**Jurnal Ekologi, Masyarakat dan Sains**
E-ISSN: 2720-9717
Volume 6, Nomor21, 2025
**ECOTAS**
https://journals.ecotas.org/index.php/ems
https://doi.org/10.55448/ems

Artikel

# Sea Surface Temperature Trends (1993–2022) at the Central–West Java Border: Climate Change Indicator

*Amir* Yarkhasy Yuliardi[1], *Sugeng* Hartono[2], *Luhur* Moekti Prayogo[3], *Agung* Tri Nugroho[1], *Diah* Ayu Rahmalia[1], *Ratna* Juita Sari[1]

[1]Study Program of Marine Science, Faculty of Fisheries and Marine Science, Universitas Jenderal Soedirman, Purwokerto
[2]Study Program of Marine Science, Faculty of Fisheries and Marine, Universitas PGRI Ronggolawe, Tuban
[3]Study Program of Aquatic Resources Management, Faculty of Fisheries and Marine Science, Universitas Jenderal Soedirman, Purwokerto
Penulis koresponden: amiryarkhasy@gmail.com

**Riwayat Artikel:**

Masuk: 09-05-2025
Diterima: 09-08-2025
Dipublikasi: 11-10-2025

Cara Mengutip:

Yuliardi, Amir, Sugeng Hartono, Luhur Moekti Prayogo, Agung Tri Nugroho, Diah Ayu Rahmalia, dan Ratna Juita Sari. 2025. "Sea Surface Temperature Trends (1993–2022) at the Central–West Java Border: Climate Change Indicator". Jurnal Ekologi, Masyarakat Dan Sains 6 (2): 189-97. https://doi.org/10.55448/j94d1w11.



**Abstrak:** Penelitian ini menganalisis variabilitas suhu permukaan laut (SST) di perairan Cilacap dan Pangandaran, Laut Selatan Jawa, periode 1993–2022 menggunakan data satelit Marine Copernicus. Analisis mencakup tren jangka panjang, fluktuasi antar-tahunan, dan pola musiman yang berkaitan dengan dinamika oseanografi regional seperti ENSO dan upwelling musiman. Hasil menunjukkan tren pemanasan SST sebesar 0,06 ± 0,02 °C per dekade yang mengindikasikan pengaruh perubahan iklim regional. Variabilitas antar-tahunan menyoroti pendinginan signifikan pada 1997 (La Niña) dan pemanasan ekstrem pada 1998 dan 2010 (El Niño). Pola musiman menunjukkan SST tertinggi terjadi Maret–Mei saat monsun barat, dan terendah Agustus–September akibat upwelling. Upwelling berperan penting dalam mengatur suhu laut dan mendukung produktivitas hayati. Temuan ini menekankan pentingnya pemantauan SST untuk pengelolaan sumber daya laut yang adaptif terhadap iklim di wilayah pesisir selatan Jawa.
**Kata Kunci:** Laut Selatan Jawa, Perubahan Iklim, Suhu Permukaan Laut, Tren Pemanasan, Variabilitas Suhu

**Abstract:** *This study analyzes the variability of sea surface temperature (SST) in the coastal waters of Cilacap and Pangandaran, South Java Sea, during the 1993–2022 period using satellite data from Marine Copernicus. The analysis covers long-term trends, interannual fluctuations, and seasonal patterns related to regional oceanographic dynamics such as ENSO and seasonal upwelling. The results show a warming trend of SST at 0.06 ± 0.02 °C per decade, indicating the influence of regional climate change. Interannual variability highlights significant cooling in 1997 (La Niña) and extreme warming in 1998 and 2010 (El Niño). Seasonal patterns reveal the highest SST from March to May during the west monsoon, and the lowest SST in August–September due to upwelling. Upwelling plays an important role in regulating sea temperatures and supporting biological productivity. These findings underscore the importance of SST monitoring for climate-adaptive marine resource management in the southern coastal region of Java.*
***Keywords:*** *Climate Change, Sea Surface Temperature, South Java Sea, Temperature Variability, Warming Trend*

## 1 INTRODUCTION

There have been many studies regarding Sea surface temperature (SST) over recent decades. The parameter is studied due to its critical role in understanding the dynamics of ocean–atmosphere interactions, particularly in tropical regions (Laurindo et al., 2022; Cheng et al., 2024). Variations in SST, both seasonal and long-term, can influence atmospheric circulation patterns and contribute to the development of major climate phenomena such as the El Niño–

Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) (Deser et al., 2009; Roxy et al., 2014).

Some studies have reported a warming trend in the western Indian Ocean and across Indonesian waters. For instance, the Indian Ocean warm pool has experienced a temperature increase of approximately 0.7 °C between 1901 and 2012 (Roxy et al., 2014). Similarly, regions in eastern Indonesia, such as the Sawu Sea and its surroundings, have shown signs of warming, which are suspected to be linked to weakened upwelling processes due to declining wind intensity and altered ocean circulation patterns (Cahyarini et al., 2014; Lee, 2004).

Indonesia, as part of the Indo-Pacific Warm Pool, plays a crucial role in modulating global climate variability (Siswandi et al., 2022; Zhou et al., 2025). Changes in sea surface temperature within this region not only influence local rainfall patterns but also contribute to the dynamics of large-scale atmospheric circulations, including the Hadley and Walker cells (Sprintall et al., 2014; De Deckker, 2016). Elevated SSTs in the region enhance evaporation rates and intensify atmospheric convection, ultimately triggering transcontinental climate disturbances such as droughts, floods, and shifts in the intensity of tropical storms in distant parts of the globe (Robinson, 2021; Singh et al., 2025).

Rising SSTs in Indonesian coastal waters have far-reaching implications. Beyond potentially exacerbating marine environmental stressors such as coral bleaching, warming trends can also affect fisheries, marine productivity, and the sustainability of coastal ecosystems (Pelu, 2024; Hidayat & Ramadhan, 2025). Moreover, SST changes serve as vital indicators for detecting long-term climate change signals in tropical regions like Indonesia, where marine climate stability is essential for ecological and socio-economic resilience.

Continuous research regarding SST is urgent in Indonesian coastal waters. Hence, a scientific investigation was conducted in one research area, namely the Border of Central Java and West Java which consists of Cilacap and Pangandaran waters. The area is part of the key coastal regions along the southern coast of Java Island, directly bordering the Indian Ocean. It is influenced by a variety of oceanographic dynamics, including seasonal upwelling, the south Java current, regional influences of the Asian–Australasian monsoon system, and unique tidal characteristics (Aldrian & Susanto, 2003; Umasangaji & Ramili, 2021; Yuliardi & Prayogo, 2023; Wijaya et al., 2024).

There is a lack of specific studies analyzing the long-term trends of sea surface temperature (SST) in the Cilacap and Pangandaran waters despite its strategic location. It is noteworthy as the availability of historical data allows us for the detection of both the direction and magnitude of SST changes relevant to local climate change issues. By applying a linear trend analysis of SST, the study aims to contribute to the development of climate adaptation policies tailored to the coastal areas. The primary objective is to examine the linear trend of SST in its waters from 1993 to 2022, with a focus on identifying the rate of sea temperature change and assessing its implications as an indicator of climate change in the southern coastal region of Java.

## 2 MATERIALS AND METHODS

### 2.1 Location

The study was conducted in the Border of Central Java and West Java, specifically in Cilacap and Pangandaran waters, directly adjacent to the Indian Ocean. The region is characterized by complex oceanographic dynamics, driven by seasonal monsoons, the southward-flowing Java Current, and periodic upwelling phenomena (Wen et al., 2023; Wijaya et al., 2024). The study focused on a fixed latitudinal transect at approximately 7.88°S, with four observation points distributed longitudinally from west to east, parallel to the Cilacap coastline. These observation points were designated as follows: Point A (7.88°S, 108.62°E), Point B (7.88°S, 108.88°E), Point C (7.88°S, 109.12°E), and Point D (7.88°S, 109.38°E) (Figure 1). This spatial configuration was designed to capture longitudinal variations in sea surface temperature (SST) across the western to eastern sectors of Cilacap waters, enabling the detection of potential spatial differences in the observed warming trends.

### 2.2 Dataset

The sea surface temperature (SST) data used in this study were obtained from the Copernicus Marine Environment Monitoring Service (CMEMS), specifically from the following product: Product ID: *MULTIOBS_GLO_PHY_TSUV_3D_MYNRT_015_012*, Dataset ID: *dataset-armor-3d-rep-weekly_202012* (Greiner et al., 2023). This dataset is derived from the ARMOR3D Level 4 global multi-observation reprocessed and analyzed product, which integrates three-dimensional fields of temperature, salinity, sea level height, geostrophic currents, and mixed layer depth. The data are provided on a regular grid with a spatial resolution of 1/8° (~0.125°) and 50 vertical levels extending from the sea surface to the ocean floor. For the purpose of this study, we extracted weekly SST data at the surface level (0 m depth) covering the period from January 1993 to January 2022. A subset of the data was taken at four observation points (Figure 2).

## 2.3 Analysis

The analysis of sea surface temperature (SST) trends in the study was conducted using a quantitative statistical approach. The process began with the extraction of SST data at 0 m depth from the Copernicus dataset, covering the period from January 1993 to January 2022. Monthly climatology was calculated by averaging SST values for each calendar month across the entire observation period. Subsequently, SST anomalies were computed as the difference between the observed monthly SST and the corresponding climatological mean for that month. The SST anomaly for time index *i* is calculated as:

$$SST_i\ Anomaly = SST_i - \underline{SST}month_i$$

Where $i$ represents the time index for each month in the time series. The monthly anomalies from the four observation points along the Cilacap coast were then averaged spatially to generate a single representative time series for the study area. To reduce short-term variability and highlight the long-term trend, the anomaly time series was smoothed using a 12-month moving average.

Trend analysis was conducted using simple linear regression on the smoothed SST anomaly time series. Time was converted into decimal years, such that January 1993 becomes 1993.00, February 1993 becomes 1993.08, and so forth. The linear regression model is formulated as:

$$A(t) = at + b$$

Where $A(t)$ is the SST anomaly at time $t$, $a$ is the slope representing the rate of temperature change per year, $b$ is the intercept, and $t$ is time in decimal years. The trend coefficient $a$ was then scaled by a factor of 10 to express the trend in units of degrees Celsius per decade (°C/decade), which is more suitable for climatological interpretation. The standard deviation of the trend was also calculated to assess variability and confidence in the results.

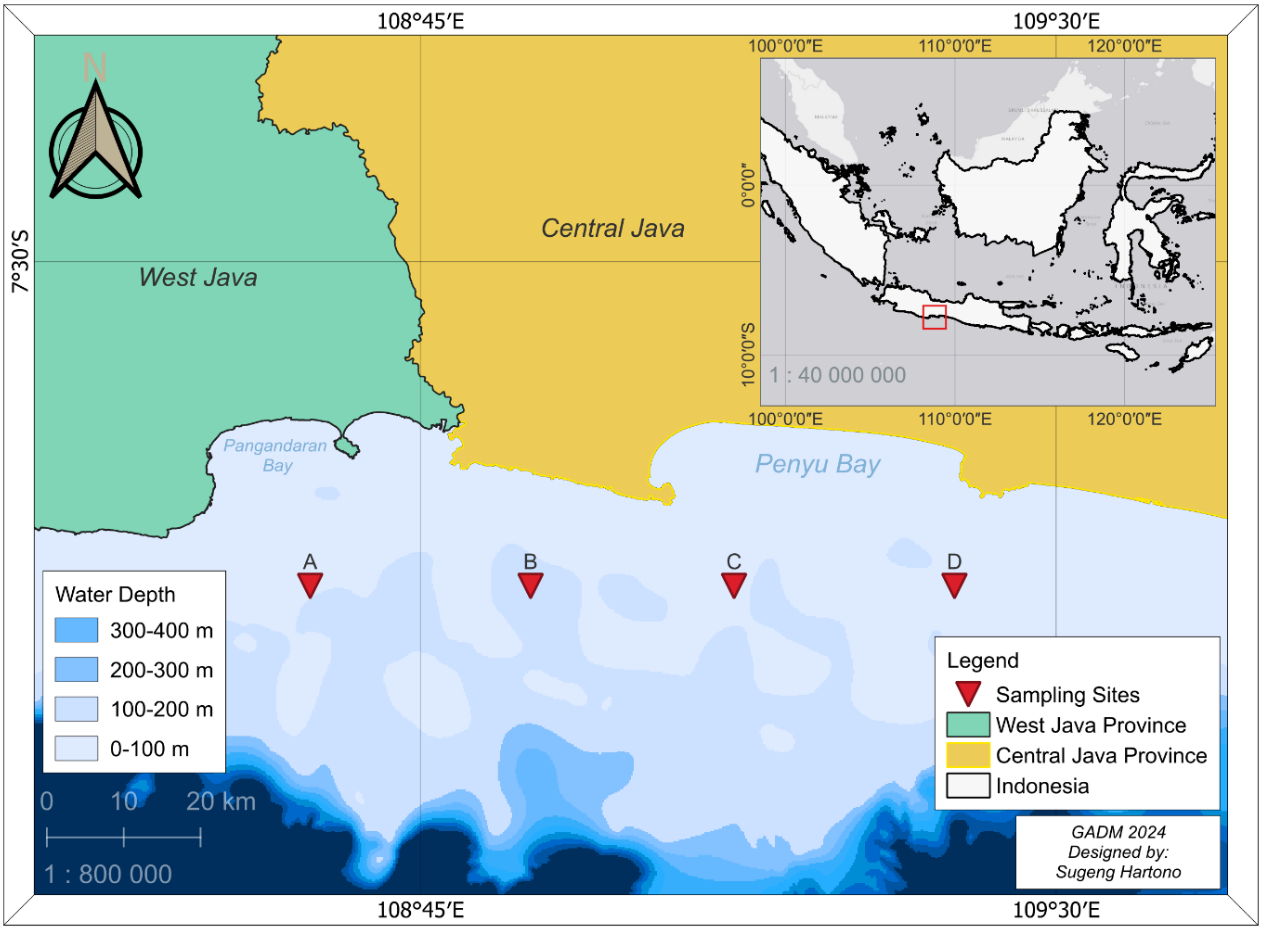


**Figure 1**. Map of the study area off the southern coast of Cilacap, Central Java, Indonesia. Four sea surface temperature (SST) sampling stations, labeled A, B, C, and D, are marked with red triangles. These stations were selected to investigate the temporal variability of SST in the coastal waters of the study region.

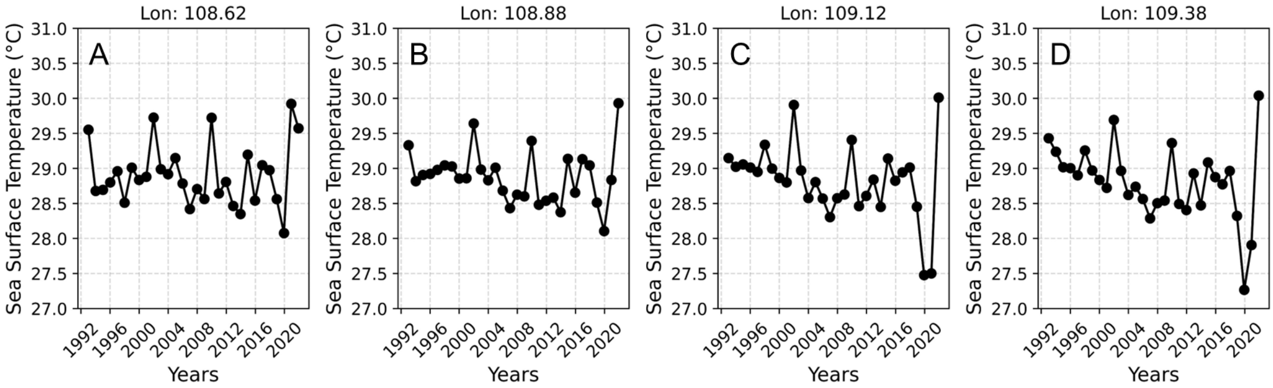


**Figure 2.** Annual mean sea surface temperature (SST) at four longitudinal coordinate points in the Cilacap waters from 1993 to 2022. Each panel (A–D) represents a specific location with the following coordinates: A (108.62° E), B (108.88° E), C (109.12° E), and D (109.38° E).

## 3 RESULT AND DISCUSSION

### 3.1 SST Linear Trend

Figure 3A illustrates the weekly sea surface temperature (SST) dynamics in the research area from 1993 to early 2022. The SST fluctuations exhibit a consistent seasonal pattern each year, with peak temperatures typically occurring during the second half of the year, particularly from October to December, while the lowest temperatures are observed between May and July. SST values generally range from 25°C to 29°C, with extreme anomalies dropping to approximately 23°C during certain years. This pattern reflects the influence of the monsoonal cycle over the southern Java region. The southeast monsoon (dry season) enhances surface cooling through strong wind-induced upwelling, whereas the northwest monsoon (wet season) introduces warmer water masses from the west (Umasangaji and Ramili, 2021; Widagdo et al., 2025). Moreover, the SST time series indicates the presence of interannual variability superimposed on the seasonal cycle, suggesting modulation by both regional and global climatic processes.

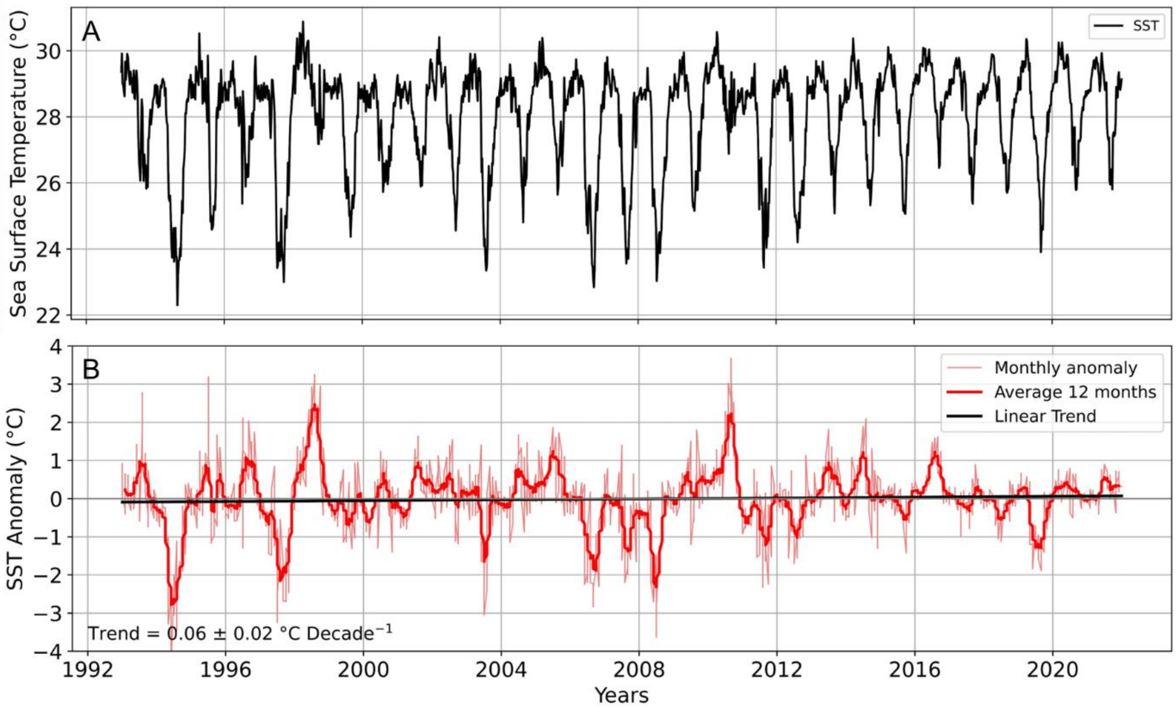


**Figure 3.** (A) Weekly mean sea surface temperature (SST) at the surface (depth = 0 m) in the Cilacap waters from January 1993 to January 2022. (B) Weekly SST anomalies with a 12-month moving average (thick red line) and linear trend line (black line).

Figure 3B presents the sea surface temperature anomalies (SST anomaly), calculated as deviations from the monthly climatological means, to capture medium- to long-term variability. The anomaly time series reveals several pronounced extreme events, including a sharp negative anomaly reaching -3.5°C in mid-1997 and positive anomalies exceeding +3°C during 1998 and 2010. These extreme deviations are associated with strong ENSO episodes (Mawren et al., 2024). The 12-month moving average (depicted as a thick red line) effectively smooths seasonal components, enabling clearer identification of long-term tendencies. The superimposed linear trend line (in black) indicates a positive SST anomaly trend of 0.06 ± 0.02 °C per decade over the nearly three-decade observation period. Although this trend appears moderate, the persistent warming of surface waters may carry substantial ecological and climatological implications, especially in sensitive coastal environments such as Cilacap. This finding aligns with broader regional patterns, where sea surface temperatures across Indonesian waters have shown a consistent warming trend, averaging around 0.19 ± 0.04 °C per decade over the past 33 years (Iskandar et al., 2020).

The observed warming trend of 0.06 °C per decade adds further evidence to regional ocean warming in the southern Java region. This trend aligns with global findings on sea surface temperature increases under ongoing climate change (Xu et al., 2021). It indicates that despite substantial interannual and seasonal variability—mainly driven by monsoonal forcing and ENSO events—a persistent long-term warming signal is evident. Ecologically, this trend may lead to shifts in fish species distribution, reduced primary productivity due to enhanced water column stratification, and increased coral bleaching risk (Setiawati et al., 2024; Sarre et al., 2024). As such, these results are critical for informing climate adaptation strategies and the sustainable management of coastal zones, especially in the context of long-term environmental change.

### 3.2 Annual Variability

Figure 4 presents annual boxplots of sea surface temperature (SST) in Cilacap waters from 1993 to 2022, offering a quantitative depiction of temperature distribution and interannual variability. Overall, the median annual SST values range between 27.5°C and 29°C, indicating relative stability with a slight upward trend during the last decade. Early years such as 1993 to 1995 exhibit narrower temperature distributions, while 1996 and 1997 display pronounced cooling, reflected by low minimum values approaching 23°C and numerous negative outliers. These conditions are consistent with the impacts of a strong La Niña event, which is known to drive significant surface cooling across the southern Java region.

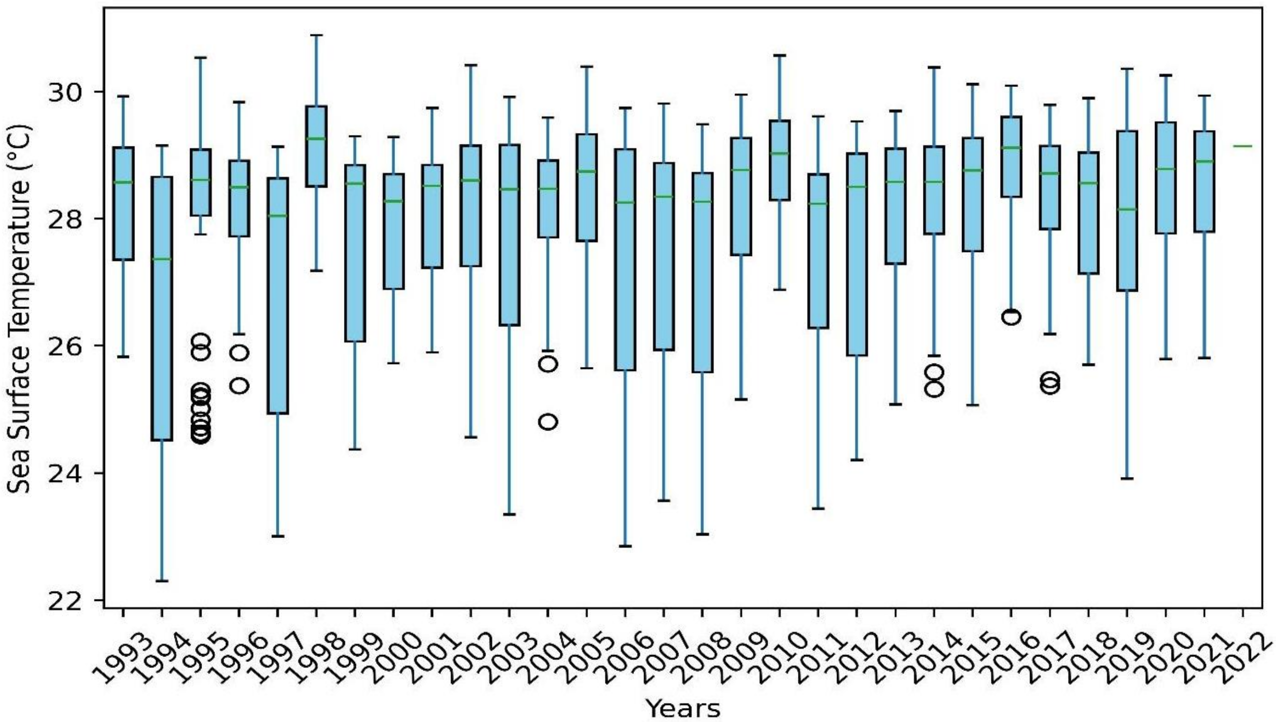


**Figure 4.** Annual boxplot of sea surface temperature (SST) in the Cilacap waters from 1993 to 2022. The horizontal line within each box represents the median, while the upper and lower edges indicate the third and first quartiles, respectively. Vertical lines (whiskers) show the range of minimum and maximum values, and circles denote outliers.

Interannual variability is clearly evident in the length of the whiskers and interquartile ranges, which reflect intra-annual temperature fluctuations. Certain years, such as 1997, 2002, and 2015, exhibit significant outliers below the normal range, indicating extreme temperature events potentially associated with oceanic dynamics or global climate phenomena. In contrast, post-2010 years show more stable temperature distributions with an upward shift, reflecting the influence of global warming trends as previously illustrated in Figure 3B.

The median SST for the past five years consistently exceeds 28.5°C, reinforcing the indication of long-term warming in this region. The annual SST variation depicted in Figure 4 also suggests that although seasonal cycles dominate monthly scales, interannual climate drivers such as El Niño and La Niña play a major role in producing extreme temperature anomalies during specific years. These changing dynamics can significantly impact local marine ecosystems, including shifts in primary productivity, changes in fish species distribution, and increased thermal stress on marine organisms such as coral reefs (Pinkerton et al., 2021; Staudinger et al., 2021; Voolstra et al., 2024).

## 3.3 Seasonal Variability

Figure 5 illustrates the seasonal fluctuation of SST in the Cilacap waters, reflecting regional oceanographic dynamics influenced by monsoonal wind patterns and upwelling activity. The SST pattern shows peak temperatures occurring between March and May, with average values exceeding 29°C. A significant temperature decline begins in June and reaches a minimum of approximately 25.8°C in September, followed by a gradual increase toward the end of the year. The sharp cooling observed from June to September is closely associated with seasonal upwelling events along the southern coast of Java (Wijaya et al., 2024). During this period, the dominance of the southeast monsoon winds drives surface water masses offshore (surface current export toward the northwest), which is compensated by the upward movement of deeper, cooler water to the surface (upwelling) (Wen et al., 2023).

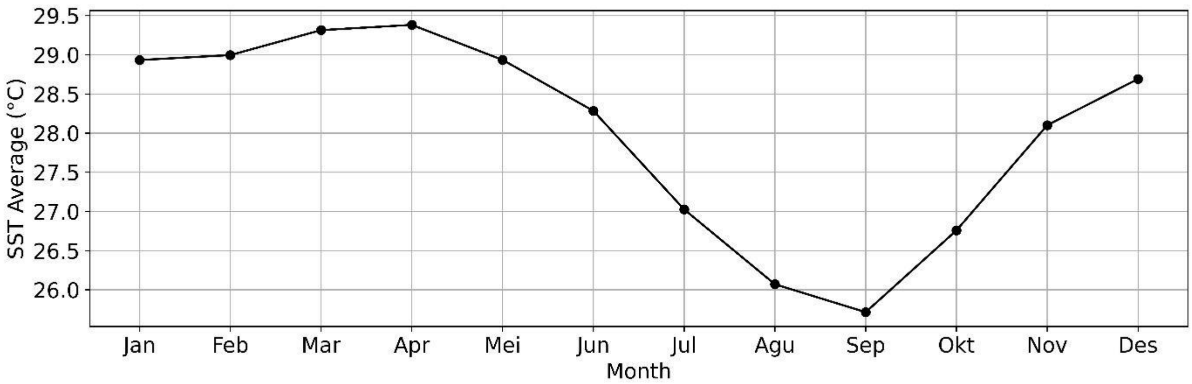


**Figure 5.** Monthly average sea surface temperature (SST) in the Cilacap waters during the period 1993–2022.

Seawater originating from deeper layers is typically colder and richer in nutrients, leading to a marked decrease in sea surface temperature during the upwelling season. This phenomenon accounts for the lowest SST values observed in August and September. The upwelling mechanism not only contributes to surface cooling but also plays a pivotal role in shaping coastal marine ecosystem dynamics (Vinayachandran et al., 2021). The upward transport of nutrient-rich waters enhances primary productivity, thereby supporting the marine food web (Satar et al., 2024). As a result, this period is often associated with increased fish catches in the southern waters of Java, including the Cilacap region (Wujdi et al., 2021; Wen et al., 2023). Overall, the seasonal SST variability in Cilacap highlights a strong connection between atmospheric dynamics, ocean circulation, and upwelling processes. A comprehensive understanding of these patterns is essential for effective coastal resource management and for improving the predictability of annual fisheries productivity.

# 4 CONCLUSION

This study reveals a warming trend in sea surface temperature (SST) in the Cilacap and Pangandaran coastal waters, with an estimated increase of 0.06 ± 0.02 °C per decade over the period 1993–2022, based on satellite observations from Marine Copernicus. Despite the presence of both seasonal and interannual variability, the observed warming indicates a signal of regional climate change. Extreme events such as the 1997 La Niña and the 1998 and 2010 El Niño episodes had substantial impacts on annual SST variability. Seasonally, peak SSTs are recorded between March and May, coinciding with the dominance of westerly winds, whereas the lowest temperatures occur from August to September, associated with seasonal upwelling that brings colder, deeper water to the surface. The upwelling does not only drive localized cooling but also enhances water productivity. Overall, the observed long-term warming trend and seasonal dynamics are crucial considerations for marine resource management and climate adaptation strategies. Based on the current research, further research is is recommended to focus on assessing the implications of these changes on marine ecosystems and fisheries in the southern Java region.

## ACKNOWLEDMENT

The author gratefully acknowledges Marine Copernicus for providing the sea surface temperature data utilized in this study. The author also extends sincere appreciation to the reviewers for their constructive comments and valuable suggestions, which have significantly improved the quality of this manuscript.

## REFERENCES

Aldrian, Edvin, and R. Dwi Susanto. 2003. "Identification of three dominant rainfall regions within Indonesia and their relationship to sea surface temperature." *International Journal of Climatology* 23: 1435-1452. Doi:10.1002/joc.950.

Cahyarini, Sri Yudawati, Miriam Pfeiffer, Intan Suci Nurhati, Edvin Aldrian, Wolf-Christian Dullo, and Steffen Hetzinger. 2014. "Twentieth century sea surface temperature and salinity variations at Timor inferred from paired coral δ18O and Sr/Ca measurements." *Journal of Geophysical Research: Oceans* 119, no. 7: 4593-4604. Doi: 10.1002/2013JC009594

Cheng, Yuan, Hao Yan, Chuck Wah Yu, and Junqi Wang. 2024. "The high-temporal and spatial resolution sea surface temperature brings new opportunities for sustainable development of the built environment in coastal cities." *Indoor and Built Environment* 33, no. 7: 1165-1169. Doi: 10.1177/1420326X241234169

De Deckker, Patrick. 2016. "The Indo-Pacific Warm Pool: critical to world oceanography and world climate." *Geoscience Letters* 3, no. 1: 20. Doi: 10.1186/s40562-016-0054-3

Deser, Clara, Michael A. Alexander, Shang-Ping Xie, and Adam S. Phillips. 2010. "Sea surface temperature variability: Patterns and mechanisms." *Annual review of marine science* 2, no. 1: 115-143. Doi: 10.1146/annurev-marine-120408-151453

Greiner, Eric, Nathalie Verbrugge, Sandrine Mulet, and Stéphanie Guinehut. 2023. "Multi Observation Production Centre Ocean 3D Temperature, Salinity, Geopotential Heights, Geostrophic Currents and 2D Mixed Layer Depth Product MULTIOBS_GLO_PHY_TSUV_3D_ MYNRT_015_012.".

Hidayat, Taopik, and Muhammad Fauzan Ramadhan. 2025. "Diplomasi Lingkungan Indonesia Melalui Coral Triangle Intiative: Peluang dan Tantangan." *Jurnal Ilmu Kelautan Lesser Sunda* 5, no. 1: 29-41. Doi: 10.29303/jikls.v5i1.128

Laurindo, Lucas C., R. Justin Small, LuAnne Thompson, Leo Siqueira, Frank O. Bryan, Ping Chang, Gokhan Danabasoglu et al. 2022. "Role of ocean and atmosphere variability in scale-dependent thermodynamic air-sea interactions." *Journal of Geophysical Research: Oceans* 127, no. 7: e2021JC018340. Doi: 10.1029/2021JC018340

Iskandar, Iskhaq, Wijaya Mardiansyah, Deni Okta Lestari, and Yukio Masumoto. 2020. "What did determine the warming trend in the Indonesian sea?." *Progress in Earth and Planetary Science* 7: 1-11. Doi: 10.1186/s40645-020-00334-2

Lee, Tong. 2004. "Decadal weakening of the shallow overturning circulation in the South Indian Ocean." *Geophysical* *research letters* 31, no. 18. Doi: 10.1029/2004GL020884

Mawren, D., J. Hermes, and C. J. C. Reason. 2024. "Mixed layer heat budget in the Mozambique channel: Interannual variability and influence of Rossby waves." *Deep Sea Research Part I: Oceanographic Research Papers* 205: 104248. Doi: 10.1016/j.dsr.2024.104248

Pelu, Fadli. 2024. "Dampak Perubahan Iklim Global terhadap Kerentanan Sosial Ekonomi Masyarakat Pesisir di Maluku." *Jurnal Akademik Ekonomi Dan Manajemen* 1, no. 4: 635-643. Doi: 10.61722/jaem.v1i4.4375

Pinkerton, Matthew H., Philip W. Boyd, Stacy Deppeler, Alex Hayward, Juan Höfer, and Sebastien Moreau. 2021. "Evidence for the impact of climate change on primary producers in the Southern Ocean." *Frontiers in Ecology and Evolution* 9: 592027. Doi: 10.3389/fevo.2021.592027

Robinson, Walter A. 2021. "Climate change and extreme weather: A review focusing on the continental United States." *Journal of the Air & Waste Management Association* 71, no. 10: 1186-1209. Doi: 10.1080/10962247.2021.1942319

Roxy, Mathew Koll, Kapoor Ritika, Pascal Terray, and Sébastien Masson. 2014. "The curious case of Indian Ocean warming." *Journal of Climate* 27, no. 22: 8501-8509. Doi: 10.1175/JCLI-D-14-00471.1

Sarre, Abdoulaye, Hervé Demarcq, Noel Keenlyside, Jens-Otto Krakstad, Salaheddine El Ayoubi, Ahmed Mohamed Jeyid, Saliou Faye, Adama Mbaye, Momodou Sidibeh, and Patrice Brehmer. 2024. "Climate change impacts on small pelagic fish distribution in Northwest Africa: trends, shifts, and risk for food security." *Scientific Reports* 14, no. 1: 12684. Doi: 10.1038/s41598-024-61734-8

Setiawati, Martiwi Diah, Herlambang Aulia Rachman, Riza Yuliratno Setiawan, Augy Syahailatua, and Sam Wouthuyzen. 2024. "The habitat preference of commercial tuna species based on a daily environmental database approach in the tropical region of the Eastern Indian Ocean off Java-Bali waters." *Deep Sea Research Part II: Topical Studies in Oceanography* 216: 105400. Doi: 10.1016/j.dsr2.2024.105400

Singh, Sarmistha, Chinju Saju, and K. Athira. 2025. "Impacts of ocean atmospheric phenomena on hydroclimate extremes." In *Sustainable Development Perspectives in Earth Observation*, pp. 119-133. Elsevier. Doi: 10.1016/B978-0-443-14072-3.00003-4

Siswandi, Andreas, Yudha Setiawan Djamil, Rima Rachmayani, Sri Yudawati Cahyarini, and Marfasran Hendrizan. 2022. "First-order analyses on the role of surface wind in the long-term contraction of the Indo-Pacific warm pool." *Indonesian Journal of Geography* 54, no. 3. Doi: 10.22146/ijg.75502

Sprintall, Janet, Arnold L. Gordon, Ariane Koch-Larrouy, Tong Lee, James T. Potemra, Kandaga Pujiana, and Susan E. Wijffels. 2014. "The Indonesian seas and their role in the coupled ocean–climate system." *Nature Geoscience* 7, no. 7: 487-492. Doi: 10.1038/ngeo2188

Staudinger, Michelle D., Abigail J. Lynch, Sarah K. Gaichas, Michael G. Fox, Daniel Gibson-Reinemer, Joseph A. Langan, Amy K. Teffer, Stephen J. Thackeray, and Ian J. Winfield. 2021. "How does climate change affect emergent properties of aquatic ecosystems?." *Fisheries* 46, no. 9: 423-441. Doi: https://doi.org/10.1002/fsh.10606

Umasangaji, H., and Y. Ramili. 2021. "Mini review: Characteristics of upwelling in several coastal areas in the world." In *IOP Conference Series: Earth and Environmental Science*, vol. 890, no. 1, p. 012004. IOP Publishing. Doi: 10.1088/1755-1315/890/1/012004

Vinayachandran, Puthenveettil Narayana Menon, Yukio Masumoto, Michael J. Roberts, Jenny A. Huggett, Issufo Halo, Abhisek Chatterjee, Prakash Amol et al. 2021. "Reviews and syntheses: Physical and biogeochemical processes associated with upwelling in the Indian Ocean." *Biogeosciences* 18, no. 22: 5967-6029. Doi: 10.5194/bg-18-5967-2021

Voolstra, Christian R., Rachel Alderdice, Luigi Colin, Sebastian Staab, Amy Apprill, and Jean-Baptiste Raina. 2024. "Standardized Methods to Assess the Impacts of Thermal Stress on Coral Reef Marine Life." *Annual Review of Marine Science* 17. Doi: 10.1146/annurev-marine-032223-024511

Wen, Chunlong, Zhenyan Wang, Jing Wang, Hongchun Li, Xingyu Shi, Wei Gao, and Haijun Huang. 2023. "Variation of the coastal upwelling off South Java and their impact on local fishery resources." *Journal of Oceanology and Limnology* 41, no. 4: 1389-1404. Doi: 10.1007/s00343-022-2031-3

Widagdo, S., V. D. Prasita, and M. Hafiz. 2025. "Upwelling Intensity During Indian Ocean Dipole Period in Southern Waters of Java." In *IOP Conference Series: Earth and Environmental Science*, vol. 1473, no. 1, p. 012015. IOP Publishing. Doi: 10.1088/1755-1315/1473/1/012015

Wijaya, Yusuf Jati, Ulung Jantama Wisha, Hasti Amrih Rejeki, and Dwi Haryo Ismunarti. 2024. "Variability of the South Java Current from 1993 to 2021, and its relationship to ENSO and IOD events." *Asia-Pacific Journal of Atmospheric Sciences* 60, no. 1: 65-79. Doi: 10.1007/s13143-023-00336-2

Wijaya, Yusuf Jati, Ulung Jantama Wisha, Lilik Maslukah, Seto Windarto, Anindya Wirasatriya, and Muhammad Zainuri. 2024. "Seasonal variation of chlorophyll-a in South Java over the past quarter-century." *Ocean Dynamics* 74, no. 8: 703-724. Doi: 10.1007/s10236-024-01629-4

Xu, Zhenhao, Fei Ji, Bo Liu, Taichen Feng, Yuan Gao, Yongli He, and Fei Chang. 2021. "Long-term evolution of global sea surface temperature trend." *International Journal of Climatology* 41, no. 9: 4494-4508. Doi: 10.1002/joc.7082

Yuliardi, Amir Yarkhasy, and Luhur Moekti Prayogo. 2023. "Analisis Komponen Harmonik dan Elevasi Pasang Surut pada Alur Pelayaran Perairan Cilacap: Harmonic Component Analysis and Tidal Elevation in Shipping Lanes in Cilacap Waters." *Jurnal Miyang: Ronggolawe Fisheries and Marine Science Journal* 3, no. 1: 41-46. Dok: 10.55719/jmiy.v3i1.644

Zhou, Xinquan, Stéphanie Duchamp-Alphonse, Xiaoxu Shi, Franck Bassinot, Eva Moreno, Xiaobo Jin, Luc Beaufort, and Chuanlian Liu. 2025. "Changes in atmospheric convection over the Indo-Pacific warm pool and coupled IOD and ENSO patterns during the last glacial maximum." *Geophysical Research Letters* 52, no. 6: e2024GL112276. Doi: 10.1029/2024GL112276