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A sensitivity study with the RCM COSMO CLM over the north and center Italy

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SUMMARY The aim of this report is to analyze the sensitivity of the precipitation and the 2-meters mean temperature on the variation of some physical, numerical and tuning parameters in the regional climate model COSMO-CLM over the north and center Italy. The simulations, at a spatial resolution of 8 km and concerning the period 1996-2000, are driven by ERA40 Reanalysis. Five different sub-areas inside the computational domain have been selected, chacterized by different orographic features; the seasonal cycle has been calculated for each simulation and compared with three different data sets: E-OBS, ETH and ARPA-EMR data set.

We would like to thank Kay Radtke (BTU Cottbus) for providing his namelist, Andreas Will (BTU Cottbus) for the helpful suggestions and the ARPA Emilia Romagna, in particular Carlo Cacciamani for the helpful suggestions and G.Antolini, R.Tomozeiu, M.S.Tesini for providing the ARPA-EMR dataset.

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1 - INTRODUCTION

The sensitivity study described in this research paper concerns the regional climate model COSMO-CLM [11], adopted by the division ISC-CAPUA of CMCC for its research activities.
COSMO-CLM is the climate version of the non-hydrostatic (explicit description of vertical acceleration of air masses) COSMO model (COnsortium for Small-scale MOdeling) employed by several European weather services for numerical weather predictions [13].

It is the only documented numerical model system in Europe designed for spatial resolutions down to 1km with a range of applicability encompassing operational numerical weather prediction, regional climate modelling, the dispersion of trace gases and aerosol and idealised studies. It is applicable in all regions of the world for a wide range of available climate simulations from global climate and NWP models. It allows to set different options for a simulation changing parameters in the so called NAMELIST blocks, each for a particular area of expertise.

In previous works, sensitivity studies on the parameterizations of COSMO-CLM have already been performed, especially to analyze the precipitation. For example, in Suklitsch at al [14] several different runs have been executed changing physical and numerical parameterizations, vertical resolution and domain size, to find a suitable setup of COSMO-CLM on the European Alpine region using a configuration with a horizontal resolution of 10 km. For all the simulations, a spin up period of four months is considered and an evaluation period of one year.
In Bachner et al. (2008) [1], the sensitivity of the summer precipitation features over Germany to the parameterizations has been evaluated, analyzing also some extreme precipitation indices. A COSMO-CLM configuration with grid size of approximately 18 km, 20 atmospherical vertical levels and 9 soil layers is investigated. The analyses are performed for the period of June, July and August of one year, leaving one month of spin-up time to the model.
The aim of this work is to find an optimal setting of COSMO-CLM to simulate temperature and precipitation in the northern and central part of Italy, including Alpine region and Po Valley. The analysis is performed leaving one year of spin-up time to the model with an evaluation period of four years. The need to optimize the COSMO-CLM configuration over this area comes from the analysis of previous simulations that showed a strong bias in these areas.
In order to match this purpose, we have tested more than 20 different configurations, differing one another for the choice of physical, numerical and tuning parameters. The 2-meters mean temperature and the total precipitation have been analyzed and compared with three different observational datasets; in this way, it has been possible to obtain a large amount of results for the determination of the best configuration on the area of interest.
The optimized namelist, successively, has been used in a long-term simulation on the northern Italy (see the Research Paper of CMCC [10]), covering the period 1971-2000, whose aim was the comparison between observations and model output in a very complex orography area such as the Alps.

This report is organized as follows: *section 2* is devoted to the description of the investigated domains and observational datasets; in *section 3*, the settings of the several configurations tested are described; in *section 4*, the results of the sensitivity study are shown comparing model and observations value of 2-meters mean temperature and total precipitation. Finally, in *section 5*, a summary of the main results and conclusions is presented.

2 - AREA OF INTEREST AND OBSERVATIONAL DATASETS

The computational domain, on which the simulations have been performed, includes the northern and central part of Italy, more specifically an area whose longitude ranges from 4.7°E to 16.7°E and the latitude from 40.8°N to 48.3°N. (see Figure1).

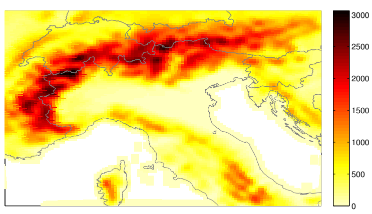

Figure 1:
The orography of the domain

Temperature and precipitation have been analyzed on five sub-domains selected inside this area (Figure 2), 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 Appenine area.

A further analysis has been performed considering the sub-domain composed by the five ones described above.

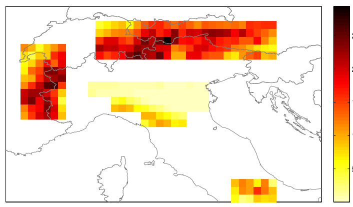

Figure 2:
The orography of all areas analyzed.

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 ERA40 Reanalysis [15] in order to have "perfect" boundary conditions. In this way, it is possible to prevent the introduction of the global model error, analyzing only the error of the regional one.
The computational grid of ERA40 Reanalysis is characterized by 320 x 160 grid points at a resolution of 1.125° (about 128km), with 49 atmospherical vertical levels and 3 soil levels (at the depth of 0.035, 0.175, 0.64 and 1.945 meters).
The computational grid of COSMO-CLM is characterized by 130 x 108 grid points at a resolution of 0.0715° (about 8km), with 40 atmospherical vertical level and 5 levels of soil (at the depth of 0.03, 0.19, 0.78, 2.68 and 6.98

meters).

The validation of the results has been performed with 3 different datasets:

1. `E-OBS` gridded dataset at a resolution of 0.25° (about 28km) for daily values of temperature on the period 1997-2000 (Figure 3). This dataset provides the best estimate of grid box averages of temperature and precipitation to enable direct comparison with RCMs [8] (for more information see the Research Paper of CMCC [16]);

2. Alpine Precipitation Analyses from High-Resolution Rain-Gauge Observations, here also called `ETH` (created by ETH, [5]) 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 the ETH datasets is available from 1971 to 1998). This dataset is one of the densest meteorological observing systems over complex topography worldwide (Figure 4) (for more information see the Research Paper of CMCC [16]);

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).

A grid has been extracted from `E-OBS` and `ETH`, and the data of COSMO-CLM have been bilinearly interpolated on these grids.
Concerning the `ARPA-EMR`, instead, there was no need to interpolate the data, being the regional climate model and observations at the same resolution.

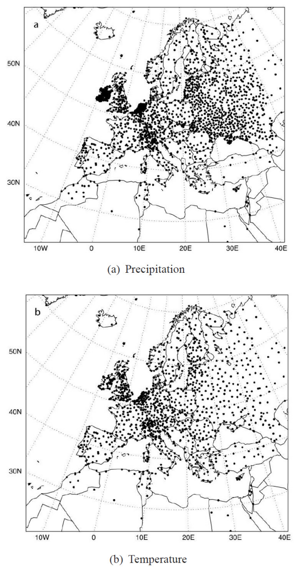

Figure 3:
The complete gridding region, showing the station network for (a) precipitation and (b) temperature of the EOBS dataset.

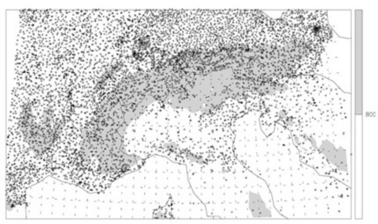

Figure 4:
Station coverage of "Alpine Precipitation Analyses from High-Resolution RainGauge Observations".

3 - DESCRIPTION OF THE CONFIGURATIONS TESTED

3.1 - THE REFERENCE NAMELIST

We have started this activity considering a reference namelist, which has been used in previous works concerning Italy and Alpine region and the whole Mediterranean area. This configuration is named **Run 2** (while **Run 1** was a

preliminary experiment).
The mean settings, common to all the configurations, are listed in Table 1. The main features of **Run 2** (both `INT2LM` and `COSMO-CLM`) are described here, while the main features of the other configurations are described in *section 3.2*.

Table 1
Main features of the COSMO-CLM configurations.

Model version of interpolator INT2LM	091216_1.10_clm2
Model version of COSMO-CLM	090213_4.8_clm13
Driving data	ERA40 Reanalysis
Num. of grid points	130 x 108
Horizontal resolution	0.0715°
Num. of vertical levels in atmosphere	40
Num. of soil levels	5
Soil scheme	TERRA_ML
Time step	40 s
Melting processes	yes
Convection scheme	TIEDTKE
Frequency of radiation computation	1 hour
Time integration	Runge-Kutta (2rd ord.)
Frequency update boundary cond.	6 hours
Frequency of writing output	3 hours

Mean features of INT2LM configuration Run 2
The sub-grid scale orography scheme used [9] deals explicitly with a low-level flow, which is blocked when the sub-grid scale orography is sufficiently high. For this blocked flow, a separation occurs at the mountain flanks, resulting in a form drag.
A multi-layer soil level has been used. Finally, a pressure based vertical coordinate on input (hybrid sigma-pressure co-ordinate) is used.

Mean features of COSMO-CLM configuration Run 2
In the COSMO-CLM model reference configuration, a 2 time-level Runge-Kutta time-split scheme is used, with a third order horizontal advection scheme.
A domain mask is used to reduce the standard coefficient for numerical diffusion for u,v and w, temperature and pressure and humidity and cloud water smoothing.

Concerning the physics, a grid-scale precipitation scheme is adopted, with a Kessler-type warm parameterization scheme without ice-phase processes. Cloud cover, water content and ice content are calculated by the default diagnostic scheme.
Concerning the specific vertical turbulent diffusion parameterization, a prognostic TKE-based scheme, including effects from subgrid-scale condensation/evaporation is used. The surface-atmosphere transfer is based on diagnostic TKE in the surface layer.
Subgrid-scale processes are included: the model is run with a moist convection parameterization, which computes the effect of moist convection on temperature, water vapour and horizontal wind in the atmosphere, and the precipitations rates of rain and snow at the ground.
Soil processes are included by running the multi-layer soil model TERRA_ML, which includes melting processes within the soil.
A BATS version is used, for the evaporation of bare soil and the transpiration by vegetation.

3.2 - THE SEVERAL CONFIGURATIONS IMPLEMENTED

Starting from the setting of **Run 2**, several numerical, physical and tuning parameters have been modified, obtaining more than 20 configurations: some of them vary from the other in just few parameters, whereas other ones are very different.
In the following, each configuration and its settings is briefly described, highlighting only the changes respect to **Run 2**. Each configuration is identified as **Run n**.

Run 3
The description of the forests has been introduced; furthermore, some parameters for the setting of the turbulent heat and for the evalua-

tion of the moisture fluxes have been modified, such as the variables for the representation of the clouds.

Run 4

In this configuration, some tuning parameters have been changed, such as additional initial and boundary data.
As for the **Run 3**, the setting of the turbulent heat and of the evaluation of the moisture fluxes have been modified, in addition to some parameterizations within numerics and turbulent diffusion, the cloud representation and the radiation scheme used.

Run 5

In addition to the variations inserted in **Run 3**, only the cloud representation has been modified.

Run 6Bis

In this case, some parameters for the setting of the turbulent heat and for the evaluation of the moisture fluxes have been modified, in addition to numerical and turbulent diffusion parameterizations and cloud representation. Moreover, the description of the forests has been introduced, along with a subgrid scale orography processes too.
The Runge-Kutta scheme has been replaced with the Leapfrog scheme. Finally, the dynamical bottom boundary condition, the order of horizontal advection scheme and the Rayleigh damping in upper levels have been modified.

Run 7

The only modification with respect to **Run 2** configuration is the filtering of the real orography in the interpolator INT2LM.

Run 8

In addition to the variations inserted in **Run 3**, the turbulent diffusion parameterization has been modified.

Run9

In addition to the variations inserted in **Run 8**, the filtering of the real orography in the interpolator INT2LM has been modified.

Run10

This configuration is like **Run 9**, but the time step has been halved.

Run12

In addition to the variations inserted in **Run 9**, the dynamical bottom boundary condition and the numerical parameterizations have been modified, in addition to the order of horizontal advection scheme and to the Rayleigh damping in upper levels.

Run13

In addition to the variations inserted in **Run 9**, the Runge-Kutta scheme has been replaced with the Leapfrog one.

Run15

In addition to the variations inserted in **Run 6bis**, the Leapfrog scheme has been replaced with the Runge-Kutta one. Moreover, the filtering of the orography has been modified, such as also a numerical parameterization.

Run16

In addition to the variations inserted in **Run 9**, some numerical parameterizations have been changed, such as the type of cloud water diagnosis too. Moreover, the subgrid scale orography processes have been introduced.

Run 17

The only difference respect to **Run 2** is the horizontal resolution, now at 0.125° (about 14km) instead of 0.0715° (about 8km).

Run 18

This configuration is like **Run 2**, but the orography filtering has been modified, such as also some parameterizations within numerics and tuning and some parameters for the setting of the turbulent heat and for the evaluation of the moisture fluxes. Finally, the order of the horizontal advection scheme and the frequency of calling of convection scheme has been changed.

Run 19

With respect to the **Run 2**, the number of vertical and soil levels has been increased.

Run 20

The only difference with respect to **Run 2** is the use of ERA-Interim as forcings, in substitution of ERA40 Reanalysis. ERA-Interim ([2], [3]) data are reanalysis of the global atmosphere covering the period 1979-2012, with several improvements with respect to the ERA40 as a result of a combination of factors. Their resolution is 0.703125° (about 79km), in contrast with the ERA40 resolution of 1.125°(about 128km).

Run 21

This configuration is like **Run 2**, but a two-step nesting approach has been utilized: a first step has been implemented at 0.28° of resolution (about 32km), then a second step at 0.0715°.

Run 22

This configuration is like **Run 2**, but with change in tuning parameters, additional initial and boundary data, numerical parameterizations and modification in boundary definition. The Runge-Kutta scheme and its order have been changed, such as the description of the forests, some parameters for the turbulent diffusion parameterization and for the cloud representation. The frequency of convection scheme and the soil scheme have been modified; finally, the subgrid scale orography processes have been introduced.

Run Fin

Finally, the settings of the configurations that seems to lead to better results have been unified.

In this list, there are two missing configurations, **Run 11** and **Run 14**: the first one has been obtained from **Run 6bis** changing only a parameter regarding the concentration of CO_2, but without any differences in the results; the second one aborted for a wrong setting of a numerical parameterization. For these reasons, the results of these two namelists have been excluded.

4 - ANALYSIS OF THE RESULTS

The performances of the simulations implemented for this study of sensitivity have been evaluated with three different observational datasets, according to the variable and to the area of interest.

The temperature values obtained have been compared with E-OBS in all the five subdomains defined in Section 2. Then, the ETH dataset has been used to validate the precipitation on NORTH and WEST areas. Finally, both temperature and precipitation have been compared with the ARPA-EMR dataset only on the Emilia-Romagna region.

4.1 - VALIDATION OF THE TEMPERATURE WITH E-OBS DATASET

The E-OBS dataset is available on the whole Europe; for this reason, it has been possible to validate the temperature values of all the areas identified in Section 2: five small areas and one including all of them.

The legend of the several configurations implemented is presented in Figure 5. Figures 6-11 show: (left) the seasonal cycle obtained with different configurations, along with the observations; (right) the seasonal cycle of the differences between model outputs and observations.

In Figure 6, the seasonal cycle in the NORTH region is shown: it is well captured by all configurations.The bias is always negative. A peak of cold bias is reached in February, when a group of configurations exceeds 2°C. The several **Run** differ one another less than 1°C in all the months, but from May to December this distance become lower. However, the underestimation never exceeds -2.2°C.

Also in the case of the WEST region (Figure 7) there is always a cold bias. In this area, the peak is reached in March (-2.1°C). With respect to the previous case, in the summer and autumn the bias is lower: for some configurations, the difference between temperature values of observation and COSMO-CLM is smaller than 1°C.

In the CENTRAL NORTH region (Figure 8), instead, there is an underestimation from November to March (with a peak in February of -1.8°C) and an overestimation from April to October (with a peak in July of 2.7°C). All configurations have the same trend, but for some of them the error is higher.

In the CENTRAL region (Figure 9), the seasonal cycle is very well captured. The bias is between -1.5°C and 1.5°C. In detail, in general there is a cold bias, with the exception of summer months and September but, unlike the other regions, the behaviour of one configuration (**Run 17**) is very different from the other ones (with a general overestimation); with the other configurations, the bias doesn't exceed 1°C.

In Figure 10, the seasonal cycle of SOUTH region is represented. Except the winter period, there is an underestimation always lower than 0.9°C: only for three configurations the bias is positive, and only in some months.

Finally, considering a domain including all five areas (Figure 11), there is a good agreement between observations and model, especially in the central months: from April to October the difference between observations and model are always under 1°C. The highest bias is reached in February, as seen also in the previous figures; moreover, the configurations differ one another less than 1°C.

Run 4, **Run 6bis** and **Run 13** have a larger bias than others in most of the regions (except for the CENTRAL NORTH): they show a higher underestimation in almost all the months. The **Run 22**, instead, is a good compromise between all the configurations in all the regions.

It is important to highlight that **Run 19** and **Run 20** (characterized by a higher number of vertical and soil levels and by the ERA-Interim as forcing respectively) show very good results in all the regions, except for the summer months in the CENTRAL NORTH, demonstrating the importance of these components in the simulations with a regional climate model.

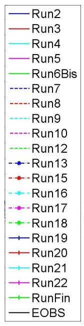

Figure 5:
Legend of the several configurations implemented.

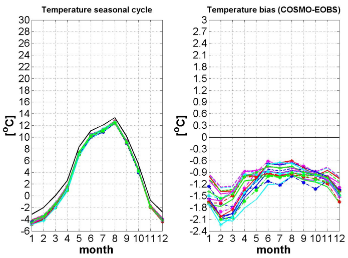

Figure 6:
Temperature seasonal cycle (left) and bias (right) of the NORTH region.

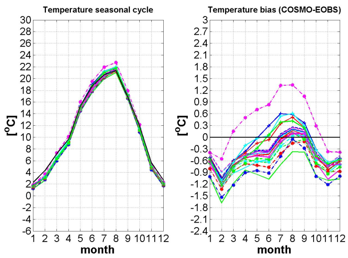

Figure 9:
Temperature seasonal cycle (left) and bias (right) of the CENTRAL region.

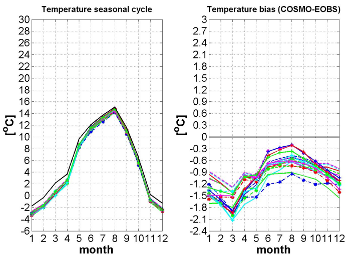

Figure 7:
Temperature seasonal cycle (left) and bias (right) of the WEST region.

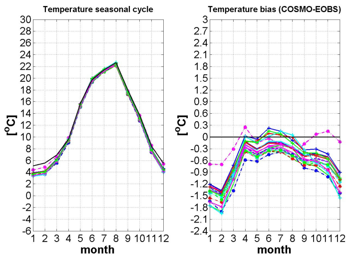

Figure 10:
Temperature seasonal cycle (left) and bias (right) of the SOUTH region.

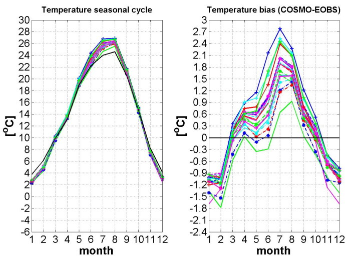

Figure 8:
Temperature seasonal cycle (left) and bias (right) of the CENTRAL NORTH region.

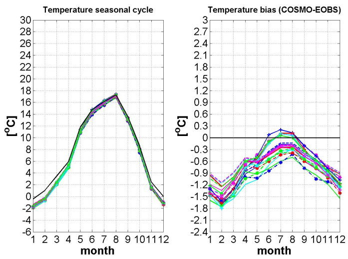

Figure 11:
Temperature seasonal cycle (left) and bias (right) considering all five regions.

4.2 - VALIDATION OF THE PRECIPITATION WITH ETH DATASET ON ALPINE REGIONS

The ETH dataset is available only for NORTH and WEST areas, so only these two subdomains have been considered for validation of precipitation. Moreover, a further area composed by these two sub-domains has been analyzed.
Also in this case, the first year has not been considered to exclude the spin up effect. In this way, only the two years 1997 and 1998 have been analyzed, being the ETH dataset available from 1971 to 1998.
The legend of the several configurations is shown in Figure 12.

Figures 13-15 show: (left) the seasonal cycle obtained with the different configurations, along with the observations; (right) the seasonal cycle of the percentage variation between model and observations.
In the case of the NORTH region (Figure 13), there is almost always an overestimation of the precipitation, except for two **Run** (**Run 17** and **Run 20**) from September to November.
This overestimation is highlighted in two configurations, **Run 5** (that reaches two peaks, one in May and one in August, respectively of 90% and 80%) and **Run 13**, leading to the conclusion that the use of a particular cloud representation (**Run 5**) and of the Leapfrog scheme (**Run 13**) brings to very different results in the analysis of the precipitation on the Alpine regions.
Almost all configurations have the same trend; in summer and in autumn the bias is lower than 30%, whereas in spring there is a stronger overestimation.
In Figure14, which refers to the WEST region, the bias is less strong than in the NORTH region: it is almost always between -25% and 25%. Also in this case, in the summer period there is a better agreement between model and observations. Moreover, the strongest bias is reached by the same two configurations that in the NORTH region showed a strong overestimation.
These general comments can be derived from Figure 15 too, where the results have been obtained considering the area composed by WEST and NORTH sub-domains.
Run 17 (characterized by a different resolution (14km instead of 8km)) and **Run 20** (characterized by the use of ERA-Interim as forcing) show a very good agreement with the observations, except in the summer months in the WEST region, in which they show a high underestimation.
Then, also in the case of the precipitation, the simulation forced by the ERA-Interim leads to a better result. Instead, for the **Run 17**, the good quality of the results is maybe due to two reasons: first, there is a lower difference in resolution between precipitation observed and modeled; then, the resolution ratio between the global model and the regional one is lower.

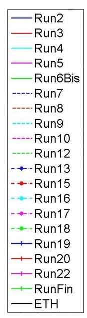

Figure 12:
Legend of the several configurations implemented.

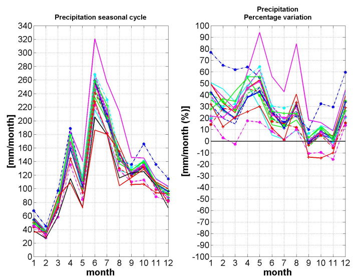

Figure 13:
Precipitation seasonal cycle (left) and percentage variation (right) of the NORTH region.

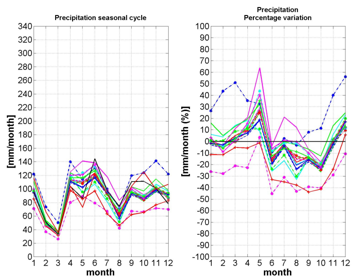

Figure 14:
Precipitation seasonal cycle (left) and percentage variation (right) of the WEST region.

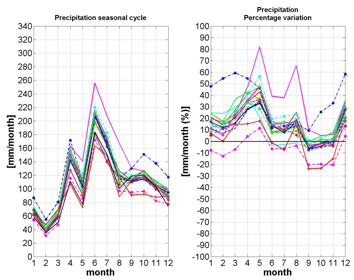

Figure 15:
Precipitation seasonal cycle (left) and percentage variation (right) considering all two regions.

4.3 - VALIDATION OF TEMPERATURE AND PRECIPITATION WITH ARPA-EMR DATASET ON THE EMILIA-ROMAGNA REGION.

The ARPA-EMR dataset is available only on the Emilia-Romagna region; for this reason, a mask has been created to select only the grid points included in the observations (Figure16).
The results have been analyzed on the period 1997-2000.

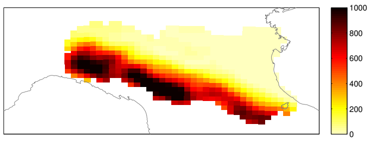

Figure 16:
The orography of COSMO-CLM on the area covering the Emilia-Romagna region.

Figure 18 shows the legend of the several configurations implemented.
In Figure17, the seasonal cycle and the bias of the temperature is represented. As highlighted already in the case of the E-OBS, there is an overestimation in the central months and an underestimation in the others. Comparing the results of the model with the ARPA-EMR dataset, the error is lower with respect to the E-OBS. The bias is between -1.8°C and 1.6°C: the two peaks are reached in February and in July respectively. The results are sensitive to the configurations, with differences up to 1°C.
For what concerns the precipitation (Figure19), instead, there is a general underestimation, with two peaks in March and especially in September, where a bias of -65% is reached. In the summer period, the bias is lower than -35% for most of the configuration. However, in general, some **Run** have strong differences with respect to the others.

Unlike the results obtained making the comparison with the other observations, **Run 13** doesn't exhibit the same error in this region, such as also the **Run 5**. Instead, the **Run 19**, characterized by more levels in the atmosphere and in the soil, shows the highest overestimation for the summer temperature and almost the highest underestimation for the precipitation in all months.

The **Run 20** leads to the highest underestimation with respect to the others, in contrast to the results obtained with the other observations in all regions; the **Run 6Bis** shows the best results.

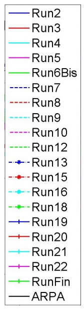

Figure 18:
Legend of the several configurations implemented.

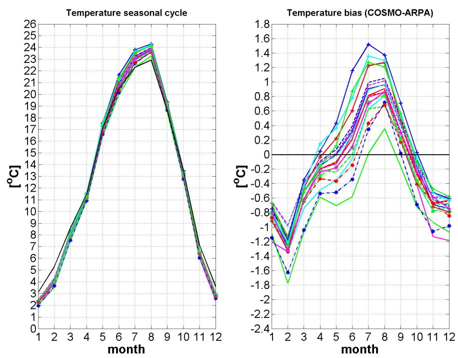

Figure 17:
Temperature seasonal cycle (left) and bias (right) of the Emilia-Romagna region.

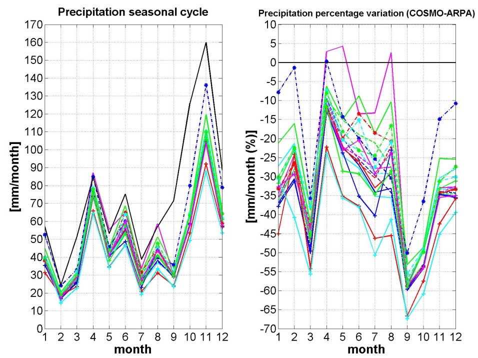

Figure 19:
Precipitation seasonal cycle (left) and percentage variation (right) of the Emilia-Romagna region.

5 - CONCLUSIONS

A sensitivity analysis has been performed, in order to find an optimal configuration over north and center Italy for the regional climate model COSMO-CLM. More than 20 configurations have been defined (changing numerical and physical parameters) and tested over the time period 1996-2000, assuming the ERA40 reanalysis as driving data.
An analysis of the results has been performed in different geographical areas, investigating the bias of temperature and the percentage variation of the precipitation in the seasonal cycles.
According with the results shown in the previous sections, it is difficult to choose the best configuration, as it should represent an optimal compromise among several factors (variables, geographical area and seasonal periods). Keeping in mind these difficulties, the configuration **Run 22** seems to be the best one and it is therefore recommended for the execution of further simulations. **Run 22** is very close to the CORDEX [6] configuration used by the CLM community for simulations over different European domains.
In this study, it shows a very good agreement between the simulated and observed temperatures, both for the EOBS and ARPA-EMR datasets, 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 configurations (the error is always under 1.5°C). Moreover, concerning the precipitation, **Run 22** highlights a low percentage variation (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.

Of course, the sensitivity activity could be carried out in several others ways, following other methodologies. For example, in Stein et al [12] a method to compute and distinguish the interactions among various factors influencing the atmospheric circulations has been developed. Unfortunately, for several reasons, it was not possible to implement a complex algorithm to find the best configuration of COSMO-CLM in the analyzed domains. In this case, the kind of sensitivity study has been performed following Dierer et al [4].
However, a more completed and detailed analysis of the big amount of results obtained will be carried out, following the methodologies of the other works in literature and calculating other indices and synthetic values.

After this study, five sets of simulations have been performed:

- an ERA40-Reanalysis driven simulation over the Alpine space (including Italy, France, Germany, Switzerland) at 8 km of resolution for the period 1971-2000 (for more information see the Research Paper of CMCC [10]);
- an ERA40-Reanalysis driven simulation over Italy, at 8 km of resolution for the period 1971-2000;
- a CMCC-MED ([7]) driven simulation over Italy, at 8 km of resolution for the period 2001-2100 with the RCP4.5 and RCP8.5 scenarios;
- an ERA40-Reanalysis driven simulation over Mediterranean region, at 14 km of resolution for the period 1971-2000;
- a CMCC-MED driven simulation over Mediterranean region, at 14 km of resolution for the period 2001-2100 with the RCP4.5 and RCP8.5 scenarios.

Bibliography

[1] S. Bachner, A. Kapala, and C. Simmer. Evaluation of daily precipitation characteristics in the CLM and their sensitivity to parameterizations. *Meteorologische Zeitschrift*, 17(4):407–419, 2008.

[2] BP. Berrisford, D. Dee, K. Fielding, M. Fuentes, P. Kallberg, S. Kobayashi, and S. Uppala. The ERA-Interim Archive. *ERA Report Series.1. Technical Report. European Centre for Medium-Range Weather Forecasts: Shinfield Park, Reading*, 2009.

[3] D. Dee, SM. Uppala, AJ. Simmons, P. Berrisford, P. Poli, S. Kobayashi, U. Andrae, MA. Balmaseda, G. Balsamo, P. Bauer, P. Bechtold, ACM. Beljaars, L. van de Berg, J. Bidlot, N. Bormann, C. Delsol, R. Dragani, M. Fuentes, AJ. Geer, L. Haimberger, SB. Healy, H. Hersbach, EV. Holm, L. Isaksen, P. Kallberg, M. Kohler, M. Matricardi, Ap. McNally, BM. Monge-Sanz, JJ. Morcrette, BK. Park, C. Peubey, P. de Rosnay, C. Tavolato, JN. Thepaut, and F. Vitart. The era-interim reanalysis: configuration and performance of the data assimilation system. . *Quarterly Journal of Royal Meteorological Society*, 137:553–597, 2011.

[4] S. Dierer, M. Arpagaus, A. Seifert, E. Avgoustoglou, R. Dumitrache, F. Grazzini, P. Mercogliano, M. Milelli, and K. Starosta. Deficiencies in quantitative precipitation forecasts: sensitivity studies using the COSMO model. *Meteorologische Zeitschrift*, 18(6):631–645, 2009.

[5] C. Frei and C. Schär. A precipitation climatology of the Alps from high-resolution rain-gauge observations. *International Journal of Climatology*, 18(8):873–900, 1998.

[6] F. Giorgi, C. Jones, and G.R. Asrar. Addressing climate information needs at the regional level: the CORDEX framework. *WMO Bulletin*, 58, 2009.

[7] S. Gualdi, S. Somot, L. Li, V. Artale, M. Adani, A. Bellucci, A. Braun, S. Calmanti, A. Carillo, A. Dell'Aquila, M. Déqué, C. Dubois, A. Elizalde, A. Harzallah, D. Jacob, B. L'Hévéder, W. May, P. Oddo, P. Ruti, A. Sanna, G. Sannino, E. Scoccimarro, F. Sevault, and A. Navarra. The CIRCE simulations: a new set of regional climate change projections performed with a realistic representation of the Mediterranean Sea. *Bull. Amer. Meteor. Soc.*, 18(6):631–645, 2009.

[8] M. R. Haylock, N. Hofstra, A. M. G. Klein Tank, E. J. Klok, P. D. Jones, and M. New. A European daily high-resolution gridded data set of surface temperature and precipitation for 1950-2006. *Journal of Geophysical Research*, 113(D20), 2008.

[9] F. Lott and M.J. Miller. A new subgrid-scale orographic drag parametrization: Its formulation and testing. *Q. J. R. Meteor. Soc.*, 123:101–127, 1997.

[10] M. Montesarchio, M.P. Manzi, L. Cattaneo, E. Bucchignani, and P. Mercogliano. Performance evaluation of a regional climate simulation with COSMO-CLM in the Alpine space. *http://www.cmcc.it/pubblicazioni/pubblicazioni/research-papers/rp0137-isc-07-2012*, 2012.

[11] B. Rockel, A. Will, and A. Hense. The regional Climate Model COSMO-CLM (CCLM). *Meteorologische Zeitschrift*, 17(4):347–348, 2008.

[12] U. Stein and P. Alpert. Factor Separation in Numerical Simulations. *Journal of the Atmospheric Sciences*, 50(14):2107–2115, 1993.

[13] J. Steppeler, G. Doms, U. Schättler, H.W. Bitzer, A. Gassmann, U. Damrath, and G. Gregoric. Meso-gamma scale forecasts

using the nonhydrostatic model LM. *Meteorology and Atmospheric Physics*, 82(1-4):75–96, January 2003.

[14] M. Suklitsch, A. Gobiet, A. Leuprecht, and C. Frei. High Resolution Sensitivity Studies with the Regional Climate Model CCLM in the Alpine Region. *Meteorologische Zeitschrift*, 17(4):467–476, 2008.

[15] S.M. Uppala, P.W. Kallberg, A.J. Simmons, U. Andrae, V.D. Bechtold, M. Fiorino, J.K. Gibson, J. Haseler, A. Hernandez, G.A. Kelly, X. Li, K. Onogi, S. Saarinen, N. Sokka, R.P. Allan, E. Andersson, K. Arpe, M.A. Balmaseda, A.C.M. Beljaars, L. Van de Berg, J. Bidlot, N. Bormann, S. Caires, F. Chevallier, A. Dethof, M. Dragosavac, M. Fisher, M. Fuentes, S. Hagemann, E. Holm, B.J. Hoskins, L. Isaksen, P.A.E.M. Janssen, R. Jenne, A.P. McNally, J.F. Mahfouf, J.J. Morcrette, N.A. Rayner, R.W. Saunders, P. Simon, A. Sterl, K.E. Trenberth, A. Untch, D. Vasiljevic, P. Viterbo, and J. Woollen. The ERA-40 re-analysis. *Quart. J. Roy. Meteor. Soc.*, 612:2961–3012, 2006.

[16] A.L. Zollo, P. Mercogliano, M. Turco, R. Vezzoli, G. Rianna, E. Bucchignani, M.P. Manzi, and M. Montesarchio. Architectures and Tools to Analyse the Impact of Climate Change on Hydrogeological Risk on Mediterranean Area. *http://www.cmcc.it/pubblicazioni/pubblicazioni/research-papers/rp0129-isc-03-2012*, 2012.