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Impact analysis of climate change on water resources in southern Italy through joint atmospheric-hydrological modeling

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SUMMARY – The impact of global climate change on water resources in a southern Italian region is investigated through joint regional climate-hydrology simulations. Regional climate modeling results from the regional models COSMO-CLM, RegCM and HIRHAM are applied in the analysis, each referring to two dynamically downscaled time slices (1961-1990 and 2070-2099) of the Global Climate Models ECHAM4 and Had3CM. The simulated data of the control period (1961-1990) are compared to daily precipitation data recorded in the analyzed region, as well as climatologic data from the Climate Research Unit (CRU) and the University of Delaware. Finally, the meteorological fields were used to drive a 5 km regular grid distributed physically-based monthly hydrological model, allowing the investigation of the evolution of the main components of the water balance until the end of the century and the respective uncertainty bounds.

Key words: Climate change, dynamic downscaling, hydrological modeling, southern Italy.

RESUME – *"Analyse de l'impact du changement climatique sur les ressources en eau en Italie du Sud à travers une modélisation atmosphérique et hydrologique conjointe". L'impact du changement climatique global sur les ressources en eau dans une région italienne du sud est testé à l'aide de simulations régionales collectives de l'hydrologie selon ce climat. Le climat régional est modélisé selon les résultats des modèles régionaux COSMO-CLM, RegCM et HIRHAM qui sont appliqués dans l'analyse, et pour chaque référence à deux tranches de temps (1961-1990 et 2070-2099) a été exécuté un downscaling dynamique des Modèles de Climat Global ECHAM4 et Had3CM. Les données simulées de la période de contrôle (1961-1990) sont comparées aux données de précipitations quotidiennes enregistrées dans la région analysée, ainsi qu'aux données climatologiques de l'Unité de Recherche sur le Climat (CRU) et de l'Université de Delaware. Finalement, les champs météorologiques ont été utilisés pour conduire un modèle hydrologique mensuel physiquement fondé distribué dans 5 km de résolution, en permettant l'étude de l'évolution des composantes principales du bilan en eau jusqu'à la fin du siècle et selon des limites d'incertitude respectives.*

Mots-clés : *Changement climatique, downscaling dynamique, modélisation hydrologique, Italie du sud.*

Introduction

Climate change can affect water resources availability in large areas of the world. The General Circulation Models (GCMs) are the best available tools for the construction of climate change scenarios, but their resolution is often unsuitable for describing changes in regional climate, especially in areas characterized by complex orography. In order to study the consequences of global climate change on local scales the GCMs data are downscaled by the Regional Climate Models (RCMs), accounting for the influence of regional and local geographic features on the atmospheric circulation. The results provided by the RCMs are more suitable to be used as input data of hydrological models, usually running at even more detailed scales. Recently, some new high resolution data from RCMs has become available, opening the perspective on high resolution water balance studies.

In this paper results from the Regional Models COSMO-CLM, RegCM and HIRHAM, each referring to two dynamically downscaled time slices (1961-1990 and 2070-2099) of the GCMs ECHAM4 and Had3CM, show the impact of global climate change in a southern Italian region, considering the IPCC SRES A2 scenario. Then, through joint atmospheric-hydrological simulations, changes in several components of the water balance in three selected catchments of the analyzed area are assessed.

Methods

The Regional Climate Models

The RCM HIRHAM is a hydrostatic model of the Danish Meteorological Institute (DMI). Its dynamical part originates from HIRLAM (High Resolution Limited Area Model) version 2 and the physical part from ECHAM4 model. The model employs a regular latitude-longitude grid with a rotated pole. The climate model RegCM has been developed at the International Centre for Theoretical Physics (ICTP), Trieste, Italy. Its dynamical core is equivalent to the hydrostatic version of the NCAR/Penn State University meso-scale model MM4. The available model projections are Lambert Conformal, Mercator and polar stereographic. COSMO-CLM (CLM) is a non-hydrostatic community regional climate model based on the Local Model (LM) of the German Weather Service (DWD). It has the same dynamic and physical core as the LM and employs regular latitude-longitude grid with a rotated pole. The climate change simulations of the HIRHAM and RegCM models were forced with HAD3AM GCM boundary data. The COSMO-CLM transient runs employed ECHAM5/MPI-OM boundary data.

Coupling with the distributed hydrological model

The joint simulations were carried out using a modified version of the distributed water balance model presented by Mendicino and Versace (2007), that simulates soil moisture and groundwater storage changes, evapotranspiration and runoff on a 5 km regular grid using data sets that include climatic drivers (temperature and precipitation), vegetation and soil properties. The original model has been improved with modules considering snow and snowmelt; furthermore, on situ data of soil use and soil hydraulic characteristics have been used.

Precipitation and 2 m temperature calculated by RegCM were directly passed to the water balance model according to Kunstmann and Stadler (2005), considering each grid-point of the meteorological model as a "fictitious" meteorological station and interpolating the data to the resolution of the hydrological model. Due to the different grid resolutions (RegCM characterized by a 20 km regular grid), meteorological model elevations differ from those considered within the hydrological model, so that temperature has been adjusted by an altitude dependent regression.

Results and discussion

The performances of the RCMs have been evaluated comparing the simulated data of the control period (1961-1990) to daily precipitation data recorded in the analyzed region, as well as precipitation and temperature data from the Climate Research Unit (CRU) and the University of Delaware. Results (Fig. 1) show that temperature simulations reasonably agree with observed data, while there is a substantial bias in the precipitation.

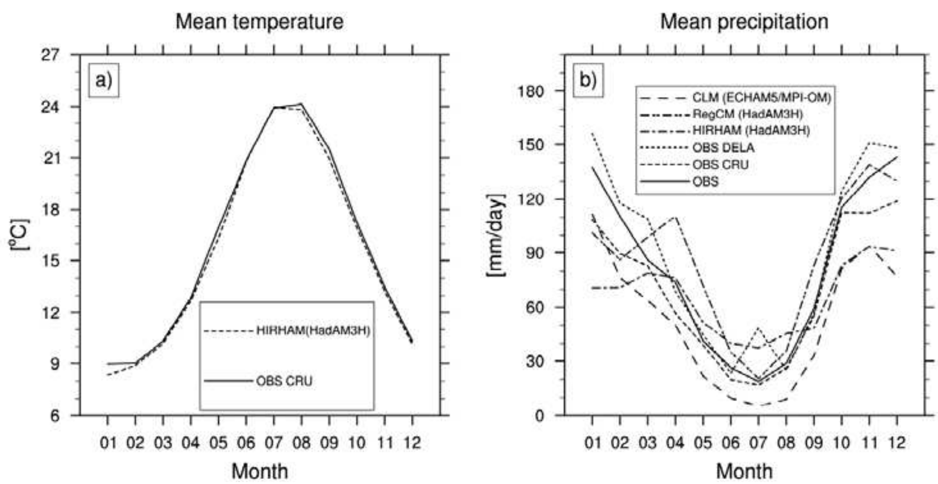

Fig. 1. Comparison between simulated data of the RCMs and observed data.

Figure 2 shows the study area (catchments used in the hydrological analysis are emphasized in black), together with the distributed changes in annual temperature and precipitation computed by RegCM between the periods 1961-1990 and 2070-2099. Even though temperature changes seem to be correlated with elevation, almost everywhere in the analyzed region an average annual increase of about 4°C is forecasted (about 3°C in winter, 3.5°C in spring and in autumn and 5.4°C in summer). The changes in annual precipitation seem to be more strongly correlated to elevation, decreasing from 10% in several coastal areas up to 25% in the mountainous zones. Forecasted mean seasonal decreases for the whole area are about 29% in spring, 43% in summer (that is anyway the season with the lowest precipitation), and 11% in autumn and winter. A slight increase is observed in October (+4%).

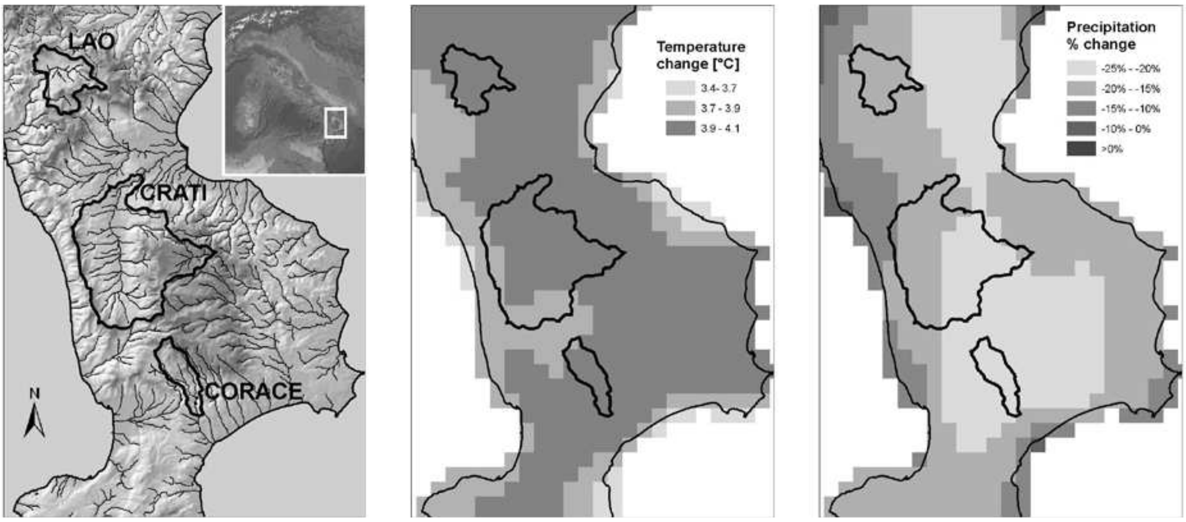

Fig. 2. Study area and distributed changes in annual temperature and precipitation computed by RegCM (1961/1990-2070/2099).

RegCM downscaled meteorological fields have been used in the hydrological model, applying the correction ratio k suggested by Kunstmann *et al.* (2004) in order to adjust precipitation data. An uncertainty analysis was also carried out, investigating how much the variability of k can affect the simulated runoff: the simulations on the period 2070-2099 have been repeated considering k, $k + \sigma$ and $k - \sigma$, where s is the standard deviation of k, computed for each cell of the grid.

The hydrological model has been applied on three catchments, Lao (279 km^2), Crati (1332 km^2) and Corace (178 km^2), characterized by different geo-lithological conditions. The runoff simulated by the model using observed precipitation and temperature data has shown good agreement with the observed runoff. Figure 3 shows for the three catchments the results obtained by the model using as input data both the observed data and the RegCM meteorological fields for the period 1961-1990, and again the RegCM fields for the period 2070-2099. In the last case three lines are drawn to show the results of the uncertainty analysis. The analyzed quantities are the evapotranspiration (ET) deficit (difference between potential and actual evapotranspiration) and the runoff. Results show that ET deficit will reach a relevant increase in the summer months for all the catchments (up to 40 mm in the month of August). The decrease in runoff instead will be less evident in the summer months, but the lower precipitation in autumn and winter will affect significantly the runoff in this periods, and even more strongly the groundwater recharge: Figure 4 shows that, even performing the uncertainty analysis, for the three analyzed catchments in any case a constant reduction in groundwater storage along the year is forecasted.

Conclusions

Three RCMs have been applied to assess the impact of global climate change in a southern Italian region, considering the IPCC SRES A2 scenario. The meteorological fields obtained by the RegCM model have been used in a hydrological model to investigate the changes in several components of the water balance between the periods 1961-1990 and 2070-2099. The results forecast a rather alarming scenario, with relevant increases in temperature and consequently in ET deficit, specially in summer months. The concurrent decrease in precipitation will reduce river runoff and, mainly, groundwater recharge. The combined effect predicted by the analyzed scenario will greatly influence the water resource management for agriculture in the area, because groundwater stored in the winter is currently the main source for irrigating the fields in the hot summer months.

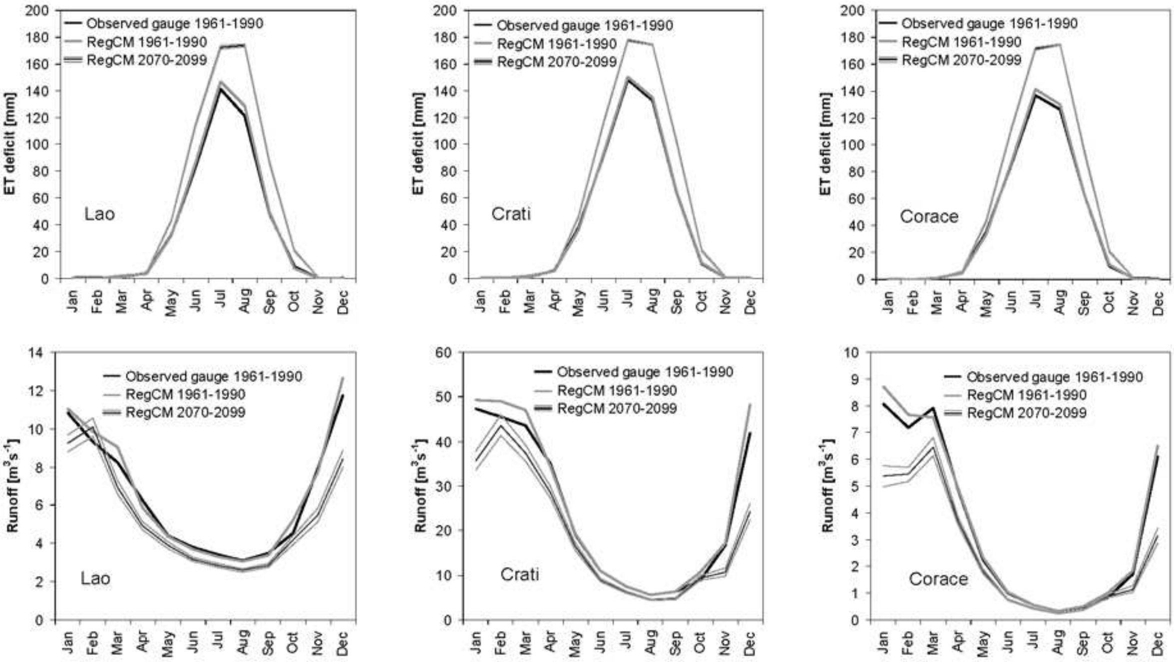

Fig. 3. Results obtained by the model using as input data the observed data and the RegCM meteorological fields for the period 1961-1990, and the RegCM fields for the period 2070-2099.

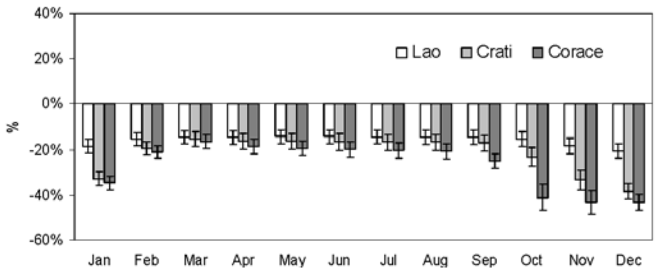

Fig. 4. Percentage changes in monthly groundwater storage (1961/1990 - 2070/2099). The vertical lines (I) show the variation obtained applying the uncertainty analysis.

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