Influences of meteorological conditions in PM2.5 levels in Krasnoyarsk city atmosphere

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Abstract. The relationship between meteorological conditions and the levels of PM2.5 in Krasnoyarsk city atmosphere for the period from 2019 to 2022 were investigated. The meteorological data of the National Centers for Environmental Prediction Global Forecast System (NCEP GFS) reanalysis model was used. PM2.5 data were obtained from the ground monitoring stations. Analysis of variances (one-way and two-way ANOVA) and the Tukey Test showed statistically significant differences for temperature inversions, months in the cold period (November-February), and calm wind. In the case of high daily PM2.5 surface and elevated inversions occurred at 69% cases and strong temperature inversions at 74%. In the reverse case, in the presence of surface and elevated temperature inversions, high daily PM2.5 occurred in 53% of cases, and the presence of strong temperature inversions in 44%.

1 Introduction

Air pollution, especially particulate matter (PM), is a major cause of premature death [1]. In Krasnoyarsk, the administrative centre of Krasnoyarsk territory, Russia, PM concentrations systematically exceed values defined by Russian environmental protection law and World Health Organization (WHO) standards.

The process influencing air pollution is very complex and depends not only on the source of the pollution, but also on meteorological conditions [2, 3]. Meteorological processes contribute significantly to adverse weather conditions (AWC). AWC are a particular combination of meteorological factors that contribute to the accumulation of pollutants in the surface layer of atmospheric air. Special consideration is given to the thermal stratification of the lower atmosphere. Temperature inversion limits vertical dispersion of pollutants in the atmosphere.

In recent years, atmospheric model data have been widely used in air pollution analysis.

The influence of meteorological characteristics on local distributions of the concentration of particulate matter PM was studied in various regions of the world are Western Europe [4, 5], South America [6], and East Asia [7].

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The University of Hong Kong has developed a methodology for air quality forecasting in Hong Kong based on the statistical processing of GFS and WRF [8].

Researchers from China based on simulations of winter concentrations of PM2.5 in WRF and WRF-Chem determined the influence of PM2.5 on the variation of predicted population mortality [9].

Scientists from Canada investigated the effect of temperature inversions on PM2.5 particulate matter levels using analysis of variance (ANOVA) to test whether the means of the inversion day PM2.5 differ significantly from the means on normal days [10].

2 Materials and methods

The study area in this work is Krasnoyarsk city. The data were obtained from ground monitoring stations [11] and meteorological information from the National Centers for Environmental Prediction Global Forecast System (NCEP GFS) reanalysis model [12].

The NCEP GFS reanalysis model consists of several hundred layers with atmospheric characteristics at various vertical levels. These are calculated on a regular horizontal grid with a spatial resolution of 0.25° (~25 km) with a frequency of 4 times per day.

The study used data from 2019-2022. Data on PM2.5 particulate matter were obtained from ground-based monitoring stations with an interval of 6 hours.

To determine the temperature inversion, the difference between the actual temperature values at three vertical levels: 1000 and 925 mb is DT1, 925 and 850 mb is DT2, and 1000 and 850 mb is DT3.

In this paper, a one-way ANOVA was used to test whether the means concentration of PM2.5 particulate matter differs significantly in the following cases: presence or absence of inversion; month of the year; presence or absence of calm wind conditions; strong temperature inversion (presence of temperature inversion on several layers simultaneously).

Two-way ANOVA was used to test the influence of both factors (temperature inversion and months of the year; temperature inversion and calm wind conditions) on the concentration of PM2.5.

The F-statistic was used to determine whether the difference in the mean values was statistically significant (1% significance level).

3 Results and Discussion

Figures 1-4 show the results of calculations by one-way ANOVA. F-statistic was used to test the statistical significance of differences. In the case of different types of temperature inversions, F-statistic are $F_{DT1}(1, 5835) = 1391$, $F_{DT2}(1, 5835) = 275$, $F_{DT3}(1, 5835) = 1661$. Depending on the months of the year is $F_{M}(11, 5832) = 152$. Depending on the presence or absence of calm wind is $F_{Sh}(1, 5835) = 52$; depending on the strong inversion is: $F_{PI}(5, 5831) = 401$. In all these cases, the significance level is 1 %.

Thus, statistically significant differences were found between the means of PM2.5 and temperature inversion, the means PM2.5 and the calm wind, the means of PM2.5 and their changes in months of the year, and the means of PM2.5 and the strong temperature inversion. The means of particulate matter PM2.5 in the case of presence inversion was significantly higher than in the absence of inversion, averaging 55 μg/m^3 and 19 μg/m^3 respectively. The means of particulate matter PM2.5 were higher in winter months than in the rest of the year, averaging 50 μg/m^3. The means of particulate matter PM2.5 in the case of calm was significantly higher than in the absence of calm, averaging 43 μg/m^3 and 24 μg/m^3 respectively. The highest means of PM2.5 particulate matter were observed during strong temperature inversions of about 70 μg/m^3. Average PM2.5 concentrations for the above cases are given in Tables 1-3.

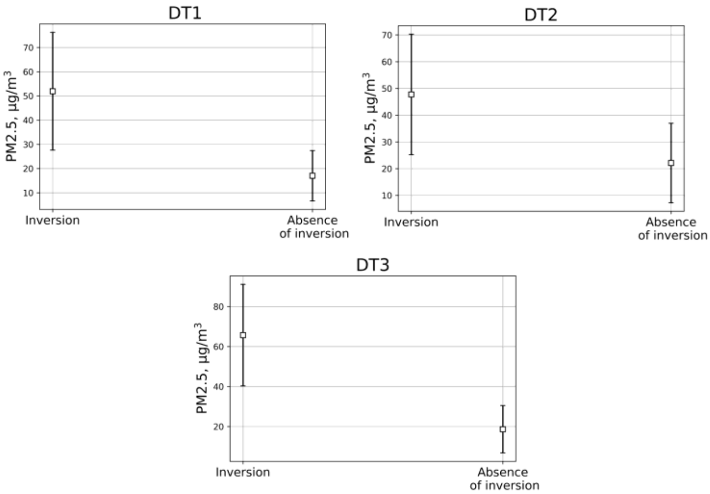

Fig. 1. One-way ANOVA results (1% significance level) for comparison of means PM2.5 in the case presence or absence of different types of temperature inversions between 2019 and 2022.

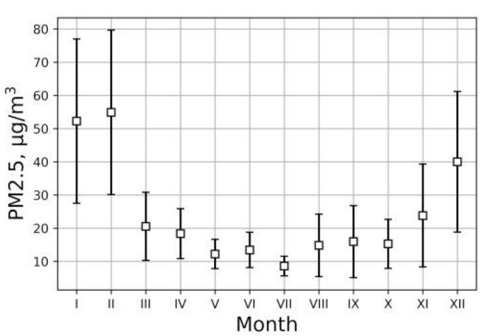

Fig. 2. One-way ANOVA results (1% significance level) for comparison of means PM2.5 depending on the months of the year between 2019 and 2022.

Fig. 3. One-way ANOVA results (1% significance level) for comparison of means PM2.5 depending on calm wind between 2019 and 2022.

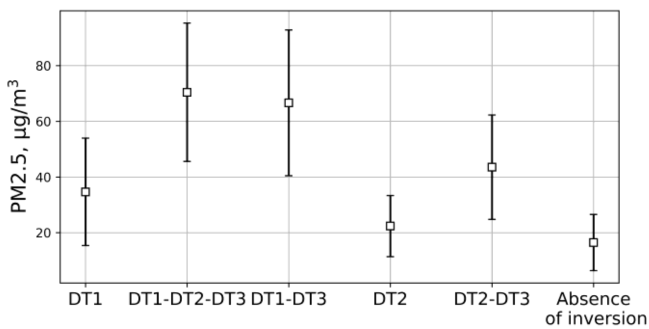

Fig. 4. One-way ANOVA results (1% significance level) for comparison of means PM2.5 depending on strong temperature inversion between 2019 and 2022.

Table 1. Average PM2.5 of months of the year between 2019 and 2022.

Month	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**
PM2.5 (µg/m^3)	52	55	21	18	13	9	15	16	12	10	24	40

Table 2. Average PM2.5 for different types of inversions and calm between 2019 and 2022.

Meteorological factor			**PM2.5 (µg/m^3)**
Temperature inversion	DT1	Inversion	52
		Absence of inversion	17
	DT2	Inversion	48
		Absence of inversion	22
	DT3	Inversion	65
		Absence of inversion	18
Calm		Calm	43
		Absence calm	24

Table 3. Average PM2.5 of depending on strong inversion between 2019 and 2022.

Inversion	**DT1**	**DT1-DT2-DT3**	**DT1-DT3**	**DT2**	**DT2-DT3**	**Absence**
PM2.5 (µg/m^3)	37	70	66	21	42	17

Multiple comparisons were made using the Tukey Test to determine which groups the means PM2.5 particulate matter was varied significantly. Significant differences were found between the means PM2.5 in January or February and the rest of the months. In addition, significant differences were found between groups with surface and elevated inversions compared to strong inversions, i.e. the presence of inversion on several layers.

High daily mean PM2.5 were singled out, i.e. the daily average PM2.5 exceeding the daily average MAC (maximum permissible concentration) 35 µg/m^3 established under Russian environmental protection law [13]. The effect of temperature inversions in this case was analyzed. Statistically significant differences (1% significance level) are determined in the presence of surface and elevated inverses (DT1) with the means 90 µg/m^3 and in the absence of the inversion at 60 µg/m^3. As well as in the case of strong inversion (DT3) with the means at 90 µg/m^3, and in the absence at 65 µg/m^3. In the case of elevated and height inversions (DT2), there are no statistically significant differences. Figure 5 shows these results.

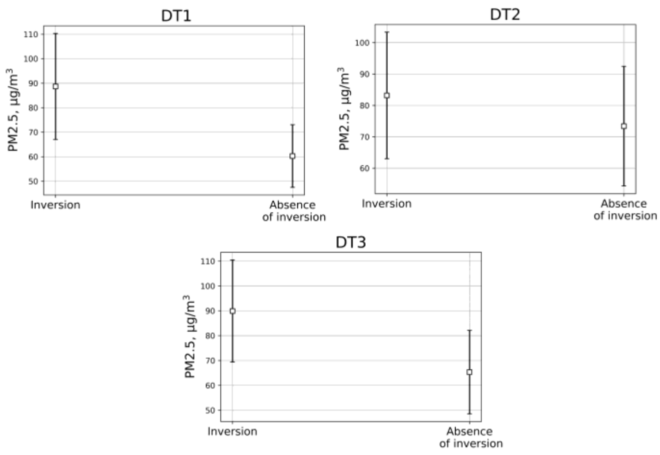

Fig. 5. One-way ANOVA results (1% significance level) for comparison of high daily mean PM2.5 depending on temperature inversion between 2019 and 2022.

In the case of high daily mean PM2.5, surface and elevated inversions (DT1) occurred in 69% of cases, strong temperature inversions (DT3) at 74%, elevated and height inversions (DT2) at 59%. If we consider the reverse situation, in the presence of surface and elevated inversions (DT1), high concentrations of PM2.5 occurred in 53% of cases, in the presence of strong temperature inversions (DT3) at 44%, in the presence of elevated and height inversions (DT2) at 19%.

Figures 6-7 show the two-way ANOVA results. F-statistic was used to test the statistical significance of differences (1% significance level).

As Figure 6 shows, the highest mean values of PM2.5 of 90 μg/m^3 were observed in the case of combination factors: the cold period (November-February) and the temperature inversion, while without temperature inversion of 30 μg/m^3. As Figure 7 shows, the highest mean values of PM2.5 were observed under calm and temperature inversion, averaging 115 μg/m^3, while in the absence of calm and inversion at 20 μg/m^3. The means PM2.5 for the above cases are given in Table 4.

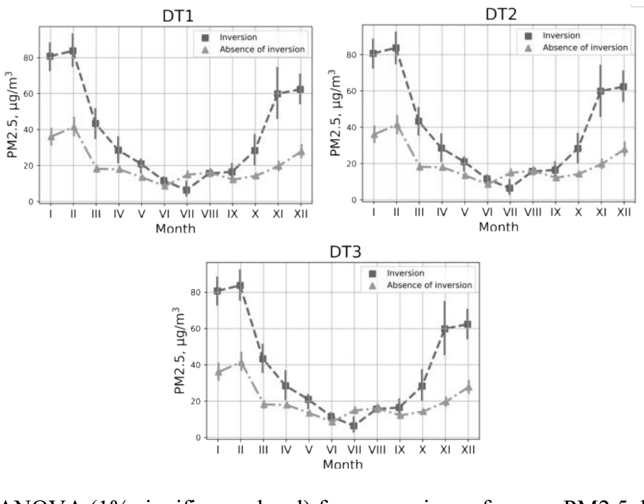

Fig. 6. Two-way ANOVA (1% significance level) for comparison of means PM2.5 depending on temperature inversion and the months of the year.

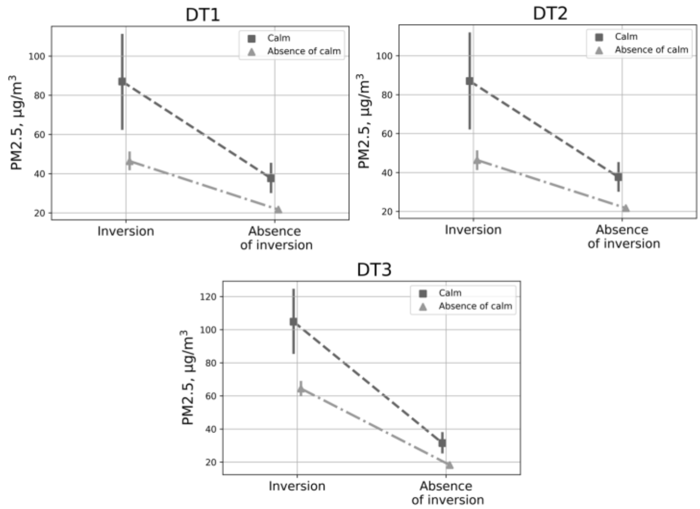

Fig. 7. Two-way ANOVA (1% significance level) for comparison of means PM2.5 depending on temperature inversion and calm wind.

Multiple comparisons were also made using the Tukey Test for groups with combinations of the months and the temperature inversions. The most significant differences in the mean values of PM2.5 between groups were observed in the case of a combination of two factors: surface and elevated inversions (DT1) and cold period (November – February) or strong temperature inversion (DT3) and cold period.

The influences of various meteorological factors in the means of PM2.5 for 4-year period from 2019–2022 were considered. Statistically significant differences were determined for temperature inversions, months in the cold period (November-February), and calm wind. These meteorological factors could be used to construct more precise air pollution prediction models, for instance, multiple linear and non-linear regression models.

Table 4. Average PM2.5 depending on temperature inversion and the months of the year between 2019 and 2022.

	PM2.5 (µg/m^3)													
	Calm wind		**Month**											
	Calm wind	**Absence of calm wind**	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**
DT1	83	51	76	82	35	32	22	14	16	24	18	28	57	61
Absence of inversion	29	17	30	36	19	18	14	9	17	17	11	15	19	28
DT2	87	46	67	71	42	19	24	14	15	10	11	13	17	50
Absence of inversion	38	22	49	52	20	19	16	8	15	16	12	15	27	38
DT3	105	64	81	83	45	30	24	15	9	18	19	24	61	63
Absence of inversion	32	18	36	43	19	18	16	13	17	18	14	16	22	24

4 Conclusion

The one-way ANOVA for the 4-years from 2019 to 2022 indicated statistically significant differences in the mean values PM2.5 for the following meteorological factors:

- Presence and absence of temperature inversion.
- The months of the year.

- Presence or absence of calm wind.
- Strong temperature inversions (presence of temperature inversion on several layers simultaneously).

The monthly distribution of the means of PM2.5 indicated that the one was higher in the winter months.

Besides, the case of high daily means PM2.5 were considered. The one-way ANOVA showed statistically significant differences in PM2.5 for the presence of surface and elevated inverses (DT1) and the presence of strong temperature inversion (DT3). In this case, surface and elevated inverses (DT1) occurred at 69%, and strong temperature inversion (DT3) at 74%.

The two-way ANOVA for the 4-year from 2019 to 2022 showed the statistical significance of both factors and their combination for the cases considered:

- Temperature inversion and the month of the year.
- Temperature inversion and calm wind.

The most significant differences in the mean values of PM2.5 occurred in the case of a combination of two factors: surface and elevated inversions (DT1) or strong temperature inversion (DT3) and cold period (November – February).

Acknowledgement

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References

1. WHO, https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health
2. S. Munir, Arab. J. Geosci., **9**, 1-13 (2016)
3. Z. Chen, D. Chen, C. Zhao, M.P. Kwan, J. Cai, Y. Zhuang, B. Zhao, X. Wang, B. Chen, J. Yang, R. Li, Environ. Int., **139**, 105558 (2020)
4. M. Stafoggia, T. Bellander, S. Bucci, M. Davoli, K. De Hoogh, F. De'Donato, C. Gariazzo, A. Lyapustin, P. Michelozzi, M. Renzi, M. Scortichini, Environ. Int., **124**, 170-179 (2019)
5. X. Liu, H. Hadiatullah, P. Tai, Y. Xu, X. Zhang, J. Schnelle-Kreis, B. Schloter-Hai, R. Zimmermann, Environ. Int., **276**, 116732 (2021)
6. R. Toro, M. Kvakić, Z.B. Klaić, D. Koračin, Environ. Int., **244**, 705-714 (2019).
7. H. Du, J. Li, Z. Wang, X. Chen, W. Yang, Y. Sun, J. Xin, X. Pan, W. Wang, Q. Ye, X. Dao, Atmos. Res., **280**, 106395 (2022)
8. L.K. Kwok, Y.F. Lam, C.Y. Tam, Atmos. Pollut. Res., **8**, 114-126 (2017)
9. M. Zhong, F. Chen, E. Saikawa, Environ. Int., **123**, 256-264 (2019)
10. J. Wallace, P. Kanaroglou, Sci. Total Environ., **407**, 5085-5095 (2009)
11. Geoportal (ground monitoring stations), http://sensor.krasn.ru/sc/
12. The Global Forecast System (GFS). Documentation, https://www.emc.ncep.noaa.gov/emc/pages/numericalforecast_systems/gfs.php
13. Sanitary rules and norms 1.2.3685-21 "Hygienic standards and requirements to ensure the safety and (or) harmlessness of human environmental factors", https://docs.cntd.ru/document/573500115