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Comparison of Swarm and GRACE time-variable gravity field at low degree spherical harmonics

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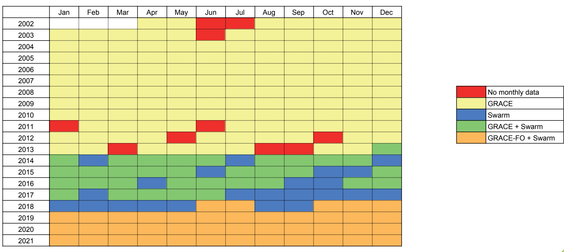
Satellite missions

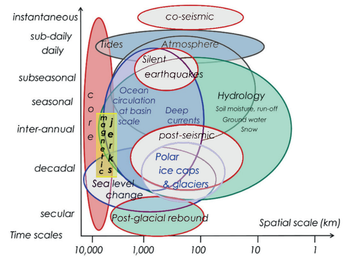
The GRACE mission, composed by twin satellites, is designed to measure Earth's gravity field variations. It was launched in 2002 and ended after 15 years in 2017. After a 11-month interruption, the GRACE Follow-On (GRACE-FO) mission came to ensure the continuity to GRACE.

The Swarm mission, launched in 2013 for magnetic measurements, also provides gravity field variations products retrieved from the tracking of the spacecraft orbit perturbations.

Swarm gravity variations products are known to be less accurate than GRACE products. Nevertheless, the space gravimetry community is trying to use Swarm to fill the gap between GRACE and GRACE-FO.



Applications

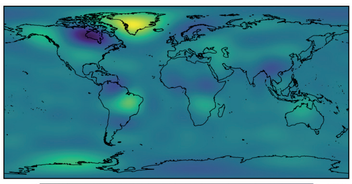


Spatial and temporal scales of physical processes which cause mass variations in the Earth system, [MANDEA et al. 2012]

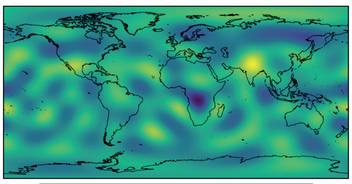
An accurate measurement of the Earth's gravity field variations offers the potential to monitor water ressources. It is also used to study gravitational tides, post-glacial rebound, sea level changes, oceanic circulation and polar ice caps variations.

Some recent studies indicate that some physical processes occurring within the Earth's fluid core and at its boundaries might be observable in the variations of the gravity field. They show a possible correlation between the variable gravity and magnetic fields at decadal time scales that might be caused by processes inside the liquid core.

Comparison between GRACE and Swarm



GRACE gravity field variations from COSTG in August 2015 truncated at degree 12



Swarm gravity field variations product in August 2015 truncated at degree 12

The Root-Mean Square (RMS) difference is computed on the grid and for common months. The RMS error of the GRACE product is near 1 cm in Equivalent Water Height (EWH) for a truncation at degree 12.

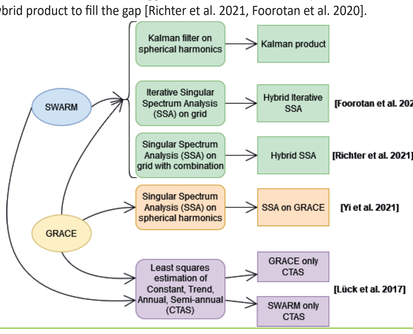
The RMS of the difference between GRACE and Swarm products truncated at degree 12 reaches 10 cm in EWH.

The noise pattern of Swarm products is visible and increases around the equator. Swarm is also sensitive to episodes of high solar activity that degrade the solution.

Gap fill techniques

The 11-month gap between GRACE and GRACE-FO makes it difficult to retrieve signals with pluri-annual and decadal temporal scales. The retrieval of an accurate gravimetric signal during the gap has become a challenge in space gravimetry.

Studies offer methods to extrapolate the GRACE product where the data is missing [Lück et al. 2017, Yi et al. 2021]. Others suggest to assimilate the Swarm product to create a GRACE-like hybrid product to fill the gap [Richter et al. 2021, Foorotan et al. 2020].



Differences between techniques

To estimate the accuracy of each non-hybrid technique, we randomly remove some months within GRACE data. We then reconstruct the missing months using the various techniques and compute the RMS difference between the reconstructed monthly solutions and the true GRACE monthly products. Hybrid techniques provide a corrected version of the Swarm products which is compared with the GRACE products.

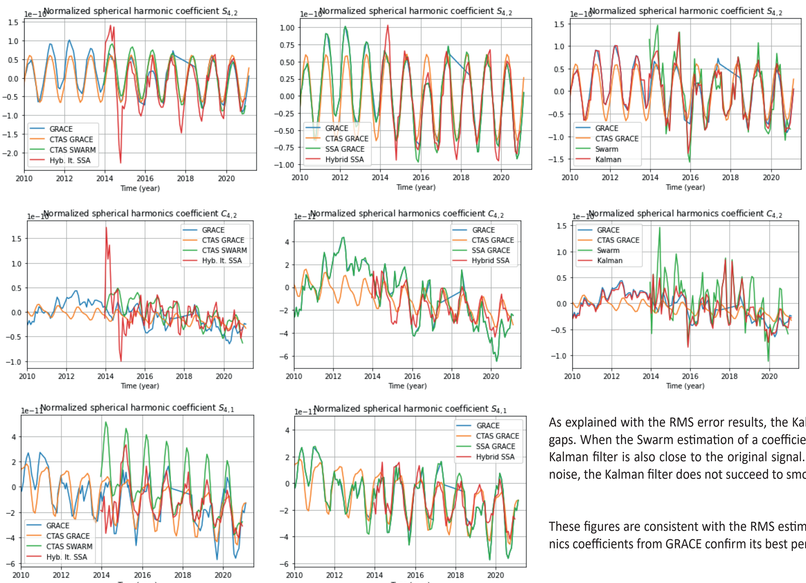
GRACE-only products are twice better than products using Swarm data. There are two possible explanations. First, we are working with low degree truncation (degree 12). Then, the addition of Swarm data does not add new information but only pollute the estimation of hybrid techniques.

The estimation of the Kalman filter is based on the spherical harmonic coefficients of GRACE and Swarm. The Swarm signal is attenuated and replaces the GRACE signal during data gaps, leading to a RMS error close to that of Swarm.

	CTAS GRACE only	CTAS Swarm only	SSA on GRACE	Hybrid SSA	Hybrid Iterative SSA	Kalman
RMS error in EWH (cm)	1.9	3.9	1.5	3.4	4.5	7.1

RMS difference between the reconstruction techniques and the original GRACE product

Time series



The time series of spherical harmonics coefficients are divided into three figures. One with GRACE product from the COSTG center, the CTAS estimation from GRACE, the CTAS estimation from Swarm and the Hybrid Iterative SSA approach. Another with GRACE product from the COSTG center, the CTAS estimation from GRACE, the SSA estimation on spherical harmonics of GRACE and the SSA hybrid estimation based on GRACE and Swarm grid products. The last one with GRACE, CTAS estimation from GRACE, Swarm and the Kalman estimation.

The first one corresponds to techniques with reconstruction issues and the second one to satisfying techniques. The CTAS estimation from Swarm often misestimates the trend, the hybrid iterative SSA has issues at the beginning of the series (also linked with the low quality of products at the beginning of the Swarm era). The hybrid SSA misestimates annual signal and does not succeed in representing non-regular events. The SSA estimation on GRACE is the closest estimation to the GRACE signal.

As explained with the RMS error results, the Kalman estimation is similar to the Swarm signal on GRACE gaps. When the Swarm estimation of a coefficient, such as $S_{4,2}$, is good enough the reconstruction of the Kalman filter is also close to the original signal. Moreover, for Swarm estimation where there is a lot of noise, the Kalman filter does not succeed to smooth the signal.

These figures are consistent with the RMS estimation of the techniques and the SSA on spherical harmonics coefficients from GRACE confirm its best performance.

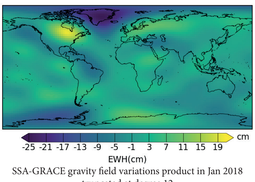
Conclusions

The uncertainty of the Swarm gravity field variations product is ten times larger than the GRACE product.

Spherical harmonics reconstruction and GRACE extrapolation approaches generate more accurate products than other approaches. The SSA with only GRACE product as input gives the best estimation compared with GRACE original product.

If there was more confidence in the Swarm estimate, the Kalman filter would be a good approach to combine the GRACE and Swarm estimates.

This assessment of the state of the art is an important addition to the search of pluri-annual signals in the Earth gravity field variations.



SSA-GRACE gravity field variations product in Jan 2018 truncated at degree 12

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