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Drivers of persistent marine heatwaves in the Mediterranean in recent years

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Summary. — The Mediterranean basin has experienced several marine heatwaves (MHWs) over the last few decades. During MHWs anomalous warm ocean temperatures are present for several days at least and can influence atmospheric circulation and negatively affect ecosystems. There is increased interest in these events as they occurred more frequently and with larger severity, fuelled by global warming trends. Here we examine the strong Mediterranean MHW of 2022, which started in May and lasted for several months. This MHW event rapidly spread through western and central Mediterranean with peak intensity at par with the record-breaking 2003 event. In this communication we focus on the drivers of the prolonged 2022/2023 case which led to its exceptional duration. We find that persistent anticyclonic conditions, that continued through fall and winter, were responsible for the persistence of the 2022/23 MHW. We also discuss recent Mediterranean conditions by analyzing near real-time observational products, and discuss the possible impacts of global warming on MHW characteristics.

1. – Introduction

The southern European-Mediterranean region has long been considered a hotspot of climate change [1] due to the increased magnitude of warming trends in the area compared to the global mean. While there is a significant trend in mean values, recently attention was also given to extreme values, as they are important for significant impacts on ecosystems [2]. Marine heatwaves (MHWs) have been identified as a key stressor to the marine environment, since warm sea surface temperatures (SSTs) can interfere with ecosystems health and indirectly affect ecosystem services, such as fisheries and aquaculture [3]. In this work we provide an updated analysis of the 2022/23 MHW conditions occurring in the Mediterranean region, which received much media interest and have been discussed in recent works [4,5]. Our analysis, making use of satellite-based SST and state-of-the-art meteorological reanalysis, shows that the anomalous conditions started in May 2022 did not disappear in 2023, marking one of the warmest years in the Mediterranean, as well as at the global scale.

2. – Data and methods

The satellite-based SST dataset we use is a daily, gap-free record provided by the Copernicus Marine Service, which covers more than four decades, from late 1981 to present with a one month delay. In particular, we use the reprocessed high-resolution product [6] currently available up to end of 2023, which compares well to in-situ observations (bias below $\sim$0.1 K).

Information on atmospheric conditions is obtained from the ERA5 reanalysis [7], a state-of-the-art system assimilating surface and satellite-observations, which provides a consistent reconstruction of the state of the atmosphere over the last eight decades. We retrieved geopotential height at 500 hPa and surface fields such as surface pressure, winds and temperature. The results here presented are based on monthly averages of the reanalysis outputs.

3. – Results and discussion

An in-depth analysis of the onset and development of the 2022/23 MHW has been presented in [5]; here we will just summarize their main results. A warm SST anomaly developed in May 2022 in the north-western part of the Mediterranean Sea, and then moved towards the southern and central basins in the following months. The warm anomaly persisted for several months, and a further warm peak occurred between December 2022 and January 2023, due to favourable atmospheric anticyclonic conditions. Figure 1 shows the evolution of the average SST for 2023, and for other years in the past. It shows that the last year (red line) has again been characterized by warm SST values, particularly high between July and August. The reprise of the anomalies in summer followed a period with values close to average. Values above normal are also seen during autumn 2023. There is a clear difference (at least 2 °C) between years in the early portion of the record and those near the end, with occasional spikes increasing the warm anomaly.

As discussed by [5], persistent anticyclonic conditions were instrumental to increase the persistence of SST anomalies. Therefore, we have inspected meteorological fields from the ERA5 reanalysis to verify the atmospheric conditions in summer 2023. Results are shown in fig. 2. Anticyclonic anomalies are found over continental Europe in June, and then dominate the Mediterranean region during July, with a pattern centered

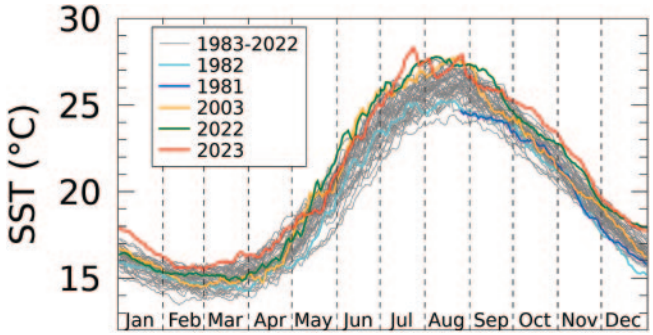

Fig. 1. – Daily time series of satellite-based Mediterranean SST for the last forty years. The early portion of the time series and years 2003, 2022 and 2023 are reported with coloured lines.

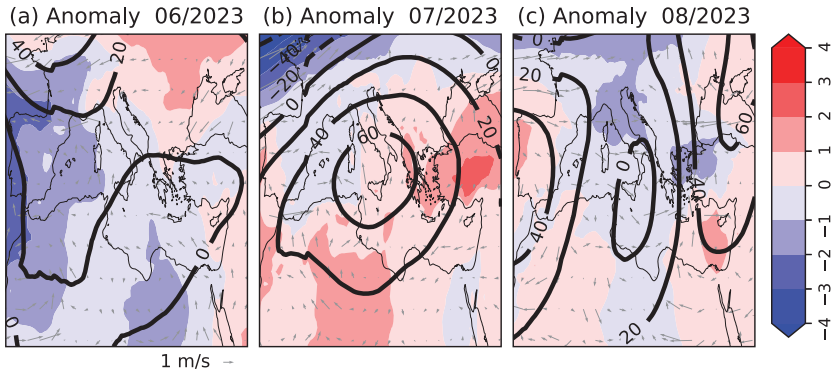

Fig. 2. – Longitude-latitude maps of anomalies of geopotential height at 500 hPa (lines, units of m), mean sea level pressure (shadings, units of hPa) and surface winds (arrows, units of m/s) for the 2023 summer months.

over southern Italy. In August, the pattern assumes a wave-like appearance, with local maxima over Iberia and the Black Sea, and compared to 2022 anomalies are more widespread, as they also interest the eastern Mediterranean basin. This flow configuration is consistent with global-scale changes in atmospheric circulation [8] with one center of action located over the Euro-Mediterranean area.

Figure 3 reports the time series of the anomalies of mid-tropospheric geopotential height and surface temperatures. As discussed by [5], positive trends can be observed for both variables in summer, and interestingly in 2023 anomalies have been strongly positive and even larger than those of 2022, suggesting a "heat-dome" effect which contributed to the warm peak in the SSTs. This long-term variation has been connected with the effects of global warming, which makes these conditions stronger and more frequent in recent years. In fact, anomalies reached their record values in 2023, even exceeding those of 2003, which featured major marine and atmospheric heatwave events.

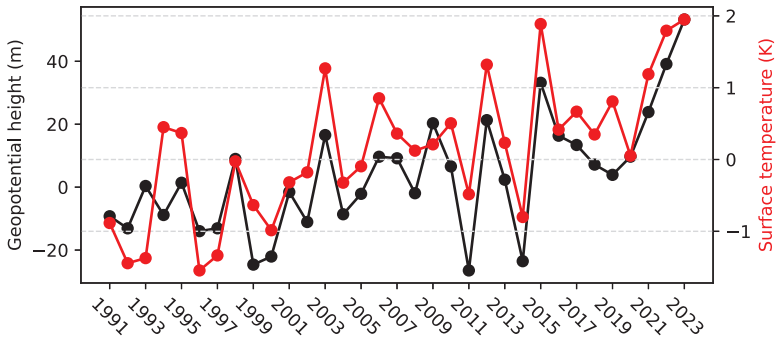

Fig. 3. – Time series of geopotential height (units of m, black line) and surface temperature anomalies (units of K, red line) for the Mediterranean region in the month of July.

4. – Conclusions

In this short paper we summarize the evolution and persistence of MHW conditions in the Mediterranean Sea between 2022 and the end of 2023. SSTs marked record values in 2023, and peak values in summer topped those reached in the previous year. Anomalous warm values in satellite-based SST are still observed at the time of writing. Similarly to the 2022 case, in 2023 we find that atmospheric circulation favoured exceptional MHW conditions, with anticyclonic atmospheric anomalies characterizing the Mediterranean region. Analysis of long-term summer tropospheric and surface fields allows us to explain the observed anomalies with the warming trends observed over the past decades. Further analysis will be required to understand the relationship between Mediterranean MHW events and surrounding regions, as well as the interactions between the ocean and land conditions, which can interact to amplify the adverse impacts of heatwave events on ecosystems and human health.

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