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# The effect of interpolation methods in temperature and salinity trends in the Western Mediterranean

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## Abstract

Temperature and salinity data in the historical record are scarce and unevenly distributed in space and time and the estimation of linear trends is sensitive to different factors. In the case of the Western Mediterranean, previous works have studied the sensitivity of these trends to the use of bathythermograph data, the averaging methods or the way in which gaps in time series are dealt with. In this work, a new factor is analysed: the effect of data interpolation. Temperature and salinity time series are generated averaging existing data over certain geographical areas and also by means of interpolation. Linear trends from both types of time series are compared. There are some differences between both estimations for some layers and geographical areas, whilst in other cases the results are consistent. Those results which do not depend on the use of interpolated or non-interpolated data and are not influenced by data analysis methods can be considered as robust ones. Those results influenced by the interpolation process or the factors analysed in previous sensitivity tests are not considered as robust results.

**Keywords***:* Climate Change, Data analysis, Western Mediterranean, linear trends.

## Introduction

The detection of changes in the oceanic or marine climate is based on the compilation of temperature and salinity data along the whole water column, the construction of time series for different depth levels and geographical areas of the world ocean, and the analysis of these time series (Levitus *et al.*, 2009; Rixen *et al.*, 2005; Ishii *et al.*, 2003). These analyses are aimed at checking whether or not mean values and variability ranges change with time or if they remain constant. The detection of long term changes in the mean values for variables of climatic interest is frequently addressed by means of linear trend estimations. Inter-annual and decadal variability is superimposed to the linear trends (if existing). This variability reinforces or counterbalances the long-term changes over periods of time of decades or so. Therefore, trend estimations can substantially change (even in sign) when calculated over such brief periods of time. Constructing high quality time series as long as possible is a priority objective in order to distinguish between the different time scales and to reduce the sensitivity of trend estimations to the impact of high frequency signals.

Several monitoring programs have been launched with this objective since the beginning of the 1990s. Prior to this date, the construction of time series must be based on the compilation of temperature and salinity data collected under different projects, not specifically designed for the long term monitoring of the oceans. Some examples of such data bases are the World Ocean Data Base (Levitus *et al.,* 2009) or, in the specific case of the Mediterranean Sea, MEDATLAS (MEDAR Group, 2002). As we move further back in time the scarcity of data increases, making the time series more sensitive to averaging methods or infilling techniques (Gregory *et al.*, 2004). Other works have also identified biases in measurement instruments such as bathythermographs (Levitus *et al.*, 2009; Domingues *et al.* 2008, Wijffels *et al.,* 2008; Gouretski and Koltermann, 2007) or ARGO profiling floats (Willis *et al.*, 2007) which could also alter trend estimations.

In the case of the Western Mediterranean (WMED), most of the studies dealing with long term changes in the properties of water masses have identified positive temperature and salinity trends for deep waters (>600m) and a salinity increase of the intermediate layer (200-600m) for the second half of the twentieth century (Vargas-Yáñez *et al.*, 2010; 2009; Rixen *et al.*, 2005; Bethoux *et*

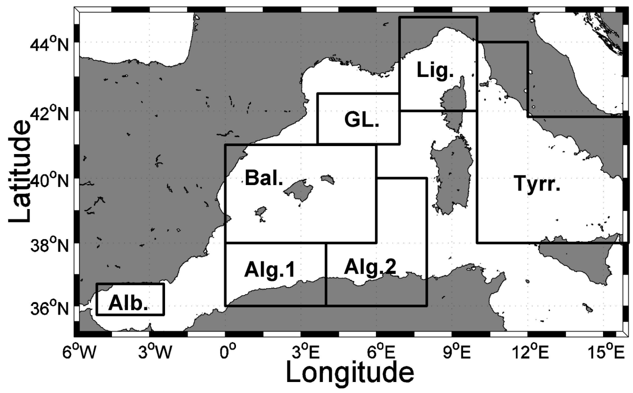



*Fig. 1:* Map of the Western Mediterranean. The seven boxes are the geographical areas where annual TS profiles were compiled from MEDATLAS data base and from the TS fields interpolated onto a 0.2º x 0.2º grid by Rixen *et al.* (2005).

*al.*, 1999; 1998; 1990 among many others). In the case of the temperature and salinity of the upper layer and the temperature of the intermediate layer, there are some differences between the results presented in different works. Some of the reasons for these discrepancies could simply be the different periods of time covered by these studies. In the present work we take into account the influence of different factors on the analysis of time series. If one result is not altered by the data analysis methods, then we establish it as a robust result and it is accepted that a physical process must be driving the observed changes. On the other hand, if the alteration of any of the factors involved in the analysis of the time series changes the results, we admit that those results cannot be accepted on the single basis of the time series statistical analysis (although they could be supported by further physical considerations). The candidate factors to have a major influence on the linear trend estimations are: 1) Averaging methods; 2) Instrumental biases; 3) Infilling techniques and 4) Using interpolated versus raw averaged data. The first three points have been analysed in Vargas-Yáñez *et al.* (2010, 2009). Hereafter the fourth one will be considered.

This work has a double objective: first, we estimate linear trends for temperature and salinity time series from seven geographical areas covering the WMED and also for the WMED as a whole. We consider the period 1945-2000 and use annually interpolated time series (see Rixen *et al.*, 2000; 2005) and annually averaged raw data. This first objective is aimed at checking the sensitivity of linear trend estimations to the use of interpolated versus averaged raw data. This sensitivity test has not been previously carried out in the Mediterranean Sea. Second, we consider those results which are not sensitive to the interpolation process. We then compare such results with previous ones in Vargas-Yáñez *et al.* (2009; 2010) and check whether or not these results are also independent from other factors such as averaging methods or the use of bathythermograph data. In this way, it is established whether or not these results are robust, that is, independent of any possible change in the analysis process.

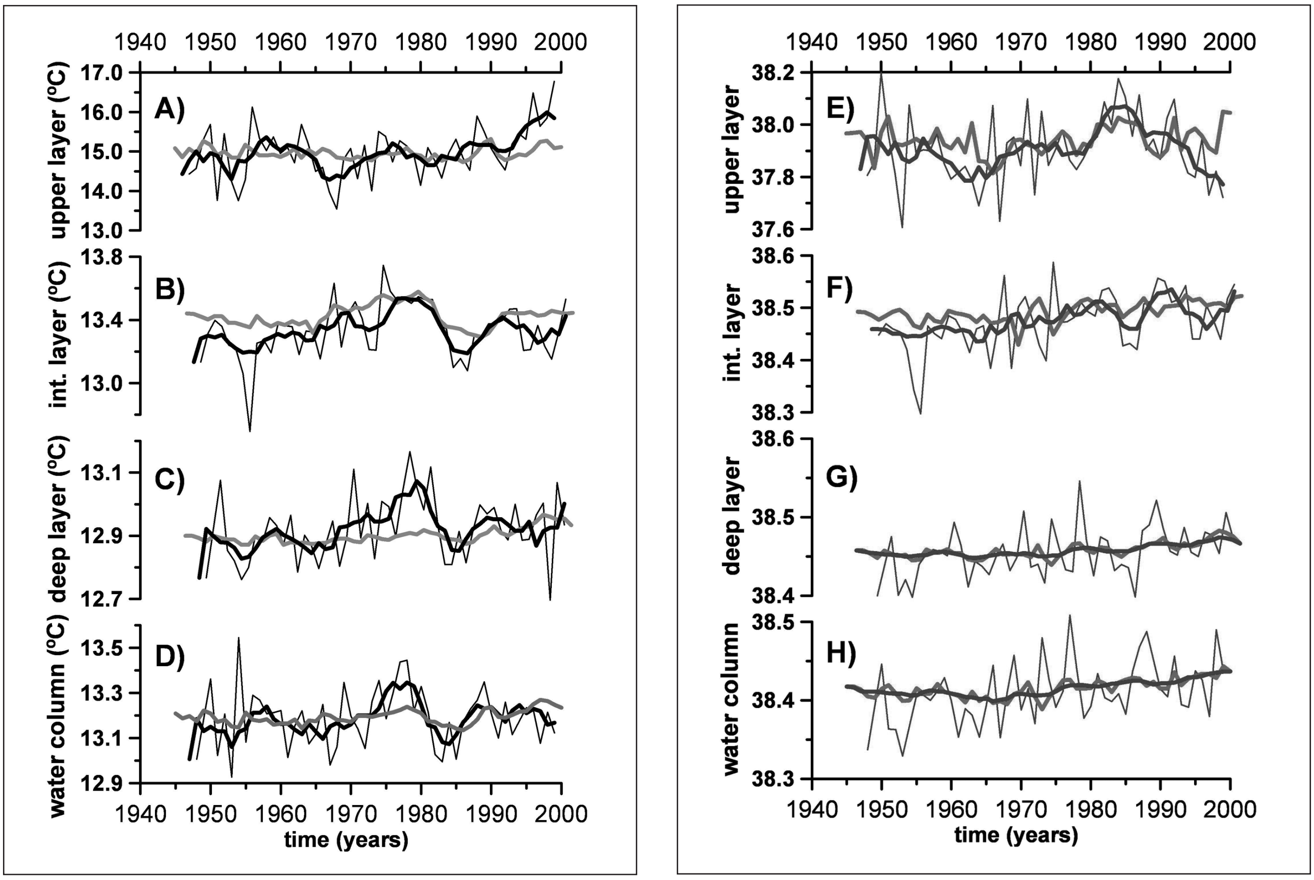
## Data and Methods

Seven areas covering most of the WMED (Fig. 1) have been defined. These areas are named as Alboran Sea (Alb.), two different areas for the Algerian basin (Alg. 1 and Alg. 2), Balearic Sea (Bal.), Gulf of Lions (GL.), Ligurian Sea (Lig.) and Tyrrhenian Sea (Tyrr.). All the available temperature and salinity profiles for each given area from MEDATLAS data base were collected (MEDAR Group, 2002). The profiles were vertically interpolated into 23 pressure levels from the surface to 2500 dbar (0 10 20 30 50 100 150 200 300 400 500 600 700 800 900 1000 1200 1400 1500 1750 2000 2250 2500 dbar). These levels were chosen in order to follow previous works and to detect changes in the main water masses in the WMED (Vargas-Yáñez *et al.*, 2010). Those profiles corresponding to the same year were grouped and averaged by seasons: winter (JFM), spring (AMJ), summer (JAS) and autumn (OND) and annual profiles were calculated from the four seasonal averages. Finally, for each geographical area we obtained 23 annual time series corresponding to the 23 pressure levels. Each time series extends from 1945 to 2000. These time series contain gaps when no profiles can be obtained for a particular region and year. Hereafter this data set will be named non-interpolated or averaged raw data.

The second data set is made of the temperature and salinity fields annually interpolated on a 0.2º x 0.2º grid by Rixen *et al.* (2000; 2005). For each of the seven areas in Fig.1, the profiles corresponding to the grid points within the limits of the geographical region were averaged. Then, the annual vertical profiles representing each box were linearly interpolated at the same pressure levels used in the first data set (non interpolated data). Finally, 23 annual time series of temperature and salinity were obtained for each of the selected boxes and for the whole WMED. This data set contains no gaps and extends from 1945 to 2000 to study the same time period analysed using raw data.

## Results

Figure 2 shows the temperature and salinity time series averaged for the seven boxes analysed and for three different layers: upper layer (0-200m, Fig. 2A, 2E), intermediate layer (200-600m, Fig. 2B, 2F) and deep layer (600m-bottom, Fig. 2C, 2G). Figures 2D and 2H show the time series of temperature and salinity vertically integrated for the whole water column. In all cases the thin black lines are the annual time series obtained from averaging raw data and the thick black lines are the same time series smoothed with a five-year running mean. The thick




***Figs 2A, B, C, D:*** Temperature evolution for the upper, intermediate, deep layer and integrated water column in the WMED obtained averaging the seven boxes in Fig. 1. Upper layer is considered as 0-200m, the intermediate layer as 200-600m and the deep one as 600m-bottom. Black thin lines are the time series obtained averaging all the MEDATLAS available profiles within each box for each year (non interpolated or averaged raw data in the text). Black thick lines are non interpolated time series smoothed with a five year running mean. Grey thick lines are time series obtained from the interpolated temperature fields averaging the annual profiles from the grid points within the boxes (interpolated time series in the text). ***Figures 2E, F, G*** and ***H*** are the same for salinity time series.

grey lines are the temperature and salinity time series obtained from annually interpolated data. The first thing that can easily be seen in this figure is the variance reduction if the interpolated time series are compared with the non-interpolated ones. In order to quantify this reduction, Figure 3 shows the standard deviation for the non-interpolated (black columns) and interpolated (grey columns) temperature and salinity time series for each of the boxes as well as for the whole WMED. The inter-annual variability of averaged time series could make it difficult to compare long term trends in both data sets, which is the primary objective of this work. For this reason, and for the case of the non-interpolated data, smoothed time series have been included (thick black lines in Fig. 2).

In addition to the change in variance, the temperature and salinity linear trends estimated in the upper layer show both quantitative and qualitative differences for the different boxes analysed (Table 1). The same differences are found in the temperature of the intermediate layer. In some boxes, trends with opposite sign can be obtained when using averaged raw data versus interpolated time series. When considering the salinity of the intermediate layer and the temperature and salinity of the deep one, there is a qualitative agreement between both data sets. In most of the boxes and for the whole WMED the time series show significant temperature and salinity trends. Nevertheless, there are important quantitative differences as linear trends estimated from interpolated data are in almost all the cases lower than those estimated from non-interpolated data. The reduction in the linear trends ranges between 50 and 70% when interpolated data are considered.

## Discussion and Conclusions

Raw data obtained for any sea region are affected by mesoscale variability. For any of the boxes analysed and for any particular month, if the TS profiles from the MEDATLAS database had a large spatial coverage, then the spatial average would filter out this variability. If monthly data were available for the twelve months of the year, the annual average would produce a further smoothing. On the contrary, if the spatial and temporal coverage is not appropriate, the short length and high frequency time scales are not properly removed. The scarcity of data and the impact of it on the averaging methods and the trend estimations have already been demonstrated in Vargas-Yáñez *et al.* (2010, 2009). The interpolation method used to generate the interpolated annual time series (see Rixen *et al.*, 2000 for the details) filters out the short length and time scales. In order to explain the variance difference between both datasets, we propose the following hypothesis: The scarcity of raw data would not allow filtering the mesoscale and short time scale variability while it would be filtered out in the interpolated data. Gregory *et al.* (2004) pointed out that interpolated data could be biased towards climatological values when large areas were not well sampled. In order to check this hypothesis we constructed a new time series of averaged or non-interpolated data. In this case, when a seasonal mean was missing (because of the lack of data), this value was substituted by a climatological value (calculated for the reference period 1960-1990). This time series are called "infilled" time series. Figure 3 (white columns) shows the standard deviation for temperature and salinity for the different layers. In the case of the upper layer, the standard deviation for the time series "infilled" with climatological values is almost the same than in the case of interpolated data and lower for the other layers and the integrated water column. This result makes us hypothesize that the difference in standard deviation between the interpolated and non-interpolated data sets is produced by the combination of several factors: first, the high frequency variability is not properly filtered out when raw data are averaged; second, the interpolation process filters the short time and space variability. Finally, the lack of data for some periods of time could produce interpolated data close to the climatological fields (mainly before the 1970s).

For some of the seven boxes, there are differences for the linear trends calculated using interpolated and non interpolated data (even in sign). When these trends are estimated for the whole WMED there is always a coincidence in sign, although there are still differences affecting the significance of the results. This can also be a consequence of the high variance of annually averaged data, associated to the data scarcity. This variability is considerably reduced when different sub-basins are averaged. Nevertheless, this kind of averaging should be considered with caution as it is not clear that linear trends are spatially homogeneous over the WMED.

Another remarkable difference is that the upper layer increases its temperature in a significant way for the whole WMED when non interpolated data are used (Table 1). For interpolated data, the linear trend for the WMED upper layer is also positive, but in this case this statistic is not significant at the 95% confidence level. In this case the significance of the upper layer for the non interpolated data is caused by the large temperature increment at the end of the time series which is smoothed in the interpolated data set. The coincidence of a large oscillation at the extreme of the time series induces a significant result indicating a warming trend. Regardless whether or not the intense warming during the 1990s is a real feature or not, this evidences another problem in the analysis of time series. Decadal and multidecadal oscillations account for temperature or salinity changes at an order of magnitude larger than the changes operating at the long term. For instance, notice the temperature drop from mid 70s to mid 80s and then the temperature increase until the early 90s. These changes, observed for the intermediate and deep layers and for the integrated water column, are much larger than the linear trends detected for the complete time series (see Table 1). Another evidence of these large decadal oscillations can be observed in the upper layer salinity (Fig. 3E). This variable experienced a sharp increase from the early 60s to mid 80s and then it decreased until 2000. Therefore, for time series extending just along a few decades, the estimation of linear trends can yield very different results depending on the initial and end points of the series and whether these extremes are located within a cool or warm sub-period. It is well known that the air temperature and the world ocean upper layer have not undergone a continuous warming during the twentieth century. This warming is mainly associated to two different sub-periods, the first one extending from 1910 to 1940 and the second one since the mid-seventies to the present. Notice that the starting point of the time series analysed in the present work is very close to the temperature maximum reached during the past warming period. This considerably reduces the magnitude of the overall change estimated for the complete period. If we move the time series initial point away from the 1940s peak, we can obtain different results. If the temperature evolution from 1952 to 2000 is analysed, a significant warming trend of 0.02 ºC/decade would be obtained.

Concerning the intermediate and deep layers there is a qualitative agreement between the results obtained using both data sets, but certainly the magnitude of the temperature and salinity changes depend dramatically on them. At this point we cannot be sure of which of them reflects the true variability that the temperature and salinity at basin (WMED) and sub-basin scales (boxes) have suffered along the second half of the twentieth century. For the case of non-interpolated data we can suspect that in some cases (mainly in the upper layer) the time series are too noisy and this noise can mask long term trends or even distort the decadal variability. In contrast, interpolated time series have lower time variability. There are large data gaps for the selected geographical areas, especially before 1970. The temperature and salinity interpolated fields could be biased towards climatological values in areas of large data gaps. The geographical areas studied in this work are affected by such large gaps, espe-

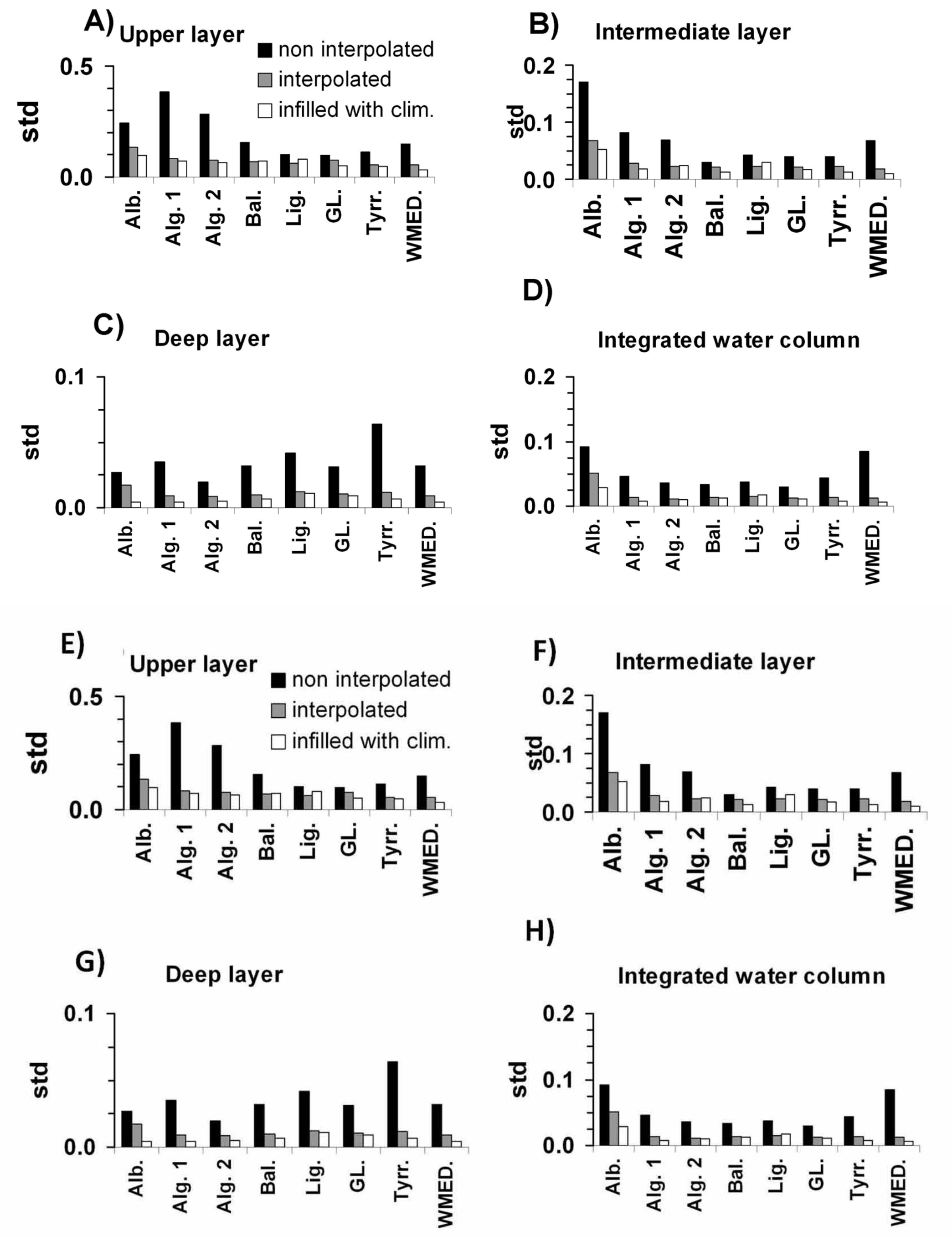
**Table 1.** Linear trends and confidence intervals for temperature and salinity time series from 1945 to 2000 for the seven boxes analysed and for the WMED. Estimations are made for the upper (0-200m), intermediate (200m-600m) and deep layer (600m-bottom) as well as for the whole water column. Figures in bold are significant at the 95% confidence level.

| **Upper layer** | **Non interpolated** | | **Interpolated** | | **Non interpolated** | | **Interpolated** | |
|---|---|---|---|---|---|---|---|---|
| | **pot. Temp. (ºC/dec)** | **CI (95%)** | **pot. Temp. (ºC/dec)** | **CI (95%)** | **Salinity (dec$^{-1}$)** | **CI (95%)** | **Salinity (dec$^{-1}$)** | **CI (95%)** |
| **Alb.** | -0.013 | 0.093 | 0.011 | 0.032 | 0.025 | 0.041 | 0.042 | 0.020 |
| **Alg. 1** | 0.061 | 0.210 | 0.013 | 0.027 | -0.059 | 0.083 | 0.006 | 0.014 |
| **Alg. 2** | **0.230** | 0.220 | 0.017 | 0.029 | **0.057** | 0.053 | -0.010 | 0.013 |
| **Bal.** | 0.087 | 0.150 | -0.005 | 0.025 | 0.025 | 0.032 | 0.009 | 0.011 |
| **Lig.** | 0.034 | 0.110 | -0.02 | 0.030 | **0.024** | 0.02 | 0.019 | 0.009 |
| **GL.** | 0.026 | 0.130 | -0.027 | 0.030 | 0.005 | 0.019 | **0.014** | 0.012 |
| **Tyrr.** | -0.021 | 0.170 | 0.006 | 0.026 | 0.019 | 0.020 | 0.007 | 0.009 |
| WMED | **0.200** | 0.120 | 0.0018 | 0.024 | 0.010 | 0.025 | 0.007 | 0.009 |

| **Intermediate layer** | **Non interpolated** | | **Interpolated** | | **Non interpolated** | | **Interpolated** | |
|---|---|---|---|---|---|---|---|---|
| | **pot. Temp. (ºC/dec)** | **CI (95%)** | **pot. Temp. (ºC/dec)** | **CI (95%)** | **Salinity (dec$^{-1}$)** | **CI (95%)** | **Salinity (dec$^{-1}$)** | **CI (95%)** |
| **Alb.** | **0.032** | 0.022 | **0.013** | 0.011 | **0.030** | 0.014 | **0.023** | 0.008 |
| **Alg. 1** | **0.038** | 0.026 | 0.004 | 0.010 | **0.032** | 0.012 | **0.006** | 0.004 |
| **Alg. 2** | 0.007 | 0.028 | 0.002 | 0.010 | **0.019** | 0.015 | 0.003 | 0.004 |
| **Bal.** | 0.011 | 0.025 | -0.001 | 0.011 | **0.007** | 0.005 | **0.004** | 0.003 |
| **Lig.** | **0.027** | 0.022 | 0.010 | 0.015 | **0.014** | 0.007 | **0.009** | 0.003 |
| **GL.** | **0.032** | 0.026 | -0.001 | 0.014 | **0.014** | 0.006 | **0.006** | 0.003 |
| **Tyrr.** | 0.016 | 0.040 | 0.011 | 0.022 | **0.014** | 0.008 | **0.009** | 0.003 |
| **WMED** | 0.018 | 0.029 | 0.005 | 0.012 | **0.016** | 0.009 | **0.006** | 0.002 |

| **Deep layer** | **Non interpolated** | | **Interpolated** | | **Non interpolated** | | **Interpolated** | |
|---|---|---|---|---|---|---|---|---|
| | **pot. Temp. (ºC/dec)** | **CI (95%)** | **pot. Temp. (ºC/dec)** | **CI (95%)** | **Salinity (dec$^{-1}$)** | **CI (95%)** | **Salinity (dec$^{-1}$)** | **CI (95%)** |
| **Alb.** | **0.029** | 0.012 | **0.009** | 0.006 | **0.010** | 0.005 | **0.004** | 0.002 |
| **Alg. 1** | **0.030** | 0.011 | **0.006** | 0.003 | **0.011** | 0.008 | **0.003** | 0.001 |
| **Alg. 2** | **0.017** | 0.007 | **0.008** | 0.003 | **0.011** | 0.003 | **0.004** | 0.001 |
| **Bal.** | **0.018** | 0.007 | **0.008** | 0.004 | **0.006** | 0.003 | **0.004** | 0.001 |
| **Lig.** | **0.041** | 0.026 | **0.013** | 0.004 | **0.016** | 0.007 | **0.005** | 0.002 |
| **GL.** | **0.019** | 0.007 | **0.010** | 0.004 | **0.014** | 0.004 | **0.004** | 0.001 |
| **Tyrr.** | **0.052** | 0.023 | **0.011** | 0.003 | **0.003** | 0.017 | **0.004** | 0.001 |
| **WMED** | **0.027** | 0.018 | **0.010** | 0.003 | **0.009** | 0.005 | **0.004** | 0.001 |

| **Integrated water column** | **Non interpolated** | | **Interpolated** | | **Non interpolated** | | **Interpolated** | |
|---|---|---|---|---|---|---|---|---|
| | **pot. Temp. (ºC/dec)** | **CI (95%)** | **pot. Temp. (ºC/dec)** | **CI (95%)** | **Salinity (dec$^{-1}$)** | **CI (95%)** | **Salinity (dec$^{-1}$)** | **CI (95%)** |
| **Alb.** | **0.036** | 0.025 | **0.011** | 0.009 | **0.017** | 0.013 | **0.019** | 0.007 |
| **Alg. 1** | **0.051** | 0.026 | **0.006** | 0.004 | **0.012** | 0.01 | 0.004 | 0.002 |
| **Alg. 2** | **0.04** | 0.025 | **0.008** | 0.005 | **0.014** | 0.008 | **0.002** | 0.002 |
| **Bal.** | **0.02** | 0.019 | 0.005 | 0.006 | **0.009** | 0.005 | **0.004** | 0.002 |
| **Lig.** | **0.031** | 0.027 | **0.009** | 0.007 | **0.015** | 0.006 | **0.007** | 0.002 |
| **GL.** | **0.02** | 0.016 | 0.006 | 0.007 | **0.012** | 0.004 | **0.005** | 0.002 |
| **Tyrr.** | 0.025 | 0.037 | **0.012** | 0.006 | **0.015** | 0.005 | **0.006** | 0.002 |
| **WMED** | **0.025** | 0.024 | **0.008** | 0.005 | **0.012** | 0.007 | **0.005** | 0.002 |




***Figs 3A, B, C, D:*** are standard deviations for the interpolated and non interpolated temperature time series in the seven boxes and for the WMED. Figure 3A) corresponds to the upper layer, B) and C) to the intermediate and deep ones and D) to the whole water column integrated from the sea surface to the bottom. ***Figures 3E, F, G*** and **H** are the same for the standard deviation of salinity time series.

cially before 1970s. We hypothesize that this could partially explain the low variance of interpolated time series when compared with non-interpolated ones.

The other objective in this work was to determine which results were robust and could be considered as well established on the basis of statistical analyses. As already reported in previous works, the WMED deep layer is warming and its salinity is increasing, at least since the mid twentieth century. This result is independent from the averaging method or the use of bathythermograph data (Vargas-Yáñez *et al.*, 2010, 2009). In the present work it is shown that this result is also independent from the use of interpolation techniques. It is frequent to include in any trend estimation the uncertainty associated to the high frequency variability superimposed on the long term trends, expressing this uncertainty as confidence intervals. If we consider the uncertainty arising from the selection of the data analysis method, we conclude that the warming trends in the deep layer are between 0.027 ºC/decade and 0.010 ºC/decade for the period 1945-2000. The salinity trends would range between 0.009 $decade^{-1}$ and 0.004 $decade^{-1}$ (Table 1). If both sources of uncertainty are combined and we consider the upper limit of the non interpolated trend (trend plus confidence interval) and the lower limit for the interpolated trend (trend minus confidence interval), this range increases to a warming rate between 0.045 ºC/decade and 0.007 ºC/decade and a salinity trend between 0.014 $decade^{-1}$ and 0.003 $decade^{-1}$. Considering the mid points in these estimations, the WMED deep layer would have increased its temperature and salinity in 0.15 ºC and 0.05 respectively from 1945 to 2000.

The intermediate layer has also increased its salinity during the second half of the twentieth century. This result is robust as it is independent from the averaging methods, the instrumental biases, the data set used and the interpolation process. Following the same approach considered for the deep layer and combining the uncertainties from each data analysis method with the uncertainty from the method selection, we can estimate that the intermediate layer increased its salinity at a rate ranging between 0.025 $decade^{-1}$ and 0.004 $decade^{-1}$, and the mean increment for the period 1945-2000 was 0.08.

Regarding the upper layer, the non interpolated data show statistically significant warming trends. Vargas-Yáñez *et al.* (2010) showed that the use of bathythermograph data yielded significant trends for the upper 200m of the WMED whilst the exclusion of these data still produced a marginally significant positive trend (90% confidence level). In the present work, different results are obtained depending on the use of interpolated or non interpolated data and therefore we cannot conclude that the upper layer warming in the WMED is a robust result on the basis of time series statistical analyses.

Nevertheless, other questions should be taken into account. First, Bethoux *et al.* (1990) hypothesized, based on energy and volume conservation equations, that the deep layer warming could only be explained on the basis of both AW and LIW warming, the two water masses contributing to the WMDW formation. Second, Skliris *et al.* (2007) have demonstrated by means of numerical models that climatological heat fluxes cannot explain the warming of the deep layers, therefore requiring an increased heat flux through the sea surface. Third, Ruiz et al (2008) have shown that the net heat flux through the sea surface in the Mediterranean Sea has undergone two distinctive periods during the second half of the twentieth century: a first period from 1951 to 1975 with a clear negative heat flux, and then a positive heat flux from 1975 to 1995. This result would be in agreement with the initial cooling phase in the upper layer (Fig. 2A) and the warming phase after 1975. As it could be expected, this simply reflects that the upper layer of the ocean responds to the heat exchange through its surface. Although Ruiz *et al.* (2008) show this oscillatory behaviour for the net heat exchange in the Mediterranean Sea, they point out that the mean value for the whole period is -1 $W/m^2$ (Table 1 in Ruiz *et al.*, 2008), lower than the heat influx through the Strait of Gibraltar and therefore they suggest that this imbalance should account for a net warming of the Mediterranean. We further speculate that this imbalance in the heat budget should produce as a first consequence the warming of the upper layer, although we have to highlight that the warming and salting of the upper layer cannot be established as a robust result on the basis of the statistical analyses.

In order to conclude, it has been demonstrated that certain changes within the WMED are robust, as the temperature and salinity increase of the deep layer and the salinity increase in the intermediate one. The present work has evidenced that this result is not influenced by the use of interpolated or non-interpolated temperature and salinity data. Previous works had already shown that these results are also independent from the averaging and infilling techniques or the already reported biases in bathythermograph data. The consideration of both the uncertainty associated to the high frequency variability and the choice of the data set or analysis method enlarges the confidence intervals for the trend estimations. Mean increments for the deep layer temperature and salinity over the period 1945-2000 are 0.15 ºC and 0.05 respectively and the salinity increase for the intermediate layer was 0.08. No robust results have been obtained for the temperature and salinity of the upper layer.

## Acknowledgements

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