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The gravity of water

Aerospace engineer Byron Tapley's satellite mission to measure gravity leads to discoveries about ice sheets, sea levels, floods and droughts

Oct. 7, 2011

NASA scientists surveying water resources around the world with a pair of satellites 320 miles above Earth noticed something unusual in northwestern India in 2009.

Farmers in the area known as the Bread Basket of India, which encompasses 438,000 square kilometers, were emptying the region's aquifer faster than it could be replenished.

Dr. Byron Tapley, director of the Center for Space Research, worked for decades for a satellite mission that would study the Earth's gravity. The Gravity Recovery and Climate Experiment mission was launched in 2002 and has provided scientists with tons of information about gravity — and shifts in the planet's water, a key component of gravity.

Further investigation showed that the water table dropped about a foot a year from 2002 through 2008 as farmers pumped more water out to irrigate crops than was being replenished by natural processes, principally rain.

"They've got a serious issue," said Matthew Rodell, a NASA hydrologist conducting the survey.

Researchers found a similar situation in California's Central Valley, which provides about 15 percent of the United States' agricultural production. Water was drawn down by 25-million-acre-feet from 2003 to 2010.

These observations come from a satellite project called the Gravity Recovery and Climate Experiment (GRACE). It measures changes in Earth's mean gravity field, which usually is the result of the movement of water. University of Texas at Austin faculty member Byron Tapley is the principal investigator of the project.

"The ability to use the measurements to look at the changes in the underground aquifers and to measure changes in the ocean bottom currents represent the first time that a satellite mission has been able to observe below the Earth's surface," said Tapley, the Clare Cockrell Williams Centennial Chair in the Cockrell School of Engineering.

Since its launch in 2002, GRACE has provided unprecedented information about changes in the oceans, ice sheets at the poles and river deltas, as well as regional aquifers like the ones in India and California.

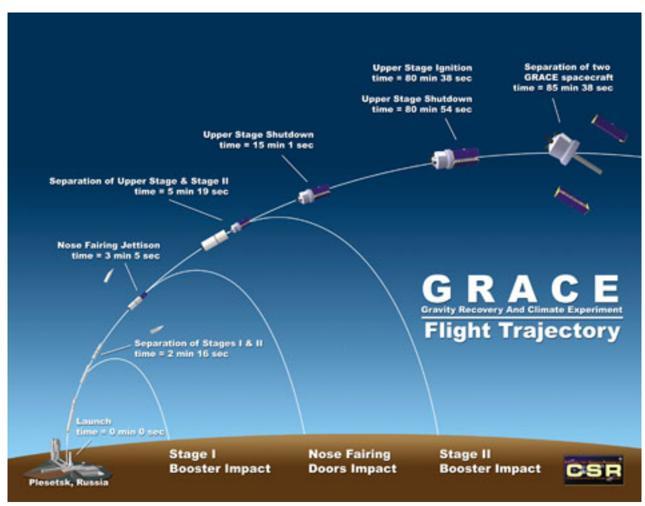
"The GRACE data allow people to directly monitor month-to-month mass variations over scales of several hundred kilometers and larger," said John Wahr, a physics professor at the University of Colorado in Boulder. He uses GRACE to study the storage of water (including snow and ice) on continents and in the polar ice sheets.

GRACE tracks changes in the amount of water stored in the soil in large river basins, groundwater depletion over large areas, and mass loss from the polar ice sheets, Wahr said. "No other method can provide this sort of large-scale information, with the completeness and accuracy obtained using GRACE."

Decades in the Making

The project provides data for 21st century science, but its roots go back to the late 1960s.

Tapley said the need for a gravity-studying mission was defined at a NASA workshop in Williamstown, Mass., in 1967. He participated in several attempts at a GRACE-like mission during the following decades without success.



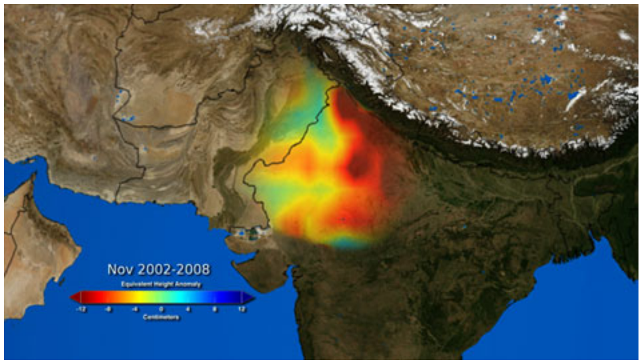
The two GRACE satellites rode into space on a single rocket. This image shows the blast-off sequence as it happened on March 17, 2002. The satellites have orbited the Earth for 3,491 days as of Oct. 7, 2011. View a larger version of this GRACE flight trajectory graphic.

The delays turned out to be a blessing because the earlier missions would have used less sophisticated technology and probably would not have lasted nearly as long.

Development of technologies such as the global positioning system and accelerometers (which measure acceleration) that could survive the rigors of space came together in the 1990s to make GRACE a much more robust mission.

"That we proposed the mission at the right time was an essential part of the GRACE mission success," Tapley said.

Assembling the technology was one thing. Finding money for the mission was something else.



Groundwater storage varied in northwestern India between 2002 and 2008, relative to the mean for the period. These deviations from the mean are expressed as the height of an equivalent layer of water, ranging from -12 cm (deep red) to 12 cm (dark blue). Watch an animation of the groundwater storage in India from the story "NASA Satellites Unlock Secret to Northern India's Vanishing Water." (Animation opens in a new browser window.)

Credit: NASA/Trent Schindler and Matt Rodell

The NASA budget would not have provided enough money for the mission that GRACE became. So Tapley worked with a colleague, Christoph Reigber, a scientist with the German space agency, to bring in that agency, Deutsche Forschungsanstalt fur Luft und Raumfahrt (DLR).

Between NASA and DLR, they obtained the $160 million needed for the project. They contracted with a German-French company to build the satellites.

The project took on even more international flavor when it partnered with Russians for the launch. On March 17, 2002, a single rocket carrying both satellites blasted off from the Plesetsk Cosmodrome, about 125 miles north of Moscow.

"Dr. Tapley was the propelling engine of the GRACE mission through all its phases," Reigber said.

He said Tapley's deep involvement in space planning programs in the U.S. and internationally, as well as his connections in research funding organizations, was instrumental in developing the project.

"With his strong belief in the benefits of international cooperative projects, heightened by his natural authority and leadership ability, he formed a strong team of scientists and technicians in the United States and Europe for the fast realization of the GRACE mission," Reigber said.

Originally scheduled for five years, it has now exceeded nine years and NASA has approved continuing the mission through 2013, Tapley said.

Project management and systems engineering activities are conducted at NASA's Jet Propulsion Laboratory in Pasadena, Calif.

At The University of Texas at Austin, Tapley and staff members monitor the daily activities of the satellites from the West Pickle Research Building in North Austin.

The Austin staff validates measurements taken by GRACE and creates the monthly data that show changes over time. They work with about 40,000 co-efficients, compared to previous missions that could capture just 5,000 co-efficients.

"The computational process was an immense step up in capability," Tapley said. "We partnered very extensively with UT's Texas Advanced Computing Center. They've been a real partner with us.

"The main solutions for these gravity models are essentially done here. We validate four base measurements. We go through these measurements and go through the process of creating the monthly solutions."

Several members of the science team and other scientists who use GRACE received their Ph.D.s at The University of Texas at Austin.

Operating in Time and Space

GRACE maps Earth's gravity fields by making accurate measurements of the distance between the two satellites, using geodetic-quality receivers and an ultra-accurate microwave ranging system between the satellites.

The high-accuracy ranging system measures variations in the distance, which are caused by small variations in Earth's mass distribution. The accuracy is as fine as 1/10 the diameter of a human hair strand.

These extremely accurate measurements, collected over the entire Earth once every 30 days, have provided a new and important capability for monitoring Earth's changes.

"Month to month, you can see changes in the gravity field," Rodell said.

By comparing month-to-month variations to long-term averages, researchers can spot anomalies with GRACE. That's how the situation in the India aquifer popped out.

Although some battery problems have cropped up in one of the two satellites, Tapley hopes that it can operate until 2016. That's the earliest the next GRACE mission, which NASA has approved, could be launched.

Connection to the successor mission, he said, is important for continuity in the climate change measurements that GRACE has started.

GRACE Discoveries

Since it was launched in March 2002, the Gravity Recovery and Climate Experiment (GRACE) mission has beamed data back to Earth that's enabled scientists to make a range of discoveries about what's happening on our planet.

Scientists have:

- **Discovered** that ice sheets on Greenland and Antarctica are melting much faster than previously thought.
- **Found** an ancient impact crater under the Antarctic ice sheets.
- **Determined** how much global sea level rise is due to melting water from ice sheets in Antarctica and Greenland.
- **Monitored** the impact of major earthquakes.

The scientists who use GRACE continue to find new ways to use the data, some of which can have immediate impact.

New uses include:

- **Flood Potential Index** — GRACE can tell where areas are near maximum water storage. Places close to the maximum storage could expect a flood situation with a little more rain.
- **Streamflow/Snowmelt Forecast** — GRACE is sensitive to accumulation and melting of the snowpack. GRACE can determine when there's more snowpack than normal and forecast additional water runoff.
- **Drought Monitoring** — GRACE can determine whether land is dryer than normal, how it compares with previous dry episodes, and whether conditions are worsening or improving. The drought maps shown on the evening news are an example of this application. A map for Oct. 3, 2011, shows extremely low percentages of surface water in Texas (PDF), which is beset by drought, and extremely high percentages of surface water in the Northeastern United States, where Hurricane Irene caused flooding in September.

"Climate measurements need continuity over multi-decade time scales to be able to separate the yearly and decadal variability from the long-term trends," he said.

For more information, contact: Tim Green, Office of the Vice President for Research, 512 475 6596;

On the home page banner: The twin GRACE satellites fly in a polar orbit 320 miles above the Earth. Every 30 days, they measure the gravity of every spot. Scientists have used the data from GRACE to find underground craters and determine that some aquifers are running low on water.

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