Handling of non-gravitational accelerations on a Callisto orbiter for orbit and gravity field determination

W. Desprats (1), D. Arnold (1), M. Blanc (2), A. Jäggi (1), M. Li (3), L. Li (3), and O. Witasse (4)
(william.desprats@aiub.unibe.ch)

(1) Astronomical Institute, University of Bern, Switzerland, (2) IRAP, Toulouse, France,
(3) NSSC, CAS, Beijing, China, (4) ESTEC, European Space Agency, Noordwijk, The Netherlands.

Introduction and Background

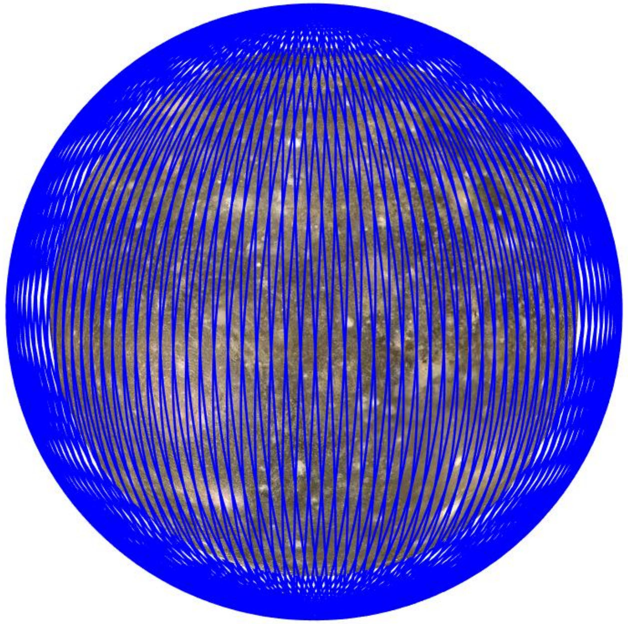
- Gan De is a Chinese exploration mission currently under study by the National Space Science Center (NSSC), Chinese Academy of Science (CAS). The mission would fly to Jupiter in the 2030’s. An orbiter would be injected into a Low Callisto Orbit to perform an extensive characterization of its surface and interior, investigate its degree of differentiation and search for the possible existence of an internal ocean.

- After an extended tour of the Jupiter system, the probe will inject into a low altitude polar and circular orbit around Callisto. Different orbit scenarios are currently under investigation. In this study, we will focus on a 5:731 Repetitive Ground Track Orbit (RGTO).

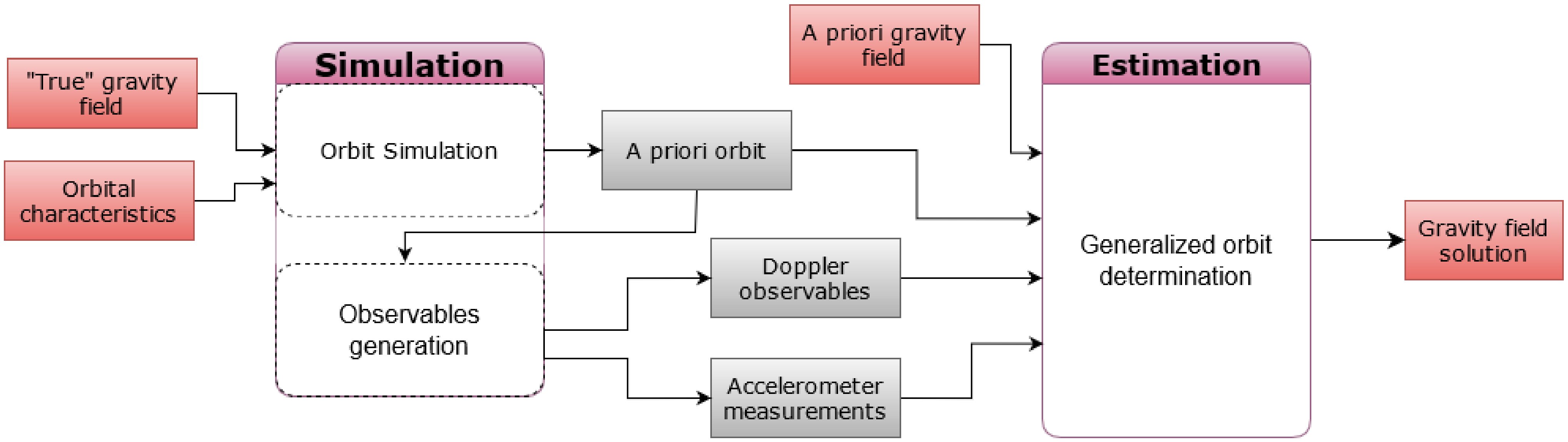
- The ground tracks of this RGTO repeat after 5 Callisto days (83.35 days), and within this period, the probe would have completed 731 orbit revolutions around Callisto.

- With these reference orbit, we were able to take into account regular manoeuvres approx. every Callisto day ($\simeq$6 m/s) to counteract the natural decay of the probe

- Using simulated radio tracking data from the orbiter, we analysed the recoverability of Callisto gravity field. We set the focus to non-gravitational accelerations and their handling in terms of orbit parameters or accelerometer.



Simulation study flowchart



- Orbit propagations in a full force model, as well as the whole gravity field recovery process were done using a development version of the Bernese GNSS Software.
- Unless specified otherwise, the gravity field coefficients are freely estimated in one iteration using true gravity field as a priori

Force model and synthetic gravity field

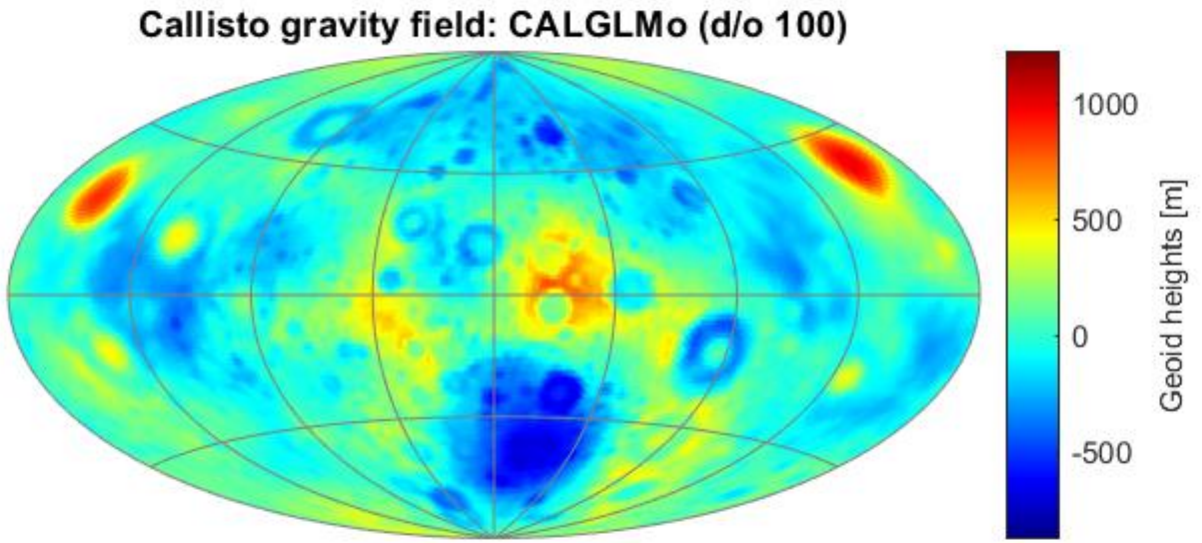
Force model:

- **Callisto:**
  - Synthetic gravity field
  - Tides (k_2=0.3)
- **Jupiter:**
  - Point mass
  - Zonal coefficient (J2 to J6)
- **Other 3rd body:**
  - Other Galilean moons
  - Sun
  - Other planets
- **Non gravitational acc. (NGA)**:
  - Direct Solar radiation pressure (SRP)
  - Planetary radiation pressure (PRP)

Synthetic gravity field:

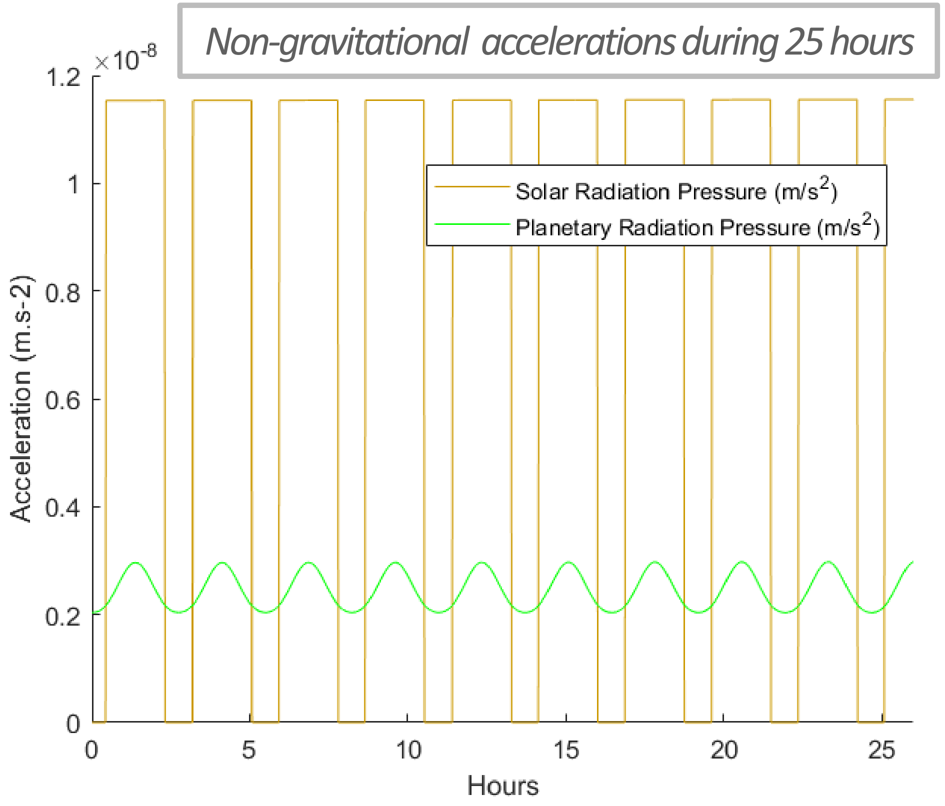
$$V(r,\lambda,\phi) = \frac{GM}{r}\sum_{n=2}^{n_{max}}\sum_{m=0}^{n}\left(\frac{R_e}{r}\right)^n P_{nm}(sin\phi)(C_{nm}cosm\lambda + S_{nm}sinm\lambda)$$

- Up to degree and order 2: from Galileo mission
- From d/o 3 to 100: Scaled Moon’s gravity field



Observables generation

- **Mission characteristics:**
  - Starting date: 01-05-2031
  - Mission duration: 90 days
  - β_{Earth}: 45° (angle between orbital plane and Earth)
  - Altitude: 200 km
  - Inclination: 89°
  - Orbital period: 165 min

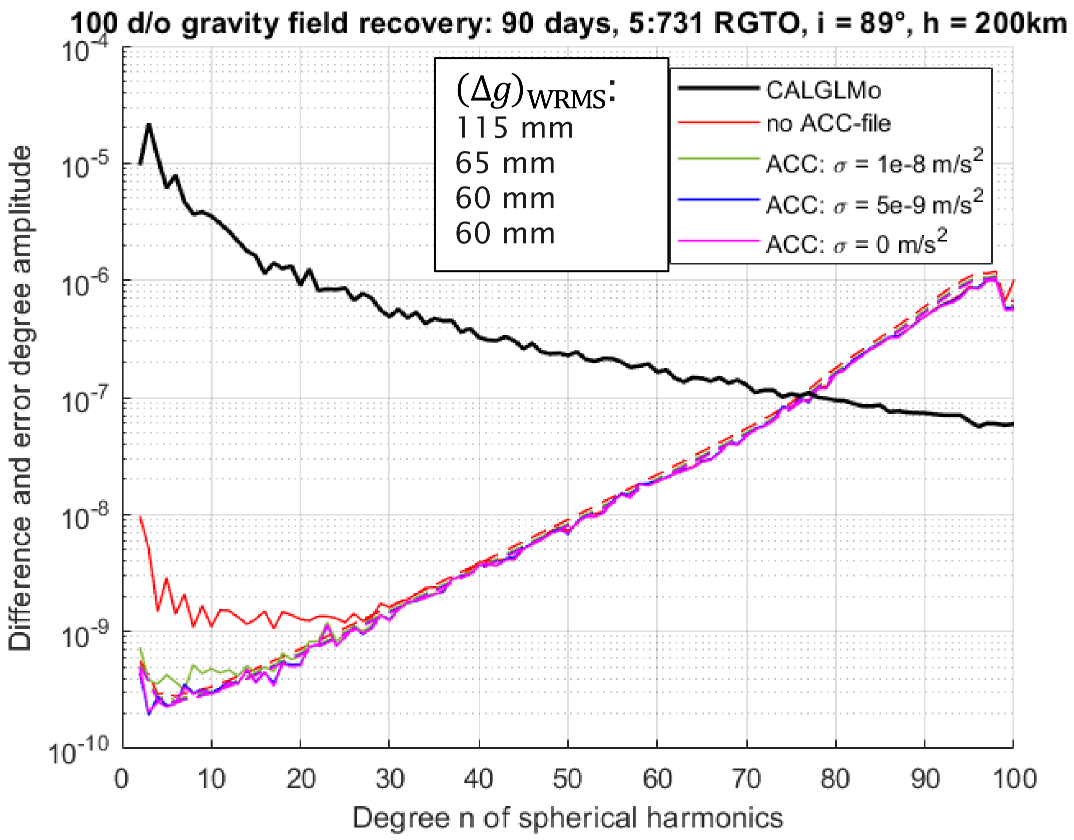


- **2-way Ka-band Doppler**:
  - Detailed noise model (incl. solar plasma):
    - σ (τ=60s) < 0.05mm/s
  - Observation time from Deep Space Network (DSN)
    - 16h/day (DSN fully available)
    - 8h/day (more realistic)

- **Satellite model (cannonball):**
  - Mass = 1500 kg
  - Cross section = 100 m^2
  - Diffuse reflectivity = 0.12

- **Accelerometer model:**
  - Data generated from evaluating SRP and PRP at 1s sampling
  - Additive white noise:
    - $\sigma = 1 \times 10^{-8}$ m/s^2 (Italian Spring Accelerometer)
    - $\sigma = 5 \times 10^{-9}$ m/s^2
  - Scaling factor and bias not considered yet

Gravity field and k2 Love number recovery using ACC data



16h/day cumulated observations on average

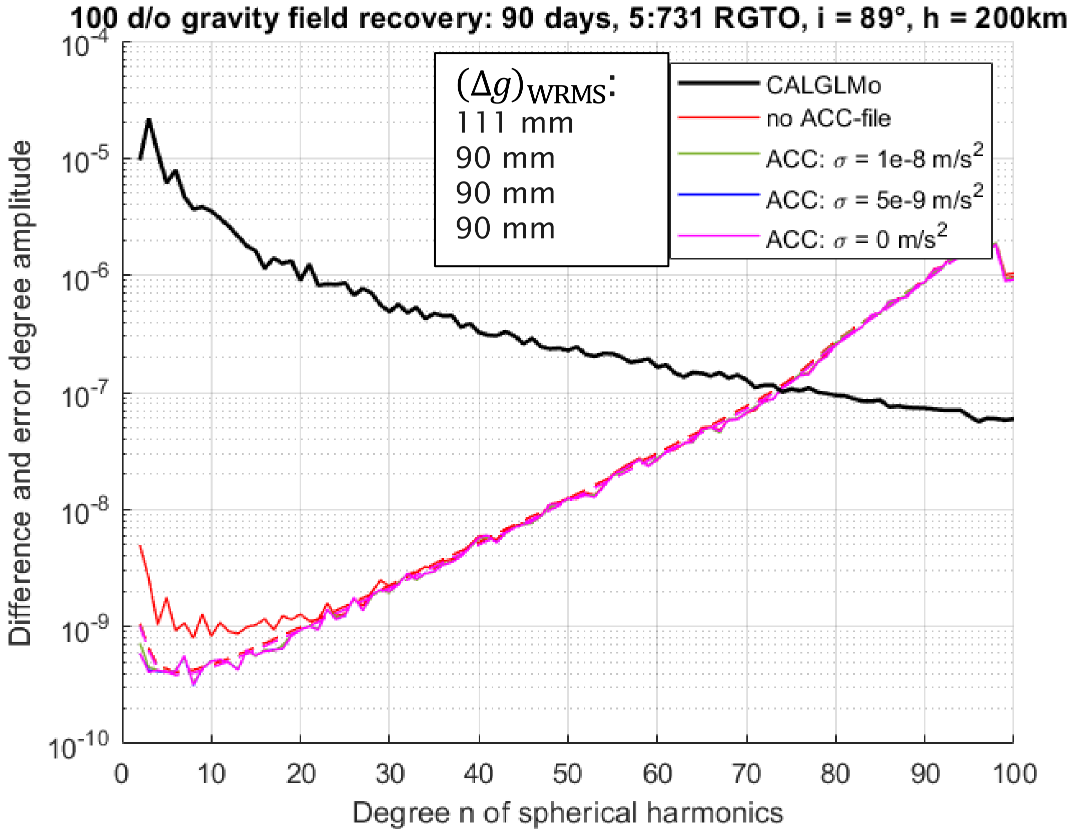
- No modelling of the NGA is detrimental for the low degree gravity field coefficients
- Considered NGA magnitude is at the level of the accuracy of the current state-of-the-art planetary accelerometer from the Italian Spring Accelerometer (ISA) ($1x10^{-8}$ m/s^2)
- Increasing the accelerometer accuracy would improve the recovery of the low-degree gravity field
- Love number k2 formal error : $2{,}1x10^{-6}$

Difference (solid) and error(dashed) degree amplitudes ($M_n = \sqrt{\frac{\sum_{m=2}^{n}(\Delta\bar{C}_{nm}^2+\Delta\bar{S}_{nm}^2)}{2n+1}}$).

Weighted RMS of geoid height differences (up to d/o 30):

$$(\Delta g)_{WRMS} = \sqrt{\frac{\sum_{\theta,\phi}\cos(\theta)\,\Delta g_{\theta,\phi}^2}{\sum_{\theta,\phi}\cos(\theta)}}$$

Gravity field recovery using ACC data



8h/day cumulated observations on average

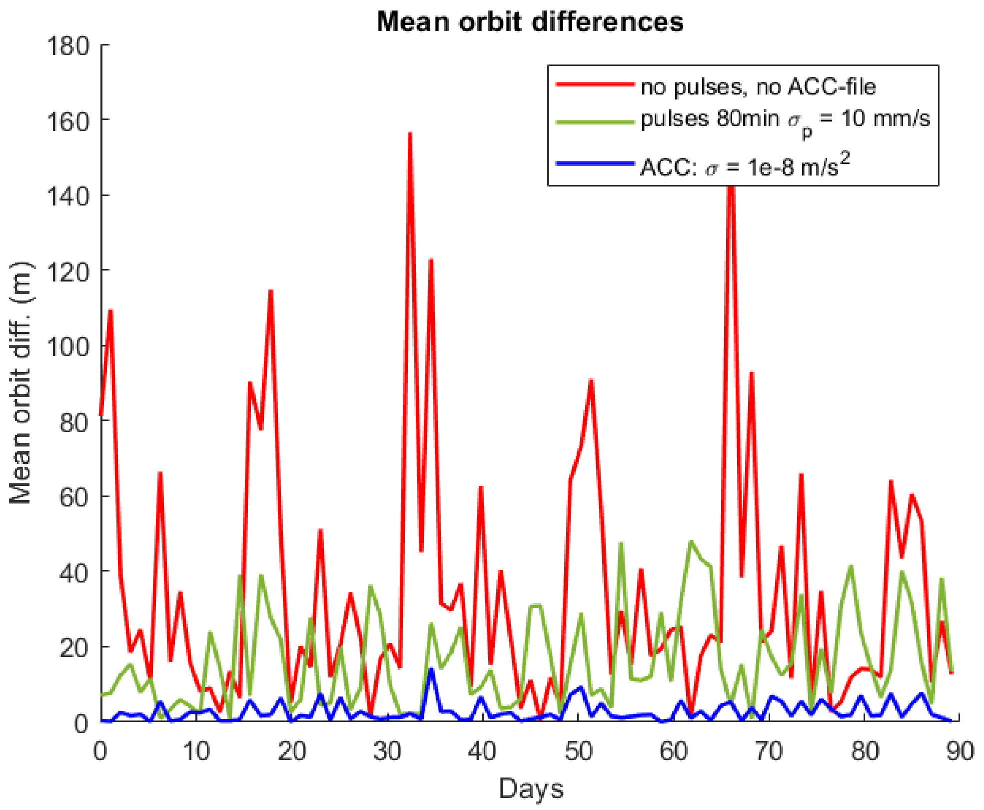
- With the more realistic observation schedule, increasing the accuracy of the accelerometer, would not really improve the gravity field solution

Difference (solid) and error(dashed) degree amplitudes ($M_n = \sqrt{\frac{\sum_{m=2}^{n}(\Delta\bar{C}_{nm}^2+\Delta\bar{S}_{nm}^2)}{2n+1}}$).

Weighted RMS of geoid height differences (up to d/o 30):

$$(\Delta g)_{WRMS} = \sqrt{\frac{\sum_{\theta,\phi}\cos(\theta)\,\Delta g_{\theta,\phi}^2}{\sum_{\theta,\phi}\cos(\theta)}}$$

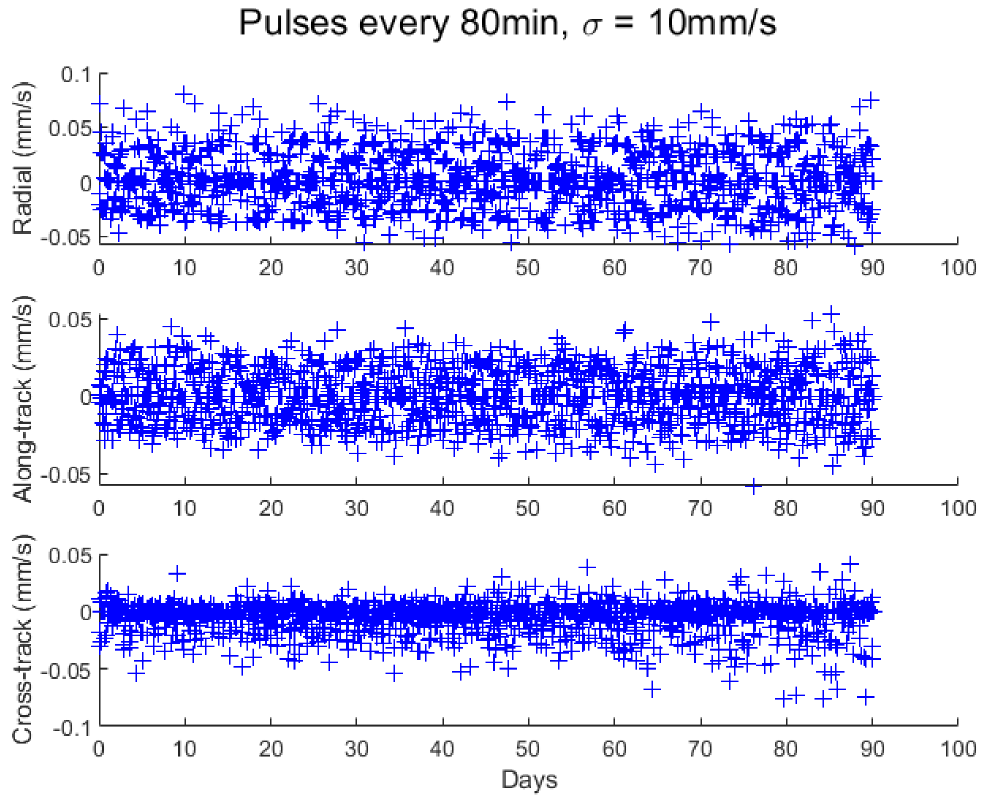
Orbit determination using pseudo-stochastic parameters



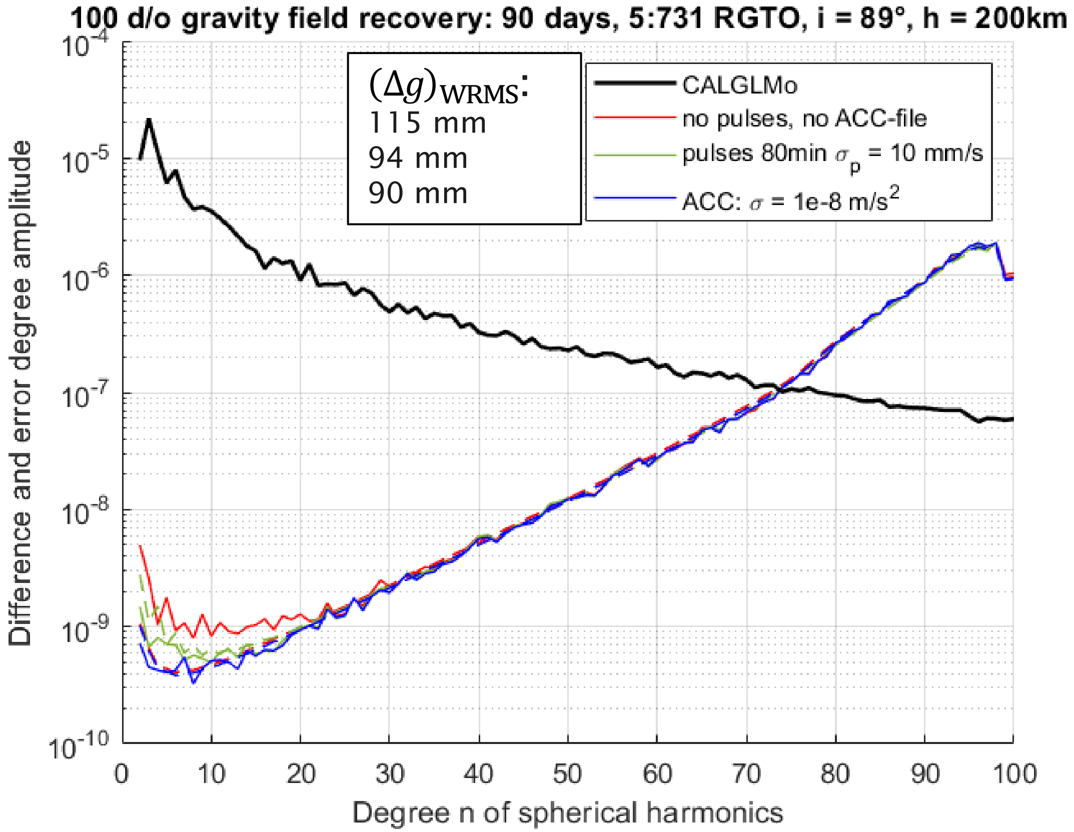
Average orbit distance between the simulated reference orbit, and the final estimated orbit for each 25h arcs.

<u>8h/day cumulated observations on average</u>

- The use of pulses (change in velocity) requires a fine tuning of the pulses characteristics (spacing and constraints), but can make up for the lack of an on board accelerometer.



Gravity field recovery using pseudo-stochastic parameters



Difference (solid) and error(dashed) degree amplitudes ($M_n = \sqrt{\frac{\sum_{m=2}^{n}(\Delta\bar{C}_{nm}^2 + \Delta\bar{S}_{nm}^2)}{2n+1}}$).

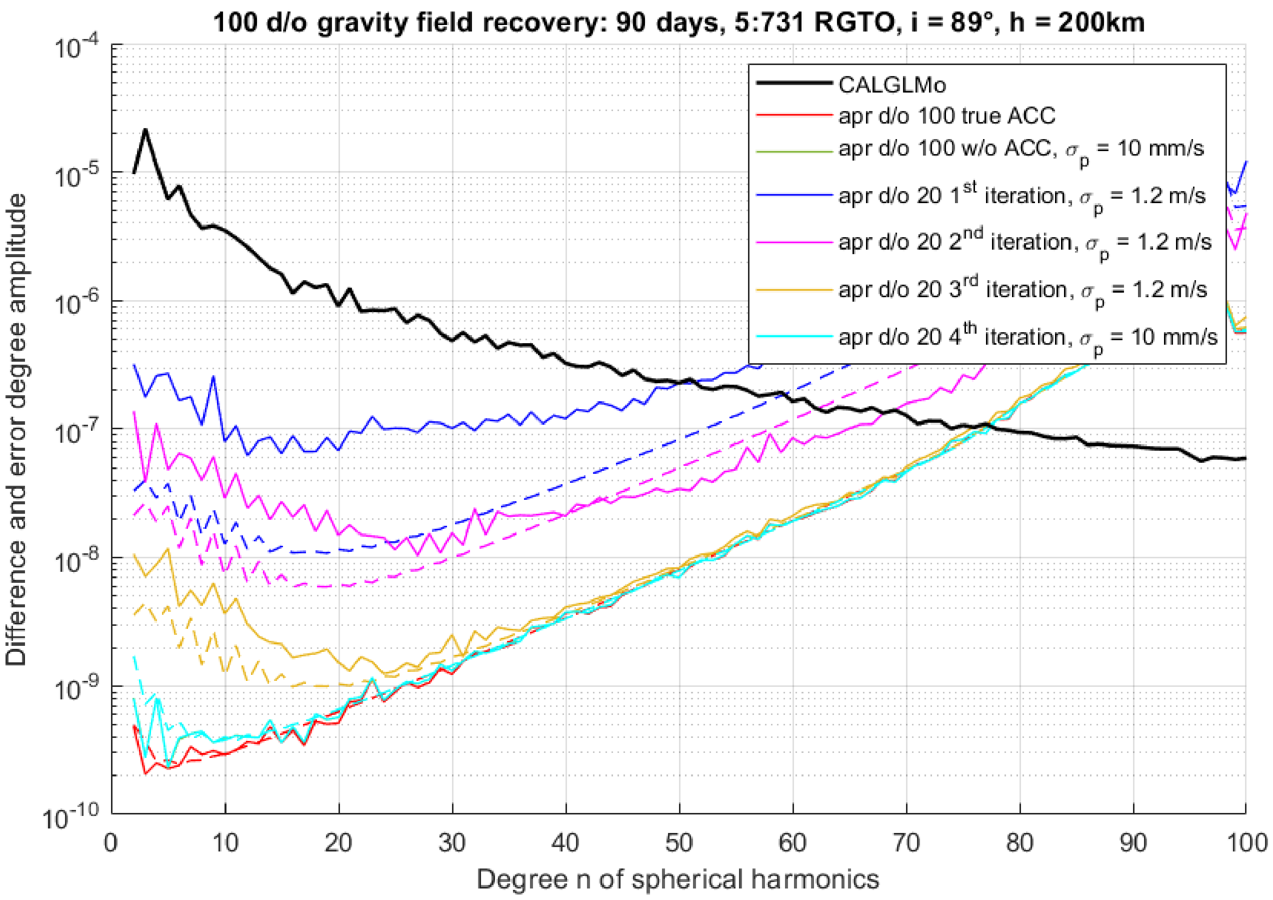
<u>8h/day cumulated observations on average</u>

- Pulses may absorb low degree gravity field signal. But with appropriate constraints, the gravity field can be still properly estimated.
- An on-board accelerometer would prevent this, and increase the quality of the recovered gravity field.

Weighted RMS of geoid height differences (up to d/o 30):

$$(\Delta g)_{WRMS} = \sqrt{\frac{\sum_{\theta,\phi} \cos(\theta)\, \Delta g_{\theta,\phi}^2}{\sum_{\theta,\phi} \cos(\theta)}}$$

Gravity field recovery starting from a degraded field



Difference (solid) and error(dashed) degree amplitudes. No accelerometer data were considered when starting from a d/o 20 gravity field. This would not change significantly the number of iterations.

- 16h/day cumulated observations on average.
- Starting from a degraded a priori gravity field, the use of pulses can help the orbit convergence.
- As an example, we considered the gravity field truncated to degree and order 20 as a priori. Higher d/o coefficients are estimated from 0.
- Using pulses with a very loose constraint (1,2 m/s) every 80 min, we iterated on the gravity field solution.
- In the last iteration, we tighten the constraints to absorb only the NGA deficiency.
- Final gravity field solution is very close to the solution when a true gravity field is considered as a priori.

Conclusions

- The low degree coefficients (up to d/o 30) of the estimated gravity field are affected by non-gravitational accelerations. But with the considered orbit and noise characteristics and mission duration the gravity field can still be estimated up to degree and order 75.
- An accelerometer would be beneficial to model non-gravitational accelerations. Considering the accuracy of the current state-of-the-art planetary accelerometer, the lowest degree gravity field are even better determined than with the pseudo stochastic parametrisation.
- Other non gravitational accelerations, such as propellant sloshing, can be larger than the considered NGA. Then, such an accelerometer would be even more beneficial.
- In case an accelerometer is not available, the use of pseudo-stochastic parameters (pulses), would still improve the gravity field solution. But the pulses characteristics would need to be carefully chosen, in order not to absorb too much of the gravity field signal.
- Stochastic pulses can also be a very useful tool to help the orbit converge when the a priori gravity field knowledge is very limited. After a few iterations on the gravity field, it can be correctly estimated.