Amazing GRACE

A pair of satellites will soon begin mapping tiny variations in Earth's gravity, allowing scientists to track the motions of mass around and beneath the globe for the first time.

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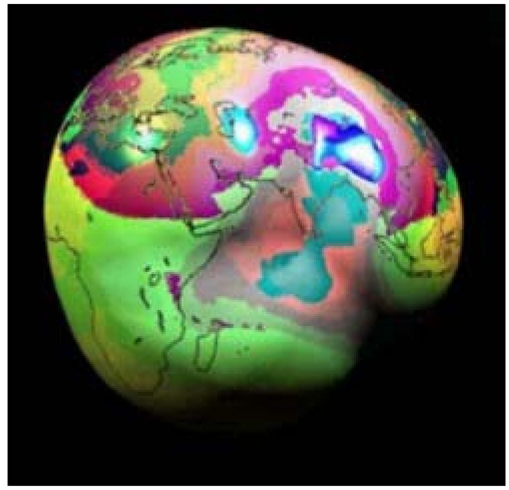

October 30, 2001: If only Sir Isaac Newton were alive today! The mastermind of humanity's first scientific theory of gravity would surely be amazed by NASA's upcoming **G**ravity **R**ecovery **A**nd **C**limate **E**xperiment. Better known as "GRACE," the mission will use a pair of satellites to map tiny variations in our planet's gravitational field.

Back in Newton's day, most scientists figured Earth's gravity was constant everywhere. After all, world travelers weighed about the same no matter where they went. And apples seemed to fall at the same rate all over our planet.

Now we know better. Our planet is lumpy and so is its gravitational field. The variations are very slight, much less than 1 percent. Nevertheless, they are important. Tiny changes in gravity, from place to place and over time, can reveal a great deal about Earth's oceans and our planet's hidden interior.

Above: An exaggerated map of Earth's "bumpy" gravity field. A low point near the coast of India marks the remains of some old mantle features associated with plate tectonics that caused India to collide with the Himalayas. A different set of mantle features creates a gravitational peak in the South Pacific. GRACE will improve the accuracy of this map 100 times. [more information]

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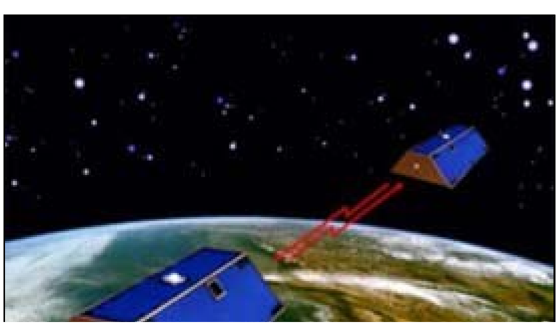
"Every month during GRACE's 5-year expected lifetime we will get a map of Earth's gravitational field," says Michael Watkins, project scientist for GRACE at NASA's Jet Propulsion Laboratory (JPL). "We'll be able to see various phenomena that involve transporting mass around -- and how much mass they're actually moving. These are things that aren't easy to see with any other type of measurement."

How can GRACE measure these subtle variations in gravity from space? After all, the satellites will be in free-fall around the Earth (like all objects in orbit), so they can't measure gravity like gravimeters on the ground do: by measuring how hard the ground pushes back against the weight of the gravimeter.

To sense gravity in free-fall, GRACE will deploy a pair of identical satellites in the same orbit -- one satellite 220 km (137 miles) ahead of the other. As the pair circle Earth, regions of slightly stronger gravity will affect the lead satellite first, pulling it slightly away from the trailing satellite. By monitoring the distance between the two with extraordinary precision (the satellites can sense a change of separation of one micron -- about 1/50th the width of a human hair), GRACE will be able to detect minute fluctuations in the gravitational field.



Left: The twin GRACE satellites will use hyper-sensitive microwave range finders to measure the distance between them. Image courtesy NASA's Jet Propulsion Laboratory .

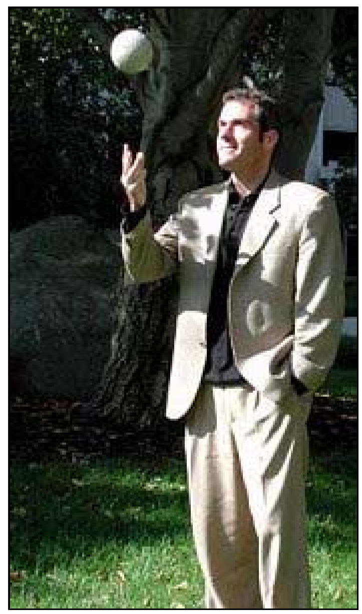
GRACE's gravity maps will have a spatial resolution of about 300 km on the ground. Scientists expect the maps to reveal plenty of complex features caused by, *e.g.*, mountains, ice sheets, and subducted oceanic plates. Earth's large-scale structure (flattened at the poles and bulging at the equator) will appear in the maps as well.

Maps of Earth's gravitational field already exist, but GRACE will improve their precision 100-fold and allow scientists to monitor changes.

Ocean studies will benefit greatly from the data. For example, GRACE maps will reveal new information about the shape of our planet's oceans. Free from other influences, the ocean surface will tend to take the shape of the "geoid," which is the imaginary surface on which the pull of gravity is everywhere equal. But sea-surface height -- routinely measured by the TOPEX/Poseidon satellite -- also varies because of large-scale ocean currents and changes in water temperature. Together, GRACE and TOPEX/Poseidon can sort out these effects.

Says Watkins: "What an oceanographer would like to know is, how much of the shape of the ocean surface is because the ocean is following the geoid -- and how much of it is interesting to oceanographers, like currents. You have to subtract off the geoid in order to get that oceanographic part."

Below: GRACE project scientist Michael Watkins conducts a low-tech gravity experiment at the Jet Propulsion Laboratory.



With a better idea of the contribution of gravity, scientists will be able to draw better conclusions about the temperatures and currents of the oceans -- vital information for understanding the global climate.

An especially exciting aspect of the GRACE mission, Watkins says, is the ability to watch changes in the gravitational field over time. Gravity is the "shadow" of mass, and mass is a crucial part of the equation for many physical phenomena. Whether it be the thinning of vast ice sheets, the flow of water through aquifers, or the slow currents of magma deep inside the Earth, having direct measurements of the amount of mass involved will enable scientists to reach better conclusions about these important natural processes.

"You can determine, for example, if the sea level is rising because there's actually more water melting into it or if the water is expanding simply due to heating," Watkins says.

"If you just measure the height of the ocean surface with an altimeter, it's hard to separate a change in volume from an increase in mass. GRACE will provide the extra information on mass that you need to understand what's really happening."

All mass is created equal in the eyes of gravity, of course, so scientists will need to don their London Fog® trench coats and do a bit of detective work to figure out "who done it?" Was a measured shift in gravity caused by the moving air masses of weather? Was it the swelling of the water level in an underground aquifer? Or was it maybe the movement of molten rock far beneath the surface of the Earth?

Fortunately, there are clues scientists can use to find the culprit.

First of all, they will "subtract off" the effects of the motions of the atmosphere. Meteorologists have become quite good at estimating the distribution of mass in the atmosphere using the reams of data produced by weather stations around the world and weather satellites circling above it. These estimates will show what part of the GRACE measurements is due to the atmosphere, allowing scientists to "peel back" the atmosphere and look at the surface and sub-surface.

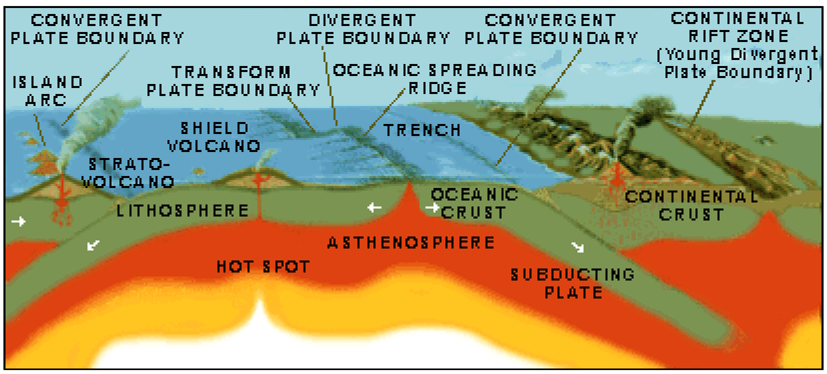
Above: With global climate change a growing concern, scientists are keeping a watchful eye on the world's ice sheets and glaciers. Image courtesy NASA's Goddard Space Flight Center .

They will then use a variety of tricks to sort out exactly what kind of mass it is -- be it water, ice, or magma -- that GRACE is watching move. These different processes have characteristic time scales. Surface waters such as lakes and rivers would be expected to produce faster changes than ocean currents, and ocean currents should produce faster changes than deep magma flows.

"The effects of convection currents in the Earth's mantle could be evidenced anywhere. An event could involve a mass flow hundreds of kilometers under the Earth, and it could be under Ohio or under the ocean or anywhere. But you don't expect that to change month to month," Watkins says. "And you can know with a fair certainty that the mass movement is a hydrologic event if you have a correlation with precipitation, for example."

In other words, scientists will use other sources of information -- such as rainfall data, geographic knowledge, and data from other satellites -- to pinpoint what event is causing the small shift in the gravitational field.

This kind of inference is a new science, Watkins points out, and methods for drawing conclusions based on GRACE data will take some time to refine.



Above: Earth is a geologically active planet -- its mass is always slowly shifting around. These motions have a different characteristic time scales than other mass movements, such as water flows. Scientists will use GRACE to study geologic, hydrologic, and glaciologic phenomena.

Once the amount of mass involved in, say, the thinning of an ice sheet has been determined, scientists will then combine that knowledge with other data in a sort of synergy that will allow for conclusions not otherwise possible.

"You can learn more by saying here's the volumetric change in the ice and here's the mass change in the ice," Watkins says. "It turns out that the combination of the laser altimeter [on TOPEX/Poseidon] and GRACE can illuminate that question much better than either one alone."

Right: This image shows changes in the Greenland ice sheet between 1994 and 1999, as measured by an airborne laser altimeter. The darker blue areas denote greater reduction in the height of the ice sheet, while light gray marks areas where the height of the sheet increased slightly. Mass data from GRACE will help researchers understand what such changes in height really mean.

Other satellites also produce data that will complement GRACE's. ICESat, for example, will precisely measure the surface of the world's ice sheets and glaciers. And NASA's upcoming Aqua mission will detect soil moisture.

"GRACE is really the only instrumentation in space that can tell you much about water storage. That data is an interesting element that we can combine with these soil-moisture measuring missions to get a much better handle on the hydrologic cycle."

GRACE's mass measurements will also be combined with the numerous types of environmental data collected the old fashioned way: by scientists on the ground.

"The combination of the data sets is what really makes the difference. That's a general trend in our science anyway -- to try to combine different data sets into computer models," Watkins says.

By sensing gravity and mass fluctuations worldwide, GRACE will add an important new data set to scientists' toolkit for studying the climate and geology of the Earth. By offering this new perspective, GRACE marks an impressive milestone as humanity continues the study of Earth's gravity that began with Newton over three centuries ago.

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Web Links

GRACE mission -- homepage containing lots of information about the GRACE mission and the amazing scientific instruments that will make such precise measurements possible.

Interview with Watkins -- "Getting the Lowdown on Gravity" -- from the NASA Jet Propulsion Laboratory website.

Ocean science at JPL -- information on how satellite data is being used to better understand Earth's oceans. Includes an image of sea-surface height generated using TOPEX/Poseidon data.

NASA Oceanography -- an overview of the many ways NASA participates in and contributes to ocean science.

TOPEX/Poseidon -- homepage for the NASA/CNES ocean surface mapping mission, from JPL

Aqua satellite -- homepage, from NASA's Goddard Space Flight Center

ICESat -- homepage, from GSFC

Earth's Fidgeting Climate -- *Science@NASA* article discussing the observed thinning of the Greenland ice sheet and the difficulty in determining humanity's role in causing such changes.

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