Dry spells analysis over the Mediterranean basin for present climate and climate change conditions using ENSEMBLES regional climate models

NOELIA LÓPEZ-FRANCA[1], ENRIQUE SÁNCHEZ[2], RAQUEL ROMERA[1] & MARTA DOMÍNGUEZ[1]

[1] Instituto de Ciencias Ambientales (ICAM). Universidad de Castilla – La Mancha
[2] Facultad de Ciencias Ambientales y Bioquímica. Universidad de Castilla – La Mancha
Noelia.LopezFranca@uclm.es

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Abstract

The hydrological stresses and specially the dry spells are one of the main climatic features of the Mediterranean regions and it can affect and lead to relevant impacts on ecosystems, agriculture and population. It is proposed the analysis of the annual mean dry spells length (DSML) from a group of Regional Climate Model (RCM) simulations of 25km horizontal resolution from ENSEMBLES European project. The capability of these RCMs to reproduce the DSML compared with ECAv6 gridded observational database is first studied in the baseline period (1961-2000). Then percentage change of the DSML from these RCMs forced by different Global Climate Models (GCMs) for future conditions (2021-2050) under A1B emission scenario respect to historical (1951-1980) climate conditions is evaluated. The results show the success of RCMs to reproduce the overall observed dry spells characteristics. A North-to-South gradient of DSML index along the Mediterranean basin is obtained in the baseline and historical periods, with the maximum length values located over Sahara desert and minimum over the mountain ranges on the northern part of the basin. High values also can be observed in the southern half of the Iberian Peninsula, western and southern coast of the Mediterranean Sea. The climate change analysis indicates a common increase of the DSML over the Mediterranean basin for all the GCM-forced RCM simulations.

Key words: Dry spells, Regional Climate Models, Mediterranean basin, Climate Change

Análisis de periodos secos en la cuenca Mediterránea en clima presente y condiciones de cambio climático a partir de modelos regionales de clima del proyecto ENSEMBLES

Resumen

Los estreses hídricos, y especialmente los periodos secos, conforman una de la principales características climáticas de las regiones Mediterráneas, pudiendo afectar y conducir a importantes impactos en los ecosistemas, agricultura y población. Se propone el análisis de la duración media anual de los periodos secos (DSML) a partir de un grupo de simulaciones de Modelos Regionales de Clima (RCM) con resolución horizontal de 25 km, procedentes del proyecto europeo ENSEMBLES. Primero, se estudia la capacidad de estos RCMs para reproducir la DSML en el periodo de referencia (1961-2000), comparándolos con la base de datos observacional ECAv6.

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Luego, se evalúa el cambio porcentual de DSML en el futuro (2021-2050) bajo el escenario de emisiones A1B respecto a condiciones de clima histórico (1951-1980) usando los RCMs forzados con diferentes Modelos Globales de Clima (GCM). Los resultados muestran el éxito de los RCMs para reproducir las características básicas del DSML observado. Para los periodos de referencia e histórico, se obtiene un gradiente Norte-Sur a lo largo de la cuenca Mediterránea, con valores máximos en el desierto del Sahara y mínimos en las principales cadenas montañosas del Norte de la cuenca. También se observan valores altos en la mitad Sur de la Península Ibérica y las costas Oeste y Sur del Mar Mediterráneo. En el análisis de cambio climático, todas las simulaciones, forzadas con GCMs, muestran un incremento general de DSML en la cuenca mediterránea.
Palabras clave: Periodos secos, Modelos Regionales de Clima, Cuenca Mediterránea, Cambio Climático.

Normalized reference
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1. Introduction

The water availability in a region is affected by many hydro meteorological variables, but the main role is played by precipitation. Its study under climate change conditions is essential in the management of the water resources system in the future (Lopez and Moreno, 2009). The description of the precipitation regimes is an entirety of several parameters, among them, the dry spells (Reiser and Kutiel, 2010). The assessment of dry spells characteristics are closely related to important natural hazards as drought and their associated impacts (Oikonomou et al., 2010). According to 4th IPCC report (Nakicenovic et al., 2000), Mediterranean basin is one of the regions where the risk of dryness is projected to increase during XXIst century. The Mediterranean region is located at the geographical transition between the mid-latitudes wet mild climate and the arid and desertic area around the tropical anticyclone belt. Due to its high geographic complexity, the Mediterranean climate yields a great variety of atmospheric precipitation regimes (Martín-Vide and López-Bustins, 2006). It presents a non-uniform precipitation spatial distribution, being scarce and irregular in many southern Mediterranean basin areas, where water availability is already a problem (Lionello et al., 2012).

A dry spell is defined as the number of consecutive days with daily amounts below a certain threshold (typically 1 mm/day). Their more relevant characteristics can be obtained from the number of events, the mean and the longest annual length of dry spells. Other several dryness-related indices have also been commonly defined: STARDEX project indices (Driouech et al., 2009; Hidalgo-Muñoz et al., 2010), WMO indices (Nastos and Zerefos, 2009; Argüeso et al, 2012; Piccarreta et al., 2013) or other drought indices that also include temperature (Vicente-Serrano et al., 2010; Heinrich and Gobiet, 2012). Some studies employ statistical methods based on frequency distribution functions of these magnitudes (Vicente-Serrano and Begueria-Portugues, 2003; Lana et al., 2006; May, 2008). The dry spells characteristics have been especially studied over Mediterranean regions due to its social impact. Many of the dry spell studies are based on rain-gauge observations (Martín-Vide et Gómez, 1999; Anagnostopoulou et al., 2003; Serra et al., 2006; Lana et al., 2008; Cindrić et al., 2010; Türkles and Tatli, 2010; Piccarreta et al., 2013). To analyse these processes over the Mediterranean basin for future climate conditions, due to its regional complexity, dynamical downscaling techniques are required (Gao et al., 2006; Lionello et al., 2012). Thus, studies that include partly or totally the Mediterranean basin have demonstrated the success of RCMs simulating dry spells (Gao et al., 2006; Beniston et al., 2007; Giorgi and Lionello, 2008; May, 2008; Sánchez et al., 2011; Argüeso et al., 2012; Giraldo and García, 2012). Regional models have also been applied over other regions to study dry spell features (Eun-Soon and Kwon, 2007; Sushama et al., 2010; She and Xia, 2013). When dealing with an ensemble of RCMs, two main methods can be used: the RCM ensemble building (Beniston et al., 2007; Heinrich and Gobiet, 2012) and the Reliability Ensemble Averaging (REA) method (Giorgi and Mearns, 2002; Giraldo and García, 2012).

This study is focused in the assessment of ten RCMs from ENSEMBLES European project modelling the historical climate and the change of the annual dry spells mean length (DSML) over the Mediterranean basin in the future (2021-2050) under A1B emission scenario conditions. Dry spells are computed at each grid point for each model and for an observational database.

The contents of this study are as follows. Section 2 describes the data and methodology employed. Section 3 presents the results of the ERA40-forced RCMs capability to simulate the DSML compared with ECA observational gridded database in the baseline period (1961- 2000). Then, DSML results of each future GCM-forced RCM simulations (2021-2050) compared with the historical period (1951-1980) also has been analysed. The Section 4 summarizes the results and presents the main conclusions.

2. Data and Methods

The observed dry spell characteristics over the Mediterranean basin are derived from the ECA version 6 daily precipitation (Haylock et al. 2008) gridded observational database (ECAv6). It has 25 km of horizontal resolution and it has been developed inside the ENSEMBLES European project (Van der Linden and Mitchell, 2009). The following ten forced RCM simulations (with 25 km horizontal resolution) have been selected from ENSEMBLES project: PROMES, HIRHAM, CLM, HadRM3Q0, HIRHAM5, REMO, RCA, REGCM3, RACMO2, CNRM-RM5.1.

To assess the ability of the RCMs to reproduce the observed climate conditions, ECAv6 database is used to validate the ERA40 reanalysis (Uppala et al., 2005) forcing RCM simulations in a baseline period (1961-2000). This is the longest common period available of the two databases. Once it is shown the ability of the RCMs to describe the baseline period DSML features, climate change signal projected by the GCM-forced RCM simulations in the near future (2021-2050) under A1B (IPCC, 2000) greenhouse gas emission scenario related to the historical period (1951-1980) is analysed. These are the two more distant 30-years periods available in the simulation period of the RCMs. The differences between them allow to inspect more clearly the potential climate change signal. The RCMs are forced by the following GCMs: PROMES, HIRHAM, CLM and HadRM3Q0 by HadCM3Q0; HIRHAM5, REMO, RCA, REGCM3 and RACMO2 by ECHAM5; and CNRM-RM5.1 by ARPEGE.

Here a dry spell is defined as the number of consecutive days without appreciable precipitation. Following the methodology of Sánchez et al. (2011), DSML is obtained as the number of days without precipitation divided by the number of spells. A dry day is defined as a day with a precipitation less than 1.0 mm, while the minimum value of a spell is 2 days.

3. Results

In this section spatial analysis of DSML over the Mediterranean basin results are presented. First, the evaluation of the ERA40-forced RCMs compared with ECAv6 observational database is presented. Then projected changes are evaluated from each GCM-forced RCM simulations as differences between the future and the historical period of the climate change simulation under A1B emission scenario are shown. It should be noted that the projected changes are presented as percentage change.

3.1 Baseline climate (1961-2000) RCMs validation: ERA40 forced simulations

The figure 1 illustrates the spatial pattern of DSML simulated by the ten ERA40-forced RCMs and the ECAv6 observational database for the whole Mediterranean basin. The observational database shows the DSML with a North-to-South gradient from maximum values over the Sahara desert around 70 to 150 days/year to minimum values around 5 days/year on northern Mediterranean regions. Minimum values are also obtained over the main mountain ranges (Pyrenees, Apennines, Alps or Carpathians). Other distinguishable orographic features are some river valleys as such as the Ebro (Iberian Peninsula) or Po (Italy) basins, with a mean duration around 10 days. These values are smaller than their surroundings. The eastern and western Mediterranean areas present higher values (around 15 days) than central Mediterranean areas (around 8 days). There is also a strong gradient inside the Maghreb area, with a length from 10 to 15 days in the Atlas mountain range to around 100 - 150 days over Sahara desert. The high values present in the central part of Turkey respect to surrounding areas are due to missing values of precipitation data in these points.

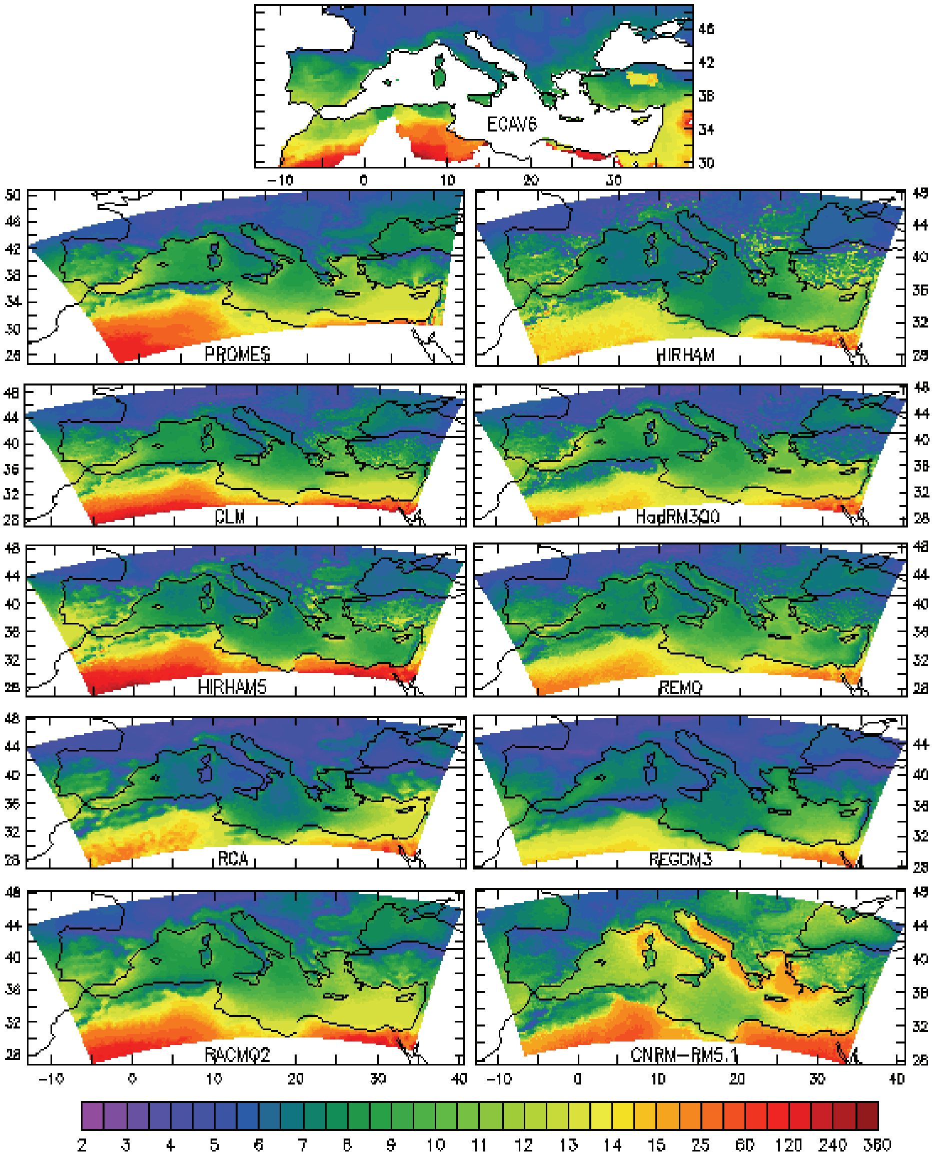

Fig. 1. Spatial distribution of DSML index (days/year) for baseline climate (1961-2000) over the Mediterranean basin.

These results are coherent with previous studies over Mediterranean areas that analyse other drought indices (Heinrich and Gobiet, 2012) and other dry spell characteristic (Nastos and Zerefos, 2009; Oikonomou et al., 2010; Sánchez et al., 2011), obtaining similar dryness features.

The ERA40-forced RCM simulations reproduce the general spatial pattern of the observational database, except at the Atlas mountain range, where all the RCMs underestimate the values (around 10 days) compared with the 15 days of length in ECAv6.Globally, PROMES, CLM, HIRHAM5 and RACMO2 present a better correspondence between the values obtained and ECAv6 database. The rest of RCMs show smaller values over the whole domain, especially at the Sahara desert. There is an overall underestimation for REGCM3 and CNRM-RM5.1 in the Iberian Peninsula.

3.2 Future climate (2021-2050) vs. historical (1951-1980) GCM-forced RCM simulations

The Figure 2 depicts the RCM simulations for the historical period (1951-1980). All the simulations describe the main characteristics of the spatial gradient observed in the baseline period. There are no relevant differences between RCMs forced by different GCMs. The Sahara desert presents the longest DSML, up to around 200 to 360 days in PROMES, CLM and CNRM-RM5.1; while the lowest values are simulated by RCA and RACMO2 in northern Mediterranean areas and some high mountain ranges, being 2-3 days. Intermediate values, around 20 days, are registered in the African and south-eastern Iberian Peninsula coasts for almost all the simulations, except by HadRM3Q0 and REMO. Moreover, RCA, REGCM3 and RACMO2 simulations show intermediate values at the eastern Mediterranean area. Central Mediterranean region presents shorter lengths (around 10 days) than East and West Mediterranean regions in all the simulations. Atlas mountain range exhibits a length around 10 days for all the simulations. It is also interesting to describe how RCMs describe the oceanic part of the domain, although there are no observational data at ECAv6 to validate them. A North-to-South gradient also is observed along the Mediterranean Sea with values between 10 - 13 days in the northern part to 25 days in the southern part. Also, values on the eastern and western (around 20 to 25 days) are longer than in the central of the sea (around 12 days) being more noticeable in RCA and RACMO2 simulations.

The percentage change in future period (2021-2050) under A1B emission scenario with respect to the historical period (1951-1980) is obtained in Figure 3. All the simulations project DSML increases from 1951-1980 to 2021-2050 in the whole Mediterranean basin. This change does not show any orographic feature. In general terms, the HadCM3-forced RCM simulations project larger changes than ECHAM5-forced RCM simulations.

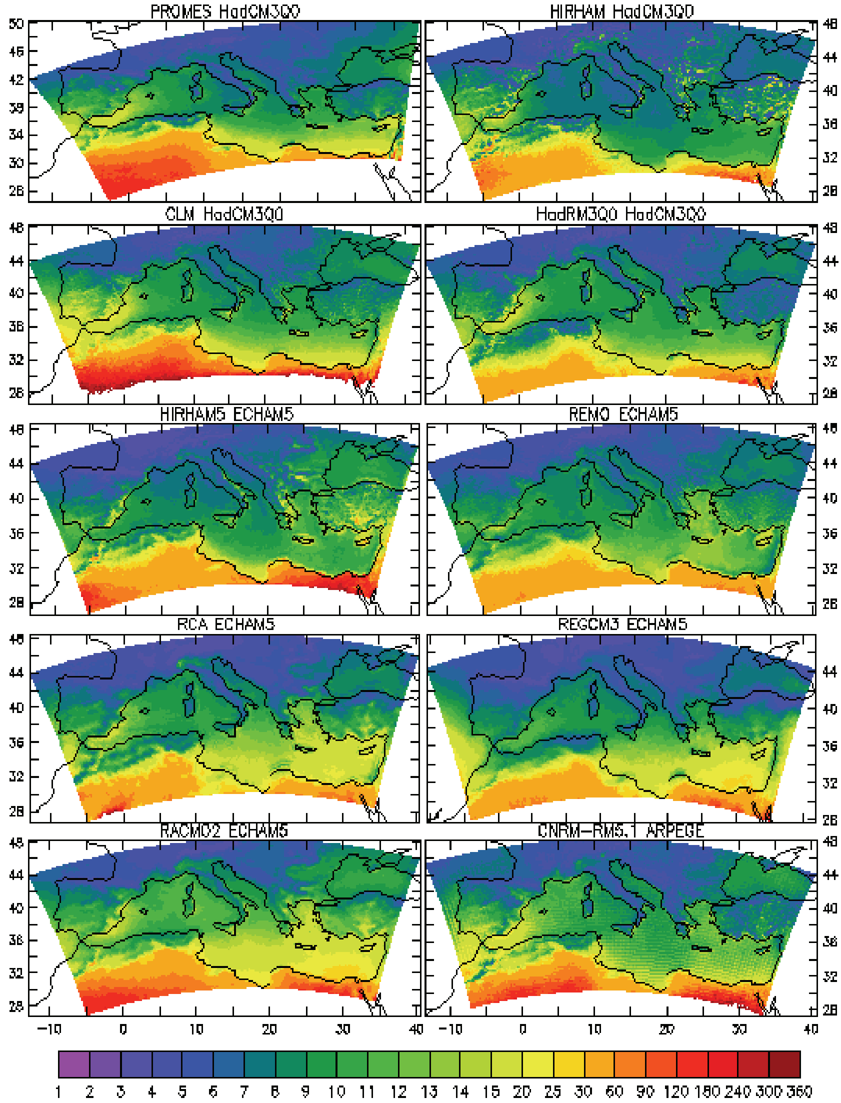

Fig. 2. Spatial distribution of DSML index (days/year) for historical climate (1951 – 1980).

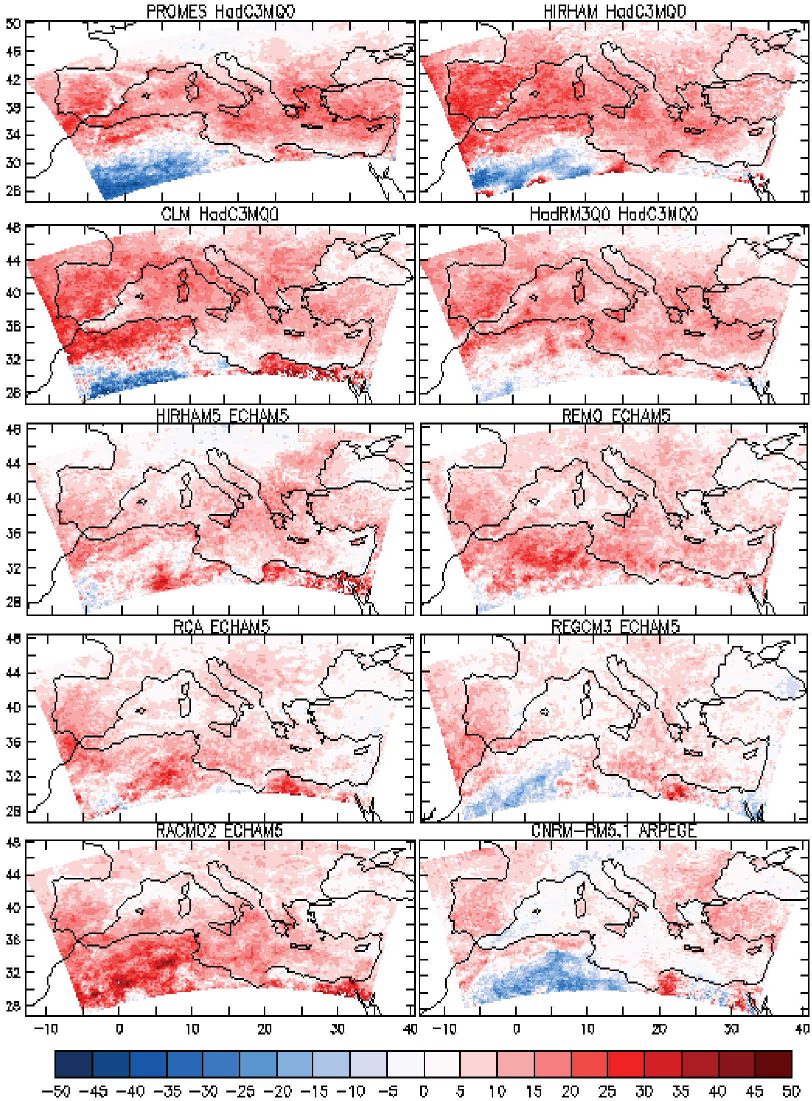

Fig. 3. Percentage change (2050-2021) – (1951-1980) of DSML under A1B emissions scenario.

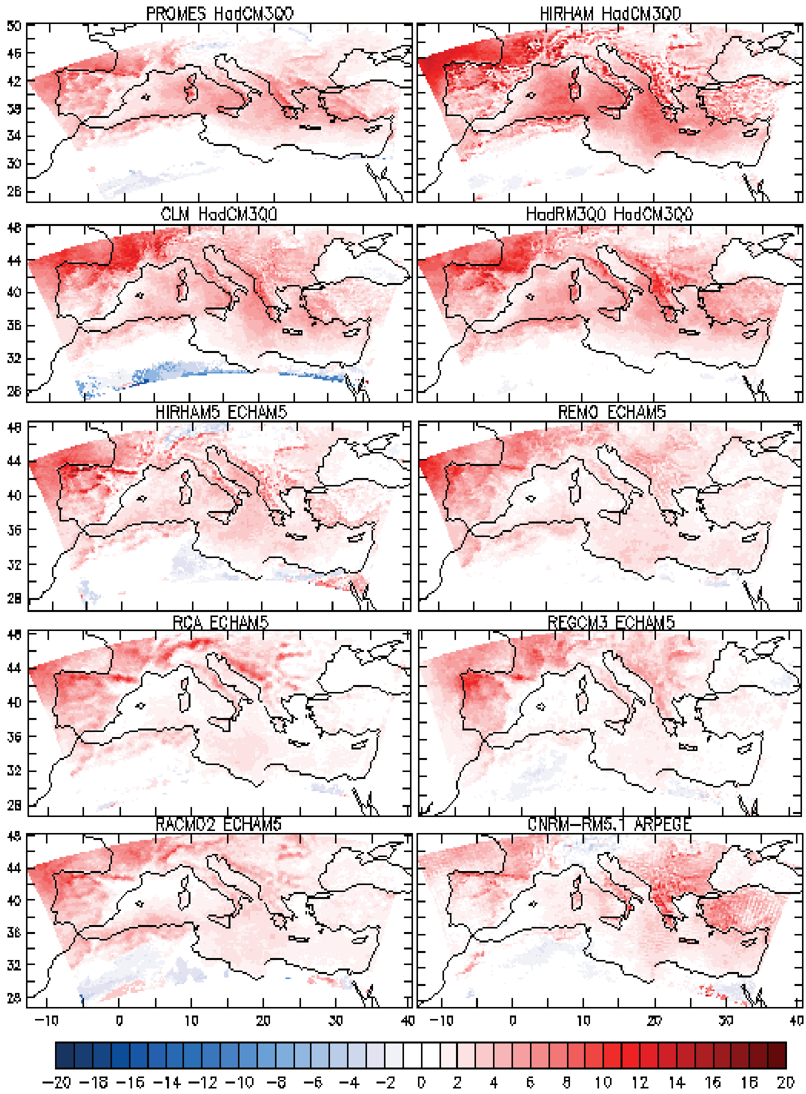

Fig. 4. Percentage change (2050-2021) – (1951-1980) of total days without precipitation (< 1 mm) under A1B emissions scenario.

The northern Mediterranean areas do not exhibit noticeable changes for most of the simulations, especially in the ECHAM5-forced RCM ones. The HadCM3-forced RCM simulations obtain the largest mean duration change over the Iberian Peninsula and Atlas mountains (by +50%), in contrast to ECHAM5-forced RCM simulations, that present a smaller (by +15%) change over the domain. The eastern Mediterranean basin displays increases by +10 % in ECHAM5-forced RCM simulations and CNRM-RM5.1, while the HadCM3-forced RCM simulations project change by +25%. Values of change over the sea follow a similar pattern of increase to what is obtained over land. Despite the forcing GCMs, some RCM simulations (PROMES, HIRHAM, CLM, REGCM3, CNRM-RM5.1), indicate a clear percentage decrease in the DSML, by -30%, over the Sahara desert. To understand this latter result, Figure 4 has been included. This figure represents the percentage change of the total number of days without precipitation.

The Sahara area presents small decreases in the same RCM simulations where in the Figure 3 a decrease in the DSML index is obtained. As this region is characterized by very long dry spells limited by very scarce rain episodes, a small change in the number of precipitation days can lead to an important change in the DSML in the future. Therefore, these changes over the Sahara region are not very relevant from a climatic perspective for dry spells analysis. Looking at other regions of the domain, a small increase of days without precipitation is shown, with a maximum by 20 % in the northern Mediterranean areas. This means that the DSML are mainly increased due to a reduction of the number of days with precipitation.

4. Summary and Conclusions

There is a close correspondence between the ECAv6 observational database and the ERA40 reanalysis-forced Regional Climate Model simulations in the baseline period (1961-2000) to describe the annual dry spell mean length over the Mediterranean regions. Therefore, the RCMs are an adequate tool to analyse DSML present characteristics and how are they projected to change under future climate conditions.

A North-to-South gradient can be observed over the Mediterranean basin regions in historical climate, with the highest values (around 70 to 150 days/year) in the Sahara desert and the lowest (around 5 days/year) in the northern Mediterranean areas. According the DSML features, six subregions into the Mediterranean basin can be distinguished: northern, eastern, central and western Mediterranean areas, Atlas Mountains and the Sahara desert. This regional-dependence result strengthens the utility of the RCMs to reproduce the influence of the Mediterranean complex regional morphology on the DSML characteristics. This is the case, for example, of the Atlas range mountain or the Ebro river basin. ENSEMBLES RCMs have been shown to adequately represent the main atmospheric circulations patterns involved in the precipitation regime (Sanchez-Gomez et al., 2009). Here we obtain, as it could then be expected, that they are also capable to describe the spatial distribution and features of the dry spell lengths over Mediterranean basin.

An increase of DSML (by +25%) under future climate conditions (2021-2050) is projected by all the simulations under A1B emissions scenario over almost all the domain except in the Sahara desert compared with (1951-1980) period. This

Sahara sub-region presents a decrease of the length in some RCM simulations up to -30%. As the Sahara region is characterised by very low number of rainy days, the small decrease of the total number of dry days obtained produces a large change of the DSML.

The GCM-forced RCM simulations do not exhibit a relevant relationship between the DSML spatial features and the GCMs used in the forcing.

The obtained results agree with previous similar studies and underline the interest of using Regional Climate Models as an essential tool to evaluate the potential changes of climate characteristics under climate change scenarios and its associated impacts in areas with a complex orography, such as the Mediterranean basin.

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