Proceeding International Conference on Religion, Science and Education (2024) **3**, 707-716

The Study of Triple-Dip La Nina Phenomenon (2020-2023) and Its Impact on Atmospheric Dynamics and Rainfall in The Indonesian Region

Bai'at Alhadid[1,*], Anwar Budi Nugroho[2]
[1]Stasiun Meteorologi Aji Pangeran Tumenggung Pranoto Samarinda, [2]Stasiun Meteorologi Sangia Nibandera Kolaka
Jl. Pipit No.150 Samarinda, 085337803083.

Corresponding author*
baiatalhadid01@gmail.com

Abstract: La Nina is one of the global-scale phenomena that occur in Pacific Ocean. In general, this phenomenon can increase rainfall in Indonesia. La Nina events can last for one year, two years, or even up to three years. When La Nina persists or lasts for three years, it is referred to Triple-Dip La Nina. One such Triple-Dip La Nina occurred during 2020 to 2023. Research on La Nina in Indonesian has been extensive. However, research specifically on Triple-Dip La Nina, particularly during 2020 to 2023, has not been conducted extensively. Therefore, this study aims to analyze Triple-Dip La Nina phenomenon that occurred during 2020 to 2023 and its impact on atmospheric dynamics and rainfall in Indonesia The results showed that the formation of the Triple-Dip La Nina was caused by the intrusion of cold anomalies from the southeastern subtropical region towards the equator of the East Pacific Ocean and the strengthening of the southeast trade wind which was associated with the east trade wind in the equatorial Pacific. Triple-Dip La Nina had varying impacts on atmospheric dynamics and rainfall in Indonesia. During each time period, only the northern and eastern parts of Indonesia, which are closest to the Pacific Ocean, consistently responded positively and were influenced by the Triple-Dip La Nina. In general Triple-Dip La Nina affects almost all regions of Indonesia during JJA (dry season) and SON (transition from dry season to rainy season) periods. During this period there was a strengthening of zonal winds (up to 5 - 7 m/s), an increase relative humidity (up to 6 - 20%) and rainfall (up to 150 mm) in almost all regions of Indonesia.

Keywords: Triple-Dip La Nina, Sea Surface Temperature, Atmospheric Dynamics, Rainfall.

Introduction

El Nino-Southern Oscillation (ENSO) is one of the interannual oscillations that demonstrates the interaction between the atmosphere and the ocean in the Pacific Ocean. It has a significant impact on weather and climate variability in tropical regions (Timmermann et al., 2018a). ENSO consists of two main phenomena, El Nino and La Nina, characterized by anomalies in sea surface temperatures in the eastern and central Pacific Ocean. ENSO events have varying periodic cycles due to the complex interaction between the atmosphere and the ocean, which is the primary driver of ENSO. This complexity of the interaction in the atmosphere and ocean in Pacific is what causes the ENSO phenomenon to be asymmetrical, so La Nina events can last for two years (Gao et al., 2022; Luo et al., 2017) or even persist for up to three years (Triple-Dip La Nina). Referring to previous research, El Nino events are less frequent, while La Nina events occur more frequently, especially since the 1990s (Zhang et al., 2022), however Triple-Dip La Nina is a relatively rare phenomenon, is has been recorded as having occurred in 1973–1976, 1998–2001, and most recently in 2020-2023.

Generaly La Nina characterized by negative anomalies in sea surface temperatures or a cooling of sea surface temperatures in the central and eastern Pacific Ocean (Ahrens, 2009). One of the methods used to detect the occurrence of La Nina is by analyzing the Oceanic Nino Index (ONI). The ONI value indicates the magnitude of sea surface

ISSN 2829-3355 | EISSN 2828-8467

temperature anomalies in the Pacific Ocean. A negative ONI value indicates the cooling of the surface waters in the Pacific Ocean, which can trigger the onset of La Nina. This is a natural response of the ocean, as when sea surface temperatures (SST) peak, they gradually decrease and transition into cold anomalies in the eastern and central Pacific Oceans. These cold anomalies can be followed by strengthening easterly trade winds, which can initiate a circulation pattern that lifts cold water from the subsurface to the surface (upwelling). As a result, the cooling of sea surface temperatures in the eastern and central Pacific Ocean continues to occur and persist consistently causes differences in air pressure between the east to central Pacific and the west Pacific. (Timmermann et al., 2018). This difference in air pressure allows zonal winds or Walker Circulation to strengthen and creates potential areas for increased convective activity and cloud formation, especially in the Indonesian region. (Hidayat et al., 2018).

Research on La Nina, especially in the Indonesian, has been quite extensive. Studies on La Nina in Indonesia typically focus on analyzing the impact of La Nina on atmospheric dynamics and rainfall. However, research on Triple-Dip La Nina, particularly the one that occurred in 2020-2023, has not been conducted extensively. Based on the background issues, research on the Triple-Dip La Nina in Indonesian, especially Triple-Dip La Nina that occurred in 2020-2023, has not been extensively conducted. Therefore, this study aims to analyze the Triple-Dip La Nina that occurred in 2020-2023 and its impact on atmospheric dynamics and rainfall in the Indonesian region. The analysis of the Triple-Dip La Nina will be carried out by examining sea surface temperature values in the Pacific Ocean region. Meanwhile, the analysis of the influence of La Nina on atmospheric dynamics will focus on zonal wind and relative humidity parameters, and the analysis of its impact on rainfall will concentrate on its influence to monthly rainfall in Indonesian. This research is conducted to understand the evolution, patterns and characteristics of the Triple-Dip La Nina 2020-2022 and the extent of its influence on atmospheric dynamics and rainfall in the Indonesian region.

Materials and Methods

Study area

This research was conducted in the Indonesian region with the following geographical boundaries: 95° E to 141° E longitude and 5° N to 11° S latitude. The study was carried out during the years 2020 to 2023, which coincided with the occurrence of the Triple-Dip La Nina phenomenon.

Procedures

The data utilized for this research consists of both observational data and atmospheric model data. The observational data includes sea surface temperature (SST) data and precipitation or rainfall data from the CHIRPS satellite. Meanwhile, the model data used in the research consists of zonal wind and relative humidity data at 850 mb level from the ECMWF model data.

The sea surface temperature (SST) data used in this study was obtained from NOAA with a spatial resolution of 0.25° and monthly temporal resolution from 1991 to 2022. This SST data was used to assess the spatial distribution of sea surface temperature anomaly (SSTA) values in the Pacific Ocean region and around the Indonesian during the occurrence of the Triple-Dip La Nina 2020 to 2023. The analysis of the influence of SST and its evolution will also be presented in the form of the Oceanic Nino Index (ONI) graphs for the Nino-3.4 region, making it easier to identify ENSO fluctuation patterns.

The CHIRPS satellite data used in this study has a spatial resolution of 0.05° and amonthly temporal resolution from 1991 to 2022. This data was downloaded from https://data.chc.ucsb.edu/products/CHIRPS-2.0/global_monthly/. The analysis of CHIRPS satellite data was conducted to understand the impact of the Triple-Dip La Nina on rainfall in the Indonesian region. Use of CHIRPS satellite data in this research because CHIRPS satellite data has shown a strong correlation and good results for monthly rainfall in Indonesia (Pratama et al., 2022)

Other data used in this research includes atmospheric model data from ECMWF. The ECMWF atmospheric model data used in this study consists of zonal wind data and relative humidity at the 850 mb level. The atmospheric model data used in this research has a spatial resolution of 0.25° and monthly temporal resolution from 1991 to 2022. This data was obtained from https://cds.climate.copernicus.eu. The analysis of atmospheric model data was conducted to understand the influence of the Triple-Dip La Nina on atmospheric conditions and dynamics in the Indonesian region.

These various datasets will be processed and presented in the form of spatial maps for each seasonal period, namely December-January-February (DJF), March-April-May (MAM), June-July-August (JJA), and September-October-November (SON) (Athoilah et al., 2017; Hidayat et al., 2018). These spatial map shows the anomaly in each seasonal period (DJF, MAM, JJA, and SON) between the average of each parameter during Triple-Dip La Nina 2020 to 2023 with the normal data or 30 years average data (1991 - 2020) in each seasonal period.

Data analysis

The data analysis in this study is conducted on SST data NOAA, zonal wind and relative humidity data ECMWF model, as well as CHIRPS satellite data. SST data analysis will be carried out by analyzing graphs of fluctuations in ONI values and spatial maps of SST anomalies for each seasonal period during the Triple-Dip La Nina 2020 to 2023. This is done to determine the evolution, patterns and characteristics of the Triple La Nina 2020 to 2023.

Meanwhile, analysis of zonal wind and relative humidity data from the ECMWF model as well as CHIRPS rainfall data will be carried out by analyzing spatial maps of anomalies for each of these parameters in each season period during the Triple-Dip La Nina 2020 to 2022. This is done to determine the magnitude of the influence and which areas are consistently affected by the Triple La Nina 2020 to 2023.

Results and Discussion

Timeline of ENSO Evolution and Analysis of Triple-Dip Evolution

The graph in Figure 1 (a) represents the fluctuation of the Oceanic Nino Index (ONI) values, which describe the existence of ENSO in the Nino-3.4 area over the past 5 years. The trend line of the average ONI values illustrates the evolution of ENSO phases, shifting from a positive phase (El Niño) followed by a negative phase (La Niña). Fluctuations in the ONI that tend to be positive occurred from April 2018 until June 2020, followed by a significant decrease in values, indicating the onset of the La Niña phase in July 2020. The consistent presence of negative ONI values was observed until March 2023. This is intriguing for study as it not only reflects the pattern of sea surface temperature oscillation but also suggests a connection to atmospheric circulation, forming atmospheric-ocean coupling.

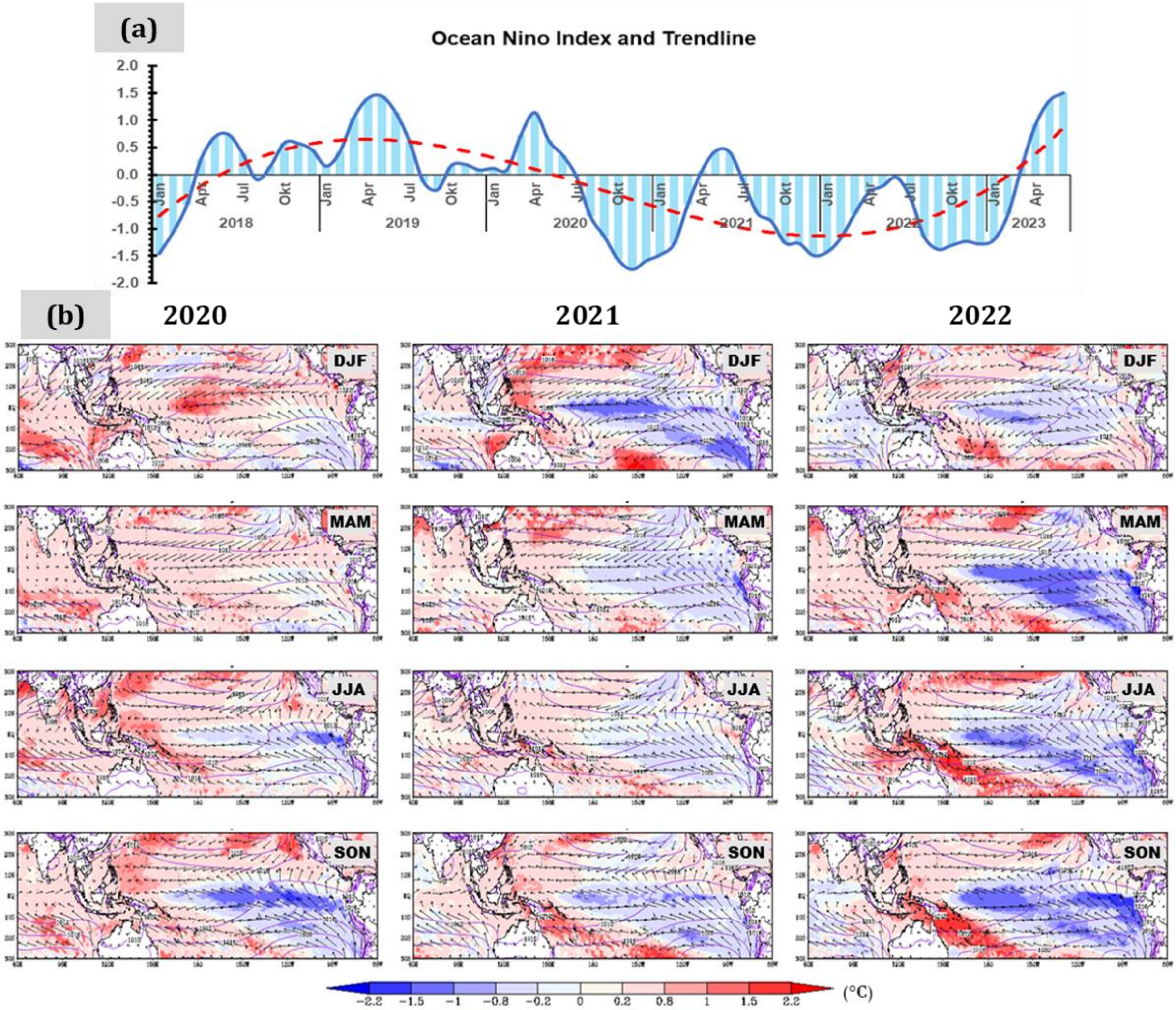

Figure 1. (a) Oceanic Nino Index (ONI) graph (blue area) and the average trendline (red line) for the period 2018 to 2023. (b) Sea surface temperature anomalies, surface wind vectors, and mean sea level pressure (MSLP) during Triple-Dip La Nina 2020 to 2022.

The dynamics of sea surface temperatures (SST) in the Pacific Ocean and surface winds (at 10 meters) have been explained in previous research through the concepts of feedback mechanisms (Bjerknes, 1969) and the charge-discharge (CD) mechanism (Jin, 1997), resulting in the periodic oscillations of ENSO. The Bjerknes feedback involves the interaction between the trade winds and sea surface temperatures in the equatorial Pacific Ocean, which influences the development and intensification of La Nina. During the Triple-Dip La Nina phase (Figure 1 (b)), a decrease in sea surface temperatures in the central and eastern Pacific leads to atmospheric pressure differences, resulting in the strengthening of the eastward trade winds. This change in wind direction leads to the dispersion of cold water in the central to western regions of the Pacific Ocean.

During the MAM 2020 period, the spatial distribution of sea surface temperature anomalies (SSTA) in the central and eastern Pacific Ocean showed diverse trends. However, there was an observed intrusion of cold anomalies from the southeast of the eastern Pacific Ocean. This cold anomaly intrusion persisted and continued to strengthen until the DJF 2021 period. This pattern also indicated atmospheric disturbances, marked by the persistent strengthening of southeast winds from the eastern subtropical Pacific region. These winds were associated with the reinforcement of the easterly trade winds along the Equatorial Pacific due to the Coriolis effect. A decrease in the intensity of the easterly trade winds in the central Pacific was observed during MAM 2021 and JJA 2021. Surprisingly, this decrease did not significantly weaken the La Niña phase. Instead, it served as a new starting point that led to an even more intense La Niña, which persisted until the early 2023. The factors driving the persistence of the Triple-Dip La Niña, as indicated by the analysis, are the intrusion of southeast winds and the presence of cold ocean currents in the eastern Pacific region.

In summary, the analysis of the ONI and spatial SSTA indicates the complexity of ENSO, which is driven by asymmetric patterns. Asymmetric patterns are the primary factors determining the formation of the Triple-Dip La Nina phenomenon 2020 to 2023. The meridional influence of persistent southeast trade winds leads to changes in SST dynamics in the eastern Pacific. These SST anomalies can persist for several seasons and spread toward the central equatorial Pacific due to interactions between the ocean and the atmosphere and the upwelling phenomenon in the ocean, which helps maintain the supply of cooler water from the subtropical regions to the deeper layers. In other words, pressure gradients and subtropical SST factors play a crucial role in sustaining and reinforcing wind patterns, which, in turn, can trigger the complexity of ENSO variations and asymmetric patterns (Fang et al., 2023).

Analysis of Zonal Wind Anomaly

Figure 2 below shows the anomalies of zonal winds on 850 mb level in the Indonesian region during each time period throughout the occurrence of the Triple-Dip La Nina 2020 to 2022. In general, the strengthening of zonal winds during each time period throughout the Triple-Dip La Nina 2020 to 2022 consistently occurs in regions of Indonesia that are relatively close to the Pacific Ocean, that are, the northern and eastern parts of Indonesia (Papua, Maluku, North Maluku, northern Sulawesi, as well as the northern and eastern parts of Kalimantan). In these regions, there is a strengthening of zonal winds reaching 1 - 7 m/s higher than their normal conditions.

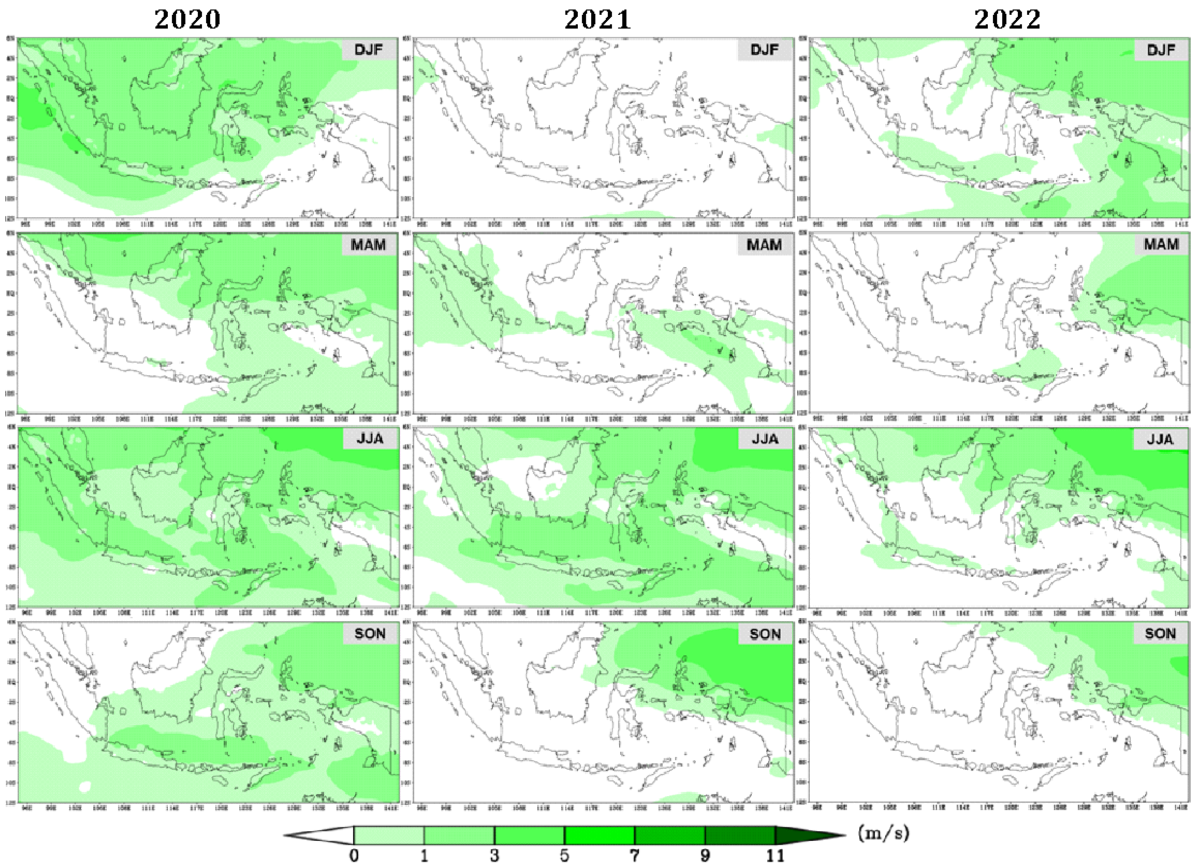

Figure 2. Zonal wind anomalies on 850 mb level in Indonesia during Triple-Dip La Nina 2020 to 2022.

In the meantime, other regions in Indonesia generally show zonal wind strengthening only during certain periods. Throughout the occurrence of the Triple-Dip La Nina 2020 to 2022, the strengthening of zonal winds compared to their normal conditions in western Indonesia (Sumatra) mostly occurred during a few time periods (JJA 2020, MAM 2021, and JJA 2021). This indicates that the occurrence of the Triple-Dip La Nina in the Pacific Ocean region has a limited impact on zonal winds or the atmospheric conditions and dynamics in western Indonesia (Sumatra).

The strengthening of zonal winds during the Triple-Dip La Nina 2020 to 2022 occurs in almost all of Indonesia, mainly during the JJA period. During this period, there is zonal wind strengthening ranging from 1 - 7 m/s compared to normal conditions. This indicates an increased movement of air masses from the Pacific Ocean to Indonesia during the JJA period. The strengthening of zonal winds during La Nina in Indonesia suggests the potential for increased movement of air masses originating from the Pacific Ocean, which can influence the amount of rainfall that occurs (Athoilah et al., 2017).

Analysis of Relative Humidity Anomaly

Figure 3 below shows the anomalies of relative humidity on 850mb level in the Indonesian region during each time period throughout the occurrence of the Triple-Dip La Nina 2020 to 2023. In general, the anomalies of relative humidity on 850mb level vary during each time period throughout the occurrence of the Triple-Dip La Nina 2020 to 2023. During the JJA 2020 period, which marks the early stages of the Triple-Dip La Nina, regions including Kalimantan, Sulawesi, parts of Java, Maluku, North Maluku, and Papua generally exhibit positive anomalies of relative humidity, indicating an increase in relative humidity in these areas. The increase in relative humidity ranges from 1% to 6% compared to normal conditions. Meanwhile, during the same time period, most of Sumatra, Bali, NTB, and NTT generally show negative anomalies of relative humidity, signifying a decrease in relative humidity in these regions compared to normal conditions. These findings indicate that during the JJA 2020 period, which represents the early stages of the Triple-Dip La Nina, it is mainly the regions closest to the Pacific Ocean, namely, the northern and eastern parts of Indonesia, that show a direct positive response in atmospheric dynamics to the occurrence of the Triple-Dip La Nina, resulting in an increase in relative humidity compared to normal conditions.

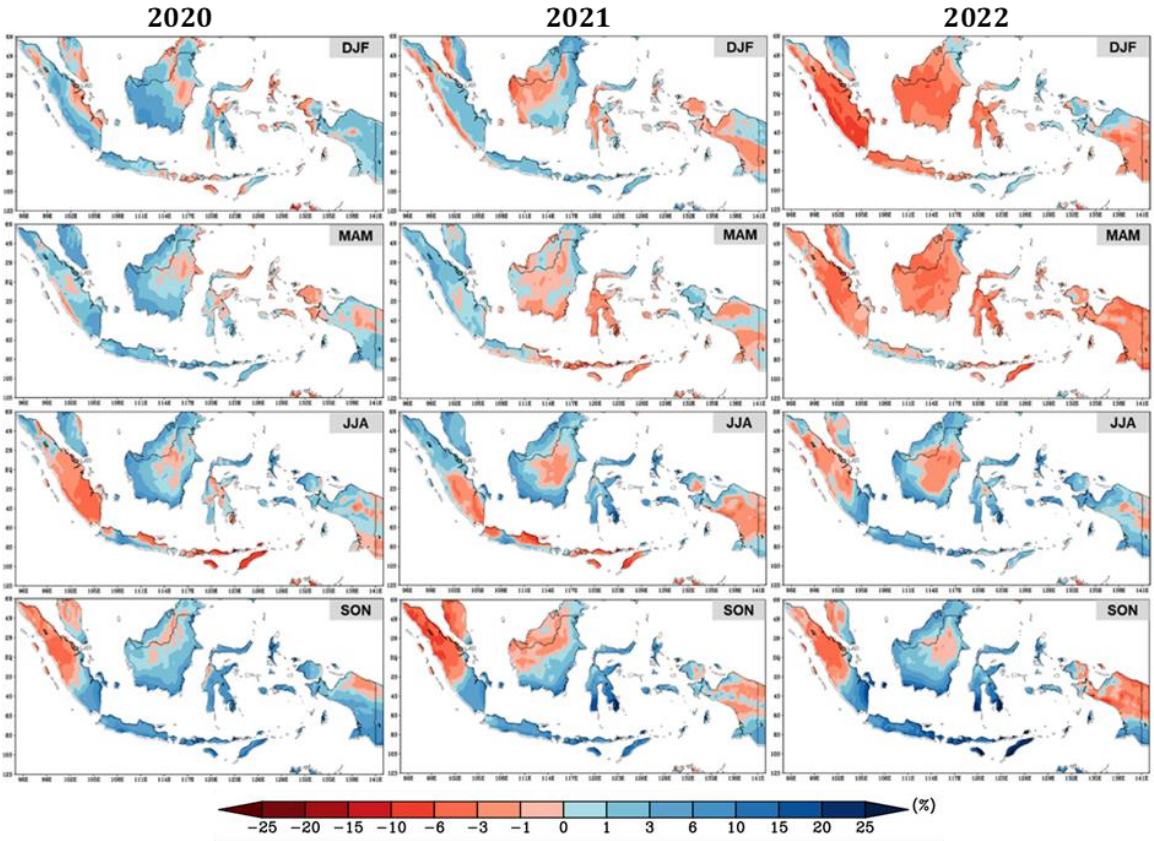

Figure 3. Relative humidity anomalies on 850mb level in Indonesian during Triple-Dip La Nina 2020 to 2022.

During the Triple-Dip La Nina 2020 to 2023, a consistent increase in relative humidity occurred in almost all regions of Indonesia (except Sumatra) mainly during the SON period. During this period, there was an increase in relative humidity ranging from 1% to 15% in almost all of Indonesia. This aligns with previous research that indicated the best correlation between the increase in relative humidity or water vapor response in the western Pacific Ocean region and the occurrence of La Nina during the SON period (Suparta et al., 2013).

In general, during each time period throughout the Triple-Dip La Nina, Sumatra is the only region in Indonesia that does not exhibit an increase in relative humidity. Instead, it generally shows negative anomalies of relative humidity, signifying a decrease in relative humidity compared to normal conditions. This can be an indication that the occurrence of the Triple-Dip La Nina does not have a significant impact on the atmospheric conditions and dynamics in western Indonesia, particularly in the region of Sumatra. This could be due to the considerable distance between the Pacific Ocean (where La Nina occurs) and the Sumatra region.

Analysis of Rainfall Anomaly

Figure 4 below shows the anomalies of rainfall in the Indonesian region during each time period throughout the occurrence of the Triple-Dip La Nina from 2020 to 2023. In general, the anomalies of rainfall in Indonesia are positive during the Triple-Dip La Nina 2020 to 2023, indicating an increase in rainfall compared to normal conditions. During the Triple-Dip La Nina, consistent increases in rainfall, ranging from 10 to 150 mm for each time period, generally occur in parts of western Papua, North Maluku, Maluku, Sulawesi, and the northern, eastern, and central parts of Kalimantan. Meanwhile, other regions like Sumatra, Java, Bali, and Nusa Tenggara generally consistently experience increased rainfall during the JJA and SON periods.

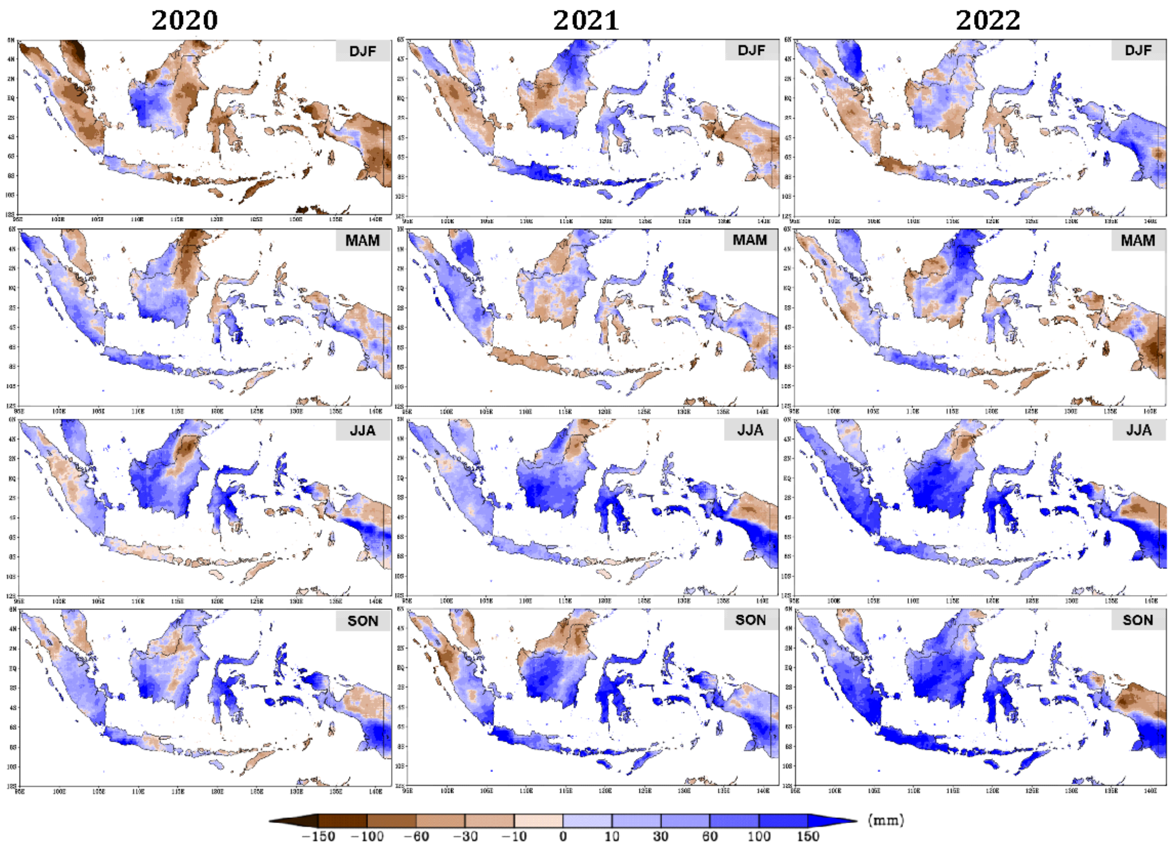

Figure 3. Rainfall anomalies in Indonesian during Triple-Dip La Nina 2020 to 2022.

During the DJF and MAM periods, there are only a few regions in Indonesia experiencing increased rainfall. The highest increase in rainfall occurs in almost all of Indonesia mainly during the JJA (dry season) and SON (transition from dry to rainy season) periods, particularly during the JJA 2022 and SON 2022 periods. The increase in rainfall during the JJA and SON periods typically ranges from 10 to 150 mm. This aligns with previous research, which generally indicates that the influence of La Nina on rainfall in Indonesia is most pronounced from June to November (JJA and SON), corresponding to the dry season and the transition from the dry to the rainy season (Aldrian et al., 2007; Kurniadi et al., 2021).

During the DJF and MAM periods throughout the occurrence of the Triple-Dip La Nina, there is a decrease in rainfall (negative rainfall anomalies) compared to normal conditions in several regions of Indonesia. Generally, during the DJF period of the Triple-Dip La Nina, there is a decrease in rainfall ranging from 10 to 100 mm in the western part of Indonesia, including parts of Sumatra, western Kalimantan, and western Java. This aligns with previous research, which indicates the presence of negative rainfall anomalies during the DJF period in several regions such as Sumatra, Kalimantan, and some eastern regions of Indonesia (Hidayat et al., 2018).

Meanwhile, during the MAM period throughout the occurrence of the Triple-Dip La Nina, there is a decrease in rainfall, which is generally observed in the southern part of Indonesia. For example, in the Java region, there is a decrease of 10 to 60 mm during the MAM 2021 period, and in Bali, NTB, and NTT regions, there is a decrease of 10 to 30 mm during the MAM 2021 and MAM 2022 periods. Additionally, during the MAM 2022 period, there is also a decrease in rainfall in some parts of Maluku and Papua, reaching 30 to 100 mm. The decrease in rainfall during the DJF and MAM periods suggests that there isn't a clear and significant correlation between rainfall and La Nina during these time periods (As-syakur et al., 2014).

Conclusions

In this study, we found a series of complex atmosphere-ocean coupling phenomena that are resulting in ideal conditions for the formation of the Triple-Dip La Nina phenomenon. reviewed from the perspective of annual sea surface temperature (SST) anomalies, prolonged negative anomalies impact the formation of a strengthened pressure gradient system (SLP) that consistently increases the intensity of eastward trade winds in the central and eastern equatorial Pacific. Through the analysis presented in the discussion, there is an asymmetric mode that plays a role in producing negative SST anomalies in the East to Central Pacific. The intrusion of SST from the southeast of central and eastern equatorial off-Pacific, identified as the result of seasonal migration, is a key factor supporting negative anomalies in the equatorial Pacific region. This mode has been in a negative phase since 2020 and supports the development of the Triple-Dip La Nina phenomenon.

In this study, we also conducted an analysis of the influence of the Triple-Dip La Nina on the variability and dynamics of the Indonesian atmosphere. The Triple-Dip La Nina from 2020 to 2023 had varied impacts. From the analysis, it was observed that there was a strengthening of zonal winds, increased relative humidity, and rainfall across almost the entire Indonesian region. However, only the northern and eastern parts of Indonesia consistently showed a significant influence of La Nina. This indicates that the implications of the Triple-Dip La Nina on spatial variations are more pronounced in regions close to the Pacific Ocean. Meanwhile, the temporal variations of La Nina's influence were more pronounced during the JJA (dry season) and SON (transition from dry to rainy season) periods, indicating zonal advection due to the strengthening of eastward trade winds pushing more moisture into the Indonesian region and causing climate variability through increased rainfall.

Acknowledgements: We Acknowledge the European Centre for Medium-Range Weather ForcastAcknowledgments are expressed in a brief; all sources of institutional, private, and corporate financial support for the work must be fully acknowledged, and any potential conflicts of interest are noted.

Conflict Of Interest: The authors declare that there are no conflicts of interest concerning the publication of this article.

References

Ahrens, C. D. 2009. *meteorologytoday_Ahrens* (9th ed.). Cengage Learning.

Aldrian, E., Dümenil Gates, L., & Widodo, F. H. 2007. Seasonal variability of Indonesian rainfall in ECHAM4 simulations and in the reanalyses: The role of ENSO. *Theoretical and Applied Climatology*, *87*(1–4), 41–59. https://doi.org/10.1007/s00704-006-0218-8

As-syakur, A. R., Adnyana, I. W. S., Mahendra, M. S., Arthana, I. W., Merit, I. N., Kasa, I. W., Ekayanti, N. W., Nuarsa, I. W., & Sunarta, I. N. 2014. Observation of spatial patterns on the rainfall response to ENSO and IOD over Indonesia using TRMM Multisatellite Precipitation Analysis (TMPA). *International Journal of Climatology*, *34*(15), 3825–3839. https://doi.org/10.1002/joc.3939

Athoilah, I., Sibarani, M. R., & Doloksaribu, D. E. 2017. ATHOILLAH2017. *Jurnal Sains Dan Teknologi Modifikasi Cuaca*, *18*, 33–41.

Bjerknes, J. 1969. Atmospheric Teleconnections From The Equatorial Pacific. In *Monthly Weather Reyiew* (Vol. 97, Issue 3).

Fang, X., Zheng, F., Li, K., Hu, Z. Z., Ren, H., Wu, J., Chen, X., Lan, W., Yuan, Y., Feng, L., Cai, Q., & Zhu, J. 2023. Will the Historic Southeasterly Wind over the Equatorial Pacific in March 2022 Trigger a Third-year La Niña Event? *Advances in Atmospheric Sciences*, *40*(1), 6–13. https://doi.org/10.1007/s00376-022-2147-6

Gao, Z., Hu, Z.-Z., Zheng, F., Li, X., & Li, S. 2022. *Meteorological Administration Guangzhou Institute of Tropical and Marine Meteorology Research Article*. https://doi.org/10.21203/rs.3.rs-1650169/v1

Hidayat, R., Juniarti, M. D., & Ma'Rufah, U. 2018. Impact of la Niña and la Niña Modoki on Indonesia rainfall variability. *IOP Conference Series: Earth and Environmental Science*, *149*(1). https://doi.org/10.1088/1755-1315/149/1/012046

Jin, F.-F. 1997. *An Equatorial Ocean Recharge Paradigm for ENSO. Part I: Conceptual Model*.

Kurniadi, A., Weller, E., Min, S. K., & Seong, M. G. 2021. Independent ENSO and IOD impacts on rainfall extremes over Indonesia. *International Journal of Climatology*, *41*(6), 3640–3656. https://doi.org/10.1002/joc.7040

Luo, J. J., Liu, G., Hendon, H., Alves, O., & Yamagata, T. 2017. Inter-basin sources for two-year predictability of the multi-year la Niña event in 2010-2012. *Scientific Reports*, *7*(1). https://doi.org/10.1038/s41598-017-01479-9

Pratama, A., Agiel, H. M., & Oktaviana, A. A. 2022. Evaluasi Satellite Precipitation Product (GSMaP, CHIRPS, dan IMERG) di Kabupaten Lampung Selatan. *Journal of Science and Applicative Technology*, *6*(1), 32. https://doi.org/10.35472/jsat.v6i1.702

Supari, Tangang, F., Salimun, E., Aldrian, E., Sopaheluwakan, A., & Juneng, L. 2018. ENSO modulation of seasonal rainfall and extremes in Indonesia. *Climate Dynamics*, *51*(7–8), 2559–2580. https://doi.org/10.1007/s00382-017-4028-8

Suparta, W., Iskandar, A., Jit Singh, M. S., Mohd. Ali, M. A., Yatim, B., & Mohd Yatim, A. N. 2013. Analysis of GPS water vapor variability during the 2011 La Niña event over the western Pacific Ocean. *Annals of Geophysics*, *56*(3). https://doi.org/10.4401/ag-6261

Timmermann, A., An, S. Il, Kug, J. S., Jin, F. F., Cai, W., Capotondi, A., Cobb, K., Lengaigne, M., McPhaden, M. J., Stuecker, M. F., Stein, K., Wittenberg, A. T., Yun, K. S., Bayr, T., Chen, H. C., Chikamoto, Y., Dewitte, B., Dommenget, D., Grothe, P., … Zhang, X. 2018. El Niño–Southern Oscillation complexity. In *Nature* (Vol. 559, Issue 7715, pp. 535–545). Nature Publishing Group. https://doi.org/10.1038/s41586-018-0252-6

Zhang, R. H., Gao, C., & Feng, L. 2022. Recent ENSO evolution and its real-Time prediction challenges. In *National Science Review* (Vol. 9, Issue 4). Oxford University Press. https://doi.org/10.1093/nsr/nwac052