

1. Introduction to COST-G

The International Combination Service for Time-variable Gravity Fields (COST-G; Jäggi et al, 2020) is a Product Center of the International Gravity Field Service (IGFS) of the IAG. COST-G continues the activities of the H2020 project European Gravity Service for Improved Emergency Management (EGSIEM, 2015-2017; Jäggi et al, 2019) to realize the long-awaited standardization of gravity-derived mass transport products.

COST-G products:

- Combined gravity field solutions in spherical harmonic (SH) coefficients (Level-2 products) derived from a weighted combination of the individual solutions generated by different Analysis Centers (ACs),
- Spatial grids (Level-3 products) of the combined solutions for hydrological, oceanic and polar ice sheets applications.

COST-G ACs:



COST-G provides consolidated monthly global gravity models in terms of SH coefficients and thereof derived grids by combining solutions from individual ACs (Fig 1). The ACs adopt different analysis methods but apply agreed-upon consistent processing standards to deliver time-variable gravity field models, e.g. from GRACE-FO low-low satellite-to-satellite tracking (LLST). The individual solutions are combined by the Analysis Center Coordinator (ACC) at AIUB.

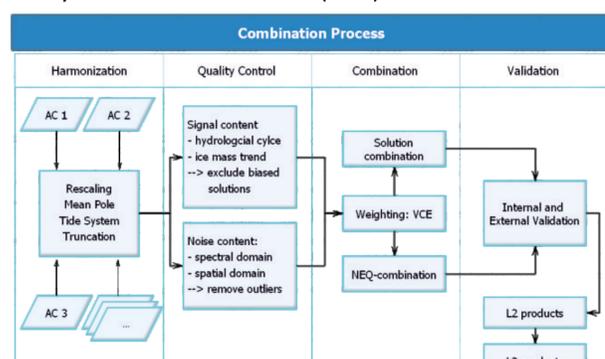


Figure 1: Work-flow of the COST-G gravity field combination.

2. Cooperation with the International Laser Ranging Service (ILRS)

COST-G closely cooperates with the ILRS, which is coordinating the global network of Satellite Laser Ranging (SLR) stations (Pearlman et al., 2002):

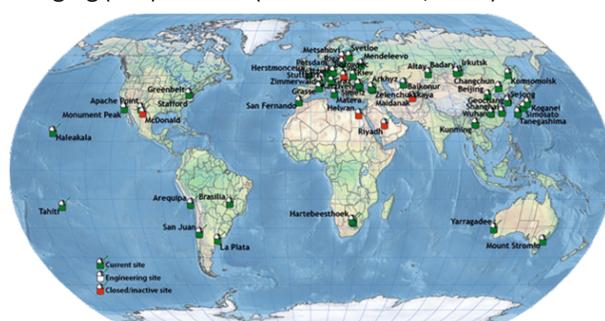


Figure 2: Global network of SLR stations contributing to the ILRS.



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ILRS products:

- weekly station coordinates,
- Earth orientation parameters (EOPs),
- geocenter variations,
- in preparation: low degree temporal gravity field variations.

The ILRS products are generated in the frame of 7 day orbit determination and network solutions of the spherical geodetic SLR satellites LAGEOS 1 and 2, ETALON 1 and 2, and LARES 2, based on the normal point (range) observations collected by the stations of the ILRS network (Fig. 2).

The individual contributions are generated by the ILRS ACs:

- Italian Space Agency, Centro di Geodesia Spaziale "G. Colombo" (ASI/CGS), Italy,
- Bundesamt für Kartographie und Geodäsie (BKG), Germany,
- Centre National d'Etudes Spatiales (CNES), France,
- Deutsches Geodätisches Forschungsinstitut (DGFI), Germany,
- ESA/ESOC, Germany,
- Joint Center for Earth System Technology/Goddard Space Flight Center (JCET/GSFC), USA
- Helmholtz Centre for Geosciences (GFZ), Germany,
- NERC Space Geodesy Facility (NSGF), UK.

The individual contributions are combined by the ILRS combination centers at ASI and DGFI (backup).

3. NGGM + SLR combination

The low degree gravity field SH-coefficient C_{20} determined from the NGGM/MAGIC pre-decessor missions GRACE/GRACE-FO is contaminated by so-called tone errors. The official recommendation is to replace it by SLR-derived values. In case of NGGM a combination with SLR on normal equation (NEQ) level is envisaged. For preparation, test combinations of GRACE/FO + SLR have been performed at AIUB (Fig. 3)

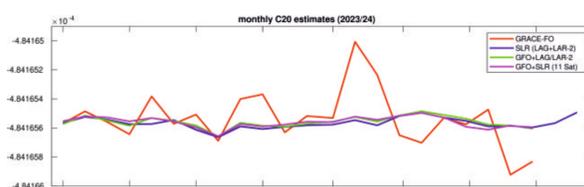


Figure 3: C_{20} -estimates determined from GRACE-FO data (red), LAGEOS/LARES-2 data (blue), and a GRACE-FO + SLR combination on NEQ-level (green), including SLR-LEOs (magenta).

The relative weights of the individual satellite NEQs are determined by variance component estimation (VCE). The corresponding formal errors (sigmas) for LAGEOS and LARES-2 (Fig. 4) reflect data screening and orbit modeling deficits that are aggravated by tight constraints on the commonly used periodic empirical accelerations that are highly correlated with the C_{20} and C_{30} gravity field coefficients.

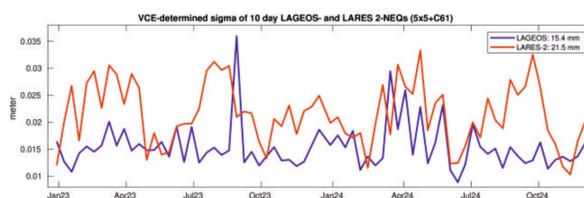


Figure 4: VCE-determined formal errors (sigmas) of the 10 day LAGEOS (blue) and LARES 2 (red) NEQs.

SLR observations to low-flying spherical satellites (e.g., LARES, Ajisai, Starlette, Stella) may be included in the combination to aid in the separation of individual SH-coefficients in SLR-only gravity field solutions, but their contribution to C_{20} in combined SLR/GRACE-FO solutions is neglectable (Fig. 3).

4. The role of uncertainty information

The monthly SLR or GRACE-FO solutions are determined by least squares procedures which rely on appropriate uncertainty assumptions of all observations and the background force models used for signal separation. The analysis approaches of the individual ACs differ by their noise modeling or absorption strategies and consequently the formal uncertainties of the monthly GRACE/GRACE-FO gravity field solutions are very diverse (Fig. 5).

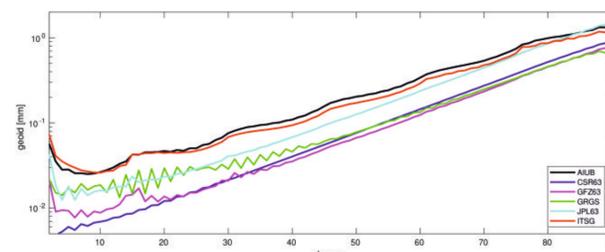


Figure 5: Degree amplitudes of formal uncertainties of current monthly GRACE-FO solutions.

The diverse noise absorption strategies render a straight-forward combination using VCE impossible. So far only ITSG and AIUB apply empirical noise modeling techniques that lead to realistic uncertainty estimates, and thus enabled the successful combination of GRACE/FO and SLR applying VCE (see Sect. 3). To overcome the problem of unrealistic uncertainty information an empirical weighting approach was developed by the EGSIEM project (Meyer et al., 2018). Alternatively, the individual ACs' contributions may be combined applying VCE on solution level (Jean et al, 2018).

6. Summary and Outlook

- COST-G offers its experience with the combination of NEQs of different GRACE ACs either with VCE or, in case of incompatible noise modeling/absorption approaches, applying an empirical weighting scheme, to the combination of NGGM/MAGIC-NEQs of different ACs.
- Experience with the combination of SLR-NEQs of different ACs will be gained as soon as the pilot project of the ILRS on gravity field determination generates first sets of SLR-NEQs.
- The feasibility of inter-technique combinations using VCE was confirmed by successful test combinations of monthly GRACE-FO NEQs and 10 day LAGEOS/LARES-2 NEQs (Fig. 6), both provided by AIUB (the GRACE-FO NEQ generated applying an empirical, i.e. realistic noise model).

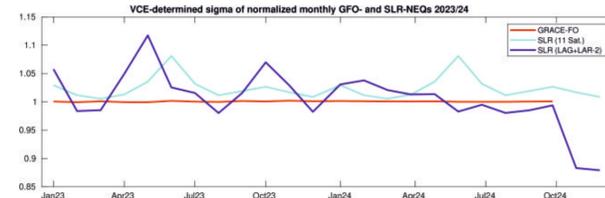


Figure 6: In the combination of normalized monthly GRACE-FO and SLR NEQs, the VCE-determined relative weights close to 1 confirm the success of the normalization of the individual NEQs.

References

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