Marine Heatwave Study Based on Copernicus OSTIA L4 Satellite-Derived Sea Surface Temperature and GIS Analysis in the Arafura Sea (1982–2024)

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Abstract: *Atmosphere and ocean interactions have driven notable increases in sea surface temperature (SST) across the Arafura Sea, resulting in frequent and prolonged marine heatwaves (MHWs). Using Copernicus OSTIA L4 SST (1982–2024) and a GIS-based analysis, we applied the Hobday et al. (2016) hierarchical detection algorithm to characterize temporal and spatial MHW patterns. We identified 65 distinct MHW events totaling 2,325 MHW-days over 1982–2024. The 2022 period exhibited the most extreme warming at 18 February–29 November 2022 (285 days) with a worst segment of 7 September–29 November 2022 (84 days), average intensity 1.43 °C and maximum anomaly 2.26 °C. Spatially, MHW frequency and duration peaked in the central–northern Arafura Sea, while coastal shallow waters showed the highest instantaneous intensities (up to 2–3 °C). Our driver analysis for the 2022 event indicates a synergy of positive net surface heat flux anomalies, enhanced shortwave radiation, negative OLR anomalies (reduced cloudiness), and weak winds / reduced latent heat flux, favoring surface heat accumulation. These results confirm an intensifying MHW trend in the region and highlight the urgent need for integrated monitoring and ecosystem-based adaptation to protect fisheries and coral ecosystems.*

Keywords: Marine Heatwaves, Arafura Sea, Remote Sensing, Sea Surface Temperature, Geospatial Analysis

Introduction

Global climate change has triggered a significant increase in sea surface temperature. According to the World Meteorological Organization data, waters around the Arafura, Banda, and Timor Seas experience warming rates 2-3 times higher than the global average. Marine heatwaves (MHWs) are phenomena of sea temperature that drastically exceed normal threshold limits.MHWs are quantitatively defined by SSTs exceeding certain thresholds, typically the 90th or 99th percentile of a probability density function (Attaqwa *et al.,* 2025). MHWs have become a serious concern due to their significant impacts on marine ecosystems and the socio-economic conditions of coastal communities. Marine heatwaves, which typically last 1-6 months, are projected to increase in duration to 11-12 months by 2050 (Oliver *et al.,* 2018). while the Arafura Sea as a strategic water body in the Indo-Pacific climate system faces serious threats from these changes that impact coastal ecosystems and national fisheries.

Intense marine heatwaves have been observed in Indonesian waters over the past 40 years (1982-2021), however comprehensive studies integrating Copernicus OSTIA L4 satellite data with spatio-temporal analysis using GIS for the Arafura Sea region remain limited. The OSTIA dataset with high resolution (1/20° or approximately 6 km) provides accurate daily sea surface temperature analysis for monitoring global ocean changes, yet the utilization of this data to analyze MHW characteristics in the Arafura Sea over the long period (1982-2024) has not been conducted comprehensively.

1.1 Literature Review

Research on marine heatwaves (MHWs) in Indonesia has been growing over the past few years, focusing on different coastal and marine regions. Beliyana *et al*. (2022) studied MHWs in the Savu Sea, East Nusa Tenggara, during 2008–2021 and found an average of two events per year with intensities of around 1.4–1.6°C, mainly influenced by net surface heat flux and weak wind conditions. In the Spermonde Islands, South Sulawesi, Gunawan *et al*. (2022) reported about three events per year with intensities ranging from 0.9–1.5°C, strongly linked to ENSO events, especially in 2016. Looking at a broader scale, Habibullah *et al*. (2023) analyzed MHWs across 11 Indonesian Fisheries Management Areas between 1982 and 2020, revealing a 93% increase in frequency, with the strongest events occurring during the decay phase of El Niño. Meanwhile, Iskandar *et al*. (2021) highlighted two major MHW events off South Java in 1998 (173 days) and 2016 (298 days), both tied to strong El Niño episodes and weakened monsoon activity. Similarly, Ningsih *et al.* (2023) examined the Makassar Strait and surrounding waters from 1982 to 2021, showing increasing trends in frequency and duration but decreasing intensity, with a 7–9 month lag between ENSO events and the onset of MHWs.

On a global scale, Oliver *et al*. (2018) analyzed records from 1925–2016 and found that MHWs have become longer and more frequent, with a 34% rise in frequency, 17% longer duration, and 54% more MHW days per year. These changes are strongly linked to rising average ocean temperatures, pointing to further intensification under climate change. In a later work, Oliver *et al*. (2021) reviewed how MHWs are defined, detected, and studied, emphasizing the role of air heat flux, ocean circulation, and large-scale climate variability, while also stressing the need for consistent frameworks and clear communication in a warming world. Supporting this, Hobday *et al*. (2016) introduced a hierarchical definition of MHWs based on a standard threshold of at least five consecutive days above the 90th percentile of a 30-year baseline, which has since become widely adopted. Holbrook *et al*. (2020) further discussed the drivers, monitoring, and prediction of MHWs, underlining the importance of better forecasting systems and integrated physical ecological approaches to support proactive management under climate risks. Beyond physical drivers, the biological impacts of MHWs are also a major concern. Smith *et al*. (2023) reviewed these effects across multiple levels, from physiological stress in individuals to shifts in populations, communities, and ecosystem services. Their work highlights how MHWs threaten biodiversity and human livelihoods, calling for stronger predictive tools and adaptive management strategies.

Methodology

2.1 Research Area

This research was conducted in the Savu Sea, located between Timor Island, Alor Island, East Nusa Tenggara Island, Sumba Island, Savu Island and Rote Island, as shown in Figure 1. The research location is within the coordinates -08° 00’ 00’’ S to -11° 00’ 00’’ S and 120° 00’ 00’’ E to 125° 00’ 00’’ E. The area is shallow (<80 m), dynamically connected to the Indo-Pacific and sensitive to surface warming. The analysis covers the period 1982–2024, during which marine heatwave events were identified and characterized. The Savu Sea was selected as the study area because it recorded the worst marine heatwave in 43 years, occurring in 2022.

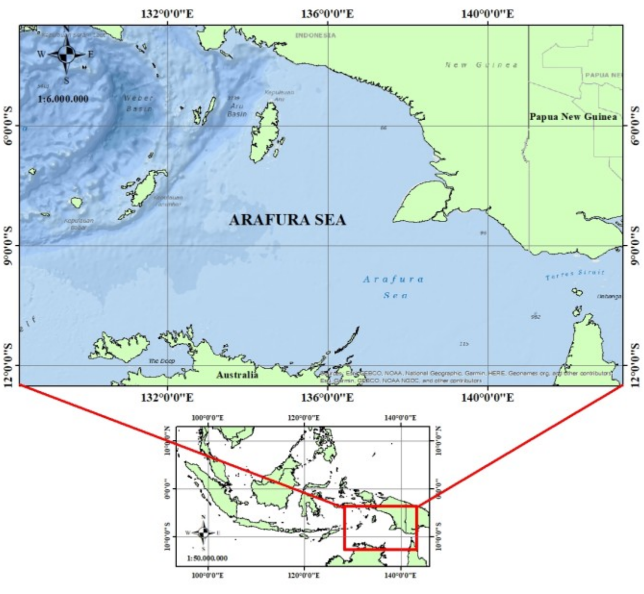

Figure 1: Research Location Map

2.2 Marine Heatwaves Detection

This study employed daily sea surface temperature (SST) data from the Copernicus OSTIA L4 Satellite-Derived SST with a spatial resolution of 0.05° × 0.05°, covering the period

1982–2024 in the Arafura Sea. The dataset for 1982–2021 was obtained from the Copernicus product SST_GLO_SST_L4_REP_OBSERVATIONS_010_011, while the dataset for 2022–2024 was obtained from SST_GLO_SST_L4_NRT_OBSERVATIONS_010_001. The data were processed to derive daily mean SST, seasonal climatology, and the threshold for MHW detection. The identification of MHWs followed the hierarchical framework proposed by Hobday *et al*. (2016), enabling the calculation of key metrics such as frequency, duration, mean intensity, and cumulative intensity. The metrics considered are annual frequency, defined as the number of events per year, annual duration, measured as the total number of days an event persists within a year, and cumulative intensity, expressed as the sum of SST anomalies over the course of each event. The marine heatwaves analyst was calculated using the following equation:

$$i_{max} = \max\,(T(t) - T_m(j))$$
$$i_{mean} = T(t) - T_m(j)$$
$$i_{var} = \sigma_{T(t)}$$
$$Where\ t_s \leq t \leq t_e,$$
$$j(t_s) \leq j \leq j(t_e),$$

σ is the standard deviation and the overbar indicates the time mean.

Climatological SST was computed following the method of Azuga and Radjawane (2022). The MHW threshold was set at the 90th percentile of daily SST based on a 30-year baseline period. An event was classified as an MHW when SST exceeded this threshold for at least five consecutive days. Furthermore, GIS analysis was applied to examine the spatial distribution and variability of MHWs in the Arafura Sea.

2.3 Net Surface Heatflux

Net surface heat flux represents the total heat exchange between the atmosphere and the ocean, playing a crucial role in air–sea interactions and the overall climate system (Tomita *et al*., 2021). It indicates how much heat is absorbed or released by the ocean atmosphere system at a given time. In this study, the calculation of net surface heat flux is based on four key components: shortwave radiation (QSWR), longwave radiation (QLWR), sensible heat flux (QSHF), and latent heat flux (QLHF). These datasets were obtained from the ERA5 radiation and heat products, available at https://cds.climate.copernicus.eu/datasets/reanalysis-era5-single-levels?tab=download. The net heat flux was calculated using the following equation:

$$\text{Net heat flux} = Q_{SWR} + Q_{LWR} + Q_{LHF} + Q_{SHF}$$

Description:

Q_{SWR} = short wave radiation

Q_{LWR} = long wave thermal radiation

Q_{LHF} = sensible heat flux

Q_{SHF} = latent heat flux

This formulation reflects the balance between incoming and outgoing heat in the ocean–atmosphere system. Spatial analysis of each component, as well as the net heat flux, was performed for the Arafura Sea during the most severe marine heatwave (MHW) events, with results presented in spatial map visualizations supported by descriptive statistics.

2.4 Outgoing Longwave Radiation

Outgoing Longwave Radiation (OLR) refers to the thermal radiation emitted from the Earth's surface and atmosphere into outer space at the top of the atmosphere (TOA) (Dewitte and Clerbaux, 2018). The OLR index is widely used to assess atmospheric variability by quantifying the energy radiated from land, ocean, and the atmosphere. In this study, OLR data were obtained from the HIRS (High-resolution Infrared Radiation Sounder) instrument aboard NOAA satellites, which provide global coverage with a spatial resolution of 2.5° × 2.5° (https://www.ncei.noaa.gov/thredds/catalog/cdr/olr-daily/catalog.html). The dataset was extracted for the Arafura Sea and used to examine the link between OLR anomalies and extreme marine heatwave (MHW) events, particularly the record-breaking event in 2022. Negative OLR anomalies can indicate reduced cloud cover, creating atmospheric conditions that enhance the likelihood of MHWs. Therefore, OLR analysis offers valuable insights into the atmospheric dynamics that influence the development and persistence of extreme marine events (Benthuyzen *et al.*, 2021). OLR anomalies were calculated as follows:

$$OLR_{anom}(t) = OLR_{mean}(t) - OLR_{mean}$$

Where:

$OLR_{anom}(t)$: OLR anomaly at time t

$OLR_{mean}(t)$: spatial mean OLR at time t

OLR_{mean} : temporal mean of OLR over the study period

2.5 Wind Condition

The wind data employed in this study were obtained from the Global Ocean Hourly Reprocessed Sea Surface Wind and Stress product, available through Marine Copernicus (https://data.marine.copernicus.eu/product/WIND_GLO_PHY_L4_MY_012_006/download?dataset=cmems_obs-wind_glo_phy_my_l4_0.125deg_PT1H_202211). The dataset includes eastward (m/s) and northward (m/s) wind components at a horizontal spatial resolution of 0.125°. This product provides sea surface wind fields and stress, derived from a combination of scatterometer measurements (Metop-A, Metop-B, Metop-C ASCAT, QuikSCAT SeaWinds, ERS-1, and ERS-2 SCAT) and ECMWF ERA5 reanalysis. Scatterometer data are used to correct biases in ERA5, thereby reducing systematic errors in the wind field. In this research, wind data were processed to investigate wind patterns during the most severe marine heatwave (MHW) events. Wind speed was calculated using the following equation:

$$V = \sqrt{u^2 + v^2}$$

where V is the wind speed (m/s), u is the eastward wind component, and v is the northward wind component (Wangdiarta *et al.*, 2024). The results are presented as spatial wind maps corresponding to the worst MHW periods.

Results and Discussion

3.1 Temporal and Spatial Analysis of Marine Heatwaves

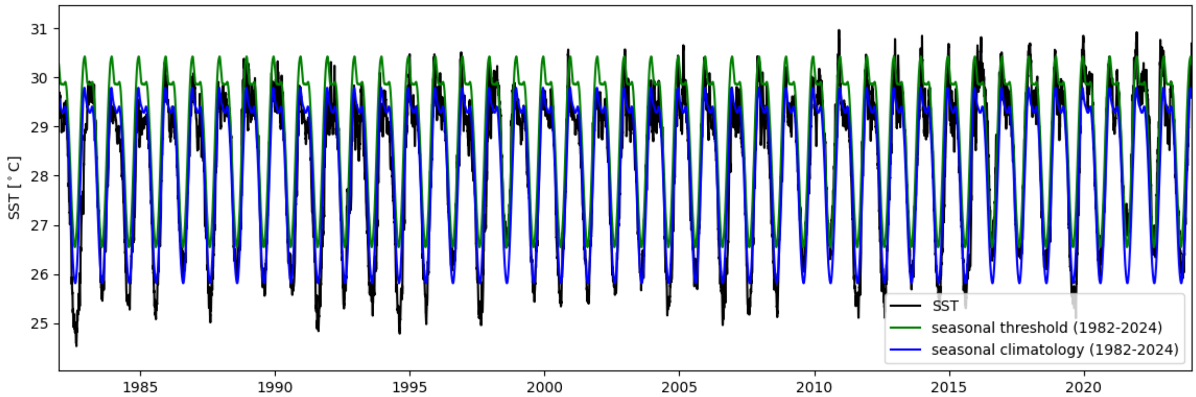

Figure 2: Mean daily SST, Climatology and MHW threshold in the Arafura Sea (1982-2024)

Table 1: Strong MHW Event in the Arafura Sea (1982-2024)

Year	Max Intensity	Avg Intensity	Max Duration (days)	First Start	Last End	Max Category
2005	1.37	1.02	19	2005-02-17	2005-03-07	Strong
2013	1.27	0.92	12	2013-02-07	2014-01-07	Strong
2016	1.78	0.98	146	2016-01-16	2016-11-15	Strong

2021	1.66	0.93	63	2021-03-22	2021-12-26	Strong
2022	2.26	0.98	99	2022-02-18	2022-11-29	Strong

Figure 2, which shows the graph of average daily sea surface temperature (SST) in the Arafura Sea, indicates a consistent upward trend in temperature from year to year. The climatology line shown in the graph serves as a reference for normal temperatures, while the MHW threshold line indicates the temperature limit at which an event can be categorized as a marine heatwave. The MHW threshold has also increased, indicating that the basic climatology of the ocean has changed significantly due to long-term warming. This is reflected in the periods when SST exceeds the threshold, which indicates that MHW events have become more frequent in the last decade. When daily SST exceeds this threshold within a certain period of time, the event is classified as an MHW according to Hobday *et al*. (2016) that MHW can occur when the period exceeds 5 consecutive days and the sea surface temperature must exceed the 90th percentile of daily climatology (usually calculated from 30 years or more of data).

The graph of average sea surface temperature, climatology, and MHW thresholds shows that since the early 2000s, temperatures exceeding the MHW threshold have become more frequent and intense. This indicates an increase in the frequency and duration of MHW, which can be linked to global climate change and ongoing ocean warming. This pattern shows an increasing tendency for MHW to occur in the last two decades. These results are in line with the findings of Oliver *et al*. (2018), which emphasize the global trend of increasing frequency and duration of MHW due to long-term ocean warming. Sea surface temperatures showed a high increase between 2010 and 2015, indicated by the black line, which rose above the MHW threshold and climatology. After that, there was another very high increase in 2022, where the temperature reached above 30 °C. The data shows that the first strong MHW event was recorded in 2005, then repeated in 2013, 2016, 2021, and 2022, with an increasing frequency after 2010. The highest maximum intensity was recorded in 2022 with an anomaly of +2.26 °C above climatology, while 2016 showed an intensity of +1.78 °C with the longest duration reaching 146 days. Both years were very significant extreme periods, and their occurrence coincided with global climate phenomena, particularly El Niño, which is known to amplify MHW events in the tropics.

Table 1 complements the temporal analysis by recording the five strongest MHW events: 2005, 2013, 2016, 2021, and 2022. Each event has different characteristics, both in terms of intensity and duration. The 2016 event had the longest duration, lasting 146 days, while the 2022 event showed the highest maximum intensity, reaching 2.26°C. The consistency of the "Strong" category in all five events indicates that the Arafura Sea periodically experiences MHWs of significant severity. A similar event also occurred in 2021 with a duration of 63 days and a maximum intensity of 1.66°C. This variability confirms that although the long-term trend shows an increase in events, each event is influenced by a combination of different local and regional factors. The emergence of MHW coincides with global climate phenomena, particularly El Niño, which is known to amplify MHW events in tropical regions. Most MHWs in the Arafura Sea begin in early February–March and can last for months, even up to a year. The increase in the frequency, intensity, and duration of MHWs has important ecological and socio-economic implications. Ecologically, MHW can cause damage to marine ecosystems, such as coral bleaching, changes in fish migration patterns, and a decline in primary productivity. From a socio-economic perspective, the Arafura Sea, which is one of Indonesia's main fishing areas, has the potential to experience a decline in fish stocks due to disruption of the marine food chain. This condition has a direct impact on fishermen and coastal communities who depend on marine resources for their livelihoods. MHW can cause damage to marine ecosystems such as coral reefs, disrupt the marine food chain, and impact fisheries, which are a source of livelihood for coastal communities (Smale *et al.*, 2019). Therefore, monitoring and modeling MHW is important for mitigation and adaptation to the impacts of climate change in Indonesia's coastal areas, especially in the Arafura Sea.

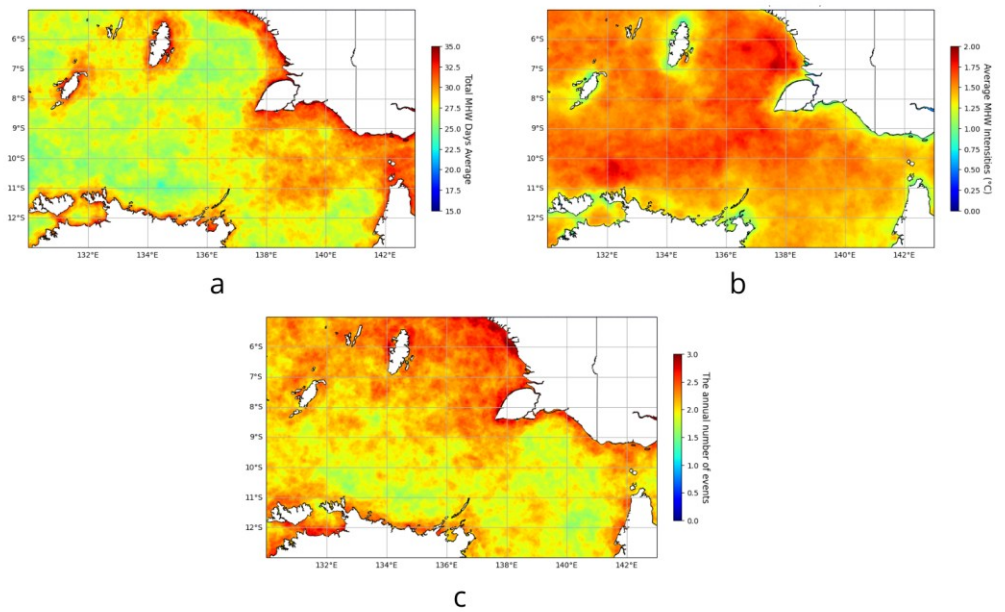

Figure 3(a). Average Daily MHWs, 3(b). Average Frequency of MHWs, 3(c). Average MHWs Intensity

Figure 3 shows the spatial distribution of marine heatwaves (MHWs) in the Arafura Sea based on three parameters: average number of days of occurrence, frequency, and intensity. The analysis results indicate that the central to northern part of the Arafura Sea is the main hotspot, characterized by the highest number of MHW days and frequencies. MHWs last for at least 20 days per year on average across most of the region, and some central and northern areas experience more than 30 days per year, as highlighted by the circled regions. This pattern indicates that these areas are more prone to prolonged and recurrent MHW events, reflecting higher levels of oceanic thermal stress. Generally, two MHW events occur annually in most parts of the Arafura Sea, while certain hotspot regions experience three or more events per year. The relationship between these two parameters, duration and frequency, shows a strong negative correlation (approximately –1), which implies that regions with more frequent events tend to have shorter average durations, consistent with Oliver *et al*. (2018).

In terms of intensity, average warming during MHW events reaches +2 °C or more in several offshore regions, particularly in the central and northern Arafura Sea. Conversely, coastal areas show lower temperature anomalies, mainly due to shallow and mixed conditions that facilitate heat exchange and reduce accumulation. The highest MHW intensities, ranging between 2.0–3.0 °C, occur near the coast, driven by shallow bathymetry and limited vertical mixing that allow faster surface warming. Consequently, the open northern and central areas are more vulnerable to prolonged and repeated extreme warming, while coastal areas are more affected by higher instantaneous intensities. This heterogeneous pattern of MHW characteristics highlights that the Arafura Sea has varying levels of vulnerability to marine heatwaves, necessitating adaptive management approaches tailored to regional conditions. These findings reinforce the conclusion that the Arafura Sea is a high-risk zone for the impacts of marine climate change, as also suggested by Johnson *et al*. (2023), and underscore the importance of ecosystem-based adaptation to safeguard marine habitats such as coral reefs and seagrass beds.

3.2 Worst MHW Event in the Arafura Sea

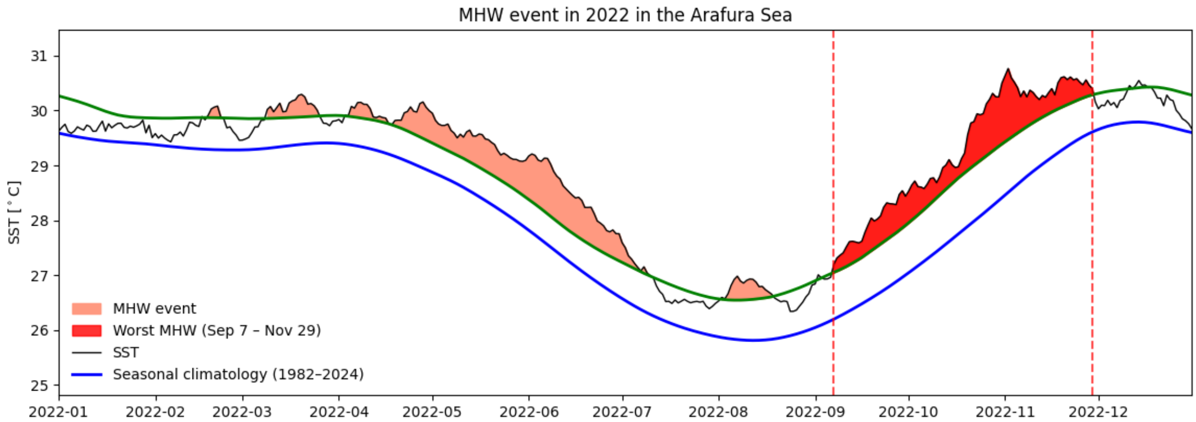

Figure 4: Worst MHW Event in Arafura Sea (2022)

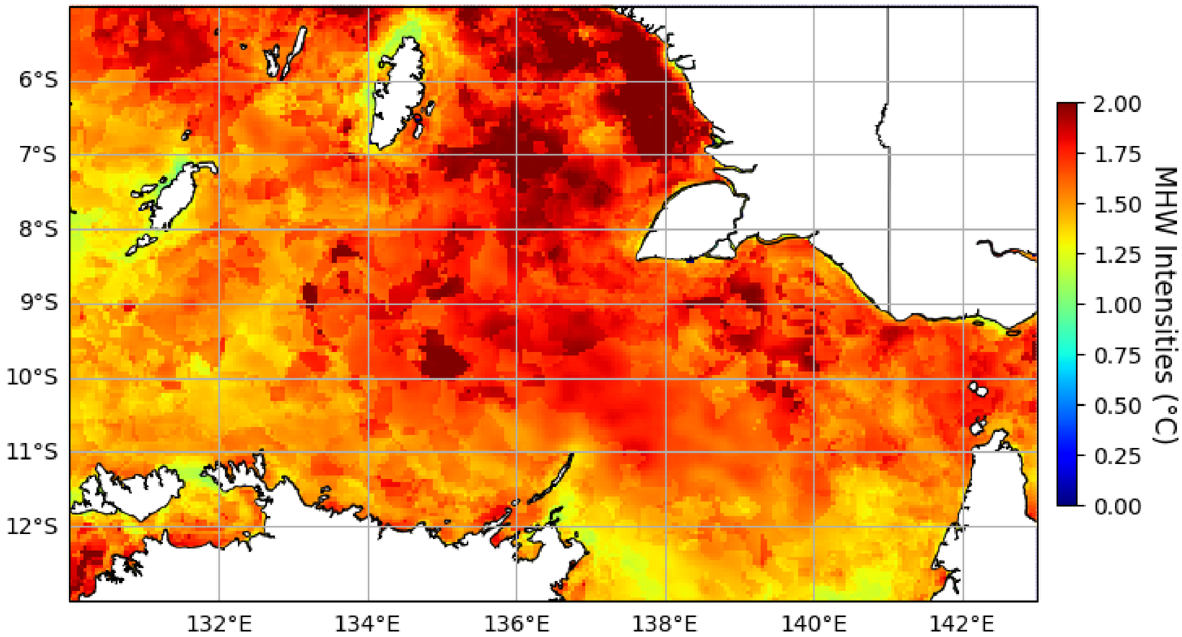

Figure 5: Intensity of Worst MHW Event in 2022

The most extreme MHW event in the Arafura Sea was recorded in 2022, lasting 99 days (18 February – 29 November 2022), with an average intensity of 0.98°C and a maximum intensity of 2.26°C. These characteristics make 2022 the longest and strongest MHW event in the last four decades. This widespread and persistent warming pattern indicates a combination of atmospheric and oceanic factors that are highly conducive to extreme anomalies. Spatially, this event was most evident in the central to northern Arafura Sea, which had previously been identified as an MHW hotspot. The highest warming intensity was found in coastal waters, especially in shallow areas, indicating that sea depth plays a role in amplifying temperature anomalies (Habibullah *et al*., 2023). The long duration and high intensity of the 2022 event have the potential to have a significant impact on marine ecosystems, including an increased risk of coral bleaching and disruption to fisheries productivity. The link between the events of 2022 and global climate factors does not appear to be as strong as in the cases of 1998 or 2016, which were associated with El Niño. This further emphasises that local processes such as weakened winds, reduced latent heat release and accumulation of heat in the ocean surface layer played a key role in making the 2022 MHW in the Arafura Sea particularly severe.

3.3 Correlation of OLR with MHW Event

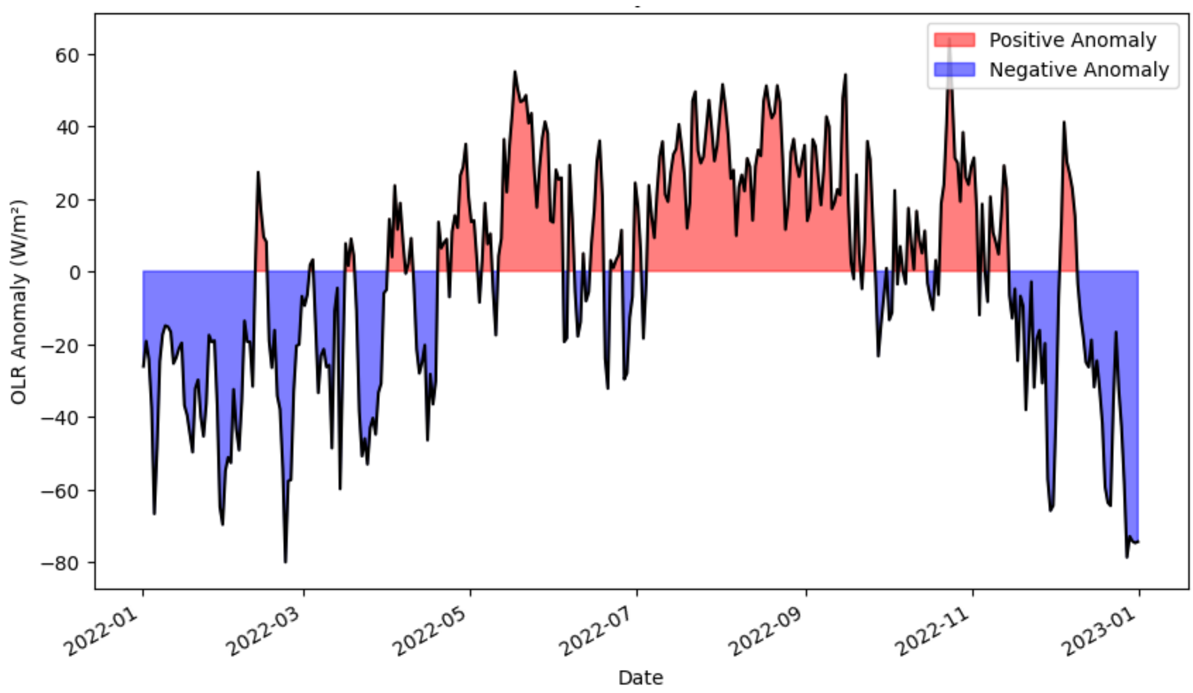

Figure 6: OLR Anomaly Time Series in 2022

The extreme MHW event in 2022 in the Arafura Sea is closely related to the Outgoing Longwave Radiation (OLR) pattern observed during the same period. The OLR anomaly showed a significant negative value over the Arafura Sea, indicating a decrease in longwave radiation released from the sea surface to the atmosphere. Physically, this means that heat release from the sea has decreased, resulting in greater energy accumulation in the surface layer and intensifying ocean warming. In addition, low OLR values are also typically associated with more humid atmospheric conditions and thin clouds, which can inhibit heat release from the ocean. Thus, negative OLR in 2022 played a key role in allowing ocean warming to persist longer and MHW intensity to increase. This is in line with previous studies (e.g. Iskandar *et al.*, 2021; Ningsih *et al.,* 2023) that emphasise the importance of radiation flux anomalies in triggering and prolonging the duration of MHW in the Indonesian region.

3.4 Correlation of Heatflux with MHW Event

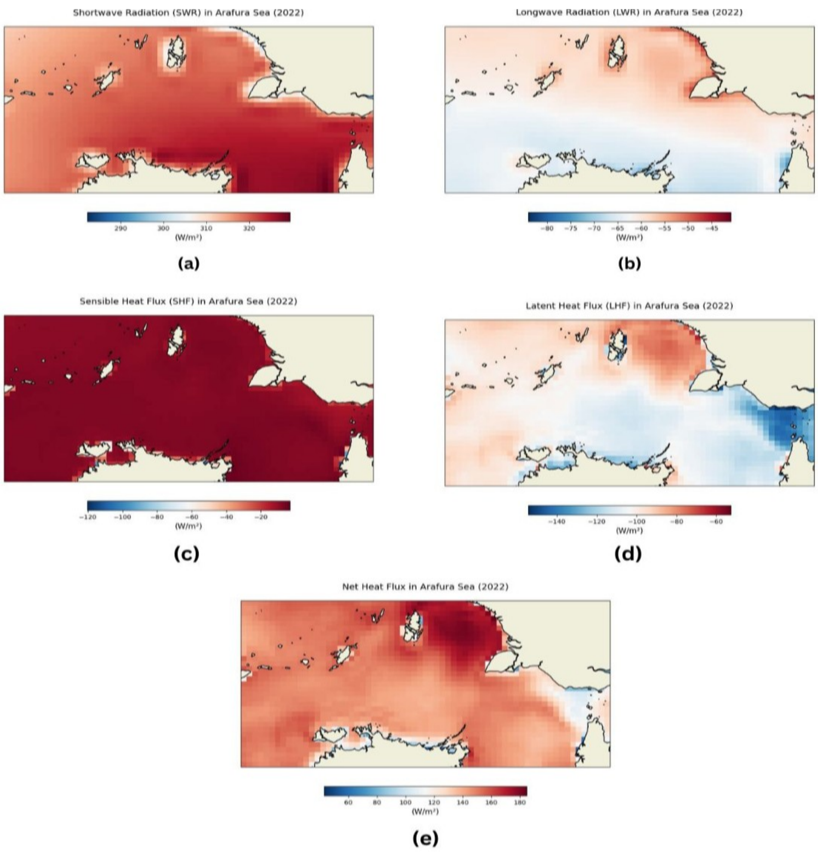

Figure 7(a) shortwave radiation, (b) longwave radiation, (c) sensible heatflux, (d) latent heatflux, (e) net heatflux Conditions in the Arafura Sea During the Worst MHW Event

The most severe MHW event that occurred in the Arafura Sea from September 7 to October 29, 2022 was marked by high sea surface temperature anomalies that lasted for a considerable period of time. Analysis of heat flux components shows that shortwave radiation (SWR) was the dominant factor, with values reaching 290–320 W/m², especially in the central to northern waters. This increase in solar radiation intensity was exacerbated by relatively clear atmospheric conditions, resulting in low cloud cover and easier absorption of heat energy by the ocean. Conversely, longwave radiation (LWR) showed a negative anomaly of around –80 to –40 W/m², indicating a reduction in heat release from the sea to the atmosphere. This condition increased heat accumulation on the sea surface, which played a direct role in strengthening the extreme temperature anomaly during that period.

In addition, the contribution of sensible heat flux (SHF) with values ranging from –120 to –20 W/m² also shows an additional energy input, although its role is smaller than that of SWR. At the same time, the latent heat flux (LHF) has a negative value of around –140 to –40 W/m², reflecting very limited cooling due to evaporation as a result of weak wind speeds in the

Arafura region. The integration of all components results in a high net heat flux (NHF), ranging from 60 to 180 W/m², as seen from the dominance of red color in almost all waters (Figure 9e). This net energy surplus is closely correlated with the intensity and duration of the MHW that occurred throughout September–October 2022. Thus, it can be concluded that the dominance of incoming energy, minimal heat release, and weak atmospheric cooling mechanisms were key factors triggering the worst MHW in the Arafura Sea in 2022.

3.5 Correlation of Wind Conditions with MHW Event

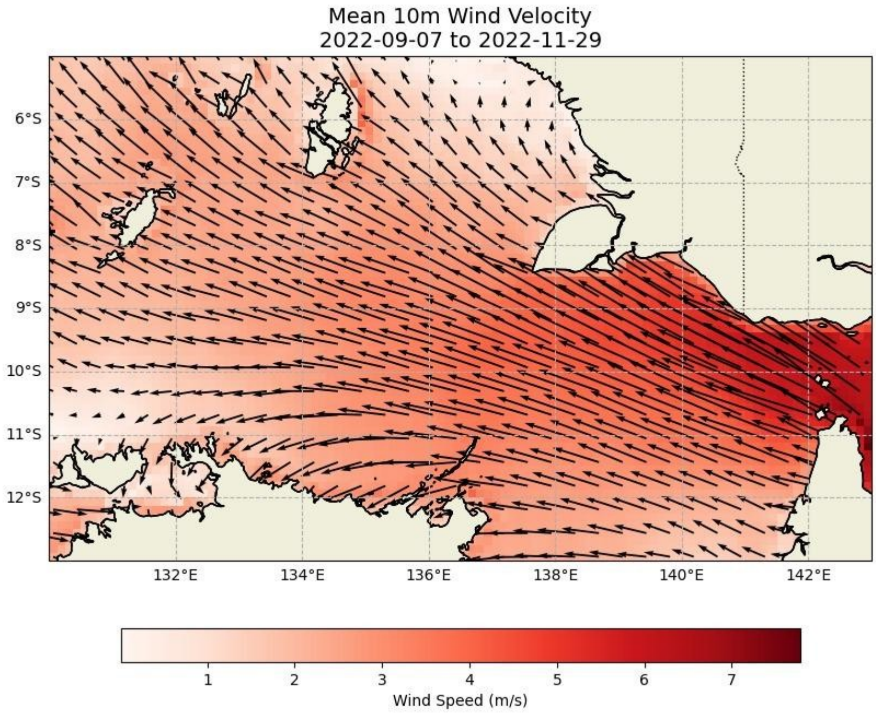

Figure 8. Wind Conditions in Arafura Sea (2022)

The role of wind in regulating latent heat release from the sea can be observed in Figure 10 (Mean 10m Wind Velocity, Sept–Nov 2022). Wind patterns in the Arafura Sea generally blow from the southeast to the northwest, with the highest speeds (>7 m/s) in the eastern part near Papua, while the western part shows lower speeds (2–4 m/s). This pattern is directly related to the distribution of Latent Heat Flux (LHF), which represents the release of latent heat from the sea to the atmosphere. The eastern and southern regions show very negative LHF values (–120 to –140 W/m²), indicating high evaporation due to strong winds. In contrast, the northern region with weak winds only reaches LHF of around –60 to –80 W/m², so that energy release through evaporation is smaller. These conditions indicate that the stronger the wind, the greater the release of latent heat, while weak winds tend to store heat in the sea for longer.

The implication of this pattern is an increased potential for marine heatwaves (MHWs) when winds weaken, as the ocean does not release heat optimally. A notable example was recorded in the Sawu Sea in 2016, when weak winds accompanied by low LHF resulted in the accumulation of ocean heat and triggered an MHW that lasted for 194 days (Attaqwa *et al*., 2025). In addition to wind factors, shortwave and longwave radiation also play an important role in the ocean energy balance. High solar radiation with low LHF accelerates heat energy accumulation, while clear atmospheric conditions with positive OLR values further strengthen ocean warming. Previous studies have also confirmed that a combination of weak winds, low evaporation, and increased radiation can increase atmospheric instability and amplify the intensity of MHWs in Indonesian waters.

Conclusion and Recommendation

This study has revealed the temporal and spatial characteristics of marine heatwaves (MHWs) in the Arafura Sea during the period 1982–2024 using Copernicus OSTIA L4 sea surface temperature data combined with GIS-based spatial analysis. A total of 65 marine heatwave (MHW) events were identified in the Arafura Sea during 1982–2024 based on Copernicus OSTIA L4 SST and GIS-based analysis. The most extreme event occurred in 2022, lasting 84 days with a +2.26 °C anomaly. MHW frequency and duration exhibit a strong negative correlation, where more frequent events tend to be shorter, while less frequent events persist longer. Spatially, the central–northern Arafura Sea is the main hotspot characterized by prolonged and repeated events, while coastal zones show higher peak intensities, reaching up to 2–3 °C due to shallow-water heating and limited mixing. The 2022 extreme event was primarily driven by positive net surface heat flux anomalies, increased shortwave radiation, and negative latent heat flux anomalies under weakened wind conditions, resulting in strong surface heat accumulation and prolonged warming. These findings indicate that MHWs in the Arafura Sea are becoming more frequent, longer, and more intense, underscoring the region's growing vulnerability to marine climate extremes.

To address these emerging risks, several recommendations are proposed. Long-term integrated monitoring should be strengthened by combining satellite and in-situ ocean–atmosphere observations to improve the detection and forecasting of future MHWs. Adaptive marine management is required to incorporate MHW information into fisheries and marine ecosystem management to minimize ecological and socioeconomic impacts. Ecosystem-based adaptation, including the conservation and restoration of coral reefs and seagrass meadows, must be prioritized to enhance natural resilience. Further research should expand the analysis to additional parameters such as chlorophyll-a, dissolved oxygen, and ocean current dynamics to improve understanding of both biological and physical responses to MHWs. Lastly, regional early-warning systems and marine policy frameworks should be developed to support sustainable marine resource management and strengthen coastal community preparedness against extreme warming events. Overall, this study reinforces the urgent need for long-term monitoring and adaptive marine management to safeguard the Arafura Sea's ecosystems and dependent communities from the escalating effects of marine heatwaves.

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