Precise estimation of regional mass trends in Greenland using a global regularized inversion of level-2 data from GRACE/GFO satellite missions

Pavel Ditmar

Department of Geoscience and Remote Sensing
Delft University of Technology

Theory: Global estimation of mass trends (in terms of EWH) from SHC trends

Functional model (the Earth oblateness is taken into account):

$$\begin{Bmatrix} \Delta\dot{\bar{C}}_{l,m} \\ \Delta\dot{\bar{S}}_{l,m} \end{Bmatrix} = \frac{\rho_w}{M_E}\frac{(1+k_l)}{(2l+1)} \iint_{\Omega_{ellip}} \dot{H}(\theta,\phi) \left(\frac{r_{ellip}(\theta)}{a}\right)^l \bar{P}_{lm}(\cos\theta) \begin{Bmatrix} \cos m\phi \\ \sin m\phi \end{Bmatrix} d\Omega_{ellip}$$

EWH trend

SHC trends

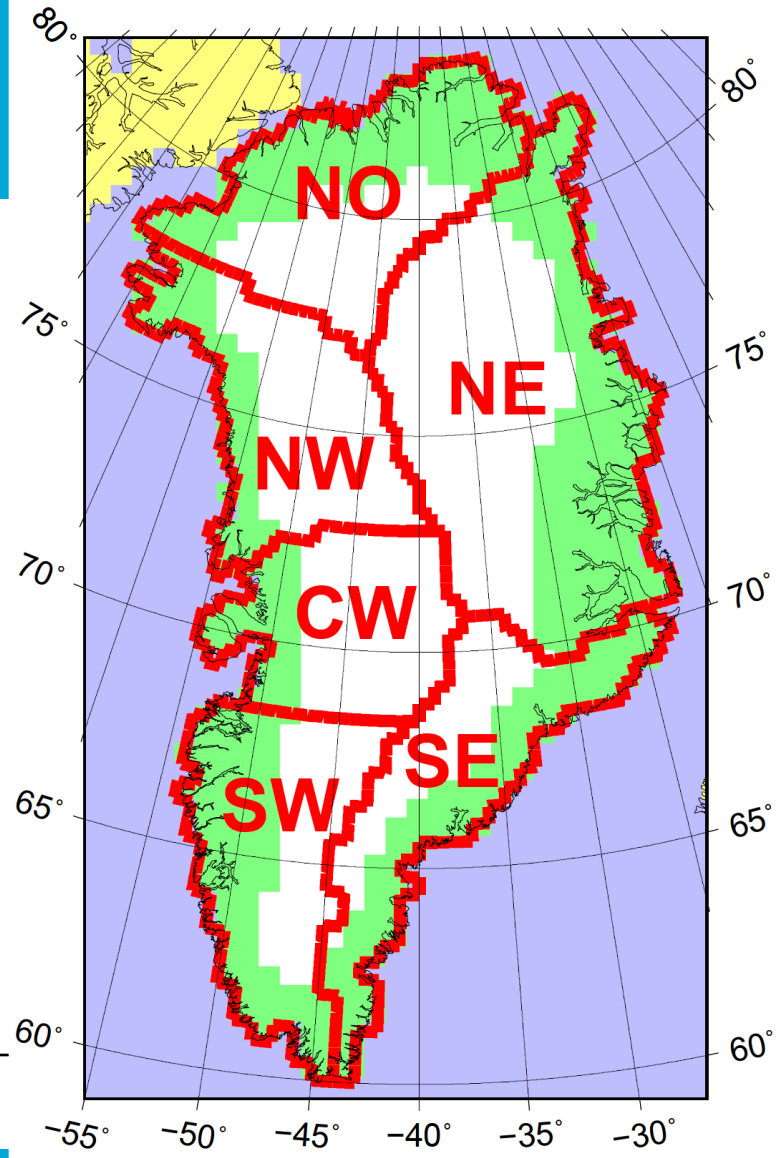
Adopted discretization: 1° x 0.4° (162,000 unknowns)

Regularization functional (1st-order Tikhonov):

$$\iint_{\Omega} \alpha(\theta,\phi) \left[\nabla \dot{H}(\theta,\phi)\right]^2 d\Omega = \min$$

Regularization parameter (always positive)

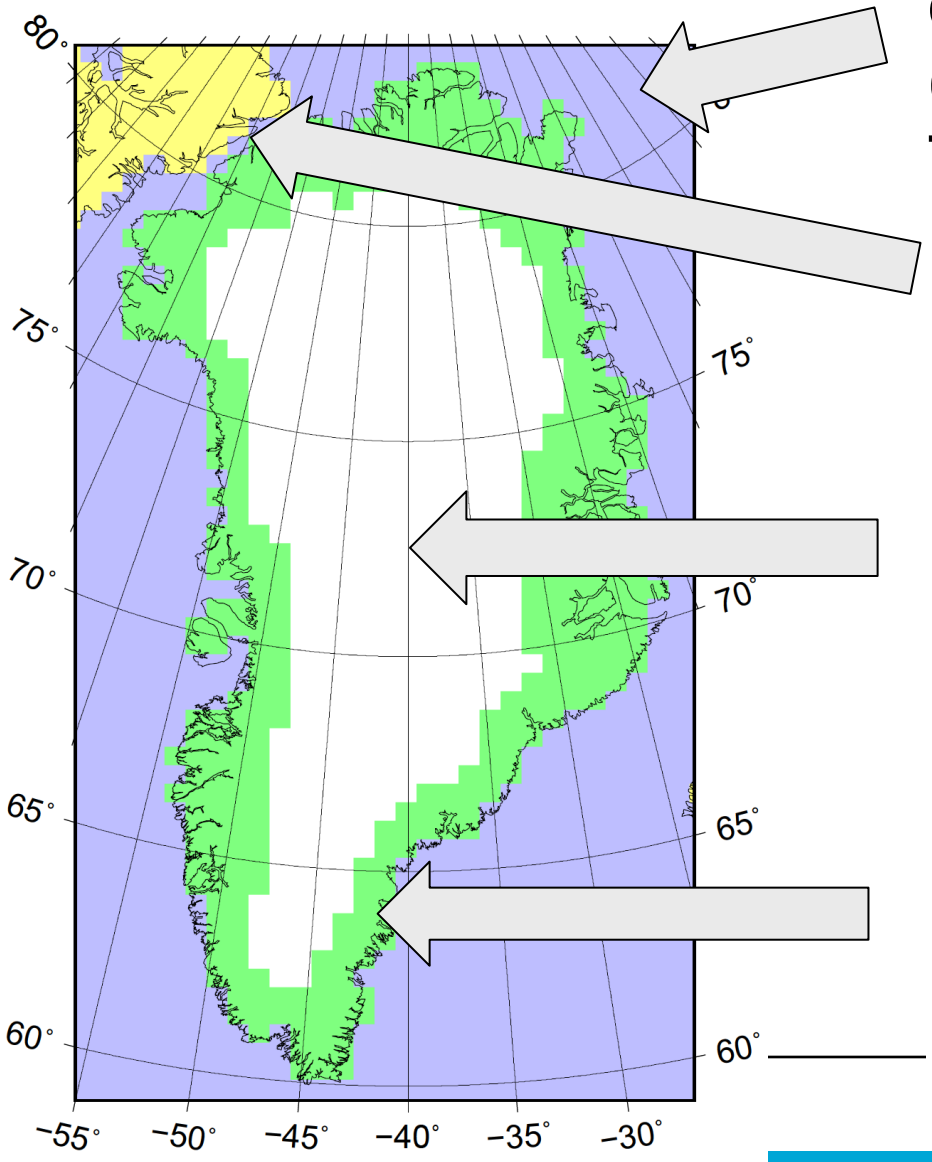
Division into Drainage Systems and optimization of regularization parameters



The goal is to optimize simultaneously the estimates of regional mass trends integrated over:

- Entire Greenland
- Individual Drainage Systems (DSs)

Adopted regularization



Ocean: $\alpha = 3 \times 10^6$
(no regularization across the coastal lines)

Land outside Greenland:
$\alpha = 3000$

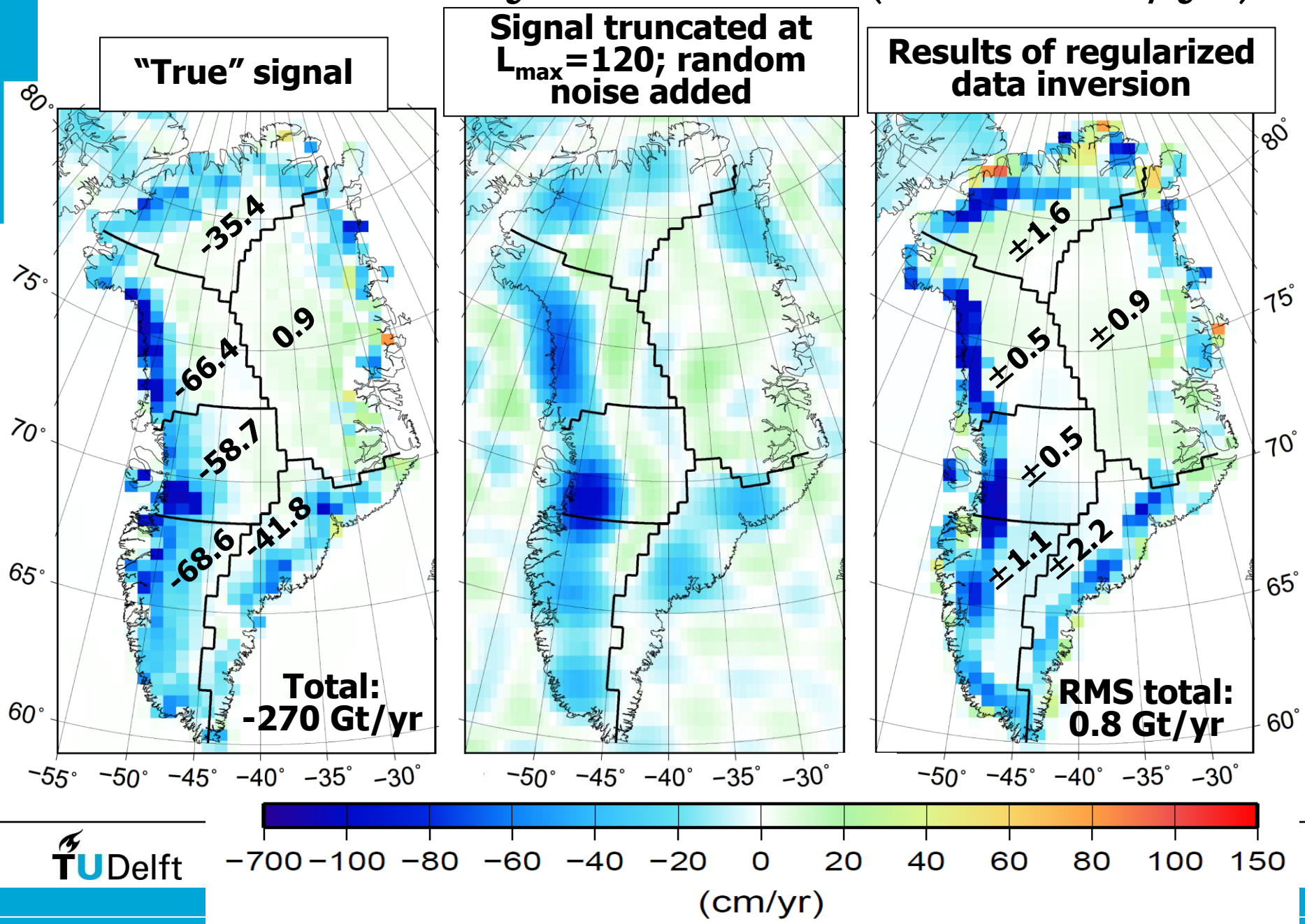
Inner part of the GrIS (> 80 km from the GrIS margin):
$\alpha = 300$

Tundra and 80-km periphery of the GrIS: $\alpha = 10^{-4}$

Numerical study: the set-up

- "True" signal:
  - Inside Greenland: Cryosat-based elevation trends in 2011-2015 (Simonsen & Srensen, 2017; ESA-CCI) – converted into EWH trends to ensure that the rate of total mass loss in Greenland is 270 Gt/yr
  - Outside Greenland: Global GRACE/GFO-based mascon solution optimized for long-term (2002-2022) trends (Loomis et al, 2021); scaled to ensure a global mass conservation
- Maximum spherical harmonic degree: 120
- Random noise: 10 realizations of realistic noise in SH coefficients

Numerical study (units: Gt/yr)



TU Delft

Numerical simulations: extended analysis of the error budget of regional mass trends

Contributor	RMS per DS (Gt/yr)	Entire Greenland (Gt/yr)
Random noise: rms based on 10 realistic error realizations	**0.7**	**0.4**

Numerical simulations: extended analysis of the error budget of regional mass trends

Contributor	RMS per DS (Gt/yr)	Entire Greenland (Gt/yr)
Random noise: rms based on 10 realistic error realizations	**0.7**	**0.4**
Signal leakage: rms based on 4 mass trend realizations (obtained by upscaling altimetry-based elevation trends over 5-year time intervals in 2003-2019)	**2.8**	**0.7**

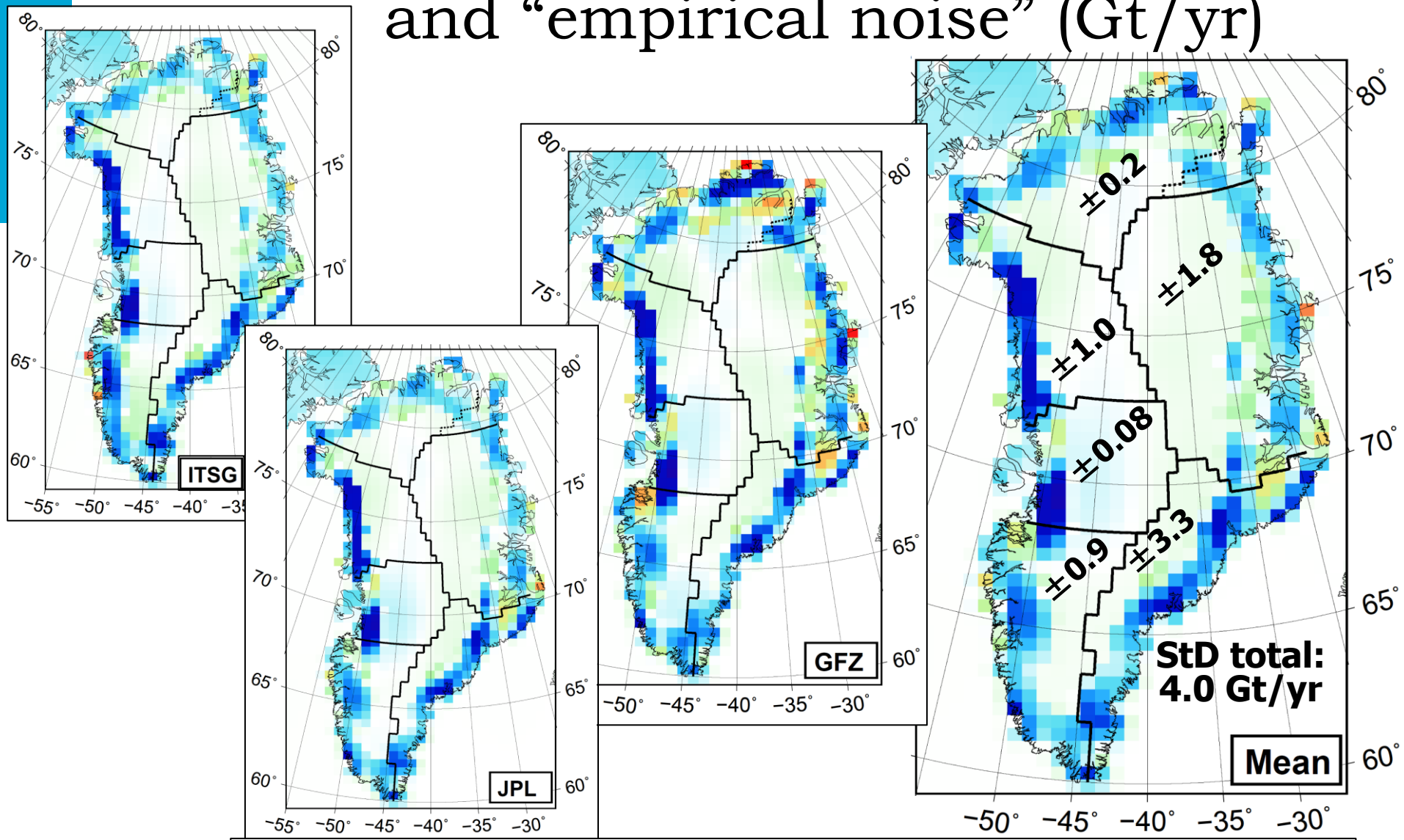
Numerical simulations: extended analysis of the error budget of regional mass trends

Contributor	RMS per DS (Gt/yr)	Entire Greenland (Gt/yr)
Random noise: rms based on 10 realistic error realizations	**0.7**	**0.4**
Signal leakage: rms based on 4 mass trend realizations (obtained by upscaling altimetry-based elevation trends over 5-year time intervals in 2003-2019)	**2.8**	**0.7**
GIA: 50% of signal from ICE-6G (VM5a) model	**2.2**	**9.1**

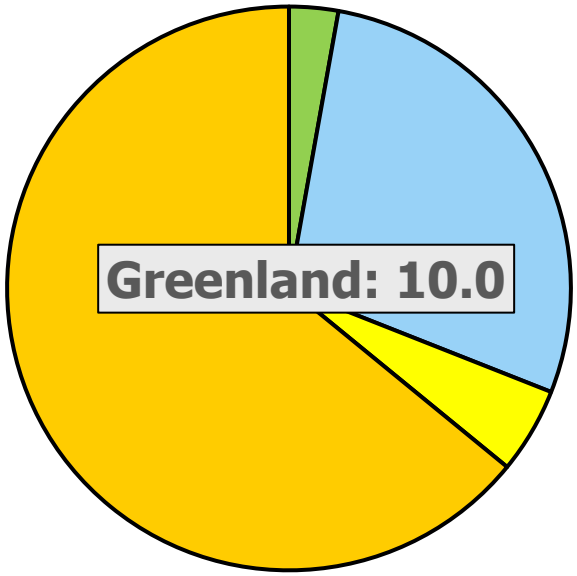
Processing of real GRACE/GFO data

- The input: GRACE/GRACE-FO monthly solutions from:
  - Graz University of Technology (ITSG-Grace2018; Kvas et al., 2019)
  - German Research Centre for Geosciences (GFZ RL06/RL06.1; Dahle et al, 2018)
  - Jet Propulsion Laboratory (JPL RL06/RL06.1; Yuan, 2018)
- Omitted coefficients: degree-1, $C_{2,0}$, $C_{3,0}$
- Time interval: Apr. 2002 – Aug. 2023
- GIA correction: ICE-6G (VM5a)

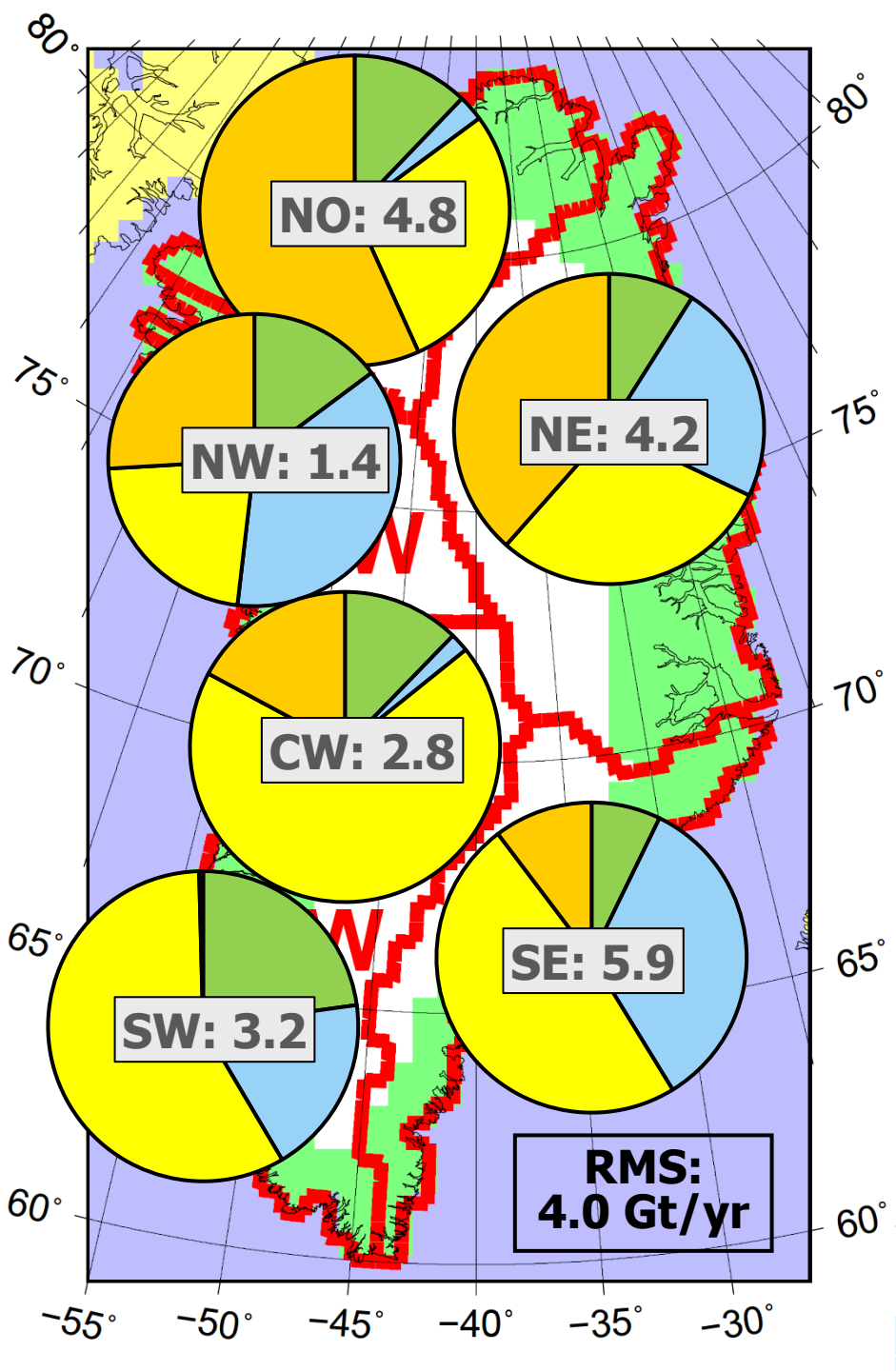
Inversion of real data (Lmax=96): results and “empirical noise” (Gt/yr)



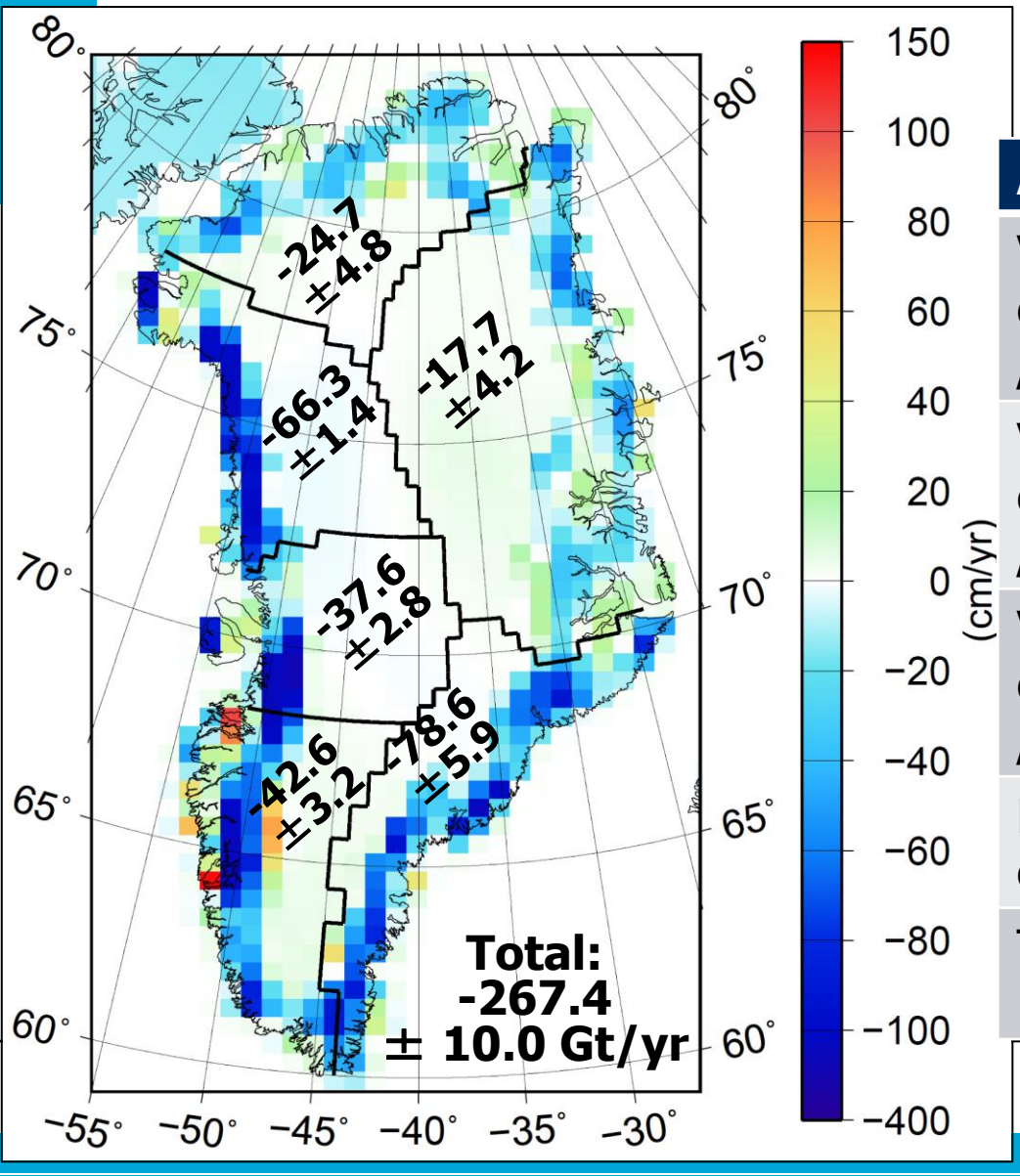
Error budget: summary (Gt/yr)



Random Empirical Signal leakage GIA

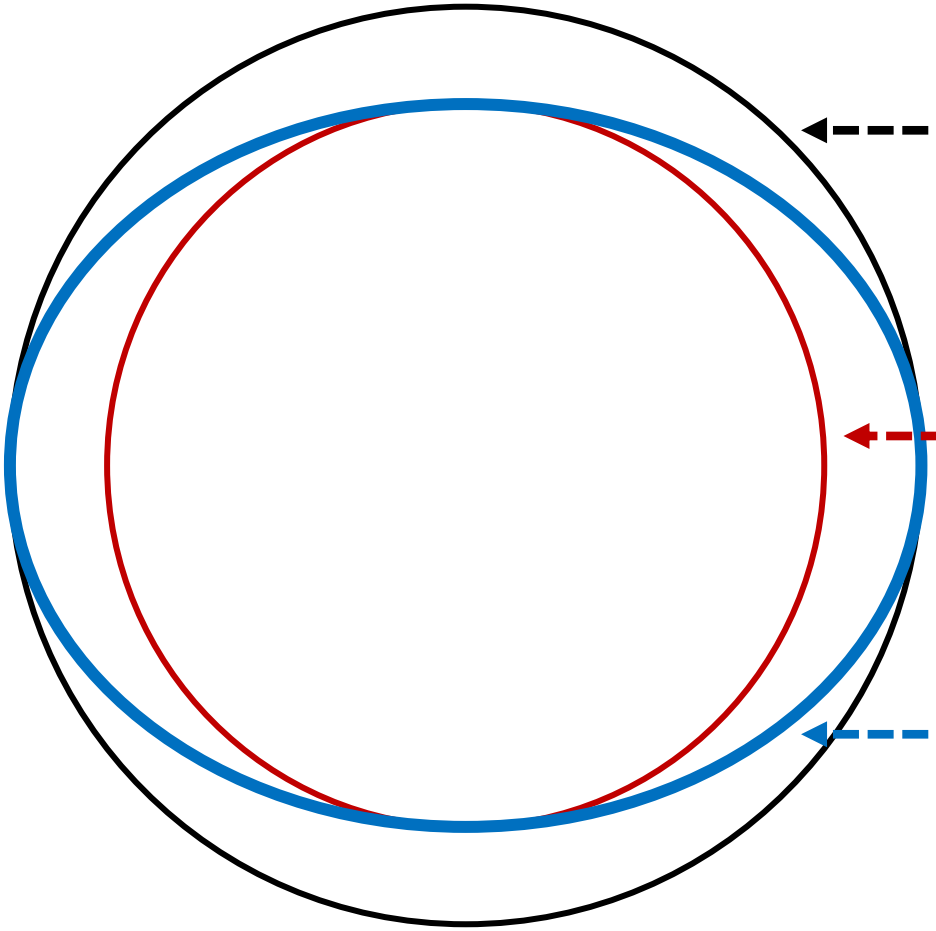


Inversion of real data (ITSG, Lmax=120): Results (Gt/yr) and comparison with other studies



Authors	Interval	Trend (Gt/yr)
Velicogna et al, 2020 / CSR	04.2002-09.2019	-261 ± 43
Velicogna et al, 2020 / JPL	04.2002-09.2019	-261 ± 45
Velicogna et al, 2020 / GFZ	04.2002-09.2019	-254 ± 47
Loomis et al, 2021	04.2002-09.2020	-282 ± 35
This study	04.2002-08.2023	-267.4 ± 10.0

Spherical Earth vs ellipsoidal Earth



R = 6378 km
Mass loss = 266.1 Gt/yr

R = 6359 km
Mass loss = 264.5 Gt/yr

Ellipsoid:
Mass loss = 267.4 Gt/yr

Conclusions

- Precise estimation of regional mass changes in Greenland is a highly relevant task
- Regularization tuned for the type of the target estimates plays a critical role
- Regional mass trends per DS and over entire Greenland can be estimated with an accuracy better than 10% in most cases
- Total mass loss in Greenland in 04.2002-08.2023 is estimated as -267.4 ± 10.0 Gt/yr

---

- Manuscript *"Estimation of regional ice mass trends in Greenland using a global inversion of level-2 satellite gravimetry data"* is under review at *Journal of Geodesy*