GRACE Newsletter

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1. Editorial

After the successful launch on March 17, 2002 the twin GRACE satellites have been orbiting the Earth for more than 4 months. The satellites are in the commissioning phase and are expected to transition into the calibration/validation phase in September. With the exception of the inertial measurement unit on GRACE 1, all sensors and instruments are operating in the science data collection mode. A preliminary assessment of the early data indicates that the sensors are meeting the mission objectives. This Newsletter No. 1 contains information on the current mission status, the GRACE orbital parameters, and the status of the satellite subsystems, the scientific instruments, the ground segment and the data processing activities.

B. Tapley (GRACE PI) Ch. Reigber (GRACE Co-PI)

Mission Description

The GRACE mission was selected as the second mission under the NASA Earth System Science Pathfinder (ESSP) May 1997. The GRACE mission will accurately map variations in the Earth's gravity field over its 5-year lifetime. The GRACE mission consists of two identical satellites flying about 220 kilometers apart in a near-polar orbit, at about 500 kilometers above the Earth.

Variations in the Earth gravity field affect the twin satellites at different times, leading to a change in the inter-satellite range. The Earth's gravity field is thus inferred from accurate measurements of the distance change between the two satellites using a K-Band microwave ranging system, along with non-gravitation force measurements from a precise accelerometer, and absolute position measurements from a GPS receiver. The system will provide scientists with an efficient and cost-effective way to map the Earth's gravity field with unprecedented accuracy. The results from this mission will yield crucial information about the distribution of mass within the Earth.

The gravity variations that GRACE will track include: changes due to surface and deep currents in the ocean; runoff and ground water storage on land masses; exchanges between ice sheets or glaciers and the oceans; and variations of mass within the Earth. Another goal of the mission is to create a better profile of the Earth's atmosphere. The results from GRACE will make a significant contribution to the goals of NASA's Earth Science Enterprise, Earth Observation System (EOS) and global climate change studies.

GRACE is a partnership between the National Aeronautics and Space Administration (NASA) in the United States and Deutsches Zentrum für Luft- und Raumfahrt (DLR) in Germany. Dr. Byron Tapley of The University of Texas Center for Space Research (UTCSR) is the Principal Investigator (PI), and Dr. Christoph Reigber of the GeoForschungsZentrum Potsdam (GFZ) is the Co-Principal Investigator (Co-PI). Project management and systems engineering activities are carried out by the Jet Propulsion Laboratory. Scientific products will be generated in a joint Science Data System managed by JPL, UTCSR and GFZ.

Current Status

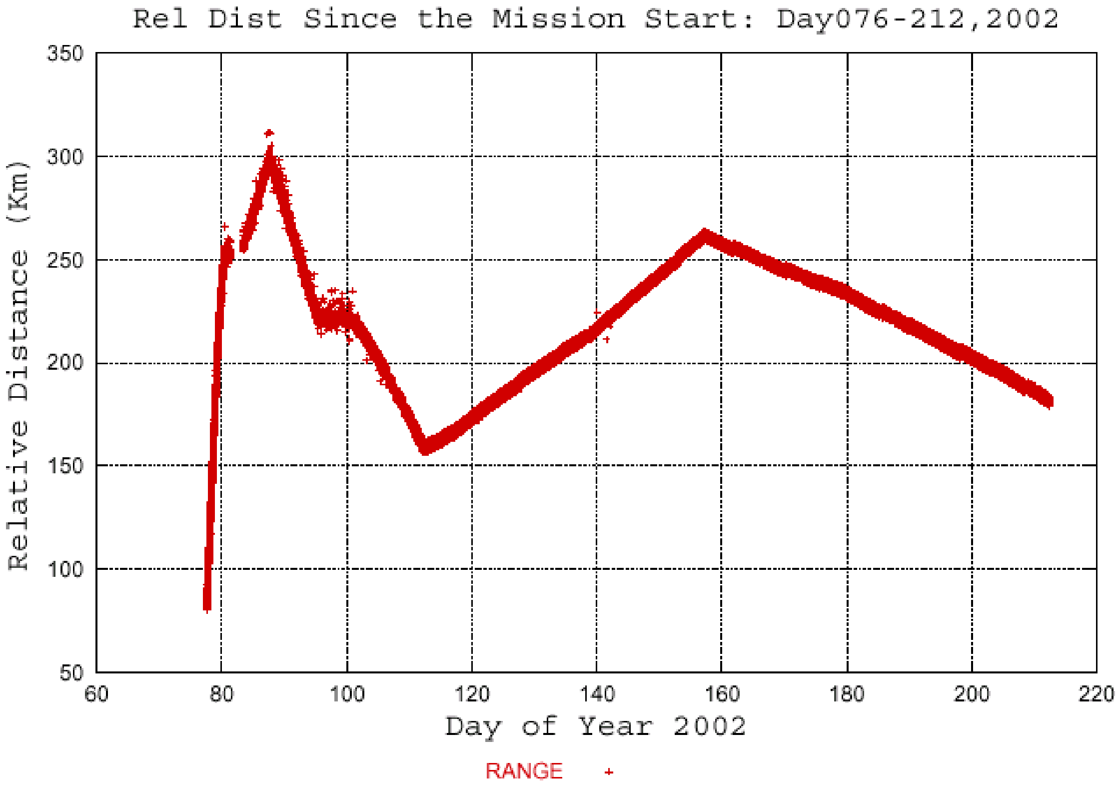
The payload-commissioning phase is currently in progress, during which in-orbit calibration and validation are under way. A dedicated software upload is planned for mid- September.

2. GRACE orbits and maneuvers

The GRACE satellites were launched from Plesetsk, Russia, at 09:21:27 (UTC), March 17, 2002. The injection orbit was on target. The achieved accuracy for altitude, eccentricity and inclination exceeded the required standards by a factor of 9, 7 and 2, respectively. The two satellites were separated from the BREEZE - Upper Stage at 10:46:50.875 UTC on March 17, 2002. The Keplerian elements at this separation epoch, in the True-of-Date reference coordinate frame are given below:

	GRACE-1	GRACE-2
Semi-major axis (km)	6876.4816	6876,9926
Eccentricity	0.00040989	0.00049787
Inclination (Deg)	89.025446	89.024592
RA Asc. Node (Deg)	354.447149	354.442784
Arg. Perigee (Deg)	302.414244	316.073923
Mean Anomaly (Deg)	80.713591	67.044158

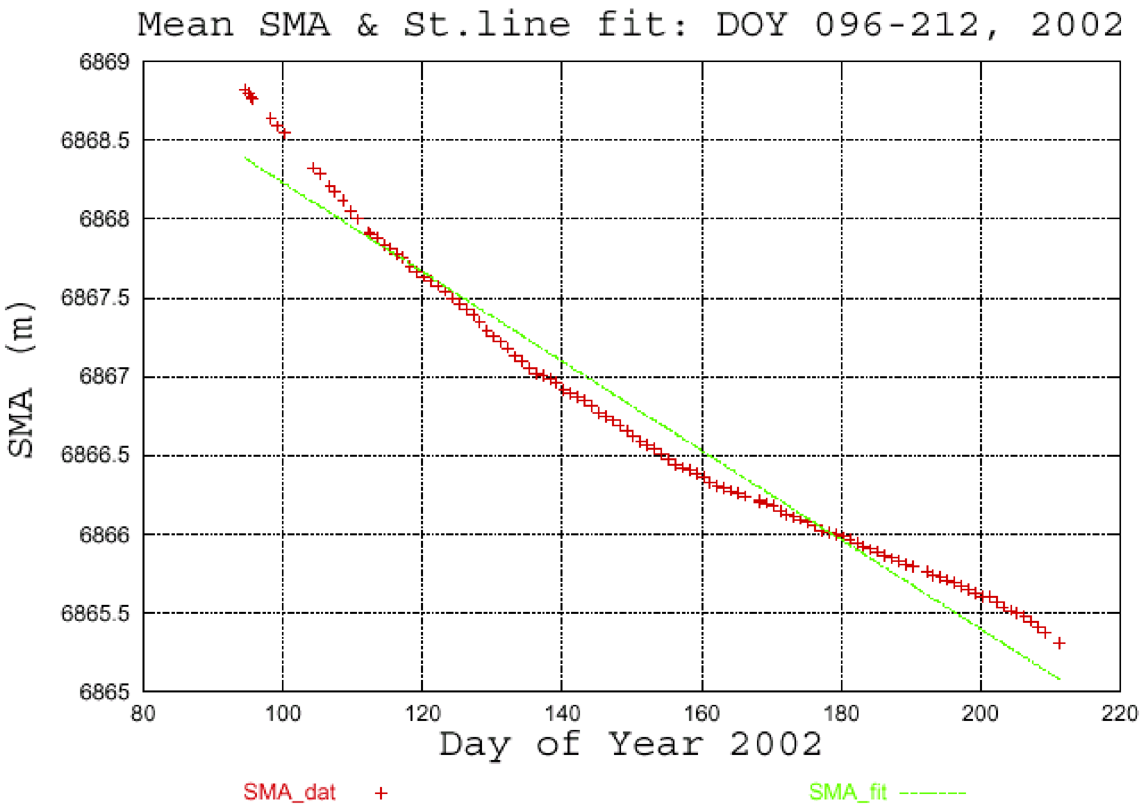
In the nominal configuration, the satellites fly 220 km apart, within ± 50 km. Several drift stop and regular orbit maintenance maneuvers have been performed to compensate for relative drift due to drag force differences. The monitoring of the separation, and the planning & execution of such maneuvers is now a routine Mission Operations System activity. Today (August 1, 2002) the mean separation distance between the satellites is about 181 km with a rate of almost 0.0 km/day. History of the relative distance between the two satellites since the day after the beginning of the mission (i.e. since DOY 77) is shown in the following figure.



In order to make precise measurements of non-gravitational accelerations, the proof mass of the accelerometer must be located at the CoM of the satellite. In order to precisely position the CoM a sequence of calibration maneuvers has been carried out. The results of these maneuvers indicated that the CoM was initially approximately 0.23 mm from the center of the accelerometer (targeted pre-flight co-location precision during assembly was projected to be 0.3 mm). The mass-trim mechanism was then successfully activated to re-center the CoM. Present estimates indicate that the two are co-located to within approximately 0.05 mm, compared to the science requirement of 0.1 mm.

In order to precisely point the K-Band antenna at the other satellite, the orientation of the K-Band bore-sight (or the vector between satellite CoM and the K-Band horn phase center) must be precisely known. This will be achieved in-flight using special attitude maneuvers. The feasibility of executing such a maneuver was successfully demonstrated on June 5, 2002. Analysis of the science data from these preparatory maneuvers shows the expected signals, which are the basis for determination of the precise alignment of the K-Band bore sight vector. Analysis is underway in preparation for the execution of the K-Band Calibration maneuvers.

Between the DOY 96 (April 6, 2002) and 212 (July 31, 2002) the mean semi-major axis for GRACE-1 decreased at an average rate of about 28.4 meters per day. The mean semi-major axis values and a straight line fit to them are shown in the following figure:



3. Satellite Subsystems Status

Overall, all the satellite sub-systems are operating in their nominal configuration. Several of the sub-systems have already undergone one or more fine-tunings, to incorporate the in-flight experiences over the past 4 months.

Power Supply: The power systems, based on Globalstar Si cells on the outer skin of the satellites, are delivering sufficient power for housekeeping and payload activities.

Thermal System: The thermal control system, which utilizes 64 individually controlled heaters, has proven to be very robust. The thermal model and heater settings have been fine-tuned based on in-flight experience. Temperature set-points and variations are in general agreement with pre-flight projections. All critical electronics & systems requiring dimensional stability are being controlled to a constant temperature.

In particular, the thermal-control stability over an orbit of the K-Band ranging system and of the accelerometer are worth mentioning, considering the stringent requirement of 0.1°C/orbit on the design.

Onboard Data Handling System

The OBDH has been performing nominally. An OBDH software upload was performed on GRACE-1 on April 18 and 19, 2002 and for GRACE-2 on April 17 and 18, 2002.

Attitude and Orbit Control System (AOCS):

Cold gas thrusters and magnetic torque rods are used to actively control/maintain the attitude of the satellite on all the three axes. Star cameras, Coarse Earth & Sun Sensors (CESS) and IMU (gyro) are used to accurately measure the attitude.

Nominally, the satellites are maintained in the "Science Mode" (SM) in which each satellite points to a predicted location of the other satellite. The leading satellite is yawed 180° relative to the flight direction, so that a K-Band ranging link can be established with the trailing satellite. Generally, however, good quality science data can also be collected when the satellites are in "Attitude Hold Mode" (AHM) in which the satellites are held in a specific orientation with respect to the local-vertical-local-horizontal.

The Coarse Pointing Modes of attitude control are used for specific operations, or as a back-up (safe) mode of pointing. In general, the K-Band tracking data is not available in these modes, depending on the mutual pointing geometry. In these modes, the CESS and the IMU or the magnetometers are used for attitude determination. Since launch, these modes have been adjusted to reduce the cold gas consumption. Flight procedures have also been adapted to ensure that time spent in these modes is minimized.

All the AOCS attitude modes have been checked out and relevant parameters are being optimized. The attitude thruster firings and the cold gas consumption have been as expected.

Based on data collected in dual-Star Camera operation, the mutual alignments between the star camera head have been corrected. As a result, in the event of Sun & Moon outages during the same revolution, the attitude control system is now capable of transitioning from one head to another. This ensures smooth attitude variations without transients.

The IMU on GRACE-1 failed approximately 1 hour and 40 minutes after launch. JPL investigations based on 10 Hz IMU diagnostic data give possible explanations: a) a failure of a laser diode controller/driver on the analog card, b) a laser diode failure, c) a failure of any of a number of the optical elements common to all three gyros, or d) an optical receiver chip failed. Because the IMU measurements can be substituted by other sensor data of the Attitude and Orbit Control System, the success of the GRACE mission is not endangered by this failure.

The cold gas consumption on both satellites are as expected and is at the level of about 3 to 4 grams per day when the satellites are in nominal AOCS Science Mode or Back-up Science Mode. GRACE-1 had a faster rate of consumption during the months of March and May when the satellite went into Coarse pointing AOCS mode. Overall cold gas consumption until July 24, 2002 for GRACE-1 is about 3.217 Kg and that for GRACE-2 is about 1.224 Kg.

4. Scientific Instruments

The sequence of scientific instrument turn-on was as follows.

Ultra-stable Oscillator (USO): March 17, 22:20:53 (GRACE-1) and March 17, 23:49:23 (GRACE-2)

GPS receiver: March 18, 07:30:36 (GRACE-1) and March 18, 10:33:00 (GRACE-2)

Accelerometer: March 21, 16:39:41 (GRACE-1) and March 21, 22:24:33 (GRACE-2)

K-Band ranging system: March 25, 13:40:01 (GRACE-1) and March 25, 08:08:59 (GRACE-2)

The Star Cameras were put into service a few hours after the GPS receivers were turned on.

There have been several notable events during the commissioning phase. The services of the main Ultra Stable Oscillator USO-001 on GRACE-1 were lost on 22 March. The fault was traced to an intermittent contact in the power harness which went un-detected prior to launch. The switch to the redundant USO-003 was performed on March 23. USO-003 is showing nominal Behavior. Preliminary analyses show that all science instruments except the SuperSTAR accelerometer on GRACE-1 operate as expected and give very promising results.

Here are some brief notes on each instrument:

Accelerometer: Both SuperSTAR accelerometers have been continuously operating until May 21, when the Instrument Control Unit (ICU) of the accelerometer on GRACE-1 stopped producing output data. Analysis between JPL and the vendor of the unit has shown that the 5-volt power supply has an intermittent failure, which is still under investigation. Currently the redundant ICU unit on GRACE-1 (turned on at 12:45 July 23 - DOY 204) is running and the heater settings for this unit will be determined in a few days. All measurement data on GRACE-1 and GRACE-2 show nominal behavior in radial, along- and cross-track directions. The bias & scale parameters for the accelerometers show good stability from day to day.

Star Camera: Star Camera data are reliably available for science analyses for both satellites. Present analyses focus on noise level, alignment and dual-head operation. Preliminary assessments suggest that the noise in roll/pitch/yaw is in the range of 120-180 micro radians, which is slightly higher than required. This might be due to inherent Star Camera assembly noise, errors in the reference attitude or rapid variations in the attitude of the satellite and is being further investigated. Also, performance during the Sun/Moon intrusion in the field of view of the camera needs to be assessed..

GPS: The GPS receiver tracks up to 10 GPS satellites. Phase and pseudo-range residuals are excellent, which has been validated by analysis of orbital fits. The receiver on Grace-1 typically goes 7 to 10 days without a reset. The receiver on GRACE-2 produces about 8% less data compared to GRCAE-1, but has a better pseudo-range fit to the data. It is re-setting more often (every few days) and tracks fewer satellites on average. This difference in behavior is still under investigation.

Both receivers continuously provide navigation solutions in the range of 6-8 m, which are used for the on-board AOCS or the ground SLR prediction generation. Occultation measurements are not yet enabled..

KBR: When the satellites are in science mode or in backup science mode, the K-Band Ranging system is performing nominally, returning good quality data at high signal-to-noise ratios. The range-free combinations show that the phase variations are being tracked to less than a milli-cycle. The data has been successfully processed for gravity field analyses & for initial K-Band Calibrations. Pre-calibration (wiggle) tests have been carried out and the overall calibration of the KBR is yet to be performed. This will be done after the performance analysis and fine-tuning of the star camera (SCA) are completed.

SLR: The CHAMP-type LRR provides a sufficiently strong reflected signal, which allows day- and nighttime measurements. With this reflector an absolute accuracy of better than 5 mm (2-way ranging) has already been achieved

The global laser tracking campaign can be regarded as remarkably successful considering the low orbit of GRACE. Presently about 3-4 passes per day and per satellite are observed by about 15 globally distributed SLR stations.

USO: Due to cabling fault, services of the main Ultra Stable Oscillator USO-001 on GRACE-1 were lost on March 22. The switch to the redundant USO-003 was performed on March 23. USO-003 is showing nominal behavior. On GRACE-2 the redundant USO-004 is operational, while the main USO-002 is off.

5. Ground Segment and Satellite Operation

The GRACE operations utilize a ground station network that includes the German ground network with stations at Weilheim and Neustrelitz and the NASA polar ground network with stations at Wallops (Virginia), Poker Flat (Alaska), McMurdo (Antarctica), and Spitzbergen Island (Norway). The satellite control center is at the German Space Operation Center near Munich Germany. The ground network and the satellite control center have performed flawlessly in the 4.5-month GRACE mission. In the months prior to launch the operations team developed numerous nominal and contingency procedures that are used to operate the satellites. These procedures, which have been refined based on the flight experience, have enabled the operations team to respond quickly to all situations. A quick response in anomaly situations is necessary in order to minimize the attitude control gas consumption.

A unique feature of this mission has been the simultaneous execution of dual-satellite control from a single operations center, in the early days after launch. The support from the NASA polar station network (NASA PGN) was crucial during the first two weeks after launch, in getting the satellites into a stable configuration and consequently secure a robust routine operation.

6. Data Processing

Data Dumping, Decoding and Level-1 Processing: The telemetry dump files (Level-0) from DLR´s raw data center (RDC) at the satellite ground station Neustrelitz are routinely acquired by the Level-1 processing centers at JPL and GFZ (backup). JPL decodes the science instrument and satellite housekeeping data and compiles the single dump files to daily files per instrument and sensor for further processing by the GRACE Science Data System (SDS).

In general, approximately 99.5 % of the raw data is successfully retrieved by the RDC & the SDS Level-1 processing centers.

The remaining work on Level-1 processing during the commissioning phase will focus on the improvement on satellite attitude data, star camera alignment and center of mass calibration.

Additionally inaccuracies due to lack of dual-star camera data and unexpected accelerometer signals ("twangs") will be investigated.

Level-2 Processing: A 20 days level-1B test data set has been provided to the GRACE Level-2 processing centers at UTCSR and GFZ to be used for instrument validation and calibration as well as for initial gravity modeling.

7. GRACE related international Meetings

Oct 16-17, 2002: **Integrated Space Geodetic Systems and Satellite Dynamics**; Joint COSPAR/IAC Panel on Satellite Dynamics (PSD1-B2.1) at the 34th Scientific Assembly of the Committee on Space Research (COSPAR), Houston, TX, USA

8. Outlook

The commissioning phase is expected to continue through September. Following the completion of this phase, activities to generate initial gravity products will be initiated and the mission will enter a six to nine month calibration/validation phase.