JOINT WMO TECHNICAL PROGRESS REPORT ON THE GLOBAL DATA PROCESSING AND FORECASTING SYSTEM AND NUMERICAL WEATHER PREDICTION RESEARCH ACTIVITIES FOR 2017

Republic Hydrometeorological Service of Serbia/RHMSS

1. Summary of highlights

[Major changes in the data processing and forecasting system during the last year]

- Migration to RMDCN-New Generation. IP bandwidth is raised to 1 Mbps.
- Virtualization of network and operational servers with VMWare and QEMU
- LAN and WAN improvement
- Placement of WIS DCPC-NC Serbia portal
- Upgrade of HPC clusters
- Implementation automated system ASU-MRL for radar data from MRL-5 radar
- Installed new radar Gematronik, S-band, dual polarization on Jasterbac mountain in Southern Serbia.

2. Equipment in use

[information on the major data processing units]

	Characteristics
LAN	LAN 100/1000 Mbps, Cisco routers (series 2500, 2600) , Cisco Catalyst Switch 2950 x9, Cisco Switch 3750 x2, Cisco Switch 2970, Cisco Catalyst Switch 4500,about 300 personal computers
LAN-WAN	Alix system board with 4 GB RAM as ADSL router at 28 Main Meteorological Stations - 4 Mbps; Wireless link to SMATSA - 8 airports at Serbia and MonteNegro;Wireless link to military users; Internet connections to Hydrometeorological service of Republika Srpska and Hydrometeorological service of Montenegro;Connection to airport Banja luka (Republic of Srpska); RMDCN-NG Connection with ECMWF, DWD-Offenbach, Austro-Control-Wiena, Hydrometeorological service of Hungary-Budapest and Hydrometeorological service of Bulgaria-Sofia
MSS servers	HP ProLiant Server DL380 x2, Windows Server 2008, HP Storageworks MSA 500,Messir-Comm (Corobor)
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
Primary data storage	NetApp model FAS2240 data storage with 60 hard drives
Secondary data storage	HP EVA 4400 data storage with 36 hard drives
Operational servers	5 HP Bladeservers, C3000 Enclosure, HP P2000 G3 Storage
VMWare virtual infrastructure	3 HP Blade servers BL 460c, C3000 enclosure, VMWare vSphere environment, Veeam backup and replication, 40 VMWare virtual machines
MARS archive server	Quantum tape library with 40 ultrium 5 tapes
IMS UDCS for data from AWS and data loggers	HP Proliant DL380G5,Windows Server 2003, Microstep Unified Data Collection System, 28 AWS, 18 data loggers
Proxmox virtual infrastructure	8 HP DL 1000 multinode servers, Proxmox virtual environment, 40 KVM virtual machines

WIS-GEO.HIDMET.GOV.RS	KVM virtual machine, 1,5 GB RAM,30 GB HD, Geonetwork v2.6.4
Satellite receiving system DWDSAT/Eumetcast	HP Workstation Z400, 6 GB RAM, 500 GB HD, openSUSE 12.3, tellicast
Satellite receiving system Meos MSG ground station	2 x PC Pentium 4,2 GB RAM,80 GB HD, Red Hat Linux release 9, MEOS-MSG -Kongsberg
Antivirus Server	VMWare virtual machine,Windows Server 2008, Kaspersky Antivirus
HP rx3600 Itanium	Integrity servers based on Intel Itanium 2 dual core 64 bits processors

Table 2: Network servers

	Characteristics
WWW server	HP DL 380, 2x Intel Xeon 3GHz, 4GB RAM, 70 GB HD, Linux CentOS 4.9, Apache Web server
FTP server	VmWare virtual machine, 1,5GB RAM, 40 GB HD, CentOS4, ProFTPD server
Mail server	KVM virtual machine, 4 GB RAM, 500 GB HD, CentOS6.5, Zimbra mail server
Firewall Server	HP Z400 workstation, 16 GB, RAM 500 GB HD, PFSense firewall software, OpenVPN, IPSec

3. Data and Products from GTS in use

- SYNOP-500 (please modify according to your situation)
- …………….
- ………..……

GTS data are received through RMDCN network, satellite receiving system DWDSAT and Internet connection.

3.1. DWDSAT

Daily is received about:

- 1300 files with synop bulletins,150 files with temp bulletins, 2100 files with OPMET bulletins.That is about 80 000 received bulletins in TAC;
- 230 files with synop bulletins in BUFR code,115 files with temp bulletins in BUFR code, 3 files with climat bulletins in BUFR code. That is about 3500 received bulletins in BUFR code;
- 417 files with Wind/Temperature charts;
- 41 files with Significant Weather Charts;
- 1500 files with analytic-forecasts charts;
- 815 files with forecasts in GRIB code;
- 45 files with forecasts in BUFR code
- 10500 files with satellite pictures in HRIT;
- 3130 files with satellite pictures in LRIT

3.2. RMDCN

1. **Channel with DWD**

Daily is received about:

- 1400 files in ASCII. That is about 75 500 OPMET and GTS bulletins in TAC;

- 1000 files with bulletins in BUFR code. That is about 10 000 OPMET and GTS bulletins in BUFR code;

2. Channel with Hungary

Daily is received about:

- 300 files in ASCII. That is about 7 500 GTS bulletins in TAC

3. Channel with Austria

Daily is received about:

- 13500 OPMET bulletins in TAC;
- 3800 OPMET bulletins in BUFR

4. Channel with ECMWF

Daily is received about:

- 30 000 files with boundary conditions for NWP

3.3 Internet connection with DWD-OFFENBACH

Daily is received about:

- 160 000 bulletins in TAC;
- 1000 bulletins in BUFR

3.4 FTP server at DWD-OFFENBACH

Daily is received about:

- 126 files with boundary conditions from DWD

3.5 Message Switching System - MSS

Message switching system is based on Messir-Comm software from COROBOR and consists of two servers with automatic change - over.

The DRP & DDS MSS (Data Receiving and Processing & Data Distribution System) are providing:

- Protocol conversions capabilities;
- Data (meteo/hydro bulletins/messages) reception, storage, prioritization, routing and forwarding;
- Messages (bulletins) creation and validation;
- Routing and storage of graphical products (NWP,WAFS of different graphical formats charts,satellite, radar, scanned and other images);
- Routing and storage locally produced images;
- Messages and graphical products reply;
- Multiple addressed messaging capabilities;
- Messages rerouting;
- Local & Remote Retrieval.

Additional Specific Data Processing Tasks on DRP & DDS server are performed / supported:

- The received Data/Products classification and storage into appropriate folders;
- SYNOP, TEMP, PILOT,…, METAR data encoding into single data elements (meteorological parameters) and coding into BUFR;
- The same parameters encoding from BUFR (single or group of parameters);

- Graphical products (FAX – DFX, System Offered Specific Graphical Products – (SOSGP), Radar & Satellite Data – R&SD) coding/encoding into/from BUFR;
- NWP products coding/encoding into/from GRIB;

Required Attributes/Objects within DRP & DDS DBMS (Data Base Management System) supports

- Meteorological/Hydrological bulletin/message described by WMO No 386 & ICAO DocNo 10;
- Single Station report described by WMO or ICAO documents and Validity Time;
- Station Lists that includes Geographical Coordinates, Observing Parameters, Observing Times and Remarks;
- The time ordered encoded single Meteorological/Hydrological parameters extracted from reports (SYNOP, TEMP, PILOT, METAR);
- Image products (e.g. satellite & radar images, scanned images);
- BUFR, GRIB data/products (Bulk Data Files with Time Stamp).

3.6 Uniform Data Collection System (UDCS) and Climate Data Bases System (CLDB)

UDCS and CLDB were established as an integral part of the Integrated Meteorological System of RHMS of Serbia.

UDSC provides all necessary functions for the work and maintenance of great meteorological networks and automated and non-automated stations with manual observations. The number of stations that can be linked by one UDCS is restricted only by the communication infrastructure in use.

Data from the stations can be collected in several ways by using various communication protocols, and UDCS fully support standard WMO codes SYNOP, METAR/SPECI, CLIMAT, GRIB, BUFR, and is open for the support to the own/national codes.

4. Forecasting system

4.1 System run schedule and forecast ranges

[general structure of a prognostic system, models in operational use, run schedule, forecast ranges]
4.1 Forecasting system is based on three global models results from outer centers:

- ECMWF, IFS model
- Ensemble (51 member) from ECMWF
- DWD model
- GFS model from NCEP,

- NMMB global model which runs within RHMSS, and three regional models: NMMB-regional, WRF_NMM, ETA on different initial and boundary conditions
- NMMB regional on ECMWF BC on a ECMWF computer

4.2 Medium range forecasting system (4-10 days)

4.2.1 Data assimilation, objective analysis and initialization

4.2.1.1 In operation
[information on Data assimilation, objective analysis and initialization]

4.2.1.2 Research performed in this field

[Summary of research and development efforts in the area]
Hybrid 3D Ensemble Variational (3D-EnVar) data assimilation system is coupled with NEMS-NMMB (Janjic and Gall, 2012.). 3D-EnVar consist of LETKF (Local Ensemble Transform Kalman Filter), Hunt et. All 2007. , 3D-Var, and GSI (Grid Statistical Interpolation) observational operators. The LETKF works with 51 ensemble members, NMMB reg, 12 km resolution with multi physics within ensemble members. EnVar uses LETKF-NMMB ensemble to calculate background error in order to produce deterministic analysis on the same resolution. Boundary conditions for the ensemble members are from ECMWF's global ensemble and for deterministic model from ECMWF's IFS model. Currently, new analysis is performed on every 6h, at 00, 06, 12, 18 UTC using 3 hours assimilation window. Data assimilated 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 occulation; 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 is running in pre-operational mode since February, 2016. and some of the initial results have been shown in (Kasic 2016).

4.2.2 Model

[Model in operational use, (resolution, number of levels, time range, hydrostatic?, physics used)]

NNMB global:
240h forecasting period, initial conditions – GFS analysis 00UTC and 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 application of spherical filters around poles, non hydrostatic, geog data resolution 2m, NCEP's Gravity Wave Drag taken from GFS model, 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 (table 4.2.2.1).

NMMB regional:
120h forecasting period, initial and boundary conditions – NMMB-global (RHMS) 00 and 12 UTC, horizontal resolution 12 km, 64 sigma-p vertical levels, model top 10mb, timestep 8 sec, Euro-Atlantic domain 20W-35E and 32N-67N, non hydrostatic, geog data resolution 1m, gravity wave drag on, 2nd 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.

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:
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 sheme, GFDL shortwave and long-wave radiation schemes, Betts-Miller-Janjic convection scheme.

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 50, 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 sheme, GFDL shortwave and long-wave radiation schemes, Betts-Miller-Janjic convection scheme.

4.2.2.1 In operation

	NMMB	WRF-NMM	ETA
Domain	Global / Regional (20W-35E, 32N-67N)	Regional, Euro-Atlantic (20W-35E, 32N-63N)	Regional, Euro-Atlantic (40W-55E, 24N-70N)
BC	GFS analyses / NMMB-global	DWD / GFS	DWD
Forecasting period	240h/120h	120h/192h	120h
Start run	00UTC / 00 and 12 UTC	00 and 12 UTC	00 and 12 UTC
Horizontal resolution	0.47*0.33 degrees / 10km	10 km	26 km
Vertical resolution	64 sigma-p vertical levels	38 sigma-p vertical levels	32 eta levels
Model top	10mb	50mb	100mb
Time step	80 sec / 20 sec	30 sec	60 sec
Numerical technique	Finite differences method with application of spherical filters around poles for global run	Finite differences method	Finite differences method
Hydrostatic	NO	NO	YES
Geog data resolution	2m / 1m	30 sec	30 sec
Gravity Wave Drag	NCEP's GWD, originaly from GFS model / NO	NO	NO
Diffusion	2nd order diffusion in horizontal and vertical	2nd order diffusion in horizontal and vertical	2nd order diffusion in horizontal and vertical
PBL	Mellor-Jamada-Janjic	Mellor-Jamada-Janjic	Mellor-Jamada-Janjic
Land-surface	LISS	NOAH	NOAH
Long wave radiation	RRTM	GFDL	GFDL
Short wave radiation	RRTM	GFDL	GFDL
Convection	Betts-Miller-Janjic	Betts-Miller-Janjic	Betts-Miller-Janjic

4.2.2.2 Research performed in this field
[Summary of research and development efforts in the area]
n/a

4.2.3 Operationally available Numerical Weather Prediction Products

[brief description of variables which are outputs from the model integration]

Products in operational use from NMMB-global model:

parameters
MSLP
Total precipitation
Temp (2m, 925mb 850mb, 700mb)
Wind (10m, 925mb, 500mb, 300mb)
Relative humidity (925mb, 850mb, 700mb)
Geopotential (850mb, 700mb, 500mb, 300mb)
Snow height
Zero degrees isotherm height

Products in operational use from NMMB-regional model:

parameters
MSLP
Total precipitation
Temperature (2m, 925mb, 850mb, 500mb)
Wind (10m, 925mb, 500mb, 300mb, PV=2)
Relative humidity (925mb, 850mb, 700mb)
Geopotential (850mb, 700mb, 300mb, PV=2)
Composite radar reflectivity
PV=2 surface height (potential vorticity)
Snow height
Freezing index (850mb, 700mb, 500mb)
Synthetic satellite imagery (IR 10.8 and WV 6.2 channel)
Potential temperature (PV=2)

Products in operational use from WRF-NMM (GFS and DWD boundary conditions) model:

Parameters
MSLP
Total precipitation
Temperature (2m, 850mb, 700mb)
Relative humidity (2m, 700mb)
Wind (10m, 500mb, 300mb)
Geopotential (850mb, 700mb, 500mb, 300mb)
Snow height
Tropopause heihgt

Products in operational use from ETA model:

Parameters
Geopotential
MSLP

Temperature
Wind
Precipitation (total and convective)
Relative humidity
Convective cloud top height and depth
Total cloud cover
Frontogenetic parameter
Turbulence
Freezing level (850mb, 700mb, 500mb)

4.2.4 Operational techniques for application of NWP products *(MOS, PPM, KF, Expert Systems, etc..)*

MOS prepared at DWD is in operational use as NWP product

4.2.4.1 In operation
[brief description of automated (formalized) procedures in use for interpretation of NWP ouput]

4.2.4.2 Research performed in this field
[Summary of research and development efforts in the area]

4.2.5 Ensemble Prediction System (EPS)

4.2.5.1 In operation
[Number of runs, initial state perturbation method, perturbation of physics?] *(Describe also: time range, number of members and number of models used: their resolution, number of levels, main physics used, perturbation of physics, post-processing: calculation of indices, clustering)*

4.2.5.2 Research performed in this field
[Summary of research and development efforts in the area]

4.2.5.3 Operationally available EPS Products

[brief description of variables which are outputs from the EPS

4.3 Short-range forecasting system (0-72 hrs)

4.3.1 Data assimilation, objective analysis and initialization

4.3.1.1 In operation
[information on Data assimilation (if any), objective analysis and initialization,] *(Indicate boundary conditions used)*

4.3.1.2 Research performed in this field
[Summary of research and development efforts in the area]

Hybrid 3D Ensemble Variational (3D-EnVar) data assimilation system is coupled with NEMS-NMMB (Janjic and Gall, 2012.). 3D-EnVar consist of LETKF (Local Ensemble Transform Kalman Filter), Hunt et. All 2007. , 3D-Var, and GSI (Grid Statistical Interpolation) observational operators. The LETKF works with 51 ensemble members, NMMB reg, 4km resolution (described below as NMMB 4km) with multi physics within ensemble members. Boundary conditions for the LETKF-NMMB ensemble members are from ECMWF's global ensemble and for deterministic model from

ECMWF's IFS model. Analysis is performed on every 3h, at 00, 03, 06, 09, 12, 15, 18, and 21 UTC using 3 hours assimilation window. Data assimilated 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 occulation; 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. 72h ahead forecast is run from the analysis. A single case experiment with 3 weeks spin-off has been performed so far.

4.3.2 Model

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 sheme, GFDL shortwave and long-wave radiation schemes, Betts-Miller-Janjic convection scheme

NMMB nested:
72h forecasting period, initial and boundary conditions – NMMB-regional 00 and 12 UTC, horizontal resolution 4 km, 64 sigma-p vertical levels, model top 10mb, timestep 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 LISS land surface sheme, RRTM shortwave and long-wave radiation schemes, without convective parametrisation.

NMMB regional on ECMWF time critical application:
72h forecasting period, initial and boundary conditions – ECMWF HR 00 and 12 UTC, horizontal resolution 4 km, 64 sigma-p vertical levels, model top 10mb, timestep 8 sec, Balkan-Mediteranian domain 3E-31E and 36N-50N, non hydrostatic, geog data resolution 2m, gravity wave drag on, 2nd order diffusion in horizontal and vertical, PBL is Mellor-Jamada-Janjic with LISS land surface scheme, RRTM shortwave and long-wave radiation schemes, full non-hydrostatic equation system.

4.3.2.1 In operation

[Model in operational use, (domain, resolution, number levels, range, hydrostatic?, physics used)]

Model	WRF-NMM	NMMB nested	NMMB EC
Domain	Regional, Balkan-Adriatic (11.5E-26E, 40N-48N)	Regional, Balkan-Adriatic (11.5E-26E, 40N-48N)	Regional, Balkan-Mediteranian (3E-31E, 36N-50N)
BC	IFS	NMMB regional	IFS
Forecasting period	72 h	72h	72h
Start run	00 and 12 UTC	00 and 12 UTC	00 and 12 UTC
Horizontal resolution	4 km	4 km	4km
Vertical resolution	45 sigma-p vertical levels	64 sigma-p vertical levels	64 sigma-p vertical levels
Model top	50mb	10mb	10mb
Time step	8 sec	8 sec	8 sec
Numerical technique	Finite differences method	Finite differences method	Finite differences method

Hydrostatic	NO	NO	NO
Geog data resolution	30 sec	30 sec	30 sec
Gravity Wave Drag	NO	NO	NO
Diffusion	2nd order diffusion in horizontal and vertical	2nd order diffusion in horizontal and vertical	2Nd order diffusion in horizontal and vertical
PBL	Mellor-Jamada-Janjic	Mellor-Jamada-Janjic	Mellor-Jamada-Janjic
Land-surface	NOAH	LISS	LISS
Long wave radiation	GFDL	RRTM	RRTM
Short wave radiation	GFDL	RRTM	RRTM
Convection	Betts-Miller-Janjic	Explicit	Explicit

4.3.2.2 Research performed in this field

[Summary of research and development efforts in the area]
Ice nuclei particle number (INP) generated by mineral dust are experimentally parameterized using the Dust Regional Atmospheric Model driven by the NCEP/NMMB atmospheric model. Predicted INP maps, as well as data in digital form, are available on the daily basis from November 2017.

4.3.3 Operationally available NWP products

[brief description of variables which are outputs from the model integration]
Products in operational use form WRF-NMM (ECMWF boundary conditions) model:

Parameters
MSLP
Total precipitation
Convective precipitation
Total cloud cover
Total convective cloud cover
Cloud thickness
Temperature (2m, 850mb, 700mb)
Relative humidity (2m, 700mb)
Wind (10m, 500mb, 300mb)
Wind gust
Geopotential (850mb, 700mb, 500mb, 300mb)
Zero degrees isotherm height
Tropopause height
CAPE
Cloud water
Cloud ice
Composite radar reflectivity
Freezing index (850mb, 700mb, 500mb)

Products in operational use form NMMB nested model:

Parameters
MSLP
Total precipitation
Temperature (2m, 925mb, 850mb, 500mb, PV=2)
Relative humidity (2m, 925mb, 850mb, 700mb)
Wind (10m, 925 mb, 500mb, 300mb, PV=2)
Wind gust
Geopotential (925 mb, 850mb, 700mb, 500mb, 300mb, PV=2)
PV=2 surface height (potential vorticity)
Synthetic satellite imagery (IR 10.8 and WV 6.2 channel)
Composite radar reflectivity
Freezing index (850mb, 700mb, 500mb)

4.3.4 Operational techniques for application of NWP products

4.3.4.1 In operation
[brief description of automated (formalized) procedures in use for interpretation of NWP ouput]
(MOS, PPM, KF, Expert Systems, etc..)

4.3.4.2 Research performed in this field
[Summary of research and development efforts in the area]

4.3.5 Ensemble Prediction System

4.3.5.1 In operation
[Number of runs, initial state perturbation method, perturbation of physics?] *(Describe also: time range, number of members and number of models used: their domain, resolution, number of levels, main physics used, for post-processing: calculation of indices, clustering)*

4.3.5.2 Research performed in this field
[Summary of research and development efforts in the area]
NMMB-LETKF data assimilation system is used to create initial state for the ensemble members. System is described in 4.2.1.2 and 4.3.1.2. At this moment ensemble members are running only in data assimilation cycles (6h ahead).

4.3.5.3 Operationally available EPS Products

[brief description of variables which are outputs from the EPS

4.4 Nowcasting and Very Short-range Forecasting Systems (0-12 hrs)

4.4.1 Nowcasting system

4.4.1.1 In operation
[information on processes in operational use, as appropriate related to 4.4]
(Note: please also complete the CBS/PWS questionnaire on Nowcasting Systems and Services, 2013)

Nowcasting based on data from manual and automatic stations, rain gauges, satellite data (every 15 minutes, SAFC products), NWP products (see 4.2 and 4.3), and radar data.

Radar data available from three Gematronik radar (S-band, two are dual polarization) using Rainbow software, composite, every 5 min, with among other products usefully for nowcasting such as: hail detection, cell tracking, precipitation accumulation, etc.
Also, in using is MRL5 radar (S and X band) via ASU-MRL5 software, every 4 min, with among other products usefully for nowcasting such as: type of weather phenomena, precipitation accumulation, hail intensity, direction of movement, etc.

4.4.1.2 Research performed in this field
[Summary of research and development efforts in the area]

4.4.2 Models for Very Short-range Forecasting Systems

4.4.2.1 In operation
[information on models in operational use, as appropriate related to 4.4]
n/a
4.4.2.2 Research performed in this field
[Summary of research and development efforts in the area]
n/a

4.5 Specialized numerical predictions

[Specialized NP on sea waves, storm surge, sea ice, marine pollution transport and weathering, tropical cyclones, air pollution transport and dispersion, solar ultraviolet (UV) radiation, air quality forecasting, smoke, sand and dust, etc.]

4.5.1 Assimilation of specific data, analysis and initialization (where applicable)

4.5.1.1 In operation
[information on the major data processing steps, where applicable]

4.5.1.2 Research performed in this field
[Summary of research and development efforts in the area]

4.5.2 Specific Models (as appropriate related to 4.5)

4.5.2.1 In operation
[information on models in operational use, as appropriate related to 4.5]

DREAM dust model
In collaboration with the University of Belgrade, Dust regional atmospheric model (DREAM) (Nickovic et al., 2001; Nickovic, 2005; Perez et al., 2006) is in operational function since 2009 . http://www.seevccc.rs/?p=8 . RHMSS participate with its dust forecasts in the WMO SDS-WAS model intercomparison/validation initiative http://sds-was.aemet.es/forecast-products/dust-forecasts/compared-dust-forecasts

DREAM is a regional model designed to predict the atmospheric flow of mineral dust aerosol. DREAM solves the Euler-type equation for dust mass continuity. Wind erosion of soil in DREAM is controlled by the type of soil (soil texture), type of vegetation (land cover), soil moisture content, and surface atmospheric turbulence. Dust emission originates from model computational points recognized as dust productive soils. Such dust source points are defined according to the USGS (United States Geological Survey) global 1 km land cover data. Unlike most other dust models, DREAM includes a viscous sub-layer between the surface and the lowest model layer (Janjic, 1994) in order to regulate dust emission as a function of the near-surface turbulence intensity. The model parameterizes the dry particle deposition (Georgi, 1986) taking into account dependence of deposition on turbulent and Brownian diffusion, gravitational settlement, and interception and impaction on surface roughness objects. The wet deposition parameterization is based on a below-cloud scavenging by precipitation. The dust concentration is driven online as a passive tracer by the NCEP/NMME regional atmospheric model (Janjic et al, 2001).The DREAM governing equation dust concentration includes turbulent mixing, vertical and horizontal advection, and wet and dry deposition. The size distribution of the dust particles is described by eight bins with effective radii of 0.15, 0.25, 0.45, 0.78, 1.3, 2.2, 3.8, and 7.1 μm. The first four bins are considered as clay particles and the remaining four as silt particles.

Initial atmospheric conditions are updated every day and boundary values of model variables are specified every six hours using the ECMWF global model. Dust concentration is initialized by merging 24-h dust forecasts from a previous day and the MACC/MODIS daily dust analyses, using a dynamic relaxation assimilation approach. Figure 1 shows an example of the operational forecast of dust load.

Currently, several other organizations are using DREAM as an operational prognostic model:

- Tel Aviv University
- Turkish Meteorological Institute
- Egyptian Meteorological Authority
- Barcelona Supercomputing Centre
- Meteorological Service of Montenegro

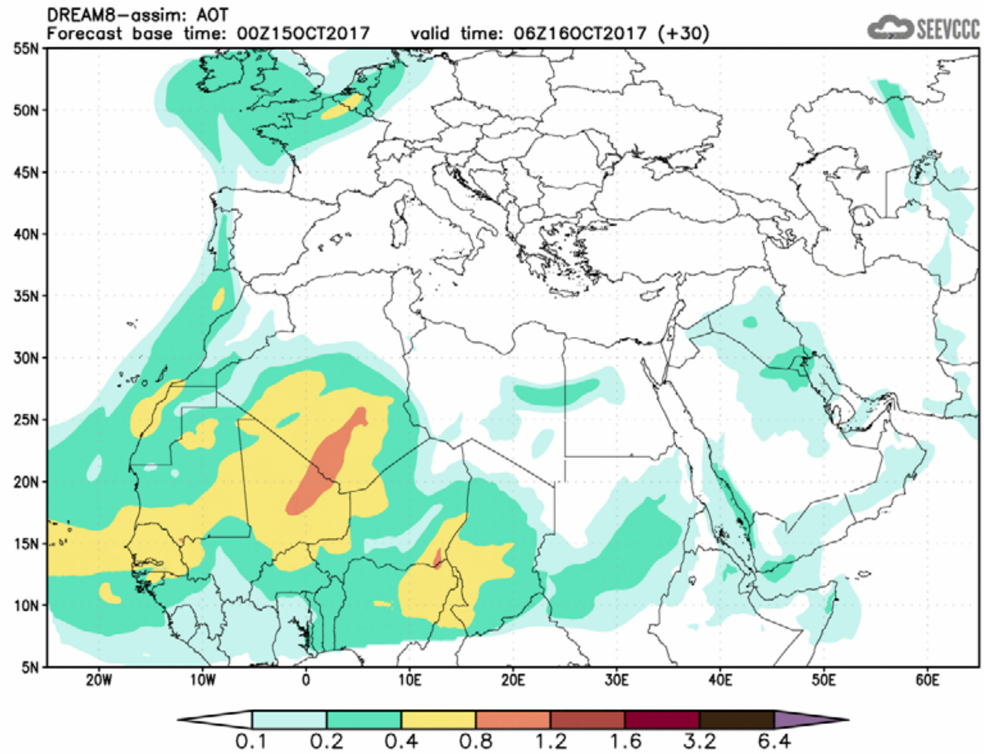


Figure 1. DREAM operational forecast of dust load http://www.seevccc.rs/?p=8

Schematic summary of the DREAM dust model

Domain	Northern Africa, Europe and Middle East
Initial data time	00 UTC
Forecast range	72 h
Atmospheric driver	NCEP/NMM regional model
Prognostic variables	Dust concentration, Aerosol optical depth, wet and dry deposition, dust vertical profiles for selected lidar observation sites
Vertical coordinate	Hybrid sigma-p, 50 layers
Vertical discretization	Finite-difference, xx vertical layers
Horizontal grid	421 x 461 points (0.025° x 0.025°) on a rotated latitude/longitude grid;

	Arakawa-E grid, see Fig. 1.
Horiz. discretization	Finite-difference, second order mass conserving positive-definite advection)
Geo-spatial data	USGS 1-km topography and landcover; STATSGO 5km soil textures
Parameterization	Dust emission based on a viscous sub-layer model (Janjic 1994; Nickovic et al, 2001, 2004; Shao et al, 1998); Dry deposition (Georgi 1988); Wet deposition – simple precipitation scavenging; interactive feedback dust-radiation scheme (Perez et al, 2006)
Data assimilation	Dynamic relaxation assimilation of the MACC dust analysis based on AOD MODIS

RHMSS has adapted the aerosol transport model DREAM (see references above) to function as a model for simulating transport of aerosol from a severe nuclear accident at a nuclear power plant. This exercise (ConvEx-3 - 2017) organized by IAEA and WMO (*WMO-TD/N° 778, Regional and Global Arrangements for the provision of transport model products for Environmental Emergency Response*) has been performed in June 2017 to simulate radiation transport conditions from the Paks Nuclear Power Plant (Central Hungary). Serbia accepted the Invitation to WMO members to participate in the ConvEx-3 (2017) experiment and has performed it succesfully. Below is an example of graphical representation of the experiment results submitted in the report to WMO and IAEA.

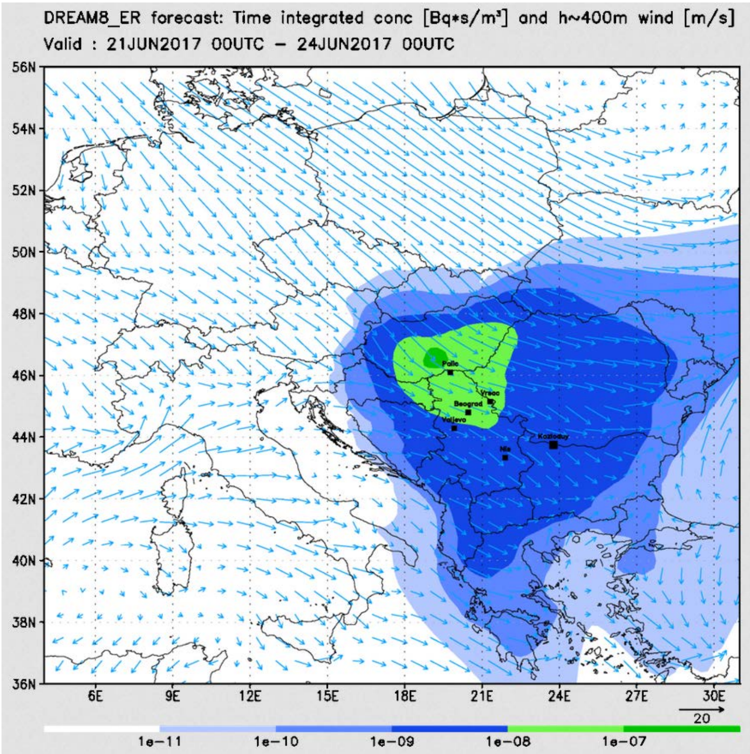


Figure 2. Radiative plume of the simulated nuclear experiment performed by DREAM model adapted for a point source aerosol release.

CropSyst Model

CROPSYST (Cropping Systems Simulation Model) is used for the simulation of growth, development and forecast of maize yield.

Application of CROPSYST model requires daily values of meteorological parameters (maximum and minimum air temperature, precipitation amount, relative humidity, solar radiation, medium wind speed), along with the data about crop (date of sowing, the thermal needs of the crop to achieve a certain phase of development etc.) and information about soil (hydropedological soil parameters used from soil sampling data and from Hydropedological studies).

.

Within RHMSS CropSyst model is operatively applied for 15 selected locations on territory of Serbia for maize crop. During period April-October daily processing of current meteorological data is constantly performed, as well as analysis of model outputs and agro-meteorological conditions necessary for the growth and development of medium-late corn hybrid.

Based on the selected products obtained by the use of the Cropsyst Model, ten days bulletin is prepared on a regular basis during period Jun - September.

The values of actual and potential evapotranspiration, daily precipitation sum and water content in soil up to 1m depth, as well as cumulative values of actual and potential evapotranspiration and daily precipitation sum since the beginning of the vegetation until data of simulation, are presented in the bulletin in a graphic form.

Besides the analyses of actual weather condition, different weather impacts on the corn growth and yield on the approaching vegetation period are estimated. Different weather conditions (dry and hot, normal, wet and cold) according to historical climate data have been defined for the period from 1st July to 31-th August. CropSyst model outputs, such as cumulative values of actual and potential evapotranspiration, precipitation sum and date of beginning pheno phases (forecasted part of the simulation), are given in the Bulletin.

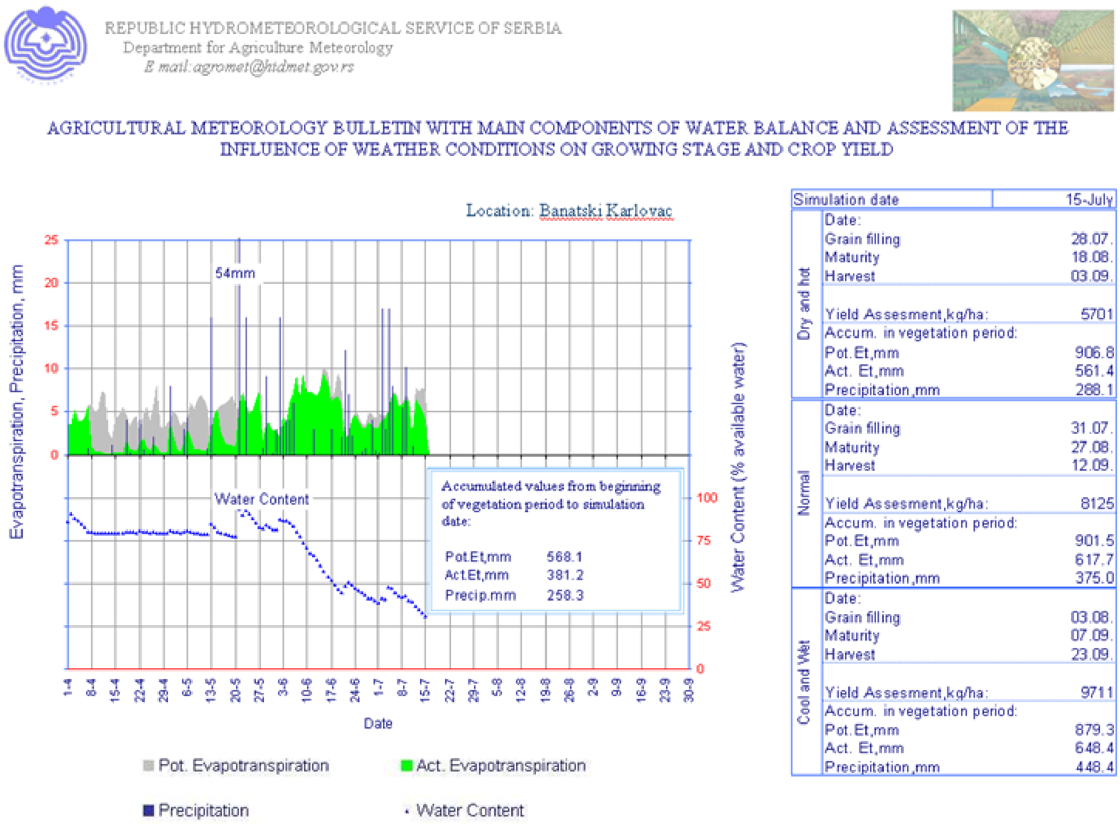


Figure 3. Example of CROPSYST model Bulletin

4.5.2.2 Research performed in this field

[Summary of research and development efforts in the area]

The DREAM model has been used to develop a parameterization on the occurance of ice due to dust-cloud interactions (Nickovic et al, 2016). The product of the parameterization is predicted ice nuclei concentration - the fraction of the aerosol capable to glaciate overcooled cloud water. Recent observational evicence (Cziczo et al, 2014),show that mineral dust particles, found as residues in the ice crystals are prevailing (61%). During ice nucleation by dust only a small number of dust particlesare sufficient to trigger the cloud glaciation process at temperatures lower than -20°C. Since dust in small concentrations is easily lifted to the mid- and upper troposphere, the cold clouds formed due to dust can be found at locations distant from dust deserts, therefore dust appears as the major ice nuclei (IN) in cold and mixed clouds and consequently affect cloud formation and eventually precipitation. This is the first model which operationally predicts IN concentration - the parameter indicating locations of cold cloud formatin dur to dust aerosol. Our current developments are an initial step toward operational use of the parameterized ice nuclei concentration in a microphysical scheme of our NWP system in order to further improve accuracy of weather prediction.

In addition, we continued to validate the model against different obsesrvaional data. DREAM is one of nine models participating in the WMO dust model intercomparison experiment (http://sds-was.aemet.es/) in which the model daily dust forecasts are is compared against the aerosol optical depth observed by the WMO global sun-photometer WMO AERONET associated network. We also performed validation of the predicted IN concentration against cold cloud observations done by cloud radars and lidars (Nickovic et al, 2016).

Over the last reporting period, the ice nucletion component of the DREAM has been extensively tested within several European projects using measurement data from their field experiments:

- "INUIT" project of the Deutsche Forschungsgesellschaft (DFG), data from the Jungfraujoch aerosol observation site in Switzerland
- GEO-CRADLE project of the EU: Coordinating and integRating state-of-the-art Earth Observation Activities in the regions of North Africa, Middle East, and Balkans and Developing Links with GEO related initiatives towards GEOSS; the observation field experiment data in Crete performed in 2006

Extensive validation model data on IN against observations lead to improved DREAM IN forecast.

HYPROM hydrology prognostic model

HYPROM model is a component of the RHMSS Earth model system. As a state of the art fully dynamic hydrometeorological system (with included full dynamic governing equations), it could be used both for short-range forecasts (flash floods), and for climate prediction (such as floodplains mapping, flows of large slow river watersheds etc.). Being fully dynamic, HYPROM does not need model calibration, as most of other hydrology modles do. Soil types are integrated into the system in order to properly treat the infiltration part of the hydrology process. We have performed and extensively tested the model capabilities to predict flash flood conditions in several extreme precipitation cases (Pejanovic et al, 2016). Resent experiments demonstrate that the model is capable to predict maxima of flash waves 7-10 hours in advance. Model developments follows the increased need of the community for better prediction of extreme hydrometeorological events, which number increases over last decades as a consequence of the climate change.

4.5.3 Specific products operationally available

[brief description of variables which are outputs from the model integration]

The output from the dust model is:

- Dust concentration,
- Dust aerosol optical depth,
- Wet and dry deposition,
- Dust vertical profiles for selected lidar observation sites
- ice nucleation concentration due to dust

The frequency of the output is 6 hours, the length of the daily forecasts is 72 hours.

4.5.4 Operational techniques for application of specialized numerical prediction products *(MOS, PPM, KF, Expert Systems, etc..)* (as appropriate related to 4.5)

4.5.4.1 In operation

"[brief description of automated (formalized) procedures in use for interpretation of specialized NP output]"

4.5.4.2 Research performed in this field

[Summary of research and development efforts in the area]

4.5.5 Probabilistic predictions (where applicable)

4.5.5.1 In operation

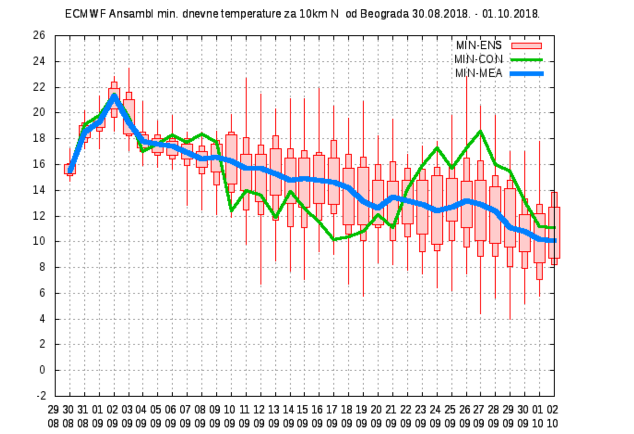
"[Number of runs, initial state perturbation method etc.]" *(Describe also: time range, number of members and number of models used: their resolution, main physics used etc.)*

4.5.5.2 Research performed in this field

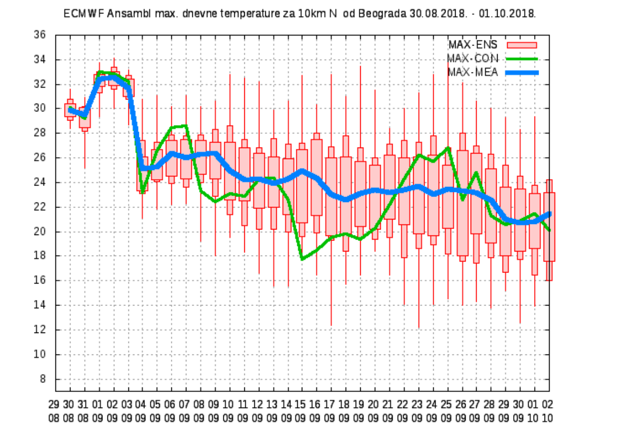
[Summary of research and development efforts in the area]

4.5.5.3 Operationally available probabilistic prediction products

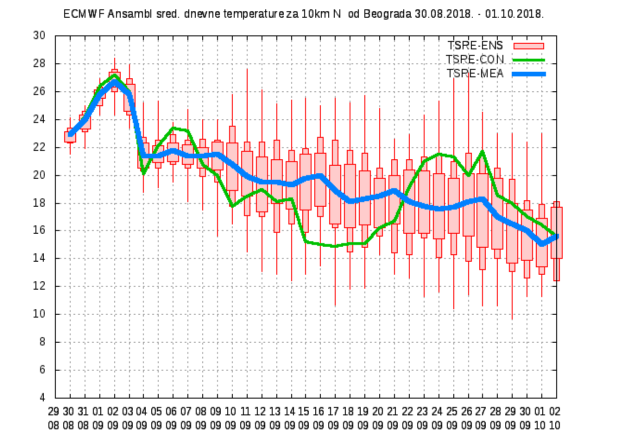
"[brief description of variables which are outputs from probabilistic prediction techniques]"
Development of ENSmeteograms for Minimum, Maximum, Mean daily temperature and Daily precipitation for 32 days ahead for several cities in Serbia based on the ECMWF IFS model.



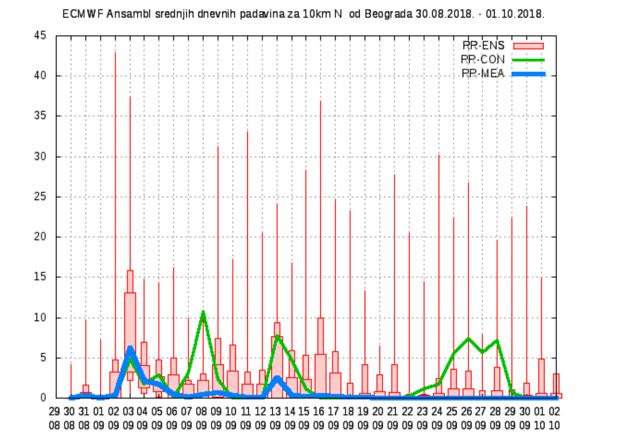
ENSmeteogram for Minimum temperature for Belgrade for 32 days ahead



ENSmeteogram for Maximum Temperature for Belgrade for 32 days ahead



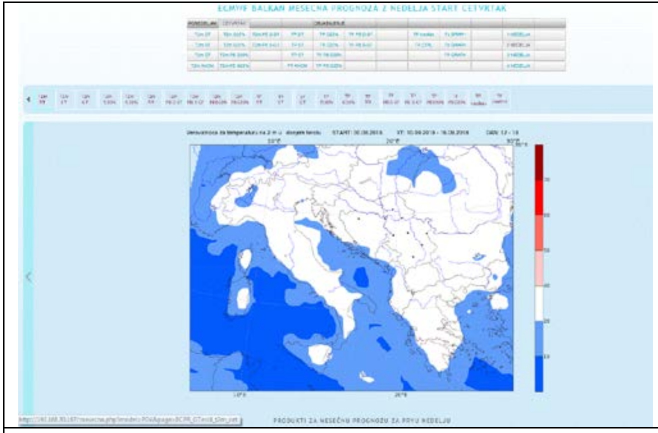
ENSmeteogram for Daily mean Temperature for Belgrade for 32 days ahead



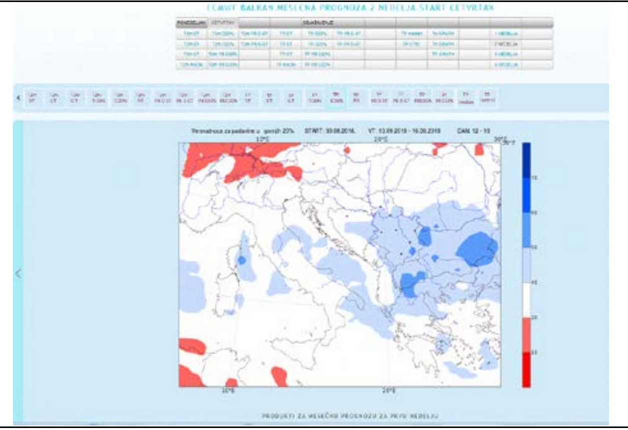
ENSmeteogram for daily precipitation sums for Belgrade for 32 days ahead

Figure 4. ENSmeteograms for Minimum, Maximum, Mean daily temperature and Daily precipitation for 32 days ahead for several cities in Serbia based on the ECMWF IFS model.

Development of the software for the presentation of the percentiles (20%, 33%, 50%, 66%, 80%) and anomalies of the weekly mean temperatures and weekly sum precipitations for 4 weeks ahead which are available on the RHMSS Intranet. Above mentioned products are based on the ECMWF IFS Model and produced by our Service twice per week (Tuesday and Friday).



Weekly mean temperatures by percentiles and anomalies for 4 weeks ahead for SEE Europe domain



Weekly precipitation sums by percentiles and anomalies for 4 weeks ahead for SEE Europe domain

Figure 5. Anomalies and percentiles of the weekly mean temperatures and weekly sum precipitations for 4 weeks ahead

Table 3. Probabilities for the different categories of meteorological parameters by days for 32 days ahead for several cities in Serbia.

BEOGRAD

Verovatnoca pojave meteoroloskih parametara

	Minimalna temperatura (C)						Maksimalna temperatura (C)						Sr. dnevne kolicine padavina (mm)					
Simbol / Datum	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
30.08.	0	0	12	88	0	0	0	0	0	0	56	44	84	14	2	0	0	0
31.08.	0	0	0	98	2	0	0	0	0	0	72	28	32	48	18	2	0	0
01.09.	0	0	0	90	10	0	0	0	0	0	4	96	88	6	4	2	0	0
02.09.	0	0	0	20	80	0	0	0	0	0	2	98	44	14	26	4	6	6
03.09.	0	0	0	64	36	0	0	0	0	0	8	92	2	8	32	22	28	8
04.09.	0	0	0	96	4	0	0	0	0	48	50	2	4	14	58	20	4	0
05.09.	0	0	0	100	0	0	0	0	0	40	58	2	6	24	54	12	4	0
06.09.	0	0	0	100	0	0	0	0	0	28	68	4	24	38	22	14	2	0
07.09.	0	0	8	92	0	0	0	0	0	32	66	2	38	30	22	10	0	0
08.09.	0	0	10	90	0	0	0	0	2	24	72	2	30	32	28	8	2	0
09.09.	0	0	20	80	0	0	0	0	2	36	56	6	20	34	26	8	6	6
10.09.	0	0	28	72	0	0	0	0	2	48	40	10	32	26	22	10	10	0
11.09.	0	4	40	50	6	0	0	0	8	44	42	6	38	28	20	8	2	4
12.09.	0	6	40	50	4	0	0	0	12	42	42	4	38	34	12	6	8	2
13.09.	0	8	36	54	2	0	0	0	12	54	34	0	30	8	26	20	12	4
14.09.	0	8	48	40	4	0	0	0	14	54	28	4	30	30	20	18	2	0
15.09.	0	4	48	44	4	0	0	0	18	32	46	4	40	24	18	14	2	2
16.09.	0	6	44	48	2	0	0	0	14	42	42	2	36	24	10	14	10	6
17.09.	0	4	46	48	2	0	0	4	20	40	30	6	36	30	14	16	2	2
18.09.	0	10	56	34	0	0	0	0	24	46	26	4	46	36	4	10	2	2
19.09.	0	12	50	36	2	0	0	0	18	48	32	2	46	28	10	10	6	0
20.09.	0	8	68	24	0	0	0	0	20	50	28	2	54	22	18	6	0	0
21.09.	0	12	64	24	0	0	0	0	16	50	34	0	50	24	10	12	2	2
22.09.	0	10	66	24	0	0	0	2	20	44	34	0	64	22	10	2	0	2
23.09.	0	14	62	24	0	0	0	4	20	40	34	2	64	20	10	4	2	0
24.09.	0	26	46	28	0	0	0	4	26	34	30	6	56	20	8	6	6	4
25.09.	0	10	64	26	0	0	0	2	20	44	28	6	60	12	18	6	2	2
26.09.	0	14	60	24	2	0	0	4	22	32	36	6	60	12	20	6	0	2
27.09.	2	20	52	22	4	0	0	4	22	36	36	2	58	28	10	4	0	0
28.09.	0	24	58	18	0	0	0	4	26	40	30	0	60	16	12	4	8	0
29.09.	2	34	52	12	0	0	0	0	40	40	20	0	62	22	4	10	0	2
30.09.	0	46	46	8	0	0	0	4	42	44	10	0	56	24	16	0	2	2
01.10.	0	46	50	4	0	0	0	4	38	48	10	0	58	18	8	10	6	0

NAPOMENA:

1. Minimalna temperatura niza od 5 C
2. Minimalna temperatura visa od 5 C i niza od 10 C
3. Minimalna temperatura visa od 10 C i niza od 15 C
4. Minimalna temperatura visa od 15 C i niza od 20 C
5. Minimalna temperatura visa od 20 C i niza od 25 C
6. Minimalna temperatura visa od 25 C
7. Maksimalna temperatura niza od 10 C
8. Maksimalna temperatura visa od 10 C i niza od 15 C
9. Maksimalna temperatura visa od 15 C i niza od 20 C
10. Maksimalna temperatura visa od 20 C i niza od 25 C
11. Maksimalna temperatura visa od 25 C i niza od 30 C
12. Maksimalna temperatura visa od 30 C
13. Suvo
14. Srednja dnevna kolicina padavina veca ili jednaka 0.1 mm i manja od 1 mm
15. Srednja dnevna kolicina padavina veca od 1 mm i manja od 5 mm
16. Srednja dnevna kolicina padavina veca od 5 mm i manja od 10 mm
17. Srednja dnevna kolicina padavina veca od 10 mm i manja od 20 mm
18. Srednja dnevna kolicina padavina veca od 20 mm

The general purpose Operational textual Bulletin for weekly mean minimum, weekly mean maximum, weakly mean daily temperature and weekly precipitation sums.

The special purpose Operational textual Bulletin with probabilistic forecast of meteorological parameters (anomaly of weakly mean temperature, weekly sums) for 4 weeks ahead for big river catchments in domain of Central Europe and West Balkans (Danube, Sava, Tisa, Drina, Morava).

4.6 Extended range forecasts (ERF) *(10 days to 30 days)*

4.6.1 Models

4.6.1.1 In operation

[information on Models and Ensemble System in operational use, as appropriate related to 4.6]

4.6.1 Model

ECMWF IFS coupled global atmosphere-ocean model 00 UTC every Monday-Thursday, variable horizontal resolution, 91 model levels, with the 51 members. All detailed information could be found on the www.ecmwf.int

4.6.1.1 In operation

[Model in operational use, (domain, resolution, number levels, range, hydrostatic?, physics used)]

	ECMWF IFS
Domain	Global
Forecasting period	1 month ahead
Start run	Every Monday and Thursday on 00 UTC
Horizontal resolution	Variable 18/36 km
Vertical resolution	91 vertical levels
Ensemble	51 members

Meteorological parameters in operational use

Parameters
Minimum, Maximum temperature on 2m (daily, weekly mean)
Total precipitation (daily, weekly mean and monthly mean)

Statistical model by analogy of the RT500/1000 hPa field of the North Hemisphere for the historical period 1949-2014, twice per month.

	Statistical model by analogy RT500/1000 hPa
Domain	Global
Forecasting period	1 month ahead
Start run	Twice per month (at the end and in the middle of the month

Parameters
Minimum, Maximum and daily mean temperature on 2m (daily, weekly mean)
Total precipitation

(daily, weekly mean and monthly mean)
Weather phenomenon (thunderstorms, snow, rain, …)

The ECMWF monthly forecasting system data has been used to issue weekly and monthly forecast for South Eastern Europe region on weekly basis. Beside basic parameters such as maximal and minimal temperature and precipitation anomalies and probabilities, SPI forecast is also produced. Statistical downscaling is used to match observed and forecast values over territory of Serbia as shown in Figure 6.

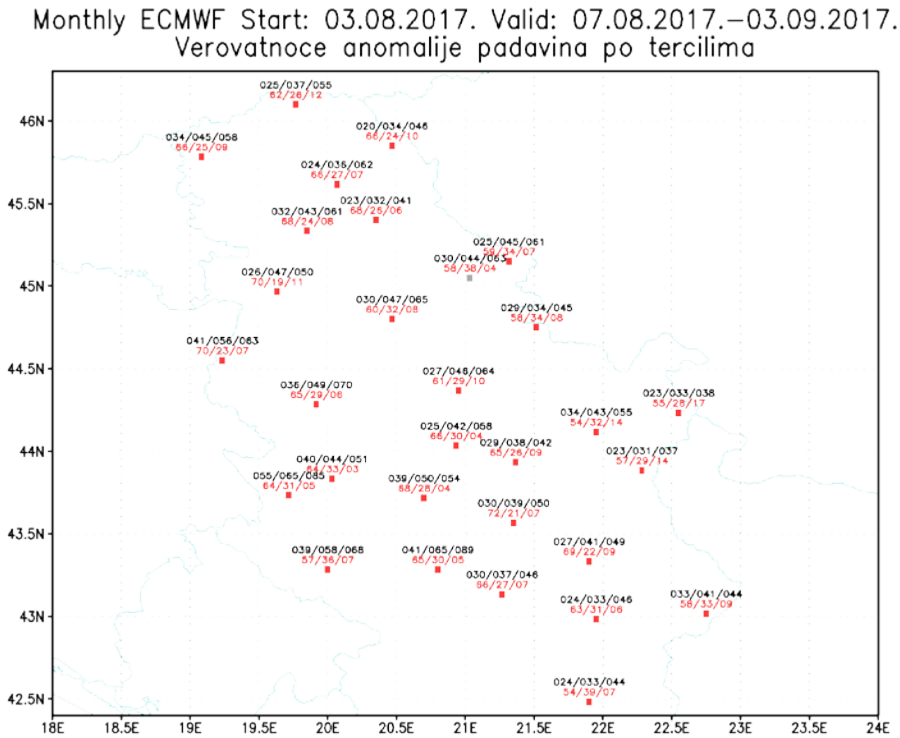


Figure 6: Forecast probabilities for equiprobable tercile categories (red) and observed climatological terciles (black)

4.6.1.2 Research performed in this field
[Summary of research and development efforts in the area]

Dynamical downscaling of monthly ECMWF monthly forecast is performed using a NMMB-regional model. Model has been tested over period of 30 years, on 8km and 15km horizontal resolution with ERA-INTERIM and ERA40 initial and boundary conditions. Encouraging results for daily rainfall rate forecast are obtained, as shown in Figure 7. below for spring season (March-April-May).

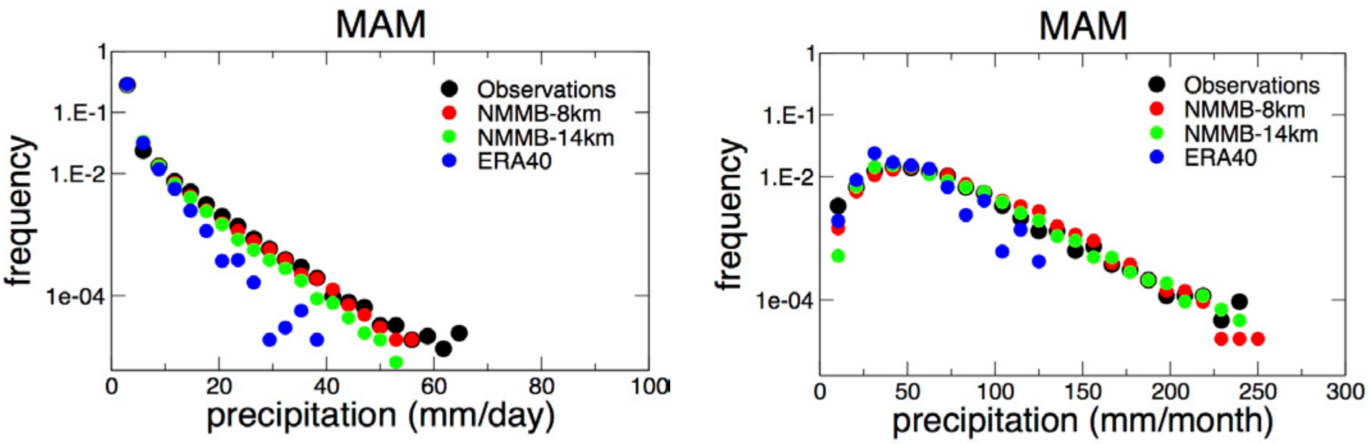


Figure 7. Verification of NMMB Climate Projections for Daily and Monthly Precipitation

RHMSS is performing the project 'Mineral Aerosol Impacts to Sub-seasonal to Seasonal Predictability (MASP)' as a Special ECMWF Project (2017-2019) with the major objective to investigate the impact of aerosol direct and indirect effects on the predictability of a prognostic model at sub-seasonal and seasonal (S2S) scales using the global NMMB model integrated with the dust aerosol model DREAM and with an ocean model. The major focus of the project is examining effects of the aerosol within the period from 3 weeks and longer. RHMSS has currently managed online coupling the dust DREAM and the global atmospheric NMMB components of the modeling system. We also performed one-month model run (April 2018), assuming for the time being dust as a passive tracer (not yet linking it with the cloud physics part of NMMB). The major dust patterns has been generally well reproduced when compared against the global CAMS dust analysis and against regional DREAM SDS-WAS prediction. In the fortcoming period, two-way dust-cloud interction will be included.

4.6.2 Operationally available NWP model and EPS ERF **products**

[brief description of variables which are outputs from the model integration]

4.7 Long range forecasts (LRF) ***(30 days up to two years)***

4.7.1 In operation

[Describe: Models, Coupled? (1 tier, 2 tiers), Ensemble Systems, Methodology and Products]

The system is based on dynamical downscaling of ECMWF seasonal forecast, using a regional atmosphere-ocean coupled model (RCM-SEEVCCC). The forecast consists of 48 ensemble members and is issued ones per month between 15th and 20th of a current month. The forecast run is for 7 months. Horizontal resolution is 0.25 degrees for atmospheric model and 0.2 degrees for the ocean model. Atmosphere is resolved with 32 and ocean with 21 vertical levels. The connection between the two components is through a coupler that performs the exchange of atmospheric surface fluxes and SST after every atmospheric physical time step. Exchanged fluxes are calculated using the atmospheric component and are used directly, without any additional parametrization.

ECMWF Sys4 seasonal forecasting model, Ocean-Atmosphere coupled Global model with 51 ensemble members. All detailed information could be found on the www.ecmwf.int

	ECMWF Sys4
Domain	Global
Forecasting period	7 months ahead

Start run	First day of the month on 00 UTC
Horizontal resolution	~ 80 km
Vertical resolution	91 vertical levels
Ensemble	51 members
Hindcast period	1981-2010

4.7.2 Research performed in this field

[Summary of research and development efforts in the area]

Preparation activities for the transition on the ECMWF Sys5, verification on monthly level and adaptation of the RCM-SEEVCCC for dynamical downscaling.

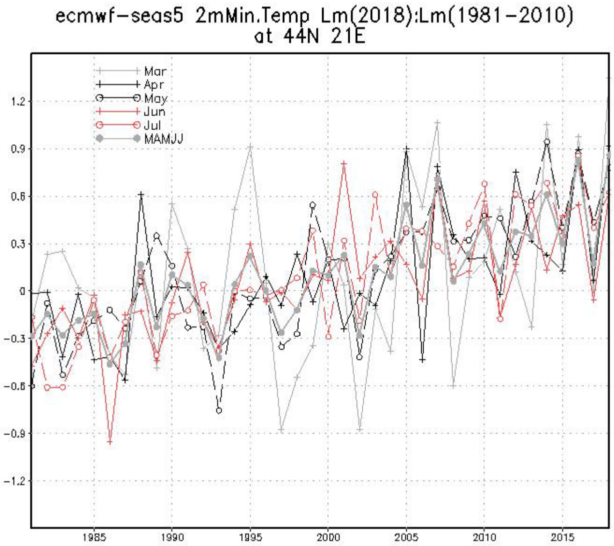


Figure 8. Verification of ECMFW Sys5 Seasonal Forecast for 2 meter minimum air temperature

4.7.2 Operationally available EPS LRF products

[brief description of variables which are outputs from the model integration]

Regional atmosphere-ocean coupled model (RCM-SEEVCCC) products

Monthly precipitation
Monthly precipitation anomaly
Monthly temperature
Monthly temperature anomaly
Seasonal precipitation
Seasonal precipitation anomaly
Seasonal temperature
Seasonal temperature anomaly
Monthly Mediterranean sea surface temperature

Parameters prepared by post processing of the ECMWF Sys4 outputs.

Parameters
Minimum, Maximum and Daily mean temperature on 2m

(monthly mean, seasonal mean)
Minimum, Maximum and Daily mean temperature anomalies on 2m (monthly mean, seasonal mean)
Total precipitation (monthly mean, seasonal mean)
Total precipitation anomalies (monthly mean, seasonal mean)

5. Verification of prognostic products

5.1 [annual verification summary to be inserted here]

Verification of medium and short range forecasting system

Verification of three operational regional numerical weather prediction models (see 4.2.2.1 and 4.3.2.1) with different initial and boundary conditions (IFS, GME/ICON, GFS) started in 2014. IFS from ECMWF is taken as a reference model. Meteorological variables verified every six hours are mean sea level pressure, temperature at 2m and wind speed at 10m. 24 hour precipitation amount and occurrence with different precipitation thresholds are verified too. Only the 00 UTC run is considered, up to 72 hours of forecast.
For model intercomparison, verification is done over the largest possible common domain of the participating models (11.5E-26E, 40N-48N). 39 synoptic stations are chosen, 33 land and 6 mountain stations. Half of them are in Serbia. Observations are from BUFR data and the nearest grid point to the station is used. Height adjustment is not used.
Calculated scores are mean error (bias), mean absolute error, root mean square error and scores from contingency table like bias score, probability of detection, false alarm ratio, critical success index (threat score), equitable threat score... Stratification of the results is annual, seasonal, monthly, time of the day (diurnal cycle) and with the lead time.

Verification of medium and short range forecasting system

Verification of three operational regional numerical weather prediction models (see 4.2.2.1 and 4.3.2.1) with different initial and boundary conditions (IFS, GME/ICON, GFS) started in 2014. IFS from ECMWF is taken as a reference model. Meteorological variables verified every six hours are mean sea level pressure, temperature at 2m and wind speed at 10m. 24 hour precipitation amount and occurrence with different precipitation thresholds are verified too. Only the 00 UTC run is considered, up to 72 hours of forecast.
For model intercomparison, verification is done over the largest possible common domain of the participating models (11.5E-26E, 40N-48N). 39 synoptic stations are chosen, 33 land and 6 mountain stations. Half of them are in Serbia. Observations are from BUFR data and the nearest grid point to the station is used. Height adjustment is not used.
Calculated scores are mean error (bias), mean absolute error, root mean square error and scores from contingency table like bias score, probability of detection, false alarm ratio, critical success index (threat score), equitable threat score... Stratification of the results is annual, seasonal, monthly, time of the day (diurnal cycle) and with the lead time.

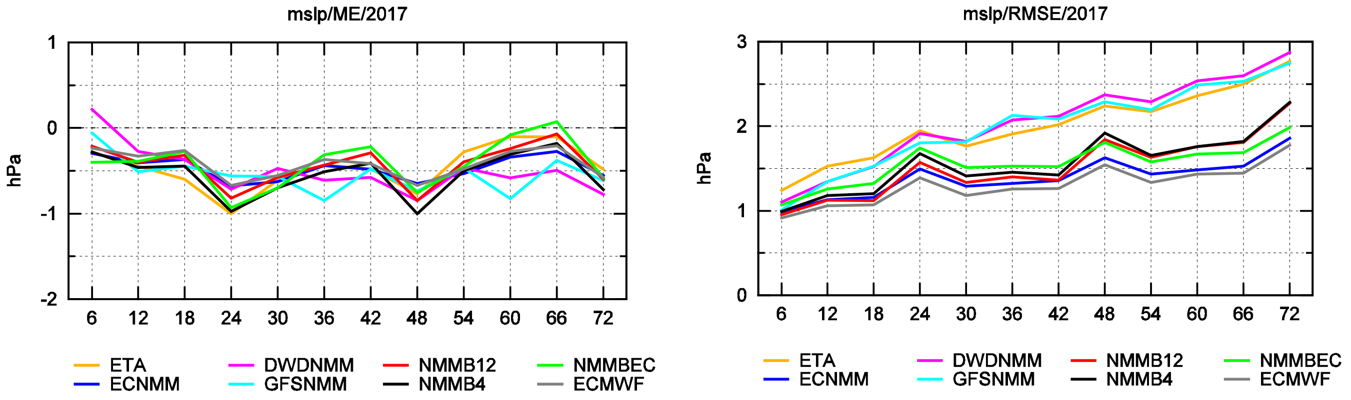


Figure 9-10. ME and RMSE of mean sea level pressure forecast as function of lead time for 2017.

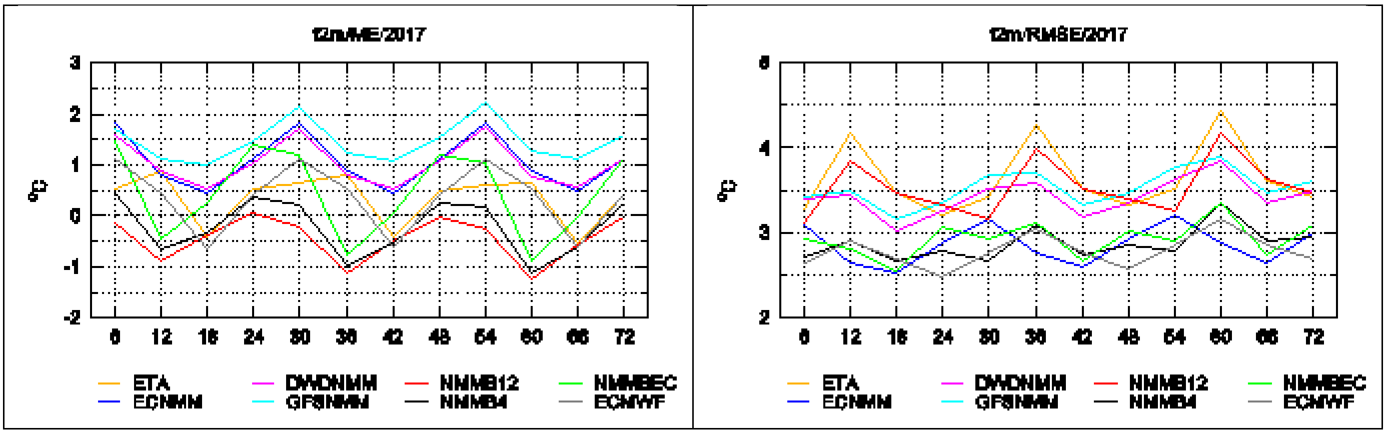


Figure 11-12. ME and RMSE of 2 meter temperature forecast as function of lead time for 2017

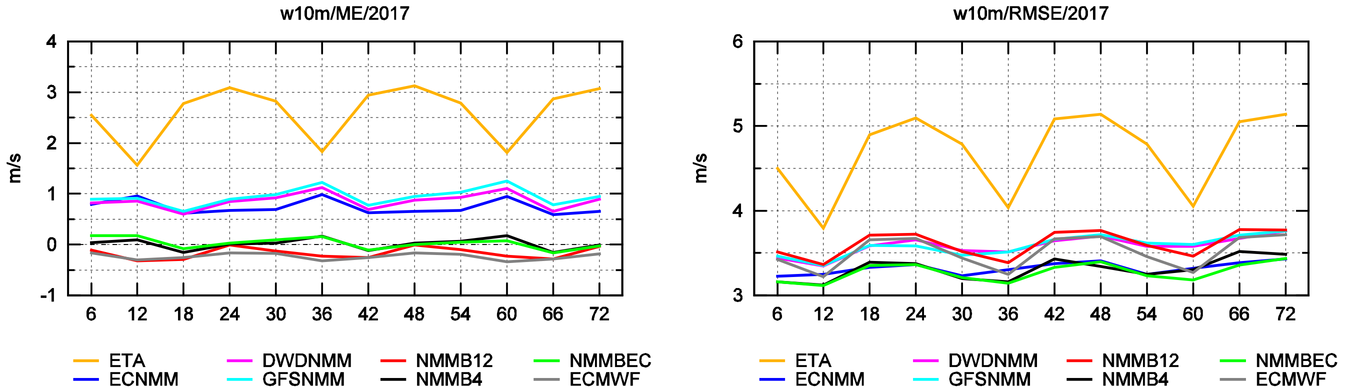


Figure 13-14. ME and RMSE of 10 meter wind speed forecast as function of lead time for 2017

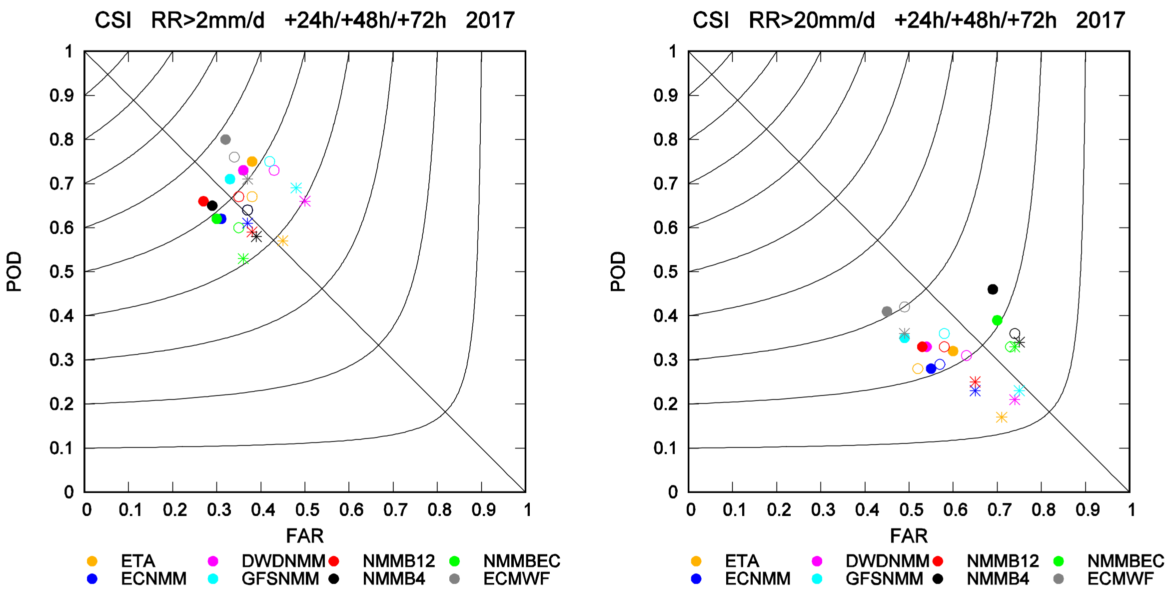


Figure 15-16. CSI contours as a function of FAR and POD of 24h precipitation forecast for 2017.

Monthly forecast verification

Statistical model by analogy outputs of the daily mean temperature on 2 m for Belgrade-Karadjordjev Park (13274) for 2015 compared to the referent climatology 1981-2010 on the daily level.

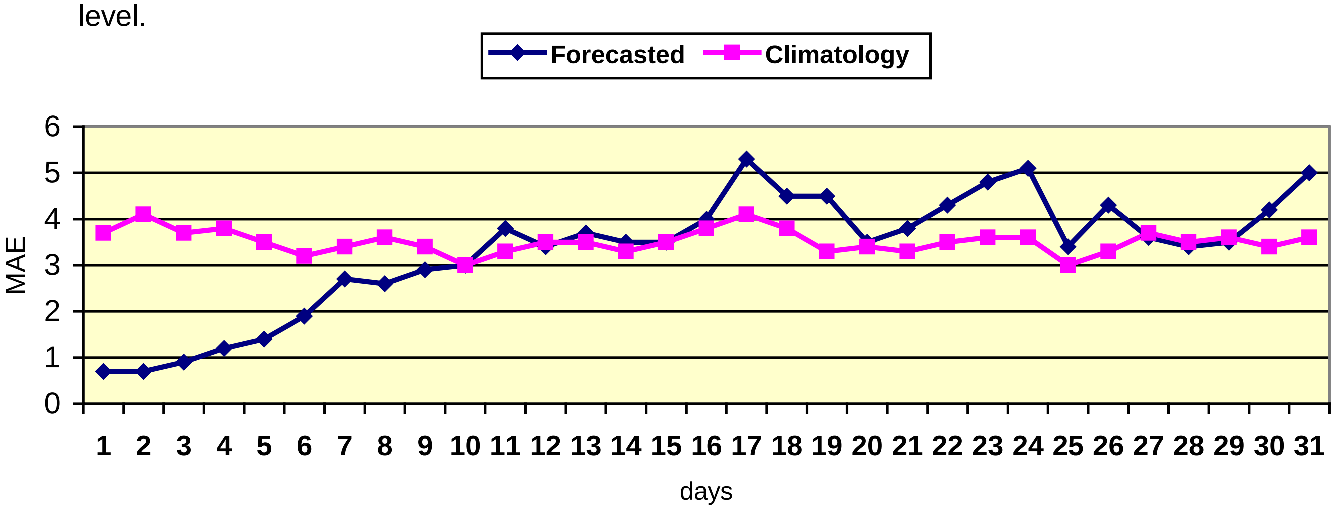


Figure 17. MAE of the statistical model by analogy of the daily mean temperature on 2m for Beograd for 2015. Comparison to the referent climatology (1981-2010) on the daily level. MAE of the model analogy outputs and referent climatology are compared to the observed values of the temperature.

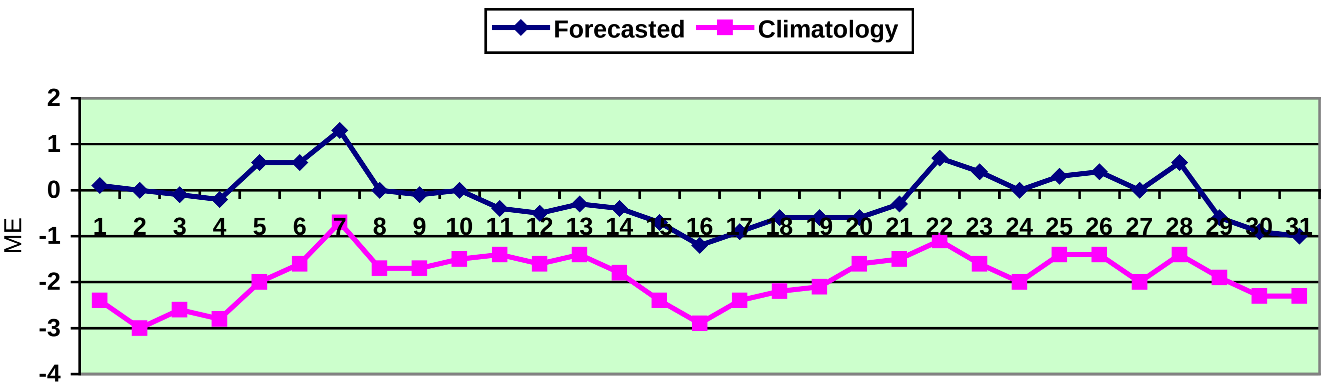


Figure 18. ME of the statistical model by analogy of the daily mean temperature on 2m for Belgrade for 2015. Comparison to the referent climatology (1981-2010) on the daily level. ME of the model analogy outputs and referent climatology are compared to the observed values of the temperature.

Long range forecast verification (RCM-SEEVCCC regional climate model)

LRF is verified in hindcast mode, as well as in real-time operating mode. Since December 2013 limited hindcast dataset is available.

Hindcast mode

Given limited computer resources, there is only one hindcast set produced starting from December, covering period from 1981-2010. There are 15 ensemble members. Forecast is 7 months in length. Verification is done at stations, using BUFR station dataset, for four different lead times. Forecast period is one month.

Produced scores and diagrams:

1. Reliability diagram and frequency histogram
2. ROC curve and ROC score
3. Talagrand diagram (rank histogram)

The below scores and diagrams are produced for equiprobable tercile categories for two parameters: monthly temperature and monthly precipitation.

Example of diagrams and scores calculated for both RCM-SEEVCCC and ECMWF seasonal forecast (hindcast mode):

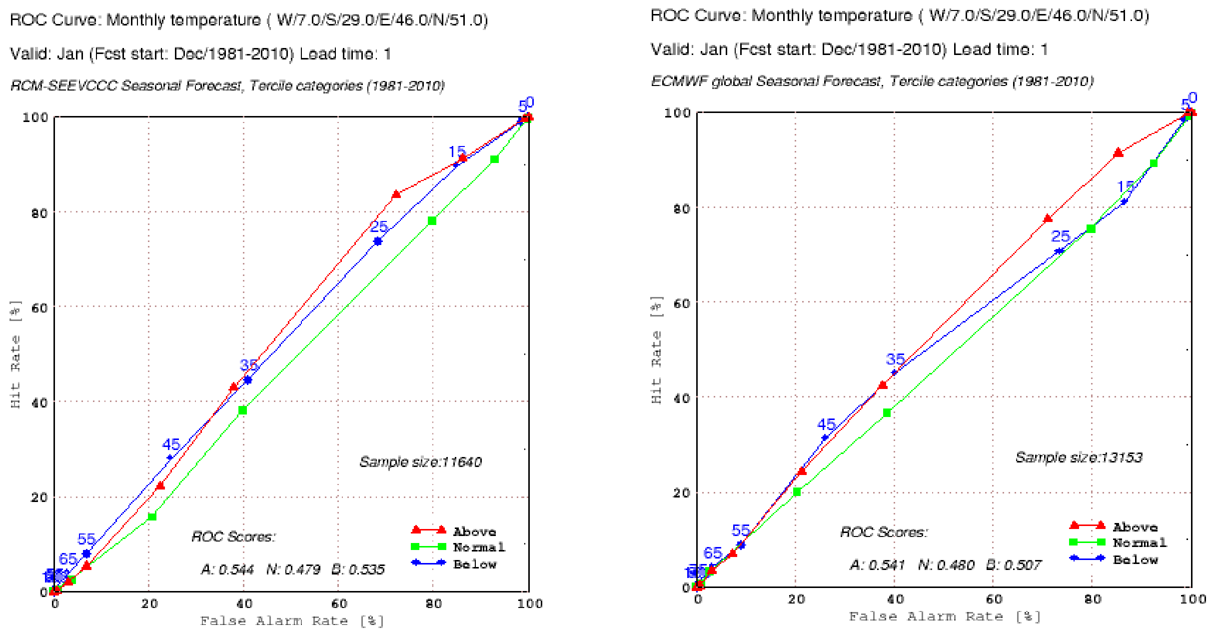


Figure 19. ROC curve, Lead time: 1 month, Parameter: temperature, Period: 1981-2010

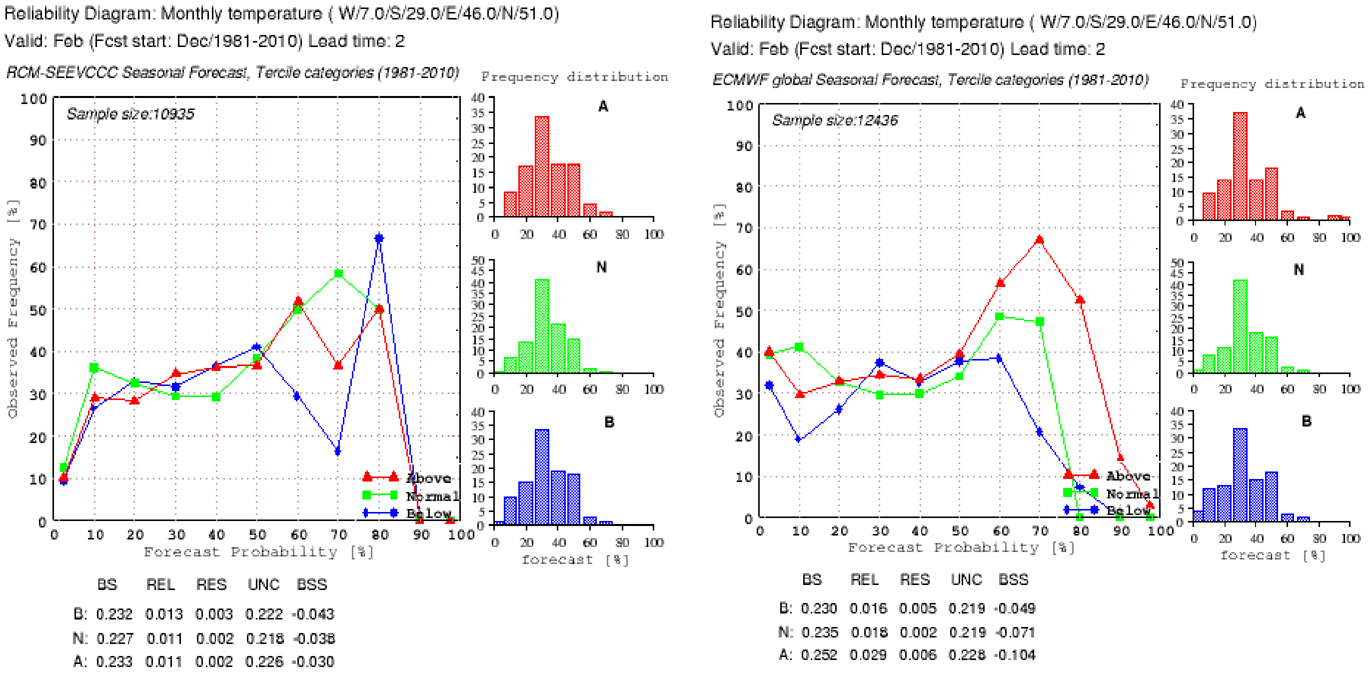


Figure 20. Reliability diagrams, Lead time: 2 months, parameter: temperature, period 1981-2010

Real-time monitoring of forecast performance

Regular monitoring of real-time seasonal forecast is done every month. Produced scores over few different regions are:

- root mean square error - RMSE
- mean absolute error - MAE
- pearson correlation coefficient (spatial) - CC
- mean error (bias) - BIAS

Above scores are derived for ensemble mean of monthly temperature and precipitation, for four lead times.

Four maps are available, showing comparison between observations and climatology, observations and forecasts, valid forecast and past year forecast, and forecast and climatology.

Example of operational forecast verification diagrams

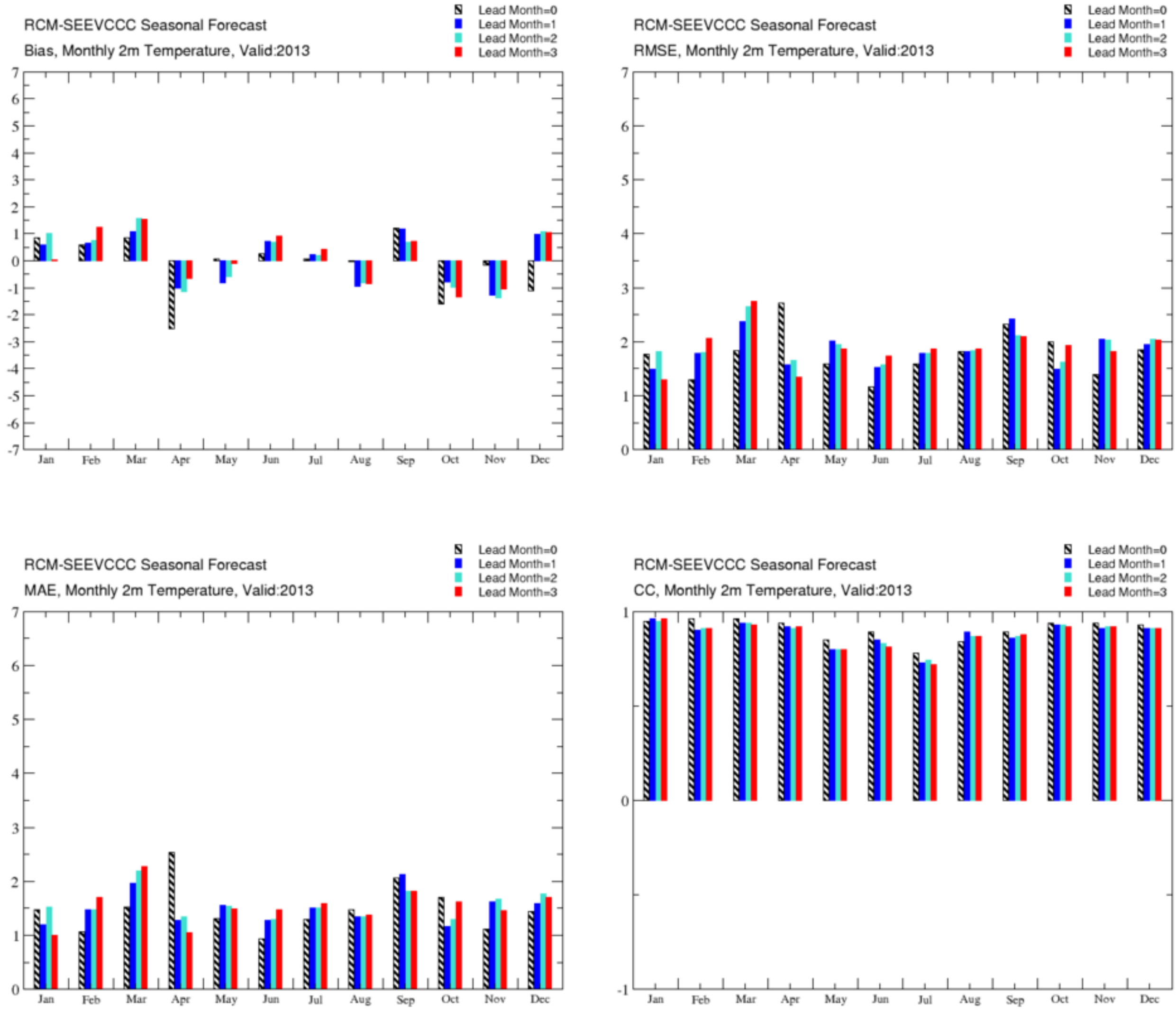


Figure 21. a. bias b. root mean square error c. mean absolute error d. Pearson correlation coefficient

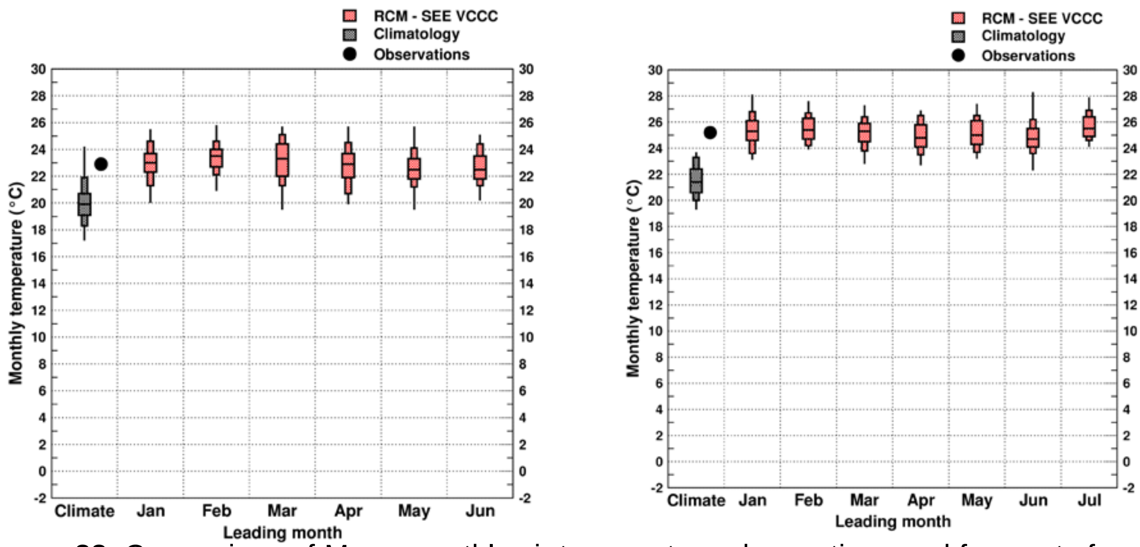


Figure 22. Comparison of Mean monthly air temperature observations and forecasts from different leading months for June (left) and July (right) 2012, period with extreme drought

Example of operational forecast verification maps

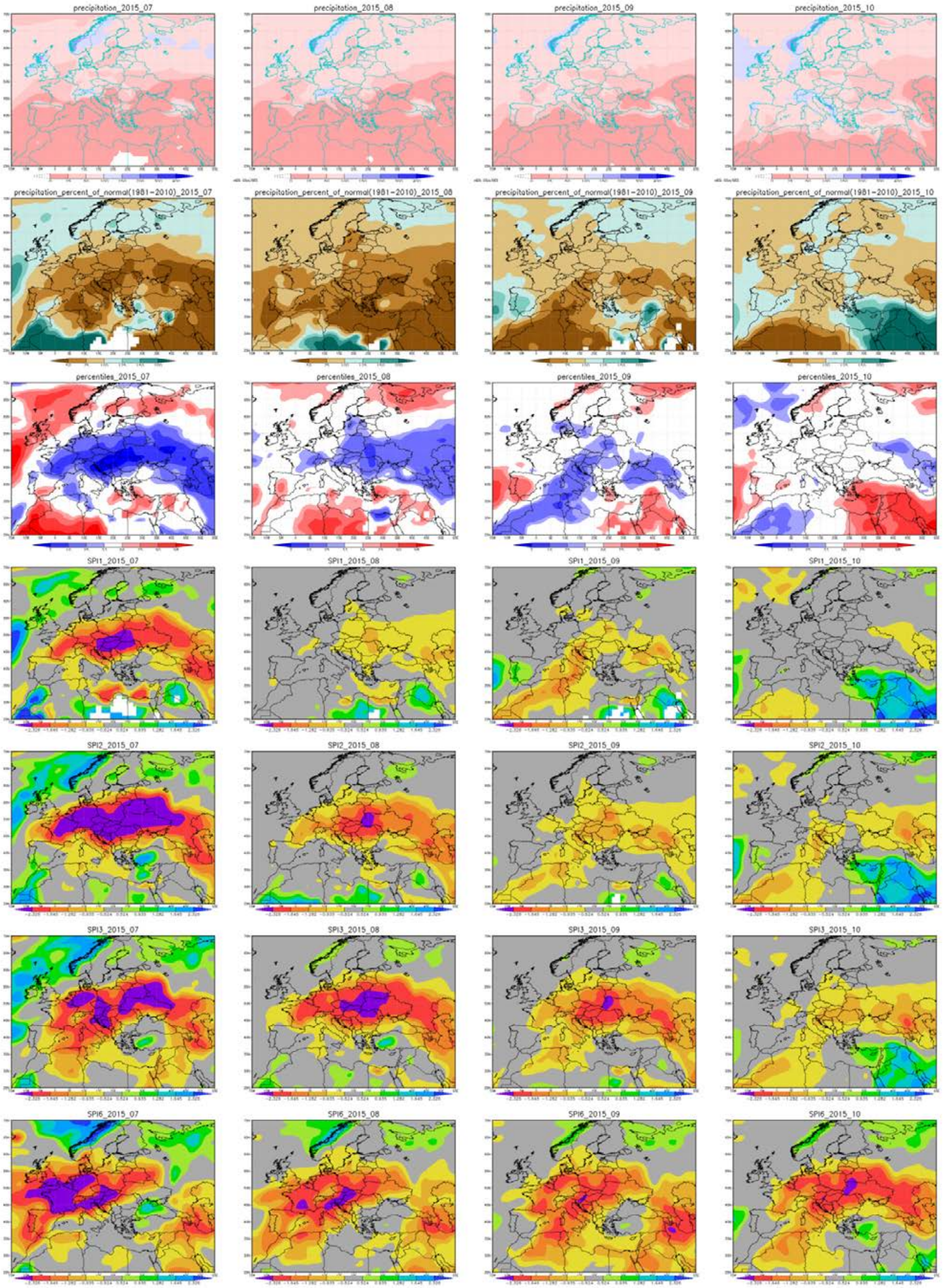


Figure 23. Observed (GPCC data) and forecasted (ECMWF seasonal forecast) of percent of normal and percentiles for accumulated precipitation; and SPI1, SPI2, SPI3 and SPI6 index.

Example of HYPROM forecast

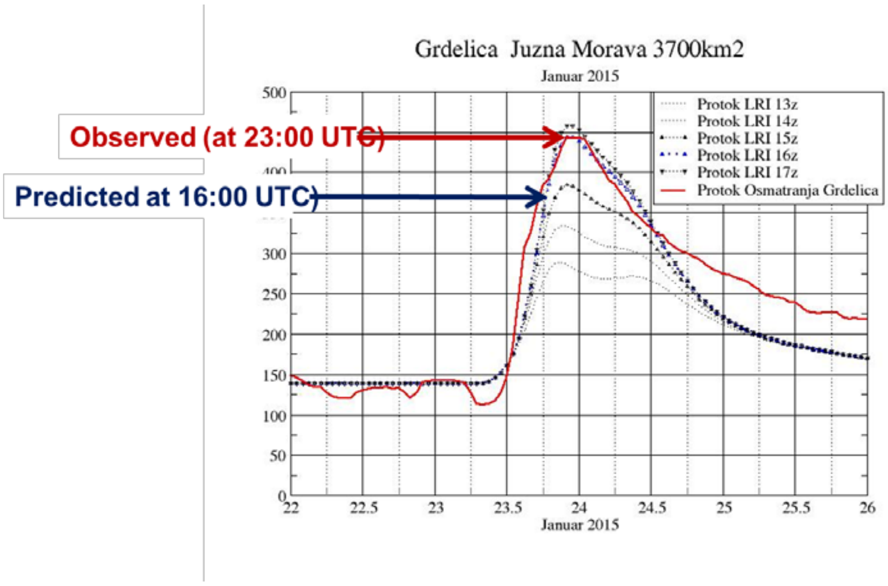


Figure 24. Case-study of flash flood in southern Serbia when HYPROM fed by the radar precipitations data demonstrates capability to predict maxima of flash waves 7-10 hours in advance

5.2 Research performed in this field

6. Plans for the future *(next 4 years)*

6.1 Development of the GDPFS

6.1.1 [major changes in the Operational DPFS which are expected in the next year]
The first pre-operational run is expected with the application of data assimilation method with numerical model as well as development of new projections of regional climate changes using regional climate model SEEVCCC/RHMSS and new IPCC scenarios (application of the Representative Concentration Pathway-RCP8.5 scenario in the first phase).

6.1.2 [major changes in the Operational DPFS which are envisaged within the next 4 years]

Within the next 4 years, among the expected changes is to significantly improve hydrometeorological early warning system on the occurrence of meteorological, climate and hydrological extreme events and disasters establishing seamless prediction weather and climate system in RHMSS

6.2 Planned research Activities in NWP, Nowcasting, Long-range Forecasting and Specialized Numerical Predictions

"[Summary of planned research and development efforts in NWP, Nowcasting, LRF and Specialized Numerical Predictions for the next 4 years]"
According to the Program for meteorological and hydrological development and research activities, the priorities have been determined for the development and research activities in the field of numerical weather forecast (NWP), climate forecast (LRF), climate modeling and climate change projections. The abovementioned Program for development and research activities includes: improvement of the Nowcasting system (0 to 2 hours) and very short-term weather forecasts (up to 12 hours) through development of specialized data bases and through assimilation of radar and satellite data WITH numerical models, improvement of short-term (12 – 72 hours) and medium-term weather forecast (72 – 240 hours), further development of climate monitoring and climate forecast system and improvement of verification system of forecast products, development of regional climate model of new generation and scenarios of regional climate changes using new

IPCC scenarios, further development of Subregional South East European virtual climate change center and Republic Hydrometeorolgical service as its host in accordance with the binding operational and highly recommended development and research functions established in the Guideline on GDPFS for WMO RA VI RCC Network (Manual on the Global Data-Processing and Forecasting System/GDPFS, WMO No. 485).

6.2.1 Planned Research Activities in NWP

On-line nesting of ~1km domain inside of NMMB 4km described under 4.3.2.

Inclusion of data assimilation system described in sections 4.3.1.2. into operational and extending this system to 4DEnVar. Since LETKF algorithm already has 4D extension included and tested this is very achievable within period of 1 year.

6.2.2 Planned Research Activities in Nowcasting

We plan to implement and use for nowcasting high resolution, very short-term numerical model with included radar and satellite data, and also to improve observation network (automatic station, rain gauges, …)

Among planned activities is to develop program for pre-processing and quality control of data as well as to establish specialized, weather limited (for the period of the last 30 years) base of available data for the needs of operational functioning and development of Nowcasting system and very short-term weather forecasts.

We also plan to improve COROBOR software for visualisation meteorological data and using in nowcasting process.

6.2.3 Planned Research Activities in Long-range Forecasting

Among planned activities is to improve climate forecast system (for the period up to seven months ahead) through development and operational use of sub-system monthly forecasts and methodology for the creation of probabilistic forecasts, as well as development of monthly and seasonal model climatology for the territory of Serbia and the region of South-East Europe.

Moreover, it is planned to develop regional climate model of new generation based on the regional numerical NMMB model and its adaption on long-term integration and development of climate monthly, seasonal, annual and decadal forecasts and climate change scenarios for the 21 century for the region of South-East Europe.

Among the future activities is the further development of Subregional South East Virtual Climate Change Center through further development of Earth Modeling system and its subsystems linking regional climate model with DREAM numerical model for forecast of sand transport, volcano dust, aerosols and with HYPROM hydrological numerical model.

6.2.4 Planned Research Activities in Specialized Numerical Predictions

It is also planned to further develop and meet the requirements of the most relevant end users (aviation, hydrology, civil protection and disaster risk management, transport, energy, public health) for Nowcasting system along with short-term forecasts as well as to experimentally issue specialized forecasts and warnings.

6.2.4.1 Planned Research Activities in developing components of the Earth Modelling System

We plan to continue with integrating different components of the Earth natural system affecting the weather in which NMMB plays a role of a module that will drive other components of the natural system, such as aerosol, ocean, soil and hydrology, and including feedback mechanisms whenever possible and useful (e.g. interactions between aerosol-atmosphere, ocean-atmosphere, aerosol-ocean, etc).

6.2.4.1 Planned Research Activities in Aerosol Modelling

Dust mineralogy. A global 1km data set on 8 minerals (+ phosphorus) in arid soils *(Nickovic et al, 2012)is developed* as a first step in providing input to dust model for predicting transport of mineral fractions in dust. Our plans are to include prediction based on the DREAM dust model of selected minerals which contribute to dust impact to weather and environment, including: direct effects due to dust-radiation interaction; indirect effects due to dust-cloud interactions; predicting environmental effects due to Fe deposition in dust into ocean. Special emphasis will be to parameterize generation of ice nuclei process caused by dust aerosol, as a precondition for improvement in treating the physics of cold clouds in the NMMB model.

Aerosol-cloud interactions. Parameterization of ice nucleation concentration due to dust will be used as an input parameter in the Thompsom dust-friendly cloud microphysics scheme in order to further improve prediction of cloud and precipitation formation.
In the following period, we plan to introduce marine aerosol as the ice nucleation agent, playing an important role in formation of the cold mixed clouds. Marine aerosol concentrations will be parameterized using the sea-salt aerosol version of DREAM combined with satellite data on the sea chlorophyll. This modelling component should fill the formation of cloud ice in the lower troposphere, currently missing in the dust-cloud interaction system.

High resolution dust modelling. In the next 4 year period, we plan to improve the treatment of dust sources in DREAM model using the satellite observations (land cover; NDVI), so replacing the current static geospatial data for dust sources specification.

We perform currently experiments addressed to West Asian haboob cases in which the DREAM model has been downscaled to several km and in which 'hot spots' of dust has been introduced as dust sources. The objective of these experiments is to demonstrate that coarser resolution of most of today's dust models cannot appropriately simulate mesoscale-to-local scale dust storms. A report to the WMO SDS-WAS dust project will be published.

Assimilation of dust-related observations. Initial experiences to use the ECMWF analyses based on MODIS satellite data as input for the DREAM model assimilation based on dynamic relaxation is positive, showing increase of the model performances. In the next period, we plan to develop an assimilation system that combines satellite data from different sources (MSG, MODIS, CALIPSO) combined with data on vertical aerosol profiling (lidars, ceilometers).

Other aerosols. In addition to dust, we plan to add to the DREAM aerosol modelling system other major aerosol components: sea salt aerosol, biomass burning and pollution/sulphates.

6.2.4.2 Planned Research Activities in integrated atmospheric-hydrology modelling

The focus of this research will be coupling of the HYPROM hydrology model (Nickovic et al, 2010) with the NMMB atmospheric model HYPROM is based on fully dynamic governing equations. It is developed to simulate overland watershed hydrology processes based on advanced numerical and parameterization methods. The model solves grid point-based shallow water equations with numerical approaches that include an efficient explicit time-differencing scheme for the gravity wave components and a physically based and numerically stable implicit scheme for the friction slope terms. NMMB precipitation forecasts will be used to provide water sources for HYPROM. HYPROM will be tested for the major Serbian and Western Balkan watersheds and its capabilities to provide operational forecast for hydrology conditions will be assessed (part of the SEECOP consortium).

7. References

[information on where more detailed descriptions of different components of the DPFS can be found] *(Indicate related Internet Web sites also)*

[information on where more detailed descriptions of different components of the DPFS can be found] *(Indicate related Internet Web sites also)*

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