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Impact of climate change on water resources status: A case study for Crete Island, Greece

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SUMMARY

An assessment of the impact of global climate change on the water resources status of the island of Crete, for a range of 24 different scenarios of projected hydro-climatological regime is presented. Three "state of the art" Global Climate Models (GCMs) and an ensemble of Regional Climate Models (RCMs) under emission scenarios *B1*, *A2* and *A1B* provide future precipitation (*P*) and temperature (*T*) estimates that are bias adjusted against observations. The ensemble of RCMs for the *A1B* scenario project a higher *P* reduction compared to GCMs projections under *A2* and *B1* scenarios. Among GCMs model results, the ECHAM model projects a higher *P* reduction compared to IPSL and CNCM. Water availability for the whole island at basin scale until 2100 is estimated using the SAC-SMA rainfall–runoff model And a set of demand and infrastructure scenarios are adopted to simulate potential water use. While predicted reduction of water availability under the *B1* emission scenario can be handled with water demand stabilized at present values and full implementation of planned infrastructure, other scenarios require additional measures and a robust signal of water insufficiency is projected. Despite inherent uncertainties, the quantitative impact of the projected changes on water availability indicates that climate change plays an important role to water use and management in controlling future water status in a Mediterranean island like Crete. The results of the study reinforce the necessity to improve and update local water management planning and adaptation strategies in order to attain future water security.

1. Introduction

Climate change is expected to affect precipitation and evapotranspiration patterns (Tsanis et al., 2011), and consequently variables such as local water availability, river discharge, and the seasonal availability of water supply (Arnell et al., 2011). As demand for freshwater on a global scale rises due to a variety of factors including population growth, water pollution and economic progress, land use and climate change render its availability into the future uncertain (Davies and Simonovic, 2011). Social and environmental aspects such as agriculture, tourism and biodiversity conservation are connected to water resources quality and availability, and therefore adaptation measures for water will be strongly bound with policies in a wide spectrum of disciplines (Iglesias et al., 2011).

The latest review on the current state of the art on climate change research for the Mediterranean region by Ludwig et al. (2011) shows that recently observed trends and projections from climate model ensembles indicate a strong susceptibility to change in hydrological regimes, an increasing general shortage of water resources and consequent threats to water availability and management. These projections enhance the necessity for more robust water management, pricing and recycling policies, in order to secure adequate future water supply and prevent tensions among users (García-Ruiz et al., 2011).

Despite the increasing research efforts, there are still considerable uncertainties in the future climate drivers and in how global hydrological systems will respond to their behaviour (Harding et al., 2011). A number of studies (e.g. Akhtar et al., 2008; Alcamo et al., 2007; Barnett and Pierce, 2009; Charlton and Arnell, 2011; Christensen and Lettenmaier, 2007; Fujihara et al., 2008; Georgakakos et al., 2012) have described the impacts of the expected climate change on global and regional water resources with respect to the various inherent uncertainties. The increasing availability of climatic outputs from general and regional circulation models provide the potential of exploring model uncertainties in predicting future climate through the use of ensembles, at global (Manning et al., 2009) but more importantly at regional scales where forcing data is often less accessible but more accurate.

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Indicative of the instability in the Mediterranean is the island of Crete, where analysis of climate models data depicts that precipitation on average is likely to be less frequent but more intense and droughts are likely to become more frequent and severe in some regions (Koutroulis et al., 2010, 2011; Tsanis et al., 2011). Shorter rainy periods and seasonality shifts could seriously affect water resources by significant reduction of water availability with wide ranging consequences for local societies and ecosystems. It is indicative that, during the last decade, the island of Crete has faced an increased number of droughts (Koutroulis et al., 2011). Moreover, the rapid development of Crete in the last 30 years has exerted strong pressures on many natural resources. Urbanization and growth of agriculture and tourism industry have strong impact on the water resources of the Island by substantially increasing water demand. Water use in Crete increased following the expansion of irrigated land by over than 55% during the period 1985–2000 (Donta et al., 2005). Regarding future water demands of the island, recent estimates forecast total uses for the year 2015 in the order of 550 Mm^3/year, which represents 7% of the mean annual precipitation. This highlights that any arising water stress issue will be due to poor extraction or retention technology rather than actual availability. It is therefore considered essential to tackle the increasingly severe water problems that the island will face via strategic policies adopting to climate change by using integrated water management systems.

This paper assesses the implications of global climate change on the water resources status for the island of Crete for a range of 24 different scenarios from a combination of projected hydro-climatological regimes, demand and supply potentials. For this purpose, "state of the art" climate model results within WATCH FP6 (Harding et al., 2011) modelling framework under *A2* and *B1* emission scenarios and FP6 ENSEMBLES (van der Linden and Mitchell, 2009) regional climate model results under *A1B* emission scenario are compared, to explore the water resources availability during the 21st century. A two-step bias correction procedure is adopted to adjust precipitation on the observed long-term frequency and intensity distribution based on the period 1970–2000 (Ines and Hansen, 2006; Law and Kelton, 1982; Wood et al., 2002). The correction involves truncating the RCM rainfall distribution and then mapping it onto a gamma distribution fitted to the observed intensity distribution. The SAC-SMA hydrological model (Burnash, 1995) is used to estimate the evolution of hydrological variables and water availability on the island of Crete. The outcome of the analysis is useful for the comprehension of the role and consequently the priority of certain water resources related infrastructure development.

2. Methodology

2.1. Framing the problem

The present water resources assessment includes various water management issues regarding actions up to present as well as future perspectives for policy, management and hydrological (climate) regime, resulting in the modelling framework presented in Fig. 1. These future scenarios include the augmentation of agricultural practices, improvement and extension of the already established irrigation network as well as tourism, permanent population and demand trends. For the purposes of this study, it's considered that demand can exceed supply, when for example scheduled irrigation is not fully satisfied. In this context, a poorly formed irrigation policy can lead to irrigation infrastructure always inferior to the demand for water resources. Furthermore, in this study water availability is defined as the sum of abstracted or potentially abstracted groundwater and available surface freshwater runoff that is or can be potentially exploited. For convenience, the reference periods were split to a historic hydrologic regime (1970–2000) and two future periods (2000–2050 and 2050–2100) and represent the spatial average of all the grid cells that cover Crete in the WATCH and ENSEMBLES domain. The observation period (1970–2000) was used for weighting of Ensembles RCMs, bias correction of Ensembles and WATCH model results and interpretation for the two future (2000–2050 and 2050–2100) periods.

2.2. Scenarios and storylines

The IPCC Third Assessment Report (TAR) has published a set of emissions scenarios, called the Special Report on Emissions Scenarios (SRES). Four scenario storylines, labelled A1, A2, B1 and B2, were the result of analyzing different possible future development pathways of the main demographic, economic and technological drivers of future greenhouse gas and sulphur emissions (Parry et al., 2004; Nakićenović et al., 2000) and a basis of a set of 40 scenarios. For the purposes of this study, three of these scenarios were chosen based on the hydrologic simulation of the WATCH and ENSEMBLES climate model input data through continuous rainfall–runoff modelling. In brief, the *B1* storyline and scenario family describes a confluent world that promotes sustainable development on a global scale, rapidly shifting towards a service and information economy based on clean and resource-efficient technologies. On the contrary, the *A2* storyline and scenario family, which is part of Scenario A or Business-as-Usual (BAU), describes a weakly globalized world with continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower. Lying somewhere between the above, the *A1B*, a subgroup of the *A1* scenario family, describes a future world of very rapid economic growth, sustainable global population, and the rapid introduction of new and more efficient technologies leading to a balance across fossil intensive and non-fossil energy sources.

The developed demand and infrastructure scenarios are based on the water practices of the local water management authority (Papagrigoriou et al., 2001) and have two basic components: *D*, the level of demand of water for the various uses, and *S* the projected water supply potential derived from the combination of the technical infrastructure and the projected water availability (dams, barrages, groundwater abstractions, etc.). For each component, two alternative storylines were established focusing on the analysis periods (2000–2050 and 2050–2100) and the different climate models projections for the various emission scenarios.

Regarding the demand component, the *Existing situation of water demand* (*D1*) storyline includes the current level of demand (2000), based on data that was assembled from irrigation and water supply authorities in the Island. The estimation of irrigation demand is based on a detailed analysis of the irrigated areas per municipality and the potential of each basins for groundwater abstractions. The *Future water demand* (*D2*) storyline depicts a realistic future water demand as it is outlined by the local irrigation facilities development programs, the future irrigation extend plans, the estimate of future population trends and a projected increase of tourism activities.

In the supply component, the *Business as usual (S1)* storyline includes all the existing works of exploitation of water resources, as they have been recorded in the frame of the "Integrated water resources management of Crete study" (Papagrigoriou et al., 2001) including dams, barrages, groundwater abstractions, etc. Finally, the *Future technical infrastructure (S2)* storyline includes the future technical infrastructure based on the proposed technical work of exploitation of water resources that has been evaluated as mature