Karlsruhe Institute of Technology

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Gravity field recovery based on GPS data of CubeSats from the Spire constellation

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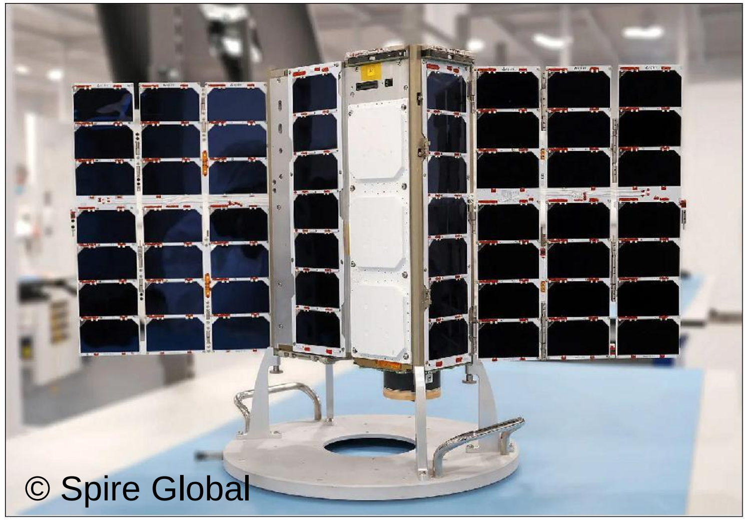
Introduction

- Can CubeSats serve as gravity field sensors?
  - A huge number of (commercial) CubeSats is collecting GPS data
  - Tracking data allows to recover large-scale gravity field information
  - Big potential to increase the spatial-temporal coverage
  - However: dual-frequency GPS receivers are needed

- Spire Global constellation
  - More than 100 CubeSats in low Earth orbit (LEO)
  - High-quality dual-frequency GPS receivers
  - Different orbital characteristics



10 x 10 x 34 cm, 4.7 kg

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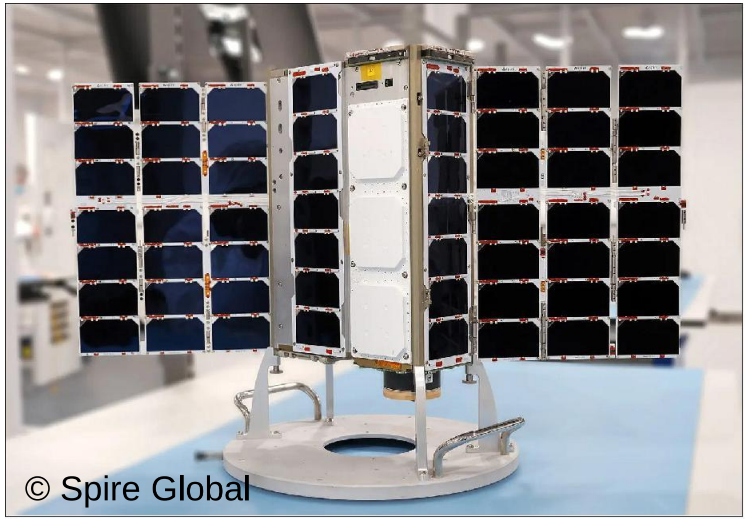
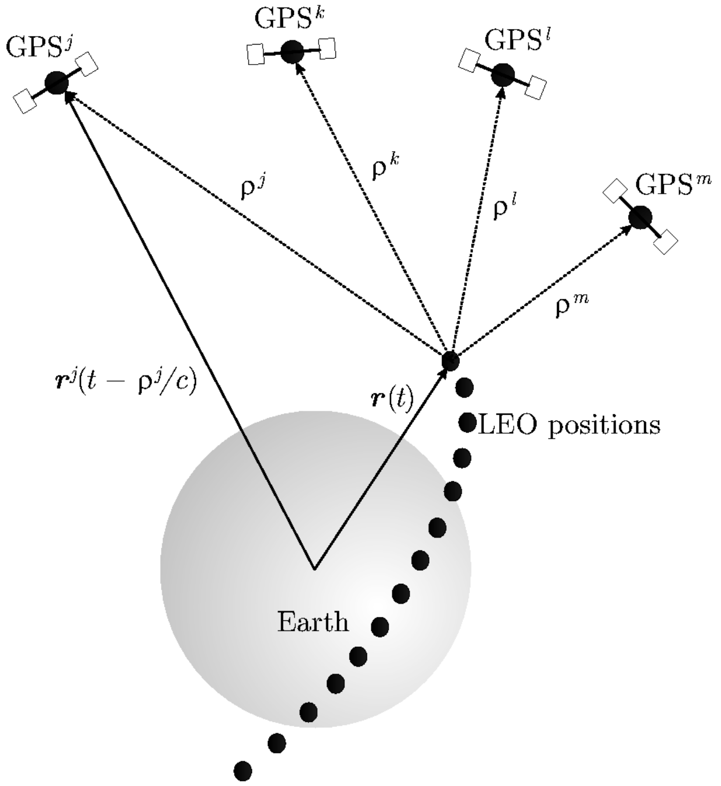


10 x 10 x 34 cm, 4.7 kg

➢ Case study based on 6 months of GPS data from 9 Spire CubeSats

Method

- **Orbit and gravity field recovery**
  - Celestial Mechanics Approach (Beutler et al., 2010)
  - Two-step procedure
    1) GPS tracking data → Kinematic orbit positions
    2) Kinematic orbit positions → Gravity field recovery



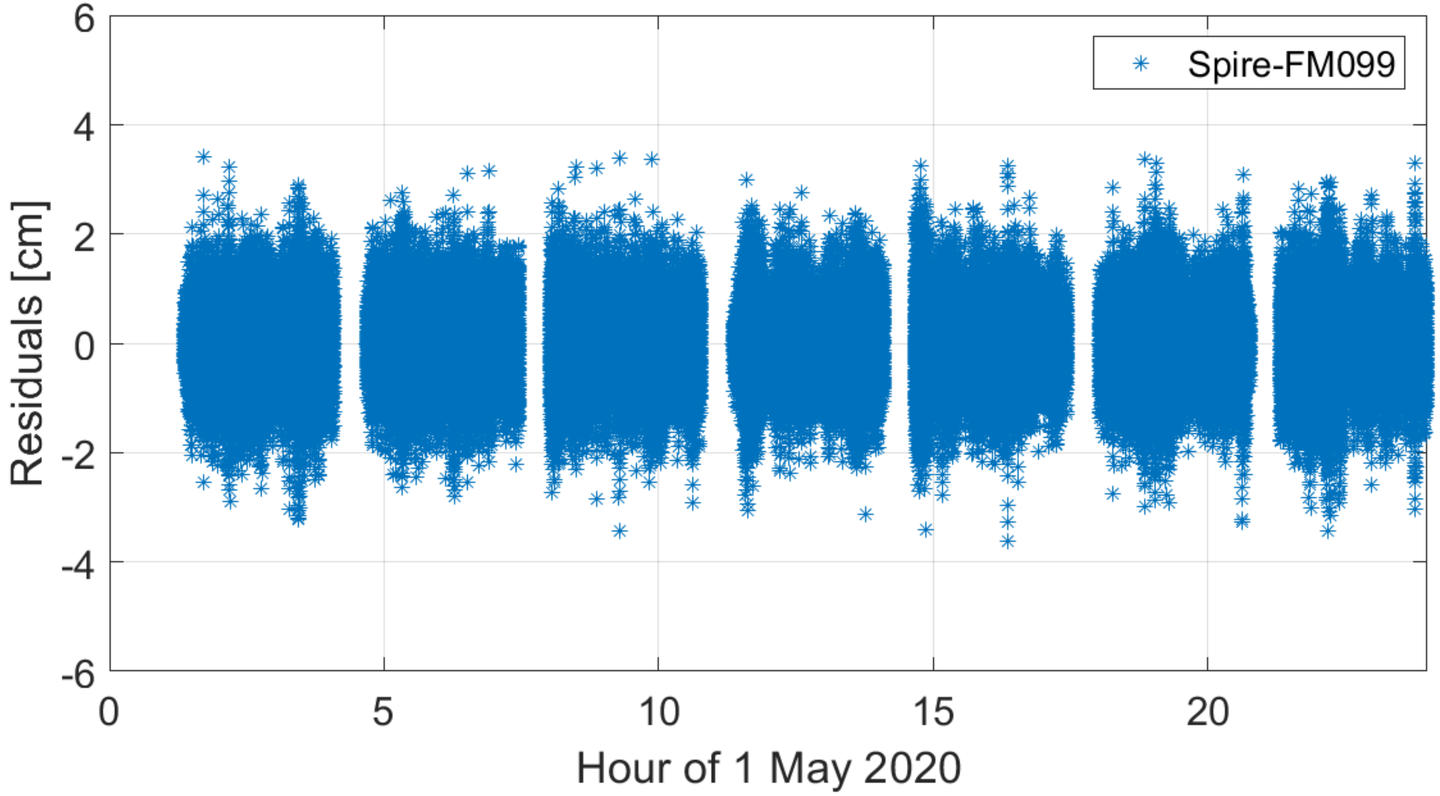
- **Processing with the Bernese GNSS software**
  - GNSS products of the CODE analysis center
  - In-flight calibrated phase center variation (PCV) maps
  - Unmodeled forces are absorbed by empirical parameters

Data overview (May – Oct 2020)

Selected Spire CubeSats	Altitude	Inclination	Sampling
FM099, FM101, FM102	~ 505 km	~ 97.5°	1s
FM103, FM104, FM106, FM107, FM108	~ 530 km	~ 97.5°	1s
FM115	~ 570 km	~ 37.0°	1s

Spire GPS data quality

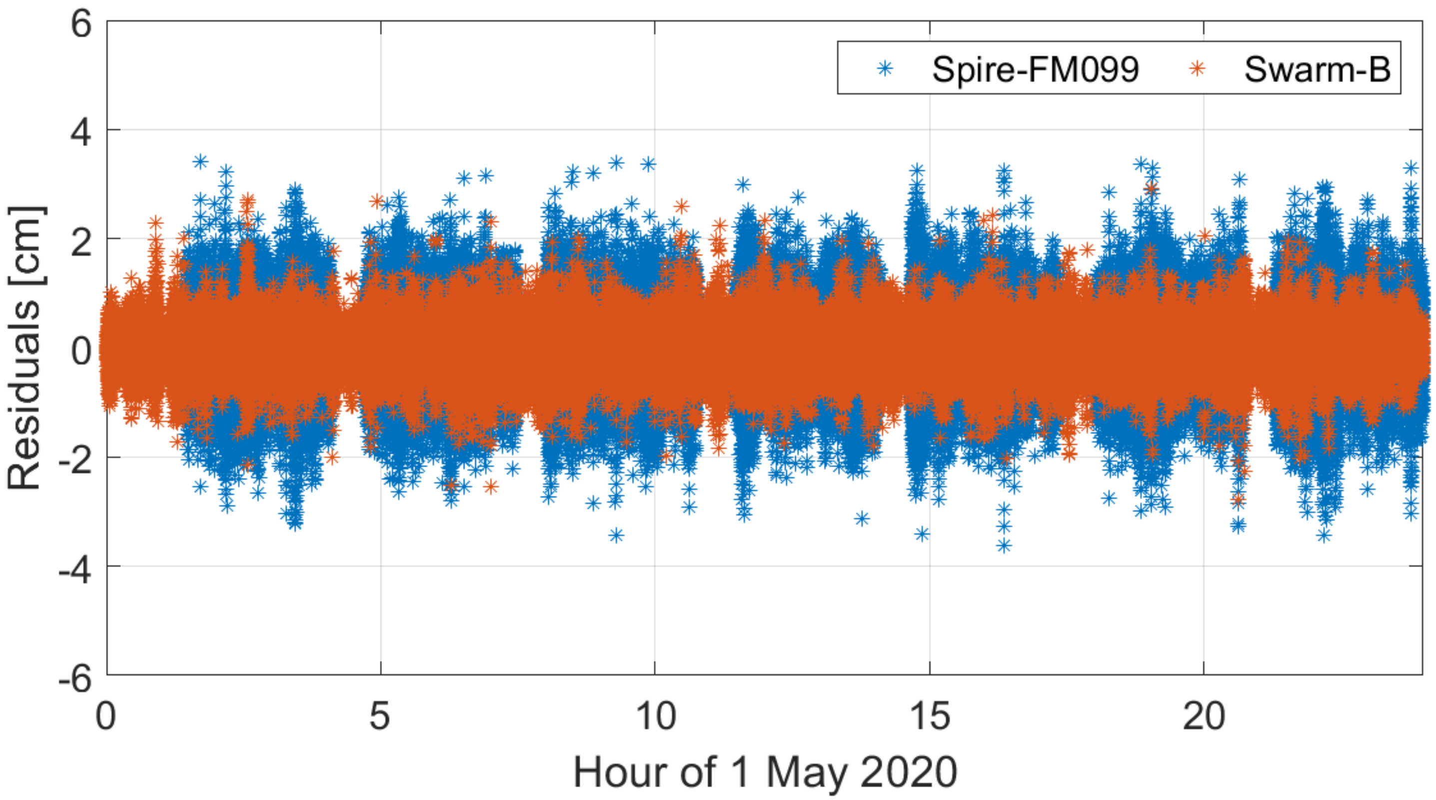
- Carrier phase residuals of kinematic orbit determination



Spire GPS data have frequent gaps

Spire GPS data quality

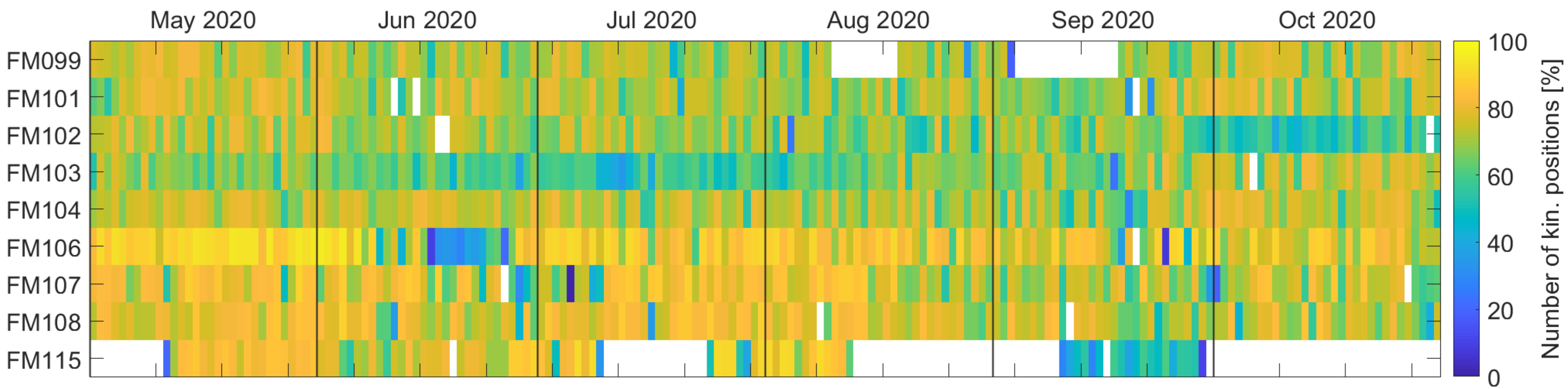
- Carrier phase residuals of kinematic orbit determination



Higher noise level compared to scientific LEO missions

Spire kinematic orbit positions

- Daily availability of derived kinematic positions



- Total availability over 6 months

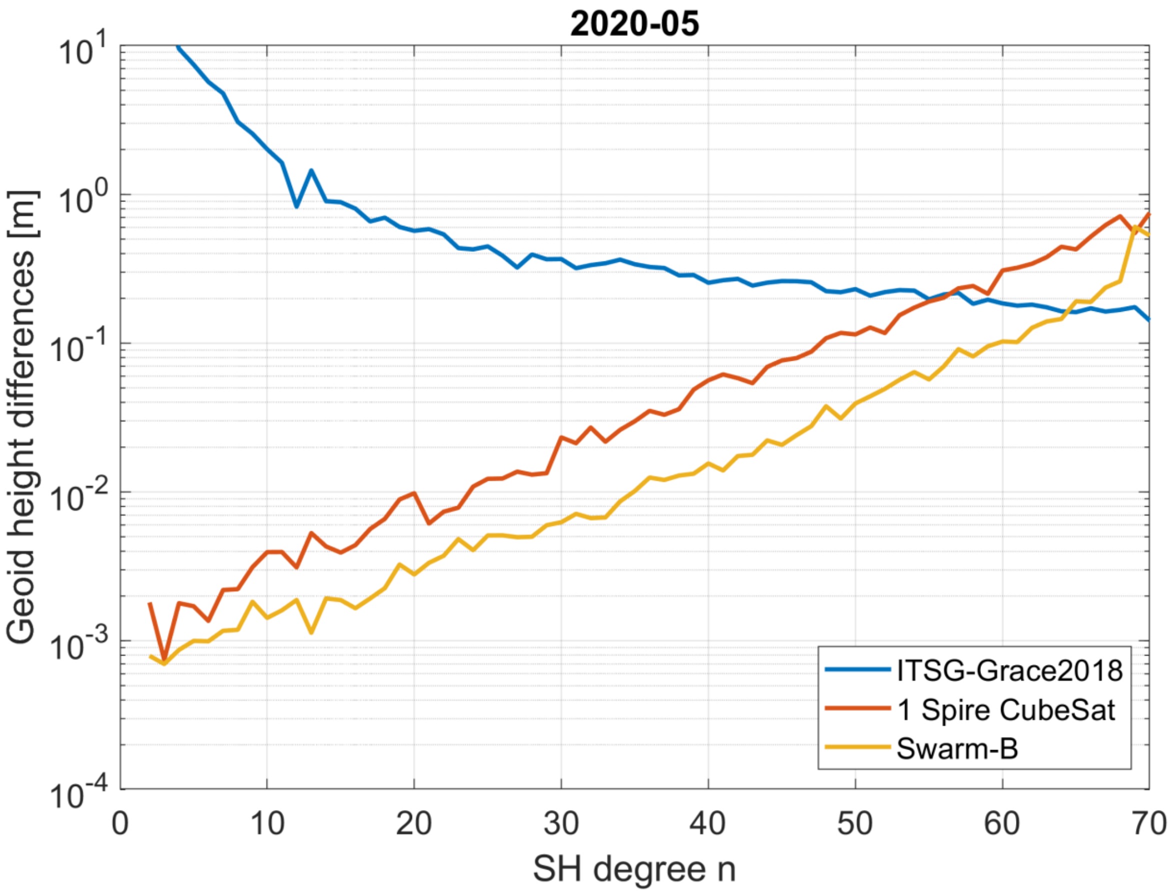
FM099	FM101	FM102	FM103	FM104	FM106	FM107	FM108	FM115
64 %	73 %	69 %	66 %	74 %	81 %	79 %	82 %	39 %

Monthly Spire-based gravity fields

Combinations at normal equation level using variance component estimation (VCE)

FM099

- Difference degree amplitudes



Differences w.r.t. monthly ITSG-Grace2018 solutions (Mayer-Gürr et al., 2018)

FM099

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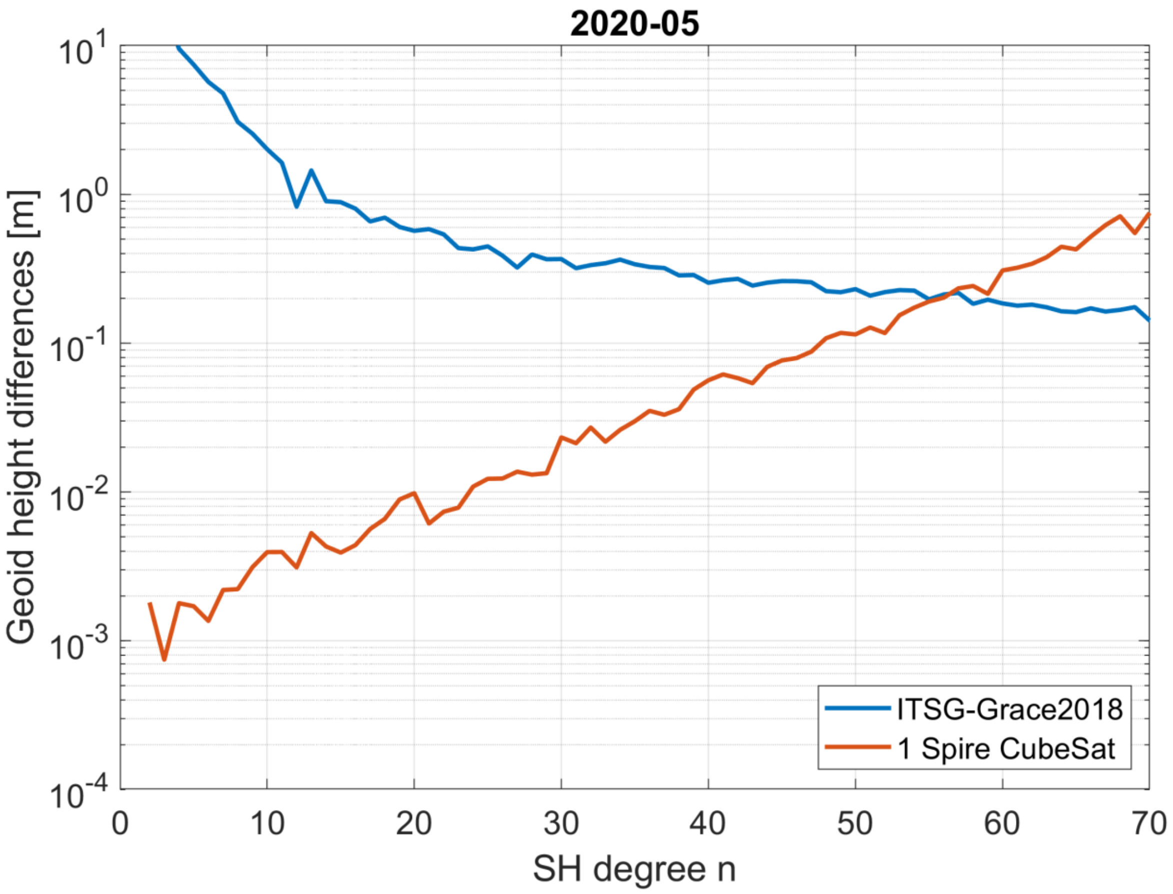
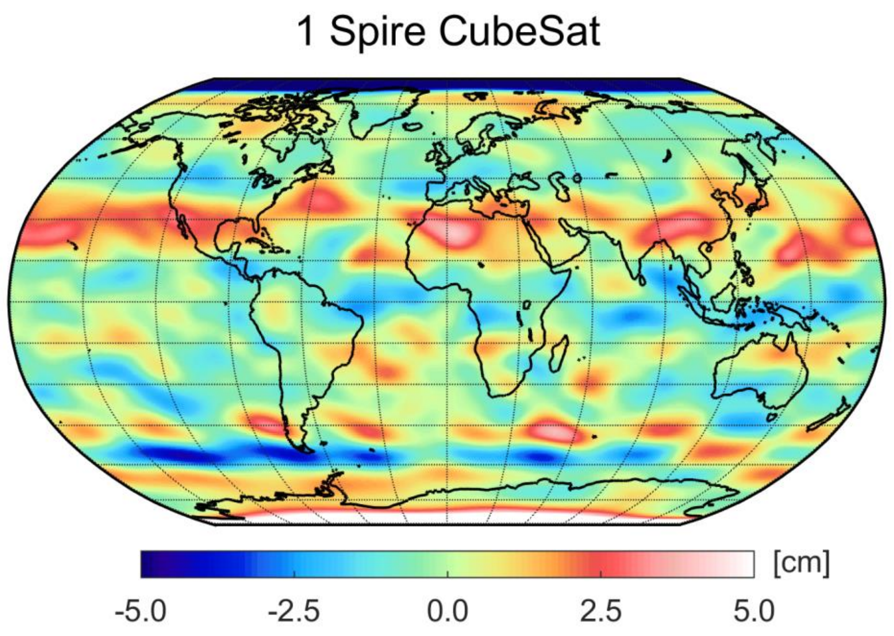
- Difference degree amplitudes



- Geoid height differences

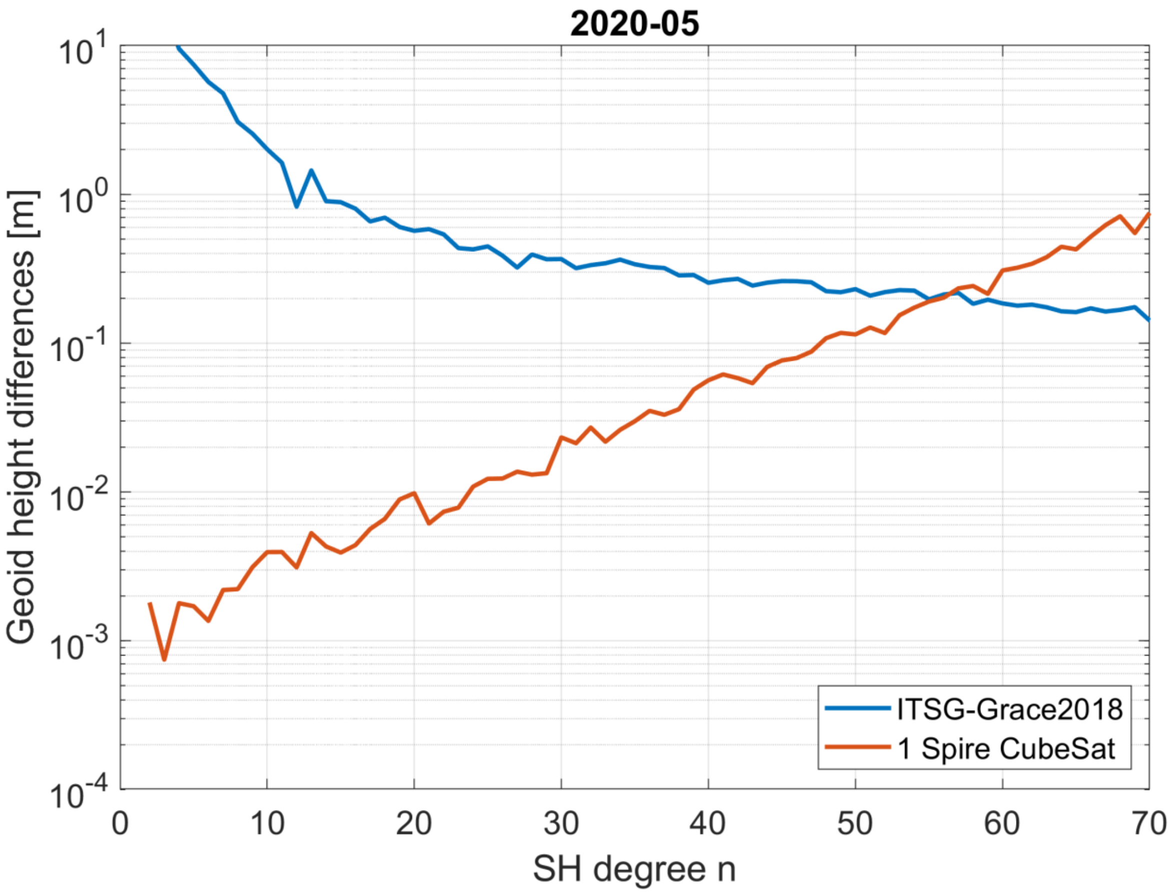


700 km Gauss filtered

Spire gravity fields

FM099

- Difference degree amplitudes



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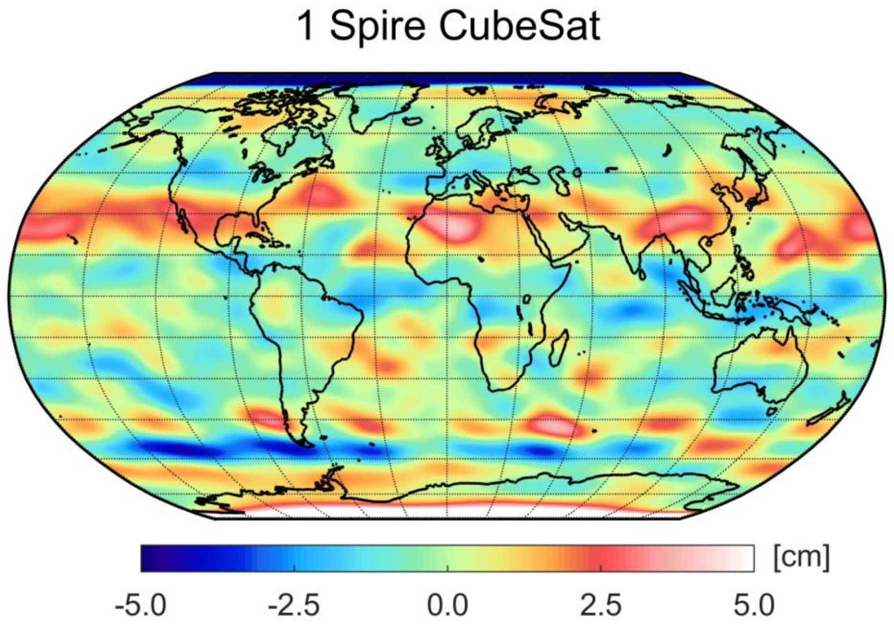
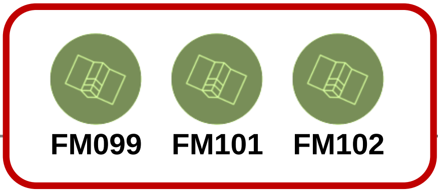


Artifacts in Est/West-direction are correlated with locations of yaw flips (under investigation)

Spire gravity fields



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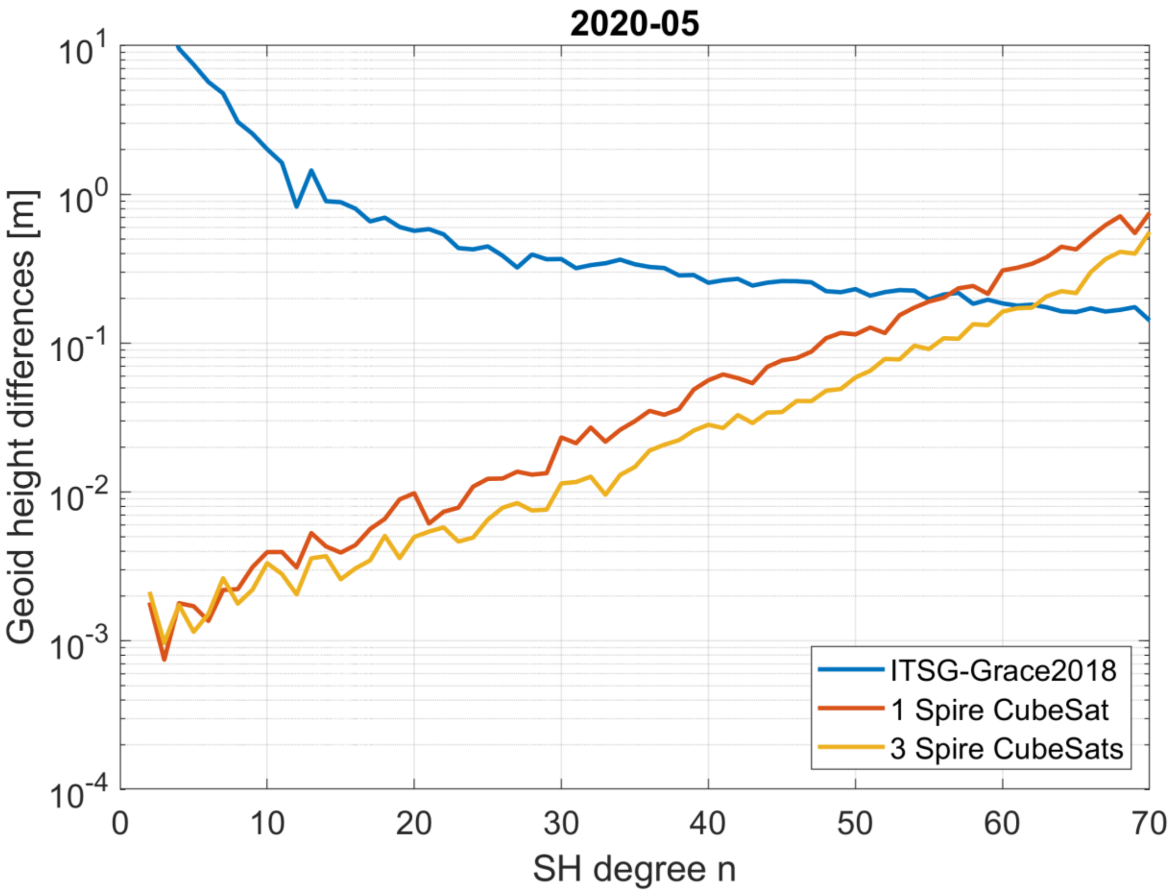

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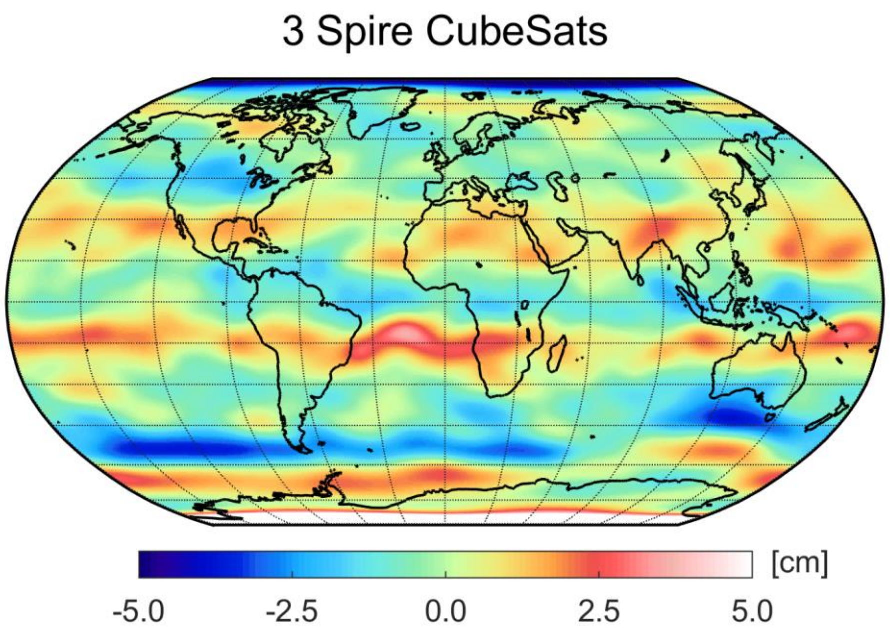
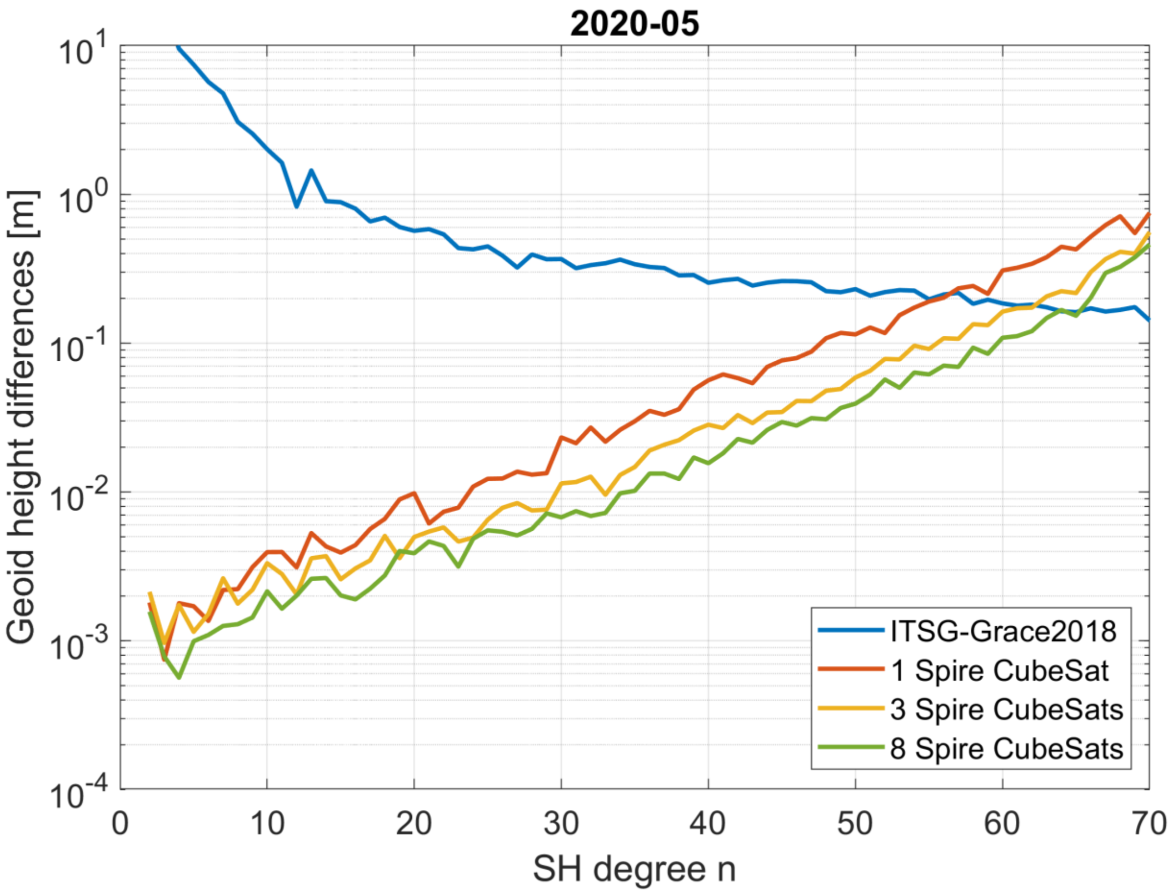
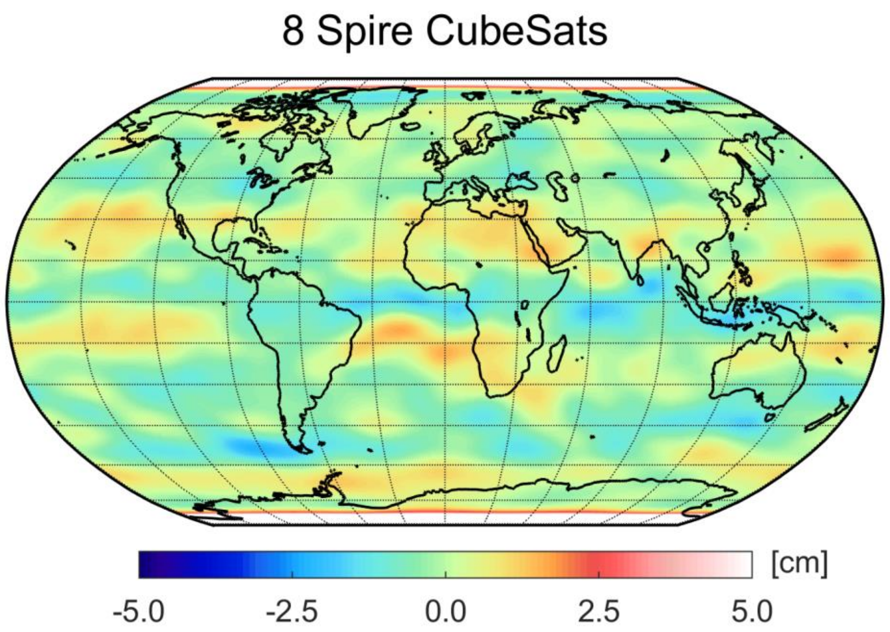


Spire gravity fields

- Difference degree amplitudes



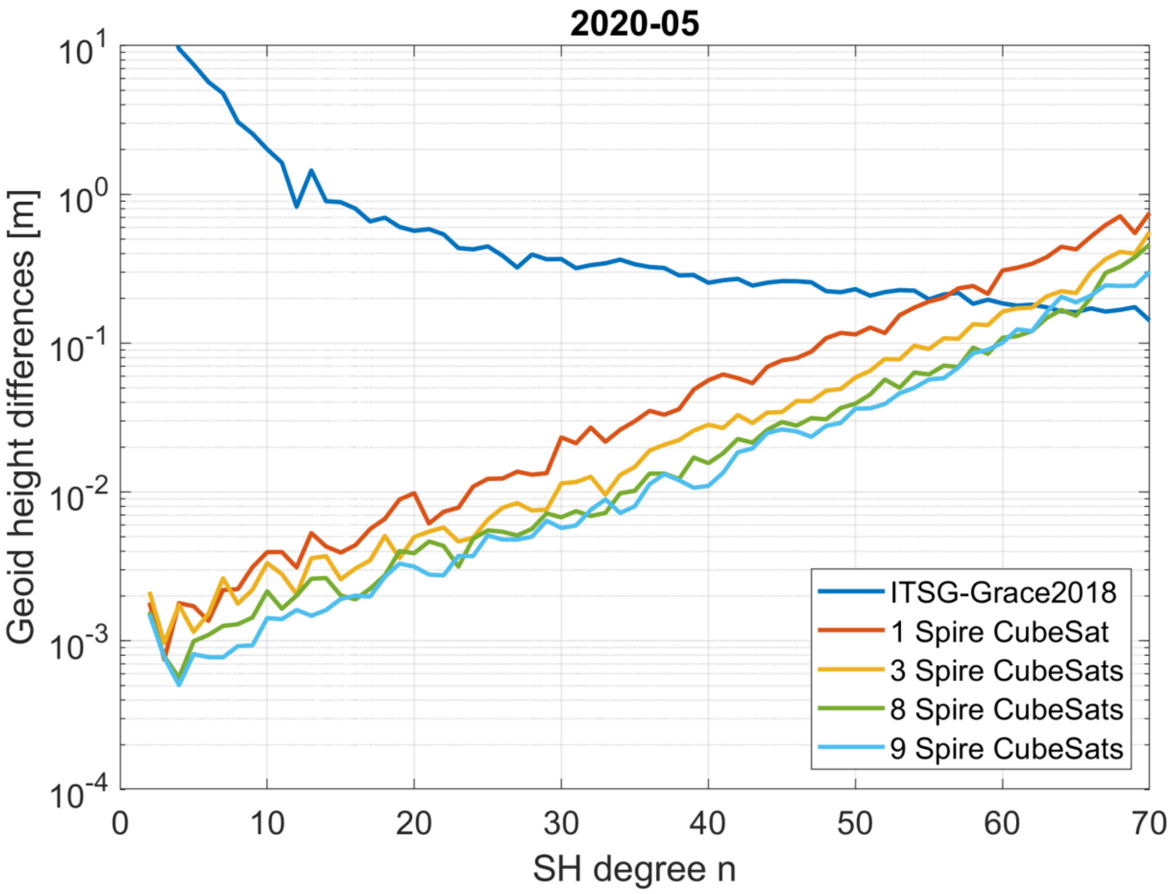
- Geoid height differences



Spire gravity fields

FM099 FM101 FM102 FM103 FM104 FM106 FM107 FM108 FM115

- Difference degree amplitudes



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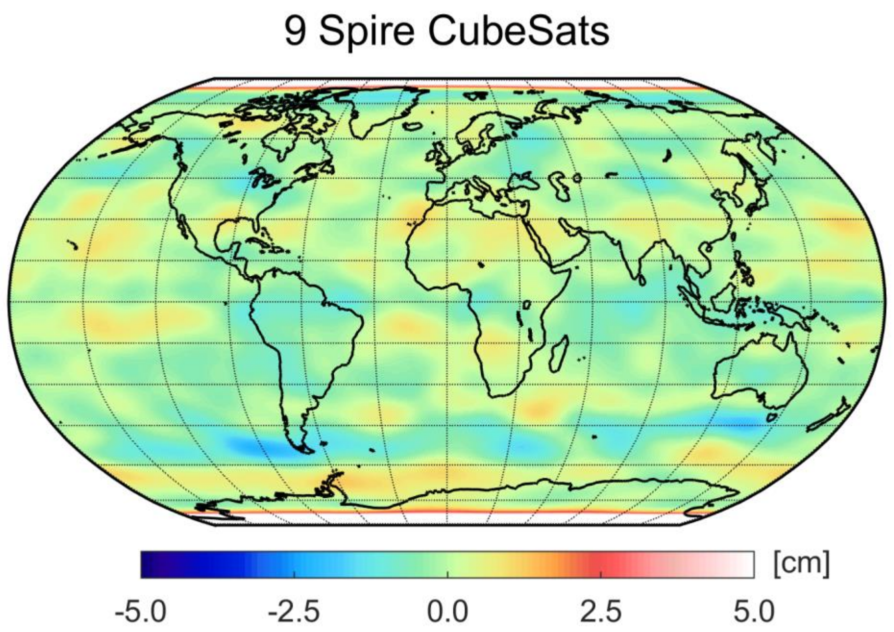

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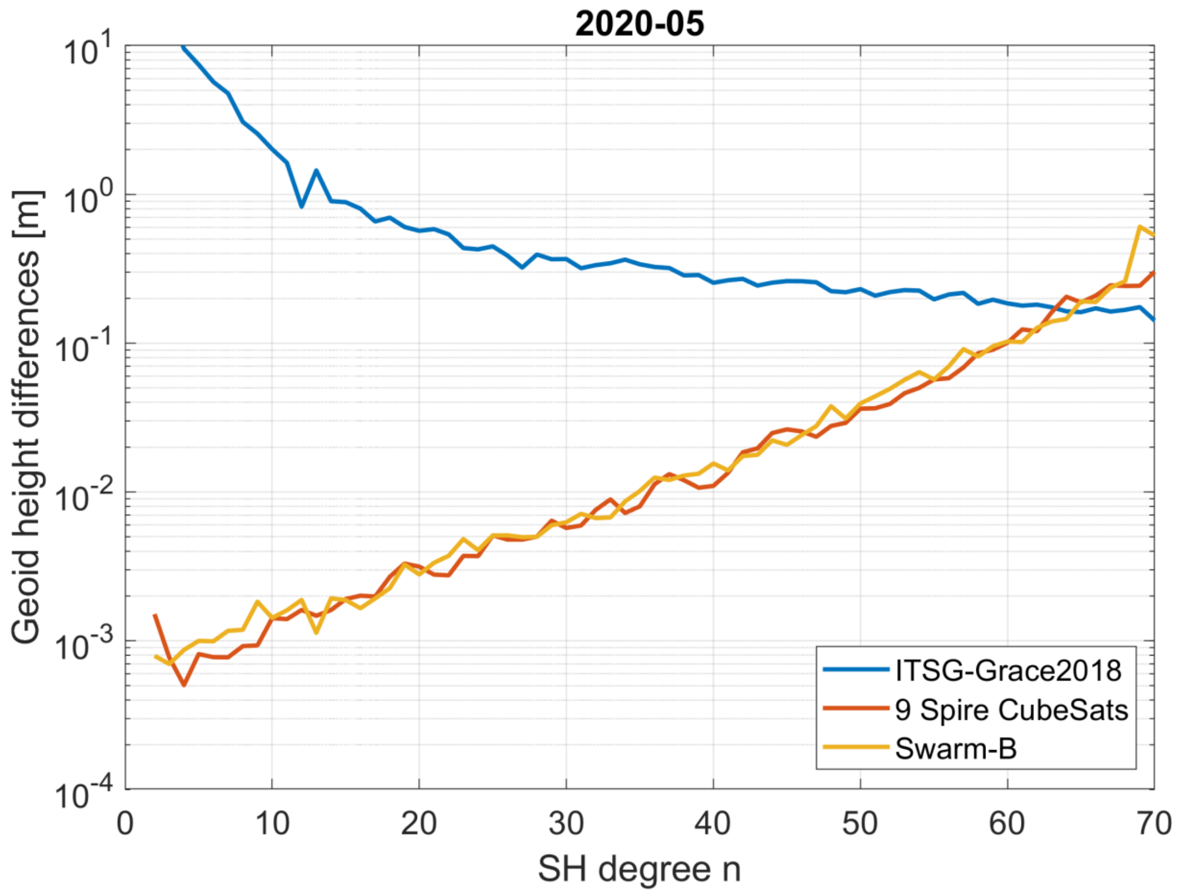
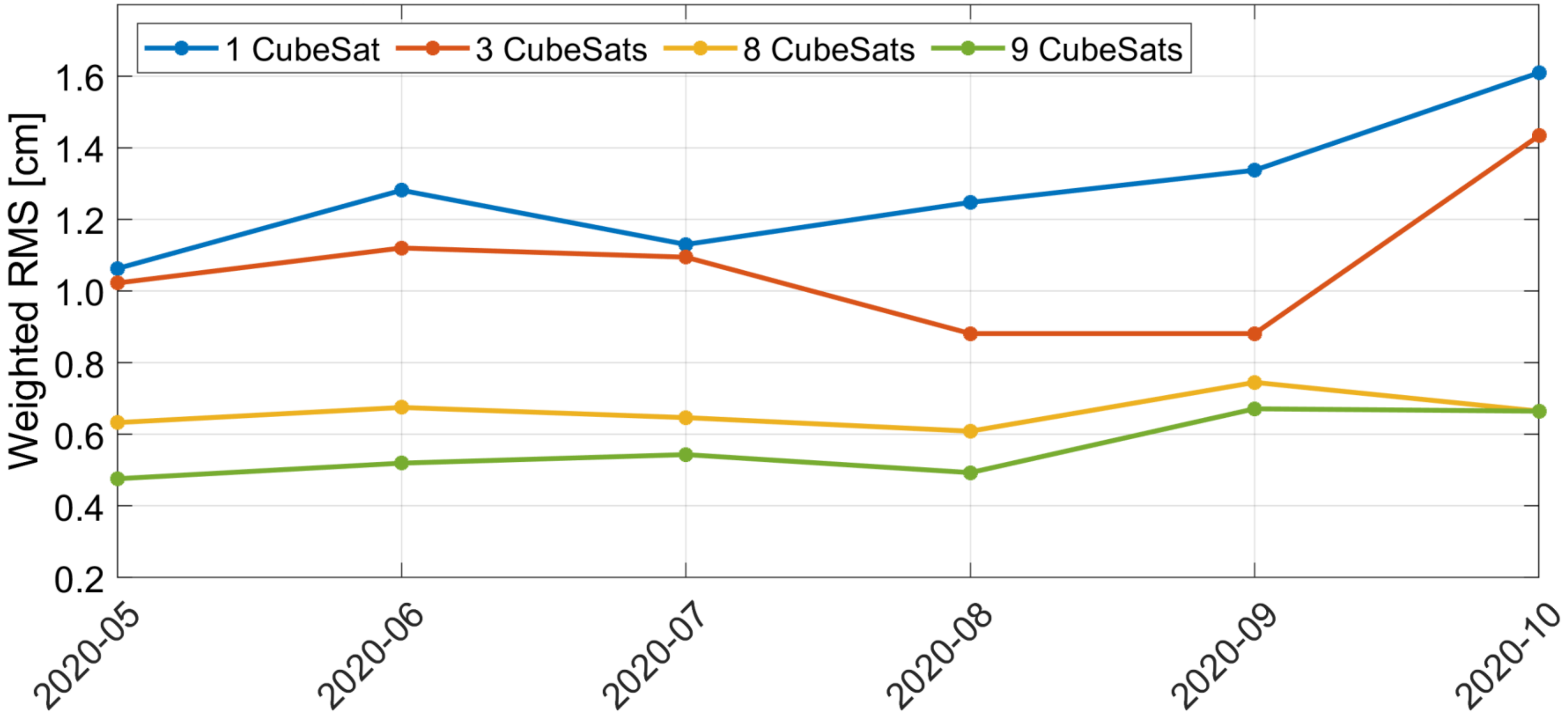


Solutions based on 9 CubeSats can reach a quality level comparable to Swarm-B

Quality of Spire gravity field solutions

- Weighted RMS values of geoid height differences



700 km Gauss filtered

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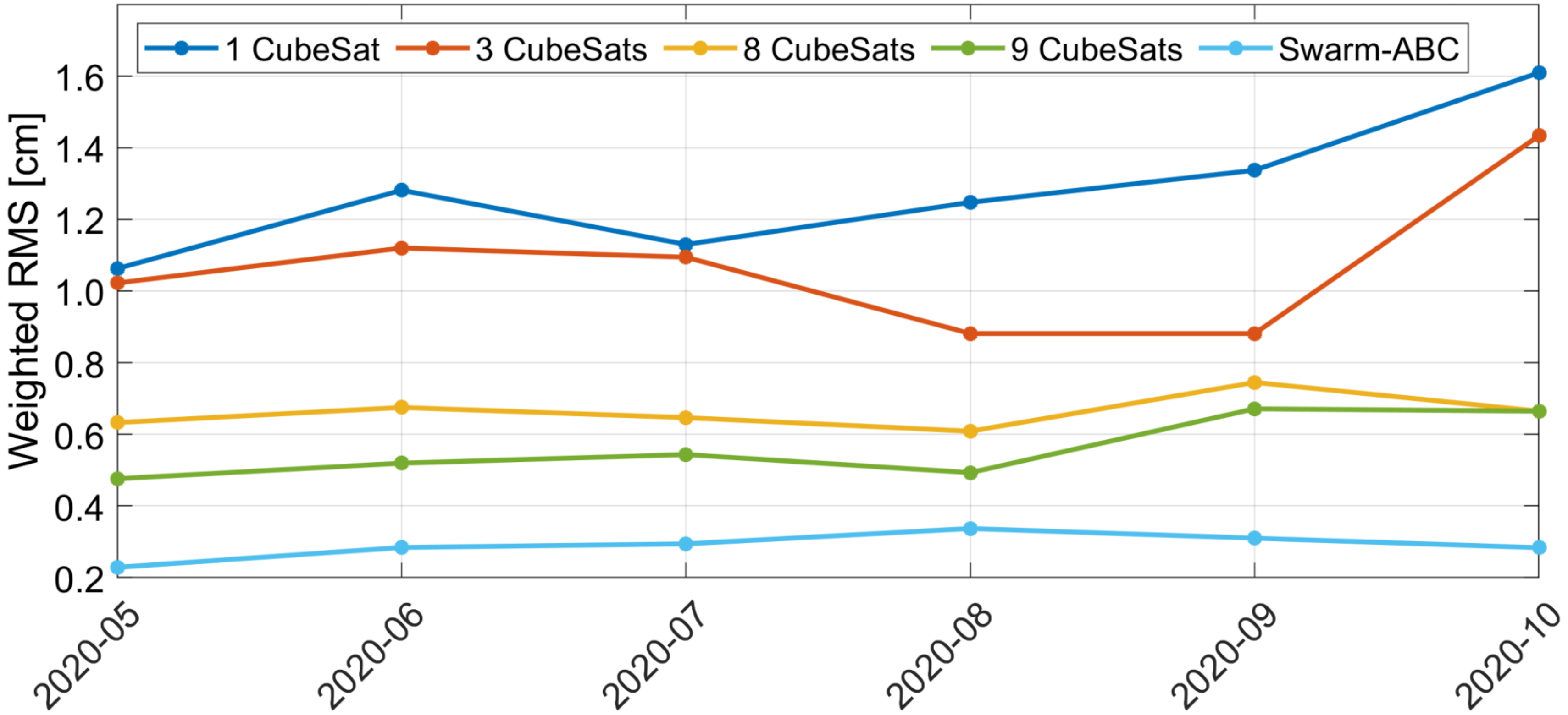
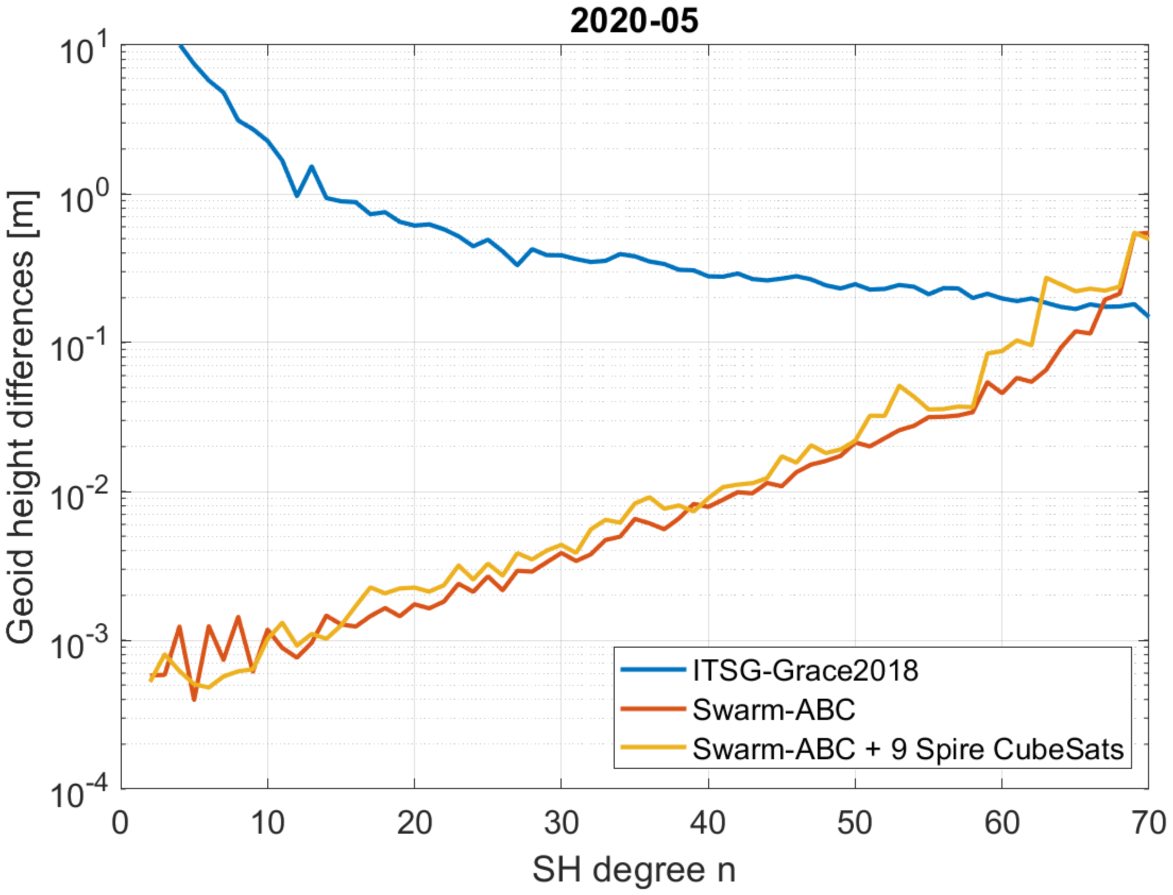


700 km Gauss filtered

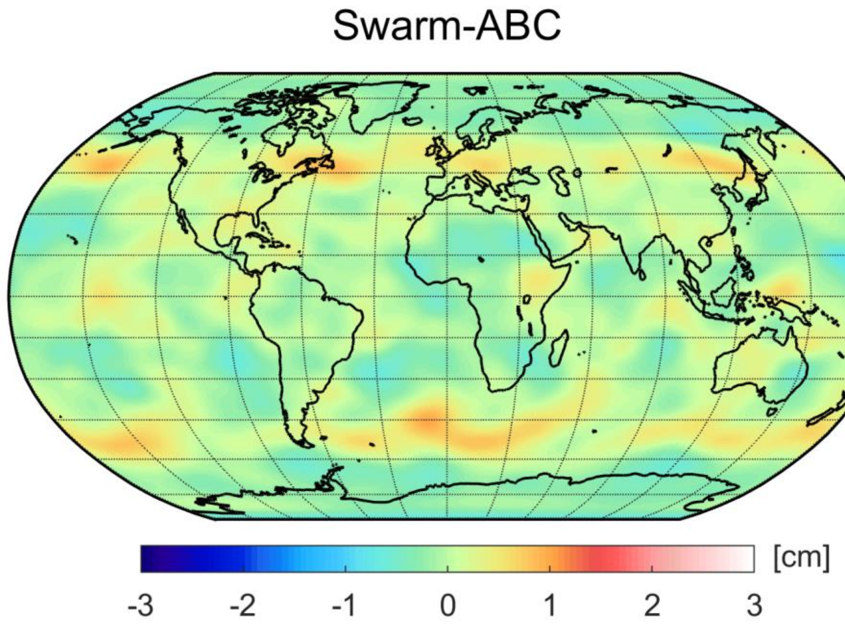
Swarm−Spire combinations

Combination of Swarm with Spire solutions

- Difference degree amplitudes

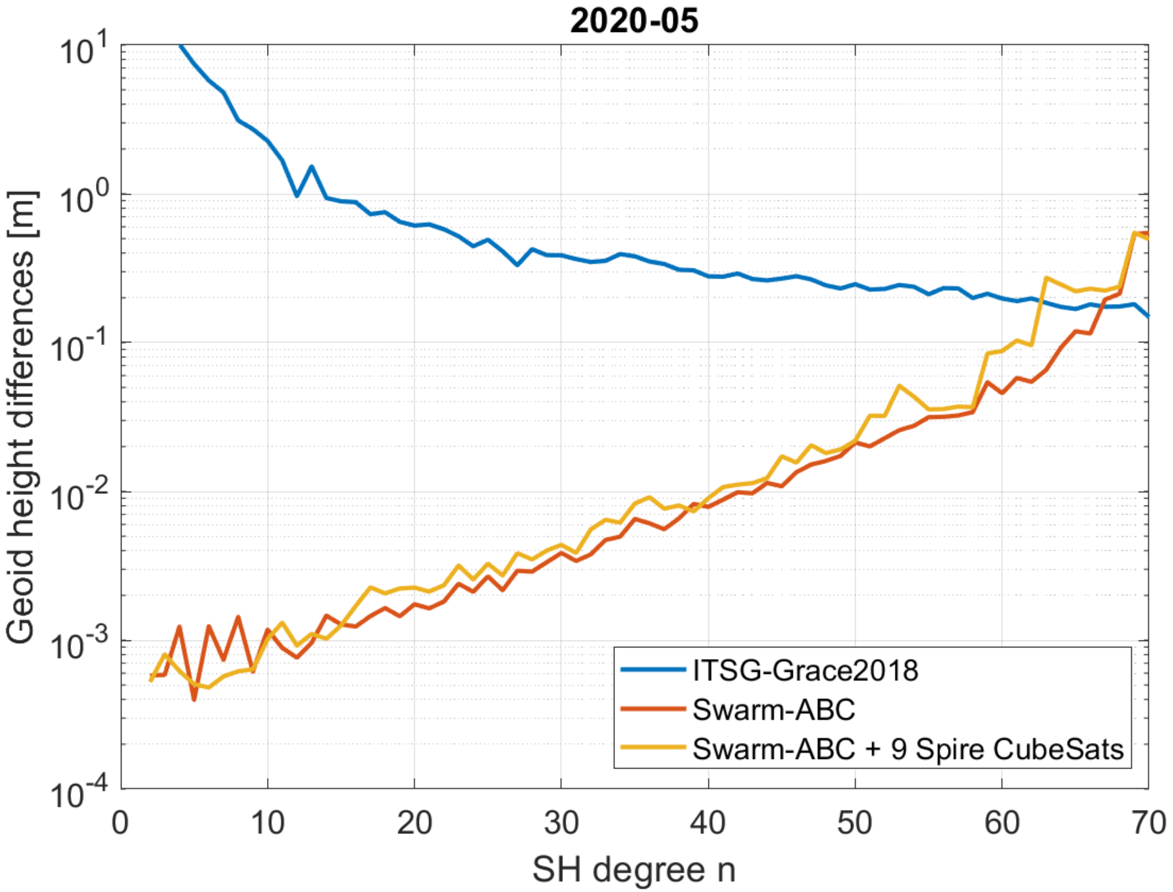


- Geoid height differences



Combination of Swarm with Spire solutions

- Difference degree amplitudes



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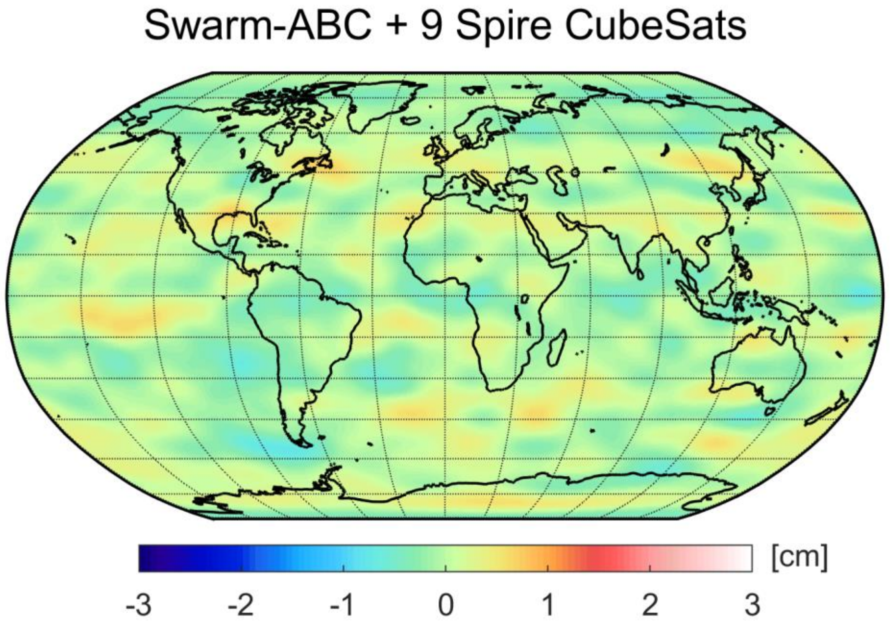

RMS improvement: ~ 10%

Combination of Swarm with Spire solutions

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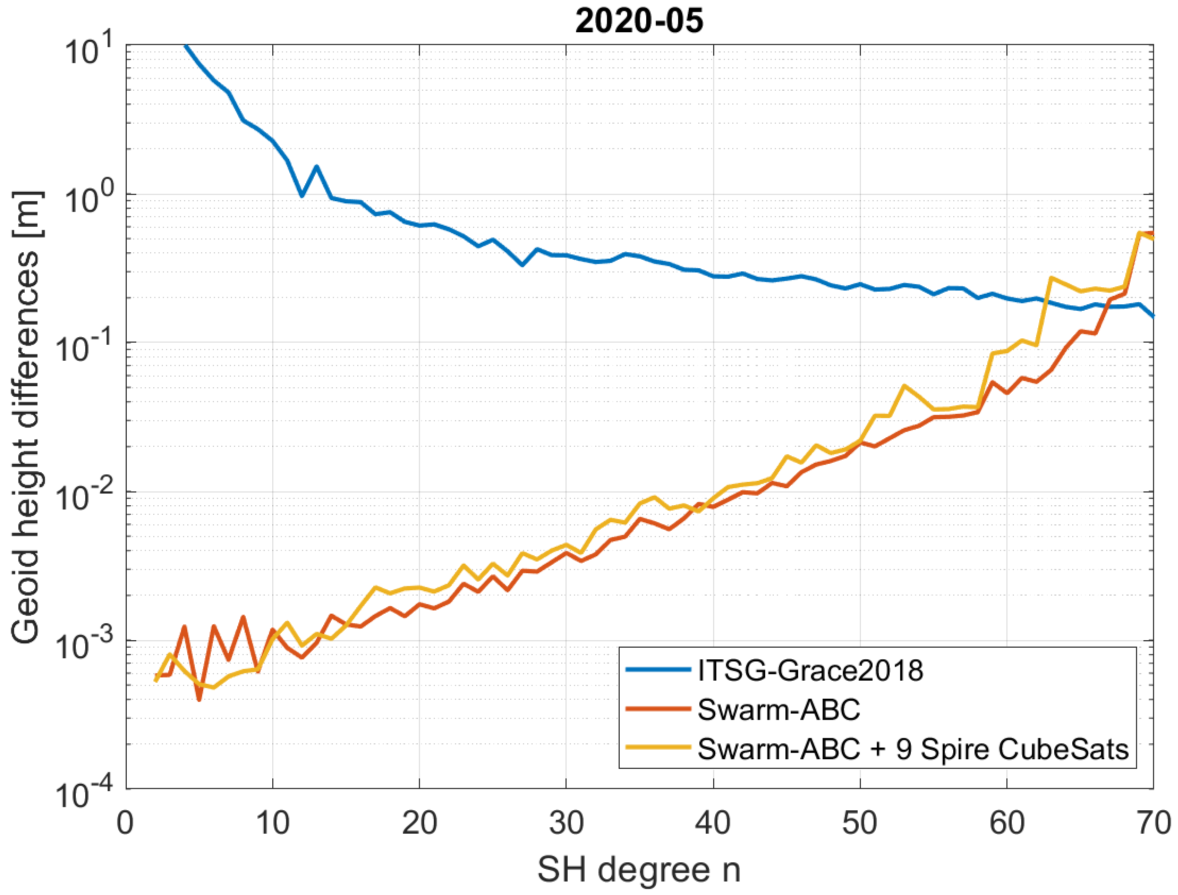
- Difference degree amplitudes



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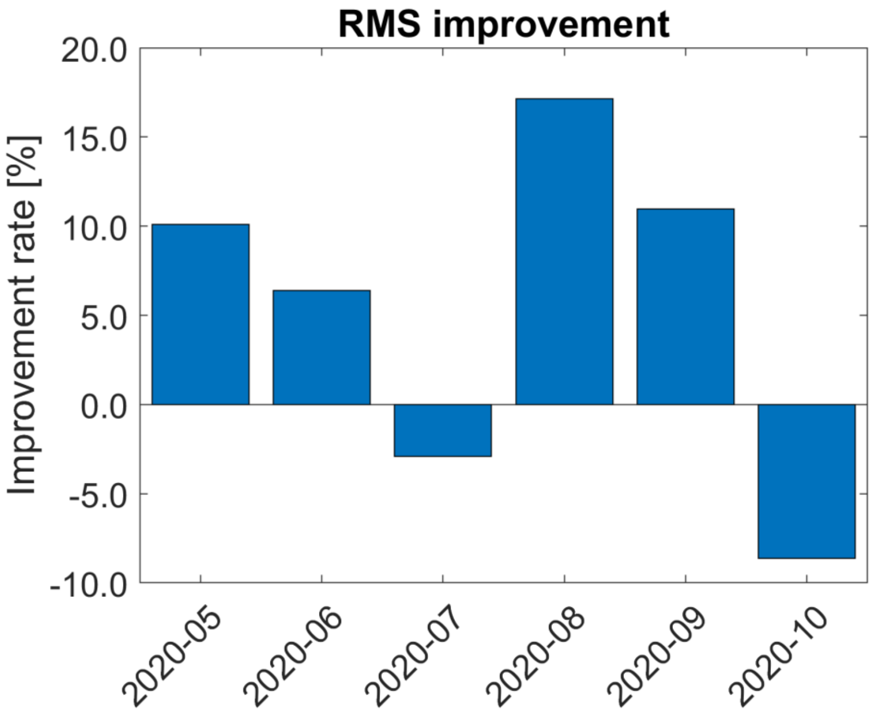


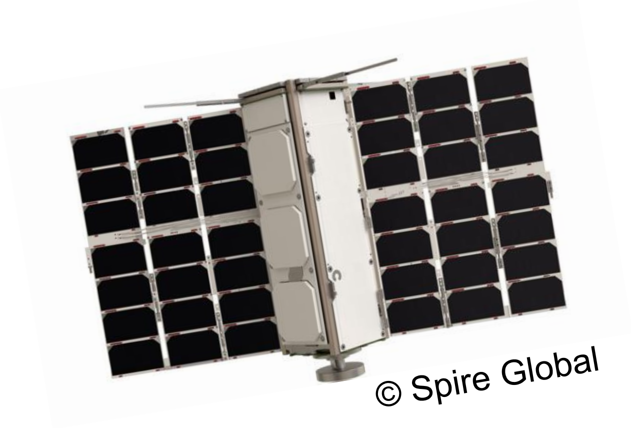
Summary and outlook

Main findings

- GPS data of Spire CubeSats allow to recover monthly gravity field solutions
- Individual CubeSat solutions cannot compete with scientific LEO missions
- Accumulation of CubeSat solutions significantly increases the quality
- Solutions based on 9 CubeSats can improve selected coefficients of a Swarm model

Next steps

- Process Spire data of further CubeSats and longer time spans
- Analysis on the impact of low-inclined CubeSats
- Feasibility to increase the temporal resolution (< 1 month)



Thank you for your attention

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Beutler G, Jäggi A, Mervart L et al. (2010): The celestial mechanics approach: theoretical foundations, Journal of Geodesy 84(10):605–624, DOI: 10.1007/s00190-010-0401-7

Mayer-Gürr T, Behzadpur S, Ellmer M et al. (2018): ITSG-Grace2018 - Monthly, Daily and Static Gravity Field Solutions from GRACE. GFZ Data Services, DOI: 10.5880/ICGEM.2018.003