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A simulation over the Mediterranean area with COSMO-CLM: assessment of the performances

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SUMMARY The present study describes the capability of the regional climate model COSMO-CLM to represent the present climate of the Mediterranean area. To this aim, a simulation over the period 1979-2011 has been performed, using as forcing the ERA-Interim Reanalyses: the purpose is to investigate the error of the regional climate model, neglecting the bias introduced by the global model. The resolution adopted is 0.125° (about 14km) and the assessment of COSMO-CLM performances has been carryed out comparing the model output with the E-OBS observational dataset.
This activity has been conducted in the framework of WP 6.2.2 of the Gemina project.

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1. INTRODUCTION

The Mediterranean region is object of several climatological studies. It is interested by the presence of different climate conditions, suffering the influences of central Europe and Africa climates. Moreover, it has been identified as a very vulnerable region to global change (Giorgi and Lionello 2008 [5]).
To evaluate and quantify the climate change of this very particular area, simulations can be performed using global climate models, adopting several IPCC emission scenarios (A1B, B1, A2 or the new RCPs).
Indeed, for this purpose, RCMs are more appropriate than GCMs, being more able to capture some specific features related to orographic characteristics that global climate models cannot well capture due to their coarser horizontal resolution (Anav et al, 2010 [1]).

As preliminary step, it is important to assess the present climate of the region of interest.
To this aim, a simulation of the recent past period 1979-2011 has been performed by using the ERA-Interim Reanalysis as forcing.
This activity represents an upgrade of a preliminary work by Cattaneo et al. (2012) [3] in which the results of a simulation covering the years 1971-2000 forced by ERA40 Reanalysis (Uppala et al., 2006 [12]) are described. In the present activity, ERA-Interim Reanalysis have been used as forcing: they are characterized by a higher horizontal resolution than ERA40 (0.7° vs 1.125°), a better formulation of background error constraint, a new humidity analysis and an improved model physics. Moreover, ERA-Interim data are continuosly updated in time.
A successive step, that will be object of a future work, is the analysis of a simulation driven by a "‘sub-optimal"’ forcing, in order to distinguish the error introduced by the regional and by the global climate models; finally, a simulation over the XXI century will be performed to assess climate change projections under different IPCC scenarios.

This report is organized as follows: in Section 2, the regional climate model adopted, the simulation set-up and the observational dataset used for validation are briefly described; in Section 3, results in terms of two-meter mean, minimum and maximum temperature and daily precipitations are shown; then, in Section 4, conclusions and future works of this activity are reported.

2. MODEL AND OBSERVATIONS

The regional climate model adopted is COSMO-CLM (Rockel et al., 2008 [8]), that is COSMO model (Steppeler et al., 2003 [10]) in Climate Mode, developed by the CLM community. It is a non hydrostatic limited-area atmospheric prediction model and it can be used for simulations on time scales up to centuries and spatial resolutions between 1 and 50 km. Due to the non-hydrostatic modelling, convective phenomena and representation of subgrid scale physical processes (such as clouds, aerosols, orography, land and vegetation properties) can be better represented; moreover, the high resolutions reached allow the use of regional climate model outputs for impact studies.
A more detailed description of COSMO-CLM main features is reported in the CMCC research paper of Bucchignani et al., 2013 ([2]).

Figure 1 depicts the oragraphy of the domain considered for this study: an appropriate number of points has been excluded in each direction in order to neglect the influence of boundary conditions in the analyses; moreover, according with the availability of observational data, a mask has been applied in order to ex-

clude those areas not covered by the observation grid (e.g some regions of Africa and sea points).
The computational grid, at a spatial resolution of 0.125° (about 14 km), is composed by 385 x 265 points, with 40 atmospherical verticals levels and 7 soil levels. ERA-Interim Reanalysis (Dee et al., 2011 [4]) has been used as forcing data: they are characterized by 512 x 256 grid points, 60 atmospherical verticals level and 3 levels of soil, with a horizontal resolution of 0.703° (about 80 km).
Analysis of results has been carried out considering the seven sub-regions shown in Figure 1, nominally `NW` (north-west area), `NC` (north-center area), `NE` (north-east area), `ALPS` (Alpine area), `SW` (south-west area), `SC` (south-center area) and `SE` (south-east area).
The time period investigated is 1980-2011: the first year (1979) has been excluded to neglect spin-up effects due to the initial conditions.

The E-OBS observational dataset (Haylock et al., 2008 [6]) has been used to validate the model results: it is a European daily high-resolution (0.25° x 0.25°) gridded data set for several variables, such as precipitation, temperature (minimum, maximum and mean values) and sea level pressure. For this study, the version 9.0 of E-OBS has been adopted, covering the period 01-01-1950/30-06-2013 and the area (25N-75N; 40W-75E).

The analyses have been conducted through the software `CLIME`: it is a special purpose GIS software integrated in ESRI ArcGIS Desktop 10.X, and developed by CMCC-ISC Division in the frame of Project GEMINA, in order to better evaluate the impact on soil of climate changes. In fact, impact models (e.g hydraulic or stability models) are usually developed in a GIS environment, since they need an accurate description of territory. CLIME has been designed to bridge the usually existing gap between atmospherical data gathered from different sources and impact communities. Once that data have been imported in GIS, it is possible to perform different kinds of operations, such as analysis of historical series and climate scenarios.

3. ANALYSIS OF RESULTS

To assess the bias of the simulation above described, the two-meter mean, minimum and maximum temperature and the total precipitation have been validated comparing the results with observations.

In addition to seasonal biases, seasonal cycles and time series, some synthetic indexes have been computed, i.e. bias, mean absolute error and root mean square error:

$$BIAS = \frac{1}{N}\sum_{i=1}^{N}(S_i - O_i) \tag{1}$$

$$MAE = \frac{1}{N}\sum_{i=1}^{N}|S_i - O_i| \tag{2}$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(S_i - O_i)^2} \tag{3}$$

where S_i is the variable value simulated by the model and O_i is the observation value. N is the number of observations over time or area of interest.

The first analysis concerns the assessment of model bias in terms of temperature. The seasonal bias map (Figure 2) of two-meter mean temperature of COSMO-CLM with

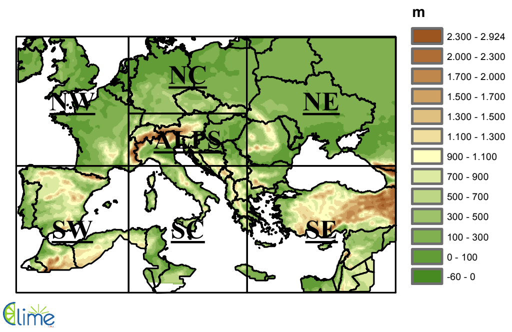

Figure 1:
Orography of the masked simulated domain (according with observational dataset availability).

respect to the observations shows a good agreement in spring and autumn, where the bias never exceeds 2°C, with the exception of some regions in eastern area. In the north part of the domain, instead, the error is close to 0°C (e.g in France, Germany, United Kingdom). Winter is interested by a general cold bias (with peaks of 4°C over Alps), whereas in summer a general hot bias occurs, higher in the eastern part of the domain.

It is important to highlight that, with the exception of the Black sea area (Ukraine and Russia), the highest peakes of model error are reached in corrispondence of the highest mountain chains, such as Alps and Carpatians, especially for the winter season. This is highlighted by the contour lines of the domain orography (the contour interval is 500 meters) depicted in Figure 2 - Figure 5.

Figure 3 and Figure 4, instead, show the differences between model and observations for minimum and maximum temperature respectively. Generally, an overestimation of the minimum one and an underestimation of the maximum one (with the exception of summer period) occurs. More in detail, the highest bias for the minimum temperature is reached in summer (about 3-4°C), where the whole domain is interested by the overestimation; in spring and autumn, the error is less pronounced, with a bias never exceeding 2°C; in winter, instead, several areas are interested by a bias close to 0°C.

For the maximum temperature, generally spring and autumn are well represented, whereas winter is affected by a general underestimation and summer by a general overestimation (with the exception of France and Germany).

Concerning precipitations, Figure 5 shows the bias in mm/day with respect to E-OBS. Several regions are interested by a good agreement between model and observations (bias between -0.5 and 0.5 mm/day). The most evident results is a general underestimation occurring in summer (in the whole domain, with the exception of the southern part).

For precipitations, a higher correspondence between model error and elevation contour lines is registered, as it is seen over Alps, Carpathians and Caucasus Mountains; the mountain chains are interested by a general overestimation of precipitations, more accentuated in spring (e.g over Alps, bias is of about 4-5 mm/day).

Furthermore, seasonal cycles and time series have been evaluated in the seven subregions depicted in Figure 1.
The bias of temperature seasonal cycles ranges between -2°C and 4°C (Figure 6 (a), (b) and (c)). The highest error occurs in summer over the north-east subregion, as already shown by seasonal bias maps, for mean, minimum and maximum values. The mimimum temperature (Figure 6 (b)) is interested by a general overestimation, in all the seasons and for all the subregions. From November to February, however, in several ares the bias is close to 0°C (never exceeding 0.5°C).
The bias of maximum temperature seasonal cycle (Figure 6 (c)) confirms the behaviour already shown by the seasonal bias maps (Figure 4): lower temperatures are simulated in winter season, whereas the opposite occurs in summer (with the exception of north-east and north-center areas, where the bias is close to 0°C). In spring, the error is related to the specific areas investigated: some regions are interested by a good agreement (`NE`, `SW` and `NW`), other by an under/overestimation of maximum temperatures. In autumn, finally, a hot bias occurs in September and a cold one in October and November. Similar considerations can be done for the mean temperature (Figure 6 (a)).
For precipitations, Figure 6 (d) shows a good agreement between model and observations, with a bias never exceeding 1.3 mm/day (occurring in Alpine region in August) in absolute value. Generally, an underestimation is registered in all the seasons, more accentuated in summer, with the exception of north-east, north-center and alpine subregions from November to May, where the overestimation, however, is always lower than 0.5 mm/day.

Concerning temperature time series (Figure 7), both model output and observations have an increasing trend of temperature values. Two-meter mean annual temperatures are well reproduced in all the subregions, especially in `NW`, `NC` and `SW` ones. In the other ones, there is a general overestimation, more pronounced for minimum temperatures (Figure 7 (d)), whereas the maximum values is characterized by a not well defined behaviour.
Finally, for the daily annual precipitation (Figure 7 (g)-(h)), in `ALPS`, `NC` and `NE` regions a difference exists in terms of trend between model and observations: a decreasing trend is simulated by COSMO-CLM whereas E-OBS observes an increase of precipitation daily values (although the estimated variations is very small). For the other subregions, a better agreement occurs, with a bias ranging between -0.7 and 0.3 mm/day.

Table 1 reports the values of synthetic indexes above described, in addition to the mean value of E-OBS for each variable considered: it provides an indication of the average error for each subregion in order to assess the reliability of performed simulation.
Generally, the same considerations already done apply here: the minimum temperature results to be the variable with the highest error; the worst performaces are obtained in `NE` and `SE` regions; moreover, the precipitation is always underestimated. This is also shown in the comparison displayed in Figure 8 and Figure 9 where it is also possible to see a good representation of the values, monthly averaged, located in the central range of the observations, especially in terms of temperature, and a high error in reproducing the highest values of temperature and precipitation. In these last pictures, the black line represents the perfect fit between simulated and observed values, whereas the

blue one represents the modeled linear actual fitting.

5. CONCLUSIONS

In this work, a temperature and precipitation bias assessment of COSMO-CLM in simulating the present climate of Mediterranean area has been presented. ERA-Interim Reanalysis have been used as forcing, to evaluate the model performances driven by "'perfect"' boundary conditions.
The validation has highlighted a quite good agreement between COSMO-CLM and E-OBS observational dataset in terms of mean values of temperature ad precipitations, whereas analyses have revealed a worse representation of minimum and maximum temperatures and of the highest values of mean temperature and precipitation. Summer is the season interested by the highest bias, both for temperature and precipitation, especially in the north-east area of the domain of interest, where peaks of 4°C and 2 mm/day (in absolute value) are reached. However, other literature works report the bias values similar to those found in this study; for example, winter cold bias and summer hot bias, as well as summer underestimation of precipitation, were already highlighted by Jaeger et al. (2008) [7], whereas the overestimation of precipitation and the temperature underestimation over the Alpine arch is in agreement with Suklitsch et al. (2008) [11].

In the future, a deeper analysis will be performed, also in terms of extreme values and PDFs, using also other observational datasets; indeed, it is worth noting that the bias found can be attributed also to the dataset used that can have, especially in some specific areas, a low quality/density of observations. Moreover, since the highest biases are found in correspondence of high orography zones, a correction based on the difference between the orography of observations and of the simulated domain will be performed.

Currently, a simulation with COSMO-CLM forced by the global model CMCC-CM [9] covering the years 1979-2005 has been completed, whereas two simulations up to 2100 employing the RCP4.5 and RCP8.5 emission scenarios are in progress, with the aim to investigate the future climate projections over the Mediterranean area.

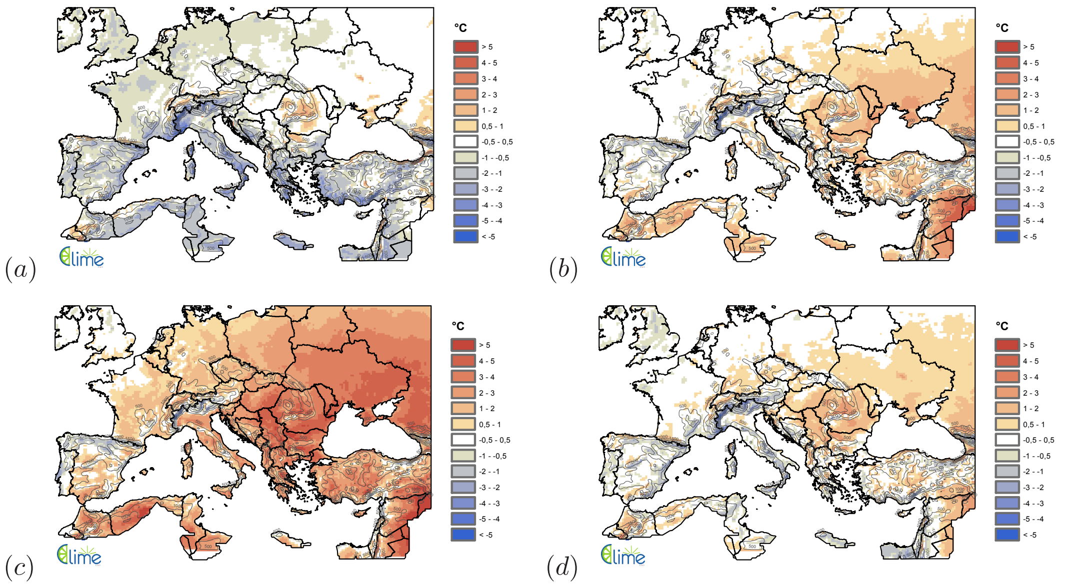

Figure 2:
Bias of two-meter mean temperature with respect to E-OBS dataset for DJF(a), MAM (b), JJA (c), SON (d). Contour lines show the elevation of the domain, with a contour interval of 500m.

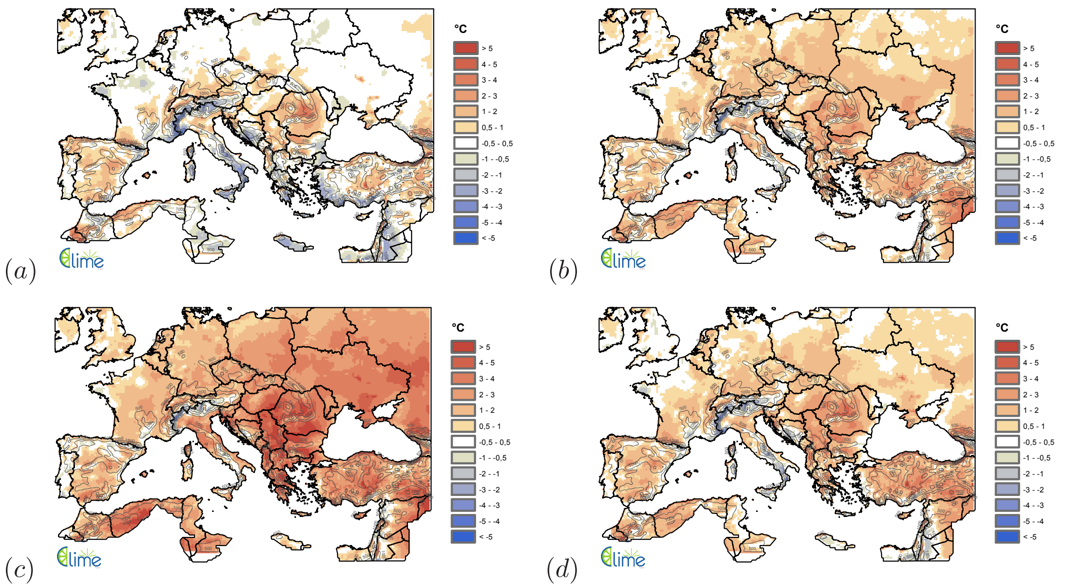

Figure 3:
Bias of two-meter minimum temperature with respect to E-OBS dataset for DJF(a), MAM (b), JJA (c), SON (d). Contour lines show the elevation of the domain, with a contour interval of 500m.

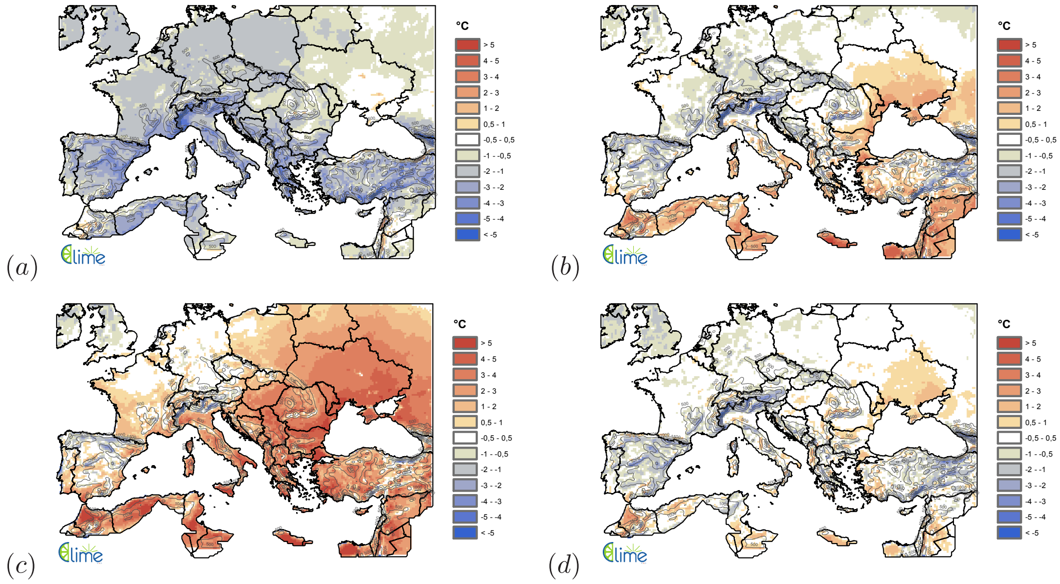

Figure 4:
Bias of two-meter maximum temperature with respect to E-OBS dataset for DJF(a), MAM (b), JJA (c), SON (d). Contour lines show the elevation of the domain, with a contour interval of 500m.

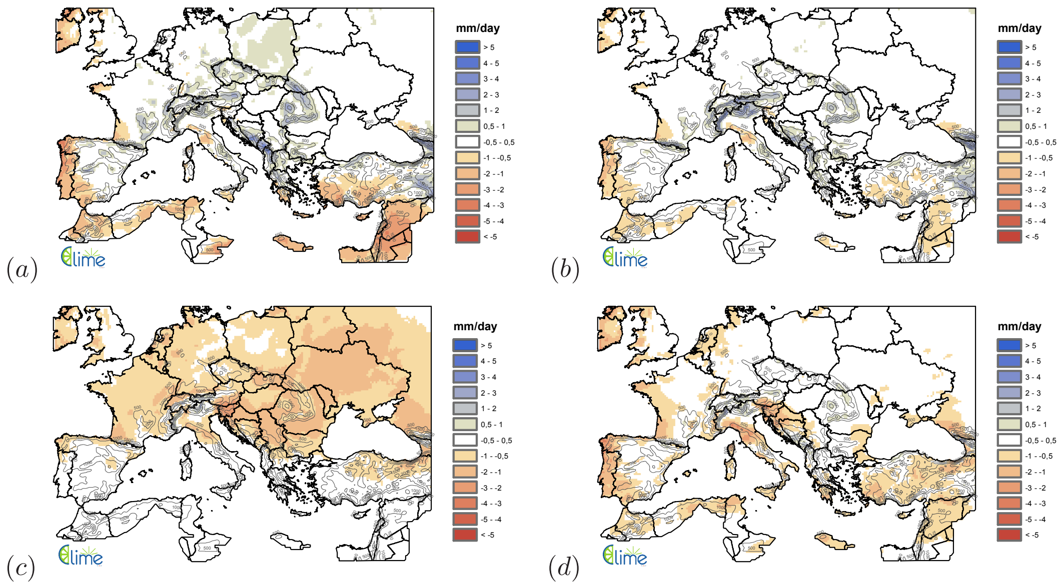

Figure 5:
Bias of daily precipitation (mm/day) with respect to E-OBS dataset for DJF(a), MAM (b), JJA (c), SON (d). Contour lines show the elevation of the domain, with a contour interval of 500m.

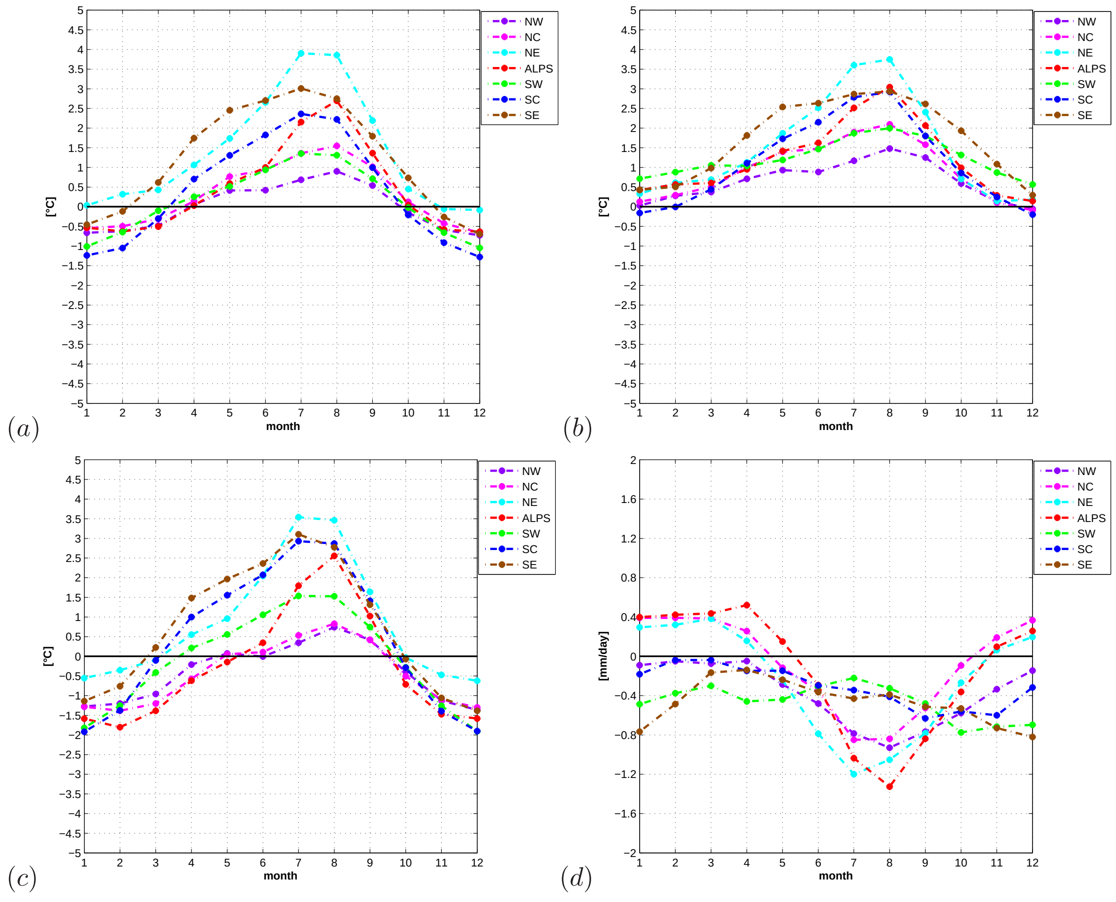

Figure 6:
Seasonal cycle bias of two-meter mean (a), minimum (b) and maximum (c) temperature and daily precipitation (d) with respect to E-OBS dataset for all the subregions selected.

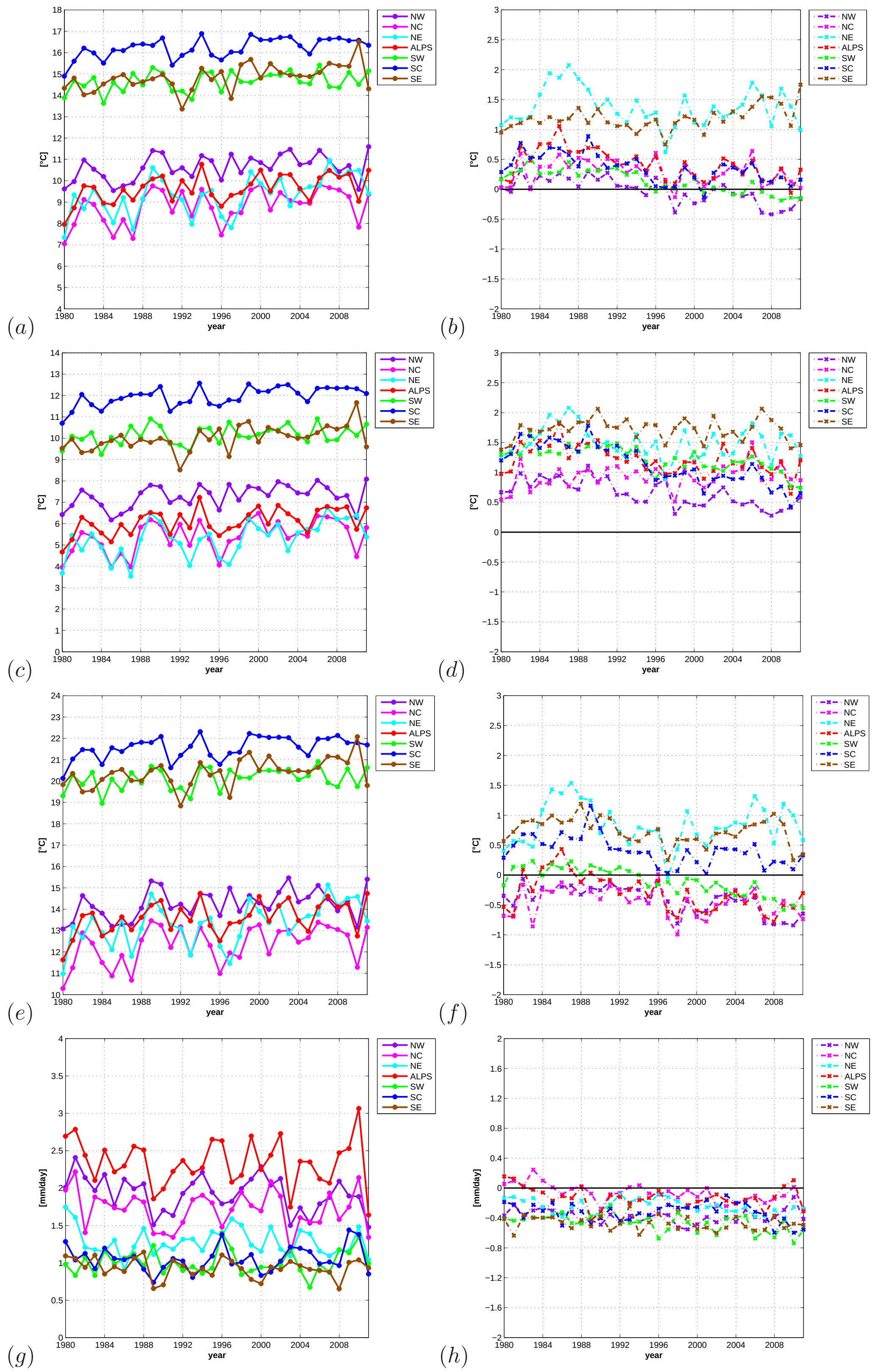

Figure 7:
Time series (left) and related bias (right) of two-meter mean (first row), minimum (second row) and maximum (third row) temperature and daily precipitation (fourth row) with respect to E-OBS dataset for all the subregions selected.

	T2M (°C)						
	NW	**NC**	**NE**	**ALPS**	**SW**	**SC**	**SE**
Obs. mean value	10.6	8.5	7.9	9.2	14.5	15.9	13.6
BIAS	-0.02	0.29	1.38	0.42	0.13	0.37	1.19
MAE	0.57	0.78	1.57	0.99	0.76	1.23	1.49
RMSE	0.68	0.97	2.08	1.3	0.9	1.43	1.82

	TMIN2M (°C)						
	NW	**NC**	**NE**	**ALPS**	**SW**	**SC**	**SE**
Obs. mean value	6.6	4.5	3.8	4.9	8.9	10.8	8.3
BIAS	0.65	0.93	1.49	1.22	1.23	1.14	1.72
MAE	0.73	1.03	1.6	1.26	1.24	1.31	1.76
RMSE	0.9	1.29	2.05	1.59	1.39	1.65	2.04

	TMAX2M (°C)						
	NW	**NC**	**NE**	**ALPS**	**SW**	**SC**	**SE**
Obs. mean value	14.7	12.8	12.5	13.9	20.2	21.2	19.7
BIAS	-0.41	-0.45	0.84	-0.3	-0.11	0.41	0.73
MAE	0.78	0.9	1.36	1.31	1.07	1.61	1.51
RMSE	0.93	1.09	1.83	1.57	1.25	1.84	1.78

	TPREC (mm/day)						
	NW	**NC**	**NE**	**ALPS**	**SW**	**SC**	**SE**
Obs. mean value	2.3	1.8	1.5	2.5	1.5	1.4	1.4
BIAS	-0.38	-0.07	-0.24	-0.13	-0.47	-0.33	-0.46
MAE	0.45	0.43	0.49	0.55	0.47	0.37	0.49
RMSE	0.56	0.53	0.65	0.72	0.59	0.48	0.6

Table 1

Synthetic indexes (observational mean value, bias, mean absolute error and root mean square error) computed for mean, minimum and maximum temperature and precipitation, for each subregion individuated.

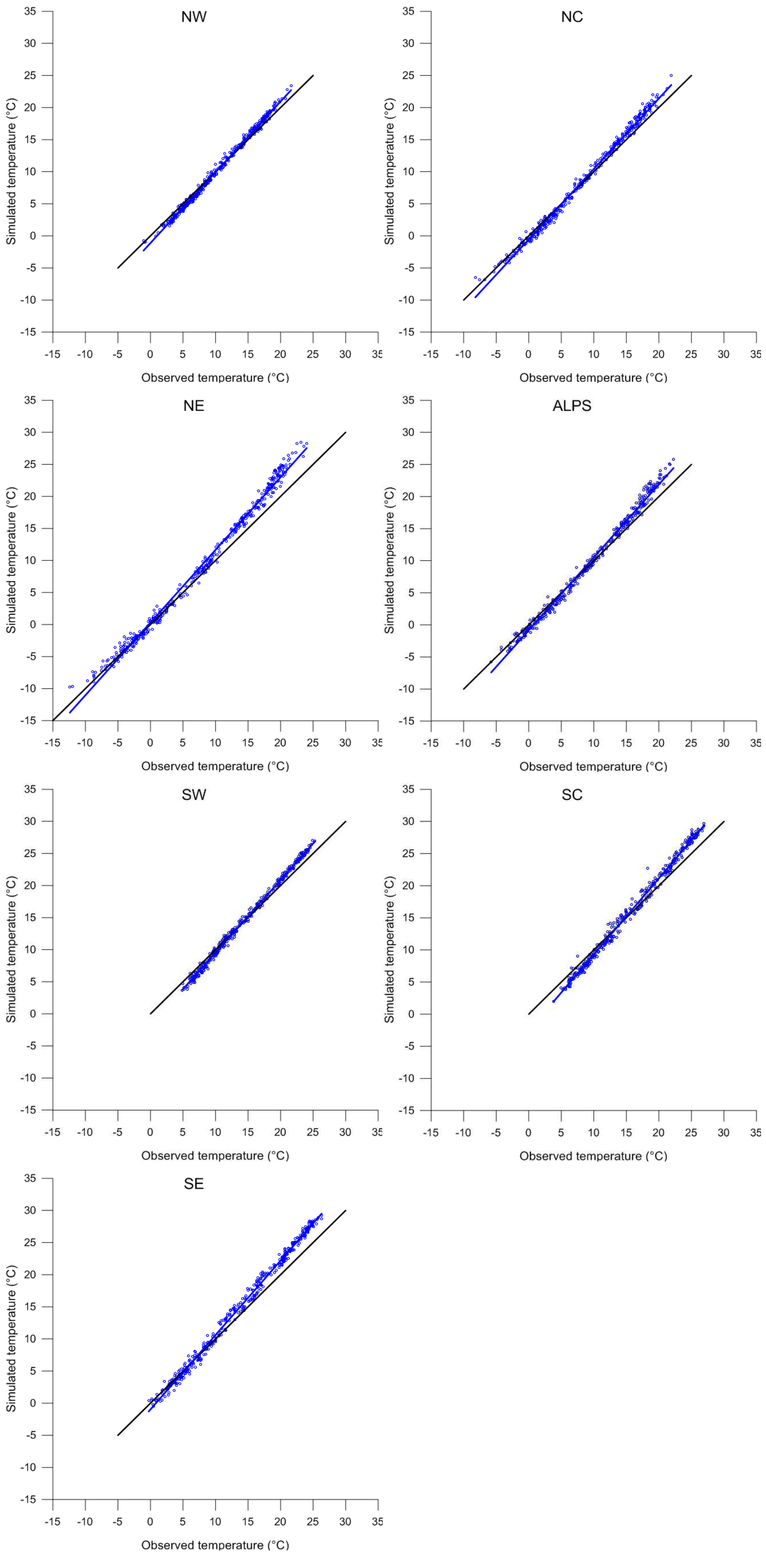

Figure 8:
Comparison between simulated and observed monthly averaged mean temperature (°C) for each subregion.

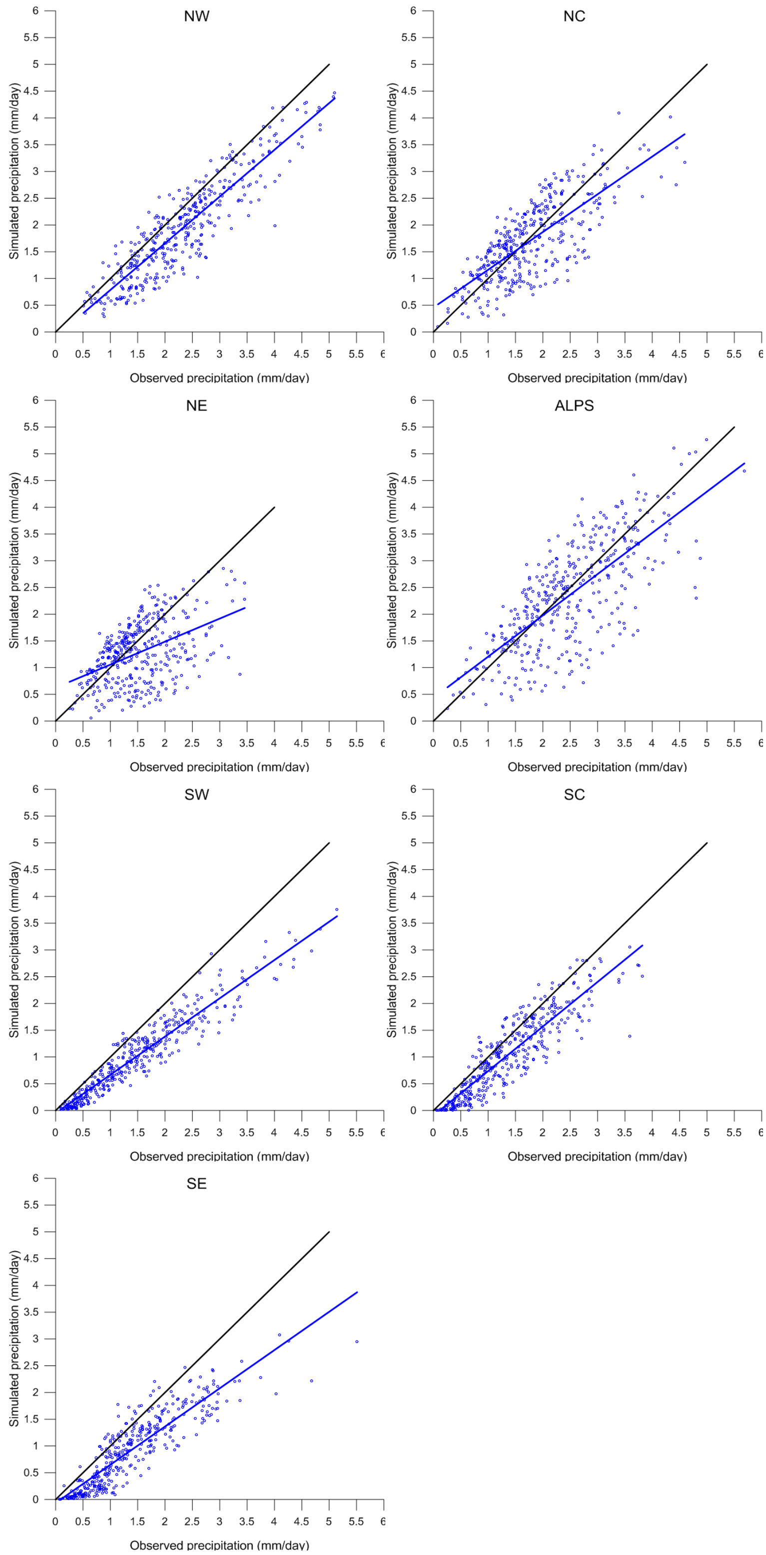

Figure 9:
Comparison between simulated and observed monthly averaged precipitation (mm/day) for each subregion.

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