RESEARCH PAPER

CENDERAWASIH HOT POOL: THE FREQUENT HIGH SEA SURFACE TEMPERATURE PHENOMENA AT CENDERAWASIH BAY, PAPUA

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Received: October 30th, 2022 / Accepted: May 4th, 2023 / Published: July 1st, 2023

https://DOI-10.24057/2071-9388-2022-156

ABSTRACT. The term "warm pool" refers to a body of water with the characteristic of SST exceeding 28°C within a particular area and a relatively long period in an annual circle. However, there are regions with an annual mean SST measured above 30°C, and we classified them as hot pools because of the conditions of intense solar radiation and low wind speed. One of the Hot Pool spots was found in Indonesia, in Cenderawasih Bay. The present study examines the existence of the Cenderawasih Hot Pool using long-term observation of satellite SST data. In order to learn more about their mechanisms, we also analyzed surface wind, surface heat flux, and surface current data. The results show that SSTs in Cenderawasih Bay have a 50% chance of exceeding 30°C within the 13 years of study (2013-2015). Heat input comes from strong solar radiation, i.e., 50% of solar radiation is more than 200 W/m^2. The location is also dominated by low wind speed, i.e., 80% wind speed of lower than 4 m/s, which caused the low latent loss in Cenderawasih Bay. Cenderawasih Bay is fully separated from surface currents during the dry and wet seasons since the easterly subsurface water flow does not enter the bay. The absence of strong currents prevents the mixing process, maintaining the high temperature in the surface layer. Those processes are discovered and they serve as compelling evidence to support Cenderawasih Bay as one of the Hot Pool areas within the Indonesian seas.

KEYWORDS: global climate; sea surface temperature; Hot Pool spot; Cenderawasih Bay

CITATION: Jalil Abd. R., Wirasatriya A., Malik A., Ramdani F., Rahmadi P., Harsono G., Setiawan R. Y. (2023). Cenderawasih Hot Pool: The Frequent High Sea Surface Temperature Phenomena At Cenderawasih Bay, Papua. Geography, Environment, Sustainability, 2(16), 77-83

https://DOI-10.24057/2071-9388-2022-156

ACKNOWLEDGEMENTS: We thank the Program of Indonesia Collaborative Research run by Hasanuddin University and Diponegoro University, for financing this research, with the number of contracts: 1269/UN4.22/PT.01.03/2020 and 193.07/UN7.6.1/PP/2020.

Conflict of interests: The authors reported no potential conflict of interest.

INTRODUCTION

The western equatorial Pacific has a big impact on the climate. The Earth's circulation is specifically affected by the warm pool, an area with average sea surface temperatures (SST) exceeding 28°C (e.g., Wyrtki 1989; Yan et al. 1992; Clement and Seager 1999; Chongyin et al. 1999; Pierrehumbert 2000; Clement et al. 2005; Thoron et al. 2005; Herweijer et al. 2005).

On the other hand, high SST in tropical regions has attracted researchers to investigate the mechanisms since the formation of high SST requires a particular atmospheric process (e.g., Ramanathan and Collins 1991; Wallace 1992; Arking and Ziskin 1994). This process is depicted by (Waliser and Graham 1993), which shows the relation between SSTs and deep convection. They utilized highly reflective cloud information from an arbitrary examination of monthly SST data with a grid spacing of 2º (produced from combined satellite observation and in situ data) and daily visible and infrared satellite image data. The highly reflective cloud increases along with the SST as it rises from 26ºC to 29.5ºC. In contrast, the highly reflective cloud diminishes with increased SST in the temperature from 29.5ºC to 32ºC. As a result, the analysis proved that several atmospheric processes impacted SSTs below and above 29.5°C.

By taking advantage of high temporal and spatial resolution SST products derived from satellite observations (i.e., daily and ≤ 25 km×25 km), several studies (Kawamura et al. 2008; Qin et al. 2007, 2008; Qin and Kawamura 2009, 2010; Wirasatriya et al. 2015, 2016, 2017a, 2020) were able to identify high SST events (i.e., more than 30°C) in specific areas and at certain periods and define them as Hot Event (HE). In summary, they concluded that considerable daily heat gains characterize the production of HE under high solar radiation and low wind speed brought on by "remote convection" mechanisms.

(Wirasatriya et al. 2015) elaborated on the climatology of HEs in the western equatorial Pacific using the SST dataset derived from satellite microwave sensors. Throughout nine years of observation (2003-2011), they discovered 71 HE cases in the western equatorial Pacific, with the majority centered on the Solomon Islands and New Guinea Island's northern coasts, which extend eastward up to 160∞W. According to the climatology, the region has solar radiation of more than 200 W/m^2 and wind speeds of less than 4 m/s. Low wind speeds heavily influence the mechanism for HE incidence in the western equatorial Pacific. Much of the equatorial region experiences sun radiation above 200 W/m^2 during the HE periods. Low wind speeds minimize latent heat loss, which results in high SSTs and HEs in specific locations. (Wirasatriya et al. 2015) also emphasized that high solar radiation and low wind speed are much more common during the development stage and less common during the decay stage. This study also demonstrated that a rise in the long-term mean SST in the western equatorial Pacific is correlated with an increase in the frequency of HE events. HEs were responsible for 51.5% of the SSTs >30°C in the warm pool region bounded by the 29.5 °C isotherms of the climatological SST. Thus, statistically, there is a relation between the occurrence of HE and the formation of the western Pacific warm pool. Moreover, (Wirasatriya et al. 2020) demonstrated the role of HE in maintaining the warm mixed layer in the western Pacific warm pool. The frequent occurrence of HE transports heat from the surface layer to the deeper layer above the thermocline to maintain the warm mixed layer in the warm pool. Since the Pacific warm pool influences the global climate's variability through coupled ocean-atmosphere dynamics and thermodynamics (e.g., Clement and Seager 1999; Herweijer et al. 2005), this becomes an example of the contribution of high SST phenomena to regulate the global climate.

Within the Indonesian seas, the frequent appearance of high SST > 30°C has been reported by (Tita et al. 2020) in Tomini Bay and by (Swandiko et al. 2021) in the Malacca Strait. Their appearances also the high solar radiation and weak wind. The morphology of the semi-enclosed waters causes the high-frequency occurrence of low wind speed by less than 4 m/s in both areas. Besides these two areas, there is no more study on the high SST phenomena within the Indonesian Seas.

The present study demonstrates the frequent high SST occurrence (more than 30°C) in Cenderawasih Bay. Cenderawasih Bay is in northern Papua Island, part of the western Pacific warm pool. It is semi-enclosed water with a deep basin, surrounded by mountain chains (Fig. 1). Cenderawasih Bay is the habitat for whale sharks (Ihsan et al. 2018). Since the area determines warm pool definition with SST climatology higher than 28°C, we call the high-frequency occurrence of SSTs higher than 30°C in the Cenderawasih Bay the Cenderawasih Hot Pool. (Wirasatriya et al. 2015) found that the duration of HE occurrence in the western equatorial Pacific is no longer than two months since HE requires a typical condition of high solar radiation and low wind speed. Thus, it is interesting to understand the mechanisms of the high-frequency occurrence of high SST in the Cenderawasih Hot Pool.

MATERIALS AND METHODS

We used the semi-daily 11 µm SST products from Moderate Resolution Imaging Spectroradiometer (MODIS) Aqua Lv3 with a spatial resolution of 0.04º×0.04º (Esaias

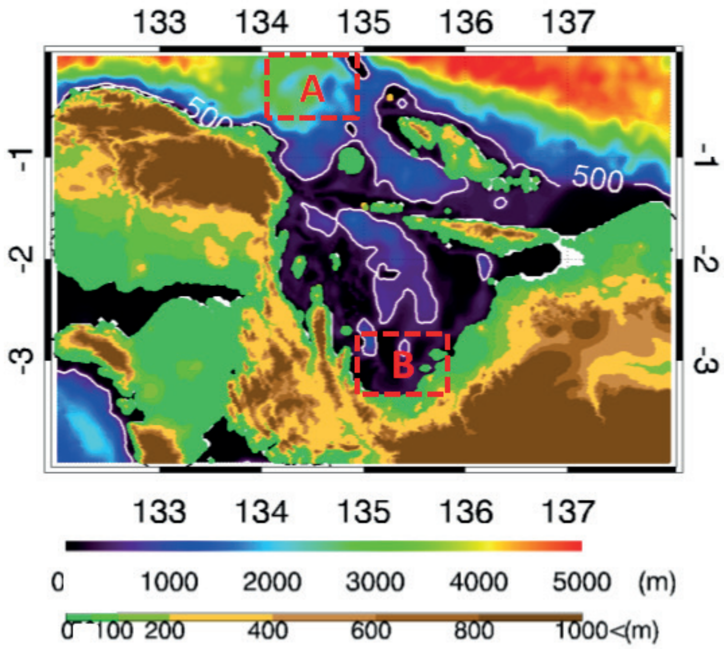

Fig. 1. Bathymetry and topography of Cenderawasih Bay. The dashed boxes A and B represent the sampling area for outside and inside Cenderawasih Bay, respectively, as shown in Fig. 5

et al. 1998) and observation period from 2003 to 2015. The MODIS SST 11 µm the Multi-Channel SST algorithm generates m by using brightness temperatures at 11 µm and 12 µm (Brown and Minnet 2009). The best accuracy was achieved by validating and testing this data against in-situ measurements (e.g., Lee et al. 2010; Qin et al. 2014; Ghanea et al. 2015).

We can obtain the Cross-Calibrated Multi-Platform (CCMP) gridded surface vector winds version 2.0 from the following website: www.remss.com, and use it to calculate surface winds. As a result, CCMP is regarded as a Level-3 ocean vector wind analysis product. They are created utilizing data from moored buoys, satellites, and model winds. The surface wind data for spatial and temporal resolutions is 0.25º×0.25º respectively and quarter daily. This wind product has greater accuracy than other wind reanalysis data.

We used a 0.5º grid from the Objectively Analyzed Air-Sea Fluxes project to analyze daily latent heat fluxes and solar radiation (Yu and Weller 2007). The period of observation for latent heat flux is from 2003 to 2015, but for solar radiation is only from 2003 to 2009 due to the availability of the data. Global 30 Arc-Second Elevation data was used to obtain topography. Global 30 Arc-Second Elevation (GTOPO30) data was used to obtain topography[1]. ETOPO, a one-arc-minute global relief model of Earth's surface that combines land topography and ocean bathymetry[2], provides bathymetry. For oceanic parameters, we used the current reanalysis data from http://marine.copernicus.eu/ to obtain the seasonal variation of the current pattern at 100 m depth in the Cenderawasih Hot Pool.

To calculate the frequency occurrence of SST within 13 years of observation, we calculate the percentage of SST > 30°C occurrence in each grid. Since high SST of more than 30°C occurs during the condition of low wind speed (i.e., < 4 m/s) and high solar radiation (i.e., > 200 W/m^2) (Wirasatriya et al. 2015), we calculated the percentage of low wind speed and high solar radiation in the Cenderawasih Bay. Furthermore, we also calculated the percentage of low latent heat release (<120 W/m^2) to explain how wind speed influences the variability of SST. The equation for calculating the percentage is as follows:

$$\%\,(x,y) = \frac{1}{n}\sum_{i=1}^{n} pi(x,y) \times 100\,\% \qquad (1)$$

where *%(x,y)* is percentage the percentage of high SST > 30°C or percentage of weak wind speed < 4 m/s or percentage of solar radiation > 200 W/m^2 or percentage of latent heat flux < 120W/m^2 at position (x,y); p*i* is the amount of SST data > 30°C or the amount of weak wind speed < 4 m/sec or the amount solar radiation > 200 W/m2 or the amount of latent heat flux < 120W/m^2 at position (x,y). Furthermore, we also analyze the climatological mean of each parameter. To create monthly and monthly climatology, all geophysical parameters are incorporated as follows (Wirasatriya et al. 2017b):

$$\overline{X}(x,y) = \frac{1}{n}\sum_{i=1}^{n} xi(x,y,t) \qquad (2)$$

where $\overline{X}$ is monthly mean value or monthly climatology value at position (x,y),   is ith value of the data at (x,y) position and time t. Next, n is the number of data in 1 month and the number of monthly data in 1 period of climatology (i.e., from 2003 to 2016 = 13 data) for monthly calculation and monthly climatology calculation, respectively. Moreover, if pixel xi is a hollow pixel, it is not included in the calculation.

RESULTS AND DISCUSSION

Cenderawasih Hot Pool

The definition of the Cenderawasih Hot Pool is described in Fig. 2, which shows the climatological mean of SST and the percentage of daily SSTs more than 30°C from 2003 to 2015 (13 years). In Cenderawasih Bay, the mean SST at the southern part of 2°S is more than 30°C, and the high SSTs are more than 50%. It means that the mean SST in Cenderawasih Bay is higher than the definition of the western Pacific warm pool which is 28°C (Wyrtki 1989), and more than 3.5 years within 2003-2015, SSTs in Cenderawasih Bay can reach more than 30°C. At the southernmost of the bay, the mean SST reaches 30.5°C, with the percentage of high SSTs being more than 70%. It has become the hottest area of Cenderawasih Bay.

In contrast, in the area outside Cenderawasih Bay, i.e., the western Pacific warm pool's offshore seas, the percentage is less than 30%. Thus, this evidence supports the definition of Cenderawasih Bay as the Cenderawasih Hot Pool. The high-frequency occurrence of high SST in Cenderawasih Bay may correspond to whale sharks' yearly appearance. (Ihsan et al. 2018) indicated the tolerance of whale sharks in high SST conditions.

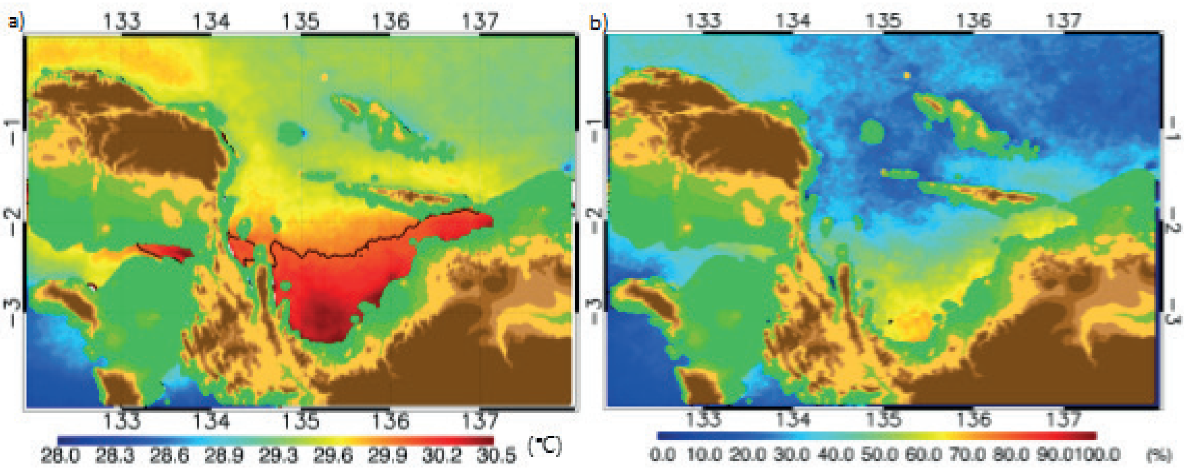

Fig. 2. Climatological mean of SST (a) and percentage of daily SSTs > 30°C during thirteen years of observation (2003-2015) (b). The black contour is 30°C

[1]https://www.usgs.gov/centers/eros/science/usgs-eros-archive-digital-elevation-global-30-arc-second-elevation-gtopo30?qt-science_center_objects=0#qt-science_center_objects

[2] https://www.ngdc.noaa.gov/mgg/global/

Atmospheric Aspect of Cenderawasih Hot Pool

Fig. 3 clearly shows that low wind speed dominates Cenderawasih Bay, i.e., 80% wind speed < 4 m/s occurred during 2003-2015. This causes low latent loss in Cenderawasih Bay. For solar radiation, the percentage of high solar radiation inside and outside Cenderawasih Bay is almost similar i.e., nearly 50%, indicating that high solar radiation is not dominant in both areas. This means that, although high solar radiation does not frequently occur, the absence of strong wind speed may maintain the latent heat loss to keep the SST in Cenderawasih Bay higher than 30°C.

To investigate how low wind speed occurs in the study area, we show the monthly climatology map of surface wind during summer and winter (Fig. 4). For both seasons, Cenderawasih Bay is protected from high wind speed due to high mountain chains in the western, southern, and eastern parts. In the northern part, small islands at the mouth of the bay prevent the strong wind speed from entering the bay. Thus, the role of topography is crucial for the occurrence of constant high SSTs in Cenderawasih Bay. The same tendencies are also found at the Tomini Bay and Malacca Strait, as indicated by (Tita et al. 2020) and (Swandiko et al. 2021).

The influence of wind speed and solar radiation on the SST variation is further examined by plotting the monthly climatology of wind speed, solar radiation, and SST at areas A and B (Fig. 1), representing the areas outside and inside Cenderawasih Bay. Seasonal variations of SSTs are observed in both areas. The minimum SSTs occur during the wet and dry seasons, while the maximum SSTs during the transition season. This seasonal SST variability is similar to the other areas in the Indonesian seas, such as the Java Sea (Wirasatriya et al. 2018), Maluku Sea (Wirasatriya et al. 2019), Halmahera Sea (Setiawan et al. 2019), etc.

For the area outside Cenderawasih Bay, SST ranges from 28.2°C to 30.6°C. It is seen that the variability of SST is controlled by wind speed and solar radiation. From January to June, when wind speed decreases from 2.2 m/s to 0.3 m/s and solar radiation is more than 200 W/m2, SST increases from 28.2°C to 30.5°C. From June to October, wind speed is lower than 1 m/s. In the absence of strong wind, the low SST in July is caused by the decrease of solar radiation to a minimum.

For the area inside Cenderawasih Bay, persistent high SST is observed as the SST ranges from 30.2°C to 31.1°C. It may be due to the low wind speed of fewer than 1 m/s for years. Thus, the variability of SST is seen as ruled by solar radiation. The minimum solar radiation causes the minimum SST in July. However, the absence of strong wind prevents latent heat loss that maintains the high SST inside Cenderawasih Bay.

The oceanic aspect of Cenderawasih Hot Pool

To investigate the oceanic aspect of the Cenderawasih Hot Pool, we plotted the current patterns at 100 m depth shown in Fig. 6. A northwestward current has been identified north of Cenderawasih Bay. During the wet season (January), the speed of this current ranges from 0.5 m/s to 0.7 m/s. During the dry season (August), when the northwesterly wind disappears (Fig. 4b), the speed of the northwestward current increases. This northwestward current is known as the New Guinea Coastal Under Current (NGCUC). NGCUC is a permanent current feature at 200 m depth regardless of the wind reversals (Tsuchiya et al. 1989). Inside Cenderawasih Bay, strong currents are absent in this area, preventing the mixing process from maintaining the high temperature in the surface layer. During the dry and wet seasons, Cenderawasih Bay is fully isolated since the westward subsurface water flow does not enter Cenderawasih Bay. Thus, this isolated basin causes the Cenderawasih Bay area to be influenced mainly by the air-sea interaction process mentioned in the previous section creating Cenderawasih Hot Pool.

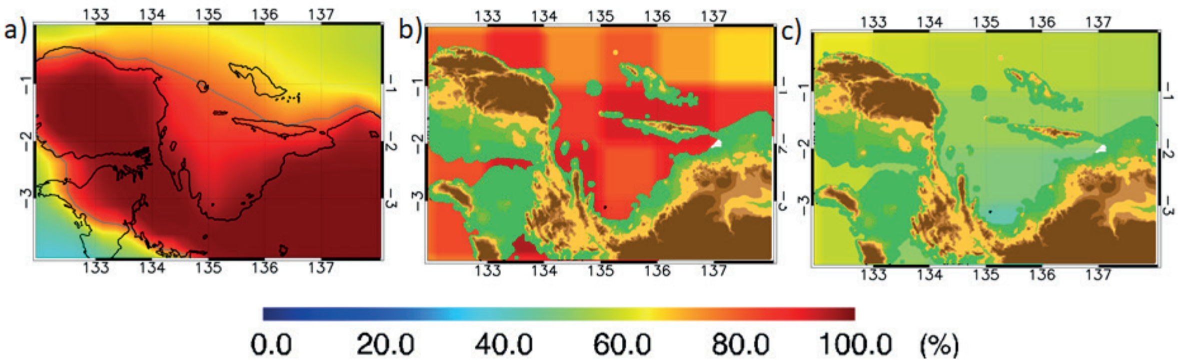

Fig. 3. The percentage of wind speed less than four m/s (a), latent heat release less than 120 W/m² (b), and solar radiation more than 200 W/m² (c)

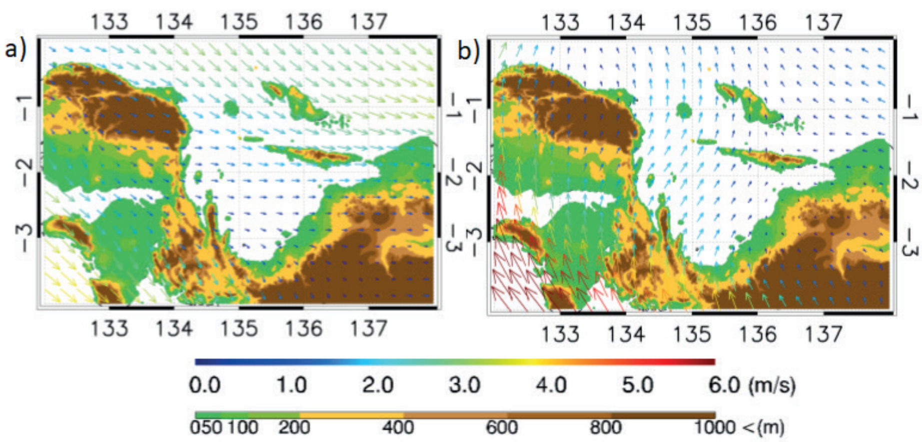

Fig. 4. Monthly climatology of surface wind speed during a) wet season (January) and b) dry season (August)

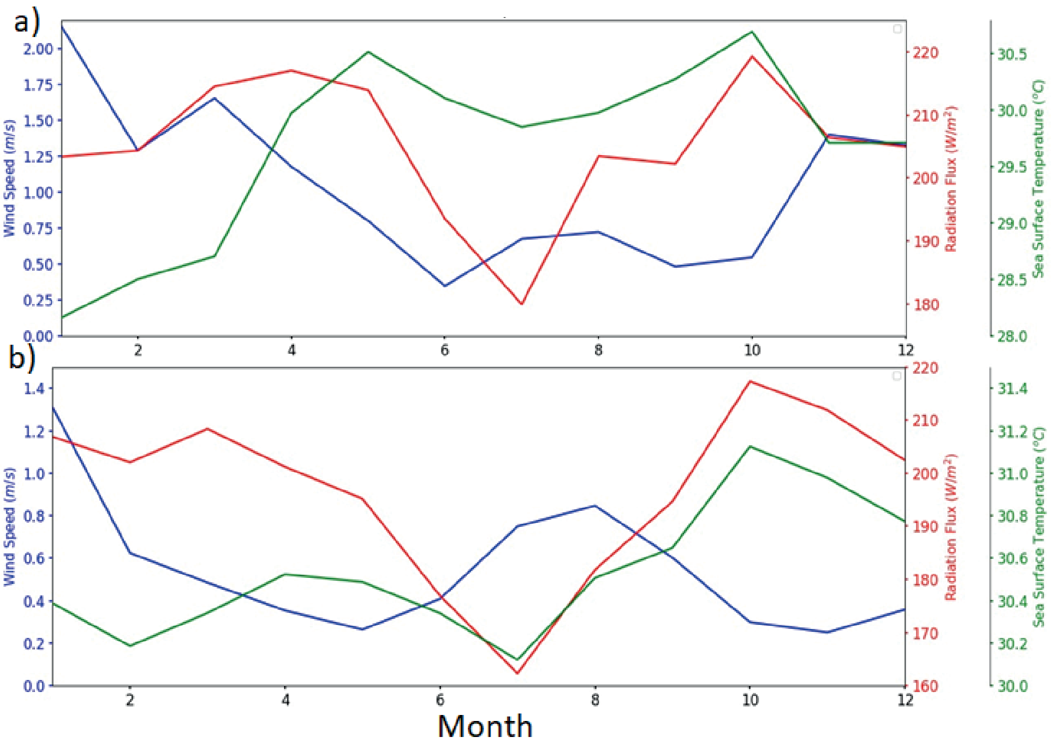

Fig. 5. Monthly climatology of SST, wind speed, and solar radiation at a) area outside and b) area inside Cenderawasih Bay, as shown in Fig. 1

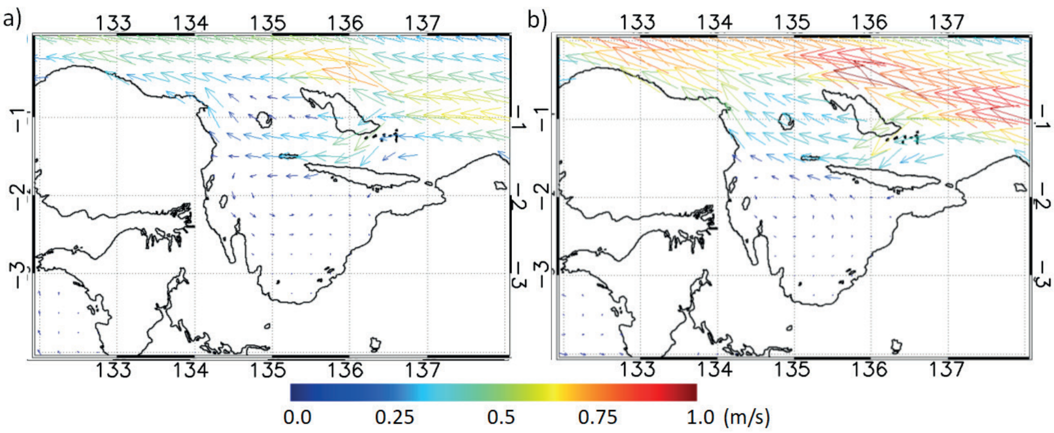

Fig. 6. Monthly climatology of current at 100 m depth in January (a) and August (b)

CONCLUSIONS

The hot Pool is used to categorize high SST episodes (>30°C) in particular areas and during specific periods (relatively long periods). Since the term "warm pool" has been used to define an area with the annual average SST distributed below 30°C in dominant, therefore "hot pool" was taken to represent the area with SST dominated above 30°C.

Under high solar radiation and low wind speed, this event is characterized by considerable daily heat gains. The constant high SST occurrence in Cenderawasih Bay, which is more than 50% of 13 years, SSTs can reach more than 30°C and are dominated by the condition of low wind speed, i.e., 80% wind speed is less than m/s along the years, also 50% solar radiation measured is more than 200 W/m^2. The current pattern at 100 m depth also shows that NGCUC does not enter Cenderawasih Bay. Thus, this indicates that Cenderawasih Bay is an isolated water. Those are the solid evidence for defining Cenderawasih Bay as the "Cenderawasih Hot Pool."

REFERENCES

Arking A. and Ziskin D. (1994). Relationship between clouds and sea surface temperatures in the western tropical Pacific. Journal of Climate, 7(6), 988-1000, DOI: 10.1175/1520-0442(1994)007%3C0988:RBCASS%3E2.0.CO;2.

Brown O.B. and Minnett P.J. (2009). MODIS infrared sea surface temperature algorithm theoretical basis document, ver 2.0, [online] Available at: https://modis.gsfc.nasa.gov/data/atbd/atbd_mod25.pdf [Accessed 25 October 2022].

Chongyin L., Mingquan M., and Guangqing Z. (1999). The variation of warm pool in the equatorial western Pacific and its impacts on climate. Advances in Atmospheric Sciences, 16(3), 378-394, DOI: 10.1007/s00376-999-0017-0.

Clement A. and Seager R. (1999). Climate and the tropical oceans. Journal of Climate, 12(12), 3383-3401, DOI: 10.1175/1520-0442(1999)012%3C3383:CATTO%3E 2.0.CO;2.

Clement A.C., Seager R., and Murtugudde R. (2005). Why are there tropical warm pools? Journal of Climate, 18(24), 5294-5311, DOI: 10.1175/JCLI3582.1.

Esaias W.E., Abbott M.R., Barton I., Brown O.B., Campbell J.W., Carder K.L., ... and Minnett P.J. (1998). An overview of MODIS capabilities for ocean science observations, IEEE Transactions on Geoscience and Remote Sensing, 36(4), 1250-1265, DOI: 10.1109/36.701076.

Ghanea M., Moradi M., Kabiri K., and Mehdinia A. (2015). Investigation and validation of MODIS SST in the northern Persian Gulf, Advances in Space Research, 57(1), 127-136, DOI: 10.1016/j.asr.2015.10.040.

Harweijer C., Seager R., Winton M., and Clement A.M.Y. (2005). Why ocean heat transport warms the global mean climate. Tellus, 57(4), 662-675, DOI: 10.3402/tellusa.v57i4.14708.

Hosoda K. (2013). Empirical method of diurnal correction for estimating sea surface temperature at dawn and noon. Journal of Oceanography, 69, 631-646, DOI: 10.1007/s10872-013-0194-4.

Ihsan E.N., Enita S.Y., and Wirasatriya, A. (2018). Oceanographic factors in fishing ground location of Anchovy at Teluk Cenderawasih National Park, West Papua: Are these factors have an effect of Whale Sharks appearance frequencies? In IOP Conference Series: Earth and Environmental Science, 116(1), 012-017, DOI: 10.1088/1755-1315/116/1/012017.

Kawamura H., Qin H., and Ando, K. (2008). In-situ diurnal sea surface temperature variations and near-surface thermal structure in the tropical hot event of the Indo-Pacific warm pool. Journal of Oceanography, 64, 847-857, DOI: 10.1007/s10872-008-0070-9.

Ming-An L., Tzeng M. T., Hosoda K., Sakaida F., Kawamura H., Shieh W. J., Yang Y., and Chang, Y. (2010). Validation of JAXA/MODIS sea surface temperature in water around Taiwan using the Terra and Aqua satellites. TAO: Terrestrial, Atmospheric and Oceanic Sciences, 21(4), 727-736, DOI: 10.3319/TAO.2009.09.07.01(Oc).

Pierrehumbert R.T. (2000). Climate change and the tropical Pacific: The sleeping dragon wakes. Proceedings of the National Academy of Sciences, 97(4), 1355-1358, DOI: 10.1073/pnas.97.4.1355.

Qin H., Kawamura H., and Kawai Y. (2007). Detection of Hot Event in the equatorial Indo-Pacific warm pool using advanced satellite sea surface temperature, solar radiation, and wind speed. Journal of Geophysical Research: Oceans, 112 (C7), DOI: 10.1029/2006JC003969.

Qin H., Kawamura H., Sakaida F., and Ando K. (2008). A case study of the tropical hot event in November 2006 (HE0611) using a geostationary meteorological satellite and the TAO/TRITON mooring array. Journal of Geophysical Research: Oceans, 113(C8), DOI: 10.1029/2007JC004640.

Qin H. and Kawamura H. (2009). Atmosphere response to a hot SST event in November 2006 as observed by AIRS instrument. Advances in space research, 44(3), 395-400, DOI: 10.1016/j.asr.2009.03.003.

Qin H. and Kawamura H. (2010). Air-sea interaction throughout the troposphere over a very high sea surface temperature. Geophysical research letters, 37(1), 1-4, DOI: 10.1029/2009GL041685.

Qin H., Chen G., Wang W., Wang D., and Zeng L. (2014). Validation and application of MODIS-derived SST in the South China Sea. International journal of remote sensing, 35(11-12), 4315-4328, DOI: 10.1080/01431161.2014.916439.

Ramanathan V. and Collins W. (1991). Thermodynamic regulation of ocean warming by cirrus clouds deduced from observations of the 1987 El Niño. Nature 351 (6321), 27-32, DOI: 10.1038/351027a0.

Setiawan R.Y., Wirasatriya A., Hernawan U., Leung S., and Iskandar I. (2020). Spatio-temporal variability of surface chlorophyll-a in the Halmahera Sea and its relation to ENSO and the Indian Ocean Dipole. International Journal of Remote Sensing, 41(1), 284-299, DOI: 10.1080/01431161.2019.1641244.

Swandiko M., Wirasatriya A., Marwoto J., Muslim, Indrayanti E., Subardjo P., Ismunarti D.H. (2021). Studi persistensi suhu permukaan laut tinggi (>30°C) di perairan Selat Malaka. Buletin Oseanografi Marina, 10(2), 162-170, [online] Available at: https://ejournal.undip.ac.id/index.php/buloma/article/download/31554/19352 [Accessed 25 October 2022] (in Indonesian).

De Garidel-Thoron T., Rosenthal Y., Bassinot F., and Beaufort L. (2005). Stable sea surface temperatures in the western Pacific warm pool over the past 1.75 million years. Nature, 433(7023), 294-298, DOI: 10.1038/nature03189.

Tita A.D.C., Wirasatriya A., Sugianto D.N., Maslukah L., Handoyo G., Helmi M., and Avianto P. (2020). Persistence of high sea surface temperature (> 30°C) in Tomini Bay. In IOP Conference Series: Earth and Environmental Science, 530(1), 012-038, DOI: 10.1088/1755-1315/530/1/012038.

Waliser D.E. and Graham N.E. (1993). Convective cloud systems and warm-pool sea-surface temperatures: Coupled interactions and self-regulation. Journal of Geophysical Research: Atmospheres, 98(D7), 12881-12893, DOI: 10.1029/93JD00872.

Wallace J.M. (1992). Effect of deep convection on the regulation of tropical sea surface temperature. Nature, 357(6375), 230-231, DOI: 10.1038/357230a0.

Wirasatriya A., Kawamura H., Shimada T., and Hosoda K. (2015). Climatology of hot events in the western equatorial Pacific. Journal of Oceanography, 71, 77-90, DOI: 10.1007/s10872-014-0263-3.

Wirasatriya A., Kawamura H., Shimada T., Hosoda K. (2016). Atmospheric structure favoring high sea surface temperatures in the western equatorial Pacific. Journal of Geophysical Research, 121(19), 11-368, DOI: 10.1002/2016JD025268.

Wirasatriya A., Sugianto D.N., and Helmi M. (2017). The Influence of Madden Julian Oscillation on the Formation of the hot event in the western equatorial pacific. In IOP Conference Series: Earth and Environmental Science, 55(1), 012-006, DOI: 10.1088/1755-1315/55/1/012006.

Wirasatriya A., Setiawan R.Y., and Subardjo P. (2017). The effect of ENSO on the variability of chlorophyll-a and sea surface temperature in the Maluku Sea, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 10(12), 5513-5518, DOI: 10.1109/JSTARS.2017.2745207.

Wirasatriya A., Prasetyawan I.B., Triyono C.D., Muslim, and Maslukah L. (2018). Effect of ENSO on the variability of SST and chlorophyll-a in Java Sea. In IOP Conference. Series: Earth and Environmental Science, 116(1), 012-063, DOI: 10.1088/1755-1315/116/1/012063.

Wirasatriya A., Sugianto D.N., Helmi M., Setiawan R.Y., and Koch M. (2019). Distinct characteristics of SST variabilities in the Sulawesi Sea and the northern part of the Maluku Sea during the southeast monsoon. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 12(6), 1763-1770, DOI: 10.1109/JSTARS. 2019.2913739.

Wirasatriya A., Kawamura H., Helmi M., Sugianto D.N., Shimada T., Hosoda K., Handoyo G., Putra Y.D.G., and Koch M. (2020). Thermal structure of Hot Events and their possible role in maintaining the warm isothermal layer in the Western Pacific warm pool. Ocean Dynamics, 70, 771–786, DOI: 10.1007/s10236-020-01362-8.

Wyrtki K. (1989). Some thoughts about the West Pacific warm pool. In Proceedings of the Western Pacific International Meeting and Workshop on TOGA COARE, Noumèa, New Caledonia: 99-109, [online] Available at: https://horizon.documentation.ird.fr/exl-doc/pleins_textes/doc34-08/30195.pdf#page=114 [Accessed 26 October 2022].

Yan X.H., Ho C.R., Zheng Q., and Klemas V. (1992). Temperature and size variabilities of the western Pacific warm pool. Science, 258 (5088), 1643-1645, DOI: 10.1126/science.258.5088.1643.

Yu L. and Weller R.A. (2007). Objectively Analyzed air-sea heat fluxes for the global ice-free oceans (1981–2005). Bulletin of the American Meteorological Society, 88(4), 527-540, DOI: 10.1175/BAMS-88-4-527.