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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).



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 ($\beta_{Earth} = 90^{\circ}$). The gravity field solution is clearly worse.



Influence of the inclination

Range of $|\beta_{\text{Earth}}|$ (°) **Figure 4:** Formal errors of the gravity field solution recovered **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.

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.

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Influence of Low Europa Orbit design on gravity field recovery

Simulation Setup

In order to compare consistently the scientific value of orbit (discussed later). For each scenario investigated, d/o 2 gravity field coefficients from Anderson et al. environment of the BSW.

During this phase, we generated high precision 2-way, influence of the Sun, of the solar system planets, and X-band Doppler tracking measurements (Moyer (2000)) of the other Galileans moons (DE430). As the influence along the orbit. The measurements generation took into of Jupiter is considerable, we also decided to integrate account the 3 Deep Space Network stations (full cov- Jupiter's zonal gravity field coefficients, up to degree 6. erage), planetary eclipses from Europa, Jupiter and the sian white noise was added on these tracking data (σ_{obs} short arcs of about 28.4h length, which correspond 50 m, $\sigma_{vel} = 1 \text{ mm/s}$) which constituted our first guess Celestial Mechanics Approach (Beutler et al. (2010)), scenarios started at the same date, which correspond to were stacked for a total of 90 days to estimate the grava favorable solar system configuration allowing us to ity field. neglected large variation of the solar plasma noise.

each orbit, the following process has been carefully re- In this simulation study, we considered a perfect a pripeated for different scenarios. Each scenario can be de- ori knowledge of the force model. As part of this force fined with a reference orbit, and a starting point on this model, we derived a synthetic gravity field for Europa: the reference orbit was propagated in the simulation (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

Sun, and Shapiro effect from the Sun and Jupiter. Gaus- The orbital elements were estimated along a series of = 0.10 mm/s) and also on the initial state vector (σ_{pos} = roughly to a third of one Europan day. Following the orbit in the orbit determination process. All the orbit the normal equation established for the individual arcs

Results





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 =

Weighted RMS of geoid height diffe

References

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

erences $\sqrt{\frac{\sum_{\theta,\phi} \cos \theta \Delta g_{\theta,\phi}^2}{gridsize}}.$

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	Cycle intertrack (at equate
	a full cycle completion	for 200km altitude RGTC
1	3.55 d	266 km
2	7.10 d	133 km
3	10.65 d	89 km
26	92.33 d	10 km

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 ($\beta_{Earth} = 0^\circ$), when the spacecraft is behind Europa with respect to Earth, and this highly affects the ground coverage. But with a completely face-on orbit $(\beta_{Earth} = 90^{\circ})$, 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 $\hat{\Omega}_E$ to be constant and equal to 0.1°/day. The RAAN variation $\hat{\Omega}$ 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 $\dot{\Omega} \approx -\Omega_E$, 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} .

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.

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Orbit design



 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).

- The influence of β_{Earth} should not be neglected. An edge-on orbit ($\beta_{Earth} = 0^{\circ}$) during the whole mission is optimal, but as long as one avoid a faceon orbit ($\beta_{Earth} = 90^{\circ}$), the quality of the recovery is reasonable.
- The polar gap from non polar orbits degrades the low order gravity field coefficients recovery.

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