Implementing and Evaluating the Weather Research and Forecast Model for the Territory of Armenia

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ABSTRACT

The article introduces an operational numerical weather prediction system based on the regional weather research and forecasting model (WRF), which has been ported and localized for the territory of Armenia and has intelligent user oriented interface. Since this system requires huge number of parallel computations, it uses the available computational resources of Armenian National GRID Infrastructure. The implementation of a mesoscale model with fine spatial resolution gives opportunity to promote weather forecasting and research that advance understanding of weather processes, improve forecasting techniques and increase the utility of forecast information with an emphasis on high-impact weather.

Keywords
Weather prediction, forecast, WRF, METEO, NWP, GRID, ArmNGI.

1. Introduction

Armenia aspires to build knowledge-based economy and information society. To reach this ultimate goal Armenian Government declared information technologies as a priority direction. In order to ensure that Armenia would not stay behind in this important area the development of different applications that need huge amount of computational resources and deployment of Armenian National Grid infrastructure [1] are in process.

The main aim of the state target program entitled "Deployment of Armenian National Grid Infrastructure" funded by the Armenian Government is to deploy Armenian National Grid Infrastructure and to develop applications in the fields of seismology, meteorology and environmental protection. Armenia also participates in the EU FP7 Project entitled "South East European eInfrastructure for regional eScience" [2]. The South-East European eInfrastructure initiatives are committed to ensuring equal participation of the less-resourced countries of the region in European trends. SEE GRID SCI leverages the SEE eInfrastructure to enable new scientific collaborations among user communities.

Numerical weather prediction (NWP) [3] is a prediction based on numerical integration of the equations of motion for the atmosphere. These are the non linear partial differential equations of dynamics, thermodynamics, mass continuity and moisture conservation. Numerical weather prediction models differ from one another in the numerical schemes and physical parameterizations they are using but also in the scale of physical phenomena taken into consideration. There are global, hemispheric, and regional scale models. The global model involves atmospheric phenomena on the whole globe, the hemispheric one – on the half globe. The regional models are applied in a specified region and depending on the resolution used they are intended to resolve mesoscale phenomena. NWP is an initial value problem and global models need representation of the initial state of the atmosphere, while regional models need both initial and boundary conditions (from a global model). Efficiency in prediction is achieved by using high performance computing. Advances in NWP have been always very closely related with advances in computing sciences as NWP requires numerical calculations that are parallelizable. The computer resources needed for NWP applications are important both in terms of CPU usage and disk storage.

At present Armenian State Hydrometeorological and Monitoring Service (ASHMMS) [4] 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. 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 in the large scale. Weather forecasting 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 mesoscale model will allow ASHMMS to have hydrometeorological information of finer resolution and to analyze changes of hydrometeorological elements at the regional scale.

Within the framework of the state program a joint team has been established consisting of leading specialists from SHMS RA, Ministry of Nature Protection and National Academy of Sciences of Armenia [5]. The main target of the team is to implement and operationally use the Weather Research and Forecasting (WRF) numerical weather prediction model for the territory of Armenia.

The WRF model [6-7] is a next-generation mesoscale forecast model and assimilation system that advances both the understanding and the prediction of mesoscale precipitation systems and promotes closer ties between the research and operational forecasting communities. Further details on WRF model are given in section 2.1 of this paper.

2. Implementation

The forecasts are computed using mathematical equations for the physics and dynamics of the atmosphere. These equations are nonlinear partial-differential and are impossible to solve analytically. Different models use different solution methods. Global models often use spectral methods for the horizontal dimensions and finite-difference methods for the vertical dimension, while regional models usually use finite-difference methods in all three dimensions. Regional models also can use finer grids to explicitly resolve smaller-scale meteorological phenomena, since they do not have to solve equations for the whole globe. The spatial resolution between the points on the computational grid for global models may be of the order of 50-100 km while for regional scale the grid spacing can be of the order of 2-10 km. Accordingly the time step for model integration is of the order of tens of minutes for global models down to some seconds for regional models (depending on the spatial resolution). Manipulating the huge datasets and performing the complex calculations necessary to numerically solve the equations on a resolution fine enough to make the results useful and timely available requires resources of supercomputers or clusters.

Nowadays some of well known global numerical models are:

- GFS - Global Forecast System Atmospheric Model,
- GEM - Global Environmental Multiscale Model,
- Unified Model,
- ECMWF – European Centre for Medium range Weather Forecasts.

Some of widely used regional numerical models are: WRF, the Regional Atmospheric Modeling System (RAMS), the Fifth Generation Penn State/NCAR Mesoscale Model (MM5), High Resolution Limited Area Model (HIRLAM), etc.

In this paper the preliminary results of the implementation (see fig. 1) of WRF regional model by using Armenian National Grid Infrastructure is discussed.

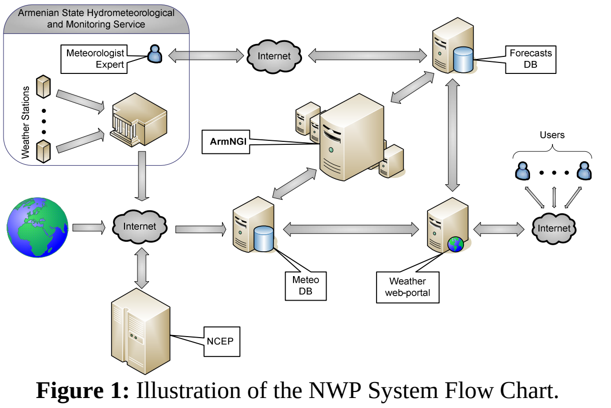

Figure 1: Illustration of the NWP System Flow Chart.

Observation data from the meteorological stations are collected at the ASHMMS. ASHMMS analyses the collected data and sends through Global Telecommunication System to the Regional and World Data Centres, 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) [8] 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 on the storage element the required meteorological data from NCEP twice a day. The core of the suggested system (the main parallel computations are done here) is the WRF (see chapter 2.1).

Mainly the Academic Scientific Network of Armenia [9] is used as a common network infrastructure to interconnect the Grid sites. The National Grid infrastructure consists of 5 Grid sites: ArmCluster [10], a 64 node cluster located in the Institute for Informatics and Automation Problems and used primarily for system software research, and 4 homogeneous 48 processors based cluster systems established in the Armenian research institutions and universities including Institute for Informatics and Automation Problems (IIAP), Yerevan State University (YSU), State Engineering University of Armenia (SEUA), Institute for Radiophysics and Electronics (IRPHE) (see fig. 2).

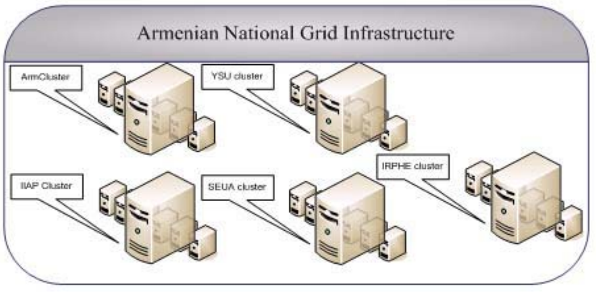

Figure 2: Armenian National Grid Infrastructure

The WRF model 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. Meteo DB and Forecast DB are based on PostgreSQL. Automated produced forecasts are stored in the Forecast DB and can be used by the meteorologist. The web-portal (see chapter 2.2) is used to access the model and database.

2.1. WRF

The WRF model is a regional next-generation mesoscale NWP and atmospheric simulation system designed for both research and operational applications. WRF is supported as a common tool for the university/research and operational communities to promote closer ties between them and to address the needs of both. The WRF has been developed in collaborative partnership of the National Center for Atmospheric Research's Mesoscale and Microscale Meteorology Division, the National Oceanic and Atmospheric Administration's NCEP and Earth System Research Laboratory, the Department of Defense's Air Force Weather Agency and Naval Research Laboratory, the Center for Analysis and Prediction of Storms at the University of Oklahoma, and the Federal Aviation Administration, with the participation of universities scientists. It is the evolutionary upgrowth of MM5 (NCAR Mesoscale Model Version 5), with more advanced physics and data assimilation system. Indeed, WRF incorporates advanced numerics and data assimilation techniques, a multiple relocatable nesting capability, and improved physics, particularly for treatment of convection and mesoscale precipitation. It is intended for a wide range of applications, from idealized research to operational forecasting, with priority emphasis on horizontal grids from meters to thousands of kilometers.

It is a supported "community model", i.e. free and shared resource with distributed development and centralized support. Now the number of registered WRF users exceeds 6000, and WRF is in operational and research use around the world. The WRF Modeling System consists of these major parts (see fig. 3):

- The WRF Preprocessing System (WPS)
- WRF with ARW or NMM core
- Post-processing and Visualization tools

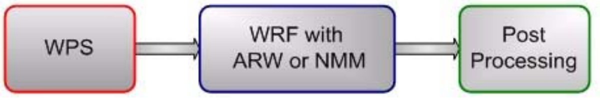

Figure 3: WRF Flow Chart

The WPS functions include defining simulation domains, interpolating terrestrial data (such as terrain, landuse, and soil types) to the simulation domain and de-gribbing and interpolating of meteorological data from another model to this simulation domain. WPS is a set of three programs, which prepare input to the real program for real simulations. Each of the programs performs one stage of the preprocessing:

- geogrid defines model domains and interpolates static geographical data to the model grid;
- ungrib extracts meteorological fields from GRIB formatted files provided by a global model;
- metgrid horizontally interpolates the meteorological fields extracted by ungrib to the model grids defined by geogrid.

The work of vertically interpolating meteorological fields to WRF model levels is performed within the real program (see fig. 4).

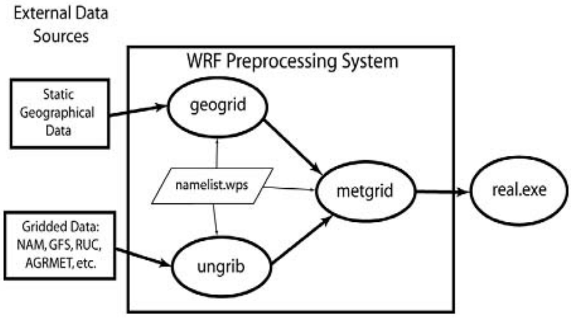

Figure 4: WPS components

Each of the WPS programs reads parameters from a common namelist file, as shown in the figure. This *namelist.wps* file has separate namelist records for each of the programs and a shared namelist record defines parameters that are used by more than one WPS program. Localization for the territory of Armenia is done by this file, defining the size and the location of all model domains, specifying nests and its corresponding resolution etc. WRF software infrastructure supports two dynamical cores:

- Advanced Research WRF (ARW) (NCAR);
- Non-hydrostatic Mesoscale Model (NMM) (NCEP/NOAA).

In the current system ARW core is used. RIP4 (Read/Interpolate/Plot) software is run as a post-processing and Visualization tool.

2.2. User Interface

The results of the prediction will be distributed to users through a Meteorological web-portal. The output files are stored in pdf, cgm and ps formats. The Weather portal has warning service. Users registered for this service can receive warning messages (e.g. by e-mail) if the corresponding meteorological parameter (e.g. temperature) exceeds the fixed value, or other criteria set up by the user. This warning email is sent to user as soon as new prediction data are inserted in the Forecast DB (see fig. 1). This portal allows executing statistical requests, e.g. retrieving average temperature for the last month, etc.

3. Results

Several experiments have been conducted on the base of AM-01-IIAP-NAS-RA Grid site to identify the most efficient option of parent and nested domains. The AM-01-IIAP-NAS-RA site consists of 48 cores (6 X Dual Intel Quad Core Xeon E5420 2.5 GHz). The model has been run for different couples of parent-nest domains with different spatial resolution (24 and 30km). The results have been compared with the observed values of temperature, precipitation and pressure.

The optimal couple of parent-nest domain has been selected on the base of experiments. The parent domain covers the broad area from Atlantic Ocean in the west to the Central Asia in the east, and from the Middle East in the south to the Polar Regions in the north (see fig. 5).

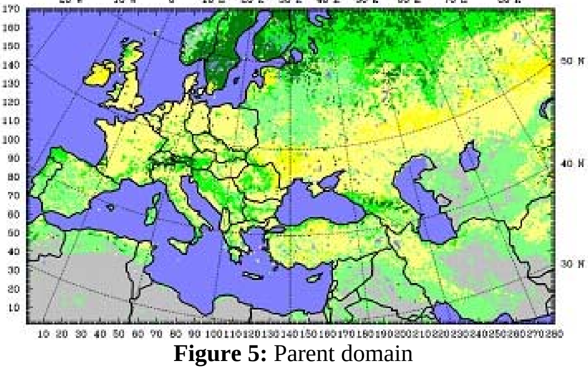

Figure 5: Parent domain

The reason of selecting this large area is to cover all the regions, where the main synoptic processes influencing the weather conditions in Armenia are originated (see fig. 6).

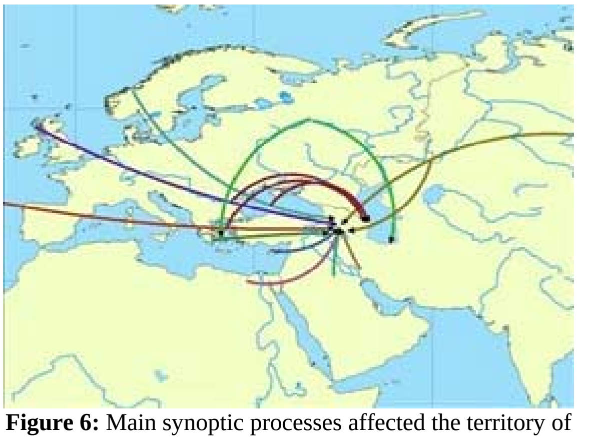

Figure 6: Main synoptic processes affected the territory of Armenia (by G.Surenyan)

The spatial resolution of the parent domain is 24 km. The nested domain covers the entire South Caucasus region with the spatial resolution 6km. (see fig. 7).

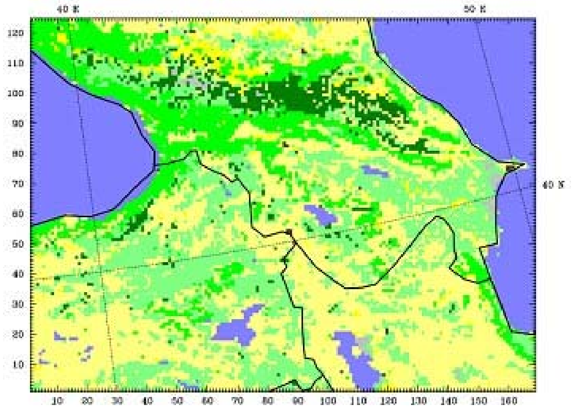

Figure 7: The nested domain selected for the experiment.

A number of experiments have been carried out in order to achieve the most efficient model running time and processors usage in IIAP cluster by using MPI and OpenMP (see fig. 8).

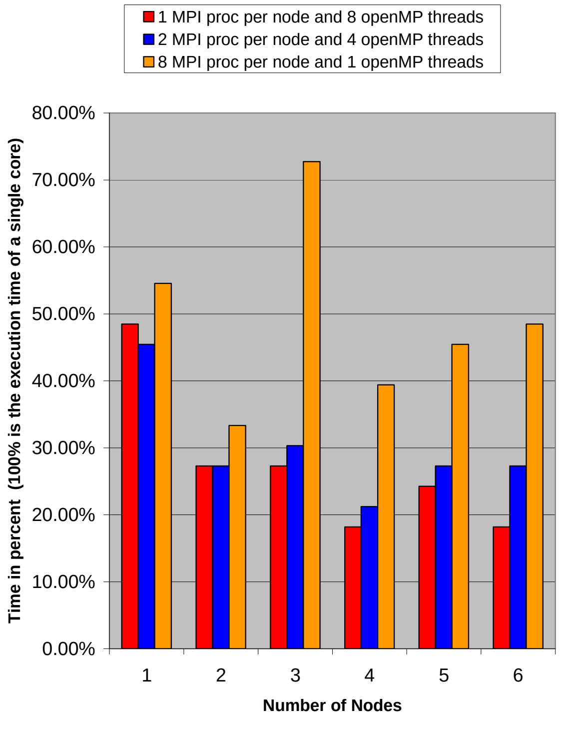

Figure 8: Experiments Results

At present the specialists of ASHMMS start using the preliminary products form WRF as an addition to currently use other products from GCM and RCM.

3. Conclusions

ASHMMS uses end products (gif, jpg, etc) of different Global and Regional NWP models with coarse resolution. The end products do not allow post-processing the charts, integrating satellite images into maps. Due to complex topography and diversity of terrain the risk of occurrence of weather hazards and climate extremes (thunderstorm-related phenomena, hail, straight-line winds, tornadoes, flash floods, lightning and so on) is very high. Therefore the prediction and warning of these phenomena will be significantly improved in terms of accuracy and lead time, through implementation of a mesoscale model.

Implementation of the WRF model with high resolution over a wide domain for Armenia gives opportunity to observe the atmospheric circulation in needed area and air mass advection from all possible directions. The selection of the domain, which covers the broad area from the Atlantic Ocean in the west to the Central Asia in the east, and from the Middle East in the south to the Polar Regions in the north, allows having the full understanding of processes that influence the weather conditions over Armenia region.

The implementation of WRF mesoscale model gives the opportunity to promote weather research and development of new tools that improve forecasting techniques and increase the utility of forecast information with an emphasis on high-impact weather.

The WRF model can serve as a basis for solving different problems, e.g. environmental, hydrological, agrometeorological, etc. Thus, WRF-CHEM module provides real time simultaneous prediction of air quality. In addition, biogenic and anthropogenic emissions, deposition, convective and turbulent chemical transport, photolysis, and advective chemical transport are all treated simultaneously with the meteorology.

4. Acknowledgement

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