Regional modelling of water storage variations from combined GRACE/-FO and GNSS data in a Kalman filter framework

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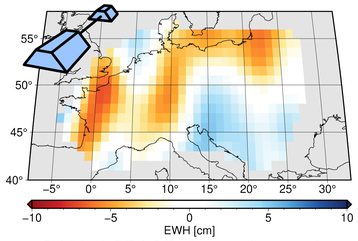
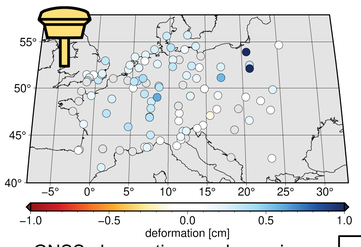
Introduction

We combine GRACE/-FO and GNSS data in a Kalman filter framework using regional modelling (space localising radial basis functions) to obtain water storage variations for a test area in central Europe.

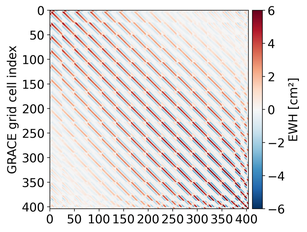
Observations + Uncertainties

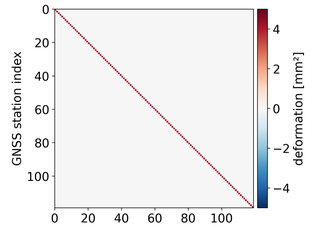


Gridded GRACE observations and covariance matrix for exemplary month (2006-02), 300 km Gaussian filtered



GNSS observations and covariance matrix (scaled unit matrix) for one exemplary month (2006-02)





Radial Basis Functions

The gravity field functional is parameterised by regional modelling in terms of space-localising radial basis functions (spherical splines).

Estimated parameters (scaling coefficients)

Gravity field functional at point $\boldsymbol{x}$

$$s(\mathbf{x}) = \sum_{i=1}^{I} a_i \Phi_i(\mathbf{x}, \mathbf{x}_i)$$

Radial basis functions located at points $\boldsymbol{x_i}$

RBF depending on spherical distance

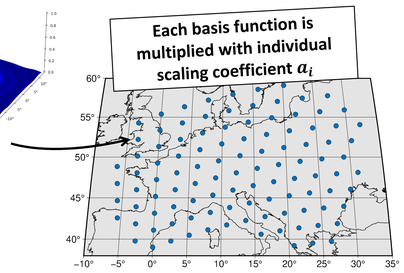
RBF shape coefficients

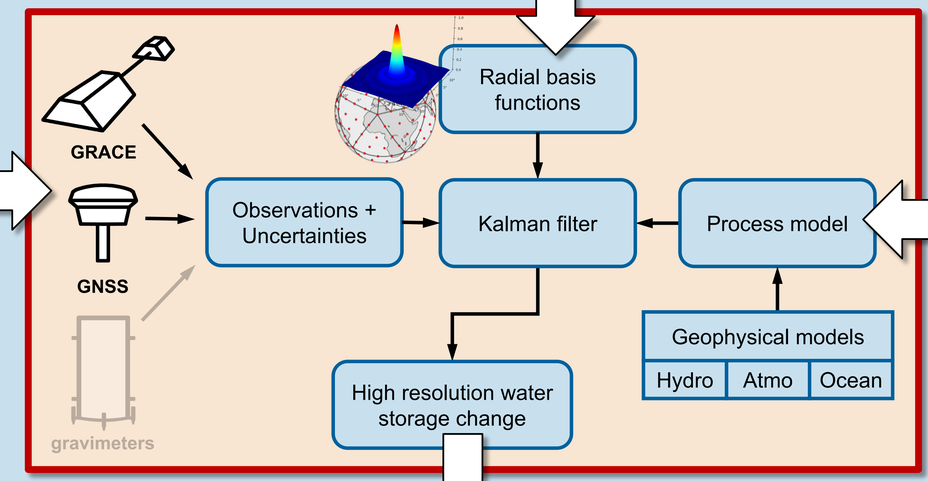
Legendre polynomials

$$\Phi_i(\mathbf{x}, \mathbf{x}_i) = \sum_{n=2}^{N} \sqrt{2n+1} \cdot \mathrm{k}_n \mathrm{P}_n(\mathbf{x} \cdot \mathbf{x}_i) \left(\frac{\mathrm{r_x}}{\mathrm{r}_{\mathbf{x}_i}}\right)^{n+1} \frac{2n+1}{4\pi \mathrm{G} \rho \mathrm{r}_{\mathbf{x}_i}} \frac{1}{1+\mathrm{k}'_n}$$

$$\Phi_i(\mathbf{x}, \mathbf{x}_i) = \sum_{n=2}^{N} \sqrt{2n+1} \cdot \mathrm{k}_n \mathrm{P}_n(\mathbf{x} \cdot \mathbf{x}_i) \left(\frac{\mathrm{r_x}}{\mathrm{r}_{\mathbf{x}_i}}\right)^{n+1} \frac{1}{\gamma} \frac{\mathrm{h}'_n}{1+\mathrm{k}'_n}$$

Radial basis functions (RBF) including the conversion to equivalent water height EWH (GRACE) and deformation (GNSS) for maximum degree N using load love numbers k'_n and h'_n





Process Model

The process model predicts the gravity field from one time step to the next.

Process Model

$$\boldsymbol{a}_t = \mathbf{B}\boldsymbol{a}_{t-1} + \mathbf{w} \qquad \mathbf{w} \sim \mathcal{N}(\mathbf{0}, \mathbf{Q})$$

Scaling coefficients

State transition matrix

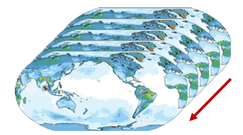
$$\mathbf{B} = \boldsymbol{\Sigma}_\Delta \boldsymbol{\Sigma}^{-1}$$

Covariance matrix of the process noise

$$\mathbf{Q} = \boldsymbol{\Sigma} - \boldsymbol{\Sigma}_\Delta \boldsymbol{\Sigma}^{-1} \boldsymbol{\Sigma}_\Delta^T$$

Stochastic prediction

Geophysical Models (ESA ESM) *



* mean, linear trend and annual signal removed

$$\boldsymbol{\Sigma} \begin{pmatrix} a_{t-1} \\ a_t \end{pmatrix} = \begin{pmatrix} \boldsymbol{\Sigma} & \boldsymbol{\Sigma}_\Delta \\ \boldsymbol{\Sigma}_\Delta^T & \boldsymbol{\Sigma} \end{pmatrix}$$

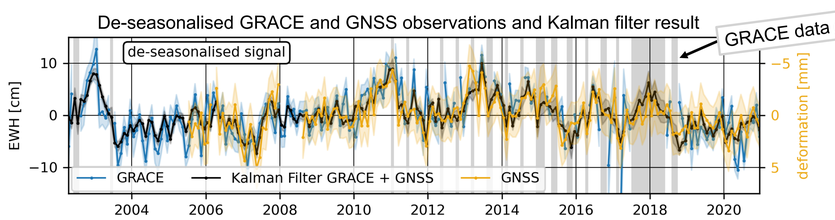
Temporal correlation:
- How fast does a signal vary at each place?

Spatial correlation:
- Where are areas with large variability?
- How much do nearby points differ?

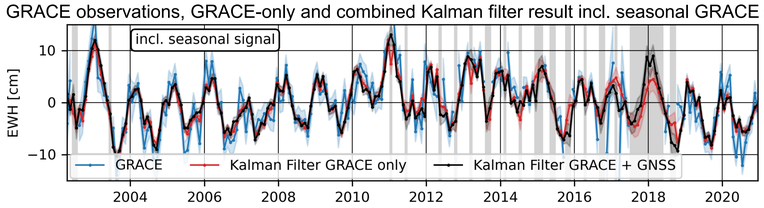
High Resolution Water Storage Change

Observation and Kalman filter time series for exemplary location (Wettzell). Kalman filter reduces observation noise, GNSS takes over during GRACE data gaps.

De-seasonalised GRACE and GNSS observations and Kalman filter result



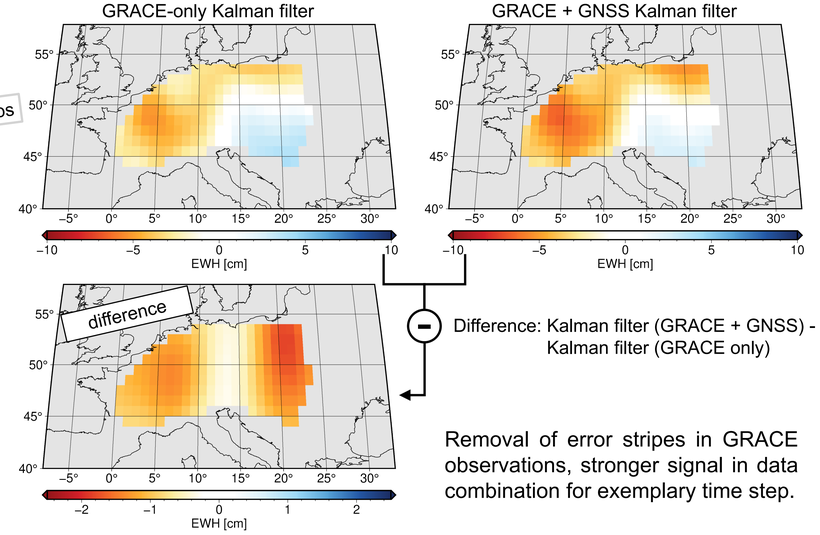
GRACE observations, GRACE-only and combined Kalman filter result incl. seasonal GRACE signal



Gridded Kalman filter results for one exemplary time step (2006-02)

GRACE-only Kalman filter

GRACE + GNSS Kalman filter



Difference: Kalman filter (GRACE + GNSS) - Kalman filter (GRACE only)

Removal of error stripes in GRACE observations, stronger signal in data combination for exemplary time step.

Conclusions & Outlook

- Regional modelling with space localising (radial) basis functions implemented in Kalman filter
- Successful use of Kalman filter framework for data combination of GNSS and GRACE/-FO observations
- Temporal and spatial noise reduction in Kalman filter result compared to observations
- GNSS takes over in Kalman filter during GRACE data gaps

Next steps:

GNSS error model and relative weighting (GRACE vs. GNSS) to be discussed

Add observations from gravimeters

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