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Numerical Weather Prediction Environment for the Territory of Armenia

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Abstract

This article is devoted to the creation and development of a numerical weather prediction environment for the territory of Armenia. One of the main features of this environment is an easy and clear web interface supporting to make numerical weather forecasts and analyze the results.

1 Introduction

Weather played one of the central roles in human history. Weather affects several things like human health, world economy, and even the relief of the Earth. As a result human beings have attempted to predict the weather informally for millennia, and formally since at least the nineteenth century. Even around 650 B.C., the Babylonians tried to predict short-term weather changes based on the appearance of clouds and optical phenomena such as haloes. Today weather forecasts are implemented by numerical weather prediction (NWP) systems based on modern technology, particularly, high performance computers (supercomputers), weather satellites, and the availability of data provided by coordinated meteorological observing networks. This has resulted in enormous improvements in the accuracy of weather forecasting. The idea of NWP (predicting the weather by solving mathematical equations) was formulated in 1904 by Vilhelm Bjerknes (1862-1951, Norwegian) and developed by Lewis Fry Richardson (1881-1953, British). These are the non-linear partial differential equations of dynamics, thermodynamics, mass continuity and moisture conservation and are impossible to solve analytically. In NWP systems these equations are solved using different numerical methods. The execution of NWP requires the use of supercomputers for two main reasons.

1. Weather prediction models are generally large code and require an execution of a large amount of parallel calculations.
2. The results of operational prediction models have to be available in an operational time.

A model is a computer program that produces meteorological information for future times at given positions and altitudes. The horizontal domain of a model is either global, covering the entire Earth, or regional, covering only part of the Earth. Regional models also are known as limited-area models. Some of actively used global models are Integrated Forecast System (IFS, European Centre for Medium-Range Weather Forecasts). Global Forecast System (GFS, National Oceanic and Atmospheric Administration, this is the only global model for which all output is available, for free), Unified Model (UM, United Kingdom Met Office), and some of regional models are Fifth-Generation NCAR/Penn State Mesoscale Model (MM5, Penn State University and the National Center for Atmospheric Research), HIRLAM (international HIRLAM program, European meteorological institutes), Weather Research and Forecasting model (WRF, National Oceanic and Atmospheric Administration, the National Center for Atmospheric Research and more than 150 other organizations and universities in the United States and abroad).

At present Armenian State Hydrometeorological and Monitoring Service (ASHMMS) [1] uses hydrometeorological products, e.g. synoptic maps, forecasts, from Russian Federal Service for Hydrometeorology and Environmental Monitoring, the European Centre for Medium-range Weather Forecasting, UNISYS, COLA/IGES, GFS to produce weather forecasts for Armenia. But in these maps Armenia is located on the very edge, that doesn't allow the detailed analysis of the weather systems affecting the area. The geographical locations of Armenia and complex mountainous relief condition the diversity of natural conditions across the country. There are six climatic zones from dry subtropical to rigorous high mountainous. Variety of hazardous weather and climate events - droughts, floods, cold spells, heat waves, mudflows, landslides, storm winds, etc. affect the socio-economic sectors and sustainable development of the country. Moreover, all above mentioned maps are outputs of global models with coarse resolution, which represent only broad features and patterns and are able to reproduce processes only in the large scale. Weather forecasting for the territory of Armenia would significantly benefit from information on the processes at spatial resolution much finer than the coarse resolution of global models. Thus, the implementation and localization of a regional mesoscale model will allow ASHMMS to have hydrometeorological information of finer resolution and to analyze changes of hydrometeorological elements at the regional scale.

As it was mentioned above to make modern forecasts it is necessary to solve two main problems:

1. *to choose a forecast model*;
2. *to get high performance computational resources to run the forecast model.*

The WRF [2] Model is a next-generation regional mesoscale numerical weather prediction system designed to serve both operational forecasting and atmospheric research needs. It features multiple dynamical cores, a 3-dimensional variational data assimilation system, and a software architecture allowing for computational parallelism and system extensibility. WRF is suitable for a broad spectrum of applications across scales ranging from meters to thousands of kilometers. It is the evolutionary upgrowth of MM5, with more advanced physics. Now the number of registered WRF users exceeds 6000, and WRF is in operational and research use around the world. Taking under consideration what was said above it is natural to choose WRF as the forecast model.

Grid infrastructures [3],[4] solve the second problem by offering a platform where computational, storage and other miscellaneous resources are available all connected by high speed networks. Grid computing is an advanced technology of the distributed parallel calculations recently intensively developed in the world. The implementation of the NWP on the base of Grid infrastructures is a natural choice. On the other hand Armenia is actively engaged in different international Grid infrastructures, such as South East European Grid Infrastructure [5] and European Grid Initiative [6]. Taking into consideration the importance of this direction, Armenian National Grid Initiative (ArmNGI) [7] was established. This represents an effort to establish a sustainable grid infrastructure in Armenia to expand the high performance computing resources with collaboration of academic and commercial participants and to improve national applications.

Currently WRF is configured and installed on the cluster of IIAP (Institute for Informatics and Automation Problems) for 2 domains. The resolutions of these domains are 25 km (parent domain) and 5 km (nested domain). The nested domain completely includes Armenia and some territories from adjoining countries. Every day the results of calculations are sent to ASHMMS. The visualization of forecasted data is done by RIP4 [8] graphical tool[9]. These results are published in refs [9].

In order to achieve good accuracy with WRF model its results should be thoroughly examined and analyzed. They should be compared with actually measured meteorological parameters and the data should be enough huge. The work like this is very boring and the probability to make mistakes is very high if no special tools are used. Besides the estimation of the deference of actually measured values and forecasted ones it is necessary to find a method to correct the forecasted values in other words to do statistical corrections. This environment gives the facility to visualize, analyze, and compare the forecasted and actually measured meteorological parameters by web interface. It also gives the facility to run WRF with customized parameters.

2 The System Structure

This system has a lot of components illustrated in the Figure 1. The main parts and connections between them show the whole path of the forecast beginning from meteorological stations to the end users.

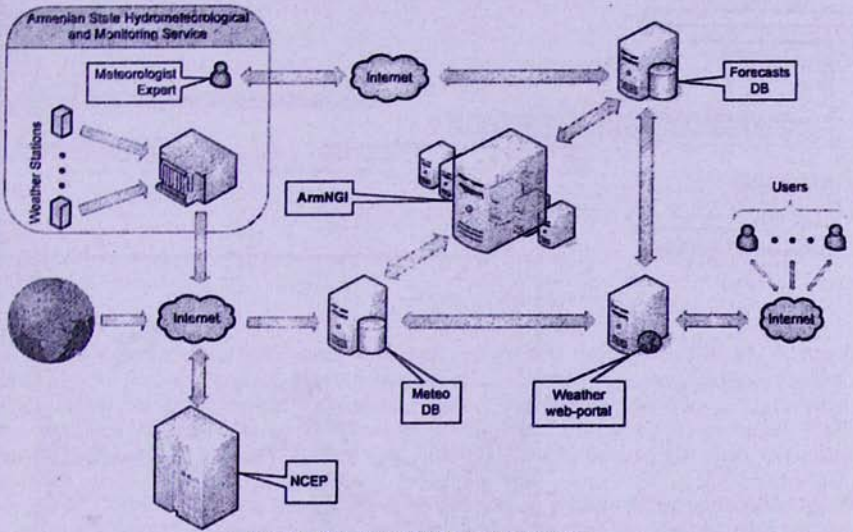


Figure 1: Illustration of the NWP System Structure.

Observation data from the meteorological stations are collected at the ASHMMS. ASHMMS analyses the collected data and sends it through Global Telecommunication System to the Regional and World Data Centers where the observation data from National Meteorological and Hydrological Services from all over the world are collected. These data are used, among other centers, by the National Center for Environmental Prediction (NCEP) [10] to construct global gridded fields through data assimilation. NCEP delivers national and global weather, water, climate and space weather guidance, forecasts, warnings and analyses to its Partners and External User Communities.

The Database retrieves and stores the required meteorological data from NCEP on the storage element twice a day. The core of the suggested system is the WRF model. The main parallel computations are done here. It is localized and configured for the territory of Armenia and ported on the Grid site. Initial condition data is taken from Meteo DB and the results of calculations are stored in Forecast DB. Automated produced forecasts are stored in the Forecast DB and can be used by the meteorologist. The access to the model output is supported by a web interface (see chapter 3).

3 Web Interface

This web interface has the following facilities:
a)to visualize and get the forecasts [11];
b)to do customized (user defined) forecasts [11];
c)to do statistical analysis [12].

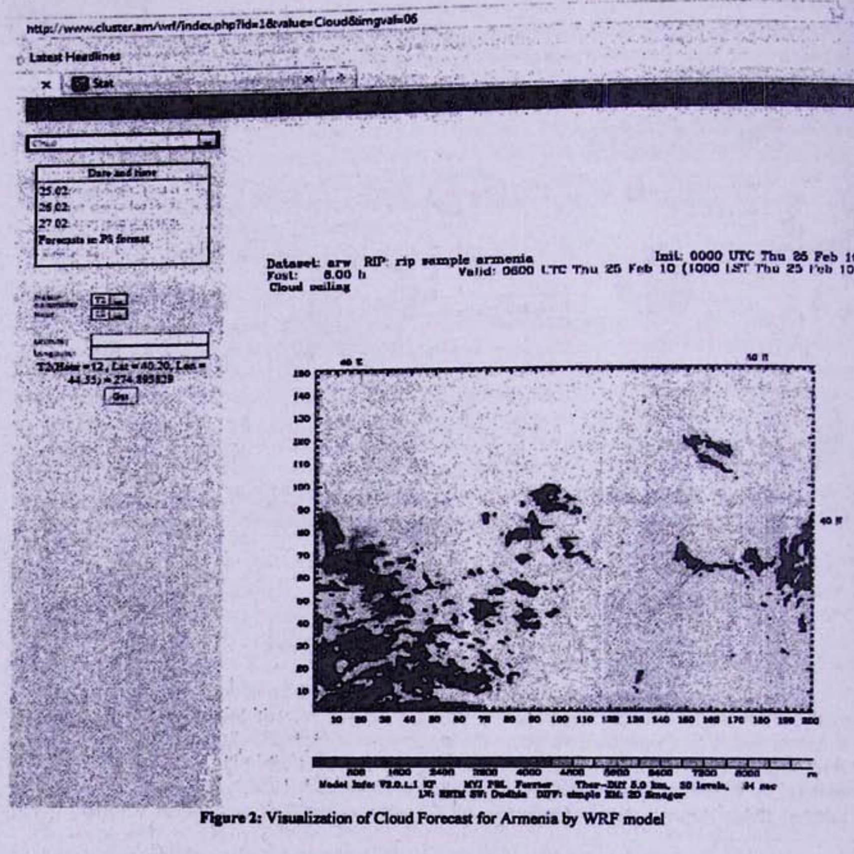
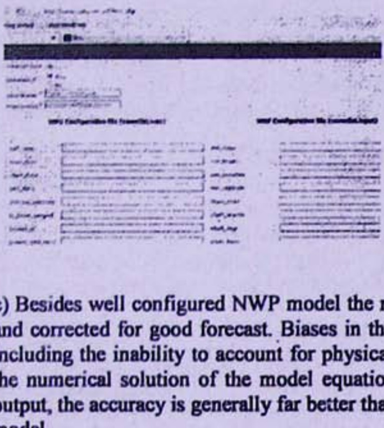


Figure 2: Visualization of Cloud Forecast for Armenia by WRF model

a) In order to provide a convenient access to the forecasted data and increase its usability an appropriate web site [11] is created. A screenshot of the web site is illustrated in Figure 2. This site gives an opportunity to choose the forecast period (00-72, 3 days forecast) and meteorological parameter (cloud, temperature, pressure, zond etc.) and drawing the appropriate map. In the example shown in the Figure 2 the meteorological parameter is cloud forecast and forecast period is 6 hours. All the forecasted data can be downloaded from this site in PS format both for parent and nested domains.

Besides the forecasts in image format this site also gives the exact forecast value for the given meteorological parameter, geographical position (latitude, longitude) and the forecast period (hour). E.g. in Figure 2 for Meteo parameter = T2 (temperature at 2 m in K), Latitude = 40.20, Longitude = 44.55 (this point is in Yerevan), Hour = 12 the required value is retrieved and printed we got T2 = 274.89.

b) In order to enhance the forecast accuracy and to make forecasts not only for the territory of Armenia the user should be able to run WRF model with any configuration. The user fills the following fields: email, name and fields of WRF configuration files (namelist.wps and namelist.input) or uploads them. The WRF model starts to run on the grid by pressing the submit button. This process will be done under meteo.see-grid-sci.eu virtual organization on any available recourse of the grid system. The user will be informed about results of execution by the email. This facility helps the user to find the best configuration in terms of forecast accuracy based on experiments.



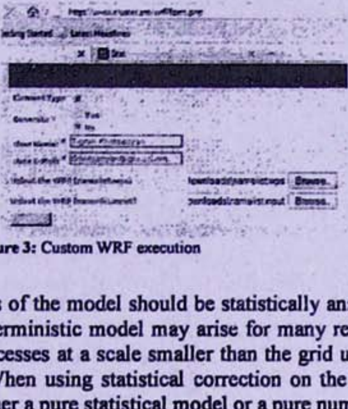


Figure 3: Custom WRF execution

c) Besides well configured NWP model the results of the model should be statistically analyzed and corrected for good forecast. Biases in the deterministic model may arise for many reasons, including the inability to account for physical processes at a scale smaller than the grid used in the numerical solution of the model equations. When using statistical correction on the NWP output, the accuracy is generally far better than either a pure statistical model or a pure numerical model.

To do statistical correction the forecasted values and then actually measured meteorological parameter values should be compared. For this reason this web site [12] (Figure 4) was created. It has the following facilities:

1. to add new data (forecast and real pair);
2. to modify the forecast;
3. to compare real, forecast and modified forecast data.

Adding new data is done by uploading csv format files. The information in these files is retrieved and stored in MySQL DB.

Modification is done by the following law:

$$\textbf{modified forecast} = a_0+a_1*f+a_2*f^2+ \dots +a_n*f^n+$$

$$b_{1,1}*r_{-1}+b_{1,2}*r_{-1}^{2}+ \dots + b_{1,m}*r_{-1}^{m}+$$

$$\cdot$$

$$\cdot$$

$$\cdot$$

$$b_{k,1}*r_{-k}+b_{k,2}*r_{-k}^{2}+ \dots +b_{k,m}*r_{-k}^{m}$$

where f_i is the forecasted value by the model, r_{-j} is the real value of the same meteorological parameter but measured j days before. All other parameters ($n,m,k,a_i,b_{i,j}$) are defined by the user (Figure 4).

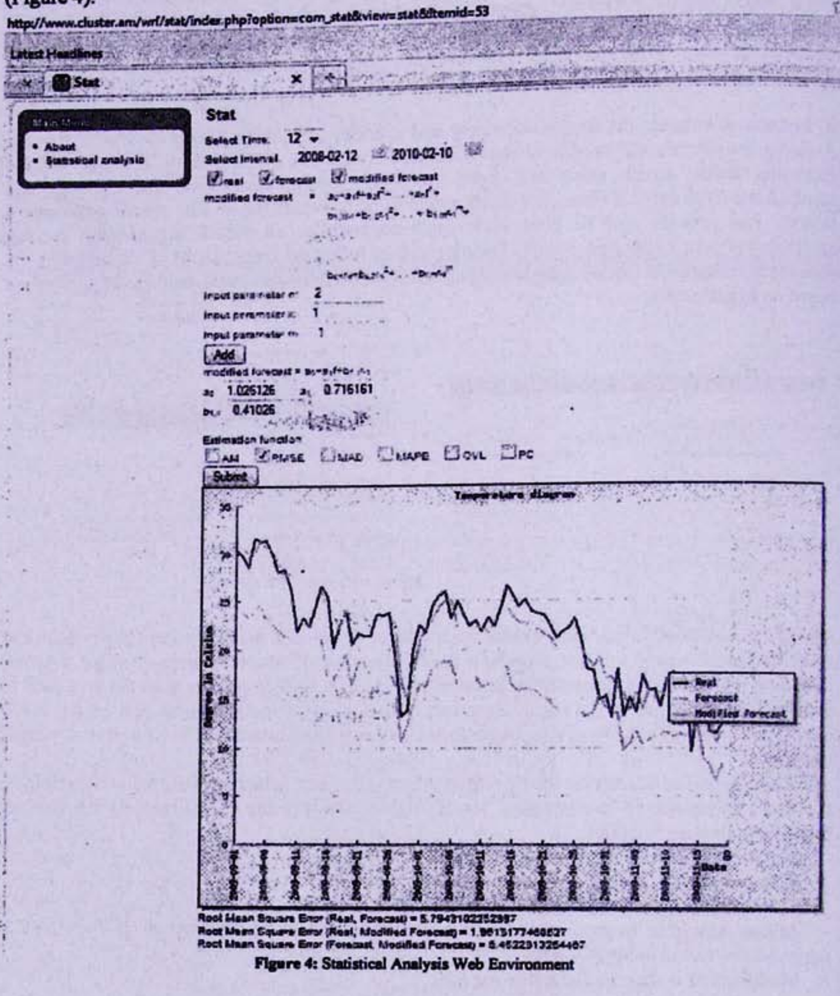


Figure 4: Statistical Analysis Web Environment

In order to estimate the model forecast and the modified forecast the following checkable functions are used in this site: root mean square error (RMSE), mean absolute deviation (MAD), Pearson's correlation (PC), overlap (OVL), arithmetic mean (AM).

In the example illustrated in the Figure 4 for the set parameters (estimation function is RMSE, **modified forecast** = 1.026126 + 0.716161 *f+ 0.41026*r_{-1}, etc.) we get the above presented graphic and

RMSE (Real, Forecast) = 5.7943102252987
RMSE (Real, Modified Forecast) = 1.9613177460527
RMSE (Forecast, Modified Forecast) = 5.4522313254467

As we can see RMSE of the modified forecast is much less than RMSE of unmodified forecast.

4 Conclusion

Numerical weather forecasting for the territory of Armenia is a need. The existing forecasts cannot wholly satisfy all the existing needs like to get high resolution accurate forecasts where Armenia should be in the center of the domain in order to have the full understanding of processes that influence the weather conditions over Armenia region, to have digital forecast files in order to do enhancement post-processings. All these requirements support the presented environment and even more: it allows visualizing the forecasts, doing statistical analysis and corrections, doing customized forecasts for any region (not only for the territory of Armenia). All these tools help to improve the accuracy level of the numerical weather forecast for the territory of Armenia. So this system serves as a research environment for a meteorologist to do more accurate forecast.

The WRF model can serve as a basis for solving different problems, e.g. environmental, hydrological, agrometeorological, etc.

References

[1] ARMSTATEHIDROMET, http://www.meteo.am
[2] Weather Research & Forecasting Model Website, http://www.wrf-model.org
[3] I. Foster, C. Kesselman, S. Tuecke, "The anatomy of the grid- enabling scalable virtual organizations", *International Journal Supercomputer Applications*, 15(3), pp. 200-222, 2001
[4] I. Foster, C. Kesselman, "Computational grids", in "The Grid: Blueprint for a New Computing Infrastructure" chpter, Morgan-Kaufman, pp. 15-51, 1999.
[5] SEE-GRID-SCI, http://www.see-grid-sci.eu/
[6] EGI Design Study web pages, http://web.eu-egi.eu/
[7] Official web-site of the Armenian National Grid Initiative Foundation, http://www.grid.am
[8] WRF Model GRAPHIC TOOLS : RIP4, http://www.mmm.ucar.edu/wrf/users/graphics/RIP4/RIP4.htm
[9] T. Khotsanyan, H. Astsatryan, A. Mirzoyan, V. Sahakyan, Yu. Shoukourian, H. Melkonyan, A. Hovsepyan, Z. Petrosyan, V. Kotroni, "Implementing and evaluating the weather research and forecast model for the territory of armenia", *Seventh International Conference on Computer Science and Information Technologies (CSIT'2009)*, Yerevan, Armenia, 2009, pp. 490-493.
[10] National Centers for Enviromental Prediction (NCEP), http://www.ncep.noaa.gov
[11] T. Khotsanyan, http://www.cluster.am/wrf/, WRF
[12] T. Khotsanyan, http://www.cluster.am/wrf/stat, Statistical analysis

Եղանակի թվային կանխատեսման միջավայր Հայաստանի տարածքի համար

Տ. Խոցանյան

Ամփոփում

Աշխատանքը նվիրված է Հայաստանի տարածքի համար եղանակի թվային կանխատեսման միջավայրի ստեղծմանն ու մշակմանը: Այս միջավայրի կարևորագույն նպատակներից մեկն է ապահովել օգտագործողին պարզ վեբ միջավայր կատարելու եղանակի թվային կանխատեսում և մշակելու այդ կանխատեսման արդյունքները: