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An integral estimation of tree-ring chronologies from subarctic regions of Eurasia

O.V. Sidorova, M.M. Naurzbaev & E.A. Vaganov
V.N. Sukachev Institute of Forest SB RAS, 660036 Akademgorodok, Krasnoyarsk, Russia
Email: ovsidorova@forest.akadem.ru

Introduction

Using the results of climatic models, some authors state that recorded global warming is directly related to the increased concentration of greenhouse gases in the atmosphere caused by the anthropogenic activity. Quantitative estimations indicate an increase in the average annual temperature in Northern Hemisphere by 0.5-0.6°C (Mann et al. 1998, Jones et al. 2001). According to calculations based on climatic models, the strongest warming should be observed in the high latitudes of the Northern Hemisphere, with an increase of 3-4°C (Kelly et al. 1982, Budyko and Israel, 1987). However, data obtained from analyses of the radial growth of trees from the sub-Arctic area of Eurasia, an area closely tied to strongest temperature changes, do not show significant changes in climatic conditions (Briffa et al. 1998, Naurzbaev and Vaganov 2000). There is also the unresolved issue of the range of natural climate fluctuations, i.e. the amplitude of near-surface air temperature changes in the high latitudes of the Northern Hemisphere during the Holocene. Tree-ring chronologies serve as a reliable instrument for the reconstruction of natural temperature fluctuations in the high latitudes over millennial time scales. Compared to the other indirect sources of climate information, these tree-ring chronologies have important advantages: Firstly, climatic information is distinctly recorded in annual tree-rings (Briffa et al. 1998, Naurzbaev and Vaganov 2000, Naurzbaev et al. 2001). Secondly, at the northern boundary of the Eurasian forests, trees reach a maximum age of 1216 years and the net of dendro-climatic "stations" evenly distributed over a vast territory of Siberia permits spatial and temporal reconstructions of temperature variation (Vaganov et al. 1999, Sidorova and Gerasimova 2005); and finally dead trees, preserved in permafrost, offer the opportunity of obtaining tree-ring chronologies over longer Holocene time scales (Shiyatov 1986, Vaganov et al. 1996, Vaganov and Naurzbaev 1999, Hantemirov 1999, Hughes et al. 1999, Naurzbaev et al. 2002, Sidorova 2001, 2003, Hantemirov and Shiyatov 2002, Grudd et al. 2002).

Materials and methods

We developed 2000-year tree-ring chronologies based on the oldest living trees, dead and sub-fossil wood well preserved in the Eastern Taimyr [72N – 102E] (Naurzbaev and Vaganov 2000, Naurzbaev et al. 2002), North-Eastern Yakutia (Indigirka) [70N – 148E] (Hughes et al. 1999, Sidorova 2001, Sidorova and Naurzbaev 2002) and also used millennia-long chronologies, produced by our colleagues from the Yamal [67N – 70E] (Hantemirov 1999, Hantemirov and Shiyatov 2002), and Sweden [68N – 20E] (Grudd et al. 2002).

To exclude age-dependent variations and to retain the maximally long-term and high frequency climatic signal the raw tree-ring width measurements were standardized by Regional Curve Standardization and corridor methods (Shiyatov 1986, Briffa et al. 1996, Esper et al. 2002).

Results

Main characteristics of these chronologies are given in the table 1.

Table 1: Statistical characteristics of regional long-term tree ring chronologies

	Standard deviation	Sensitivity	Correlation coefficient of low pass filtered data ($p<0.05$)			
Chronologies			Sweden	Yamal	Taimyr	Indigirka
Sweden	1.28	0.74	*1.00*			
Yamal	0.73	0.81	0.24	*1.00*		
Taimyr	1.52	0.80	0.14	0.35	*1.00*	
Indigirka	1.21	0.80	0.17	0.20	0.25	*1.00*

All four tree-ring chronologies show a high standard deviation of 0.73 - 1.52 and sensitivity of 0.74 – 0.81. After RCS standardization (Shiyatov 1986, Briffa et al. 1996, Esper et al. 2002) all four tree-ring chronologies are smoothed with a low pass 41-year filter. The chronologies show significant correlation coefficients of low frequency variability (long-term) and insignificant correlation of high (from year to year) variability. It means that summer temperatures on annual basis mainly differ in various sectors of the Subarctic. The more careful analysis indicates that the percentage of years with the same warm or cold calendar years for the whole northern Eurasia does not exceed 20% for the last two millennia (Vaganov et al. 1996, Naurzbaev et al. 2003, Sidorova 2003).

In an earlier part of the analysis of spatio-temporal variability of tree growth in high latitudes of Eurasia it was clearly shown that the local tree-ring chronologies significantly correlate within an area of up to 600-800 km in the west-eastern direction. Thus, millennial chronologies represent various tree-ring growth and climatic variability for large sectors of the Subarctic. Summer temperature variability explains 60-70% of total variability in tree-ring indices.

The combined chronology for Northern Eurasia was calculated as first principal component (Fig. 1).

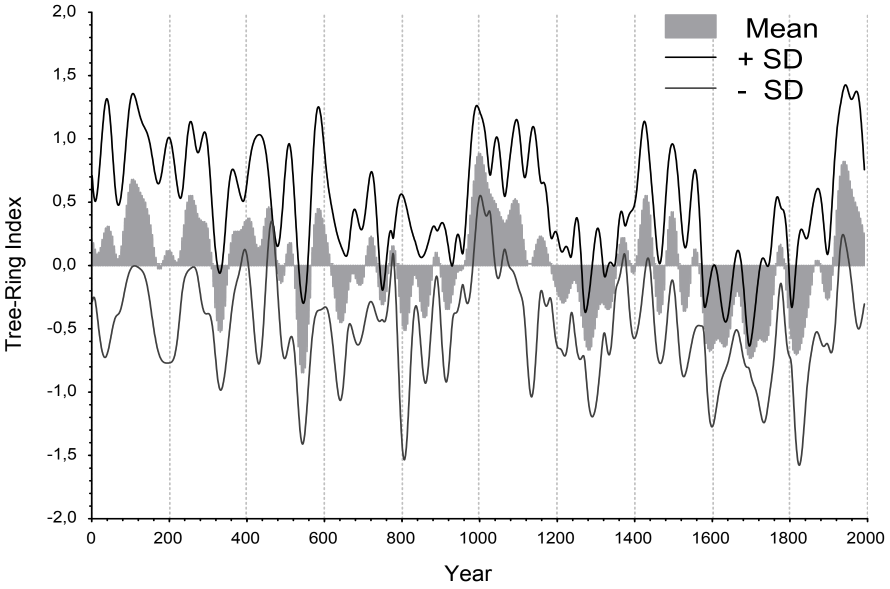

Figure 1: Combined northern Eurasia tree-ring chronology

In figure 1, we can see several warm periods (first to fifth century), the Medieval Warm Period (the maximum increase during the 10th to 12th centuries) and current warming in the middle 20th century and abrupt cooling during the middle of the 16th century and the end of the 19th century. The long-term changes in Northern Eurasia have a similar character during the last 1250 years (Fig. 2).

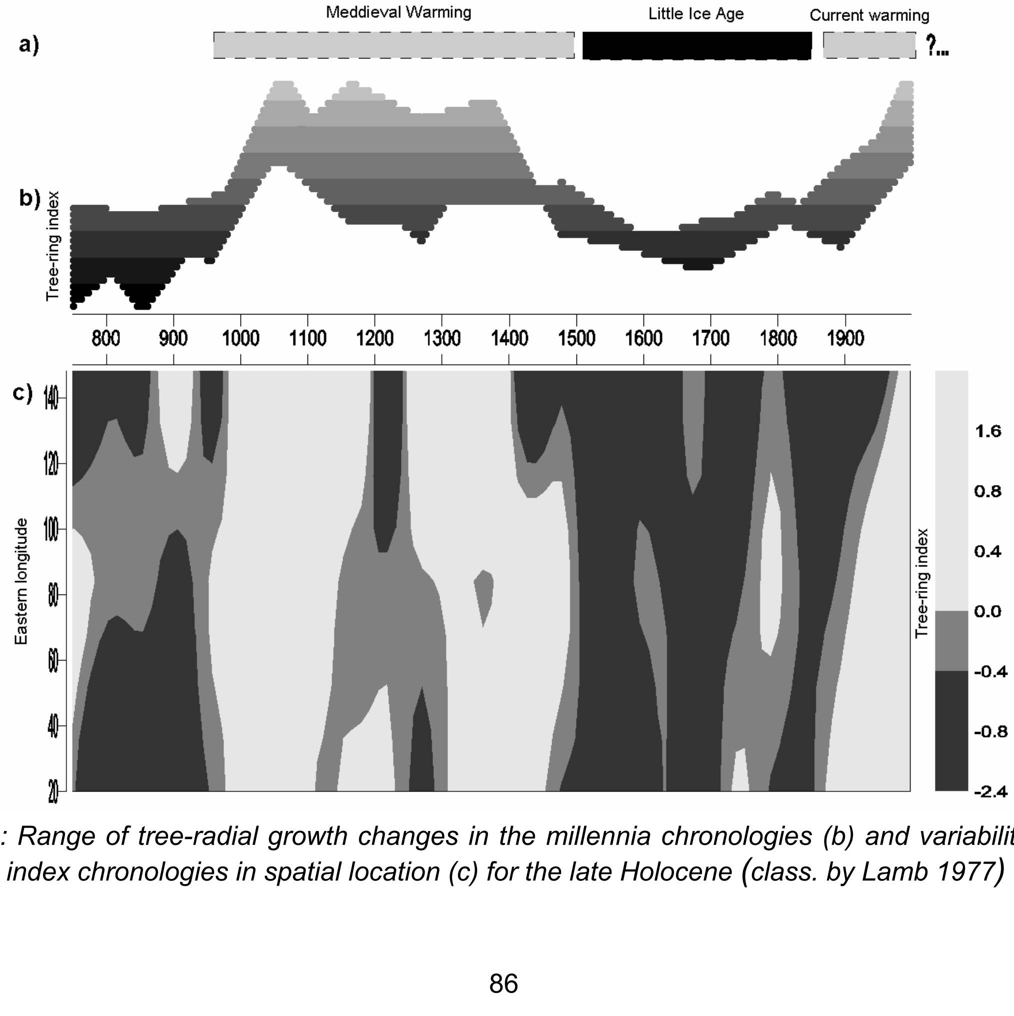

Figure 2: Range of tree-radial growth changes in the millennia chronologies (b) and variability of the tree-ring index chronologies in spatial location (c) for the late Holocene (class. by Lamb 1977) (a)

Medieval warming (MWP) lasted from the 10th to the 12th century and the 15th-century warming was followed by cooler conditions during the Little Ice Age (LIA) with lowest temperatures in the 17th century. The current warming which started at the beginning of the XIX century does not exceed the amplitude of the Medieval Warming. In the last century tree-ring growth is more intensive in the western Subarctic part than in the eastern part. All millennial chronologies fixed Medieval Warming, which has two phases - XI, XII and middle of the XIII, XIV separated by a short period of growth depression (late XII - middle XIII). The radial growth depression was longer in the western part of Eurasia, but more severe in the eastern part. Moreover, all chronologies fixed the radial growth reduction in the LIA (early XVI - XIX) and before MWP.

Let us consider the fragments of the combined tree-ring chronology in the early Medieval Warming and current warming. The estimates (increase by 0.82 and 0.95 for the last 100 years) testify that the mean rate of the long-term growth increase is approximately equal in both periods but the amplitude somewhat disagrees.

For each chronology we calculated the response function and developed a temperature reconstruction for the last 1000 years. We used data of closely located meteostations for each region. In table 2 the main statistical characteristics of reconstruction models for all four millennia chronologies are shown.

Table 2: Calibration model results of June-July air temperature reconstruction

Chronologies/ meteostations	Statistics of instrumental series			Statistic of reconstruction models		
	Calibration period, years	Mean temperature, °C	Variance, °C	Correlation coefficient for index chronologies and 5-years moving average series	F-statistics	Synchronism coefficient, %
Sweden/ Karesuando	1830-1838 1951-1980	11.5	1.71	0.48/0.60	$F_{1.37} = 11.3$; $p<0.01$	67
Yamal/ Salekhard	1883-1995	11.1	1.80	0.60/0.74	$F_{1.111} = 63.4$; $p<0.01$	72
Taimyr/ Katanga	1933-1996	8.8	1.70	0.60/0.66	$F_{1.62} = 33.7$; $p<0.01$	63
Indigirka/ Chokurdakh	1945-1989	7.9	1.54	0.61/0.71	$F_{1.43} = 25.2$; $p<0.01$	68

The correlation between temperature and tree-ring indices is highly significant and still increases after smoothing. It means that agreements of long changes of radial growth and summer temperature are higher than in the year-to-year variability. Let us compare the quality values of mean summer temperature by results of reconstruction for each century of the last millennia (table 3).

Table 3: Quantitative estimates of mean summer air temperature for the last millennia.

Century	Sweden		Yamal		Taimyr		Indigirka	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
X	10.2	1.06	10.6	.66	8.6	1.68	8.5	1.38
XI	11.1	.83	10.6	.60	8.9	1.40	9.6	1.96
XII	9.7	.82	10.5	.52	9.0	1.61	9.4	1.44
XIII	9.7	.70	10.4	.44	7.4	1.42	8.4	1.73
XIV	10.3	.84	10.4	.56	8.1	1.74	8.4	1.51
XV	11.0	.75	10.6	.67	8.5	1.25	7.9	1.34
XVI	10.7	1.04	10.3	.45	7.6	1.18	8.1	1.44
XVII	9.3	.90	10.3	.46	7.3	1.18	8.1	1.45
XVIII	9.8	1.04	10.4	.47	8.2	1.23	7.6	1.10
XIX	10.7	1.15	10.1	.49	7.8	1.51	7.4	1.00
XX	11.1	.85	11.0	.78	8.9	1.28	8.0	1.02
Mean	10.2		10.5		8.2		8.3	
(t_{max} t_{min})	1.8		0.9		1.7		2.2	

From this table we can see that the range of summer air temperature changes was about 2°C, the only exception being Yamal. For this region there was defined less temperature reduction. The current warming manifests more in the western part of Eurasia and less in the eastern part. The MWP shows higher values of temperatures in the eastern part of Eurasia and approximately equal values in the western part in comparison with the current one. The difference in average temperature of current and Medieval Warming compared to Little Ice Age is not so large -1.5°C and is heterogeneous in space: higher in the eastern part and low in the west.

We compared our Eurasian average chronology with the well-known large-scale Mann's temperature reconstruction from the last IPCC report (Mann et al. 1998) (Fig. 3).

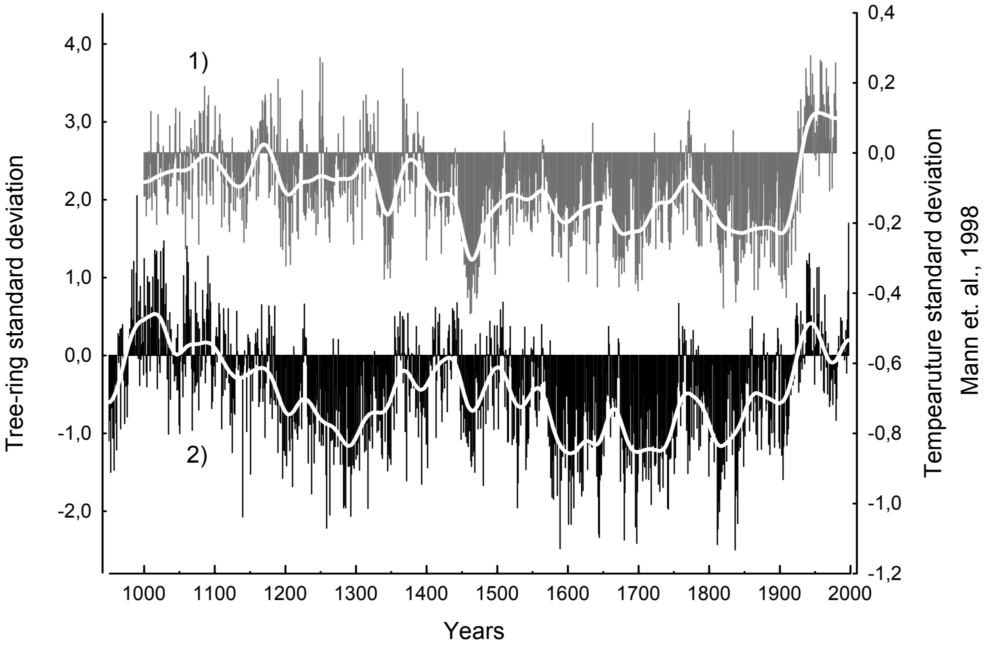

Figure 3: Comparison of Eurasian (1) and large-scale temperature (2) reconstructions

The reconstructions differ markedly in their amplitudes (0.6°-0.8°C for the Northern Hemisphere and 2.5°-3.0°C for Northern Eurasia). The curve for Northern Eurasia, however, does not show an abrupt temperature increase in the last century as seen in the hemispheric reconstruction. The significant synchronism between the two curves is noted in decadal to century temperature fluctuation. Also years and periods are revealed indicating synchronous volcanic activity: 1259, 1600, 1641, 1812-1815, 1912, 1960 (Briffa et al. 1996, Sidorova and Naurzbaev 2000).

So, an integral estimation of tree-ring growth spatial-temporal conjugation was carried out based on a tree-ring width network of the subarctic zone of Siberia, Ural and Scandinavia for the last 2000 years. Phase and amplitude disagreements of the annual growth and its decadal fluctuation in different subarctic sectors of Eurasia changed by synchronous fluctuation when century and longer growth cycles were considered. Long-term changes of radial growth indicate common character of global climatic variation in the subarctic zone of Eurasia. Medieval Warming occurred from Xth to XIIth centuries and XVth century warming are changed by Little Ice Age with the cooling culmination taking place in the XVIIth century. Current warming started at the beginning of the XIXth century and presently does not exceed the amplitude of medieval warming. The tree-ring chronologies do not indicate unusually abrupt temperature rise during the last century, which could be reliably associated with greenhouse gas increasing in the atmosphere of our planet. The modern period is characterized by heterogeneous warming effects in the subarctic regions of Eurasia.

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