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Climate change projections of medicanes with a large multi-model ensemble of regional climate models

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ABSTRACT

Cyclones with tropical characteristics, usually called medicanes, occasionally develop over the Mediterranean Sea. Possible future changes of medicanes are a matter of concern due to their large damage potential. Here we analyse a large set of climate change projections with regional climate models (RCMs) from the ENSEMBLES project. The aim is to increase our knowledge about the future evolution of medicanes, advancing previous studies along several important lines: use of a large ensemble of RCMs, nested in many different GCMs, and covering a long continuous time period (up to 150 years). The main overall results are a future reduction in the number of medicanes and an increase in the intensity of the strongest medicanes, in agreement with other studies. But the large size of the ensemble reveals some important model-related uncertainties. The frequency decrease is not statistically significant in many of the subset of simulations that extend to 2100, with two simulations even showing no frequency decrease at all. Large decadal changes affect the frequency of medicanes, emphasizing the need for long period simulations. The increase in extreme intensity shows a clear dependence on the GCM driving the simulations. In contrast to the overall results, a few simulations also show changes in the monthly distribution of medicanes, with less winter cases and more autumn and late summer cases. Some environmental variables have been explored in an attempt to offer physical explanations for these results. A plausible reason for the overall decrease of the frequency of medicanes is the projected increase in vertical static stability of the atmosphere. A relevant result is that the general and clear increase in average static stability is unable to stop several simulations projecting higher maximum winds in the future. This could indicate that the increased SST and latent heat fluxes may overcome the limitation of a higher overall static stability, if favourable conditions for medicane genesis indeed occur. This is a worrying possibility, as the strongest damages are associated with the most intense cyclones.

1. Introduction

The Mediterranean Sea is a region with a high density of cyclones (> 1500 cyclones/year according to Campins et al., 2011), which are responsible for heavy precipitation and strong wind events (Trigo et al., 2000; Jansà et al., 2001; Bocheva et al., 2007; Nissen et al., 2010). Mediterranean cyclones are often responsible for considerable damage mainly in the Mediterranean islands and coastal zones, due to their greater exposure to strong winds and floods. A better understanding and description of these extreme meteorological phenomena in the present climate can be crucial to understand and predict the response of the Mediterranean climate to global climate change during the current XXIst century.

Not all the Mediterranean cyclones have the same characteristics: some recent studies have focused on cyclones with tropical characteristics (axial thermal symmetry and warm core) over the Mediterranean Sea, the so called medicanes (an acronym for Mediterranean Hurricanes). The singular situation of the Mediterranean Sea favours the development of such tropical-like cyclones. The Gibraltar Strait is the only communication with the Atlantic Ocean so the water exchange is very limited and the Mediterranean water temperature may reach very high values in September. Another special feature of the Mediterranean Sea is the surrounding orography: high mountains like the Alps surround the basin and modify the circulation, favouring the generation of baroclinic cyclones, which later may develop into medicanes.

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Different studies have shown that medicanes do not happen in all locations of the Mediterranean Sea with the same probability. In the climatological studies by Tous and Romero (2013) and Cavicchia et al. (2014a), the same two preferred regions of occurrence were identified (Ionian Sea and Balearic Islands), although the methodology they used was based in the former case on satellite images and in the latter on numerical simulations. The combined satellite and numerical approach used in Miglietta et al. (2013) identified fourteen medicanes that show a similar geographic distribution as those cases described in the literature from 1999 to 2012.

From a modelling perspective, the use of General Circulation Models (GCMs) to analyse medicanes is not possible due to the typical size of the medicanes and the low resolution of GCMs, as medicanes have typically a diameter of <300 km (Walsh et al., 2014). Therefore, the use of higher resolution models, such as Regional Climate Models (RCMs), is necessary. Chapter 14 of the last IPCC report (Christensen et al., 2013) pointed out the important spread in the number of cyclones detected by different RCMs, which is similar to the changes expected in the future scenarios or to the natural interannual variability. The use of a model ensemble allows to take into account the large spread among different climate models, which represents added value in comparison with studies using only one RCM (e.g. Cavicchia et al., 2014b; Walsh et al., 2014).

Gaertner et al. (2007) used an ensemble of RCMs from the PRUDENCE European project (Christensen and Christensen, 2007), with a grid spacing of 50 km, to analyse projections of future intense cyclones over the Mediterranean Sea. That study detected for the first time a future risk of tropical cyclone development over the Mediterranean Sea, and stressed the need for higher resolution and a more complete ensemble of RCMs (higher number of RCMs, use of different GCMs or different emission scenarios). It is expected that the number of detected cyclones may increase using higher resolution models, as smaller cyclones could be missed if the resolution used is too coarse (Pinto et al., 2005). The ENSEMBLES project (Van der Linden and Mitchell, 2009) extended the analysis from PRUDENCE by increasing the number of RCMs, the number of GCMs, and reducing the horizontal grid spacing (25 km). The simulated period was also much longer than in PRUDENCE.

The present study aims to analyse climate change projections of medicanes, advancing previous studies along several important lines: use of a large ensemble of RCMs, nested in several different GCMs, and covering a long time period (up to 150 years). These are the advantages of the ENSEMBLES project compared to PRUDENCE. First, the ERA40 forced simulations for 1961–2000 period are evaluated against the available observational information about medicanes to determine the capability of these RCMs to describe the observed characteristics. Then, both present (1951–2000) and future climate periods (reaching 2050 for all the simulations and 2100 for many of them) are analysed. Several characteristics of the simulated medicanes are studied: frequency, intensity, regional and monthly distribution, as well as their changes under future climate change conditions from a multi-model RCM perspective. Some environmental variables affecting medicanes are analysed, to provide physical reasons for the future evolution of medicanes and the spread among different simulations.

2. Methodology

Ten RCMs from the ENSEMBLES European Project (see Table 1), with a horizontal grid spacing of 25 km, nested in ERA40 (evaluation period) and in six different GCMs (scenarios) have been used. ERA40 driven simulations (1961–2000) are compared with a database of observed medicanes (Miglietta et al., 2013). The GCM driven simulations cover both a present climate period (control run) from 1951 to 2000 and a future climate period (scenario run) from 2001 to 2050 (four simulations) and from 2001 to 2100 (nine simulations). Some RCMs have been nested in more than one GCM (Table 1 shows the different RCM/GCM combinations).

The months selected for the study are from August to January, as most of the medicanes occur during late summer, autumn and early winter (Cavicchia and von Storch, 2012; Miglietta et al., 2013).

The Mediterranean Sea has been divided in three zones (see Fig. 1) in order to study the regional distribution of medicanes: Western (longitude <10°E), Central (longitude >10°E and <24°E) and Eastern (longitude >24°E). Those subregions are comparable to the ones described in Giorgi and Lionello (2008). Here, the cyclones are assigned to a subregion when they reach their maximum intensity as a medicane.

2.1. Cyclone detection method

The cyclone detection method described by Picornell et al. (2001) based on sea level pressure (SLP) has been used. August to January daily SLP averages are analysed to identify the pressure minima. A Cressman filter with a radius of 200 km is next used (Sinclair, 1997) to smooth out noisy features appearing in the SLP field. Weaker cyclones are filtered out through a SLP gradient threshold, and a radius of 400 km around every SLP minimum is used for determining the cyclone extent.

Table 1
Summary of models, institutions, periods and scenarios used in the present study.

		RCM (Institution)									
		RCA3 (C4I)	ALADIN (CNRM)	CLM (ETHZ)	HadRM3Q16 (HC)	HadRM3Q3 (HC)	RACMO (KNMI)	HIRHAM (METNO)	REMO (MPI)	RCA (SMHI)	PROMES (UCLM)
	ERA40	1961–2000	1958–2000	1961–2000	1959–2000	1959–2000	1958–2000	1961–2000	1961–2000	1961–2000	1961–2000
GCM	**ECHAM**	A2 1951–2050					A1B 1950–2100		A1B 1961–2100	A1B 1951–2100	
	ARPEGE		A1B 1951–2100								
	BCM							A1B 1951–2050		A1B 1961–2100	
	HCQ0			A1B 1951–2099				A1B 1951–2050			A1B 1951–2050
	HCQ16				A1B 1951–2099						
	HCQ3					A1B 1951–2099				A1B 1951–2100	

ERA40, European Centre for Medium range Weather Forecsts (ECMWF) reanalysis product; GCM, General Climate Model; ECHAM, ARPEGE, BCM, HCQ0, HCQ16 and HCQ3 are the names of the GCMs; RCM, Regional Climate Model; RCA3, ALADIN, CLM, HadRM3Q16, HadRMQ3, RACMO, HIRHAM, REMO, RCA and PROMES are the names of the RCMs; C4I, Community Climate Change Consortium for Ireland; CNRM, Centre National de Recherches Météorologiques (France); ETHZ, Swiss Institute of Technology; HC: Hadley Centre; KNMI: The Royal Netherlands Meteorological Institute; METNO, The Norwegian Meteorological Institute; MPI, Max Plank Institute; SMHI, Swedish Meteorological and Hydrological Institute; UCLM, Universidad de Castilla-La Mancha.

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