A comparison of GRACE/-FO and altimetry derived regional hydrological mass balance: example of the Caspian Sea

Louis-Marie Gauer [(1)], Kristel Chanard [(1)], Raphaël Grandin [(1)] and Luce Fleitout [(2)]

(1) Université de Paris Cité, Institut de physique du globe de Paris, CNRS, IGN, Paris, France
(2) Laboratoire de Géologie, École Normale Supérieure, Université PSL, CNRS, Paris, France

Introduction

Tapley et al., 2004 Landerer et al., 2020

Gravity **R**ecovery **A**nd **C**limate **E**xperiment missions measure spatio-temporal varitions of the Earth's gravity field, giving access to:

- continental water storage
- ice and snow variations
- ocean bottom pressure
- Glacial Isostatic Adjustment (GIA)
- Major earthquakes
- and more

But, two major issues in the GRACE/-FO solutions:

1. Significant unphysical noise as North/South stripes must be filtered, causing signal attenuation & leakage

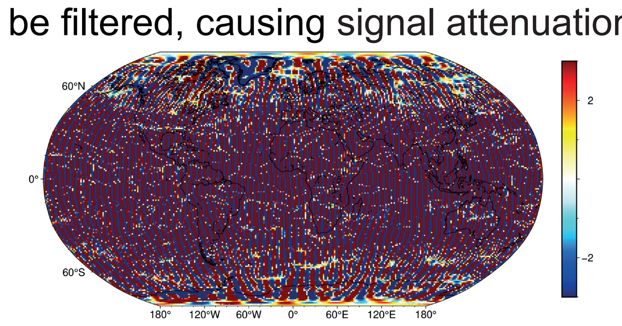


Figure 1: Unfiltered GRACE gravity field

2. Large observationnal gaps

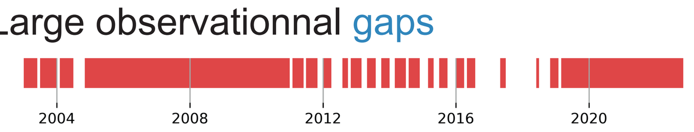


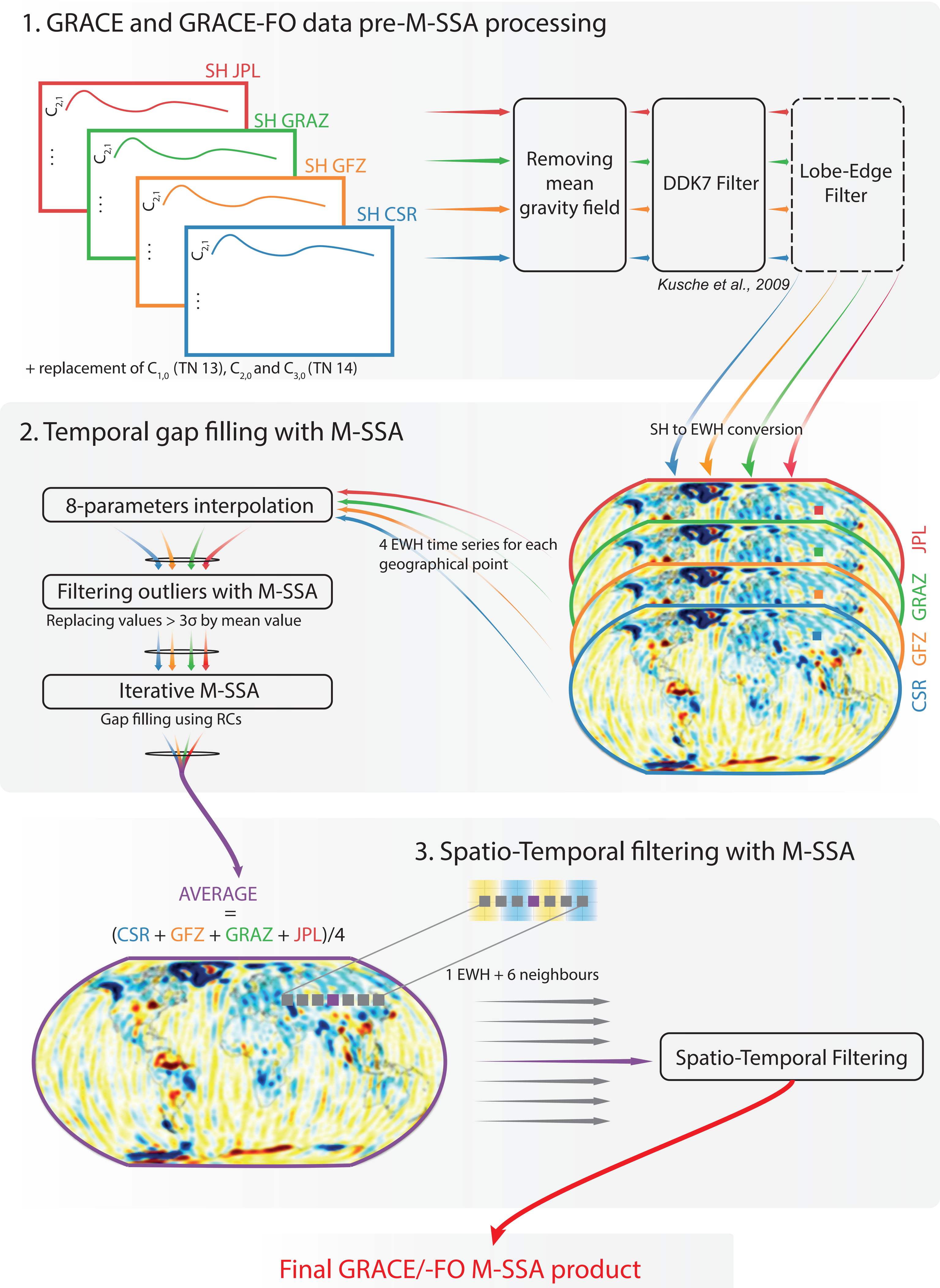
Figure 2: Available JPL GRACE/GRACE-FO monthly solutions

How to use GRACE/-FO to estimate regional hydrological mass balance ?

1. Create a processing method to adress the two major issues of GRACE using here Multichannel-Singular Spectrum Analysis (M-SSA, *Ghil et al., 2002; Plaut et Vautard, 1994; Prevost et al., 2019*)

2. Develop a forward modeling method to isolate gravity signals of a known hydrological source from the processed GRACE data

1. Processing method



2. Final GRACE/-FO product

Linear trend of the gravity field anomalies between 2003 and 2022

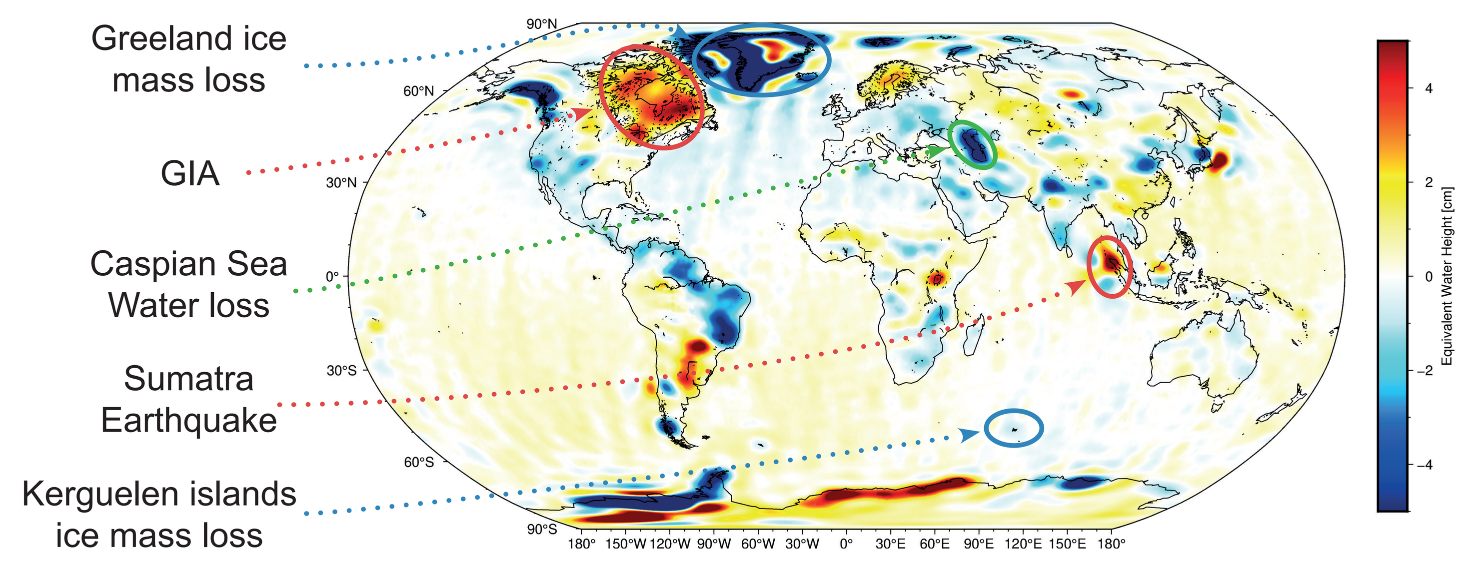


Figure 3: 2003-2022 GRACE/-FO M-SSA linear trend in Equivalent Water Height (EWH) per year [cm/yr]

Remaining signal over the oceans

We evaluate residual noise level of the GRACE/-FO solutions once dominant geophysical signals have been removed using parametric functions, namely a degree-3 polynomial function, reflecting linear trends and multi-annual signals, annual and semi-annual signals driven by the hydrosphere.

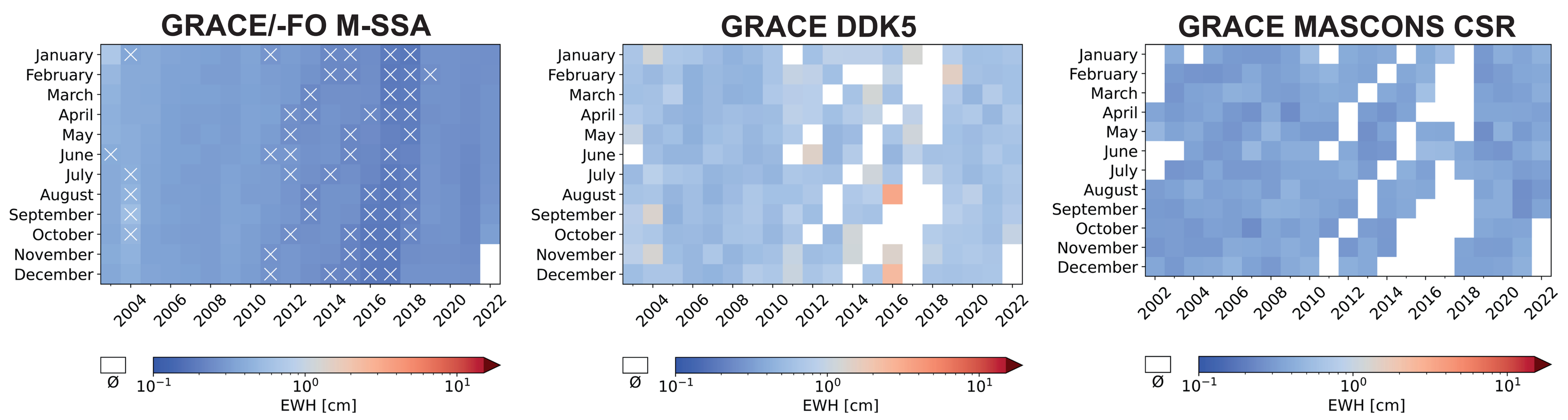


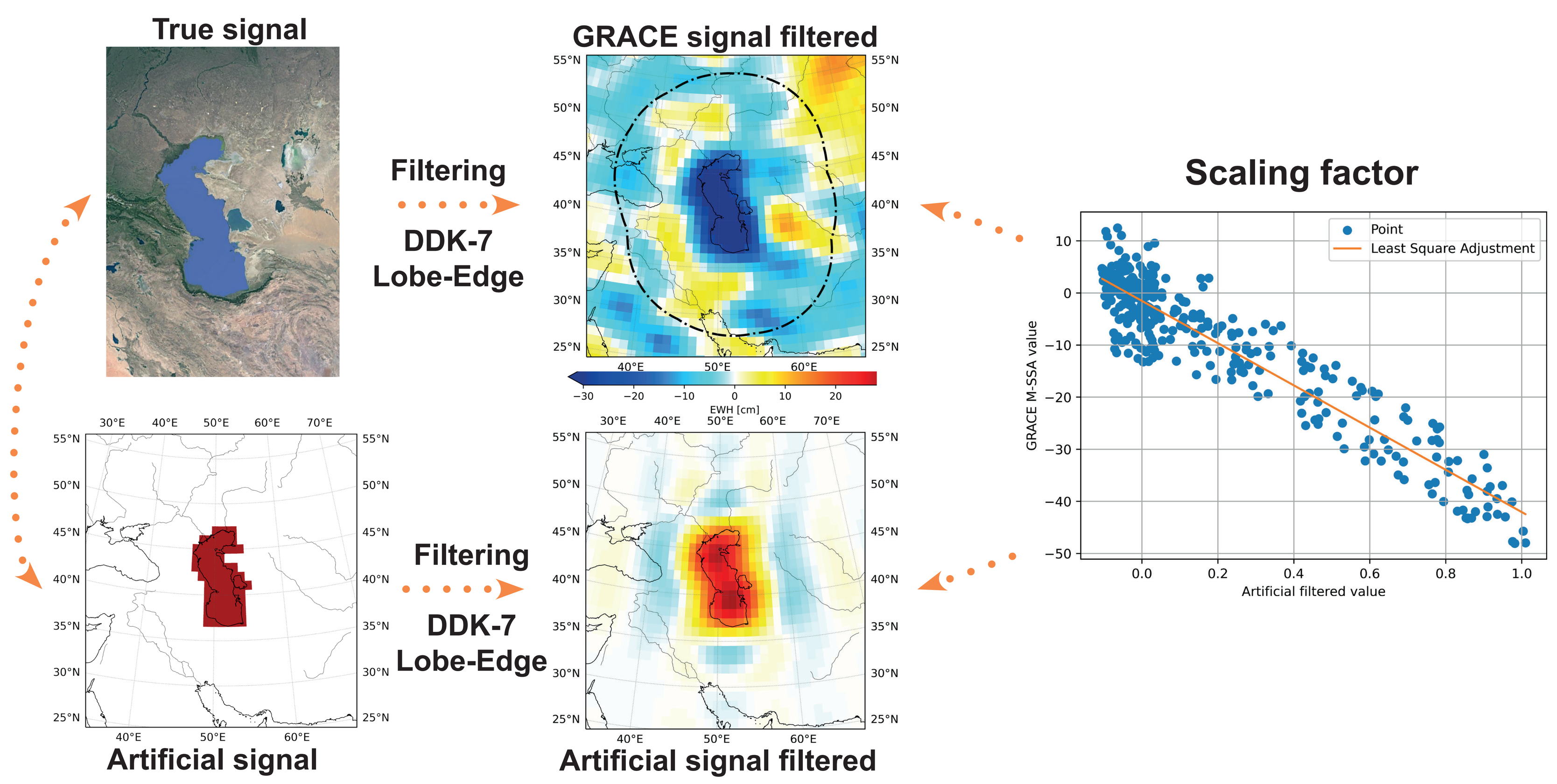
Figure 4: Mean residual signal in the ocean after having removed a degree 3 polynomial and a half-annual and annual signal using (from left to right) : GRACE/-FO M-SSA, GRACE DDK5 and GRACE MASCONS CSR

Our processing method allow us to reach a residual signals over the ocean comparable to CSR mascons solution without requiring *a priori* information or regularisation.

3. Forward modelling method

Chen et al., 2017

- Necessary filtering of GRACE/-FO data causes geophysical signals attenuation and leakage
- We develop a forward modelling method which accounts for our filtering strategy
- For each GRACE/-FO monthly solution:



→ GRACE/-FO based regional hydrological mass balance accounting for filtering

4. Validation with independent datasets

Comparison satellite altimetey : Caspian Sea

- We compare GRACE/-FO derived hydrological mass variations with satellite altimetry records of Sea Surface Level over the Caspian Sea
- We correct volume variations estimated from altimetry from water thermal expansion (steric effect) and elastic ground deformation induced by hydrological unloading
- A 90 km^3 annual amplitude difference remains to be explained

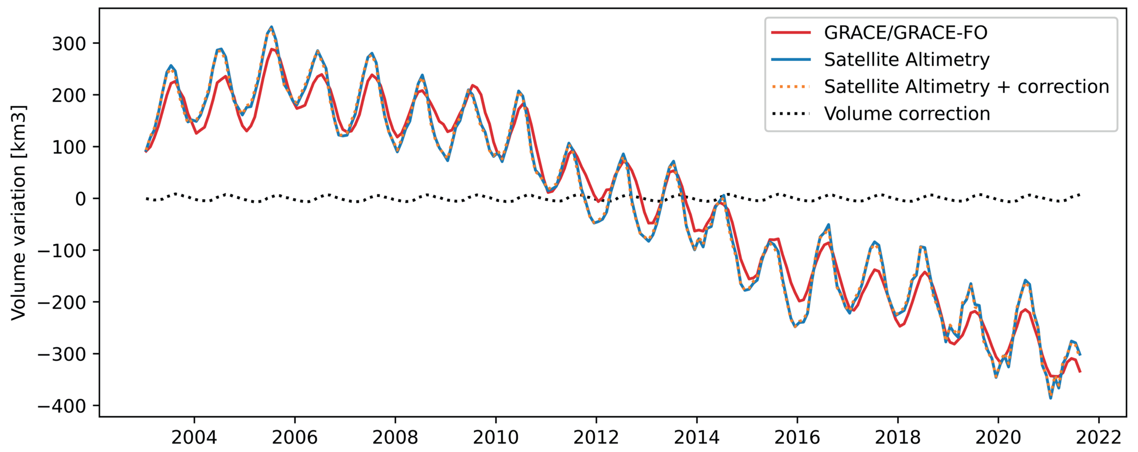


Figure 5: Volumes variations of the Capian Sea from GRACE/-FO M-SSA and altimetry

Hypothesis to explain annual differences

Northern part of the Caspian Sea covered by ice in winter.
Effect on satellite altimetry ?

Hydrological models show large annual variations around the Caspian Sea.
Effect on GRACE/-FO estimates for the Caspian Sea ?

Altimetry data shows variations of the Sea Surface Level along satellite track.
Should we average sea level over the entire Caspian Sea?

Comparison to dam impoundment

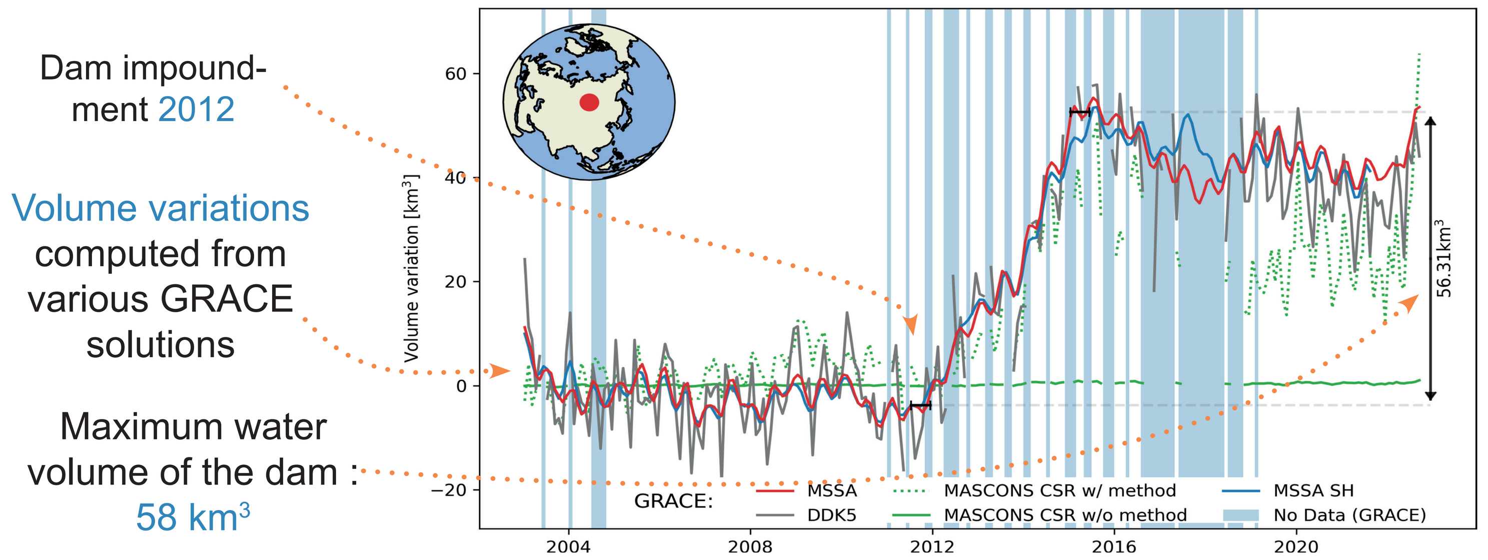


Figure 6: Volumes variations of the Boguchany dam estimated using various GRACE/-FO solutions

Conclusions & Perspectives

- We propose a new GRACE/-FO Level-3 Solution with an improved Signal to Noise Ratio
- We develop a method to estimate regional hydrological mass balance of known sources from GRACE/-FO observations that accounts for filtering artefacts
- Comparison of results to independent altimetry data over the Caspian Sea reveal a 90 km^3 annual amplitude difference that remains to be explained
- Method performances are however highlighted for a dam impoundment over which we retrieve 97% of the expected hydrological signal

What's next ?

- Ice mass balance for the smallest polar islands seen by GRACE/-FO (Kerguelen Islands)
- Refine ice mass loss spatial resolution by inverting InSAR ground deformation around glaciers

Kerguelen islands
49.5°S, French Overseas Territories

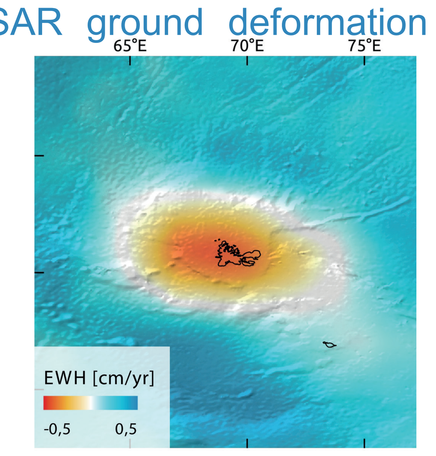


Figure 7: GRACE/-FO M-SSA 2003-2022 linear trend

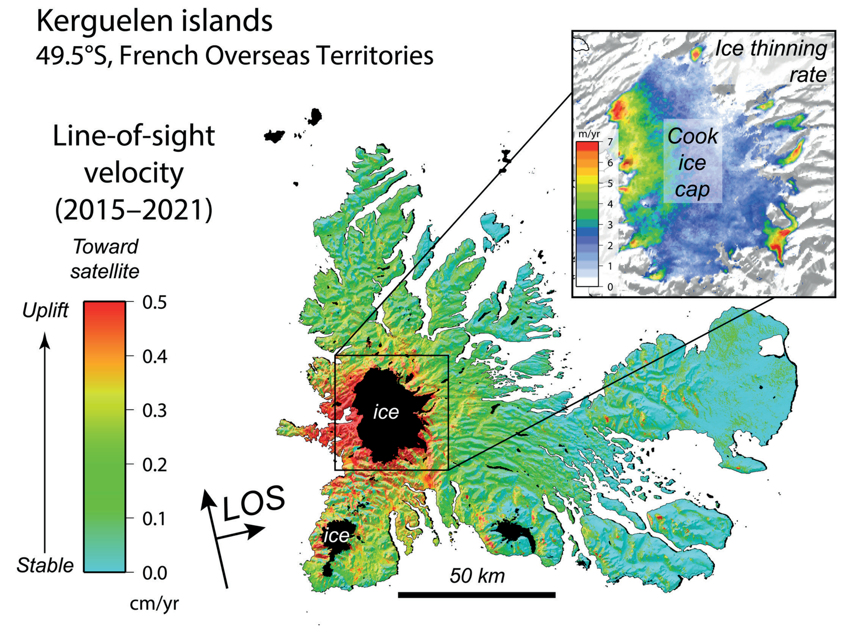


Figure 8: Line of Sigth (LOS) Sentinel-1 velocity & ice thinning rate

Acknowledgments

The GRACE Level-2 data used are provided by CSR (https://dx.doi.org/10.5067/GRGSM-20C06), JPL (https://dx.doi.org/10.5067/GRGSM-20J06), GFZ (https://dx.doi.org/10.5880/GFZ.GRACE_06_GSM), ITSG GRAZ (http://ftp.tugraz.at/outgoing/ITSG/GRACE/ITSG-Grace_operational/monthly/monthly_n96/). This work was supported by the Centre National d'Études Spatiales (CNES)

gauer@ipgp.fr

References

- Gauer, L. M., Chanard, K., & Fleitout, L. (In Rev). Data-driven gap filling and spatio-temporal filtering of the GRACE and GRACE-FO records
- Prevost, P., Chanard, K., Fleitout, L., Calais, E., Walwer, D., van Dam, T., & Ghil, M. (2019). Data-adaptive spatio-temporal filtering of grace data. Geophysical Journal International, 219 (3), 2034–2055.
- Kusche, J., Schmidt, R., Petrovic, S., & Rietbroek, R. (2009). Decorrelated grace time-variable gravity solutions by gfz, and their validation using a hydrological model. Journal of geodesy, 83 (10), 903–913.
- Ghil, M., Allen, M., Dettinger, M., Ide, K., Kondrashov, D., Mann, M., . . . others (2002). Advanced spectral methods for climatic time series. Reviews of geophysics, 40 (1), 3–1.
- Landerer, F. W., Flechtner, F. M., Save, H., Webb, F. H., Bandikova, T., Bertiger, W. I., . . . others (2020). Extending the global mass change data record: Grace follow-on instrument and science data performance. Geophysical Research Letters, 47 (12), e2020GL088306.
- Tapley, B. D., Bettadpur, S., Watkins, M., & Reigber, C. (2004). The gravity recovery and climate experiment: Mission overview and early results. Geophysical research letters, 31(9).
- Chen, J. L., Wilson, C. R., Tapley, B. D., Save, H., & Cretaux, J. F. (2017). Long-term and seasonal Caspian Sea level change from satellite gravity and altimeter measurements. Journal of Geophysical Research: Solid Earth, 122(3), 2274-2290.