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Torrential Rain Forecast using the Mesoscale Model WRF-ARW

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Annotation. Using a mesoscale model WRF-ARW[1] we made a torrential rain episode forecast on January 5-6, 2014 in the province of Khuzestan (Iran) with an advance time of 24, 48 and 72 hours. To find an optimal scheme of forecast we made numerical experiments with six sets of physical parameterizations. During the numerical experiments we were able to identify that the model showed the most sensitivity to cloudiness parameterization. The rating of a forecast made on an independent material showed that the used set of parameterizations of the model WRF-ARW allows to give satisfactory forecasts of heavy rainfall with an advance time of 24 hours.

Key words: Mesoscale model, Weather forecast, Parameterization of physical processes.

One of the main goals of this study was to predict heavy rainfall in the south-west of Iran using mesoscale model. Mesoscale models are widely used in many major and regional meteorological centers. Their popularity is due to a relatively simplified forecasting technology (compared with global operational models), and the ability to use less powerful computers. At the same time, the flexibility of settings and ties to a specific place allows mesoscale models to obtain good results in the short-term forecasts. The WRF model got the greatest distribution among mesoscale models.

WRF model (Weather Research and Forecasting) is one of the most versatile and modern systems of atmospheric modeling. As a free distributed software product, it has been widely and successfully used for weather forecasting in research centers and meteorological services in various countries and it is still developing. As an effective tool for solving many problems in the physics of the atmosphere, this model is used for research purposes: monitoring of air pollution, the study of climate, modeling a various mesoscale phenomena (in particular, the breezes, convective and other phenomena[2, 3].

The model is based on a numerical solution of an atmosphere hydrodynamics equations taking into account the processes in the upper layer of the land or water. Sub-grid scale processes are taken into account by means of parameterization. In the WRF model we can use a large number of parameterizations of physical processes that can be combined. This study uses

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the version WRF 3.5. of the model. To describe the physical processes of under grid-scale in the atmosphere and on the underlying surface the following blocks set is offered:

1. Microphysics (mp_physics) includes such processes as water vapor, clouds, precipitation[4-9].
2. Parameterization of radioactive processes (ra_lw_physicsi ra_sw_physics), which take into account the long-wave and short-wave solar radiation[4, 10-13].
3. Parameterization of the surface layer (sf_surface_physics) take into account the processes of heat and moisture exchange between the atmosphere and the underlying surface. The model offers five options of parameterizations[14-16].
4. Parameterization of the processes on the underlying surface and in the soil (sf_sfclay_physics)[1, 17].
5. Parameterization of the planetary boundary layer (bl_pbl_physics) takes into account the turbulence in the boundary layer and in the free atmosphere, the vertical gradients of air and wind temperature, the height of the boundary layer, the cloud formation processes. The model suggests six variants of parameterizations that may be used in different specific weather conditions[15,16, 18].
6. Cloudiness parameterizations (cu_physics) allow to predict the properties of both the ascending and descending flows, to consider the processes of air mixing in the clouds and in the environment, to simulate the unloading of clouds and precipitation, to assess the productivity of precipitation. The submitted 4 different parameterizations allow to assess the development processes, the entire cloudiness as well as separate clouds[15, 16, 19-21].

METHODS

In the first stage WRF model has been installed on a personal 12-nuclear computer with Intel i7 processor at the Department of Meteorology, Climatology and Atmosphere ecology of Kazan (Volga Region) Federal University. For geographic dimensioning we chose an estimated area with a horizontal spatial resolution of 9x9 km and 41 vertical level. Time resolution was 30 seconds.

Analyzes fields and forecasts of the global model GFS (USA) were used as the initial data. Forecast fields with advance time of 72 hours were taken with a readability of the time for 3 hours. In the second stage of working with the model we solved the problem of determining the optimal set of parameterizations for the area of the study, in order to assess their impact on the success of the forecast. When launching the model we used parameterization schemes, listed in Table 1. We used 6 types of parameterizations (WRFA - WRFF). The calculation was done for the landfill 999h729 km (111 nodes in the zonal and 81 node in the meridional direction), with a step of integration over the space of 9 km. The center of the rated operating conditions was located at coordinates 31 ° N. and 49 ° east longitude.

WRF model allows to get forecast fields of different types of precipitation. In this work we received forecasts of two types of precipitation "Accumulated total cumulus precipitation (mm)" and "Accumulated total gridscale precipitation (mm)" in the province of Khuzestan for 5 and 6 January 2014. The first type of precipitation forecast applies only to the accumulated convective (cumulus) precipitation, and the second to the total amount of accumulated precipitation, caused by global advective processes.

The choice of date is due to the presence of heavy precipitation and initial data.

WRF model was run six times (for 6 parameterizations) for each date and with different advance time (24, 48, 72 hours). Thus, we made not less than 36 numerical experiments. During each new start new different theoretically substantiated parameterizations appeared, and calculations for different sets of parameterizations of physical processes were made, which are characteristic for the season and the synoptic situation. For the modeling's that have been completed successfully, we made an assessment of the quality of the forecast received from observations on six stations listed in Table 2, located in different parts of the province of Khuzestan (Abadan city, Ahvaz city, Mesdzhede-Soleiman city, Omidiye city, Safi Abad and Bushehr).

The analysis of synoptic charts (of the on-land field)at 06 and 12 hours of Universal

Coordinated Time (UTC), January 6, 2014, showed that the area of Khuzestan province at 12 hours has been influenced by a vast cyclone with a minimum pressure of 1014 hPa. The central part of the area was crossed by a warm front. Then the cyclone shifted to the south-east, the front moved with the cyclone. In the province of Khuzestan we observed squalls, thunderstorms and torrential rain. In the south-eastern part of the considered territory (Omidiye, Bushehr)we observed strong torrential rain (06 h). The air temperature changed over the territory, from 8 ° C in the north to 14 ° C in the south. The most intense convective phenomena moved to the southeast of the territory.

Network observations of the weather stations, and the forecasts of the field of meteorological variables obtained by the model WRF-ARW were used as input data for the assessment of the forecast.

The aim of this study was to evaluate the possibility of using a mesoscale numerical model WRF-ARW for short-term prediction of torrential

Table 1. Parameterization scheme used in the prognosis

	WRF A	WRF B	WRF C	WRF D	WRF E	WRF F
mp_physics	Thompson	Eta (Ferrier)	WSM6	WSM5	WSM5	Lin (Purdue)
ra_lw_physics	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG
ra_sw_physics	RRTMG	CAM	Dudhia	Dudhia	Dudhia	Goddard
sf_sfclay_physics	Monin-Obukhov (Janjic Eta) scheme	Monin-Obukhov scheme	Monin-Obukhov (Janjic Eta) scheme	Monin-Obukhov (JanjicEta) scheme	Monin-Obukhov (Janjic Eta) scheme	Monin-Obukhov (Janjic Eta) scheme
sf_surface_physics	unified Noah land-surface model	RUC land-surface model	Noah-MP (multi-physics) Land Surface Model	Noah-MP (multi-physics) Land Surface Model	Noah-MP (multi-physics) Land Surface Model	Noah-MP (multi-physics) Land Surface Model
bl_pbl_physics	Mellor-Yamada-Janjic (Eta) TKE scheme	YSU scheme	Mellor-Yamada-Janjic (Eta) TKE scheme	Mellor-Yamada-Janjic (Eta) TKE scheme	Mellor-Yamada-Janjic (Eta) TKE scheme	Mellor-Yamada-Janjic (Eta) TKE scheme
cu_physics	Betts-Miller-Janjic	Betts-Miller-Janjic	Kain-Fritsch	Kain-Fritsch	Grell-Devenyi	Kain-Fritsch

Table 2. The selected stations and their actual data in heavy precipitation

WMO codes	Name of Station	Lon X	Lat Y	Alt Z (<)	The amount of precipitation (mm) January 5, 2014 (UTC)				January 6, 2014 (UTC)			
					6	12	18	24	6	12	18	24
40831	Abadan	48,25	30,37	6	7	1	0	8	4	0,6	0	0
40811	Ahvaz	49,65	31,33	22	0	0,2	0	4	5	12	1	0
40812	Mesdzhede-Soleiman	48,38	31,93	320	0	0	0	0	7	19	10	6
40833	Omidiye	49,6	30,77	27	0	0	0	9	25	8	3	0
40794	Safi Abad	48,42	32,27	82,9	0	0	0,3	0,7	3	10	2	0
40857	Bushehr	50,82	28,9	8,4	4	7	0,5	8	41	23	7	1

Rainfall in mm corresponds to the accumulated amount in the previous 6 hours rain in the territory of Khuzestan.

The quality of the forecast was assessed by the mean error *e* and the root-mean-square error e_k:

$$e = \frac{1}{N}\sum(x_f - x_v) \qquad ...(1)$$

$$e_k = \sqrt{\frac{1}{N}\sum(x_f - x_v)^2} \qquad ...(2)$$

In the formulas (1) and (2) we used the following notation: x_f - The predicted value of a meteorological quantity; x_v - The corresponding observed (checking) value; *N* - the number of estimated terms.

The analysis of numerical experiments

WRF model on the whole satisfactorily reproduces precipitation, falling during the period of Torrential rain, including the phase of precipitation.

In most cases, the model successfully reproduces the presence of precipitation. But there was some exceeding the forecast on the coastal stations. Tables 1-2 show the correlation coefficients (the sample size was 48 values: 4 periods, 2 days, 6 stations) predictive and actual evidence for some predictions.

Table 3. The correlation coefficient of actual and predicted precipitation sums in all weather stations at 5-6 January 2014

The correlation coefficient	WRF A	WRF B	WRF C	WRF D	WRF E	WRF F
	0,7	0,77	0,69	0,29	0,74	0,6

Correlation which is significant at the 0.05 level (2-sides.) is enhanced in bold.

Table 4. Assessment of the quality of the forecast with an advance time of 24 hours at 5 of January, 2014

Name of station	Quality characteristics	Precipitation, mm					
		WRF A	WRF B	WRF C	WRF D	WRF E	WRF F
Abadan	e	-2	1	1,2	-1,9	0,1	-1,3
	e_k	3,6	3,1	1,4	4,3	0,4	4,1
Ahvaz	e	-1,4	0,5	1,3	-2,2	1,1	-1,8
	e_k	4,4	2,9	1,5	4,4	1,9	4,4
Mesdzhede-Soleiman	e	-0,7	-0,3	0,3	-1,9	-0,1	-1,1
	e_k	2,1	2	0,4	3,9	0,2	4,7
Omidiye	e	-0,3	-0,5	0,3	-2,1	-0,1	-1,2
	e_k	1,7	2	0,4	4,1	0,2	4,6
Safi-Abad	e	-1,1	-0,2	0,7	-1,9	0,1	-1,1
	e_k	2,6	2	0,9	4	0,4	4,4
Bushehr	e	-1,2	-0,7	0,7	-1,8	0,1	-1,4
	e_k	1,9	1,9	0,9	3,6	0,5	4,6
average value	-1,1	0	0,8	-2	0,2	-1,3	
average value	2,7	2,3	0,9	4,1	0,6	4,5	

In such work[22], the authors compared the actual and calculated supply of water in the snow according to the WRF model and showed that the model in all cases significantly (2-5 times) understates its value. At the same time, they noted that the main reason is the use of the forecast of global model GFS as the initial conditions, which unsatisfactorily reproduces the process of snow accumulation[22]. In this work, we noted that WRF model systematically underestimate the average daily air temperature. A similar systematic underestimation of the average daily air temperature in the initial period of snow melting is characteristically for the global model GFS.

In general, the use of precipitation forecast using WRF model for the calculation of snowmelt significantly more effective than the interpolation of observation network data, which is often accompanied by significant errors in the assessment of both quantity and phase of precipitation[22].

Forecasts for WRF model were made up using dynamic ARW core for a period of 72 h and 48 h. However, they showed a poor quality of forecasts. Therefore, in further calculations we used forecast fields for a period of 24 hours only. Tables 4 and 5 show errors of precipitation forecast at 5 and 6 of January 2014 respectively.

According to the results of calculation of the average error, we can be seen that the predictive values were both above and below the actual values. Root-mean-square error of the precipitation forecast on the stations considered at the 5th January (Table. 4), was in parameterization: WRFA from 1,7 to 4,4 mm, WRFB from 1,9 to 3,1 mm, WRFC from 0,4 to 1,5 mm, WRFD from 3,6 to 4,4 mm, WRFE from 0,2 to 1,9 mm and WRFF from 4,1 to 4,7 mm.

Root-mean-square error of the precipitation forecast on the stations considered at the 6 of January (Table. 5) was greater than at the 5th of January. WRFA from 6,4 to 11,9 mm, WRFB from 2 to 6,8 mm, WRFC from 7,2 to 10,3 mm, WRFD from 10,5 to 12,2 mm, WRFE from 3,9 to 6,1 mm and WRFF from 13,9 to 22,7 mm.

Table 5. Assessment of the quality of the forecast with an advance time of 24 hours at 6 of January, 2014

Name of station	Quality characteristics	Precipitation, mm					
		WRF A	WRF B	WRF C	WRF D	WRF E	WRF F
Abadan	e	6,4	0,8	-8,1	-5,3	-3,2	-6,5
	e_k	8,4	5	10	10,5	4,4	15,5
Ahvaz	e	4,6	3,3	-7	-0,3	-0,5	-7,5
	e_k	6,5	6,8	7,2	12,2	6,1	16,9
Mesdzhede-Soleiman	e	6,9	-1	-9,3	-5,3	-3,1	-5,3
	e_k	11,2	2	10,1	10,7	4,3	14,6
Omidiye	e	6,4	-1,5	-9	-5,3	-3,2	-5,3
	e_k	10,7	2,2	9,5	10,6	4,4	14,4
Safi-Abad	e	7,1	-0,5	-9	-5	-3,2	0
	e_k	11	2,2	9,6	10,8	4,4	22,7
Bushehr	e	7,4	-1	-9,5	-5,8	-3	-8
	e_k	11,9	2,1	10,3	10,6	3,9	13,9
average value e	6,5	0	-8,7	-4,5	-2,7	-5,4	
average value e_k	10	3,4	9,5	10,9	4,6	16,3	

Thus, the performed numerical experiments show that the best results are obtained from the precipitation forecast using WRFB and WRFE parameterization schemes.

A detailed analysis of parameterizations shows that a correct accounting of the physical processes of cloudiness formation (**cu_physics** parameter) has an exceptionally great influence on the accuracy of the forecast proves. This is clear from a comparison of WRFE and WRFD parameterizations sets, which differ only in this parameter. A simple accounting of deep and shallow convection (Scheme Kain-Fritsch, WRFD) is insufficient. Best results are obtained by the use of schemes that additionally take into account good vertical mixing (Scheme Bees-Miller-Janjic, WRFC) and multi-layer multi-parameter ensemble method (Grell-Devenyiensemble, WRFE).

Good results (WRF B) were obtained in a more accurate accounting of short-wave radiation (CAM scheme: it has the possibility to account the optical properties of some types of aerosols and small gas components in 19 spectral intervals), topsoil (RUC Land Surface Model), as well as the structure of the boundary layer (Yonsei University scheme). However, without additional numerical experiments it is difficult to give significant preference for any of these parameterizations.

CONCLUSION

Our study showed that WRF-ARW model can be successfully applied to the prediction of heavy precipitation in subtropical conditions with flat and mountainous relief. In this work, we made settings for the WRF-ARW model for forecast in the province of Khuzestan in the nodes of horizontal area 999h729 km in the nodes of grid 9x9 km and with 41 levels vertically. A series of numerical experiments were made using different parameterizations for the prediction of rainfall in Khuzestan province with an advance time of 24, 48 and 72 hours.

To obtain more reliable and valid conclusions about the effect of a particular parameterization (their combination) on the quality of the forecast, we have to make additional fairly extensive numerical experiments. During the numerical experiments it is also necessary to check the influence of the grid step, the use of inserted grids, varying the size of the rated operating conditions, and many other factors that can affect the quality of the forecast.

Summary

After the study of the heavy rain episode of 5-6 of January 2014 in the province of Khuzestan we established that the used set of parameterizations of the model WRF-ARW allows to give satisfactory forecasts of heavy rainfall with an advance time of 24 hours.

Among all the studied parameterizations the model showed the most sensitivity to cloudiness parameterization. Best results are obtained by the use of schemes that additionally take into account good vertical mixing (Scheme Bees-Miller-Janjic, WRFC) and multi-layer multi-parameter ensemble method (Grell-Devenyiensemble).

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