Hydrol. Earth Syst. Sci. Discuss., 9, 9425–9454, 2012
www.hydrol-earth-syst-sci-discuss.net/9/9425/2012/
doi:10.5194/hessd-9-9425-2012

Hydrology and Earth System Sciences Discussions

Regional climate models downscaling in the Alpine area with Multimodel SuperEnsemble

D. Cane[1], **S. Barbarino**[1], **L. A. Renier**[2], **and C. Ronchi**[1]

[1]Regional Agency for Environmental Protection – Arpa Piemonte, Torino, Italy
[2]IPLA Spa, Torino, Italy

Received: 12 June 2012 – Accepted: 31 July 2012 – Published: 13 August 2012

Correspondence to: D. Cane (daniele.cane@arpa.piemonte.it)

Published by Copernicus Publications on behalf of the European Geosciences Union.

Regional climate models downscaling in the Alpine area

D. Cane et al.

Abstract

The climatic scenarios show a strong signal of warming in the Alpine area already for the mid XXI century. The climate simulations, however, even when obtained with Regional Climate Models (RCMs), are affected by strong errors where compared with observations, due to their difficulties in representing the complex orography of the Alps and limitations in their physical parametrization.

Therefore the aim of this work is reducing these model biases using a specific post processing statistic technique to obtain a more suitable projection of climate change scenarios in the Alpine area.

For our purposes we use a selection of RCMs runs from the ENSEMBLES project, carefully chosen in order to maximise the variety of leading Global Climate Models and of the RCMs themselves, calculated on the SRES scenario A1B. The reference observation for the Greater Alpine Area are extracted from the European dataset E-OBS produced by the project ENSEMBLES with an available resolution of 25 km. For the study area of Piedmont daily temperature and precipitation observations (1957–present) were carefully gridded on a 14-km grid over Piedmont Region with an Optimal Interpolation technique.

Hence, we applied the Multimodel SuperEnsemble technique to temperature fields, reducing the high biases of RCMs temperature field compared to observations in the control period.

We propose also the first application to RCMS of a brand new probabilistic Multimodel SuperEnsemble Dressing technique to estimate precipitation fields, already applied successfully to weather forecast models, with careful description of precipitation Probability Density Functions conditioned to the model outputs. This technique reduces the strong precipitation overestimation by RCMs over the alpine chain and reproduces well the monthly behaviour of precipitation in the control period.

HESSD
9, 9425–9454, 2012

1 Introduction

The Alps are a very sensitive region for the impacts of the climate change: the temperatures increased here more than the world average (Ciccarelli et al., 2008), and the projections for the XXI century show again an increase higher than the average.

Piedmont Region is located in North-Western, at the South-Western edge of the Alpine chain. The Environmental Protection Agency of Piedmont Region is in charge of producing reliable scenarios of the variation of climatic parameters in the changing climate, to allow the evaluation of the impacts on mountain hydrology (project ACQWA, www.acqwa.ch), on the wildfire potential (project ALPFFIRS, www.alpffirs.eu, for more details see Cane et al, 2012), on the permafrost (project PERMANET www.permanet-alpinespace.eu/), on the alpine lakes (project SILMAS, www.silmas.eu), on mountain biodiversity (EU-INTERREG project "Biodiversità una risorsa da conservare"), heat waves in the Po Valley towns (Nicolella and Cane, 2012) and any other study of impacts affecting the regional environment.

The temporal scope of our work is the mid XXI century, to drive conclusions that can be used to concrete adaptation measures to the climate change in a reasonable time.

We then chose to focus on a single scenario, instead of a range of different scenarios, because for the time interval of interest the larger variations are among the different models, while the different scenarios do not differ so much (Randall et al., 2007).

Our evaluation is then based on Regional Climate Models (RCMs) calculated by the EU project ENSEMBLES on the SRES scenario A1B basis: all the model runs refer to the same grid including Europe.

We established two study areas: the Greater Alpine Area (GAR, Fig. 1), including all the Alps (coordinates: 3.00–20.25° E/41.50–51.25° N), and a smaller box covering Piedmont Region (OI, Fig. 2) with higher resolution data (coordinates: 6.5625–9.4375° E/44.0625–46.4375° N).

The reference observations for the GAR are extracted from the European gridded dataset E-OBS produced by the EU project ENSEMBLES (Haylock et al., 2008). Daily

HESSD
9, 9425–9454, 2012

temperature and precipitation observations (1961-present) from this dataset are available at a resolution of 25 km.

For the study area of Piedmont daily temperature and precipitation observations (1957–present), collected by The Environmental Protection Agency of Piedmont Region, were carefully gridded on a 14-km grid over Piedmont Region with an Optimal Interpolation (OI) technique. More details can be found in Sect. 2.

As suggested by the name, the Multimodel techniques require several model outputs, which are combined together to obtain collective evaluations. Their use in the climatic simulation is recommended by the Intergovernmental Panel on Climate Change (Knutti et al., 2010).

The simplest Multimodel is the "Poor Man Ensemble", which is an average of different models, without any bias correction or weighting.

In the Multimodel SuperEnsemble technique (Krishnamurti et al., 1999) the models are unbiased and weighted with an adequate set of weights calculated during the so-called training period, with comparison with the observations. This technique is widely applied to weather forecast models (an example in Piedmont can be found in Cane and Milelli, 2006) and to seasonal climate forecasts (Krishnamurti et al., 2000). The standard Multimodel SuperEnsemble technique is here applied to the temperature fields using the period 1961–1980 as training dataset to calculate weights and to obtain daily fields of reanalyses (1981–2000) and scenarios (1981–2050).

A new probabilistic Multimodel SuperEnsemble Dressing, with careful description of precipitation Probability Density Functions conditioned to the model outputs was applied to the precipitation fields. This technique allows for a better correction of precipitation biases depending from the value of the forecast precipitation. For more details, please see Sect. 2.

In Sect. 3 we describe our results, first of all with a validation of the Multimodel techniques in the control period in Piedmont region, and then evaluating the future scenario both in Piedmont and in the whole Alpine area.

2 Description of the technique

2.1 Regional climate models and large scale data

The RCMs simulations used in this paper are a selection of 7 RCMs runs from the ENSEMBLES project (Table 1), carefully chosen in order to maximise the variety of leading Global Climate Models and of the RCMs themselves, and with a data amount compatible with our elaboration and storage facilities. Models descriptions can be found at http://ensemblesrt3.dmi.dk/.

For each model reanalysis runs from the ECMWF ERA-40 reanalysis (1961–2000) and scenario runs (1961–2100) on SRES scenario A1B are available on a common grid at a resolution of 25 km.

We interpolated the daily data from the models to the GAR and OI grids with a simple bi-linear interpolation. The use of such an interpolating technique can introduce biases, but the Multimodel techniques include a bias removal before applying the model average.

E-OBS, produced by the EU project ENSEMBLES, is a European land-only daily high-resolution gridded data set for precipitation and minimum, maximum, and mean surface temperature from 1950 to the present. The data set has been designed to provide the best estimate of grid box averages rather than point values to enable direct comparison with RCMs (here the 25-km resolution dataset is employed). The authors employ a three-step process of interpolation, by first interpolating the monthly precipitation totals and monthly mean temperature using three-dimensional thin-plate splines, then interpolating the daily anomalies using indicator and universal kriging for precipitation and kriging with an external drift for temperature, then combining the monthly and daily estimates. Interpolation uncertainty is quantified by the provision of daily standard errors for every grid square.

HESSD
9, 9425–9454, 2012

2.2 Optimal interpolation of Piedmont data

Regarding the gridded dataset of daily temperature and precipitation data over Piedmont, an Optimal Interpolation (OI) technique is used to assimilate the row and high density ground station data, arbitrarily displaced in the region, on a selected regular three-dimensional grid map based on a background field (BF) (Kalnay, 2003).

Only for temperature, the background field is obtained by a linear tri-dimensional downscaling of ERA-40 archive from 1957 to 2001 and of the ECMWF objective analysis from 2002 to 2009 on a selected grid (0.125° resolution, with careful description of the complex orography of the region).

The use of ERA-40 on the regional area is suggested by checking that the main climatological signals (trends, etc.) were congruent with the signals resulted from a station subset working in the period 1950–2000 in Piedmont (Ciccarelli et al., 2008). Where this preliminary congruence checking was not clear (i.e. for precipitation) the row station data themselves provided the background field at first level of gridding process.

The method enables to weight the contribute to the temperature/precipitation value on each grid point from the nearest observation data, through suitable parameters. A careful modulation of these parameters as a function of the data density and the use of an external background field help to achieve the time homogeneity and the spatial coherence of the final dataset.

2.3 Standard Multimodel SuperEnsemble technique

The conventional SuperEnsemble forecast (Krishnamurti et al., 2000) constructed with bias-corrected data is given by

$$S = \overline{O} + \sum_{i=1}^{N} a_i \left(F_i - \overline{F_i} \right) \quad (1)$$

HESSD
9, 9425–9454, 2012
Regional climate models downscaling in the Alpine area
D. Cane et al.

where F_i is the i-th model forecast, $\overline{F_i}$ is the mean of the i-th forecast over the training period, $\overline{O}$ is the observed mean over the training period, a_i are regression coefficients obtained by a minimisation procedure during the training period, and N is the number of forecast models involved.

The calculation of the parameters a_i is given by the minimisation of the mean square deviation in the training period T .

$$G = \sum_{k=1}^{T} (S_k - O_k)^2 \tag{2}$$

By derivation $\left(\frac{\partial G}{\partial a_i} = O\right)$ we obtain a set of N equations, where N is the number of models involved. We then solve these equations using Gauss-Jordan method (Press et al., 1992).

A scheme of the technique can be found in Fig. 3.

The standard Multimodel SuperEnsemble technique was applied to the temperature fields using the period 1961–1980 as training dataset to calculate weights and to obtain daily fields of reanalyses (1981–2000) and scenarios (1981–2050).

2.4 Probabilistic Multimodel SuperEnsemble dressing

A new probabilistic Multimodel SuperEnsemble Dressing, with careful description of precipitation Probability Density Functions (PDFs) conditioned to the model outputs was applied to the precipitation fields.

For each model we evaluated the PDF of observations conditioned to the model forecast in the training period, we fitted the obtained PDFs with a Weibull distribution (after checking for the best fit function among a large set of possible candidates) and we used these fitted data for the interpolation and extrapolation of the distribution characteristics for a wide range of precipitation forecasts.

HESSD

9, 9425–9454, 2012

Regional climate models downscaling in the Alpine area

D. Cane et al.

The PDFs are then weighted with the inverse of the Continuous Ranked Probability Score of the models in the training period to obtain a "Multimodel PDF".

Figure 4 shows an example of our technique evaluated on an ensemble of 4 models. For any given value of precipitation forecasted by the model, a model-specific PDF is evaluated (here shown in blue, red, green and black), and the final Multimodel PDF is obtained with the correct weights (in pink). The vertical lines represent the original "deterministic" value, while the green vertical line associated with the Multimodel distribution is the average of the Multimodel PDF. The obtained average value can differ significantly from the rude average of the input models (the so-called Poor Man Ensemble), but the availability of a bias-corrected PDF allows also to widen the ensemble spread, trying to correct the under-dispersion of the multi-model ensemble (in this example).

This technique allows for a better correction of precipitation biases depending from the value of the forecast precipitation. For more details and a verification on weather forecast models, please refer to Cane and Milelli (2010).

The Probabilistic Multimodel SuperEnsemble Dressing technique was applied to the precipitation fields using the period 1961–1980 as training dataset to calculate weights and to obtain daily fields of reanalyses (1981–2000) and scenarios (1981–2050).

For any given day a value is extracted randomly from the PDF so-obtained to give a unique time series of precipitation. The use of a random extraction is justified by the large number of the samplings (∼25 000 in the considered period) and by the uncorrelation between the scenarios and the observations.

HESSD
9, 9425–9454, 2012

3 Results

3.1 High resolution data in Piedmont

We tested the technique on the past data, splitting the control period of the models into two halves: the first one (1961–1980) used as training period, the second one (1981–2000) as forecast period.

We decomposed the models and Multimodel time series in the trends and seasonal component with the Seasonal Decomposition of Time Series by LOESS (Cleveland et al., 1990) and compared them with the observation series.

The Multimodel SuperEnsemble temperature fields show a very good reduction of model biases (Fig. 5) and an almost perfect reproduction of the temperature monthly statistics (Fig. 6). In this paper we show only the validation results of the maximum temperature, but those of minimum temperature have identical skill. Please notice that, in the control period, the reanalyses and scenario runs from the models show not only strong biases towards the observed temperature, but, more worrying, the trends sometime differ in a very significant way, and the reanalysis and scenario runs from the same model very often show a different behaviour.

The Walter and Lieth (1960–1967) diagrams referred to precipitation produced by climate models show very strong biases (up to 200 % during winter months) in the Alpine region when compared with observations. In Fig. 7 we compare the Walter and Lieth diagrams after removing each model yearly averaged bias, to obtain a fair comparison with Multimodel which is almost unbiased. Multimodel does not show very large biases in any month and reproduces quite well the precipitation annual distribution, both in time and amount. Only two input models out of seven have quite comparable skill, not taking in account their large average biases.

Nevertheless, the Multimodel post-processing of precipitation allows correcting the statistical properties of the models to reduce the strong models biases, to reproduce the correct precipitation monthly statistics and the average number of consecutive dry periods (more than 5 days without precipitation, namely < 1 mm), Fig. 8.

HESSD
9, 9425–9454, 2012
Regional climate models downscaling in the Alpine area
D. Cane et al.

On the other hand, it is less effective in reproducing the observed average number of consecutive wet periods defined as more than 5 days with precipitation larger than 1 mm. Being that in the Southern Alps the probability of having a dry day (and therefore to extract a dry day and interrupt a wet days series) is much higher than the probability of having a wet day (and then to interrupt a dry day series), the probabilistic sampling from the Multimodel PDF can introduce a gap in a continuous series of wet days. We are evaluating a technique to avoid this problem by substituting the "white noise" random number generation used to extract the values from the distribution with a function describing the correct correlation between the consecutive days of rain, but this work is still ongoing.

Figures 9–11 show the difference between the Multimodel SuperEnsemble scenario data averaged over the period 2031–2050 with respect to the period 1981–2000, as a function of the season (comparison was made on the scenario for better consistency, but the scenario is very close to observations). The scenario projection shows a significant increase of the temperatures over the region. This increase is shown also by the original RCMs, but the post-processed data allow a better characterization of the alpine region, with an increasing and more realistic variance of temperature variations as a function of the altitude, thanks to the calibration with observations.

In particular, maximum temperatures averaged in the study area show significant increase in winter (+0.8 °C), spring (+1.4 °C), summer (+1.6 °C) and autumn (+1.2 °C limited to the mountains). Maximum temperatures during spring and summer increase more on the plains than in the mountains.

Minimum temperatures show significant increase in winter (+1.1 °C), spring (+1.3 °C), summer (+1.8 °C) and autumn (+1.3 °C limited to the mountains). Minimum temperatures during autumn and winter increase more on the plains than in the mountains.

Precipitations at the annual scale show a slight decrease (not statistically significant with 95 % confidence level), while on a seasonal basis they show a significant decrease in spring (−9 mm month^{-1} only in the western Alps), summer (−22 mm month^{-1}), with

HESSD
9, 9425–9454, 2012

few differences among mountains and plains and in autumn, (−26 mm month^{-1} limited to the mountains).

3.2 The Greater Alpine area perspective

To enlarge our perspective, we applied the same techniques to the whole Alpine areas included in the GAR region. As mentioned above, the reference observations were extracted from the E-OBS dataset, and a preliminary comparison was made with the higher resolution gridded dataset covering Piedmont Region to check their compatibility over the common geographical area. Very few meteorological stations used to produce the two dataset are in common, so they can be considered independent each other.

The two datasets agree very well in the trends of maximum and minimum temperatures and also maximum temperature absolute value, while the OI minimum temperatures are warmer than the E-OBS ones by almost 1 °C. The differences can be explained only partially with a different average elevation of the two datasets, and will be the object of a further investigation.

Anyway, we are mainly interested in variations rather than absolute values, then the strong agreement between the dataset trends in temperature allows for a comparison.

Precipitations agree quite reasonably if we take the average over the whole common area, but when we look at specific points in the higher mountains the climate regime described by the two dataset is quite different, then the comparison is more difficult.

First of all, we repeated the validation of the Multimodel results in the control period, with the same agreement already shown for the high resolution dataset.

Figures 12–14 show the difference between the Multimodel SuperEnsemble scenario data averaged over the period 2031–2050 with respect to the period 1981–2000, as a function of the season.

The minimum and maximum temperatures show an increasing trend everywhere, not always significant, in particular in spring and autumn. During summer and winter

HESSD
9, 9425–9454, 2012

the major increases occur in the Southern part of the dominium, with temperature increases up to 2 °C/50 yr in the Po valley.

If we compare the results in Piedmont with the OI ones, we can see that the GAR signal is similar but weaker and flatter, with less emphasis on the Alpine chain.

As in the OI case, the annual precipitation average over the GAR area does not vary in a significant way, and a significant decrease can be seen only in spring. The timing of the precipitation decrease differs from that observed on the OI grid, and this mismatch can arise from the different precipitation regimes as seen by the two observation datasets. The decrease shown by the GAR data is quite light compared to the one described by the high resolution dataset. We cannot then drive a definitive conclusion about the precipitation behaviour from these two different evaluations.

4 Conclusions and future developments

Multimodel techniques can be used fruitfully to better evaluate the climatic parameters in complex orography regions. Multimodel SuperEnsemble provides a good estimation of temperature and data in Piedmont, with a very good reduction of the biases and a good reproduction of the monthly variations. We introduce here the first application of a new probabilistic Multimodel SuperEnsemble Dressing to precipitation, providing a reasonably good estimation of the precipitation regime in Piedmont.

We evaluated and validated the Multimodel results on two independent datasets, the E-OBS dataset and an high resolution Optimal Interpolation of the Piedmont station data.

Regarding the common geographical area of the two calibration datasets (Piedmont), the temperatures show similar behaviour in the mid-XXI century scenario, with a general increase compared with the control period, significant in all the seasons except for autumn. The OI data show stronger increases in the higher elevation, while the E-OBS data have the same signal with no elevation dependence.

HESSD
9, 9425–9454, 2012

On the other hand, precipitation variations in the scenario depend more on the observations used for the calculation of the Multimodel. In both calibrations, precipitation is not projected to change significantly at an annual scale, while at a seasonal scale we found a decrease in summer precipitation with the OI dataset and in spring for the E-OBS dataset.

As concerns the Greater Alpine Region, the projection to the mid XXI century shows a quite uniform temperature increase between plain and mountain regions in all the seasons, except than in spring, when the increase is significant only in the mountains. Precipitation does not show any significant annual variation, and on a seasonal basis it shows a significant decrease in spring only.

We are evaluating a technique to better describe the correlation of the daily precipitation and to allow a more correct random extraction of a given day from the Multimodel-corrected PDF.

Several impact studies are ongoing with the use of these data, about mountain hydrology, wildfire potential, permafrost, alpine lakes biology, mountain biodiversity, heat waves.

Acknowledgements. This work was partially funded by the European Project ALP FFIRS under the European Regional Development fund of the Alpine Space Program, reference number 15-2-3-IT, and by the European Union FP7 Integrated Project ACQWA (project reference 212250). The ENSEMBLES data used in this work was funded by the EU FP6 Integrated Project ENSEMBLES (Contract number 505539) whose support is gratefully acknowledged.

References

Cane, D. and Milelli, M.: Weather forecasts obtained with a Multimodel SuperEnsemble Technique in a complex orography region, Meteorol. Z., 15, 207–214, 2006.

Cane, D. and Milelli, M.: Can a Multimodel SuperEnsemble technique be used for precipitation forecasts?, Adv. Geosci., 25, 17–22, doi:10.5194/adgeo-25-17-2010, 2010.

Cane, D., Wastl, C., Barbarino, S., Renier, L., Schunk, C., and Menzel, A.: Fire potential evaluation in the climatic scenario: an Alpine area perspective, Agr. Forest. Meteorol., submitted, 2012.

Ciccarelli, N., von Hardenberg, J., Provenzale, A., Ronchi, C., Vargiu, A., and Pelosini, R.: Climate variability in north-western Italy during the second half of the 20th century, Global Planet. Change, 63, 185–195, 2008.

Cleveland, R. B., Cleveland, W. S., McRae, J. E., and Terpenning, I.: STL: A seasonal-trend decomposition procedure based on loess, J. Official Stat., 6, 3–73, 1990.

Haylock, M. R., Hofstra, N., Klein Tank, A. M. G., Klok, E. J., Jones, P. D., and New, M.: A European daily high-resolution gridded dataset of surface temperature and precipitation, J. Geophys. Res.-Atmos., 113, D20119, doi:10.1029/2008JD010201, 2008.

Kalnay, E.: Atmospheric modeling, data assimilation and predictability, Cambridge Univ. Press, 341 pp., 2003.

Knutti, R., Abramowitz, G., Collins, M., Eyring, V., Gleckler, P. J., Hewitson, B., and Mearns, L.: Good Practice Guidance Paper on Assessing and Combining Multi Model Climate Projections, in: Meeting Report of the Intergovernmental Panel on Climate Change Expert Meeting on Assessing and Combining Multi Model Climate Projections, edited by: Stocker, T. F., Qin, D., Plattner, G.-K., Tignor, M., and Midgley, P. M., IPCC Working Group I Technical Support Unit, University of Bern, Bern, Switzerland, 2010.

Krishnamurti, T. N., Kishtawal, C. M., LaRow, T. E., Bachiochi, D. R., Zhang, Z., Williford, C. E., Gadgil, S., and Surendran, S.: Improved weather and seasonal climate forecasts from Multimodel SuperEnsemble, Science, 285, 1548–1550, 1999.

Krishnamurti, T. N., Kishtawal, C. M., LaRow, T., Bachiochi, D., Zhang, Z., Williford, C. E., Gadgil, S., and Surendran, S.: Multi-model superensemble forecasts for weather and seasonal climate, J. Climate, 13, 4196–4216, 2000.

HESSD
9, 9425–9454, 2012

Regional climate models downscaling in the Alpine area

D. Cane et al.

Nicolella, M. and Cane, D.: Indices bio-meteorologiques en Piemont: evaluation de l'impact du changement climatique avec down-scaling de modeles climatiques regionaux, Proceedings of the Association Internationale de Climatologie, XXVème Colloque, September 2012.

Press, W. H., Flannery, B. P., Teukolsky, S. A., and Vetterling, W. T.: Numerical Recipes in Fortran, Cambridge University Press, Cambridge, p. 256, 1992.

Randall, D. A., Wood, R. A., Bony, S., Colman, R., Fichefet, T., Fyfe, J., Kattsov, V., Pitman, A., Shukla, J., Srinivasan, J., Stouffer, R. J., Sumi, A., and Taylor, K. E.: Cilmate Models and Their Evaluation, in: Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, edited by: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M., and Miller, H. L., Cambridge University Press, Cambridge, UK and New York, NY, USA, 2007.

Ronchi, C., De Luigi, C., Ciccarelli, N., and Loglisci, N.: Development of a daily gridded climatological air temperature dataset based on a optimal interpolation of ERA-40 reanalysis downscaling and a local high resolution thermometers network, Poster presentation at 8th EMS Annual Meeting and 7th European Conference on Applied Climatology, Amsterdam, The Netherlands, 2008.

Walter, H. and Lieth, H.: Klimadiagramm-wetatlas, G. Fisher, Jena, 1960–1967.

HESSD

9, 9425–9454, 2012

Regional climate models downscaling in the Alpine area

D. Cane et al.

Table 1. The models used in the Multimodel SuperEnsemble evaluation.

Acronym	Reg. Clim. Model	Global Clim. Model	Run by
DMI	HIRHAM5	Arpege	Danish Meteorological Institute
ICTP	REGCM3	ECHAM5	The Abdus Salam Intl. Centre for Theoretical Physics
HC	HadRM3Q0	HadCM3Q0	Hadley Centre for Climate Prediction and Research
CNRM	RM4.5	Arpege	Météo-France CNRM/GMGEC/EAC
ETHZ	CLM	HadCM3Q0	Swiss Institute of Technology (ETHZ)
KNMI	RACMO2	ECHAM5	The Royal Netherlands Meteorological Institute
MPI	REMO	ECHAM5	Max Plank Institute – Hamburg

HESSD
9, 9425–9454, 2012

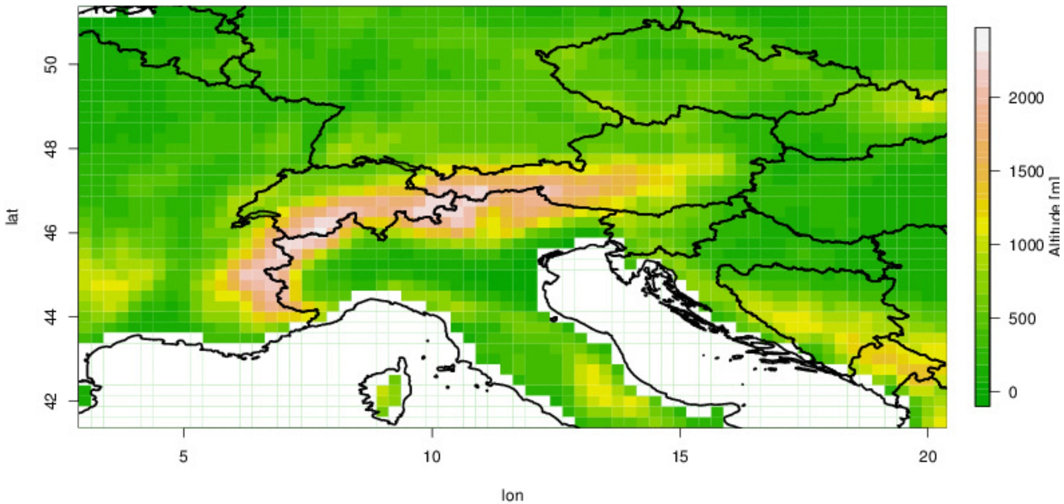

Fig. 1. The Greater Alpine Area map.

HESSD
9, 9425–9454, 2012

Regional climate models downscaling in the Alpine area

D. Cane et al.

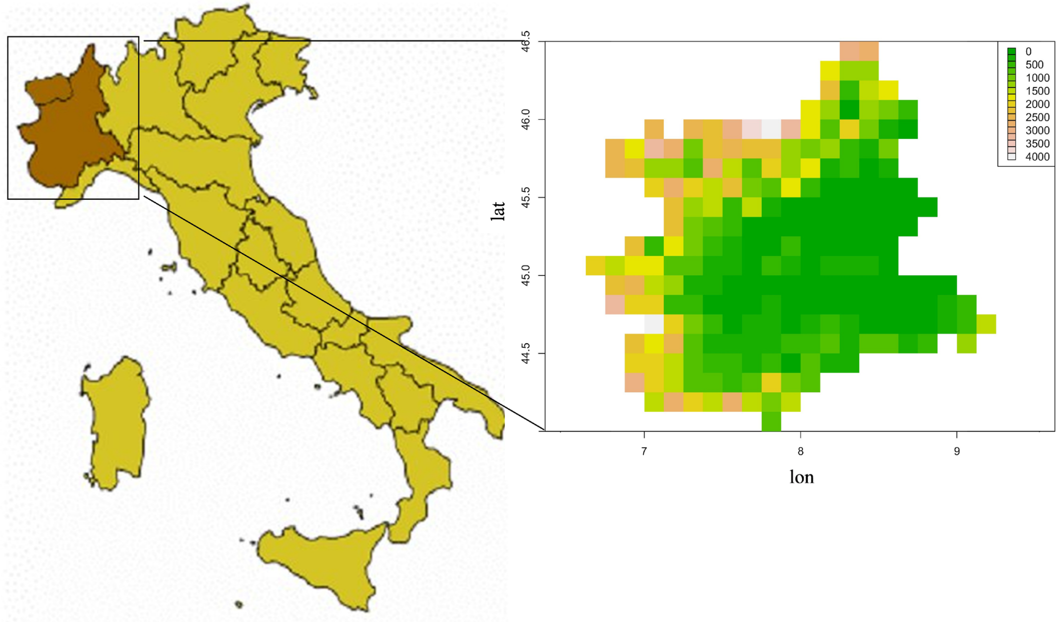

Fig. 2. The Optimal Interpolation map.

HESSD
9, 9425–9454, 2012

Regional climate models downscaling in the Alpine area

D. Cane et al.

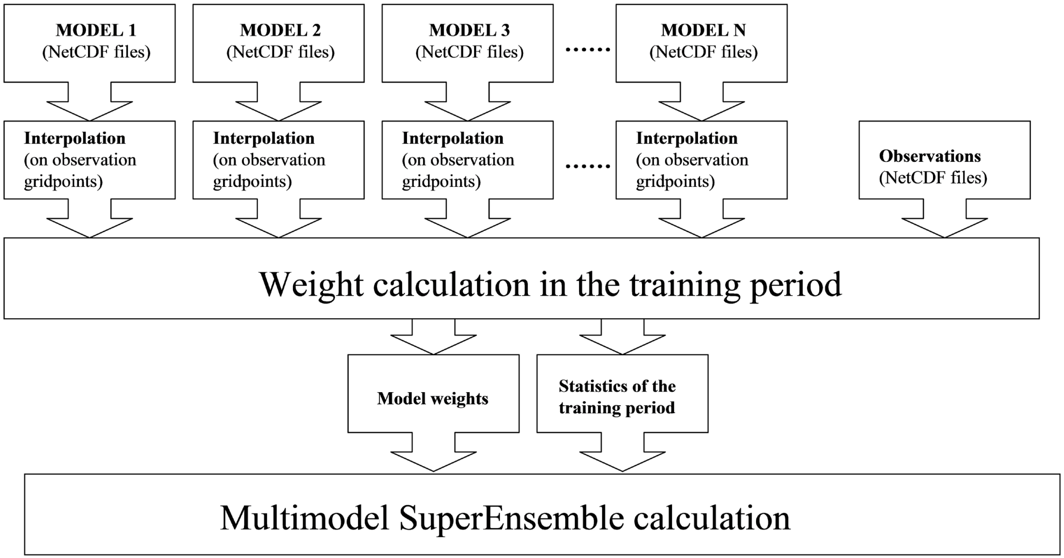

Fig. 3. Scheme of the standard Multimodel SuperEnsemble technique.

HESSD
9, 9425–9454, 2012

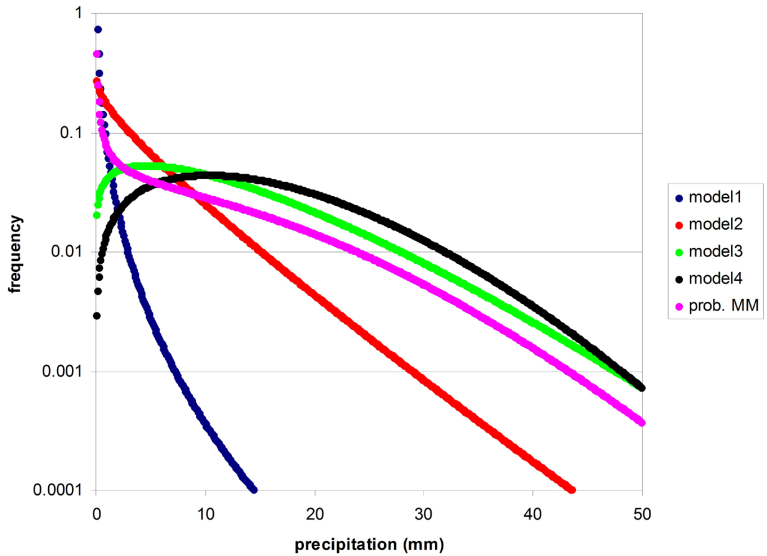

Fig. 4. Scheme of the probabilistic Multimodel SuperEnsemble Dressing technique: Probability Density Function of observed data conditioned to different models and forecast values, together with the final Probability Density Function evaluated with Multimodel.

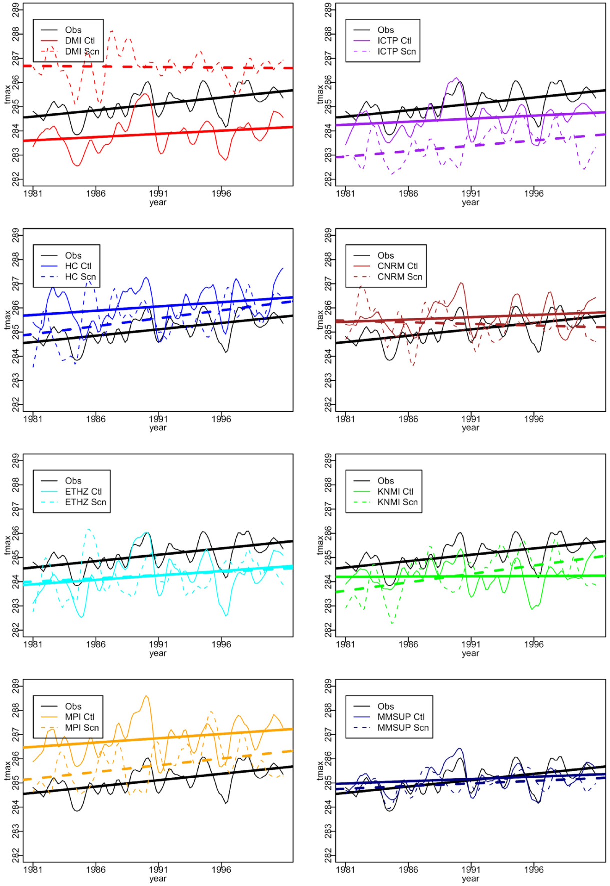

Fig. 5. Comparison between trends from observations obtained with Optimal Interpolation of Piemonte data (black lines), reanalysis runs (solid lines) and scenario runs (dashed lines) for different models (acronyms in Table 1) and Multimodel SuperEnsemble (MMSUP) in the period 1981–2000. Multimodel training period: 1961–1980.

HESSD
9, 9425–9454, 2012

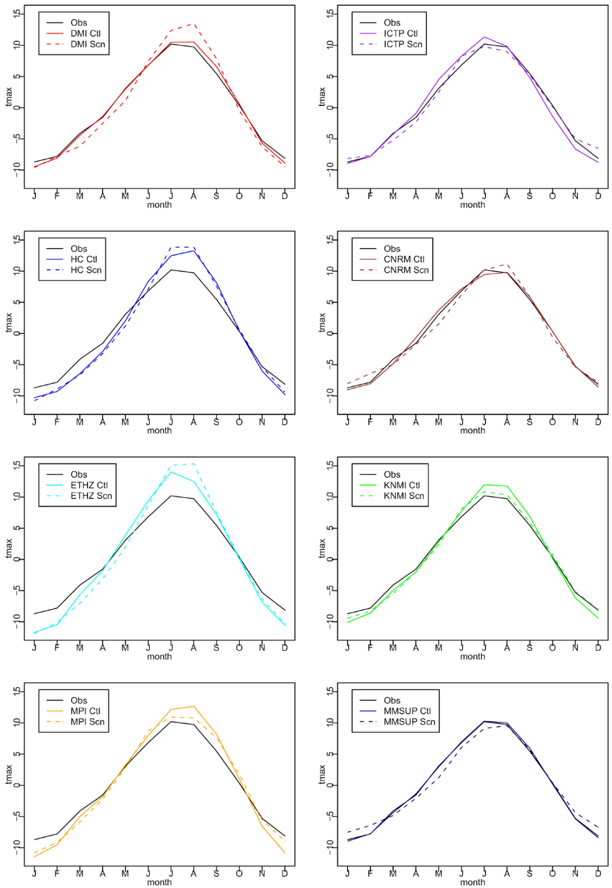

Fig. 6. Comparison between seasonal component from observations obtained with Optimal Interpolation of Piemonte data (black lines), reanalysis runs (solid lines) and scenario runs (dashed lines) for different models (acronyms in Table 1) and Multimodel SuperEnsemble (MMSUP) in the period 1981–2000. Multimodel training period: 1961–1980.

HESSD
9, 9425–9454, 2012

Title Page
Abstract | Introduction
Conclusions | References
Tables | Figures
◀| |▶
◀ ▶
Back | Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

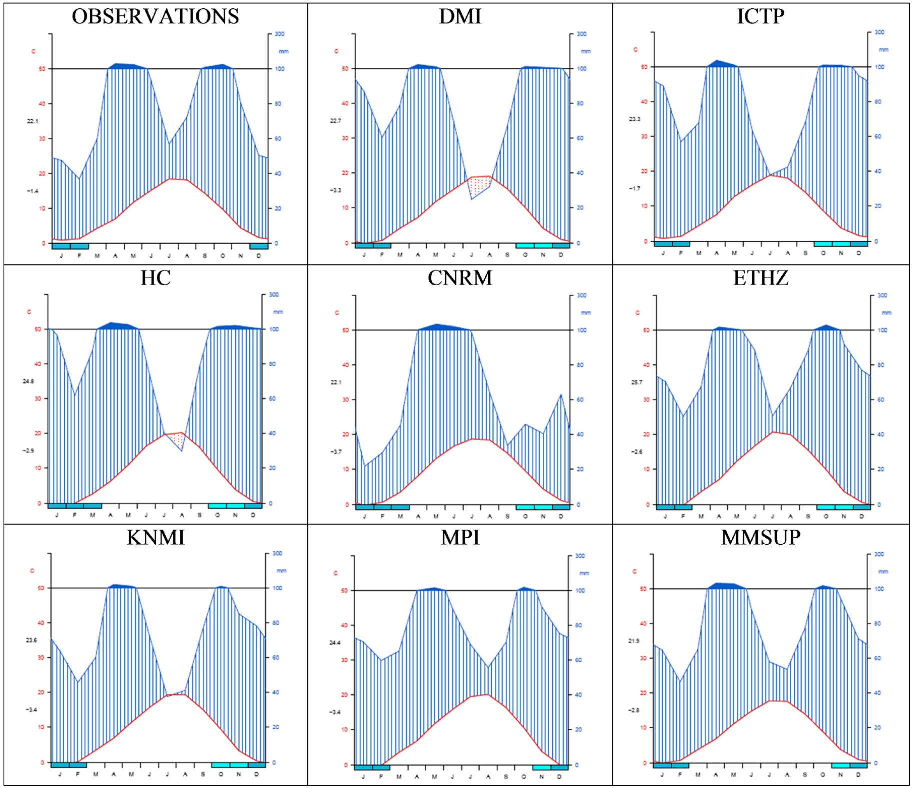

Fig. 7. Walter and Lieth diagrams of the models and Multimodel (MMSUP) for the values averaged over Piedmont OI gridpoints, period 1981–2000. The yearly averaged bias was subtracted from each monthly value.

HESSD
9, 9425–9454, 2012

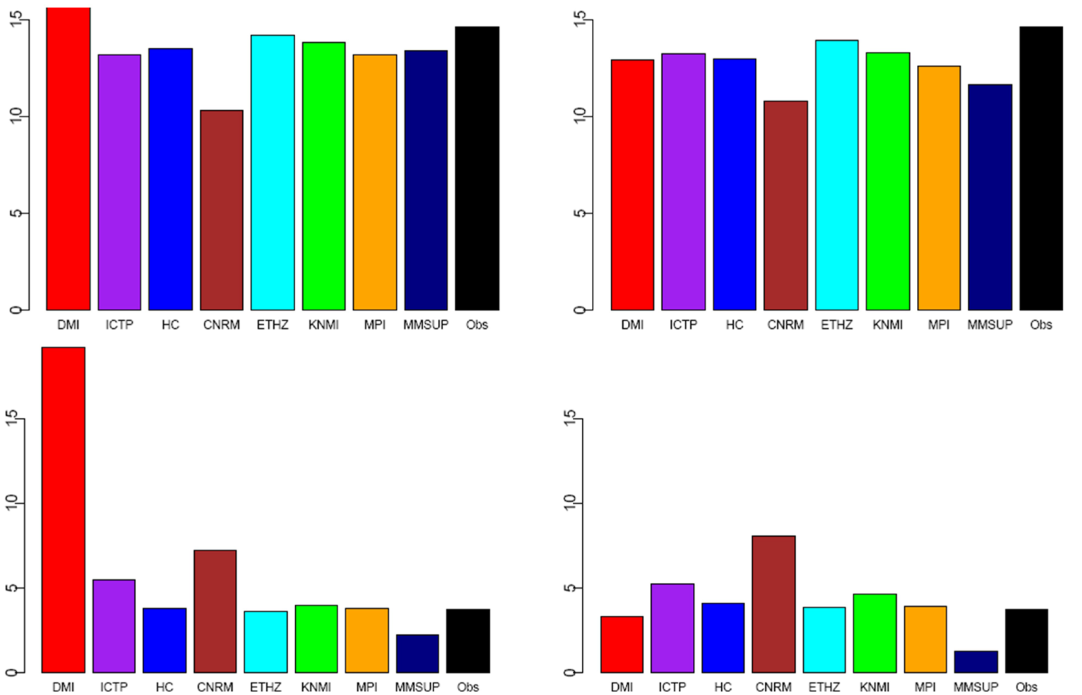

Fig. 8. Top panels: number of dry periods (5 consecutive days with precipitation $< 1\,\mathrm{mm\,yr^{-1}}$) for reanalysis (left panel) and scenario (right panel); bottom panels: number of wet periods (5 consecutive days with precipitation $> 1\,\mathrm{mm\,yr^{-1}}$) for reanalysis (left panel) and scenario (right panel); input models (colours), Multimodel (blue) and observations (black), period 1981–2000. Precipitation is calculated as the average over the Piedmont gridpoints.

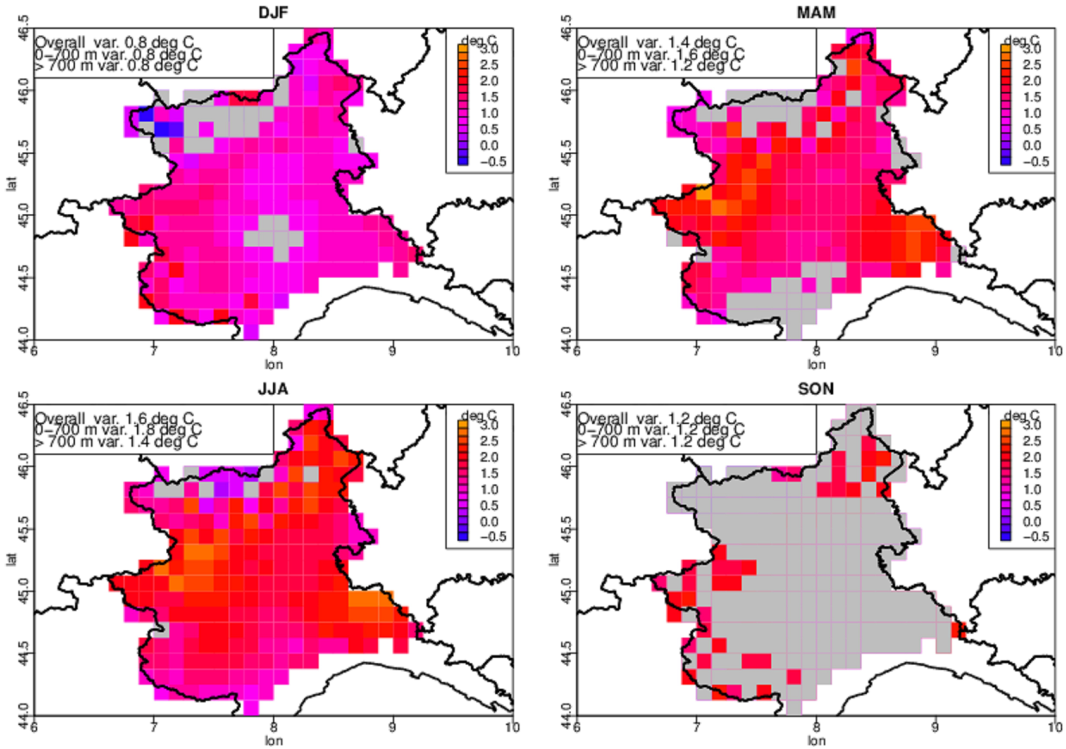

Fig. 9. Difference between the Multimodel SuperEnsemble scenario maximum temperatures averaged over the period 2031–2050 with respect to the period 1981–2000, as a function of the season (T-test conf. level 95 %) in Piemonte region. In the upper left boxes overall averages over significant points and altitude bands averages are shown.

HESSD
9, 9425–9454, 2012

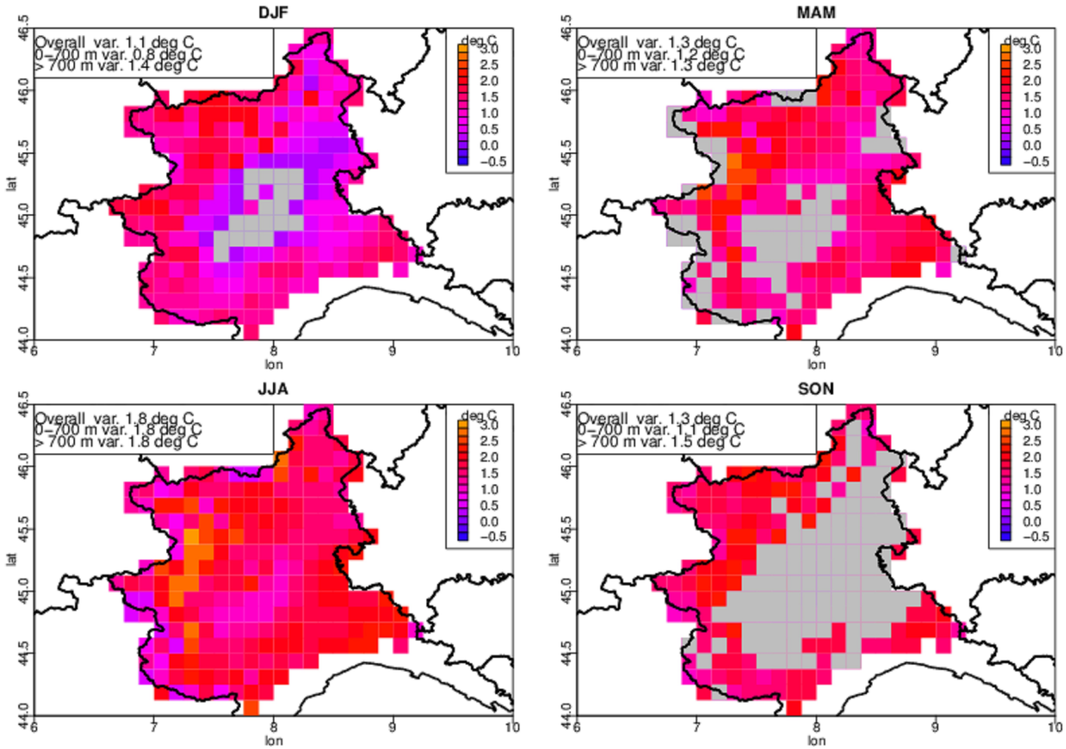

Fig. 10. Difference between the Multimodel SuperEnsemble scenario minimum temperatures averaged over the period 2031–2050 with respect to the period 1981–2000, as a function of the season (T-test conf. level 95 %) in Piemonte region. In the upper left boxes overall averages over significant points and altitude bands averages are shown.

HESSD
9, 9425–9454, 2012

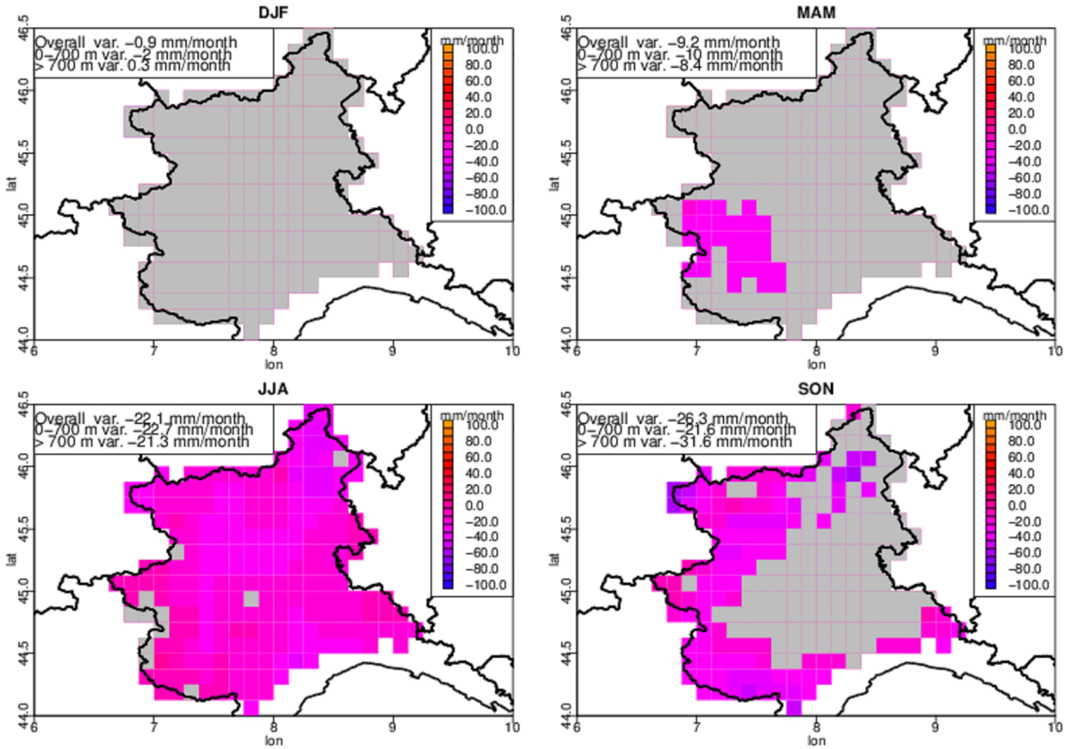

Fig. 11. Difference between the Multimodel SuperEnsemble scenario precipitation averaged over the period 2031–2050 with respect to the period 1981–2000, as a function of the season (T-test conf. level 95 %) in Piemonte region. In the upper left boxes overall averages over significant points and altitude bands averages are shown.

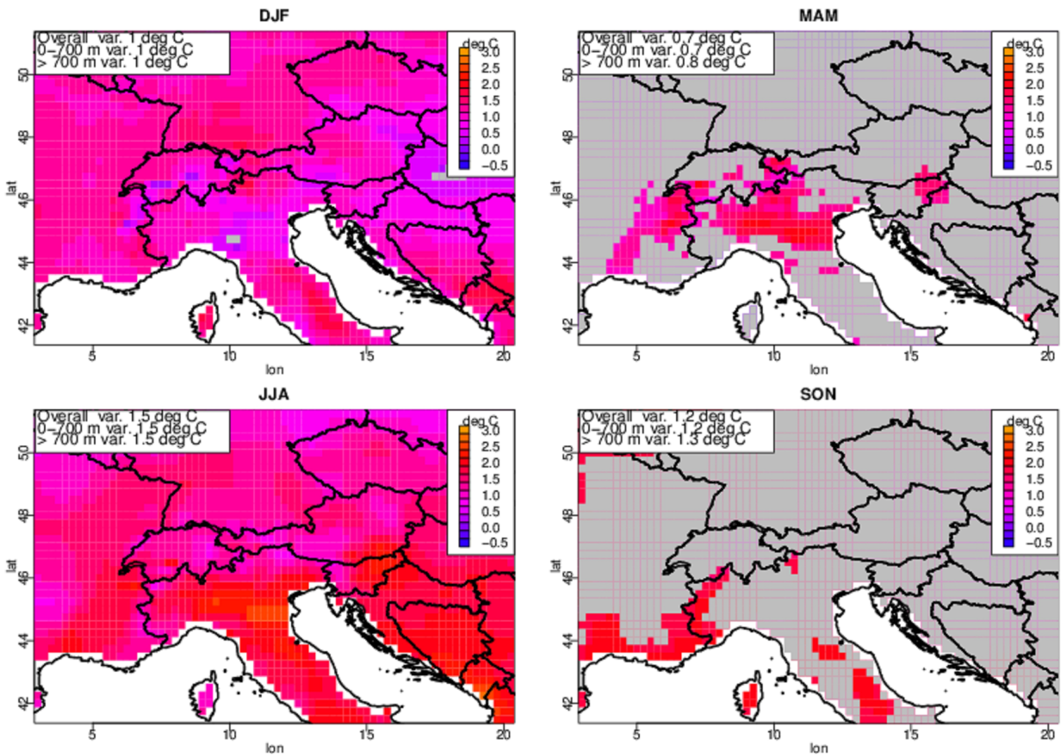

Fig. 12. Difference between the Multimodel SuperEnsemble scenario maximum temperatures averaged over the period 2031–2050 with respect to the period 1981–2000, as a function of the season (T-test conf. level 95 %) in the GAR area.

HESSD
9, 9425–9454, 2012

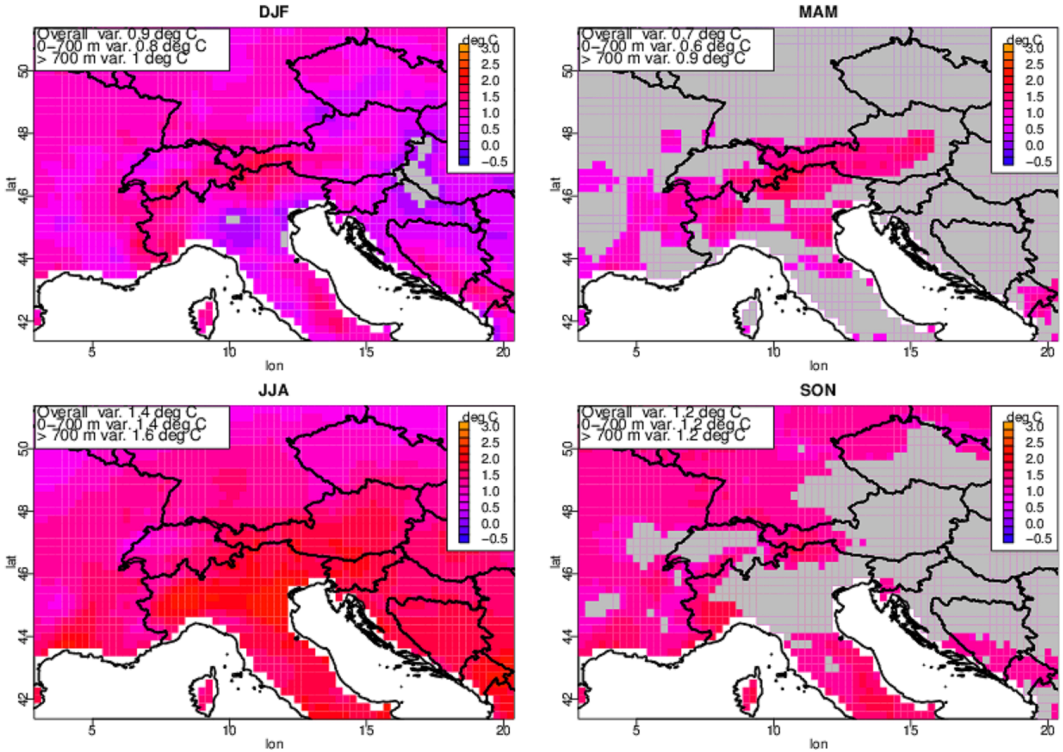

Fig. 13. Difference between the Multimodel SuperEnsemble scenario minimum temperatures averaged over the period 2031–2050 with respect to the period 1981–2000, as a function of the season (T-test conf. level 95 %) in the GAR area.

HESSD
9, 9425–9454, 2012

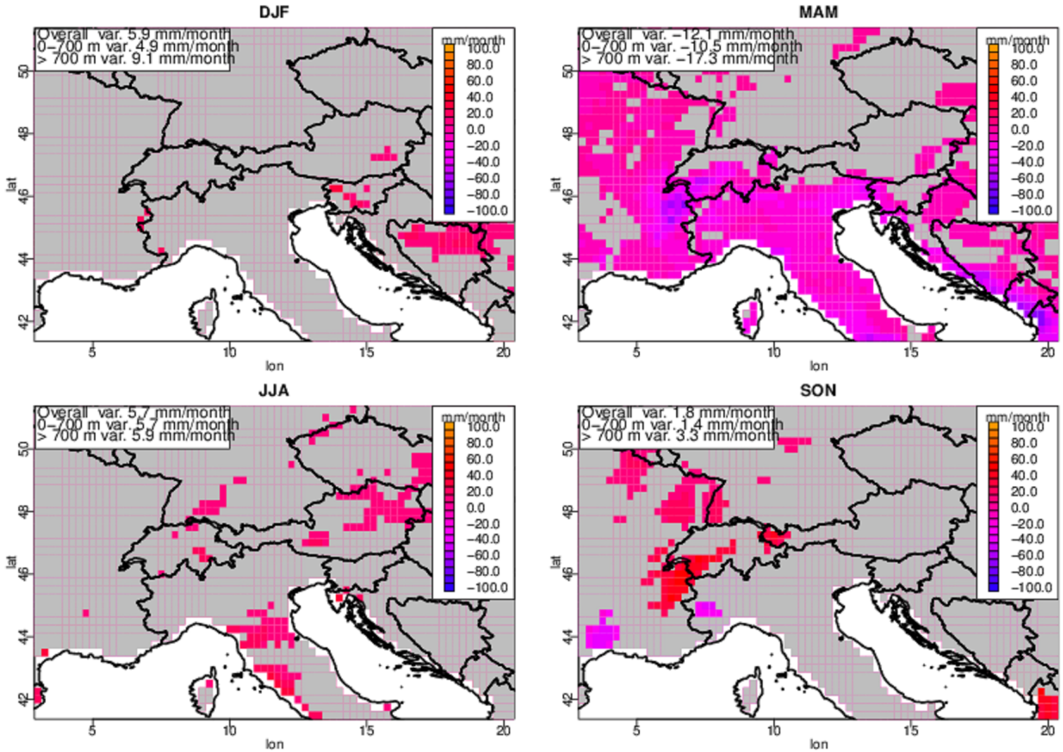

Fig. 14. Difference between the Multimodel SuperEnsemble scenario precipitation averaged over the period 2031–2050 with respect to the period 1981–2000, as a function of the season (T-test conf. level 95 %) in the GAR area.

HESSD
9, 9425–9454, 2012