

Understanding Earth starts with understanding its gravity

by Laura Sánchez | Deutsches Geodätisches Forschungsinstitut (DGFI-TUM), Technische Universität München, Germany
 Derek van Westrum | NOAA's National Geodetic Survey (NGS-NOAA), USA
 George Vergos | GravLab, Aristotle University of Thessaloniki (DGS/AUTH), Greece

Accurate knowledge of the Earth's gravity field is essential for understanding its shape, interior structure and fluid systems. This knowledge allows us to quantify mass distribution and changes, thereby supporting the monitoring of the oceans, hydrology, ice sheets, sea levels, and mantle-crust dynamics. Geodesy measures the Earth's gravity and represents it in the form of mathematical equations (known as gravity field models) that are essential for informed research in geophysics, glaciology, hydrology, oceanography, climate research, mineral exploration, and the precise determination of satellite and space vehicle orbits and positioning.

Gravitation and Earth's gravity

Gravitation is the force that pulls objects towards each other. It acts as an invisible glue, holding everything together. Generally, bigger objects exert a stronger gravitational pull than smaller ones. On Earth, gravitation keeps us on the ground and makes things fall. Your weight is the result of the Earth's gravitational pull on your body's mass. In space, gravitation keeps planets orbiting the Sun, moons orbiting planets, and satellites orbiting Earth. The closer two objects are, the stronger their gravitational pull on

each other. Gravitation is everywhere. Every object with mass, whether a tiny dust particle or a huge planet, exerts a gravitational pull on everything else. Mass matters: The heavier an object is, the stronger its gravitational pull. Gravitation is always attractive. Gravitation always pulls objects together; it never pushes them apart. The gravitational force that an object experiences due to the Earth's mass is called gravity.



Why is it important to know about Earth's gravity?

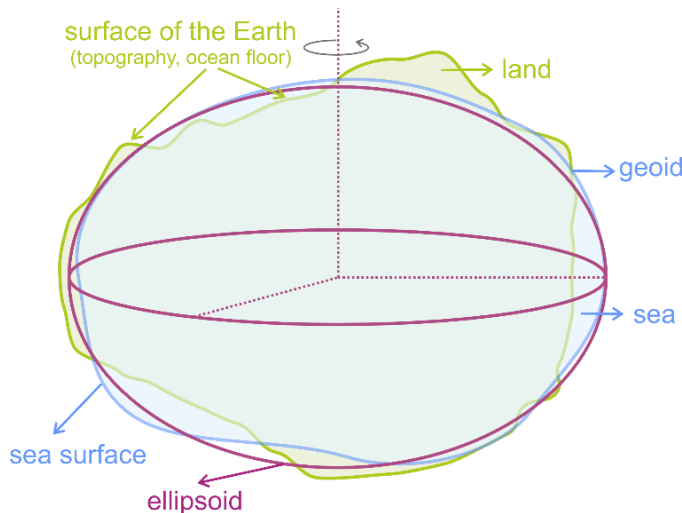
The different materials and structures that make up the Earth have varying mass densities and move relative to each other, resulting in variations in gravity over space and time. Therefore, the precise knowledge of the Earth's gravity is fundamental to provide information about the

Earth's shape, its interior and fluid envelope. It is essential for many Earth research areas, such as quantifying mass distribution and mass transport, monitoring oceanic currents, continental hydrology, ice mass balance and sea level, and dynamics of mantle and crust. Knowledge on the Earth's gravity is not only relevant for geodesy but also for other geosciences, such as geophysics, glaciology, hydrology, oceanography, and climatology.

The role of Geodesy: The Earth's gravity and its perfect twin

Geodesy is the science of measuring the Earth's shape, rotation and gravity. To precisely determine the variations in the Earth's gravity, geodesists use a mathematical model of the Earth as a reference body. This model is called the ellipsoid and is a mathematical apparatus of the planet. This model has the same size and

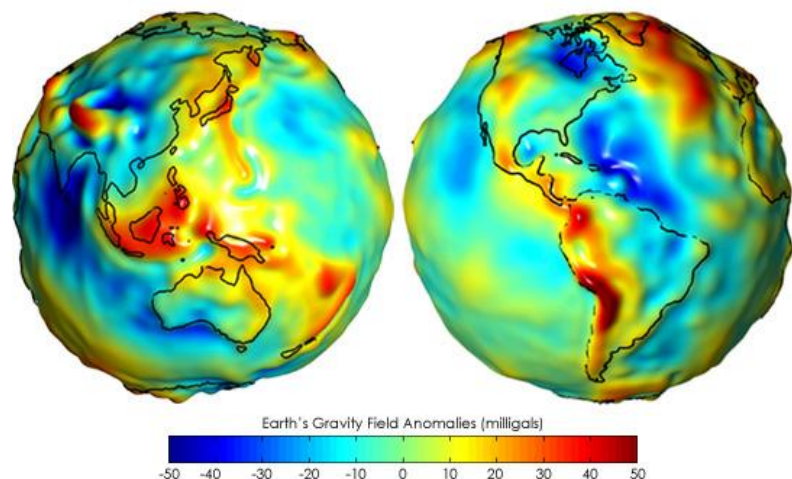
flattening as the Earth, contains the same mass as the Earth and rotates at the same rate as the Earth. The difference is that the mass distribution inside the ellipsoid is assumed to be homogeneous, unlike the real Earth. In this way, geodesists concentrate on determining the gravity differences between the real Earth and the ellipsoid.



The shape of the ellipsoid (its equatorial radius and flattening) is calculated based on the geoid. The geoid can be understood as the shape the ocean surface would take if it would cover the entire Earth and were influenced only by the Earth's gravity and rotation, without influence of winds, currents, and tides. In rough terms, the geoid coincides with the mean sea level and serves as the zero surface for measuring heights above mean sea level.

Tracing Earth's moving masses and climate change

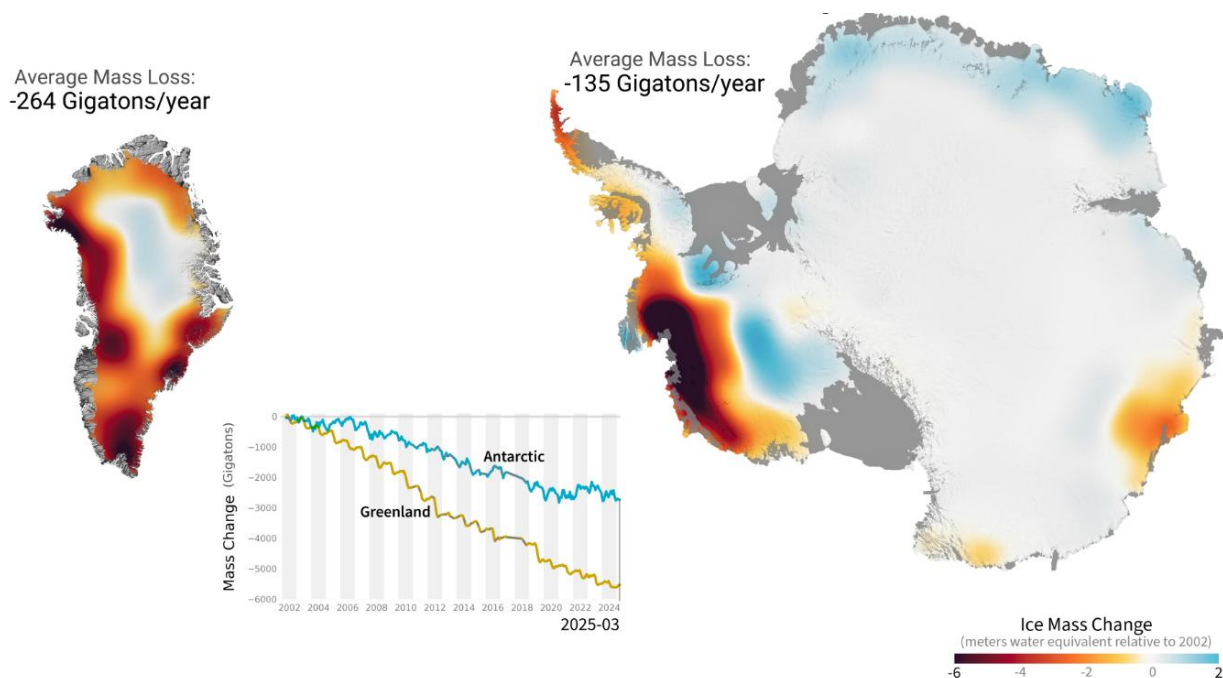
By comparing the real Earth's gravity and the gravity of the ellipsoid, geodesists determine gravity anomalies, i.e., discrepancies of the real gravity with respect to the mathematical model. A positive anomaly at a specific location indicates that the Earth has an excess of masses with respect to the ellipsoid. In the same way, if the anomaly is negative, it indicates a defect of masses in the Earth with respect to the ellipsoid. Changes in the anomalies over time indicate that the gravitational pull at that specific location has changed, i.e., the mass



Gravity anomalies show how much the Earth's gravity differs from that of the ellipsoid. Yellow, orange and red areas indicate places where the Earth's gravity is stronger than that of the ellipsoid; for example, in the Himalayan Mountains in Central Asia or around the Pacific Ring of Fire. Conversely, progressively darker shades of blue indicate areas where the Earth's gravity is weaker; for example, in the area around Hudson Bay in Canada or Indian Ocean. Courtesy of NASA/JPL-Caltech.

distribution has changed, due to some natural phenomenon. In this way, geodesists measure the mass transport throughout the Earth. Outcomes of geodesy in this regard provide the foundation to estimate, for example, loss of masses in the polar ice caps, changes in the Earth's interior after strong earthquakes, or variations in terrestrial water

storage, which in addition to the ice caps also includes glaciers, snow cover, soil moisture, groundwater, surface water bodies, water in biomass, etc. This information is essential for monitoring the effects of climate change and understanding the global hydrological cycle to manage water resources efficiently.



These images show the changes in the mass of polar land ice inferred from satellite gravity measurements since 2002. Orange and red shades indicate areas that have lost ice mass, while light blue shades indicate areas that have gained it. White indicates areas where there has been little to no change in ice mass since 2002. Between 2002 and 2023, Antarctica shed approximately 150 gigatons of ice per year, causing the global sea level to rise by 0.4 millimetres per year, while Greenland shed approximately 270 gigatons of ice per year, causing the global sea level to rise by 0.8 millimetres per year. Courtesy of NASA/JPL-Caltech.

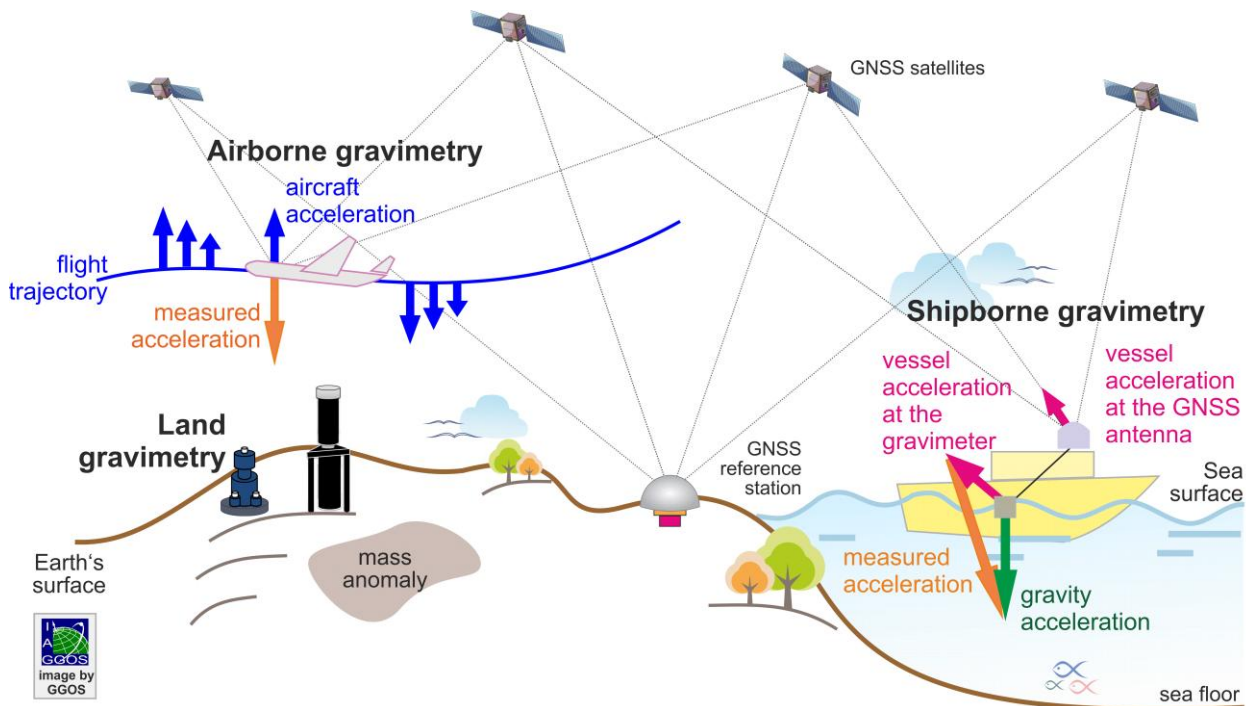
Measuring gravity from space and Earth

Geodesists utilise satellites and ground-based gravity meters to measure gravity. Satellite gravimetry is essential for modelling geodynamic processes in the ocean and solid Earth, revealing mass redistribution across the Earth components, computing the global geoid (the reference surface for physical heights) and determining precise satellite orbits, especially for positioning and navigation satellites, low Earth orbiters, and Earth observation missions. The global geoid, which can be thought as approximated by the mean level of the oceans, is essential for studying sea level changes, modelling ocean circulation, and monitoring the state of the hydrosphere. Globally observed gravity quantities are

essential for detecting mass density anomalies in the Earth's crust and mantle to study the Earth's interior dynamics, as well as for revealing major tectonic structures and subsurface processes. Satellite gravimetry provides a unique, global, and homogeneous data set of mass anomalies within or on the surface of the Earth. However, current satellite gravimetry is unable to resolve structures smaller than a few hundred kilometres. To increase the spatial and temporal resolutions of the satellite gravimetry and be able to detect short-term and small-scale mass changes, terrestrial gravimetry is essential. Terrestrial gravimeters can detect changes in mass distribution within a radius of a few hundred

meters from the instrument with an astonishing accuracy of a few parts per billion. Thus, terrestrial gravimetry is an important tool to monitor low-frequency seismicity, volcanic systems, geothermal reservoirs, effects of irrigation or water withdrawal, impacts of large building projects,

etc. Terrestrial gravity data is also essential for geophysical prospection, and it is widely used in the exploration of natural resources like oil and gas, as well as in mining and in geotechnical, archaeological, metrological and geomatics studies.



Gravimetry is the measurement of gravity. Gravity measurements can be based on the analysis of satellite orbits, using sensors on dedicated gravity satellite missions, or using terrestrial techniques, specifically, airborne gravimetry, shipborne gravimetry and land-based gravimetry. The acceleration of an object under the influence of Earth's gravity, g , ranges from approximately 9.78 ms^{-2} (at the equator) to about 9.83 ms^{-2} (at the poles).

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Geodesy is the science of measuring the Earth's shape, rotation and gravity, which allows for the study of its interior and mass systems. Since the density of Earth's materials varies and they move over time, the strength of gravity varies across space and time. Geodesists detect these variations by comparing observations of the real gravity with a simplified reference model called ellipsoid. The differences between the two (gravity anomalies) reveal changes in mass, such as ice loss, water movement or shifts following earthquakes. Geodesy is therefore essential for monitoring climate change, water resources, ocean circulation, sea level variations and the dynamics of the Earth's interior. Measurements are made using satellites, which provide global data, and ground-based gravity metres, which capture local, high-resolution changes. Together, these measurements provide crucial information for geophysics, hydrology, glaciology, oceanography, climatology, resource exploration and engineering.

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

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