

Precise orbit determination and accelerometer data modelling of the GRACE Follow-On mission

Papanikolaou, Thomas

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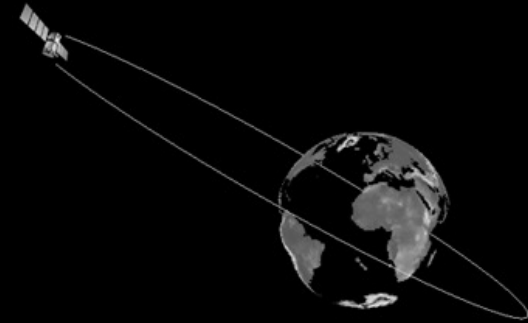
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Precise orbit determination and accelerometer data modelling of the GRACE Follow-On mission

Thomas Loudis Papanikolaou

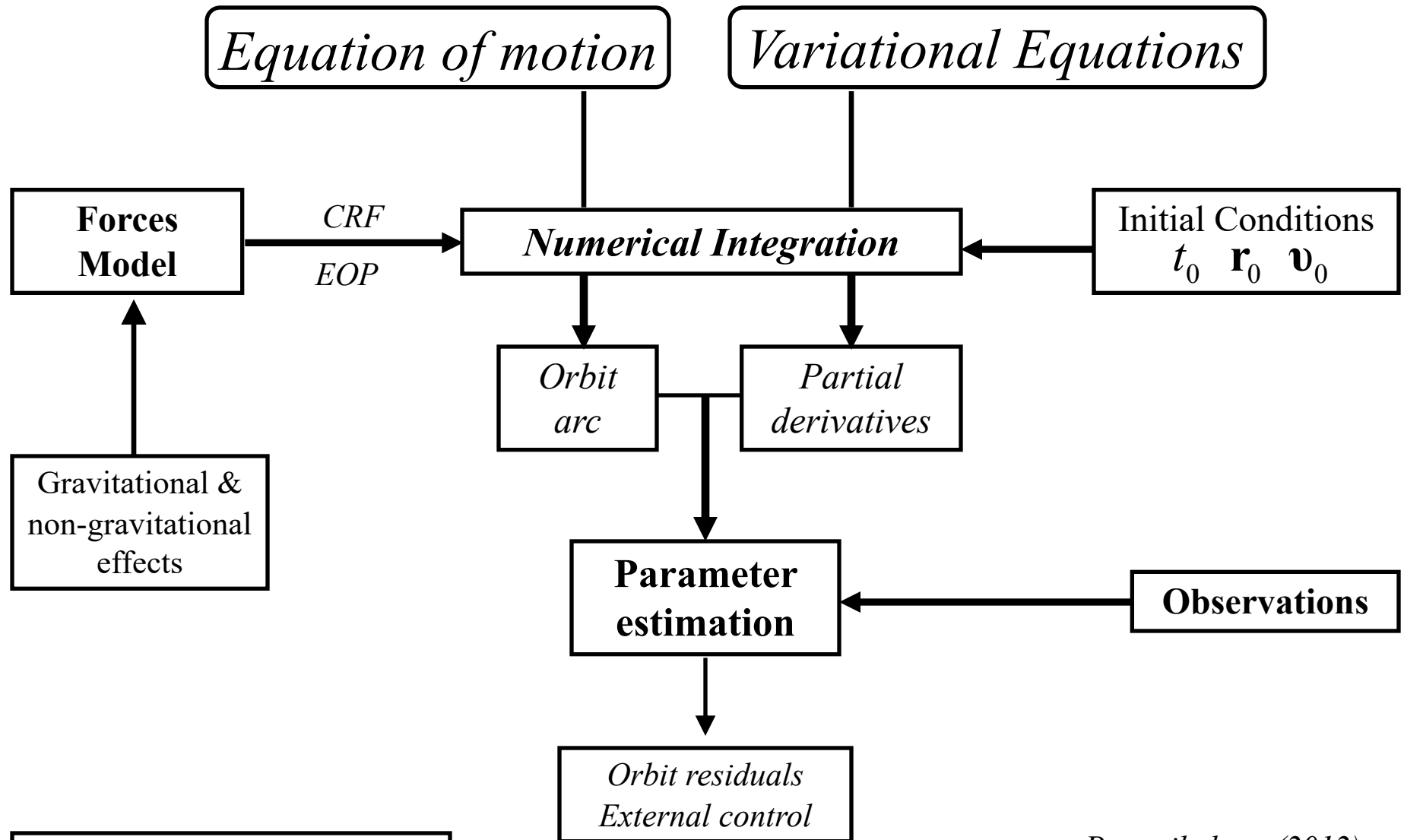
Aalborg University, Copenhagen, Denmark (thomasp@plan.aau.dk)

GRACE/GRACE-FO Science Team Meeting 2022

18 – 20 October 2022, GFZ Potsdam, Germany

Outline

- Dynamic Orbit Determination application to GRACE-FO
- GRACE-FO acceleromer calibration modelling
- Empirical parameter estimation (accelerations, 1-CPR)
- LRI intersatellite ranging data analysis



| <u>GRACE-FO orbital dynamics and Accelerometer calibration modelling</u> | |
|---|---|
| Orbit arc length | Daily orbit arcs |
| Earth Orientation | IERS Conventions 2010 (Petit and Luzum 2010) and updates |
| EOP | IERS 08 C04; IAU2006/200A |
| Numerical Integrator | Gauss-Jackson 12 th order; RKN7(6)-8 start integrator (Papanikolaou and Tsoulis 2016) |
| Integration step | 10 sec |
| Pseudo-Observations | Kinematic Orbit XYZ (Suesser-Rechberger et al. 2020) |
| Gravity Model (d/o) | GOCO06s (Kvas et al. 2019) |
| Planetary/Lunar Ephemeris | DE423 (Folkner et al. 2009) |
| Solid Earth Tides | IERS Conventions 2010 (Petit and Luzum 2010) |
| Ocean Tides | FES2014b model (Lyard et al. 2021) |
| Pole Tide | Solid Earth Pole Tide and Ocean Pole Tide (IERS Conventions 2010) |
| Atmosphere and Ocean De-Aliasing effects | AOD1b RL06 data processing (Dobslaw et al. 2017) |
| Relativistic effects | IERS Conventions 2010 (Petit and Luzum 2010) |
| Accelerometers | ACC1B data (McCullough et al. 2019) + estimated parameters: Full Scale matrix (9 parameters), Bias (XYZ), (optional: Bias drift 1 st and 2 nd order) |
| Empirical Forces of periodic terms | One-Cycle per revolution (1-CPR) accelerations |
| Empirical accelerations (bias) | Piecewise Accelerations per 1 revolution with interval 15 min in orbital frame (RTN) or spacecraft frame (SRF) |
| Intersatellite range-rate data | Laser Ranging Interferometry LRI1B (as observations and external validation tool) K-Band Ranging KBR1B (as external accuracy assessment) |
| External Orbit Comparison | GNV1B orbit data (Wen et al. 2019) |

GRACE-FO accelerometer calibration modelling

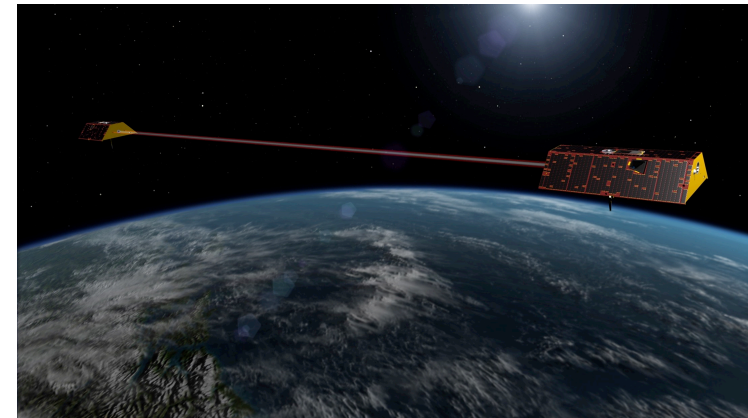
- **Calibration modelling:** Bias, Full Scale matrix (9 parameters), Bias Drift (1st and 2nd derivatives) as optional estimation (replaced via estimation of empirical parameters)
- **Empirical accelerations:** Piecewise-Constant accelerations per 1rev/1h, time interval 15 to 30 min
- **Periodic accelerations:** 1 cycle per revolution (sin and cos terms)
- **Reference Frame:** Orbital frame (RTN or TN) or Spacecraft frame (SRF)

$$\mathbf{f}_{\text{non-grav}} = \mathbf{f}_{\text{acc}} + \mathbf{a}_{\text{bias}} + \mathbf{a}_{\text{CPR}}$$

$$\mathbf{f}_{\text{acc}} = \mathbf{b} + \mathbf{R} * \text{ACC}_{1\text{B}} + (\dot{\mathbf{b}}t + \ddot{\mathbf{b}}t^2)$$

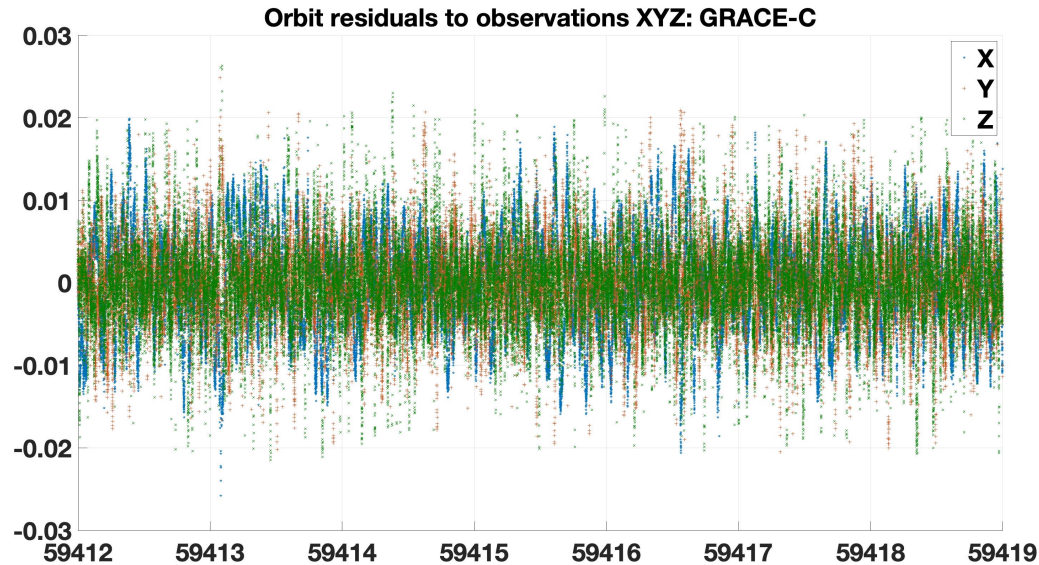
$$\mathbf{a}_{\text{bias}}(t) = \sum_i \delta(t - t_i) \cdot \mathbf{a}_{t_i} \quad \begin{array}{l} \text{at predefined epochs} \\ t_i^0 < t_i \leq t_i^0 + \Delta t \end{array}$$

$$a_{\text{CPR}}^e = C_e \cos(u) + S_e \sin(u)$$

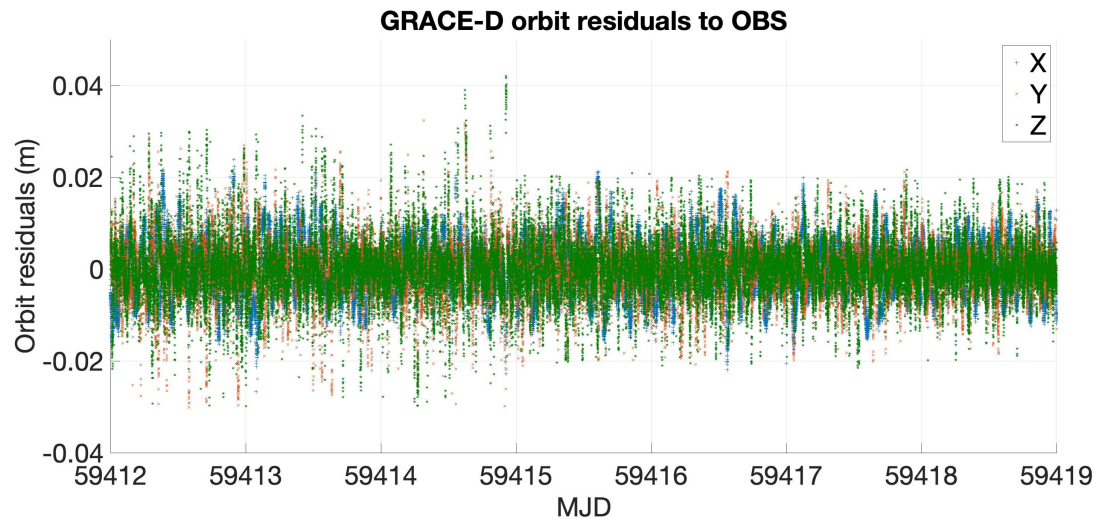


GRACE Follow-on mission (Credit: NASA)

GRACE-FO orbit residuals: Weekly analysis

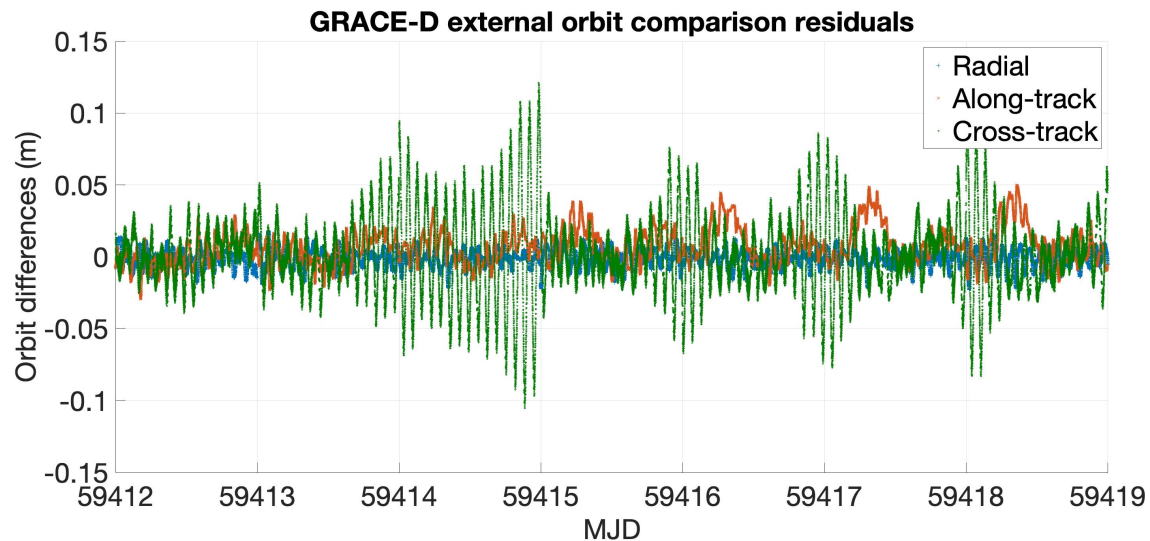
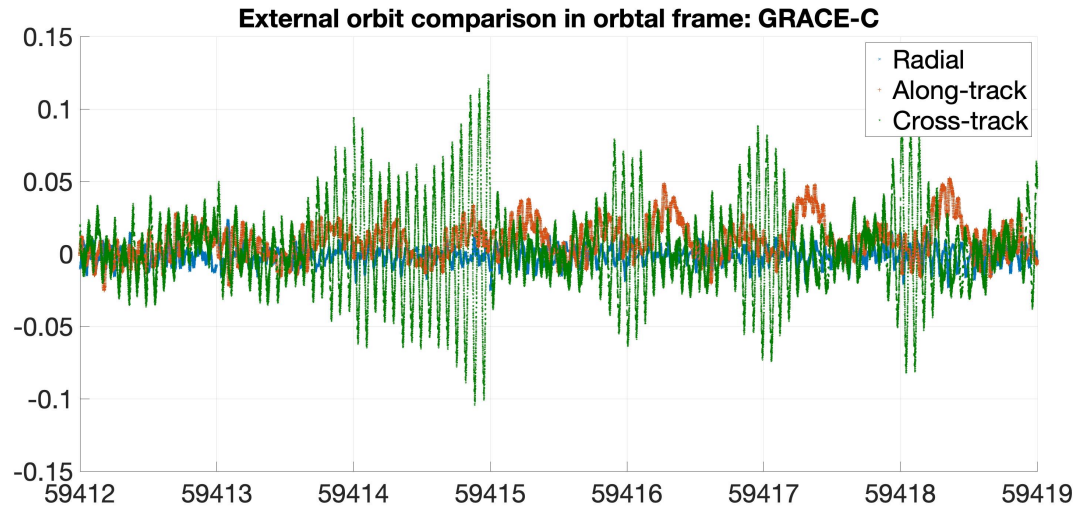


RMS: 8.8 mm

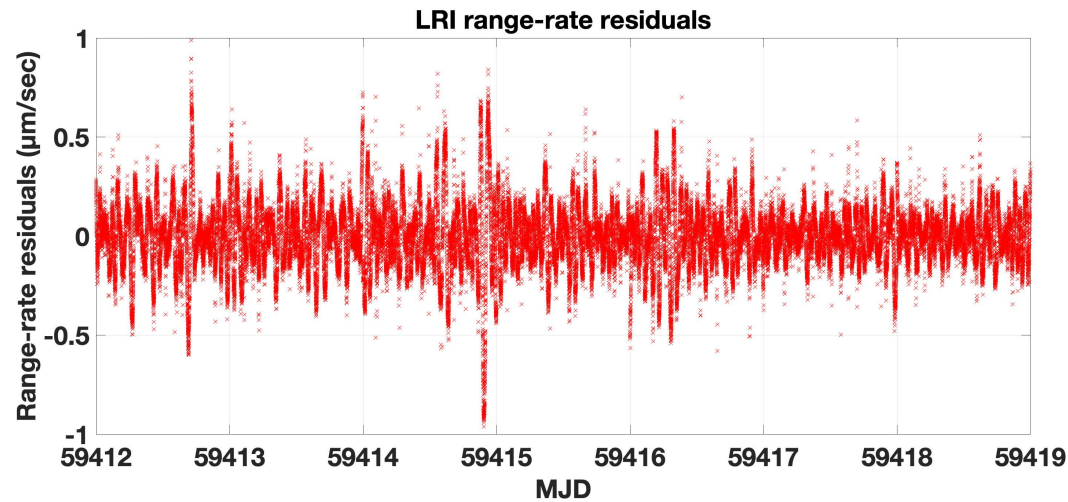


RMS: 9.7 mm

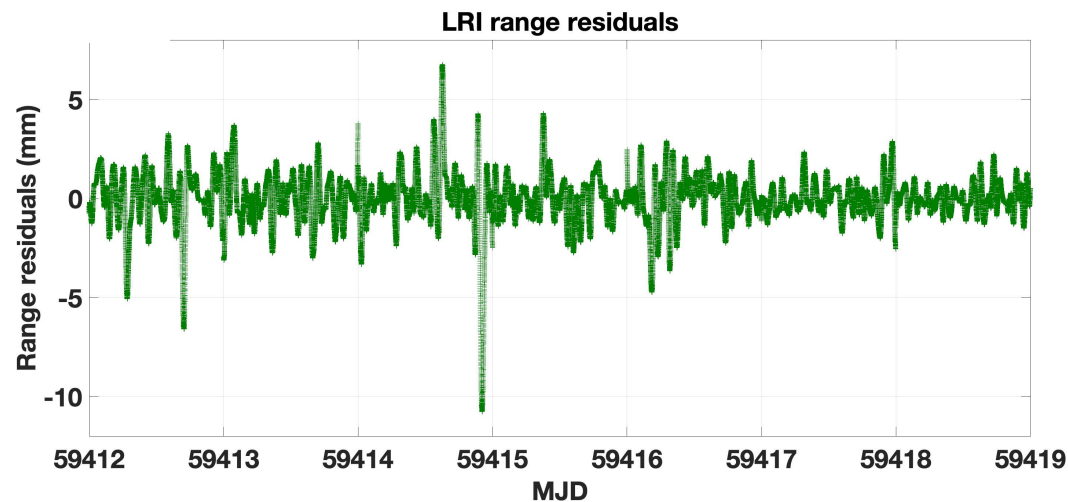
GRACE-FO external orbit comparison



GRACE-FO LRI range & range-rate data



RMS: 1.5 $\mu\text{m}/\text{sec}$



RMS: 1.3 mm

GEORB

GEORB (GEodetic ORBit analysis)

- Precise Orbit Determination of LEOs
- Data analysis of satellite gravity missions (GRACE-FO, GRACE, GOCE)
- Orbit Design of future satellite missions
- References: Papanikolaou (2022; 2012), Papanikolaou and Tsoulis (2018)
- Release as open source (<https://github.com/Thomas-Loudis/georb>)

Summary and Future steps

- GRACE-FO orbit determination (few mm to cm)
- Accelerometer calibration modelling (calibration parameters and empirical bias accelerations per revolution)
- LRI range-rate residuals at few $\mu\text{m}/\text{sec}$
- LRI range-rate to be applied as observations (preliminary results show improvement)
- LRI range-rate as constraints of the accelerometer calibration parameters over the along-track (and normal track) direction

Thank you for your attention