COSPAR 2025 Symposium, Nicosia

How orbit data of nano-satellites can contribute to study the Earth's gravity field

T. Grombein, A. Miller, M. Lasser, D. Arnold, A. Jäggi

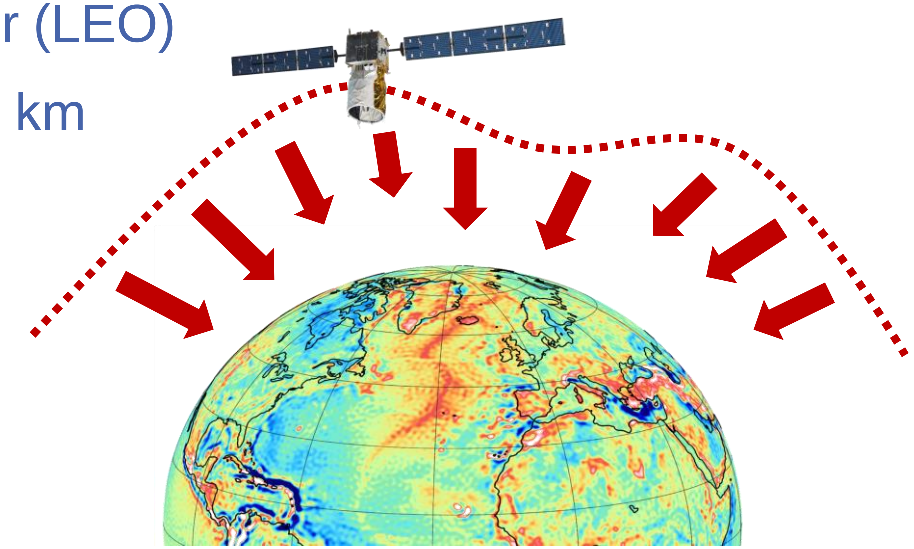
[1] Geodetic Institute, Karlsruhe Institute of Technology [2] Astronomical Institute, University of Bern

Introduction

Any satellite may serve as a gravity field sensor

Low Earth Orbiter (LEO)

~ 200 − 2000 km



Satellite’s orbit is influenced by gravity field variations

Slides inspired by D. Arnold

Introduction

GNSS satellites

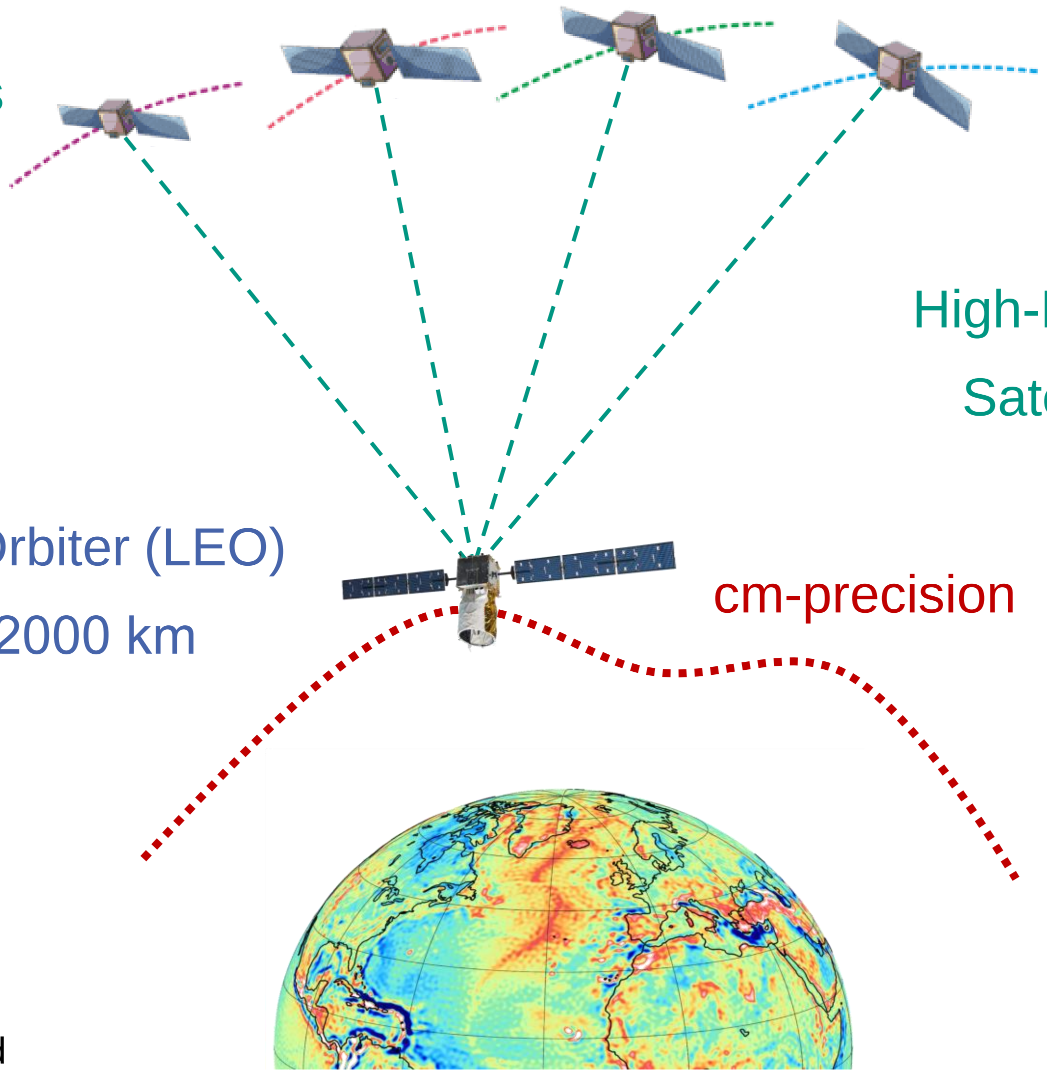
~ 20.000 km

High-Low Satellite-to-Satellite-Tracking

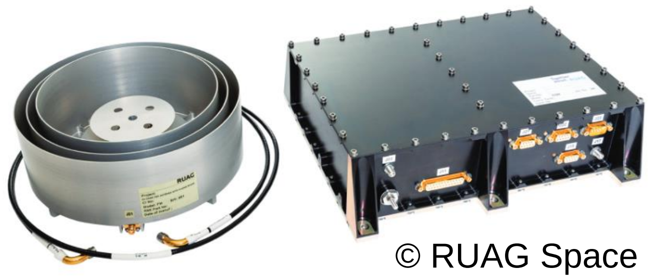
Low Earth Orbiter (LEO)

~ 200 − 2000 km

cm-precision



GNSS antenna and receiver



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Slides inspired by D. Arnold

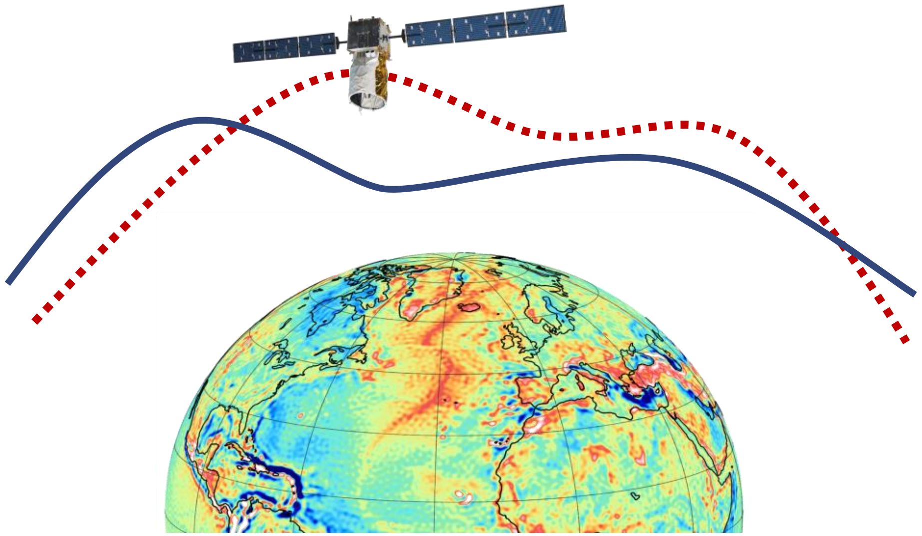
Introduction

GNSS
tracking data

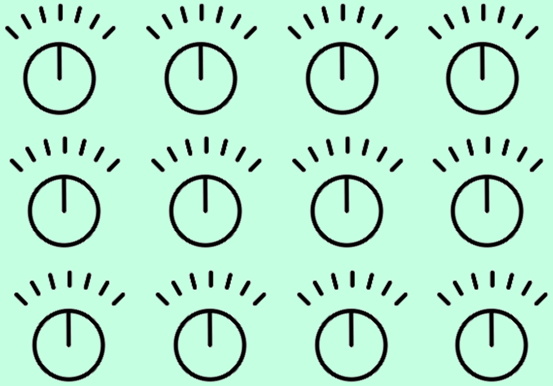
Observed orbit ⇔ Simulated orbit

Comparison

Equation of motion
based on force models
(e.g., gravity field)



Gravity field tuning



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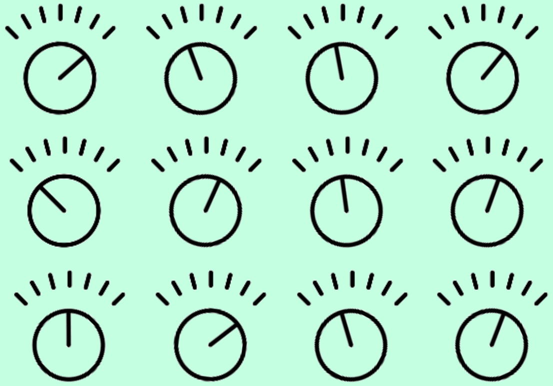

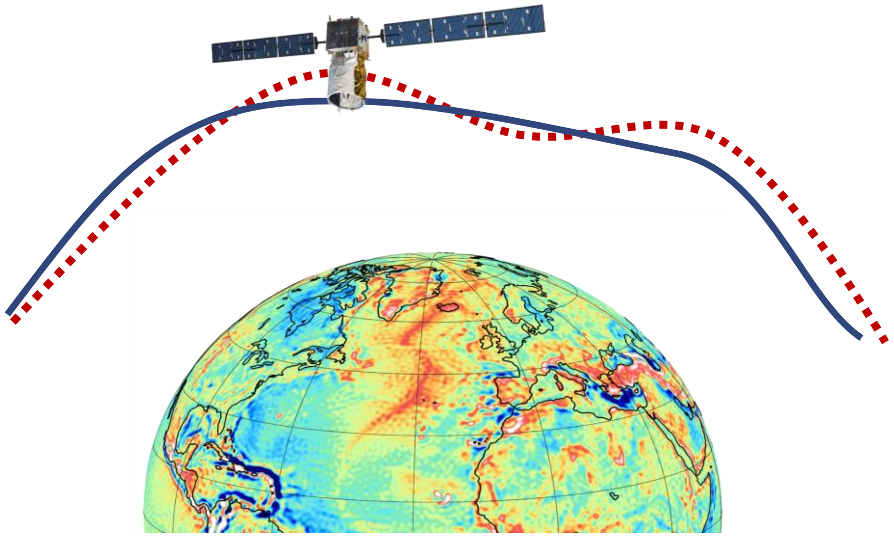

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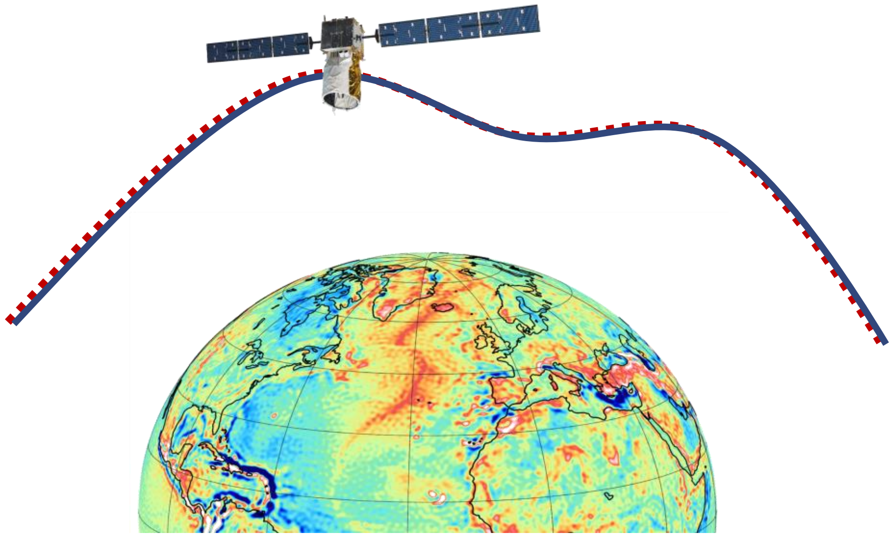

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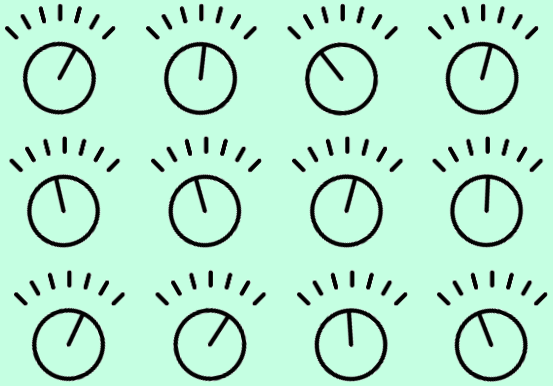


Slides inspired by D. Arnold

Use of commercial satellite mega-constellations

Potential

Huge amount of observations

Faster global ground track coverage

Increased spatial-temporal resolution

Mega-constellations

© N. Nienaß

Limitations

Restricted sensitivity (long-wavelength)

Dual-frequency GNSS receivers needed

Limited data access and quality

Data and method

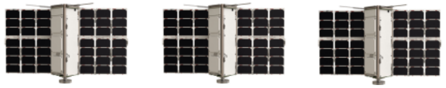
Spire CubeSats: Data overview (May – Oct 2020)

Karlsruhe Institute of Technology

8 Sun-synchronous orbits (inclination 97.5°)

FM099 FM101 FM102

- Altitude: 505 km



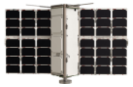
FM103 FM104 FM106 FM107 FM108

- Altitude: 530 km

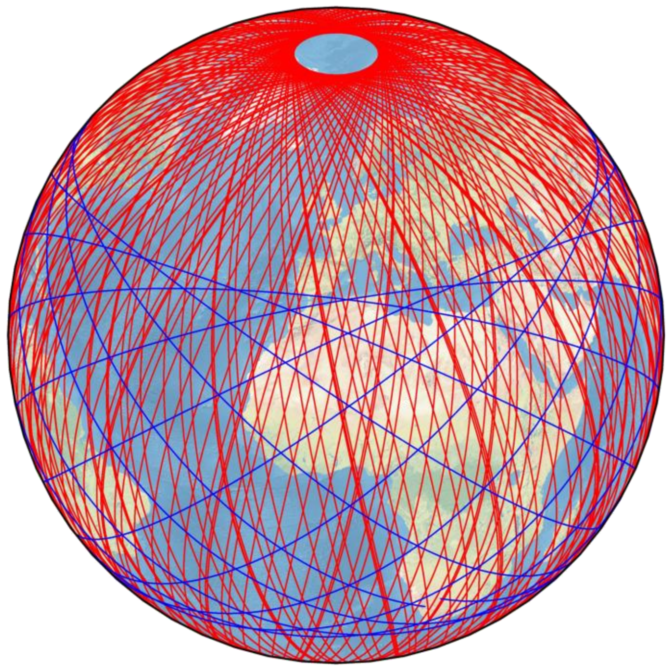
1 Low-inclined orbit (inclination 37.0°)

FM115

- Altitude: 570 km



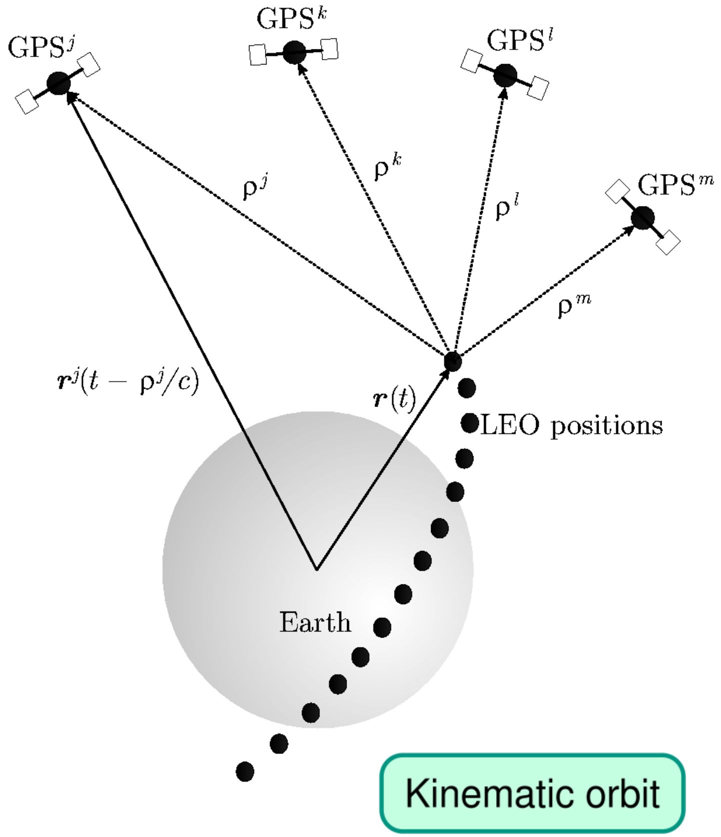
Ground track coverage after one day



Gravity field recovery method

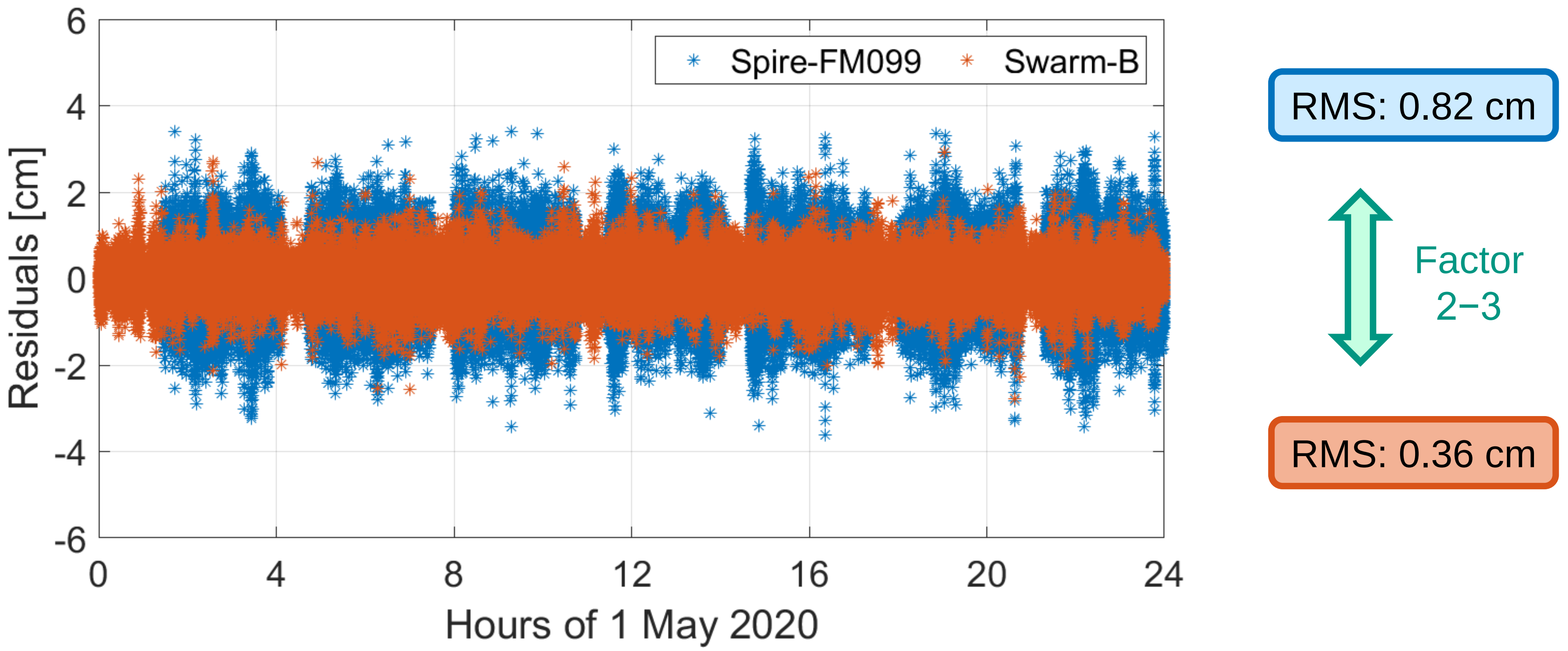
- Celestial Mechanics Approach (two-step procedure)

- Processing with the Bernese GNSS software
  - GNSS products of the CODE analysis center
  - In-flight calibrated phase center variation (PCV) maps
  - Unmodeled forces are absorbed by empirical parameters
  - Estimation of monthly gravity field coefficients up to degree and order 70 without applying any regularization.



Quality of GPS data

- GPS carrier phase residuals of kinematic orbit determination

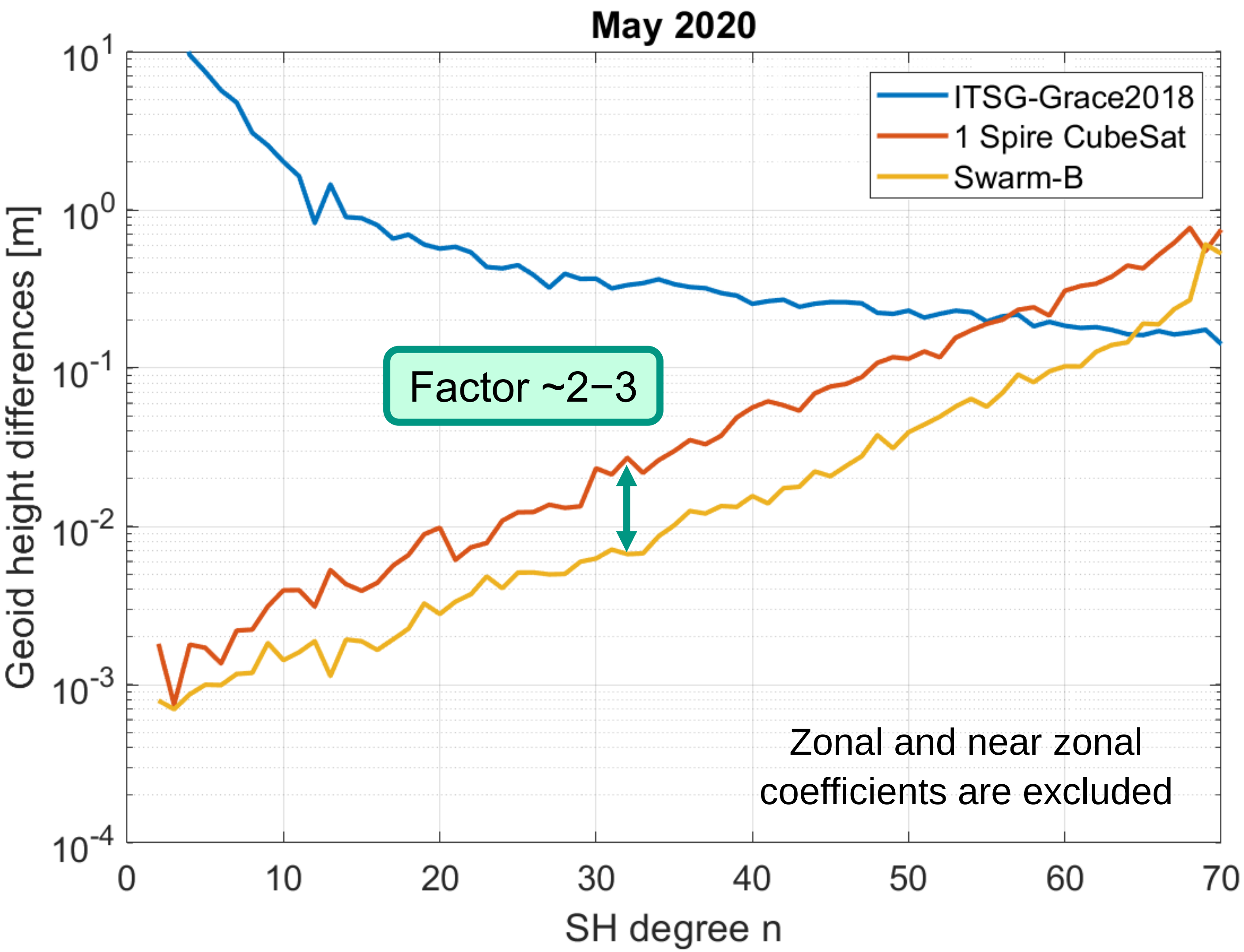


Spire gravity field solutions

Difference degree amplitudes (w.r.t. ITSG-Grace2018)

Spire

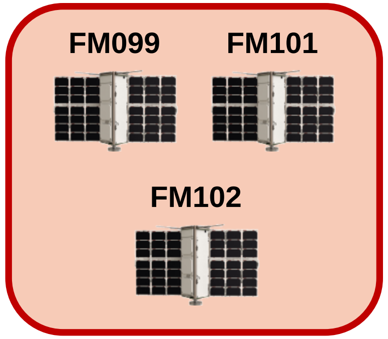
1 CubeSat



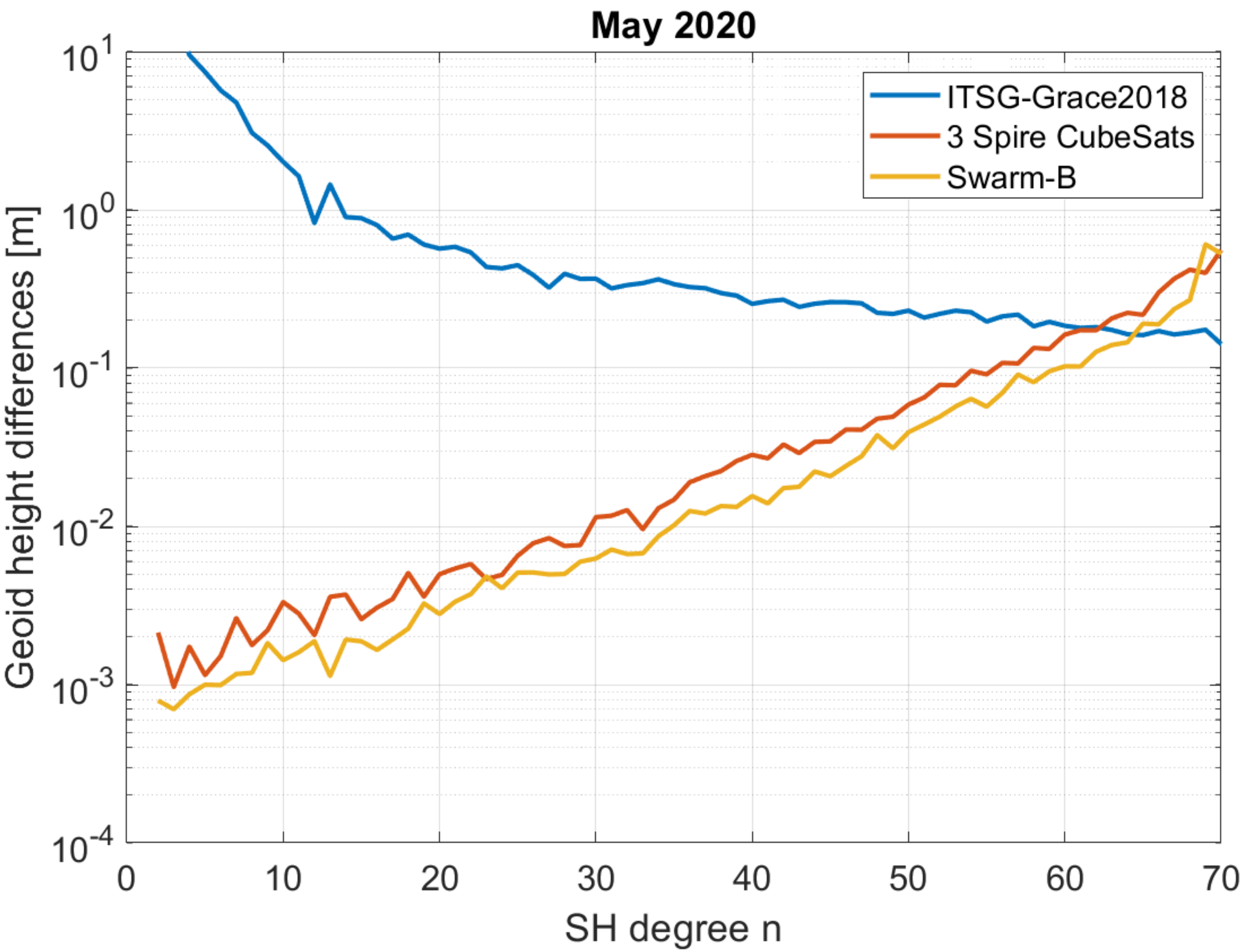
Swarm-B

Difference degree amplitudes (w.r.t. ITSG-Grace2018)

Spire



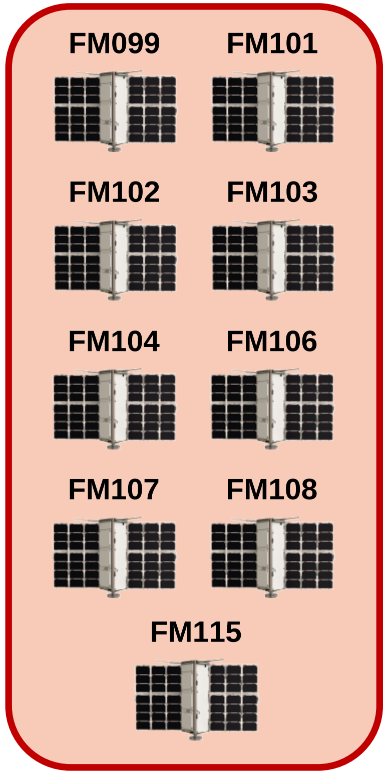
3 CubeSats



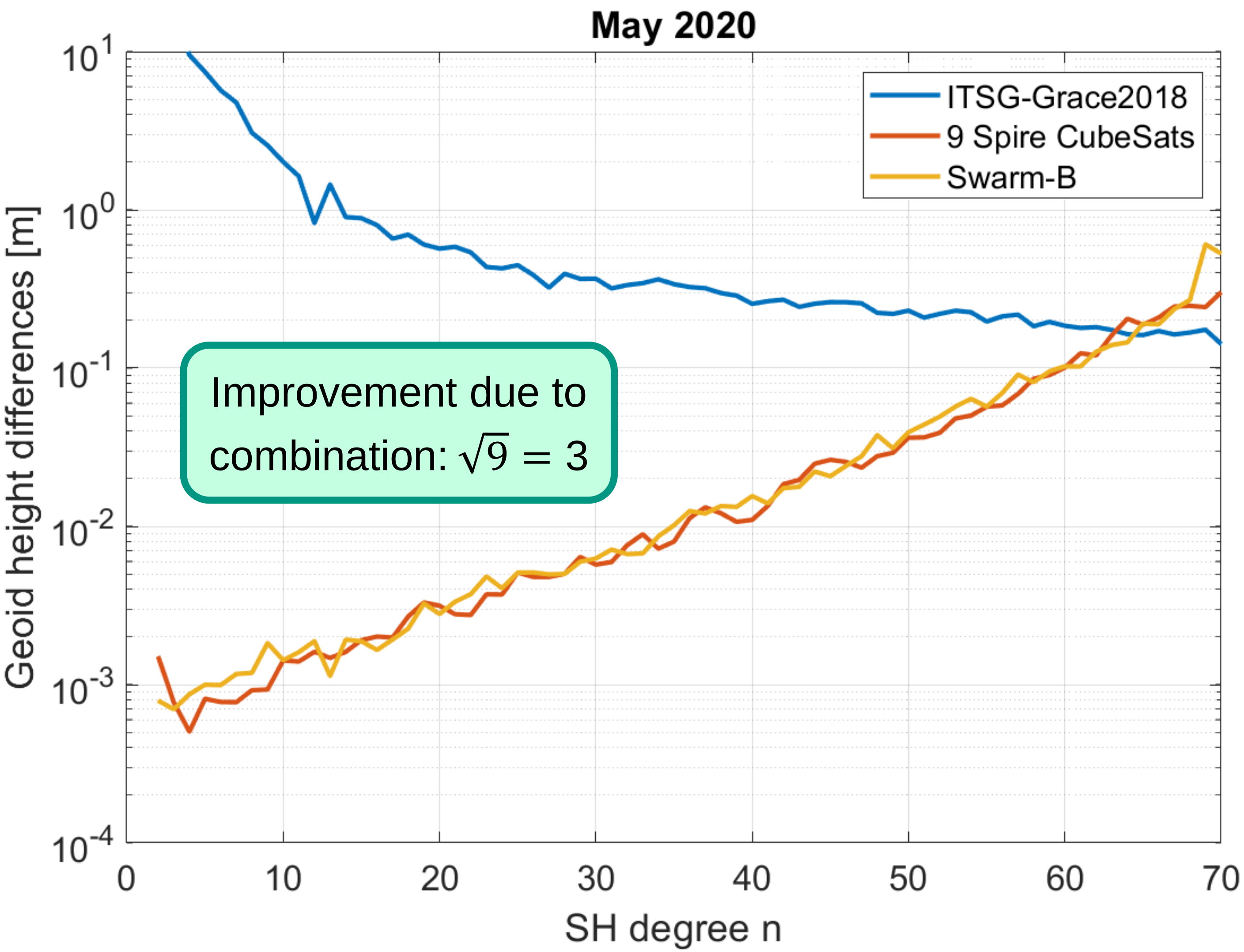
Swarm-B

Difference degree amplitudes (w.r.t. ITSG-Grace2018)

Spire



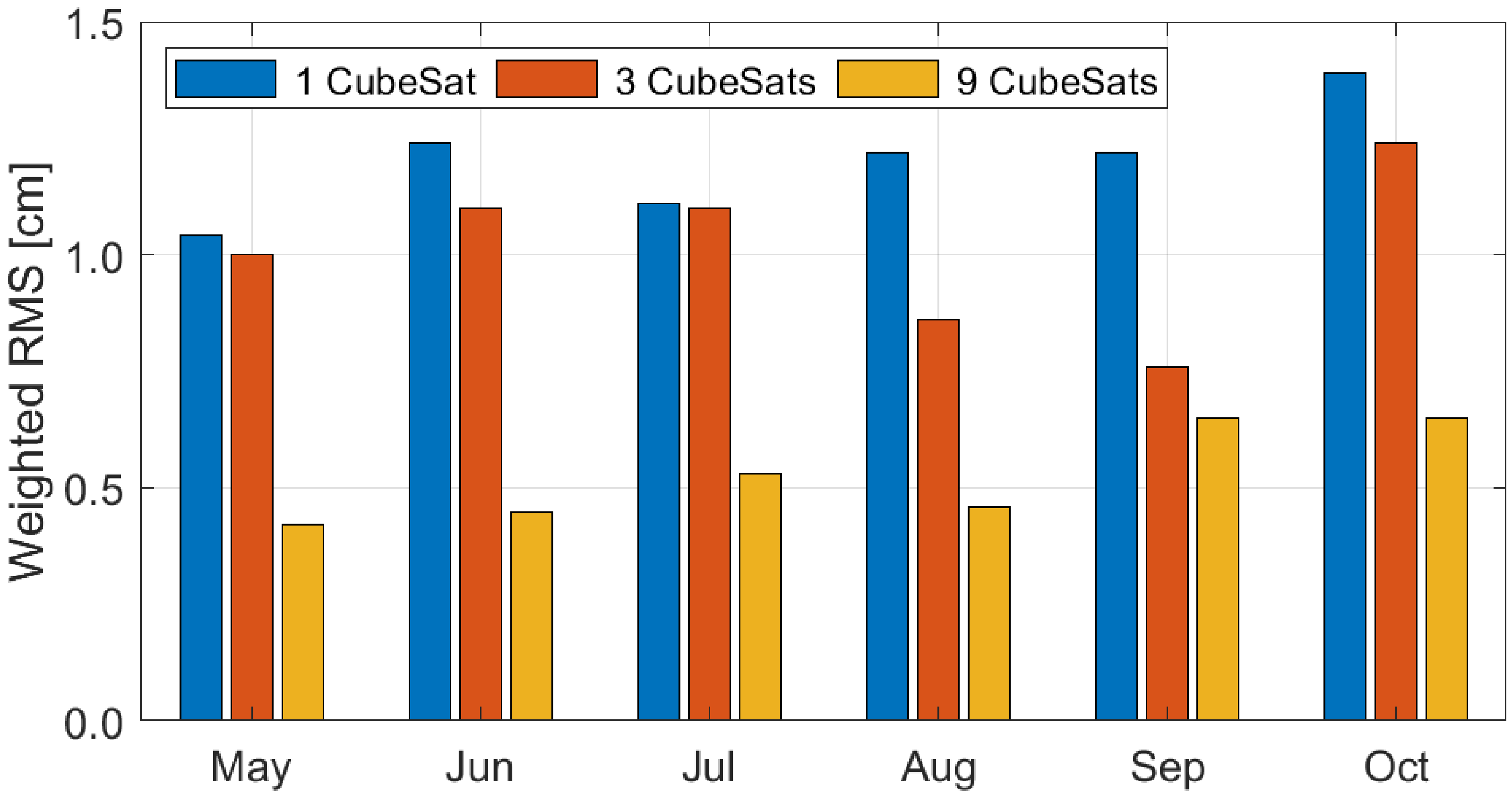
9 CubeSats



Swarm-B

Geoid height differences (w.r.t. ITSG-Grace2018)

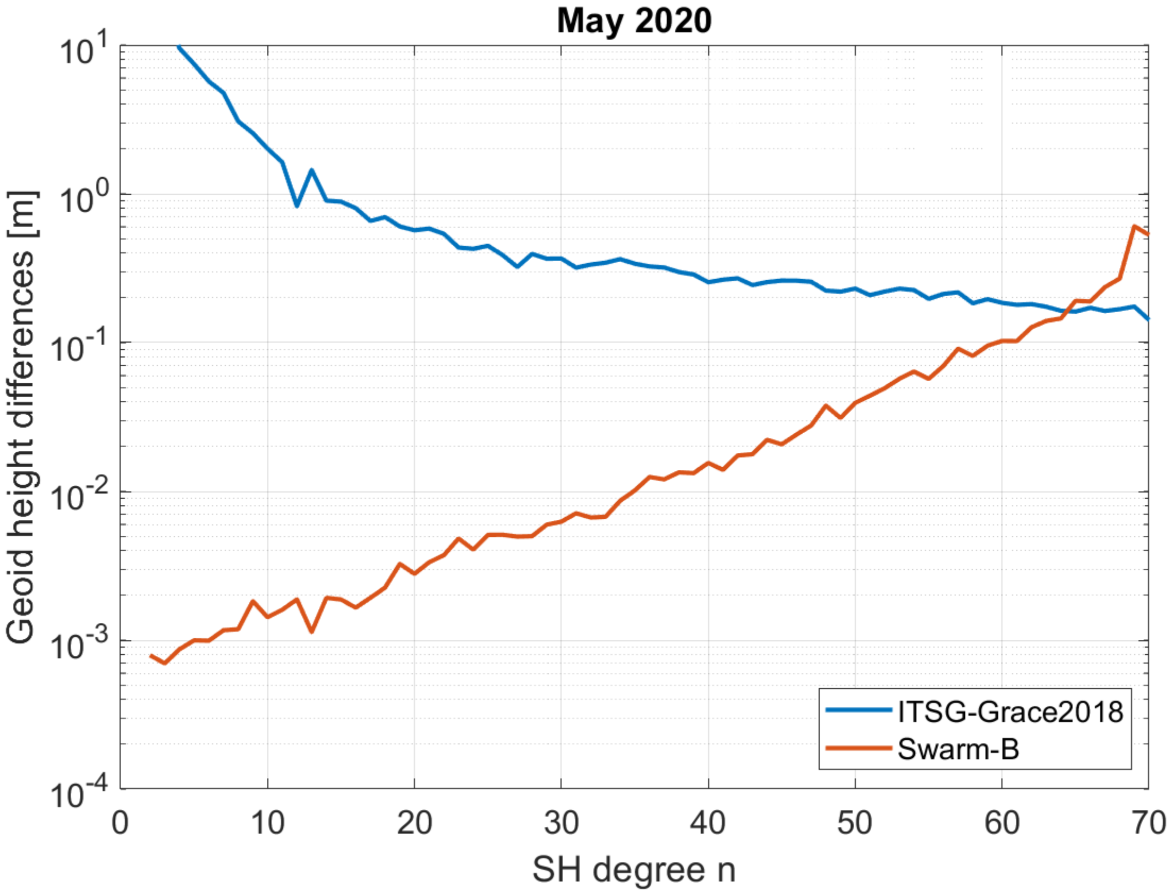
- RMS values of geoid height differences



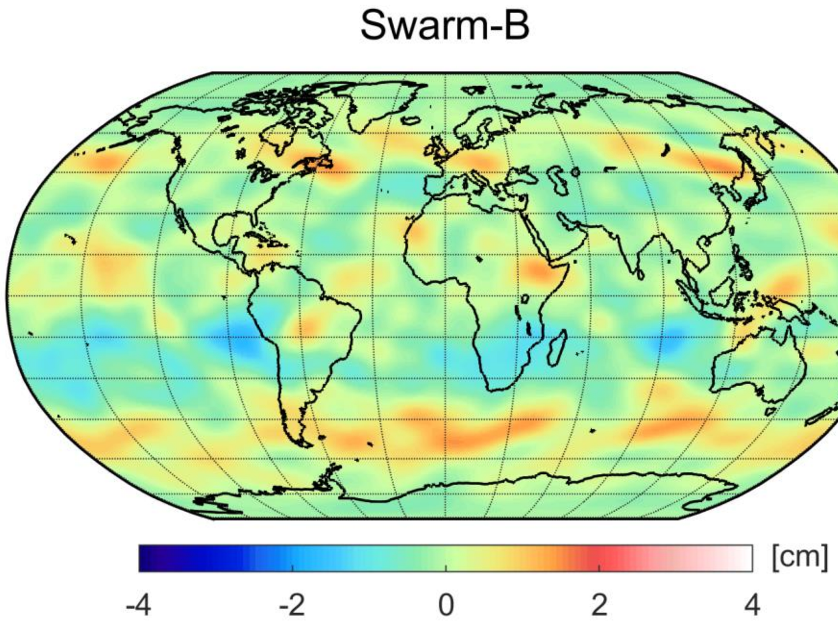
Swarm–Spire combinations

Swarm−Spire combinations

- Difference degree amplitudes

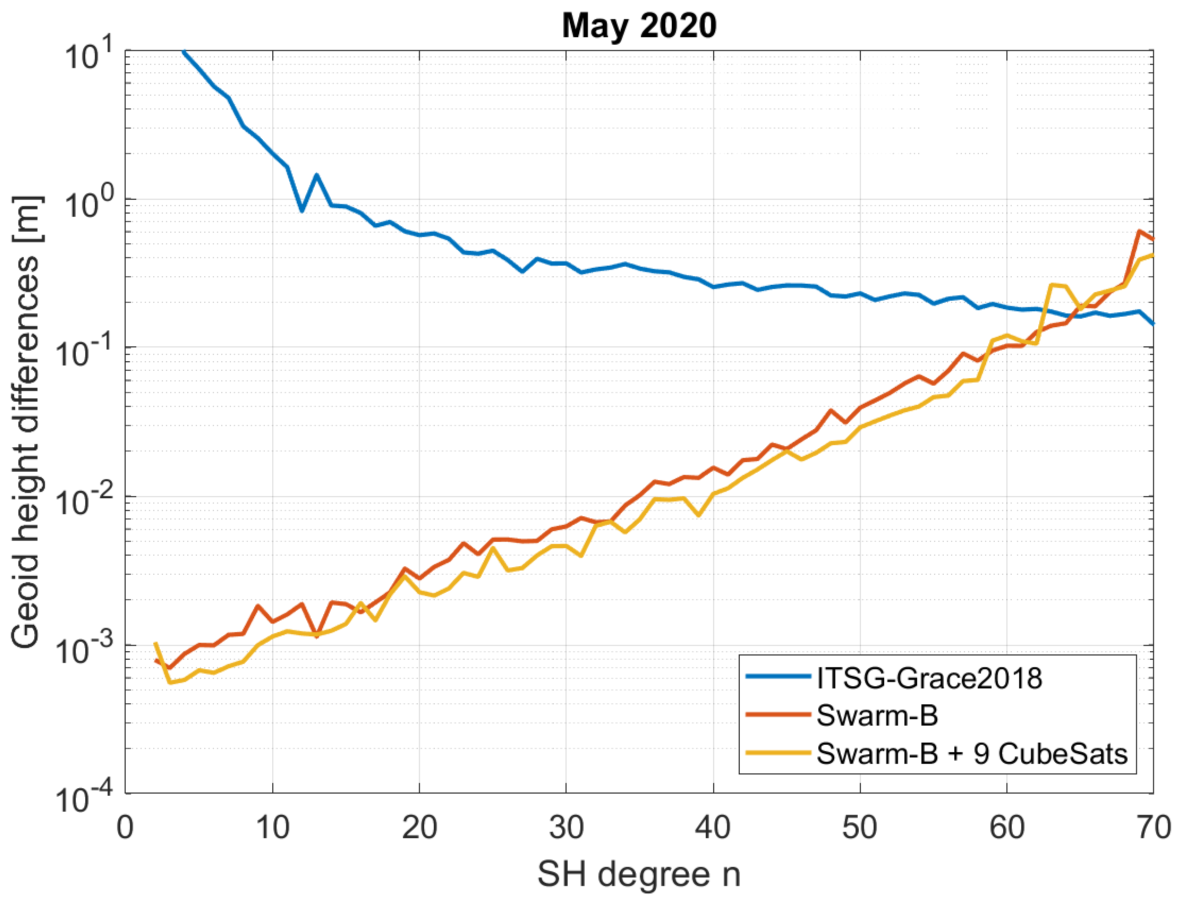


- Geoid height differences

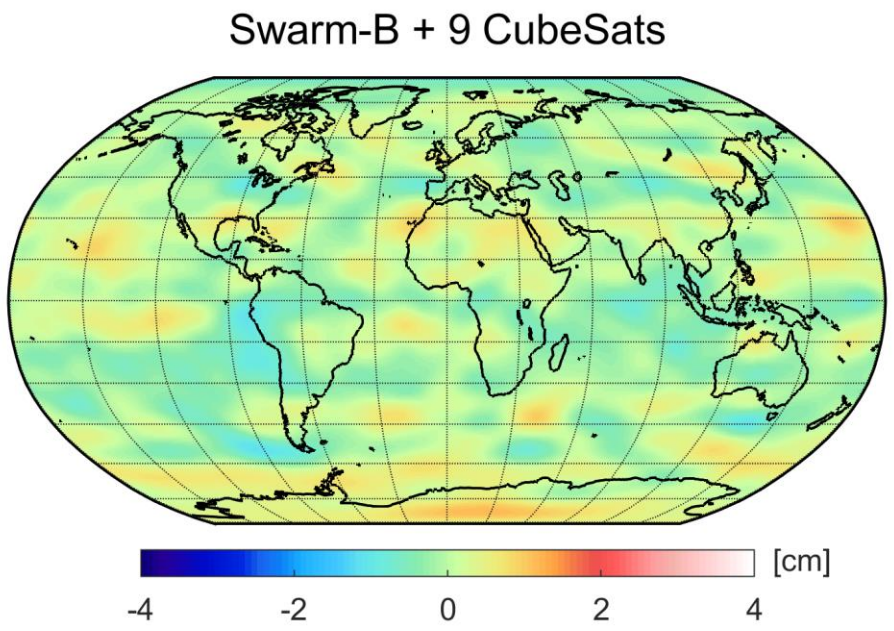


Swarm−Spire combinations

- Difference degree amplitudes



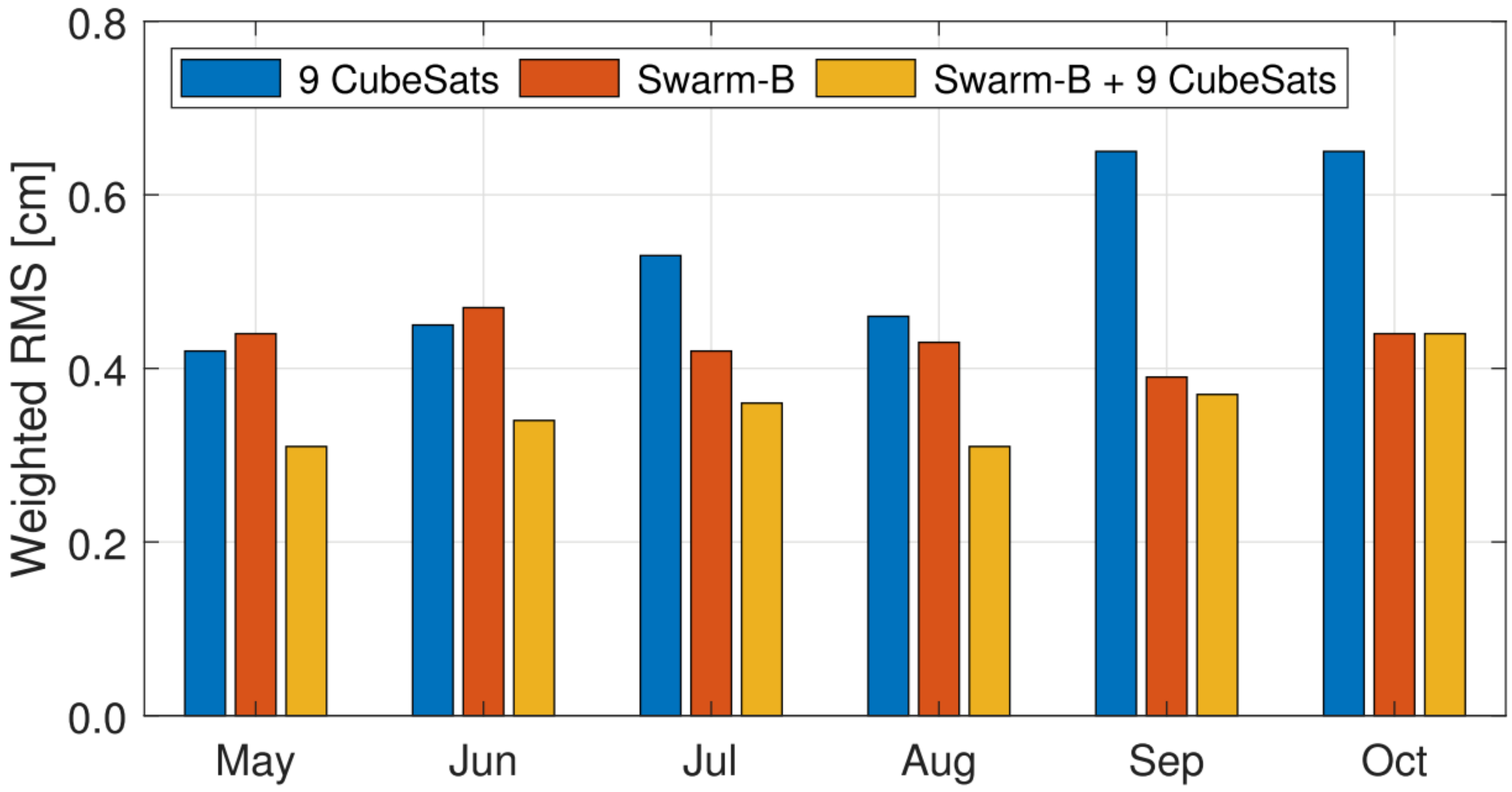
- Geoid height differences



RMS improvement: ~ 30%

Swarm−Spire combinations

- RMS values of geoid height differences



Summary and outlook

Take home messages

1) GNSS data of Spire CubeSats allow to recover monthly gravity fields
2) Individual CubeSat solutions cannot compete with scientific missions
3) Accumulation of CubeSat solutions significantly increases the quality
4) Solutions based on 9 CubeSats can improve a Swarm-B model

Next steps

- Study time-variable gravity field signals (longer time series)
- Increase the temporal resolution (sub-monthly solutions)
- Explicit modeling of non-gravitational forcers

Thank you for your attention

We acknowledge the support from Spire Global and the provision of Spire data by ESA

Grombein T, Arnold D, Lasser M, Jäggi A (2025)

Gravity field recovery based on GNSS data of nano-satellites: a case study for the Spire CubeSat constellation

Journal of Geodesy 99:78, https://doi.org/10.1007/s00190-025-01998-8

grombein@kit.edu