Sea Surface Temperature (SST) analysis during ElNiño - LaNiña in the Java Sea

Yosafat D Haryanto¹, Nelly F Riama², Rezfiko Agdialta³ and Agus Hartoko⁴

¹ State College of Meteorology Climatology and Geophysics, Pondok Aren, South Tangerang 15221, Indonesia
² Center of Research and Development, BMKG, Kemayoran 10720, Indonesia
³ Palembang Climatology of Station, Indonesia Meteorology Climatology and Geophysics, Palembang, South Sumatera, Indonesia
⁴ Coastal Resource Management, Faculty of Fisheries and Marine Sciences, Diponegoro University, Tembalang, Semarang 50275, Indonesia

*ynosafatdonni@gmail.com

Abstract. El Niño-La Niña effected climate conditions in Indonesia. The purpose of this study was to analyze the SST during El Niño - La Niña. The data used is the ENSO index SST Niño 3.4 anomaly in 1986-2017 and also SST data in the year of the El Niño-La Niña event with weak, moderate, and strong. It found that SST tended to be higher during El Niño than its normal average in the Java Sea by 29°C, while the normal SST is 28.94°C. La Niña SST in the Java Sea has an average of 29.06°C which is 0.6°C warmer than its normal average temperature. It can be concluded that El Niño-La Niña conditions do not greatly affect SST in the Java Sea. SST tends to be warmer during El Niño-La Niña than its normal average in the Java Sea. The average of SST is lower/cooler at 109.5 - 110.5º East Longitude than that of at the other longitudes. This is due to the mixing current of the cold water mass flow from the South China Sea with the mass of water from the Makassar Strait, each of which carries nutrients.

1. Introduction

Sea Surface Temperature (SST) is the result of the initial interaction between the atmosphere and the ocean. The results of these interactions can be in the form of direction and speed of wind, rainfall, waves, sea water turbidity, and sea depth. Indonesia is oceanographically exposed to shallow sea (less than 200m depth) and deep sea (more than 200m depth) which clearly have different SST characteristics. Evaporation of seawater followed by condensation in the atmosphere is the main heat transfer mechanism which occurs between the ocean and the atmosphere. The heat needed to evaporate the water is released into the atmosphere when the vapor condenses to form clouds. Moreover, the sea has a great heat storage capacity due to the high specific heat of the water. As a consequence, the oceans can absorb and release a lot of heat with a slight change in water temperature [1]. The characteristics of SST as one of the oceanographic parameters include characterizing the sea water mass and having a correlation with the condition of the underneath water layer. Thus, the occurrence of such phenomena in the oceans can be analyzed. In other words, the presence of SST is immensely important for marine organisms as it affects metabolic activity and reproduction. [2] stated that changes in SST bring greatly important biological implications for the discomfort of most marine lives, including phytoplankton, zooplankton, seaweed, small fishes, and large fishes.
SST is an important oceanographic parameter for studying dynamic and global climatic variations, such as ElNiño - LaNiña [3]. ElNiño - LaNiña is a large-scale interaction phenomenon between sea and air which occurs in the tropical Pacific Ocean [4]. ElNiño can cause a decrease in rainfall and an increase in air temperature with prolonged dry season [5]. Moreover, LaNiña can cause more than that in normal years [6]. On global climate scale, ElNiño – LaNiña intensely affect weather and climatic conditions in Indonesia. The difference in warm pools in the Pacific Ocean becomes like a seesaw system which alternates within an event period of 2-7 years. The diversity of SST has a very significant influence on the metabolic activity and breeding of organisms in the ocean [7]. The results of SST data analysis indicate that SST anomaly variations in the East Sea of Japan are influenced by ElNiño - LaNiña events [8]. Susanto and Marra [9] stated that changes in temperature and chlorophyll-a in the sea are influenced by ElNiño - LaNiña. The study of ElNiño - LaNiña variability showed that there is an impact on changes in fisheries productivity, including small pelagic fisheries, especially lemuru [10] which affects the distribution of fish. This study aimed to analyze the effect of ElNiño - LaNiña on Sea Surface Temperature by using anomaly data to spatially and temporally analyze the variability of rainfall and water mass in the Java Sea.

2. Method
The material used in this study included data of satellite imagery results, data resulted from re-analysis (re-analysis of a phenomenon) and the results of observations on an automatic tool provided by official agencies and offices to be used freely in any study. This study used quantitative statistical data analysis methods started by conducting data collection management on ENSO Index of SST Niño 3.4 Anomaly (cpc.ncep.noaa.gov/data/indices/) SST anomaly condition in the Niño region 3.4 for 3-monthly period from 1986 to 2017 along with average Sea Surface Temperature (SST) data in the period of ElNiño and LaNiña which occurred in the range of 1986 and 2017 in the Java Sea with 2° to 10° south latitude and 105° to 116° east longitude coordinates in the form of netcdf data (.nc). The reason for using the ENSO Index for SST Niño 3.4 Anomaly was because the parameters used in the index were oceanographic parameters, i.e. SST anomaly, so it was considered to be more suitable when it was compared to other SOI indices which use other atmospheric parameters, such as air pressure.

The Enso Index data of SST Niño 3.4 Anomaly for 3 monthly period were then averaged using statistical applications to produce an average of annual ENSO Index in the period from 1986 to 2017. The results of the data processing were then used as a reference in determining ElNiño-LaNiña events as in the strong, medium, weak and normal phase. The average sea surface temperature data during the ElNiño and LaNiña years were then processed using a spatial data processing application to produce the interpolation of the sea surface temperature map. The results of the data processing were hence described using descriptive analysis methods to see the variability of sea surface temperature during the ElNiño and LaNiña events.
Figure 1. The location of the Java Sea.

Figure 1 is the research location that is located in the Java Sea with 2° to 10° south latitude and 105° to 116° east longitude coordinates. ENSO index is the result of SST anomaly calculation in the Pacific Ocean. This following equation of SST anomaly value in the Niño 3.4 region is used to determine the ENSO index:

$$\Delta SPL_{3.4} = SPL_a - SPL_m$$ (1)

where $\Delta SPL_{3.4}$ is the SST anomaly value in Niño 3.4 region. SST $a$ is the actual SST value; in this case this is the monthly average of SST in the actual month in the Niño 3.4 region and the SST$m$ is the average SST value based on a long series of data in the Niño 3.4 region. On the basis of above anomaly calculation results, the next step was to determine the SST anomaly criteria in Niño 3.4 region which was used as the ENSO index based on BMKG (BMKG is local abbreviated term for Meteorological, Climatological, Geophysical Agency) standards [11] i.e.:

- Strong El Niño : >2.0
- Moderate El Niño : 1.0 – 2.0
- Weak El Niño : 0.5 – 1.0
- Normal/Neutral : ± 0.5
- Weak La Niña : (-0.5) – (-1.0)
- Moderate La Niña : (-1.0) – (-2.0)
- Strong La Niña : < (-2.0)

Satellite data for SST were obtained using NCEP / NCAR (NOAA) satellite. The data were processed in the following steps: satellite data were downloaded from website www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.surface.html. Moreover, the downloaded El Niño-La Niña data analysis were the annual data so that the data can be processed using GraDS software while still using data.nc format. In addition, the downloaded data has possessed coordinate information (has rectified) so it was unnecessary to carry out rectification process. The next stage was to analyze El Niño-La Niña with SST anomaly on the variability of rainfall and water mass in the Java Sea.

3. Results and discussion
The El Niño - La Niña phenomena can be identified based on the deviation of Sea Surface Temperature (SST) in the Niño 3.4 region of the Pacific Ocean. The SST during El Niño in the central and eastern regions of the Pacific Ocean warms up. In contrast, SST in the territory of Indonesia
becomes lower than it is in normal condition and vice versa when La Niña occurs. The difference of SST variation in the Java Sea during El Niño - La Niña with the average annual SST definitely reflects the impact of El Niño - La Niña. Therefore, this will be used to determine the criteria for SST anomaly variation based on Niño Index 3.4 which divides ENSO phenomena into moderate to strong El Niño and La Niña. Moderate El Niño occurred in 1994, 2002, 2006, and 2009 while strong El Niño occurred in 1997 and 2015, and La Niña occurred in 1998, 2000, 2008 and 2010.

Figure 2. ENSO Index in Niño Region 3.4 (Pacific Ocean) based on the criteria of El Niño - La Niña for the Period of (1986 – 2017).

Figure 2 shows the ENSO Index in Niño Region 3.4 (Pacific Ocean) based on the El Niño - La Niña Criteria for the Period (1986 - 2017). Normal or neutral period and the occurrence of El Niño - La Niña were analyzed for 32 years (1986-2017) based on the ENSO index in the Niño 3.4 region (Pacific Ocean). Moderate El Niño occurred in 1994, 2002, 2006, and 2009. Moreover, strong El Niño happened in 1997 and 2015. Meanwhile, La Niña phenomenon occurred in 1998, 2000, 2008 and 2010.

Figure 3. SST Condition (in °C) during the years of the occurrence of Moderate El Niño in the Java Sea.
Figure 3 shows the interpolated map of the research location SST during Moderate El Niño event that was occurred in 1994, 2002, 2006, and 2009 with the average SST as high as 29°C in the Java Sea, while the average SST in Java Sea waters in neutral or normal years was 28.94°C. The rate of SST increase in the Java Sea ranges from 0.2 – 0.3 °C/decade (Bappenas [local term for National Development Planning Board], 2018). SST conditions in 1994 ranged from 27.80-29°C. Furthermore, most of the SST in the Java Sea from 2002 to 2006 ranged from 28.40-29 °C. In 2009, the SST increased to 29.2-29.60 °C. However, in areas located at 4 – 5° South Latitude and 113 – 114° East Longitude, the average SST was 28.5 °C.

Figure 4. SST condition (°C) during the years of strong El Niño in the Java Sea.

Beside, Figure 4 shows the interpolated map of the research location SST during the year of strong El Niño event in 1997 and 2015. Strong El Niño occurred in 1997 and 2015 with average SST in the Java Sea as high as 29 °C, while neutral/normal SST was 28.94 °C. SST in 1997 mostly ranged from 27.80 – 29 °C. In 2015 SST increased from 28.4 – 29.60 °C. The increase in SST ranging from (29.86 – 30.48 °C) also occurred in Cenderawasih Bay area in the northern waters of Papua during the occurrence of El Niño (Hartoko, 2009).

Figure 5. SST condition (°C) during the years of La Niña in the Java Sea
La Niña, the opposite of El Niño, happened in 1998, 2000, 2008 and 2010 as shows on Figure 5 that is interpolated map of La Niña event. The average SST during La Niña in Java Sea was around 29.06 °C which was warmer than its normal average, 28.94 °. In 1998 and 2010 the SST ranged from 29 – 30.20 °C, while in 2000 and 2008 the SST ranged from 28.40 – 29 °C. La Niña is marked by the increase of SST in Indonesian waters, and the increasing rainy conditions in Indonesian territory [12].

Figure 5. Interpolated map of La Niña event.

The ENSO index for the years when El Niño – La Niña occurred in the period of (1986 – 2017) and there is also a Hovmuller diagram that shows on Figure 6 elaborating the conditions of SST for 32 years in the period of (1986-2017). At 109.5 – 110.5° East Longitude, it could be seen that the average SST was lower/cooler than that of at the other longitudes. This could explain the existence of mixing current of the cold water mass flow from the South China Sea with the mass of water from the Makassar Strait which each carry nutrients besides there was also a wind mixing event. This mass flow of cold water contained mixing water masses so that the area had an abundance of chlorophyll-a. Current mixing process is a process of mixing warm and cold water mass. This event can occur because it is influenced by the wind blowing around the waters which results in two water masses mixture [13]. Marshal et al [14] stated that wind mixing is the process of mixing sea water masses due to wind influence.
Figure 7. SST Trend (°C) in the Java Sea for 32 years during the period of 1986–2017.

Figure 7 described the value of SST trend for 32 years in the period of (1986 - 2017) in the Java Sea. This trend value indicated an increase of SST in the Java Sea. The same thing was also stated by [15] stating that the trend value of SST in the Java Sea has increased for 30 years in the period of (1971 – 2000). The warmer the SST is, the more water vapor is distributed into the atmosphere so that the greater the rainfall would be; thus there is a strong correlation between rainfall and SST. Changes in SST are known to have a major influence on rainfall variability and are also associated with the changes in SST anomaly patterns [16]. Hendon [17] stated that the variability of SST Nino 3.4 affects 50% of rainfall variability throughout Indonesia.

Monthly average of SST in the Java Sea was 28.60 °C. During the peak of the rainy season in the month of DJF (December, January, February), SST increased by 29.02 °C in average and decreased in JJA/the peak of dry season at around 28.05 °C. SST in Nino 3.4 at the central and eastern parts of the Pacific Ocean caused the occurrence of El Niño-La Niña phenomena which affected weather and climate in the regions of Indonesia [18]. The El Niño phenomenon was characterized by SST anomaly with positive value of more than 0.5 °C (if the SST anomaly was greater than + 2.0 °C, it was categorized as strong El Niño) and the La Niña phenomenon was characterized by SST anomaly with negative value of less than -0.5 °C [19]. The SST during El Niño tended to be higher than the normal average in the Java Sea at 29 °C, while the SST is normally 28.94 °C. At the occurrence of La Niña, SST in Java Sea waters had 29.06 °C average which was warmer than its normal average.

4. Conclusion
In the years for medium El Niño, i.e. 1994, 2002, 2006, and 2009, and the years for strong El Niño event, 1997 and 2015, the average sea surface temperature showed 0.6°C warmer difference compared to the sea surface temperature in normal condition. Such conditions also occurred in the years of La Niña events in 1998, 2000, 2008, and 2010. This proved that El Niño and La Niña conditions did not really affect the sea surface temperature conditions in the Java Sea waters. During the El Niño and La Niña events, sea surface temperatures in the Java Sea tend to be warmer than its normal average. At longitude 109.5 - 110.5°EL, it could be described that the average sea surface temperature was lower or cooler than that at the other longitudes. This might be due to the mixing current of the cold water mass flow from the South China Sea with the mass of water from the Makassar Strait, each of which carries nutrients as well as wind mixing.
References

[1] K. Sverdrup, A. Duxbury, and A. Duxbury, Fundamentals of Oceanography Fifth Edition, New York : Mc Graw Hill Higher Education, 2006.

[2] Bappenas, “Ringkasan Eksekutif Rekonstruksi dan Proyeksi Iklim Laut Kaji Ulang Rencana Aksi Nasional Adaptasi Perubahan Iklim (RAN-API)” (Jakarta : Kementerian PPN/Bappenas, 2018.

[3] S. Cahyarini S, “Rekonstruksi Suhu Permukaan Laut Periode 1993 – 2007 Berdasarkan Analisis Kandungan Sr/Ca Koral dari Wilayah Labuan Bajo, Pulau Simeuleu,” Jurnal Geologi Indonesia, vol. 6, no. 3, pp. 129-134, 2013.

[4] Yue W, Liu L, and Xiaotong Z, “Influence of El Niño events on sea surface salinity over the central equatorial Indian Ocean,” Enviromental Research, vol. 182, 2020.

[5] Kaewthongrach R, Chidthaisong A, Charuchittipan D, Vitasse Y, Sanwangseri M, Varnakova P, … LeClerc M, “Impacts of a strong El Niño event on leaf phenology and carbon dioxide exchange in a secondary dry dipterocarp forest.” Agricultural and Forest Meteorology. 287, 107945, 2020.

[6] Moura M, Dos Santos, A, Da Silva S, Pimentel S, De Andrade M, Silva F, … de Carvalho J. “Relation of El Niño and La Niña phenomena to precipitation, evapotranspiration and temperature in the Amazon basin,” Science of The Total Environment, 2018.

[7] Prasetya A and Suwarso, “Produktivitas Primer dan Kelimpahan Ikan Layang (Decapterus spp.) hubungannya dengan Fenomena ElNiño - LaNiña, di Selat Makassar bagian Selatan Marine Fisheries.,” vol. 1, no. 1, pp. 47-56, 2010.

[8] C. Hong, K. Cho, and H Kim, “The relationship between ENSO events and sea surface temperature in the East (Japan) Sea,” Progress in Oceanography, vol. 49, no. 1, pp. 21–40, 2001.

[9] D. Susanto, T Moore, and J Marra, “Effect of the 1997/1998 El Niño on Chlorophyll-a Variability along the Southern Coast of Java and Sumatera.” J. Oceanography. Vol. 18, no. 4, pp. 124-127, 2005.

[10] Kunarso, “Pengaruh Monsun, El Nino, Dan IOD Terhadap Waktu Dan Daerah Penangkapan Ikan Tuna Di Samudra India Bagian Timur”. Thesis. Bandung: Institut Teknologi Bandung, 2014.

[11] F. Nabilah, Y. Prasetyo and A. Sukmono, “Analisis Pengaruh Fenomena El Niño- La Niña terhadap Curah Hujan Tahun 1998-2016 Menggunakan Indikator ONI (Oceanic Nino Index)(Studi Kasus: Provinsi Jawa Barat)” Jurnal Geodesi Undip, vol. 6, no. 4, pp. 402-412, 2017.

[12] IPCC (Intergovernmental Panel on Climate Change), “Climate Change 2007 – the Physical Sciences Basis : Contribution of Working Group I to the Fourth Assesment Report of the IPCC,” Cambridge : Cambridge University Press, 2007.

[13] A. Andita Zainuri M, Anindyaw, Lilik M, Petrus S, Agus A, and G. Handoyo, “Analisis Sebaran Klorofil-A dan Suhu Permukaan Laut sebagai Fishing Ground Potensial (Ikan Pelagis Kecil) di Perairan Kendal, Jawa Tengah.” Bulletin Oceanografi Marina, vol. 7, no. 2, pp. 67-74, 2018.

[14] J. Marshall and R. Plumb R, Atmosphere, Ocean, and Climate Dynamics : An Introductory Text. Elsevier Academic Press. USA.

[15] Sulistya W and A. Hartoko, Meteorologi dan Sifat Lautan Indonesia. Pusat Penelitian dan pengembangan BMKG, 2009.

[16] F. Estintingybas and E. Aldrian, “Analisis Korelasi Curah Hujan dan Suhu Permukaan Laut Wilayah Indonesia, serta Implikasinya untuk Prakiraan Curah Hujan (Studi Kasus Kabupaten Cilacap),” J. Agromet Indonesia, vol. 21, no. 2, pp. 46-60, 2007.

[17] H. Hendon Indonesian Rainfall Variability : Impacts of ENSO and Local Air-Sea Interaction. American Meteorology Society, vol. 16, no. 4, pp. 1775-1790, 2003.
[18] V. Moron, A. Robertson, and R. Boer, “Spatial Coherence and Seasonal Predictability of Monsoon Onset over Indonesia,” *J Climate*, vol. 21, pp. 1-11, 2008.

[19] A Ibnu, M Rini, and D Deassy, “Analisis Spasial Pengaruh Kejadian El Niño kuat Tahun 2015 dan La Niña lemah Tahun 2016 terhadap Kelembaban, Angin dan Curah Hujan di Indonesia” *Jurnal Sains & Teknologi Modifikasi Cuaca*, vol. 18, no. 1, pp. 33-41, 2017.