# Geodetic Gravity

## *Measuring Earth's mass distribution to define height, monitor change, and connect geodesy from local to global scales*

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*Gravity is more than the force that keeps us on the ground; it is a window into the Earth's changing mass. Tiny variations in Earth's gravity field reveal the movement and redistribution of water, ice, oceans, and mass within the solid Earth. By measuring these changes over time and across the globe, geodesy provides the foundation for accurate heights, reliable positioning, and a better understanding of how our planet is changing.*

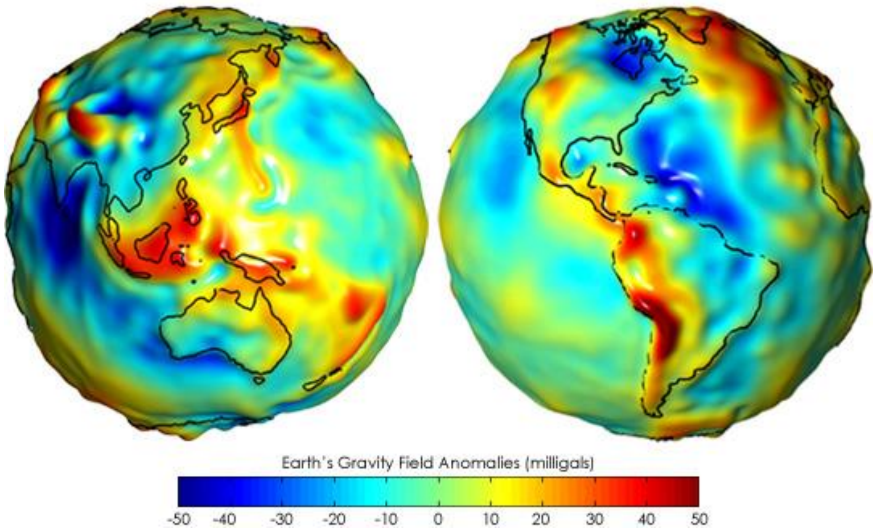
## Gravity: More Than Just "Down"

### *Gravity feels constant and un-changing to us in everyday settings, but it isn't*

Earth's gravity field varies subtly (up to 0.5%) from place to place, reflecting the shape of the planet, its rotation, and the distribution of mass from surface rocks and groundwater to deeper structures within the crust, mantle, and core.

By measuring gravity and its spatial and temporal variations, geodesists model the *level* reference surfaces that define physically meaningful heights, connecting GNSS positioning to local positioning methods (e.g. levelling), and monitor processes such as tides, water movement, deformation, and long-term mass redistribution.

Without geodetic gravity, there is no physically consistent height system, and no complete description of how the Earth system changes through time.



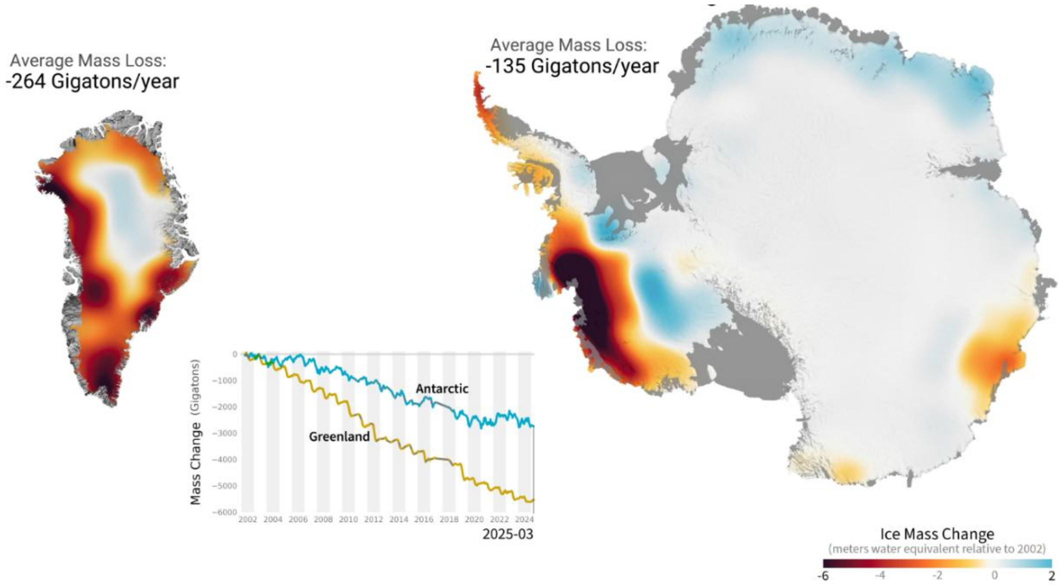

*The colours show variations in Earth's gravity across the globe. Yellow, orange and red indicate areas where gravity is stronger, such as the Himalayan region in Central Asia and parts of the Pacific Ring of Fire. Progressively darker shades of blue indicate areas where gravity is weaker, such as around Hudson Bay in Canada and parts of the Indian Ocean. Credit: NASA/JPL-Caltech, Public Domain.*

## Gravity as a Measure of Mass Distribution and Change

What makes gravity uniquely powerful is that it responds directly to mass itself, not just to surface shape or visible boundaries. Variations in topography, geology, crustal structure, groundwater, oceans, ice, and deeper density contrasts all leave measurable signatures in the gravity field.

This means gravity integrates signals across the land, oceans, and solid Earth, and can reveal processes that are otherwise hidden beneath the surface. Some of these signals define the broad structure of the gravity field needed for geopotential modelling and physical heighting, while others record temporal changes such as tides, hydrological redistribution, elastic deformation, and long-term mass change.

Though often small, these gravity signals are measurable, and fundamental to modern geodesy.




*These images show changes in the mass of polar ice sheets derived from satellite gravity observations since 2002. Orange and red areas indicate ice mass loss, while light blue areas show ice mass gain. White areas represent little or no change. Between 2002 and 2023, Antarctica lost an average of approximately 150 gigatons of ice per year, contributing about 0.4 millimetres per year to global sea-level rise. Greenland lost approximately 270 gigatons per year, contributing about 0.8 millimetres per year to global sea-level rise. Credit: NASA/JPL-Caltech, Public Domain.*

## How Geodetic Gravity Is Measured

Geodetic gravity relies on a suite of complementary techniques that measure gravity at different spatial and temporal scales.

**Static techniques include *Absolute gravimeters***, including classical free-fall systems and emerging quantum instruments, provide precise absolute gravity values at a single location and epoch, and ***superconducting gravimeters*** which continuously record tiny temporal variations in gravity at fixed sites. They are sensitive to signals associated with Earth tides, ocean loading, atmospheric effects, hydrology, and elastic deformation, making them essential for observing time-variable gravity.

**Spatial mapping techniques include *Relative terrestrial gravimeters*,** which measure gravity differences between locations for local and regional surveys. ***Satellite gravity missions,*** such as GRACE, GRACE Follow-On, and GOCE, which recover the gravity field and its change at regional to global scales. ***Airborne scalar gravimetry and gravity gradiometry***, which map the gravity field and its gradients efficiently across large areas.

## GGOS: Connecting gravity to the Earth system

GGOS, the Global Geodetic Observing System, coordinates global geodetic observations to provide a ***consistent, long-term picture of Earth's shape, rotation, and gravity field***.

From the GGOS perspective, gravity is not an isolated measurement. It is:

- Integrated with satellite positioning and reference frames
- Combined with ground-based and space-based observations
- Interpreted within Earth-system models

This integration allows GGOS to transform subtle gravity changes into ***actionable knowledge*** about:

- Sea-level rise
- Ice-sheet mass balance
- Groundwater depletion
- Solid Earth deformation
- Global mass transport

In short: ***gravity connects Earth's moving parts into one coherent story***.

## Why Geodetic Gravity Matters to Society

Geodetic gravity matters because it is part of the physical framework that allows societies to define height consistently, monitor changes in water and ice, and maintain the geodetic reference systems on which positioning depends.

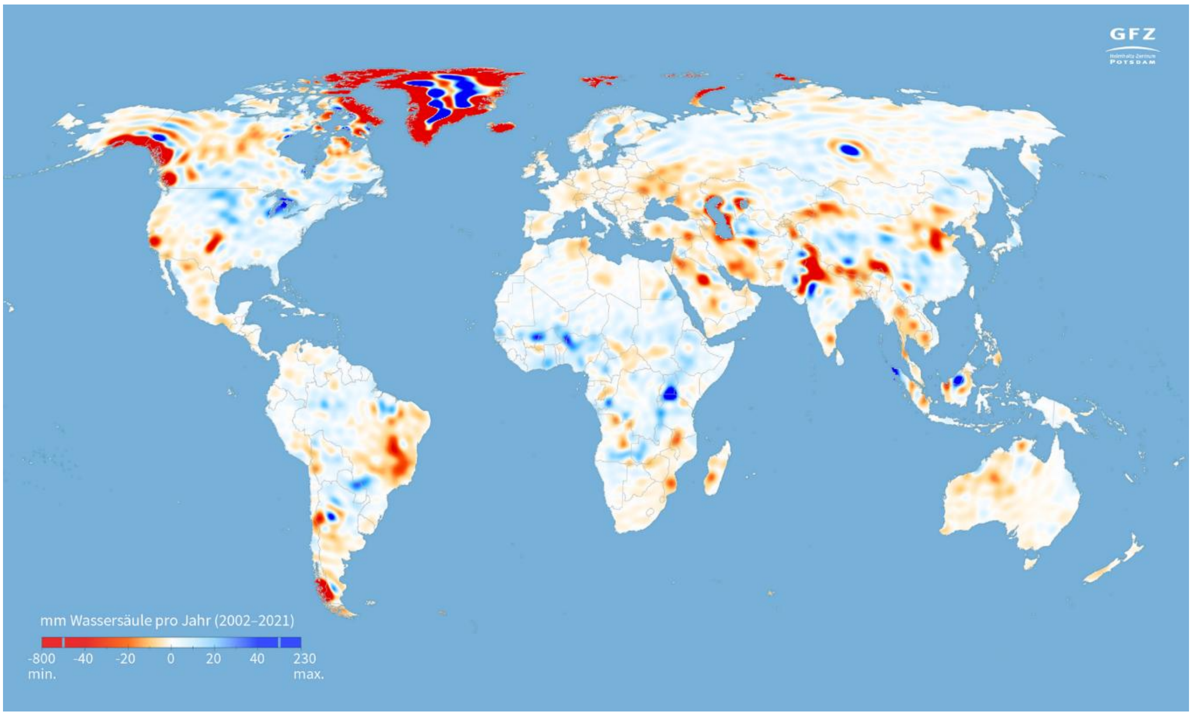
By linking GNSS to physically meaningful heights, gravity supports the practical needs of engineering, flood assessment, and infrastructure development. By reflecting mass change, it also provides critical insight into groundwater depletion, ice loss, sea level processes, deformation , volcanic and mantle dynamics, and broader Earth system change.

Geodetic gravity is both a scientific observable and a foundational societal capability, and GGOS is designed to deliver ***long-term, stable, globally consistent observations***.

## Why continuity and coordination matters

Many gravity signals of geodetic interest are easily obscured by noise, instrumental drift, or gaps in observations. This means that continuity is just as important as precision. Continuity matters in both time and space. Long, stable time series are needed to resolve tides, deformation, hydrological change, and other subtle temporal signals. Broad and continuous gravity coverage is also needed to model the height reference surfaces that allow heights to be determined accurately and consistently.

Reliable gravity monitoring and modelling therefore depends on sustained observations from space and from the ground, including satellite gravity missions, absolute and superconducting gravimetry, and co-located multi-technique geodetic stations tied together through common standards and reference systems. Without this coordinated and long-term approach, subtle gravity signals related to Earth processes cannot be separated confidently from noise, and the physical surfaces needed for height system definition cannot be recovered with confidence.




*The map shows long-term changes in terrestrial water storage derived from GRACE and GRACE-FO satellite observations from 2002 to 2021. Red indicates water loss, while blue indicates increases in water storage. Water losses are evident along the Alaskan coast and in Patagonia, associated with glacier melt, and in northeastern China around Bohai Bay and the Yellow Sea and in northern India, where long-term groundwater overuse for irrigation has caused substantial depletion. In contrast, the blue area around Lake Victoria in southern Africa reflects the recovery of the lake's water levels from historically low levels in the early 2000s. Credit: GFZ German Research Centre for Geosciences.*

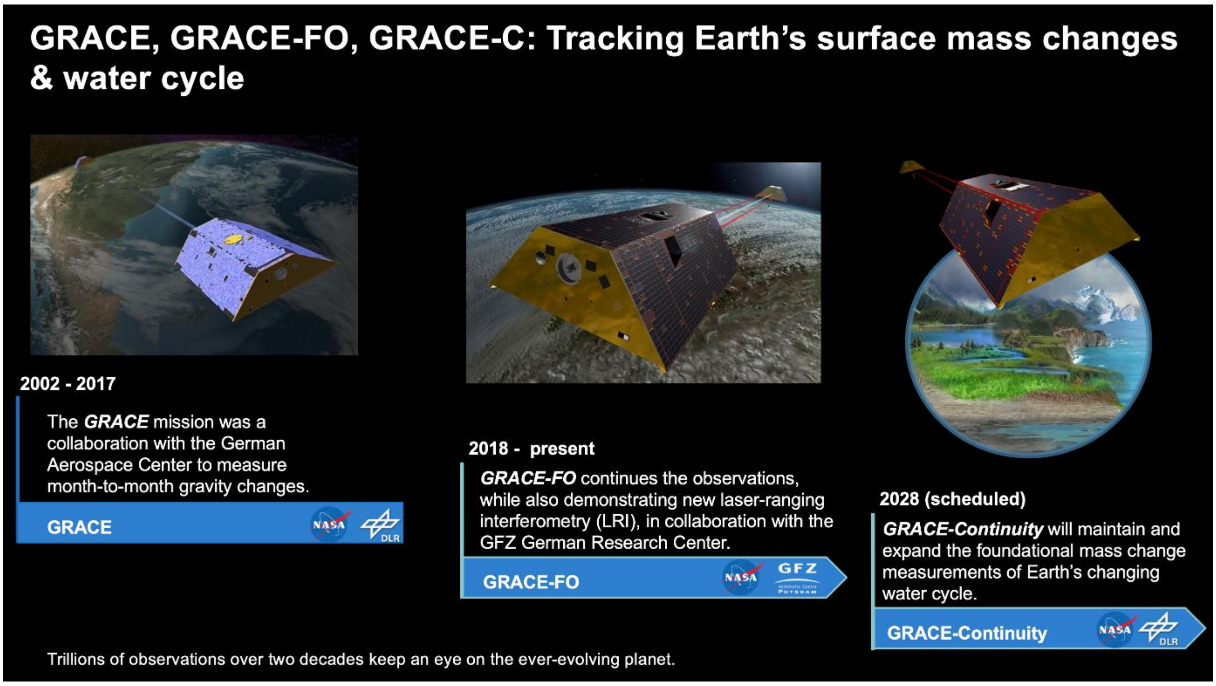
## Gravity as an Essential Geodetic Variable

Within GGOS, gravity is recognized as part of the emerging concept of ***Essential Geodetic Variables (EGVs)***, measurements that are fundamental for monitoring and understanding Earth-system change.

EGVs provide the ***geodetic foundation*** for:

- Climate observing systems
- Ocean and hydrological monitoring
- Integrated Earth-observation frameworks

Geodetic gravity is ***essential infrastructure for knowledge***.




*Satellite gravimetry measures changes in Earth's gravity field by observing tiny variations in the motion and separation of satellites in orbit. These measurements are used to determine changes in Earth's mass distribution, including the movement of water, ice, and ocean mass, as well as signals from the solid Earth. Missions such as GRACE, GRACE Follow-On, and GRACE-C therefore provide a unique global view of how mass is redistributed across and within the Earth system. Credit: NASA/JPL-Caltech, Public Domain.*

RECAP

### *Why geodetic gravity matters*

Geodetic gravity reveals where mass is distributed within the Earth and how that distribution changes through time. It underpins physically meaningful height, strengthens geodetic reference systems, and helps track the movement of water, ice, oceans, and the solid Earth.

Measured precisely and sustained over time, geodetic gravity becomes a powerful tool for understanding and managing a changing planet.

Through GGOS, these insights become ***globally consistent, openly accessible, and scientifically robust***, supporting decisions that affect societies worldwide.

***Geodetic gravity reminds us that even the smallest signals can carry the biggest stories, if we measure them well, and together*.**

## Find out more

Web geodesy.science/ggos/egv/global-earth-gravity-field/

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