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Gravity Field Simulator for the Evaluation of Future Gravity Field Mission Concepts

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Introduction

Shortcomings of currently operated satellite gravity missions and the geophysical signals derived from the resulting gravity field models can be attributed to several issues: the specific characteristics of the measurement signal and its error (covariance) structure, superposition of different geophysical signals, the specific orbit configuration and the related space and time resolution leading to aliasing effects. Many of these limitations can be reduced by satellite formations, i.e., a constellation of several satellites orbiting in parallel.

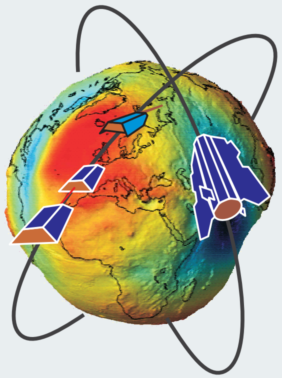
For the design of future gravity field mission concepts, the investigation of the specific characteristics of different formation concepts and their potential to reduce the above-mentioned problems is of great importance. Therefore, a numerical test environment is set up, which allows to investigate the specific characteristics of different formation concepts under simplified, but still realistic conditions.

Simulator Architecture

Meas. concepts & Gravity field functionals

The gravity field simulator generates observation time series for the most commonly used observation concepts and gravity field functionals:
- GPS-SST (potential, accelerations, ...);
- inter-satellite tracking (ranges, range rates);
- gradiometry.

The observation time series are defined along arbitrary orbits (realistic orbits, ideal repeat orbits). Optionally, realistic stochastic models and noise time series are applied.



Gravity Field Signals

Gravity field signals which can be synthetized include:
- static gravity field models
- direct and solid Earth tides
- ocean tides
- non-tidal temporal variation signals (hydrology, ocean, cryosphere, atmosphere).

Correspondingly, also aliasing problems (related to periodic and non-periodic temporal variation signals) and signal separation problems (contribution by individual geophysical sources) can be investigated.

Gravity Field Recovery

In this closed-loop environment, gravity field models are recovered from the observation time series, applying either a rigorous adjustment, or a block-diagonal approximation (in the case of ideal repeat orbits).

Numerical Case Studies

Exemplarily, the simulator shall be applied to demonstrate the benefit of satellite formations. This is done in an extremely simplified environment: the observation type is the gravitational potential, which is measured noise-free along ideal repeat orbits.

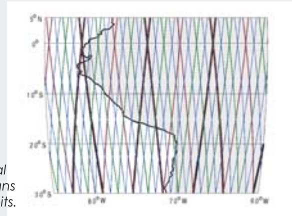


Fig.2: Improving spatial resolution by means of interleaved orbits.

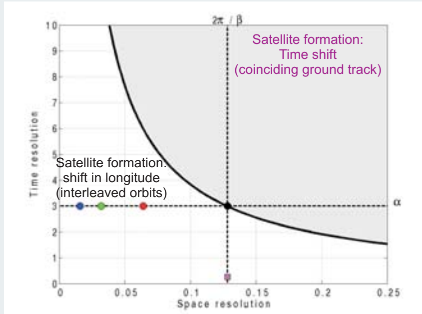


Fig.1: Resolution space of a repeat orbit of α days and β revolutions (after: Sneeuw, 2007).

Fig. 1 shows the resolution space for an ideal repeat orbit of α days and β revolutions. The product of space and time resolution is constant, i.e., a higher space resolution automatically means a lower time resolution. Consequently, the single-satellite concept can never perform better than the black hyperbola, and only satellite formations can reach the enhanced resolution space in the lower left of the hyperbola.

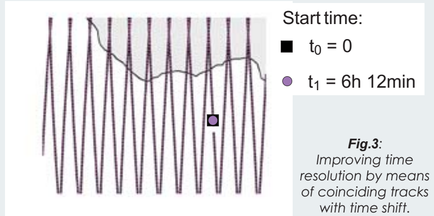


Fig.3: Improving time resolution by means of coinciding tracks with time shift.

How to derive a degree/order 200 gravity field model in 3 days?

This case study is based on a 3-days repeat orbit configuration (cf. *Fig. 2*). A single orbit (black) has a very low spatial resolution, which is improved by a second orbit interleaved (red). Successively interleaving orbits (green, blue) improve the ground track distribution further.

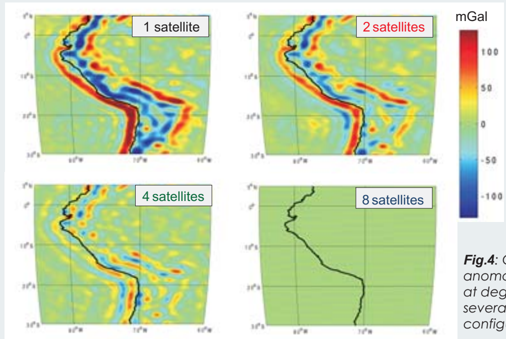


Fig.4: Cumulative gravity anomaly errors [mGal] at degree/order 200 for several satellite configurations.

Along these orbits, gravity signals are computed based on the global gravity model EGM96, complete to degree/order 200, and the gravity field is recovered. *Fig. 4* shows the (omission) errors in terms of gravity anomalies of the individual orbit configurations. Using 8 satellites in parallel, already after 3 days a gravity field model up to degree 200 can be resolved.

How to get rid of ocean tide aliasing?

One of the key problems with GRACE is tidal aliasing. In this simulation, the ocean tide signal related to the constituent M2 is superposed to the (noise-free) static gravity field signal (D/O 50) along a 10 days repeat orbit. *Fig. 5 (left)* shows the deterioration of the static gravity field estimates by this high-frequency temporal variation signal.

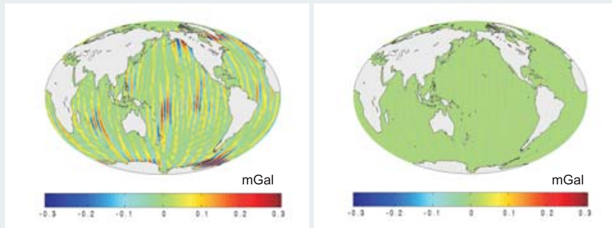


Fig.5: Tidal aliasing in the static gravity field solution due to the M2 ocean tide (left); improvement by increasing the time resolution (right), optimized for this specific problem.

The temporal resolution of the configuration is improved by a second satellite, which follows the first satellite on the identical track, but with a time delay of a quarter period of M2 (~6h 12min). *Fig. 5 (right)* demonstrates, that by this increase of the temporal resolution, optimized for the M2 signal, the static gravity field can be perfectly recovered.