Wildfires and the spread of smoke from forest fires in the Krasnoyarsk territory in summer 2019

A A Gosteva¹, O E Yakubailik²,³ and N Y Shaparev²

¹Federal Research Center Krasnoyarsk Science Center of the SB RAS, 660036, Krasnoyarsk, Russia, Akademgorodok, 50
²Institute of Computational Modelling SB RAS, 660036, Krasnoyarsk, Russia, Akademgorodok, 50/44
³E-mail: oleg@icm.krasn.ru

Abstract. Forest fires in the Siberian regions of Russia received significant attention in the media and social networks in the summer months of 2019, much more than in previous years. There was an impression of a significant increase in their number and area. However, satellite monitoring data showed that this is just half the truth. The forest areas covered by fires were indeed significant, but at the same time comparable in values with a number of previous seasons. And a strong increase was not observed. Moreover, a significant part of the summer period in the territories where firefighting is carried out (firefighting zone), the area of fires was about half as much as in the previous year. Our research has shown that, most likely, the reason for the increased attention to this topic is associated with significant smoke from forest fires in the territory of Siberia due to unique meteorological conditions such as the distribution of areas of high pressure, lack of precipitation, and so on. This hypothesis has been confirmed by the results of analysis of the spatial and temporal distribution of the ultraviolet aerosol index calculated from the data of OMPS instrument of the Suomi-NPP meteorological satellite.

1. Introduction

Vast areas of Siberia and the Russian Far East are sparsely populated and inaccessible. In particular, there are areas where for a thousand kilometers there is not a single settlement. For this reason, the state system of operational monitoring of fires and firefighting is divided into several zones: the zone in which immediate firefighting actions are taken when a fire occurs (firefighting zone), and the monitoring-only zone, for which the operational services are limited solely to monitoring the development of fires, since it is not economically feasible to engage in firefighting there, and most often it is technically impossible due to the remoteness of these territories.

Extensive forest fires in Siberia in July and August 2019 were recorded. Until mid-July, a noticeable number of fires were observed throughout the territory, both in the monitoring zone and in the fire-extinguishing zone. From mid-July and approximately until mid-August, the fires were concentrated mainly in remote, hard-to-reach areas in the North of the region, in monitoring-only zones (figure 1).

Significant public attention to the topic of forest fires arose in mid-July. At that point in time, for the first time in the summer of 2019 in major cities of Siberia, such as Krasnoyarsk, Novosibirsk, Kemerovo, and so on, there was a significant excess of the standard limit concentrations of particulate matter (PM25) in the atmosphere. On some days, this excess was 2-3 times more. Poor environmental
conditions in places where people live in large numbers caused a great resonance in society, increased attention to this topic, and motivated to understand the details of the problem.

Figure 1. Area of fires in the Krasnoyarsk territory in the summer of 2019.

The formation of particulate matter in the atmosphere is caused by various factors, one of which is just the smoke of fires, the results of combustion of organic substances. At the same time, methods for assessing the state of the atmosphere and determining the presence of aerosols in it using remote sensing methods based on satellite data are well known today [1, 2, 3]. In this context, our task was to study the spatial and temporal dynamics of the spread of smoke plumes of forest fires in the considered time, based on remote sensing data.

2. Materials and methods
Atmospheric aerosol has a noticeable effect on the intake of solar radiation. To date, several methods for estimating the attenuation of solar radiation by aerosol have been developed and used in practice. The most commonly used parameter is the aerosol optical thickness (AOT), which is the integral by height of the aerosol attenuation coefficient [4]. The AOT value can be measured with good accuracy using remote methods, including satellites. More than a dozen satellite AOT measurement instruments with various technical characteristics have been created, including daily measurement systems with a spatial resolution of up to 1 km per pixel. Numerous studies have shown a high correlation between the satellite-measured AOT values and ground-based measurements of particulate matter (PM2.5) concentrations [5-8]. However, this approach has a number of significant disadvantages: algorithms for determining AOT are practically not applicable for water surfaces, for surfaces with a high reflection coefficient (for example, snow-covered territories), in cloudy conditions, and so on.

An alternative method, proposed in 1996, is based on the use of several spectral ranges in the ultraviolet part of the spectrum [9, 10]. It is called the multichannel spectral contrast method. This method is based on Rayleigh's law, according to which the intensity of scattered light is inversely proportional to the fourth power of the wavelength of the exciting light, i.e. radiation with a shorter wavelength is scattered more strongly. In a clear molecular atmosphere with a low reflectivities, the \(\lambda^{-4}\) wavelength dependence of molecular scattering produce up to 50% difference in the backscattered ultraviolet radiances between 340 and 380 nm. Since aerosols and clouds typically add a radiance component that is weakly wavelength dependent, they reduce the \(I_{340}/I_{380}\) spectral contrast. By observing the decrease in spectral contrast, you can estimate the amount of atmosphere aerosol.
The amount of aerosol in the atmosphere can be estimated using the ultraviolet aerosol index ($UVAI$):

$$UVAI = -100 \log_{10} \left[ \frac{I_{330}}{I_{380}}_{\text{obs}} - \frac{I_{330}}{I_{380}}_{\text{calc}} \right]$$

where $I_{330}$ и $I_{380}$ represent observed and calculated backscattered radiances at two ultraviolet wavelengths in 330-380 nm range (where ozone absorption is negligible).

In practice, the dimensionless value of $UVAI$ is usually in the range of 0 to 5 units, with values of <0.2 corresponding to clean transparent air, and values of >1 indicating an increased degree of atmospheric pollution, and values of 5.0 indicates heavy concentrations of aerosols that could reduce visibility or impact human health.

In our study, $UVAI$ data has been obtained from the OMPS (Ozone Mapping Profiler Suite) instrument installed on the Suomi-NPP weather satellite. The sensor has a spatial resolution of 50 km, and data is generated once a day. The Earth Remote Sensing Center of the Krasnoyarsk Scientific Center of the Siberian Branch of the Russian Academy of Sciences receives data from this satellite [11].

It is worth noting it is difficult to conduct ground-based observations of the spread of smoke from forest fires, which spreads over long distances. However, the data of the OMPS instrument allows us to build thematic maps of the aerosol index for each day. And the spatial resolution of the device allows us to track the dynamics of the spread of smoke plumes from specific fires on a global and regional scale [12].

3. Results and discussion

A spatial and temporal analysis of data on smoke in Siberia during the time under review (July, August 2019) has been performed. The results of OMPS satellite data processing have been compared with ground-based observations at environmental monitoring posts in several cities. In general, the results on atmospheric pollution obtained by these two methods are very well matched.

Let’s look at some of the results in detail. Fires in the period under review were mainly observed near the borders of three regions of Russia: the North-Eastern zone of the Krasnoyarsk territory (Evenkia) with the server regions of the Irkutsk region and the South-Western part of Yakutia – the upper right section on the maps figure 2; the heat points of fires there are marked in red.

**Figure 2.** The spread of a smoke plume in Siberia (from the Urals to Lake Baikal) in the summer of 2019: a) July 14, b) July 20, c) July 21, d) July 24. Red dots indicate active fires.
Traditionally used in monitoring systems, background images mosaic based on operational satellite MODIS/VIIRS data complicates analysis, since it is difficult to navigate them due to the fact that smoke plumes overlap with clouds and it is not always possible to clearly understand what part of the territory we are observing (figure 3) [13]. A composite image collected on the base of different types of data helps analyzing the situation. For example, in figure 3 thermal points of active fires, defined by the infrared thermal range, are marked on the image in red. For these reasons, the above figure 2 uses a single cloudless background, over which the values of the aerosol index UVAI are shown.

![Composite image data from the visible and infrared thermal ranges: white areas correspond to clouds and smoke plumes, and red dots indicate active fires.](image)

On July 14, the prevailing wind direction was North-East, and the fire plume spread to the South-West, towards Kazakhstan (figure 2a). This plume went exactly through Krasnoyarsk, without affecting Novosibirsk and Tomsk. That is why the corresponding graph on figure 4 shows at the time of "July_14" that air pollution "in the red zone" is observed only in Krasnoyarsk.

After a slight pause of a few days, the dramatic development of smoke over Central Siberia began. During the period from 21 to 27 July, the smoke of forest fires gradually spreads over the territory of more than 5 thousand kilometers, from the Urals to Chukotka (figure 2). A unique "island of smoke" is formed over the central part of Eurasia. The reasons for this formation are associated with a unique combination of meteorological characteristics, the distribution of areas of high and low pressure, the lack of precipitation, and so on. Air monitoring stations installed in cities show a significant excess of the standard concentrations of suspended particles in the atmosphere (figure 4).

During this period, there was a significant public response associated with high air pollution in cities; atmospheric pollution sensors register 2-3 times excess of standards.

4. Conclusions
Objective information about the causes of air pollution is becoming more and more important at the present time, in the conditions of increased attention to environmental problems. Air quality monitoring systems are currently in operation in most Russian cities, and concentrations of pollutants are being measured. In particular, Krasnoyarsk is one of the most disadvantaged cities in Russia in terms of air quality, and Krasnoyarsk has now 3 independent air monitoring systems [14]. The purpose of such systems is usually to identify the main sources of air pollution, which are large industrial enterprises in general.
At the same time, it is obvious that even the most detailed urban environmental monitoring system, with a large number of sensors, will not tell anything about the level of pollution outside the city. The only system solution may be to combine ground-based measurement data with satellite information. As the experience of recent years shows, for Krasnoyarsk and a number of other Siberian cities, forest fires in the middle of summer make a significant contribution to atmospheric pollution. Satellite data from remote sensing allow us to assess the impact of forest fires on urban air pollution and, in combination with data from urban environmental monitoring networks, to assess their contribution to the overall level of pollution.

References
[1] Fioletov V, M, Krotkov N, McArthur L, Kerr J, Wardle D, Herman J, Meltzer R, Mathews T and Kaurola J 2004 UV index climatology over the United States and Canada from ground-based and satellite estimates J. Geophys. Res. 109 D22308
[2] Park Y, Sokolik I and Hall S 2018 The impact of smoke on the ultraviolet and visible radiative forcing under different fire regimes Air, Soil and Water Research 11
[3] Haywood Y and Shine K 1995 The effect of anthropogenic sulfate and soot aerosol on the clear sky planetary radiation budget Geophys. Res. Lett. 22 603
[4] Zhdanova E and Chubarova N 2018 Spatial variability of aerosol optical thickness on the territory of Moscow and Moscow Region by satellite and ground based data Sovr. Probl. DZZ Kosm. 15 236
[5] Matson M, and Holben W 1987 Satellite detection of tropical burning in Brazil Int. J. Remote Sens. 8 509
[6] Xu G and Zhong X 2017 Real-time wildfire detection and tracking in Australia using geostationary satellite: Himawari-8 Remote Sensing Letters 8 1052
[7] Wang P, Cao J, Tie X, Wang G, Li G, Hu T, Wu Y, Xu Y, Xu G, Zhao Y et al 2015 Impact of Meteorological Parameters and Gaseous Pollutants on PM2.5 and PM10 Mass Concentrations during 2010 in Xi’an, China Aerosol and Air Quality Research 15 1844
[8] Yu P, Toon O, Bardeen C, Zhu Y, Rosenlof K, Portmann R, Thornberry T, Gao R, Davis S, Wolf E et al. 2019 Black carbon lofts wildfire smoke high into the stratosphere to form a persistent plume Science 365 587
[9] Hsu N, Herman J, Bhartia P, Sefton C, Torres O, Thompson A, Gleason J, Eck T and Holben B 1996 Detection of biomass burning smoke from TOMS measurements Geophys. Res. Lett.
23 745

[10] Herman J, Bhartia P, Torres O, Hsu C, Seftor C and Celarier E 1997 Global distribution of UV-absorbing aerosols from Nimbus 7/TOMS data J. Geophys. Res. 102 16911

[11] Yakubailik O, Romas'ko V and Pavlichenko E 2019 Complex for reception and real time processing of remote sensing data E3S Web of Conferences 75 03003

[12] Krasnoshchekov K and Yakubailik O 2019 Methods and algorithms for remote sensing of particulate pollution from space at regional level CEUR Workshop Proceedings 2534 288

[13] Kadochnikov A, Tokarev A, Zavoruev V and Yakubailik O 2019 Prototype of city environmental monitoring system based on geoportal technologies IOP Conference Series: Materials Science and Engineering 537 062052

[14] Yakubailik O, Kadochnikov A and Tokarev A 2018 Web geographic information system and the hardware and software ensuring rapid assessment of air pollution Optoelectronics, Instrumentation and Data Processing 54 243