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GENERATING BOUGUER ANOMALY MAP FROM AIRBORNE GRAVITY DATA (A CASE STUDY IN SOUTH EAST SULAWESI)

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ABSTRAK

Pengukuran terestrial dapat memberikan data gravitasi yang akurat, tetapi mahal dan memakan waktu untuk area yang luas dan terpencil. Pengukuran airborne gravity sebenarnya sudah dilakukan di Indonesia sejak tahun 2008 oleh Technical University of Denmark (DTU) bekerja sama dengan Badan Informasi Geospasial (BIG). Tujuan dari proyek ini adalah untuk mengembangkan model geoid. Data tersebut sebenarnya dapat digunakan untuk keperluan geofisika dan geosains lainnya. Penelitian ini bertujuan untuk meningkatkan akurasi data airborne gravity untuk menghasilkan peta anomali Bouguer lengkap yang akurat. Data yang digunakan adalah data airborne gravity di Provinsi Sulawesi Tenggara yang dikumpulkan pada tanggal 29 September 2008 sampai dengan 1 Oktober 2008. Tahap pertama pengolahan adalah menghilangkan kesalahan akibat akselerasi pesawat. Tahap kedua dari pemrosesan adalah low pass filtering. Data airborne gravity yang telah difilter kemudian diterapkan untuk menghitung anomali Bouguer lengkap. Perbandingan peta anomali airborne bouguer dan peta anomali bouguer terestrial lembar kendari menunjukkan korelasi lebih dari 83%. Kesimpulan dari penelitian ini adalah bahwa pengolahan lanjut data airborne gravity dapat meningkatkan keakuratan dan keandalan data airborne gravity untuk menghasilkan peta anomali bouguer lengkap. Hasil penelitian ini juga menunjukkan bahwa data arsip airborne berpotensi digunakan untuk keperluan geofisika dan geosains di Sulawesi Tenggara dan Indonesia.

Kata kunci : airborne gravity, geoid, Bouguer anomaly.

ABSTRACT

Terrestrial measurements can provide accurate gravity data, but it is costly and time-consuming for large and remote area. Airborne gravity measurements have actually been carried out in Indonesia since 2008 by Technical University of Denmark (DTU) in collaboration with the Geospatial Information Agency (BIG). Purpose of the project was to develop a geoid model used for converting elevations from GPS/GNSS measurements that refers to ellipsoid to orthometric elevations that refer to sea level. The data can actually be explored so that it can be used for geophysical and other geoscience purposes, but the data must be carefully treated and extracted into observational gravity data. This study aims to improve the accuracy of gravity airborne data to produce an accurate complete Bouguer anomaly map. The data used in this study were airborne gravity data over Province of Southeast Sulawesi collected on September 29, 2008 to October 1, 2008. Variation in flight height at the time of consecutive data introduced new horizontal acceleration vector. It must be treated as a noise in the measurement of gravity data. The first stage of processing was to eliminate noise due to aircraft acceleration. Gravity data measured in aircraft conditions accelerating more than 5 m.s-2 were eliminated. In this stage, the gravity data were reduced from 64481 observation points to 4900 observation points. The second stage of processing was low pass filtering to eliminate the remaining surges in gravity data. Airborne gravity data that have been snooped and filtered were then applied to calculate the complete Bouguer anomaly. Visually, a complete Bouguer anomaly map through the enhancement process produced a finer map compared to maps from airborne gravity data without enhancement. Comparison of airborne Bouguer anomaly map and terrestrial Bouguer anomaly maps of Kendari sheet showed a correlation of more than 83%. The conclusion of this study was that the enhancement of the airborne data significantly increases the accuracy and reliability of the airborne gravity data for generating a complete bouguer anomaly map. The results of this study also indicated that the airborne archive data has the potential to be used for geophysical and geosciences purposes in Southeast Sulawesi and Indonesia.

Keywords : airborne gravity, geoid, Bouguer anomaly.

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1. INTRODUCTION

Gravity measurements have been carried out for decades by several institutions in Indonesia, both government and private (Supriyanto et al, 2018; Setyawan et al, 2015). In general, gravity data are used for geophysical and geodetic purposes. For geophysic, gravity data is used for providing Bouguer anomaly map to identify mineral resources, water depletion analysis, fault delineation, and many more. For geodesy, gravity data is the main data in determining geoid (Hofmann-Wellenhof & Moritz, 2005).

Geoid is a model for converting geodetic height to orthometric height. Geodetic height is elevations above ellipsoid as observed by GNSS (Global Navigational Satellite System) or GPS (Global Positioning System), while orthometric height is elevation above mean sea level as measured by spirit levelling. An accurate geoid can be obtained when applying gravity data with dense distribution and adequate accuracy. Indonesian geoid can actually be calculated using various gravity data collected by many institution in Indonesia. Due to lack of information about measurement methods, combining gravity data from several sources lead to less reliability of geoid.

Raw data in the form of gravity data is generally difficult to obtain in the process of gravity data sharing. Institutions generally tend to provide processed data in the form of gravity anomalies instead of raw observation gravity data. One of the data that available for research is gravity anomaly data measured by the airborne gravimetry method. The campaign was organized by BIG and DTU in 2008 to 2011 to determine geoid of Kalimantan, Sulawesi and Papua (Pahlevi et al, 2015).

Although the government has already compiled airborne gravity data for more than a decade, BIG still recommends the geoid from EGM2008 for converting geodetic height to orthometric height in Indonesia region. This is subject to low accuracy of geoid generated from airborne gravity in eastern Indonesia. The difficulties of getting a geoid with centimeter accuracy might be contributed by less accuracy of airborne gravity data imperfection of calculation algorithm related to specific physical condition of Indonesia region.

Geoid modelling is generally carried out using the Stokes and Molodensky approach. The geoid accuracy in Sulawesi calculated using the Molodenky approach is still in the decimeter fraction (Pahlevi et al, 2019).. Molodenky approach are commonly applied since it does not need rock density data while Stokes approach requires reduction of the subsurface mass with bouguer correction and terrain correction. The possibility of errors in defining rock density results in the use of the Molodensky method. However, the Stokes method can provide geoids with high accuracy if the rock density below the surface is accurately determined. Based on these problems, this study aims to create a bouguer anomaly map that is used to determine the density for geoid modelling with the Stokes .

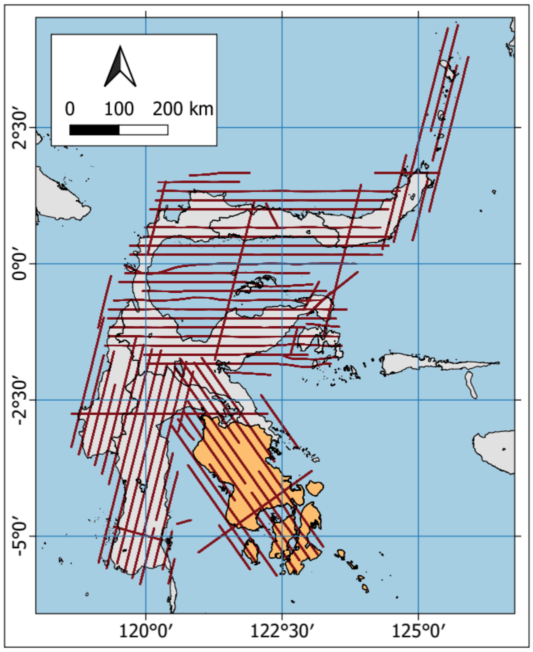

Figure 1. Airborne gravity lines over Sulawesi

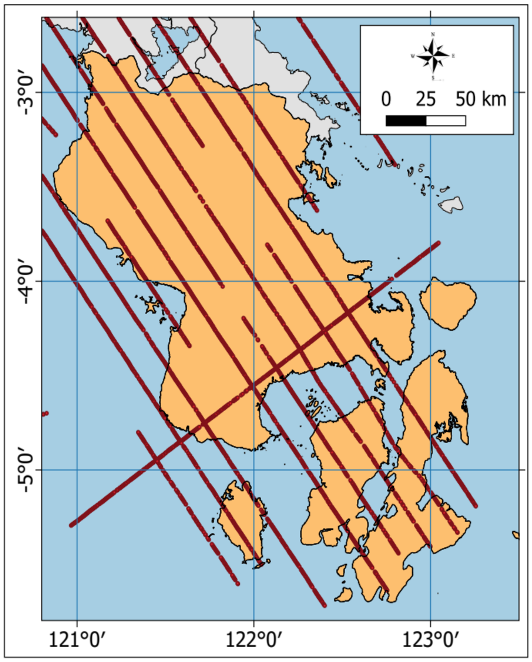

Figure 2. Airborne gravity lines over South East Sulawesi

2. METHOD OF RESEARCH

2.1 Data and Equipment

Airborne gravity measurements were carried out with several pathways that run from northwest to southeast following the landforms of Southeast Sulawesi Province as shown in Fig 1 and Fig 2. The acquisition of airborne gravity data was carried out on September 29, 2008 to October 1, 2008. Aircraft altitude of data acquisition varied between 2907 m to 4273 m above sea level. The variation in flight height was due to differences in topography and the weather. The speed of the aircraft ranged from 239 to 326 km per hour. Variation of speed theoretically introduced horizontal acceleration that must be measured accurately.

2.2 Reconstruction of Airborne Gravity Data

Airborne gravity data of Sulawesi were available in form of free air gravity anomaly. There are difference perspectives between geodesy and geophysics about gravity anomaly (Hackney and Featherstone, 2003). In geodesy, gravity anomaly (Δg) is recognized as difference between actual gravity (g) on geoid and normal gravity ($\gamma 0$) on reference ellipsoid as follow:

$$\Delta g = g - \gamma_0 \quad (1)$$

Situation of gravity anomaly scheme can be seen at Fig.3.

In Molodensky perspective, gravity anomaly is defined as difference between gravity on topography and normal gravity on telluroid. Telluroid is imaginer surface whose normal gravity potential is equal to actual gravity potential on earth's surface as shown by Fig. 4.

In geophysics, gravity anomaly might be defined as a difference between actual gravity (g0) and normal gravity ($\gamma 0$) on the same level as follow

$$\Delta g = g_0 - \gamma_0 \quad (2)$$

In geodesy, gravity anomaly is computed in different level, because it is used for computing vertical distance between ellipsoid and sea level.

In geodesy, difference of actual gravity and normal gravity on the same level is called gravity disturbance as follow

$$\delta g = g_P - \gamma_P \quad (3)$$

It can be computed on sea level, ellipsoid reference, or other predefined levels.

To obtain the gravity on geoid, observed gravity on earth surface must be downwarded to geoid using gravity gradient and mass reduction, namely free air reduction and bouguer reduction. In geodesy perspective, free air anomaly is formulated as

$$\Delta g_{FA} = g_P - \gamma_0 + 0.3086.H \quad (4)$$

where gP is observed gravity on topography.

For airborne gravity survey case, gravity is measured on the aircraft in specific altitude (H) above geoid or sea level. Since BIG provide data of Free Air Anomaly and aircraft position, then observed gravity on aircraft can be reconstructed by applying Eq. 4.

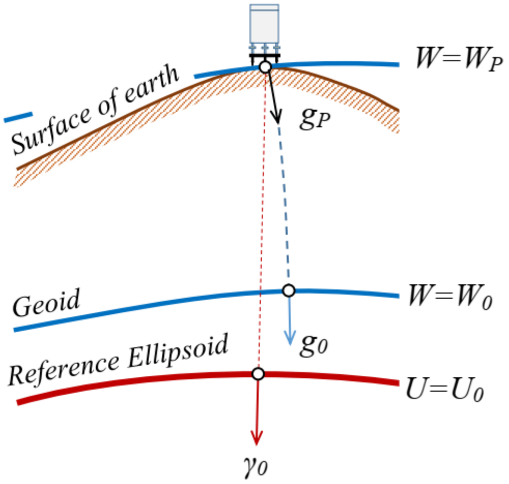

Figure 3. Gravity anomaly in Stokes perspective

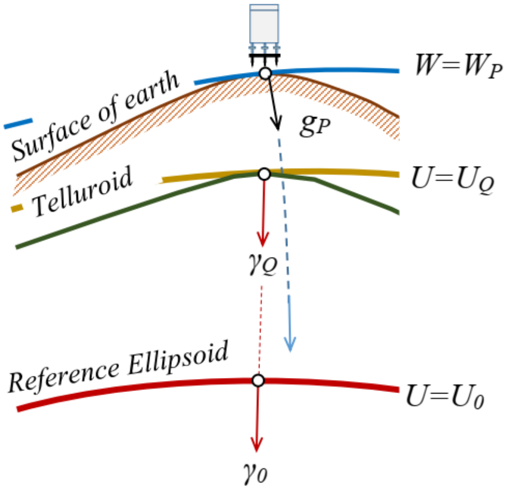

Figure 4. Gravity anomaly in Molodensky perspective

2.3 Quality Checking

Quality of airborne data can be assessed from cross over data. Difference of gravity data between northwest to southeast line and northeast to southwest line was vary from 2.10^{-5} to 8.10^{-5} m.s^{-2}. Misfit of east to west line to northwest to southeast line was between 43.10^{-5} to 82.10^{-5} m.s^{-2}. The longitudinal line was indicated as gross error or unprocessed sufficiently and it must be excluded for further process

2.4 Computation of Complete Bouguer Anomaly

Gravity anomaly for subsurface density analysis is obtained by reducing the gravity to the same reference plane. The process of gravity reduction without taking into account the effect of subsurface mass is known as Free Air reduction, as shown below.

$$\delta g_F = \frac{2.\gamma_e}{a}\left(1 + f + m - 2f.\sin^2\varphi\right)h - \frac{3\gamma_e}{a^2}.h^2 \qquad (5)$$

This research applied gravity disturbance instead of gravity anomaly in geodesy perspective.

The Free Air effect only states the height relation to the gravity value without taking into account the mass effect below the surface. In fact, the mass affects value of gravity. The Bouguer reduction aims to eliminate the effect of mass below measurement point to the level as follow

$$B = -2.\pi.G.\rho.H = -0.041935235.\rho.H \qquad (6)$$

where B is Bouguer reduction in m.s^{-2}, ρ is rock density, G is Newton's gravitational constant, H is orthometric height above mean sea level in meter. This research applied global density of 2.67 g.cm^{-3}. Above sea area, Bouguer correction was treated as positive reduction using 1.64 g.cm^{-3} due to compensation of sea water density of 1.03 g.cm^{-3}.

Since Bouguer reduction assumes the surface of the earth around the point of gravity measurement as a slab, it requires terrain correction to compensate actual topographic surfaces which are higher or lower than the slab (Hwang et al., 2002). Terrain correction in gauss quadrature form is shown by Eq. 7.

$$TC = G\rho \int_x \int_y \int_{z=h_p}^{h} \left[\frac{(z-h_p).dx.dy.dz}{\left[(x-xp)^2 + (y-yp)^2 + (z-hp)^2\right]^{3/2}} \right] \qquad (7)$$

3. RESULT AND DISCUSSION

Various atmospheric conditions cause changes in aircraft speed which impact on acceleration measured by gravimeter. Horizontal acceleration computed from on board RTK GPS between the two consecutive points ranges from -0.287 m.s-2 to 0.323 m.s^{-2} or equivalent to -28700 mgal to 32300 mgal. The acceleration vector must be calculated accurately to obtain an accurate gravity value. Gravity data measured in aircraft conditions accelerating more than 5 m.s^{-2} were eliminated. In this stage, the gravity data were reduced from 64481 observation points to 4900 observation points. Another accuracy checking was cross over gravity data. Gravity data from the intersecting direction is used to calculate the average difference and standard deviation of the main and transverse path data. Appling this quality control procedure, the amount of observation fallen to only 3537 data left.

Free air anomaly archives data were inverted to observed gravity on 4000 m above reference ellipsoid. Due to variation of flight altitude, actual gravity must be upwarded or downwarded to specific level using free air correction in Eq. 5. Gravity above land area varied from 976860 to 976975 mgal while mean and standard deviation of data were 976907.994 mgal and ± 20.937 mgal as shown by Fig. 5.

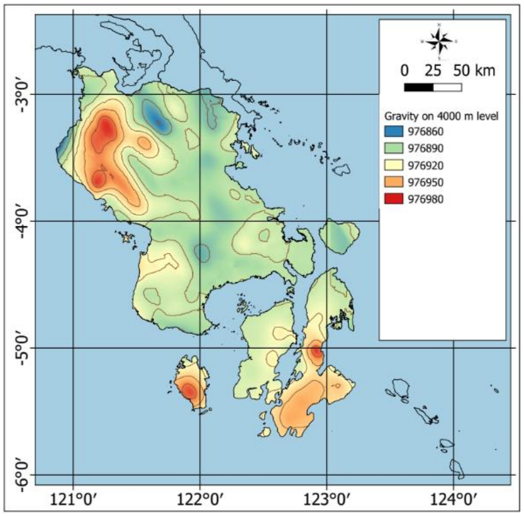

Figure 5. Gravity on 4000 m above sea level

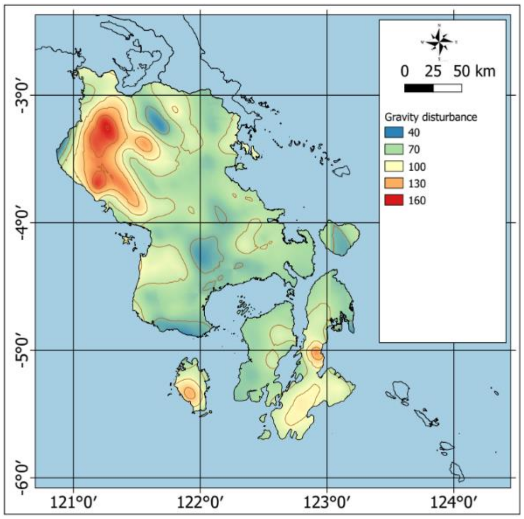

Figure 6. Gravity disturbance

Gravity disturbance were then calculated using observed gravity and normal gravity on 4000 m level. Above land area, they varied from 43.258 to 154.171 mgal while mean and standard deviation of data were

82.026 mgal and 20.375 mgal as shown by Fig. 6. To ensure that accuracy of computation, the result can be compared to gravity disturbance calculated from EGM2008. It was confirmed that airborne data had similar pattern with satellite based data. Resampling the airborne data into EGM2008 resolution gave that correlation of both data was 74%. It indicated that previous filtering was sufficient to deliver accurate airborne gravity data.

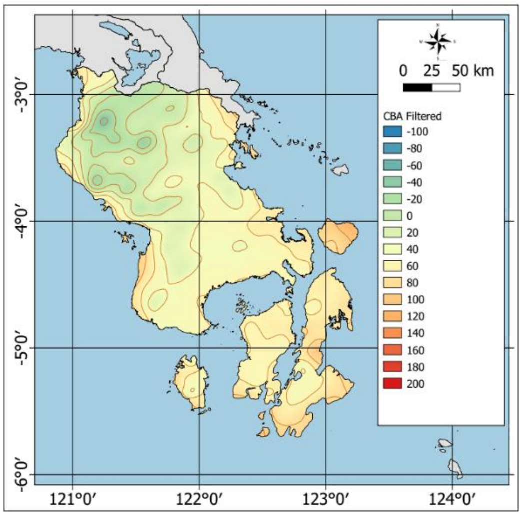

Figure 7. Bouguer anomaly from airborne gravity data of South East Sulawesi

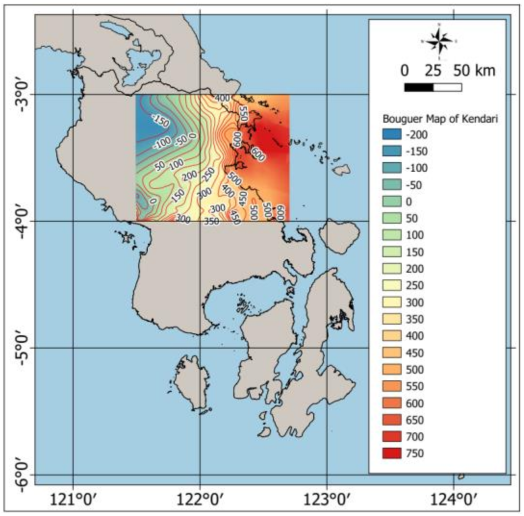

Figure 8. Bouguer anomaly map from terrestrial gravity data of Kendari.

Bouguer and terrain correction were computed using Eq. 6 and Eq. 7 to obtain Complete Bouguer Anomaly (CBA). Again, in this case, CBA occupied gravity disturbance instead of gravity anomaly. This process used SRTM30 as a land elevation data and GEBCO data for sea depth. For computation consistency, the terrain data referred to sea level were converted to elevation above ellipsoid using geoid undulation from EGM2008. CBA above land area varied from -70.363 to 119.678 mgal while mean and standard deviation of data were 41.088 mgal and 27.486 mgal as shown by Fig. 7. Accuracy of bouguer anomaly were analyzed by comparing airborne based map to terrestrial based map. This research occupied Bouguer Map of Kendari sheet (Sobari et al., 2007) for validation. According to regression analysis, coefficient of determination were 83%.

4. CONCLUSION

Airborne gravity data could generate accurate bouguer anomaly map. Airborne gravity data could produce smoother bouguer anomaly map because measurements were covering almost all areas to locations that are not covered by terrestrial measurements. Correlating airborne gravity and satellite based data indicated that airborne gravity were suitable for further geophysical analysis. According to statistical analysis by comparing airborne based to terrestrial based, it is concluded that bouguer anomaly map from airborne gravity data were suitable for geological prospecting

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