Temporal Gravity Variations in GOCE Release 6 Gravitational Gradients

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Introduction: GOCE Gravitational Gradients

Gravity Field and steady-state **O**cean **C**irculation **E**xplorer

- Mission period: 2009-2013
- Objective: highly-resolved (d/o 280 – 300) static global geoid

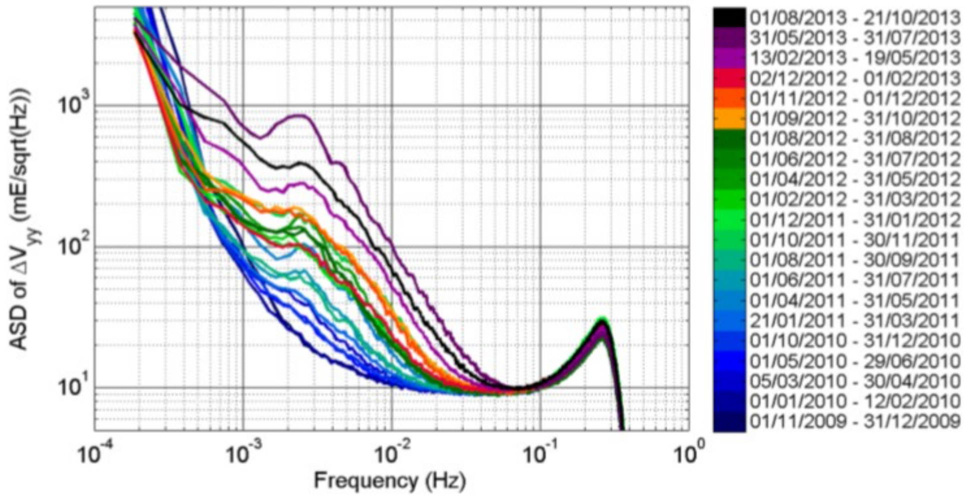
Can we identify temporal gravity variations in GOCE gravitational gradients?

Figure extracted from Van der Meijde et al. (2015)

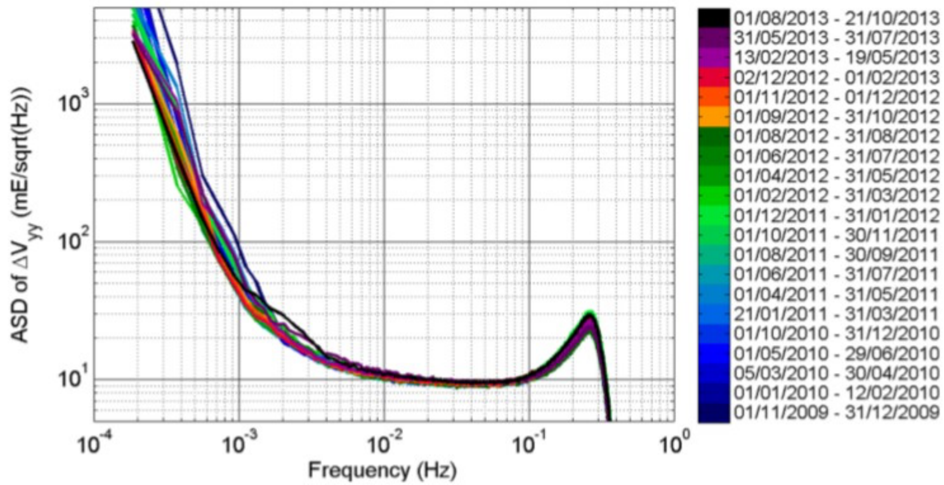
Introduction: GOCE Gravitational Gradients

E.g. Siemes et al. (2019): New GOCE gradiometer data calibration

Noise in release 5 gradients:



Noise in release 6 gradients:



→ stationary statistical properties

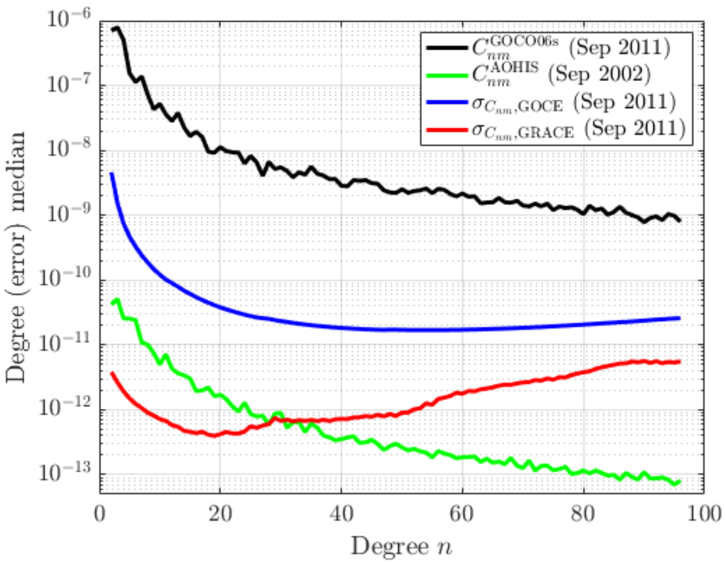
→ reduced low-frequency noise in gradients

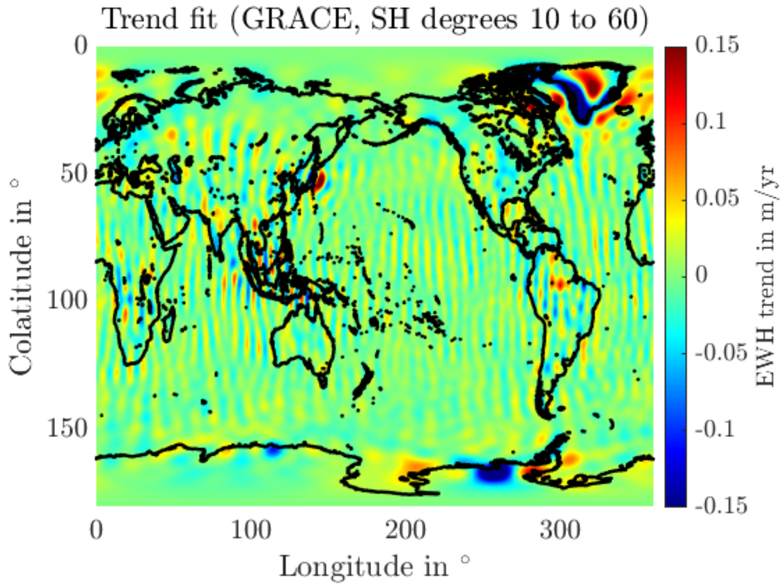
=> reduced long-wavelength noise in models

Figures extracted from Siemes (2017): Amplitude spectral density (ASD) of gravity gradient residuals ΔV_{yy}

Introduction: Research Questions

- Which temporal signals can GOCE resolve on its own?
- Compared to GRACE-only, are GRACE/GOCE combination models better in resolving time-variable signals?





- Globally, GOCE errors larger than time-variable signal
- High-amplitude regional signals: Greenland, Antarctica

AOHIS signal coefficients: ESA ESM (Dobslaw, 2015); GRACE models: ITSG-Grace2018 (Mayer-Gürr, 2018); GOCO06s model: Kvas, 2019

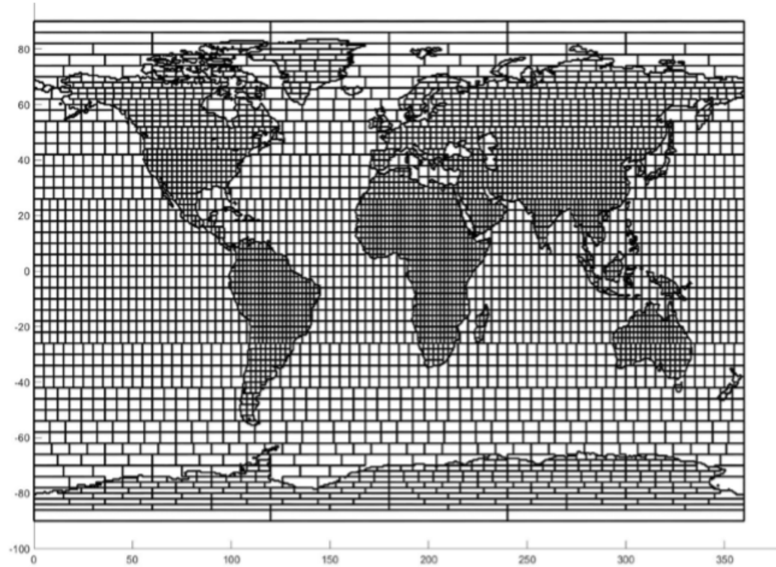
Methods: Data Processing

- 2 complementary approaches:

❖ Mass Concentrations (Mascons) Approach

- 0.5°x0.5° gridded point masses are grouped to mascons
- resolution: 4°x4° over ocean, 2°x2° over land
- 5016 mascons in total

$$\Delta V_{ij}(\vec{x}(t_k)) = \sum_{m=1}^{N_{\text{masc}}} \Delta\rho_m(t_k) \sum_{p \in N_m} f_{ij}\left(\vec{x}_p, \vec{x}(t_k), \vec{q}(t_k)\right) \cdot \text{Area}_p$$



❖ Spherical Harmonics (SH) Approach

$$V_{ij}(\vec{x}(t_k)) = \frac{\partial}{\partial x_i}\frac{\partial}{\partial x_j}\left(\frac{GM}{r}\left\{1 + \sum_{n=1}^{\infty}\left(\frac{a}{r}\right)^n \sum_{m=0}^{n} \bar{P}_{nm}(\cos\theta)\left[\bar{C}_{nm}\cos(m\lambda) + \bar{S}_{nm}\sin(m\lambda)\right]\right\}\right)$$

- GOCE/GRACE combination models:

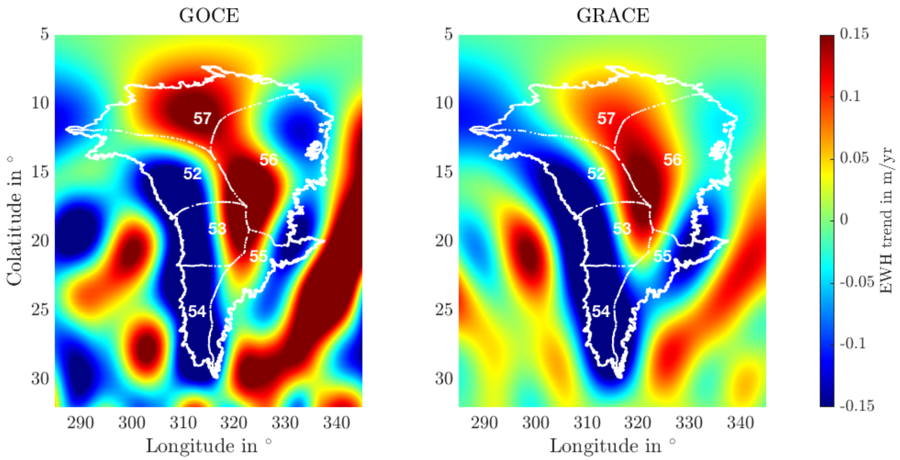
  normal equations from GRACE and GOCE are added and solved

Results: Greenland Ice Mass Signals from GOCE gradients-only

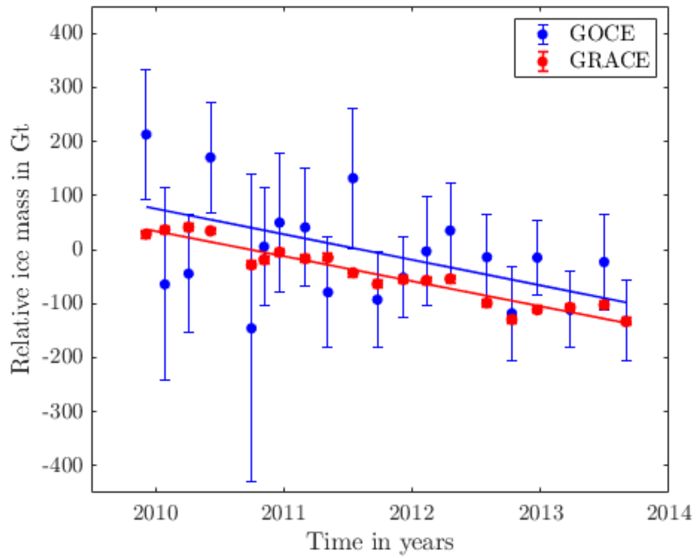
➢ Which temporal signals can GOCE resolve on its own?

❖ SH approach:

EWH trends (degrees 10 to 60):



Mass trend for catchment 54:



GOCE: -47 ± 19 Gt yr^{-1}

GRACE: -46.3 ± 1.3 Gt yr^{-1}

- GOCE trends not significant for all catchments!

GOCE-only:

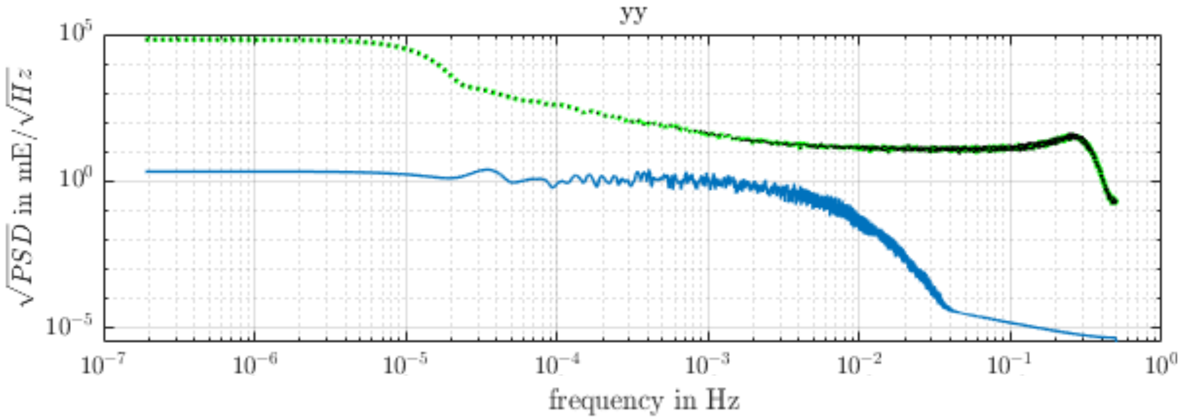
- resolves spatial pattern of the trend
- still strong noise at large scales => SNR < 1

❖ Mascon approach:

no time-variable signals resolved using GOCE-only (despite spatial high-pass filtering)

Results: Signal-to-Noise Ratio in Gravitational Gradients

Analyze the data SNR based on synthetic signals + noise

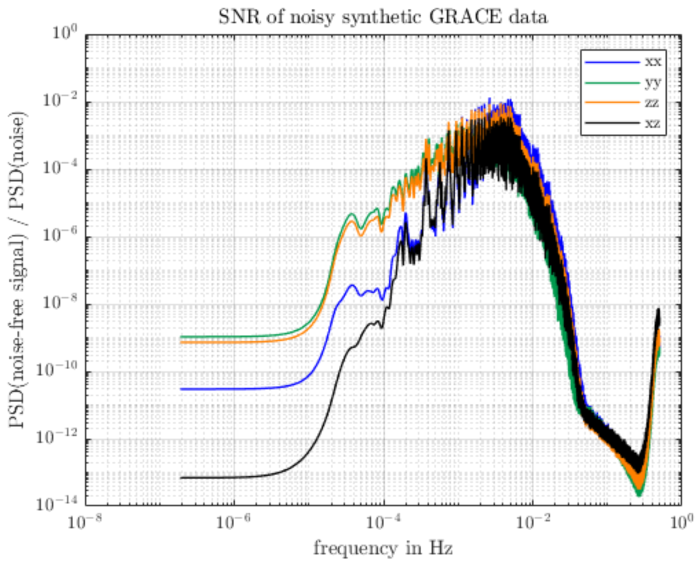


← $\sqrt{\text{PSD}}$ of:

noise-free synthetic gradients (signal)

colored noise

noisy signal



- SNR < 1 for all frequencies
- noise-free signal strongest below 10 mHz
- noise weakest above 5 mHz

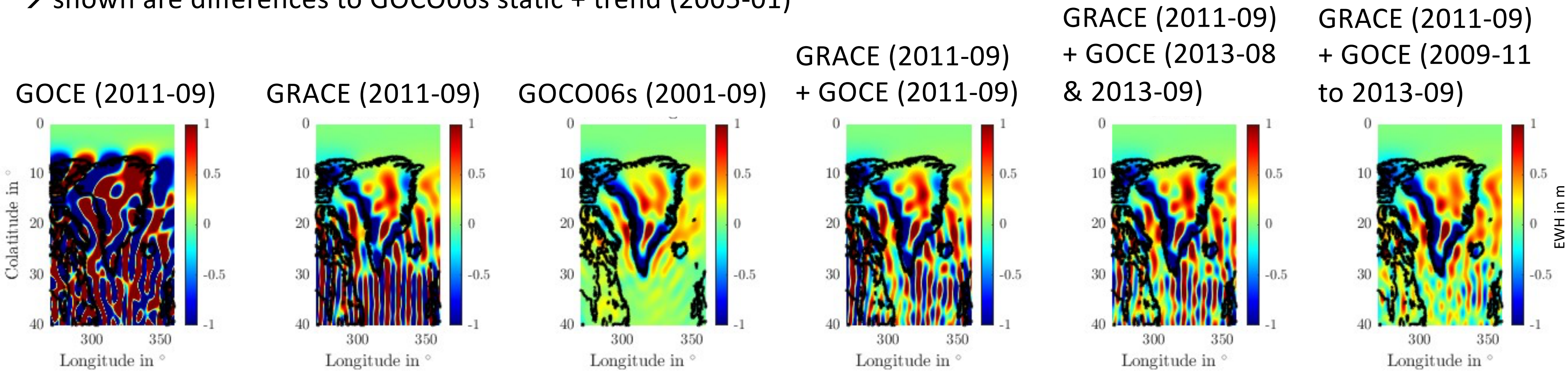
=> noisy signal most sensitive to TV signals between 5 and 10 mHz

Results: GRACE/GOCE combination models

➢ Does GOCE add time-variable signal to GRACE?

❖ SH approach: d/o 96 models for September 2011 (degrees 10 to 96)

→ shown are differences to GOCO06s static + trend (2005-01)



Combination models:

- no additional time-variable signals compared to GRACE-only
- reduced longitudinal noise due to numerical stabilization of NEQs

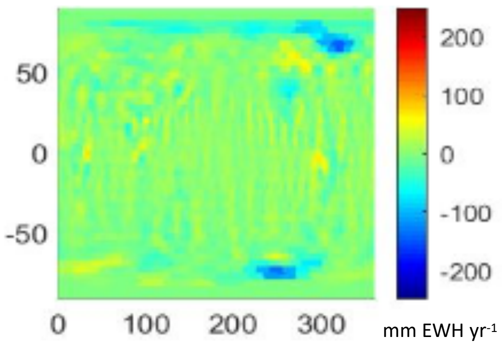
  => the more GOCE data added, the larger the SNR

Results: GRACE/GOCE combination models

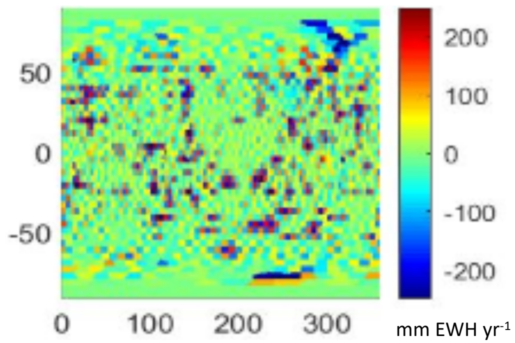
➢ Does GOCE add time-variable signal to GRACE?

❖ Mascon approach: global EWH trends

GRACE-only (d/o 45)



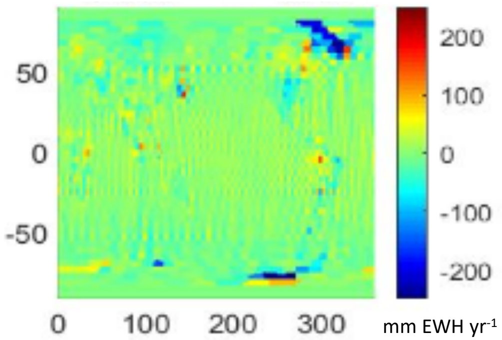
Combination ($\mathrm{d/o_{GRACE}} = 45$, $\mathrm{d/o_{GOCE}} = 60$)



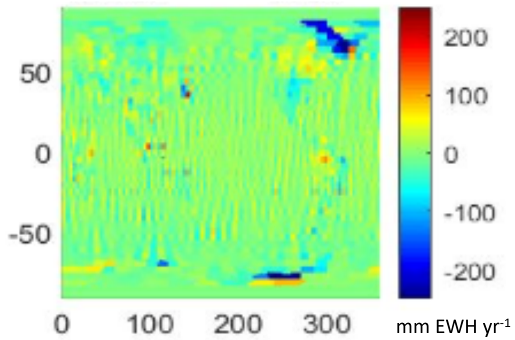
If GRACE limited to d/o 45:

- GOCE adds time variable signal
- combination shows stronger noise than d/o 60 GRACE-only

GRACE-only (d/o 60)



Combination ($\mathrm{d/o_{GRACE}} = \mathrm{d/o_{GOCE}} = 60$)

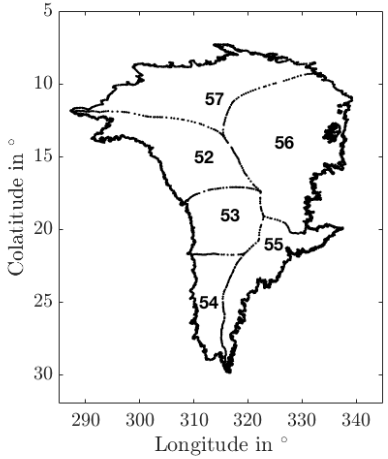


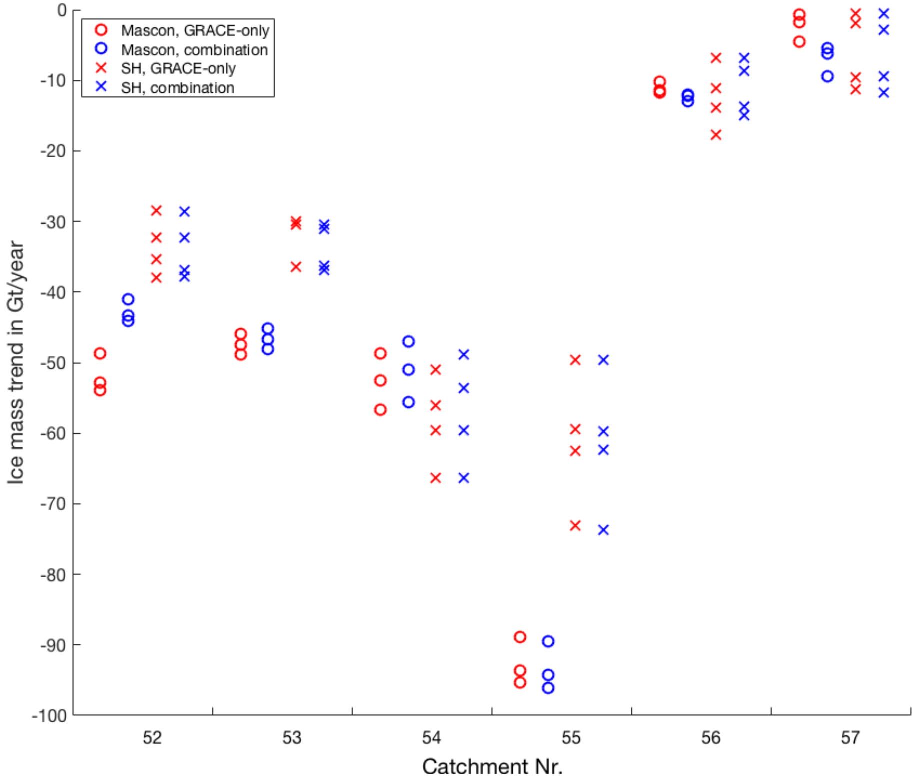
If GRACE included up to d/o 60:

- no information added by GOCE

Results: GRACE/GOCE combination models

Compare ice mass signals estimated by SH and Mascon approach:





- no systematic effect between GRACE and combination trends found

- SH underestimates trends
  - ➢ first tests indicate that spatial leakage effects could be the cause
  - ➢ methods presented by Horwath and Dietrich (2009) could be used to compensate this effect

❖ SH approach: SH degrees 2 to 60/96, with/without polar gap wedge coefficients

❖ Mascon approach: weighting of high-frequency (n=97-120) zero-coefficients is $w_{hf} = 10^{22},\ 10^{23}, 10^{24}$

Conclusion: GOCE for Time-Variable Gravity Signals

Time-variable signals in GOCE gradients:

- GOCE gradients allow to resolve time-variable signals, but no additional signal parts compared to GRACE have been found
- GOCE/GRACE combination models show reduced longitudinal stripes, but same signal amplitudes + resolution as GRACE-only
- reason are high noise amplitudes at large scales in GOCE data

Comparison of approaches:

❖ SH approach: - long-wavelength noise partly removed when eliminating coefficients of n < 10
- mass trend estimation requires compensation of leakage-out effects

❖ Mascon approach: - difficult to reduce long wavelength noise a-posteriori, as long wavelengths not very well represented by the regional base functions
- no "polar gap" problem.

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Acknowledgements

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