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Estimating the Accuracy of the Very Heavy Snowfall Forecast in the Urals by the WRF Model

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Abstract—The results of the forecast of two heavy snowfalls registered on October 18 and 23, 2014 in the Urals using the WRF model are presented. The application of the WRF-ARW atmospheric model to the computation of weather forecasts for the conditions of heavy widespread precipitation in the form of snow is considered. The obtained estimates of precipitation forecast are compared with the estimates of the GFS NCEP global model. The results demonstrate that both models have approximately the same accuracy of precipitation forecast in the context of the process under consideration.

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1. INTRODUCTION

The very heavy snowfall is a frequent severe weather event in Russia and other northern countries. The significant duration of the cold period, active cyclonic activity in the Urals, and the closeness of this region to the Arctic seas and Atlantic Ocean form conditions for frequent snowfalls. The mathematical modeling of the atmosphere of various scales is widely used for forecasting precipitation including winter precipitation [4, 5, 10, 14]. The WRF model is one of the most widespread instruments for modeling mesoscale atmospheric processes. The cases of formation of severe weather events in winter using the WRF model have been studied in [11–13, 15, 16]. The potential of the WRF model for the territory of Russia have been studied for separate cases of precipitation in the form of snow [1, 2, 6]. The paper presents the results of the forecast of two heavy snowfalls registered on October 18 and 23, 2014 in the Urals using the WRF model.

2. SYNOPTIC CONDITIONS AND WEATHER TYPICAL OF HEAVY SNOWFALLS IN THE URALS

The average long-term frequency of heavy snowfalls in the Middle Urals in October is 17% [9]. According to the data of observations at the weather station network, the snowfalls which reached a criterion of a severe weather event were registered in the Middle Urals in October 2014 [8]. The 12-hour total precipitation was from 20 to 32 mm of precipitated water [7] that makes up 40–90% of the monthly precipitation norm. The snow cover was formed two weeks before the average long-term dates, and snow depth reached 35 cm in the Middle Urals and 57 cm in the North Urals. The early formation of snow cover resulted in the blocking of a part of agricultural equipment in the fields. The traffic in Perm and Yekaterinburg was paralyzed due to the snowfall for 24 hours.

The first very heavy snowfall (October 18) occurred under the influence of the warm front of the polar system, and the second one (October 23) was caused by the occlusion front. Let us consider the development of synoptic processes in more detail.

In the first case the cloud system of the warm part of the polar front started influencing the territory of the Urals as early as on October 16 and caused moderate and heavy snowfalls in the south of the Perm krai. The surface frontal line was directed along 55 N and passed from the center of the cyclone in the area of Ryazan through Nizhny Novgorod, Kazan, and Ufa. According to the surface chart for 00:00 UTC on October 16, 2014, the temperature contrast in the frontal zone was equal to 2 C/100 km; according to the 500–1000 hPa thickness chart, 36 gpdam/1000 km.

The maximum temperature of the air mass over the Perm krai formed on October 16 under the influence of the southern periphery of the low cold anticyclone, was from –5 to 1 C. The air mass of the warm sector of the western young cyclone was heated to 12–17 C and moved to the northeast. The width of the transition zone between these air masses was equal to 200 km, and the maximum air temperature in it varied from 2 to 6 C. During the next day the temperature contrast in the upper-level frontal zone remained the same, whereas the contrast in the atmospheric surface layer in the zone of the quasistationary front increased to 4 C/100 km due to cold advection and radiative cooling in front of the front (over the Urals). For this reason moderate and heavy snowfalls continued on October 17 and the precipitation zone extended and embraced the south of the Sverdlovsk oblast and the north of the Chelyabinsk oblast.

In the surface chart for 00:00 UTC on October 18 the warm front was oriented from the center of the cyclone at the stage of the maximum development in the area of Kazan along the southern border of the Perm krai through the Chelyabinsk oblast to Kazakhstan. The intense advection of heat and moisture as well as the divergence of isohypses in the middle troposphere caused the surface pressure drop in front of the warm front on the territory of the Urals (the barometric tendency reached –4.2 hPa/3 hours). The increase in pressure (5 hPa/100 km) and temperature (5 C/100 km) gradients led to the surface frontogenesis on October 18 and, hence, to the precipitation rate increase that, in turn, caused a very heavy snowfall.

In the second case, in the surface chart for 12:00 UTC on October 22, 2014 the cyclone generated on the polar front in the area of Helsinki on October 20 (p_0 = 994.1 hPa, the barometric tendency is –1.3 hPa/3 hours). It was located near the western slope of the Ural Mountains at the stage of filling (p_0 = 993.4 hPa, the barometric tendency is 0.3 hPa/3 hours). The cyclone moved with the speed of more than 30 km/hour following the steering flow from northwest to southeast. The maximum development of the cyclone was observed in the morning on October 22 in the area of Kazan (the minimum pressure in the center was 989.9 hPa). The cyclonic vortex was observed up to the level of 500 hPa.

As the cyclone was approaching the Ural Ridge, in its frontal part (over the northern areas of the Perm krai) the pressure rise (the barometric tendency at 18:00 UTC on October 22) was registered due to the flow convergence. Then, during the cyclone movement the pressure drop began on the lee side of the ridge on the territory of the Sverdlovsk and Chelyabinsk oblasts (the barometric tendency varied from –0.8 to –2.0 hPa/3 hours). As a result, two centers of low pressure were formed in the surface chart for 00:00 UTC on October 23. One was located near the windward slope of the ridge (near Kudymkar), and the other, near the lee slope (near Chelyabinsk), i.e., the segmentation of the cyclone occurred. The cyclone located over the South Urals developed and continued moving to the northeast. The low-pressure center over the Ural Prikamye rapidly disappeared. The orographic occlusion was formed over the Middle Urals (the air temperature at the level of 850 hPa varied from –6 to –8 C). The main temperature contrast was situated in front of the occlusion front over the northern areas of the Sverdlovsk oblast (it reached 2.1 C/100 km in the surface chart for 00:00 UTC on October 23). The strengthening of northern wind to 13 m/s and cold advection along the eastern slope of the Ural Mountains resulted in the front intensification, and the rate of widespread snowfalls increased up to 15–20 mm/12 hours. On October 23–24 in the north of the Sverdlovsk oblast snow depth reached 57 cm.

According to the data of the Hydrometcenter of Russia, the natural synoptic period (n. s. p.) was developing over the first natural synoptic area on October 16–20, 2014 which consisted of two elementary synoptic processes (e. s. p.), namely, October 16–18 and October 19–20; the natural synoptic period on October 21–24 consisted of two e. s. p., namely, October 21–22 and October 23–24. According to the classification of synoptic processes proposed by A.L. Kats, the meridional macroprocess of Z-form characterized by the mainly negative anomalies of average daily air temperature in the Middle Urals developed in both n. s. p. [3].

3. RESULTS OF NUMERICAL PREDICTION OF THE HEAVY SNOWFALL

The forecasts based on the WRF V3.2.1 model were made using the ARW dynamic core for 48 hours with the start at 00:00 UTC of the current day. The model was run with the spatial resolution of 10 km and temporal resolution of 60 s, data was issued every 3 hours. The results of computations for 15, 27, and 39 hours from the forecast start were used for the further analysis to provide coincidence with the precipitation measurement time at weather stations.

The following parameterizations of physical processes were used for the modeling:

—cloud microphysics: the Thompson scheme;

—long-wave radiation fluxes: the RRTM (Rapid Radiative Transfer Model) scheme;

Table 1. Skill scores of the forecasts of precipitation amount by two models

Date of the model run start in October 2014	Accuracy according to the Manual [8], %			Absolute error, mm		
	from 03:00 to 15:00 UTC of the current day	from 15:00 UTC of the current day to 03:00 UTC of the next day	from 03:00 to 15:00 UTC of the next day	from 03:00 to 15:00 UTC of the current day	from 15:00 UTC of the current day to 03:00 UTC of the next day	from 03:00 to 15:00 UTC of the next day
15	–	–	91/93	–	–	0.6/0.6
16	92/93	98/96	93/92	0.5/0.8	0.2/0.2	0.1/0.3
17	91/90	78/79	74/80	0.2/0.4	3.3/4.2	4.1/3.5
18	77/83	66/68	74/76	2.8/2.3	1.9/2.4	2.8/2.5
19	79/79	–	–	2.1/2.1	–	–
21	–	–	79/75	–	–	1.8/2.8
22	77/80	77/80	69/75	2.1/2.1	2.1/1.9	1.8/1.8
23	74/82	85/79	81/74	2.1/1.6	1.0/1.2	0.7/1.0
24	80/78	–	–	0.7/0.9	–	–
Mean	81/84	81/80	80/81	1.5/1.4	1.7/2.0	1.7/1.8

Note: The numerator is by the WRF model and the denominator is by the GFS model.

Table 2. Skill scores of the forecast of a heavy snowfall (6–19 mm/12 hours) by two models

Forecast time		Model integration time, hour	Pearce–Obukhov criterion	Forecast accuracy, %	Number of missed targets	Number of false alarms
Date, October 2014	UTC					
16	15:00	15	0.95/0.95	96/96	0/0	2/2
16	15:00	39	0.95/0.78	96/96	0/1	2/1
17	3:00	27	–	98/98	1/1	0/0
18	3:00	27	0.73/0.79	85/87	5/2	2/4
18	15:00	15	0.58/0.73	80/85	4/6	5/1
18	15:00	39	0.68/0.76	76/83	6/5	5/3
19	3:00	27	0.38/0.18	83/78	3/4	5/6
19	15:00	15	0.27/0.08	74/70	7/12	5/2
19	15:00	39	0.07/–0.03	70/67	13/14	1/0
22	15:00	15	0.58/0.58	80/78	4/3	5/7
22	15:00	39	0.49/0.45	78/70	6/3	4/11
23	3:00	27	0.49/0.50	78/78	9/8	1/2
23	15:00	15	0.79/0.88	93/96	2/1	1/1
23	15:00	39	0.67/0.73	89/93	3/3	2/0
24	3:00	27	0.93/0.64	93/96	0/1	3/1
24	15:00	15	0.00/0.00	96/96	2/2	0/0
24	15:00	39	0.00/0.00	96/96	2/2	0/0

Note: The numerator is by the WRF model and the denominator is by the GFS model.

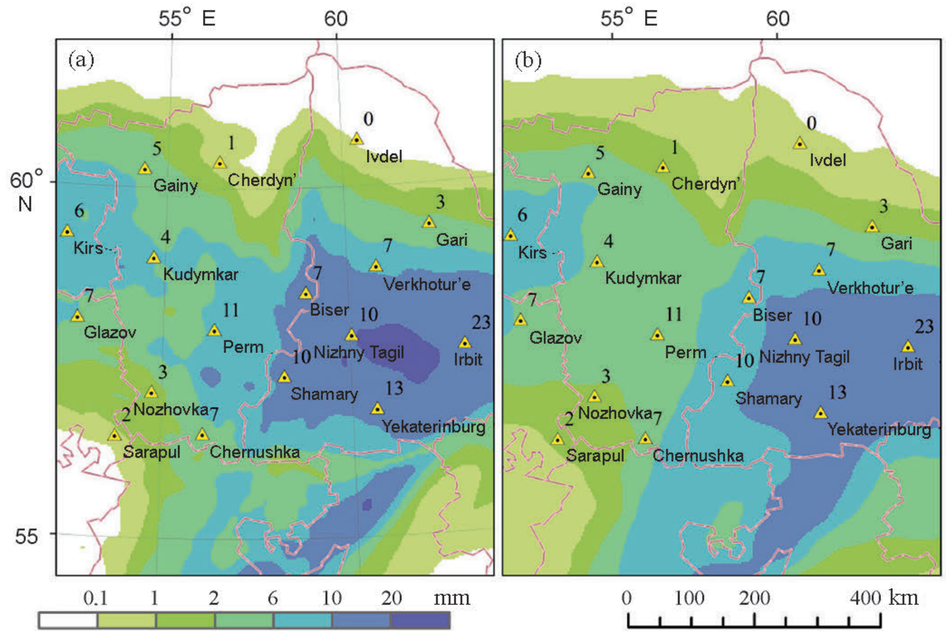
—short-wave radiation fluxes: the Dudhia scheme;

—surface layer: the Monin–Obukhov scheme with the Carlson–Boland viscous sublayer and standard similarity functions;

—underlying surface and soil: the NOAH scheme;

—boundary layer: the Yonsei University scheme.

To assess the accuracy of the model-based precipitation forecast, the data were used from 46 weather stations located on the territory of the Perm krai, Udmurt Republic, and the Sverdlovsk and Kirov oblasts. The 12-hour simulated and observed values of the amount of precipitation were compared. Model values of precipitation for each station were obtained by interpolation between the model grid points.



Observed and predicted total precipitation for October 18, 2014. The numerals near the names of weather stations are the observed total precipitation, mm. The colored fields are the predicted total precipitation. (a) Computation by the WRF model; (b) computation by the GFS model.

Table 3. Skill scores of the forecast of the very heavy snowfall (20 mm/12 hours)

Weather station	Model integration time, hour	Observation time		Amount of precipitation, mm	
		Date, October 2014	UTC	Actual	Computed by WRF/GFS model
Okhansk	27	18	3:00	21	21.2/18.0
Kungur	27	18	3:00	21	24.5/22.5
Bol'shaya Sosnova	27	18	3:00	20	30.1/19.1
Nev'yansk	15	18	15:00	28	19.3/15.6
Nev'yansk	39	18	15:00	28	22.4/20.5
Irbit	15	18	15:00	23	16.3/13.5
Irbit	39	18	15:00	23	15.5/14.1
Gari	15	23	15:00	20	17.6/14.8
Gari	39	23	15:00	20	17.1/16.1

Heavy snowfalls observed on October 16–24, 2014 in the Urals were caused by synoptic-scale processes. Therefore, to determine the performance of the WRF-ARW mesoscale model, besides the traditional approaches based on the computation of the accuracy of the forecast of solid precipitation following the Manual [8] and on the determination of the absolute error of the forecast, the GFS NCEP global model (USA) was used as an additional criterion. This model prognostic fields were presented by the data at the points of the 0.5   0.5 regular grid. The results of computations presented in Table 1 demonstrate that an insignificant increase in the forecast accuracy in case of the passage from GFS to WRF-ARW is observed only for absolute errors. The estimate of forecast accuracy based on the Manual [8] in GFS model turned out to be even slightly higher. The absence of the accuracy estimates of forecasts of the precipitation amount for some 12-hour periods is associated with the fact that the phenomenon was neither predicted and observed in these periods.

The computation of the accuracy of the forecast of heavy snowfalls (the total 12-hour precipitation is from 6 to 19 mm [8]) was based on the following characteristics: the Pearce–Obukhov criterion, total accuracy of the forecast, hit rate, and the number of false alarms and missed targets (Table 2). These data demonstrate that both global and mesoscale models simulate the large-scale precipitation field adequately in the majority of cases. The models also simulate adequately the areas where the precipitation with the maximum rate was observed (see the figure). However, the maximum amount of precipitation obtained from the WRF model data turns out to be much larger than that obtained from the data of the global model; this is, probably, because the mesoscale model contains the more detailed description of the experimental area orography.

The forecast of heavy snowfalls based on the WRF model estimated using the Pearce–Obukhov criterion has higher reliability than that based on GFS: its mean value is 0.50 from the WRF model computations and 0.47 from the global model. The Pearce–Obukhov criterion for October 17 was not computed because the the phenomenon was predicted by both models but was not observed. The accuracy of the precipitation forecast based on the Manual [8] and computations of two models differed by not more than 5% in the majority of cases (Table 2). Both for the global and mesoscale models the number of missed targets is slightly larger than the number of false alarms (61/39% for WRF and 62/38% for GFS). The clear dependence of WRF and GFS forecast accuracy on specific features of synoptic location was revealed. For example, the minimum total accuracy of the forecast was registered on October 19, when heavy snowfalls were observed in the rear part of the cyclone and were shower-type. The data from Table 3 indicate that the WRF model provides the forecast of the very heavy snowfall (which was registered at six stations) with higher accuracy than the GFS model.

4. CONCLUSIONS

Two cyclones accompanied by cold weather and heavy snowfalls passed over the Urals on October 16–24, 2014. In that period the amount of precipitation up to 60 mm of snow water equivalent was registered at some stations. The assessment of the process of formation of widespread precipitation using the WRF-ARW and GFS models demonstrated that both models adequately simulate the generation of large-scale precipitation zones. The passage from the global to mesoscale model revealed no considerable increase in the accuracy of the forecast except the cases of a very heavy snowfall (20 mm/12 hours). Both models worse predict precipitation in the rear part of the cyclone. The Pearce–Obukhov criterion for such case at 15:00 UTC on October 19, 2014 for the integration time of 39 hours amounted to 0.07 and –0.03, respectively, for the computations based on the WRF and GFS models.

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