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Numerical Weather Forecasting System WRF-Ukraine

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Abstract *The software system of numerical weather prediction for Ukrainian territory is presented. The computational kernel of the system is the numerical weather prediction model WRF. The developed software include automated means of visualization of the results of calculations and their statistical postprocessing and correction with the use of neural network and measurements.*
Key words: numerical weather prediction, software system.

1.Introduction

Around the world meteorological services use numerical weather prediction models to predict the detailed distribution of meteorological elements (wind speed and direction, rainfall, etc.) in time and space. These models are used not only for weather forecasting, but also for decision making in various sectors such as aviation, responding to natural disasters and others.

In 2000-2003 in Ukraine for the first time a system of numerical weather prediction MM5-Ukraine based on American regional model MM5 [1] and a corresponding set of programs [2] was developed. The results of the operational weather forecasting system MM5-Ukraine are available on the Internet site METEOPROG [3]. The system MM5-Ukraine has been used to predict floods in Transcarpathia [4], the transportation of radionuclides in the atmosphere [5], etc. The importance of improving the accuracy of forecasting was revealed during this work. The accuracy of weather forecasting models depends on many factors. Among them the most important are: a) the diversity of physical processes, which are described by equations of the model and the physical parameterization, b) the accuracy and resolution of input data, c) the possibility of learning (assimilation) of measurement data in the calculation model. At present, the further development of the meteorological model MM5 stopped since, with the support of the National Center for Atmospheric Research USA, a new numerical weather model - WRF [6] was developed, which, as is the MM5, freely distributed on the Internet. WRF model provides more sophisticated physical parameterizations and methods of measurement data assimilation than MM5, which creates the potential for improving the quality of site METEOPROG by using the model WRF. However, to estimate that opportunity, software system should be created that allows not only to obtain and visualize the results of the calculations, but also to compare these results in the first place, with measurements, and secondly, with the ones received for similar conditions using MM5-Ukraine. The following sections describe software system WRF-Ukraine established for this purpose.

2. Forecasting System WRF-Ukraine

2.1. Meteorological model WRF

In a three-dimensional numerical weather prediction model WRF [6] the complete system of non-hydrostatic equations of hydro-thermodynamics of atmosphere is solved numerically, which includes the equation of continuity, the momentum transfer equation (taking into account the effects of compressibility), moisture transport and energy balance. The user model proposed library various parametrization processes in the atmospheric boundary layer, cloud formation and rainfall. The model implemented to create the field of embedded computing and the use of algorithms for data assimilation of observations. σ-vertical coordinate system is used in WRF, that allows you to describe the difficult terrain and «chess» grid horizontally. In integrating the equations of hydrodynamics is splitting along the lines (in the horizontal direction is a clear pattern, as in the calculation of vertical flow and velocity - implicit), and physical processes. WRF is a regional model, so for its initialization and set the boundary conditions are necessary results of calculations of global numerical weather prediction models. The cycle of the WRF model is composed of training data, including horizontal and vertical interpolation on a grid model, improving the interpolated data through the assimilation of meteorological observations and radiosondes and numerical integration.

2.2. Adapting the WRF model for Ukraine

Calculation domain of WRF-Ukraine is 3000x3000x10 km and the centre point: 47.3 º N and 32,4 º E Thus, the computational area covers the territory of Ukraine. Horizontal resolution: 100 nodes from west to east and 106 from north to south, the grid step along these lines is identical, and is 30 km. (in MM5-Ukraine uses horizontal grid step of 27 km.). Vertical resolution - 14 levels, the minimum vertical step ≈ 50 m. To solve the problem of meteorological forecasting, system of equations of hydrodynamics of atmosphere should be supplemented by initial and boundary conditions. As the initial conditions must be specified three-dimensional distribution of the three components of the fields of speed, temperature, pressure and humidity. As the boundary conditions the values of temperature, humidity and velocity should be specified on the sides and on the upper boundary of the region, as well as the values of heat, moisture and momentum fluxes at the lower boundary of the area adjacent to the Earth's surface. The initial distribution, in principle, can be constructed using the interpolation of measurements on the territory of Ukraine and as the boundary conditions on the sides and top of the domain constant values can be assigned to the variables. However, this method does not take into account the impact of the global atmospheric circulation on the development of meteorological fields in Ukraine. Therefore, to set initial terms and conditions on the sides and upper limits of reasonable use of the data model forecasts the global atmospheric circulation. In MM5-Ukraine for this purpose use is made operational forecasts predict the National Center for Atmospheric NCEP (USA) (Kushchan and others, 2005). Forecast fields NCEP model for a projected 168 hours of time defines the initial and boundary conditions for the meteorological variables in the WRF-Ukraine. Boundary conditions at the surface depends on the properties of the surface. The following data on the surface: surface height above sea level, the category of surface according to the U.S. Geological Survey USGS (for example, forest, water, etc.), vegetation type, soil type, the average seasonal temperatures, the average albedo. The relevant data, as well as for MM5-Ukraine were taken from USGS.

2.3. Visualization and post processing subsystem

A software subsystem that allows to visualize and compare the measurements and modeling results of WRF-Ukraine and MM5-Ukraine. Measurement data and the output files of models WRF-Ukraine and MM5-Ukraine are used as input data for the system. The system generates graphics with the results of forecasts and measurements, as well as a text file with the errors of prognoses of MM5 and WRF models. The subsystem can also automatically build a spatial (two dimensional) distribution of meteorological elements from the results of calculations and measurements. There is also a possibility to to draw cross sections of fields of the meteorological elements. The work was carried out in the OS Suse Linux 10.1. Integral rainfall accumulated from the start of the forecast, calculated by WRF and MM5, as well as measured, for the convenience of comparison, converted to the rainfall rates (mm / h) and interpolated in time. The program txt2bin creates a binary file with measurements in accordance

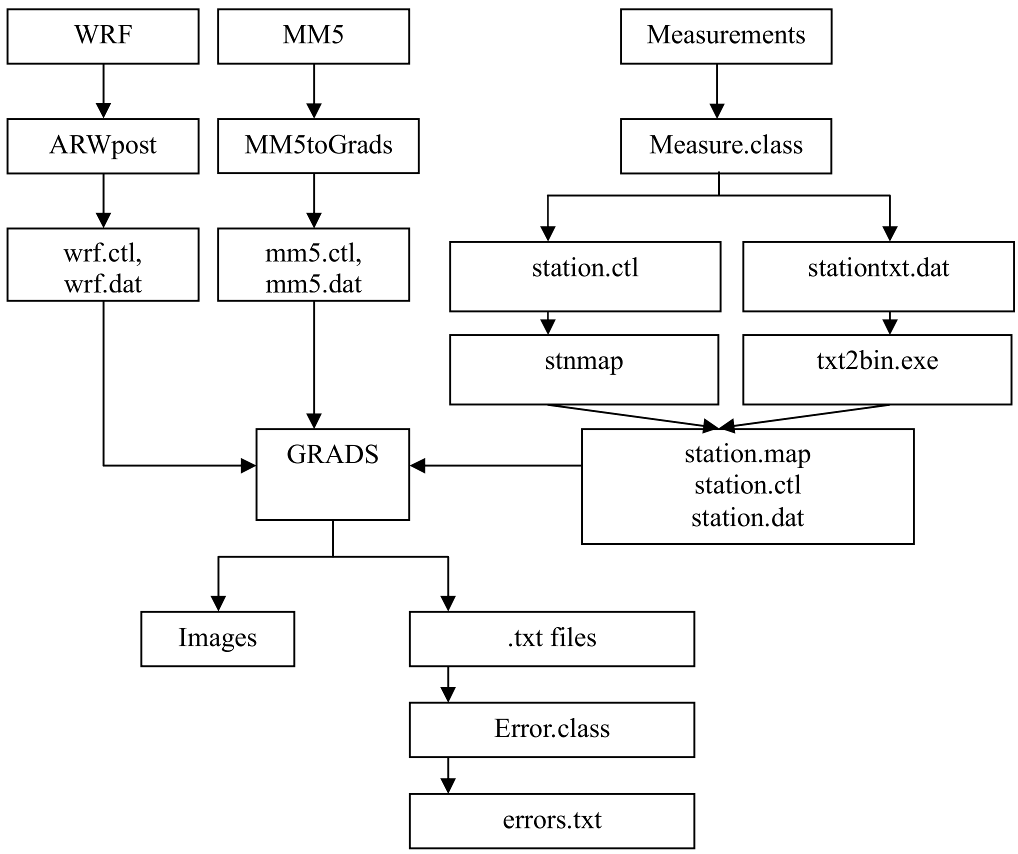

Fig. 1. Scheme subsystem visualization and data processing of numerical weather prediction and measurement

with GRADS format. GRADS scripts read the input .ctl, .dat, and .map files and create graphs based on the variables of time and text files with the values of variables. The object of class Error - reads text files, calculates the error and writes them in a file errors.txt. To develop the system freely available programs were used: GRADS (scripts to plot graphs and interpolate data), Java SDK, C. Fig. 1 provides a diagram of the visualization and processing subsystem. Object of the class Measure — processes the file with the measurements, record results in the output file stationtxt.dat, and creates a file station.ctl, which contains a description of the contents of the file station.dat.

2.4. Subsystem for postprocessing results with neural net.

Postprocessing archive predictions and measurements is a promising way to further refine predictions

[7]. In this paper, the results of post-subsystem is designed to clarify the predictions of temperature and precipitation for the item using a neural network. The subsystem is implemented in the MATLAB 7.0. Used neyroset direct distribution with two hidden layers (15 +1 neuron in each of the layers). The activation function of the first layer is $\tan sig(x) = 2/\left(1+e^{-2x}\right)-1$, and $purelin\left(x\right) = x$ for the second layer. At the entrance are submitted data forecasting system MM5-Ukraine for 48 hours at the exit of the network that is a vector, consisting of a forecast of temperature (or 6-hour rainfall amounts) for 48 hours for selected stations. When training was formed out of the measurement data.
Consider the structure of the input matrix P.

$$
\begin{aligned}
&P = \left[V_1, V_2, V_3, ..., V_N\right],\\
&V_i = \left[mm, dd, hh, nh, M_1, M_2, ..., M_K\right], \quad (1)\\
&M_j = \left[landuse, tc, dt, rh, grt, u, v, rain\right],
\end{aligned}
$$

where N - number of time moments, for which the forecast is required, V_i - input vector for corresponding to time moment i, mm, dd, hh, nh - month, day of month, hour of day from 0 to 23, hour counted from the start of prognosis accordingly, M_i - part of the input vector, which corresponds to model data for one node of the mesh, $landuse, tc, dt, rh, grt, u, v, rain$ - land use, temperature at 2 m, dew point, relative humidity, temperature of land surface, x, y - components of wind speed, accumulated precipitations. Thus, it is the existence of a functional relationship between the projected values in the next four nodes and true. This dependence may be more complex than just a linear relationship, corresponding to a linear interpolation because submesh processes arising from the impact on the value of meteorological elements in the points of local features of underlying surface. Approximation of this dependence by using neural network is the purpose of training. The procedure of learning 'trainlm' – backward propagation of error, where minimizing the quadratic function of deviation from the target result is performed using a known Levenberg-Marquardt's minimization algorithm.

3. The results of WRF-Ukraine

To demonstrate the capabilities of WRF-Ukraine and the comparison with MM5-Ukraine let's consider forecast results form WRF-Ukraine started on 29 January 2007, 00 h and finished on March 1, 2008, 00 h and April 22, 2008, 00 h. The duration of the prognosis is 48 h. For comparison, predictions with measurements subsystem visualization and processing of the results were processed 107 land-based weather stations in Ukraine. These models are linearly interpolated in terms of weather, and for each station construction schedule 3, the corresponding forecasts MM5-Ukraine forecast WRF-Ukraine and the measurement results. For example, in Fig. 2 presents the calculated and measured time according to the speed of rainfall and temperature in Kiev. Similar graphs can be constructed for an arbitrary point in which the meteorological station. Examples of the calculated mean error for all stations to various meteorological elements and the different timing of the forecast given in Table 1. As Table 1 shows the results of WRF-Ukraine did not reveal the specific advantages of this model, compared with MM5-Ukraine. Of course, a full comparison of the two models require the accumulation of a full backup calculations. However, the data suggest that the improved results WRF-Ukraine compared with MM5-Ukraine can only be achieved with new means of data assimilation, such as 3DVAR, which are not included in full in the supply of MM5.

Table 1. Examples calculated using the sub-visualization and processing errors forecasts mean surface temperature (C), the absolute value of wind speed (m / s), the intensity of rainfall (mm / h) for the different timing of the forecast.

The total variance(WRF)		The total variance (MM5)	
The forecast from 29 January 2007 00 h.			
wind speed (m / s)	2,368	wind speed (m / s)	2,233
Temperature (K)	2,382	Temperature (K)	2,884
intensity of rainfall (mm / h)	0,045	intensity of rainfall (mm / h)	0,036
Forecast from 1 March 2008 00 h.			
wind speed (m / s)	3,376	wind speed (m / s)	3,273
Temperature(K)	1,829	Temperature (K)	1,797
intensity of rainfall (mm / h)	0,373	intensity of rainfall (mm / h)	0,345
Forecast from 22 April 2008 00 h.			
wind speed (m / s)	2,574	wind speed (m / s)	2,603
Temperature (K)	3,025	Temperature (K)	2,493
intensity of rainfall (mm / h)	0,819	intensity of rainfall (mm / h)	0,644

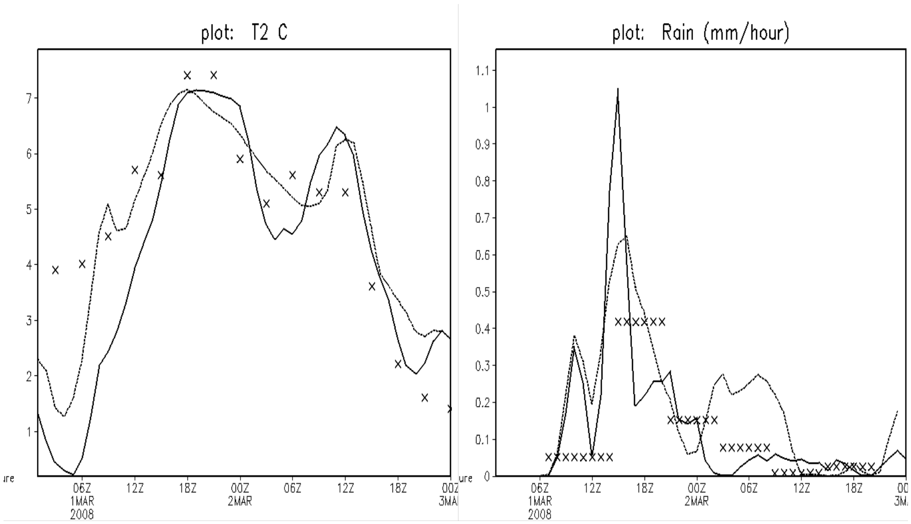

Fig. 2. Dependence on the time of the intensity of rainfall (mm / h, right) and the surface temperature (º C, left) in Kiev on the results of forecasts WRF-Ukraine, MM5-Ukraine and measurement of 1 March 2008 00ch. The black solid line - WRF, dotted - MM5, the point - the measurement.

As an example of the use of the post processing with neural networks let's consider the results obtained as a result of learning Neural network for data backup of MM5-Ukraine from 1 January 2007 to 30 March 2008. The training was conducted for each of the stations in isolation, with 20% of training vectors selected randomly were used for testing during training and the early termination of education. Testing was done on the network data for April 2008. Calculated mean (rms) and systematic (bias) deviation of the forecast temperature for the entire period of testing (30 days, see Table 1) and for each 48-hour period forecast separately. Table 2 presents the results of data-linear interpolation calculations MM5-Ukraine to the point of measurement of the four closest nodes. With the linear interpolation takes into account the difference in heights of the station and the grid nodes (temperatures are given to the same height, it is considered that the vertical temperature gradient - 6 K / km), the discarded units located above the water surface.

Table 2. Standard and biases predicted surface temperature for April 2008 for different stations in the use of neural networks and linear interpolation

Station	Lin. int. (rms, K)	Neural net (rms, K)	Lin. int. (bias, K)	Neural net (bias, K)
Kyiv	2.12	1.9	-0.56	0.1
Rahov	2.32	2.04	-0.79	-0.4
Cherkassy	1.85	1.98	0.22	0.33
Nikopol	1.87	1.90	-0.01	0.24
Alushta	3.34	2.42	1.63	0.1
Mizhgirya	2.36	2.14	0.50	0.49
Nikolayev	1.90	2.2	0.12	0.66
Odessa	2.96	2.11	1.32	0.95
Pozhezhevka	2.35	1.75	0.70	0.58
Rivne	1.64	1.75	-0.26	-0.6
Selyatin	3.05	2.40	1.37	0.68
Turka	2.56	2.02	0.36	0.43
Donets'k	1.77	1.70	-0.1	0.0004
Zaporizhzhia	1.84	2.11	0.09	0.45
Kolomya	1.97	2.13	0.19	-0.31
Sevastopol	2.32	1.83	0.42	0.39
Angarsk pass	2.24	2.0	-0.55	0.1
Bilovodsk	3.05	2.63	0.45	-0.29
Debaltsevo	1.82	1.97	-0.11	0.14
Dzhankoy	1.7	1.89	0.25	0.6
Izum	2.42	2.44	-0.11	0.32
Kerch	1.58	1.65	0.27	0.25
Kirovograd	1.66	1.62	0.17	0.51

Preliminary results suggest that the neural network leads to a deterioration compared with linear interpolation, when the quality of linear interpolation good (rms <2 K) - for example, for exactly, Nikolaeva, Cherkassy. It is hoped that this deterioration
will be overcome through training for a longer period. However, when the linear interpolation of poor quality (rms> 2K) using neural network leads to an improvement, which is especially noticeable in the case of coastal stations (Alushta, Odessa, Sevastopol) in the case of mountain stations (Rakhiv, Mizhgirya, Selyatin, Pozhezhevka, Play, etc. .). Fig. 3 presents examples of errors of 48-h. forecasts for April 2008 for several of the stations in Table 2. The marked improvement in the quality of prediction with neural network in case of coastal stations, is due to very rough approximation of the coastline at 30 km grid by MM5, while near the shoreline daily temperature at the station is extremely sensitive to the distance from shore. Similarly, for the mountain stations daily temperature sensitive not only to the height of the station above sea level, which is explicitly included in the linear interpolation of MM5-Ukraine, but also the orientation of the slopes, which are located on the station (Bellasio R., et.al., 2005).

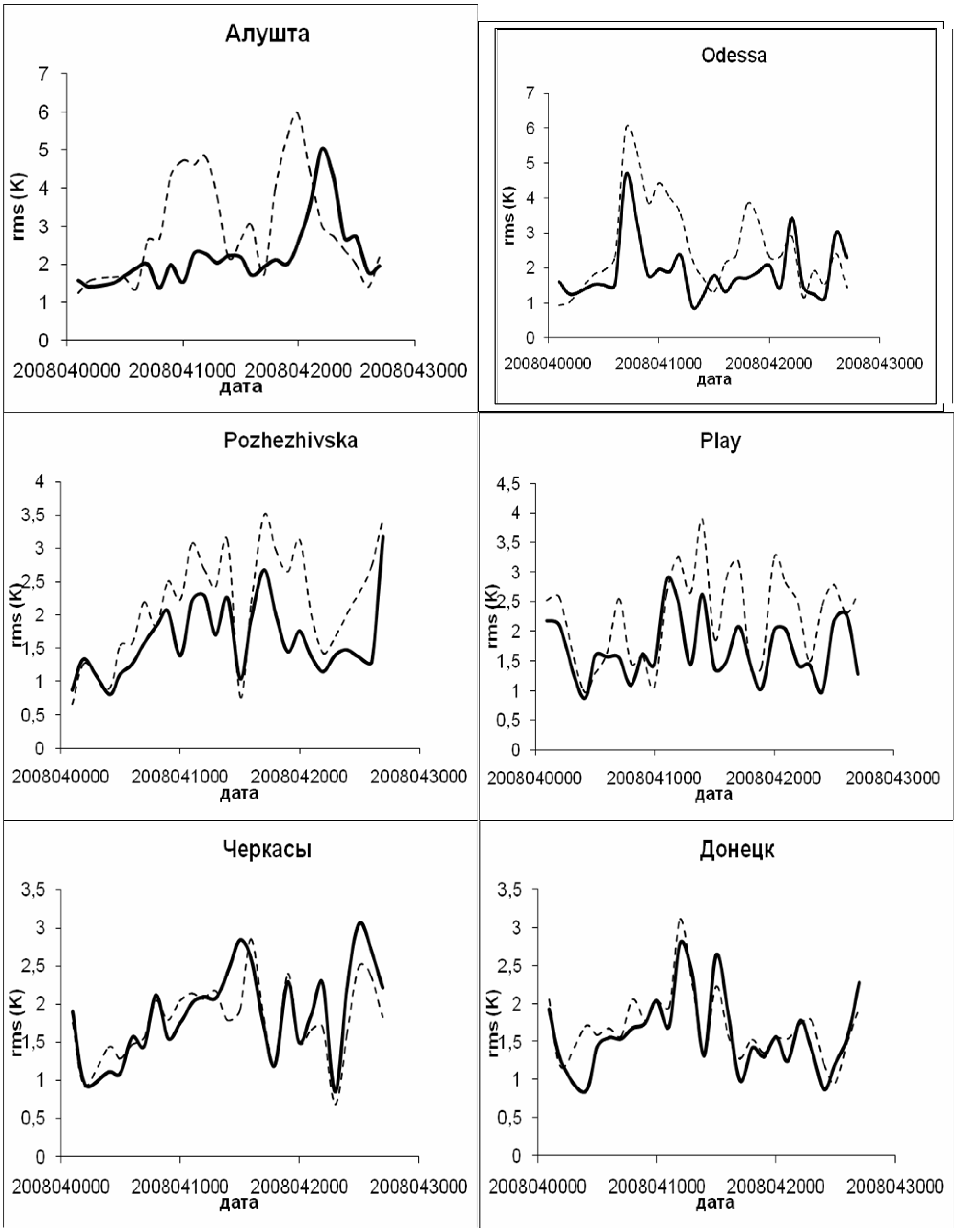

Fig. 3. Standard error 48 hours forecasts surface temperature for each 48-h. term forecast for April 2008 using a linear interpolation (dotted line) and using a neural network (black solid line).

4. Conclusions

A system of numerical weather prediction WRF-Ukraine was developed, which is based on advanced weather research model WRF. Prognostic fields of global atmospheric circulation model NCEP are used in the WRF-Ukraine. A subsystem of visualization and processing is created to automate the process of verification of WRF-Ukraine, and comparing the results of calculations of this system with the calculations of existing analogue in Ukraine - a system of numerical weather prediction MM5-

Ukraine, [2], [3]. For several dates MM5-Ukraine and WRF-Ukraine were compared, which did not show significant improvement in the new model results. However, a detailed comparison of the quality of forecasting of MM5 and WRF requires an independent study.

A subsystem was created based on archival model and measurement data and neural net technology. The learning was performed on archive of measurements and MM5-Ukraine model data starting from January 2007 to March 2008. Verification of the neural network on data for April 2008 showed that the stations where the mean square error of temperature was high (> 2K) the use of a neural network can reduce the error in temperature forecast for April by 0.1-0.65 K. At the same time reducing errors in temperature for separate 48 hours forecasts could be much more significant and reach 4 C.

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