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TRENDS IN RIVER AND LAKE ICE IN MONGOLIA

Batima Punsalmaa[1], Batnasan Nyamsuren[2] and Bolormaa Buyndalai[3]

ABSTRACT

Rivers and lakes in Mongolia are covered by ice 0.8-3.2 meters thick for five or six months each winter season. Small rivers are even frozen to the bed. Thus ice is an important component of the hydrological regime for surface waters in Mongolia. More than 40 forms/processes (border ice, ice pan, ice boom, frazil ice etc) of ice occur on the rivers in Mongolia during the cold season. The average date of first ice occurrence on rivers is third week of October. The freezing of the rivers continues from the end of October to third and last week of November. The ice cover duration averages 145 days. During the last 60 years, the annual mean air temperature in Mongolia has increased 1.66^{0}C with winter temperature increasing 3.61^{0}C, spring-autumn temperature 1.4-1.5^{0}C, and summer with no clear trend. Temperature has increased rapidly in the March, May, September and November and as a consequence the ice regimes of the Mongolian rivers has changed. Ice phenology has shifted by 3-30 days in terms of freeze-up and break-up dates and ice cover duration has shortened. Maximum ice thickness has also decreased from the 1960's to 2000.

Key words: river ice, ice phenology dates, ice thickness.

Indtroduction

Mongolia is a mountainous country with an average elevation of 1580m a.s.l. The highest peak is the 4374m Khuiten in the far western Altai range, where glaciers and deep, boulder-strewn valleys are reminders of the last Ice Age. The lowest altitude is 560 m in the east, in Lake Khukh.

The rivers in Mongolia originate from the three large mountain ranges: Mongol-Altai, Khangai-Khuvsgul, and Khentii. The upland watersheds are small and relatively isolated. Stream flows are low in volume and steep slopes cause relatively high velocities and scouring of silt and clay, leaving rocks, gravel, and sand on the stream bottoms.

Ice is one of the important elements of the hydrological regime of surface water in Mongolia because the rivers and lakes in Mongolia are covered by thick ice layers of 0.8-3.2 meter for five or six months each winter season. Small rivers are even frozen to the bed. However, many rivers do not completely freeze along the length because ice cover is discontinuous in steep reaches. Ice on the river plays significant roles in not only for the hydrological regime (water level rise due to ice jams, freeze-up and beak-up etc.), but also in river chemistry (oxygen, particulate matter regime, sediment transportation etc.), biology (water weed, organism habitat, lifecycle, etc.), and economy (water supply, energy generation, navigation etc.) during the different stages of formation as water cooling, freeze-up, ice thickness growth, break-up and ice jam.

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The Intergovernmental Panel on Climate Change (IPCC) reports thatclimate warming is more pronounced in Northern Hemisphere. Several authors state that changes in the cryosphere (glaciers, sea ice, ice caps, permafrost, lake and river ice) is an important and sensitive indicator of past global, regional as well as local climate change that is less subject to certain bias than air temperatures (Ross D.Brown et all, 2002, Livingstone, 1997). Climate plays predominant role in ice formation. Our study objectives are to find whether river and lake ice phenology (dates of ice forms, freeze-up, break-up, and maximum ice thickness) can be an indicator of past climate change in Mongolia.

Monitoring, data and methodology

Monitoring: The National Agency for Meteorology, Hydrology and Environment Monitoring is responsible for national network of hydrological observations including various components of river ice processes. The network of hydrological monitoring consists of about 120 gauging sites at more than 70 rivers. The Institute of Meteorology and Hydrology (IMN) is responsible for analyzing the observed data.

Table 1. The ice regime characteristics of selected rivers and lakes of Mongolia.

Nº	Name of the rivers and stations	Basin	Coordinate	Period of observation	Cachment area, km^2 (Surface area for lakes)	Average Ice freeze up date	Average Ice break up date	Average Ice cover duration	Average Maximum ice thickness
				Rivers					
1	Kherlen-Choibalsan	POB	48.04-114.30	1951-1999	71500	9-Nov	10-Apr	139	201
2	Onon-Dadal	POB	48.37-110.40	1945-1999	8810	14-Nov	21-Apr	147	258
3	Khalhgol-Sumber	POB	47.37-118.37	1971-1999	15200	15-Nov	13-Apr	129	192
4	Baidrag-Bayanburd	IDB	46.40-99.16	1966-1999	15277	17-Nov	6-Apr	129	120
5	Tyin-Bayankhongor	IDB	46.08-100.04	1972-1999	2125	18-Nov	15-Apr	135	181
6	Bogd-Uliastai	IDB	47.44-96.57	1961-1999	1610	18-Nov	11-Apr	146	133
7	Bulgan-Bulgan	IDB	46.06-91.33	1963-1999	4432	24-Nov	27-Mar	116	249
8	Sagsai-Buyant	IDB	48.35-89.33	1961-1999	4290	13-Nov	13-Apr	133	285
9	Khovd-Ulgii	IDB	48.59-89.87	1959-1999	22057	3-Nov	21-Apr	148	235
10	Ider-Zurtkh	AOB	48.56-100.10	1959-1999	9070	10-Nov	18-Apr	153	220
11	Khanui-Erdenemandal	AOB	48.36-101.20	1972-1999	4760	15-Nov	19-Apr	152	292
12	Eg-Khantai	AOB	49.34-103.12	1958-1999	1010	15-Nov	16-Apr	134	175
13	Khoittamir-Tamir	AOB	47.29-100.53	1959-1999	2990	4-Nov	6-Apr	116	82
14	Kharaa-Baruunkaraa	AOB	49.32-105.54	1945-1999	9580	15-Nov	7-Apr	132	135
15	Eree-Eree	AOB	49.38-106.50	1959-1999	9310	16-Nov	22-Apr	141	200
16	Muren-Muren	AOB	49.35-100.08	1960-1999	1890	7-Nov	12-Apr	150	174
17	Tuul-Ulaanbaatar	AOB	47.53-106.56	1945-1999	6300	13-Nov	22-Apr	149	178
				Lakes					
18	Uvs-davst	IDB	50.32-92.29	1965-1999	3518	25-Nov	5-May	154	128
19	Khuvsgul-Khatgal	AOB	50.29-100.10	1965-1999	2760	30-Nov	30-May	168	144
20	Buir-Zagasnyyildver	POB	47.49-117.53	1973-1999	615	12-Nov	19-Apr	148	154

Data: River ice information has been collected by the IMH as hydrometric observations and measurements at gauging sites since 1945. Ice thickness is measured manually on 10th, 20th and last day of a month. Dates of first ice and water clearing of ice, freeze-up, break-up and occurrence of other form of ice are recorded at the same sites. More than 40 forms (border ice, ice pan, ice boom, frazil ice, bottom ice, hanging ice dam etc) of ice occur on Mongolian rivers during cold season. The average date of first ice occurrence on rivers is third decade of October. The rivers freeze-up takes place from the end of October through the third and last week of November. The ice cover duration averages 145 days. The longest duration of ice cover is recorded at the river Tes (165-180 days). The spring ice break-up occurs in third and last weeks of April. Some data of hydrological characteristics and ice regime of selected rivers and lakes are given in Table 1.

Twenty gauging sites (Figure 1) of different scale and climatological characteristics were selected from the national monitoring network according to basin size, varying climatic and basin characteristics, as well as availability and homogeneity of time series.

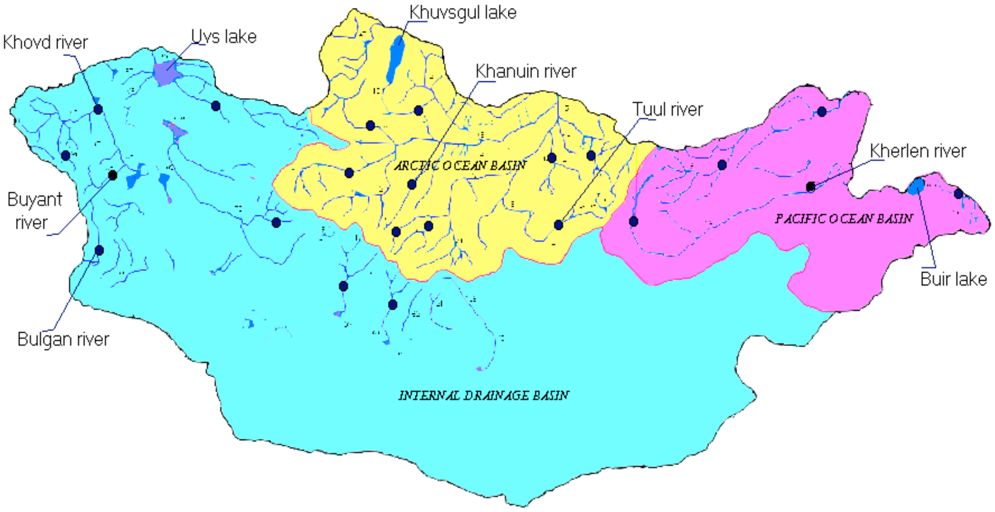

Figure 1. Selected hydrometric measurement sites used in this study.

(*The names of rivers and lakes written outside of the map is those that have been illustrated in following figures as an example*)

Systematic observations at the selected twenty sites over the past 30-55 years were used studying our present study. The longest time series is for the Tuul River, starting in 1944 and the shortest is for the Khalkhgol River, starting in 1971. The period of observation coincides roughly with the reference years of World Meteorological Organization's base years 1961-1990, as for climate change studies. These rivers have special value because they are not affected by local anthropogenic factors; Mongolia is a sparsely populated with only two and one half million inhabitants over a 1.5 million km^2 territory.

Information collected at each study site included the timing of first ice, freeze-up, break-up, ice cover duration, water clear of ice, and annual maximum ice thickness. All these data were assembled for observation years in spreadsheet, trends were estimated by linear regression.

Air temperatue trends were analysed from the nearest meteological stations to the stream-ice gauging stations.

Results and discussions

Climate and its changes in last 60 years: Mongolian annual mean temperature ranged from $–8.3^0$C to $+8.3^0$C. It was -4^0C in the Altai, Hangai, Hentein and Huvsgul mountainous region and $–6.8^0$C in the mountains and big river valleys, $+2^0$C in the desert-steppe, and $+6^0$C in the southern Gobi.

The zero degree Centigrade iso-line for annual temperature coincides with 46^0N latitude separating the mountainous area from the Gobi-desert area. Permafrost soils were distributed in area with annual mean temperature of -2^0C. The average temperature of January was -25^0C in river valley, $-15 –20^0$C in the Gobi, and $-12\text{-}15^0$C in the southern Gobi (Natsagdorj, 2000).

During last 60 years the annual mean air temperature increased by 1.66^0C, winter temperature by 3.61^0C, and spring-autumn temperature by $1.4\text{-}1.5^0$C. Temperature has increased most rapidly in March, May, September and November, the time when river ice processes take place (Natsagdorj, 2000).

As a result of increased temperatures in the cold season, dates of ice events have changed (Autumn and Spring ice occurrence, ice cover duration, and maximum ice thickness).

Freeze-up and break-up dates in rivers: Freeze-up and break-up dates have change from three days to one month, more specifically a 10-30 day later start of freeze-up in the rivers flowing from the Mongol Altai mountains, a 5-10 day later freeze in the rivers flowing from Khangai and Khentii mountains, but only 2-5 days in the rivers flowing from Khan Khukhii mountains.

Changes in ice phenology dates correspond to an increase in air temperatures of autumn and spring months when river ice processes take place. October temperatures have increased by only 0.5°C degree while November temperature has increased by 3°C degree in the lower basin of the Kherlen in the last half of the 1900s. October and November air temperature and dates first ice as well as freeze-up for the period of record in the lower catchment of the Kherlen River are plotted in Figure 2. The Kherlen River originates in the Khentii mountain and flows throughout the eastern steppe region. As can be seen from the figure there are no trend in autumn ice phenology dates until mid of 1970s. However clear increasing trend appears to start in the mid of 1970s. Linear regression application to the entire record shows an average 8 and 9 days delay of first ice and freeze up dates respectively. If the first half of the period is ignored the rates are almost doubled. Similarly October and November air temperature and dates of first ice and freeze-up for the observed period in the upper catchment of the Khovd River are plotted in Figure 3. The Khovd River flows from the Mongol-Altain mountains in the western region. First ice occurrence and freeze-up dates have shifted 13 days later at the Khovd River for increased air temperature by 3°C and 2°C degrees in October and November respectively.

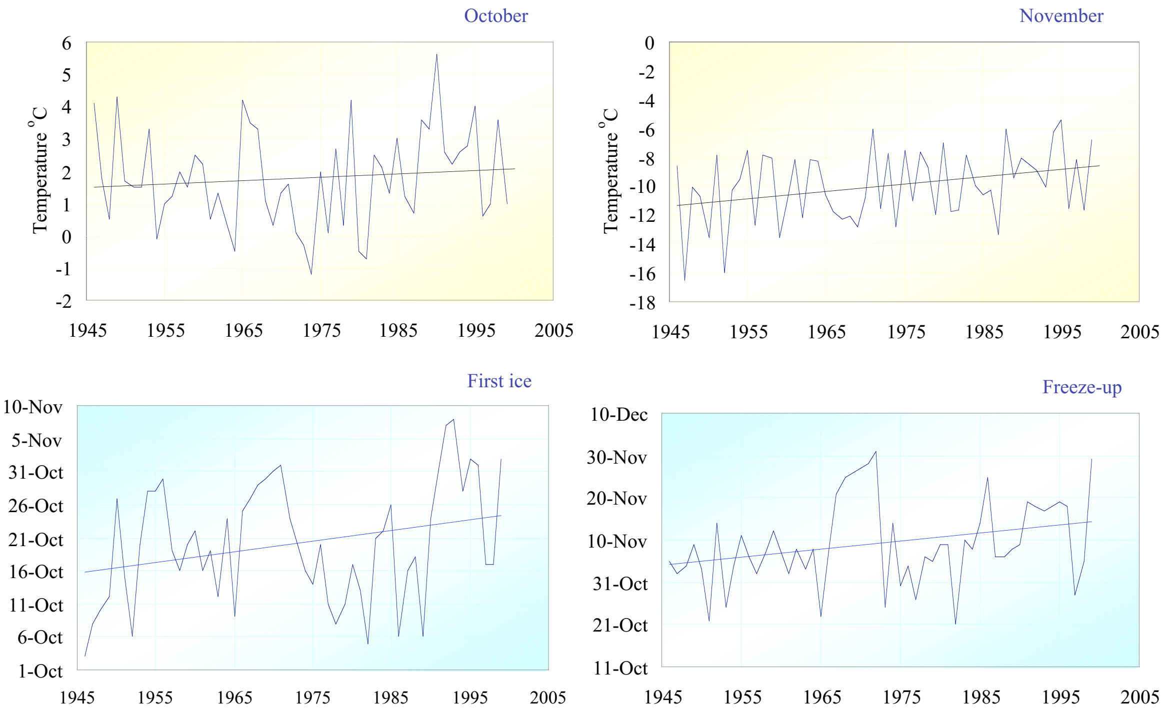

Figure 2. Changes in October-November temperature and ice starting (Linear regression: slope=0.16 day/year; R^2=0.08) **and freeze-up dates** (Linear regression: slope=0.19 day/year; R^2=0.09) **at the lower catchment of the Kherlen River located in eastern region of Mongolia.**

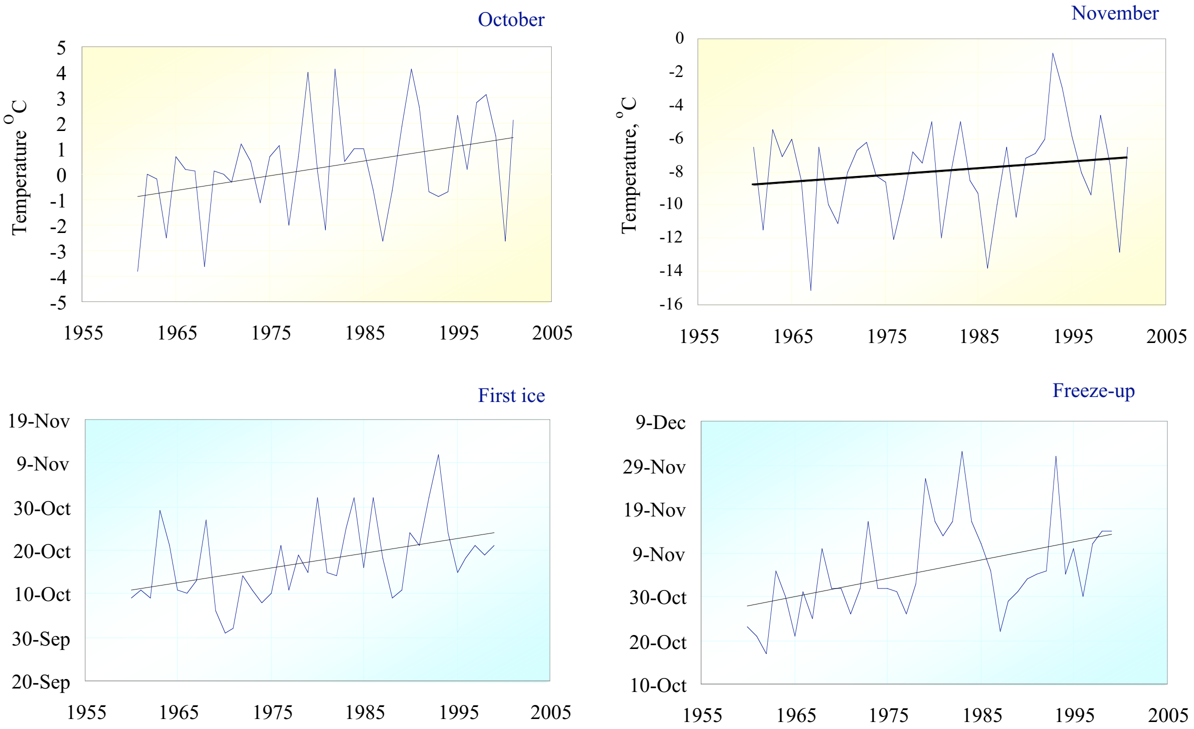

Figure 3. Changes in October-November temperature and ice starting (Linear regression: slope=0.33day/year; R^2=0.18, significance level: 99%) **and freeze-up dates** (Linear regression: slope=0.42 day/year; R^2=0.21, significance level: 99%) **at the upper catchment of the Khovd River located in most western region of Mongolia.**

Similarly, dates of water ice and break-up and disappearance in Spring started earlier by 5-30 days, 10-30 days earlier break-up in rivers flowing from the Mongol Altai and Khangai mountains, 8-12 days earlier in the rivers flowing from western slope of the Khentii mountains but only 3-5 days in the rivers flowing from eastern slope of the Khentii mountains and Ikh Khyangan mountains. The largest change in ice breakup has occurred in the Mongol Altai mountains and in The Khanuin River flows from the northern slope of the Khangain mountains. A trend of 32 days towards an earlier breakup date, significant at the level of 99.9%, at the Baitag station of the Bulgan River and 21 days towards an earlier breakup date, significant at the level of 99%, at the Erdenemandal station of the Khanuin River are shown in Figure 4.

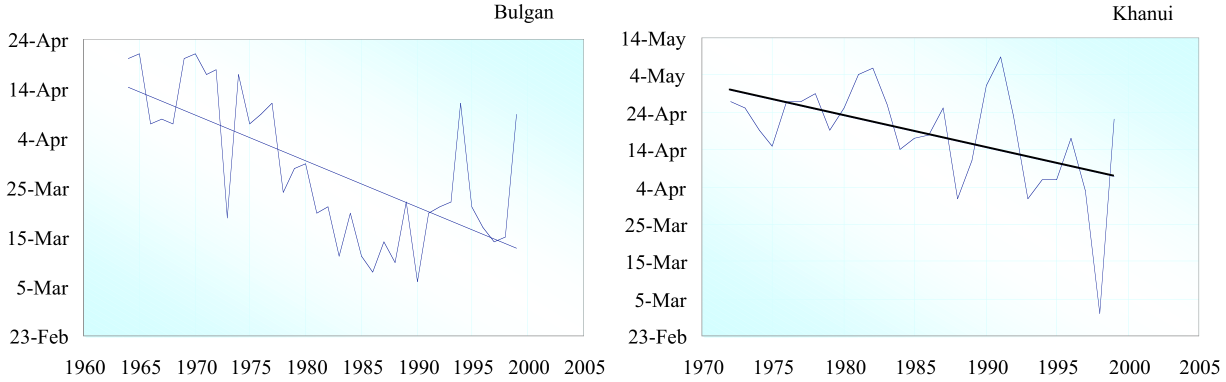

Figure 4. Trends in ice break-up dates in the Bulgan River (Linear regression: slope=-0.93day/year; R^2=0.45**) that flows from the southern slope of the Mongol-Altain mountans and Khanui river (**Linear regression: slope=-0.85day/year; R^2=0.25**) that flows from the northern slope of the Khangain mountains**

Shifts in break up dates are longer than in freeze up dates. The averaged number of days in river ice freeze up and break up is similar that has been found with in other places (Gitay, er al., 2001: averaged value for later freeze up and earlier break up is 8.7 and 9.8 days respectively in the northern hemisphere; Beltaos, 2002: 11 d/c earlier break up in Canada, Kuusisto, 2003: 13 days earlier break up in Finland).

October and November temperatures do not correlate well with dates of freeze-up at most of the sites, nor do March and April temperatures correlate well with break-up dates.

At higher altidutes river ice break up date correlates with the sum of winter negative temperatures. But in most of the cases break up date correlates relatively good with dates when air temperature becomes above 0^oC in spring. Figure 5 illustrates relationship between river ice break up dates and dates when air temperature crosses 0^oC in spring at the Choibalsan station of the Kherlen and at the Muren station of the Delgermuren River. Also there were found some good correlation between freeze up dates and dates when air temperature becomes below 0^oC in autumn.

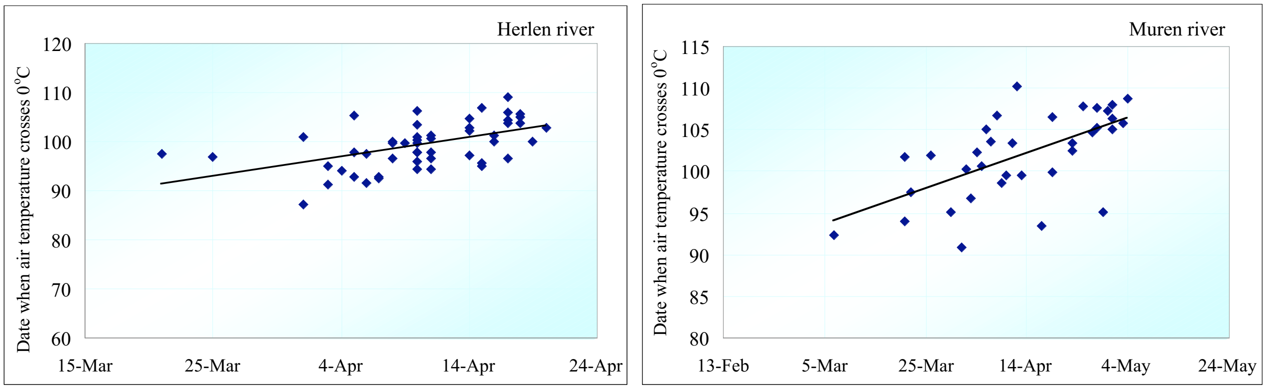

Figure 5. Relationship between dates of break up and air temperature crosses 0°C in spring at the Herlen River (Linear regression: slope=0.40 day/year; R^2=0.28**) and Delgermuren River (**Linear regression: slope=0.21 day/year; R^2=0.38**) r.**

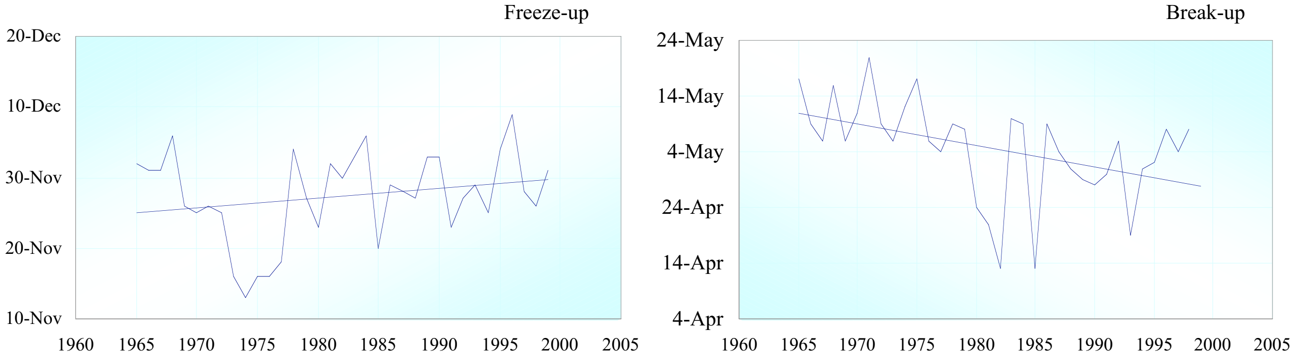

Figure 6. Trends in freeze-up (Linear regression: slope= 0.14 day/year; R^2=0.09, significant level: 50%**) and break-up (**Linear regression: slope=-0.38day/year; R^2=0.19, significant level: 99%**) dates in the Uvs lake locates in the north-western part of Mongolia.**

Freeze-up and break-up dates in Lakes: We also have studied the lake ice in order to better understand the nature of sensitivity of ice to past climate change considering a possible hydraulic effects in addition to climatic impacts in river ice than in lakes. There are only three (Uvs, Khusgul and Buir) lakes that have more or less longer time series on ice measurements.

The Uvs is saline lake that locates in the north-western part of the country. It is the biggest lake in terms of surface area (3350 km^2) in Mongolia. The depression of the Uvs lake is the coldest place in the country. Also the Uvs Lake is one of the Strictly Protected Area of Mongolia and fall within the Altai-Sayan Ecoregion, one of outstanding Global 200 Ecoregions. Data report shows 5 days delay in freeze-up but it is statistically not significant. It has experienced an earlier start of break-up by about 15 days (Figure 6).

The Khuvsgul is the deepest (262 m) fresh water lake in Mongolia, and contains 93 per cent of country's fresh water resources. It is also is the second biggest freshwater lake in Asia. There were about 20 days toward and backward shifts in freeze-up and break-up dates respectively. Similar results have been found in the freshwater lake Buir that is located in the most eastern part of the country.

Changes in dates of freeze up and breakup were similar for lakes and rivers. These changes in river and lake ice dates reflect clear trends in regional climate.

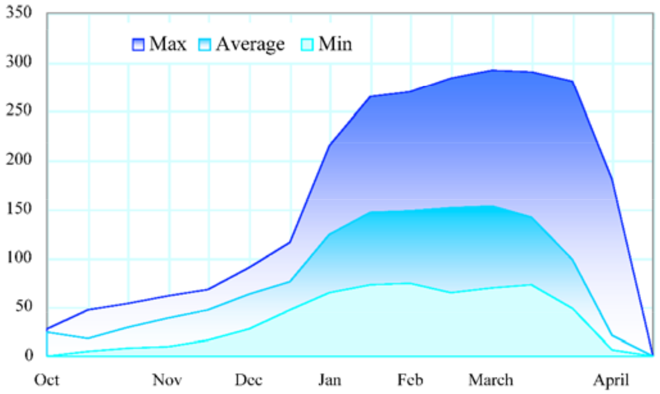

Figure 7. Ice cover growth at the Khanuin River that flows from the northern slope of the Khangain mountains of Mongolia.

Changes in timing of break-up were greater than changes in freeze-up, perhaps because greater warming has occurred in winter than in other seasons. With a delayed start of autumn ice and earlier break-up in Spring, the duration of ice cover on the rivers has shortened considerably.

Maximum ice thickness: Usually ice cover develops with the formation and growth of border ice at the rivers that becomes sufficiently thick in the end of January to be stable and begin growing out across the river. Further grows slowly and reaches its maximum in March (Figure 7). During the ice cover growth, frazil, anchor ice and hanging dams are common.

The climate in Mongolia is strongly continental with large fluctuations between day and night temperatures. Thus, freeze-up dates are sensitive to cooling during night and break-up dates are more sensitive to warming during day, while ice thinkness may reflect the average of day and night. Thus, annual maximum ice thickness could be a more accurate measure of climate change than are ice phenology dates.

The annual maximum ice thickness decreased from the 1960s to 2000 (Figure 8). The decrease was 40-100 cm in rivers flowing from the Mongol Altai, 20-80 cm in rivers flowing from the Khangai and Khuvsgul mountains, and 20-40 cm in rivers flowing from the Khentii mountains (Batima, 2003). Dates of annual maximum ice thickness had no clear trends over the years.

Changes in timing of ice phenology dates, ice thickness differed depending on geographical location: rates of change were much higher in colder regions than in warmer regions. For example: the number of days in delayed start of freeze-up and earlier break-up was longer in the western region (in Mongol Altain mountain's rivers) than in central (Khangai and Khuvsgul mountain's rivers) and eastern region (lower catchment of Knentii mountain's river).

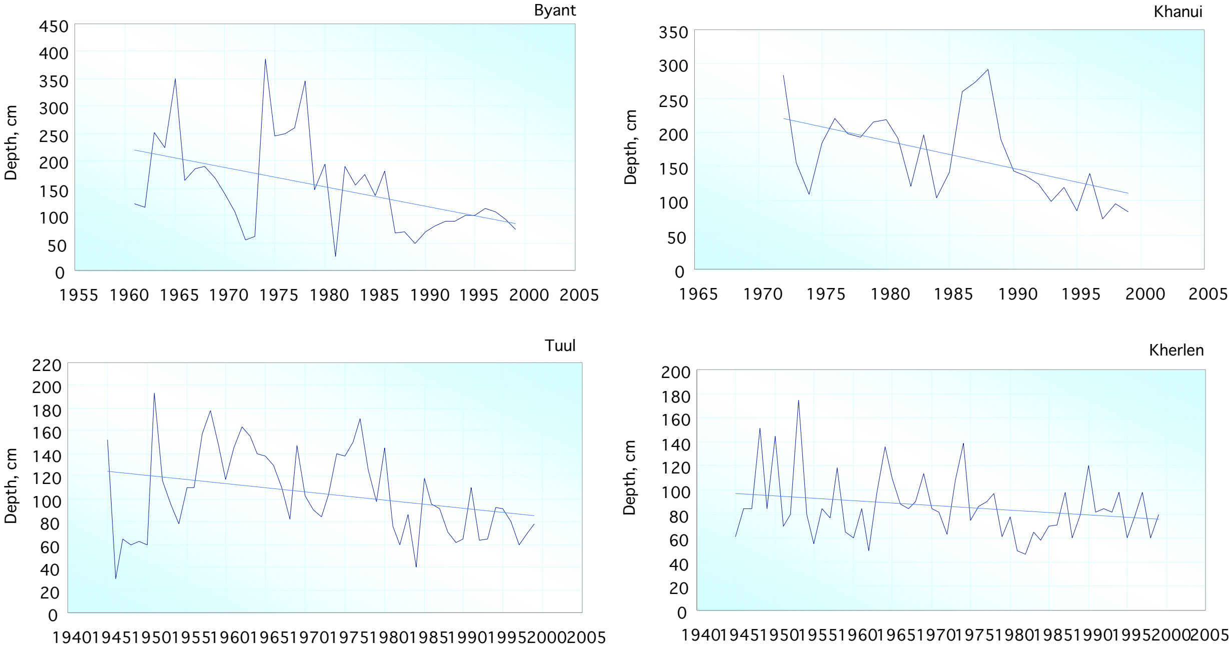

Figure 8. Time series of annual maximum ice thickness in four Mongolia Rivers (Buyant (Linear regression: slope= -3.64 cm/year; R^2=0.22, significance level: 99% **), Khanui (**Linear regression: slope= -4.08 cm/year; R^2=0.28; significance level: 99%**), Tuul (**Linear regression: slope= -0.71 cm/year; R^2=0.12, significance level: 90%**), and Kherlen (**Linear regression: slope= -0.16 cm/year; R^2=0.11, significance level: 90%**). The sites were in the lower catchment of Buyant and Kherlen and the middle catchment of the Khanuin and Tuul Rivers. The River Buyant flows from the Mongol-Altai mountains and the River Tuul flows from the western slope of the Knentii mountain.**

Conclusions

During last 60 years the annual mean air temperature in Mongolia increased by 1.66^{0}C, 3.61^{0}C in winter and 1.4-1.5^{0}C in spring-autumn. Temperature increased most rapidly in March, May, September, and November that are when river ice processes take place.

River and lake ice is an indicator of climate change in Mongolia. Shifts in freeze-up and break-up dates range from three days to a month. Consequently ice cover duration has shortened. Maximum ice thickness has decreased.

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