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Using the numerical WRF model for the prediction of weather parameters in Tomsk Region

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Relevance of the work is due to the need to improve the quality of weather forecasts in different regions, including in Western Siberia, where is high frequency of the hazards in different seasons.
The results of the forecast of air temperature, barometric pressure and precipitation are presented. The calculations were made with using of the mesoscale meteorological model WRF for conditions of Tomsk region, town Tomsk and its suburbs. The different weather conditions in 1999, 2000 and 2012 years were considered.
Model based calculations were made at Tomsk State University claster «SKIF CYBERIA». Various parameterization schemes were used for the calculations.
Combinations which best describe physical processes in the atmosphere, taking into account weather conditions and of the spatial scale were picked up. The set of parametrizations of physical processes, which provides the best accuracy results forecast of the meteorological values were defined. Checking of two schemes of microphysics of the clouds at forecast precipitation were performed. Work is of interest to improve mesoscale forecast of weather on the similar by physiographic conditions of the territories.

Keywords: the weather forecast; the prognostic WRF system; the parameterization of physical processes; Tomsk region.

Introduction

Current numerical atmospheric models have become a common tool for atmosphere and weather prediction research for different terms. The successful weather research and forecasting depends on the accurate assessment of current atmosphere, computer technology involved, methods of solution to hydrothermodynamic equations and the selection of parameterization of physical processes at subgrid scale.

This research is aimed at improving the quality of weather forecasts, last but not least dangerous phenomena predictions. At present the accuracy of short-term weather forecasts (from 12 hours to 3 days) exceeds 90%. The accuracy of dangerous phenomena predictions is within 55–90%.

The high frequency of dangerous phenomena is observed in West Siberia in different seasons, e.g. according to the 2010 data received from eight federal districts, the Siberian Federal District , West Siberia included, experienced the greatest number of dangerous and unfavorable weather phenomena, its share being 28%, which is < 28% than in 2009 [1].

The forecasts are less accurate in the warm season due to the lack of mechanisms serving to identify local convective phenomena of relatively small spatial size (km. tens of km). These phenomena include rain showers, thunderstorms, hails, gale force winds. It is essential that using numerical modelling one can make the prediction of various atmospheric parameters, both spatial and temporal, over the large territory. Numerical weather prediction models are relevant for urban areas with high-tech manufacturing (large cities, industrial areas, airports, etc.).

Numerical weather predictions such as air temperature, atmospheric pressure and precipitation for Tomsk region, Tomsk and its suburbs were made using the mesoscale Weather Research and Forecasting (WRF) model, version 3.4.1 [2].

Model description and calculations

The Weather Research and Forecasting (WRF) model, version 3.4.1. was used in the study. This model is widely used to assess the physical condition of the atmosphere and weather forecast at atmospheric research centers and weather service stations in many countries and it is still being developed. The model is based on the numerical solution to the atmosphere hydrothermodynamic equations in terms of processes in the upper layer of the surface and water. The model makes it possible to use a large number of parameterizations at subgrid scale which can be employed in different combinations. This includes parameterizations of cloud microphysical processes; radiation processes taking account of short and long wave radiation; surface layer processes taking account of heat and moisture exchange between atmosphere and surface; planetary boundary layer describing its basic processes and affecting free atmosphere; clouds.

Model based calculations were made at Tomsk State University claster «SKIF CYBERIA».

At the first stage the work on system run up was done, i.e. meteorological situation, bench-mark data, weather maps were selected, visualization of calculations was made, maps were produced.

For geographical gridding three nested areas with different spatial resolution were chosen – 1. West Siberia, 2. Tomsk region 3. Southern Tomsk region, Tomsk included. For the first area the temporal resolution accounted for 10 minutes, for the other two areas – 30 seconds . The data provided by National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR) were used for reanalysis.

The Grid Analysis and Display System (GrADS) cluster for results' visualization was used. Using GrADS one can simulate meteorological data in two dimensional fields and bind data to geographical mesh as well as fit data into the base map.

At the second stage the goal of identifying the optimal parameterization set for study area in order to evaluate their efficiency for the system functionality and predictions was set.

Based on modeling the predictions of air temperature and pressure across Tomsk region in different seasons for the following periods – November 7–8, 1999; May 6–8, 1999; July 2–4, 2000 were made. The dates were selected on the ground of meteorological processes when the days with dangerous or unfavorable weather were fixed.

In selecting parameterization for each meteorological process, the WRF model was run 3 times. On each subsequent running different theoretically substantiated parameterizations were established, thereafter the calculations for different parameterizations of physical processes peculiar for the season and meteorological process were made. For simulations that were successfully completed the qualitative assessment of predictions at four sites located in different parts of study region Tomsk (southern part of region), Alexandrovskoe (south western part), Kolpashevo (cetral part), Pudino (south western part of Tomsk region) were made. Factual weather data were taken from the website [3]. In order to evaluate the model, the second nested scope was used; the quality of predictions was evaluated by average error — and average square error — ε [4].

$$\varepsilon = \Sigma(x_f - x_v)/N \tag{1}$$

$$\varepsilon_k = (\Sigma(x_f - x_v)^2/N)^{1/2} \tag{2}$$

In formulas (1) — (2) the following notation are taken: x_f — the predicted value of the meteorological parameters; x_v — the actual value; N — the number of the evaluated timing.

Analysis of numerical experimental results

Air temperature atmospheric pressure

In making calculations curtain contingency cases occurred:

— Computation discontinuity after a lapse of time and the program issued error caused by parameterizations discrepancy for planetary boundary and surface layers;

— Abnormally large errors occurrence caused by interaction of multidirectional factors including parameterizations conflict;

— Computation discontinuity caused by parameterizations conflict in «short and long wave radiation» section.

In most cases the program successfully completed the prediction. The comparative results of predicted and factual data for some events are given below.

The cloudy and rainy weather was observed in Tomsk region on November 7–9, 1999. At that period the snow cover setting was recorded, i.e. the aggregate of direct and indirect links unstable in time between weather parameters both in boundary atmospheric layer and in the surface layer was observed. The model was run for the three days, the data output being given with the time interval of three hours. The results bias in air temperature and atmospheric pressure is shown in Table 1.

Table 1. Qualitative assessment of numerical predictions on November 7–9, 1999

Station	Characteristics of the quality	The air temperature,°C	Pressure, hPa
Tomsk	ε	−1.7	–0.9
	ε_k	2.7	7.1
Alexandrovskoe	ε	0.0	–0.5
	ε_k	4.2	2,5
Kolpashevo	ε	2.1	–0.6
	ε_k	4.2	1.7
Pudino	ε	2.2	–1.8
	ε_k	4.5	3.1

According to the results of average error, the predicted values are found to be either bigger or lower than the actual ones. The standard error of air temperature prediction at the study sites accounted for 2.7–4.5°C, air pressure — 1.7–7.1 hPa.

Weather forecast for May 6–8, 1999.

On May 6, 1999, the weather was fair with some cloud. There was no rain. On May, 7, 1999, the increase of wind with shower and thunderstorm was recorded at 12 study sites.

The compute mode was comparable. The results are given in Table 2. The predicted values of air temperature at all the sites turned out to be lower at the average. The standard error of air temperature prediction at the study sites made up a little more than 3°C, air pressure — 3–5.9 hPa.

Table 2. Qualitative assessment of numerical predictions on May 6-8, 1999

Station	Characteristics of the quality	The air temperature,°C	Pressure, hPa
Tomsk	ε	–0.8	–0.8
	ε_k	3.2	3.0
Alexandrovskoe	ε	–0.8	2.2
	ε_k	3.2	4.2
Kolpashevo	ε	–0.8	–0.8
	ε_k	3.3	5.9
Pudino	ε	–0.8	2.2
	ε_k	3.1	3.6

Weather forecast for July 2–4, 1999

At that period the weather was cloudy in Tomsk region. The precipitations were scattered. On July 3, the dangerous phenomenon – the thundershower with gale force wind was recorded in the north of region. The results of numerical predictions are given in Table 3.

The standard error of air temperature prediction didn't exceed 3°C.

Table 3. Qualitative assessment of numerical predictions on July 2–4, 1999

Station	Characteristics of the quality	The air temperature,°C	Pressure, hPa
Tomsk	ε	–0.1	–0.9
	ε_k	3.0	1.2
Alexandrovskoe	ε	1.7	–1.3
	ε_k	2.7	2.0
Kolpashevo	ε	0.0	1.2
	ε_k	2.6	5.0
Pudino	ε	–0.4	–0.1
	ε_k	3.0	0.8

Precipitations

In order to get the information on probability of precipitation predictions with regard to the available parameterizations, the numerical simulations were made. In view of this, 2 parameterizations of cloudiness and microphysics were implemented – Lin's and Goddard's schemes.

In our research the Purdue Lin scheme and the Goddard Cumulus Ensemble Model scheme were used. In the Purdue Lin scheme six classes of hydrometeors are included: water vapor, cloud water, rain, cloud ice, snow and graupel. This is a relatively sophisticated microphysics scheme in WRF, and it is the most suitable for use in research studies [5].

The Goddard Cumulus Ensemble Model scheme is mainly based on Lin et.al. However, the Goddard microphysics schemes have several modifications. There is an option to choose either graupel or hail as the third class of ice. Graupel modeling is added [6].

The results of simulation at the 00 h. (UTC), on June 11 to 00 h. June 13, 2012 were obtained. At that time the unsettled weather was observed in Tomsk suburbs, on June 15 light showers were recorded from 1 p.m. at the Bogashovo airport, Tomsk weather service station.

The output data was received every hour. In the model the initial conditions were derived from the SLAV model numerical results. The calculations were made in three embedded grids centered at 56.5° N.L., 85° E.L. (Tomsk city). The size if the first (parent) area was 450×450 km, the second embedded area – 150×150 km, the third one – 50×50 km. All the three areas comprised the Bogashovo airport (which is located 14 km off east-western Tomsk suburbs), the weather service station (which is located in the southern suburbs of Tomsk), the TOP-station of IOA SB RAS, making meteorological and atmospheric air composition observations (the eastern part of Tomsk). The atmospheric layer from surface up to 30 km height was calculated and irregular vertical 34 layer grid condensing toward surface was used.

The numerical results were compared with the meteorological observations made at the weather service station (the measurement period – 6 hours), the TOP-station (every hour), the airport (every hour).

The research was made by multiple use of the WRF modeling system. Wind speed at a height of 10 m over land (V, m/s) was calculated; air temperature – at a level of 2 m (t), (the results are given in °C); specific air humidity – at a level 0f 2 m (Q, g/kg); air pressure – at a level of the station (P, 9 hPa); the temperature of top soil and surface (°C); cumulated total convective precipitations; rain intensity; lower and upper border of convective layer.

GCE scheme- based calculations

The comparative results of meteorological parameters using the model are given below.

Таблица 4. Meteorological value prediction errors in accordance with the Goddard scheme

Characteristics	Airport			TOP-station			
	t,°C	P, hPa	V, m/s	t,°C	P, hPa	Q, g/kg	V, m/s
ε	5.2	1.0	1.0	3.1	4.3	5.5	2.2
ε_k	5.8	1.0	1.3	4.2	4.5	6.2	2.6

The calculation results can be considered satisfactory for temperature, pressure, wind speed. The calculation error is high enough for humidity.

Parameterization-based calculations of microphysics processes in clouds by the Goddard scheme didn't reveal any precipitations either at the observation sites or at the territory of the third embedded area.

Consequently, in our case the precipitation prediction can't be considered satisfactory.

Lin scheme- based calculations

The use of the Lin scheme gave most satisfactory results of precipitation predictions. According to the calculations, the signs of rain were fixed from 5 a.m. (0.005 mm/h), gradually increasing by 2 p.m. From 2 p.m. to 6 p.m. the amount of precipitation made up to 1.3 mm/h. The last time the precipitation being fixed was 10 p.m. However, the calculations showed the precipitations only in the most south-western parts of the region. They were not predicted at the weather service station, the airport and the TOP-station.

Actually, the rain was fixed at the weather service station from 2 p.m. to 6 p.m. At 6 p.m. cloudy weather (the amount of clouds was 9 Sc) was observed at the weather service station, at 12 noon and 3 p.m. there were clouds of middle level as well as of high level. Clouds were fixed from 2 p.m. to 6 p.m. at a high of 9–10 kilometers.

Unfortunately, the precipitations at the TOP-station are not measured, although the increase in relative humidity was fixed at 2 p.m. – from 50–60% to 82–91%, implying the high probability of rainfall.

According to observations, light shower was fixed from 1 p.m. to 2 p.m. at the airport. Cb clouds could be seen from 1 p.m. to 3 p.m.

As a result, the calculations based on the Lin scheme gave the most reliable results. The error in the rain belt location made up approximately 10 km. In assessing the quality of precipitation predictions it is considered be significant if the distance between the observed precipitation belt and predicted one is <50 km [5]. The time of precipitations was consistent with the model at the weather service station.

Summary

1. The implementation of the weather forecast model for Tomsk region proved to be promising in the context of its use in different seasons and upon various weather conditions including unfavorable and dangerous weather phenomena.

2. The calculated parameters of model accuracy appear to be satisfactory at this stage.

3. Different schemes of parameterizations were selected based on numerical calculations. The most suitable patterns describing physical atmospheric processes consistent with weather conditions and spatial scale were chosen, the most accurate of all the predictions being the following set of physical processes parameterizations:

– long- and shortwave radiation – the RRTMG scheme [5];

– surface layer – the similarity scheme by Janjic. The processes peculiar for the surface layer are described. The scheme is based on the similarity law by Monin-Obukhov. It includes a viscous layer, a degree of roughness, eddy turbulent fluxes [5];

– underlying surface – the Noah LSM scheme [5];

– planetary boundary layer – the Mellor-Yamada-Janjic (MYJ) scheme. The account is taken of full-scale range of atmosphere turbulence;

– cloudiness – the Betts-Miller scheme [5].

4. The account was taken of transfer of heat and humidity from the surface, the amount of clouds in calculating radiation. The number of surface layers equaled to 5. It is necessary to include the snow cover in cold seasons.

5. In precipitation prediction the most reliable of the two schemes of cloud microphysics turned out to be the Lin scheme. The actual time of precipitations and their amount were calculated. The calculated area of precipitations is 10 km shifted in relation to the actual area of precipitations. The previous study showed that the WSM5 scheme gave the reliable results in predictions of precipitation areas and their amount.

We consider it reasonable to continue the study of the WRF model for atmosphere parameters predictions in Tomsk region as well as in Tomsk suburbs. In the nearest future we are planning to apply the WRF model to other schemes of parameterizations of cloud microphysics.

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