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Response of the sea surface temperature to heatwaves during the France 2022 meteorological summer

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Abstract. Summer 2022 was memorable and record-breaking, ranking as the second hottest summer in France since the beginning of the measurements, with a seasonal average of 22.7°C. In particular, France experienced multiple record-breaking heat waves. As the main heat sink of the Earth system, the oceans are at the forefront of events of this magnitude, which enhance oceanic disturbances such as marine heat waves. In this study, we investigated French maritime basins sea surface temperature to determine the ability of satellite measurements to track the response of surface waters to these events. Despite some gaps in data availability, we showed that during the meteorological summer of 2022, the mean sea surface temperature was between 1.3°C and 2.6°C above the long-term average (1982-2011). A focus on the heat wave from 31 July to 13 August was carried out and showed a significant sea surface temperature response to the heat wave with maximum temperatures measured locally at 30.8°C in the North-western Mediterranean sea. Beyond the response to intense surface air temperatures, the contribution of other atmospheric variables was not negligible. Thus, we have shown that France experienced an August with above-average surface solar radiation correlated with below-average total cloud cover and anomalies in the distribution and intensity of wind speeds. The response to these different contributions depends on the hydrodynamic conditions, in particular the tides that ensure turbulent mixing. This is why the response is more pronounced in the Mediterranean, where the absence of dynamic mixing (below-average surface wind speed) is associated with an absence of tides. Our results were in line with previous studies and we confirmed here that even if the Mediterranean is a climate change hotspot, all maritime front are affected by a warming of surface waters. Our study therefore demonstrated the need for an efficient and sustainable operational system combining polar orbiting and geostationary satellites to prevent the alterations that threaten the oceans in the context of climate change.

1 Introduction

Anthropogenic influence on the climate is unequivocal and results in an Earth's global energy imbalance as highlighted by the shifts in the global average atmospheric temperatures distribution (Eyring et al., 2021). The ocean's contribution to the energy balance of the Earth's system, in relation with the extensive volume and the inherent thermal capacity, is greater than that of

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any other component (continents, atmosphere, glaciers). As a matter of fact, the oceans absorb more than 90% of the thermal excedent of the system which leads to an increase in their global heat content, thus to a rise in the global ocean temperatures (Cheng et al., 2019). The ocean heat content (hereafter OHC) is a key indicator in the analysis of global warming (Von Schuckmann et al., 2016). Although this increase is widespread, there are both horizontal differences, with a greater contribution from the Southern Ocean of the global heat uptake (Sallée, 2018) and vertical discrepancies, with a greater uptake from the 0-700m depth layer (Bindoff et al., 2019).

This ocean internal energy imbalance has direct consequences on the properties of the system, its dynamics, its contribution to the water cycle and also as a unique biotope. Such changes in the global OHC have direct impacts on the sea-level rise (Cazenave et al., 2018), the total water vapor column (Trenberth and Shea, 2005), continental glacier platforms melting (Rignot et al., 2014) and decline in the ocean dissolved oxygene (Keeling et al., 2010). In shorter time period, climate disruptions enhance the intensity and frequency of both atmospheric and oceanic extreme events. Among others oceanic events, marine heatwaves (hereafter MHWs), defined by Hobday et al. (2016) as events of anomalously warm water temperature having specific characteristics (spatial extent, duration, intensity), have emerged as a key field of research due to their substantial impact on ocean ecosystems (Sen Gupta et al., 2020). Although the extent of such events are not limited to the ocean surface (Schaeffer and Roughan, 2017), MHWs are mainly detected and identified using sea surface temperatures (hereafter SSTs) measurements (Hobday et al., 2016; Benthuysen et al., 2018).

Beyond the detection of MHWs, SST is a fundamental variable in an oceanographic monitoring and forecasting system from daily to climatic timescales. However, both the operational and the climatic needs are based on a spatial and temporal coverage of observations that cannot be fulfilled by *in situ* measurement means alone. Due to their global spatial coverage and their usable spatial and temporal resolution, satellite SST measurements meet these operational and climatic requirements and are now integrated in forecasting systems (Donlon et al., 2012; Minnett et al., 2019; O'Carroll et al., 2019).

During the 2022 meteorological summer (June-July-August), Western Europe and more specifically France have experienced a range of atmospheric heatwaves caused by either a heat dome originating from an adiabatic compression of the Atlantic air particles (11th-25th of July and 31th-13th of August) or southerly advection of Saharian hot air masses called a heat plumes (15th - 19th of June). As seen in the Figure 1 representing the anomaly in the 500 hPa geopotential altitude, the first phenomena is associated to a planetary wave swell and enhanced by southerly warm advection while the June southerly advection is originating from an isolated cold pool over the Iberian Peninsula. These synoptics conditions resulted in anomalously changes in most of the variables influencing ocean energy balance among them the 2m air temperature with anomalies that excedeed 5°C over Western-Europe (Fig.2). Among them, France experienced, during the 2022 climatological summer, record-breaking surface air temperatures (in terms of both intensity and earliness), higher than average solar radiation (in combination with an unsual scattered cloud cover) and wind speed negative anomalies.

In the following study, we assessed the capabilities of operational satellite SST measurements to describe the response to the atmospheric heatwaves that hit France during the 2022 meteorological summer and the influence of some of the main components of the ocean energy balance on such impacts.

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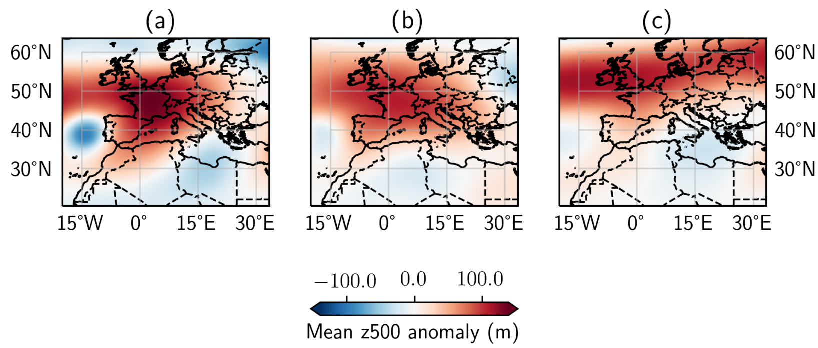

Figure 1. ERA5 reanalysis of the mean geopotential height at 500 hPa pressure level anomaly for a) June, b) July, c) August heatwaves as compared to the 1991-2020 climatology.

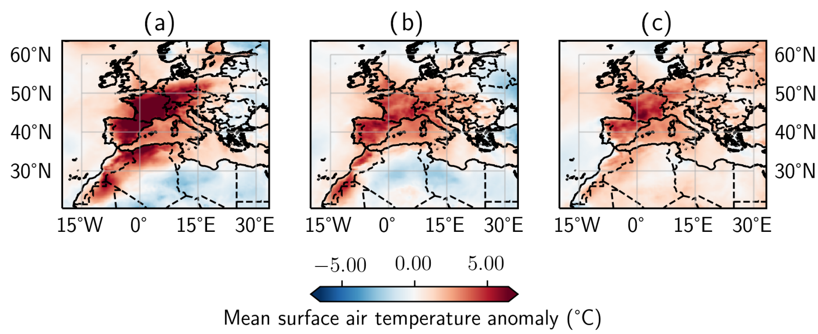

Figure 2. Same as Fig.1 for mean surface air temperature anomaly for a) June, b) July, c) August.

2 Study sites

Although this study focuses on the responses to the heatwaves that affected France, this meteorological extremes events have a spatial extension that is not limited to land borders. Thus, three distinct ocean areas including both coastal and open ocean zones, as presented in the Figure 3, with inherent characteristics, have been selected in this study.

- **Area EC**: The English Channel characterized by strong tidal currents that enhanced the water column mixing, thus help to hold cooler sea surface temperature,

- **Area BB**: Bay of Biscaye, part of the Atlantic ocean composed of a deep abyssal plateau ending in underwater canyons, the most famous of which is that of Capbreton ending 300m from the shore. This area is directly affected by the atmospheric zonal flux.

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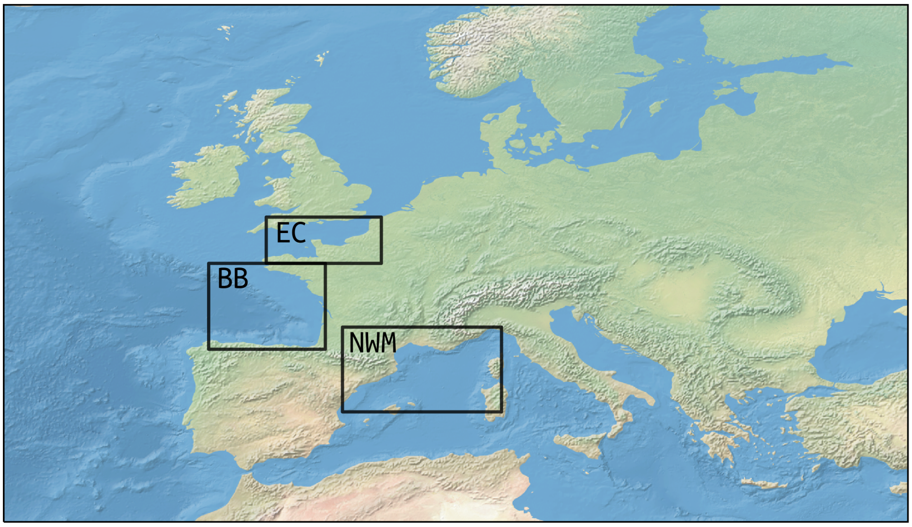

Figure 3. Subdivision used in this study. The subbasins considered are the English Channel (EC), the Bay of Biscaye (BB) and the North-western Mediterranean Sea (NWM).

– **Area NWM**: North-Western Mediterranean Sea sub-basin (Gulf of Lions & Balearic basin) used in the Copernicus Marine Environment Monitoring Service (CMEMS) Mediterranean Sea validation procedure as mentioned in Lazzari et al. (2021). This area directly influenced by Mistral and Tramontane regional winds influencing recurrent upwelling phenomena and is of particular interested in comprehensive study of the Mediterranean water cycle and its implications for climate studies (Drobinski et al., 2014; Ruti et al., 2016)

3 Data/Methods

3.1 Atmospheric reanalysis

The overview of the exceptional weather situation in France during the summer of 2022 is based on the systematic analysis of different meteorological variables influencing the upper-ocean energy balance (Equation B1). The forcing data used were from the ERA5 reanalysis regridded to a regular latitude-longitude grid of 0.25 degrees (Hersbach et al., 2020). Both hourly and monthly were used, the first to compute daily and weekly mean while the second were used to compute the 1991-2020 climatological mean.

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3.2 Sea surface temperature data

3.2.1 Operationnal SST product

The Advanced Very High Resolution Radiometer (AVHRR) on-board Metop satellites enables retrieval of SST twice daily at 1km resolution over the entire globe. The Ocean and Sea Ice Satellite Application Facility (OSI SAF) provides users with operational products of SST in near real time (https://osi-saf.eumetsat.int/). In particular it has been delivering operational Metop/AVHRR SST products since 2007. In this study the specific OSI SAF product used is the level-3C (mono-sensor collated) from Metop-B labelled as OSI-201-b (https://osi-saf.eumetsat.int/products/osi-201-b). It is a global $0.05°$ gridded product available twice daily.

SST retrieval from AVHRR data relies on MAIA version 4 cloud mask (NWP SAF, 2017) and is based on a split-window algorithm using two infra-red bands at 10.8 and 12.0 μm which coefficients are tuned so that the retrieved SST has a global zero bias against drifting buoy measurements at about 20cm depth, see for example Marsouin et al. (2015). Since 2017, operational production of Metop SST includes an algorithm correction scheme. This scheme has been designed to mitigate the SST algorithm inherent biases due to changing atmospheric conditions: negative biases with respect to drifting buoy measurements where and when the atmosphere is very wet such as in the Inter-Tropical Convergence Zone and positive biases where and when the atmosphere is very dry (see Figure 14 in Marsouin et al., 2015). It is based on the use of Numerical Prediction model output of atmospheric profiles (pressure, temperature and humidity) and RTTOV radiative transfer model (Saunders et al., 2018). This algorithm correction scheme is described in Le Borgne et al. (2011) and in the OSI SAF Algorithm Theoretical Baseline Document (ATBD) for Low Earth Orbiter SST products (OSI SAF, 2018).

As the product is operational, it is necessary to be aware of the biases inherent in the data. In order not to introduce biases related to the diurnal cycle, only night-time data have been analysed. However, these data are aggregated over a time window of 12 hours centered at midnight UTC. For the studied area, the night-time data are acquired at 21:30 local time, thus in the westernmost part of the domain data are acquired at dusk in summer time. Therefore, data with a solar zenith angle smaller than 95° are removed to avoid analysing daytime SST. OSI SAF SST products are delivered along with a per-pixel Quality Level (QL) which reflects the quality of the retrieval. This includes considerations about potential contamination by cloud and mineral dust aerosols. The QL is ranging from 0 (no data) to 5 (best available quality).

3.2.2 SST analysis

An analysis of satellite derived SST was used to compute a daily climatology to compare to operational SST. It is the version 2.1 of the European Space Agency Climate Change Initiative (ESA CCI) level 4 Climate Data Record (Good et al., 2019; Merchant et al., 2019) which is based on the AVHRR and the Along Track Scanning Radiometer (ATSR) sensors. It is a daily global gap-free product available from 1981 to 2016 on a regular latitude/longitude grid at 0.05 degrees resolution.

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3.2.3 SST climatology and anomaly

The study of SST anomalies requires, in a first step, the construction of a reliable monthly climatology for the period 1982-2011. Monthly climatological averages were obtained by averaging the daily data presented in the section using the Climate Data Operator tool (Schulzweida, 2022).

In a second step, the daily OSI SAF data were filtered in order to reduce the biases of the analyses (especially on the calculation of spatial averages). In this study, only data with a QL equal to 3, 4 or 5 have been used, as recommended in the Product User Manual (OSA SAF, 2018). Following this first filtering, it is necessary to ensure that the number of measured pixels is representative of the area. To avoid biases in the spatial averages, only the days where the measurements concern at least 50% of the total surface area are kept. Finally, to limit the disturbances in the SST analysis, the daily analysis of the anomalies was done by taking a sliding window over 3 days. This also limits the noise that might be introduced by the diurnal cycle and to consider only lower frequencies. Any changes in the SST retrieval process have been done during the study period which proves the SST are homogeneously distributed in both space and time.

Anomalies are then calculating by taking the differences between the daily SST value and the long-term value one (1982-2011).

4 Results

4.1 Daily sea surface temperature evolution over the 2022 meteorological summer

The first objective of an operational product is to provide a daily usable monitoring for use by the forecasting services. However, these conditions are ideal cases and are therefore not met in all basins every day. Thus a significant part of the data is not available depending on multivariate conditions (clouds, aerosols, low quality data). This share varies for each basin and is compiled in the Figure 4. One can note that the English Channel, with 60% of missing data, is more impacted than the Bay of Biscaye basin (33%) and the North-Western Mediterranean Sea (22.7%) where the data are missing only until the beginning of July. These missing data do not follow a regular pattern and are rather related to the applied filtering conditions. Looking specifically at the heatwave periods, the missing data do not allow for a systematic analysis of the response of the three basins to either the early heatwave in June 2022 and the July 2022 one. However, response of the July 2022 heatwave is conceivable for BB and for NWM. Finally, only the response to the August 2022 heatwave is feasible for the three basins. This is the reason why the analysis of the SST response to heatwaves focused on August 2022 event.

Despite this lack of data, it is possible to have an overview of the exceptional summer 2022 that affected these basins. It can be seen from Table 1 and Figure 4 that all three basins have undergone a range of warmer than average SSTs with the strongest response from the NWM basin (mean daily anomaly of 2.6 °C and maximum of 4.3°C). More remarkable is there are not only one day, at the basin scale, where the temperatures are within the normal temperatures range or below. Furthermore, the response of the NWM basin is clear with an increase of the average SSTs of 2.7°C between the 6th of July and the 20th of July (among these the basin experienced 12 continuous days with an average anomaly over 3°C) and of 1.4°C between the

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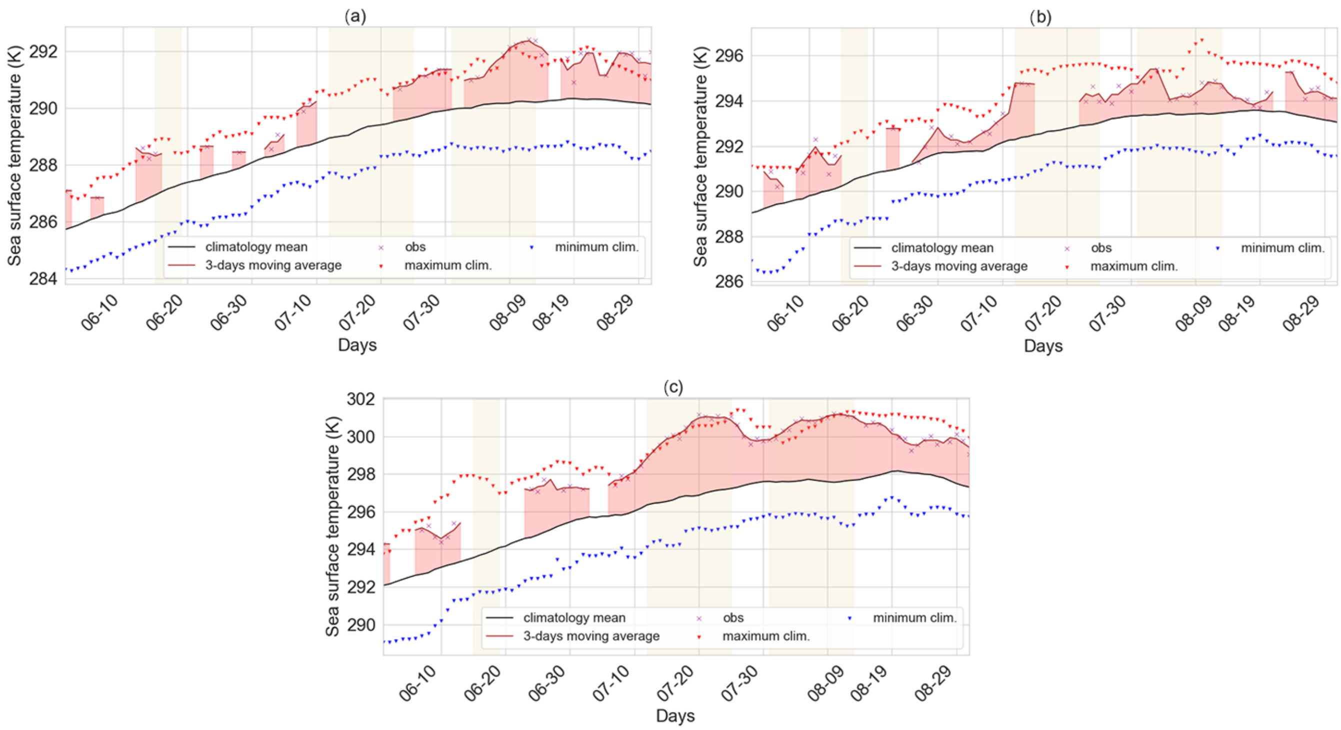

Figure 4. Time series of the summer 2022 daily SSTs measured by METOP-B spatially averaged over the sub-basin: a) EC, b) BB and c) NWM. Atmospheric heatwaves periods are represented with yellow shading. Brown line is representative of the 3-day SST moving average and compared to the 1982-2011 ESA-CCI climatological mean (black line).

31th of July and the 11th of August (among these the basin experienced 9 continuous days with an average anomaly over 3°CC during). The ocean surfaces are therefore anomalously warm throughout the summer. This is also highlighted by the variability which was kept between 0.5°C and 0.8°C revealing that, with the exception of specific episodes, SSTs remain in the same order of magnitude and stay close to the climatological maximum.

One can say less about the daily variability of the SSTs as this is dependent on the data availability. However, the response of the NWM on a daily timescale is evident during both July and August heatwaves.

4.2 Response to the 2022 August heatwave

This section is focusing on the August heatwave as it is less affected by the low data availability and all three basins can be analysed. The August heatwave started on 31 July 2022 and ended on 13 August 2022. During this period, SSTs were abnormally high with temperatures constantly above the climatological norm (Table 4). The table A1 presents the spatial average and the maximum value for both SSTs and anomalies for each basin during the August 2022 heatwave. The mean SSTs by

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Table 1. Nighttime SST analysis over the 01 June to 31 August 2022 period. Mean values hereafter refers to spatially averaged data. Maximum represents the highest daily spatially averaged value over the 2022 meteorological summer.

Sub-regions	Mean SST (°C)	Max. SST (°C)	Standard deviation (°C)	Max. anomaly (°C)	Mean anomaly (°C)	Anomaly standard deviation (°C)
EC	17.6	18.7	1.6	2.2	1.4	0.5
BB	20.3	21.8	1.1	2.4	1.3	0.6
NWM	26.1	28.3	1.9	4.3	2.6	0.8

basin average (standard deviation inside the brackets) over this period were respectively 18.7°C (0.57°C), 21.4°C (0.48°C) and 27.6°C (0.46°C) for the EC, BB and NWM while the maximum SSTs on average were respectively 19.4°C, 22.2°C and 28.4°C. This is reflected by warmer than the average surface water compared to the 1982-2011 period. As a matter of fact, mean SST anomalies were respectively 1.7°C (EC), 1.2°C (BB) and 3.1°C (NWM). Positive temperature anomalies were found throughout the majority of the ocean surface and the trend of increase is spatially uniform (Figure 5). 98% of the EC and 90% of the BB extent endured warmer than average SSTs while 100% of the North-western Mediterranean sea was warmer than the climatology during this event. Looking at individual value within each basin is also representative of the local response of such phenomenon. For example, the maximum temperature reached 30.8°C in the NWM basin on the 4th of August 2022. In terms of anomalies, the minimal anomaly measured in the NWM during the event was of 2.2°C and the maximum one of 7.9°C. This reveals the extensive response of the basin but also the range of SSTs variability.

As mentioned in the section 4.1, SSTs were already abnormally warm before the August event. In order to identify the unique contribution of the heatwave and prevent from any bias, the anomalies were debiased by subtracting the anomalies of the previous week (Figure 6). The bias-corrected anomalies show that the impact was pronounced in the English Channel , with an increase of 70% of the mean anomaly in a week (0.7°C) while the Mediterranean basin saw a weaker response of only 15% (0.4°C). The BC basin responded firstly by a warming of the SSTs then a sharp decline of 1.4°C between the 3rd and the 5th of August. The SSTs stayed steady until the 9th of August before starting to increase again. This impacted the response of the BB with an increase of only 20% (0.2°C) compared to the previous week.

4.3 Contribution of atmospheric/oceanic variables

In this section, the contribution of atmospheric and oceanic variables to the peristence of abnormal sea surface temperature is analysed. As presented in the section 3.2, the atmospheric variables are derived from the ERA5 reanalysis.
The heat wave in August 2022 occurred in an atmosphere that was already excessively energetic with a solar radiation anomaly stronger than the August 1991-2020 climatology (Figure 7a). Apart from the extreme South East of France, most of the area experienced mean anomalies over 50 W.m^{-2} (reaching 85 W.m^{-2} in South Brittany). This anomaly is significantly correlated

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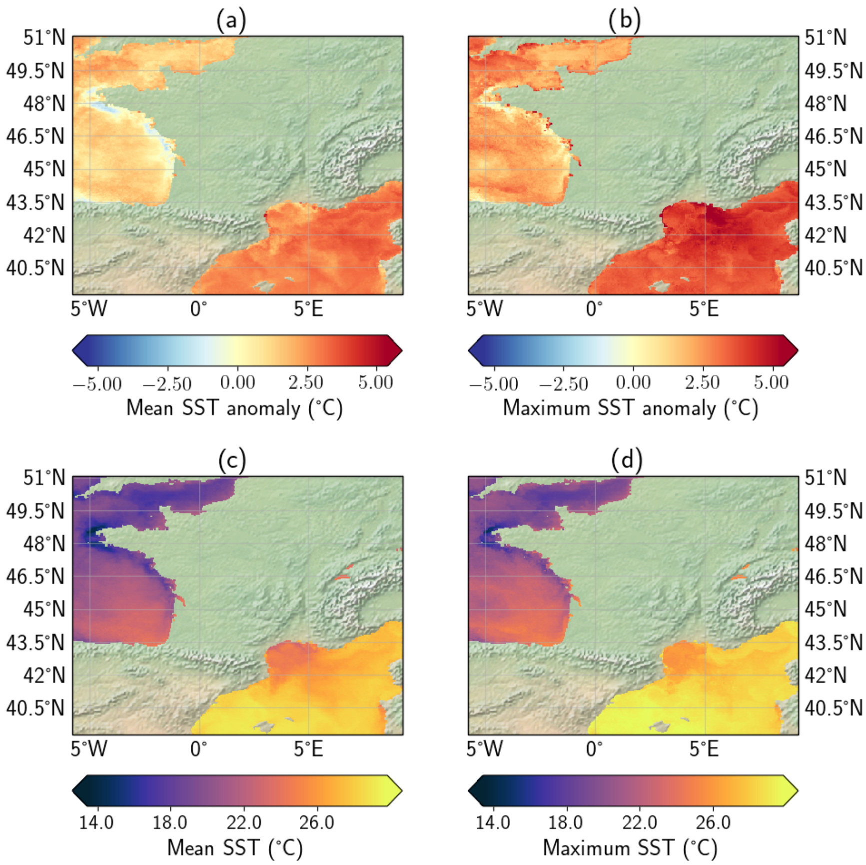

Figure 5. Response of the SSTs to the 31 July 2022 - 13 August 2022 heatwave: a) Mean SST anomaly , b) Maximum SST anomaly, c) Mean SST values and d) Maximum SST values. Anomalies are relative to the 1982-2011 average.

with the total cloud cover anomaly (Pearson correlation coefficient of 0.90). The mean anomaly over the whole domain reaches -17% while the North of France and specifically Brittany have undergone the maximum average anomaly of -37%.

As for the mean wind, two zones stand out (Figure 7b). On the one hand, the BB zone experienced stronger surface wind speed on its basin (with a maximum average anomaly of 1.9 $m.s^{-1}$ during the heatwave events) compared to the August 1991-2020 average. In addition to this, the average direction of the episode was oriented in a north-easterly flow, which accentuated the mixing and thus the upwelling phenomenon on the coast. This mixing with colder deep waters accentuates the cooling of the surface waters (-1 °C between on the 12th and the 19th), which may explain the drop in SST in the basin from 10-11 July.

On the other hand, the Gulf of Lions experienced a negative surface wind speed anomaly (with a minimum average anomaly of -3.7 $m.s^{-1}$ during the heatwave events) due to a significant absence of the Mistral, oriented in a north flow, and Tramontane, oriented in a north-westerly flow, which are the main drivers of the Mediterranean turbulent mixing in the Gulf of Lions. In addition to the lack of turbulent mixing, absence of wind results a reduced contribution of turbulent latent energy flux as ocean

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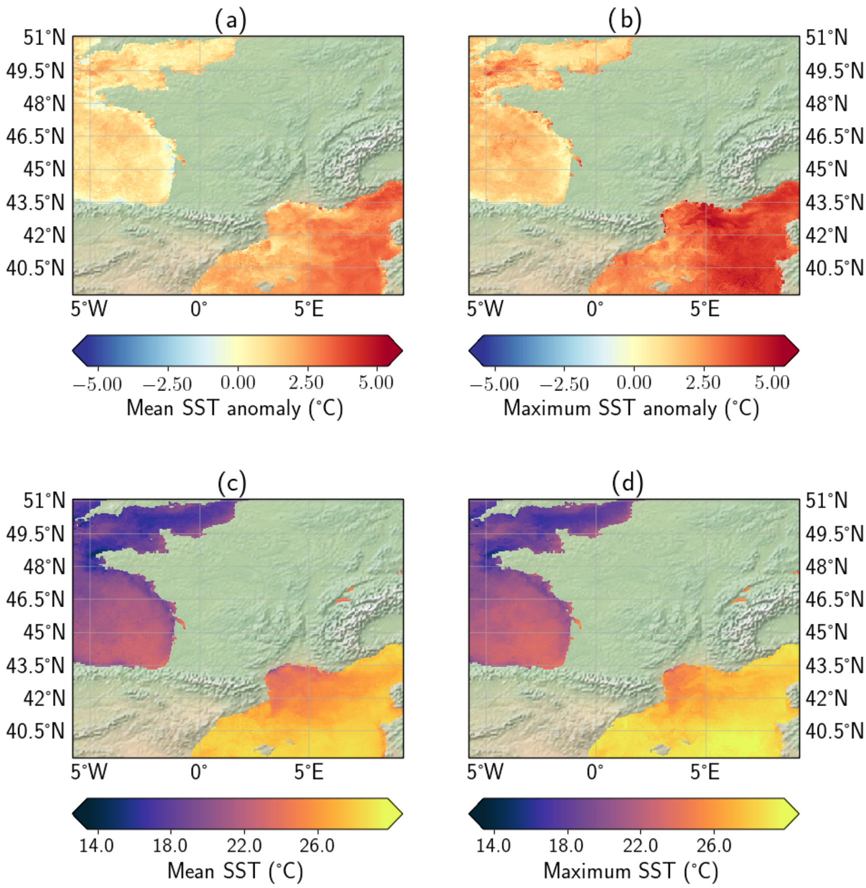

Figure 6. Same as figure 5 for the period 23th - 30th July.

energy sinks.

Results for the EC are more complex to interpret because of the dynamical response to the horizontal advection initiated by the tides. From the 10th-11th of August, the EC has been subject to high tides which initiated a effective turbulent mixing, thus a decrease in the SSTs.

5 Discussion/Conclusions

In this study, we investigated the response of sea surface temperatures to the anomalous warm summer 2022 over France using the OSI SAF satellite SST products. Accuracy of such products had been proved to be sufficient in an operational framework (O'Carroll et al., 2012). We also assessed whether some of the main components influencing the ocean energy balance could explain these anomalies (Equation B1). To our knowledge, this is one of the first study to examine the thermal response using only near-real time products at a country scale and by integrating sub-basins with distinct characteristics (English Channel,

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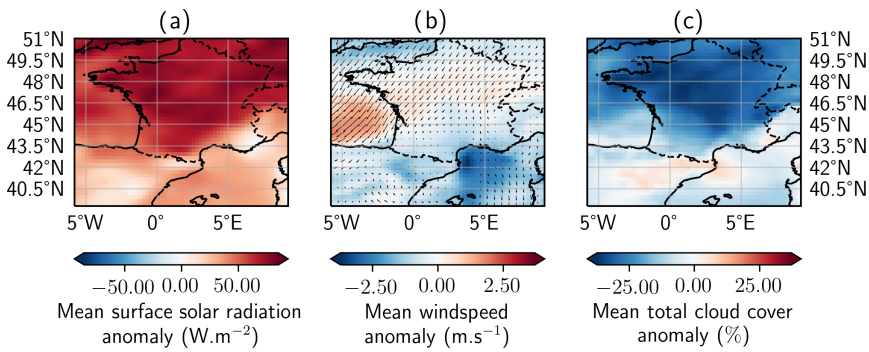

Figure 7. Atmospheric variables conditions during the August 2022 heatwave; a) surface solar radiation anomaly, b) 10-m wind speed anomaly over France. Anomalies are compared to the 1991-2020 climatology. Data originate from ERA5 reanalysis.

Bay of Biscaye and North-Western Mediterranean Sea). In comparison, Olita et al. (2007) studied the contribution of the 2003 heatwave on the Mediterranean sea SSTs using both satellite observations and a 3-D ocean model which needs computation costs that are limited and can be incompatible with the operational framework of monitoring SSTs. Kodaira et al. (2020) used a mix of SST satellite, Argo floats and cruise data to assess the Arctic sea ice decrease and warming SST in response to an atmospheric blocking episode. Although, most of the related studies investigated the warmer than average SST feedback on atmospheric temperatures (Feudale and Shukla, 2011; Duchez et al., 2016) or assess the occurrence of marine heatwaves (Chen et al., 2014; Darmaraki et al., 2019a).

Despite a significant lack of data, especially in early summer and for the EC area, we found a distinct warming signal of the SST in response to the atmospheric heatwaves that affected France during the 2022 summer. The strongest response was found on the NWM basin (with a maximum average SST anomaly of 4.3°C) which is in line with observations (Bensoussan et al., 2019) and modeled evolution (Darmaraki et al., 2019b) confirming the Mediterranean Sea is a "hotspot" for climate change (Giorgi, 2006).

Atmospheric blockages have been shown to influence the multi-decadal variability of the North Atlantic (Häkkinen et al., 2011). Here, we show that, in addition to atmospheric blockages, more dynamic phenomena, such as heatwaves initiated by cold drops off the Iberian Peninsula resulting from a static meander of the jet stream ("omega" atmospheric blocking system), can contribute to the variability of SST. Thus, in situations when there is an excess of solar radiation and a lack of cloud coverage, the increase in SSTs is modulated by regional effects such as wind anomalies that drive the turbulent mixing of surface waters. In such situation, a thermal stratification occurs, making impossible any exchange with the colder deep waters. This effect is clearly visible as the Mediterranean is not subject to tides, unlike the English Channel where tides impact the SSTs as seen in the Ushant Front (Chevallier et al., 2014; Karagiorgos et al., 2020). In such areas, the possibilities of mixing is limited and the SST warming is enhanced. However, some driving factors of the upper-ocean heat budget such as the turbulent heat

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flux, the vertical advection or the surface currents were not analysed in this study. A model analysis integrating the various possible drivers influencing the upper-ocean heat budget would help to prove the causality and found any other process or covariance that might influence the SSTs tendency. We found that SSTs responded to extensive and persistant heatwaves in July and August, however the response to shorter events like the one in June could not be studied.

Developing such operational framework to measure daily SSTs might have several implications for monitoring essential oceanic variables and for ensuring a sustainable oceanic environment. Among them monitoring marine heatwaves (MHWs) and investigating their occurrence and impacts is one of the most straightforward outcomes of studying SSTs variability (Oliver et al., 2021). These events have doubled in the last 30 years and are projected to increase both in term of frequency and intensity in the future (Frölicher et al., 2018). As seen in this study for summer 2022, MHWs are recurrent in the Mediterranean Sea (18 days in July 2022 and 12 days in August 2022 with SSTs close or over the maximum climatology) in recent years and it remains one of the main impacted area with projected MHWs that will be 4 times more intense and 42 times more severe than current events (Darmaraki et al., 2019b).
These trends are not consequence-free. They drive fundamental, irreversible modification of marine ecosystems and all the ecosystem services provided to society (Smith et al., 2021, 2022). More generally, SSTs variability impacts biological variables such as Chlorophyll-a, main tracer of primary productivity (Behrenfeld et al., 2006; Dunstan et al., 2018). As such, extreme MHWs events like the "Blob" in the North-Eastern Pacific in 2013-2015 have had disastrous consequences on the fauna and flora of the ocean, but also on the ocean primary productivity (Cavole et al., 2016). Daily monitoring of SSTs, as proxy, would, thus, be crucial to understand and forecast changes in biological responses at regional and global scale (Doney et al., 2012). Among them the detection of harmful algal blooms that might endangered several coastal zone, shifts in community organisation (from temperate to tropical species) and prevention in mass mortalities of endemic species (Garrabou et al., 2022; Smith et al., 2022).

The main limitations of such approach is its sensitivity to missing data due mainly to cloud cover or atmospheric dust aerosols. To prevent the detection of anomalously warm SSTs, we could have used some combined products such as OSTIA (Donlon et al., 2012) which produce gap-free global SST data. However these data are generally interpolated and thus might end up hiding some specific trends or introducing biases in the SSTs analysis (Stobart et al., 2015). A possible way of improvements would be to combine these satellite observations to specific-model developed to detect large-scale anomalously warm SSTs based on the approach of Hobday et al. (2016). Currently the detection model is unidimensional and developments of a simple dynamical two-dimensional model would helps to track water temperature anomalies in the upper-ocean layer and to understand temperatures feedbacks within the mixed layer. More generally, development activities must pursue with the implementation of models capable of assimilating these observations and integrate dedicated physical/biogeochemical processes will accentuate both the precision and the reliability of this monitoring. This will provide a more general view of the processes and feedbacks involved, but also access to the responses of the surface layer of the ocean where there is a systematic gap in observations.

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One of the levers for improvement should also come from an evolution of observation techniques. In this study, only data from the polar-orbiting satellite Metop-B were used. It will be judicious to use a consistent synergy between polar orbiting satellites and geostationary satellites in order to obtain a significant gain for the monitoring of SSTs (Vanhellemont et al., 2014; Minnett et al., 2019). Indeed, geostationary satellites, because of their temporal resolution, ensure a systematic monitoring of surfaces but are limited in their contribution by their spatial resolution. Also, the new generation of meteorological satellites with Meteosat Third Generation and Metop-SG will ensure a more precise monitoring in time and space with interesting nominal resolutions to locate systems with smaller characteristic lengths while being able to monitor larger scale systems with ideal temporal resolutions for operational purposes (Holmlund et al., 2021). This study focused on the 2022 meteorological summer which should not hide the fact that the meteorological situation in France is still abnormal with continuous surface air temperature over long-term average. This situation have major implications on the Mediterranean Sea and a more systematic study of the response of the whole Mediterranean basin, including September, would help to assess the implications of persisting atmospheric heatwaves.

All this confirms the need to work on SST operational products such as the one developed within the OSI SAF project and to contribute to new products such as ocean color in the view of application frameworks linked to the fields of biogeochemistry and physics and to prevent deep alterations that threaten the oceans in the context of climate change.

Code and data availability. All post-processing codes are available on Zenodo in the following repository: https://10.5281/zenodo.7194099 (Guinaldo, 2022).

Data used in this study are open-source and freely available. OSI SAF L3b can be found here: https://osi-saf.eumetsat.int/products/osi-201-b. ERA5 reanalysis can be found here: https://cds.climate.copernicus.eu/. ESA-CCI SST product can be found here: https://catalogue.ceda.ac.uk/uuid/62c0f97b1eac4e0197a674870afe1ee6. All these data were accessible on the date of the manuscript submission.

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Appendix A: SST statistics over each studied basin

Table A1. Nighttime average SST analysis over the 31th July - 13th August 2022 period. Mean values hereafter refers to spatially averaged data. Maximum represents the highest daily spatially averaged value over the time period.

Sub-regions	Mean SST (σ) (°C)	Mean SST anomaly (°C)	Max. anomaly (°C)	Max. SST (°C)	Bias-corrected SST anomaly [a] (°C)
EC	18.7 (0.57)	1.7	2.5	19.4	0.65
BB	21.4 (0.48)	1.2	2.02	22.2	0.15
NWM	27.6 (0.46)	3.1	3.9	28.4	0.43

[a] bias corrected SST anomaly correspond to the difference between the mean anomaly calculated during the August 2022 heatwave and the one calculated during the week before

Appendix B: Upper-ocean energy balance

Several processes are key drivers of the SSTs variability, among them one can mentions horizontal and mixing or net surface heat flux. A mathematical approach of the upper-ocean layer heat budget had been detailed by Moisan and Niiler (1998) as follows upon the hypothesis of the fluid incompressibility and the Boussinesq approximations:

$$\frac{\partial T_m}{\partial t} = \underbrace{-\bar{\mathbf{u}}\nabla T_m}_{A} + \underbrace{\kappa_h \Delta T_m}_{B} - \underbrace{\frac{1}{H}\left[\kappa_v \frac{\partial T}{\partial z}\right]_{-h}}_{C} - \underbrace{\left(\frac{T_m - T_{-h}}{H}\right)\left[\frac{\partial h}{\partial t} + \mathbf{u}_{-h}\nabla h + \omega_{-h}\right]}_{D} + \underbrace{\frac{q_{rad} + q_{turb}}{\rho_0 c_p H}}_{E} \qquad \text{(B1)}$$

where T_m, H, ρ_0 and c_p are respectively the mean temperature, the depth, the mean density and the specific heat capacity of the surface mixed layer, $\mathbf{u}$ is the 2-D horizontal vector and ω is the vertical velocity vector. κ_h and κ_v are respectively the horizontal and vertical diffusivity coefficients. q_{rad} is the net radiative flux and q_{turb} is the net turbulent flux. The mention $-h$ refers to the bottom of the mixed layer as the vertical axes is oriented in the direction ocean surface to the atmosphere.

This equation helps to understand the contribution of each component. The SST tendency is dependent on the horizontal advection (A), the horizontal (B) and vertical (C) mixing, the entrainment (D) and the ocean-atmopshere interface heat flux (E). One can notice the contribution of the solar shortwave radiation (through component E) and the windspeed (component B and C) on the SSTs evolution.

Author contributions. TG, SS and HR designed the study, TG carried it out. TG developed the code and performed the analysis. TG wrote the manuscript with contributions from SS. All co-authors discussions and revisions of the manuscript.

Competing interests. The authors declare that they have no conflict of interest

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