

# Time-variable gravity field recovery from reprocessed GOCE precise science orbits

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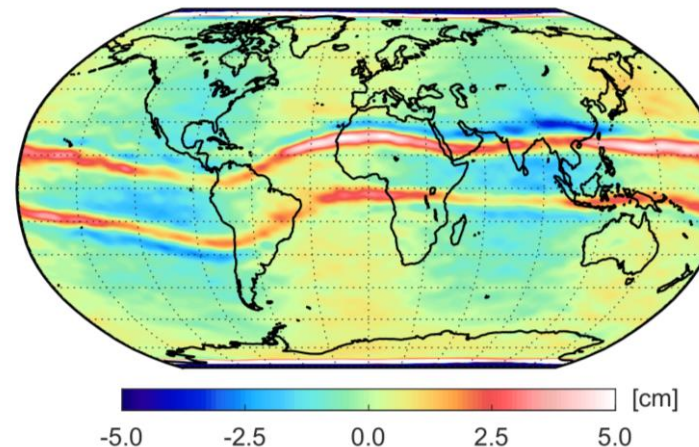
# Introduction

- ESA's satellite mission GOCE (2009 – 2013)
  - Gravity Field and Steady-State Ocean Circulation Explorer
  - Sun-synchronous orbit, mean altitude ~255 km
  - Core instrument: Gravity gradiometer (consisting of six accelerometers)



- Satellite-to-Satellite Tracking (SST)
  - Two dual-frequency GPS receivers
  - Primary instrument for
    - GPS-based orbit determination
    - GPS-based gravity field recovery
- ESA's GOCE Reprocessing campaign

- Issues with operational GOCE orbits ([Jäggi et al., 2015](#))



- Orbit positions affected by large ionospheric changes
- Limitations for (time-variable) gravity field recovery

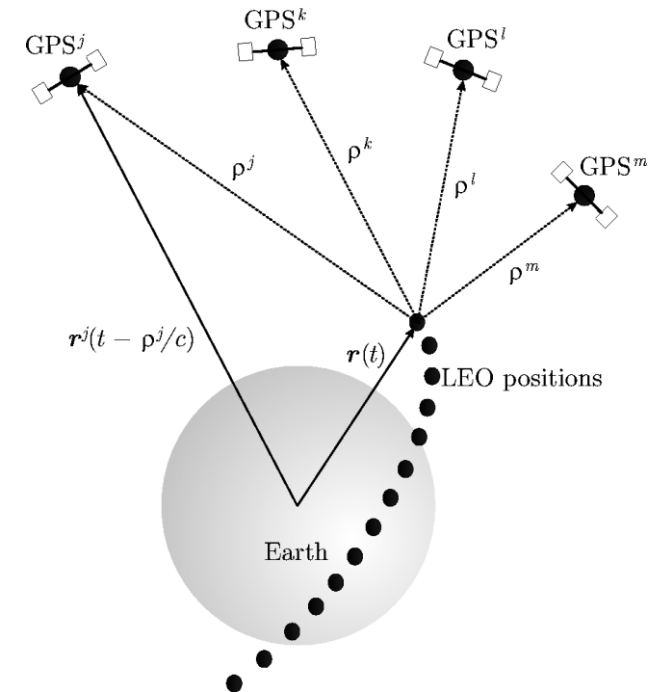
# GOCE Reprocessing Campaign at AIUB

- Reprocessing of GOCE Precise Science Orbits (PSO)
  - Bernese GNSS software using reprocessed GPS products (Sušnik et al., 2020)
  - GPS data weighting strategy to mitigate ionospheric effects (Schreiter et al., 2019)
    - Unweighted and weighted reprocessed PSO
- Gravity field recovery (Celestial Mechanics Approach)
  - 1-sec reprocessed kinematic GOCE positions + covariance information
  - Use of GOCE accelerometer (ACC) data as part of the force model
- Computed gravity field solutions:

Reprocessed PSO  
(unweighted)

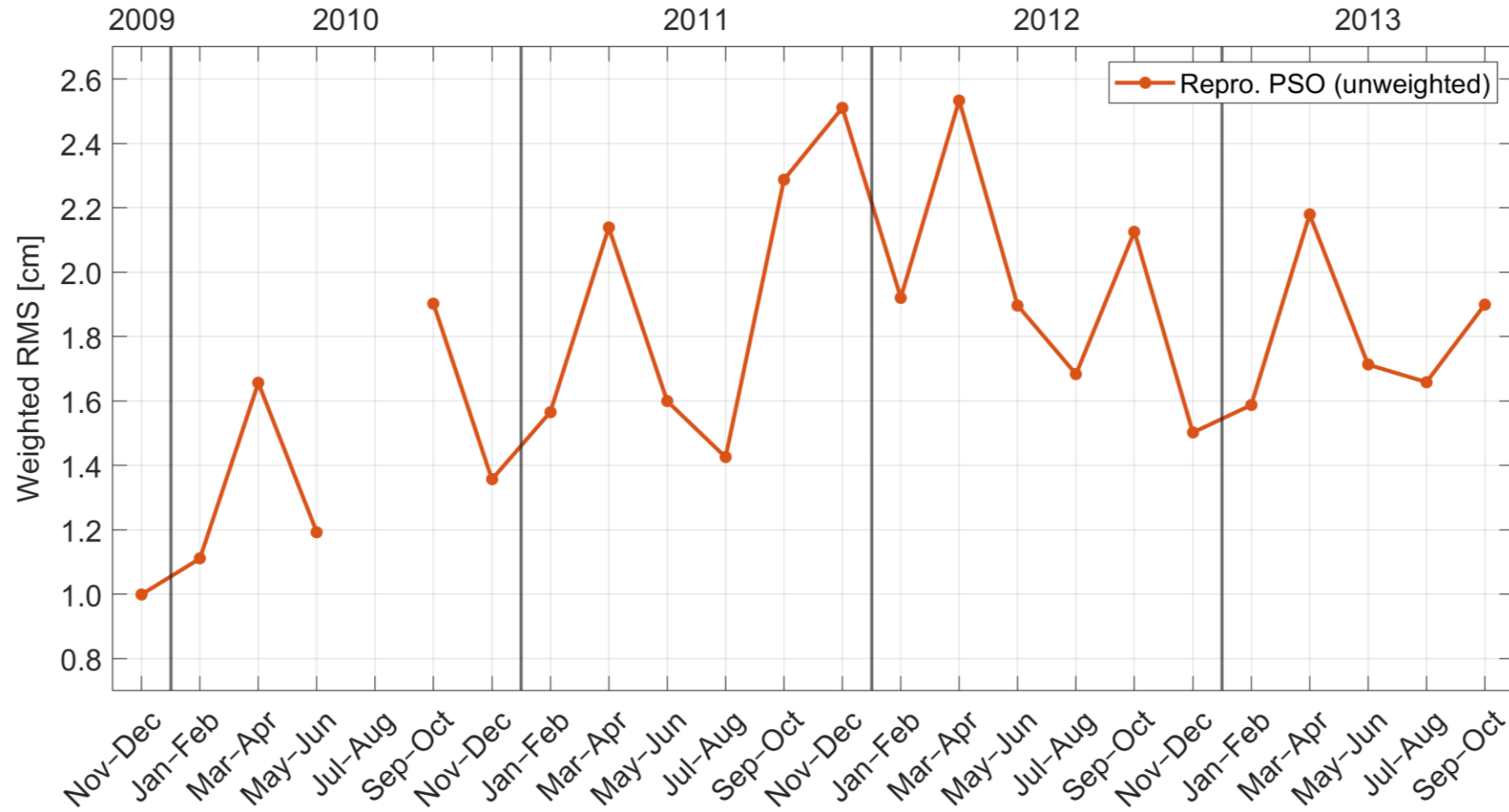
Reprocessed PSO  
(weighted)

Reprocessed PSO  
(weighted)  
+ ACC data



# GPS-based gravity field recovery with GOCE

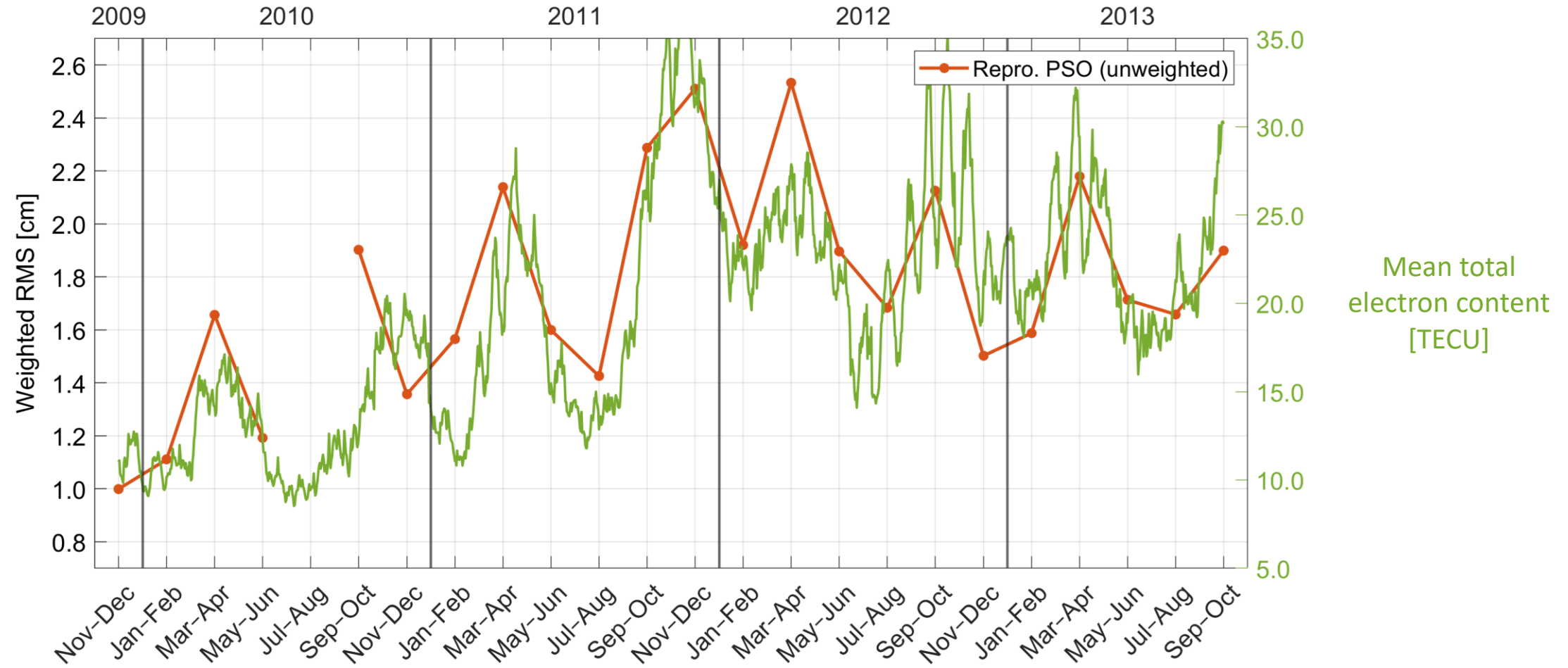
- Quality of bi-monthly gravity field solutions



Geoid height differences  
w.r.t. ITSG-Grace2018  
(300 km Gauss-filtered)

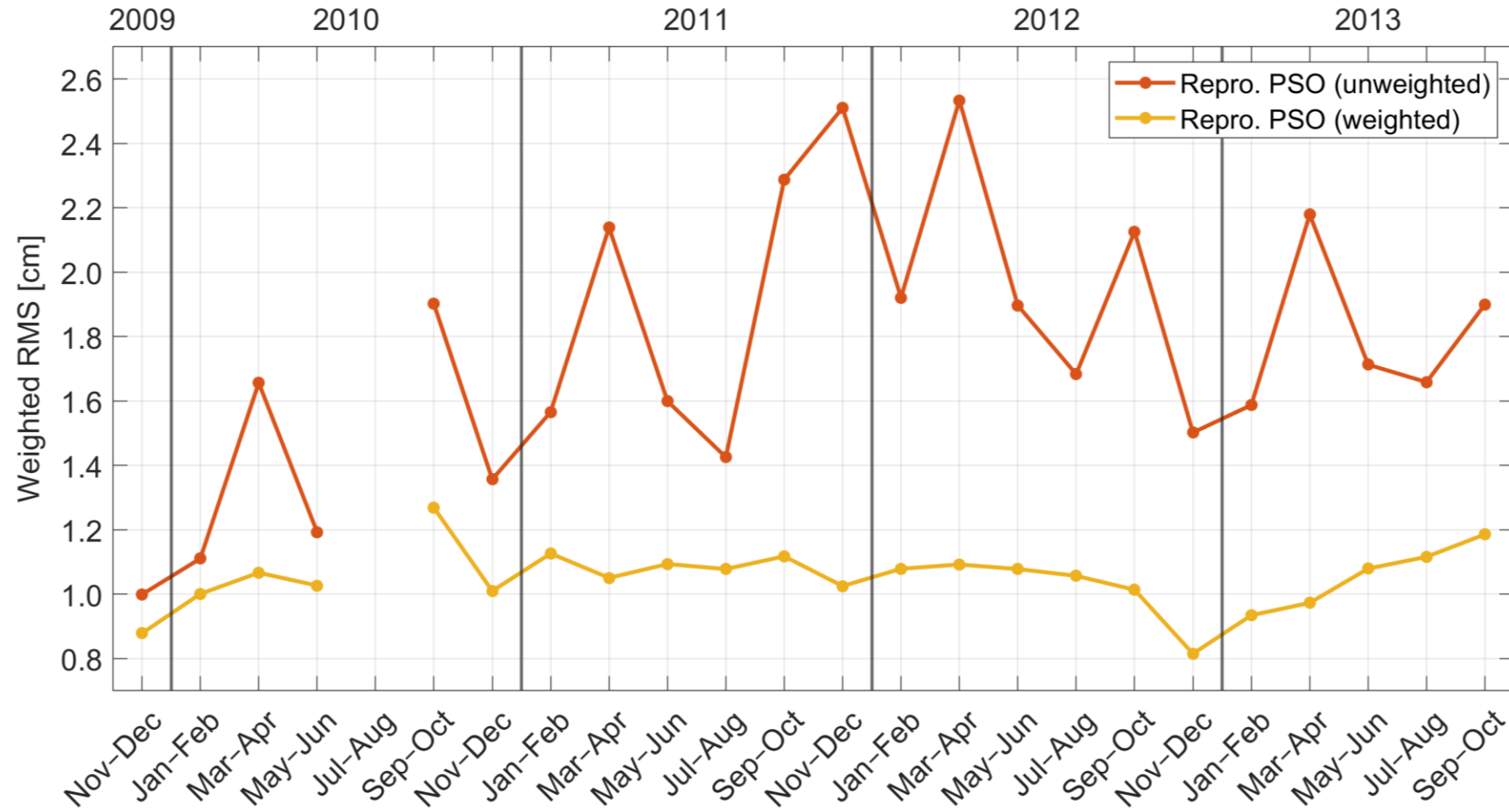
# GPS-based gravity field recovery with GOCE

- Quality of bi-monthly gravity field solutions



# GPS-based gravity field recovery with GOCE

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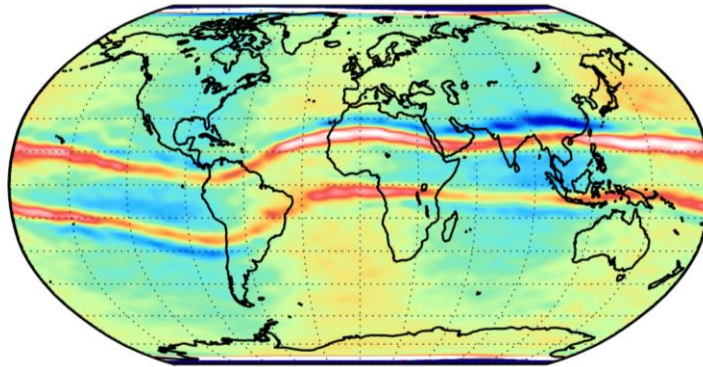
Geoid height differences  
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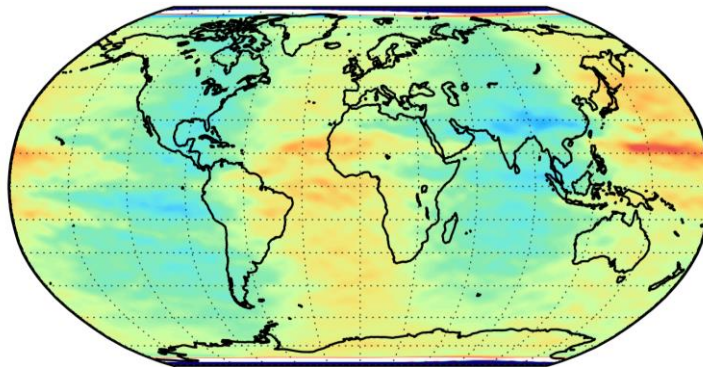
# Improvements in long-term solutions

- Geoid height differences

unweighted  
PSO



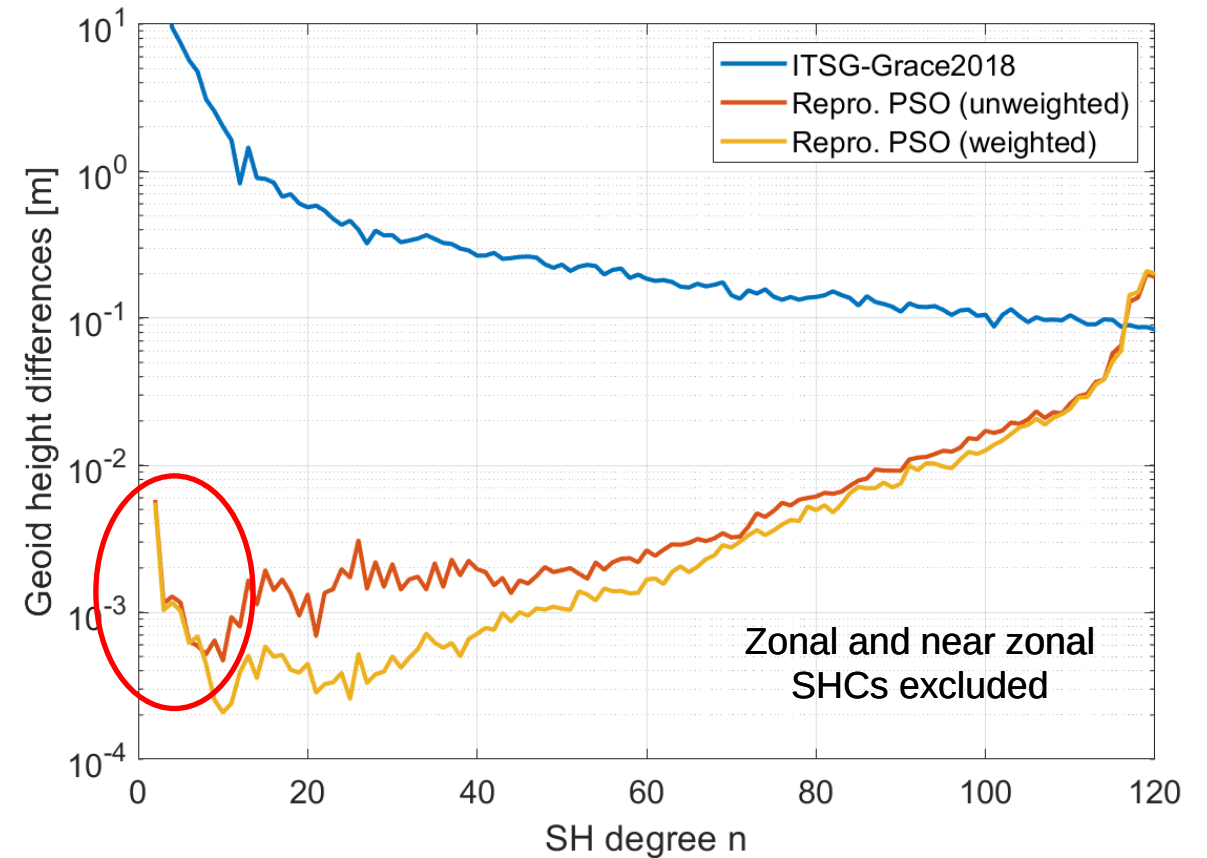
weighted  
PSO



-5.0 -2.5 0.0 2.5 5.0 [cm]

Geoid height differences

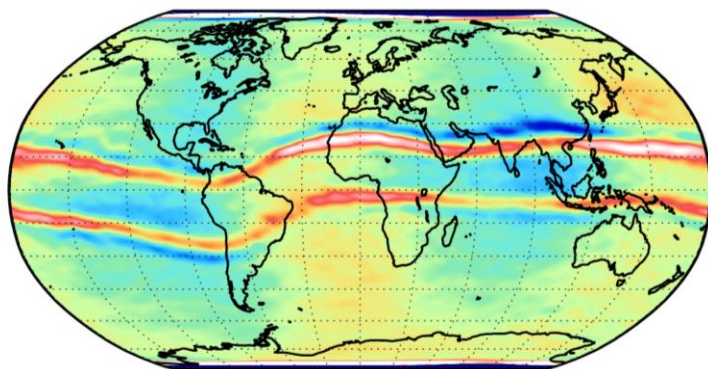
- Difference degree amplitudes



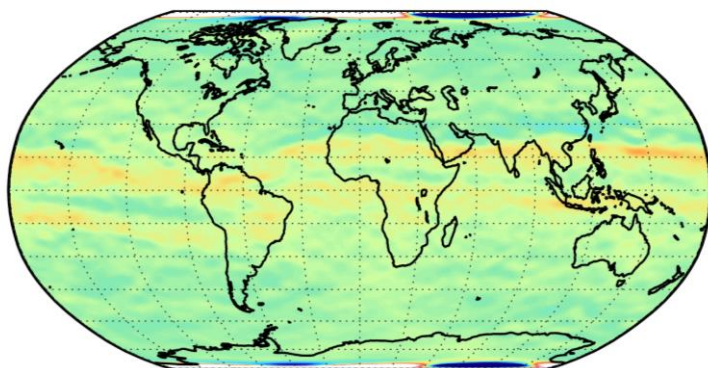
# Improvements in long-term solutions

- Geoid height differences

unweighted  
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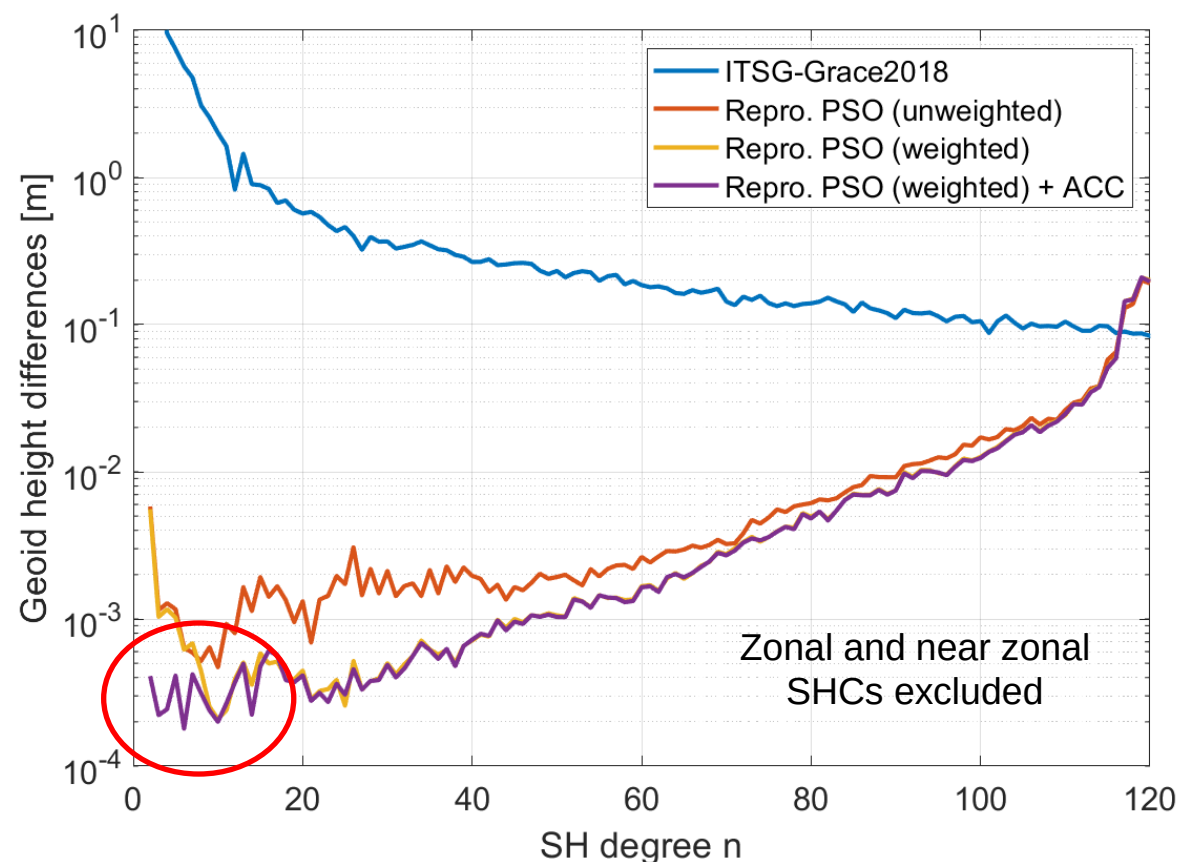


weighted  
PSO  
+  
ACC



Geoid height differences

- Difference degree amplitudes





# Time-variable gravity field recovery

- Set up of (static) SH coefficients up to d/o 120
- Parameter transformation on the level of normal equations (for coefficients up to d/o 10)

$$x_k = \underbrace{a_k \cdot [\omega(t_i - t_0)]}_{\text{Trend term}} + \underbrace{b_k \cdot \cos[\omega(t_i - t_0)]}_{\text{Cosine term}} + \underbrace{c_k \cdot \sin[\omega(t_i - t_0)]}_{\text{Sine term}} + \underbrace{d_k}_{\text{Offset}}$$

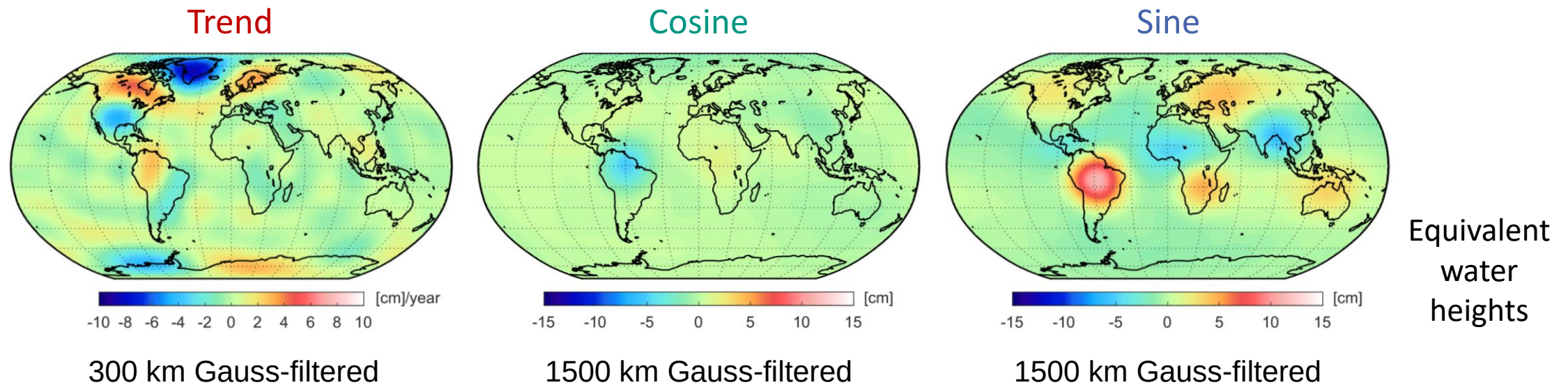
← Annual variations →

# Time-variable gravity field recovery

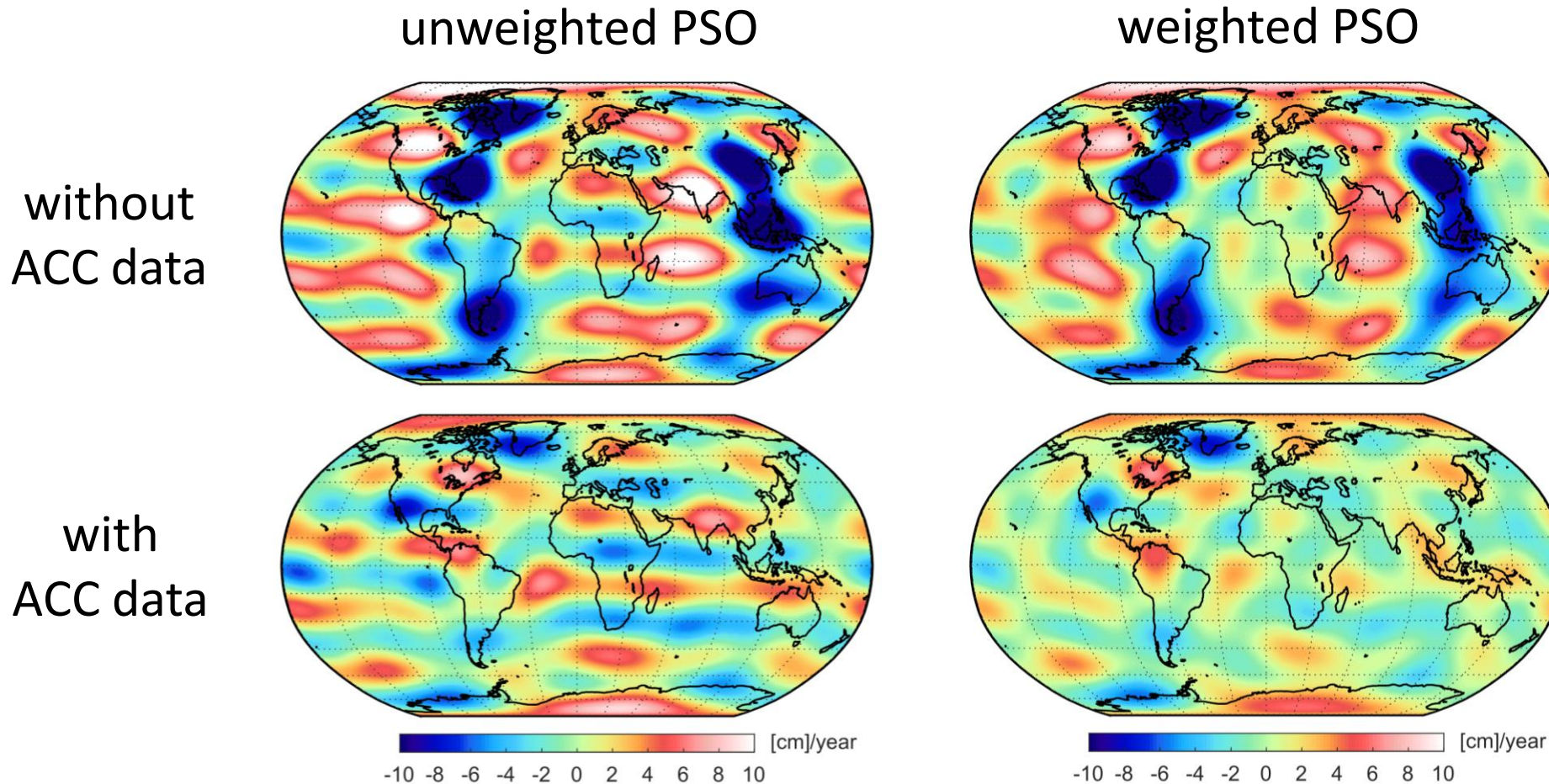
- Set up of (static) SH coefficients up to d/o 120
- Parameter transformation on the level of normal equations (for coefficients up to d/o 10)

$$x_k = a_k \cdot [\omega(t_i - t_0)] + b_k \cdot \cos[\omega(t_i - t_0)] + c_k \cdot \sin[\omega(t_i - t_0)] + d_k$$

- Reference values from GRACE K-band data (a posteriori fit of monthly ITSG-Grace2018 solutions)



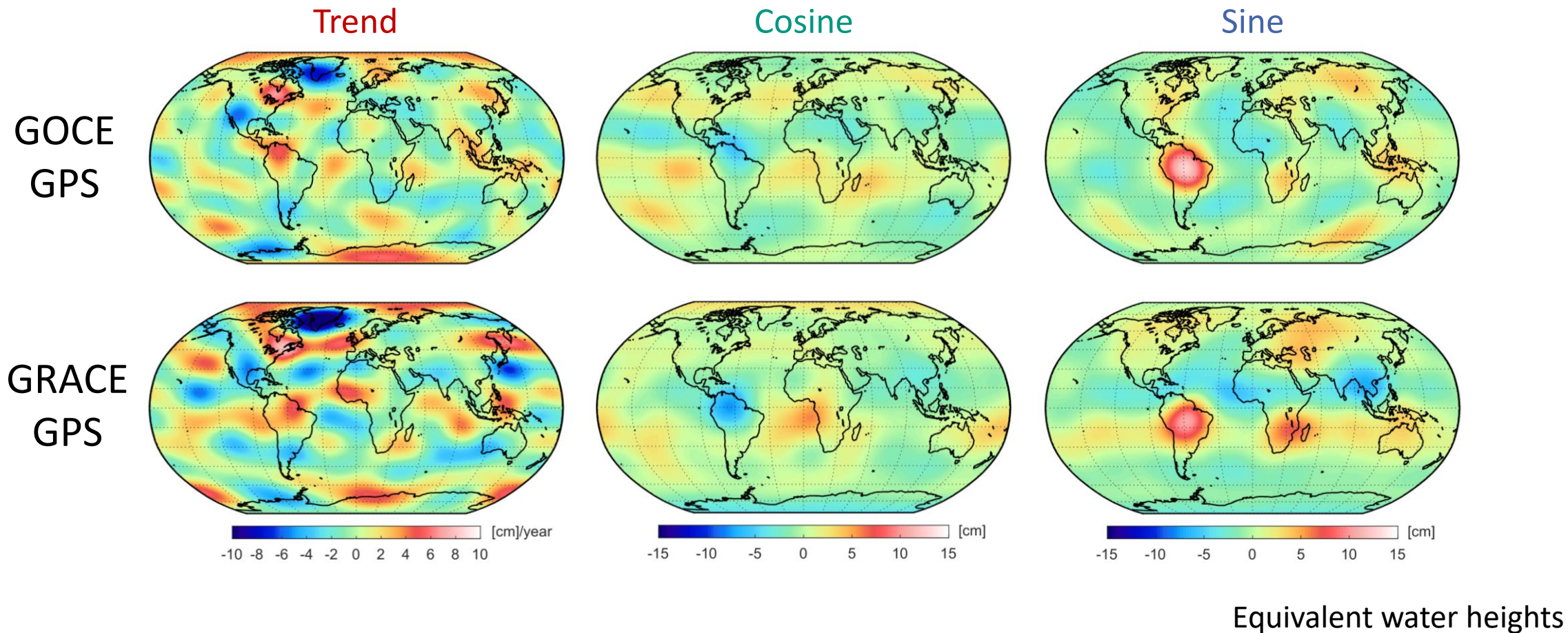
# Estimated trends from GOCE (Nov 2009 – Oct 2013)



Equivalent water heights



# Time-variable gravity field signals (Nov 2009 – Oct 2013)



# Summary

- Complete reprocessing of the GOCE Precise Science Orbits (PSO)
- Improved GPS-based gravity field recovery based on reprocessed PSO
- Time-variable gravity field recovery from reprocessed PSO
  - Major time-variable signals can be recovered from about 4 years of GOCE-GPS data
  - Use of GOCE accelerometer data is crucial to derive meaningful linear trends
  - Temporal variations obtained from GOCE are comparable to those from GRACE-GPS data



RMS values w.r.t.  
ITSG-Grace2018

| Solution  | Trend<br>[cm/year] | Cosine<br>[cm] | Sine<br>[cm] |
|-----------|--------------------|----------------|--------------|
| GOCE-GPS  | 1.27               | 1.44           | 1.37         |
| GRACE-GPS | 1.87               | 1.35           | 1.01         |



# References

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Jäggi A, Bock H, Meyer U, Beutler G, van den IJssel J (2015): GOCE: assessment of GPS-only gravity field determination. Journal of Geodesy 89(1):33–48, DOI:10.1007/s00190-014-0759-z

Schreiter L, Arnold D, Sterken V, Jäggi A (2019): Mitigation of ionospheric signatures in Swarm GPS gravity field estimation using weighting strategies. Annales Geophysicae 37(1):111–127, DOI:10.5194/angeo-37-111-2019

Sušnik A, Grahsl A, Arnold D, Villiger A, Dach R, Beutler G, Jäggi A (2020): GOCE: Validation of the EGSIM-REPRO GNSS orbits and satellite clock corrections. Remote Sensing 12(14):2322, DOI:10.3390/rs12142322

Publication in preparation:

Arnold D, Grombein T, Schreiter L, Sterken V, Jäggi A: Reprocessed precise science orbits and gravity field recovery for the entire GOCE mission.

Thank you for your attention

