E3S Web of Conferences **223**, 03021 (2020) https://doi.org/10.1051/e3sconf/202022303021
RPERS 2020

Analysis of temperature inversions during periods of adverse weather conditions in Krasnoyarsk in the winter period of 2019-2020

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Abstract. The work is devoted to the search for relationships between the pollution of the atmosphere of Krasnoyarsk by particulate matter and temperature inversion – an increase in temperature with height in the surface layer of the atmosphere. The research is based on reanalysis data of the NASA GFS meteorological model for air temperature at different altitudes of the atmosphere and the results of measurements of concentrations of particulate matter in the air monitoring system of the FRC KSC SB RAS, as well as information about officially declared periods of adverse weather conditions. The results obtained allow us to conclude that there is a high degree of correlation between these values, and that it is possible to use the GFS model data to predict the environmental situation.

1 Introduction

The problem of air pollution in large cities in the world is acute. Numerous studies show that there is a link between increased concentrations of airborne particulate matter (PM) and deterioration in human health in metropolitan areas [1]. A sharp increase in the concentration of pollutants occurs during the period of adverse weather conditions, which contribute to the accumulation of industrial and automobile emissions. [2]. However, not only the anthropogenic factor, but also natural processes contribute to the creation of unfavorable environmental conditions. For example, temperature stratification of the lower atmosphere can cause temperature inversion, that is, a layer of warm air that limits the vertical dispersion of harmful impurities in the atmosphere [3].

Temperature inversions arise because layers of greater or lesser thickness are located in the surface layer of the atmosphere at different heights, in which the decrease in temperature greatly slows down, stops, or vice versa, instead of decreasing temperature with height, it increases. Their properties are the height of the lower and upper boundaries, vertical thickness (layer thickness) and intensity (inversion value). Temperature inversions are divided into 3 types: surface (the lower boundary is located at ground level), elevated (the lower boundary is located at a certain height from the surface) and free atmosphere inversions (the height can vary greatly) [4, 5, 6].

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 https://doi.org/10.1051/e3sconf/202022303021

According to the Ministry of Ecology and Rational Nature Management of the Krasnoyarsk Territory, in Krasnoyarsk, from January 2019 to February 2020, 8 periods of adverse weather conditions were established: in 2019 - from 8 to 13 February, from 26 to 28 November, from 5 to December 6, from December 23 to December 24 and from December 27 to 30; in 2020 - from 10 to 13 January, from 14 to 18 February and from 25 to 27 February [7]. These periods are characterized by low wind speeds and airborne particulate matter (PM) values well above the daily average maximum permissible concentration (0.035 mg/m^3).

Figure 1 shows an image of the study area, namely the Krasnoyarsk city and its surroundings. It is a city with a population of over 1 million people, located along the Yenisei River at a distance of about 40 kilometers.

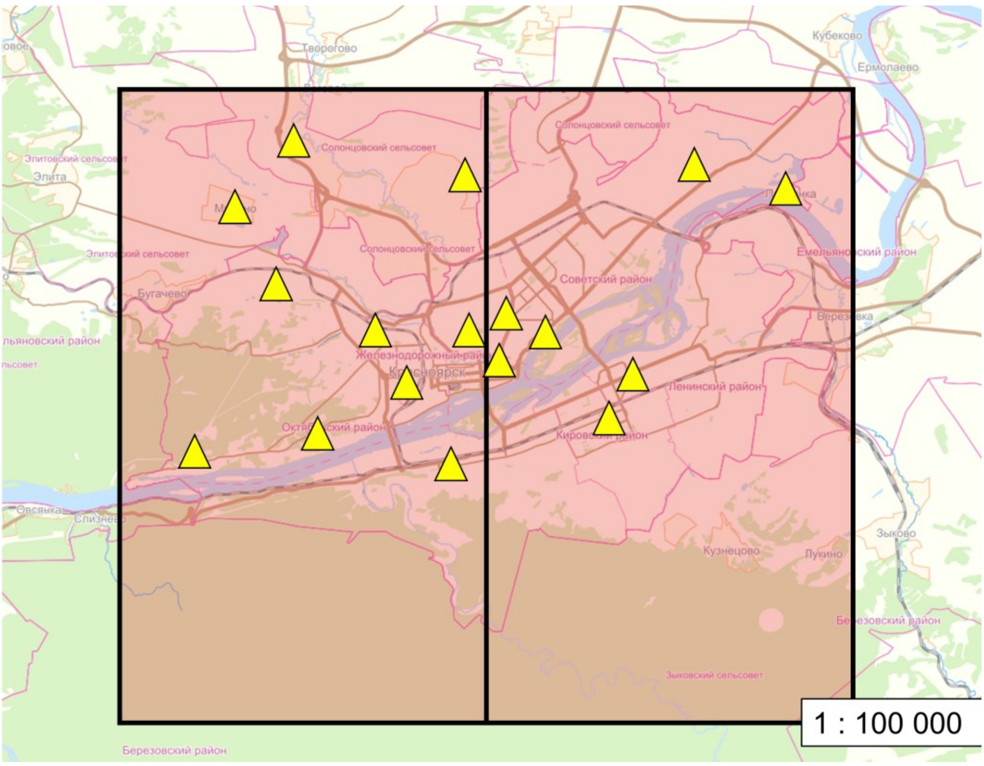

Fig. 1. Study area: Krasnoyarsk city and its surroundings.

In Figure 1, yellow triangles denote 17 ground-based ecological monitoring stations of the Federal Research Center of the Krasnoyarsk Science Center Siberian Branch of Russian Academy of Sciences (FRC KSC SB RAS), two cells corresponding to the regular grid of the NASA GFS (Global Forecast System) weather forecast model are shown in light red.

In this work, the meteorological conditions in the city of Krasnoyarsk in the winter period of 2019-2020 were studied using data from ground-based monitoring posts and meteorological information from the GFS weather forecast model.

2 Materials and methods

The GFS model is a numerical weather prediction system containing a global computer model and variation analysis performed by the United States National Weather Service (NWS). This model is a collection of four separate models: atmosphere, ocean, land / soil, and sea ice. This is one of the world's most famous meteorological models. Global data analysis and forecasting is carried out 4 times a day. The weather forecast is available up to 16 days ahead [8]. Since January 2015, the horizontal resolution of the GFS model data is 0.25 degrees (about 25 km).

GFS model data is in *.grib2 format. This data format is standardized by the World Meteorological Organization (WMO) and is designed to store historical and forecast weather data [9]. Each individual file contains more than 500 layers of different meteorological information at more than a hundred vertical levels.

In this work, we used actual data from the analysis of air temperature at the ground level and at heights of 750 and 1500 m [10].

The processing of the initial data of the GFS model consisted of several stages. At the first stage, the resulting files were cropped according to the specified coordinates corresponding to the city of Krasnoyarsk, and layers containing information about the air temperature at a certain height. Then, the data trimmed by coordinates and layers was converted into tabular files in *.csv format. These procedures were performed using special scripts written in Python using the wgrib2 program. The wgrib2 program is specially designed by the GFS model data producer for reading and converting *.grib2 data [11].

At the second stage of processing, the contents of the resulting *.csv files were combined into one large common *.csv file using a small program written in the C language. Further processing and analysis of data was carried out in Microsoft Excel software.

The inversion layers were identified by obtaining the difference between the temperature data at different heights. Temperature inversion was defined as the case when the difference gave a negative value. For example, if a negative value was obtained between the temperature difference on the surface and at an altitude of 750 m, the inversion was considered surface or elevated, if between 750 and 1500 m - an elevated or high-altitude inversion (inversion of the free atmosphere). If the surface/elevated and high-altitude inversions were recorded simultaneously, then this was considered a powerful inversion.

Also, the work used data on the concentration of suspended solid particles in the air PM2.5 and wind speed, which were obtained on the geoportal of the ICM SB RAS [12]. The daily average PM2.5 data were averaged over all available observation sites in the city to obtain the daily average PM2.5 concentration values for the entire city of Krasnoyarsk.

3 Results and discussion

An archive of data was obtained for the period from January 1, 2019 to April 30, 2020, containing information on air temperature at surface level and heights of 750 and 1500 meters, average daily PM2.5 particle concentrations and information on wind speed for the city of Krasnoyarsk.

Figure 2 shows the variations in PM2.5 concentration and wind speed over the city of Krasnoyarsk from November 1, 2019 to February 29, 2020.

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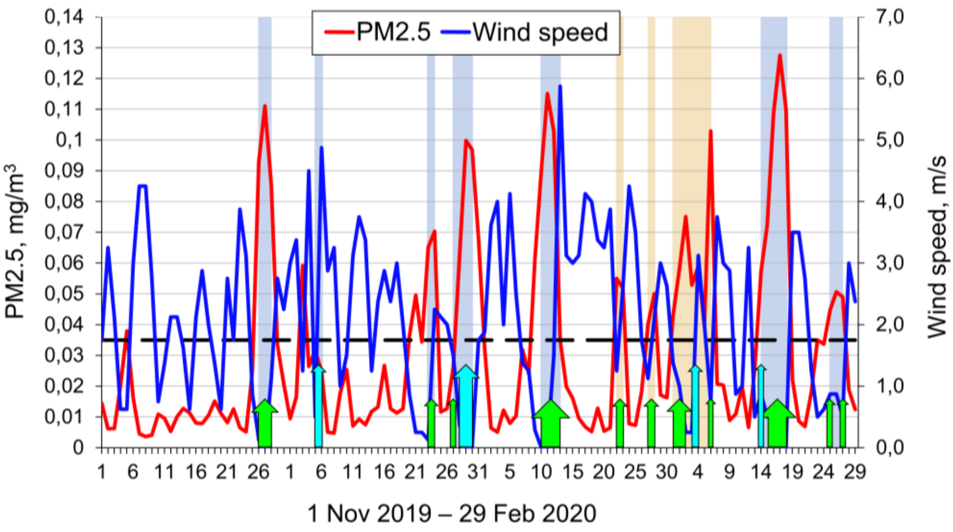

Fig. 2. Changes in the average daily values of PM2.5 concentration and wind speed in the city of Krasnoyarsk in winter 2019-2020. The dotted line indicates the value of the average daily maximum permissible concentration of PM2.5, equal to 0.035 mg/m^3.

Figure 2 shows the following data:

- the blue vertical stripes indicate the official periods of adverse weather conditions in the city of Krasnoyarsk, and
- the orange vertical stripes indicate the periods identified on the basis of data analysis when the daily average PM2.5 concentration values significantly exceeded the maximum permissible concentration, which is 0.035 mg/m3 in accordance with Russian legislation.

Arrows are plotted on the abscissa:

- green arrows indicate periods when surface or elevated temperature inversion was present;
- blue arrows indicate periods when powerful inversion was present.

Here in the figure 2, three features stand out. First, the relationship between the values of the average daily PM2.5 concentration and wind speed. Whenever PM2.5 concentration values significantly exceeded the maximum permissible value, wind speed was extremely low or absent. Second, in all periods when PM2.5 concentration values significantly exceeded the daily average maximum allowable value, temperature inversions were observed over the city. Third, in addition to the official regimes of adverse weather conditions, characterized by increased values of PM2.5 concentration, in the period from November 1, 2019 to February 29, 2020, 3 more periods were identified with a similar nature of meteorological conditions and the level of air pollution. This means that the methods used by official government services to predict unfavorable weather conditions are imperfect and sometimes do not determine the upcoming periods of high air pollution.

The table shows the results of the analysis of the atmosphere of the city of Krasnoyarsk in the winter period of 2019-2020 according to the obtained data.

Table 1. Data on the state of the atmosphere of the city of Krasnoyarsk and its surroundings in the winter period of 2019-2020

Date	**PM2.5, mg/m³**	**Wind speed, m/s**	**Temperature inversion**
1-5 Jan 2019	0,029-0,175	0,125-2,75	All days. Surface or elevated
11-13 Jan 2019	0,048-0,073	0,875-1,125	January 12 and 13. Surface or elevated
23-25 Jan 2019	0,057-0,106	0-0,75; 2,4 – 25 Jan	January 24 and 25. Surface or elevated
08-13 Feb 2019	0,064-0,165	0,25-0,8 11,625 – 13 Feb	All days. Surface or elevated
26-28 Nov 2019	0,085-0,111	0-0,125	November 26 and 27. Surface or elevated
05-06 Dec 2019	0,025-0,032	0,5; 4,9 – 6 Dec	All days. Powerful
23-24 Dec 2019	0,065-0,07	0,125-2,25	All days. Surface or elevated
27-30 Dec 2019	0,026-0,099	0-1,5	All days. Powerful
10-13 Jan 2020	0,035-0,115	0-1,5; 5,9 – 13 Jan	All days. Surface or elevated
22-23 Jan 2020	0,052-0,055	1,25-2,6	All days. Surface or elevated
27-28 Jan 2020	0,04-0,05	1,125-2,125	All days. Surface or elevated
31 Jan - 06 Feb 2020	0,039-0,075	0,25-3,125	All days. January 31, February 1, 2, 5, 6 - surface or elevated. February 3 and 4 February - powerful
14-18 Feb 2020	0,057-0,127	0-0,87	All days. Surface or elevated
25-27 Feb 2020	0,045-0,05	0,5-0,87	All days. Surface or elevated

In this table, eight out of fourteen periods are the official periods of adverse weather conditions in the city. The remaining six periods are identified in the process of data analysis. All the periods presented are characterized by daily average values of PM2.5 concentration exceeding the maximum permissible concentration, as well as low wind speed in the city and the presence of temperature inversions. In four cases, the wind speed sharply increased on the last day of the period, while the PM2.5 concentration on that day dropped significantly. The prevailing type of detected inversions is surface or elevated. In the official period from 5 to 6 December 2019, the average daily concentration of PM 2.5 in the city did not exceed the daily average value of the maximum permissible concentration.

4 Conclusions

As a result of this work, a relationship was shown between high values of the average daily PM2.5 concentration and wind speed in the city of Krasnoyarsk. The presence of temperature inversions during periods of adverse weather conditions was revealed. Data analysis revealed an additional six periods when the daily average PM2.5 concentration significantly exceeded the maximum allowable value, in addition to the official eight periods of adverse weather conditions. The predominant type of identified temperature inversions is surface or elevated.

Analysis of meteorological data of high spatial resolution, for example, the GFS model, helps to solve problems related to the study of the lower atmosphere and its pollution, and can also play an important role in more accurately identifying periods of adverse weather conditions and their forecasting.

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