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Improved hydrological model parametrization for climate change impact assessment under data scarcity — The potential of field monitoring techniques and geostatistics

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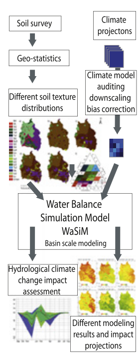
HIGHLIGHTS

- soil texture field sampling campaign
- regionalization of soil properties using Regression Kriging
- significant reduction of all hydrological quantities in the spring season
- improved hydrological modeling results with improved soil information
- improved modeling of soil water content with improved soil information

GRAPHICAL ABSTRACT



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ABSTRACT

According to current climate projections, Mediterranean countries are at high risk for an even pronounced susceptibility to changes in the hydrological budget and extremes. These changes are expected to have severe direct impacts on the management of water resources, agricultural productivity and drinking water supply. Current projections of future hydrological change, based on regional climate model results and subsequent hydrological modeling schemes, are very uncertain and poorly validated. The Rio Mannu di San Sperate Basin, located in Sardinia, Italy, is one test site of the CLIMB project. The Water Simulation Model (WaSiM) was set up to model current and future hydrological conditions. The availability of measured meteorological and hydrological data is poor as it is common for many Mediterranean catchments. In this study we conducted a soil sampling campaign in the Rio Mannu catchment. We tested different deterministic and hybrid geostatistical interpolation methods on soil textures and tested the performance of the applied models. We calculated a new soil texture map based on the best prediction method. The soil model in WaSiM was set up with the improved new soil information. The simulation results were compared to standard soil parametrization. WaSiMs was validated with spatial evapotranspiration rates using the triangle method (Jiang and Islam, 1999). WaSiM was driven with the meteorological forcing taken from 4 different ENSEMBLES climate projections for a reference (1971–2000) and a future (2041–2070) times series. The climate change impact was assessed based on differences between reference and future time series. The simulated results show a reduction of all hydrological quantities in the future in the spring season. Furthermore simulation results reveal an earlier onset of dry conditions in the catchment. We show that a

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solid soil model setup based on short-term field measurements can improve long-term modeling results, which is especially important in ungauged catchments.

1. Introduction

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) highlights an expected increase in air temperature throughout the 21st century. Those projections are a robust feature across climate models and the temperature increase is nearly the same for all Representative Concentration Pathway (RCP) scenarios (Collins et al., 2013). There is scientific consensus that precipitation patterns and sums are expected to change by the end of the century (Christensen et al., 2007). However, higher uncertainties are expected for the projected future change of precipitation sums, distributions and intensities. In contrast to a great number of climate change and climate model downscaling studies, the amount of studies focusing on regional hydrological impact assessment of climate change is manageable (Raposo et al., 2013).

Climate change is expected to have a distinct impact on Europe. Many recent studies (summarized in Christensen et al. 2013, EEA, 2013) indicate a strong north–south impact gradient for Europe. While for northern Europe an increase of precipitation, runoff and floods is projected, Christensen et al. (2013) show for the Mediterranean region that the recent (1981–2012) trends in annual mean air temperature distinctly exceed the global mean land trend. Giorgi (2006) found that the Mediterranean area is one of the most prominent “hot-spots” with regards to climate change by the end of 21st century. It is expected, that annual mean temperatures will rise more than the global average in this region, with largest increment in summer. Moreover, the majority of the Global and Regional Circulation Models (GCM & RCM) foresee summers characterized by an increase, in frequency and total sums, of extreme daily precipitation despite a decrease in average precipitation in the Mediterranean area. Thus there are strong signs that longer lasting dry periods, will lead to an increased risk of droughts, interrupted by extreme intense precipitation (Christensen et al., 2007; Zollo et al., 2012; Raposo et al., 2013). Arnell (1999), Alcamo et al. (2007), Falloon and Betts (2010) and other authors showed that for the Mediterranean countries a significant reduction of precipitation, runoff and ground water recharge is projected. Raposo et al. (2013) found that the recharge of water bodies may concentrate in the winter season and dramatically decrease in the summer–autumn season leading to an increased dry season duration which is exacerbating the current problems in water supply.

In order to quantify climate change effects on a catchment scale, Xu et al. (2005) suggests performing the following three steps:

1. Choose the outputs of different climate projections from GCMs or RCMs using different emission scenarios
2. Find and apply downscaling techniques to the GCMs & RCMs outputs, to match those with the scales needed for the impact assessment modeling
3. Apply the downscaled data into a hydrological model, to model and study future changes in the hydrological budgets in the study area.

With this procedure a spatial feasibility for hydrological impact modeling can be achieved, but it comes together with the confinement that the uncertainties of the modeling results will increase. For the more precise assessment of current and future hydrological conditions on the climatological timescale, a complex modeling chain is required (Muerth et al., 2013).

In a hydrological climate impact assessment study of the French coastal catchments, Lespinas et al. (2014) simulated a mean reduction of discharge by 55% (IPCC emission scenario A2) and 46% (IPCC emission scenario B2) for the summer season of the time series 2070–2100, by forcing the hydrological model GR2M with different PRUDENCE RCMs. In contrast to the work of Lespinas et al. (2014) and Raposo et al. (2013), most of the few studies that have been published on regional hydrological climate change impact assessment in the Mediterranean, use simple average annual climate data (Molina-Navarro et al., 2014). Furthermore projections of future hydrological changes based on regional climate modeling results are very uncertain and modeling schemes often poorly validated (Ludwig et al., 2010). In many Mediterranean catchments long-term time series of recorded discharge and climate variables that are needed to calibrate and validate process-based hydrological models are not available. The lack of information is one reason why the amount of studies focusing on regional hydrological impact assessment of climate change is low (Raposo et al., 2013). Thus, in order to meet the needs of policy makers and stakeholders for the adaptation to climate change, hydrological modeling capabilities must be adapted and improved to overcome existing limitations (Ludwig et al., 2010).

Process-based hydrological models require numerous soil and vegetation parameters in an appropriate spatial and temporal resolution. Although it is known that the response of those models is sensitive to the quality of soil data, adequate soil information is missing in many cases. Spatially explicit data of soil properties are needed on the one hand to link catchment characteristics and distributed hydrological model parameterization (Götzinger and Bárdossy, 2006) and on the other hand to understand and predict plant water responses to changing climate conditions (Browning and Duniway, 2011)

The European FP-7 project CLIMB aimed to project climate induced changes on the hydrology of the Mediterranean Basins by investigating 7 test sites located in the countries Italy, France, Turkey, Tunisia, Gaza and Egypt. CLIMB employed a combination of novel geophysical field monitoring concepts, remote sensing techniques and integrated hydrological modeling to improve process descriptions and understandings and to quantify existing uncertainties in climate change impact analysis (http://www.climb-fp7.eu).

The presented study was conducted in the catchment of the Rio Mannu di San Sperate located approximately 30 km north of Sardinia's capital Cagliari. The catchment was already affected by multi-drought periods between 1990 and 2000 (Piras et al., 2014). Long-term records of hydrologic quantities like discharge as well as reliable soil texture information were not available for the catchment. This lack of observed data hampers a solid setup and parametrization of process-based hydrologic models and increases uncertainties in the modeling results. A prediction of hydrological quantities in ungauged basins is one of the grand challenges in hydrology. To tackle this challenge, hydrological modeling needs to accept and integrate multi-scale heterogeneity of climate, vegetation, soil and topography within the basin and needs to learn about interactions of those parameters from field observations and patterns in the data (Sivapalan, 2003).

For this study we applied the following workflow:

(i) We conducted a soil sampling campaign in the Rio Mannu catchment (RMB) to gain knowledge about soil properties and heterogeneity within the basin
(ii) We tested different deterministic and hybrid geostatistical interpolation methods like Multi-Linear Regression, Inverse Distance Weighting, Ordinary Kriging and Regression Kriging C (Odeh