DOES THE LENGTH OF STATION RECORD INFLUENCE THE WARMING TREND THAT IS PERCEIVED BY MONGOLIAN HERDERS NEAR THE KHANGAI MOUNTAINS?

¿Puede la disponibilidad temporal de datos determinar el calentamiento percibido por las tribus nómadas de mongoles cerca de las montañas Khangai?

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ABSTRACT.– Temperatures changes can be difficult to infer from changes in vegetation patterns or other ecological changes, yet warming can be inferred through changes in the habits of people who live in close connection with their natural environment. Herders near the Khangai Mountains of central Mongolia have perceived a warming trend in recent years. Since it is difficult to determine the exact time period over which perceived warming has occurred, we examined the statistical difference in changes based on the length of data and the specific period of record used in the analysis. We used temperature data from five meteorological stations for up to 50 years (1961-2010). We examined varying lengths of record from 15 to 50 years with varying start periods (1961 through 1986), based on the length of record. We found that the most statistically significant changes occurred for the longest time periods and for the annual average minimum temperatures. We also found that one very cold winter, in particular 2009-2010 decreased the warming trend and for shorter periods of record reduced the statistical significance.

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RESUMEN.– Los cambios de temperatura pueden ser difíciles de inferir a partir de los cambios en los patrones de vegetación u otros cambios ecológicos. Sin embargo, el calentamiento se puede inferir a través de cambios en los hábitos de las personas que viven en estrecha relación con su entorno natural. Los pastores de las montañas de Mongolia central, cerca deKhangai, perciben una tendencia hacia el calentamiento en los últimos años. Ya que resulta difícil determinar el período de tiempo exacto durante el que se ha producido el calentamiento, se analizó la diferencia estadística de los cambios en función de la longitud de los datos y el período de registros utilizado en el análisis. Hemos utilizado los datos de temperatura de cinco estaciones meteorológicas con 50 años de registros (1961-2010). Se examinaron diferentes longitudes de registro (de 15 a 50 años) con períodos de inicio diferentes (1961 a 1986). Se comprobó que los cambios estadísticamente más significativos se registran en los períodos más largos y considerando las temperaturas mínimas medias anuales. También se encontró que un invierno muy frío, en particular (2009-2010) disminuyó la tendencia al calentamiento.

Palabras clave: Cambio climático, calentamiento, Mongolia, significación estadística, percepción de los grupos nómadas.

1. Introduction

Mongolia is a country known for its vast rangelands. Over 83% of the country is dominated by this type of land cover/use (Angerer *et al.*, 2008). Recent threats to rangeland health include changes in the traditional nomadic use and management of pastureland, increasing pressure from changes in livestock numbers and composition of herds, and desertification (Angerer *et al.*, 2008; Dagvadorj, 2010). Other environmental threats include increasing pollution from urban expansion, mining, and climate change (Dagvadorj, 2010).

Steppe vegetation condition is critical to herder livelihoods. Climate variability has altered vegetation (e.g. Yu *et al.*, 2003; Angerer *et al.*, 2008); specifically plant production has been limited by temperature and water supply changes (Yu *et al.*, 2003). These changes are particularly critical in mountain steppe areas which provide highly productive forage for grazing livestock and a source of water supply for more arid desert steppe rangelands downstream (Angerer *et al.*, 2008; Fassnacht *et al.*, 2011).

The water supply for most herders and smaller communities comes from resources that are influenced by climate variability. Approximately 36 percent of the country's population relies on water from shallow groundwater wells and 10 percent rely on water from rivers, with the remainder of the popula-

tion using municipal water supplies derived mainly from groundwater (Dagvadorj, 2010). Access to these resources is critical for the daily needs of pastoralists, including their livestock. Herders have reported diminished volumes in lakes and rivers and lowering groundwater levels (Fassnacht *et al.*, 2011). These decreases may be linked to a variety of factors such as irrigation and agriculture needs, mining, and climate changes (Dagvadorj, 2010).

Many of Mongolia's rivers flow from headwaters in the country's mountain ranges, including the Khangai Range in the west-central region. Between 50 and 75 percent of the country's annual runoff is derived from the mountains, mostly as rainfall, and the mountains contribute a significant portion of the groundwater baseflow that has a relatively short residence time (Dagvadorj, 2010). Precipitation in Mongolia is spatially variable by elevation and latitude, with about 50 mm falling annually on Gobi desert regions to 400 mm in northern mountain regions (Davagadorj, 2010). It is characterized by relatively intense rainfall events with most of the precipitation occurring between April and September (Davagadorj, 2010). Due to this spatial variability, trends in precipitation are not regionally consistent. Precipitation amounts and trends can vary significantly from station to station, especially in the more arid regions of the country (Batima *et al.*, 2005; Jamiyansharav, 2010).

Climate changes, such as variations in precipitation amounts and the occurrence of precipitation, may be inferred by changes in vegetation patterns or other ecological changes. It is more difficult to quantify changes in temperature. However, temperature changes, such as warming through an increase in minimum temperatures, can be inferred through changes in the habits of people who live in close connection with their natural environment (Alexander *et al.*, 2011).

Temperature trends play an indirect but critical role in the water budget, by affecting evapo-transpiration, precipitation timing and distribution, and/or phase of precipitation. Potential evapo-transpiration exceeds precipitation throughout Mongolia, and increasing temperatures may exacerbate this effect (Dagvadorj, 2010). In the drier steppe regions, early season warming raises evapo-transpiration rates delaying the onset of spring green up, especially when rains are delayed, increasing the risk of rangeland degradation (Yu *et al.*, 2003; Jamiyansharav, 2010). For those areas with streamflow reliant on mountain snowmelt, changes in precipitation phase can affect the seasonal timing of streamflow (Barnett *et al.*, 2005a). Therefore, the examination of temperature changes and trends is necessary to understand changes in hydrology and other resources.

1.1. Mongolian Temperature Regimes

Mongolia has a four-season climate with hot summers and long cold winters. Fluctuations in temperature from season to season, from day to day, and even over a single day can be great. Minimum temperatures can be colder than -52 degrees Celsius and maximums can be warmer than 43 degrees Celsius (Fassnacht *et al.*, 2011). Periods of extended heat and drought combined with subsequent long periods of cold and winter storms result in *dzud* (winter disaster) events that have caused large animal and even some herder mortality, loss of billions of dollars, and have severely impacted herder's livelihoods (Angerer *et al.*, 2008; Dagvadorj, 2010; Marin, 2010).

Our climate is changing, and global temperature trends are well-documented (e.g. Solomon *et al.*, 2007; Hansen *et al.*, 2010). Indices of temperature extremes for central and southern Asia suggest that there is a decrease in the diurnal temperature ranges, and an increase in the number of warm nights/days for the period from 1961 to 2000 (Klein Tank *et al.*, 2006). Temperatures in Mongolia follow this trend, with warming recorded across the country (Batima *et al.*, 2005; Jamiyansharav, 2010). Central Mongolia has experienced long-term temperature increases of 2 to 4 degrees Celsius per century (Jamiyansharav, 2010). Some potential problems for pastoralists due to this warming include an increase in drought conditions, rapid warming then re-freezing periods in winter leading to ice-crusted rangeland, and possibly an increasing recurrence of *dzud* (Batima *et al.*, 2005; Davgadorj, 2010).

Global and large regional trends vary from local data gained from individual weather stations (Pielke *et al.*, 2002). In Mongolia, most long-term meteorological stations are located at an *aimag* (province) center or occasionally at a *soum* (county) center, so each station typically represents approximately 100,000 km². Temperature and the magnitude of trends are expected to vary from location to location due to spatial heterogeneity of landscape characteristics and seasonality. For example, in a study of data from 17 Mongolian meteorological stations, annual winter maximum temperatures increased at 14 stations, but decreased at three others (Jamiyansharav, 2010). The indigenous climate knowledge of pastoralists, especially nomadic people, may help bridge the spatial gap between local, point-collected weather data and the influence of large regional trends (Marin, 2010).

Since changes in resource availability are of utmost importance to pastoralists (Batima *et al.*, 2005), surveys have been conducted to collect indigenous knowledge covering a broad range of climatic change topics and events, including extremes in precipitation, drought, and winter storms (Marin, 2010; Fassnacht *et al.*, 2011). These surveys describe changes in Mongolian herder lifestyle as they have attempted to adapt to environmental changes (Marin,

2010), and they provide context for meteorological data analyses (Fassnacht*et al.*, 2011).

1.2. Herder Observations

Temperature changes over the past decades observed by herders were referenced to changes in seasonal extremes. These were exemplified by questions about warmer and/or cooler days and nights, and the onset of seasonal changes such as snowmelt. Specific statements from surveys in 2010 included that summer days seemed hotter yet summer nights were cooler, and winters seemed warmer than those in the past (Fassnacht *et al.*, 2011). Recent surveys in 2011 in Bayankhongor *aimag* suggested that spring temperatures were cooler than in the past but that snow amounts had decreased with earlier melting. One herder commented that there was a lot of snow this year (winter of 2010-2011), but another mentioned that snowmelt patterns have "*changed a lot*" compared to 20 years ago. Though some herders in the recent surveys perceived that winters now were cooler than in the past, one commented that, "*winter is like fall-no real winter*." This observation is consistent with those from previously conducted surveys. The herders have observed temperature changes, but how far back in time is their period of reference and how does a variable period of record influence the station-based trends?

This paper aims to determine how the significance and rate of temperature trends are affected by the duration of the record, i.e., number of years, and the specific period of record, i.e., the start and end years. The available period of instrumented record will be used for each station. An individual extreme event is examined to determine if it will alter the statistical period of record analysis. Specifically, it is asked whether a single cold winter will reduce the trend and/or statistical significance of increasing temperature.

2. Study Areas

This study examines local scale temperature variability and focuses on stations in three *aimags* in central Mongolia that represent both the mountain steppe and desert steppe regions. The Khangai Mountains divide the *aimags*; Arkhangai is to the north, Bayankhongor is south, and Uvurhangai is located to the east. Five meteorological stations are used: Erdenemandal and Tsetserleg (Arkhangai *aimag*), Arvaikheer (Uvurkhan-gai *aimag*), and

Bayankhongor and Horiult (Bayankhongor *aimag*) (Figure 1). The three north-ern-most stations are in the mountain steppe of the Khangaimountains, Arvaikheer is in a more arid eastern edge of the mountain region while Horiult is in the desert steppe. The Erdenemandal and Tsetserleg stations are associated with Ikhtamir*soum*, while Bayankhongor and Horiult are associat-ed with Jinst*soum*, as presented in the herder surveys by Fassnacht *et al.* (2011).
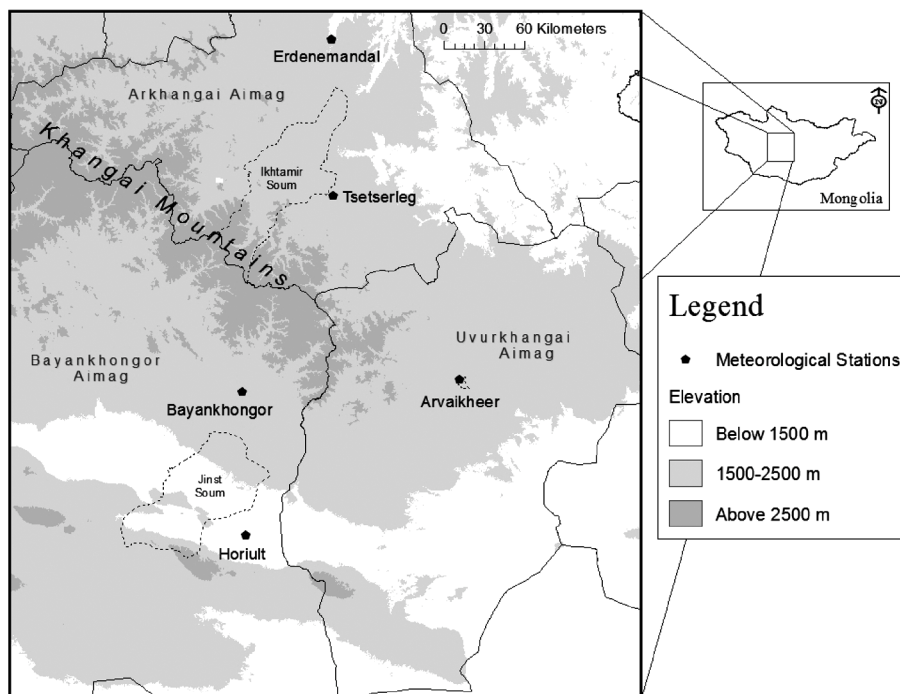

Figure 1. Map of study locations.
Figura 1. Mapa de los lugares de estudio.

3. Methods

Meteorological data for this study were collated from two sources. Daily minimum and maximum temperature data for the Erdenemandal, Tsetserleg, Bayankhongor, and Horiult stations were obtained from the Mongolian Institute of Meteorology and Hydrology <http://www.icc.mn/Meteoins/

index.html>. The longest length of record was 50 years (1961-2010) for Tsetserleg station, with a similar length of record for Erdenemandal (started in 1964) and Bayankhongor (started in 1963). Data collection at Horiult started in 1976. The Arvaikheer temperature data were obtained from the Global Historical Climatology Network of the National Climatic Data Center managed by the United States National Oceanic and Atmospheric Administration <http://www.ncdc.noaa.gov/ghcnm/>. There were substantial gaps in the daily maximum temperature data at Arvaikheer so only the minimum temperature data were used. Continuous data were available from 1969 through 1998 (Figure 2).
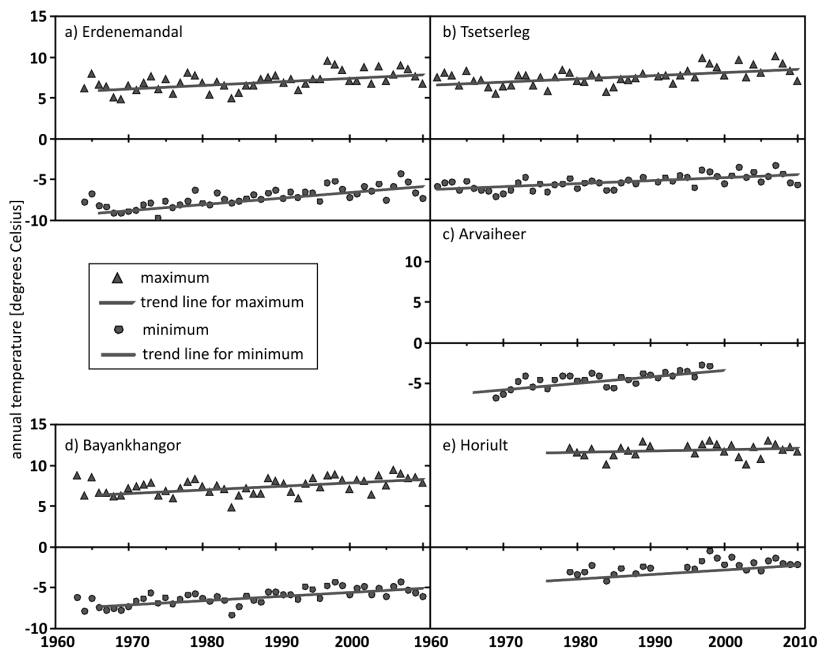

Figure 2. Annual maximum and minimum temperatures for the five meteorological stations.
Figura 2. Temperaturas máximas y mínimas anuales para las cinco estaciones meteorológicas.

Annual average minimum and maximum temperatures were computed from daily data when there were less than 15 days of missing data. Typically periods of missing data were continuous and a month or more in duration. These temperature time series were analyzed using the non-parametric Mann-Kendall test for a monotonic increasing or decreasing trend with slope

estimates or rates of change in degrees per century derived from the non-parametric Sen's method. The Mann-Kendall test determines the significance level of the change and is often reported at the 0.1, 1, 5 and 10% levels. For this study 1, 5 and 10% significance levels are reported. As these methods are non-parametric, they allow for missing values, are robust with regards to not being biased by outliers, and the data do not need to conform to any particular type of distribution (Gilbert, 1987).

To assess the significance of trends of different record lengths and time periods, calculations were run for record lengths of 50 to 15 years at decreasing five year intervals. Time periods analyzed ranged from the longest record of 1961 to 2010 to the shortest period of 1996 to 2010. The length of record analyzed and time period were dependent upon the data available. These station-based analyses were performed in light of local traditional knowledge. Quantitative hydro-climate surveys and open ended discussion were conducted with herders prior to and during the summer of 2010 (Fassnacht *et al.*, 2011). Herders with at least 14 years of experience in the field ranging in age from 30 to 78 years of age were asked to provide perceptions of climate change over the last 20 years. Temperature changes were assessed through examination of changes in seasonal conditions and length/timing of seasons (Fassnacht *et al.*, 2011).

Very cold winters in Mongolia are one type of extreme winter event called a *dzud* (Begszuren *et al.*, 2004). The winter of 2009-2010 was quite cold in the area of the Khangai Mountains in Mongolia (Fernandez-Gimenez *et al.*, 2011). Thus we compared the statistical analysis up to 2010 to the same length of record shifted two years earlier, i.e., up to 2008, to examine how the cold *dzud* of 2009-2010 changed the station analysis.

4. Results

The most significant trends were for the daily minimum temperatures (Table 1). These increasing trends were generally warmer (more) for the minimum than the maximum temperatures. The average temperatures (not shown) were statistically a combination of the minimum and maximum temperatures. Overall, the warming trend of longer time periods and including the more recent years (up to 2010) were the most statistically significant and often this warming trend was greater (Table 1).

Tsetserleg station has the longest records, and it exhibited highly significant changes, at the 0.001 statistical significance level (not shown), for lengths of record from 30 to 50 years. Erdenemandal followed a similar pattern with highly significant trends from 25 to 45 years, with one period of 20 years

being highly significant from 1981 to 2000. Trends at Bayankhongor were also highly significant from lengths of 30 to 40 years. For stations with shorter lengths of record, only the longest periods of 35 years at Horiult and 30 to 35 years at Arvaikheer were highly significant (Table 1).

Table 1. Rates of temperature change for annual i) maximum and ii) minimum temperatures in degrees Celsius per century as a function of length of record and period (start-end years) of record. Significant rates are presented with three significant figures and are in italics for 10 % significance, in italics and underlined for 5 % significance, and in italics, underlined and bold for 1 % significante. Non-significant rates are report with one significant figure. Years with no data are represented as N/A.

Tabla 1. Tasas de cambio de la temperatura anual i) máximas y ii) mínimas en grados centígrados/siglo como una función de la longituud de registro y el período de registro. Las tasas significativas se presentan con tres cifras significativas, en cursiva para el 10 % de significación, en cursiva y subrayado para el 5 % de significancia, y en cursiva subrayado y en negrita para el 1 % de significación. Los años sin datos se representan como N/A.

ai) Erdenemandal maximum

length of record	1961	1966	1971	1976	1981	1986	1991	1996
45	N/A	4.40						
40	N/A	4.36	4.04					
35	N/A	4.44	3.84	4.77				
30	N/A	3	4	5.62	7.20			
25	N/A	4	1	6.71	8.86	5		
20	N/A	1	2	2	12.7	6	4	
15	N/A	11.4	-7	4	9	9	6	-5

aii) Erdenemandal minimum

length of record	1961	1966	1971	1976	1981	1986	1991	1996
45	N/A	7.12						
40	N/A	7.28	6.61					
35	N/A	7.85	6.81	6.38				
30	N/A	7.85	7.55	6.41	5.98			
25	N/A	8.70	7.43	7.38	6.38	5.02		
20	N/A	6.53	8.64	6.46	9.55	6.58	6	
15	N/A	7	10.2	6.46	7.98	10.7	6	8

bi) Tsetserleg maximum

length of record	1961	1966	1971	1976	1981	1986	1991	1996
50	3.69							
45	3.46	5.01						
40	2.81	5.06	4.59					
35	1	4.96	4.57	5.42				
30	0	3.93	4.35	5.92	6.98			
25	-1	4	2	5.55	7.53	6.28		
20	0	3	-1	4	8.67	7.53	5	
15	-5	7	-4	-1	6.59	11.0	8	-4

bii) Tsetserleg minimum

length of record	1961	1966	1971	1976	1981	1986	1991	1996
50	3.57							
45	3.91	4.45						
40	3.56	5.04	3.84					
35	3.07	5.15	4.44	4.16				
30	2	5.38	4.14	5.13	3.96			
25	0	4.88	4.00	5.26	5.20	3		
20	-1	4	2	5.58	5.66	4	2	
15	-2	6	0	4	6.11	6	4	-3

LEGEND — period of record (start-end years)

length of record	1961	1966	1971	1976	1981	1986	1991	1996
50	61-10							
45	61-05	66-10						
40	61-00	66-05	71-10					
35	61-95	66-00	71-05	76-10				
30	61-90	66-95	71-00	76-05	81-10			
25	61-85	66-90	71-95	76-00	81-05	86-10		
20	61-80	66-85	71-90	76-95	81-00	86-05	91-10	
15	61-75	66-80	71-85	76-90	81-95	86-00	91-05	96-10

significance level:
0.01
0.05
0.10
NOT

cii) Arvaikheer minimum

length of record	1961	1966	1971	1976	1981	1986	1991	1996
50	N/A							
45	N/A	N/A						
40	N/A	N/A	N/A					
35	N/A	7.72	N/A	N/A				
30	N/A	6.98	6.11	N/A	N/A			
25	N/A	6.88	5.17	7.15	N/A	N/A		
20	N/A	9.59	2.81	5.34	9.69	N/A	N/A	
15	N/A	20.0	1	2	7.84	12.7	N/A	N/A

di) Bayankhongor maximum

length of record	1961	1966	1971	1976	1981	1986	1991	1996
45	N/A	4.18						
40	N/A	3.50	3.87					
35	N/A	3.80	2.98	4.75				
30	N/A	3	3	4.00	6.38			
25	N/A	2	1	5	6.08	5.42		
20	N/A	1	-1	3	8.25	4	5.34	
15	N/A	10.3	-6	2	8	7	3	3

dii) Bayankhongor minimum

length of record	1961	1966	1971	1976	1981	1986	1991	1996
45	N/A	5.10						
40	N/A	5.62	3.91					
35	N/A	6.38	4.19	4.63				
30	N/A	5.96	4.63	5.30	5.68			
25	N/A	5.08	3.25	6.88	7.61	3.78		
20	N/A	5	1	4.98	10.9	4.96	1	
15	N/A	12.5	-4	3	11.7	9.84	1	-5

ei) Horiult maximum

length of record	1961	1966	1971	1976	1981	1986	1991	1996
35	N/A	N/A	N/A	2				
30	N/A	N/A	N/A	1	2			
25	N/A	N/A	N/A	4.00	2	-1		
20	N/A	N/A	N/A	4	4.81	-4	-3	
15	N/A	N/A	N/A	4	11.3	3	-15.1	-3

eii) Horiult minimum

length of record	1961	1966	1971	1976	1981	1986	1991	1996
35	N/A	N/A	N/A	5.36				
30	N/A	N/A	N/A	4.69	5.43			
25	N/A	N/A	N/A	8.05	4.68	4.03		
20	N/A	N/A	N/A	5	8.53	2	3	
15	N/A	N/A	N/A	6	5	8.85	-4	0

The statistically significant rates of change at the 0.001 to 0.1 levels for each station varied based on the period of record analyzed. For Erdenemandal the greatest rate of warming was for the 15 year period from 1971 through 1985, while the lowest rate of change was for a 25 year period from 1986 to 2010. Similarly at Tsetserleg, the highest rate of change was for a 15 year period from 1981 through 1995, while the lowest rate of change was a 35 year period from 1961 to 1995 (Figure 3). Several negative rates of change were noted for the maximum temperature at all stations and at Tsetserleg, Bayankhongor and Horiult for the minimum temperature. Most of these cooling trends were for shorter periods of record (15 to 20 years). Only the maximum temperature at Horiult for the 15 year period from 1991 to 2005 was statistically significant at the 0.1 level. The trend decreased during that time period at a rate of 15.1 degrees per century, while it increased at a rate of 11.3 degrees per century (0.05 significance level) for the same length of record 10 years earlier (1981 to 1995).

The rate of change for Bayankhongor was highest for a 15 year period (1966 to 1980) for both the maximum and minimum temperatures, yet the lowest rate of change for that station was a 25 year period (1971 to 1995). Similarly at Horiult, the greatest significant warming of minimum temperatures was a 15 year period (1986 to 2000) while the lowest rate of change was a 25 year period starting the same year (1986 to 2010). The same patterns exist for the minimum temperatures at Arvaikheer where the highest warming was a 15 year period (1966 to 1980) and the lowest was a 20 year period (1971 to 1990).

In Arkhangai *aimag*, the annual minimum temperatures for 2009 and 2010 were the coolest in the decade, except 2005 (Figure 2a and 2b). The average of the November through March daily maximum and minimum temperatures were the coldest on record at Tsetserleg and the fourth coldest at Erdenemandal. At the latter station 2005 was almost as cold and was the only other winter in the previous three decades that was similarly cold. At Tsetserleg only the 1968-1969 winter had more individual cold days than 2009-2010. At Erdenemandal there were more cold days in 1968-1969, 1976-1977, and 2004-2005 than during the winter 2009-2010. The rate of temperature increase was higher for the periods ending in 2008 compared to those ending in 2010 (Table 2). When the increase was statistically significant it was greater at Tsetserleg than Erdenemandal. For the shorter lengths of record the significance was greater for the periods up to 2008 with an additional significant length of record period (Table 2).
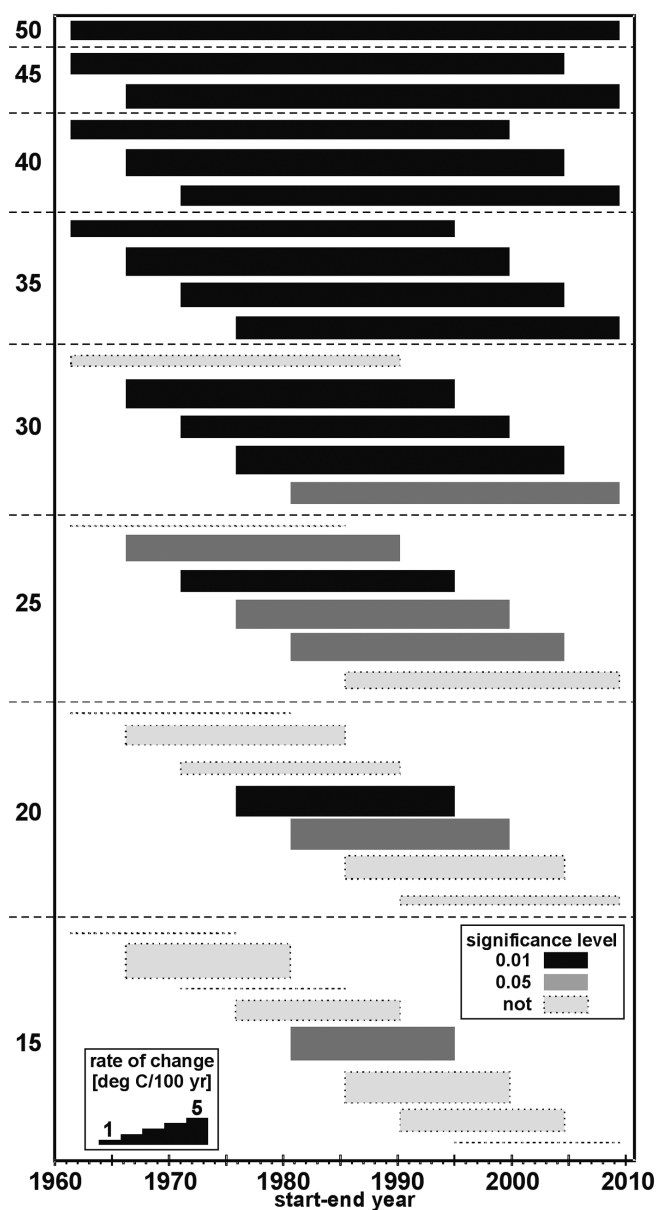
Figure 3. Graphical representation of the period and length of record calculations for the annual minimum temperature at Tsetserleg. The bar thrchness represents the rate of change.
Figura 3. Representación gráfica del período y la duración de los cálculos para la temperatura mínima anual en Tsetserleg.

Table 2. Rates of temperature change for annual i) maximum and ii) minimum temperatures in degrees Celsius per century as a function of length of record (15 to 35 years) for period ended at 2010 and at 2008. Significant rates are presented with three significant figures and are in italics for 10 % significance, in italics and underlined for 5 % significante, and in italics, underlined and bold for 1 % significance. Non-significant rates are report with one significant figures.

Figura 2. Tasas de variación anual de la temperatura i) máximas y ii) mínimas en grados centígrados/siglo en función de la longituud de registro (de 15 a 35 años) para los períodos finalizados en 2008 y 2010. Las tasas significativas se presentan con tres cifras significativas, en cursiva para el 10 % de significación, en cursiva y subrayado para el 5 % de significancia, y en cursiva subrayado y en negrita para el 1 % de significación. Los años sin datos se representan como N/A.

a) Erdenemandal

length of record	i) maximum up to 2008	2010	ii) minimum up to 2008	2010
35	*5.83*	*4.77*	*7.13*	*6.38*
30	*7.62*	*7.20*	*6.49*	*5.98*
25	*9.50*	5	*7.46*	*5.02*
20	6	4	*6.53*	6
15	5	-5	10	8

b) Tsetserleg

length of record	i) maximum up to 2008	2010	ii) minimum up to 2008	2010
35	*6.45*	*5.42*	*5.44*	*4.16*
30	*7.47*	*6.98*	*5.20*	*3.96*
25	*11.4*	*6.28*	*7.04*	3
20	*9.17*	5	4	2
15	7	-4	3	-3

significance level
0.01
0.05
0.10
NOT

5. Discussion

The most significant trends were for the daily minimum temperatures (Table 1). This is consistent with other studies in semi-arid regions of the world (e.g., Pielke *et al.*, 2002), including Mongolia, where research has documented increasing winter temperatures, warming annual minimum temperatures and decreasing numbers of cold days with minimum air temperatures below -5 degrees C (e.g. Batima *et al.*, 2005; Jamiyansharav, 2010; Dagvadorj, 2010). Changes in minimum temperatures may have the most effect on natu-

ral resources such as increasing or delaying plant growth in spring and changing rain/snow regimes (Yu *et al.*, 2003).

The base period of temperature analysis used in global and regional studies varies. For the GISS (Goddard Institute for Space Studies) global analysis it is from 1951 to 1980, due to decent global data coverage and that it is a time remembered by most adults (Hansen *et al.*, 2010). Other studies, especially those examining sites in Asia, use periods such as 1961 to 2000 or later due to the length of record available (Klein Tank *et al.*, 2006; Marin, 2010). This analysis examined multiple time periods, due to the availability of data and the correlation to local knowledge. The data for one of the five stations (Tsetserleg) have been collected since 1961, while three started in the mid-1960s (Arvaikheer only had a good minimum temperature record and it ended in the late 1990s). The Horiult station only has data from 1976 to present. Clustering of relatively higher rates of change at a high 0.001 level of significance (not shown) occurs for the 30 year period of 1966 to 1995 for four out of the five selected stations. This period is similar to those chosen for baseline temperature analysis in other studies and could be a time of reference for comparison purposes with greater amounts of statistically significant change occurring during that period.

Temperature changes are important to analyze as they influence many other natural processes. Warming (and cooling) drive processes such as evapotranspiration and the distribution and timing of precipitation events which can negatively affect pastoralists due to their reliance on naturally pastured livestock (Dagvadorj *et al.*, 2010). Changes in minimums are more important than maximums or means in terms of biomass production, especially when warming temperatures limit moisture availability and delay green-up in the dry steppes (Yu *et al.*, 2003). Unfortunately, specific temperature changes are difficult to quantify when recalling climate phenomena of the past from memory.

Recent herder surveys (Fassnacht *et al.*, 2011) recorded a perception by some that the current winters are cooler than those in the past, yet one herder commented that, "*winter is like fall; there is no no real winter*". It is interesting to note that one of the herders who perceived cooler winters was younger than age 30. Recent winters in most areas have been much cooler than those in the 1990's, so how far back in time a person considers may influence their perception of change. For example, the herder that commented that winter temperatures now were more like fall (implying warmer winter temperatures) was nearly 50 years old. His memory back 20 years in time could have extended back to the mid-1980's when winter temperatures were on average cooler than winters in the 2000's.

Variability in temperature change trends may be related to larger-scale cyclicity. Periodicities are generally attributed to natural processes such as solar radiative forcing, large-scale patterns of circulation, and volcanism (Barnett *et al.*, 2005b). In an analysis of trend and periodicity, Chen and Grasby (2009) found that the start of an instrumented climate record relative to the phase of a particular cyclic phenomenon has a strong impact on estimation of trend. Their work shows that this impact lessens with lengthening record.

Utilizing the longest record lengths results in the highest statistical significance for temperature trends. Shorter periods of record support both higher and lower, and even negative trends with much variability depending upon period of record examined (Table 1). For a majority of the sites, the shortest periods that retained significance were those of the 15 year period from 1986 to 2000. The rates of change however for these short lengths of time were usually several degrees Celsius warmer per century than those for longer lengths of record.

Station location can also influence variability in the climate change trends. Many mountainous stations are higher than 1800 metres in elevation. Connections to climatic warming with elevation have been studied and while there is no strict relation, it has been shown that the heterogeneous terrain of mountainous areas can lead to unequal climate trends especially in areas of incised valleys and flat locations (Pepin and Lundquist, 2008). The stations of Erdenemandal and Tsetserleg have the greatest number of highly statistically significant time periods. These two stations are located on the northern side of the Khangai Range, in more variable terrain than the other three stations. Bayankhongor is on the southern side of the mountain range and is also in somewhat rugged terrain. That station also has more highly significant periods than either Horiult or Arvaikheer.

Quantification of temperature trends based on a few point locations is problematic, especially related to issues of scale when interpolating or extrapolating meteorological data for use in modeling efforts (Daly, 2006). Regional averaging tends to smooth the effects of local temperature and other climate trends, and may hide important local trends (Pielke *et al.*, 2002). For example, the average rate of highly significant temperature change in Erdenemandal is several degrees per century higher than most of the other station locations. Simple averaging of the highly significant trends of all five stations leads to a value that is several degrees lower per century than those at Erdenemandal. Perhaps the impacts of the ecological changes at Erdenemandal could be greater than those occurring at other locations with increasing minimum temperatures. This is where local knowledge of climate could be connected with regional models to test model applicability in an area (Marin, 2010).

Though not specifically examined in this paper, memory often favors extreme events. This is likely true of extremes of climatic conditions. Analysis of temperature minimums over varying time periods relates to extremes in that minimum temperature events such as the severely cold winter of 2009-2010 can affect longer-term climatic trendlines (Table 2). A comparison was made between periods excluding or before the 2009-2010 *dzud* years (up to 2008) and including (up to 2010) the anomalously cold winter. It illustrated that removing those years increased the significance of warming temperature trends and the rate of change. Temperature trend rates in most locations became lower for shorter periods including the cold winters. Interestingly, the effect of a cold winter on change in trend from up to 2008 to up to 2010 is minimized with an increase in length of record of 30 years but then increases for 35 years (Table 2).

In their analysis, Chen and Grasby (2009) used mainly synthetic data to illustrate the possible implication of the sampling period on the rate and significance of change, specifically sampling within a much longer cycle so that a highly significant upward or downward trend could actually just be part of a longer term oscillation. However, an individual extreme year could greatly influence pastoralists and others directly reliant on climate. In this case, the herders throughout Mongolia were devastated by the extreme cold of 2009-2010 with approximately 8.5 million livestock (20% of the livestock in Mongolia) perishing directly or indirectly from the *dzud*, affecting approximately 28% of Mongolia's population (UN Mongolia Country Team, 2010). The herders in Bayankhongor *aimag* were previously affected by a *dzud* in 1999-2002, and were thus more prepared for the 2009-2010 extreme cold (Fernandez-Gimenez *et al.*, 2011). Those in Arkhanagai were less prepared.

Statistically one extreme season decreased the rate of warming and for the moderate lengths of record, decreased the significance (Table 2). While different than what Chen and Grasby (2009) showed, this highlights the importance of proper analysis and interpretation of results. The implications of a changing climate, especially with an altered or possibly decreased preparedness for extremes, can be quite pronounced for those who live on the land and can provide local knowledge of change. This local knowledge can help inform and interpret environmental and climate change (see Alexander *et al.*, 2011 for examples).

Changing minimum temperatures can affect production of vegetation needed by livestock, changes to water supplies, and even a change in the amount and type of clothing needed to survive (Yu *et al.*, 2003; Batima *et al.*, 2005; Angerer *et al.*, 2008; Fassnacht *et al.*, 2011). Large-scale regional analyses and models are useful for national-level climate change mitigation and adaptability planning (Dagvadorj *et al.*, 2010), but local scale conditions will likely

dictate changes in herder behavior as evidenced by responses to climate surveys (Marin, 2010; Fassnacht *et al.*, 2011).

6. Conclusion

In all cases, the most significant trends were those represented by the longest lengths of record. The most significant rates of change were not the highest or lowest rates of change at each station. The most highly significant rates of change in degrees per century were not uniform from station to station and covered a range of more than 5 degrees Celsius per century. Overall, the highest and most significant rates of change were approximately the 20 year period from 1981 to 2000, with a second clustering of significant values from 25 to 35 years in duration, starting in 1966 and extending until 1990 or 2000. This second period brackets the first cluster and may represent similar information on a longer time frame.

Increases in minimum temperatures are the most significant at a range of record lengths with a maximum of 50 years to about 30 years. A mid-range time period with higher rates of temperature change in degrees Celsius per century spanned the years from 1966 to 1995. Herder responses to climate surveys represent conditions experienced over a range of time periods. Observations however, often correlate with the documented changing climate trends. While the greatest statistical significance is noted with the longest records, shorter periods and extremes may more accurately represent the climate variability that is mentioned when herders are asked to recall natural phenomena of the past.

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