The potential use of satellite gravity data for oil prospecting in Tanimbar Basin, Eastern Indonesia

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Abstract. One way to increase oil and gas production in Indonesia is through the geophysical study for new deposits in Basins frontier, i.e., Tanimbar basin in Province of Maluku, Eastern of Indonesia. The Tanimbar basin is located in an area known as the Outer Banda Arc. Gravity is a usually geophysical method used for the sedimentary basin. But for the regional scale, the method requires an expensive cost and long time-consuming. In this research, we use the satellite gravity data provided by Scripps Institution of Oceanography, University of California San Diego. This data has a low resolution of 1.5 km for 1 pixel and also free access. The satellite data will be compared with the gravity ground survey. The data was acquired by the University of London and Bandung Institute of Technology in 1987. The gravity satellite can show a more contrasting of geological structure compared to the ground survey, as well as syncline and anticline; the anomaly is indicated by the relatively high Bouguer data (3.5 to 25 mGal). The high anomaly is also influenced by tectonic activity from inner and Outer Banda Arc that exists in eastern Indonesia. The sub-sedimentary basin is represented by the low Bouguer anomalies (-40 to -25 mGal) that correlated well to ground survey data. Based on the result, it can be concluded; the satellite gravity is potentially used for delineating the sedimentary basin in Tanimbar Island.

1. Introduction
Indonesia is one of the countries with great hydrocarbon potential in the world, but the level of oil production in Indonesia is gradually decreased, this is due to the ratio of oil and gas reserves is not comparable with those issued. One of the efforts to increase the production, it is necessary to study the prospects of new basins, especially in areas that have not been explored such as the Tanimbar basin in Tanimbar Island, Eastern Indonesia. Based on tectonics, the island has similarities to the nearby basins that has been shown to produce hydrocarbons, i.e., Abadi gas field on the PSC block Masela – INPEX. So the island can be a new prospect of hydrocarbon reserves for Indonesia [1].

Based on the geological map (Figure. 1) the anticline and syncline areas are in Batimafudi formation on the Southern part of Tanimbar Island. This formation consists of sandstone rocks, lamination, and clay pellets. In most parts of the basin investigation, modern seismic data is relatively insufficient. In the current low oil price environment, the researchers are looking for cost-effective ways of exploring and targeting seismic acquisition. Gravity data has been widely used in frontier
basins to understand the sedimentary and geological structure [2] and also frequently used as planning of seismic acquisition [3]. In another case, gravity is an important method for delineating the fault structure in the subsurface, as an important method for geothermal study, and also the potentially used for archaeo-geophysics [4], but to cover a large area, the ground method is considered ineffective because it can spend a longer time than the airborne survey [5]. However, the airborne belongs to an expensive method, therefore in some developing countries, the airborne is not the best solution method to do, especially when the oil and gas prices are low, it is necessary to have a further study on the effective methods that more quickly and economically.

In this paper, we present a geological structure of Tanimbar basin using Gravity radar altimeter mission's data from satellite Geosat and ERS-1. The data was obtained by Scripps Institution of Oceanography, University of California San Diego and available for free access. To validate the basin and the geological structure, in this surveys, the satellite data were combined with gravity ground survey. The ground survey data was conducted using a LaCoste-Romberg instrument by the University of London and the Geological Research and Development Centre (GRDC) in 1987 [6] and sponsored by Union Texas (SEA) and Idemitsu Oil Development Company, and also in 1980, the data were acquired by Bandung Institute of Technology.

![Figure 1. Geological map of the study area. The black line shows the geology and fault structure of Tanimbar Island [7].](image)

Furthermore, the different measurement time between the ground survey (1980) and the satellite acquisition (2011) will cause both of these data to produce different anomalous patterns, it caused by different topography factors at the time of data acquired, mainly in satellite gravity; the free-air anomaly only associated with the topography data from the surveys area. In this research, the Bouguer data from the ground will reduction process to becomes a new standard ellipsoid model that possible to compare with the gravity data; the anomalies are relative to the International Terrestrial Reference Frame ITRF (WGS84).
2. Data and methodology

The gravity method involves measuring the earth’s gravitational field at specific locations on the earth’s, the data reflect lateral variations of density in the subsurface and is mainly used for basement structural mapping of sedimentary basins [8]. The method works when buried objects have different masses, which are caused by the object having a greater or lesser density than the surrounding material. The measured gravity data is influenced by factors such as topography, tides, and the earth’s shape and rotation. These factors must be removed before interpreting gravity data for subsurface features [5].

In this research, we use Gravity radar altimeter mission’s data from Geodetic Satellite (GEOSAT) and European Remote Sensing1 (ERS-1) with a 1-minute grid that possible to obtain 1.5 km for one pixel. GeoSat is an earth observation satellite belonging to U. S. Navy, while the ERS-1 satellite is the first earth observation satellite launched by the European Space Agency. TOPEX Altimetry Satellite was first launched on August 10, 1992 by NASA in collaboration with CNES (French space agency) which aims to measure the wide-scale topography and oceanic dynamics. From the altimetry satellite, it can produce several data; i.e., topography, geoid, and free air that used to calculate the Bouguer anomaly.

Figure 2. Bouguer anomaly maps in Tanimbar Island overlaid by geological fault structure (a) The Bouguer data was obtained from the ground survey, the red dot is a data distribution acquired by ITB in 1980, and black dots by the University of London in 1987 and 1989 (b) The Bouguer anomaly from Gravity Satellite, the red box is a further areas study.

3. Result and discussion

The data obtained from the satellite is free air anomaly. The free air anomaly data is the difference between observed gravity and theoretical gravity that has been computed for latitude and corrected for an elevation of the station above or below the geoid. So the free air anomaly data is then used to construct a Bouguer anomaly map with assumed the contrast density in the area is sediment (2.3
g/cm³). One advantage of the gravity method is not only measured on the surface but also in the air (airborne). Figure 2 shows the different responses between the gravity data collected by ground measurements and Satellite survey in the Tanimbar Islands.

Figure 2(b) shows the Bouguer anomaly in the Tanimbar Islands overlain by the geological structure that varies between -40 to 23 mGal. High Bouguer anomaly values are shown in the west and eastern part of the study area, while low Bouguer anomaly is located in the center part that extends to the northeast-southwest. The same pattern of anomalies is also shown in the survey ground data (Figure 2(a)). It has indicated a good data correlation between the ground and satellite survey. In addition, the low anomaly is also caused by the lack of tectonic activity on the central part of the Tanimbar Islands. While on the Southeast and Northwest part dominated by high anomaly Bouguer that varies between -5 to 1 mGal, it is indicated as an area influenced by tectonic activity caused by Banda arc. This arc is the interaction of active plates, i.e., Asian, Australia, and the Pacific plate. Furthermore, the data responses obtained from both methods are very different, e.g. on the north and west side of the island which characterized by low anomaly based on the ground survey while on the satellite is shown by high anomaly data. The difference response is due to the slight station in the ground survey data. Figure 3 shows a comparison of residual Bouguer gravity that obtained from ground and satellite surveys in the Southern of Tanimbar Islands; the figure is only focused in case of fault structure, syncline and anticline area.

**Figure 3.** The comparison of residual Bouguer anomalies in the southern of Tanimbar Island. (a) and (c) is derived from ground survey. (b) and (d) in satellite survey. The geological structure, i.e. thrust fault, syncline, and anticline that shown by the black line.
Based on Figure 3(a) and (b), the maps shown the similar patterns of residual Bouguer anomaly that obtained from ground and satellite survey in the south part of the island; this anomaly can be interpreted as a thrust fault that correlated to the geological structure. The satellite gravity can show a very contrast anomaly than the ground survey, for example on the north side of the island the satellite gravity is the same pattern with a fault structure derived from geological maps, but the ground data is unable to show the contrast of the fault. In another side, the area which has a potential of hydrocarbon, i.e., syncline and anticline it is indicated by the relatively high Bouguer anomaly on both of measurements as shown in Figure 3(c) and (d). Specifically, all of the synclines and anticlines that obtain from geological maps also can be map clearly by the satellite surveys. While in the ground data, the anomaly only possible to show on the east side. The different responses from both methods caused by the data distribution are more relative less in the ground survey.

The comparison data that obtained from both methods is up to 20 mGal. The ground data is still influenced by regional effects, while there is no regional trend on satellite data because the 1-minute grid is relatively closely measurement for regional studies. In general, the gravity satellite data with a resolution of 1.8 km can be mapped the details of fault structure that extends from West to East. These faults correspond to the structure obtained from the geological data. While the Bouguer anomaly contrast in the ground survey data is only able to show the structure of faults on the southern part of the island.

In order to map the basin in all area; on-shore and off-shore, it is necessary to measure the gravity at sea, but the ground instrument is not possible to use. The shipborne is one of the gravity instrument that possible to measure the data in the ocean, but the instrument still also belong to expensive methods. One advantage of the satellite measurement is the gravity data not only available access on the land but also on the ocean area. Figure 4 shows the Bouguer anomaly on the onshore and offshore that can be used for delineating the sub basin in the Tanimbar Island.

![Figure 4. Bouguer anomaly maps (including off-shore) obtained from Satellite survey. The white dotted line (A, B, C, and D) are interpreted as a sub-basin of Tanimbar Basin.](image-url)
Referring to Ref. [10], the gravity data obtained from the ERS-1 satellite corresponds to the shipborne measurement, while the RMS between both data is 16.5 mGal. The shipborne data is consistently influenced by the regional effects. Furthermore, the TOPEX satellite shows the small RMS comparison with shipborne data i.e. 2.70 to 6.0 mGal, therefore the satellite can be used for basin analysis in all area including the ocean. Based on Figure 4, the map shows the Bouger anomaly that varies between –65 to 37.5 mGal. High anomaly data is dominated in the ocean, while the low anomaly is confirmed to the island area. In a location which estimated as a basin area, the data also dominated by low low Bouger anomaly that varies from -30 to -20 mGal. The basin pattern that shown by the white dash line (Figure 4) is an agreement with the basin area that derived from Ref. [6] used ground measurement.

4. Conclusion
Based on the comparison of both methods in Tanimbar Island, it can be concluded that the anomalies obtained from the satellite are in agreement with the ground data. In most locations, the satellite data can be imaging clearly the fault structure than the ground measurement, also in another case such as syncline and anticline can be shown very contrast anomalies from the satellite data. One advantage of the satellite measurement, the data also possible to obtain on the ocean areas. Based on the result, satellite gravity has become the potential method to identify the fault and basin structure in the frontier hydrocarbons investigation. For regional studies, the gravity satellite can also be used as a faster and more economical alternative method than the ground measurement. However, for a comprehensive result, it is needed further studies on the comparison of both measurements in other locations, including in relatively local areas.

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