The influences of sea surface temperatures on the rainfall onset in the west-south region of Aceh

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ABSTRACT

Rainfall variability is influenced by several annual global and regional phenomena including the influence of monsoons, El Niño Southern Oscillation (ENSO), Indian Ocean Dipole (IOD), La Niña, and local climates. Sea surface temperature is one of the elements that affect weather patterns in Indonesia. This is because sea surface temperature plays an important role in the evaporation process, thus affecting cloud formation and subsequently affecting rainfall. The purpose of this study was to obtain information about the effect of sea surface temperatures on the onset in the West South Aceh region. The method used in this study is the correlation method between sea surface temperature anomalies (SST) and rainfall. The results of this study show that rainfall in the West-South region of Aceh varies greatly and has an equatorial pattern. The equatorial pattern is characterized by a rainfall type with a bimodal shape or there are two rain peaks during the year, namely around March and October. A positive anomaly in the West-South region of Aceh indicated that the rainfall at that time was higher than normal. Meanwhile, negative anomalies indicate that rainfall in the region is lower than normal conditions. The beginning of the average rainy season that occurs in the Southwest Aceh region starts on the 25th which occurs in September and ends until February. The beginning average rainy season that occurs in the West-South region of Aceh, starts on the 25th basis which occurs in September, and ends until February. The highest onset occurred in the Southwest Aceh area, which was 0,2059, and the beginning of the lowest rainy season or regression occurred in the West Aceh area, which was 0,0122.

Introduction

Indonesia is a country in Southeast Asia that is crossed by the equator and is located between the continents of Asia and Australia, as well as between the Pacific and Indian Ocean. Indonesia is the largest archipelagic country in the world and is one of the tropical countries that have two seasons, i.e., rainy and dry seasons.

As surrounded by the oceans, it then affects the variability of rainfall in Indonesia. Rainfall variability in Indonesia is influenced by various phenomena such as: monsoon, El Niño, La Niña, Indian Ocean Dipole (IOD), and local climate influences (Qian, 2008; Qian et al., 2013; Supari et al., 2018). In general, the rainy season in Indonesia occurs from October to March, while the dry season occurs from April to September even though it may differ over certain regions.

Surrounded by vast oceans, the climate in the tropics is affected by changes in sea surface temperature (SST). Ocean temperature is one of the factors that affect climate variability in Indonesia (Affandi et al., 2012; Aldrian & Susanto, 2003). This is because SST plays an important role in the evaporation process so it affects cloud formation and further drop the rainfall (Habibie & Nuraini, 2014; Irkhos & Sutarno, 2008). Many sectors are influenced by SST, e.g., the productivity of waters and in the field of fisheries (As-syakur & Prasetia, 2010; Juneng & Tangang, 2005; Sukresno, 2008).

Global warming increases the occurrence of global droughts, heat waves, and the frequency of tropical storms. Rising global temperatures will lead
to the melting of north and south polar ices, resulting in the expansion of seawater masses, and sea level rise. Global warming will also cause seasonal shifts as a result of changes in rainfall patterns (Khodijah, 2015; Yana et al., 2014).

The determination of seasons in Indonesia by the Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG) is carried out by analyzing rainfall data at ground station for dekad period (i.e., ten-day cumulative rainfall). The rainfall based on BMKG is classified into three categories, i.e., normal, below normal, and above normal.

Based on the provisions made by the BMKG the rainfall onset is characterized by a dekad rainfall of more than 50 mm and followed by a minimum of two subsequent dekads. Meanwhile, the beginning of the dry season is characterized by a dekad rainfall of less than 50 mm and followed by a minimum of two consecutive dekads. The onset and dry condition are not always the same. Consequently, the seasons could shift that may lead to longer dry season or the retreat of the rainy season.

One of the factors that cause seasonal shifts in Indonesia is the IOD. The latter event has a strong effect on rainfall fluctuations during the dry season (As-syakur, 2012). The IOD could cause a decrease or increase in SST accompanied by a decrease or increase in rainfall over Indonesian archipelago.

Aceh Province consists of 23 districts that have different climate characteristics among regions. One of the differences between those regions is the difference on the onset of each region. The West-South region of Aceh is an area directly facing the Indian Ocean so that it has high rainfall due to evaporation from the sea. Geographically, the location of West-South Aceh is located starting from, Aceh Jaya, Aceh Barat, Nagan Raya, Aceh Barat Daya, and Aceh Singkil.

Research on the relationship of SST to the onset has been widely investigated. However, in the West-South region of Aceh, there is still no more detailed study. Therefore, this study aims to determine the effect of SST on the onset in the West-South region of Aceh. The purpose of this study is to investigate the effect of SST on the onset in the West-South region of Aceh.

Materials and Methods

The research location is the West-South region of Aceh in five different districts. They are Aceh Jaya (04°22’-05°16’ N and 95°10’-96°03’ E), Aceh Barat (2°00’-5°16’ N and 95°10’ E), Aceh Barat Daya (96°34’57”–97° 09 ’19” E and 3°34’24”-4° 05’37” N), Nagan Raya (4.17°N 96.5°E ), and Aceh Singkil (2°02’00”–2°36’40” N and 97°04’54”–98°11’47” E). The map of the study site is shown in Figure 1.

Rainfall data is originated from CMORPH which cover a spatial resolution of 0.25° latitude x 0.25° longitude. It is a monthly rainfall data from 1998-2021. The data is summed up for ten days to calculate dekad. Thus, there are three dekads every month, i.e., DI, DII, and DIII. DI is from the 1st to the 10th day, DII is from the 11th to the 20th day, DIII is from the 21st to the end of the month. The rainfall onset is calculated from the average onset of the rainy season each year in every district. If the rain is above 50 mm and occurs consecutively for two dekads then it is said that the rainy season has arrived. The length of the rainy season is calculated from the average length of the rainy season each year in every district. SST is originated from 1998-2021. It is a monthly average data with 0.25° spatial resolution.

Rainfall data in every district is divided into three dekads (i.e., DI, DII, and DIII). One dekad is for 10 days. If the rain height exceeds 50 mm and occurs consecutively for two dekads, it is concluded that the rainy season has arrived. The end of the rainy season is indicated when the rain height in the final months of the rainy season is less than 50 mm which occurs consecutively for two dekads. And to investigate the relationship between SST and the onset in the West-South region of Aceh, a correlation analysis was carried out between the rainfall and the SST anomaly.

Data Analysis

The following formula is used to find the correlation between two variables:

$$r_{xy} = \frac{n \Sigma xy - (\Sigma x)(\Sigma y)}{\sqrt{(\Sigma x^2 - (\Sigma x)^2)} \sqrt{(\Sigma y^2 - (\Sigma y)^2)}}$$
Information:
\( r \) = correlation
\( n \) = amount of data
\( x \) = SST anomaly
\( y \) = rainfall

Results

**The Correlation between Rainfall and SST in Aceh Jaya**

The rainfall pattern in the West-South region of Aceh is an equatorial-type climate which is characterized by a bimodal shape or two peaks of rainfall. Figure 2 is the average monthly rainfall in Aceh Jaya district from 1998 to 2021. In Aceh Jaya, two peaks of rainfall are found on April and October. The highest rainfall occurred on April with 278 mm, while the lowest occurred on February with 139 mm of rainfall.

The correlation between rainfall and SST in Aceh Jaya is shown in Figures 3 and Figures 4.

The results of the correlation between rainfall and SST in Aceh Jaya are shown in Figures 3 and Figures 4.

**The Correlation between Rainfall and SST in Aceh Barat**

Figure 5 shows the average monthly rainfall in the Aceh Barat district from 1998 to 2021. Aceh Barat district has two peaks of rainfall that occurred on April and November. The highest is 406 mm which occurs on November, while the lowest on July with 140 mm in height.

The correlation between rainfall and SST in Aceh Barat for 23 years, i.e., 1998-2021 are shown in Figures 6 and Figures 7.
Figure 6. Correlations between the onset and the Aceh Barat SST anomaly.

Figure 7. Correlation between the length of the rainy season and the SST anomaly of Aceh Barat.

The average onset in Aceh Barat district fell in the 25th dekad which occurred at the beginning of September (Appendix 2). Figure 7 shows that in this district the onset of the rainy season is about 1 dekad advance and the average length of the rainy season is about 17 dekad lasting from September to February.

The correlation between rainfall and SST in Aceh Barat Daya

Figure 8 shows the average monthly rainfall in Aceh Barat Daya from 1998-2021. Aceh Barat Daya has two main peaks of rainfall. The first on April while the second on October. The highest monthly rainfall average is 285 mm which occurs on November while the lowest occurs in December which is 136 mm in height.

The correlation between rainfall and SST in the Aceh Barat Daya for 23 years from 1998-2021 are shown in Figures 9 and Figures 10.

Figure 9 shows that the onset is about 1 dekad advance from the average (normal). The average onset in Aceh Barat Daya district occurred in 26th dekad on September (Appendix 3). The average
length of the rainy season lasts for 12 *dekad* that occur from September to January.

**The correlation between rainfall and SST in Nagan Raya**

Two peaks of rainfall were found from monthly rainfall averages of Nagan Raya district. The first occurs on April while the second on November. The highest rainfall with 262 mm in height occurs on November, while the lowest occurs in June, which is 97 mm.

![Figure 11. Average monthly rainfall in Nagan Raya.](image)

The correlation between rainfall and SST in Nagan Raya for 23 years from 1998-2021 are shown in Figures 12 and Figures 13.

![Figure 12. Correlations between the onset and the SST anomaly in Nagan Raya.](image)

Figure 12 show that the onset is about 1 *dekad* advance and the average onset fell in the 28th *dekad* that occurs on early October (*Appendix 4*). In Figure 13, the average length of the rainy season is about 10 *dekad* which occur from October until January.

**The correlation between rainfall and SST in Aceh Singkil**

Two peaks of rainfall were found based on the calculation of average monthly rainfall in Aceh Singkil district for 23 years. The first occurs on April while the second occurs on November. Figure 14 shows that the highest monthly rainfall in Aceh Singkil is 344 mm which occurs on April, and the lowest occurs on November which is 113 mm.

![Figure 13. Correlation between the length of the rainy season and the SST anomaly in Nagan Raya.](image)

![Figure 14. Monthly average rainfall in Aceh Singkil.](image)

The correlation between rainfall and SST in Aceh Singkil district for 23 years 1998-2021 are shown in Figures 15 and Figures 16.
Rainfall in the West

Discussion

Rainfall in the West-South Region of Aceh

Wang et al. (2004) stated that in determining the onset there are several different criteria and it is still a controversy among experts. In this case, there are five methods used to determine the onset, i.e., wind data, outgoing longwave radiation (OLR) data, a combination of wind and OLR data, daily rainfall data, and a combination of rainfall and wind data. In this case, Moron et al. (2009) states that the onset is characterized by the beginning of the monsoon. Daily rainfall is the amount of rainfall recorded in a single day, while dekad rainfall is the amount of rainfall for 10 days. It is said that the onset is when the rain height is more than 50 mm and occurs successively on as many as two dekad. Meanwhile, it is said that the end of the rainy season when the rain height is less than 50 mm it occurs successively for two dekad.

The West-South part of Aceh is generally a plateau with mountains. This condition causes the air to become rapidly saturated due to the urgency of rising on the slopes of the mountains. Saturated air will condense and form rain clouds resulting in rain falling around the mountains. Rainfall in the West-South region of Aceh is higher than in the eastern region of Aceh because this region is located in the windward.

Hermawan (2010) stated that Indonesia in general can be divided into 3 main climate patterns, i.e., monsoonal, equatorial, and local patterns, by looking at these rainfall patterns for a year. Rainfall patterns in each region vary greatly due to several factors such as geographical location, topography, and others. Vitri and Marzuki (2014) revealed that rainfall variability are caused by several factors, both local and global. Setiawan (2012) stated that the potential impacts of climate change are changes in rainfall patterns, increases in air temperature, and sea surface temperature rise.

Based on dekad average rainfall data from 1998-2021 in the West-South region of Aceh, the rainfall pattern in this region is equatorial. Rainfall patterns in this region with the lowest rainfall occurred from March to July. Rainfall can be interpreted as the level of rainwater collected in a flat, non-pervasive, and non-flowing place. This is reinforced by Tjasyono et al. (2008) stating that rainfall is 1 mm that is if the area is 1 square m in a flat place accommodated by water as high as 1 mm assuming it does not evaporate, does not permeate, and does not flow.

Sea Surface Temperature (SST) in the West-South region of Aceh

SST in the tropics usually follows seasonal patterns as it is heavily influenced by meteorological factors such as rainfall, evaporation, air humidity, air temperature, and wind speed. Gustari (2009) states that in the Indian Ocean generally a lower-than-usual SST is found on the west coast of Sumatra. The spread of SST in the Western season in January shows warm SST looks dominant on the West and South sides. The existence of high cloud closures in the West season is related to the blowing of Western monsoon winds that carry a lot of water vapor which causes the clouds to become thick and covering the atmosphere.
Boer and Faqih (2004) stated that there are five factors that affect climate variability in Indonesia, i.e., the meridional cycle, zonal cycle, monsoon wind activity, local influences, and tropical cyclones. The phenomenon of climate anomalies that occurs is an implication of the dominance of one of several factors among the five factors.

According to As-syakur (2012) IOD activities affect rainfall fluctuations during the dry season. Climate anomalous phenomena in the tropics that are common and most dominant include ENSO and IOD. In this case, Hendon (2003) stated that La Niña causes quite high rainfall even during the dry season. In accordance with the statement of Ashok et al. (2004) that there is a clear influence on rainfall in Indonesia will be significant if there is an El Niño and positive IOD and negative IOD simultaneously.

Boer and Subbiah (2005) state that the onset which usually occurs around mid-September can retreat to 4-6 days during an El Niño year or advance to mid-August in a La Niña year. This incident is known as a wet drought. Reinforced by Aldrian et al. (2004) that the start date is defined as the first wet day of the first 5-day sequence to receive 40 mm which is not followed by a sequence of 10 dry days receiving less than 5 mm in the next 30 days from the start date. Onset is calculated from August 1 because August to September is the driest month in Indonesia.

Martono and Wardoyo (2017) stated that the ENSO phenomenon greatly affects rainfall conditions, especially in the Indonesian region which is located in the southern part of the equator. SST is also concerned with the phenomenon of upwelling and downwelling. When the upwelling phenomenon occurs, the mass of seawater on the surface will be replaced by a colder mass of seawater in the deeper water column. Reinforced by Kaufman (2010) that the identification of upwelling areas can be known with a colder SST compared to the surroundings.

The relationship of SST anomalies to the onset in the West-South region of Aceh

Rainfall affects thermocline fluctuations. The condition of the atmospheric environment that occurs at a time when rainfall increases is that the level of cloud cover is high. This causes the sun's thermal energy to be blocked from entering the sea so that the thermocline becomes shallow or its thickness decreases. Meanwhile, when rainfall decreases, the level of cloud cover also decreases so that the solar thermal energy that enters the water column increases. Kunarso et al. (2012) states that this can make a lot of sun enter the seawater column so that the thermocline layer drops and its thickness increases. Solar activity affects the rainfall conditions of an area. In accordance with the statement from Sinambela et al. (2008) that the position of the sun around the equator causes a high sea surface temperature so that the area around the equator gets the intake of wet air masses.

Naylor et al. (2007) state that rainfall in Indonesia is regulated by austral-Asian monsoons whose beginnings take place from the sea to the Southeast during the austral spring. SST affects high and low rainfall. It is reinforced by Hamada et al. (2002) that this is the season when ENSO exerts the strongest influence on rainfall in Indonesia. A high SST will cause high evaporation to occur, resulting in a high chance of the formation of convective clouds that cause rain. In accordance with the statement of Aldrian (2008) that an increase in SST can result in an increase in the availability of water vapor which encourages high rainfall.

The results of the correlation analysis between rainfall in the West-South region of Aceh and the SST anomaly each year show that the coefficient values vary greatly and have an equatorial pattern. The equatorial pattern is characterized by a type of rainfall with a bimodal shape or there are two peaks of rain during the year, i.e., around March and October. Based on the correlation data between rainfall data and SST anomalies, it can be seen that there is a relationship between rainfall and SST.

Based on the correlation results that have been made, there are several districts that show positive correlation results and negative correlation results. A positive correlation suggests that the increase in SST in the zone is related to increased rainfall in the region. Meanwhile, negative correlation results show that the increase in SST in the zone is related to decreased rainfall in the region. In accordance with Rahayu et al. (2018) that a decrease in sea surface temperature when IOD is positive will have an effect on reducing rainfall intensity.

Rainfall anomalies are used to analyze excess or lack of rainfall that occurs at one time. Every 1 °C increase or decrease in SST anomaly than the onset will advance or retreat from the average. In the West-South region of Aceh, the onset in each region varies. Some areas have progress or setbacks at the beginning of the rainy season. To see the closeness of the relationship between SST and the beginning of the rainy season, namely by correlating the two data. According to Hasan (2003) correlation analysis is a method used to determine whether there is a relationship between variables. If there is a change between variables, the change that occurs in one of
the variables can be in the form of a positive correlation, negative correlation, no correlation, or perfect correlation. The highest correlation of the onset occurred in Aceh Barat Daya district (Figure 9), i.e., 0.2059 that occurred in the 26th decad, and the length of the rainy season last for 12th decad. Meanwhile, the lowest correlation occurred in Aceh Barat district (Figure 6) which was 0.0122 that occurred in the 25th decad in average, and the length of the rainy season last 17th decad. This is due to the variability of the climate in the West-South region of Aceh.

**Conclusion**

Rainfall in the West-South region of Aceh varies widely and has an equatorial pattern. The equatorial pattern is characterized by a type of rainfall with a bimodal shape or there are two peaks of rain during the year, namely around March and October. The average onset that occurs in the region begins on the 25th day which occurs in September and ends until February. The West-South region of Aceh has high rainfall because the area is facing directly toward the Indian Ocean. Positive anomalies in the West-South region of Aceh indicate that rainfall at that time was higher than normal. Meanwhile, negative anomalies indicate that rainfall is lower than in normal conditions. At the beginning of the rainy season the highest occurred in the Southwest Aceh area, namely 0.2059, and the beginning of the lowest rainy season, which occurred in the West Aceh area, was 0.0122. It is hoped that future research can be studied more fully on other factors that affect rainfall such as Indian Ocean Dipole (IOD), Madden Julian Oscillation (MJO), and others so that it can be used as information and literature for future research.

**References**


Dani, et al. (2024)
### Appendix 1. Decade rainfall of Aceh Jaya

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### Appendix 2. Decade rainfall of West Aceh

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Dani et al. (2024)
Appendix 3. Decade rainfall of Southwest Aceh

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Appendix 4. Decade rainfall of Nagan Raya

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Dani et al. (2024)
### Appendix 5. Decade rainfall of Aceh Singkil

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