# HL-SST and SLR - bridging the gap between GRACE and GRACE-Follow On

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## Motivation

Due to the decommissioning of GRACE before the launch of GRACE-Follow On a data gap of at least 12 month occurs. The data gap should be bridged in order to:

- have a consistent long term time series,
- allow the connection of GRACE and GRACE-Follow On time series and
- cross-validate GRACE and GRACE-Follow On.

We propose a combination of high-low satellite-to-satellite tracking and satellite laser ranging.

## HL-SST - Processing

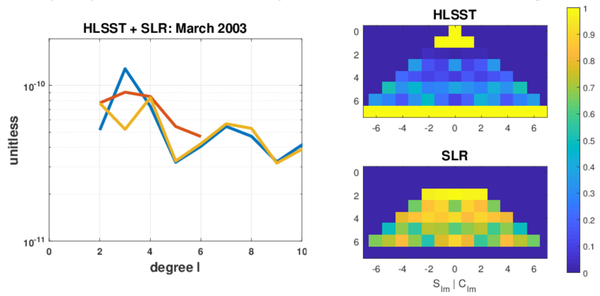
- Kinematic orbits provided by AIUB and IfG for 27 satellites: Grace A/B, CHAMP, GOCE, Swarm A-C, Cosmic 1-6, TerraSARX, TandemX, Jason 1-3, Sentinel 1 A/B, 2A, 3A, SAC-C, CNOFS, Kompsat5, MetOpA, MetOpB
- Acceleration approach with accelerometer data used if available
- Empirical stochastic error modelling based on residuals
- No regularization and no a priori model / information

## SLR – Processing

- SLR observations to 9 satellites: Lageos 1/2, LARES, Starlette, Stella, Larets, AJISAI,Beacon-C, Blits
- Estimation of gravity parameters together with station coordinates, ERP, geocenter and range biases
- Combination of SLR solutions at the normal equation level

## Combination of HL-SST and SLR

- Combination of combined HL-SST and combined SLR solutions at the normal equation level
- Relative weighting found by calibrating the degree RMS of the estimated standard deviations with the difference degree RMS w.r.t. a static field for degrees > 40 (noise-dominated section)
- Exemplary contribution analysis for March 2003 till degree 6



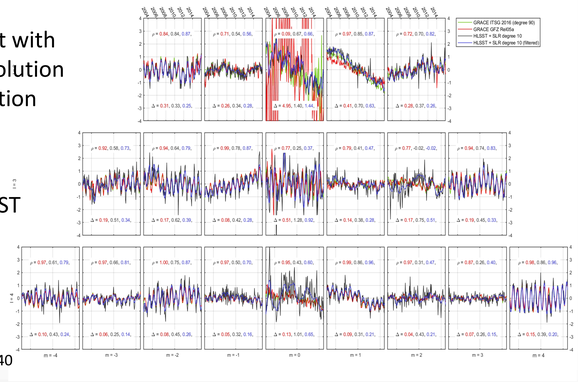

- Degree 2 up to 100% determined by SLR with decreasing impact for higher degrees and stronger contributions from HL-SST

## Low-degree coefficient time series

Degree 2:
Excellent agreement with ITSG-GRACE 2016 solution due to SLR contribution

Degree 3 + 4:

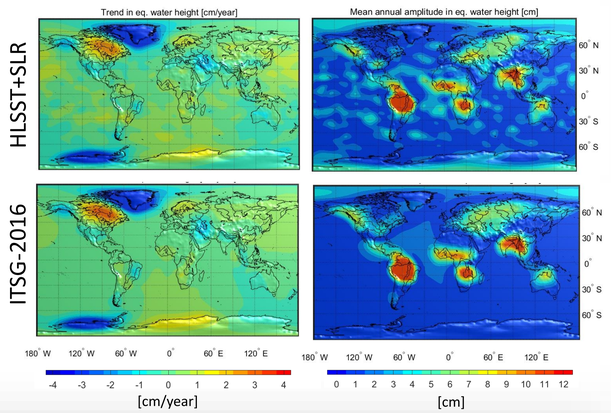
- predominately derived from HL-SST
- coefficient-wise very good agreement
- at times spurious oscillations, e.g. $C_{40}$




## Spatial analysis

Gaussian filtering with 750km

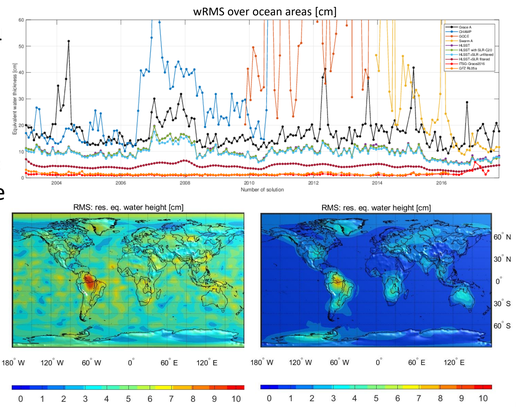
- Excellent agreement of the trend and the mean annual signal
- HL-SST+SLR solution with a higher noise level (cf. ocean)




## Time series analysis

Gaussian filtering with 750km

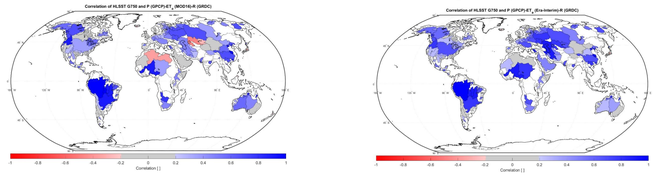
- Improvement of a factor 4 w.r.t. a single satellite solution visible in the wRMS over ocean areas
- Elevated noise level in the HL-SST+SLR solution in the RMS of the residual
- Subtle inter-annual variations and high-frequency variations unrecoverable due to noise



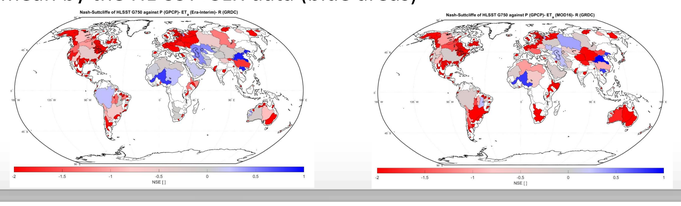

## Correlation with Hydrology

Gaussian filtering with 750km

- Excellent correlation due to fit of the annual signal (phase information)



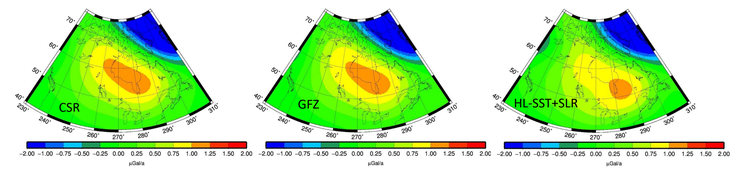
- Nash-Suttcliffe coefficient: little information gain beyond the long-term mean by the HL-SST+SLR data (blue areas)



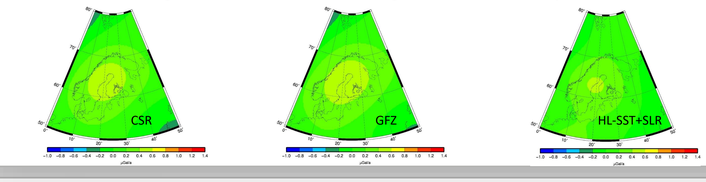
## Glacial Isostatic Adjustment

Gaussian filtering with 750km

North America: good agreement with GRACE but underestimation of the amplitude and artefact in the south-western area




Scandinavia: origin well centered but again reduced amplitude




## Conclusions

HL-SST is able (and probably the best chance) to bridge the gap between GRACE and GRACE-Follow On but:

- it is limited in spatial resolution to about 750 km,
- it is limited to strong signals due to a higher noise level,
- it is restricted to long-term signals, i.e. primarily the annual and trend signals.

Time series of spherical harmonic coefficients from 2003 to November 2017 is submitted to ICGEM and will be publicly available.

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