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Performance comparison of three high resolution configurations over Alpine region

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SUMMARY In this work, a comparison among three configurations of COSMO-CLM model at different resolution (0.125°, 0.0715° and 0.02°) is presented through a performance test over a very complex terrain area: the Alpine region. The following analyses focus on a time period ranging from 1980 to 2009 for temperature, and from 1980 to 2008 for precipitation: all simulations have been respectively compared with E-OBS and EURO4M observational datasets.
The results obtained show that 0.02° configuration grants performance inprovements especially for mountain areas, usually characterised by a strong bias forcing most simulations into colder temperatures and heavier precipitations when compared to reference observations.

1. INTRODUCTION

The need for climate change information at the regional-to-local scale is one of the central issues within the global change debate and for the planning of climate policies, in particular for adaptation to climate change (IPCC, 2007 [29]). A great effort of the research community is on the assessment of the present and future climate conditions considering the effect of anthropogenic climate changes. Furthermore, several studies are conducted to provide relevant information for climate impact studies and for climate change mitigation and adaptation strategies. For this last scope, in particular, it is essential to produce reliable and accurate climate projections at high spatial resolution (Giorgi, 2006 [13]).
Global Climate Models (GCMs) are the most advanced tools to simulate the response of the climate to the different IPCC emission scenarios, but their spatial resolution is not fine enough to provide information at regional scale (Christensen et al., 1997 [8]). To satisfy the requirements suggested by impact communities, a downscaling of GCM model output is performed by means of Regional Climate Models (RCMs), thus providing a better representation of relevant atmospheric processes, also due to a deeper description of important surface features such as orography (Giorgi et al., 2001 [14]).
As a preliminary and essential step, it is necessary to assess if the adopted RCM is able to well represent the present climate of the investigated area, in order to provide future climate projections (Kotlarski et al., 2014 [27]; Coppola and Giorgi, 2010 [9]).
In this view, numerous works have been carried out to analyse the RCM performances comparing simulation outputs with available observations (e.g. Jacob et al., 2007 [23], Jaeger et al., 2008 [24]), assessing if RCMs reveal good capability in reproducing the most important climate features when forced by "perfect boundary conditions" provided by Reanalysis, to exclude possible further errors introduced by the usage of GCMs. In this context, in the framework of PRUDENCE (Christensen et al., 2007 [7]), ENSEMBLES (van der Linden and Mitchell, 2009 [35]) projects and CORDEX initiative (Giorgi et al., 2009 [15]), several RCMs have been evaluated, generally showing good agreement with observations, although deficiencies still remain. Indeed, it is worth noticing that RCM results are influenced by different sources of uncertainties, such as the adopted forcing data, observational datasets used for the evaluation and specific model parameterisations.
Furthermore, it has been proved that changing horizontal resolution can lead to different model performances. In particular, some studies show that a higher spatial resolution is linked to an improvement of results (e.g. Bucchignani et al., 2015 [4]), especially for complex areas, such as the Alpine region. Indeed, Alps represent one of the most difficult areas to describe through regional climate models. They are influenced by several climate conditions (Beniston, 2005 [3]) and are characterized by different climatic gradients, frequent extreme events of precipitation, perennial snow and ice (Gobiet et al., 2013 [16]) and other phenomena associated to the orography (Schär et al., 1998 [31]).
Moreover, their complex topography (they are the most relevant topographic ridge of Europe, with both numerous valleys and very high peaks) and land sea distribution are the cause of synoptic-scale disturbances, leading to several mesoscale flow features and precipitation processes (Frei et al., 2003 [12]; Heimann, 1997 [19]; Buzzi and Foschini, 2000 [5]).
Previous works (e.g. Bucchignani et al., 2015 [4] and Kotlarski et al., 2012 [26]) have already

assessed the added value of high horizontal resolution simulations to better reproduce the main features of the atmospheric variables over this area.

In particular, in Montesarchio et al. (2014) [28] it has been carried out a comparison between two simulations covering the Alpine region performed by using the RCM COSMO-CLM (Rockel et al., 2008 [30]) at 0.125° (about 14km) and 0.0715° (about 8km) of resolution respectively. The produced analyses concerning mean and extreme values of temperature and precipitation show a better agreement with observations when the finest scale is adopted, especially in terms of temperature.

Following this direction, the last years have witnessed an increase of studies exploring regional climate and weather simulations with horizontal resolution of 1 kilometre scale. The advantage of using a so high spatial resolution is double: first, a better representation of real topography is guaranteed; then, it is possible to switch off the deep convection parameterisation in the RCM simulation. Indeed, in Weisman et al. (1997) [38] a resolution of 4km in non-hydrostatic models is considered sufficient to explicitly reproduce convective systems, without the usage of parameterizations. This is a very crucial point, being these kind of parameterisations one of the major sources of uncertainties in regional climate modelling (Fosser et al., 2014 [11]).

An interesting result obtained through simulations at these resolutions is an improvement in the description of the precipitation field. For example, Hohenegger et al. (2008) [21] analysed a cloud-resolving simulation performed with COSMO-CLM at 0.02° of resolution (about 2.2km) comparing the results with a coarser simulation (0.22°, about 25km) over the whole Alpine region, finding a better localization of precipitation maxima, a reduction of the cold bias and, more important, an improvement in the representation of precipitation diurnal cycle. This last point has also been addressed in Fosser et al. (2014) [11], highlighting that the added value of a so high horizontal resolution simulation is recorded especially on sub-daily scale, rather than monthly or daily ones. Furthermore, in Kendon et al. (2012) [25] the results of a simulation at 1.5km resolution over a region of the United Kingdom show, with respect to a 12km simulation, a better representation of spatial and temporal structures of heavy rain and precipitation diurnal cycle (as already found in the above cited works), in addition to a reduction of light rain (generally overestimated by RCMs). Finally, the work of Ban et al. (2014) [2] analyses a comparison between a convection-parameterising simulation at 12km resolution and a 2.2km convection-resolving simulation over Alpine region for the period 1998-2007: generally, the finest configuration allows an improvement in terms of precipitation and temperature diurnal cycles, frequency of summer heavy hourly events and reproduction of scaling of precipitation extremes with temperature, but it also highlights a more pronounced warm and wet bias over Alps.

In this work, the effects induced by the usage of very high-resolution COSMO-CLM configurations over the Alpine regions were investigated, comparing three simulations characterized by different resolutions: 0.125° (about 14 km), 0.0715° (about 8 km) and 0.02° (about 2.2 km). The first two simulations were forced by ERA-Interim reanalysis (Dee et al., 2011 [10]), while 0.02° one was nested into the 0.0715° one. The analyses have been focused on two-meter temperature (mean, maximum and minimum) and precipitation.

This report is organized as follows: in Section 2, the regional climate model used to perform the simulations is described, along with the main settings of the three configurations implemented and the observations used to evaluate the model performances; in Section 3, an analysis of results is presented; finally, conclusions are shown in Section 4.

2 - MODEL AND DATA

2.1 - THE REGIONAL CLIMATE MODEL

The regional model used in the present work is COSMO-CLM (Rockel et al., 2008 [30]), the climate version of COSMO-LM weather model (Steppeler et al., 2003 [32]), developed by the CLM Community. It is characterized by a non-hydrostatic formulation, that allows a better representation of convective phenomena and sub-grid scale physical processes. It has been widely adopted in several European projects, such as PRUDENCE (Christensen et al., 2007) and CORDEX (Giorgi et al., 2009), showing a good capability in reproducing the mean climate features of the areas analysed, with a mean bias in the same order of other state-of-art RCMs.
In this study, the following simulations have been analyzed:

- CCLM_14, characterized by a spatial resolution of 0.125° (about 14km), driven by ERA-Interim (Dee et al., 2011 [10]) and covering all the European countries surrounding the Mediterranean area (the largest domain in Figure 1)
- CCLM_8, characterized by a spatial resolution of 0.0715° (about 8km), driven by ERA-Interim and covering the Italian peninsula and part of the neighboring states (intermediate domain in Figure 1)
- CCLM_2.2, characterized by a spatial resolution of 0.02° (about 2.2km), nested into CCLM_8 and covering a smaller area centered over the Alpine space (the smallest domain in Figure 1)

The first two simulations have been carried out over the period 1979-2011, while the third one over 1979-2009. The three simulations have been performed using the version 4.8_clm19 of COSMO-CLM and the version 1.10_clm2 of the interpolator INT2LM.

It is worth noting that the performances of the coarsest simulations (*CCLM_14* and *CCLM_8*) have been already widely evaluated (Bucchignani et al. (2015) [4]) over the whole Italian peninsula, showing a general good agreement with several observational datasets, both in terms of mean temperature and precipitation. Furthermore, *CCLM_8* output has been used as input of hydrological/hydraulic models to reproduce the water distribution over Po basin (Vezzoli et al., 2014 [36], Vezzoli et al., 2015 [37]).
In Table 1, the main differences among the three configurations are summarized. For all simulations, numbers of vertical and soil levels have been set to 40 and 7 respectively; moreover, a third order Runge-Kutta scheme has been used for the time integration and the multi-layer soil and vegetation model TERRA_ML to regulate land-surface interactions.

The simulations have been performed on IBM iDataPlex DX360M4 supercomputer of CMCC, installed at Lecce (Italy): it is a cluster of 482 nodes (7712 cores) interconnected with network FDR InfiniBand. This machine provides a computing power of about 160 TFlops and it is inserted in the Top500 list of the most powerful supercomputers in the world.
It is worth to say that, from a computational point of view, *CCLM_2.2* is much more time consuming than *CCLM_8*, requiring about 8 days to simulate one climatological year using 1024 cores, against about 1 day for *CCLM_8* with the same number of cores.

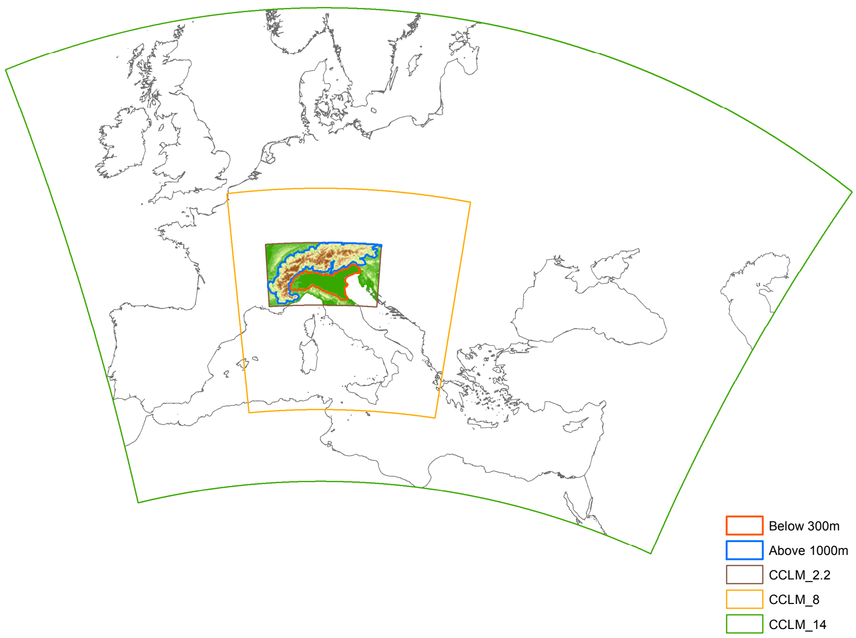

Figure 1:
Orography of the domain simulated by CCLM_2.2 (smallest one), highlighting the two subregions considered for the analyses (in red and blue). The big domain over Mediterranean area is covered by CCLM_14, while the intermediate one represents CCLM_8.

Table 1
Main differences between the two implemented COSMO-CLM configurations. It is possible to find more about used convection schemes on Tiedke, 1989 [34].

	CCLM_14	**CCLM_8**	**CCLM_2.2**
Driving data	ERA-Interim Reanalysis	ERA-Interim Reanalysis	CCLM_8
Horizontal resolution	0.125° (about 14km)	0.0715° (about 8km)	0.02° (about 2.2km)
Num. of grid points	385 x 265	224 x 230	390 x 230
Time step	100 s	40 s	10 s
Convection scheme	Tiedtke	Tiedtke	Shallow convection based on Tiedtke
Frequency of radiation computation	1 hour	1 hour	15 min
Maximal turbulent length scale	500 m	500 m	150 m
Critical value for normalized over saturation	4	4	1.6

2.2 - OBSERVATIONAL DATA

The model output has been evaluated against two different observational datasets:

E-OBS (Haylock et al., 2008 [18]) : an European daily high-resolution (0.25° x 0.25°) gridded data set for precipitation, minimum, maximum and mean surface tem-

perature and sea level pressure for the period 1950-2012. Thanks to its spatial and temporal coverage, it is widely used to evaluate RCMs temperature and precipitation over Europe.
It must be taken into account that this dataset is affected by a number of potential uncertainties, due to incorrect station location and inhomogeneities in the station time series, such as also to inaccuracy in the interpolation process in areas with a low number of station points or complex terrains, such as mountains (Hofstra et al., 2009 [20]).
Hereinafter, it will be referred as *EOBS*.

EURO4M-APGD ([Isotta et al., 2014 [22]) : a daily precipitation high-resolution gridded dataset (spacing of about 5km) covering the Alpine region for timeframe 1971-2008. It has been constructed, starting from high-resolution rain-gauge data, with a distance-angular weighting scheme that integrates climatological precipitation-topography relationships.
Hereinafter, it will be referred as *EURO4M*.

2.3 - EVALUATION METHOD

Simulations have been compared over periods 1980-2008 (precipitation) and 1980-2009 (temperature), each one obtained by a time intersection between model outputs and observed datasets; the year 1979 has been neglected as it is considered as spin-up. Furthermore, analyses have been carried out both on seasonal means over the whole simulated domain (from which an appropriate number of points has been excluded in each direction to neglect influence of boundary conditions), and spatial means over two different subregions shown in Figure 1: the first one includes points with orography above 1000m; the second one, instead, covers all points with orography below 300m.

In order to assess the model performances, seasonal bias maps, annual cycles, time series and PDFs have been computed, in addition to the following quantities:

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

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

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

where S_i and O_i are respectively the simulated and observed values at the i-th time step, and N is the number of time steps under exam.

Seasonal bias maps have been carried out regridding the model output on the observational dataset grid, using a Natural Neighbour interpolation technique. The other indices have been instead calculated on the native grid, without performing interpolation.
All analyses presented in this work have been performed by *Clime* (Cattaneo et al., 2014 [6]), a special purpose GIS software integrated in ESRI ArcGIS Desktop 10.X, developed at CMCC (REMHI Division) in the framework of Project GEMINA in order to easily evaluate multiple climate features and to study climate changes over specific geographical domains.

3 - RESULTS

Figure 2 and Figure 3 show mean temperature (°C) and precipitation (mm/day) values from EOBS and EURO4M datasets respectively for the four seasons (DJF, MAM, JJA, SON), while bias distributions are displayed in Figure 4 and Figure 5.
Concerning mean temperature, all simulations are generally affected by a cold bias over mountainous chains (Alps and Apennines),

with the highest peak in winter over Piedmont region, while a warm bias is recorded over Po Valley in the other seasons, especially for summer.
In flat areas, *CCLM_14* and *CCLM_8* show similar values, while *CCLM_2.2* is affected by the highest overestimation. It is worth noting that such behaviour is partially inherited by its forcing data (*CCLM_8*), which is already characterized by a hot bias, due to a COSMO-CLM inadequacy in reproducing the atmospheric dynamics of this area, associated to an error in representing heat fluxes and cloud cover (a detailed explanation is provided in Bucchignani et al., 2015 [4]). Also Hohenegger et al. (2008) [21] showed that the finest simulation reveals warmer temperatures over Po Valley, leading to a more pronounced overestimation, compared with the ones produced by coarser configurations, probably ascribed to an evapotranspiration inhibition caused by a lower soil moisture content. Moreover, according to Ban et al. (2014) [2], the stronger temperature overestimation, obtained with a 0.02° resolution convection-resolving simulation with respect to the coarsest one, is connected to a reduced cloud cover and to the usage of a smaller turbulent length scale (also introduced in *CCLM_2.2* simulation), in addition to generally drier soil conditions of the finest configuration. However, it is worth noting that EOBS dataset is not characterized by a resolution suitable enough to appreciate the benefits of a very high resolution simulation, such as the one described in this work.

As regards precipitation, *CCLM_14* and *CCLM_8* show very similar results (the most noticeable difference is a stronger negative bias of *CCLM_14* in Po Valley during summer). *CCLM_2.2* is affected by a more pronounced underestimation with respect to *CCLM_8* (more evident in summer and autumn), but it tends to better represent the precipitation amount over areas with very high orography. The wet bias over Alpine arc is less pronounced in *CCLM_2.2*, especially in summer, when the convection permitting scale is expected to have a stronger influence over precipitation. This kind of bias was also found in several literature works (Montesarchio et al., 2014 [28], Haslinger et al., 2013 [17] and Suklitsch et al., 2008 [33]) and is partially ascribed, especially for winter season, to a systematic error in raingauge measurements (Adam and Lettenmaier, 2003 [1]; Isotta et al., 2014 [22]).
Such results basically agree with Hohenegger et al. (2008) [21], where a cloud-resolving simulation (0.02° of resolution) performed with COSMO-CLM over Alpine region on July 2006 produced much better performances than a coarser simulation at 0.22° (about 25km) resolution. During summer and autumn, precipitation peaks over Apennines and eastern part of the domain are strongly underestimated by all the three simulations, especially *CCLM_2.2*.
Annual cycles (Figure 6) confirm the results above described. *CCLM_2.2* outperforms *CCLM_8* and *CCLM_14* over the subregion with orography higher than 1000m, but it shows worse performances in the subregion with orography lower than 300m. More specifically, temperature annual cycles are correctly reproduced by all the simulations in both the areas, with a general underestimation during winter months and a general overestimation over plain areas. For precipitation, the finest simulation is characterized by constant strong dry bias over the plain areas with respect to the coarser ones, whereas it is more precise on mountain areas showing better values, along with *CCLM_14*. The analysis of time series (Figure 7) shows that *CCLM_2.2* is affected by the lowest temperature underestimation

in high orography areas (except for minimum values), producing instead a positive bias in flat zones (the other simulations act similarly). For precipitation, results are basically consistent with annual cycles, with *CCLM_2.2* values very close to observations on mountain subregion.
Looking at the synthetic indices tables (Figure 8), *CCLM_2.2* confirms to have the smallest precipitation bias over mountainous areas from December to May, but it strengthens the precipitation underestimation in the other months of the year, when its BIAS reaches the values of -0.67 mm/day (JJA) and -0.26 mm/day (SON). It is necessary to pinpoint that, although *CCLM_2.2* shows the highest BIAS in some seasons, it is always characterized by the lowest MAE value (this misleading behaviour is due to an error compensation in the computation of BIAS value, since positive errors may be counterbalanced by negative ones), proving a general better agreement with EURO4M with respect to other simulations. Furthermore, the strongest discrepancy between model and observations are reached in spring for all the simulations, but also in this case MAE values confirm that *CCLM_2.2* shows better performances over high orography areas. In plain subregion, all simulations are affected by a general underestimation, with *CCLM_2.2* proving to be the least accurate compared to the others, reaching 1.48 mm/day of BIAS in autumn, while *CCLM_8* seems to have the best performances in this environment.
For temperature, similar considerations can be made. In mountain subregion, BIAS and MAE values are considerably reduced when looking at *CCLM_2.2*, except for winter, when all simulations have similar results characterized by the strongest underestimation. For low orography areas, the high temperatures produced by 0.02° simulation generate the strongest overestimation during most of the year, with BIAS reaching 3.12 °C in summer; on the other hand, they compensate the general understimation affecting all simulations in winter, granting *CCLM_2.2* the best performances during this season.
The analysis of precipitation PDF (Figure 9) has been conducted considering all values of distribution (top) and considering only days with precipitation greater than 1 mm/day (bottom). In the first case, *CCLM_2.2* exhibits a higher number of drizzle events (daily precipitation below 1mm/day) and less heavier precipitation occurrences with respect to *CCLM_8* and *CCLM_14* in both subregions analysed. This leads to a worsening of the results over the flat area (where other simulations reach a better agreement with EURO4M, showing a closer probability distribution for weak precipitation) but to a substantial enhancement of the performances over the mountainous subregion, showing a considerable accuracy in most cases. For all resolutions, there are not visible differences with observations for values over 20mm/day, probably due to the lack of a significant number of occurrences. This is particularly evident when the probability distribution of only wet days is taken into account (bottom panels of Figure 9): an increase of the extreme precipitation events is pointed out in *CCLM_2.2*, which results in simulated values closer to the observed ones.
Moreover, probability distributions show *CCLM_8* and *CCLM_2.2* sharing a similar behaviour to EURO4M for high orography areas, while in the other region all simulations have a wider Gaussian distribution than observed data, especially *CCLM_2.2*.
The analysis of mean temperature PDFs (Figures 10 and 11, top panels) reveals that all simulation distributions are spread on a broader spectrum than EOBS data, since they are characterized by a higher occurrence of extreme values (both cold and hot) especially in plain subregion. The same behaviour can

be also seen for maximum (Figures 10 and 11, middle panels) temperature, while for minimum (Figures 10 and 11, bottom panels) they are rather affected by a positive shift of simulated values (generally higher than observations).

4 - SUMMARY AND CONCLUSIONS

In this work, a comparison among simulations at different resolutions (0.125°, 0.0715° and 0.02°) carried out with the regional climate model COSMO-CLM over Alpine region has been presented, with the aim to analyse the possible improvement of performances induced by the usage of a smaller grid spacing (about 2.2km), thanks to which it is possible a better representation of surface properties and an explicit treatment of deep convection.
All simulations have been analysed over two subdomains with strictly distinct orography, in order to evaluate their performances in different environment settings. Results highlight that resolution change from 0.0715° (*CCLM_8*) to 0.02° (*CCLM_2.2*) may heavily affect the performances of simulated data, since their analysis results show significant differences in most cases. In fact, the latter simulation achieves a different response when mountainous and plain regions are taken into account: such configuration works better than the others when used over high orography (higher than 1000m) areas, but it seems less adequate in representing atmospheric variables for terrains with orography lower than 300m.
More in detail, *CCLM_2.2* is characterized by warmer temperatures and a stronger precipitation underestimation over Po Valley, but it also reduces wet and cold biases over mountainous regions, with an improvement in reproducing extreme precipitation events.
It is noteworthy that 0.02° configuration seems to inherit the bias of *CCLM_8*, especially in terms of temperature over Po Valley. Its tendency to produce warmer temperatures over this area was already found in Ban et al. (2014) [2] and Hohenegger et al. (2008) [21].
Nevertheless, the non-negligible bias found over plain areas requires to adopt a better setup for the represented configuration. Preliminary results of a sensitivity activity demonstrate how the configuration is very sensitive to the usage of a different microphysics parameterization scheme for grid scale precipitation and to a different maximal turbulent length scale, possibly leading to a reduction of hot and especially dry biases over Po Valley.

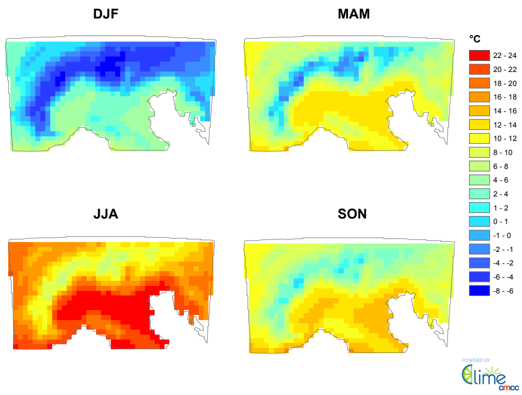

Figure 2:
Seasonal means of daily temperature of E-OBS dataset

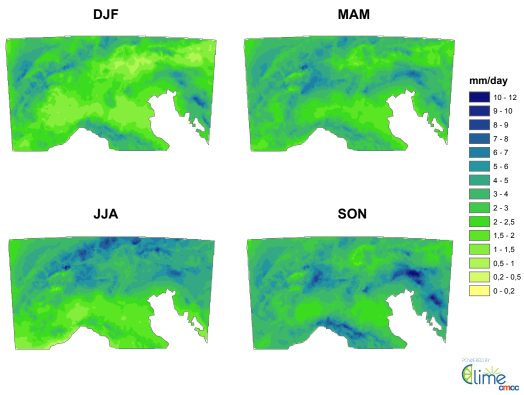

Figure 3:
Seasonal means of daily precipitation of EURO4M dataset

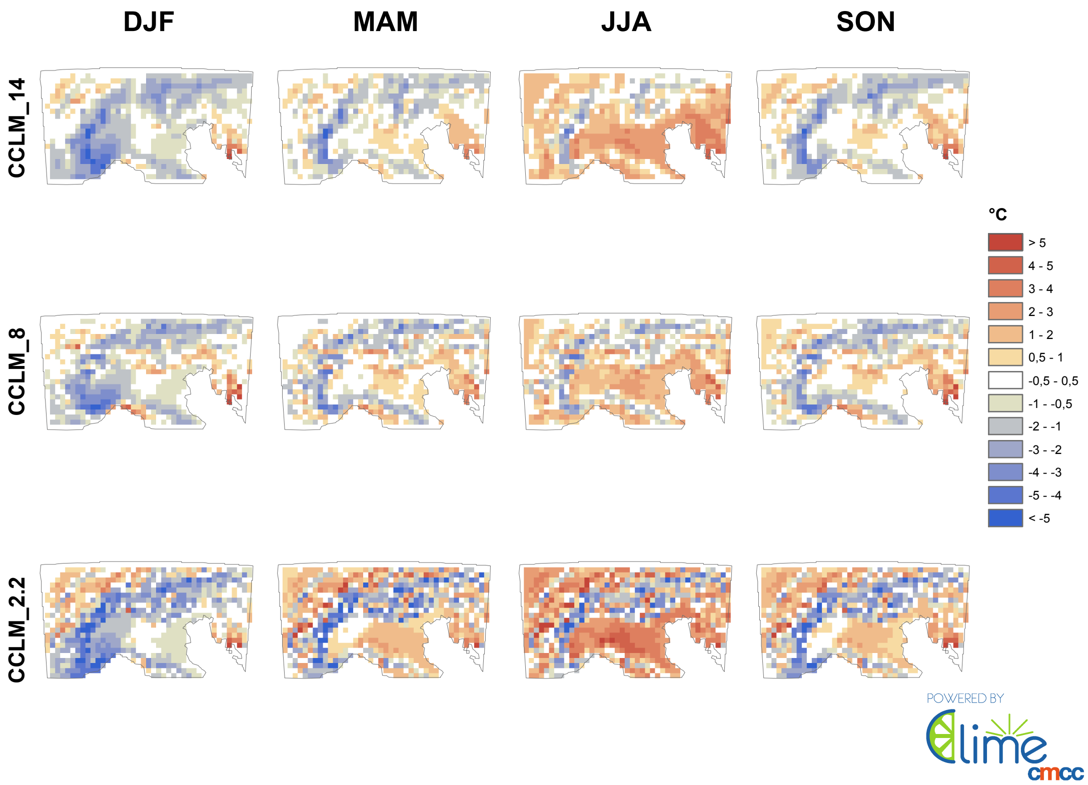

Figure 4:
Seasonal bias of mean temperatures of CCLM_14 (upper row), CCLM_8 (middle row) and CCLM_2.2 (lower row) with respect to E-OBS for DJF(first column), MAM (second column), JJA (third column), SON (fourth column).

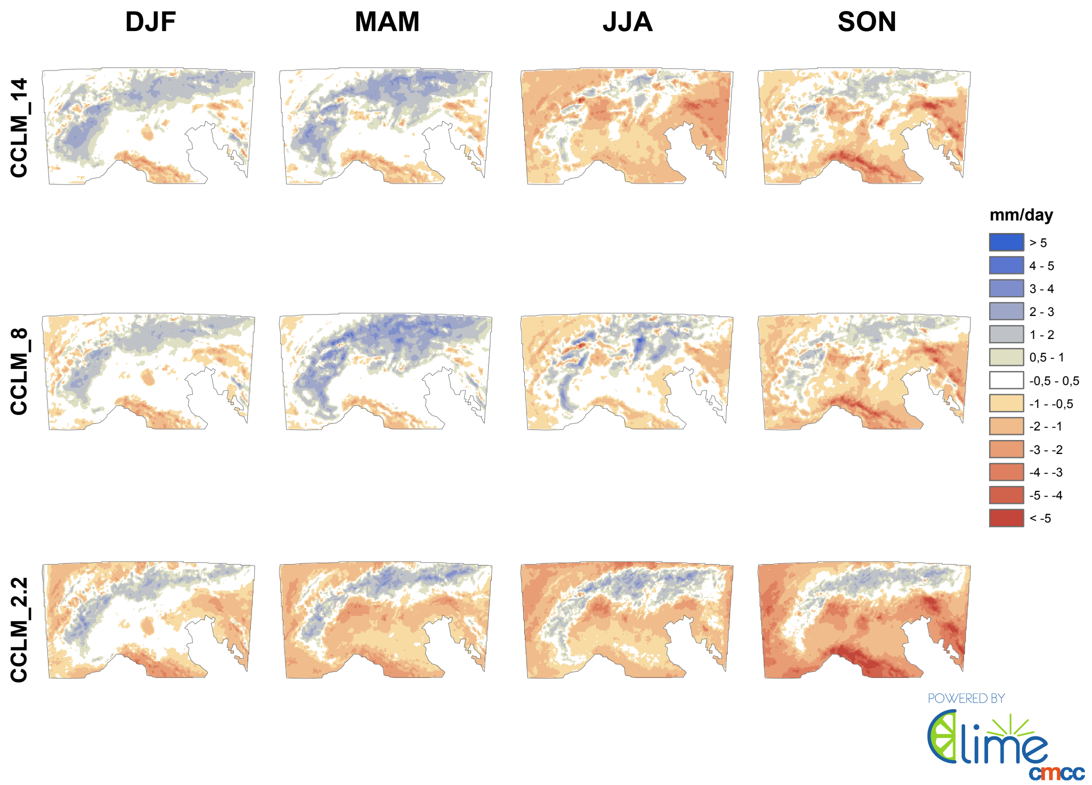

Figure 5:
Seasonal bias of daily precipitations of CCLM_14 (upper row), CCLM_8 (middle row) and CCLM_2.2 (lower row) with respect to EURO4M for DJF(first column), MAM (second column), JJA (third column), SON (fourth column).

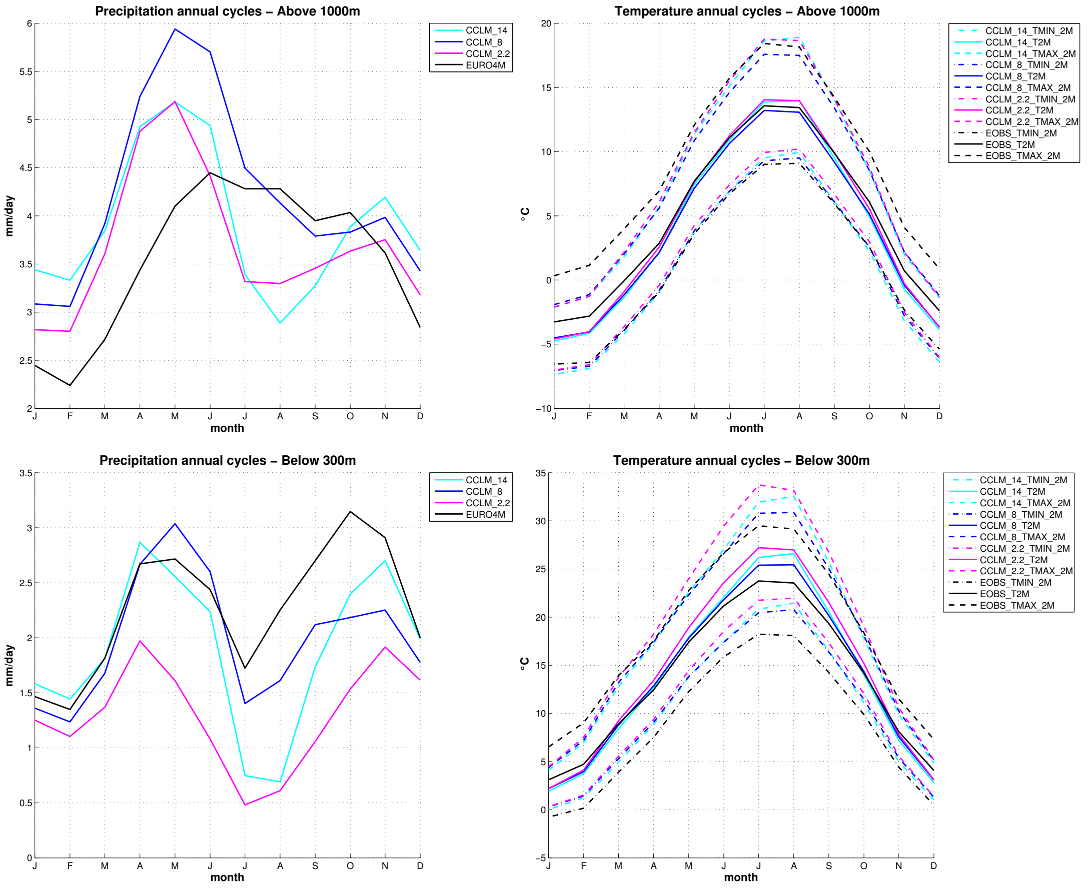

Figure 6:
Precipitation (left) and temperature (right) annual cycles of observational datasets (E-OBS and EURO4M) along with CCLM_2.2, CCLM_8 and CCLM_14 simulations, for both analysed subregions(above 1000m (top) and below 300m (bottom)). Mean, minimum and maximum values of temperature have been considered.

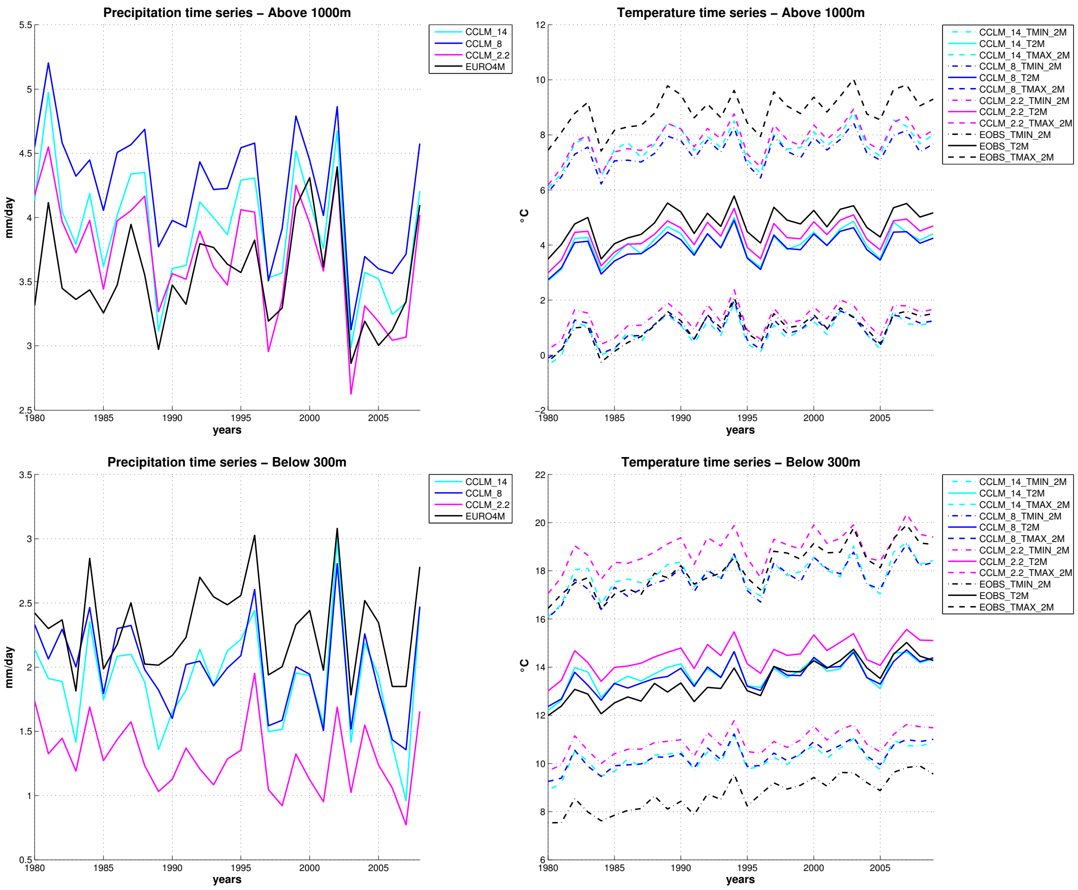

Figure 7:
Precipitation (left) and temperature (right) time series of observational datasets (E-OBS and EURO4M) along with CCLM_2.2, CCLM_8 and CCLM_14 simulations, for both analysed subregions (above 1000m (top) and below 300m (bottom)). Mean, minimum and maximum values of temperature have been considered.

TEMPERATURE (°C)

	Below 300m				Above 1000m				
	Mean value	BIAS	MAE	RMSE	Mean value	BIAS	MAE	RMSE	
CCLM_14	2,80	-1,15	1,59	1,97	-4,26	-1,43	1,55	1,80	DJF
CCLM_8	3,04	-0,90	1,34	1,66	-4,07	-1,24	1,29	1,48	
CCLM_2.2	3,11	-0,84	1,29	1,60	-4,11	-1,28	1,31	1,48	
EOBS	3,94				-2,83				
CCLM_14	13,01	0,08	1,08	1,38	2,75	-0,76	1,04	1,30	MAM
CCLM_8	13,16	0,22	0,86	1,09	2,72	-0,79	0,86	1,05	
CCLM_2.2	13,85	0,91	1,20	1,44	3,10	-0,41	0,62	0,80	
EOBS	12,93				3,50				
CCLM_14	24,99	2,15	2,33	2,77	12,94	0,22	0,82	1,06	JJA
CCLM_8	24,25	1,40	1,58	1,88	12,33	-0,39	0,55	0,69	
CCLM_2.2	25,96	3,12	3,13	3,32	13,11	0,39	0,55	0,68	
EOBS	22,84				12,72				
CCLM_14	13,93	0,06	1,31	1,67	4,57	-0,99	1,16	1,40	SON
CCLM_8	14,03	0,16	1,03	1,31	4,63	-0,93	0,98	1,14	
CCLM_2.2	14,84	0,97	1,49	1,81	5,06	-0,50	0,72	0,89	
EOBS	13,87				5,56				
CCLM_14	13,73	0,29	1,58	2,02	4,04	-0,74	1,14	1,41	YEAR
CCLM_8	13,67	0,23	1,20	1,51	3,94	-0,84	0,92	1,12	
CCLM_2.2	14,49	1,05	1,78	2,18	4,33	-0,45	0,80	1,01	
EOBS	13,44				4,77				

PRECIPITATION (mm/day)

	Below 300m				Above 1000m				
	Mean value	BIAS	MAE	RMSE	Mean value	BIAS	MAE	RMSE	
CCLM_14	1,68	0,01	1,12	2,58	3,48	0,96	1,66	2,76	DJF
CCLM_8	1,46	-0,20	0,95	2,14	3,20	0,68	1,37	2,32	
CCLM_2.2	1,33	-0,33	0,95	2,16	2,94	0,42	1,30	2,29	
EURO4M	1,66								
CCLM_14	2,41	-0,02	1,62	3,15	4,65	1,23	2,25	3,41	MAM
CCLM_8	2,46	0,03	1,45	2,70	5,03	1,61	2,30	3,33	
CCLM_2.2	1,65	-0,78	1,56	3,04	4,55	1,13	2,10	3,26	
EURO4M	2,43				3,42				
CCLM_14	1,21	-0,95	1,70	3,36	3,73	-0,62	2,63	4,26	JJA
CCLM_8	1,86	-0,30	1,58	3,08	4,77	0,42	2,39	3,75	
CCLM_2.2	0,72	-1,44	1,72	3,50	3,67	-0,67	2,30	3,90	
EURO4M	2,16				4,34				
CCLM_14	2,28	-0,71	1,92	4,11	3,79	-0,09	2,09	3,78	SON
CCLM_8	2,19	-0,80	1,75	3,71	3,87	-0,01	1,88	3,45	
CCLM_2.2	1,50	-1,48	1,96	4,26	3,61	-0,26	1,88	3,58	
EURO4M	2,99				3,88				
CCLM_14	1,89	-0,42	1,59	3,35	3,91	0,37	2,16	3,60	YEAR
CCLM_8	1,99	-0,32	1,44	2,97	4,22	0,68	1,99	3,26	
CCLM_2.2	1,30	-1,01	1,55	3,33	3,70	0,15	1,90	3,32	
EURO4M	2,31				3,54				

Figure 8:
Temperature (left) and precipitation (right) synthetic indices for CCLM_2.2, CCLM_8 and CCLM_14 with respect to the reference datasets, for the two subregions analysed. Colour palettes are used to highlight indices, depending on their values (blue to red for temperature, orange to purple for precipitation).

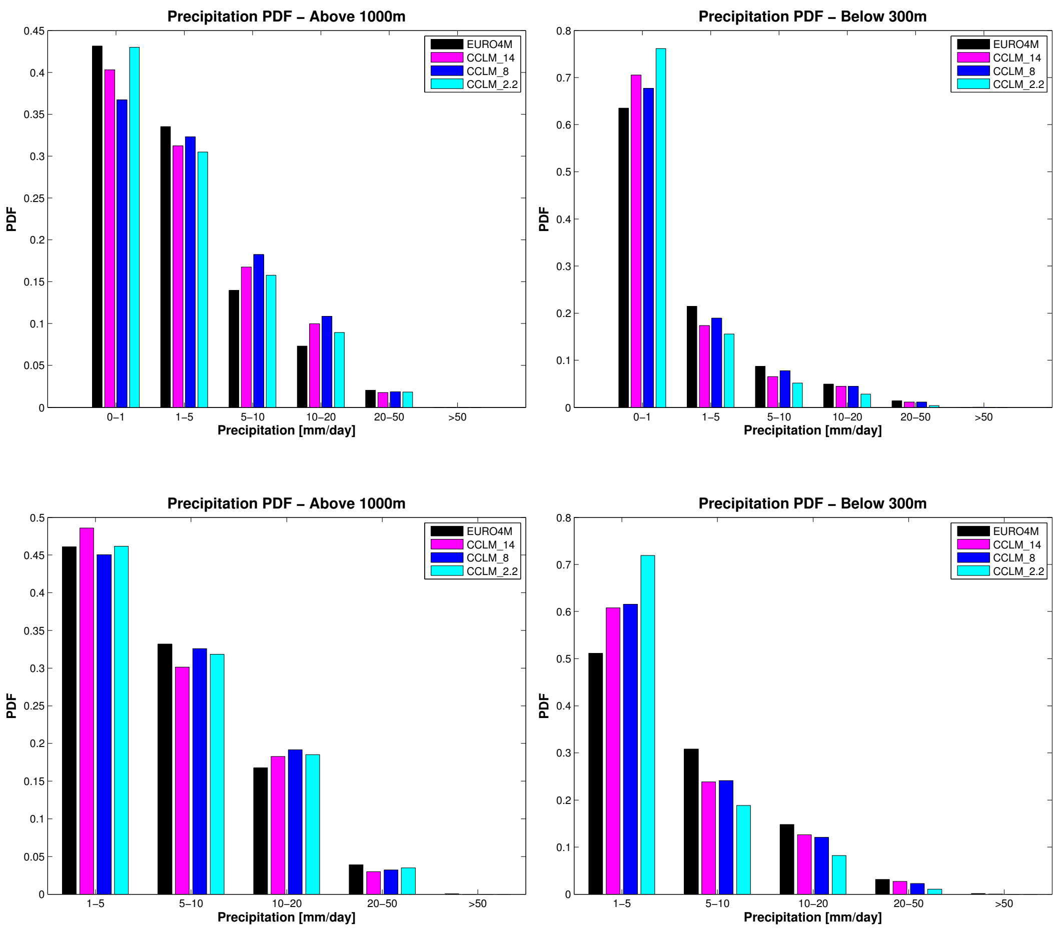

Figure 9:
Precipitation probability distribution function of EURO4M observational dataset along with CCLM_2.2, CCLM_8 and CCLM_14 simulations for for both analysed subregions (above 1000m (left) and below 300m (right) , for all values of distribution (top) and for only days with precipitation greater than 1 mm/day (bottom).

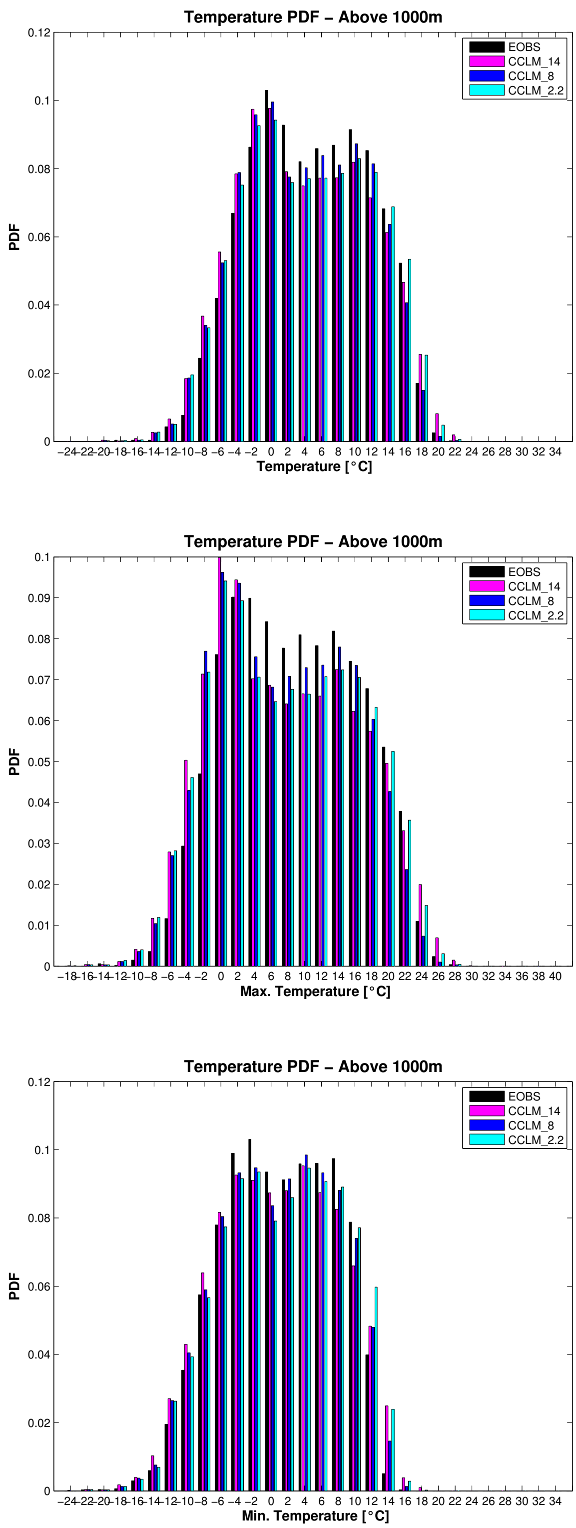

Figure 10:
Temperature probability distribution function of E-OBS observational dataset along with CCLM_2.2, CCLM_8 and CCLM_14 simulations for for high orography subregion (above 1000m), for mean (top), maximum (middle) and minimum (bottom) daily values.

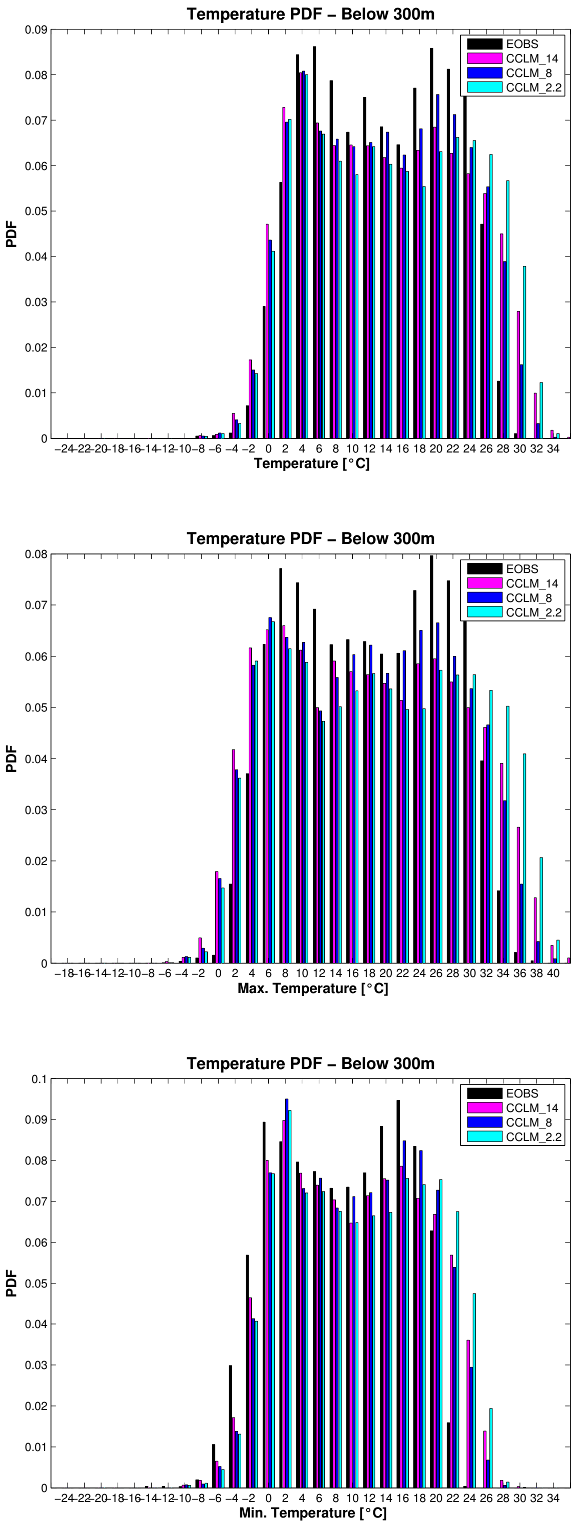

Figure 11:
Temperature probability distribution function of E-OBS observational dataset along with CCLM_2.2, CCLM_8 and CCLM_14 simulations for for low orography subregion (below 300m), for mean (top), maximum (middle) and minimum (bottom) daily values.

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