OBSERVED CLIMATE CHANGE IN MONGOLIA

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OBSERVED CLIMATE CHANGE IN MONGOLIA[2]

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Abstracts

The paper discusses the observed seasonal and spatial changes of temperature and precipitation, as well as some climate extremes indices. Observations from 60 sites distributed across Mongolia have been used for the analysis. Results from a study on trend analysis show that the annual mean surface air temperature in Mongolia has risen by 1.66^{o}C, warming faster in Winter than in Summer, during the 1940-2001 period. Warming is more pronounced in the high mountainous areas and their valleys, and less in the Gobi desert. The STARDEX extremes indices software is used to calculate extreme indices, such as heat wave duration, cold wave duration, maximum number of consecutive dry days, and maximum number of consecutive wet days.

There has been a statistically insignificant decrease of annual precipitation. Spatially, annual mean precipitation has been decreasing in central Mongolia but increasing in both the eastern and western regions of the country. Seasonally, both Winter and Spring precipitation have decreased, while Summer and Autumn have registered no changes. The intense drought spells that have taken place in recent years are most likely due to increased temperature and decreased precipitation.

This study has been done within a study on “Potential impacts of climate change and vulnerability and adaptation assessment for grassland ecosystem and livestock sector in Mongolia”.

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Key words: temperature, precipitation, heat wave duration and cold wave duration.

Introduction

Mongolia is one of the largest landlocked countries in the world, extending between the latitudes of 41°35'N and 52°09'N and the longitudes of 87°44'E and 119°56'E and covering 1,564 square kilometers. The longest distance from west to east is 2,392 km, and from north to south 1,259 km. The average altitude is 1,580 meter above sea level. Administratively, Mongolia is divided into 21 *aimags*. *Aimags* are divided into *soums*, of which there are more than 330 (Figure 1).

Mongolia has reason to be concerned about climate change. The country's vast population depends on livestock and other climate-dependent sectors. The sub-sector of animal husbandry employs 47.9 per cent of the total population, produces 34.6 percent of agricultural gross production, and accounts for 30 percent of the country's export: clearly, animal husbandry plays a major role in the national economy. Rangeland ecosystems and pastoral systems are complex, with numerous interactions among the biotic components of the system and with human society. Any adverse impact of a changing climate on pasture availability would threaten forage yield, livestock productivity, and, ultimately, local and national food production capacity (NAPCC, 2000). Hence, environment and climate condition play a key role in the sustainable development of the country.

Climatic variability appears to be the major driving factor of livestock dynamics in Mongolia. The rising temperature and uncertainties in rainfall associated with global warming are likely to increase the frequency and magnitude of climate variability and extremes. On the other hand, changes in climate also increase the risk of unexpected changes in nature and environment. The greater the rate and magnitude of change, the greater the risk of negative impacts.

Observed climate parameters would certainly define the feedbacks sufficiently both to understand the key processes and to improve the focused research and measure progress. Therefore, our study aimed to analyze the observed seasonal and spatial changes in temperature, precipitation, and climate extremes indices, and to make the results available for climate change studies. Detailed analysis of past and present climate conditions will increase our confidence in our ability to usefully assess climate feedback processes like impact, vulnerability, and adaptation.

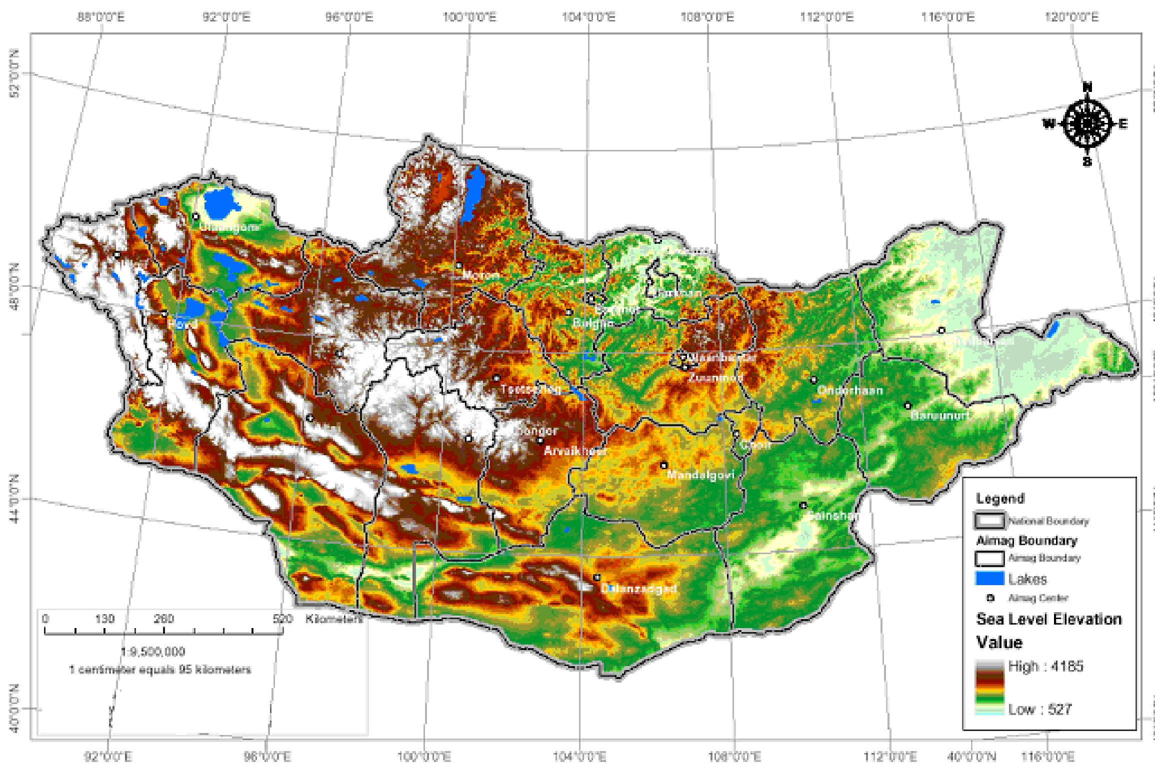

Figure 1. Geographic elevation map of Mongolia.

Data and methodologies

Data: We selected sixty meteo-stations (Figure 2), distributed evenly over the territory of Mongolia. Our main source of climatological data is The Clicom data base, which operates from the Institute of Meteorology and Hydrology. As well as daily data on air temperature, the Clicom database provides monthly and daily data concerning air temperature, sunshine duration, humidity, and soil moisture. These data are available from 1961 to 2002. For the trend analysis, monthly mean data have been extended back to 1940 from the paper archive data, in order to present changes for the greatest possible period. Snow cover data was available only for the 1971-2000.

Extremes indices like heat wave duration, cold wave duration, and maximum number of consecutive dry and wet days were calculated from the daily data for the 1961-2001 period at 25 meteo-stations (Figure 3).

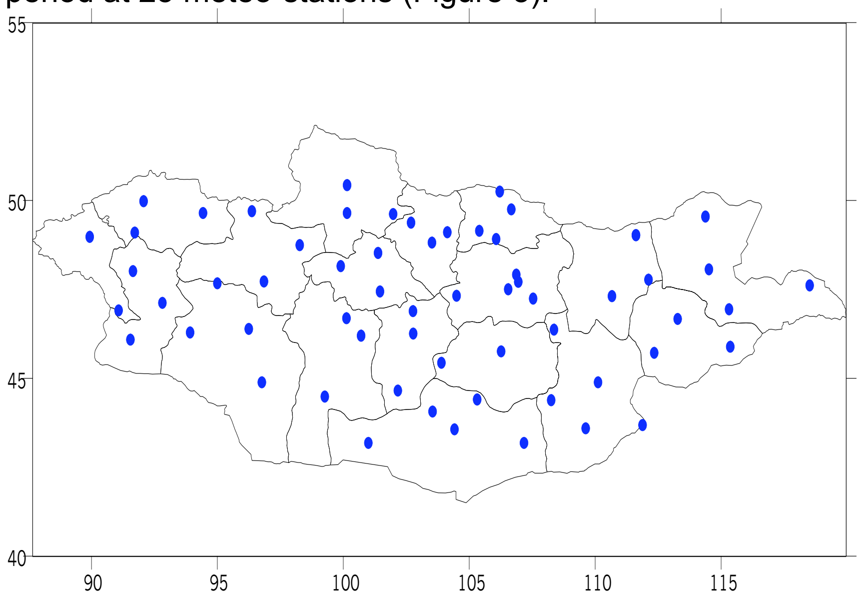

Figure 2. Locations of meteo-stations where trend analysis for temperature and precipitation have been conducted

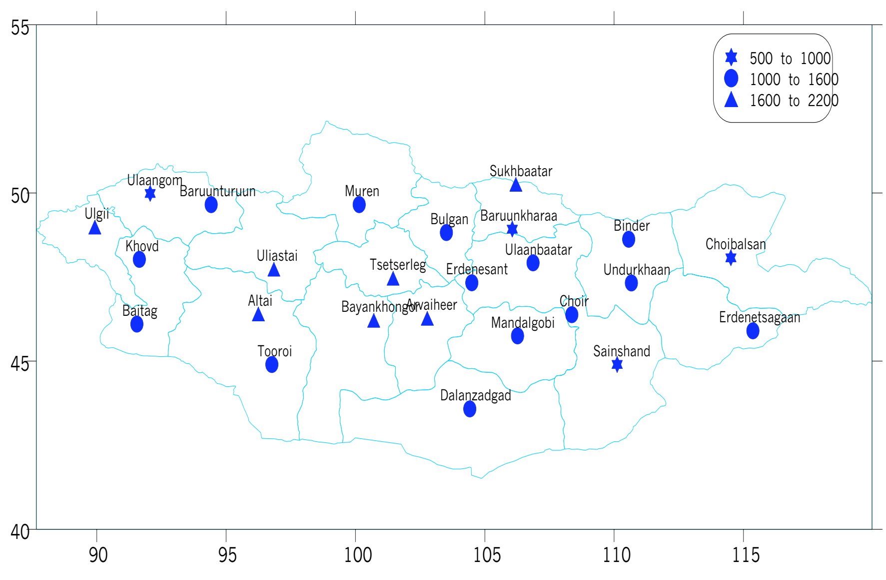

Figure 3. Locations of meteo-stations where Extremes indices have been calculated (✶ stations located at 500-1000 m above see level, ✸ stations located at 1000-1600 m above see level, ▲ stations located at 1600-2200 m above see level)

Methods: Linear regression (in some cases second order Polynomial) has been used to analyse the trends of the observed monthly mean data of temperature, precipitation, and extremes indices.

Since the different meteo-stations have different time series lengths, the normalized anomalies of temperature for the country have been calculated as:

$$D_T = \frac{1}{N}\sum_{i=1}^{N}\frac{\left(T_i - \overline{T}\right)}{\sigma_T}$$

where D_T is normalized temperature anomaly, Ti is the observed $\overline{T}$ temperature, [I assume there should be a character here] is mean temperature, N is number of meteo-stations, and _$_T$-is standard deviation.

The same equation has been used to calculate the country's normalized precipitation anomalies.

Extremes indices have been calculated using the STARDEX extremes indices software (Version 3.0). The methodology of calculating the indices is described in the web site: http://www.cru.uea.ac.uk/project/stardex. The STARDEX extremes indices software was developed from the program ClimateIndices, originally written at the US National Climatic Data Centre (NCDC) by Tom Peterson and Byron Gleason in 1999. The first version included about 20 climate indices, to which a further twenty were added by Malcolm Haylock from the Australian Bureau of Meteorology in 2000 on a visit to NCDC. After receiving the code from the European Climate Assessment (ECA), work for STARDEX was then undertaken by Colin Harpham of King's College London, and a further dozen indices were added relating to wet and dry spells. The code was then tidied and converted to a subroutine by Malcolm Haylock, now with the Climatic Research Unit. Finally, two further indices were added relating to cold-wave duration and no-defrost days.

The STARDEX extremes indices software comprises two elements: a Fortran subroutine ("extremes_indices") that calculates all the indices for a single location, and a program ("station_indices") that uses the above subroutine to process station data in a standard input format. All of the extremes indices are calculated in a single station. In the file indices.inc, users can set the start and end years (minyr=1950, maxyr=2002) for the analysis. Data outside of this period are ignored and do not have to exist over the entire period. There are several user-defined parameters that need to be set in the program before compiling. The parameters that we selected for our calculation are:

start year of base period for normals =1961
end year of base period for normals =2001
minimum rain for wet day classification ("wd_cutoff") =1.0

Heat Wave Duration is the number of days per period, in intervals of at least 6 consecutive days:

$$T_{xij} > T_{xinorm} + 5$$

T_{xij} is the daily maximum temperature at day i of period j, and T_{xinorm} is the calendar day mean, calculated for a 5-day window and centered on each calendar day during a specified period.

Cold Wave Duration is the number of days per period where, in intervals of at least 6 consecutive days,

$$T_{nij} < T_{n\ inorm} - 5$$

T_{nij} is the daily minimum temperature at day i of period j, and T_{ninorm} is the calendar day mean, calculated for a 5-day window and centered on each calendar day during a specified period.

Max no. consecutive dry days is the largest number of consecutive days where:

$$R_{ij} \leq \text{wd\_cutoff}$$

R_{ij} is the daily precipitation amount for day *i* of period j, and "wd_cutoff" is a user-specified variable.

Max no. consecutive wet days is the largest number of consecutive days where:

$$R_{ij} > \text{wd\_cutoff}$$

R_{ij} is the daily precipitation amount for day *i* of period j, and "wd_cutoff" is a user-specified variable.

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^oC. It is $+8.5^oC$ in the warmest regions of the Gobi and south Altai deserts, and -7.8^oC in the coldest region of the Darkhad depression.

January is the coldest month, with average temperatures of $–15^0C$ to $–35^0C$. Broken down by region, it is -30 to -34^0C in the valleys of the Altai, Khangai, Khuvsgul and Khentii mountains; -25 to -30^0C in the high mountainous area; -20 to -25^0C in the steppe; and –15 to -20^0C in the Gobi desert. The record low temperature of -56^0C was recorded at the Uvs lake depression on 31 December, 1972.

July is the warmest month. The average air temperature in July is lower than 15^0C in the Altai, Khangai, Khuvsgul and Khentii mountainous area; $15\text{-}20^0C$ in the valleys of mountainous area; and $20\text{-}25^0C$ in southern part of the Eastern steppe and the Gobi desert. The record high temperature is $+44^0C$, observed at Khongor *soum* of Darkhan-Uul *aimag* on 24 July, 1999.

Systematic meteorological observations began in the early 1940s. There is not much recorded or published information on historical climate of Mongolia. Only a few spot points on short period extremes have been recorded in history books (Dorjsuren, 1961, Tsevel, 1966, Tsedevsuren, 1983).

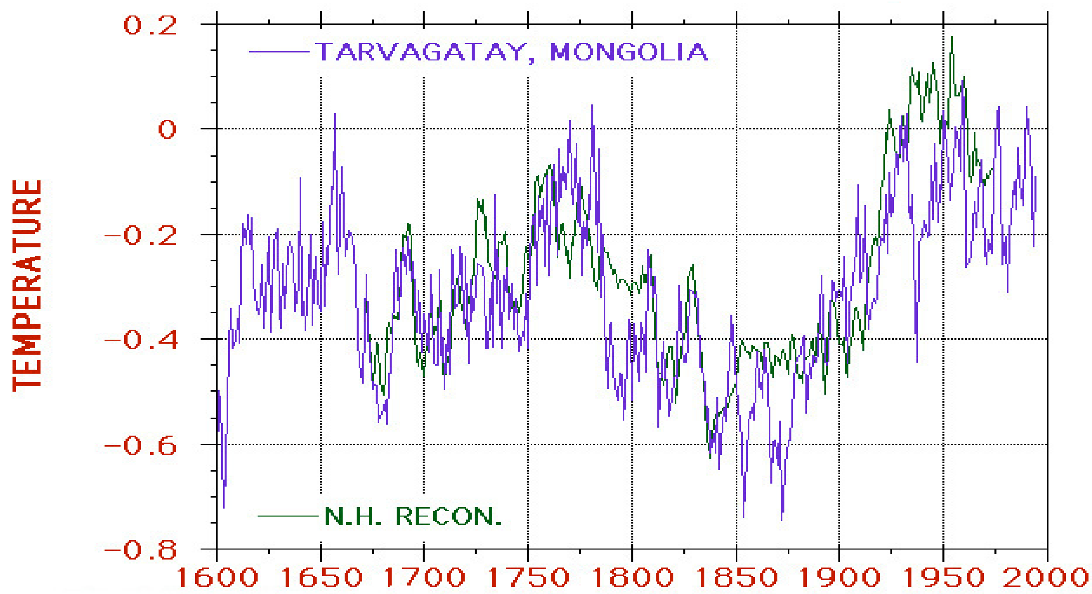

Figure 4. The Northern Hemisphere temperature anomaly reconstruction with the Mongolian series. (__ is Northern Hemisphere temperature anomaly, __ Mongolian temperature anomaly**)**
(Source: Jacoby et al., 1996)

Some effort has been made to reconstruct the historical climate on the basis of tree-ring analysis (Lobelius, et al. 1993; Gordon et al. 1996, Jacoby et al. 1996, 1999; Enkbat and Mijiddorj 1996, Namhai and Mijiddorj 1993). The Mongolian-American Tree-Ring Project (MATRIP) has done the most in this area. In this study, the Mongolian proxy record for temperature extends back over 450 years, sampling the three main species: Siberian pine (*Pinus sibiricaDu Tour*), Scots pine (*P.sylvestris L.),* and Siberian larch (*Larix sibiricaLedebour*). One of the sampling sites was in the Tarvagtain mountains located in western Mongolia. The Tarvagatay tree ring-width index series matches up well with large-scale reconstructed and recorded temperatures for the Northern Hemisphere and the Arctic. Figure 4 illustrates the plot of the Northern Hemisphere temperature reconstruction, contrasted with the Mongolian (Tarvagtain mountain) series (Jacoby et al. 1996), where increased temperatures are clearly seen over the past hundred years.

The longest reconstruction was made on the sample taken from Sologotyn Davaa, located in north-central Mongolia, (Figure 5). According to this (Pederson et al.,

2001) inference of temperature for the past 1700 years, the twentieth century is the warmest century in Mongolia in the last thousand.

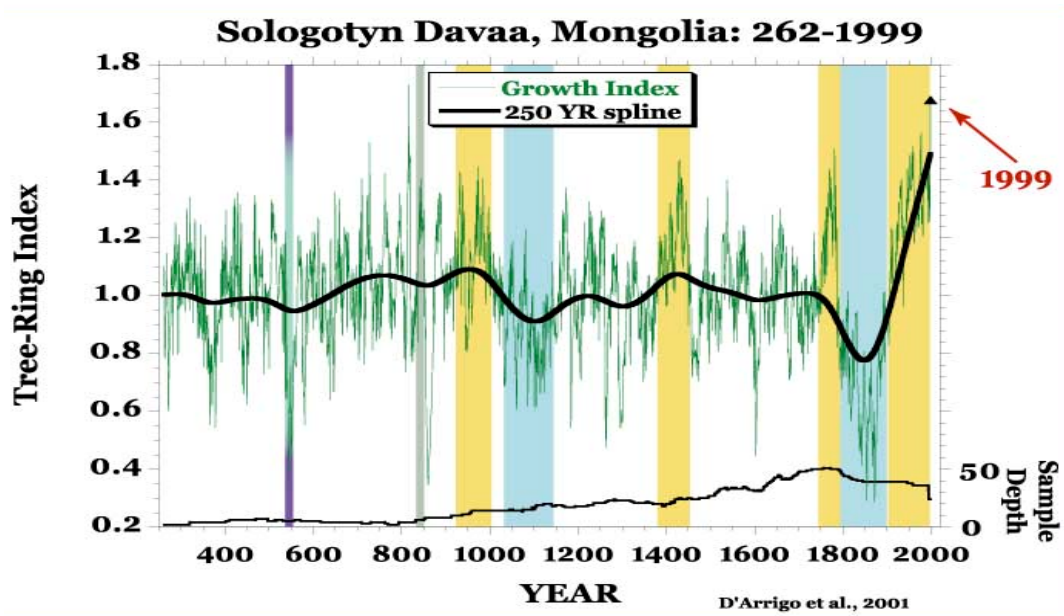

Figure 5. Tree-Ring Index for Mongolia (Source: D'Arrigo et al., 2001)

The yellow bars represent periods of above average warmth.

The blue bars represent periods of above average cool temperatures.

The country is semi-arid to arid. Precipitation varies both in time and space. Annual mean precipitation is 300-400 mm in the Khangai, Khentein and Khuvsgul mountainous region; 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. The maximum precipitation (138 mm/day) recorded since 1940 occurred on 5 August, 1956 at Dalanzadgad, and the second-greatest (121 mm/day) on 11 July, 1976 at Sainshand. Dalanzadgad and Sainshand are the center of the Gobian *aimags*. Although annual precipitation is low, its intensity is high. For example, an intense rainstorm of 40-65 mm may fall in a single hour.

Clear skies in winter due to high anticyclone dominance over Mongolia results in less snowfall. Snow contributes less than 20% to total annual precipitation. The first snowfall usually occurs sometime from the middle of October to the beginning of November. Usually, this first snowfall is short-lived and disappears due to late autumn warming and wind. Sometimes late first snowfalls persist as snow cover in mountainous regions.

The data on snow cover formation (which occurs when more than 50 percent of an area covered by snow), snow cover clear-up date (which occurs when more than 50 percent of snow cover melts away), and snow depth and density are the most important issues for pastoral animal husbandry. These parameters differ depending on geographical and climate conditions. According to the Agro-meteorological Reference Book of Mongolia (1989), the duration of stable snow cover is 120-150 days in mountainous regions, 70-120 days in the eastern steppe and 30-60 days in the Gobi desert region.

Snow cover forms in mid-October in the forest steppe and the Altai Mountains, in the second half of October in the steppe, and in the first half of November in the Gobi Desert. Snow cover clears up in late April in the forest steppe and Altai Mountains, mid-April in the steppe regions, and in February in the Gobi Desert. Snow that falls in late spring (after the clearing of winter snow cover) stays for several days, covering large areas. We call this “last snow cover.” Sometimes last snow cover occurs even in June. For example, it snowed on 16 June, 1971 in Tariat *soum* of Arkhangai *aimag*; on 4 June, 1990 and on 25, June 1991 in Khatgal *soum* of Khuvsgul *aimag;* and on 5 June, 1991 in Galuut *soum* of Bayankhongor *aimag*. The starting and ending dates of snow cover and the number of days with snow cover in different ecological zones are given in Table 1. These dates are averaged from 1970-2001 data.

Table 1. Starting and ending date of snow cover and number of days with snow cover (1970-2001)

	Day, Month				Days
Natural zones	Date of first snow fall	Date of snow cover formation	Date of snow cover clear up	Formation of last snow cover	Duration of snow cover
Forest steppe	16 Oct	19 Nov	13 Mar	27 Apr	115
Steppe	22 Oct	28 Nov	6 Mar	15 Apr	100
Altai mountain	14 Nov	14 Nov	24 Jan	I26 Apr	70
Desert steppe	9 Nov	18 Nov	2 Feb	2 Apr	65

As shown in Table 1, the formation date of stable snow cover is similar in all regions, but the clear up date is almost one month earlier in the Altai mountains and the Gobi regions than it is in the forest steppe and steppe regions.

The average depth of snow varies from 0.5 to 25 cm. In regions where snow cover stands for 50 or more days, maximum depth is reached in February and March. In regions where snow cover stands less than 50 days, maximum depth of snow depends on intensity and duration of snowfall at the time.

Observed changes in climate

Trends in temperature

The global average annual surface air shows signs of recent climate warming: it has increased between 0.3-0.6^{o}C within the last hundred years (IPCC, 1995). According to the IPCC reports, all ten of the warmest years ever measured globally for the last 120 years occurred after 1980, of which six happened after 1990, 1998 being the warmest year ever measured. This track of global changes was observed in Mongolian temperature trends as well. The normalized anomalies of annual mean temperatures for Mongolia are illustrated in Figure 6. According to this figure, there were 30 cases when air temperature anomaly was positive during 1940-2001, but 23 of these cases occurred after 1970. Similarly, all 8 cases that exceeded a 1°C anomaly were observed after 1990, including three consecutive years in 1997, 1998 and 1999. The year 1998 was also the warmest year ever measured instrumentally in Mongolia. Clearly, the number and duration of hot days is increasing.

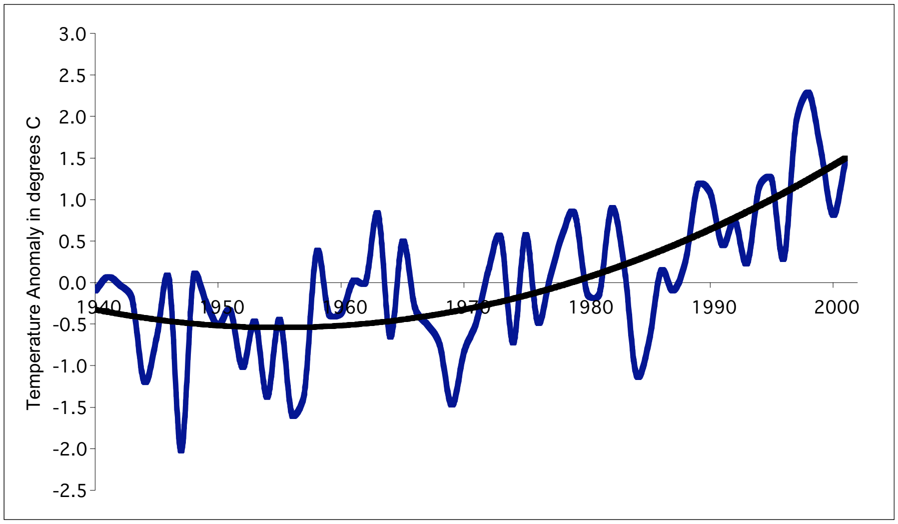

Figure 6. Temperature trend for the period 1940-2001

The blue line is Normalized anomalies of air temperature.
The black line is second order Polynomial

Second order Polynomial application to the total record shows an average 1.66^{0}C* increase in air temperature for the last 60 years, with clear warming from the beginning of the 1970's intensifying towards the end of the 1980's.

Obviously, temperature increases vary both in time and in space. The warming has been most pronounced in Winter, with mean temperature increase of 3.61^{0}C. Spring and Autumn temperatures have risen 1.4-1.5^{0}C. There is no clear increasing or decreasing trend in Summer air temperature. Figures 7 and 8 show the trends of summer and winter temperatures at Knovd, one of the 21 *aimag* centres located in the Mongol Altai mountain valley of western Mongolia, and Dalanzadgad, located in the southern Gobi, to illustrate the spatial differences in temperature changes. Linear regression application , when fitted into the trend at Khovd, gives 0.88^{0}C and 4.04^{0}C increases in summer and winter air temperature at levels of 95% and 99%, respectively. At Dalanzadgad, it gives 0.49^{0}C increase in summer temperature and 0.81^{0}C in winter temperature. Neither trend is statistically significant.

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* *For the period 1961-1990 (climate change base year), the annual mean air temperature has risen 1.38^{0}C.*

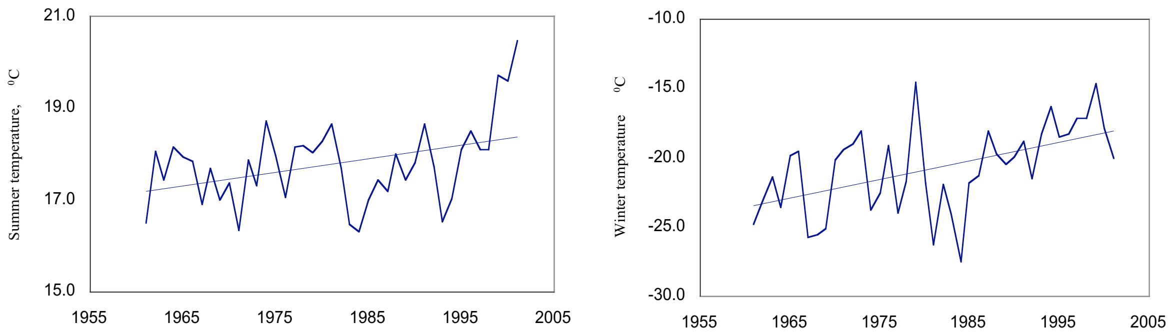

Figure 7. Summer (Linear regression: slope=0.029 ^0C /year; R^2=0.16, significance level: 95%) **and winter** (Linear regression: slope=0.135 ^0C/year; R^2=0.27, significance level: 99%) air temperature trends at Khovd.

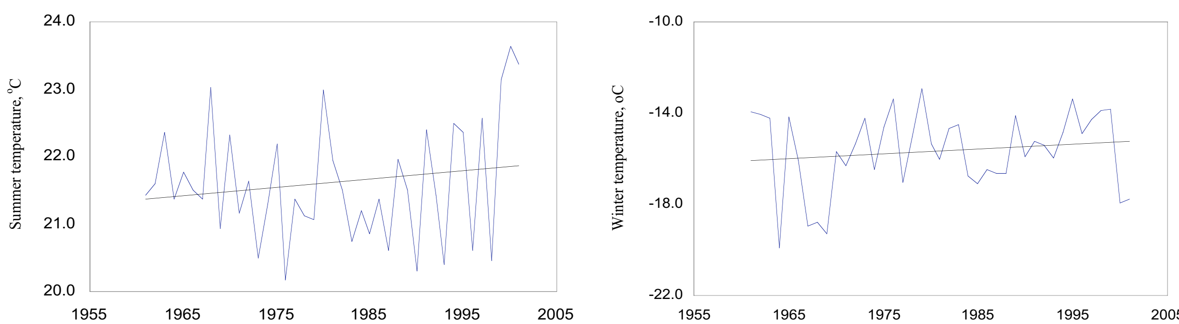

Figure 8. Summer (Linear regression: slope=0.012 ^0C /year; R^2=0.03) **and winter (**Linear regression: slope=0.02 $^{\mathbf{0}}C$ /year; R^2=0.02**) air temperature trends at Dalansadgad.**

As mentioned above, the average air temperature in July (the warmest month) is 15-25^0C. So when air temperature reaches 25-30^0C, it is considered a hot day in Mongolia. Even though there is no clear increasing trend in Summer temperature, there is evidence of longer duration of hot days. Long-lasting hot days have various negative practical consequences on human health and natural ecosystems, as plants vanish, streams dry, forest-steppe firest increase, and so on.

The biggest trends of Heat Wave Duration (HWD) are statistically significant. According to the linear regression, Heat Wave Duration has increased by 8-18 days, depending on geography. Greater increases (15-18 days) have been found in the Khan-Khokhii mountainous region of the Great Lakes Basin (Baruunturuun in Figure 9) and in the western part of the Khangain mountains (Tosontsengel in Figure 9). In the region of Mongol-Altai and in the Khentii mountainous area, the

HWD have increased by about 10-12 days (Ulgii, Baruunkharaa and Ulaanbaatar in Figure 9), and in the Gobi region (Dalanzadgad in Figure 9) by 6-8 days.

In 1998, which was the warmest year of the last century, HWD reached 70 days in high mountains and 30 days in the Gobi desert, which was one of the most highly anomalous events to happen in the last 40 years. Even though such long HWD were not observed afterwards, Mongolia experienced four subsequent years (1999-2002) of drought.

Results from Cold Wave Duration (CWD) calculations show clear decreasing trends. On average, CWD have shortened by 13 days. Greater decline (up to 20 days of CWD) has been observed in the Khangain mountainous (Tosontsengel) region and in the Uvs lake basin (Baruunturuun), while less has occurred in the Mongol-Altain and Khentii mountainous (Ulgii, Ulaanbaatar) region and in the Gobi (Dalansadgad).

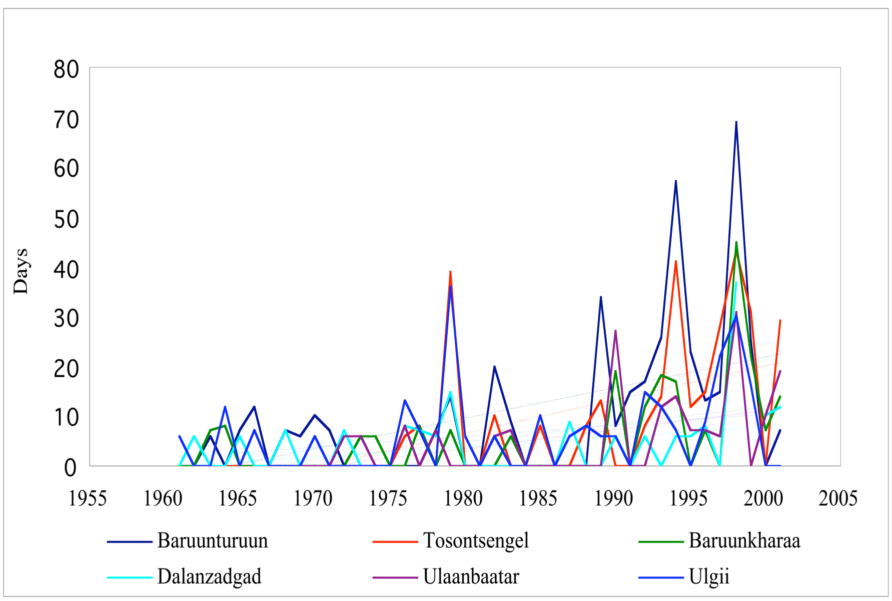

Figure 9. Trends in heat wave duration (solid lines) and linier regression (dashed lines) at the representative meteo-stations at Baruunturuun (Linear regression: slope=0.61day/year; R^2= 0.24, significance level=99%)**, at Tosontsengel** (Linear regression: slope=0.68 day/year; R^2= 0.23, significance level=99.9%), **at Batunnkharaa** (Linear regression: slope=0.33 day/year; R^2= 0.12, significance level=99%), **at Dalanzadgad** (Linear regression: slope=0.20 day/year; R^2= 0.13, significance level=95%), **at Ulaanbaatar** (Linear regression: slope=0.38 day/year; R^2= 0.21, significance level=99%), **at Ulgii** (Linear regression: slope=0.22 day/year; R^2= 0.10, significance level=95%), **of different climatic zones.**

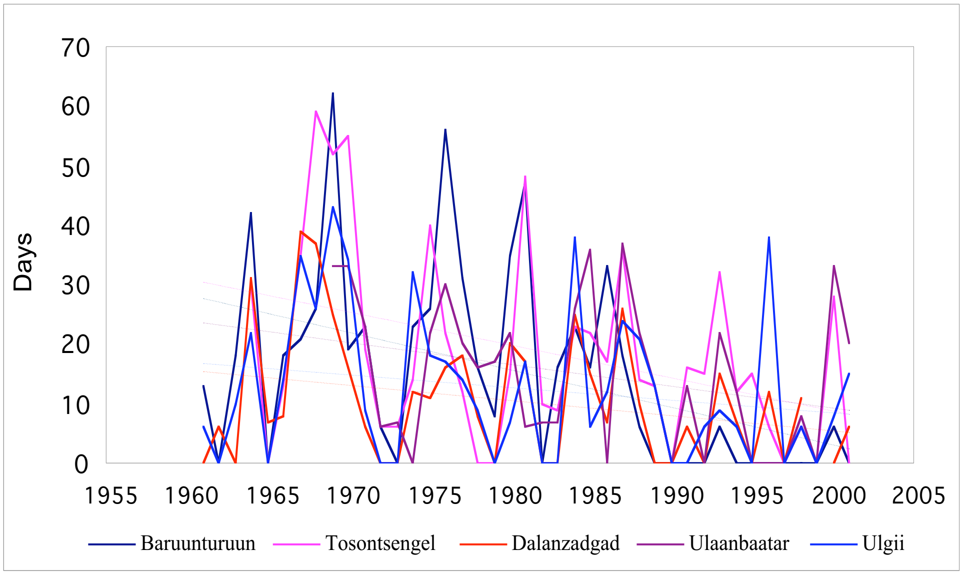

Figure 10. Trends in Cold wave duration (solid lines) and linier regression (dashed lines) at the representative meteostations at Baruunturuun (Linear regression: slope=-0.62day/year; R^2= 0.21, significance level=99%)**, at Tosontsengel** (Linear regression: slope=-0.56 day/year; R^2= 0.16, significance level=99.0%)**, at Dalanzadgad** (Linear regression: slope=-0.26 day/year; R^2= 0.12, significance level=95%), **at Ulaanbaatar** (Linear regression: slope=-0.38 day/year; R^2= 0.09 significance level=95%), **at Ulgii** (Linear regression: slope=-0.2 day/year; R^2= 0.10, significance level=95%), **of different climatic zones.**

Trends in Precipitation

Second order Polynomial, when fitted to the normalized anomalies of annual mean precipitation for the 1940-2001 period, shows a slight downward trend for the country base (Figure 11). Seasonally, Winter and Spring precipitation has decreased slightly, while there have been no change in Summer and Autumn precipitation. None of these trends are statistically significant (Figure 12).

The changes in annual precipitation have a very localized character; i.e., decreasing at one site and increasing at another nearby. This is one of the specific traits of precipitation distribution in the arid areas of Mongolia. Certainly, precipitation changes at local level have more practical implications than does the average precipitation for the country. Spatially, annual precipitation decreased by 30-90 mm on the north-eastern slope of the Khangai mountains, in the western slope of the Khentii mountains, and downstream from the Orkhon and Selenge river basins. Precipitation increased by 2-60 mm in the Mongol Altai, in the Uvs lakes basin, and on the western slope of the Khangai mountains; and by 30-70 mm in the southern part of the Eastern steppe region (Figure 13).

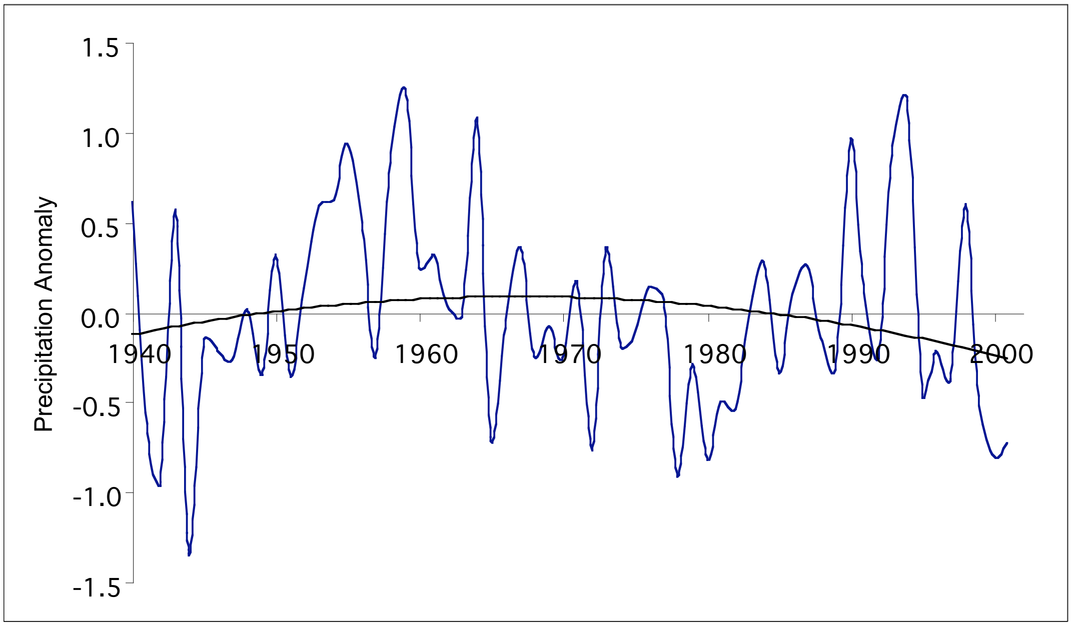

Figure 11. Normalized anomalies of annual mean precipitation for 1940-2001 period.

The blue line is Normalized anomalies of air temperature.
The black line is second order Polynomial

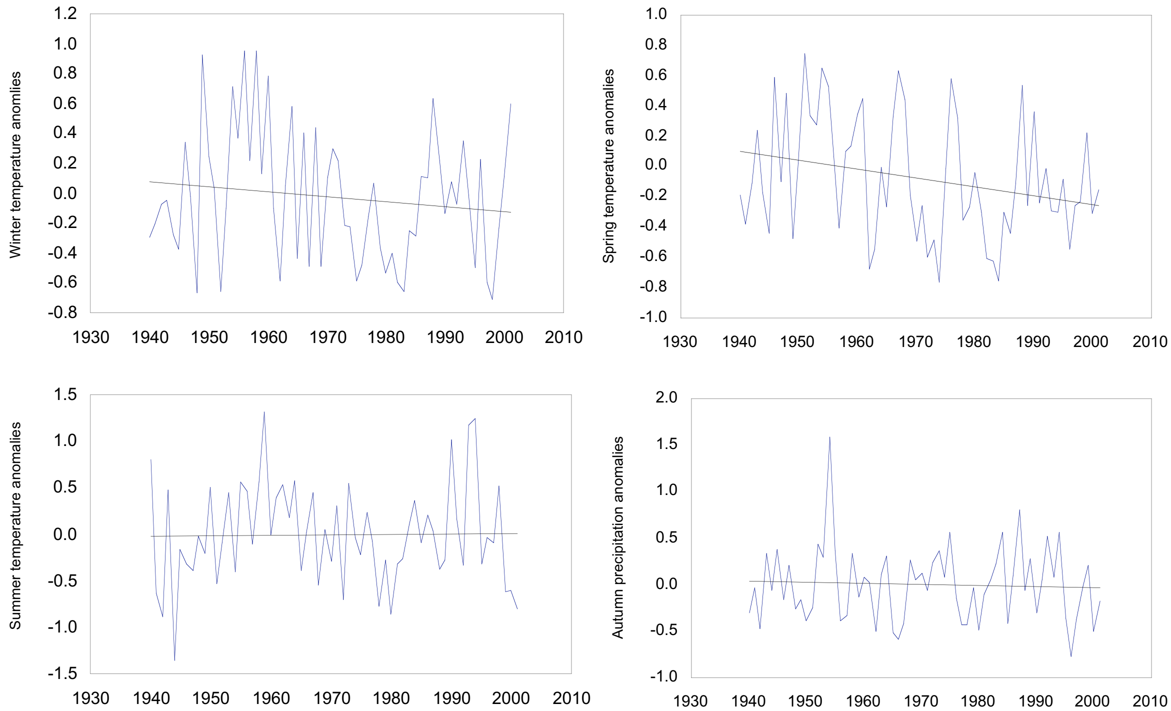

Figure 12. Normalized anomalies of seasonal precipitation for 1940-2001 period.

The blue line is Normalized anomalies of precipitation.
The black line is linear regression line

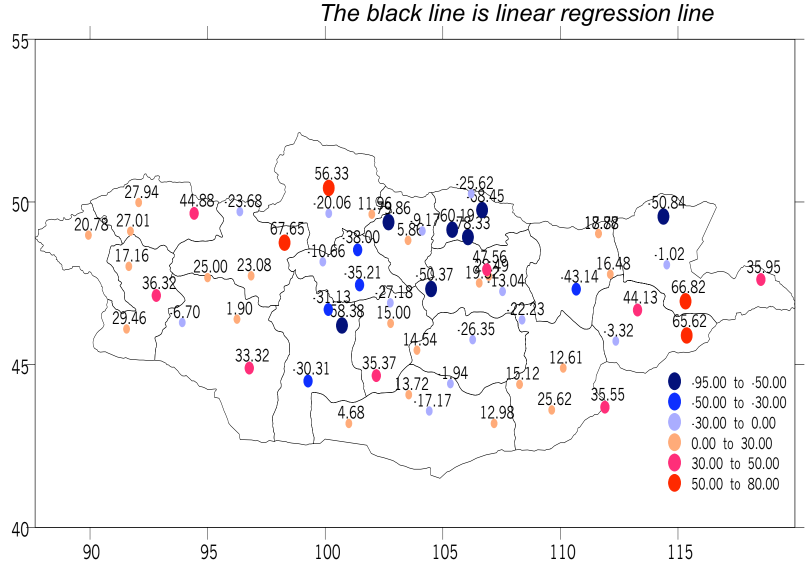

Figure 13. Annual precipitation changes in the last 30 years, mm

The magnitude of alteration changes in precipitation is 5-2%, regardless of whether it's increasing or decreasing . A 90% significant trend determines where changes are more than 40 mm, or more than 20% of annual mean value. Figure 14 illustrates increased precipitation (65 mm) at Erdenetsagaan, located in the extreme southeastern part of the country, and decreased precipitation (78 mm) at Baruunkharaa in the north.

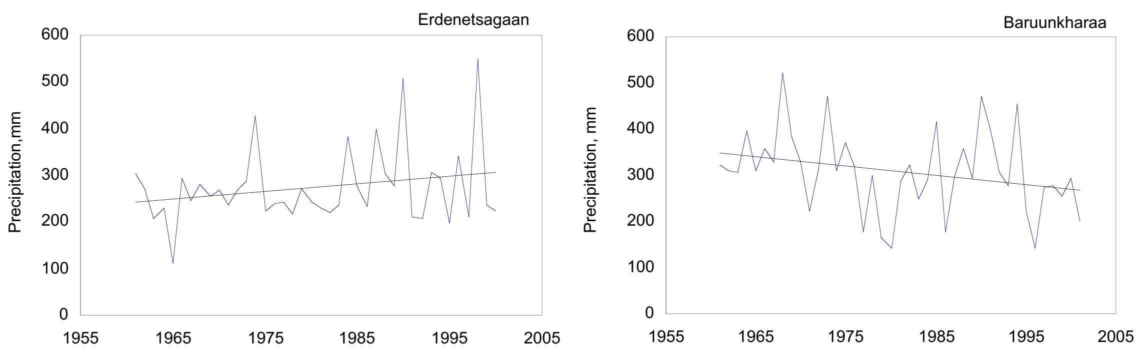

Figure 14. Trends in precipitation at Erdenetsegaan (Linear regression: slope=1.64mm/year; R^2= 0.069, significance level=90%), **and Baruunkharaa** (Linear regression: slope=-1.96 day/year; R^2= 0.070, significance level=90%)

The last 30 years of records show that the first significant snowfall of autumn tends to occur earlier, and that the last snow covers that occur at the end of spring or the beginning of summer tend to last longer. The stable snow cover formation date occurs earlier in the forest steppe and the eastern part of the country and later in other parts. The Snow cover clea-up date is 10 days earlier in western Mongolia and 3-5 days earlier in central and eastern Mongolia (Erdenetsetseg, 2002). Most trends are not statistically significant, although trends of 10 or more days towards an earlier clearing of snow cover are significant at a level of 90% at some stations. As an example, snow cover clear-up date records at Baruunturuun (located in the Khankhohii mountains of western Mongolia) and Khujirt (located in the southern slope the Khangain mountains of central Mongolia) are shown in Figure 15.

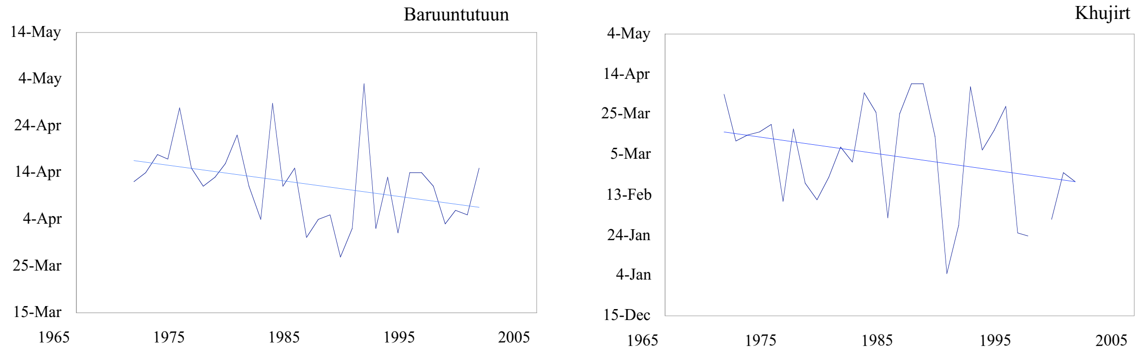

Figure 15. Trends of snow melting date for the last 30 years in the different meteo- stations. Baruunturuun (Linear regression: slope=-0.34 day/year; R^2= 0.12, significance level=90%)**, Khujirt is located in the central Mongolia** (Linear regression: slope=-0.84 day/year, R^2=0.098 significance level=90%).

On average, there was no statistically significant change in the maximum number of consecutive dry days. However, the maximum number of consecutive dry days tends to increase in central Mongolia, where annual mean precipitation has decreased. The maximum number of consecutive dry days tends to decrease in southeastern Mongolia, where annual mean precipitation has increased. The maximum number of consecutive wet days remained unchanged in most of the area, however (Figure 16 and 17).

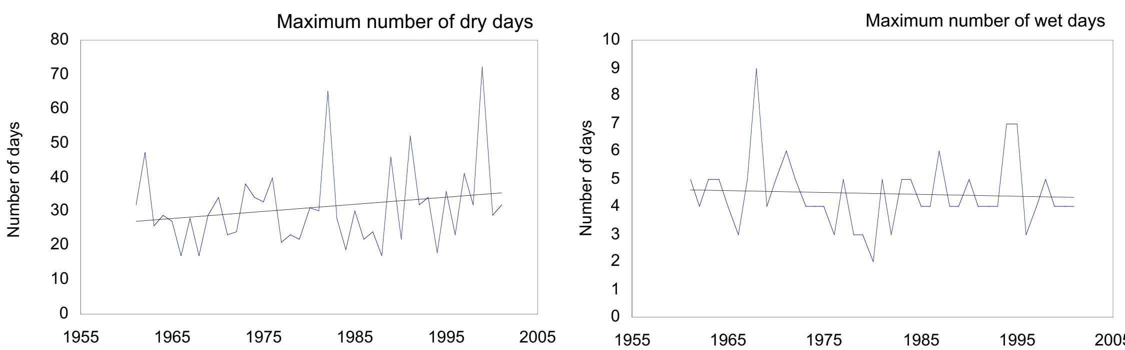

Figure 16. Changes in maximum number of consecutive dry and wet days at Baruunkharaa

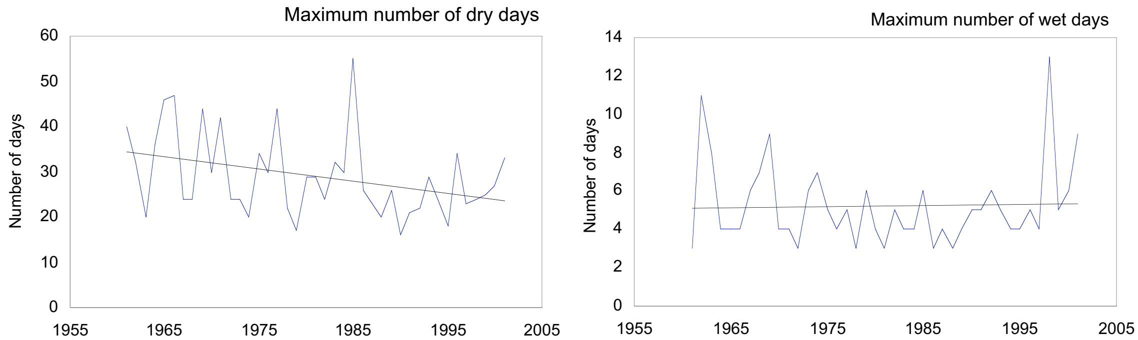

Figure 17. Changes in maximum number of consecutive dry and wet days at Erdenetsagaan

Discussions and conclusions

The Mongolian climate is getting warmer and slightly drier. Warming is most pronounced in the high mountainous area and their valleys, and least in the Gobi desert. Precipitation has tended to decrease slightly. This paper did not aim to discuss climate change impact, but certain impacts of these changes have already been observed in the Livestock sector, which is one of the major economic sectors of Mongolia. Therefore, we have brought together here a few examples of impacts resulting from observed climate change in Mongolia. Mongolia's livestock are raised in open pastures that directly depend on climate condition year round. Natural events such as drought and severe winter (called "*dzud*") are serious extreme events in Mongolia that cause high damage to not only the Livestock sector but also to the national economy.

Increased air temperature and HWD, along with unchanged precipitation, are the likely causes of the Summer droughts. Traditionally, animals build up the necessary weight, strength, and fat reserves during summer to enable them to cope with the harsh winter and spring. There are usually droughts every year somewhere in Mongolia, but when their duration and affected areas increase, these can lead to increased impact on livelihood. Water and forage are the most important resources for livestock, so the most direct impact on pastoralists' livelihoods is the drying up of water sources and declining of forage resources for livestock. A decline in these resources' availability greatly affects livestock conditions, milk production, and ultimately herders' livelihood security, since their lives depend on livestock and livestock products. Mongolia experienced its worst droughts in the Summers of 1999, 2000, 2001, and 2002, which affected 50-70%

of Mongolian territory. About 3000 water sources including 680 rivers and 760 lakes dried up during these long-lasting droughts (Davaa, 2004).

Harsh and long-lasting summer drought is the main factor which causes *dzud* to occur during the Winter. In the Mongolian language, the term *dzud* describes a natural disaster that occurs in the cold season (i.e., Winter and Spring) and represents a threat to human and livestock populations. Summer droughts of 1999-2002 caused the most severe *dzud* in recorded history in the Winters of these years (Natsagdorj 2002). At first glance, it seems that herders could benefit from mild Winters caused by increased winter temperature, shortened CWD, and less snow. However, some unexpected and unfavorable phenomena; e.g., sudden rapid warming in winter, unusually high snowfall, surge snow and wind storms, etc. have taken place in the last decade. Short, rapid (2-5 days) warming in Winter leads to melting snow cover. Melted water does not infiltrate but creates ice sheet on the ground surface since the ground is still frozen. Such cases create difficulties in grazing of animals on pastures, limiting their ability to get food. During this multitude of *dzud,* about 10 million animals have been killed. Such long-lasting (three consecutive years) winter *dzud* following summer drought had not happened in Mongolia in the last 60 years. The damage still has not been repaired.

Soil moisture usually does not inhibit vegetation growth in spring. Thus, spring precipitation is especially important to get the pasture grass growth started. Earlier melting of snow cover and decreased Spring precipitation probably resulted in a decrease of April-May pasture biomass by 20-40 % in the largest grazing areas of the steppe and the forest steppe (Bolortsetseg 2003).

This study of observed changes is very short compared to the time scale of global climate change, and it may not be able to provide clear/adequate answers to what happened and what should be done, but the results can help point to the emerging issues and needs of livestock in the face of potential climate change in Mongolia.

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