Recent Vegetation Fire Incidence in Russia

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Abstract

MODIS hotspot data from NASA have now become a standard means of evaluating vegetation fires worldwide. Remote sensing is the most effective tool for large countries like Russia because it is hard to obtain exact, detailed forest fire data. Accumulated MODIS hotspot data of the nine years from 2002 to 2010 may allow us to assess recent changes in the vegetation fire incidence in Russia. This kind of analysis using various satellites is useful in estimating fire intensity and severity, burnt area, fire return interval and emission of greenhouse gases such as CO_2. This paper discusses recent changes in the incidence of vegetation fires across the entire area of Russia based on analysis results of MODIS hotspot data. Firstly, Russia and its vicinity (covered area: 40°-75°N, 30°-180°E) were divided into 135 regions with equal intervals of 5° latitude and 10° longitude. Introducing an annual mean hotspot density measure (AMHD, number of hotspots/km^2/yr), enabled Russian regional and seasonal fires to be analyzed and compared. In addition to this analysis, a detailed analysis was carried out for the Yakutsk region of Sakha using long-term weather data from 1830 to the present, recent daily weather data, hotspot data in 2002 and other data. The background to the intense fire activity near Sakha was determined by considering drought conditions and daily changes of air temperatures.

Key words: Boreal forest, burnt area, hotspot, MODIS, vegetation fire

1. Introduction

The Russian Federation is the largest country in the world with a total area of 17,075,400 km^2, occupying nearly a third (31%) of Eurasia, the total area of which is about 54,492,000 km^2. It is located in the northeastern part of the Eurasian continent. This area is dominated by boreal forest, or taiga, which has a total area of about 12,000,000 km^2, comprising about a third of the world's forest cover. About 70 percent of the world's boreal forest is in Eurasia, mostly in Russia. Russia contains about 6,200,000 km^2 of boreal forest (Tchebakova *et al*., 1994).

At least two large fires occurred in Russia in the first decade of the new century. In 2002, many large-scale forest fires occurred near Yakutsk, the capital of the Sakha Republic in Siberia, burning a total area estimated at over 23,000 km^2 – the largest reported in Sakha since 1955 and about ten times greater than mean burnt area of protected forests, or about 2,400 km^2. In 2003, forest fires near Lake Baikal in Siberia were especially severe, and the total burnt area in Russia (Siberia) that year was estimated in excess of 234,000km^2.

Studies on forest fires in vast areas of Russian taiga are continuing intensively from various points of view. Remote sensing is one of the most effective tools for large countries like Russia because it is very hard to obtain exact and detailed forest fire data. MODIS hotspot data from NASA has become a standard method for evaluating vegetation fires worldwide. Moderate Resolution Imaging Spectro-radiometer (MODIS) on board the NASA Earth Observing System Terra and Aqua satellites provides global fire observation of unprecedented quality (Csiszar *et al*., 2005). According to Mouillot and Field (2005), the burned area has increased since the 1980s, probably a reflection of decreased funding for fire fighters. Due to such policies, recent fire activity in the southern part of Far East Russia, near the border with China, and in Mongolia, may have increased. In addition, Kasischke (2000) reported that during summer, the risk of fire was high in this region due to relatively low rainfall (averaging < 300mm). Campbell and Flannigan (2000) reported that recent trends toward warmer, drier summers associated with global climate change are expected to increase the number and size of boreal forest fires. Recent regional fire events appear to support these predictions. Flannigan *et al*. (2009) reported that to date, research suggests a general increase in area burned and fire occurrence but there is a lot of spatial variability, with some areas of no change or even decreases in area burned and occurrence. Tchebakova *et al*. (2009) concluded that in a warming climate, fuel load accumulates due to replacement of forest by steppe together with frequent fire weather promoting high risks of large fires in southern Siberia and central Yakutia, where wildfires would create habitats for grasslands because the drier climate would no longer be suitable for forests. Conard and Davidenko (1998) reported that the large percentage of human-caused fires in Russia's boreal ecosystems suggests the critical importance of fire management and fire suppression for maintaining desirable fire regimes and preventing decreases in fire-return interval and loss of carbon storage in these ecosystems.

In this paper, recent changes in the incidence of vegetation fires across the entire area of Russia are discussed using analytical results of MODIS hotspot data (more than 3 million) from 2002 to 2010. In addition to this analysis, a detailed analysis is carried out for the Yakutsk region of Sakha using long-term weather data and other data. The background to the intense fire activity near Sakha is discussed by illuminating drought conditions and daily changes in air temperatures (Hayasaka, 2003, 2004).

2. Data & Methods

2.1 Satellite data

Satellite image and hotspot data were obtained courtesy of the MODIS Rapid Response Project at NASA/GSFC. Terra and Aqua acquired more than three million hotspot data for the study area (Russia and vicinity: 40°-75° north latitude (N), 30°-180° east longitude (E)) for the period 2002-2010. (Aqua was not launched until July 2002, therefore there are usually fewer fires reported for 2002.)

To discuss recent activity of vegetation fires in Russia, this paper introduces annual mean hotspot density (number of hotspots/(km^2 yr)). As the area of Russia and vicinity is enormous, the above mentioned study area (30°-75°N, 30°-180°E) was equally subdivided by five degrees in latitude and ten degrees in longitude. This made a total of 135(=7×15) regions. However, the distance of any certain degree in longitude varies according to its latitude value, so seven different areas of each region have to be calculated considering latitude values. In this paper, the approximate area of each region was calculated by using the distances of the latitude and longitude intersecting at the center of each region.

2.2 Climate and forest fire data

Weather data measured at Yakutsk, Sakha obtained from Russian scientists (personal communication) were used to discuss the effect of weather conditions on fire activity. Monthly mean temperature data from May of 1829 to 2009 and daily mean temperature from January 1 of 1930 to 2007 were analyzed.

Monthly precipitation data from January of 1891 to 2009 were analyzed. Forest fire history data (only number of fires and burnt area of each year) provided by the Sakha Ministry of Forestry and private communication with Russian scientists (personal communication) were used to determine fire trends from 1955 to 2009.

3. Study Areas

In this study, two study areas were used. The first one was for the entire region of Russia (30° to 75 °N, 30° to 180°E) to grasp vegetation fire tendencies in Russia and nearby countries. The second one was for the Sakha region (59° to 65°N, 117° and 134°E) to discuss local forest fire activity in Siberian boreal forests.

3.1 Overview of Russia

Figure 1 provides a map of Russia and its vicinity. There are several countries in this map. The major countries are Russia, Mongolia, China, Kazakhstan and Ukraine. Russia roughly covers 41° - 82°N, and 19° - 169°E. Moscow, the capital of Russia, is located near the east side of Europe. Most of the area of Russia is in the region called Siberia. The Yenisey River, one of the major rivers of Russia, runs from south to north and is found in the center of map in Fig. 1. This river divides Siberia into West and East Siberia. The west side of West Siberia covers the Ural Range. The east side of East Siberia ends at the border with Sakha (about 106°-112°E). The region to the east of this border is called the Russian Far East.

Most of Siberia has a subarctic climate with severe winters, very cold but relatively low precipitation. Mountains in the south of Russia block the flow of warm air masses from the Indian Ocean while cold air masses from the Arctic sea enter through the plains on the west and north. Either June or August is the wettest month for most of Siberia, but monthly precipitation is less than 100 mm.

3.2 Boreal forest (taiga) in Russia

Figure 2 provides a map of forest distribution in Russia. Other major eco-regions in Russia are Arctic tundra in the northernmost area and grassland (steppe) and semi-desert in the southern area.

In Russia, about 50% of the land area (8,500,000 km^2) is covered by forest. Around 77% of the forest consists of conifer trees (larch 36%, pine 19%, spruce 15%, Siberian pine 7% (area based %)). Russia has about half the conifer trees in the world and a third of the taiga.

West Siberia has the so-called dark taiga composed mainly of spruce and cedar (SC in Fig. 2). On the contrary, forests in East Siberia and the Far East are not so dark due to an abundance of larch (L in Fig. 2). Pine forests spread from West to East in Russia (P in Fig. 2). Thin forests (SL in Fig. 2) composed of spruce, larch and pine, exist just south of the tundra area (white area in the northern part of the map in Fig. 2).

3.3 Overview of Sakha

Sakha, a Russian Federation republic located in Far-Eastern Siberia, lies between 56° to 73° north latitude (a distance of about 1,900 km) and 106° to 160° east

Fig. 1 Map of Russia and its vicinity.

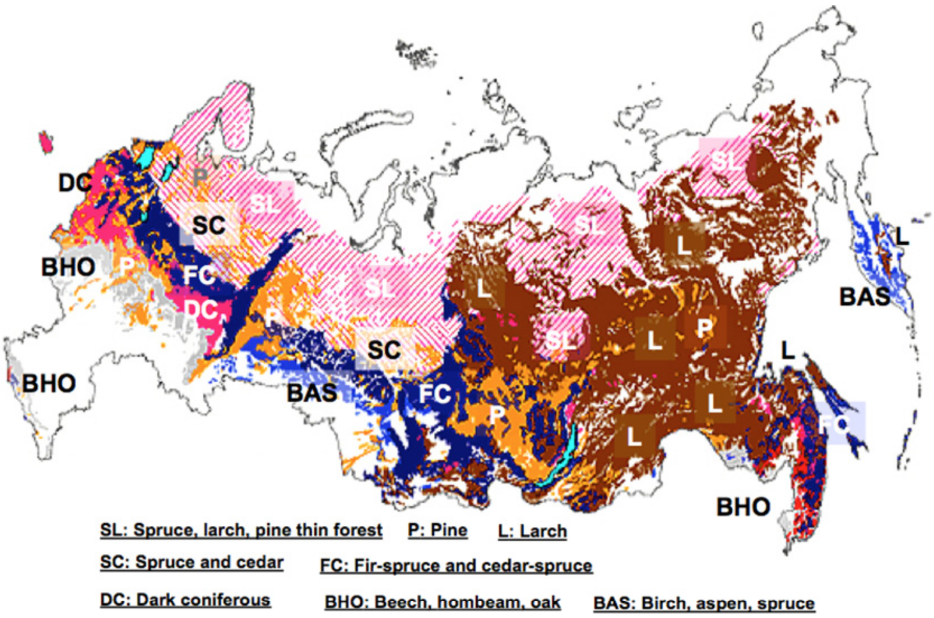

Fig. 2 Map of forest distribution.

longitude (a distance of about 2,700 km at around 62.5°N). Sakha's boreal forest, or taiga, lies mainly to the south of the Arctic Circle. Yakutsk, the capital of Sakha, is located at 62.1°N and 129.8°E. Sakha's forest covers about 1,430,000 km^2 and consists mainly of larch, pine and spruce, with a ground cover of *Vaccinium vitis-idaea*, moss and lichens. Crown fires are not so frequent, but fires caused by human activity are responsible for the majority of fires.

4. Results and Discussion

4.1 Fire trends – yearly and monthly tendencies from 2002 to 2010

The total number of hotspots from 2002 to 2010 for the study area of all of Russia (30° to 75°N, 30° to 180°E) was about three million (3,001,007). Figure 3 gives annual and monthly trends. The bar graph of each year consists of six bar graphs, from April to August. They were compiled from the start of April to the end of August in turn.

Figure 3 shows annual vegetation fire trends. From simple statistics on hotspot data, the annual average number of hotspots(μ) was 333,445, with a standard deviation(σ) of 109,954. From Fig. 3, the highest vegetation fire year was 2003(+1.93σ). Here, +1.93 is the factor of the standard normal distribution. 2002(0.92σ) and 2008(0.74σ) followed. 2006 and 2009 were average fire years. Other years, 2004, 2005 and 2010, were relatively low fire years. The lowest fire year was 2007(1.04σ).

Figure 3 also shows monthly fire tendencies. As the bar graphs for each year have six months of bar graphs, for April to September, the simple monthly average number of hotspots can be calculated as 55,574(=μ/6= 333,445/6). The average bar graph height can be found in the bottom (April) bar graph for 2010. In Fig. 3, largest number for each month were found in April in 2008, May in 2003, June in 2003, July in 2003, August in 2002, and September in 2002. As each of these highest bar graphs of each month has the month name on it, you can find them easily in Fig. 3. The numbers of hotspots indicated for each were 136,792; 186,286; 87,829; 88,151; 148,249; and 87,887, respectively. Among them, the largest number of hotspots occurred in May 2003, most of which were due to severe fires in the mountainous forest area near Chita. The second largest number of hotspots occurred in August 2002 and was caused mainly by severe forest fires near Yakutsk in Sakha.

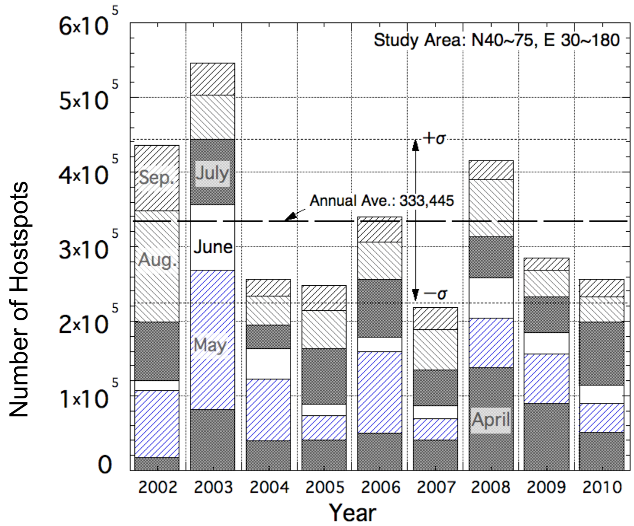

Fig. 3 Vegetation fire tendency in the entire Russian region from 2002 to 2010.

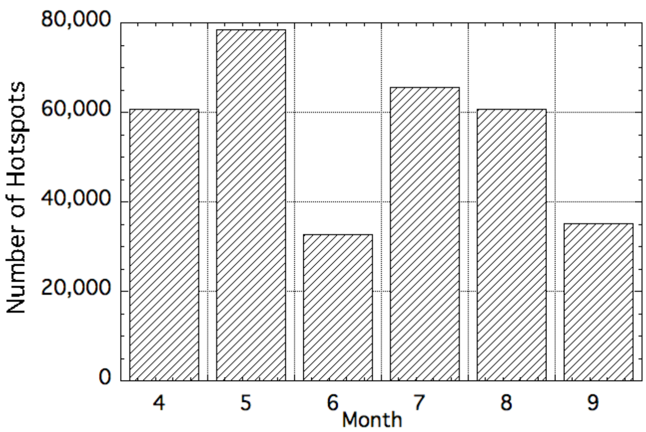

Fig. 4 Vegetation fire monthly tendency in the entire Russian region from 2002 to 2010.

To grasp monthly fire trends in the study area, the average number of hotspots was calculated. They were 60,631 for April, 78,380 for May, 32,781 for June, 65,673 for July, 60,777 for August and 35,203 for September. These are shown in Fig. 4. From Fig. 4, we may say there were two fire seasons in this study area. Namely "spring fires" occurring in April and May and "summer fires" occurring in July and August.

4.2 Fire trends – Hotspot spatial and temporal distribution

4.2.1 Hotspot Density Distribution in All of Russia

Figure 5 shows the annual values of the mean hotspot density (AMHD) for 112 grids to identify severe fire areas. The base map for Fig. 5 was made by plotting all hotspot data in 2003 on a Google map (Mercator projection). The total number of hotspots in 2003 was 545,676, shown as red dots in Fig. 5. The sizes of the hotspots, however, were exaggerated to show the existence of fires in high latitude areas and remote areas. This hotspot distribution in 2003 was partially related to AMHD and clearly shows a Russian fire belt from west to east located around 50°-55° north latitude.

AMHD was simply calculated by the following equation.

$$\text{AMHD} = (\text{total number of hotspots}) / (9(\text{years}) \times (\text{approximate grid area})),$$

where 9 was the number of years from 2002 to 2010 and the approximate grid area was simply calculated using the distances at the grid center, namely the 10° length of longitude and 5° length of latitude. Thus, the unit of AMHD is number/(km^{2}yr), allowing fire activities of each grid to be compared directly. In Fig. 5, AMHD for each grid is shown by a black circle with white color scale circles of three different radii. The scales of the smallest, middle and largest circles represent 20, 40 and 60×10^{-3}/(km^{2}yr), respectively.

From Fig. 5, the highest AMHD (68.2×10^{-3}/(km^{2}yr)) was found in the Irkutsk area. This very high density was simply the result of severe fires in Chita in 2003. The second highest AMHD (47.4×10^{-3}/(km^{2}yr)) occurred south of Moscow. As this region is Russia's main cropland, most fires there may be related to agricultural activities such as harvesting, cultivation and so on. The third highest AMHD (35.6×10^{-3}/(km^{2}yr)) was in the central-northern part of Kazakhstan. Fires in this region also may be related to agricultural activities.

One grid of Sakha, on west side of Yakutsk, had the fourth largest AMHD (35.4×10^{-3}/(km^{2}yr)). Vegetation fires near Yakutsk will be discussed in detail below.

4.2.2 Seasonal fire distribution

From monthly hotspot distribution maps, a unique fire occurrence tendency was found. To elucidate this seasonal tendency, the July hotspot distribution in the study area was plotted in Fig. 6. All July hotspot data from 2002 to 2010 were plotted with red dots on the same Google map as in Fig. 5. The size of the black circle in each grid shows the ratio of the number of hotspots found in July to the total number of hotspots from April to September. The ratio is shown as a percentage. The ratio of each black circle can be read with the help of four scale circles of 25, 50, 75 and 100%. Their sizes are shown on the right at the bottom of Fig. 6.

Figure 6 shows that higher latitude grids tended to have a higher percentage. In particular, the five grids above 70° north latitude tended to have a high ratio. The ratios of five grids from west to east at the top of Fig. 6 are 100, 99.9, 100, 92.5, and 97.8%, respectively. Thus, the ratios in other northern grids are relatively high, as shown in Fig. 7. The total number of grids with percentages higher than 50% was 31. Five were in grids at 75°N, twelve were in grids at 67.5°N, nine were in grids at 62.5°N, four were in grids at 57.5°N and one was in a grid at 52.5°N.

This July vegetation fire trend was entirely unique but can be explained by air temperature and precipitation trends. For most regions in this study area, July is the warmest and wettest month. Therefore, vegetation fires could occur under warmer air temperature and lower precipitation conditions. This effect of weather factors on vegetation fires will be discussed later in detail.

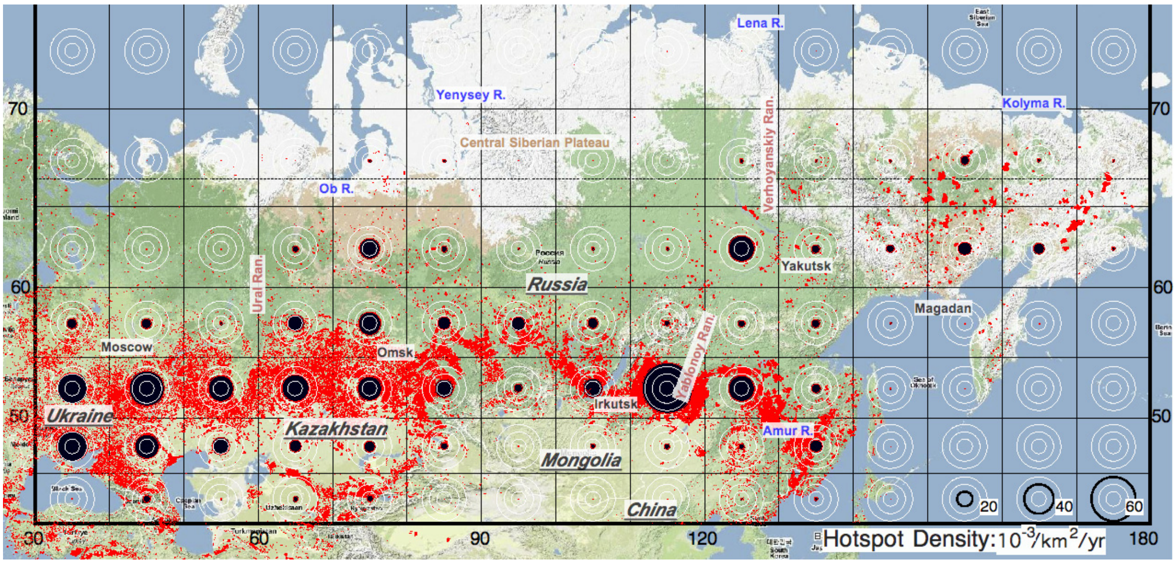

Fig. 5 Map of annual hotspot density in Russia and its neighboring countries.

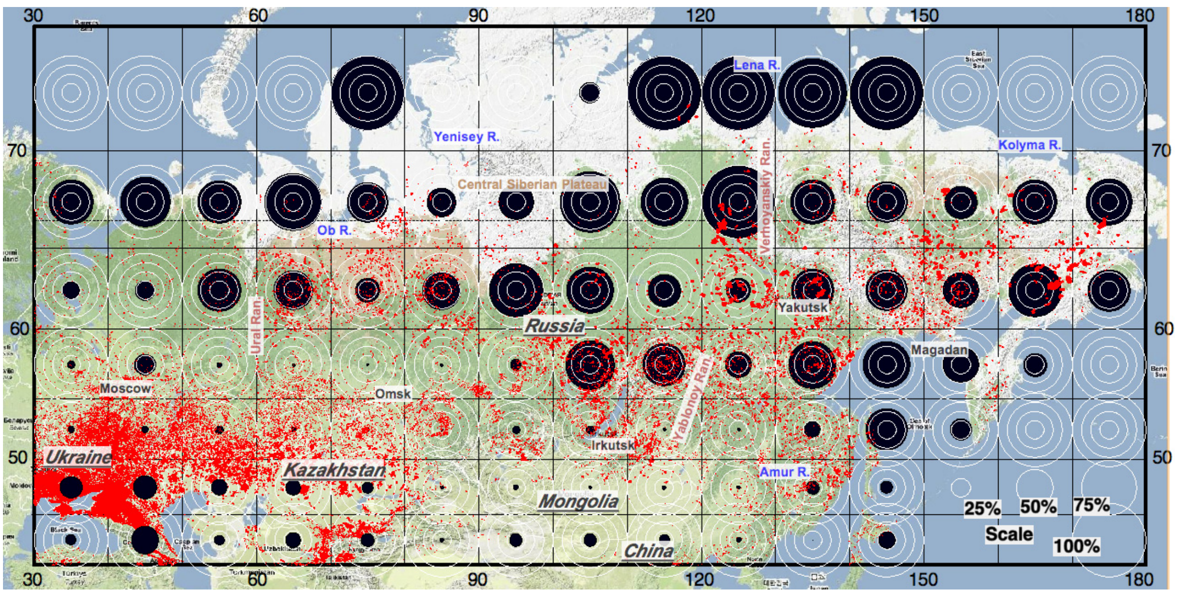

Fig. 6 Map of July hotspot distribution and occurrence ratios (in percentages).

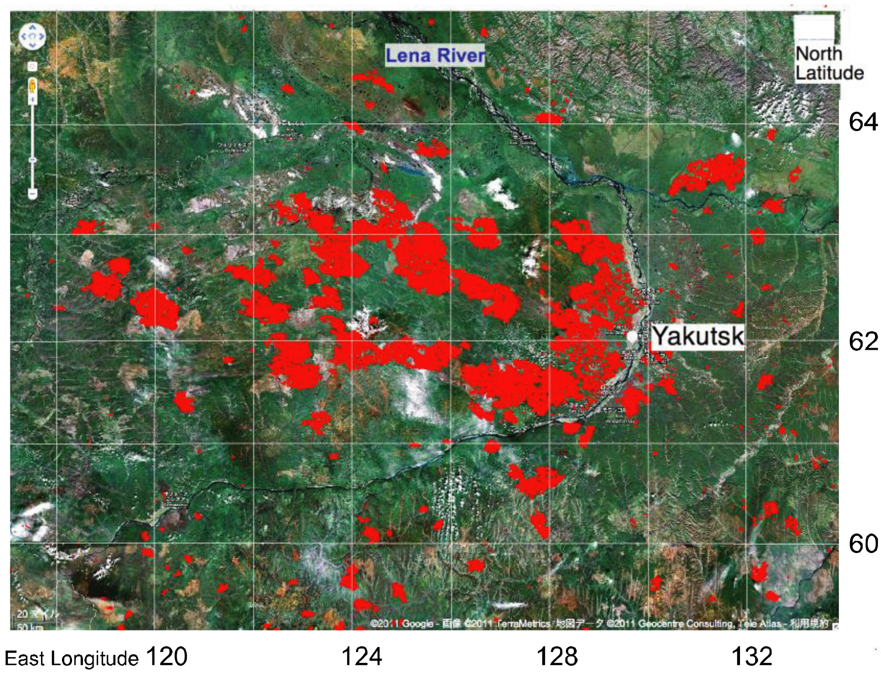

Fig. 7 Map of Yakutsk area of Sakha and 2002 hotspot distribution.

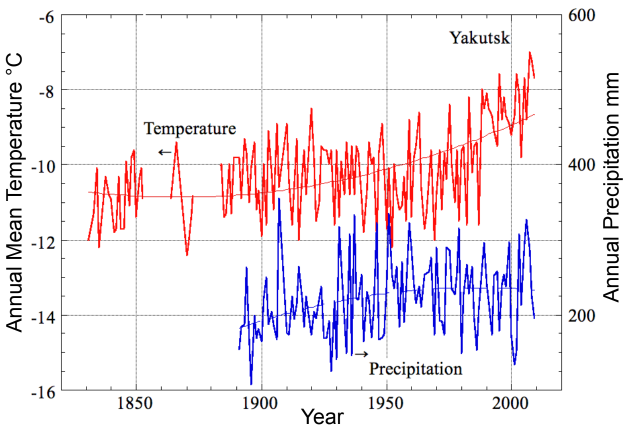

Fig. 8 Annual mean air temperature and precipitation trends.

5. Vegetation Fires in Sakha

The study area for Sakha was between 59° and 65°N latitude and 117° and 134°E longitude. Figure 7 shows a map of the Yakutsk vicinity based on Google maps. The hotspot distribution in 2002 was plotted upon this map using red squares.

5.1 Temperature and precipitation trends

Figure 8 shows trends in annual mean air temperature from 1830 to 2009 and precipitation from 1891 to 2009. According to Fig. 8, the annual mean air temperature started to increase from about –11°C in 1900. The recent mean air temperature is around –8°C. We may say a temperature rise of about 3°C occurred, but this rise was mainly caused by a wintertime temperature rise. A considerable temperature rise from April to July was also found in Sakha due to apparent climate change from the 1990s.

On the other hand, annual precipitation showed an increasing trend from around 1900. This increase is also mainly due to wintertime precipitation, but a drastic decrease in precipitation was also found in August in Sakha, dropping to only 50% of that before the 1990s.

Thus, weather conditios of higher temperatures and lower precipitation may be related to recent fire activities in Sakha.

5.2 Fire history

Forest fire history data (number of fires and burnt area each year) provided by the Sakha Ministry of Forestry and private communication with Russian scientists were used to determine fire trends from 1955 to 2009 (Fig. 9). The bar graph in Fig. 9 indicates the burnt area, but only for the so-called protected forest area in Sakha. The area of protected forest accounts for 42% of the total forest area in Sakha. The burnt area varied from 3.35 km^2 in 1973 at the smallest, to 8,834 km^2 in 1955. The average annual burnt area during the 55 years from 1955 was 1,810 km^2. Figure 9 does not show the number of fires, but this number varied from 28 in 1973 to 1,417 in 1955. The average number of fires was 521. Unfortunately, there are no precise data related to lightning available in Sakha, but it is believed that forest fires in Sakha are mainly caused by human activities. In the future, the contribution of lightning can be clarified if precise lightning observation can be carried out in Sakha.

In 2002, fires started in May under conditions of strong southerly maximum wind velocities of 8 m/s and high air temperatures near 30°C, causing many fires near the Lena River. After these fires, there occurred no marked rainfall exceeding 5 mm/day until the beginning of June. Major fires started just after a cyclone with rain and lightning passed near Yakutsk at the beginning of June. Major fires also occurred in mid-August and

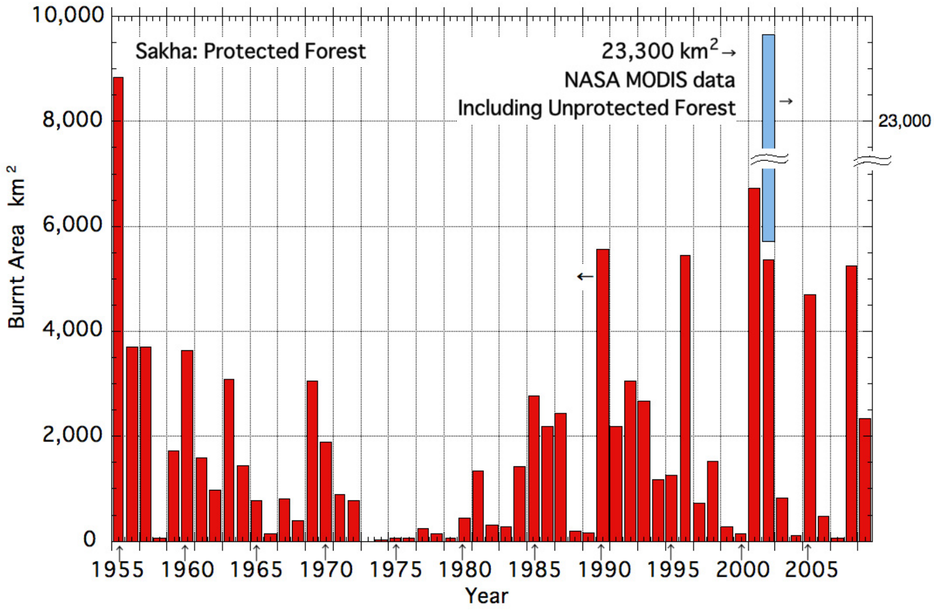

Fig. 9 Protected forest fire history of Sakha from 1955.

Table 1 Trends in forest fires and weather in Yakutsk.

Peroiod	Number of Fires	Burnt Area km²	Precipitation* mm						Ave. Temperature* ℃					
			Apr	May	Jun	Jul	Aug	Sep	Apr	May	Jun	Jul	Aug	Sep
0. Average 1955–2005	546	1,797	9.0	18.4	34.9	36.1	35.8	28.5	−6.3	6.7	15.7	18.8	15.0	5.7
1. Average 1955–1989	517	1,420	9.9	17.6	35.6	37.2	39.9	28.5	−6.7	6.4	15.3	18.6	14.9	5.8
2. Average 1990–2005	609	2,624	6.6	20.6	32.9	33.0	23.0	28.8	−5.2	7.6	16.9	19.3	15.3	5.5
Difference (2.–1.)	92	1,204	−3.4	3.0	−2.7	−4.2	−16.9	0.3	1.4	1.1	1.6	0.7	0.4	−0.3

(*: data from Jan. 1995 to Jul. 2002)

September. Many of them were re-activated fires or so-called holdover fires (D. Latham & E. Williams, 2001), as confirmed by satellite images from NASA MODIS. The total area of protected forest burned in 2002 was the second largest since 1955 (Fig. 9), but the estimated total burnt area according to satellite imagery was about 23,300 km^2, as shown with the highest bar in Fig. 9. The largest burnt area in 2002, shown in Fig. 9, implies the burnt area in Sakha would be larger if the burnt area of unprotected forests and fields were also included.

5.3 Recent fire tendencies

Table 1 summarizes Sakha forest fire and weather trends. The average number of fires and area burned each year for three different periods – 1955-2005, 1955-1989, and 1990-2005 – are summarized to show how fire activity increased in Sakha between 1990 and 2005. The average number of fires and burnt area from 1990 to 2005 exceeded that for the other two periods. The average burnt area from 1990 to 2005 was 1.85 times greater than that between 1955 and 1989.

To determine the cause of this increase in fire activity in Sakha, we studied trends in precipitation and average temperature, as summarized in Table 1. Weather data from May 1829 to July 2002 are from the Sakha Weather Station (62.1°N, 129.8°E, 103 m). The decrease in precipitation during the fire season from April through September from 1990 to 2002 ranged between 2.7 and 16.9 mm compared to that between 1955 and 1989. Precipitation markedly decreased by 16.9 mm in August, but the increase in temperatures during the fire season ranged from 0.4°C to 1.6°C compared with those from 1955 to 1989. No marked temperature rises such as that in Alaska were found, but warmer spring trends from April through June were clear.

In addition to this spring weather change, trends in lower precipitation and higher temperatures were also found in August, when precipitation was –16.9mm lower than normal and temperatures were 0.4°C warmer than normal. This drier trend in August may provide an opportunity for holdover fires to be to re-activated.

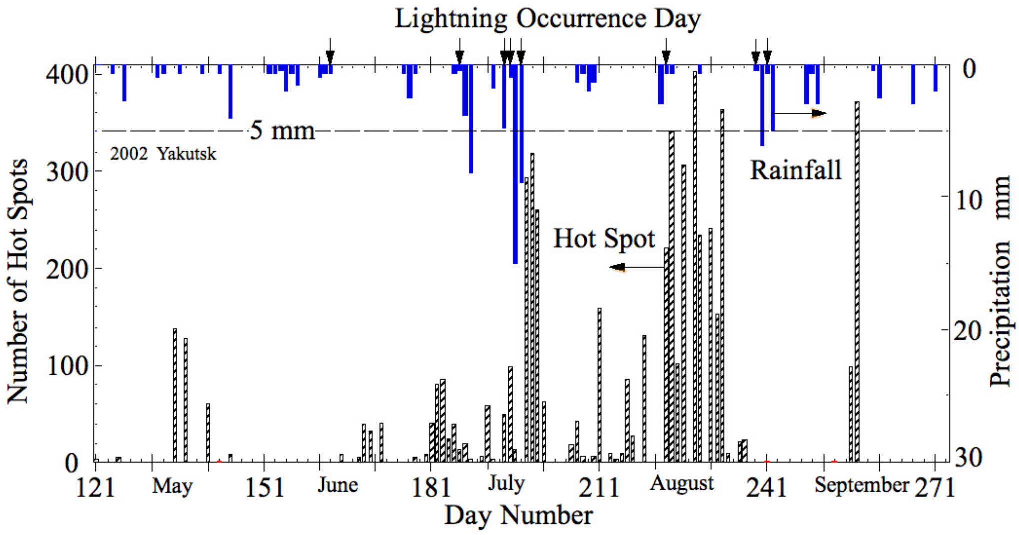

Fig. 10 Hotspots, rainfall and lightning in 2002.

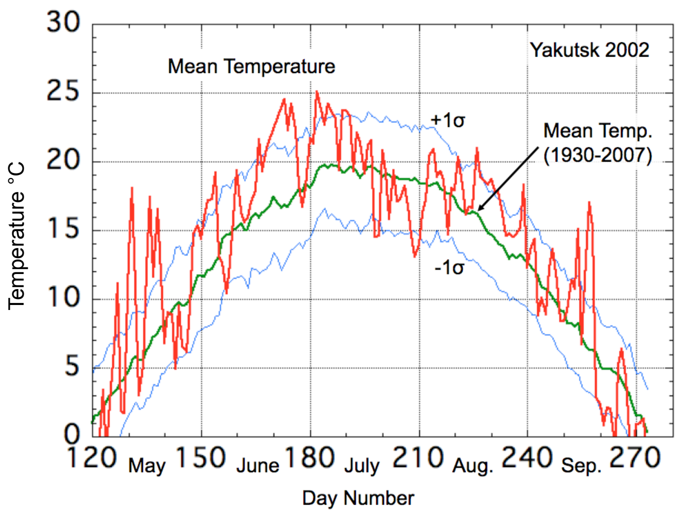

Fig. 11 Daily mean air temperature in 2002.

5.4 2002 Fires

In 2002, fires (hotspots) in Sakha started from the middle of May, as shown with bar graphs in Fig. 10. In this figure, precipitation and lightning are indicated by bar graphs and arrows. The y axis for precipitation is inverted. According to Fig. 10, the fires started in the middle of May, and severe fires occurred in the middle of July and August. Precipitation is a natural extinguisher for most vegetation fires, but the rainfall in May and June was too weak. There was no rainfall of more than 5 mm. Rainfall of less than 5 mm is usually too weak to put out fires. In June, only three rainfalls of more than 5 mm occurred. From this trend, we may say severe fires in August 2002 occurred due to drought conditions from May.

Figure 11 shows daily mean air temperatures in 2002 . In this figure, the daily mean air temperature (period: 1930-2007) is shown along with the standard deviation. The air temperatures in 2002 varied, with mostly higher than normal values from the middle of May to the middle of September. Most fire occurrences in Fig. 10 coincided with high air temperatures (+1σ).

6. Conclusions

Recent vegetation fire tendencies of almost each of the 120 regions in Russia were analyzed using MODIS hotspot data from 2002 to 2010. Comparisons among each region were carried out by introducing AMHD (annual mean hotspot density; number of hotspots/ (km^2yr)). The major conclusions for Russian regional and seasonal fires are:

1. The distribution of the AMHDs clearly shows a Russian fire belt located around 50°-55° north latitude.
2. The highest AMHD ($68.2\times10^{-3}/(km^2yr)$) was in the Irkutsk region (50°-55°N, 110°-120°E) exclusively arising from severe fires in the Chita area in 2003.

3. The second highest AMHD ($47.4\times10^{-3}/(km^2yr)$) was located in a region southeast of Moscow (50°-55°N, 40°-50°E) and may be related to agricultural activities.
4. The third and fourth highest AMHDs (41.3 and $40.7\times10^{-3}/(km^2yr)$) were in two regions of Ukraine (45°-50N° and 50°-55°N, 30°-40°E), also related to agricultural activities.
5. The three regions: Kazakhstan (50°-55°N, 60°-70°E), Sakha (65°-65°N, 120°-130°E) and the Amur River (50°-55°N, 120°-130°E) were next in fire frequency after the above four highest regions. Their AMHD values were 35.6, 35.4 and 35.2, respectively.
6. We may say July is a fire month for most Siberian regions at high latitudes (> 55°N), because more than 50% of all hotspots there occurred in July. This percentage became higher for further northern latitudes. A detailed analysis for the Yakutsk region in Sakha using long-term weather data since 1830, recent daily weather data, hotspot data in 2002 and other data, clearly shows large fire activities in the boreal forest or taiga. The major conclusions for the Yakutsk fires are:
7. The Sakha region (65°-65°N, 120°-130°E) had the sixth highest AMHD of $35.4\times10^{-3}/(km^2yr)$ due to severe fires in 2002.
8. The severe Sakha fires of 2002 can be explained by the precipitation patterns and mean air temperature changes from May to September.
9. Severe fires in August 2002 occurred under drought conditions (only three rainfalls of more than 5 mm) from May.
10. The air temperatures in 2002 varied, with mostly higher than normal values from the middle of May to the middle of September. Many hotspots or fires were recorded especially when air temperatures were excessively high (+1σ).

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References

Campbell, I. D. and M. D. Flannigan (2000) Long-term perspectives on fire-climate-vegetation relationships in the North American boreal forest. *Ecological Studies*, 138: 151-172, Springer.

Conard, S. G. and E. P. Davidenko (1998) Fire in Siberian boreal forests – Implications for Global Climate and Air Quality, USDA Forest Service General Technical Report, PSW-GTR-166.

Csiszar, I., L. Denis, L. Giglio, C. O. Justice and J. Hewson (2005) Global fire activity from two years of MODIS data, *International Journal of Wildland Fire* 2005, 14: 117-130.

Flannigan, M. D., M. A. Krawchuk, W. J. de Groot, B. M. Wotton and L. M. Gowman (2009) Implications of changing climate for global wildland fire, *International Journal of Wildland Fire*, 18: 483-507.

Hayasaka, H. (2003) Recent tendencies of forest fire and lightning in Alaska, Bulletin of Japan Association for Fire Science and Engineering, 53(1): 17-22. (in Japanese)

Hayasaka, H. (2004) Large Forest Fires Occurred in Yakutsk Area and Lightning, *Proceedings of Japan Association for Fire Science and Engineering*, 266-268. (in Japanese)

Kasischke, E. S. (2000) Boreal ecosystems in the global carbon cycle, *Ecological Studies*, 138: 19-30, Springer.

Latham, D. and E. Williams (2001) *Lightning and Forest Fires,* Academic Press, p.375.

Mouillot, F. and C. B. Field (2005) Fire history and the global carbon budget, *Global Change Biology*, 11: 398-420.

Tchebakova, N. M., R. Monserud and D. I. Nazimova (1994) A Siberian vegetation model based on climatic parameters, *Canadian Journal of Forest Research,* 24: 1597-1607.

Tchebakova, N. M., E. Parfenova1 and A. J. Soja (2009) The effects of climate, permafrost and fire on vegetation change in Siberia in a changing climate, *Environmental Research Letters*, 4.

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