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SENSITIVITY OF CRU AND ERA5 PRECIPITATION DATASETS TO ENSO FORCINGS FOR INDONESIAN CLIMATE DURING 1970-2024

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ABSTRAK

Data observasi presipitasi sebagai bagian dari parameter iklim untuk wilayah teritorial se dunia dapat diperoleh dari stasiun monitor di darat dan di udara. Studi ini melaporkan dua jenis data presipitasi di Indonesia antara 1970–2024 yang disediakan oleh Climatic Research Unit (CRU), University of East Anglia, UK untuk stasiun monitor di darat dan ERA5, generasi kelima dari European Centre for Medium-Range Weather Forecasts (ECMWF) untuk pengukuran satelit. Tujuan penelitian ini adalah membandingkan sensitivitas kedua jenis data presipitasi terhadap pengaruh ENSO dengan cara menentukan seberapa kuat El Niño dan La Niña memengaruhi variabilitas intensitas curah hujan di Indonesia. Metode yang digunakan dalam penelitian ini adalah mengakses laman yang kredibel untuk pengumpulan dan pemrosesan data presipitasi di Indonesia dan temperatur muka laut selama observasi berlangsung. Hasil-hasil penelitian dan pembahasan terkait adalah sebagai berikut. El Niño and La Niña menunjukkan sifat asimetrik, dimana kedua fenomena alam tersebut berpengaruh terhadap data presipitasi di Indonesia yang diperoleh dari dua teknik pengukuran. Pertama, data presipitasi CRU dan ERA5 sesuai dengan tahun-tahun kejadian ENSO ekstrem. Kedua, meskipun terdapat perbedaan signifikan antara intensitas curah hujan yang dilaporkan oleh CRU dan ERA5, data presipitasi CRU dan ERA5 bersifat *self-consistent* dalam mendeskripsikan fenomena alam. Ketiga, dengan tingkat resolusi yang lebih tinggi data presipitasi ERA5 terbukti lebih sensitif terhadap pengaruh ENSO ekstrem daripada data presipitasi CRU untuk kondisi iklim di Indonesia.

Kata Kunci: *Presipitasi*, *Sensitivitas*, *ENSO*, *El Niño*, *La Niña*

ABSTRACT

Observational precipitation datasets for countries around the globe as part of climate parameters are available in time-series acquired from ground-based and satellite-based monitoring stations. This study reports two datasets for rainfall variability in Indonesia during 1970–2024 provided by Climatic Research Unit (CRU) University of East Anglia, UK for the ground-based data and ERA5, the fifth version of European Centre for Medium-Range Weather Forecasts (ECMWF) for the satellite-based measurements. The main aim of the study was to examine sensitivity of both datasets to climatic ENSO forcings, determining how strong El Niño and La Niña events influenced Indonesian rainfall variability. The methods in this study included accessing reliable sites for collecting and processing Indonesian precipitation datasets of different techniques and sea surface temperature data during observations. The results and corresponding discussions are summarised as follows. While El Niño and La Niña events indicate asymmetric behaviours, the ENSO forcings affect the precipitation datasets derived from two measurement techniques. Firstly, the datasets from CRU and ERA5 are coincident with years of extreme ENSO events. Secondly, despite the apparent difference in magnitude between observed rainfall intensities,

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the CRU and ERA5 datasets are found to be self-consistent in describing natural phenomena. Thirdly, with a higher resolution ERA5 datasets are more sensitive to the ENSO forcings than CRU datasets when applied to climatic conditions in Indonesia.

Keywords: *Precipitation*, *Sensitivity*, *ENSO forcings*, *El Niño*, *La Niña*

INTRODUCTION

El Niño–Southern Oscillation (ENSO) is a global climate phenomenon that emerges from variations in winds and sea surface temperatures (SSTs) due to complex air-sea interaction along the tropical Pacific. Such variations are in irregular patterns but with some similarities in cycles. While the occurrence of ENSO is unpredictable, it affects regional climate not only in the tropics and subtropics but also in remote areas of higher latitudes through teleconnections in the atmosphere (McPhaden et al., 2020; Santoso et al., 2022; Li et al., 2023). The ENSO is widely known to have two opposing phases (with a neutral phase is present in between), namely the warm phase called El Niño and the counter cool phase called La Niña (Geng et al., 2019; Chen et al., 2021; Ehsan et al., 2024), each with its own characteristics. El Niño episodes are commonly signalled by sustained warming of the sea surface than normal (average) conditions in the central and eastern equatorial Pacific Ocean and La Niña episodes come into play when continual cooling of the central Pacific waters occurs (Sayol et al., 2022; Torres et al., 2023; Parra et al., 2024). The Southern Oscillation refers to the atmospheric component of the ENSO, coupled with the observed changes in SST in the equatorial Pacific (Timmermann et al., 2018; Liu et al., 2022; Freund et al., 2024).

In practice, El Niño or La Niña is a twist, climatic atmospheric-oceanic phenomenon occurring in the equatorial Pacific with five consecutive 3-month running mean SST anomalies in a Niño 3.4 region that is above or below a threshold of +0.5°C or -0.5°C. This standard of measure is known as the Oceanic Niño Index (ONI). Scientists have classified the strength of El Niño (La Niña) based on SST anomaly measurements exceeding the threshold in a particular region of the equatorial Pacific. The most commonly used region is the region of Niño 3.4, geographically bordered by 5˚N – 5˚S and 120˚W – 170˚W (see Fig. 1), where the threshold is a positive (negative) SST departure, which is greater than or equal to +0.5°C (below than or equal to -0.5°C), respectively, for each case from a normal condition.

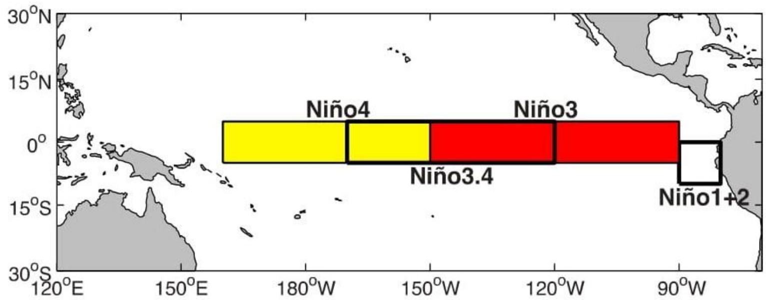

Figure 1. Niño regions in the central-eastern equatorial Pacific used to characterise ENSO, where the region of Niño 3.4 is commonly used for identifying El Niño and La Niña arrivals (taken from Figure 1 of Kozar et al. (2012)).

The ENSO impacts upon the Earth's climate system by affecting climate parameters, such as temperature and precipitation patterns worldwide. The dynamics of the ENSO includes phase transitions driven by changes in SST and corresponding atmospheric circulation. This is

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a major source of climate variability at interannual time-scales (Le & Bae, 2019; Glantz & Ramirez, 2020; Iwakiri & Watanabe, 2021) and can lead to extreme weather events, such as severe droughts and wildfires (Shikwambana et al., 2022), flood risks (Song et al., 2023), and in the context of climate-related hazardous events in Indonesian territory (Ariska et al., 2024; Hanifa & Wiratmo, 2024; Hendrawan et al., 2025). Such disasters could lead to failures in agriculture, food security, public health and accessibility, increasing environmental, social, economic, and humanity problems amongst affected countries (Glantz & Ramirez, 2025).

In Indonesia, the impacts of El Niño (La Niña) are reduced (increased) rainfall intensity over the whole territory. This may lead to droughts (floods) and potential wildfires (landslides) in some parts of the country (see Fig. 2 for comparison various types of hazardous occurrences in Indonesia between 1980–2024).

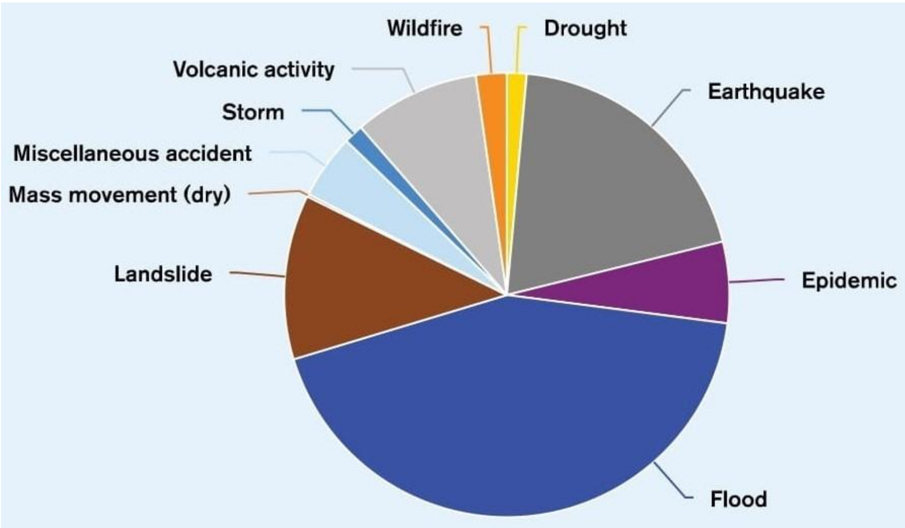

Figure 2. Relative distributions of various hazards in Indonesia between 1980–2024, including climate-related hazards: floods 46.4%, landslides 12.6%, droughts 1.4%, and wildfires 2.0% of the full events (from https://climateknowledgeportal.worldbank.org/country/indonesia/natural-disasters-historical).

Given the increasing frequency and intensity of extreme climate-related hazards (droughts, floods, and landslides) where both floods and landslides take a major portion of up to 60% of the total events during the observation, a better understanding of ENSO forcings (either El Niño or La Niña) and their effects on variations in rainfall intensity is of fundamental significance. Such an understanding enables us to develop the concept of early warning–early action for disaster mitigation in response to the worst impacts on society at risk (Glantz & Ramirez, 2020; Kurniadi et al., 2023; Glantz & Ramirez, 2025; Hendrawan et al., 2025).

As rainfall variability is monitored using two measurement techniques, this study aims to examine sensitivity of precipitation datasets provided by ground-based stations and those collected by satellites with respect to changes in atmospheric-oceanic conditions in the central-eastern Pacific waters. We determine how strong El Niño or La Niña influences precipitation in Indonesia during observation times between 1970–2024. This time interval is chosen as such examples of extreme events involving El Niño and La Niña are already taken into account. Knowledge of this issue is essential for climate scientists and decision makers at all levels.

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METHODS

Data for Indonesian rainfall variability (annual precipitation) in this study were taken from Climatic Research Unit (CRU), University of East Anglia, UK with precipitation datasets available between 1901–2024 and ERA5, the fifth generation of European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis for global climate with datasets available between 1950–2024, but then we only used a period of 1970–2024 datasets for examination. The CRU offers Indonesian precipitation datasets using a gridded 0.5º x 0.5º (50 km x 50 km) resolution for free at https://climateknowledgeportal.worldbank.org/country/indonesia/climate-data-historical. Whilst, the ECMWF provides ERA5 considered as one of the finest reanalysis climate products using a smoother gridded 0.25º x 0.25º (25 km x 25 km) resolution, accessible for free at https://climateknowledgeportal.worldbank.org/country/indonesia/era5-historical. Complete explanatory notes in great details on the scope of these datasets are made available by World Bank Group (WBG), which has managed Climate Change Knowledge Portal (CCKP) for promoting a high-level assessment of climate risks for developing countries worldwide, freely accessible at https://climateknowledgeportal.worldbank.org/guidance-note.

Data for SSTs and their associated anomalies (available in months between 1950–2025) collected from the Niño 3.4 were accessible at https://www.cpc.ncep.noaa.gov/data/indices for years of observation. The anomalies were calculated using the NOAA Extended Reconstructed Sea Surface Temperature version 5 (ERSSTv5) (see Huang et al. (2017) in details). These data, referred here to the ONI values, were used to demonstrate years of El Niño and La Niña events between 1970–2024, examined if there was a significant decrease or increase in precipitation. In other words, we tested consistency between the SST anomaly data and precipitation datasets. Having tested the consistency, the next step was to examine the sensitivity of CRU and ERA5 precipitation datasets to ENSO forcings due to extreme El Niño and La Niña events.

RESULTS AND DISCUSSIONS

Results

The widely used index is ONI, where its values represent ENSO states: a neutral pase if $-0.5 < \text{ONI} < 0.5$ is satisfied, El Niño if $\text{ONI} \geq 0.5$ is fulfilled, and La Niña if $\text{ONI} \leq -0.5$ is achieved. This index is provided by Climate Prediction Center (CPC), National Centers for Environmental Prediction (NCEP), National Oceanic and Atmospheric Administration (NOAA) using ERSSTv5 for global SST datasets from the Niño 3.4 region, freely accessible at www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/detrend.nino34.ascii.txt.

Figure 3 shows observational data for the ONI records representing SST anomalies in time-series from January 1950 to January 2025. The black lines limit lower and upper bounds on the neutral phase between -0.5ºC ≤ ONI ≤ 0.5ºC. For a prolonged period of 1970–2024, there were 4 extreme El Niño events in 1972/73, 1982/83, 1997/98, and 2015/16 with the ONI were valued for 2.1ºC, 2.2ºC, 2.4ºC, and 2.6ºC, respectively, demonstrating a steady increase in the observed SST anomalies in the warm phase (Huang et al., 2017) in the last 50 years.

During the same period of time, there were 6 strong La Niña events in 1973/74, 1975/76, 1988/89, 1999/2000, 2007/08, and 2010/11 with the ONI were measured to be -2.0ºC, -1.7ºC, -1.8ºC, -1.7ºC, -1.6ºC, and -1.6ºC, respectively. It follows that no clear patterns of the anomalies were detected for the cold phase (Chen et al., 2021; Geng et al., 2023) in the last 50 years, indicating different behaviours between the warm phase (El Niño) and cold phase (La Niña) of the ENSO (Timmermann et al., 2018; Geng et al., 2019; McPhaden et al., 2020).

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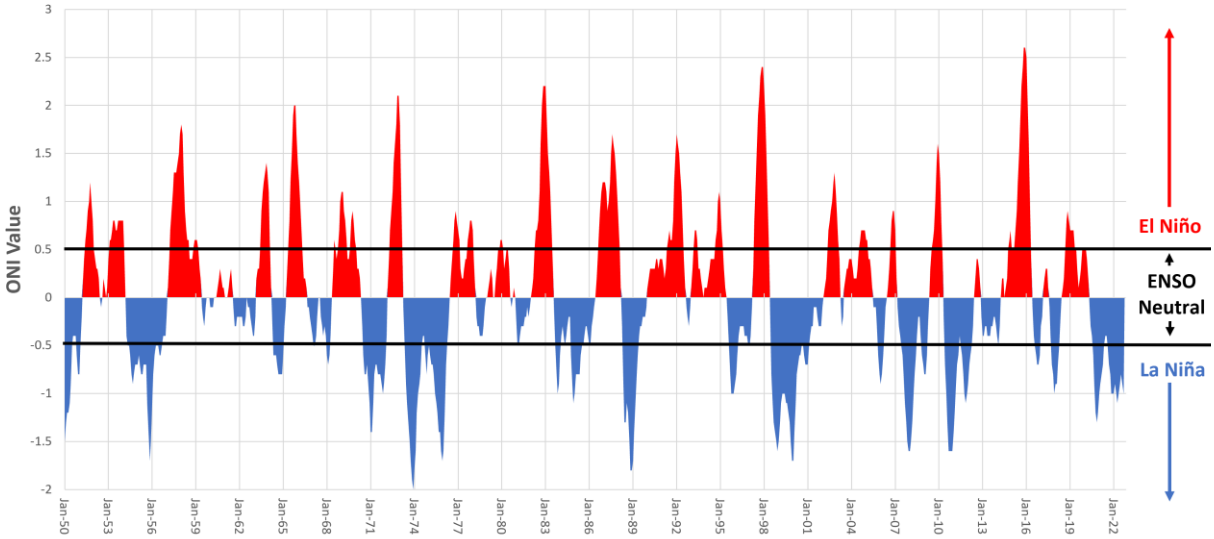

Figure 3. The ONI values for SST anomaly measurements collected from the Niño 3.4 region between 1950–2025, but only seen from January 1950 to January 2022. The missing part upon the right-end for placing each ENSO phase (involving observational data for the SST anomalies from January 2022 to January 2025) does not influence information content hence conclusions (from https://mrcc.purdue.edu/index.php/climate_watch/special_topics/enso-indices-and-past-events).

During the same period of time, there were 6 strong La Niña events in 1973/74, 1975/76, 1988/89, 1999/2000, 2007/08, and 2010/11 with the ONI were measured to be -2.0ºC, -1.7ºC, -1.8ºC, -1.7ºC, -1.6ºC, and -1.6ºC, respectively. It follows that no clear patterns of the anomalies were detected for the cold phase (Chen et al., 2021; Geng et al., 2023) in the last 50 years, indicating different behaviours between the warm phase (El Niño) and cold phase (La Niña) of the ENSO (Timmermann et al., 2018; Geng et al., 2019; McPhaden et al., 2020).

Figure 4 provides annual precipitation datasets in Indonesian territory acquired during 1970–2024 observations using two different techniques of measurements of rainfall intensity. While the first technique utilised CRU ground-based stations to obtain ground-based datasets, the second one used ERA5 satellite measurements to collect air-based datasets. It should be noted here that precipitation is a measure of the total accumulated amount of any form of water falling from the atmosphere over a particular region and a specific period of time, commonly measured in a depth unit (in mm or cm) (see, for example, Hanifa & Wiratmo (2024)). Whilst, rainfall intensity is defined as the rate at which rain falls onto the Earth's surface, usually comes with a depth (in mm or cm) per unit of time (in a month) (see, for example, Lee (2015)).

However, for a sufficiently long period of measurement it assumes that the predominant source of precipitation comes from rain; other sources of water falling from the atmosphere, such as hail and snow are in extremely small amounts relatively compared to that from rain. Given such definitions of precipitation and rainfall intensity, then it is safe to calculate directly the intensity of rainfall in a region for a certain year by dividing the precipitation measured over the region by 12 to obtain the average monthly intensity in the region of interest. For example, according to Fig. 4, precipitation over Indonesia in 1970 was recorded to be 2966 mm by CRU and 3393 mm by ERA5, meaning that rainfall intensities over Indonesian territory in 1970 were about 247 mm/month (CRU) and about 283 mm/month (ERA5). The significant difference in

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the observed precipitation hence the intensity of rainfall between CRU and ERA5 datasets is understood because Indonesia is a country with diverse landscapes and topographies, making the land-based measurements difficult that may lead to potential biases of the data provided (see for further details at https://climateknowledgeportal.worldbank.org/guidance-note).

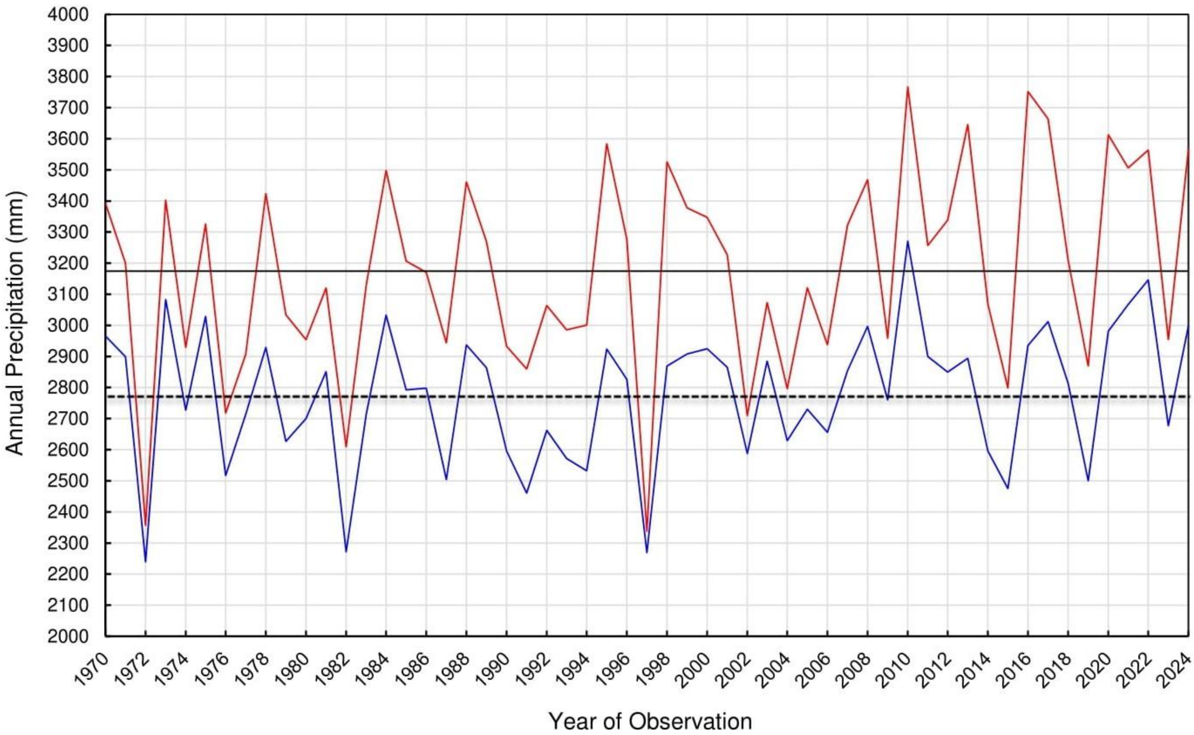

Figure 4. The graphs showing time-series measurements of annual precipitation in Indonesia between 1970–2024 collected from ground-based monitoring stations by CRU datasets (blue) and air-based observatories by ERA5 datasets (red). The black solid-line represents 3173 mm for the annual precipitation taken from ERA5 datasets whereas the black dashed-line shows 2778 mm for the annual precipitation collected from CRU datasets (both the lines are available from the annual mean of precipitation).

Discussions

Here we first discuss by further taking as much as possible information from Fig. 3, relevant to the characteristics of El Niño and La Niña episodes. Atmospheric conditions during El Niño are generally dryer (with hotter surface temperature in some sense but not discussed here) (Sayol et al., 2022; Torres et al., 2023; Parra et al., 2024). With the steadily increasing ONI values hence the SST anomalies in the equatorial Pacific between 1970–2024 (seen as increased peaks of the red graph in Fig. 3) for the last 4 extreme El Niño in 1972/73, 1982/83, 1997/98, and 2015/16 but not followed by the same trend in the ONI hence the SST anomalies for the last 6 strong La Niña in 1973/74, 1975/76, 1988/89, 1999/2000, 2007/08, and 2010/11, we argue for asymmetric behaviours in the strength of the warm (El Niño) and cold (La Niña) ENSO phases. However, we find consistency between Fig. 3 and Fig. 4 in that the observed precipitation decreases or increases significantly at times when El Niño or La Niña takes place. This information is of essential importance for decision makers to set up appropriate response to worsening conditions possibly experienced by community at risk, such as potential droughts

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leading to wildfires and potential flash-floods resulting in landslides (Kurniadi et al., 2023; Ariska et al., 2024; Glantz & Ramirez, 2025; Hendrawan et al., 2025).

Another consistency comes from CRU and ERA5 precipitation datasets, visually shown as two separate graphs in Fig. 4. Although the apparent difference in magnitude of the intensity measured as the annual precipitation for El Niño and La Niña episodes is clearly visible, both datasets follow the same trend in that the red peaks are coincident with the blue peaks during El Niño hits and that similar situations also take place for the lowest intensities in red and blue during La Niña strikes (see Kurniadi et al., 2023; Ariska et al., 2024 for further comparison). This information provides us with some levels of confidence that CRU and ERA5 datasets are self-consistent, accurately enough to describe a natural phenomenon through numerical values, reflecting what was happening during the observations.

The most difficult task to do in determining characteristics of CRU and ERA5 datasets is to select which one of the two datasets is more sensitive to the ENSO forcings than the other. In response to this, we focus on years when El Niño episodes took place in 1972/73, 1982/83, 1997/98, and 2015/16 with which we need only to examine points of the lowest intensities from the last 4 El Niño given by CRU (blue) and ERA5 (red) time-series graphs, as shown in Fig. 4. The 1972/73 and 1997/98 El Niño events are remarkably different from the other two cases as their lowest intensities of the CRU and ERA5 datasets are almost the same in size. It reflects that the datasets given by ERA5 are more sensitive to the influence of extreme El Niño events than those provided by CRU. This is sensible as ERA5 datasets are acquired from satellites and are created using a better gridded 0.25º x 0.25º resolution for greater details than CRU datasets obtained from ground stations using only a gridded 0.5º x 0.5º resolution. It is thus understood that scientists in the world have used ERA5 datasets for developing their climate models.

CONCLUSIONS

We have examined precipitation datasets in time-series acquired from ground-based and satellite-based observatories and reported two datasets for Indonesia rainfall variability during 1970–2024 provided by CRU, UK for the ground-based data and ERA5 for the satellite-based measurements. The primary aim of the present study is to examine sensitivity of both datasets to climatic ENSO forcings by determining how strong El Niño and La Niña events influence rainfall variability in Indonesia. We have used reliable, open sites for collecting and processing precipitation datasets in Indonesia from different techniques and sea surface temperature data during observations. The resulting findings and corresponding discussions are given as follows. While El Niño and La Niña strongly indicate asymmetric behaviours, the ENSO forcings affect the precipitation datasets. Firstly, the datasets from CRU and ERA5 are in good coincidence with years of extreme ENSO events. Secondly, despite the apparent difference in magnitude between the observed rainfall intensity, the CRU and ERA5 datasets are in self-consistency when describing atmospheric-oceanic phenomena. Thirdly, with a higher level of resolution ERA5 datasets are proved to be more sensitive to the ENSO forcings than CRU datasets when applied to climatic conditions in Indonesia. Further work is then needed to incorporate data for surface temperature into climate parameterisation within the context of Indonesian climate.

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Atmospheric Administration (NOAA), US from which the ONI data representing SST anomaly measurements are available for free.

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