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Assessment of COSMO-CLM performances in simulating the past climate of Italy.

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SUMMARY This paper analyzes the capabilities of the regional climate model COSMO-CLM to simulate the main features of the observed climate over the entire Italian domain. Two simulations on the period 1971-2000, driven by ERA40 Reanalysis and by the CMCC-MED global model respectively, have been performed at a spatial resolution of 8 km. 2-meters mean temperature and daily precipitation have been analyzed comparing their values with EOBS observational dataset, along with an analysis of the total cloud cover and geopotential at 500hPa and 850hPa compared with ERA-Interim Reanalysis.

1 - INTRODUCTION

The main motivation for the present work is to analyse the capabilities of the regional climate model COSMO-CLM [19] in simulating the main features of the observed Italian climate.
Italy is located in Southern Europe and belongs to the Mediterranean area, affected by the arid climate of the North-Africa and by the temperate and rainy climate of central Europe [10]. Moreover, it is characterized by a very complex and heterogeneous topography, ranging from high mountain chains, such as Alps and Appenines, to several coastal areas, being Italy almost totally surrounded by the Mediterranen Sea.
A coarse subdivision of the Italian climate can be made selecting, at first, only two parts, according to Lo Vecchio and Nanni, 1995 [14]: a continental zone (northern Italy) and a peninsular zone (central and southern Italy). Instead, in this work, for a more detailed analysis, three areas have been identified based on the climatic conditions of Italy, following the paper of Coppola and Giorgi, 2010 [8]: a cold region (NORTH area), a temperate region (CENTRAL area) and a semi-arid region (SOUTH area).
For a better representation of these particular climatic features, a high horizontal spatial resolution is needed. For this purpose, regional climate models are recommended for simulations on the Italian peninsula. In fact, at the resolution of the global climate models, Italy is not well delineated or not even captured [8].
For this purpose, the regional climate model COSMO-CLM has been adopted. It was also used in the PRUDENCE project (Christensen et al., 2007 [7]) with competitive results (Rockel et al., 2008 [18]), showing the same range of accuracy as other RCMs.
This validation paper is a first step for a study on the climate change projections over Italy on the XXI century; indeed, the evaluation of the model error in reproducing the past climate is essential to a better quantification of the temperature and precipitation change in the future.
To this aim, a further simulation with the regional climate model COSMO-CLM, using the CMCC-MED global model as forcings, is currently in progress for the period 2001-2100 under the RCP4.5 scenario conditions.

This report is organized as follows: Section 2 is devoted to a general description of the regional climate model COSMO-CLM and its settings, and of the observational dataset used; in Section 3, the validation of several variables has been performed, both for the simulation driven by the ERA40 Reanalysis and the simulation driven by the global climate model CMCC-MED. Finally, in Section 4, a summary of the main results and conclusions is presented.

2 - MODEL AND DATA

2.1 - THE REGIONAL CLIMATE MODEL COSMO-CLM AND ITS SET-UP

The regional climate model used in this work is COSMO-CLM (Rockel at al., 2008 [19]), the climate version of the COSMO-LM weather model (Steppeler et al., 2003 [20]) (to more information, see the Research Paper [22]). An important feature of COSMO-CLM is the non hydrostatic formulation, that allows to better resolve convective phenomena and to use horizontal spatial resolutions lower than 20 km (Bohm et al., 2006 [3]). Higher resolution, with respect to the global climate model one, allows a better description of the terrain topography and, consequently, of the phenomena strictly related to

the orography, such as the precipitation.
The COSMO-CLM model version used in this research is 4.8_CLM13, whereas for the interpolator INT2LM the version is 1.10_CLM2.
Two simulations have been performed: the first one is forced by the ERA40 Reanalysis (Uppala et al., 2006 [21]) and the second one by the global climate model CMCC-MED (Gualdi et al., 2012 [11]). The ERA40 Reanalysis are characterized by a horizontal resolution of 1.125° (about 128 km), 49 vertical levels and 3 soil levels, while ECHAM5 (atmospherical component of the CMCC-MED) by a horizontal resolution of 0.75° (about 85km), 31 vertical levels and 4 soil levels.
Analyzing the differences between the first simulation results and observational dataset, it is possible a characterization of the error related only to the regional climate model COSMO-CLM, as "perfect" boundary conditions have been used. From the comparison with the second one, instead, the influence of the global model on the results can be analyzed (in this case, the error cannot be trace back to the regional or global model in a specific way).
The horizontal resolution adopted in both the simulations is 0.0715° (about 8 km). The area of interest is 3°-20°E / 36°-50°N and the period simulated is 1971-2000, but the time period investigated is 1972-2000: the first year of the simulation has been neglected in the analysis to exclude the spin-up effects due to the initial conditions.
In Table 1, the main features of the simulations are summarized.

Table 1
Main features of the COSMO-CLM set-up.

Driving data	ERA40 Reanalysis CMCC-MED model
Horizontal resolution	0.0715° (about 8km)
Num. of grid points	224 x 230
Num. of vertical levels in the atm.	40
Num. of soil levels	7
Soil scheme	TERRA_ML
Time step	40 s
Melting processes	yes
Convection scheme	TIEDTKE
Frequency of radiation computation	1 hour
Time integration	Runge-Kutta (3rd ord.)
Frequency update boundary cond.	6 hours

The validation has been performed on the Italian domain; for a more specific analysis, three different subdomains have been selected based on the characteristic of the Italian climate (see Figure 1):

1. `NORTH` : 5.625° to 15.625°E; 43.875° to 47.125 °N;
2. `CENTRE` : 9.625° to 16.875°E; 41.375° to 43.875 °N;
3. `SOUTH` : 7.625° to 19.125°E; 36.125° to 41.375 °N.

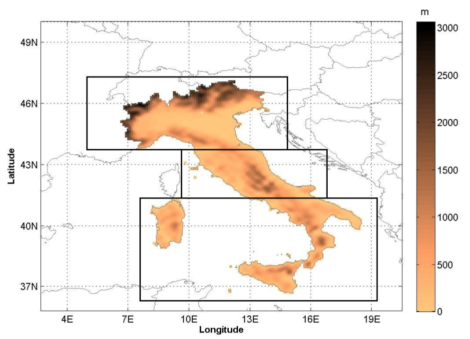
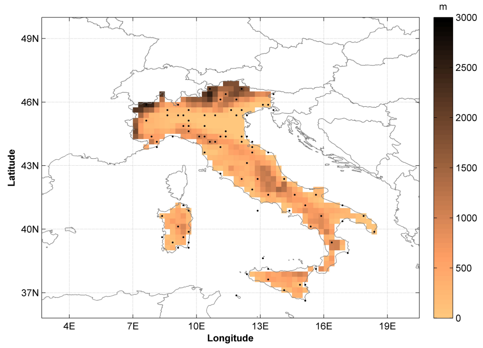


Figure 1:
Orography of the Italian domain with the three considered subdomains.

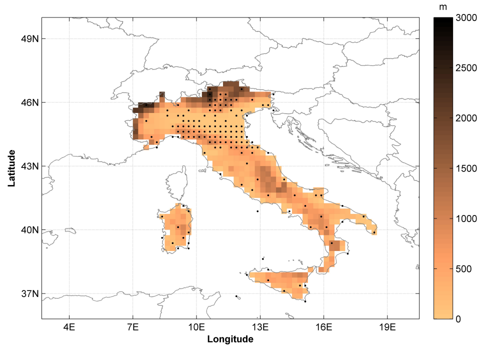
2.2 - OBSERVATIONAL DATASET

The model evaluation for both the simulations has been performed by using the EOBS dataset: 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 (Haylock et al., 2008 [12]).
Figure 2 shows the orography of the EOBS dataset over the Italian domain, with the representation of the stations location for the temperature and precipitation.
It must be taken into account that this dataset is obtained through an interpolation of the station values and then it is affected by a number of potential uncertainties, since generally the interpolation accuracy decreases as the network density decreases and the error increases in complex terrains, such as mountains (Hofstra et al., 2009 [13]).
Furthermore, to carry out an evaluation of the geopotential at 500hPa and 850hPa and of the total cloud cover, the ERA-Interim data (Berrisford et al., 2009 [2]; Dee et al., 2011 [9]), at a resolution of 0.703125° (about 79km), have been used. Several works performed a comparison between them and the results of regional climate models, such as Cardoso et al., 2012 [6], in which they have been used to calculate error statistics on the precipitation in the Iberian peninsula.
The ERA-Interim are reanalysis of the global atmosphere covering the period since 1979 (originally, ERA-Interim ran from 1989, but the 10 year extension for 1979-1988 was produced in 2011) and continuing in real time; for this reason, the time period investigated to perform the geopotential and total cloud cover analysis is 1979-2000.



(a) temperature



(b) precipitation

Figure 2:
Orography of the EOBS on the Italian domain. In each picture, the location of the EOBS stations are represented, for temperature (upper) and precipitation (bottom) respectively.

3 - RESULTS

In this section, the comparison between the results of the two simulations and the observational datasets is shown. For the temperature (*section 3.1*) and the precipitation (*section 3.2*), the seasonal spatial values have been investigated for the whole Italian domain, in addition to the seasonal cycles and the time series on the three subdomains described in *section 2* (NORTH, CENTRE and SOUTH). The comparison has been carried out with the EOBS dataset and the COSMO-CLM outputs have been bilinearly interpolated on its grid.
In *section 3.3* and *section 3.4*, instead, the

seasonal spatial values of total cloud cover and geopotential at 500hPa and 850hPa have been analyzed for the whole Italian domain, comparing the COSMO-CLM results with the ERA-Interim Reanalysis. The simulation outputs have been bilinearly interpolated on the ERA-Interim grid.

3.1 - TEMPERATURE

First, the capability of the model in reproducing the spatial features of the climate over the analyzed domain has been investigated.
Figure 3 shows the seasonal spatial values of the differences in 2-meters mean temperature (in °C) between the COSMO-CLM output and the EOBS observational dataset.
The most evident result is the difference between the output of the simulation driven by ERA40-Reanalysis and the one driven by the global climate model CMCC-MED: the second one has a more pronounced bias in all seasons, with a general underestimation up to -5°C in winter.
The analysis of Figure 3 reveals a cold bias over the mountainous areas (Alps and Appennines) in all the seasons and for both the simulations.
Concerning the ERA40 driven simulation (left column of Figure 3), the observed bias does not exceed 3°C in absolute value: the highest bias is registered in winter and summer. In winter, there is a general underestimation of the temperature (up to -3°C in the Ligurian Alps), except in the Po Valley and in the north-east part of Italy, where there is a good agreement with a slight overestimation (at most 0.5°C). In summer, instead, except on the Alps and on the Appenines, in which there is a slight cold bias (up to -1°C), an overestimation occurs, with a peak of 2.5-3°C over the Adriatic coast and in the south of Sicily. The difference between simulated and observed temperature in spring and autumn is lower: for spring, the bias ranges from -2°C (reached on Alps in Piedmont) to 1°C (on the Adriatic coast); for autumn, the behaviour is roughly the same, but with a slightly more cold bias.
Concerning the CMCC-MED driven simulation (right column of Figure 3), as said before, it is affected by a cold bias in all seasons, more pronounced in winter; only the summer shows a different trend: with respect to the regions in which the summer temperature of the ERA40 driven simulation highlights a hot bias, in this one a better agreement (at most 0.5°C of difference) is registered, whereas on Alps and Appennines a colder bias is found.
The results of the comparison could be, however, influenced by the number of stations of the EOBS dataset in the Italian area: as shown in Figure 2(a), the density of weather stations is very low, with the exception of Lombardia (western part) and Emilia-Romagna (Appennine area) regions.
Successively, the mean values, averaged over the three selected subdomains described in *section 2*, have been analyzed in order to study the model ability to represent the seasonal cycles and the time series of the 2-meters mean temperature.
The seasonal cycles (Figure 4(a)) are very well captured by both the simulations, in all the regions. The highest error occurs in the winter season and the CMCC-MED driven simulation always underestimates the temperatures, as already highlighted in the seasonal spatial differences.
Analyzing the time series (Figure 4(b)), this general underestimation is more evident, especially for the simulation forced by the global model.
It is important to take into account that the time series of the CMCC-MED driven simulation must be only seen in terms of trend, and not as a representation of the mean tempera-

ture of the specific years.
Concerning the time series of NORTH and CENTRE regions, the trend lines appear almost parallel for both the model outputs and observations, although in the case of the simulation forced by the global model the temperature growth is slower, especially in the CENTRE region (see also Table 2). In the case of SOUTH region, instead, the temperature trend of observed value is the highest, and unfortunately it is not well reproduced by the simulations. In fact, for the EOBS, the trend is of about 5.6°C per 100 years; for the ERA40 driven simulation is of about 4°C per 100 years, whereas for the CMCC-MED driven simulation is of about 2°C.
However, all the sets of data (observation and two simulations) highlight an increase of the mean temperature in all the regions in agreement with several literature works (Perini et al.,2007 [16]; Brunetti et al.,2002 [4]). Unfortunately, it is difficult to make a detailed comparison with other papers because in the literature the studies are conducted over different observation periods and in different regions [15].

Table 2
Temperature trends for each subdomain, for EOBS dataset and ERA40 and CMCC-MED driven simulations respectively (°C per year).

	EOBS	ERA40 driven simulation	CMCC-MED driven simulation
NORTH	0.0445	0.0423	0.0395
CENTRE	0.0486	0.0420	0.0258
SOUTH	0.0561	0.0396	0.0208

3.2 - PRECIPITATION

Figure 5 shows the seasonal spatial values of the differences in precipitation (in mm/day) between the COSMO-CLM output and the EOBS observational dataset.
With respect to the temperature, the differences between the simulation driven by ERA40-Reanalysis and the one driven by the global climate model CMCC-MED are less evident.
For all seasons, in particular for spring and summer, an overestimation over the Alps occurs for both the simulations. However, in general the bias is between -4 mm/day and 5 mm/day.
Comparing the results of the two simulations, the same bias pattern is observed in winter, but with a stronger overestimation for CMCC-MED driven simulation on the Alps and on the central and southern Italy. In the case of the simulation forced by the ERA40-Reanalysis, the differences with the observations do not exceed 2 mm/day in absolute value. In spring, instead, the differences for both the simulations are the same, with a peak on the Alps up to 5 mm/day and a general slight overestimation on the south part of Italy (at most 1 mm/day). In summer, there is a very good agreement, except on the Alps; in fact, the bias is between -0.5 mm/day and 0.5 mm/day, but in the case of the CMCC-MED forced simulation the differences in CENTRE and SOUTH regions are close to 0 mm/day. In autumn, finally, the bias features for the two simulations are very similar and the highest difference with the observations occurs in Tuscany (-3 mm/day).
As for the temperature, also in the case of the precipitation the values of the biases could be influenced by the low number of stations of the EOBS dataset (as shown in Figure 2(b)). Only the Emilia-Romagna region has a denser stations network.
To analyze the capability of the model in reproducing seasonal cycles and time series, the mean values over NORTH, CENTRE and SOUTH subdomains have been investigated.
Concerning the seasonal cycles (Figure 6(a)), in the NORTH region a strong overestimation of the daily precipitation in April, May and June (about 1.5 mm/day) is observed for both the simulations; moreover, in January, February

and March the CMCC-MED driven simulation shows higher differences with respect to the one driven by the ERA40. In the other months, instead, there is a better agreement.
In CENTRE and SOUTH regions, instead, the seasonal cycle is very well captured, with a peak of at most 1 mm/day in some months.
About the time series (Figure 6(b)), a trend of precipitation decrease is found, for the EOBS observational dataset and for both the simulations.
As highlighted for the temperature, the precipitation time series of the CMCC-MED driven simulation must be only seen in terms of trend, and not as a representation of the value of the specific years.
Comparing the observations and the CMCC-MED forced simulation, for NORTH and CENTRE regions the trend lines are almost paraller showing, in the case of the NORTH subdomain, the same trend value (-1.5 mm/day per 100 years, see Table 3), whereas for the SOUTH subdomain, the simulated precipitation has a lower decrease than the observed one.
The ERA40 forced simulation, with respect to the CMCC-MED forced one and to the EOBS, shows a stronger decrease of the precipitation in all the regions, especially in the NORTH one with a trend of -5.2 mm/day per 100 years.
However, in general, there is a reduction of total precipitation in the whole domain, in agreement with Buffoni et al.,1999 [5], Piervitali et al.,1998 [17] and Coppola and Giorgi,2010 [8]. Also for precipitation, the trend values obtained in this work are not directly comparable with the literature papers due to the different time period considered.

Table 3
Precipitation trends for each subdomain, for EOBS dataset and ERA40 and CMCC-MED driven simulations respectively (mm/day per year).

	EOBS	ERA40 driven simulation	CMCC-MED driven simulation
NORTH	-0.0153	-0.0522	-0.0153
CENTRE	-0.0080	-0.0365	-0.0086
SOUTH	-0.0149	-0.0358	-0.0038

3.3 - TOTAL CLOUD COVER

In this paragraph, the total cloud cover validation is shown, using the ERA-Interim Reanalysis, on the period 1979-2000.
Being the total cloud cover misured in percentage, the differences shown in Figure 7 are expressed in percentage too.
The first consideration is that the simulation forced by CMCC-MED has a general overestimation, especially in the summer and spring seasons in which a peak of 30% occurs on the northern part of the domain. In the other seasons, instead, the bias does not exceed 20%.
This overestimation is stronger with respect to the ERA40 driven simulation, in all the seasons and in the whole domain.
Concerning this last simulation, the area with the worst performance is the Po basin. Winter and autumn are the seasons with the best results; in particular, in the first one the bias is not well defined, but never higher than $\pm$10%, while the second one is characterized by a more defined tendency to overestimate the total cloud cover (under 10%). In spring and summer, instead, the bias is stronger, especially in the north-east part of the domain, where a peak of 20% occurs. With the exception of the winter months, the only area that shows a slight underestimation of the total cloud cover is the south-west one.

3.3 - GEOPOTENTIAL

Figures 8-9 show the percentage variation, with respect to the ERA-Interim Reanalysis, of the geopotential at 500hPa and at 850hPa respectively. It is worth noting that in these pictures the

colorbar scales are different for the two simulations, to allow a better visualization of the error. For both the simulations and for both the geopotential pressure levels, the differences are very low (less than 2%). In Figure 8, the CMCC-MED driven simulation has a general underestimation, more pronounced in spring months; in summer and autumn seasons, instead, the error is lower.
Concerning the ERA40 driven simulation, the percentage variation is close to 0%. In particular, in spring and autumn seasons there is the best agreement with respect to the ERA-Interim (under 0.1%); summer and winter have higher error (however under 0.2%) and show an opposite trend: in winter an underestimation occurs, while in summer an overestimation.
For what concerns the geopotential at 850hPa (Figure 9), the comparison with ERA-Interim shows higher differences with respect to the geopotential at 500hPa, indeed the 850hPa level is closer to the earth surface (about 1500m) and so it is more influenced by the orography. As a consequence, in some grid points of the Alpine region, there is a higher error with respect to the reanalysis data.
The simulation forced by the CMCC-MED model leads to a general underestimation of the geopotential, especially in spring (2%). In winter, the underestimation is more evident in the northern part of the domain, while in the southern one is less than 0.5%. Summer and autumn, finally, show better results, with a percentage variation of about 0.5%.
The ERA40 driven simulation shows a general positive bias in autumn and in winter, except in Alpine region, and a general negative bias in spring and summer. In the comparison with the ERA-Interim, there are some areas, whose locations are different in each season, with an error close to 0%.

4 - CONCLUSIONS

In this present study, an assessment of COSMO-CLM performances over Italy has been carried out, analyzing the results of two simulations on the period 1972-2000: one driven by the ERA40 Reanalysis and one by the global climate model CMCC-MED. Three subdomains have been investigated for a more precise evaluation of the model errors based on the climatic features of Italy.
The analysis shows general better results for the ERA40 forced simulation, as expected due to the use of the "perfect" boundary conditions, in all the comparisons, except the trend values of the precipitation.
The main conclusions are summarized in the following.

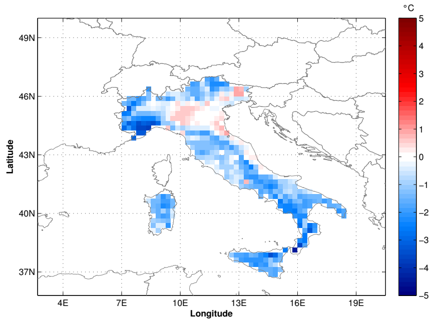
Temperature. There is a general underestimation in winter and a general overestimation in summer, but on the mountains a cold bias always occurs, in all the seasons; concerning the seasonal cycles, they are well captured in all the three regions investigated.

Precipitation. In all the seasons, on the Alps a wet bias has been observed, more evident in spring months. This result is confirmed in the seasonal cycle of `NORTH` region, whereas in the other ones there is a good agreement.

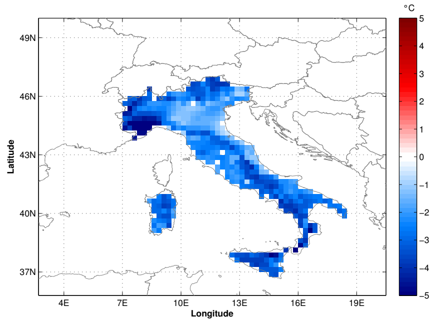
Total cloud cover. This variable shows a general overestimation (more pronunced in the case of the simulation forced by CMCC-MED), especially in spring and summer.

Geopotential. The simulation driven by the ERA40 has an error close to 0%, for both the pressure levels considered (500hPa and 850hPa), while the CMCC-MED driven simulation shows a slight underestimation, at most 2%.

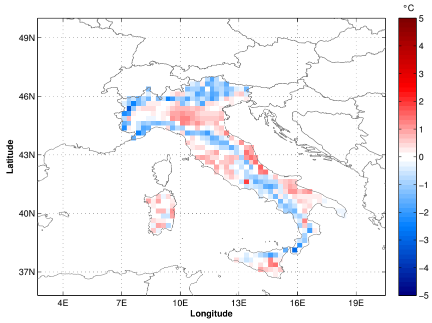
It is worth noting that the error found on the Alps (cold and wet bias) can be attributed not only to the model, but also to the observation values, because often the measurement stations are not at high altitudes, with a consequent low-elevation station bias (Adam and Lettenmainer,2003 [1]).
Concerning the trend analysis, in this study an agreement with literature values has been shown: an increase of temperature is observed in the period 1972-2000, whereas for the precipitation a decrease has been found. However, a comparison of the exact value of these trends with other studies is difficult due to the difference in periods and regions investigated.
Currently, a simulation on the period 2001-2100 is running in order to assess the changes in the future climate over Italian peninsula, both in term of mean changes and of extreme values. The RCP4.5 scenario is considered, while a future step will be a simulation employing the RCP8.5 scenario.



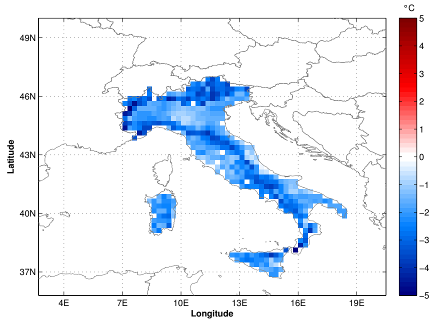
(a) winter - ERA40



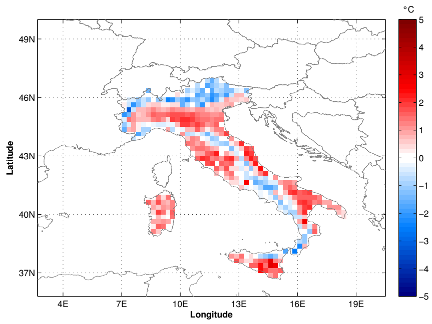
(b) winter - CMCC-MED



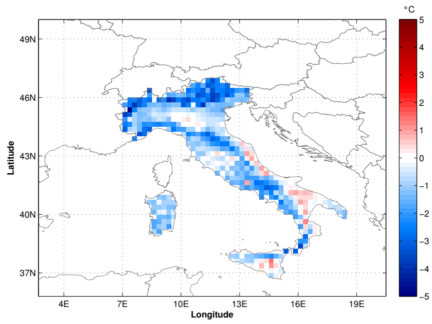
(c) spring - ERA40



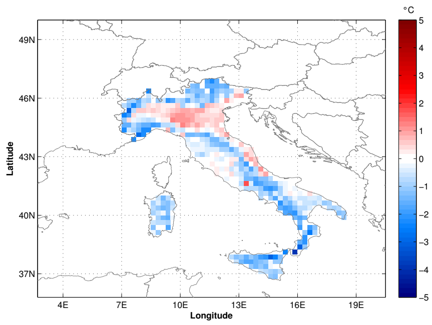
(d) spring - CMCC-MED



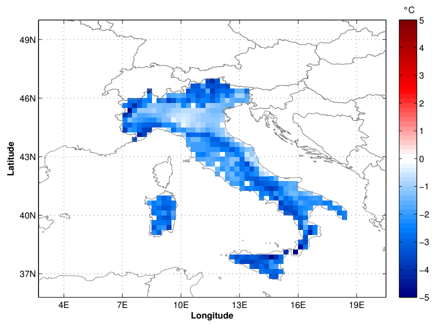
(e) summer - ERA40



(f) summer - CMCC-MED

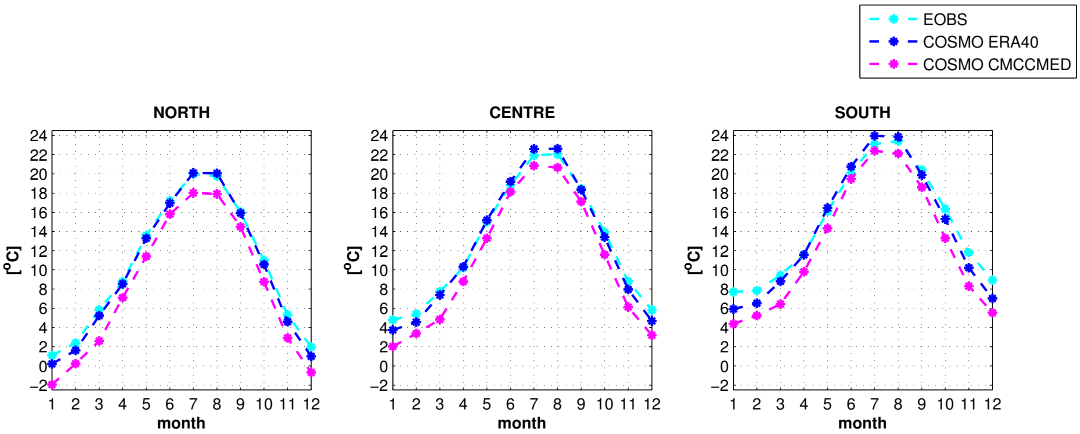


(g) autumn - ERA40

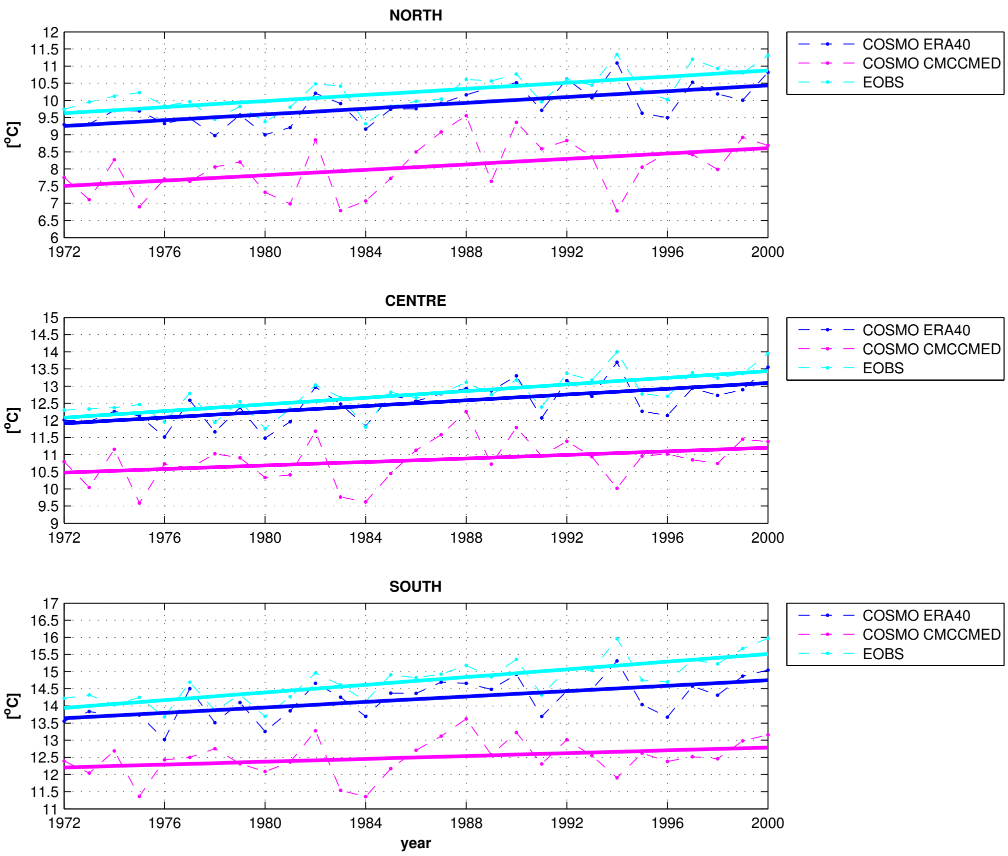


(h) autumn - CMCC-MED

Figure 3:
Seasonal differences, in terms of 2-meters 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).

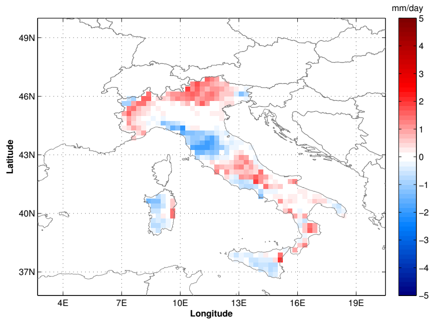


(a) seasonal cycles

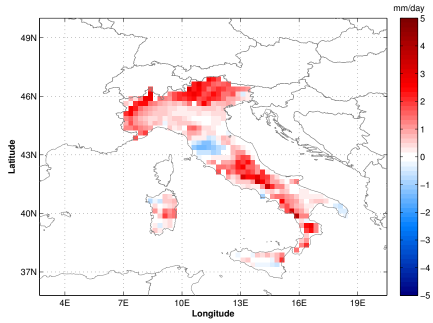


(b) time series

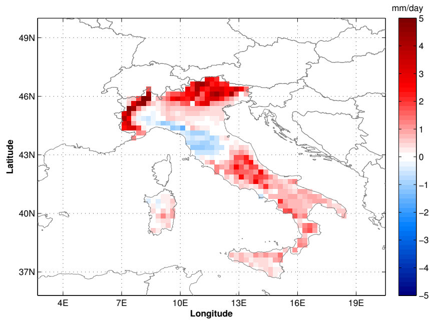
Figure 4:
Seasonal cycles (a) and time series (b) of the 2-meters mean temperature, for each subdomain investigated.



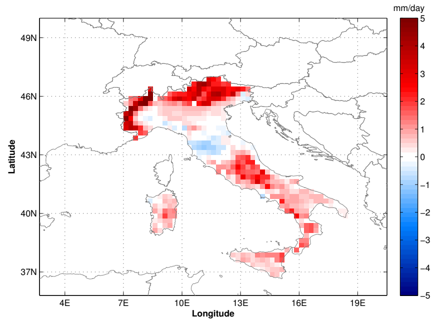
(a) winter - ERA40



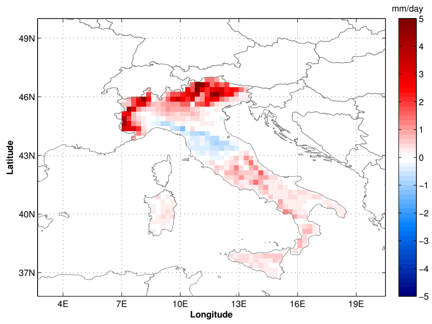
(b) winter - CMCC-MED



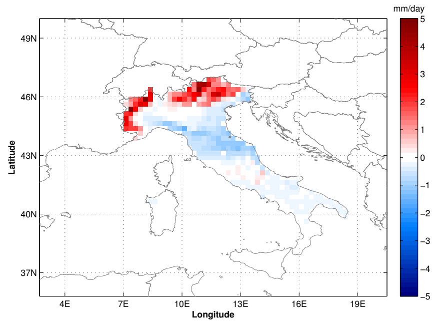
(c) spring - ERA40



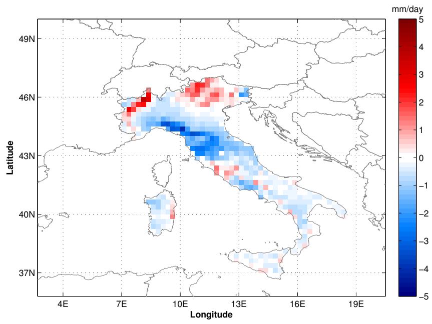
(d) spring - CMCC-MED



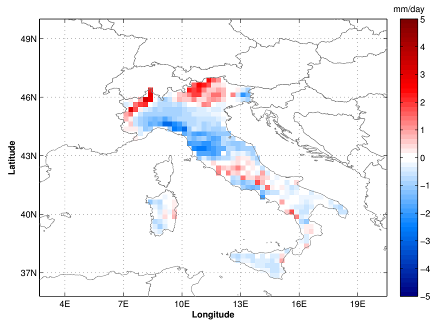
(e) summer - ERA40



(f) summer - CMCC-MED

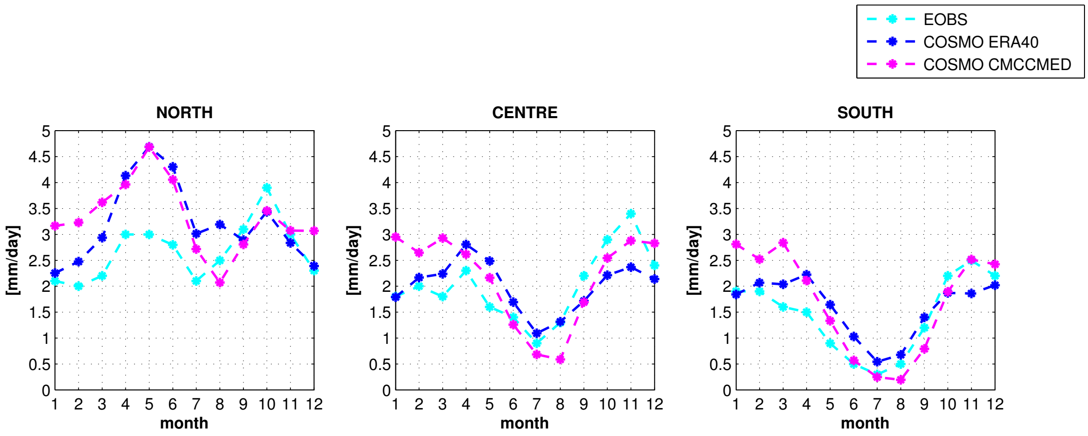


(g) autumn - ERA40

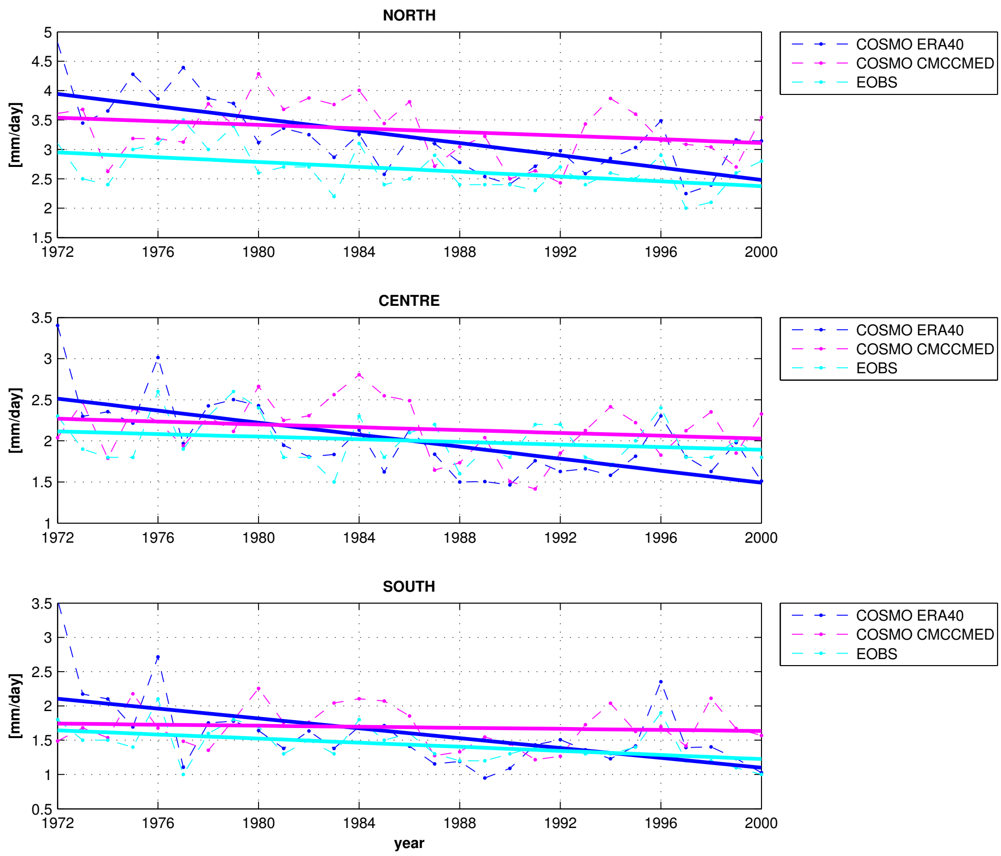


(h) autumn - CMCC-MED

Figure 5:
Seasonal differences, in terms of daily precipitation (mm/day), 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).

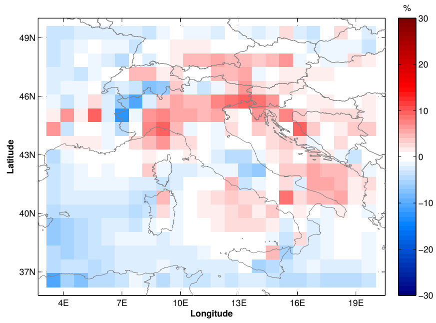


(a) seasonal cycles

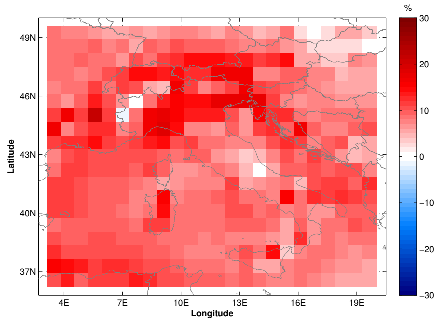


(b) time series

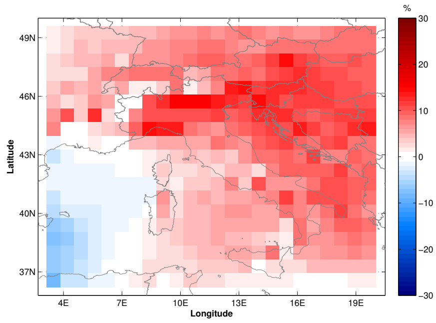
Figure 6:
Seasonal cycles (a) and time series (b) of the daily precipitation, for each subdomain investigated.



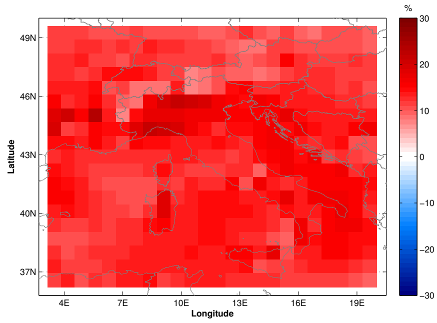
(a) winter - ERA40



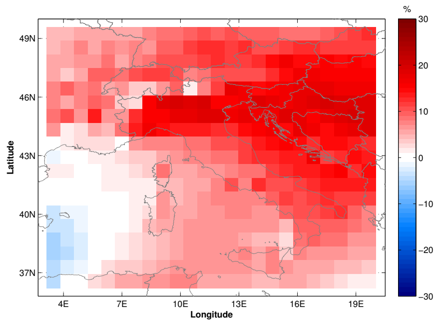
(b) winter - CMCC-MED



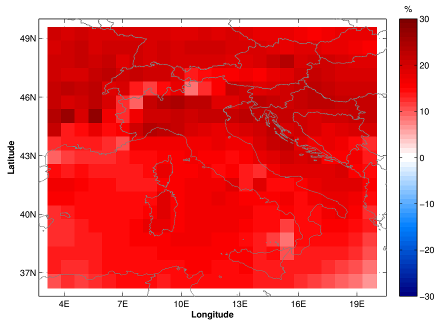
(c) spring - ERA40



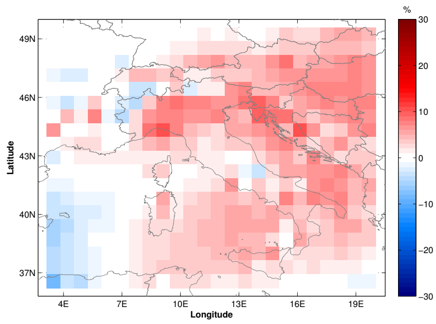
(d) spring - CMCC-MED



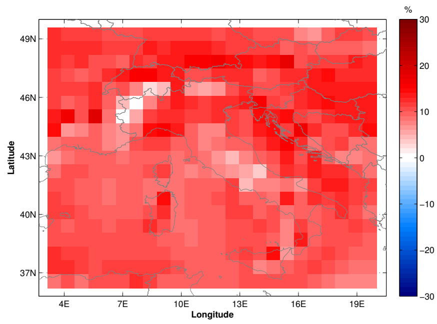
(e) summer - ERA40



(f) summer - CMCC-MED

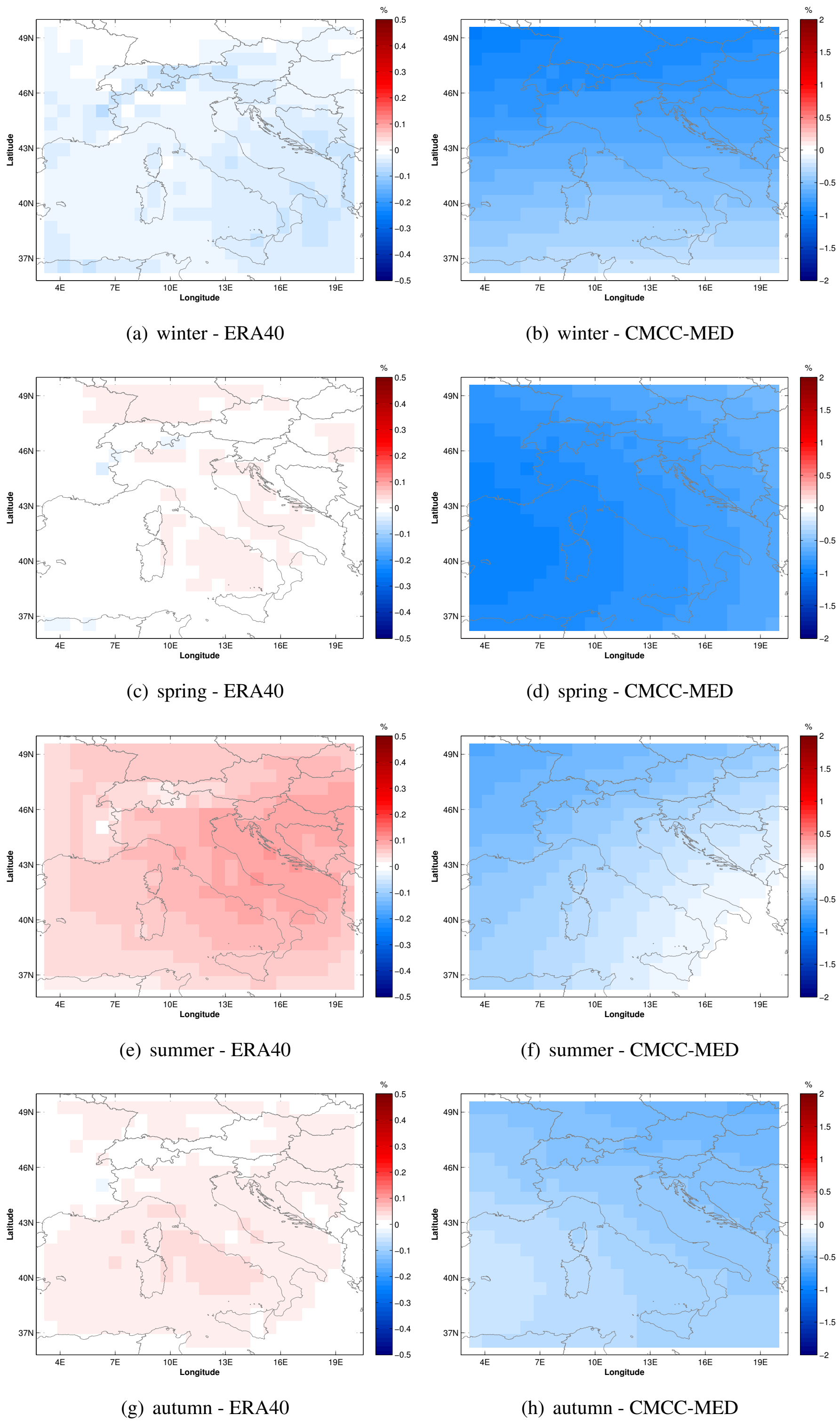


(g) autumn - ERA40



(h) autumn - CMCC-MED

Figure 7:
Seasonal differences, in terms of total cloud cover (%), between the output of COSMO-CLM and ERA-Interim Reanalysis, for the simulation forced by ERA40 Reanalysis (left) and the simulation forced by CMCC-MED global model (right).



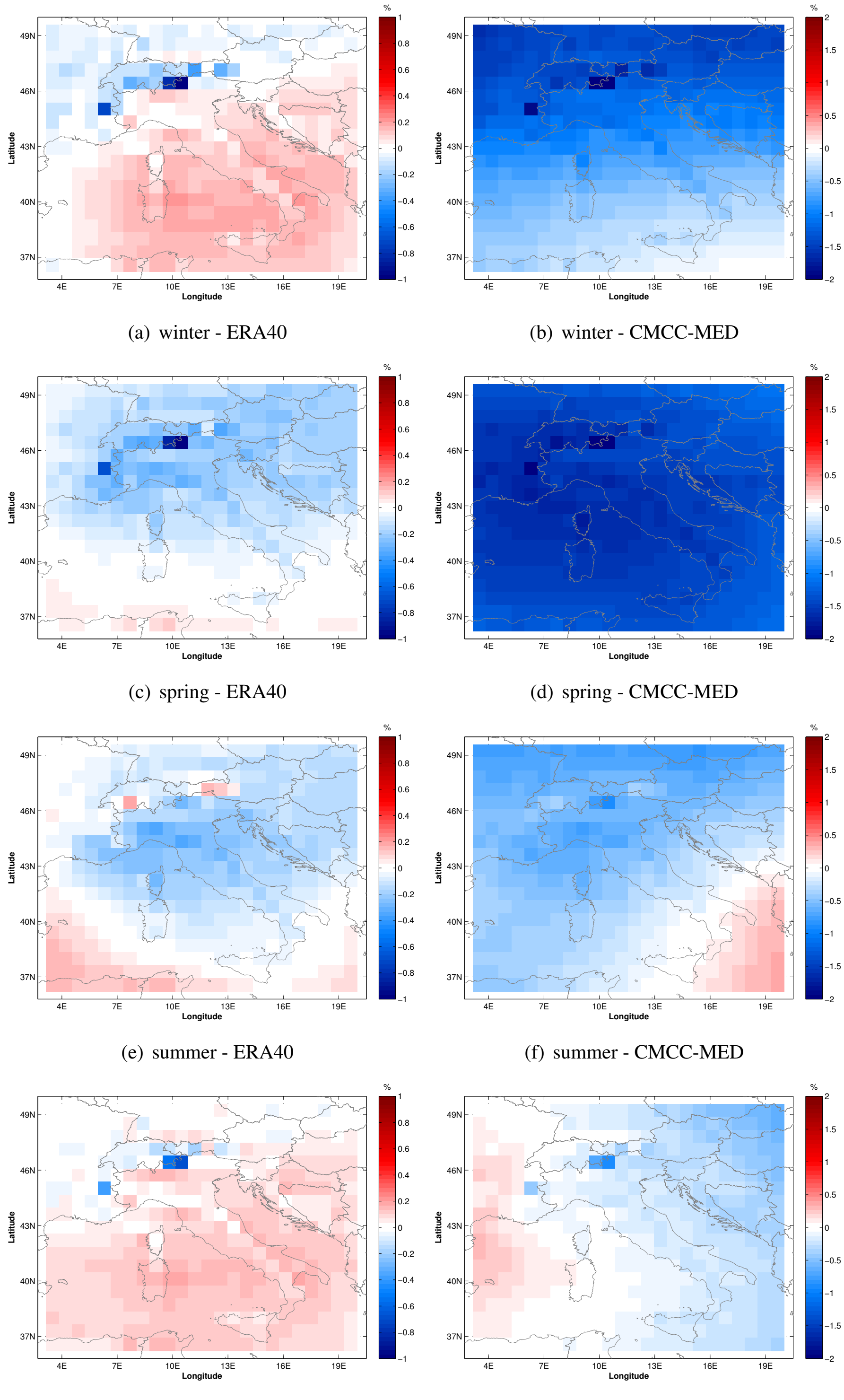
(a) winter - ERA40 (b) winter - CMCC-MED

(c) spring - ERA40 (d) spring - CMCC-MED

(e) summer - ERA40 (f) summer - CMCC-MED

(g) autumn - ERA40 (h) autumn - CMCC-MED

Figure 8:
Seasonal percentage variations, in terms of geopotential at 500hPa, between the output of COSMO-CLM and the ERA-Interim Reanalysis, for the simulation forced by ERA40 Reanalysis (left) and the simulation forced by CMCC-MED global model (right).



(a) winter - ERA40

(b) winter - CMCC-MED

(c) spring - ERA40

(d) spring - CMCC-MED

(e) summer - ERA40

(f) summer - CMCC-MED

(g) autumn - ERA40

(h) autumn - CMCC-MED

Figure 9:
Seasonal percentage variations, in terms of geopotential at 850hPa, between the output of COSMO-CLM and the ERA-Interim Reanalysis, for the simulation forced by ERA40 Reanalysis (left) and the simulation forced by CMCC-MED global model (right).

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