Complex forecasts of heavy snowfalls in the Urals with global and mesoscale numerical models

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Abstract. This paper presents an assessment of short-term numerical forecasts of precipitation in the cold period of the Urals. The use of global (GEM and GFS) and mesoscale (WRF) models in forecasting of heavy snowfalls is considered. The reliability levels of the 15-h and 27-h forecasts with the GEM, GFS, and WRF models are approximately equal. The 39-h forecasts with the WRF model are least accurate. The dependences of the quality of model forecasting on synoptic-scale environments, seasonal patterns, geographical location, and topography are obtained. The heavy snowfall events formed by a warm front, a cold front, and in the northern part of a cyclone are predicted with satisfactory accuracy. The least successful numerical forecasts are obtained for non-frontal precipitation in the warm sector of a cyclone. All three models tend to overestimate the precipitation amount during the cold period: the number of false alarms exceeds the number of missed events. The numerical forecasts of precipitation during the cold period have higher reliability levels for the territory of Western Urals than for the Eastern Urals region.

1. Introduction
Heavy snowfalls are one of the hazardous weather phenomena and may cause significant damage to various branches of economy [1–3]. To minimize the risk of economic losses a forecast of heavy snowfalls should be successful and early.

Nowadays the main data source for a short-term precipitation forecast is the global and mesoscale numerical atmospheric models. The accuracy of short-term forecasts of heavy snowfalls often does not correspond to the demands of consumers, especially in areas with complex orography. Some approaches are being developed to improve numerical forecasts of precipitation. For example, the divergences of the Q-vector and the equivalent-potential vortex at the saturation stage (in the 925–700 hPa layer) are calculated to identify the heavy convective snowfalls which were not predicted by global numerical models [4, 5]. New parametrization schemes are introduced to describe the sub-grid effects of orography on the spatial distribution of precipitation [6].

The mesoscale atmospheric models provide a more detailed simulation of the precipitation fields taking into account the state of the underlying surfaces [7]. However, the output of global models used as initial data to drive mesoscale models often contains significant errors. These errors affect the quality of mesoscale models. For instance, simulated precipitation zones may be significantly shifted in relation to observed precipitation, which has significant effects on the accuracy of forecasting by mesoscale models [8]. Thus, the selection of global atmospheric model data to drive the mesoscale

model has a critical importance for the reliability of mesoscale forecast. At the same time, an increase in the spatial resolution of global numerical models up to 10–25 km allows one to exclude the use of mesoscale models for the forecast of heavy snowfalls in some cases [9].

2. Data and methods

In this study we used two global atmospheric models (the GEM and GFS) and the mesoscale WRF model for short-term forecasts of heavy snowfalls in the Ural region. The real-time data of global models are free-available on the ftp-servers of Canadian and U.S. National Weather Services. We developed scripts for automated downloading of operational 27-h forecast data (in GRIB-2 format). Only one variable (accumulated precipitation) was downloaded, which allowed us to significantly reduce the data amount. A short description of the GFS and GEM model data is presented in Table 1 (see also review [10] for more details).

Table 1. Short description of global atmospheric model data.

Model name	Developer (country)	Horizontal grid size	Spatial resolution of downloaded data	Number of vertical levels
GFS	National Center for Environmental Prediction (NCEP), USA	13 km	0.25°	64
GEM	Canadian Meteorological Center (CMC), Canada	0.14°	0.24°	120

Also, we used the mesoscale WRF model v 3.8.1 with the ARW dynamic core [11]. The WRF model is installed on the computational cluster "PGNIU-Kepler", which consists of 8 computer units iDataPlex DX360 M4 based on IntelXeonE5 processors and NVidiaTeslaK20 video adapters. The accepted WRF model settings are shown in Table 2.

Table 2. WRF model settings for heavy snowfall forecasts.

Characteristic	Setting
Horizontal grid resolution	7.2 km
Grid points	600×600
Number of vertical levels	42
Topography	U.S. Geological Survey (USGS) DEM (30s)
Simulation length	27 h, with preliminary assimilation of objective analysis data for 12 h
Output data time step	1 h
Dynamic core	ARW
Integration time step	36 s
Initial and boundary conditions	GFS forecast with 0,5° grid size
Cloud microphysics	Thompson's scheme
Planetary boundary layer	scheme of the Yonsei University
Underlying surface	Noah model
Shortwave and longwave radiation	rapid radiative transfer model (RRTM)
Surface layer	Monin-Obukhov scheme with Carslon-Boland viscous sub-layer and standard similarity functions
Convection	explicit simulation (without parameterization)

The NDFD tkDegrib 2.02 and ArcGIS 10.3 (ESRI, USA) software is used for decoding the output model data and performing subsequent calculations. The GFS model output GRIB-2 files are processed only with ArcGIS, without preliminary decoding.

The simulated precipitation amount is calculated for 03, 15, 27, and 39 h from the time of model run (00 UTC), which corresponds to the time of precipitation measurement by weather stations. As a result, we could compare the accumulated precipitation according to the numerical forecasts and the weather station measurements. The data from 48 weather stations located in Perm region, Sverdlovsk region, and Udmurtia Republic were used to estimate the accuracy of the numerical forecast. The simulated precipitation amount at the weather station locations is extracted with the use of the zonal statistic tool of ArcGIS 10. Then the forecast accuracy assessment is performed using the Pirs-Obukhov criteria and other characteristics recommended by the guidance document 52.27.284–91 [12].

During the study period (between January 2016 and January 2018), 57 heavy snowfall events occurred in the study area (Perm and Sverdlovsk regions). We used the threshold value of the precipitation amount for "heavy snowfall" events ($\geq$ 6 mm/12h) which is recommended by the Russian Hydrometeorological Service [13].

3. Results

Table 3 presents the general assessment of accuracy of numerical forecast of heavy snowfalls. It can be noted that the reliability of 15-h and 27-h forecasts of the GEM, GFS, and WRF models is satisfactory (Pirs-Obukhov's value: P $\geq$ 0,4) and approximately equal. However, the 39-h forecasts are substantially less successful for all models. The 39-h forecasts of the WRF model are least accurate.

Table 3. Accuracy assessment of numerical forecast of heavy snowfalls related to forecast-time interval (15/27/39 h, respectively).

Forecast success parameter	Numerical model		
	GEM	GFS	WRF
Pirs-Obukhov's value	0.40/0.50/0.28	0.44/0.47/0.29	0.44/0.43/–0.01
Percentage of successful forecasts (in total), %	90/90/90	91/88/92	90/88/85
Percentage of successful positive forecasts (predictability of events), %	44/66/30	49/55/52	49/62/11

The accuracy of short-term numerical forecast of precipitation depends not only on model settings (including the initial and boundary conditions, parameterizations of sub-grid processes, horizontal model resolution, and the number of vertical levels), but also on the features of synoptic-scale processes in the atmosphere [14]. Taking into account the features of a synoptic situation, it is possible to eliminate some forecast uncertainty.

The influence of synoptic-scale environments on the reliability of forecast of heavy snowfalls is shown in Figure 1. In general (for all models), heavy snowfall events which are formed on the warm front, on the cold front, and in the northern part of a cyclone are predicted with satisfactory accuracy. Furthermore, the WRF model forecasts are successful for the snowfalls which took place in the rear part of the cyclone. The GEM model forecast can be used with relatively high reliability in the majority of synoptic situations, except for the non-frontal precipitation in the warm sector of the cyclone. In total, the least successful forecasts are also obtained for this type of synoptic situation.

The influence of the seasonal factor on the reliability of forecasts for the GEM, GFS, and WRF models is estimated based on the analysis of the seasonal variability of negative (missed events) and positive (false alarms) forecast errors. All three models tend to overestimate the precipitation amount during the cold period, especially in February and March. Therefore, the number of false alarms exceeds the number of missed events. This feature is less typical for the WRF model forecasts.
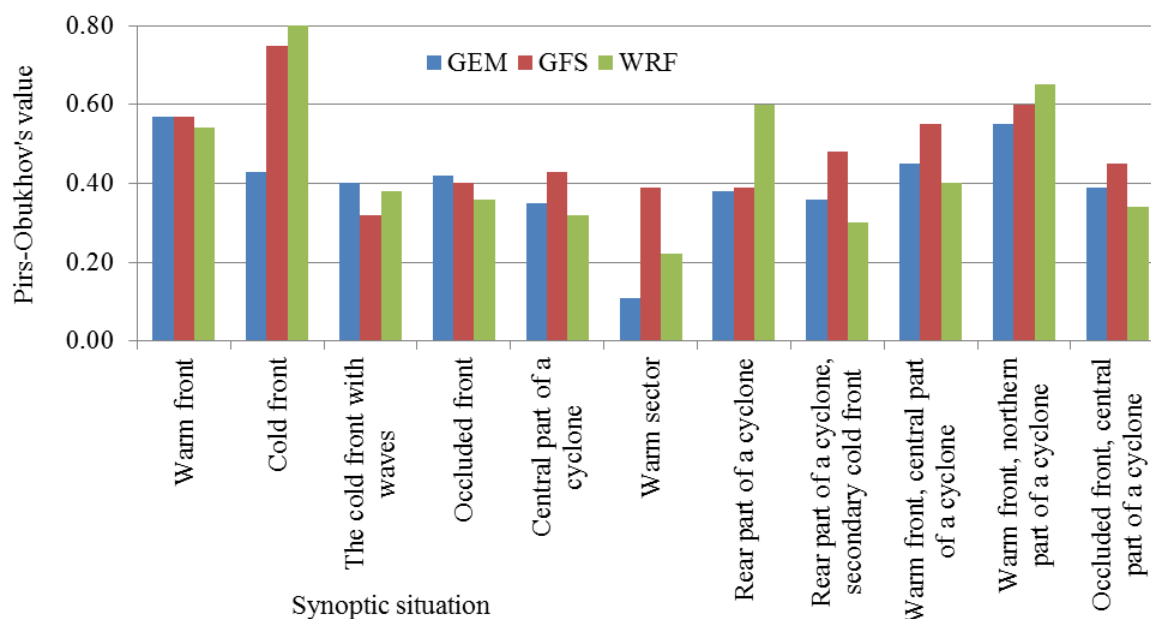
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Figure 1. The influence of synoptic-scale environments on the reliability of heavy snowfall forecasts by GFS, GEM, and WRF models.

In the middle of the winter season, the number of missed heavy snowfalls may exceed the number of false alarms. But during the spring season false alarms strongly prevail (Figure 2). Similar conclusions have been made earlier for the WRF model [15]. However, these patterns can sometimes be violated. For example, in an extremely cold November of 2016 all three numerical models missed many snowfall events. Thus, the prevailing type of forecast errors depends on the air temperature. If a heavy snowfall happens under low temperature conditions, the probability of it being missed by the model is higher.
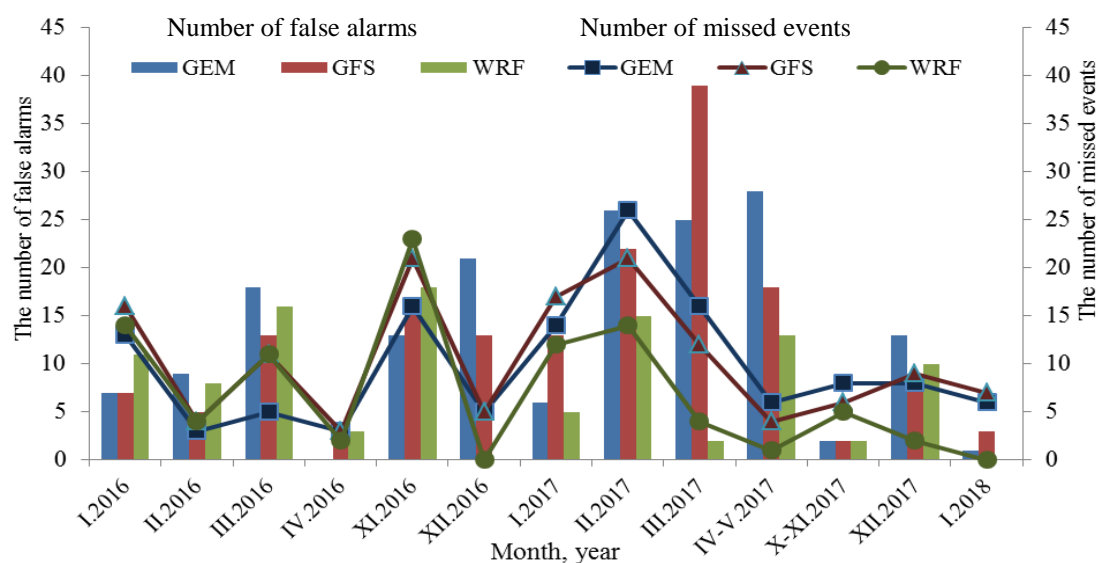

Figure 2. The number of false alarms and missed events at forecast of heavy snowfalls by GFS, GEM, and WRF models.

The Urals is a region with complex topography. Low and plain relief prevails in the western and eastern parts of the region. The mountainous part is represented by the Northern and Middle Urals. Thus, the altitude of the meteorological stations varies from 62 to 463 m above sea level. The reliability of heavy snowfall forecasts depends on the spatial position of a weather station (Table 4). By the example of the WRF model, we can conclude that the numerical forecast of precipitation during the cold period has higher reliability for the territory of Western Urals than for the Eastern Ural region.

Table 4. Assessment of precipitation forecast by WRF model
depending on the spatial position of weather stations (March 2016).

Indicators of success	Western Ural		Eastern Ural	
	forecast-time interval, h			
	15	27	15	27
Pirs-Obukhov's value	0.65	0.38	0.45	0.19
Percentage of successful forecasts (in total), %	69.5	56.9	63.1	49.1
Percentage of positive forecasts (predictability of events), %	67.3	56.1	56.6	45.1
Number of false alarms	6	8	3	14
Number of missed events	2	5	2	6

4. Conclusions

The results of this study show that the forecast of heavy snowfalls should be comprehensive and should take into account the features of synoptic-scale environments, seasonal patterns, geographical location, and topography.

Acknowledgments

References
[1]   Bedritskiy A, Korshunov A and Shaymardanov M 2017 Vliyaniye opasnykh gidrometeorologicheskikh yavleniy na ustoychivoye razvitiye ekonomiki Rossii *Meteorologiya i gidrologiya* **7** 59–67
[2]   Pishchalnikova E and Kalinin N 2016 *Usloviya formirovaniya i prognoz obilnykh snegopadov v Permskom kraye* (Perm: Perm State Univ. Publ.) p 168
[3]   Fargey S, Henson W, Hanesiak J and Goodson R 2014 Characterization of an unexpected snowfall event in iqaluit, nunavut, and surrounding area during the Storm Studies in the Arctic field project *J. of Geoph. Res.* **119**(9) 5492–511
[4]   Kalinin E and Yusupov Y 2013 Metod prognoza silnykh konvektivnykh osadkov v kholodnyy period goda *Meteorologiya i gidrologiya* **4** 19–28
[5]   Wetzel S and Martin J 2001 An operational ingredients-based methodology for forecasting midlatitude winter season precipitation *Wea. Forecasting* **16** 156 –67
[6]   Choi H and Hong S 2015 An updated subgrid orographic parameterization for global atmospheric forecast models *J. of Geoph. Res.* **120**(24) 445–57
[7]   Wang H, Yu E. and Yang S. 2011 An exceptionally heavy snowfall in Northeast china: Large-scale circulation anomalies and hindcast of the NCAR WRF model *Meteorol. and Atmos. Physics* **113**(1) 11–25

[8]   Kalinin N, Vetrov A, Pishchalnikova E, Sviyazov E and Shikhov A 2016 Otsenka kachestva prognoza ochen silnogo snegopada na Urale s pomoshch'yu modeli WRF *Meteorologiya i gidrologiya* **3** 55–62

[9]   Pishchalnikova E, Kalinin N, Vetrov A, Shikhov A, Sviyazov E and Bykov A 2016 Prognoz silnogo i ochen silnogo snegopada na Urale na osnove modeli WRF *Trudy Gidromettsentra Rossii* **359** 58–72

[10] Tolstykh M 2016 Globalnyye modeli atmosfery: sovremennoye sostoyaniye i perspektivy razvitiya *Trudy Gidromettsentra Rossii* **1** 5–33

[11] Skamarock W *et al* 2008 A Description of the Advanced Research WRF Version 3. NCAR Techn. Note – 475 + STR p 125

[12] Nastavleniye po kratkosrochnym prognozam pogody obshchego naznacheniya. Federalnaya sluzhba po gidrometeorologii i monitoringu okruzhayushchey sredy (Rosgidromet) 2009 (Obninsk: IG-SOTSIN) p 62

[13] Rukovodyashchiy dokument. Metodicheskiye ukazaniya. Provedeniye proizvodstvennykh (operativnykh) ispytaniy novykh i usovershenstvovannykh metodov gidrometeorologicheskikh i geliogeofizicheskikh prognozov 1991 (Leningrad: Gidrometeoizdat) p 149

[14] Pishchalnikova E, Kalinin N, Shikhov A and Bykov A 2018 Chislennyy prognoz silnykh osadkov v kholodnyy period goda na territorii Permskogo kraya *Gidrometeorologicheskiye issledovaniya i prognozy* **367** 135–45

[15] Pyankov S, Shikhov A, Kalinin N, Sviyazov E. 2018 A GIS-based modeling of snow accumulation and melt processes in the Votkinsk reservoir basin *J. of Geograph. Sci.* **28**(2) 221–37