A comparison between the 2010 and 2016 El-Ninõ induced coral bleaching in the Indonesian waters

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Abstract. Severe coral bleaching events are always associated with El-Ninõ phenomenon which caused a rise in ocean temperature between 1-2°C and that they potentially kill the corals worldwide. There were at least four severe coral bleaching events occurred in the Indonesian waters. This study aims to compare the coral bleaching events of the 2010 and 2016 and their impact on corals in Indonesian waters. Long-term (2002-2017) remotely sensed night time sea surface temperature (SST) data acquired from Aqua MODIS Satellite were used in the analysis. Here, we calculated the mean monthly maximum (MMM) of SST as SST in normal condition in which coral can adapt to temperature; the differences between high SST in each pixel during coral bleaching events of the 2010/2016 and MMM SST, called hot spot (HS); and how long has HS occupied a certain water body, called degree of heating weeks (DHW, °C-week) and then mapped it. Results show that the MMM SST for the Indonesian waters is 29.1°C. Both bleaching events of 2010 and 2016 started and finished in the same periods of Mar-Jun and they nearly have the same pattern, but bleaching magnitude of the 2016 was stronger than 2010 with the mean SST about 0.4°C higher in May-June. The percentage of impacted areas of strong thermal stress on corals of Alert-1 plus Alert-2 status was higher in 2016 (39.4%) compared to 2010 (31.3%). Coral bleaching events in the 2010 and 2016 spread in almost all Indonesian waters and relatively occurred in the same places but with small variation in the bleaching sites that was caused by the strength/weakness of El-Ninõ and upwelling phenomenon as well as the role of Indonesian through flow (ITF).

1. Introduction
Coral bleaching events with the worst impact in all tropical or subtropical seas of the world take place episodically with El Ninõ phenomenon [1-7], which causes a rise in sea temperature 1-2°C or warmer and can heat a water body for 4-8 weeks or longer that will stress or potentially kill corals worldwide [1-4, 6-8-13]. When corals are in a stressful condition due to sea temperature rise during El-Nino event, corals expel their symbiont, a single-cell micro algae genus Symbiodinium known as zooxanthellae, which lives in coral tissues [1, 6, 8-11]. As a consequence, the variation and the beautiful color of corals become white, pale, or purple as the color of limestone, the skeleton of corals. This phenomenon is defined as coral bleaching [5,14-17]. Physiologically, bleached corals are damaged and, in the long periods, bleaching often leads to high levels of coral mortality [18-20].

There are four significant global coral bleaching events due to global warming induced by the El Ninõ which have been reported all over the world including in the Indonesian waters. However, the US National Oceanic & Atmospheric Administration (NOAA) mentioned only three global bleaching
events [21]. The bleaching events in 1982/83 that killed 95% corals in the Galapagos Islands [22] were not included. Thus, the first global bleaching event associated with the extremely strong El Niño that rose the global ocean temperature about 2°C and destroyed about 16% of the world’s coral was in 1997/98 [8,23-24]. The second was during a mild El Niño in year 2010 that elevated sea temperatures and caused mass bleaching of reefs in many parts of the world [25]. The third was the current global warming due to strong El Niño in the 2015/16 which was announced by NOAA as the longest and the most extensive bleaching event on record; impacting some reefs in consecutive years [21,26].

Despite a large number of reports and scientific papers on the coral bleaching events from all seas of the world, the specific coral bleaching events in Indonesian waters are still rarely studied and could hardly be found in scientific journals although bleaching events frequently occurred. In Indonesia, the first coral bleaching was reported in 1983 from the Pari Island, Seribu Islands [27-29]. Significant coral bleaching in 1997/98 has been reported to occur in various Indonesian waters [30], but again, rare publications were available. The widespread bleaching events of 2010 [31] have begun to be reported by at least 50 coral watch organizations consisting of individuals, dive centers, NGOs, academics and research institutions [32]. Several scientific papers are also beginning to emerge [31,33-36]. The longest and the most extensive bleaching event on record in 2015/16, that impacted some reefs of Indonesian waters, was reported by various organizations as in 2010 but so far only one paper was issued [6].

In addition, some scientific papers on coral bleaching in Indonesian waters began to emerge in 2010; Mostly discussed the impacts of coral bleaching on reduction of coral covers and coral species diversity the changes of benthic habitats and reef-associated biota such as reef fishes and other benthic biota [33-36]. Only one or two papers revealed the mass bleaching event and its dynamics through an analysis of SST rise which was caused by El Niño [31]. In 2017, a paper on coral stress in Bunaken (North Sulawesi) waters was published, but the stress was not due to the El-nino of 2016 [6].

The events of coral bleaching caused by the rising of global sea temperature which is induced by El Niño have been monitored following a standard procedure of calculation of corals stress by NOAA coral reef watch program [37]. By this standard procedure, NOAA generated monthly or seasonal coral bleaching warning system and prediction maps on a global scale. These maps are widely used and adapted in all tropical countries for predicting and monitoring the bleaching events. However, such kind maps are too coarse (5 km by 5 km) for evaluating bleaching events in details at small islands or reefs, such as in the many reefs of Indonesia. Thus, in order to more understand and monitor the coral bleaching events in the Indonesian waters, it is necessary to generate a similar NOAA maps for the scale of Indonesian territorial waters. Based on above backgrounds, therefore this paper aims to add more data and information about El-Niño induced coral bleaching by mapping and comparing the bleaching events between 2010 and 2016 as well as studying the effects of bleaching on corals.

2. Methodology
2.1. Source of coral bleaching data

The sources of coral bleaching data used in this study both in 2010 and 2016 consist of primary and secondary data. The primary data were obtained mainly from the field observation at the sites of coral reef rehabilitation and management programs (COREMAP) in the Mentawai and Nias Islands (west Sumatra), Spermonde and Selayar Islands (South Sulawesi), Wakatobi Islands (Southeast Sulawesi), Biak and Raja Ampat Islands (Papua) and other places (Bintan). Coral bleaching was accidentally discovered during the COREMAP survey by the researchers from Research Center of Oceanography (RCO). The secondary data were obtained from various sources such as individuals, dive centers, NGOs (Reef Check Indonesia, Coral Reef Alliance, TNC, WWF), academics, college students and research/government institutions such as Ministry of Marine Affair and Fisheries (MMAF).

Coral bleaching data collected from primary or secondary data consist of various information, i.e. coral bleaching location, date, reporter’s name and affiliation, and various remarks such as observation methods, (snorkeling, photographs, or hearing from news), bleached coral species, colors and their percentage covers, degree of corals severity either during and after bleaching events, sea temperature,
duration of sea temperature occupies a water body called degree heating weeks (DHW). Here is an example of reports on coral bleaching events from primary field observation. Bleaching location: Badi Island (Spermonde Islands), Date: June 19, 2010, Reporter: Researchers from RCO-LIPI, Remarks: Bleaching occurred in April-June, Pictures were taken in June, DHW > 8°C.week (severe bleaching): Bleached taxa: Acropora, non-Acropora, soft corals, and even sea anemone. Below are examples taken from secondary reports. Location: Parigi, Tomini Bay, Date: May 27, 2010, Reporter: Yayasan Palu Hijau, Remarks: Bleaching occurred in April-June, Pictures were taken in June, DHW > 8°C. Week (severe bleaching): Bleached taxa: Pocillopora, Faviid, Stylopora, Encrusting (see Table 3).

2.2. Source of SST data
Since coral bleaching events are caused by global ocean temperature rise that are triggered by El-Nino, monitoring the ocean temperature (SST) effectively and efficiently using remote sensing techniques through the utilization of satellite data is very important. The advantages of satellite-derived SST are vast in coverage at high resolution compared to any other form of conventional collected SST data [39]. Among the satellite derived SST products, MODIS has been providing high quality global SST for over a decade (~15 years) from a single sensor [39,40] and used for a wide variety of studies in the field of earth’s climate system, weather forecasting, and oceanographic research, e.g., ocean circulation modelling and the complexity of ocean surface currents, large scale SST anomalies that indicated climate perturbations such as El-Niño events, upwelling regions, ocean biology, including coral reefs and algae blooms [39-42] and many other wide-range topics.

Therefore, in this study, we used monthly SST data from 2002 to 2017 (15 years) derived by Thermal infrared (TIR) sensor of MODIS (Moderate Resolution Imaging Spectroradio-meter) at 11 μm bands of Aqua satellite with a ground resolution of 4 km by 4 km intensively. These SST data are available in the Giovanni (Geospatial Interactive Online Visualization ANd aNalysis Infrastructure) online data system web which are developed and maintained by the NASA GES DISC [43]. The SST data used in the analysis are night time SST to avoid sun glare and wide variations of SST during day time [12]. SST data used covered all Indonesian waters from latitude of 12° South and 8° North, and longitude of 92-142° East. These observed regions are also included as a part or whole region of neighboring countries such as Malaysia, Singapore, Brunei and Timor Leste.

2.3. Data analysis
The principal analysis in this study followed the standard method of NOAA which is described in details in [12]. Firstly, we collected long-term (2002-2017) night time SST data from Giovanni Web. Secondly, we calculated maximum mean monthly night SST (MMM) or SST at the normal condition which assumes that corals can adapt to seawater temperatures in these long periods (15 years) data. Third, we then calculated the differences between high night time SST due to the impact of El Niño during bleaching events of the 2010 and 2016 and MMM SST (SST in the normal condition), called hot spot (HS). Hence, HS = SST in bleaching period of 2010/2016 – MMM SST. The next step is to determine how long the HS occupied a certain water body, called degree Heating Weeks (DHW, weeks-°C). Based on the HS and DHW values, the coral bleaching alert system, as well as the monthly maps of HS and accumulated DHW of Mar-Jun 2010/2016 for Indonesian waters can be generated for determining the impacts of coral bleaching in a particular site. Figure 1 shows the flow chart of the procedure.

3. Result and Discussion
3.1. About SST data derived from Aqua-MODIS satellite
The performance of study on the global scale SST anomalies that indicated climate perturbations such as El-Niño events always depend on the accuracy of SST measured by the sensor which means accurate global measurements of SST are critical to understanding the past, current and future climate change [40]. Therefore, the satellite sensor must be stable to conduct long time measurement of SST, must be capable to detect the small changes of trends as small as 0.1°C within a decade, and must be validated using SST measured from ships and other platforms (Argo buoy) as ground truth [44].

![Flow chart of methodology and criteria in determining the status of coral bleaching](image)

Figure 1. Flow chart of methodology and criteria in determining the status of coral bleaching [12].

Results of SST validation measured by MODIS sensors agreed well with in situ buoy SST of the Yellow Sea coastal waters, China with squared correlation coefficients (R²) of 0.987, a bias of 0.06 °C, a standard deviation (STD) of 0.85 °C, and a root mean square error of 0.85 °C [45]. MODIS derived-SST achieves an excellent performance at night-time with accuracies to the order of 0.35 °C compare to in situ SST measurements derived from ARGO buoy data in the Canary Islands-Azores-Gibraltar area [46]. The SST derived from MODIS sensor in the South China Sea have biases ranging from –0.19°C to –0.34°C and STD errors ranging from 0.58 °C to 0.68 °C [47]. Study of [41] shows that the MODIS SST are comparable in accuracy to the SST derived from the Advanced Very High-Resolution Radiometer (AVHRR) sensor of Pathfinder satellite of NOAA. The AVHRR sensor data have been extensively used by NOAA for generating the global and regional scale of monthly or seasonal coral bleaching warning system and prediction maps. Thus, based on many validations, it is no doubt that sensor MODIS of Aqua satellite can also be used for this study.

3.2. Distribution of HS in the bleaching events of the 2010 and 2016
Tabel 1 shows long-term of night time SST data (2002-2017) measured by 11 µm TIR Band of Aqua-MODIS satellite. From the calculation, the MMM SST is 29.1 °C. It means that the thresholds in which corals can tolerate the sea water temperatures is 29.1 °C. Above this value, corals begin to stress
depending on how large the differences between the high SST at bleaching events of the 2010/16 to MMM SST called as a hot spot (HS). Hence, HS=SST at the bleaching events of 2010/16 - 29.1 °C.

Figure 2 shows the plot of normal long-period SST of 2002-2017 and high SST due to EL-Niño events that induced coral bleaching of 2010 and 2016. Both bleaching events of 2010 and 2016 started and finished in the same months of March and June, while the SST in January-February and in July-December of 2010 and 2016 was lower than MMM SST which means no coral bleaching occurred during those months. However, the average SST at bleaching events in May and June of 2016 were stronger than in May and June 2010 with ranges about 0.3-0.4 °C but if the SST differences of those 2006 and 2010 are calculated on the pixel bases, there are many pixels show the SST exceed 1 °C. Figure 3 shows the monthly map of HS distribution from March to June which also indicated that HS in 2016, especially the warning status (HS > 1 °C, DHW ≤ 4 °C-week), was distributed wider than in 2010. Thus, that indicated that the overall magnitude of HS 2016 was stronger than that of 2010.

Table 1. Monthly night time SST of the Indonesian waters (2002-2017) derived from 11 µm TIR band of Aqua-MODIS. Highlight rows indicate SST at bleaching events of 2010 and 2016. Bold number is the MMM values.

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 2002 | -   | -   | -   | -   | -   | 28.2| 27.7| 27.6| 28.1| 28.5| 28.8|     |
| 2003 | 28.2| 28.1| 28.7| 29.2| 29.2| 28.2| 28.0| 27.7| 27.8| 28.2| 28.6| 28.2|
| 2004 | 28.3| 28.1| 28.8| 29.2| 29.2| 28.6| 27.8| 27.5| 27.4| 28.0| 28.5| 28.4|
| 2005 | 28.3| 28.7| 29.0| 29.0| 28.8| 28.7| 28.4| 28.0| 28.1| 28.3| 28.5| 28.3|
| 2006 | 28.0| 28.4| 28.9| 28.9| 28.5| 28.5| 28.0| 27.5| 27.3| 27.5| 28.2| 28.5|
| 2007 | 28.2| 28.5| 28.6| 28.9| 29.1| 28.7| 28.0| 27.7| 27.7| 28.0| 28.4| 28.5|
| 2008 | 28.3| 27.3| 28.4| 28.8| 28.6| 28.0| 28.9| 27.7| 28.0| 28.4| 28.6| 28.3|
| 2009 | 28.0| 27.8| 29.0| 29.4| 29.2| 28.5| 28.0| 28.3| 28.3| 28.7| 28.7|     |
| 2010 | 28.1| 28.8| 29.3| 29.6| 29.5| 28.8| 28.7| 28.7| 28.9| 28.8| 28.6|     |
| 2011 | 28.1| 28.1| 28.3| 28.8| 28.9| 28.4| 28.0| 27.1| 27.4| 28.1| 28.1| 28.7|
| 2012 | 28.5| 28.5| 28.5| 28.9| 28.5| 29.2| 28.0| 27.6| 27.0| 28.2| 28.7| 28.8|
| 2013 | 28.2| 28.7| 29.1| 29.4| 29.4| 29.1| 28.0| 27.9| 28.3| 28.6| 28.7|     |
| 2014 | 28.2| 28.1| 28.6| 29.2| 29.4| 29.0| 28.3| 27.9| 28.2| 28.1| 28.6| 28.6|
| 2015 | 28.3| 28.4| 28.7| 29.1| 29.1| 29.0| 28.6| 27.2| 27.8| 27.9| 28.6| 28.9|
| 2016 | 29.0| 28.9| 29.3| 29.6| 29.9| 28.6| 28.6| 28.7| 28.7| 28.9| 28.8|     |
| 2017 | 28.3| 28.5| 28.7| 29.2| -   | -   | -   | -   | -   | -   | -   | -   |

MMM 28.3 28.3 28.8 29.1 29.0 28.8 28.3 27.8 27.9 28.2 28.6 28.6

Figure 2. SST in the normal condition of 2002-2017 and high SST in the bleaching events of 2010 and 2017.
In March 2010, the no thermal stress status (HS ≤ 0°C) covered very wide areas at about ¼ (31.2%) of the total study site areas (8ºN-12ºS; 91-142ºE) and spread mostly in the north part of Indonesia. This status distributed in the South China Sea, Sulawesi, Halmahera, Maluku, Seram Seas, which was influenced by South China Sea water masses in the west part and tropical Pacific Ocean (TPO) water masses in the middle and east part of Indonesian waters (Figure 3). No thermal stress status areas decreased in April (18.0%) and May (15.3%), but increased again in June (29.1%) with almost the same areas as in March 2010 (Table 2). However, the distribution of this status in June was in very different pattern compared to the one in March 2010, which spread mostly in all south part of Indonesian waters such as the south waters of Jawa, Bali, West and East Nusa Tenggara (NTB and NTT) Islands, and Arafura Seas that are under the influences of the Indian ocean water masses (Figure 3). Low SST of the no thermal stress status in June 2010 was due to strong upwelling that pushed cold water masses from the Indian Ocean to the Arafura and Banda Seas and even farther into the Seram and Maluku Seas [31]. Upwelling is a blessing for coral bleaching events. On a local scale, small upwelling (several tens to several hundred square meters) can reduce coral bleaching events by decreasing temperatures or fluctuating environmental temperatures, so over time corals become more resistant to temperature [11]. As an example, upwelling that occurred in Tayrona National Park, Colombia in Nov-Dec 2010 has reduced the intensity of the coral bleaching events by lowering the SST from 28 ºC to 21 ºC between December 2010 and February 2011 [48].

![Table 2. Percentage of monthly (Mar.-Jun) HS and DHW areas in bleaching events of 2010 and 2016.](image)

| No | Category                     | Coral Bleaching Events of the 2010 | Coral Bleaching Events of the 2016 |
|----|------------------------------|-----------------------------------|-----------------------------------|
|    |                              | Mar. Apr. May Jun. Mar.-Jun.     | Mar. Apr. May Jun. Mar.-Jun.     |
| 1  | HS ≤ 0°C; No thermal stress | 31.2 18.0 15.3 29.1 18.9         | 28.3 15.9 11.9 18.8 11.9          |
| 2  | HS 0-1 ºC; Watch             | 38.8 51.5 49.6 28.4 13.9         | 28.1 43.0 48.5 38.8 14.0          |
| 3  | HS > 1ºC; DHW < 4, Warning   | 12.1 12.5 16.9 23.4 18.0         | 23.9 22.8 20.4 23.8 16.8          |
| 4  | HS > 1 ºC; DHW 4-8, Alert-I  | 0.1 0.2 0.3 1.2 17.2            | 1.7 0.5 1.3 0.8 15.4             |
| 5  | HS > 1 ºC; DHW > 8, Alert-II | 0.0 0.0 0.0 0.0 14.1            | 0.0 0.0 0.0 0.0 24.0             |
| 6  | LAND                         | 17.8 17.8 17.8 17.8 17.8        | 17.8 17.8 17.8 17.8 17.8          |
|    | Total                        | 100 100 100 100 100             | 100 100 100 100 100              |

Furthermore, the percentages of watch status (HS: 0-1 ºC) areas of March to June 2010 were higher than the no thermal stress status, which cover an areas of > ¾ (38.8%), ½ (51.5%), ~½ (49.6%) and ~¼ (28.4%) of total study sites in March, April, May and June 2010, respectively (Table 2) with random distribution in all study sites.

The warning status (HS > 1 ºC, DHW ≤ 4 ºC-week) in March to May 2010 was distributed in limited areas of Aceh, west coast of North Sumatra, in the Seribu, Karimun Jawa Islands and Situbondo of eastern Jawa Island, the north of Bali and Lombok Islands, Pangkajene (South Sulawesi) and Wakatobi Islands (Southeast Sulawesi), Tomini Bay, Ambon and the islands in the south of West and East Nusa Tenggara (NTB and NTT) with percentage cover areas of HS 12.1, 12.5 and 16.9%, respectively (Table 2). In June, warning status spread wider in the west coast of Sumatra Island from Aceh down south to Padang that covered many islands (Nias to Mentawai Islands), Malacca and Karimata Straits, East Kalimantan (Derawan Islands) and the offshore of Cendrawasih Bay with percentage cover areas of 23.4%. The Alert-1 status (DHW 4-8 ºC-week) areas tended to rise from 0.1% in March to 1.3% in June, but almost none (~ 0 %) for Alert-2 status (DHW > 8 ºC-week).

In the year of 2016, the areas of no thermal stress status (HS ≤ 0ºC) has the simillar pattern as that in 2010 which distributed in the north part of Indonesian waters during March to May 2016 but with less percentage of cover areas (28.3, 15.9, and 1.9) compared to those of March to May 2010 (31.2, 18.0, and 15.3) (Figure 3, Table 2). On the contrary, in June, the areas of no thermal stress status...
distributed in the south part of Indonesian waters (Figure 3), with percentage of cover areas of June 2016 (18.8%), also less than June 2010 (29.1%) about 10.3%. This fact proves that the coral bleaching events of 2016 was stronger compared to the ones in 2010. This is also supported by the fact that averages of SST in the bleaching event of May-June 2016 was higher than May-June 2010 at about 0.3-0.4 °C as shown in Figure 2. Therefore, the strong upwelling as in June 2010, wherein its impact reached the Seram and Sulawesi Seas, can be weakened by coral bleaching events of 2016. The watch status (HS: 0-1 °C) areas of April to May 2016 also had the same pattern as those of April to May 2010, but for June 2016 the watch status areas was higher than in June 2010 at about > 10.4%.

**Figure 3.** Monthly distribution maps of HS (March-June) in the bleaching events of 2010 (left) and 2016 (right) derived using 11 µm TIR band of Aqua-MODIS satellite data.
The warning status (HS > 1 °C, DHW ≤4 °C-week) areas of March and April 2016 also had a similar pattern to that of 2010, but this status spread wider and started in the Malacca Strait, the west coast of Sumatra Island from Aceh down to the Padang, and farther to the open waters of Indian Ocean at approximately 7-10 degrees westward of the Sumatra Island’s coast line. The warning status was also found with scatter spots on the north coast of East Jawa, Bali and Lombok Islands, and in the Pangkep and Wakatobi Islands. The warning status of March and April 2016 covers an area of 23.9% and 22.8%, respectively, nearly twice than in March-April 2010 (Table 2). In May and June 2016, this status still exists on the west coast of Sumatra Island, while the new warning status started to develop on the Karimata Strait, which was influenced by the South China Sea water mass, and on the south and east coast of the Kalimantan Island with covered areas of 20.4% and 23.8% respectively that was nearly the same in March and April 2016.

The Alert-1 status appears in the Tomini Bay and along the south coast of Timor in April 2016, which covered a small area of 1.7%. This status was also found in Aceh in May, and in Malacca Strait and Bangka Island in June with a coverage of 1.3% and 0.8%, respectively. Based on this status, it is clear that the magnitude of coral bleaching at the Alert-1 status of 2016 from March to May was stronger (1.7, 0.5, and 1.3%) compared to the Alert-1 status of 2010 (0.1, 0.2 and 0.3 %), the coral bleaching with Alert-2 status in 2016 was almost none (~ 0%) which is the same as in 2010.

In general the coral bleaching events of 2010 and 2016 had the same pattern that started, developed and finished in the same periods of March to June (Figure 2), except the bleaching strength was different. The bleaching event strength of 2016 that was stronger than the one in 2010 was also proven by the Oceanic Niño Index (ONI). The ONI during the bleaching events of 2016 was categorized as very strong (ONI ≥ 2 °C), while in 2010 was categorized as moderate (ONI 1.0-1.5 °C) (Figure 4) [49]. However, there are little local variations of coral bleaching from one place to another. These variations may be due to the role of Indonesian through flow (ITF) that provides a sea link between the tropical Pacific Ocean (TPO) and Indian Ocean (IO) which is composed of the intricate patterns of passages and seas of varied dimensions [50]. The ITF carries warm tropical waters from the Pacific to the Indian Oceans which regulates the coupled ocean and atmosphere climate system with linked to ENSO (El- Niño and La Niña) Phenomenon and Asian monsoon, and affects regional circulation of the ocean, SST pattern and marine ecosystems [51,52].

3.3. Severity of corals during bleaching events of the 2010 and 2016 and its impacts
The total accumulated maps of DHW from March-June of 2010 and 2016 (Figure 5) indicate the severity of coral bleaching events of those years. These maps accurately show bleaching occurrence sites in almost all Indonesian waters that cover at least 15 provinces (Aceh/site #1, North Sumatra/ site #2, West Sumatra/site #3, Central Java/site #4, East Java/site#5, Bali/site #6, NTB/site #7, NTT/site #8).
#8, South Sulawesi/site #9, Southeast Sulawesi/site #10, Maluku/site #11, Central Sulawesi/site #16, East Kalimantan/site #19, West Kalimantan/site #20, Riau Islands/site #17) including 2 neighboring countries; Malaysia/site #M1-3 and Singapore/site #S1. There are many waters such as East Java, South Kalimantan, Bangka Belitung, Tomini Bay and others that show severe coral bleaching events but there are no observation/records from those areas.

The warning and Alert-I status in Figure 5 had higher coverage areas in the 2010 (17.2%) compare to 2016 (15.4%). On the contrary, the Alert-II status, in which corals were exposed to thermal stresses which may result in wide bleaching and potentially kill corals of 2016 events, had wider coverage areas (24.0%) than 2010 (14.1%) (Table2). The corals severity distribution in Figure 5 shows also the differences magnitude of bleaching events between 2016 and 2010, which agrees well with the bleaching severity information collected from various sources as listed in Table 3 and Figure 6.

On the other hand, the sites where coral bleaching did not occur in the 2010 and 2016 (Figure 5) appeared in the north Kalimantan Islands (Sabah, Malaysian waters), in some sites of Sulawesi Sea (Bunaken, Morotai, Sangihe, and Talaud Islands; site #15), Halmahera Seas (Morotai, Sangihe-Talaud Islands; site #14), Cendrawasih Bay (Supiori, Biak, Numfor, Padaido Islands; site #13). In 2016, Gorontalo (site #18), Raja Ampat (site #12), Ambon (site #11), and Aru Islands (site #11) were free from bleaching events. MFMA reported bleaching events in site #8 (Solor and Lembata (NTT), site #11 (Aru Islands), site #15 (Bunaken Island), and site #18 (Gorontalo), but those were not detected in the Figure 5. In addition, field observation in site #11 indicated that no coral bleaching occurred [53].

In the shallow water of Bunaken Island, [6] reported in their paper that almost all reef flats showed evidence of mortality of Porites, Heliopora and Goniastrea corals, representing 30% of Bunaken reefs. Mortality was related to sea level variations, with increased aerial exposure time during a few months. In September 2015 the sea level was at its lowest in the past 12 years as observed using remotely sensed satellite altimeter data [6]. However, our results show that corals in Bunaken (site #15) were free from severe bleaching events both in 2010 and 2016, since they do not appear on the maps of Figure 5 with status of no thermal stress on corals (HS < 0°C). Meanwhile, in the eastern of Arafura Sea, coral bleaching did not occur in the 2010 due to strong upwelling phenomenon [31] as well as in the 2016, although upwelling was weakened by strong or severe bleaching in the south of Timor Island (Figure 5) that reached to north Australia as reported in [20].

The variation sites of bleaching events/non-bleaching events were due to the strength/weakness of ITF that was influenced by El Niño/La Niña phenomenon and, in some cases, reinforced by local air-sea interactions [51, 54]. For example, the TPO warm water masses that enter the South China Sea (SCS) through Luzon Strait throughflow (LS-TF) are large during El Niño, while small during La Niña. Those water masses flow southward to Karmata Strait then enter to the Jawa Sea and move eastward to reach the Makassar Strait [51]. The pattern of water masses movement in the SCS as stated by [51] is in line with both of the DHW maps of Mar-Jun 2010 (weaker condition) and Mar-Jun 2016 (stronger condition) as clearly seen in Figure 5.

The massive coral bleaching events in the Indonesian waters show a tendency that the period of bleaching is becoming shorter, i.e. four severe bleaching events reported firstly in the 1983/83 took 14-15, 12, and only 6 years to next the bleaching event in 1997/98, 2010 and 2016, respectively. Coral bleaching also tends to spread more widely and with stronger magnitudes, resulting in dramatic changes to the reefs that lead to corals extinction [8]. Modeling result on coral bleaching indicates that if corals cannot withstand the sea temperature rises of 0.2-1.0°C/decade then within 30-50 years ahead the bleaching event will occur every two years or even annually [10] while [5] stated that the bleaching phenomenon every two years have been in sight since the 1980s. The decreasing of coral reefs due to coral bleaching would have direct consequences especially to local communities which depends on part or on the whole on coral reefs’ goods and environmental services (coastal protection, food security and tourism) for supporting their livelihood [6, 59, 60].
Figure 5. DHW maps showing Coral bleaching severity sites of the 2010 (top) and 2016 (bottom) collected from our field observations and many sources as listed in Table 3. Circles, respectively indicate the occurrence of coral bleaching in the Indonesian waters (white), Malaysian (pink), Singaporean (cyan), and the sites that coral bleaching did not occur (blue). See Figure 3 for legend.

4. Conclusions
The El-Niño induced coral bleaching in the Indonesian waters in the 2010 and 2016 have been studied using long-term (2002-2017) monthly night SST data acquired from Aqua-MODIS satellite. The MMM SST or SST in the normal condition for corals to adapt in the Indonesia waters is 29.1°C. The differences of high SST induced by El-Niño of 2010 and 2016 and the normal MMM SST were mapped. Based on these maps, the coral bleaching events can be recognized from start to end in the same month period of March and June (4 months period).

Outside of those periods, there are no bleaching events detected. However, bleaching events of the 2016 had higher magnitude compared with the 2010 and reached its peak in May to June. The distribution of coral bleaching severity at Alert-1 and Alert-2 covered total areas of study sites of 31.3% and 39.4% in the bleaching events of the 2010 and 2016, respectively. The severity map of coral bleaching generated in this study can pinpoint the locations of bleaching events both from our field observations and also from information obtained from many sources.
| Site           | Province                  | Times& Locations                        | Bleaching severity and corals impacted                  | Sources     |
|---------------|---------------------------|-----------------------------------------|--------------------------------------------------------|-------------|
| 1. Aceh       | Sabang & west, Aceh Jun.2010 | 2010: Mar-May Sibolga, Apr.-Jun. Nias   | Mild, DHW 4-8°C-Week, Acr and non-Acr, but Acr more dominated in Nias | 31          |
| 2. North Sumatra |                              | 2010: Mar-May Sibolga, Apr.-Jun. Nias   | Mild to serve, DHW 4-8°C-Week, Acropora and resistant genera, Psammacora | Indiv., Gov., Field Obv., 38 |
| 3. West Sumatra |                              | 2010: Jun.; Padang                      | Mild to serve, DHW 4-8°C-Week, Acropora and resistant genera, Psammacora | Indiv., Gov., Field Obv., 38 |
| 4. Central Java |                              | 2010: Karimun Jawa Islands              | DHW 4-8 °C-week, n/a bleeding information              | Gov., NGO   |
| 5. East Java  |                              | 2010: Sibutondo                          | DHW >8 °C-week, n/a bleeding information              | Indiv., NGO, 39 |
| 6. Bali       |                              | 2010: May, Pemuteran                    | Mild to severe, DHW 4-8 °C-Week; 40-60% bleached; Acropora and Porites | Indiv.      |
| 7. NTB,       |                              | 2010: Apr-Jun; All Giliis. Lombok       | Mild to serve, DHW 4-8 °C-week 10-50% bleached; Acropora (table and branching), Pocillopora, Favia, Seriatopora hystrix | Indiv., NGO, 39 |
| 8. NTT        |                              | 2010: Apr, Tabulolong, Kupang           | Mild to severe, DHW 4-8 °C-week; 90% bleached for natural and 50% for transplanted corals; Montipora and Acropora | Indiv.      |
| 9. South Sulawesi |                             | 2010: Apr-Jun; Pulau Badi              | Mild to serve, DHW 4-8 °C-week; 60% bleached, Acropora, non-Acropora, soft corals, sea anemone | Indiv., 31, 35; Gov. |
| 10. Southeast Sulawesi |                    | 2010: May-Jun Buton Island             | DHW 4-8 °C-week, n/a bleeding information              | Indiv., 31, 36 |
| 11. Maluku     |                              | 2010: May-Jun, Ambon Island            | Mild, DHW 4-8 °C-week; Bleached taxa Acropora (branching) Seriatopora, Montipora and soft corals | Indiv. 53   |
| 12. West Papua |                              | 2010: Apr-Jun., Kofiau, Misol, Raja-4   | Mild, but not detected in Figure 4, n/a information    | NGO         |
| 13. Papua      |                              | 2010/16 : Apr-Jun.; Biak Numfor         | No Bleaching Reported, not detected in Figure 4.       | ---         |
| 14. North Maluku |                              | 2010/16 : Apr-Jun.; Morotai Island      | No Bleaching Reported, not detected in Figure 4.       | ---         |
| 15. North Sulawesi |                             | 2010/16 : Apr-Jun.; Bunaken, Bitung    | No Bleaching Reported, not detected in Figure 4.       | ---         |
| 16. Central Sulawesi |                         | 2010: May; Perigi, Tomini Bay           | Severe, DHW >8 °C-week; 80-100% bleached, Pocillopora | NGO         |
| 17. Riau Islands |                              | 2010: May-Jun; Bintan, Natuna Islands   | Mild to Severe; DHW 4-8 °C-week; Bleached taxa Acropora, soft corals, some coral in Natuna died | 31          |
| 18. Gorontalo  |                              | 2010/16 : Apr-Jun.; Nothern part       | No Bleaching Reported, not detected in Figure 4.       | ---         |
| 19. East Kalimantan |                              | 2010: Mar-Jun. Derawan Islands          | DHW 4-8 °C-week, n/a bleeding information              | Gov.        |
| 20. West Kalimantan |                             | 2010: Mar-Jun. Maratua Islands          | DHW 4-8 °C-week, n/a bleeding information              | Gov.        |
| M Malaysia    |                              | 2010: Apr-Jun.; Perhentian, Tioman, Redang Islands | Severe, DHW >8 °C-week; 50% bleached to 20 m depth, Taxa unknown | 55, 56      |
| S Singapore   |                              | 2010: Apr.; Satumu Islands              | Severe, DHW 12 °-week, SST 32 °C; 50% bleached        | 57          |
Generating such kind of map by using sensor (MODIS, AVHRR) with higher resolution (1 km by 1 km) will improve the analyses. Thus, this method can be used efficiently in COREMAP-LIPI program to monitor coral bleaching events, to analyze the impacts caused on coral reef ecosystem, and to make proper diagnostic for conducting mitigation after climate-induced disturbances. Since there is a tendency that the period of coral bleaching to become shorter in the near future, it is necessary to observe the recovery rate of coral reefs as well as its associated components affected by coral bleaching.

Figure 6. Coral bleaching events in several Indonesian waters in the 2010 (left:1-5) and 2016 (right:6-9). 1. Severe bleaching in Aceh [58]; 2. Mild Bleaching in Sibolga (Photos: Abu Salatalohy); 3. Corals died due to severe bleaching in Natuna Island [31]; 4. Severe bleaching in Pangkep Islands [31]; 5. Severe bleaching in Wakatobi Islands (Photos: Nurul Dhewani); 6. Severe bleeding in Mentawai Islands (Photos M. Abrar); 7. Mild bleeding in Tapanuli Tengah (Photos: M. Abrar), 8. Severe bleeding in Merak Island, west Sumatra waters (Photos; Indrawadi Mantari; [38]); 9. Serve Bleaching in Sekotong, Lombok (Photos:Ofri Johan, [59]).

Acknowledgments
Analyses and visualizations used in this study were produced with the Giovanni online data system, developed and maintained by the NASA GES DISC. We would like to thank to Abu Salatalohy and
Nurul Dhewani in providing us coral bleaching photos. We thank the reviewers for useful reviews, comments or clarifications and suggestions that have helped clarify the text.

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