Effects of Extreme Climate Change in 2016 and Its Correlation with EWH Variability in Indonesia

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Abstract. Gravity Recovery and Climate Experiment (GRACE) satellite mission, which is dedicated specifically to the Earth’s gravity change monitoring, also can be used to observe water mass variations. GRACE data is provided through measurements of temporal mass variations, primarily water volume variations such as surface water and groundwater changes. GRACE satellite data can be obtained in monthly spherical harmonics coefficients depicting the change of surface mass density. This study investigates the effects of extreme climate change during 2016 in Indonesia by utilizing the GRACE data. Here, the surface mass density change is converted into equivalent water height (EWH). Since the amount of rainfall in Indonesia indirectly dominates the water mass variability, the EWH is then compared with the precipitation over the same period of this study. The result showed that during 2016, the highest and lowest EWH was presented in August with the highest value of 23.527 cm over the Aceh region and the lowest EWH of 0.665 cm over the Nusa Tenggara region. The most increased precipitation during 2016 is in the Kalimantan region, with a value of 0.610 mm/hr in February. The lowest one is in the Nusa Tenggara region, with a value of 0.009 mm/hr in August. For comparison with the EWH, the precipitation rates were converted into monthly precipitation in cm. The correlations between EWH and precipitations variabilities showed different results in different study zones, with the highest correlation in zone 6, which covers North Kalimantan. In comparison, the lowest correlation occurred in zone 25, which covers Yamdena and Tragan islands’ area in the Moluccas.

Keywords: GRACE, Equivalent Water Height (EWH), Precipitation

1. Introduction
Gravity Recovery and Climate Experiment (GRACE) satellite mission, which is dedicated specifically to the Earth’s gravity change monitoring, also can be used to observe water mass variations [1][2]. GRACE data is provided through measurements of temporal mass variations, which are primarily variations in water volume such as surface water and groundwater changes [1]. Water mass variations obtained from GRACE satellite data can be presented in Equivalent Water Height / Thickness (EWH / EWT) [2]. EWH is a monthly solution difference (e.g., a potential interference, geoid undulation) caused by mass redistribution in gravity measurements. There are measurement effects (such as air pressure and tides) that can be modeled and eliminated from the measurement data. After removing the measurement effect, the remaining value is caused by water redistribution [3].
Climates are the average weather condition of a large area for at least 30 years, so the climates are more stable. Climates are influenced by the geographical location and topography of the Earth [4]. Climate change is the changes in climate elements that tend to rise or fall significantly [5]. Climate change in Indonesia is indicated by changes in the season’s main parameters, including changes in rainfall patterns [4]. Climate variations are closely related to water masses’ distribution on the Earth’s surface [6]. Because the mass of water in Indonesia’s territory is dominated by the amount of rainfall, indirectly, the variation in the value of EWH in Indonesia also shows variations in rainfall or seasons. The year 2016 was the hottest [7] [9], which is the temperature anomaly is 0.94 °C [9]. The temperature anomaly during 2016 in Indonesia can be seen in Figure 1.

The very strong El Ninò causes the extreme temperature anomaly condition at the beginning of the Pacific Ocean [9]. The variability and climate change in Indonesia in 2016 also be seen from increased annual rainfall in 2016 compared to 2015, with the highest rainfall rate of 428 mm/day in Subulussalam, Aceh [7]. Sutopo Purwo Nugroho, as Head of the Center for Data, Information and Public Relations of BNPB, said that the number of disasters in 2016 in Indonesia was 2,342 disasters which were the most disasters since 2002. The number of catastrophes in 2016 increased by 35% from the previous year (2015). 92% of disasters that occurred in Indonesia in 2016 were hydrometeorological disasters which were dominated by floods, landslides, and tornadoes [11].

Sixteen provinces are affected by extreme climate change [12]. These provinces were experiencing drought. These are Banten, West Java, Central Java, DIY, East Java, Bengkulu, Papua, NTB, NTT, South Sumatra, South Sulawesi, Lampung, Riau, South Kalimantan, Central Kalimantan and Bali. Most drought occurs in Central Java, Lampung, West Java, East Java, South Sumatra, and NTB. The following pictures are some of the phenomena of hydrometeorological disasters in 2016 in Indonesia.
2. Data and Methodology

Figure 3. shows Indonesia, which is the location of this study. Geographically, Indonesia lies between the longitude 95° East and 141° East, and between latitude 11° South and 6° North. The latitude also shows that Indonesia is located in the equatorial region.

Located on the equatorial line means that the length of day and night in Indonesia is almost the same. Furthermore, the intensity of sunlight received during the day and night is very contrasting, and it will cause the nature of the weather during the day and the night to be different. This process constantly happens so that Indonesia has apparent weather variations. Therefore, if there is a change in the average weather variations, it can be observed [11].

As seen from Figure 3, Indonesia is an archipelago that extends from west to east. For the analysis purpose, this study area was then divided into zones with a coverage area of 5° × 5°. The area that will be considered in this study is Indonesia’s territory only (Figure 4).

Figure 2 Droughts [13] and floods [14] in 2016

Figure 3 Study area which covers Indonesia
Figure 4 Zone partition for the Indonesia region. Each zone covers an area of 5° × 5°.

2.1. Data

GRACE level 2 satellite data in the form of spherical harmonics coefficient were used to develop mass variabilities. Unfortunately, in 2016, only nine GRACE gravity field monthly solutions were available: January, February, March, May, June, July, August, November, and December. The data was freely available and downloaded from ftp://podaac.jpl.nasa.gov/allData/grace/L2/CSR/RL06/. Processing GRACE level 2 satellite data requires some supporting data [12], namely the C20 spherical harmonic coefficient data. The data is needed because the C20 coefficient (degree 2 order 0) from the GRACE satellite has an uncertain value, estimated from Satellite Laser Ranging (SLR). This data can be downloaded from ftp://ftp.csr.utexas.edu/pub/slr/degree_2/.

The degree 1 spherical harmonic coefficient data to estimate degree 1, which is at the center of the Earth's mass, was downloaded from ftp://podaac.jpl.nasa.gov/allData/tellus/L2/degree_1/.

The last data needed for developing EWH is Glacial Isostatic Adjustment (GIA) correction data which can be downloaded from ftp://podaac.jpl.nasa.gov/allData/tellus/L3/pgr/GIA_n100_mass_0km.txt.

For comparison, this study used precipitation/rainfall data which also depicting water mass variability. Precipitation data of TRMM 3B43 from the TRMM satellite mission was chosen. The TRMM 3B43 data was downloaded at http://mirador.gsfc.nasa.gov.

2.2. Methodology

The GRACE L2 data in spherical harmonic coefficients were converted to surface mass density using the following formula [2].

$$
\Delta \bar{\sigma}(\phi, \lambda) = \frac{2\pi a \rho_{\text{ave}}}{3} \sum_{l} \frac{2l + 1}{1 + kl} W_l \sum_{m=0}^{l} \bar{P}_{lm}(\sin \phi) (\Delta C_{lm} \cos (m\lambda) + \Delta S_{lm} \sin(m\lambda))
$$

The change in the Earth’s gravitational potentials measured by the GRACE satellite is provided by $\Delta C_{lm}$ and $\Delta S_{lm}$. $\phi$ and $\lambda$ are latitude and longitude of geodetic coordinates, respectively; $a$ is the spherical radius of the Earth, $\bar{P}_{lm}$ is a Legendre function, $k_l$ is a love number, $W_l$ is the weight of the frequency error at a high degree; $l$ and $m$ are the degree and order of the spherical harmonics, $C_{lm}$ is the cosine coefficient, and $S_{lm}$ is the sine harmonic coefficient [15]. The value of surface mass expressed as EWH is obtained using $\Delta \bar{\sigma}/\rho_w$, where $\rho_w$ is water density [2].

Precipitation obtained from TRMM satellite data is provided as the value of monthly averaged precipitation in mm/hr. The total rainfall in one month (PCP) is computed by multiplying the value by 24 hr and the number of days in a particular month. Then, to see the relationship between water mass
changes from GRACE and the precipitation/rainfall from TRMM data, we calculate the correlation between the time series of the EWH and PCP during 2016.

3. Result and Discussion

3.1. EWH From GRACE Level 2

Equivalent Water Height (EWH) extraction from spherical harmonic data is done using GRACE_Matlab_Toolbox. The results show the monthly EWH values in January, February, March, May, June, July, August, November, and December (Figure 5). The negative values of EWH can be interpreted as a lack of water so that it can be indicated as decreasing mass. The opposite idea is also applied to the areas with positive EWH values. From Figure 5, it can be seen that from January to July, the value of EWH in Indonesia is generally less than 5 cm. That means almost all areas in Indonesia were indicated to have decreasing water mass during that period.

In January, the only area with a positive EWH value was Sumatra, while the other regions had small EWH values. In January, the smallest EWH value occurs over Sulawesi, extending southward towards Nusa Tenggara and Bali's islands. In February, almost all of Indonesia's regions were indicated to experience drought, except for the eastern part of Indonesia (Papua island) and some parts of Sumatra (western part of the island of Sumatra, covering Banda Aceh and small islands, including Weh Island, Sabang). In March, a reasonably significant drought began to occur from Malaysia's direction to Sumatra's central part. However, the opposite happened on the island of Kalimantan, followed by the Makassar Strait and the Java Sea. In March, this region experienced an increased value of EWH, as well as in May. The decline in EWH value is more prominent in the Sumatran region, while there is an increased EWH value in Kalimantan, followed by the Makassar Strait and the Java Sea. However, in June, the value of EWH in Kalimantan and its surroundings has decreased drastically. The value of this EWH has decreased a lot in July, extending from Sumatra and Kalimantan's direction. Also, there has been a decline in the value of EWH in the southern part of Irian Jaya. In August, the value of EWH increased in Sumatra, Kalimantan, and Java but decreased in the Southeastern Nusa region. In November, the value of EWH increased across Indonesia but again decreased (but not significantly).
Figure 5 EWH variability in Indonesia during 2016
Figure 6 Spatial dan temporal variability of precipitation (averaged precipitation in mm/hr) in Indonesia during 2016.
3.2. Precipitation

The precipitation value is extracted from TRMM 3B43 data that has been downloaded. Figure 6 shows the variation in rainfall in Indonesia based on the TRMM data. The figure shows that from January to May, it is indicated that Indonesia experienced dryness (little rain) except for Kalimantan, Java, and the eastern part of the island of Sumatra. In June, there was an increase in precipitation throughout Indonesia, but again there was a decrease in the following month. In July, low rainfall values began to occur in East Nusa Tenggara, extending to Sulawesi, Java, and Kalimantan regions. However, the opposite happened in the north of Irian Jaya and the west of Sumatra. In August, there was a very significant decline in all of Indonesia, except for Sumatra's western part. From October to November, this low rainfall is increasingly shifting towards the east and is followed by an increase in rainfall. In September, increased rainfall occurred on the island of Sumatra and parts of the island of Kalimantan. In the following months, almost all Indonesia regions experienced an increase in rainfall, except for Sulawesi, Bali, and Southeastern Nusa (NTT and NTB). In November, the increase in rainfall occurred only in Sumatra. However, this increase occurred throughout Indonesia in the following month (December).

3.3. Time Series and Trend

The trend and time series of EWH and PCP values are plotted based on the division of Indonesia’s territory (area of 5°x 5°). Table 1 contains the linear equation of each region’s EWH and PCP trend, composed of y elements: EWH or PCP values, and x, which indicates time.

| Zone | Linear trend equation EWH | Linear trend equation PCP |
|------|---------------------------|---------------------------|
| 1    | $y = 2.012x - 20.649$     | $y = 2.874x + 1.789$      |
| 2    | $y = 0.649x + 12.797$     | $y = 2.186x + 6.210$      |
| 3    | $y = 0.571x - 6.235$      | $y = 3.225x - 2.398$      |
| 4    | $y = 0.245x - 1.797$      | $y = 2.981x + 0.249$      |
| 5    | $y = 0.335x + 1.2423$     | $y = 2.187x + 7.9012$     |
| 6    | $y = 0.0667x - 0.5967$    | $y = 1.8595x + 3.095$     |
| 7    | $y = 0.2436x - 1.0599$    | $y = 2.6158x + 0.7434$    |
| 8    | $y = -0.1938x + 2.3139$   | $y = 2.678x + 3.4717$     |
| 9    | $y = 0.0404x + 3.6751$    | $y = 0.1623x + 28.556$    |
| 10   | $y = 0.1757x - 1.9385$    | $y = 0.3317x + 19.182$    |
| 11   | $y = 0.0023x + 0.9666$    | $y = -0.7582x + 36.376$   |
| 12   | $y = 0.0001x + 4.0814$    | $y = -0.0513x + 29.986$   |
| 13   | $y = 0.1644x - 1.0231$    | $y = 1.069x + 12.701$     |
| 14   | $y = -0.1041x + 0.8405$   | $y = 1.2867x + 8.5609$    |

| Zone | Linear trend equation EWH | Linear trend equation PCP |
|------|---------------------------|---------------------------|
| 15   | $y = -0.0815x + 1.3042$   | $y = 1.4037x + 13.045$    |
| 16   | $y = -0.1233x + 2.2207$   | $y = 1.5484x + 16.218$    |
| 17   | $y = -0.2302x + 3.3611$   | $y = 1.9192x + 13.185$    |
| 18   | $y = -0.293x + 4.003$     | $y = 1.2415x + 16.407$    |
| 19   | $y = -0.0224x + 2.8533$   | $y = 0.0151x + 30.297$    |
| 20   | $y = 0.4054x + 1.3099$    | $y = -0.3369x + 27.778$   |
| 21   | $y = 0.6585x - 1.4703$    | $y = -0.3254x + 24.013$   |
| 22   | $y = 0.0977x - 0.5672$    | $y = -0.8213x + 24.09$    |
| 23   | $y = -0.2397x + 2.4627$   | $y = -0.5518x + 20.038$   |
| 24   | $y = -0.2717x + 2.8714$   | $y = -0.1831x + 18.085$   |
| 25   | $y = 0.4654x - 0.3746$    | $y = -0.5057x + 31.953$   |
| 26   | $y = 0.5116x - 0.5895$    | $y = -0.0606x + 34.142$   |
| 27   | $y = 0.4255x - 0.8401$    | $y = 0.3144x + 24.976$    |
| 28   | $y = -0.101x + 0.4285$    | $y = 0.0711x + 6.5928$    |

Table 1 shows both trends (PCP and EWH) are varied. The trend of EWH shows ten zones experiencing a downturn. All of these zones are located in eastern Indonesia, starting from the island of Sulawesi, Nusa Tenggara (Nusa Tenggara Timur and Nusa Tenggara Barat) to Papua. The EWH value in other regions are positive trends.

The trend of PCP shows that nine zones have a downturn. All of these areas are located in southern Indonesia, including the island of Sumatra, the islands of Bali and Nusa Tenggara (Nusa Tenggara Timur and Nusa Tenggara Barat). Meanwhile, other regions are experiencing an uptrend.
Changes in the EWH and PCP Value and its comparison with the precipitation value can be seen in Figures 8 and 9.

![Figure 7](image_url) The trend in the EWH and PCP from zone 1 to zone 14
Figure 8 The trend in the EWH and PCP from zone 15 to zone 28

3.4. Correlation between EWH and PCP

Table 2. shows that the correlation of the two data (EWH and PCP) is dominated by medium down. This can be interpreted that extreme climate change (in this case indicated by increasing temperature and rainfall) in 2016 did not affect EWH because changes in EWH depend on many things, such as geological disasters and global warming. However, the positive correlation between these two data shows that the greater the rainfall intensity, the more water will be absorbed into the ground to exceed the limit one day, and there will be flooding. This is due to climate change which will affect the rate at which the surface water cycle changes. There are only two parts with a strong correlation, namely amount and 17, and began with a strong correlation between EWH and PCP, namely section 16. This is because climate change takes a very long time and changes slowly. The observation area, which only
covers Indonesia’s territory, cannot represent climate change significantly because it can only be seen from the rainfall and temperature.

Table 2. Correlation between EWH and PCP for the whole year of 2016

| Zone | Correlation Values | Category |
|------|--------------------|----------|
| 1    | 0.237              | weak     |
| 2    | 0.571              | medium   |
| 3    | 0.120              | very weak |
| 4    | -0.082             | very weak |
| 5    | 0.657              | strong   |
| 6    | 0.717              | strong   |
| 7    | 0.490              | medium   |
| 8    | 0.139              | very weak |
| 9    | 0.077              | very weak |
| 10   | 0.296              | Weak     |
| 11   | 0.338              | Weak     |
| 12   | 0.373              | Weak     |
| 13   | 0.387              | Weak     |
| 14   | 0.275              | Weak     |
| 15   | 0.396              | Weak     |
| 16   | 0.146              | Very weak |
| 17   | -0.126             | Very weak |
| 18   | -0.135             | Very weak |
| 19   | 0.057              | very weak |
| 20   | -0.222             | Very weak |
| 21   | 0.117              | Very weak |
| 22   | 0.029              | Very weak |
| 23   | 0.444              | medium   |
| 24   | 0.359              | weak     |
| 25   | -0.470             | Very weak |
| 26   | -0.015             | Very weak |
| 27   | 0.336              | Weak     |
| 28   | 0.044              | Very weak |

4. Conclusion
This study showed that the highest EWH value during 2016 was 8.66 cm in August (in the Aceh region), while the lowest EWH value was in the Nusa Tenggara region month. The most significant rainfall is in the Kalimantan region with a value of 0.61 mm/hour in February 2016, while the lowest rainfall is in the Nusa Tenggara region in August. However, the correlations between EWH and PCP over Indonesia, which mostly week, showed that the variability of EWH was not significantly affected by rainfall intensity. Nevertheless, extreme phenomena of climate change still affect the distribution of surface water masses.

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