Gydrometeoizdat: 267 p. (in Russian).

Schweingruber, F. H., Briffa, K. R. and Jones, P. D. 1991 Yearly maps of summer temperatures in Western Europe from AD. 1750 to 1975 and Western North America from 1600 to 1982: Results of a radiodensitometrical study on tree rings. *Vegetatio* 92: 5–71.