Asian Journal of Aquatic Sciences, April 2025. Vol 8, Issue (1) 72-78
e-issn: 2716-4608
p-issn: 2655-366X

ANALYZING THE RELATIONSHIP BETWEEN THE IOD (INDIAN OCEAN DIPOLE) AND ENSO (EL NIÑO–SOUTHERN OSCILLATION) ON SEA SURFACE TEMPERATURE AND RAINFALL VARIABILITY IN THE WATERS OF WEST SUMATERA

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ABSTRACT

This research examines the influence of the Indian Ocean Dipole (IOD) and El Niño–Southern Oscillation (ENSO) on sea surface temperature (SST) and rainfall variability in the coastal waters of West Sumatra over the period 2014–2024. The analysis draws on the Dipole Mode Index (DMI), Niño 3.4 index, SST, and rainfall data, processed using MathWorks and Excel. Regression analysis between field and satellite-derived SST data showed a strong correlation ($R^2 = 0.936$), confirming the reliability of satellite data for this study. Findings reveal that positive IOD and El Niño events are generally associated with cooler SSTs and reduced rainfall. In contrast, negative IOD and La Niña phases correspond to warmer SSTs and increased rainfall. The IOD appears to exert a more pronounced influence on SST variability than ENSO. Notably, the combined occurrence of a positive IOD and El Niño amplifies the decline in SST and rainfall. At the same time, the combination of a negative IOD and La Niña enhances increases in these variables. These results highlight the significant role of large-scale climate mode in shaping regional oceanographic and atmospheric conditions in the West Sumatra region.

Keywords: IOD, ENSO, Sea Surface Temperature, Rainfall, West Sumatra

1. INTRODUCTION

Indian Ocean Dipole (IOD) and the El Niño–Southern Oscillation (ENSO) are significant global climate phenomena that significantly influence oceanographic and atmospheric conditions across the Indonesian archipelago. ENSO is characterized by periodic changes in sea surface temperature (SST) in the central and eastern tropical Pacific Ocean. These variations arise from interactions between the ocean and atmosphere, subsequently affecting weather patterns across various regions of the globe[1].

In contrast, the IOD is driven by differences in SST anomalies between the western and eastern Indian Ocean, which can result in either cooling or warming of sea surface temperatures, accompanied by corresponding decreases or increases in rainfall[2]. SST anomalies are not exclusive to the Pacific Ocean; they also occur in the Indian Ocean. The IOD represents coupled ocean-atmosphere anomalies in the western and eastern parts of the Indian Ocean, influencing the surrounding maritime region, including Indonesian waters[3].

Both phenomena influence SST and rainfall variability in Indonesia, including West Sumatra Province[4]. In tropical regions such as Indonesia, ENSO events can disrupt the timing and intensity of the wet and dry

Received: 16 February 2025
Accepted: 3 April 2025

seasons, potentially prolonging drought conditions or intensifying rainfall, depending on the phase of the event.

The waters off the coast of West Sumatra are located along the western margin of the island of Sumatra, adjacent to the eastern Indian Ocean, and intersected by the equator. This unique geographical setting makes the region highly sensitive to fluctuations in SST and precipitation, which are driven by multiple climate variables, including SST anomalies, the IOD, seasonal monsoonal winds, and ENSO, particularly as indicated by the Niño 3.4 index.

Increases in SST are generally associated with higher evaporation rates and enhanced atmospheric moisture, which can lead to increased rainfall[5]. Although previous studies have examined the individual and combined impacts of IOD, ENSO, and monsoons on SST and rainfall across various parts of Indonesia[6-9], there remains a lack of focused research on how these phenomena specifically affect SST and rainfall variability in the coastal waters of West Sumatra. This research addresses this gap by analyzing the variability of sea surface temperature and rainfall during IOD and ENSO events in the waters off West Sumatra. The study area extends from 0° 25' 48.69" N to 5° 0' 28.43" S and from 95° 57' 0.21" E to 102° 0' 26.25" E, encompassing a broad portion of West Sumatra's offshore region. A descriptive statistical approach is applied to satellite-derived and observational data from 2014 to 2024.

Through this analysis, the study seeks to elucidate the mechanisms by which IOD and ENSO modulate ocean-atmosphere interactions in the region. This study assumes that the IOD and ENSO play a significant role in driving variability in SST and rainfall in the study area, with IOD expected to have a more dominant effect. This research explicitly explores the patterns of SST and rainfall under different climate phases and evaluates the interaction effects when IOD and ENSO phases co-occur.

2. RESEARCH METHOD

Time and Place

This research was conducted in the Pieh Island Conservation Area, West Sumatra Province, from October 2024 to February 2025 at the Physical Oceanography Laboratory, Department of Marine Science, Universitas Riau.

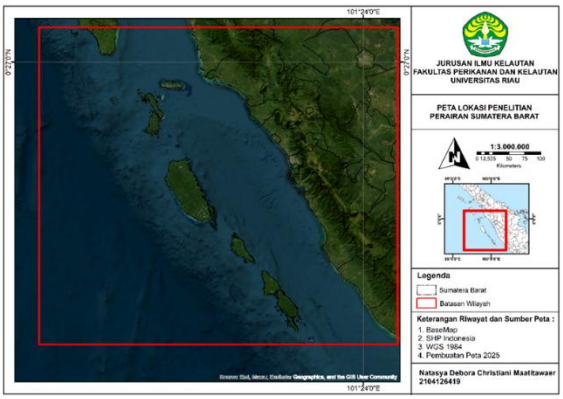


Figure 1. Map of research location

Method

The method used in this research is a survey method for data collection in the field and a descriptive statistical method for data processing and analysis. The data used in this study are field SPL data, Copernicus SPL data, Copernicus rainfall data, Dipole Mode Index (DMI) data, NOAA, and NOAA Nino 3.4 Index data.

Procedures

DMI and *Niño* 3.4 Index:

DMI and Niño 3.4 data are processed in graphical form using MATLAB. These index values identify IOD (positive, negative, neutral) and ENSO (El Niño, La Niña, neutral) phases according to applicable thresholds.

SST Data

Data processing in MATLAB involves creating maps of sea surface temperature (SPL) distribution and anomalies in the waters of West Sumatra over 11 years (2014–2024). The downloaded SPL data is first downsampled to monthly resolution using MATLAB and then further aggregated into seasonal, annual, and climatological datasets. The processed data is used to generate maps showing the spatial

distribution and anomalies of SPL across the 11 years. These maps are then analyzed descriptively concerning relevant literature, including books, journals, and previous studies on IOD, ENSO, and sea surface temperature.

Rainfall

Rainfall data is analyzed and correlated with extreme IOD and ENSO events during the study period. A descriptive analysis is conducted to observe trends and patterns of the global climate's influence on seasonal rainfall intensity.

3. RESULT AND DISCUSSION

IOD Phenomenon in West Sumatera Waters

The IOD phenomenon is depicted through the DMI. The DMI for 11 years (2014-2024) is shown in Figure 2.

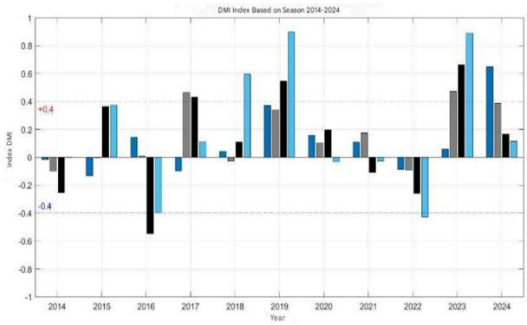


Figure 2. DMI chart 2014-2024

Figure 2 shows that the highest DMI value during the 2014-2024 period occurred in the second transitional season of 2019 with a value of +0.897, indicating a Positive IOD phase. During this period, the eastern waters of the Indian Ocean, including the west coast of Sumatra, experienced a cooling of the SST. This process affects the decrease in SPL and rainfall in this region. Conversely, when the lowest value occurred in the eastern season of 2016 with a value of -0.548, it signaled a negative IOD. This phase shows warming conditions in the east of waters of the Indian Ocean, including West Sumatra. This triggers heat buildup at sea level and increased rainfall due to increased air humidity and cloud formation[10].

ENSO Phenomenon in West Sumatera Waters

A Niño 3.4 index describes the El Niño Southern Oscillation (ENSO) phenomenon. This index measures changes in SST in the central Pacific that affect global weather patterns. The data analyzed in this period spans 11 years, from 2014 to 2024 (Figure 3).

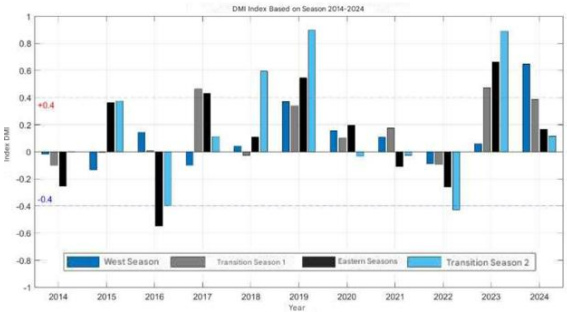


Figure 3. *Niño* 3.4 index chart 2014-2024

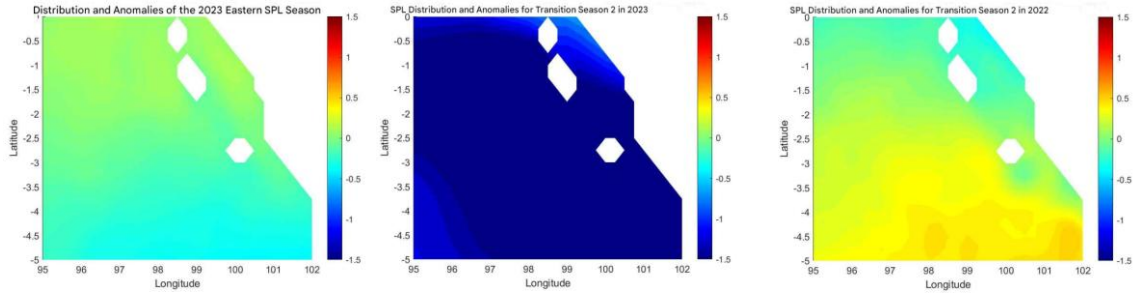
Figure 3 shows that the El Niño phenomenon occurred in several periods with indices above +0.5. The strongest El Niño event occurred in the western season of 2015-2016, with the index reaching more than +2.43. A similar phenomenon occurred in the second transitional season of 2023, with an index of around +1.78. During El Niño periods, sea level experiences positive anomalies with increases of tens of centimeters in the Eastern Pacific Ocean and negative anomalies in the Western Pacific Ocean[11]. In contrast, La Niña phenomena occur when the index is below -0.5. One of the strongest La Niña events occurred in the second transitional season of 2019, with a value of -0.986. Another La Niña event occurred in the second transitional season of 2016 with an index of around -0.68. During the La Niña period, positive sea level anomalies are observed in the Indonesian region, and negative sea level anomalies around the Eastern Pacific Ocean region[12].

Effect of IOD and ENSO on SST Anomalies in West Sumatra Province

Variability of sea surface temperature (SST) anomalies in West Sumatra waters during the 2014-2024 period shows a close relationship with the occurrence of the IOD and ENSO phenomena. During the 2015-

2016 El Niño period, SPL anomalies significantly increased, especially in the eastern and transitional seasons II. This condition contributed to decreased rainfall due to a reduced supply of water vapor to the atmosphere. In 2019, negative SPL anomalies predominantly occurred in transition season II, coinciding with the positive phase of the IOD. The positive IOD phenomenon is characterized by cool SST in the eastern Indian Ocean, including the waters of West Sumatra. As a result, the Indonesian region, especially West Sumatra, experiences drier atmospheric conditions and decreased rainfall intensity. In 2020-2021, a shift occurred, where SST anomalies show a positive trend during the western season and transition season II. This increase is related to the La Niña phase, which, despite the general cooling in the eastern Pacific Ocean, causes an accumulation of heat energy in western Indonesia. An increase in water vapor supply accompanies this condition, thus supporting the intensification of rainfall in West Sumatra. Furthermore, in 2022-2023, the SST anomaly is again dominated by negative values, especially in transition season II, in line with the continuation of the La Niña phase. However, a change in pattern occurs in 2024, where the SPL anomaly shows a positive increase in all regions.

The combination of a positive IOD phase and El Niño, as observed in the eastern monsoon - transitional season 2 of 2023, amplifies the cooling of SPL. Conversely, the combination of negative IOD and La Niña phases, as observed in transitional season 2 of 2022, enhanced the warming of SPL. The SPL distribution map during the positive IOD and El Niño phases and the SPL distribution map during the negative IOD and La Niña phases can be seen in Figure 4.



(a) (b)

Figure 4. SPL distribution map: (a) Combination of positive IOD and El Niño P\phase; (b) Combination of negative IOD phase and La Nina

Note: Positive IOD and El Niño combined occurred in two consecutive seasons (2023), while the combination of Negative IOD and La Niña occurred only in one season (2022).

In the second transitional season of 2023, there was a decrease in SPL; the anomaly value reached -1.64°C. This decrease in SPL is accompanied by a decrease in rainfall to 44.8 mm, the lowest in the last 11 years. This process is related to the positive IOD phenomenon and El Niño that occurs in that season. According to Sukresno et al.[13]; Utama et al.[14], positive IOD shifts cloud formation activity to the west, resulting in less moisture and rain opportunities in western Indonesia. In addition, El Niño, which is characterized by an increase in SPL in the central and eastern Pacific region, can weaken cloud formation in Indonesian waters due to a shift in atmospheric circulation patterns towards the Central Pacific. This shows that IOD and El Niño dynamics directly influence West Sumatra waters on a seasonal time scale.

Different conditions occur in the second transitional season of 2022 when the SPL increases with an anomalous value of 0.36°C. As a result, rainfall increased to 1166.29 mm. This phenomenon is related to the negative IOD phase that occurred then, characterized by a DMI index value of -0.427. In this phase, the SPL in the eastern part of the Indian Ocean increases, encouraging increased humidity and cloud

formation activity in West Sumatra[15,16]. Overall, the observed SPL anomaly dynamics suggest that the interaction between the IOD and ENSO phenomena is important in controlling regional climate variability in West Sumatra waters.

Data Validation

Regression tests between field and Copernicus SPL data showed a robust correlation with an R^2 of 0.936 and a small error value (SE), indicating that satellite data accurately represent SPL conditions in the field[17].

These results conclude that the SPL value from Copernicus data can be used in this study because the processed data is accurate enough to represent the actual SPL value of the water area under study.

The Effect of IOD and ENSO on Rainfall in West Sumatra Province

West Sumatra's waters directly face the Indian Ocean, causing these waters to be affected by the IOD phenomenon significantly enough to greatly affect the temperature distribution pattern and cause differences in rainfall intensity in West Sumatra Province. Rainfall data on positive and negative IOD phases are presented in Table 1.

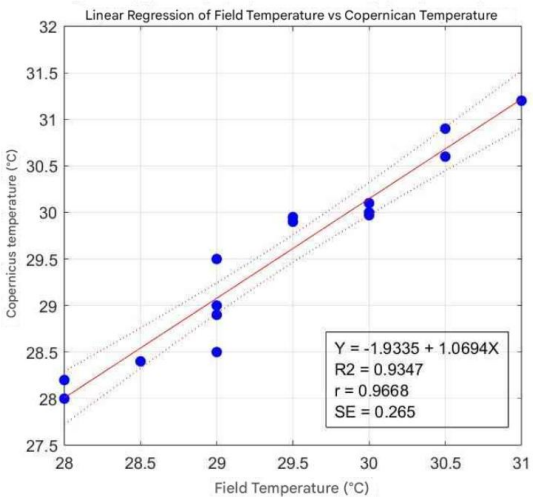


Figure 5. Graph of regression test results of SPL values

Table 1. Rainfall data of IOD and ENSO phenomena

Parameters	Rainfall value (mm)	Seasons	Phenomenon
Highest	1.166,29	Transition II 2022	IOD Negatif
	1.302,78	Transition II 2016	*La Niña*
Lowest	44,8	Transition II 2023	IOD Positif *El Niño*

The average rainfall during the positive IOD and El Niño phases is 44.8 mm, while the average rainfall during the negative IOD and La Niña periods is 1166.29 mm. Based on these values, it can be explained that during the positive IOD and El Niño phases in the West Sumatra area, there has been a decrease in rainfall intensity due to the formation of cloud masses occurring in the western part of the Indian Ocean, while in the negative IOD and La Niña phases the rainfall intensity tends to be higher, this is thought to be due to the formation of cloud masses occurring in the eastern part of the Indian Ocean which includes West Sumatra Province, causing high rainfall in this period.

This study's results align with research conducted by Millenia et al.[16], who stated that during El Niño and positive IOD, there is a decrease in SPL, which results in low rainfall. Conversely, SPL increases during La Niña and negative IOD, followed by increased rainfall.

4. CONCLUSION

IOD and ENSO phenomena significantly affect West Sumatra waters' sea surface temperature (SST) variability and rainfall. Positive IOD and El Niño phases caused a decrease in SPL to -1.64°C and a decrease in rainfall to 44.8 mm, while negative IOD and La Niña phases increased SPL by 0.36°C and increased rainfall to 1166.29 mm. IOD was shown to have a

dominant influence on SPL compared to ENSO, with ENSO acting as an amplifying or attenuating factor. This study confirms the importance of monitoring IOD and ENSO phenomena in supporting local climate prediction and coastal area management in West Sumatra. However, this study is limited to descriptive analysis based on observational data, so further numerical modeling studies are needed to strengthen the results. The findings of this study may also contribute to developing early warning systems and more adaptive strategies for marine resource management in the region.

REFERENCES

1. Nabilah, F., Prasetyo, Y., & Sukmono, A. Analisis Pengaruh Fenomena El Nino dan La Nina terhadap Curah Hujan Tahun 1998-2016 Menggunakan Indikator ONI (Oceanic Nino Index)(Studi Kasus: Provinsi Jawa Barat). *Jurnal Geodesi Undip*, 2017; *6*(4): 402-412
2. Rahayu, N.D., Sasmito, B., & Bashit, N. Analisis Pengaruh Fenomena Indian Ocean Dipole (IOD) terhadap Curah Hujan di Pulau Jawa. *Jurnal Geodesi Undip*, 2018; 7(1): 57-67.
3. Nur'utami, M.N., & Hidayat, R. Influences of IOD and ENSO to Indonesian Rainfall Variability: Role of Atmosphere-Ocean Interaction in the Indo-Pacific Sector. *Procedia Environmental Sciences*, 2016; *33*: 196-203
4. Narulita, I. Pengaruh ENSO dan IOD pada Variabilitas Curah Hujan di DAS Cerucuk, Pulau Belitung. *Jurnal Tanah dan Iklim,* 2017; 41(1): 45-60.
5. Sari, J., Pancariniwati, S., & Pratiwi, A. Analisis Sebaran Curah Hujan Wilayah Menggunakan Metode SPI dan Hubungannya dengan Indikator Iklim di Provinsi Sumatera Barat. *Seminar Nasional Geomatika,* 2017.
6. Adiwira, H., Purba, N.P., Harahap, S.A., & Syamsuddin, M.L. Variabilitas Suhu Laut pada Kejadian IOD (*Indian Ocean Dipole*) di Perairan Barat Sumatera Menggunakan Data Argo Float. *Depik*. 2018; 7(1): 28- 41.
7. Khaldun, M.H.I., Wirasatriya, A., & Suryo, A.A.D. The Influence of Indian Ocean Dipole (IOD) on the Variability of Sea Surface Temperature and Precipitation in Sumatera Island. *In IOP Conference Series*: *Earth and Environmental Science*, 2018; 165(1): 012008
8. Juniarti, L., Jumarang, M.I. & Apriansyah, A. Analisis Kondisi Suhu dan Salinitas Perairan Barat Sumatera Menggunakan Data Argo Float. *Physics Communication*, 2017; 1(1): 74-84.
9. Wirasatriya, A., Setiawan, R.Y., & Subardjo, P. 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*, 2017; *10*(12): 5513-5518.
10. Asyam, A.M.D., Rochaddi, B., & Widiaratih, R. Hubungan ENSO dan IOD terhadap Suhu Permukaan laut dan Curah Hujan di Selatan Jawa Tengah. *Indonesian Journal of Oceanography*, 2024; 6(2): 165-172.
11. Pampanglola, S.M.N.T. Estimation of Sealevel Variability Around the Java Sea and Karimata Strait Using Cryosat-2 Altimeter, *IOP Conference Series: Earth and Environmental Science*, 2019; 389: p.012021.
12. Yustiana, M., Zainuri, M., Sugianto, D.N., Batubara, M.P.N., & Hidayat, A.M. Dampak Variabilitas Iklim Inter-Annual (El Niño, La Niña) terhadap Curah Hujan dan Anomali Tinggi Muka Laut di Pantai Utara Jawa Tengah. *Buletin Oseanografi Marina*, 2023; 12(1): 109-124
13. Sukresno, B., Jatisworo, D., & Kusuma, D.W. Analisis Multilayer Variabilitas Upwelling di Perairan Selatan Jawa. *Jurnal Kelautan Nasional*, 2018; 13(1): 15

14. Utama, A.F., Maulana, A., Alfany, D., Dharma, C.S., & Harsono, G. Pemetaan Kriteria Upwelling di Wilayah Kepulauan Karimata Menggunakan Parameter Suhu Permukaan Laut dan Klorofil-a pada Bulan Mei 2023. *Jurnal Hidrografi Indonesia*, 2023; *5*(2): 99–104.
15. Hafizhurrahman, I., Kunarso, K., & Suryoputro, A.A.D. Pengaruh IOD (*Indian Ocean Dipole*) terhadap Variabilitas Nilai Serta Distribusi Suhu Permukaan Laut dan Klorofil-A pada Periode Upwelling di Perairan Sekitar Bukit Badung Bali. *Jurnal Oseanografi*, 2015; 4(2): 423-433.
16. Millenia, Y.W., Helmi, M., & Maslukah, L. Analisis Mekanisme Pengaruh IOD, ENSO dan Monsun terhadap Suhu Permukaan Laut dan Curah Hujan di Perairan Kepulauan Mentawai, Sumatera Barat. *Indonesian Journal of Oceanography* (IJOCE), 2022; 4(4):87-98.
17. Tanjung, A. *Rancangan Percobaan*. Tantaramesta. Bandung, 2024.