PASSAGE 2

How Do Scientists Study Ice Sheets?

Three indirect methods for measuring ice sheets

Until recently, scientists had to rely on indirect methods to estimate the changing mass of the ice sheets. One method is to use a computer **model**: a numerical simulation that attempts to reproduce all the processes going on in an ice sheet. “The problem is that there’s much that we don’t know about those processes, so the models are good but not great,” explains geophysicist Isabella Velicogna, who works at both the University of California, Irvine, and NASA’s Jet Propulsion Laboratory.

A second way to measure changes to the ice sheets is to use **altimetry**: determining elevation by measuring the satellite-to-surface round-trip time of a radar pulse. “Basically you measure the change in the surface of the ice sheets and convert this to mass,” says Velicogna. “You have to assign some density but we have to estimate it, so the error can be up to 50 percent.”

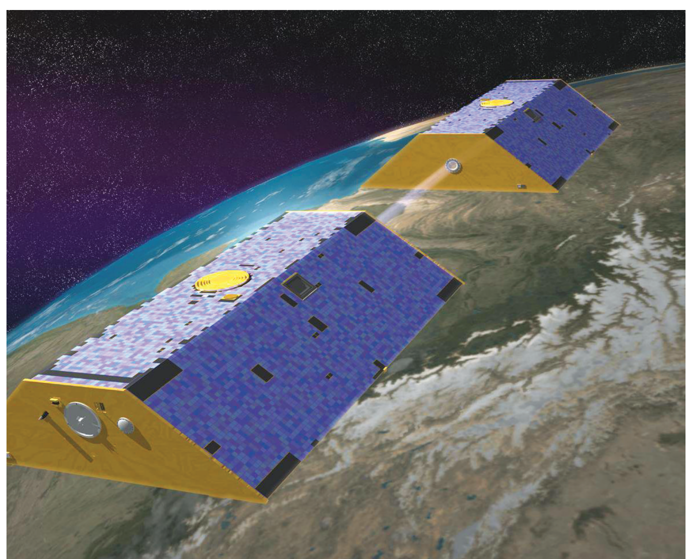
A third method measures what’s called the **mass budget**, which estimates how much mass is being gained or lost from the ice sheet over time. This method is labor intensive. It requires scientists to observe the ice closely with staked markers, and to examine layering by digging into the snowpack or studying the walls of crevasses.

Each of these methods is independent, and the three measurements complement each other, but calculations still involve a large margin of error.

NASA proposes a new approach

In the mid-1990’s, a NASA team had a very interesting idea. The group of scientists and engineers proposed “weighing” Earth’s water by measuring its gravitational force. “Newton’s laws tell us that anything that has mass will have a gravitational attraction,” explains GRACE project scientist Michael Watkins. “The bigger the mass, the more gravity there is.” That means a mountain exerts more gravitational pull than a hill, and an ocean more than a stream. Earth’s gravity is not the same wherever you go. This distribution is called Earth’s gravitational field.

“We realized, after decades of looking at satellite orbits, that if we could design a mission accurate enough to observe those small changes, we could actually watch the polar ice caps melt,” says Watkins. His team proposed that by regularly measuring changes in the gravitational field with satellites, they could indirectly track the motions of large masses of water as they cycle around Earth. The result was a satellite mission called GRACE, which stands for Gravity Recovery and Climate Experiment.



GRACE, twin satellites launched in March 2002, are making detailed measurements of Earth’s gravitational field.

Image source: NASA/JPL

Two GRACE satellites work in tandem

Because satellites use Earth's gravitational field to stay in orbit, they're sensitive to its changes. For example, when a satellite flies over a high-mass area, like a mountain range or an ice cap, the increase in gravitational force causes it to be pulled towards the high-mass area. After the satellite passes the area, the gravitational force pulls in the opposite direction, slowing the satellite back down. These changes measure the mass of that mountain range or ice cap.

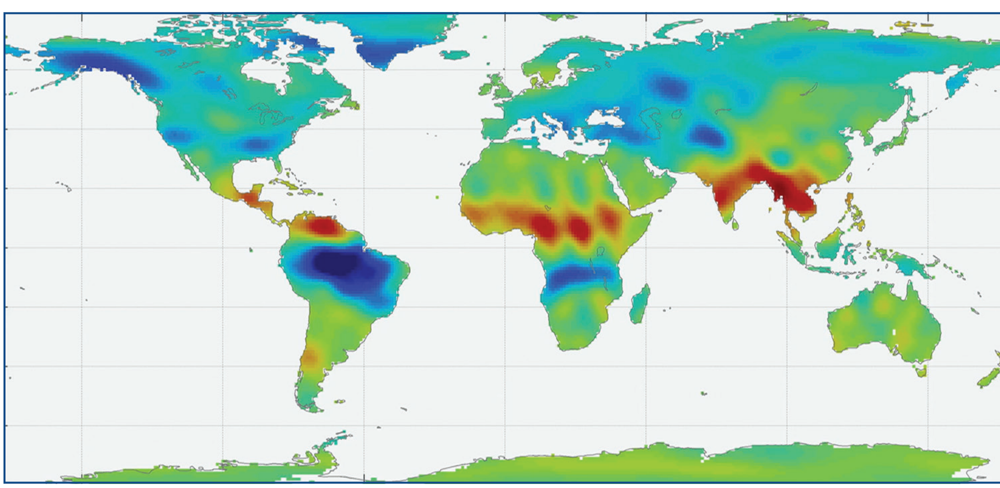
The best way to observe those minute changes in velocity is to observe one satellite with another. So GRACE scientists and engineers decided to launch two identical spacecraft, which follow each other in a pole-to-pole orbit 500 kilometers (310 miles) above Earth. The key component in generating this type of a gravity map is the distance between the two satellites, which orbit 220 kilometers (140 miles) apart. The GRACE satellites constantly gauge the distance between them by beaming microwave signals back and forth. The ranging system is sensitive enough to detect minuscule changes—as small as 10 micrometres, approximately one-tenth the width of a human hair—across those 220 kilometers. That delicate dance produces a gravitational field map for the strip of Earth beneath the spacecraft—and thus, its concentrations of mass.

"Weighing" Earth's water and mapping its movements

Changes in the solid Earth are too slow to measure on a month-to-month basis. But water is always in flux: monsoons come and go, ice freezes and thaws, one season yields to the next. "If you actually look at the gravitational field from one month to the next, what's changed the most is Earth's thin fluid layer—the oceans and rivers, the polar ice caps, the groundwater," says Watkins.

The GRACE satellites began orbiting in March 2002, and provide the first global coverage of the Earth's gravity field from a single source. They circle Earth once every 90 minutes, which is 15 times a day, taking 30 days to map Earth's entire gravitational field. The satellites effectively "weigh" Earth's shifting water resources far more precisely and comprehensively than ever before. Obtaining equivalent data on land would be impossible. It would require a massive array of equipment, and a huge crew working year-round.

For the first time, scientists can see how fresh water is being distributed across the continents, and study its movement across different scales of space and time. "The nice thing about GRACE is that it gives us this holistic measurement of a region, from an area the size of Illinois to the globe itself," says NASA scientist Jay Famiglietti, a hydrologist. "When we start looking at the whole Earth,



Monthly map created by GRACE. Blue areas are wetter than usual. Red areas are drier than usual.

Map source: NASA

and thinking about how water moves from the ocean to the land and how those changes compare to changes in the great ice sheets, we see some very interesting things. GRACE has made an incredible contribution to how we understand the dynamics of water storage on land."

A remarkably accurate view from space

As the GRACE dataset grows, it is revealing long-term changes in Earth's water with unprecedented accuracy. In addition to tracking the movement of glaciers, the instruments are sensitive enough to measure changes in ocean currents, river basins, reservoirs, aquifers—cracks and spaces below Earth's surface where groundwater is found—and even how much water is in the ground after it rains. "A lot of our infrastructure was built on the assumption that there were no long-term trends in water storage," says Famiglietti. "But GRACE shows that there are in fact changes, and that we have to deal with them."

PASSAGE 2

Stop & Think Questions

Based on the Text

1. **What kinds of data are the scientists collecting? How does this compare to your answer from Passage 1?**
2. **What methods are scientists using to collect their data?**
3. **Explain how the GRACE satellites are used to determine the distribution of fresh water on Earth.**

Looking Ahead

4. **What questions do you think scientists are trying to answer with this data?**