PSD.1-0025-21
COSPAR-2021-Scientific Assembly
28 January - 4 February 2021, Sydney, Australia

Influence of Low Europa Orbit design on gravity field recovery

W. Desprats[1], S. Bertone[2,3], D. Arnold[1], A. Jäggi[1], M. Blanc[4]
[1] Astronomical Institute, University of Bern, Switzerland
[2] University of Maryland, Baltimore County, USA
[3] NASA Goddard Space Flight Center
[4] IRAP, CNRS-Université Paul Sabatier, Toulouse, France

Introduction

The characterization of Europa's surface and interior ocean and ice shell is key to explore the habitability of the fourth largest moon of Jupiter. Europa Clipper will largely contribute to our knowledge of Europa with multiple dedicated flybys. However, global mapping can only be significantly improved by means of an orbiter with high inclination and low altitude, as it will be done in the case of Ganymede by JUICE. This was the strategy of several mission proposals (Blanc et al. (2020)).

Having a spacecraft orbiting Jupiter moon Europa would enable a detailed recovery of Europa's gravity field, by means of spacecraft tracking data. But gravity field recovery is not the only science one could expect to be done with an orbiting spacecraft. There are other science objectives which might have different orbit requirements.

A specific difficulty in designing suitable orbits in the Jovian system is related to the orbit stability, which is highly impacted by the influence of Jupiter as a third body exerting strong perturbations on a Europa orbiter. This results in additional mission constraints for potential science orbits. Knowing the value of certain orbits for gravity field recovery will help the final trade off in the orbit selection process. This analysis has been performed based on closed-loop simulations using a development version of the Bernese (GNSS) Software (BSW).

Simulation Setup

In order to compare consistently the scientific value of each orbit, the following process has been carefully repeated for different scenarios. Each scenario can be defined with a reference orbit, and a starting point on this orbit (discussed later). For each scenario investigated, the reference orbit was propagated in the simulation environment of the BSW.

During this phase, we generated high precision 2-way, X-band Doppler tracking measurements (Moyer (2000)) along the orbit. The measurements generation took into account the 3 Deep Space Network stations (full coverage), planetary eclipses from Europa, Jupiter and the Sun, and Shapiro effect from the Sun and Jupiter. Gaussian white noise was added on these tracking data (σ_{obs} = 0.10 mm/s) and also on the initial state vector (σ_{pos} = 50 m, σ_{vel} = 1 mm/s) which constituted our first guess orbit in the orbit determination process. All the orbit scenarios started at the same date, which correspond to a favorable solar system configuration allowing us to neglected large variation of the solar plasma noise.

In this simulation study, we considered a perfect a priori knowledge of the force model. As part of this force model, we derived a synthetic gravity field for Europa: d/o 2 gravity field coefficients from Anderson et al. (1997), higher coefficients from the Moon's gravity field, up to d/o 50, with an appropriate scaling. In addition, solid tides were considered as well as the gravitational influence of the Sun, of the solar system planets, and of the other Galileans moons (DE430). As the influence of Jupiter is considerable, we also decided to integrate Jupiter's zonal gravity field coefficients, up to degree 6.

The orbital elements were estimated along a series of short arcs of about 28.4h length, which correspond roughly to a third of one Europan day. Following the Celestial Mechanics Approach (Beutler et al. (2010)), the normal equation established for the individual arcs were stacked for a total of 90 days to estimate the gravity field.

Orbit design

Repetitive Ground Track Orbits

The ground tracks of a m:R Repetitive Ground Track Orbits (RGTO) repeats after m Europan days (3.55 days), and within this period, the probe would have completed R revolution around Europa. It is beneficial for the observation of time varying phenomena on the ground surface, as repeated observations of a given point of the surface are ensured. With these reference orbits, we were also able to take into account regular manoeuvres to counteract the natural decay of the probe.

m	Number of days for a full cycle completion	Cycle intertrack (at equator) for 200km altitude RGTO
1	3.55 d	266 km
2	7.10 d	133 km
3	10.65 d	89 km
26	92.33 d	10 km

Table 1: RGTO have a constant minimum gap between the ground tracks at the equator (intertrack), which can be detrimental to the gravity field recovery. With m=26, there is no ground track repetition during the mission duration (90 days).

RGTO exists at all inclination. However, for each inclination, only a set of altitudes can be achieved. Based on the repetition rate, the inclination and the range of altitude, we used a polynomial approach (Cinelli et al. (2015)) to compute the approximate orbital elements of a given RGTO. Then we performed a differential correction to compute a fully repetitive orbit. This orbit computation was done using Hill model [ref], which takes into account the influence of Europa and Jupiter as a mass point, and the effect of Europa's J2 and C22.

Earth beta angle

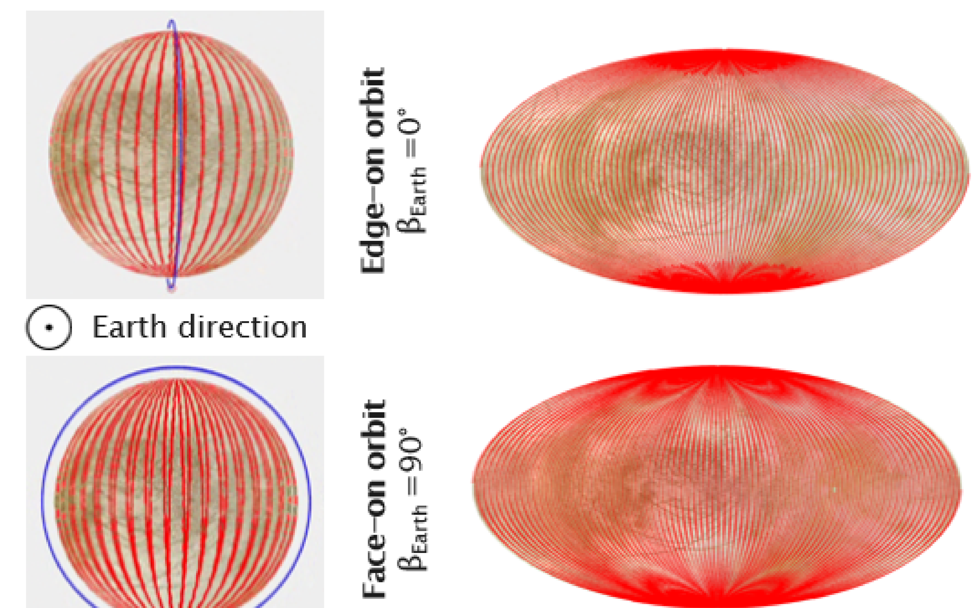

Figure 1: Left: 2:79 RGTO (blue) and ground tracks (red), seen from Earth, when the probe is visible from Earth. **Right**: Ground coverage of Europa in the two β_{Earth} configurations.

The angle between the orbital plane of the probe and the Earth direction (β_{Earth}) plays an important role in gravity field recovery. Nearly half of the observations can't be tracked by Doppler observations with a completely edge-on orbit ($\beta_{Earth} = 0°$), when the spacecraft is behind Europa with respect to Earth, and this highly affects the ground coverage. But with a completely face-on orbit (β_{Earth} = 90°), the sensitivity of the gravity signal along the line of sight is at stake.

In order to investigate its influence, we decided to consider scenarios where the β_{Earth} range is limited during the mission . β_{Earth} variation is $\dot{\beta}_{Earth} = \dot{\Omega}_E + \dot{\Omega}$. The Earth elongation Ω_E from Europa is approximated to the Earth elongation from Jupiter. Due to the relative short mission duration, and because of the favorable solar system configuration, we can approximate $\dot{\Omega_E}$ to be constant and equal to 0.1°/day. The RAAN variation $\dot{\Omega}$ is proportional to the inclination cosine. For near circular orbit, with an altitude between 100km and 200km, $\dot{\Omega} \in$ [-0.74, 0.74] °/day. We can find orbits for which $\dot{\Omega} \approx -\dot{\Omega_E}$, thus with a low-varying β_{Earth} angle.

At different orbit inclination, the larger range of β_{Earth} influence was also considered (see Fig. 5). To investigate the influence of this parameter, we chose different starting point within the complete cycle, but with an identical starting date, thus different initial β_{Earth}.

Results

Repetition rate and Earth beta angle

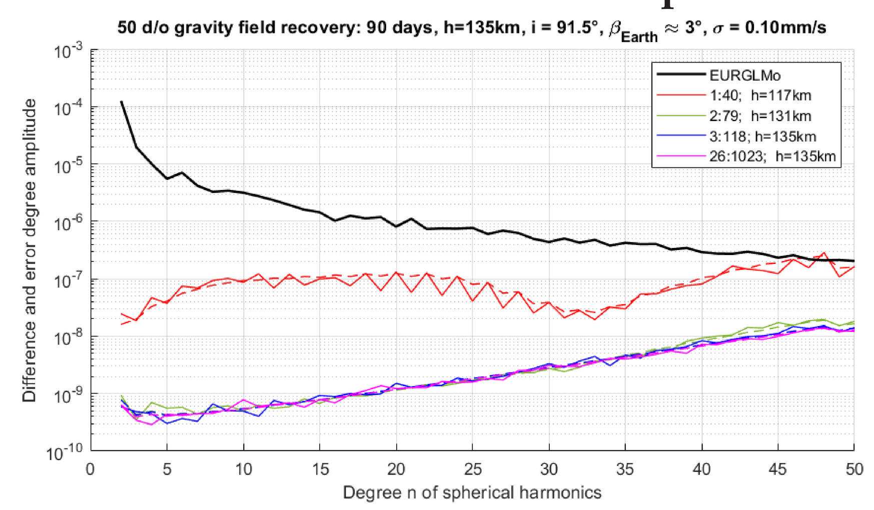

Figure 2: Synthetic gravity field (EURGLMo) as a reference. Difference (solid) and error (dashed) degree amplitudes. When the ground coverage is too sparse (m=1), the number of visible ground tracks is more important than the sensitivity of the gravity signal along the line of sight..

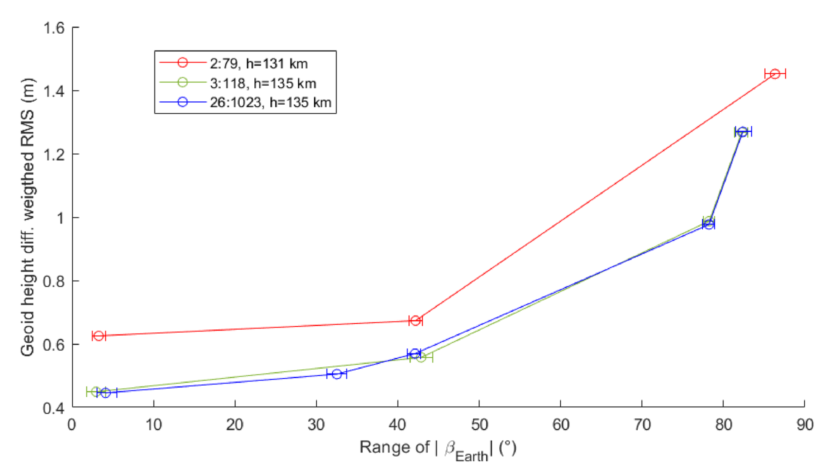

Figure 3: Weighted RMS of geoid height differences as a function of β_{Earth}. 3:118 and 26:1023 RGTO lead to a very similar d/o 50 gravity field solution. Generally, one should avoid a face-on orbit (β_{Earth} = 90°). The gravity field solution is clearly worse.

Influence of the inclination

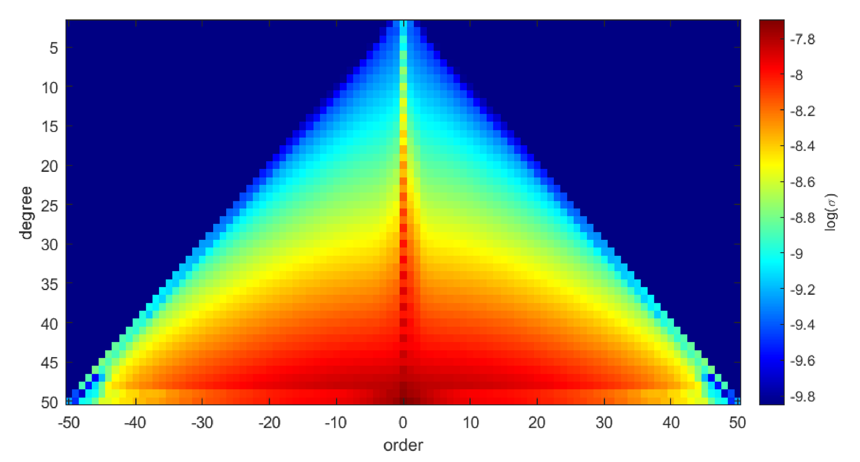

Figure 4: Formal errors of the gravity field solution recovered from a 3:118 RGTO (h=128km, i=80°, β_{Earth} =-31.8° ±36.2°). A non-polar orbit have an unobserved gap in the polar regions of the celestial body. Thus, the low order gravity field coefficients will be degraded in comparison with the use of a polar orbit.

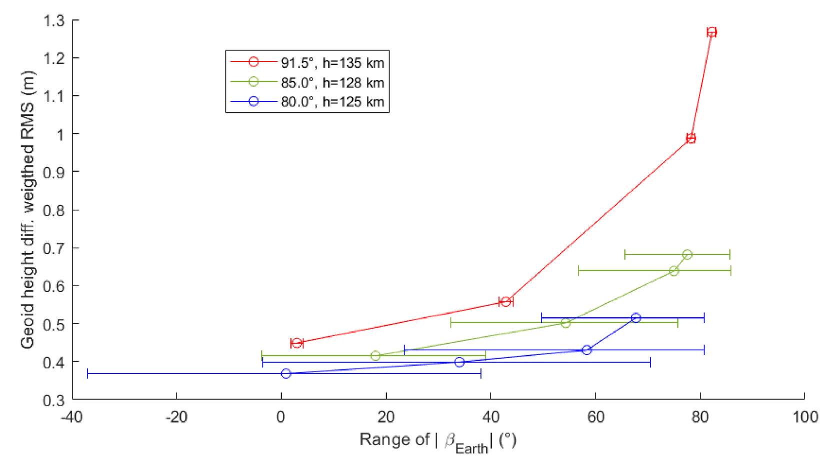

Figure 5: Weighted RMS of geoid height differences. The horizontal bars represent the range of β_{Earth} during the 90 days mission. Note that the altitude of the orbits play a large role here.. Similarly to Fig.3, a face-on orbit configuration is detrimental to the gravity field recovery.

Influence of altitude

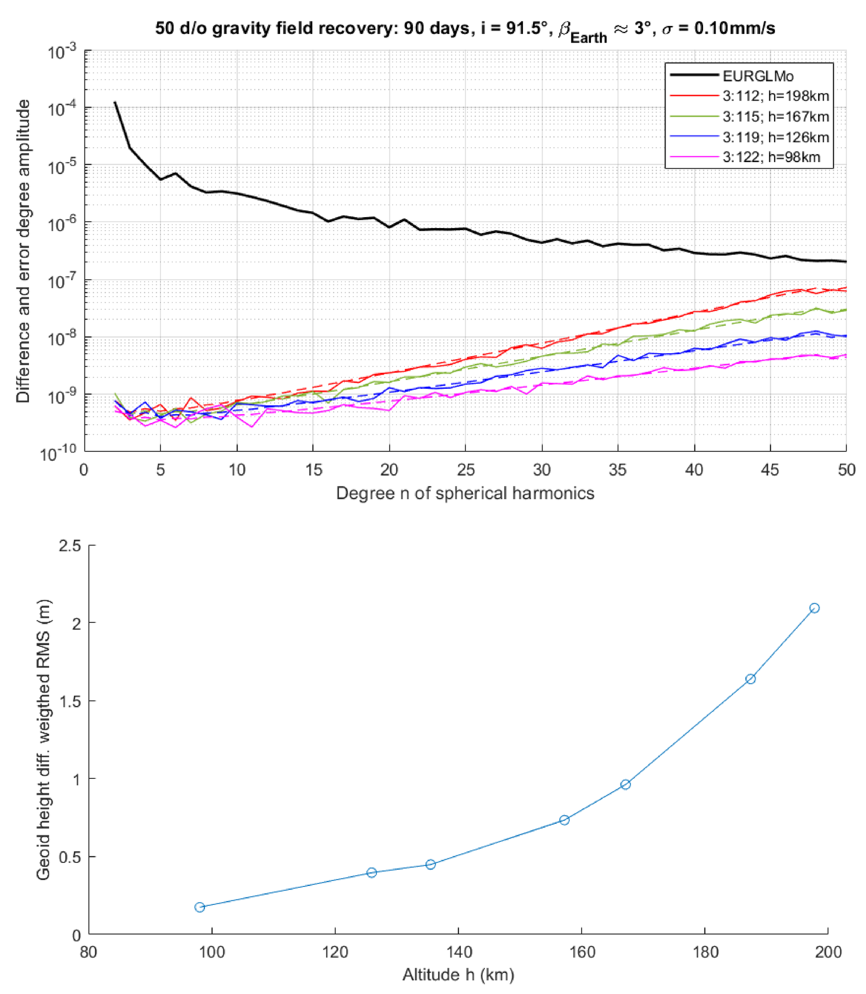

Figure 6: Gravity field solution for orbits with different inclination with m=3 and β_{Earth} close to 0° during the 90 days. **Left**: Synthetic gravity field (EURGLMo) as a reference. Difference (solid) and error (dashed) degree amplitudes. **Right**: Weighted RMS of geoid height differences. One could expect to recover a gravity field up to a degree and order more than 50.

Difference degree amplitude: $M_n = \sqrt{\frac{\sum_{m=2}^{n}(\Delta\overline{C}^2_{nm}+\Delta\overline{S}^2_{nm})}{2n+1}}$.

Weighted RMS of geoid height differences $\sqrt{\frac{\sum_{\theta,\phi}\cos\theta\Delta g^2_{\theta,\phi}}{gridsize}}$.

Summary

- The use of a RGTO whose ground tracks repeats after enough time (m=>3) is not detrimental to a 50 d/o gravity field recovery, but the case m=1 is to be avoided.
- The lower the orbit altitude is, the better the gravity field can be recovered, but they require more orbit maintenance.
- The influence of β_{Earth} should not be neglected. An edge-on orbit ($\beta_{Earth} = 0°$) during the whole mission is optimal, but as long as one avoid a face-on orbit ($\beta_{Earth} = 90°$), the quality of the recovery is reasonable.
- The polar gap from non polar orbits degrades the low order gravity field coefficients recovery.

Acknowledgements

Calculations were performed on UBELIX (http://www.id.unibe.ch/hpc), the HPC cluster at the University of Bern. This study has been funded with the support of the Swiss National Foundation (SNF).

Poster compiled by W. Desprats, December 2020
Astronomical Institute, University of Bern, Bern
william.desprats@aiub.unibe.ch

References

Anderson et al., 1997 *Europa's differentiated internal structure: Inferences from two Galileo encounters*. Science 276.5316: 1236-1239.
Beutler et al., 2010 *The celestial mechanics approach: theoretical foundations*. J Geod 84:605-624
Blanc et al., 2020 *Joint Europa Mission (JEM): a multi-scale study of Europa to characterize its habitability and search for extant life*. Planetary and space science 193: 104960.
Cinelli et al., 2015: *Polynomial equations for science orbits around Europa*. Celestial Mechanics and Dynamical Astronomy 122.3:199-212.
Moyer, 2000 *Formulation for Observed and Computed Values of Deep Space Network Data Types for Navigation*. JPL Publications

Contact address

William Desprats
Astronomical Institute, University of Bern
Sidlerstrasse 5
3012 Bern (Switzerland)
william.desprats@aiub.unibe.ch