Analysis of the downscaled ERA40 reanalysis performed with the NMMB model

Vladimir Djurdjević and Aleksandra Kržič

DELIVERABLE INFORMATION	
WP:	WP3 Mapping and Harmonising Data & Downscaling
Activity:	3.4 Development of downscaling scenarios
WP Leader:	RHMSS
Activity leader:	RHMSS and CMCC
Participating partners:	RHMSS and CMCC
Authors:	Vladimir Djurdjević and Aleksandra Kržič
E-mail:	vdj@ff.bg.ac.rs aleksandra.krzic@hidmet.gov.rs

Content

List of figures

1. Introduction

One of the tasks of WP3 Mapping and Harmonizing Data & Downscaling is to develop downscaling scenarios. The first step, prior to creating the scenarios, is to perform simulation of the present climate and to verify regional model performance under so-called perfect boundary settings.

In this report, we have presented capability of NMMB regional climate model to simulate present climate. Perfect boundary conditions, ERA40 reanalysis, are used for simulation. Simulations are done for the period 1971-2000 and two resolutions of 14 and 8 km. Low resolution model domain (Figure 1.1 green) covers the whole project area while high resolution simulation is done on the smaller domain covering four pilot areas – Covasna and Caracal county in Romania and Budapest and Veszprem in Hungary (Figure 1.1 purple).

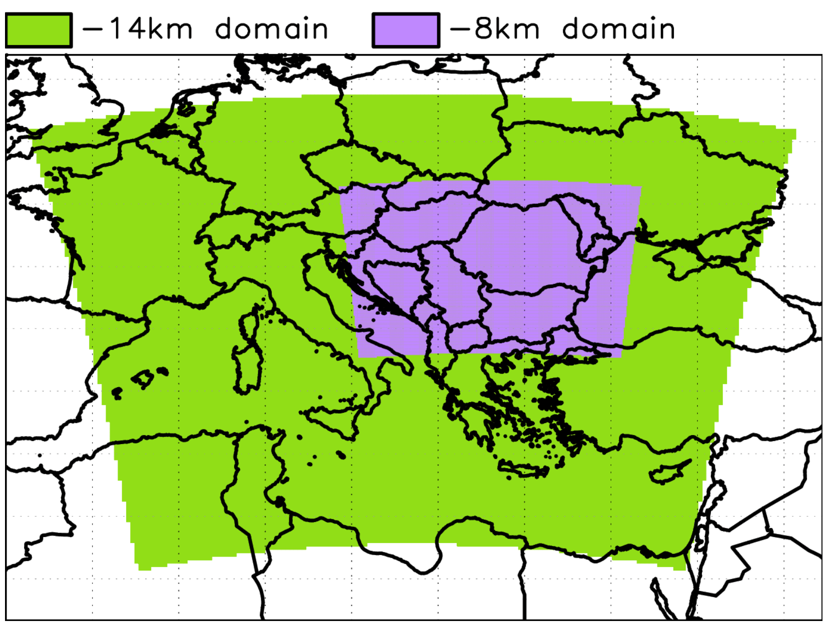

Figure 1.1 Model domains

2. The regional climate model NMMB

In recent years, the unified Non-hydrostatic Multi-scale Model (NMMB) developed at NCEP (Janjic, 2005; Janjic and Gall, 2012; Janjic et al., 2011, 2013), has been used for a number of operational and research applications in Republic Hydrometeorological Service of Serbia (Djurdjevic et al., 2013). The NMMB can be run as a global and as a regional model. The global version is run on the regular latitude-longitude grid while the regional version uses rotated latitude-longitude grid. In addition, there is a possibility to run model in a global setup with several on-line nested regional domains, which can be stationary or moving depending on user choice.

The main characteristics of the model dynamical core are that horizontal differencing preserves many important properties of differential operators and conserves a variety of basic and derived quantities including energy and enstrophy (Janjic and Gall, 2012). Model also includes the novel implementation of the nonhydrostatic dynamics (Janjic et al., 2001; Janjic, 2003). Vertical coordinate in model is sigma p-hybrid coordinate.

For grid-scale convection parameterization Betts-Miller-Janjic scheme (BMJ) is implemented (Betts, 1986; Betts and Miller, 1986; Janjic, 1994) and for turbulence model use Mellor-Yamada-Janjic (MYJ) turbulence closure sub-model (Mellor and Yamada, 1974; Mellor and Yamada, 1982; Janjic, 1990). For radiation user can choose between two radiation schemes, rapid radiative transfer model (RRTM) (Mlawer et al., 1997) and Geophysical Fluid Dynamics Laboratory (GFDL) radiation model (Fels and Schwarzkopf, 1975; Lacis and Hansen, 1974). Also two land surface packages are available, NOAH land surface model (Ek et al.,2003) and Land Ice Seas Surface model (LISS) (Vukovic et al., 2010, Janjic, 1996). Finally, for cloud microphysics two packages are also available, cloud microphysics scheme of Ferrier et al. (2002) and microphysics following Zhao and Carr (1997).

The regional version of the NMMB recently replaced the WRF NMM as the main NCEP's operational short range forecasting model for North America (NAM).

3. Methodology

3.1 Data

Verification of the regional climate model NMMB performance is done by verifying important features of four key variables: daily and monthly mean temperature and daily and monthly accumulated precipitation. For this purpose four datasets are used: ERA40, E-OBS, CARPATCLIM and observations.

ERA-40 is an ECMWF re-analysis of the global atmosphere and surface conditions which cover 45-year period, from September 1957 to August 2002. Resolution of used data is 2.5x2.5° and 6h in the space and time, respectively.

E-OBS is a European land-only daily high-resolution gridded data set for precipitation, surface temperature and sea level pressure for the period 1950–2006 and resolution of 25 km (Haylock et al., 2008). After the ENSEMBLES project ended, ECA&D staff continued to maintain and update the E-OBS gridded dataset.

Since low resolution of ERA40 and low density of stations, especially for precipitation, over south-east Europe in E-OBS (Figure 3.1), more detailed datasets from CARPATCLIM project were used as well as observations for Serbia.

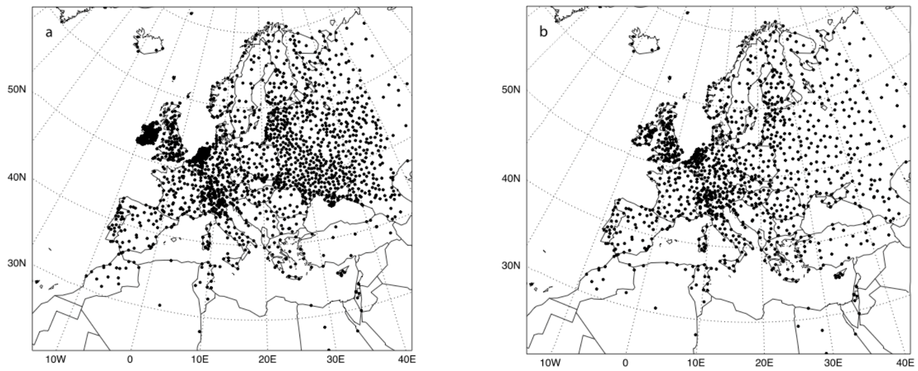

Figure 3.1 E-OBS station network for precipitation (left) and temperature (right)

In the CARPATCLIM project a freely available, high resolution, gridded, homogenised and harmonised database has been produced for the larger Carpathian Region (www.carpatclim-eu.org). The data cover the period from 1961 to 2010 with the temporal resolution of 1 day and spatial resolution of 0.1˚x0.1˚. Climatological grids cover the area between latitudes 44°N and 50°N, and longitudes 17°E and 27°E.

For verification of model performance over Serbia, datasets from Serbian observational network are applied. Precipitation and 2 m temperature (T2m) from 46 main and climatological stations for the period 1971-2000 are used (Figure 3.2).

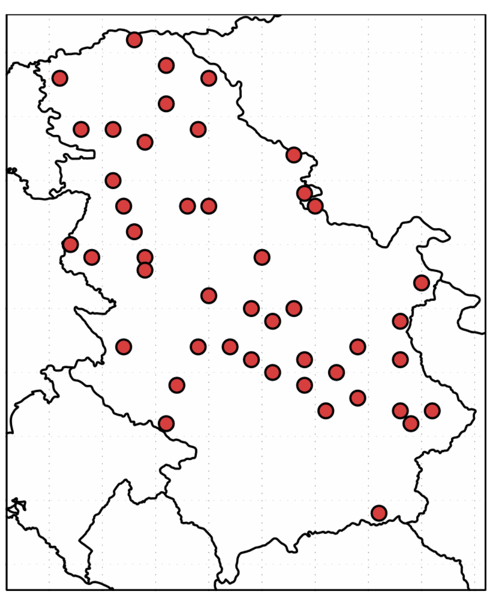

Figure 3.2 Meteorological stations in Serbia with complete datasets for the period 1971-2000

3.2 Verification scores

In this report we will use four common verification scores widely accepted for model verification: Bias, Mean absolute error (MAE), Root mean square error (RMSE) and correlation coefficient (CC).

Bias is defined as

$$Bias = \frac{1}{N}\sum_{i=1}^{N}\left(F_i - O_i\right) \qquad (1)$$

Mean absolute error is defined as

$$MAE = \frac{1}{N}\sum_{i=1}^{N}\left|F_i - O_i\right| \qquad (2)$$

Root mean square error is defined as

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(F_i - O_i\right)^2} \qquad (3)$$

Correlation coefficient is defined as

$$CC = \frac{\sum_{i=1}^{N}\left(F_i - \overline{F}\right)\left(O_i - \overline{O}\right)}{\sqrt{\sum_{i=1}^{N}\left(F_i - \overline{F}\right)^2}\sqrt{\sum_{i=1}^{N}\left(O_i - \overline{O}\right)^2}} \qquad (4)$$

F_i is model variable value and O_i corresponding observed value while $\overline{F}$ and $\overline{O}$ are corresponding mean values of F_i and O_i. N is number of observations over time or area of interest.

4. Temperature verification

Figure 4.1 depicts spatial distribution of average annual mean temperature from four datasets (ERA40, E-OBS, NMMB on 14 km and NMMB on 8 km resolution) for the period 1971-2000 is presented. It can be seen that with increasing the resolution more detailed representation of the T2m field is obtained. In ERA40 dataset local temperature characteristics are not visible due to sparse grid of data. Only north-south temperature gradient can be recognized. Clear change of the temperature with the height is visible in E-OBS dataset, and even more pronounced in the model on 8 km resolution. The largest differences between E-OBS and NMMB 8km is in the Pannonian Basin (~1 °C). In NMMB 14km regional temperature patterns are captured but not the mountain peaks.

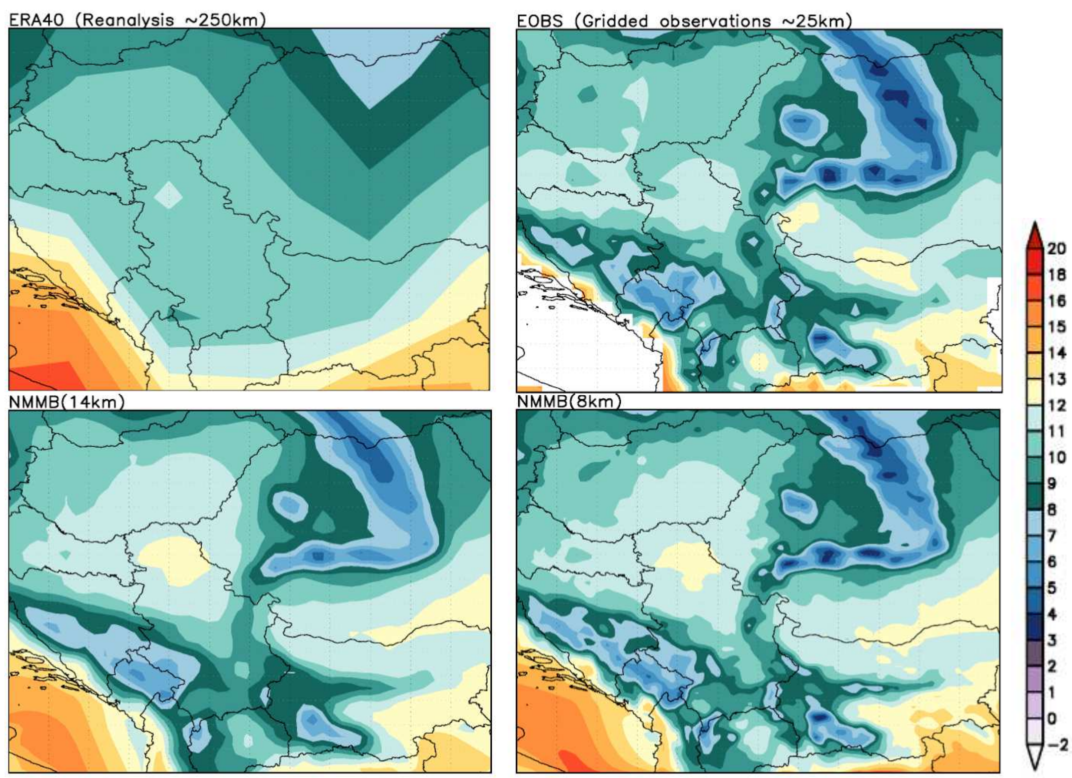

Figure 4.1 Average annual mean temperature (°C) for the period 1971-2000

Four verification scores of T2m for ERA40 and E-OBS datasets as well as simulated with the model on 14 and 8 km resolution, over Serbia, are given in Table 1 for daily mean and in Table2 for monthly mean temperatures.

The largest bias in both cases is for the E-OBS T2m (-0.62 °C), while according to MAE and RMSE, E-OBS has the best scores indicating that E-OBS systematically underestimates value of T2m, but not the time of occurring of extremes. Comparing the simulations with NMMB climate model, better results are obtained with the higher resolution and for monthly mean temperatures. ERA40 and E-OBS have something better MAE and RMSE than modelled datasets just because they are observation dependent. All four datasets have high correlation coefficient (CC > 0.95).

Table 1. Average scores of daily mean temperatures for Serbia and for the period 1971-2000

	TG	BIAS	MAE	RMSE	CC
ERA40	10.6	-0.07	1.5	1.9	0.98
E-OBS	10.0	-0.62	1.0	1.2	0.99
NMMB 14km	10.6	-0.04	2.0	2.6	0.96
NMMB 8km	10.7	0.06	1.7	2.2	0.98

Table 2. Average scores of monthly mean temperatures for Serbia and for the period 1971-2000

	TG	BIAS	MAE	RMSE	CC
ERA40	10.6	-0.07	0.87	1.0	1.0
E-OBS	10.0	-0.62	0.79	0.86	1.0
NMMB 14km	10.6	-0.04	1.14	1.36	0.99
NMMB 8km	10.7	0.06	1.0	1.2	0.99

Spatial distribution of errors is presented in Figure 4.2. Bias is in the range from -2.0 °C to 2.0 °C in all station, but most of them have bias from -1.0 °C to 1.0 °C. It can be observed that the smallest bias is in northern part of Serbia for ERA40 and E-OBS datasets, from -0.5 °C to 0.5 °C. E-OBS has lager cold bias (< -1.0 °C) in the south and south-east Serbia as well as NMMB 14km and NMMB 8 km, while ERA40 in central and eastern Serbia. In addition, ERA40 dataset is more than 2 °C warmer than observations at some stations in western Serbia. The largest warm bias can be seen in northern Serbia (1.0 °C – 1.5 °C) for NMMB simulation on 14 km resolution which is reduced by increasing the resolution of the model. Generally, NMMB simulation on 8 km resolution has the best score for the whole Serbia.

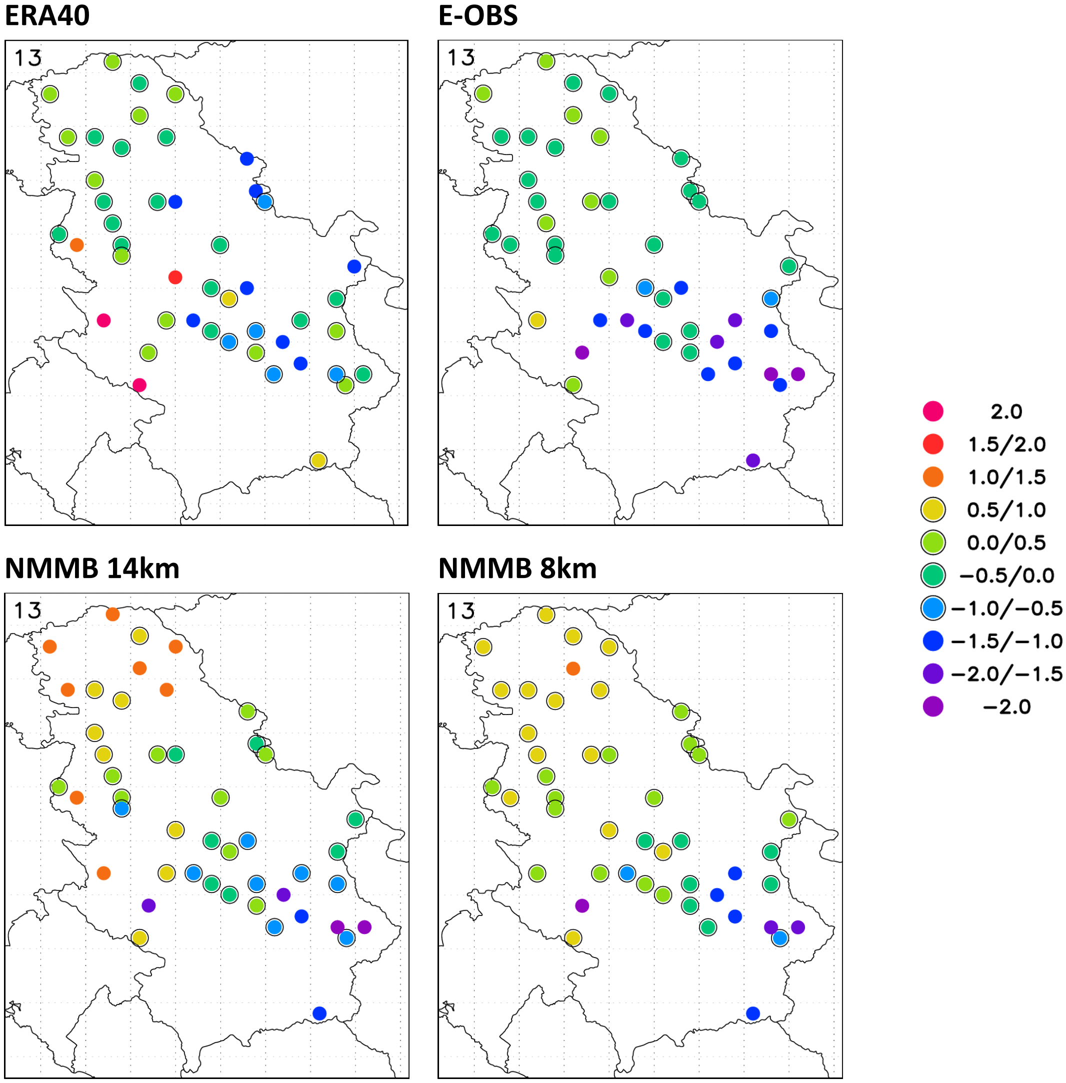

Figure 4.2 Average bias of daily mean temperature

Area average of mean annual cycle of monthly mean temperature is presented in Figure 4.3. NMMB model on 8 km resolution has the best agreement with the observations in summer months (June, July and August, Figure 4.3). The largest discrepancies are in winter when the model is colder and in some months in spring and autumn when is warmer. NMMB 14km has minor deviations from NMMB 8km (Figure 4.3 bottom). In all months E-OBS is colder than observations and NMMB 8km (Figure 4.3 upper right) unlike ERA40 which corresponds well with the observations (Figure 4.3 upper left).

Looking at the annual values there is overlapping between observations, model results and ERA40 T2m. Again, E-OBS is colder than other datasets.

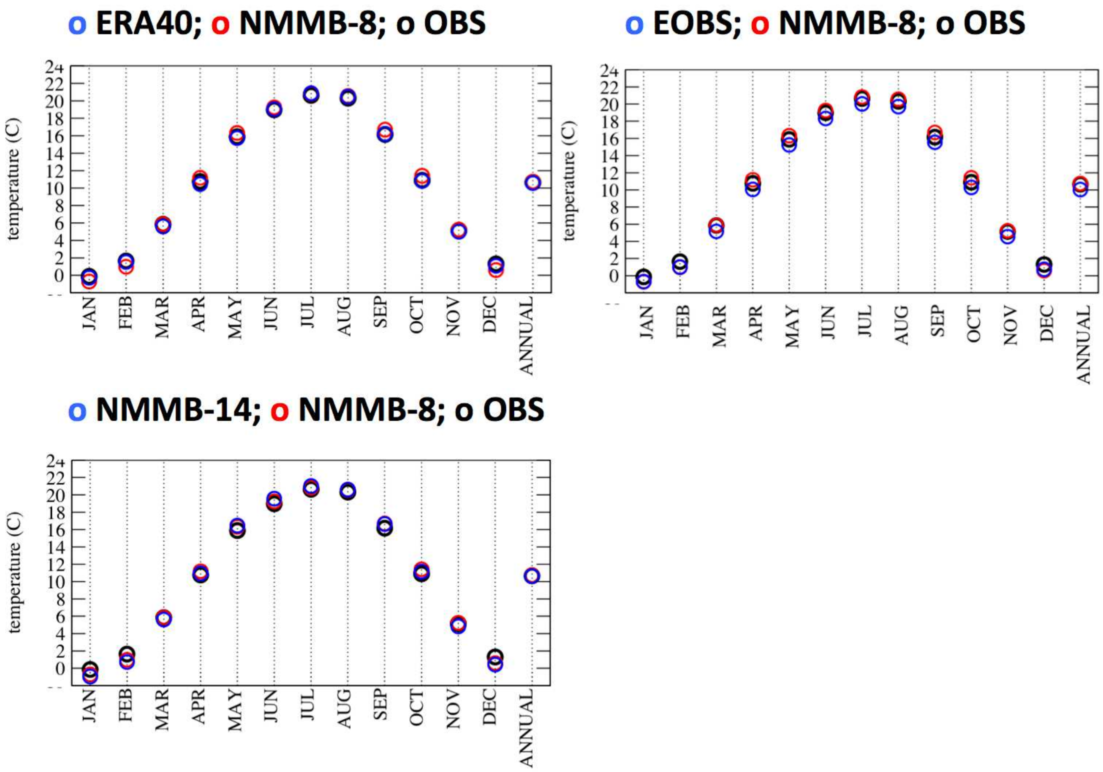

Figure 4.3 Average annual cycle of monthly mean temperature

5. Precipitation verification

In Figure 5.1 we present average annual precipitation amount for period 1971-2000 and five different data sets:

1. reanalysis ERA40 data;

two gridded data sets:

2. E-OBS with resolution of 25 km,
3. CARTAPTCLIM with resolution of 10 km;

and results from two NMMB integrations:

4. NMMB with 14 km,
5. NMMB with 8 km resolution.

In comparison to temperature we introduced new gridded data set, CARTAPTCLIM, with higher horizontal resolution than E-OBS. Since CARTAPTCLIM data cover only area of Carpathian Mountains, other data is displayed only for this region. In addition, because domain of high resolution NMMB integration covers only part of this domain upper part of panel is undefined (Figure 5.1 down right).

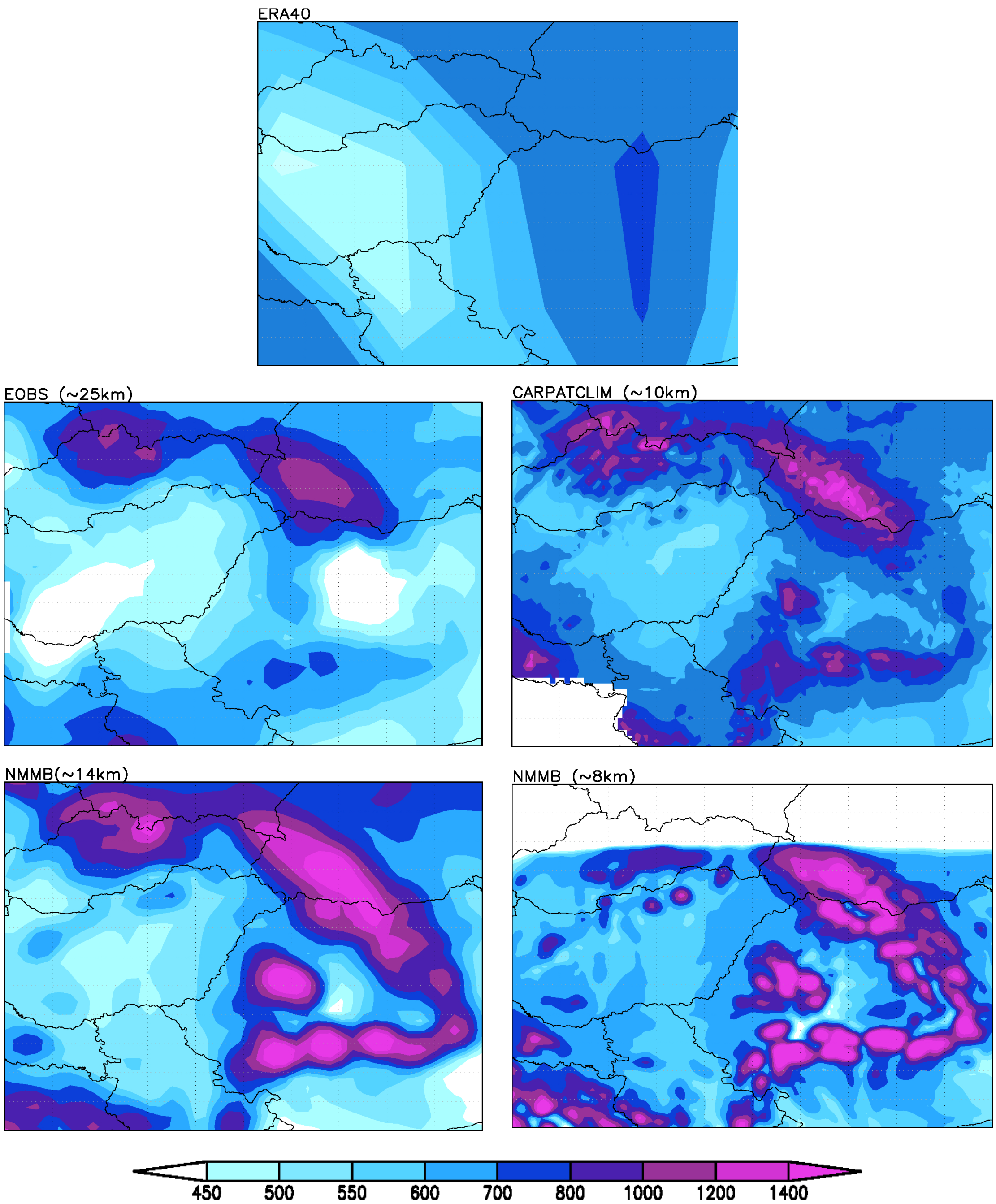

Figure 5.1 Average annual precipitation amount (mm/year) for period 1971-2000

It is evident from five panels in Figure 5.1 that with higher data resolution precipitation field exhibits more complex structure, mainly related to topography structure. This increase in complexity of field structure is evident even when comparing two gridded data. Some of this difference between E-OBS and

CARTAPTCLIM comes not only because of increased resolution of grid but meteorological station network used for construction of CARTAPTCLIM is much denser in comparison to network used for E-OBS. For this reasons we can assume that CARTAPTCLIM data is closest to 'reality'. It is clear that in some regions E-OBS data have clear negative bias in average annual precipitation amount over south-west Hungary and central-north Romania and that local maximums located on mountain peaks are underestimated in comparison to CARTAPTCLIM as well. Contrary to this, high-resolution NMMB integration probably has some overestimation of annual precipitation on mountain peaks, but in lowland regions where E-OBS shows clear lack of precipitation, model results seem to be much closer to precipitation from CARTAPTCLIM data. This simple visual check exercise clearly demonstrate that even downscaling of low resolution reanalysis with regional model can produce valuable information on local scale and even outperform gridded data set in some aspects, in this case long term average annual precipitation field, especially over region with pure coverage with direct meteorological measurements from which gridded climatology is derived.

For further analysis on model results we calculated two verification scores, bias and correlation coefficient (CC) for daily and monthly accumulated precipitation using observations from 46 meteorological stations in Serbia. Together with scores for model results we calculated corresponding scores for ERA40 reanalysis and E-OBS data. Comparison of the model, reanalysis and E-OBS scores can give us insight in to model performance in comparison to these data sets.

Table 3. Average scores of daily precipitation amount for Serbia and for the period 1971-2000

	RR (mm/month)	BIAS (mm/day)	BIAS (%)	CC
ERA40	41.8	-0.46	-23.2	0.53
E-OBS	52.28	-0.12	-5.1	0.85
NMMB 14km	50.23	-0.18	-9.4	0.40
NMMB 8km	53.30	-0.08	-4.6	0.53

In Table 3 scores of daily precipitation are presented. Bias score is presented as mean difference between corresponding data set and observation, averaged over period of 30 years, but also as a ratio of this difference and long term mean of corresponding observation and presented in percent. As we can see for daily precipitation (Table 3) lowest bias of 0.08 mm/day has high resolution NMMB integration followed by E-OBS and 14 km NMMB integration. Strongest negative bias is found for ERA40 data set, which is not surprising since reanalysis data have lowest resolution and, as we saw in Figure 5.1, with such a low resolution almost none of the regional characteristics is resolved. Highest correlation coefficient is for E-OBS data, 0.85 that can be expected, because even with biased results in gridded climatology phase error is controlled through map construction using observations day by day. Correlation coefficients for NMMB are 0.53 and 0.4 for 8 km and 14 km integrations respectively and 0.53 for ERA40 data. For NMMB monthly accumulation correlation coefficients are significantly higher 0.86 and 0.81 for 8 km and 14 km integrations respectively (Table 4) and, as we can see, high resolution integration has higher correlation coefficient than reanalysis data set.

Table 4. Average scores of monthly precipitation amount for Serbia and for the period 1971-2000

	RR (mm/month)	BIAS (mm/month)	BIAS (%)	CC
ERA40	41.8	-14.0	-23.2	0.82
E-OBS	52.3	-3.5	-5.1	0.98
NMMB 14km	50.2	-5.6	-9.4	0.81
NMMB 8km	53.3	-2.5	-4.6	0.86

To examine spatial distribution of precipitation error on Figure 5.2 mean bias of daily precipitation for each station is presented. As we can see for E-OBS and NMMB 8km only few stations have absolute bias larger than 20% and majority of stations have bias between -10 and +10 %. Negative bias of ERA40 data is mainly connected to western and central parts of Serbia. Also, there is a clear improvement of high resolution model results in comparison to integration with 14 km resolution, especially in central and south-east parts of Serbia, characterized with complex topography. In the northern parts of Serbia, Pannonian Basin, main difference between two model integrations is presence of slight negative bias (about -10 %) in 14 km resolution integration and slight positive bias in 8 km resolution integration.

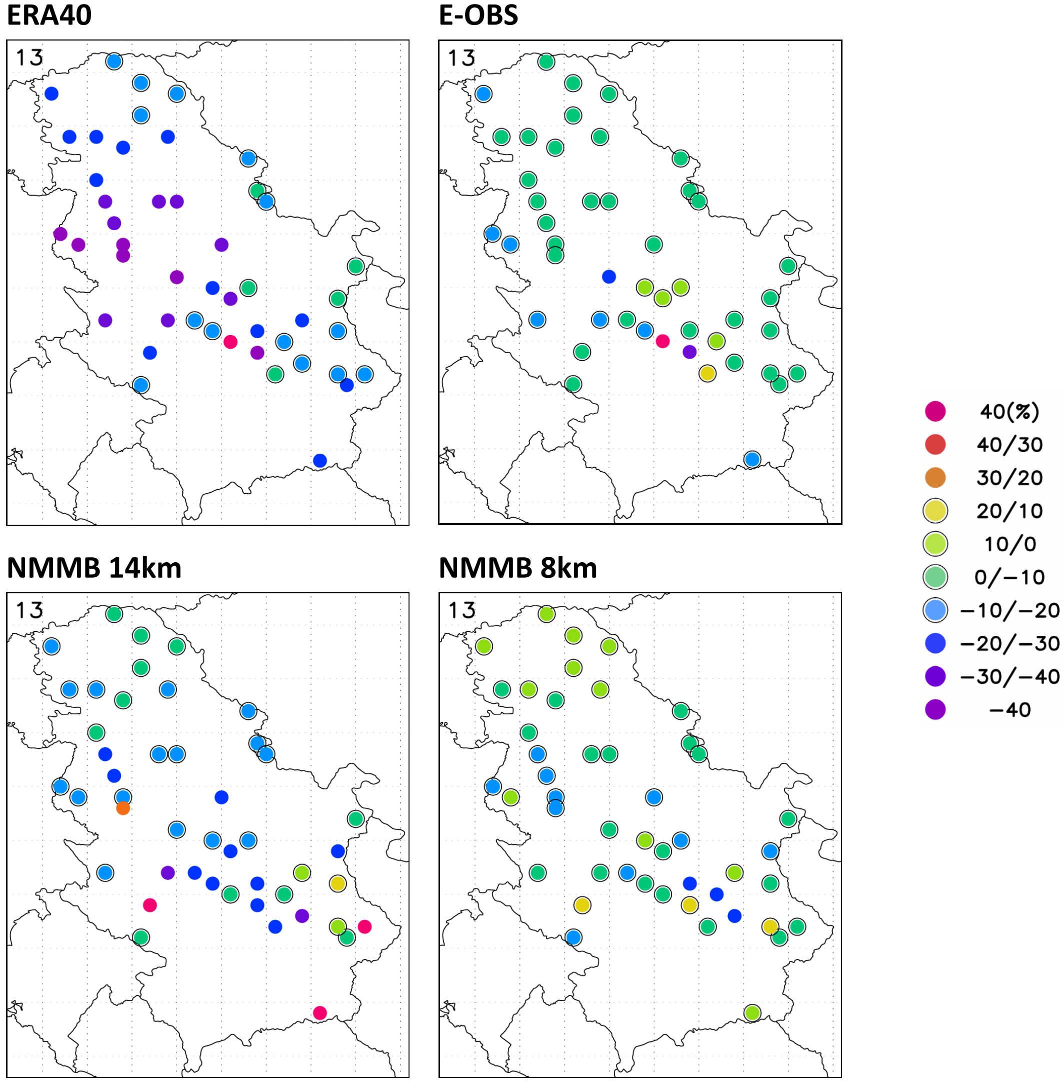

Figure 5.2 Average bias of daily precipitation amount

In Figure 5.3 area averaged mean annual cycle of daily precipitation is presented. As we can see negative ERA40 bias is mainly over period from April to November (Figure 5.3 upper left panel) and it's probably related to pure representation of convective system in low resolution model used for production of reanalysis. So it is obvious that with such a low resolution, model is not capable to correctly capture convective processes in atmosphere dominantly present during the warmer part of the year. Contrary to this, high resolution NMMB is capable to better represent small-scale convective processes giving much less biased result especially for period from April to September. Also, comparing two NMMB integrations (Figure 5.3 lower left panel) this reduction negative precipitation bias is evident for summer months Jun, July and August, when convective processes and high daily precipitation accumulation strongly contributed to monthly totals (Tosic and Unkasevic, 2013). It is noteworthy that only month when NMMB did not reduce ERA40 negative bias is October.

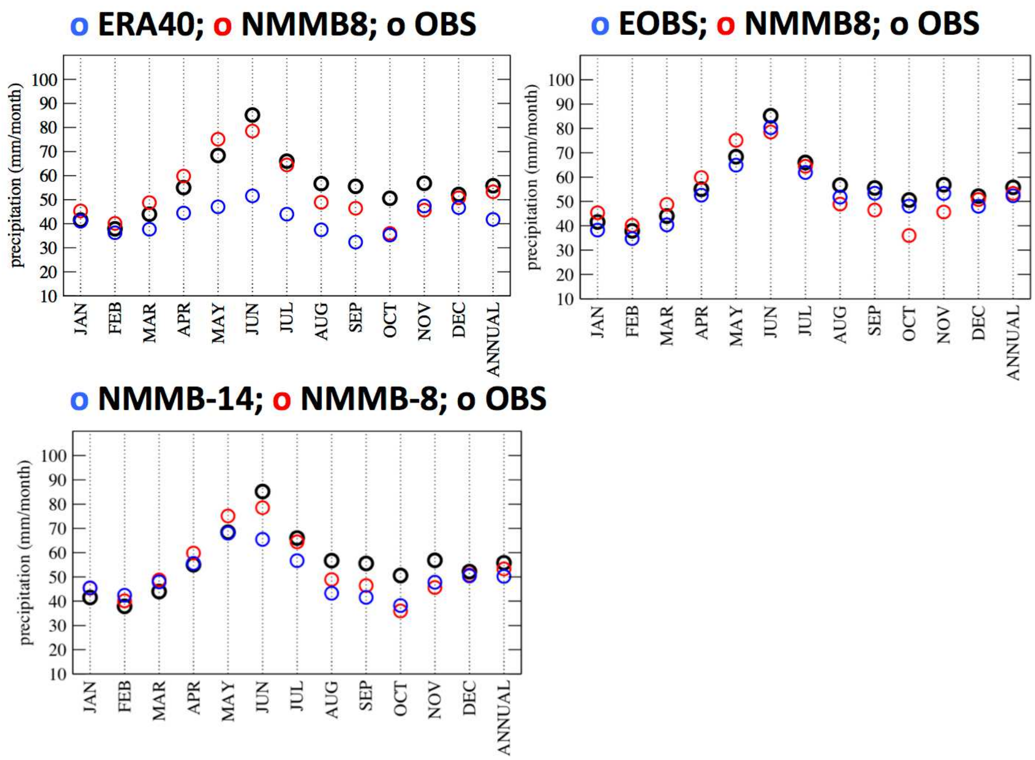

Figure 5.3 Average annual cycle of daily precipitation for Serbia

To put more details on issue about summer precipitation, distributions of daily precipitation are presented in Figure 5.4 and 5.5 for monthly precipitation. Distributions are calculated for four seasons, December-January-February (DJF), March-April-May (MAM), Jun-July-August (JJA) and September-October-November (SON). For daily precipitation distributions is evident that ERA40 data set follow observed distributions only for daily accumulation about 10 mm/day and especially large discrepancy is for accumulations above 20 mm/day. Both results from NMMB downscaling show much better agreement to observations in all seasons. Largest difference between 8 km and 14 km downscaling is for summer months. Although for JJA season 8 km integration have largest displacement from observations, extreme part of distribution is much better represented in comparison to 14 km integration. In low resolution NMMB integration largest daily accumulation is about 70 mm/day and observed maximum and simulated with high resolution NMMB is close to 100 mm/day. This result clearly shows that high resolution model run is indispensable for realistic representation of climatology of summer convective precipitation. Similar conclusion can be drawn from monthly precipitation distributions presented in Figure 5.5.

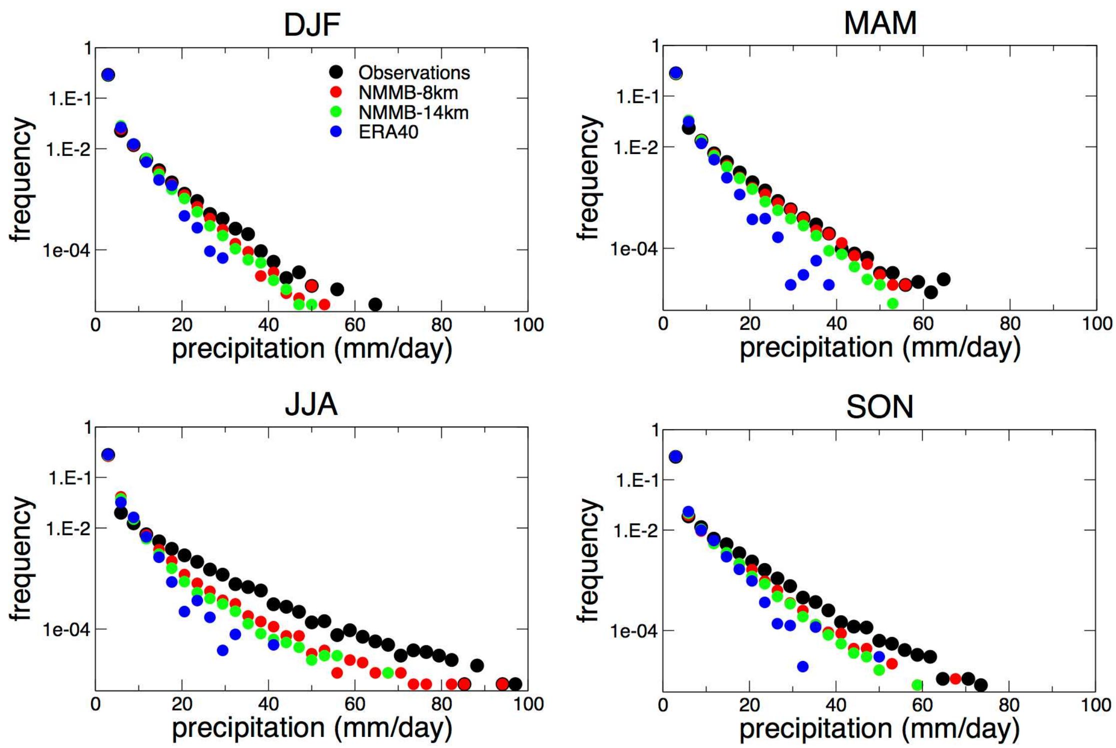

Figure 5.4 Distribution of daily precipitation amount per season for Serbia

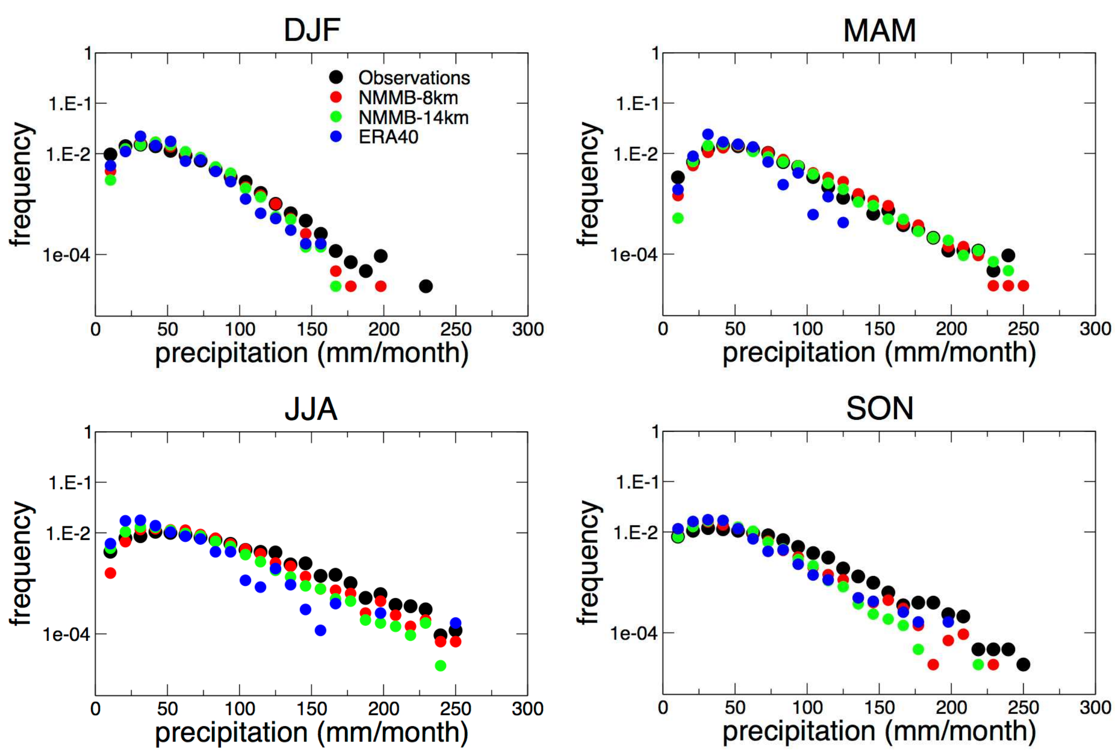

Figure 5.5 Distribution of monthly precipitation amount per season for Serbia

6. Conclusions

NMMB model performance of ERA40 downscaling on two resolutions 14 km and 8 km is verified using standard verification scores over territory of Serbia against data from national meteorological network. Also, model results are compared with scores of two gridded observation datasets E-OBS (Haylock et al., 2008) and CARPATCLIM (Szalai et al., 2012) with 25 km and 10 km resolution respectively and ERA40 reanalysis. Presented results show that model is capable for reproduction of observed climate characteristics and its' performance is in line with results of other similar experiments performed with the state of the art regional climate models (Heikkila et al., 2010; Soares et al., 2012). Averaged annual bias of daily mean temperature is about 0.1 °C and mean annual bias of daily precipitation accumulation is about -0.1 mm/day. As we have shown comparing 8 km and 14 km integration, high-resolution downscaling experiment integration shows improvement in overall model performance, especially in reduction of negative monthly precipitation bias during summer months in northern part of Serbia, common to many regional climate simulations (Hagemann et al., 2004; Ruml et al., 2012) and known as a summer drying problem. Detail analysis of daily precipitation distributions revealed that reason for this is convection permitted resolution of model, which enables better representation of summer heavy precipitation episodes. In addition, over some regions of Serbia, in comparison with E-OBS gridded observations, model shows better results in terms of mean annual precipitation accumulation.

The data provided by the NMMB model could be distributed to the ORIENTGATE partners via an FTP server set up. Access request should be addressed to Aleksandra Kržič (aleksandra.krzic@hidmet.gov.rs; CC to vdj@ff.bg.ac.rs).

7. References

Betts, A. K.: A new convective adjustment scheme. Part 1: Observational and theoretical basis, Q.J.Roy.Meteorol.Soc., 112,677–691, doi:10.1002/qj.49711247307, 1986.

Betts, A. K. and Miller, M. J.: A new convective adjustment scheme, Part II: Single column tests using GATE wave, BOMEX, ATEX and arctic air-mass data sets, Q. J. Roy. Meteorol. Soc.,112, 693–709, doi:10.1002/qj.49711247308, 1986

Djurdjevic V., Janjic Z., Pejanovic G., Vasic R., Rajkovic B., Djordjevic M., Vujadinovic M., Vukovic A., Lompar M., 2013: NCEP's multi-scale NMMB model in the

Hydrometeorological Service of Serbia: experiences and recent model developments, EGU General Assembly, Geophysical Research Abstracts, Vol. 15, EGU2013-8217, 7-12 April 2013, Vienna.

Ek, M. B., Mitchell, K. E., Lin, Y., Rogers, E., Grunmann, P., Ko-ren, V., Gayno, G., and Tarpley, J. D.: Implementation of Noahland surface model advances in the National Centers for Environ-mental Prediction operational mesoscale Eta model, J. Geophys.Res., 108, 8851, doi:10.1029/2002JD003296, 2003.

Fels, S. B. and Schwarzkopf, M. D.: The simplified exchange ap-proximation - A new method for radiative transfer calculations, J. Atmos. Sci., 32, 1475–1488, 1975

Ferrier, B. S., Jin, Y., Lin, Y., Black, T., Rogers, E., and DiMego, G.: Implementation of a new grid-scale cloud and precipitation scheme in the NCEP Eta Model, in: Proceedings of the 15th Conference on Numerical Weather Prediction, 280–283, 2002

Hagemann, S., Machenhauer, B., Jones, R., Christensen, O.B., Deque, M., Jacob, D., Vidale, P.L. (2004) Evaluation of water and energy budgets in regional climate models applied over Europe. Clim. Dynam. 23, 547–567.

Haylock, M.R., N. Hofstra, A.M.G. Klein Tank, E.J. Klok, P.D. Jones, M. New. 2008: A European daily high-resolution gridded dataset of surface temperature and precipitation. J. Geophys. Res (Atmospheres), 113, D20119, doi:10.1029/2008JD10201

Heikkila U, Sandvik A, Sorterberg A (2010) Dynamical downscaling or ERA-40 in complex terrain using WRF regional Climate model. Clim Dyn.

Janjic, Z. I.: Physical package for step-mountain, Eta coordinate model, Mon. Weather Rev., 118, 1429–1443, 1990.

Janjic, Z. I.: The Step-Mountain Eta Coordinate Model: Further Developments of the Convection, Viscous Sublayer, and Turbulence Closure Schemes, Mon. Weather Rev., 122, 927–945, 1994.

Janjic, Z. I., 1996: The surface layer in the NCEP Eta Model. Eleventh conference on numerical weather prediction, Norfolk, VA, 19–23 August 1996. Amer Meteor Soc, Boston, MA, pp 354–355.

Janjic Z. I., Gerrity J. P. Jr, Nickovic S. (2001) An alternative approach to nonhydrostatic modeling. Mon. Wea. Rev. 129: 1164–1178

Janjic, Z. I.: A Nonhydrostatic Model Based on a New Approach, Meteorol. Atmos. Phys., 82, 271–285, 2003

Janjic, Z. I. (2005) A unified model approach from meso to global scales, Geophys. Res. Abstr., 7, SRef–ID: 1607–7962/gra/EGU05–A– 05582.

Janjic, Z., Janjic, T., and Vasic, R. (2011) A Class of conservative fourth order advection schemes and impact of enhanced formal accu- racy on extended range forecasts, Mon. Weather Rev., 0, null, doi:10.1175/2010MWR3448.1.

Janjic, Z., and R.L. Gall, 2012: Scientific documentation of the NCEP nonhydrostatic multiscale model on the B grid (NMMB). Part 1 Dynamics. NCAR Technical Note NCAR/TN-489+STR, DOI: 10.5065/D6WH2MZX.

Janjic Z, Djurdjevic V, Vasic R, Ferrier B and Lin H-M, 2013: NCEP's Multi-scale Eulerian NMMB model, EGU General Assembly, Geophysical Research Abstracts, Vol. 15, EGU2013-6557, 7-12 April 2013, Vienna.

Lacis, A. A. and Hansen, J. E.: A parameterization for the absorp-tion of solar radiation in the Earth's atmosphere, J. Atmos. Sci., 31, 118–133, 1974.

Mellor, G. and Yamada, T.: A hierarchy of turbulence closure mod- els for the planetary boundary layer, J. Atmos. Sci., 31, 1791– 1806, 1974.

Mellor, G. L. and Yamada, T.: Development of a turbulence clo- sure model for geophysical fluid problems, Rev. Geophys. Space Phys., 20(4), 851–875, 1982.

Mlawer, E. J., Taubman, S. J., Brown, P. D., Iacono, M. J., and Clough, S. A.: Radiative transfer for inhomogeneous atmo-spheres: RRTM, a validated correlated-k model for the long-wave, J. Geophys. Res., 102, 16663–16682, 1997.

Ruml M., Vukovic A., Vujadinovic M., Djurdjevic V., Rankovic-Vasic Z., Atancakovic Z., Sivcev B., Markovic N., Matijasevic S., Petorvic N., (2012) On the use of regional climate models: Implications of climate change for viticulture in Serbia, Agricultural and Forest Meteorology, 158, 53-62. doi: 10.1016/j.agrformet.2012.02.004

Soares, P.M.M., R.M.Cardoso, J. de Medeiros, P.M.A. Miranda, M. Belo-Pereira and F. Espirito-Santo (2012) WRF high resolution dynamical downscaling of ERA-Interim for Portugal. Climate Dynamics. Doi: 10.1007/s00382-012-1315-2.

Szalai, S. et al. (2012) Climate of the Greater Carpathian Region. Final Technical Report. www.carpatclim-eu.org.

Tosic, I., Unkasevic, M., 2013: "Extreme daily precipitation in Belgrade and their links with the prevailing directions of the air trajectories", Theor. Appl. Climatol. 111 br. 1-2, str. 97-107.

Vukovic A., Rajkovic B., Janjic Z.: Land Ice Sea Surface Model: Short Description and Verification, 5th International Congress on Environmental Modelling and Software, 5-8 July 2010, Ottawa, Ontario, Canada.

Zhao, Q. Y., and F. H. Carr, 1997: A prognostic cloud scheme for operational NWP models. Mon. Wea. Rev., 125, 1931-1953.

www.carpatclim-eu.org