Proceedings of an International Conference
Corvallis, Oregon; Raleigh, North Carolina; Gatlinburg, Tennessee
September 13 - 25 , 1988

Organized in connection with the 1972 US-USSR Environmental Protection Agreement (Project 02.03-21)

and sponsored by the

US Department of Agriculture–Forest Service
US Environmental Protection Agency

Northeastern Forest Experiment Station
370 Reed Road, Broomall, PA 19008

A 1009 Year Tree-Ring Reconstruction of Mean June-July Temperature Deviations in the Polar Urals

Donald A. Graybill
Laboratory of Tree-Ring Research
University of Arizona
West Stadium, Rm. 105
Tucson, AZ 85721, U.S.A.

Stepan G. Shiyatov
Institute of Plant and Animal Ecology of the
Ural Division of the USSR Academy of Sciences
Sverdlovsk, 620008 USSR

We have made a reliable reconstruction of average June-July temperature departures for the period of A.D. 961-1969 using tree-ring width variation of *Larix sibirica* from the north Polar Urals of the USSR. This is the first dendrochronological reconstruction of seasonal temperature over the past millennium for the sub-Arctic. It is of considerable interest, not only because of its length, but also for the reason that it may contain information about trends and long-term variation in temperature over large areas. The tree-ring chronology (Shiyatov #1-4a, 1986) was developed from ring-width series taken from both living and dead individuals near treeline at elevations of 150-380m just south of the Kara Sea. The region around the Kara Sea is thought to be one that is particularly sensitive to long-term trends and variations in temperature over the Arctic and even the Northern Hemisphere. This is based on an analysis of instrumented values of surface air temperatures for the period of 1881-1980 (Kelly *et al.*, 1982).

Individual tree-ring series were initially crossdated with each other and all rings were assigned calendar years based on the known collection dates of the living series. Ring-widths were measured to the nearest 0.01mm and then each series was treated with the Corridor Method of Standardization (Shiyatov and Mazepa, 1987). Seventy-six of these series were combined by simple averaging to form a tree-ring index chronology for the region.

Changes in the strength of the common signal in chronologies such as these are of interest. As sample size per year decreases, usually near the early part of one, generalizations about the reliability of a reconstruction developed from it during those years may need to be tempered. A useful measure for consideration of this is the Subsample Signal Strength (SSS) (Wigley *et al.*, 1984). This estimates the variance agreement that might be obtained with reduced numbers of a fuller sample of series. It was possible to make an estimate of the SSS with a subset of 13 ring-width index series that

Table 1. Chronology subsample signal strength.

N of series	Variance agreement	First year with this N
1	.69	960
2	.83	1017
3	.89	1018
4	.92	1042
5	.94	1086
6	.96	1089
7	.97	1094
8	.98	1108
9	.98	1141
10	.99	1142
11	.99	1170
12	.99	1172
13	1.00	1190

were included in this chronology during the period of 1800-1960. The results presented in Table 1 also include the earliest years in the chronology where the numbers of series range from one to thirteen. This provides an approximate guide to the reliability of the reconstruction in those early years. The overall strength of the common signal is estimated by two other figures that includes the amount of variance held in common (61 percent) and the signal-to noise ratio (25.8:1). These values are in the uppermost range for chronologies considered to be useful as temperature indicators (Fritts, 1976; Graybill, 1982, 1985; and Wigley *et al.*, 1984).

Instrumented temperature series used in this study are from a monthly mean value data set that is available for the Northern Hemisphere on a grid of 5° latitude by 10° longitude (Jones *et al.*, 1985). These are expressed as departures in degrees celsius from a 1951-1970 normal period. Values for the period of 1881-1969 were selected from the grid point nearest the tree-ring data, latitude 65°N, longitude 70°E.

The relationship between tree growth and monthly mean temperature departures was investigated with simple correlation procedures. The strongest relationship occurs during the months of June and July, essentially the growing season at this latitude. The correlation for the early summer average of values with the tree-ring series is +0.78 ($p<0.01$). High positive correlations between ring-width growth and summer temperature have commonly been found in other studies at similar high latitudes. Cooler temperatures apparently limit growth processes while warmer temperatures enhance them. (Jacoby and Cook, 1981; Briffa *et al.*, in press).

Time-series and other statistical characteristics of both data series were evaluated for the purpose of determining their suitability for use in linear regression analysis. Common problems that are encountered in climatic and tree-ring series are non-normality and autocorrelation. For various statistical reasons, neither characteristic is desirable when the series are to be used in Ordinary Least Squares regression (Wonnacott and Wonnacott, 1981). The tree-ring indices are not normally distributed and show moderate but significant persistence. They were prewhitened after an ARMA(I,I) model was found to be the best fit (Box and Jenkins, 1976). The resultant white noise residuals are normally distributed. The temperature series exhibits slight but significant autocorrelation and is normally distributed. This series was, however, not prewhitened due to the limited amount of persistence involved and to uncertainty about the representativeness of this 89 year data set as a realization of the longer term autocorrelation structure.

Several calibration-verification trials using simple linear regression were made to determine how adequately the white noise residuals of the tree-ring indices could predict the temperature departures. The first set of two analyses successively used one half of the data over the period of 1882-1969 for calibration and the other half for verification. A set of three trials successively used two-thirds of the data for calibration and the remaining one-third for verification. A set of four trials was conducted in a similar fashion. Results of these trials were acceptable in terms of the evaluation of standard goodness-of-fit criteria, and in terms of the characteristics of the regresion residuals. The results of several associated tests commonly used in dendroclimatic research that are presented in Table 2 also suggested that the tree-ring white noise residual series was a reliable estimator of the temperature series (Fritts, 1976). Given the high quality of these results and a desire to consider the fullest possible range of

Table 2. Calibration and verification test summary. (Symbols explained below)

Calibration period		Verification period						
	r^2_a		r^2	s	P	t	W	RE
1926-1969	.42a	1882-1925	.75a	a	a	a	a	.60
1882-1925	.75a	1926-1969	.42a	a	a	a	a	.18
1912-1969	.58a	1883-1911	.56a	a	a	a	a	.61
1883-1911, 1941-1969	.54a	1912-1940	.66a	a	a	a	a	.67
1883-1940	.62a	1941-1969	.51a	a	a	a	a	.52
1904-1969	.59a	1882-1903	.54a	a	a	r	a	.64
1882-1903, 1926-1969	.48a	1904-1925	.86a	a	a	r	a	.77
1882-1925, 1948-1969	.65a	1926-1947	.45a	a	a	a	a	.15
1882-1947	.66a	1948-1969	.36a	r	r	a	a	.40
FINAL CALIBRATION 1881-1969 r^2 = .60								

r_a^2 = r^2 adjusted for degrees of freedom, alpha = .01
r^2 = variance explained, alpha = .01
s = first difference sign test, alpha = .01
P = product means test, alpha = .01
t = Student t-test, alpha = .10
W = Wilcoxon matched pairs signed ranks test, alpha - .10
RE = reduction of error test
a = null hypothesis not rejected
r = null hypothesis rejected

covariation in developing the final calibration equation used for reconstruction, data for the full 89 years of common period were analyzed. Sixty percent of the variance in the two series is in common, the covariance is significant at the 0.001 level and the regression residuals do not show abnormal outliers or significant autocorrelation. A reconstruction of average June-July

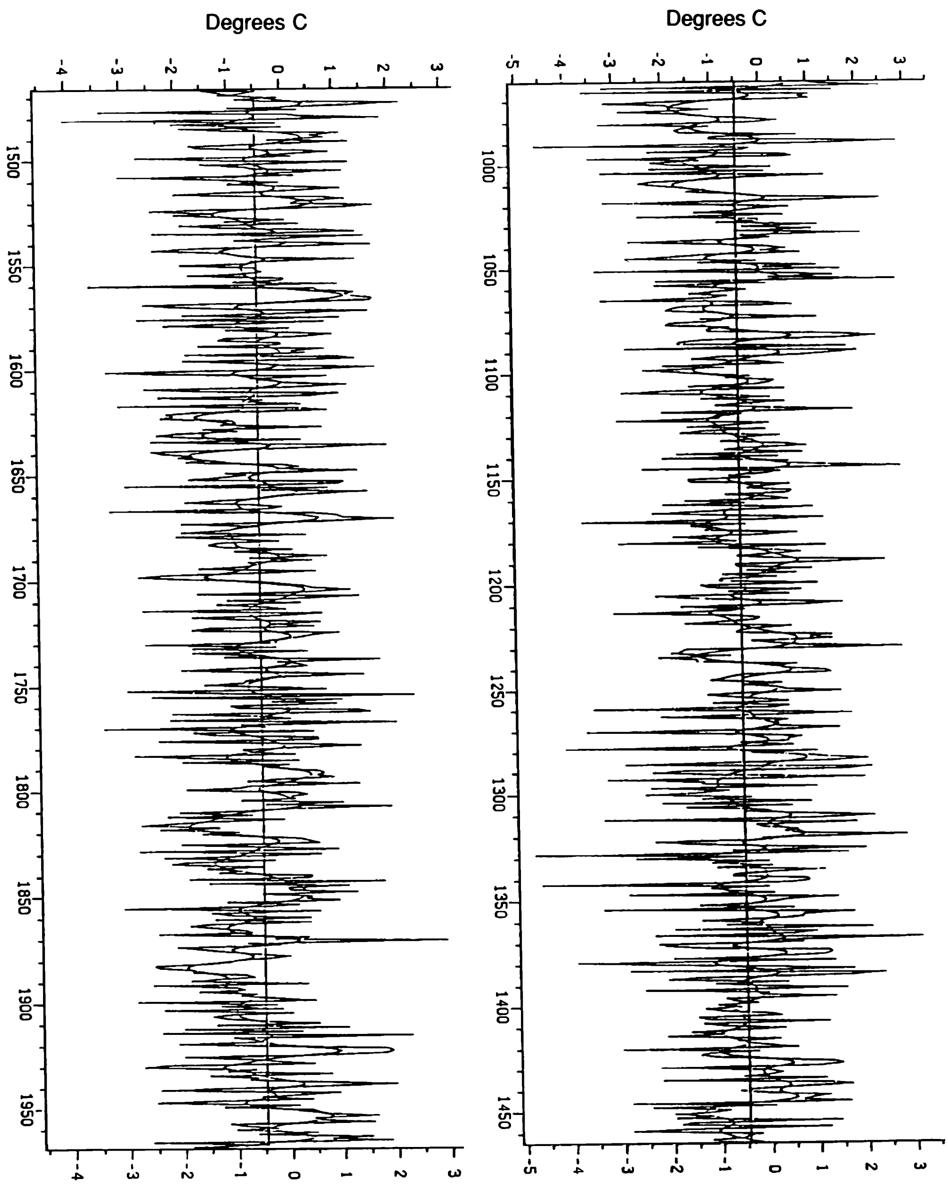

Figure 1. Reconstructed mean June-July temperature departures, North Polar Urals, A.D. 961-1969

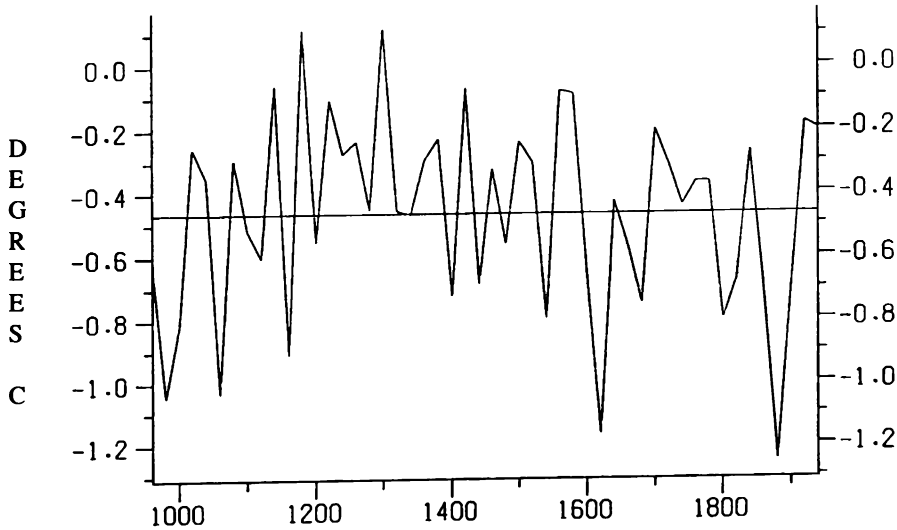

Figure 2. Twenty year averages of reconstructed mean June-July temperature departures, North Polar Urals, A.D. 961-1969.

temperature departures was then developed for the period of A.D. 961-1969.

Reconstructed early summer temperature deviations over the past millennium are illustrated in Figure 1. Twenty year non-overlapping averages of those values are shown in Figure 2 to aid in recognition of predominant kinds of trends. One of the more striking patterns is the rise in values from near 1100 to the highs of the 1200's-1300's, followed on the long term by an overall decline in values, but with some increase since the lows of the 1600's. This larger pattern as well as several of the major peaks in values (near 1200, 1300, the mid-1500's and near 1700) are reminiscent of Lamb's (1966) reconstructed temperature record for central England. Additionally, certain major features of our reconstruction such as the low values of the 1600's, and those of the 1800's that are followed by a sharp increase in 20th century values are seen in many other high latitude and altitude tree-ring chronologies. Space limitations here preclude further discussion of this.

Now, most of the constituent tree-ring series forming the chronology range in age from about 220-400 years, although a few are of shorter length. Given this, and the fact that standardization can remove trends that are at the same or greater length than the series in question, the ability of this reconstruction to mirror longer term trends may be questioned. There are, however, important field observations that bear on this issue. Dead series in this chronology are from elevations of 100-120m above the highest currently living trees. All of the former that were living in the early mid-1600's had dramatic growth decline at that time and their demise occurred then or shortly thereafter. This is also the time period when the majority of the oldest living trees found at the current elevational treeline germinated, although some found here date to the mid-1500's. Therefore, it is possible that the longer term trends in temperature departures are at least reasonably estimated. The two different elevational groupings of trees provided continuous monitors of temperature variation at their respective locations and sequentially their records may have captured those trends.

Further evaluation of the results obtained here may be possible as the development and analysis of other long tree-ring chronologies in the sub-Arctic proceeds (Bartholin, 1984). Quantitative information derived from a spatial field of long tree-ring chronologies should prove useful for evaluating models of long-term climatic variation on regional and hemispheric scales, or even for testing hypotheses about the global nature of phenomena such as the Little Ice Age (Grove, 1988).

Literature Cited

Bartholin, T. S. 1984. Dendrochronology in Sweden. In *Climatic Changes on a Yearly to Millennial Basis.* N. A. Morner and W. Karlen (eds). Reidel Publishing Company.

Briffa, K. R., P. D. Jones, J. R. Pilcher and M.K. Hughes. n.d. Reconstructing Summer Temperatures in Northern Fennoscandia Back to 1700 A.D. Using Tree-Ring Data from Scots Pine. In press, *Arctic and Alpine Research.*

Box, G. E. P., and G. M. Jenkins. 1976. *Time Series Analysis: Forecasting and Control.* Holden-Day, San Francisco.

Fritts, H. C. 1976. *Tree Rings and Climate.* Academic Press, London.

Graybill, D. A. 1982. Chronology Development and Analysis. *In Climate from Tree Rings.* M. K. Hughes, P. M. Kelly, J. R. Pilcher, and V. C. LaMarche, Jr. (eds). pp. 21-28. Cambridge University Press, London.

Graybill, D. A. 1985. *Western U. S. Tree Ring Index Chronology Data for Detection of Arboreal Response to Increasing Carbon Dioxide.* No. 026 in the U. S. Department of Energy Green Book Reports on the Response of Vegetation to Carbon Dioxide series. Laboratory of Tree-Ring Research, University of Arizona, Tucson.

Grove, J. M. 1988. *The Little Ice Age.* Methuen.

Jacoby, G. C. and E. R. Cook. 1981. Past Temperature Variations Inferred From a 400 Year Tree-Ring Chronology from Yukon Territory, Canada. *Arctic and Alpine Research* 13(4):409-418.

Jones, P. D., S. C. B. Raper, B. D. Santer, B. S. G. Cherry, C. Goodess, R. S. Bradley, H. F. Diaz, P. M. Kelly and T. M. L. Wigley. 1985. *A Grid Point Surface Air Temperature Data Set for the Northern Hemisphere, 1851-1984.* U.S. DOE Technical Report, TR022, U. S. Department of Energy Carbon Dioxide Division, Washington D.C.

Kelly, P. M., P. D. Jones, C. B. Sear, B. S. G. Cherry and R. K. Tavakol. 1982. Variations in Surface Air Temperatures: Part 2, Arctic Regions, 1881-1980. *Monthly Weather Review* 110:71-83.

Lamb, H. H. 1966. *The Changing Climate.* Methuen.

Shiyatov, S. G. 1986. *Dendrochronology of the Upper Forest Boundary in the Urals.* Nauka, Moscow (in Russian).

Shiyatov, S. G. and V. S. Mazepa. 1987. Some New Approaches in the Construction of More Reliable Dendrochronological Series and in the Analysis of Cycle Components. *Methods of Dendrochronology-I, Proceedings of the Task Force Meeting on Methodology of Dendrochronology: East/West Approaches.* IIASA, Laxenberg, Austria.

Wigley, T. M. L., K.R. Briffa and P. D. Jones. 1984. On the Average Value of Correlated Time Series with Applications in Dendroclimatology and Hydrometeorology. *Journal of Climate and Applied Meteorology* 23:201-213.

Wonnacott, T. H. and R. J. Wonnacott. 1981. *Regression: A Second Course in Statistics.* Wiley. New York.