Analysis of the downscaled climate simulations performed with the COSMO-CLM model, including assessment of the bias.

Myriam Montesarchio, Alessandra Lucia Zollo, Leone Cavicchia and Paola Mercogliano

List of acronyms .................................................................................................................................................................................2
1. Introduction ...............................................................................................................................................................................2
2. The regional climate model COSMO-CLM ........................................................................................................................3
3. Simulations performed over the SEE domain ......................................................................................................................4
3.1. COSMO-CLM validation for the XX century: ERA40 and CMCC-MED driven simulations ...............6
3.2. COSMO-CLM climate projections up to 2100: the A1B scenario ........................................................................9
3.3. COSMO-CLM validation for the XX century: ERA40 and CMCC-CM driven simulations ..........12
4. The simulations performed over some pilot cases .............................................................................................................14
4.1. COSMO-CLM validation for the XX century: ERA40 and CMCC-CM driven simulation ..........15
4.2. COSMO-CLM climate projections up to 2070: the RCP4.5 and RCP8.5 scenarios ....................18
5. Conclusions .............................................................................................................................................................................20
6. References ...............................................................................................................................................................................22
APPENDIX A  A sensitivity study with the RCM COSMO-CLM ....................................................................................23
APPENDIX B  An evaluation of the model skill to reproduce extreme events in the ORIENTGATE region 25
List of acronyms

20C3M IPCC Scenario with greenhouse gasses increasing as observed through the 20th century
A1B IPCC scenario describing a future world of very rapid economic growth, low population growth and rapid introduction of new and more efficient technology
COSMO Consortium for Small-scale Modeling
COSMO-CLM COSMO model in CLimate Mode
COSMO-LM COSMO Local Model
CMCC Centro Euro-Mediterraneo sui Cambiamenti Climatici
CMCC-CM Coupled atmosphere-ocean general circulation model developed at CMCC
CMCC-MED Global climate model developed at CMCC, based on CMCC-CM with a focus on the Mediterranean region
CMIP3 Coupled Model Intercomparison Project Phase 3
CMIP5 Coupled Model Intercomparison Project Phase 5
EOBS European daily OBServational dataset
ERA40 Reanalysis of meteorological observations from September 1957 to August 2002 produced by the European Centre for Medium-Range Weather Forecasts (ECMWF)
GCM Global Climate Model
IPCC Intergovernmental Panel on Climate Change
RCM Regional Climate Model
RCP4.5 Representative Concentration Pathways (radiative forcing of about 4.5 W/m² at stabilization after 2100)
RCP8.5 Representative Concentration Pathways (radiative forcing higher than 8.5 W/m² in 2100)
SEE South-East Europe

1. Introduction

The goal of this work is to describe the regional climate simulations for the XX and XXI centuries carried out by the CMCC with the RCM COSMO-CLM in the framework of the activity 3.4 of the Orientgate project.

As first step, in order to quantify the uncertainties regarding the use of COSMO-CLM, a sensitivity study has been performed on a selected area. The aim was to find an “optimal” configuration, changing tuning, physical and numerical parameters, in order to reduce the bias in terms of 2meter temperature and precipitation (see Appendix A).
Then, the simulations for the XX century have been performed in order to test the regional model capabilities in reproducing the present climate; to this aim, COSMO-CLM has been forced both by the “perfect” boundary conditions ERA40 Reanalysis and by “sub-optimal” conditions provided by the CMCC global climate models: CMCC-CM, a coupled atmosphere-ocean general circulation model and CMCC-MED, based on CMCC-CM but with a focus on the Mediterranean region.

For the XXI century, instead, three different IPCC scenarios have been considered: A1B (CMIP3), RCP4.5 and RCP8.5 (CMIP5).

These simulations have been performed at 14km of horizontal resolution over the whole South-East Europe (SEE) area and at 8km of horizontal resolution over a smaller domain including some selected pilot cases: Puglia, the Autonomous Province of Trento, upper Austria, Budapest and Veszprem.

With respect to the work scheduled in the frame of activity 3.4 of Orientgate project, all the planned simulations have been completed, with the exception of the simulations over the whole SEE domain at 14km of horizontal resolution forced by the CMCC-CM following the new RCPs scenarios. These simulations will be available at the end of 2013.

In addition, in the Appendix B the skill of the COSMO-CLM model for the study of extreme events in the ORIENTGATE region is evaluated by analyzing strong mesoscale storms that affect the region producing severe impacts, known as medicanes due to their resemblance with tropical hurricanes.

2. The regional climate model COSMO-CLM

At CMCC, the regional climate model COSMO-CLM (Rockel and Geyer, 2008) is currently used to perform climate simulations: it is the climate version of the COSMO-LM model (Steppeler et al., 2003), which is the operational non-hydrostatic mesoscale weather forecast model developed initially by the German Weather Service and then by the European Consortium COSMO.

Successively, the model has been updated by the CLM-Community, in order to develop also a version for climate application (COSMO-CLM). The development of COSMO-CLM has been driven by two main reasons (Rockel et al., 2008): the first was the idea of developing one model able to simulate both weather and climate, and the second was the need of introducing a non-hydrostatic formulation, in order to have a convection resolving weather simulation. This is a very important topic, due to the difficulty in predicting the effects of this phenomenon, such as sudden high intensity rainfall. COSMO-CLM can be used with a spatial resolution between 1 and 50 km even if the non-hydrostatic formulation of the dynamical equations in LM made it eligible especially for the use at horizontal grid resolution lower than 20 km (Böhm et al. 2006). These values of resolution are usually close to those requested by the impact modellers; in fact these resolutions allow to describe the terrain orography better than the global models, where there is an over- and underestimation of valley and mountain heights, leading to errors in precipitation estimation, as this is closely related to terrain height. Moreover the non-hydrostatic modelling provides a good description of the convective
phenomena, which are generated by vertical movement (through transport and turbulent mixing) of the properties of the fluid as energy (heat), water vapour and momentum. Convection can redistribute significant amounts of moisture, heat and mass on small temporal and spatial scales. Furthermore convection can cause severe precipitation events (as thunderstorm or cluster of thunderstorms). Another advantage related to the usage of COSMO-CLM, with respect to other climate regional models available, is that the continuous development of LM allows improvements in the code that are also adopted in the climate version, ensuring that the central code is continuously update.

The mathematical formulation of COSMO-CLM is made up of the Navier-Stokes equations for a compressible flow. The atmosphere is treated as a multicomponent fluid (made up of dry air, water vapour, liquid and solid water) for which the perfect gas equation holds, and subject to the gravity and to the Coriolis forces. The model includes several parameterizations, in order to keep into account, at least in a statistical manner, several phenomena that take place on unresolved scales, but that have significant effects on the meteorological interest scales (for example, interaction with the orography).

3. Simulations performed over the SEE domain

Over the SEE domain (Figure 1), two sets of simulations at 0.125° (about 14km) of horizontal resolution have been performed. The first one is composed by numerical simulations forced by the following data:

1. ERA40 reanalysis data (Uppala et al., 2006) (horizontal resolution of 1.125°, about 128km), to assess the model performance with “perfect” boundary conditions, for the period 1971-2000;
2. CMCC-MED (Gualdi et al. 2012) “sub-optimal” forcing data, following the IPCC 20C3M protocol (horizontal resolution of 0.75°, about 85km), for the period 1971-2005;
3. CMCC-MED forcing data under A1B scenario conditions, for the period 2006-2100.

All these simulations are already available for the Orientgate partners.

Then, to consider RCPs emission scenarios, we had the need to perform another set of numerical simulations since we had to change the COSMO-CLM settings in order to specify the particular CO₂-concentration representative of the RCPs emission scenarios.
Furthermore, the boundary conditions under RCPs scenarios are provided by the CMCC-CM (Scoccimarro et al., 2011) global model.
So, we had to perform again the simulations for the control period in order to evaluate model performances using this new settings.

So, four simulations at 0.125° of horizontal resolution are scheduled, driven by the following data:

1. ERA40 reanalysis data for the period 1971-2000;
2. CMCC-CM “sub-optimal” forcing data for the period 1971-2005;
3. CMCC-CM forcing data under RCP4.5 scenario conditions, for the period 2006-2100;
4. CMCC-CM forcing data under RCP8.5 scenario conditions, for the period 2006-2100.

Up to now, only the simulations over the time period 1971-2000 has been already carried out whereas, concerning the XXI century, they are still in progress.
Figure 1: Orography of the SEE domain (3-34E; 33-51.5N).

The performances evaluation of all these simulations is carried out by using the EOBS observational dataset (Haylock et al., 2008): it is an European daily high resolution (0.25° x 0.25°) gridded data set for precipitation, minimum, maximum and mean surface temperature and sea level pressure for the period 1950-2010.

This dataset has been designed to provide the best estimate of grid box averages rather than point values to enable direct comparison with RCMs.

This section is organized as follows:
1. in subsection 3.1, the performances evaluation of COSMO-CLM in simulating the past climate is described, considering the first set of simulations;
2. in subsection 3.2, the climate projections under A1B conditions are analysed;
3. in subsection 3.3, finally, the validation of COSMO-CLM is presented considering the second set of simulations.

Figure 2: Location of the E-OBS stations for precipitation (right) and temperature (left).
3.1. COSMO-CLM validation for the XX century: ERA40 and CMCC-MED driven simulations

Considering the first set of simulations described in section 3, in this subsection the analyses of COSMO-CLM capability in simulating the past climate are described.

Figure 3 shows the seasonal spatial values of the differences in 2 meter mean temperature between the COSMO-CLM output and the EOBS observational dataset. The period taken into account for the validation is 1972-2000; the first year of the simulation (1971) is neglected to exclude the spin-up effects due to the initial conditions.

The simulation driven by the global climate model CMCC-MED is characterized by a general cold bias, with the exception of the summer months in the area between Adriatic coast and the Black sea. In particular, winter and spring are the seasons interested by the highest temperature underestimation, with a peak of about -4°C.

Concerning the ERA40 driven simulation, instead, it is characterized by a general hot bias, more pronounced in summer, where the highest overestimation reaches about 3-4°C. Over Alps and Apennines, instead, there is always a temperature underestimation (up to -3°C), that is also present in winter in the Mediterranean regions.

Concerning the daily precipitation, Figure 4 shows the bias of the simulations forced by the ERA40 Reanalysis and by the CMCC-MED for the period 1972-2000.

The first consideration is that the differences between the simulations driven by the two different forcings are less evident with respect to the case of the 2 meter mean temperature. The most evident feature is a precipitation overestimation over the mountainous regions for both the simulations. Summer season is characterized by a good agreement, with a bias never exceeding 1.5 mm/day in absolute value, whereas in spring a strong overestimation occurs up to 4 mm/day.

For the simulation driven by CMCC-MED, winter and autumn seasons have a greater overestimation with the respect to the ERA40 driven simulation. In particular, in winter there is a peak of 5 mm/day along Adriatic eastern coast.

It must be taken into account that the comparison with the EOBS dataset can be affected by potential uncertainties; in fact, EOBS is based on the interpolation of stations values, and in some regions the low network density can cause a decrease of the interpolation accuracy (Hofstra et al., 2009).

In Figure 5, the seasonal cycles and the PDFs of 2 meter temperature and precipitation are represented for both simulations and for the observational dataset.

The temperature seasonal cycle is very well captured by both the simulations. The highest bias is present from November to April in the CMCC-MED driven simulation with an underestimation of about 2°C.

For the precipitation, instead, an overestimation (higher in the case of the ERA40 forced simulation) in spring and an underestimation in autumn occur.

In the PDFs, for the temperature the simulation forced by the GCM is characterized by higher probability of the low temperature values, instead for the precipitation both the simulations attribute a larger probability to the high precipitation values.
Figure 3: Seasonal differences, in terms of 2m mean temperature (°C), between the output of COSMO-CLM and EOBS dataset, for the simulation forced by ERA40 Reanalysis (left) and the simulation forced by CMCC-MED global model (right). From top to bottom, DJF, MAM, JJA and SON seasons are represented.
Figure 4: As in Figure 3, but for daily precipitation (mm/day).
3.2. COSMO-CLM climate projections up to 2100: the A1B scenario

Concerning the climate projections related to the A1B scenario, Figure 6 shows the differences between the two periods 2072-2100 and 1972-2000. A general warming is simulated in all the seasons and for the whole domain. The values range between 2°C and 6°C. The highest temperature increase occurs in winter in the north-east part of the domain, with a warming up to 6°C, instead in summer, in the same area, the lowest warming is projected (2°C). In spring, the warming is more pronounced in mountainous areas, whereas in autumn the temperature increase is more homogenous, with a general warming of about 3.5-4°C.

The temperature PDFs (Figure 7) for the two periods 2072-2100 and 1972-2000 highlight a distribution shift toward higher temperature values for the future period, more evident in winter and summer, where a stronger increase of the mean values occurs. Moreover, in all the seasons, with the exception of summer, the probabilities of the cold values steeper increase in the end of XXI century.
Figure 6: 2m temperature climate projections (°C) for the period 2072-2100 vs 1972-2000 considering the A1B scenario. In the first row of the picture, DJF (left) and MAM (right) seasons are represented, whereas in the second row JJA (left) and SON (right) are shown.

Figure 7: 2m temperature (°C) PDFs for the two periods 1972-2000 and 2072-2100 considering the A1B scenario. In the first row of the picture, DJF (left) and MAM (right) seasons are represented, whereas in the second row JJA (left) and SON (right) are shown.
For what concern the precipitation (Figure 8), the seasons with the most evident differences between future and past periods are winter and autumn: in winter, an increase is simulated over the Alpine arc and over the eastern Adriatic coast, up to 3 mm/day; in autumn, instead, a stronger decrease is projected in several areas of the domain, such as western Alps and south-east Adriatic coast. In spring and summer, no significant variations are registered, with a slight increase in MAM and a slight decrease in JJA.

In the precipitation PDFs (Figure 9), the differences between the two considered periods are less evident with respect to the temperature case.

In winter, an increase of the probability of the high precipitation values is projected and the opposite occurs for the low values. In spring, instead, in the future a higher variance and a lower probability of the modal precipitation value are simulated; finally, in summer and autumn, higher probability is attributed to the low precipitation values.

Figure 8: As in Figure 6, but for the daily precipitation (mm/day).
3.3. COSMO-CLM validation for the XX century: ERA40 and CMCC-CM driven simulations

Now, the validation of COSMO-CLM is presented considering the second set of simulations described in the section 3.

In the Figure 10, the seasonal spatial bias of the 2 meter mean temperature with respect to the EOBS observations is shown.

The first consideration is that the simulation forced by the CMCC-CM model (right panels of the picture) is characterized by a general cold bias, more accentuate in winter (up to -5°C). Only in summer there is a different behaviour, with a temperature underestimation in the western part of the domain and an overestimation in the eastern one.

In the simulation driven by the ERA40 Reanalysis (left panels of the picture), the summer season has a high temperature overestimation (up to 4-5°C) in the eastern area, stronger with respect to the bias highlighted by the global model driven simulation in the same area.

In winter, a general underestimation occurs, more evident in Piedmont region (3-4°C), with the exception of the northern part of the simulated area where the bias is close to 0°C.

Spring and autumn, finally, show a fair good agreement with the observational dataset, with a bias never exceeding 2°C.

For the precipitation (Figure 11), the differences between the bias features of the two simulations are less evident compared with the case of temperature.

Figure 9: As in Figure 7, but for the daily precipitation (mm/day).
The general trend is a precipitation overestimation in winter, in spring and over the mountainous regions in all the seasons.

In summer, a slight underestimation is verified in the central-eastern part of the domain (1 mm/day), whereas in the southern one the bias is close to 0 mm/day. In autumn, instead, COSMO-CLM shows good performances, with the exception of an overestimation over the mountainous areas and an underestimation in Tuscany region.

The highest precipitation bias is reached in spring and in winter, especially in the south-east Adriatic coast (5 mm/day).

**Figure 10:** As in Figure 3, but for the second set of simulations described in the section 3.
The simulations performed over some pilot cases

For five selected Orientgate pilot cases (Puglia, the Autonomous Province of Trento, upper Austria, Budapest and Veszprem), another set of simulations has been performed at 0.0715° (about 8km) of horizontal resolution. It covers the domain shown in the Figure 12 and the forcing data considered are:

1. ERA40 reanalysis data for the period 1971-2000;
2. CMCC-CM “sub-optimal” forcing data for the period 1971-2005;
3. CMCC-CM forcing data under RCP4.5 scenario conditions, for the period 2006-2070;
4. CMCC-CM forcing data under RCP8.5 scenario conditions, for the period 2006-2070.

All these simulations are already available for the Orientgate partners.
4.1. COSMO-CLM validation for the XX century: ERA40 and CMCC-CM driven simulation

At first, the validation in terms of temperature is carried out and in the Figure 13 the seasonal spatial bias is presented for the two simulations forced by ERA40 and CMCC-CM respectively. As for the performances evaluation shown in the Section 3.3, also in this case there is a strong difference between the simulation forced by the perfect boundary conditions and the simulation forced by the GCM. This last one shows a general high underestimation, especially in winter, where a peak of -5°C is reached over the west Alpine arc; only the summer shows a different behaviour in the eastern part of the domain, with a slight hot bias.

For the simulation forced by ERA40 Reanalysis, instead, the model error does not exceed 3°C in absolute value: the highest bias is registered in winter, with an underestimation up to 3°C in the Ligurian Alps, and in summer, with a general overestimation (up to 2.5°C).

In spring and autumn, there is a lower bias with respect to the EOBS observational dataset, with an error never exceeding 2°C.

However, in all the seasons, the analysis reveals a cold bias over Alps and Apennines.

Figure 14 shows the seasonal spatial values of the differences in terms of precipitation between the COSMO-CLM output and the EOBS.

All the seasons highlight an overestimation over the Alps for both the simulations, more pronounced in spring and winter.

Comparing the results of the two simulations, in winter the CMCC-CM driven simulation has a higher overestimation (up to 5 mm/day) over the whole domain, especially over Alps and eastern Adriatic coast.

In spring, the bias for both the simulations has the same features, with a peak of 5 mm/day. In summer, instead, there is a good agreement, except over the Alps: the bias is between -0.5 mm/day and 0.5 mm/day, with an error close to 0 mm/day in the case of the CMCC-CM forced simulation in the south Italy. In autumn, finally, there is an underestimation up to 3 mm/day in Tuscany region.

In addition, also the capability of the model in reproducing seasonal cycles have been investigated (Figure 15).

The temperature seasonal cycle is generally well reproduced, but the simulations driven by CMCC-CM presents an underestimation in all the months of about 2-3°C.
For the precipitation, instead, the ERA40 Reanalysis driven simulation show a strong overestimation from April to June, a very slight underestimation in October and November and a fair good agreement in the other months. The CMCC-CM driven simulation is characterized by a general overestimation, with the exception of August and September, more accentuated from January to June.

Figure 13: As in Figure 3, but for the simulations at 8km of horizontal resolution.
Figure 14: As in Figure 4, but for the simulations at 8km of horizontal resolution.
4.2. COSMO-CLM climate projections up to 2070: the RCP4.5 and RCP8.5 scenarios

In this section, the differences between the two periods 2042-2070 and 1972-2000 are analyzed, both for the RCP4.5 and RCP8.5 scenarios, in terms of 2meter temperature (Figure 16) and daily precipitation (Figure 17).

A general warming is projected in the future, more pronounced in winter and summer.

In all the seasons, the scenario RCP8.5 highlights a warming of 1.5°C higher than the RCP4.5 scenario.

The spring season in the RCP4.5 scenario and the autumn in the RCP8.5 are characterized by a very homogeneous warming, with an increase of 2°C and 3.5°C respectively.

The most evident difference between the two considered periods occurs in summer for the scenario RCP8.5 with a temperature increase of also 5.5°C in the western part of the simulated domain.

For the precipitation, the two scenarios differ each other in all the seasons, especially in winter.

A precipitation increase is simulated in spring over the north-east area over the Alpine arc, more pronounced for the RCP8.5 scenario (up to 1.5 mm/day). In summer, a strong decrease of precipitations occurs over the whole Alpine arc, also in this case higher and covering a wider area for the RCP8.5 scenario (-3 mm/day). In autumn, instead, the RCP4.5 scenario projects a precipitation increase in the north-east part of the domain whereas for the RCP8.5 no significant variations are registered.
Figure 16: Seasonal climate projections in terms of 2m temperature (°C) following the two scenarios RCP4.5 (left) and RCP8.5 (right): 2042-2070 vs 1972-2000.

Figure 17: As Figure 16, but for the daily precipitation (mm/day).
5. Conclusions

In this work, some analysis concerning the simulations performed in the framework of the activity 3.4 of Orientgate project has been carried out.

The main results are:

- the 2meter mean temperature and precipitation bias is in according to the bias of the regional climate simulations performed in the ENSEMBLE project (van der Linden and Mitchell, 2009);
- for the temperature, there is an evident difference between the simulations forced by the reanalysis and by the GCM: this last one is characterized by a general cold bias (with the exception of summer). ERA40 driven simulation, instead, shows a general overestimation, with the exception of the mountainous region;
- for the precipitation, the difference between the ERA40 and GCM forced simulations is less evident, with a general overestimation over the mountainous areas;
- climate projections show a general temperature increase (for all the scenarios used) whereas a great spatial variation surrounds the signal of rainfall change;
- the new IPCC RCPs scenarios highlight a stronger warming in the future compared to the A1B one, higher in the case of the RCP8.5 scenario.

It is worth noting that the bias found can be attributed not only to the model, but also to the observation datasets, due to the low density stations, especially in the mountainous regions.

The data provided by the COSMO-CLM model could be distributed to the Orientgate partners via an FTP server set up at the CMCC. Access request should be addressed to Myriam Montesarchio (myriam.montesarchio@cmcc.it).

The data will be provided in NetCDF files containing daily values of the available parameters, summarized in Table 1.

<table>
<thead>
<tr>
<th>Meaning</th>
<th>Field</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accumulated flux of surface moisture</td>
<td>AEVAP_S</td>
<td>kg/m²</td>
</tr>
<tr>
<td>Surface albedo (shortwave radiation)</td>
<td>ALB_RAD</td>
<td>%</td>
</tr>
<tr>
<td>Average solar radiation budget (surface)</td>
<td>ASOB_S</td>
<td>W/m²</td>
</tr>
<tr>
<td>Average thermal radiation budget (surface)</td>
<td>ATHB_S</td>
<td>W/m²</td>
</tr>
<tr>
<td>Total cloud cover</td>
<td>CLCT</td>
<td>%</td>
</tr>
<tr>
<td>Mean sea level pressure</td>
<td>PMSL</td>
<td>Pa</td>
</tr>
<tr>
<td>Surface pressure</td>
<td>PS</td>
<td>Pa</td>
</tr>
<tr>
<td>Relative humidity in 2m</td>
<td>RELHUM_2M</td>
<td>%</td>
</tr>
<tr>
<td>Temperature in 2m</td>
<td>T_2M</td>
<td>K</td>
</tr>
<tr>
<td>Minimum temperature in 2m</td>
<td>TMIN_2M</td>
<td>K</td>
</tr>
<tr>
<td>Maximum temperature in 2m</td>
<td>TMAX_2M</td>
<td>K</td>
</tr>
<tr>
<td></td>
<td>Symbol</td>
<td>Unit</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>--------</td>
<td>-------</td>
</tr>
<tr>
<td>Dew-point temperature in 2m</td>
<td>TD_2M</td>
<td>K</td>
</tr>
<tr>
<td>Daily total precipitation</td>
<td>TOT_PREC</td>
<td>kg/m²</td>
</tr>
<tr>
<td>Zonal wind in 10m</td>
<td>U_10M</td>
<td>m/s</td>
</tr>
<tr>
<td>Meridional wind in 10m</td>
<td>V_10M</td>
<td>m/s</td>
</tr>
<tr>
<td>Maximum wind in 10m</td>
<td>VMAX_10M</td>
<td>m/s</td>
</tr>
<tr>
<td>Temperature of surface</td>
<td>T_S</td>
<td>K</td>
</tr>
</tbody>
</table>

**Table 1**: Main daily variables available for the Orientgate partner
6. References


P. van der Linden and J.F.B. Mitchell (eds.) 2009: ENSEMBLES: Climate Change and its Impacts: Summary of research and results from the ENSEMBLES project. Met Office Hadley Centre, FitzRoy Road, Exeter EX1 3PB, UK. 160pp.
A sensitivity study with the RCM COSMO-CLM

To find an optimal setting of the regional climate model COSMO-CLM, a sensitivity study has been carried out changing numerical, physical and tuning parameters performing more than 20 simulations. The results in terms of 2 meter mean temperature and total precipitation have been compared with three different observational datasets obtaining a large amount of results for the determination of the best configuration on the area of interest. The analyzed domain includes an area ranging from 4.7°E to 16.7°E for the longitude and from 40.8°N to 48.3°N for the latitude (see Figure A). A horizontal resolution of 0.0715° (about 8km), 40 atmospheric vertical levels and 5 levels of soil have been used.

![Orography of the domain analysed for the sensitivity study.](image)

For the analyzes of the results, five subareas have been individuated, characterized by different orographic and climatic features:

- NORTH: 8.5 to 14.5°E, 46.2 to 47.5°N. It is located on the Alps, close to Austria;
- WEST: 5.9 to 7.4°E, 44.2 to 46.7°N. It is located on the Alps, close to France;
- CENTRAL NORTH: 8.2 to 10°E, 45 to 45.6°N and 10 to 12.2°E, 44.6 to 45.4°N, on the Po Valley;
- CENTRAL: 9 to 10°E, 44.4 to 45°N and 10 to 11.5°E, 44.1 to 44.55°N, close to Po Valley;
- SOUTH: 13 to 14.4°E, 41.3 to 42.3°N, close to Apennine area.

A further analysis has been performed considering a domain composed by all the five subdomains described above.

The time period investigated is 1996-2000, but the first year has been neglected in the analysis to avoid the spin up effects of the initial conditions. All the simulations are driven by the "perfect" boundary conditions provided by the ERA40 Reanalysis, in order to not include the error introduced by the global model error, but only the error of the RCM.

The results have been validated by using 3 different datasets:

1. EOBS gridded dataset (previously described) at a resolution of 0.25° (about 28km) for daily values of temperature on the period 1997-2000;
2. Alpine Precipitation Analyses from High Resolution Rain Gauge Observations (here called ETH (Frei and Schär, 1998)), at a resolution of 0.25° x 0.17° (about 28x20km) for daily values of precipitation on the period 1997-1998 (only two years because this
datasets is available from 1971 to 1998). This dataset is one of the densest meteorological observing systems over complex topography worldwide.

3. ARPA-EMR data set (daily temperature and precipitation) on an irregular triangular grid, interpolated at 8km on the period 1997-2000 (data provided courtesy of ARPA-EMR).

The results of this work have shown a difficulty in the choice of the best configuration, as it should represent an optimal compromise among several factors (variables, geographical area and seasonal periods).

The chosen configuration, used for the execution of the simulations described for the Orientgate activities, differs from the starting one, used in previous works, in several aspects, such as: tuning parameters, numerical parameterizations, boundary definition, Runge-Kutta scheme and its order, forests description, turbulent diffusion parameterization, cloud representation, frequency of convection scheme, soil scheme and subgrid scale orography processes.

This chosen configuration is very close to the CORDEX one (Giorgi et al., 2009) used by the CLM community for simulations over different European domains.

The results obtained using this COSMO-CLM setting show a very good agreement with observed temperatures, leading on the mountainous regions to a lower underestimation in winter and summer seasons and in Emilia Romagna to a lower summer overestimation with respect to other tested configurations (the error is always under 1.5°C). Moreover, concerning the precipitation, the chosen configuration highlights a low percentage bias (under 30%) in all the regions investigated and in almost all the months; only in May (in the comparison with the ETH dataset) and in March and September (in the comparison with the ARPA-EMR dataset) the bias is higher.

References


An evaluation of the model skill to reproduce extreme events in the ORIENTGATE region

The performance of the model for the study of extreme weather events in the ORIENTGATE region is assessed through the analysis of rare destructive storms affecting the area. Medicanes (*Mediterranean hurricanes*), strong mesoscale cyclones with tropical-like features, are known to develop occasionally over the Mediterranean Sea. Medicanes are considered rare phenomena, since only a few have been directly observed. They are however associated with severe damage on coastal areas, caused by the strong winds and extreme precipitation. In at least one case, occurred in Southern Italy in 1996, several casualties were reported, due to heavy flooding (480 mm accumulated in one day) after the landfall of a medicane. In another case, that hit the Apulia region in 2006, winds above 40 m/s were measured, and severe damage has been documented.

Several of the cases studied in the literature developed over the Ionian Sea, producing impacts on coastal areas in the Orientgate region.

Due to the small space scale of medicanes (typical radius is in the range 100 - 150 km) high resolution atmospheric fields are necessary to model such events.

For all the reasons mentioned above, medicanes constitute a very good test for the model’s ability to reproduce extreme events in the region of interest.

Two events documented in the literature were therefore analyzed in the COSMO-CLM simulations, at two different resolutions of 25 km and 10 km. In order to ensure that the simulation results do not depend on initial conditions (“climate mode”), the starting date precedes the formation of the medicane by about two weeks.

The following observational data were used for validation:

1. NOAA “SeaWinds” product at 6-hour time resolution. SeaWinds contains gridded, high resolution ocean surface vector winds and wind stresses, derived from multiple satellites on a global 0.25° grid for the period 9 July 1987 - present.

2. Mean sea level pressure fields from ECMWF operational analysis data, at 0.25° grid resolution.

In order to assess the added value of the high-resolution data, the model results have been also compared with a state-of-the-art reanalysis product, the NASA’s MERRA reanalyses, featuring a 0.5 degrees horizontal resolution and 72 vertical levels.

The January 1995 medicane developed along the Ionian coast of Greece on the night of January 15 and moved then southwestwards travelling towards the coast of Libya during the following 48 hours; during that time observations by ships cruising the Mediterranean reported winds up to 30 m/s, heavy precipitation and positive temperature anomalies in the vicinity of the center of the storm.

Figure B shows a comparison of mean sea level pressure on Jan 16 at 00 UTC in ECMWF analysis, MERRA reanalyses and in 25 km resolution and 10 km resolution simulations, together with the medicane track. There is a good agreement on the position of the pressure minimum in the three charts. The pressure value at the minimum is 1014 hPa in the ECMWF diagram, 1010 hPa in the MERRA reanalysis, 1016 in the coarse resolution, and 1000 hPa in the high resolution run. The 10 km resolution simulation also exhibits steeper pressure
gradients.

**Figure B:** January 1995 medicane sea level pressure (200 Pa contours) and track (blue dots). Top left: ECMWF operational analysis. Top right: MERRA reanalysis. Bottom left: 25 km resolution COSMO-CLM simulation. Bottom right: 10 km resolution COSMO-CLM simulation (bottom right).
The September 2006 medicane has the smallest radius and shortest lifetime among all known cases; on the other hand, it is the case with the strongest wind speed and lowest pressure minimum recorded. It is therefore expected to be a representative test for the model’s ability to reproduce smaller and more intense medicanes. The storm crossed the Salento peninsula in Apulia on September 26th, where ground stations measured extreme wind speeds and considerable damage was produced. It then traveled northwestwards over the Adriatic Sea and the afternoon of the same day it made landfall on northern Apulia, where it dissipated.

Mean sea level pressure on Sept 26 at 12 UTC in ECMWF operational analysis and model simulations, along with the medicane track as reconstructed in the low resolution and high resolution simulations, is shown in Figure D. The difference in the position of the minimum between the two model simulations reflects the different storm velocities. The pressure value at the minimum is 996 hPa in the ECMWF analysis, coarse resolution simulation, and high-resolution simulation. The medicane is not visible in the MERRA reanalysis. Wind speed in satellite observation and model simulations on Sept 26 at 12 UTC is shown in Figure E. The maximum wind speed of 22 m/s reported in the satellite measurements is reproduced with good accuracy in both the 25 km and 10 km resolution simulations.
**Figure D:** September 2006 medicane sea level pressure (200 Pa contours) and track (blue dots). Top left: ECMWF operational analysis. Top right: MERRA reanalysis. Bottom left: 25 km resolution COSMO-CLM simulation. Bottom right: 10 km resolution COSMO-CLM simulation (bottom right).
We conclude that the regional model is able to reproduce medicanes with good accuracy. Not only are the medicanes generated at about the correct time and location, but also their intensity is well simulated. The degree of accuracy of the values of the atmospheric fields produced by the model in the vicinity of the storm depends on the resolution; most details are fully resolved only in the high-resolution (10 km) simulations. The depths of pressure minima coincide with good accuracy with the ones found in large-scale analyses of comparable resolution in the 25 km resolution simulation, while a deepening due to the better resolved cyclone fine structure generally occurs in the high resolution simulations. The value of wind speed in the coarse resolution simulations, on the other hand, tends to be underestimated by 10-30% with respect to the one inferred from satellite-based measurements.

**Figure E**: September 2006 medicanes wind speed (m/s). Top: SeaWinds measurement. Bottom left: 25 km resolution COSMO-CLM simulation. Bottom right: 10 km resolution COSMO-CLM simulation (bottom right).