COMPARISON OF Triple-Dip LA NIÑA IN 2020-2023 WITH STRONG AND WEAK LA NIÑA EVENTS ON INDONESIAN RAINFALL AND SST

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ABSTRACT

The Triple-Dip La Niña event that occurred from 2020 to 2023 was a rare phenomenon characterized by enhanced convection and extreme rainfall. This study aims to quantify and compare rainfall and SST during different La Niña conditions, and to analyze the factors driving rainfall variability over these events. This research examines three La Niña events: Triple-Dip (2020-2023), strong (2010-2011), and weak La Niña (2017-2018), within Indonesia, located between 6°N-11°S and 95°E-141°E. In this study, satellite-based rainfall, SST and surface wind data served as primary data sources, which were analyzed using anomaly map. Triple-Dip and strong La Niña events exhibit similar spatial patterns of anomalies in rainfall and sea surface temperature (SST). During the JJASON period, these phenomena led to increased rainfall across much of Indonesia, including regions such as Sumatra, Western and Central Kalimantan, Sulawesi, parts of Maluku, Papua, Western Java, the waters off western Sumatra, the Natuna Sea, Java Sea, Banda Sea, and Arafura Sea. This season also saw a rise in SST throughout most of Indonesia. Conversely, during the December to May period, Triple-Dip and strong La Niña resulted in reduced rainfall in areas like Sumatra, Java, Kalimantan, Sulawesi, Maluku, and Papua, along with a decrease in SST in the Natuna Sea, Java Sea, Flores Sea, and the Indian Ocean, from the western waters of Sumatra to the southern waters of Java. In contrast, weak La Niña events displayed a more scattered pattern of rainfall anomalies, though the SST anomaly distribution was largely similar to that of Triple-Dip and strong events, except during June-August. During June-August, weak events showed a decline in SST in the Southern Java Sea. The increase in rainfall during La Niña events was particularly notable during June-November, attributed to the elevated SST across most of Indonesia.

Key-words: *Triple-Dip La Niña; Rainfall; Sea Surface Temperature, Indonesia.*

1. INTRODUCTION

Indonesia is located in the tropical region between two continents, i.e., Asia and Australia; and two oceans i.e., Pacific and Indian Oceans. This makes Indonesia become a country with high rainfall (Ramadhan *et al*., 2020). Rainfall in Indonesia is strongly affected by monsoon wind which is known as Asian-Australian Monsoon System. The Asian (Australian) monsoon is defined by northwesterly (southeasterly) winds that move from Asia (Australia) to Australia (Asia), carrying moist (dry) air and resulting in a rainy (dry) season across much of Indonesia (Griffiths *et al*., 2009; Chang *et al*., 2005; Chang *et al*., 2006; Alifdini *et al*., 2021; Ferijal and Fauzi, 2024). This wind pattern is also referred to as the northwest monsoon or simply west monsoon (WM), which reaches its peak between December and February (DJF), and the southeast monsoon or simply east monsoon (EM), which is most intense from June to August (JJA). From March to May (MAM) and from September to November (SON) are known as the transition I and transition II seasons, respectively. In the longer timescale, El Niño Southern Oscillation (ENSO) that occurs in the Pacific Ocean becomes the main

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driver for interannual climate variability within the Indonesian Region including rainfall (Simanjuntak *et al*. 2022). ENSO have two main phases, i.e. La Niña and El Niño. La Niña (El Niño) happens when sea surface temperature (SST) in the middle and east equatorial Pacific cooler (warmer) than usual. Ocean Nino Index (ONI) have been widely used to identify the ENSO phase (Haile *et al*., 2021). ONI is obtained by measuring SST in Nino 3.4 (120-170°W, 5°N-5°S). When the SST anomaly ≥0,5°C indicating El Nino phase, anomaly between (-0.5) to 0.5°C: neutral, dan anomaly ≤ (-0,5°C) indicating La Niña. These phenomena cause increasing/decreasing rainfall in Indonesia (Yustiana *et al*., 2023). During La Niña, strong easterly winds moves warm water masses to Indonesia. This condition cause boots the convection, which lead to increasing precipitation and causing extreme rainfall (Rodysill *et al*., 2019).

Study about the impact of La Niña to the rainfall in the Indonesian Region have been conducted by many researchers (e.g., Prasetyo *et al*., 2017; Hidayat *et al*., 2018; Firmansyah *et al*., 2022; Zaini *et al*., 2024). However, La Niña that happened in 2020-2022 is special case since it happened consecutively for 3-years which is called Triple-Dip La Niña. Historically, Triple-Dip La Niña happened in 1973-1976 and 1998-2001, then happened again in 2020-2023. Although some of study about Triple-Dip La Niña in 2020-2023 have been conducted (e.g., Shi *et al*., 2023; Zhang *et al*., 2024), the impact of this phenomena on Indonesian rainfall is not extensively studied. Alhadid and Nugroho (2024), have found that there were increasing on zonal wind strength, relative humidity, and rainfall in Indonesia during the Triple-Dip La Niña. This condition significantly happened in north and east Indonesia during JJA and SON. However, the comparison between these phenomena with previous La Niña events has not been explained yet. In this study, we aim to show a comparison of the impact of Triple-Dip La Niña in 2020-2023 with strong La Niña (2010-2011) and weak La Niña (2017-2018) on Indonesian rainfall and SST. Then, the factors that cause the rainfall and SST variability during those periods is analyzed. This study used remote sensing techniques to collect data for wide area coverage. The data is constructed from multiple satellites to obtain gap-free data. Then, this data is analyzed seasonally, i.e. west (DJF), transition I (MAM), east (JJA), and transition II (SON).

2. STUDY AREA

Our study area is Indonesian archipelago which is located between the coordinate 95-141°E and 11°S-6°N (**Fig. 1**). Indonesia has five major islands, such as Sumatra, Kalimantan, Java, Sulawesi, and Papua. Positioned between the continents of Asia and Australia and near the Pacific Ocean, Indonesia's climate is significantly influenced by monsoon winds and the ENSO phenomenon, which are crucial in shaping the country's rainfall patterns. According to Aldrian and Susanto (2003), regions in Indonesia have been categorized based on their rainfall characteristics. In particular, southern Indonesia, Maluku, and northern Sulawesi are heavily impacted by ENSO. Additionally, monsoon wind patterns affect various parts of Indonesia, with the eastern season typically being dry and the western season generally experiencing more rain.

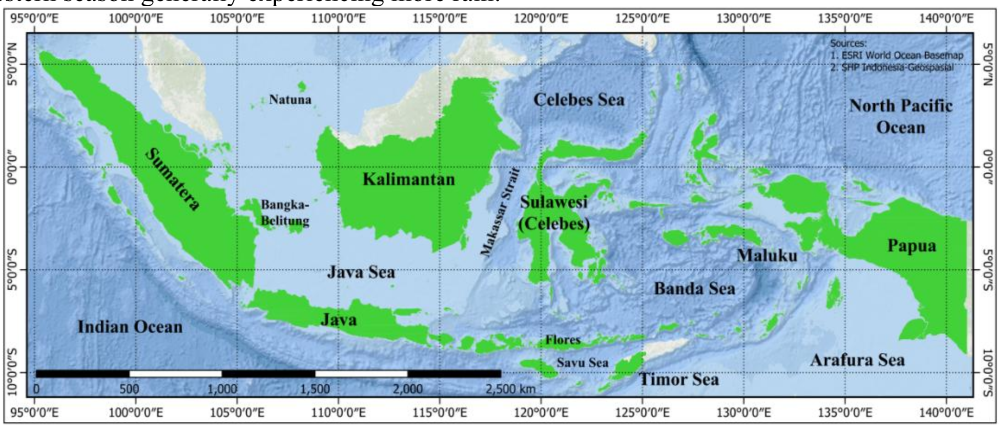

Fig. 1. Study area.

3. DATA AND METHODS

3.1. Data

The La Niña periods were identified using Nino 3.4 Index, which derived from https://www.cpc.ncep.noaa.gov/ when the index value is lower equal than -0.5°C (Rohmat *et al.*, 2023; Nurafifah *et al.*, 2022). We used period of Triple-Dip La Niña during 2020-2023, which was compared to the strong La Niña (2010-2011) and weak La Niña (2017-2018) periods (**Fig. 2**). For the rainfall data, we used CPC Morphing Technique (CMORPH) daily rainfall, with the spatial resolution up to 0.25°. The SST data derived from Operational Sea Surface Temperature and Sea Ice Analysis (OSTIA) with the spatial resolution of 0.05°. OSTIA uses infrared and microwave, also in-situ measurement for collecting the SST data. This data would be filtered based on wind speed for representing fundamental SST (Cuervo *et al.*, 2022). The wind data used Cross-Calibrated Multiplatform (CCMP) with the spatial resolution up to 0.25° and interval up to 6 hours (Mears *et al.*, 2022). This data represents wind speed for 10 m above sea surface. The CMORPH, OSTIA, and CCMP data were downloaded for period of 2007-2023.

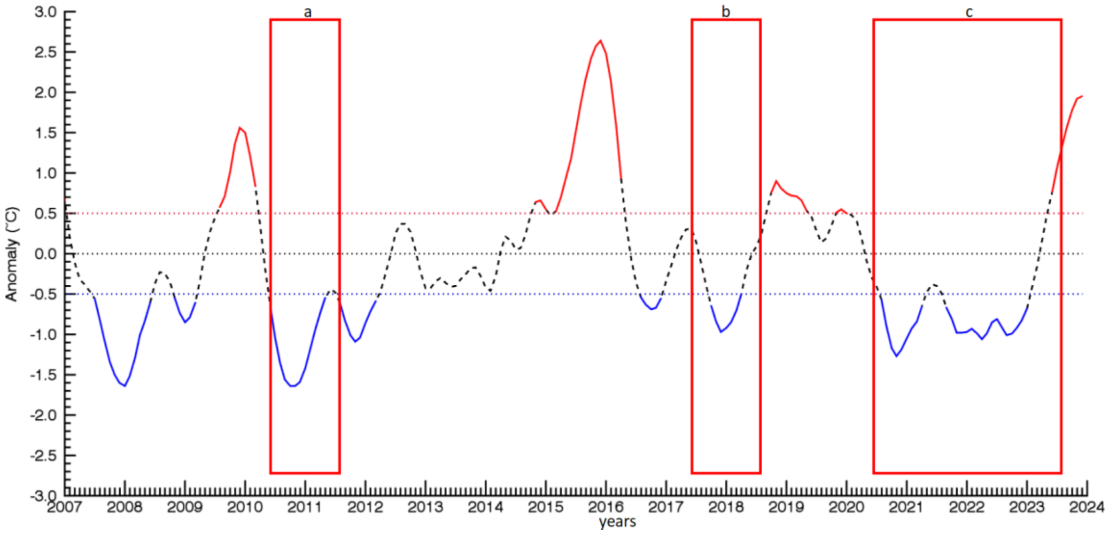

Fig. 2. Historical ONI index shows El Nino (red), La Niña (blue), and Neutral (dashes) phases from 2007 to 2023. The red boxes are the period of a) strong, b) weak and c) triple dip La Niña analyzed in this study.

3.2. Climate Data Calculation

This study used a quantitative method. The quantitative method is a systematical study method that uses numbers and statistical analysis (Millenia *et al.*, 2022). This method is used to identify the correlation between rainfall and La Niña phenomena. We extracted the rainfall, SST, and wind data, then compiled monthly and seasonally. The seasonally-compiled data would be compiled into climatology using equation (1) (Wirasatriya *et al.*, 2017). The

The formula is expressed as follows:

$$\bar{X}(x,y) = \frac{1}{n}\sum_{i=1}^{n} xi\,(x,y,t) \quad (1)$$

where: $\bar{X}(x,y)$ is monthly mean value or monthly climatology value at position (x,y), $xi(x,y,t)$ is ith value of the data at (x,y) position and time t. Furthermore, n is number of data in *1* month and number of monthly data in *1* period of climatology (i.e., from 2007 to 2023 = 17 data) for monthly calculation and monthly climatology calculation respectively. Next we calculated anomaly of triple-dip, strong and week La Niña periods seasonally from their climatology (2007-2023).

3.3. Statistical and Spatial Analysis

The Rainfall, SST, and wind data were analyzed seasonally. Triple-Dip La Niña data was compared with strong and weak La Niña. Precipitation was diagnosed spatially based on Aldrian and Susanto (2003), where climatic regions classified as southern Indonesia (from south Sumatra to Timor Island, southern Kalimantan, Sulawesi, and part of Irian Jaya), northwest Indonesia (from northern Sumatra to northwestern Kalimantan), and including Maluku also the northern part of Sulawesi. Statically, rainfall and SST data would be correlated with the Nino 3.4 Index using Pearson Correlation (2) (Nurafifah *et al*., 2022). The formula is expressed as follows:

$$r = \frac{n\sum XY - \sum X \sum Y}{\sqrt{\{n\sum X^2 - (\sum X)^2\}\{n\sum Y^2 - (\sum Y)^2\}}} \quad (2)$$

where: *r, X, Y* and *n* are correlation coefficient value, independent variable, dependent variable and amount of data, respectively.

4. RESULTS AND DISCUSSIONS

4.1. Rainfall Variability During La Niña Periods

During La Niña periods, the average rainfall calculated for the Indonesia Region (6°U-11°S dan 95°E-111°E). Triple-Dip La Niña during JJA(DJF) shows rainfall up to 6.22 (8.70) mm/day, strong La Niña shows rainfall up to 7.01 (8.46) mm/day, and weak La Niña shows rainfall up to 6.39 (7.87) mm/day (**Table 1**). This condition indicates a dry (wet) season during JJA (DJF), which has been mentioned by previous research (Mulsandi *et al*., 2024). From the anomaly data, that triple-Dip indicates increasing rainfall during JJA (0.84 mm/day), SON (1.46 mm/day), and DJF (0.71 mm/day) while decreasing rainfall during MAM (-0.21 mm/day). Strong La Niña shows an increase in rainfall during JJA (1.63 mmm/hari), SON (1.78 mm/day), DJF (0.47 mm/day), and MAM (0.83 mm/day). Weak La Niña indicates increased rainfall during JJA(SON) up to 1.01(1.20) mm/day and decreased rainfall during DJF(MAM) up to -0.12(-0.18) mm/day. This study reveals that La Niña's impact is more conspicuous during JJASON than DJFMAM. Kurniadi *et al*. (2021) reported that ENSO influence on Indonesia's rainfall is more significant during the dry season (JJA). Alhadid dan Nugroho (2024) also found that the increase in Indonesia's rainfall during Triple-Dip Niña is more pronounced during JJASON, which is supported by previous research (Nur'utami and Hayasaka, 2022; Aldrian and Susanto, 2003).

Table 1.

Average and Anomaly of Rainfall, SST, and Wind Speed during different La Niña Conditions.

Periods	Season	Rainfall (mm/day)	Anomaly (mm/day)	SST (°C)	Anomaly (°C)	Wind Speed (m/s)	Anomaly (m/s)
Triple-Dip La Niña (2020-2023)	JJA	6.22	0.84	28.97	0.38	3.88	-0.22
	SON	7.16	1.46	29.19	0.39	1.36	-0.17
	DJF	8.70	0.71	29.14	0.07	2.55	0.34
	MAM	6.49	-0.21	29.53	0.05	2.73	-0.08
Strong La Niña (2010-2011)	JJA	7.01	1.63	29.10	0.51	3.36	-0.73
	SON	7.47	1.78	29.44	0.64	1.55	0.03
	DJF	8.46	0.47	29.06	-0.01	2.85	0.63
	MAM	7.53	0.83	29.18	-0.30	2.60	-0.22
Weak La Niña (2017-2018)	JJA	6.39	1.01	28.67	0.09	4.35	0.25
	SON	6.90	1.20	29.04	0.24	1.73	0.25
	DJF	7.87	-0.12	29.15	0.07	2.57	0.36
	MAM	6.51	-0.18	29.45	-0.03	3.68	0.84

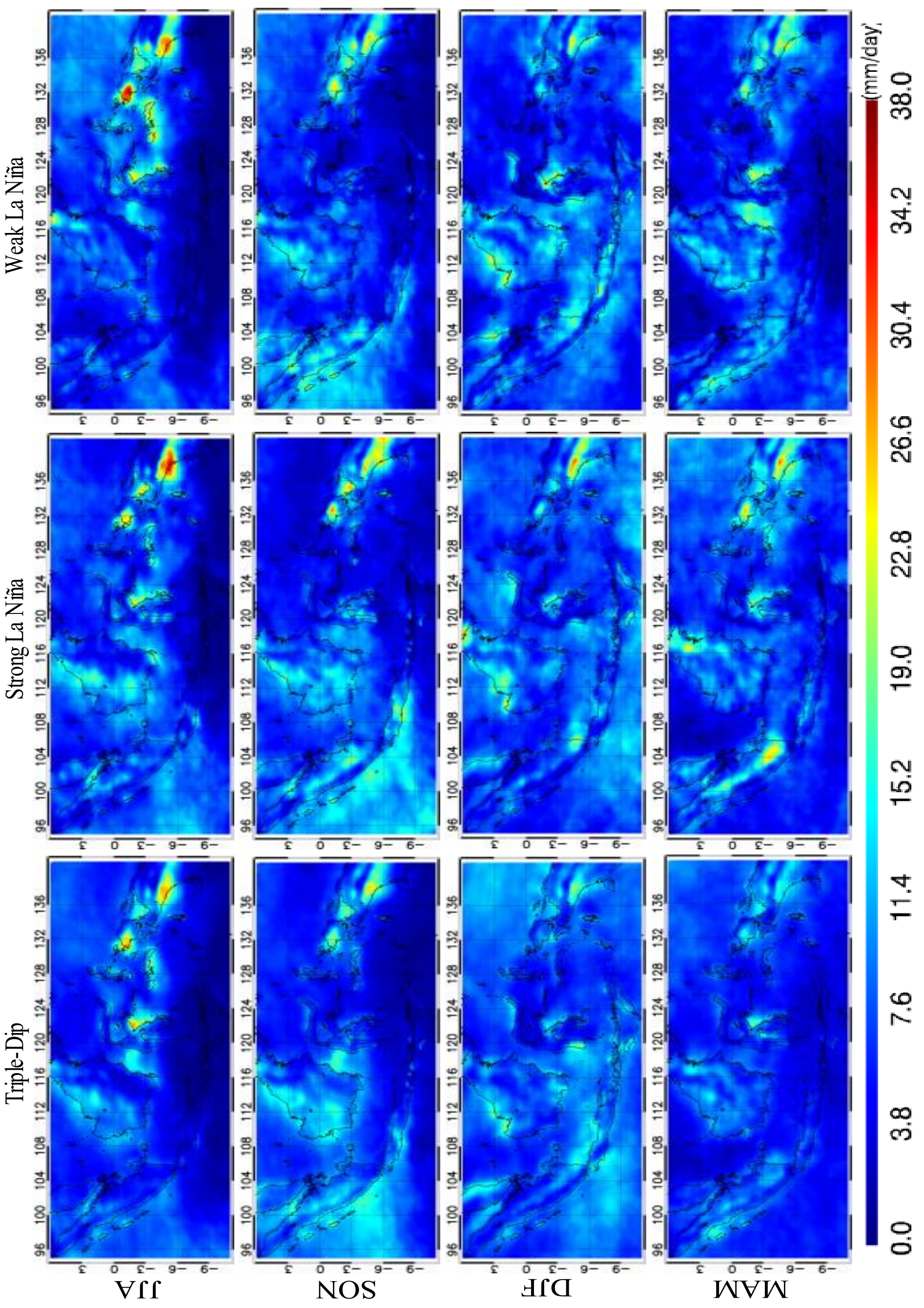

Fig. 3. Rainfall distribution during La Niña Periods in east season (JJA), transition II (SON), west season (DJF), and transition I (MAM).

La Niña periods indicate light rain up to 19.0 mm/day in Sumatra, Kalimantan, Western Java, Sulawesi, Maluku, and Papua. Those periods also indicated moderate rainfall, around 22.8-34.2 mm/day in Central Sumatra, Maluku, Western Papua, and Papua during JJASON. Triple-Dip and Strong La Niña show negligible rainfall around Central and Western Java, Bali, and Nusa Tenggara. Most of Java Island experienced insignificant rainfall during weak La Niña. Those conditions indicate a dry season in Indonesia during this season. Siswanto *et al*. (2022) have mentioned that the peak of the dry season in Indonesia occurred during July-August (JJA), while the wet season was during December-February (DJF). The three periods of La Niña during SON show Java, Bali, and Nusa Tenggara experiencing light rainfall. Strong La Niña shows rainfall up to 22.8 mm/day in Sumatra, Central Kalimantan, Central Java, Southern Sulawesi, Makassar Strait, and the Western waters of Sumatra. On the other hand, Triple-Dip and weak La Niña show the Banda Sea, Timor Sea, and parts of the Arafura Seas experiencing insignificant rainfall (**Fig. 3**).

During DJFMAM, most parts of Indonesia experienced light rainfall of up to 7.6 mm/day in the La Niña periods. Triple-Dip during DJF indicates rainfall of up to 15.2 mm/day in Southern Sumatra, Central Java, parts of Southern Kalimantan, parts of Southern Sulawesi, parts of Nusa Tenggara, and parts of the Southern waters of Java. Strong La Niña shows similar conditions in Southern Sumatra (up to 22.8 mm/day), Western and Southern Sulawesi, parts of Nusa Tenggara, parts of Papua (up to 30.4 mm/day), and parts of Arafura to Timor Sea. Weak La Niña during DJF shows similar conditions in Southern Sumatra, Central and Eastern Java, Southern Kalimantan, Western and Southern Sulawesi (up to 22.8 mm/day), and Papua (up to 22.8 mm/day). During MAM, Triple-Dip shows rainfall up to 15.2 mm/day in Northern Sumatra, Northern Kalimantan, Western Sulawesi, and Papua.

Strong La Niña shows rainfall of up to 22.8 mm/day in Sumatra, Northern Kalimantan, Western Sulawesi (up to 15.2 mm/day), and Papua (up to 26.6 mm/day). Weak La Niña during MAM indicates parts of Bali Nusa Tenggara, Timor, Southern waters of Java, Savu Sea, and Natuna Sea experience negligible rainfall. Rainfall of up to 22.8 mm/day can also be found in Northern Sumatra, Makassar Strait, Western Sulawesi, and Papua (**Fig. 3**). In this case, DJF indicates the wet season in Indonesia.

Triple-Dip and strong La Niña periods during JJA indicate an increase in rainfall of up to 3.0-6.0 mm/day in Sumatra, Western and Central Kalimantan, Sulawesi, parts of Maluku, Papua (up to 12.0 mm/day during strong La Niña), Western Java, western Sumatra waters, Natuna Sea, Java Sea, Banda Sea, and Arafura Sea. Triple-Dip also shows similar conditions in Makassar Strati dan Maluku Sea. During strong La Niña, this condition also occurred in the Flores and Sulawesi Sea. Weak La Niña shows an increase in rainfall of up to 3.0 mm/day around Southern Sumatra, Western Kalimantan, Sulawesi, Maluku (up to 9.0 mm/day), Western Papua (up to 9.0 mm/day), and Papua. Triple-Dip and strong La Niña during this season indicate a decrease in rainfall of up to 3.0 mm/day in Northern Kalimantan, Western Papua, the northern part of Papua, and parts of Sumatra (except Triple-Dip). Decreasing rainfall also occurred during weak La Niña in Western and Central Java, Timor Island, Southern Papua, the Indian Ocean, and parts of the Timor Sea and the Arafura Sea. During SON, Triple-Dip and weak La Niña caused rainfall increase in Sumatra (except the Northern), Kalimantan (except the Northern), Sulawesi, Maluku, Papua (except the Northern), Java to Nusa Tenggara, Indian Ocean, Natuna Sea, Java to Banda Sea, Sulawesi Sea, Timor Sea, and Arafura Sea. Strong La Niña also shows rainfall increase of up to 12 mm/day in the parts of Papua and Indian Ocean. During DJFMAM, Triple-Dip and strong La Niña caused a rainfall decrease in Sumatra, Java, Kalimantan, Sulawesi, Maluku, and Papua.

During DJF, weak La Niña caused rainfall to increase by up to 3.0-9.0 mm/day in Central Java to Eastern Nusa Tenggara, which did not occur in other periods. Strong La Niña also showed similar conditions during MAM in Central Java to Nusa Tenggara, including Timor Island, while causing a rainfall increase of up to 15.0 mm/day in Southern Sumatra (**Fig. 4**). This study reveals that the Triple-Dip La Niña caused an increase in rainfall in most of Indonesia which is in line with previous studies (Alhadid and Nugroho, 2024; Aldrian and Susanto, 2003). Ariska *et al*. (2024) also mentioned that La Niña caused rainfall increases in most of Indonesia during August-October (ASO).

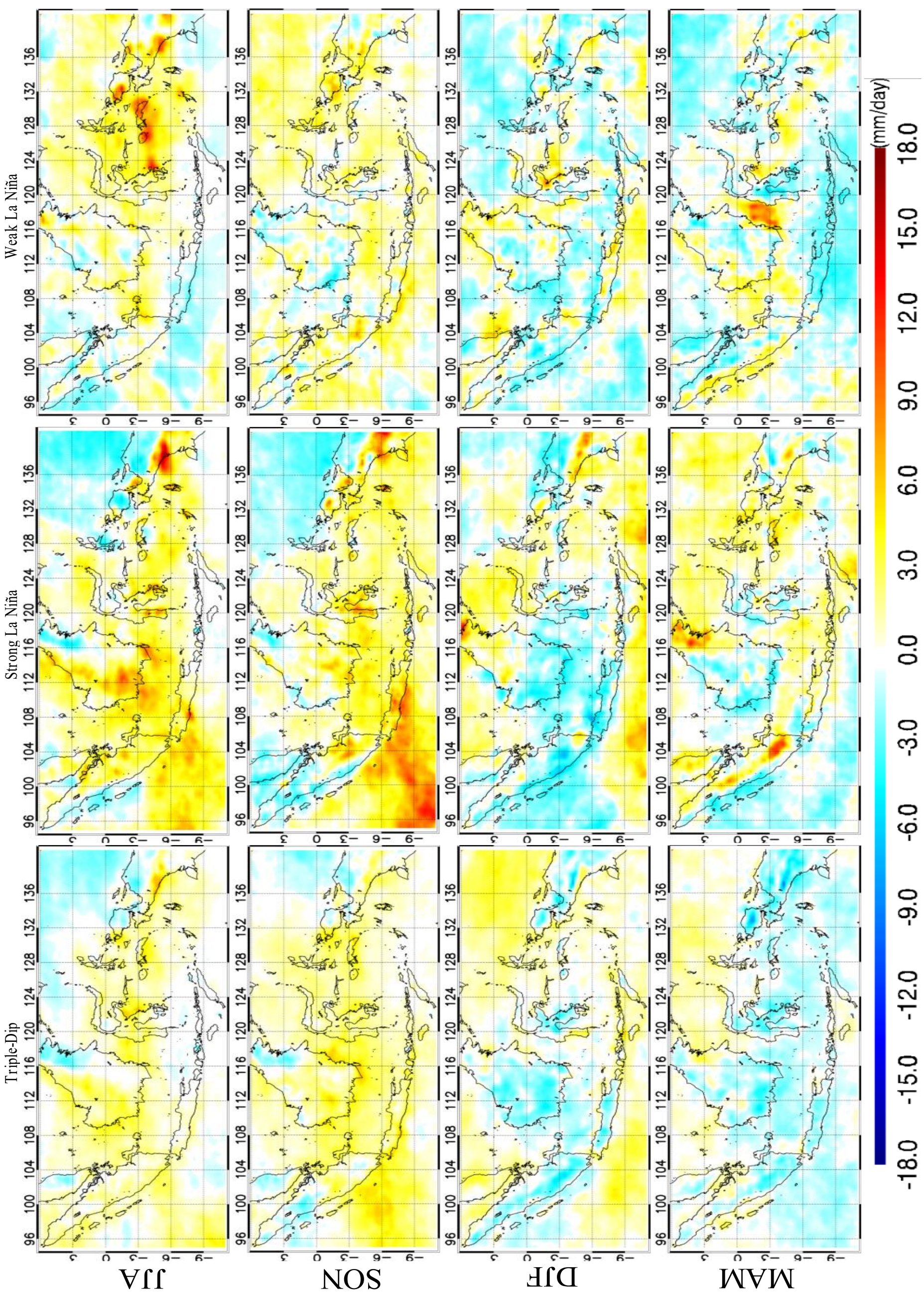

Fig. 4. Rainfall Anomaly during La Niña periods in east season (JJA), transition II (SON), w However, weak La Niña experiences a decline in SST up to 0.3°C around the Natuna Sea, Java Sea,

4.2. SST and Wind Variability During La Niña Periods

The three La Niña periods during JJASON indicate SST up to 30°C in Northern Indonesia, including the Malacca Strait, the Pacific Ocean, Natuna, Sulawesi, and Maluku Sea, due to lower wind speeds around 1.7-3.3 m/s (**Fig. 5**). The southern parts of Indonesia indicate lower SST around 26.0-29.0°C in the Southern waters of Indonesia, including Southern Java, Savu, Timor, and the Arafura Sea due to higher wind speed, around 6.7-9.2 m/s (**Fig. 6**). During JJA, Weak La Niña shows SST in the Java Sea at 28.0°C, lower than Triple-Dip (29.0°C) and Strong La Niña (29.5°C). During this period, the Southern Java Sea, Savu, and the Arafura Sea indicated similar conditions, where the SST was around 25.0-27.5°C. The wind in the Southern Java Sea during La Niña blows up to 8.3-10.0 m/s and is relatively parallel along the coastline. This condition triggers the occurrence of Ekman Transport and upwelling in that area (Wirasatriya *et al*. 2020; Rachman *et al*., 2024).

Triple-Dip, strong, and weak La Niña shows lower SST around 26.5°C in the Natuna Sea during DJF. The wind speed was up to 5.8 m/s from the north, which supports low SST water input in this area. Research by Zandika *et al*. (2024) mentioned that strong winds during DJF blew from the north to the south, supporting cool water from the northern Natuna Sea. On the other hand, most of Indonesia's eastern waters, including the Pacific Ocean, Sulawesi, Maluku, Banda, Arafura, and the Timor Seas, indicate higher SST around 28.5-30.0°C. During this season, strong La Niña also indicates SST around 28.0-28.5°C in the Indian Ocean (the Western water of Sumatra to the southern waters of Java), shown by a weak period with lower intensity.

Triple-Dip and strong La Niña caused SST to increase to 0.3-0.7°C during JJA in most of Indonesia, including the Indian Ocean, Natuna Sea, Java Sea, Sulawesi Sea, Maluku Sea, Flores Sea, Banda Sea, Savu Sea, the Western Pacific Ocean, Arafura Sea, and Timor Sea. Strong La Niña indicates an increase in SST of up to 1.7-1.3°C in the Maluku Sea, which makes it different from Triple-Dip. On the other hand, Strong La Niña experienced a decrease in SST up to 0.3°C in the Southern Java Sea and Natuna. This is due to the reduction of wind speed to around 0.8-5.0 m/s in some areas, especially the western waters of Sumatra, Natuna to Java Sea, and Makassar Strait. During SON, strong La Niña causes a decline in SST up to 2.0°C in the Southern Java Sea. This area experiences an increase in SST during weak La Niña, which is indicated by a decline in the negative anomaly. However, Triple-Dip events during SON are relatively similar to the previous season. The three La Niña periods cause SST to increase to 0.3-0.7°C in Sulawesi waters, the Maluku Sea, the Makassar Sea, and the Pacific Ocean, indicated by the positive anomaly.

Negative anomalies occurred in the Natuna Sea, Java Sea, the Indian Ocean, Savu Sea, Timor Sea (except weak La Niña), parts of the Arafura Sea (except Triple-Dip), Banda Sea (except Triple-Dip), and Flores Sea. In this case, Arafura and the Banda Sea indicate a 0°C anomaly during Triple-Dip, and the Timor Sea experiences a positive anomaly during weak La Niña. A different condition occurred during MAM, where Triple-Dip caused an increase in Arafura and the Banda Sea up to 0.3°C. Strong La Niña experienced an increase in SST to 0.3-0.7°C in the Hindia Ocean, Java Sea, Flores Sea, Banda Sea, Maluku Sea, Arafura Sea, and Timor Sea. This period also shows a decrease in SST up to 1.3°C in the Natuna Sea. However, weak La Niña experiences a decline in SST up to 0.3°C around the Natuna Sea, Java Sea, Flores Sea, Banda Sea, and Maluku Sea, which makes this period different from others (**Fig. 7**). This condition occurs due to an increase in wind speed to 2.5-3.3 m/s in that area. In this study, most of Indonesia's waters experienced an increase in SST during JJASON in Triple-Dip and strong La Niña. This is in line with Asyam *et al*. (2024), which shows an increase in SST and Rainfall in Indonesia during La Niña. In MAM, stronger wind speed during Strong La Niña causes SST to be cooler than triple dip La Niña.

However, an inconsistency found in MAM when the coolest SST during strong La Niña did not correspond to the maximum wind speed in the area of southern Indonesia. The maximum wind speed is found during weak La Niña. We assume that there is another mechanism that prevents the strong wind speed cools SST during weak La Niña which may related to the surface radiation flux, or intra-seasonal disturbance. This is left for the future study.

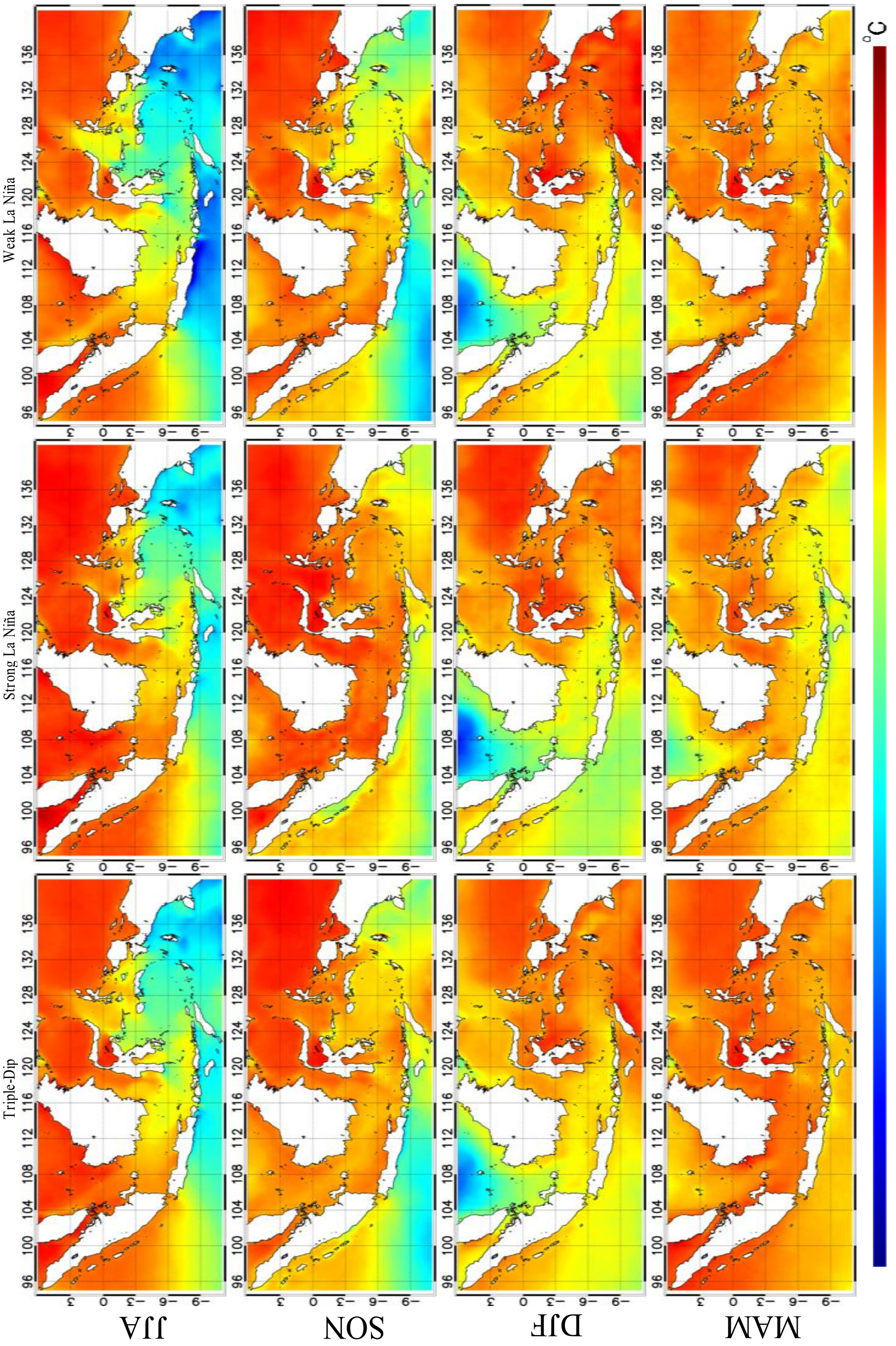

Fig. 5. SST distribution during La Niña periods in east season (JJA), transition II (SON), west season (DJF), and transition I (MAM).

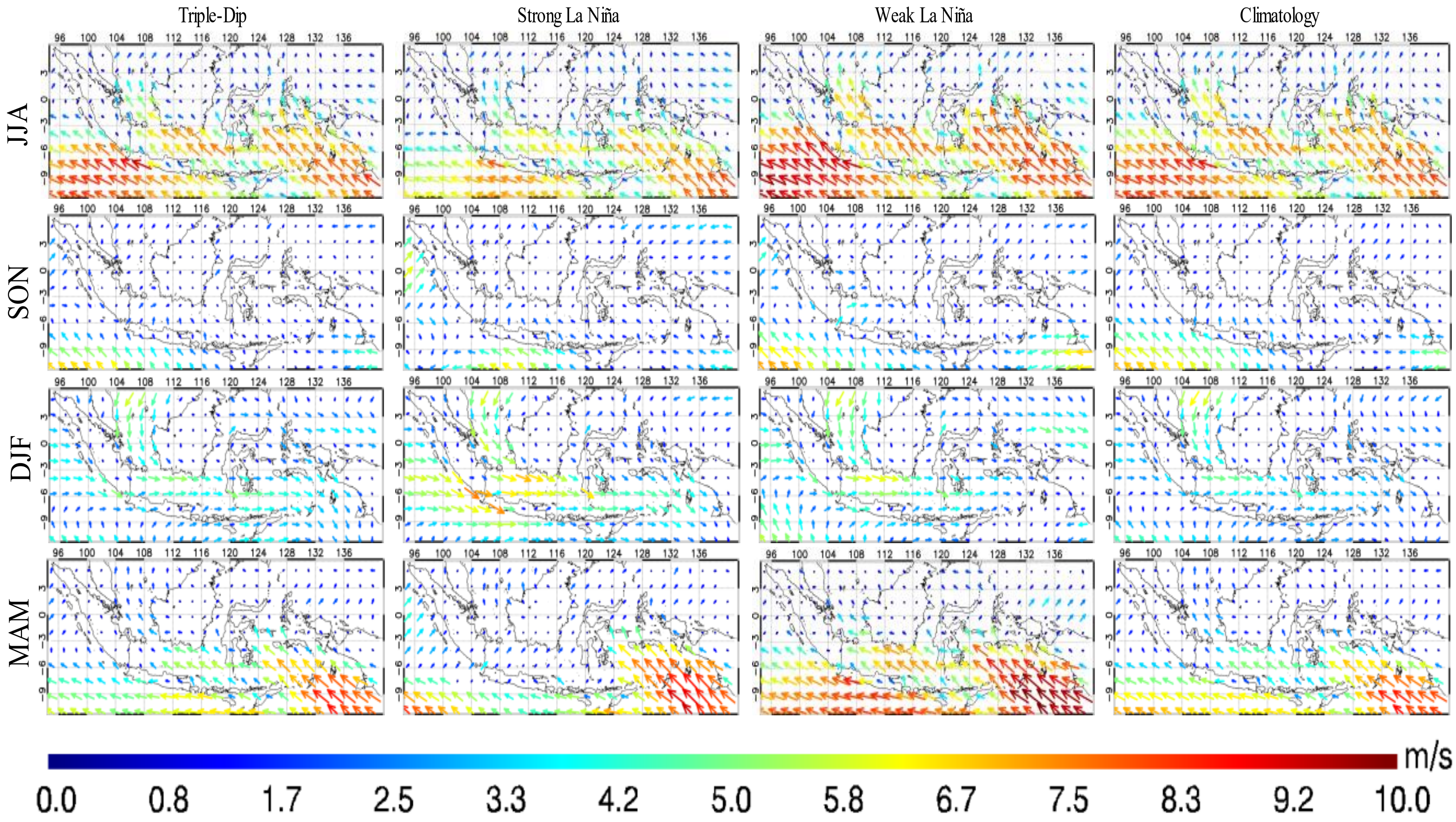

Fig. 6. Surface wind distribution during La Niña periods and climatology in east season (JJA), transition II (SON), west season (DJF), and transition I (MAM).

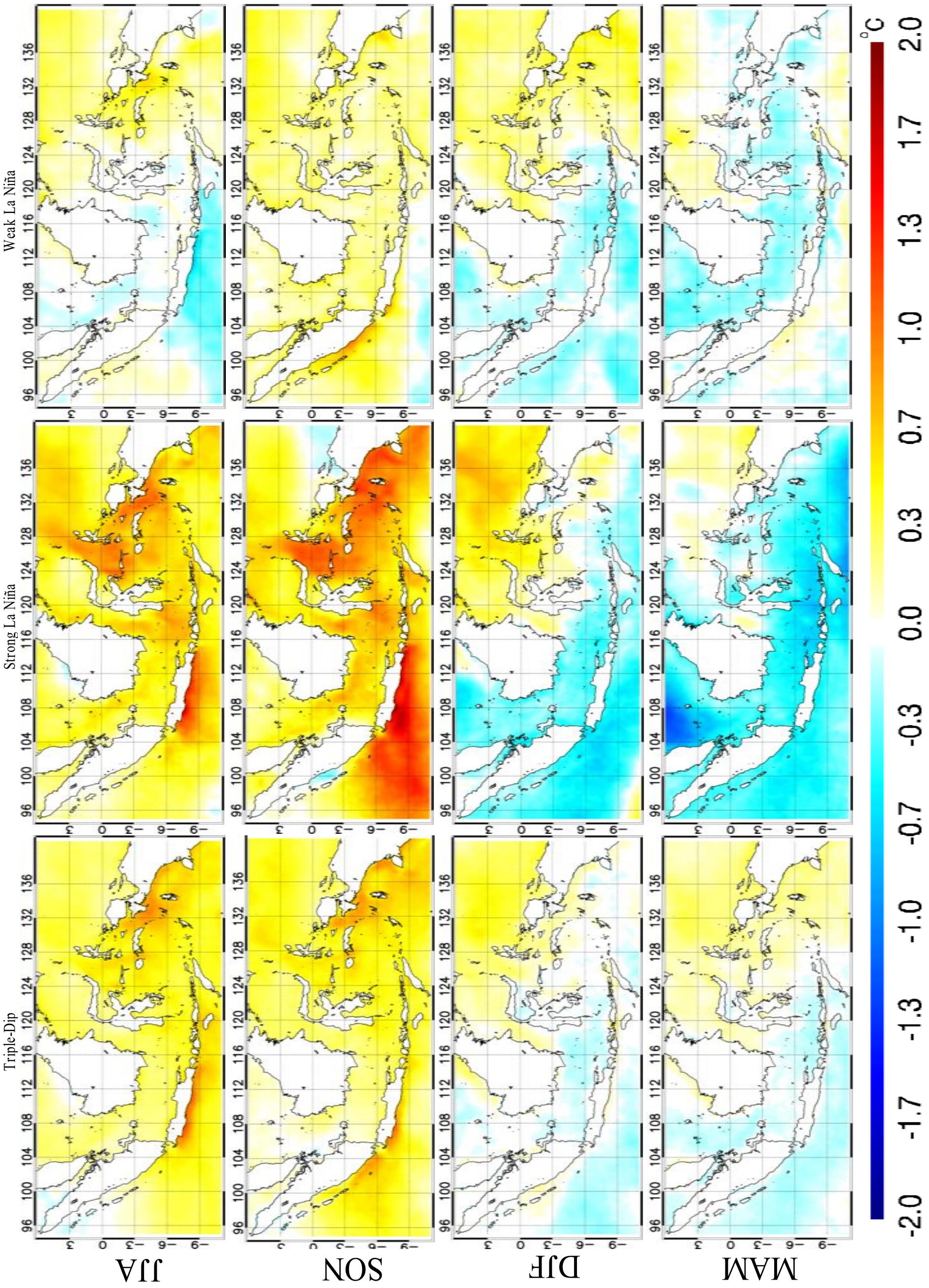

Fig. 7. SST anomaly during La Niña periods in east season (JJA), transition II (SON), west season (DJF), and transition I (MAM)

4.3. Spatial correlation analysis

To quantify the relation among ENSO, rainfall and SST, spatial correlation analysis is provided in **Fig. 8**. Most of Indonesia indicates a correlation value up to -0.8 during JJASON, except for the northern part of Sumatra and the northern part of Papua. ENSO during DFJ shows a positive correlation in Northern Sumatra, Central Java, parts of Nusa Tenggara, parts of Kalimantan, parts of Kalimantan, parts of Sulawesi, and parts of Papua in the range 0.2-0.4. During this season, Central and Southern Sumatra, parts of Kalimantan, Sulawesi, Timor Island, and Maluku show negative correlation values up to 0.2-0.4. MAM shows different conditions, where most of the Islands in Indonesia, including the western coast of Sumatra, Kalimantan (except the Nothern), Sulawesi, Maluku, Papua, and Java to Nusa Tenggara have a positive correlation up to 6.0. Ariska *et al*. (2024) found that rainfall in Indonesia is sensitive to the change in SST in the Pacific and Indian Oceans. Aldrian and Susanto (2003) found that Southern Indonesia, Southern Kalimantan, Sulawesi, parts of Papua, Maluku, and Northern Sulawesi have significant responses of a rainfall pattern to ENSO during JJASON. Hidayat *et al*. (2018) found that Nino 3.4 exhibits an inverse correlation during every season, except MAM. This study reveals that ENSO's influence on Indonesia's rainfall was more pronounced during JJASON (Kurniadi *et al*. 2021). ENSO and SST show similar conditions, where an average correlation during JJA(SON) was around -0.43(-0.49).

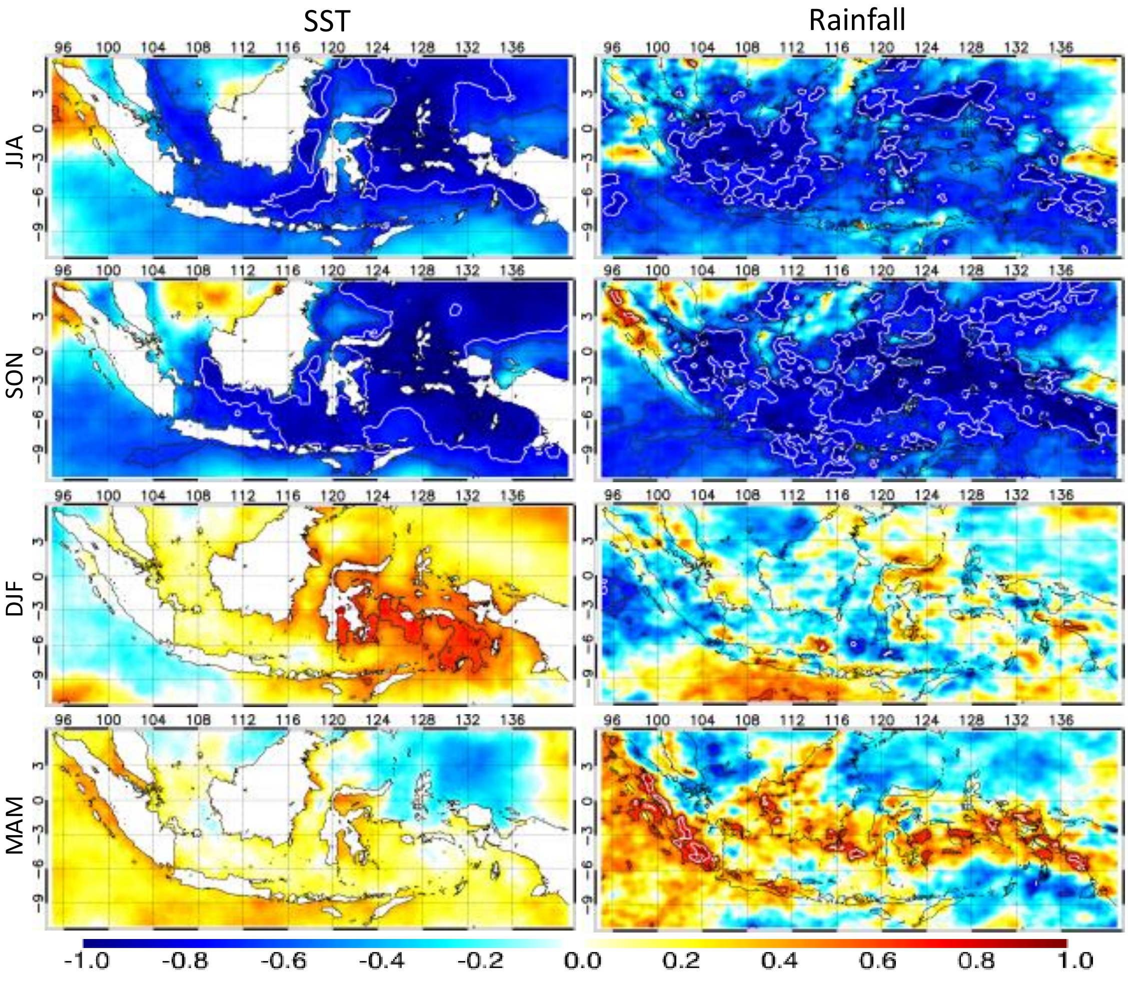

Fig. 8. ENSO correlation to Rainfall and SST where black and white contours show p-values of 0.05 and 0.01, respectively.

Most of Indonesia's waters indicate a strong negative correlation of up to -0.8. The western water of Northern Sumatra shows a strong positive relation up to 0.4 during JJA and in the Natuna Sea during SON. During DJFMAM, most of Indonesia's water shows a positive correlation up to 0.6. During DJF, a negative correlation of up to 0.3 was found in some areas, like the western waters of Sumatra and the southern water of Western Java. This condition also occurs in parts of the Natuna Sea (up to 0.3), the Sulawesi Sea, the Maluku Sea, and the Western Pacific Ocean (up to 0.6). Hendon (2003) reported a strong negative correlation between ENSO and SST around Indonesia. This study reveals that the correlation of ENSO and SST varies in season.

The occurrence of La Niña (El Nino) was indicated by a decline (incline) of the SST in the Pacific. In this case, a negative correlation between ENSO and Indonesia's SST represents the occurrence of La Niña caused an increase in Indonesia's SST. Research by Dewi *et al*. (2020) found that during the La Niña (El Nino), the SST in the Java Sea tends to be cooler (warmer) in the northwest monsoon and tends to be warmer (cooler) in the southwest monsoon, which is representing a negative correlation in Java Seas.

4.4. Discussion

Triple-Dip La Niña is a rare phenomenon, which happened in 1973-1976, 1998-2001, and occurred again in 2020-2023. According to Shi *et al*. (2024), this Triple-Dip La Niña (2020-2023) occurs after the neutral phase, which makes it different from previous Triple-Dip events. This study found that Triple-Dip La Niña in 2020-2023 was influenced by the North Pacific Meridional Mode (NPMM) and South Pacific Meridional Mode (SPMM) through tropical and extra-tropical interaction. This interaction causes negative SST anomalies and strengthens easterly wind anomalies in the equatorial Pacific.

Zhang *et al*. (2024) found that robust cross-equatorial southern wind anomalies contribute to cooling the SST in the Central and Eastern Pacific due to westward zonal flow anomalies in the upper ocean and upwelling anomalies along the eastern coast. This condition shifted the SST cooling pattern to the southeastern tropical Pacific and Sustained the La Niña state. Fadhilah *et al*. (2024) mentioned that this Triple-Dip phenomenon influenced SST anomalies and controlled rainfall around the Pacific Area, including Indonesia. Alhadid and Nugroho (2024) reported that the Triple-Dip La Niña caused most of Indonesia's region to experience zonal wind strengthening, relative humidity, and rainfall increase. Triple-Dip and strong La Niña periods in all seasons reveal relatively similar anomaly patterns of rainfall, SST, and wind. During JJASON, Triple-Dip and Strong La Niña caused an increase in rainfall in most of Indonesia, including Sumatra, Western and Central Kalimantan, Sulawesi, parts of Maluku, Papua, Western Java, western Sumatra waters, Natuna Sea, Java Sea, Banda Sea, and Arafura Sea. Alhadid and Nugroho (2024) also reported an increase in those areas during Triple-Dip La Niña. During this season, the increase in SST occurs in most of the Indonesia region. Warmer SST enhances evaporation, which contributes to increasing the air humidity. This condition leads to the development of a convective cloud, leading to inclined rainfall. Lu *et al*. (2023) found that an area with warmer SST has abundant participation. The wind also influenced the increase in precipitation and SST. In this case, the wind blew from the east to the west in the Western Pacific Ocean, containing more moisture due to the warmer SST in that area. In this case, the decreasing wind speed in most of Indonesia caused SST increase, contributing to the development of convective clouds and increasing the rainfall in Indonesia.

Alhadid and Nugroho (2024) explained that the strengthening of eastward trade winds increased air humidity in the Indonesian region and caused rainfall to increase. During DJFMAM, Triple-Dip and strong La Niña caused a decrease in rainfall in Sumatra, Java, Kalimantan, Sulawesi, Maluku, and Papua, as reported by Alhadid and Nugroho (2024). The SST declined during this season in the Natuna Sea, Java Sea, Flores Sea, and the Indian Ocean (the western water of Sumatra to the southern water of Java). This condition occurred due to the incline of wind to 0.8-5.8 m/s across the Java, Flores, Banda, Arafura, and Timor Seas.

On the other hand, weak La Niña shows an increase in rainfall in Southern Sumatra, Western Kalimantan, Sulawesi, Maluku, Western Papua, and Papua. This event also caused an inclination of SST in most of Eastern Indonesia, including Sulawesi, Maluku, Arafura, Timor Seas, and the Western Pacific Ocean during JJA. This season also shows negative anomalies up to 0.3°C in Southern Java, which indicates a decline in the SST. This condition occurred due to the monsoon wind. The wind blew from the southeast to the northwest at 8.3-10.0 m/s and parallel to the coastline. Nurlatifah *et al*. (2021) found that high-speed monsoonal wind in Southern Java during JJA develops Eddy currents, leads to the occurrence of upwelling, and contributes to cooling the SST. This condition occurred during DJF in Natuna, Java, Southern Java, and Flores Seas, including the Banda and Arafura Seas during MAM. Puryajati *et al*. (2021) found that SST in the Natuna Sea declined during this season due to the peak speed of the monsoonal wind. Yulihasti *et al*. (2021) also found that the South China Sea during DFJ experienced a decline in SST due to the monsoon wind containing cool air from Asia. Wangdiarta *et al*. (2024) found that SST in Masalembo declined because of cold water input induced by the west monsoon during La Niña.

The increase in rainfall and SST during the La Niña events occurs more significantly during JJASON than DJFMAM. This condition occurred due to the SST increase in almost all regions of Indonesia during JJASON. This condition leads to inclined evaporation, which contributes to enhanced air humidity. On the other hand, warmer air led to an updraft, which increased rainfall in most of Indonesia. The cooler SST in the Pacific Ocean during the La Niña events reduces the air temperature and increases the air density. This condition develops updraft in Indonesia and downdraft in the Pacific Ocean. The occurrence of this mechanism indicates the strengthening of the Walker cycle, as explained by Zaini *et al*. (2024). This study also reveals that Triple-Dip and strong La Niña show relatively identical rainfall, SST, and wind spatial anomaly patterns, even with different intensities. The weak La Niña events show a more scattered rainfall anomaly spatial pattern. During the Triple-Dip and strong La Niña, a strengthening of wind anomaly in the Western Pacific contributed to the inclined air humidity and strengthening of Walker Circulation in Indonesia, as reported by several previous studies (Alhadid and Nugroho, 2024; Hidyat *et al*., 2018; Mulsandi *et al*., 2024; Nur'Utami and Hayasaka, 2022).

5. CONCLUSIONS

Using satellite-based rainfall, SST and surface wind data, we compare the condition of Triple-Dip and strong La Niña in different seasons within the Indonesian region. Triple-Dip and strong La Niña reveal similar spatial anomaly patterns of rainfall, and SST. Triple-Dip and Strong La Niña during JJASON caused an increase in rainfall in most of Indonesia, including Sumatra, Western and Central Kalimantan, Sulawesi, parts of Maluku, Papua, Western Java, western Sumatra waters, Natuna Sea, Java Sea, Banda Sea, and Arafura Sea. The increase in SST during this season occurred in most of the Indonesian region. During DJFMAM, Triple-Dip and strong La Niña caused a decrease in rainfall in Sumatra, Java, Kalimantan, Sulawesi, Maluku, and Papua. This season also shows a declined SST in the Natuna Sea, Java Sea, Flores Sea, and the Indian Ocean (the western water of Sumatra to the southern water of Java). Weak La Niña shows a scattered spatial pattern of rainfall anomaly. However, the spatial distribution of SST anomaly was relatively similar to Triple-Dip and Strong Events, except during JJA. During JJA, Weak events indicate a declined SST in the Southern Java Sea. The increased rainfall during La Niña events was more pronounced during JJASON due to the inclined SST in most of Indonesia's region.

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