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TREE-RING RECORDS OF LATE HOLOCENE CLIMATE CHANGE IN THE HANGAY MOUNTAINS, MONGOLIA

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INTRODUCTION

The climate of Mongolia is harshly continental. As Blyakharchuk et al. (2007) details, continental areas far removed from any moderating oceanic influence are highly sensitive to climatic changes. The convergence of the major cyclonic and anti-cyclonic air masses causes great seasonality, and daily temperatures can vary widely. Mongolia is dominated by the Siberian High during the winter, and precipitation occurs mostly in the summer (Jacoby et al., 1996).

Detailed climate data for Mongolia is sparse. Recorded temperature data does not exist prior to about 1940 and has many missing values, particularly in the 1980s. Rural station data often extend only back to the 1960s and may be interrupted during the 1980s and 1990s. As such, proxy reconstructions become important in trying to determine a long-term climate history for Mongolia. There is a history of climate research in Mongolia, but much of the data remains unpublished or un-translated to English. As of 1999, pollen research conducted by Russian and Mongolian scientists starting in the mid-1960s was mostly unavailable to English-speakers except as summarized by Gunin et al. (1999). Likewise, tree ring research in Mongolia prior to the early 1990s is limited and difficult to obtain (Jacoby et al., 1999).

Dendrochronology is a valuable way to reconstruct past climates due to the high resolution and sensitivity of the record that tree rings preserve. Recognizing that tree rings could provide greater understanding of the late Holocene climate, in 1995 the Mongolian-American tree ring project (MATRIP) was started through the Tree Ring Lab of the Lamont Doherty Earth Observatory, which has since published extensively on various climate factors and reconstructions based on tree ring analysis (e.g. Jacoby et al., 2003). MATRIP's data will be discussed below, but in general its data shows good correlation between climate trends in Mongolia and the rest of the Northern Hemisphere. Both the Northern Hemisphere record and the Mongolian tree-ring record show warming in the 20th Century (Jacoby et al., 2003).

Study Site

The Hangay Mountains form an approximately 600 km northwest-southeast trending elevated plateau in central Mongolia. Elevations range from approximately 2000 to 3700 m with the highest peak, Otgon-Tenger, reaching 3905 m. Past glaciation was extensive, and the high peaks in the western portion of the range still maintain permanent snow fields (Gunin et al., 1999). Temperatures in the Hangay can vary between -25º C in winter and nearly 20º C in summer in recent years, as recorded at the Muren weather station, located in the northern Hangay region (49.6º N, 100.2º E, 1283 m above sea level), approximately 150 km north of Egiin Davaa.

The Egiin Davaa region (47º N, 100ºE) of the central Hangay reaches altitudes in excess of

3500 m. Evidence for extensive past glaciation is abundant in well-defined cirques and moraine complexes, but there are currently no glaciers or permanent snow fields in the region. The modern climate supports periglacial features above 2250 m, including cryoplanation terraces, patterned ground, solifluction lobes, and local palsen. Permafrost exists within 1 m of the surface. Modern vegetation communities include scattered Siberian larch (Larix sibirica) forests on north-facing slopes with limited vertical range (Fig.1), common small willows (Salix spp.), uncommon birch (Betula spp.), and one observed juniper (Juniperus sp.).

Figure 1: Typical larch stand in the Egiin Davaa region.

METHODS

Cores were taken from Siberian larch using increment borers. All cores are from trees between 2197 and 2636 m above sea level and on north-facing slopes. Trees occur on steep slopes and some ridge tops, with the total vertical extent in most individual stands not exceeding approximately 150 m. In general, the substrate is grassy with boulders, although in thicker forests the underlying vegetation is lush and the forest floor consists of vegetative duff. Extensive heart rot made obtaining complete cores difficult, and fire and insect damage was noted on many trees.

For processing, the cores were air-dried and glued into mounting grooves. They were then sanded flat using progressively finer sand paper up to 2000-grit to expose and clarify the rings. Measurements were obtained by examination under a microscope using an electronic microcaliper linked to a microcomputer. Analysis of ring widths employed the computer programs CRONOL and YUX, both available as free downloads from the Dendrochronology Program Library on Henri D. Grissino-Mayer's Ultimate Tree-Ring Web Pages (Grissino, 2007). Spectral analysis used the Caterpillar SSA 3.30 program available from the GistaT Group (GistaT Group, 2007).

RESULTS

Results indicate that the sampled trees are more water-sensitive than temperature-sensitive. A field control group for temperature and precipitation influences on tree growth is available from a four-tree sample set from a single site. The four sampled trees are all from the same stand (47º 22.105'- 47º 22.141' N, 100º 09.499'- 100º 08.256'E) and have similar aspects (320-330º), but vary slightly in elevation from 2197 m to 2270 m. The three upper trees were without obvious access to water, but the lowest tree was adjacent to the Chuluut Gol with access to an abundant water supply. When ring widths are plotted as a function of time, the wet and dry trees separate into distinct growth trends (Fig. 2). The tree with an abundant water supply shows much higher annual growth than the trees with limited access to water, indicating that the trees above are likely water-stressed.

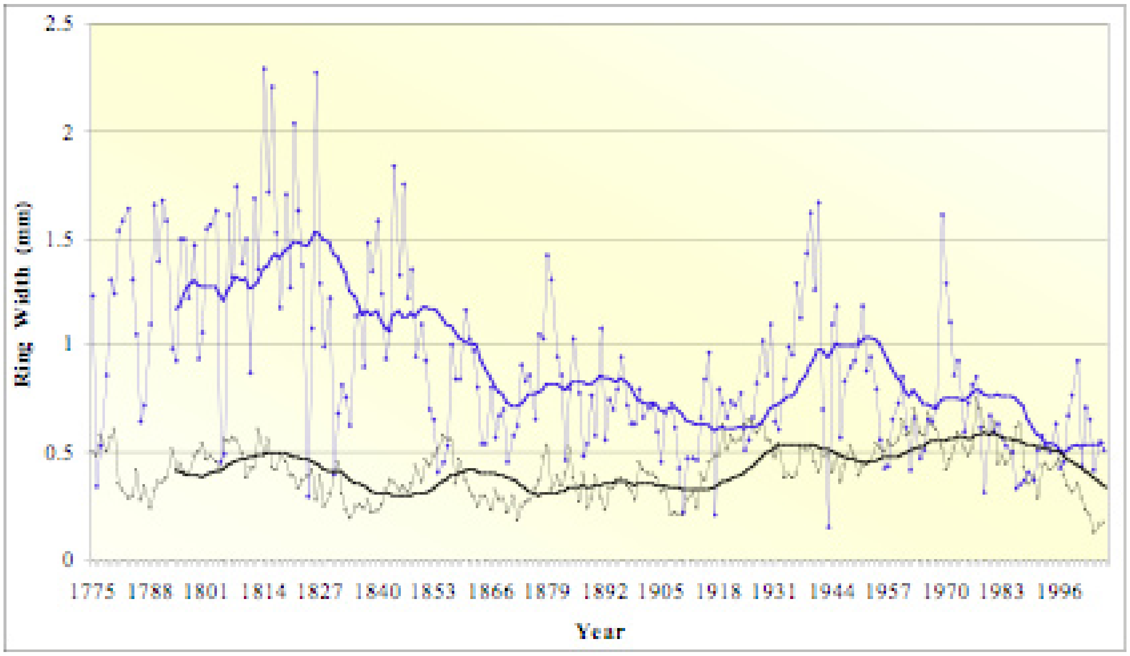

Figure 2: Plot of ring width as a function of time, with trees separating into distinct trends based on water availability. Black line shows average of 3 trees without ready access to water, with 20-year moving average. Blue line shows tree adjacent to abundant water supply, with 20-year moving average.

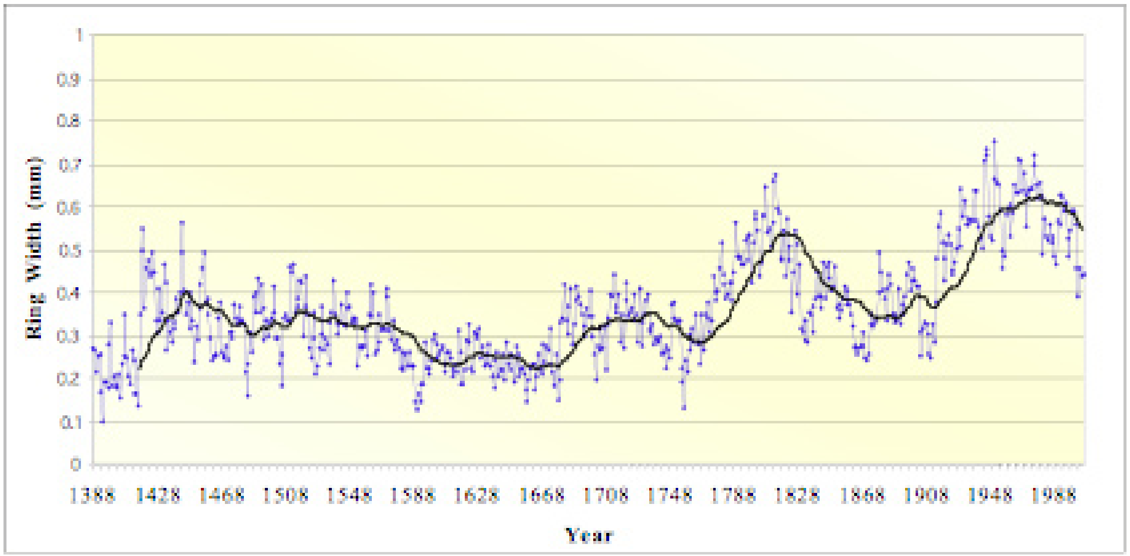

Figure 3: Raw ring width chronology, averaged (sample size = 9). Thick line represents 30-year moving average.

A greater than 600-year chronology was obtained by averaging the growth rates of collected trees with good long-term records (sample size = 9), as shown by Figure 3. While the chronology is not standardized chronology, it gives an idea of the changing growth rates of the trees in the Egiin Davaa region. Growth appears to be highly variable, indicating a high degree of sensitivity to climatic influence.

High growth rates occur at the end of the 18th Century to the early years of the 19th Century, and very high growth rates for the 20th Century are evident, an unusual signal given the typical reduction in growth as a tree ages. Growth rates

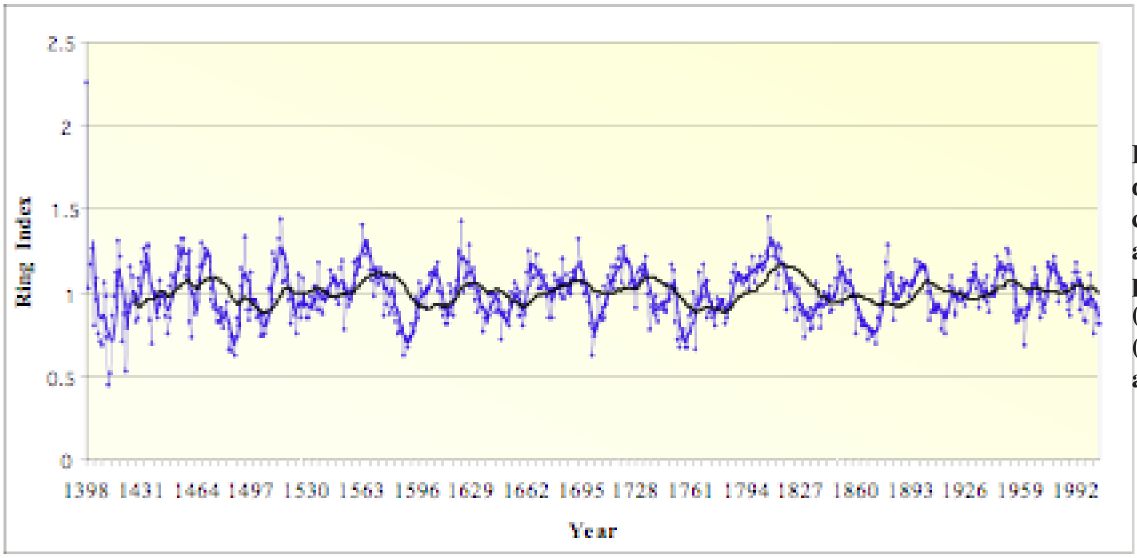

Figure 4: (Left) Standardized, averaged chronology showing approximately 50-year periodicity in 5-year (blue) and 30-year (black) moving averages.

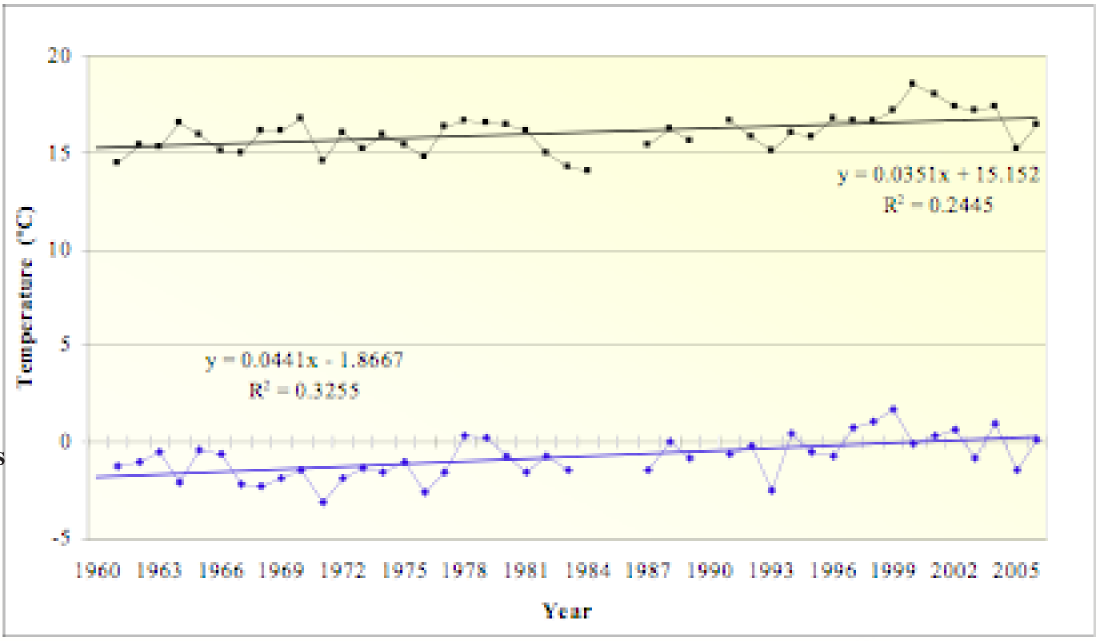

Figure 5: (Right) Historical temperature variation at Muren weather station (49.6º N, 100.2º E, 1283 m above sea level, approximately 150 km north of Egiin Davaa). Blue line represents summer (June, July, August) temperatures with linear trend. Black represents annual temperatures with linear trend. Both linear trends increase toward the end of the 20th Century.

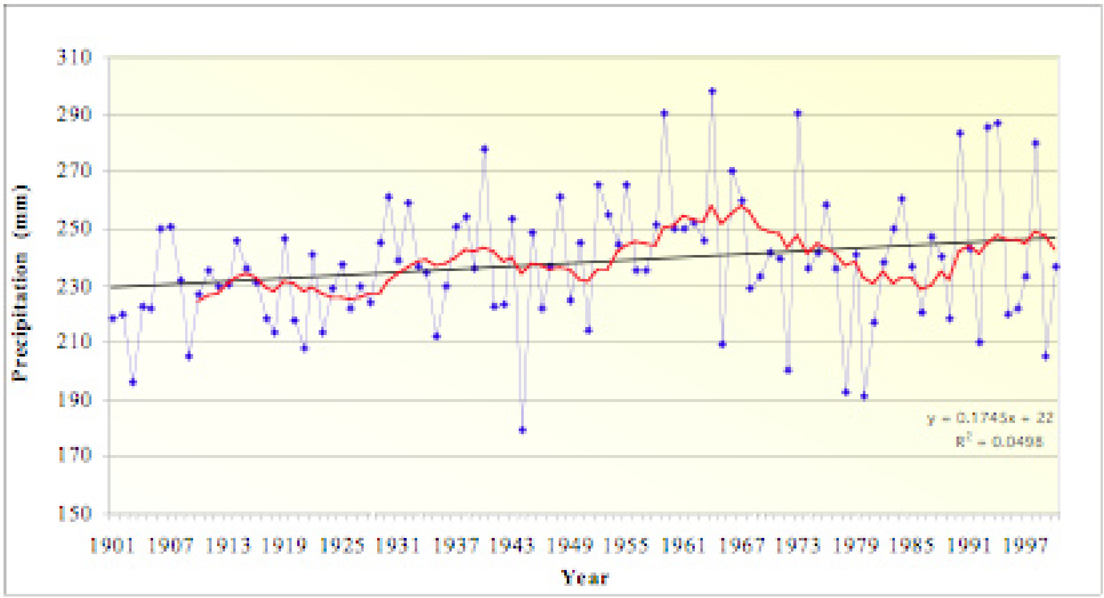

Figure 6: (Left) Recorded precipitation, Mongolia. Blue line represents average recorded data, with black linear trend showing overall increase in the 20th Century. Ten-year moving average (red) shows decrease in precipitation from 1965-1980 due to four severe droughts in that time period.

appear to peak during the 1950s and have fallen consistently since then, though they are still higher than any rates earlier in the record. Difficulties were encountered when detrending the raw ring widths using CRONOL. The trees appear to follow more complex growth and aging patterns than typical trees showing a good climate signal. When detrending curves were fitted, an appropriate signal-to-noise ratio could not be obtained and too much signal was removed. This left a flat trend at variance with expected patterns, based both on past research by the MATRIP group and visual examination of the raw trends. For this reason, raw ring widths are used herein and data obtained is thus more qualitative than might be expected. It is hoped that with more rigorous statistical analysis useful growth indices may be obtained.

While detrending the data posed the problems discussed, removal of the growth trends did reveal an oscillatory pattern to tree growth. The most prominent periodicity appears to be approximately 50 years (Fig. 4). More detailed spectral analysis confirms a prominent periodicity between 54 and 57 years.

DISCUSSION

Recorded temperature and precipitation data for Mongolia, including the Hangay region, are extremely limited and thus difficult to correlate to tree records. Incomplete temperature data beginning in 1960 from the Muren weather station, approximately 150 km north of Egiin Davaa, shows a general increasing trend with interannual variability of approximately 2º C. After 2000, the recorded temperature high point, both the average annual temperature and the summer (June-July-August) temperature decrease (Fig. 5) (NCDC, 2007). Precipitation data specific to the Hangay is unavailable. Data for Mongolia as a whole shows an overall increase for the 20th Century as well as an increase in the interannual variability towards the 2nd half of the century (Fig. 6) (Mitchell, 2003). A period of severe droughts from 1965 to 1980 is also evident.

Twentieth Century growth in the Egiin Davaa trees is consistent with both the increasing temperature and increasing precipitation shown by the available data as well as the periods of severe drought between 1965 and 1980. Records obtained by the MATRIP group (Jacoby et al, 1996, 1999, 2003) from Sol Dav, an elevational timberline site in the Hangay located at 48º 17.51'N, 98º 55.87'E (approximately 100 km northwest of Egiin Davaa) show consistent growth increases in the 20th Century. Additionally, Mann's (1999) temperature reconstruction for the Northern Hemisphere correlates well with records from the MATRIP group for the 20th Century. Of note in the Egiin Davaa record is the sustained overall increase in growth (Fig. 3) despite aging of the trees, which suggests that growth conditions were considerably more favorable in the 20th Century.

However, the decrease in growth in the later 20th Century does not correlate with the recorded climate data. This may be due to the interdecadal periodicity observed, or could be due to drought stress from 1965 to 1980, as shown in Figure 6. Additionally, Batima et al. (2005) suggest that annual precipitation in the Hangay decreased 30-90 mm from 1941 to 2001. The large peak at the end of the 18th Century exceeds growth rates for the later part of the 20th Century, a finding not correlated with any other data available. This could be due to the problem of comparing standardized ring indices with raw ring widths; the high peak in the 18th Century may be influenced by the aging trend not removed from the Egiin Davaa tree data. D'Arrigo (2001) found a lowered growth index for some Mongolian trees in 1815 and 1883, but major volcanic eruptions do not appear to have influenced growth in the Egiin Davaa region. There is no unusual depression for the years shortly after the 1783 eruption of Laki in Iceland and Mt Asama, the 1815 eruption of Tambora, or the 1883 eruption of Krakatoa from the Egiin Davaa trees.

Examination of the averaged chronology did not appear to show any sensitivity to the more common periodicities found in climate research, such as the El Niño-Southern Oscillation (ENSO) or other common decadal-scale periodicities. However, the interdecadal 54-57 year periodicity is consistent with a 50-70 year periodicity recognized by Mann et al. (1995) as possibly tied to the ENSO variations and controlled by the Pacific North American pressure anomaly. In addition, a tangential but possible connection may be made with fisheries off the coast of South America, high-latitude tree ring records, and oxygen isotope ratios from Greenland. A paper written for the United Nations (Klyashtorin, 2001) found that these three records all showed a strong periodicity at 54-56 years. However, no mechanism was proposed. Further research would be valuable.

The growth trends found in the Egiin Davaa trees show moderate correlation with past research, but in general appear to show trends different than those most past climate research has indicated. Detailed analysis of the trees by site reveals large differences in growth patterns between sites which correlate poorly, possibly indicating local factors as large influences in tree growth. Given the extreme sensitivity of periglacial environments to climatic influence, it seems reasonable to suggest that factors influencing growth trends may include site-specific depth to permafrost, wind velocity and direction, soil moisture and drainage (influenced by slope), aspect, stand dynamics, downvalley cold air drainage, or human-influenced grazing, cutting, or fires.

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