The Impact of the Eastern Mediterranean Teleconnection Pattern on the Mediterranean Climate

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ABSTRACT

The objective of this study is to investigate the impact of the eastern Mediterranean teleconnection pattern (EMP) on the present and future climate of the eastern Mediterranean during winter. For the present climate, daily precipitation and maximum and minimum surface temperature station data are employed for the period of 1958–2003. For the future climate, datasets of the same parameters are derived from the Hadley Centre Regional Climatic Model (HadRM3P) for the period of 2070–2100, using two Intergovernmental Panel on Climate Change (IPCC) emission scenarios for the evolvement of the future atmospheric concentrations of greenhouse gases. The investigation of the impact was based on the regularized canonical correlation analysis (RCCA), while qualitative estimations were performed for each phase of the pattern. It was found that the pattern indeed affects the mean winter patterns of temperature, precipitation, and their extreme events with inverse impacts between the two phases. More specifically, a positive phase of EMP is associated with a decrease in temperatures and an increase in precipitation, while the opposite occurs during the negative phase of EMP. In the future, the present impact according to each phase persists and intensifies in most of the cases. However, results are quite different between the two scenarios, because of the different estimated future shift of the EMP poles.

1. Introduction

As a significant component of natural climatic variability, teleconnections play an important role in determining changes of the regional climate. In the Mediterranean region, which lies in the transitional zone between northern Africa and southern Europe, the most prominent influence of an independent large-scale circulation mode is the North Atlantic Oscillation (NAO; Rodo et al. 1997; Dunkeloh and Jacobiet 2003; Martin et al. 2004; Türkes and Erlat 2003). More specifically, the eastern Mediterranean region is characterized by cooler and drier conditions during the positive phase of NAO, while the negative phase is related to anomalously warm and wet conditions (Xoplaki et al. 2000; Feidas et al. 2004). Hurrell (1995) has demonstrated that the decrease of precipitation totals during the previous decade in the whole Mediterranean is related to the persistent positive mode of the NAO, leading to enhanced westerlies over eastern North Atlantic and northward shift of the storm tracks. Consistent with these results, Feidas et al. (2007) claimed that the downward trend of annual and winter precipitation in Greece may be attributed to the rising trend of NAO, while Türkes and Erlat (2005) found that the variability of winter precipitation in Turkey is significantly correlated with the variability of NAO indices.

The role of other teleconnection patterns on the eastern Mediterranean temperature and precipitation regime have also been demonstrated, such as North

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Sea–Caspian pattern (NCP; Kutiel et al. 2002) and the eastern Atlantic–west Russia pattern (EAWR; Krichak and Alpert 2005). The NCP in its positive phase causes below normal temperature in the Eastern Mediterranean, while the negative phase is associated with positive temperature anomalies (Kutiel et al. 2002). During the negative (positive) phase of EAWR wetter (drier) than-normal weather conditions prevail over a large part of the Mediterranean region (Krichak et al. 2002).

Changes in the chemical composition of the atmosphere in the last decades, resulting from enhanced human activities, are expected to influence the structure and intensity of the teleconnection patterns in the future, and subsequently their implications on the regional climate (Ulbrich and Christoph 1999; Hu and Wu 2004). This issue appears to be the subject of current climatological research with the aid of global circulation models (GCMs) and either regional climatic models or statistical downscaling methods. The European Modeling the Impacts of Climate Extremes (MICE) project recently demonstrated that under increasing temperature conditions, fewer but more intense storms are expected over northern Europe in the future period of 2070–2100. The Mediterranean will generally become warmer and drier, with prolonged droughts being commonplace in summer while a higher proportion of rainfall will fall on very wet days (Hanson et al. 2007).

In a previous study, Hatzaki et al. (2007) identified an upper-tropospheric teleconnection pattern between the eastern Mediterranean and northeastern Atlantic in the geopotential field during winter. This pattern that will be referred to as the eastern Mediterranean teleconnection pattern (EMP), was found to be more intense at 300 and 500 hPa during winter, weakens at lower levels, and ceases to exist at 1000 hPa. The negative and positive phase of the EMP were discriminated and it was found that during the negative phase a positive anomaly of 500-hPa geopotential heights forms over the eastern Mediterranean and northern Africa, implying an increased anticyclonic circulation, while during the positive phase a cyclonic anomaly predominates. Furthermore, Hatzaki et al. (2006) demonstrated, with the aid of both correlation and principal component analysis (PCA), that the EMP remains a component of the upper-level atmospheric circulation in the future, with an eastward shift of the two poles relative to present climate.

The objective of this study is (a) to investigate the impact of EMP on the mean and extreme temperature and precipitation regime of the eastern Mediterranean during winter for the present climate, using station data and (b) to estimate its possible impact in the future, under a warmer global climate, in accordance with future changes of EMP, using output data from a regional climate model.

2. Data

In this study the following datasets are employed for the present climate. (a) Datasets of daily geopotential height are obtained from the National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) reanalysis (Kalnay et al. 1996) for the isobaric level of 500 hPa. The datasets cover the period of 1958–2003 on a 2.5° latitude × 2.5° longitude grid for the quarter-spherical window extended from 0° to 90°N, and from 90°W to 90°E. (b) Datasets of daily precipitation and maximum and minimum temperature of 50 meteorological stations are also obtained. The stations that cover the eastern Mediterranean area are mostly located near the shoreline (Fig. 1) for the same period. Greek station data series, obtained from the Hellenic National Meteorological Service and through the European Statistical and Regional Dynamical Downscaling of Extremes for European Regions (STARDEX) project, have been checked using the standard normal homogeneity test (Alexander 1986) and can be considered homogeneous (Maheras et al. 2004, 2006). The Cyprus data series have undergone quality control by the Meteorological Service of Cyprus, which provided the data. The rest of the Mediterranean stations data series are available from National Climatic Data Center (NCDC), choosing those stations whose data series cover the examined time period. NCDC datasets have undergone extensive automated quality control to correctly decode as much of the synoptic data as possible and to eliminate many of the random errors found in the original data (information available online at http://www.ncdc.noaa.gov/oa/climate/climatedata.html).

For the future climate, the study is based on the following datasets: (a) 500-hPa geopotential height of the Hadley Centre Global Circulation Model (HadAM3P) on a 2.5° × 2.5° grid for the period of 2070–2100 and (b) gridded data of daily precipitation and maximum and minimum surface temperature for the eastern Mediterranean region, as derived from the Hadley Centre Regional Climatic Model (HadRM3P), with a resolution of 0.44° × 0.44° for the same period. Both models are driven with the observed sea surface temperature (Johns et al. 2003; Jacob et al. 2007). HadAM3P data became available through the European Union (EU) STARDEX project, while HadRM3P data through the EU MICE project.

These datasets for the future climate were based on two Intergovernmental Panel on Climate Change (IPCC)
emission scenarios for the evolution of the future atmospheric concentrations of greenhouse gases: A2a and B2a. In particular, the A2a scenario results in medium-high emissions, with atmospheric CO$_2$ concentrations reaching 715 ppm and global temperatures expected to increase by around 3.3°C by the 2080s. The B2a emission scenario is medium low, with CO$_2$ concentrations at 562 ppm and global temperatures expected to increase by around 2.3°C by the 2080s (Nakicenovic and Swart 2000).

3. Methodology

Since EMP was mainly identified from December to February, the mean winter values for each time series were calculated. Winters were extracted for each year using the December data of the previous year, according to this standard definition of winter, reducing the datasets by 1 yr.

A standardized teleconnection index is usually employed to determine the strength of a pattern and examine its time variations and implication to regional climate (Brunetti et al. 2002; Quadrelli and Wallace 2004). To define the EMP index (EMPI), the exact position of the two base points, representing the two poles, was determined. In this attempt, the results of both correlation and rotated principal component analyses (RPCA) at 500 hPa were taken into account, to appropriately employ the dynamic variability of the pattern throughout the whole year (Hatzaki et al. 2007).

Finally, the index was defined in the present climate as follows: \( \text{EMPI} = Z_{500}(52.5^\circ\text{N}, 25^\circ\text{W}) - Z_{500}(32.5^\circ\text{N}, 22.5^\circ\text{E}) \), where \( Z_{500} \) is the mean winter geopotential height at 500 hPa of the grid point that forms each pole, respectively (Fig. 2).

For the future climate, Hatzaki et al. (2006) have demonstrated with the aid of RPCA that the overall pattern is retained; however, the two EMP poles appear to be shifted in relation to their present positions (Fig. 2). Therefore, because of the apparent shift of the two poles of the pattern, the EMPI needs to be revised for both scenarios, as compared to the definition for the present climate. The index is then redefined, as follows: for the control run, \( \text{EMPI}_{\text{control run}} = Z_{500}(47.5^\circ\text{N}, 22.5^\circ\text{W}) - Z_{500}(30^\circ\text{N}, 27.5^\circ\text{E}) \); for the A2a scenario, \( \text{EMPI}_{\text{A2a}} = Z_{500}(60^\circ\text{N}, 12.5^\circ\text{W}) - Z_{500}(42.5^\circ\text{N}, 27.5^\circ\text{E}) \); and for the B2a scenario, \( \text{EMPI}_{\text{B2a}} = Z_{500}(47.5^\circ\text{N}, 2.5^\circ\text{W}) - Z_{500}(30^\circ\text{N}, 32.5^\circ\text{E}) \).

After defining the EMP index for the present and future winter periods, the positive and negative phases of EMP were identified with the aid of corresponding standardized index, as follows: \( z_i = (\text{EMPI}_i - \text{EMPI}_{\text{avg}})/\sigma \), where the \( \text{EMPI}_i \) is the index value of the year \( i \), and \( \text{EMPI}_{\text{avg}} \) is its long-term average and \( \sigma \) the corresponding standard deviation for the present period of 1958–2003 or the future period of 2070–2100 under the two scenarios. Each value was classified in the positive and negative phase of the pattern, using the threshold value of 0.5. The positive phase of the index indicates that the difference between the geopotential heights of

![Fig. 1. Geographical chart of the eastern Mediterranean basin, where the location of the stations is displayed.](image-url)
the two centers appears diminished, while during the negative phase this difference is increased (Hatzaki et al. 2007).

To investigate the relationship between the EMP and the regional rainfall or temperature regime in the eastern Mediterranean, a sophisticated statistical method, the regularized canonical correlation analysis (RCCA), was employed. Canonical correlation analysis (CCA) has been widely used to investigate the impact of large-scale circulation on the regional rainfall or temperature regime (Xoplaki et al. 2000; Dunkeloh and Jacobit 2003; Bartzokas et al. 2003; Wallace et al. 1992; Barnett and Preisendorfer 1987). In general, CCA allows the investigation of the linear relationship between two different fields and determines optimal pairs of concomitant spatial patterns that account for the maximum amount of variance within the two time series separately, and, at the same time, their optimally correlated time components. Pairs of spatial patterns (canonical loadings) are derived from the two datasets, in such a way that the correlation of their time coefficients (canonical scores) is maximized, giving a measure of the degree of association between the two temporal patterns. The canonical scores, representing the intensity of the atmospheric circulation mode, are normalized to unity, so that the canonical correlation patterns represent the typical strength of the corresponding spatial patterns (Von Storch and Zwiers 1999). Here, the RCCA is applied to seek correlations between two data matrices $X$, $Y$ when the number of columns (variables) exceeds the number of rows (observations). As the number of variables increases, greatest canonical correlations are nearly 1 resulting from recovery of the canonical subspaces that do not provide any meaningful information. To deal with this problem, a regularization step is included in the calculations by adding a regularization parameter $\lambda_1, \lambda_2$ on the diagonal of each correlation matrix of $X$ and $Y$, respectively, and so allow the inversion (Leurgans et al. 1993).

In the present study, the calculations were performed with the aid of the statistical language R (Gonzalez et al. 2008). The RCCA was applied to the gridded data of mean winter NCEP–NCAR geopotential height values for the region extending from 60°W to 60°E and from 25° to 70°N and to the corresponding station data of precipitation and maximum and minimum temperature for the eastern Mediterranean region. Because we compare observational data with gridded data, standardized anomalies were obtained at each grid point and each station by subtracting the long-term winter mean from the original values (Bretherton et al. 1992). The RCCA has been similarly applied on the model data for the pair of the 500-hPa HadAM3P geopotential height data and the HadRM3P surface data of precipitation and minimum and maximum temperature for the control run data (1960–90), as well as for the future scenarios A2a and B2a (2070–2100).

To further assess and quantify the impact of the EMP on the present climate of the eastern Mediterranean, the composite anomalies of the mean winter precipitation and maximum and minimum temperature during the either positive or negative EMP phase was calculated.
from the corresponding long-term mean value of the present period, 1958–2003. Similarly, composite anomalies of the same parameters were calculated for the future positive or negative phase from the corresponding average value of the future period of 2070–2100. This calculation was held for each station for the present climate and for the corresponding HadRM3P grid points that are nearest to each station for the future climate. The statistical significance of the anomalies has been examined at the 0.05 significance level.

The identification of the climatic extremes was performed with the aid of climatic indices that were easy to understand and relevant to the practical needs of policy makers. In this study, temperature and precipitation indices were selected from the list of climate change indices recommended by the World Meteorological Organization (WMO) and STARDEX. The indices were selected in such a way as to best represent the duration and intensity of extreme events at each station (grid), without requiring the use of fixed threshold values that are not applicable for all stations (grids).

More specifically, in this study the following indices were employed: (a) the maximum number of consecutive dry days (CDD), representing the length of dry spells, (b) the total precipitation amount divided by the number of days with precipitation equal to or greater than a threshold of a specific period (SDII), serving as measure of rainfall intensity, (c) the 90th percentile of maximum temperature (Tmax90), representing extremely warm episodes, and (d) the 10th percentile of minimum temperature (Tmin10), representing extremely cold episodes. The indices were calculated on a seasonal basis for the entire present and future periods in the eastern Mediterranean and the composite anomalies were calculated for each phase of each index. It should be mentioned that for the calculation of the indices complete data series are preferred, and for this reason a smaller number of stations is employed as compared to the mean distributions, resulting in reduction of the covered area.

### 4. Model validation

The validation of all future datasets was performed for the period of 1960–90 (control run), which is the standard validation period used in most climate modeling studies. The validation of the HadAM3P 500-hPa geopotential heights was performed against the corresponding NCEP–NCAR values, which were used as “observed reference,” for the present period of 1960–90. The HadRM3P output was verified against the corresponding station data for the period of 1960–90.

Anagnostopoulos et al. (2008) have compared the HadAM3P and the NCEP geopotential values at the isobaric level of 500 hPa on a seasonal basis over the greater European area and the Atlantic. For winter, it was shown that the biases between the two datasets are comparable to the natural variability of 500-hPa geopotential height, while the two datasets exhibit similar variability over the entire examined area, except over the African and subtropical Atlantic part, whereas the HadAM3P data are characterized by lower variability. Furthermore, Hatzaki et al. (2006) have demonstrated that the HadAM3P winter values are higher compared to the corresponding NCEP–NCAR values over the region of the northern pole of the EMP (northwestern Europe), with maximum bias reaching 35 gpm, while no significant biases (less than 15 gpm) are evident over the region of the southern pole (the eastern Mediterranean).

Moreover, the variability of the two datasets is similar (the standard deviation ratio ranges between 0.9 and 1).

Concerning the HadRM3H, the older version of the HadRM3P, the gridded sea level values were extrapolated to the corresponding station height using the mean vertical temperature gradient and they were validated against data of the nearest station during the baseline period of 1960–90. Jacob et al. (2007) found a mean winter bias of temperature and precipitation in the whole Mediterranean of −0.34°C and −0.6 mm day⁻¹, respectively (see Table 1). HadRM3H also presents a slightly higher interannual variability compared to the Climatic Research Unit (CRU) observational dataset, reflecting the fact that the driving HadAM3H, the older version of the HadAM3P, is too zonal, resulting in a wet climate in central and northern Europe as opposed to a dry and colder climate in the Mediterranean region (Van Ulden et al. 2007). In summer, HadRM3H is too warm and dry compared to CRU observational data, exhibiting a bias of over 3°C in temperature and −0.27 mm day⁻¹ in precipitation, and there is also a
clear signal that HadRM3H modeled temperature variability is larger than suggested by the CRU dataset, while precipitation variability is closer to the observations. The overestimation of the summer temperature variability in the Mediterranean region is probably due to the overdrying of the surface in HadRM3H, causing very high temperatures in late summer (Lenderink et al. 2007).

In the examined region of the eastern Mediterranean, the values for temperature were highly correlated over the entire examined period, reaching up to 0.97. The biases between the model and station data indicate an underestimation of temperature (from 1° to 4°C) over Greece and Turkey and an overestimation over Israel. The precipitation model data are characterized by correlation of 0.4–0.5 over Greece (and mainly over the islands), which is more likely associated with non-adequate representation of the orography and smaller-scale condensation processes by the climate model. Hanson et al. (2007) concluded that the HadRM3P tends to underestimate temperature extremes and to overestimate precipitation extremes over Europe. Moreover, they claimed that the interannual variability of precipitation is in relative good agreement with observations in winter. Barring et al. (2006) have also concluded that the HadRM3P model is generally drier than the observations over Europe and suggested that land–sea contrast and local topography factors may account for the model inability to represent precipitation.

The next step of validation of the HadAM3P model with respect to the examined EMP pattern was to investigate the capability of the model to reproduce the pattern in the control run. For this reason, rotated principal component analysis was applied, using varimax rotation for the principal components (PCs; Horel 1981) in the model mean winter values of geopotential height at 500 hPa. Similarly to the method used by Hatzaki et al. (2007), the first four PCs are retained that satisfy the empirical criterion of each component explaining more than the 10% of the total variance, trying to keep the PCs with physical interpretability (Kushnir and Wallace 1989). These PCs share 70% of the total variance, approximately. According to Fig. 3, which presents the spatial patterns associated with the first four PCs, the model has indeed substantiated expected patterns of the upper-air circulation over the examined region: the eastern Atlantic pattern (Fig. 3a), the Polar–Eurasian pattern (Panagiotopoulos et al. 2002; Fig. 3b), and the NCP (Fig. 3c), while the EMP emerges as the forth component (Fig. 3d), explaining 13% of the total variance. Therefore, it is found that the EMP poles, as derived during the control run, almost coincide with those derived from NCEP data (Fig. 2), supporting the notion that the future shift of the poles does not entirely reflect a model bias. However, the HadAM3P simulates a reduced relative importance of EMP because the pattern is represented as the forth component, rather than as the first one in the present climate (Hatzaki et al. 2007).

5. Impact on the present climate

a. Precipitation

Applying the RCCA on the standardized anomalies of geopotential heights and precipitation, it was found...
that the second RCCA pair reveals the EMP in the field of geopotential heights (Fig. 4). It was found that when an anomalous high predominates over the Eastern Mediterranean, signifying the negative EMP phase, the precipitation over this region is below normal, especially over the southern Aegean Sea and eastern edge. On the contrary, an upper-level cyclonic anomaly, which is actually associated with the positive EMP phase, leads to an increase in precipitation over the eastern Mediterranean.

More specifically, during the positive phase, the examination of the composite anomalies reveals that the

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**FIG. 4.** Canonical correlation loadings of the RCCA pairs for the standardized anomalies of 500-hPa geopotential heights and (a) precipitation, (b) maximum temperature, and (c) minimum temperature for the present climate (NCEP–NCAR). The dashed contours indicate negative values.

**FIG. 5.** Composite anomalies of winter mean precipitation during the (a) positive and (b) negative phase of EMP for the present climate (1958–2003). The dashed contours indicate negative values; contour interval (CI) is 0.1 mm day$^{-1}$.

Shaded areas indicate statistically significant anomalies.
increase is of 0.4–0.6 mm day\(^{-1}\) over the south Aegean, while it substantially intensifies toward the eastern edge of the basin (Cyprus and Israel), reaching up to 1 mm day\(^{-1}\). The increase is weaker (of 0.1–0.3 mm day\(^{-1}\)), but not statistically significant over Greece and Turkey (Fig. 5a).

During the negative phase (Fig. 5b), a substantial decrease becomes prominent over south Aegean Sea, North Africa, and Cyprus, with peak values of 0.8 mm day\(^{-1}\) over the southeastern Aegean Sea, while the statistically insignificant precipitation decrease is found over northern Greece.

Figure 6 shows the composite anomalies of the CDD and SDII indices during the two phases of EMP. It can be seen that during the positive phase an increase of SDII (Fig. 6a) is observed mainly over the Aegean Sea (1.1 mm day\(^{-1}\)) and a decrease of CDD (Fig. 6c), up to 3 days in southeastern Aegean Sea. These results are consistent with the behavior of precipitation during this phase (Fig. 5a). During the negative phase, an overall decrease of daily intensity is found, with maximum value of 1.6 mm day\(^{-1}\) over Turkey (Fig. 6b). The CDD presents a substantial increase in the southern area (Fig. 6d) (maximum +3.5 days over southern Aegean), while decreases in the northern area (maximum of −3 days over northwestern Greece).

These changes of the precipitation regime of the eastern Mediterranean in either phase of EMP agree well with the occurrence of extreme wet or dry years. For instance, 1981 is characterized by an exceptional positive peak of the EMP index (Hatzaki et al. 2007) and is indeed reported as an extreme wet winter in western Turkey (Türkes 1996), where maximum positive precipitation anomalies were found (Fig. 5a). The winter of 1990, which is considered as extremely dry in Israel (Kutiel and Paz 1998) and in the southeastern Aegean islands (Livada and Assimakopoulos 2007), is assigned to the negative phase with the highest index value (Hatzaki et al. 2007), confirming our results for precipitation decrease and CDD increase over the southeastern part of the examined area. More generally, the anomalous northerly flow, which characterizes the atmospheric circulation during the positive EMP phase, has been demonstrated to contribute to a precipitation increase over the eastern Mediterranean (Kutiel and Paz 1998; Dunkeloh and Jacobseit 2003).

b. Temperature

Figures 4b,c display the canonical loadings of the first RCCA pair between the standardized anomalies of 500-hPa geopotential heights and temperatures, respectively. It was found that positive (negative) geopotential height anomalies over the eastern Mediterranean, forming the negative (positive) EMP phase, lead to increased (decreased) maximum and minimum temperatures.
More specifically, during the positive phase, the decrease of the maximum temperature anomalies range between 0.4°C and 0.8°C over the Greek area and North Africa, while peaks (−1.8°C) are found over continental Turkey (Fig. 7a). During the negative phase, the apparent increase (Fig. 7b) is greater over the western edge of the examined area, with maximum value of 1°C, while it is in the remaining examined area.

Consistent with the impact of the positive phase on the maximum temperature anomalies distribution, the mean minimum temperature reveals an overall significant decrease over the examined region with similar distribution and greater magnitude (Fig. 7c), peaking at −2.4°C. On the contrary, during the negative phase, a statistically significant increase is found over the whole area, with maximum values of 0.8°C over continental Greece (Fig. 7d).

According to Fig. 8, where the anomalies of the indexes Tmax90 and Tmin10 are displayed, a decrease becomes evident during the positive phase for both indices over the examined area. This decrease is more prominent for Tmin10, where a peak of 0.9°C is found over the Aegean Sea and 1.1°C over northern Greece, suggesting an increase of the extremely cold episodes. The opposite behavior is observed during the negative phase, when both Tmax90 and Tmin10 increase, by 1°C and 1.3°C, respectively, especially over continental Greece.

The temperature increase during the negative phase is consistent with the warming in the eastern Mediterranean observed when anomalous southerly flow prevails (Maheras et al. 1999), since this flow is a characteristic of the negative phase (Hatzaki et al. 2007). Furthermore, extreme cold or warm years in Greece are indeed assigned to the positive or negative EMP phases, respectively, and confirm the above-mentioned temperature changes, such as 1992 (positive phase), an extremely cold winter (Feidas et al. 2004; Flócas et al. 2005) and 1994 (negative phase), an extremely warm year (Feidas et al. 2004).

### 6. Impact on Future Climate

From Fig. 2, it becomes evident that the EMP prominently translates to the north during the A2a scenario, while it moves eastward during the B2a scenario, as compared to the control run. This shift seems to be consistent with projected northward displacement and intensification of the storm track with increasing greenhouse concentrations over northeast Atlantic (Ulbrich and Christoph 1999; Hu and Wu 2004; Bengtsson et al. 2006) and corresponding eastward extension and
weakening of the storm track over the eastern Mediterranean (Bengtsson et al. 2006).

The study of EMP impact on future climate includes the application of RCCA between HadAM3P geopotential height data and HadRM3P precipitation and maximum and minimum temperature data for each scenario. The comparison was done with the corresponding control run data of the two models. It was demonstrated that the control run indeed depicts the main RCCA pairs between the two fields while it captures the EMP pattern and its impact on the three climatological regimes of the eastern Mediterranean, as shown in Fig. 9. However, the model simulates the EMP impact with reduced relative importance, as the EMP appears in the fourth canonical pair for precipitation, in the third for maximum temperature, and in the fifth for minimum temperature.

a. Precipitation

Figure 10a shows the canonical loadings of the first pair of RCCA between geopotential height and precipitation for the B2 scenario, where the impact of EMP on the future precipitation regime is depicted. From Fig. 10a, it can be seen that the same relationship, being depicted in the control run (Fig. 10a), is also represented in the future: increase (decrease) of precipitation over the major examined area during the positive (negative) phase of EMP.

Consistent with the RCCA results, the composite anomalies of winter precipitation for the positive phase and for the B2a scenario demonstrate a statistically significant increase over the southern part of the examined area, and especially over the southeastern edge, with maximum anomaly of 0.4 mm day$^{-1}$ (Fig. 11a), while in the rest of the examined area the anomalies are statistically negligible. On the contrary, a statistically significant decrease is observed over northwestern Greece and Asia Minor of 1 mm day$^{-1}$. During the negative phase (Fig. 11b), negative anomalies of winter precipitation are observed over the examined area, especially over the eastern edge, with a maximum value of 1.2 mm day$^{-1}$. On the contrary, northwestern Greece is adversely characterized by a precipitation increase with maximum anomalies of 1 mm day$^{-1}$. Under the A2a scenario, similar distribution of composite anomalies was found during the two phases, but with higher magnitude (not shown).

The intensity index SDII continues to exhibit higher values when the positive EMP phase prevails in the future under the B2a scenario, which is evident in the entire examined area (Fig. 12a). During the negative phase, the apparent decrease of the index in the present climate exists (Fig. 12b), but intensifies up to 1.8 mm day$^{-1}$ over southern Greece. Nevertheless, an increase of 1.6 mm day$^{-1}$ is observed over the eastern areas. For the A2a scenario, during the positive (negative) phase intensity
reduction (increase) covers the examined area (not shown).

For CDD, the distribution of composite under the future B2a scenario is rather confusing: during the positive phase a decrease is evident over the sea (−3 days) and an increase over the continental areas (+2 days), while during the negative phase the opposite distribution is observed. For the A2a scenario, the length of the dry spells is reduced (increased) during the positive (negative) phase over the examined area, with higher anomaly values for the positive phase (not shown).

b. Temperature

According to Figs. 10b,c, the RCCA between the future geopotential height values and the maximum/minimum temperature values demonstrated similar relationship as compared to the control run (Figs. 9b,c). Therefore, the EMP impact on temperature regime is also identified as the first RCCA pair, for both maximum and minimum temperature. More specifically, a decrease (increase) of maximum and minimum temperature occurs over the whole examined area during the positive (negative) phase of the EMP.

For B2a scenario, during the positive phase, an overall decrease of Tmax and Tmin is observed, with values as high as 1.5°C (Figs. 11c,e). During the negative phase, the increase of Tmax and Tmin reaches the value of 2°C over continental areas, while the anomalies are statistically significant in the major part of the examined area. Similar results were deduced for the A2a scenario, which are, however, statistically insignificant for Tmin (not shown).

The composite anomalies of the index Tmax90 during the two phases of EMP in the future B2a scenario (Figs. 13 a,b) are negative (positive) anomalies during the positive (negative) phase, similarly to the present climate (Fig. 8). However, the anomalies become higher (up to −1°C and 1.5°C during the positive and negative phase, respectively) in the future. Under the A2a scenario, the sign of anomalies is consistent with the B2a scenario, but with higher magnitude (not shown). Concerning the Tmin10, the positive phase in the future is characterized by an overall decrease in the entire examined area (except for the western part) and peaks over continental Greece (Fig. 13c). During the negative phase, an apparent increase is found in both scenarios (Fig. 13d).
7. Discussion and conclusions

In this study, an attempt is made to estimate the impact of the eastern Mediterranean teleconnection pattern (EMP) on the temperature and precipitation regime of the eastern Mediterranean. Furthermore, the influence of EMP on the intensity of cold or warm extremes, length of extreme dry spells, and precipitation intensity was investigated.

It was found that the EMP affects the regional climate of the eastern Mediterranean with inverse impact between the two phases. More specifically, a positive phase of EMP is associated with a decrease in temperature and an increase in precipitation, while the opposite occurs during the negative EMP phase. It should be noted that the impact seems to be more prominent on the temperature regime, than on precipitation, and moreover, on the mean rather than the extreme climatic regime.

Following the mean distribution of precipitation, the positive phase is characterized by an increase of the precipitation intensity and a decrease of the length of extreme dry spells. During the negative phase, a decrease of the precipitation intensity was observed. The dry spells are reduced over Greece; however, they lengthen over the remaining area. These changes during both phases are more prominent in southeastern part of the eastern Mediterranean basin. For the temperature, the impact seems to be more intense during the negative (positive) phase for maximum (minimum) temperature. These changes accordingly influence the behavior of cold extremes associated with significant decrease (increase) during the positive (negative) phase.

Projected future changes of the mean winter temperature and precipitation regime and extremes were then investigated, being associated with expected

FIG. 10. Canonical correlation loadings of the RCCA pairs for the standardized anomalies of 500-hPa geopotential heights and (a) precipitation, (b) maximum temperature, and (c) minimum temperature for the future climate (B2a scenario). The dashed contours indicate negative values.
variations of the EMP location and intensity, under two different IPCC scenarios (A2a and B2a) for the evolvement of the future atmospheric concentrations of greenhouse gases. It was found that the EMP continues to influence the regional climate of the eastern Mediterranean in the future, under warmer global conditions, similarly to the present climate. Future precipitation over the eastern Mediterranean area seems to increase (decrease) during the positive (negative) phase for both scenarios, as was observed in the control run. The higher composite anomalies of precipitation reduction during the negative phase (as compared to the corresponding increase during the positive phase) are consistent with the overall predicted precipitation decrease in the future winter (Räisänen et al. 2004) and the decrease of cyclone frequency over the eastern Mediterranean (Lionello et al. 2002; Anagnostopoulou et al. 2006).

Future temperatures seem to increase (decrease) during the negative (positive) phase, consistent with the temperature response to EMP in the control run. The increase during the negative phase is higher compared to the corresponding decrease during the positive phase, again complying with the overall temperature decrease that is expected in the future for the eastern Mediterranean (Räisänen et al. 2004). The projected impact of EMP on the mean regime is in accordance with the impact on the extreme events.

Of course, it should be noted that because serious uncertainties and limitations related to the future climatic scenarios have been stressed by the international bibliography (e.g., Osborn 2004; Bengtsson et al. 2006; Stephenson et al. 2006; Solomon et al. 2007), the results of this study for the future impact of EMP should be considered with caution. In our case, the results for the
composite anomalies in the future reflect model biases, as implied by differences in the location of the EMP poles and, subsequently, the redefinition of the index and assignment of the future winters to each phase.

Also, the temperature impact over the sea is subjected to the continental character of HadRM3P model, as noted in section 4. On the contrary, the RCCA results are not subjected to the definition of the two phases.

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**Fig. 12.** Composite anomalies of winter mean values of the indexes (top) SDII and (bottom) CDD during the (a), (c) positive and (b), (d) negative phase of EMP for the future climate (B2a scenario). The dashed contours indicate negative values; CI is 0.2 mm day$^{-1}$ and 0.5 days for SDII and CDD, respectively.

**Fig. 13.** Composite anomalies of winter mean values of the indices (top) Tmax90 and (bottom) Tmin10 during the (a), (c) positive and (b), (d) negative phase of EMP for the future climate (B2a scenario). The dashed contours indicate negative values; CI is 0.1°C.
Furthermore, the HadRM3P simulation biases are larger for precipitation, as compared to the temperature. Moreover, Hanson et al. (2007) demonstrated that the HadRM3P tend to underestimate temperature extremes and thus future values may be even higher than indicated in the simulations, while the simulated precipitation extremes are more pronounced. Because the pattern was found to exist in the future climate, this study intends to trace if/how the future behavior and the signal of EMP will affect the eastern Mediterranean climate. The relevance of the study to the future projections of the eastern Mediterranean climate is important, because it reveals the EMP as another component of natural climatic variability, apart from the well-known teleconnection patterns (e.g., Stephenson et al. 2006), and, thus, it can contribute to explain the intraannual variations of regional climate. Furthermore, better knowledge of the EMP impact on regional climate provides a better basis for downscaling of the global climatic model simulations over the examined region in winter (Haylock et al. 2006; Tolika et al. 2007). Then, the future hint of the EMP impact better addresses the assumption of stationarity in the downscaling scenarios (Drijfhout et al. 2008), which implies that observed relationships are applicable to a future warmer climate.

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