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European Gravity Service for Improved Emergency Management

GRACE Status

(mostly based on Ops Team Meeting May 3/4 & JSG Telecon June 1)

Frank Flechtner

EGSIEM General Assembly, DLR Oberpfaffenhofen

June 8-9, 2017

HORIZON 2020

Current Mission Overview

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Launched: March 17, 2002

On-orbit life is 15.2 years (5555 days)

Initial altitude: 485 km

Current altitude: ~ 330 km (-70 m/d)

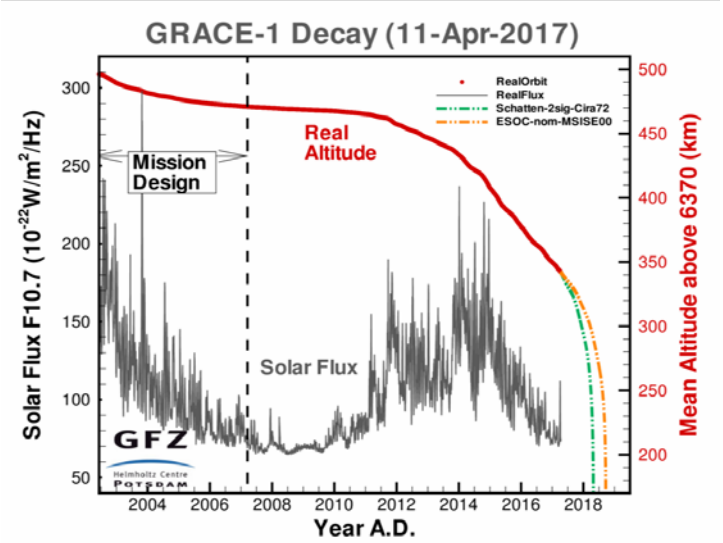
Operations Challenge: Operate as long as possible to support important on-going data utilization and to satisfy connection of the GRACE science record with GRACE FO

Current Utilization:

Monthly GRACE solutions support the US National Drought Monitor

EGSIEM hazards evaluation exercise is underway and GRACE input is necessary through October for pre- operational evaluation exercise

Numerous on-going science studies require measurements through 2017



Mission Lifetime Issues:

Altitude Decay - Drag estimates predict lifetime until May 2018

Battery Capacity - Uncertain, but current strategy projects possible operation through 2017.

Propellant for Attitude Control: Projections estimate operations until June 2018

Single String Instrument Failures: Could end the nominal mission at any point

159 Monthly Solutions

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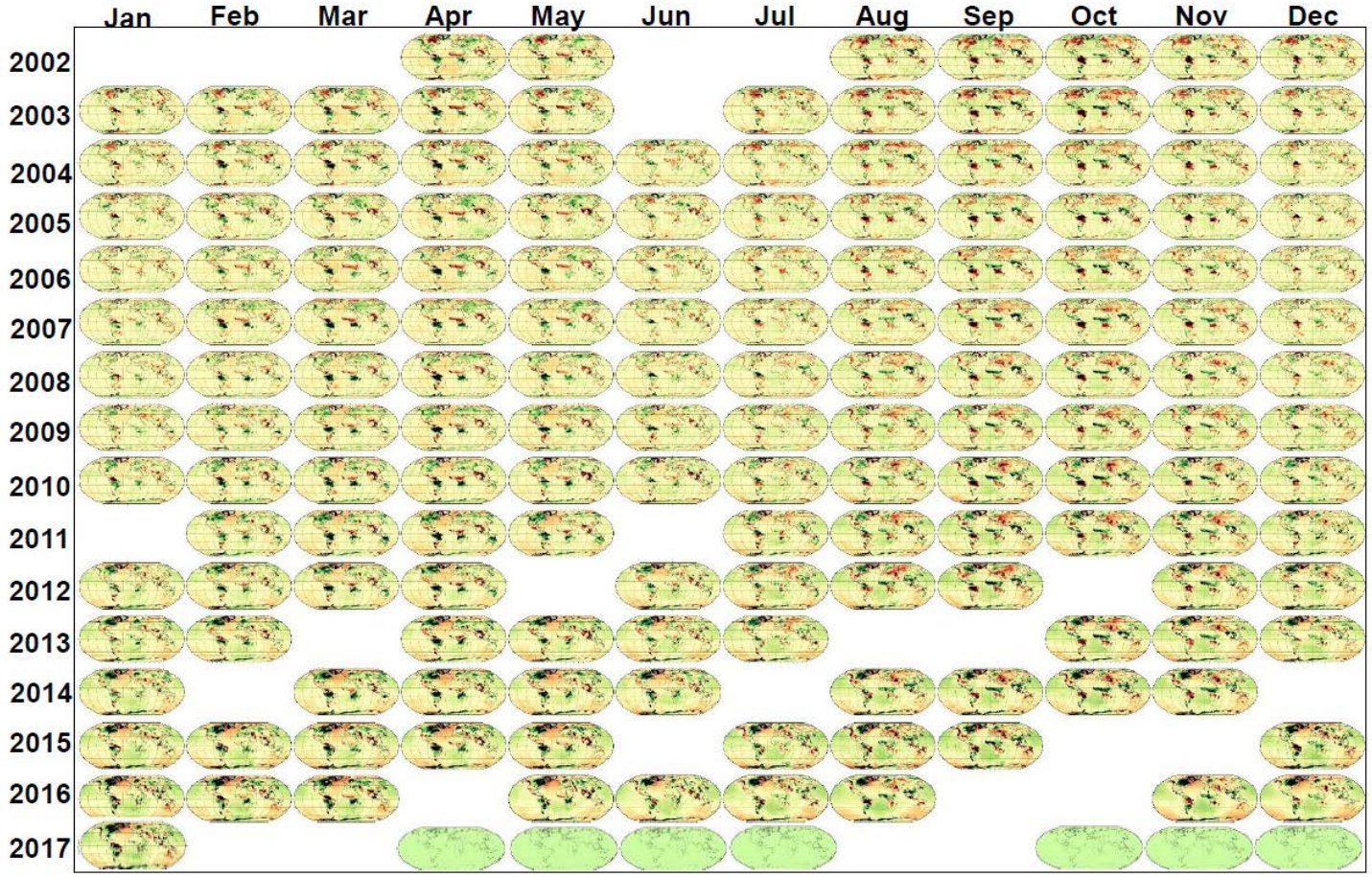

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May 3/4 Ops Team Meeting Consensus

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- Battery Capability - No change since December 2016
  - Voltage and capacity are sufficient to continue operating through Beta'=0 crossing in early August and beyond.
- Fuel – Remaining fuel is now known; the large uncertainty reported at prior JSG meetings has been clarified.
  - GRACE 2: 3.5 kg remain (as of April 4); nominally need 1.2 ± 0.2 kg per 162 day Beta' cycle; sufficient for 2 more full Beta' cycles (> 1 year)
  - GRACE 1: 4.3 kg remain; sufficient for over 2 more years of GRACE 1 operations
- Altitude – Latest predictions project reentry occurring between April and Sept. 2018
- Various operations improvements have enabled the team to handle low voltage brownouts to reduce the associated fuel loss.

From technical perspective, operation beyond the end of June 2017 is feasible and there is no technical reason to terminate the mission.

Current Science Data Collection Approach

- Beginning in September 2016, the accelerometer on GRACE 2 was turned off:
  - Operation of the Inter-Satellite Microwave Ranging System is possible in all sunlight intervals
  - As a mission extension option, the GRACE 2 Accelerometer has been powered off and the Microwave Ranging System will operate in sunlight periods only
    - The GRACE 1 accelerometer data will be "transplanted" and applied to GRACE 2 for data processing.
    - For May a near total sun light interval allowed operation of the GRACE 2 Accelerometer almost the complete month to enable collection of a complete monthly measurement set
  - For times within ± 20 days of Beta'=0, the science instruments, except the IPU and the USO, will be powered off to reduce battery stress during the period of longest eclipse.
  - This period coincides with ± 6 days around Beta" =0 where the low voltage brownout occurs.
- The quality of the solutions for November and December, 2016 and January 2017 are consistent with the solution accuracy for Post 2011 solutions

SDS Status

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- Routine automated (V02) Level-1 Processing (with some handholding): Q/L and L1B final
- ACC transplant from GRACE-A to GRACE-B routinely executed as part of the Level-1 Processing
  - Development of ACC thruster imbalance response in progress
- Spacecraft attitude reconstruction reprocessing including ACC angular accelerations on going (V03).
  - 2008 and 2014 delivered to SDS processing centers
  - Reprocessing of complete mission is anticipated in August 2017

Transplant ACC Data Generation

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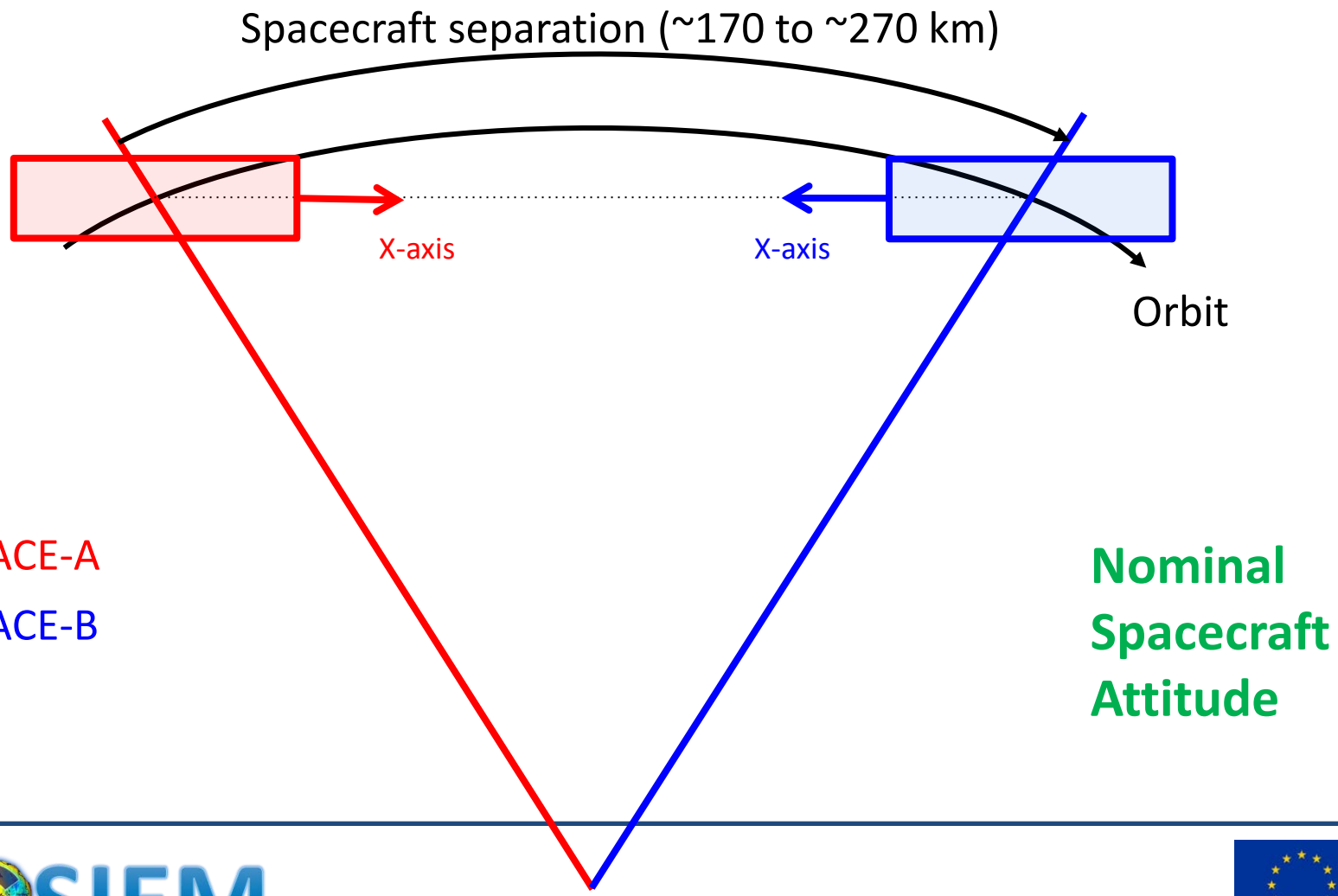

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Transplant ACC Data Generation

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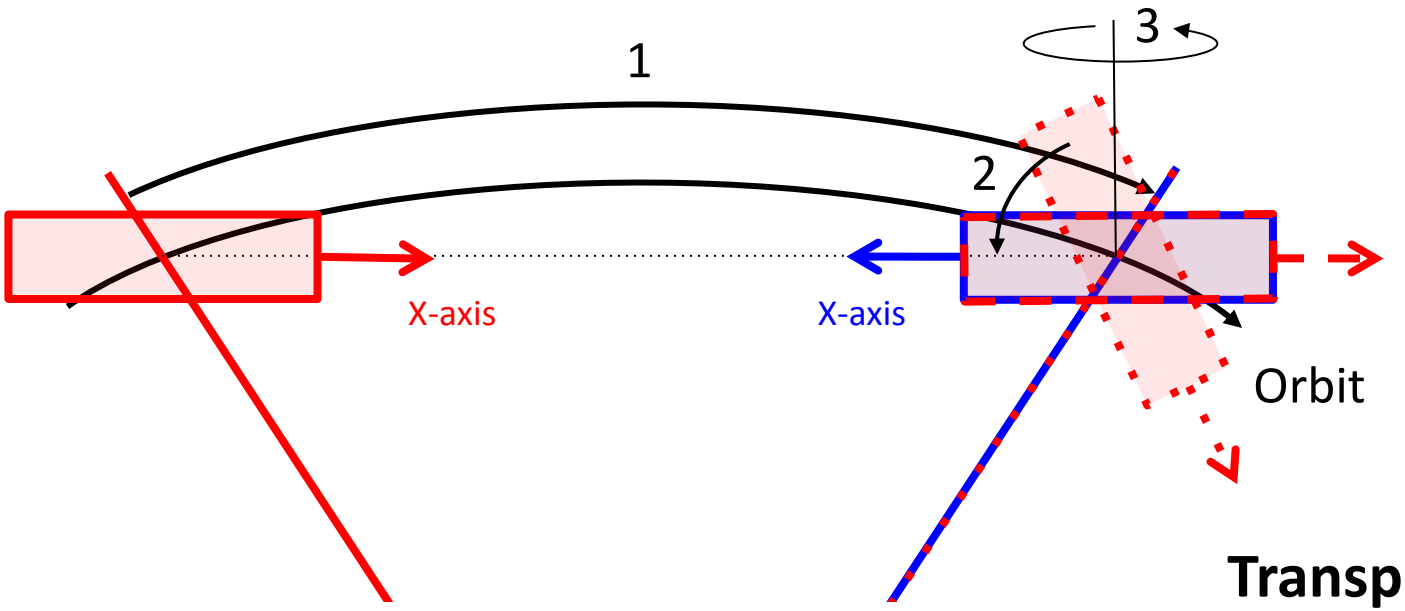

GRACE-A

GRACE-B

1) Time shift derived from spacecraft separation
2) Correct spacecraft orientation for pitch rate
3) Reverse spacecraft orientation
4) Remove GRACE-A ACC thrust response
5) Add GRACE-B ACC thrust response

Transplant Procedure (Nominal Space-craft Attitude)

Transplant ACC Data Generation

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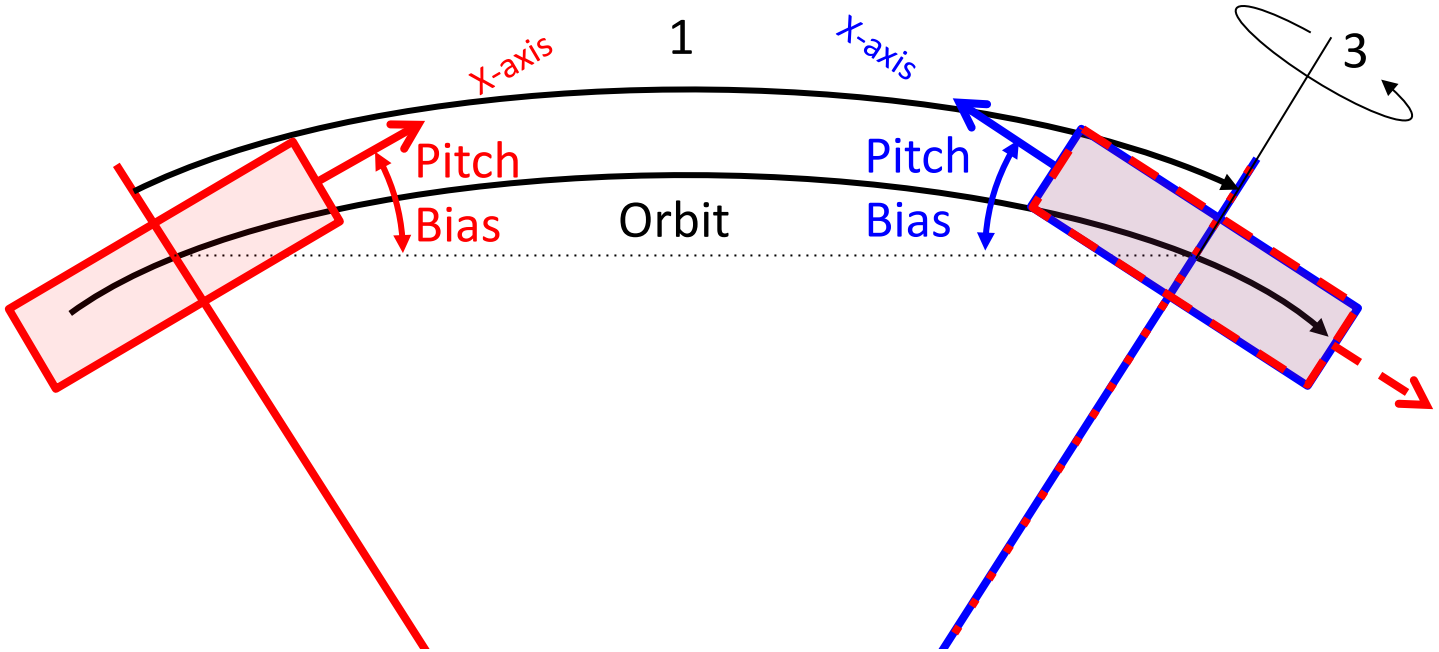

GRACE-A

GRACE-B

1) Time shift derived from spacecraft separation
2) No pitch rate attitude correction
3) Reverse spacecraft orientation
4) Remove GRACE-A ACC thrust response
5) Add GRACE-B ACC thrust response

Transplant Procedure (With Pitch Bias)

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Single Accelerometer L2 Accuracy 06/2016

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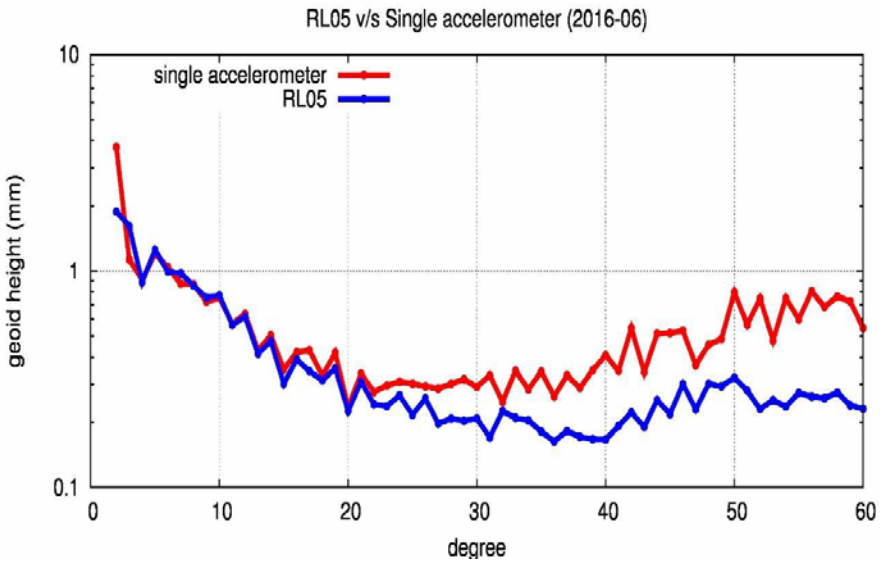

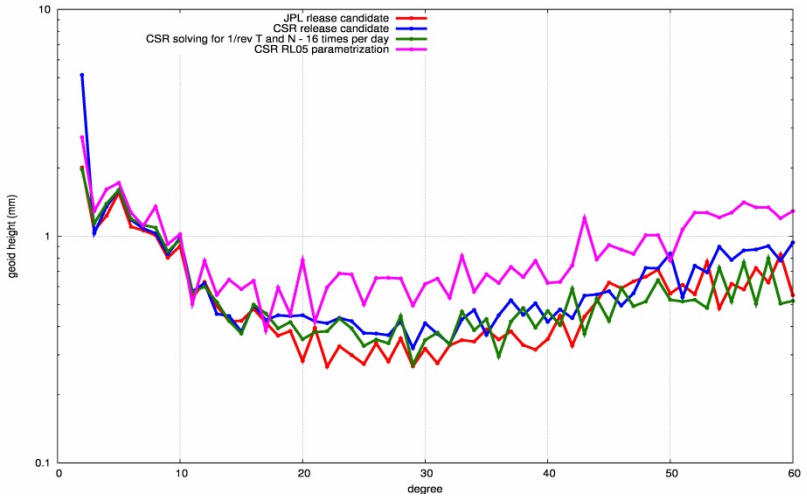

- Up to degree 20, the single accelerometer solution has comparable signal power to the RL05 solution.
- Above Degree 20, there is more noise in the signal accelerometer solution.
- The overall accuracy, between Degrees 50 and 60, is a factor of 2 less accurate than the dual accelerometer results, but still provides very important science data.
- There are several options for reprocessing that will improve the final quality of these solutions

CSR RL05 Nov 2017

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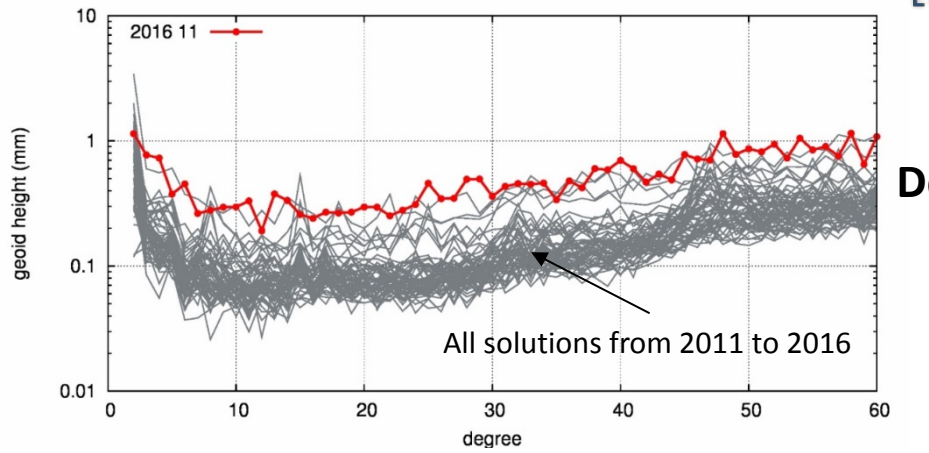
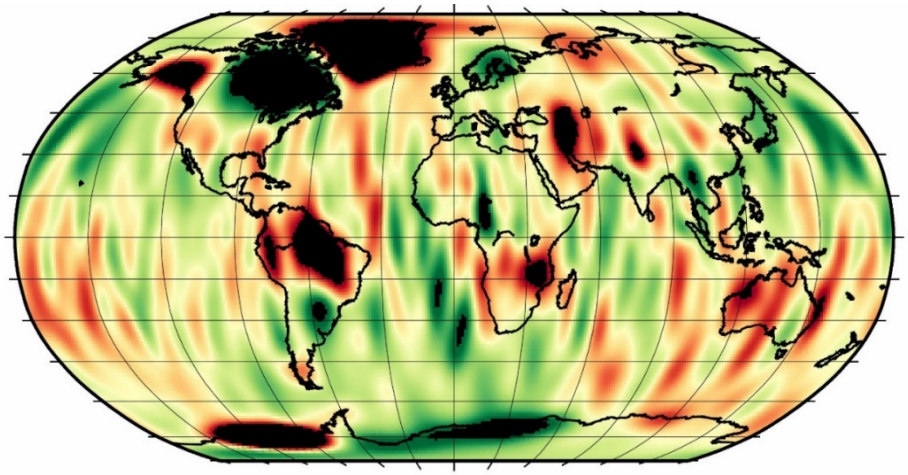
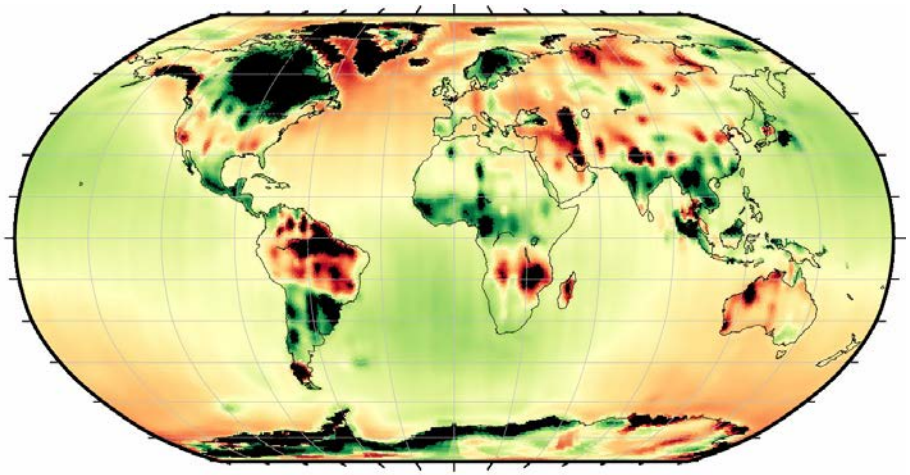


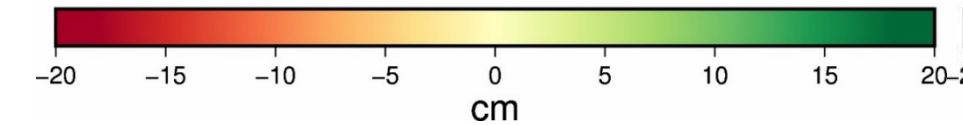
Degree variance of the SHC Error

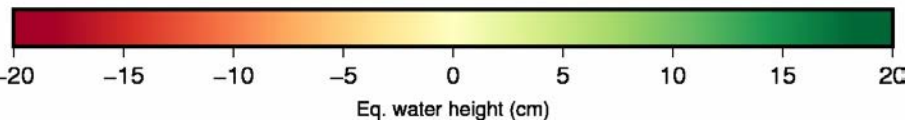
500 km smoothing



Mascons







CSR RL05 Dec 2017

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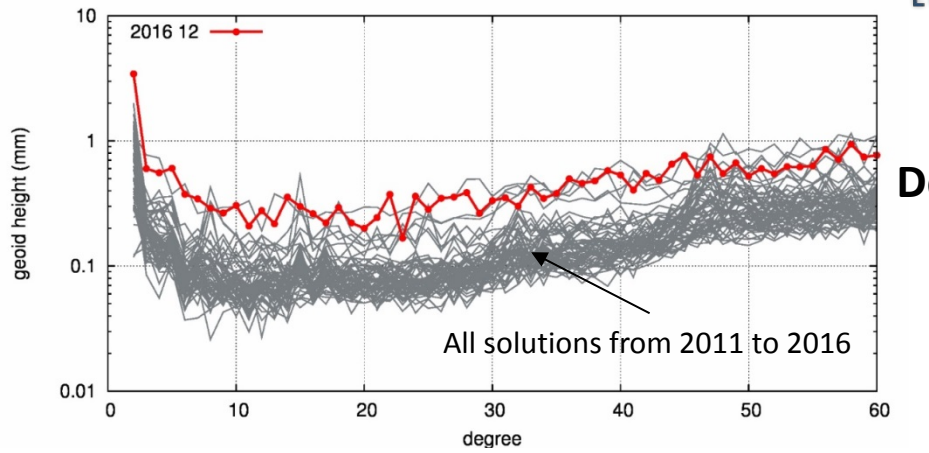

Degree variance of the SHC Error

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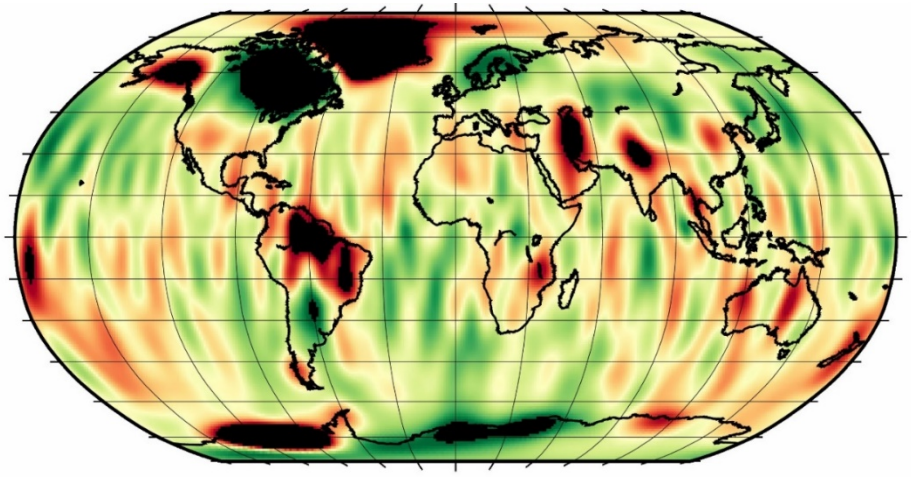

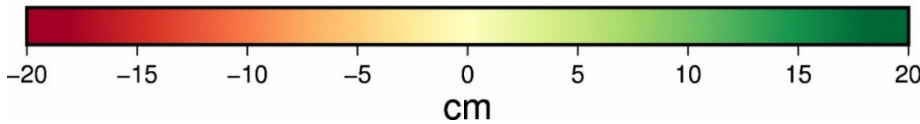

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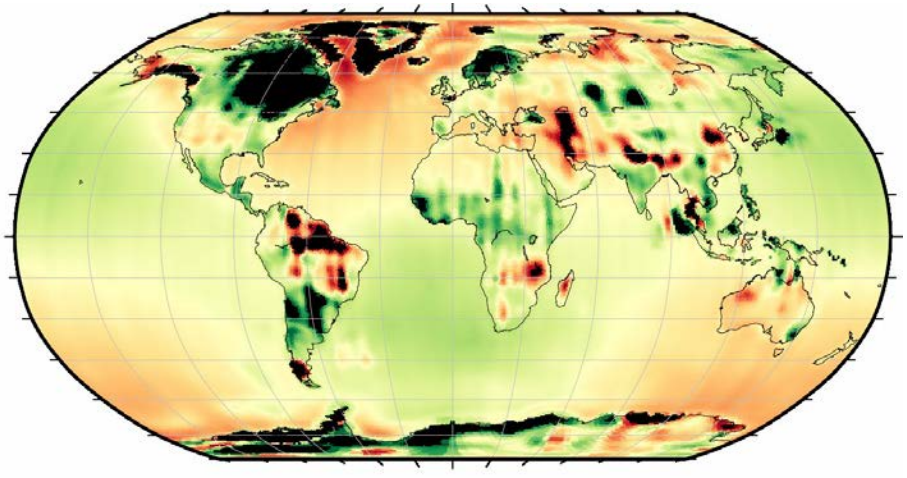

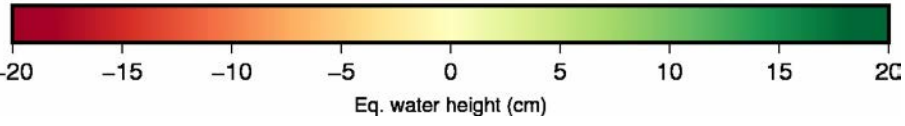

CSR RL05 SHC error assessment

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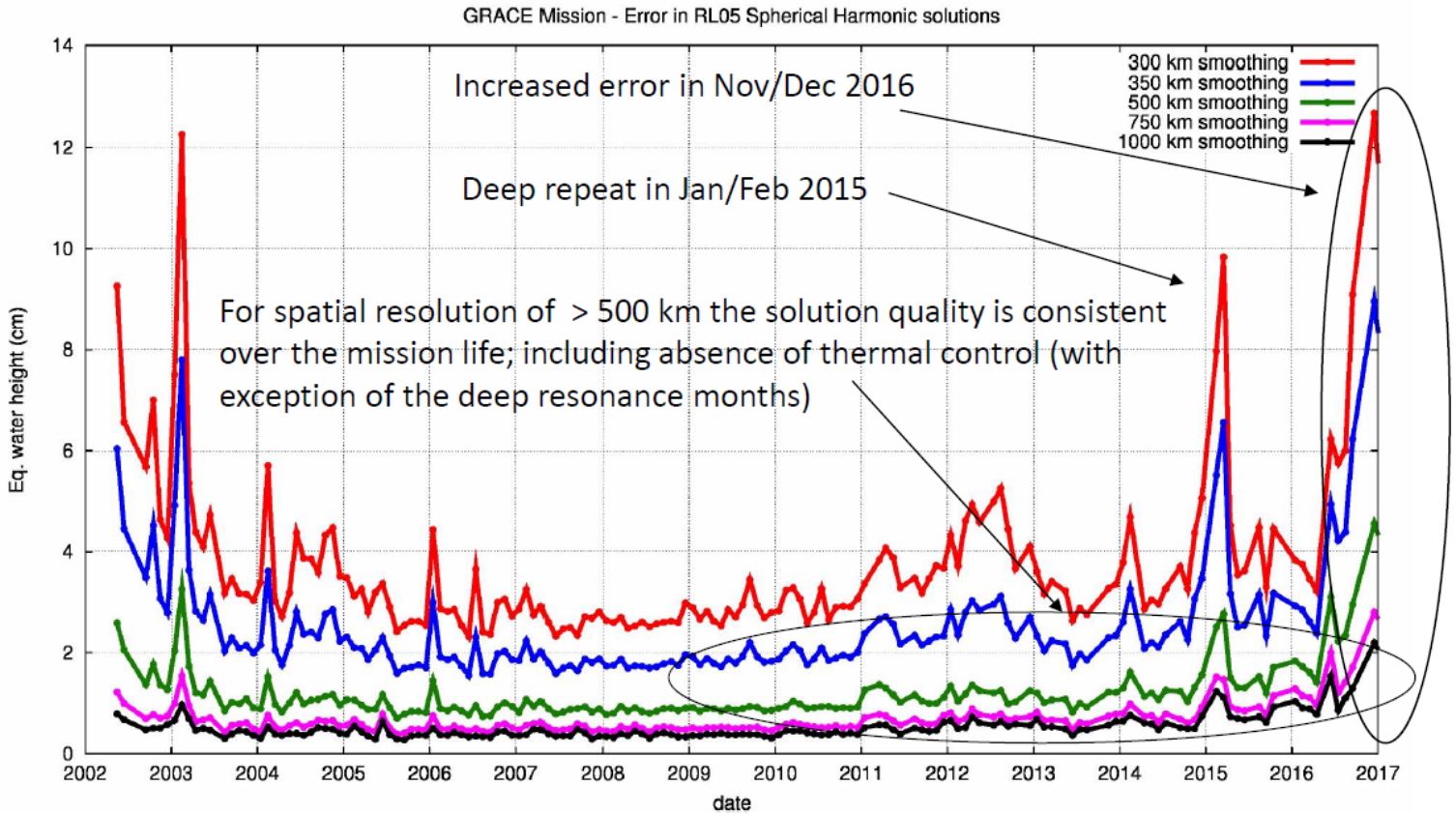
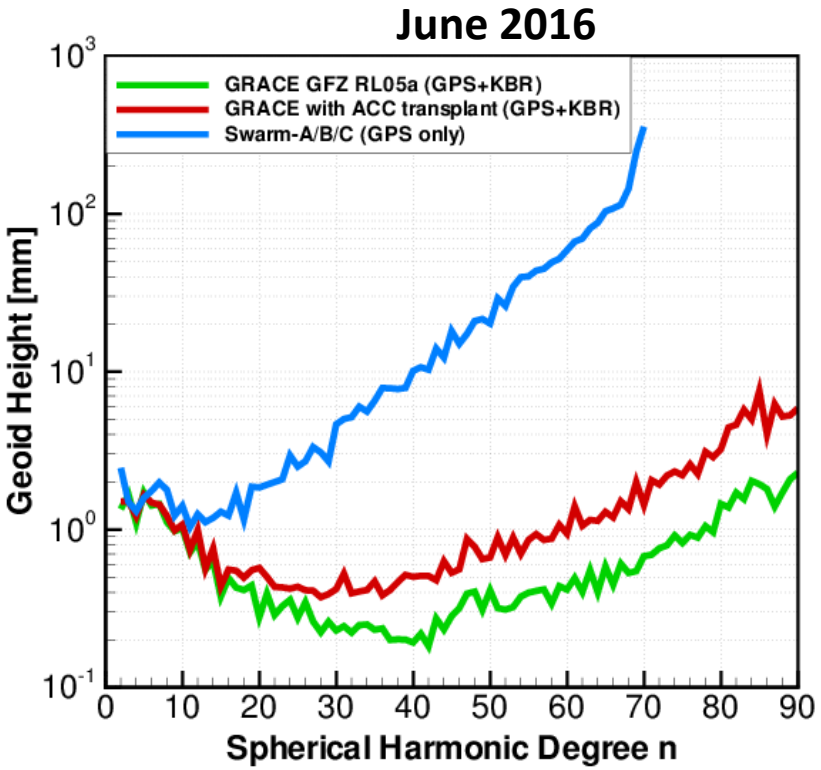


RL05 SHC error = Grid RMS of (RL05 GSM – Mascons SHC)

Summary Dual Satellite Mission Extension

- The current mission operations mode is structured to extend the dual satellite mission life.
- The Single Accelerometer option has enabled extended operations in the current mission environment.
- Operation beyond the end of June 2017 is feasible and there is no technical reason to terminate the mission
- The science results from this mode of operation are slightly degraded at the shorter wavelength signal level, but the resulting level of accuracy still provides important data for a number of science and application studies.

Single Satellite Mission



- As long as Dual Satellite KBR measurements are available, resulting gravity field solutions are far superior, as compared to GPS-only solutions
- From previous studies it can be assumed that a GRACE-A GPS-only solution will likely be slightly better than a corresponding Swarm-A/B/C solution
- SLR-based gravity field determination can provide additional information, but only for very low degrees
- Combined GPS hl-SST + SLR solutions can help to detect annual and (large-scale only!) inter-annual variations, but their spatial resolution is limited, when compared to even degraded GRACE KBR solutions

Based on these results, it is recommended that the project focus on the dual satellite option, only.

PI, Co-PI and Project Assessment

- Analysis of the November through January solutions indicate that scientifically important data are being obtained in the current mission operations mode
- On emerging from the February-March, 2017 deep shadow period, the operational capacity of the GRACE 2 satellite was in much better condition than expected.
  - Better operations procedures during the shadowing period and a refined post shadow fuel estimate of the fuel indicates more fuel on board than previously anticipated.
- This projects the ability to operate through the next occultation period, with a possible extension through December 2017.
- This extension would:
  - Minimize the date record gap between GRACE and GRACE FO
  - Increase the current mission data record, with six extremely valuable additional monthly solutions, and extend the mission data collection through 2017
  - Support the EGSIEM emergency response validation campaign and other operational applications such, as the North American Drought Monitor

Recommendation

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The mission should be continued past July 1, 2017 until one of the satellites is lost or until useful science data can no longer be collected.

The JSG should reconvene in October to discuss future mission operations

Status as of today (June 8)

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- The GRACE-B Accelerometer Instrument Control Unit (ICU) has been switched-on again on May 2 at 12:08 and switched-off on May 24 at 18:40.
- KBR data available for 60 minutes per orbit (June 6)
- Monthly products not generated for days 1-31 but slightly shifted (see SDS newsletter), e.g. for GFZ
    - Nov. 2016: November 14 and December 9 (21 days)
    - Dec. 2016: December 11 and January 6 (27 days)
    - Jan. 2017: January 7 and February 2 (27 days)
- On 29 March 2017 the +1 and –1 deg pitch angles were set to 0 deg on both spacecraft to improve the quality of the synthesized GRACE-B ACC1B data. TBD if this was really a good idea…

Effect of pitch bias on phase center correction

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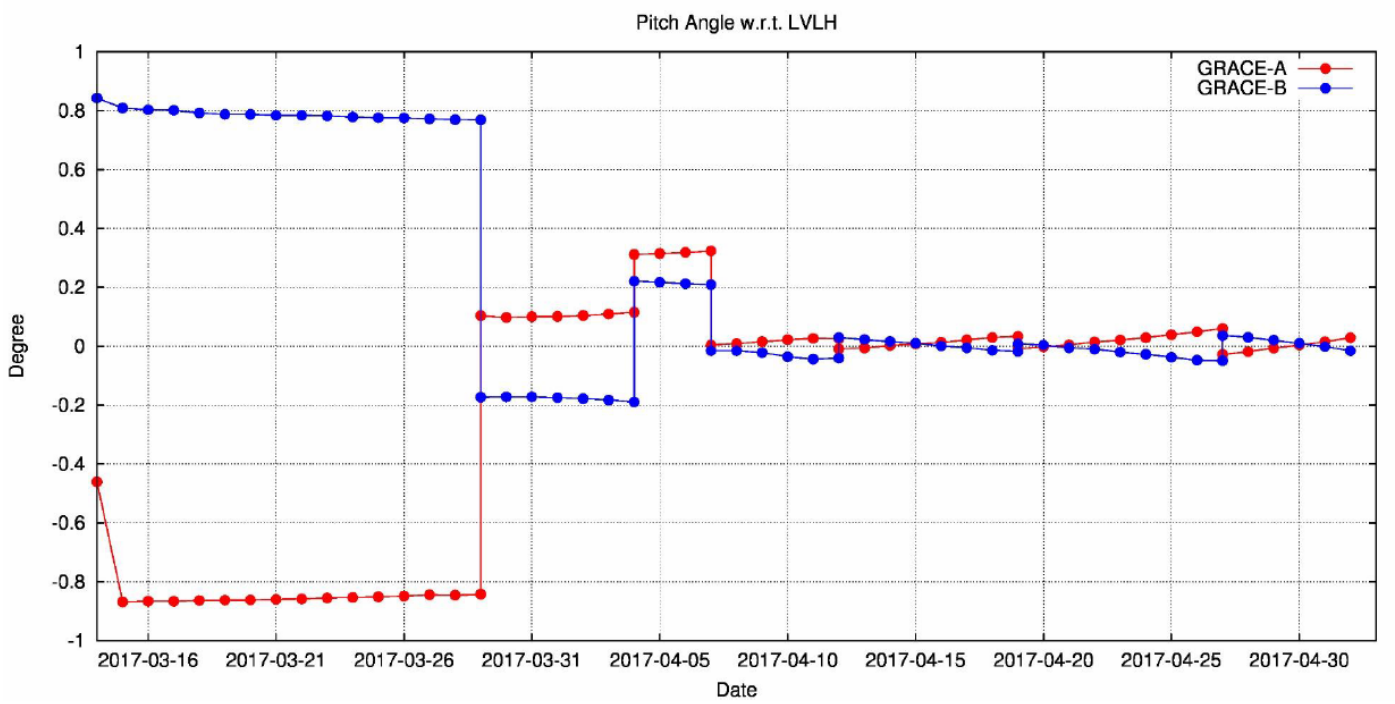
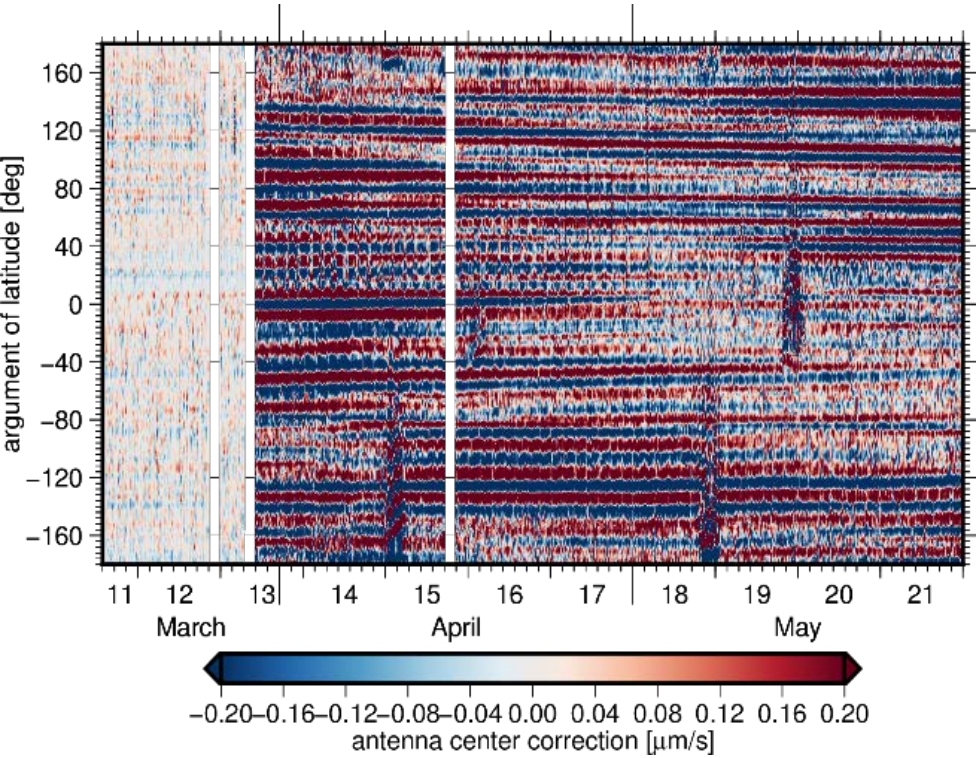
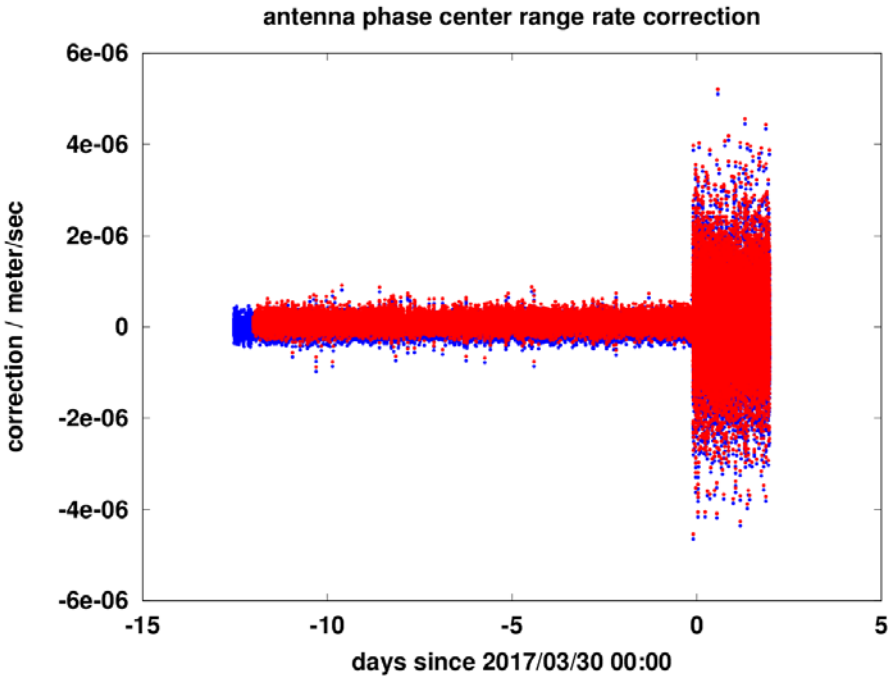


Effect of pitch bias on phase center correction

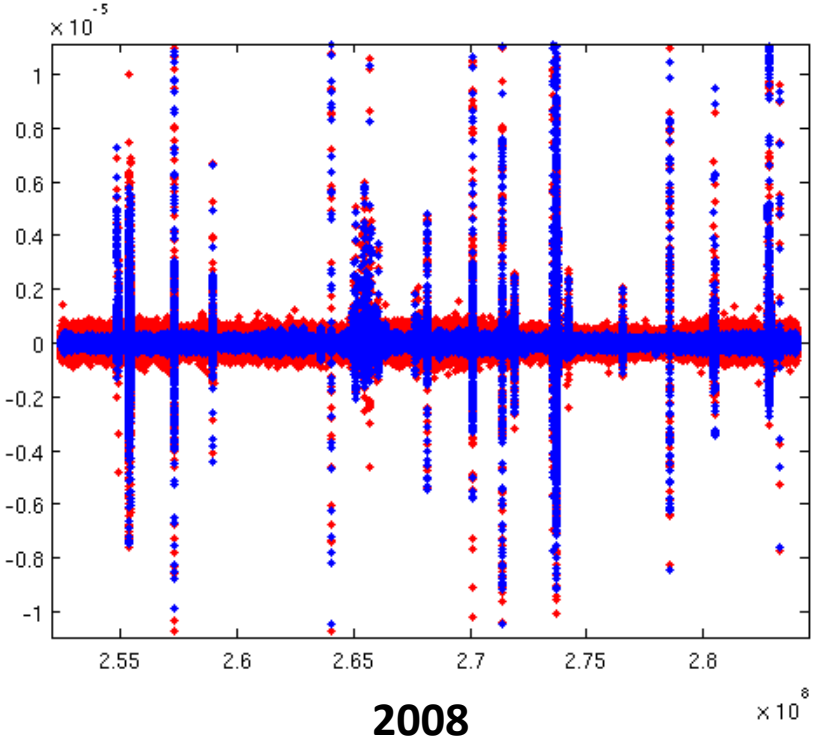


Graz with own calculated phase center corrections

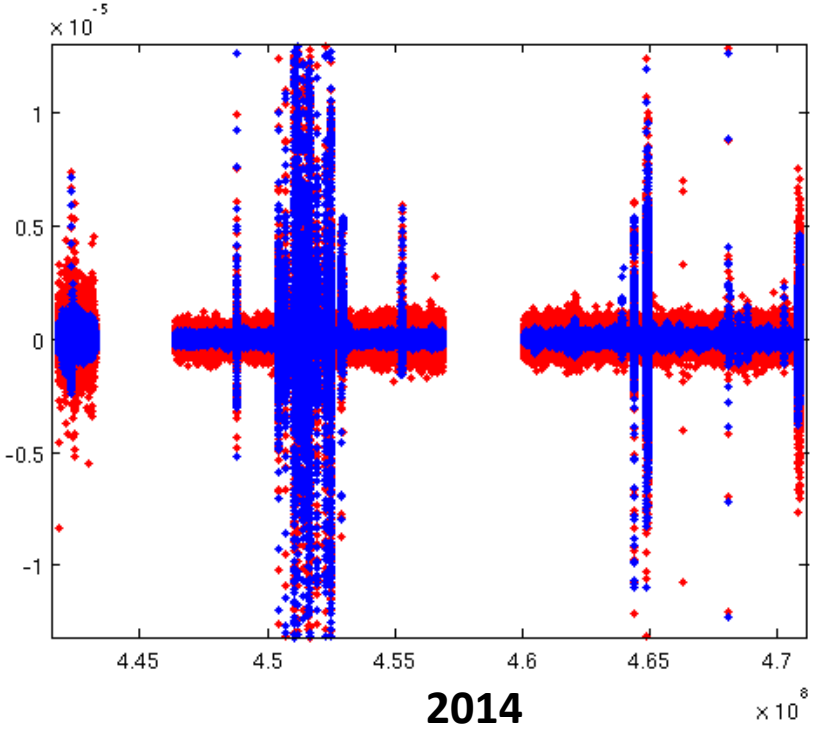
JPL phase center corrections (blue QL, red L1B)



RL02 & RL03 JPL L1B phase center correction



2008



2014

JPL phase center corrections (blue RL03, red RL02)

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