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Sea Surface Temperature in the Mediterranean: Trends and Spatial Patterns (1982–2016)

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Abstract—Oceans play a key role in energy storage in the global Earth–Ocean–Atmosphere system. Within this framework, the knowledge of past evolution and future trends of sea surface temperature is crucial for the future climate scenarios. Previous studies have highlighted the role of sea surface temperature as an important ingredient for the development and/or intensification of heavy precipitation events in the Western Mediterranean basin but have also highlighted its role in heat waves in Europe. In this study, a consistent warming trend has been found for daily sea surface temperature data series derived from satellites (1982–2016) for the whole Mediterranean region and for different temporal scales, from daily to monthly, seasonal and decadal estimates. Additionally, spatial clustering analysis has been run to look for its spatial structure. Two main distribution modes have been found for sea surface temperature in winter and summer, while spring and fall show transitional regimes. Winter mode shows a north-to-south increasing gradient banded structure while summer regime presents a set of well-differentiated areas.

Key words: Sea surface temperature, warming, trend, spatial patterns.

1. Introduction

According to the Fifth Assessment Report of the IPCC (2013) most of the global energy change inventory is stored in the oceans; about 93% of the increase in Earth's energy inventory in the period from 1971 to 2010 has induced warming of the oceans, while its upper layer (0–700 m deep) accounts for 64% of the total. This huge storage of energy has led to an increase in global sea surface temperature (SST hereafter) and a rise in global sea level. Additionally, in the near-term projection chapter of the IPCC report, (Kirtman et al. 2013) say that it is very likely that global averaged SST will increase in the near term. An increase that will likely keep going in the longer term ocean warming for centuries in all scenarios, even if greenhouse gases emissions are decreased or concentrations kept constant (Collins et al. 2013).

Hartman et al. (2013) state that the number of heavy precipitation events over land has increased in more regions than it has decreased since 1950, while (Kirtman et al. 2013) say that frequency and intensity of heavy precipitation events over land will likely increase on average in the near term, but with regional differences. For longer term projections (Collins et al. 2013) more intense individual storms are expected as temperatures increase.

In the Mediterranean, SST has been shown as an important ingredient for the onset and/or intensification of heavy precipitation events (HPE), especially in its western basin. During the last years a number of research papers have investigated the relationship between SST and precipitation in the area, mainly by means of numerical modelling with mesoscale models for HPE (Pastor et al. 2001; Lebeaupin et al. 2006; Katsafados et al. 2011; Miglietta et al. 2011; Pastor et al. 2015) or with regional models for global precipitation (Bozkurt and Sen 2011). There have also been studies looking for statistical correlation between Mediterranean SST and precipitation; Turuncoglu (2015) found that precipitation over the Anatolian Peninsula is very sensitive to the SST of the surrounding seas. But Mediterranean SST does not only affect (is correlated to) precipitation in the Mediterranean basin but also to precipitation and flooding in Central Europe (Volosciuk et al. 2016) and the Sahel (Rowell 2003). Other authors have also found that Mediterranean SST played a role in the persistence and intensification of the summer 2003 heatwave in Central Europe (Feudale and Shukla 2007, 2011a, b). It is

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therefore clear that a good knowledge of SST climatology, spatial patterns and trends is a main concern regarding Mediterranean and European climate trends and projections, especially in the case of HPE events.

Standardised sea surface temperature in situ observations, mainly from trading ships, started on the second half of the nineteenth century according to the rules agreed in the Brussels Maritime Conferences on 1853 (Rayner et al. 2006). The collections of such historical data and its integration with recent observations have provided a very useful tool to monitor global change. Since the middle of the twentieth century data from ocean profilers and drifting buoys were incorporated to the global observation of SST. From the 1970s, the onset of the satellite era, SST data collection experienced a great improvement both in terms of spatial and temporal coverage. Gridded SST datasets can be used to analyse spatial patterns and trends globally or in regional basins, like the Mediterranean.

In the last years, some authors have investigated SST warming for the Mediterranean basin or sub-basins. Rixen et al. (2005) found, from in situ observations, an increase in the average temperature of the upper layer (0–150 m) of the Mediterranean of 0.5 °C from 1980 to 2000, while Belkin (2009) calculated a higher increase of 1.4 °C from 1978 to 2003. From AVHRR sensors on board on satellites, longer SST data series have been studied; Criado-Aldeanueva et al. (2008) found a trend for SST of 0.06 °C/year for the global Mediterranean basin (1992–2005), while Nykjaer (2009) separated the Mediterranean in its western and eastern basins and found different trends for both in a longer period from 1985 to 2006. In the case of the Western basin he found a 0.03 °C/year and a higher 0.05 °C/year for the Eastern basin. Skliris et al. (2012) used two different data bases to investigate decadal variability of SST in the Mediterranean. They found different total increases in SST for the 1985–2008 period for the whole Mediterranean (0.89 °C), the Western (0.62 °C) and Eastern (1.01 °C) basins. For the 1982–2012 period, Shaltout and Omstedt (2014) found a warming trend of 0.36 °C/decade for the Mediterranean basin and a higher 0.51 °C/decade for the Black Sea. These latest studies indicate the need of understanding spatial patterns in the Mediterranean SST field. In his doctoral thesis, Pastor (2012) used clustering techniques to look for differentiated SST areas in the Mediterranean, finding two main regimes for SST distribution in winter and summer for the 1985–2009 period. Another aspect that has also been investigated recently is the role of SST in the global water cycle. At a global level, Durack et al. (2012) described the intensification of the global water cycle from 1950 to 2000 following the "rich get richer" mechanism with fresh sea regions becoming fresher and salty regions becoming saltier in response to observed warming and also showing a close relationship between evaporation/precipitation rate and sea surface salinity. Skliris et al. (2016) also stated an intensification of the water cycle for both observational data and climate projections. Mariotti (2010) studied the relationship between evaporation/precipitation and SST in the Mediterranean finding a significant increase in evaporation since the mid-1970s, preceded by a descent during 1965–1975. In her work, Mariotti states that the evaporation increase was primarily driven by SST increase and remarks the importance of evaporation in observed salinity changes in the Mediterranean. The timing of evaporation cycles found by Mariotti roughly coincides with the SST long-term cycle found by Marullo et al. (2011), whose study describes a 70-year cycle for a reconstructed SST time series (1854–2008) in the Mediterranean that shows a decrease in SST from the mid-1960s to the late 1970s and then changes to an increase until the end of the series in 2008.

Recently, the Group for High Resolution Sea Surface Temperature[1] (GHRSST) has established a framework and set of best practices for processing and sharing SST data in a coordinated and standard way convenient for scientists and data users. This has allowed having new databases, reprocessed to meet the quality standards of the group, for the study of SST. In this paper, the authors have used one of these data bases to extend the above-mentioned studies across a longer time period and to investigate spatial behaviour of SST in the Mediterranean. The next section of this paper describes the SST data used and statistical methodologies applied; Sect. 3 presents the

[1] GHRSST website: https://www.ghrsst.org/.