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# Impact of El Niño - Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) on Air Temperature in Bengkulu City

Mardho Tillah Edkayasa, Elfi Yuliza, Lizalidiawati*

Department of Physics, Faculty of Mathematics and Natural Sciences, University of Bengkulu, Bengkulu 38371, Indonesia

*Corresponding author. Email: lizalidiawati@unib.ac.id

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**Abstract**

Bengkulu City has experienced rising air temperatures due to climate variability events, particularly ENSO and IOD. This study analyzes the relationship between ENSO, IOD, and air temperature in Bengkulu over the past 20 years (2004-2023) using data from Meteorological and Climatology stations, as well as ONI and DMI indices from NOAA. Pearson and multiple correlation analyses show a temperature increase of 0.08-0.1°C per year. ENSO has a stronger influence than IOD, especially on maximum temperature ($r$ = 0.28-0.38). To strengthen the analysis, multiple linear regression was applied, revealing that ONI had a statistically significant positive effect on average air temperature, while DMI showed a weaker and insignificant influence ($R^2$ = 0.10-0.11). A phase-based composite analysis revealed that average temperatures peaked during El Niño combined with Positive IOD phases, highlighting their synergistic warming effect, with maximum temperature reaching 35.9°C (February 2019), and the lowest minimum temperature recorded at 18°C (September 2019). The temperature increase during El Niño poses risks such as prolonged dry seasons, increased drought, and disruption of coastal ecosystems. Therefore, adaptation measures such as early warning systems and water resource management must be integrated into regional planning, particularly in agriculture and health sectors in Bengkulu.

**Keywords**: Air temperature; Bengkulu City; Climate Variability; ENSO; IOD.

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## Introduction

As a tropical coastal region, Bengkulu experiences temperature fluctuations influenced by global climate phenomena, particularly the El Niño-Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) (Wardani et al., 2023; Ismail et al., 2020). ENSO is a major climate phenomenon that alters Pacific Sea surface temperatures and subsequently affects global and regional weather patterns, including in Indonesia (Millenia et al., 2023). Meanwhile, IOD is an ocean-atmosphere interaction phenomenon in the Indian Ocean that causes differences in sea surface temperatures between the western and eastern parts of the ocean (Pillai et al., 2024; Kaboth-Bahr et al., 2024). Both phenomena significantly impact Indonesia’s climate and air temperature, including in coastal regions like Bengkulu.

ENSO and IOD significantly influence global climate patterns through their individual and interactive effects. ENSO, characterized by variations in sea surface temperatures in the Pacific Ocean, drives extreme weather events such as droughts and floods worldwide (Yu et al., 2017). Meanwhile, the IOD, involving anomalous fluctuations in sea surface temperatures in the Indian Ocean, can modulate ENSO effects, particularly in the Southern

Hemisphere (Andrian et al., 2024). During El Niño, air temperatures tend to rise, especially in urban areas, with surface temperature increases reaching up to 2.5°C higher than regions with different land cover (Eboy & Kemarau, 2023). This increase occurs due to reduced rainfall, which dries out the land and causes it to absorb more heat. Additionally, decreased cloud cover allows more solar radiation to reach the Earth's surface, while lower humidity levels make temperatures feel even hotter (Loeb et al., 2024; Liu et al., 2024; Wardani et al., 2023). Conversely, during La Niña, increased rainfall contributes to cooling effects through latent heat release from precipitation and enhanced cloud cover, which limits incoming solar radiation (McPhaden et al., 2023; Zhong et al., 2024). Previous studies by Stuivenvolt-Allen et al. (2024) and Xia et al. (2017) shown that ENSO intensity and frequency have shifted due to global warming, impacting temperature patterns in tropical regions. Moreover, a variant of ENSO known as ENSO Modoki has become more frequent in recent decades, exhibiting different impacts on temperature and precipitation compared to classical ENSO, particularly in western Indonesia (Zaini et al., 2024; Marathe & Karumuri, 2021).

Besides ENSO, IOD also plays a crucial role in influencing air temperatures in Eastern Sumatra. The positive IOD phase, when coinciding with El Niño, exacerbates temperature increases and reduces rainfall, intensifying drought conditions in Eastern Sumatra (Akhsan et al., 2023). El Niño combined with positive IOD leads to extreme temperature increases, which can impact various sectors such as agriculture and public health (Mishra et al., 2022). Since 1965, the frequency of simultaneous El Niño and positive IOD events has increased, indicating a potential shift in climate patterns that could affect the maritime continent's temperature in the long term (Xiao et al., 2022). In contrast, the negative IOD phase tends to increase rainfall, often leading to lower air temperatures due to atmospheric cooling effects (Zheng et al., 2024; Nasution et al., 2023).

Although this study primarily focuses on ENSO and IOD's impact on air temperatures in Bengkulu, other factors such as urbanization and land use changes must also be considered. Rapid urbanization can enhance the urban heat island effect, contributing to higher temperatures in city areas (Kong, 2025; Purohit, 2024). The conversion of green areas into built-up zones worsens this effect by reducing soil moisture and increasing surface albedo, which directly influences air temperature rises (Abudukade et al., 2023).

On a regional scale, several studies have examined the impact of ENSO and IOD on air temperatures across Indonesia. According to Ariska et al. (2022), a study conducted in Palembang indicated that during El Niño, air temperatures increased while rainfall decreased, whereas La Niña produced the opposite effect. Research in coastal Sumatra also found that during strong El Niño events, average air temperatures increased by 0.26-0.29°C per decade compared to normal conditions (Akhsan et al., 2023; Yuniasih et al., 2022). However, research specifically investigating the relationship between ENSO, IOD, and air temperatures in Bengkulu remains limited. Most of Previous studies have focused on rainfall rather than air temperature and have mostly been conducted outside Sumatra Island (Novianti et al., 2023).

Therefore, this study aims to fill this research gap by analyzing the relationship between ENSO, IOD, and air temperature variability (minimum, maximum, and average) in Bengkulu from 2004 to 2023. The findings are expected to provide scientific insights into the impact of global climate variability on air temperatures in coastal Sumatra and serve as a reference for climate change adaptation planning, particularly for sectors reliant on weather conditions, such as agriculture, fisheries, and public health.

## Materials and Methods

This study was conducted in Bengkulu City using air temperature data from Indonesian Agency for Meteorological, Climatological and Geophysics (BMKG) Fatmawati Soekarno Meteorological Station and Bengkulu Climatology Station for the period of 2004-2023. NOAA provided the data for the Oceanic Nino Index (ONI) and Dipole Mode Index (DMI).

Before conducting the analysis, all datasets underwent a quality control process. For the temperature data from Fatmawati Soekarno Meteorological Station and Bengkulu Climatology Station, outlier detection was performed using the Interquartile Range (IQR) method, and missing values were cross-checked with neighboring stations. The time series plots were visually inspected to ensure continuity and eliminate abrupt anomalies. Duplicate entries and inconsistencies were corrected manually. Validation was conducted for ONI and DMI indices to match the temporal resolution with the monthly climate data used in this study. No seasonal adjustment was applied to preserve the original variability linked to ENSO and IOD events.

Air temperature data were converted into monthly averages prior to analysis and subsequently processed using statistical and temporal analysis tools. The relationship between ENSO, IOD, and air temperature was analyzed using multiple methods, including Pearson Correlation to obtain the linear relationship between ONI, DMI, and air temperature (minimum, maximum, and average), formulated in Equation 1 (Turney, 2024):

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\,\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}} \quad (1)$$

Where $r$ is the correlation coefficient, $x_i$ and $y_i$ are variable values, index $i$ represents each data point in the dataset, running for 1 to n, where n is the total number of observations, $\bar{x}$ and $\bar{y}$ are the averages of each variable (Turney, 2024). Next, Multiple Correlation was used to assess the strength of the relationship between air temperature $(Y)$ and ENSO $(X_1)$ and IOD $(X_2)$ simultaneously, calculated using Equation 2 (Najarzadeh, 2020):

$$R = \frac{\sqrt{r_{y1}^2 + r_{y2}^2 2r_{y1}r_{y2}r_{12}}}{1 - r_{12}^2} \quad (2)$$

where $R$ is the multiple correlation coefficient between the dependent variable $Y$ (air temperature) and the two independent variables $X_1$ (ONI) and $X_2$ (DMI); $r_{y1}$ and $r_{y2}$ are the Pearson correlation coefficients between $Y$ and each independent variable; $r_{12}$ is the Pearson correlation between ONI and DMI (Najarzadeh, 2020).

Multiple linear regression was applied to strengthen the statistical analysis and determine the combined influence of ONI and DMI on maximum air temperature. The regression model is expressed as follows in Equation 3:

$$T_{\text{avg}} = \beta_0 + \beta_1(\text{ONI}) + \beta_2(\text{DMI}) \quad (3)$$

where $T_{\text{avg}}$ is the monthly average air temperature, $\beta_0$ is the intercept, and $\beta_1$ and $\beta_2$ are the regression coefficients representing the influence of ONI and DMI, respectively. The model's statistical performance was evaluated using the coefficient of determination ($R^2$), F-statistic, and *p*-values of each predictor to determine the strength and significance of the relationship.

Furthermore, a phase-based composite analysis was conducted by categorizing each month into ONI and DMI phase combinations to assess how different ENSO and IOD conditions interact to influence air temperature. ONI values were classified into El Niño (ONI ≥ +0.5), La Niña (ONI ≤ -0.5), and Neutral (-0.5 < ONI < +0.5), while DMI values were classified into Positive IOD (DMI ≥ +0.4), Negative IOD (DMI ≤ -0.4), and Neutral (-0.4 < DMI < +0.4). Monthly air temperature data were grouped accordingly and averaged for each combination. This approach does not involve anomaly-based climatological composites but allows a direct comparison of temperature responses across specific ENSO-IOD phase combinations.

The results of this analysis provide insights into how ENSO and IOD influence air temperature variability in Bengkulu over the long term.

## Results and Discussion

*Average Air Temperature Fluctuations*

The average air temperature in Bengkulu City has shown an increasing trend over the period of 2004-2023 (Figures 1 and 2). Seasonal fluctuations appear consistent, following an annual cycle with several significant temperature peaks. This consistent upward trend aligns with global warming patterns and reflects long-term climatic shifts, as depicted by the trend line.

Based on Figure 1, the dark blue line represents fluctuations in the average air temperature, while the red line indicates the trend of the average air temperature. The average air temperature at Fatmawati Soekarno Meteorological Station in Bengkulu has shown an increasing trend from 2004 to 2023. Seasonal fluctuations remain consistent with the annual cycle, and the trend line in the graph indicates a gradual rise in temperature. The highest recorded temperature occurred in May 2023, reaching 28.3°C, possibly influenced by a moderate El Niño event (ONI = 0.5).

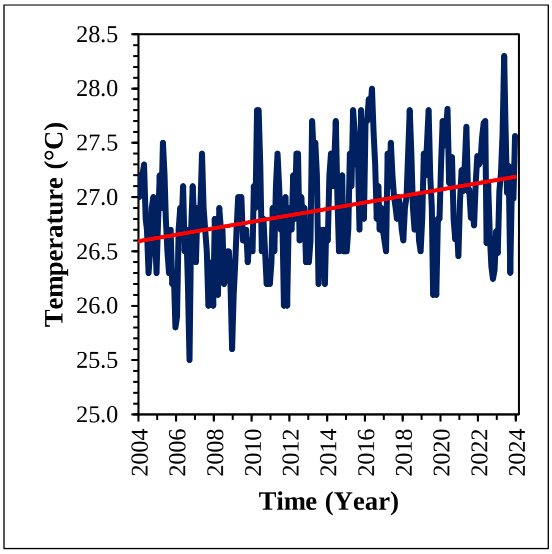


**Figure 1.** Average Air Temperature Trend at Fatmawati Soekarno Meteorological Station, Bengkulu (2004-2023).

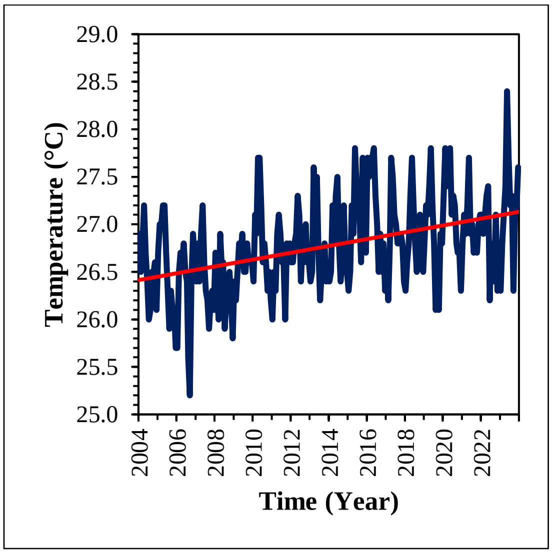


**Figure 2.** Average Air Temperature Trend at Bengkulu Climatology Station (2004-2023).

Jiang et al. (2025) confirmed that 2023 recorded the highest-ever global mean surface temperature (GMST), with El Niño warming and rising sea surface temperature (SST) as the primary contributing factors. Their study highlights how El Niño-induced warming and SST anomalies significantly contributed to the record GMST in 2023. This supports the finding that the temperature rise in Bengkulu in May 2023 is likely part of a broader global warming trend. Additionally, the accelerated warming trend observed in their study suggests that increasing temperatures and extreme climate variability may persist, emphasizing the need for further research on regional climate impacts.

Meanwhile, Figure 2 illustrates the average air temperature pattern at Bengkulu Climatology Station, which also exhibits a similar increasing trend. The highest recorded temperature was 28.4°C in May 2023. Although there are slight differences between the two stations, the nearly identical upward trend suggests that local air temperature variability in Bengkulu City is closely correlated with global climate change.

*Impact of ENSO and IOD on Average Air Temperature Trends*

Based on Figure 3, the average air temperature trend from 2004 to 2023 shows an overall increase.

The trendline equation at Fatmawati Soekarno Meteorological Station indicates an increase of 0.00008°C per month (approximately 0.0096°C per decade), while at Bengkulu Climatology Station, the rise reaches 0.0001°C per month (or 0.012°C per decade). Although this increase is relatively small, it suggests a consistent long-term temperature change. Previous studies, such as Hansen et al. (2017) and Tan (2024), indicate that even minor but continuous warming trends can contribute to shifts in climate patterns, increased frequency of extreme weather events, and changes in local atmospheric dynamics. The IPCC (2021) estimates a global warming trend of approximately 0.2°C per decade, making these observed trends appear small but still relevant in a regional context.

ENSO and IOD influence air temperature, as seen in May 2023 when temperatures peaked (28.3°C at the Meteorological Station and 28.4°C at the Climatology Station) under moderate El Niño (ONI = 0.5) and neutral IOD (DMI = 0.02). El Niño increases air temperature, with impacts varying by intensity and duration. On the other hand, the warming trend is also influenced by global climate variability. During La Niña periods, the average air temperature tends to be lower than during El Niño, although the long-term trend remains upward. This suggests that temperature changes in Bengkulu are more strongly influenced by ENSO than by IOD, which has a weaker impact on average air temperature fluctuations.

A study by Jiang et al. (2025) highlights that El Niño has a significant influence on global mean surface temperature (GMST), with 2023 exemplifying this effect. While the Indian Ocean Dipole (IOD) plays a less dominant role, the warming trend persists, emphasizing ENSO's primary influence on temperature fluctuations. Their findings reinforce the notion that the temperature variations in Bengkulu are part of a broader global warming pattern, where ENSO-driven changes outweigh the effects of other climate phenomena. This further supports the observed trend that temperature increases during El Niño events are more pronounced, whereas the cooling effect of La Niña is insufficient to counteract the long-term warming trajectory.

*Maximum Air Temperature Fluctuations*

Based on Table 1, the maximum temperature at Fatmawati Soekarno Meteorological Station and Bengkulu Climatology Station exhibited significant fluctuations from 2004 to 2023. The peak temperatures were recorded in February 2019 (35.9°C) and May 2018 (36°C), coinciding with a Moderate El Niño (ONI = 0.7) and a Neutral to Slightly Negative IOD (DMI = -0.06). The trendline indicates a gradual increase at a rate of 0.0001°C per month at the Meteorological Station, with a slightly higher rate at the Climatology Station. Although small, this trend suggests an increase in extreme temperatures due to global warming and regional climate variability.

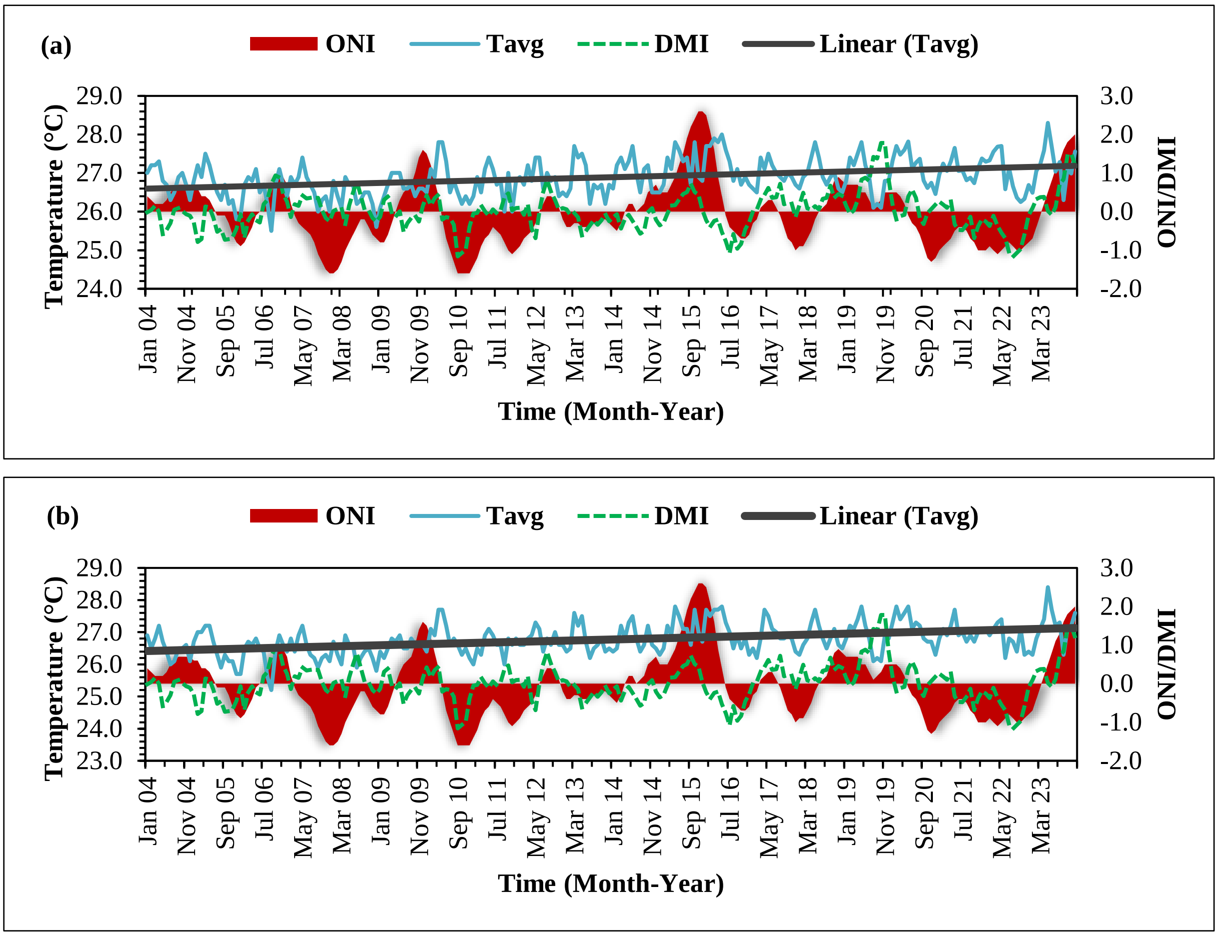


**Figure 3.** Time Series Graph of ENSO and IOD Events on Average Air Temperature at (a) Fatmawati Soekarno Meteorological Station, Bengkulu and (b) Bengkulu Climatology Station (2004-2023).

**Table 1.** Maximum temperature data for the 2004-2023 period.

| Observation Station | *T*max | | Index | |
|---|---|---|---|---|
| | Value | Time | ONI | DMI |
| Meteorological | 35.9 | Feb-19 | 0.7 | -0.06 |
| Climatology | 36 | May-18 | -0.2 | 0.14 |

Maximum temperatures tend to be higher during El Niño due to reduced rainfall and humidity, whereas during La Niña, temperatures are lower due to increased precipitation. The data in Table 1 confirms that ENSO has a more dominant influence on maximum temperature compared to IOD. A study by Ferreira & Badinger (2023) also found that El Niño significantly increases average temperatures, particularly in December, across various cities in Brazil. Their analysis of historical climate trends indicates that this phenomenon is accompanied by decreased rainfall, exacerbating hot conditions. Thus, the stronger relationship between ENSO and maximum temperature observed in Bengkulu aligns with the patterns identified in their study, although regional factors may also influence the intensity of its impact.

*Impact of ENSO and IOD on Maximum Air Temperature Trends*

Based on Figure 4, the trend of maximum air temperature from 2004 to 2023 shows a stable increase. The trendline equation indicates a rise in maximum temperature of 0.0001°C per month at the Meteorological Station, with a slightly higher rate at the Climatology Station. Although small, this trend reflects long-term warming due to global climate variability.

ENSO significantly influences fluctuations in maximum temperature. For example, in February 2019, the Meteorological Station recorded a maximum temperature of 35.9°C during a moderate El Niño event (ONI = 0.7) and a Neutral to Slightly Negative IOD (DMI = -0.06). Similarly, in May 2018, the maximum temperature at the Climatology Station reached 36°C despite being in a Weak La Niña phase (-0.2) and a Weak Positive IOD (DMI = 0.14). This indicates that El Niño tends to increase maximum temperatures, especially when rainfall decreases and humidity is lower. On the other hand, La Niña does not always significantly reduce maximum temperatures, as other factors such as solar radiation and regional atmospheric conditions also play a role. Meanwhile, the influence of IOD on maximum temperature in Bengkulu is relatively weak and does not always align with observed trends.

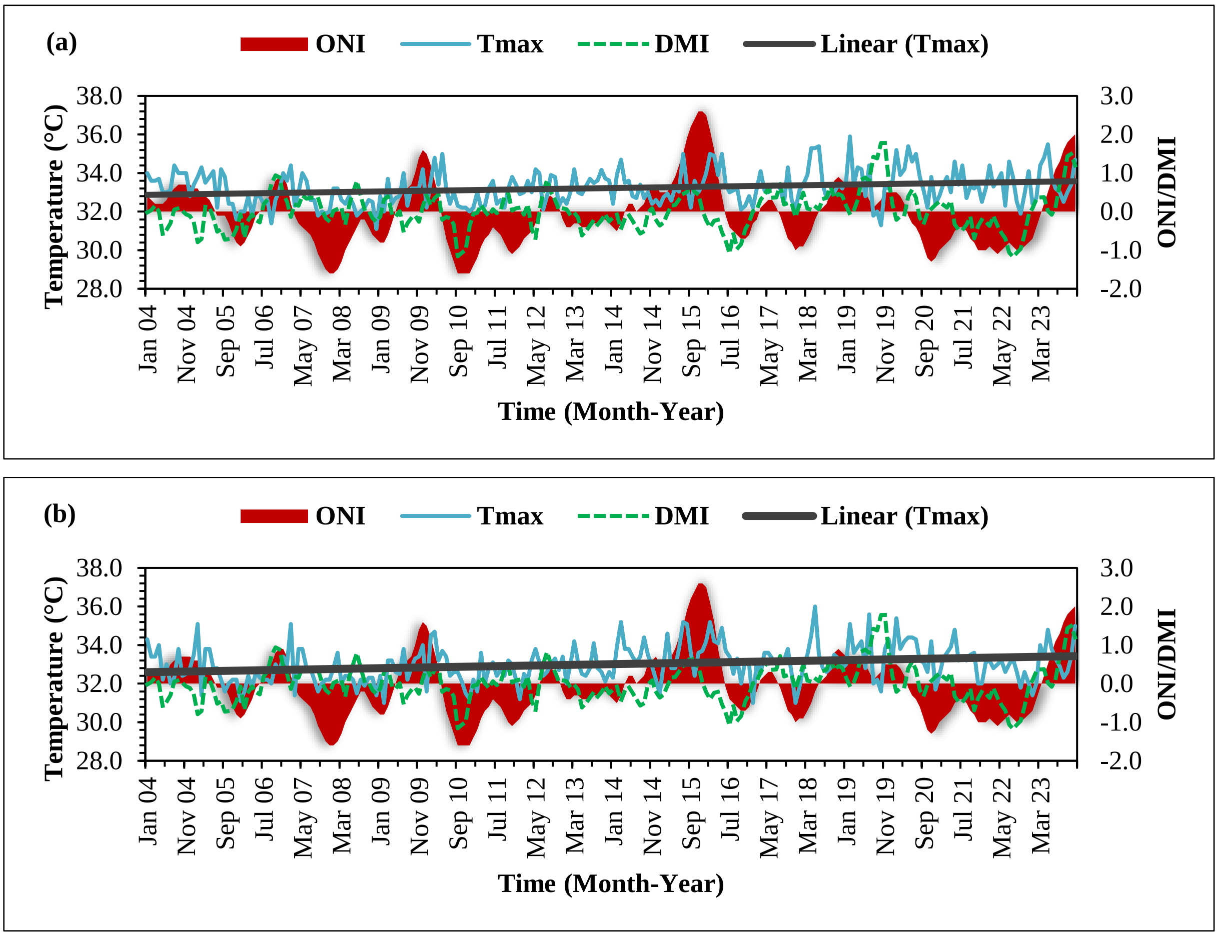


**Figure 4.** Time Series Graph of ENSO and IOD Events on Maximum Air Temperature at (a) Fatmawati Soekarno Meteorological Station, Bengkulu and (b) Bengkulu Climatology Station 2004-2023.

*Minimum Air Temperature Fluctuations*

Based on Table 2, the minimum air temperature showed significant fluctuations from 2004 to 2023. The lowest recorded temperature occurred in September 2019, reaching 18°C at the Meteorological Station and 19°C at the Climatology Station, when the ONI was at 0.2 (Neutral tending towards Weak El Niño) and the DMI reached 1.38 (Strong Positive IOD). This indicates that minimum temperature is more influenced by local atmospheric factors and regional circulation rather than ENSO. The trendline shows a gradual increase, at a rate of 0.00008°C per month at the Meteorological

Station and 0.0001°C per month at the Climatology Station, indicating long-term temperature changes due to global warming and shifts in regional climate patterns.

**Table 2.** Minimum temperature data for the 2004-2023 period.

| Observation Station | $T$min | | Index | |
|---|---|---|---|---|
| | Value | Time | ONI | DMI |
| Meteorological | 18 | Sep-19 | 0.2 | 1.38 |
| Climatology | 19 | Sep-06 | 0.5 | 0.71 |
| | 19 | Dec-10 | -1.6 | -0.39 |
| | 19 | Jan-15 | 0.5 | -0.36 |
| | 19 | Sep-19 | 0.2 | 1.38 |

The fluctuation pattern of minimum temperature is more complex compared to maximum temperature. El Niño does not always significantly increase minimum temperature, while during La Niña, minimum temperature tends to be more stable. IOD also does not show a consistent relationship pattern, indicating that minimum temperature variability is more influenced by local factors such as humidity, cloud cover, and coastal atmospheric dynamics in Bengkulu.

*The Influence of ENSO and IOD on Minimum Air Temperature Trends*

Figure 5 indicates a gradual upward trend in minimum air temperature in Bengkulu from 2004 to 2023, with estimated increases of 0.00008°C/month at the Meteorological Station and 0.0001°C/month at the Climatology Station. However, the influence of ENSO and IOD phases on minimum temperature appears limited and inconsistent, suggesting a more substantial contribution from local atmospheric factors. For instance, the lowest temperature (18°C) occurred in September 2019 during a weak El Niño and strong positive IOD (ONI = 0.2, DMI = 1.38), yet similar extremes were not observed in other ENSO/IOD phases. These suggest that local atmospheric conditions-such as humidity, cloud cover, and coastal circulation have a stronger role in shaping minimum temperature trends than global climate indices. Overall, minimum temperature variations in Bengkulu are more complex than those of maximum or average temperature.

*Composite Analysis of ENSO and IOD Phases on Air Temperature*

A simplified phase-based composite analysis was conducted by grouping monthly temperature data according to ONI and DMI classifications to understand better the combined influence of ENSO dan IOD on air temperature variability. Each month from 2004 to 2023 was assigned to a specific ENSO-IOD phase based on ONI and DMI thresholds, resulting in five main combinations: ONI+ DMI+, ONI− DMI−, ONI+ DMI−, ONI− DMI+, and Neutral (ONI & DMI both within neutral range).

This approach does not calculate climatological anomalies, but instead averages observed temperature values within each phase group. The classification reflects the typical phase interactions of ENSO and IOD over three-month intervals, following climatological conventions. By using this grouped composite method, the study aims to highlight the general temperature response associated with different ENSO-IOD combinations. This form of phase-based composite classification is widely used in climate research to isolate the effects of concurrent climate drivers.

The average temperature values under each category are presented in Tables 3 and 4, revealing clear differences in Bengkulu's temperature response depending on the specific ENSO-IOD phase interaction.

The Table 3 also includes predicted average temperatures ($T_{p-avg}$) calculated using a multiple linear regression model based on ONI and DMI values (see Equation 4). These predicted values are intended to estimate the statistical contribution of climate drivers on air temperature and are not expected to perfectly match observed values due to the influence of local atmospheric factors not captured in the model.

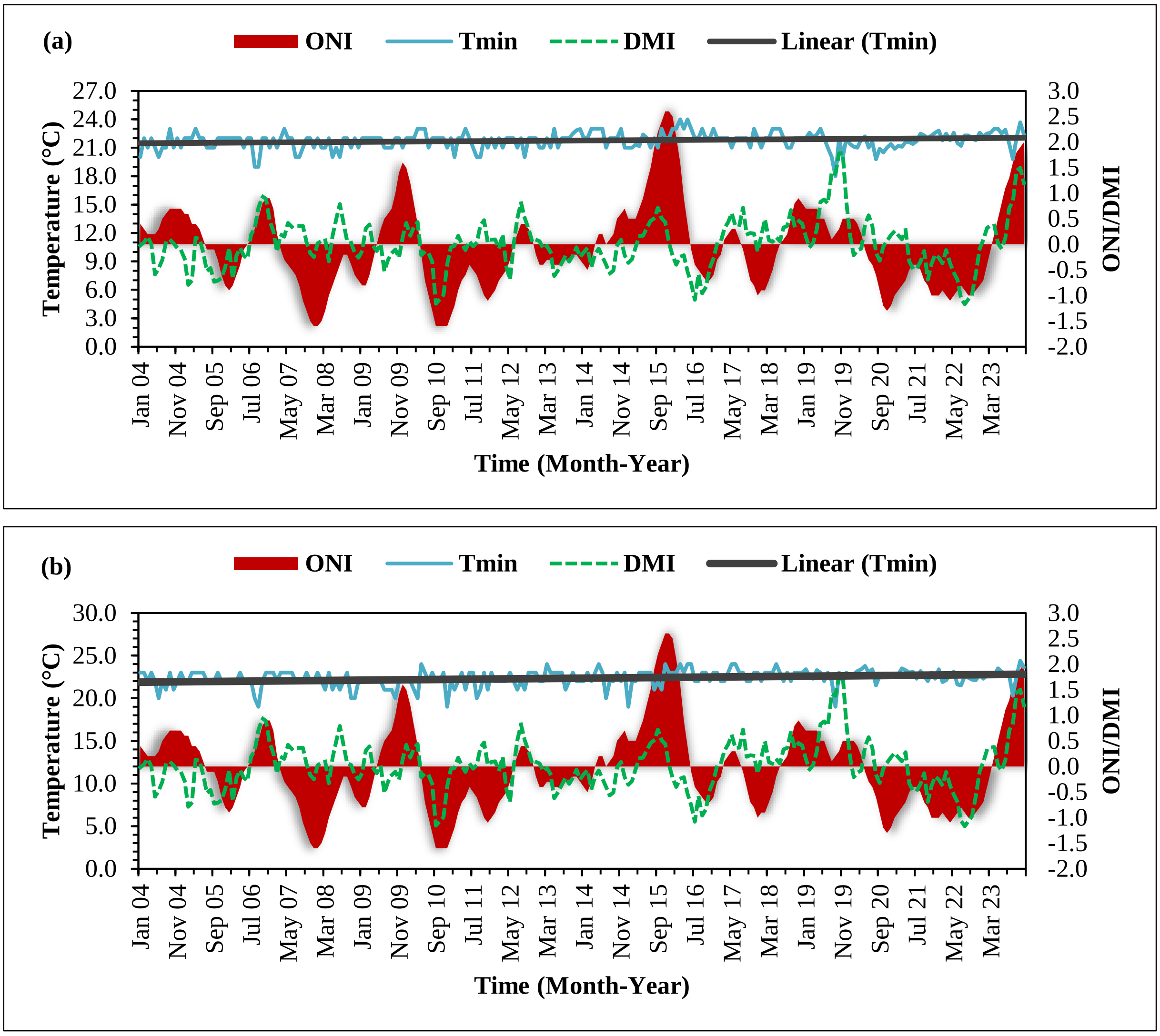


**Figure 5.** Time Series Graph of ENSO and IOD Events on Minimum Air Temperature at (a) Fatmawati Soekarno Meteorological Station, Bengkulu and (b) Bengkulu Climatology Station 2004-2023

**Table 3.** Classification of ENSO (ONI) and IOD (DMI) Phases and Corresponding Monthly Air Temperatures (Minimum, Average, and Maximum) at Fatmawati Soekarno Meteorological Station, Bengkulu (2004-2023).

| Classification | Time | *T* | | | Index | |
|---|---|---|---|---|---|---|
| | | ***T*avg** | ***T*p − avg** | ***T*max** | **ONI** | **DMI** |
| El Niño and Positive IOD | Sep-15 | 26.7 | 27.2 | 32.2 | 2.2 | 0.72 |
| | Oct-15 | 27.8 | 27.3 | 33.6 | 2.4 | 0.51 |
| | Nov-15 | 26.9 | 27.4 | 33.0 | 2.6 | 0.44 |
| La Niña and Negative IOD | Sep-10 | 26.5 | 26.7 | 32.3 | -1.6 | -1.16 |
| | Oct-10 | 26.2 | 26.7 | 32.2 | -1.6 | -1.07 |
| | Nov-10 | 26.4 | 26.7 | 32.2 | -1.6 | -0.99 |
| Normal | Apr-05 | 27.5 | 27.0 | 33.5 | 0.4 | 0.13 |
| | May-05 | 27.2 | 27.0 | 33.8 | 0.3 | 0.11 |
| | Jun-05 | 26.8 | 26.9 | 34.1 | 0.1 | -0.16 |

Based on data from the Fatmawati Soekarno Meteorological Station in Bengkulu, the ONI+ DMI+ category, representing the combination of El Niño and Positive IOD, occurred from September to November 2015. During this period, air temperature experienced a significant increase. In September 2015, the minimum temperature was recorded at 21.0°C, the average temperature at 26.7°C, and the maximum temperature at 32.2°C. By October 2015, the minimum temperature rose to 23.0°C, the average temperature reached 27.8°C, and the maximum temperature peaked at 33.6°C, supported by an ONI index of 2.4 and a DMI of 0.51. The peak of El Niño occurred in November 2015, marked by a slight decrease in maximum temperature to 33.0°C, while the average temperature remained high at 26.9°C. The ONI value increased to 2.6, indicating that this period was strongly influenced by the intensity of El Niño. The impact of this combination is illustrated in Figure 6a, which shows the trend of rising air temperatures during this period.

The ONI- DMI- category, representing the influence of La Niña and Negative IOD, occurred from September to November 2010. Data from the Fatmawati Soekarno Meteorological Station in Bengkulu indicate that air temperatures were lower compared to El Niño periods. In September 2010, the minimum temperature was recorded at 22.0°C, the average temperature at 26.5°C, and the maximum temperature at 32.3°C, with an ONI index of -1.6 and a DMI of -1.16. Similar conditions continued in October, with the average temperature slightly decreasing to 26.2°C while the maximum temperature remained around 32,2°C. By November 2010, the average temperature rose again to 26.4°C, while the ONI value remained at -1.6 and the DMI increased to -0.99, indicating that the influence of La Niña persisted but had begun to weaken. The graph in Figure 6b illustrates the air temperature patterns during this period, showing that temperatures were relatively lower compared to El Niño periods.

Meanwhile, the period from April to June 2005 was categorized as Normal, with no significant influence from ONI or DMI. During this time, air temperatures remained relatively stable, with minimum temperatures ranging between 22.0°C and 23.0°C and maximum temperatures between 33.5°C and 34.1°C. The ONI and DMI indices values were close to zero, indicating no significant ENSO or IOD anomalies affecting air temperatures drastically. This stability is also reflected in Figure 6c, which shows a more consistent temperature pattern compared to El Niño or La Niña periods.

**Table 4.** Classification of ENSO (ONI) and IOD (DMI) Phases and Corresponding Monthly Air Temperatures (Minimum, Average, and Maximum) at Bengkulu Climatology Station (2004-2023).

| Classification | Time | $T$ | | | Index | |
|---|---|---|---|---|---|---|
| | | $T$avg | $T$p − avg | $T$max | ONI | DMI |
| El Niño and Positive IOD | Sep-23 | 26.3 | 27.0 | 32.3 | 1.6 | 0.84 |
| | Oct-23 | 27.1 | 27.0 | 32.6 | 1.8 | 1.44 |
| | Nov-23 | 27.2 | 27.0 | 33.4 | 1.9 | 1.50 |
| La Niña and Negative IOD | Sep-16 | 26.9 | 26.8 | 33.3 | -0.6 | -0.96 |
| | Oct-16 | 26.5 | 26.7 | 32.0 | -0.7 | -0.84 |
| | Nov-16 | 26.8 | 26.7 | 33.2 | -0.7 | -0.46 |
| Normal | Jun-18 | 27.2 | 26.8 | 33.5 | 0.0 | 0.06 |
| | Jul-18 | 26.8 | 26.8 | 32.8 | 0.1 | 0.33 |
| | Aug-18 | 26.5 | 26.8 | 32.6 | 0.2 | -0.36 |

The same analysis was conducted on data from the Bengkulu Climatology Station, as shown in Table 4, revealing a similar pattern. The period from September to November 2023 fell under the ONI+ DMI+ category, indicating a temperature increase due to El Niño combined with a Positive IOD. In September 2023, the minimum temperature was recorded at 20.3°C, with an average temperature of 26.3°C and a maximum temperature of 32.3°C. The warming trend continued into October and November, with the maximum temperature reaching 33.4°C in the final month. The graph in Figure 7a illustrates that this temperature increase pattern is like that of 2015, reinforcing the conclusion that the El Niño combined with a Positive IOD contributes to significant warming in Bengkulu.

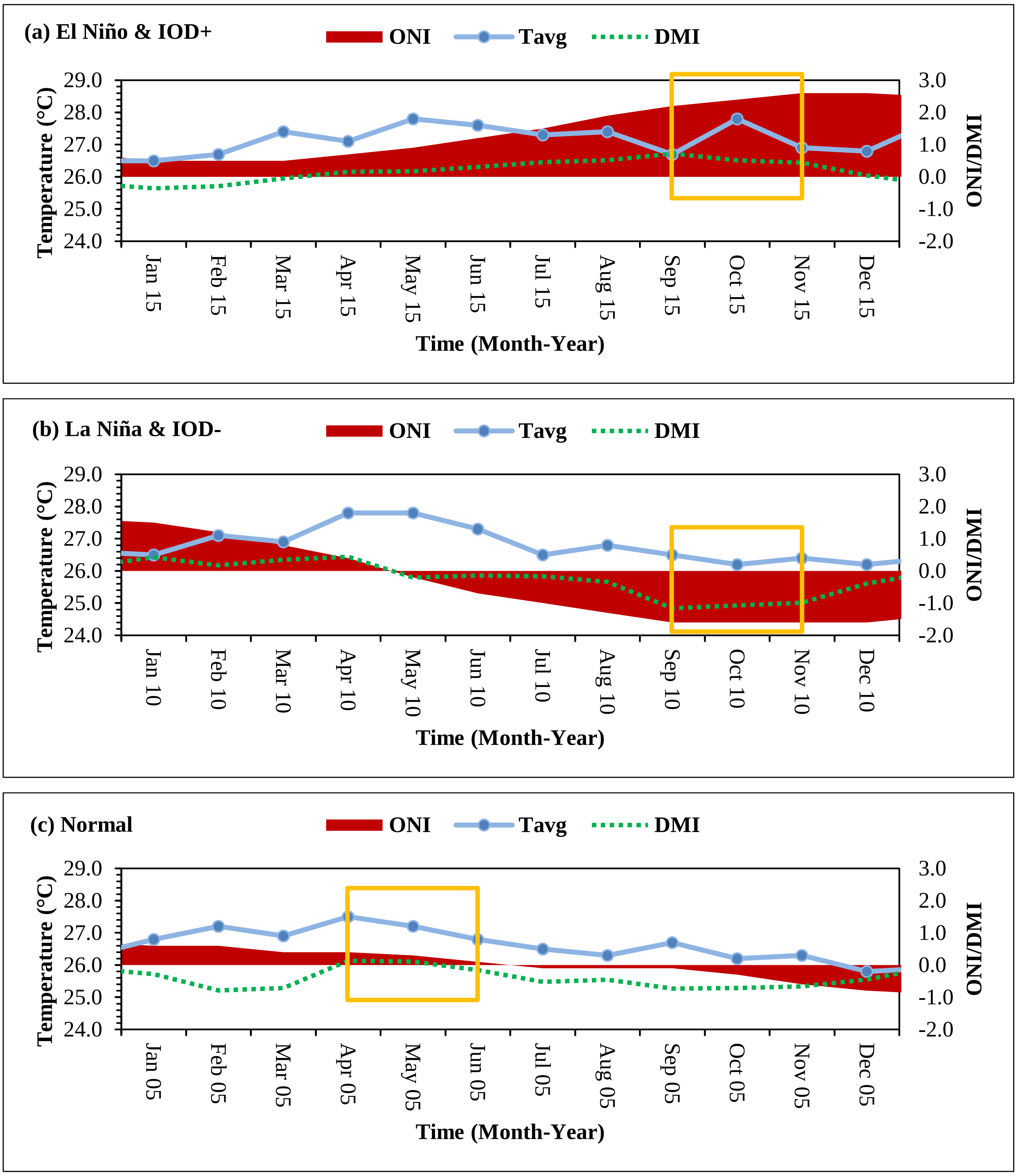


**Figure 6.** Average Air Temperature Trends During (a) El Niño and Positive IOD (Sep-Nov 2015), (b) La Niña and Negative IOD (Sep-Nov 2010), and (c) Normal Conditions (Apr-Jun 2005) at Fatmawati Soekarno Meteorological Station, Bengkulu.

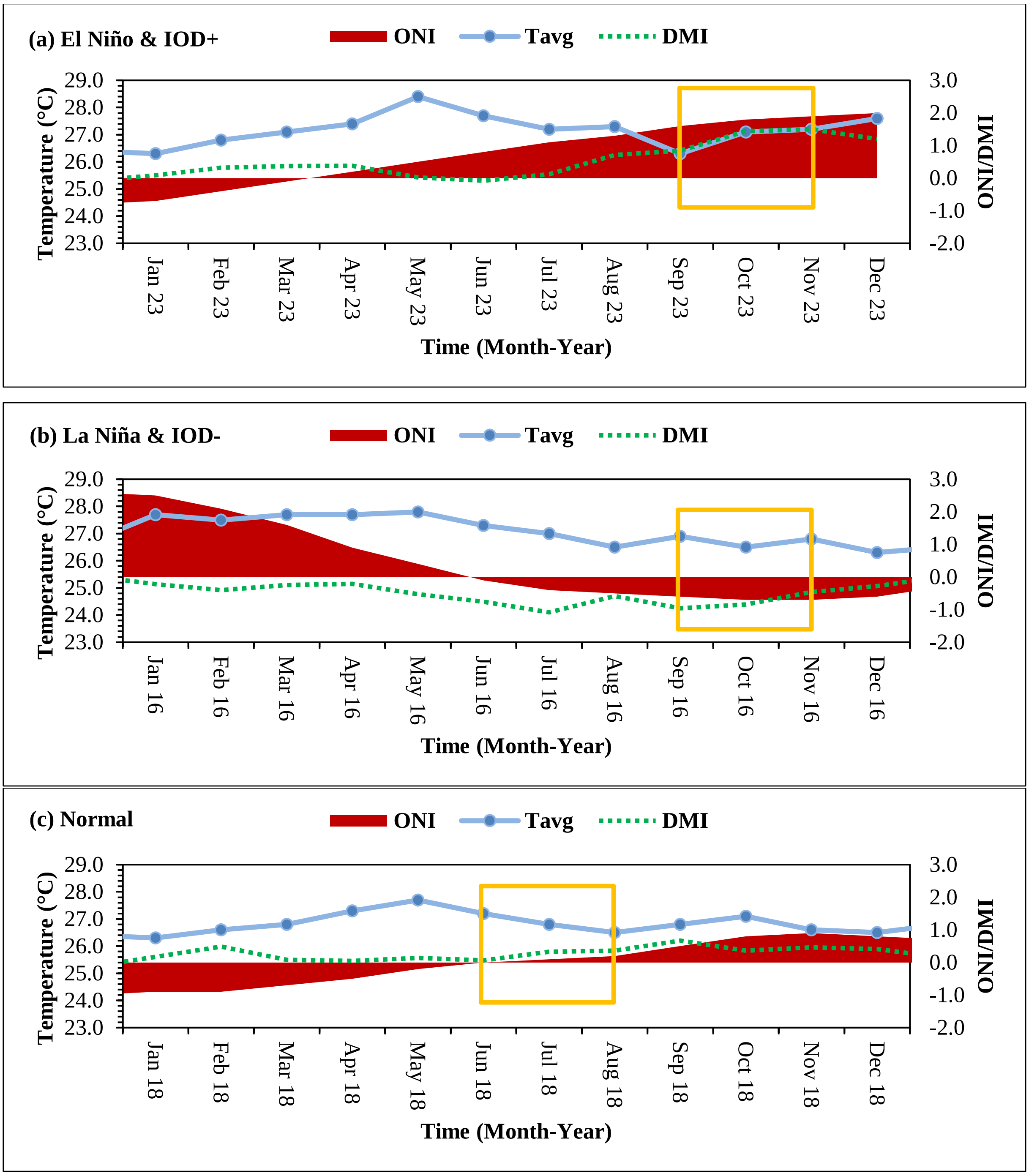


**Figure 7.** Average Air Temperature Trends During (a) El Niño and Positive IOD (Sep-Nov 2023), (b) La Niña and Negative IOD (Sep-Nov 2016), and (c) Normal Conditions (Jun-Aug 2018) at Bengkulu Climatology Station

In Table 4, predicted average temperatures ($T_{p-avg}$) were calculated based on a multiple linear regression model using ONI and DMI as predictors (Equation 5). These estimates help illustrate how large-scale ocean-atmospheric interactions influence temperature, while acknowledging that regional and local processes also affect actual observations.

Conversely, the ONI- DMI- category occurred from September to November 2016, during which air temperatures were lower compared to normal conditions. In September, the average temperature was recorded at 26.9°C, slightly higher than in October, which saw a decrease to 26.5°C. By November, the average temperature rose again to 26.8°C, indicating that the effects of La Niña were still dominant but began to weaken toward the end of the year. The graph in Figure 7b illustrates a more stable temperature trend compared to the El Niño period, though it remained lower than normal conditions.

The Normal category, which occurred from June to August 2018, exhibited more stable temperatures without the influence of El Niño or La Niña. The average temperature ranged from 26.5°C to 27.2°C, with a maximum temperature reaching 33.5°C in June. The absence of extreme temperature increases or decreases during this period indicates that atmospheric and oceanic conditions were in equilibrium. Figure 7c illustrates a more consistent temperature pattern compared to other extreme conditions.

From this classification, it can be concluded that ONI+ DMI+ has the greatest warming impact on air temperature in Bengkulu, while ONI- DMI- tends to lower temperatures. Meanwhile, the Normal category represents more stable conditions without significant temperature changes.

*Correlation of Air Temperature with ONI land DMI*

Correlation analysis using Equation (1) for Pearson correlation shows that ONI has a positive relationship with the average air temperature in Bengkulu, although it falls within the weak to moderate category ($r$ = 0.29-0.32), while DMI exhibits a weaker correlation ($r$ = 0.01-0.04). Multiple correlation using Equation (2) slightly enhances this relationship, with values of 0.31 at the Meteorological Station and 0.36 at the Climatology Station.

Minimum temperature exhibits a weaker correlation, with ONI ranging between 0.07–0.11, while DMI shows a negative association at Meteorological (-0.20) and near zero at Climatology (0.01). Multiple correlations using Equation (2) for minimum temperature remain low (0.28 in Meteorological and 0.10 in Climatology), indicating that local factors play a more dominant role. Conversely, maximum temperature has a stronger correlation with ONI (0.28 in Meteorological and 0.38 in Climatology), while its relationship with DMI remains weak (-0.03 to 0.07). The multiple correlation using Equation (2) for maximum temperature increases to 0.32 in Meteorological and 0.42 in Climatology, suggesting that the combination of ONI and DMI has a greater impact on maximum temperature.

To strengthen the statistical interpretation of the correlation analysis, a multiple linear regression was conducted using ONI and DMI as independent variables, with average air temperature as the dependent variable. Based on Equation (3), the regression model aims to identify the extent to which ENSO and IOD jointly contribute to variations in air temperature in Bengkulu.

At the Meteorological Station, the regression equation obtained is shown in Equation (4):

$$T_{\text{avg}} = 26.91 + 0.19(\text{ONI}) - 0.11(\text{DMI}) \quad (4)$$

The model yielded an $R^2$ value of 0.0965, indicating that approximately 9.7% of the variation in average air temperature can be explained by ONI and DMI. The coefficient for ONI was statistically significant ($p$ < 0.001), showing a positive association with higher temperatures. In contrast, DMI showed a weaker negative influence ($p$ = 0.077), suggesting that its contribution to temperature variation is less dominant and not statistically conclusive.

At Climatology Station, the regression result is presented in Equation (5):

$$T_{\text{avg}} = 26.79 + 0.20(\text{ONI}) - 0.10(\text{DMI}) \quad (5)$$

This model produced a slightly higher $R^2$ value of 0.1092. Again, ONI was found to have a significant positive effect ($p$ <

0.001), whereas DMI remained statistically insignificant ($p$ = 0.127). These results are consistent with the previous correlation findings, confirming that ENSO-particularly El Niño events-has a stronger influence on air temperature in Bengkulu compared to IOD. A summary of the regression statistics is presented in Table 5.

Although the regression model demonstrates a statistically significant relationship between ONI, DMI, and average air temperature, the differences between observed values ($T_{\text{avg}}$) and predicted values ($T_{\text{p-avg}}$) are expected. This is because the model only includes large-scale ocean-atmospheric indices and does not account for local and regional climatic influences, such as humidity, cloud cover, local wind patterns, and land surface characteristics. Consequently, the predicted values are not intended for precise forecasting, but rather to illustrate the statistical contribution of ENSO and IOD in explaining air temperature variability in Bengkulu.

Overall, ONI has a greater influence on Bengkulu's air temperature compared to DMI, which tends to have a minor or statistically insignificant effect. This pattern is consistently observed in both the correlation and regression analyses. The regression results provide stronger statistical evidence: ONI was shown to have a significant positive influence on temperature, while DMI’s effect was weaker and not significant at the 95% confidence level. Although the $R^2$ values in both regression models were relatively low-suggesting that other atmospheric factors, such as monsoonal wind patterns, likely play a more decisive role-the results confirm that ENSO, especially during El Niño events, remains a dominant driver of warming in Bengkulu. These correlation results are summarized in Table 6.

**Table 5.** Multiple linear regression summary for average air temperature with ONI and DMI.

| Observation Station | Variable | Coefficient ($\beta$) | Std. Error | $t$-value | $p$-value |
|---|---|---|---|---|---|
| Meteorological | Intercept | 26.91 | 0.07 | 384.4 | <0.001 |
| | ONI | 0.19 | 0.05 | 4.12 | <0.001 |
| | DMI | -0.11 | 0.06 | -1.78 | 0.077 |
| | $R^2$ | 0.0965 | | | |
| Climatology | Intercept | 26.79 | 0.08 | 334.9 | <0.001 |
| | ONI | 0.20 | 0.04 | 4.46 | <0.001 |
| | DMI | -0.10 | 0.06 | -1.53 | 0.127 |
| | $R^2$ | 0.1092 | | | |

**Table 6.** Pearson and Multiple correlation coefficients of ONI and DMI with air temperature.

| Observation Station | $T$ | Pearson Correlation | | Multiple Correlation |
|---|---|---|---|---|
| | | $r$ ONI | $r$ DMI | |
| *Meteorological* | $T$min | 0.11 | -0.20 | 0.28 |
| | $T$avg | 0.29 | 0.01 | 0.31 |
| | $T$max | 0.28 | -0.03 | 0.32 |
| *Climatology* | $T$min | 0.07 | 0.01 | 0.10 |
| | $T$avg | 0.32 | 0.04 | 0.36 |
| | $T$max | 0.38 | 0.07 | 0.42 |

**Table 7.** Comparison of ENSO and IOD influence on air temperature in various regions.

| Study | Location | Influence | | Other Influencing Factors |
|---|---|---|---|---|
| | | ENSO | IOD | |
| This Study | Bengkulu City | Dominant ($r = 0.28 - 0.38$) | Weak/Not Significant ($r = -0.03 - 0.07$) | Monsoon wind patterns, geographical factors. |
| Prasetyo et al. (2021) | Java Island | Not Significant ($r \approx 0$) | Moderate - Strong ($r = 0.42 - 0.77$) | Asian Monsoon, Indian Ocean influence. |

This finding contrasts with the results of Prasetyo et al. (2021), who reported that IOD had a stronger correlation with air temperature fluctuations in Java, while ENSO showed no significant relationship. The discrepancy may be attributed to differences in regional atmospheric circulation; Java is more influenced by Indian Ocean dynamics and the Asian Monsoon, whereas Bengkulu-situated on Sumatra's western coast-is more directly affected by the Walker Circulation, particularly during El Niño phases. Therefore, the influence of climate variability on air temperature is inherently regional, shaped by both atmospheric conditions and geographical location. A broader comparison of this study with another research is presented in Table 7.

## Conclusion

Over the past 20 years, Bengkulu City has experienced a steady increase in air temperature, with an annual warming trend of approximately 0.08-0.1°C. ENSO was found to have a stronger influence than IOD, particularly during El Niño phases that correlate with elevated maximum temperatures ($r$ = 0.28-0.38). In contrast, minimum temperatures showed weaker correlations, suggesting that local atmospheric dynamics may play a more substantial role in nighttime cooling.

These findings are supported by multiple linear regression results, which showed that ONI has a statistically significant positive effect on average air temperature. At the same time, DMI’s influence was weaker and not significant. Although the explained variance is modest ($R^2$ = 0.0965-0.1092), the regression model confirms ENSO-especially El Niño-as a dominant driver of temperature variability in Bengkulu.

The phase-based composite analysis further revealed that the highest average temperatures occurred during ONI+ DMI+ conditions, while the lowest were observed under ONI− DMI− phases. These findings underscore the synergistic impact of ENSO and IOD in modulating regional temperature variability, particularly during extreme climate phases.

The convergence of results across trend analysis, correlation, regression, and composite classification highlights the importance of incorporating real-time ENSO and IOD monitoring into local early warning systems. Adaptive measures-such as water resource management, rainwater harvesting, and reservoir optimization-are crucial to mitigate the prolonged dry seasons associated with El Niño. Future research should explore how regional warming affects agriculture, public health, and coastal ecosystems in Bengkulu. Developing predictive models that integrate ENSO and IOD indicators may significantly improve regional climate resilience and preparedness.

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collection, and analysis throughout this research.

## Author Contribution

**Mardho Tillah Edkayasa:** Developed the research concept and objectives, designed the methodology, and collected climate data from reliable sources. Conducted data processing and statistical analysis of temperature trends, including the impacts of ENSO and IOD, using Microsoft Excel. Performed Pearson correlation, multiple linear regression, and composite analysis to evaluate relationships between variables and identify anomalies in climate variability. Drafted the manuscript by integrating research findings with relevant literature and formulating the overall discussion.

**Elfi Yuliza:** Guided the journal writing process and the structure of academic writing, and critically reviewed and revised the manuscript to ensure its quality for publication.

**Lizalidiawati:** As the primary supervisor, provided intensive guidance throughout the research process, assisted in climatological analysis, and offered in-depth insights for interpreting the results.

## Conflict of Interest

The authors declare no conflict of interest. The content of this manuscript has been reviewed and approved by all authors. They affirm that the material is original, has not been published previously, and is not under consideration for publication elsewhere.

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