Determining Major Climatic Factors and Their Variations in the Central Agricultural Region of Mongolia

Sh. Oyuntuya[1], D. Damiran[2], P.J. Stevens[2], B. Dorji[1], D. Azzaya[3]
[1]Mongolian State University of Agriculture
[2]University of Saskatchewan, Canada
[3]Institute of Meteorology and Hydrology, Mongolia

Abstract
In accordance of the World Meteorological Organization, the weather conditions between 1961 and 1990 is defined as the climate and mean of climatic factors over that time-period is considered as the climatic normal. Climate is formed as a result of interactions between atmosphere, hydrosphere, lithosphere (geosphere), biosphere, and cryosphere. It develops and changes due to various external factors, periodic and non-periodic fluctuations in these systems. Number of studies has shown some strong indications of global warming in Mongolia. Objective of this study was to determine the changes and trends in the major climatic factors such as annual air temperature and precipitation in Orkhon-Selenge Basin, the Central Agricultural Region of Mongolia, over the last 15 years (1991-2006). Our study has revealed that over the past 15 years, from 1991 to 2006, the mean annual air temperature in the Central Agricultural Region of Mongolia has risen by 0.7-1.2 degrees Celsius or 0.04-0.07 degrees Celsius per year. Consequently, there has been higher frequency of years exhibiting drought like conditions negatively impacting vegetation growth. The warming has been causing a higher frequency of occurrence of drier years with moisture deficit for vegetation growth

Introduction
In recent years, the topic of climate change, in particular global warming has become critical issue around the world. In Mongolia, global warming is considerably affecting the country's natural ecosystems as well as socio-economic system. Further, alteration in vegetation coverage, water supply and renewable resources will inevitably follow climate change. Mongolia is situated between Central Asian high mountain ranges at the altitude of 1580 m above sea level, and displays harsh continental climatic condition. These conditions can cause distinctive expression of climate change on the territory. The main sector of Mongolian economy is agricultural sector and agro-climatic condition plays an important role for effective functioning of livestock and crop industry in the sector.
The main goal of this study was to determine changes in the climate in Orkhon-Selenge Basin, the Central Agricultural Region of Mongolia, specifically in air temperature and precipitation over the last 15 years, from 1991 to 2006. The following objectives were set up to achieve this goal:

1. To evaluate long term changes and trends of air temperature, its monthly and yearly patterns;
2. To determine the time-period when air temperature warms up reaching above 5 and 10 degrees Celsius, or cools down, and total heat change;
3. To determine long term changes and trends of precipitation;

Materials and Methods

Data used in the study were collected from different agro-meteorological stations in the Central Agricultural Region of Mongolia: the 1984-2006 data were obtained from Darkhan (49^0 28’ N, 105^0 54’ E), the 1965-2006 data - from Sukhbaatar (50^0 14’ N, 106^0 12’ E), and the 1961-2006 data - from Bulgan (48^0 48’ N, 103^0 33’ E), Khutag (49^0 23’ N, 102^0 42’ E), and Baruunkharaa (48^0 19’ N, 106^0 4’ E) stations, the air temperature data were analyzed as a 10-day average and the precipitation data - as a 10-day total. The time-period when air temperature stabilizes and reaches above 5 and 10 degrees Celsius in the spring and autumn was determined by interpolation equation, total active temperature – by adding the temperatures over the time-period when air temperature reaches above 5 and 10 degrees C in the ascending order, total effective temperature - by subtracting the biological 0 degree of crops/forages from the 10-day average temperature and adding the difference in the ascending order. Moisture thermal coefficient (MTC) was estimated by Selyaninov (1928) method.

Results

Thermal regime, its change

Mean annual air temperature was below 0^0 C or -0.12 to -1.25^0 C from the 1961-1990 data as recorded by the meteorological stations of the study area, while warmer air temperatures, up to above 0^0 C or 0.01 to 1.0^0 C in all stations, except -0.36^0 C in Bulgan station, were recorded by the 1991-2006 data. Hence, the estimated change was 0.73-1.22^0 C and it varied depending on the geographical conditions and features.

Table 1. Change in Air Temperature

Meteorological Station	Mean Annual Temperature(^{0}C) 1961-1990	1991-2006	Change (^{0}C)	Long Term Trend Line Equation	
Bulgan	-1.25	-0.36	0.89	Y=0.028x-1.66	R^2=0.255
Khutag	-0.72	0.01	0.73	Y=0.026x-1.06	R^2=0.143
Sukhbaatar	-0.12	1.0	1.12	Y=0.051x-0.74	R^2=0.504
Darkhan	-0.53	0.56	1.09	Y=0.096x-0.93	R^2=0.523
Baruunkharaa	-1.07	0.15	1.22	Y=0.045x-1.72	R^2=0.447

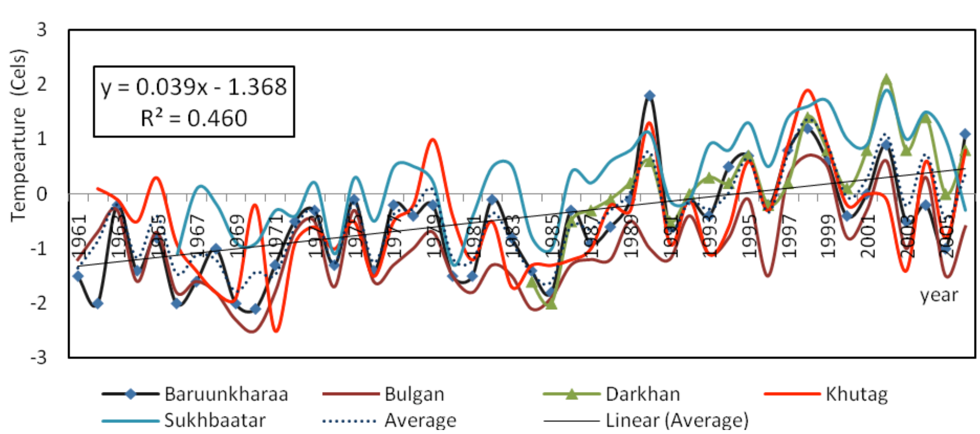

Figure 1. Long-term trend of mean annual air temperature Y-axis Temperature (Celsius)

This means that air temperature has risen in average by 0.04-0.07^0 C, if assume the increase was stable and even in every year. In reality, though, such a stable and even condition is hardly possible to observe.

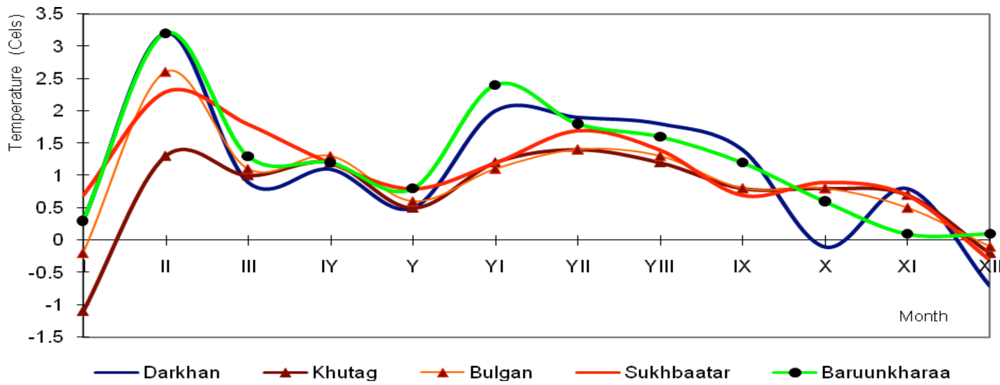

Figure 2. Change in air temperature (by month) Y-axis Temperature (Celsius)

Total of 960 estimates of monthly variations in mean air temperature was calculated, of which 53.2% has indicated that it was warmer, 30.2% - at or about the long term average, and 16.6% - cooler than the long term average level. This demonstrates that warming process has been quite intensive in the study area. In Orkhon-Selenge Basin, the air temperature warms up and reaches above 5^0 C at around April 3 to May 11, cools down from September 13 to October 30, and the time-period when air temperature reaches above 5^0 C continues for 152-167 days.

Table 2. Period and Number of Days when Air Temperature Warms and Reaches Above 5^{0}C or Cools Down

Meteorological Station	Period when Air Temperature Reaches 5° C							
	Spring /month, day/			Autumn /month, day/			Average Duration /day/	Trend Line Equation
	Early	Late	Mid	Early	Late	Mid		
Darkhan	4.IY	8.Y	21.IY	1.X	30.X	14.X	167	y = 0.714x + 158.38 R^2 = 0.251
Bulgan	13.IY	11.Y	27.IY	13.IX	10.X	26.IX	152	y = 0.037x + 151.54 R^2 = 0.003
Khutag	5.IY	6.Y	21.IY	18.IX	16.X	2.X	164	y = 0.274x + 157.55 R^2 = 0.16
Sukhbaatar	3.IY	9.Y	21.IY	21.IX	19.X	5.X	166	y = 0.351x + 159.04 R^2 = 0.196
Baruunkharaa	4.IY	6.Y	20.IY	20.IX	19.X	4.X	164	y = 0.343x + 156.14 R^2 = 0.292

The study has found that the 1991-2006 warm period length average was 2-3 days longer compared to the previous years' results in other studies, which suggests strongly that of warm period duration has increased. Air temperature warms up reaching above 10^0 C from April 21 to June 8 and cools down from August 24 to September 30 and the time-period when temperature is above 10^0 C continues for 108-129 days, which is 2 days longer compared to the above mentioned results.

Table 3. Period and Number of Days when Air Temperature Warms and Reaches Above 10^0C or Cools Down

Meteorological Station	Period when Air Temperature Reaches 10^o C							
	Spring /month, day/			Autumn /month, day/			Average Duration /day/	Trend Line Equation
	Early	Late	Mid	Early	Late	Mid		
Darkhan	24.IY	5.YI	15.Y	6.IX	27.IX	10.IX	129	y = 0.853x + 119.19 R^2 = 0.2759
Bulgan	3.Y	8.YI	21.Y	24.YIII	15.IX	4.IX	108	y = 0.193x + 103.49 R^2 = 0.0769
Khutag	21.IY	18.Y	4.Y	2.IX	25.IX	14.IX	125	y = 0.225x + 119.95 R^2 = 0.1046
Sukhbaatar	21.IY	26.Y	8.Y	31.YIII	30.IX	15.IX	129	y = 0.213x + 124.01 R^2 = 0.0488
Baruunkharaa	30.IY	26.Y	13.Y	31.YIII	27.IX	13.IX	124	y = 0.223x + 119.07 R^2 = 0.1296

The analysis of comparison of average number of days above 5 and 10^0 C in 1961-1990 with the same variable in 1991-2006 has revealed that there was higher number of days with temperature above 5^0 C, indicating spring and autumn seasons getting longer. Warm temperature estimated by total active and effective temperatures above 5 and 10^0 C showed that total effective temperature and active temperatures above 5^0 C have increased by 148.6-211.2^0 C and 176.8-255.0^0 C, respectively, whereas total effective and active temperatures above 10^0 C - by 135.0-216.8^0 C and 141.9-287.2 ^{0}C, respectively.

Table 4. Total Heat, its Change

Total Heat	Duration (year)	Meteorological Station				
		Bulgan	Khutag	Sukhbaatar	Darkhan	Baruunkharaa
Total heat above 5^0C	1961-1990	1102.3	1348.3	1520.4	1448.0	1451.8
Effective	1991-2006	1255.3	1496.9	1687.0	1646.0	1663.0
Difference		**153.0**	**148.6**	**166.7**	**198.0**	**211.2**
Total heat above 10^0C	1961-1990	456.3	656.1	788.0	724.4	746.1
Effective	1991-2006	598.9	791.1	949.1	941.2	922.3
Difference		**142.6**	**135.0**	**161.2**	**216.8**	**176.2**
Total heat above 5^0C	1961-1990	1841.3	2171.2	2327.3	2245.5	2171.8
Active	1991-2006	2018.1	2370.4	2524.1	2500.5	2384.8
Difference		**176.8**	**199.2**	**196.8**	**255.0**	**213.0**
Total heat above 10^0C	1961-1990	1518.3	1896.5	2077.5	1983.2	1991.2
Active	1991-2006	1719.9	2038.5	2249.1	2270.4	2217.6
Difference		**201.6**	**141.9**	**171.5**	**287.2**	**226.4**

If compare these increases with the previous years' estimations, heat supply levels for medium maturity wheat varieties were 81.2% in Bulgan, 92.8% in Khutag, and 99.2% in Baruunkharaa, indicating good heat levels, and in 1991-2006 these values were even higher, 94.5, 112.3, and 121.8%, respectively. In other words, warming has benefited the heat supply level increasing it by 13.3-22.6%.

Precipitation regime, its change

In our study area, Orkhon-Selenge Basin, long-term mean annual precipitation was 293.8-339.8 mm, but the amount has decreased by 6.4-43.5 mm in 1991-2006. The highest decline was observed in Baruunkharaa and the lowest – in Bulgan station.

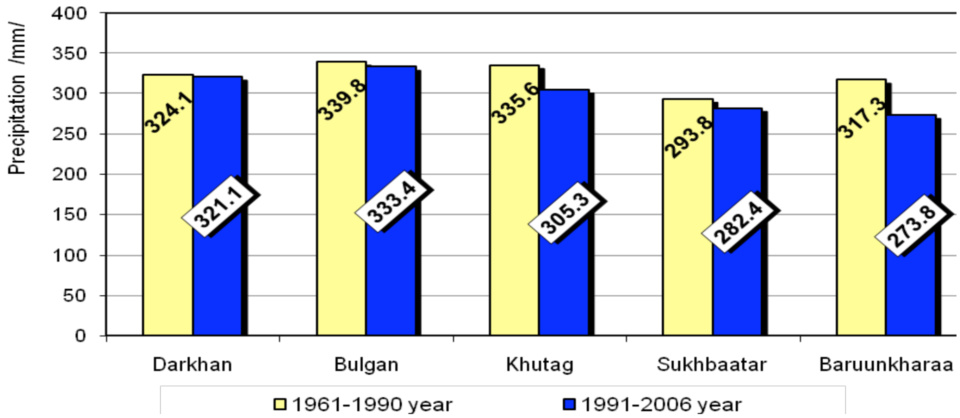

Figure 3. Amount of total annual precipitation

Change in the precipitation amount for the entire region presented by the mean monthly precipitation showed that while it was slightly higher in I, Y, XI, XII months everywhere in the study area, it decreased in other months, indicating the change has been uneven. In YII month, the warmest month of a year, the mean monthly precipitation was higher by 4.0-12.4 mm in Khutag and Bulgan, whereas in other places it was lower by 9.3-15.9 mm. This is related to the strong altitude difference between the locations, since Khutag and Bulgan are located at around 300 m higher than the other stations.

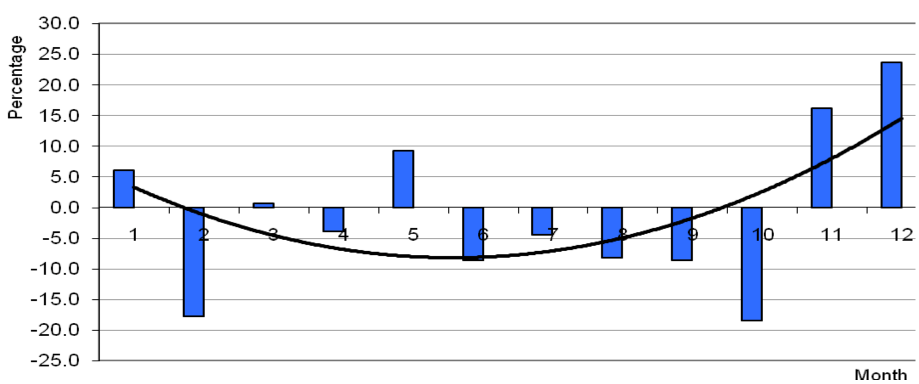

Figure 4. Change in monthly distribution of precipitation in a year (percentage)

The study also found that 29.7% of the 960 variation estimates of mean total monthly precipitation was above the long-term average, 21.7% - at around, and 48.6% - below the average. This could be regarded as another evidence of declining amount of precipitation in the region. Precipitation received in warm season, by the 1961-1990 average, accounted for 92.6-96.1% of total annual precipitation, whereas in 1991-2006 average, this amount decreased to 91.9-95.4%, thus was down by 0.6-1.3%.

Moisture thermal coefficient

In agro-meteorology, the factor that takes into account both air temperature and precipitation combined is moisture thermal coefficient (MTC). Moisture thermal coefficient estimated based on the 1961-2006 mean data of Y-YIII months or the vegetation growing season, indicated that there was wet condition in Bulgan (1.7), moist in Khutag (1.4), less moist in Sukhbaatar (1.3) and Baruunkharaa (1.1), and dry in Darkhan (0.4).

Table 5. Moisture thermal coefficient (1961-2006 average)

Month	Meteorological Station				
	Khutag	Bulgan	Sukhbaatar	Baruunkharaa	Darkhan
May	0.9	1.6	0.8	0.6	0.5
June	1.1	1.3	1.0	1.0	0.3
July	1.9	2.2	1.2	1.3	0.3
August	1.6	1.8	1.3	1.4	0.3

In the study, general trend of MTC variations for 45 years is expressed by the y=-0.017x+1.7013 equation, where a declining tendency was observed.

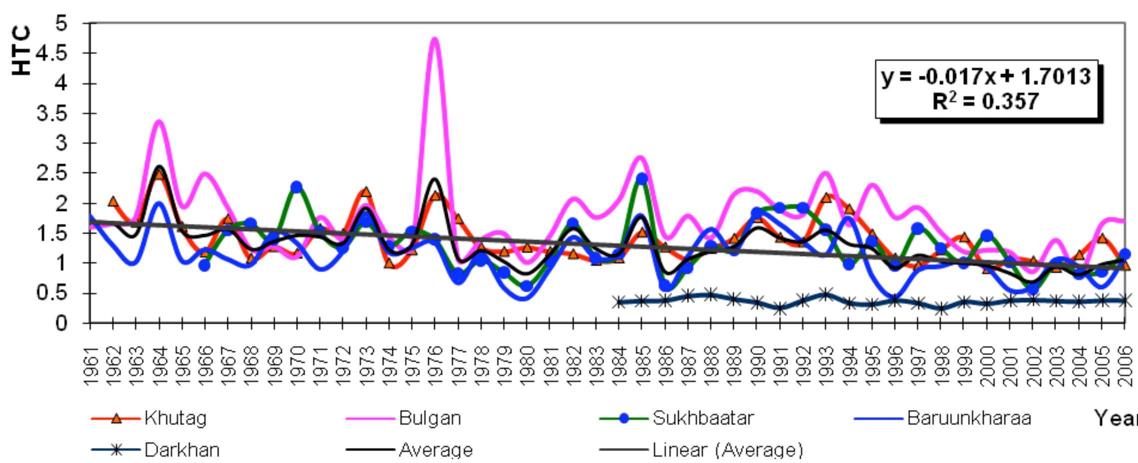

Figure 5. Long-term MTC trend

Mean MTC in 1990-2006 decreased by 0.1-0.2 as compared to long term average, which suggested that the trend of insufficient moisture condition for plant growth likely resulted from the air temperature rise and precipitation fall. Thus, for the 30 years, 1961-1990, throughout the study area, 9 wet, 6 moist, 12 less moist, and 3 moderately dry years have been observed, whereas for the 15 years since 1991, there have been 1 wet, 2 moist, 4 less moist, 8 moderately dry, and 1 dry year. Although it was in different order of occurrence, evidently there have drier years with lower precipitation been prevailing for the last 15 years. Furthermore, for the 8 years, 1998-2005, the area continued to experience some moderately dry to dry (2002) years (Figure 5).

Discussions

As World Meteorological Organization reported, the warmest years on the earth that occurred after 1860, when started using meteorological instruments, were 1998, 2001, and 2002, and the warmest decade of the 20th Century occurred in 1990s (Azzaya 2004). Such warming of air temperature may mean that the 46^{o} latitude borderline, which separates 0 degree isotherm, could disappear. This will support a study prediction, that investigated 21st century climate change impact observed on Mongolian natural zones, about a possible dislocation of Gobi desert zone or its shift to northwards. Our study results concur with the findings of other studies on air temperature, carried out in Mongolia. Specifically, the studies pointed out increased air temperature in cold season than in other seasons (Dagvadorji, Batjargal 1999, 2004, Gomboluudev, Azzaya 2003, Regzedmaa 2003, Namkhaijantsan 2005) and that precipitation in warm season has been declining, whereas in cold season it has been increasing (Regzedmaa, Gombodash 2004, Enkhjargal, Amarjargal, Altandolgio 2003). Although no cooling down of summer temperature was observed in the study region.

Conclusions

1. Air temperature in Orkhon-Selenge Basin in 1991-2006 has risen by 0.73-1.22 as compared to long term average, annual mean air temperature has been recorded above 0 degree Celsius in most places except Bulgan, and warming of this rate was inclined to continue further.
2. For the same period, total annual precipitation has decreased by 6.4-43.5 mm. Warm season precipitation has declined by 0.6-1.3% and accounted for 91.9-95.4% of total annual precipitation.
3. Moisture thermal coefficient has decreased by 0.1-0.2 and continued to decline further, which demonstrates a possibility of occurring borderline shifts of the natural zones in Mongolia.

References

Azzaya D. Relationship between ambient temperature and plant growth condition, Research Institute of Meteorology and Hydrology, UB, 1996, No. 18, p. 81-86.

Azzaya D. Agro-meteorological evaluation of plant growth conditions in the Central Agricultural region of Mongolia, PhD dissertation, UB, 1997, pp. 120, 126.

Gringoff E. G, Popova V.V, Strashnii V.H, Agrometeorology, Leningrad, Hydrometeopublishing, 1987, p. 184-187.

Jukov V. A, Polevoi A. H, Bitchenko A.H, Danielov S.A. Mathematical methods of evaluations of agro-meteorological resources, Leningrad, Hydrometeopublishing, 1989, p. 9-20.

Agro-meteorological resources of Mongolia, Encyclopedia, UB, 1996, pp. 249, 258-259, 285-286.

Oyuntuya Sh. Determining the effects of some climatic factors on surface cover using the LANDSAT-TM and NOAA satellite data, (based on the Orkhon-Selenge basin data), PhD dissertation, 2008.
Handbook of meteorological information services for agricultural industry, UB, 1987, p. 20.