

## Recent warming in the Balearic Sea and Spanish Mediterranean coast. Towards an earlier and longer summer

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### RESUMEN

Este trabajo analiza los cambios recientes en la temperatura del mar Balear y las tierras costeras circundantes. Para el análisis de la temperatura terrestre se han utilizado registros mensuales de varios observatorios litorales en el contorno de la cuenca Balear en el periodo 1960-2010, y para el análisis de la temperatura superficial del mar (SST, por sus siglas en inglés) se utilizaron imágenes térmicas mensuales de satélite procedentes del Physical Oceanography Distributed Active Archive Center (PO.DAAC) disponibles para el periodo 1985-2009. Se observa un incremento de la temperatura desde finales de la década de 1980, especialmente notable en los últimos 25 años, con tasas de 0.039 °C/año en tierra para el periodo 1960-2010 y 0.026 °C/año para el mar durante el periodo 1985-2009. El análisis estacional de las tendencias muestra que en los últimos 25 años las mayores tasas de calentamiento se producen durante la transición primavera-verano, con tasas máximas en el mes de junio (0.12 °C/año en tierra y 0.08 °C/año en el mar). Los resultados evidencian una tendencia hacia el adelantamiento y prolongación de la estación estival en las últimas décadas, tanto en tierra como en mar.

### ABSTRACT

This paper analyses recent changes in the temperature of the Balearic Sea and surrounding coastal areas. Monthly temperature data from several weather stations located around the Balearic basin have been used to obtain land temperatures during the period 1960-2010, and monthly thermal satellite images from the Physical Oceanography Distributed Active Archive Center (PO.DAAC) covering the period 1985-2009 have been processed to obtain sea surface temperatures (SSTs) in the Balearic Sea. A rise in temperature has been observed since 1980 and increasingly in the last 25 years, with an average warming trend of 0.039 °C/year on land for the period 1960-2010 and 0.026 °C/year in SSTs for 1985-2009. The seasonal analysis showed that, in the last 25 years, higher trends were registered during the transition from spring to summer, with the highest warming rates in June (0.12 °C/year on land and 0.08 °C/year in SSTs). Results show a recent tendency towards earlier and longer summers both on land and sea.

**Keywords:** Air temperature, sea surface temperature, global warming, Mediterranean Sea, Balearic Sea, temperature trends, seasonal and temporal variability.

### 1. Introduction

At the present time there seems to be a reasonable consensus among the scientific community about the increase in global average air temperature during the 20th century, especially during the last three decades. The IPCC Fourth Assessment Report (AR4) gives a rate of warming in land temperatures for the Northern Hemisphere ranging from 0.072 to

0.089 °C/decade during the period 1901-2005 (IPCC, 2007). Although there is some disagreement as to whether this warming is due to climate variability or climate change, numerous studies confirm the global warming on regional, continental and global scales in the last decades (Easterling *et al.*, 1997; Jones *et al.*, 1999; Jones and Moberg, 2003). However, different rates are given depending on the spatial scale

(global, regional or local), the geographical area and the period of time considered.

The Mediterranean has been identified as one of the “hot-spots” in future climate change projections because it is an especially vulnerable environment (Giorgi, 2006; Lionello *et al.*, 2006; Giorgi and Lionello, 2008; Lejeusne *et al.*, 2010). There are many factors behind this assertion: (1) it is a transitional region between mid-latitudes and subtropical climate regimes; (2) it is dominated by the Mediterranean Sea, a semi-enclosed sea which is an important source of moisture and a heat reservoir, that has also been considered as a miniature ocean by physical, chemical, climatic and environmental studies (Bethoux *et al.*, 1999); and (3) the Mediterranean environment has experienced a strong human impact since ancient times due to demographic pressure, agricultural exploitation, urbanization and, more recently, coastal tourism. Many works (Bethoux *et al.*, 1990, 1998; Rholin and Bryden, 1992; Vargas-Yáñez *et al.*, 2005, 2008, 2010) confirm the increase in temperature in deep, intermediate and surface Mediterranean waters, and others explore the effects of this warming in the biology and ecology of organisms in the sea (see the review by Lejeusne *et al.*, 2010) as well as its role in fisheries fluctuations (Tzanatos *et al.*, 2014). It is important to further increase our knowledge of regional, seasonal and decadal variability on temperatures in the Mediterranean environment as temperature changes interact with pollution, overfishing, sea level changes or acidification, and can trigger major changes in the ecosystems.

In the Iberian Peninsula, during the last two decades, many papers have been published which attempt to explain the spatial and temporal variability of temperature at national, regional or local level. Most studies agree that there has been an increase in temperature from the 1970s onward (Esteban-Parra *et al.*, 1995, 2003; Serra *et al.*, 2001; Morales *et al.*, 2005; Salat and Pascual, 2006; Brunet *et al.*, 2007; Homar *et al.*, 2010; Del Río *et al.*, 2011; El Kenawy *et al.*, 2012). Amongst them, we highlight those that explore the monthly, seasonal and annual variability of the warming trends. In their study of temperatures in Castilla-León (Spain) for the period 1945-1996, Morales *et al.* (2005) found significant positive trends only in winter, but when analyzing a shorter and more recent series (1972-1995) they obtained a clear increasing trend for the spring (0.058 °C/year)

and summer (0.057 °C/year). Del Río *et al.* (2011), using data from 473 weather stations distributed all over Spain for the period 1961-2006, observed a significant positive trend at national scale with rates of 0.1-0.2 °C/decade. They also found that summer and spring are the seasons with the largest contributions to annual trends, with rates of 0.3 °C/decade, and a maximum rate recorded in June (around 0.5 °C/decade). Similar results can be inferred from Brunet *et al.* (2007), also covering the whole of Spain and based on 22 weather stations for the period 1850-2005. These authors obtained a warming rate of 0.1 °C/decade for the whole period and indicated that autumn and winter contributed slightly more than spring and summer to the annual warming over the 1850-2005 period. However, a detailed reading of this work shows that for the most recent decades, between 1973-2005, the highest warming rates are in spring (0.77 °C/decade) and summer (0.67 °C/decade). More recently, El Kenawy *et al.* (2012), in a study about variability of temperature over northeastern Spain (the region between the Pyrenees and the Iberian system) based on data from 19 weather stations for the period 1920-2006, obtained warming rates of 0.1 °C/decade and pointed out that the warming observed during this period was mainly due to the increase of temperature from the 1970s. A deeper analysis based on 128 stations for the period 1960-2006 led them to the conclusion that the warming is faster during the warm-half of the year (spring and summer) than in the cold-half (winter and autumn) and that coastal areas have warmed at higher rates than inland areas. A maximum warming trend of 0.22 °C/decade was obtained in summer for the period 1920-2006, and a maximum of 0.66 °C/decade in spring when the period considered was restricted to 1960-2006.

This idea of a larger increase of temperature during the warm seasons had previously been pointed out by other authors. In a study based on the analysis of the climatic series of air and sea surface temperature (SST) of the oceanographic station L'Estartit, located on the Catalan coast (Spain), for the period 1974-2005, Salat and Pascual (2006) obtained mean rates of 0.6 °C/decade and 0.3 °C/decade for air temperature and SST, respectively, with the highest trend in air temperature (+0.8 °C/decade) observed for the period April-June. The impression that the higher warming rates observed in recent decades are due to

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