Coastal Gravity Anomalies from Retrackted Geosat/GM : A Case Study in Bali, Indonesia

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Key words: Altimeter, gravity anomalies, retracker, Geosat/GM

SUMMARY

Geoid is the equipotential surface of the Earth's gravity field which best fits in a least squares sense with global mean sea level. Geoid determination needs gravity data in land and in the ocean. Gravity data in the ocean can be derived by shipborne gravity, airborne gravity, gravity satellite, and altimetry satellite. Airborne gravity have not measured in Bali, Indonesia. Shipborne gravity has covered some part of the ocean of North of Bali, so we used altimetry data from Geosat/GM to derive gravity data in the ocean of Bali. Bali has shallow water, the depth about 300-800 metres below mean se lea level. It makes the altimeter waveforms have corrupted. An improved threshold retracker (Hwang et al., 2006) and subwaveform threshold retracker (Yang et al., 2012) are developed. We used these retracker to improved gravity anomaly over waters around Bali island. Least Square Collocation is used to compute gravity anomaly from Geosat/GM altimeter data. Subwave threshold retracker outperforms the other one. Use of retrackted SSHs improves the accuracy of gravity anomalies by about 29% for subwave threshold retracker and 25% for improve threshold retracker.

SUMMARY

Geoid adalah bidang ekipotensial medan gayaberat yang berimpit secara least square dengan muka air laut rata-rata global. Penentuan geoid membutuhkan data gayaberat di darat dan di laut. Data gayaberat di laut dapat diperoleh melalui pengukuran *shipborne gravity, airborne gravity,* satelite gayaberat, dan satelit altimeter. Di Indonesia, pengukuran gayaberat menggunakan *airborne gravity* baru dilaksanakan di beberapa daerah, yaitu Sulawesi, Kalimantan, dan Papua. Sedangkan di perairan sekitar Bali belum dilakukan pengukuran airborne gravity. Data gayaberat di perairan di sekitar Bali diperoleh dari pengukuran shipborne gravity dengan cakupan yang tidak merata dan rapat. Untuk mendapatkan data gayaberat di perairan sekitar Bali, digunakan data altimeter dari Geosat/GM. Perairan Bali adalah laut dangkal yang memiliki kedalaman sekitar 300-800 meter di bawah permukaan laut rata-rata. Hal ini menyebabkan muka gelombang altimeter mengalami gangguan. Pada tahun 2006 telah dikembangkan Improved threshold retracker oleh Hwang et al. Pada tahun 2012 juga telah dikembangkan subwave threshold retracker oleh Yang et al. Kami menggunakan 2 retracker rersebut untuk meningkatkan kualitas data gayaberat di perairan sekitar Bali. Berdasarkan hasil yang didapatkan , subwave threshold retracker unggul dibandingkan improve threshold retracker , dan penggunaan kedua retracker ini telah meningkatkan ketelitian data gayaberat sekitar 29% bila menggunakan subwave threshold retracker dan 25% bila menggunakan improve threshold retracker.

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1. INTRODUCTION

This paper is inspired by paper of Hwang et al., 2012, Yang et., al 2006, and Deng and Featherstone., 2006. By those papers, we implemented some altimetry retracker in waters around Bali, Indonesia

Radar altimeters permanently transmit signals to Earth, and receive the echo from the surface. measuring the satellite-to-surface round-trip time of a radar pulse. The magnitude and shape of the echoes (or waveforms) also contain information about the characteristics of the surface which caused the reflection (http://www.aviso.altimetry.fr/en/techniques/altimetry/principle.html). The relationship between the power of the signal transmitted by a radar altimeter and the backscattered power that is received by the altimeter is fundamentally important to altimetry.

The profile of backscattered power (i.e., waveform) from a satellite radar altimeter is described by the Brown model as

$$P(t) = \frac{A}{2}\left[\operatorname{erf}\left(\frac{t-\tau}{\sqrt{2}\sigma}\right)+1\right]\begin{cases}1 & t<\tau \\ \exp\left(-\frac{t-\tau}{\alpha}\right) & t\geq\tau\end{cases} \quad (1)$$

where P(t) is the return power of a Brown waveform, A is the amplitude of the power, σ is associated with the slope of the leading edge governed by SWH, t is the time of gate, τ is the center of the leading edge, α is an exponential decay parameter in the trailing edge, and erf is th error function.

Over the deep oceans without land interference, the waveform created by the returning altimeter pulse generally follow the ocean model of Brown (1977), and the corresponding range can be properly determined using the result from on onboard retracker. Near coastal, altimeter waveform may be corrupted due to less reliable geophysical and environmental corrections and by the noisier radar returns from the generally rougher coastal sea state and simultaneous returns from reflective land in inland water (Deng and Featherstone., 2006). A processing tachnique, known as waveform retracking can be used to retrack the corrupted waveform and improve the ranging accuracy of altimeter derived sea surface height (SSH). SSH are often used to derive gravity anomalies. Yang et al (2006) and Hwang et al (2012) show the waveform retracking can improved the accuracies og gravity anomalies in shallow waters.

Retracking is a procedure of waveform data post processing that aims to improve parameter estimates over those given as part of the standard altimeter “geophysical data products”. These parameters include the range correction due to the estimation algorithm used and the limited computational time on board the satellite . It is determined through estimating the offset of the actual tracking gate, whick is related to the midpoint on the leading edge, from the predesigned tracking gate that is used by default during on satellite processing. This correction is then applied to the range calculated by the onboard algorithm Waveform retracking methods can be classified into two categories (Deng and Featherstone., 2006).

Waveform retracking methods can be classified into two categories, based on funtional fit, and based on statistics. Several algorithm have been developed to retrack waveform over different reflecting syrfaces. For example the threshold retracker (wingham et al., 1986), improved threshold retracker (yang et al., 2006), and subwave threshold retrackrer (Hwang et al., 2012).

Waters around Bali, Indonesia is classified as shallow water. Data elevation model from Shuttle Radar Topography Mission (SRTM) shows that the depth over waters around Bali is about 300 – 800 metres below mean sea level as we can see on figure 1. Bali has a small island in Southeast of Bali and very near with Lombok island. Those features makes altimeter signal should be corrupted in that area.

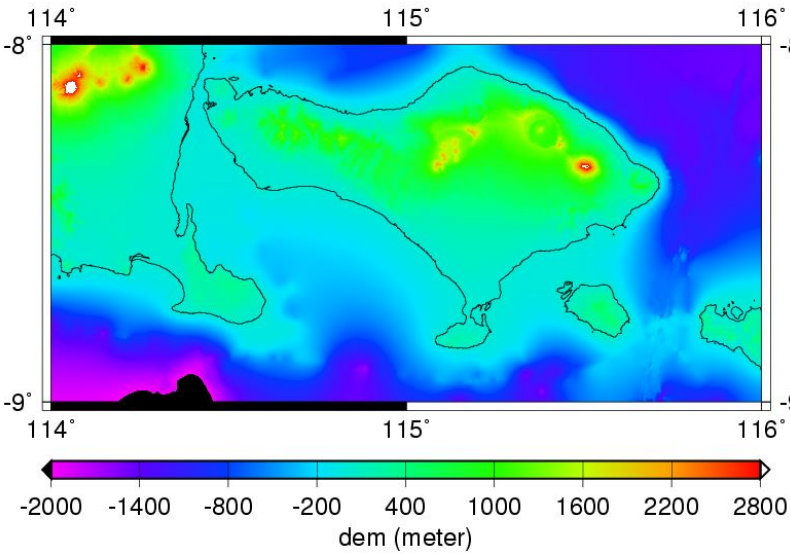


Figure 1. Data Elevation Model of Bali Inland and Waters Around Bali From SRTM 3” Resolution

This paper implemented subwave threshold retracker to improve gravity anomalies over waters around Bali island. This retracker first identifies the leading edge based on subwaveform correlation analysis, then compute the retracking gate using a threshold retrackers to assess its performance in the waters around Bali. Improvements in gravity anomalies by this method will be presented. We also implemented improve threshold retracker in the same area and compared them.

2. SUBWAVE THRESHOLD METHOD

Subwave threshold retracker derive the leading edge to reduce the error in the estimated arrival time of the pulse in four steps (Hwang et al., 2012).

1. Obtain an accurate reference leading edge from the Brown Model.
2. The subwaveform correlation is used to derive the optimal subwaveform. Correlation is a statistical method used to described the dependence between two observed arrays. This method is adapted to analyze the relationship between two waveform. A Correlation coefficient is computed as:

$$r = \frac{S_{r'r}}{\sqrt{S_{r'}S_r}} \quad (2)$$

where

$$S_{r'} = \frac{1}{k-1}\sum_{i=1}^{k}(P_{r'}(i) - \bar{P}_{r'})^2 \quad (3)$$

$$S_r = \frac{1}{k-1}\sum_{i=1}^{k}(P_r\ \ (i) - \bar{P}_r\ \ )^2 \quad (4)$$

$$S_{r'r} = \frac{1}{k-1}\sum_{i=1}^{k}(P_{r'} - \bar{P}_{r'})\,(P_r(i) - \bar{P}_r) \quad (5)$$

where $P_{r'}(i)$ and $P_r(i)$, i -1,....,k are the return powers of the reference waveform and an arbitrary waveforms, respectively. $\bar{P}_{r'}$ and $\bar{P}_r$ are the average powers. $S_{r'}$ and S_r are the standard deviations of powers, and the $S_{r'r}$ is the covariance of the two time series of powers from the reference waveform and arbitrary waveforms. Waveform is consists of three parts, noise, leading edge, and trailing edge.
3. the leading edge is determined after analysing the optimal subwaveform
4. the retracking correction is derived from the leading edge with the threshold retracking.
   Once the leading edge is identified, the retracking gate, which must fall within this subwaveform, is determined by the threshold retracking (Davis, 1997). This method computes retracking gate using the formula

$$A = \sqrt{\sum_{i=1}^{i\ sample} P_i^4(t) / \sum_{i=1}^{i\ sample} P_i^2(t)} \quad (6)$$

$$P_N = \frac{1}{5}\sum_{i=1}^{5} P_i \quad (7)$$

$$T_l = (A - P_N).Th + P_N \quad (8)$$

$$G_r = G_{k-1} + (G_k - G_{k-1})\frac{T_l - P_{k-1}}{P_k - P_{k-1}} + i_{first} \quad (9)$$

where i_{sample} is number gates of the leading edge, A is the amplitude of the leading edge, $P_i(t)$ is the normalized power of waveform at the ith gate, P_N is the average value of the first five normalized power, T_h is threshold value, G_k is the retracking gate.

Range computation then computed by

$$C = (G_r - G_T) \vartriangle R \quad (10)$$

G_T is the theoritical gate and $\vartriangle R$ is the range corresponding to one gate. The method for computing A is the same with the method for the OCOG retracking

The subwave threshold retracker used FORTRAN program. First step of this program is computes cross correlation between the reference waveform and the subwaveforms of full waveform (containing all return power) to determine the leading edge for retracking. The retracking gate of this subwaveform is then determined by the threshold retracking

3. IMPROVED GRAVITY ANOMALY FROM RETRACKTED SSH

We applied subwaveform threshold retracker in Geosat/GM altimeter to improve gravity anomaly. The U.S. Navy launched GEOSAT, or the Geodetic Satellite, in 1985. GEOSAT was designed to collect closely spaced tracks for precise mapping of the Earth's geoid over the ocean. GEOSAT provided global wind speed and significant wave height derived from radar altimeter, collected during the Geodetic Mission (GM), March 1985-September 1986. The orbit had a repeat period of 72 days for the GM. he sampling period was every second, which equates to every 7 kilometers along the ground track (National Snow and Ice Data Center). Each set of waveforms contains 60 return power.

Our study area is 9^0S<latitude<8^0S , 114^0E<longitude<116^0E. In this study, we used 2 retracker, improve threshold, and subwave threshold. The SSH retrackted of Geosat/GM then used to derive along track geoid gradient observed, *e*. The next step is remove reference geoid and compute along-track residual gradients (Hwang et al., 2006) by:

$$e_{res} = e - e_{long} \quad (11)$$

where e_{res} = geoid gradien residual, e = geoid gradient observed, e_{long} = geoid gradient reference (long wavelength).

To compute gravity anomaly residual, g_{res}, we used the standard remove procedure in the least square collocation (LSC) (Hwang et al., 2006).

$$\Delta g_{res} = C_{\Delta ge}(C_{ee} + C_{nn})^{-1} e_{res} \tag{12}$$

where e_{res} = is a vector of residual geoid gradients, $C_{\Delta ge} C_{ee}$ and C_{nn} are covariance matrices for gravity anomaly-gradient, gradient-gradient, and noise of gradient, respectively. C_{nn} is diagonal matrix holding the noise of variances of geoid gradients.

Once we get gravity anomaly residual, we can compute gravity anomalies, by:

$$g = g_{res} + g_{long} \tag{13}$$

Based on the result of this research, subwaveform retracker outperforms the improve threshold retracker by few mgal in the accuracy of computed gravity anomalies.

For longwavelength component, we used EGM 2008 with highest degree.

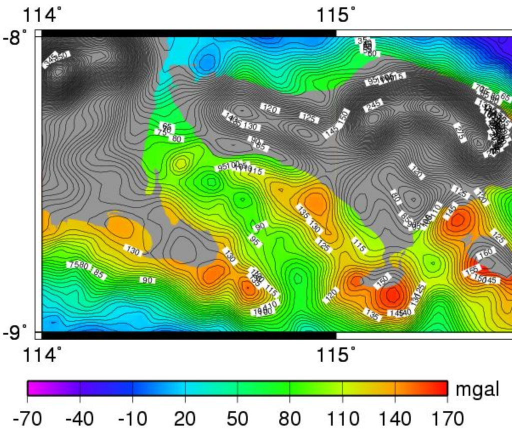
4. COMPARISON GRAVITY DATA DERIVED FROM SSH RETRACKTED WITH SHIPBORNE GRAVITY

We used three data sets of gravity anomalies by LSC using three data sets, raw data, and retrackted SSH by using improve threshold retracker and by using subwave threshold retracker. The results of gravity anomalies then compared by shipborne gravity. National Geophysical Data Center (NGDC) collected international shipborne gravity datas. The shipborne gravity data over the waters around Bali are measured at 1964 to 1993.

Table 1 shows the statistics of the difference between the compute gravity anomalies and the shipborne gravity anomalies.

Description	Mean	Standard Deviation
Raw SSH- Shipborne Gravity	1.811	12.353
SSH Retracted by Improve threshold retracker-shipborne gravity	1.345	11.122
SSH Retracted by subwaveform threshold retracker-shipborne gravity	1.285	10.307

Based on table 1, we can see that both retracker have improve accuracy gravity anomalies by about 29% and 25% by using subwaveform threshold retracker and improve threshold retracker, respectively.



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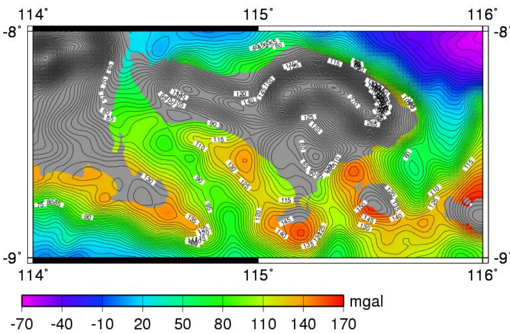

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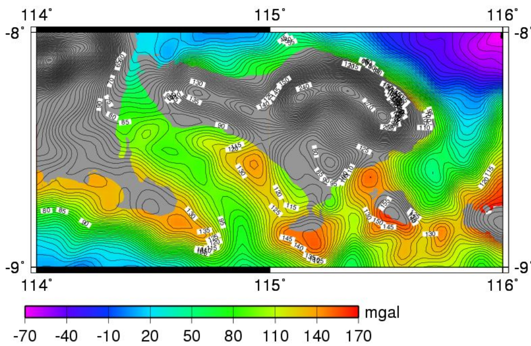

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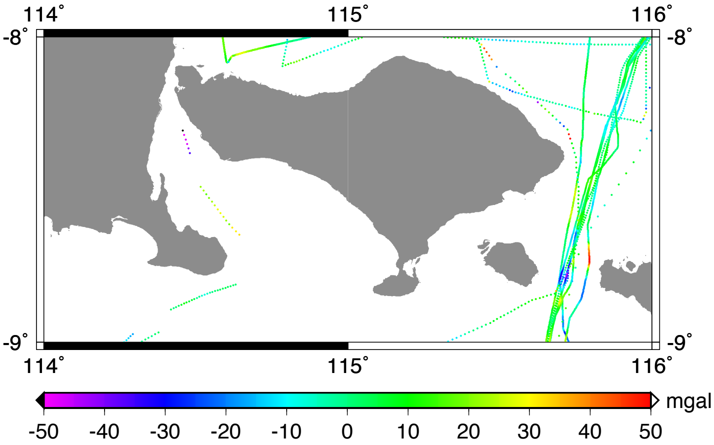
Figure 2. Contours of Gravity Anomalies Using raw SSHs (a) and Retrackted SSH (Improve Threshold Retracker (b) and Subwaveform threshold retracker (c))

Figure 2 shows that anomaly gravities derived from raw SSH has rough contours while anomaly gravities from retrackted SSH has smooth contours. We concerned at a location northeast of Bali island and a marine area nearby Penida and Lombok Island. Some gravity artifacts at concerned area are dissapeared after retracted.



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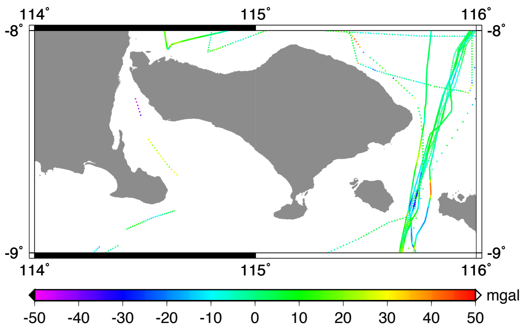

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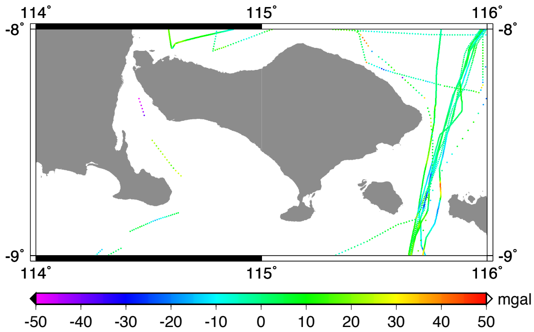

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Figure 3. Distributions of Difference Between Gravity Anomalies Derived by Altimeter and Shipborne Gravity , a, Raw Data, b. Imrove threshold Retracker, c. Subwaveform Threshold Retracker

Figure 3 shows the difference between the compute gravity anomalies and the shipborne gravity data. Figure 1 is correlated with figure 3 that at the same concerned area, there are bigger different gravity anomaly value between altimeter derived before retrackted and shipborne gravity than after retrackted and shipborne gravity. Figure 3 also shows that improve threshold retracker has bigger value of different gravity anomaly altimeter derived and shipborne gravity than subwave threshold retracker.

5. CONCLUSION

Gravity anomalies can be derive from altimeter data, Geosat/GM. Shallow water around Bali made altimeter subwaveform corrupted. To improve the SSH and gravity anomalies, we used subwaveform threshold retracker and improve threshold retracker. Least Square Collocation is used to compute gravity anomalies from SSH retrackted. Subwave threshold retracker outperforms the other one. Use of retrackted SSHs improves the accuracy of gravity anomalies by about 29% for subwave threshold retracker and 25% for improve threshold retracker.

REFERENCES

Brown G S, 1977, The Average Impulse Response of a Rough Surface and its Application , IEEE Trans Antenna Propag , 25(1), 67-74

Deng X, Featherstone W.E, 2006, A Coastal Retracking System for Satellite Radar Altimeter Waveforms: Application to ERS-2 Around Australia, Journal of Geophysical Research

Davis, C.H., 1997. A robust threshold retracking algorithm for measuring ice-sheet surface elevation change from satellite radar altimetry. IEEE Transactions on Geoscience and Remote Sensing 35 (4), 974–979.

Fu LL, Cazenave A, 2001, Satellite Altimetry and Earth Sciences: a handbook of techniques and application, Academic, San Diego

Hwang C, Guo J, Deng X, Ying Hsu H, Liu Y, 2006, Coastal Gravity anomalies from Retrackted Geosat/GM Altimetry: Improvement, Limitation, and the Role of Airborne Gravity Data, Journal Geodesy, 80, 204-216

Wingham, D.J., Rapley, C.G., Griffiths, H., 1986. New techniques in satellite altimeter tracking systems. In: Proceedings of IGARSS 88 Symposium. September, Zurich, Switzerland, pp. 1339–1344.

Yuandang Y, Hwang C, Jui Hsu H, Dongchen E, Wang H, 2012, A Subwaveform Threshold Retracker for ERS-1 Altimetry: A Case Study in the Antartic Ocean, Computer and Geosciences, 41, 88-98

BIOGRAPHICAL NOTES

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