

# GRACE and GRACE-FO Level-1 V04 Data Processing Status



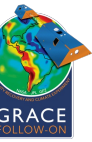
Christopher McCullough  
on behalf of the  
Science Data System Team from JPL, CSR, and GFZ

NASA Jet Propulsion Laboratory  
California Institute of Technology

2024 GRACE/GRACE-FO Science Team Meeting  
October 8, 2024



# Overview



- Transition to IGS20
- KBR/GPS POD/USO Performance
- Attitude Reconstruction
- Accelerometer
- GRACE/GRACE-FO Reprocessing



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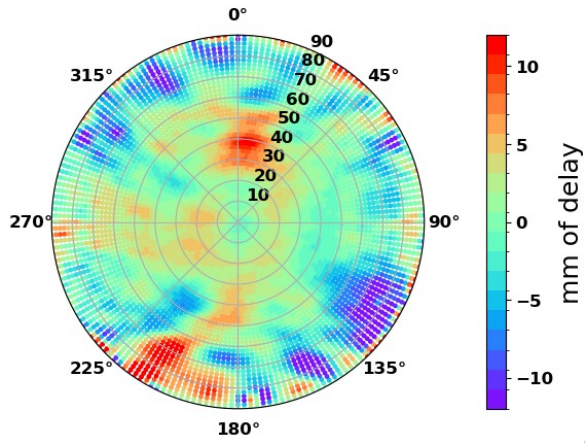


# Transition to IGS20



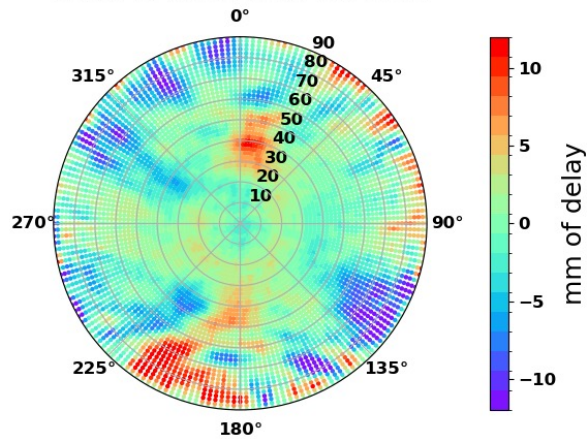
- Level-1 POD processing has transitioned from IGS14 to IGS20:
  - concurrent with the JPL FLINN GPS orbits/clock product switch
  - products from 2024-08-25 and onward
- GRACE-FO antenna maps in IGS20 were generated using JPL's reprocessed products between 2019-2024

GRACE-C Phase Antenna Map IGS14



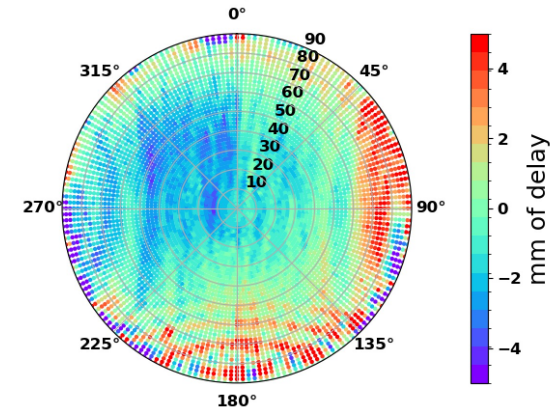
2024/10/08

GRACE-C Phase Antenna Map IGS20



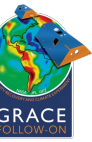
GSTM 2024

GRACE-C Phase antennaMap difference IGS20-IGS14





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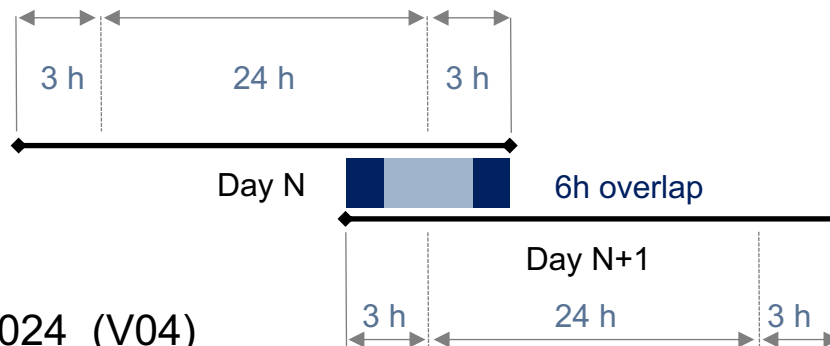


# KBR / GPS POD / USO Performance



## Performance Metrics:

- 1) Spacecraft trajectory comparison between overlapping consecutive orbit arcs
- 2) Spacecraft clock synchronization on overlapping arcs
- 3) (KBR – GPS) range difference
- 4) USO frequency stability



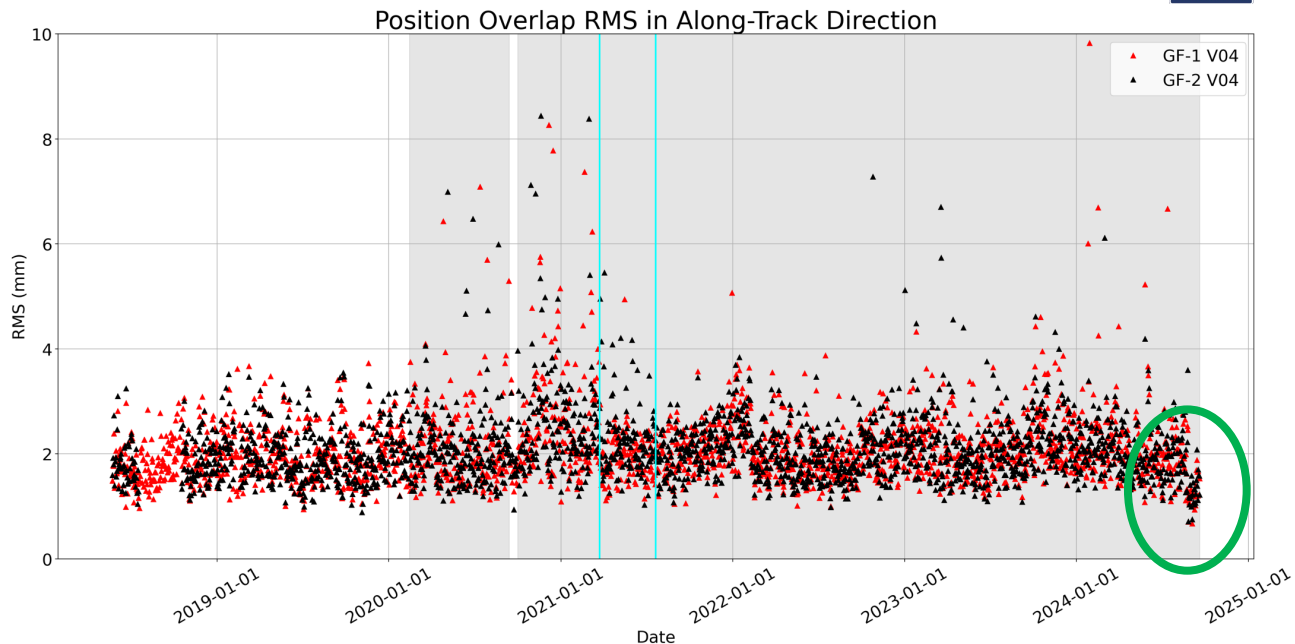
GRACE-FO: May 28, 2018 – Sep, 19 2024 (V04)



# GPS POD: Orbit Overlaps



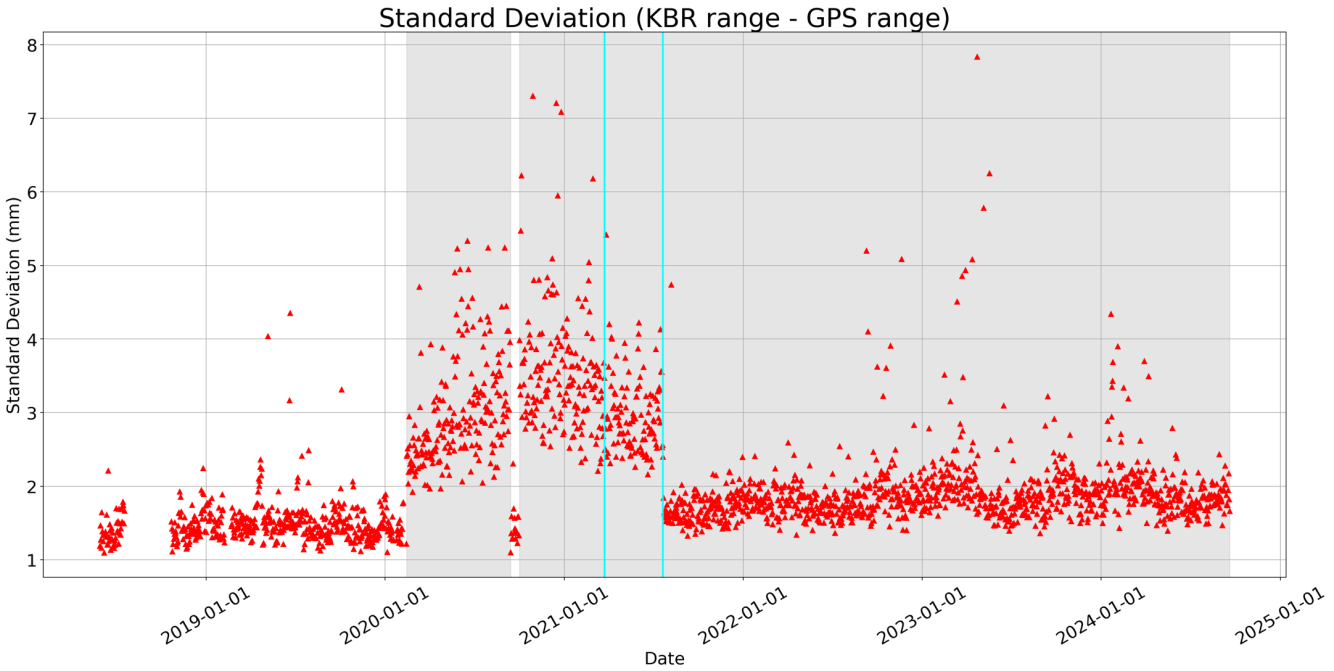
- **2021 software updates mitigate impacts of GPS Flex-power (grey regions)**
- Performance has ample margin for science data products (Level-2/3)
- Small improvement in quality after the switch to IGS20



**Performance continues to exhibit high quality**



# Inter-Satellite Range Difference



- **2021 software updates mitigate impacts of GPS Flex-power (grey regions)**
- Performance has ample margin for science data products (Level-2/3)

**Performance continues to exhibit high quality**



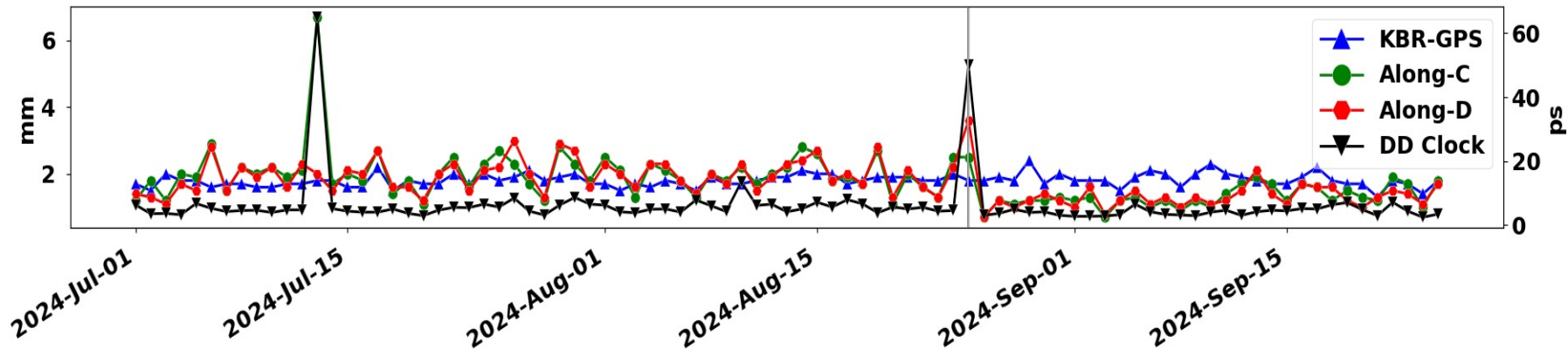


# Zoom in on the Transition to IGS20



- Quality of some Level-1 POD metrics slightly improved after the switch
- 1-year Level-2 test showed no significant trends in gravity field recovery

GRACE-FO Performance Metrics  
Vertical grey switch to IGS20



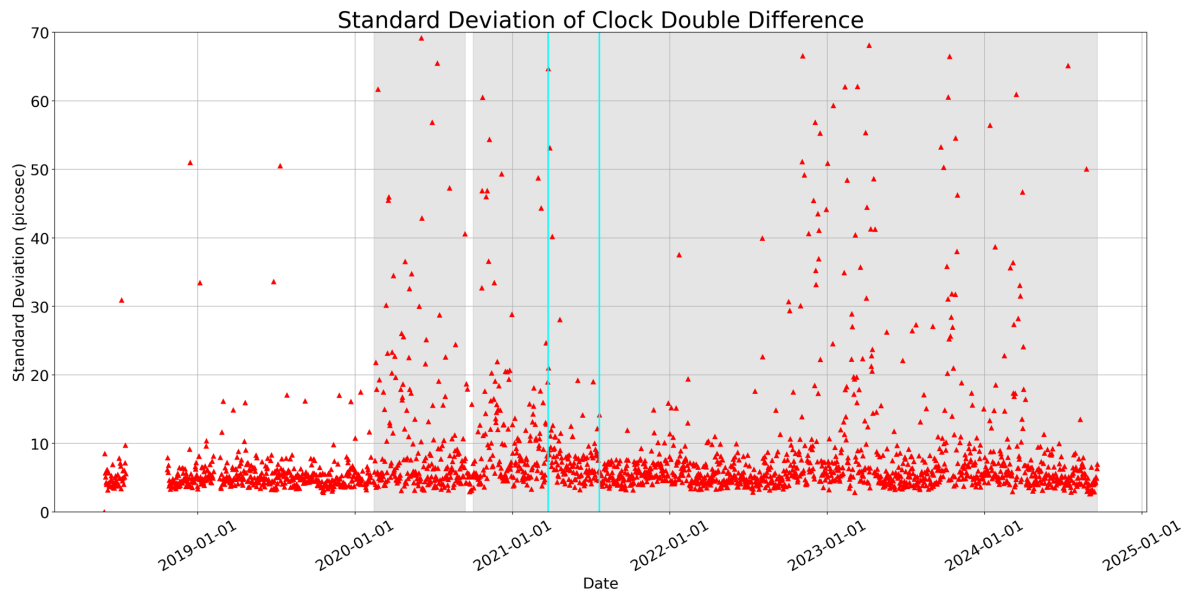


# Clock Performance



Spacecraft clock synchronization on overlapping arcs: direct measure of our relative time error:  $(\text{Clk}_C - \text{Clk}_D)_1 - (\text{Clk}_C - \text{Clk}_D)_2$

- **2021 software updates mitigate impacts of GPS Flex-power (grey regions)**
- Increased solar activity has increased volatility.
- Ample margin for science data products (Level-2/3).



**High quality performance satisfies requirements\***

\*Requirement:  $< 150 \text{ ps}$  ( $\approx 0.5 \text{ micron}$ )



# USO Frequency Stability



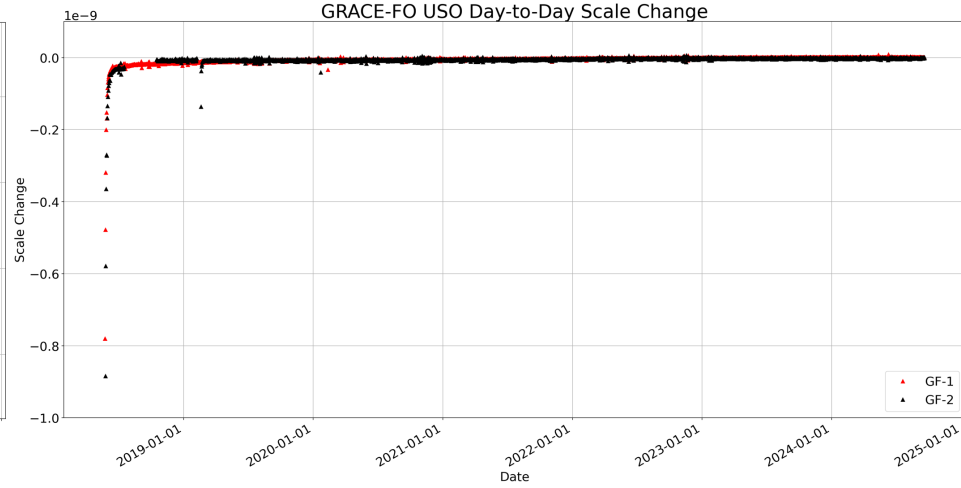
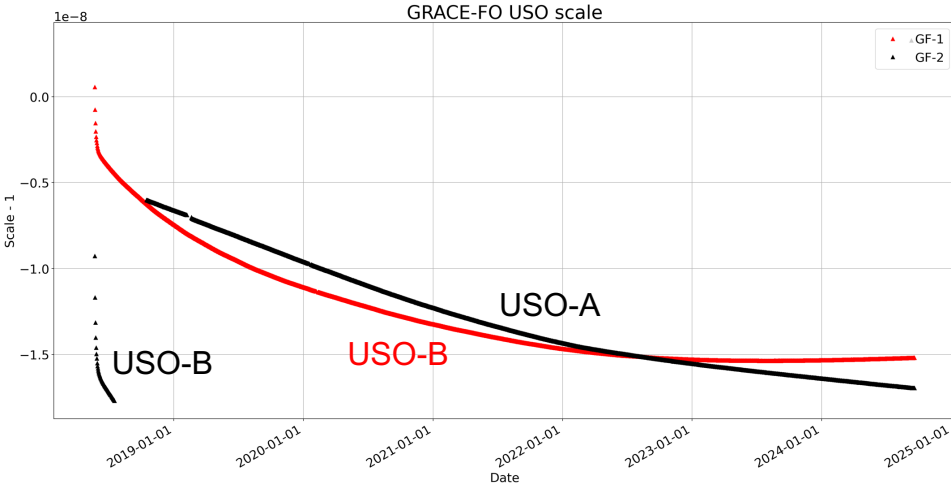
GRACE-FO USO nominal frequencies:

GF-1:  $f_0 = 4.832000e6$  Hz

GF-2:  $f_0 = 4.832099e6$  Hz

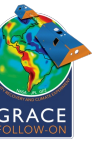
**USO frequency continues to be stable to much better than 1 part per billion**

$$\text{USO frequency scale} = \frac{\text{nominal freq.}}{\text{determined freq.}}$$





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# Attitude Reconstruction - Sensors



- 1) **Star Cameras**
  - 3 star camera heads
  - provides absolute attitude with respect to the inertial frame
- 2) **Inertial Measurement Unit (IMU)**
  - 4 fiber optic gyroscopes (as planned, gyro 4 turned off on 2019-03-13)
  - relative attitude in terms of angular rates
- 3) **Accelerometer**
  - relative attitude in terms of angular accelerations
  - not used for attitude data fusion on GRACE-FO
- 4) **LRI Fast Steering Mirror (LSM – LRI FSM)**
  - relative attitude in terms of pitch/yaw pointing angles
  - has been tested for attitude data fusion – not operational
- 5) **Magnetorquers (MTQ)**
  - relative attitude in derived angular accelerations
  - Used operationally (for ACC data processing only)



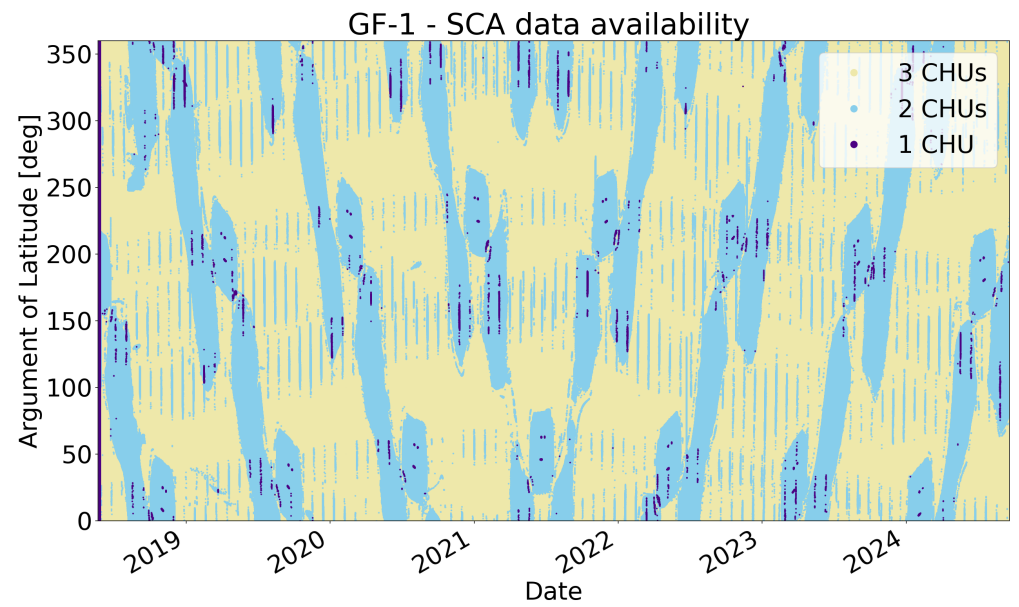
# Attitude Reconstruction – SCA Data Availability



Valid SCA data availability over the mission lifetime:

- 3 camera head units: 74.1 %
- 2 camera head units: 25.8 %
- 1 camera head unit: 0.1 %
- 0 camera head units: 0.0 %

**SCA data availability continues to meet expectations and performs well**





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# Accelerometer - Status



## GF1:

- nominal performance (impulse response issues), no changes
- Operating in NRM (Normal Range Mode)

## GF2:

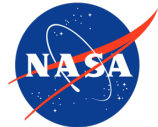
- Performance degraded shortly after launch, with highly correlated noise across all accelerometer axes
- Current operations continue in NRM, persisting noise features

Calibrated Level-1 ACT data product, for GF1, consisting of:

- Outlier detection and removal
- Thruster modeling

Hybrid transplant ACH data product, for GF2





# Accelerometer – ACX2 Bundle



Accelerometer data is available in the ACX2 bundle:

- Currently includes improvements to accommodate processing in wide-pointing mode
- Thruster modeling includes values regressed against the spacecraft regulator pressure differential (version 1)

The ACX2 bundle includes:

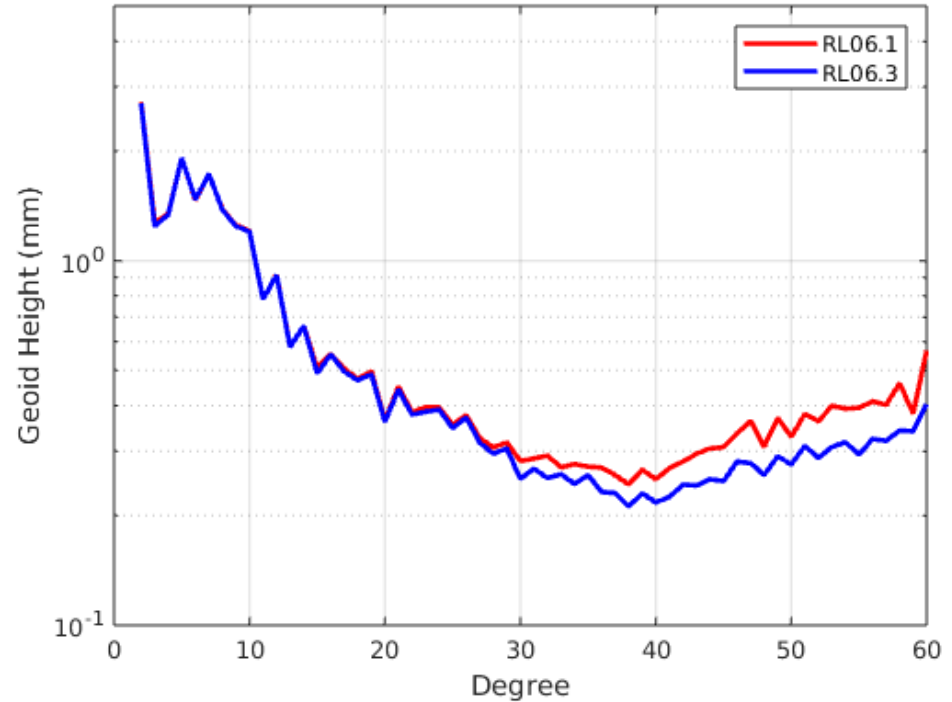
- AC0 – thruster model (version 0 - no regulator pressure regression)
- AC1 – thruster model (version 1 – regulator pressure regression)
- ACH – final combined product to be used for Level-2 processing



# Accelerometer – Gravity Field Improvements



- The ACH data included in the ACX2 bundle corresponds to the Level-2 RL06.3 gravity field solutions
- Significant gravity field improvements in wide deadband mode attitude pointing – [see JPL Level-2 talk](#)





# Accelerometer - Summary



- An update to the calibrated accelerometer product is currently publicly available which uses information derived from the GF2 accelerometer (ACH – within the **ACX2** bundle)
- The **ACX** for fine pointing, **ACX2** for wide-pointing months:

ACX Launch - 22/12/31	ACX2 23/1/1 – 23/2/28	ACX 23/3/1 – 23/6/30	ACX2 23/7/1 - present
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- Development utilizes GF2 data in an effort to provide a robust calibration that will continue to provide high quality results as the spacecraft environment evolves
- Subsequent releases will incorporate further analysis and optimally calibrate the accelerometer data for use in diverse spacecraft environments



# Overview



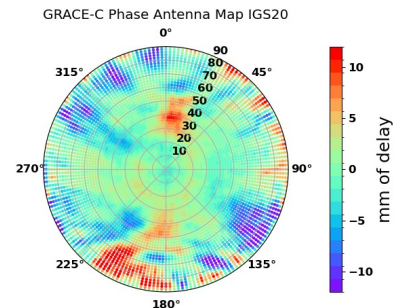
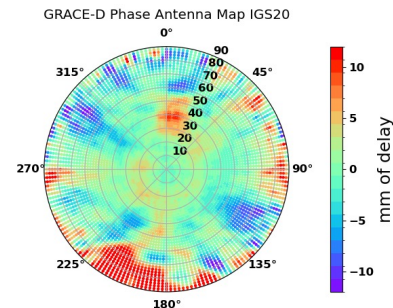
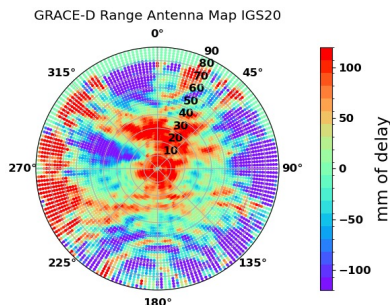
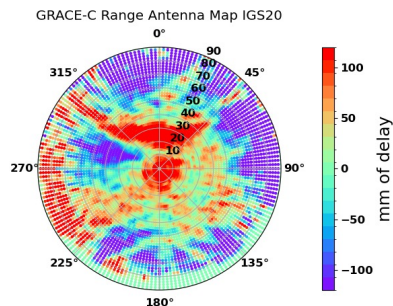
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# Reprocessing – GRACE-FO



- A reprocessing of GRACE-FO Level-1 data will be called version 'V05' and provide updates to:
  - Homogenize the entire POD time series with IGS20
  - Update ACH processing
  - Update LRI processing (see talk by Fahnestock)
  - Provide HRT (high resolution thermistor) data
  - Other minor improvements and optimizations

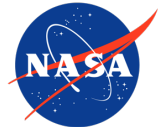




# GRACE Reanalysis Overview – (v05/RL07)



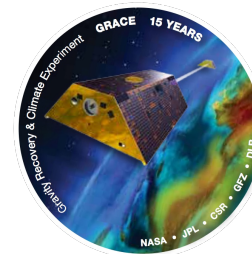
- Goal is to judiciously reprocess GRACE with the same software and configuration used for GRACE-FO to ensure consistent, stable, long-term multi-mission Climate Data Record
- Initial reprocessing and validation, at Level-1/2, with IGS14 was performed for 2004-2016
- Reprocessing was temporarily put on hold to accommodate updates to IGS20 – due the operational nature of GRACE-FO, it was prioritized before updates were made for GRACE



# GRACE Reanalysis Overview – (v05/RL07)



- This is planned to be the final Level-1 reprocessing for GRACE (excluding future ACC transplant improvements) and processed as version ‘V05’. It includes:
  - Improved precision orbit determination
    - Transition to IGS20 (seasonal geocenter should improve the dynamic modeling)
    - GPS data editing
    - Increased GPS processing data rate
    - Updated antenna maps
  - Updated SCA time tag correction
  - Improved ACC transplant data (utilizing lessons learned from GRACE-FO)
- Level-2 processing will be released as RL07 - **see SDS Level-2 talks**

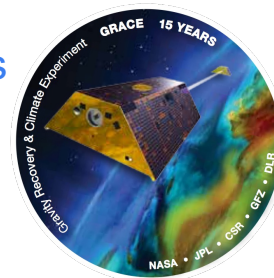




# GRACE Reanalysis Status – (v05/RL07)



- Level-1
  - In progress – processing of GPS POD data to estimate new antenna maps consistent with IGS20
  - In progress – testing of ACC transplant updates
  - Pending – processing of the nominal mission (2004-2016)
  - Pending – processing of the non-nominal mission (2002-2003 and 2016-2017)
- Level-2
  - Pending – validation of final Level-1 processing
  - In progress – optimization of Level-2 processing strategies (gravity field improvements are evident in JPL RL06 to RL07 – see SDS Level-2 talks and poster by Matthias Ellmer)
  - Several options for updated background/de-aliasing models are being discussed (AOD, tide models, etc.), as well as updates to processing, parameterization, etc. – see CSR Level-2 talk







Thank you!!