The influence of meteorological factors on forest fires in the boreal zone of Northwest Russia

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Abstract. The paper deals with the problem of the pyrogenic situation in the forest fund of the Boksitogorsk district of the Leningrad region, which has been in existence for half a century. Long-term statistical data on the occurrence of fires and weather factors in the study area were used. The analysis of the relationship between meteorological factors and fire occurrence and spread was carried out. The methods of descriptive statistics, and correlation and cluster analyses were used. The relationship between the amount of precipitation and average temperatures for the period from April to September was obtained, and the probability of fire occurrence in the study region assessed. There was a trend towards an increase in the average positive temperatures for the period April–September against the background of a stable regime of atmospheric precipitation. The cause of forest fires is an anthropogenic factor, since no dry thunderstorms have been recorded. The continuing trend toward an increase in average temperature over the spring-summer period will not pose a threat, if the atmospheric precipitation regime persists over the same period, and appropriate fire-fighting measures are applied in the study area.

1. Introduction
The problem of forest fires is one of the most important for the Russian forest sector. This problem requires the solution of a whole range of tasks related to fire management, with an increase in the volume of preventive fire-fighting measures and their efficiency.

In recent years, the attention of many international researchers has been drawn to the relationship between atmospheric processes and the emergence and development of forest fires [1–6]. At the same time, meteorological factors play an important role in all stages of fire development, from its initiation to the elimination of combustion. It is known that dry, hot weather creates the most favourable conditions for the emergence and spread of fires.

When assessing a natural fire hazard over a long-term period, it is necessary to take into account climatic factors in the form of a typical annual weather pattern [7]. The following meteorological factors belong to the pyrological characteristics of climate, obtained in the analysis of long-term observations for the fire hazardous period: temperature regime; relative humidity; the amount of precipitation and the number of days with rain.

2. Methods and Materials
To analyze the relationship between the long-term dynamics of forest fires with meteorological factors for the fire hazardous season (April–September), we used data on forest fires for 1970–2019 (50 years)
and the corresponding weather data for the Boksitogorsk district of the Leningrad region (meteorological station of the second category in Efimovsky settlement).

Boksitogorsk region is located on the Tikhvin ridge of the Valdai Upland. The largest areas are occupied by hilly-moraine formations, which are typical landscape forms for the study region. The forest area is 65% of the total area of the district.

The analysis of long-term data was carried out using Statistica 12.5, descriptive statistics tools, and correlation and cluster analyses.

3. Results and Discussion
The current forest area of the Boksitogorsk region is 505,073 hectares. The annual average area of fires was 21 ha and the median value was 1.2 ha (table 1). Let's define the fire rate of forests using the following formula [8]:

\[ P(f) = \frac{N_f}{N_{fs}} = \frac{38}{46} = 83\% , \]

where, \( P(f) \) – the probability of fire occurrence, %; \( N_f \) – the number of recorded seasons with fires in a given time interval, seasons; \( N_{fs} \) – number of fire seasons considered, seasons.

Table 1. Descriptive statistics.

| Variable                      | Mean | SD  | Median | Maximum | Sum   |
|-------------------------------|------|-----|--------|---------|-------|
| Overall area (ha)             | 21.4 | 55.3| 1.2    | 322     | 986   |
| Quantity of fires (pcs)       | 8.95 | 12.7| 4.5    | 60      | 412   |
| Average temperature (°C)      | 11.9 | 2.1 | 12.1   | 14.4    | –     |
| Average air humidity (%)      | 73.4 | 11.2| 74.5   | 81      | –     |
| Average number of days with precipitation (days) | 10.2 | 1.9 | 10.3   | 12.8    | –     |
| Average atmospheric precipitation (mm) | 65.2 | 16.3| 67.3   | 90.2    | –     |

To determine the most important weather factors for the dynamics of fires for the research period, Pearson's correlation coefficients were calculated using the Statistica software package (table 2). The analysis showed very weak relationships between temperature, air humidity, number of days with precipitation and the number and area of fires. In the study area, the amount and area of pyrogenic impact on the forest fund was significantly influenced by the amount of precipitation for the period April-May. Apparently, in the zone of excessive moisture and soil leaching regime, this factor makes it possible to reduce the number of fires in the forest fund.

Table 2. Correlation analysis.

| Variable                      | Overall area (ha) | Quantity of fires (pcs) | Average temperature (°C) | Average humidity (%) | Average number of days with precipitation (days) | Average atmospheric precipitation (mm) |
|-------------------------------|-------------------|-------------------------|--------------------------|----------------------|-----------------------------------------------|--------------------------------------|
| Overall area (ha)             | 1.00              | 0.66                    | 0.11                     | 0.00                 | -0.17                                         | -0.31                                |
| Quantity of fires (pcs)       | 0.66              | 1.00                    | 0.13                     | 0.04                 | -0.12                                         | -0.23                                |
| Average temperature (°C)      | 0.11              | 0.13                    | 1.00                     | 0.83                 | 0.58                                          | 0.46                                 |
| Average air humidity (%)      | 0.00              | 0.04                    | 0.83                     | 1.00                 | 0.83                                          | 0.67                                 |
| Average number of days with precipitation (days) | -0.17 | -0.12 | 0.58 | 0.83 | 1.00 | 0.85 |
| Average atmospheric precipitation (mm) | -0.31 | -0.23 | 0.46 | 0.67 | 0.85 | 1.00 |
The performed regression analysis of the influence of the considered meteorological factors on the occurrence of fires in the area under consideration showed that with a decrease in air humidity and the number of days with precipitation for the period April-September the occurrence and area of forest fires increase. Considering changes in the main meteorological factors affecting the occurrence of fires, one can observe a stable amount of precipitation for the period April-October and an increase in positive temperatures over the observation period (figures 1-4).

![Average temperature (°C)](image)

**Figure 1.** Average air temperature (April-September) for the observation period.

![Average atmospheric precipitation (mm)](image)

**Figure 2.** Average precipitation (April-September) for the observation period.
The total amount of precipitation of the season is not a factor that significantly affects the area and number of forest fires (figure 5). A more important factor is the number of days with precipitation (figure 6). This makes perfect sense, since the total amount of precipitation for six months is more likely to influence precipitation of the season than a specific number of days with precipitation.

Higher average air temperatures for the period April–September lead to an increase in the number of fires, even against the background of an increase in the amount of precipitation during the same time period. It is likely that higher temperatures increase evaporation and drying out of the upper soil horizons and forest litter, which leads to an increase in the number of fires.

When considering the factors associated with the amount of precipitation, the number of days with precipitation and air humidity (figures 7–9) on the number of fires, it can be noted that even with a large number of days with precipitation, the likelihood of forest fires may increase.
During the study period, four anomalous, in relation to the burned area, years (1978, 1992, 1997 and 1999) were identified, which is likely to be associated with the dry period in May-June in the study area, and with the reform of forest fire protection. In 2002 and 2008, the increase (compared with the average data for the observation period) in the area of fires was associated with anthropogenic impact as a result of an increase in unauthorized logging in the study area during this period. In 2010, abnormally dry weather was observed, which, combined with anthropogenic factors, led to an increase in the area of fires.

This fact is decisive in predicting possible pyrogenic situations for the forests of the study area and should be taken into account when carrying out fire-fighting activities.

4. Conclusions
Analysis of long-term meteorological data for the study area shows that for half a century there was a trend towards an increase in the average positive temperatures for the period April-September, while the amount of precipitation remained unchanged.

In general, the occurrence of fires in this area is caused by an anthropogenic factor, since no dry thunderstorms have actually been recorded. The ratio of the areas affected by forest fires and the total area of the forest fund did not exceed 1%. The continuing trend toward increase in the average temperature over the spring-summer period will not pose a threat if the atmospheric precipitation
regime persists over the same period, accompanied by appropriate fire-fighting measures in the study area.

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