V04 Level-1 data processing status for GRACE and GRACE Follow-On

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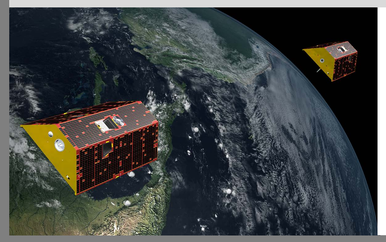
GRAVITY RECOVERY AND CLIMATE EXPERIMENT FOLLOW-ON



Launch: May 22, 2018
from Vandenberg Air Force Base, USA
on SpaceX Falcon 9 rocket

Orbit: altitude: 490.8 km
inclination: ~89 deg (polar orbit)
s/c distance: 220 km +- 50 km
1 orbit rev: 94 min

Mission: NASA & GFZ (German Research Centre for Geosciences)

GRACE-FO L1 DATA AVAILABILITY

A complete L1A/L1B data set is available since initial switch on of the instruments, except for the following days:

- 2018, July 19 - Oct 21 - IPU and MWA switched off on GF-2
- 2019, Feb 8 - Feb 20 - all payload instruments switched off on GF-2
- 2020, Jan 19 – Jan 23 - GF-2 satellite entered safe mode when the on-board clock was corrupted by a single bit flip in the GPS integer seconds counter in the IPU that tracks GPS time
- 2020, Feb 8 – Feb 12 - GF-1 experienced same problem as GF-2 in February 2020

GRACE DATA REPROCESSING

- Final reprocessing of 15+y of GRACE data [2002-2017] is currently in progress
- For the final release, GRACE L1 data is processed using GRACE-FO L1 software
  - This will ensure data consistency between GRACE and GRACE-FO. In addition, GRACE and GRACE-FO L1 V04 data will be reprocessed with consistent background models and parametrization (L2 RL07) to ensure a bias-free +20y data record of Earth's gravity and mass changes
  - Reprocessing of 15+y of GRACE data is also the ultimate validation of the GRACE-FO software
- The major differences between the s/w versions and configurations are highlighted in the table. The full list will be provided at the time of the data release
- In version V04, significant improvement of the orbit determination has been achieved, which is reflected in both GRACE-FO and GRACE L1 data as well as in the gravity field solutions

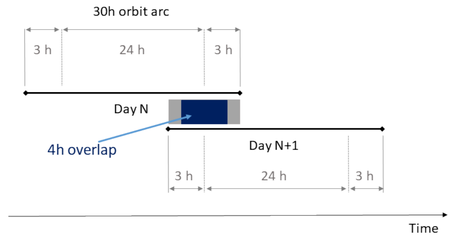
	V02	V03	V04
POD: data rate for orbit and clock solution	300 s	--	10 s
POD: GPS antenna cals	300 s	--	10 s
KBR: Time-of-flight relativistic effects	NO	NO	YES
Attitude (SCA1B)	SCA only	SCA+ACC (Kalman filter)	SCA+IMU (KF) - GRACE-FO SCA+ACC (KF) - GRACE

LEVEL-1 DATA DOCUMENTATION & ACCESS

- GRACE-FO Level-1 Handbook (Link)
- GRACE-FO Level-1 Release Notes (Link)
- GRACE-FO Calibrated Accelerometer Data Products (ACT) (Link)
- GRACE-FO Sequence-Of-Events file (SOE) (Link)
- Data download: PO.DAAC & ISDS
  https://podaac.jpl.nasa.gov/GRACE-FO
  https://isdc.gfz-potsdam.de/grace-fo-isdc/

PRECISE ORBIT/CLOCK DETERMINATION AND K-BAND RANGING PERFORMANCE

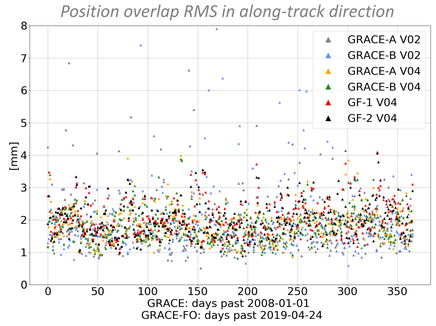
Metrics for performance statistics:
1 - Spacecraft trajectory comparison between overlapping consecutive orbit arcs
2 - Spacecraft clock synchronization on overlapping arcs
3 - (KBR – GPS) range difference



Each orbit arc is an independent OD solution. The comparison of the data overlaps informs about the precision of the POD and of the clock estimation.

1. Spacecraft trajectory comparison between overlapping consecutive orbit arcs

Position overlap RMS in along-track direction



GRACE-A V02: 1.93 ± 1.32 mm
GRACE-B V02: 1.95 ± 1.06 mm

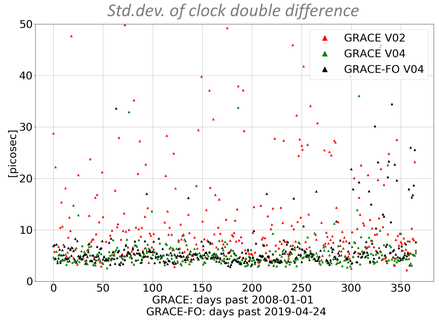
GRACE-A V04: 1.84 ± 0.51 mm
GRACE-B V04: 1.87 ± 0.97 mm

GF-1 V04: 1.96 ± 0.50 mm
GF-2 V04: 2.01 ± 1.27 mm

Performance consistent and meets expectations

2. Spacecraft clock synchronization on overlapping arcs

Std.dev. of clock double difference



$$\Delta dt = (t_{N+1}^{GF1} - t_N^{GF1}) - (t_{N+1}^{GF2} - t_N^{GF2})$$

Δdt ... clock double difference
$t_{N+1}^{GFx} - t_N^{GFx}$ ... clock difference between the current and the next day using the overlap data for GF-1 and GF-2, resp.

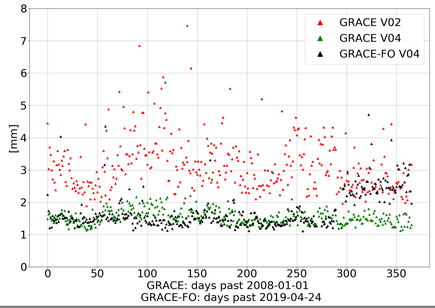
GRACE V02: 13.0 ± 21.8 ps
GRACE V04: 5.8 ± 7.9 ps
GRACE-FO V04: 7.2 ± 9.0 ps

Requirement:
< 160 ps (≈ 0.5 micron)

Performance exceeds requirements
Significant improvement compared to GRACE V02

3. (KBR – GPS) range difference

Std.dev. of (KBR – GPS) inter-satellite range differences



$$\Delta\rho = \rho_{GPS} - \rho_{KBR}$$

$\Delta\rho$ ... inter-satellite range difference
ρ_{GPS}, ρ_{KBR} ... inter-satellite range independently derived from GPS and KBR data

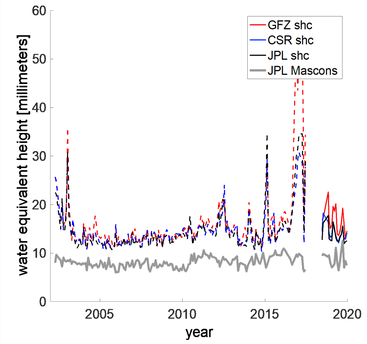
GRACE V02: 3.2 ± 1.3 mm
GRACE V04: 1.6 ± 0.6 mm
GRACE-FO V04: 1.7 ± 0.6 mm

Significant improvement compared to GRACE V02

Note: The elevated GRACE-FO values starting from 2020-02-14 are due to change of the signal power of the GPS satellites

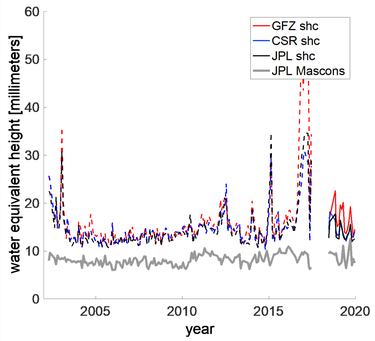
GRACE/GRACE-FO GRAVITY ERRORS EVALUATION

The error characteristics of the first two years of GRACE-FO gravity fields are consistent with the monthly fields obtained from GRACE at all spatial scales.



GRACE and GRACE-FO gravity and mass change errors are evaluated as a function of spatial scale to demonstrate the continuity of the data record between the two missions.

The figure shows the root mean square error over the global ocean for the three SDS GRACE (dashed) and GRACE-FO (solid) spherical harmonic solutions (SHC), and for the JPL Mascons (grey), for different Gaussian averaging radii, which to first order is representative of the spatial resolution of the filtered data. A decorrelation filter (Swenson and Wahr, 2006) has been applied to the SHC data.

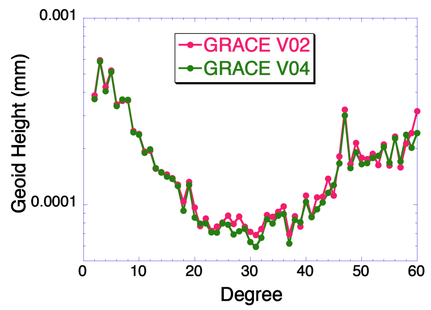


183 monthly gravity field models are available between 2002-04 and 2020-03.

Here, the evolution of GRACE L1 V02&V03/L2 RL06 (dashed lines) and GRACE-FO L1 V04/L2 RL06 (solid lines) gravity field errors over time at 300 km smoothing radius is shown. Geocenter and C20/C30 contributions are not included.

The current GRACE-FO errors can likely be reduced further by instrument and data calibrations (e.g., KBR phase center calibration, ACC transplant and calibration)

GRACE MOTHLY GRAVITY MODELS



Degree variances of the monthly gravity field solution for August 2008 – comparison of L1 V02&V03/L2 RL06 and L1 V04/L2 RL07 solution.

The new solution shows improvement especially in the mid frequencies (degrees 18-45).

These two solutions use the same L2 dynamic model and parametrization. GPS editing is slightly different.

SUMMARY

- Almost two years of GRACE-FO L1 V04 data is now available with exception of several days due to onboard issues
- With current instrument performance and calibrations, GRACE-FO is providing continuity of the global mass change data record at a consistent level with GRACE
- All GRACE-FO V04 performance metrics for KBR/GPS POD/USO are comparable or better than GRACE V02
- Final GRACE L1 V04 data reprocessing is currently ongoing. The major improvement in the orbit determination leads to a incremental improvement of the monthly gravity field solutions

EGU General Assembly 2020
Vienna, Austria
May 4-8, 2020