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Assessment of ERA-Interim driven simulation over Italy with COSMO-CLM

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SUMMARY This study presents the results of a dynamically downscaled high resolution (about 8 km) climate simulation over Italy, produced with COSMO-CLM model, forced by ERAInterim reanalysis and covering the time period from 1979 to 2011. Model results have been analysed in terms of two-meter temperature and precipitations. The main aim of this work is to assess the capabilities of high-resolution simulations in reproducing the main features of the Italian climate, in order to provide a reliable tool for impact studies on local scale. Validation of results has been performed comparing model output with different observational data.

1 - INTRODUCTION

The report represents an upgrade of the activity started in 2012 and described in [18], aimed to analyse the capabilities of the regional climate model COSMO-CLM in simulating the main features of the observed Italian climate. Reanalysis and climate scenario datasets have coarse horizontal resolutions, good enough to reproduce many aspects of large-scale climate, but unable to represent many processes and systems that drive regional and local climate variability, where the consequences of climate change will be mostly felt. These limitations are greatly amplified in areas of difficult geomorphology, like complex orography, irregular coastlines, and regions with heterogeneous land cover, where regional and local thermal and mechanical circulations are forced by surface heterogeneity. Italy is a good example of the need of high resolution climatology, being characterized by a very complex topography, ranging from high mountain chains, such as Alps and Apennines, to several coastal areas, being Italy almost totally surrounded by the Mediterranen Sea. In fact, at the resolution of the global climate models, Italy is not well delineated or not even captured. Moreover, Italy is characterized by different climate conditions and, according with Coppola and Giorgi, 2010 [5], at least three different climate areas can be identified.

The capabilities of the regional climate model COSMO-CLM (Rockel et al., 2008) [12] to simulate the main features of the observed climate of Italy have already been assessed in [18]. In that work, a simulation driven by ERA40 Reanalysis [16] was analyzed with respect to E-OBS dataset for temperature and precipitation. The present work would represent a step forward: a simulation driven by ERA-Interim Reanalisys [6] has been performed and assessed. ERA-Interim Reanalisys present significant advances with respect to ERA40, since they are characterized by a higher horizontal resolution (0.7° vs. 1.125°), a better formulation of background error constraint, a new humidity analysis and an improved model physics. ERA-Interim uses mostly the sets of observations acquired for ERA40, supplemented by data for later years from ECMWF's operational archive.

Moreover, it is important to underline that in the present work validation is performed using not the only gridded dataset E-OBS as in [18], but also very high resolution observational datasets provided by regional Italian ARPAs, making a good improvement with respect to previous literature works, where the comparison was made only with lower resolution datasets, so smoothing out many features that can be seen by the high resolution simulation. Results of the present analysis will be useful to perform climate change projections over Italy on the XXI century: model error evaluation in reproducing the past climate is essential to a better evaluation of the climate projections provided by the same model.

This report is organized as follows: Section 2 is devoted to a general description of the regional climate model COSMO-CLM and its settings, of the observational dataset used and of the GIS tool CLIME used for post processing; Section 3 contains the analysis of results, while in Section 4, conclusions are 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) [12],[13], the climate version of the COSMO-LM weather model (Steppeler et al., 2003) [15]. The use of a non-hydrostatic scheme (explicit description

of vertical acceleration of air masses) and the finer horizontal resolution (less than 10 km) are expected to allow a more realistic representation of orographically controlled local meteorological features (Kotlarski et al. 2005). [10]. The COSMO-CLM model version used in this research is 4.8_CLM13, whereas for the interpolator INT2LM the version is 1.10_CLM2.
The simulation performed is forced by ERA-Interim Reanalysis [6] produced by ECMWF using 4D-variational analysis on a spectral grid with triangular truncation of 255 waves (corresponds to approximately 80 km) and a hybrid vertical coordinate system with 60 levels. The ECMWF global model is used for the forward integration in the 4D-variational analysis and the temporal length of the variational window is 12 h. This reanalysis covers the period from 1979 to present day.

The horizontal resolution adopted in the regional model is 0.0715° (about 8 km). The area of interest is 3°-20°E / 36°-50°N (Figure 1), the period simulated is 1979-2011, but the first year of the simulation has been neglected in the analysis to exclude the spin-up effects.
In Table 1, the main features of the simulation are summarized.

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

Driving data	ERAInterim Reanalysis
Horizontal resolution	0.0715° (about 8 km)
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

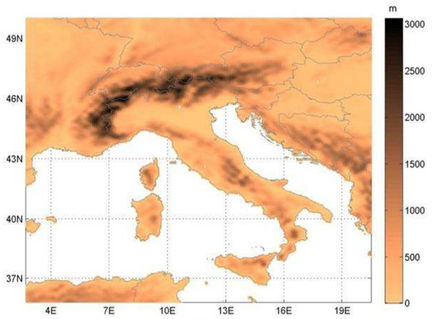
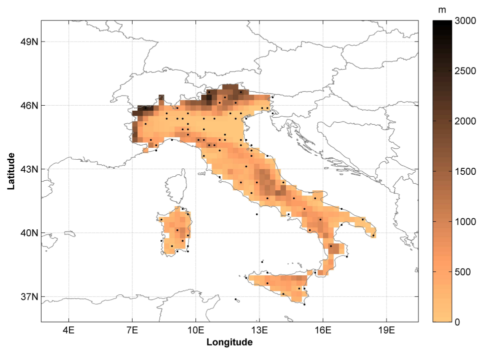


Figure 1:
Orography of the simulated domain.

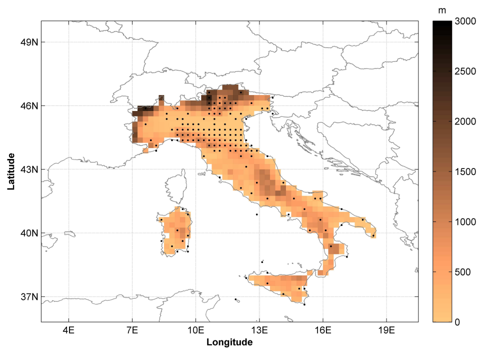
2.2 - OBSERVATIONAL DATASET

Model evaluation for the whole Italian domain has been performed using the E-OBS dataset (Haylock et al., 2008) [8]: it is a 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 1950-2012. This dataset has been designed to provide the best estimate of grid box averages rather than point values to enable direct comparison with RCMs. Figure 2 shows the orography of the E-OBS dataset over the Italian domain, with the representation of the station locations for 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 interpolation accuracy decreases as the network density decreases and the error increases in complex terrains, such as mountains (Hofstra et al., 2009) [9]. In particular in south Italy it is evident the the number of station is very low, leading to a poor accuracy of E-OBS dataset for this area.

For this reason, in order to perform more accurate validations, several regional datasets have been considered. The first one is a gridded



(a) temperature



(b) precipitation

Figure 2:
Orography of E-OBS on the Italian domain. Location of E-OBS stations are represented for temperature (top) and precipitation (bottom) respectively.

dataset provided by ARPA Piemonte (Italian Regional Agency for Environment Protection) (Ronchi et al. 2008) [14]. This dataset refers to the Piemonte region (Italy), is characterized by 15 km spatial resolution, covers the time period 1958-2011 and has been generated by the Optimal Interpolation technique of observed data. The other datasets are collections of station data and have been provided by regional ARPAs. The following regions have been considered: Veneto (period 1980-2000), Toscana (period 1980-2000), Emilia-Romagna (period 1980-2000) and Calabria (period 1980-2000).

2.3 - THE GIS TOOL CLIME

All images presented in this report have been obtained using CLIME, 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, definition of different kinds of downscaling techniques (to increase the resolution up to hundreds of meters).

3 - RESULTS

In this section, results of the simulation are compared with observational datasets and analyzed. Moreover, the effectiveness of the current simulation is also compared from a qualitative point of view with the output of the ERA40 driven simulation presented in [18], cited as ERA40D (bias maps are not reported here, but can be found in [18]).

3.1 - TEMPERATURE

Simulated values of two-meter temperature (T2m) have been compared with E-OBS dataset considering the time period 1980-2011.

Figure 3 shows the mean T2m bias distribution (°C) of COSMO-CLM for winter (DJF), spring (MAM), summer (JJA) and autumn (SON) seasons. In winter, a general underestimation of temperature is registered, especially in the Ligurian Alps and in Calabria. Bias values are generally growing towards south Italy: this is also due to the low number of observed stations located here and, as a consequence, to the lower quality of E-OBS dataset. Compared with ERA40D, current simulation in DJF is slightly colder over North Italy, leading to a better description of Po valley temperature. In summer, no significant differences are highlighted with respect to ERA40D, so a general overestimation is observed, particularly evident over Po valley. This hot bias is partially due to an underestimation (about 0.7 °C) of E-OBS data with respect to the real temperature (discussed later). However, the main reason of the bias is the shortcoming of the model in reproducing atmospheric dynamics typical of the area considered: in general, many RCM and GCM models overestimate summer temperature in semi-arid regions (e.g. Iberian peninsula, north Africa) [4]. In COSMO-CLM, it is caused [2] by a strong soil moisture depletion potentially induced by an unduly positive soil-moisture precipitation feedback; particularly, it is evident that COSMO-CLM is characterized by an underestimation of latent heat flux and, as a consequence, of the overestimation of sensible heat flux. Moreover, biases in the net incoming short wave due to an underestimation of cloud cover and potentially erroneous reflectivity of clouds might cause such an overestimation of T2m. Even in spring and autumn, current simulation provides results similar to ERA40D, with a general cold bias over Alps and Apennines, a moderate hot bias along Adriatic coast, while temperature over Po valley is slightly better described with respect to ERA40D.

Seasonal cycles and time series of T2m, averaged over the whole Italian area, have been evaluated and compared with E-OBS dataset. The seasonal cycle (Figure 4 -a) is very well captured (average bias 0.2 °C) with a slight underestimation in winter and a moderate overestimation in summer. An analysis of the time series (Figure 4 -b) shows a good agreement until 1998; successively, the model tends to underestimate the values of T2m, even if the shape of the series is anyway well reproduced. Trend lines exhibit a growing temperature over the years. Trend value is higher for E-OBS: however, according to MannKendall results, values are not statistically significant for a confidence level of p-value of 5 %.

It is worth noting that the T2m bias found can be attributed not only to the regional model, but also to low quality of E-OBS dataset since, as shown in Figure 2, station distribution is very rare, especially in south Italy. For this reason, model output has been compared also with regional observational datasets provided by ARPAs. Figure 5 shows the mean T2m bias distribution (°C) of COSMO-CLM over Emilia Romagna (time period 1980-2011) for winter (DJF), spring (MAM), summer (JJA) and autumn (SON) seasons. In spring and autumn, a very good agreement is registered, with bias close to zero in almost the whole region. Hot bias in summer is still significant, but less evident than the one shown in Figure 3. The central part of the region is affected by a cold bias in winter.

Figure 6 shows the mean T2m bias distribution (°C) of COSMO-CLM over Calabria (time period 1980-2011). The central part of the region, characterized by high altitude, is affected by a cold bias in all the season: however results in this area are not very significant, due to the low number of stations located here. In the remaining part of the region, a good agreement

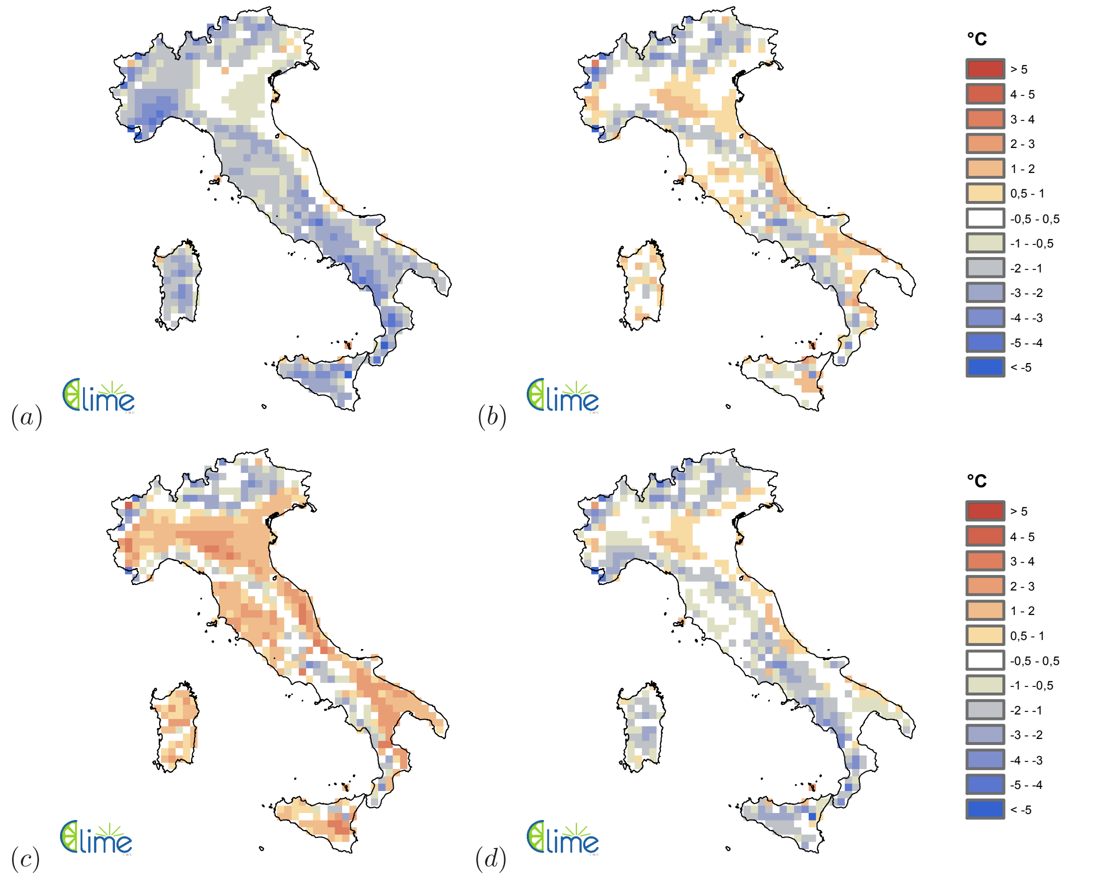


Figure 3:
Bias of two-meter temperature with respect to E-OBS dataset, for DJF(a), MAM (b), JJA (c), SON (d)

is registered.

3.2 - PRECIPITATION

Simulated values of precipitation have been compared with E-OBS dataset considering the time period 1980-2011. Figure 7 shows the precipitation bias distribution (mm/day) of COSMO-CLM for winter (DJF), spring (MAM), summer (JJA) and autumn (SON) seasons. In winter, map of bias is substantially unchanged with respect to ERA40D, with overestimation in the Alpine area and an underestimation over Toscana. The rest of Italy exhibits a bias close to zero. The amount of precipitation evaluated by the current simulation in summer is generally lower than ERA40D, leading to a better description of the Alpine precipitation, but to a slight underestimation over north-center Italy. The south-center Italy instead exhibits a bias close to zero. Results are similar to ERA40D in autumn (strong underestimation over Toscana, analyzed later), and in spring (moderate underestimation over Toscana and strong overestimation in Alpine space).
Concerning the wet bias registered at high altitudes in almost all the seasons, it is worth noting that precipitation measurements are generally affected by a systematic error [1], larger at high altitudes, caused by hydrometeor deflections (due to wind), leading to a large undercatchment of precipitation (Frei et al, 2003) [7], quantified over Alps in 40 % in winter and 12 % in summer. Another source of uncertainty is related to a low station density or to a not uniform distribution, which affects especially extreme values.

Seasonal cycles and time series of total precipitations, averaged over the whole Italian area, have been evaluated and compared with E-OBS dataset. The seasonal cycle (Figure 8(a)) is well reproduced by the model (average bias 0.01 mm/day), but with a overestimation in spring (due to the wet bias on Alps) and an underestimation in autumn (mainly due to the dry bias in Toscana and south Italy already discussed). Time series (Figure 8(b)) is pretty well reproduced over the whole considered period. Trend lines exhibit a modest precipitation reduction over the years and are very close each other: however, according to MannKendall results, trends are not statistically significant, for a confidence level of p-value of 5 %.

It is important to point out that also for precipitations, the bias found is due also to low quality of the E-OBS dataset. Precipitation data have also been compared with regional observational datasets provided by ARPAs. Figure 9 shows the seasonal maps of precipitation bias (in mm/day) for Veneto (period 1980-2000). In all seasons, bias is lower of about 1 mm with respect to the one shown in Fig. 7, leading to an excellent agreement in winter and autumn. In the other two seasons, overestimation is confirmed but with a less extent and limited to a well-defined (high orography) area.

Figure 10 shows the same maps for Piemonte (period 1980-2011). In spring and autumn, bias distribution is very close to the one shown in 7. In winter and summer instead, results are better in the central part of the region (low altitude), with a bias close to zero, while in the northwest area (high altitude), a wet bias of about 2-3 mm/day is registered.

Figure 11 shows the same maps for Toscana (period 1980-2000). The underestimation already highlighted in all seasons with respect to E-OBS is confirmed, but with lower intensity (of about 1 mm/day). The most intense bias is observed in Autumn, revealing a shortcoming of the model in reproducing precipitations typical of this season in the region considered. This difficulty of COSMO-LM (meteorological version) has also been documented in [11] and has been experienced also by other climatic models, such as MIP-Med (MPI) and CNRM (Meteo France) [3].

Figure 12 shows the same maps for Emilia Romagna (period 1980-2000). In winter, spring and summer an excellent agreement is registered, with bias close to zero in almost all the region. In autumn, the underestimation is confirmed, especially on the boundary with Toscana (Apennines area).

Figure 13 shows the same maps for Calabria (period 1980-2011). In this region, with the exception of summer, underestimation is stronger with respect to the one registered in 7. This is due to the fact that E-OBS precipitations in this region are underestimated over the whole year, as shown in Fig. 14, where the seasonal cycles obtained with E.OBS and with ARPA dataset are compared.

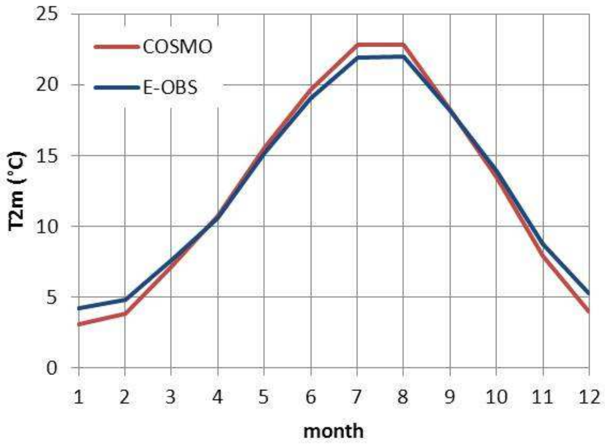
4 - CONCLUSIONS

In this work, an analysis of a RCM simulation over Italy at spatial resolution of about 8 km has been presented. The non-hydrostatic RCM COSMO-CLM has been adopted to simulate the period (1979-2011) using the ERA Interim-Reanalysis, as "perfect" boundary conditions. Validation has been carried out in terms of two-meter temperature (T2m) and precipitation, comparing model results with observational datasets.

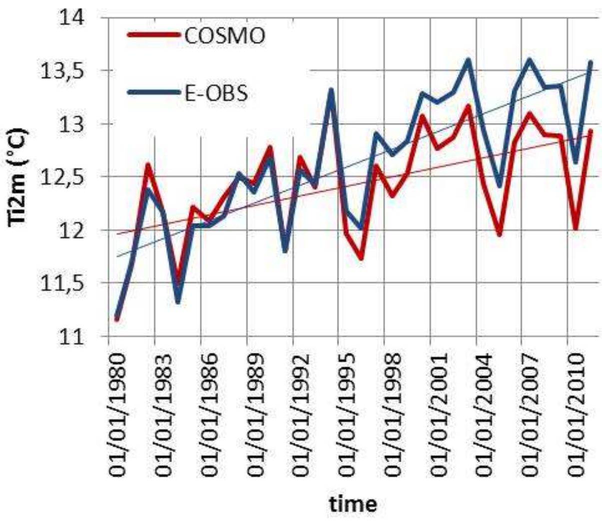
Values of mean T2m show a general good agreement with observations. Seasonal bias maps with respect to E-OBS display a negative bias in winter and positive one in summer, while in spring and autumn a cold bias affects high altitude areas and a hot bias affects Adriatic coast. Maxima biases of 3°C are confined in local areas of the domain (e.g. Ligurian Alps and part of Po Valley). Evidence of model good accuracy in simulating mean T2m is given by the seasonal cycle (average bias 0.2 °C). A comparison with available regional datasets has revealed that part of the bias is due to the low quality of E-OBS, since the station distribution is very rare, especially in south Italy.

Concerning precipitations, model works quite well and computed bias with respect to available observations is always lower than 2-3 mm/day, with a pronounced seasonal variation. Indeed, winter and summer present a very low bias. A larger overestimation is observed on the Alpine arc in spring, while an underestimation is observed in Toscana in autumn. Comparisons with accurate regional datasets have highlighted a better agreement, revealing a partial inadequacy of E-OBS dataset over Italy. In conclusion, although biases are still not negligible, results of the simulation allow for a satisfactory representation of the Italian climate, being the values of bias found lower than the typical values that typically affect regional climate simulations [17].

Currently, simulations over the period 2005-2100 are running in order to assess the changes of the future climate over Italian peninsula, both in term of mean changes and of extreme values. The RCP4.5 and RCP8.5 scenarios are considered.



(a) seasonal cycles



(b) time series

Figure 4:
Seasonal cycles (a) and time series (b) of the 2-meter mean temperature.

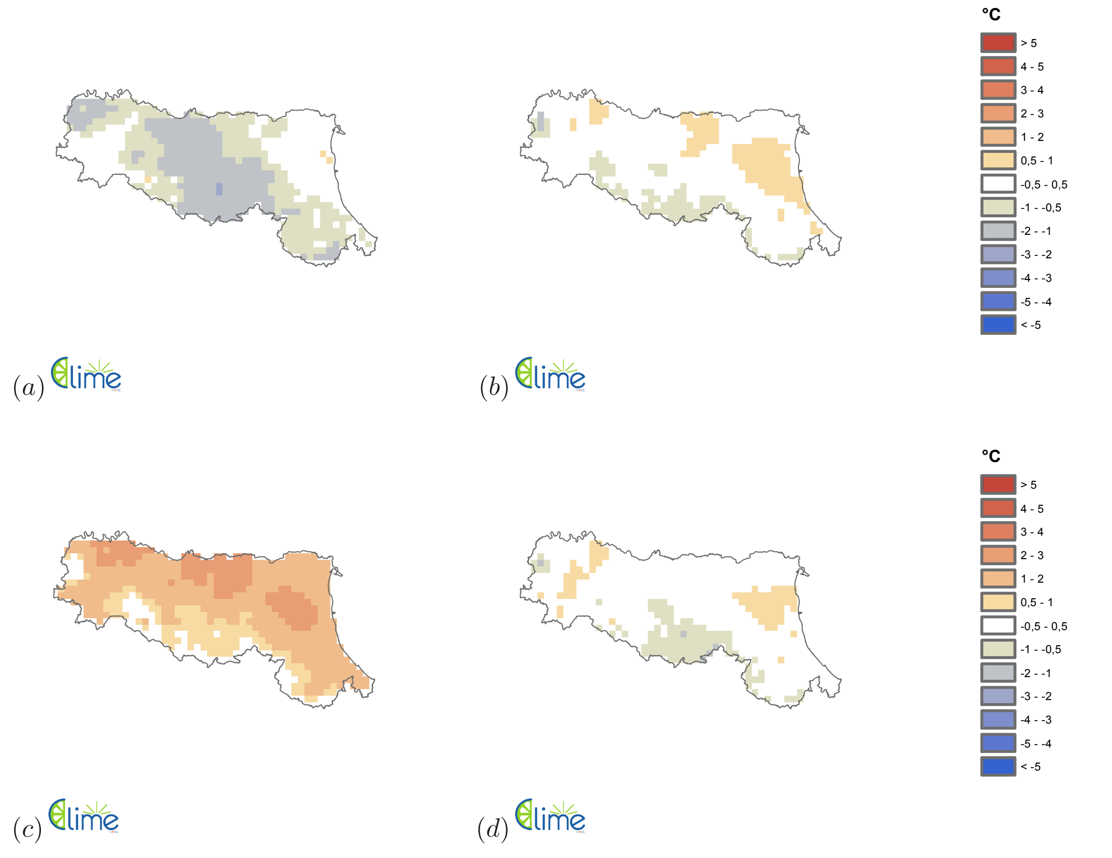


Figure 5:
Bias of two-meter temperature with respect to ARPA Emilia Romagna dataset, for DJF(a), MAM (b), JJA (c), SON (d)

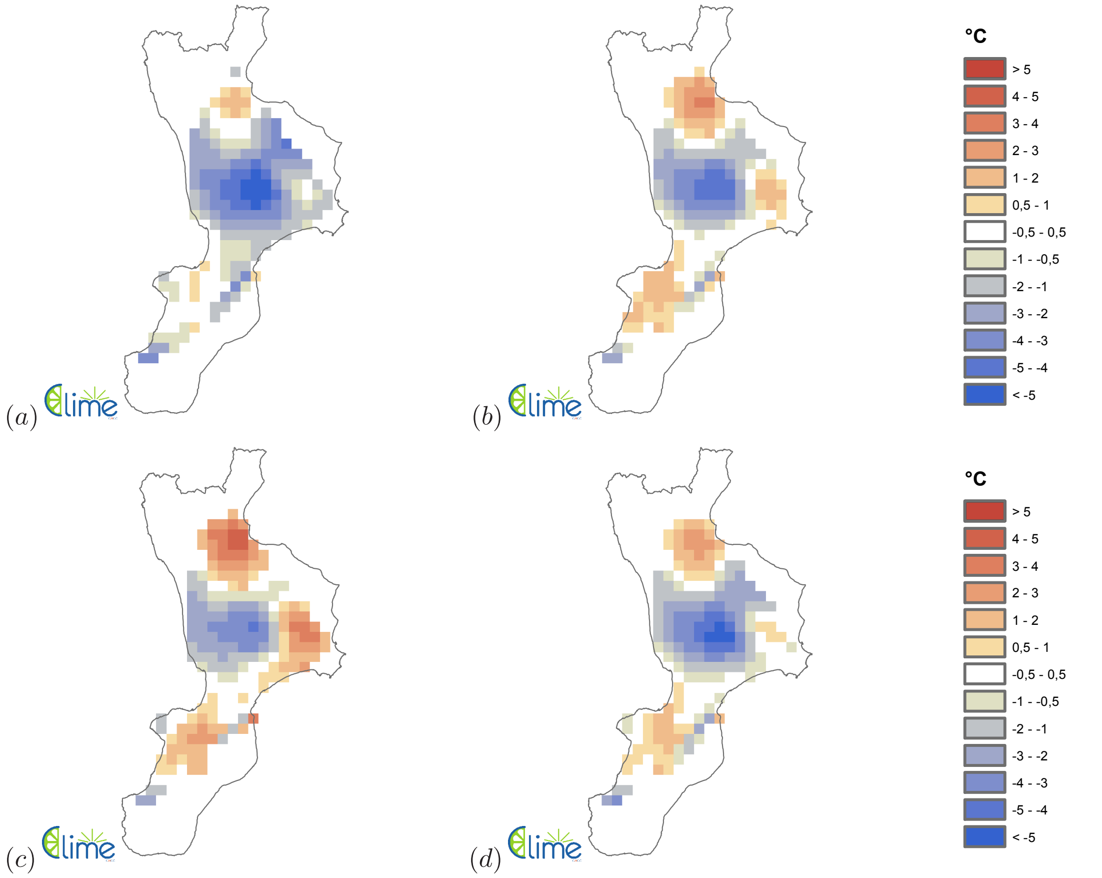


Figure 6:
Bias of two-meter temperature with respect to ARPA Calabria dataset, for DJF(a), MAM (b), JJA (c), SON (d)

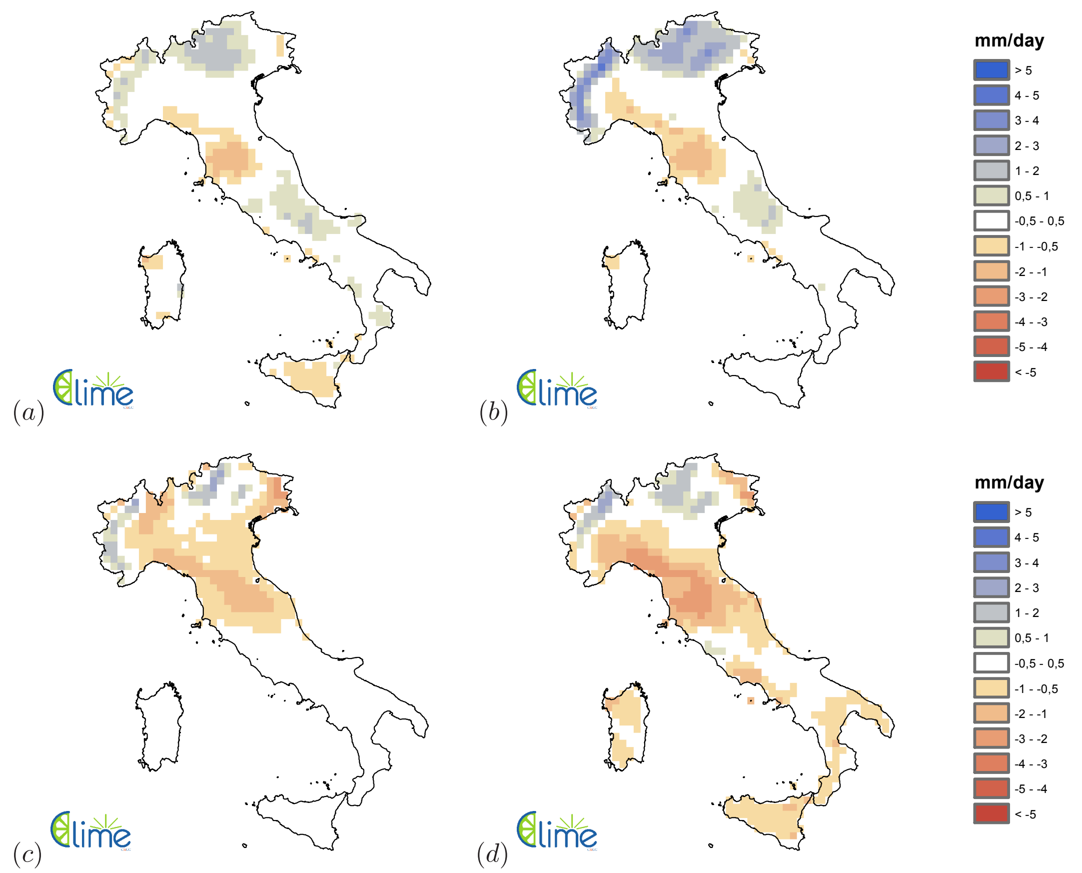
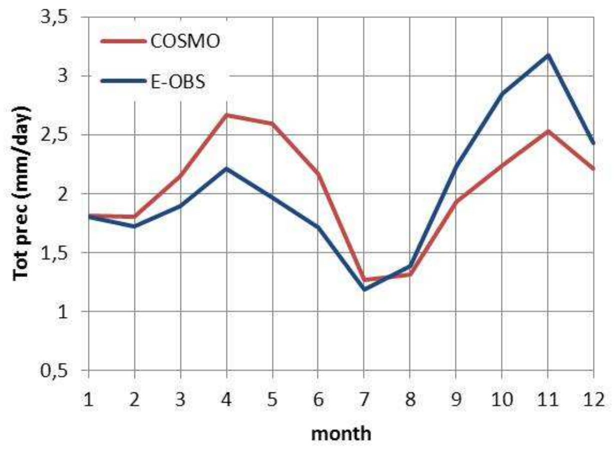
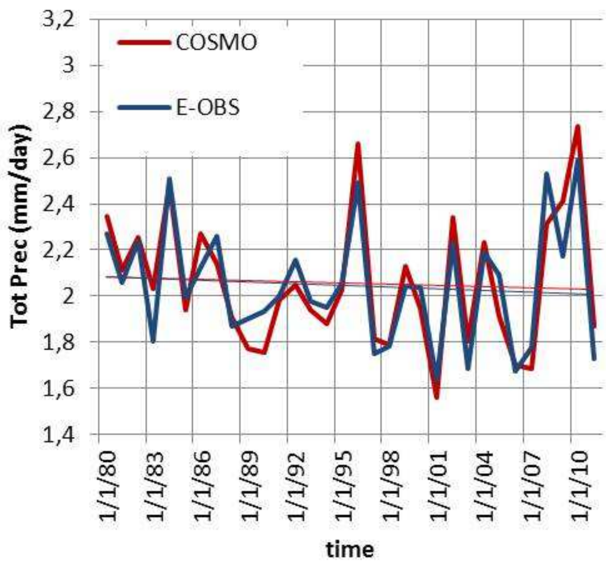


Figure 7:
Bias of daily total precipitation with respect to E-OBS dataset, for DJF (a), MAM (b), JJA (c), SON (d)



(a) seasonal cycles



(b) time series

Figure 8:
Seasonal cycle (a) and time series (b) of total precipitation.

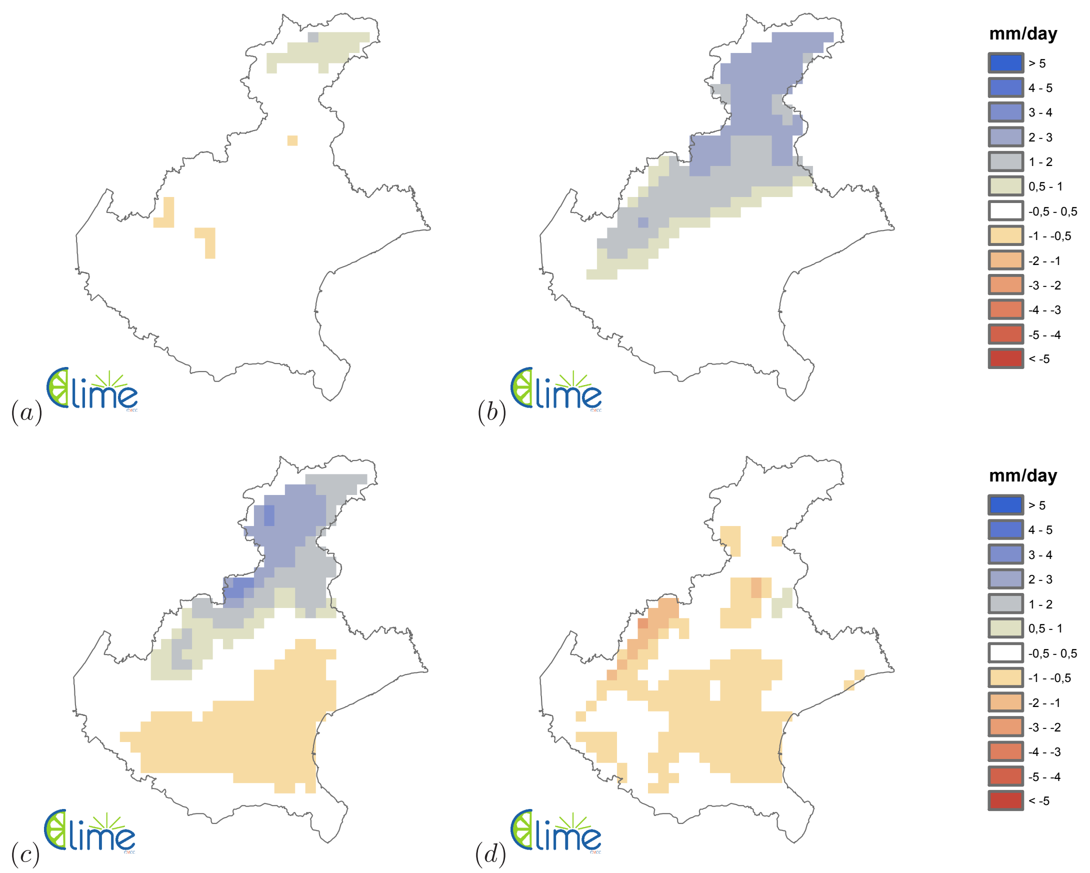


Figure 9:
Bias of daily total precipitation with respect to ARPA Veneto dataset, for DJF (a), MAM (b), JJA (c), SON (d)

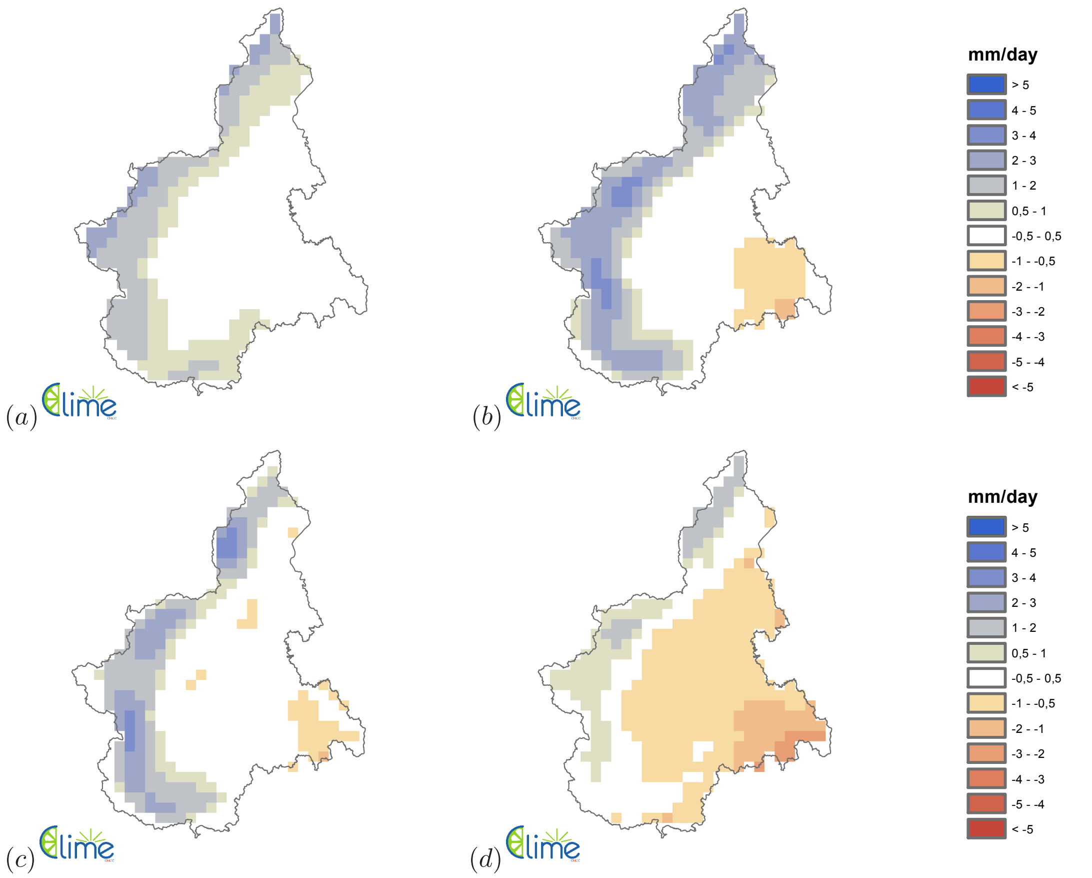


Figure 10:
Bias of daily total precipitation with respect to ARPA Piemonte dataset, for DJF (a), MAM (b), JJA (c), SON (d)

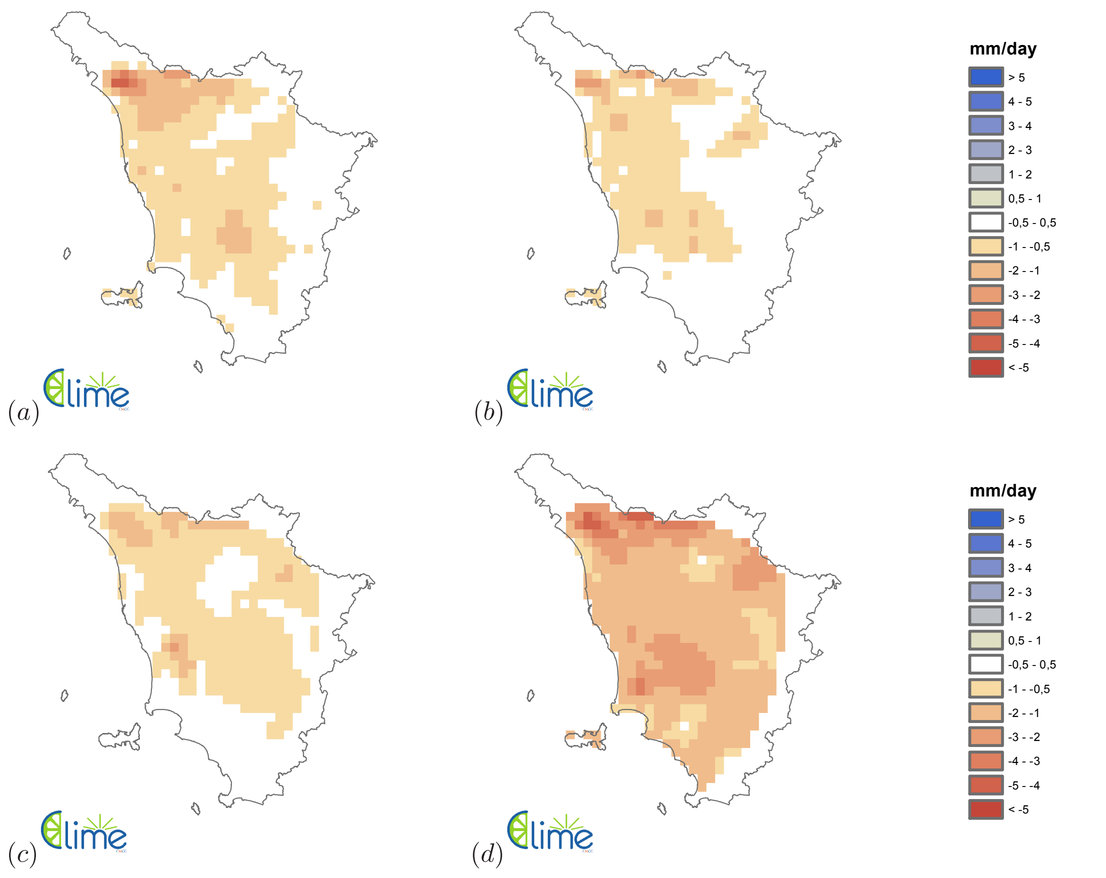


Figure 11:
Bias of daily total precipitation with respect to ARPA Toscana dataset, for DJF (a), MAM (b), JJA (c), SON (d)

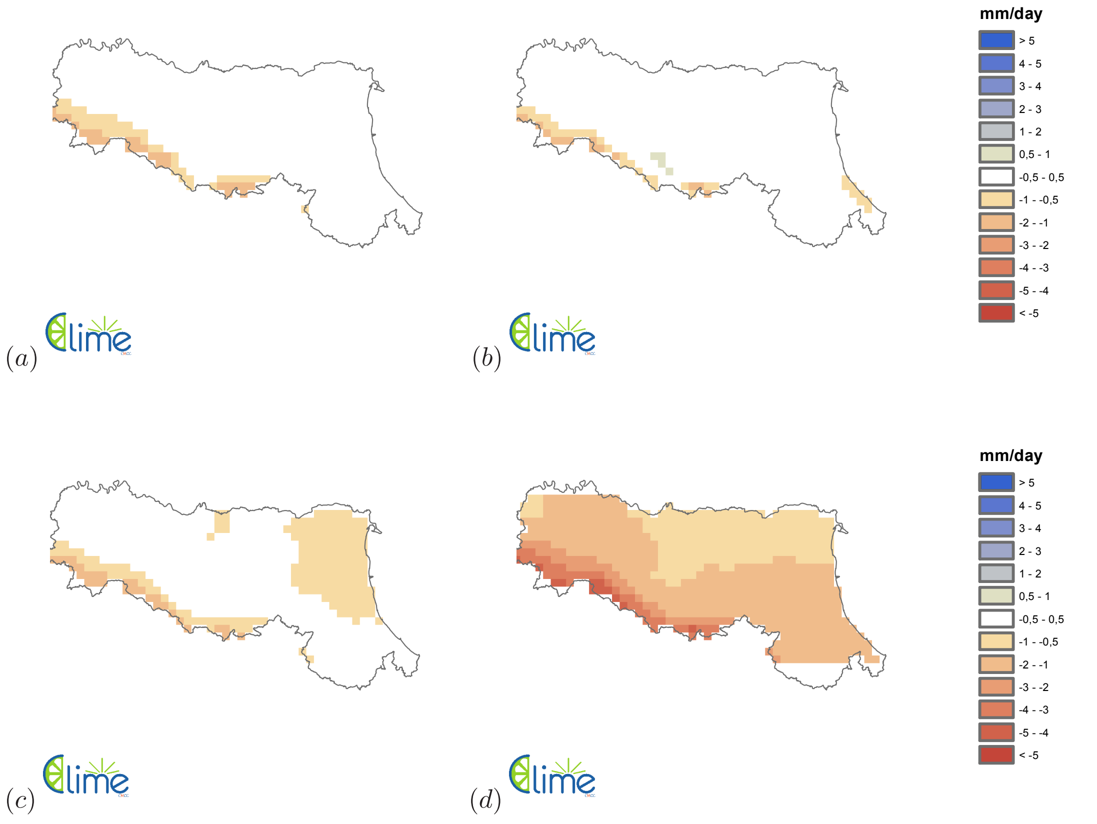


Figure 12:
Bias of daily total precipitation with respect to ARPA Emilia Romagna dataset, for DJF (a), MAM (b), JJA (c), SON (d)

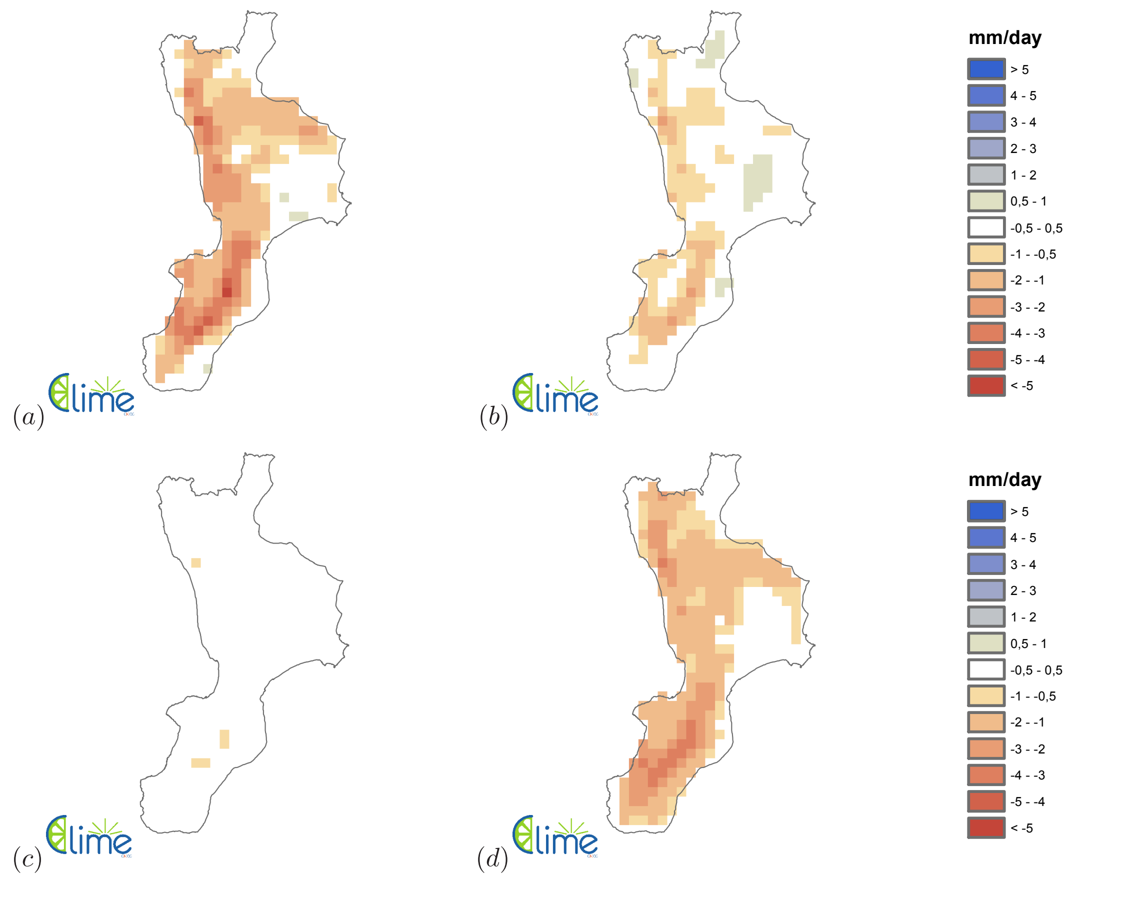


Figure 13:
Bias of daily total precipitation with respect to ARPA Calabria dataset, for DJF (a), MAM (b), JJA (c), SON (d)

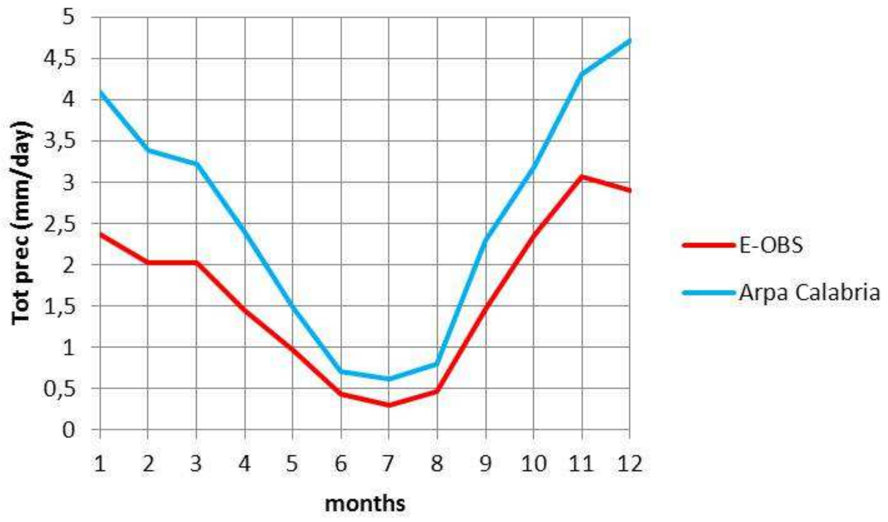


Figure 14:
Seasonal cycle of total precipitation over Calabria for E-OBS and ARPA Calabria datasets.

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