Introduction

In recent years several studies, publications and projects dealt with future gravity mission studies for time variable gravity field recovery of the successive era of GRACE and GRACE-FO. Besides improved satellite and sensor technology (e.g. laser interferometry, drag-free systems) sophisticated satellite formations and multi-satellite formations indicate a great potential for improving sensitivity and isotropy and mitigating aliasing effects. Especially pendulum formations and Bender constellations, which consist of two inline satellite pairs – one on a near polar orbit and the other on an inclined orbit (Figure 1) – showed very promising results. Since pendulum formations are regarded as hardly feasible due to serious technological problems (e.g. large range rates and high precision active satellite pointing) the Bender constellations which make use of mature-inlne formations are regarded as an appropriate choice. In addition, the Bender constellation outperforms the pendulum design (i) in the low degree spherical harmonics ($l < 25-40$) and (ii) in the spatio-temporal sampling due to the double tandem design (i.e. observability of short time interval solutions, e.g. 3 days or shorter). Simulation studies show that Bender constellations can lead to improvements of a factor of 5-10 compared to the standard inline formation. Due to the great potential of Bender scenarios ESA called for the project “Assessment of Satellite Constellations for Monitoring the Variations in Earth’s Gravity Field”

Objectives

Main objective

1. Assessment of Bender constellations for optimal time-variable gravity field retrieval and monitoring of mass distribution and transport.

Secondary objectives

1. Consolidate science and mission requirements for a Next Generation Gravity Mission
2. Optimization of orbit design and spatio-temporal sampling
3. Exploitation of gravity retrieval methods that reduce temporal and spatial aliasing.
4. Investigation of post-processing methods dedicated to Bender scenarios that reduce anisotropic errors
5. Establish an error budget for the post-processed time-variable gravity field models.

The structure of the project team and its competence related to the objectives and workflow of the project are displayed in Figure 2.

Structure and competence of the consortium

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Figure 4: repeat mode selection from figure of merit based on homogeneity of groundtrack gap evolution

The result of the GA (Figure 5) indicates a high stability of the SCs’ fitness values w.r.t. the choice of SC parameters. Most of the variations within the grey band are caused by $\Omega_d$ optimum at $90^\circ$ and $240^\circ$ while the fitness is insensitive to $\Omega_m$. Since $\Omega_d$ is changing during the mission lifetime due to the nodal drift of the inclined pair the fitness of a SC will vary during the mission lifetime, too.

Science and Mission Requirements

Consolidated science and mission requirements for a future gravity mission are defined, including the figures of merit (Figure 3) for applications in geosciences. The impact of the identified science and missions requirements on applications in geosciences is summarized in the figures of merit (Figure 3) as well as the gain compared to state-of-the-art GRACE solutions

Mission Requirements

1. The NGGM shall deliver global observations between $90^\circ$ and $-90^\circ$ latitudes where small deviations within 1° are allowed.
2. The NGGM shall deliver observations for at least 11 years covering one solar cycle such that related effects can be observed for a complete cycle.
3. The NGGM shall observe the geoid with 1 mm accuracy at 3 days intervals with 500 km spatial resolution and at 10 days intervals with 150 km spatial resolution.
4. For modelling tides based on a long term data set, the NGGM orbit shall be chosen such that the constituents can be decoded by taking into account aliasing periods.

Optimization of satellite constellation

In order to reduce the enormous space an orbit and satellite constellation (SC) parameters a dedicated selection strategy is applied. In the first step the search space is reduced based on (i) experience from previous studies and (ii) Quick-Look/Reduced-Scene Tool (QLT/RST) simulations. In the second step a genetic algorithm (GA) is applied to the remaining search space.

The identified search space from step 1 consists of:

- repeat mode (l/p) of each pair for $h < 340$ km (from air drag considerations)
- inclination $I_1$ of polar pair between $88^\circ$ and $92^\circ$ (avoiding polar gap)
- inclination $I_2$ of inclined pair within $65^\circ$ – $75^\circ$ or $115^\circ$ – $125^\circ$ (from semi-analytic QLT and RST)
- $\Omega_d$ and $\Omega_m$ between both pairs
- inter-satellite distance $\Delta$ between 75 - 100 km (from semi-analytic QLT and technical constraints)

In addition to the GA the homogeneity of the groundtrack gap evolution can be used as criteria for optimum repeat mode selection (Figure 4). Repeat orbits with a homogeneous gap evolution should be favoured and large unobserved gaps should be avoided.

Figure 6: result from genetic algorithm (left) and dependence of solution on $\Omega_d$ and $\Omega_m$ (right); results based on 10 day solutions up to maximum degree $L_{\max} = 100$

Figure 7: standard processing vs. WASe approach (daily fields up to degree $L = 10$), initial formation, hydrological aliasing only

References & Acknowledgement

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