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

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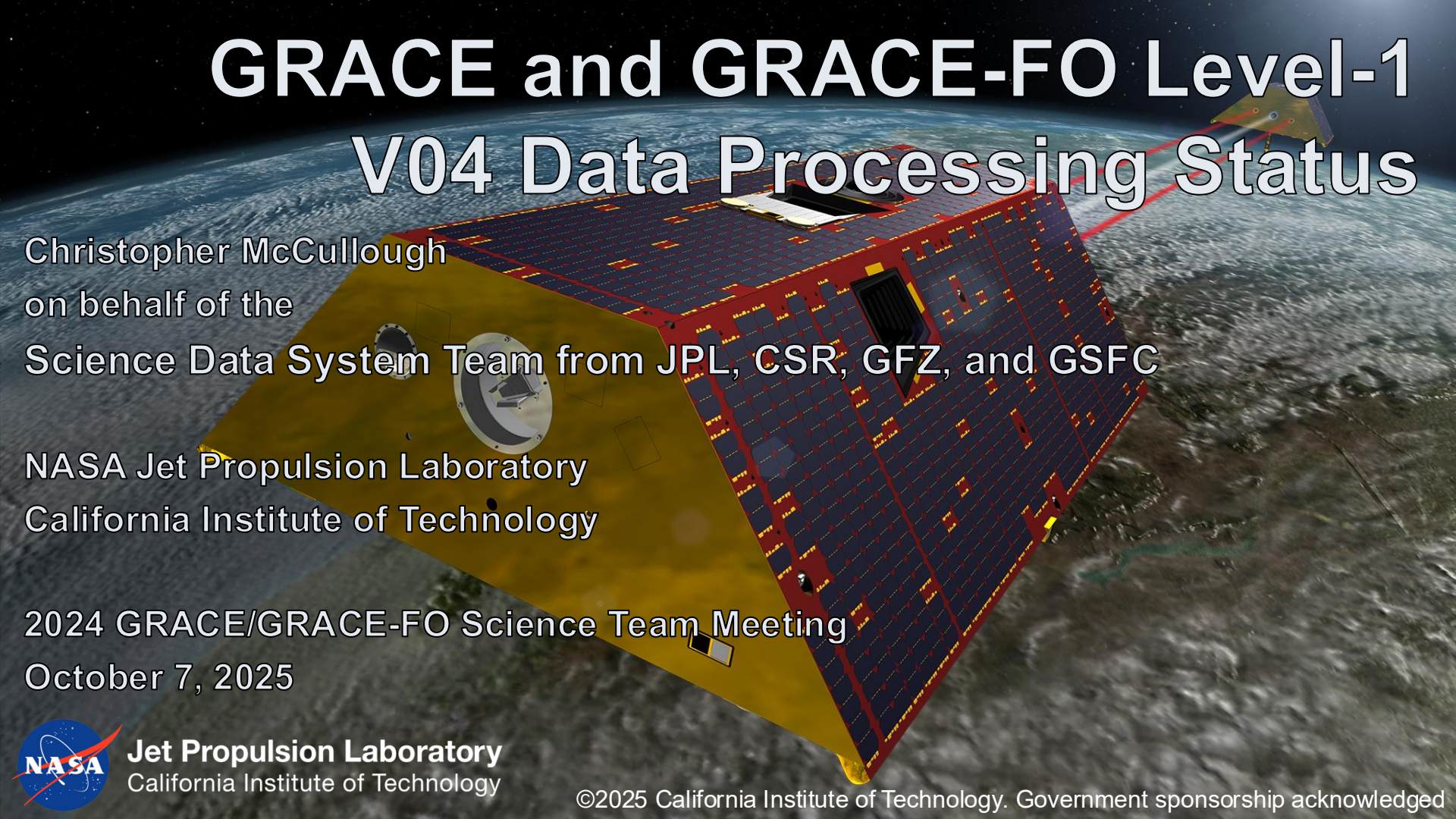

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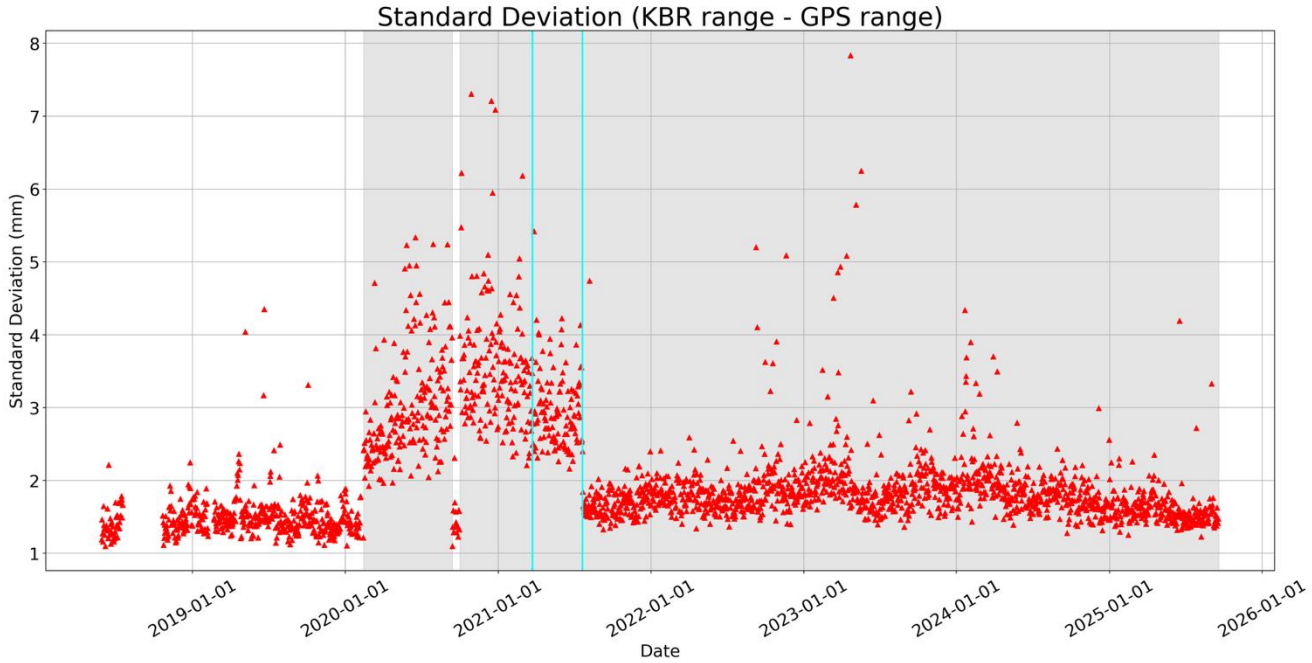
Level-1 Performance Metrics
Inter-Satellite Range Difference



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

All Level-1 performance metrics continue to exhibit high quality

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

GF2 accelerometer data is available in the ACX2 bundle:

- Continues to include processing designed for optimal use 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 - Summary

- The current calibrated accelerometer product for GF2 is the ACH1B product (currently publicly available within the **ACX**/**ACX2** bundles)

- The **ACX** for fine pointing, **ACX2** for wide-pointing months:

ACX	ACX2	ACX	ACX2
Launch - 22/12/31	23/1/1 – 23/2/28	23/3/1 – 23/6/30	23/7/1 - present

- 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

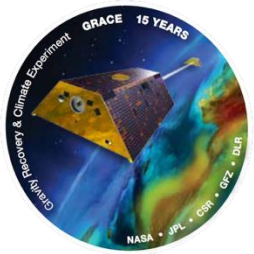
- Subsequent releases will incorporate further analysis and optimally calibrate the accelerometer data for use in diverse spacecraft environments

Reprocessing Overview – (v05/RL07)

- Reprocessing of GRACE/GRACE-FO Level-1 data is called version ‘V05’
- Corresponding Level-2 reprocessing will be called RL07
- GRACE
  - 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 IGS20, has been performed for 2004-2016
  - Planned to be completed by the end of 2025
- GRACE-FO
  - Software updates and initial reprocessing in progress
  - Planned to be completed in Spring 2026

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

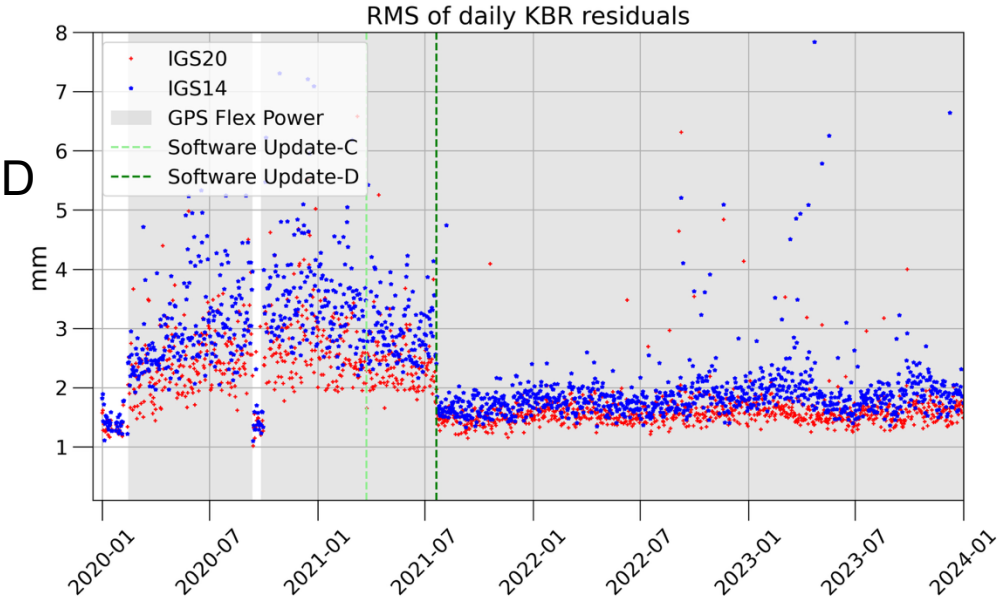


GRACE Reanalysis Status – (v05/RL07)

- Level-1
  - Complete – processing of GPS POD data to estimate new antenna maps consistent with IGS20
  - Nearing completion – processing of the nominal mission (2004-2016)
  - In progress – processing of the non-nominal mission (2002-2003 and 2016-2017)
  - In progress – testing of ACC transplant updates
- Level-2
  - In progress – validation of final Level-1 processing
  - Complete – optimization of Level-2 processing strategies (gravity field improvements are evident in RL06 to RL07) – see SDS Level-2 talks
  - Complete - updated background modeling – see SDS Level-2 talks

GRACE-FO Reanalysis Status – (v05/RL07)

- Level-1
  - Homogenize the entire POD time series with IGS20
  - Update ACH processing (reanalysis of accelerometer characteristics throughout the mission)
  - Update LRI processing
  - Provide HRT (high resolution thermistor) data
  - Other minor improvements and optimizations



- Level-2
  - Processing strategies, parameterization, and background model updates consistent with GRACE RL07

Thank you!!

Back-Up & More Detail

KBR / GPS POD / USO Performance

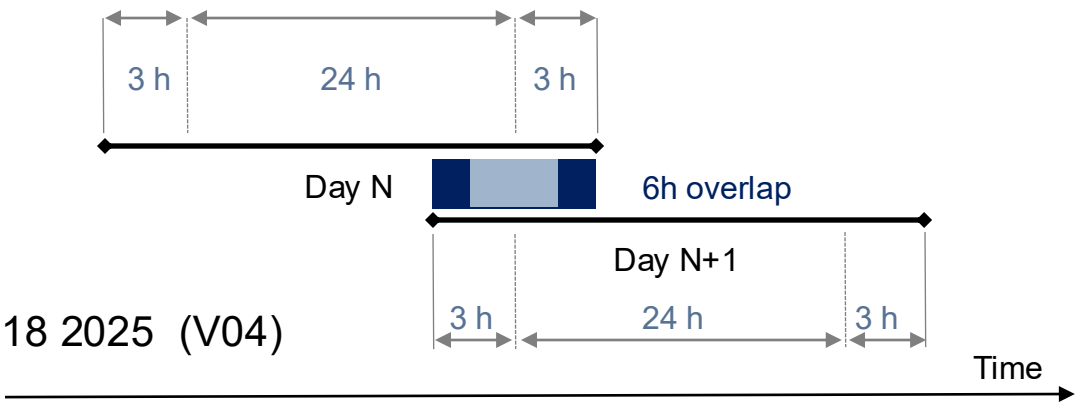
Performance Metrics:

1) Spacecraft trajectory comparison between overlapping consecutive orbit arcs

2) Spacecraft clock synchronization on overlapping arcs

3) (KBR – GPS) range difference

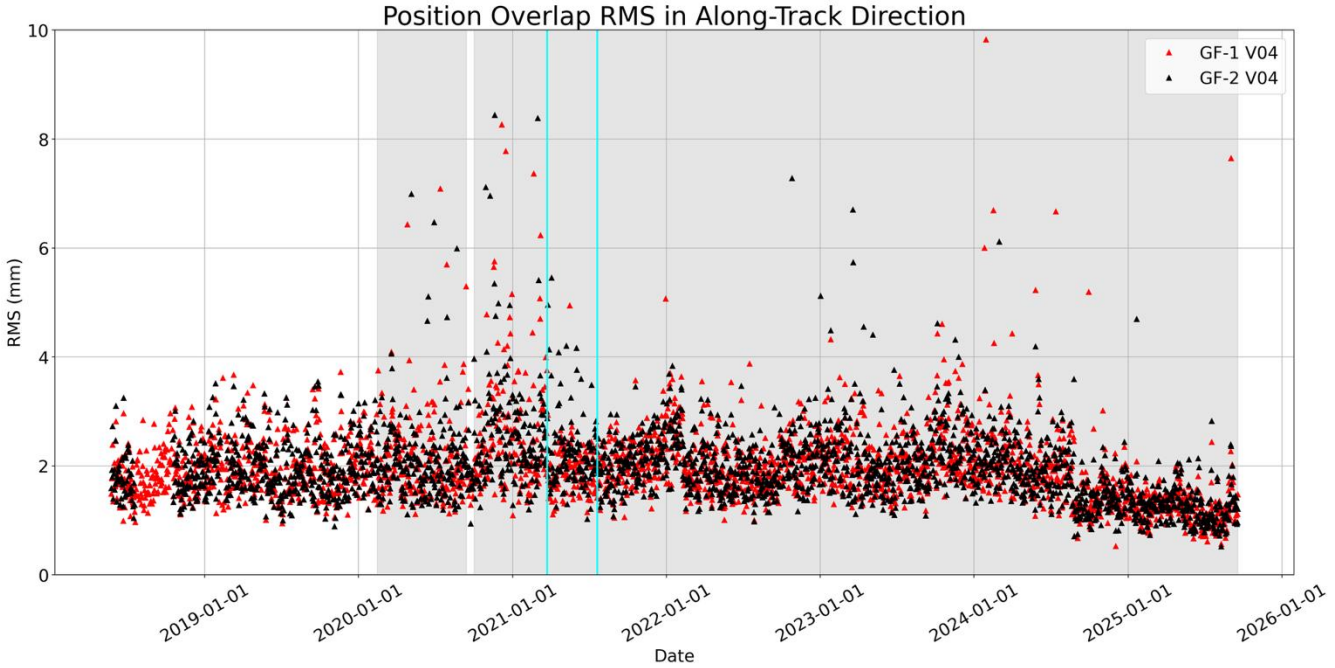
4) USO frequency stability



GRACE-FO: May 28, 2018 – Sep, 18 2025 (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

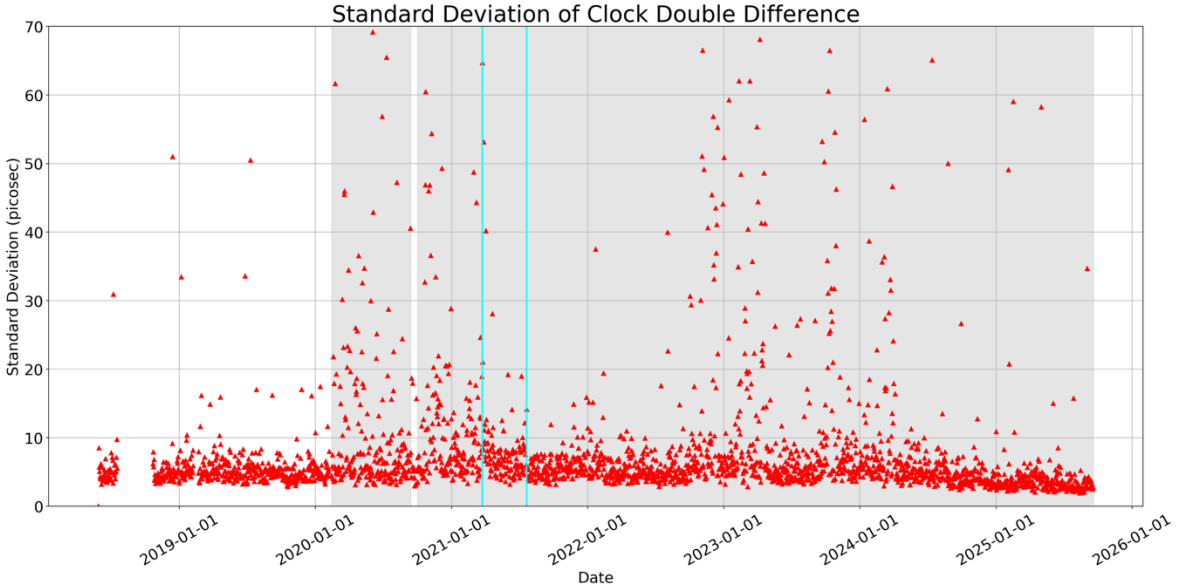


Performance continues to exhibit high quality

Clock Performance

Spacecraft clock synchronization on overlapping arcs: direct measure of our relative time error: $(Clk_C - Clk_D)_1 - (Clk_C - Clk_D)_2$

- **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 ps (≈ 0.5 micron)

USO Frequency Stability

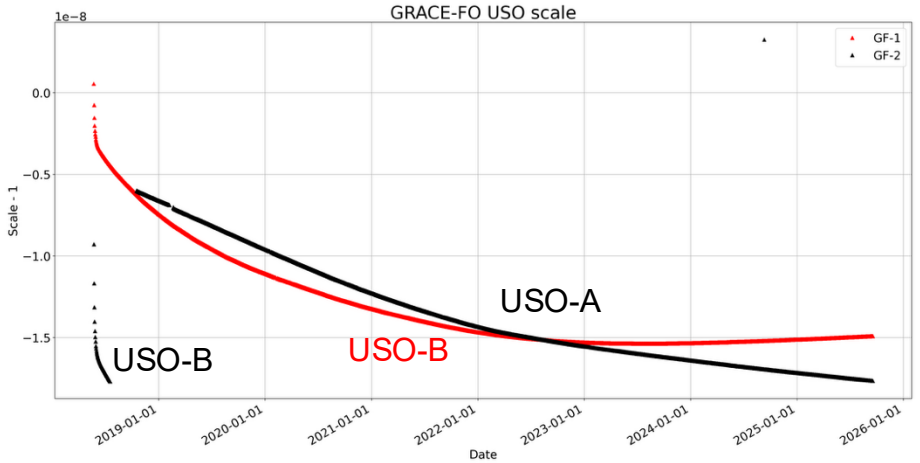
GRACE-FO USO nominal frequencies:

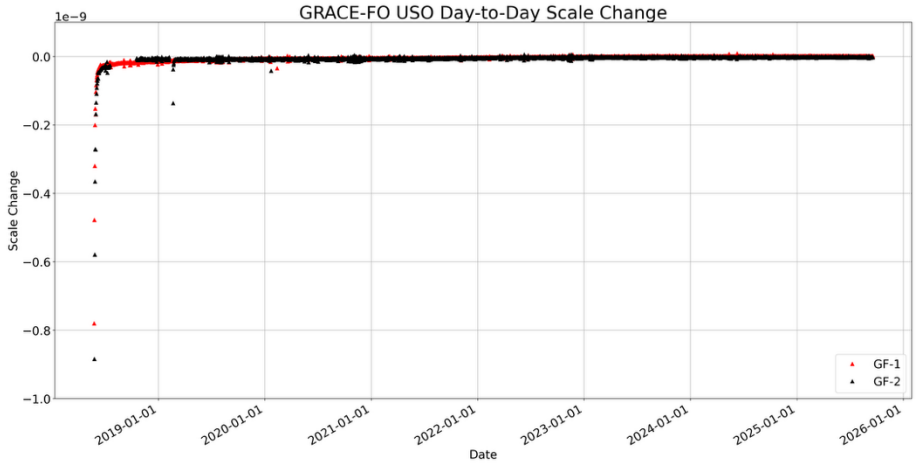
GF-1: f_0 = 4.832000e6 Hz

GF-2: f_0 = 4.832099e6 Hz

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

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





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: 74.2 %
- 2 camera head units: 25.7 %
- 1 camera head unit: 0.1 %
- 0 camera head units: 0.0 %

SCA data availability continues to meet expectations and performs well