Correlation Between GGMPlus, Topex and BGI Gravity Data in Volcanic Areas of Java Island

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Abstract. There are several secondary gravity data on the internet that can be freely accessed and downloaded for research purposes. These gravity data include Topex Gravity data, which provides free-air gravity data, BGI (Observation Gravity data, Free-Air, Complete Anomaly Bouguer), and GGMPlus Gravity Data. GGMPlus gravity data is gravity data with the smallest grid spacing compared to Topex and BGI data, with a grid spacing of approximately 200 meters. This data consists of 5 data sets, including Gravity Disturbance and Gravity Acceleration data. This study correlates between Topex and BGI free-air data with GGMPlus data (Gravity Disturbance and Gravity Acceleration), and BGI Observation Gravity data with GGMPlus (Gravity Disturbance and Gravity Acceleration) data using Pearson correlation technique. Correlated data are gravity data in volcanic regions in Central and East Java. As a result, Gravity Disturbance data on GGMPlus is equivalent to Free-Air Gravity Data on Topex and BGI, while Gravity Accelerations Data is equivalent to BGI Observation Gravity data, with a correlation level above 95%.

1. Introduction
Utilizing the earth's gravity data is essential in a geophysical and geological study from regional to a global scale. At a regional scale, gravity information can be used efficiently in a variety of geological challenges related to upper crust exploration, such as in the field of natural disaster mitigation (i.e., detecting and modeling active faults), studying the characteristics of natural resources (i.e., modeling geothermal and volcanic systems), and various other subsurface reconstruction [1] and modelings [2].

Understanding of the Earth's gravitational field is fundamental not only for the geophysics field but also crucial for various uses in the geology and geodesy field from regional to global scales [3]. On a global scale, gravity information is used in determining the shape of the earth, calculating artificial satellite orbits, monitoring changes in earth's mass, including use in the field of geophysics in terms of mapping the shape of the lithosphere, and tracking the geodynamic structure of the earth system [4].

This gravity data can be obtained through direct measurements using a gravity-meter or through several gravity data providers. Some gravity data that can be collected free of charge include free-air gravity data provided by Topex, gravity data provided by Bureau Gravimetric International (BGI) including measurement data on the land surface, sea, and theoretical gravity data models) [5], and GGMPlus gravity data.

GGMPlus is a gravity field model based on GRACE (ITG2010) satellite data, GOCE satellite (TIM-4), EGM2008, and gravity topography. The new picture of Earth's gravity from GGMplus
includes data on acceleration of gravity, components of radial and horizontal fields, and quasigeoid heights with several points more than 3 billion points covering 80% of the Earth's landmass in ± 60°. GGMPlus provides five gravitational field functions, namely acceleration of gravity, gravity disturbance, vertical north-south, and east-west vertical deflection and quasigeoid height [6]. The method used in the development of GGMplus is combining GRACE and GOCE satellites with EGM2008. Then, the spherical harmonic synthesis of the gravitational field is carried out, forward modeling and calculating normal gravity on the surface. All three processes are combined to obtain a high-resolution gravity model [7].

Compared to Topex and BGI data, GGMPlus data has advantages in terms of data density. GGMPlus data has a data resolution of approximately 200m [9]. This study aims to study the types of data from GGMPlus disturbance and GGMPlus acceleration by comparing and correlating them with other comparative gravity data, i.e., Topex and BGI gravity data. By knowing this type of data, it can be applied as preliminary data on subsurface exploration using the gravity method and as an alternative to field data for academic research purposes in the Covid-19 pandemic era.

2. Methods
This study covered the gravity data set of Topex, BGI, and GGMPlus at the volcanic area in Central and East Java, Indonesia, using correlation analysis.

2.1 Study area
The study area covering 8 volcanic areas as shown in figure 1,

![Figure 1. Study areas includes: (a) Merapi-Merbabu, (b) Lawu, (c) Wilis, (d) Arjuno-Welirang-Kawi, (e) Bromo-Tengger-Semeru, (f) Iyang-Argopuro, (g) Ijen-Raung, and (h) Bromo-Tengger-Semeru-Iyang Argopuro volcano areas.](image)

In this study, gravity data obtained from https://topex.ucsd.edu/cgi-bin/get_data.cgi for Topex data, https://bgi.obs-mip.fr/ for BGI data, and Http://ddfe.curtin.edu.au/gravitymodels/GGMplus for GGMPlus data. The data coordinates of this study are in the volcanic zone, which extends from 110.20 to 113.80 (Longitude) and -8.30 to 7.50 (Latitude), detailed shown in table 1.
Table 1. Coordinates range of each volcanic area

| Area                              | Coordinate       | Latitude | Longitude |
|-----------------------------------|------------------|----------|-----------|
|                                   |                  | Min  | Max  | Min  | Max   |
| Merapi-Merbabu Volcanoes (a)      |                  | -7.70 | 7.70 | 110.20 | 110.60 |
| Mount Lawu (b)                    |                  | -7.80 | -7.50 | 111.00 | 111.35 |
| Mount Wilis (c)                   |                  | -8.00 | -7.65 | 111.55 | 111.93 |
| Arjuno-Welirang-Kawi Volcanoes (d)|                  | -8.10 | -7.63 | 112.30 | 112.65 |
| Bromo-Tengger-Semeru Volcanoes (e)|                  | -8.20 | -7.80 | 112.80 | 113.10 |
| Mount Iyang-Argopuro (f)         |                  | -8.20 | -7.83 | 113.40 | 113.75 |
| Ijen-Raung Volcanoes (g)         |                  | -8.20 | -7.90 | 113.95 | 114.30 |
| BGI Land Gravity and GGMPlus datas (h) |              | -8.30 | -7.60 | 112.73 | 113.80 |

So that the gravity data points to be compared have the same position, the GGMPlus Disturbance and GGMPlus Acceleration data are extracted using Matlab software (test_access_ggmplus.m) based on the position reference from Topex and BGI gravity data, so that the GGMPlus Disturbance and GGMPlus Acceleration data sets have the same coordinates, so it is ready to be analyzed qualitatively and quantitatively.

2.2 Correlation analysis

After each gravity data set is downloaded, then correlation analysis is performed using Pearson correlation analysis with the formula,

$$r = \frac{\sum(x-x\overline{x})(y-y\overline{y})}{\sqrt{\sum(x-x\overline{x})^2\sum(y-y\overline{y})^2}}$$  (1)

where $r$ is the correlation coefficient (dimensionless), ranging from -1 to 1 inclusive and reflects the extent of a linear relationship between two data sets, $x$ and $y$ are independent and dependent values, as the tested data set variable.

The first step in this research, is making a gravity anomaly map to carry out a qualitative analysis, and analyze the correlation of Topex free-air gravity data sets with GGMPlus disturbance and GGMPlus acceleration in the volcanic area, i.e. (a) Merapi-Merbabu, (b) Lawu, (c) Wilis, (d) Arjuno-Welirang-Kawi, (e) Bromo-Tengger-Semeru, (f) Iyang Argopuro, and (g) Ijen-Raung volcanoes (figure 1). The next step is to analyze ground gravity measurement data (BGI) with GGMPlus disturbance and GGMPlus acceleration in the Bromo-Tengger-Semeru-Lamongan-Argopuro Volcano area (h area in figure 1). Each correlation analysis above uses the Pearson correlation (equation 1) in Microsoft Excel.

3. Results and discussions

From the qualitative analysis of Topex gravity anomaly maps of GGMPlus Disturbance, GGMPlus Acceleration, and Topex free-air gravity anomaly maps, Topex free-air gravity maps have similarities with GGMPlus Disturbance anomaly maps, as shown in Figure 2 (a) and 2 (b). Figure 2 is a Topex free-air anomaly map, the GGMPlus Disturbance anomaly map (b), and the GGMPlus Acceleration anomaly map in the volcanic regions Mount Merapi and Merbabu.

With the same position and amount of data (625 data), GGMPlus Disturbance gravity anomaly data (Figure 2 (b)) has a better resolution compared to Topex free-air anomaly data (Figure 2 (a)). Merapi and Merbabu volcanoes, which are two different volcanoes, in Topex free-air anomaly data, appear as a single anomaly and are indistinguishable. In contrast, in GGMPlus Disturbance, Mount Merapi and Merbabu appear as two different and indistinguishable gravity anomalies, as well as those seen in gravity data GGMPlus Acceleration (Figure 2 (c)). Topex free-air gravity anomaly data and GGMPlus Disturbance have a very high correlation value close to one, which is 0.95. GGMPlus Disturbance data is equivalent to Topex free-air data with a similarity of 95%.
Figure 2. Map of gravity data of the Merapi-Merbabu volcanoes area: (a) Topex free-air data, (b) GGMPlus Disturbance, and (c) GGMPlus Acceleration, with 625 gravity stations.

For the gravity anomaly data in other volcanic regions, i.e., Lawu, Wilis, Arjuno-Welirang-Kawi, Bromo-Tengger-Semeru, Iyang-Argopuro, and Ijen Raung volcanoes, GGMPlus Disturbance gravity values have very high correlation coefficients, as well as with the previous (Merapi-Merbabu volcanoes). The correlation coefficient values obtained were close to one or above 0.96 or had a similarity above 96%. The complete results of the calculations obtained can be seen in table 2.

In the next step, GGMPlus Disturbance and GGMPlus Acceleration data were also compared and correlated with land gravity measurement data accessed from BGI data. At this stage, GGMPlus Disturbance and GGMPlus Acceleration are compared and correlated with Gravity Observation data and BGI Free-Air gravity data, with the same data points and positions as the BGI data. The results of this comparison are displayed on the gravitation anomaly map, as shown in Figure 3.
Table 2. Number of gravity data stations, maximum-minimum values, and the calculation of the correlation coefficient between Topex free-air gravity data with GGMPlus Disturbance and GGMPlus Acceleration at several different volcanic locations.

| Area                        | Number of Stations | Free Air Topex | GGMPlus Disturbance | GGMPlus Accelerations | Correlations of Free Air Topex with |
|-----------------------------|--------------------|----------------|----------------------|-----------------------|-----------------------------------|
| (a) Merapi-Merbabu Volcanoes| 625                | 16.20          | 212.20               | 26.20                 | 264.81                            |
| (b) Lawu Volcano            | 418                | -20.30         | 269.50               | -30.30                | 291.46                            |
| (c) Wilis Volcano           | 506                | -13.30         | 268.40               | -7.81                 | 280.59                            |
| (d) Arjuno-Weirang-Kawi Volcanoes | 638           | 4.60           | 290.60               | 13.32                 | 305.53                            |
| (e) Bromo-Tengger-Semeru Volcanoes | 475       | -6.80          | 380.30               | 8.20                  | 372.67                            |
| (f) Iyang-Argbapro Volcano  | 374                | 15.40          | 360.30               | 14.22                 | 328.52                            |
| (g) Ijen-Raung Volcanoes    | 418                | 63.90          | 396.60               | 71.90                 | 388.86                            |

Figure 3. Map of gravity data of the Bromo-Tengger-Semeru-Lamongan-Argopuro volcanoes area: (a) Observation Gravity of BGI data, (b) Free Air gravity of BGI data, (c) GGMPlus Acceleration, and (d) GGMPlus Disturbance.
BGI data that used in this research is observation gravity data and Free Air G data from ground gravity measurements (36 data), with the coordinates of the area with latitude from -8.3000 to -7.6000 and longitude 112.730 to 113.8000 which covers the areas of Bromo, Semeru, Lamongan, and Argopuro volcanoes. From Figure 3, the gravity anomaly map observation (g Obs) BGI (Figure 3 (a)) has similarities to the GGMPlus Disturbance anomaly map (Figure 3 (c)), while the BGI free-air gravity anomaly map has similarities to the GGMPlus Acceleration anomaly map. The results of quantitative analysis using the correlation method, the correlation of GGMPlus Disturbance data with BGI free-air data is 0.99, GGMPlus Disturbance with g BGI Observation data 0.16, the correlation between GGMPlus Acceleration with BGI free-air anomaly 0.19 and correlation between GGMPlus Acceleration with gravity data BGI observations is 0.97. Similar to the previous results, the correlation results with land measurement data, the GGMPlus Disturbance data is identical to the free-air gravity data, and the GGMPlus Acceleration data is equivalent to Observation gravity data.

4. Conclusion
GGMPlus Disturbance and GGMPlus Acceleration data, in general, have better resolution compared to Topex and BGI free-air gravity data. GGMPlus Disturbance has a very high correlation with Topex and BGI free-air data. GGMPlus Acceleration data has a very high correlation with Observation Gravity (gObs) of BGI terrestrial gravity data, in other words, Gravity Disturbance data on GGMPlus is equivalent to Free-Air Gravity Data on Topex and BGI. In contrast, GGMPlus Accelerations data is equal to Observation Gravity (gObs) data, with a correlation level above 95%.

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