Genetic-algorithm based search strategy for optimal scenarios of future dual-pair gravity satellite missions

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Introduction

Research into time-variable gravity field recovery for future satellite missions is focusing on the use of double satellite pairs (Figure 1) in a Bender constellation. The primary objective is to achieve higher temporal and spatial resolutions. However, the search space for finding optimal scenarios of double pair is vast as the performance of the mission scenarios is a function of the orbital parameters of both pairs. The inclinations of each pair, the evolution of ground-track pattern distribution of the missions within time, missions' altitudes, relative ascending node angles of the pairs and inter-satellite distances within each pair have important impacts on the gravity recovery quality of the mission scenarios.

This work employs genetic algorithms on top of the expertise from previous studies to find optimal scenarios for retrieving the geophysical signals. In fact, the genetic algorithm approach is used as the main search strategy tool of this research, where restrictions from our previous experiences are considered in the running process as well. Moreover, experience-based knowledge is also employed for tuning the results from the genetic algorithm. The procedure also utilizes time-series analysis to study the behavior of the geophysical signals in long time period. The geophysical signals and error models for atmosphere, ocean, hydrology, ice, solid Earth and ocean tides are taken from former studies, as well as from our consideration.

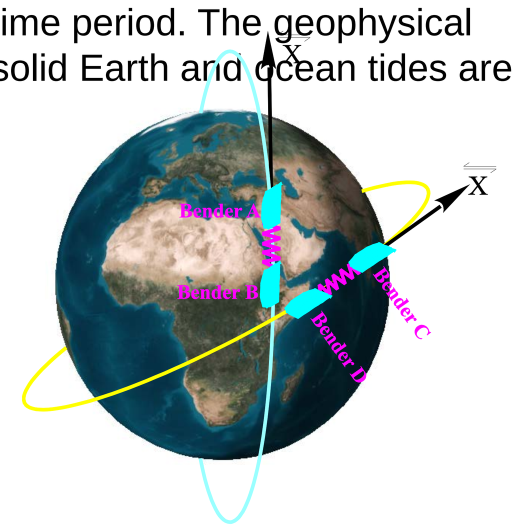

Figure 1: Dual-pair (Bender) constellation

Science and Mission Requirements

Within the ESA SC4MGV project "Assessment of Satellite Constellations for Monitoring the Variations in Earth's Gravity Field", the consolidated science and mission requirements for a future gravity mission have been defined. The anticipated impact of the identified science and missions requirements on applications in geosciences is summarized in Figure 2 as well as the gain compared to state-of-the-art GRACE solutions.

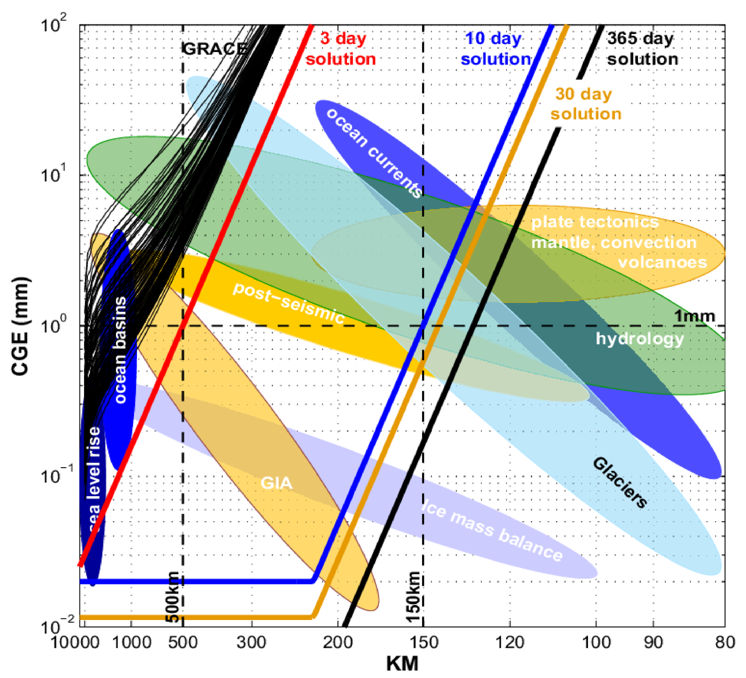

Figure 2: Anticipated performance in terms of spatial vs. cumulative geoid error (right).

Mission Requirements

1) The NGGM mission shall deliver global observations between +90° and -90° latitude where small deviations within 1° are allowed .
2) The NGGM mission 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.

Optimization of satellite constellation

In order to reduce the enormous search space of orbit and satellite constellation (SC) parameters a dedicated search strategy is applied. In the first step the search space is reduced based on (i) experience from previous studies and (ii) Quick-Look/Reduced-Scale 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 (β/α) of each pair for $h \geq 340$ km *(from air drag considerations)*
- inclination I_{pol} of polar pair between 88° and 92° *(minimizing polar gap)*
- inclination I_{inc} of inclined pair within 65° – 75° or 105° – 115° *(from semi-analytic QLT and RST)*
- free $\Delta\Omega$ and ΔM between both pairs
- intersatellite distance ρ 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 3). In order to have bertter coverage of the Earth and higher saptial resolution, repeat orbits with a homogeneous gap evolution should be favoured and large unobserved gaps should be avoided.

Gap-filling optimization

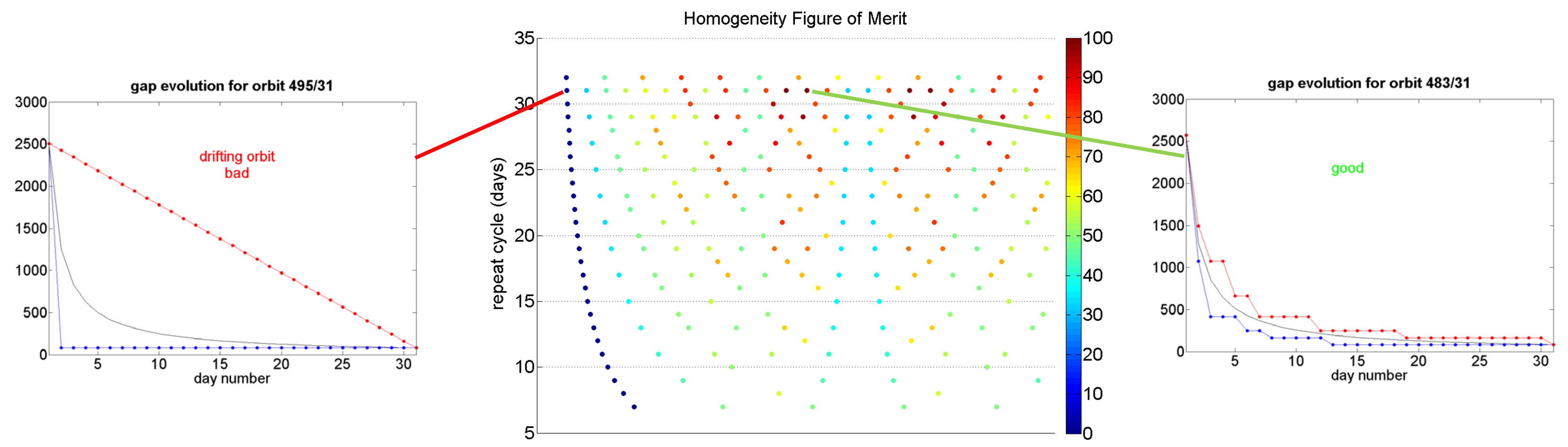

Figure 3: repeat mode selection from figure of merit based on homogeneity of ground-track gap evolution.

The result of the GA (Figure 4), for maximum SH degree/order 100, indicates a high stability of the SC's fitness values w.r.t. the choice of SC parameters. Most of the variations within the grey band are caused by $\Delta\Omega$ (optimum at 90° and 240°) while the fitness is insensitive to ΔM. Since $\Delta\Omega$ 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, as well.

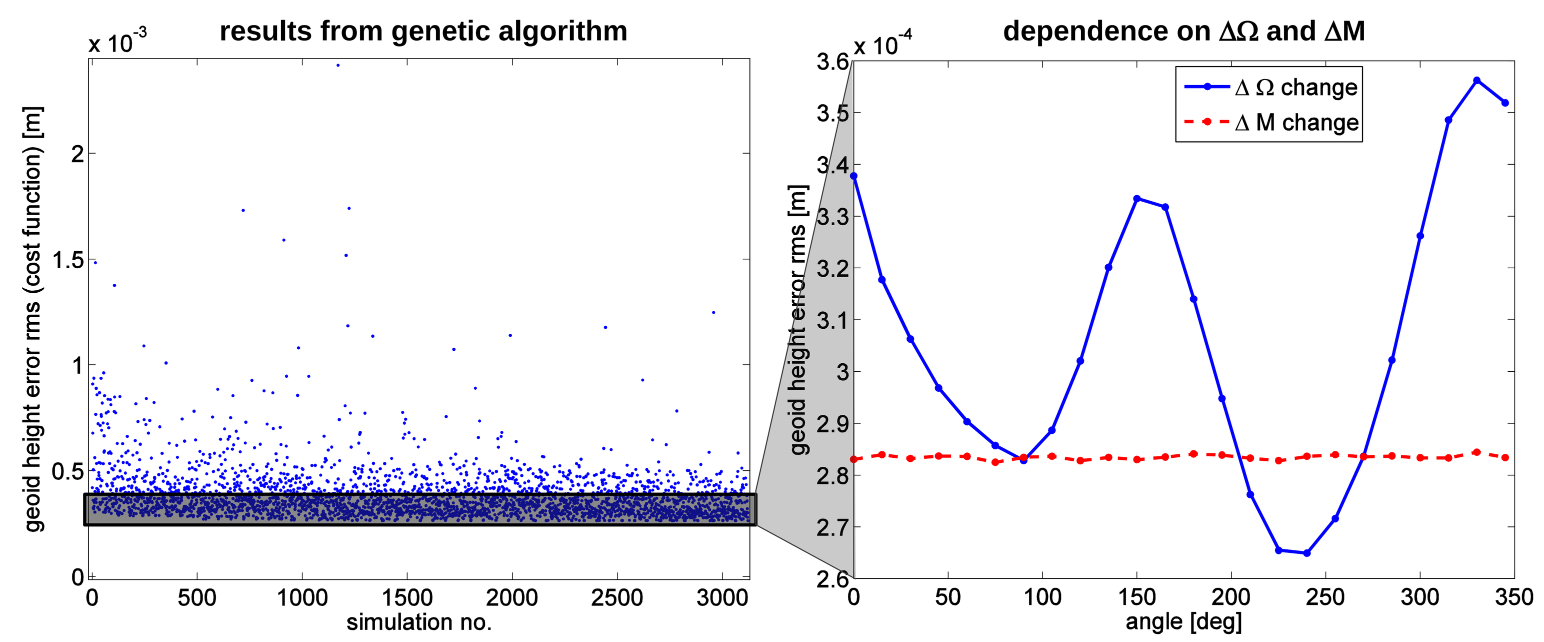

Figure 4: result from genetic algorithm (left) and dependence of solution on $\Delta\Omega$ and ΔM (right); results based on 10 day solutions up to maximum degree L_{max} = 100

In the first iteration, five best SCs (Table 1) have been selected from the GA results and are thoroughly validated using a number of criteria, among them various spectral criteria (e.g. degree-RMS, isotropy, …) and spatial benchmarks (e.g. basin average RMS) and geophysical time series analysis (total water storage changes …) are applied in order to scrutinize the SCs. Figure 5 presents an excerpt of the validation. Besides the mean degree RMS and the spread around the mean, the total water storage change RMS of the recoved minus the simulated fields for 251 basins is shown. Both type as well as other performance criteria allowed to identify our fifth scenario as the best performing.

Table 1: Selected optimal scenarios (based on GA results and technical considerations (please note that in order to have better coverage of the higher latitudes, the inclinations of scenarios 2 and 4 have been tuned to higher angles).

scenario	β/α [rev./day]	inclination [deg.]	altitude [km]	sub-cycle [day]
1	484/31 478/31	89 66	363.3 384.6	13 12
2	493/32 249/16	89 70	423.6 347.6	5 7
3	493/32 269/17	91 114	427.1 351.2	5 6
4	453/29 311/20	92 70	366.4 351.2	8 9
5	172/11 460/29	92 115	361.9 342.5	3 7

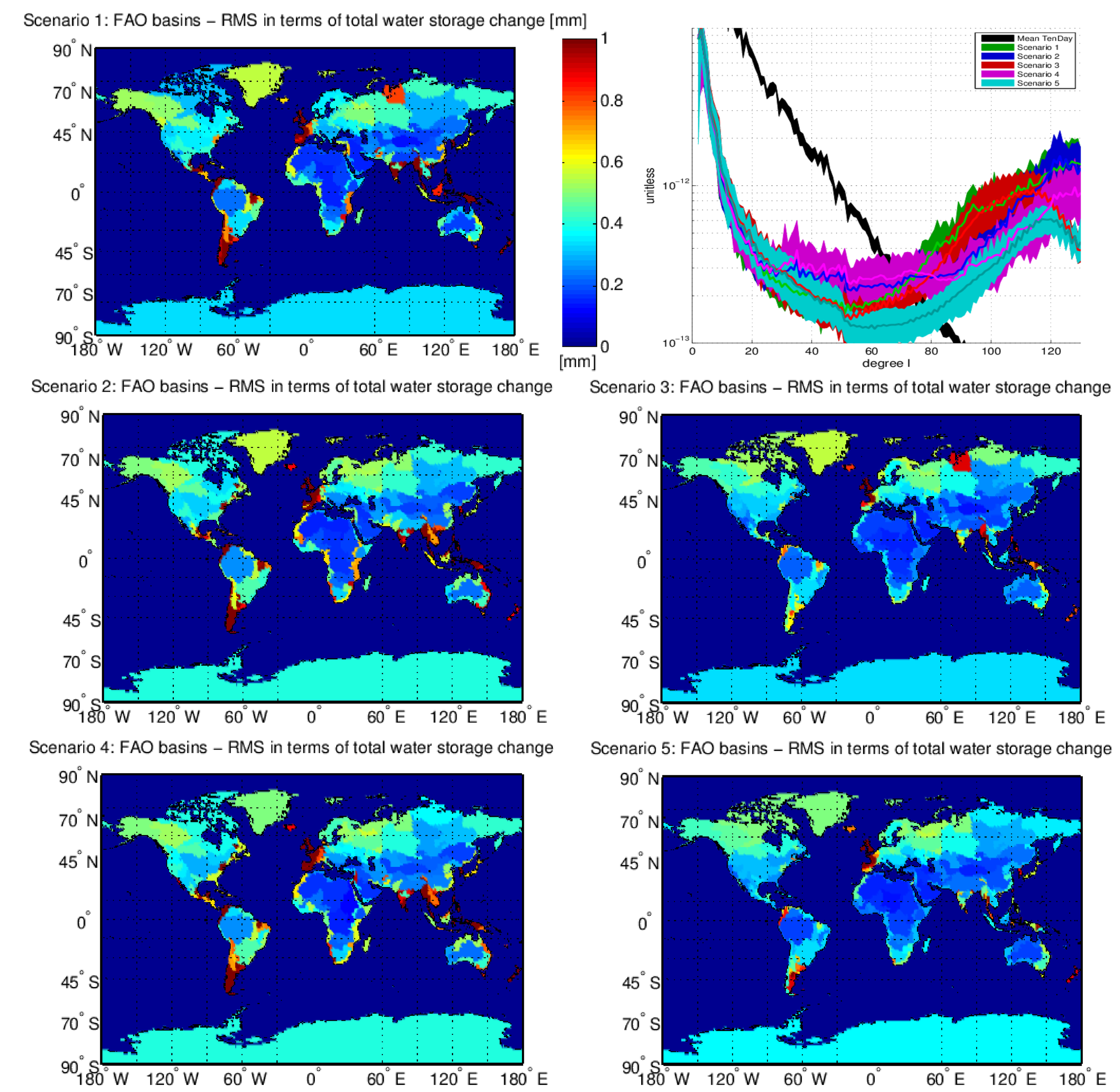

Figure 5: RMS in term of total water storage change [mm] and degree RMS of the selected SC's; in the degree-RMS the band denotes the spread of the 1-year time series of 10 day solutions

Acknowledgement

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