Impact of Doppler radar reflectivity and velocity data assimilation on quality of precipitation forecasting in Belarus in different seasons

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Introduction:

Severe weather (strong precipitation and wind) forecast remains of the biggest problems in **numerical weather prediction (NWP)**. Modern remote sensing system allows tracking of rapidly developing convective processes and provide additional data for numerical weather models practically in real-time. **Assimilation of Doppler weather radar** data allows to specify the position and intensity of convective processes in atmospheric numerical models.

The primary objective of this study is to **evaluate the impact of horizontal reflectivity and radial velocity assimilation in the WRF-ARW** mesoscale model for the territory of **Belarus**.

Specifically, we focus on influence of assimilated radar data into **wind speed and precipitation amount** forecasts in **different seasons** during **2017-2020** years over the territory of **Belarus**.

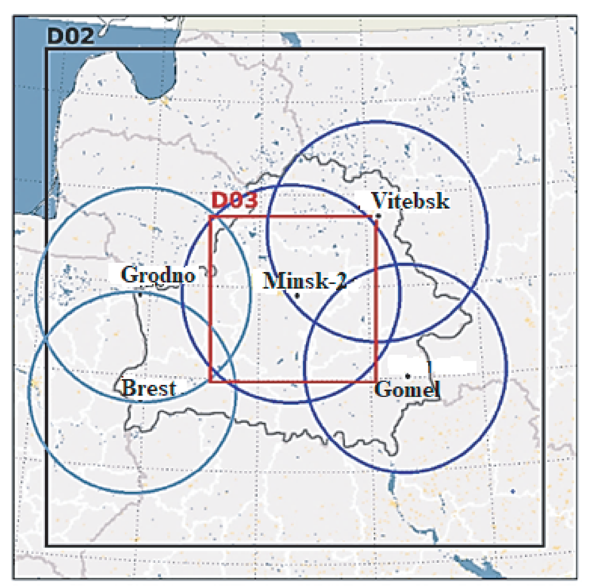
Objectives:

- Create **radar data quality control system** and **prepare radial velocity** data and **horizontal reflectivity** for **assimilation** into WRF-ARW model;
- Generate of **WRF-ARW background error** for assimilation by **WRF 3DVAR**;
- Simulate **11 cases** of **precipitation** and **strong wind over 2017-2020 years** in **Belarus**;
- Make **statistical** and **object-oriented verification** of **precipitation amount** and **wind speed** in **belarusian weather stations**.

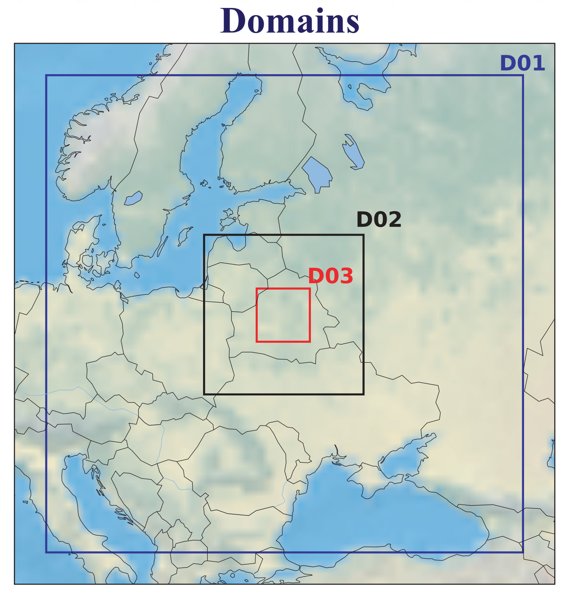
Modelling Details

MODEL	WRF-ARW 4.0
INITIAL AND BOUNDARY CONDITIONS	GFS (Global Forecast System), every 3 h, 0.25°×0.25°
HORIZONTAL AND VERTICAL RESOLUTION	3 nested domains: 9 km, 3 km, 1 km. 40 Eta-levels
TIME STEP/ SIMULATION DURATION	50 S/ +24 h cold start
PARAMETRIZATION	-WSM6 -Kain-Fitch (no convection parametrization on 3 km, 1 km)
RADAR DATA PROCESSING TECHNICS	Filter Gabella; Fuzzy echo classification filter
ASSIMILATION TECHNICS/ PARAMETERS	3DVAR Horizontal reflectivity and radial velocity from Minsk-2, Homel, Vitebsk Doppler weather radars
SIMULATION DATE	2017-07-14 12 UTC, 2017-08-02 12 UTC, 2017-08-10 18 UTC, 2017-08-24 00 UTC, 2019-01-26 12 UTC, 2019-05-03 06 UTC, 2019-09-25 12 UTC, 2020-01-23 00 UTC, 2020-02-18 12 UTC, 2020-04-17 12 UTC

Radars



Domains



Processing radar data:

First step:

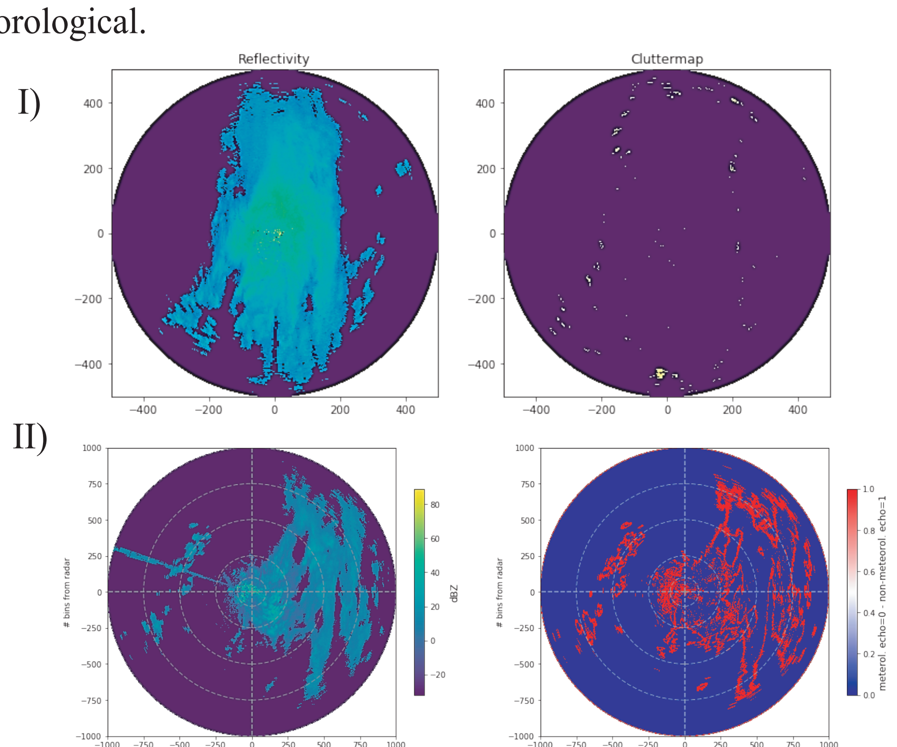
Create **quality control system** for preparation of **radar data** from **3 belarusian dual polarization Doppler radars** (Minsk-2, Homel, Vitebsk):

- **Anomaly detection** and **removal** non- meteorological echo by two-step method:

I) 2-level **Gabella filter** is used [1]. The algorithm of this filter is aimed at removing interference from objects (surface, buildings, etc.), which have significant spatial heterogeneity and variability of the signal distribution. The second part of filter is based on analysis of the spatial continuity of the distribution of the signall. If a certain threshold value is exceeded within the considered pixel, the noise is considered non-meteorological.

II) **Fuzzy echo classification** based on fuzzy logic [2]. Radar characteristics for detecting non-meteorological echoes are: **differential reflectivity (ZDR); correlation coefficient between horizontal and vertical reflectivity (RHOV); differential phase (PHIDP); Doppler speed (VRAD); static clear sky map**. For each of parametr the algorithm uses a trapezoidal function to determine whether the radio echo belongs to a non-meteorological class. Based on predefined weights, a linear combination of degrees of membership is calculated. If the linear combination exceeds the threshold value, the radio signal is considered non-meteorological.

The **wradlib** library was used.



1)Belhydrom 2)BSU 3)NOMREC

Assimilation techniques:

Second step:

- Preprocessing and converting radar observation: **transformation of coordinates**, **error calculation,** generate **ob.radar** (**reflectivity, radial velocity data, observation errors**.).
- Generate **be.dat** (the background error covariance matrix (B). **NMC** method (The National Meteorological Center). Ten 1-day-forecasts which were calculated.
- Radar data assimilated **WRF 3DVAR** method based on the cost function was used:

$$J(x)=\frac{1}{2}(x-x_b)^T B^{-1}(x-x_b)+(y-y^o)^T R^{-1}(y-y^o)$$

x - a vector of analysis; ***xb*** - a vector of the first guess (from real.exe output); ***B*** - the background error covariance matrix; ***yo*** - a vector of observation, ***y*** - a vector of model-derived observation transformed by the observation operator ***H (y=H(x))***; ***R*** - the observational and representativeness error covariance matrix.

The main task is to find the **minimum of incremental cost function**. In this study the **conjugate gradient** method is used. This method based on the **estimation of three components** of the **control variable transformation**.

The assimilation of **radial velocity** made by calculation of distance between radar station and data point, wind components (*u, v, w*) and vertical fallspeed of hydrometeor, which based on the rainwater mixing ratio. The obsereved **radar reflectivity** assimilated indirectly though rain mixing ratio.

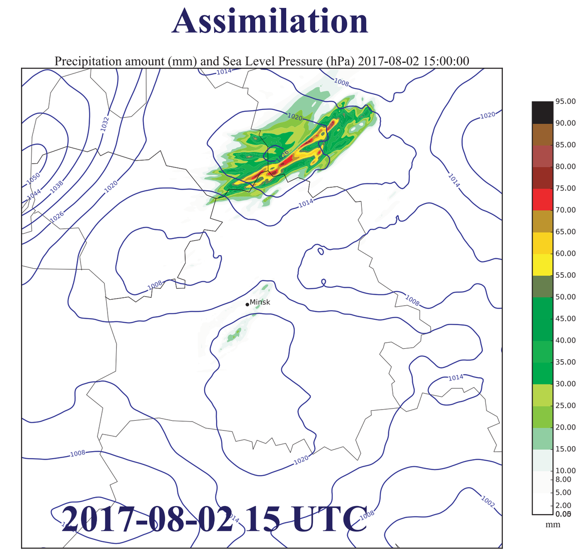
Modelling Cases:

The **11 days (+24h)** of different synoptic situations include **heavy convective precipitation (more 55 mm/12 h), wind gusts (24 m/s), cold fronts from Southern cyclones, anticyclones, fog** and etc. during **2017-2020** years over **Belarus**. The simulations were implemented in **2 modes** (**«Assimilation» and «No Assimilation»**) in **3 spatial resolutions (9 km (D01) - 3 km (D02) - 1 km (D03)).**

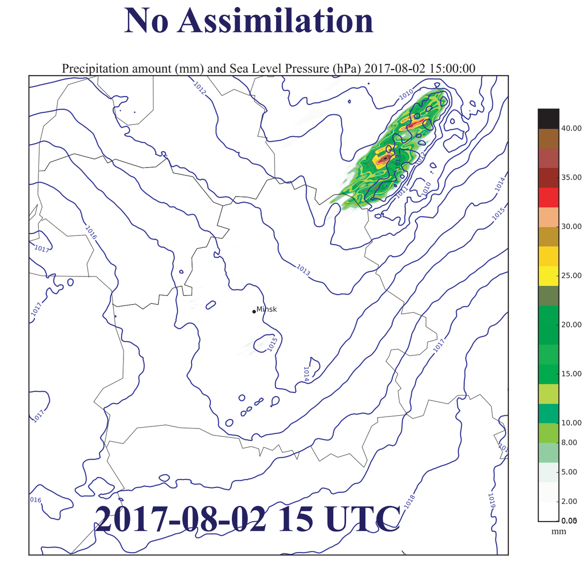
Results:

All **«Assimilation»** and **«No Assimilation»** forecasts were verified. The **Mean Error (ME), Mean Absolute Error (MAE), Root Mean Square Error (RMSE), correlation (R)** for **temperature 2 m (T2), mean sea level pressure (MSPL), wind speed 10 m (WND) and precipitation amount** were calculated for statistical evaluation. **The object-oriented verification (MODE)** was implemented for evaluation the accuracy of prediction the rainfall centers location. In cases where heavy precipitation occurred at the hours close to the initial time of forecast, radar data assimilation allowed to simulate the development of active convective processes in the earlier hours. In cases without data assimilation, precipitation occurred several hours later.

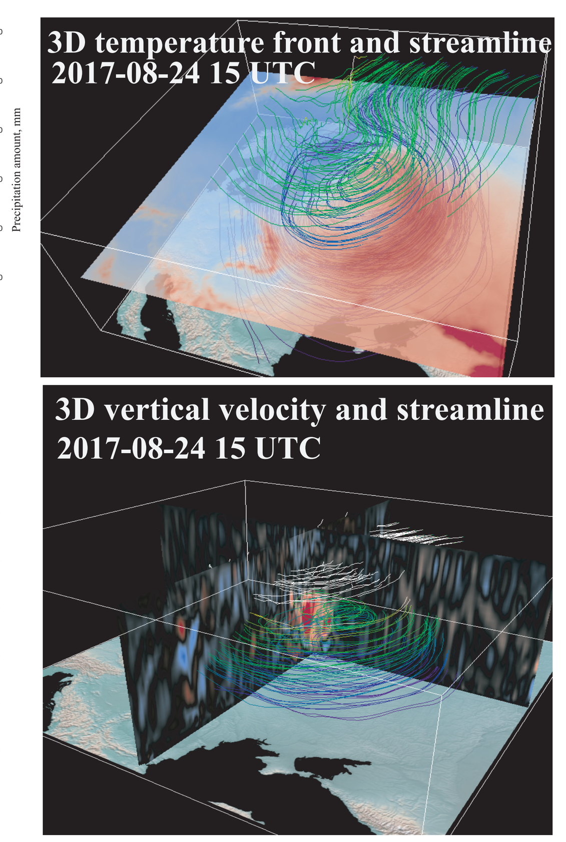
Assimilation

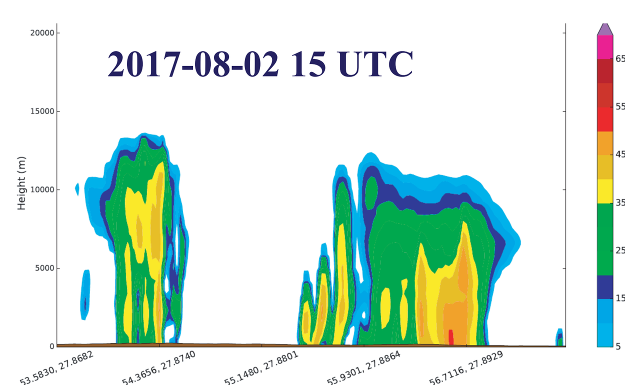


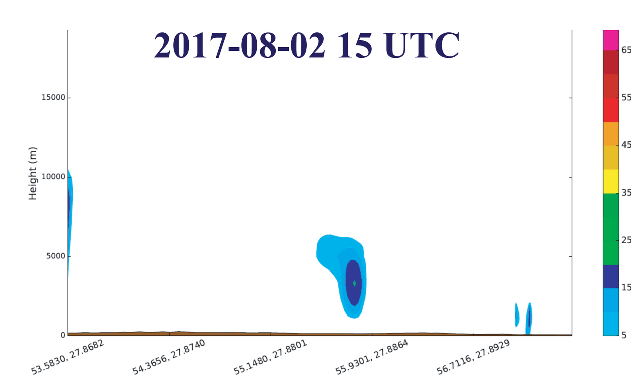
No Assimilation



Assimilation 3D MODEL

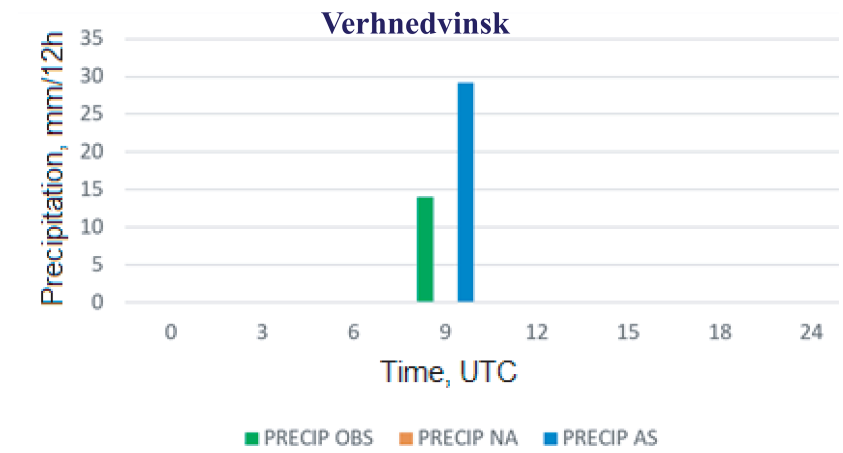




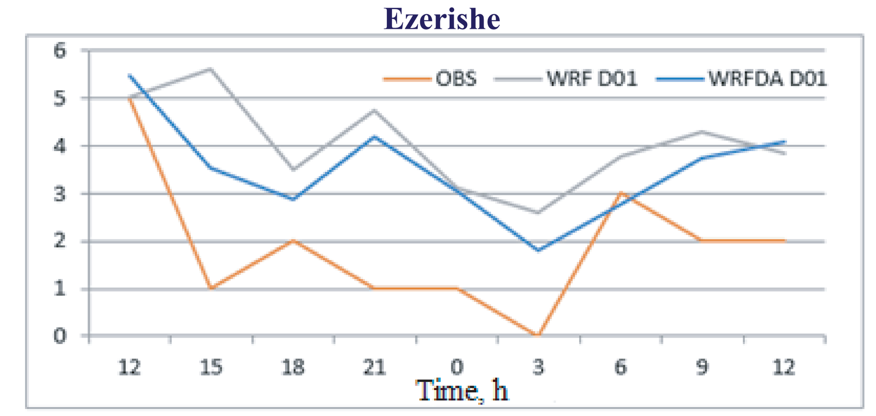


Precipitation amount forecast mm/12h and wind speed 10 m on Verhnedvinsk and Ezerishe stations 2017-08-02 12 UTC (OBS - observation, PRECIP NA, WRF D01 - No Assimilation, PRECIP AS, WRFDA D01 - Assimilation)

Verhnedvinsk



Ezerishe



Statistical verification:

The **verification** of the **wind speed 10 m (m/s)** forecasts **of all cases** showed a **decrease of RMSE** in the early hours (before +12 h) in most cases of forecasts. In most all cases the difference **in nighttime error** between the variant **with assimilation** and **without model** runs **decreases**.

Statistic verification of the wind speed forecasts at 10 m (m/s) for all cases +3, +6 h

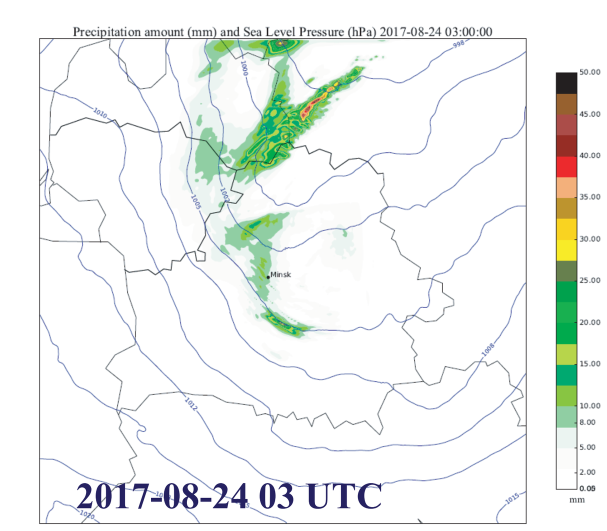
	ME		MAE		MSE		R	
Time/ Mode	No AS	AS	No AS	AS	No AS	AS	No AS	AS
+3	0.98	0.84	1.73	1.44	2.25	2.14	0.84	0.86
+6	1.74	1.41	1.97	1.89	4.18	3.26	0.67	0.71

Accuracy of precipitation amount verification (mm/12h) for all cases

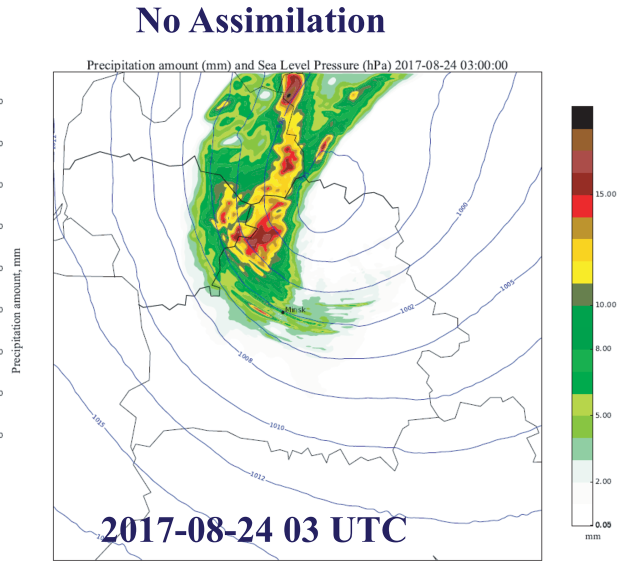
Statistical parameters	Without Assimilation	With Assimilation
PC (Accuracy of all forecasts),%	78	79
POD (Probability detection),%	85	86
PODN (Probability of non-detection),%	74	77
FAR (False Alarm),%	29	27

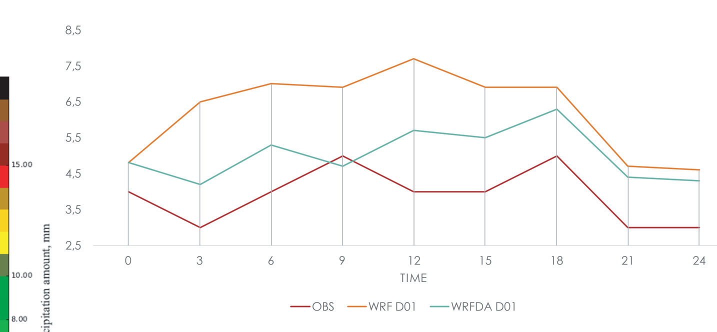
An object-oriented assessment (MODE) of precipitation zone forecasts allows to tell about more accurately prediction of orientation and location of cold fronts position, which produced severe weather. Radar data assimilation decrease the number of false alarms in comparison with case without assimilation.

Assimilation



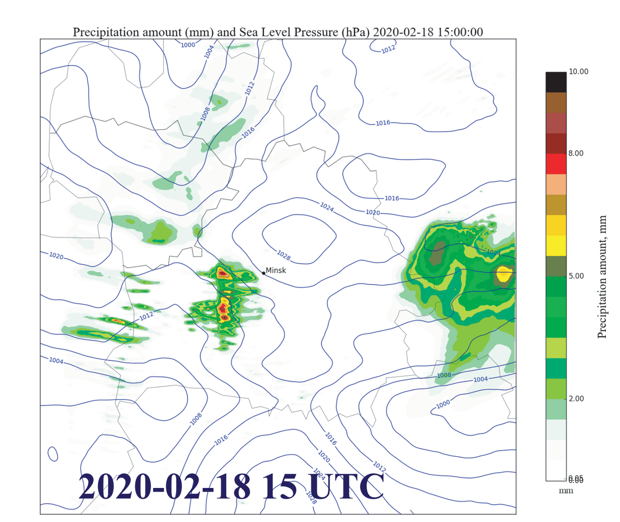
No Assimilation



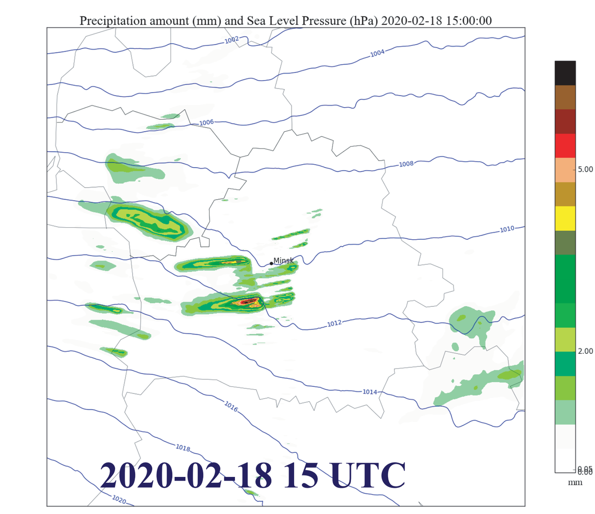


Wind speed forecast at 10 m (m/s), OBS – Verhnedvinsk station observations, WRF D01 – without assimilation, WRFDA D01 – with assimilation, 24.08.2017

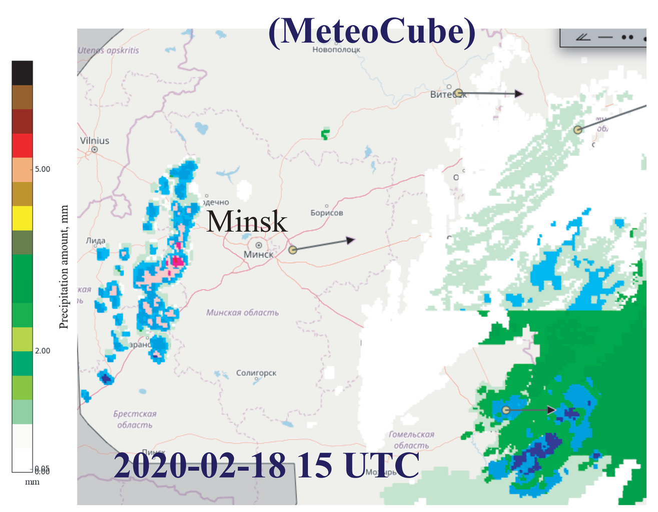
Assimilation



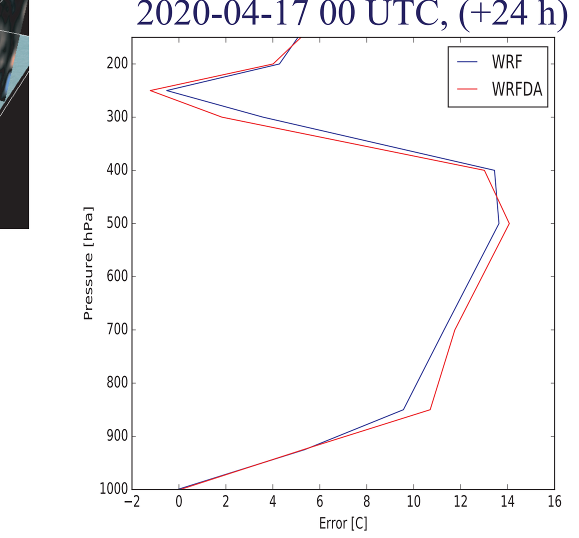
No Assimilation



Radar observations (MeteoCube)



Temperature error profile Brest station 2020-04-17 00 UTC, (+24 h)



The analysis of the vertical temperature profile forecast showed a decrease the error in the surface layer and above the isobaric surface of 450 hPa.

Conclusions:

- Verification of **horizontal reflectivity** and **radial velocity assimilation impact** on **precipitation** and **wind forecasts** for **territory Belarus** by **WRF** model for different seasons of the year was made. **11 cases** were simulated in **2 modes** (**with assimilation and without assimilation**).
- The **radar data assimilation** from **3 Doppler weather radars** made it possible to **reduce** the **wind 10 m forecast error** in the early hours.
- In cases **with data assimilation**, the **position and orientation** of the **precipitation centers** for most cases **were more accurately modeled**. The **maximum positive effect** was observed **in heavy rainfall in summer**. Despite this, a **fairly large number of false alarms** are observed for both modes. In the case **of assimilation**, their percentage **is less**.
- The influence on the forecast of the **temperature** and **pressure fields** was **neutral**.
- The difference in forecasts the **wind speed 10 m error** between modes **is reduced at nighttime.**

References:

1. Gianfranco Vulpiani, Mario Montopoli, Luca Delli Passeri, Antonio G. Gioia, Pietro Giordano, and Frank S. Marzano. On the use of dual-polarized c-band radar for operational rainfall retrieval in mountainous areas. Journal of Applied Meteorology and Climatology, 51(2):405–425, Feb 2012. doi:10.1175/JAMC-D-10-05024.1.
2. Crisologo, I., Vulpiani, G., Abon, C.C. et al.. Polarimetric rainfall retrieval from a C-Band weather radar in a tropical environment (The Philippines) // Asia-Pacific J Atmos Sci. 2014. 50 (Suppl 1). P. 595.