The investigation of space-time dynamics of forest fires and cloudiness in the North-Asian region based on the NOAA satellite data

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The space-time dynamics of forest fires and cloud cover in the North-Asian region, apart from local factors, depends, to some extent, upon solar-terrestrial relationships. Based on the AVHRR / NOAA radiometer data, the space-time dynamics of forest fires and cloud cover during the last five years in the latitude range 40–74°N has been analyzed. It is shown that forest fires are observed from May to September, mainly, during three summer months with the activity maximum in the second half of summer. In the phase of maximum of the 11-year cycle of solar activity, a trend is observed of shifting forest fires to the north. In the seasonal behavior for the period from May to August we observed a decrease of cloud cover, and from August to September its increase. During this period, the shift of cloudiness from the north and south to the region of 56–66°N was observed that can be caused by the latitude displacement of the trajectories of Atlantic cyclones, which determine the weather at the territory from Europe up to 140th meridian in the northern Asia in the phase of the maximal solar activity.

Introduction

Every year, vast forest areas at the territory of Russia are destroyed by fires, that is accompanied by significant economical losses, destruction of timber and forest ecosystems. As a result of forest fires, a large body of combustion products, aerosol particles, and greenhouse gases are emitted in atmosphere. For the most part, the degree of forest fire danger depends on the quantity of atmospheric precipitation (humidity), temperature, and thunder activity, whose indirect indicator is the cloudiness. With the advent of satellite observational systems, the monitoring of the cloud cover and forest fires became possible throughout the whole territory of observation, but not just at isolated points.

The atmospheric precipitation in the north of Asian continent, as a whole, can be determined by the humidity transfer by cyclones from the North Atlantic and the seas of the Arctic Ocean. The moisture content of cyclones, spreading up to the river Lena basin, greatly decreases when passing through the Middle-Siberian plateau determining the orography of the Yenisei and Lena interfluve. The general trend in the many-year behavior of annual sums of precipitation during the last 50 years is negative, as the data show, kindly given us by the Yakutsk base of the aircraft forest protection.

It is well known that the variations of the atmospheric circulation, investigated during several centuries, are connected with the level of solar activity.[1] The circulation variations are observed both during the 11-years cycle of solar activity and at shorter periods of time. Many authors point out changes in the atmospheric ground pressure and the height of geopotential surfaces following the geomagnetic disturbances or solar flares and accompanied by the bursts of solar cosmic rays (SCR).[1] This is also supported by observations of variations of the cloud cover and the number of thunderstorm discharges over a period of Forbush decreases of the intensity of galactic cosmic rays and bursts of SCR.[2]

The historic data[3] testify that in the periods of increased solar activity in the region of extratropical maximum the pressure grows, and in high latitudes it falls that results in shifting of cyclone trajectories to the pole. There are literature data[4] supporting the dependence of cyclone trajectories in the northeastern Atlantic and Europe on the phase of the solar cycle. At the age of solar maximum the “northern” way of cyclones is shifted to the south, while the “south” way is shifted to the north at the amplitude variation about 10° of latitude.

The proofs of the fact are available[3] that main characteristics of the atmospheric circulation structure in the Northern Asia up to 140°E (stable regions of the low pressure and anticyclones) are also shifted to the north during the period of increased solar activity, and at a low solar activity they are shifted to the south. The latitude dependence of the total radiation variations, i.e., cloudiness, in the 11-years cycle of solar activity is explained by the latitude shift of atmospheric cyclones trajectories.[5]

The goal of this paper is to investigate the distribution and dynamics of the cloud cover and forest fires during the May–September period, their variations from year to year and over the chosen latitude zones.

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Experimental method

Since 1995, the Institute of Cosmophysical Research and Aeronomy SB RAS conducts investigations in the framework of the program of remote sensing of pollutions, based on the domestic receiving station SKANOR. Using the data of the AVHRR / NOAA[6] scanning radiometer, the effective on-line monitoring of the flood and forest fire situation, cloudiness, and industrial pollution zones has been conducted.[7,8,9]

To investigate the distribution and dynamics of forest fires, the Yakutia territory was divided into three latitude zones: southern (56°–62°) $S_{f.s}$, central (62°–68°) $S_{f.c}$, and northern (68°–72°) $S_{f.n}$. The northern boundary of the northern zone corresponds to the boundary between forest tundra and the tundra. The detection of forest fire sites was conducted, based on the AVHRR / NOAA data, by the specialized automated multistage algorithm.[10]

The cloudiness was determined in three latitude zones (southern zone – 56°–40°, $S_{c.s}$; central zone – 56°–66°, $S_{c.c}$; northern zone – 66°–74°, $S_{c.n}$). For each of the three zones, the data on the cloud coverage of the Earth's surface and open regions were taken from each revolution. We calculated the cloudiness in each zone as a ratio (%) of the area covered by clouds to the total zone area. Values of the cloudiness were averaged over 24 hours. The measurements were performed from May to September, because it is difficult to distinguish the cloudiness against the background of snow during winter months. To consider the dynamics of the cloudiness distribution, the ratios of cloudiness values in the central zone to the southern one ($S_{c.c}$ / $S_{c.s}$) and central zones to the northern one ($S_{c.c}$ / $S_{c.n}$), averaged over years, were taken.

Results and discussion

The cloudiness is minimal in July in all three latitude zones (Fig. 1*a*).

It decreases from April to July and increases from August to October.

The value of the ratio of cloudiness in central zone to that in the northern and southern zones increases from 1998 to 2000 (Fig. 2*a*), which corresponds to the concepts on the cloudiness variation in Europe depending on the solar activity.[4,11] The 1998–2000 period corresponds to the increased solar activity.

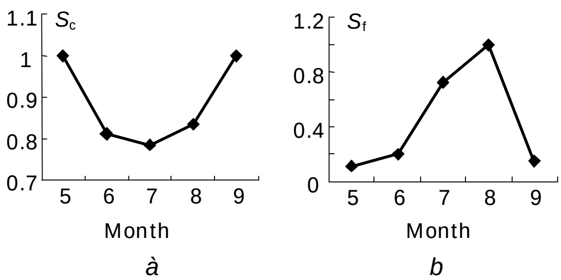

Fig. 1. Variations of cloudiness S_c (*a*) and forest fire S_f (*b*) areas over a period from May to September.

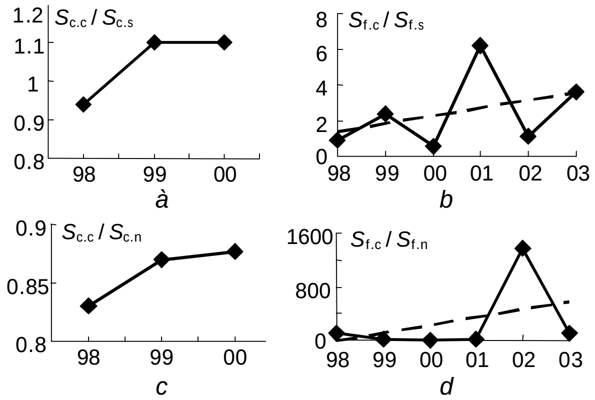

Fig. 2. The relation between the cloudiness and the fire areas for latitude zones in 1998–2003: the ratio of the cloudiness in the central zone to that in the southern zone (*a*); the ratio of the fire areas in the central zone to that in the southern zone (*b*); the ratio of the cloudiness in the central zone to that in the northern zone (*c*); the ratio of the fire areas in the central zone to that in the northern zone (*d*).

The satellite monitoring of the cloudiness was performed from 8.00 a.m. to 8.00 p.m. Note that in the northern zone the minimum (20%) in the cloudiness daily behavior is observed at 4.00–5.00 p.m., a low minimum (5%) at 10.00–11.00 a.m., and a small maximum (5%) from 12.00 a.m. to 3.00 p.m. The same pattern is observed for the southern zone. But the minimum (30%) is observed here at 11.00–12.00 and the maximum (25%) – from 12.00 a.m. to 4.00 p.m.

The forest fires in the Yakutia are observed from May to September, mainly during three summer months with a maximum at the summer second half in July (Fig. 1*b*). The greatest amount of forest fires was observed in July and August. The seasonal behavior observed by us, corresponds to that presented in Ref. 12. A disastrously large number of fires in the second half of summer is caused by melting the soil upper layer and following drying the underwood. This takes place at a low amount of precipitation in the second half of summer, which corresponds to the decrease of cloudiness in our observations.

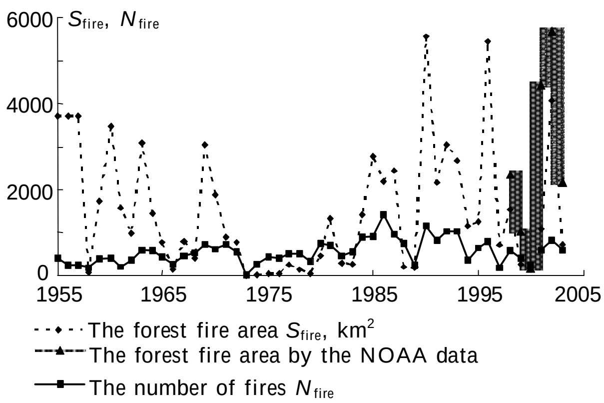

Fig. 3. Annual-average dynamics of forest fires over a period from 1955 to 2003.

Figure 3 shows the forest fire distribution over a period from 1955 to 2003. From 1998 to 2000, we observe a smooth decrease of forest fire areas in the Yakutia. The minimum of fires falls on 2000 year. Further, during two years we observe a sharp increase in the forest fire areas. In the trend over the 6-year period of satellite observations, some increase of the number of forest fires is observed. The greatest increase is observed in the central latitude zone, and the least one – in the northern latitude zone.

Figure 4 shows a summary map presenting the total area of forest fires over a period from 1998 to 2003. We can observe the absence of forest fires in the northwestern part of the Yakutia and their small number in the western part. This can be associated with the climate humidity in these regions and low density of population. On the one hand, when comparing this map with the map of atmospheric precipitation,[13] we can point out that there is a good agreement between the areas with high forest fire concentration and the areas with less than 250–200 mm amount of the annual-average precipitation. On the other hand, special attention must be given to the agreement between the areas with high forest fire concentration and the increased density of population. That is, apart from the natural factors, the ethnogeny activities of the people also affect the number of forest fires. The number of forest fires is determined by a coincidence of these two factors.

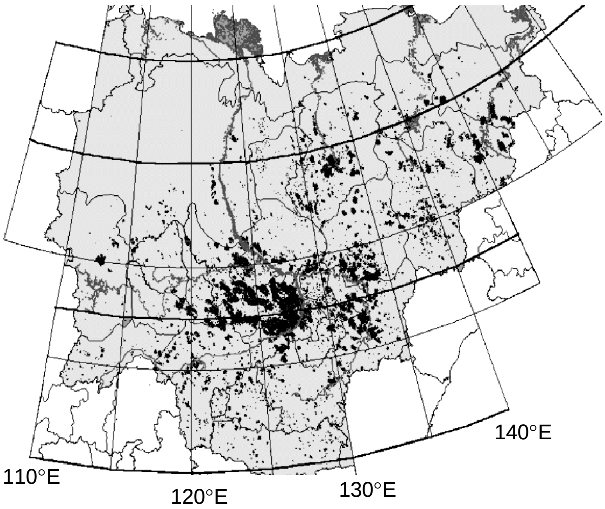

Fig. 4. The map of forest fire distribution over a period from 1998 to 2003: bold lines are latitudinal zone boundaries (56°N, 62°N, 68°N, 72°N).

The retrospective analysis of numerous trunk cuts of old larches together with fire traces on the annual rings shows that the forest fires in the Yakutia are rather widespread phenomena with a definite periodicity. Individual specimens aged 300 years bear the traces of up to ten forest fires, which happened every ten or twenty two years.[14] Based on the data of the aircraft monitoring of forest fires during the last 50 years, the 20-year period can also be distinguished (Fig. 3).

Analysis of the long-term behavior of the annual temperature during the observation period from 1947 to 1995 is indicative of the temperature drop started from the middle 1940s and lasted to the end of 1950s – early 1960s. Then it grew warmer in the southern part of the investigated region, and then the climate warming extended to the northern regions. During all this period the climate warming and cooling of durations from 4 to 8 years were observed against the background of more significant temperature changes with a period of 10–12 years.[15] As a whole, throughout the entire observation period, a clearly defined positive trend was observed in the many-year behavior of the air temperature.

The general trend in the long-term behavior of annual sums of precipitation for the last fifty years in Yakutia was negative. As indicated above, the air temperature correlated (while the thunder activity anticorrelated) with the 11-year cycle of solar activity.[16] The humidity and cloudiness on a scale of the Northern Hemisphere also anticorrelated with the solar activity. However, on smaller scales, they behaved depending on the latitude and orography and were determined by variation of ways of cyclones and anticyclones. Therefore, the forest fire danger in the region under study varied in a complicated manner in accordance with the solar activity cycle.

Conclusion

The number and areas of forest fires in the Northern Asia during the second half of summer are mainly determined by the thunder activity, temperature, and humidity. These parameters depend, to some extent, on the solar activity, whose manifestations are determined by the latitude of the observation site. The latitude dependence is due to the displacement of ways of motion of Atlantic cyclones, determining the weather at the territory from Europe to 140th meridian in the Northern Asia, as well as the points of origin of regional cyclones.

The cloudiness over the Yakutia decreases from May to August, and from August to September it increases. From 1998 to 2001, based on the satellite monitoring data, a general shift of cloudiness and forest fires in the latitude direction is observed that is likely to be due to the shift of trajectories of Atlantic cyclones, which determine the cloudiness and precipitation in the greater part of Yakutia.

The forest fires in Yakutia are observed from May to September, mainly during three summer months with maximum in the second half of summer. The presence of the variation with a period of more than five years was recorded. The data of the Yakutsk airbase of forest protection show that this variation corresponds to the 22-year variation of dry periods.

The absence of forest fires in the north-western part of the Yakutia, and a small number of fires in its western part can be due to relatively increased humidity in these regions and to low density of population. A comparison between the map of the forest fire distribution and the map of atmospheric precipitation[13] shows that there is a good agreement between the areas with high concentration of forest fires and the areas with the annual mean precipitation amount less than 250–200 mm. At the same time, a coincidence of areas with high concentration of forest fires and an increased density of population in these regions has also engaged our attention. Thus, it may be suggested that the number of forest fires is determined by not only weather and geographic peculiarities of the North-Asian region (the existence of the permafrost zone, the continental climate, etc.) but also by technogenic factors.

It should be also noted that the obtained data testify that the standard structure of geoecological monitoring should be supplemented with new elements (Remote sensing technologies) when investigating the northern geosystems. These elements, oriented to studying the reasons and regularities of forest fires, require the development of special-purpose computerized means as the most important part of the system for monitoring geoecological conditions in the North-Asian region.

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