

Research Article

The Mediterranean Oscillation Teleconnection Index: Station-Based versus Principal Component Paradigms

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Received 15 September 2013; Revised 23 October 2013; Accepted 29 October 2013

Academic Editor: Anthony R. Lupu

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Two different paradigms of the Mediterranean Oscillation (MO) teleconnection index have been compared in this work: station-based definitions obtained by the difference of some climate variable between two selected points in the eastern and western basins (i.e., Algiers and Cairo, Gibraltar and Israel, Marseille and Jerusalem, or south France and Levantine basin) and the principal component (PC) approach in which the index is obtained as the time series of the first mode of normalised sea level pressure anomalies across the extended Mediterranean region. Interannual to interdecadal precipitation (P), evaporation (E), $E-P$, and net heat flux have been correlated with the different MO indices to compare their relative importance in the long-term variability of heat and freshwater budgets over the Mediterranean Sea. On an annual basis, the PC paradigm is the most effective tool to assess the effect of the large-scale atmospheric forcing in the Mediterranean Sea because the station-based indices exhibit a very poor correlation with all climatic variables and only influence a reduced fraction of the basin. In winter, the station-based indices highly improve their ability to represent the atmospheric forcing and results are fairly independent of the paradigm used.

1. Introduction

The Mediterranean Sea (Figure 1(a)), a semi-enclosed basin that extends over 3000 km in longitude and over 1500 km in latitude with an area of $2.5 \cdot 10^{12} \text{ m}^2$, communicates with the Atlantic Ocean through the Strait of Gibraltar and with the Black Sea through the Turkish Bosphorus and Dardanelles Straits. An Atlantic inflow through the Strait of Gibraltar is necessary to balance the freshwater and salt budgets since evaporative losses (E) are not balanced by precipitation (P) and river runoff (R). The circulation in the Mediterranean Sea is influenced to a large extent by the heat and freshwater air-sea exchanges which depend on the meteorological and oceanic conditions [1] and they also play a key role in dense water formation and hence in the Mediterranean Thermohaline Circulation [2]. As a consequence, they affect the characteristics of the Mediterranean water masses and then may potentially influence the Atlantic Ocean circulation via changes in the properties of the Mediterranean Outflow [2–5]. For these reasons, the improvement of our knowledge of heat and water budgets and their long-term variability is

a challenge for the scientific community of the Mediterranean region and is thought to be crucial to understand the Mediterranean circulation and climate and their evolution under climate change.

Indices of large-scale climate modes are very helpful to this aim since they provide an integrated measure of weather linked more to the overall physical variability of the system than to any individual local variable. Among these indices, the North Atlantic Oscillation (NAO) is one of the most prominent modes of the northern hemisphere climate variability (see [6–8]; [9] for a recent review). Other modes such as the East-Atlantic (EA) [10–12], the East-Atlantic-West Russia (EA-WR) [10–12], or the North Sea-Caspian Pattern (NCP) [13–16] also have a major impact on various meteorological parameters in the Mediterranean basin and Europe. But more specifically for the Mediterranean Sea, Conte et al. [17] suggested the possible existence of a Mediterranean Oscillation (MO) as a consequence of the dipole behaviour of the atmosphere in the area between the western and eastern Mediterranean. Differences in temperature, precipitation, circulation, and other parameters between both basins were

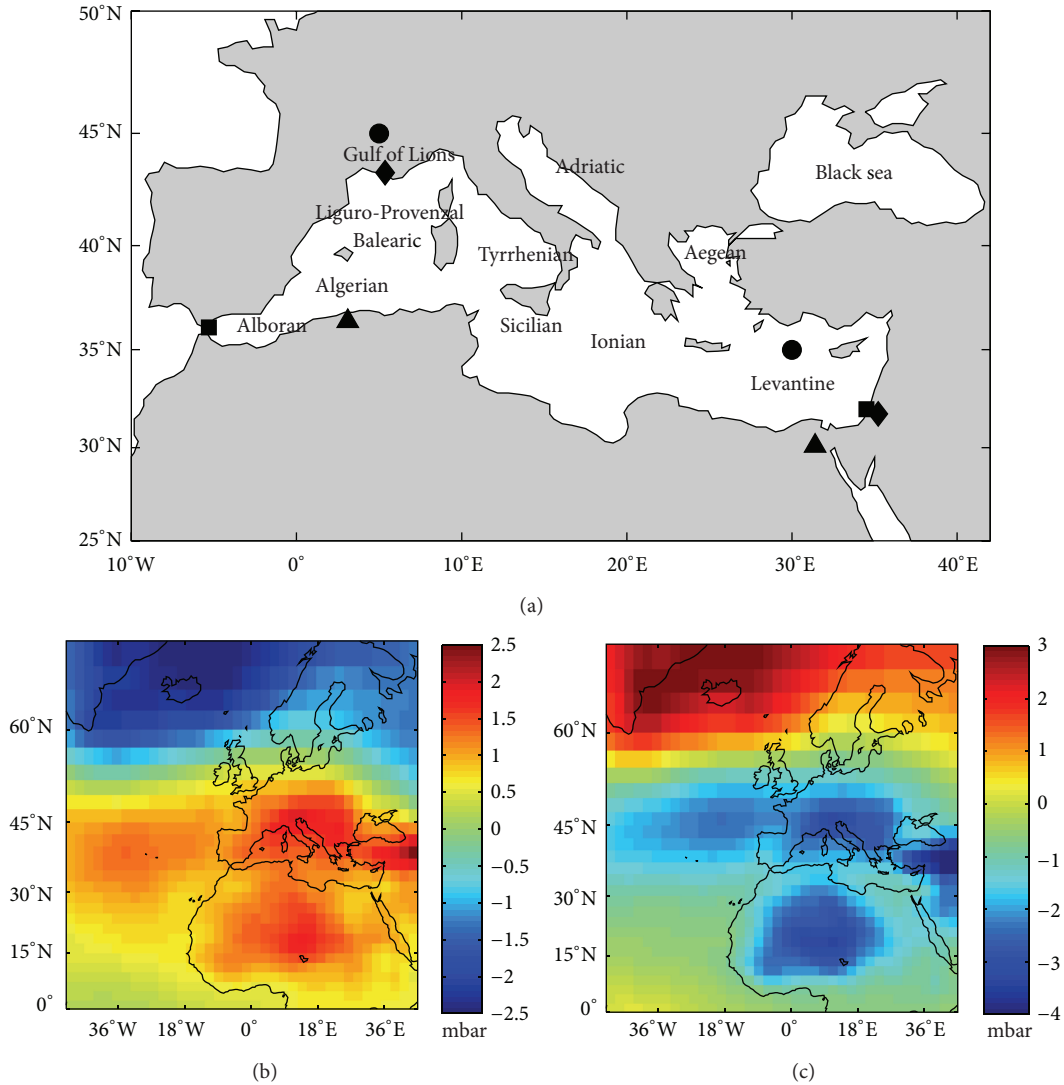


FIGURE 1: (a) Map of the Mediterranean Sea. The main basins and subbasins are indicated. Symbols are placed in the locations selected for pressure differences in the station-based MO indices (a triangle for Algiers-Cairo, a square for Gibraltar-Israel, a circle for France-Levantine, and a diamond for Marseille-Jerusalem). ((b)-(c)) Composites of sea level pressure anomalies (mbar) in the 1958–2008 period during the positive (higher quartile, (b)) and negative (lower quartile, (c)) phases of the MO_{PC} index.

attributed to this MO [17–22] and an index to measure the intensity of this dipole-like behaviour was proposed.

Climatic indices have been traditionally derived either from the simple difference of some climate variable between two locations or from the Principal Components (PC) approach. Conte et al. [17] defined MO index as the normalised 500 hPa geopotential heights difference between Algiers (36.4°N, 3.1°E) and Cairo (30.1°N, 31.4°E). A second version of the index [23] can be calculated based on sea level pressure differences between Gibraltar northern frontier (36.1°N, 5.3°W) and Lod Airport Israel (32.0°N, 34.5°E). In order to obtain an index more suitable for the Central Mediterranean, Brunetti et al. [24] defined MO index as the normalized sea level pressure difference between Marseille and Jerusalem. This index was found to present good correlation with total precipitation and number of wet days

in Italy [24]. More recently Papadopoulos et al. [11, 12] introduced the Mediterranean index as the sea level pressure difference between south France (45°N, 5°E) and Levantine Sea (35°N, 30°E). These two points are orientated in a NW-SE direction and are likely to reflect more accurately the realistic dipole pressure pattern. Within the PC approach, Suselj and Bergant [25] proposed a MO index definition based on EOF analysis of sea level pressure anomaly fields over an extended Mediterranean region and Gomis et al. [26] also adopted this definition to study its influence in the flow exchange through Gibraltar.

In contrast to NAO and the other teleconnection indices, which have been extensively studied, only a few previous works focus on the MO index and more research is required. In this work, we compare the influence of the different MO indices in heat and water budgets in the Mediterranean Sea.

To this aim, we correlate interannual to interdecadal precipitation, evaporation, freshwater budget ($E-P$), and net heat flux with MO indices to establish their relative importance in the climatic variables. The work is organised as follows: Section 2 describes the data and methodology; Section 3 presents and discusses the results both from a regional and global approach, and finally Section 4 summarises the conclusions.

2. Data and Methodology

Several MO definitions, traditionally used in the literature, have been used for comparison: the Algiers-Cairo MO index (MO_{AC}) has been computed following the definition of Conte et al. [17] and the Gibraltar-Israel MO index (MO_{GI}) following that of Palutikof [23], defined in Section 1. Daily records of these two indices have been obtained from the Climate Research Unit (University of East Anglia) for the period 1958–2008 and seasonal and annual means have been obtained by averaging daily values. Monthly values of the Marseille-Jerusalem MO index (MO_{MJ}) have been computed according to Brunetti et al. [24] from the sea level pressure database of the National Center for Environmental Prediction (NCEP)—National Center of Atmospheric Research (NCAR), referred as NCEP hereinafter [27]. Monthly time series of the France-Levantine MO index (MO_{FL}), introduced by Papadopoulos et al. [11, 12], have been kindly received from Dr. Papadopoulos. The MO spatial pattern from the PC approach has been computed as the first mode of normalised sea level pressure anomalies across the extended Mediterranean region ($30^{\circ}W-40^{\circ}E$ in longitude, $30^{\circ}N-60^{\circ}N$ in latitude) which exhibits a single centre located over the Central and Western Mediterranean, which remains fairly steady in all seasons. The MO index (MO_{PC}) is then obtained as the corresponding time coefficients of the first PC mode. Since we define the positive phase when sea level pressure anomaly above the Mediterranean is positive, MO_{PC} and all the other MO indices will be positively correlated.

Monthly means from January 1958 to December 2008 of precipitation, evaporation, and surface heat fluxes have been retrieved from the NCEP reanalysis project, which is run at T62 spectral resolution (approximately a grid size of $1.9^{\circ} \times 1.9^{\circ}$) with 28 sigma levels. Auxiliary data of monthly mean sea level pressure at $2.5^{\circ} \times 2.5^{\circ}$ for the period 1958–2008 have also been retrieved from the NCEP database. Seasonal means have been computed by averaging JFM (winter), AMJ (spring), JAS (summer), and OND (autumn) monthly data and Mediterranean spatially averaged time series have been obtained by averaging all grid points over the sea. Linear correlation maps have been used to identify coupled patterns between the climatic variables and the MO indices. The statistical significance of the correlation has been computed by transforming the correlation matrix in a t -student distribution with $N - 2$ degrees of freedom, where N is the number of element of the analysed time series. With this procedure, each time series of a specific grid point for any of the variables is transformed into a t statistic used to compute the probability of getting a correlation as large as the observed value by random chance, when the true

correlation is zero. If the obtained value is small (in our case lower than 0.05) then the correlation is considered significant. Time filtering into low and high frequency components is achieved using a 5-year running mean to take into account the long time scale effects of the indices. A complementary composite analysis has also been performed to highlight the asymmetries between the positive and negative phases of the indices, defined as the upper and lower quartiles of the MO time series over the period 1958–2008. The effect in the climatic variables is computed in terms of the average anomalies during the positive/negative phases of the indices with respect to the complete time series on each grid point. Only the points where the results are statistically different from zero (according to a Student's t -test at 95% significance) have been represented.

3. Results and Discussion

3.1. Annual and Interannual Variability. Table 1 shows the correlation (absolute value) between the climatic variables and the different MO indices analysed. On an annual basis (upper panel), the MO_{PC} index gives the best correlation for all variables and also influences more extensive areas of the basin (in brackets, the fraction of points significantly correlated). At decadal timescales (5-year running means), the indices tend to increase the correlation, especially MO_{PC} that influences most of the Mediterranean (see Figure 2). Pettenuzzo et al. [28] highlighted the importance of the choice of a long period (i.e., decadal variations) for budget studies in the Mediterranean, since the long time scale effects of the indices must be taken into account because of their direct implication on the climatic variables. Basin-wide, MO_{PC} shows again the highest correlation with P (-0.74), E (-0.53), and Q (-0.71) and among the station-based indices, MO_{AC} gives a reasonably good correlation with $E-P$ (0.53), whereas MO_{MJ} provides good results for P (-0.67); see Table 2.

Anticorrelation with P is expected because the MO positive phase produces a sea level pressure anomaly field (Figure 1(b) for MO_{PC}) that strengthens and modifies the orientation of prevailing westerly winds and associated storm-track activity which cause dry anomalies in the Mediterranean region, whereas the negative phase (Figure 1(c) for MO_{PC}) is linked to intense cyclogenesis over the central/western Mediterranean that produces anomalously wet conditions over most of the basin and hence negative correlation with P . Precipitation anomalies during the positive and negative phases (higher and lower quartiles) of the MO_{PC} index (the other MO indices only affect a reduced area of the basin on annual basis) are shown in Table 3. MO_{PC} exerts a strong influence with precipitation anomalies close to 100 mm/year on average over most of the basin. Higher anomalies are observed in the northern Mediterranean in both phases with values up to -200 mm/year during the positive phase in the Ionian and Levantine subbasins and up to 250 mm/year during the negative phase in the Ionian and north Adriatic (Figures 3(a) and 3(b)).

Anticorrelation with E is again expected since, in its negative phase, anomalously low pressure over the whole

TABLE 1: (a) Mean absolute correlation at 95% significance level between annual and decadal (5-year running means) MO indices and climatic variables (P , E , $E-P$, and net heat flux, Q). The fraction of points significantly correlated is shown in brackets. (—) indicates that the correlation is not significant in more than 95% of the basin. (b) The same as above but for winter (JFM) season. The highest correlation for each variable is highlighted in bold.

(a)										
	Annual means					5-year means				
	MOI _{PC}	MOI _{AC}	MOI _{GI}	MOI _{FL}	MOI _{MJ}	MOI _{PC}	MOI _{AC}	MOI _{GI}	MOI _{FL}	MOI _{MJ}
P_{NCEP}	0.46 (59%)	0.45 (51%)	0.33 (6%)	0.41 (18%)	0.44 (40%)	0.62 (69%)	0.57(51%)	0.37 (8%)	0.40 (32%)	0.52 (79%)
E_{NCEP}	0.45 (47%)	—	—	0.32 (10%)	—	0.58 (58%)	—	—	0.40 (37%)	0.43 (44%)
$E-P_{NCEP}$	0.41 (42%)_d	0.26 (26%)	0.30 (9%)	0.38 (30%) _d	0.41 (27%)	0.52 (59%)_d	0.52 (46%)	0.33 (8%)	0.41 (29%) _d	0.45 (42%) _d
Q_{NCEP}	0.47 (71%)	0.39 (33%)	—	0.31 (8%)	0.34 (11%)	0.64 (79%)	0.37 (20%)	—	0.41 (46%)	0.48 (68%)
(b)										
	Winter means					5-year winter means				
	MOI _{PC}	MOI _{AC}	MOI _{GI}	MOI _{FL}	MOI _{MJ}	MOI _{PC}	MOI _{AC}	MOI _{GI}	MOI _{FL}	MOI _{MJ}
P_{NCEP-W}	0.50 (71%)	0.55 (73%)	0.46 (49%) _d	0.46 (55%) _d	0.53 (59%)	0.66 (81%)	0.65 (81%)	0.57 (72%)	0.63 (67%) _d	0.65 (77%)
E_{NCEP-W}	0.39 (38%) _d	0.50 (49%)_d	0.31 (10%) _d	0.42 (42%) _d	0.39 (44%) _d	0.50 (54%)	0.49 (49%)	0.40 (37%) _d	0.40 (37%) _d	0.43 (46%)
$E-P_{NCEP-W}$	0.45 (59%)	0.42 (59%)	0.45 (33%)	0.43 (48%)	0.45 (54%)	0.60 (77%)	0.56 (78%)	0.55 (76%)	0.59 (69%)	0.59 (79%)
Q_{NCEP-W}	0.39 (42%) _d	0.51 (57%)_d	0.32 (16%) _d	0.43 (46%) _d	0.37 (51%) _d	0.55 (58%)	0.53 (57%)	0.42 (38%)	0.40 (39%) _d	0.47 (45%)

TABLE 2: Correlation at 95% significance level between the MO indices and the Mediterranean-averaged variables (P , E , $E-P$, and net heat flux, Q) on annual basis (a) and for winter season (b) at decadal (5-year running means) timescale. (—) indicates that correlation is not significant. The highest correlation for each variable is highlighted in bold.

(a)					
	5-year med-averaged annual basis				
	MOI _{PC}	MOI _{AC}	MOI _{GI}	MOI _{FL}	MOI _{MJ}
P_{NCEP}	-0.74	-0.42	—	-0.30	-0.67
E_{NCEP}	-0.53	—	—	—	-0.34
$E-P_{NCEP}$	—	0.53	—	—	0.28
Q_{NCEP}	-0.71	—	—	-0.30	-0.44
(b)					
	5-year med-averaged winter				
	MOI _{PC}	MOI _{AC}	MOI _{GI}	MOI _{FL}	MOI _{MJ}
P_{NCEP-W}	-0.87	-0.82	-0.67	-0.62	-0.79
E_{NCEP-W}	-0.35	-0.32	—	—	—
$E-P_{NCEP-W}$	0.75	0.71	0.74	0.79	0.80
Q_{NCEP-W}	-0.49	-0.42	—	—	—

basin is observed (see Figure 1(c) for MO_{PC}). This favors colder and dryer air masses from the continental regions that generate more severe weather conditions over the northern and eastern Mediterranean and hence an intensification of evaporative losses to the atmosphere (109 mm/year on average, see Table 3, and values above 400 mm/year in the Levantine subbasin, Figure 3(d)). In this phase, the dipole of anomalously low pressure over Central Europe and Turkey (Figure 1(c)) brings colder and dryer air masses from continental regions to the Levantine subbasin that enhances evaporative losses in this area. Conversely, the positive MO

TABLE 3: Mediterranean averaged anomalies in the 1958–2008 period during the positive (higher quartile) and negative (lower quartile) phases of the selected MO_{PC} index. Units are mm/year for P , E , and $E-P$ and $W m^{-2}$ for Q . Anomalies of opposite sign across the basin are shown separately by a /. The fraction of points where the anomaly is significantly different from zero is shown in brackets.

	MO _{PC}	
	CA+	CA-
P_{NCEP}	-93.8 (84%)	88.0 (72%)
E_{NCEP}	-83 (92%)	109.0 (79%)
$E-P_{NCEP}$	78.3/-75.3 (62%)	139.8/-94.4 (79%)
Q_{NCEP}	-10.3 (92%)	13.4 (92%)

phase is associated with higher than average pressure over the Mediterranean and North Africa (Figure 1(b)) that promotes a shift of the wind trajectories toward lower latitudes. Warmer and moister air masses are then conveyed toward the Mediterranean leading to milder winters and a decrease in the evaporative loss, similarly as shown by Hurrell [29] for the NAO.

For the freshwater budget ($E-P$), a clear bimodal pattern is observed at decadal timescales (see Figure 2(c) for MO_{PC}): in the North-Central Mediterranean, $E-P$ is positively correlated (0.5-0.6) with MO_{PC} index, whereas in the Levantine subbasin anticorrelation is observed (close to -0.6). This dipolar behaviour (subindex d in Table 1) can be explained based on the different sensitiveness of E and P to the MO_{PC} index in those regions. In the Central basin, P is dominant and changes in $E-P$ follow those of $-P$ (hence, positive correlation is expected). In contrast, the Levantine subbasin is highly sensitive to E (see Figure 2(b) and discussion above) and changes in $E-P$ follow those of E (hence, negative correlation). In this case, the negative phase of MO_{PC} index exerts stronger influence (Table 3), with positive anomalies

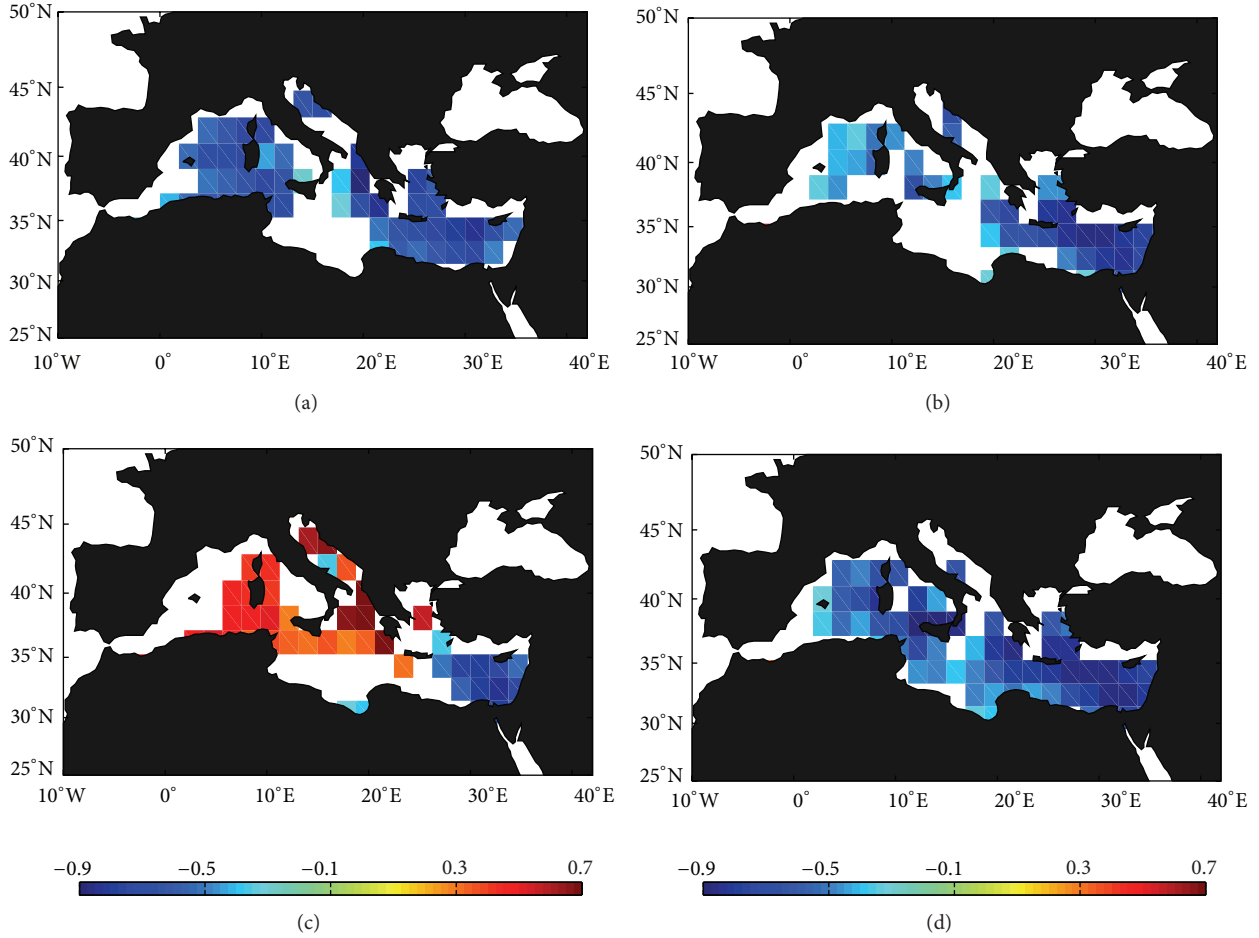


FIGURE 2: Correlation spatial pattern (95% significance) between decadal (5-year running means) MO_{PC} index and the selected climatic variables: precipitation (a), evaporation (b), freshwater budget $E-P$ (c), and net heat flux (d) for the period 1958–2008.

up to 400 mm/year in the Levantine basin and negative anomalies about -200 mm/year above $35^\circ N$ (Figure 3(f)).

As shown by Criado-Aldeanueva et al. [30], the net heat flux variability is mostly determined by the latent heat variability and this contribution becomes the main source of interannual variability. Since latent heat is directly related to evaporation, similarity between Figures 2(b) and 2(d) is expected and composite spatial patterns during the positive and negative phases (not shown) are very similar to those of E (see Figures 3(c) and 3(d)). However, better correlation is observed with MO_{PC} for net heat flux (see also Table 1) due to the contribution of the other components (i.e., sensible heat) that correlate well with MO_{PC} . Notice that the sign of the correlation is negative because we have selected net heat flux positive toward the atmosphere (the same as evaporation).

Correlation among the different MO indices is presented in Table 4. MO_{FL} and MO_{MJ} are highly correlated ($r = 0.76$), as expected from the nearby locations selected for their definition, whereas MO_{GI} is poorly correlated with most MO definitions. This explains the similar results of Table 1 for MO_{FL} and MO_{MJ} and the worse performance of MO_{GI} , whose orientation does not seem to catch accurately the realistic dipole pressure pattern. In summary, on an annual basis,

TABLE 4: Correlation (95% significance level) among all the selected MO indices (annual time series): MO_{PC} based on principal component analysis and the other station-based MO indices (MO_{AC} for Algiers-Cairo; MO_{GI} for Gibraltar-Israel; MO_{FL} for France-Levantine; and MO_{MJ} for Marseille-Jerusalem; see text for details).

	MO_{PC}	MO_{AC}	MO_{GI}	MO_{FL}
MO_{AC}	0.41			
MO_{GI}	n.s	0.36		
MO_{FL}	0.50	0.42	0.40	
MO_{MJ}	0.62	0.66	0.59	0.76

the MO_{PC} based on principal component analysis is the most effective teleconnection index to monitor heat and freshwater budgets in the Mediterranean Sea because the station-based indices exhibit a poor correlation with all climatic variables and only influence a reduced fraction of the basin.

3.2. Winter and Interwinter Variability. In winter (or even the cold part of the year), the atmosphere is dynamically more active and the ocean response to atmospheric forcing is higher. Large-scale patterns of atmospheric variability have

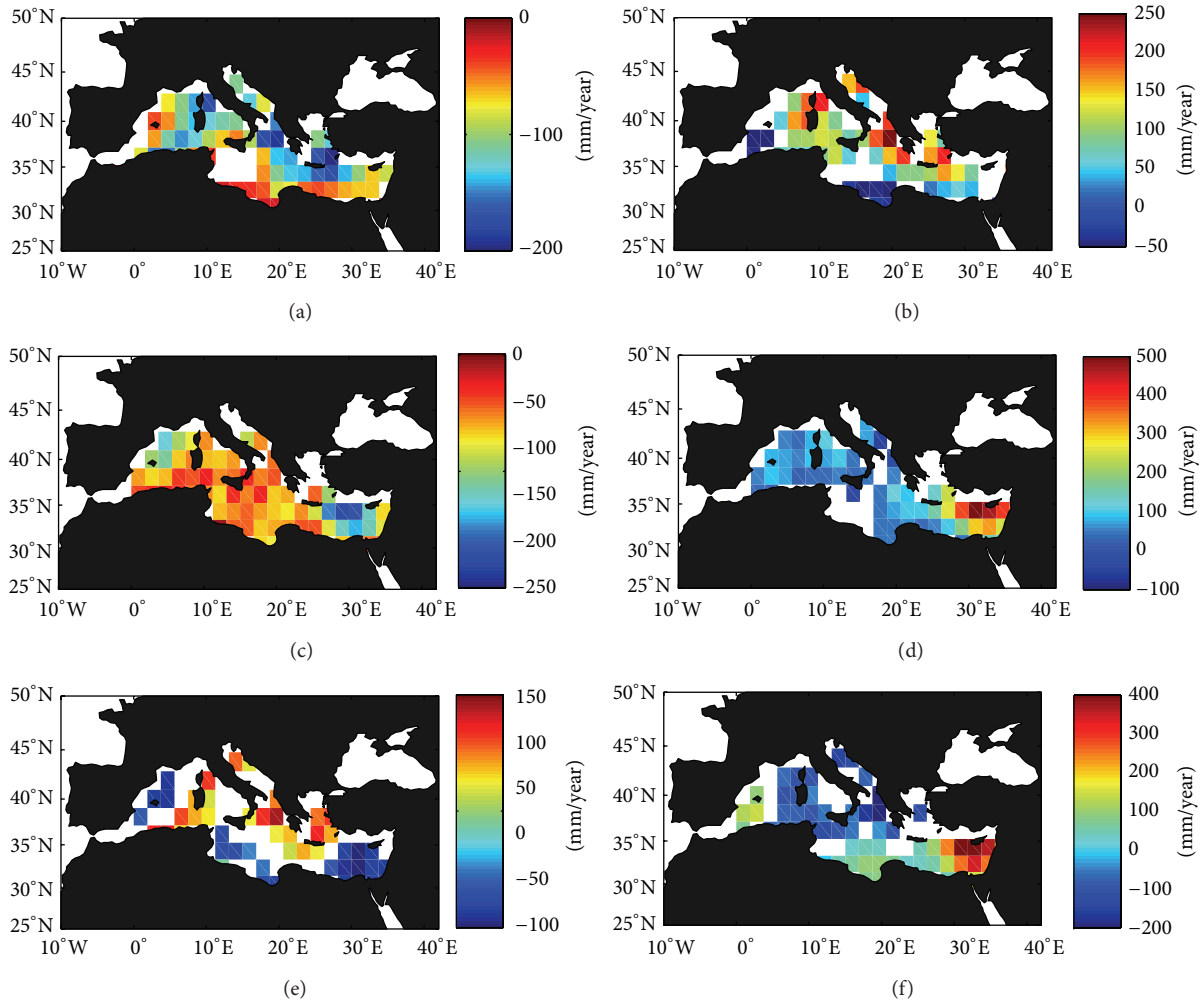


FIGURE 3: Composite of precipitation ((a)-(b)), evaporation ((c)-(d)), and freshwater budget $E-P$ ((e)-(f)) anomalies (mm/year) under the positive (higher quartile, left column) and negative (lower quartile, right column) phases of MO_{PC} index.

the potential to generate major changes in the strength of the air-sea coupling, while this is not the case in summer [10]. Winter heat loss events have been linked to the Eastern Mediterranean Transient [31], deep water formation processes [11, 12], and the recent deep water production in the western Mediterranean from 2004 to 2006 [32, 33]. For this reason, most studies focus on this season and the same analysis has been performed for all MO indices in wintertime, when pressure patterns over the Mediterranean are better established and the station-based indices are likely to improve their ability to represent the atmospheric forcing. The first issue to be noticed is that the correlation among all MO indices is much higher now (above 0.7 in most cases, Table 5) and similarity in their effect on climatic variables is then expected.

Table 1 (lower panel) displays the correlation results (absolute value) between the winter variables and the different MO indices analysed (results are fairly similar if the period is extended to the entire cold season from November to March). On an annual basis, MO_{AC} shows the highest correlation for P , E , and Q , whereas $E-P$ is better correlated with

TABLE 5: Correlation (95% significance level) among all the selected MO indices (winter-averaged time series): MO_{PC} based on principal component analysis and the other station-based MO indices (MO_{AC} for Algiers-Cairo; MO_{GI} for Gibraltar-Israel; MO_{FL} for France-Levantine; and MO_{MJ} for Marseille-Jerusalem; see text for details).

	MO_{PC}	MO_{AC}	MO_{GI}	MO_{FL}
MO_{AC}	0.74			
MO_{GI}	0.73	0.62		
MO_{FL}	0.74	0.65	0.76	
MO_{MJ}	0.87	0.80	0.81	0.93

MO_{PC} . Figure 4 shows the correlation spatial patterns for MO_{PC} and MO_{AC} (representative of all station-based indices) and similarity is rather evident. Winter precipitation is highly correlated with both indices ($r \geq 0.5$ on average, Table 1) with higher (negative) values in the western basin (Figures 4(a)-4(b)), whereas positive correlation is restricted to the south-easternmost areas. Winter precipitation is generally linked to storm-track activity related to pressure distribution and

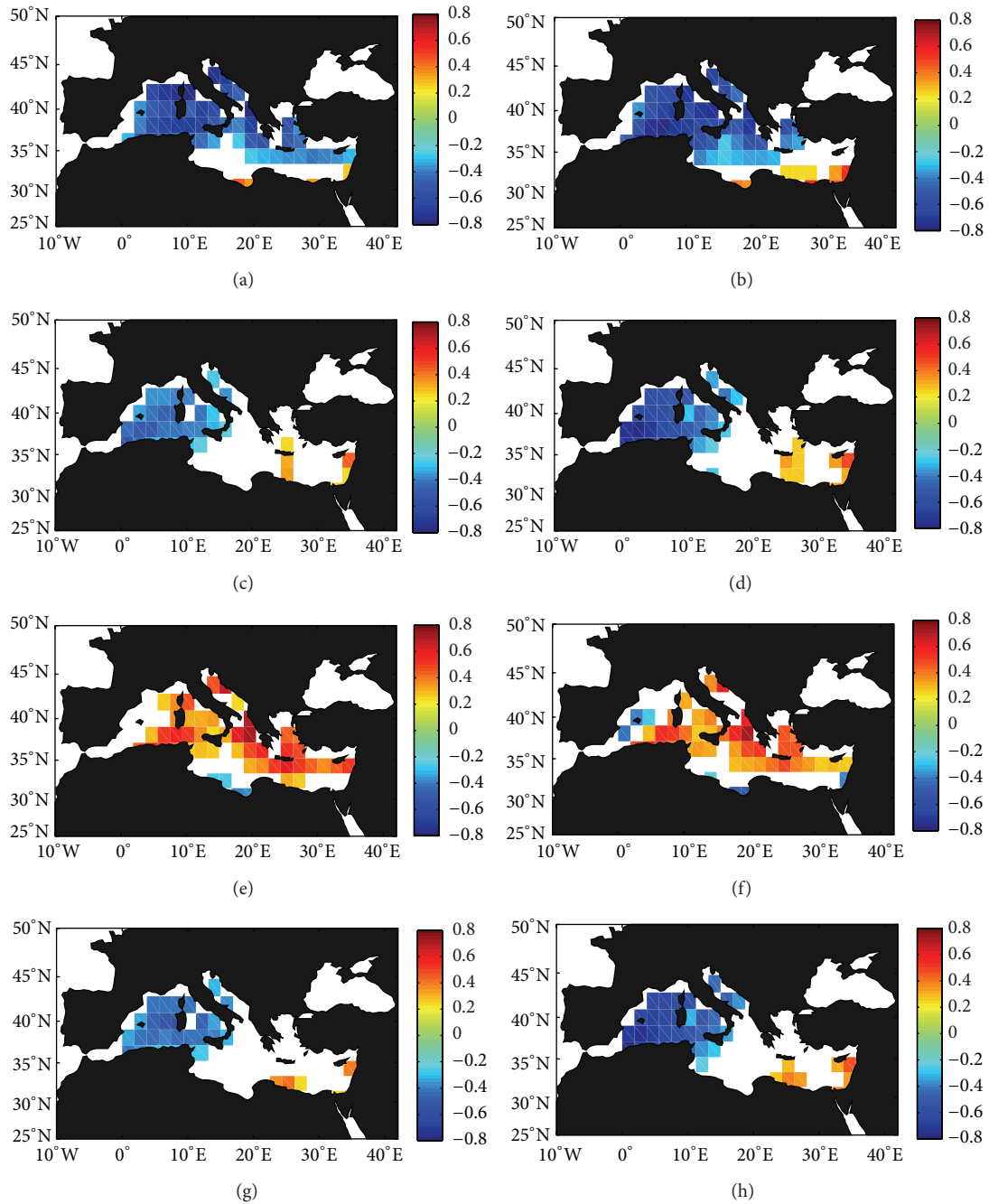


FIGURE 4: Correlation spatial pattern (95% significance) between winter-averaged MO_{PC} (left column) and MO_{AC} (right column) indices and the selected climatic variables: precipitation ((a)-(b)), evaporation ((c)-(d)), freshwater budget $E-P$ ((e)-(f)), and net heat flux ((g)-(h)) for the period 1958–2008.

hence captured by atmospheric indices, whereas in summer most of precipitation across the Mediterranean region is of convective origin and is poorly correlated with the large-scale atmospheric forcing.

Winter evaporation is not so well correlated with the atmospheric indices (~ 0.5 on average for MO_{AC} and about 0.4 for the other MO indices, Table 1). All MO indices (with the only exception of MO_{GI} , which only affects E in a much reduced fraction of the basin) produce a dipole response with negative correlation in the western basin and positive in

the eastern (Figures 4(c)-4(d)). This dipole is more evident for MO_{AC} (Figure 4(d)), for which more points are significantly correlated at 95%. However, it is important to mention that the dipole behaviour is clearly revealed if the significance is set to 90%. The winter freshwater budget $E-P$ is well correlated with the MO indices (~ 0.45 on average for MO_{PC} and MO_{AC} over almost 60% of the basin and similar results for the other MO indices; see Table 1). Correlation is positive almost everywhere (Figures 4(e)-4(f)) due to the dominant effect of precipitation in winter and the positive correlation

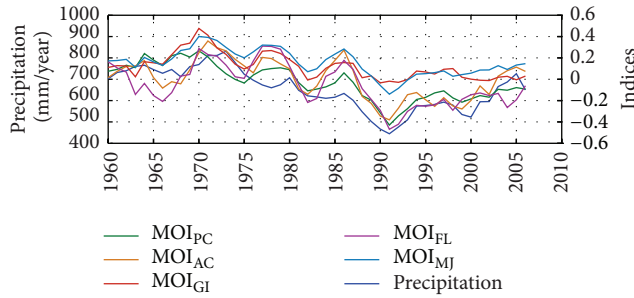


FIGURE 5: Time series of decadal (5-winter running means) Mediterranean-averaged winter precipitation (mm/year, left axis) and the selected MO climatic indices (right axis, MO_{AC} for Algiers-Cairo; MO_{GI} for Gibraltar-Israel; MO_{FL} for France-Levantine; MO_{MJ} for Marseille-Jerusalem; and MO_{PC} based on principal components analysis). Notice that the interannual variability is of interest more than the value of the indices itself.

with E in the western basin (remember that, on annual basis, the evaporation contribution was dominant in extensive areas of the Levantine basin, Figure 2(c)). As previously mentioned, the net heat flux spatial pattern (Figures 4(g)-4(h)) and correlation results (Table 1) are very similar to those of evaporation because latent heat is the main source of interannual net heat variability [30].

At decadal timescales (5-winter running means), all MO indices tend to improve the correlation with the climatic variables (and also the fraction of points significantly correlated) and similarity among them is even more evident, MO_{PC} providing slightly the highest correlation in general (see values in Table 1). It is important to mention that the dipole response revealed at winter-averaged annual basis (especially for E and Q) tends to reduce at decadal timescale, probably due to a masking of the results in the long-time period. Basin-wide, high (negative) correlation is observed for winter precipitation with all MO indices, especially MO_{PC} , with $r = -0.87$ (Table 2; see Figure 5 for time series). Winter $E-P$ is also very well correlated with the indices, MO_{MJ} reaching the highest value ($r = 0.80$). Notice that evaporation and net heat flux are poorly (or not significantly) correlated with the MO indices due to its dipole influence that promotes correlation of opposite sign in the eastern and western basins.

To summarise, during wintertime the station-based indices highly improve their ability to represent the well-established atmospheric pressure pattern over the Mediterranean and all of them tend to converge to similar results. MO_{AC} gives the highest correlation for most winter-averaged variables and reveals more clearly the well-known dipole response of the eastern and western basins. At decadal timescales, all MO indices show fairly similar results (slightly higher for MO_{PC} , Table 1 in bold).

4. Summary and Concluding Remarks

Two different paradigms of the Mediterranean Oscillation teleconnection index have been analysed in this work: station-based definitions obtained by the difference of some climate variable between two selected points in the eastern

and western basins (Algiers-Cairo for MO_{AC} , Gibraltar-Israel for MO_{GI} , Marseille and Jerusalem for MO_{MJ} , or France-Levantine for MO_{FL}) and the principal component (PC) approach in which the MO_{PC} index is obtained as the time series of the first mode of normalised sea level pressure anomalies across the extended Mediterranean region ($30^{\circ}W-40^{\circ}E$ in longitude, $30^{\circ}N-60^{\circ}N$ in latitude). We have correlated interannual to interdecadal precipitation (P), evaporation (E), $E-P$, and net heat flux with the different MO indices to compare their relative importance in the long-term variability of heat and freshwater budgets over the Mediterranean Sea.

On an annual basis, the PC paradigm is the most effective tool to assess the effect of the large-scale atmospheric forcing in the Mediterranean Sea because the station-based indices exhibit a very poor correlation with all climatic variables and only influence a reduced fraction of the basin. A disadvantage of the station-based indices is that they are fixed in space and are significantly affected by small-scale and transient meteorological events that introduce noise [34, 35]. In contrast, we have shown that the principal component approach provides a more optimal representation of the full spatial pattern and constitutes a better paradigm for the large-scale atmospheric forcing.

In winter, the atmosphere is dynamically more active and large-scale patterns of atmospheric variability have the potential to generate major changes in the strength of the air-sea coupling than in other seasons. Pressure patterns over the Mediterranean are better established and the station-based indices highly improve their ability to represent the atmospheric forcing. MO_{AC} gives the highest correlation for most winter-averaged variables and reveals more clearly the well-known dipole response of the eastern and western basins. However, all MO indices show fairly similar results, especially at decadal timescales.

Acknowledgments

This work has been carried out in the frame of the P07-RNM-02938 Junta de Andalucía Spanish-funded project. Javier Soto-Navarro acknowledges a postgraduate fellowship from Conserjería de Innovación Ciencia y Empresa, Junta de Andalucía, Spain. NCEP data have been provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their website at <http://www.esrl.noaa.gov/psd/>. MO_{GI} index has been obtained from the Climate Research Unit (CRU), University of East Anglia at their website <http://www.cru.uea.ac.uk/cru/data/moi/>. MO_{AC} has been computed for the authors by Ian Harris from CRU routines for which the authors are indebted to him. The authors are also very grateful to Dr. V. Papadopoulos for sharing his MO_{FL} data and to Dr. Jacobeit for his assistance.

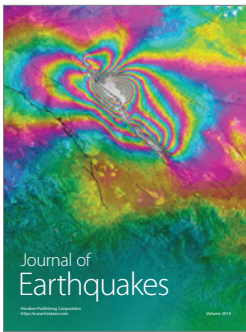
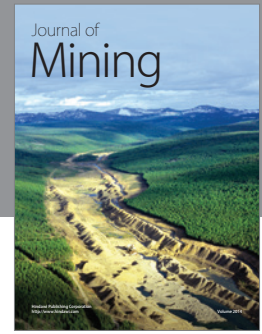
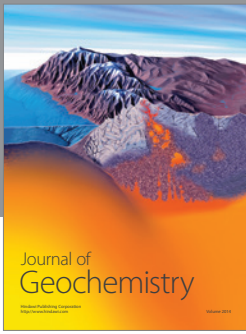
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