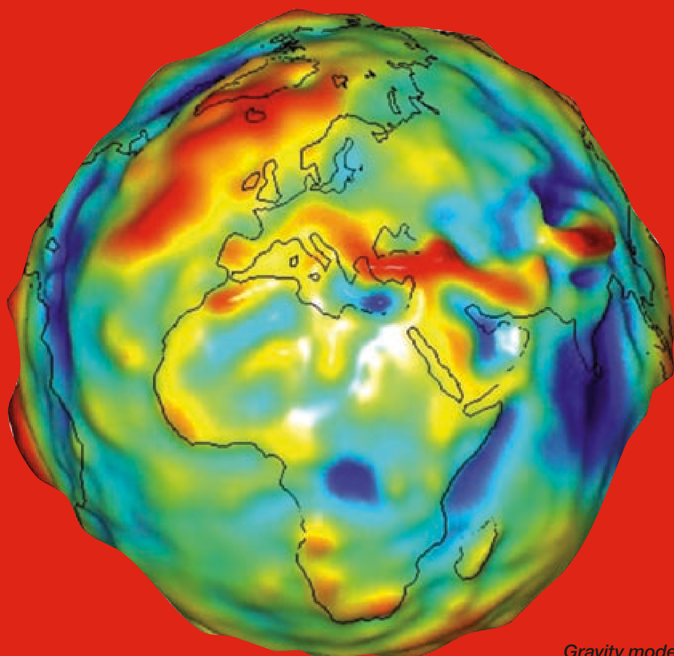
The Road to GRACE

BY EDGAR S. (AB) DAVIS



Gravity model figure of Europe and Africa prepared by The University of Texas Center for Space Research as part of a collaborative data analysis effort with the NASA Jet Propulsion Laboratory and the GeoForschungsZentrum Potsdam.

Image Credit: NASA/University of Texas Center for Space Research

On March 17, 2002, twin satellites comprising the flight segment of the Gravity Recovery and Climate Experiment (GRACE) were launched by a Russian Rockot launch vehicle from the Plesetsk Cosmodrome into orbit 300 miles above the earth. The successful launch of that science mission represented not just a technological achievement but years of planning, re-planning, negotiation, and persuasion. The early history of the program suggests some of difficulties and rewards of international cooperation.

LEFT: GRACE launched from the Plesetsk Cosmodrome, a former Intercontinental Ballistic Missile (ICBM) site in northern Russia.

RIGHT: View of the twin satellites in a clean room.

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Measuring Earth's Gravitational Field

The aim of the GRACE experiment is to map the strength of Earth's gravity field at given latitudes, longitudes, and times. To measure ocean surface currents using satellite altimetry from TOPEX-Poseidon, oceanographers needed measurements of mean ocean geoid (sea level without the influence of tides and weather) improved by a factor of twenty—from an uncertainty of about 20 cm to about 1 cm. During the concept design phase, it became clear that GRACE could exceed this requirement by more than a factor of twenty-five, and it could do it every month. This remarkable performance extended to the land as well. Among other things, GRACE is now being used to measure both seasonal and year-to-year variations in the storage of water in the world's major watersheds; in the amount of ice stored on Greenland and Antarctica; and the degree to which the sea level is rising due to the addition of water that up to now has been stored on land.

The twin GRACE satellites, separated by 105–165 miles (and by about thirty seconds in time), fly in essentially the same circular orbit under the influence of Earth's total mass. Mass near the earth's surface is not uniformly distributed. The first satellite speeds up along its circular orbit as it approaches a concentration of mass on the surface and slows down after it passes by. Approximately thirty seconds later, the second satellite experiences the same effect. The resulting fluctuation in satellite-to-satellite range is related to the magnitude and extent of mass concentration. A microwave link between the twins measures the ever-changing range with submicron precision. The range measurements and the nongravitational forces on each satellite are recorded ten times per second and sent to the ground twice a day. Every thirty days, the accumulated data is converted to a new mathematical model of the gravity field.

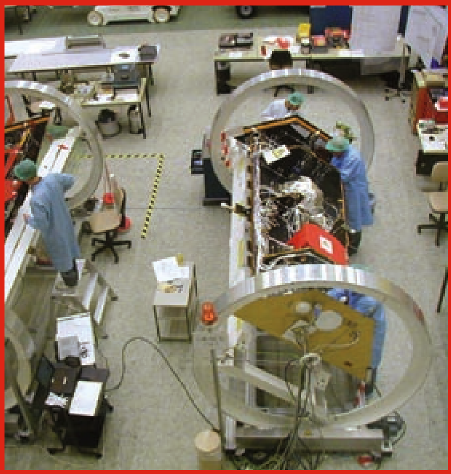
After participating in European Space Agency (ESA)– and NASA-led studies for gravity missions that failed to move out of the study phase, I assumed responsibility for developing the GRACE mission concept into a flight project in 1992. By the summer of 1994, the instrumentation design had taken shape, and we had refined the requirements on twin satellites well enough to begin discussions with potential contractors. I took the requirements on a tour to leading small satellite suppliers in the United States. No one had a design that came close to meeting the mission's requirements for thermal control and structural stability, and no one had experience with the ultra-sensitive accelerometer that we needed to measure the nongravitational forces on the satellite. Furthermore, the United States had given up on developing the kind of accelerometer that was needed.

An International Effort

In the United States we tend to assume that our technologies are the best in the world. This is counterproductive hubris. For GRACE, we used ultra-sensitive accelerometers from France, star cameras from Denmark, custom satellites with an ultra-stable structure from Germany, and a Russian launch vehicle with a custom dual-satellite dispenser. We found it easy to adapt to the Russians' logical and well-defined processes for completely meeting a customer's technical and operational requirements. But it did take long hours to negotiate every point through interpreters and document everything in writing in both Russian and English. It paid off in an efficient six-week launch campaign at Plesetsk with six feet of snow. The Russian-supplied launch vehicle delivered exceptional performance. The Rockot exceeded all GRACE requirements by a factor of three or more.

Our European contractors all worked on fixed-price contracts, so we knew we would get their best people. More importantly, every decision with the European suppliers was made with an accurate assessment of the cost.

The path to international cooperation had its twists and turns as well as opportunities and setbacks. At the July 1995 International Union of Geodesy and Geophysics meeting in Boulder, NASA's John LaBrecque organized a meeting of all the known proponents of various concepts for measuring Earth's gravity field. At that meeting, Dr. Christoph Reigber of GFZ-Potsdam, Germany's geosciences research center, presented the German plans for a single-satellite gravity and magnetic field



mission and expressed interest in the GRACE concept that I presented. LaBrecque suggested that we explore a cooperative U.S.–German mission.

When we took the concept to DARA, the German space agency, the head of DARA's Earth sciences program said a study would be a waste of time because they didn't have the money for the full mission after the approval of CHAMP (CHAllenging Mini-satellite Payload). But DARA had no objection to Reigber using GFZ-Potsdam funds for the study. And we found a potential German ally for our concept at the meeting. Two people introduced themselves as representing DLR's German Space Operations Center, GSOC. I only vaguely knew of its existence, but I made a spur-of-the-moment decision to put my trust in the GSOC and committed to give them responsibility for GRACE mission operations. While the prospects for cooperation looked bleak, we accepted an invitation to visit GSOC the next day. We found a modern but underutilized facility. There were five empty control rooms; in the sixth, a lone operator was monitoring the ten-year-old RoSAT mission, an X-ray observatory. Missions like GRACE were clearly important to their future.

I went on to GFZ-Potsdam with Reigber and drafted an agreement to facilitate NASA sponsorship of the joint feasibility study. In November 1995, I returned to GFZ-Potsdam for six weeks. Reigber arranged for me to share an office with his systems engineering team from Dornier Satellite Systems who were working on CHAMP. I understood that I would be working with this group on the feasibility study, but it soon became clear that my study was not on their radar screen. They were preparing for the CHAMP project's preliminary design review and assumed that I was there for the same purpose. I did help with the systems aspects of hosting the receiver, which NASA had agreed to supply to the CHAMP project. It took some time, but in the process I found that Dornier Satellite Systems had special technical capabilities that were essential to the success of the GRACE mission. Instinctively, Reigber knew that I would connect with the team from Dornier on the GRACE project.

The time at GFZ-Potsdam put me contact with ONERA, the French aerospace lab. The French space agency, CNES, had agreed to supply an accelerometer built by ONERA to CHAMP. In Potsdam, I learned a lot from Bernard Foulon and Pierre Touboul about the limitations and capabilities of their ultra-precise accelerometer. The unit could be easily tailored to the GRACE requirement. The technical competence and integrity of the ONERA team was quickly apparent. They had no peer in the field of ultra-sensitive accelerometers. We needed their device for GRACE.

GFZ-Potsdam planned to use a Russian COSMOS rocket acquired through a German-Russian partnership to launch CHAMP, but a second Russian launch vehicle option was under development by another German-Russian partnership—the Rockot. Both vehicles had the payload capacity and fairing size needed to launch the twin GRACE satellites. I worked out five options for launching the twin GRACE satellites, two on the COSMOS and three on the more capable Rockot.

We still faced serious hurdles. A plan for U.S.–German cooperation on GRACE was shaping up in my study—NASA would supply the GRACE instrumentation and the launch on a Russian launch vehicle, and DARA would supply the satellite and the mission operations—but the plan proved to have a fatal flaw. The Space Transportation Policy of 1994 provided that a NASA payload could only fly on a foreign launch vehicle provided by a foreign government under a no-exchange-of-funds agreement. NASA could not purchase, or contribute to the purchase of, the Russian launch vehicle without a presidential waiver.

Shortly after this problem became apparent, SS/Loral came to the Jet Propulsion Laboratory and described how the GlobalStar satellite bus might be adapted to carry science instruments. The GlobalStar bus didn't come close to meeting the GRACE requirements, but SS/Loral mentioned their corporate connection to Dornier on the GlobalStar project. That suggested a new plan. I saw a way to buy satellites from Dornier through SS/Loral, so NASA could supply the instrumentation and the twin GRACE satellites, and DARA could supply the

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Russian launch vehicle and the mission operations. SS/Loral and Dornier agreed to pursue the plan. NASA issued the call for a proposal to the Earth System Science Pathfinder program (ESSP). I needed DARA's commitment to the plan.

The timing could not have been worse. The funding for the space program in Germany was being cut by 25 percent and DARA staffing was to be reduced and merged into the DLR. But we needed their signature on a letter supporting our step-one proposal to NASA. We needed to meet with them and negotiate a commitment. Reigber was very concerned and discouraged us from coming to Germany. We took his name off the cover page of our presentation but included him as the proposed co-principle investigator. Trusting us not to embarrass him, he came to our meeting with DARA. GSOC was also represented. Our proposal met with a positive response from DARA management. With Reigber's help, we moved to discussing the content of the supporting letter for the step-one proposal. The new plan was sensitive to German industrial policy regarding reunification, foreign policy regarding strengthening economic ties with Russia, and the reality of a limited budget for space missions. The Germans committed to be part of the step-one proposal. It took similar finesse to get them to be a part of the step-two proposal.

But six months after GRACE was selected for the NASA-ESSP program and two months after JPL received funding for the project, the head of the DLR was planning to tell the NASA administrator that the DLR did not have the funds for GRACE and would not participate in the project. I could only think that he had received bad advice in making this decision. The night before his meeting with the NASA administrator, I obtained the number of the hotel in Washington, D.C., where he was staying and called Reigber in Rio de Janeiro. Reigber awoke the head of DLR at 1:00 a.m. I can only imagine what was said. The next morning, the head of the DLR told the administrator that Germany would cooperate on the GRACE mission. Within a month, the contract between JPL and Dornier was executed. About a year later, NASA and DLR signed the memorandum of understanding, and DLR had selected the Rockot launch vehicle for the mission. The project had a successful mission confirmation review and NASA approved the mission for implementation.

Some Key Points

1. Success stemmed from the essential work of gathering an international team with the skills and capabilities that GRACE required, building relationships, and getting essential commitments.
2. Establishing cooperation with the Germans on GRACE depended on having a respected German scientist, Christoph Reigber, as an advocate for the project. His vision, leadership, and diplomacy with German officials were critical.
3. We created a deal that was sensitive to German policy objectives and a budget crisis in the German space program. In a business-as-usual arrangement, DLR would have purchased the satellites and NASA would have supplied the launch. By reversing responsibility, the DLR's budget for the implementation phase was reduced by about a factor of four.

In the face of long odds, persistence has paid off. For more than five years, GRACE has been measuring and mapping variations in Earth's gravitation. It has shown how much water is used for irrigation in Northern India and near the Aral Sea. It has determined that Greenland's ice is melting much faster than expected, at a rate of 150 to 250 cubic kilometers a year. (One cubic kilometer is about 264 billion gallons of water.) ●

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