

Dependences in the pillar 'Earth's gravity field' of GGOS - description using UML notation

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Abstract. Earth's gravity field is one of three pillars of the Global Geodetic Observing System (GGOS). Gravity measurements are made using both classical methods by the means of ground measurement facilities (relative and absolute gravimetry) and methods based on the satellite techniques (SLR, missions CHAMP, GRACE, GOCE) or airborne gravimetry. The main objective of this GGOS pillar is to determine geoid's shape, Earth's static gravitational potential and temporal variations induced by solid Earth processes and mass transport in the global water cycle. The paper presents relationships between the main classes of diagrams of the Earth's gravity field described using UML (Unified Modelling Language). Such description can be helpful in the analysis of the gravitational field pillar linkages with other pillars of GGOS. The main purpose of this paper is to give the full explanation of connections between all Earth's gravity field GGOS components. Key words: Earth's gravity field, UML, GGOS

1 Introduction

Geodesy is the science of geometry, gravity field, and rotation of the Earth determination. It also describes their evolution in time. Recently, especially due to satellite techniques and accuracy improvement, geodesy plays a significant role in studying the Earth system. The description of this system is very difficult because of continuous changes (e.g. climate change), inherent dynamics and

many complex relations between its components. Data collected using various techniques complement each other. The Global Geodetic Observing System (GGOS) was established by the International Association of Geodesy (IAG) in July 2003. The idea was to combine all geodetic measurement techniques to take full advantage of them. GGOS is a part of the Global Earth Observation System of Systems (GEOSS). The project is important because it allows a more complete understanding of the Earth's characteristics (Plag and Pearlman 2009). Observations and products are provided not only to scientists but also for non-scientific applications (IAG Services). Observations serve as the basis for many societal areas: disaster prevention, provision of resources like energy and water, and protection of the biosphere (Plag *et al.*, 2009).

The main purpose of this paper is to introduce the full description of connections between various GGOS components. Understanding the relations and dependences within GGOS is necessary for appropriate usage of its products. The authors' intention is to show and explain examples of such relations connected to the part of GGOS that is described as the 'Earth's gravity field' and to present these relations using the Unified Modelling Language (UML) structure diagrams. UML is the formal language and graphical notation used to model and describe reality in object-oriented analysis and programming (OMG UML, 2010). Analysis of interrelations between observation techniques and the Earth's gravity field were presented in Pachelski *et al.* (2008).

2 Terrestrial and satellite techniques used for measurements of the Earth's gravity field

In this section dependences between classes representing main objects related to the terrestrial and satellite techniques in the pillar 'Earth's gravity field' of GGOS (Fig. 1) are presented.

The main task of geodesy is to determine geoid's shape - the surface of constant gravity potential on the basis of measurements of astronomical and geodetic satellite (satellite altimetry), gravity and leveling.

We are going to discuss selected techniques of measurement of the Earth gravitational field, which are being used to determine shape of the geoid.

Terrestrial surveying techniques use such instruments as gravimeters or gradiometers. Due to the constructions of gravimeters they can be divided into the following groups: static (steady state observations of the gravitational mass of the sensor) or dynamic (observations of motion of the body in a gravitational field). Due to the types of measurements relative (differential), and absolute (by directly measuring the acceleration of a mass during free fall in a vacuum) measurements can be distinguished.

Absolute gravimeters measure the local gravity. The low-frequency variations of gravity at particular sites are usually determined using observations gathered with an absolute gravimeters. For example, the FG5 absolute gravimeter is an instrument that determines the gravity value by measuring time of free fall of a unit mass (ballistic measurement).

Relative gravimeters compare the value of gravity at one point with another. They must be calibrated at a location where the gravity is known accurately, and then transported to the location where the gravity is to be determined. They measure the ratio of the gravity at the two points. Temporal variations of the gravity field at a given site is measured using superconducting gravimeters. The superconducting gravimeter is a relative instrument but very stable in time.

Comparing the ground measurements to the airborne gravimetry it can be said that airborne gravimetry is more efficient and effective. It became possible with the development of the GPS (Global Positioning System) technique. The purpose of the airborne gravimetry is to recover the Earth's gravity field on the medium – frequency gravity signal, which will fill the gap between the terrestrial gravity field measurements and global gravity models (Hein, 1995).

Due to the recent satellite technology development satellite observations are the main contribution to the gravity field determination. Today, artificial satellites play a crucial role in determination

of the Earth's gravity field. The geopotential model can be determined, for example, by the means of laser tracking of satellites such as LAGEOS or TOPEX/POSEIDON. The very important step concerning resolution and precision of the model has been provided by the satellite missions such as CHAMP (Reigber *et al.*, 1999), GRACE (Gravity Recovery and Climat Experiment) (Tapley *et al.* 2004), and GOCE (Gravity field and steady-state Ocean Circulation Explorer) (Rehban *et al.* 2000). These temporal and space gravity measurements provide information of the variability of mass around the globe (atmosphere, ocean and hydrology).

Within the GGOS the following international geophysical and geodetic services are responsible for data gathering and analyzing: IGFS (International Gravity Field Service), IGeS (International Geoid Service), ICGEM (International Center for Global Earth Models), and BGI (Bureau Gravimetric International). The main goal of IGFS is to manage collection, validation, archiving and dissemination of the gravity data, to unify gravity products for the needs of GGOS and to take care of services assigned to them.

3 Theory – pillar 'Earth's gravity field'

The diagram in Fig. 2 presents various dependencies between classes, which represent different types of concepts (objects) related to the GGOS pillar called 'Gravity field'. Position of a point is described by geocentric, ortho-Cartesian XYZ coordinates (e.g. in the ITRF – International Terrestrial Reference Frame), which can be converted to the latitude (B or φ), longitude (L or λ) and ellipsoidal height (h). Ellipsoidal height has only geometrical meaning and it represents a distance between a given point on the physical Earth surface and an ellipsoid (e.g. WGS-84) measured along the normal line to the ellipsoid. The diagram presents four different types of heights based on geopotential value C , which expresses the difference of the geoid's potential and the potential at the particular point on the Earth surface. This value stands for a work to be performed against gravity force to carry the unit mass (1 kg) from the geoid (potential W_0) to the point, where the

potential is equal to the one at the point. To obtain the geometric height the geopotential value C has to be divided by the force, which is representative for the distance along the plumb line. This representative force (acceleration for unit mass) is equal 10 m/s^2 for geopotential heights. When considering dynamic heights, this value corresponds to normal gravity acceleration at 45° latitude (Cassinis formula). Determination of the representative gravity for orthometric heights (mean real gravity value g_m along the plumb line) is much more complex. It can be calculated by measuring the gravity on the Earth surface and then reducing it using the Poincare-Prey's reduction for the half of the analyzed point's height. Different methods of gravity reduction (calculation of the gravity on the geoid based on the values measured on the physical Earth surface), like Faye's and Bouguer's reductions, are presented in the Fig. 2. As a consequence of the reduction definition, a concept of anomalies has to be introduced. An anomaly is a difference between real gravity on the geoid (obtained using proper reduction) and normal gravity on the ellipsoid (or normal spheroid). Different types of anomalies can be distinguished according to different types of reductions (e.g. Bouguer's or Faye's anomalies). Gravimetric anomalies can be used for the determination of plumb line deflections on the geoid (Vening-Meinesz formulae), which in turn enable determination of the geoid's shape (more precisely its undulations) using Stokes formula. Determination of the geoid's local shape is mainly performed by means of astronomical-geodetic or astronomical-gravimetric levelling, which take the advantage of the relationship between geoid's undulation changes and plumb line deflections (absolute, relative or gravimetric). The diagram in Fig. 2 specifies the reference ellipsoid for relative (local ellipsoid) and absolute (geocentric ellipsoid) deflections. To determine normal heights (based on the Molodensky's theory) mean normal gravity values are needed. They can be calculated by adding inverse Faye's reduction for the half of the point's height to the normal gravity on the ellipsoid. Normal heights correspond to telluroid points' heights.

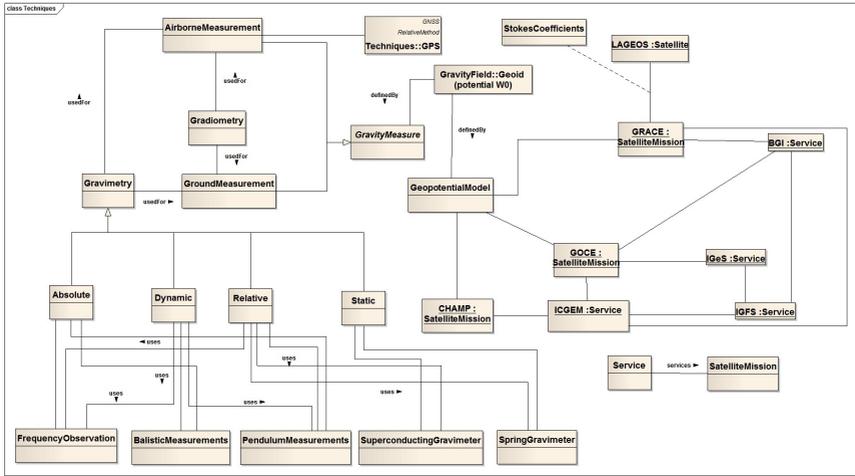


Figure 2. Dependencies between classes in the pillar 'Earth's gravity field'

4 Summary

The paper presents a description of the main relationships between different classes of the GGOS pillar 'Earth's Gravity Field', where each class represents a particular conceptual notion relevant to the gravity. The primary goal is to show a very complex structure of dependencies between different segments and to describe this part of geodesy by the means of standard general-purpose modelling language UML. However, it is useless to analyse one selected segment of geodesy separately of the others, especially without a reference to satellite techniques (and, in a consequence, GGOS pillar related to geometry and kinematics). All diagrams presented here are the result of preliminary analyses and they play a major role as a frame for further more detailed analyses, including relationships with other GGOS pillars. Modelling of all of the most important GGOS relations will facilitate ordering and linking together all terms and elements and it will help to use theory of geodesy for geophysical phenomena monitoring.

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