The Grid Optimization of The Terrestrial Gravity Survey (Case Study: Central Part of Java Island)

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Abstract. BIG has conducted gravity data by using several methods, namely terrestrial gravity and airborne gravity to produce high accuracy of the geoid. The terrestrial gravity survey was carried out using the grid method, and BIG does not have any guidance on the size of the used grid interval size. We try to divide the grid interval into four different sizes of grids, those are 5 km, 10 km, 15 km, and 20 km. A case study in the central part of Java Island, at Semarang and Yogyakarta in 2019, using Scintrex CG-5 relative terrestrial gravimeter equipment. By using the integral stokes and Least Square Collocation (LSC) approaches, the gravimetric geoid is obtained from each grid interval. We compared gravimetric geoid with geometric geoid on 179 vertical benchmarks and obtained the results of the 5 km grid interval having the smallest average value of 0.273 meters ± 0.310 with the most appropriate conformity test.

Keywords: terrestrial gravity, gravimetric geoid, geometric geoid

1. Introduction

The Indonesian geoid model (Ina-Geoid 2020) that has been produced by Geospatial Information Agency (BIG) has varying accuracy in each island [1]. The accuracy of the geoid is strongly affected by the gravity data distribution [2]. BIG has conducted gravity data throughout Indonesia by using several methods, namely measuring gravity on the ground or terrestrial gravity and gravity measurements using aircraft or airborne gravity [1]. The advantage of terrestrial gravity data is it has high accuracy, and the disadvantage is it cannot cover an inaccessible area such as valleys, lakes, swamps, etc., besides that the gravity data conduction need a relatively long time [3]. Due to the geographical condition, large and archipelago, the terrestrial method is ineffective, so since 2008 BIG conducted airborne gravity surveys in every mainland such as Kalimantan, Sulawesi, Papua, Sumatera, Jawa, Bali, Nusa Tenggara, and Maluku [1].

Airborne gravity data has a higher economic value compared to terrestrial data, but in the organizing of vertical references system in this case the gravimetric geoid model, terrestrial data is needed to improve geoid accuracy better or in levels <5cm [4]. In addition to increasing the accuracy of the geoid, terrestrial data also functions as calibration and validation of airborne data [5]. In the process of collecting terrestrial data, BIG conducted a terrestrial gravity survey using the grid method and extending along national roads. Data from the grid method are used for geoid modeling, while the elongated method is used for calibration and validation of airborne data. In theory, the width of the grid interval is inversely proportional to the geoid accuracy [6, 7, 8]. In this paper, we discuss the relative terrestrial gravity survey of the grid method and the data processing method carried out by BIG and discuss how many grids are optimal for high accuracy geoid. The results of this paper are expected to assist BIG in making a relative terrestrial gravity survey guideline.

2. Data and Methodology
2.1. Data
The data were taken in 2019 using Scintrex CG-5, in the Yogyakarta and Semarang area, both of that are located in Central part of Java Island. The measurement method using a looping method that is tied to GBU (Main Gravity Pillar) namely GBU16 at Semarang around February 2019 on 111 points with daily drift average of 58.461 mgal. GBU14 and GBU32 were used in Yogyakarta for the survey that was conducted around March 2019 on 133 points with daily drift average of 159.483 mgal. The coordinate data used GNSS (Global Navigation Satellite System) RTK (Real-Time Kinematic) tied to the nearest CORS (Continuation operating Reference Station).

2.2. Terrestrial Gravity Data Processing
The gravity observation data (gobs) on the surface of the earth is affected by systematic errors due to the influence of tides and drift of the equipment [2] (equation 2.1). Tidal correction as a correction to the moon and the sun's force. Drift correction as a correction due to spring shaking in the equipment.

\[ g_{\text{obs}} = g_{\text{point}} - \text{drift} - \text{tidal} \]  

The gravity anomaly (\( \Delta g \)) (equation 2.3) is the difference in observed gravity (gobs) and normal gravity (\( \gamma_0 \)) on the surface of the reference ellipsoid [2] (equation 2.2). The \( \varphi \) in the equation below stands for the latitude of the given area that needs to be calculated.

\[ \gamma_0 = 9.780327(1 + 0.0053024 \sin^2\varphi + 0.0000056 \sin^2\varphi) \]  

\[ \Delta g = g_{\text{obs}} - \gamma_0 \]  

2.3. Geoid modeling
Geoid determination using gravity anomaly is defined by the Stokes formula (equation 2.4). R equals to the distance from the center of the earth to the approximates point on the earth’s surface, G stands for the gravity value, \( \Delta g \) is the gravity anomaly, S(\( \psi \)) is Stoke’s function and \( d\sigma \) stands for the integration unit. The Stokes formula [9] requires a well-distributed gravity data and cover the whole earth to model an accurate geoid model by dividing the geoid signals into three components, namely (1) the long-wavelength component, which contains the global information which can be derived from satellite gravimetry, (2) the medium wavelength, which consists of regional information, whose data...
are obtained from terrestrial gravity data, and (3) the short-wavelength which consists of local information which can be derived from topography model.

\[ N = \frac{R}{6\pi\epsilon_0} \Delta g \cdot S(\psi) \ d\sigma \]  
\[(2.4)\]

To create a geoid, the remove-restore theory is used. The remove-restore theory is an integration of Formula Stokes through topographic mass regulation \[9\]. This is done by reducing the RTM (Residual Terrain Model) \((\text{equation} \ 2.5)\), resulting in gravity anomaly residual \((\Delta \text{g}_{\text{res}})\) \(\Delta g_{\text{FA}}\) equals to free-air anomaly gravity, \(\Delta g_{\text{GM}}\) is the anomaly of the Global Geoid Model and \(\Delta g_{\text{h}}\) equals to terrain contribution. The effect of the topography on the surface of a long wave is removed and then restored \((\text{equation} \ 2.6)\) at the end of the counting process \[10\]. \(N\) stands for the geoid undulation, \(N_{\text{res}}\) is the geoid residual, \(N_{\text{GM}}\) is the undulation from the Global Geoid Model and \(N_{\text{h}}\) means indirect effect from the topography.

\[ \Delta g_{\text{res}} = \Delta g_{\text{FA}} - \Delta g_{\text{GM}} - \Delta g_{\text{h}} \]  
\[N = N_{\text{res}} + N_{\text{GM}} + N_{\text{h}} \]  
\[(2.5)\]  
\[(2.6)\]

To determine the geometric geoid, the geoid undulation \((N)\) \((\text{equation} \ 2.7)\) is obtained from the height difference between ellipsoid or geometric height \((h)\) and orthometric height \((H)\). The geometric geoid undulation can be calculated if both geometric and orthometric height at a certain point is known. The geometric geoid is used as quality control or validation.

\[ N = h - H \]  
\[(2.7)\]

2.4. Methodology

![Figure 2. Flowchart of data processing.](image-url)
The results of the terrestrial gravity in Semarang and Yogyakarta are divided into 4 grid groups, namely the 5 km, 10 km, 15 km, and 20 km grid groups. Gravity data in each grid is processed into a Free Air gravity anomaly using Gravsoft Package Software (Gredu, Gradj, Grano) [11], then geoid modeling is done using NCTU Package Software [12]. The long wave used for geoid modeling is EGM08 degrees 360, which has been combined with GOCE data at a low degree (http://icgem.gfz-potsdam.de) [13], the short wave used is SRTM30 (http://srtm.cgiar.org/srtmdata/). The results of the remove process are residual gravity anomaly, which is going to be converted into residual geoid undulations using the Least Square Colocation (LSC) method. The residual geoid undulations are then added with long-wave undulations and shortwave undulations to become total geoid undulations. Geometric geoid data used for geoid validation are leveling, relative gravity, and GNSS data in 2019 between Semarang and Glagah tidal stations. With as many points as 179 points.

![Figure 3. Pillars used for validating the calculated geoid gravimetric.](image)

3. **Result and Analysis**

The results of processing gravity data into gravity anomalies based on grid groups are shown in Figure 4. The gravity anomalies are in the range of -100 to 200 mgal. The range of gravity anomaly at intervals of 5 km is more varied when compared to intervals of 10 km, 15 km, and 20km, where the greater the interval grid size, the data density and the range of gravity anomaly values will also be greater.
(a) 5 km of grid interval size
(b) 10 km of grid interval size
(c) 15 km of grid interval size
(d) 20 km of grid interval size

Figure 4. Gravity anomaly is based on interval grid size.

Gravity anomaly data processing into gravity anomaly residual, remove stage, results in visualization of gravity anomaly residuals as shown in Figure 5. The range of gravity anomaly residual from -100 mgal to 50 mgal. This shows that gravity anomaly (Free-air anomaly) signals in that range cannot be detected only with global models. Also, the range of gravity anomaly residual will be greater in the southern part of the study area.
The residual gravity anomalies are then processed using Least Square Collocation (LSC) method into residual geoid undulations. Based on Figure 6, the residual geoid undulations are in the range of -1 meter to 0.5 meters. Besides, the level of detail of the geoid undulation is directly proportional to the size of the gravity data grid used. The closer the data used, the more detailed residual geoid undulation will be.
The restore stage resulting in total geoid undulation or commonly referred to as Gravimetric Geoid. The results of the visualization of gravimetric geoid based on the grid size used can be seen in Figure 7. In general, the range of Gravimetric Geoid from -20 meters to 40 meters. The highest undulation value ranges from 25 to 30 meters, mostly in the southern part of the study area. Meanwhile, the lowest undulation values range from 20 to 25 meters, and most are located in the northern part of the study area.

Figure 6. Residual geoid undulation
The purpose of geoid validation is to test the accuracy of the resulting geoid model. This was done by subtracting the total value of geoid (gravimetric geoid), as obtained from the previous step, with the geometric geoid from GNSS-Leveling measurements on the vertical benchmark. 179 vertical benchmarks used for geoid validation spread along the Semarang – Glagah route. The results of the statistical calculation of the geoid validation performed are presented in table 1.

The 5 km, 10 km, 15 km, and 20 km grid sizes produce geoids with an average for each model ranging from 0.273 m to 0.381 m. It is known that the greater the grid size interval used, the difference between

| Grid size | Data | Max (m) | Min (m) | Average (m) | S. D (m) | RMS (m) |
|-----------|------|---------|---------|-------------|----------|---------|
| 5 km      | 262  | 0.614   | -0.226  | 0.273       | 0.310    | 0.146   |
| 10 km     | 81   | 0.559   | -0.199  | 0.286       | 0.316    | 0.135   |
| 15 km     | 44   | 0.666   | -0.131  | 0.337       | 0.366    | 0.143   |
| 20 km     | 28   | 0.790   | -0.146  | 0.381       | 0.409    | 0.149   |
gravimetric undulation and geometric undulation will be even greater. The average difference in the
undulation value between the four geoids ranges from 1.3 cm to 10.8 cm. When reviewing the standard
deviation, it is known that the value ranges from 0.310 m to 0.409 m, with a difference between the
standard deviations for each regional geoid of approximately 1 cm.

Meanwhile, based on the RMS error, it is known that the value of RMS error doesn’t have much
variation for geoid model with 5 km, 15 km, and 20 km intervals, with the range, is between 0.143 m
to 0.149 m with RMS error difference around 0.3 – 0.6 cm between models. The smallest RMS error
is produced by the geoid model with a 10 km interval, which is 13.5 cm.

To determine the suitability between gravimetric undulation with the geometric undulation, the
conformity test is carried out by comparing the two undulations. Figure 8 shows the results of the
conformity test of each geoid model produced. Based on Figure 8, the greater the grid size interval
used, the resulting gravimetric undulation patterns will increasingly avoid the geometric undulations.
This is indicated by the gap size between gravimetric undulation and geometric undulation for geoid
models with gravity data intervals of 15 km and 20 km greater than the gap for geoid models with data
intervals of 5 km and 10 km.

4. Conclusions
By dividing the grid size interval into 4, namely 5 km, 10 km, 15 km, and 20 km, the closer the data
interval used, the variation of the data used is also increasing with a more varied range. The closer the
data interval is used, the precision of the data will better. The less frequent measurements of gravity
data intervals used, the conformity between the gravimetric geoid model and the geometric geoid model
that is referred to will decrease. A 5 km grid size interval is more optimal for making geoid models with higher accuracy. However, it is not effective if only uses terrestrial data, to accelerate the making of high precision geoid requires other data such as airborne gravity data. The terrestrial gravity survey is optimally applied in big cities so that the geoid model in the area can be improved.

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