Climate change in The Lesser Sunda Islands: The harsh region in the maritim continent of Indonesia

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Abstract. The Lesser Sunda islands, i.e. Bali, West and East Nusa Tenggara are locus of the harsh climate regime in Indonesia. The research was conducted in 2020 by a Descriptive method that aims to identify occurrence of climate change represented by anomalies of sea surface temperature (SST), air temperature, precipitation, and wind vector. The study area was focused on the convergence zone of the South Indian Ocean extending from 0° to 10°S, and 114° to 130°E. The temporal observation was at a peak of the rainy season in February and a transition period in March and April. Changes in climate variables were quantified by a test of two linear regression slopes and a binomial probability. Climate data were acquired from the International Research Institute (IRI) in a span of 30 years (1990 to 2020), with exception of air temperature from 1920 to 2020. Results showed that rainfall and SST had changed since 2005, and air temperature since 1995. Rainfall was significantly decreased afterward. SST and air temperature subsequently increased. The impact of climate change was compounded by wind vector anomalies in February, March and April. In conclusion, the Lesser Sunda Islands had experienced the ongoing climate change, indicated by lowering annual rainfall by 130.8 mm, increasing SST by 0.8°C and air temperature by 0.1°C in a decade respectively. In addition, Persistence Westerly winds through the end of April possibly induced severe flooding, on the other hand, the early emergence of southeast Trade winds before April could result in severe drought.

1. Introduction
Indonesian maritime continent is highly sensitive to climate change [1] for two major reasons, namely archipelagoes with tiny islands, and reliance of the most population on climate-sensitive agriculture and fisheries [2]. The maritime continent is primarily the given name to the Southeast Asia region which comprises countries possessing many islands, peninsulas and shallow seas, namely Indonesia, Philippines and Papua New Guinea[3]. It is situated in a tropically warm pool between the Indian and Pacific Oceans. The region is significant from a climatology perspective because it owns coincident factors with the global circulation system, the Pacific and the Indian Ocean. Its geographic location and topography, both contribute to the development of the tropical warm pool, i.e. the warmest oceans on Earth [4].

In this regard, Lesser Sunda Islands are a part of the harshest tropical climate in the Indonesia maritime continent. They are situated at the ‘cross position’ of key global climate drivers, that are: Indonesia through Flow (ITF) of warm Pacific water to Indian ocean at Lombok strait [5], El-Nino and La-Nina phenomena associated with a Walker cycle in Pacific equator [6], Southern Oscillation Index
(SOI) due to sea surface pressure gradient between Darwin (Indian Ocean, Australia) and Tahiti in the Pacific equator [7], Indian Dipole Mode concerning sea surface temperature gradient between eastern African sea and west coast of Sumatera, Indonesia [8], and exposure to seasonal Asia wet monsoon (September to April) and Australia dry monsoon winds (May to October) [9].

Unfortunately, drastic potential climate change has emerged in this century [10], upon which an integrative and holistic approach is required [11] to enable the vulnerable areas e.g. Lesser Sunda Islands are well protected and secured from short and long-term impact of climate change on community livelihood, biodiversity’s, environment, and national assets [12]. Scientific initiatives have been carried out to deal with the matter. For example, trend of annual rainfall across Indonesia was projected negative within the period of 1950s to 1997, with exception of Banyuangi (east Java) Bali, Lombok, Sumbawa and Kupang, and Waingapu (Papua) the trend was slightly positive [13]. However, the rainfall trend for Lombok was corrected in following research, which revealed that rainfall trend within a period of 1961 to 2008 was negative [14] with data in a period of 1983 to 2013 was also negative [15], and from 1950 to 1997 in Lesser Sunda Islands was negative. Future seasonal rainfall in West Nusa Tenggara was projected to declining around 1% by 2030, and 6% by 2050 [16]. That means water demand for first crops, rice and secondary crops will not be fulfilled. The climate in the Lesser Sunda region is very complicated in which global and local factors simultaneously incorporate in affecting climate variability. Atmospheric temperature, sea surface temperature and wind vector anomaly are common factors attributed to an erratic climate in the Lesser Sunda region.

In addition, Lesser Sunda region is becoming a top national priority in terms of economic development strategy. There have been three super-priority projects being developed in the region where there will be the host for world-class tourism destinations, namely culture base tourism in Bali, natural and sports base tourism in Lombok, and wild life ecotourism in Komodo Island, East Nusa Tenggara [17]. The sustainability of environment in the Lesser Sunda Islands is the key element to gain a national goal to promptly recovery from current economic crisis.

Take into account those reasons, the issue of climate change always flourishes and relevant to be addressed for the future of Lesser Sunda Islands. The most distinguished indigenous macro and micro flora and fauna inhabitants the Wallace border of Lesser Sunda Islands [18]. Those who are living on terrestrial, fresh water and seawater ecosystems would be at serious threat if the climate change could not be properly mitigated. Killing fishes because of the disappearance of plankton in the Peruvian sea was the worst story in dealing with a long history of El-Niño; sea water sharply increased beyond normal average on the west coast of South America [19]. Bleaching of sea worms was due to sea temperature increase by more than 0.5°C above normal average in 2017 which is one of the most popular cultural icons at Samoa islands, in the Pacific equator [20]: like Nyalé event in southern beaches of Lombok [21]. The latest proof of devastated impact of climate change was an unprecedented natural disaster in East Nusa Tenggara and, the eastern part of West Nusa Tenggara. Escalating seawater temperature out of normal average followed by developing of a minimum pressure in situ which triggered a severe tropical cyclone, Seroja at off the south of Timor island on April 3rd, 2021 [22].The disaster turned the dream of innocent local community into a nightmare. Finally, it would be the main objective of this paper was to identify occurrence of climate change indicated by anomalies of sea surface temperature (SST), air temperature, precipitation, and wind vector in the Lesser Sunda Islands.

2. Method
The research was carried out using a descriptive method focused on climate parameters, namely air temperature, sea surface temperature, precipitation and wind vector direction. All data represented climate parameters in the Lesser Sunda regions, such as Bali, West and East Nusa Tenggara. Sea surface
temperature for Lesser Sunda regions was represented by data SST recorded at 115°E, 9.5°S. The site was convergence zone in the southern Indian Ocean extending from 0° to 10°S.

2.1. Data sources
All climate data for this research were freely downloaded from following official sources:
BMG (Bureau of Meteorology and Geophysics): http://www.bmg.go.id/ [23];
International Research Institute (IRI): http://iri.deo.columbia.edu/iri/ [24];
Meteoblue: https://www.meteoblue.com/en/weather/ [25];
Stat World 2020: https://stat.world/biportal [26];
Rainman International: http://www.dpi.qld.gov.au./climate [27];
NOAA: https://www.ncdc.noaa.gov./cag/ [28].

2.2. Statistical analyses

2.2.1. Linear regression. A linear regression model was applied to describe the relationship between two variables using a straight line [29] to express trend of change in climate parameters, namely annual rainfall and sea surface temperature overtime of 1990 to 2020. The statistical relation between variable independent (time of observation) or X and dependent variable, climate variables (Y) is expressed as follows [30]:

\[ Y = \beta_0 + \beta_1 X + \epsilon \] (1)

The actual values of Y observed climate data from time to time are assumed random. Parameter \( \beta_0 \) is an intercept of the linear line, \( \beta_1 \) is a slope or a regression coefficient, and \( \epsilon \) is a random error which is normally and independently distributed with a mean of zero and variance of \( \sigma^2 \). The independent variables (X) are referred to as a predictor variable, and the dependent variable, Y was also referred to as the response to climate change. The least square estimates of \( \beta_1 \) and \( \beta_0 \), were calculated using the following equation [31]:

\[ \hat{\beta}_1 = \frac{\sum_{i=1}^{n} y_i x_i - \left( \sum_{i=1}^{n} y_i \right) \left( \sum_{i=1}^{n} x_i \right)}{\sum_{i=1}^{n} (x_i - \bar{x})^2} \] (2)

\[ \beta_0 = \bar{y} - \hat{\beta}_1 \bar{x} \] (3)

where \( \bar{y} \) is the mean of all the observed values and \( \bar{x} \) is predictor variables (time of year) at which the observations were taken. There was an estimation of the mean value of the response, E(Y) and the fitted value, \( \hat{y} \), for a given value of the predictor variable, \( x_i \). It was different from the corresponding observed value, \( y_i \). The difference between the two values is called residual, \( e \), that is [31]:

\[ e_i = y_i - \hat{y}_i \] (4)

2.2.2. Test of significance regression coefficient. Hypothesis test on the regression coefficient of simple linear regression was carried out by assuming that the random error term, \( \epsilon \) is normally and independently distributed with a mean of zero and variance of \( \sigma^2 \) [36]. Here the \( t \)-test was used to test the regression coefficients, \( \beta_1 \) [30] for rainfall and SST trends for 1990 to 2020. A statistic based on the two-sided \( t \) distribution was used to prove that the slope, \( \beta_1 \) is equal to some constant value, \( \beta_{1,0} \). The test statistic (\( T_0 \)) for this test was [31]:
Where $s_0(\hat{\beta}_1)$ was calculated as [31]:

$$s_0(\hat{\beta}_1) = \sqrt{\frac{\sum_{i=1}^n e_i^2}{\sum_{i=1}^n (x_i - \bar{x})^2}}$$

(6)

The test statistic, $T_0$ follows a $t$-distribution with $(n - 2)$ degrees of freedom, where $n$ is the total number of observations (in the year). The null hypothesis, $H_0$, is accepted if the calculated value of the test statistic [41] is such that:

$$t_{\alpha/2,n-2} < T_0 < t_{\alpha/2,n-2}$$

(7)

where $t_{\alpha/2,n-2}$ and $-t_{\alpha/2,n-2}$ are critical values for the two-sided hypothesis. The $t$ distribution is the percentile of the $t$ distribution corresponding to a cumulative probability of $(1- \alpha/2)$ and $\alpha$ is the significance level and the value of $\beta_{1,0}$ was zero.

2.2.3. Test for significance of two regression coefficients.

The hypothesis test to compare two regression coefficients was conducted with a similar procedure, but $\beta_{1,0}$ was assigned as $\beta_2$ which is the regression coefficient of the other linear regression [30]. First of all, assumes homogeneity of variance and calculate pooled variance, $S^2_{y,x}$ as follows [31]:

$$S^2_{y,x} = \frac{SSE_1 + SSE_2}{n_1 + n_2 - 4}$$

(8)

where $SSE_1$ is the sum of square regression-1, and $SSE_2$ was the sum of square error regression-2. Then calculate the standard error of difference between two slopes, $Se_0$ [31] as:

$$Se_0 = \sqrt{\frac{S^2_{y,x}}{SSx_1} + \frac{S^2_{y,x}}{SSx_2}}$$

(9)

Therefore, the difference between $\beta_1$ and $\beta_1$ was calculated as:

$$t_0 = \frac{\hat{\beta}_1 - \hat{\beta}_2}{Se_0}$$

(10)

The null hypothesis, $H_0$, $\beta_1 = \beta_2$ was accepted if the calculated value of the test statistic ($T_0$) was such that:

$$t_{\alpha/2,N-4} < T_0 < t_{\alpha/2,N-4}$$

(11)

2.2.4. Binomial probability test. A binomial probability distribution test was run to see if observed results differ from what was expected. The formula was as follows [30]:

$$P(x) = \binom{n}{x} p^x q^{n-x} = \frac{n!}{(n-x)!x!} p^x q^{n-x}$$

(12)
P(x) is declared as the probability of random variable x takes particular value, in a random experiment, n is many trials or period of observation (years), which was 5 times, in this case, n! is n factorial, p was equal to 0.5 (50%) which is a probability of getting success in one trial associated with each sample point for one trial having two possibilities, i.e. in this case, wet year (rainfall or SST from normal to dry year with rainfall and SST below normal or below average. q = 1 - p the probability of getting a failure in one trial. Mean value, μ, variance, σ² and standard deviation, σ for a random variable in a binomial distribution is given by:

\[ μ = n \cdot p \] (13)
\[ σ² (s²) = n \cdot p \cdot (1 - p) \] (14)
\[ σ (s) = \sqrt{n \cdot p \cdot (1 - p)} \] (15)

3. Results and discussion

3.1. A brief of Lesser Sunda Islands
The southeastern archipelagoes of Indonesia are well known as Lesser Sunda Islands or “Kepulauan Nusa Tenggara” (Indonesian name). These archipelagoes are a part of the Indonesia Maritime Continent in the Southeast Asia region [31]. The main Lesser Sunda Islands, from west to east are: Bali, Lombok, Sumbawa, Flores, Sumba, Timor, Alor archipelago, Barat Daya Islands, and Tanimbar Islands. They have located in the north of Australia continent [3]. The lesser Sunda Islands together with the Greater Sunda Islands make-up of the Sunda Islands which are lined by Sunda volcanic arc formed by subduction, along the Sunda Trench in the Java Sea [32] (see on Figure 1).

![Figure 1. The lesser Sunda Islands.](https://en.Wikipedia.org/wiki/Lesser_Sunda_Islands)[3].

Geologically, the Lesser Sunda Islands consist of two distinct archipelagoes, i.e. the northern archipelagoes, which include Bali, Lombok, Sumbawa, Flores, and Wetar are volcanic in origin. Several volcanoes played a role as an orographic factor, e.g. Mount Rinjani on Lombok, Tambora on Sumbawa. The northern archipelagoes were formed during the Pliocene (15 million years ago) resulted from Australian and the Asian plates collision. The northern archipelagoes are relatively similar in history, characteristics, geological and ecological processes with the southern Maluku Islands. However, Bali was attached to the Asian continent. The islands of the southern archipelagoes including Sumba, Timor, and Babar, are non-volcanic and appear to belong to the Australian plate, which continue the same island arc to the east. Lying at the collision of two tectonic plates, the Lesser Sunda
Islands comprise some of the most geologically complex and active regions in the world [32]. The Lesser Sunda islands have the driest climate in Indonesia, i.e. tropical dry broadleaf forests, except Bali is montane rain forests. In contrast, the tropical moist forests prevail in most of Indonesia [33].

3.2. On land air temperature

The global annual air temperature had increased by an average rate of 0.07°C per decade from 1880 to 2019 and over twice that rate, +0.18°C was in 1981 [34]. The temperature steadily increased in 140-years period and reached the highest peak, +0.99°C in 2016, in coincidence with strong El-Nino in 2015/2016 [53]. It was followed by the second warmest, +0.95 in 2019. The third highest was +0.93°C in 2015 [35].

The current research focused on the Lesser Sunda Islands reveals that trend of atmospheric temperature over a century (1920-2020) in Indonesia and the Lesser Sunda Islands was positive with a rate for both 0.09°C per decade (see on Figure 2). This figure was 0.02°C higher (28.5%) than the global record (0.07°C per decade). Position on the equator and close to the driest continent of Australia makes it reasonable for the Lesser Sunda Islands to have a high temperature rate [36].

![Figure 2. Air temperature in the Lesser Sunda Islands: a) longterm trends in a century (1920-2020), and b) trend of air temperature before and after 1995.](image)

As shown in Figure 2b that air temperature in the lesser Sunda Island had changed since 1995 when a shifting point was in 1994. This was 13 years after global temperature reached its twice rate +0.18°C in 1981 base on the World Meteorology Organization reference period, 1961-1990. The annual temperature change rate was +0.007 between 1920 and 1994 and became 0.01°C (0.1°C per decade) afterward (1995 to 2020. It significantly increased by 143%. It means that air temperature had increased by 0.1°C in a decade. This 0.01°C of temperature increase per year is equal to 8.94 MJm⁻² of solar radiation intercepted by land’s surface per annum. It is equivalent to 36.5 m³ water loss from the soil surface per hectare every year. In otherwords, evaporation increased by 3.6 mm year⁻¹ [37].

The highest temperature in the Lesser Sunda region was in 2016 with a deviation of +0.78°C (average 27.3°C). This figure was relatively lower than the Global highest record, +0.99°C in the same year. Effect of changes in air temperature resulted in the change of wind pattern that brings the monsoons in Asia, rain, drought, and making climate unpredictable [38].

3.3. Sea surface temperature

Sea surface temperature (SST) is the temperature of water at the ocean surface. It is an important physical attribute of oceans. SST is strong indicator of pollution and climate change [39]. Global oceans SST gradually increased at a constant rate of 0.0072°C/year or (0.13°F) from 1901 to 2015 [60]. The SST for
Lesser Sunda regions was represented by the Indian Ocean SST recorded at 115°E, 9.5°S for a period of 30 years from 1990-2020 as well as data of SST surrounding the lesser Sunda Islands. The trend of SST in convergence zone of the Indian Ocean is presented in Figure 3. It is indicated from Figure 4 that long-term SST slightly increased by 0.03°C/year in the period 1990-2020 when the average was 28.47 ±0.5°C. The SST in the Indian Ocean had shifted to a new positive trend since a period 2005 to 2020, with a rate of +0.02°C/year (Figure 4). The change was significantly different from about 5 times.

The highest deviation of the SST was +0.93 (29.61°C) in 2016 with an average of 28.64±0.55°C. At the same time, the temperature on terrestrials of Lesser Sunda Islands was at a peak, 27.3°C. So, there was 2.31°C of a temperature gradient between lands and SST in 2016. The argument is that oceans or water absorb more heat than lands do, so the sea conserves more heat energy, and slowly releases the heat energy [40].

![Figure 3](image1.png)

**Figure 3.** Sea surface temperature in the Indian Ocean (115°E, 9.5°S): a) trend of SST in a period of 1990-2020 and b) transition time of sea surface temperature change.

Therefore, SST of the sea is relatively higher than in lands where heat energy is rapidly declined than ocean does. The ocean circulation transport warm and cold water around the globe [41]. In this case, Pacific warm water is continually transported to Indian Ocean through Lesser Sunda. This process could maintain SST high in the lesser Sunda seas [5].

![Figure 4](image2.png)

**Figure 4.** Sea surface temperature in The Indian Ocean (115°E, 9.5°S): a) before temperature change in 2005, and b) after temperature change.
Changes in sea surface temperature can alter marine ecosystems in several ways, namely affecting species diversity of plants, animals, and microbes inhabited in a particular location, alter migration and breeding patterns of the seaborne organism, threatening sensitive ocean life such as corals, and change the frequency and intensity of harmful algal blooms [42]. Over long-term, increases in sea SST could also affect vertical circulation patterns (upwelling) in ocean that bring nutrients from the deep sea to surface waters (surface water eutrophication), changes in reef habitat, declining in fish populations, which in turn could affect fisheries who depend on fishing for food or jobs. Warm temperature and eutrophication cause Jellyfish Aurelia spp to bloom which has a socio-economic impact on coastal environment, i.e. interfering with fisheries, aquaculture, power plant and tourism [43].

An increase in sea surface temperature can trigger storm formation of tropical cyclones and shift storm tracks which potentially contribute to severe drought in some areas, and extreme rainfall in other areas. Increases in sea surface temperature are also expected to lengthen the growing season for certain bacteria that can contaminate seafood and because food transmitted diseases which cause increasing risk of community health [44].

3.4. Rainfall in the Lesser Sunda Islands
Precipitation have effects on human well-being and ecosystems. Rainfall affects amount of surface water and groundwater which are available for drinking, irrigation, and industry. It also influences river flooding and can determine what types of animals and plants (including crops) can survive in a particular place [40]. Changes in precipitation can disrupt a wide range of natural processes, particularly if the change occur quickly then plant and animal species can adapt [45]. Sea surface temperature has profound effects on the global climate in which increase in SST has led to an increase in the amount of atmospheric water vapor in the oceans and melting snows. Water vapor from evaporated oceans feeds weather systems that produce precipitation, which in turn increases the risk of heavy rain [46]. The trend of long-term rainfall in the Lesser Sunda Islands is presented in Figure 5.

![Figure 5. Long-term trend of rainfall in the Lesser Sunda Islands in a period of 1990-2020.](image)

It can be seen from Figure 5 that rainfall in the Lesser Sunda region steadily decreased throughout 1990 to 2020, with decrease rate of -2.7 mmyear\(^{-1}\). However, statistical analyses proofed that there was a significant change in rainfall patterns during the period. The change of rainfall trend had occurred since 2004/2005 in which the change was in opposite trends; before 2005 there was positive, +10.4 mmyear\(^{-1}\) and negative, -13.08 mmyear\(^{-1}\) afterward. Each value of the slop was significant (Figure 6), and Both slops
were also significantly different with $t_{pool} = 1.186 > t_{table} = 0.864$ at a significant level, $\alpha = 5\%$ and degree of freedom 26. It means that the trend of rainfall in the Lesser Sunda Islands was a strong indicator that climate had changed since 2005.

![Graph](image)

**Figure 6.** Change of rainfall trend in the Lesser Sunda Islands: a) trend in a period 1990-2004), and b) trend in a period 2005-2020.

The monthly pattern and distribution of rainfall in Lesser Sunda Islands are presented in Figure 7. It can be seen from Figure 7a that mostly rainfall occurred in January, February, March, April and December. There were only January and February classified as wet months with rainfall >200 mm, March, April and December are moist months with rainfall 100-200 mm, and the rest 7 months were dry months. Overall, the climate of Lesser Sunda regions is semi-arid tropics of type D3, D4 and E (Oldeman system) where there are only 2-3 wet months, and more than six dry months per year [47].

![Graph](image)

**Figure 7.** Rainfall pattern in Lesser Sunda Islands: a) monthly rainfall, and b) rainfall in particular site in Lesser Sunda Islands.

It is also described in Figure 7(b) that annual rainfall in the Lesser Sunda Islands successively decreased to the east from Bali (1794 mm), Lombok (1499 mm), Sumbawa (1378 mm) and NTT (930 mm). The annual average for Lesser Sunda Islands was 1400 mm. If the decreasing rate was 13.08 mm/year, then the annual rainfall in Lesser Sunda Islands had declined by 0.9%. This figure was close to a projected value of 1% for West Nusa Tenggara by 2030 [16]. In other words, the change of rainfall in Lesser Sunda Islands was faster than predicted.
The possible explanation for this result is that the El-Niño phenomena, had altered rainfall patterns over the Pacific and Indian Ocean [48]. It developed when trade winds push the warm surface water of the equatorial Pacific to the east [49]. A similar pattern of rainfall has been observed everywhere in which variance of precipitation dramatically increased; wet areas became wetter, and arid areas were dryer. In addition, general changing patterns are as follows: (a) increase precipitation in high latitudes (Northern Hemisphere), (b) reductions in Asia, Australia and the Small Island States in the Pacific and (c) increased variance in equatorial regions [50].

### 3.5. Binomial distribution

Binomial distribution is the most widely known discrete distribution [51]. The binomial distribution had been used for several assumptions [52], namely, (a) rain event is assumed as an identical trial, (b) each trial has only two possible outcomes denoted as a dry year or normal, (c) each trial or year is independent of the previous year, and (d) the terms \( p \) (maximum probability) and \( q \) remain constant throughout the observation periods (5 years). If \( p \) is the probability of getting dry year on any one year and \( q = (1 - p) \) is the probability of getting a normal year on any one year.

Binomial distribution for rainfall in a period of five years commenced from 1990 to 2020 is presented on Figure 8 which can be interpreted as follows.

![Binomial distribution](image)

**Figure 8.** Binomial distribution of rainfall events in Lesser Sunda Islands from 1990 to 2020.

It was common for dry year in the Lesser Sunda Islands took place around mean value \((\mu)\) i.e. 2.5 dry years in 5 years, however, it would be unusual for dry year to occur less than \((\mu - \sigma)\) i.e. 0 and 1, or dry year more than \((\mu + \sigma)\) i.e. 3, 4 and 5 in five year period. Data show that binomial distribution before 2015 was 0.3125 and had suddenly dropped to 0.1562 since 2005. So, frequency of dry year had increased since 2015 and became a strong indicator of climate change.

### 3.6. Wind vector anomaly in the Lesser Sunda Islands

The Indian Ocean is linked to Pacific Ocean wind disturbances and SST changes [24]. For the southern case, warm waters preceded heavy rain in the eastern Indian Ocean, which preceded strong westerly winds. A cooling of the sea surface followed the wind-rain system. These events moved through the ocean passage between Indonesia and Australia, along with a coupling of convection, wind, and sea surface temperatures [53]. From November to February, north-west and westerly Asian monsoon flow over the Indonesian region which cause rain, on the other hand, in April Southeast Trade wind is starting to indicate the onset of dry season in the Lesser Sunda Islands [54]. Data of the most common wind vector direction in the Lesser Sunda Islands is described in Figure 9 and wind vector anomaly was observed in two categories, namely wind vector direction during dry year and wet year (see on Figure 10).
Figure 9 describes the most common direction of winds in one year in the Lesser Sunda Islands, overall wind direction in Lesser Sunda Island mostly from South East and east-south East (see on Figure 9d). If it is observed more specifically for individual islands then wind direction was more complex. The wind direction in Bali (see on Figure 9a) mostly from East South East, South East and South. In West Nusa Tenggara, wind mostly from South East, and followed bay East South East, then South (Figure 9b). In East Nusa Tenggara was quite similar from mostly from South East, and followed by East South East (see on Figure 9c).

Results show that drought or wet years in Lesser Sunda Islands were attributed to wind vector anomalies (see on Figure 10). There were three sites, where anomaly wind direction was identified to result in drought in Lombok and Sumbawa islands, namely South Indian Ocean at 105°-110°E, 8.5°-15°S; West Coast of Sumatera at 95°-110°E, 5°N-5°S, and Natuna’s sea at 105°-115°E, and 5°N-10°N. If winds direction was heading westward at the west coast of Sumatera, to the north at Natuna’s sea and no winds heading north from the west coast of Western Australia, then a severe drought occurred in Lombok and Sumbawa. These anomalies frequently appeared in November, December and February [54].

The current study in the Lesser Sunda Islands reveals that wind vector anomalies in February, March and April are closely linked to rainfall patterns. Westerly, North-West, and South-West winds, and occasionally North East wind (see on Figure 10a) when persistently flowed in February, March and April induced heavy rain in most of Lesser Sunda Islands.

Figure 10. Wind direction in coincidence with rainfall pattern in the Lesser Sunda Islands: a) when Wet, and b) when Drought (Note: F → February, M → March, and A → April).
It seems that Westerly winds or the Asian monsoon wind during a transition period (March –April) had beneficial effect on contributing rainfall in the last season. It likely happened when the Indian Dipole Mode was negative. It means that Indian Ocean winds were heading east from eastern African seas bearing water before Indonesia. This wind countered trade wind from west coast of Western Australia to form South West wind converging to the Lesser Sunda Islands, mainly Bali and Lombok [55].

In contrast, during drought years, Westerly wind was disappeared before April (see on Figure 10b). It was weakening or turned right heading to Australia before approaching to Lesser Sunda Islands. At the same time, Southeast Trade Wind promptly emerged, as well as East Wind, and South Wind. The Southeast Trade wind was originated from Pacific, passing through between Australia and Papua New Guinea to Lesser Sunda Islands. It passed over and carried away water pavor from the Lesser Sunda region. The south wind is dry winds originated from Australia. This wind absorbed moisture from air of the Lesser Sunda Islands and transported it to other areas. The east wind was also dry. It is presumed that the Easterly wind was a part of lee-wind that originated from leeward areas of Jaya Wijaya summit, in West Papua [56].

4. Conclusion

Common indicators used worldwide by the United Nation of World Meteorology Organization were considered to identify climate change in the Lesser Sunda Islands, such as air temperature, sea surface temperature, precipitation and wind rose. The period for all parameters was 30 years, from 1990 to 2020, except for air temperature was 100 years, from 1920 to 2020. Statistical analyses strongly confirmed that the climate in the Lesser Sunda Islands had significantly changed since 2005. On Land air temperature had increased by 0.1°C in a decade, starting from 1995. Sea surface temperature had elevated by 0.8°C in a decade since 2005. Precipitation had decreased by 130.8 mm (9.3%) in a decade since 2005. Wind vector anomaly was more frequent in line with variability of those parameters, namely sea surface temperature in the Indian Ocean. Promptly onset of the Southeast Trade wind was dominant in overwhelming an erratic rainfall in the Lesser Sunda Islands. Fail to promptly address mitigation scenarios to the changes of climatic variables in the region would be a real threat for, environment, biodiversity’s, community livelihood as well as economic assets.

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**Acknowledgment**

It is to acknowledge the significant contribution of the Research Center for Water Resource and Agroclimate University of Mataram that had provided local climate data, and also our appreciation to the University of Mataram for free access internet during global data collecting or downloading.