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Recent Tendency of Mongolian Wildland Fire Incidence: Analysis Using MODIS Hotspot and Weather Data

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ABSTRACT

Mongolian wildland fires are a human-made disaster like some floods as shown by these fire disasters becoming prominent around the 1990s due to opening up of the country. The worst fire losses were in 1996, costing 192% of the GDP. This study reports recent wildland fire incidence and climate relationships analyzed using NASA-MODIS hotspots (fires) and NOAA weather data. Fires are categorized into spring fires from April to June in pasture areas, summer fires in July and August in forested areas, and autumn fires in September and October in forested areas. Fires frequently occur after 10 rainless days, while several millimeters of daily precipitation reduces the extent of fire. A weeklong effective humidity of below 35% coincided with large fires. In the seven most recent years, average temperatures increased by 3.4ºC in July and summer precipitation decreased by about 50%, while the fire disaster intensity increased. The fires were mainly human caused, began at relatively low altitudes after the snow melt in April, and moved to higher-altitude areas in May. From 2001 to 2007, around 30% of forest areas were affected; the Selenge, Khentii, and Dornod provinces were the most fire prone. The severest spring and autumn fires occurred on May 5, 2007 and September 22, 2002.

Keyword: Wildland fire, Global warming, Boreal forest, MODIS, Effective humidity
Short running title: Mongolian Wildland Fires

1. INTRODUCTION

Wildland fires play a major role in determining the spatial and temporal dynamics of forest ecosystems as they degrade forests. In Mongolia, about 95% of steppe and forest fires are human caused (IFFN-26, 2002) or anthropogenic. Fire-susceptible larch and pine forests growing on permafrost are vulnerable to fires. In 1996, the worst forest and steppe fires occurred, with a burnt forest area of 23,636 km^2 and 78,308 km^2 of burnt pastures in a total of 417 fires. During the 1996 to 1998 period, 29 people died, 82 were injured, 11,700 head of livestock perished, and 1,066 communication facilities and 263,000 km^2 of pasture and forest areas were burned. The country suffered large-scale fires in 1968-1969, 1977-1978, 1985-1987, 1991-1992, 1996-1998, and 2000-2002 (Enkthur et al., 2005). Mongolia is vulnerable to climatic extremes and variability with severe droughts frequently occurring in the summer months. In Mongolia, extremely hot weather with record temperatures of up to 60ºC at ground level badly affect hay and crop production and have caused serious forest fires (Nandintsetseg et al., 2007). To implement measures to protect forests from wildland fires, the characteristics of fires and their relation to weather parameters need to be intensively investigated. There are several papers describing various aspects of forest fires in different areas of the world. Hayasaka et al. (2005) described Alaskan large-scale forest fires in 2004 based on weather components. Under climate conditions with higher air temperatures and lower precipitation, large forest fires occurred near Yakustk, Sakha in 2002 (Hayasaka, 2003). However, it is very difficult to find scientific research papers related to forest fires in Mongolia. There are a few reports focusing on weather condition and fire statistics reports (Enkthur et al., 2005). Jacoby et al. (2003) described the temperature and precipitation conditions of Mongolia, and extreme climatic events in Mongolia are explained by Batima et al. (2005). They clarify which weather components are responsible for recent Mongolian climate warming but do not refer to wildland fires.

In this paper, we discuss the recent wildland fire conditions in Mongolia from various scientific points of view. Mongolian wildland fire history, recent wildland fire detection, causes, tendency, and distribution are thoroughly discussed in this paper considering climatic conditions.

2. METHODOLOGY

2.1 Fire (MODIS hotspot) data

MODIS hotspot data are obtained using software developed by NASA based on the NASA ATBD-MOD14 algorithm (Giglio and Descloitres, 2003) where, MODIS geolocation data are used as input. The active fire products of MODIS obtained from Web Fire Mapper (Justice et al., 2002) clearly show and describe hotspot occurrence. Daily hotspot data from January 2001 to October 2007 were visualized and analyzed to determine fire occurrence tendencies. Hotspot data and images acquired by Terra and Aqua (NASA: MODIS Rapid Response System) were analyzed comprehensively to clarify fire trends. ArcView 3.3 software was used to position the hotspots over a digital map of Mongolia. Plotting of hotspots over accurate coordinates of Mongolia was performed with the help of Google Earth software.

2.2 Weather data

This paper analyzes daily weather data from January 2001 to November 2007 obtained from the NCDC Climate Services Branch of the World Meteorological Organization (WMO, 2007). The reliability of historic weather data in recorded and published information of the climate of Mongolia is unfortunately poor, and some abnormal summertime temperature data in the database were disregarded. The weather components considered are temperature in degrees centigrade, precipitation in millimeters, air pressure in hectopascals, relative humidity a percentage, wind speed in meters per second, and wind direction. Weather maps by NACSIS (2007), the Electronic Library Service of the Meteorological Society of Japan, were used and analyzed to elucidate the connection between weather and fire. The wind direction and wind speed data on the Weather Underground website (http://www.wunderground.com/history/) is found to be relatively reliable and thus used for comparison with the NCDC weather data.

3. GENERAL INFORMATION ON MONGOLIA

3.1 Weather

Historical weather records of Mongolia for the Ulaanbaatar weather station are obtained from a data encyclopedia named Rika-nen-pyo (Chronological Scientific Tables). **Figure 1** shows air temperatures and precipitation in Ulaanbaatar. The figure shows that temperatures are increasing considerably in winter. The mean temperature was -3.2ºC from 1891 to 1902, and from 1971 to 1999, this value was -1.3ºC. The annual mean air temperature for Ulaanbaatar has increased significantly, by about 1.9ºC. In Ulaanbaatar, the mean air temperature at present in spring (April-June) is 7.7ºC, in summer (July-August), it is 15.2ºC, and in autumn (September-October), it is 4.2ºC. The maximum air temperature has increased by about 1.8ºC in the last three and half decades. The situation clearly indicates the influence of global warming as the temperature changes in Mongolia are in agreement with worldwide twentieth-century warming (Jacoby et al., 2003). In northern Mongolia, mean temperatures have increased by 1.8ºC in the last four decades (Nandintsetseg and Goulden, 2003).

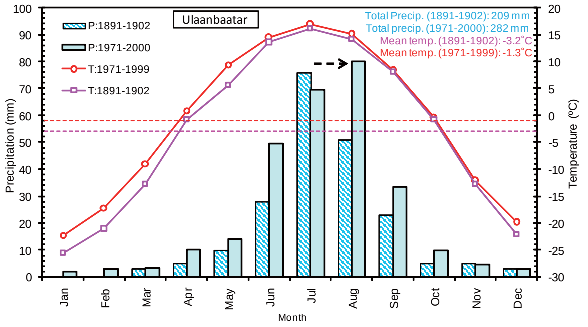

Fig. 1. Air temperature and precipitation in Ulaanbaatar, Mongolia.

[Weather data source: Rika-nen-pyo (Chronological Scientific Tables), Maruzen]

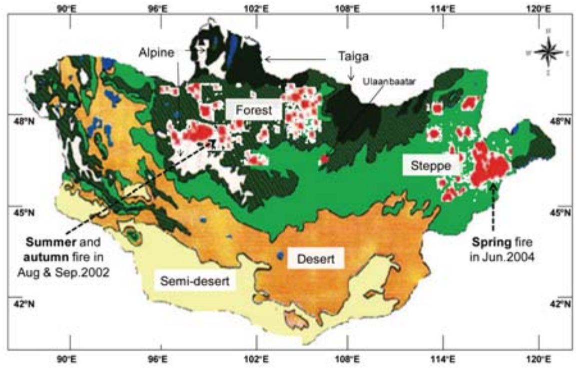

Fig. 2. Vegetation zones in Mongolia.

Figure 1 also depicts precipitation data of the past and present in Mongolia. In recent years, the average value of winter (November-February) and autumn precipitation has increased. Summer precipitation has also increased, but the precipitation peak has shifted from July to August.

3.2 Landscape

Forest and grassland (steppe or pasture and prairie) areas of Mongolia comprise 8.1% and 70% of the total land area of 1,565,000 km^2 (IFFN-26, 2002). It is assumed that most of today's steppe vegetation is on former forest areas that have been degraded by fire. Between 1974 and 2000, about 9.1% (16,000 km^2) of the forest cover was lost. The southern edge of boreal forest and permafrost overlap in the northern part of the country. The northern forested high mountain ranges feature alternating dry areas and lake-covered basins. The pastureland in the transitional zone between the boreal forest and steppe is the so-called forest-steppe zone.

3.3 Vegetation

Figure 2 shows the vegetation zones of Mongolia as well as spring fires in the steppe area and summer and autumn fires in the forest area. The major tree species in the forest is larch (Enkhsaikhan, 1998). The predominating forest species are larch (*Larix sibirica*), pine (*Pinus sylvestris*), birch (*Betula platyphylla*), cedar (*Pinus sibirica*), spruce (*Picea spp.*), and saxaul (*Haloxylon ammodendron*).

The forest-steppe in Mongolia extends over 375,000 km^2 (Wallis de Vries et al., 1996). The northern larch and pine forests in the easternmost forest area and the eastern steppe zone are fire-affected areas that comprise about one fifth (20%) of the total land area. In this area, the high fire incidence is largely due to the dominant light-needled conifers adjacent to the steppe areas. There is boreal forest vegetation in the north in the Selenge, Khentii, and Bulgan provinces (locally called AIMAG), and the areas south of the Dornod and Sukhbaatar provinces are characterized by steppe vegetation.

3.4 Fire history

The history of fires in Mongolia from 1963 to 2000 is shown in **Figure 3** where, the dark bars, and the diagonal line bars show the burnt areas of forest and pasture, respectively, and the line graph shows the number of fires. Annual data from 1963 to 1999 were obtained from the International Forest Fire News (IFFN-26, 2002) country archive of Mongolia. In the 1960s, the mean annual burnt forest and pasture areas were 1,169 km^2 and 3,532 km^2, respectively, with 64 fires recorded. Burnt pasture areas increased considerably in the 1970s and 1980s, and the high-

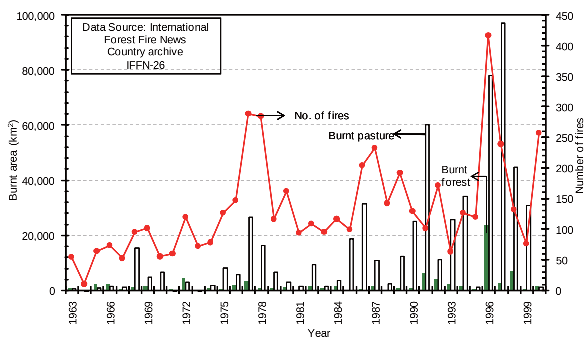

Fig. 3. Details of the fire history of Mongolia (1963 - 2000).

[Data Source: International Forest Fire News, Country archive of Mongolia, IFFN-26, 2002] est number of fires here was 289 in 1977 with 26,727 km^2 of burnt pasture area. In the 1990s, the fire hazard reached the highest level so far. The largest fire episodes in 1996 affected 101,944 km^2 and in 1997, there was 100,010 km^2 of burnt area, a five-fold increase compared with the burnt areas of the previous decade (see **Fig. 3**).

The northern forest areas of Khovsgol, Bulgan, Selenge, Khentii, and Dornod and the pasture areas of Dornod and Sukhbaatar were largely burnt in these fire episodes. Combining the burnt areas of forest and pasture, the third and fourth-largest fires occurred in 1991 and 1998, respectively. The mean annual number of fires was 130 up to 1999, with the incidence of fires increasing decade by decade probably due to ongoing changes in climatic patterns; steppe and forest fires are directly or indirectly related to the recent warming climate (Nandintsetseg et al., 2007) and there has been a major influence on pasture conditions. Recent large-scale fires have changed the forest from a sink to a source of carbon in both tropical and boreal forests due to increases in the incidence of fires and worsening global warming conditions (Hayasaka, 2006).

4. RESULTS AND DISCUSSION

4.1 Recent trends in weather conditions

Precipitation, air temperatures, and fires (hotspots: March to October) from 2001 to 2007 are shown in **Table 1**. The bottom line in **Table 1** represents monthly average precipitation and temperature values from 1971 to 2000; values other than hotspots in **Table 1** show departures from average values for the precipitation (ΔP) and temperature (ΔT).

There are numerous large precipitation ΔP values in **Table 1**. The low precipitation in the summer months of July and August is especially remarkable, and this situation is most directly related to the forest fire incidence in Mongolia. The highest ΔP value was 60 mm for July and August of 2002, which is equivalent to precipitation reductions of -86% and -75%, respectively. The total precipitation in July and August of 2002 was 30 mm (20% of the average), and this affected the fire situation directly. **Table 1** shows the average ΔP for July and August to be 30 mm (-43%) and 44 mm (-56%), respectively, suggesting about a 50% reduction in precipitation in the summer months. The maximum ΔP of 63 mm (-78%) was in August 2004, followed by 42 mm (-60%) in July. Similar values are also shown for July and August of 2001, 2003, 2005, and 2007. The spring fire peak occurs in May (29% of all spring fires, see **Table 2**) though the positive ΔP is somewhat high in May 2001 and May 2003. In both cases, there were significant amounts of precipitation (total precipitation of 36 mm in May 2001 and 52 mm in May 2003) after the appearance of the fire peaks. In June 2004, total precipitation was 3 mm and 82 mm before and after fire peaks. Therefore, **Table 1** suggests that recent summertime (July and August) precipitation is greatly decreasing in Mongolia and that these two months of relative

Table 1. Recent changes in precipitation and air temperature in Mongolia.

Year	No. of Hotspots (Mar.-Oct.)	ΔP (Precipitation) mm								ΔT (Temperature) ºC							
		Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
2001	1179	1	16	26 *(4+36)	-10	-58	-30	-15	-7	1	1	0	3	2	2	2	1
2002	7295	3	3	37	5	-60	-60	-18	2	3	0	1	4	5	4	1	-3
2003	2429	-2	-8	38 *(0+52)	-28	-2	-58	8	-7	0	2	0	2	2	-1	1	0
2004	3554	3	4	6	35 *(3+82)	-42	-63	1	-7	-2	4	1	4	3	2	2	0
2005	2886	1	0	-1	-25	-26	-37	-9	-9	-1	1	0	3	5	3	1	2
2006	4409	0	-4	57	-22	15	-54	-17	0	2	-2	-1	2	2	3	2	1
2007	7598	8	-5	5	-26	-36	-9	-33	-8	-2	2	3	5	5	4	4	-1
Average departure		2.0	0.9	24.0	-10.1	-29.9	-44.4	-11.9	-5.1	0.1	1.1	0.6	3.3	3.4	2.4	1.9	0.0
Average (1971-2000)		3.3	10.0	14.0	49.5	69.5	79.9	33.5	9.9	-9.0	0.9	9.4	14.4	16.9	15.1	8.3	-0.3

ΔP and ΔT show departures from average precipitation and average temperatures, respectively. Values in bold font and solid rectangles represent very large departure values and months with the highest fire incidences, respectively.

* Precipitation before and after fires in May 2001, May 2003, and June 2004.

[Calculations were performed based on NCDC weather data from Ulaanbaatar weather station, Mongolia.]

Table 2. Monthly hotspot incidence in Mongolia (2001 - 2007).

Month	Year							Monthly total (%)	% of hotspots
	2001	2002	2003	2004	2005	2006	2007		
Mar.	3	3	10	4	14	28	17	79(1%)	Spring 57%
Apr.	241	146	356	199	234	1790	322	3288(11%)	
May	598	103	1314	203	618	1740	4035	8611(29%)	
Jun.	117	62	231	2249	391	287	1424	4761(16%)	
Jul.	8	290	123	333	106	35	942	1837(6%)	Summer 12%
Aug.	42	1509	22	54	10	22	97	1756(6%)	
Sep.	169	4983	18	197	140	179	468	6154(21%)	Autumn 31%
Oct.	1	199	355	315	1373	328	293	2864(10%)	
Total	1179	7295	2429	3554	2886	4409	7598	29350	100%

[The hotspot data source is the University of Maryland, NASA/GSFC, FIRMS, Maryland, USA.]

drought affect the forest fire occurrences in autumn.

Temperature increases in June and July are noticeable and have a strong influence on fire incidence. In recent years, there have been abnormal temperature departure (ΔT) values in June and July (see **Table 1**). A ΔT of 5ºC occurred in July of 2002, 2005, and 2007; in June, the ΔT reached 4-5ºC. The average ΔT for June and July was 3.3ºC and 3.4ºC. For 2007, the records show the largest ΔT of 5ºC for June and July. This situation suggests that the air temperature in Mongolia has increased in the summer months, June and July, at a rate of about 3ºC. Average ΔT values (**Table 1**) suggest a situation of climatic change in Mongolia, with the highest hotspot peak in September 2002 following 4 to 5ºC temperature rises in the previous three months. This situation undoubtedly affects the fire incidence in Mongolia, which has reported rapid warming during the past several decades (IPCC, 1992; 1996). Very low precipitation or drought conditions in association with considerable temperature rises resulted in the largest autumn fires in September 2002 and largest spring fires in May 2007.

Precipitation is an important factor in controlling fires because rain is the only natural extinguisher of fires, and precipitation also strongly influences soil moisture as well as the availability of fuel for fires. Miyanishi and Johnson (2002) reported that soil moisture in the organic matter containing layers of soil plays a critical role in smoldering combustion of deeper organic horizons. **Figure 4** shows the relationship between precipitation and hotspot numbers from 2002 to 2007, where the horizontal axis represents precipitation in millimeters and the vertical axis represents the number of hotspots. Each data point in the graph represents the value of hotspot numbers and the corresponding amount of precipitation in a one-day period. A period of 20 days was taken into consideration for precipitation and hotspot occurrence and is designated as DN (Day Number) in the figure. **Figure 4** clearly illustrates that the maximum number

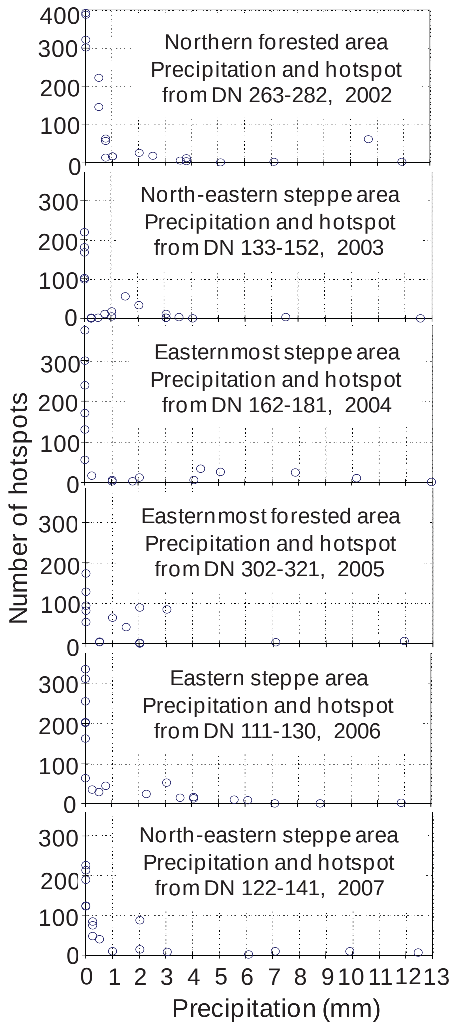

Fig. 4. Precipitation versus hotspot numbers 2002 - 2007.

of hotspots was found under zero-precipitation conditions, and this situation is common in the case of 2004, 2005, 2006, and 2007. Moreover, an increase in the amount of precipitation decreases the number of hotspots greatly. We may say that several millimeters of precipitation is effective in suppressing hotspots or fires (see **Fig. 4**).

4.2 Recent fires

4.2.1 Recent fire detection

Figure 5 shows areas burnt by fires obtained from satellite data and official data records for 2001 to 2007. Burnt areas at hotspots were estimated assuming that one hotspot is equal to 1 km^2 and that there is no overlap among hotspots. Annual burnt area data from official records for 2001 to 2007 were collected from the National Remote Sensing Center (NRSC), Mongolia, and data on burnt forest and pastures showed the highest values in 2007 with values of 9,081 km^2 and 21,400 km^2. The fire history for 1963~2000 differs from the recent 2001~2007 data and shows a different pattern. Recent Mongolian satellite official data records are inadequate and unreliable, and based on MODIS Aqua and Terra images, satellite data are sometimes unable to detect pasture fires well under thick cloud layers and dense smoke as occurred in 2003. There is also the possibility of data overlap, which could have occurred in 2002. Additionally, satellite remote sensing is not used systematically to assess the extent and impact of fires (FAO, 2006). From 1996 to 1998, about 788 fires were detected primarily by satellite, helping to limit destruction considerably. The accuracy of detected fire hotspots (detection rate) is estimated to be 76.9% of the total number of fires from 1995 to 1999 (IFFN-26, 2002). But to investigate the fire situation precisely for a country like Mongolia, it is useful to rely on satellite data other than those of official data records.

Figure 6 illustrates forest fires captured by the Terra satellite in Zavkhan province on September 22, 2002. The location of the fire area is the south of the subdivisions (locally termed SUM) Tosontsengel and Ikh-Uul. This fire area is about 138 km northeast of the provincial capital Ulaistai. The area is characterized by dense forest on the northern slopes of high mountains with elevations of about 2500 m.

An approximate estimate of burnt areas from the number of hotspots has been calculated for the above fire area. Based on the calculations of hotspot occurrences in 2002, the estimated total burnt area is twice the burnt area of the fire reports, suggesting large disparities between fire reports and satellite data for 2002 and 2003. This implies that the fire data from the Mongolian Remote Sensing Center may contain human error or that fire detection by satellite was not ideal for 2002 and 2003.

From 2001 to 2007, the monthly hotspots detected by MODIS are presented in **Table 2**. The percentage of monthly and fire season hotspot incidence is also shown in **Table 2**. Based on seasonal hotspot occurrence, spring, summer, and autumn fires comprise about 57%, 12%, and 31% of the total number of fires. The largest number of hotspots was 8,611 (29%) in May, the second-highest number of hotspots was 6,154 (21%) in September, and the third highest was 4,761 (16%) in June. The number of summer fires

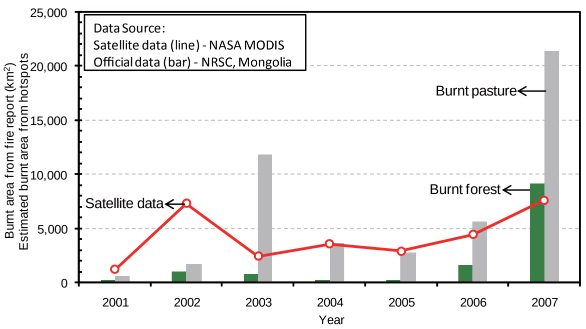

Fig. 5. Satellite data and fire report data on burnt areas 2001 - 2007.

[Data source: Satellite data – NASA MODIS and official record for burnt area – National Remote Sensing Center, Mongolia]

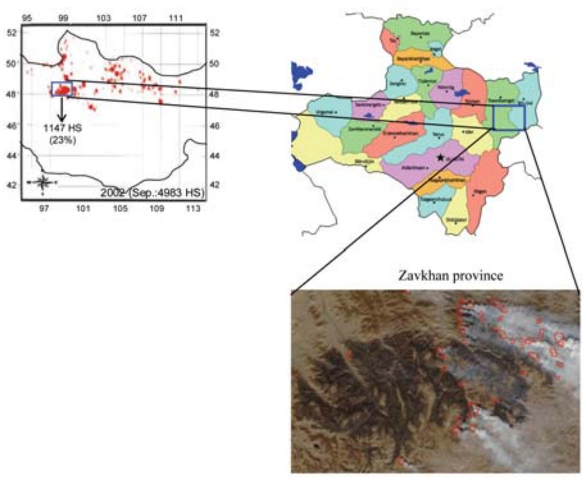

Fig. 6. Forest fires in Zavkhan province recorded by Terra on September 22, 2002.

is small because summer has the highest seasonal precipitation. Therefore, May and September can be regarded as the most fire-prone months in spring and autumn respectively in Mongolia.

4.2.2 Large fires

Figure 7 illustrates the distribution of hotspots (fires) in the latest seven years (2001-2007) across Mongolia. The recent fire distribution in **Figure 7** clearly shows that the majority of fires occurred in the northern and eastern forest and steppe regions. The northern forested high mountains (average altitude of about 1500 m) and the eastern steppe (average altitude of about 800 m) areas are affected by fires almost every year. Fires in Selenge, Khentii, and Dornod occurred every year. There were fires in Bulgan in 2002, 2003, 2005, and 2007, and in Sukhbaatar in 2004, 2005, and 2006. From the distribution of hotspots and measurements utilizing Google Earth software, it can be estimated that about 30% (52,500 km^2 of 175,000 km^2) of the total forest area was affected by fires. The pastureland of the forest-steppe zone is severely prone to fires. The western mixed forest area and southern semi-deserts and deserts can be regarded as fire-free areas.

Figure 8 shows the fire incidence using daily hotspot data from March 2001 to October 2007. **Figure 8** also has daily data on precipitation and air pressure. The day number in **Figure 8** is by the Julian Day calendar (day number counted from January 1st). Mongolian fires were classified into three categories: spring fires from April to June, summer fires in July and August, and autumn fires in September and October. Analysis of the hotspot data yields a distinct autumn fire peak in forested areas with 665 hotspots on September 22, 2002 (see **Fig. 8**). The severest spring fire was on May 5, 2007 with 630 hotspots. Most of the fire peaks appear within two to five days of the start of the fire, suggesting that fires in Mongolia have a strong relationship with climatic conditions. In recent years, pasture fires occurred every spring except in 2002. Summer fires in July and August and autumn fires in September and October occurred in both forest and pasture areas in 2002, 2003, 2005,

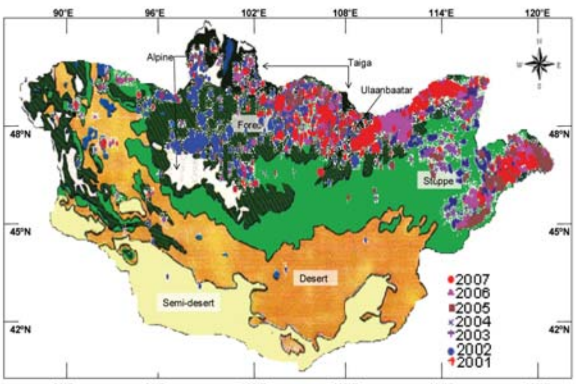

Fig. 7. Hotpot (fire) distribution in forest and steppe areas of Mongolia (2001 - 2007).

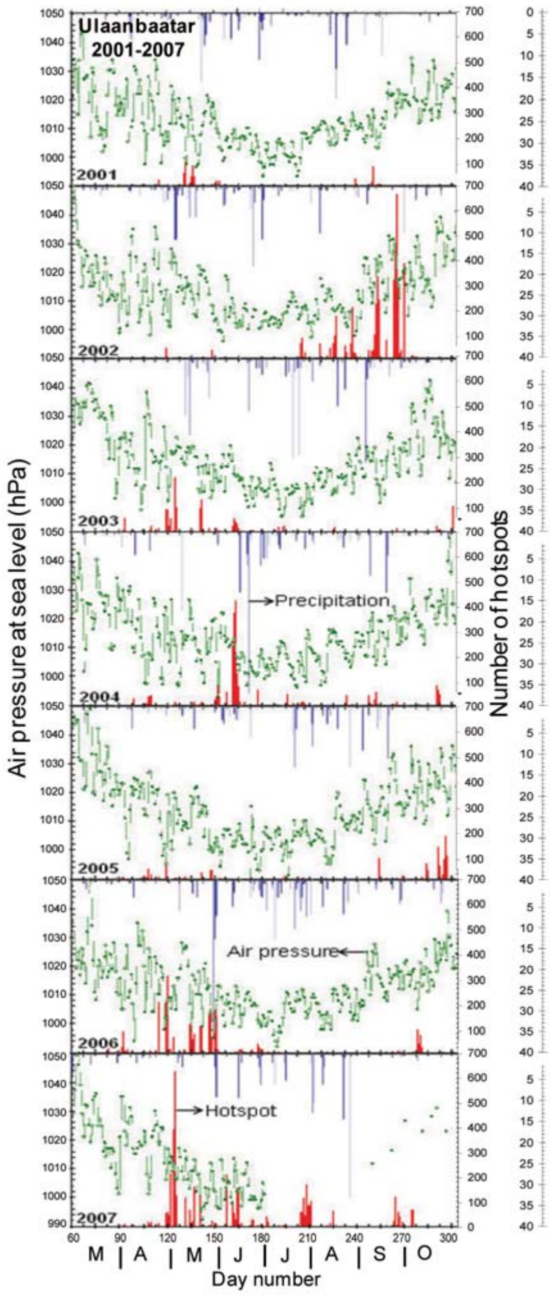

Fig. 8. Fire occurrence tendency using hotspots. (Precipitation, bars from top of figures; hotspots, bars from bottom of figures; air pressure shown by line graphs) [Weather data source: NCDC, Ulaanbaatar weather station, Mongolia]

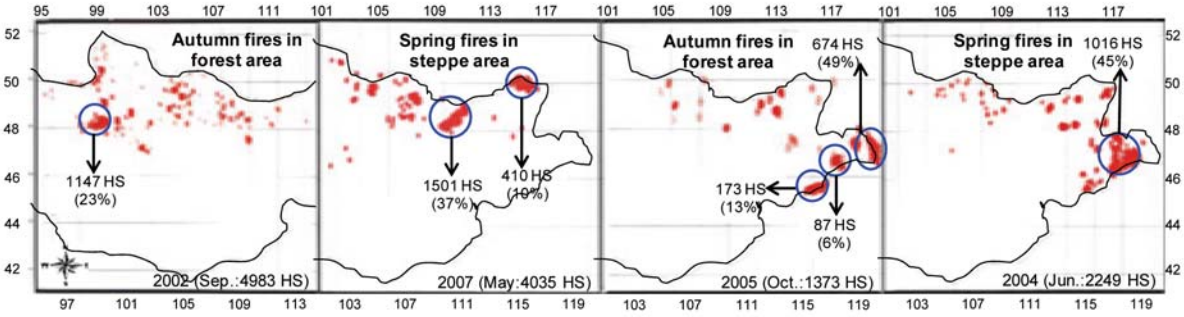

Fig. 9. Location of the most recent four largest fires in Mongolia.

[HS: Number of hotspots in a fire. The numbers in parentheses are the ratios of all hotspots in this month.]

and 2007 (**Fig. 8**). **Figure 9** illustrates the locations and percentage of hotspots for the four largest fires in Mongolia. The recent two largest autumn fires were in September 2002 and October 2005. About 23% of fires (1147 hotspots) were in the forest areas of Zavkhan province in September 2002, while 49% fires (674 hotspots) were detected in the easternmost forest areas of Dornod province in October 2005. There were spring fires in Khentii and south Dornod provinces in May 2007 and June 2004, respectively.

About 37% of fires (1501 hotspots) in Khentii and 45% fires (1016 hotspots) in Dornod were in steppe vegetation. From the location of the hotspots, the forest and steppe areas of Selenge, Khentii, and Dornod provinces are the most fire prone in Mongolia. A notable feature of Mongolian fires is that the appearance of the largest fires occurs following several rainless days. Fires frequently occur when precipitation is zero or very low. All the fire peaks in recent years appear after droughts or 10 to 13 rainless days, and **Figure 10** shows the top four fires among those that followed rainless days. The flat, unchanging, accumulated precipitation indicates drought because the increments in accumulated precipitation is near zero. However, summer and autumn fires are greatly influenced by rainless days or drought conditions as well as by the increased temperature. In recent years, the largest autumn fire (September 22, 2002) and the largest spring fire (May 5, 2007) incidence occurred under high-temperature and severe drought conditions. Overall, about two weeks of drought or days without rain could trigger devastating fires in Mongolia. Subsequently, reductions in effective humidity as well as a low moisture content of the vegetable matter as fuel and an ambient micro-environment enhance any fires occurring at this time. Frequent spring fires every year (except 2002) occur after very low precipitation from November to March. Summer fires in July and August would not occur because the relatively large monthly precipitation of more than 75 mm prior

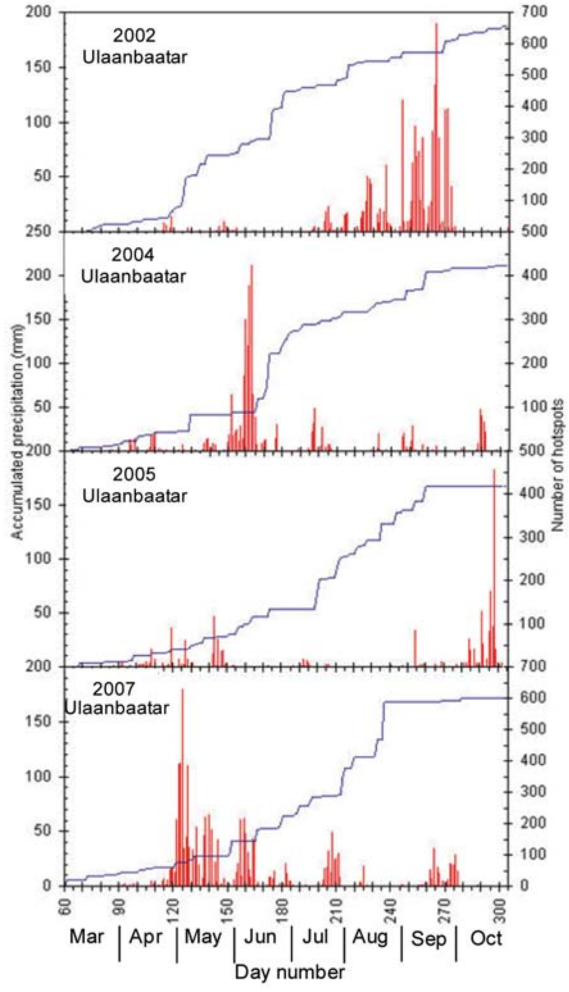

Fig. 10. Accumulated precipitation plotted with hotspot numbers

(March - October 2002, 2004, 2005, and 2007).

[Weather data source: NCDC, Ulaanbaatar weather station, Mongolia] to July would suppress them.

Severe summer and autumn fires would occur under drought conditions as happened in 2002, 2004, and 2007. In 2002, fires started in mid July and lasted until the end of September, with a total number of hotspots of 7,295. The highest number of hotspots (7,598) was in 2007 with prolonged fires from late April to early August. The highest number of hotspots in autumn was 665 occurring on September 22, 2002 after a cold front had passed on September 16 and 17 after 40 days of drought (August to September) conditions.

4.2.3 Fire propagation

There is a rapid air temperature rise of about 10ºC per month in spring (**Fig. 1**) especially from March (-9˚C) to May (9.4˚C), and the average air temperature rises above freezing in April resulting in snow melting. The occurrence of spring fires in April and May could be closely related to snow melting because vegetation in pasture areas is exposed to air just after the snow melting and thus becomes good fuel for fires. Flammable long grass fuels dry more easily and earlier than those of forest stands. Northerly winds (3~5 m/s) accelerate fire phenomena in April, while fuel in mixed forest and pasture areas take more time to dry and become flammable. Fires ignited at low altitudes start to spread to higher altitudes and subsequently, the forest areas are ignited slightly later than the pasture areas. **Figure 11** shows the propagation of fires from relatively low- to relatively high-altitude areas in spring; fires start comparatively late in forest areas, namely in May. Each data point represents an independent fire that was found to ignite in the steppe area in early spring and with the advancement of time, fires gradually occurred in the forest area. To obtain vegetation area information, Google Earth software is used. Each fire point was checked for steppe, forest-steppe, and forest through Google Earth images. The vegetation zones are also clearly shown in **Figure 2**. However, fires tend to start after snow melting in April (0.9ºC) and end around the start of snowfall in October (-3ºC); overall, the dried fuels of pasture areas ignite earlier than those of mountainous forest and pasture zones and consequently, fires spread towards higher altitudes.

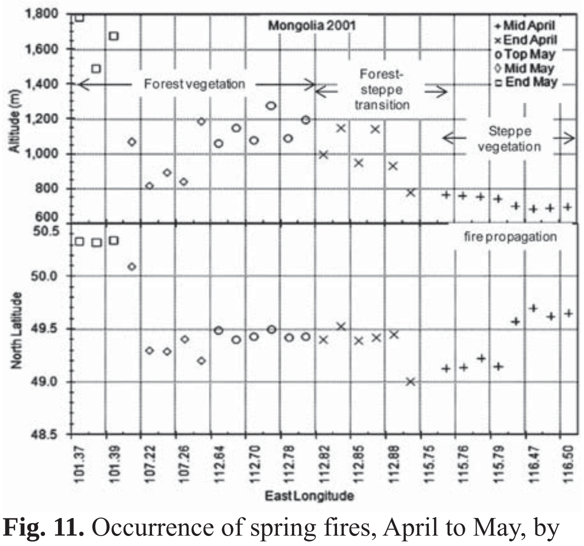

Fig. 11. Occurrence of spring fires, April to May, by longitude versus latitude and altitude.

Steppe (pasture) fires occur regularly in the relatively lower eastern part of Mongolia. Fires in lower-altitude (800 m) pasture areas tend to start from April when the temperature rises above 0ºC, while fires in higher-altitude (about 1500 m) forests and pasture areas start from May (**Fig. 11**) when the average temperature rises above 9ºC. In winter, vegetable matter at low altitudes subject to an absence of precipitation promotes the starting of fires in April. The high-altitude mountainous regions are cooler than the low-altitude pasture regions and the average altitude in the mid-sized mountains reaches 1500-1600 m while the mean altitude of pastures or valleys is 800-900 m. In spring, low-altitude pasture areas of about 700 meters are affected by fires; in April, fires occur here especially on southern and western slopes.

4.2.4 Effective humidity

Effective humidity can be used as an indicator of fire-promoting conditions in Mongolia; many fire phenomena have been explained using effective humidity. Humidity close to mountain barriers and away from the ocean is typically low, and the effective humidity for peak fire weeks was calculated to evaluate the moisture content that was directly related to fire phenomena. The results are presented in **Table 3**. The effective humidity for a peak fire week and the corresponding month was calculated using Equation (1),

$$He = (1-r)\,(H_0 + rH_1 + r^2H_2 + \ldots) \qquad (1)$$

where He = effective humidity; r = a constant (here, 0.7 is used); H_0 = humidity of the current day; H_1 = humidity of the previous day; H_2 = humidity two days before; and so on.

Table 3 describes the effective humidity and

Table 3. Effective humidity and precipitation in peak fire weeks.

Year	Peak hotspot number	Effective Humidity (H_{e7}), % (Peak fire week)	Effective Humidity (H_{em}), % (2001~2007)	Precipitation mm (Peak fire week)	Monthly avg. precipitation (1971~2000)
2001	160 (DN 132)	26 (DN 126-132)	37 (May)	1.0 (DN 126-132)	14.0 mm
2002	665 (DN 265)	32 (DN 259-265)	58 (Sep.)	0.0 (DN 259-265)	33.5 mm
2003	220 (DN 125)	22 (DN 119-125)	42 (May)	0.0 (DN 119-125)	14.0 mm
2004	423 (DN 163)	22 (DN 157-163)	65 (Jun.)	0.0 (DN 157-163)	49.5 mm
2005	455 (DN 298)	43 (DN 292-298)	54 (Oct.)	0.0 (DN 292-298)	9.9 mm
2006	336 (DN 113)	33 (DN 107-113)	36 (Apr.)	1.0 (DN 107-113)	10.0 mm
2007	630 (DN 125)	21 (DN 119-125)	28 (May)	0.0 (DN 119-125)	14.0 mm

DN: day number by the Julian Day calendar

H_{e7}: effective humidity of peak fire weeks

H_{em}: effective humidity of peak fire months

[Effective humidity was calculated based on weather information from Ulaanbaatar weather station, Mongolia.]

precipitation of peak fire weeks as well as the corresponding months. **Table 3** shows that an effective humidity below 35% for one week was a good indicator of big fires in Mongolia except in 2005. The effective humidity and precipitation was very low at the time of a fire peak, and precipitation was 0 for all the fire peak weeks except in 2001 (1 mm) and 2006 (1 mm). The prevailing condition of more than 10 rainless days affected effective humidity reduction in the peak fire weeks and was one of the major factors that resulted in large fires.

5. CONCLUSIONS

Mongolian wildland fires and their relation to weather parameters were analyzed using MODIS hotspot and weather data. The conclusions from the discussion may be summarized as follows:

1. Wildland fire disasters in Mongolia were categorized into three kinds: spring fires in pasture areas, summer fires, and autumn fires both in forest areas. Low winter precipitation (monthly average <20 mm) and an air temperature rise of about 10ºC from March to May could trigger spring fires after snow melting in April. Fires in pasture areas occurred every spring except 2002. Recently, the largest spring fire happened in May 2007 with 630 hotspots.
2. Summer fires occurred in forest areas in July and August of 2002, 2004, and 2007 under long drought conditions. But fires did not occur when there was average, normal monthly precipitation (60-90 mm). Reductions in the extent of fires were observed with daily precipitation of at least 10 mm.
3. Autumn fires occurred mainly in forest areas under drought conditions with more than 10 rainless days in 2002, 2003, 2005, and 2007 when the effective humidity decreased to below 35%. The largest autumn fires happened in September 2002 with 665 hotspots.
4. Wildland fires in Mongolia tend to start soon after snow melting and end around the time that snowfall starts. Fires tend to start from low-altitude (about 800 m) pasture areas in April and gradually move to relatively high-altitude (about 1500 m) forest and pasture areas in May.
5. In the last seven years, around 30% of Mongolian forest areas have been affected by fires. The forest and steppe areas of Selenge, Khentii, and Dornod provinces were the most fire prone. In recent years, May and September were the months with the highest fire incidence.
6. Under global warming conditions, the years 2001 to 2007 have seen temperature increases of 3.4ºC in July and summer with precipitation decreases of about 50% when compared to the last three decades (1971-2000).

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REFERENCES

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

Enkhsaikhan, D., 1998. State of forest resources in Mongolia. In: Proceedings Ecology and Sustainable Development, Vol.3, Ulaanbaatar.

Enkthur, D., Chuluunbaatar, T., Olzvoi, D. and D. Zezenbat, 2005. Report on the Mongolian delegation to the consultation of the regional central Asia wildland fire network, Irkutsk, Russian Federation. p.8.

FAO Forestry Paper-151. Fire management-global assessment 2006. p.76. ftp://ftp.fao.org/docrep/fao/009/a0969e/a0969e00.pdf

Giglio, L. and J. Descloitres, 2003. "An Enhanced Contextual Fire Detection Algorithm for MODIS." Remote Sensing of Environment 87(2-3): 273-282.

Hayasaka, H., 2006. Forest fires in tropical and boreal forests. In: International Workshop on Tropical Rain Forest and Boreal Forest Disturbance and Their Affects on Global Warming, Palangka Raya-Indonesia.

Hayasaka, H., Nakau, K., Kushida, K., Fukuda, M., Martyn, P. and T. DeFries, 2005. Alaska large forest fires in 2004 and weather - discussion based on satellite and weather data. The 6th Symposium on Fire and Forest Meteorology/Interior West Fire Council Conference, Canmore, AB.

Hayasaka, H., 2003. Forest fires and climate in Alaska and Sakha: Forest fires near Yakutsk. The 5th Symposium on Fire and Forest Meteorology and the 2nd International Wildland Fire Ecology and Fire Management Congress, Orlando, FL.

International Forest Fire News (IFFN)-26, 2002. Fire situation in Mongolia. Global fire monitoring center (GFMC), pp.75-83.

IPCC, 1992. Climate change 1992. In The Supplementary Report to the IPCC Scientific Assessment, Houghton J. T., Callander B. A.,Varney S. K. (eds). Cambridge University Press: Cambridge; 200.

IPCC, 1996. Climate change 1995. The science of climate change. Technical summary, (eds) J. T. Houghton, L. G. MeiraFilho, B. A. Callander, N. Harris, A. Kattenberg,K. Maskell, Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge.

Jacoby, G., Pederson, N. and R. D'Arrigo, 2003. Temperature and precipitation in Mongolia based on dendroclimatic investigations, Chinese Science Bulletin, 48 (14): 1474-1479.

Justice, C.O., Giglio, L., Korontzi, S., Owens, J., Morisette, J.T., Roy, D., Descloitres, J., Alleaume, S., Petitcolin, F., and Y. Kaufman, 2002. The MODIS fire products. Remote Sensing of Environment, 83: 244-262

Miyanishi, K. and E. A. Johnson, 2002. Water relations of forest fuels. Forest Fires – behavior and ecological effects. pp.96-137. Academic press, USA.

Nandintsetseg, B., Greene, S. and C. E. Gouldenc, 2007. Trends in extreme daily precipitation and temperature near lake Hovsgol, Mongolia. International Journal of Climatology, 27: 341-347.

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

National Center for Science Information Systems (NACSIS), 2007. http://www.wtec.org/loyola/digilibs/c_10.htm

Wallis de Vries, M. F., Manibazar, N. and S. Dugerlham, 1996. The vegetation of the forest-steppe region of Hustain Nuruu, Mongolia. Vegetatio, 122: 111-127.

World Meteorological Organization (WMO), 2007. Resolution 40, NOAA policy. http://www.ncdc.noaa.gov/cgi-bin/res40.pl?page=gsod.html