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FUTURE CHANGES IN THE OCCURRENCE OF EXTREME PRECIPITATION EVENTS IN EASTERN MEDITERRANEAN

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ABSTRACT

The aim of this study is to estimate future potential changes in duration of extreme dry and wet spells and rainfall intensity in Eastern Mediterranean. For this purpose, daily precipitation amounts, deriving from the regional climate model of UK Hadley Centre HadRM3P have been used for the present (1960-1990) and the future period 2070-2100 on 0.44° x 0.44° latitude by longitude grid. Future data are based on B2 IPCC emission scenario.

For the identification of precipitation extremes three climatic indices were employed: a) CWD (Maximum number of consecutive wet days), b) CDD (Maximum number of consecutive dry days) and c) SDII (quotient of precipitation amount of wet days and the number of wet days of the period). They were calculated for the present and future period, on a seasonal and annual basis.

A general future tendency was found towards drier Eastern Mediterranean, with reduced rainfall intensity. Longer dry spells are expected in all seasons, except autumn, with the largest increase in the southern part of the area. Extreme wet spells will shorten everywhere during all seasons, except autumn. Precipitation intensity was found reduced for all seasons and mostly for summer in South Aegean Sea.

KEYWORDS: daily precipitation, climatic indices, wet-dry spells, precipitation intensity, HadRM3P.

1. INTRODUCTION

Growing atmospheric concentrations of greenhouse gases are associated with changes in the average climate (Houghton *et al*., 2001). Recently, the attention of the climatic research has shifted to likely future behavior of the occurrence and intensity of extreme events under climate change (Kostopoulou and Jones, 2005; Frich *et al*., 2002; Tebaldi *et al.*, 2006; Casas *et al*., 2007). It is stated that potential changes in extreme events can generate greater impact on human activities and natural environment than mean climatic changes (Kunkel *et al*., 1999a). Especially, the study of precipitation extreme events can be particularly meaningful, since these events can generate important natural hazards and associated social impacts. Following this perspective, the analysis of extreme precipitation events in the present and future climate is of great importance.

Detection of future changes in extreme precipitation is performed with the aid of climatic models that refer to different spatial scales: a) General Circulation Models (GCM) that simulate the climate on a global scale b) Regional Climate Models (RCM) that simulate regional climate with a smaller resolution, based on better topography representation. The RCM require as an input, data of a broader area, as derived by the GCM.

Mediterranean basin is one of the most sensitive areas regarding the future precipitation extreme conditions, since it lies in the transitional zone between Northern Africa and Southern Europe (Meteorological Office, 1962). The Mediterranean area is dominated by regular aridity during summer and recurrent periods of drought or extreme precipitation events during rainy seasons (Kunkel *et al*., 1999b). The European project MICE (Modelling the Impacts of Climate Extremes) recently demonstrated with the aid of RCM that Mediterranean is expected to become generally drier with prolonged droughts commonplace in summer and reduced rainfall in winter, while a higher proportion of rainfall will fall on very wet days (Holt and Palutikof, 2004). Future climatic projections, as derived by recent regional models studying Europe and Mediterranean, generally agree with a decrease of precipitation in the Mediterranean following the CO_2 increase (Houghton *et al*., 2001; Hanson *et al.,* 2007).

For Eastern Mediterranean, the research of precipitation extremes is more complicated, as compared to other Mediterranean areas, due to the complex topographical features and the sparse station data. Recent studies have shown an increasing tendency of dry spell length during the last two decades in Eastern Mediterranean (Anagnostopoulou *et al*., 2003; Kutiel, 1985), as well as a tendency towards drier conditions (Kutiel *et al*., 1996; Turkes, 1996; Tolika *et al*., 2004).

The aim of this study is to estimate future potential changes in duration of extreme dry and wet spells and rainfall intensity in Eastern Mediterranean, for the future period 2070-2100 under certain evolvement of the future atmospheric concentrations of greenhouse gases, on annual and seasonal basis, with the aid of the results of a regional climatic model. The identification of the precipitation extremes was performed with the aid of climatic indices that were found to be homogeneous, easy to understand and relevant to the practical concerns of policy makers.

2. DATA AND METHODOLOGY

The studying area is the Eastern Mediterranean, which extends from the Ionian Sea to the Cyprus area (Figure 1). Daily precipitation amounts are used, as derived from the regional climatic model of the UK Hadley Centre, HadRM3P, covering the present period 1960-1990 (control run) and the future period 2070-2100. The data are available on 0.44° x 0.44° latitude by longitude grid (equivalent to about 50 km x 50km) through the European project MICE (Modelling the Impacts of Climate Extremes). The regional model is also extended vertically from surface to stratosphere, separated in 19 levels and up to the height of about 30 kilometres, while it is stretched vertically under the surface of earth up to four levels. Furthermore, the model includes the atmospheric physical processes at the surface of the earth, and is able to simulate the sulphur cycle with an understandable way (Hanson *et al*.). The future data are based on the B2 IPCC emission scenario, as set by the IPCC-SRES (Inter-governmental Panel on Climate Change-Special Report on Emission Scenarios). This scenario is a medium low scenario, regionally oriented, that considers CO_2 concentrations at 562ppm and expected global temperature increase by around 2.3°C until 2080 (Nakicenovic and Swart, 2000).

In order to verify the appropriateness of the model to simulate the regional climate in future in Eastern Mediterranean, the model data are compared with station data for the time period 1960-1990. This particular reference period has been widely adopted by modelers because it is not associated with important anthropogenic changes in the chemical composition of the atmosphere that mainly occurred during the recent two decades. It is also recommended by the WMO as the standard period for calculating normals. For this purpose, linear correlation analysis between the time series of each station and the nearest grid point was performed on a seasonal and annual basis. Then, the quotient of the standard deviation of the two datasets was assessed on seasonal and annual basis (model data / station data), to compare the variability of model output with station data for the present period. The station data are available through the framework of the European research project STARDEX (STAtistical and Regional dynamical Downscaling of EXtremes for European regions), the European Climate Assessment and Dataset (ECA & D), the National Climatic Data Center (NCDC) and the Meteorological Service of Cyprus. The station network includes 7 countries, covering the European and Asian side of the Mediterranean Sea with 39 stations distributed within the Eastern Mediterranean region (see Figure 1). More specifically, there are 21 stations in Greece, 8 in Turkey, 2 in Cyprus, 4 in Israel, 2 in Syria, 1 in Lebanon and 1 in FYROM.

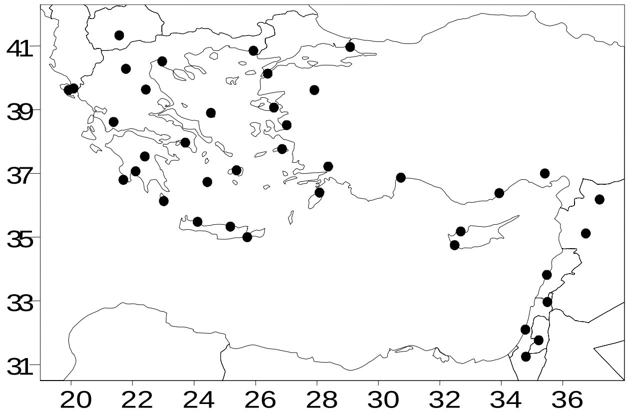

Figure 1. The examined area of Eastern Mediterranean.
The dots represent the position of the stations used

Climatic extreme precipitation events are defined with the aid of three climatic indices. The indices are recommended by the joint Working Group on Climate Change Detection of the World Meteorological Organization – Commission for Climatology (WMO-CCL) and the research program on Climate Variability and Predictability (CLIVAR), as well as from the European research project STARDEX. More specifically, in this study the following indices are employed: a) **CDD** (Maximum number of consecutive dry days), representing the maximum length of dry spells b) **CWD** (maximum number of consecutive wet days), representing the maximum length of wet spells, and c) **SDII** (Simple Daily Intensity Index,) expressing the quotient of the precipitation amount of wet days and the number of the wet days of the specified period, serving as measure of rainfall intensity. All three indices do not require the meaningful employment of fixed threshold values, which are not applicable for all stations. Furthermore, they could be considered indicators of moderate climate extremes (e.g. events that have a return period of 1 year or less), since it is not possible to look at more extreme events when only 31 years of data are available and their relation to climate variability with any statistical confidence.

As dry day is defined the day with rainfall less than 1mm, while a wet day is a day with precipitation amount greater than or equal to 1mm. The indices are calculated for the present period 1960-1990 and for the future period 2070-2100, employing model data on a seasonal and annual basis. Then, the differences between future averages (2070-2100) of seasonal and annual values and corresponding present values (control run) for all three indices are computed (future minus present).

3. MODEL VALIDATION

The validation of model data against station data of daily precipitation for the present period in Eastern Mediterranean has demonstrated that there is a quite good agreement between the two datasets. The comparison of the spatial distribution of the mean seasonal and annual values between the two datasets demonstrated that the model shows a coherent pattern: the highest precipitation amounts are found in Western Greece and southeastern Aegean Sea, during winter, autumn and on annual basis, while summer precipitation amounts are small, especially over the islands of Aegean Sea, Israel and Syria (Xoplaki *et al*., 2000; Kutiel *et al*., 1996; Tsvieli and Zangvil, 2005). The correlation coefficients are in general low, as compared to temperature data (Hanson *et al*., 2007), reaching the value of 0.6-0.7 (Figure 2). This is possibly associated to non-adequate representation of the topography and smaller scale condensation processes by the climate model (Barring *et al*., 2006) The correlation improves in winter (not shown), as compared to the other seasons, and over land than over sea, since the precipitation regime is mostly controlled by synoptic scale systems, rather than topographical factors during this period of the year (Haylock and Goodness, 2004). The highest correlation coefficient was found in Western Greece and West coastal Turkey. On annual basis, it was found that the variability of precipitation model data is about 1.1 to 1.3 times greater than the variability of station data over the land, while over the sea the variability of the station data is 1.5 to 2 times greater than the model data (Figure 3), consistent with the results of Jacob *et al.* (2007) for the whole Mediterranean. For winter (not shown), the variability of precipitation model data was estimated about 1.3 times greater than the variability of station data over the land. The opposite is observed over the sea, where the variability of the station data is 1.2 to 1.7 times greater than the model data. The variability of precipitation values is underestimated by the model output (control run) for spring, summer and autumn in almost the whole examined area, by 0.5 to 0.8 (not shown).

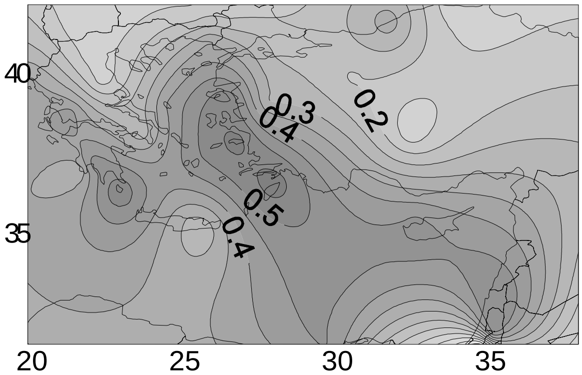

Figure 2. Correlation coefficients between model and station precipitation data on annual basis for the period 1960-1990 over the examined region

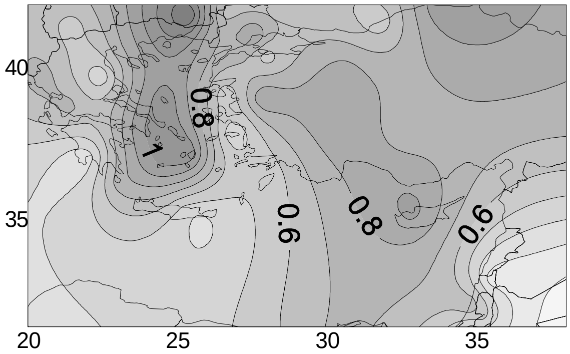

Figure 3. Quotient of standard deviations of the model and the station precipitation data calculated on annual basis for the period 1960-1990 over the examined region

4. RESULTS-DISCUSSION

The assessment of CDD index demonstrated that, in general, the length of extreme dry spells increases in the future, as compared to the present climate on annual basis, in accordance with the results of Frei *et al*. (1998) for Europe and Gibelin and Deque (2003) for Mediterranean. The magnitude of change varies spatially and seasonally. More specifically, during winter, the future CDD is greater in almost the whole Eastern Mediterranean, except in North Western Greece, where no significant change was found. Southern Aegean, Crete and West Cyprus present the largest increase of dry spell length, of about 6 to 7 days (Figure 4a). In spring, extreme dry spells are longer in the future in the whole examined area, with no substantial variations (Figure 4b). In summer, CDD index presents the highest increase, as compared to winter and spring, with maximum values being found mainly in the continental West Greece (10-14 days), and west coast of Turkey (10 days) (Figure 4c). Contrary to the other seasons, the duration of extreme dry spells is slightly reduced at about 2 to 6 days, in autumn in almost the whole examined area (Figure 4d). Therefore, it seems that the apparent drying of Eastern Mediterranean continue in future, in agreement with Kostopoulou and Jones (2005), especially in the dry period of the year and the wetter regions.

Following the future increase of dry spells, the wet spells are expected to reduce annually, in accordance with Holt and Palutikof (2004) for Mediterranean. The length reduction increases from winter to summer, when it is maximized. More specifically, extreme wet periods shorten during winter, everywhere by about 0.5 to 1.3 days, except in west Crete and west Cyprus, where there is no significant change. The greatest reduction (1.3 days) was noticed in Eastern Aegean Sea, Turkish coast and Southern continental Greece (see Figure 5a). For summer, the magnitude of the reduction of the CWD increases in the whole examined area, reaching to 1.6 days in northwest Greece and north coastal Turkey (Figure

5c), which are climatologically the wettest regions (Xoplaki *et al*., 2000; Turkes, 1996). However, a substantial increase is expected in the eastern part of the examined area, in Israel, Syria and Cyprus, where becomes as high as 0.6 days. Similar regional results with summer were found for spring, with comparable decrease magnitude (figure 5b). Contrary to the other seasons, autumn is characterized by an overall increase of the wet length duration in the future, ranging from 0.2 to 1.6 days, while no significant change was found in Macedonia, western Greece, and southeastern edge of the studying area. The maximum increase was observed in southern Aegean and the Turkish coast (Figure 5d). Thus, it can be stated that in the future the wettest areas of Greece show a reduction of extreme wet spells length during the wet period of the year.

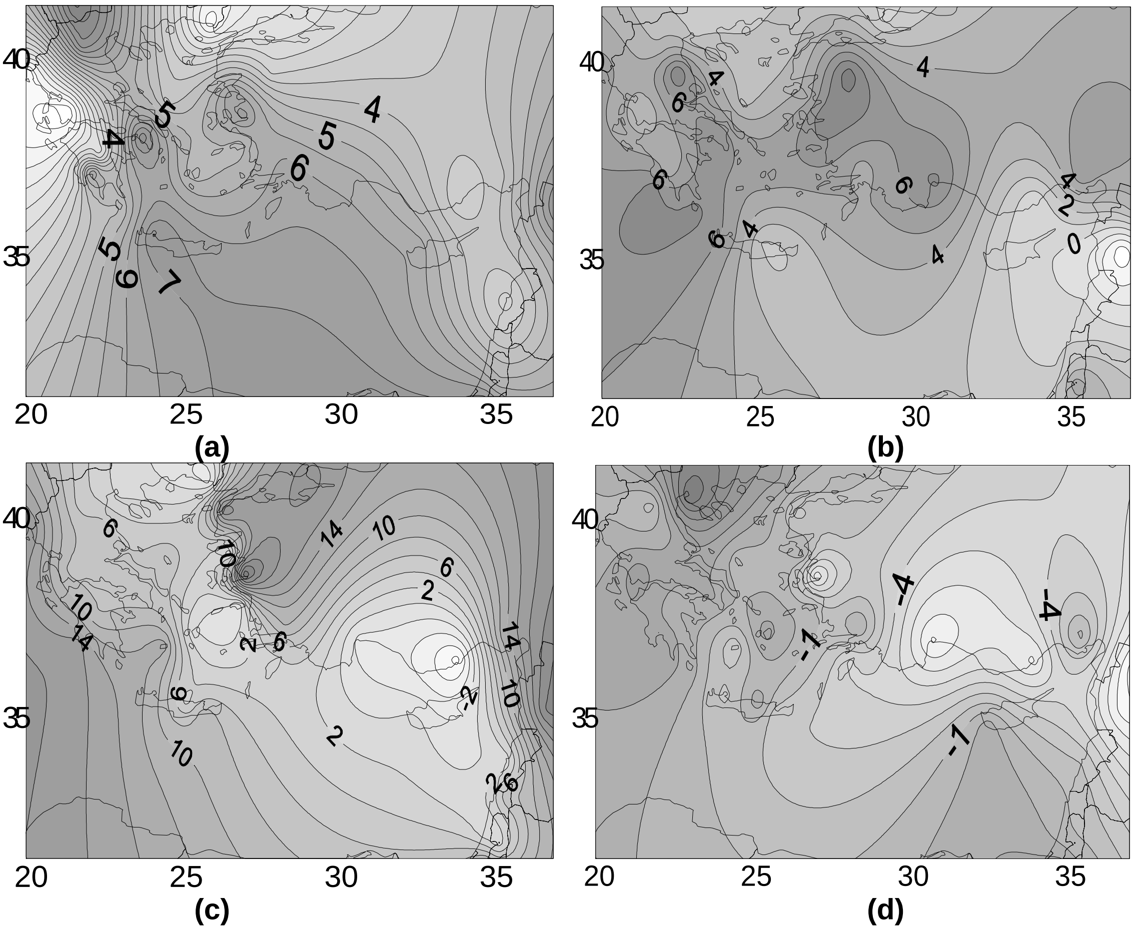

Figure 4. Absolute differences of CDD between future (2070-2100) and control run (1960-1990) for (a) winter, (b) spring, (c) summer, (d) autumn

The SDII index presents small increase in the future, with significant spatial and seasonal variability. The highest annual increase appears in Crete and central Aegean Sea, as well as in Syria, reaching up 1.2 mm d^{-1}, in accordance with Tolika *et al*. (2004). No significant difference was found in western Greece, eastern Aegean Sea and southern Turkey, which are climatologically characterized by high precipitation amounts. These results are consistent with Kostopoulou and Jones (2005). In winter, a slight reduction (up to 1 mm d^{-1}) of rainfall intensity is evident, mainly in the Greek mainland, while an increase of similar magnitude prevails in Aegean Sea, Crete, Cyprus and Turkey (Figure 6a). No substantial change was found in the remaining area. In spring, the reduction prevails in almost all the examined area, apart from Cyprus and Israel where it slightly increases (up to 0.4 mm d^{-1}). The magnitude of the decrease reaches to 1 mm d^{-1} (Figure 6b). Similar pattern of the SDII change is displayed in summer, with, however, lower magnitude (Figure 6c). In autumn, the rainfall intensity presents an increase in the future (Figure 6d), in agreement with the results of Frei *et al*. (1998), deriving from a regional climate model simulation over Europe. The maximum value of increase (of 1.4 mm d^{-1}) is expected in south Aegean Sea and along the western coast of Turkey. The overall increase of rainfall intensity in the eastern part of the examined region complies with the expected frequency increase of intense cyclones in the region of Cyprus (Anagnostopoulou *et al.*, 2006).

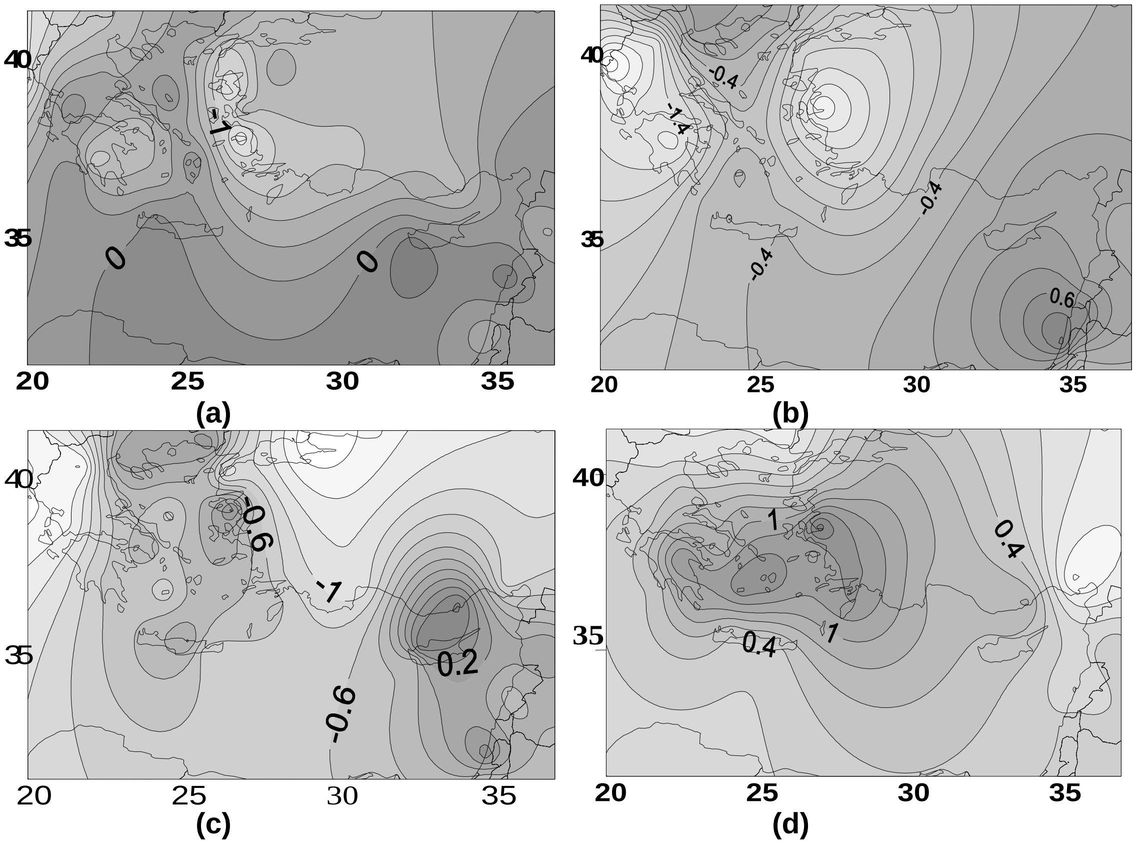

Figure 5. Absolute differences of CWD between future (2070-2100) and control run (1960-1990), for (a) winter, (b) spring, (c) summer, (d) autumn

5. CONCLUSIONS

In this study an attempt is made to estimate future potential changes in duration of extreme dry and wet spells and rainfall intensity in Eastern Mediterranean, for the future period 2070-2100, as derived from the results of the regional model HadRM3. For this purpose, three climatic indices have been employed: the maximum number of consecutive dry days (CDD) and wet days (CWD) represent the length of dry and wet spells, respectively, while the index SDII the rainfall intensity.

The employment of climatic indices to study the behavior of extreme precipitation events seems to be a useful and consistent approach, since they represent persistent dry and wet spells and heavy rainfall days for each station, without using different threshold values for each station, while they are relevant in terms of impacts. Furthermore, this approach can be transferable across a range of different climatic regimes and makes the results in Eastern Mediterranean comparable with those in other European regions.

Our analysis demonstrated a general future tendency towards longer extreme dry spells and accordingly shorter extreme wet spells for all seasons, except autumn, when the opposite behavior is predicted. The maximum increase of dry spell length is expected in winter in the southern part of Eastern Mediterranean basin, as well as in spring, reaching up to about 7 days.

The length of extreme wet spells is everywhere reduced in future, except in Crete, Cyprus and the eastern part of the examined area, where a slight change was found. The magnitude of reduction increases from winter to summer, when it is maximized in northwest Greece. On the contrary, in autumn, extreme wet spells are longer in future, especially in Aegean Sea and west coast of Turkey.

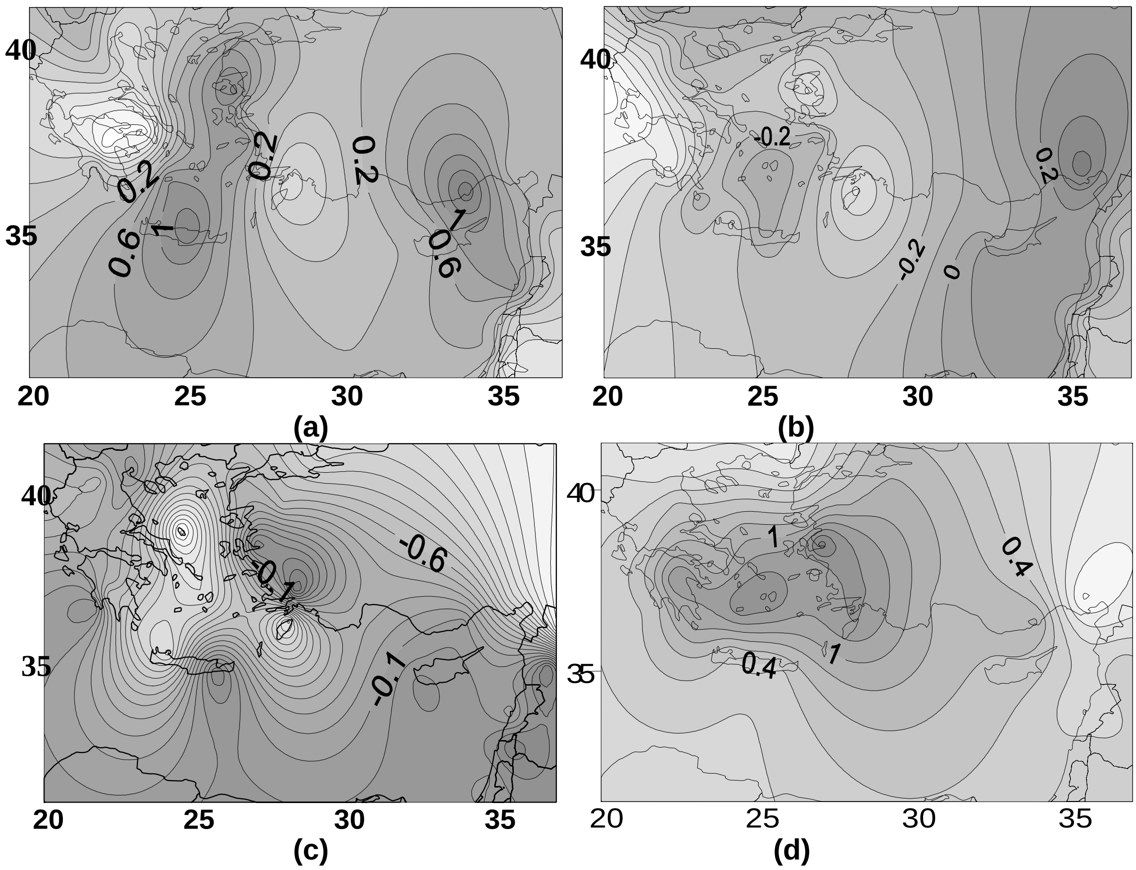

Figure 6. Absolute differences of the Simple daily intensity index (SDII) between future (2070-2100) and control (1960-1990), for (a) winter, (b) spring, (c) summer, (d) autumn

Future changes of rainfall intensity are smaller and show substantial spatial and seasonal variability. The rainfall intensity decreases in winter, spring and summer, but increases in autumn. The greatest reduction is found in summer in south Aegean region.

Overall, it can be concluded that eastern Mediterranean tends to be drier in future and with reduced rainfall intensity. However, it should be mentioned that there are uncertainties in the response of climate and its variability that are driven by the fact that there is much we do not understand about the workings of the climate system and, hence, they arise because of incorrect or incomplete description of key processes and feedbacks in the model, such as ocean-atmosphere interaction, carbon cycle, aerosol chemistry and clouds. Besides, the natural variability of the climate, due to internal oscillations of the climatic system, as well as to external forces - such as sun and volcanoes - is expected to continue in the future, but it is not taken into account by the future projections. Finally, the uncertainty in regional climate change is caused by the difficulty to include in the GCMs the regional characteristics, such as the terrain and their impact in future changes. Although the results of the present study provide a generalised plan of the future response of precipitation extremes to global warming in Eastern Mediterranean, they should be handled with caution, as implied by the above mentioned uncertainties. Further work is conducted within the European project ENSEMBLES, aiming to develop an ensemble prediction system for climate change, based on global and regional models developed in Europe and to quantify and reduce the uncertainty in the representation of physical, chemical, biological and human-related feedbacks in the Earth System.

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