Integrated Earth Modeling System at Hydrometeorological Service of Serbia

Republic Hydrometeorological Service of Serbia
(host of the South East European Virtual Climate Change Center – SEEVCCC and WIS DCPC-Belgrade)

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Topics

- Integrated Earth Modeling System
  - NMM-B unified atmospheric model
  - HYPROM hydrology prediction model
  - DREAM dust-aerosol model
  - MIT Ocean model (not covered in this presentation)
- NWP models run operationally at RHMSS
- Climate change experiments
- Seasonal Prediction System
- HPC + scalability

Integrated Earth Modeling System (**IEMS**) at RHMSS
- Numerical models in use -

WMO RA VI-Europe RCC mandatory functions

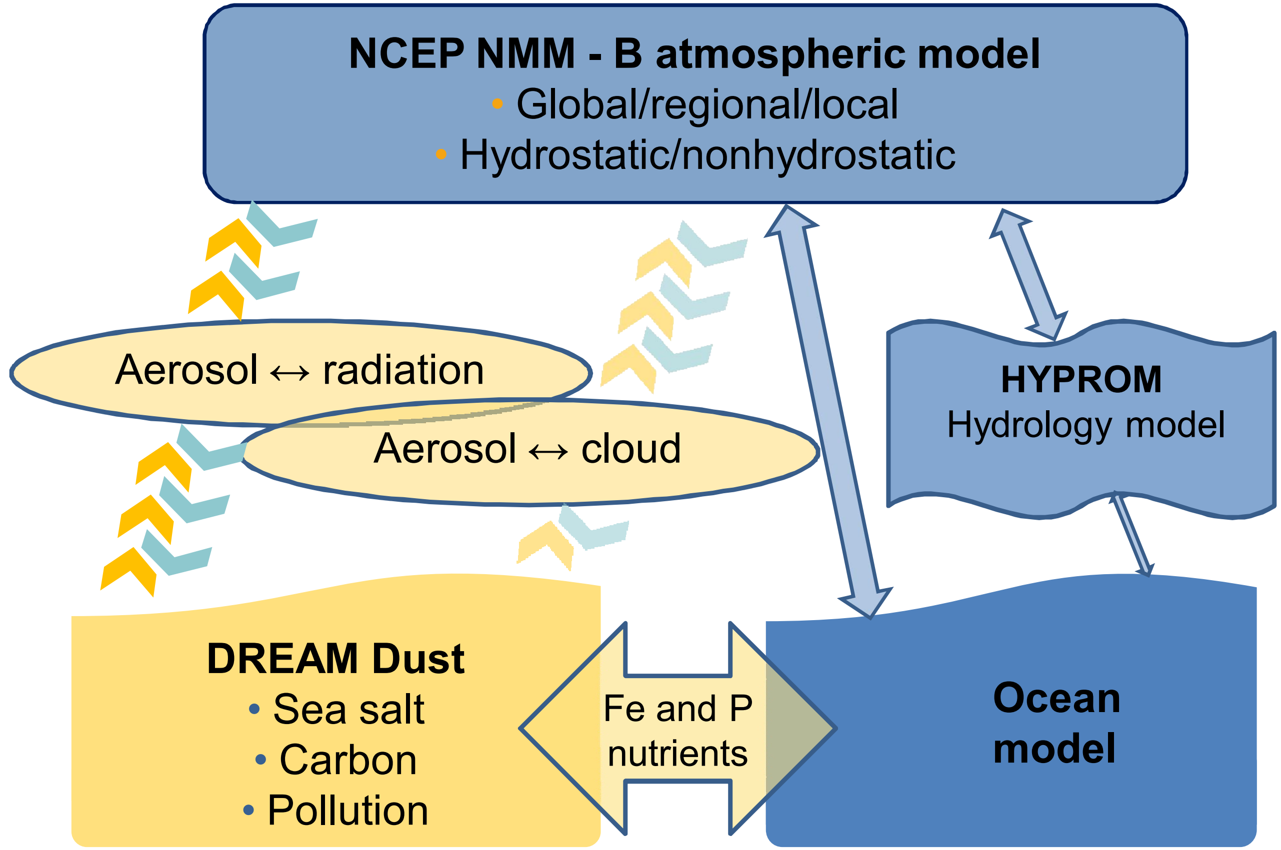
RCC Highly recommended functions
SEEVCCC Integrated Earth Modeling System

WMO RA VI RCC-Network
Implementation Plan
Pilot RA VI RCC Network Nodes

Climate Data
Lead: KNMI/Netherlands
(SEEVCCC/RHMS-Serbia)

Climate Monitoring
Lead: DWD/Germany
(SEEVCCC/RHMS-Serbia)

LRF
Lead: Météo-France & ROSHYDROMET
(SEEVCCC/RHMS-Serbia)



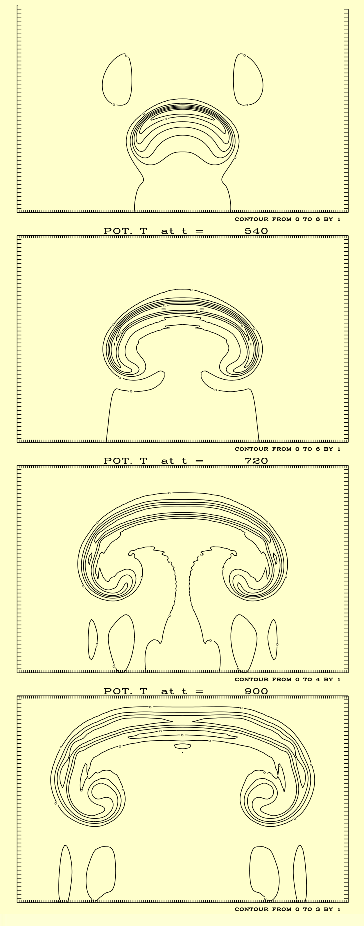
Nonhydrostatic *Multiscale* Model on the B grid (NMMB) + Discretization Principles ……

Zaviša Janjić/NOAA/NCEP (WMO: IMO Prize 2012)

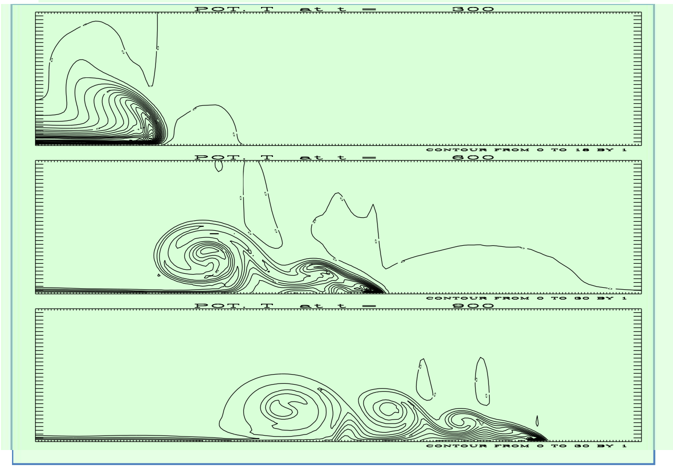
- Intended for wide range of spatial and temporal scales (from meso to global, and from weather to climate)
- Further evolution of WRF Nonhydrostatic *Mesoscale* Model (NMM)
- Built on NWP and regional climate experience (Janjic et al., 2001, MWR; Janjic, 2003, MAP; Janjic & Gall, 2012, NCAR)
- Pressure based vertical coordinate, nondivergent flow remains on coordinate surfaces
- Conservation of important properties of the continuous system aka “mimetic” approach in Comp. Math. (Arakawa 1966, 1972, …; Jacobson 2001; Janjic 1977, …; Sadourny, 1968, … ; Tripoli, 1992 …)
  - Nonlinear energy cascade controlled through energy and enstrophy conservation (finite-volume)
  - A number of properties of differential operators preserved
  - Quadratic conservative finite differencing
  - A number of first order (including momentum) and quadratic quantities conserved
  - Omega-alpha term, transformations between KE and PE
  - Errors associated with representation of orography minimized
  - Mass conserving positive definite monotone Eulerian tracer advection

2D very high resolution tests

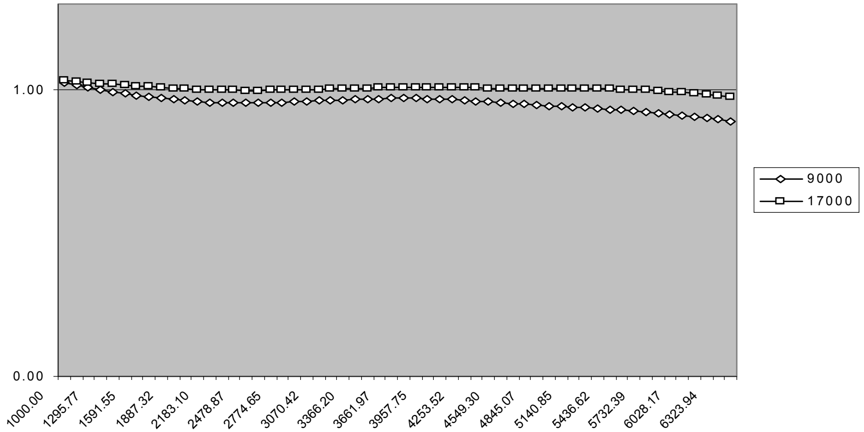
Warm bubble, 100 m resolution



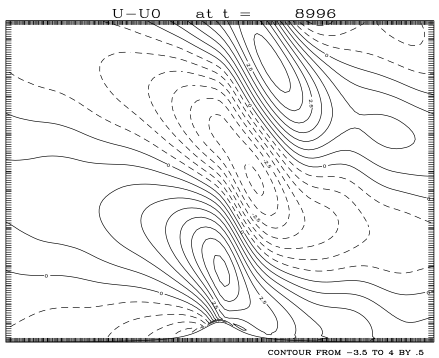
Cold bubble, 100 m resolution

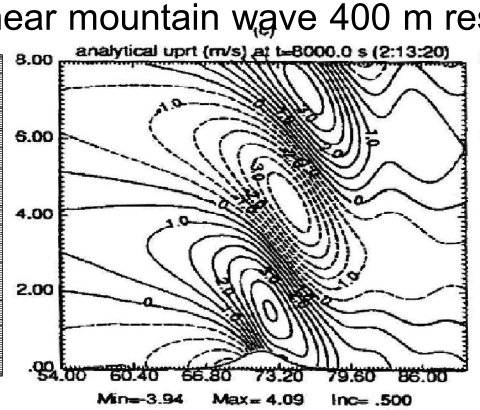


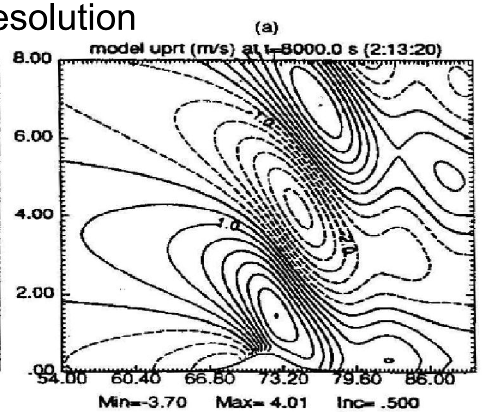
Normalized vertical momentum flux, 400 m resolution



Nonlinear mountain wave 400 m resolution

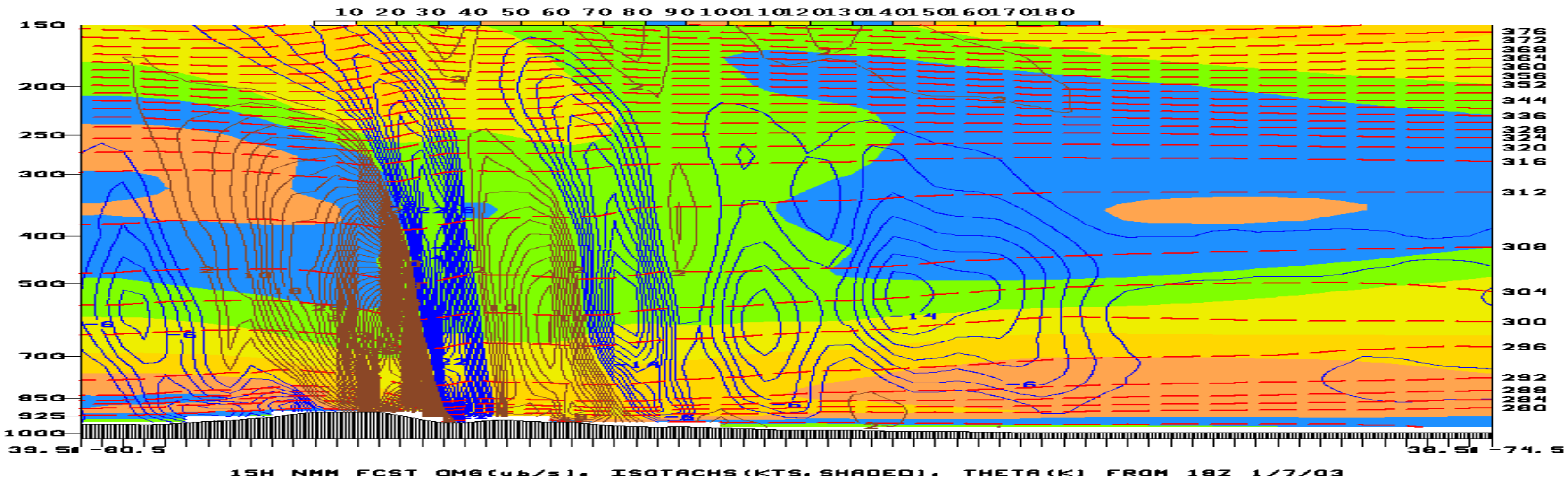




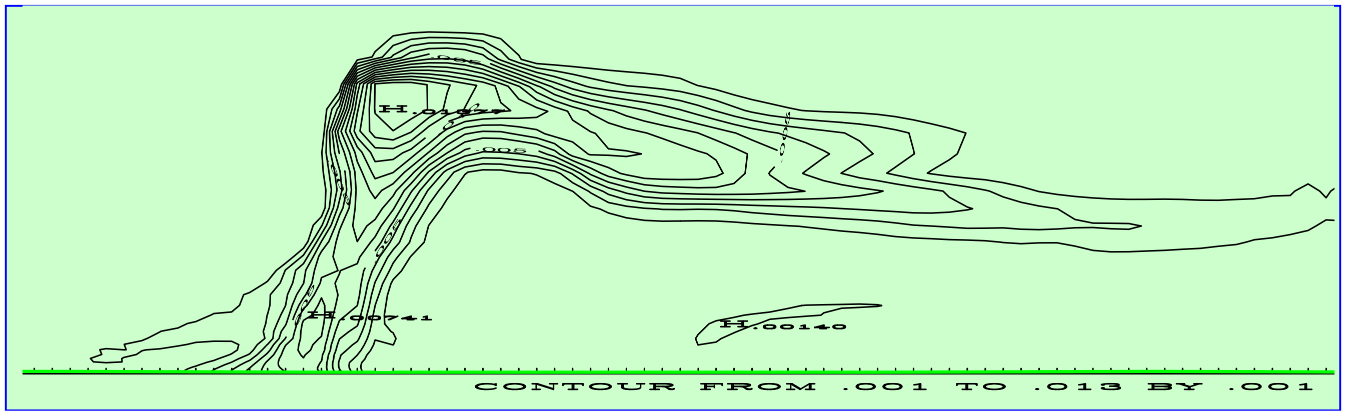


Full compressible NMM Analytical (Boussinesque) ARPS (Boussinesque)

Mountain waves, 8 km resolution

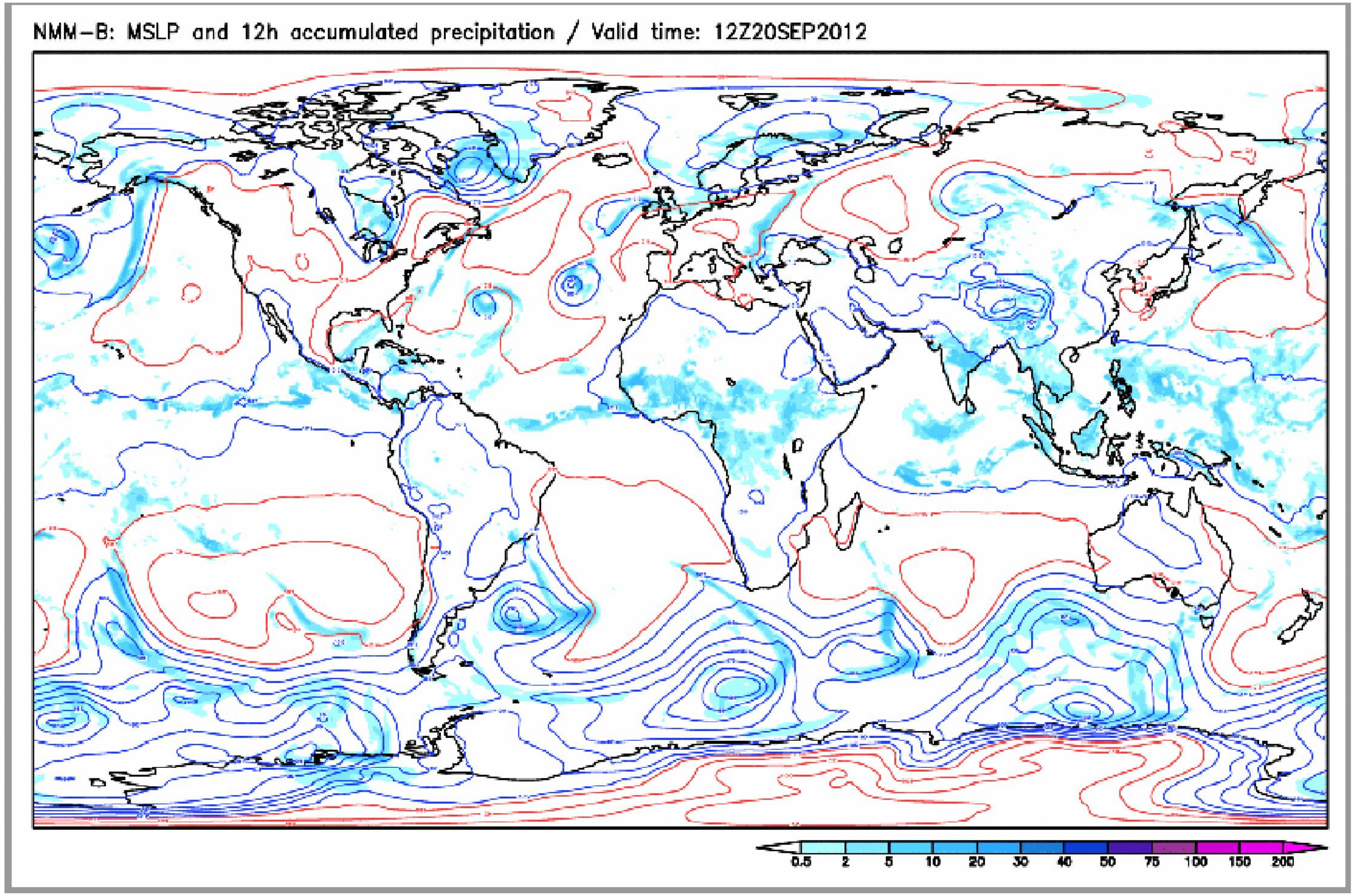


Convection, 1 km resolution



NMMB

- Global domain
- Horizontal res 0.48 x 0.36 degrees
- Vertical res 64 levels
- 10 days forecast
- Initial conditions from GFS

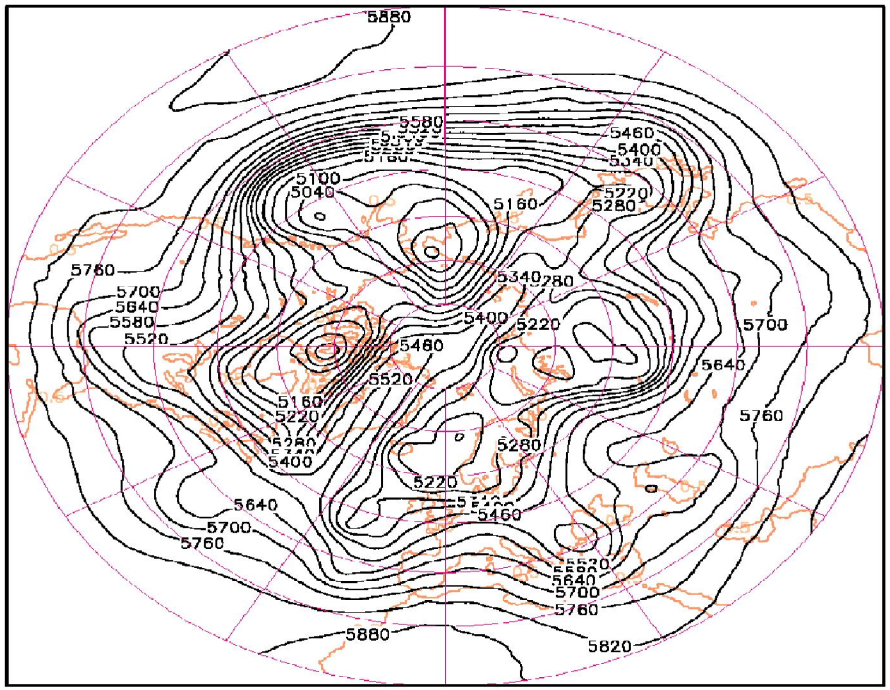


Non-hydrostatic Multiscale Model Global Forecast

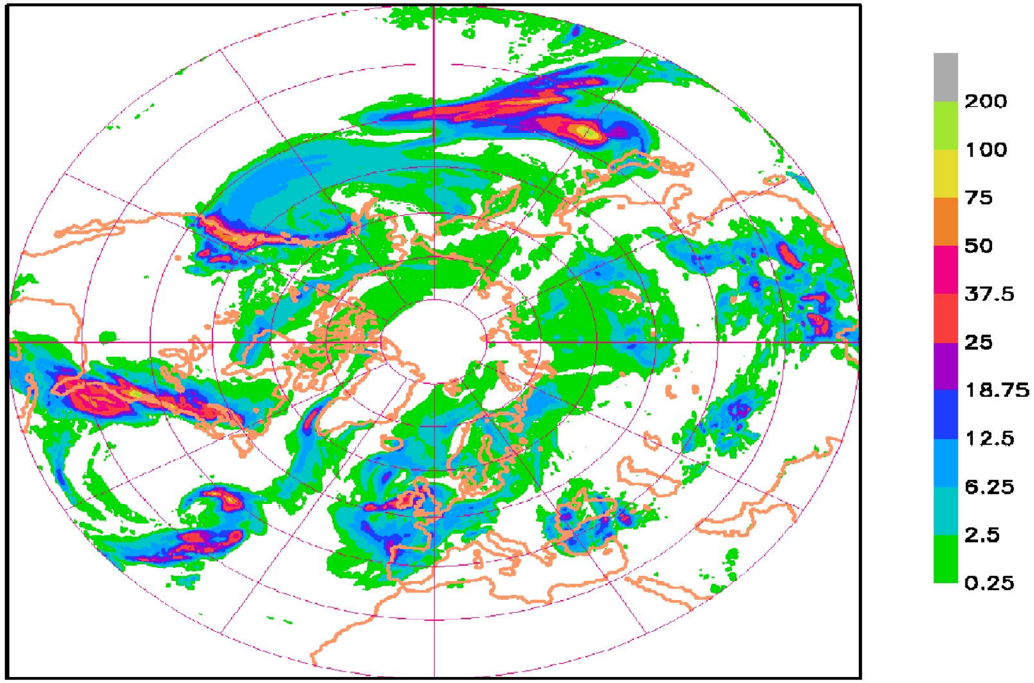
SEEVCCC

- **Model**: NCEP’ s NMM-B
- **Model run**: 7UTC start, 10 days forecast
- **Model resolution**: ~30 km

Geop. Height [gpdam] 500 hPa on 2010/03/29_00Z+000h
Valid: 2010/03/29_00Z

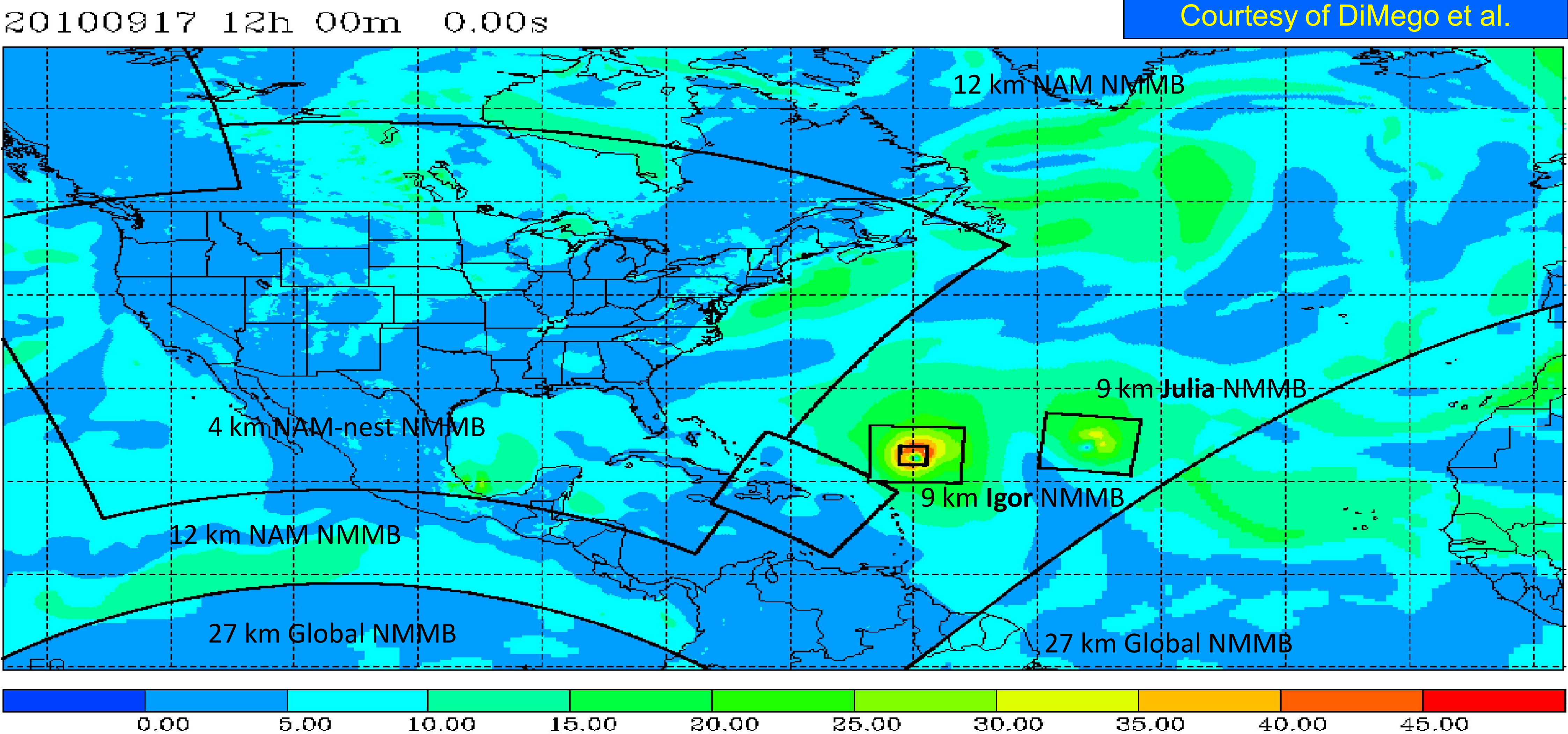


Tot. Precip [mm] on 2010/03/29_00Z+024h
Valid: 2010/03/30_00Z



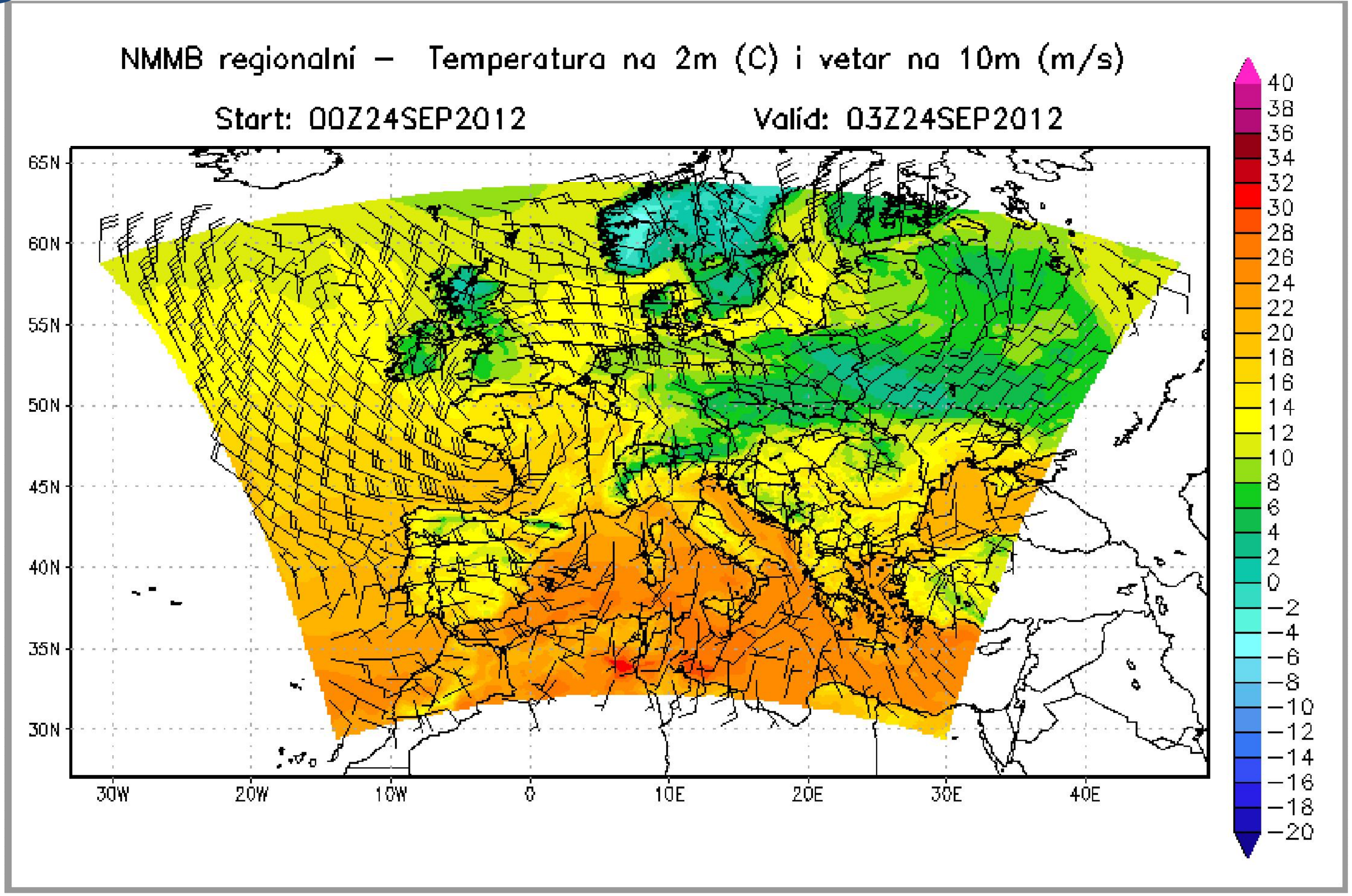
Hypothetical NMMB Simultaneous Run
Global [with Igor & Julia] and NAM [with CONUS nest]

Courtesy of DiMego et al.



NMMB - regional

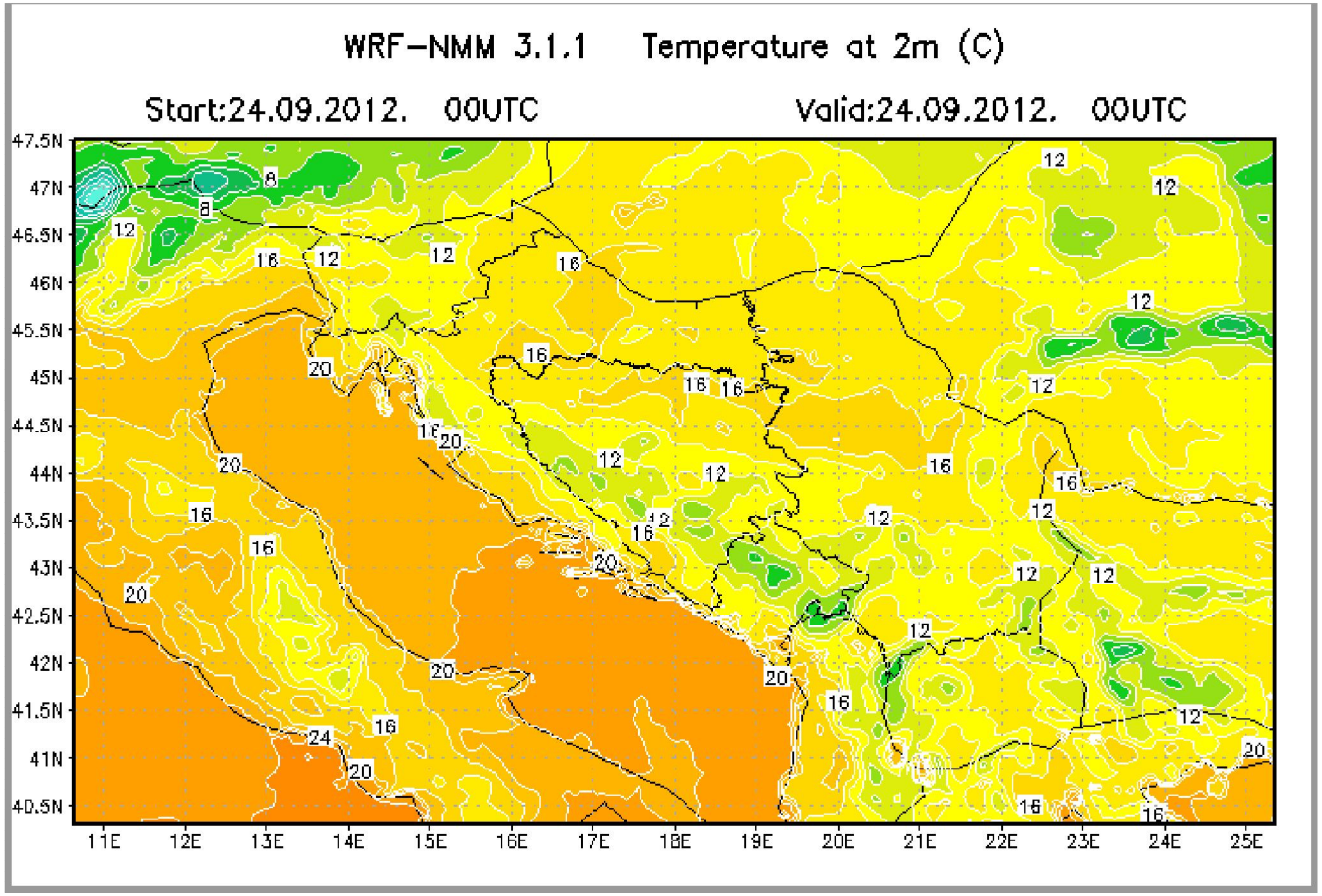
- Europe and West Atlantic
- Horizontal resolution 8 km
- 481x385 points
- Timestep 24 seconds
- Forecast for 192 hours
- Lateral and boundary conditions from GFS



Republic Hydrometeorological Service Of Serbia

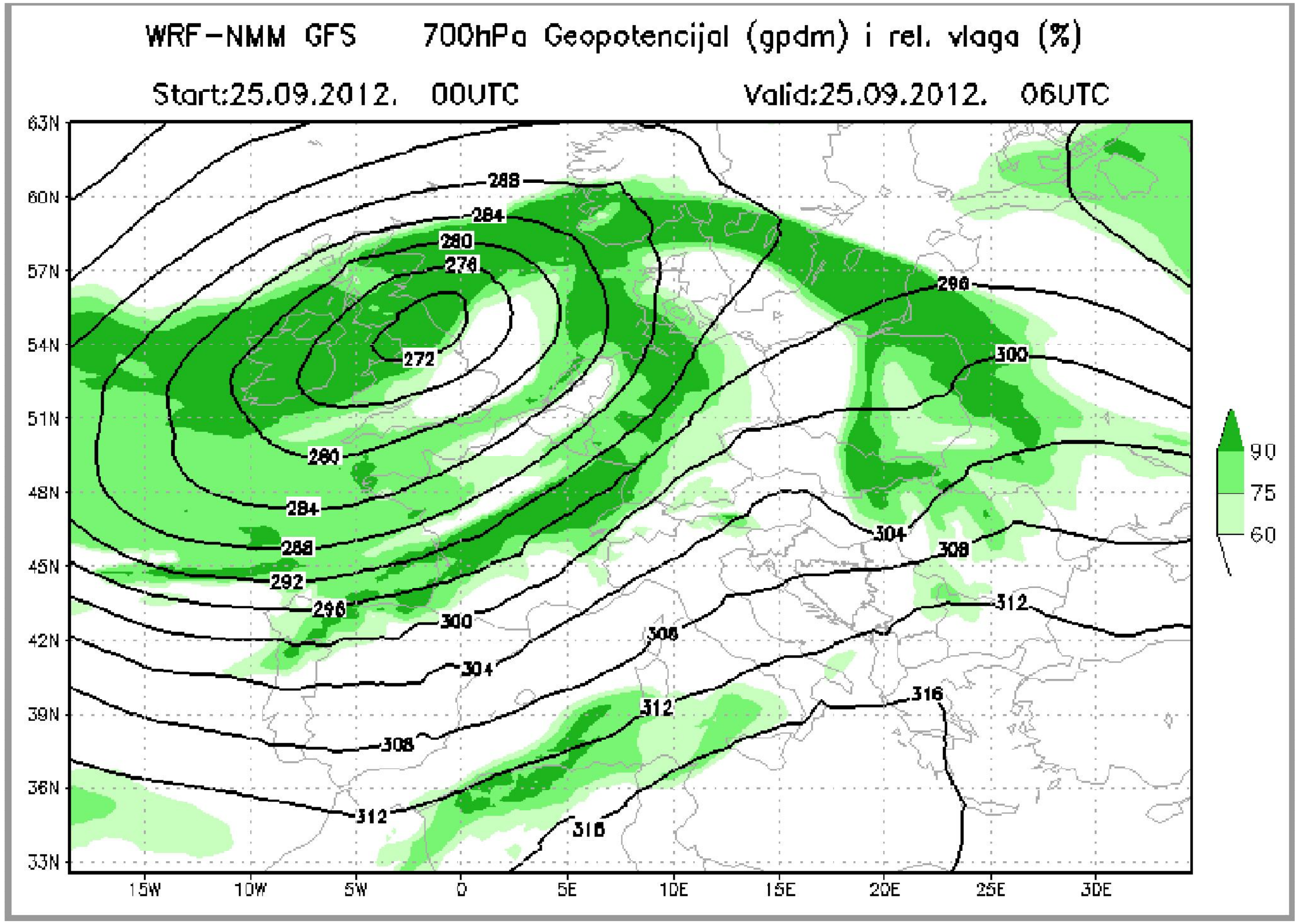
WRF NMM

- Balkan and Adriatic sea
- Horizontal resolution 4km
- 220x 290 points
- Timestep 8seconds
- Forecast for 72 hours
- Lateral and boundary conditions from ECMWF



WRF NMM

- Europe and West Atlantic
- Horizontal resolution 12km
- 260x 500 points
- Timestep 30 seconds
- Forecast for 120 (192) hours
- Lateral and boundary conditions from DWD (GFS)



Hydrology component of IEMS - HYPROM model -

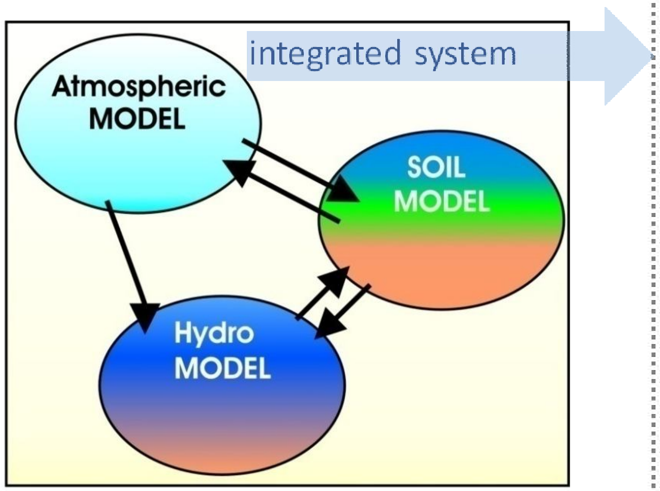
• HYPROM model is developed to simulate overland watershed processes. It is designed to be easily applied to different watersheds and across a broad range of spatial scales, from local to regional and global. HYPROM can be useful tool for predicting short-term flood events, as well as for water balance assessments and climate studies (Nickovic et al., 2010).

• HYPROM consists of two sub-models: two-dimensional representation of overland flow and one-dimensional river routing component that collects the excess water in a drainage basin. It uses real topography, river routing and soil texture data from USGS datasets.

• HYPROM model is driven with the advanced non-hydrostatic NCEP/NMM-E atmospheric model (Janjic et al., 2001; Janjic, 2003), which is widely used to produce operational weather forecasts. It simulates precipitation and calculate surface and base runoff from rainfall and snowmelt using the NMM-E land surface scheme.

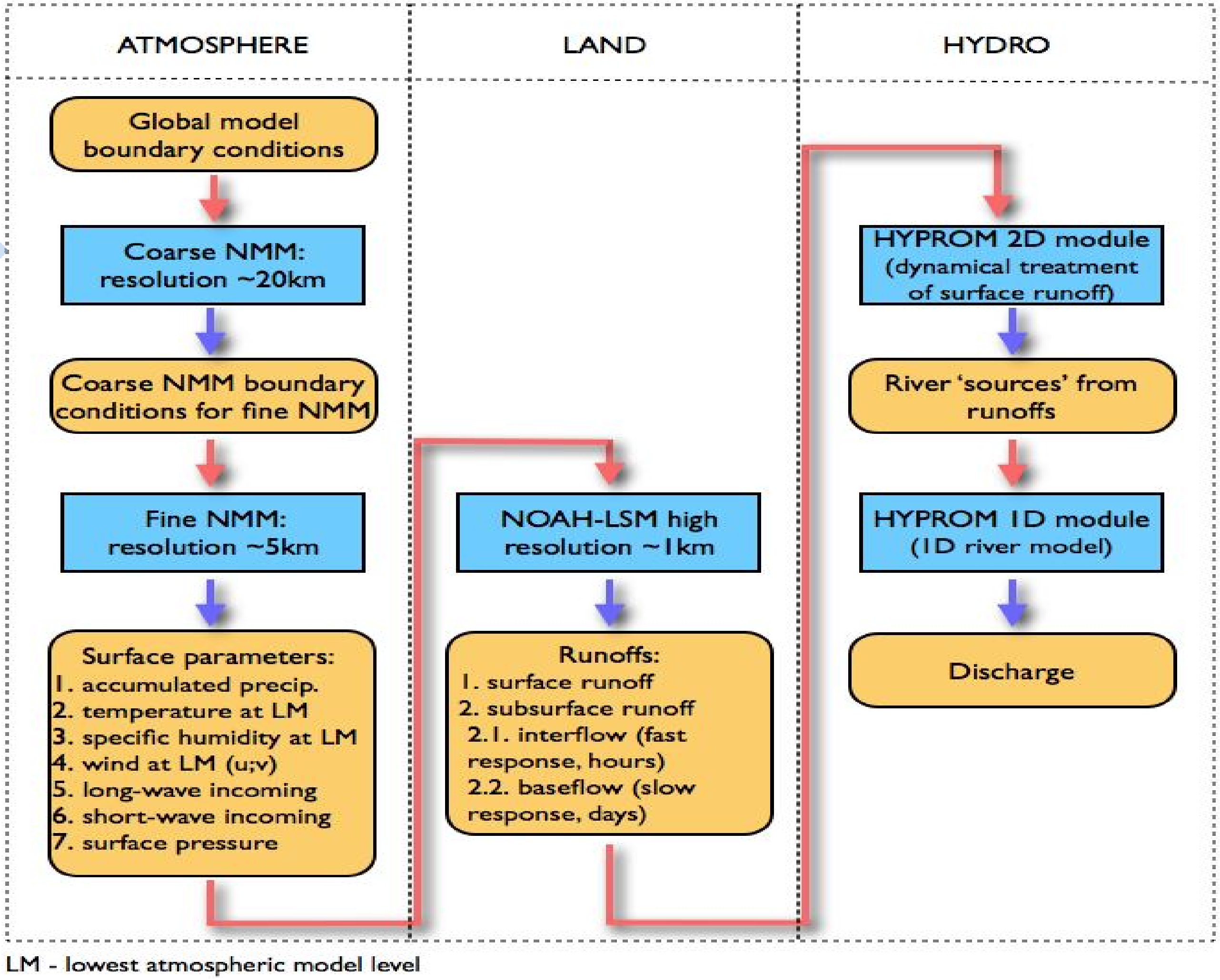
HYdrology PROgnostic Model

Atmosphere: NMM E non-hydrostatic model
Land: NOAH land surface model
Hydrology: HYPROM 2D – surface runoff
HYPROM 1D – river routing



DATASETS:

HYDRO1k USGS topography
HYDROSHED-500m
FAO soil texture data
USGS land use data



Governing equations

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + g\left[\frac{\partial h}{\partial x} + S_{fx} - S_{0x}\right] = 0$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + g\left[\frac{\partial h}{\partial y} + S_{fy} - S_{0y}\right] = 0$$

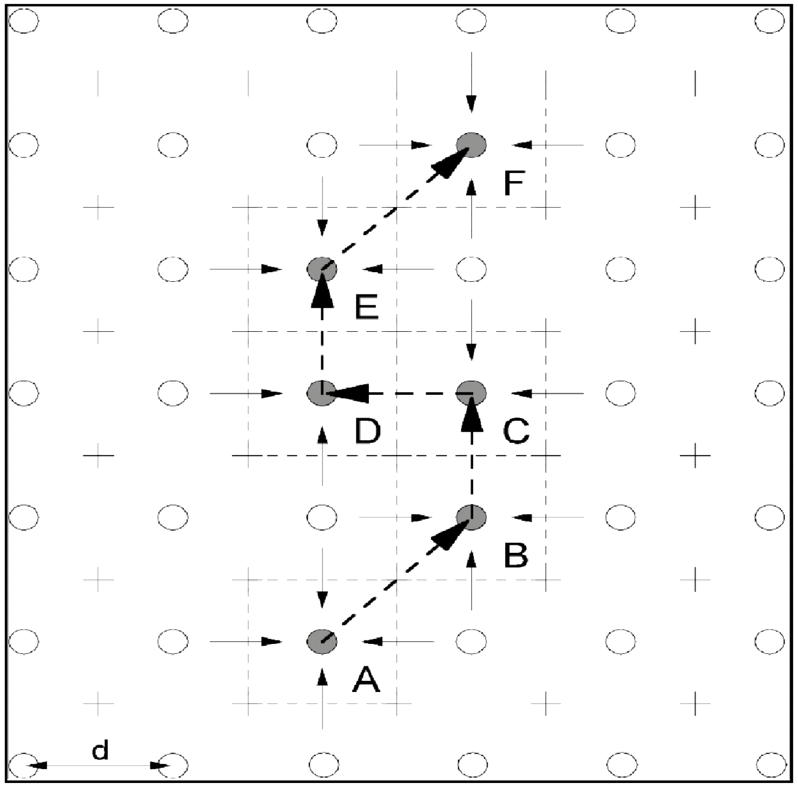
$$\frac{\partial h}{\partial t} + \frac{\partial (hu)}{\partial x} + \frac{\partial (hv)}{\partial y} + \dot{H} = 0$$

$$\left.\begin{aligned} &\frac{\partial U}{\partial t} + U\delta_s \overline{U}^s + g\delta_s (R + h_s) + \frac{n^2 |U|}{\overline{R^{4/3}}^s} U = 0 \\ &\frac{\partial R}{\partial t} + \delta_s\left(\overline{R}^s U\right) + \dot{R} = 0 \end{aligned}\right\} \text{One-D River routing}$$

○ h - points

+ u,v -points

A-B-C-D-E-F river points

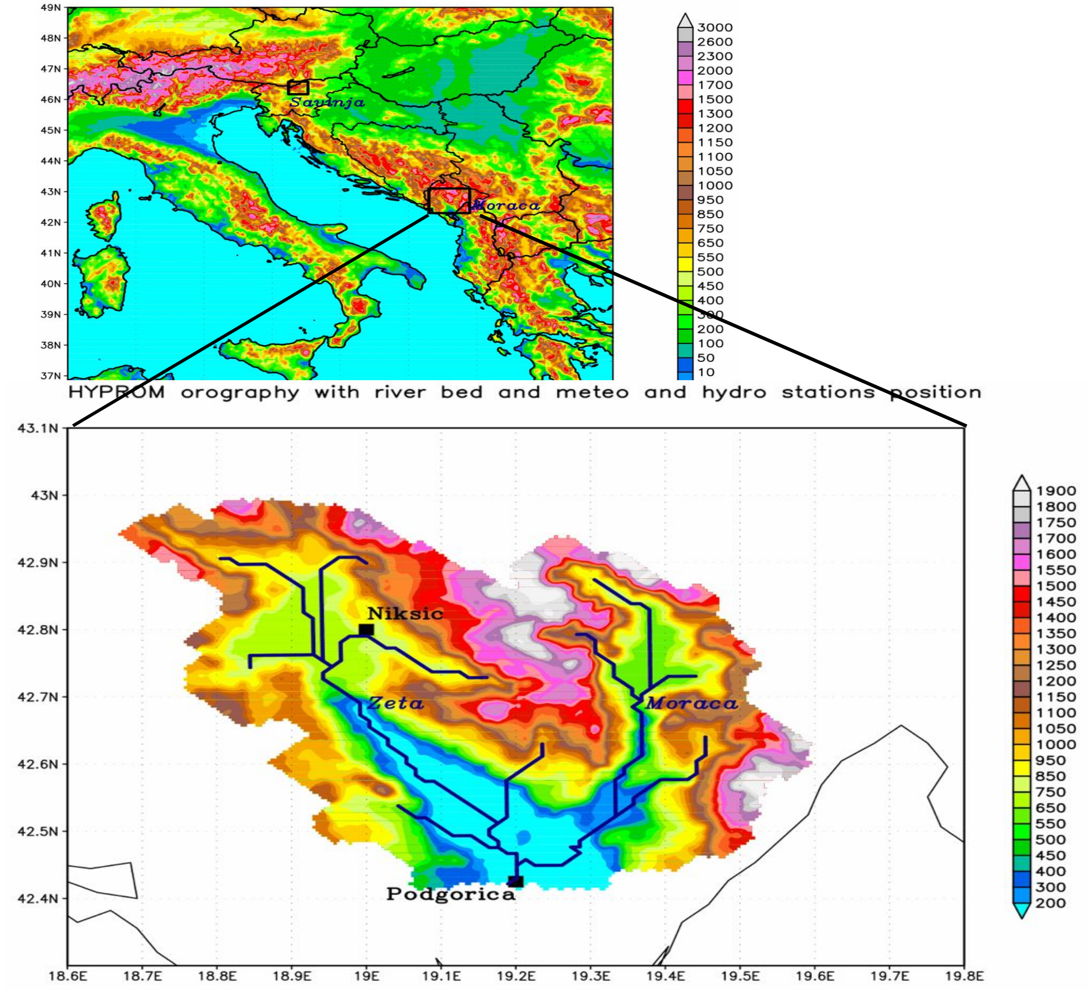


- dynamical treatment of overland flow (NO kinematic approximation!)
- numerically stable implicit time scheme for the friction term
- new numerical technique for preventing grid decoupling noise
- suitable for long term and flash flood simulations
- computationally efficient

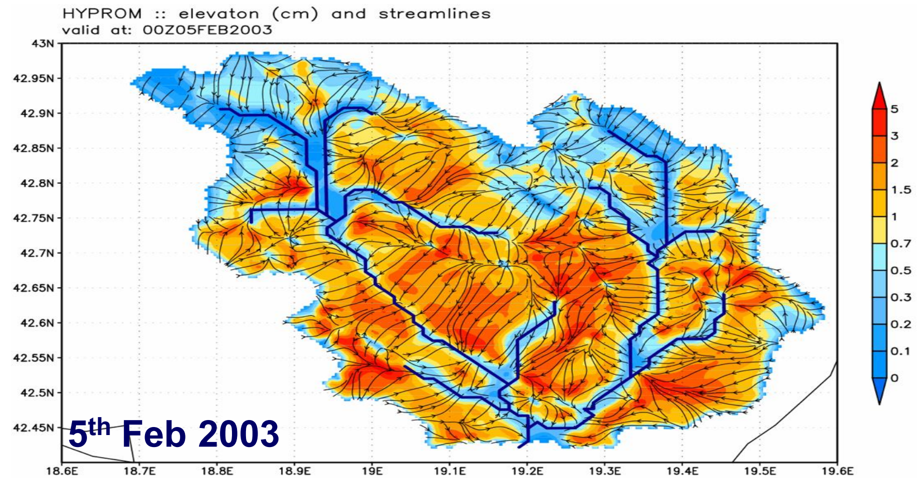
Ničković S. et al, 2010: HYPROM hydrology surface-runoff prognostic model, *Water Resource Research*

The Moraca river (Montenegro)

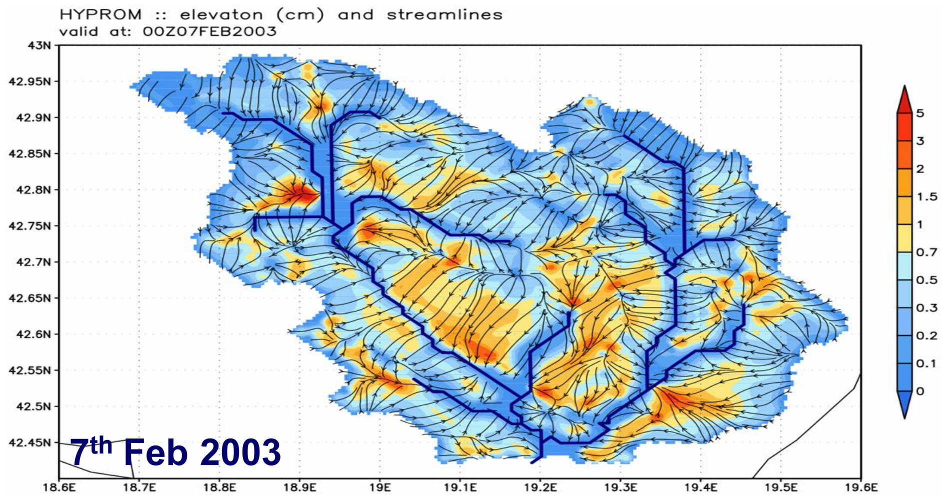
Podgorica basin: 2600 km^2



heavy rain event

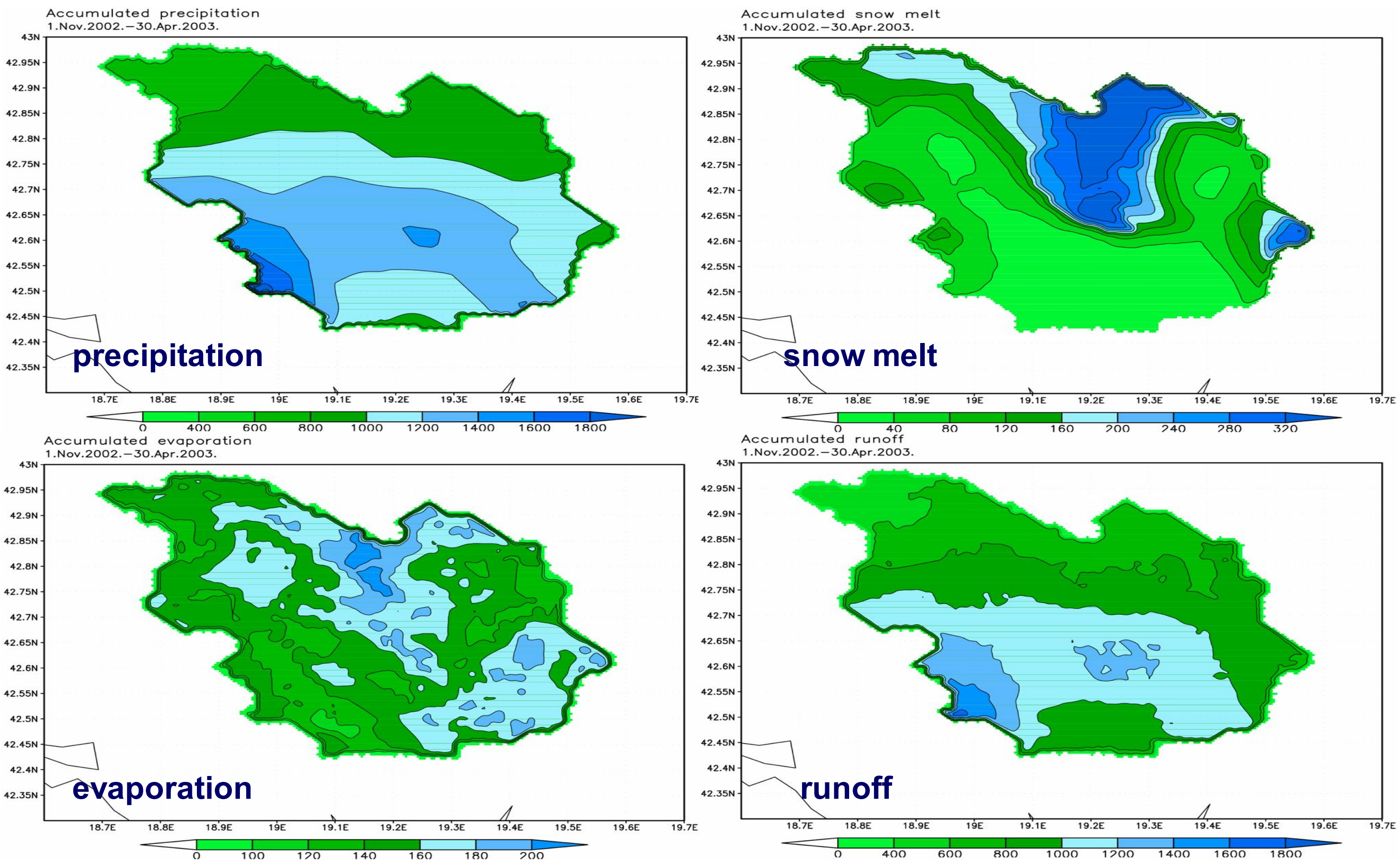


surface runoff and streamlines

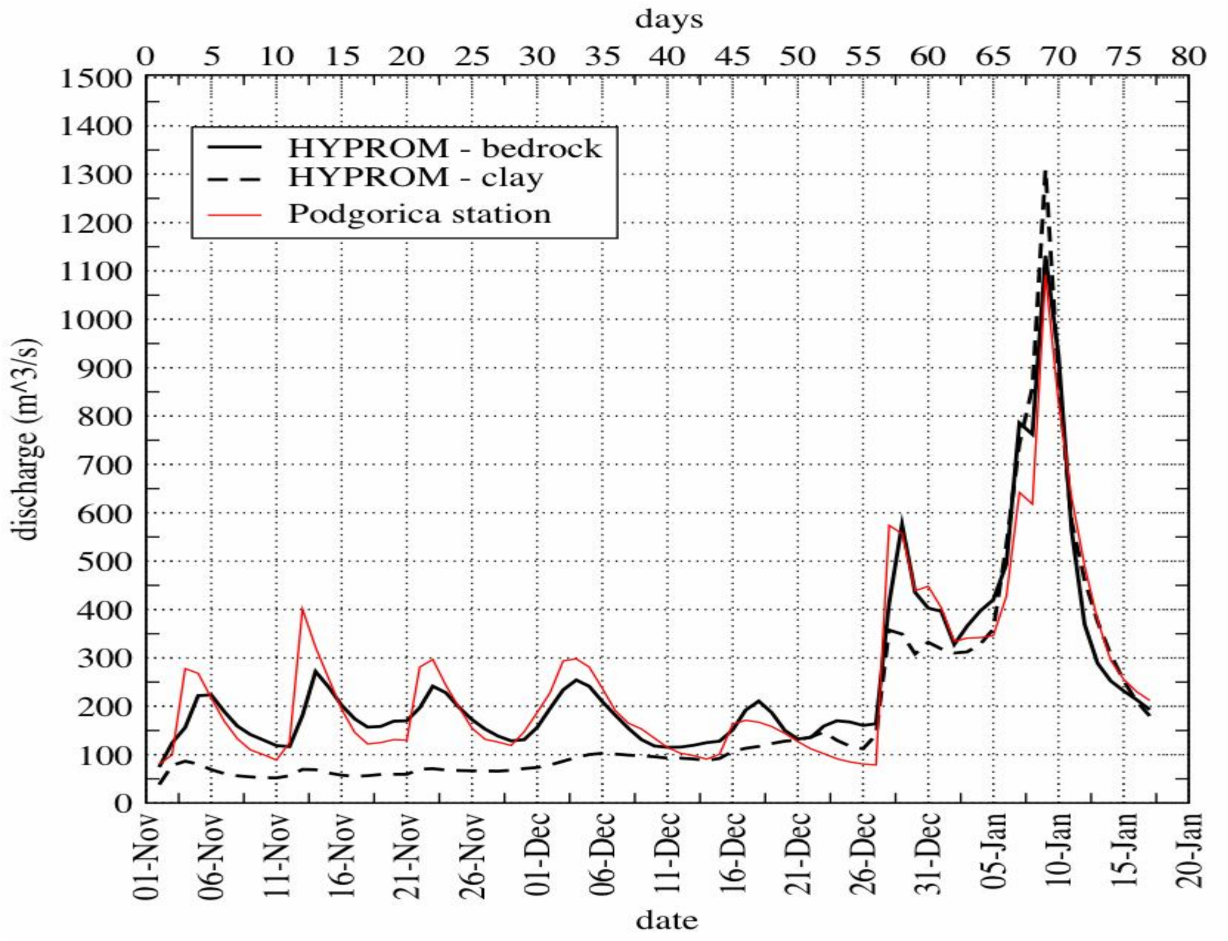


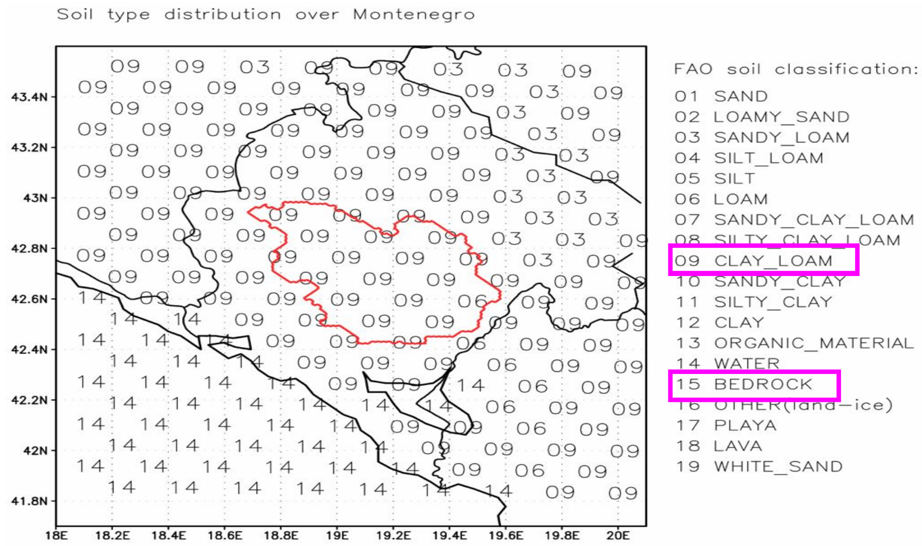
Water budget components (NMM-E)

six months accumulations: November 2002 – April 2003



Sensitivity to soil type

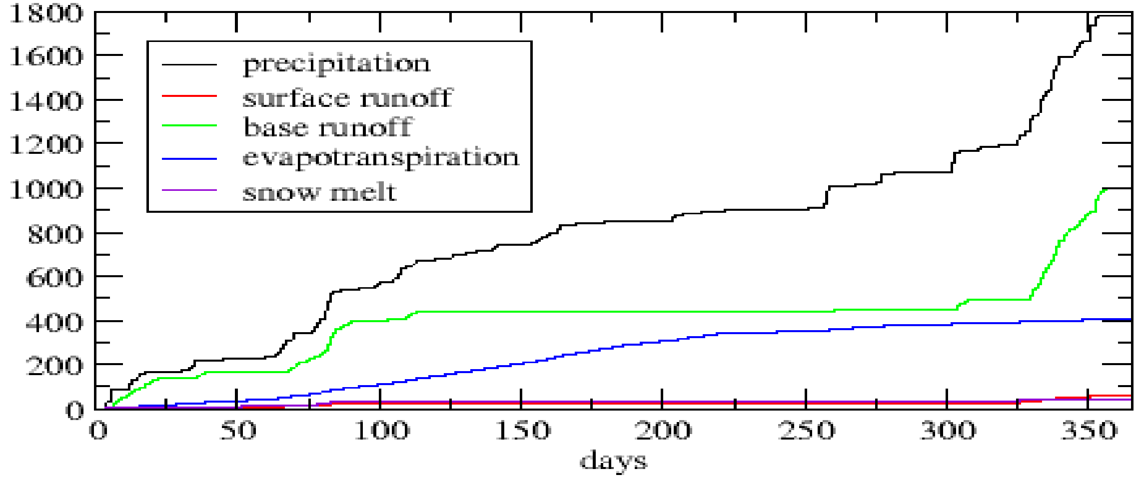




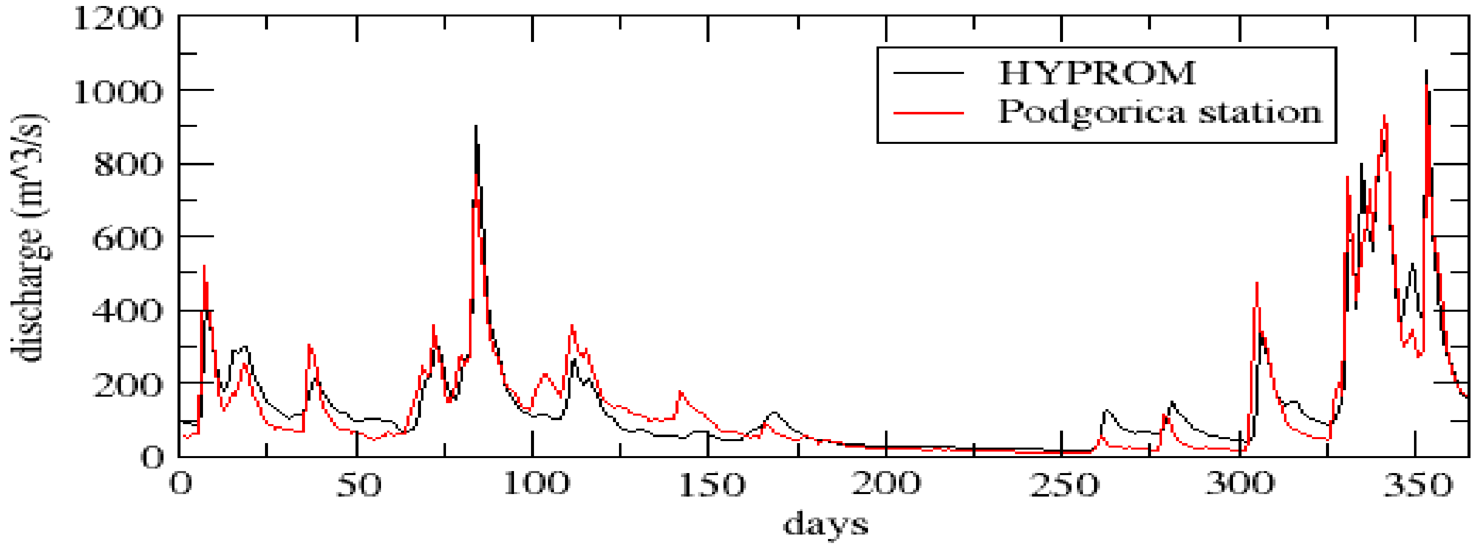
parameter	Clay Loam (09)	Bedrock (15)
sat. diffusivity	0.113×10^{-4}	0.136×10^{-3}
sat. conductivity	2.45×10^{-6}	1.41×10^{-4}
porosity	0.465	0.20
CH constant	8.17	2.79

case 2008

water budget components 2008 accumulations

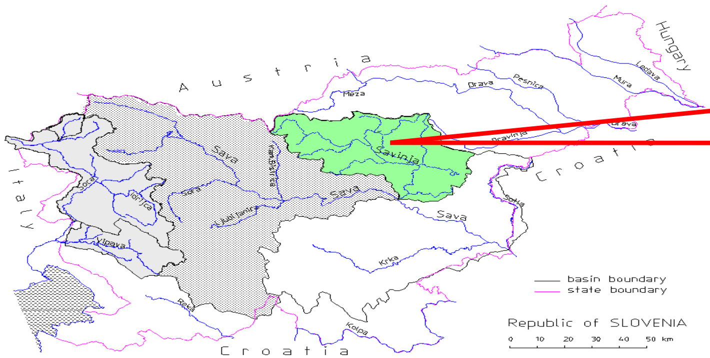


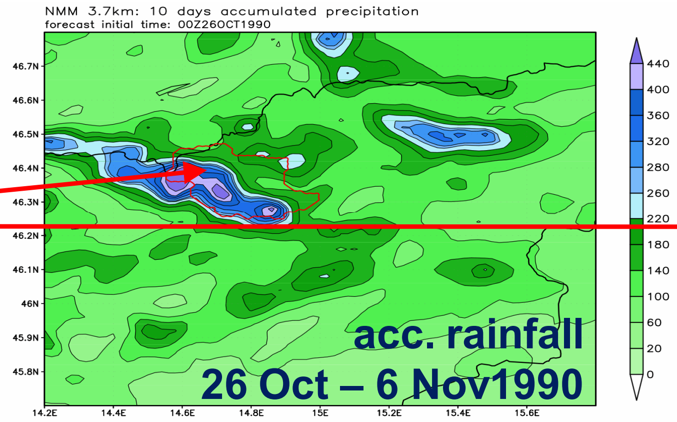
model vs. observations discharge 2008

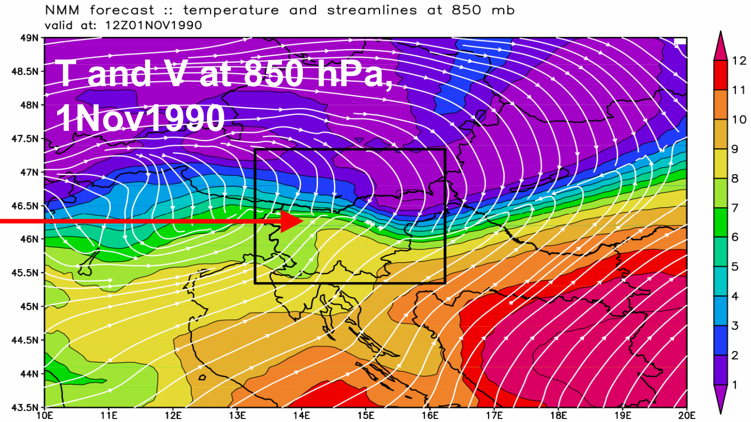


The Savinja river (Slovenia) – flash flood example

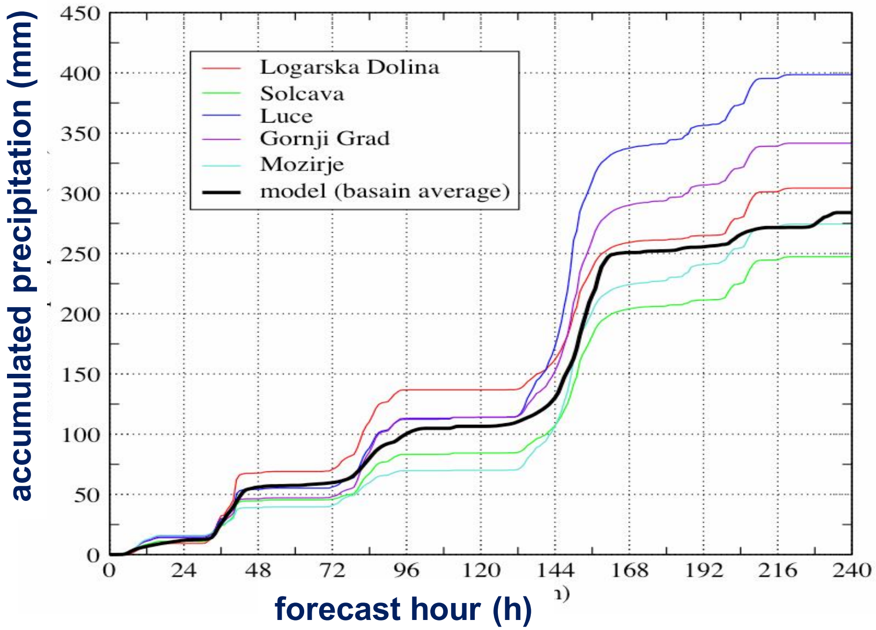
26/10 – 6/11 1990

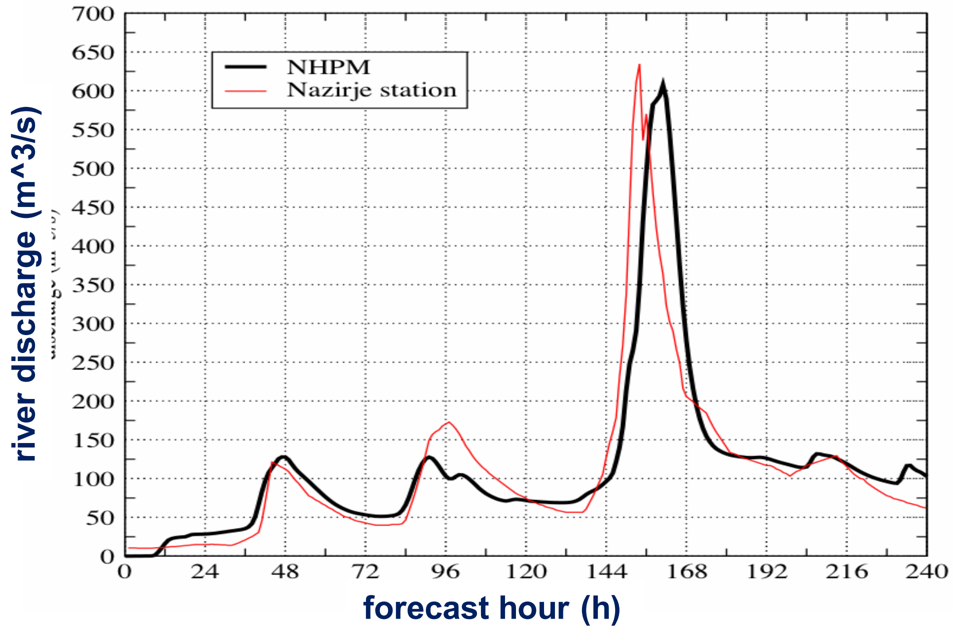






model vs. observations

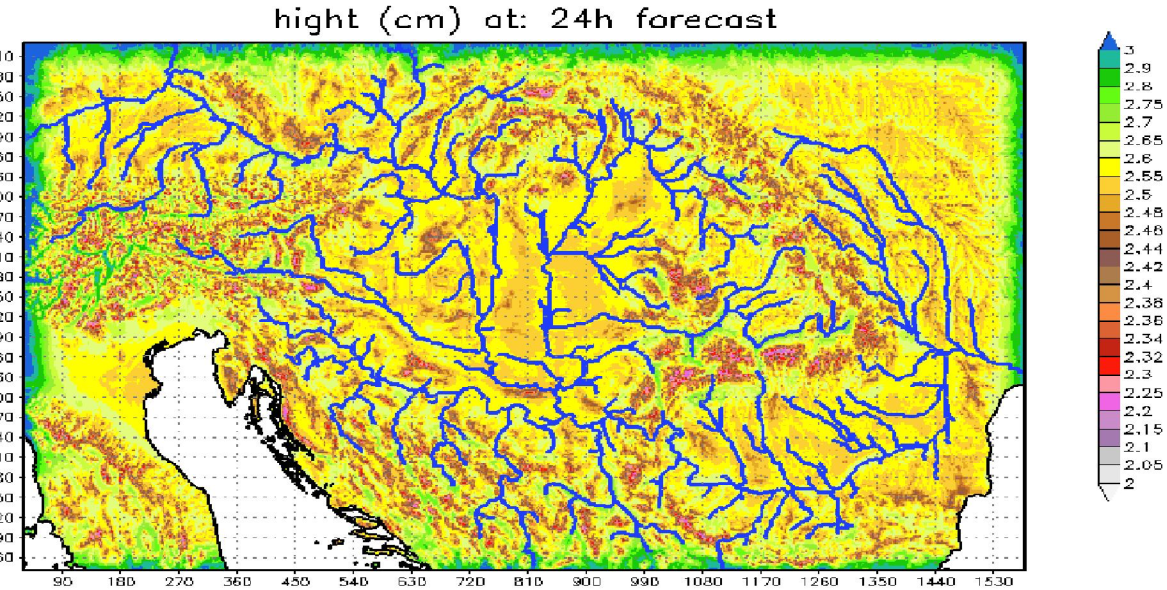




Future work using HYPROM

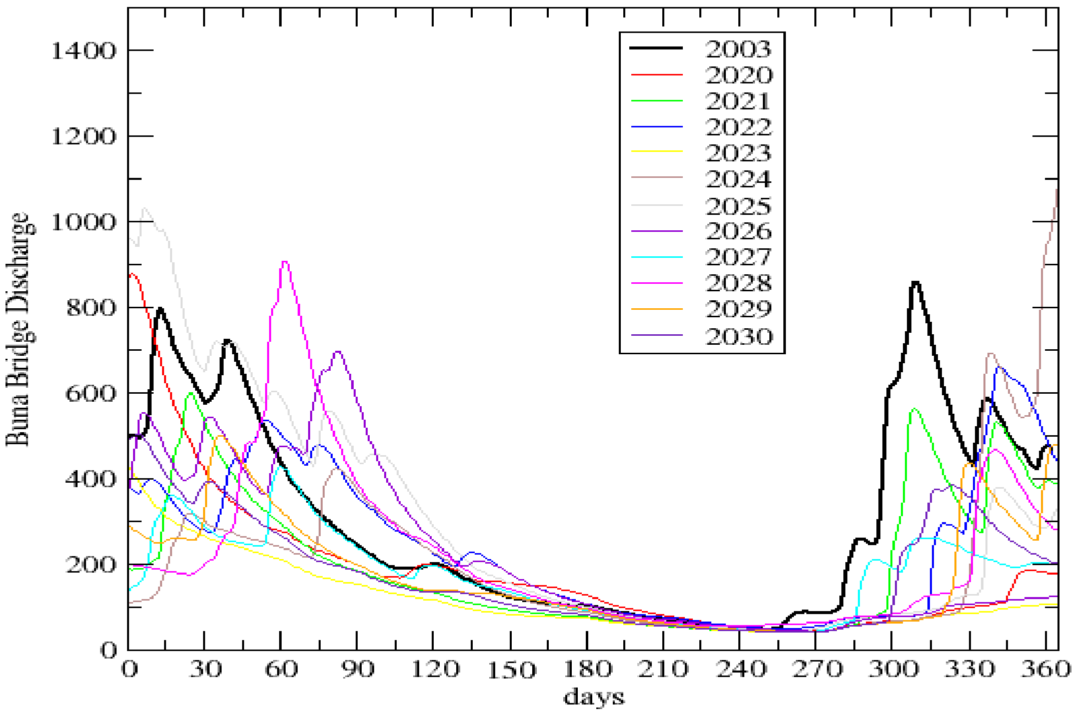
HYPROM + NCEP's NMM-B

large river basins



Danube basin experiment

climate studies



Bojana river: Buna Bridge discharge

dynamical groundwater flow

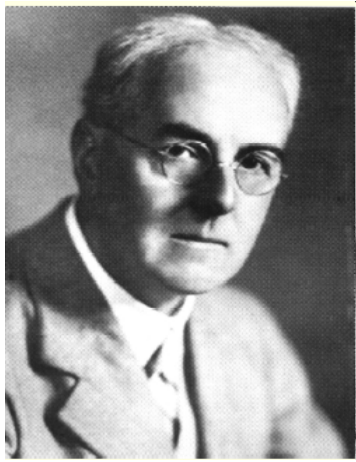
Aerosol component of IEMS DREAM dust model

- DREAM model is developed as an add-on component of the atmospheric model and is designed to simulate and/or predict the atmospheric cycle of mineral dust aerosol. It solves the Euler-type partial differential nonlinear equation for dust mass continuity. Dust concentration is one of the governing prognostic equations in an atmospheric numerical prediction model (Janjic, 1990, 1994, and references thereinafter).

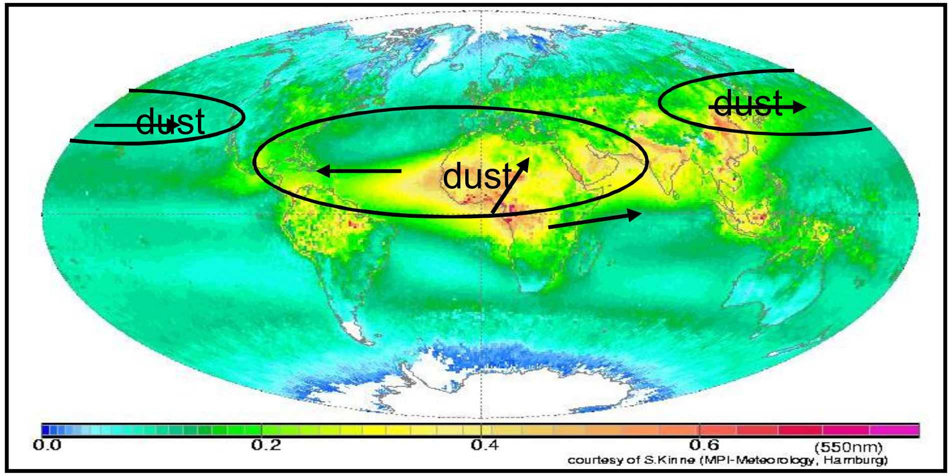
- DREAM simulates all major processes of the atmospheric dust cycle (Nickovic et al., 2001). During the model integration, calculation of the surface dust emission fluxes is made over the model cells declared as deserts. A viscous sub-layer parameterization regulates the amount of dust mass emission for a range of near-surface turbulent regimes. Once injected into the air, dust aerosol is driven by the atmospheric model variables: by turbulence in the early stage of the process when dust is lifted from the ground to the upper levels; by winds in the later phases of the process when dust travels away from the sources; and finally, by thermodynamic processes and rainfall of the atmospheric model and land cover features which provide wet and dry deposition of dust over the Earth surface.

Richardson's "Forecast Factory“: a pioneering attempt to predict weather

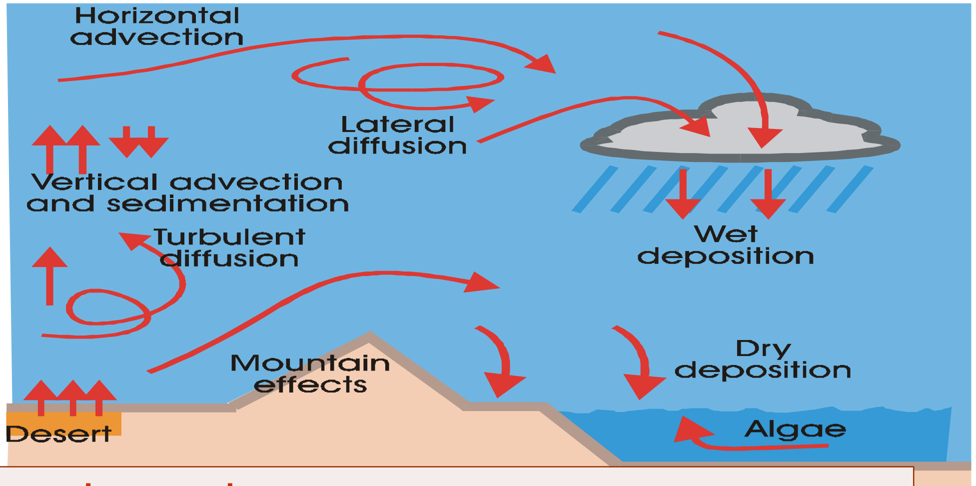
…In 1922, Lewis Fry Richardson developed the first numerical weather prediction (NWP) system. Richardson's method, based on simplified versions of Bjerknes' "primitive equations" of motion and state (and adding an eighth variable, for **atmospheric dust**) reduced the calculations required to a level where manual solution could be contemplated. His own attempt to calculate weather for a single eight-hour period took six weeks and ended in failure….



SDS PROCESS

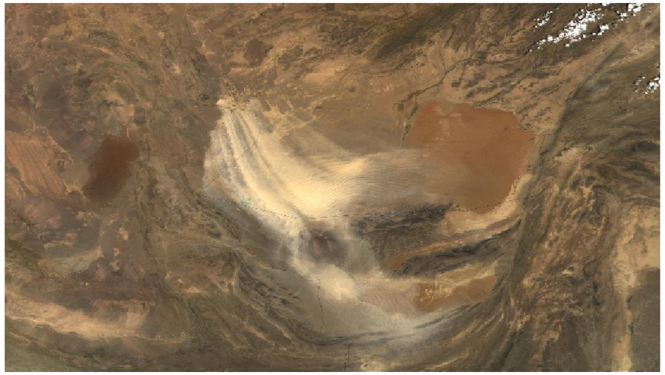


Source: S. Kinne MPI, Hamburg, Germany



Driven by and interacting with the atmosphere

Global process based on local origins



Afghanistan dry lake dust sources MODIS 2, June 2001

- Dust component on-line driven by atmospheric models

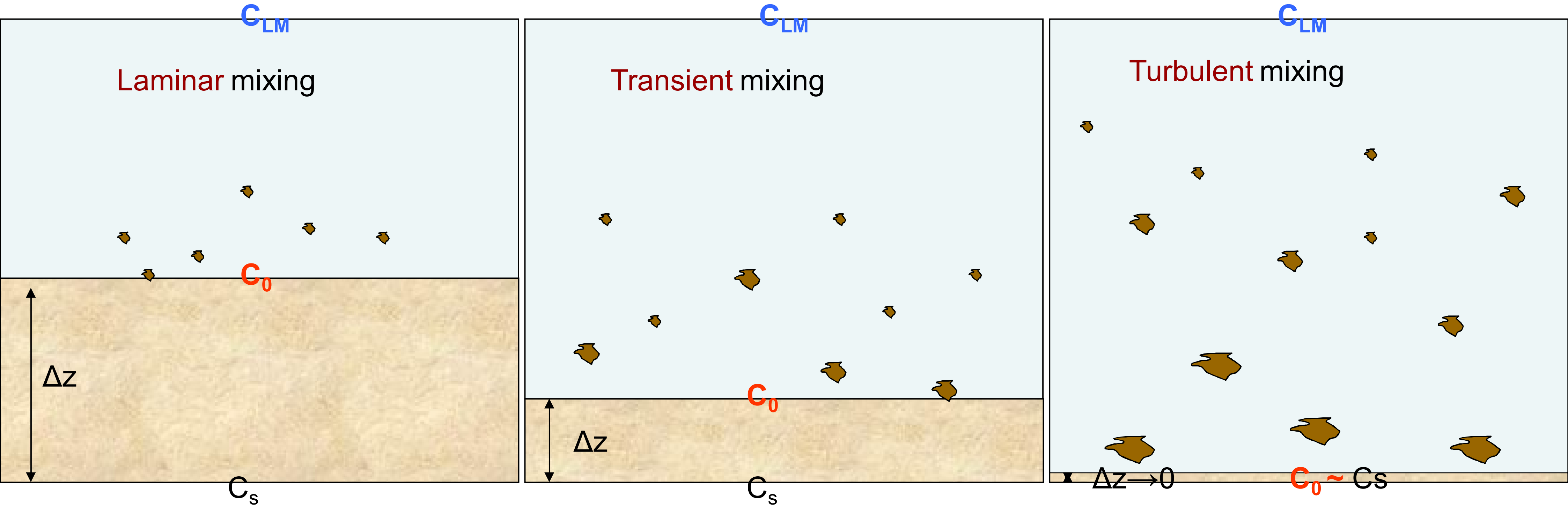
- Parameterization of all major atmospheric dust phases

- **Emission**
- **Turbulent mixing**
- **Long-range transport**
- **Wet/dry deposition**

Impacts of Sand and Dust

- Human Health (asthma, infections, meningitis in Africa, valley fever in the America' s)
- Agriculture (negative & positive impacts)
- Marine productivity
- Aviation (air disasters)
- Ground transportation
- Industry (Semi-conductor, tourism, etc)

Viscous sub-layer concept

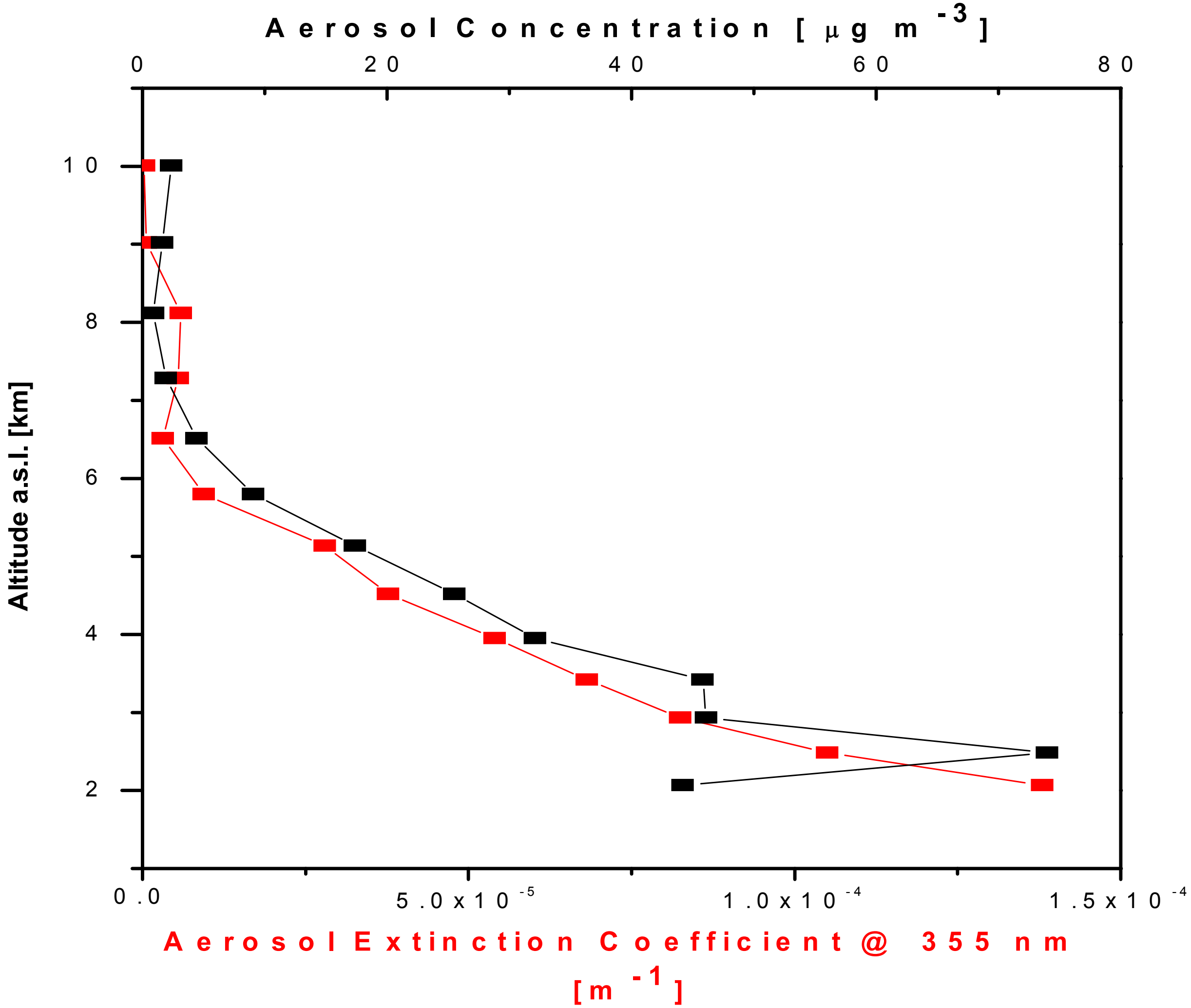


$$C_0 = \frac{C_S + \omega C_{LM}}{1 + \omega} \qquad \omega = \frac{\left(\frac{K_{Csfc}}{\Delta z}\right)}{\left(\frac{\lambda}{z_C}\right)}$$

Ničković et al, 2001, JGR

HOW GOOD/BAD ARE DUST MODELS?
Example: Model validation against lidar observations

A systematic comparison between DREAM model and Potenca EARLINET lidar observations
May 2000 – April 2005 period



Can desert dust explain the outgoing longwave radiation anomaly in the UK operational model over the Sahara?
Haywood, et al., JGR 2003

Adding dust into atmospheric models can improve weather forecasts (Ničković, 2004)

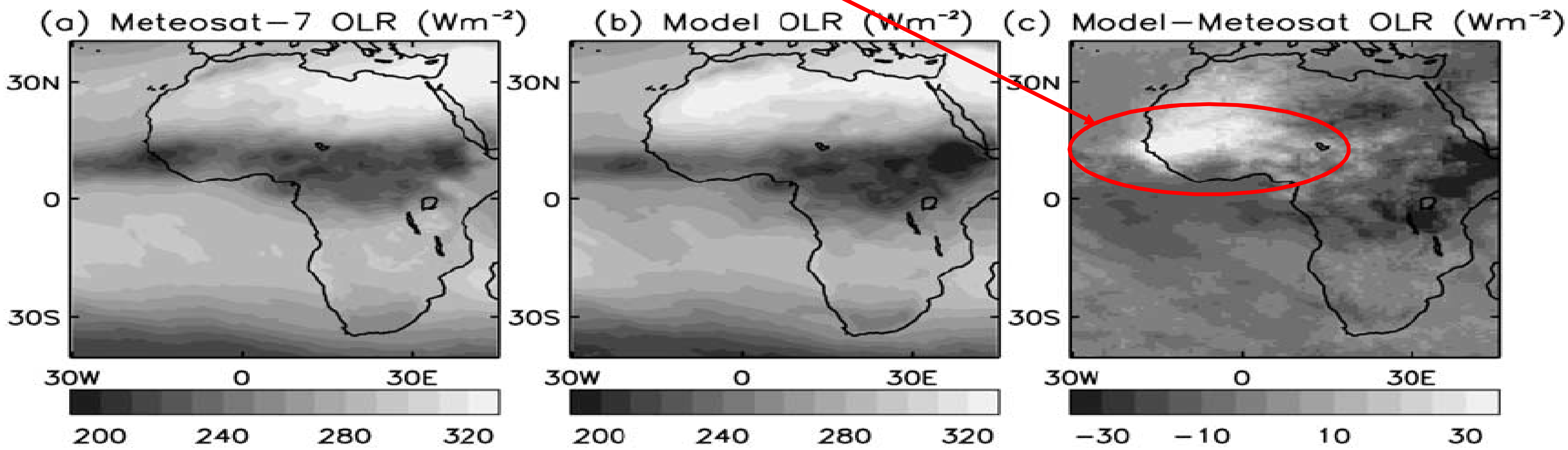
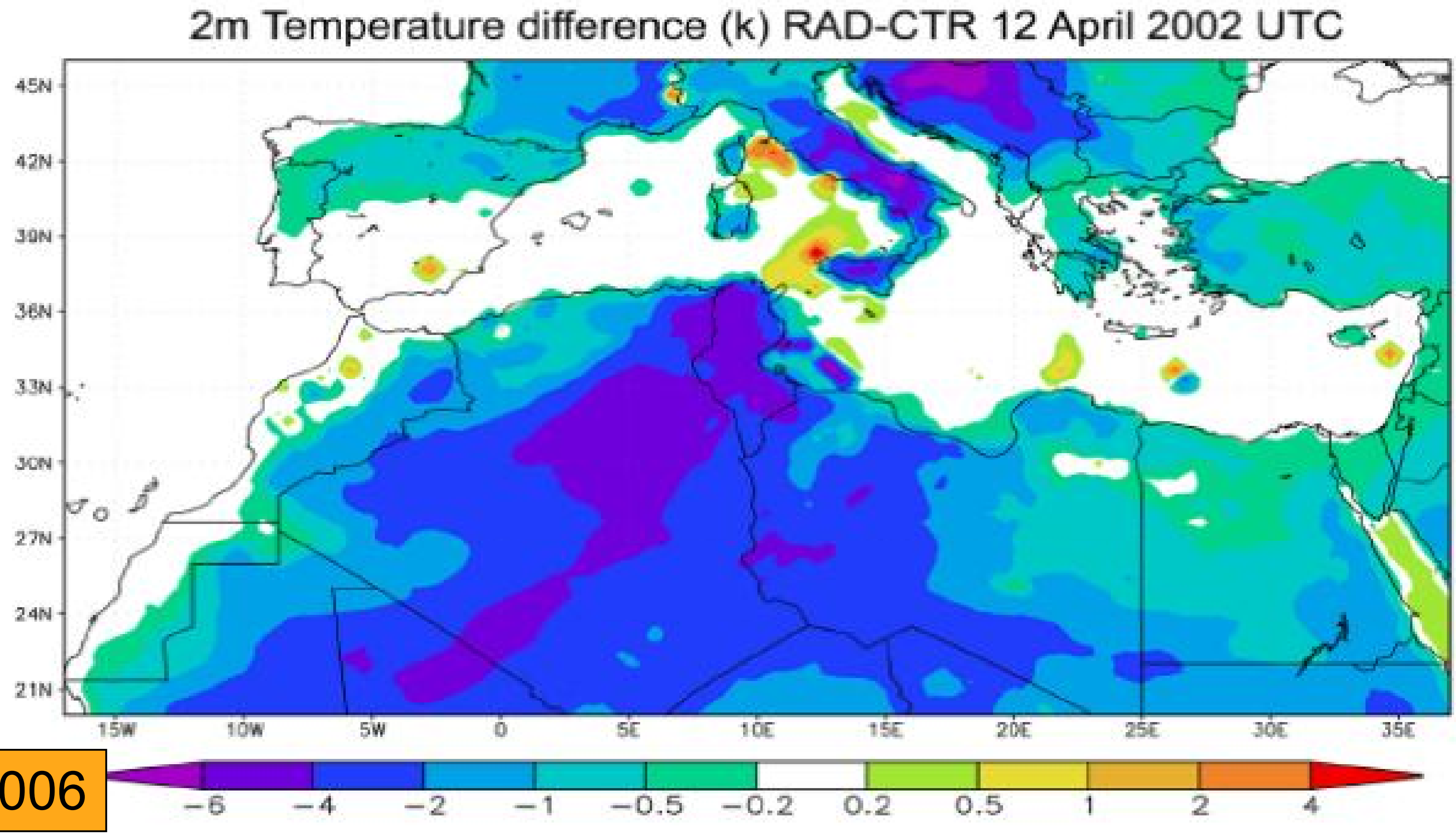


Figure 1. The July 2003 monthly mean for (a) OLR_{Met7}, (b) OLR_{model}, and (c) $OLR_{model} - OLR_{Met7}$. The monthly mean consists of the average of the monthly mean of the OLR diagnosed at 0000 UTC, 6000 UTC, 1200 UTC, and 1800 UTC. Units are Wm^{-2}. See color version of this figure in the HTML.

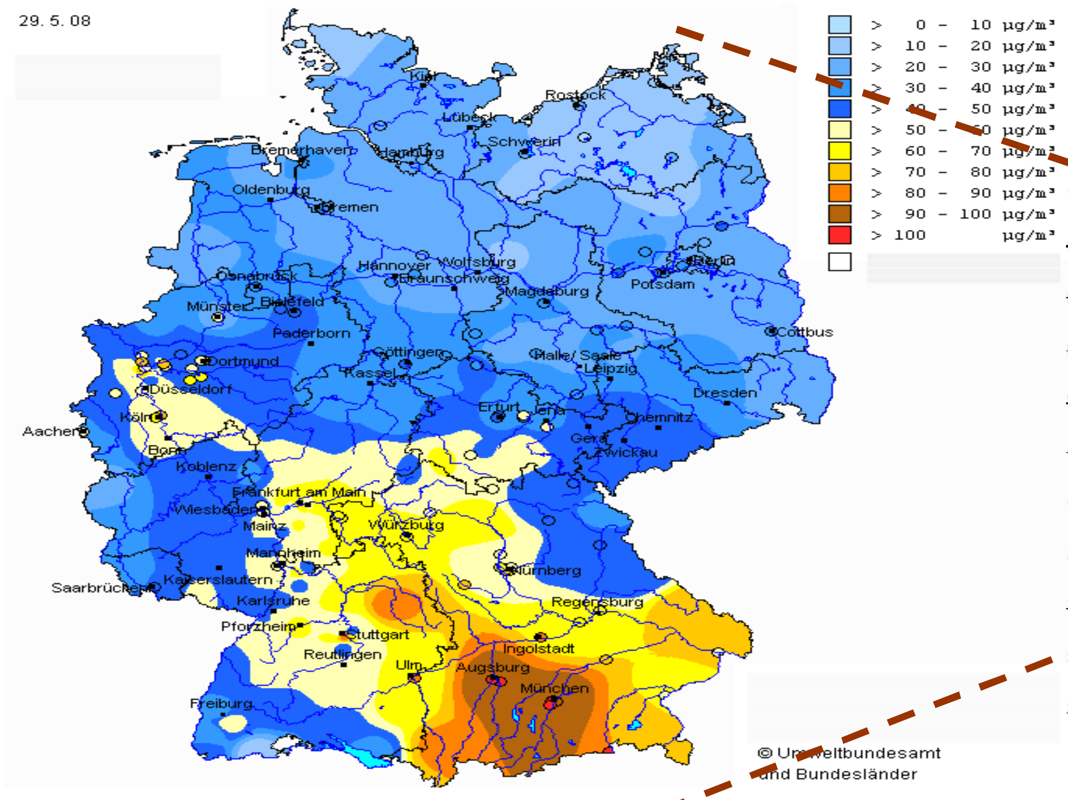
Impact on radiation: Cooling surface atmosphere by ~5^{O}C



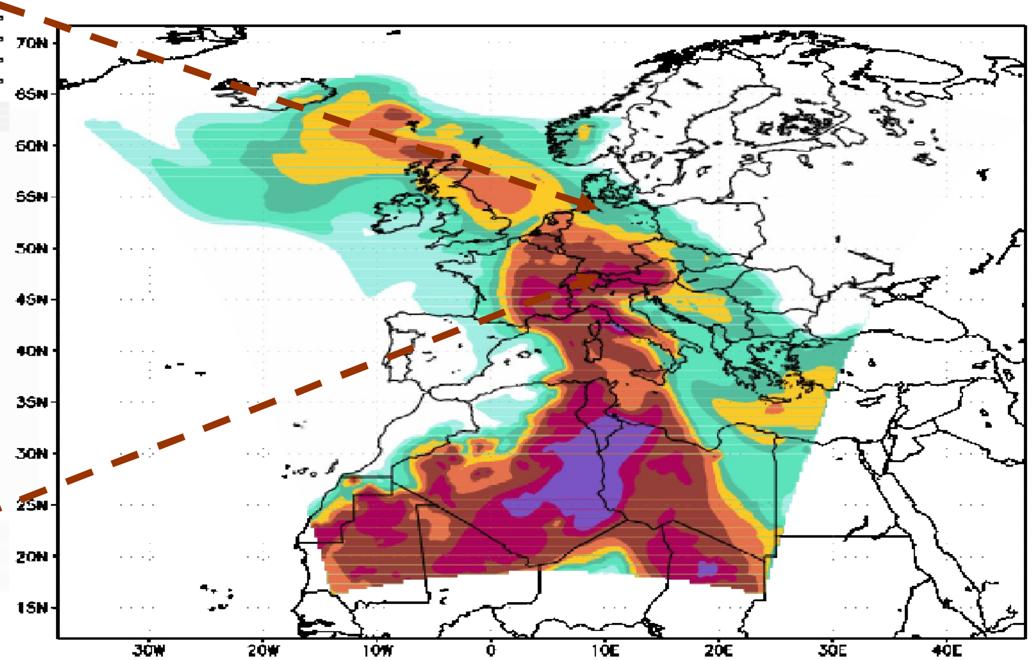
Perez et al, 2006

Figure 10. Vertical cross-sections between latitudes 30°N and 40°N along longitude 12°E of (a) the extinction coefficient at 550 nm from RAD and (b) the atmospheric temperature difference between RAD and CTR on the 12 April 2002 at 1200 UTC. (c) Horizontal distribution of 2m temperature difference over the whole domain.

A Large Dust Transport Event Into Central Europe May 2008

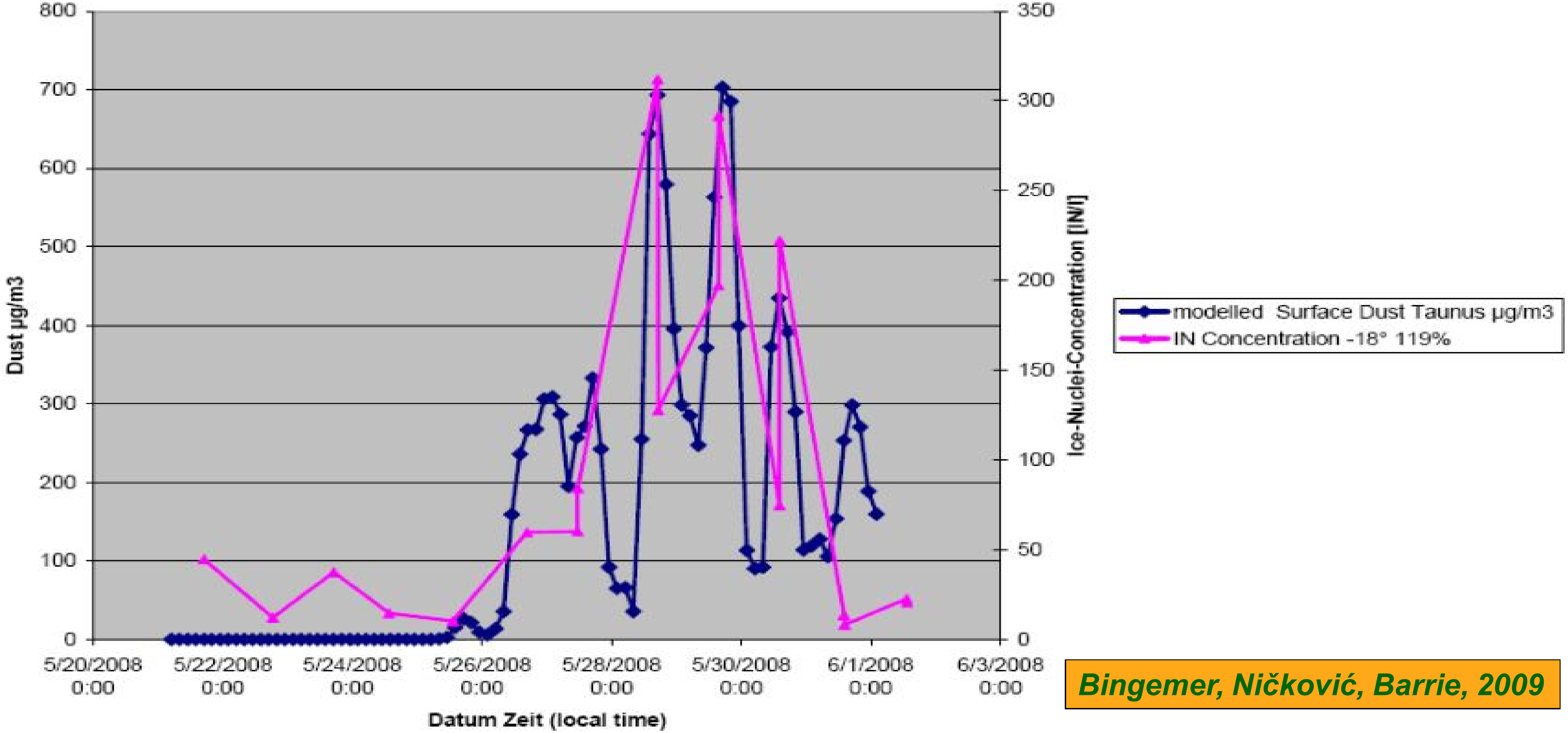


Dust-measurements (PM10) –
29.05.08 (German Environ. Service)
[Klein et al. 2008]



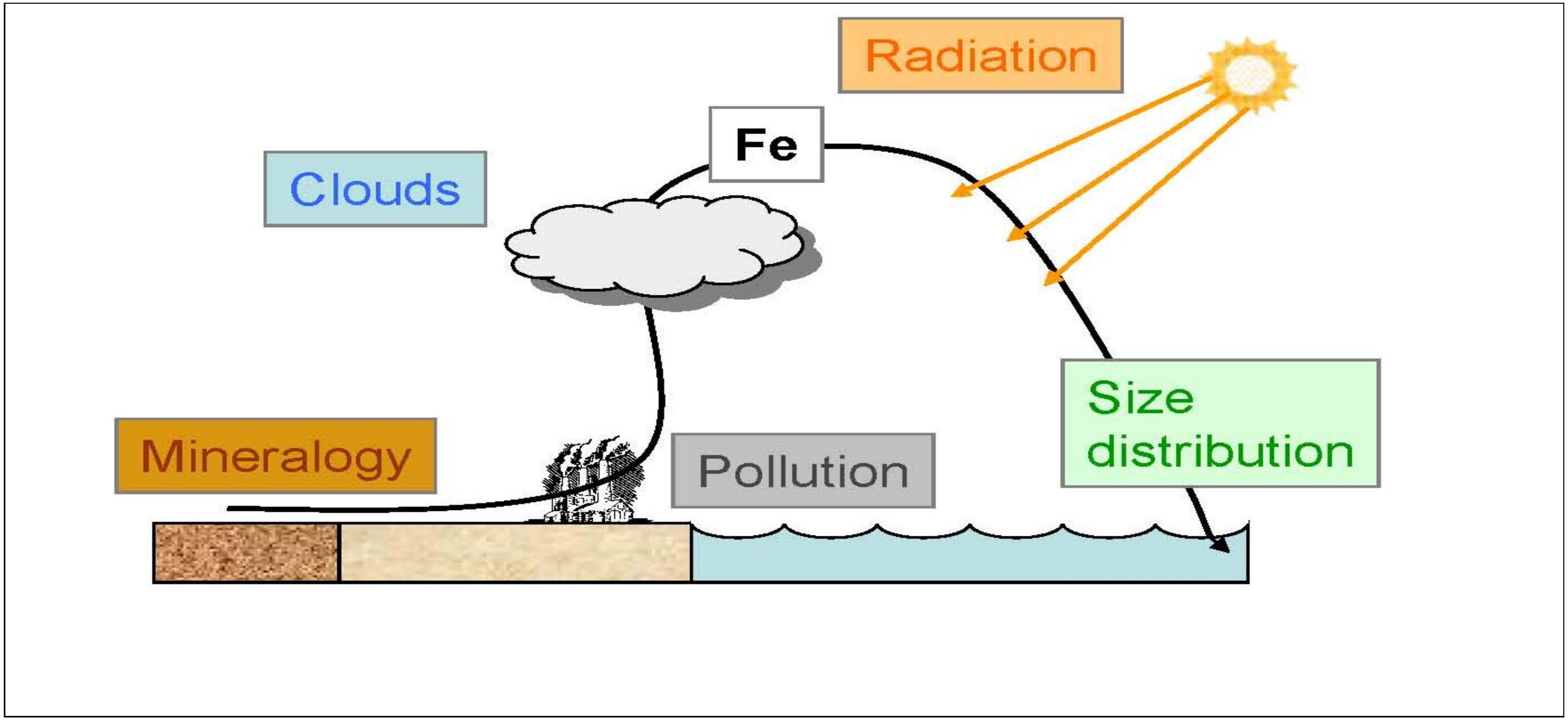
Dust surface concentration- simulation 29.05.08
(DREAM model)
[Bingemer, Ničković, Barrie, 2009]

Comparison of DREAM Model Aerosol Mass with Ice Nuclei Measurements at Kleinerfeldberg Frankfurt 20 May – 3 June 200



Bingemer, Ničković, Barrie, 2009

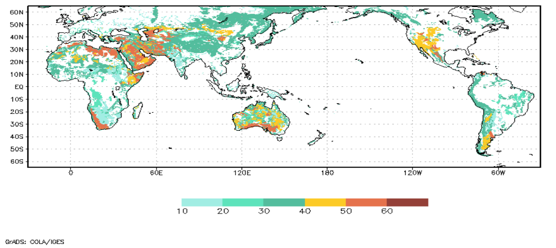
ATMOSPHERIC IRON PROCESSING AND OCEAN PRODUCTIVITY



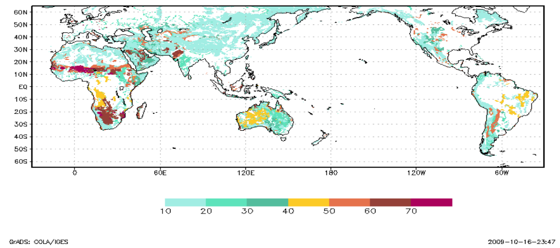
Significance of mineral composition in desert soils

- Fe and P embedded in dust → ocean nutrients
- Cloud ice nucleation sensitive to mineral composition
- Hypothesis: Fe as an enhancement factor in meningitis outbreaks (Thompson, 2008)

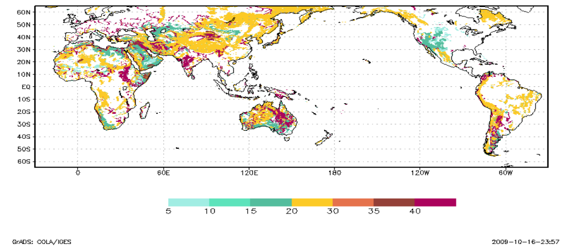
Illite



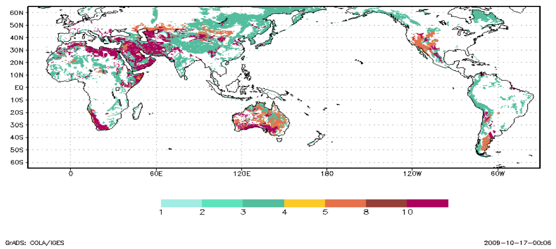
Kaolinite



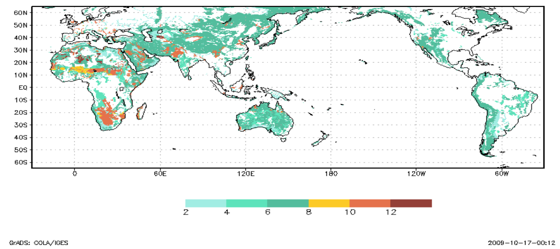
Smectite



Calcite



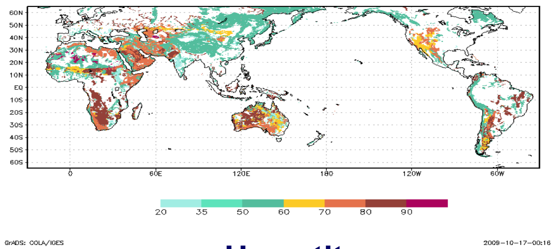
Quartz



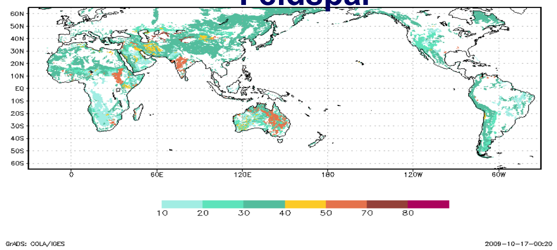
Clay soils

Silt soils

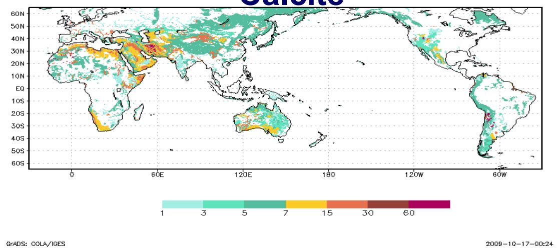
Quartz



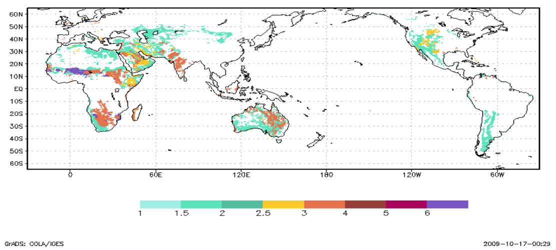
Feldspar



Calcite



Hematite



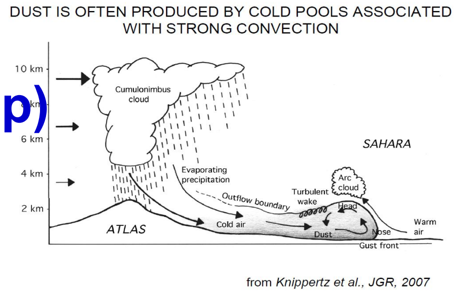
Global 1km resolution Mineral Database:
Fe-containing minerals (Ničković et al, 2012),
Database available from: http://www.seevccc.rs/GMINER30/

Phoenix (Arizona) Haboob, 5 July 2005

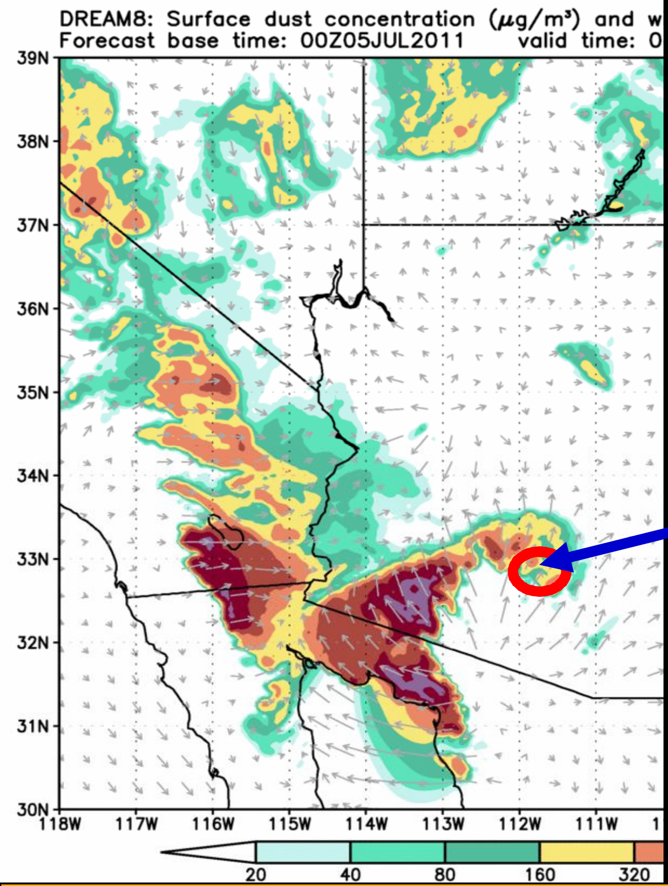
7:45 PM
Phoenix as the dust storm neared.

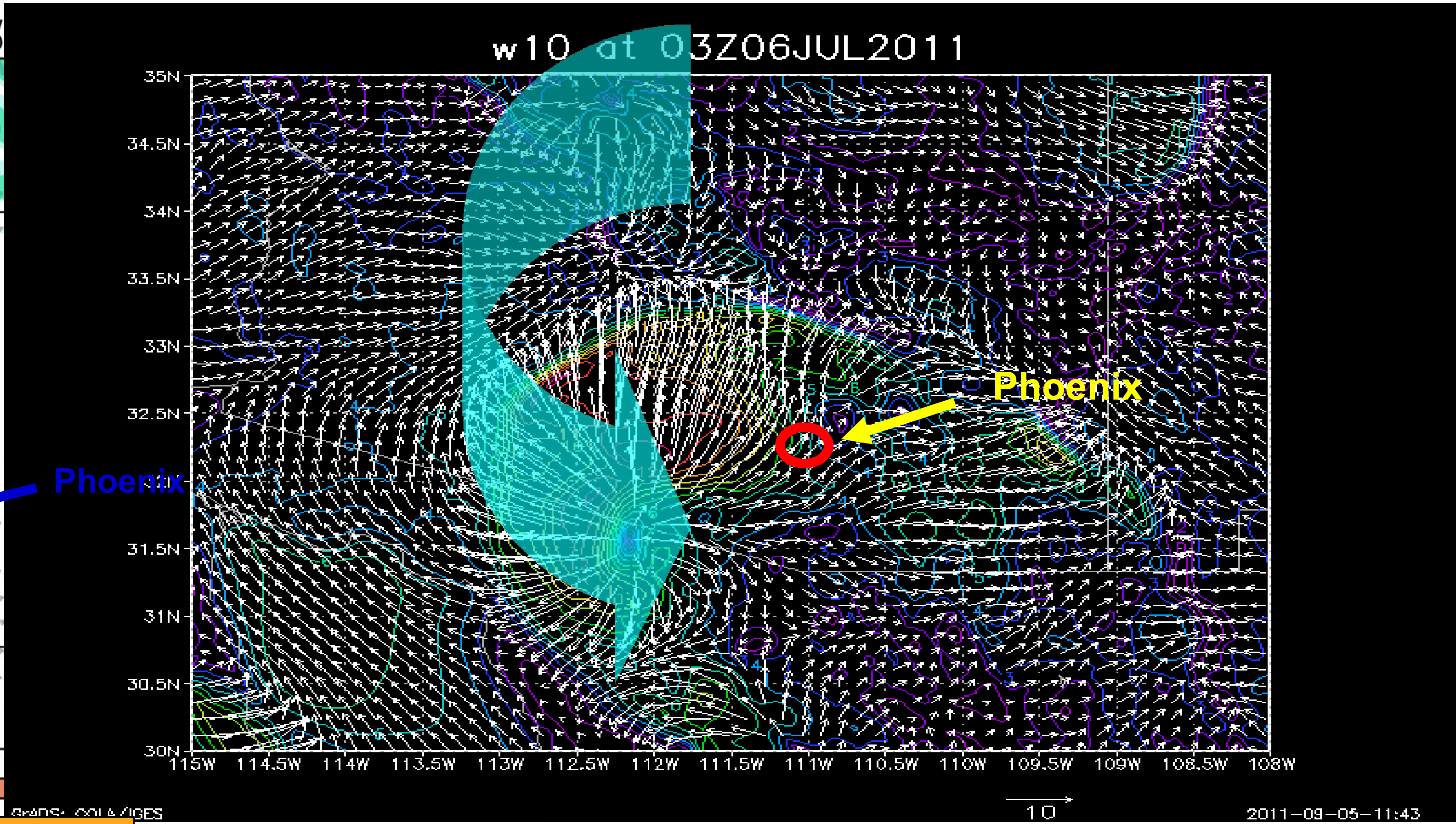
W.A.Sprigg, S. Ničković, G. Pejanović, J. Galgiani, A. Vuković

Successful simulation of the Phoenix Haboob: NMME-DREAM
(collaboration: SEEVCCC and Chapman University dust modeling group)



DUST SIMULATION: 6-km model





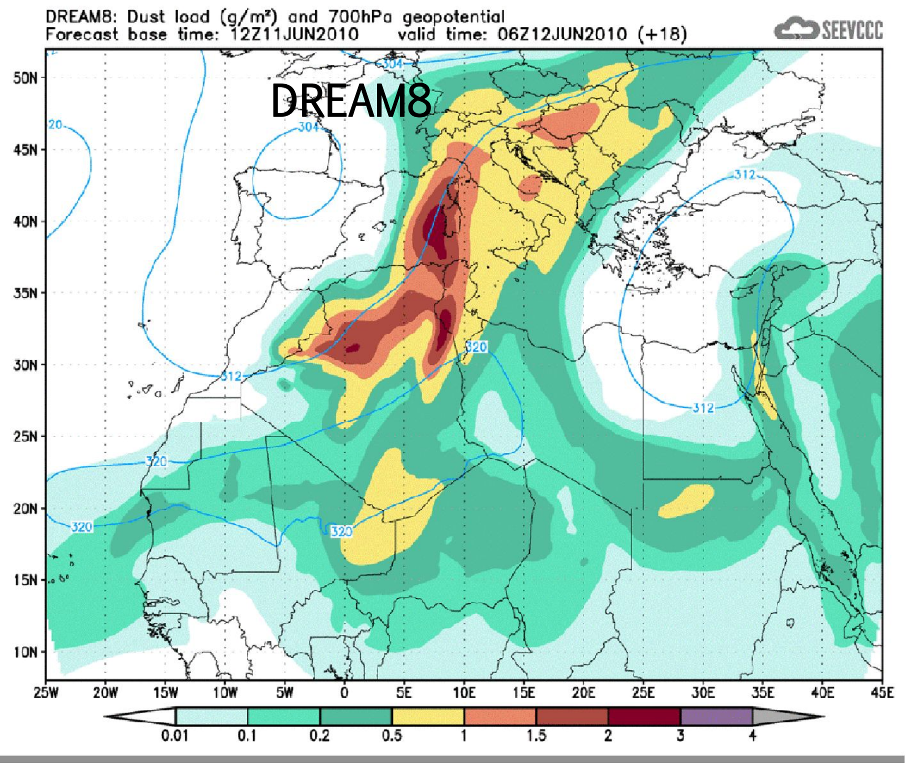
W.A.Sprigg, S. Nickovic, G. Pejanovic, A. Vukovic

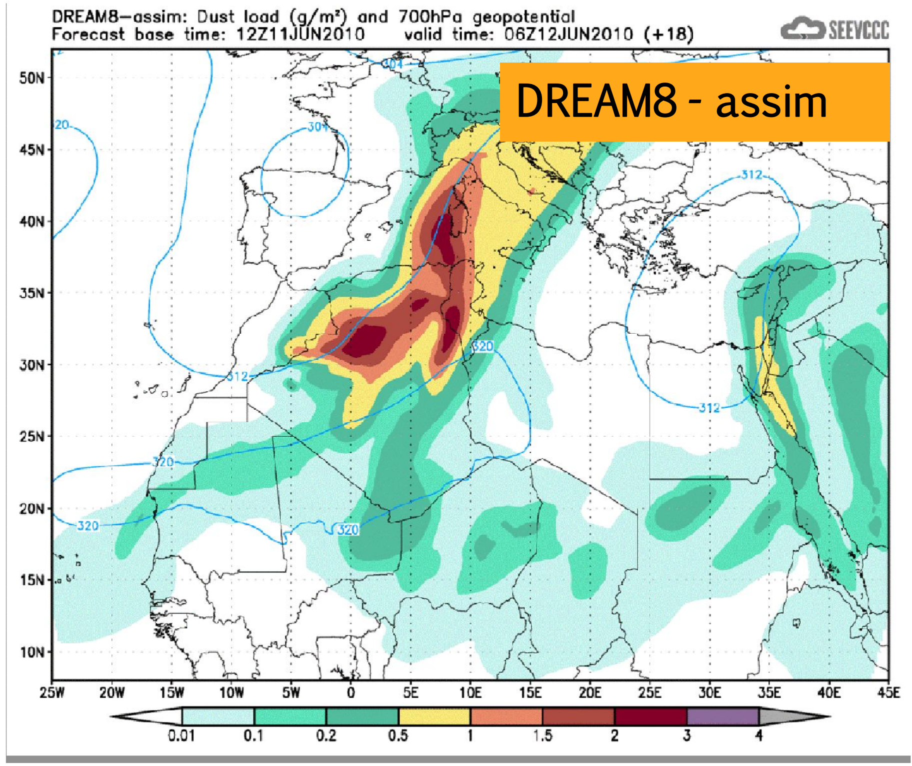
Operational dust forecast: DREAM + dust assimilation

DREAM8: DUST REGIONAL ATMOSPHERIC MODEL
WITH 8 CATEGORIES FOR PARTICLE SIZES

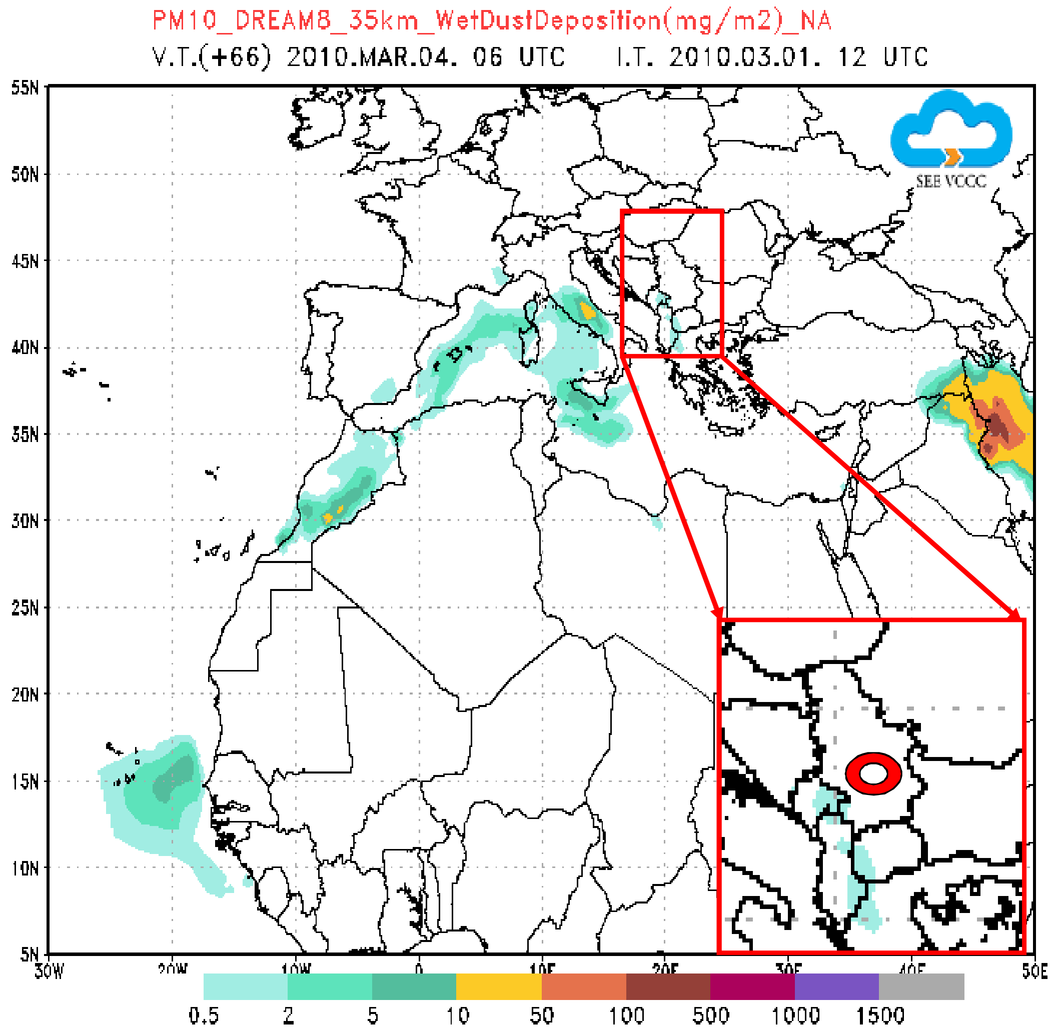
model run from June 11th 2010 12UTC

- **model runs:** 12UTC start ; +72h forecast
- **model resolution:** 1/3 degrees (~35km)
- **models:** DREAM8 and DREAM8-assim
(assimilation using ECMWF dust aerosol analysis)

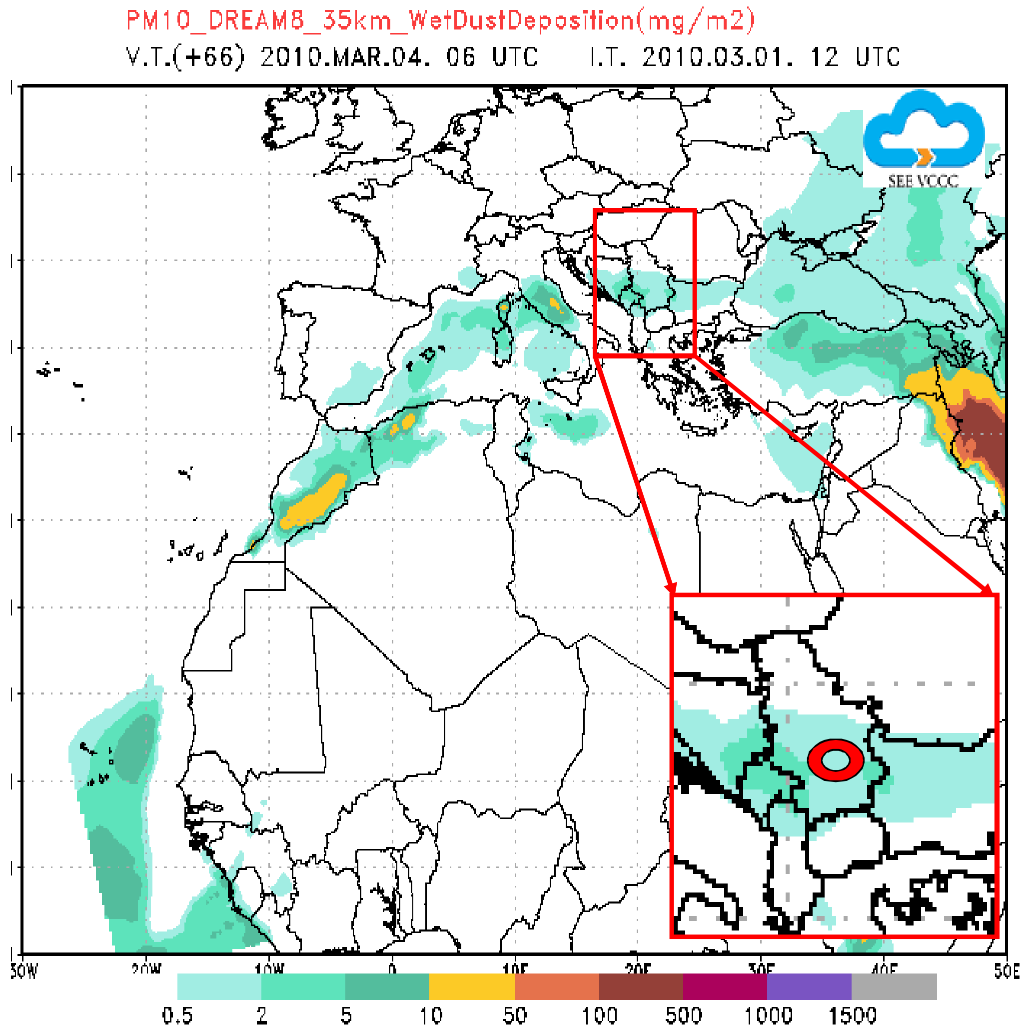




WET DEPOSITION
NO ASSIMILATION



WET DEPOSITION
ASSIMILATION



04 March 2010
Case of yellow snow observed in the Kopaonik ski resort (location marked with)

Fennec Project: Dust Forecast

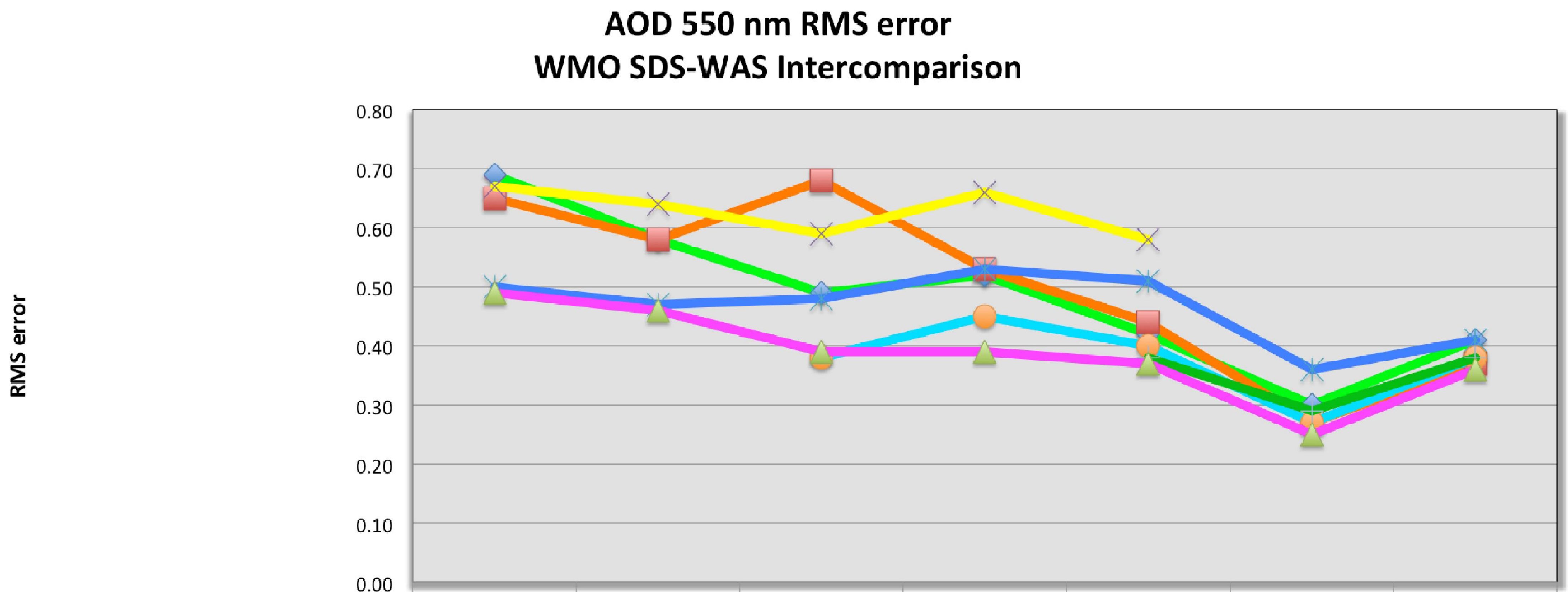
SEEVCCC

FENNEC is a consortium project involving Universities of Oxford, Leeds, Reading, Mainz, Cologne, University College London, UK Met Office, Institute Pierre-Simon Laplace and Laboratorie d'Aerologie.

Main goals of the project are better understanding of processes characterizing Saharan climate and dynamics of desert planetary boundary layer, as well as determining mechanisms of dust emission.
In order to fulfill these aims, **several measuring campaigns were carried out providing additional measurements of meteorological parameters and dust aerosol in Sahara**.

Although not formally participating in FENNEC, **SEEVCCC** supported the project by providing dust forecasts during field measurement campaigns. Forecasts were issued twice per day.

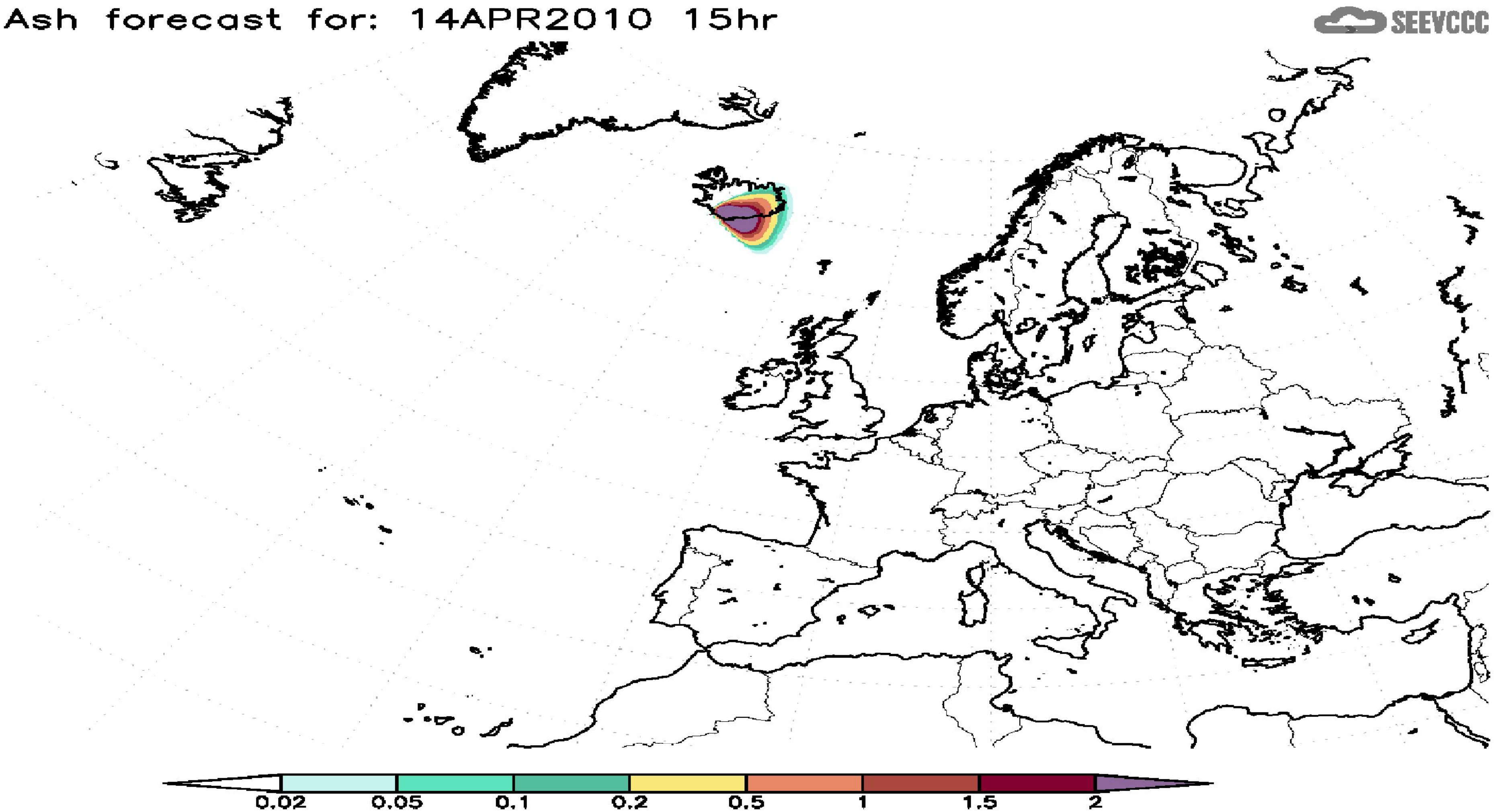
forecasts available on
http://www.seevccc.rs/FENNEC
http://www.fennec.imperial.ac.uk/



	Mar	Apr	May	Jun	Jul	Aug	Sep
BSC_DREAM8b (Barcelona)	0.69	0.58	0.49	0.52	0.42	0.3	0.41
MACC-ECMWF (Reading)	0.65	0.58	0.68	0.53	0.44	0.27	0.37
CHIMERE (Palaiseau)	0.67	0.64	0.59	0.66	0.58		
NMMB/BSC-Dust (Barcelona)	0.5	0.47	0.48	0.53	0.51	0.36	0.41
U.K. MetOffice (Exeter)			0.38	0.45	0.4	0.27	0.38
NASA GEOS-5					0.38	0.29	0.38
DREAM8-NMME-SEEVCCC (Belgrade)	0.49	0.46	0.39	0.39	0.37	0.25	0.36

DREAM model – experimental forecast of volcanic ash

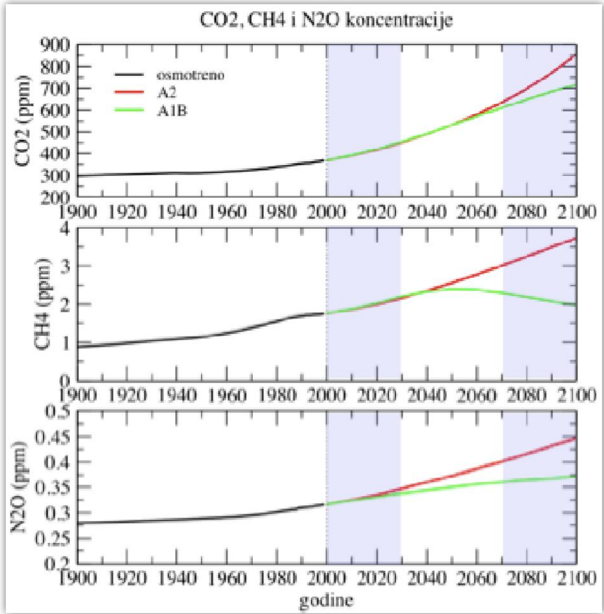
Eyjafjallajokull eruption (starting date: April 14th 2010) - animation



Climate projections performed with

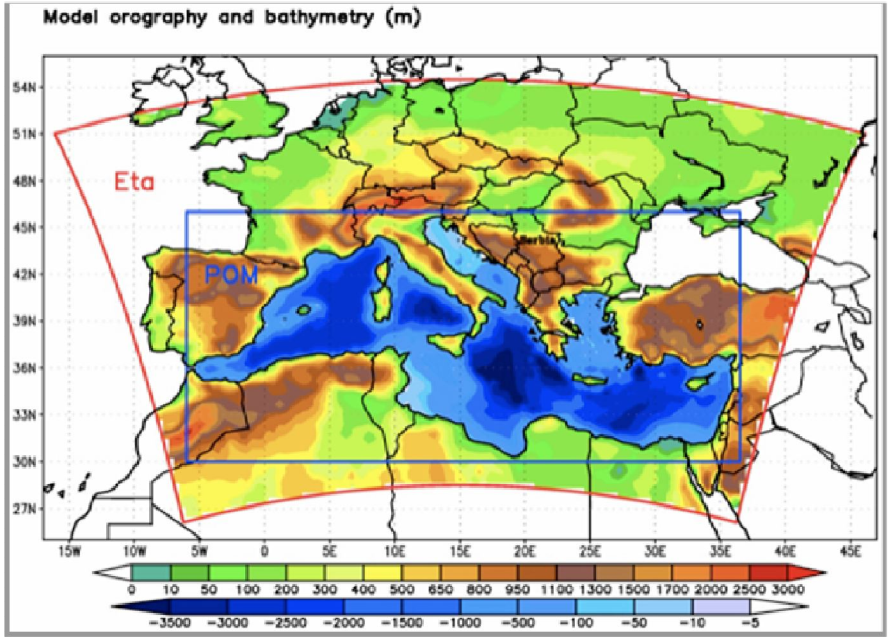
RCM – SEEVCCC:

- **fully coupled atmosphere – ocean model**
- Euro-Mediterranean region
- resolution: ~35km atmosphere ; ~20km ocean
- initial and boundary conditions: SINTEX-G, 120km



RCM-SEEVCC climate runs are used for climate change impact studies in different sectors:

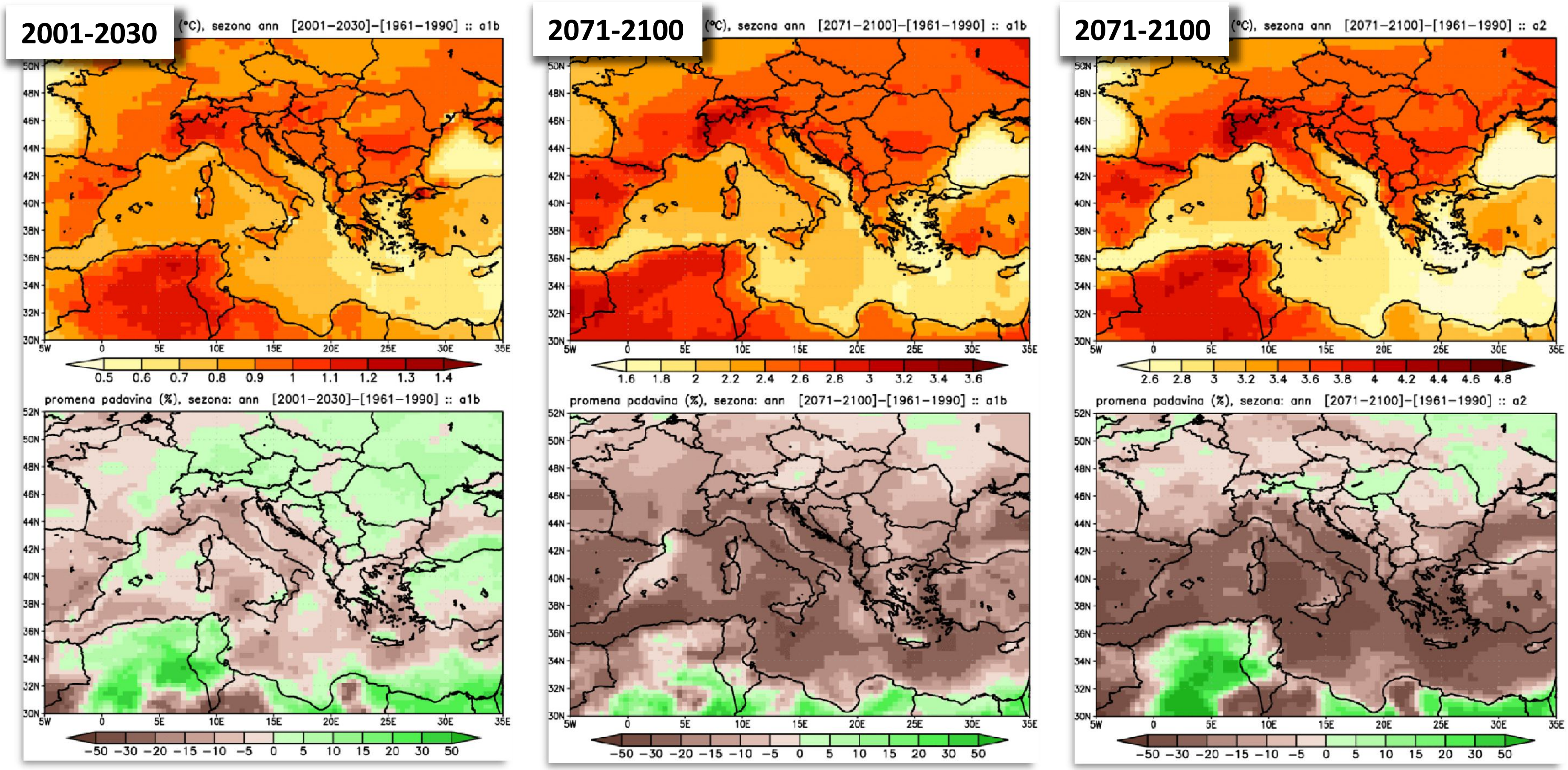
- agriculture
- forestry
- hydrology
- energy
- human health



Experiment	Time slice
20c3m (present climate)	1961-1990
A1B SRES	2001-2030, 2071-2100
A2 SRES	2071-2100

Djurdjević and Rajković (2008, 2010)

Annual temperature and precipitation change:



SEASONAL FORECAST

- Seasonal forecast is scientifically based approach for providing information on climate characteristics for several months or several seasons ahead. Seasonal forecast has much in common with numerical weather prediction (NWP) in sense that both approaches relay on numerical integration of complex hydrodynamics equations.
On the other hand, seasonal forecast's goal is mainly to predict monthly and seasonal anomalies from long term climatology, rather than to provide a day to day forecasts of weather patterns, as it is the case in NWP. For further reading please ECMWF web page on this topic.

- SEEVCCC started to issue seasonal forecast for South East Europe region from June 2009. The system is based on dynamical downscaling of ECMWF seasonal forecast, using a regional atmosphere-ocean coupled model (RCM-SEEVCCC). The forecast consists of 41 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.

Long Range Forecast – Seasonal forecast

- **Probabilistic forecast**

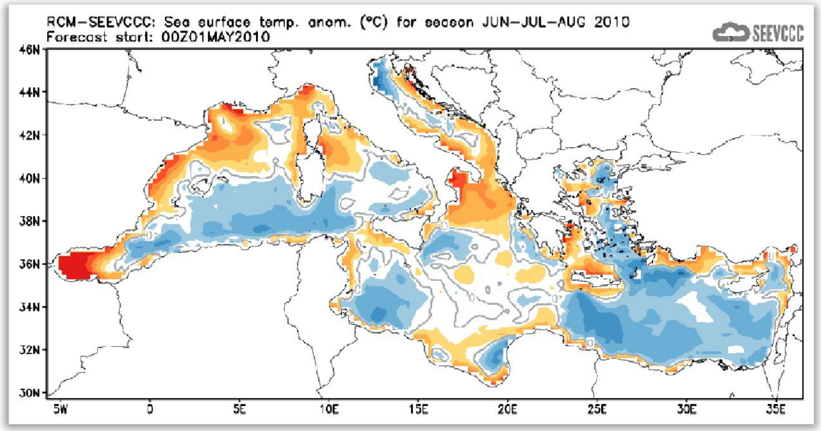
regional dynamical downscaling using fully coupled atmosphere-ocean Regional Climate Model

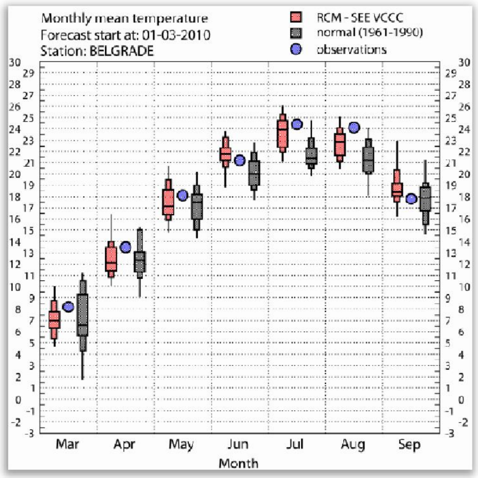
- **RCM-SEEVCCC LRF**

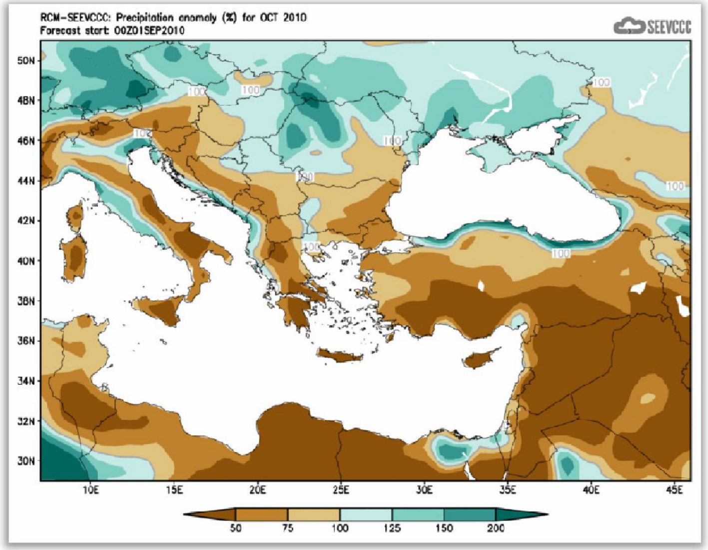
provides statistical summary of the atmosphere and ocean state in forthcoming season.

- model start: 16th of each month
- forecast duration: 7 months (~215 days)
- model resolution: ~35km atmosphere ; ~20km ocean
- model domain: Euro - Mediterranean region extended towards Caspian Sea
- **51 ensemble members!**
- initial & boundary conditions: ECMWF, ~75km

data soon available in GRIB form for partner countries



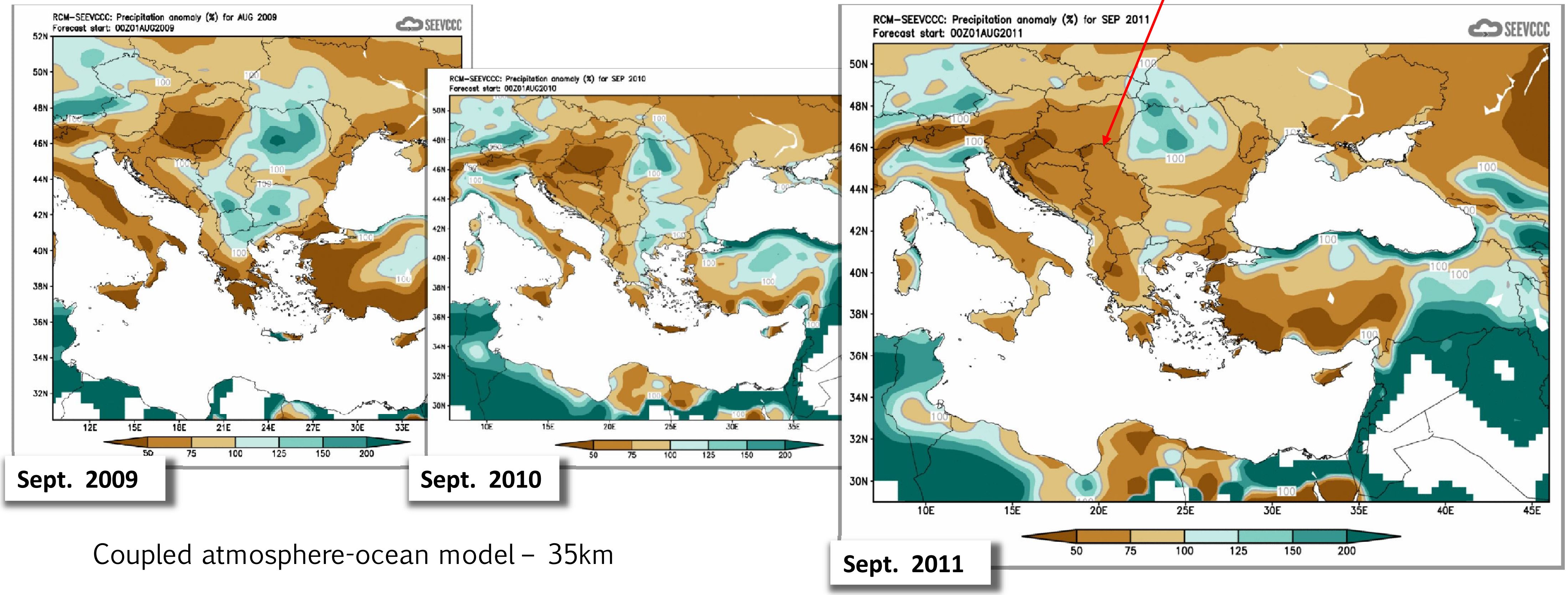




http://www.seevccc.rs/

LRF forecast RCM - SEEVCCC model

Rainfall deficiency in September 2011



Sept. 2009

Sept. 2010

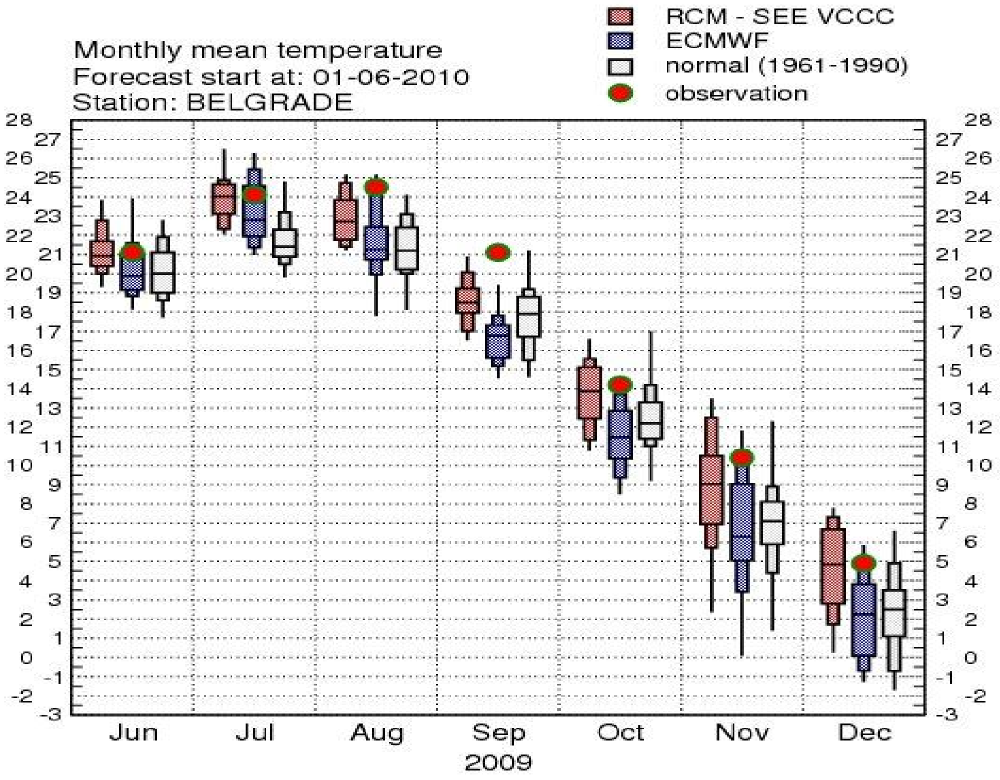
Sept. 2011

Coupled atmosphere-ocean model – 35km

Seasonal Ensemble Forecast example: issued at June 2009

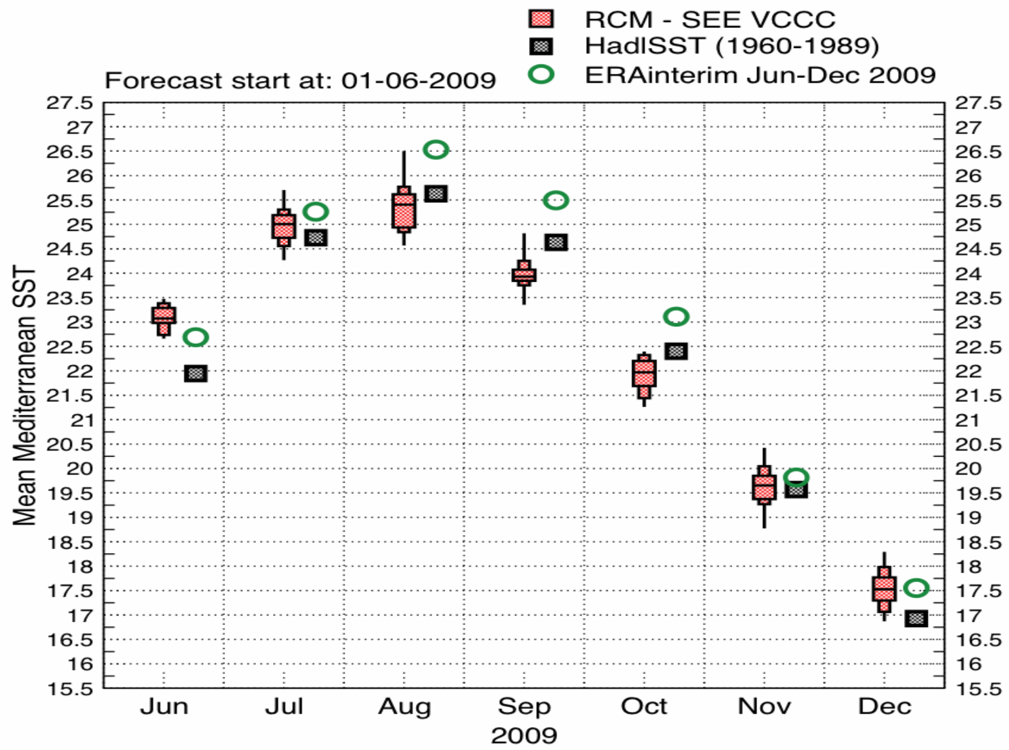
Monthly mean 2m temperature, Belgrade

RCM-SEEVCCC .vs. ECMWF .vs. climatology .vs. observations

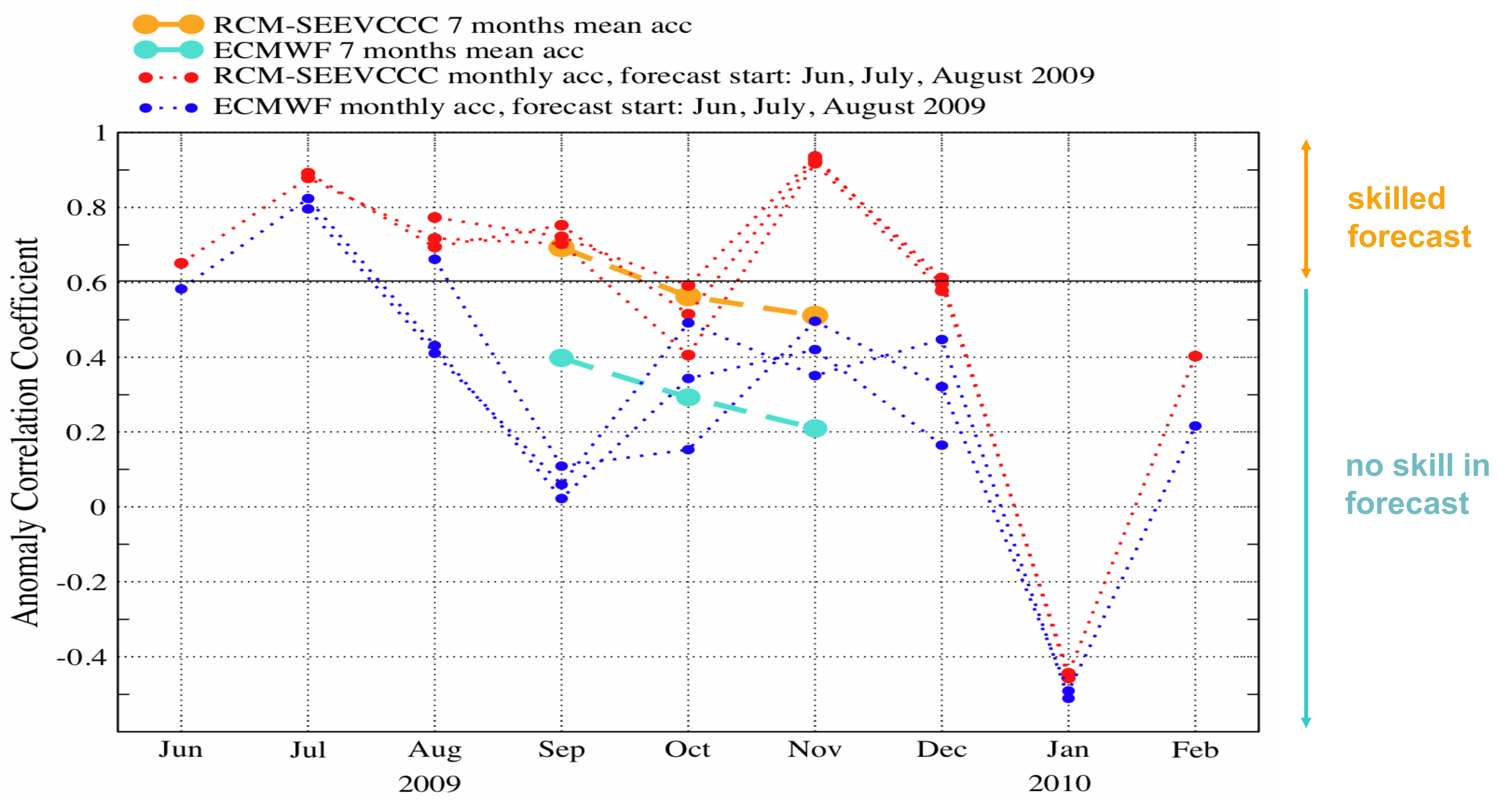


Monthly mean Mediterranean SST

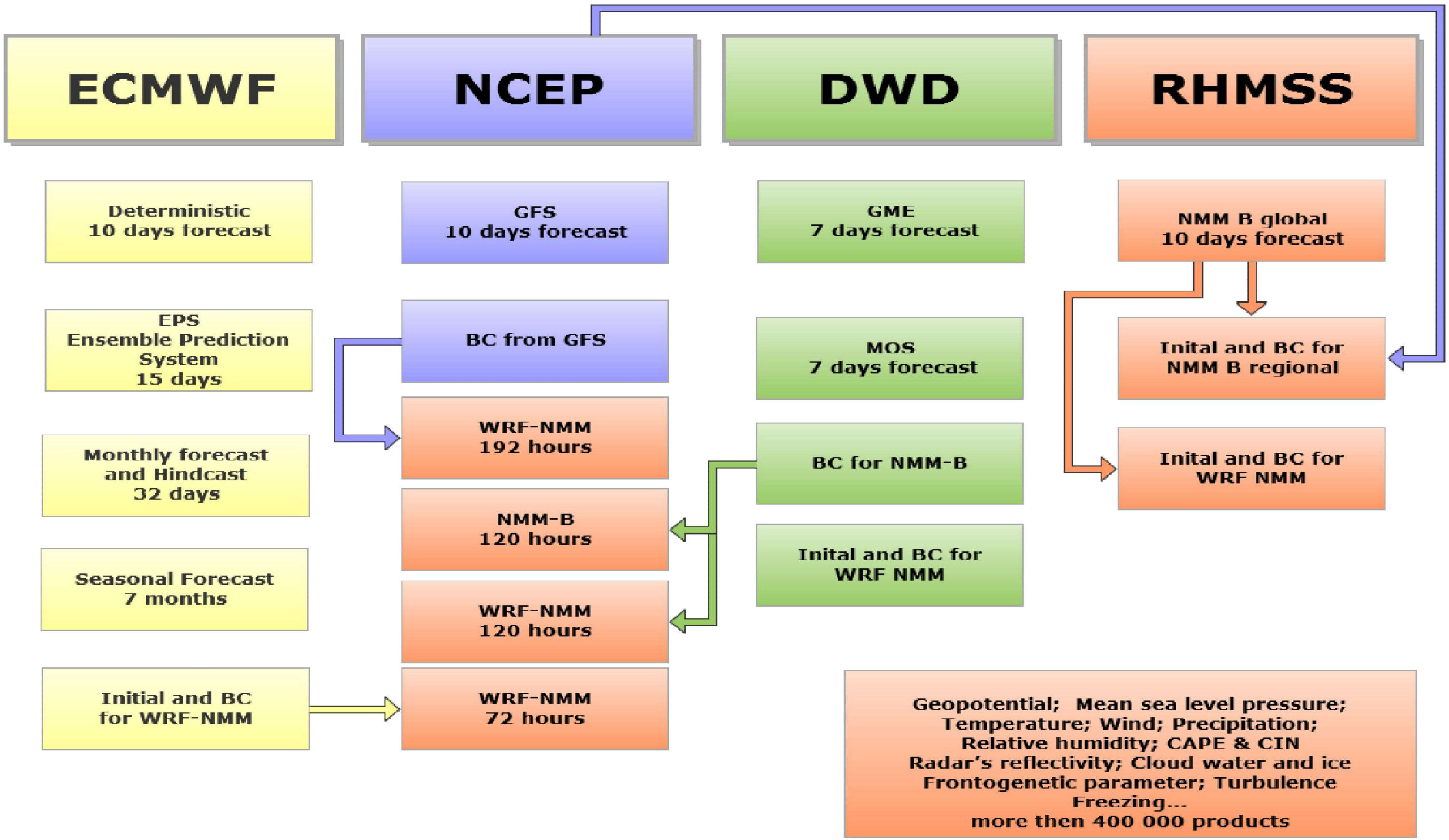
RCM-SEEVCCC .vs. Hadley obs .vs. ERAinterim reanalysis



Seasonal Ensemble Forecast – ACC score



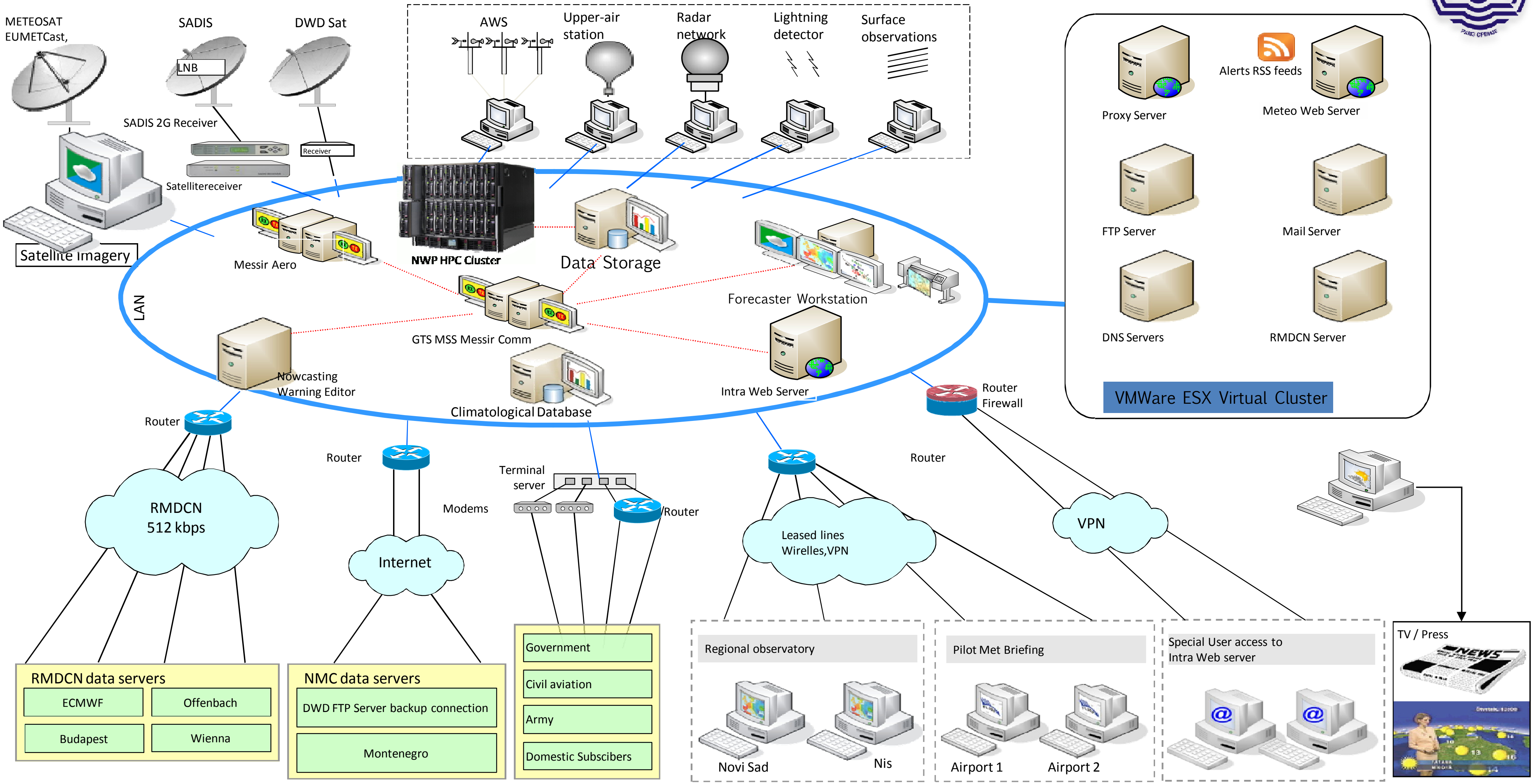
Republic Hydrometeorological Service Of Serbia



DCPC-Belgrade and RCC operational functions

- collecting climate data, monitoring and detecting climate change in SEE
- development of seasonal and long range forecast
- climate watch and issuing warnings on the occurrence of climate anomalies and extremes
- climate database management and exchange of data and information
- development and implementation of regional climate models for climate projections
- development and implementation of regional climate models for seasonal climate forecast
- use of regional climate models for downscaling and/or regional reanalysis

Computer and Telecommunication system of the NMS of Serbia



“Super”computing facilities

HPC cluster in RHMS Serbia

Credit to Michael Lough, Hewlett-Packard

HP Old cluster 2007

16 BL2x220c servers in a C7000 chassis
32 compute nodes
Infiniband based (interconnection 20 Gb/s)
16 are G5 (Each compute node is equipped with two Intel Quad-core Xeon E5450 processors running at 3.0 GHz along 16 GB of DDR2 memory) (Nehalem processors)
16 are G6 (Each compute node is equipped with two Intel Quad-core Xeon E5620 processors running at 2.4 GHz along 16 GB of DDR2 memory) (Nehalem processors)

HP New cluster 2012

Infiniband based (interconnection 40 Gb/s)
G7 32 BL2x220c servers in a C7000 chassis (Each compute node is equipped with two Intel 6-core Xeon E5645 processors running at 2.4GHz along 24 GB DDR3 memory) (Westmere processors)

Scalability

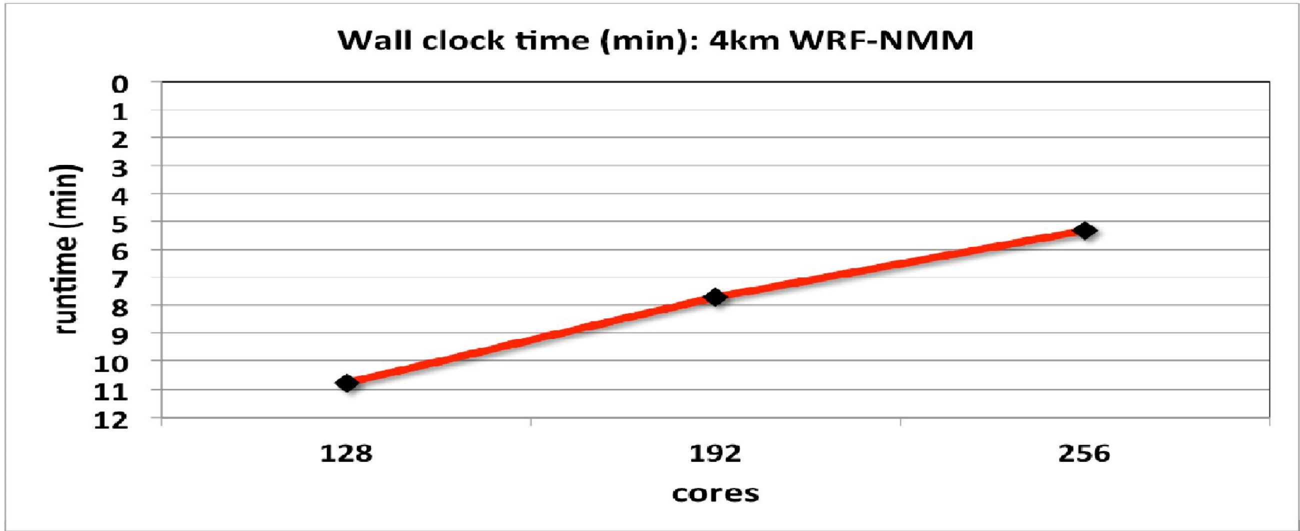
Scalability – WRF NMM

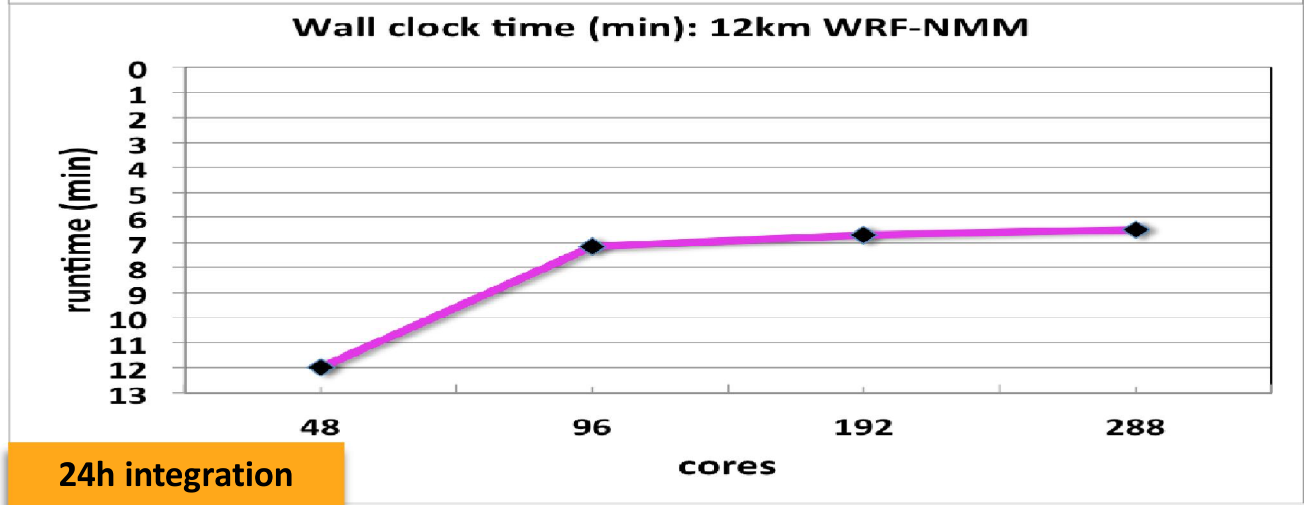
Switching from 128 to 256 cores decreased runtime **2x**

applied to WRF NMM regional model
with resolution of 4km and 220x290 points

Switching from 48 to 96 cores decreased runtime **1,67x**

applied to WRF NMM regional model
with resolution of 12km and 260x500 points





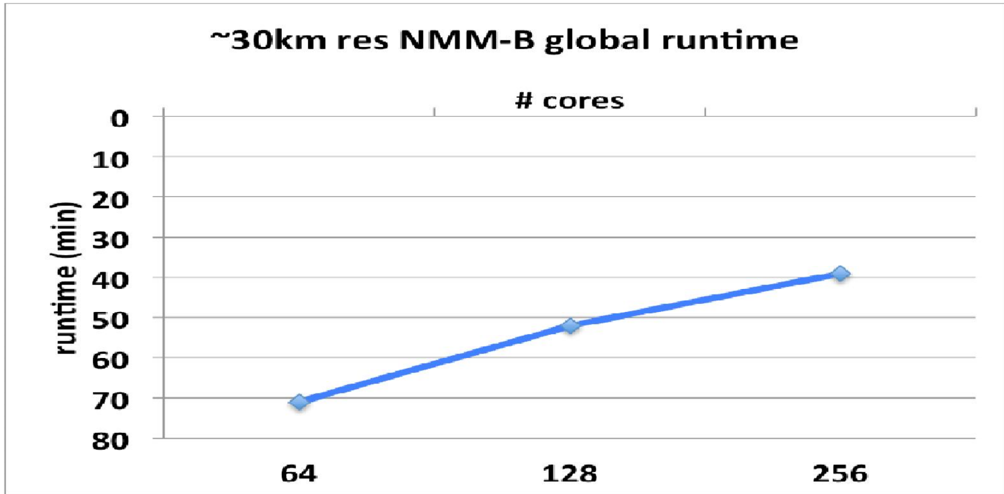
Scalability NMM-B

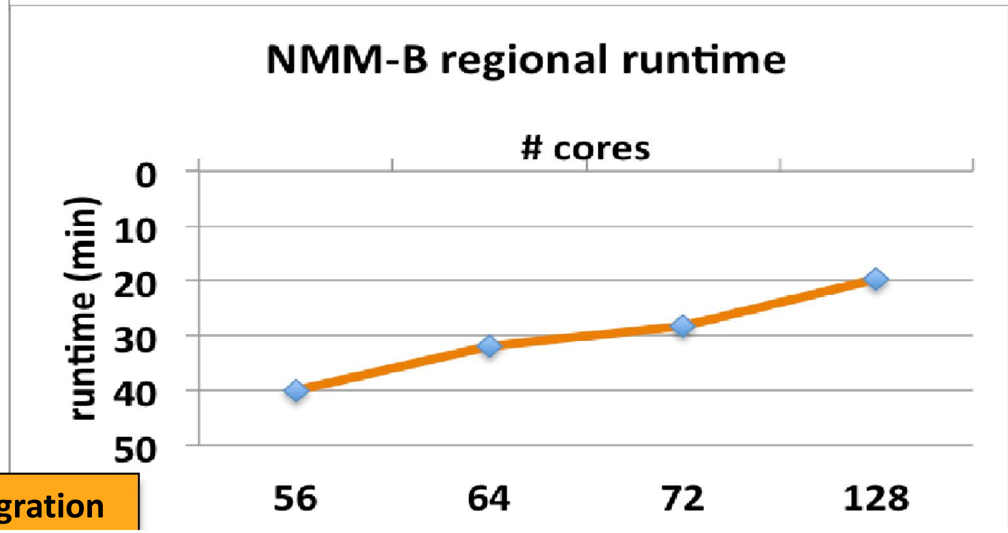
Switching from 64 to 256 processors decreased runtime **1,8x**

applied to NNMB global model;
resolution 769 x 541 points

Switching from 56 to 128 processors decreased runtime **2 x**

applied to NNMB regional model;
resolution 481x385 points



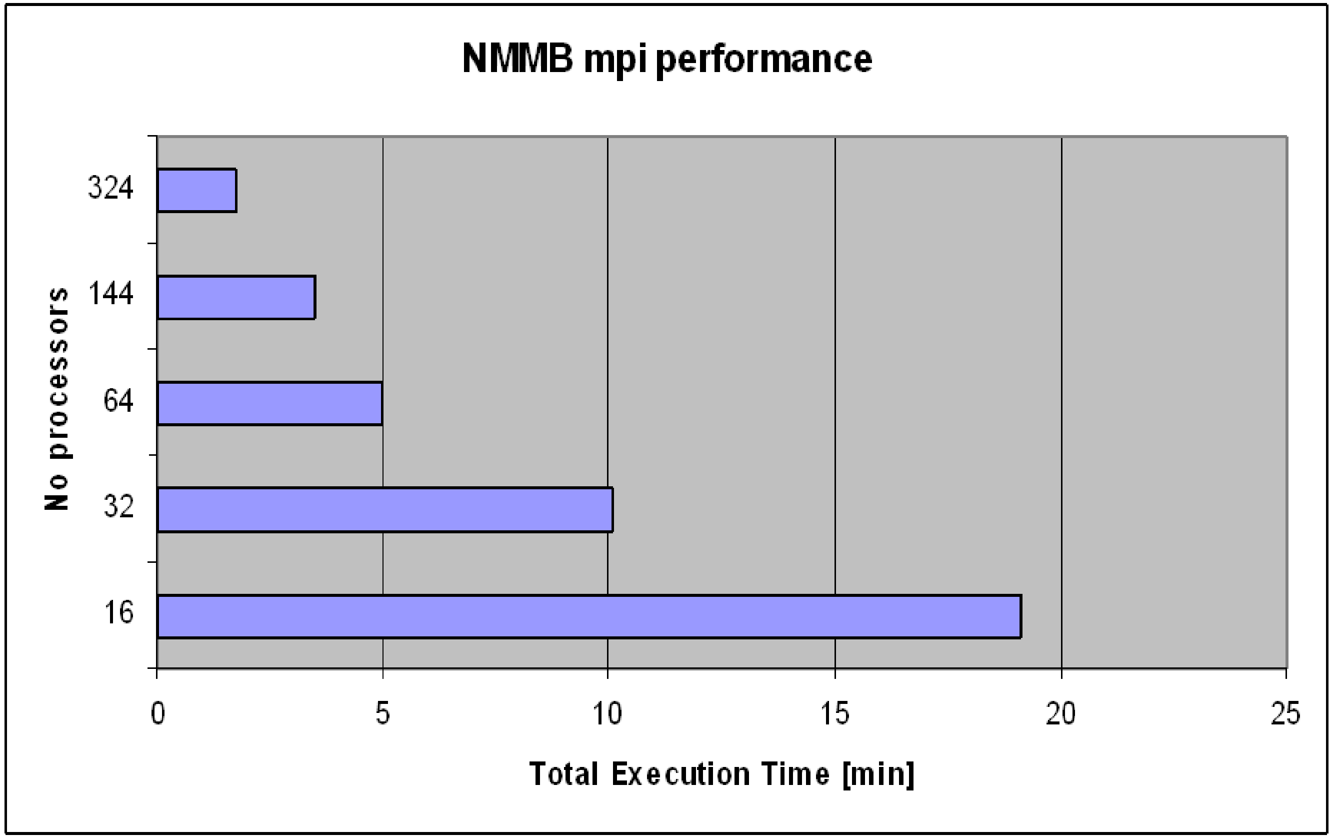


48h integration

Scalability NMM-B regional

Switching from 16 to 324 cores decreased runtime **10 x**

applied to NNMB regional model
resolution: 289x241x64;
Horizontal res: 9km;
Time step: 20 sec



12h integration

Scaling on Zeus/NOAA

Courtesy of
Prof. Zaviša Janjić
(NOAA/NCEP)

(Zeus - A 382 Tflop SGI based high performance computing system)

- Global, *nonhydrostatic*, full physics
- Resolution 1149 x 811 x 64, ~ 24 km
  - 500 processors, 7.9 wall clock min/day
  - 1000 processors, 4.7 wall clock min/day
  - 2000 processors, 3.3 wall clock min/day
  - 4000 processors, 2.8 wall clock min/day,
    (1 year of simulation in < 17 hours, climate studies?)

Courtesy of
Prof. Zaviša Janjić
(NOAA/NCEP)

Scaling on Zeus/NOAA

(Zeus - A 382 Tflop SGI based high performance computing system)

- Global, *nonhydrostatic*, full physics
- Resolution 2305 x 1623 x 64, ~ 12 km
  (8 x more work than 1149 x 811 x 64, ~ 24 km)
  - 3600 processors, 7.6 wall clock min/day
  - Super scaling!

Courtesy of
Prof. Zaviša Janjić
(NOAA/NCEP)

Scalability – NMM-B

NMM-B, global, nonhydrostatic, full physics

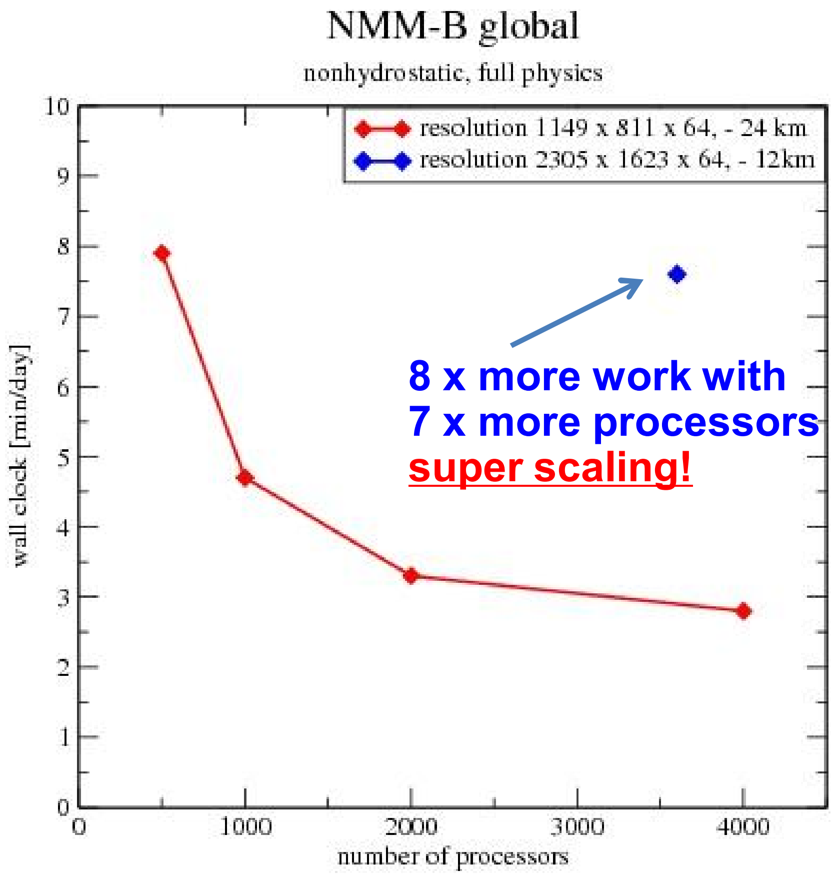
Resolution: 1149 x 811 x 64 ~ 24 km

4000 cores – 2.8 min/day
1 year of simulation in < 17 hours, climate studies?

Resolution: 2305 x 1623 x 64 ~ 12 km

requires 8 x more work then 24 km resolution
same time as 24 km simulation with 7 x more processors!

Technology for ~ 10 km resolution operational global forecasts already exists! Resolutions less than <10 km possible soon.



РХМЗ СРБИЈЕ

Thank you.