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THE IMPACT OF ENSO ON EXTREME RAINFALL ON PAPUA ISLAND

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Abstract
One of the sea surface temperature anomaly phenomena that affects rainfall in Indonesia is the El-Niño Southern Oscillation (ENSO) that occurs in the Pacific Ocean. This also has an impact on rainfall in Papua Island, considering the geographical position of the island which is directly facing the Pacific Ocean. The impact of rainfall can potentially be at an extreme level. This study aims to analyze the impact of ENSO on extreme rainfall in Papua Island in 2002-2022. The extreme rainfall indices used are total annual rainfall on wet days (PRCPTOT) and extremely heavy precipitation days (Rnn). The data of this study were studied using daily rainfall data from BMKG and ERA 5 reanalysis. The method for calculating the extreme rainfall index value used the Non-Parametric Mann-Kendall Test. Before the Non-Parametric Mann-Kendall Test was conducted, quality control of rainfall data was carried out to ensure data reliability, including simple linear regression and Inverse Distances Weight techniques. The results of the study showed the impact of ENSO on extreme rainfall on the island of Papua with the emergence of La-Niña on changes in extreme rainfall trends in 2002-2022. Changes in the PRCPTOT and Rnn trends tend to increase dominantly influenced by La-Niña in the DJF, MAM and SON periods.

Keyword: *ENSO; Extreme Rainfall; Papua*

Abstrak
Salah satu fenomena anomali suhu permukaan laut yang mempengaruhi curah hujan di Indonesia adalah *El-Niño Southern Oscillaton* (ENSO) yang terjadi di Samudera Pasifik. Hal ini juga berdampak pada curah hujan di Pulau Papua, mengingat posisi geografi pulau tersebut yang berhadapan langsung dengan Samudera Pasifik. Dampak curah hujan tersebut dapat berpotensi pada tingkat ekstrem. Penelitian ini bertujuan untuk menganalisis dampak ENSO terhadap curah hujan ekstrem di Pulau Papua tahun 2002-2022. Indeks curah hujan ekstrem yang digunakan adalah total curah hujan tahunan pada hari basah (PRCPTOT) dan hari-hari curah hujan sangat lebat (R*nn)*. Data penelitian ini dikaji menggunakan data curah hujan harian dari BMKG dan reanalisis ERA 5. Metode perhitungan nilai indeks curah hujan ekstrem menggunakan Uji Mann-Kendall Non-Parametrik. Sebelum dilakukan Uji Mann-Kendall Non-Parametrik dilakukan *quality control* data curah hujan untuk memastikan keandalan data yang meliputi regresi linear sederhana dan teknik *Inverse Distances Weight*. Hasil penelitian menunjukkan dampak ENSO terhadap curah hujan ekstrem di pulau papua dengan kemunculan La-Niña pada perubahan tren curah hujan ekstrem tahun 2002-2022. Perubahan tren PRCPTOT dan R*nn* cenderung meningkat dominan yang dipengaruhi La-Niña pada periode DJF, MAM dan SON.

Kata Kunci: *ENSO; Curah Hujan Ekstrem; Papua*

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INTRODUCTION

Rainfall is the total amount of rainwater that falls in a certain period that plays an important role in the continuity of life on earth (Tulak et al., 2001). Rainfall is also an indicator of climate change (Syarifuddin et al., 2023). In general, rainfall is greatly influenced by the ENSO phenomenon (Yuggotomo et al., 2014), especially in Indonesia. This is because Indonesia's position is close to the convection region when the ENSO phenomenon occurs. The magnitude of the influence of ENSO on rainfall is very reasonable considering Indonesia's position in the western Pacific Ocean. The influence of ENSO on rainfall in Indonesia is largely determined by the strength or weakness of the ENSO that occurs. The potential for heavy rain in Indonesia is due to the increasingly strong La-Niña (Dewi & Marzuki, 2020).

The Meteorology, Climatology and Geophysics Agency (BMKG) shows that Indonesia's rainfall, especially in the western part of West Papua and the western part of Papua until the middle of the 1991-2020 period, is relatively high (3000-4500 mm/year). This figure is much higher than the average rainfall in Indonesia, which is 2000 mm (Azzahra et al., 2023). This is in accordance with the statement of the National Aeronautics and Space Administration (NASA) that areas around the equator have higher rainfall than other areas, with the location of Papua Island being between 0º 20' LS -10º 42' LS and stretching from 131º BT -151º BT. Another study conducted by (Lestari et al., 2018) found 2 areas with high rainfall (>350 mm/month), one of which was the southeastern Papuan islands. In addition, areas with relatively high rainfall were also seen in western Papua. Previous research conducted by Azzahra, et al. (2023) using hourly rainfall data for the period March 13, 2022 to October 17, 2022 from Manokwari, Fakfak, and Kaimana Regencies showed that rainfall in this area was categorized as very heavy. Another study conducted by Syarifuddin (2023) with the aim of identifying patterns of changes in rainfall trends in Sorong City based on annual rainfall, rainy days (HH), rain fraction, Consecutive Dry Days (CDD) and Consecutive Wet Day (CWD) using daily rainfall data for the period 2007-2020 in the Sorong City area, showed that the rainfall trend experienced a decrease marked by a negative slope of 81.16 mm/year with a decrease in the rainy day trend of -1.1692 days/year. The rain fraction trend showed negative values in all categories of rainfall intensity with an increase of -0.1029%. Then for the CDD and CWD trends there was an increase marked by a positive slope of 0.8703 and 0.211 days/year. Based on previous research in the Papua region, it can be seen that research examining the impact of ENSO on extreme rainfall in Papua Island using rainfall data from the last 20 years has not been carried out.

The purpose of this study is to analyze the impact of ENSO on extreme rainfall in Papua Island during the period 2002-2022. The results of this study can provide information for stakeholders whose activities depend on climate conditions, especially in Papua Island, especially in the agriculture, livestock and forestry sectors. In addition, the results of the study are expected to be a guideline and consideration for policy makers in developing climate change adaptation and mitigation strategies, as well as a reference for knowledge for the community related to the impacts of extreme climates.

METHODS
1. Location

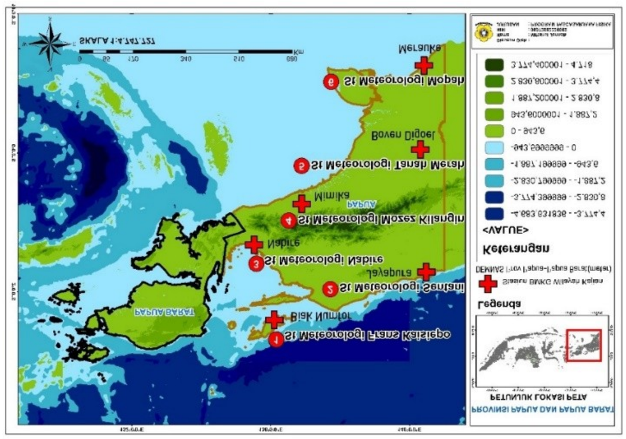

Figure 1. Location of the BMKG Observation Station on Papua Island

2. Data

The data used in this study are rainfall data recorded at the Meteorology, Climatology and Geophysics Agency (BMKG) station as in (Table 1) and rainfall reanalysis data from The European Centre for Medium-Range Weather Forecast, Reanalysis 5th Generation (ERA5 ECMWF) during the period 2002 - 2022. The type of research used is quantitative and qualitative research, namely research that uses data in the form of numbers and uses statistical data analysis and statistical data interpretation. As a qualitative research because it correlates the results of data processing with the ENSO phenomenon.

Table 1. BMKG Observation Stations on Papua Island

No.	Station Name	Latitude	Longitude	Elevation	Information Data Used
1.	Frans Kaisiepo Meteorological Station	-1.19069	136.10361	3	Data starting from 2002 to 2022
2.	Mopah Meteorological Station	-8.52019	140.41568	0	Data starting from 2002 to 2022
3.	Mozez Kilangin Meteorological Station	-4.53006	136.89348	30	Data starting from 2002 to 2022
4.	Nabire Meteorological Station	-3.35210	135.52000	3	Data starting from 2002 to 2022
5.	Sentani Meteorological Station	-2.57000	140.48000	96	Data starting from 2002 to 2022
6.	Tanah Merah Meteorological Station	-6.10000	140.31000	97	Data starting from 2002 to 2022

3. Methods

3.1 Extreme Rainfall Index

The Extreme Rainfall Index used in the research is as in (Table 2):

Table 2. Extreme Rainfall Index used in the Research

No.	Index	Description	Definition	Unit
1.	PRCPTOT	Wet Day	*Total annual rainfall on wet days*	mm
2.	Rnn	Extremely Heavy	*Very Heavy Rainfall on Rainfall Days*	Day

3.2 Trend Analysis and Magnitude of Change

The Mann-Kendall statistic provides a final conclusion in the form of the direction of change (positive or negative) and the degree of significance. The Mann-Kendall test is a test to determine whether or not there is a change in data, either positive or negative. The calculation of the Mann-Kendall test statistical value is carried out using the equation (Lestari et al., 2018). The initial value of the Mann-Kendall statistic (S) is assumed to be 0 (for example, there is no tendency). If the data value from the following time period is higher than the data value from the previous time period, S is added to 1. Conversely, if the data value from the following time period is lower than the data value from the previous period, S is reduced by 1. The results of all stages produce the final value of S.

$$S_i = \sum_{j=i+1}^{n} sign\left(x_j - x_i\right) \qquad (1)$$

$$S = \sum_{i=1}^{n-1} S_i \qquad (2)$$

with x_i and x_j being sequential data with data length n. The sign value is obtained using equation (1).

$$sign\left(x_j - x_i\right) = \begin{cases} +1, x_j - x_i > 0 \\ 0, x_j - x_i = 0 \\ 1, x_j - x_i < 0 \end{cases} \qquad (3)$$

Then calculate the normalized statistical value Z using the equation (Sugiyono., 2011). A positive Z value indicates an increasing trend, while a negative Z value indicates a decreasing trend.

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}}, S > 0 \\ 0, S = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}}, S < 0 \end{cases} \qquad (4)$$

where $Var(S)$ is the variance obtained by equation (10). While N is the number of years of rainfall data.

$$Var(S)=\frac{N(N+1)(2N+5)}{18} \quad (5)$$

Calculating changes in extreme index values is done using the Sen's Slope method. The value produced by the Sen's graph is the magnitude of the change that occurs during the observation period. The Sen's Slope equation for a number of N pairs of data samples is like equation (6).

$$Q_i=\frac{(x_j-x_i)}{j-i}, j=i+1\, dan\, i=1,2,3,\ldots N \quad (6)$$

The values of N and Q_i can be sorted from smallest to largest, Sen's Slope uses the median $Q_i(Q_{med})$ which is calculated as follows :

$$Q_{med}=\begin{cases} Q\left[\frac{N+1}{2}\right] if\ N=odd \\ \frac{Q\left[\frac{N}{2}\right]+Q\left[\frac{N+1}{2}\right]}{2} if\ N=even \end{cases} \quad (7)$$

A positive Q_{med} value indicates an increasing trend, a negative value indicates a decreasing trend, while a value of zero indicates that there is no trend.

3.3 Significance Test

Significance test using t-test is conducted to determine whether reanalysis data significantly influences BMKG data. The significance level α that is often used is α = 5% (α = 0.05) and degrees of freedom (df) = n-2 (Yuliara, 2016).

$$t=r\sqrt{\frac{n-2}{1-r^2}} \quad (8)$$

Note :

$t=$ ¿ t_{hitung}

$n=$ ¿ Amount of Data

$r=$ ¿ correlation coefficient

RESULTS AND DISCUSSION

The figure below provides information on the results of the extreme rainfall index for each station from the PRCPTOT and *Rnn* indices.

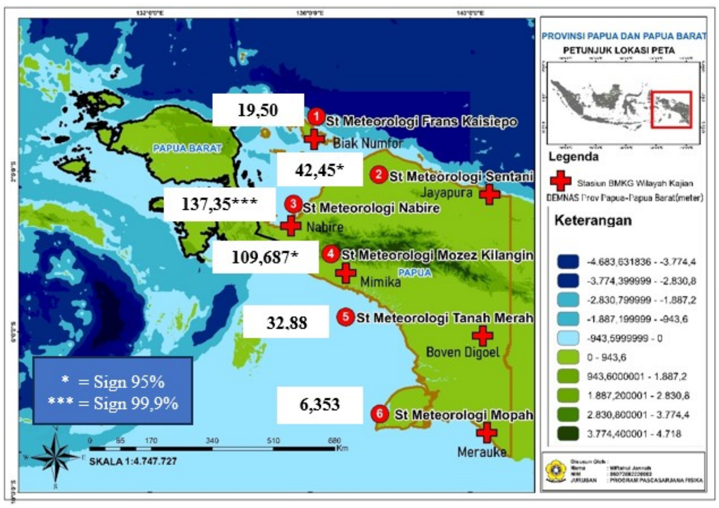

Figure 2. Sen's Slope PRCPTOT at 6 Observation Stations in the Papua Region

Based on Figure 2, the increasing trend of PRCPTOT at the Frans Kaisiepo Meteorological Station (1) is 19.50 mm/20 years or 390 mm/year; Sentani Meteorological Station (2) is 42.45 mm/20 years or 849 mm/year; Nabire Meteorological Station (3) is 137.35 mm/20 years or 2747 mm/year; Mozez Kilangin Meteorological Station (4) 109.687 mm/20 years or 2194 mm/year; Tanah Merah Meteorological Station (5) 32.88 mm/20 years or 658 mm/year; Mopah Meteorological Station (6) 6.353 mm/20 years or 127.06 mm/year. Figure 3 below shows the trend of the PRCPTOT index at 6 observation stations in the Papua region.

The PRCPTOT index in the figure 3 shows that the total annual rainfall has an increasing trend that occurs at 6 observation stations. The highest (lowest) increase occurred at the Nabire Meteorological Station (Mopah Meteorological Station) with a total annual rainfall increase of 2747 mm/year (127.06 mm/day). At the Nabire Meteorological Station (3) the highest PRCPTOT time series (7262.7 mm) occurred in 2016.

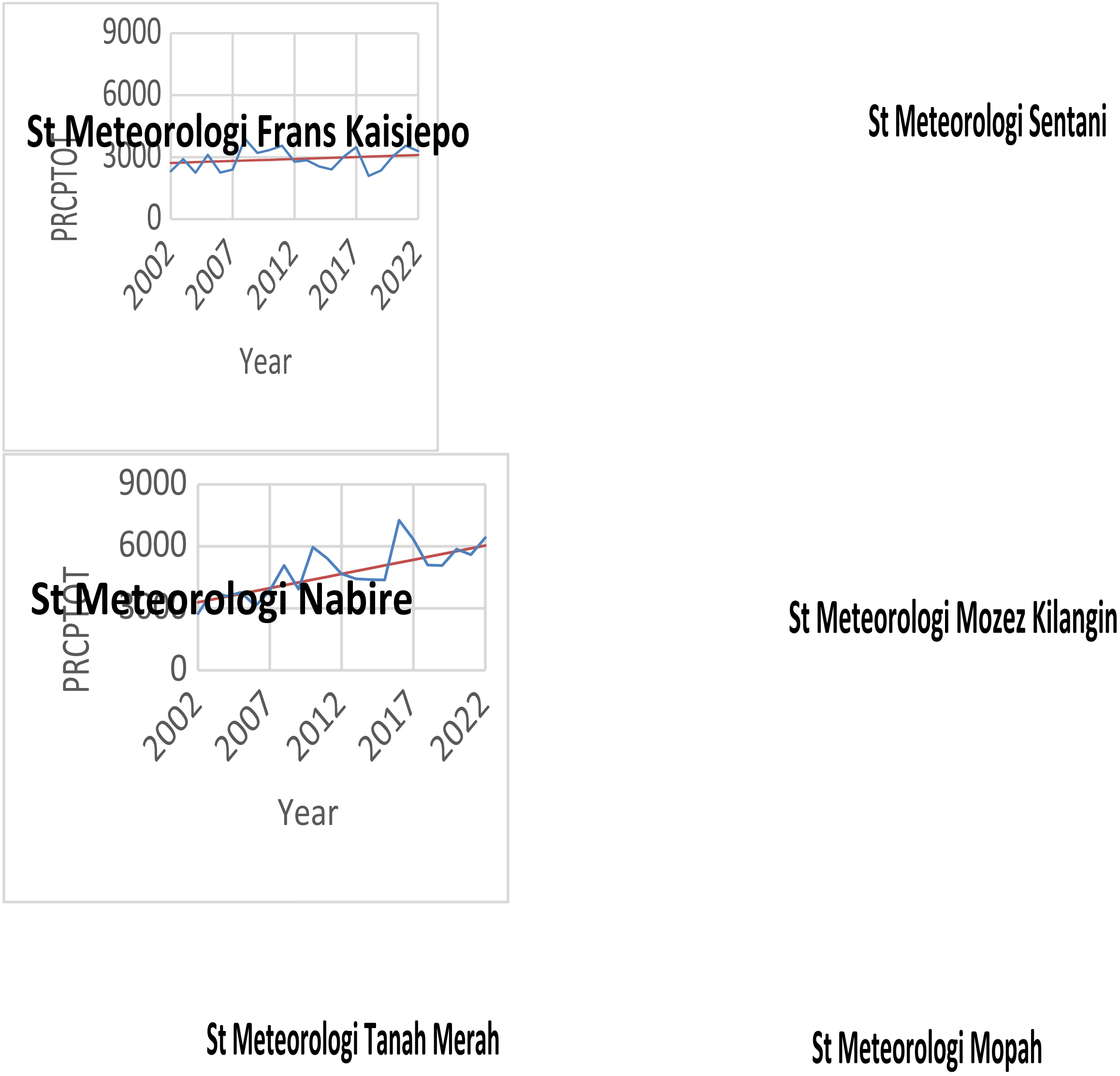

Figure 3. Trend of Extreme Rainfall Index PRCPTOT at 6 Observation Stations in Papua Region

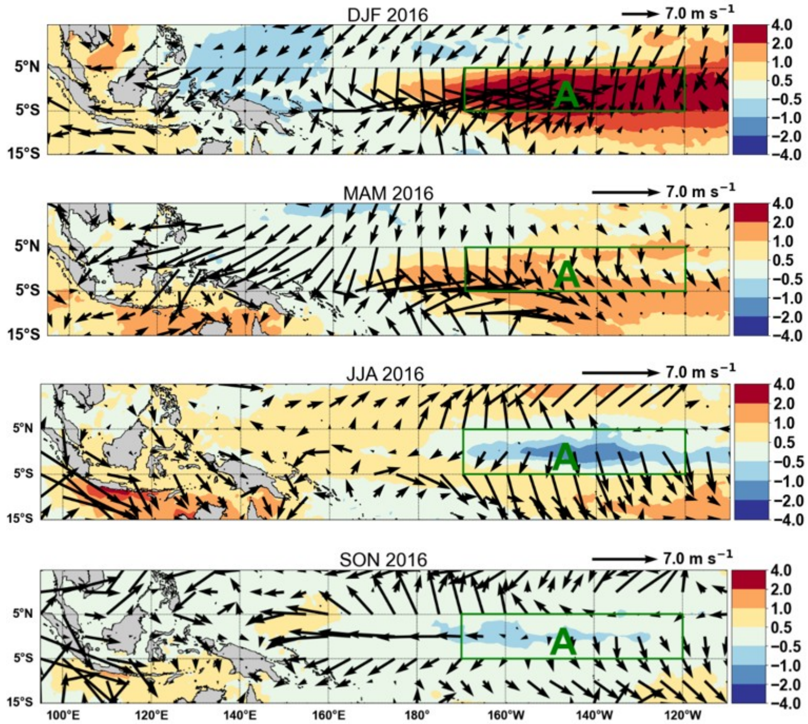

Figure 4. SST and Wind Anomalies in 2016

Figure 4 shows the SST and wind anomalies in 2016. Based on the Niño 3.4 index, it shows El Niño activity and the emergence of La Niña that occurred during the SON period (Lestari et al., 2018). The SST and wind anomalies in the DJF and MAM seasons appear warmer, when compared to other regions. In this season, the trade winds blow from the West Pacific to the East, causing the SST in the East Pacific to increase, which is marked by the emergence of a warm pool. This should cause the formation of rain clouds in the West Pacific to decrease due to weak evaporation due to the colder SST because the warm pool moves to the East Pacific, resulting in a rainfall deficit. In the JJA season, the trade winds slowly reverse direction along with the SST in the Pacific which decreases, cooler than the DJF and MAM seasons, until in the JJA season the trade winds blow from the East Pacific to the West, causing the activity of sea water mass convection to increase, which supports cloud formation. This causes the potential for rainfall in the West Pacific, including Indonesia, to experience a rainfall surplus.

Thus, Nabire Meteorological Station experienced the highest PRCPTOT in addition to the emergence of La Niña activity that occurred in the SON season. This is thought to have occurred because of its location in the northern lowlands of Papua, according to research by Aser Rouw (2014) showing that the equatorial rainfall pattern in the DJF and MAM seasons increased strongly and in the SON season, the highest rainfall pattern in the northern lowlands which averaged a peak in March (MAM) and August (JJA) reached 400-300 mm. In the JJA season, the trade winds were seen slowly reversing direction from the East Pacific to the West, this condition also coincided with the SST in the Pacific being colder than in the DJF and MAM seasons. In the SON season, the trade winds blew stronger from the East Pacific to the West which caused a surplus of rainfall in Indonesia, especially in Papua Island.

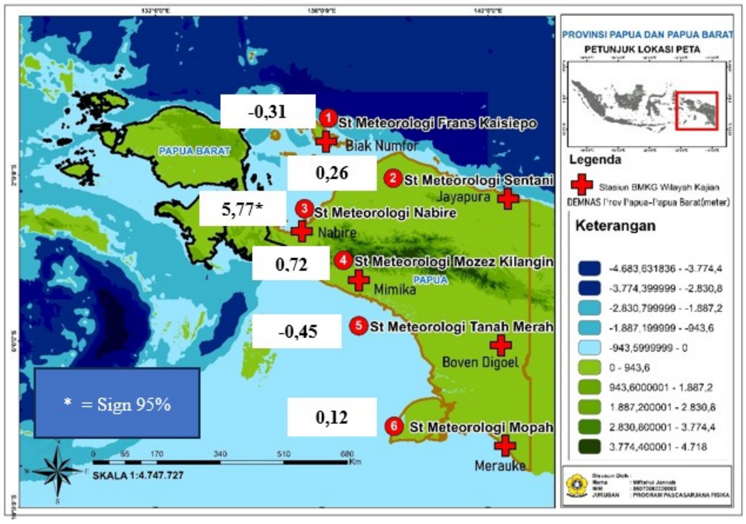

Figure 5. Sen's Slope Rnn at 6 Observation Stations in the Papua Region

Based on Figure 5, the Rnn increase trend at Sentani Meteorological Station (R18mm) (2) is 0.26/20 years or 5 days/year; Nabire Meteorological Station (R35mm) (3) is 5.77/20 years or 115 days/year; Mozez Kilangin Meteorological Station (R42mm) is (4) 0.72/20 years or 14 days/year; Mopah Meteorological Station (R21mm) is (6) 0.12/20 years or 2 days/year. The decreasing trend of Rnn at Frans Kaisiepo Meteorological Station (R22mm) (1) is (-0.31)/20 years or 6 days/year; Tanah Merah Meteorological Station (R36mm) (5) is (-0.45)/20 years or 9 days/year. Figure 6 below shows the trend of Rnn index at 6 observation stations in Papua region.

The *Rnn* index in the figure 6 shows the number of days with extreme rainfall limits experiencing the highest (lowest) increase at the Nabire Meteorological Station (Mopah Meteorological Station) with the number of days with extreme rainfall limits increasing for 115 days/year (2 days/year). At the Nabire Meteorological Station (3) the highest Rnn time series (280 days) occurred in 2013.

St Meteorologi Frans Kaisiepo

St Meteorologi Sentani

St Meteorologi Nabire

St Meteorologi Mozez Kilangin

St Meteorologi Tanah Merah

St Meteorologi Mopah

Figure 6. Trend of Extreme Rainfall Index Rnn at 6 Observation Stations in Papua Region

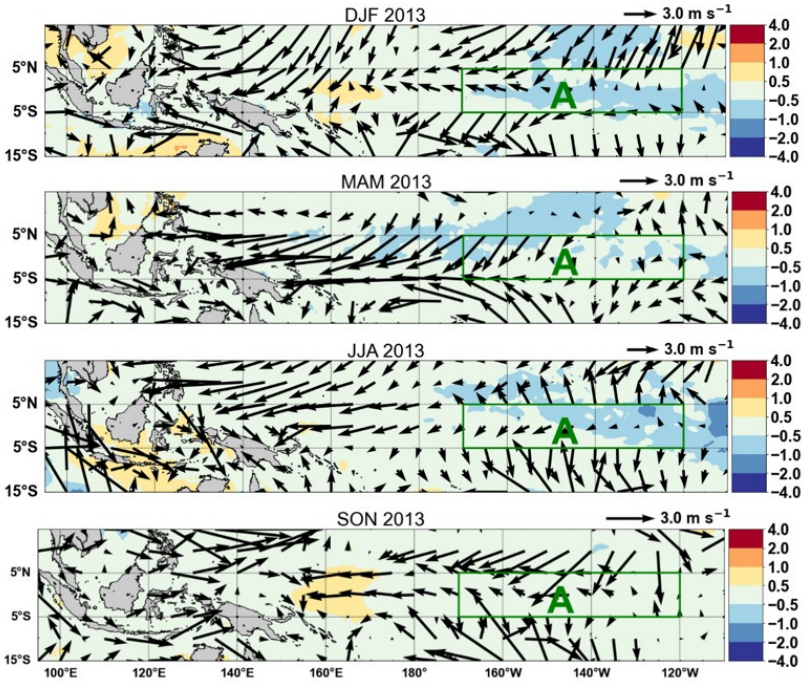

Figure 7. SST and Wind Anomalies in 2013

Figure 7 shows the SST and wind anomalies in 2013. Based on the figure, in 2013 there was no dominance of colder and warmer SST in the DJF, MAM, JJA and SON seasons. However, the Nabire Meteorological Station experienced the highest Rnn. This is thought to be due to its location in the northern lowlands of Papua, according to research by Aser Rouw (2014) showing that the equatorial rainfall pattern in the DJF and MAM seasons increased strongly and in the SON season, the highest rainfall pattern in the northern lowlands with an average peak in March (MAM) and August (JJA) reached 400-300 mm.

CONCLUSION

The trend changes that tend to increase influenced by SST and wind anomalies in the DJF, MAM and SON seasons have an impact on conditions in Papua Island becoming wetter. The positive PRCPTOT trend at 6 observation stations indicates a tendency for total annual rainfall to increase, with the highest total annual rainfall at the Nabire Meteorological Station occurring in 2016 at 7262.7 mm. The positive Rnn trend at 4 observation stations (Sentani, Nabire, Mozez Kilangin and Mopah Meteorological Stations) indicates a tendency for days exceeding the extreme rainfall limit to increase, namely 280 days in 2013.

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