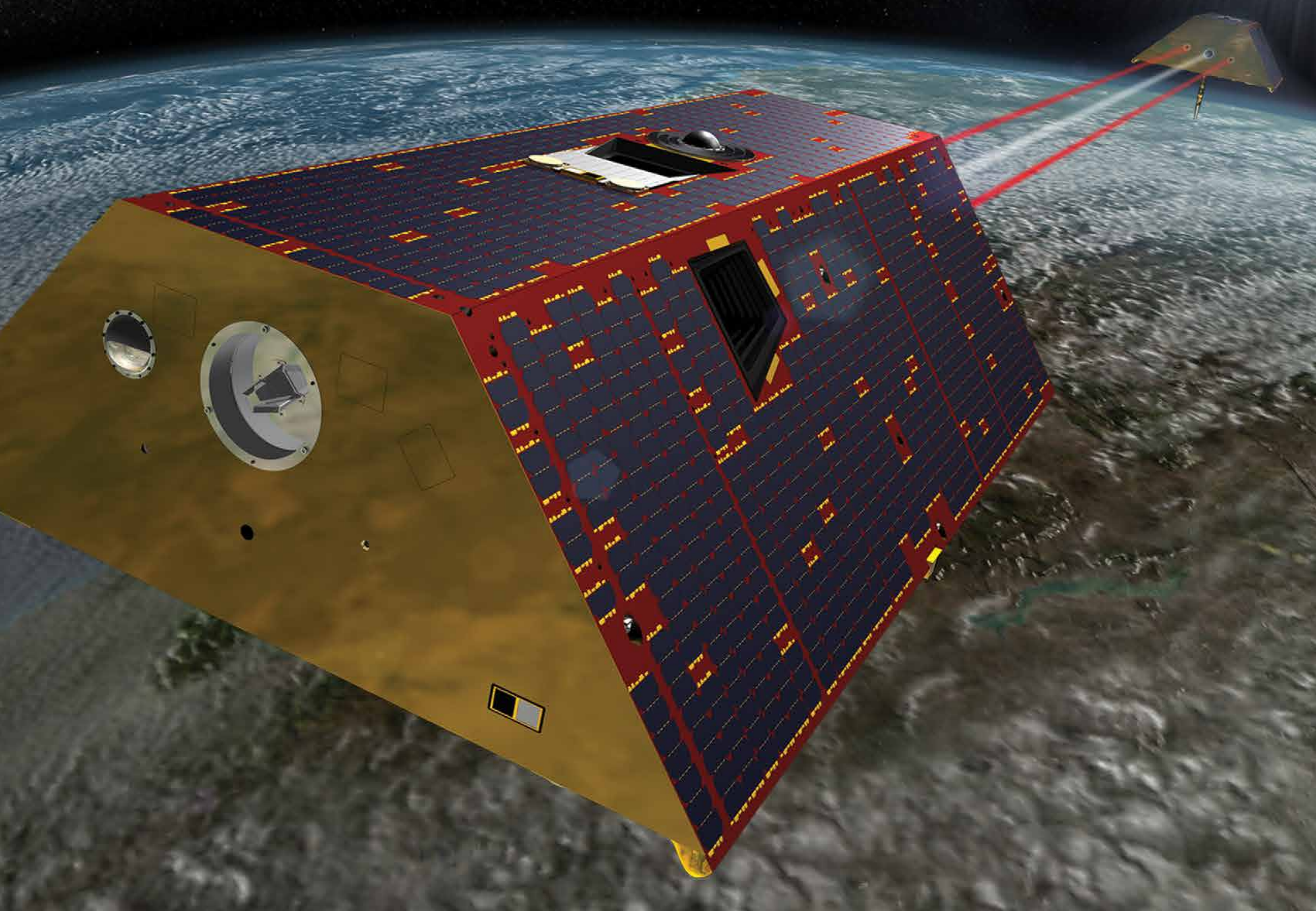
National Aeronautics and Space Administration

GRACE-FO

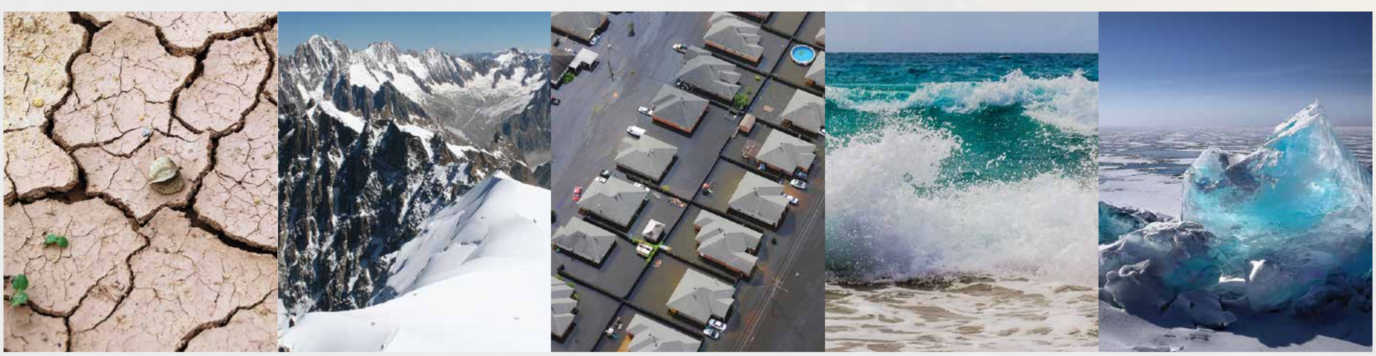
Gravity Recovery and Climate Experiment Follow-On

Tracking Earth's Mass in Motion



Water Storage • Ice Sheets & Glaciers • Sea Level • Solid Earth

Changes in how mass is distributed within and between Earth's atmosphere, oceans, groundwater and ice sheets are fundamental indicators of the large-scale dynamics of the planet. For more than 15 years, NASA's Gravity Recovery and Climate Experiment (GRACE) mission monitored mass changes every month with far-reaching impact on our understanding of the Earth system and how it is evolving. GRACE Follow-On (GRACE-FO) continues the legacy of GRACE, tracking Earth's water movement and surface mass changes across the planet. Monitoring changes in ice sheets and glaciers, near-surface and underground water storage, the amount of water in large lakes and rivers, as well as changes in sea level and ocean currents provides an integrated global view of how Earth's water cycle and energy balance are evolving—measurements that have important applications for everyday life.



Gravity Recovery and Climate Experiment Follow-On: *gracefo.jpl.nasa.gov*

Cover image: Artist's conception of the Gravity Recovery and Climate Experiment Follow-On (GRACE-FO) satellites in orbit around the Earth.

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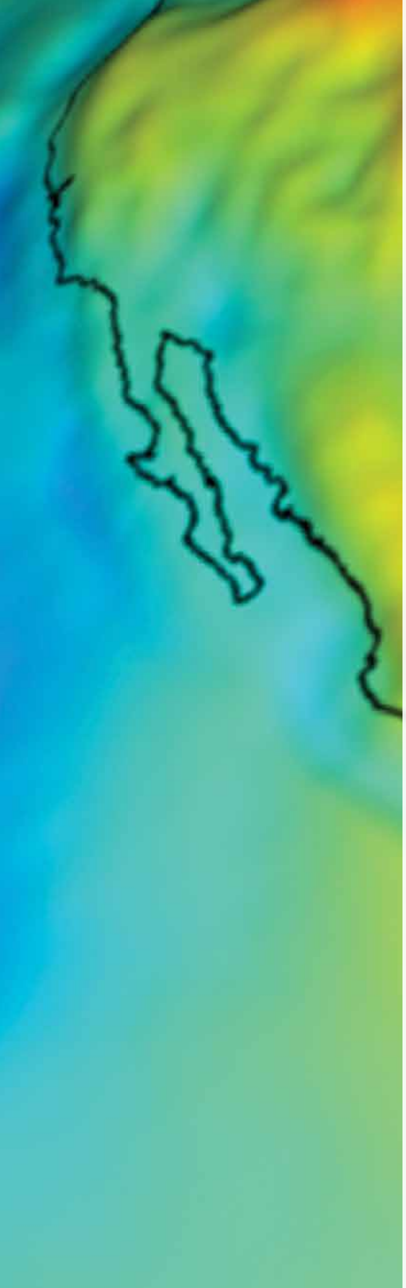
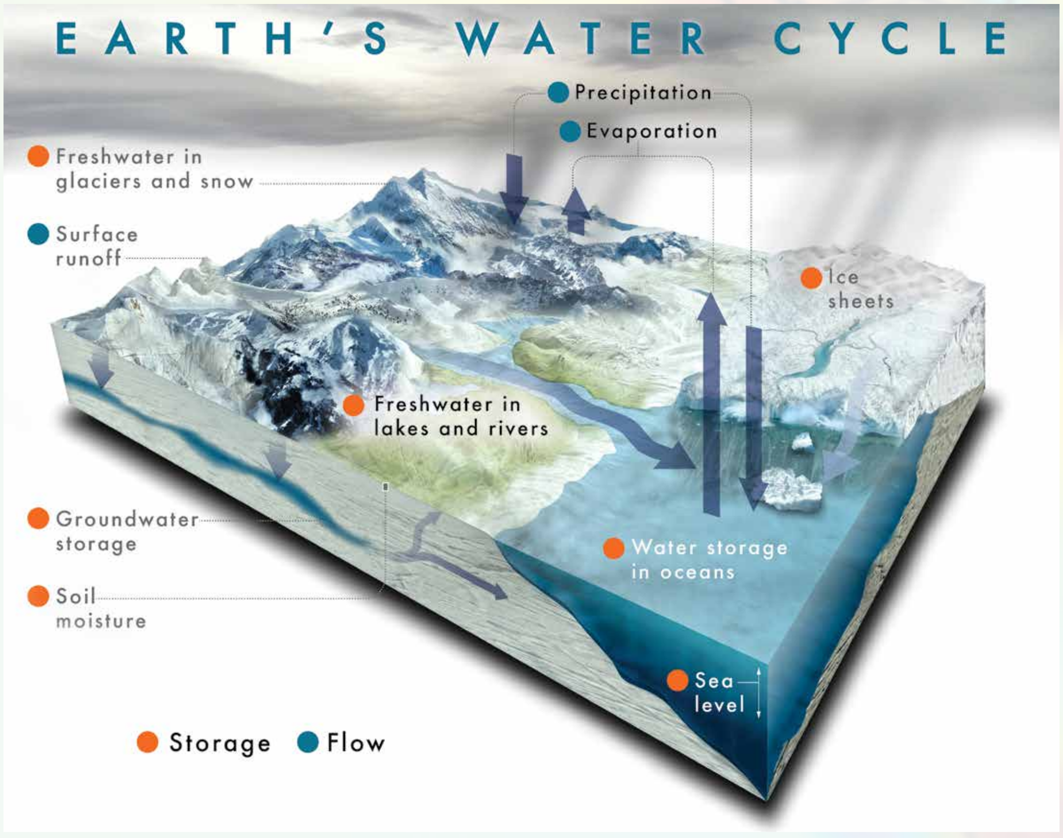


Image credit: University of Texas Center for Space Research and NASA

Mass Transport and Gravity Change On Earth

Panta rhei—"Everything flows." These famous words by the Greek philosopher Heraclitus express the truth that our complex world is ever changing and evolving. Even Earth's gravity field is continually changing. The pull of gravity varies naturally from place to place on Earth, depending on the mass distribution; greater mass exerts a stronger gravitational pull. But gravity also changes constantly as mass moves. While the masses of Earth's land features, such as mountains and valleys, change relatively slowly, the amount of water above, on or below a particular location can vary seasonally, monthly, weekly and even daily as water cycles between the subsystems (e.g., atmosphere, land, ocean, glaciers, polar ice caps and underground).

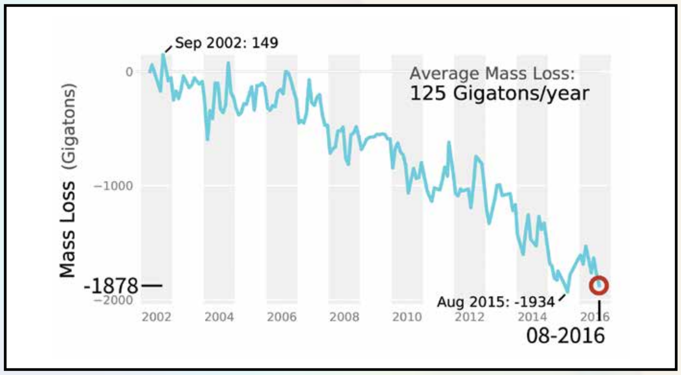
On Earth, the processes that couple and transport water and energy are fundamental to today's most pressing climate science challenges; however, keeping track of Earth's evolving water system is a formidable task. Water constantly changes its shape, form and state as it is cycled between the ocean, atmosphere and land. It is in plain sight in lakes, rivers and seas. It infiltrates the soil and groundwater. It accumulates on the ground as snow and can be stored as ice on glaciers and ice sheets, sometimes for hundreds and thousands of years. This makes it challenging to comprehensively observe and measure just how much water cycles between Earth's subsystems. But regardless of whether water is solid, liquid or vapor, visible or invisible, it has one attribute that does not change: its mass.

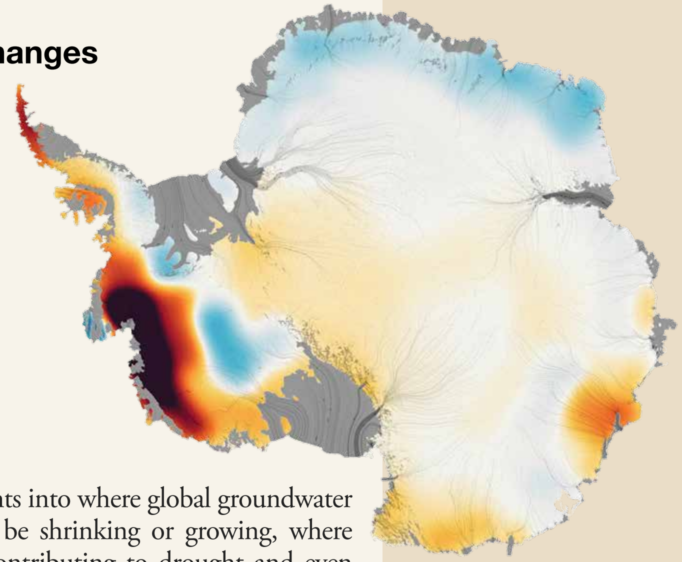


[*Right*] Changes in Earth's gravity field are due primarily to variations in water content as it moves through the water cycle—one of Earth's most powerful systems. Earth's gravity field is continually changing, mostly (but not solely) due to seasonal and climatic changes in water storage and flow.

Image credit: NASA/JPL-Caltech

GRACE Observations of Antarctic Ice Mass Changes





[*Above*] The mass of the Antarctic ice sheet has changed over the last several years. Research based on observations from GRACE indicates that between 2002 and 2016, Antarctica shed approximately 125 gigatons of ice per year, causing global sea level to rise by 0.35 millimeters (0.01 inches) per year.

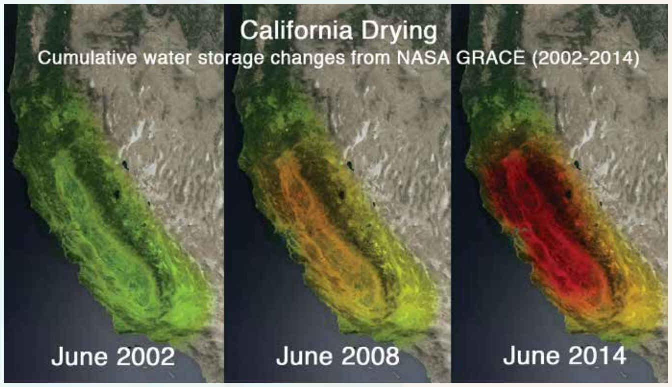
Image credit: NASA/JPL-Caltech/ University of California, Irvine

Because everything that has mass inevitably has a gravitational pull associated with it, a unique twin satellite observing system has been used to measure the changing forces of gravity to track and follow Earth's water masses from the top of the Himalayas to the deepest ocean depths and deep underground. The measurements contribute to the assessment and monitoring of the Earth's heat and sea level budgets.

Given that the force of gravity is an ever-present driving force in the Earth system, it should come as no surprise that people have sought to describe and quantify its static component since ancient times. These efforts led to the development of the field of *geodesy*, the science branch that accurately measures the size and shape of the Earth, defined by the Earth's geometry and gravity field, and the Earth's position and orientation in space. The field of geodesy took a major leap forward in 2002, when NASA and the German Aerospace Center (DLR) launched the Gravity Recovery and Climate Experiment (GRACE) satellite mission to map Earth's static gravitational field *and* how it changes from month to month. Circling the Earth every 90 minutes for over 15 years at an altitude of 350-500 kilometers (about 217-310 miles), the twin GRACE spacecraft closely tracked how their relative positions in space are affected by Earth's gravity.

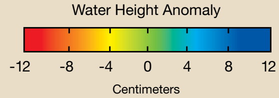
GRACE's monthly maps of regional gravity variations provided new insights into how the Earth system functions and responds to change. Among its innovations, GRACE for the first time measured the loss of ice mass from Greenland and Antarctica; improved our understanding of the processes responsible for sea level rise and ocean circulation; provided insights into where global groundwater resources may be shrinking or growing, where dry soils are contributing to drought and even forest fires; and monitored changes in the solid Earth (e.g., from earthquakes). After more than 15 productive years in orbit—lasting three times longer than originally planned—the satellite mission ended science operations in late 2017. During its operation, GRACE provided truly global gravity measurements 100 times more accurate, and at spatial and temporal resolution higher, than had ever been achieved before from space, providing the much-needed measurements for characterizing how water is transported and cycled through the Earth system.

From mid-2018 on, the GRACE Follow-On (GRACE-FO) mission will continue GRACE's legacy. Monitoring changes in ice sheets and glaciers, underground water storage, the amount of water in large lakes and rivers, and changes in sea level, provides a unique view of Earth's evolving climate as well as its water and energy cycles, with far-reaching benefits for its people. Measuring the redistribution and transport of mass around Earth is an essential observation for understanding current and future changes of the Earth's hydrosphere and its subcomponents.



[*Left*] NASA GRACE data show mass loss in much of California's Central Valley due to groundwater extraction. By June 2016 [not shown], groundwater had not recovered to June 2008 values, even after record-setting rainfalls. Warm colors (yellow, orange and red) indicate mass loss over time.

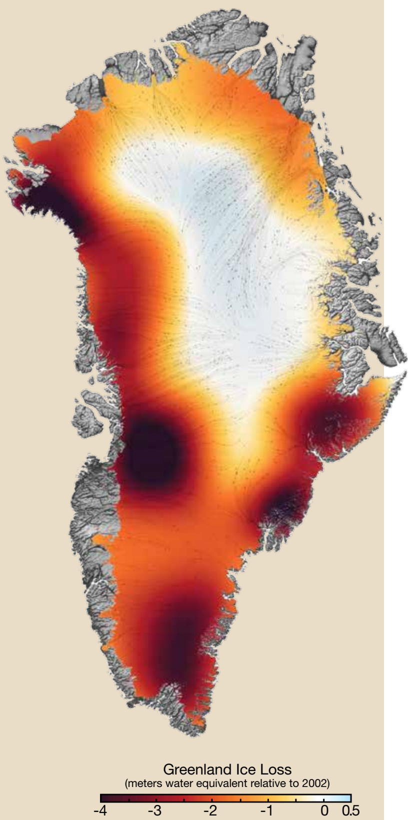
Image credit: NASA/JPL-Caltech/ University of California, Irvine



The First GRACE Mission: A Legacy of Discoveries

"Revolutionary" is a word you hear often when people talk about the first GRACE mission. The twin GRACE satellites, launched on March 17, 2002, have transformed scientists' view of how water moves and cycles between the ocean, land and atmosphere, and how water storage and availability are affected by droughts, floods and human intervention.

In March 2017, GRACE celebrated the fifteenth anniversary of its launch. The discoveries achieved using GRACE data reflect the work of researchers worldwide, who have developed innovative techniques to use the data and combine them with other observations and models for new insights into complex Earth system processes, as well as for applications.



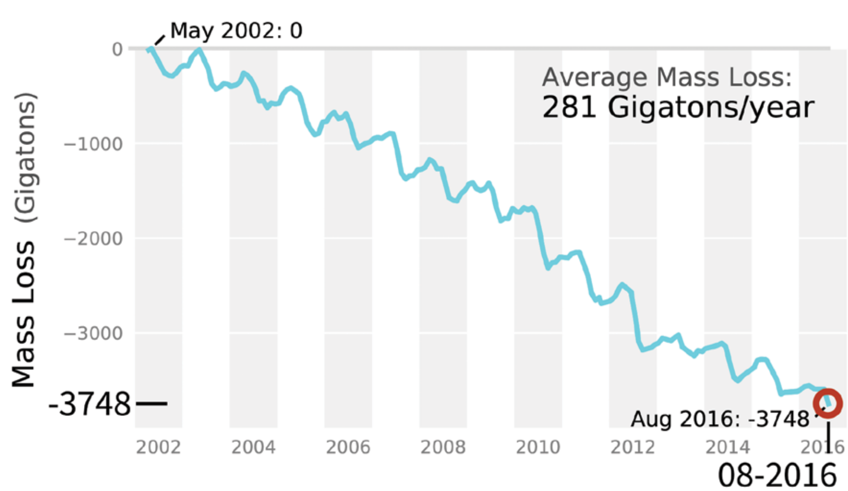
[*Above*] Research based on observations from the GRACE satellites indicates that between 2002 and 2016, Greenland shed approximately 280 gigatons of ice per year, causing global sea level to rise by 0.8 millimeters (0.03 inches) per year. This image, created from GRACE data, shows changes in Greenland ice mass from 2002 to 2016. Orange and red shades indicate areas that lost ice mass. The largest mass decreases of up to 30 centimeters (11.8 inches) (equivalent-water-height) per year occurred along the West Greenland coast.

Image credit: NASA

Melting Ice Sheets

Antarctica is one of the world's toughest places to collect data, and Greenland isn't far behind. Measuring how fast these ice sheets are melting is crucial to better understand rates and variations of sea level rise around the world. In the mid-2000s, GRACE data were used to clearly show that ice losses from Greenland and Antarctica were significantly larger than previous estimates from more indirect observations had suggested. Since GRACE launched, its measurements show Greenland has been losing about 280 gigatons of ice per year on average, and Antarctica has lost almost 120 gigatons a year with indications that both melt rates are increasing. To give perspective on how much water this is, a single gigaton of water would fill about 400,000 Olympic-sized swimming pools!

GRACE Observations of Greenland Ice Mass Changes



Underground Water

Water stored in soil and aquifers below Earth's surface is very sparsely measured worldwide. Before GRACE, hydrologists were skeptical if they would be able to use the data to reveal unknown groundwater depletion. However, over the last decade, by measuring mass changes with GRACE, scientists from NASA, and around the world, have found more and more locations where humans are pumping out groundwater faster than it is replenished. For example, in 2015, a team of researchers published a comprehensive survey showing a third of Earth's largest groundwater basins are being rapidly depleted. Adding the GRACE data to other existing sources of hydrological data has led to the development of a more efficient and sustainable approach to water management.

Dry soils can add to drought risk or increase the length of a drought. To help monitor these changes, NASA provided data on deep soil moisture and groundwater from GRACE to the National Drought Mitigation Center each week, using a hydrology model to calculate how the moisture was changing throughout the month between one map and the next. The data were used to prepare weekly maps of U.S. drought risk.

continued on next page

[*Above*] NASA and the German Aerospace Center (DLR) collaborated to design and launch GRACE. NASA provided the satellites; developed the instruments and some of the satellite components; maintained overall mission management, data validation and storage; and has responsibility for the science data products. The DLR provided the launch services and operations activities. The science data products are produced at CSR, GFZ and JPL.

Image credit: Astrium/GFZ

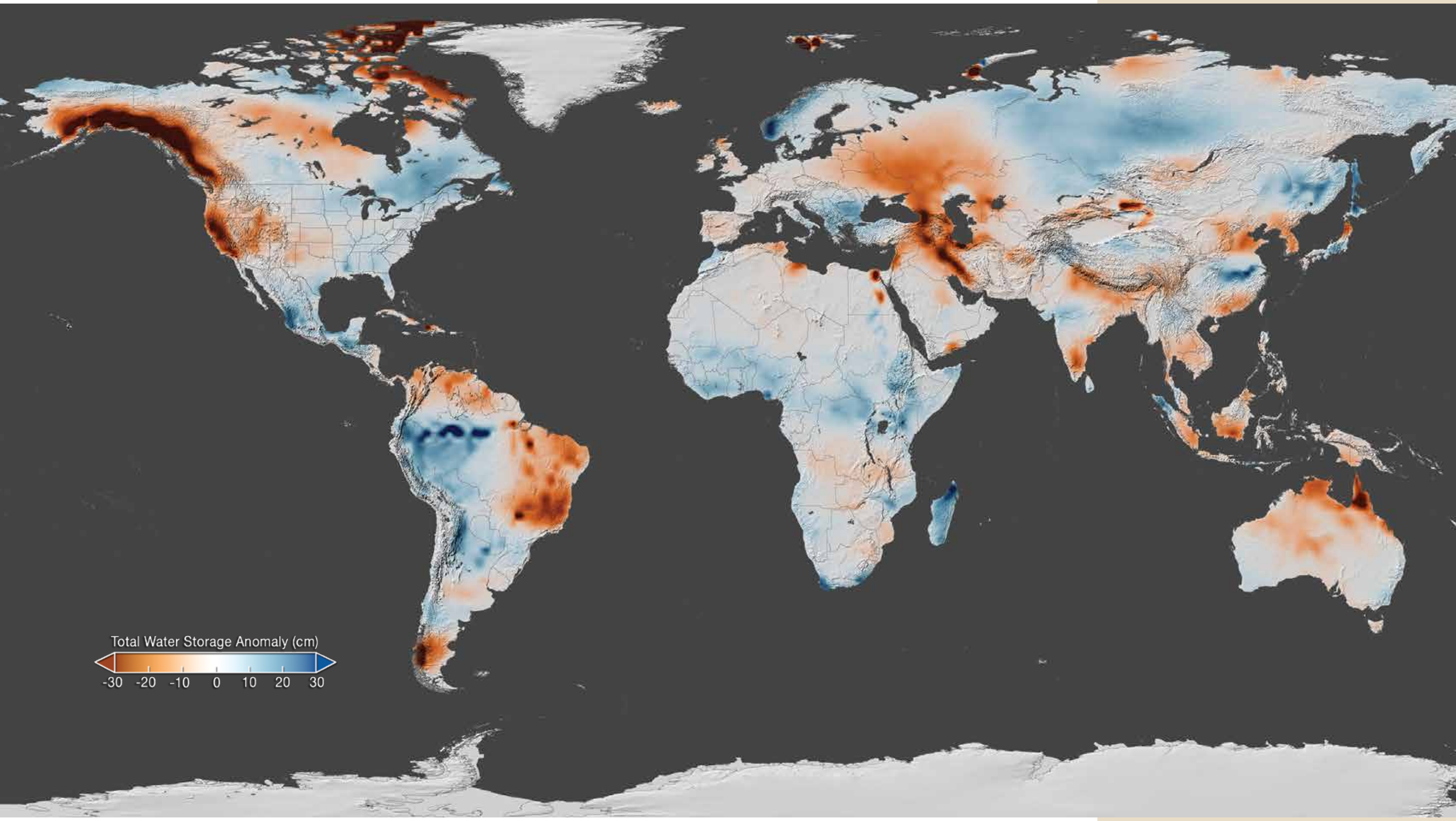


Image credit: NASA's Scientific Visualization Studio

[*Above*] The gravity variations measured by GRACE can be used to determine water storage on land. By comparing current data to an average over time, scientists can generate an anomaly map to see where terrestrial water storage has decreased or increased. This map, created using GRACE data, shows the global terrestrial water storage anomaly in April 2015, relative to the 2002-2015 mean. Rust colored areas show areas where water has decreased, and areas in blue are where water levels have increased. Note the significant decreases in water storage across most of California are related to groundwater, while decreases along the Alaska coastline are due to glacier melt.

[*Right*] Between early 2010 and summer 2011, global sea level fell sharply—by about a quarter of an inch, or half a centimeter. Using data from the GRACE satellites, researchers showed that the drop was caused by the very strong La Niña that began in late 2010. This periodic Pacific Ocean climate phenomenon changed rainfall patterns around the world, moving huge amounts of Earth's water from the ocean to the continents, primarily to Australia, northern South America and Southeast Asia—as shown in the small world map in the upper left corner.

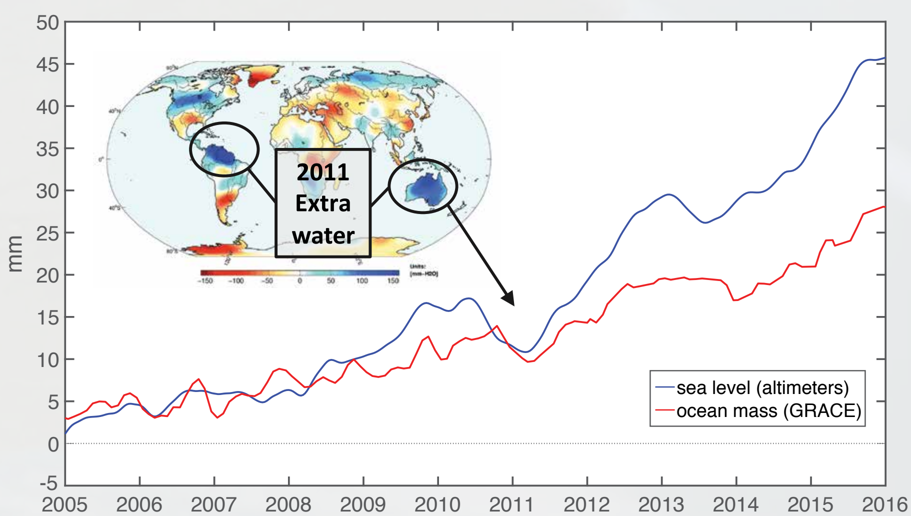
Image credit: NASA/JPL-Caltech

Image credit: NASA/JPL

Sea Level

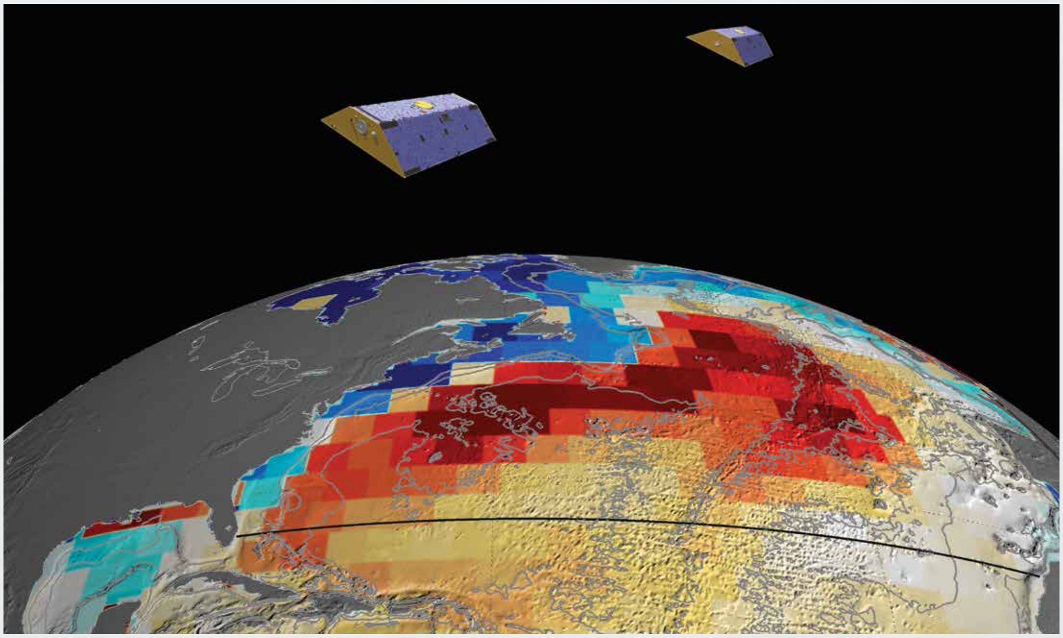
Sea level is rising because melting ice from land is flowing into the ocean and seawater is expanding as it warms. Since 1992, very precise, continuous measurements of sea level heights worldwide have been made by the NASA-CNES TOPEX/Poseidon mission and the successor Jason series of sea level altimetry missions. Altimeter measurements show how much sea level has risen, but not what causes it to rise—i.e., how much of the observed rise is from thermal expansion of seawater and how much is from increased volume due to ice melting and land runoff.

GRACE measured the monthly mass change of the ocean, and enabled us to distinguish between changes in water mass and changes in ocean temperatures. An example of the value of this ability was a study that documented a sizable—if temporary—drop in sea level and linked it to changes in the global water cycle that was disrupted by the large La Niña event in 2011. The study showed that the water that evaporated from the warm ocean, causing the drop in sea level, was mostly rained out over Australia, South America and Asia. The finding provided a new view into the dynamics and connections that shape the global water cycle.



Ocean Currents

When combined with measurements from sea surface height-measuring satellite altimeters, GRACE observations have greatly improved the precision of ocean current estimates. Beyond this classic application for ocean currents, GRACE observations have also directly been used to assess changes of large-scale current systems. At the bottom of the atmosphere—on Earth's surface—changes in air pressure (a measure of air's mass) tell us about flowing air, or wind. At the bottom of the ocean, changes in water pressure tell us about flowing water, or currents. A team of scientists at NASA developed a way to isolate the signal found in GRACE data indicating tiny pressure differences at the ocean bottom that are caused by changes in deep ocean currents. The measurements showed that a significant weakening in the overturning circulation, which a network of ocean buoys recorded in the winter of 2009-10, extended several thousand miles north and south of the buoys' latitude near 26 degrees north. The new measurements from GRACE agreed well with estimates from the buoy network, confirming that the technique can be expanded to provide estimates throughout the Atlantic and beyond. Because ocean currents distribute heat across the planet, any changes in ocean currents are important indicators of how our planet is responding and evolving in a warming climate.



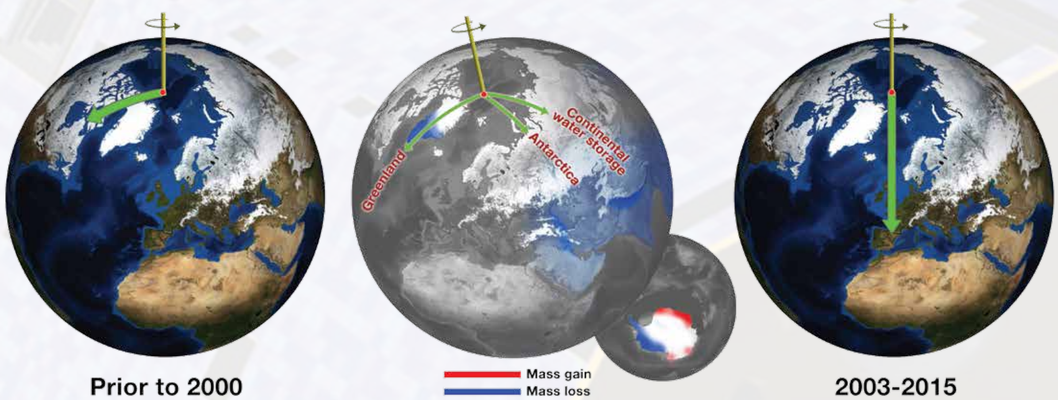
[*Left*] NASA's GRACE satellites (artist's concept) measured Atlantic Ocean bottom pressure as an indicator of deep ocean current speed. In 2009, this pattern of above-average (blue) and below-average (red) seafloor pressure revealed a temporary slowing of the Atlantic Ocean ocean currents. The resulting reduction in heat transport was associated with an exceptionally cold winter over Northern Europe. Satellite gravimetry provides a valuable tool to assess the state of vital large-scale ocean currents.

Image credit: NASA/JPL-Caltech

Solid Earth Changes

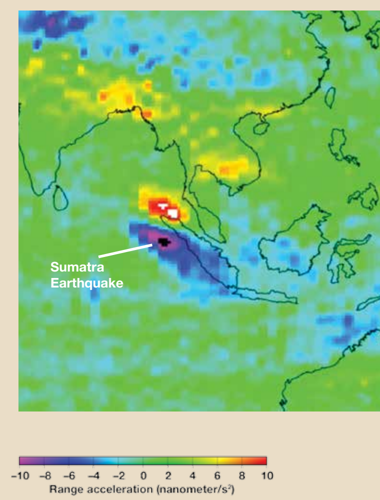
The viscous mantle under Earth's crust is also moving ever so slightly in response to mass changes from water near the surface. GRACE has a community of users that seek to quantify these shifts. Scientists at NASA used GRACE data to calculate how ice sheet loss and groundwater depletion have actually changed the rotation of Earth as the system adjusts to these movements of mass. Like a spinning top, any change in the distribution of mass will cause the Earth's axis to shift, wobble and readjust. GRACE helps to pinpoint those rotation changes and understand their causes.

In addition, some large earthquakes move enough mass for GRACE to detect. During 15 years in orbit, GRACE was able to measure the instantaneous mass shifts from several large earthquakes, and monitor the large, but slow tectonic mass adjustments that go on for months and even years after an earthquake. These measurements provide unprecedented insights into what is happening far below Earth's surface during and after big quakes, such as the 2004 Sumatra event and 2011 Tohuku (Japan) quake, both of which caused devastating tsunamis.



[*Above*] Before about 2000, Earth's spin axis was drifting toward Canada [green arrow, left globe]. NASA scientists calculated the effect of changes in water mass in different regions [center globe] in pulling the direction of drift eastward and speeding the rate [right globe]. These images show the relationship between continental water mass and the east-west wobble in Earth's spin axis. Losses of water from Eurasia correspond to eastward swings in the general direction of the spin axis, and Eurasian gains push the spin axis westward. Image credit: NASA/JPL-Caltech

Earthquake Signal Visible in GRACE Data



[*Above*] The GRACE satellites are sensitive to minute changes in Earth's mass, and the science team measured the gravity changes associated with mass shifts of Earth's crust caused by the December 2004 Sumatra earthquake. The quake changed the gravity over this region by one part in a billion.

Image credit: NASA/JPL-Caltech/University of Texas Center for Space Research

GRACE Follow-On: Mission Overview

Starting in 2018, the GRACE Follow-On joint mission by NASA and the German Research Centre for Geosciences (GFZ) will continue the successful GRACE data record. The GRACE-FO mission builds on and extends the capabilities of its predecessor, and also includes an experimental instrument that promises to be more accurate and allows for the detection of even smaller gravitational signals. In orbit, the twin satellites will provide accurate measurements of changes in Earth's gravitational field at least every 30 days, and allow for the tracking of changes and redistribution in Earth's near-surface mass. In addition, each of the satellites will use GPS antennas to supply at least 200 profiles of atmospheric temperature distribution and water vapor content daily—see *Measuring Atmospheric Temperature and Humidity* on Page 11.

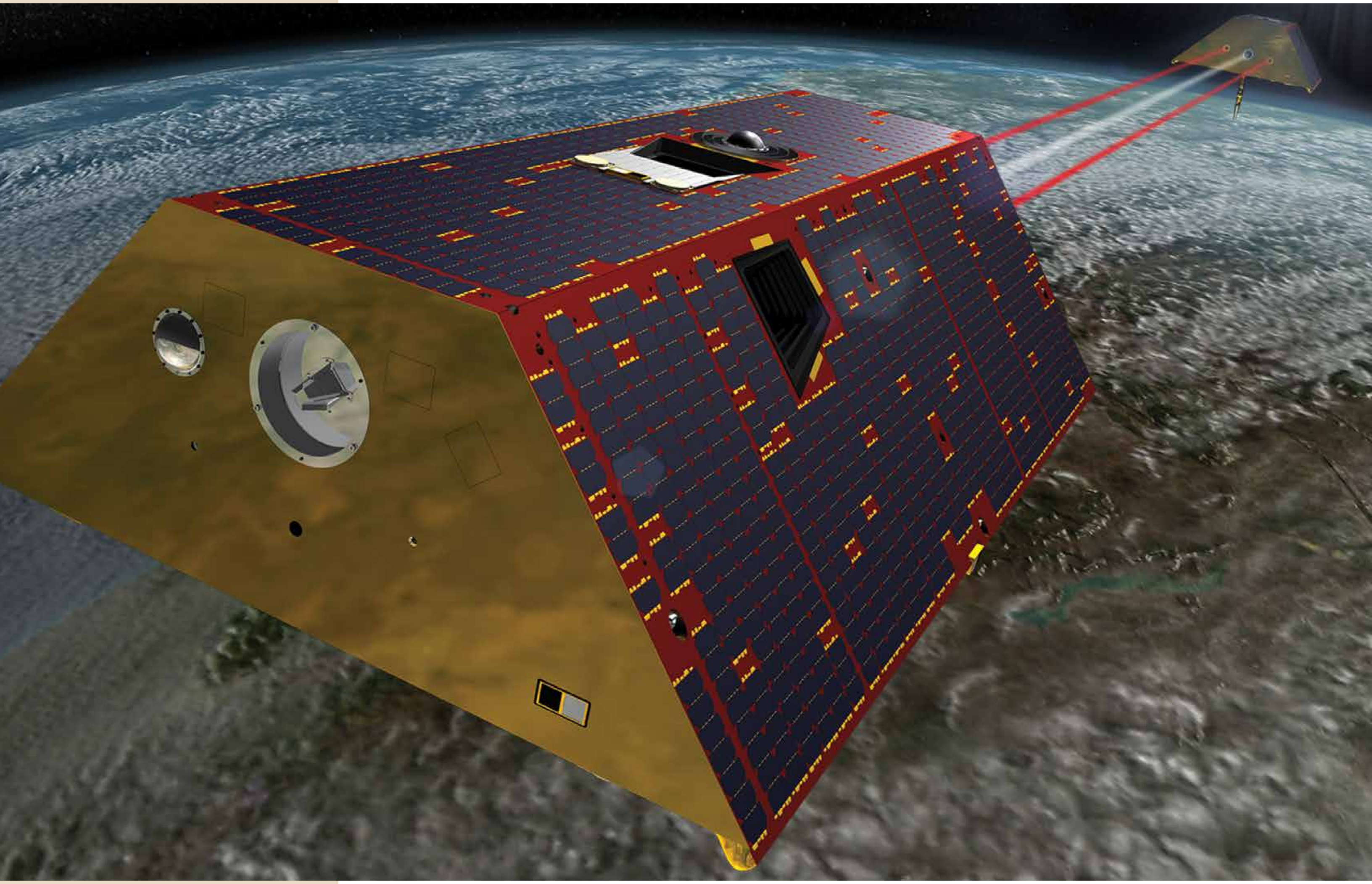
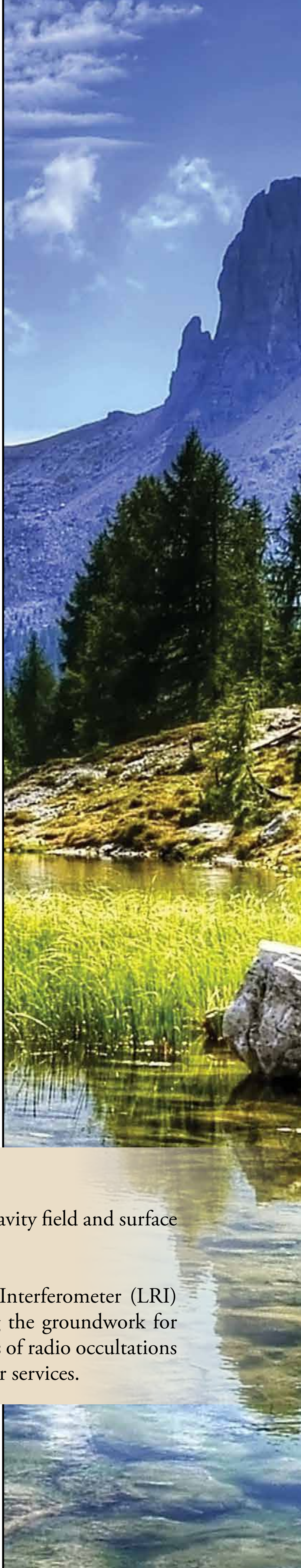


Image credit: NASA

Like its predecessor, the GRACE-FO mission consists of two identical satellites orbiting Earth at about 220 kilometers (137 miles) apart at an initial altitude of approximately 490 kilometers (305 miles). One of the unique aspects of GRACE and GRACE-FO is that the satellites themselves are effectively the "instruments." Unlike other Earth-observing satellites equipped with instruments pointing down at Earth's surface, the GRACE-FO satellites instead "look" at each other. Together, they represent a single measurement system. One satellite will follow the other along the same polar orbit, with both continually sending ranging signals to each other and carefully tracking any changes in the distance between the two satellites. When the GRACE-FO satellites encounter a change in the distribution of Earth's mass—such as a mountain range or reduced mass of underground water—the distance between the two satellites will change. By precisely and continuously tracking this change to within a fraction of the thickness of a human hair during each orbit every month, regionally and temporally varying gravity changes can be measured with high precision.

GRACE-FO will be able to make accurate measurements, thanks in part to the innovative use of two technologies: a microwave ranging system based on global positioning system (GPS) technology, and a very sensitive *accelerometer*—an instrument that measures the forces on the satellites besides gravity (e.g., atmospheric drag or solar pressure). GRACE-FO will use the same two-way microwave-ranging link as GRACE, called the Microwave Instrument (MWI). The MWI operates using two frequencies—at 24 GHz (K-band) and 32 GHz (K_a-band)—and is capable of measuring the distance between the two satellites to within one micron—about the diameter of a blood cell, or a small fraction of the width of a human hair. This allowed the GRACE satellites to detect gravitational differences on the planet's surface with a precision equivalent to a change of 1 centimeter (0.4 inch) in water height across areas of about 340 kilometers (approximately 211 miles) in diameter.

With the same kind of microwave ranging system, GRACE-FO satellites can expect to achieve a similar level of inter-satellite ranging precision. But they will also test and demonstrate an experimental instrument using lasers instead of microwaves, which promises to improve the precision of the separation distance measurements on future generations of GRACE satellites by a factor of about 20, thanks to the laser's higher frequencies. The instrument, developed jointly between NASA's Jet Propulsion Laboratory, the Max Planck Institut für Gravitationsphysik (Germany), and GFZ, is called the Laser Ranging Interferometer (LRI). The LRI is a stepping stone for future missions to enhance gravity measurements. It will also measure changes in the angle between the two spacecraft and thus support the conventional microwave-ranging observations. Together, the very precise measurements of location, force and orbital change translate into an observation of gravity with improved accuracy.



GRACE-FO Mission Objectives

The *primary objective* is to continue the high-resolution monthly global maps of Earth's gravity field and surface mass changes of the original GRACE mission over a period of five years.

The *secondary objectives* are to demonstrate the effectiveness of a novel Laser Ranging Interferometer (LRI) in improving the Satellite-to-Satellite Tracking (SST) measurement performance, laying the groundwork for improved future space-gravimetry missions. GRACE-FO will also continue measurements of radio occultations for operational provision of vertical atmospheric temperature/humidity profiles to weather services.

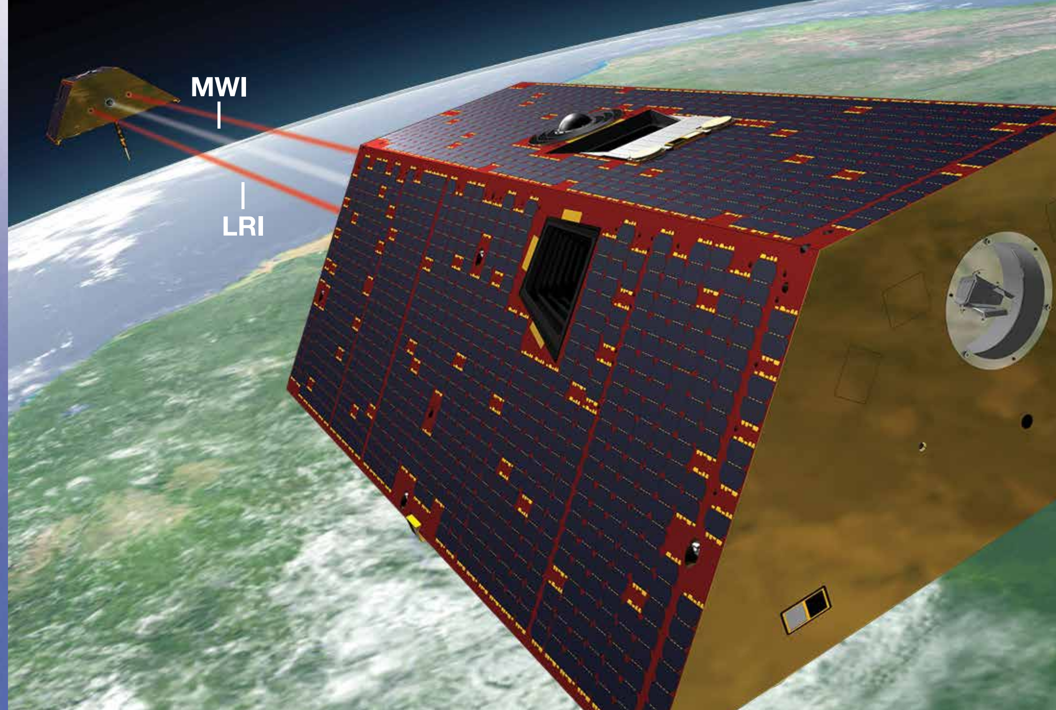


Image credit: NASA

[*Above*] The experimental Laser Ranging Interferometer (LRI) is expected to provide better ranging precision than GRACE's MWI system. LRI is being tested on GRACE-FO as an enabling technology for the next-generation of mass change missions.

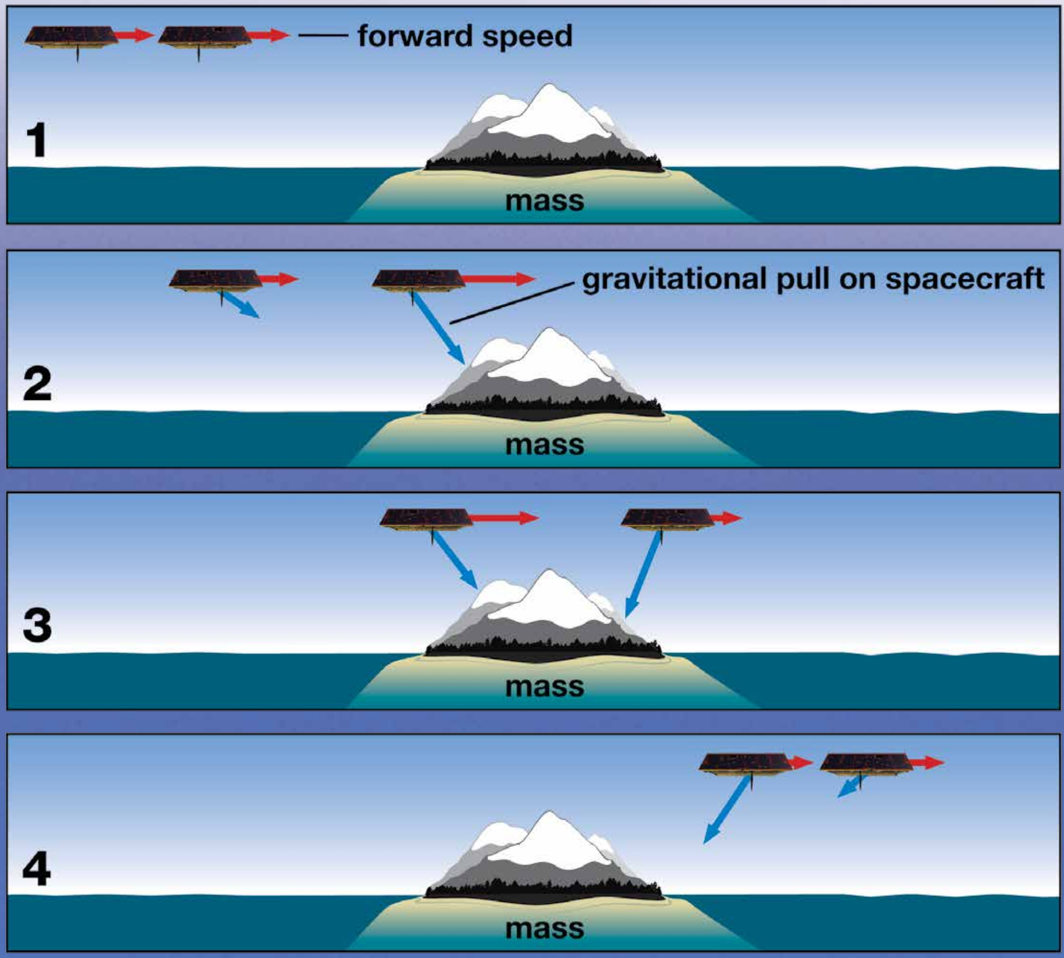
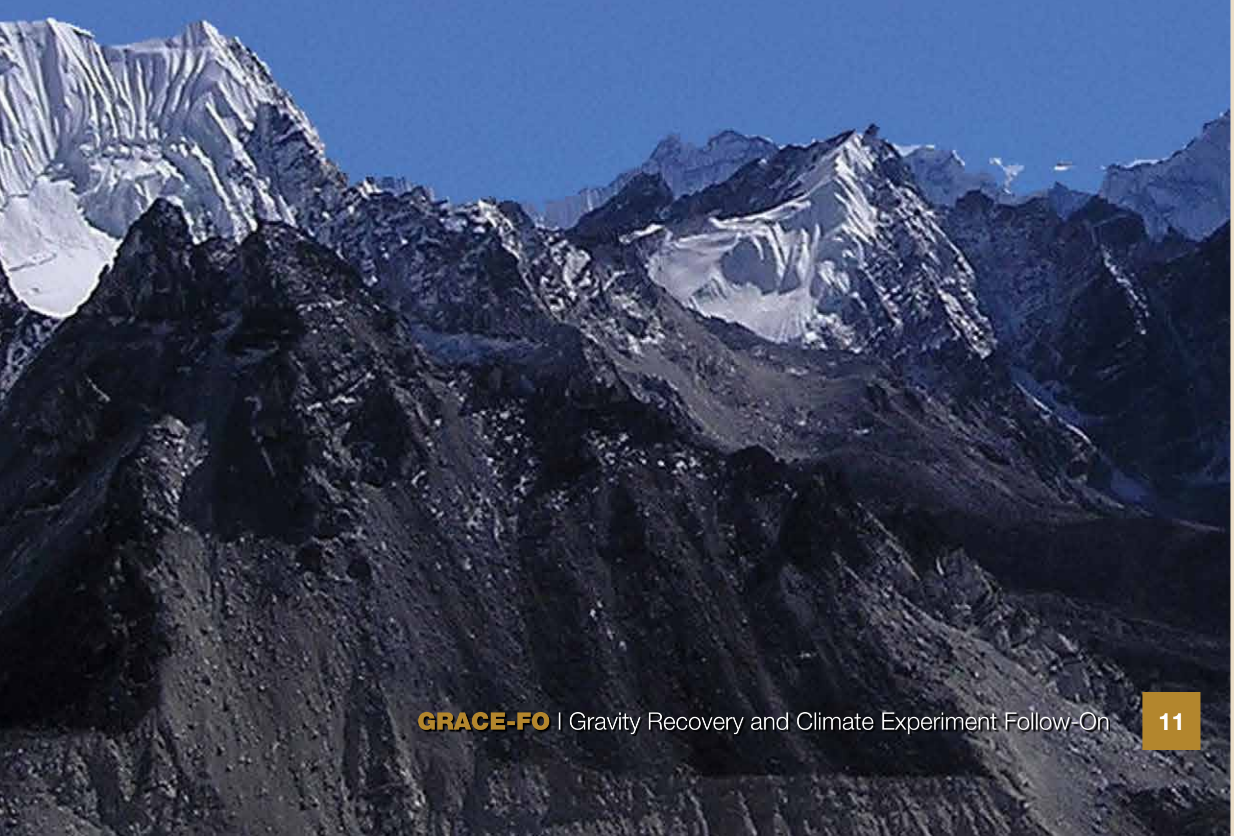


Image credit: NASA

[Above] *How GRACE-FO Works*. This simplified example illustrates the movements of the satellites as they pass southward from the Caribbean Sea across Colombia and Peru (i.e., a denser landmass) to the Pacific Ocean. The two satellites begin over the ocean (Panel 1), but when the leading spacecraft encounters land, the land's higher gravity pulls it away from the trailing spacecraft, which is still over water (Panel 2). Once the second satellite encounters the land, it too is pulled toward the mass and consequently toward the leading spacecraft (Panel 3). When the lead spacecraft moves back over water, it is pulled back slightly by the land, while the trailing spacecraft continues over the land. Once both spacecraft are back over water, the trailing spacecraft is slowed by the land (Panel 4) before returning to its original distance behind the leading spacecraft.



Measuring Atmospheric Temperature and Humidity

While the main global positioning system (GPS) receivers on the first GRACE mission were used for precise orbit determination, a set of secondary GPS antennas measured the bending of the signals between GRACE and GPS satellites that were low over the horizon. This way, the GPS signals graze and pass through Earth's atmosphere—known as *occultation*. The GPS radio waves are altered slightly as they pass through the atmosphere due to refractive effects, and these changes can be analyzed to create atmospheric profiles including refractivity, temperature, pressure and humidity. Radio occultation measurements complement and continue a long series of similar data obtained by sensors on other satellites and are very useful for weather forecasting and climate studies.

GRACE-FO will provide at least 200 daily near-real-time occultation observations from each satellite—data that are used operationally worldwide by leading weather centers to improve global weather forecasts. Over longer time scales, the GPS radio-occultation data are contributing to climate variability studies.

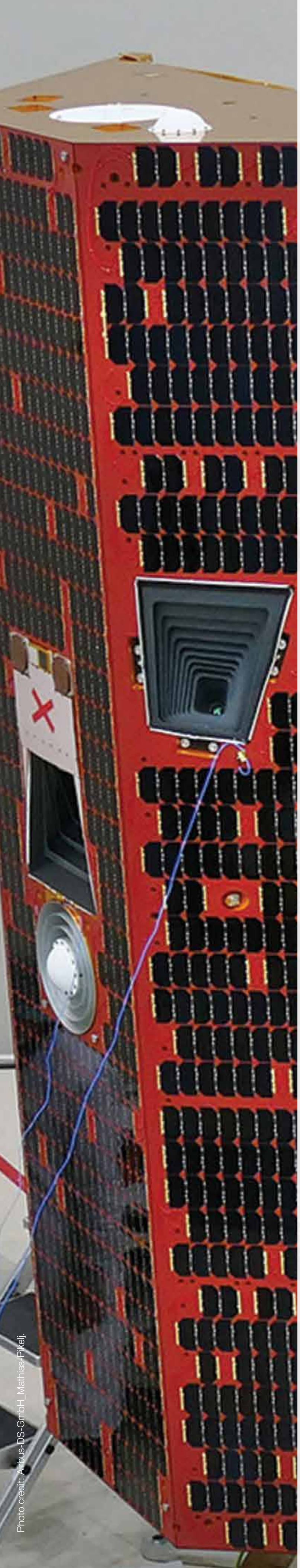
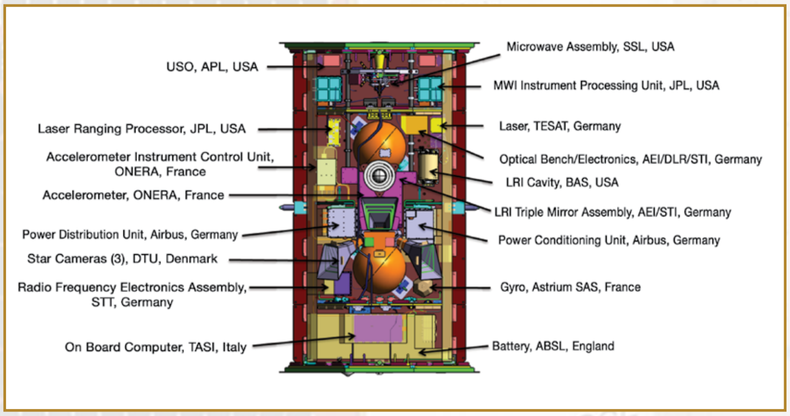


Photo credit: Airbus-DS-GmbH_Mathias-Pikelj.

Spacecraft Design and Launch

The GRACE-FO satellites follow the successful design of the original GRACE spacecraft. Each identical satellite is 1.94 meters (6.36 feet) wide, 3.12 meters (10.25 feet) long and 0.72 meters (2.36 feet) high, with a mass of 600 kilograms (1,323 pounds). Both spacecraft are covered in solar panel arrays that power the satellites.

The GRACE-FO satellites will be launched together from Vandenberg Air Force Base in California into Earth orbit on a SpaceX Falcon 9 launch vehicle as a shared ride with five communications satellites. The GRACE-FO satellites will be deployed first from the launch vehicle into a low-Earth, near-polar orbit, after which the launch vehicle will



[*Left*] The GRACE-FO satellites are nearly identical. The Microwave Interferometer (MWI) will measure the minute range variations, while the global positioning system (GPS) will keep track of the spacecraft position relative to Earth's surface, and onboard accelerometers will record forces on the spacecraft other than gravity, such as atmospheric drag and solar radiation

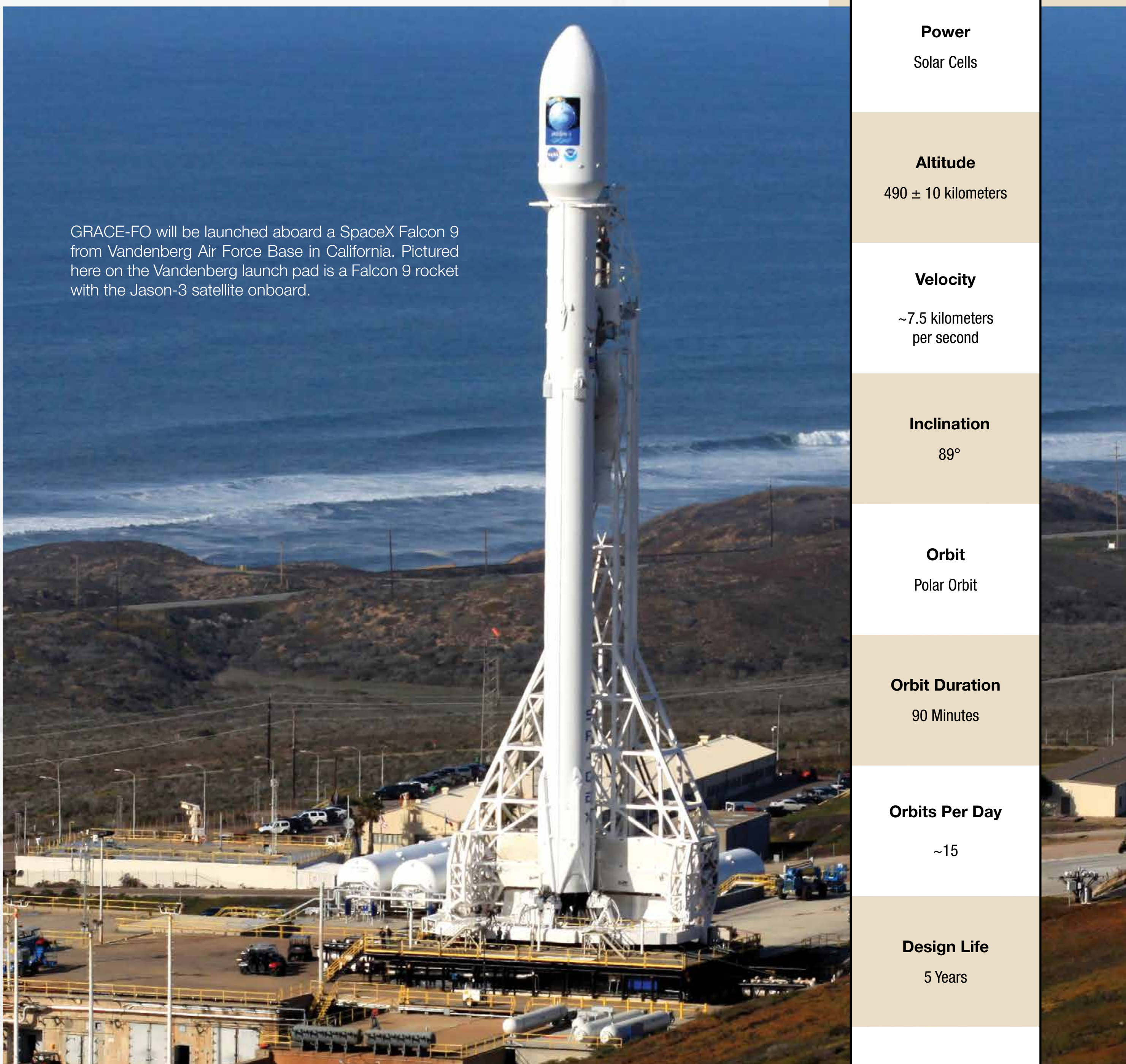
Image Credit: Airbus-DS, GmbH

Photo credit: Airbus DS GmbH-A.Ruttloff

[*Above*] The GRACE-FO satellites were assembled by Airbus Defence and Space in Germany with major components from a number of countries including Denmark, England, France, Germany, Italy, Sweden, and the U.S. This photo shows the satellites inside the IABG testing facility in Munich, Germany.

continue on to a higher orbital altitude before releasing the communications satellites.

The GRACE-FO twin satellites, after release at an altitude of about 490 kilometers (305 miles), will be maneuvered to a separation distance of about 220 kilometers (137 miles) apart. As the satellites circle Earth, the ranging technology will measure separation between the satellites at the micrometer level, and the GPS sensor will provide the location of the satellites in their orbits. These observations will then be combined and processed using supercomputers to estimate month-to-month gravity and surface mass variations.



GRACE-FO will be launched aboard a SpaceX Falcon 9 from Vandenberg Air Force Base in California. Pictured here on the Vandenberg launch pad is a Falcon 9 rocket with the Jason-3 satellite onboard.

Photo credit: NASA/Kim Shiflett

GRACE-FO at a Glance

Size (of each satellite)	1.94 meters wide, 3.12 meters long, .72 meters high
Mass	600 kilograms
Power	Solar Cells
Altitude	490 ± 10 kilometers
Velocity	~7.5 kilometers per second
Inclination	89°
Orbit	Polar Orbit
Orbit Duration	90 Minutes
Orbits Per Day	~15
Design Life	5 Years
Fuel Life	>5 Years

Image credit: NASA

Ground System and Data Products

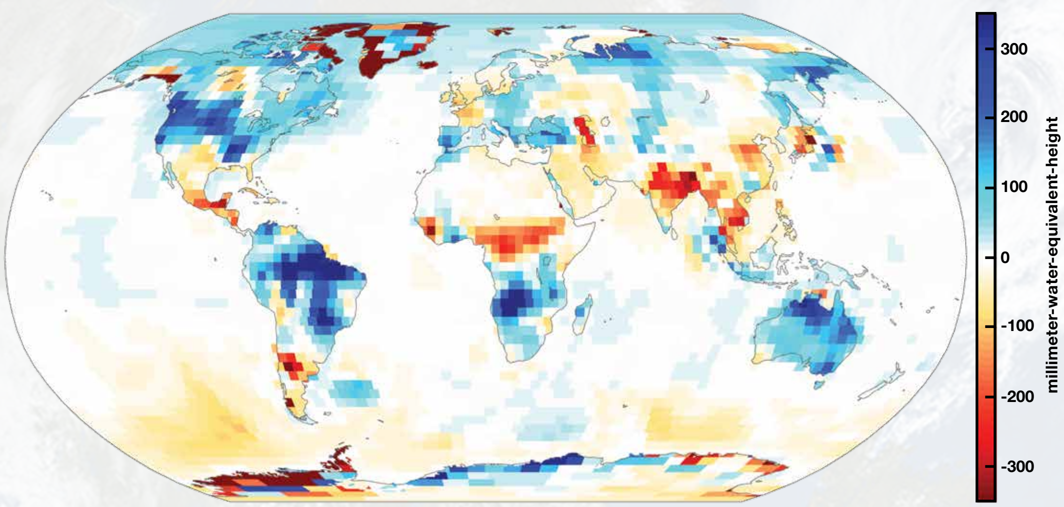
The GRACE-FO mission ground system includes all the assets needed to command and operate the twin satellites in orbit, as well as manage, process and distribute their data.

To communicate with the satellites, the German Space Operations Center (GSOC) in Oberpfaffenhofen (Germany) sends commands through ground stations in Weilheim or Neustrelitz (Germany) directly to the GRACE-FO satellites. Once data have been collected onboard the spacecraft, they are transmitted to the two German stations or to the GFZ station in Ny-Ålesund, Norway. From there, all received telemetry is sent to the Raw Data Center (RDC) in Neustrelitz, Germany, and to the Physical Oceanography Distributed Active Archive Center (PO.DAAC) at JPL in Pasadena, California, as well as to the Information System and Data Center (ISDC) at GFZ in Potsdam (Germany), and the University of Texas Center for Space Research (UT-CSR) for monitoring and further analysis. GSOC provides real-time monitoring of the spacecraft status and functions, and will send new software commands as necessary for optimal operations.

High-resolution, monthly global models of Earth's gravity field will be freely available at grace.jpl.nasa.gov/data

Data from the GRACE-FO satellites are returned every 96 minutes. Once GRACE-FO is fully operational, high-resolution, monthly global models of Earth's gravity field will be freely available at *grace.jpl.nasa.gov/data*.

These data will inform hydrologists about up-to-date land water storage conditions, provide glaciologists with accurate measurements of glacier and ice sheet mass changes, allow oceanographers to assess global and regional sea level and ocean current variations, among other uses. Data from GRACE-FO are expected to provide new perspectives of Earth's ever-changing water cycle that will benefit society for years to come.



[*Above*] The distribution of global mass anomalies for April 2011 (relative to the 2005-2010 average) reveals relatively wet (blue colors) and relatively dry areas (red colors). Over the continental United States, the dark blue colors reveal the extent of above average winter and spring precipitation that year, which led to significant flooding over parts of the Missouri River basin. Unusual and higher-than-normal water storage over Australia was linked to a temporary drop in global mean sea level.

Image credit: NASA/JPL-Caltech

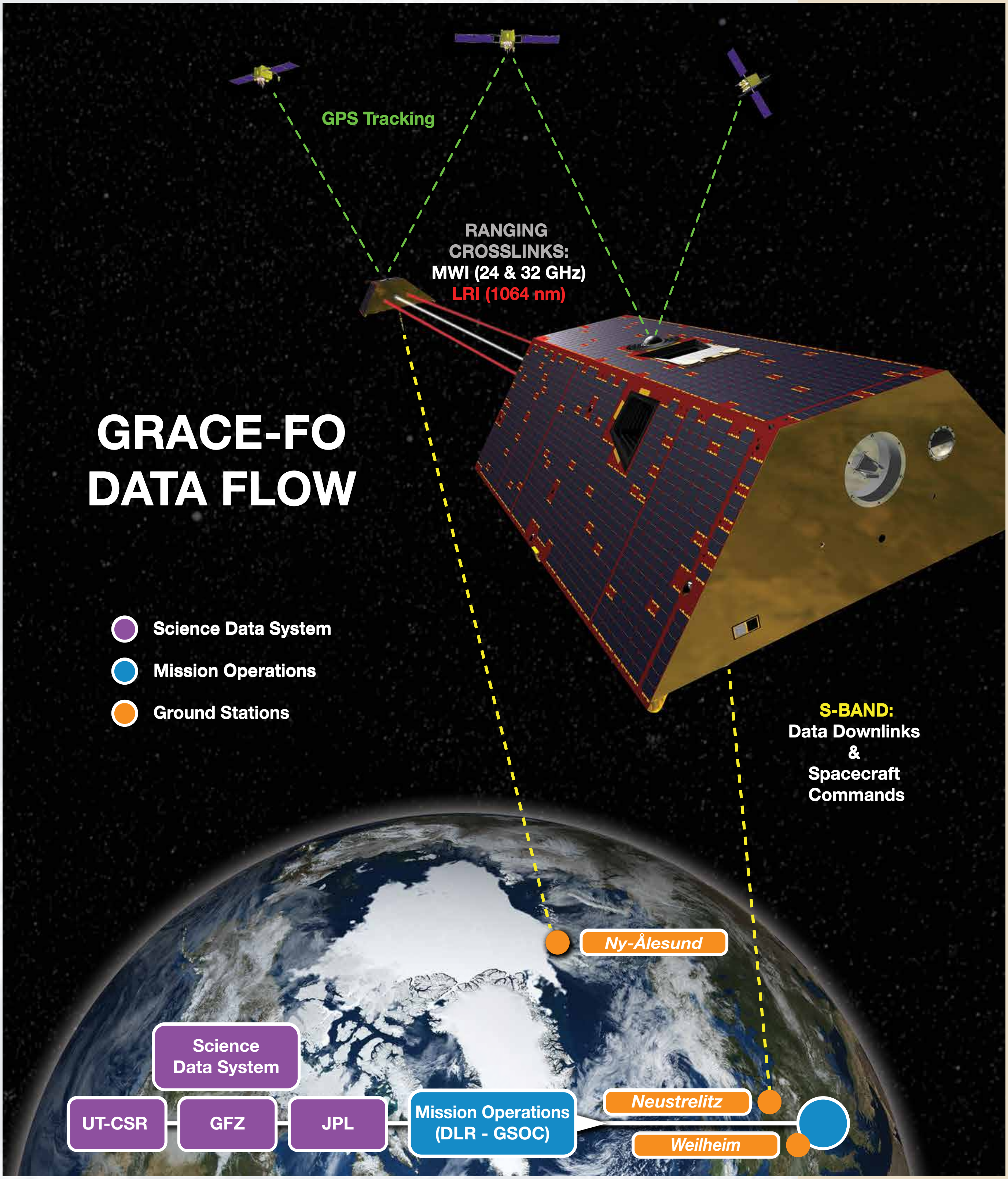


Image credit: NASA

This graphic shows how data travel from the GRACE-FO satellites to receivers on the ground. The measurement and housekeeping data are stored onboard the GRACE-FO satellites and relayed to ground stations when the satellites pass over at least once a day.




Applications and Benefits to Society

Among the applications of GRACE-FO mission data are improvements to our understanding and forecasting of freshwater availability, droughts, agricultural resources, sea level rise, climate change and solid Earth changes. Data from GRACE-FO—along with information from other Earth-observing satellites and airborne missions, combined with ground-based data—will lead to advances in Earth system science for years to come.

Monitoring Freshwater Resources

Water resource managers rely on accurate estimates of underground water storage like those provided by GRACE and soon GRACE-FO to monitor freshwater resources necessary for human activities including public consumption, irrigation and sanitation—among other uses.

Enhanced Prediction Skills for Weather and Climate

By providing GPS radio-occultation measurements daily, coupled with an improved understanding of the global water cycle, data from GRACE-FO will help advance Earth system analysis and weather and climate forecast modeling.

Improved Forecasting Capabilities for Drought and Flood Risk

Too much or too little water can have huge impacts on people around the world. The agricultural community, wildfire managers and other decision-makers will use GRACE-FO data to provide weekly maps of drought risk.

Improved Predictions of Flood Potential

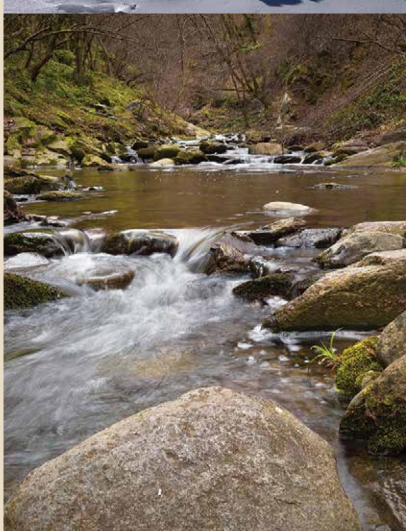
GRACE-FO will provide a means to observe monthly variations in total water storage within large river basins. The terrestrial water storage signal defines the time-variable ability of land to absorb and process water, and accounts for the water beneath the surface. Water storage information from GRACE-FO will allow users to assess the predisposition of a river basin to flooding as much as 5–11 months in advance.

Improved Sea Level Change Prediction and Ocean Current Monitoring

Data from GRACE-FO will allow scientists to keep a close eye on sea level and determine—in conjunction with other observations—how much of the change is due to warming, ice melting or runoff from land. Ocean bottom pressure measurements from GRACE-FO will also enable the tracking of deep ocean current changes.

Better Solid Earth Monitoring

Data from GRACE-FO will also record mass changes originating from earthquakes, tsunamis, volcanic eruptions and the Earth's crust as it adjusts to other mass changes such as loss of land ice. This effectively provides a window into the interior of our planet, and gives researchers new data to infer material properties deep below the surface.



"GRACE was a pioneering mission that advanced our understanding across the Earth system—land, ocean and ice. The entire mission team was creative and successful in its truly heroic efforts over the last few years, extending the science return of the mission to help minimize the gap between GRACE and its successor mission, GRACE Follow-On."

Michael Watkins

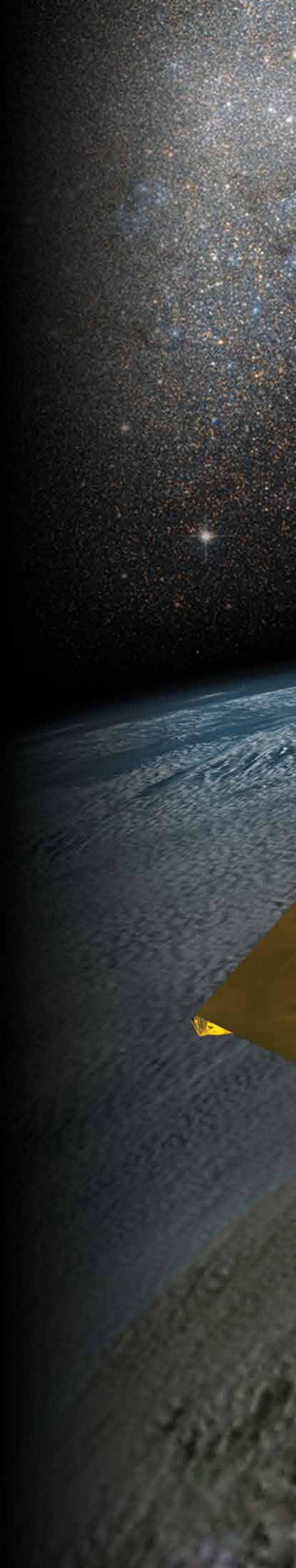
Director of NASA's Jet Propulsion Laboratory
and GRACE-FO's Science Team Lead

"GRACE-FO allows us to continue the revolutionary legacy of GRACE. There are sure to be more unexpected and innovative findings ahead."

Frank Webb

Project Scientist
GRACE-FO

Image credit: NASA



National Aeronautics and Space Administration

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