SPATIOTEMPROAL RELATION BETWEEN SEA SURFACE TEPMERATURE AND CLOUD CONVECTION IN THE MEDITERRANEAN BASIN DURING WARM SEASON

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ABSTRACT

This study comprises an effort to examine the possible spatial connection between SST and cloud convection in the whole Mediterranean Basin during the warm season (April to September) where frequent convection occurs. For this study, the Mediterranean basin is split into three parts (western, central and eastern) and the possible relation is studied in each part separately. It was finally found, a clear negative correlation at monthly basis in the whole Mediterranean or as well as in the three examined parts for the warm season of the years 2010 and 2011. Maps with spatial distribution for the corresponding parameters have been also created to present and identify their local maxima and minima. It is included a discussion to investigate in depth the mechanics that may cause this negative correlation.

1. INTRODUCTION

The spatial and temporal variation of Sea Surface Temperature (SST) is essential for a wide variety of environmental studies. This parameter is considered as a key factor in the air-sea heat transfer and has significant impact on many physicochemical processes (e.g. [1], [2], [3]). The SST along with its relations with other physical parameters and phenomena, play also an important role in the interpretation of climatic changes over a geographical region.

The Mediterranean basin is a semi-enclosed sea area with small water exchanges (mainly through Gibraltar Strait) surrounded by a complex topography, and characterized by numerous vital physical ecosystems. The coastline of the Mediterranean Sea is also characterized by many contiguous increasing human induced activities and interventions.

On the other hand, the Mediterranean basin is characterized by intense convective activity (e.g. [4], [5]) especially during the warm season of the year. The cloud convection influences physical environment and human lives and sometimes causes damage to properties and infrastructure (e.g. [6], [7]). As a consequence, the Mediterranean basin can be considered as an important area to examine air-sea interactions and more specifically, the relation between SST and cloud convection.

The relation of SST and cloud convection have been widely studied in the previous years, but there are numerous publications, mainly concerning ocean areas and the Inter Tropical Convergence Zone (ITCZ) (e.g. [8] and [9]). Nevertheless, such studies about mid-latitude areas and especially dedicated in the Mediterranean Sea, remain sparse, many of them use model simulations and refer to specific case studies (e.g. [10], [11], [12]).

It is noted that in general, the SST is in positive relation with cloud convection and there is an upper threshold at about 27^{o}C to 29^{o}C, where above this value, the relation becomes negative. However, there are recent studies using more accurate datasets that provide slightly different type of relation between these parameters ([13]).

Nevertheless, it is mentioned that both parameters are importantly affected by many other factors like the shortwave (longwave) downwelling (upwelling) solar radiation, the large scale atmospheric dynamics and the water masses exchange. In addition to this, local factors like topography and human induced activities can also contribute to large scale air-sea interactions. Thus, area-specific studies can contribute further to investigate the type and the intensity of the examined relation in the study areas.

This study investigates the possible spatiotemporal connection between SST and maritime cloud convection in the whole Mediterranean Basin during the warm season (April to September) and concludes interesting results.

2. DATA AND METHODOLOGY

In this study, we selected monthly data of SST with spatial resolution of 9 km and spectral center in 11.0μm MODIS, derived from NASA's MODIS (MODerate resolution Imaging Spectroradiometer) instrument on board of Terra and Aqua satellite platforms.

More effort required the gathering of the cloud convection dataset, where there used the Meteosat imagery and more specifically the channels with spectral centers 10.8 μm and 12.0 μm. After preprocessing the suitable dataset (conversion of digital pixel values to Brightness Temperature and georeference of selected image scenes), we applied an

algorithm to detect convective cloud pixels. More specifically, we selected three-hourly Meteosat data (with spatial resolution variation of 4-5 km in the study area) and we summarized - at monthly basis - all the pixels above sea regions characterized as convective ones. We mention here that one pixel is characterized as convective if the corresponding Brightness Temperature value (BT) is below 230K and the Brightness Temperature Difference $DBT_{(10.8\mu m-12.0\mu m)}$ smaller than 2.5K ([14]). The temperature difference threshold was used to avoid cirrus clouds that have similar BT with convective cloud tops but are optically thinner than the convective clouds. It is mentioned that the combination of these two thresholds, isolates cold cloud tops, optically thick that can represent satisfactorily convective cloud tops.
After collection and preprocessing of the chosen data, we split the Mediterranean Sea in three parts (western, central and eastern) and we calculated the monthly statistics for the SST and the convection (Fig.1). We also applied spatial interpolation techniques to create monthly surfaces regarding SST and convection to highlight areas, calculating local minima and maxima so that to better interpret the results.

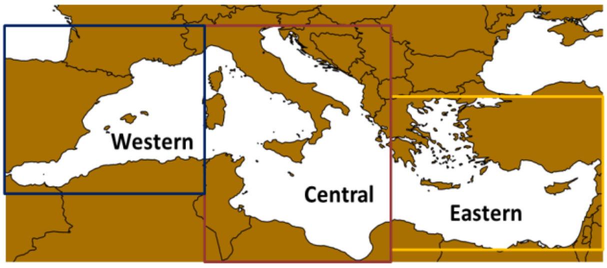

Figure 1. The study area and its three parts (western, central and eastern).

More specifically, during the analysis of the datasets, we calculated the mean monthly values of SST and the mean monthly convective frequency. It is mentioned here that, as mean convective frequency (frequency of occurrence) we defined the ratio of the total number of pixels that were characterized as convective to the total number of different pixels (locations) that were detected as convective. Hereinafter we call this ratio as "MCF" for brevity.
In a second step, we split (as above-mentioned) the Mediterranean basin in three parts and we calculated the monthly values of these two parameters of these sub-regions (Fig.1).

3. RESULTS

3.1. Correlation of parameters

The results regarding the correlation between mean monthly SST and the mean monthly convective frequency (MCF) are presented in the Fig.2. Every dot at Fig. 2 represents a mean monthly value of SST and the corresponding value of MCF. The total number of dots comes from the three different parts of the Mediterranean during the two warm seasons (3 parts x 6 months x 2 years = 36 pairs of values).

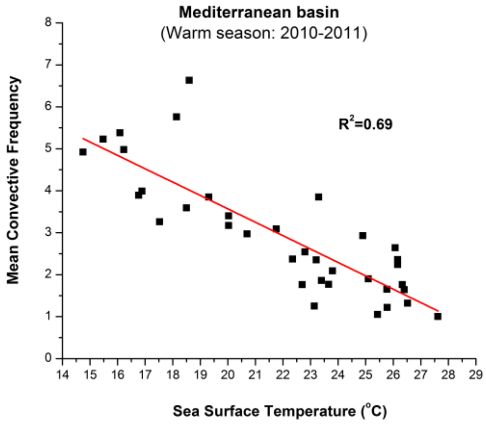

Figure 2. Monthly variations of SST and MCF using mean values of the three different parts of the Mediterranean Sea during the warm season of 2011-2012.

In the Fig.2 it can be seen a clear negative relation (adjusted R^2 = 0.69) between the mean convective frequency in the Mediterranean Sea and the relative mean monthly values of SST.
The negative correlation found in the Fig.2, requires further investigation. So, we examined separately each one of the three geographical parts of the Mediterranean Basin to obtain a more detailed conclusion about the areas that may contribute more significantly in this kind of correlation.
The next three Figures (Fig.3, Fig.4 and Fig.5) illustrate the graphs providing the scatterplots of the monthly mean values of SST and MCF in the western, central and eastern part of the Mediterranean Basin.

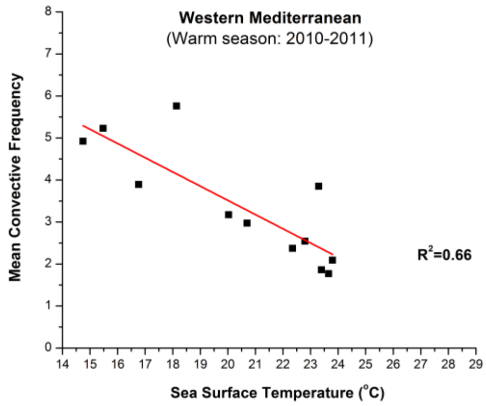

Figure 3. Correlation between SST and MCF for the Western part of the Mediterranean Sea.

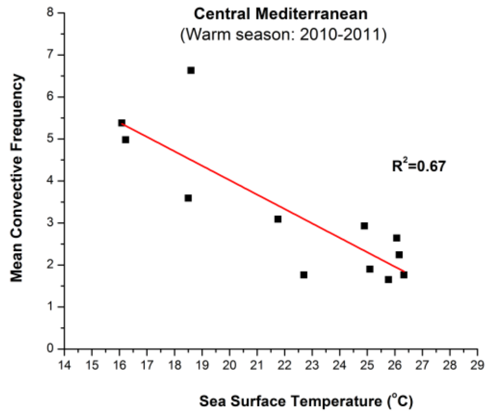

Figure 4. Correlation between SST and MCF for the Central part of the Mediterranean Sea.

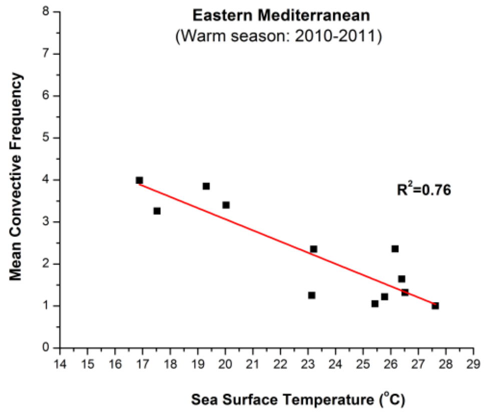

Figure 5. Correlation between SST and MCF for the Eastern part of the Mediterranean Sea.

The negative correlation of the mean monthly SST and the maritime MCF exist in each one of the three geographical parts of the Mediterranean Basin (Fig.3, Fig.4 and Fig.5). The most significant correlation (R^2 = 0.76) is presented on the eastern part, while in the western and the central part, the correlation has almost identical value (the value of the adjusted correlation coefficient differs at 0.01).

By observing the values of y-axes at Fig.3, Fig.4 and Fig.5 it is concluded that the western part has the most frequent convective occurrence in monthly basis, the central part has slightly lower values, while in the eastern part the maritime convective occurrence seems to be rarer compared to the other two regions.

Regarding the monthly SST, the western part is the most cold sea region compared to the central and the eastern parts while the higher values are presented in the eastern part ([15]).

3.2. Temporal variations

The temporal variations of the SST and MCF for the two-year period can be seen in the Fig.6.

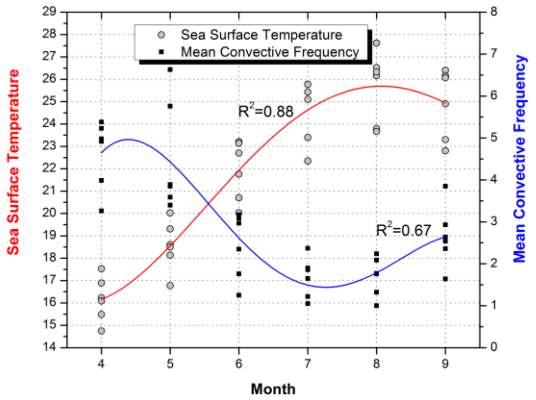

Figure 6. Monthly variations of SST and MCF for the whole Mediterranean Basin and the study period (two warm seasons).

In the Fig.6 it can be noticed the opposite mean variations of the SST and MCF. Additionally, we fit the mean monthly values with a 4^{th} order polynomial function with satisfactory correlation coefficients (that is 0.88 for the SST and 0.67 for the MCF). The fitting curves helped us to detect a transition period between July and August for the whole Mediterranean Sea, where the SST reaches its maximum mean monthly value while the convection occurrence in the sea is at its minimum level in monthly basis. More analytically, the mean monthly evolution of the SST (Fig.6) shows increasing values as we move from the spring to the summer, reaches its maximum values in August and then starts gradually to decrease.

The MCF has an opposite behavior (Fig.6). Firstly, there is a maximum between April to May that concurs with results of relative studies that examine the cloud convection in the study area ([4], [5], [16], [17]). In the following, as we move into the summer season, the maritime convection is decreasing reaching its minimum mean monthly occurrence, in the July. After this date the MCF is starting to increase gradually and more smoothly than its decreasing rate.

A time lag in the variations of these two parameters can be also noticed in the Fig.6 but is smaller than a month. This result we believe that it is owed to the shape of fitting curves and the amount of the used data. In addition to this, we have to mention that we used monthly datasets and as a consequence, every change inside this temporal scale, it's not considered as an important one.

3.3. Spatial Distributions

For better presentation and inferring conclusions, we also have created map representations to illustrate the spatial distribution of the mean SST and the total MCF considering all the months of the two selected warm periods.

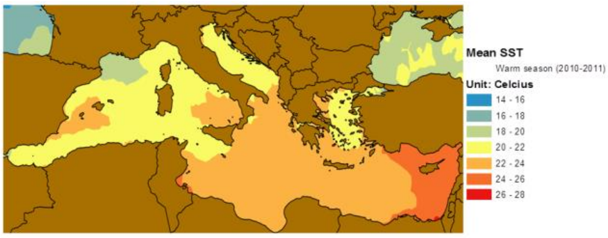

Figure 7. Spatial distribution of the mean SST during warm season of the years 2010 and 2011.

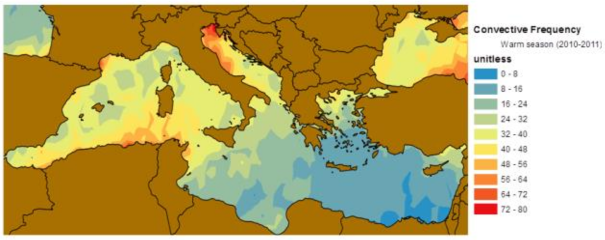

Figure 8. Spatial distribution of total Convective Frequency during warm season of the years 2010 and 2011.

Observing Fig.7, it is characteristic the different mean temperature profiles for the three parts that we divided the Mediterranean Sea (Fig.1). The western part is in general the most cold sea region ([15]), with mean temperatures between 20^{o}C and 22^{o}C. In the Gulf of Lyons the temperature is even lesser. The same temperatures with the western Mediterranean Sea has also found in the Adriatic Sea and the north-eastern Aegean that are located in the central and the eastern parts, respectively. The rest of the central part of the Mediterranean and significant amount of the Eastern one, belong to the same temperature profile. The warmest marine region is located in the Middle East (24^{o}C - 26^{o}C).

Regarding the total maritime convective frequency (Fig.8), there were found three significant local maxima in the Mediterranean Sea in the studying two-year warm seasons. One is located in the gulf of Lyons, the other in the northern and western Adriatic Sea and the third is the largest one, located in the sea regions of Algeria and Tunisia. Characteristic is also, the extend area at the eastern part of the Mediterranean Sea, which has the lower convective activity.

Finally, a statistical analysis (Analysis Of VAriance "ANOVA") was conducted to answer the question if the monthly mean differences of the parameter values are statistically significant or not. More precisely, we have checked if the monthly data distributions of the mean SST per pixel for the two-year warm season period are statistically different. The same statistical analysis has done using the mean SST values per pixel (for every pixel, a mean SST value is calculated using the all relative monthly values), for the three different parts of the Mediterranean Sea (Fig.1).

Following the statistical analysis of the data distributions of SST, the same has done for the convective frequency (occurrence of convection per pixel). The monthly distributions about convective frequency for the whole Mediterranean Sea as well as the distributions of the MCF for the three geographical sub-regions (Fig.1), are checked if they are statistically different according to their mean values.

In the Tab.1, information about the statistical tests were implemented, are provided.

Table 1. Results of ANOVA statistical test to evaluate the statistical significance of the distributions mean values.

Parameter	Kind of test	Result
Mean monthly SST distributions for the whole Mediterranean Sea	One-way ANOVA	At the 0.05 level, the population means are significantly different
Mean SST distributions for the three different parts of the Mediterranean Sea	One-way ANOVA	At the 0.05 level, the population means are significantly different
Mean monthly Convective frequency distributions for the whole Mediterranean Sea	One-way ANOVA	At the 0.05 level, the population means are significantly different
Mean Convective frequency distributions for the three different parts of the Mediterranean Sea	One-way ANOVA	At the 0.05 level, the population means are significantly different

In the Tab.1, it can be seen that for all the checked data distributions, it was concluded that the mean values of the relative distributions are statistically different. Regarding the SST the mean values in both of the monthly distributions and the distributions of the different parts of the Mediterranean basin, are statistically different at the 95 % significance. The same results were extracted for the convective frequency distributions.

Conclusively, these results highlight that all the mean values of the Fig.2 to Fig.6 and consequently the variations in time in space can be considered significantly different, giving an additional worth about the relative conclusions.

4. CONCLUSIONS

The spatiotemporal relation between SST and cloud convection in the Mediterranean Sea is studied during the warm season of the years 2010 and 2011. The satisfactory spatial resolution (finer than 10 km) of the datasets allowed a detailed analysis of these parameters. We highlight at this point that as convective pixels are considered only those that represent very cold and optically thick cloud regions (more details in the paragraph 2).

The first and the major conclusion is that there is a negative correlation (Fig. 2) between monthly mean SST and the maritime cloud convection (expressed as mean convective frequency “MCF”).

Additionally, we divide the Mediterranean Basin in three different parts (western, central and eastern as can be seen in Fig.1) to examine if this type of correlation appears only in specific areas or not. It was found (Fig.3, Fig.4 and Fig.5) that the negative correlation between these two parameters, exists in all the parts of the Mediterranean Basin. These conclusions are in opposition with the positive correlation that it has been extensively referred especially for oceanic areas in the ITCZ, however, it seems to be in accordance with other studies using the Mediterranean Sea as an area of interest. Characteristic is the study [18], where model estimations and satellite SST data (AVHRR) were used in order to examine spatial trends and distributions of SST in the whole Mediterranean, the correlation with basic atmospheric parameters and future scenarios. In this study, it was found that there is a significant negative correlation in monthly SST with the precipitation and the total cloud cover.

We believe that the negative correlation between SST and cloud convection we found in this study, is owed to local atmospheric circulation phenomena that push warm air masses above colder ones, causing warm-front like situations. The absence of synoptic conditions for long periods and large areas in the Mediterranean during the warm season, allow to temperature differences between land and sea in local to regional scale to play a significant role in this relation. Furthermore the topography, the local air circulation and the land characteristics play also an important role in convection during the warm season.

More specifically, during this period (and especially during spring) the land can obtain significant higher temperature values than sea areas. The warmer land heats air masses above it and when they move to the sea they are converged with colder ones, causing a warm-front air movement above sea that is possible to lead to convection. However, the convection caused by a warm front is often weak and rarer than the convection that comes from cold fronts.

The land breeze phenomenon caused by the land-sea thermal differences may also contribute to maritime cloud convection, but it is in general weaker that the sea breeze regarding the formation of convection.

As the SST is rising during summer months, the daily thermal differences with land are decreasing and this may cause similar temperature profiles for the air masses above sea and land surfaces. This possible homogeneity in the temperature and the absence of other factors may cause air significant advection and/or vertical mixing deteriorates the possibility the maritime cloud convection to be triggered.

On the other hand, the instability that can be caused through thermal heating of air masses above a sea region with high SST may be not enough to trigger convection at least in the case of the Mediterranean Sea and in monthly basis. Similar results were found in a case study where the sea-land thermal differences and their role to their offshore convection were examined [12]. One of the conclusions of this study is that an atmospheric stability aloft that was detected, prevented the formation of convection.

Other factors like the levels of humidity, the air temperature differences between land and sea surfaces and the vertical distribution of the air temperature play also an important role in cloud convection but may not be affected significantly by the SST changes and consequently, the increase of SST may not increase the maritime convective frequency of occurrence in a monthly basis.

Moreover, the convective activity in the greater area of Mediterranean basin, especially in warm season is closely related to the topography and is located mainly above land, coastline and on the lee side of the main mountain ridges ([4], [5], [16]). Similar results are also found in our study where the maxima of the maritime cloud convection are located northern of Atlas mountain ridge (in the sea of Algeria and Tunisia), the gulf of Lyon and the northern parts of Adriatic Sea (Fig.8). These areas with local maxima in “MCF” are concurred with local minima in the mean SST (Fig.7).

Another important conclusion of the study is depicted in Fig. 7 and Fig.8. It can be seen that there is a horizontal gradient in the mean SST and cloud convection and mainly in mean SST (Fig.7). Moving from the western to the eastern parts of the Mediterranean Sea, the mean SST during the warm season is increasing while the total convective frequency is in general decreasing with exceptions, the local maxima previously mentioned.

The negative correlation between the two parameters examined here during the warm season can be also seen in the temporal evolution of the mean monthly values for these two parameters (Fig.6). As we move from spring to summer them mean monthly SST is increasing while the MCF is decreasing. There is also a transition period from mid July to August, in which the two parameters obtain their maximum and minimum mean values respectively. In the following – as we move to gradually to the autumn – the convection starting to increase and the mean SST is decreasing.

Such interesting conclusions of this study have already led us to examine additional parameters and test more datasets so that to obtain an even more integrated and stable conclusions about the type of relation between the corresponding parameters. Future work will include the analysis of SST and cloud convection datasets for more years and the use of additional parameters like air humidity and air temperature in different atmospheric profiles (from the surface to the upper level of the troposphere) in order to obtain a more clear conclusion about the instability above the sea and the available amounts of water vapor that contribute to the cloud convection.

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