Ocean circulation from altimetry and GOCE data

CE678A Physical Geodesy | 2020-21 I
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The Gravity Field and Steady-State Ocean Circulation Explorer (GOCE) was the first of ESA's Living Planet Programme satellites intended to map in unprecedented detail the Earth's gravity field. Launched on 17 March 2009, GOCE mapped the deep structure of the Earth's mantle and probed hazardous volcanic regions. It brought new insight into ocean behaviour; this in particular, was a major driver for the mission. By combining the gravity data with information about sea surface height gathered by other satellite altimeters, scientists were able to track the direction and speed of geostrophic ocean currents. The low orbit and high accuracy of the system greatly improved the known accuracy and spatial resolution of the geoid (the theoretical surface of equal gravitational potential on the Earth).After the time-lapse and long-wavelength studies from Gravity Recovery and Climate Experiment (GRACE) a new sensor was available for determination of the Earth's gravity field and geoid with high accuracy and spatial resolution.

The primary goal of GRACE is the measurement of the temporal variations of the Earth's gravity field, caused by the transport of masses and their redistribution in the Earth system. While the goal of GOCE is maximum spatial resolution, the GRACE mission aims at maximum precision at some expense in terms of spatial resolution. The two types of gravity field information are complementary and vastly important for Earth system science. The GRACE time series reveal the path and to some extent the size of mass movements, related to and caused by processes such as melting ice sheets, the global water cycle, sea level variations, post glacial mass re-adjustments and others. GOCE, on the other hand, provides one global and detailed map of spatial gravity and geoid variations. On top, GOCE also provides gravity gradients, i.e., the three-dimensional second derivatives of the gravitational potential.

1 Theory

Measuring the ocean's steady-state circulation is a central objective of the GOCE mission. The link between GOCE and the ocean's circulation arises through the dominant role Earth's gravity plays in shaping the ocean's surface. In static equilibrium the ocean's surface would coincide exactly with the particular equipotential surface of Earth's gravity known as the geoid. However, small deviations from the geoid on the order of 1 m arise due to ocean dynamic processes driven by wind and buoyancy forcing. The ellipsoidal height of the ocean's surface $h(t)$ at any instant t is given by

$$h(t) = N + \eta(t) \tag{1}$$

where N is the geoid height and $\eta(t)$ is the instantaneous ocean dynamic topography. The dynamic topography $\eta(t)$ plays the role of the orthometric height H.

It is common practice to consider the dynamic topography as consisting of a time-mean $\overline{\eta}$ and a time-dependent component $\delta\eta(t)$. Through repeat track sampling, satellite altimetry alone can deliver the latter with an accuracy of less than 2 cm. The former, known as the mean dynamic topography (MDT) $\bar{\eta}$, may be obtained by subtracting an estimate of the geoid from an altimetric mean sea surface (MSS) $\bar{h}$.

$$\bar{\eta} = \bar{h} - N \tag{2}$$

One of the grand challenges of satellite geodesy has been to measure the geoid globally with sufficient accuracy that it can be subtracted from an altimetric MSS to reveal the MDT with sufficient accuracy and spatial resolution to be useful to oceanography.

The link between the MDT and ocean's steady-state (i.e. time-mean) circulation arises because the ocean is largely in geostrophic balance. That is, for the open ocean, the dominant large-scale dynamical balance is between the Coriolis force and horizontal pressure gradients. Thus, if we know the MDT, the geostrophic surface currents may easily be determined according to:

$$u = -\frac{\gamma}{f\,R}\frac{\partial\overline{\eta}}{\partial\phi} \tag{3}$$

$$v = \frac{\gamma}{f\,R\cos\phi}\frac{\partial\overline{\eta}}{\partial\lambda} \tag{4}$$

where u, v are the elements of the geostrophic current vector, $f = 2\omega_e \sin\phi$ is the Coriolis force, ω_e is the angular velocity of the Earth, R is the mean radius of the Earth, ϕ is the latitude, λ is the longitude, and γ is the normal gravity.

2 Project work

The main goal of the project is to estimate the geostrophic current vector from the geoid and mean sea surface information, which are both derived from geodetic data.

3 Data

For the project, use **static models** from **ICGEM** website. Select satellite only models that include GRACE and GOCE data. The geoid model for the chosen geopotential model can be calculated in the website. Select the grids and choose geoid of reference ellipsoid WGS84 then perform the calculation of grids.

The SSH data is available as 10 day datasets from TOPEX/Poseidon and Jason series of satellites and as 35 day datasets from SARAL/AltiKa, an Indo-French mission every 35 days, but at a higher spatial density than the former. Take these two datasets for a period of about three years and find the mean sea surface on a $0.1^\circ \times 0.1^\circ$ equiangular grid. Remove the geoid model computed from ICGEM website and compute the gradient to estimate the **geostrophic current** of the seas around India (50° E - 110° E, 20° S - 30° N). It must be noted that all the SSH data are referred to TOPEX/Poseidon ellipsoid, therefore, the elevations must be transformed to the WGS ellipsoid.

4 Technical report and software documentation

As per the protocol, you will need to submit a short report (maximum 5 pages including graphs and figures), software written as a toolbox and its documentation. The report must be structured as follows: abstract, introduction, mathemtical details, methods, results, discussion and conclusion. Use the manuscript submission format of International Association of Geodesy Symposia given at `https://www.springer.com/series/1345`. Your project will be evaluated for ease of use of the software, the clarity of your documentation and the scientific quality of your report. All results should be reproducible, and therefore, please submit your code that you used for creating your figures, tables and other results. Otherwise, the results will be considered plagiarised. Plagiarism of any form will be dealt with severely. Since it is a project work, you are also expected to do some literature review and study about the project topic at your end.

5 Evaluation

The evaluation for the project will be continous, and therefore, you will have weekly deliverables.

Week 1	Literature review and data collection
Week 2	Exploration of data and data visualization
Week 3	First results
Week 4	Final results, project report, software and its documentation

6 References

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3. http://eo-virtual-archive1.esa.int/Index.html