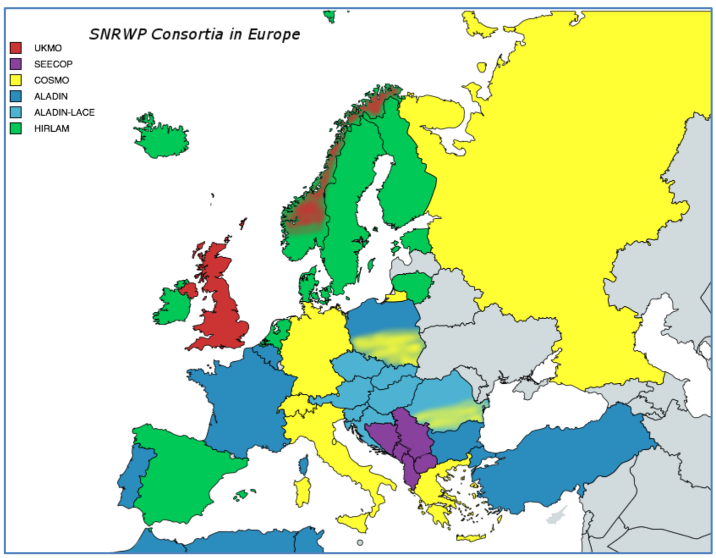
South-East European Consortium for Operational weather Prediction (SEECOP)

Modelling Concepts and Plan of Activities for 2016-2021

1. Introduction

The establishment of the South-East European Consortium for Operational weather Prediction Consortium (SEECOP) has been initiated by the South-East European Virtual Climate Change Center (SEEVCCC)[1] partners who put into force the SEECOP Agreement which specifies the conditions for the collaboration between the SEECOP Members[2].



SEECOP consortium (coloured pink)

The SEECOP objective is to establish collaboration between Country Members addressed to providing state-of-the-art NWP products based on the application of the Nonhydrostatic Multiscale Model on B-Grid (NMMB model (Janjic 2009)) of NCEP[3] for both research and

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[1] SEEVCCC, hosted by the Republic Hydrometeorological Service of Serbia (RHMSS), brings together scientists in climate research and operations in order to perform development and operational functions for climate monitoring, long range forecast, and monthly forecast. R&D and operational activities are based on the products from numerical modeling of the integrated Earth system, and their applications in agriculture, forestry, energetics and environment.

[2] The National Meteorological and Hydrological Services (NM(H)Ss) of the following WMO Member States: the Republic of Albania, the Federation of Bosnia and Herzegovina (Bosnia and Herzegovina), the Republic of Srpska (Bosnia and Herzegovina), the former Yugoslav Republic of Macedonia, Montenegro and the Republic of Serbia.

[3] National Centers for Environmental Prediction, USA

development activities; in addition, to use NMMB products as drivers for operational of environmental forecasts of different kinds (aerosol, hydrology, etc.). Within SEECOP, Members agreed to share the available expertise, data, modelling and technical resources in NWP and therefore reduce overlapping in NWP activities in the region; to organize trainings for the use of the NMMB system and related applications; to enhance the operability of NWP.

2. Seamless Concept for Prediction of Weather and Climate

SEECOP follows the concept of so-called *seamless weather and climate prediction* – a trend in numerical weather prediction (NWP) and climate modelling communities to use generally the same atmospheric modelling systems for scales from days to seasons and beyond, which are coupled with other Earth system components such as: soil, chemical composition, oceans, land-surface, and surface hydrology.

According to the World Climate Research Program (WCRP) report on the seamless concept (Shukla, 2009), there is no scientific basis to draw artificial boundaries between meso-scale prediction, synoptic scale prediction, seasonal prediction, and decadal prediction. However, practical considerations of computing and of model complexity may require different prediction systems for different time scales. The simulation and prediction of meso-scale systems, synoptic scale disturbances, intra-seasonal, seasonal and inter-annual variations are intimately linked, and therefore, it is suggested that future research on prediction of weather and climate be carried out in a unified framework.[4] A fundamental principle of seamless prediction is that the coupled atmosphere-ocean-land-aerosol-hydrology system exhibits a wide range of dynamical, physical, biological and chemical interactions involving a continuum of spatial and temporal variability of the overall system. Early ideas on the needs to integrate the Earth system components to interact through different feedback mechanisms has been advocated by Nickovic (2002), who suggested two-way coupling within a seamless Earth system model in order to increase the quality of forecasts.

In order to address the question of predictability in terms of the statistics of high impact local weather events it is required that the models used for seasonal prediction also resolve and simulate the local weather events. It is therefore essential that the models for predicting

[4] A good part of this section has been taken from http://www.nws.noaa.gov/ost/climate/STIP/FY09CTBSeminars/shukla_021009.pdf. This paper describes the concept of seamless prediction and its evolution during the establishment of the COPES (Coordinated Observation and Prediction of the Earth System) framework of the World Climate Research Program (WCRP), where the concept was first presented in 2005.

daily, weekly, monthly and seasonal variation be unified. In other words, very high-resolution models without the parameterizations of deep moist convection must be extended at least up to a season to predict the statistics of high impact weather events within a season. It can be conjectured that since the parameterizations of moist convection in coarse-resolution models are the main source of uncertainty in simulation and predicting seasonal means, models that can explicitly simulate organized cloud systems with moist convection will enhance the predictability of weekly and monthly averages during a season.

SEEVCCC has formed the seamless prediction principle and it has been mainly conducted by the modelling experts from the Republic Hydrometeorological Service of Serbia (RHMSS), the University of Belgrade, and scientists from the Serbian diaspora, who designed an Earth system model structure by integrating a variety of NCEP atmospheric models (including NMMB) and models for the aerosol transport, hydrology dynamics, soil processes and ocean circulation (Janjic et al, 2001; Djurdjevic and Rajkovic, 2008; Nickovic et al, 2001; Pejanovic et al, 2011). A natural extension of SEEVCCC was the launching of SEECOP in order to exploit the existing modelling expertise in the SEE region and already developed software and expert infrastructure. Following the suggestions to use unified atmospheric models (one model for all scales, from local to global) in the seamless system (*...The simulation and prediction of meso-scale systems, synoptic scale disturbances, intra-seasonal, seasonal and inter-annual variations are intimately linked, and therefore, it is suggested that future research on prediction of weather and climate be carried out in a unified framework...*(Shukla, 2009)) it was a natural choice to choose the NMMB model (Janjic 2009) for both SEECOP and SEEVCCC activities. Namely, NMMB has been designed in such a way that the same software code could be used either over a limited or global geographic domain, with the use of an on/off switcher for hydrostatic or nonhydrostatic executions (see APPENDIX).

3. Current NWP activities in SEECOP

Most of the SEECOP partners already have experience in NWP modelling, which is an important basis and a starting point for collaborating in the Consortium. The experiences range from:

- using and interpreting ready NWP products from external sources;
- running different NWP models (mostly NCEP or NCAR WRF-based (ARW and NMM) models);

- implementation of the newest-generation NCEP NWP system – NMME and NMMB;
- developing new applications based on the NWP models.

Current operational NWP activities of Members

<u>The former Yugoslav Republic of Macedonia</u>

Operational activities in Weather Analysis and Forecast Department at Hydrometeorological Service of Macedonia

The main operational work of weather forecasters in the Department of Weather Analysis and Forecast is making the analyses of atmospheric conditions and the forecasts of meteorological parameters and the future development of the atmosphere, as follows: short-range forecast (for 1 to 3 days in advance), medium-range forecasts (up to 10 days in advance), and nowcasting or very short-range weather prediction (a few hours in advance), which is used as a basis for issuing weather alerts and early warnings.

The weather forecasts are mainly based on the use of the global models whose products are available on the Internet, the main ones being GFS and ECMWF. Occasionally, for some specific parameters, our department utilizes the other models data (e.g. SKIRON, UKMO or some others). A number of meteorological parameters, such as: weather charts, vertical cross-sections maps and meteograms have been analysed in a daily operational procedure. The forecast products are used up to 240 hours ahead, with an emphasis on those to 168 hours or up to 7 days in advance, which is the basis for the preparation of daily operational weekly weather forecasts for Macedonia by regions and cities.

Of particular benefit is the access to ECMWF products, such as the standard fields, Epsigrams and products from the Ensemble Prediction System (e.g. Extreme Forecast Index compared to the temperatures, wind, precipitation, etc.). Due to the lack of a graphics station, particularly the interactive use of the visualization tool via the Internet, Eccharts, so that we can combine a number of output products from ECMWF according to our needs and choice.

The list of meteorological parameters that can be visualized is large and contains a number of parameters to which we have no access via other models. In the last 5 years we have been extensively using the ECMWF model and we are very satisfied by it. As with other models we consider that the main constraint or weaker portion is the accurate forecast of precipitation and other meteorological parameters. However, the ECMWF model quite well predicts the spatial and temporal distribution of the intensity of precipitation, as well as the tendency of temperature values.

In terms of short-term weather forecasts, our department has been using the products of the non-hydrostatic limited area model WRF-NMM since 2004/5, and the WRF-NMM v3.1 was installed and upgraded in 2008. The model is running on server computers twice a day with GFS initial fields with resolution 1° x 1°lat/lon degree and the boundary conditions taken each 6 hours from the public directory of NCEP. The model is running in nested mode with two model domains. The large model domain covers Europe and has 22 km horizontal grid resolution, 38 model levels and the duration of forecast is extended to 120 hours. The model outputs are different weather geopotential, temperature, cloudiness, wind, accumulated rainfall, hourly rainfall, CAPE, emagrams, meteograms, TV maps and other products. In addition, the model has a module for dust transport from Sahara. The nested model domain (domain 2) covers the whole territory of Macedonia and the initial and boundary conditions are taken from the operational run of the version which covers Europe. The horizontal resolution of the model is 1.8 km with the time step of 5 seconds and forecast period of 48 hours. The model output provides: wind, CAPE, LI, radar reflectivity at different geopotential height, visibility, relative humidity, 2 m temperature, hourly precipitation, cloudiness and other parameters at different pressure levels. In addition, a module for air quality based on CALGRID and CALPUFF has been installed and running, related to surface base and convective base runoff, forest fire indexes, and other charts including TV maps. Occasionally, we use the products of the WRF-NMM and ETA models from the Republic Hydrometeorological Service of Serbia, available on their web portal. The products derived from the nonhydrostatic models are partially used for the forecasts of some instability indices and products available from the global models. Certainly in terms of now-casting, especially in connection with the rapid development of hazardous weather events the most useful products in our practice are those provided by satellite and radar data and images.

Based on our experience with the daily use of products, our general assessment is that the WRF-NMM model shows a greater accuracy in the prediction of wind currents, the distribution of moisture, as well as the distribution of precipitation and the type of hydrometeors, while in terms of the amount of rainfall due to the low defined threshold, the rainfall is overestimated. Also, there is a bias in terms of temperature values. The problem with the model that is operationally running at HMS is mainly due to the long processing time, which is a result of the computer performances and slow Internet. Also, we do not have adequately trained and a sufficient number of staff who would deal with the problems of numerical modelling, making interventions on the existing models and working on their improvement, which we believe is the main objective of the establishment of this Consortium. Of course, it requires an organized and systematic approach to this issue, which would define priorities, staffing and education.

Our present and further research work is related to developing and testing the WRF-NMM v3.6 with a different initialization setup and model configuration and its verification with observational data. Also, the WRF-ARW model v3.6 and 3.7 have been tested by some experts with the initial and boundary conditions taken from ECMWF. In addition, our further scientific and research activity is connected with developing a suitable algorithm based on the WRF and Cloud Model for more advanced forecasting of heavy convective rainfall and definition of convective weather indices and flooding alert.

Prepared by:

Ivana Petrovik, Analysis and Forecasting Division, Head

Kostadnika Arsovska, Senior Collaborator

NWP portion and English translation:

Dr. Vlado Spiridonov, Associate Professor

HMS – State and International Advisor

Skopje, 23 June 2016

Republic of Serbia

Models used operationally for NWP

NNMB (Janjic and Gall, 2012) global:

240h forecasting period, initial conditions – 120h forecasting period, initial conditions – GFS analyses 00 and 12 UTC, horizontal resolution 0.47*0.33 degrees, 64 sigma-p vertical levels, model top is at 10mb, time step 80 sec, global domain, finite differences method with the application of spherical filters around poles, non-hydrostatic, geog data resolution 2m, NCEP's Gravity Wave Drag taken from the GFS model, 2nd order diffusion in horizontal and vertical, PBL is Mellor-Jamada-Janjic with the NOAH land surface scheme, GFDL shortwave and long-wave radiation schemes, Betts-Miller-Janjic convection scheme (table 4.2.2.1).

ETA:

120h forecasting period, initial and boundary conditions – DWD model, 00 and 12 UTC, horizontal resolution 26km, vertical resolution 32η layers, Euro-Atlantic domain 24N-70N and 40W-55E, hydrostatic.

WRF-NMM (Janjic et. al, 2014):

192h forecasting period, initial and boundary conditions – GFS model 00 and 12 UTC, horizontal resolution 10km, vertical resolution 38 sigma-p levels, model top 50mb, time step 30 sec, Euro-Atlantic domain 20W-35E and 32N-63N, non-hydrostatic, geog data resolution 30s, gravity wave drag off, 2nd order diffusion in horizontal and vertical, PBL is Mellor-Jamada-Janjic with NOAH land surface scheme, GFDL shortwave and long-wave radiation schemes, Betts-Miller-Janjic convection scheme.

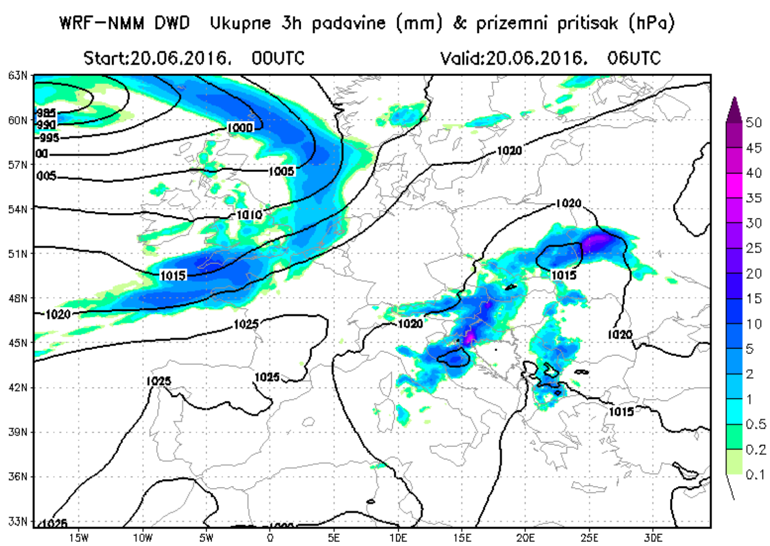


Illustration: WRF-NMM

WRF-NMM:

120h forecasting period, initial and boundary conditions – DWD model 00 and 12 UTC, horizontal resolution 10km, vertical resolution 38 sigma-p levels, model top 50mb, time step 30 sec, Euro-Atlantic domain, 20W-35E and 32N-63N, non-hydrostatic, geog data resolution 30s, gravity wave drag off, 2nd order diffusion in horizontal and vertical, PBL is Mellor-Jamada-Janjic with the NOAH land surface scheme, GFDL shortwave and long-wave radiation schemes, Betts-Miller-Janjic convection scheme.

WRF-NMM:

72h forecasting period, initial and boundary conditions – ECMWF, IFS 00 and 12 UTC, horizontal resolution 4 km, vertical resolution 45 sigma-p layers, model top 50mb, time step 8 sec, Balkan-Adriatic domain, 40N-48N and 11.5E-26E, non-hydrostatic, geog data resolution 30s, gravity wave drag off, 2nd order diffusion in horizontal and vertical, PBL is Mellor-

Jamada-Janjic with NOAH land surface scheme, GFDL shortwave and long-wave radiation schemes, Betts-Miller-Janjic convection scheme.

NMMB regional:

120h forecasting period, initial and boundary conditions – NMMB-global (RHMS), initialized at 00 and 12 UTC, horizontal resolution 12 km, 64 sigma-p vertical levels, model top 10mb, time step 20 sec, Euro-Atlantic domain 20W-35E and 32N-67N, non-hydrostatic, geog data resolution 1m, gravity wave drag on, 2^{nd} order diffusion in horizontal and vertical, PBL is Mellor-Jamada-Janjic with LISS land surface scheme, RRTM shortwave and long-wave radiation schemes, Betts-Miller-Janjic convection scheme.

NMMB nested:

72h forecasting period, initial and boundary conditions – online nested into NMMB-regional, model starts at 00 and 12 UTC, horizontal resolution 4 km, 64 sigma-p vertical levels, model top 10mb, time step 8 sec, Balkan-Adriatic domain, 40N-48N and 11.5E-26E, non-hydrostatic, geog data resolution 30s, gravity wave drag off, 2^{nd} order diffusion in horizontal and vertical, PBL is Mellor-Jamada-Janjic with LISS land surface scheme, RRTM shortwave and long-wave radiation schemes, without convective parametrization.

NMMB 4km:

72h forecasting period, initial and boundary conditions – ECMWF, model starts at 00 and 12 UTC, horizontal resolution 4 km, 64 sigma-p vertical levels, model top 10 mb, time step 8 sec, Balkan-Mediterranean domain, 36N-50N and 3E-31E, non-hydrostatic, geog data resolution 30s, gravity wave drag off, 2^{nd} order diffusion in horizontal and vertical, PBL is Mellor-Jamada-Janjic with LISS land surface scheme, RRTM shortwave and long-wave radiation schemes, without convective parametrization. This model runs inside of EC-FLOW on ECMWF's Cray supercomputer.

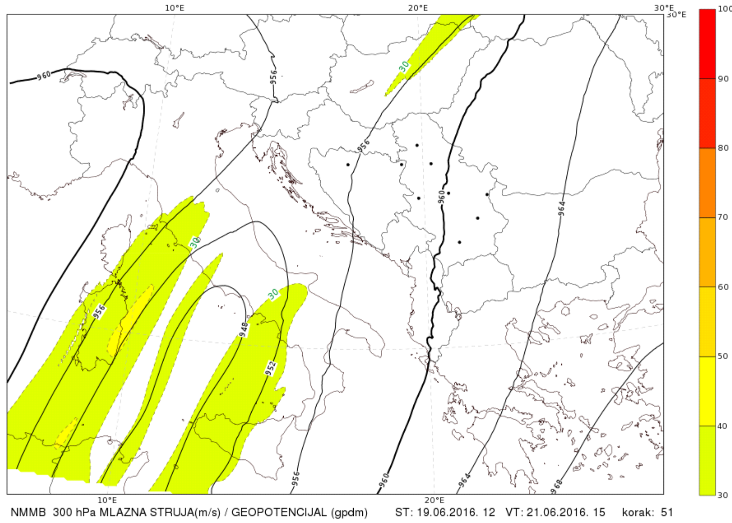


Illustration: NMMB 4km

Research and experimental activities in NWP

One version of the NMMB regional model with data assimilation is running in pre-operational mode in the NWP division of RHMSS. The model setup is described above as NMMB regional. The data assimilation system is a hybrid 3D Ensemble Variational (3D-EnVar). The 3D-EnVar consists of the LETKF (Local Ensemble Transform Kalman Filter), Hunt et al, 2007, 3D-Var, and GSI (Grid Statistical Interpolation) observational operators. LETKF works with 51 ensemble members, NMMB reg, with 12 km resolution and with multi physics within ensemble members. EnVar uses the LETKF-NMMB ensemble to calculate background error in order to produce a deterministic analysis in the same resolution. Boundary conditions for the ensemble members are from ECMWF's global ensemble and for the deterministic model from ECMWF's IFS model. Currently, a new analysis is performed each six hours, at 00, 06, 12, 18 UTC using a three-hour assimilation window. A forecast for three days in advance is run from those analyses four times a day. Assimilated data include: upper-air soundings from radiosondes and dropsondes (ADPUPA), surface stations (ADPSFC), ships and buoys (SFCSHIP), aircrafts (AIRCFT), and various types of remote sensing of winds (PROFLR, VADWND, SATWND, SPSSMI, QKSWND); GPS radio occultation; and radiances from SEVIRI – m10; AMSUA – metop-a, metop-b, aqua, nnp, n15, n18, n19; AIRS – aqua; IASI – metop-a, metop-b; HIRIS4 – metop-a, metop-b, nnp, n19; CRIS – nnp; ATMS - nnp, and MHS – metop-a, metop-b, nnp, n18, n19 satellite sensors. The system has been running in pre-operational mode since the beginning of February, 2016, and some of the initial results have been shown in Kasic, 2016.

Another version of NMMB (described above as NMMB 4km) with data assimilation has been tested for a single test case. The data assimilation system was the same as for NMMB regional, with the main difference being that the analyses were produced every three hours.

On-line nesting of NMMB with 1.33 km resolution has been tested inside of operational NMMB 4km described above.

Computational resources:

HPC Cluster – "new": 32 Blade servers BL 2x220c generation 7, 2 Blade C7000 enclosure;

HPC Cluster – "old": 16 HP Blade servers BL 2x220c generation 5 and 16 Blade servers BL 2x220c generation 6.

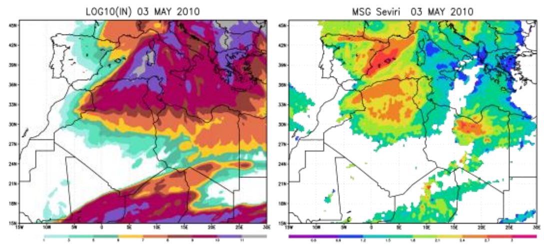
As a full member of the European Centre for Medium-Range Weather Forecasts (ECMWF), RHMSS has dedicated 106,199 KSBU at the ECMWF's Cray supercomputer for 2016.

Parameterization of the number of ice nuclei formed due to dust

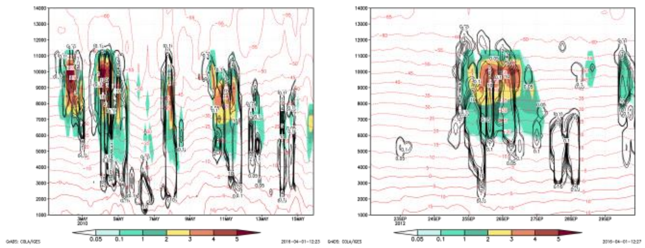
RHMSS has developed a coupled real-time forecasting atmosphere-dust forecasting system (Nickovic et al., 2016), which predicts the number of ice nuclei (n_{IN}) formed due to dust aerosol, as an online model variable. The n_{IN} number is the major external parameter in cold cloud heterogeneous ice nucleation microphysics schemes which is currently used either as a pre-specified constant or as a climatology value.

This development is a result of the scientific evidence on the dominant role of dust in cold cloud formation (Cziczo, 2013; Atkinson et al, 2014) which motivated a number of research groups to link cloud microphysics schemes with the parameterizations of dust-affected n_{IN} in atmospheric models (DeMott et al, 2015; Niemand et al, 2012; Steinke et al, 2015).

Such new component represents a step towards the operational prediction of cold clouds and associated precipitation. To our knowledge, this is the first time that all ingredients needed for dust-induced cold cloud formation have been predicted in an operational forecasting mode within one modelling system. For our study, the immersion and deposition modes of freezing were assumed to be dominant for the ice formation process. A significant correlation between the model and the observed conditions for icing has been achieved.



Model $\int n_{IN}$dz,; MSG-SEVIRI satellite ice water path



$\log_{10}$ (IWC $\times 10^{-6} \frac{kg}{m^3}$) obtained from Doppler radar reflectivity using the Cloudnet algorithm (solid black line contour plot) vs. DREAM $\log_{10}$ (n_{IN}) (coloured contour plot), in the period 1-15 May 2010 (left), and 22-30 September 2012 (right)

In 2017, we plan to introduce the operational prediction of n_{IN} into one of the NMMB cloud schemes and to test the impacts of the methodology on cloud and precipitation prediction. We also plan to provide the SEECOP community with n_{IN} gridded fields that the partners could use in their NWP cloud schemes.

Prediction of flash floods by integrating the NMMB model and the HYPROM Hydrology Prediction Model

(See more in *Hydrology predictions* in the next Section)

Prepared by:

Bojan Kašić, Analyst for Data Assimilation, RHMSS NWP Division

Belgrade

<u>Montenegro</u>

Models used operationally for NWP in the IHMS of Montenegro

20 July 2016

NMM-E, HiRES (Janjic, Gerrity and Nickovic, 2001):

- 96h forecast period
- Initial conditions from the ECMWF global deterministic model
- Two runs – 00 UTC and 12 UTC

- Horizontal resolution DLMD=1./25., DPHD=1./25.
- Time step DTB=15.
- Vertical levels LM=38
- Domain (TLM0D=17.5, TPH0D=42.8) with (wbd=-4.8, sbd=-4.0),
- GFDL shortwave and long-wave radiation schemes
- Betts-Miller-Janjic convection scheme

WRF NMM v3.7.1 about 11km:

- 144h forecast period
- Initial conditions from the ECMWF global deterministic model
- One run – 00 UTC
- Horizontal resolution dx=dy=0.1 degree
- Time step dt=30s
- Vertical levels e_vert = 38
- Domain ref_lat=39.875, ref_lon=14.375, e_we=196, e_sn=216

WRF NMM v3.7.1 about 3km:

- 144h forecast period
- Initial conditions from the ECMWF global deterministic model
- Two runs – 00 UTC and 12 UTC
- Horizontal resolution dx=dy=0.03 degrees
- Time step dt=10s
- Vertical levels e_vert = 40
- Domain ref_lat=41.50, ref_lon=18.90, e_we=110, e_sn=170

WRF NMM v3.7.1 about 1km:

- 144 h forecast period
- Initial conditions from WRF NMM v3.7.1 about 3km model
- Two runs – 00 UTC and 12 UTC
- Horizontal resolution dx=dy=0.01 degree
- Time step dt=3s
- Vertical levels e_vert = 60
- Domain ref_lat=42.60, ref_lon=19.20, e_we=100, e_sn=250

WRF NMM v3.7.1 about 9km:

- 120h forecast period

- Initial conditions from NCEP/USA global deterministic model
- Two runs – 00 UTC and 12 UTC
- Horizontal resolution dx=dy=0.08333 degrees
- Time step dt=30s
- Vertical levels e_vert = 40
- Domain ref_lat=42.875, ref_lon=16.375, e_we=100, e_sn=170

WRF NMM v3.7.1 about 3km:

- 120h forecast period
- Initial conditions from WRF NMM v3.7.1 about 9km model
- Two runs – 00 UTC and 12 UTC
- Horizontal resolution dx=dy=0.03 degree
- Time step dt=10s
- Vertical levels e_vert = 40
- Domain ref_lat=41.50, ref_lon=18.90, e_we=110, e_sn=170

Eta-DREAM

- 120h forecast period
- Initial conditions from the NCEP/USA global deterministic model
- One run – 00 UTC
- Horizontal resolution DLMD=1./3.,DPHD=1./3.
- Time step DTB=120.
- Vertical levels LM=24
- Domain (TLM0D=10., TPH0D=33.0) with (wbd=-28.8 , sbd=-16.0)

WAM (Wave Model)

- 120h forecast period
- Initial conditions from WRF NMM v3.7.1 about 11km
- One run – 00 UTC
- Three downscalings – 0.25, 0.125 and 0.625 degrees, Mediterranean Area, East Mediterranean, and the Adriatic Sea.

Experimental activities in NWP and plans for the future

IHMS has finished the implementation of the Advanced Research WRF (ARW) model with input data from ECMWF and NCEP-USA, and some initial steps with WRF-Chem (the Weather Research and Forecasting (WRF) model coupled with Chemistry).

The plan is to create and implement operational verification software for the models and start with the implementation of a data assimilation system in high resolution model of about 1km for the area of Montenegro.

By the end of 2016, IHMS plans to start the NMMB model in the experimental phase and later on, during 2017, to put it in operational use.

Computational resources:

- Beo-Wulf cluster (since 2008), with 32 nodes;
- Beo-Wulf cluster (since 2004), with 4 nodes;
- 3 PCs with i7 cpu on 4.0Ghz;
- 1 PC with P4 on 3.2 GHz.

Prepared by:

Ms Sanja Pavicevic, IHMS Deputy Director, sanja.pavicevic@meteo.co.me,

Mr Angel Marcev, Chief of IHMS Group for Numerical Modeling, angel.marcev@meteo.co.me

4. SEECOP Activities Plan 2016-2021

According to the SEECOP Agreement, a number of activities shall be carried out within the Consortium. The activities based on specific objectives as specified in the document will in general include different NWP activities such as: Data assimilation and use of observations; Diagnostics, validation and verification; Aspects of modelling implementation and operations; Specific NWP-related applications driven by NMMB; Technical aspects such as automatic execution procedures and graphical interpretation; Training.

Model validation; Case studies

To determine the value of weather forecasts, we need to measure it against the observed state of the atmosphere. In many cases forecasts perform well according to the standard skill scores (RMS, bias, correlation) used for verification, but sometimes do not fulfil users' expectations. Following the recommendations of WMO, the conventional skill scores will be complemented with those developed to satisfy some specific user needs. SEECOP will also work on introducing this specific category of verification scores such as: Methods for dichotomous (yes/no) forecasts based on contingency tables (usually used for precipitation);

Threat score for precipitation; Object oriented scores (contiguous rain areas method where rainfall patterns are validated by considering location, volume, and pattern errors).

An additional tool to better understand the behaviour of the Consortium prognostic model will be performing model experiments for series of specific atmospheric, preferably high-impact weather cases such as: torrential rains, heat waves, extreme wind conditions, surface icing, fog, etc. For this purpose, an inventory of cases accompanied with as much observational data of different kinds as possible will be established. SEECOP Members will be encouraged to participate in the model executions and corresponding intercomparisons for selected cases.

Training workshops

During the mid-term period, 2-3 workshops on different NWP issues would be organized. The first workshop planned for 2017 would be devoted to a hands-on training on the use of the NMMB prognostic system. The subsequent workshops could be addressed to the subjects such as data assimilation, validation/case studies or other issues of common interest.

Data assimilation, model aspects

Most of the current atmospheric models used by the Consortium members are based on the ready external global model products (such as ECMWF, NCEP) used for specifying initial conditions of the operational model executions. Such approach is a reasonable choice if there is no added component for the assimilation of meteorological observations. However, in order to further increase the accuracy of NWP, data assimilation should be included to determine the best possible atmospheric state using the observations and short-range forecasts. Data assimilation is typically a sequential time-stepping procedure, in which a previous model forecast is compared with newly received observations; subsequently, the model state is updated to reflect the observations, after which a new forecast is initiated, and so on. The update step in this process is usually referred to as the *analysis*; the short model forecast used to produce the analysis is called the *background*.

The first attempts to introduce data assimilation into the NMMB system have already been performed in RHMSS. They have been based on the GISS NCEP Kalman filtering approach which uses satellite observations. Another Kalman filter approach developed by the Deutscher Wetterdienst (DWD) will be also implemented and tested. Both schemes will have been extensively tested and validated in sensitivity experiments by the end of 2017. The data assimilation described above, or assimilations of other types will be introduced in the mid-term period, using different observations (conventional measurements, radars, satellites, etc.) by Members whose computer and man-power resources could support this task.

The Consortium Members should work on developing a common software for 1- and 2-way model nesting, in order to provide a very high resolution NMMB downscaling. The first results in performing this mid-term task could be expected by the end of 2017. In the chain of nested models the key input would be the use of the NMMB global version already run by RHMSS. During 2017, regular global NMMB products would be available at the dedicated Consortium web page.

Surface conditions

Over the mid-term period, a new generation of high-resolution NMMB (estimated to approach 1km or less, down to ~100m for some applications) quasi-stationary geo data (such as land cover, soil types, topography, etc.) should be introduced into the Consortium modelling system. The introduction of the new geo data at the same time will be beneficial for the NMMB model versions executed with coarser resolutions.

One of the soil parameters of extreme importance is soil wetness used to describe soil initial conditions in NMMB. Currently, this parameter is far from being sufficiently accurate; it is typically obtained as output from external (e.g. ECMWF) modelling systems. SEECOP will consider the use of satellite-based high-resolution observations of the surface soil moisture (a promising option would be the future ESA Sentinel-1 measurements). Earth observation of the near-surface soil moisture content is of tremendous scientific and application interest for understanding the interactions between water, energy and biochemical fluxes, the forecasting of meteorological and hydrological events, crop yield predictions, etc.

NMMB aerosol transport component; aerosol-atmosphere interactions

The Dust Regional Atmospheric Model – DREAM (Nickovic et al, 2001; Pejanovic et al, 2011) has been implemented in 2011 within SEEVCCC to perform daily forecasts of the atmospheric dust transport driven for the moment with the NMME model. DREAM simulates the atmospheric cycle of the mineral dust aerosol: dust emission, turbulent diffusion, vertical and horizontal advection, lateral diffusion, and wet and dry deposition. DREAM is the most widely used model worldwide, applied for research and operational purposes in more 20 organizations, including those from Serbia, Montenegro, and the former Yugoslav Republic of Macedonia. DREAM has also been used to forecast/simulate other types of aerosols: pollen, volcanic ash and sea salt.

An ongoing development in RHMSS is addressed to implementing a parameterization scheme in the NMM-DREAM model that takes into account dust-cloud interactions. Recent researches clearly indicate that dust appears as a perfect natural cloud seeder responsible for ice nucleation in more than 60% of cold clouds (Cziczo, 2013; Nickovic et al, 2016). During 2016/2017, the predicted ice nuclei (IN) concentration will be introduced into the NMMB Thompson cloud microphysics (Thompson and Eidhammer, 2014), replacing the dust climatology used in the original Thompson code with the predicted dust and related predicted IN. In 2016/2017, the predicted 3D ice nuclei (IN) concentration will be made publicly available to the Consortium as an input parameter to cloud microphysics schemes in the Partners' models.

During the mid-term period, the new method (indirect aerosol effect) will be extensively tested. It is expected that with NMMB clouds and precipitation will be predicted more accurately. In addition, direct aerosol effects (aerosol-radiation interactions) will also be developed and implemented into the NMMB operations.

Hydrology predictions

The HYPROM hydrology surface-runoff prognostic model (Nickovic et al, 2010; Pejanovic et al) has been developed to predict surface hydrology conditions. Currently, HYPROM is used in RHMSS to test the model's capabilities to forecast floods for several selected cases in the SEE region. The model has been developed to simulate overland watershed processes using the full dynamics numerical of the governing equation system. Since no major simplification of the governing system is used (e.g. a kinematic approximation), this permits representation of different hydrology scales ranging from short-term processes (e.g. flash floods) to the flows of large, slow river watersheds. Unlike most current hydrology models, HYPROM requires no calibration against the long discharge data for a particular river basin. HYPROM can be driven either by precipitation from an atmospheric model or by observed precipitation. Recently, HYPROM has been integrated within the NMMB model in a two-way coupled manner (Vujadinović, 2015).

During the mid-term period, HYPROM will be extensively tested for a series of torrential/flood cases in the region. Within that period, a user-based interface will be developed to provide a simple setup of the model and its efficient execution for a selected river basin. A water pollution component will be added to the model in order to predict the surface and sub-surface transport of polluted substances. In the long term, the integrated NMMB-HYPROM system should be run operationally in order to increase the accuracy of NWP through the atmosphere-hydrology feedback mechanisms.

Consortium web site updates; Consortium outreach

In 2016, the Institute of Hydrometeorology and Seismology of Montenegro (IHMS) launched the Consortium web site (seecop.meteo.co.me). With the assistance of all SEECOP members, the web site will be regularly updated with news, events and documents related to the Consortium. The web site will therefore be a place to promote the SEECOP activities. In addition, the model data exchange will also be performed on the web server through a protected ftp server.

As a continuous task, the promotion of SEECOP will be performed through media news and social networks, as well as through active collaboration with the European Working Group on Limited-Area Modelling (EWGLAM) and the EUMETNET's Coordination – Short-Range Numerical Weather Prediction (C-SRNWP) programme and participation in their activities.

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APPENDIX

NMMB model

The NCEP's Nonhydrostatic Multiscale Model on the B grid (NMMB) (Janjic, 2005; Janjic and Black, 2007; Janjic et al., 2011) has been designed for a broad range of spatial and temporal scales and follows the general modelling philosophy of the NCEP's WRF NMM grid-point dynamical core (Janjic et al., 2001; Janjic, 2003). However, in contrast to the WRF NMM that uses the Arakawa E grid, the NMMB was reformulated for the Arakawa B grid. The NMMB uses the regular latitude-longitude grid for the global domain, and rotated latitude-longitude grid in regional applications. The nonhydrostatic component of the model dynamics is introduced through an add–on module so that it can be turned on or off depending on the resolution.

In the model, the "isotropic" finite-volume horizontal differencing is employed that conserves a variety of basic and derived dynamical and quadratic quantities and preserves some important properties of differential operators. The second-order energy and enstrophy conserving scheme is used for horizontal advection of momentum, but the fourth-order scheme that turned out to be the best in nonlinear tests (Janjic et al., 2011) is available as an option, too. The conservation of energy and enstrophy by the second-order scheme, and the experimentally demonstrated control over the nonlinear energy cascade by the fourth-order scheme, improve the accuracy of the nonlinear dynamics of the model on all scales, and render the model suitable for extended integrations without excessive dissipation.

Conservative polar boundary conditions are specified in the global limit. The polar filter selectively reduces tendencies of the wave components of the basic dynamical variables that would otherwise propagate faster in the zonal direction than the fastest wave propagating in the meridional direction.

In the vertical, the hybrid pressure-sigma coordinate is used (Simmons and Burridge, 1981; Eckerman, 2009). The forward-backward scheme (Janjic, 1979) is employed for horizontally propagating fast waves, and an implicit scheme is used for vertically propagating sound waves.

A slightly off-centred Adams-Bashforth scheme is applied for non-split horizontal advection of the basic dynamical variables and for the Coriolis force (Janjic et al., 2001; Janjic, 2003). Instead of being slightly unstable, due to off-centring, the scheme becomes weakly dissipative. Even though the instability of the second-order Adams-Bashforth scheme is very weak, and can be tolerated in practice, the weakly damping off-centred scheme is preferred, since, strictly speaking, unstable schemes do not converge. Even though the off-centred scheme is formally of the first-order accuracy, the actual magnitude of its truncation error remains close to that of the second-order Adams-Bashforth scheme due to very small off-centring.

On the B/E semi-staggered grids the advection time step can only be about twice longer than the forward-backward adjustment time step because longer time steps can be used for the adjustment terms than on the C grid. So the Adams-Bashforth scheme for advection with the same time step as that used for the adjustment terms costs the same as a two-step iterative scheme with twice longer time step. Moreover, since there is no time splitting, there is no need for iterating the adjustment terms, and the short time steps reduce the time stepping errors. So, the non-iterative, non-split Adams-Bashforth scheme offers significant savings, and at the same time its short time step reduces numerical errors.

In order to eliminate the computational stability problems due to thin vertical layers, the Crank-Nicholson scheme is used to compute the contributions of vertical advection. As a compromise between the requirements for computational affordability and accuracy, a fast Eulerian conservative and positive definite scheme was developed for model tracers (Janjic et al., 2009). Conservative monotonization is applied in order to control over-steepening within the conservative and positive definite tracer advection step.

A variety of physical parameterizations have been coupled to the model. This variety will be further extended within the NOAA Environmental Modelling System (NEMS). The standard operational, and thoroughly tested in NWP and regional climate applications physical package includes the nonsingular Mellor-Yamada-Janjic (MYJ) level 2.5 turbulence closure for the treatment of turbulence in the planetary boundary layer (PBL) and in the free atmosphere (Janjic, 2001), the surface layer scheme based on the Monin-Obukhov similarity theory (Monin and Obukhov, 1954) with viscous sub-layer over land and water (Zilitinkevich, 1965; Janjic, 1994), the NCEP NOAH land surface model (Ek et al., 2003) or the LISS model by Janjic (Vukovic et al., 2010), the GFDL long-wave and shortwave radiation (Fels and Schwarzkopf, 1975; Lacis and Hansen, 1974), the Ferrier grid-scale clouds and microphysics (Ferrier et al., 2002), the Betts-Miller-Janjic convection scheme (Betts, 1986; Betts and Miller, 1986; Janjic, 1994, 2000). The lateral diffusion is formulated following the Smagorinsky nonlinear approach (Janjic, 1990). Additionally, the RRTM radiation (Mlawer et al., 1997) with aerosol capability has been coupled to the NMMB model.

As can be seen from the brief model description given above, the NMMB satisfies all the requirements for regional climate research set up by SEEVCCC, and therefore represents a good choice for the driving atmospheric model of the SEEVCCC Earth modelling system. Namely,

- The NMMB model covers multiple spatial scales, from meso to global
    - It is non-hydrostatic (on the small scale end)
    - It is global (on the large scale end)
- The NMMB model is suitable for extended integrations
    - It is quadratic conservative
    - It has sufficiently accurate conservative, positive definite and monotone tracer transport
    - It allows the use of minimal non-physical dissipation
- The standard NMMB physics converges with resolution
- The NMMB radiation formulation is capable of interacting with particulate and gaseous aerosols
- The NMMB turbulence closure is physically well founded
- The NMMB moist processes (grid scale and convection) are capable of interacting with aerosols and radiation
- The NMMB model is computationally efficient and scalable

Even though the NMMB model is currently a state-of-the-art atmospheric model, its ongoing support by the NCEP and other partners will ensure that it will remain up to date. The continuous development of atmospheric models is necessary.

While model dynamics typically do not change much over time, the model physics are subject to more frequent changes. For example, the atmosphere exchanges a large portion of its energy through the Earth surface, which renders the treatment of surface processes very important.