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Trends in extreme daily precipitation and temperature near Lake Hövsgöl, Mongolia

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Abstract:

A long-term (1963–2002) set of daily maximum and minimum temperature and precipitation data are analyzed for the Hövsgöl Basin area, Mongolia. Six indices of extreme temperature and eight indices of extreme precipitation are examined. Results suggest that climate conditions over northern Mongolia are changing as indicated by a warming trend identified during the study period. Significant increases are detected in the annual number of hot days and warm nights in this region. Associated with these changes are concomitant decreases in the annual number of cold days and cold nights. The number of days with precipitation has increased slightly while the annual total precipitation has not significantly increased in northern Mongolia. On an average, there was no significant decrease in the maximum number of consecutive dry days or increase in the wet days. The 5-day precipitation total showed a small increase. Copyright © 2006 Royal Meteorological Society

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1. INTRODUCTION

The Mongolian territory is landlocked and surrounded by high mountains in the north and southwest, and located in the transition zone between the great Siberian taiga and the Central Asian desert, which belongs to the central parts of the Eurasian continent. Taiga is a region of boreal forest, the largely evergreen forest vegetation of northern areas of the Northern Hemisphere, south of the arctic and subarctic tundra regions (Morris, 1992). Traditional Mongolian animal husbandry is closely associated with a nomadic pastoralism with seasonal migrations dependent on natural climate conditions (Natsagdorj and Sarantuya, 2004).

Mongolia has reason to be concerned about climate change; northern Mongolia has already warmed by almost 1.8 °C over the last 40 years (Nandintsetseg and Goulden, 2003). There has been even greater warming in other high-latitude locations such as Siberia and Alaska, especially in the winter and early spring (Hansen *et al.*, 1999). Mongolia's population depends on nomadic pastoralism and other climate dependent sectors; thus, environment and climatic conditions play a key role in the sustainable development of the country. For example, climatic variability appears to be the major driving factor for livestock dynamics in Mongolia (Barfield, 1993). The rising temperature and uncertainties in precipitation intensity and duration associated with a changing climate are likely to increase the impact of climate variability and extremes. Mongolia's livestock are raised in open pastures that directly depend on climatic conditions year round. Different kinds of natural hazards such as drought, flood, hard winters, land degradation, desertification, strong winds and sand storms, and steppe and forest fires that may be directly or indirectly related with recent climate warming in someway, have a major influence on pasture conditions. Increased interest in exploiting natural resources is also affecting ecosystem conditions of Mongolia's pastureland (Erdenetuya, 2004).

Extreme climatic events in Mongolia can cause serious damage not only to the livestock sector but also to the national economy (Batima *et al.*, 2005). A dzud is a Mongolian term for extreme weather conditions associated with a harsh winter, including dust storms or blizzards. Blizzards typically happen once or twice a year; people are killed every year in these storms. In addition, the ground can become frozen so hard that animals cannot graze and water cannot be easily extracted. Although Mongolia is a country with a continental climate and low precipitation, occasionally intense snowfalls can cause herd animals to drown in the snow. A dzud's impact depends on the interaction of the climatic episode, the physical condition of livestock, and other socioeconomic factors. The condition of livestock is affected by a number of factors, including conditions of summer pastures in some areas and inadequate winter fodder preparation. These are the most common

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indirectly contributing causes of livestock losses during winter. In addition to its economic impact, there are also significant human repercussions of dzuds. These include increased malnutrition, greater morbidity and mortality among vulnerable groups, and school absenteeism. Examples of extreme dzuds can be found when examining the winters of 1999–2000 and 2000–2001. The 1999–2000 dzud affected 450 000 herder family members (one-fifth of the total population) directly and killed about 3 million animals–approximately 10% of all livestock, with most deaths occurring in the spring, when animals were at their weakest, before pastures could regenerate (Asian Development Bank Report, 2005). The loss of livestock exceeded 10 million animals in a 3-year-period of dzuds between 1999 and 2002, and more than 12 000 families were left without livestock (Natsagdorj *et al*., 2004). In addition to the dzud and its impacts described above, Mongolia is also prone to experience other types of severe weather. For example, frequent severe droughts can occur during the summer months. Extreme heat, with record temperatures of up to 60 °C at ground level, have affected hay and crop production and caused serious forest fires.

Thus, as illustrated earlier, Mongolia is extremely vulnerable to climatic extremes and variability. Therefore, in addition to the long-term trends identified and described by the IPCC (2001) and others, there is also the need to examine trends not only in the mean, but also their variability and extreme events. For example, Karl *et al.* (1999) have assessed changes in climate extremes over many parts of the world during the past century. They reported a reduction in the number of extremely cold days, and an increase in the number of extremely hot days. Extreme precipitation events have increased in the United States, China, Australia, Canada, Norway, Mexico, Poland, and Russia (Groisman *et al*., 1999). Klein Tank *et al.* (2006) found that temperature and precipitation extremes have increased for Central and South Asia. They found that the trends in maximum temperature extremes are smaller than the trends in minimum temperature extremes. Climate extremes are receiving increased attention, because the impacts of climate change are felt most strongly through changes in the extremes (Klein Tank *et al.* (2006). Yan *et al.* (2002) found a gradual reduction of the number of cold days in China over the twentieth century and an increase in the number of warm days since 1961. In the study of Liu *et al.* (2005), about two-thirds of all time series for 1961–2000 exhibit increasing trends in indices of precipitation extremes; additionally, coherent regions with increases and decreases are found.

Systematic meteorological observations began in Mongolia in the early 1940s. Although the potential impact of climatic variability is significant, there is little recorded or published information on the historical climate of Mongolia (Batima *et al*., 2005). Only a few spot points on short period extremes have been recorded in the literature (Tsedevsuren, 1983). Thus, the motivation for this paper is to develop an assessment of the long-term records in Mongolia to examine the nature of the recent changes, if any, in climatic extremes.

2. STUDY AREA (OVERVIEW OF MONGOLIA'S CLIMATE)

Mongolia's climate is characterized by long and cold winters, dry and hot summers, low precipitation, high temperature fluctuations, and a relatively high number of sunny days (an average of 260) per year. Accordingly, there are not only four sharply distinct seasons, but also quite distinctive months within each of them. The annual average air temperature for Mongolia is 0.7 °C. It is +8.5 °C in the warmest regions of the Gobi and south Altai deserts, and −7.8 °C in the coldest region of the Darkhad depression for the 1961–2001 period. The country is semiarid to arid. Precipitation varies both in time and space. Annual mean precipitation is 300–400 mm in the Khangai, Khentein, and Hövsgöl mountainous regions; 150–250 mm in the steppe; 100–150 mm in the steppe-desert; and 50–100 mm in the Gobi desert. About 85% of total precipitation falls from April to September, of which about 50–60% falls in July and August for the 1961–2001 periods.

The average air temperature has significantly increased by 1.66 °C for the last 60 years, with clear warming from the beginning of the 1970s intensifying toward the end of the 1980s. The warming has been most pronounced in winter, with a mean temperature increase of 3.6 °C. Seasonally, winter and spring precipitation has decreased slightly, while there has been no change in summer and autumn precipitation, but none of these trends is statistically significant (Batima *et al*., 2005).

The purpose of this paper is to discuss changes in extreme climatic events in the vicinity of Lake Hövsgöl in northern Mongolia. This area, as part of northern Eurasia, has been undergoing rapid warming during the past several decades (IPCC, 1992, 1995). The Hövsgöl region is located in the transition zone between the Siberian taiga, the Steppe, and the Central Asian Desert. The steppe biome is a dry, cold, grassland that is found in all of the continents except Australia and Antarctica. It is mostly found in the United States, Mongolia, Siberia, Tibet, and China. Humidity is typically low because Steppes are located away from the ocean and close to mountain barriers (Benders-Hyde *et al*., 2000).

2.1. Station selection

Data sets from four meteorological monitoring stations around Lake Hövsgöl have been selected. The Hövsgöl graben extends southward from the Eastern Sayan Mountains. A graben is a depressed block of land bordered by parallel faults. Lake Hövsgöl lies between 50°30′ and 51°35′ North, and 100°15′ and 100°40′ East at 1645 m a.s.l. in northern Mongolia near the border with Russia. The complete watershed of the lake has been protected within Hövsgöl National Park since 1994 (Figure 1).

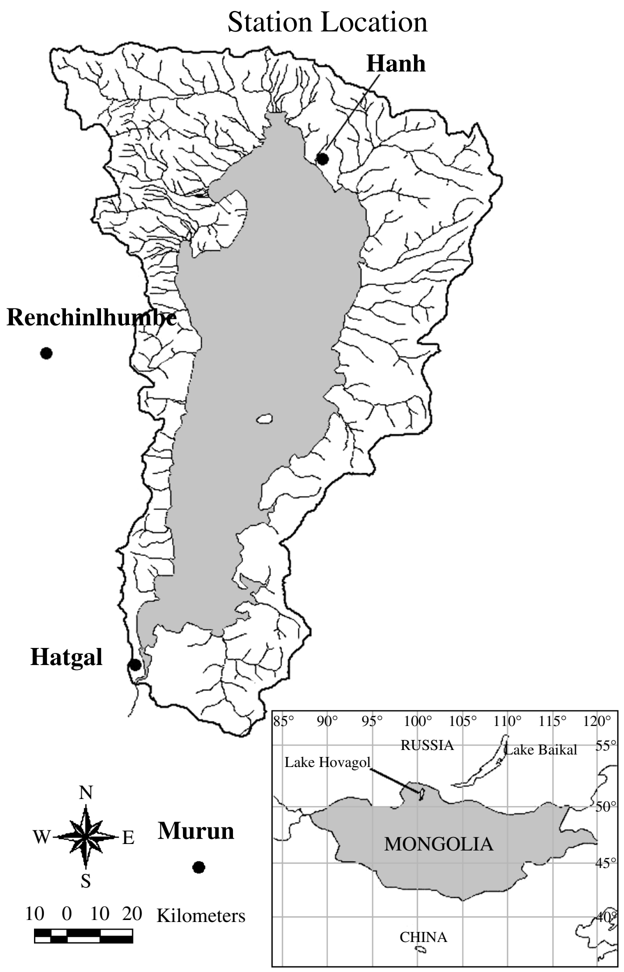

Figure 1. Station location and outline of Lake Hövsgöl, Mongolia with tributary streams (Map courtesy of W. C. Hession).

The Hövsgöl Basin has a harsh continental climate with sharply defined seasons and with large annual and diurnal temperature fluctuations. The average air temperature ranges from 12 °C in July to −21 °C in January, with an absolute maximum of 35 °C and absolute minimum of −49 °C for the 1963–2002 period. Winter temperature inversions are strong in the large valley systems but these are of less importance close to the lake (Kozhova *et al.*, 1989). Mean annual air temperature recorded at the nearest climate station at Hatgal (southern shore of Hövsgöl) is −4.5 °C between 1963 and 2002. The area is semiarid, with precipitation occurring mainly in summer months with a peak of approximately 100 mm in July. At Hövsgöl Lake, the mean annual precipitation is 300 mm, increasing to 550 mm in the high mountains for the 1963–2002 period. As mentioned in the preceding text, there has been an increase in temperature over the last 40 years of 1.8 °C (1963–2002, Hatgal Meteorological Station data). In addition to the analysis of the Hatgal data, comparable trends in temperature changes, extreme daily temperature and precipitation have been analyzed from three other northern Mongolian meteorological monitoring stations, Hanh (north end of the lake), Renchinlhumbe (70-km west of the lake) and Murun (100-km south of the lake).

3. DATA ANALYSIS METHODS

This study uses daily maximum and minimum temperature and precipitation data from the Clicom (Climate computing) database, which has been obtained from the Mongolian Institute of Meteorology and Hydrology. These data are available from 1963 to 2002. The data have undergone a series of data quality evaluation procedures from the Mongolian Meteorological Institute. Data quality control or assurance refers to attempts by data processing personnel to minimize errors and possibly remove mistakes from an observation data set. While the actual quality control may use numerical formula or visual inspections of graphs, at the core of most techniques are some basic statistical relationships. The relationships fall mainly into three categories: (1) Relationship of data elements to themselves (e.g. outliers to long-term means), (2) Relationships to nearby data (e.g. neighbor checks), (3) Relationships to some other data parameter (Richard and Masika, 2002).

Quality control procedures include periodic instrument calibrations, site checks, data examination for reasonableness, and data validation. We are using 39 years of meteorological data between January 1963 and December 2002 from four stations.

From the internationally agreed WMO–CCL/CLIVAR list of over 50 climate change indices (Peterson *et al.*, 2001; Nicholls and Murray, 1999), a set of 14 indices of climate extremes were selected (Table I). Of this set, six indices refer to temperature and eight indices to precipitation. The temperature indices describe cold extremes as well as warm extremes. The precipitation indices describe wet extremes. Extreme climate indices for this study are based on the 1st and 99th percentiles. As there are 365 days in a year, the 1st percentile is the 4th lowest value, and the 99th percentile is the 4th highest.

4. EXTREME PRECIPITATION AND TEMPERATURE TRENDS

4.1. *Trends in temperature extremes*

Climate conditions of northern Mongolia are changing as indicated by a long-term warming trend during the last 40 years. In winter, warming has been greatest over the midlatitude Northern Hemisphere continents, including Mongolia (IPCC, 2001). Changes in climate variability and extremes of weather and climate events have received increased attention in the last few years. Understanding changes in climate variability and climate extremes is made difficult by interactions between the changes in the mean and variability (Meehl *et al.*, 2000).

Mean daily maximum and minimum temperatures have been calculated for each year of the period 1963–2002 at four stations. Time series of the annual mean maximum and minimum temperatures are shown and averaged

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Table I. Definitions of the indices of temperature and precipitation extremes.

Indices of cold temperature extremes	
Cold nights	Frequency of days with minimum temperature below 1963–2002 mean 1st percentile
Cold days	Frequency of days with maximum temperature below 1963–2002 mean 1st percentile
Frost days	Frequency of days with minimum temperature below 0 °C
Indices of warm temperature extremes	
Hot days	Frequency of days with maximum temperature above 1963–2002 mean 99th percentile
Warm nights	Frequency of days with minimum temperature above 1963–2002 mean 99th percentile
Summer days	Frequency of days with maximum temperature above 25 °C
Indices of precipitation extremes	
Precipitation days	Frequency of days with at least 2 mm of precipitation
Extreme frequency	Frequency of daily rainfall exceeding the 1963–2002 mean 99th percentiles
Extreme intensity	Average intensity of events greater than or equal to the 99th percentile each year, i.e. in the four wettest events
Extreme proportion	Percentage of annual total rainfall from events greater than or equal to the 99th percentile, i.e. received in the four wettest events
Heavy precipitation days	Frequency of days with precipitation amount $\geq$10 mm
Consecutive wet days	Greatest number of consecutive days $\geq$1 mm
Consecutive dry days	Greatest number of consecutive days $\leq$1 mm
Highest 5-day precipitation amount	Greatest precipitation sum for 5-day interval

over all four stations in Figures 2 and 3 respectively. The maximum temperature has significantly increased by 1.8 °C and the minimum temperature by 1.95 °C, since 1963.

Figures 4 and 5 show that the 1963–2002 time series in the indices of frost days ($p < 0.05$) and summer days ($p < 0.05$) both indicate significant warming. The result for northern Mongolia average annual number of frost days shows a decrease in approximately 12 per year by the end of the study period. For 'summer days', the change is five per year (recall that 'summer days' refers to frequency of days with maximum temperature above 25 °C). Consequently, averaged over northern Mongolia, there are 12 fewer frost days. However, in 2002, the warmest year on record, there were actually 18 more summer days.

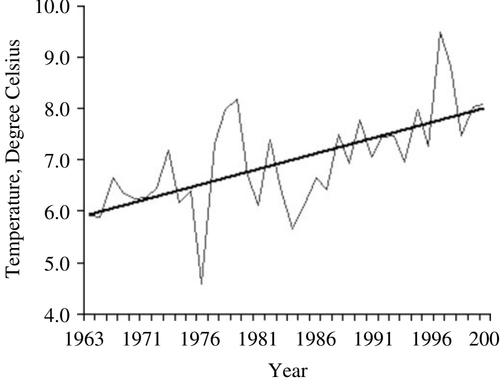

Figure 2. Time series of mean maximum temperature, 1963–2002. Linear trend is shown by the regression line.

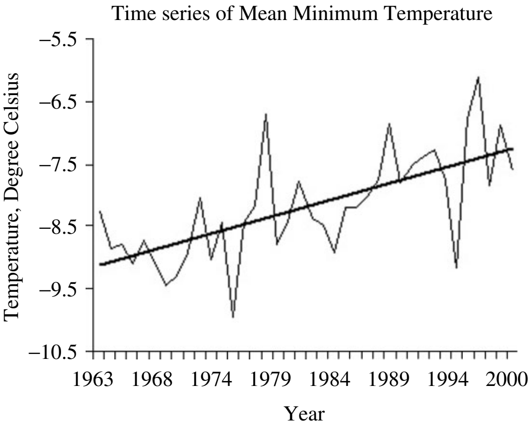

Figure 3. Time series of mean minimum temperature, 1963–2002. Linear trend is also shown by the regression line.

Time series of the average frequency of days with minimum temperature below the 1st percentile and above 99th percentile are calculated. These indices provide a guide to the areas experiencing unusually frequent warm maximum temperatures or cold minimum temperatures (Nicholls and Murray, 1999). The number of days above the 99th percentile or below the 1st percentile are calculated on the high-quality 1963–2002 daily temperature data set. The 1963–2002 station trends in the annual number of hot days and warm nights significantly increased, whereas the frequency of cold days and cold nights significantly declined. While much of the world reports greater warming in mean monthly minimum temperature than in the mean maximum temperature (Easterling *et al*., 1997),

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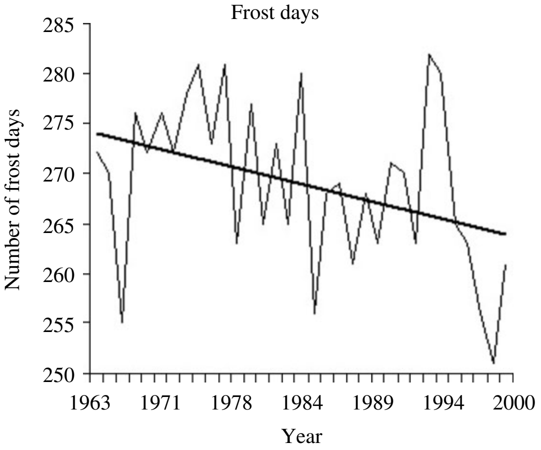

Figure 4. Frequency of days with minimum temperature below 0 °C. The trend-line is computed by linear regression.

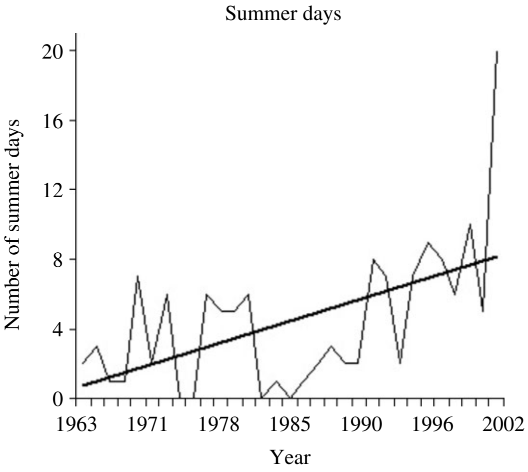

Figure 5. Frequency of days with maximum temperature above 25 °C. The trend-line is computed by linear regression.

the northern Mongolia changes in maximum and minimum temperature extremes correspond closely to each other.

The time series of these regional average indices are given in Figure 6. This figure shows the decline in the number of cold days and cold nights, and the increase in the number of hot days and warm nights through the 1963–2002 period. Note that there was a substantial increase in the number of hot days and warm nights across the region in the last year examined (2002), coinciding with the globe's warmest year in the period of instrumental records. The number of cold nights and cold days have been reduced by 4–6 days, respectively, and the number of hot days and warm nights increased by 5–7 days for the 1963–2002 period.

4.2. Trends in precipitation extremes

Total annual precipitation averages approximately 300 mm with most of the precipitation falling in midsummer. Wintertime precipitation is mostly snow but on south-facing slopes tends to sublimate. Analysis shows that there is a general pattern where wet and dry years alternate with one heavy rain year typically followed by 2–3 dry years. Annual precipitation changes show a slight increase from 1963 to 2002 around the Hövsgöl

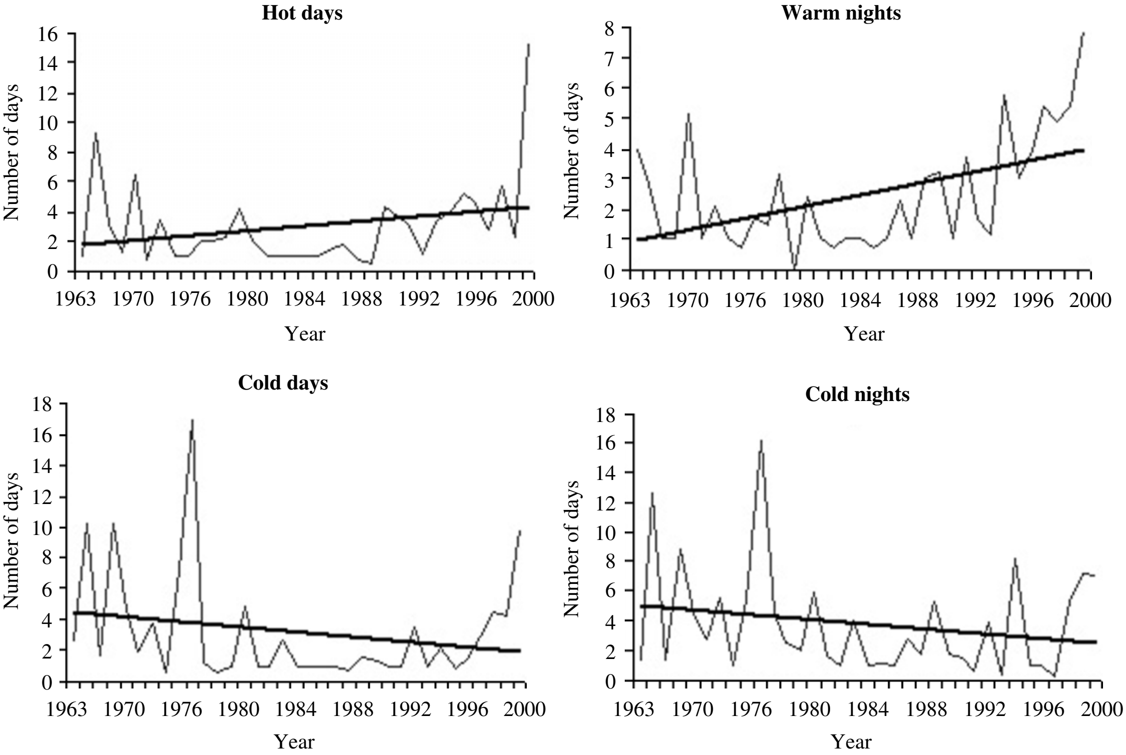

Figure 6. Time series of the regional averages of the frequency of hot and cold days, warm and cold nights. The trend-line is computed by linear regression.

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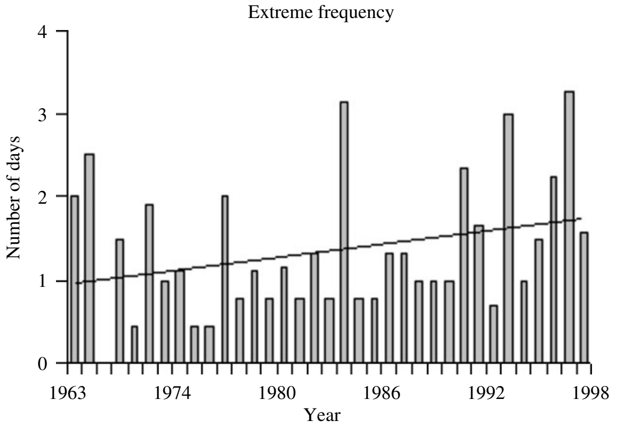

Figure 7. Mean percent of the total annual precipitation coming from events greater than or equal to the 99th percentile of daily precipitation. The trend-line is computed by linear regression.

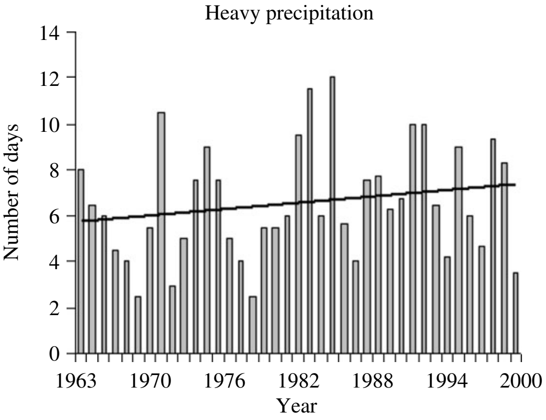

Figure 8. Time series of heavy precipitation (frequency of days with precipitation amount >10 mm). The trend-line is computed by linear regression.

Basin. The number of precipitation days (with at least 2 mm of precipitation) has not significantly increased in the Hövsgöl Basin area during the last 40 years.

The extreme frequency, intensity and proportion are calculated for the daily precipitation. Examination of extreme precipitation indicates that heavy precipitation increases where precipitation increases and decreases where precipitation decreases (Groisman *et al.*, 1999). One measure of extreme precipitation is the percentage of total because of events above the 99th percentile. Examination of Figure 7 indicates the frequency of extreme precipitation events to be increasing, but the regression slope is not significant.

There has been a weak decline in the average intensity of the highest four precipitation events each year in the Hövsgöl Basin. The proportion of annual precipitation from extreme events also shows a modest increase. The number of days with precipitation greater than or equal to 10 mm shows a weak upward trend in northern Mongolia since 1963 (Figure 8).

Another measure of extreme precipitation is the greatest 5-day precipitation total. Often the heavy rains that induce flooding occur over the course of several days and should be captured by this index. The 5-day precipitation total is also increasing, but the trend-line is not statistically significant.

There was no statistically significant change in the maximum number of consecutive dry days. However, the maximum number of consecutive dry days tends to decrease in northern Mongolia, where annual mean precipitation has increased. The maximum number of consecutive wet days has not significantly increased in the area.

5. DISCUSSION AND CONCLUSIONS

As described above, any analysis of climate change needs to examine the details of the characteristics of the change. Specifically, since humans and the environment often respond to extremes rather than mean conditions, it is important to determine the variability or trends in a range of extreme values, rather than just mean conditions. This study, as part of a collaborative project between the Mongolian Academy of Sciences and The Academy of Natural Sciences, Philadelphia, has examined such meteorological trends in an environmentally sensitive area in northern Mongolia. This type of extreme-event trend analysis has not previously been investigated for northern Mongolia. The climate of the Hövsgöl region, northern Mongolia is warming. Warming is most pronounced in the high mountainous area and their valleys. The mean maximum and minimum temperatures have significantly increased almost 2 °C between 1963 and 2002 in the area. Mongolia's livestock are raised in open pastures that directly depend on climate condition year round. Natural events such as drought and severe winter are serious extreme events in Mongolia that cause high damage not only to the livestock sector but also to the national economy (Batima *et al.*, 2005).

This study shows that in this area there have been significant decreases in the frequency of cold extremes and increases in the frequency of hot extremes. In the southern part of the Lake Hövsgöl region, for example, warm nights are increasing faster, but the frequency of cold extremes has decreased faster in the Murun area. Maximum peaks in the frequency of hot days and warm nights in 2002 were reported at the stations. There has been a pronounced increase in warm extremes rather than a decrease in cold extremes.

The frequency of extreme precipitation events has shown a weak increase, one change that may be an important environmental impact is the upward trend in the 5-day precipitation accumulations. This would suggest an enhancement of the overall hydrologic cycle in the region, which could have significant impacts (in terms of flooding, water availability, etc.) on the local environment.

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REFERENCES

Asian Development Bank Report (ADB). 2005. *Mongolia: Country Environmental Analysis*. Printed in the Philippines: Publication Stock No. 100405. http://www.adb.org/Documents/Studies/Ctry-Environmental-Analysis/2005/MON/default.asp.

Barfield TJ. 1993. *The Nomadic Alternative*. Prentice Hall: New Jersey, NJ.

Benders-Hyde E, Nelson Ann, Nelson Karl. 2000. *Blue planet biomes. West Tisbury School*. http://www.blueplanetbiomes.org.

Batima P, Natsagdorj L, Gomboluudev P, Erdenetsetseg B. 2005. Observed climate change in Mongolia. *AIACC Working Paper* **13**: 4–25.

Easterling DR, Horton B, Jones PD, Peterson TC, Karl TR, Parker DE, Salinger MJ, Razuvayev V, Plummer N, Jamason P, Folland CK. 1997. Maximum and minimum temperature trends for the globe. *Science* **277**: 364–367.

Erdenetuya M. 2004. Pasture productivity changes in Mongolia. Map Asia 2004. Beijing, China.

Groisman P, Karl T, Easterling D, Knight R, Jamason P, Hennessy K, Suppiah R, Page C, Wibig J, Fortuniak K, Razuvaev V, Douglas A, Førland E, Zhai P. 1999. Changes in the probability of extreme precipitation: important indicators of climate change. *Climatic Change* **42**: 243–283.

Hansen J, Ruedy R, Glascoe J, Sato M. 1999. GISS analysis of surface temperature change. *Journal of Geophysical Research* **104**: 30 997–31 022.

IPCC. 1992. Climate change 1992. In *The Supplementary Report to the IPCC Scientific Assessment*, Houghton JT, Callander BA, Varney SK (eds). Cambridge University Press: Cambridge; 200.

IPCC. 1996a. Climate change 1995. *The science of climate change. Technical summary*, (eds) JT Houghton, LG Meira Filho, BA Callander, N Harris, A Kattenberg, K Maskell, Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge.

IPCC. 2001. In *Climate Change 2001: The Scientific Basis*, Houghton JT, Ding Y, Griggs DJ, Noguer M, van der Linden PJ, Dai X, Maskell K, Johnson CA (eds). Cambridge University Press: Cambridge; 881.

Karl TR, Nicholls N, Ghazi A. 1999. CLIVAR/GCOS/WMO: workshop on indices and indicators for climate extremes. *Climatic Change* **42**: 3–7.

Klein Tank AMG, Peterson TC, Quadir DA, Dorji S, Zou X, Tang H, Santhosh K, Joshi UR, Jaswal RK, Sikder A, Deshpande NR, Revadekar JV, Yeleuova K, Vandasheva S, Faleyeva M, Gomboluudev P, Budhathoki KP, Hussain A, Afzaal M, Chandrapala L, Anvar H, Amanmurad D, Asanova VS, Jones PD, New MG, Spektroman T. 2006. Changes in daily temperature and precipitation extremes in Central and South Asia. *Journal of Geophysical Research* **111**: D16105, DOI:10.1029/2005JD006316.

Kozhova OM, Shagdarsuren O, Dashdorzh A, Sodnom N. 1989. *Atlas of Lake Hövsgöl*. Cartographic Ministry of USSR: Moscow; 118, [In Russian].

Liu B, Xu M, Henderson M, Qi Y. 2005. Observed trends of precipitation amount, frequency, and intensity in China, 1960–2000. *Journal of Geophysical Research* **110**: D08103.

Meehl GA, Karl T, Easterling DR, Changnon S, Pielke R Jr, Changon D, Evans J, Groisman PY, Knutson TR, Kunkel KE, Mearns LO, Parmesan C, Pulwarty R, Root T, Sylves TR, Whetton P, Zwiers F. 2000. An introduction to trends in extreme weather and climate events: Observations, socioeconomic impacts, terrestrial ecological impacts, and model projections. *Bulletin of the American Meteorological Society* **81**: 413–416.

Morris C. 1992. *Academic Press Dictionary of Science and Technology*. Academic Press: San Diego, CA.

Nandintsetseg B, Goulden CE. 2003. Climate and climate change study of the Lake Hövsgöl Basin Area. *Papers in Meteorology and Hydrology* **25**: 38–52.

Natsagdorj L. 2004. Evaluation of climatic factors leading to desertification in Mongolia. In NAMHEM Mongolia. *The Sixth International Workshop Proceedings on Climate Change in Arid and Semi-arid Regions of Asia*, 88–99.

Natsagdorj L, Sarantuya G. 2004. On the assessment and forecasting of winter-disaster (Atmosphere caused dzud) over Mongolia. In NAMHEM Mongolia. *The Sixth International Workshop Proceedings on Climate Change in Arid and Semi-arid Regions of Asia*, 71–87.

Nicholls N, Murray B. 1999. Workshop on indices and indicators for climate extremes: Asheville, NC, USA, 3–6 June 1997. Breakout Group B: Precipitation. *Climatic Change* **42**: 23–29.

Peterson TC, Folland C, Gruza G, Hogg W, Mokssit A, Plummer N. 2001. *Report on the Activities of the Working Group on Climate Change Detection and Related Rapporteurs 1998–2001*. International CLIVAR Project Office Southampton: UK; 143.

Richard S, Masika KMD. 2002. Data quality control methods. *Report of the climate information and prediction services (CLIPS)*: training workshop for eastern and southern Africa; 9–10.

Tsedevsuren D. 1983. *Study of Difficulties Caused by Meteorological Events in Central and Eastern Region*, Vol. 8, Publication of Institute of Meteorology and Hydrology: Ulaanbaatar.

Yan Z, Jones PD, Davies TD, Moberg A, Bergstrom H, Camuffo D, Cocheo C, Maugeri M, Demaree GR, Verhoeve T, Thoen E, Barriendos M, Rodriguez R, Martin-Vide J, Yang C. 2002. Trends of extreme temperature in Europe and China based on daily observations. *Climatic Change* **53**: 355–392.