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Global Warming Detected by Tree Rings from Mongolia

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ABSTRACT

In the year 2000 we culminated a successful five year investigation of climate change by completing a preliminary east-west transect across Mongolia. An earlier tree-ring study at Tarvagatay Pass, Mongolia indicated unusual warming during the 20th century similar to other paleo-investigations of the northern hemisphere. This record had represented one of the few tree-ring records for central Asia. New data from several sites in western Mongolia confirmed the preliminary temperature.

The highest twenty-year growth period for the composite record is from 1973-1994. The western Mongolian record was significantly correlated with the Taimyr Peninsula and two northern hemisphere temperature reconstructions reflecting large-scale temperature patterns while showing some important regional differences.

These differences should prove useful for climate models. We have also developed a millennial length temperature-sensitive record at the Solongotyin Davaa site (formerly Tarvagatay Pass) using relict wood and living trees. Conspicuous features over the last 1000 years are a century scale temperature decline punctuated by the end of the Little Ice Age in the late-1800s and 20th century warming.

The record also shows a cold period early in the 12th century and warm intervals late in the 10th, early in the 15th and at end of the 18th centuries. Despite a limited sample size before 900 AD, the long Solongotyin Davaa record is useful in indicating severe cold events and suggests some cold intervals nearly as severe.

These tree ring series, spanning much of the circumpolar northern treeline, have been compiled to create a long-term reconstruction of the Earth's temperature over centuries. The new chronology, in addition to its value as a detailed record of Mongolian climate, provides independent corroboration for such hemispheric and global reconstructions and their indications of unusual warming during the 20th century.

Keywords : Mongolia, tree-rings, temperature reconstructions, dendroclimatology, twentieth-century warming, Northern Hemisphere.

Introduction

Much of Northern Asia is lacking in high-resolution palaeoclimatic data coverage. This vast region thus represents a sizeable gap in data sets used to reconstruct hemispheric-scale temperature trends for the past millennium.

Mongolia is a continental land area with forests restricted mainly to the northern third of the country, primarily on north-facing slopes. At locations in the western mountains far removed from towns, there is little disturbance due to human activity and excellent opportunities for dendroclimatic study of old-growth trees in alpine timber-line settings(i.e., at the elevational limits of survival) (Fig 1).

Since 1995, members of MATRIP(the Mongolian-American Tree-Ring Project) have been collecting wood samples from climatically sensitive locations in Mongolia for dendroclimatic studies of both temperature (Jacoby et al., 1996, D'Arrigo et al., 2000, 2001, Gordon and Baatarbileg, 2003) and precipitation(Pederson et al., 2000).

The causes and mechanisms of decadal to century-scale Holocene climate variability are still not well understood, necessitating the generation of high-resolution proxy records of climate spanning recent centuries to millennia (e.g., Cook et al., 1991). Some of these data have been compiled into networks for development of large-scale, even global, temperature reconstructions covering the past several centuries(Jacoby and D'Arrigo, 1989; Bradley and Jones, 1993; D'Arrigo and Jacoby, 1993; Overpeck et al., 1997; Mann et al., 1998) and up to the last millennium(Mann et al., 1999; Esper et al., 2002). Prior to ca. 1600, however, there are increasing errors in the estimated trends (Mann et al., 1999; Esper et al., 2002). These uncertainties result largely from the scarcity of millennial records, particularly for remote regions of Eurasia.

Trends resemble those of other Eurasian paleoseries, and hemispheric-scale reconstructions over the past millennium. More chronologies such as Sol Dav are essential to improve coverage in the uncertain earlier centuries of these reconstructions and their estimates of natural variability relative to recent anthropogenic change.

By comparing the tree rings with other evidence, it will improve understanding of whether the anthropogenic (human-induced) release of trace gases into the atmosphere is the cause of recent warming, or whether other factors, such as solar or volcanic activity, have played more critical roles in the Earth's climate in recent years.

To help meet the need for millennial time series

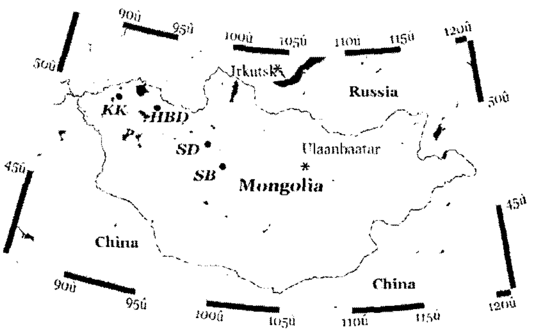

Fig. 1. Map of Mongolia showing locations of alpine timber-line sites and other locations mentioned in text.
KK = Siberian larch; HBD = Siberian larch; SD = Siberian pine; SB = Siberian larch.

(Briffa and Osborn, 1999), we have produced an extended tree-ring width chronology of Siberian pine (Pinus sibirica Du Tour) at Solongotyn Davaa (Sol Dav), an elevational timberline site in the Tarvagatay Mountains of Mongolia (Fig. 1).

The temperature fluctuations inferred from the Mongolian tree rings are strikingly similar to those seen in a network of tree ring records from sites at northern and alpine treeline in North America, Europe and Russia, including the Taymir Peninsula in Siberia (Jacoby and D'Arrigo, 1989; Bradley and Jones, 1993; D'Arrigo and Jacoby, 1993; Overpeck et al, 1997; D'Arrigo et al. 1999; Mann et al, 1999).

These global climatic changes may have profound effects in Mongolia, which has a largely agrarian-based economy. Livestock and food crops are major enterprises and land management for these purposes is extremely important. The greater understanding of climate extremes and possible causes gleaned from tree rings and other extended records can lead to better planning and agricultural management in the future.

Materials and Methods

In this paper, we better replicate and confirm initial findings(Jacoby et al., 1996) by presenting a regional-scale composite of four chronologies produced from elevational treeline forests in northwestern Mongolia. One of the chronologies (Khalzan Khamar, KK) is from a site in the Altai Mountains; two (Horin Bugatyin Davaa, HBD, and Suuleen Bagtraa, SB) are in the Hangai Mountains; and one (Solongotyin Davaa, SD), is in the Tarvagatay Mountains, a northeastern extension from the Hangai (Fig 1).

The higher elevations have permanent or semi-permanent snowfields, ice and/or permafrost. The trees, of Siberian pine and larch(*Larix sibirica Lebedour*), were sampled at or very near timber-line(exceeding 2200 m elevation) in settings where temperature, rather than drought stress, appears to be the limiting factor to growth. We base this interpretation on the presence of lush ground vegetation, water seepage, correlations with climate, and other considerations(Jacoby et al., 1996).

Additional sampling at Sol Dav has now yielded abundant relict wood material (and updated living tree records through 1999). The ring-width measurements from the relict collections were cross-dated with each other and with living tree data by visual alignment of ring characteristics and computer-assisted dating techniques (Stokes and Smiley, 1968; Holmes, 1983). Conservative detrending employed negative exponential or straight line curve fits, or stiff splines to remove age-related growth trends (Fritts, 1976; Cook, 1985; Cook and Kairiukstis, 1990). Splines (with a 50% frequency-response cutoff) between 300 and 700 years were used in 10/99 cases. During standardization (Cook, 1985), a power transform technique was used to stabilize the variance and residuals from the fitted curves were computed to avoid potential bias in calculation of indices Cook and Peters, 1997). The final chronology (Fig 2) consists of 38 radii from 19 living trees and 61 radii from 32 relict trees.

There are very few meteorological stations in the general vicinity of the Sol Dav site, and these are only several decades in length (Jacoby et al, 1996; Jacoby et al., 1999). The nearest and longest individual station record is at Irkutsk, Russia, just north of the Mongolian border; this station shows a significant positive trend over the past 100 years ($r = 0.66$). Irkutsk is hundreds of kilometres from the tree-ring sites and at much lower elevation (470 m, Fig 1). Despite these considerations, annually averaged (August to July) Irkutsk temperatures and gridded temperatures for Mongolia based largely on the Irkutsk station (4550N, 95100E, P. Jones) had shown significant positive correlation with the original Sol Dav series (e.g., from 1882 to 1993, $r = 0.45$ with the gridded data for the growth year; Jacoby et al., 1996). Correlation for the four-chronology PCA scores is $r = 0.57$ with Irkutsk temperatures over 18831996. More detailed methodology well explained in this proceeding Pederson et al.

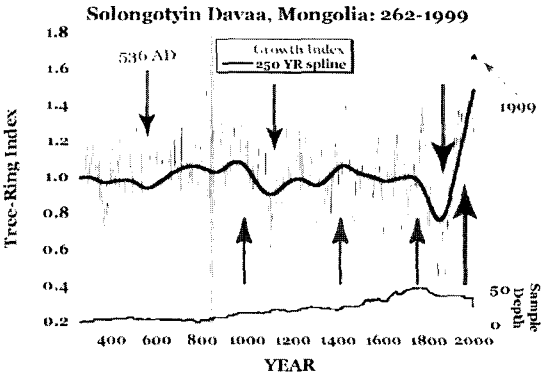

Fig. 2. 1738 years (AD 262-1999) of temperature variability are inferred from tree-ring widths of Siberian pine at Solongotyin davaa (Sol Dav), a timberline (2420 m) site in Mongolia. This chronology can account for 33% of the temperature variance from 1882-1993. The warmest conditions over the past millennium are during the20th century. The 1999 rings width has the highest index value over the past millennium. Both warmer and colder intervals are inferred during the "Medieval Warm Epoch".

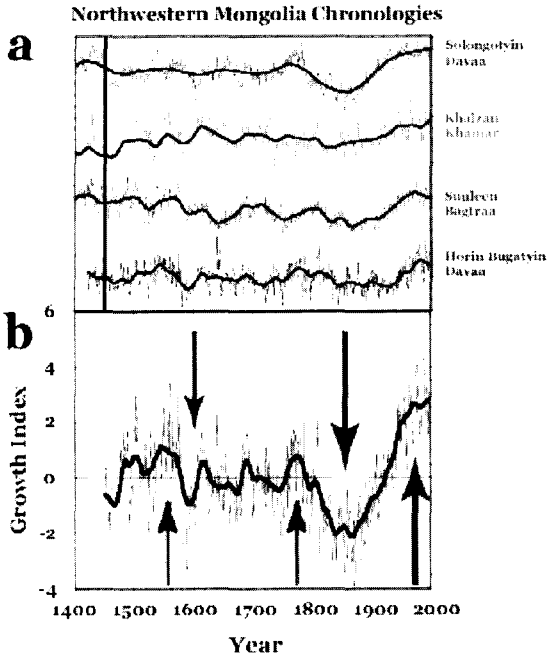

Fig. 3. Northwestern Mongolian chronologies. Using Principal Component analysis the four chronologies (graph a) were combined into one series (graph b). Time-series of four ring-with chronologies(indices) for 1450-1998. Vertical line is indicated at AD 1450 where common period of analysis begins. Chronology lengths are: KK 1326-1998; HBD 1422-1998; SD 262-1998; and SB 1363-1999. The final series indicates 2 cool periods during the late 16th and 19th century. Warm periods are seen in the mid 16th and late 18th century.

Results

The 20-year interval from 1974 to 1993 is the highest such period over the length of record. Furthermore, 17 of the 20 highest growth years have occurred in the twentieth century(since 1946). There are, however, some comparable periods of inferred warmth for some of the sites during other intervals (e.g., 1520-1580 at SB and HBD; and 1760-1790 at SD and HBD) (Fig 3). The lowest 20-year period occurs from 1854 to 1873, just prior to the recent warming.

We compare the PCA scores to two annual Northern Hemisphere temperature reconstructions: a new reconstruction based solely on tree-rings and another based on various proxy and other data sources(Mann et al., 1999; Esper et al., 2002) (Fig 4). The former is based on tree-ring data from 21 mesic to hydric sites at either latitudinal or elevational tree-line in northern latitudes (modified from Jacoby and D'Arrigo, 1989; D'Arrigo and Jacoby, 1993; D'Arrigo et al., 1999). This particular set of sites was selected for balanced geographic representation, and accounts for 66% of the variance in recorded annual temperatures. Tree-ring data for years t and t+1 were used in a principal component regression to estimate temperature for year t. Correlations with the Mongolia series and these reconstructions are 0.67(with tree-ring reconstruction) and 0.47 with Mann reconstruction (0.58 with Esper/Cook chronologies) over ad 1655-1973 and 1450-1980, respectively. The four chronologies also load closely with the 21 tree-ring chronologies used in the reconstruction above, which included data from North America, Scandinavia and Russia, as well as one Mongolian series. This agreement between such widely separated sites further suggests a common climatic signature.

Trends seen in the Mongolia PCA record track those indicated in the above large-scale reconstructions, with higher growth indicating warmer temperatures and lower growth cooler conditions. Common trends include pronounced cooling in the early to middle 1800s during the last phase of the 'Little Ice Age'(Grove, 1988) and a subsequent warming trend for this century(Fig 4). Similar fluctuations have been noted in other long-term records of temperature for north Asia (e.g., Zang, 1980).

The new data provide independent evidence for the trends seen in the large-scale temperature estimates, which included no or very limited data coverage from north central Asia. In particular, these new data provide

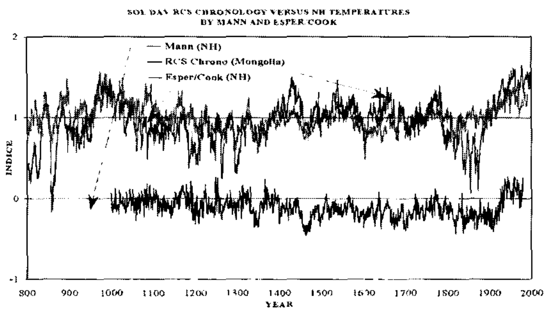

Fig. 4. Comparison two proxy-based reconstructions of mean Northern Hemisphere Temperature changes over the past millennium including uncertainty levels (Esper et al. 2002; Mann et al. 1999) and Sol. Dav chronology from Mongolia

independent support for the interpretation that recent warming is unusual in nature (Briffa and Osborn, 1999). The twentieth-century rise in common variance between series could suggest a common climatic forcing which is increasing relative to regional differences. As noted, we interpret the climatic signal at the tree-line sites in Mongolia to be primarily due to temperature. Apparent loss of temperature sensitivity in some northern tree-ring series has been observed in recent decades, attributed to drought stress and other factors (Jacoby and D'Arrigo, 1995; Briffa et al., 1998; Vaganov et al., 1999). Yet such decreased sensitivity is not clearly evident in these tree-line data from Mongolia. Careful site selection is critical for identification of those trees and locations where the response to temperature has not been diminished.

The Solongotyin series is most reliable after 850 (gray bar indicates 850 AD). Important features from 850-1999 includes: extended cold intervals in the 12th and 19th centuries and warm intervals during the late 10th, early 15th, late 18th and the last half of the 20th century. At the time of sampling (Aug. 21, 1999), the 1999 ring was not fully formed. Despite this, it is the largest ring of the last 1150 years and the 2nd largest of the entire record. This indicates trees at Solongotyin Davaa are reflecting the unusual warming observed (some of the greatest warming observed on the Earth) in central Asia instrumental records.

Conclusion

Additional palaeorecords are essential for evaluation of climatic change, including detection of possible recent anthropogenic influences. One key challenge is to decrease the large degree of error found for the earlier half of this millennium in existing hemispheric-scale temperature reconstructions (Mann et al., 1999; Esper et al 2002).

Relict wood materials are now being used to extend the living tree records back to the millennial scale for Mongolia and these other locations. Besides the Mongolia series, other primarily temperature-related tree-ring chronologies for northern Eurasia have recently been developed for the Taymir Peninsula, Russia(Jacoby et al., 2000) and elsewhere in Siberia (Briffa et al., 1995; Hughes et al., 1999, Vaganov et al., 1999). These and other such records will prove useful in future generations of temperature reconstructions, but much more data is needed (Briffa and Osborn, 1999).

The new data will contribute significantly to existing geographical coverage while helping to decrease the level of uncertainty inherent in present large-scale reconstructions of climate variability.

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