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# On the relationship between the decadal oscillations of the northern Ionian Sea and the salinity distributions in the eastern Mediterranean

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[1] We study the impact of decadal inversions of the Ionian upper layer circulation (denominated as Adriatic-Ionian Bimodal Oscillation System) on thermohaline properties of the Levantine and Cretan Seas. Lagrangian drifter data and surface geostrophic currents show that the Atlantic Water (AW) flow is well organized and most intense when the Ionian circulation is cyclonic. During the Ionian anticyclonic phase, the AW spreading pathway is the longest, contributing to its prolonged mixing and higher salinity once it reaches the Levantine. Thus, the Levantine basin is subject to less dilution by AW during the anticyclonic surface circulation phase. Empirical orthogonal function analysis of the sea level shows a large-amplitude circular feature in the northern Ionian which matches the cyclonic/anticyclonic gyre obtained from Lagrangian measurements. Furthermore, it reveals the out-of-phase variability of the North Ionian Gyre and the Aegean and Levantine sea levels. We further show that the surface salinity of the Levantine basin variation is out of phase with that of the Ionian surface layers. Salinity variations of the deepwater column in the Aegean are out of phase with the Ionian surface salinity values, owing probably to a fast transfer of the surface salinity changes via winter deep convection. The changing of the Levantine and Cretan Seas' salinity parallel to the Ionian circulation inversions suggests that the preconditioning for the eastern Mediterranean transient (EMT) is driven by internal processes. As the Ionian inversions are cyclical events, we conclude that the EMT is not an isolated episode but potentially a recurrent phenomenon.

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## 1. Introduction

[2] Numerous numerical and experimental studies have documented that the Ionian upper layer basin-wide circulation undergoes reversals on decadal scales passing from anticyclonic to cyclonic and vice versa [*Pinardi and Navarra*, 1993; *Pinardi et al.*, 1997; *Demirov and Pinardi*, 2002; *Larnicol et al.*, 2002; *Pujol and Larnicol*, 2005; *Vigo et al.*, 2005]. *Demirov and Pinardi* [2002] showed by numerical simulations that around 1987–1988 a reversal from the cyclonic to the anticyclonic mode took place. The circulation reversal was explained in terms of different atmospheric forcing. The initial phase of the reversal from the cyclonic to the anticyclonic basin-wide circulation in 1986–1987 was also demonstrated from in situ CTD data [*Malanotte-Rizzoli et al.*, 1997]. The Atlantic Ionian Stream (AIS) entering the Sicily Channel bifurcates in the Ionian; the northeastward branch meanders anticyclonically bringing the AW into the Ionian interior while the southern branch brings the AW to the Levantine. The subsequent reversal from anticyclonic to cyclonic mode in 1997 was documented from altimetric data [*Larnicol et al.*, 2002; *Pujol and Larnicol*, 2005]. *Borzelli et al.* [2009] showed that the reversal was associated with the vorticity transfer due to redistribution of water masses in the final stage of the eastern Mediterranean transient (EMT) [*Roether et al.*, 1996]. Subsequently, *Gačić et al.* [2010] showed from altimeter data that another passage from the cyclonic to the anticyclonic mode took place around 2006 and suggested that reversals of the North Ionian Gyre (NIG) occur on decadal timescales owing to the interaction between the Adriatic and Ionian Seas. This phenomenon, named the Adriatic-Ionian Bimodal Oscillation System (BiOS), is driven by a feedback mechanism that functions owing to the

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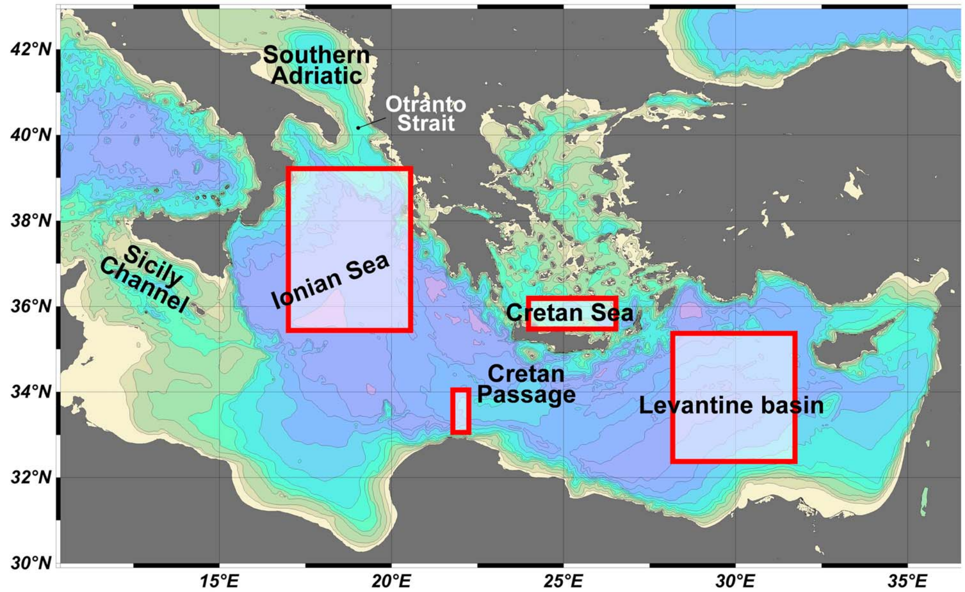


**Figure 1.** Study area. Boxes denote zones in the Ionian, Levantine, and Aegean Seas where average salinity values were calculated. The box extending from the African coast northward represents the area between 33°N and 34°N, 0.5° latitude large, and centered at 22°E where surface geostrophic currents were computed.

differences in salinity between the waters originating from the eastern Mediterranean (EMed) and Atlantic Water (AW) entering from the Sicily Channel. The AW has relatively low salinity, while the EMed waters (Levantine Intermediate Water (LIW) and Cretan Intermediate Water (CIW)) are warmer and more saline. Thus, the Ionian interior is the crossroads of transiting waters: it is influenced by either AW or EMed waters depending on the basin-wide circulation pattern. The water mass brought into the northern Ionian by the cyclonic or anticyclonic NIG eventually enters the Adriatic where it mixes vertically through open-ocean convection [*Gačić et al.*, 2002]. Therefore, another important ingredient in driving the BiOS is the winter convection in the Adriatic that produces dense water of varying salinity and density as a function of the thermohaline properties of incoming waters. This dense water then flows out from the Adriatic and fills the deep layer of the Ionian Sea. The Adriatic is therefore a varying baroclinic vorticity source affecting the Ionian circulation as a function of the salinity and density of the waters that take part in the dense water formation processes. More specifically, under the cyclonic circulation pattern, the Levantine waters spread into the Ionian interior and enter the Adriatic, while anticyclonic circulation brings AW into the Ionian interior and eventually into the Adriatic [*Civitarese et al.*, 2010].

[3] Changes in the Ionian basin-wide circulation pattern thus have an impact on the salt content variations in the upper thermocline layer of the basin interior. Owing to an increased spreading of AW, the surface layer salt content is lower during the anticyclonic circulation period than during the cyclonic one, when the influence of Levantine waters is more pronounced [*Malanotte-Rizzoli et al.*, 1999]. The variations in the thermohaline properties of the upper layer due to the surface circulation inversions in the Ionian are subsequently conveyed to the deep layer via winter convection in the Adriatic.

[4] During the anticyclonic phase of the NIG, the flow of the AW toward the Levantine is partly deviated northward in the Ionian, and consequently the AW has a longer pathway and residence time on its way toward the Levantine. Therefore, the AW has more time for mixing with the adjacent waters before reaching the Cretan Passage (i.e., the passage connecting the Ionian and the Levantine basins; see Figure 1), and the Levantine basin thus becomes saltier than it would be if the AW were spreading directly toward east. Consequently, there should be less dilution of the Levantine basin by AW.

[5] In contrast, during the cyclonic phase of the NIG the AW reaches the Cretan Passage and the Levantine basin by the shortest route, traveling directly from the Sicily Channel eastward. Under these conditions there should be more dilution of the Levantine upper thermocline layer. The importance of the Ionian circulation in the salinity variations and in the deepwater formation processes in the Aegean and Adriatic Seas has been clearly demonstrated by numerical simulations [*Demirov and Pinardi*, 2002].

[6] In the early 1990s the EMed circulation experienced a shift in the location of the dense water formation, from the Adriatic to the Cretan Sea [*Roether et al.*, 1996]. This shift, termed the EMT, was a prolonged two-step process, with a first phase (from 1987 to 1991) during which the deep water within the Cretan Sea became saltier, followed by a second phase (from 1991 to 1995) characterized by a strong cooling and further salinity increase [*Artale et al.*, 2006; *Lascaratos et al.*, 1999; *Theocharis et al.*, 1999]. Further evolution of the EMT is described in detail by *Roether et al.* [2007].

[7] The aim of this paper is to examine from experimental data whether the salinity increase within the Cretan Sea, that is, the preconditioning phase of the EMT, was the

consequence of the salt redistribution in the EMed operated by the BiOS mechanism during its anticyclonic mode. To seek for a possible impact of the BiOS on the sea level and salt content variations in the Levantine and, thus, on the preconditioning for the EMT-like phenomena we carried out a detailed comparison between the Ionian, Cretan and Levantine basins. If an impact of the BiOS on the salinity in the Levantine were shown, it would mean that the preconditioning favorable for the EMT was not a single episode but a recurrent (decadal) feature in the Mediterranean dynamics. Furthermore, the same mechanism (the BiOS) underlying the preconditioning of the EMT-like events would explain the shift from the Adriatic to the Cretan Sea (and again to the Adriatic) as the dense water source for the EMed. In fact, possible out-of-phase variations between the salt content in the upper layer in the Ionian Sea and Levantine basin can easily be extended to the Adriatic and the Cretan Sea.

[8] This paper is organized as follows. In section 2 the data are described and details of calculations of the geostrophic flow, construction of quasi-Eulerian surface current maps, averaging of the zonal geostrophic currents, vertical salinity averaging and sea level empirical orthogonal function (EOF) analysis are given. In section 3 results are presented, while section 4 contains discussion and conclusions.

## 2. Data and Analysis

[9] We used salinity data from CTD measurements from all available cruises carried out between 1985 and 2009 in the Ionian, Levantine and Cretan Seas within the framework of international as well as Italian and Hellenic research projects. We took into account all stations deeper than 1000 m that were located within the areas indicated in Figure 1. From all the profiles available for each cruise, average salinities and their standard deviations were calculated for the layers between 0 m and 250 m, and between 250 m and the bottom. The 250 m depth was chosen in order to encompass the whole layer potentially occupied by the AW as in some parts of the Levantine it can be found as deep as 200 m [*Özsoy et al.*, 1989].

[10] Remotely sensed data consisted of weekly objective maps of the absolute dynamic topography (ADT) over the entire Mediterranean Sea (i.e., the region bounded by 30°N–46°N, 5°W–36.875°E) in the period January 1993–December 2009. ADT maps were extracted from the merged (multimission) altimetric delayed-time Mediterranean data set, sampled on a regular spatial grid of 1/8° × 1/8° [*Ducet et al.*, 2000].

[11] The geostrophic velocity field was estimated from ADT maps using the relationship $(u\ v) = \frac{g}{f}\left(-\frac{\partial\eta}{\partial y}, \frac{\partial\eta}{\partial x}\right)$, where $\eta$ is the ADT, $g$ is the gravity, $f$ is the Coriolis parameter, and $u$ and $v$ are the zonal and meridional components of the velocity.

[12] The flow through the Cretan Passage was represented by the spatially averaged zonal component of the geostrophic velocity. It should be noted, however, that geostrophic velocities estimated in this way may be affected by errors due to inaccuracy in the representation of the geoid (i.e., the shape of the equipotential surface for the gravity field). In continental seas these errors may be important, but they are randomly distributed in space. Therefore, a spatial averaging process, when performed over regions large enough to consider the representation of the geoid adequate (i.e., at least 0.5° × 0.5°; see for details http://www.aviso.oceanobs.com/fileadmin/documents/data/tools/hdbk_duacs.pdf), is expected to remove these errors and provide a rather good representation of the mean flow over the area under study. Zonal components of the surface geostrophic current were calculated from weekly ADT maps and then averaged over an area in the Cretan Passage 0.5° longitude wide and centered at 22° E, extending from 33° to 34°N. (Figure 1). The averaging area was not extended northward up to the Peloponnesos coast in order to avoid the noise introduced by the interannual variability of the Pelops Gyre [*Robinson et al.*, 1991].

[13] Sea surface structure variability was analyzed by means of EOF analysis of the ADT time series. EOFs were computed using the standard spatial EOF decomposition technique outlined by *Borzelli* [2008]. To proceed with EOF analysis, the data matrix **D** was constructed from the set of ADT maps as $(\mathbf{D})_{i,j} = d(x_i, t_j)$, where $d$ is the ADT fluctuation around the spatial mean at pixel $x_i$ and date $t_j$. The covariance matrix was built up by right multiplying **D** by its transpose and scaling the resulting matrix by $N$-1, with $N$ being the number of sea pixels in each input map. EOFs computed in this way are in physical units and normalized to the corresponding standard deviation. However, this normalization is not practical and it is more convenient to normalize EOFs and express the results in terms of dimensionless EOFs (see *Borzelli* [2008] for details). In practice, defining $Y_l$ as the $l$th dimensionless EOF, the basic relationship between coefficients ($c_1$), dimensionless EOFs ($\gamma_1$), and spatial fluctuation of the ADT field is

$$d(x_i, t_j) = \sum_l \gamma_l^{1/2} Y_l(x_i) c_l(t_j). \quad (1)$$

[14] The Lagrangian data used in this study come from a variety of satellite-tracked drifters (mostly SVP and CODE designs) [see *Menna et al.*, 2010; P.-M. Poulain et al., On the surface circulation of the Mediterranean Sea, submitted to *Journal of Physical Oceanography*, 2011] measuring the near-surface currents between 0 and 15 m below the sea surface. In the area of interest (Ionian Sea and Cretan Passage), the drifter data span the period November 1993 to December 2009, including a total of 383 individual tracks. After editing and interpolation [*Poulain et al.*, 2004; *Hansen and Poulain*, 1996], the drifter positions were used to compute velocities by finite differences. The drifter data were subsequently low-pass-filtered to remove inertial and tidal signals (cutoff period of 36 h) and subsampled at 6 h intervals.

[15] Surface wind products (Cross-Calibrated MultiPlatform winds) [*Atlas et al.*, 2009] and surface geostrophic velocities derived from the satellite-derived ADT were interpolated at the drifter positions and used in simple regression models in order to estimate the currents directly induced by the winds, that is, the Ekman velocities [*Menna et al.*, 2010; Poulain et al., submitted manuscript, 2011]. These currents were removed from the low-pass-filtered drifter velocities to create time series of surface geostrophic currents measured in situ by the drifters.

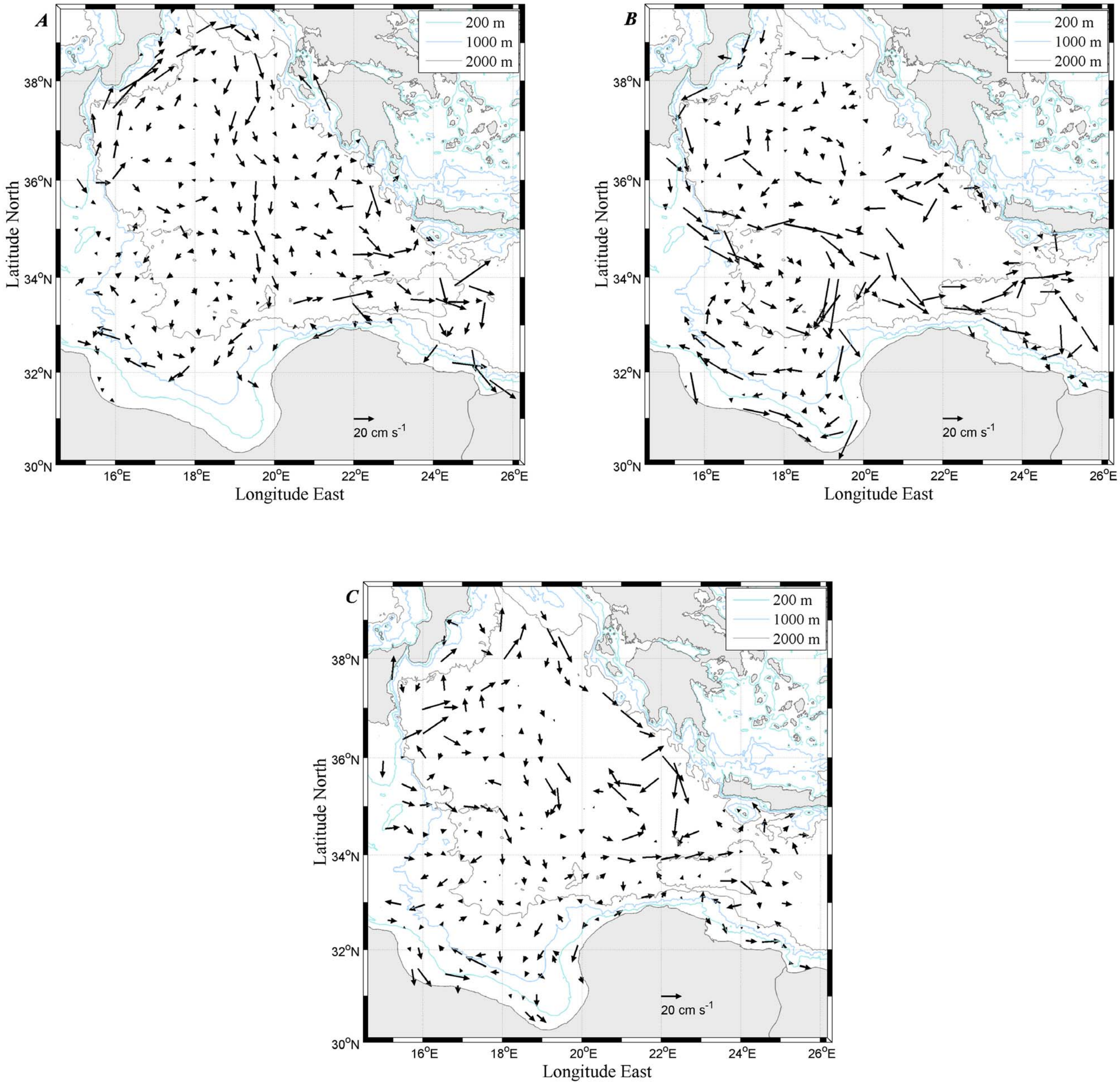


**Figure 2.** Average quasi-Eulerian current field for 2 year intervals: (a) 1995–1996, (b) 1998–1999, and (c) 2006–2007.

[16] Pseudo-Eulerian maps of mean surface geostrophic circulation were computed for three periods of 2 years each with a relatively large amount of Lagrangian data in the study area. The period spans were for the following years: 1995–1996, 1998–1999 and 2006–2007. The criterion for choosing the averaging periods was that they should be representative of the different modes of the NIG circulation as recorded in the literature (see section 1). More specifically the first averaging period should represent the anticyclonic circulation pattern before the reversal in 1998. The second period was chosen to be representative of the cyclonic circulation mode which occurred between 1998 and 2005, while the third period covers a part of the most recent anticyclonic circulation phase appearing after 2005. The velocities were averaged in nonoverlapping geographical bins of 0.5° × 0.5° and bins with fewer than five observations were excluded.

## 3. Results

[17] Quasi-Eulerian surface current maps show clearly two different modes of the Ionian circulation: anticyclonic in periods 1995–1996 (Figure 2a) and 2006–2007 (Figure 2c) and cyclonic in the period 1998–1999 (Figure 2b). Furthermore, comparison of the average quasi-Eulerian surface current field in the anticyclonic and cyclonic NIG regime reveals prominent differences in the AW eastward propagation. In the presence of the anticyclonic meander (average surface current field for the period 1995–1996) there was no direct AW flow eastward, while during the cyclonic NIG

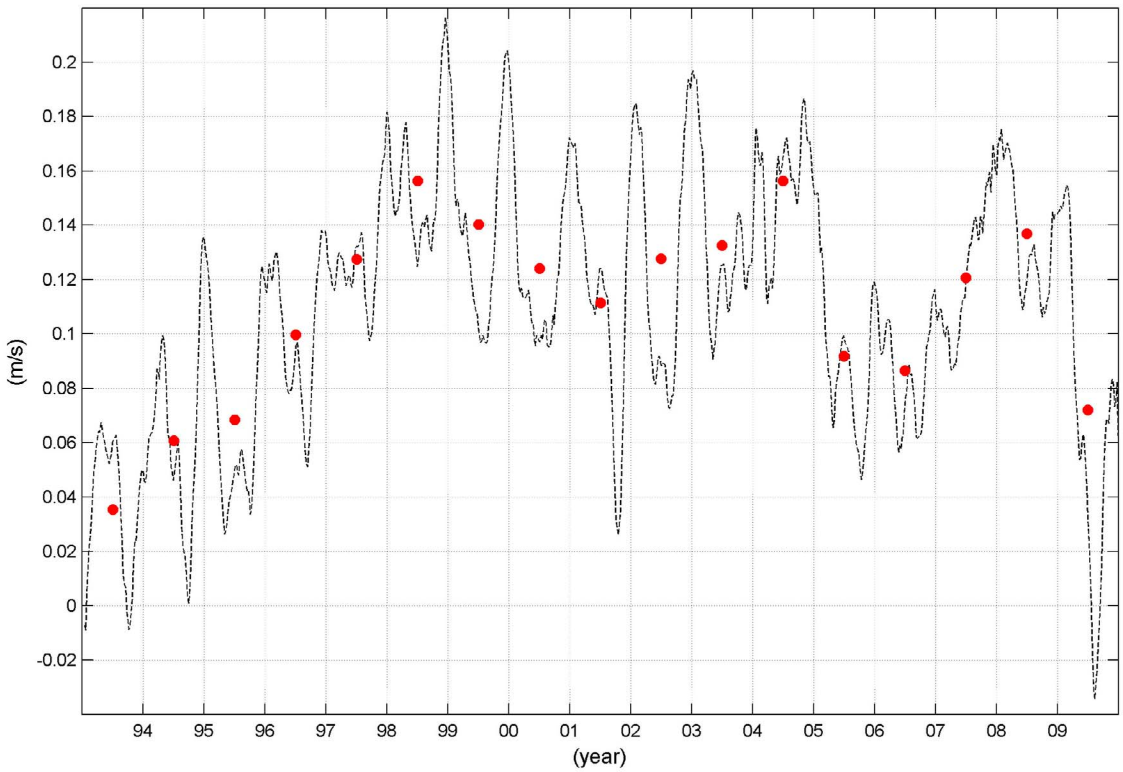


**Figure 3.** Mean zonal component of the surface geostrophic current computed over the area between 33°N and 34°N and centered at 22°E. Dashed line connects weekly low-pass values filtered by a nine-point moving average, while red dots represent annual averages.

phase (average surface current field for the period 1998–1999) there was an organized eastward current directly from the Sicily Channel to the Cretan Passage in the form of the Mid-Ionian Jet (MIJ). Subsequently, after 2005 there were clear indications of the most recent surface circulation reversal in the Ionian and the concurrent disappearance of the MIJ. Therefore, during the anticyclonic circulation in the Ionian the AW became saltier owing to the prolonged mixing and at the same time, as we show, its eastward flow weakened.

[18] The AW flow in the Ionian is mainly confined to the ~100 m thick surface layer [*Alhammoud et al.*, 2005]. Therefore, the intensity of the AW eastward transport can be reasonably well represented by the surface geostrophic flow in the Cretan Passage, which corresponds to the currents below the mixed layer. Yearly mean zonal flow was computed (Figure 3), and it was defined positive for eastward flow, that is, the current flowing into the Levantine. Negative average values represent situations in which the inflow is weaker than the outflow from the Levantine; that is, the AW flow is relatively weak. Conversely, positive values mean the prevalence of the inflow over the outflow and the intensification of the AW flux. The time series shows that most of the time the flow was toward east with only rare inversions, of a duration shorter than a year, that occurred only before 1995 and after 2009. A prevalence of the eastward surface flow is to be expected as it compensates for the counterflow in deeper layers. Generally, weak positive averaged flow occurred until 1996, that is, during the period when the NIG was anticyclonic deviating the AW flow northeastward into the Ionian interior [*Gačić et al.*, 2010] and weakening the eastward surface currents in the Cretan Passage. During the entire period of the NIG cyclonic circulation (1997–2005) the section-averaged geostrophic flow in the Cretan Passage attained large positive values, suggesting the intensification of the surface inflow in the Levantine basin. Thus, in that period the Levantine was presumably under stronger impact of the AW than before 1997. After 2005, when anticyclonic meander reappeared in the Ionian [*Gerin et al.*, 2009], the inflow suddenly decreased and after an intermediate rebound, even became negative in the second half of 2010. Negative zonal currents do not necessarily mean a net westward flow as our averaging area does not cover the entire width of the Cretan Passage. The temporal evolution of the propagation pathway of the AW and the surface exchange between the Ionian and the Levantine basins should affect the salinity of the surface layer as well as the water density in general.

[19] In order to analyze the salt content variations in the Ionian basin and the Levantine and Cretan Seas, and their relationships for different Ionian circulation patterns, the average salinity was calculated from all available CTD data for the three areas. In the Ionian the averaging area was located in its northern portion (Figure 1) in order to be representative of the NIG. The position of the averaging area in the Levantine was chosen attempting to minimize the influence of Ierapetra and Mersa-Matruh gyres [*Robinson et al.*, 1991], although it was not possible to avoid them completely. The third area for calculations of the average salinity occupied the Cretan Sea (Figure 1). The salinity was

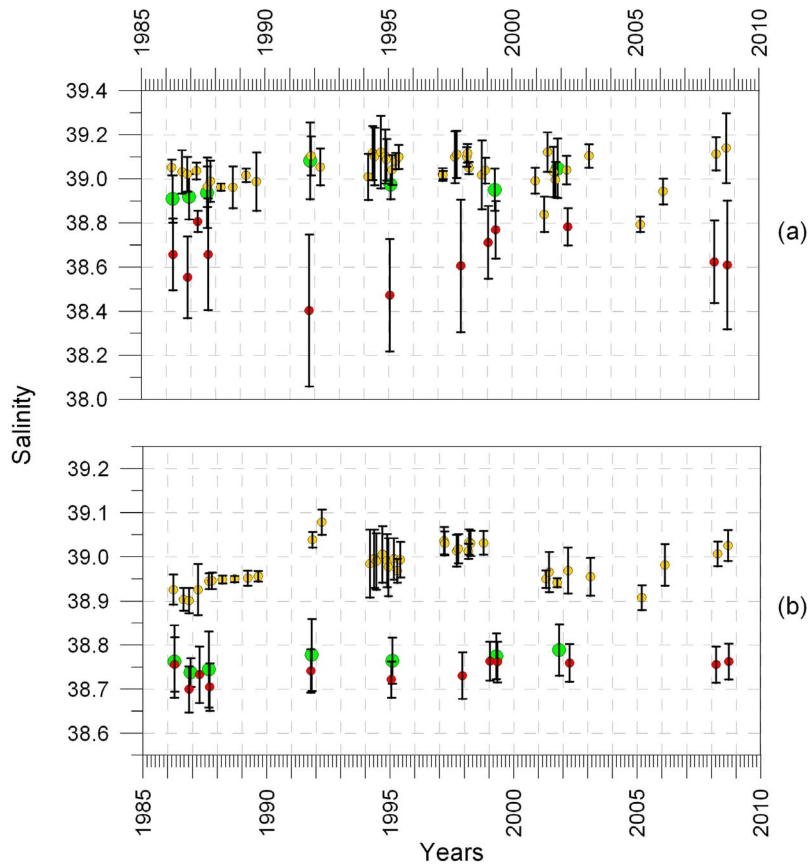


**Figure 4.** Average salinities for the north Ionian (red dots), Levantine (green dots), and Cretan (yellow dots) seas for (a) the surface layer (down to 250 m) and (b) the layer between 250 m and the bottom. Vertical bars denote the one standard deviation interval around the mean.

averaged over the 250 m surface layer and over the layer between 250 m and the bottom. Time series of the vertically and horizontally averaged surface layer salinity in the Ionian show that the 1990s (Figure 4) were generally characterized by salinities lower than those of the late 1980s and early 2000s. This feature is explained in terms of the circulation in the area; in the 1990s the anticyclonic NIG was present, bringing AW into the basin interior (Figure 2a). On the other hand, in the late 1980s [*Demirov and Pinardi*, 2002] and the early 2000s (Figure 2b), the NIG circulation was cyclonic and associated with the direct AW pathway from the Sicily Channel to the Cretan Passage. At the same time, the Levantine waters presumably spread northward into the Ionian interior and eventually Adriatic Sea owing to the cyclonic circulation. Although the quantity of experimental data in the Levantine is rather small, there is evidence that in the 1990s in concomitance with anticyclonic Ionian circulation, salinities in the Levantine reached values larger than in the 1980s (Figure 4) when the Ionian was characterized by cyclonic curvature. As documented by *Malanotte-Rizzoli et al.* [1999], in the late 1980s in the transition phase from the cyclonic to the anticyclonic mode in the Ionian there was still a direct pathway of AW from the Sicily Channel to the Cretan Passage and this created enhanced dilution of Levantine surface waters. Thus the anticyclonic NIG, as shown above from the surface flow pattern and the surface geostrophic currents, weakened the spreading of the AW into the Levantine causing the salinity increase, while the cyclonic NIG in the 1980s and 2000 intensified the AW inflow into the Levantine and its dilution.

[20] The long-term surface salinity variations in the Cretan Sea appeared rather weak. Conversely, the deeper part of the water column (between 250 m and bottom) in the Cretan Sea displayed more pronounced decadal salinity variations that were out of phase with surface salinities in the Ionian and in phase with those in the Levantine. This indicates the rapid vertical transfer of the salinity signal in the Cretan Sea from the surface layer to depth, probably due to winter convection. Salinity variations in the deep layers of both Levantine and Ionian basins showed no significant long-term variability, suggesting a rather slow renewal of the intermediate and deep waters partly due to decoupling of the surface layer from deeper portions of the water column as a consequence of the weak winter vertical mixing. When interpreting relationships in the salinity variations between different subbasins, it is important to notice generally large standard deviations around the mean values due to both vertical and horizontal salinity variability. Especially large standard deviations are evident in the surface layer of the Ionian Sea where the presence or absence of the AW signal in some parts of the averaging area gives rise to the heterogeneous spatial salinity pattern.

[21] The most energetic first EOF mode of ADT, which is responsible for almost 30% of the total variance, displayed a

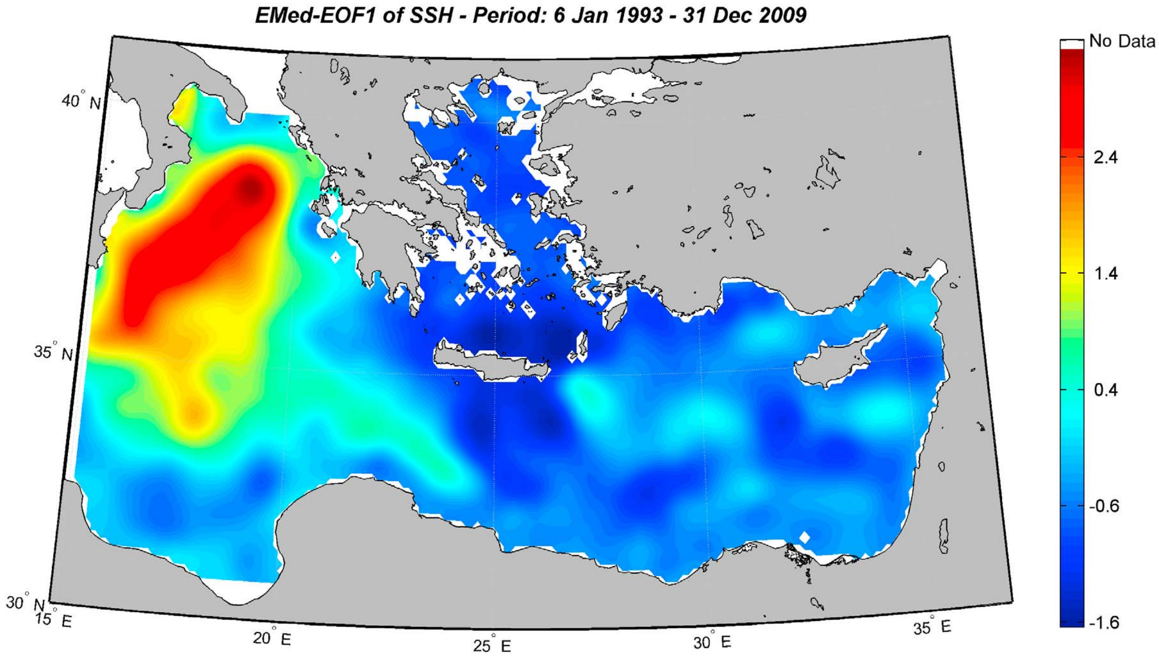


**Figure 5.** Spatial pattern of the first EOF mode (sea surface high (SSH)) of the absolute dynamic topography (ADT) in dimensionless units in the eastern Mediterranean.

spatial structure characterized by a high-amplitude circular pattern in the northwestern Ionian which was of the opposite sign with respect to the Cretan Sea and a large portion of the Levantine (Figure 5). Its amplitude as a function of time shows prevalently decadal variability (Figure 6). Superimposed seasonal variations had relatively small amplitudes that could not change the sign of the sea level departures from the average and reverse the subbasin surface geostrophic circulation pattern. The prevalence of the amplitude of the interannual variability in the eastern Mediterranean circulation over that of the seasonal cycle has been demonstrated by numerical simulations [*Pinardi et al.*, 1997]. The high-amplitude circular feature in the first EOF sea level mode in the Ionian coincided with the cyclonic or anticyclonic NIG circulation pattern as evident from the quasi-Eulerian current fields. The EOF spatial structure multiplied by its amplitude as a function of time suggests that during the Ionian anticyclonic circulation (before 1998

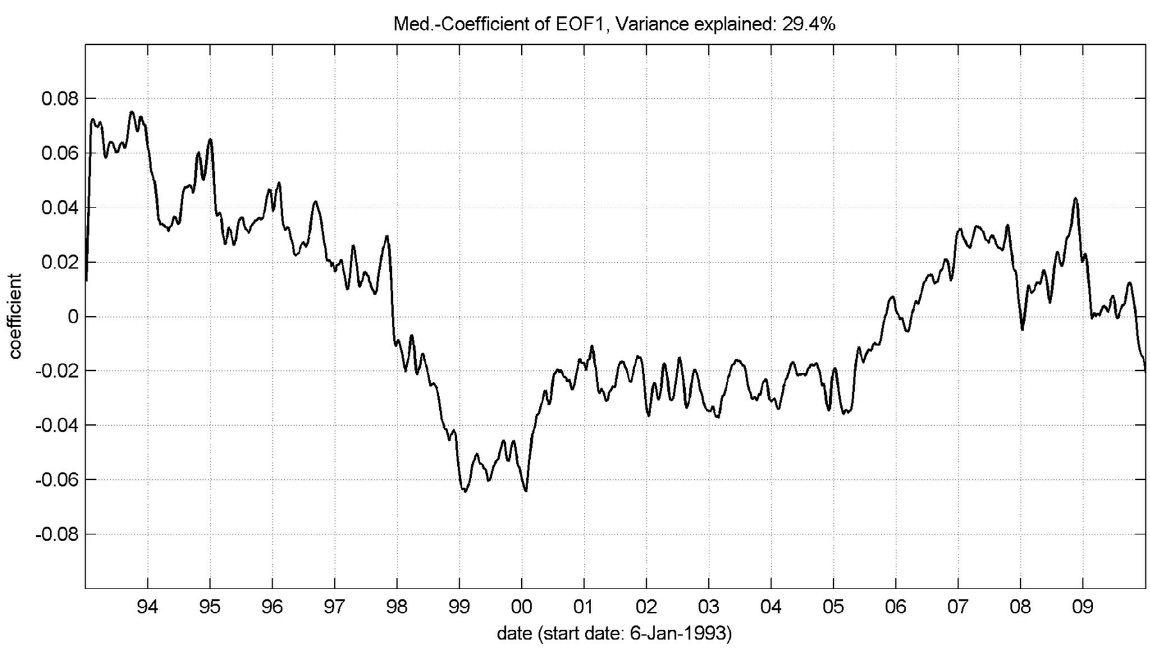


**Figure 6.** The normalized time series of the first EOF-mode coefficient of ADT in the eastern Mediterranean.

and to a large extent after 2006) the sea level in the Cretan Sea and in the Levantine basin reached minimum values. Conversely, during the Ionian cyclonic period (between 1997 and 2005) the sea level in the Cretan Sea and Levantine basin attained its maximum. The noted prevalence of the interannual variability over the seasonal one in the sea level and the correspondence of the high-amplitude circular pattern with the surface current maps suggest that the seasonal variations in the NIG are relatively weak.

## 4. Discussion and Conclusions

[22] The analysis of the zonal component of the surface geostrophic current demonstrates that, during the NIG cyclonic phase, the flow of AW through the Cretan Passage was intensified. Conversely, during the anticyclonic NIG the AW spreads into the Ionian interior and eventually into the Southern Adriatic, while the eastward flow in the Cretan Passage weakened. The surface currents obtained by Lagrangian measurements in the Ionian and Levantine Seas show that in the cyclonic phase the MIJ extended zonally from the Sicily Channel to the Cretan Passage determining the direct pathway of the AW eastward. In contrast, the MIJ was completely absent in the presence of the anticyclonic meander in the Ionian. These observations agree with experimental results by *Malanotte-Rizzoli et al.* [1999] as well as with numerical simulations by *Demirov and Pinardi* [2002], which identified significant changes in the EMed circulation in the late 1980s. They showed that an anticyclonic meander developed in the Ionian Sea and, deflecting the fresher AW from its course toward the Levantine and the Cretan Seas, resulted in salinification of the two basins. *Malanotte-Rizzoli et al.* [1999] showed that between 1987 and 1991 in the upper layer of the Ionian the salt content decreased owing to the massive invasion of AW in its central part caused by strengthening of the anticyclonic circulation. The different penetrations of the AW into the Levantine basin during the Ionian cyclonic and anticyclonic circulation periods have also been documented, comparing the 1995 and 1999 zonal salinity distributions [*Manca*, 2000]. In 1995 as in 1991, the AW largely accumulated in the Ionian owing to the anticyclonic circulation. At the same time, as we also show here, in the Levantine high-salinity water dominated the entire water column. In 1999, with the cyclonic NIG the AW penetrated directly into the Levantine causing freshening of its upper layer. Furthermore, we document that the upper layer salinity variations in the Ionian and the Levantine are out of phase as a consequence of recurrent inversions of the Ionian circulation pattern and concomitant changes in the AW pathway. These variations confirm the hypothesis that a dilution of Levantine waters by intensified AW inflow, and its salinification due to the weakening of the AW inflow, occur during the cyclonic and anticyclonic NIG phases, respectively. During the high-salinity intervals in the Levantine basin, the salt is directly transferred to deeper layers of the Cretan Sea via winter convection as happened during the EMT. This feature has been documented from the salinity data presented here as well as from previous studies [*Theocharis et al.*, 1999]. In this paper, from the EOF sea level analysis we also show that variations associated with the NIG represent the most energetic ones. The seasonal signal is not strong enough to invert cyclonic or anticyclonic decadal circulation regime. It is also demonstrated that when the NIG sea level reaches its maximum both Levantine and Cretan sea levels are at their minimum and vice versa.

[23] The impact of the BiOS on the Levantine surface water dilution may also explain the alternating predominance of the Cretan and the Adriatic Seas as dense water sources for the eastern Mediterranean: when the cyclonic NIG brings salty water into the Adriatic, the Levantine as well as Aegean surface waters are diluted and buoyant owing to the intense AW inflow. The Adriatic is thus more prone to vertical convection when the Cretan Sea is highly buoyant. Conversely, the anticyclonic NIG increases the buoyancy in the Adriatic, increasing at the same time the surface salinity and decreasing buoyancy in the Levantine and Cretan Seas.

[24] The interchange of the Adriatic and Aegean as dense water sources is revealed by numerical simulations within long-term climatic studies [*Artale et al.*, 2006]. *Roether et al.* [2007] suggested that the Aegean can assist the Adriatic salinity preconditioning owing to the small differences in density between the dense waters produced in the two basins. Other numerical exercises carried out for the specific period 1988–1993 documented the collapse of the Adriatic Deep Water formation concurrent with enhanced Cretan Deep Water production [*Samuel et al.*, 1999]. In this latter paper, however, the phenomenon is explained in terms of changes in winter winds and intermediate water pathways. Therefore the varying pathway of the AW in the Ionian, and the intensity of its eastward flow as dictated by the NIG circulation reversals, determines the preconditioning of the EMT-like phenomena as a recurrent process. This in turn eventually leads to the switch of dense water formation from the Adriatic to the Cretan Sea, but only under favorable winter climatic conditions, that is, during severe winters over the Aegean region. Furthermore, this would suggest that the EMT preconditioning is an internally driven process, as already suggested by *Artale et al.* [2006], associated with the change in the circulation in the Ionian [*Demirov and Pinardi*, 2002] or more specifically driven by the Adriatic-Ionian BiOS. In conclusion, as a consequence of the relationship between the BiOS and the Levantine and Aegean salt content, and the successive Cretan Sea preconditioning, the EMT was probably not a single event but is potentially a recurrent phenomenon.

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