Introduction to Geophysics

[ES 3004 / ES 7020]

Semester 2, AY2025–2026

Nanyang Technological University

Tutorial
Gravity Changes from Greenland Ice Mass Loss (GRACE)

1. Physical motivation

The Earth's gravity field is not constant in time. Any redistribution of mass inside or on the surface of the Earth modifies the gravitational attraction that can be measured from space. Large ice sheets are particularly important in this respect because they store enormous amounts of mass and can change rapidly on decadal timescales.

The GRACE and GRACE–FO satellite missions were designed to measure *temporal variations* of the Earth's gravity field. One of their most important applications is the quantification of ice mass loss from Greenland and Antarctica. In this tutorial, you will use Level–3 GRAVIS products to analyze Greenland ice mass changes and convert them into gravity variations.

2. What the GRAVIS data represent

The GRAVIS Level–3 products used in this tutorial are provided as *Equivalent Water Height* (EWH), expressed in millimeters. EWH is defined as the thickness of a uniform layer of water that would produce the same gravity signal as the observed mass redistribution. EWH is not ice thickness, but a gravity-equivalent quantity. It allows us to work directly with gravity-derived mass changes without explicitly inverting the gravity field ourselves. The data are provided on a regular latitude–longitude grid over Greenland and sampled monthly over the GRACE/GRACE–FO mission period.

3. Reading and inspecting the data

The MATLAB script first inspects the NetCDF file metadata to identify the three-dimensional variable that depends on longitude, latitude, and time. This ensures that the script remains robust even if variable names change between data releases.

Longitude, latitude, and time vectors are then read from the file. The time variable is converted into calendar dates using a reference epoch provided in the metadata. This allows the gravity and mass time series to be plotted using real calendar years rather than abstract indices.

4. Early, late, and difference fields

To highlight long-term ice mass change, two snapshots in time are selected:

- an early snapshot at the beginning of the GRACE record (around 2002)
- a late snapshot near the end of the available record.

The difference between these two fields isolates the cumulative mass change over more than two decades. Mapping the early field, late field, and their difference provides a clear spatial picture of where ice mass has been lost.

5. Greenland-averaged time series

In addition to spatial maps, the script computes a Greenland-wide average of the EWH signal by averaging over all grid points at each time step. This produces a single time series that shows the temporal evolution of total ice mass change.

This time series highlights both the long-term downward trend associated with ice loss and shorter-period variability related to seasonal and interannual processes.

6. From mass change to gravity change

GRACE does not measure ice mass directly; it measures changes in gravity. To make this connection explicit, the tutorial includes an exercise that converts EWH into gravity change using the Bouguer slab approximation. For an infinite horizontal slab of thickness h and density ρ, the gravity change at the surface is

$$\Delta g = 2\pi G\rho h, \tag{1}$$

where G is the gravitational constant.

In this tutorial:

- h is the equivalent water height converted from millimeters to meters,
- ρ is the density of water,
- Δg is converted from m/s^2 to microGal (μGal).

Although simplified, this approximation provides a physically meaningful estimate of the gravity signal produced by ice mass loss.

7. Interpretation of gravity change maps

The resulting gravity change map over Greenland shows predominantly negative anomalies, indicating a reduction in mass. The largest negative signals occur near the margins of the ice sheet, where ice loss has been most pronounced.

The magnitude of the gravity change reaches several hundred microGal when integrated over more than two decades. While this signal is extremely small in absolute terms, it is well within the detection capability of satellite gravimetry and illustrates the remarkable sensitivity of GRACE and GRACE–FO.

8. Time evolution and animation

Finally, the script animates the monthly evolution of the EWH field. This visualization allows students to see how ice mass loss develops spatially and temporally, rather than only comparing two snapshots.

Such animations are particularly useful for building intuition about how gravity observations reflect continuous mass redistribution rather than static structures.

9. Key takeaways

By the end of this tutorial, you should understand that:

- GRACE measures time-variable gravity, not ice thickness directly,
- gravity changes can be interpreted in terms of mass redistribution,
- satellite gravimetry provides direct geophysical evidence of climate-driven ice mass loss,
- simple physical approximations allow us to translate gravity signals into meaningful quantities.

This tutorial demonstrates how gravity measurements connect large-scale Earth system processes to quantitative geophysical observations.