GEODESY

Geodesy is the study of the size and shape of Earth's surface

Earth is not a perfect sphere. The distance around the equator is slightly longer than the distance around Earth through the Poles. The shape of Earth is called the geoid. This is a type of ellipsoid, or squashed ball.

CONNECTIONS

- RADIO WAVES from QUASERS help scientists measure the shape of Earth.
- Scientists use geodesy to predict EARTHQUAKES and VOLCANOES, and study OCEANS.
- Geodesy is essential for MAPS AND MAPPING used in NAVIGATION and SURVEYING.

Most people think Earth is perfectly round, like a ball. However, this is not quite true. Earth is actually slightly squashed between the North and South Poles. The distance from the North to South Pole, about 7,900 miles (12,713 km), is slightly less than the distance across the equator, about 7,926 miles (12,756 km). The reason for this bulge across the equator is that Earth is spinning about an axis through the North and South Poles, turning once every day (see DAY). Those regions nearest to the axis have less outward force applied to them than those farther away, and so the equator is pushed outward. One can imagine this force, called the centrifugal force, by thinking of children standing on a spinning roundabout, with those children nearest the center feeling less push than those at the edge.

Although this bulging is small in comparison to Earth's size, at about 0.003 of its diameter, it is still an important effect. For example, 20 miles error in a map would make it almost useless. Knowing Earth's shape is also important for predicting earthquakes, for modeling ocean currents, and even for in the automatic guidance systems in military missiles. Scientists devote a whole discipline of engineering to

CORE FACTS

- Earth is not a perfectly round ball, but is actually slightly squashed across the North and South Poles.
- The study of the size and shape of Earth is called geodesy. Its mathematical shape is called the geoid.
- Today's scientists use satellite GPS technology and radio telescopes to measure Earth to accuracies of inches over several kilometers.
- The study of Earth's gravity field is also a subject of geodesy, since Earth's shape causes slight variations in the strength of gravity.

this one problem, called geodesy. This is from the Latin word *geodese* meaning "in relation to Earth." Geodesy measuring techniques are some of the most advanced in physics, some having errors less than 1 inch (2.5 cm) over 1,000 miles (1,600 km).

Earth's shape

The mathematical shape of Earth is called the geoid. Scientists currently know the geoid to an accuracy of about 3 feet 3 inches (1 m) worldwide, although in many places it is known more accurately. One can think of the geoid as the extension of mean sea level to land. Suppose all land was changed into liquid and fell into a smooth surface, then this shape would be the geoid. In practice, there are hills and valleys rising and falling, making the topography of Earth's surface. Even though these features seem large to humans, they are small on a planetary scale. For example, an apple expanded to Earth's size would have a skin as thick as the solid crust, with mountains and gorges being only tiny features.

When measuring the geoid, scientists convert the results into a mathematical surface. The simplest shape, which dates back to ancient Greece, is a perfectly round ball, or sphere. Since scientists know the world is not quite spherical, they instead use a surface called an ellipsoid, which is a distorted sphere. (An American football also approximates to an ellipsoid, but is stretched instead of flattened like the geoid). While an ellipsoid approximates the geoid reasonably well, up to about 300 feet (91 m) accuracy over a continent, it is still not completely exact, and more complicated surfaces are used in geodesy.

How Earth is measured

Scientists have measured the size and shape of Earth for thousands of years. The Greek mathematician Eratosthenes (c.276–c.196 B.C.E) used the angles cast by shadows at different points on Earth's surface to calculate a circumference of about 25,000 miles (40,234 km), remarkably close to the actual length of 24,901 miles (40,074 km) at Earth's equator. Today scientists use radio waves and satellites to measure distances with incredible accuracy.

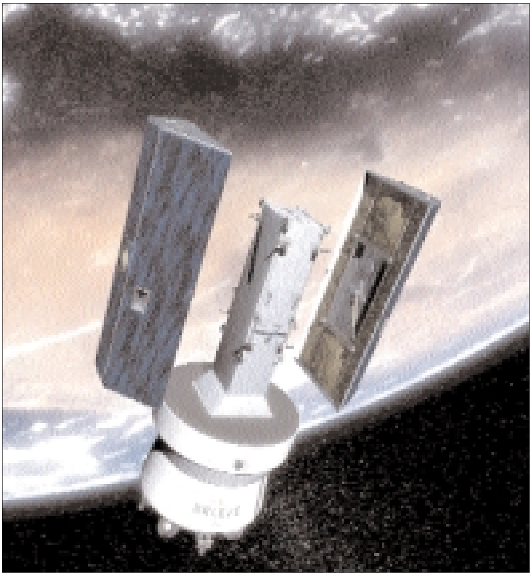
The Global Positioning System (GPS) is a particularly useful technique for accurately finding the position of an object, and thus measuring Earth. The GPS navigation system is based on 24 space satellites, called NAVSTAR (NAVigation Satellite Timing and Ranging), which are built and maintained by the U.S. military. Each GPS satellite continuously transmits radio signals describing the satellite's position and the time the signal was sent. A GPS receiver can then decodes these signals to find its position. Typically, hand-held receivers are accurate to around 90 feet (27 m), while surveying or military-grade devices have errors of less than 15 feet (4.5 m). The GPS device calculates its position by locating three satellites and finding the distance to each. This distance is equal to the time that the signal takes to travel to the receiver multiplied by the speed of radio waves, about 186,000 miles per hour (300,000 km/h).

Very Long Baseline Interferometry (VLBI) is another technique for measuring the distance between two telescopes very precisely. It uses radio waves emitted from quasars—extremely distant radio sources many billions of lightyears from Earth (see QUASARS). Scientists measure how much longer the signals take to reach one telescope after the other. They can then calculate the distance between telescopes using the speed of radio waves. Typical accuracies are a fraction of an inch over an entire continent. Quasars make very good sources because they do not move, unlike stars which travel around the galaxy. Furthermore, quasar radio waves are less affected by Earth's atmosphere than visible starlight.

Gravitational geodesy

In addition to examining Earth's shape, geodesy also studies the closely related problem of the strength of Earth's gravity (see GRAVITY). Discovered by the British physicist Isaac Newton (1642–1727), gravity is a force between masses. The gravity of a huge mass like Earth keeps objects stuck to the surface. The gravitational pull of Earth on an object is called the object's weight. If the planet were a perfect, uniform sphere, then gravity would be the same everywhere on its surface. However, Earth bulges at its equator and is made from different materials unevenly spread throughout its interior. This causes the gravity field to vary slightly across its surface. These changes are very small, but instruments can measure how a body's weight differs at separate places on Earth.

The twin GRACE satellites detaching from their launch vehicle. The GRACE program is designed to measure the changes in Earth's gravity field. Much of these changes is caused by the movement of magma beneath the crust, but GRACE will also be sensitive enough to detect the fluctuations produced as glaciers melt or ocean currents shift direction.



ELLIPSES AND ELLIPSOIDS

Most people are familiar with the circle, a perfectly round curve in two-dimensions (see GEOMETRY). Similarly, the sphere is a ball-like surface that is everywhere the same distance from its center. However, mathematicians have names for other shapes. A particularly useful curve is called an ellipse, which looks like a flattened circle. A simple way to construct an ellipse is to cut a circle from card, tilt it relative to the ground, and look at its shadow. This shape occurs frequently in nature—for example, the planets move on ellipses as they orbit the Sun.

Just as the sphere is the three-dimensional version of the circle, mathematicians consider the ellipsoid to be the three-dimensional version of an ellipse. Looking like distorted sphere, an ellipsoid's profile in any direction always makes an ellipse. To good approximation Earth is shaped like an ellipsoid, with its equator almost circular but its side view making an ellipse. This means the distance between the North and South Poles is slightly shorter than the distance across the equator. Another familiar ellipsoid is an American football, although this shape is elongated rather than flattened.

A CLOSER LOOK

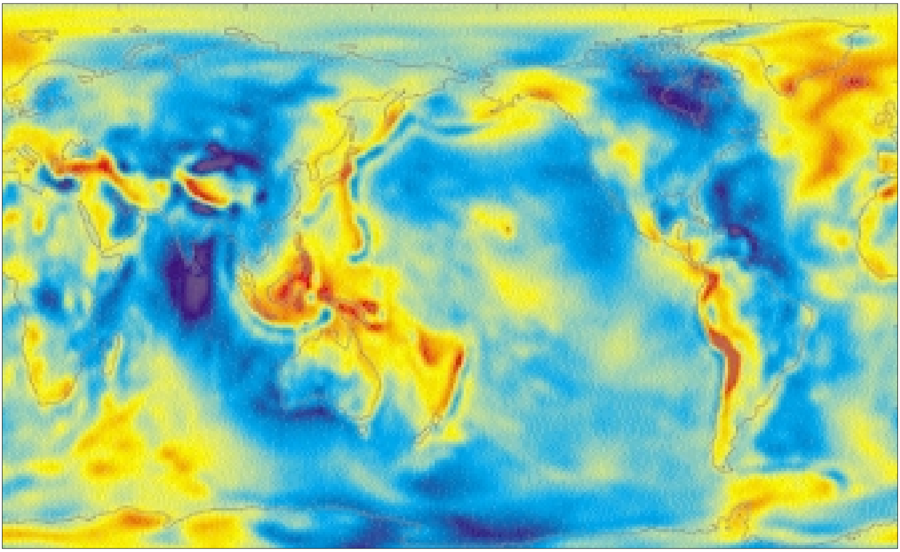
Scientists use instruments called gravimeters to measure the strength of gravity (see GEOPHYSICS). One type examines the acceleration of a ball dropped down a tube. Another type looks at how quickly a pendulum swings back and forth under the force of gravity. These measurements are complicated by Earth spinning, which also exerts a force on an object (see CORIOLIS FORCE). Modern gravimeters are so accurate they can detect hollow underground passages or where people are standing nearby.

Accurate gravity measurements are important for geodesy because scientists can calculate the shape of Earth from Newton's laws of gravity. (Newton predicted Earth was an ellipsoid from his theory, half a century before it was experimentally measured.) Thus the gravity field gives a complementary method to GPS and VLBI surveys. Moreover, surveyors need the value and direction of the gravity field when planning hydroelectric dams or other massive buildings. Another important application of gravitational geodesy is for predicting the orbit of satellites. While circling Earth they move closer or further away as the gravity field changes in strength. This effect is crucial for GPS satellites, since their position is part of the data for calculating an object's position.

Applications of geodesy

Many people use the geoid without ever noticing it. The most common application is for calculating GPS elevations above mean sea level, which is an everyday tool of construction engineers and surveyors. Meanwhile, GPS devices are becoming commonplace in some leisure activities, such as hiking and mountaineering, and trucking and taxi companies use them to track vehicles. Soldiers need to locate their precise position, both for operations on the battlefield and for aiming munitions. Cruise missiles, such as the Tomahawk Land Attack Missiles, also use a GPS guidance system.

Geodesy is also important for mapping, to give an accurate reference surface on which to position land features. These maps are used for many applications,



A map showing the changes in Earth's gravity field across its surface. In the red areas gravity is strongest; in the blue zones it is weakest. The fluctuations in gravity are caused by the shape and composition of the planet.

such as protecting environmental resources, the safe navigation of shipping, urban management, mining operations, and the precise definition of international and state boundaries (see GEOGRAPHIC INFORMATION SYSTEMS). The success of military ground operations during modern warfare is also highly dependent on maps. For example, the U.S. Defense Mapping Agency supplied 4,500 maps for the 1990 Desert Storm operations in Kuwait and Iraq.

Earthquake prediction and volcano modeling require very accurate charts of how Earth's surface changes with time. From changes in the geoid, scientists model how the continental plates float on Earth's liquid mantle. By giving an insight into the dynamics of the planet's interior, this also helps explain Earth's geology. Meanwhile, data about the level of the seabed and the shape of Earth is an important input into models of ocean currents and climatology (see CLIMATOLOGY; CURRENTS, OCEANIC.)

New technological instruments are made possible with extremely accurate models of Earth and its gravity field. For example, Inertial Navigation Systems (INS) are sophisticated devices that find the position and velocity of a vehicle solely by sensing acceleration. All acceleration is caused by force, which the INS device measures and uses to calculate the distance and direction it has traveled. A precise knowledge of the gravity field is needed for these calculations. Such navigation systems are particularly useful when there is no reception of signals from satellites, such as when under water or the ground.

The practice of Geodesy is not just applicable to Earth, but also to other planets or large moons. Launched in 1998, NASA's Mars Global Surveyor satellite circles the red planet 12 times a day, continuously building a detailed map of its surface features and overall shape. On board it has accurate wide angle cameras and laser altimeters to make accurate measurements of the topography and geoid. This data will be important for future Mars exploration and is already proving useful for modeling the climate. Similar satellites are planned for other planets, most notably the Europa Orbiter Mission that plans to reach the icy moon of Jupiter in 2010.

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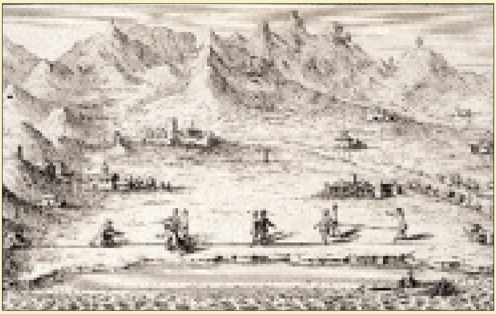
IS EARTH SQUASHED OR STRETCHED?



Over the 17th and early 18th centuries there was an intense argument between English and French scientists about the shape of Earth. Guided by the calculations of Isaac Newton, the English claimed Earth is like a squashed ball. Conversely, the French believed the Italian astronomer Giovanni Domenico Cassini (1625–1712), who said Earth was stretched or egg-shaped. Neither side would back down, claiming the other's measurements or calculations were wrong.

In 1735 the French Academy of Sciences decided to settle the dispute by sending geodetic expeditions to Peru and Lapland, near the equator and North Pole respectively (pictured above in Peru). Each expedition measured the roundness of Earth at their particular destination, finding Earth is more rounded at the equator than in the north. These measurements proved Earth is a squashed ball, as Newton had predicted.

HISTORY OF SCIENCE

See also: CLIMATOLOGY; CORIOLIS FORCE; CURRENTS, OCEANIC; DAY; EARTH, PLANET; EARTH, STRUCTURE OF; GEOGRAPHIC INFORMATION SYSTEM; GEOMETRY; GRAVITY; PLATE TECTONICS; TOPOGRAPHY.

Further reading:

Leick, A. 2004. *GPS Satellite Surveying*. New York: John Wiley.
Torge, W. 2001. *Geodesy*. Berlin: Walter de Gruyter.

THE FUTURE OF THE GLOBAL POSITIONING SYSTEMS

One of the most important instruments for finding Earth's shape are GPS receivers, which can determine altitude, latitude, and longitude on land, in the air, and at sea. Initially put in place by the U.S. military, at a cost of $12 billion, GPS devices are becoming commonplace as navigational aids. They can even be found in some cell phones. The European Union has plans to develop another GPS network.

Some technology experts predict that over the next decade GPS receivers will be ubiquitous. Every automobile, ship, aircraft, and dispatch system could contain one. Moreover, all military systems in technologically advanced nations are expected to become reliant on GPS technology in some way. Futurists also imagine tracking their children and pets with miniature GPS receivers, possibly as implants, wristbands, or even sewn into clothing.

Yet skeptics also worry about the possible impact on society. They imagine a world where a person's location could always be found, unless they left behind all technological devices. Governments and law enforcement agencies might be able to track anyone and check on their activities. Whether this Big Brother situation will happen is debatable, although it is certain that widespread use of GPS devices will change people's lives in new and exciting ways.

LOOKING TO THE FUTURE