Indonesia Land Surface Temperature Variation during 2001 – 2020

Munawar Munawar (✉ Munawar@unsyiah.ac.id)

Universitas Syiah Kuala Fakultas Matematika dan Ilmu <https://orcid.org/0000-0002-8694-2431>

Tofan Agung Eka Prasetya

Airlangga University Faculty of Public Health: Universitas Airlangga Fakultas Kesehatan Masyarakat

Rhysa McNeil

Prince of Songkla University

Rohana Jani

Universiti Malaya

Suhaimee Buya

Prince of Songkla University

Research Article

Keywords: Indonesia, climate change, LST variation, NASA MODIS, Stable

Posted Date: August 17th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-724820/v1>

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Abstract

Indonesia, as the largest archipelago in the world, still depends on agriculture and fisheries activities. Climate change will affect agricultural yields and fish catches, so research on climate change is essential for Indonesia and neighboring countries. Land Surface Temperature (LST) is a critical indicator in climate science to measure the temperature of an area. This study examines the LST variation and seasonal pattern with 189 sub-regions covering 5 main islands of the Indonesia archipelago with 105 pixels (95 km) distance apart. The data was downloaded from NASA MODIS and covered a 20-year from 2001 to 2020. Overall, Indonesia has had a stable LST with a total average increase of 0.009°C (95% confidence interval: $-0.041, 0.059^{\circ}\text{C}$).

1. Introduction

Climate change is currently the center of attention for many countries, including Indonesia. It is designated by increasing temperatures, rising sea levels, and an escalation in the spread of diseases, which has many impacts on human life and the environment (Mimura, 2013; Rossati, 2017; Wu et al., 2016). Temperature is one of the crucial indicators of climate change. We can use Land surface temperature (LST) to measure the temperature in an area. In addition to the distribution of temperatures by pixels. LST classes can also exhibit a spatial-temporal distribution (Rahmad et al., 2019). A study in South Tangerang, a region with the highest population growth in the Banten province of Indonesia, showed that the LST has increased $0.4\text{--}0.7^{\circ}\text{C}$ per year, mainly due to housing growth and decrease vegetation density (Oktavianingrum et al., 2020). Being the largest country in Southeast Asia by area, Indonesia LST will affect the LST of neighboring countries and other countries in Asia, Australia, and their maritime areas.

The meteorology, climatology, and geophysics agency (BMKG) has predicted that Indonesia will increase air temperature from $0.2\text{--}0.3^{\circ}\text{C}$ from 2020–2030 because of global warming (Case et al., 2007). The temperature in Indonesia is projected to increase in the range of $2.0\text{--}2.5^{\circ}\text{C}$ by the year 2100 based on its emissions scenario A1B IPCC, and use of energy in a balanced manner between non-fossil fuels and fossil will minimize the increase of temperature (Met Office Hadley Centre, 2011; Rejekiningrum, 2014). On the other hand, the increase of Indonesia's LST could be due to the change of land use/land cover (LU/LC) from agriculture, mining, and housing development to meet human needs (World Bank, 2010). According to the environment critical index, an area is defined as a critical environment condition if the LST increases and the Normalized Difference Vegetation Index (NDVI) decreases density (Fadlin et al., 2020). In Indonesia in 2018, it is known that critical land comprised 9.45 million hectares and very critical land 4.55 million hectares (KLHK RI, 2019).

Indonesia is an archipelago located on the equator and between Asia and Australia and bounded by the Indian and Pacific oceans (Verstappen, 2014). Indonesia has a 1.9 million km^2 land area with a total area including seas of 5.2 million km^2 (World Bank et al., 2013). Consisting of tens of thousands of islands,

Indonesia has a tropical climate with high rainfall and high chemical weathering. Indonesia has a complete diversity of tropical animals and plants (Federal Research Division, 2011).

With a population of 267.7 million people, Indonesia is dependent on the economy of agriculture and marine products. An increase in population can cause a rise in waste, mainly emitted from non-metabolic activities, resulting in climate change (Kurnia et al., 2016). Expansion of settlement and agricultural areas, especially for palm oil cultivation, will expand the forest and environmental damage. Sumatra and Kalimantan have experienced massive reductions for development purposes (Margono et al., 2014). The Indonesian government has committed and implemented an agenda to reduce climate change, reduce carbon emission, reforestation, and improve the former mining site (KLHK RI, 2018).

This study investigates the seasonal daily LST patterns and variations from 2001 to 2020 in Indonesia. Stakeholders in Indonesia could use the findings of this research to prevent more severe environmental damage.

2. Materials And Methods

2.1. Study Area

Indonesia is the largest archipelago globally (Jepson, P., 2012) and is located in southeast Asia at 96° – 142° longitude and 7° to -9° latitude.

Indonesia has 5 super-regions consisting of 21 smaller regions, as shown in Fig. 1. Sumatra contains 5 of these smaller regions, Kalimantan has 6, Java and Bali 2, Sulawesi 3, and Papua 5. Each region consists of 9 sub-regions. Each sub-region consists of 47 pixels in a 7×7 array, distributed with 105 pixels (95 km) of equal distance between sub-regions to avoid overlapping or spatial correlation. We did not investigate the Nusa Tenggara and Maluku islands because they are too small to be affected by LST. The distribution of the sub-regions of Indonesia according to the geographical area is shown in Table 1. The number of regions in each super-region depends on its size.

Table 1. Super Region and Region of Indonesia

No	Super Region	Geographical Area	Region Code
1	Sumatra Latitude: 5.55 to -4.95 Longitude: 95.32 to 105.77	1. Aceh	A
		2. North Sumatra	B
		3. Riau & West Sumatra	C
		4. Jambi & Bengkulu	D
		5. South Sumatra	E
2	Kalimantan Latitude: 3.94 to -3.06 Longitude: 115.97 to 115.86	1. North Kalimantan	F
		2. West Kalimantan	G
		3. East Kalimantan	H
		4. West-Central Kalimantan	I
		5. Central Kalimantan	J
		6. South Kalimantan	K
2	Java & Bali Latitude: -6.22 to -8.34 Longitude: 105.97 to 115.09	1. West Java	L
		2. East Java and Bali	M
4	Sulawesi Latitude: 1.46 to -5.15 Longitude: 124.85 to 120.26	1. North Sulawesi	N
		2. Central Sulawesi	O
		3. South Sulawesi	P
5	Papua Latitude: -1.00 to -8.00 Longitude: 130.70 to 140.80	1. Sorong, Manokwari, Fak-fak	Q
		2. Yapen waropen, Mimika, Puncak Jaya	R
		3. Jayapura	S
		4. Jayawijaya	T
		5. Merauke	U

2.2. Data

We downloaded the LST data from NASA MODIS and VIIRS Land Products Global Subsetting and Visualization Tool start from January 2001 up to January 2020 (ORNL DAAC, 2018). The Tera satellite produces the LST data for daytime and nighttime. The database consists of average temperatures every 8 days with a dimension of 3×3 km and includes the central point 0.859 km^2 area so that the total number of rows in the data is 887 for years 2001 to 2020. The separation between sub-regions is needed to reduce the spatial correlation. The sample or sub-regions should not be placed on the water area because Tera Satellite NASA MODIS only has the LST data on the land.

2.3 Methods

Cubic spline functions are described as piecewise polynomials of degree n . The joined pieces are called knots. A spline function of degree n is a continuous function with $n - 1$ continuous derivative (Wahba, 1990; Wold, 1974). The cubic spline function is:

$$S(t) = a + bt + \sum_{k=1}^p c_k (t - t_k)_+^3 \quad [1]$$

where $S(t)$ is the spline function at time t in Julian calendar, and the defined knots are $t_1 < t_2 < \dots < t_p$ and $(t - t_k)_+^3$ equals $S(t)$ for $t > t_p$ and a, b, c_k are the coefficients

of the combination between the linear and cubic spline model.

We used the combination of a cubic spline model and a linear model as shown below (Wongsai et al., 2017):

$$s(t) = a + bt + \sum_{k=1}^{p-3} c_k \left[(t - t_k)_+^3 - d(t - t_{p-2})_+^3 + e(t - t_{p-1})_+^3 - f(t - t_p)_+^3 \right] \quad [2]$$

We have utilized the cubic spline for each sub-region and region to determine the seasonal pattern in each year. To minimize spatial and autocorrelation, the seasonally adjusted time series LST was manipulated. We worked the seasonally adjusted time series to transform the data by subtracting fitted seasonal patterns. The multivariate regression coefficients were assessed to detect the increase or decrease in the LST with a 95% confidence interval of mean daily LST. We operated R software to analyze the data and generate the visualization (Team, 2018).

3. Results And Discussion

We presented region B (North Sumatra) to show the west part of Indonesia on Sumatra island (Fig. 2). The first sub-region of region B is located at 2.93 latitudes and 99.38 longitudes and includes Sordang Bolon of Simalungun District. The seasonal pattern (Fig. 2) and seasonally adjusted time series (Fig. 3) for 21 regions of Indonesia were created to examine the seasonal pattern and trend of LST.

Figure 2 indicates that the average temperatures corresponded to the same day for each of the 19 years. The solid red curves show the fitted natural spline function with 8 knots; blue crosses denote the knots. With two peaks in March and September, there is a clear seasonal trend.

The lowest LST during the rainy season corresponded to day 1 (in January), and the highest LST corresponded to day 267 (in September) between 2001 and 2020. The lowest average of day LST was 24.9°C which occurred in sub-regions 3 and 5.

The estimated ar1 and ar2 were very low from the second-order autoregressive model, indicating that the time series of daily temperatures were independent. The mean-correcting outcomes to obtain the plots are shown in Fig. 3.

Figure 3 shows that the LST decreased in sub-regions 2, 4, and 6, LST increased in sub-regions 7 and was stable in the remaining sub-regions over the 19 years. The p-values for linear models (zero knots) with two parameters suggested a statistically significant decrease or increase in sub-regions 2, 4, 6, 7. The solid curves in the right panel show fitted cubic splines with seven knots with different scales compared to the left panels of red curves with significant p-values for sub-regions 1, 2, 4, 5, 6, and 7.

A multivariate regression model was used to adjust for the spatial correlation and estimate the LST change. The mean daily LST of (-0.141) was statistically significant, as shown in the bottom-right panel

Loading [MathJax]/jax/output/CommonHTML/fonts/TeX/fontdata.js terval of (-0.237, -0.045)°C per decade.

Every region has sub-regions with different colored dots based on the z-values from the regression model. Figure 4 showed that region A (Aceh) had 4 sub-regions in which the LST increased, 1 sub-region in which the LST was likely to have increased, 2 sub-regions in which the LST was stable and 2 sub-regions in which the LST decreased. The region had a stable trend in LST with an average increase of 0.06°C (95% CI: -0.053, 0.173) per decade.

Sumatra super region increased in LST per decade. Aceh had a stable LST, North Sumatra had a decrease, Riau & West Sumatra and Jambi increased, and South Sumatra had a slight decrease in LST. Java and Bali super region had a slightly increased LST in West Java and decreased in East Java and Bali. Kalimantan super region increased in LST in North Kalimantan, West Kalimantan, West-Central Kalimantan, Central Kalimantan. It was stable in East Kalimantan (the planned area for the new capital of Indonesia) and a slight decrease in South Kalimantan. Sulawesi super region decreased in North Sulawesi and South Sulawesi, and a slight decrease in Central Sulawesi. Papua super region had a slight decrease in Sorong, Manokwari, Fak-fak, and Jayawijaya. It decreased in Yapen Waropen, Mimika, Puncak Jaya, stable LST in the Jayapura region and a slight increase in Merauke.

Figure 4 also shows the variation for each region. Sumatra had 2 regions in which the LST increased. Borneo had many regions with an increase in LST. Overall, Indonesia had a stable LST on average. The average LST increased in Sumatra and Borneo islands, decreased in Java & Bali, and Sulawesi island and was stable in Papua island.

The increase in LST in the sub-regions is affected by the LU/LC transitions. In Borneo island, the increase in LST was partly due to the rapid growth of oil palm plantations, which is the leading cause of forest loss and fragmentation (McAlpine et al., 2018). The combination of elevated population density and high levels of biodiversity makes Indonesia, along with a massive 80,000 km coastline and 17,508 islands, one of the most vulnerable countries affected by climate change (Case et al., 2007)

The increase in LST in Indonesia was 0.009°C (95% CI: -0.041, 0.059°C) per decade and was considered stable, as shown by the confidence interval plot in Fig. 5. The average LST in Indonesia is still lower than the global LST average (95% confidence interval 0.85, 0.95) from 1950 to 2000 (Rohde et al., 2013). It is feared that the increase in world LST will result in a decline in main agricultural products such as rice, wheat, soybeans and corn (Zhao et al., 2017). According to some researchers, the LST in areas near the equator will have a stable LST trend, and areas close to the poles will decrease in LST (Berezin et al., 2012; Gillespie, 2014). Mountainous areas, such as Cameron island in Malaysia, have increased LST due to LU/LC changes (How Jin Aik et al., 2020).

Figure 5 also showed Sumatra and Kalimantan islands had significant increases in LST, 0.076°C with 95% confidence interval (0.01, 0.141°C) and 0.125°C with 95% confidence interval (0.056, 0.193), respectively. Java & Bali and Sulawesi islands decrease LST, and Papua island had a slight decrease of -0.042°C (95% CI: -0.108, 0.025) $^{\circ}\text{C}$ per decade on average. The increase of LST in Sumatra and

Kalimantan, Yananto & Dewi (2017) found an increase of hotspots in South Sumatra for Sumatra and Central Kalimantan for Kalimantan in 2015 during the period from 2011 to 2015.

Conclusions

We have shown that there have been variations in LST in the sub-regions of Indonesia using a cubic spline model. With the characteristic of Indonesia comprising many islands and coastal areas, the average LST in Indonesia will be influenced by the temperature of the islands and oceans. This study showed an increase of LST in Sumatra and Kalimantan island, even though Sumatra has many mountains and a large lake and Kalimantan has mountains. The increase is presumably due to the massive deforestation and urban development over the past 20 years.

Java & Bali had decreases in LST, even though Java & Bali are known as regions in Indonesia with high population density. Papua had a slight decrease in LST, even though it consists of dense tropical forests and mountains (Sam et al., 2020). Sulawesi's LST has decreased, most likely because the island is relatively small and likely to be influenced by water and cloud cover (Maru et al., 2015). In the area off Rottnest island near western Australia, both air-sea heat flux influences the mean of the annual cycle (Pearce et al., 2006).

Indonesia had a stable trend in LST on average with an increase in LST of 0.009°C (95% CI: -0.041 , 0.059°C) per decade, equating to an increase of 1°C per century. This situation will worsen if all stakeholders do not improve the environmental sector, such as replanting damaged areas. Measures that can reduce the greenhouse effect must be encouraged. For further research, the variation of LST needs to be assessed on a large island such as a continent. The addition of more variables such as NDVI and LU/LC would also be helpful.

Declarations

Funding: Not available

Conflict of interest: This research is a original research, hence there is no potential conflict of interest.

Availability of data, material and code: The data and the code that support the findings of this study are available by request.

Authors' contributions: Munawar Munawar and Tofan Agung Eka Prasetya obtained the data and performed it statistically, Rhysa McNeil and Rohana Jani contributed to statistical analyses, discussion and interpretation results. Suhaimee Buya focused on the R command and created the figures. All authors contributed to writing and editing the manuscript.

Ethics approval: Not Applicable

Consent for publication:

I, the undersigned, give my consent to the publication of identifiable details, including figures and or details within the text ("Material and Code") to be published in the above Journal and Article.

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Figures

Figure 1

Area of the study showing 21 regions (A – U)

Figure 2

Seasonal pattern of LST in Region B (North Sumatra) of Indonesia

Figure 3

Seasonally adjusted LST in Region B (North Sumatra)

Figure 4

Changes in mean daily LST in Indonesia, 2001 – 2020

Figure 5

Indonesia 2001 – 2020 movement of LST ($^{\circ}\text{C}/\text{decade}$)