Using WRF mesoscale model to restore temperature profile in atmosphere boundary layer in Tomsk

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ABSTRACT

In the paper, the possible use of a WRF mesoscale model for the detailed restoring of a temperature profile in the atmosphere boundary layer (ABL) during winter anticyclone is studied. The correctness of air temperature modeling as well as the possible use of a WRF model for predicting a vertical temperature distribution was shown.

Keywords: temperature profile, atmospheric boundary layer, Tomsk, temperature profiler MTP-5, WRF model

1. INTRODUCTION

It is essential to model a thermal structure of the atmospheric boundary layer (ABL) in order that one can forecast current dangerous weather events. This involves inversions exerting pernicious influence on aviation (icing, foggy conditions, ceiling zero), as well as increasing the level of anthropogenic air pollution [1, 2].

Mesoscale meteorological models for local atmospheric research have been widely used in the last few years. A WRF model is one of the general-purpose systems for the atmosphere simulation. It is efficiently used for weather forecasting at scientific research centers and weather services all over the world and it is being continually improved [1, 3].

2. DESCRIPTION OF THE EXPERIMENT

The WRF (Weather Research and Forecasting, version 3.4.1) was applied in this study [4].

The model is based on the numerical method of equation solution in thermo- and hydro dynamics of atmosphere in terms of heat-mass-exchange in the top soil or water. The prediction accuracy of ground values according to the literature ranges from 0,85–1,5 ° C [5]. In the WRF model various representations of processes at a subgrid scale, which can be accounted for by parametrisation, are considered. The advance time by the WRF model comes up to 24 hours.

The calculations were made in three nested scopes with the shared center at latitude 56°,5 N and longitude 85°E (the city of Tomsk) . The first nested scope is West Siberia, the mesh size – 9 km; the second nested scope is Tomsk region, the mesh size – 3 km; the third nested scope is Southern Tomsk region, whose size being 50×50 km, its mesh size – 1 km [6]. For the first nested scope the temporal resolution was chosen to be 10 minutes whereas for the other two it was 30 seconds. The calculated atmosphere layer ranged from the surface up to the height of 30 km, where we used a vertical irregular grid consisting in 34 layers which grew thick towards the surface.

Finally, the appropriate parameters were selected: air temperatures at the simulated σ- levels in the atmosphere boundary layer. Eventually, the predictions of air temperatures at different layers of ABL in the area of Bogashovo Airport (Tomsk) on simulated days were obtained.

In order to carry out numerical experiments based on the WRF mesoscale model of high resolution as well as verify its validity, the calculations were made for three days with different weather conditions:

- 13.12.2012 yr. – a daily mean temperature was –37,9° C and it was less than a normal one (anomalous cold weather);
- 26.01.2013 yr. – a daily mean temperature was–2,1°C and it was more than a normal one (thawing weather) ;
- 26.02.2013 yr. – a daily mean temperature was –17,0 °C and it was within climatological normal (climatological normal).

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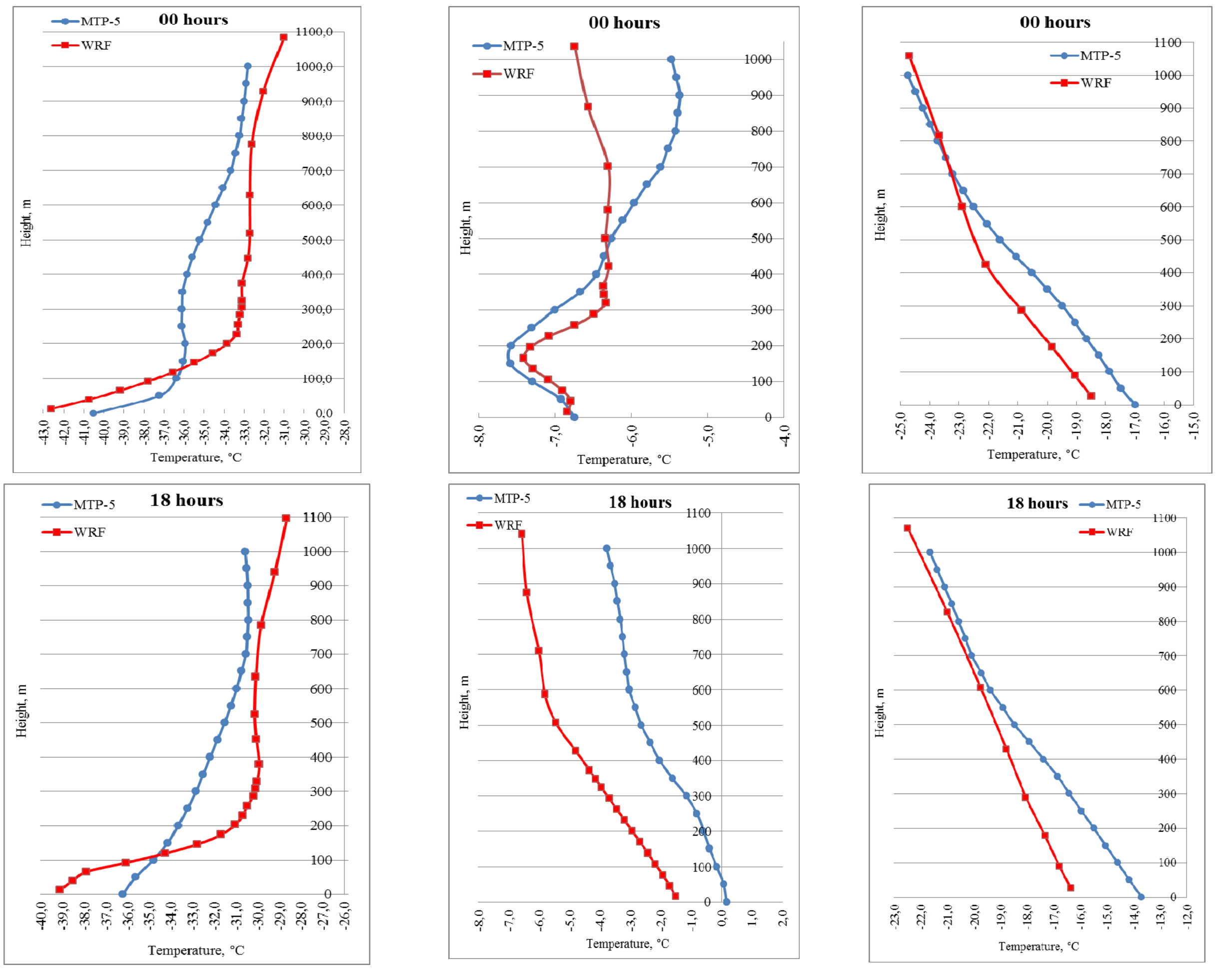
Consequently, numerical experiments were carried out for the cold months of the year, when the most unfavorable and dangerous conditions of air pollution were created.

3. RESULTS

In this paper, the data on 4 hours of observation were analyzed (00, 06, 12, 18 local hours). The predicted profile was compared to a real one at a given time shown by the temperature profiler MTP-5 (its sensibility makes up 0,5 °C). The results are given in Figure1.



13.12.2012 26.01.2013 26.02.2013

Figure 1 – Vertical temperature profiles by the temperature profiler and the calculations made by using a WRF mesoscale model

Given in table 1 are values of absolute difference (Δt) between measured air temperature profiles and those of calculated by the model on the simulated days.

As can be seen, the model was valid for certain hours during the anomalous cold weather when it defined the distribution of air temperatures at altitudes and fixed the surface inversion from the ground up to height of 300– 1000 m. The biggest discrepancy between the real and simulated profiles (Δt) was observed at the heights of 200–450 m. In the surface layer (up to 150 m) the temperatures were overestimated. The least values of absolute difference for all the hours during December 13, 2012 were marked at the heights of 600–1000 m (Table 1).

Table 1 – Absolute difference between measured air temperate profiles and those of calculated by the model in 13.12.2012 yr., 26.01.2013 yr., 26.02.2013 yr.

13.12.2012 yr.											
Height, m / Time, UGT	0	50	100	150	200	250	300	350	400	450	500
0	–2,1	–3,0	–0,8	0,5	2,1	2,8	2,9	2,9	2,8	2,8	2,3
6	1,9	–1,8	–2,1	–0,8	1,4	2,5	3,0	2,8	2,6	2,4	2,2
12	2,6	1,0	1,3	2,2	2,9	2,7	2,4	1,8	1,1	0,4	–0,2
18	–2,9	–2,7	–1,0	1,6	2,7	2,6	2,7	2,6	2,2	1,8	1,3
Height, m / Time, UGT	550	600	650	700	750	800	850	900	950	1000	–
0	1,9	1,5	1,1	0,7	0,6	0,5	0,7	0,7	0,9	1,2	–
6	1,9	1,6	1,2	1,0	1,0	1,0	1,0	1,3	1,5	1,6	–
12	–0,6	–1,1	–1,2	–1,2	–1,0	–0,9	–0,8	–0,6	–0,3	0,1	–
18	1,0	0,9	0,6	0,5	0,6	0,6	0,7	0,9	1,2	1,4	–
26.01.2013yr.											
Height, m / Time, UGT	0	50	100	150	200	250	300	350	400	450	500
0	–0,2	0,1	0,2	0,2	0,5	0,5	0,6	0,4	0,2	0,0	–0,1
6	2,6	2,6	2,5	1,5	0,6	–0,3	–1,1	–1,6	–1,9	–2,0	–2,1
12	–2,1	–2,3	–2,2	–2,2	–2,2	–2,1	–1,9	–1,9	–1,7	–1,5	–1,6
18	–1,7	–1,8	–2,0	–2,1	–2,3	–2,5	–2,6	–2,5	–2,6	–2,7	–2,8
Height, m / Time, UGT	550	600	650	700	750	800	850	900	950	1000	–
0	–0,2	–0,3	–0,5	–0,7	–0,9	–1,1	–1,1	–1,2	–1,3	–1,3	–
6	–2,1	–2,1	–2,1	–2,1	–2,2	–2,3	–2,3	–2,4	–2,4	–2,4	–
12	–1,6	–1,7	–2,0	–2,1	–2,3	–2,3	–2,5	–2,5	–2,7	–2,8	–
18	–2,9	–2,8	–2,8	–2,8	–2,9	–2,9	–2,9	–2,9	–2,9	–2,8	–
26.02.2013 yr.											
Height, m / Time, UGT	0	50	100	150	200	250	300	350	400	450	500
0	–1,4	–1,2	–1,2	–1,4	–1,5	–1,5	–1,4	–1,5	–1,4	–1,3	–0,9
6	–1,5	–0,5	0,4	0,7	0,7	0,6	0,4	0,3	0,2	0,0	0,0
12	0,1	0,5	0,3	0,2	0,2	0,1	–0,1	–0,4	–0,6	–0,7	–0,6
18	–2,5	–2,3	–2,2	–2,2	–2,0	–1,9	–1,7	–1,5	–1,2	–0,9	–0,6
Height, m / Time, UGT	550	600	650	700	750	800	850	900	950	1000	–
0	–0,6	–0,4	–0,2	–0,1	0,1	0,1	0,2	0,2	0,3	0,4	–
6	0,0	0,0	–0,1	–0,2	–0,2	–0,2	–0,2	–0,2	–0,2	–0,3	–
12	–0,5	–0,4	–0,4	–0,3	–0,3	–0,3	–0,2	–0,2	–0,1	–0,1	–
18	–0,5	–0,3	–0,3	–0,1	–0,2	–0,3	–0,4	–0,3	–0,3	–0,4	–

In the event of thawing (26.01.2013 yr.) the model most realistically defined the distribution of air temperatures up to the height of 450 m at 00 hour. It showed quite well the raised inversion with the lower boundary at the height of 200 m. At the height of above 450 m the temperature defined by the model started gradually falling. Therefore, the difference between a measured and simulated temperatures started inconspicuously rising (Figure 1).

The analysis of temperature profiles for 12 and 18 hours showed lapse rate as it follows from the calculations and measurements. The model coincided with the actual temperature distribution, the temperature by the model being decreased. The maximal values of absolute difference were marked above 800 m height. The minimal values Δt were marked at the height of 400–450 m at 00 and 12 h and at the height of 200 – 250 m at 06 h (Table 1).

At the time when a daily mean temperature of air was within climatological normal the model happened to closely restore the temperature profile in ABL at all the hours. According to the data obtained by the temperature profiler , no temperature inversion was observed at the study hours in February 26, 2013. The model could simulate the same trends in temperature changes by altitude. Both real and predicted data show the temperature decrease in the layer. The maximal fit of predicted air temperatures to the measured ones was observed at above 500 m height at the study hours.
The estimated accuracy of predicted values of temperatures at the altitudes in ABL was made comparing the predicted data to the real measured data. The estimation was made according to the basic documents [5, 7–8]. In Table 2, the estimated accuracy of air temperatures at different altitudes is given.

Table 2 – The estimated accuracy of air temperatures using the WRF model

The day	Accuracy characteristics	Time			
		00	06	12	18
13.12.2012 yr.	Mean forecast error	1,1	1,3	0,5	0,9
	Forecast root mean square error	1,9	1,9	1,5	1,8
	Mean forecast absolute error	1,7	1,7	1,3	1,6
26.01.2013 yr.	Mean forecast error	–0,3	–1,0	–2,1	–2,6
	Forecast root mean square error	0,7	2,1	2,1	2,6
	Forecast root mean square error	0,6	2,0	2,1	2,6
26.02.2013 yr.	Mean forecast error	–0,7	0,0	–0,2	–1,0
	Forecast root mean square error	1,0	0,5	0,4	1,3
	Forecast root mean square error	0,8	0,3	0,3	1,1

The analysis of statistical discrepancy in the event of anomalous cold showed that their values did not exceed 2°C. The errors revealed upward bias of temperature at all hours pertaining to the real one.
In the event of thawing, the temperature prediction errors were more than 2 °C. The mean forecast error shows downward bias of real temperatures.
The analysis of statistical discrepancy of air revealed that at all hours, apart from 06 hour, there was downward bias of a predicted air temperature. As a whole, in the period when a mean daily temperature was within climatological normal, the discrepancy did not exceed 0,5 °C . This indicates a good numerical forecast result.
In order to value the connection between temperature profiles by the profiler and the WRF model, correlation coefficients (r) were calculated (Table 3) [9, 10].
The analysis showed significant correlation between two sets of data two rows of data.

Table 3 – Correlation coefficients (r) between two sets of data the rows of predicted and real data

Days	Time			
	00	06	12	18
13.12.2012	**0,84**	**0,83**	**0,89**	**0,88**
26.01.2013	0,58	-0,10	**0,98**	**1,00**
26.02.2013	**0,99**	0,55	**0,99**	**0,99**
Statistically significant correlation coefficients are given in bold type				

4. CONCLUSIONS

1. At the air temperatures near climatological normal, the comparison of calculations made by the WRF mesoscale model with real measurements, demonstrated robustness of modeling air temperatures in ABL.
2. During the period of temperature anomalies (more or less than normal) the model showed some uncertainty in measurements.

3. During the period of anomalous cold the model exceeded the predicted temperature values at all hours. During anomalous warm weather and climatological normal the model underestimated the calculated data.
4. Absolute difference (Δt) between height profiles of air temperatures built by both MTП-5PE data and the WRF model did not exceed 3°C in absolute value.
5. The most precise results of forecasting air temperature were obtained in the layer at the height of above 600m.

Our results allow the WRF model to be used for forecasting a temperature profile in the atmosphere boundary layer in the area of Tomsk as well as for forecasting dangerous weather events.

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REFERENCES

[1] Kizhner, L. I., Barashkova, N. K., Akhmetshina, A. S., Bart, A. A., Starchenko, A. V. "Forecast of precipitation in the area of Bogashevo airport using the WRF model", Atmospheric and Oceanic Optics, vol. 27, issue 2, 187–194 (2014).
[2] Starchenko, A.V., Bart, A.A., Zuev, V.V., Shelekhov, A.P., Barashkova, N.K., Akhmetshina, A.S. "Chislennoe i jeksperimental'noe issledovanie sostojanija atmosfernogo pogranichnogo sloja vblizi ajeroporta Bogashevo", Vestnik Kuzbasskogo gosudarstvennogo tehnicheskogo universiteta, №6 (94), 3–8 (2012) [in Russian].
[3] Kizhner, L.I., Nakhtigalova, D.P., Bart, A.A. "Ispol'zovanie prognosticheskoj modeli WRF dlja issledovanija pogody Tomskoj oblasti", Vestnik Tomskogo gosudarstvennogo universiteta, vol. 358, 219–224 (2012) [in Russian].
[4] "ARW Version 3 Modeling System User's Guide", http://www.mmm.ucar.edu/wrf/users/ docs/user_guide_v3 / (20 December 2010) [in Russian].
[5] Kizhner, L.I., Barashkova, N.K., Kuzhevskaya, I.V. [Atmosfernye processy: dinamika, chislennyj analiz, modelirovanie], Izd-vo «TML-Press», Tomsk, 310 p. (2010) [in Russian].
[6] Zuev, V.V., Shelekhov, A.P., Shelekhova, E.A., Starchenko, A.V., Bart, A.A., Bogosloslovsky, N.N., Prokhanov, S.A., Kizhner, L.I "Izmeritel'no-vychislitel'nyj kompleks dlja monitoringa i prognoza meteorologicheskoj situacii v ajeroportu", Optika atmosfery i okeana, vol. 26., № 08, 695–700 (2013) [in Russian].
[7] RD 52.27.284-91 [Metodicheskie ukazanija. Provedenie proizvodstvennyh (operativnyh) ispytanij novyh i usovershenstvovannyh metodov gidrometeorologicheskih i geliogeofizicheskih prognozov. – Vved. 01.011992. – Jelektronnyj fond pravovoj i normativno-tehnicheskoj dokumentacii], http://docs.cntd.ru/document/1200068360 , (23 February 2014) [in Russian].
[8] RD 52.27.724- 2009 [Nastavlenie po kratkosrochnym prognozam pogody obshhego naznachenija] IG-SOCIN, Obninsk. 50 p. (2009) [in Russian].
[9] Vereschtagin, M.A., Naumov, A.P., Shatalinsky, K.M. [Statisticheskie metody v meteorologii], Izd-vo Kazanskogo universiteta, Kazan, 111 p. (1990) [in Russian].
[10] Gruza, G.V., Reytenbakh, T.G. [Statistika i analiz gidrometeorologicheskih dannyh], Gidrometeoizdat, Leningrad, 215 p. (1982) [in Russian].