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Results of the Dendrochronological Studies in Mongolia

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Abstract

The Mongolian-American Tree-Ring Project was initiated in 1995 to develop longer climatic records in Mongolia and to help establish capabilities in Mongolia for independent tree-ring analyses. The records from old-aged trees can provide more complete information about the variations in the climate system and aid in planning for future changes or variations in climate. Many areas of Mongolia have been investigated and tree-ring samples collected. Dendroclimatic records of temperature extending back more than one thousand years and precipitation records of over 300 years have been developed. These records show that global warming is present in Mongolia and that variations in precipitation and stream-flow appear to show some solar influence. Scientists and students trained by the project are now engaged in tree-ring studies in various areas of Mongolia. The project is expected to continue for the next several years.

Key words: Dendrochronology, dendroclimatology, temperature, precipitation, Mongolia

Introduction

The project engages in dendroclimatic research, instruction in research methods, and development of tree-ring research facilities in Mongolia. Dendroclimatic research uses the annual growth parameters from climate-sensitive, old-aged trees to reconstruct and extend the records of climate variations. These longer records are extremely valuable because recorded meteorological data is too short in time to represent fully the variations, extremes, and trends in climate variation. The Mongolian-American Tree-Ring Project (MATRIP) originated in the spring of 1995 through discussions between scientists at the Tree-Ring Laboratory (TRL) of Lamont-Doherty Earth Observatory of Columbia University in the City of New York, USA, and members of the Mongolian Academy of Sciences (MAS) who were visiting New York. Invitations were issued to Drs. Rosanne D'Arrigo and Gordon Jacoby to come to Mongolia for further discussions and initial sampling in the summer of 1995. After discussions with the MAS staff to define the purposes of the project and establish communications with the appropriate government and academic agencies and individuals; logistical arrangements were made to start the first sampling expedition.

The Hydro-meteorological Research Institute and Institute of Botany of MAS supported these first efforts. Cooperative Agreements were signed between the last two institutes and the Lamont Tree-Ring Laboratory. Trees were sampled at five locations in central and western Mongolia. Old-aged trees of Siberian larch (*Larix sibirica*) and Siberian pine (*Pinus sibirica*) were sampled. The late Professor S. Davaajamts accompanied one sampling trip to the region around Monastery Manzshiriin Hiid, where spruce trees (*Picea obovata*) were also sampled. All the sampling was done nondestructively, using Swedish increment corers. At one site at elevational tree-line in the Mt. Tarvagatai, part of the Khangai Mountains (Figure 1, #2,24) the ring-width pattern observed in the field obviously showed evidence of unusual warming in increasingly wider rings during the 20th century and other low frequency ring-width patterns seen in temperature stressed trees sampled around the world (Jacoby & D'Arrigo, 1989). This finding (quantified and analyzed) presented in Jacoby *et al.* (1996) demonstrated the potential value of dendroclimatic research in Mongolia.

Development of the MATRIP Project

A proposal was written to the National Science Foundation of the USA for research support to continue studies in Mongolia and to help develop tree-ring research facilities in Mongolian institutions. This proposal was drafted with

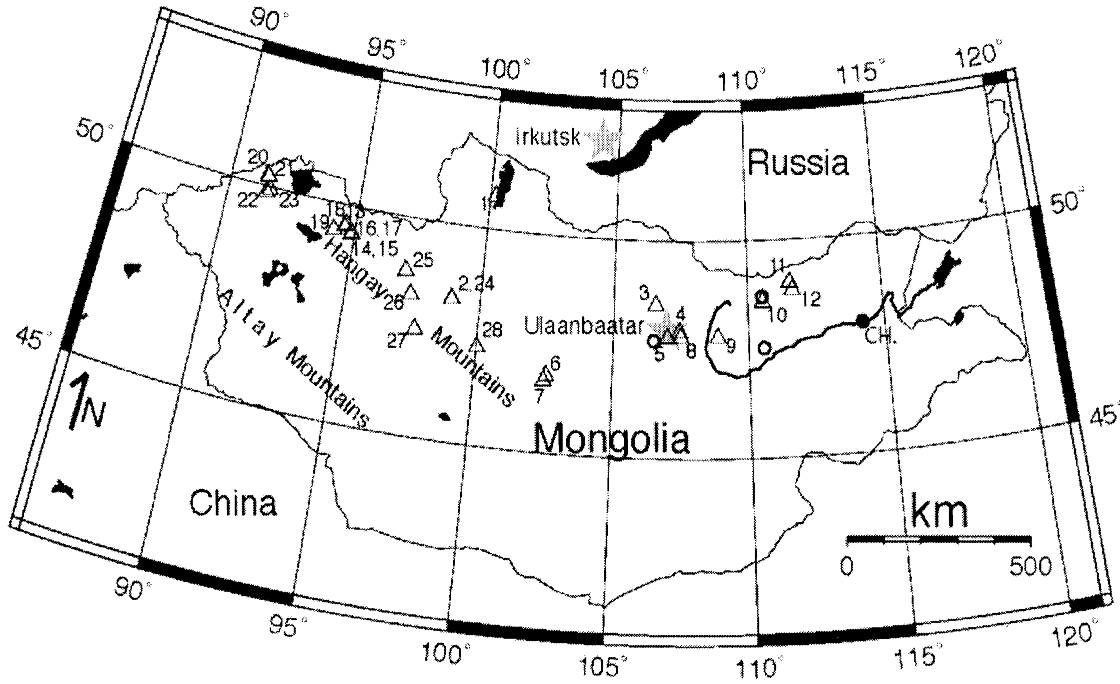


Fig. 1. Map of MATRIP tree-ring sample collection sites in Mongolia. The numbers correspond to site numbers in the text and CH indicates the location of the Kherlen River gaging station

consideration of the recommendations of the MAS for a research program that would be scientifically sound, produce results useful for management of natural resources, and contribute to the technological and intellectual development of Mongolian research. The proposal was funded starting in the fall of 1996, too late for any field work in that year so the main sampling efforts started in 1997.

Tree-ring sampling in central and western Mongolia was undertaken in the summers of 1997-1999. Locations where samples were taken are shown in Figure 1. In 1997 most effort was in sampling low elevation locations where tree growth was believed to be strongly influenced by precipitation. Ring-width data from these trees could be used to reconstruct variations in past precipitation and stream-flow. In 1998 the western part of the Mongolian forests were sampled. High elevation tree-line locations were sampled where tree growth was largely limited by temperature and the ring-width data could be used to make evaluations of variations in temperature. In 1999 the first location in the Tarvagatai Mountains was revisited to collect samples from the abundant relict wood present at the site. By cross-dating with data from old living trees, these naturally preserved dead trees could be used to extend the temperature record back beyond the limit of living tree ages. Trees were sampled at several other locations, some at low elevations for precipitation studies and some at high elevation tree-line for temperature studies. Dr. N. Baatarbileg of the Department of Forestry, Faculty of Biology, National University of Mongolia (NUM), made most of the arrangements for sampling and became the major collaborator from the Mongolian side. He has visited the Lamont-Doherty Tree-Ring Laboratory twice for learning tree-ring methods and joint research. In 1997 MATRIP started the development of tree-ring research capabilities in Mongolia. A tree-ring measuring machine was brought to Mongolia to give colleagues and students the ability to process tree-ring samples. This machine is interfaced with a minicomputer to rapidly process tree core samples. Lectures and instruction were given about tree-ring fundamentals, methods, and applications in all years since 1997.

In 2000 a Dendrochronological Fieldweek was held in Mongolia, organized by MATRIP personnel and colleagues. Lectures and instruction were provided to students and interested scientists from various institutions of Mongolia. Additionally, as incentive for forestry graduate students to use tree-ring analysis in their studies and research, a MATRIP scholarship was established to support students for their master's degree in forestry. The first award was in 1999 and there have been two subsequent awards. The recipient of the first award received his degree in 2002.

Scientific Results of the First Four-year Grant

Temperature. A comparison between annual temperatures for Mongolia and the northern hemisphere show that the trends in Mongolia reflect the same general trends. This is true for recorded temperature and for multi-century temperatures as indicated by tree-ring series. Previous analyses of recorded temperatures by Dagvadorj & Mijiddorj (1996) showed increases for fall, winter and spring temperatures but decrease in summer temperature for the 1940 to 1995 period. Dagvadorj & Mijiddorj (1996) also note the following changes in the recorded temperatures: winter heating degree days are less, the growing season is longer by about 10 to 20 days due to the warmer spring and fall, the extreme heat in summer is less, and annual temperatures have increased by about 1.8°C in Western Mongolia, 1.0°C in Central Mongolia, and 0.3°C. in Eastern Mongolia. Longer records produced by the MATRIP studies show increasing temperatures over the recent century and other low-frequency trends that are in agreement with other paleo-temperature records (e.g. Jacoby *et al.*, 1996; D'Arrigo *et al.*, 2000; D'Arrigo *et al.*, 2001).

As noted above, in addition to using samples from living trees, we have increased the length of the tree-ring record by cross-dating and including wood samples from dead relict trees. At the location in the Mt. Tarvagatai we collected many pieces of relict wood along with cores from the old-aged living Siberian pine trees. The resulting chronology extends back to 262 AD (Fig. 2), and is described by D'Arrigo *et al.* (2001). Replication is one of the essential requirements for confirming dendroclimatic records. We included three other high elevation tree-ring records from our sites in Mongolia and, using principal component analysis (PCA) (Cook & Kairiukstis, 1990), generated a time series based on the first eigenvector of the four tree-ring series. This series was compared statistically and graphically (Fig. 3) with two other proxy temperature series (D'Arrigo *et al.*, 2000). The low frequency trends in the Mongolian time series correspond very well graphically with the other two series and the correlations are 0.67 and 0.47 with a Northern Hemisphere temperature reconstruction (modified from Jacoby & D'Arrigo, 1989; Jacoby *et al.*, 1999) and one described by Mann *et al.* (1999), respectively.

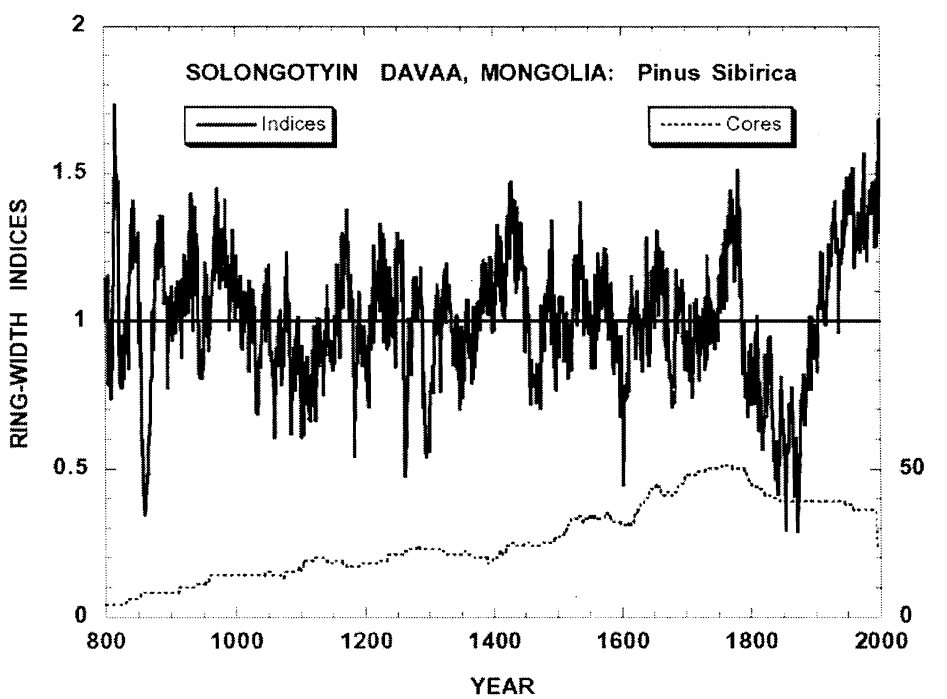


Fig. 2: Plot of the ring-width indices from the Solongotyn Davaa site. The sample size before 800 AD is small and variations may be less representative.

Precipitation and Streamflow. Significant recent changes in precipitation and streamflow have

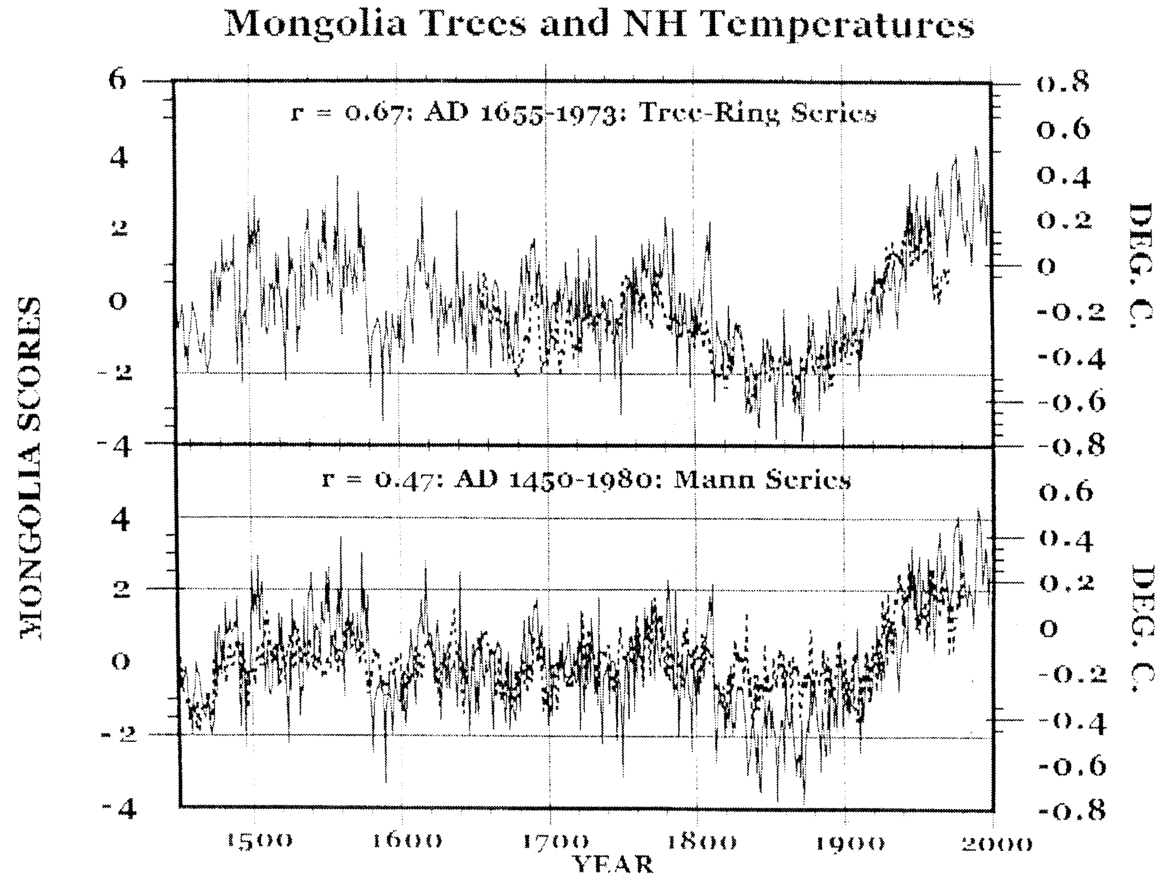


Fig. 3. Plots of the first eigenvector from four temperature sensitive, tree-line sites (solid lines) with two Northern Hemisphere temperature reconstructions (dashed lines)

occurred for Central Mongolia. The recorded data from 1940 to present shows an increase in total annual precipitation, compatible with precipitation trends estimated by GCMs. Two of the ring-width chronologies from moisture-sensitive, lower forest border sites were used to make reconstructions of precipitation and streamflow (other sampling data are not finalized). We developed monthly precipitation series for central Mongolia by combining data from eight precipitation gage stations. Missing values were estimated using data from the next nearest station. The combining of stations reduces the noise that may be present in a single station (Blasing *et al.*, 1981) and is more representative of the area being studied. The streamflow data are from one station, Kherlen River, near the city Choibalsan (Fig. 1, "CH").

The associated drainage basin includes the Urgun Nars tree-ring site and the Zuun Mod site is just outside the western edge of the basin. In the recorded data, the drought of 1944 was the most severe and there is a general trend upward since then until the past three years. This year is also the most extensive drought of the 20th century in the record reconstructed from historical information by Mijiddorj & Namhai (1993). The tree-ring data from Urgun Nars (Fig. 1, #10) in east central Mongolia had the highest variance explained by monthly precipitation data. The sampled species is Scots pine (*Pinus sylvestris*). Using the data from January of the prior year through October of the current or growth year, precipitation could explain 58% of the tree-ring variation using the 1941-1995 period. The standard chronology from ARSTAN (Cook 1985) was used in the modeling. Correlations with monthly precipitation indicated a positive response to mid-summer through fall precipitation of the prior year and to spring and summer of the current year. Results were similar for the other moisture-stress tree-ring data from a location called Zuun Mod (Fig. 1, #8) in central Mongolia. The trees at Zuun Mod are Siberian larch. The variance explained by the precipitation data is 46 % for the same 1941-1995 period. Merging of the two series

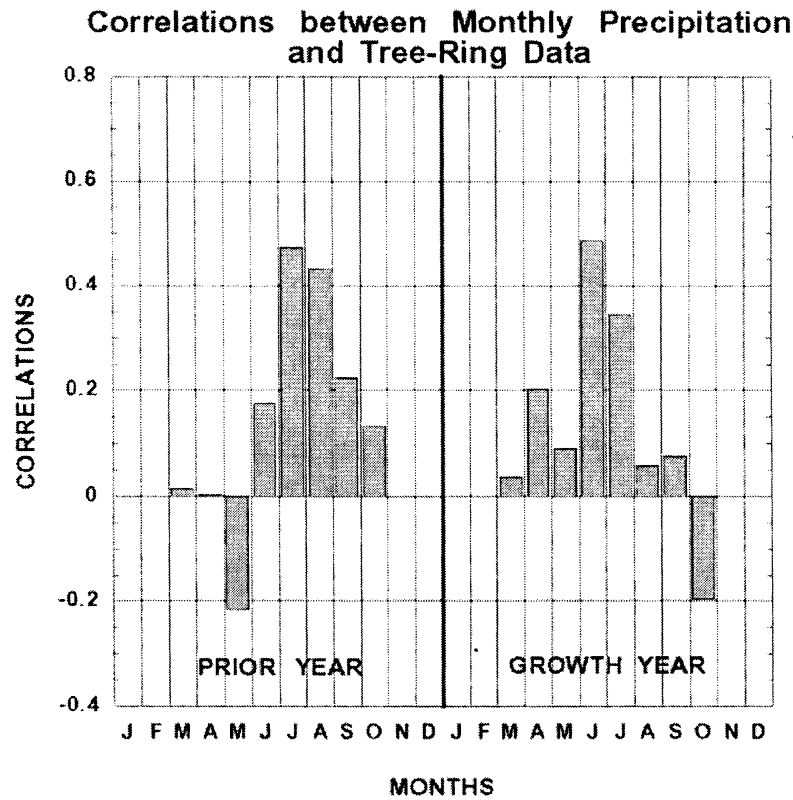


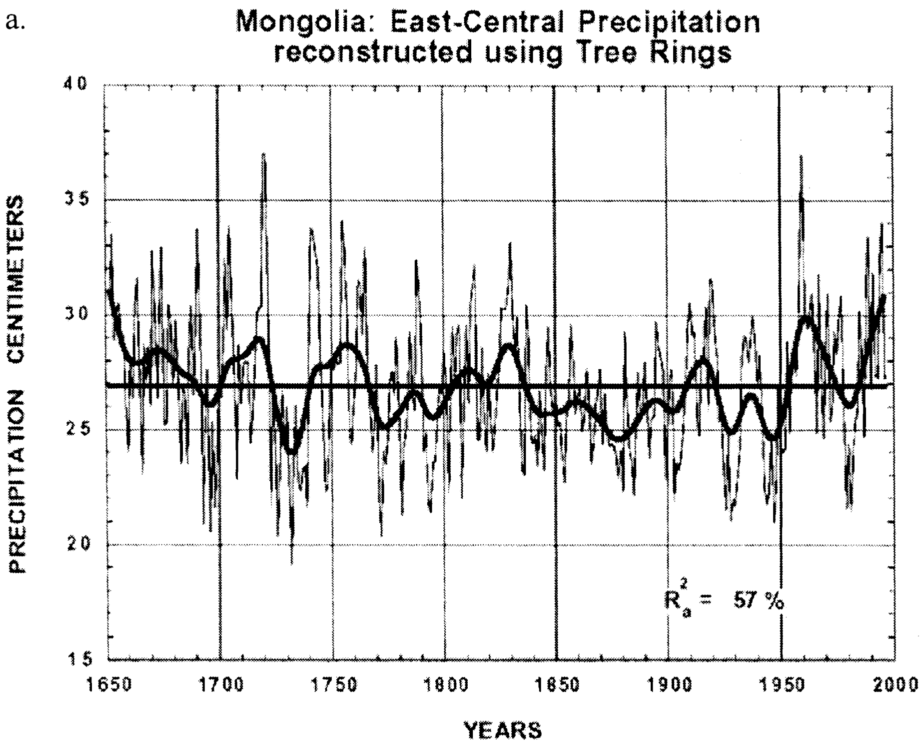
Fig. 4. Correlations between monthly mean temperatures and the first eigenvector from two moisture stress sites in Mongolia

by principal component analysis (PCA) produces a single series that has 61% of its variance explained by the precipitation data. This first eigenvector series was then used as the predictor for precipitation and streamflow.

The annual precipitation for a year extending from prior July to current June was estimated using the first eigenvector as a predictor. The model included ring-width indices for the current year and for the following year because the correlations indicated the effect of prior year precipitation on the next year's growth (Fig. 4). The model explained 57% (R2 after adjusting for degrees of freedom lost due to the regression) of the variation in annual precipitation for the July through June period. Due to the shortness of the meteorological record, calibration-verification analyses were not performed. The reconstruction is shown in Fig. 5a.

The Kherlen river streamflow near Choibalsan city also shows good correlations with the tree-ring data (Fig. 1, "CH"). There is a seasonal shift towards higher correlations later in the year compared to the precipitation results. Much of this shift may be due to the lag between precipitation in the central mountains and the streamflow measured in the East. Based on the individual monthly correlations, models were made for annual flow from prior August through current July and summer flow from April through August of the growth year. The best models used only the first eigenvector to estimate the annual flow. Adding in lagged tree-ring data did not improve the models as it did for the precipitation reconstruction. The tree-ring data explained 51.2 % of the variance for annual streamflow and 38.6 % for summer flow. The annual flow reconstruction is shown in Fig. 5b.

Both the precipitation and streamflow reconstructions are in agreement in the 1920s when both tree-ring reconstructions and the historical reconstruction show severe drought (Mijiddorj & Namhai, 1993). The reconstructions show a mild drought in the 1820s but not as severe a drought as that shown in the historical reconstruction in the 1820s, especially 1827. The tree-ring reconstruction is for central and east central Mongolia whereas the historical reconstruction is for all Mongolia. Therefore some of the differences may be due to different geographical coverage. Our most recent sampling also indicates much spatial variation in precipitation in Mongolia. More tree-ring a.



b.

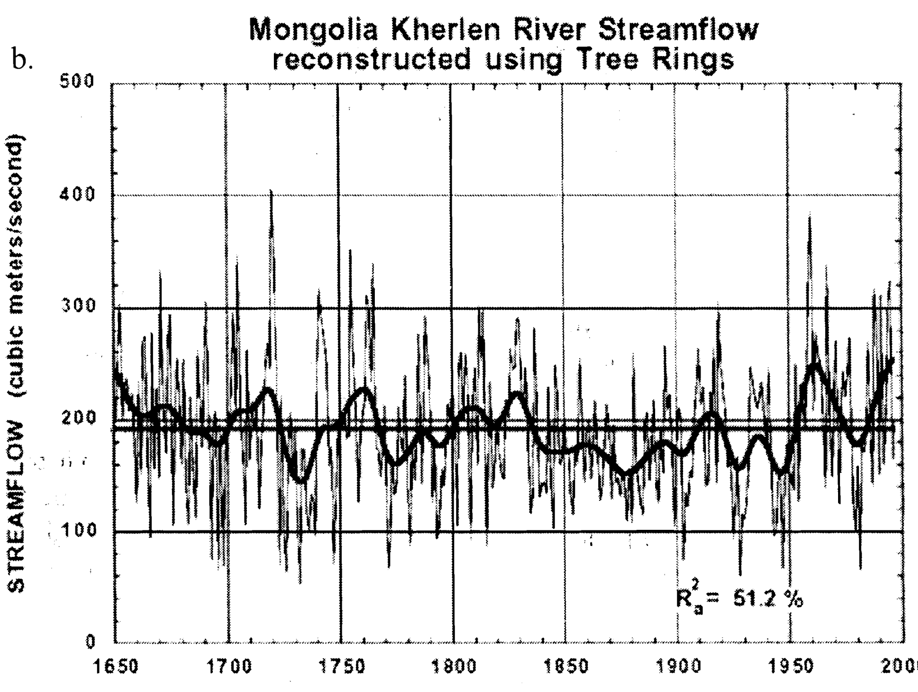


Fig. 5. a (top) Reconstruction of precipitation in east-central Mongolia and b (bottom) Reconstruction of streamflow at the Kherlen River gaging station

reconstructions are needed before full comparisons can be made.

Spectral Analyses. Some earlier studies indicated quasi-solar periodicities in Mongolian tree-ring data (e.g. Lovelius *et al.*, 1992) and drought (Mijiddorj & Namhai, 1993). Our analyses indicate that periodicities are very dependent on the tree response to climate. Temperature-sensitive trees as represented by the Sol Dav site trees have very weak periodicities. The trees from moisture sensitive sites show much more spectral power, indicating periodicities in the solar ranges (23.8-20.3, 12.8, 10.8-year range) and 3.6-2.1-year ranges (Pederson *et al.*, 2001). The quasi-solar periodicities in moisture-stressed trees and in drought occur in analyses of tree-ring data and drought in the coterminous United States of America (Cook *et al.*, 1997), and were previously proposed by Douglass (1919). Quasi-solar periodicities attract much discussion for two reasons. It indicates a response to solar activity and it confers some predictability of drought occurrence. The periodicity also attracts much criticism because a full mechanism is yet to be presented for the quasi-solar influence, although there are a few theoretical mechanisms (Hoyt & Schatten, 1997; Shindell *et al.*, 1999). All the spectral properties of the Mongolian tree-ring series warrant further investigation and interpretation beyond the scope of this paper.

Second Four-year Research Program

Beginning activities. As the first 4-year grant for MATRIP ended, a second 4- year grant was applied for and funded by the Paleoclimate Program of the US National Science Foundation. This new financial support allowed continued research and teaching beginning in 2001. Trees at several new locations were sampled for precipitation studies and two locations that had been sampled earlier were updated. In 2001 a series of lectures were presented at the Faculty of Biology, NUM and individual instruction was given to several students in tree-ring methods and data processing and analyses.

In 2002 two instructors and 5 students went into the Khentii Mountains, near Ulaanbaatar for instruction and experience in field methods and sampling. One objective was to obtain temperature-sensitive tree samples from upper elevation tree-line. Surveys were made of different areas and one location was sampled intensively for both living trees and relict wood samples. Living trees of up to 750 years in age were found. The eastern Mongolia regions were visited, and 2 locations were sampled near Bayankhongor in west-central Mongolia. These most recent samples will be processed in Lamont Tree-ring Laboratory and Department of Forestry, NUM during the winter of 2002-2003.

Future MATRIP Research

We expect the MATRIP efforts to continue into the future and the level of tree-ring research at NUM to increase in the next years. A Cooperative Agreement was signed in July of 2002 between the Lamont Tree-Ring Laboratory and the Faculty of Biology, NUM. The third MATRIP scholarship was awarded and it is anticipated that there will be three more awards. There are many geographic regions of Mongolia where tree-ring research can make important contribution to knowledge of the natural environment. There are other applications in addition to dendroclimatology (forest inventory, silviculture, fire ecology, dating of historical and archaeological wood objects etc.) where tree-ring analysis can be useful.

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