Research papers

CENTRO EURO-MEDITERRANEO
PER I CAMBIAMENTI CLIMATICI

ISC – Impatti sul Suolo e sulle Coste

Climatic study of precipitation and temperature distribution over the Alps and the Italian Peninsula, using the High-Resolution Regional Climate Model COSMO-CLM

Christina Oikonomou, **Research Associate**
Centro euro-Mediterraneo per i Cambiamenti Climatici, CMCC

Centro Euro-Mediterraneo
per i Cambiamenti Climatici
www.cmcc.it

April 2010 ■ RP88

Summary

This report is concentrated on the High-Resolution Regional Climate Model COSMO-CLM and the climatic and statistical analysis of the model's results concerning the precipitation and temperature on the Alpine area and the Italian Peninsula. The study represents a first attempt aimed to investigate the impact of climate change in these areas. For this purpose, firstly, an observational database for Italy and the Alpine area was created, which was used for the validation and statistical analysis of the COSMO model results.

Then, a climatic analysis was performed for the precipitation and temperature data that derive from two regional climate simulations of the climate of the XX century (control run) using the model *Cosmo-CLM* and employing for the generation of boundary conditions, respectively, ECHAM4 T106 (~ 120km resolution, 12h time resolution) driving data and ERA40 (~ 120km resolution, 6h time res.). The space resolution of both simulations was 14Km (1/8 with respect to the global model) and the time step 150 sec. The study concerned the Alpine area extending from 2° -20° East and 40° - 52° North, for the time period 1971-2000. Furthermore, precipitation and temperature data output that derived from the regional climate simulation of the *Cosmo-CLM* model for the period 2000-2100, were studied. For the future simulation, the IPCC A1B emission scenario was employed. The space resolution of the simulation was 14Km (1/8 with respect to the global model) and the time step 150sec. The ECHAM4 global driving data were used. The model output for both time periods were compared in order to detect any potential future changes in the precipitation and temperature spatial distribution over the Alpine area.

Finally, due to the still occurring misrepresentation of local climate in regional climate model COSMO-CLM, statistical post processing was applied to overcome this problem leading to qualitatively enhanced climate information.

More specifically, in the frame of the activity of the European project TRUST, the statistical bias correction method Quantile Mapping was performed for the local area of Veneto (11.5°-12°E , 45.8°-46.3), in order to compare and analyze the relation of atmospheric parameters from climate model simulations to meteorological observations.

The results of the study are presented analytically in following section.

Keywords: Regional climate model Cosmo-CLM, climate change, Alps, Italy, Bias Correction, Quantile Mapping, precipitation, temperature

JEL Classification:

Address for correspondence:

Oikonomou Christina
PhD on Climatology - Climate Change
National and Kapodistrian University of Athens
Department of Physics
Division of Physics of Environment and Meteorology
Agidos 16, 11631, Athens, Greece

e-mail: chriskater25@windowslive.com

CONTENTS

1. Observational database for Italy and the Alpine area

For this purpose, firstly, an effort for collecting daily and monthly precipitation data for the area of interest was made, in order to create a complete database of observational precipitation and temperature data. This database, which was used for the validation and statistical analysis of the COSMO model results, is presented in the following list:

AVAILABLE DATA LIST

1. **Monthly precipitation and temperature station data for Europe**

Source: http://cdiac.ornl.gov/ftp/ndp041/

(GHCN= The Global Historical Climatology Network: Long-Term Monthly Temperature, Precipitation, Sea Level Pressure, and Station Pressure Data)

Period: it depends on the station. About 20 Italian stations

2. **Daily precipitation and temperature station data (1955 – now) (Italy, but also available for Europe)**

Source: http://eca.knmi.nl/dailydata/index.php
http://www.ncdc.noaa.gov/oa/climate/climatedata.html#daily

ECA (European Climate Assessment)
NCDC (National Climate Data Center)

For 54 Italian stations (figure 1.)

3. **CRU monthly precipitation and temperature (gridded 0.5° x 0.5°, global, 1901-2000, format= .cdf files)**

Source: http://users.ictp.it/RegCNET/postproc.html
http://www.cru.uea.ac.uk/cru/data/

4. **CRU Monthly gridded temperature data Alpine area (5° x 5°, 1961-1990)**

Source: http://www.cru.uea.ac.uk/cru/data/temperature/

5. **Monthly precipitation gridded for Alpine area (1971-1990, resolution 25km)**

Source: http://www.map.meteoswiss.ch/map-doc/rr_clim.htm#Versions

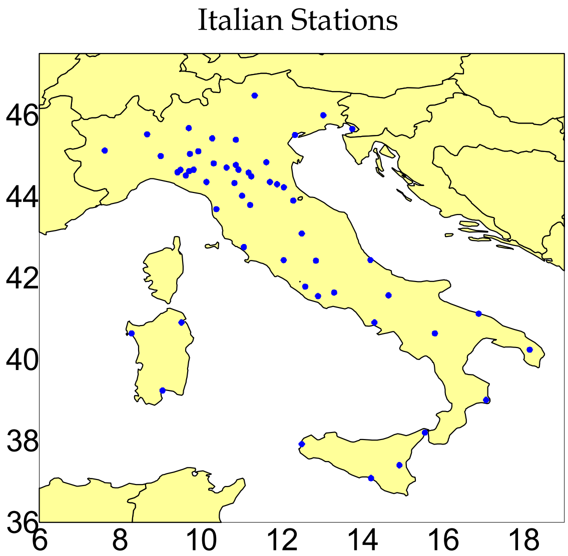


Figure1. *Available stations with precipitation and temperature data for the period 1955-2009*

2. Statistical and climatic analysis of regional climate model COSMO results over Italy and Alpine area, contributing to the project AdaptAlp (Adaptation to Climate Change in the Alpine Space) *(AdaptAlp, WP4 (work package: Water Regime), Activity 2:Improved regional climate model data set for the Alpine space)*

For the first part of the activity 2 of the project AdaptAlp (Sub-activity 2.1) a climatic analysis was performed for the precipitation and temperature data that derive from two regional climate simulations of the climate of the XX century (control run) using the model *Cosmo-CLM* and employing, correspondingly, ECHAM4 T106 (~ 120km resolution, 12h time resolution) driving data and ERA40 (~ 120km resolution, 6h time res.). The space resolution of both simulations was 14Km (1/8 with respect to the global model) and the time step 150sec. The study concerned the Alpine area extending from 2° -20° East and 40° - 52° North, for the time period 1971-2000 (Figure 2).

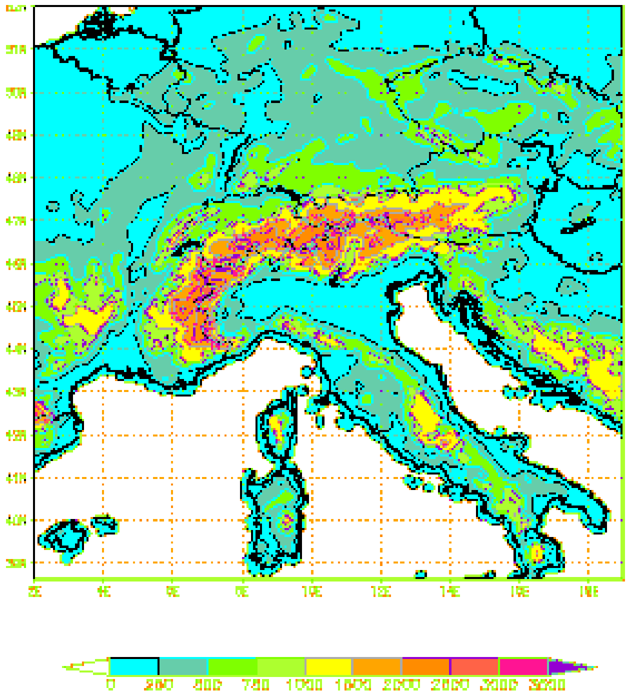


Figure 2. *Orography of the area of interest (2° -20° E , 40° - 52°N). The altitude is given in meters (m).*

Firstly, comparing the mean seasonal 2m temperature results of the two simulations for the period 1971-2000 over the Alpine area, it was found that in general, all seasons, temperature bias are largest over the northern part of the area. In all seasons, mean temperature values resulting from the simulation with driving data ECHAM4 are greater than those resulting from the simulation using the ERA40 driving data, in almost all the examined area, except from small parts of southern marine areas. Moreover, in all seasons, Croatia-Bosnia shows the largest temperature bias, compared to other areas. Spatial distribution of winter mean temperature bias shows large spatial variability compared to the distributions of the other seasons, which are more uniform. This is maybe due to the fact that during winter the circulation is more intense and quickly changes from place to place. The pre-mentioned results can be seen in the following Figure 3.

On monthly scale, the average 2m temperature values for the period 1971-2000, over Alpine area, demonstrates that in all the months, the simulation driven by ECHAM4 data produces higher temperature values than the simulation driven by ERA40 (Figure 4).

Then, the mean seasonal precipitation (mm/day) for the same period deriving from the simulation with driving data ECHAM4 was compared with the precipitation results coming from the simulation using the ERA40 driving data. It was found that in general, during all seasons, a great part of the Alpine area presents the largest precipitation bias of ECHAM4 and ERA40 runs, implying the great effect of orography in model precipitation results. In the Alpine area, during winter and autumn, precipitation values resulting from ECHAM4 run are greater than those resulting from ERA40 run. Oppositely, in summer and spring, precipitation values from ECHAM4 are smaller than those from ERA40. In the Mediterranean Sea areas, precipitation values from ECHAM4 run are smaller than the corresponding from ERA40 run, for all seasons. The previous results are shown at the following Figure 5.

On monthly scale, the average precipitation (mm/day) for the period 1971-2000 over the same area, presents an underestimation of summer precipitation by ECHAM4 run output in relation with ERA40 run outputs, and an minor overestimation of precipitation for the rest months.

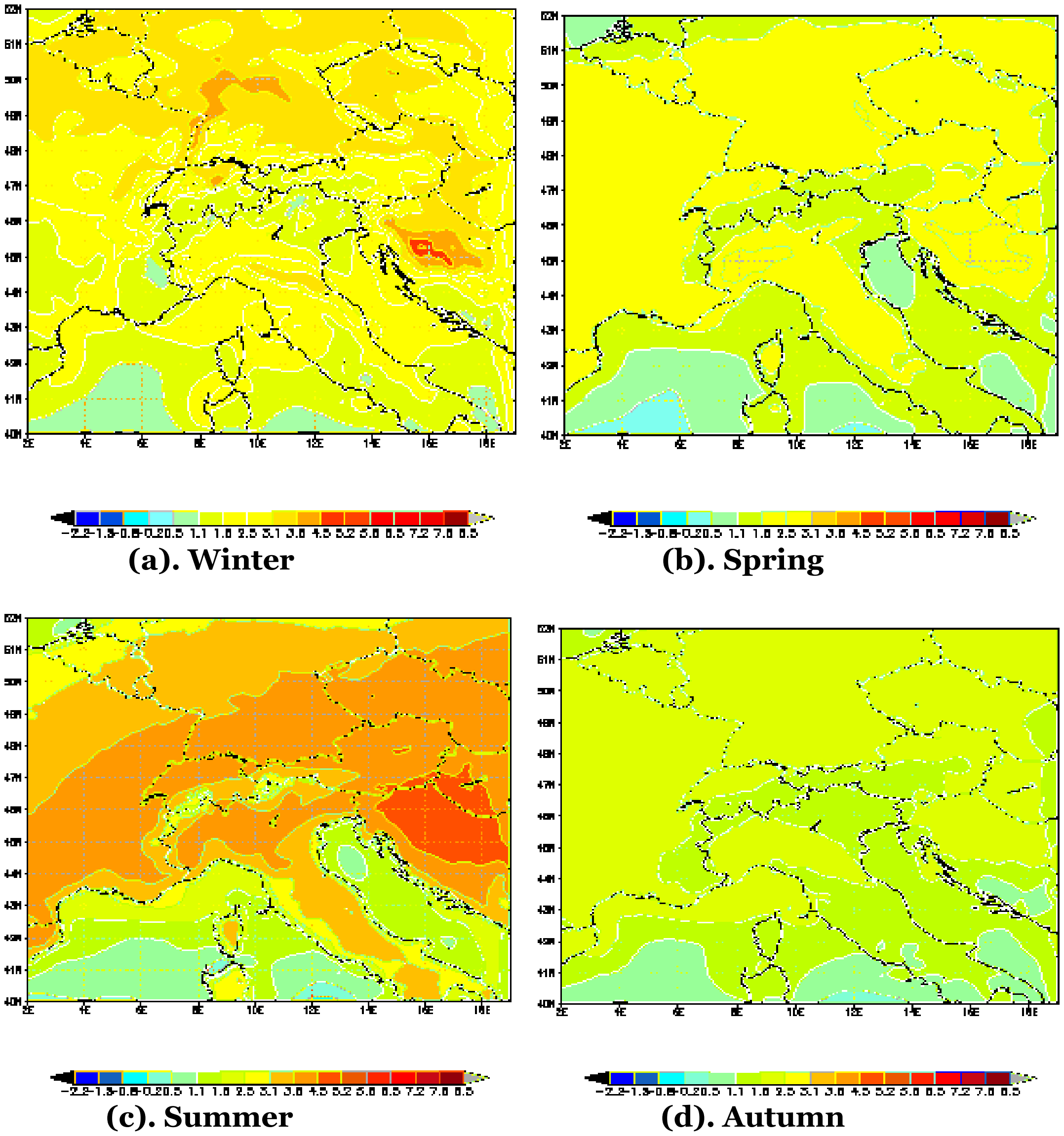


Figure3. *Mean 2m temperature bias (ECHAM4run – ERA40run) for the period 1971-2000 over the Alpine area.*

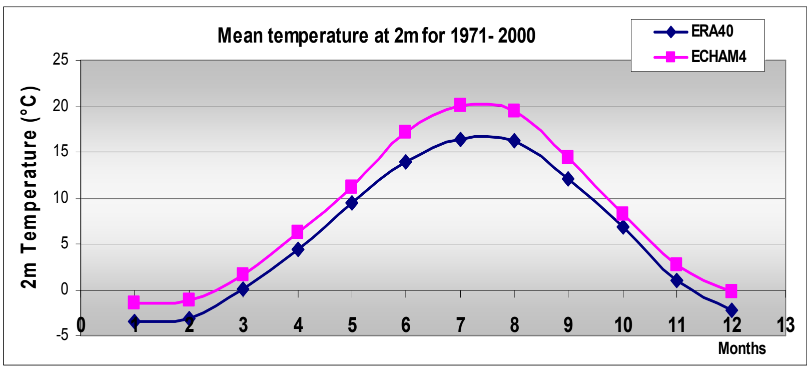
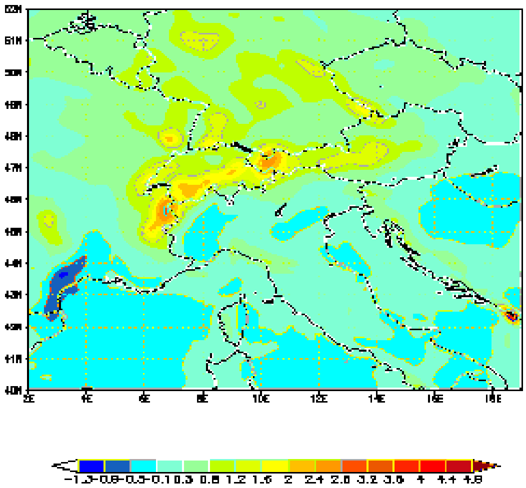
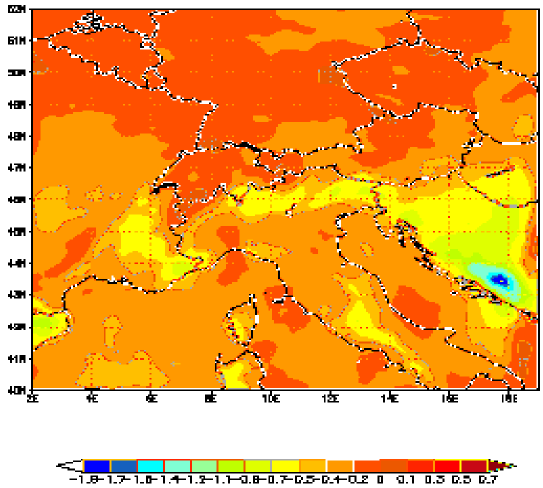


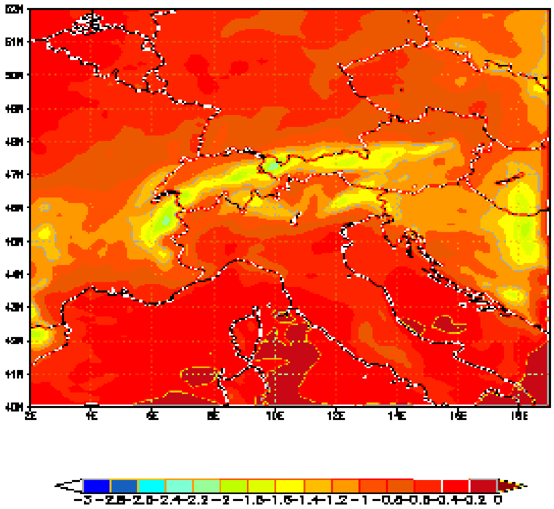
Figure 4. *Averaged monthly 2m temperature for the period 1971-2000, over the Alpine area (6-14 E ,44-48 N)*, *a) simulation with ERA40 driving data (blue line) b) simulation with ECHAM4 driving data (pink line).*



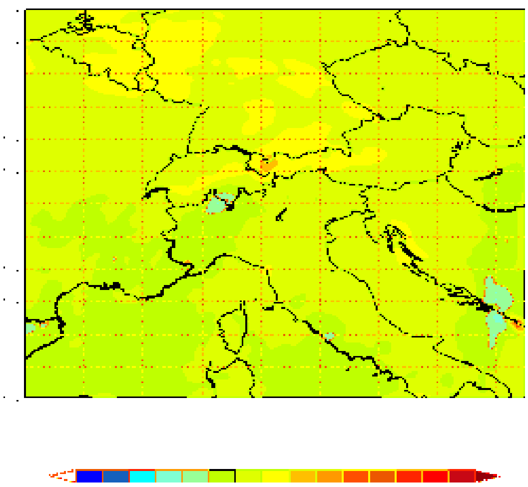
(a). Winter



(b). Spring



(c). Summer



(d). Autumn

Figure5. *Mean precipitation bias (ECHAM4run – ERA40run) for the period 1971-2000 over the Alpine area.*

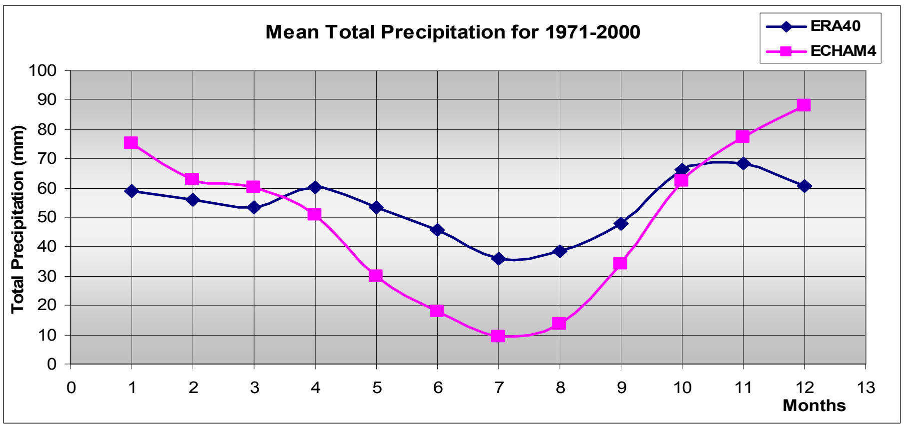


Figure 6. *Averaged monthly precipitation for the period 1971-2000, over the Alpine area (6-14 E ,44-48 N), a) simulation with ERA40 driving data (blue line) b) simulation with ECHAM4 driving data (pink line).*

For the second part of the activity 2 of the project AdaptAlp (Sub-activity 2.2) a climatic analysis was performed for the precipitation and temperature data that derived from the regional climate simulation of the *Cosmo-CLM* model for the period 2000-2100. For the future simulation, the IPCC A1B emission scenario was employed. The space resolution of the simulation was 14Km (1/8 with respect to the global model) and the time step 150sec. The ECHAM4 global driving data were used. The study concerned the Alpine area extending from 2° -20° East and 40° - 52° North, for two time periods 1901-2000 and 2001-2100 (Figure 2). The model output for both time periods where compared in order to detect any potential future changes in the precipitation and temperature spatial distribution over the Alpine area.

Firstly, the model data were validated by using the gridded observational CRU data (5°x5°) for the period 1961-1990. As it can be seen from Figure 7, the averaged monthly temperature for the period 1961-1990, is underestimated by the model for all months except from the summer months, June, July, August, where there is a very good approximation of temperature by the model.

Concerning the validation of precipitation model data, the monthly gridded observational data of precipitation for Alpine area with the resolution of 25Km for the period 1971-1990 were employed. As it can be seen from Figure 8., the model underestimates monthly precipitation for the summer months May, June, July and August, and overestimates precipitation for the winter period October to March. For April and September there is a very good agreement between model and observational precipitation.

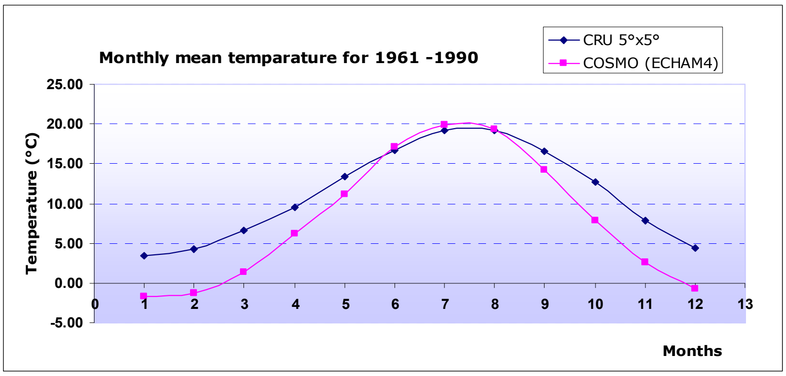


Figure 7. *Averaged monthly 2m temperature for the period 1961-1990, over the Alpine area a) simulation with ECHAM4 driving data (pink line), b) CRU gridded temperature data*

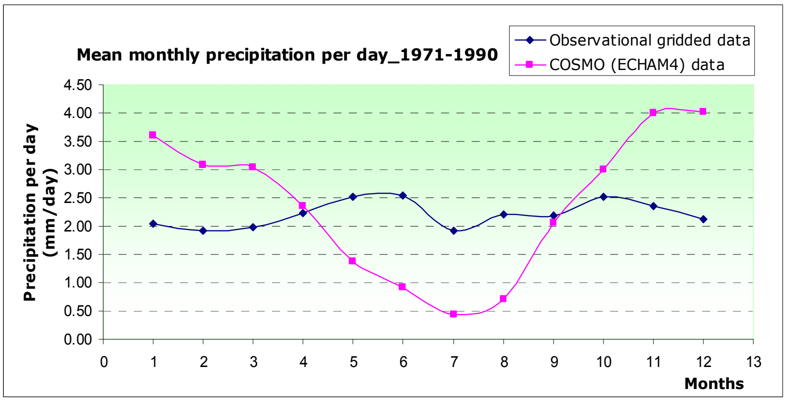
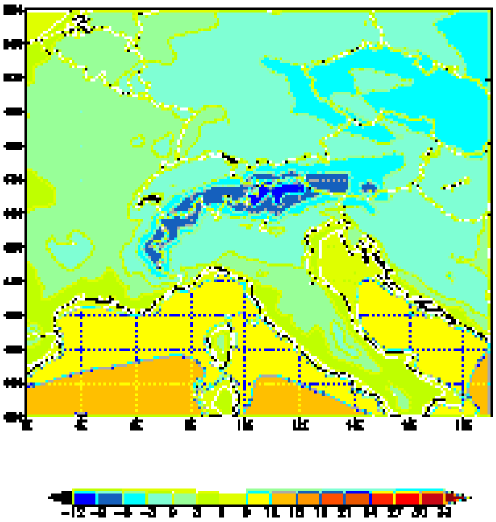


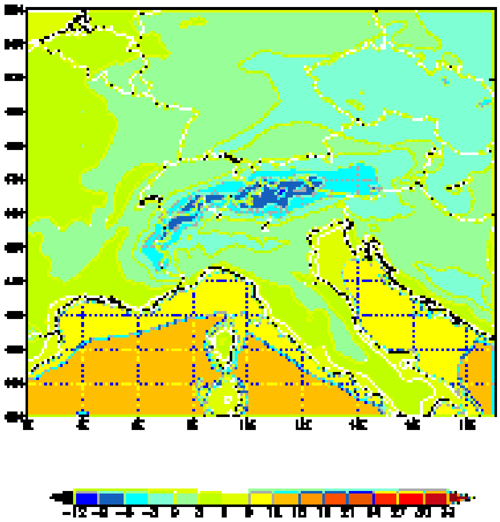
Figure 8. *Averaged monthly precipitation for the period 1971-1990, over the Alpine area a) simulation with ECHAM4 driving data (pink line), b) Observational gridded data (resolution 25Km)*

The comparison of model temperature data between the XX and the XXI (A1B) centuries, on a seasonal basis, demonstrates that both in winter and autumn, mean temperature values increase in the XXI century, as compared to the past XX century values, not only at the Alpine area but at all the examined area. Similarly, to winter and autumn, mean temperature values increase in XXI century, both in summer and spring, in all examined area as well.

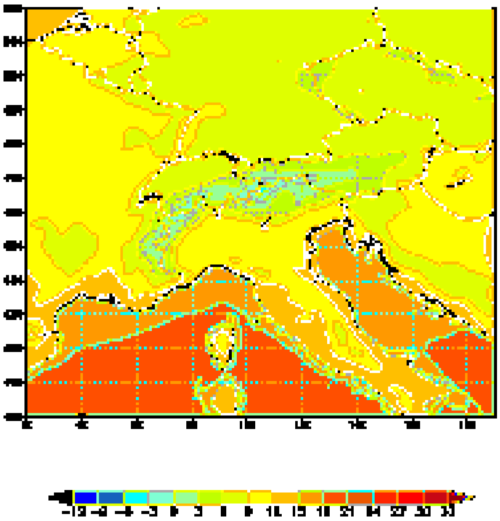
On monthly scale, the mean monthly 2m temperature for the future period is increased as compared to the corresponding temperature of the past period for all months (Figure 10).



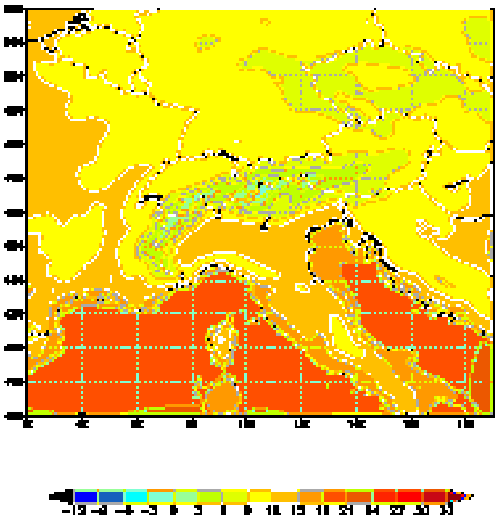
(a1). Winter_XX century



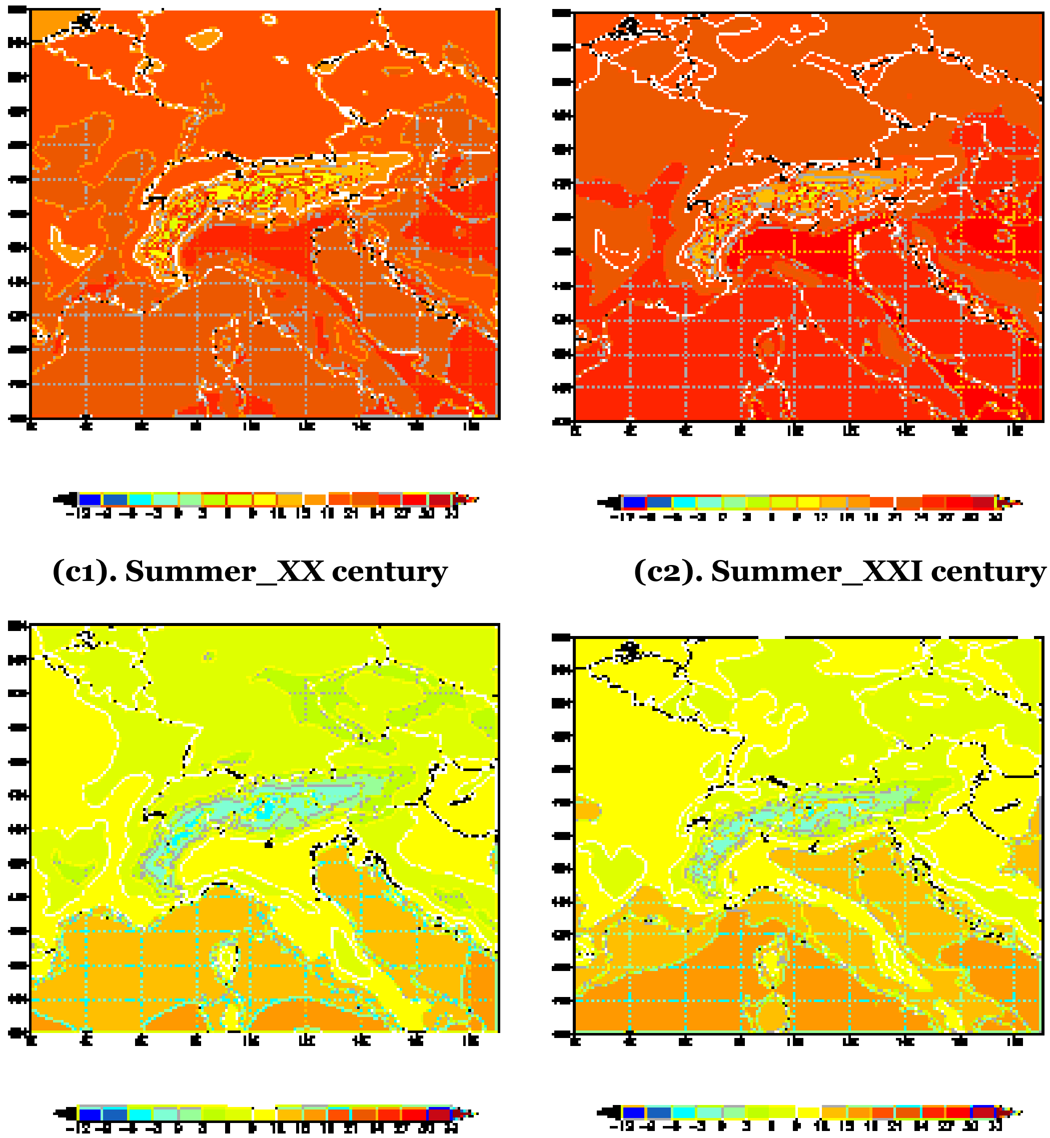
(a2). Winter_XXI century



(b1). Autumn_XX century



(b2). Autumn_XXI century



(c1). Summer_XX century **(c2). Summer_XXI century**

(d1). Spring_XX century **(d2). Spring_XXI century**

Figure 9. *Mean seasonal 2m temperature (°C) for XX and XXI centuries over the Alpine area*

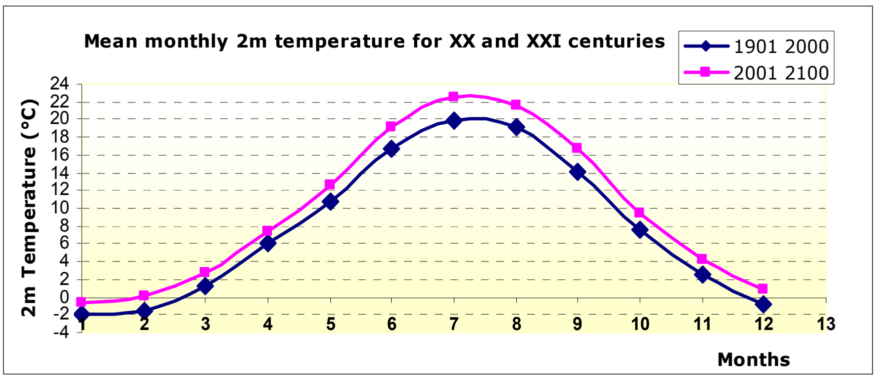
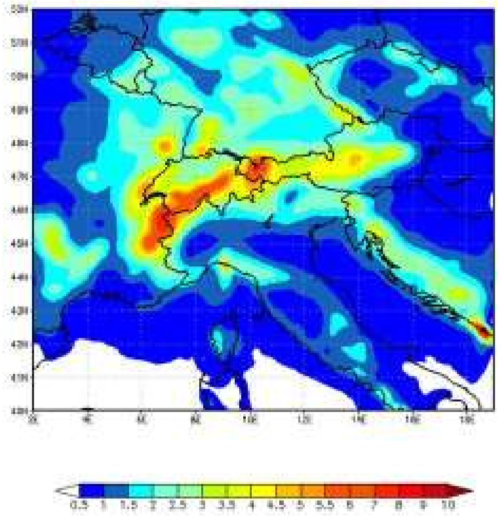
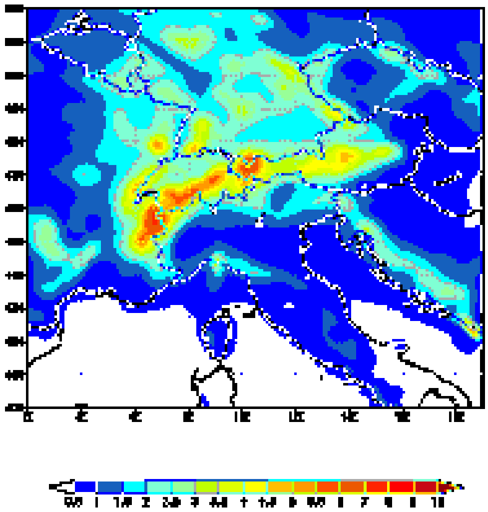


Figure 10. *Mean monthly 2m temperature for XX and XXI centuries over the Alpine area*

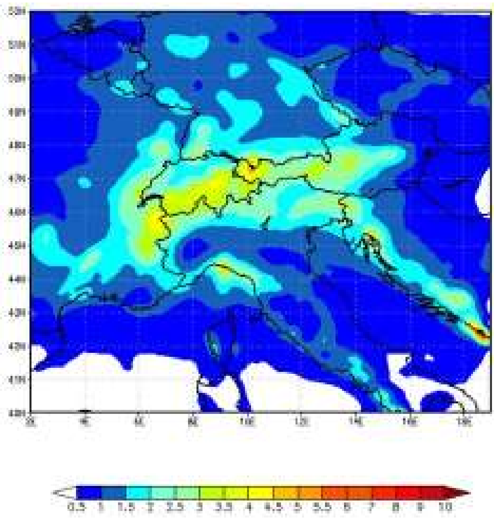
Concerning precipitation results, the comparison of model precipitation data between the XX and the XXI (A1B) centuries, on a seasonal basis, has shown that during winter, there is a slight decrease of precipitation over the Mediterranean Sea and central-south Italy in the XXI century. In autumn, the future decrease of precipitation is more obvious comparing to winter spatial precipitation distribution. Moreover, in the same period, the precipitation over the extended Alpine area is reduced in the XXI century. Opposite to winter, in the Mediterranean Sea precipitation do not seem to decrease significantly in the XXI century in autumn. In summer, precipitation is obviously decreased over the Alpine area in the XXI century. In spring, there is a slight decrease of precipitation in the XXI century, over the extended Alpine area and Italy. All previous results, are presented at the following Figure 11.



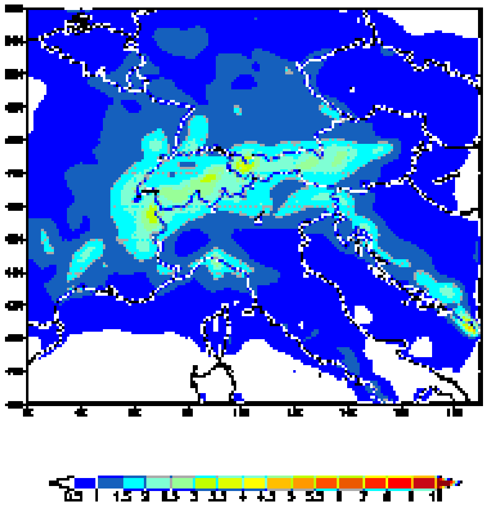
(a1). Winter_XX century



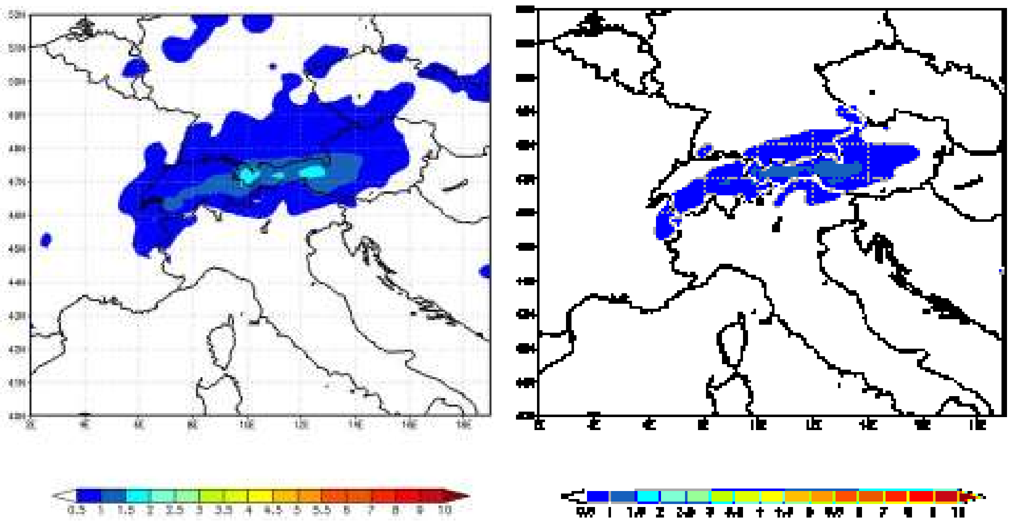
(a2). Winter_XXI century



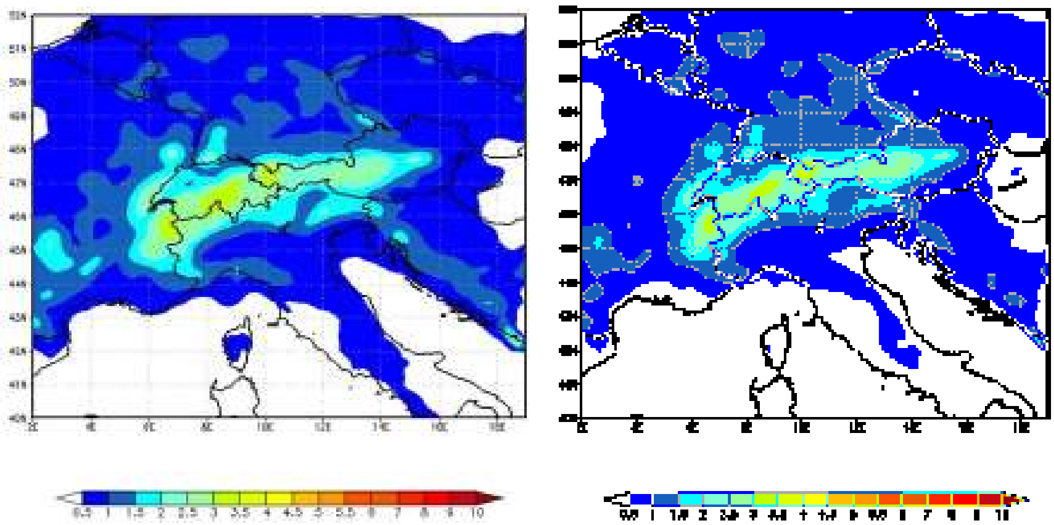
(b1). Autumn_XX century



(b2). Autumn_XXI century



(c1). Summer_XX century **(c2). Summer_XXI century**



(d1). Spring_XX century **(d2). Spring_XXI century**

Figure 11. *Mean seasonal precipitation (mm/day) for XX and XXI centuries over the Alpine area*

3. Performance of the statistical bias correction method named Quantile Mapping, for the area of Veneto (11.5°-12°E , 45.8°-46.3), contributing to the European project TRUST *(Tool for regional scale assessment of groundwater storage improvement in adaptation to climate change)*

Due to the still occurring misrepresentation of local climate in regional climate model COSMO-CLM, statistical postprocessing is applied to overcome this problem leading to qualitatively enhanced climate information. Bias correction methods compare and analyze the relation of atmospheric parameters from climate model simulations to meteorological observations. There are several error correction methods such as multiple linear regression (MLR) (Huth, 1999), local scaling (LS) (Schmidli et al., 2006) and quantile mapping (QM) (Wood et al., 2004; Dettinger et al., 2004).

The simplest kind of bias correction corrects for a systematic discrepancy in the mean by "rescaling" the mean of the simulations to match the observations. Similarly, a discrepancy between the variance of the simulations and the observations can be corrected by assuming a probability distribution (such as the normal distribution) and mapping normalized anomalies (i.e. standard deviations from the mean) between the simulated and observed populations. In many cases, however, the true form of the probability distributions of the simulated and observed data is not known with any certainty and the two probability distributions are not necessarily of the same form or statistically well behaved. In these cases a "quantile based" bias correction scheme can be used to "translate" between the simulated and observed populations (Wood et al., 2002). This technique is called **Quantile Mapping**, and it is believed to be more efficient than the other methods because it systematically removes the median differences to zero and adopts the RCM variance characteristics to equal the observed one. For this reason, this method is applied for the bias correction of precipitation data for the the specific area of Veneto and Friuli Venezia Giulia, extending from 11.5E to 12E and from 45.8N to 46.3N (defined as TRUST area).

More specifically, the Quantile mapping bias correction method was applied so as to correct the daily and monthly precipitation model data of, the TRUST area both for present (2001-2008) and for the future (2009-2030). The model precipitation data derive from the application of the regional climate model COSMO-CLM with the spatial resolution of 8 km.

The Quantile mapping was performed with the aid of the freely available CumFreq program, for the periods 2001-2008 and 2009-2030, both on daily and monthly basis. It should be noted here that if a group of simulated values has a particular "signal" contained within it, the translation process will tend to reproduce in the output the signal present in the input. An extremely wet hydrologic simulation, for example, will always map to an extremely wet observed value. As long as the fundamental physical processes that define the quantile map for the simulations are not significantly altered over time and the simulations capture the essential signals accounting for variability, the bias correction scheme should produce a reasonably not changed "image" of the raw simulated data in the observed space (Hamlet et al, 1999).

Furthermore, concerning the precipitation data of the **future** period (2009-2030), they were transformed and corrected using the same cumulative frequency equation that was used for the bias correction of the precipitation data of the past period 2001-2008, under the following assumptions:

(a) that, even under differing climate conditions, the combination of simulated weather conditions that yielded a particular daily temperature or precipitation value in the simulated training period, if encountered at another time, will yield – in the real world – a similar value,

(b) that, even in a climate changed world, almost all daily values will be within the range of values encountered in the 21-year training period. The range of values will be (mostly) the same, with only the **frequency** with which, say, warmer values occur changing along with the occurrence of a relatively few much-warmer-than-ever before values,

(c) the statistical relations used in many, more elaborate statistical-downscaling procedures can be transferred beyond their historical training periods (or even from one model to another) (Dettinger et al, 2004, Wilby et al, 1998) and

(d) that regional climate-dynamics models calibrated in one period will necessarily be transferable to other, different climate forcing. The present approximation is assumed to be adequate for the analyses of long-term river responses to climate changes presented here (Dettinger et al, 2004, Wilby et al, 1998)

Firstly, the Quantile mapping was applied at the averaged time series of precipitation that derived from the 24 station time series and the averaged time series that came from the time series of the model grid points included in the area of interest (11.5E-12E, 45.8N-46.3N). The method was performed for the period 2001-2008 and the period 2009-2030, both for averaged daily and monthly precipitation values over the considered area.

For the past period 2001-2008, as it can be seen from figure 1(a,b,c), in general, the mean precipitation value per day for each month is closer to the corresponding observed value, indicating that the quantile mapping can perform well for correcting the model simulated precipitation values for this area. This result is more obvious at figure2 (a,b,c), where the absolute difference between the station and the model corrected precipitation value is always smaller than the corresponding difference between the station value and the initial model precipitation value, in general most of the months of the same period. Similarly, daily precipitation values that were simulated by the model, are satisfyingly improved, as it can be seen at figures 3a, 3b and 4a, 4b, and can approximate quite well the observational values in most cases.

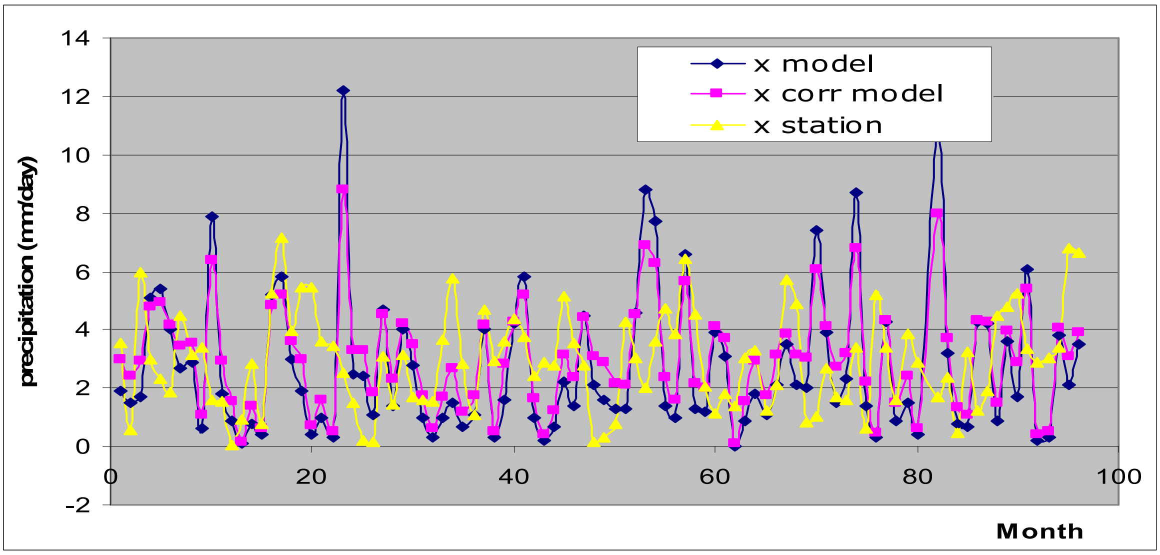


Figure1a. *Mean Precipitation (mm/day) for each month of the period 2001-2008, a) for observational data, b) for model data, and c) for model corrected data, over the TRUST area.*

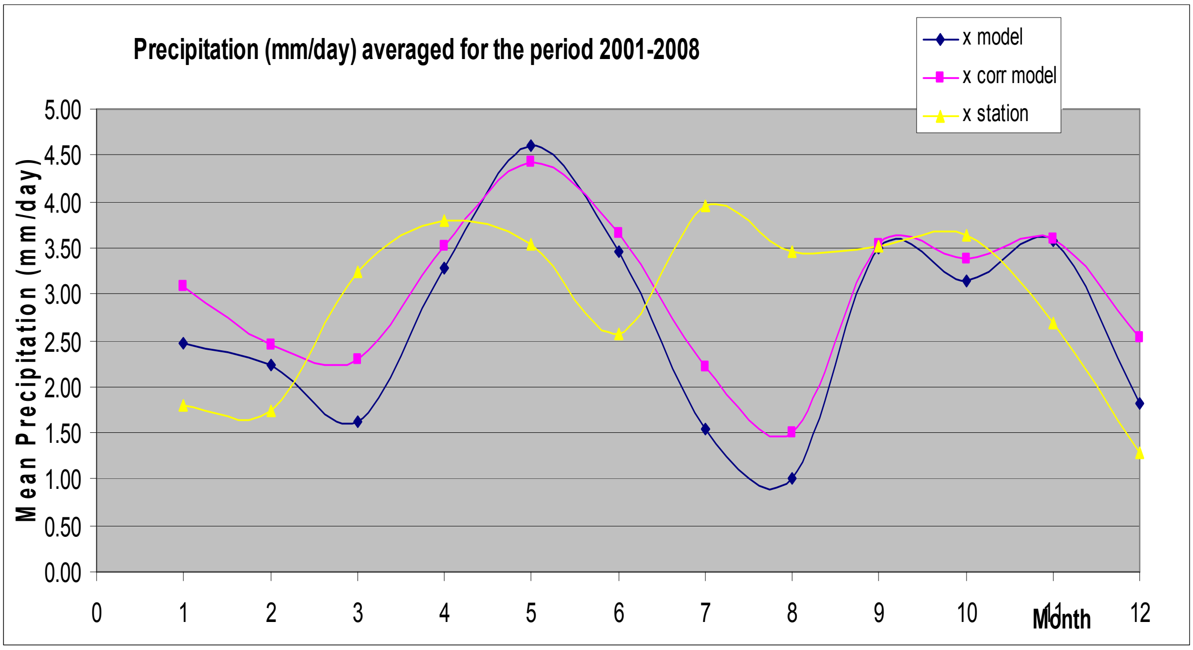


Figure1b. *Monthly averaged precipitation (mm/day) for the period 2001-2008, a) for observational data, b) for model data, and c) for model corrected data, for the TRUST area.*

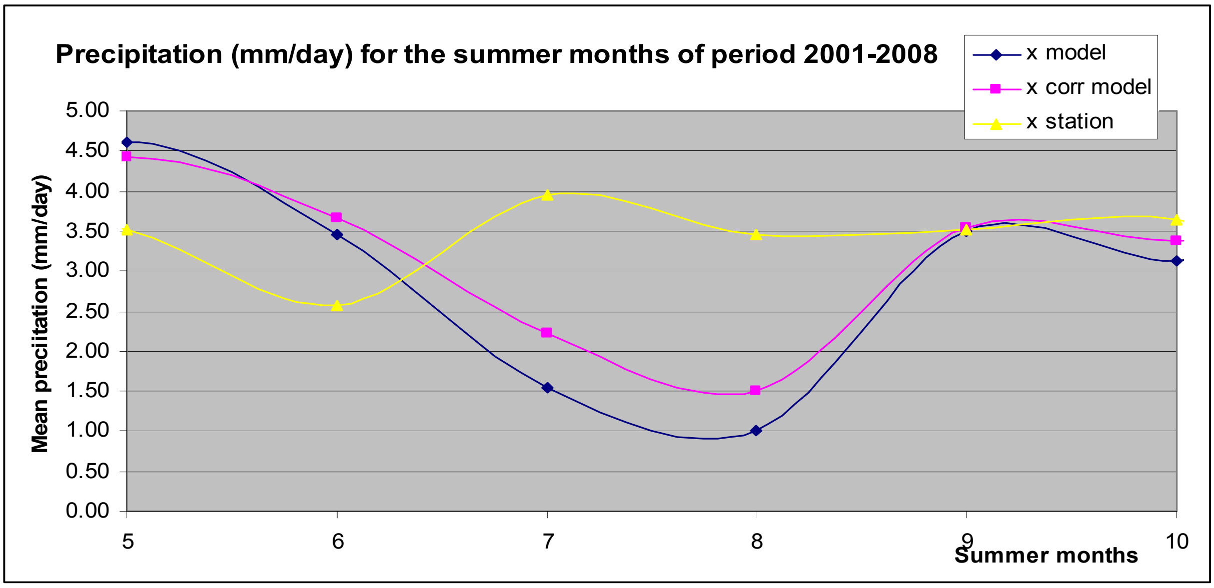


Figure1c. *Monthly averaged precipitation (mm/day) for the summer months (June to September) of the period 2001-2008, a) for observational data, b) for model data, and c) for model corrected data, for the TRUST area.*

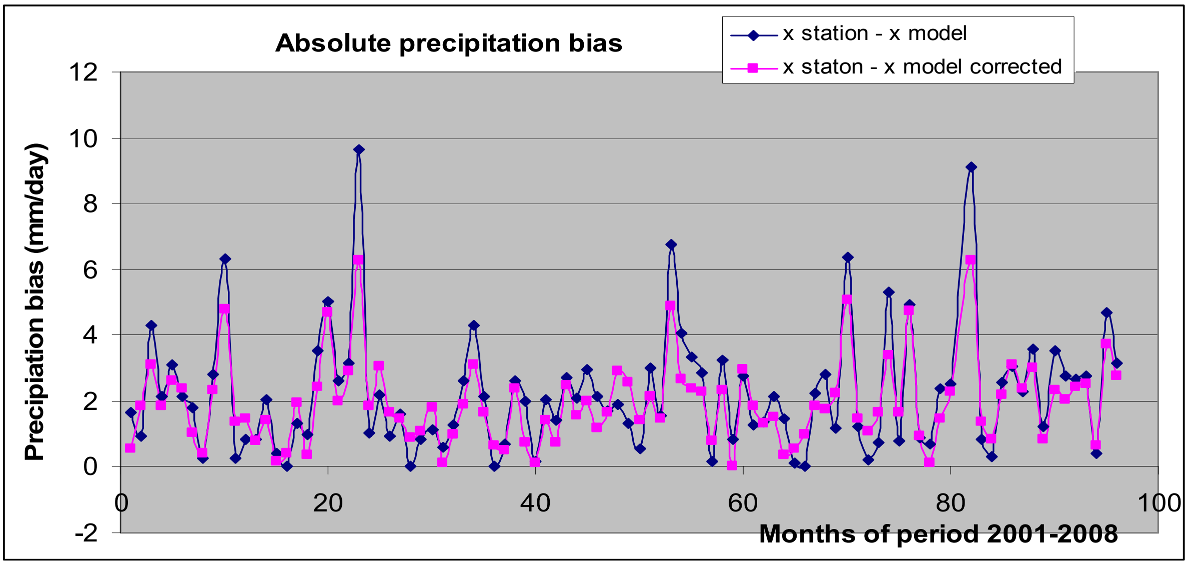


Figure2a. *Absolute bias of monthly averaged precipitation (mm/day) for the period 2001-2008, a) (Station value – model value) blue colored line and b) (Station value – model corrected value) pink colored line, for the TRUST area.*

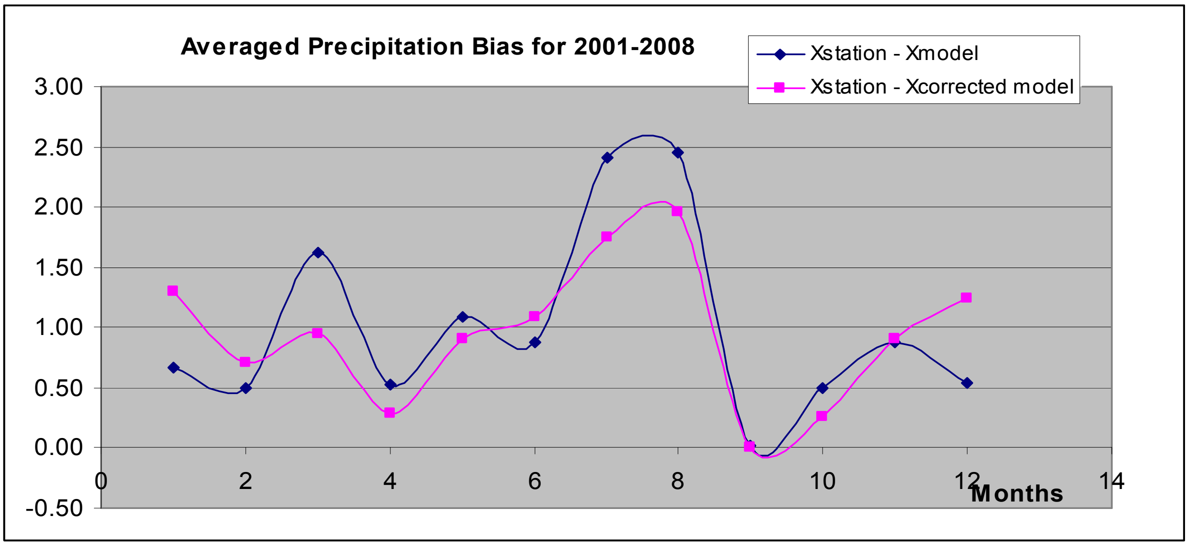


Figure2b. *Absolute bias of monthly averaged precipitation (mm/day) for the period 2001-2008, a) (Station value – model value) blue colored line and b) (Station value – model corrected value) pink colored line, for the TRUST area.*

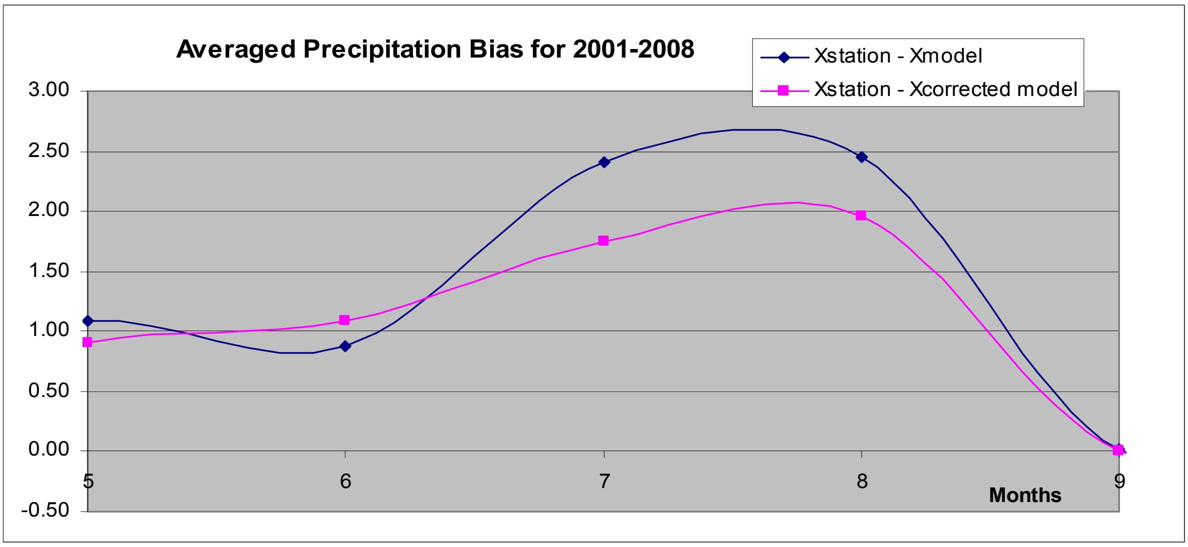


Figure2c. *Absolute bias of monthly averaged precipitation (mm/day) for the summer months (June to September) of the period 2001-2008, a) (Station value – model value) blue colored line and b) (Station value – model corrected value) pink colored line, for the TRUST area.*

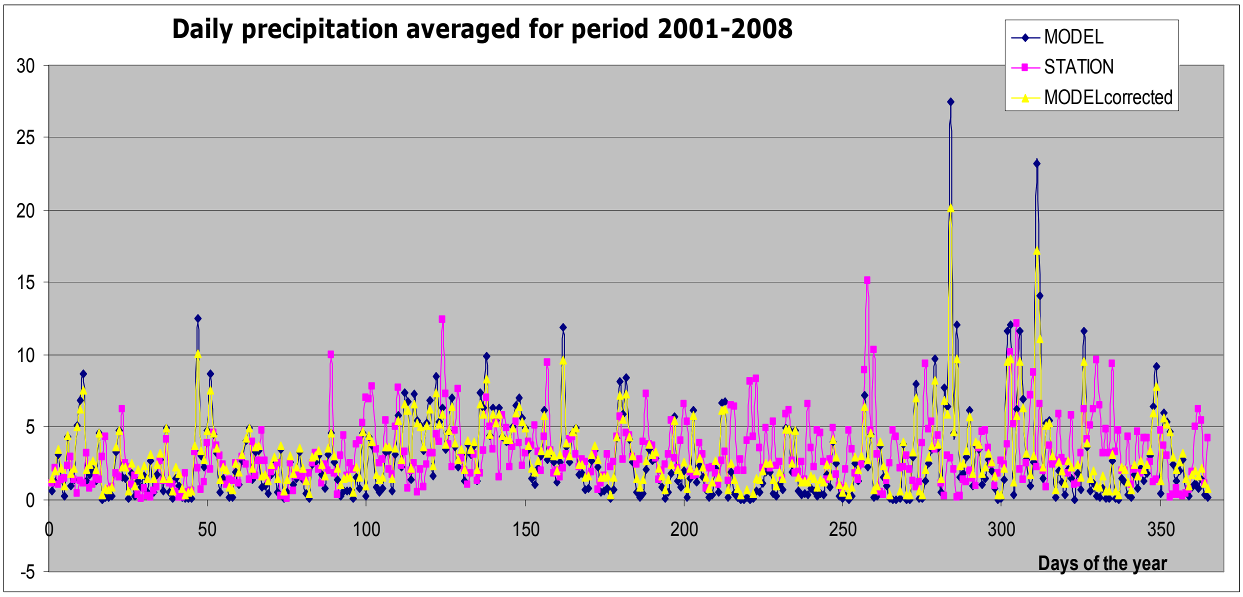


Figure3a. *Daily averaged precipitation (mm/day) for the period 2001-2008, a) for observational data, b) for model data, and c) for model corrected data, for the TRUST area.*

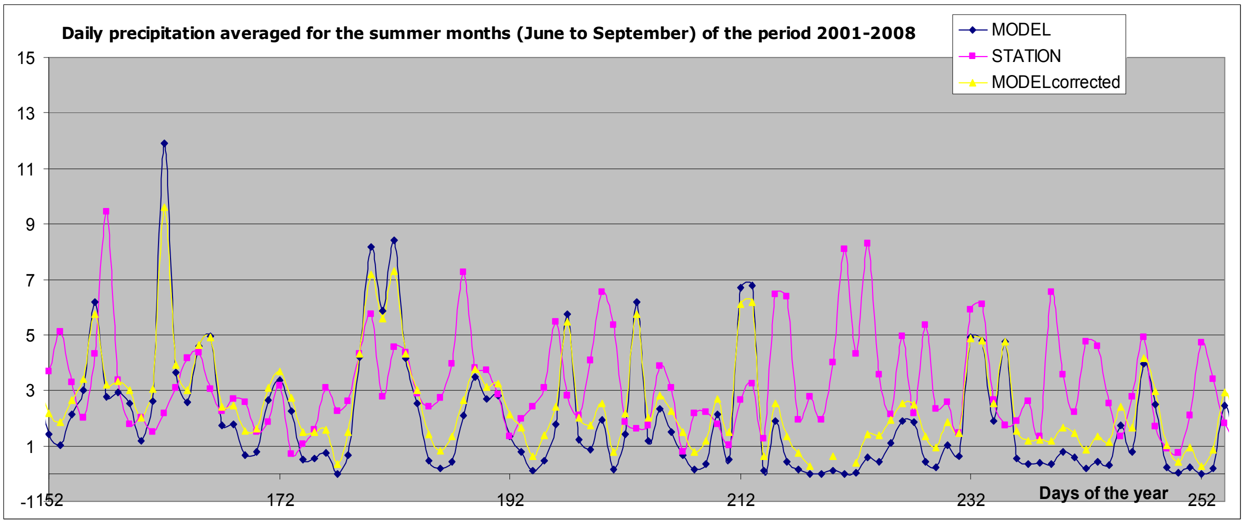


Figure3b. *Daily averaged precipitation (mm/day) for the summer months (June to September) of the period 2001-2008, a) for observational data, b) for model data, and c) for model corrected data, for the TRUST area.*

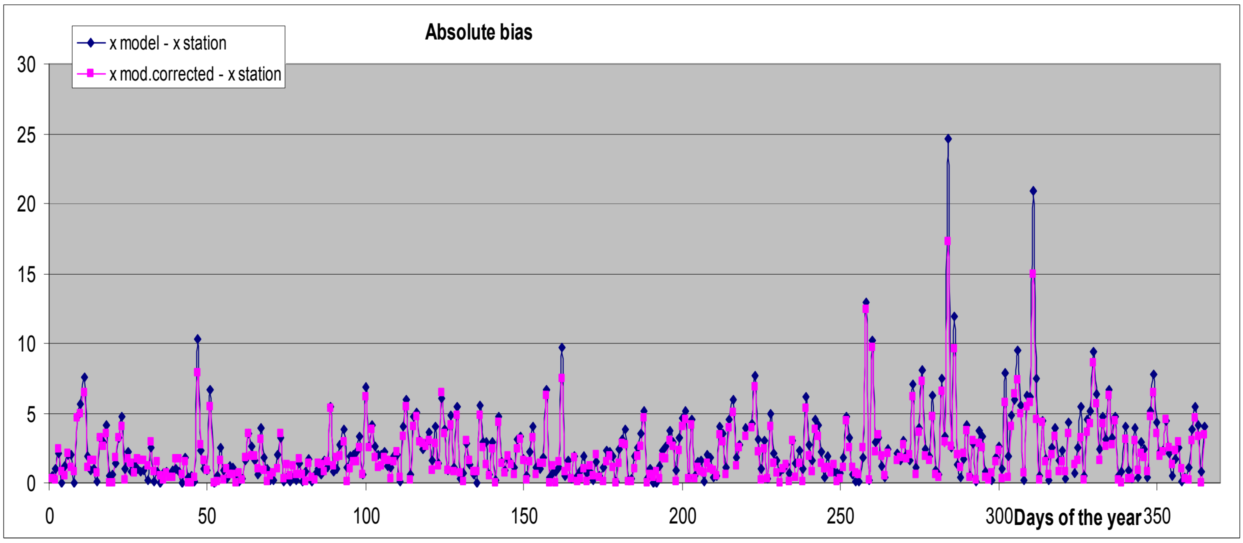


Figure4a. *Absolute bias of daily precipitation (mm/day) averaged for the period 2001-2008, a) (Station value – model value) blue colored line and b) (Station value – model corrected value) pink colored line, for the TRUST area.*

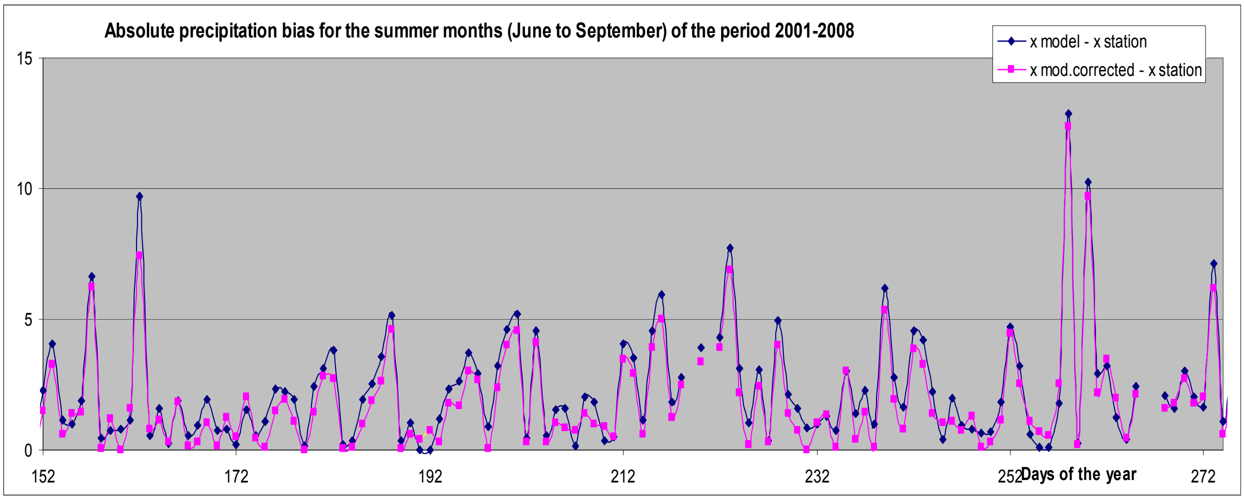


Figure4b. *Absolute bias of daily precipitation (mm/day) averaged for the summer months (June to September) of the period 2001-2008, a) (Station value – model value) blue colored line and b) (Station value – model corrected value) pink colored line, for the TRUST area.*

Since, it was found that summer precipitation is greatly underestimated by the model, the bias correction method was applied specifically for the summer months (June, July, August, September) for the period 2001-2008. As it be seen at figure 5, the corrected model precipitation values are closer to the station values for the most of the summer months of the period 2001-2008, and they are no more underestimated. Additionally, in most of the summer months, the absolute difference between the corrected model value and the observational value are smaller than the bias of the initial simulated precipitation value from the corresponding observational value (figure 6). On daily scale, it can be seen that the rate of underestimation of daily summer precipitation by the model is reduced using the bias correction quantile mapping method, but still remains in most of the months (figure 7). However, the absolute bias of the corrected model daily values from the observational values are smaller than the corresponding bias of the initial model values from the station values in the greatest number of summer months of the period 2001-2008.

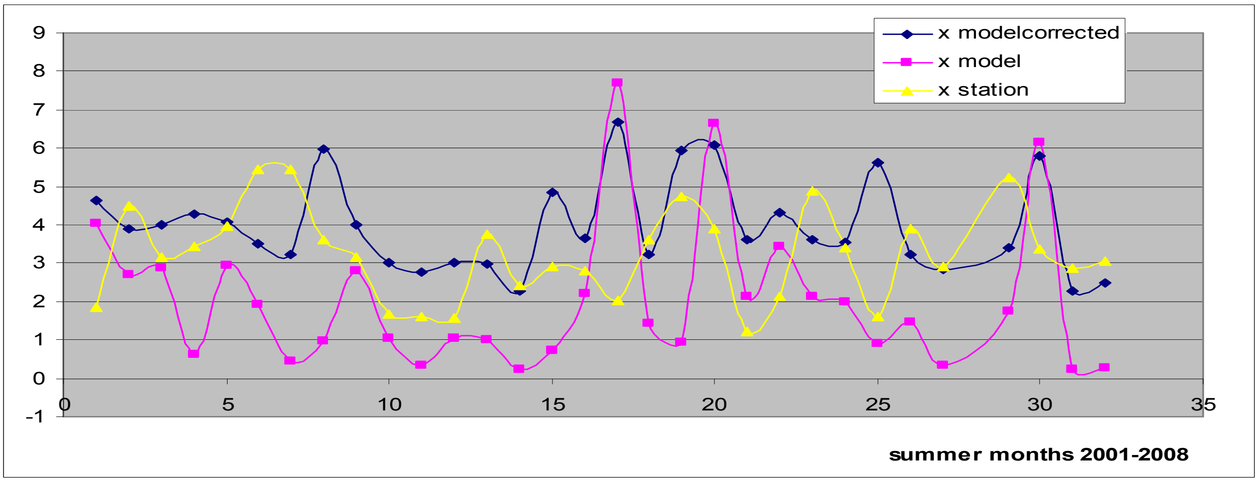


Figure5. *Summer monthly averaged precipitation (mm/day) for the period 2001-2008, a) for observational data, b) for model data, and c) for model corrected data, for the TRUST area.*

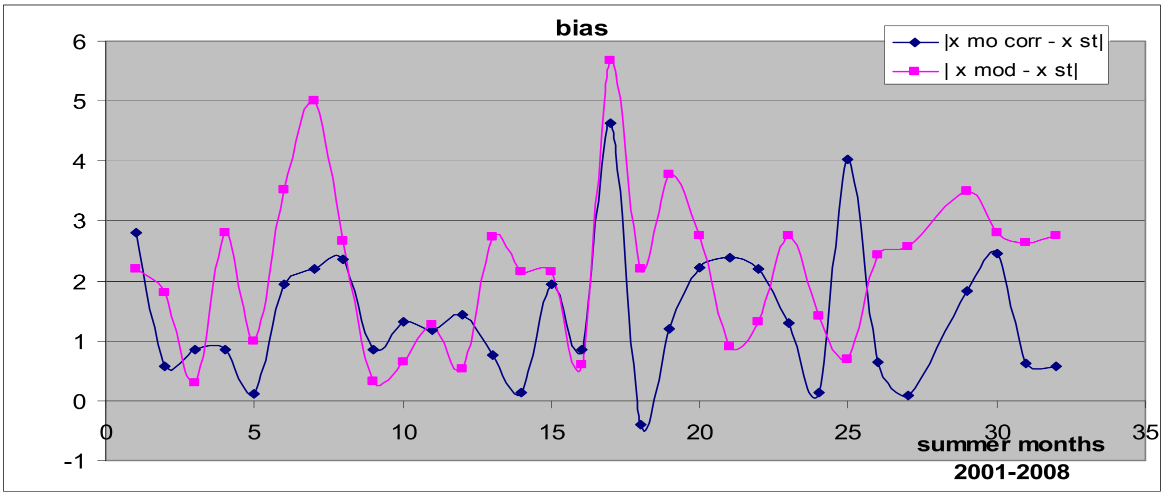


Figure 6. *Absolute bias of summer monthly averaged precipitation (mm/day) for the period 2001-2008, a) (Station value – model value) pink colored line and b) (Station value – model corrected value) blue colored line, for the TRUST area.*

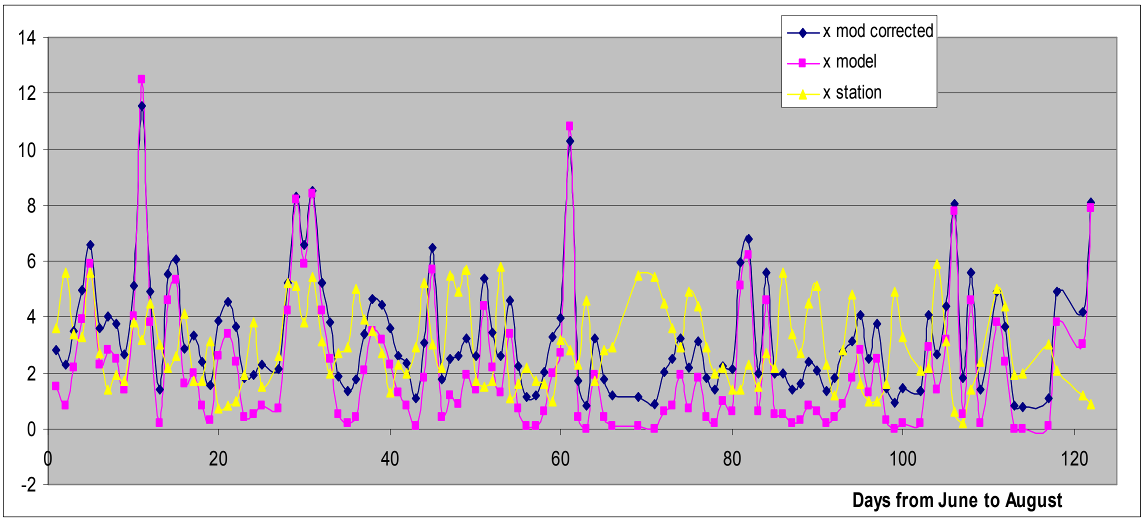


Figure7. *Summer daily averaged precipitation (mm/day) for the period 2001-2008, a) for observational data, b) for model data, and c) for model corrected data, for the TRUST area.*

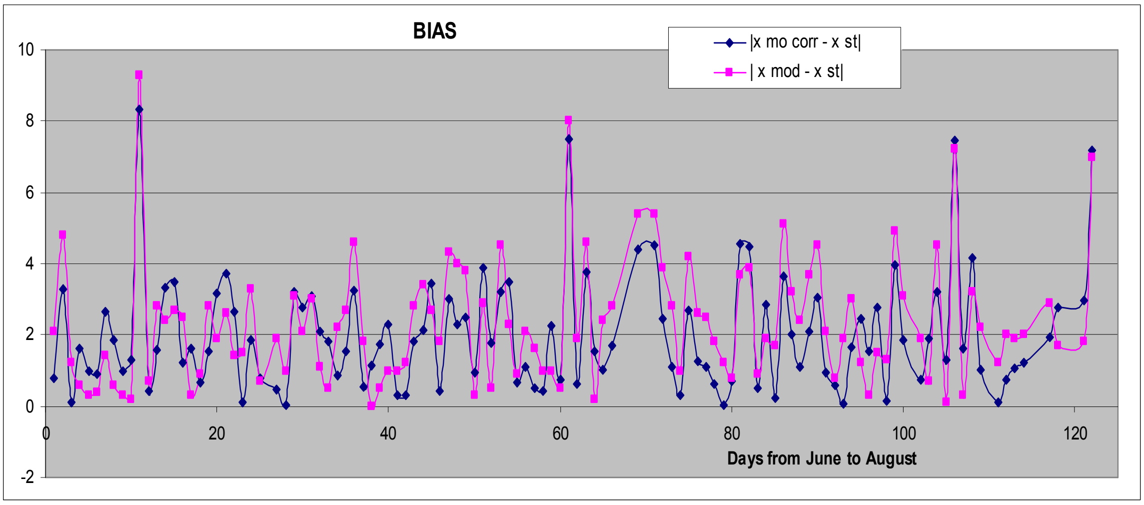


Figure 8. *Absolute bias of summer daily averaged precipitation (mm/day) for the period 2001-2008, a) (Station value – model value) pink colored line and b) (Station value – model corrected value) blue colored line, for the TRUST area.*

Concerning the bias correction of the precipitation data of the period 2009-2030, as it is stated previously, it is possible to use the same cumulative frequency equations that are found to fit well at the precipitation data of the past period 2001-2008. In general, as it is demonstrated in figure 9, the corrected mean precipitation values (mm/day) for each month of the period 2009-2030, are a little greater than the initial simulated model values. Similarly, the averaged monthly values for each month of the year, for the period 2009-2030, are greater than the initial simulated values (figure 10a, 10b). In general, it can be concluded that quantile mapping is an effective bias correction method that can be used for the correction both of present and of future simulated precipitation values deriving from the regional climate model COSMO-CLM over the specific area.

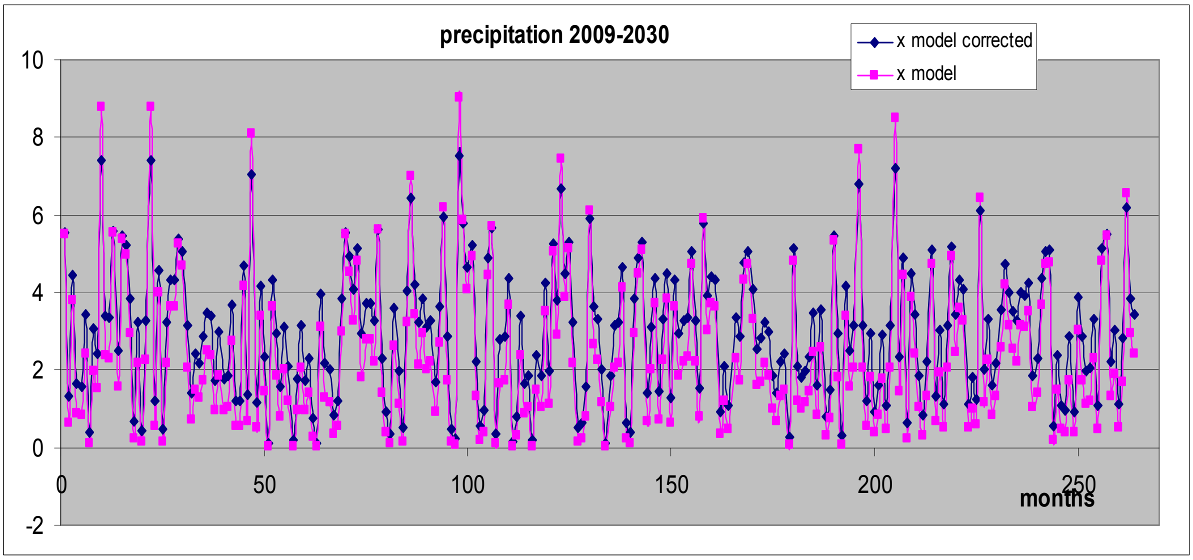


Figure 9. *Mean precipitation (mm/day) for the months of the period 2009-2030, a) for the simulated model data, and b) for the model corrected data, over the TRUST area.*

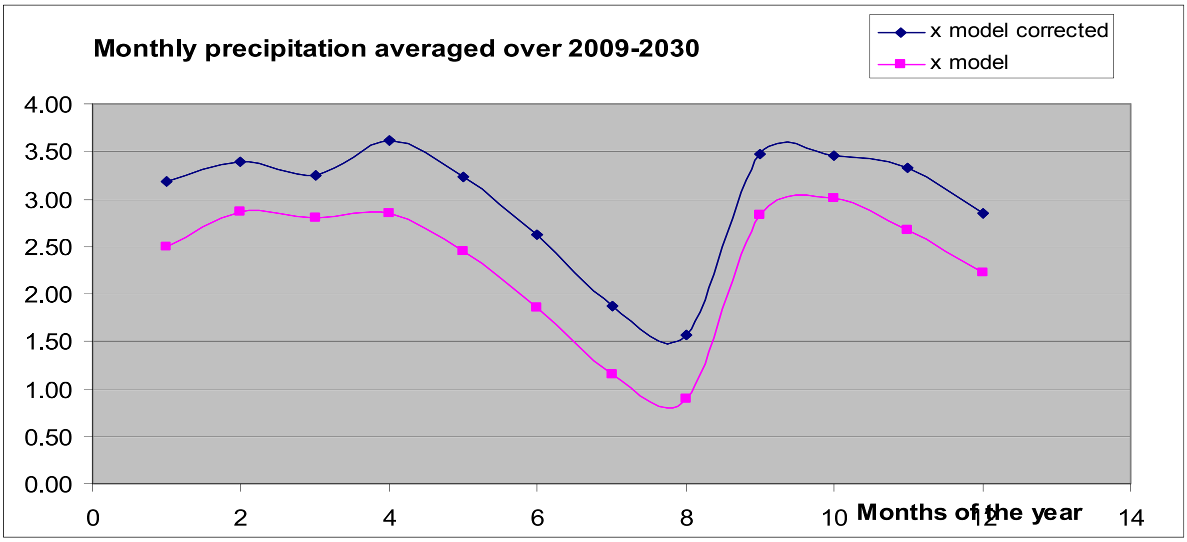


Figure 10a. *Monthly averaged precipitation (mm/day) for the averaged year over the period 2009-2030, a) for the simulated model data (pink line), and b) for the model corrected data (blue line), over the TRUST area.*

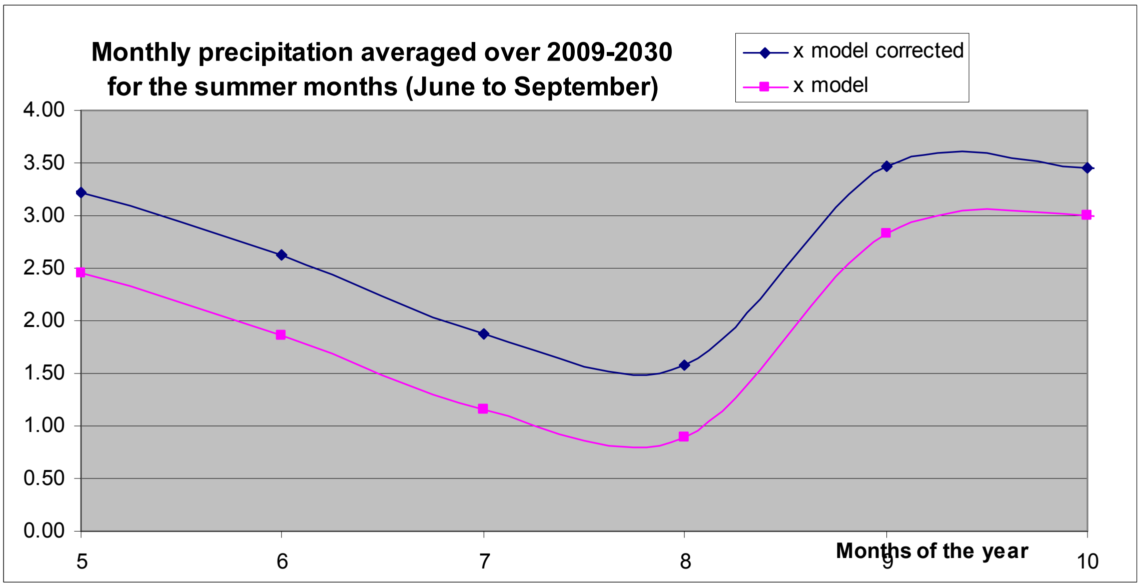


Figure 10b. *Monthly averaged precipitation (mm/day) for the summer months(June to September) of the averaged year over the period 2009-2030, a) for the simulated model data (pink line), and b) for the model corrected data (blue line), over the TRUST area.*

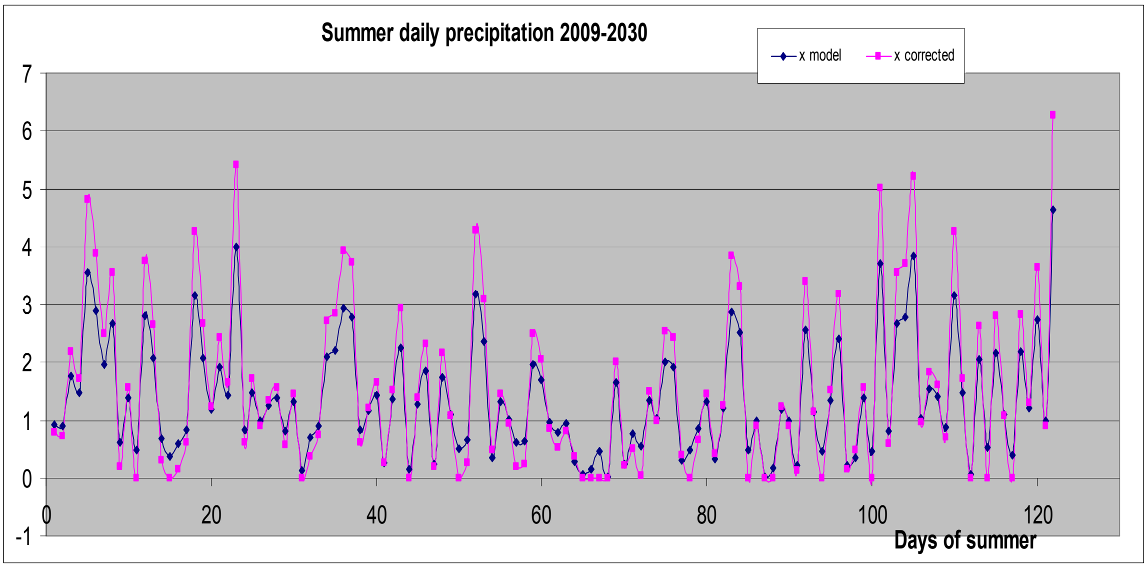


Figure 11. *Mean daily precipitation (mm/day) for the summer months of the period 2009-2030, a) for the simulated model data, and b) for the model corrected data, over the TRUST area.*

Finally, in order to perform the bias correction method for more areas of the Veneto and Friuli Venezia Giulia (TRUST project area of interest) a complete database of precipitation model and observational data was produced both for the present (2001-2010) and for the future period (2010-2030), so as to be used as input data for the program that performs the quantile mapping.

4. References

Hamlet, A.F., Lettenmaier, D.P., 1999, Effects of Climate Change on Hydrology and Water Resources in the Columbia River Basin, J. AWRA , 35 (6), 1597-1623

Dettinger, M.D., D.R. Cayan, M.K. Meyer, A.E. Jeton, Simulated hydrologic responses to climate variations and change in the Merced, Carson, and American river basins, Sierra Nevada, California, 1900-2099, Clim. Change, 62, 283-317, 2004.

Wilby, R. L., Wigley, T. M. L., Conway, D., Jones, P. D., Hewitson, B. C., Main, J., and Wilks,D. S.: 1998, 'Statistical Downscaling of General Circulation Model Output: A Comparison of Methods', *Water Resour. Res.* **34**, 2995–3008.

Wood, A.W., Maurer, E.P., Kumar, A. and D.P. Lettenmaier, 2002, Long range experimental hydrologic forecasting for the eastern U.S. J. Geophys. Res., 107(D20), 4429, doi:10.1029/2001JD000659.

Wood, A.W., L.R. Leung, V. Sridhar, D.P. Lettenmaier, Hydrologic implications of dynamical and statistical approaches to downscale climate model outputs, Clim. Change, 62, 189-216, 2004.

Huth, R., Statistical downscaling in central Europe: evaluation of methods and potential predictors, Clim Res., 13, 91-101, 1999.

Schmidli, J., C. Frei, P.L. Vidale, Downscaling from GCM precipitation: A benchmark for dynamical and statistical downscaling methods, Int. J. Climatol., 26, 679-689, 2006.