FINAL TECHNICAL REPORT ON SMALL GRANT FOR EXPLORATORY RESEARCH

Project title: A multimillennial temperature reconstruction from far north-eastern Eurasia

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Technical information

A paper entitled 'Natural variability of summer temperature in far north-eastern Eurasia recorded in tree rings', authors M.K.Hughes, E.A.Vaganov, S.Shiyatov, R.Touchan and G.Funkhouser, is in preparation. A primary set of tree-ring samples is housed at the Laboratory of Tree-Ring Research, University of Arizona, with replicate samples held at my Russian colleagues laboratories in Krasnoyarsk and Ekaterinburg. It is our intention to make primary and derived data available electronically through World Data Center 'A' for Paleoclimatology in Boulder, Colorado.

Background

The instrumental record of climate is rarely more than 90 years in length at continental locations, and most records are much shorter. This is particularly true in remote mountainous areas, and in high latitude regions such as much of Siberia. Although these short instrumental records are valuable in the study of interannual natural variability, they are not capable of revealing the structure of multidecadal and longer variability. Even in the case of decadal variability, only a few realizations of any mode of behavior may be represented by the instrumental record.

In order to gain an understanding of the full range of natural climate variability from interannual to millennial time scales, we must use historical documents and natural climate archives with resolution of one year or better. These include tree rings, annually laminated sediments, and the annual layers of certain very high elevation or very high latitude ice caps. The project dealt with one of these kinds of records, tree rings, but the results will be coordinated with other projects dealing with ice cores, laminated sediments and historical documents through the PAst Global changES (PAGES) project of the International Geosphere-Biosphere Program (IGBP).

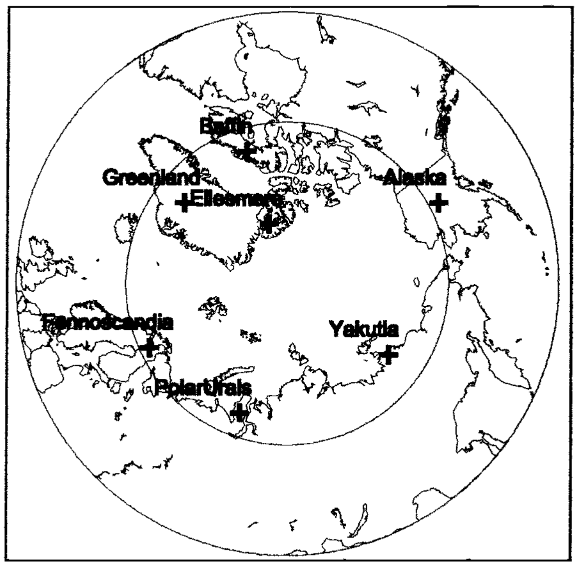

Figure 1 Annual-resolution, 1000 year and longer climate records in the Arctic

Approach

There is a pressing need for 1000 year and longer climatic records in order to describe accurately the climate of the last millennium, and to assess the nature and causes of natural climatic variability on interannual to century time scales (Hughes and Diaz, 1994). Few such records exist outside western North America (Hughes, 1995), but a start has been made in some other regions, notably northern Eurasia (Briffa et al, 1992; 1995, Graybill and Shiyatov, 1992). It has already been established that the annual rings of trees from northern Siberia contain excellent records of summer temperature (Graybill and Shiyatov, 1992; Briffa et al, 1995; Vaganov, Shiyatov and Mazepa, in press). My aim in this project was to test the feasibility of establishing further millennial and multimillennial reconstructions of summer temperature in the Russian subarctic, particularly in Yakutia.

In addition to the annual resolution GISP2 and GRIP records (Greenland; Mayewski et al, 1993), work is under way on Holocene-length summer temperature reconstructions using tree rings in Fennoscandia (Briffa et al,1992) and the Polar Urals/Yamal peninsula area (Graybill and Shiyatov, 1992; Briffa et al, 1995) (Figure 1). The region we propose to investigate (Yakutia; the Lena-Indigurka lowlands) is fully 80 degrees East of the Polar Urals sites and 120 degrees East of northern Fennoscandia. To the east, the next existing annual resolution records more than 1000 years long are on Baffin (J.Overpeck, personal communication) and Ellesmere Islands (R.S.Bradley,personal communication; Koerner and Fisher, 1990) (another 120 degrees of longitude distant). Work is in hand on building long tree-ring chronologies in Alaska, (Graumlich, 1991; Jacoby and D'Arrigo, 1991). The target region is not far from the most distant position possible from existing Arctic records, and so could provide interesting and potentially very instructive comparisons with them. The Lena-Indigurka lowlands seemed to be one of the most immediate prospects for adding to the existing set of very high latitude annual resolution Holocene-length proxy data within a few years.

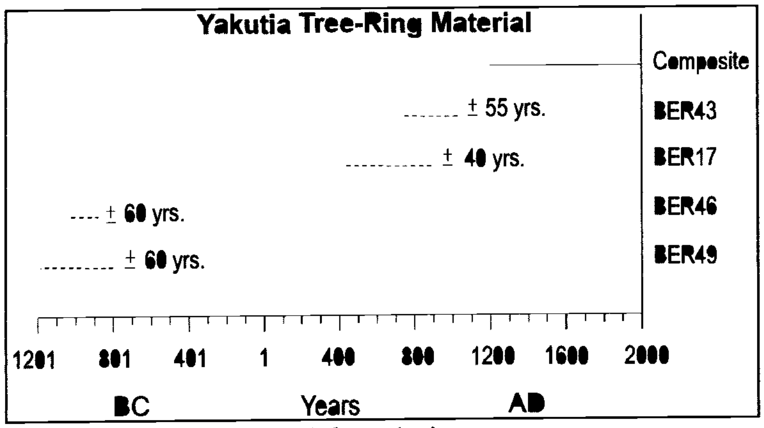

Figure 2 Temporal extent of chronologies

It has been confirmed that subfossil wood exists that might be used to build multimillennial temperature reconstructions in this region? I have worked closely with Russian colleagues Drs. Shiyatov and Vaganov. They had earlier reported the widespread occurrence of subfossil larch wood (*Larix kajenderi*) in the alluvial deposits of the Lena-Indigurka lowlands, often exposed by river action. This wood is also mentioned in a number of published reports (Sheludjakova, 1938; Ustiev, 1966). Tolstov (1956), reports trunks and stumps in the banks of channels and ravines near Chokurdakh, being exposed by water flow and the thawing of permafrost. In August 1994 we conducted preliminary field work in this region, and located a considerable quantity of subfossil wood in excellent condition, with only a small proportion made unusable by reaction wood resulting from the trees tilting on heaving ground. We also sampled many living trees, which have ages of up to 600 years, with annual radial increments of the order of 0.2 mm. Most of the subfossil wood was found in river beds, but we also identified another potentially rich source of wood from times before the earliest years of currently living trees, namely thermokarst lakes. Combining living tree samples and logs from river beds, we have already established well-replicated larch tree-ring chronologies from the area close to Chokurdak which extend back to A.D. 1200, and we have radiocarbon dates for material taken from the same river beds from the fifth through ninth centuries A.D. and the thirteenth through ninth centuries B.C. (Figure 2). We observed many situations in which wood could be, and indeed has been, preserved in this landscape, with its thousands of rivers and lakes, as well as its intense permafrost and thermokarst features. **These results and observations, and information provided by the Institute of Geology in Yakutsk, concerning logs protruding from permafrost exposures, indicate that we will be able to extend our tree-ring records back further in time, perhaps ultimately through the whole Holocene.**

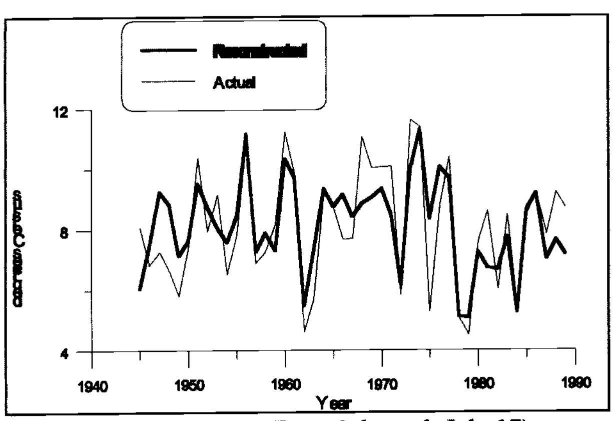

Figure 3 Early summer (June 6 through July 17) temperature at Chokurdak

Climate signal. Our colleagues D.

A. Graybill and S. Shiyatov (1992) established that larch tree rings at high latitude contain a high quality record of summer temperatures and that this record could be many centuries long. The materials collected in summer 1994 give further evidence of the high dendrochronological quality of larch material from the far North. Ring boundaries are distinct, circuit uniformity is excellent, and reaction wood is clearly identifiable, but much less prevalent than had been expected. Mean sensitivity is very high (circa 0.75, with approximately 0.75% missing rings), the first order autocorrelation of ring widths is moderate (circa 0.38, compared to 0.46 in the Polar Urals) and mean correlation between trees is high (about 0.54, with n>300). Correlations between the seven site chronologies established from a region of approximately 220 km diameter average 0.66 for the 355 year common period. These results indicate that there is a strong regional signal in the patterns of wide and narrow rings in the larch trees of the region near to Chokurdak. There are a number of meteorological stations within the area that will be useful for calibration of the tree-ring record (for example, Chokurdak), for some of which daily data are available in electronic form (Razuvayev et al, 1993). This is of particular value at high latitudes, where the growth season is extremely short and the use of monthly climate data is inappropriate.

There are strong correlations between a composite regional ring width chronology derived from a selected subset of the larch materials collected in August 1994, and early summer temperatures at Chokurdak. Early summer was defined as June 6 through July 17 on the basis of the recorded patterns of temperature and the strength of correlation with the tree-ring chronology. Our calculations of regression between the tree-ring series and mean surface temperature at Chokurdak used the period A.D. 1945 to 1989. This last year was determined simply by the availability of records, whereas the starting year was chosen after an analysis of the instrumental data. There were a number of missing data problems in the years before 1945. Calibration R^2 was 0.62 ($F=71.2$, $p<0.0001$) and $R^2_{prediction}$ 0.60. $R^2_{prediction}$ is used in cross-validation, giving 'some indication of the predictive capability of the regression model' (Montgomery and Peck, 1992, p.177). If the single outlier year 1975 is censored, calibration R^2 rises to 0.66 ($F=83.6$, $p<0.0001$) (Figure 3). **Thus, it is clear that a strong summer temperature signal may be extracted from larch tree-rings at high latitudes in Siberia, including locations in the target region.**

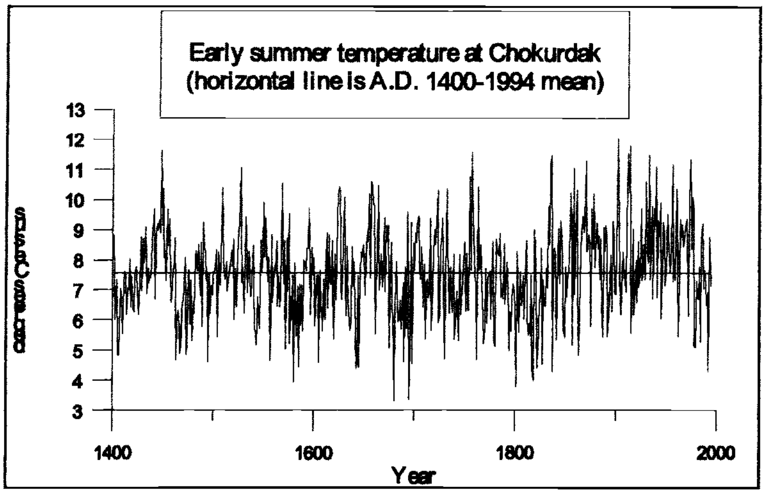

Figure 5 Early summer temperature at Chokurdak (truncated at AD 1400 because of sample depth)

Time scales of variability. As shown in Figure 4, the preliminary sample taken in August 1994 allows us to reconstruct early summer temperatures in this region for much of the last millennium, and the possibility exists of extending this to earlier millennia. Figure 4 shows that the 20th century has warmer early summer temperatures than the whole period since A.D. 1400 (8.2°C compared to 7.6°C for the longer period, in spite of the dramatic decline in temperatures since 1978 (mean for 1978-1994 is reconstructed as 6.9°C). This reconstruction was based on a carefully selected and treated subset of samples, chosen so as to maximize the low-frequency climate signal (i.e. decadal to century time scale changes). Preliminary analysis of spectra of the reconstructed summer temperature series indicate that there are multidecadal and century time scale variations in temperature in this region, for example the predominantly cold periods in the late fifteenth, sixteenth and seventeenth centuries, and in the late eighteenth and early nineteenth centuries, and the predominantly warm periods in the mid-fifteenth, mid-seventeenth and eighteenth centuries, and in the period since the mid-nineteenth century. Of these features, higher temperatures in the twentieth century are shared with other records of temperatures in high northern latitudes, (Briffa et al, 1995; Jacoby and D'Arrigo, 1991). There is also evidence of quasi-periodic behavior at higher frequencies in the record of Chokurdak early summer temperatures. Multi-taper spectral analysis (Thomson, 1982) shows peaks at 15.1, 7.0, 3.7, 3.4 and 2.3 years ($p<0.001$). After treatment with a data-adaptive high-pass filter, additional peaks at 53.9, 25.3, 11, 8.8, 8.6, 7.8, 4.9 and 3.1 years were detected ($p<0.001$). None of these spectral peaks account for more than 2 or

3% of the total variance of the time series, most much less. We will be able to explore these variations with the existing record, which is well replicated for 600 years, but cannot analyze longer wavelengths, which probably account for more variance, reliably without a much longer record. **In order to establish a record of multi-decade to century scale natural variation, to be used in studying both non-periodic and periodic fluctuations, a record longer than the present one is needed, preferably several thousand years long. A major result of the SGER award is that the likely feasibility of this has been demonstrated.**

References

Briffa, K. R., Jones, P. D., Bartholin, T. S., Eckstein, D., Schweingruber, F. H., Karlén, W., Zetterberg, P., and Eronen, M.: 1992, 'Fennoscandian summers from A.D. 500: temperature changes on short and long time scales', *Climate Dyn.*, **7**, 111-119.

Briffa, K.R., Jones, P.D., Schweingruber, F.H., Shiyatov. S. and Cook, E.R. 1995. Unusual twentieth-century summer warmth in a 1000-year temperature record from Siberia. *Nature*, **376**, 156-159

Graybill, D. A. and Shiyatov, S. G.: 1992, 'Dendroclimatic evidence from the northern Soviet Union', *In* R. S. Bradley and P. D. Jones (eds.), *Climate Since A.D. 1500*. London: Routledge, pp. 393-414.

Graumlich, L. J. 1991. High-latitude tree-ring data: records of climatic change and ecological response. In *International Conference on the Role of the Polar Regions in Global Change: Proceedings of a Conference held June 11-15, 1990 at the University of Alaska Fairbanks,* ed. by G. Weller, C. L. Wilson, B. A. B. Severin. Geophysical Institute, University of Alaska Fairbanks, and Center for Global Change and Arctic System Research, University of Alaska Fairbanks: pp. 565:569.

Hughes, M.K. 1994. Tree-ring evidence of surface temperature variation during the past 1000 years. *Paläoklimaforschung*, 16, 61-72.

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.

Jacoby, G. C. and R. D. D'Arrigo 1991. Global change and thermal history as recorded by northern North American tree-ring data. In *International Conference on the Role of the Polar Regions in Global Change: Proceedings of a Conference held June 11- 15, 1990 at the University of Alaska Fairbanks,* ed. by G. Weller, C. L. Wilson, B. A.B. Severin. Geophysical Institute, University of Alaska Fairbanks, and Center for Global Change and Arctic System Research, University of Alaska Fairbanks: pp.599:605.

Koerner, R. M. and D. A. Fisher 1990. A record of Holocene summer climate from a Canadian high-Arctic ice core. *Nature* **343**, 630-631.

Mayewski, P. A., L. D. Meeker, M. C. Morrison, M. S. Twickler, S. I. Whitlow,

K. K., Ferland, D. A. Meese, M. R. Legrand, and J. P., and Steffensen 1993. Greenland ice core 'signal' characteristics: An expanded view of Climate Change. *J. Geophys.Res.* *98*, 12839-12847.

Montgomery, D.C. and Peck, E. 1992. *An introduction to linear regression analysis*. Wiley, New York.

Razuvyev, V.N., Apasova, E.G. and Martuganov, R.A., 1993. *Daily temperature and precipitation data for 223 USSR stations. ORNL/CDIAC-56*. Carbon Dioxide Information Analysis Center, Oak Ridge, TN

Sheludjakova, V.A.: 1938,' Vegetation of the Indigurka River basin', *Soviet Botany*, **4-5**, 43-79. In Russian

Thomson, D.J.: 1982, 'Spectrum estimation and harmonic analysis', *Proc. IEEE*, 70, 1055-1096.

Tolstov, A.N.: 1956,' Traces of ancient tree growth', *Nature*, **10**, 102-104. In Russian

Ustiev, E.K.: 1966,' *On the other side of night*.' Moscow: Mysi. 310 pp. In Russian

Vaganov E.A.,Vysotskaya L.G.,Shashkin A.V. In press. Using cell chronologies in seasonal tree growth analysis and dendroclimatology. *Radiocarbon*, 1996

Vaganov E.A.,Shyiatov S.G.,Mazepa V.S. In press. *Dendroclimatic study in Ural-Siberian subarctic* (mono-graph), Novosibirsk, Nauka,