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RESEARCH ARTICLE

THE SUCCESS OF SATELLITE GRAVIMETRY IN GEOPHYSICAL INVESTIGATIONS

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ABSTRACT

Terrestrial measurements of gravity data are limited to only accessible areas. Areas that are not easily accessible due to lack of access route, security, cost etc. are found unfavorable for terrestrial measurements. These among others lead to the development of satellites to fill those gaps. Satellites have been used for data acquisition for years and have recorded a great success in numerous ways. This paper presents the principle of operation of such satellites. The successful geophysical researches carried out using satellite acquired gravity data from existing literature were also discussed. The researches applied the satellite gravity data for numerous applications notably ground water survey, hydrology, geothermal survey, Mineral and hydrocarbon explorations, lithological characterization (Edge/boundary detection, depth estimation), Modeling of magma chamber, volcanic subsurface survey, characterization of upper atmospheric density etc. Satellite gravity survey is found to be very essential and relatively more advantageous compared to terrestrial survey because the human effort in data acquisition is less, it has wider coverage in small time, access to places that cannot be accessed on ground. It is therefore recommended that the functions of the satellites should be further expanded using new innovations like machine learning and artificial intelligence in order to increase efficiency.

KEYWORDS

Satellites, Gravity method, Geophysics, Gravimetry, Earth characterization

1. INTRODUCTION

The goal of Geoscientists is to infer about the subsurface of the earth which will bring about new knowledge. This effort helps to find out about the economic structures beneath the earth and the safety status of lives. The urge to have a perfect image of the subsurface structures necessitated the adoption of modern technology in the process (Dahuwa et al., 2018). Geophysical techniques play an imperative function of reducing cost and risk by employing valuable tools for the preliminary investigation of field sites to characterize subsurface features prior to any intrusive investigation.

In Geophysics, physics principles are applied using mathematical methods to study the earth's interior. A lot of inquiries are carried out using geophysical methods for economic, archeological, environmental, engineering, and other purposes. We have numerous geophysical methods in existence with each method insightful to a valuable physical property. The area application of each method depends on the physical property it responds to. For example, the magnetic method is suitable for the location of buried magnetic substances defending on their magnetic susceptibilities. Likewise, seismic method and resistivity method are apt in the location of water table due to the fact that saturated and dry rocks can be separated from each other by their seismic velocity and electrical conductivity (Dahuwa et al., 2018).

Gravity method is among the methods used widely in environmental, engineering, archaeological and other subsurface investigations. Developments recorded recently in observation, data processing and data analysis brought by advancement in technology made gravity method efficient, sensitive with a wide range of applications. Gravity method deals with measurement of the change in gravitational field of the earth at different locations by instruments known as gravimeters. It is a potential field method which means it does not require external energy for measurement. The instruments used to measure gravity known as gravimeters are many. Each gravimeter differs from the other due to differences in accuracy. In recent years, the choice of changing platform in geophysical measurement from ground to aerial platform brought about an appreciable development. This led to the employment of satellites for gravity data acquisition. The purpose of this research is to extract the merits and demerits of using satellites by reporting the successes recorded using the satellite acquired gravity data in geophysical surveys.

Many geophysical investigations were carried out using satellite gravity data and were successful for a number of applications. Some of the applications include detection of marine gravity anomalies, Hydrology, modelling of Magma chamber and volcanic subsurface, Geothermal Survey, Detection of edges and faults of subsurface structures (Xioyun et al., 2022; Zhu et al., 2020; Jiang et al., 2019; Pivetta et al., 2022; Apriliana et al., 2021; Minarto et al., 2021; Bouman et al., 2013; Alhassan et al., 2021; Muhammad, 2019; Kadirov et al., 2023).

So many satellites are used for gravity data acquisition. Some of these satellites include LANDSAT, GRACE, GOCE, Q-SAT, Skylab, GEOS3, SEASAT, Geosat, ERS1, and ERS2 among others. This paper presents the principle

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of operation of some of such satellites as well as the advantages of one over the other. Researches that used the data acquired by such satellites were reviewed. The paper went a long way to discuss the reasons why satellite data acquisition should be adopted by other researchers. It has also sorted out who necessarily needs satellite gravity data and why it is good for his kind of research.

2. Gravity Survey

The gravity method is a Potential field method, a non-destructive technique which focuses on measuring the differences in acceleration due to gravity at specified locations. The method depends on the fact that materials on earth have different bulk densities (mass) which lead to variations in gravitational field (Klokocnik et al., 2017; Klokocnik et al., 2020; Eppelbaum, 2019). The variations when interpreted using mathematical and statistical methods leads to determination of geometry, depth, and density of buried bodies in locations. The method works when buried objects have masses different from others, which are caused by the objects that have a greater or lesser density than the surrounding material (A and T, 2019). The method is among the methods used widely in environmental, engineering, archaeological and other subsurface investigations. Size of the gravity anomaly (object that caused the variation of value of gravitational acceleration) is very small (measured in μGal) which implies that special attention is needed during data collection for reliable anomalies to be observed (Alhassan et al., 2021).

Gravity data measurements are made either on the earth surface (terrestrial) or on ship (shipborne) in early days. However, Some areas are not easily accessible due to lack of access route, security, cost etc. This made terrestrial measurements unfavorable in such situations. These among others lead to the development of satellites to fill those gaps of accessibility, reliability and wider coverage. Satellites have been used for data acquisition for years and have recorded great success in numerous ways. The present study focused on reviewing some research performed using satellite gravity data in order to reveal its success.

3. Some oF the Satellites Used for Gravity Data Acquisition

3.1 Grace

Gravity Recovery and Climate Experiment (GRACE), is a NASA mission consisting of twin satellites that were launched in 2002. The satellites are in the same route around Earth, one about 220 kilometers (137 long hauls) in front of the other at an altitude of 460 kilometers (286 long hauls) above the Earth's face. Together, they measure Earth's gravity field with a perfection lesser than any former instrument. As the super eminent satellite passes over an area on Earth of slightly stronger gravity, it detects an increased gravitational pull and pets up ever so slightly, therefore adding its distance from the running satellite. Again, the super eminent satellite slows down when it passes over an area of slightly weaker gravity, dwindling the distance between the two satellites. The changes in distance between the satellites are so minute-- about one- tenth the range of a mortal hair-- that they're undetectable by the mortal eye. GRACE measures these changes using an instrument that generates beats of microwave oven energy-- a largely energetic form of electromagnetic radiation-- that brio back and forth between the two satellites. The distance between the satellites is determined by the time a microwave oven palpitation takes to travel from one satellite to the other and back. GRACE maps the entire graveness field of Earth every 30 days. Changes in gravity over time can reveal important details about polar ice wastes, ocean position, ocean currents, Earth's water cycle and the interior structure of the Earth.

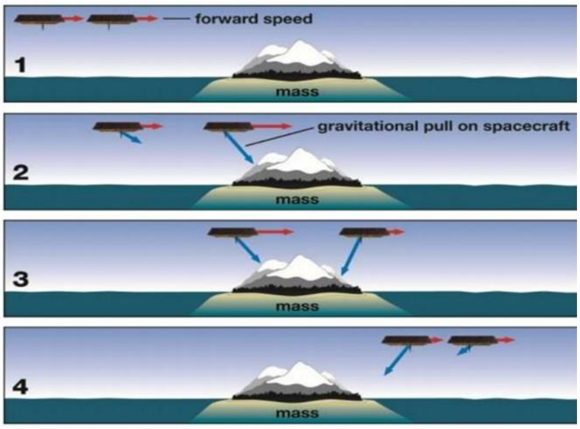

Figure 1: Two satellites used for gravity data acquisition (NASA website 2023)

3.2 GOCE

GOCE (Gravity Field and Steady-State Ocean Circulation Explorer) satellite was launched in the year 2009 by European space agency. It has three-axis servo-controlled, capacitive accelerometers (Jorg et al., 2013).

3.3 Taiji-1

The Taiji- 1 satellite has nearly 180 kg weight, with a drag-free control and an optic metrology as crucial dimension system. It was launched to an indirect dawn/ dusk sun synchronous route, with about 600 km altitude and 97.67 ° inclination angle. The route has a sun- facing and stable angle that provides the battery with constant power force and a stable temperature grade for the platform. The coordinate system of the orbit is in X, Y and Z. X-axis represents the direction of the flight, Z- axis represents the radial direction, and Y- axis is defined by the right- hand rule (Zhang et al., 2023). The satellite platform has a very stable system of controlling heat. The system of controlling station and route contains magnetometer, star trackers, magnetorquer, sun detector, cold gas thrusters, gyroscopes and the regulator. numbers 2 and 3 show the armature of Taiji- 1.

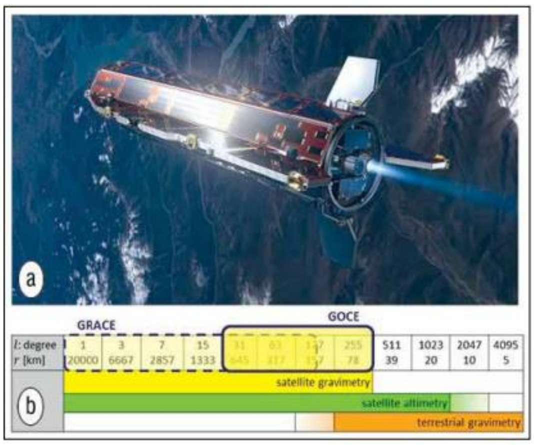

Figure 2: The GOCE satellite (courtesy ESA) (Jorg et al., 2013)

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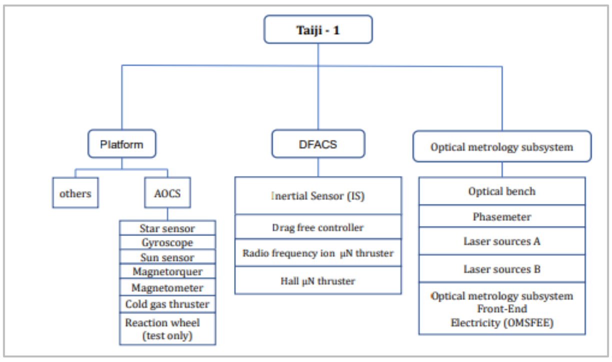

Figure 3: Block diagram for the architecture of Taiji-1 (Zhang et al., 2023)

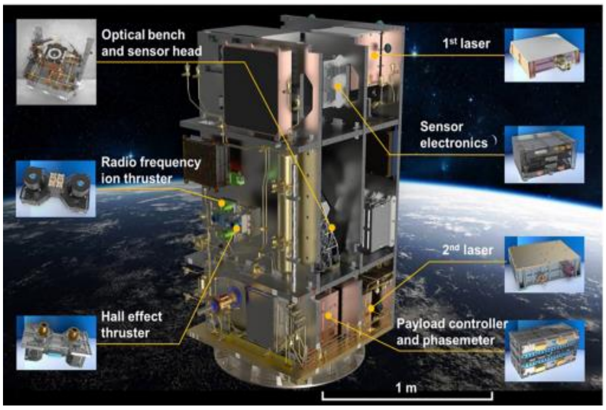

Figure 4: The layout of the payloads of Taiji-1 (Zhang et al., 2023)

3.4 LANDSAT

The Landsat program is the longest running enterprise that acquires the Earth's satellite image. It is a NASA/USGS joint program. It was launched on 23th July, 1972 with the name 'Earth Resources Technology Satellite' later renamed as Landsat 1 in 1975. Landsat 9 (launched in 2021) is the most recent in the series. The landsat satellites have instruments that have acquired many images of the earth which are accessible at Earth Explorer via earthexplorer.usgs.gov

3.5 Q-SAT

Q-SAT satellite is one of the latest satellites launched to measure earth's gravity. It was launched by Tsingua University China in 2020 (Zhaokui et al., 2022)

3.6 SEASAT

The SEASAT satellite was launched in 1978. It revolves around a circular orbit with about 800 km altitude. It circles the earth each day 14 times. About 95% of the surface of the earth was covered by SEASAT after 36 hours. It transmits a radar signal continuously which bounced off the surface of the sea. The travel time of the signal to and from the surface of the sea (two way travel time) is observed and the height is then calculated which is used to find gravitational field acceleration (Alhassan et al., 2021).

3.7 GGMplus

The GGMplus is also used during acquisition of Earth's gravity field data. It has a resolution of about 220 m for all terrestrial and sea areas between ± 60 degrees latitude. It has several advantages over other satellites, one of which is better spatial resolution on gravitational anomalies. This implies that we can use the data for a preliminary mapping (to get overview). The GGMplus data have used for many applications during geophysical prospection like Sehah that applied the data to model the shape of the magma chamber of Slamet Volcano, Indonesia. The GGMplus data according to Sehah has good accuracy in interpreting the subsurface structure of areas (Sehah et al., 2022).

Table 1: Altitude of some of the satellites

Satellite	Altitude (km)
GRACE	460
Taiji	600
SESAT	800

Table 2: Coverage of Some of the satellites

Satellite	Coverage
GRACE	maps the entire Earth's gravity field monthly
SEASAT	covers 95% of earth's surface every 36hrs
GGMplus	terrestrial and sea areas

4. Discussion

The unmapped sections of the earth are many due to the limitations of land and marine surveys before the evolution of airborne (Aerial and Satellite) measurements. Recent improvements in accurate airborne location with Global Positioning System (GPS) carrier phase data made the practice of airborne measurement practice accepted widely in effort to solve the limitations of land and marine surveys (Geodesy, 2016). Satellite gravimetry contributed significantly in deriving gravity products which lead to the provision of significant information on the gravitational field of the earth at universal or local scales. The satellite gravimetric products used mostly by researchers are the World Gravity Maps and Grids (WGM) that indicate the first gravity anomalies calculated in spherical geometry with respect to a genuine Earth model. Almost all the entire earth can be accessed with long range airborne survey.

The GRACE mission when compared to GOCE has higher precision (at wavelengths longer than 330 km). On the other hand, GOCE has higher sensitivity at wavelengths less than 160 km, (with less sensitivity compared to GRACE at long wavelengths). Ling performed an assessment of the accuracy of the gravity field obtained from satellite-altimetry in the Arctic Ocean by comparing it with shipborne gravity measurements (Ling et al., 2022). The satellite data encompass almost all the important information present in the shipborne data. The difference between the two is negligible. This has contributed to reiterating the fact that Satellite data is sufficient for gravity surveys even in marines. Kadirov suggested that the Combination of conventional gravity measurements with advanced gravity transformations derived from satellites will yield novel physical-tectonic characteristics such as subsurface inhomogeneities, detection of compression zones, detection of deep faults, and dilatation (Kadirov et al., 2023).

Pivetta performed an analysis which focused on changes in density based on satellite and ground based measurements of climatic origin in the high mountains of South America and Asia (Pivetta, 2022). After comparing it with the GRACE-FO mission, they concluded that the mission of quantum gravity significantly aided the climatic mass gain detection of the lakes as well as mass loss of glaciers, which made smaller mass features

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distinguishable thereby detecting smaller mass losses. Therefore recommended exploitation of quantum technology based absolute gravimeters, clocks and gradiometers as the forefront instruments to support the QSG gravity mission in the future (Pivetta, 2022). This means that satellites need to work with Quantum technology gravimeters to optimize the earth's gravity field observation and reduce aliasing phenomena.

Many geophysical investigations were carried out using satellite gravity data and were successful for a number of applications. Some of the applications include detection of marine gravity anomalies, Hydrology, modeling of Magma chamber and volcanic subsurface, Geothermal Survey, Detection of edges and faults of subsurface structures (Pivetta, 2022; Xioyin et al., 2022; Zhu et al., 2020; Jiang et al., 2019; Apriliana et al., 2021; Minarto et al., 2021; Bouman et al., 2013; Alhassan et al., 2021; Muhammad, 2019; Kadirov et al., 2023).

5. Conclusion

Satellite gravity data is believed to be helpful and useful. Using satellites for gravity data acquisition is easier compared to other gravimeters. It takes a short period of time to map a huge area of land and allows easy access to places that are inaccessible on ground. The major challenge is high cost of satellite installation and maintenance which individuals or small organizations cannot afford. This has been addressed by organizations like National Aeronautics Survey Agency (NASA) and Bureau Gravimetric International (BGI) that can freely provide data on request in order to support research. Many researchers nowadays utilize satellite gravity data in researches that invite the use of gravity data. The principle of operation of such satellites was discussed as well as their applications.

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