An estimate of the E-P of the Mediterranean Sea between 1979 and 2000 using satellite precipitation data

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ABSTRACT Monthly, high-resolution data of precipitation measured from satellite and recently made available (DAAC-GPCP) constitute the basis for an assessment of the evolution of the difference between evaporation and precipitation (E-P) of the Mediterranean Sea between 1979 and 2000. Evaporation data are obtained from NCEP re-analyses. The analysis of data shows an increase in evaporation and a decrease in precipitation, and consequently, an increase of the E-P for the two decades. Adopting two recent estimates for the river runoff, the mean water budget (E-P-R) is evaluated, resulting in good agreement with measures carried out during the CANIGO experiment. Considerations regarding possible connections with main climate indexes show the well-known relation between the precipitation rate in the Mediterranean and NAO index, while a clear connection with ENSO appears difficult to demonstrate clearly.

1. Introduction

The evaluation of the water budget of the Mediterranean Sea is of primary importance to understand the responses of the Mediterranean basin to external forcings, both natural and anthropogenic. A review of the recent studies dedicated to the Mediterranean water budget can be found in Mariotti *et al.* (2002a).

The recent availability of precipitation data measured from satellite in the frame of the Global Precipitation Climatology Project (GPCP: WMO/ICSU, 1990; Huffman *et al.*, 1997) provides a new source to estimate the Mediterranean hydrological cycle. The traditional rain gauge measurements made by ships of opportunity or the rainfall data obtained by interpolation from coastal stations cannot offer the same spatial-temporal coverage and resolution as the satellite-based measurements. The free access to such precipitation temporal series over the ocean gives us the opportunity to evaluate not only the long-term annual value of evaporation and precipitation (E-P), but also its evolution during the previous two decades. Moreover, by adopting two recent river runoff estimates, we can calculate the mean water exchange at the Strait of Gibraltar.

The goal of this paper is to demonstrate the validity of the satellite-based rainfall data evaluating the inter-annual variability of the difference between E-P between 1979 and 2000. We calculate the areal average of E-P over the Mediterranean basin using gridded data of precipitation and evaporation fields. Our results are satisfactory and provide interesting indications about the decadal variability, also sustained by some considerations about the possible connections with climate indexes.

2. Data and methodology

In this paper, we analyse different data sets of monthly estimates of precipitation and evaporation. In the following, we briefly describe the data sets currently used. For a complete documentation (including the reference websites) the reader may refer to the bibliography section.

a) DAAC-GPCP Global Combined Precipitation Data. This global precipitation data set is a merged analysis that incorporates precipitation estimates from low-orbit-satellite microwave data, geosynchronous-orbit satellite infrared data, and rain gauge observations. For the present work, we have considered a data set that provides monthly gridded surface precipitation (mm/day) for the period covering January 1979 to December 2000. The original 2.5 x 2.5 degree gridded precipitation data originated at NOAA National Climate Data Center was re-gridded to a 1 x 1 degree grid by the Distributed Active Archive Center (DAAC). The original data set is formally referred to as the "GPCP Version 2 Combined Precipitation Data Set", which is often abbreviated to "GPCP Combined Data Set" or "Version 2 Data Set". It has been produced for the GPCP, an international effort organized by GEWEX/WCRP/WMO to provide an improved long-term precipitation record over the globe [for details see WMO (1985) and WMO/ICSU (1990)].

b) JAEGER Climatological Global Monthly Mean Precipitation. This data set contains the monthly mean of climatological precipitation values (mm/month) estimated over a 2.5 degree latitude by 5-degree longitude grid. The climatology used for this data set covers the period from 1931 to 1960, over the continents, and the period from 1955 to 1965, over the oceans. For a general description of the gridding method adopted see Jaeger (1983).

c) LEGATES Surface and Ship Observation of Precipitation. This data set consists of a global climatology of monthly mean precipitation values (mm/month), using traditional land-based rain gauge measurements and shipboard estimates, consisting of 24,635 spatially independent terrestrial station records and 2,223 oceanic grid point records, spanning the period from 1920 to 1980. The data are corrected for gauge-induced systematic errors caused by wind, wetting on the interior walls of the gauge and evaporation from the gauge. The corrected monthly precipitation values are then interpolated to a 0.5 x 0.5 degree grid using a spherically based interpolation procedure (Legates and Willmott, 1990).

d) NCEP/NCAR Reanalysis Monthly Means – Evaporation. The NCEP/NCAR Reanalysis project is using a state-of-the-art analysis/forecast system to perform data assimilation using past data from 1948 to the present. A subset of the original data has been processed to create monthly means. The evaporation monthly means (mm/month) estimates are obtained from the latent heat net flux (W/m^2) netcdf file belonging to the "Surface Flux Data" category. The data set analysed here is organized as a T62 Gaussian grid with 192 x 94 points (approximate resolution of 1.9 degree) and covers the period from January 1948 to December 2000.

e) HOAPS satellite-derived global climatology of freshwater flux. Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite Data (HOAPS) data set covers a time period from July 1987 to December 1997 and gives a large database for local, regional and global comparison studies of the satellite-derived parameters with various other climatologies. Ocean-atmosphere evaporation and precipitation rates were computed with recently developed methods from SSM/I and AVHRR data. All retrieval methods have been validated in comprehensive comparison studies with *in situ* measurements and some of the results are shown in the HOAPS web site. In this work, we have used monthly estimates of precipitation and evaporation (mm/h) at 1 degree of spatial resolution, from a homogeneous period covering January 1988 to December 1996 (since the SSM/I-instrument was turned off, no data are available for December 1987 and irregular for several pentads and days during the time period).

2.1. Precipitation data

The novelty of this work is constituted by the precipitation estimates adopted. As previously hinted, in this section, we analyse monthly rainfall data obtained by satellite measurements, merged with traditional gauge observations. Unlike Mariotti *et al.* (2002a), we used the precipitation data set provided here by DAAC-GPCP at a 1 degree resolution, from 1979 to 2000. The higher resolution becomes particularly important especially where coastal stations are surrounded by hills or mountains: the gridded datum relative to such areas can be affected by the larger amount of rain that has fallen over the land, thus overestimating the precipitation which actually reaches the sea. For this reason, we have selected those grid boxes from the original data set where the values of precipitation were not strongly affected by the presence of land. Then, we computed the areal averages over the whole Mediterranean basin.

In order to validate the choice of the data set used for the computation of the hydrological budget, we show the monthly averages of GPCP 22-year (1979-2000) and HOAPS 9-year (1988-1996) with Legates (Legates and Willmott, 1990) and Jaeger (1983) climatologies of Mediterranean Sea (Fig. 1a). The seasonal evolution of DAAC-GPCP data set is correctly reproduced, showing maxima in autumn (about 70 mm in November and December) and a minimum value of 12 mm in July. The figure also shows that the Jaeger climatology's estimates are always higher than the Legates ones, reaching differences on the order of 15 mm in November and December. If we compare the two periods of 10 years corresponding to Jaeger and HOAPS, it clearly appears that, from 60s to 90s, the precipitation on the Mediterranean Sea has generally decreased, especially between March and June (order of 7-8 mm per month) and has increased by the same amount only in February, August and October. The GPCP estimate during the period covered by the HOAPS database (1988-1996) gives a contradictory response: strong decrease between December and March, less than 5 mm of absolute difference during the other months. The annual mean over these 9 years, 485 mm, is 55 mm lower than the Jaeger one, while HOAPS is only 11 mm less.

The GPCP 22-year mean of 503 mm/yr is significantly higher than a previous mean of 310 mm/yr estimated by Bethoux (1977) and then confirmed by Bethoux and Gentili (1999). A similar discrepancy between satellite and traditional measurements was also found in a recent study of Boukthir and Barnier (2001), who computed the climatic mean for the period 1988-1993. Their data were extracted from ERA15, the reanalysis project carried out at the ECMWF, and from a previous version (grid resolution of 2.5°) of the GPCP data set. The ERA15 climatic mean is 310 mm/yr, which compares better with many previous estimates, and that from GPCP is 450 mm/yr. In a study of the hydrological cycle in the Mediterranean for the period 1979-1993, Mariotti *et al.* (2002a) confirm values of basin-averaged precipitation ranging from 331 to 477 mm/yr among different data sets (re-analyses: NCEP and ECMWF, observations: CMAP and CRU). However, it appears that satellite-derived rainfall measurements are generally higher than the traditional gauge measures extracted by data from ships and coast stations.

This aspect was also highlighted in other recent studies. On the global scale, Gruber *et al.* (2000) compared NCEP/NCAR and ECMWF re-analyses data with GPCP 2.5 degree resolution data between 1988 and 1993: the latter are larger than the re-analyses especially in the wet tropical areas and over the storm tracks of the mid-latitudes of both hemispheres. In their concluding remarks, the authors say that the "relatively coarse space and time resolution is not always suitable for other applications, such as hydrological and water resource purposes. This has encouraged us to develop the 1 x 1 degree daily data set which we feel will meet many of the scientific needs of those other users, as well as the climate community". More recently, Pinori *et*

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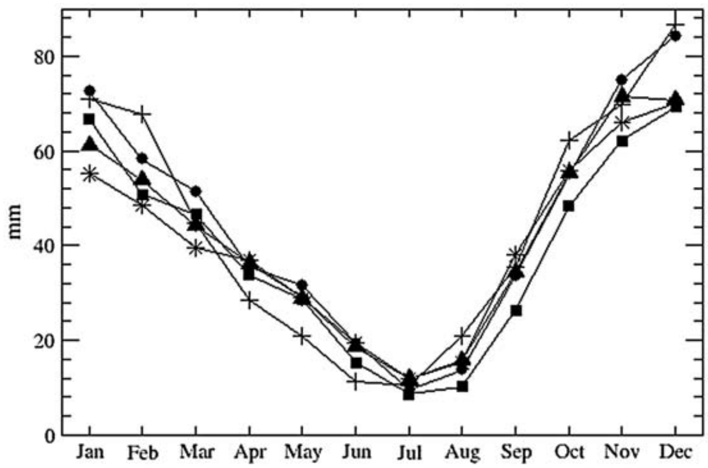

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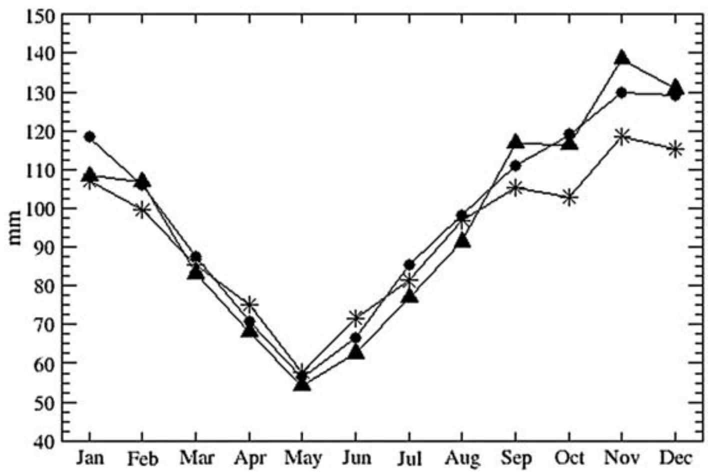

Fig. 1 - Monthly averages of precipitation on Mediterranean Sea: a) DAAC-GPCP mean between 1979 and 2000 (▲), DAAC-GPCP mean between 1988 and 1996 (✻), HOAPS mean between 1988 and 1996 (+), Legates climatology between 1920 and 1980 (■), Jaeger climatology between 1955 and 1965 (●); b) NCEP climatology between 1948 and 2000 (●), NCEP mean between 1988 and 1996 (▲), HOAPS mean between 1988 and 1996 (✻).

al. (2001) compared the rainfall satellite-based estimation and rain gauge measurement during a flood event in north-western Italy observing that, even if the correlation between the IR estimates an the gauges appears good, the Meteosat data tend to overestimate the rain gauge especially for the higher values. Nevertheless, the SSM/I estimates show lower values than the rain gauge mean rainfall rate, probably due to the different spatial resolution. The authors also confirm the improvement due to the combined method (also adopted by GPCP project), developed especially for severe events.

2.2. Evaporation data

The data set used to estimate the evaporation, NCEP/NCAR T62-grid re-analyses of latent heat fluxes, is here compared with the HOAPS data set. In Fig. 1b we show the climatological evaporation on Mediterranean Sea extracted from NCEP re-analyses (from 1948 to 2000), the monthly means between 1988 and 1996 calculated adopting the same data, and the 9-year HOAPS data set.

The differences between NCEP climatology and 88-96 NCEP-mean are always lower than 10 mm, while HOAPS data show differences slightly higher than 10 mm between October and January. The monthly means relative to the 9-year periods considered differ especially from September to December. In this case, satellite-derived estimates of evaporation are lower than those of re-analyses. The absolute maximum is reached in November in all three data sets: HOAPS, 119 mm, NCEP climatology, 130 mm, NCEP88-96, 138 mm; the absolute minimum in May: HOAPS, 58 mm, NCEP climatology, 56 mm, NCEP88-96, 54 mm. The annual means are: NCEP climatology, 1178 mm, NCEP88-96, 1154 mm, HOAPS, 1117 mm. These values are within the range indicated by the climatologies analysed by Mariotti *et al.* (2002a) in the period 1979-1993, which are between 934 and 1176 mm/yr (re-analyses: NCEP and ECMWF, observations: UWM/COADS). Our data results are higher than the average of 920 mm/yr recently computed by Boukthir and Barnier (2001) from ERA15 data set (they confirm that their mean is significantly lower than many previous estimates), but are very low if compared with two estimations of Bethoux and Gentili (1994), 1540 mm/yr, and of Gilman and Garret (1994), 1360 mm/yr.

3. E-P on the Mediterranean Sea and an estimate of the hydrological budget

In order to estimate the difference between E-P on the Mediterranean Sea between 1979 and 2000, we have adopted the DAAC-GPCP precipitation estimates and NCEP/NCAR evaporation re-analyses as our working data sets. The DAAC-GPCP data set was chosen because it represents the only free-access database of satellite-based precipitation at 1 degree of resolution covering this period. Moreover, the present study allows us to demonstrate the value of such data set. The NCEP/NCAR re-analyses are also a free-access database and provide us high-resolution evaporation estimates in the period concerned.

In Fig. 2a we show the 22-year mean evolution of E-P estimated on the whole Mediterranean basin. Evaporation is always larger than precipitation, thus showing the well-established characteristic of the Mediterranean Sea to be a concentration basin.

It demonstrates how evaporation increased by a mean rate of 7 mm/yr, while precipitation decreased by a mean rate of 4 mm/yr. As a result, the water deficit E-P (Fig. 2b) increased by a mean rate of 11 mm/yr. The evolution of the difference between evaporation and precipitation can give us an idea of the variation of the net Mediterranean outflow V_o across the Strait of Gibraltar. According to numerical applications to the Mediterranean Sea summarized by Garrett (1996) and calibrated with direct flow measurements by Bryden *et al.* (1994), an empirical formula for the outflow in Sv (with E and P in m/yr) is $V_o = 1.1(E\text{-}P)^{1/3}$. Applying this formula to our data set we have computed the evolution of V_o from 1979 to 2000 (not shown): it gives an increase of the outflow through the Strait of Gibraltar, with values starting from 0.87 Sv in 1979 to 1.02 Sv at the end of the 90s, thus following the growth of E-P. However, comparing our data with the direct measurements of 0.7 Sv acquired in 1985-1986 during the GIBEX experiment (Bryden and Kinder, 1991), we have to account in the same period for a value larger than 0.2 Sv. Garrett (1996) proposed a value for V_o of 0.9 Sv (which agrees with ours), from an estimate of E-P of 0.52 m/yr. According to Bethoux and Gentili (1999), values of fluxes at the Strait of Gibraltar have to be greater than fluxes at the Strait of Sicily (1.2 Sv: Astraldi *et al.*, 1996). They conclude that the estimates of the mean outflow of the Strait of Gibraltar of about 0.7-0.9 Sv cannot agree with these long-term current measurements.

In order to assess the water budget of the Mediterranean Sea (E-P-R), we consider 0.65 m/yr as the 22-year mean of E-P coming from our data, while the evaluation of the river runoff annual mean (R) represents a critical point. In their freshwater budget, Bethoux and Gentili (1999) considered the estimate calculated by Margat (1992): 505×10^9 m^3/yr, which means an annual riverine runoff in the Mediterranean Sea of 202 mm (assuming the area of the Mediterranean equal to 2.5×10^{12} m^2), without considering the Nile river discharge and the Black Sea net outflow. According to Johnson (1997), “ninety percent of the 2700 m^3/s average Nile flow is now diverted for irrigation and lost by evaporation”; this means that the net Nile’s outflow to the Mediterranean is less than 4 mm/yr, a value that appears quite low if compared to the Black Sea outflow, re-estimated by Bethoux and Gentili (1999) from Aegean Sea budgets to be 182×10^9 m^3/yr, corresponding to 73 mm/yr. Adding such values, the total runoff of 275 mm/yr (279 mm/yr considering also the Nile’s outflow) represents an estimate that doubles that carried out by Boukthir and Barnier (2001) of 140 mm/yr, based on historical data from UNESCO reports computed from 20 years (1974-1994) of non-continuous records. Another estimate is one from Mariotti *et al.* (2002a), computed on historical time series from Mediterranean Hydrological Cycle Observing System (MED-HYCOS) and Global Runoff Data Center (GRDC) archives for the period 1979-1993, being of 100 mm/yr, *i.e.* appreciably lower than the previous ones. We decide to choose a constant value of the river runoff because of the difficulties of evaluating the variations that occurred during the two last decades, even if many authors - among others, Bethoux and Gentili (1999) who estimated a decrease in the layer of freshwater input at the sea surface of 3.6 cm/yr due to human impact on the Ebro and Nile outflows - agree on a substantial decrease.

Considering as mean river runoff on the whole basin the extreme values given respectively by Bethoux and Gentili (1999), 275 mm/yr, and Mariotti *et al.* (2002a), 100 mm/yr, we can give an estimate of Mediterranean water budget, E-P-R, between 375 and 550 mm/yr, the higher value being consistent with Mariotti *et al.* (2002a). Therefore, the net inflow V_i - V_o (evaluated as E-P-

R in Sv) at the Strait of Gibraltar results between 0.03 and 0.04 Sv. Following Bethoux and Gentili (1999), the resulting "inflow V_i should represent 21 times the water deficit in order to balance salt budget and the water deficit, E-P-R, about 5% of V_i or V_o". This means that the values of V_i and V_o are very similar, and the estimation of their difference constitutes a critical point in the determination of the water budget.

Recent measurements of the flow through the Strait of Gibraltar have been performed in 1996-1997 in the frame of the interdisciplinary project CANIGO (CANary Island Azores Gibraltar Observations) of the EU-MAST III program. The upper layer transport (V_i) is 0.81 ± 0.06 Sv and the lower layer transport ($-V_o$) is -0.76 ± 0.06 Sv (Send and Baschek, 1999). The difference results 0.05 ± 0.12 Sv which is in very close agreement with our estimate of 0.03 ÷ 0.04 Sv.

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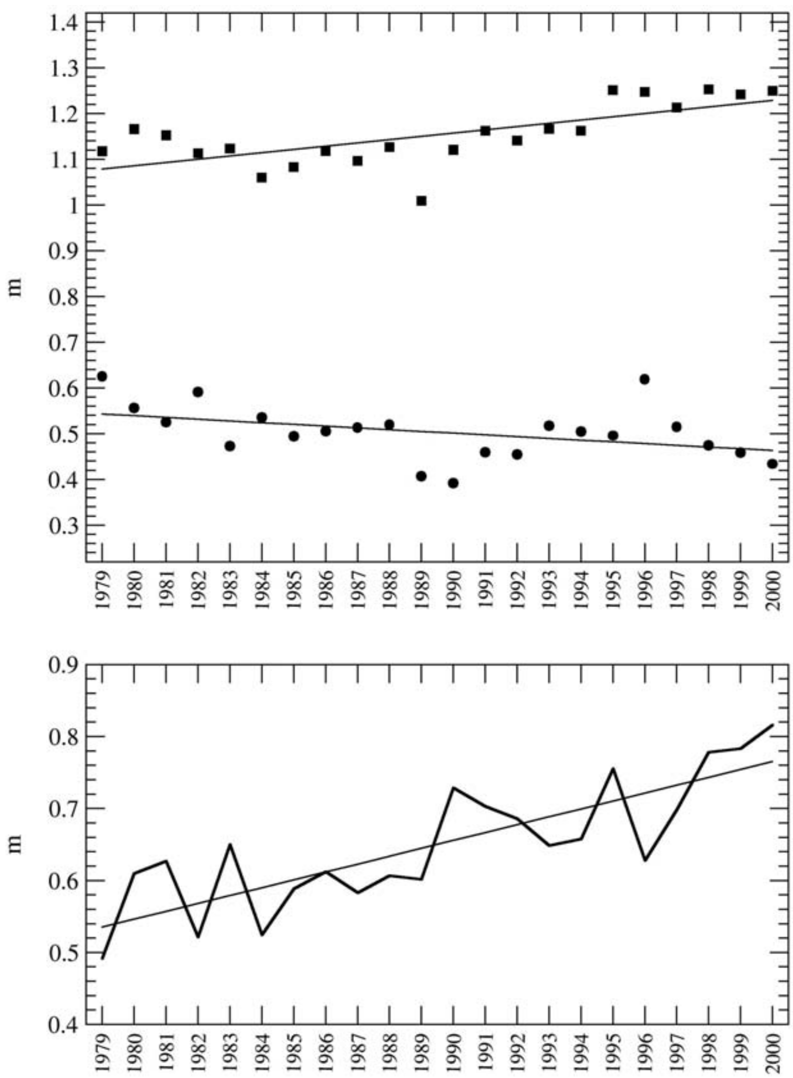

Fig. 2 - a) DAAC-GPCP precipitation (●), NCEP/NCAR evaporation (■), with respective linear regressions.
b) E-P evolution on Mediterranean Sea between 1979 and 2000 with linear regression.

4. Connections with global climatic indexes

4.1. North Atlantic Oscillation index

The North Atlantic Oscillation (NAO) is one of the most dominant modes of the global atmospheric circulation variability. In particular, it represents the principal component of winter climate variability in the north Atlantic region between central North America and Europe, extending its influence also into Europe and northern Asia. The NAO is basically a large-scale seesaw in atmospheric mass between the subtropical high and the polar low. The NAO index is defined as the sea-level pressure difference between 2 stations located near the “poles” of the oscillation. Stykkisholmur (Iceland) is used as the northern station; Lisbon (Portugal), Ponta Delgada (Azores) or Gibraltar is used as the southern station. The choice of the southern station can influence the index especially in season others than winter (Jones *et al.*, 1997). In this paper we have chosen the Jim Hurrell’s monthly indexes (Hurrell, 1995), based on the Lisbon station.

The NAO index exhibits two different phases: positive and negative, each of them corresponds respectively to anomalous increased and decreased pressure gradient between the two large-scale baric features. Let us evidence the effects on Europe and on the Mediterranean basin. The positive phase means augmented and stronger winter storms crossing the Atlantic Ocean on tracks located more northerly, thus resulting in mild and wet winters in northern Europe and a decrease in precipitation especially over the eastern Mediterranean. On the contrary, during the negative phase the winter storms decrease in number and show a zonal pathway, bringing moist air into the Mediterranean and cold air to northern Europe.

A linear regression of the NAO annual index during the analysed period (1979-2000) shows an increasing trend throughout the two decades (see Fig. 3a), which is clearly correlated with the decrease in precipitation over the Mediterranean Sea described in the previous sections. The NAO positive phase dominates, with only five strong negative episodes (annual values less than -1: 1980, 1985, 1987, 1995 and 1996). If we consider the more significant winter indexes, the stronger negative values (less than -1) reduce to 1979 and 1996, which represent the two main minima of the 22-year period and correspond to the two major precipitation maxima, with annual mean value higher than 0.61 m/yr over the whole Mediterranean Sea (the mean over the 22 years is 0.50 m/yr, as shown in section 2.1.).

From the DAAC-GPCP gridded data set of precipitation, we can also extract the estimates relative to the western and the eastern basins (not shown). In 1979 and 1996 we observe maxima of precipitation over the western basin, respectively 0.72 m/yr and 0.76 m/yr, substantially higher than the mean relative to the 22 years of 0.57 m/yr. In the same years, the annual value of precipitation reaches also its maxima over the eastern Mediterranean, 0.57 m/yr and 0.54 m/yr respectively with respect to the 22-year mean value of 0.46 m/yr (another high value occurs in 1982, 0.55 m/yr, but it does not correspond with a such negative NAO index).

The main effect of the positive phase is also confirmed: in 1983, the mean annual rainfall reached the minimum value between 1979 and 1988 (0.47 m/yr), and corresponds to a long-term positive NAO phase characterizing the first half of the 80s. A long positive phase occurs also in the winters between 1988 and 1995, and the high values of the winter index in 1989 and 1990 are correlated with low precipitation amounts, respectively 0.41 m/yr and 0.39 m/yr, the absolute minimum of the whole period of study. The decrease in this phase is particularly strong over the eastern basin (not shown), which exhibits in 1990 its absolute minimum, 0.34 m. The recent positive period corresponding to the last years of the 1990s (with the absolute NAO index monthly maximum of 6.9 in September 2000) shows a decrease in rainfall over the whole basin, and especially in the eastern sector, which between 1996 and 2000 diminished from 0.54 to 0.39 m/yr.

4.2. El Niño-Southern Oscillation index

The El Niño-Southern Oscillation (ENSO) represents one of the main modes of oscillation of global climate variability. The expression "El Niño" describes the warm phase of a naturally occurring oscillation of the sea surface temperature (SST) in the tropical Pacific Ocean: as this oscillation is related with the atmosphere, the term ENSO is now commonly used. Southern Oscillation refers in fact to a seesaw shift in surface air pressure between eastern and western tropical Pacific Ocean. El Niño and its counterpart, La Niña, represent the opposite phases of the oscillation, with the former referring to a warming of the eastern tropical Pacific, and the latter a cooling. The inter-annual cycle (every 4-7 years) of warming/cooling is strongly associated with sea level pressure: the difference between the SLP measured at Darwin and that measured at Tahiti defines the Southern Oscillation Index (SOI). A La Niña event results in a positive SOI, an El Niño event results in a negative SOI. During normal conditions, SST in the western tropical Pacific is about 6-8°C warmer than the eastern part. This large scale temperature gradient is caused by the north-easterly trade winds blowing across the tropical Pacific that move the warm surface water westward, a cold ocean current flowing up along the coast of Chile, and the upwelling of cold deep water off the coast of Peru. When the influence of these cold water masses

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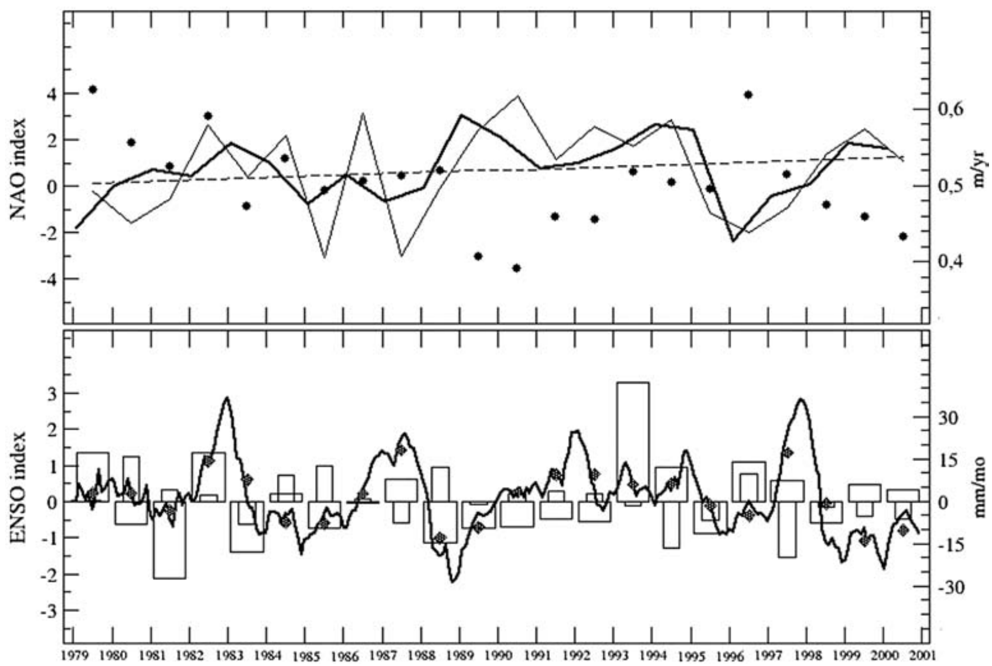

Fig. 3 - a) NAO indexes: annual (light line) and winter (solid line; the dashed line is the linear regression) between 1979 and 2000; DAAC-GPCP rainfall on Mediterranean Sea (dots). b) ENSO indexes: Niño3.4 monthly (solid line); Niño3.4 annual (diamonds) between 1979 and 2000; DAAC-GPCP precipitation anomalies with respect to the climatological mean on western Mediterranean Sea during September-Ocober-November (SON, large bars) and March-April-May (MAM, narrow bars).

diminishes, the ocean surface of eastern and central Pacific warms up: this results in an El Niño event. When the injection of cold water masses intensifies, the surface of the eastern Pacific cools: this results in a La Niña event.

The effects of the ENSO are particularly strong over the Pacific Ocean and the surrounding regions: an El Niño event is associated with increased rainfall across the southern United States and in Peru, causing destructive floods, with dry conditions in the west Pacific, often accompanied by droughts and brush fires in Australia. The bibliography concerning ENSO and its causes and effects is very vast, but few results have been produced on the eventual connections with the Mediterranean. In a recent article, Mariotti *et al.* (2002b) performed a composite analysis of ENSO events, indicating that during El Niño, western Mediterranean rainfall varies according to the season. In particular, the amount of precipitation on the western basin has a 10% increase in the autumn preceding the mature phase of an event, corresponding to a rainy season arriving earlier compared to the climatology. Conversely, the rainfall in the western Mediterranean decreases by 10% in the spring after the mature phase of an event, which corresponds to a rainy season retreating earlier compared to the climatology. They have found significant correlation between autumn (September-October-November; SON) and spring (March-April-May; MAM) rainfall measured for western Mediterranean (derived from four different data sets: CRU48-96, NCEP79-93, ERA79-93 and CMAP79-97) and the Niño3.4 index. This index is based on the SST anomaly with respect to the long-term average in a particular region of the Pacific Ocean. Among the different regions, the Niño3.4 region (5°S – 5°N; 170°W – 120°W) is generally preferred in terms of widespread global variability.

The correlation expressed also appears in our data. In Fig. 3b we show the Niño3.4 indexes and the precipitation anomalies relative to the season (MAM and SON) with respect to the climatological mean on the western Mediterranean, derived from DAAC-GPCP data set. It is clear how before three of the main El Niño events, in 1982-83, in 1994-95 and in 1997-98 (the latter was one of the strongest El Niño events), the SON precipitation is higher than the average and the MAM is lower, respectively after and before the mature phase of the event. And considering the annual precipitation on the whole Mediterranean basin (Fig. 3a), the event that occurred in 1982-83 is also associated with a maximum in the rainfall amount during 1982 (in a positive NAO phase) and a minimum in 1983.

However, these observations could be merely speculative, and in need of more robust motivations. Quadrelli *et al.* (2001) performed a standard principal component analysis over monthly precipitation anomalies for the winters between 1979 and 1995. Differing from the conclusions reached in the article by Mariotti *et al.* (2002b), they argued that there is no clear connection between Mediterranean precipitation patterns and El Niño SST anomalies during winter.

5. Conclusions

The inter-annual evolution of E-P of the Mediterranean Sea between 1979 and 2000 has been estimated using precipitation data coming from the high-resolution satellite measurements provided by the DAAC-GPCP 1 x 1 degree precipitation data and the NCEP/NCAR evaporation re-analyses. Precipitation and evaporation data have been validated with other data sets. The calculations show a substantial increase of evaporation and a decrease of precipitation clearly correlated with a mean positive NAO phase during the previous two decades. As a result, it is shown that between 1979 and 2000, E-P increased by a mean rate of 11 mm/yr.

Adopting two different estimates of river runoff, we have evaluated the hydrological budget E-P-R between 375 and 550 mm/yr. It corresponds, in Sverdrup, to the net inflow V_i - V_o at the Strait of Gibraltar, that results between 0.03 and 0.04 Sv. This estimate of the water budget agrees with the field experiment CANIGO carried out in those years.

Regarding the relations with the global climate indexes, the clearest appears to be one between precipitation rate in Mediterranean and NAO index, while a connection with El Niño events at the moment seems not to be supported enough by data.

The DAAC-GPCP rainfall estimates used here constitute the novelty of this work: our results demonstrate their validity and the accuracy of such data. We strongly encourage the oceanographic and climate community to take into account satellite-based precipitation measures, merged with the traditional rain gauge observations, for their future works.

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HOAPS: http://www.hoaps.zmaw.de

NAO: http://www.met.rdg.ac.uk/cag/NAO/main.html
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