GRACE Follow-on: Mission Status and First Mass Change Observations

IUGG 2019
Montreal

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URS282569

Overview – in a nutshell

Nominal GRACE-FO Launch:
May 22, 2018

Launch-Early Orbit Phase (LEOP):
May-22 – May-26, 2018

In-Orbit-Checkout (IOC):
May-27, 2018 – Jan-27, 2019

First Science Data:
May 30, 2018

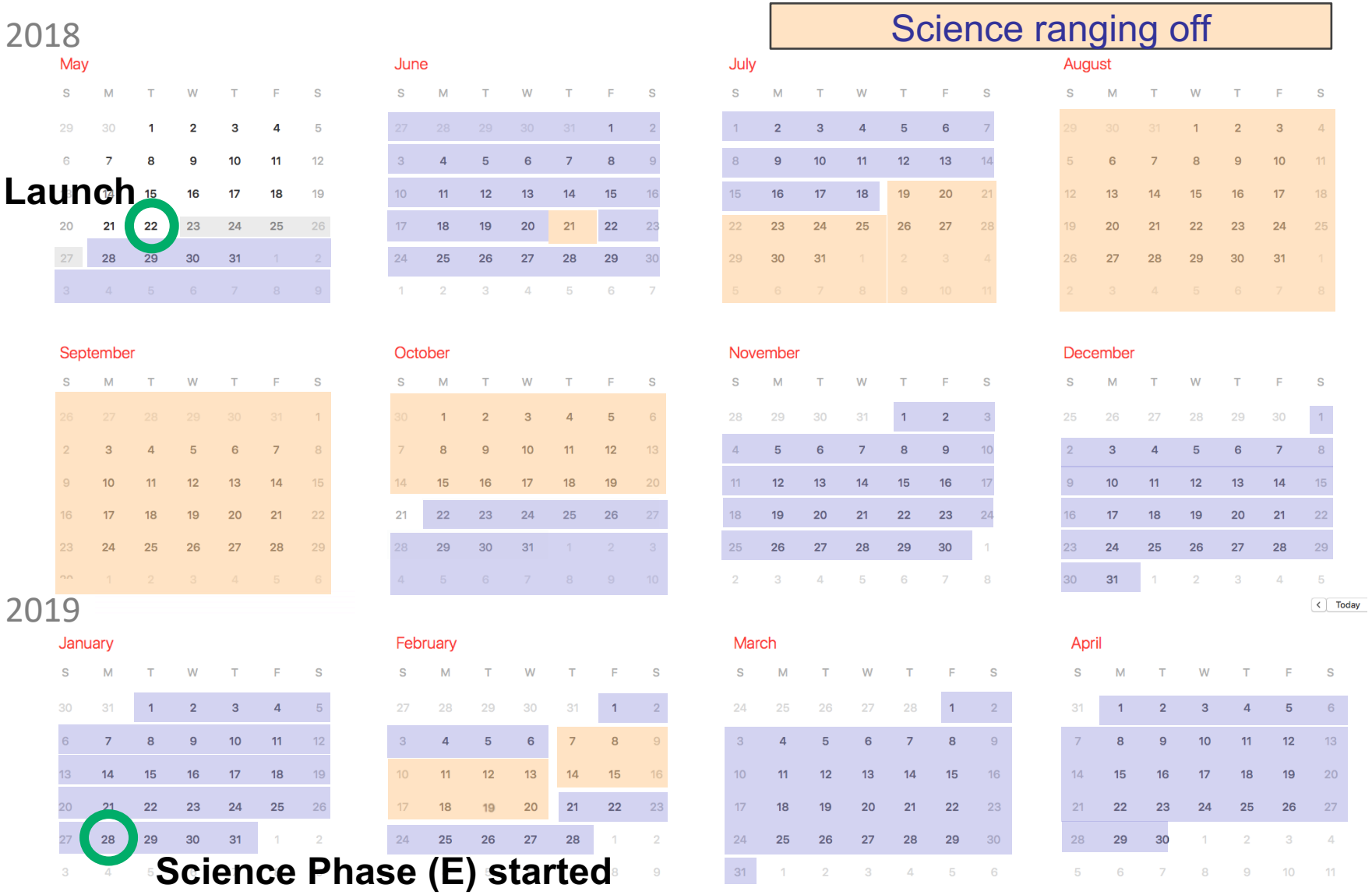
Start of Science Phase (E):
Jan 28, 2019

First Data Delivery:
May 28, 2019

LEOP / IOC / Science Phase (E)

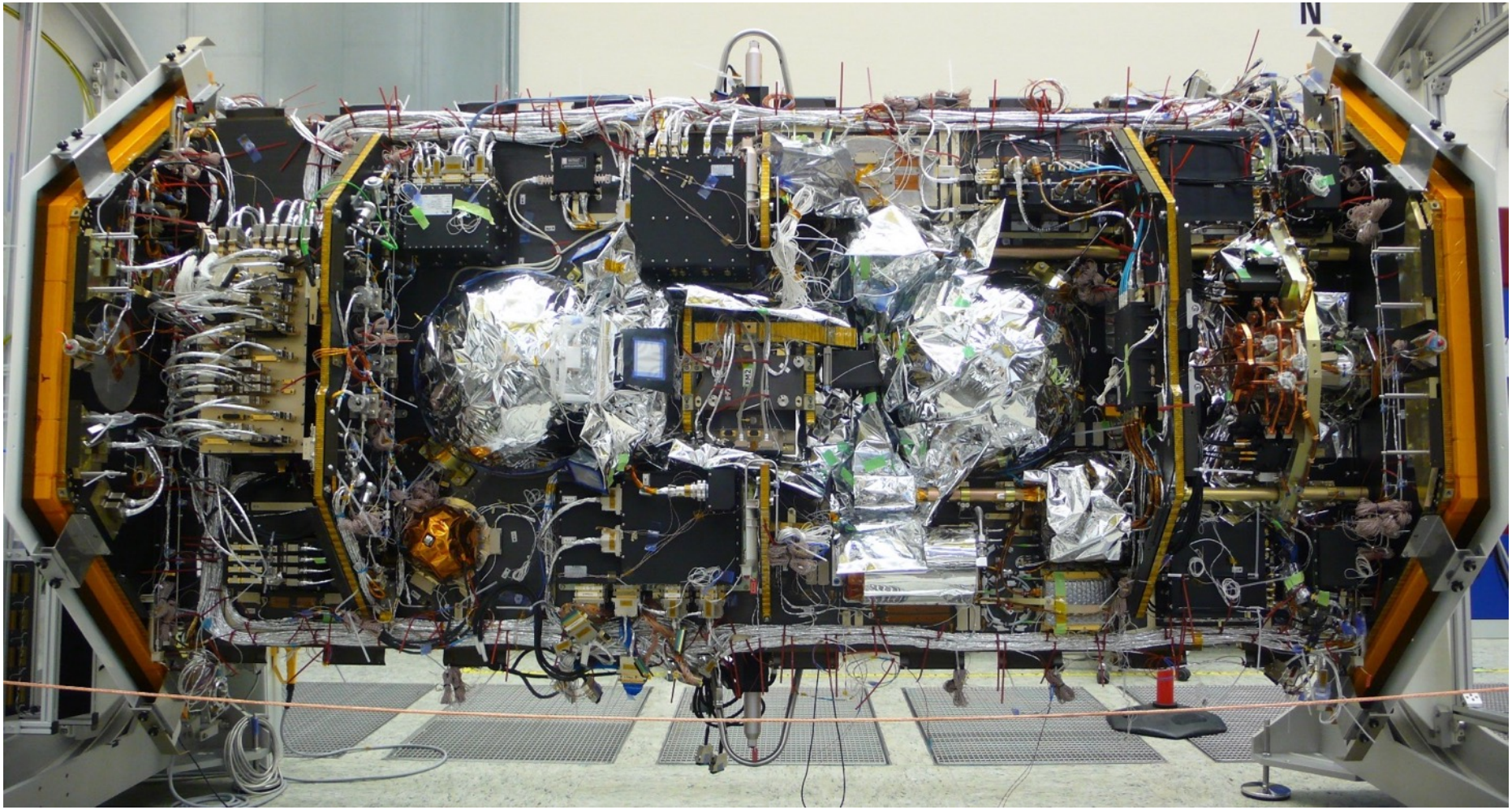
Science ranging ON

Science ranging off



Instrument Performance

Microwave Ranging Instrument
GPS Receivers
Star Cameras
Accelerometers
Laser Ranging Interferometer



Instrument Performance

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GPS Receivers
Star Cameras
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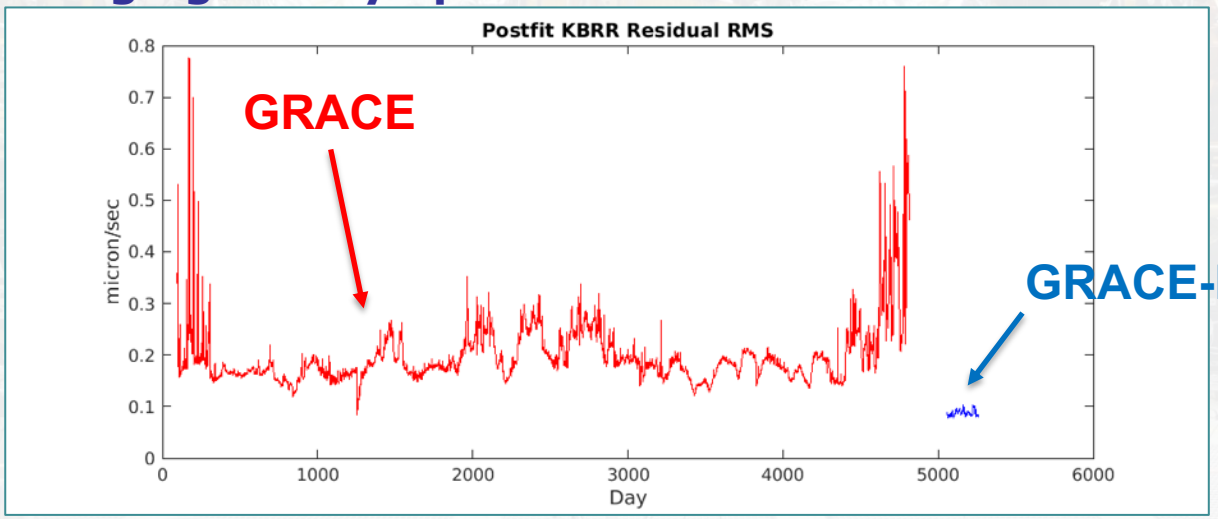
Precision Orbit Determination (POD) – Fully operational

- JPL has determined GPS orbits, clocks, antenna phase-center maps
- Very good POD performance, with an RMSD(GPS-KBR) of only **1.4 mm** (GRACE 1.6 mm)
- We are using GPS high-rate data (10s)

GPS POD Performance consistent with GRACE, and meets expectations.

K/Ka Band Ranging – Fully operational



KBR Performance better than GRACE, and meets expectations.

Instrument Performance

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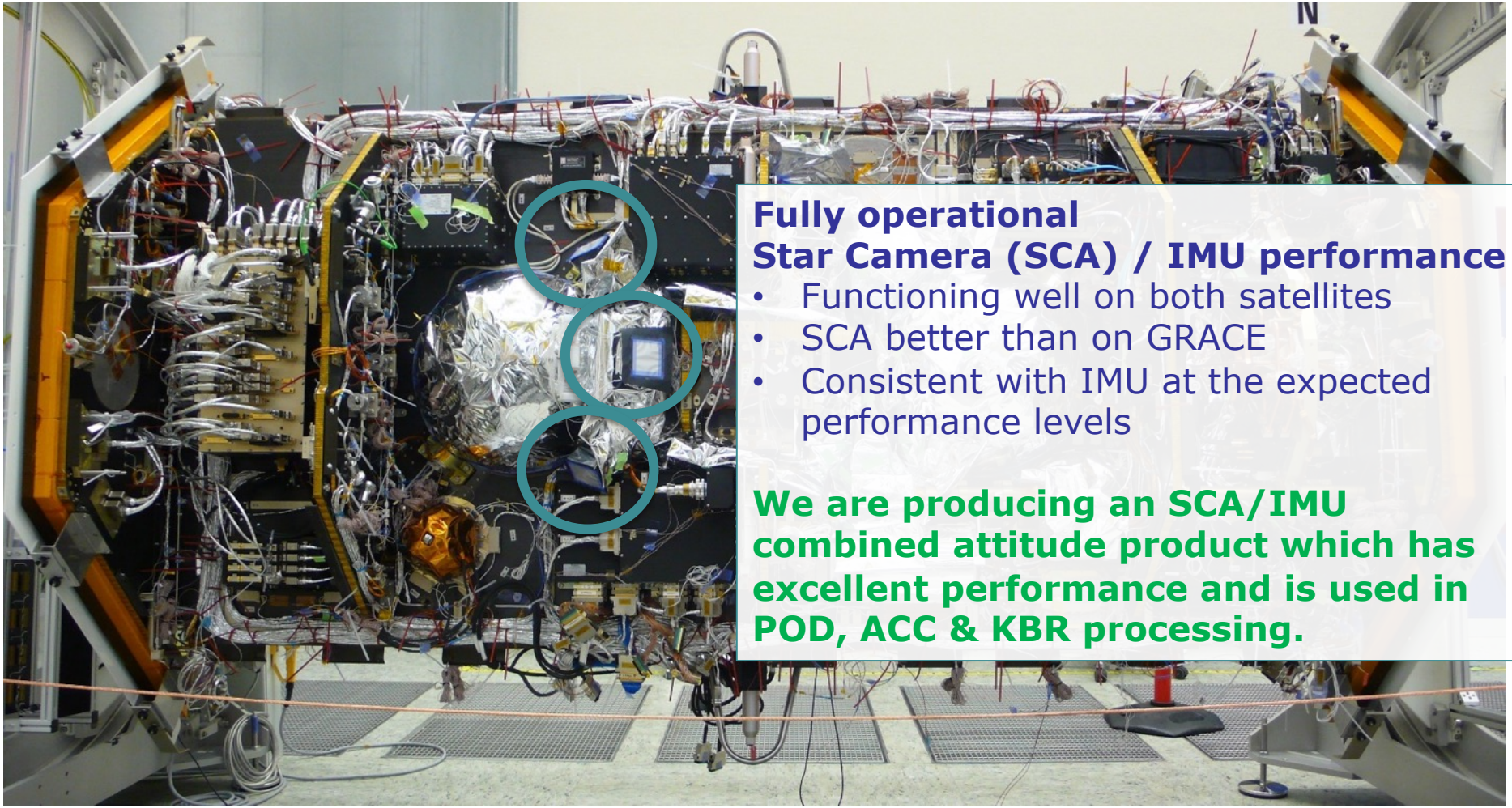


Fully operational
Star Camera (SCA) / IMU performance

- Functioning well on both satellites
- SCA better than on GRACE
- Consistent with IMU at the expected performance levels

We are producing an SCA/IMU combined attitude product which has excellent performance and is used in POD, ACC & KBR processing.

Instrument Performance

Microwave Ranging Instrument
GPS Receivers
Star Cameras
Accelerometers
Laser Ranging Interferometer

- **Operational:** Measuring real non-gravitational accelerations (robust data editing for some outliers)
- AOCS operations are being optimized to put thruster-related accelerations within the ACC measurement band
  - Need longer thruster firings (>0.5s) to resolve corresponding accelerations
  - Initial Level-1 data release will use a calibrated thruster-ACC-response model that has been shown to work well

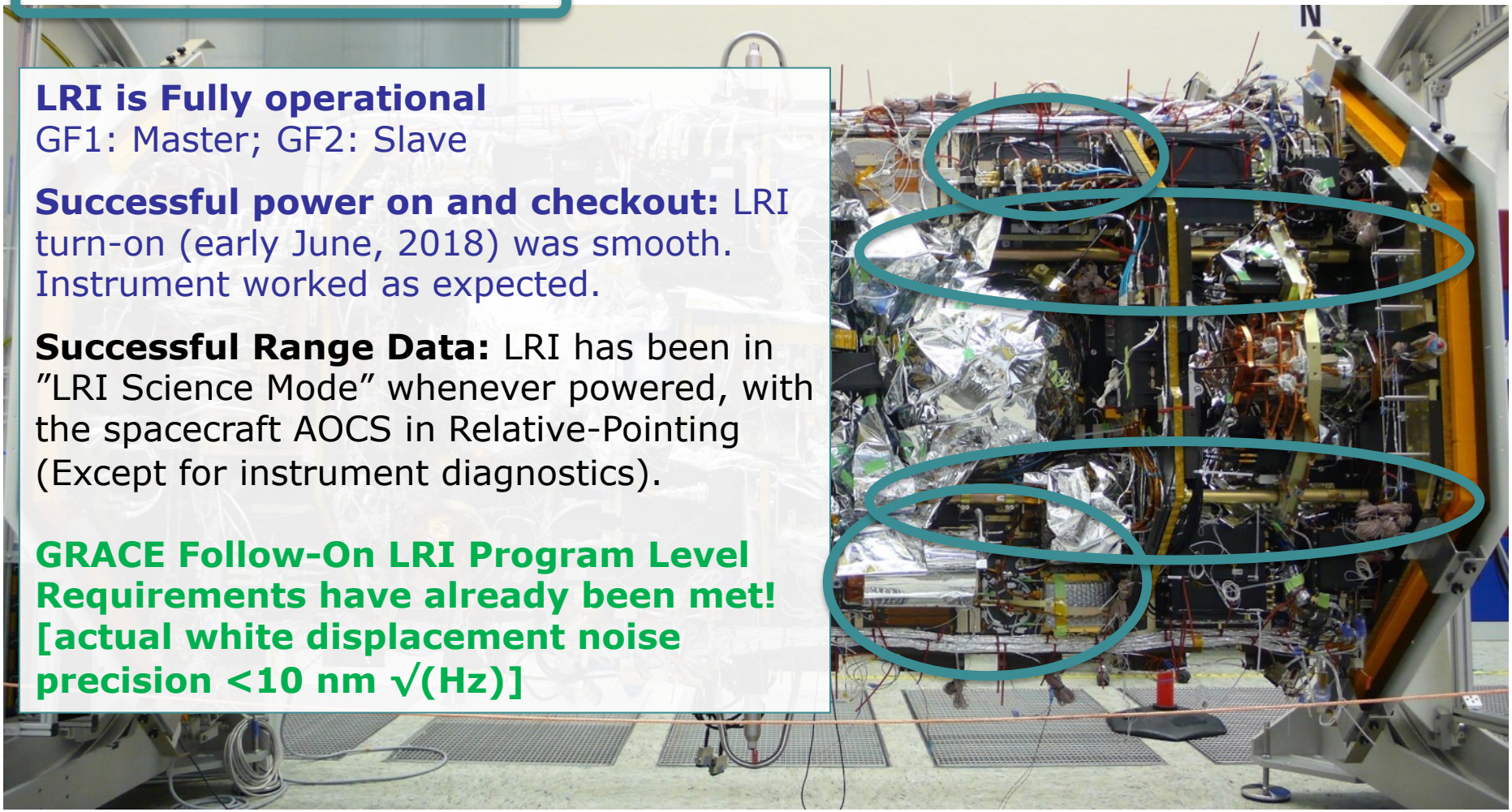
GF1, with data edits, is performing as well or slightly better than the original GRACE-A/B ACC.

- **GF2: ACC is underperforming relative to GF1**
  - SDS team has identified and is improving a calibration scheme that removes much of the common mode noise, and applies thermal corrections

Note: for first Level-1 data release, we will use a full ACC transplant (GF1 to GF2), which yields good gravity results.

Instrument Performance

Microwave Ranging Instrument
GPS Receivers
Star Cameras
Accelerometers
Laser Ranging Interferometer



LRI is Fully operational
GF1: Master; GF2: Slave

Successful power on and checkout: LRI turn-on (early June, 2018) was smooth. Instrument worked as expected.

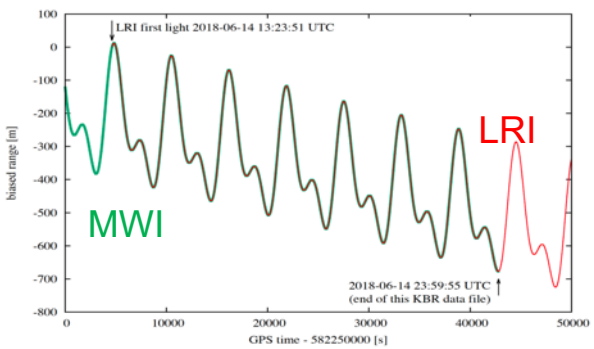
Successful Range Data: LRI has been in "LRI Science Mode" whenever powered, with the spacecraft AOCS in Relative-Pointing (Except for instrument diagnostics).

GRACE Follow-On LRI Program Level Requirements have already been met! [actual white displacement noise precision <10 nm √(Hz)]

Technology Demo: Laser Ranging Interferometer

GRACE Follow-On LRI Program Level Requirements have already been met!

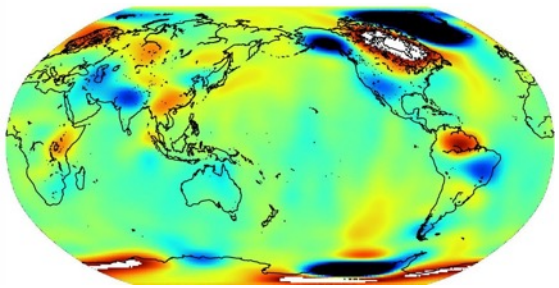
LRI and MWI Range over time



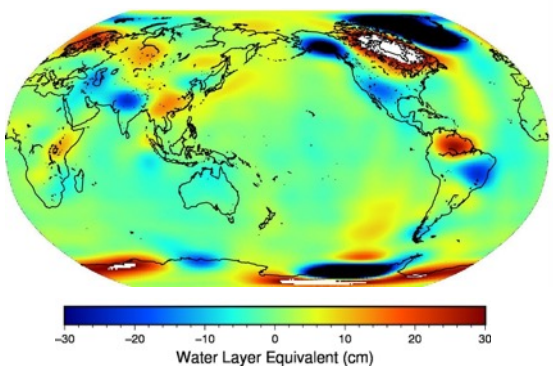
- Using either the KBR or LRI data to produce a gravity field yields very consistent results
- As expected, LRI data, in combination with the other observables (ACC, GPS, SCA/IMU) resolves similar features of Earth's monthly mass anomalies

LRI vs MWI Gravity field

LRI (July-2018)

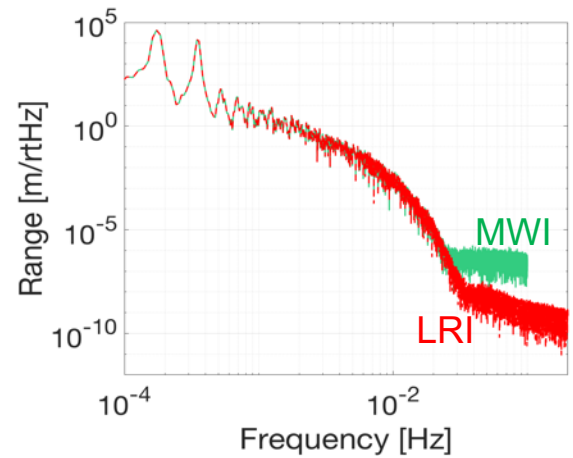


MWI (July-2018)



[Figures from UT-CSR]

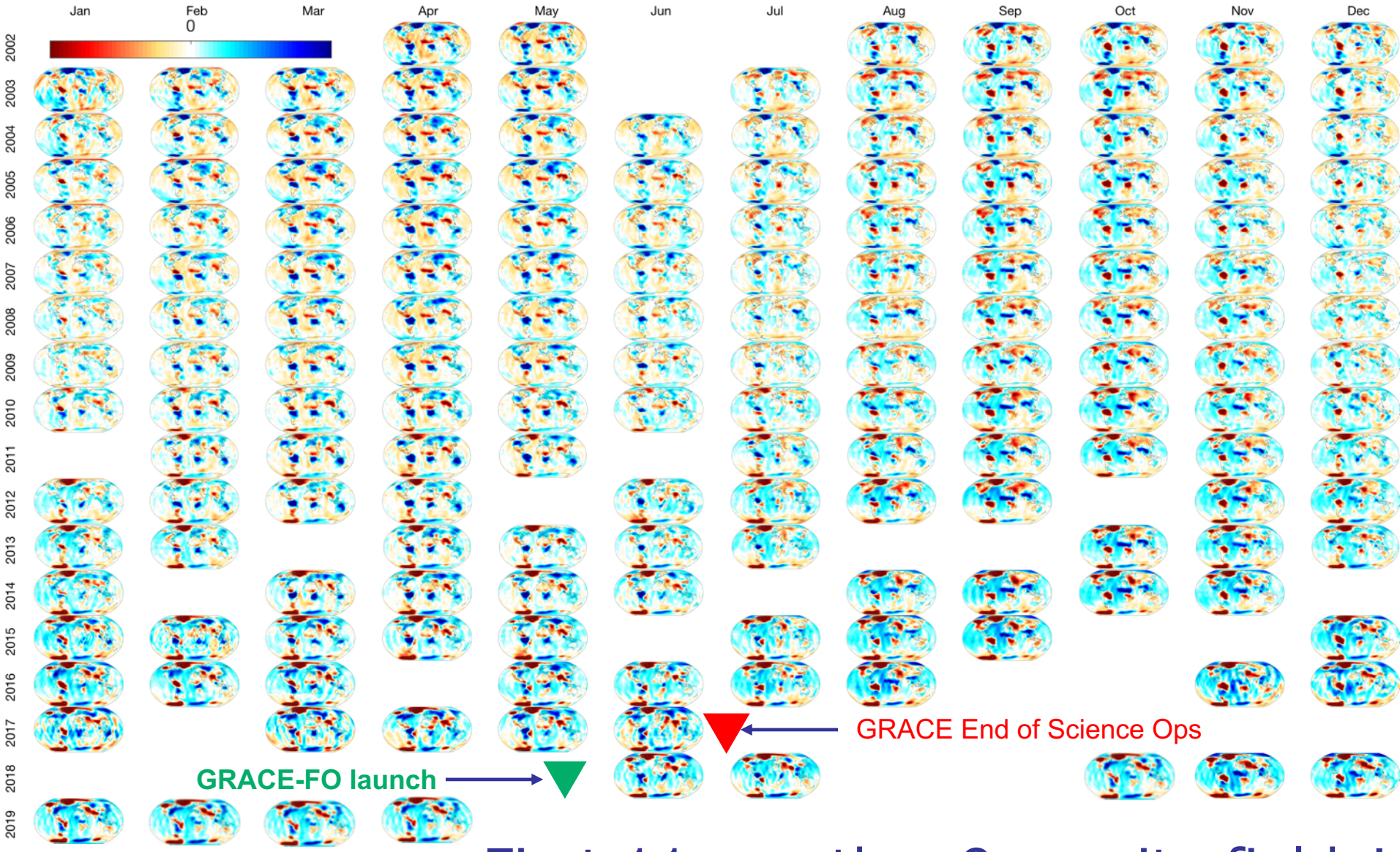
LRI and MWI Spectral Density



GRACE-FO LRI has met the white displacement noise precision capability goal of below 0.3 microns/√(Hz)

- *Demonstrated at < 10 nanometer/√(Hz);*
- *Improvement over the MWI capability of greater than 100 times*

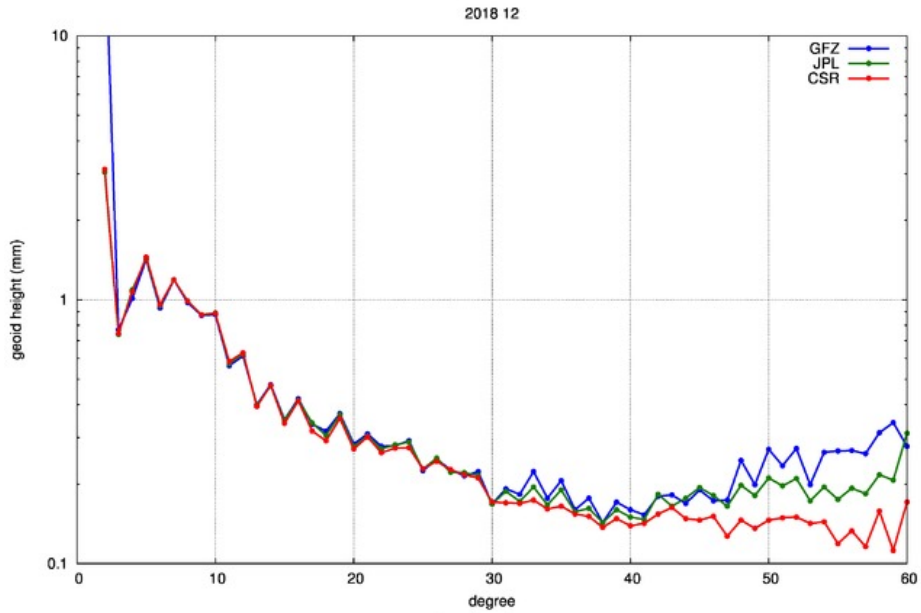
Continuity: from GRACE to GRACE-FO

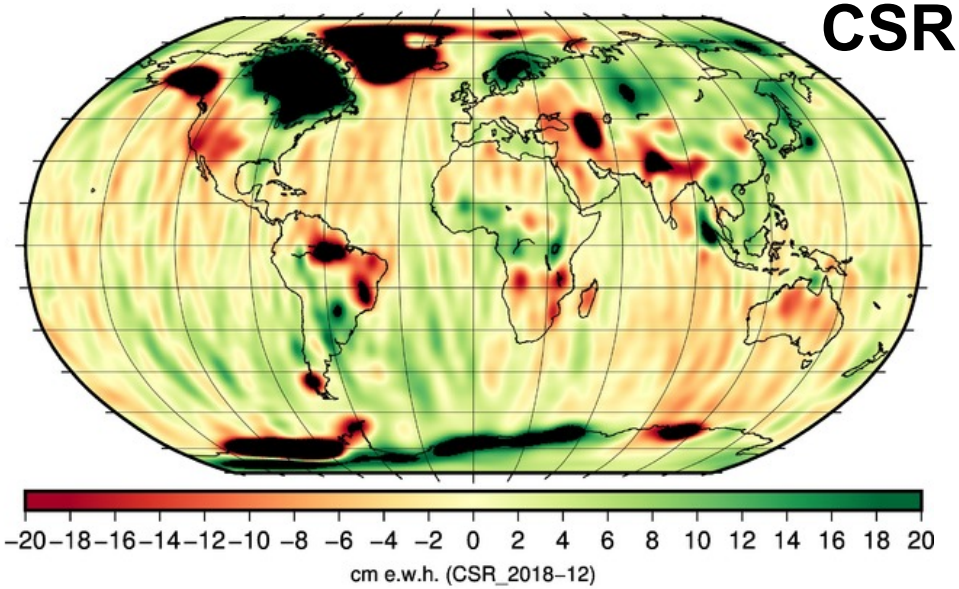


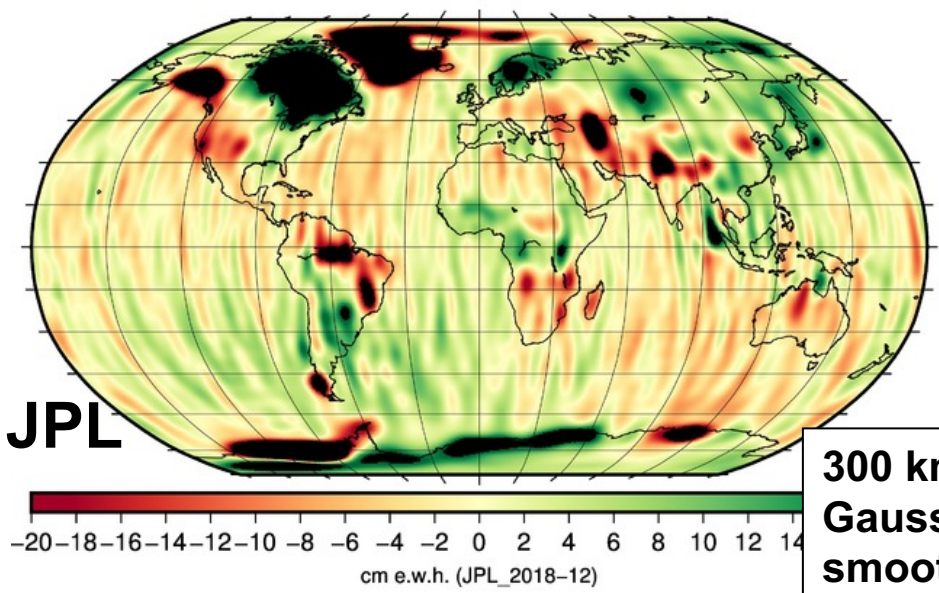
First 11 months: 9 gravity fields!

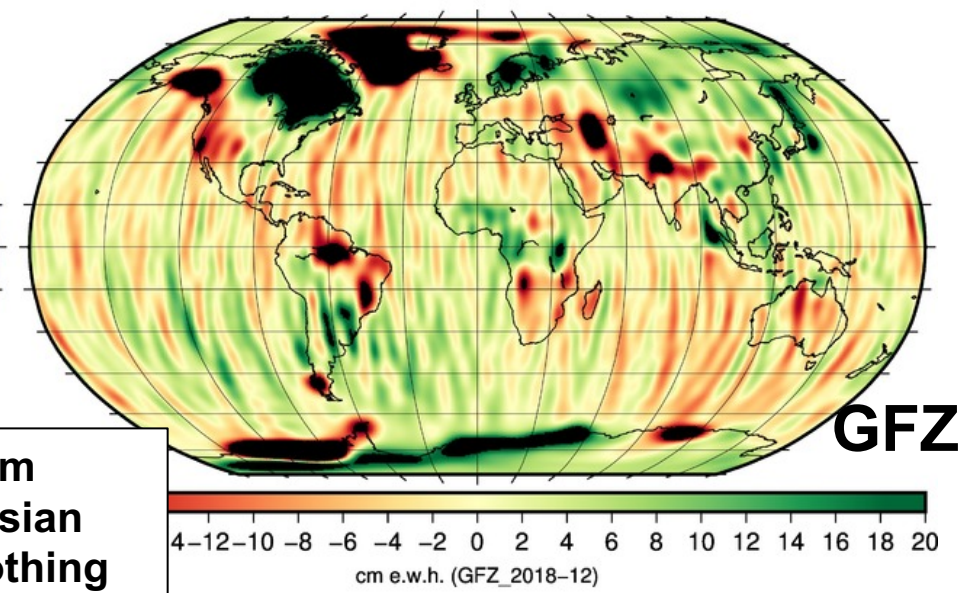
SDS Consistency

December 2018





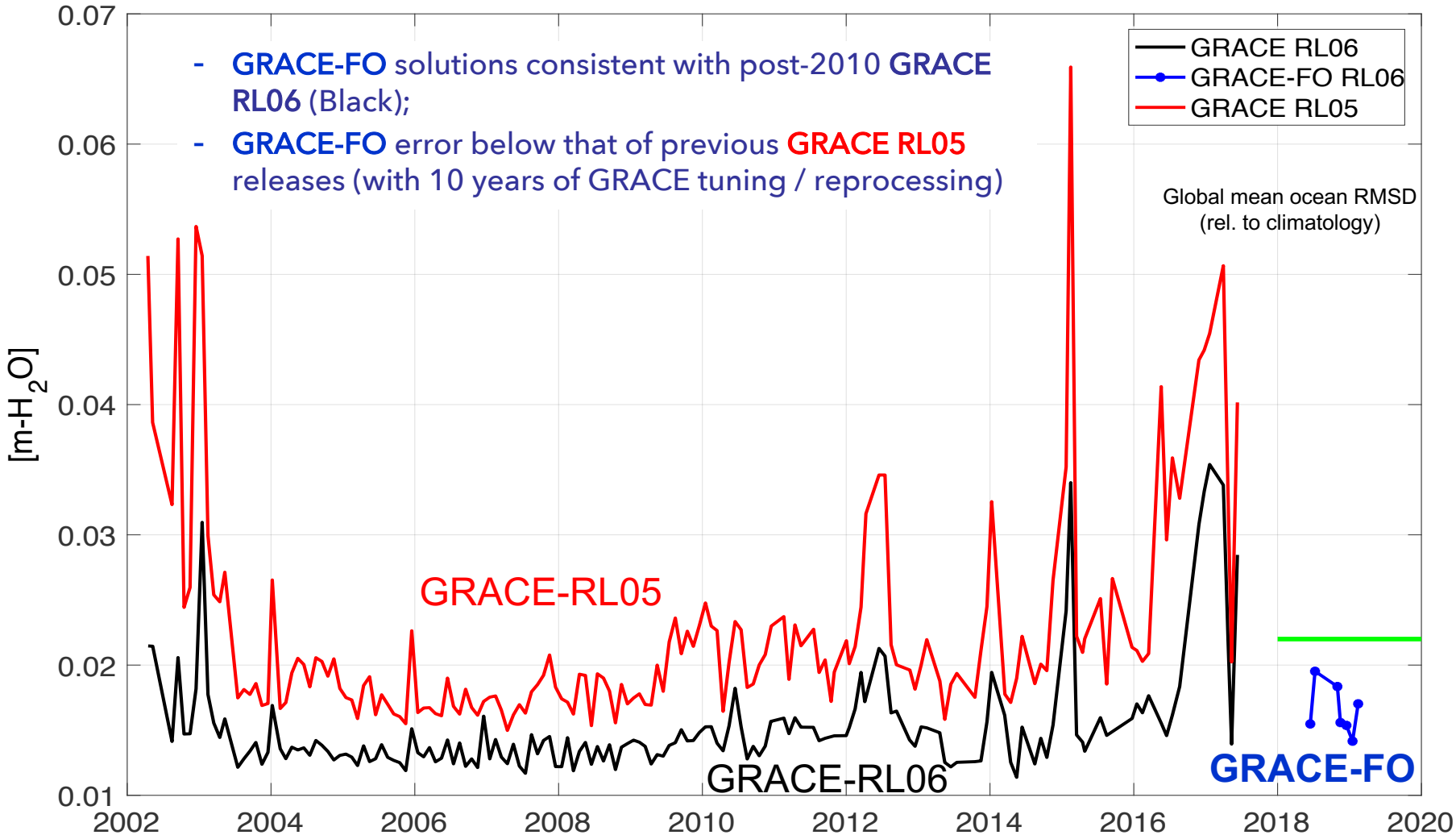




300 km Gaussian smoothing

GRACE-FO Performance

GRACE-FO performance meets the Level 1 science and technology requirements.



Continuity

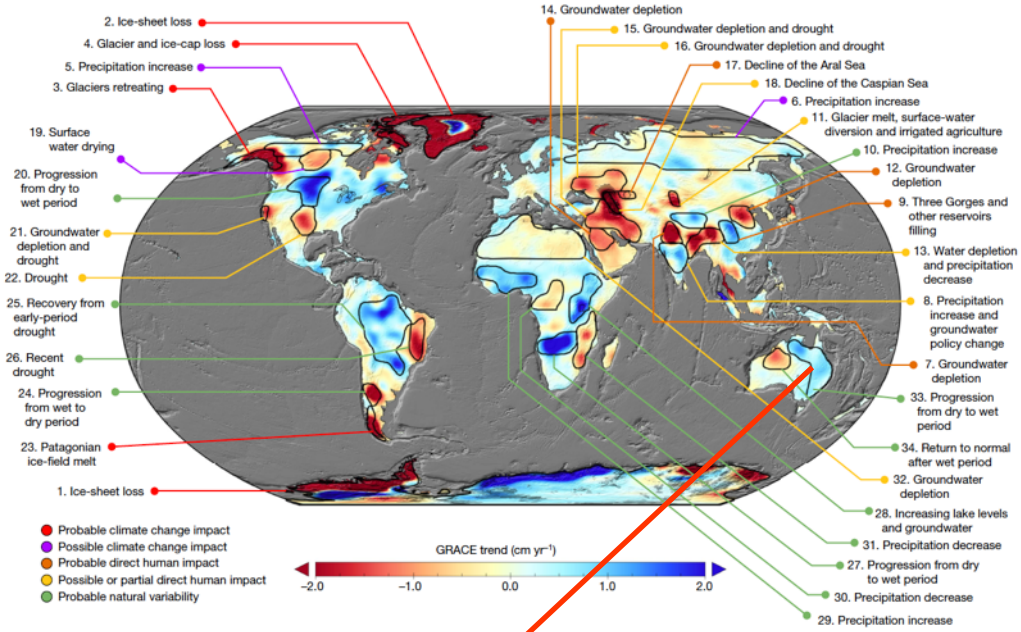
ANALYSIS

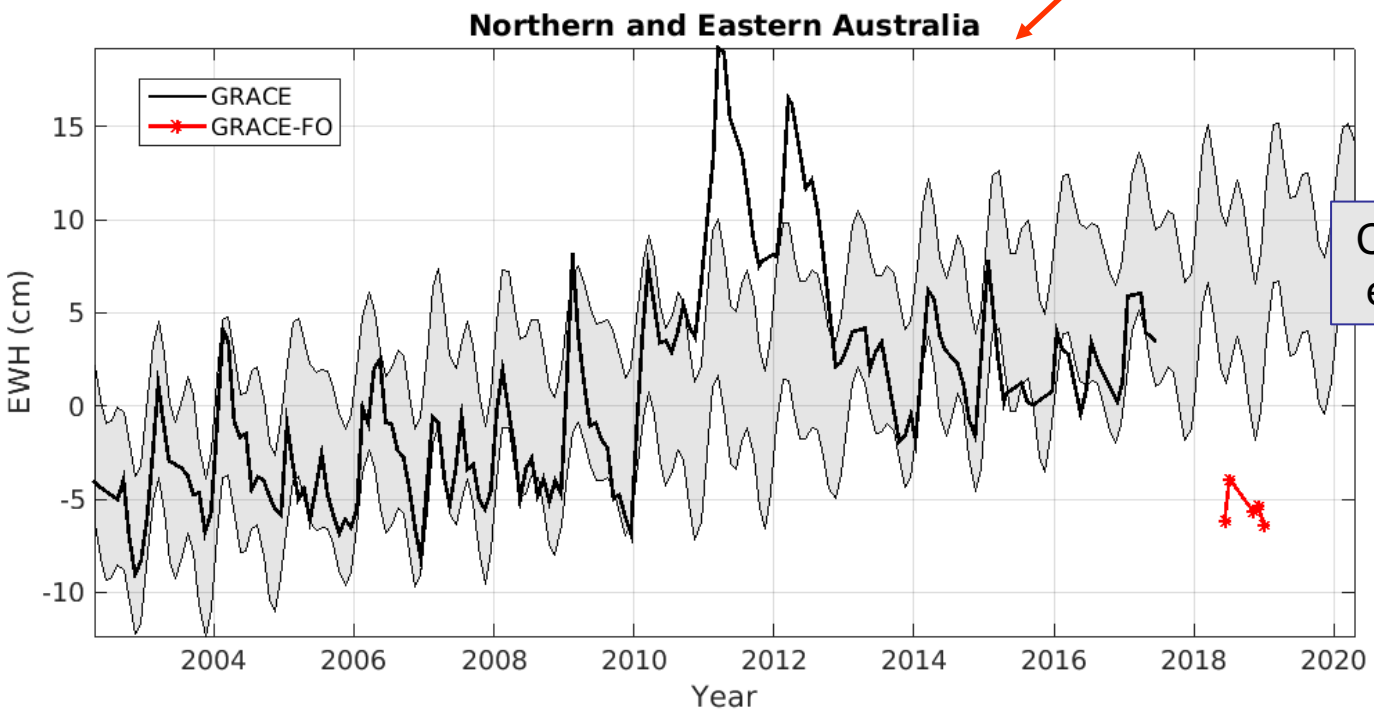
https://doi.org/10.1038/s41586-018-0123-1

Emerging trends in global freshwater availability

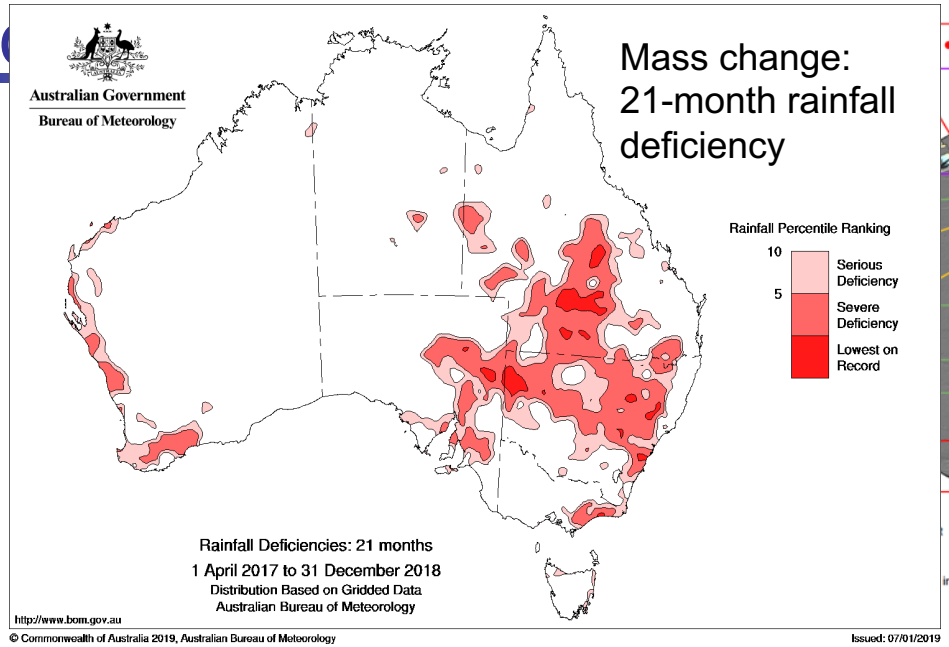
M. Rodell[1*], J. S. Famiglietti[2,5], D. N. Wiese[2], J. T. Reager[2], H. K. Beaudoing[1,3], F. W. Landerer[2] & M.-H. Lo[4]

Natural Variability and Recent Drought





Climatological extrapolation


Australian Government
Bureau of Meteorology
Mass change:
21-month rainfall
deficiency
Rainfall Percentile Ranking
10
5
Serious Deficiency
Severe Deficiency
Lowest on Record
Rainfall Deficiencies: 21 months
1 April 2017 to 31 December 2018
Distribution Based on Gridded Data
Australian Bureau of Meteorology
http://www.bom.gov.au
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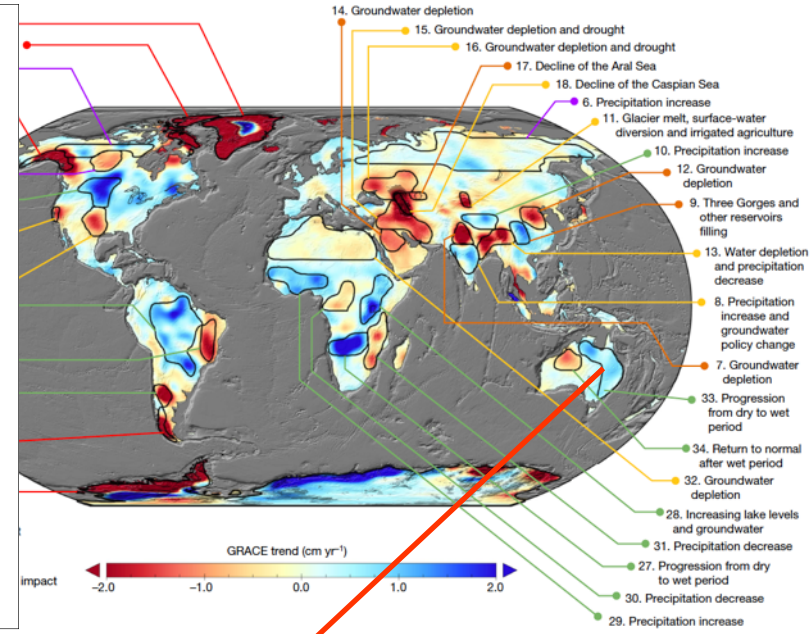
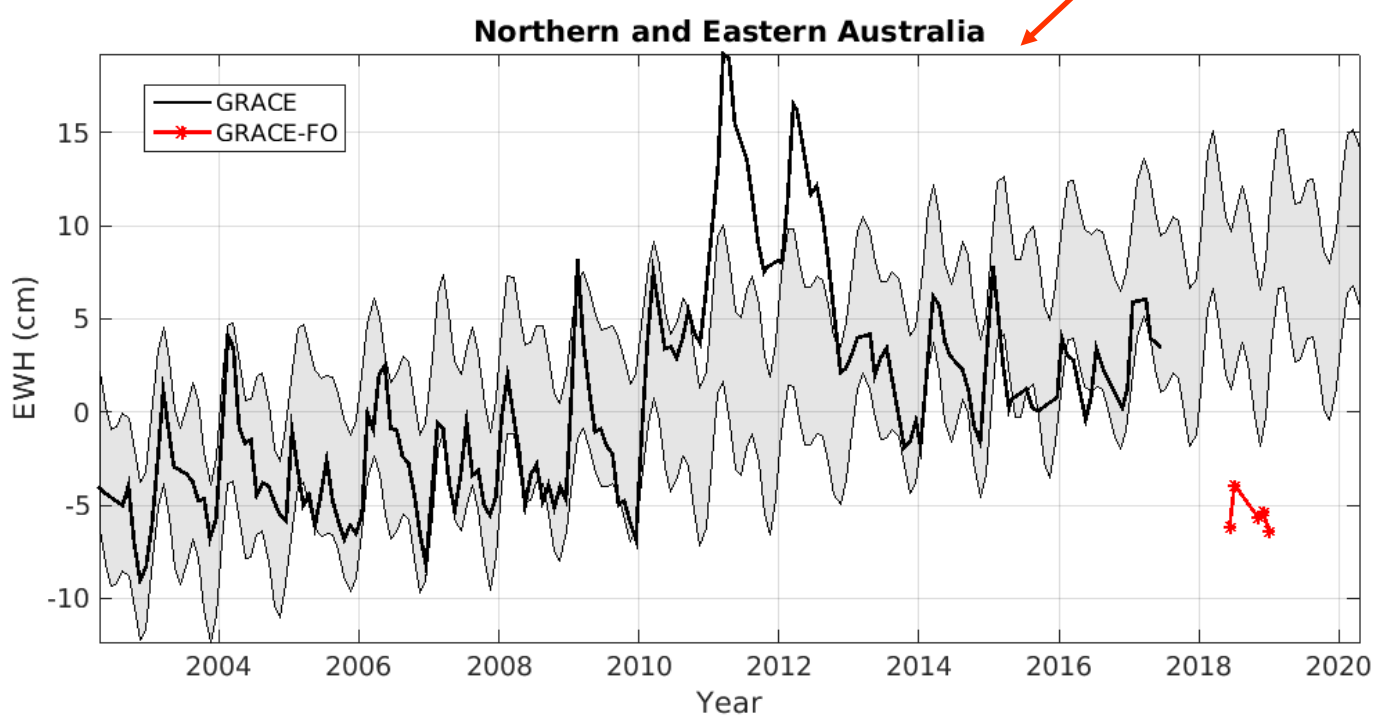
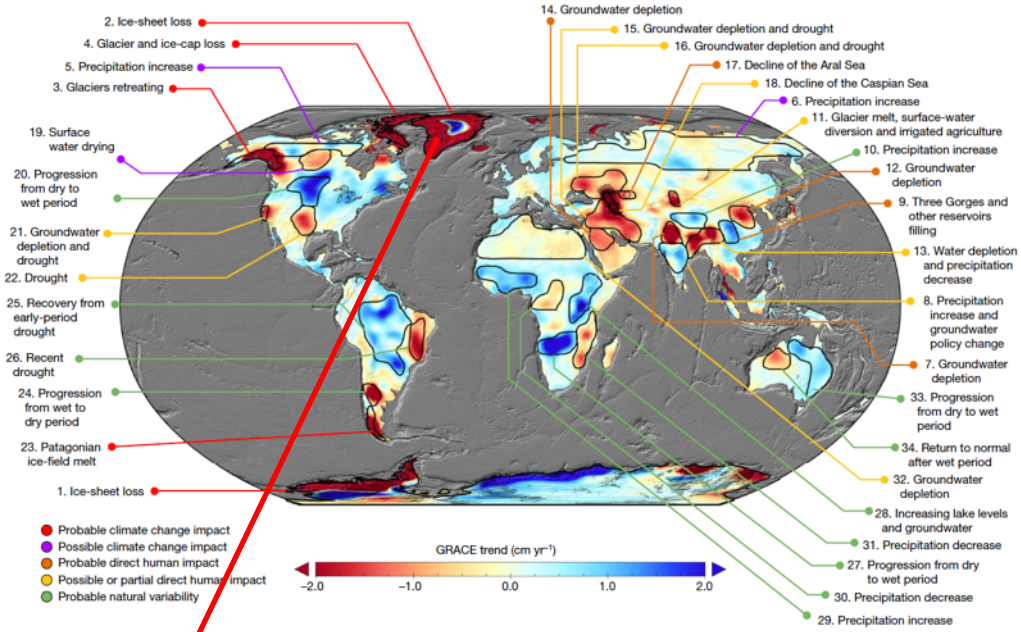
Issued: 07/01/2019

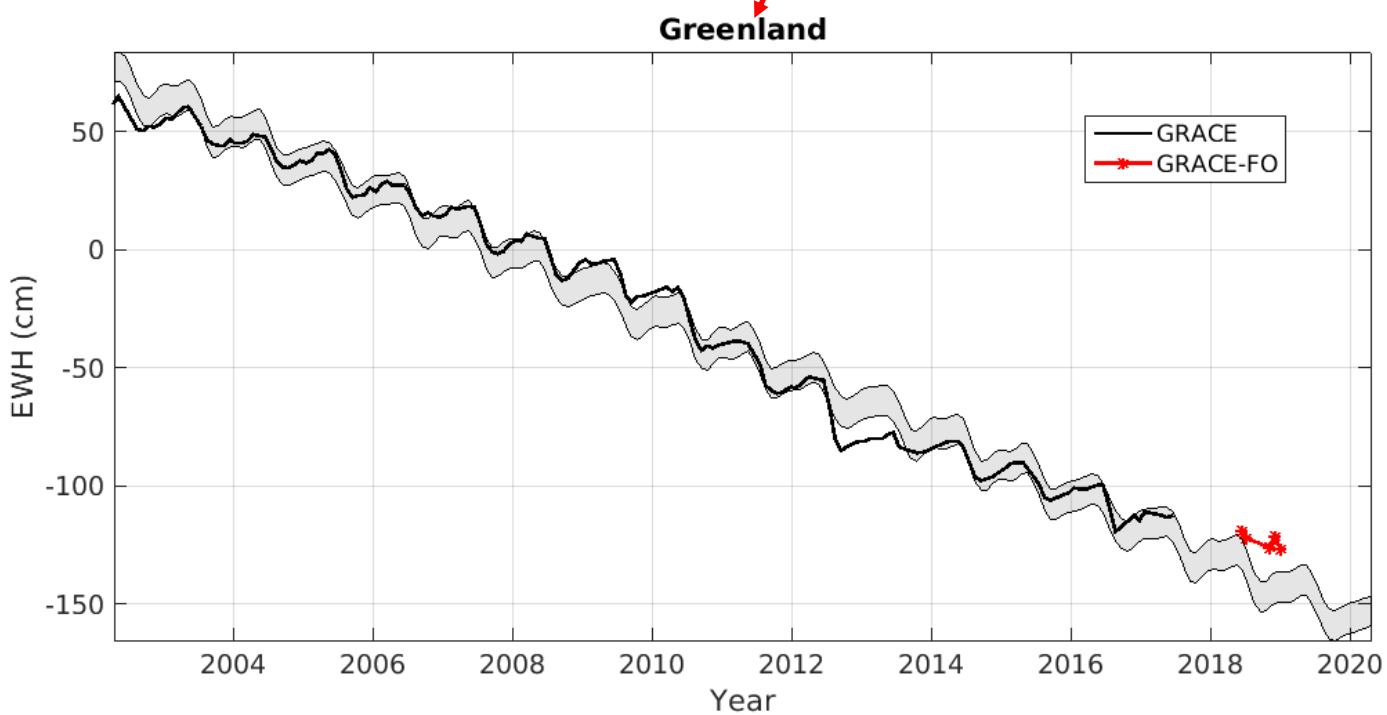

14. Groundwater depletion
15. Groundwater depletion and drought
16. Groundwater depletion and drought
17. Decline of the Aral Sea
18. Decline of the Caspian Sea
6. Precipitation increase
11. Glacier melt, surface-water diversion and irrigated agriculture
10. Precipitation increase
12. Groundwater depletion
9. Three Gorges and other reservoirs filling
13. Water depletion and precipitation decrease
8. Precipitation increase and groundwater policy change
7. Groundwater depletion
33. Progression from dry to wet period
34. Return to normal after wet period
32. Groundwater depletion
28. Increasing lake levels and groundwater
31. Precipitation decrease
27. Progression from dry to wet period
30. Precipitation decrease
29. Precipitation increase
GRACE trend (cm yr⁻¹)
−2.0
−1.0
0.0
1.0
2.0


Northern and Eastern Australia
GRACE
GRACE-FO
EWH (cm)
15
10
5
0
-5
-10
2004
2006
2008
2010
2012
2014
2016
2018
2020
Year

Continuity

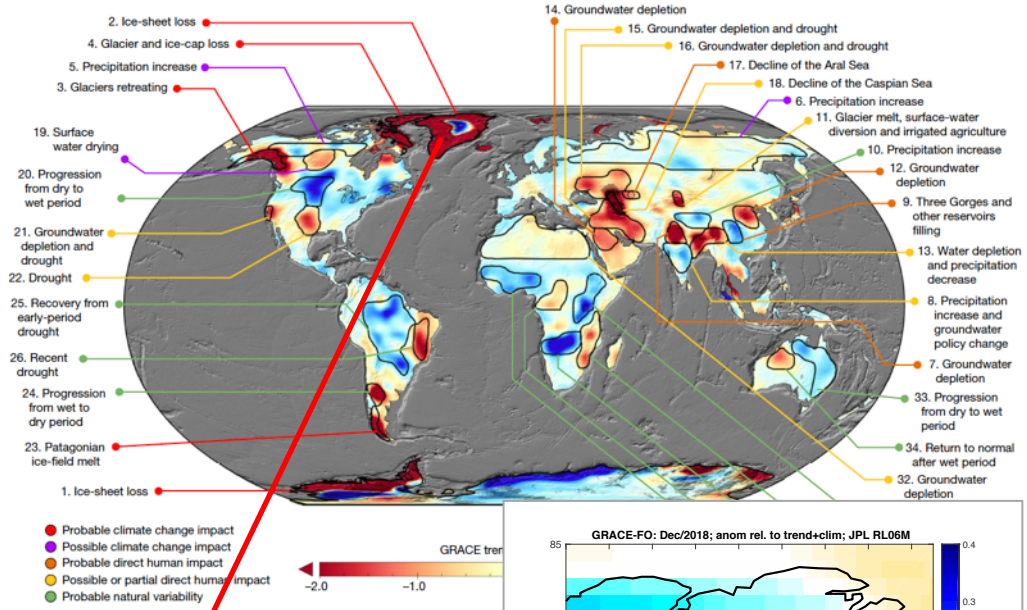
Change in Ice Mass Loss Rate?

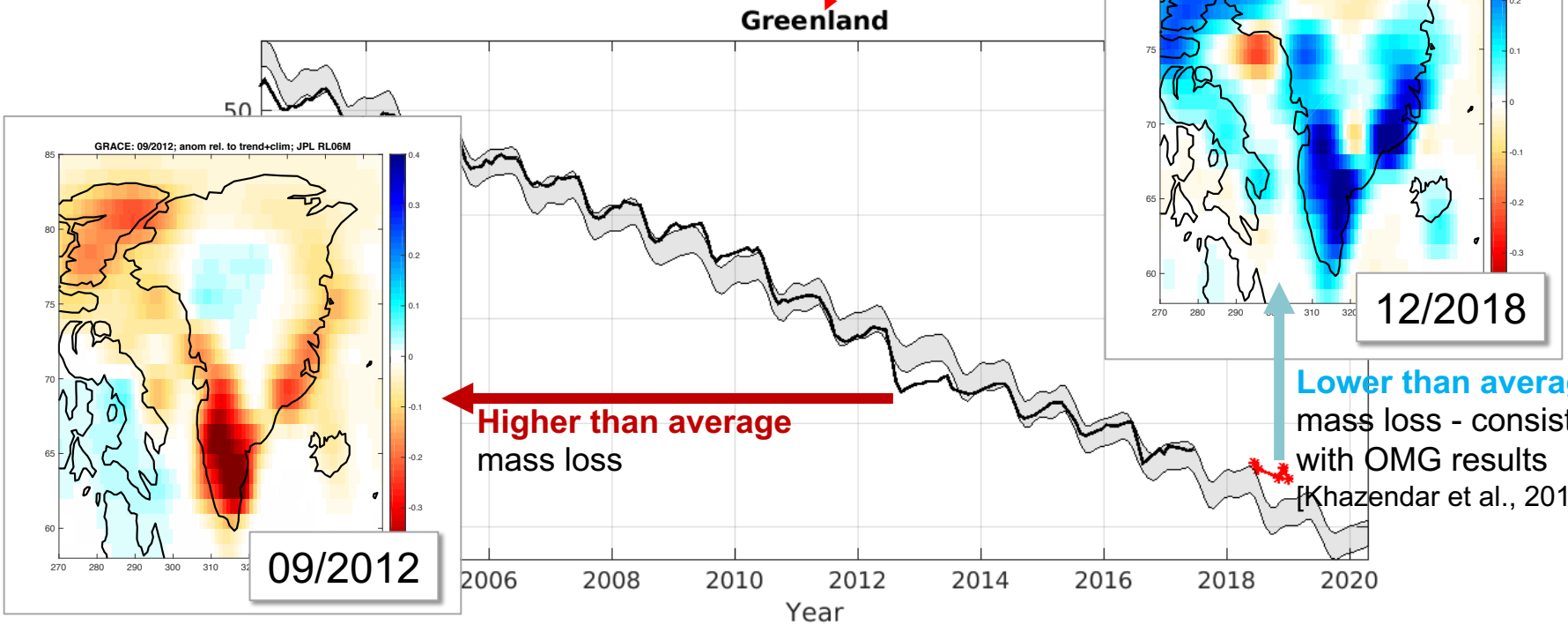




Continuity

Change in Ice Mass Loss Rate?





Higher than average mass loss

Lower than average mass loss - consistent with OMG results [Khazendar et al., 2019]

Looking Ahead

Radio Occultation (OCC)

- OCC testing completed last week
- Some MWI software modification will be uploaded before OCC is enabled operationally
- Will collect minimum of 200 profiles / day

KBR calibration

- KBR calibration is being revised to accommodate GF2 ACC performance
- Will carry out KBR calibration in next couple of months
- Calibration is a data processing calibration (not on MWI instrument), will be applied on all collected science data

Mission Duration

- Planned & funded mission duration is 5 years from launch, through May 2023, and the satellites carry enough fuel to last well beyond.
- Based on current predictions of solar activity, satellites could remain above 350 km through early 2026.

Summary **We have an operational GRACE successor in space!!!**

- GRACE-FO instruments and measurement systems are functioning and producing science quality data
- Since launch, 9 preliminary monthly gravity fields have been produced to date
  - L1B products are of good quality (same or better than GRACE) except for ACC1B (GF2)
  - Showing mass change signals consistent with long-term trends & climatology from GRACE (interannual variations apparent)
- GRACE-FO performance meets the Level 1 science and technology requirements
- SDS is finalizing verification and validation before
  - Level-1 data release on May-28, 2019
  - Level-2 data release on July-28, 2019
  - Check **https://gracefo.jpl.nasa.gov** & **https://isdc.gfz-potsdam.de**

Looking forward to see you at the next GRACE-FO Science Team Meeting 2019 on Oct 8-10 in Pasadena, USA!

Backup

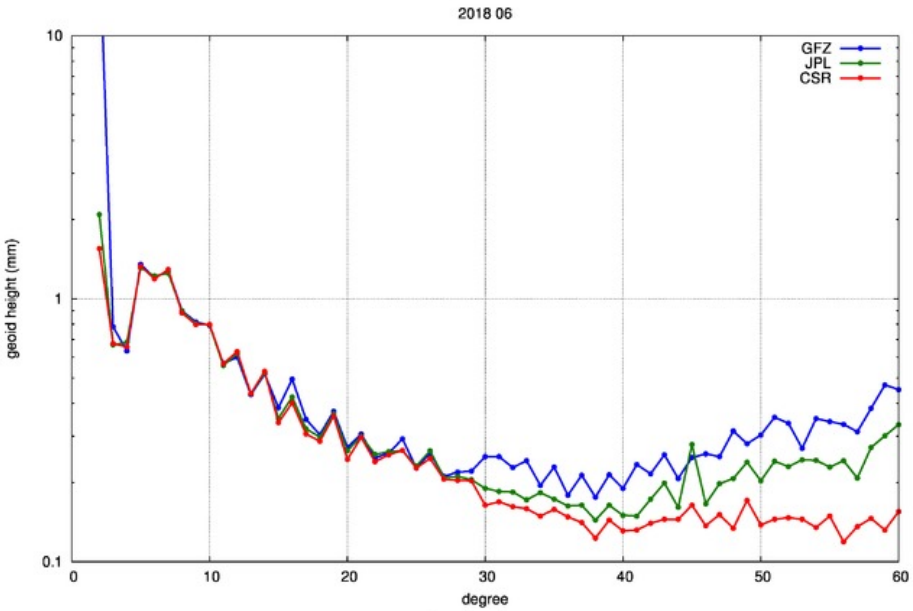
Processing Details (Level-1 and Level-2 V&V)

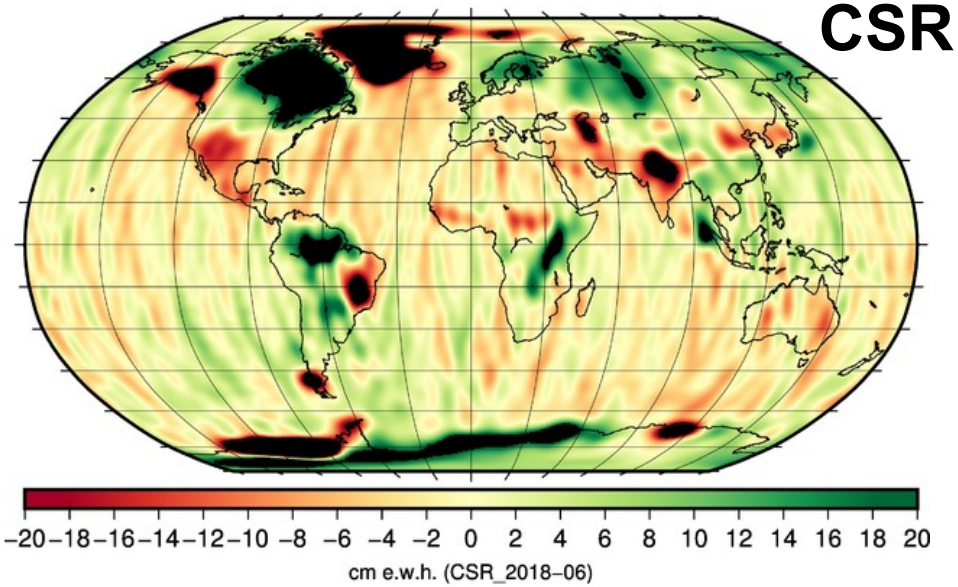
- L1B data:
  - SCA1B, KBR1B: based on **STR+IMU combination** for attitude
  - Accelerometer: **ACT1B product** (new!)
    - GF1: phantom spikes removed, roll/pitch/yaw thrusts removed and restored via a calibrated model
    - GF2: transplanted from GF1 (all 3 axes, corrected as described above), thrusts restored via a calibrated model

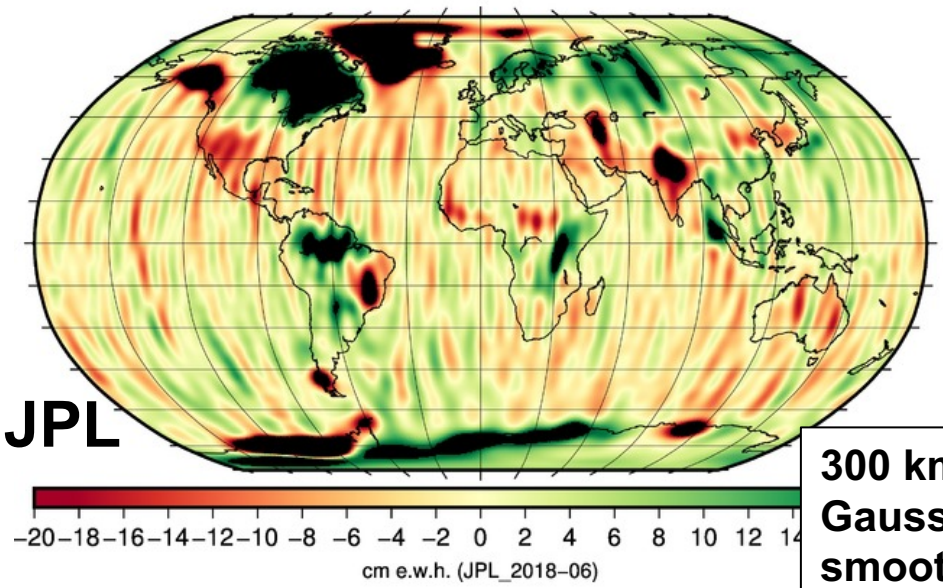
- Changes in processing strategy compared to GRACE RL06:
  - JPL: RL06 standards; parametrization changes: **ACC full scale matrix is estimated once per month rather than once per day**
  - GFZ: RL06 standards; parametrization changes: **ACC full scale matrix estimated once per month has been added**
  - CSR: RL06 standards („2-step approach" same as GRACE RL06); parametrization changes: **ACC full scale matrix is estimated once per month rather than once per day**

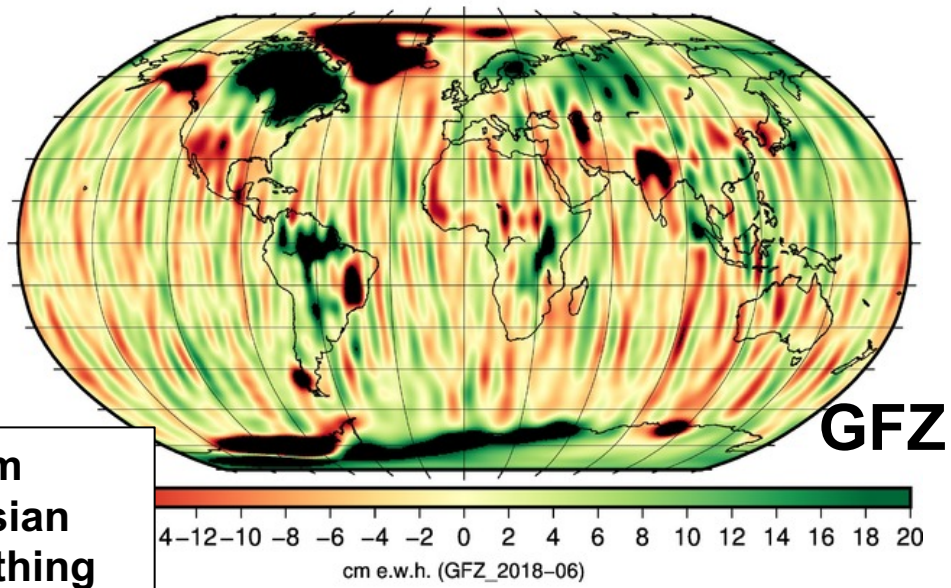
SDS Consistency

June 2018









300 km Gaussian smoothing