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# Mediterranean Sea climatic indices: monitoring long term variability and climate changes

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**Abstract.** We present a new product composed of a set of thermohaline climatic indices from 1950 to 2015 for the Mediterranean Sea such as decadal temperature and salinity anomalies, their mean values over selected depths, decadal ocean heat and salt content anomalies at selected depth layers as well as their long times series. It is produced from a new high-resolution climatology of temperature and salinity on a 1/8° regular grid based on historical high quality in situ observations. Ocean heat and salt content differences between 1980–2015 and 1950–1979 are compared for evaluation of the climate shift in the Mediterranean Sea. The spatial patterns of heat and salt content shifts demonstrate in greater detail than ever before that the climate changes differently in the several regions of the basin. Long time series of heat and salt content for the period 1950 to 2015 are also provided which indicate that in the Mediterranean Sea there is a net mean volume warming and salting since 1950 with acceleration during the last two decades. The time series also show that the ocean heat content seems to fluctuate on a cycle of about 40 years and seems to follow the Atlantic Multidecadal Oscillation climate cycle indicating that the natural large scale atmospheric variability could be superimposed on to the warming trend. This product is an observations-based estimation of the Mediterranean climatic indices. It relies solely on spatially interpolated data produced from in-situ observations averaged over decades in order to smooth the decadal variability and reveal the long term trends with more accuracy. It can provide a valuable contribution to the modellers' community, next to the satellite-based products and serve as a baseline for the evaluation of climate-change model simulations contributing thus to a better understanding of the complex response of the Mediterranean Sea to the ongoing global climate change. The product is available at https://doi.org/10.5281/zenodo.1210100.

## 1 Introduction

During the twentieth century the Mediterranean Sea has undergone profound and rapid changes. Temperature and salinity have increased with accelerating changing trends the last decades (Rohling and Bryden, 1992; Vargas-Yáñez et al., 2010a;

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Schroeder et al., 2017) reflecting apparently the global warming tendency (Levitus et al., 2012). Because of its geographical position, its small size (reduced volume to area size ratio) and being enclosed between continents, the Mediterranean Sea is very sensitive and responds quickly and stronger than the open ocean to climate changes e.g. changes to atmospheric forcings and/or anthropogenic influences (Bethoux et al., 1999; Schroeder et al., 2017). Moreover, the Mediterranean region has been identified as one of the hot-spots for future climate change in the world (Giorgi, 2006) where changes are expected to be largest. Climate model projections show an acceleration of warming, salinization as well as sea level rise at the twenty first century (Somot et al., 2008; Mariotti et al., 2008; Giorgi, 2006; Giorgi and Lionello, 2008; Adloff et al., 2015; Stocker et al., 2014) with a potential strong impact to the marine environment, its effective management and thus to the human welfare (Stocker et al., 2014; Füssel et al., 2017). In turn, the Mediterranean Sea has an essential role in influencing the global thermohaline calculation regulating thus the global climate (Lozier et al., 1995; Béthoux et al., 1998; Rahmstorf, 1998). As a concentration basin (where evaporation exceeds precipitation) it exports at intermediate depths salty water through the Strait of Gibraltar to the Atlantic, a major site of dense water formation for the global thermohaline circulation. In this context, monitoring the changes of the ocean heat content (OHC) and ocean salt content (OSC) of the Mediterranean Sea is of fundamental importance.

The ocean is the dominant component of the Earth's heat balance, and most of the total warming caused by climate change is manifested in increased OHC. Good estimates of past changes in OHC are essential for understanding the role of the oceans in past climate change and for assessing future climate change (Stocker et al., 2014). However, accurate assessments of the OHC are still a challenge, mainly because of insufficient and irregular data coverage.

The Mediterranean Sea has a very high spatial and temporal variability at all scales, from small turbulence to basin scale processes (Fusco et al., 2003). Three main water masses are found, the surface, the intermediate and the deep waters which form a special flow regime characterized by an active thermohaline (overturning) circulation: a) one shallow cell that extends over the two basins and communicates directly with the Atlantic Ocean and consists of the inflowing Atlantic Water and the return flow of saltier Mediterranean Water and, b) two separate deep overturning cells, in the Western and the Eastern Basins with several sites of deep water formation e.g. in Gulf of Lions at West and South Adriatic, Aegean Sea in the Eastern Basin (Tsimplis et al., 2006, and references therein). Several temporal and spatial scales (basin, sub-basin and mesoscale) interact to form an extremely complex and variable circulation. Complexity and scales arise from multiple driving forces, from strong topographic and coastal influences and from internal dynamical processes. The seasonal, interannual and decadal variability are associated to the internal variability of the climatic system. The variability of the atmospheric circulation patterns induce variations at the water masses either by changing temperature and salinity properties through fresh water and heat fluxes or indirectly by changing the main circulation pathways which in turn can produce changes in the preconditioning phases previous to intermediate and deep water production or redistributing salt and heat content in the water column (Schroeder et al., 2012, and references therein).

Two major abrupt changes have been recorded in the Mediterranean in the last decades which induced important changes to the heat and salt contents. Between late 1980s and middle 1990s an interannual variation, the Eastern Mediterranean Transient (EMT), strongly influenced the intermediate and deep water masses pathways and characteristics (Malanotte-Rizzoli et al., 1999; Lascaratos et al., 1999; Klein et al., 1999; Roether et al., 1996). During that event, the circulation of the Eastern

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Mediterranean experienced a dramatic change from the surface layers to the bottom. Dense water of Aegean origin replaced the resident Eastern Mediterranean Deep Water (EMDW) of Adriatic origin. Inducing the uplifting of the Ionian deep waters, the EMT significantly modified the characteristics of the water masses flowing through the Sicily Strait, while the remarkable presence of salty Cretan Intermediate Water (CIW) (Klein et al., 1999) in the Ionian Sea enhanced the salt export from the Eastern to the Western Mediterranean at the end of 1990s. The EMT affected not only the nearby Tyrrhenian Sea, but also the Western Mediterranean Deep water production (Schröder et al., 2006; Schroeder et al., 2017). After 2000, the dense waters of Aegean origin were no longer dense enough to reach the bottom layer and the Adriatic Sea regained its role as primary source of dense water (Theocharis et al., 2002; Manca, 2003).

Heat and salt contents are calculated from temperature and salinity differences in relation to mean climatological reference values integrated over a particular reference depth and study area (see next section for more details). To detect their long term tendency, long time series extending to more than a few decades are needed in order to identify the natural climate long term oscillations and quantify any remaining trends related to global warming. In small areas where the data coverage is sufficient, OHC/OSC changes are calculated directly from the in-situ measurements. But in large basin scale, where the coverage is not good enough we need to interpolate the data to fill the gaps. In such cases, the noise from the interpolation schemes is an additional source of uncertainty. In 2000, Levitus, using the World Ocean Database (https://www.nodc.noaa.gov/OC5/WOD/pr_wod.html), was the first who spoke about the warming of the global oceans and quantified the interannual-to-decadal variability of the heat content. Since then, periodical updates are released based on additional data, corrections of the time-varying systematic bias in expendable bathythermograph data and corrections of some ARGO float data. He also showed that the correction of bathythermographs reduces the interdecadal variability but the long-term trends remain similar (Levitus et al., 2009). An analogous study in the Mediterranean showed that including or not the bathythermographs in the OHC estimates of the Western Mediterranean does not significantly change the results (Vargas-Yáñez et al., 2010b). In 2012, he reports that for the period 1955–2010, the heat content of the World Ocean for the 0–2000 m layer increased by 24.0±1.9x$10^{22}$ J corresponding to a rate of 0.39Wm$^{-}$2 (per unit area of the World Ocean) and a volume mean warming of 0.09°C. This warming corresponds to a rate of 0.27 W m$^{-2}$ per unit area of Earth's surface. The heat content of the World Ocean for the 0–700 m layer increased by $16.7\pm1.6\times x10^{22}$ J corresponding to a rate of 0.27 W m$^{-2}$ (per unit area of the World Ocean) and a volume mean warming of 0.18°C. He also reports that the 0–700 m ocean layer accounted for approximately one-third of the warming of the 0–2000 m layer of the World Ocean (Levitus et al., 2012). It is worth mentioning that the ARGO array of profiling floats (their deployment started in 2000), improved significantly the in-situ observations spatial coverage and the thereafter assessments for the 0–2000 m but there are still many regional seas uncovered (observations there come mainly from hydrographic cruises).

In the Mediterranean, many works since the late 1980s have been carried out trying to quantify the trends for the temperature and salinity and determine what causes underlie these (such as global warming or anthropogenic climate change due to main rivers damming). Table 1 in Vargas-Yáñez et al. (2008); Manca et al. (2004), and in Table 1 in Skliris et al. (2018) summarize the main findings. An analysis of the results show that there are differences between them arising from: a) the input data (in-situ or interpolated data or model or satellite) b) their spatial and temporal variability, c) the choice of the climatological reference, d) the quality control procedures, e) the instruments accuracy f) the mapping techniques e.g. the gridding and infilling

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methodologies such as optimal interpolation or variational inverse methods used to fill the data gaps and obtain a gridded 3D continuous field and time series thereafter as well as what assumptions are made in areas of missing data (Jordà et al., 2017).

Some of the above findings are outlined below. The increasing trend is more evident in the salinity than the temperature. The temperature and salinity of the deep waters of the Western Mediterranean are increasing. In the Eastern Mediterranean, for the intermediate layer there is no general consensus. Rixen et al. (2005) using the MEDATLAS climatology (MEDAR Group, 2002) found an increase of OHC and OSC about [1.3–1.5] $10^{21}$ J and [1.4–1.6] $10^{14}$ $m^3$ respectively, over the whole Mediterranean for the period 1950–2000, corresponding to volume mean T and S anomalies of about [0.09–0.10]°C, and [0.035–0.04] respectively. During the last decades, the Western Mediterranean OHC and OSC are increasing with an accelerating tendency of the western deep waters towards higher temperatures and salinities since the 1950s, with the process accelerating after the second half of the 1980s. The variation of the intermediate layers is attributed to decadal variability. Skliris et al. (2018) identified a strong basin-scale multi-decadal salinification, particularly in the intermediate and deep layers of order 0.015 pps/decade, by analyzing the inter-annual objectively analyzed gridded fields from EN4 from the Met Office Hadley Center (subversion En4.1.1., http://www.metoffice.gov.uk/hadobs/en4) and MEDAR/MEDATLAS climatology (MEDAR Group, 2002), for two references periods, 1950–2002 and 1950–2015. Schroeder et al. (2016), analyzing in situ data found that over the period 1950–2010, the deep Western Mediterranean Deep Water heat and salt contents increased almost steadily, with an acceleration after the middle 1980s. Below 1000 m, the Mediterranean underwent the strongest salinity gain in the world ocean (Skliris et al., 2014).

The objective of this work is to contribute to the efforts of the oceanographic community to quantify with more accuracy the T/S and OHC/OSC variations by providing a new product based on additional and more recent observations which have been averaged in time and interpolated in space in an optimal way in order to smooth the decadal noise and reveal the long term trends. The new product is expected to give a more detailed insight into the spatial pattern of the changes for the whole Mediterranean and the decadal variability of OHC/OSC. The originality of this product compared to the existing ones is that we: a) use a higher spatial and temporal resolution gridded fields of T/S anomalies, b) provide a large-basin scale spatial patterns for the trends of the decadal T/S and OHC/OSC anomalies, c) provide long-term time series of the decadal anomalies, c) provide 30–year averages for evaluating the climate shift in the Mediterranean. The finer spatial resolution of the input data climatology is filtering out the noise induced by the mesoscale features but at the same time is such that it smoothes less the large scale features. The temporal resolution is such that it smoothes the strong seasonal, interannual and decadal variability so as the final product to be able to resolve in more details the climatic variability and identify possible warming trends. Three layers were considered in this work as representative of the main water masses found in the Mediterranean: 0–150 m, 150–600 m, 600–4000 m respectively for the surface, intermediate and deep waters, as in Robinson et al. (2001), and one additional 0–4000 m for the whole water column and volume assessments.

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## 2 Data and Methods

### 2.1 Data Sources

Gridded horizontal fields from a new high resolution climatology of temperature and salinity for the Mediterranean (Iona et al., 2018) were used as input data. These fields were produced using the SeaDataNet temperature/salinity historical data collection V2 (INGV, 2015, available at http://sextant.ifremer.fr/record/8c3bd19b-9687-429c-a232-48b10478581c/). The SeaDataNet collection comprises 213542 temperature and 138691 salinity profiles from in-situ measurements for the 1911 to 2015 period. The gridded fields cover the geographical region -6.25°W–36.5°E, 30°–46°N on 31 standard depth levels from 0–4000 m: [0, 5, 10, 20, 30, 50, 75, 100, 125, 150, 200, 250, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1400, 1500, 1750, 2000, 2500, 3000, 3500, 4000]. The spatial resolution is 1/8° × 1/8°. The seasonal scale is: winter (January-March), spring (April-June), summer (July-September), fall (October-December). The gridding of the in-situ observations was done with the Data Interpolating Variational Analysis (DIVA) software tool that allows the spatial interpolation of data in an optimal way, comparable to optimal interpolation (OI) using a finite-element method (Beckers et al., 2014; Troupin et al., 2012). The input gridded data are listed below. They are stored in netCDF files and are accessible from the Zenodo platform:

1. *Annual climatology (reference)*, obtained by analyzing all data (regardless month or season) for the whole period from 1950 to 2015. Used as a mean reference that subtracted from the annual decadal climatology to obtain the T/S anomalies. It is available here: https://doi.org/10.5281/zenodo.1146976.

2. *Annual decadal climatology*, obtained by analyzing all data regardless month or season for each of the 57 running decade from 1950–1959 to 2006–2015. It is available here: https://doi.org/10.5281/zenodo.1146957.

3. *Seasonal Climatology (reference)*, obtained by analyzing all data of the whole period from 1950 to 2015 falling within each season. This climatology used as a mean reference that subtracted from the seasonal decadals to get the anomalies. It is available here: https://doi.org/10.5281/zenodo.1146953.

4. *Seasonal decadal climatology*, obtained by analyzing all data falling within each season for each of the 57 running decade from 1950–1959 to 2006–2015. It is available here: https://doi.org/10.5281/zenodo.1146938.

The input data used for the current work have been already evaluated with existing comparable products in the region such as SeaDataNet and WOA13 monthly climatologies (Iona et al., 2018). It is important to notice that in the used input climatology, each gridded field is accompanied by an error field that allow one to assess the reliability of the input data. This helps to objectively identify areas with poor data coverage, mask them and exclude them for further processing.

### 2.2 Definitions

**Anomalies:** In all products, temperature and salinities anomalies have been used. Anomaly is defined as the difference between the value of a grid point and a mean climatological reference.

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**Mean climatological references** :

- Annual climatology used as reference for the annual decadals,
- Seasonal climatology used as reference for the seasonal decadals.

**Climates:** the World Meteorological Organization (WMO) recommendation of using 30-year averages (climate normals) for describing climate conditions was used in this study (WMO, 2011). Climate shift is defined as the difference between two successive 30–year averages.

**Linear trends:** they were computed by linear regression with a constant term.

It is noted that in the climate shifts presented in this work, the period 1950 to 1979 contains three decades and the period 1980 to 2015 contains six years more because the period from 2000 to 2015 is treated as a decade. This was done for two reasons: a) not exclude the recent data from the representations of the regional patterns of the climate shifts (or the oldest ones if the study period was shifted later than 1950), b) the averaging of the additional recent years actually does not change the qualitative results of the comparison of the two successive periods. The user of course can choose between any period and average the decades according to the needs of each study since the available product includes all 57 running decades from where the climates are computed.

## 2.3 Process Outline

First, seasonal and annual decadal fields of temperature and salinity anomalies (T/S) at each standard depth were generated. Next, T/S vertical averages were calculated for the four layers, 0–150 m, 150–600 m, 600–4000 m, 0–4000 m. The thickness of the layers was used as weights for the vertical averaging calculated as the half of the distance between adjacent depths. The following weights were used for the 31 standard depth levels: 2.5, 5, 7.5, 10, 15, 22.5, 25, 25, 25, 37.5, 50, 50, 75, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100, 175, 250, 375, 500, 500, 500, 500. For the estimation of the OHC anomalies the following methodology was used. Each T/S anomaly at each standard depth is associated with a volume which consists of the area of the 1/8° × 1/8° longitude/latitude grid multiplied by the thickness of each layer e.g. the vertical weights. By multiplying the volume with the T anomalies and by the density of sea water and by the specific heat, we obtain the OHC anomaly of a specific grid point at each standard depth. By integrating over a depth layer and over all the analysis area, we obtain the OHC anomaly (in Joules) for the whole Mediterranean Sea according to the following equation:

$$OHC = \rho C_p \sum_{i=1}^{n} dxdy \int_{z_1}^{z_2} \Delta T dz. \quad (1)$$

The areal density of OHC (in J/m$^2$) is obtained by integrating the vertical average $T$ anomaly over a depth layer according to the equation:

$$\text{Areal Density OHC} = \rho C_p \int_{z_1}^{z_2} \Delta T dz, \quad (2)$$

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where: $\rho$ = 1028 kg $m^{-3}$ the density of reference seawater, $C_p$ = 3985 J $kg^{-1}$ °C the specific heat of sea water, n = the number of grid points, dx = 10951.1 m , dy = 13897.2 m, $\Delta T$ the temperature anomaly, $z_1$ and $z_2$ the upper and lower depths. The dx, dy are the longitude (1/8°), latitude (1/8°) steps of the output grid transformed from degrees to meters. A mean basin volume is estimated at $3.86 \times 10^{15}$ $m^3$ and corresponds to mean wet volume of the analysis grid of the interpolation. For the OSC, the same methodology is used except that we do not multiply by $(\rho C_p)$, the term that converts temperature to thermal energy (heat).

### 2.4 Climatic indices content

The produced climatic indices for the whole Mediterranean Sea (-6.25°W–36.5°E, 30°–46°N) consist of:

- Annual and seasonal T/S anomalies at 31 standard depths, for 57 running decades from 1950–1959 to 2006–2015.
- Annual and seasonal T/S vertical averaged anomalies at four layers (surface, intermediate, deep and whole column), for 57 running decades from 1950–1959 to 2006–2015.
- Annual and seasonal areal density of OHC/OSC anomalies in four layers (surface, intermediate, deep and whole column), for 57 running decades from 1950–1959 to 2006–2015.
- Annual and seasonal linear trends of T/S, OHC/OSC anomalies at four layers (surface, intermediate, deep and whole column) for all 57 decades.
- Annual and seasonal time series of T/S, OHC/OSC anomalies at four layers (surface, intermediate, deep and whole column) over the whole Mediterranean Sea.
- Differences of two 30-year averages of annual and seasonal T/S anomalies at 31 standard depths for the period 1950 to 2015.
- Differences of two 30-year averages of annual and seasonal T/S, OHC/OHC anomalies for the period 1950 to 2015, at four layers (surface, intermediate, deep and whole column).

All data are stored in netCDF files except the time series that are in ascii format and are accessible at: https://doi.org/10.5281/zenodo.121010

## 3 Results

We outline below some of the capabilities of the new product. The explanation of the long term variability patterns that are revealed and attribution of possible causes is out of the scope of this work. A short overview of these was given in the introduction to facilitate the viewing of the products for those readers who are not familiar with the Mediterranean complex dynamics. For the evaluation of the Mediterranean Sea climate changes we compare two successive 30–year averages of heat and salt content anomalies of the period 1950 to 2015. The 30-years periods are averages of three successive decades, the first

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one is referring to the decades 1950–1959 to 1979–1979 and the second, 1980–1989 to 2000–2015. Figure 1 illustrates the geographical distribution over the whole Mediterranean of the 30 year climate shift as the OHC differences between the period 1980–2015 and 1950–1979 in the upper 5–150 m (Fig. 1(a)), 150–600 m (Fig. 1(b)), 600–4000 m (Fig. 1(c)), and 5–4000 m (Fig. 1(d)).

From the surface layer until 150 m the climate shift is not uniform. Western Mediterranean surface layer (Fig. 1(a)) has experienced warming almost everywhere expect the Gulf of Lions and the North Tyrrhenian–Ligurian East basins, and this could be linked with the Western Mediterranean Transient (WMT) climate shift, a phenomenon started in mid–2000s with deep water formation events which changed the properties of the intermediate and deep layers in the Western Mediterranean (Schroeder et al., 2016). The surface layer of Eastern Mediterranean (Fig. 1(a)) is cooling with a noticeable cooling spot at the Ierapetra gyre. We see the same with surface patterns at the intermediate layers from 150–600 m but with about half of the strength of the surface (Fig. 1(b)). The deep waters are warming almost everywhere except the southern Adriatic, the southern Levantine and south west Ionian basin (Fig. 1(c)).

Regarding the salinity, it is important to notice that in the whole Western Mediterranean there is a clear OSC increase throughout the whole water column (Figs. 2(a)–2(b)) while in the Eastern Basin we see that the spatial pattern is not uniform and a notable salt content increase is observed in the areas of deep water formation e.g. South Adriatic and Aegean Sea. According to the bibliography, this is the Eastern Mediterranean Transit (EMT) signature on the intermediate and deep waters not only at the Eastern Mediterranean but at the whole basin (Klein et al., 1999; Theocharis et al., 1999; Rixen et al., 2005; Schroeder et al., 2016). Notable salt increases are found at the Shikmona gyre and south west Ionian following the patterns of the heat content. These increase have been identified in others studies (Skliris et al., 2018; Vargas-Yáñez et al., 2010a; Bethoux et al., 1999; Rohling and Bryden, 1992), but not with the details included in these spatial regional based views.

To illustrate the temporal variability of the thermohaline content, the annual OHC and OSC anomalies for six discrete periods 1950–1959 to 2000–1015, for the three layers (5–150 m, 150–600 m, 600–4000 m) and the whole water column (5–4000 m) are shown in Figs. 3(a)–3(b). We can easily see that except the strong spatial variability shown in Fig. 1 and Fig. 2, there is a similar irregular pattern from one decade to another. One remarkable feature in these distributions is the acceleration and the substantial heat and salt gain of the deep layer (600–4000 m) starting from 1990. It is also found that the correlations (significant at the 95% confidence level) between the decadal Atlantic Multidecadal Oscillation (AMO) index and the decadal OHC averages are: 0.69 for the 0–150 m, 0.64 for the 150–600 m, 0.63 for the 600–4000 m and 0.76 for the whole column 5–4000 m. The corresponding correlations with North Atlantic Oscillation (NAO) index are: 0.23, -0.22, 0.50 and 0.38. These findings seems to be in agreement with the bibliographical references, where observed acceleration from satellite data of the Mediterranean waters warming during the 1990s could be attributed to the positive phase of AMO (Macias et al., 2013).

To get a more detailed insight in the long-term fluctuations we show at Fig. 3(c), times series of the decadal OHC and OSC anomalies integrated over the whole column depth and area of the Mediterranean Sea. There are changes, slowdowns and accelerations throughout the studying period and we can distinguish three main periods: a) from 1960 to late 1970s with an increasing trend in salt but a decreasing heat trend, b) from 1980 to 1990 with no significant changes, and c) from the 1990 to today with strong OHC/OSC increasing trends (Skliris et al., 2018). For the study period from 1950–2015 there is a

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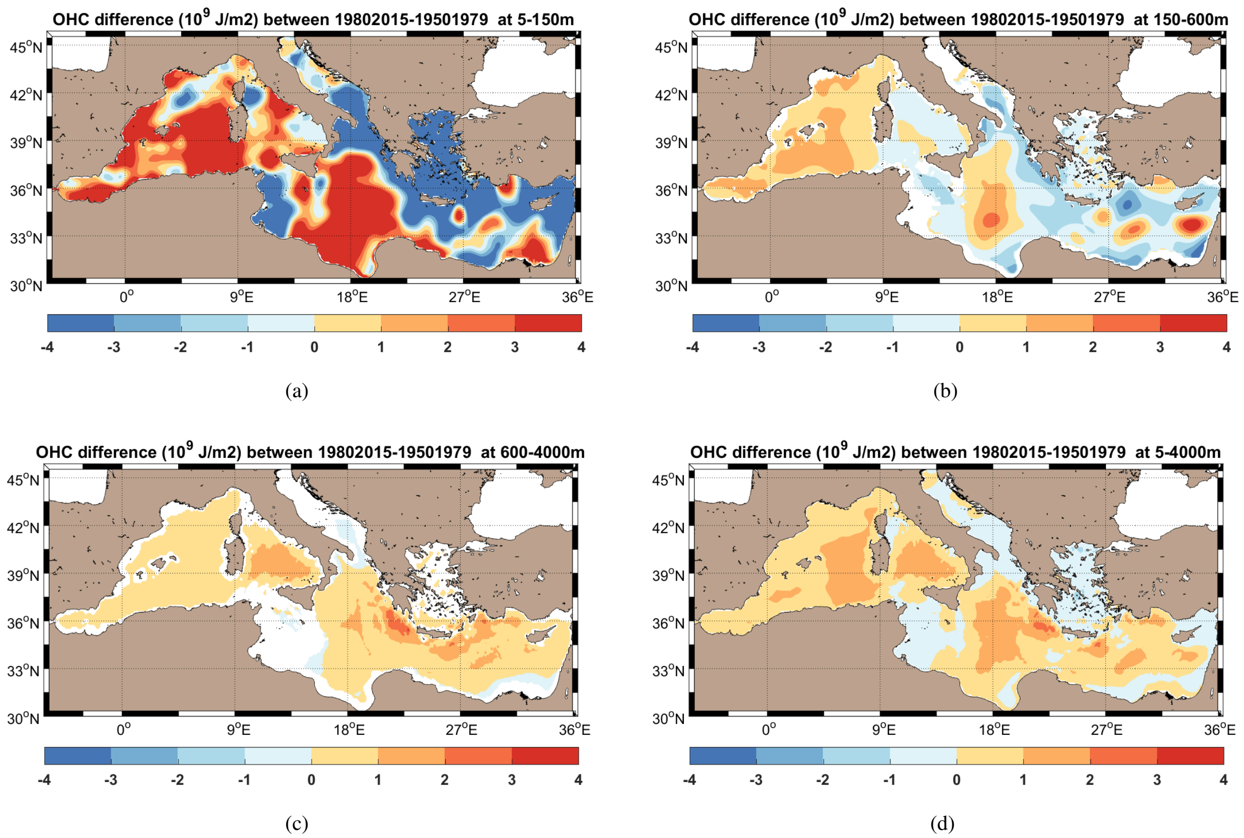


**Figure 1.** Climate shift of areal density of Ocean Heat Content in $10^9$ J/m$^2$ between two 30–year periods 1980–2015 and 1950–1979 for: (a) 5–150 m, (b) 150–600 m, (c) 600–4000 m, (d) 5–4000 m.

(statistically significant) spatial overall increase of heat and salt content of about (3.8±0.5) ($10^{20}$ J/decade) and (4.7±0.4) ($10^{13}$ ppt m$^3$) respectively, which corresponds to a temperature increase of about 0.024°C/decade and a salinity increase of about 0.012 ppt/decade. These estimates for temperature and salinity increases are about 30% and 60% higher than the one estimated by Rixen et al. (2005). The temperature increase is 50% higher than the one estimated for the global ocean by Levitus et al. (2012).

To provide evidence that our results of the decadal OHC and OSC anomalies changes are not biased because of the time averaging used to define the analysis periods (averaging over the decades), we computed a 57–year trend for the period 1950–1959 to 2000–2015 based on the decadal T/S anomalies averaged over the four depth layers. As reference, the annual climatology of all years was used. Figure 4 illustrates the statistically significant spatial pattern of the linear trends for temperature (°C/decade, Fig. 4, left-hand side) and salinity (ppt/decade, Fig. 4, right-hand side). The trend for the whole water column (Fig. 4(g) and Fig. 4(f)) reveals that for the salinity (Fig. 4(f)) there is a positive trend everywhere which can lead to the conclusion that the estimations for the salt content increase for the period 1950–2015 are robust enough. The temperature pattern reveals two main

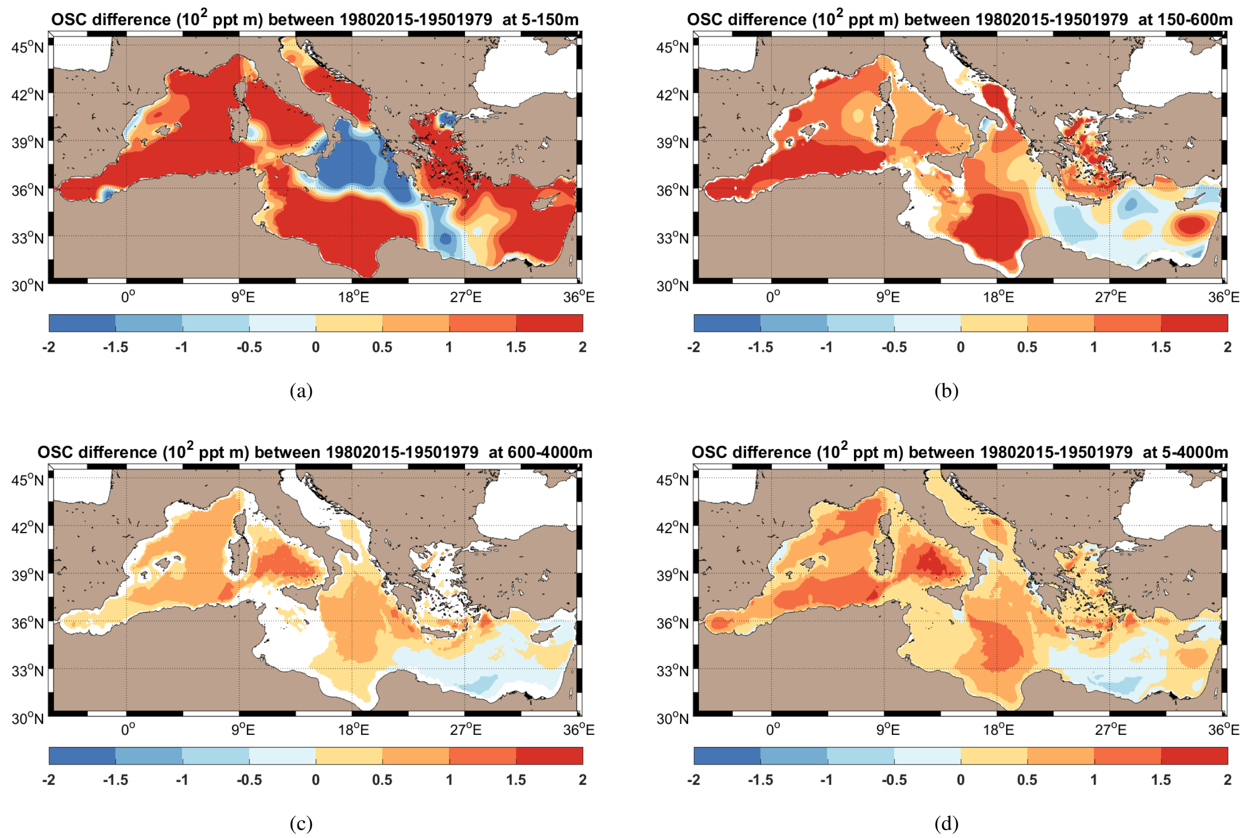


**Figure 2.** As in Figure 1 for the climate shift of areal density of Ocean Salt Content in $10^2$ ppt m between two 30–year periods 1980–2015 and 1950–1979 for: (a) 5–150 m, (b) 150–600 m, (c) 600–4000 m, (d) 5–4000 m.

areas of long-term decreasing trends (Fig. 4(g)), the Aegean and the South Adriatic Sea which could be responsible for the smaller rate of the heat uptake compared to the salt content increase. The results show a noisy and patchy spatial pattern of the temperature anomaly trend at the first 600 m (Figs. 4(a) and 4(c)) more noisy than the one for the salinity (Figs. 4(b) and 4(h)). This pattern reveals the climatic residual of the circulation patterns with spatial scales larger than 300–400 km which of the correlation scale of the analysis of the gridded inputs fields. At the surface (Fig. 4(b)) the salinity trend is positive almost everywhere in the Mediterranean Sea, while in the intermediate depths (Fig. 4(h)) we distinguish the strong positive trends at the areas of deep water formation at the Eastern Mediterranean, South Adriatic and Aegean Sea which can be linked with the Eastern Mediterranean Transient the late 1980s and early 1990s (Malanotte-Rizzoli et al., 1999; Lascaratos et al., 1999; Klein et al., 1999; Roether et al., 1996). This strong signal can be also traced out at the Alboran Sea and the south Algerian basin (Fig. 4(d)), the outflow path of the LIW towards the Atlantic Ocean, a result that is in agreement with the bibliography (Millot et al., 2006).

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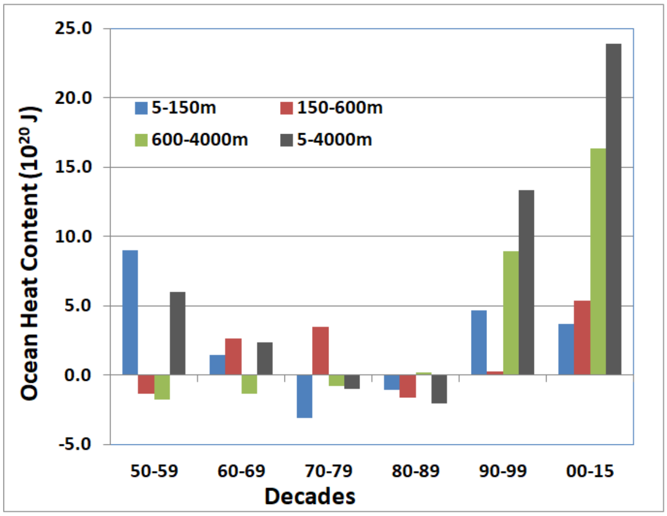
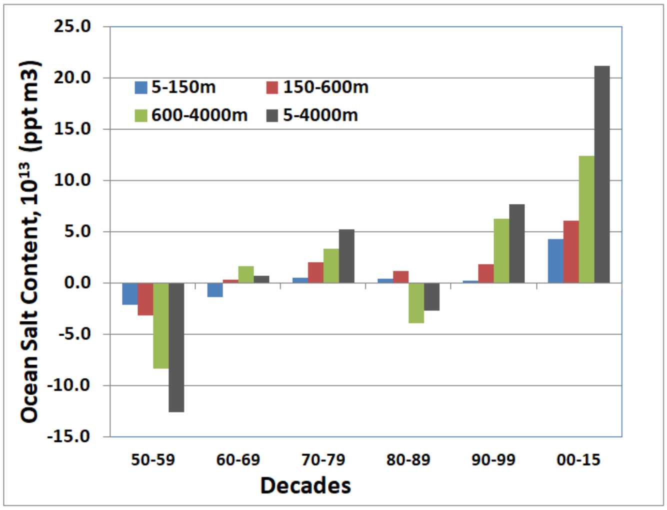
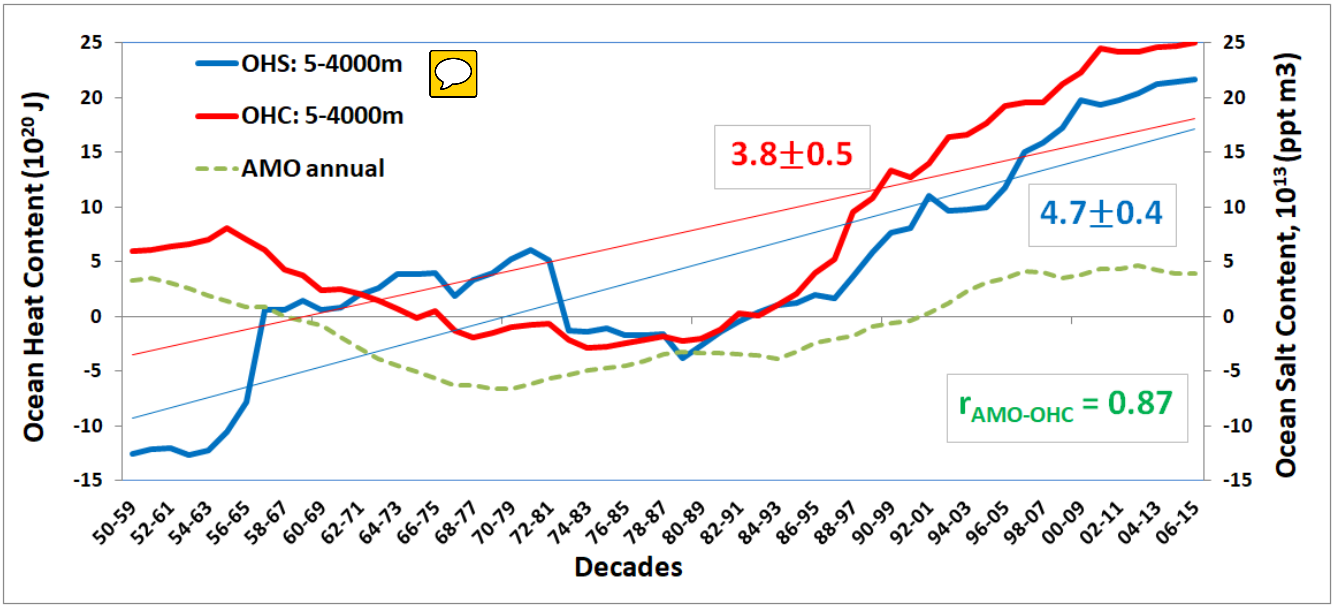



(a)




(b)




(c)

**Figure 3.** Decadal anomalies of OHC (a) and OSC (b) in 5–150 m, 150–600 m, 600–4000 m, 5–4000 m. OHC anomalies are in $10^{20}$ J and OSC in $10^{13}$ ppt $m^3$. (c) Volume integrals of OHC ($10^{20}$ J) and OSC ($10^{13}$ ppt $m^3$) anomalies at 5–4000 m over the whole Mediterranean Sea. Trend values (per decade) are given for OHC (in red) and OSC (in blue). AMO annual values (multiplied by 25 to resemble OHC shape) are shown with green dots. The significant at the 95% confidence level correlation between annual AMO (normal and not multiplied values) and decadal OHC is shown in green.

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## 4 Conclusions

We presented a new product of climatic indices for the Mediterranean Sea oriented to the description and study of the long term variability and climate change of the area. The assessment of the T/S and OHC/OSC changes is a key priority for monitoring the climate changes in a focal region such as the Mediterranean. So far, the insufficient spatial and temporal coverage of historical in-situ data induced large uncertainties and differences among the used approaches especially to large basin scale estimations. Thanks to improved data repositories in terms of abundance and quality like SeaDataNet and state of the art mapping techniques implemented by the DIVA software tool, we are able to interpolate in an optimal way and produce high resolution products that can fill data gaps and be used in a more efficient way by many applications for the study of the past, present and future climate changes. Future improvements include the use of density climatological field instead of a constant value at the OHC estimations. Such a density gridded field is not currently available as input since we interpolate T/S separately but it would be possible to derive from the T/S gridded fields. Another improvement concerns the correction of the historical bathythermographs data although previous studies indicated that it does not alter the final results.

## 5 Code and data availability

The netCDF Operators (NCO) command-line programs and the mathematical and statistical algorithms of GSL (the GNU Scientific Library) were used for the manipulation and analysis of the netCDF gridded fields of temperature and salinity of the Mediterranean Atlas (functions gsl_fit_linear, gsl_stats_covariance, gsl_stats_sd) NCO toolkit is available here: http://nco.sourceforge.net/. The GNU Scientific Library (GSL) is available here: http://www.gnu.org/software/gsl. The climatic indices are distributed through Zenodo at the following link: https://doi.org/10.5281/zenodo.1210100. DIVA interpolation software is distributed Zenodo (https://zenodo.org/record/836727) and GitHub (https://github.com/gher-ulg/DIVA).

*Author contributions.* A.I. created the climatic indices product, wrote the first version of the manuscript and prepared the figures. J.-M.B., S.W., C.T., A.T. and S.F. reviewed the manuscript. S.I., C.T. and S.W. formatted the document in LaTeX.

*Competing interests.* The authors declare no competing interests.

*Disclaimer.* It cannot be warranted that the product is free from errors or omissions. Correct and appropriate product interpretation and usage is solely the responsibility of data users.

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## References

Adloff, F., Somot, S., Sevault, F., Jordà, G., Aznar, R., Déqué, M., Herrmann, M., Marcos, M., Dubois, C., Padorno, E., and et al.: Mediterranean Sea response to climate change in an ensemble of twenty first century scenarios, Climate Dynamics, 45, 2775–2802, https://doi.org/10.1007/s00382-015-2507-3, https://link.springer.com/content/pdf/10.1007%2Fs00382-015-2507-3.pdf, 2015.

Beckers, J.-M., Barth, A., Troupin, C., and Alvera-Azcárate, A.: Some approximate and efficient methods to assess error fields in spatial gridding with DIVA (Data Interpolating Variational Analysis), Journal of Atmospheric and Oceanic Technology, 31, 515–530, https://doi.org/10.1175/JTECH-D-13-00130.1, http://journals.ametsoc.org/doi/abs/10.1175/JTECH-D-13-00130.1, 2014.

Bethoux, J., Gentili, B., Morin, P., Nicolas, E., Pierre, C., and Ruiz-Pino, D.: The Mediterranean Sea: a miniature ocean for climatic and environmental studies and a key for the climatic functioning of the North Atlantic, Progress in Oceanography, 44, 131–146, https://doi.org/10.1016/s0079-6611(99)00023-3, https://www.sciencedirect.com/science/article/pii/S0079661199000233, 1999.

Béthoux, J.-P., Gentili, B., and Tailliez, D.: Warming and freshwater budget change in the Mediterranean since the 1940s, their possible relation to the greenhouse effect, Geophysical Research Letters, 25, 1023–1026, https://doi.org/10.1029/98gl00724, http://onlinelibrary.wiley.com/doi/10.1029/98GL00724/abstract, 1998.

Fusco, G., Manzella, G. M. R., Cruzado, A., Gačić, M., Gasparini, G. P., Kovačević, V., Millot, C., Tziavos, C., Velasquez, Z. R., Walne, A., and et al.: Variability of mesoscale features in the Mediterranean Sea from XBT data analysis, Annales Geophysicae, 21, 21–32, https://doi.org/10.5194/angeo-21-21-2003, https://www.ann-geophys.net/21/21/2003/, 2003.

Füssel, H.-M., Jol, A., Marx, A., Hildén, M., Aparicio, A., Bastrup-Birk, A., and et al, A. B.: Climate change, impacts and vulnerability in Europe 2016. An indicator-based report, Tech. rep., European Environment Agency, https://doi.org/10.2800/534806, ISBN: 978-92-9213-835-6, 2017.

Giorgi, F.: Climate change hot-spots, Geophysical Research Letters, 33, , https://doi.org/10.1029/2006gl025734, https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2006GL025734, 2006.

Giorgi, F. and Lionello, P.: Climate change projections for the Mediterranean region, Global and Planetary Change, 63, 90–104, https://doi.org/10.1016/j.gloplacha.2007.09.005, https://www.sciencedirect.com/science/article/pii/S0921818107001750, 2008.

INGV: Mediterranean Sea - Temperature and salinity observation collection V2, Tech. rep., Istituto Nazionale di Geofisica e Vulcanologia, Sede di Bologna, https://doi.org/10.12770/8c3bd19b-9687-429c-a232-48b10478581c, 2015.

Iona, A., Theodorou, A., Watelet, S., Troupin, C., and Beckers, J.-M.: Mediterranean Sea Hydrographic Atlas: towards optimal data analysis by including time-dependent statistical parameters, Earth System Science Data Discussions, pp. 1–29, https://doi.org/10.5194/essd-2018-9, https://www.earth-syst-sci-data-discuss.net/essd-2018-9/essd-2018-9.pdf, Under revision., 2018.

Jordà, G., Von Schuckmann, K., Josey, S., Caniaux, G., García-Lafuente, J., Sammartino, S., Özsoy, E., Polcher, J., Notarstefano, G., Poulain, P.-M., and et al.: The Mediterranean Sea heat and mass budgets: Estimates, uncertainties and perspectives, Progress in Oceanography, 156, 174–208, https://doi.org/10.1016/j.pocean.2017.07.001, https://www.sciencedirect.com/science/article/pii/S0079661116300817, 2017.

Klein, B., Roether, W., Manca, B. B., Bregant, D., Beitzel, V., Kovacevic, V., and Luchetta, A.: The large deep water transient in the Eastern Mediterranean, Deep Sea Research Part I: Oceanographic Research Papers, 46, 371–414, https://doi.org/10.1016/s0967-0637(98)00075-2, https://www.sciencedirect.com/science/article/pii/S0967063798000752, 1999.

Lascaratos, A., Roether, W., Nittis, K., and Klein, B.: Recent changes in deep water formation and spreading in the eastern Mediterranean Sea: a review, Progress in Oceanography, 44, 5–36, https://doi.org/10.1016/s0079-6611(99)00019-1, https://www.sciencedirect.com/science/article/pii/S0079661199000191, 1999.

Levitus, S.: Warming of the World Ocean, Science, 287, 2225–2229, https://doi.org/10.1126/science.287.5461.2225, http://science.sciencemag.org/content/287/5461/2225, 2000.

Levitus, S., Antonov, J. I., Boyer, T. P., Locarnini, R. A., Garcia, H. E., and Mishonov, A. V.: Global ocean heat content 1955-2008 in light of recently revealed instrumentation problems, Geophysical Research Letters, 36, n/a–n/a, https://doi.org/10.1029/2008gl037155, https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2008GL037155, 2009.

Levitus, S., Antonov, J. I., Boyer, T. P., Baranova, O. K., Garcia, H. E., Locarnini, R. A., Mishonov, A. V., Reagan, J. R., Seidov, D., Yarosh, E. S., and et al.: World ocean heat content and thermosteric sea level change (0-2000 m), 1955-2010, Geophysical Research Letters, 39, n/a–n/a, https://doi.org/10.1029/2012gl051106, https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2012GL051106, 2012.

Lozier, M. S., Owens, W. B., and Curry, R. G.: The climatology of the North Atlantic, Progress in Oceanography, 36, 1–44, https://doi.org/10.1016/0079-6611(95)00013-5, https://www.sciencedirect.com/science/article/pii/0079661195000135, 1995.

Macias, D., Garcia-Gorriz, E., and Stips, A.: Understanding the Causes of Recent Warming of Mediterranean Waters. How Much Could Be Attributed to Climate Change?, PLoS ONE, 8, e81 591, https://doi.org/10.1371/journal.pone.0081591, http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0081591, 2013.

Malanotte-Rizzoli, P., Manca, B. B., d' Alcala, M. R., Theocharis, A., Brenner, S., Budillon, G., and Ozsoy, E.: The Eastern Mediterranean in the 80s and in the 90s: the big transition in the intermediate and deep circulations, Dynamics of Atmospheres and Oceans, 29, 365–395, https://doi.org/10.1016/s0377-0265(99)00011-1, https://www.sciencedirect.com/science/article/pii/S0377026599000111, 1999.

Manca, B., Burca, M., Giorgetti, A., Coatanoan, C., Garcia, M.-J., and Iona, A.: Physical and biochemical averaged vertical profiles in the Mediterranean regions: an important tool to trace the climatology of water masses and to validate incoming data from operational oceanography, Journal of Marine Systems, 48, 83 – 116, https://doi.org/10.1016/j.jmarsys.2003.11.025, http://www.sciencedirect.com/science/article/pii/S0924796304000090, tracer Methods in Geophysical Fluid Dynamics, 2004.

Manca, B. B.: Evolution of dynamics in the eastern Mediterranean affecting water mass structures and properties in the Ionian and Adriatic Seas, Journal of Geophysical Research, 108, , https://doi.org/10.1029/2002jc001664, https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2002JC001664, 2003.

Mariotti, A., Zeng, N., Yoon, J.-H., Artale, V., Navarra, A., Alpert, P., and Li, L. Z. X.: Mediterranean water cycle changes: transition to drier 21st century conditions in observations and CMIP3 simulations, Environmental Research Letters, 3, 044 001, https://doi.org/10.1088/1748-9326/3/4/044001, http://iopscience.iop.org/article/10.1088/1748-9326/3/4/044001/pdf, 2008.

MEDAR Group: MEDATLAS/2002 database. Mediterranean and Black Sea database of temperature salinity and bio-chemical parameters. Climatological Atlas, Tech. rep., Ifremer, 4 Cdroms, 2002.

Millot, C., Candela, J., Fuda, J.-L., and Tber, Y.: Large warming and salinification of the Mediterranean outflow due to changes in its composition, Deep Sea Research Part I: Oceanographic Research Papers, 53, 656–666, https://doi.org/10.1016/j.dsr.2005.12.017, https://www.sciencedirect.com/science/article/pii/S0967063706000112, 2006.

Rahmstorf, S.: Influence of mediterranean outflow on climate, Eos, Transactions American Geophysical Union, 79, 281–281, https://doi.org/10.1029/98eo00208, http://onlinelibrary.wiley.com/doi/10.1029/98EO00208/abstract, 1998.

Rixen, M., Beckers, J.-M., Levitus, S., Antonov, J., Boyer, T., Maillard, C., Fichaut, M., Balopoulos, E., Iona, S., Dooley, H., Garcia, M.-J., Manca, B., Giorgetti, A., Manzella, G., Mikhailov, N., Pinardi, N., Zavatarelli, M., and the Medar Consortium: The Western Mediterranean Deep Water: a proxy for global climate change, Geophysical Research Letters, 32, L12 608, https://doi.org/10.1029/2005GL022702, http://www.agu.org/pubs/crossref/2005/2005GL022702.shtml, 2005.

Robinson, A., Leslie, W., Theocharis, A., and Lascaratos, A.: Mediterranean Sea Circulation, Encyclopedia of Ocean Sciences, pp. 1689–1705, https://doi.org/10.1006/rwos.2001.0376, http://www.sciencedirect.com/science/article/pii/B012227430X003767, 2001.

Roether, W., Manca, B. B., Klein, B., Bregant, D., Georgopoulos, D., Beitzel, V., Kovacevic, V., and Luchetta, A.: Recent Changes in Eastern Mediterranean Deep Waters, Science, 271, 333–335, https://doi.org/10.1126/science.271.5247.333, http://science.sciencemag.org/content/271/5247/333, 1996.

Rohling, E. J. and Bryden, H. L.: Man-Induced Salinity and Temperature Increases in Western Mediterranean Deep Water, Journal of Geophysical Research, 97, 11 191–11 198, https://doi.org/10.1029/92jc00767, https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/92JC00767, 1992.

Schröder, K., Gasparini, G. P., Tangherlini, M., and Astraldi, M.: Deep and intermediate water in the western Mediterranean under the influence of the Eastern Mediterranean Transient, Geophysical Research Letters, 33, https://doi.org/10.1029/2006gl027121, https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2006GL027121, 2006.

Schroeder, K., Garcìa-Lafuente, J., Josey, S. A., Artale, V., Nardelli, B. B., Carrillo, A., Gačić, M., Gasparini, G. P., Herrmann, M., Lionello, P., and et al.: Circulation of the Mediterranean Sea and its Variability, The Climate of the Mediterranean Region, p. 187–256, https://doi.org/10.1016/b978-0-12-416042-2.00003-3, https://www.sciencedirect.com/science/article/pii/B9780124160422000033, 2012.

Schroeder, K., Chiggiato, J., Bryden, H. L., Borghini, M., and Ben Ismail, S.: Abrupt climate shift in the Western Mediterranean Sea, Scientific Reports, 6, https://doi.org/10.1038/srep23009, https://www.nature.com/articles/srep23009, 2016.

Schroeder, K., Chiggiato, J., Josey, S. A., Borghini, M., Aracri, S., and Sparnocchia, S.: Rapid response to climate change in a marginal sea, Scientific Reports, 7, https://doi.org/10.1038/s41598-017-04455-5, https://www.nature.com/articles/s41598-017-04455-5, 2017.

Skliris, N., Marsh, R., Josey, S. A., Good, S. A., Liu, C., and Allan, R. P.: Salinity changes in the World Ocean since 1950 in relation to changing surface freshwater fluxes, Climate Dynamics, 43, 709–736, https://doi.org/10.1007/s00382-014-2131-7, https://link.springer.com/article/10.1007%2Fs00382-014-2131-7, 2014.

Skliris, N., Zika, J. D., Herold, L., Josey, S. A., and Marsh, R.: Mediterranean sea water budget long-term trend inferred from salinity observations, Climate Dynamics, p. 1–20, https://doi.org/10.1007/s00382-017-4053-7, https://link.springer.com/article/10.1007%2Fs00382-017-4053-7, 2018.

Somot, S., Sevault, F., Déqué, M., and Crépon, M.: 21st century climate change scenario for the Mediterranean using a coupled atmosphere–ocean regional climate model, Global and Planetary Change, 63, 112–126, https://doi.org/10.1016/j.gloplacha.2007.10.003, https://www.sciencedirect.com/science/article/pii/S0921818107001774, 2008.

Stocker, T., Qin, D., Plattner, G.-K., Tignor, M., Allen, S., Boschung, J., Nauels, A., Xia, Y., Bex, V., and Midgley, P., eds.: Climate Change 2013 - The Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, chap. Technical Summary, Cambridge University Press, https://doi.org/10.1017/CBO9781107415324, 2014.

Theocharis, A., Nittis, K., Kontoyiannis, H., Papageorgiou, E., and Balopoulos, E.: Climatic changes in the Aegean Sea influence the eastern Mediterranean thermohaline circulation (1986-1997), Geophysical Research Letters, 26, 1617–1620, https://doi.org/10.1029/1999gl900320, https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/1999GL900320, 1999.

Theocharis, A., Klein, B., Nittis, K., and Roether, W.: Evolution and status of the Eastern Mediterranean Transient (1997–1999), Journal of Marine Systems, 33-34, 91–116, https://doi.org/10.1016/s0924-7963(02)00054-4, https://www.sciencedirect.com/science/article/pii/S0924796302000544, 2002.

Troupin, C., Sirjacobs, D., Rixen, M., Brasseur, P., Brankart, J.-M., Barth, A., Alvera-Azcárate, A., Capet, A., Ouberdous, M., Lenartz, F., Toussaint, M.-E., and Beckers, J.-M.: Generation of analysis and consistent error fields using the Data Interpolating Variational Analysis

Earth Syst. Sci. Data Discuss., https://doi.org/10.5194/essd-2018-51
Manuscript under review for journal Earth Syst. Sci. Data
Discussion started: 23 April 2018


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(Diva), Ocean Modelling, 52-53, 90–101, https://doi.org/10.1016/j.ocemod.2012.05.002, http://www.sciencedirect.com/science/article/pii/S1463500312000790, 2012.

Tsimplis, M. N., Zervakis, V., Josey, S. A., Peneva, E. L., Struglia, M. V., Stanev, E. V., Theocharis, A., Lionello, P., Malanotte-Rizzoli, P., Artale, V., Tragou, E., and Oguz, T.: Chapter 4 Changes in the oceanography of the Mediterranean Sea and their link to climate variability, in: Developments in Earth and Environmental Sciences, edited by Lionello, P., Malanotte-Rizzoli, P., and Boscolo, R., pp. 227–282, Elsevier, https://doi.org/10.1016/s1571-9197(06)80007-8, https://www.sciencedirect.com/science/article/pii/S1571919706800078, 2006.

Vargas-Yáñez, M., Moya, F., Tel, E., García-Martínez, M. C., Guerber, E., and Bourgeon, M.: Warming and salting in the western Mediterranean during the second half of the 20th century: inconsistencies, unknowns and the effect of data processing, Scientia Marina, 73, 7–28, https://doi.org/10.3989/scimar.2009.73n1007, http://scientiamarina.revistas.csic.es/index.php/scientiamarina/article/view/1038/1080, 2008.

Vargas-Yáñez, M., Moya, F., García-Martínez, M., Tel, E., Zunino, P., Plaza, F., Salat, J., Pascual, J., López-Jurado, J., and Serra, M.: Climate change in the Western Mediterranean Sea 1900–2008, Journal of Marine Systems, 82, 171–176, https://doi.org/10.1016/j.jmarsys.2010.04.013, https://www.sciencedirect.com/science/article/pii/S0924796310000783?via%3Dihub, 2010a.

Vargas-Yáñez, M., Zunino, P., Benali, A., Delpy, M., Pastre, F., Moya, F., García-Martínez, M. d. C., and Tel, E.: How much is the western Mediterranean really warming and salting?, Journal of Geophysical Research, 115, https://doi.org/10.1029/2009jc005816, https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2009JC005816, 2010b.

WMO: Guide to Climatological Practices, Tech. rep., World Meteorological Organization, Geneva, Switzerland, https://library.wmo.int/pmb_ged/wmo_100_en.pdf, ISBN 978-92-63-10100-6, 2011.

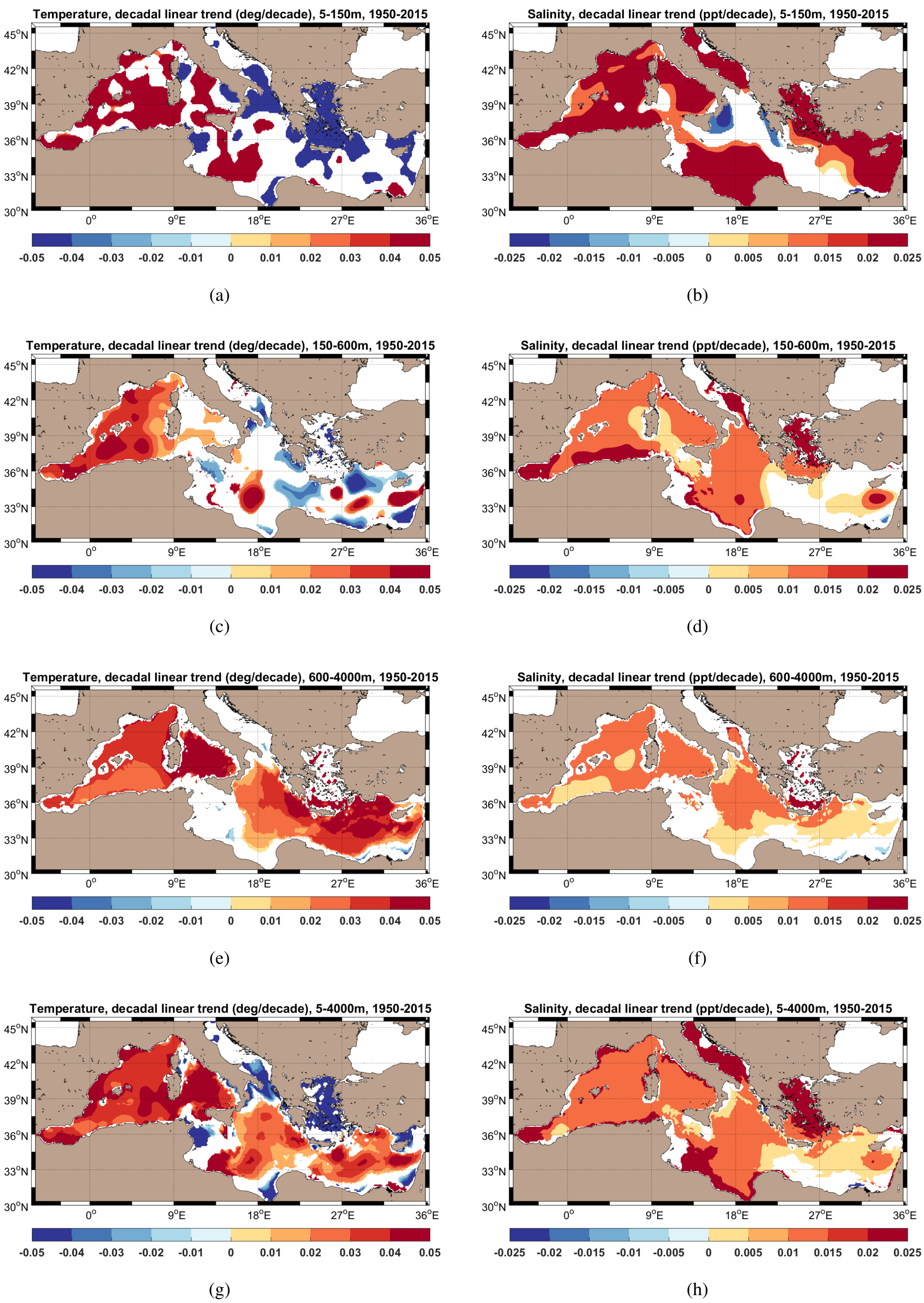


**Figure 4.** 57–year liner trend of temperature (left panel) and salinity anomalies (right panel) averaged over 5–150 m, 150–600 m, 600–4000 m, 5–4000 m, in °C/decade and ppt/decade, respectively. Regions where the linear trend is not significant at the 95% confidence level are not plotted.