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

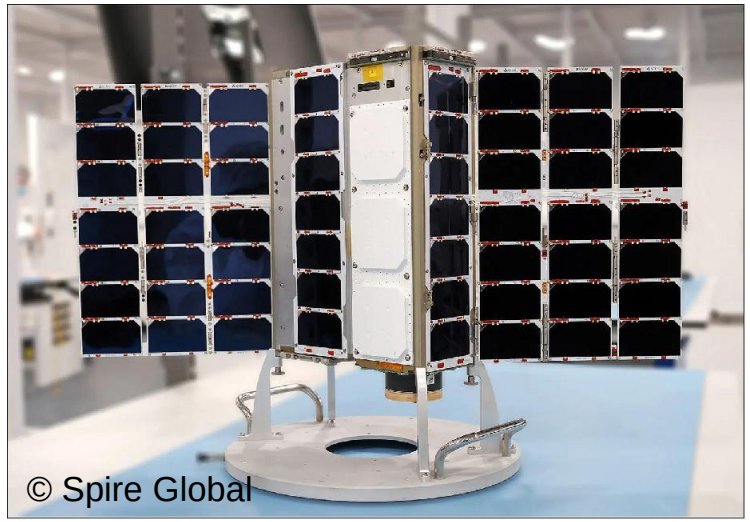
T. Grombein[1,2], D. Arnold[2], C. Kobel[2], M. Lasser[2], A. Jäggi[2]

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

# 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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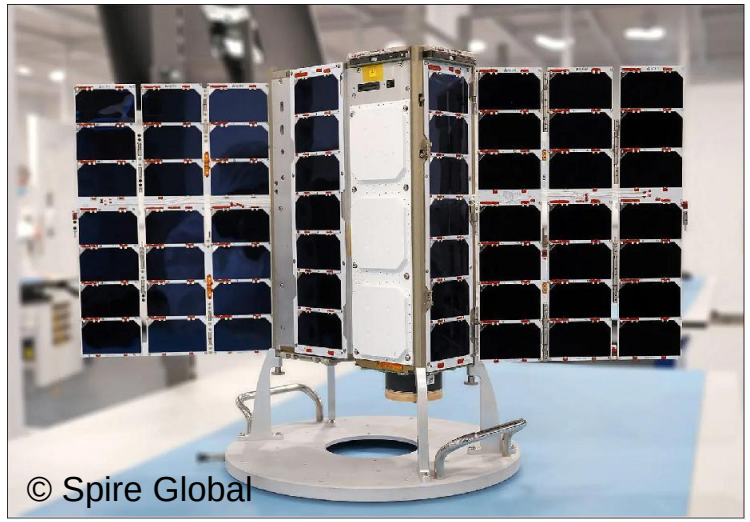


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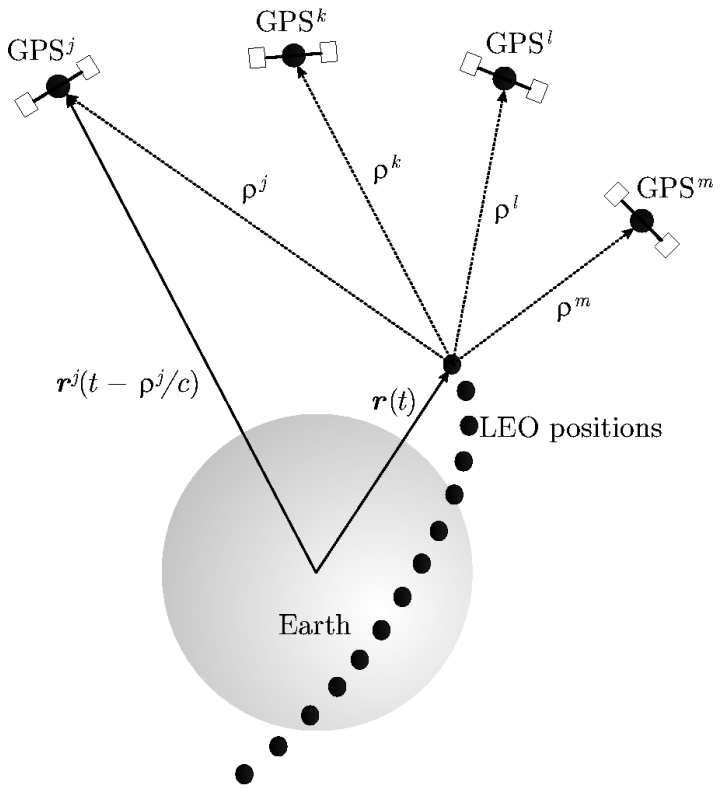
➢ Case study based on 6 months of GPS data from 9 Spire CubeSats

# 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



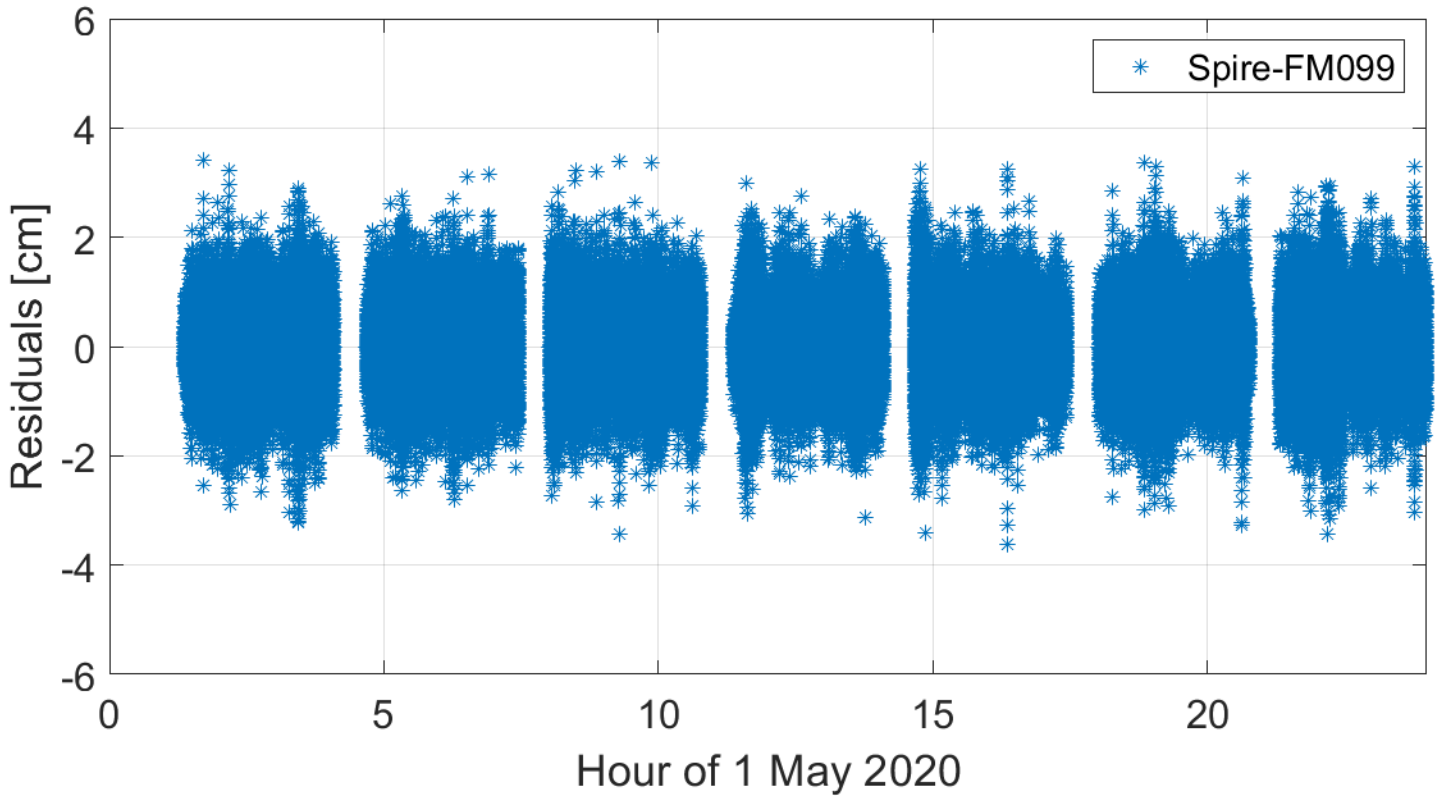

- Processing with the Bernese GNSS software
  - GNSS products of the CODE analysis center
  - In-flight calibrated phase center variation (PCV) maps
  - Unmodeled forces are absorbed by empirical parameters

# 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

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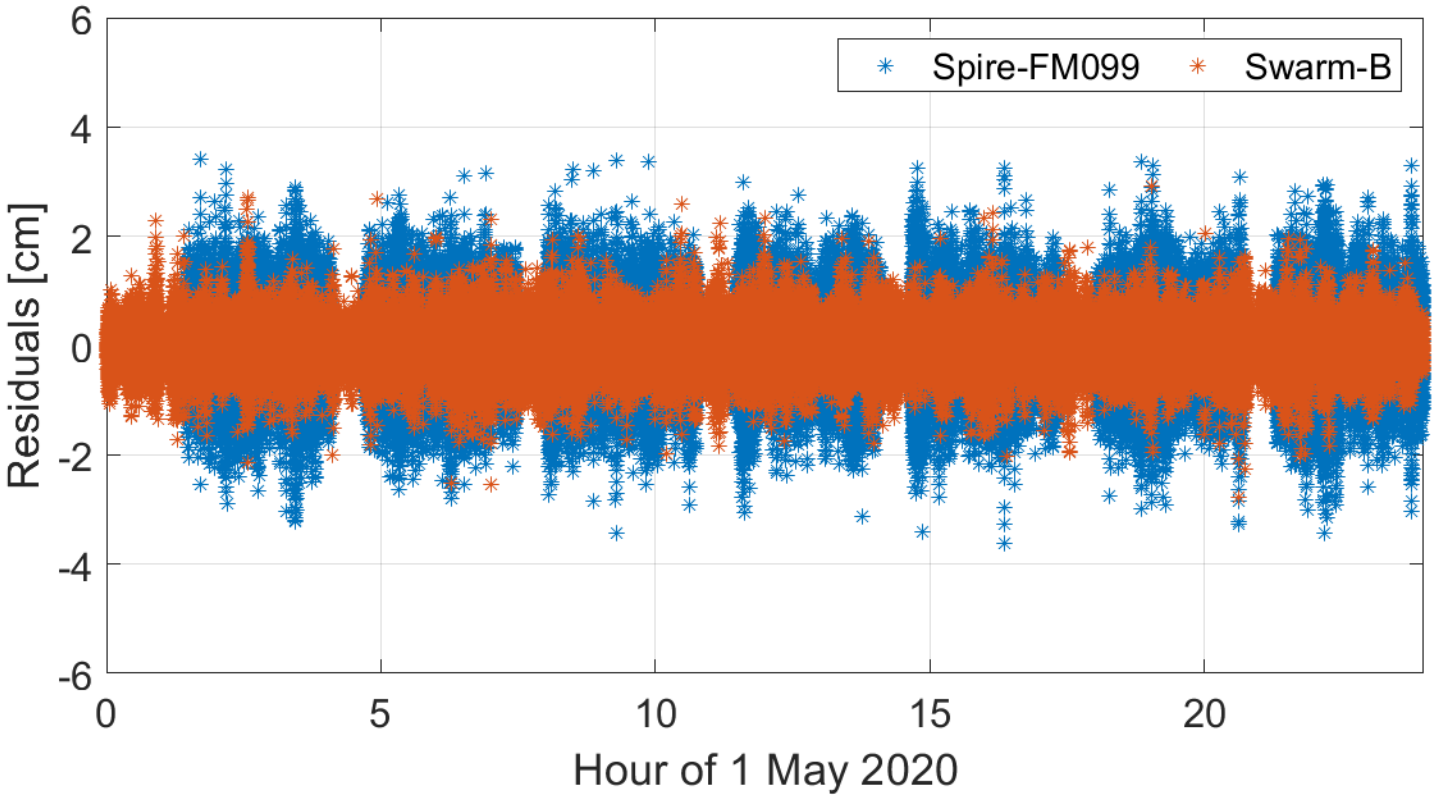
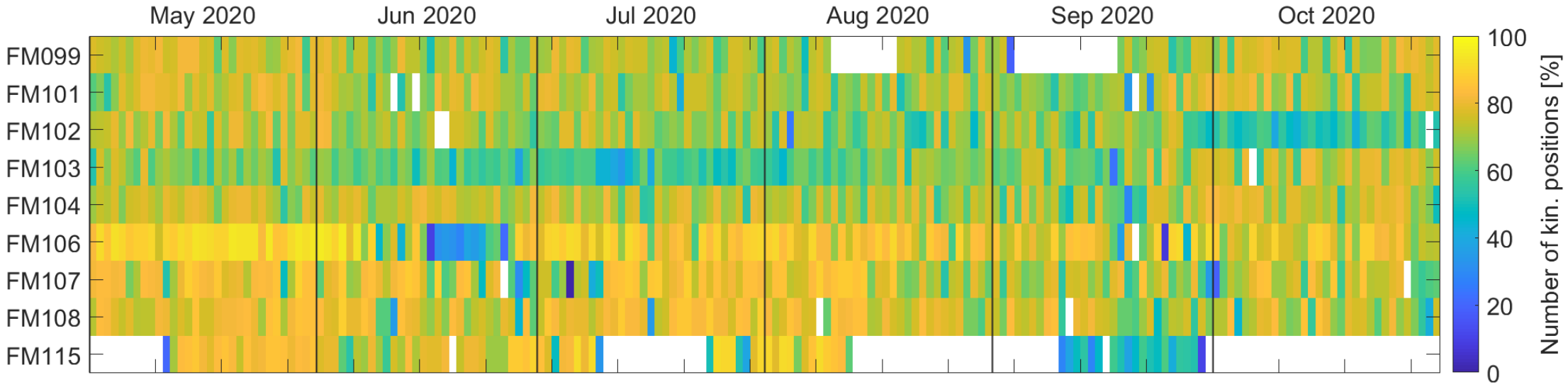



Higher noise level compared to scientific LEO missions

# 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 % |

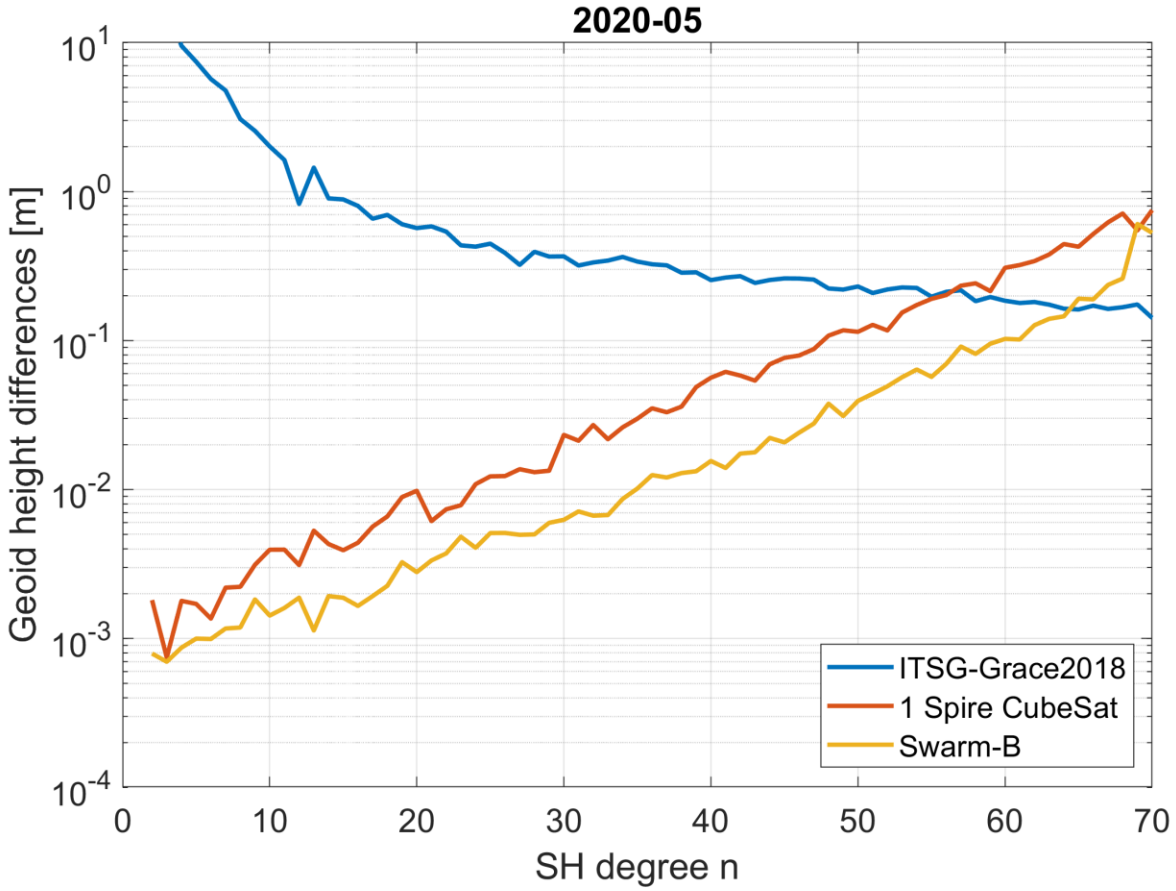
# Monthly Spire-based gravity fields

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

# Spire gravity fields

FM099

- Difference degree amplitudes




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

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FM099

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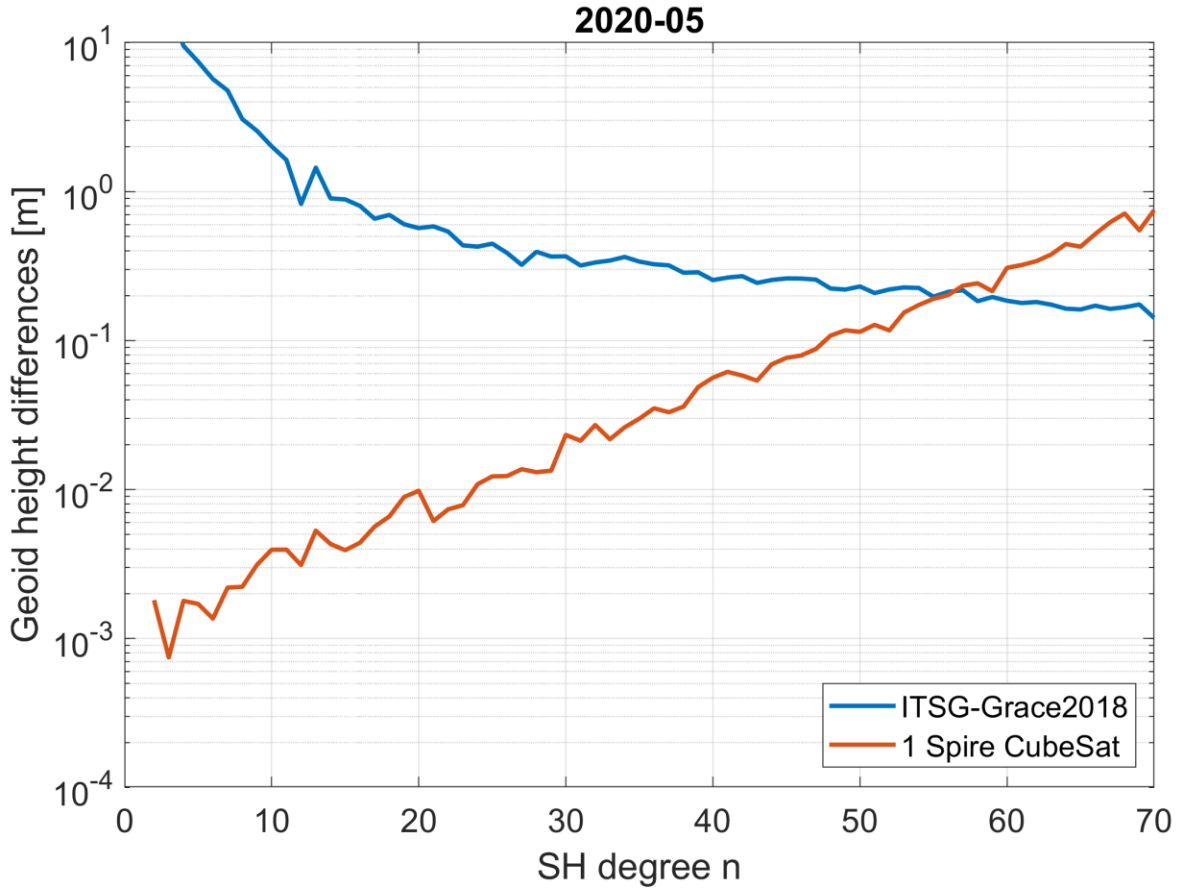
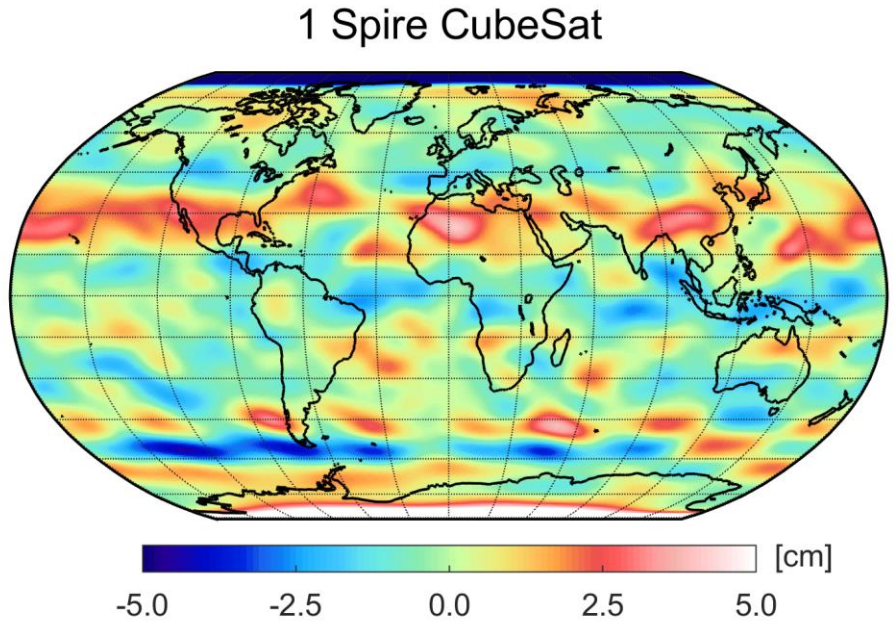



- Geoid height differences




700 km Gauss filtered

# Spire gravity fields

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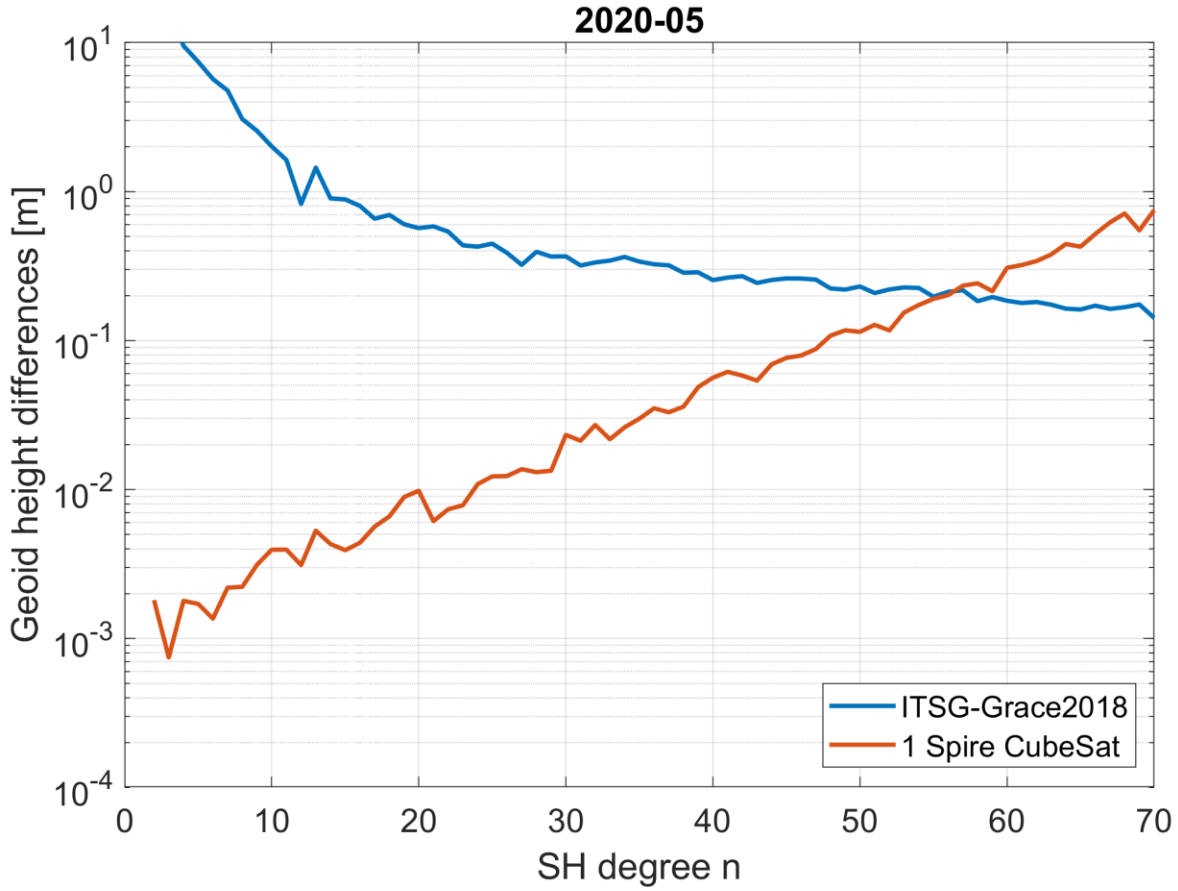


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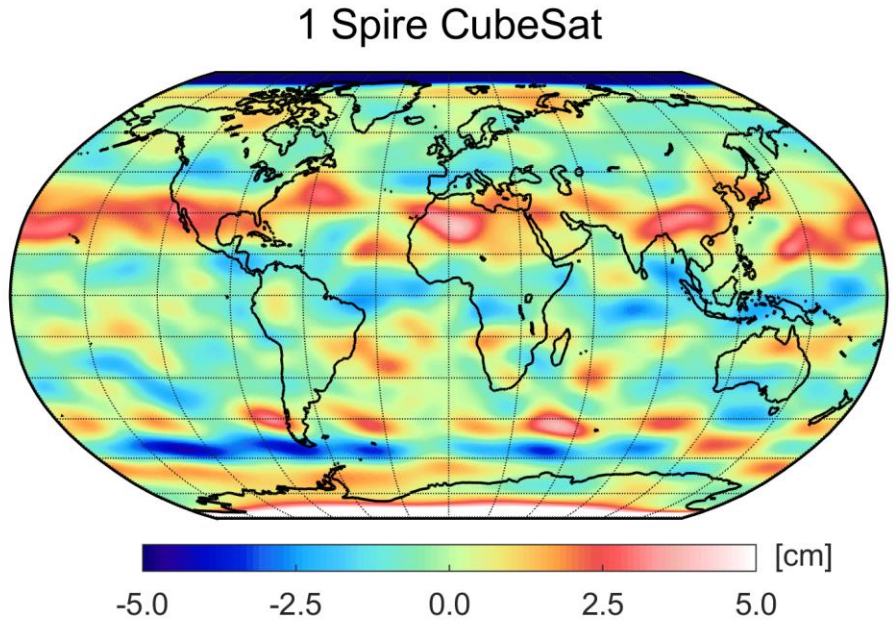
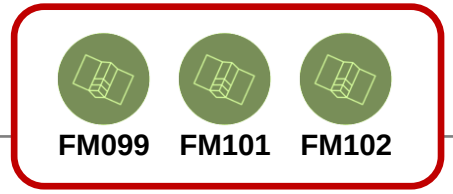



Artifacts in Est/West-direction are correlated with locations of yaw flips (under investigation)

# Spire gravity fields

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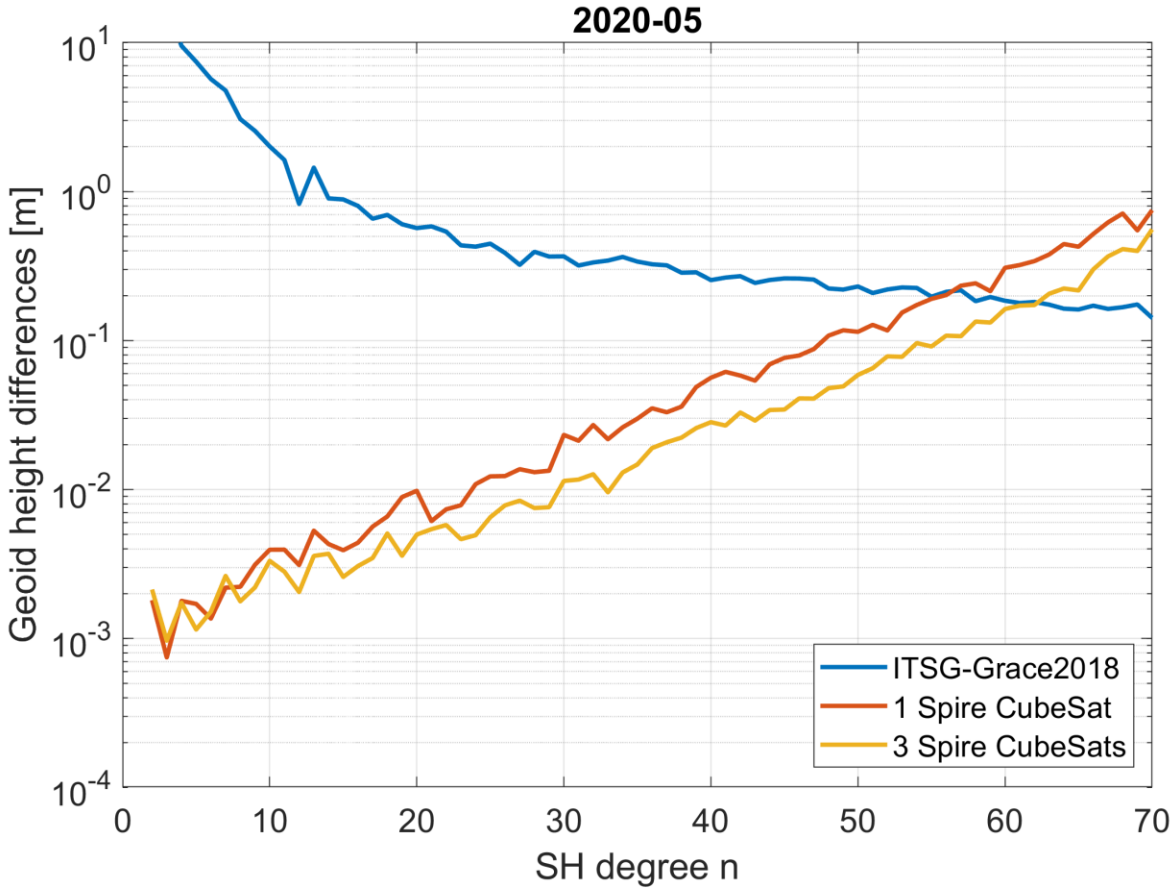


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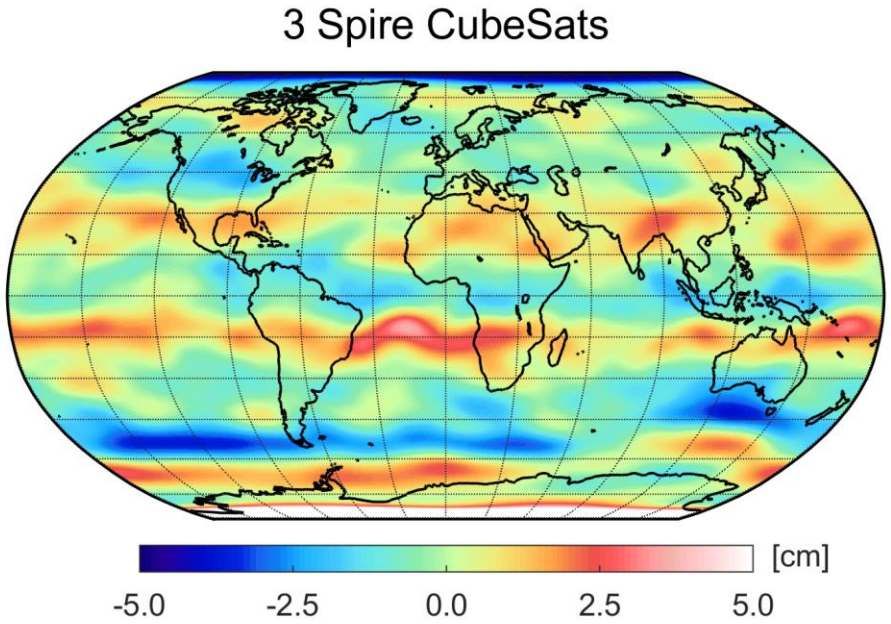

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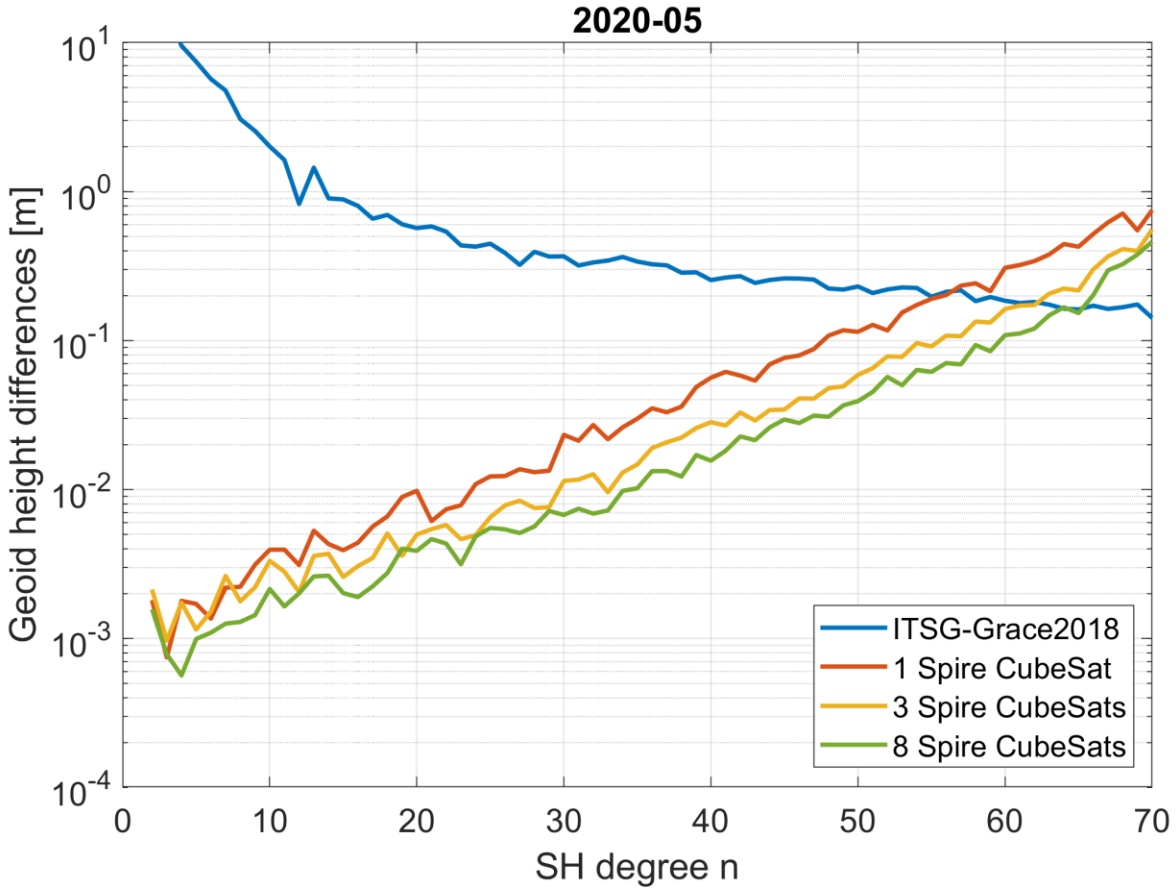


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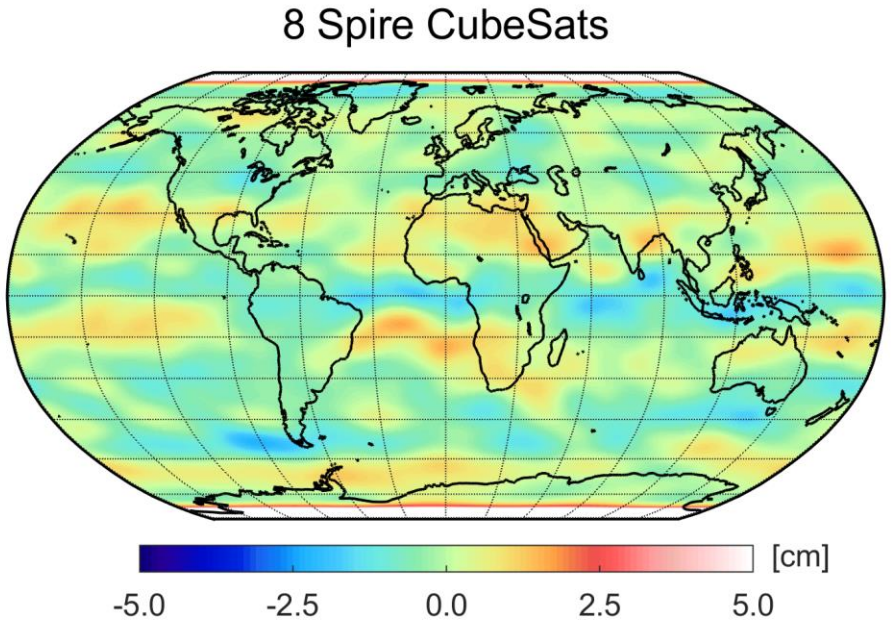

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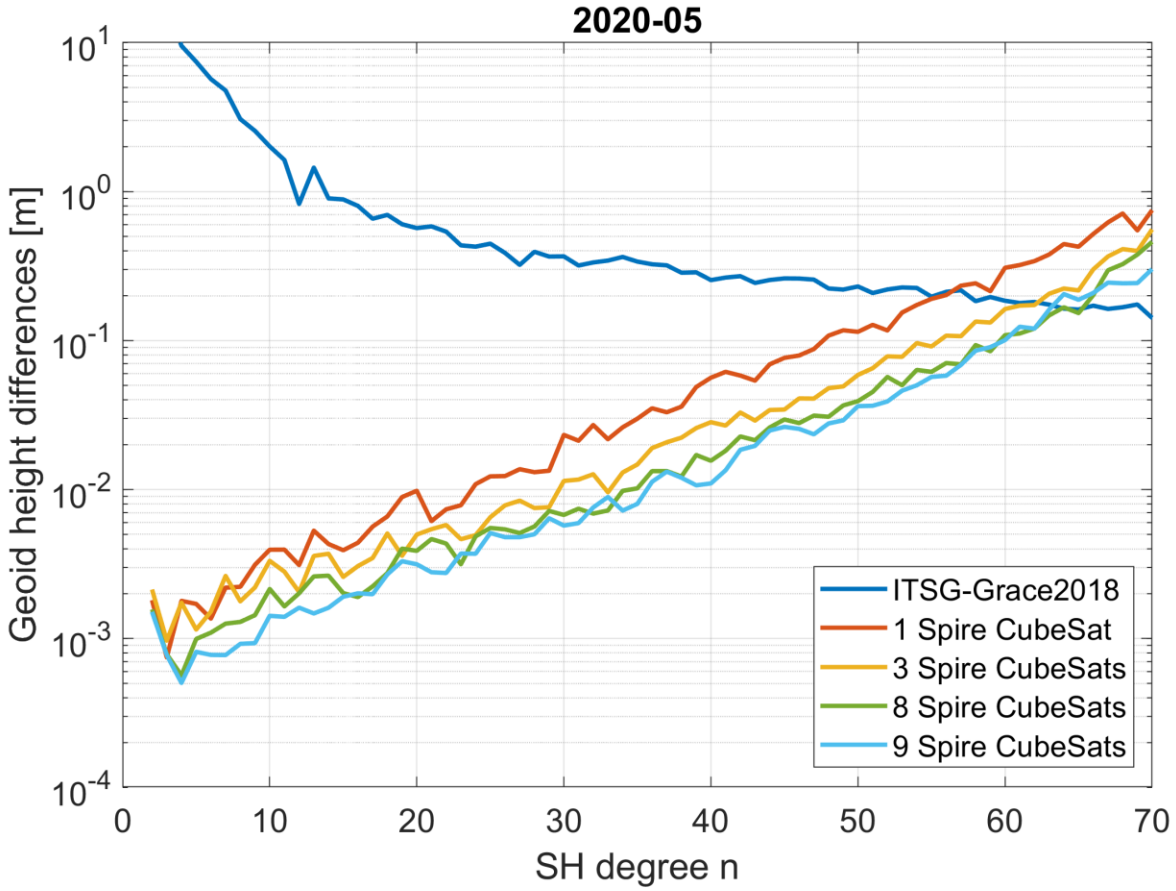


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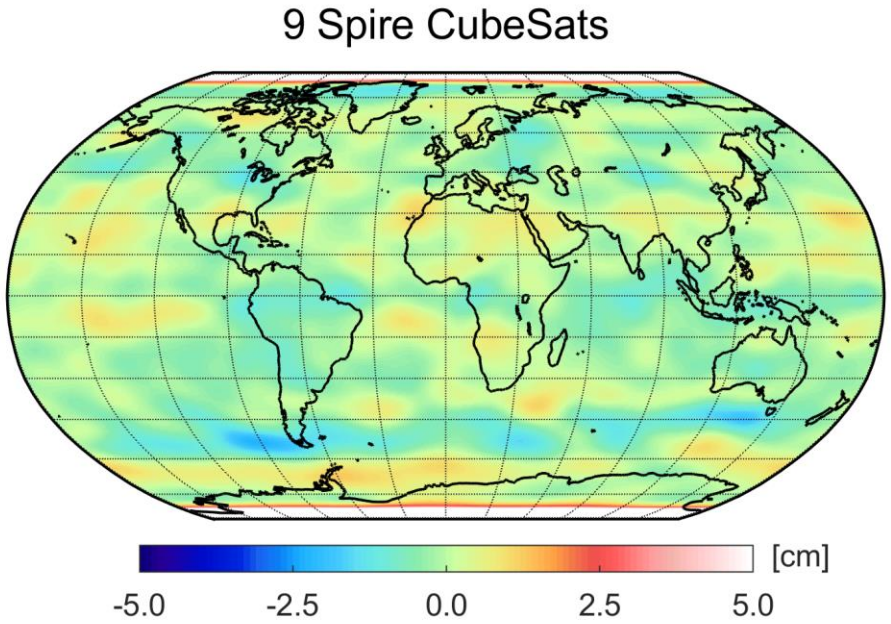

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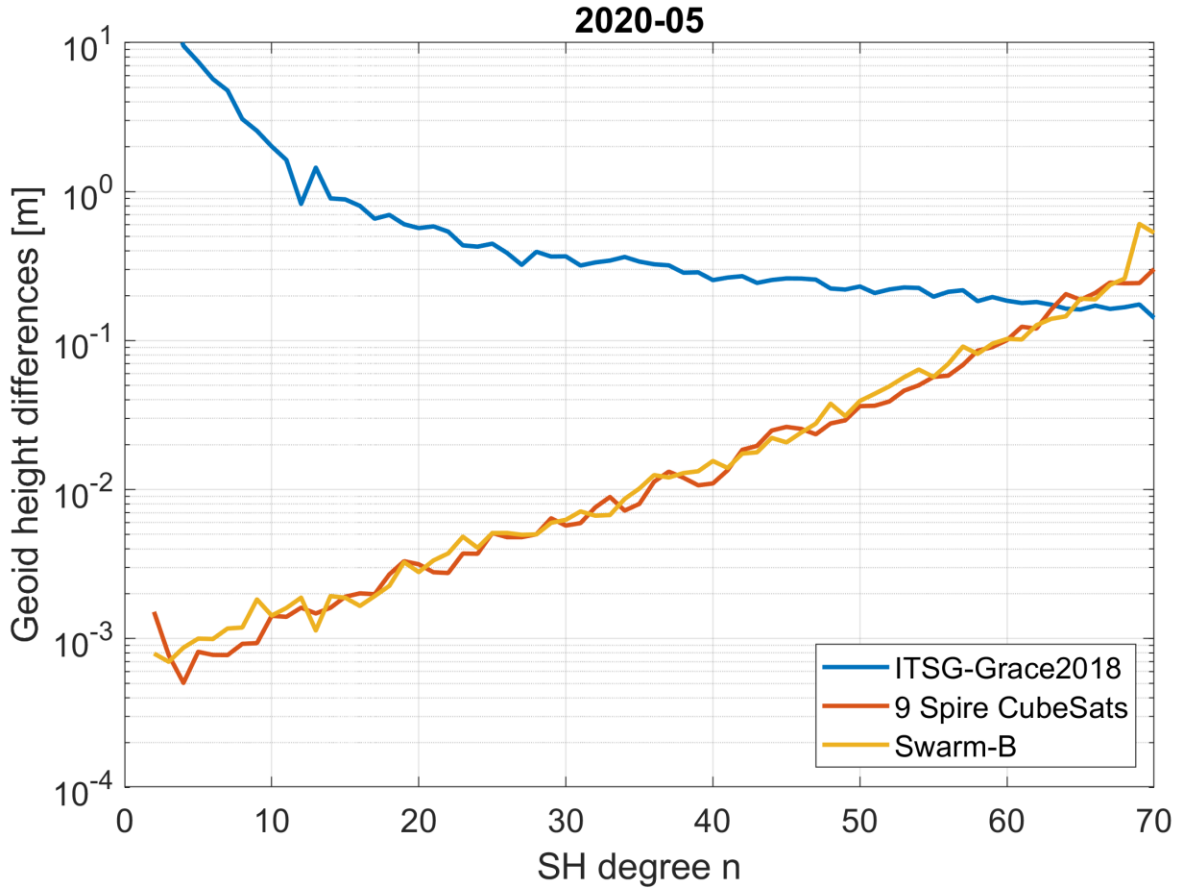
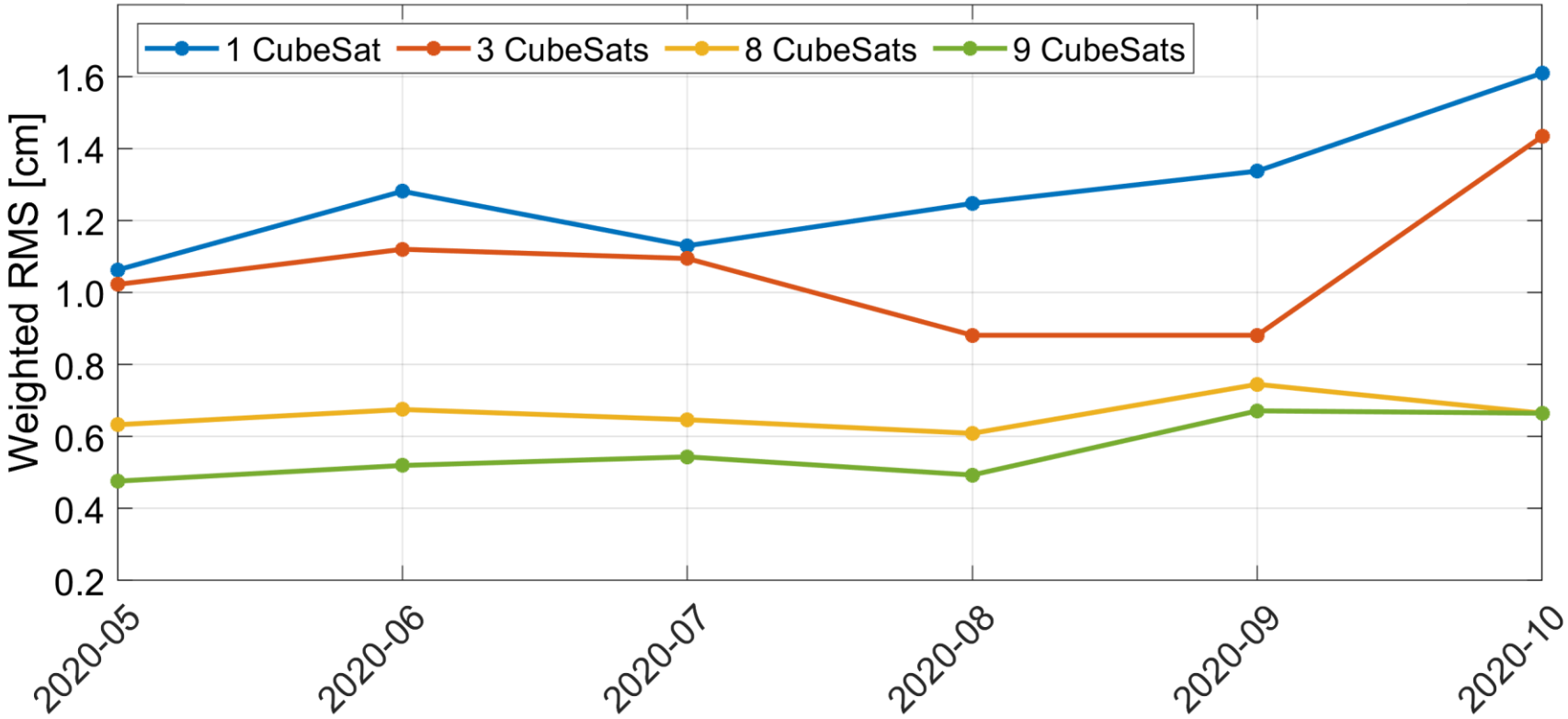



Solutions based on 9 CubeSats can reach a quality level comparable to Swarm-B

# Quality of Spire gravity field solutions

- Weighted RMS values of geoid height differences




700 km Gauss filtered

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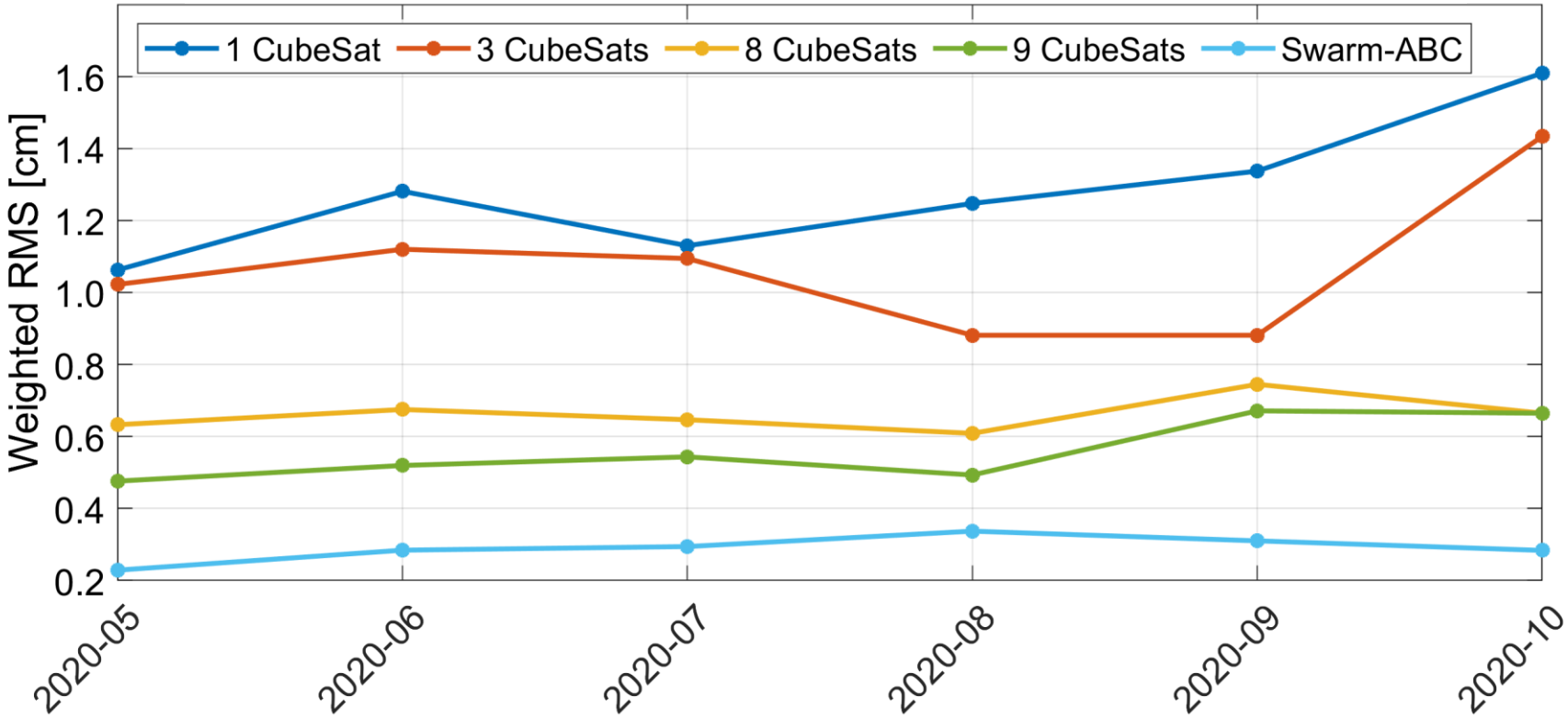
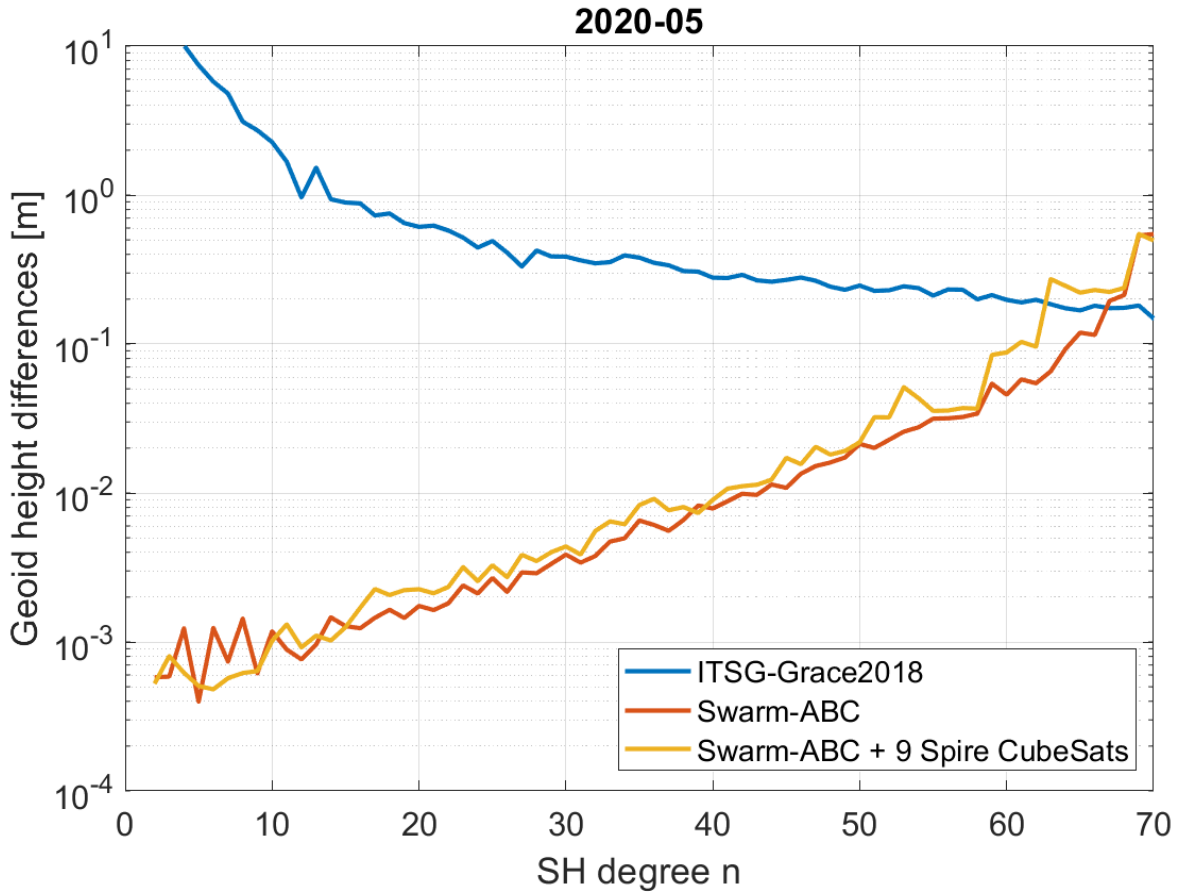



700 km Gauss filtered

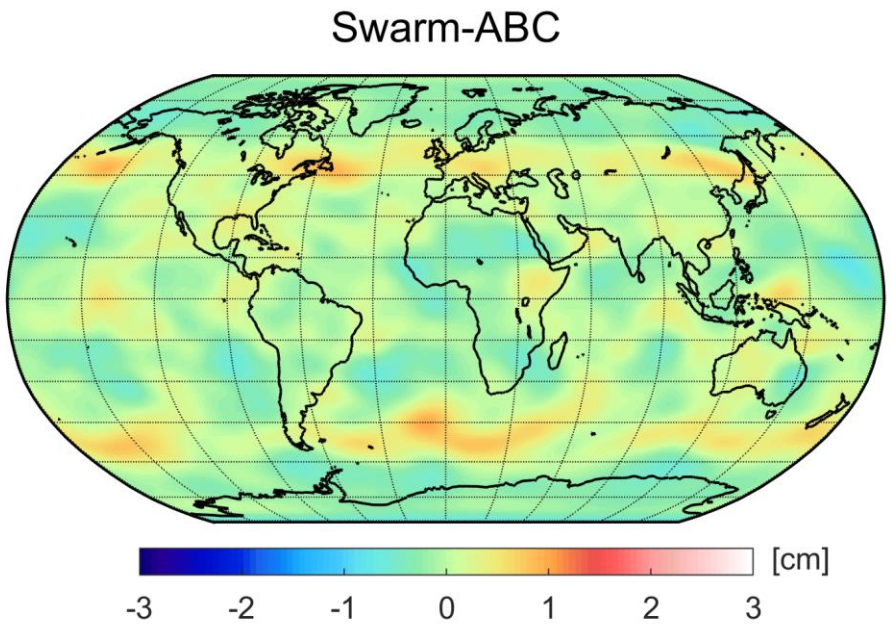
# Swarm−Spire combinations

# Combination of Swarm with Spire solutions

- Difference degree amplitudes




- Geoid height differences



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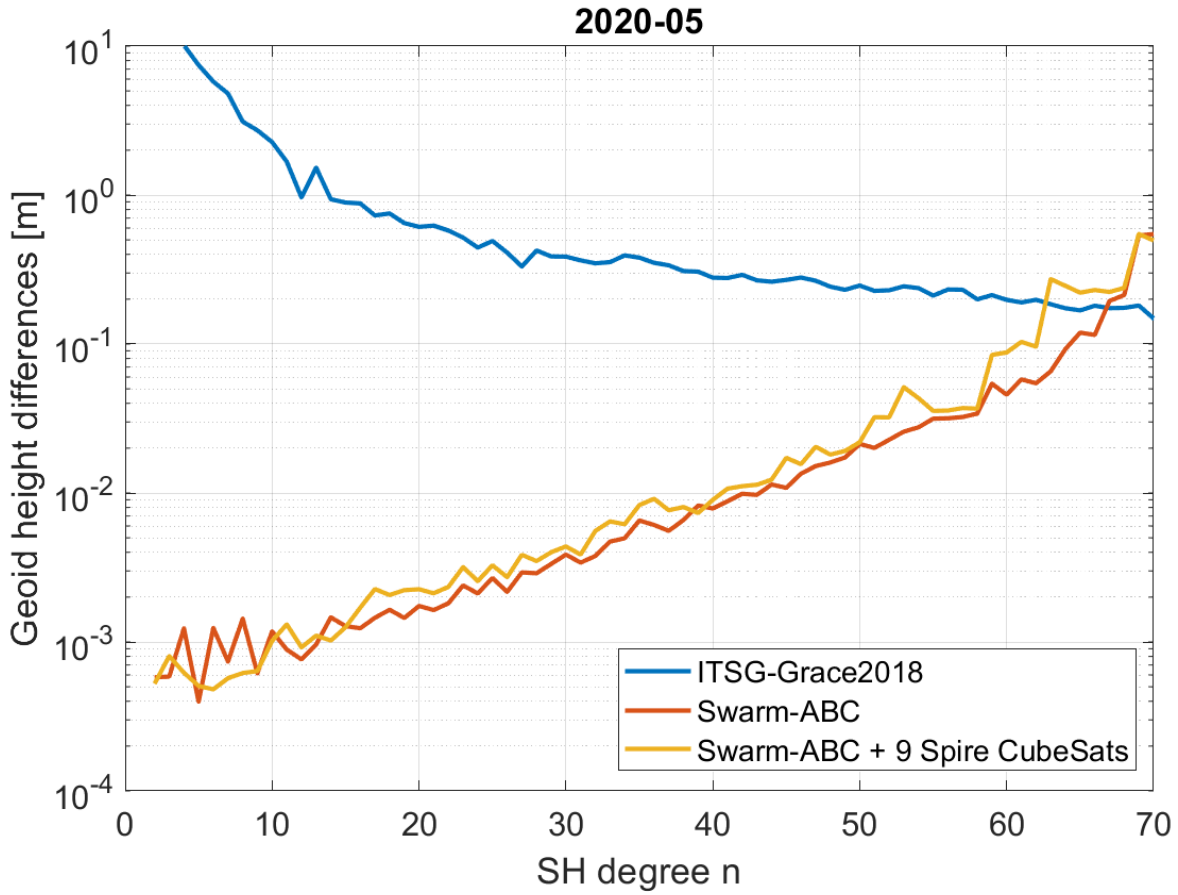


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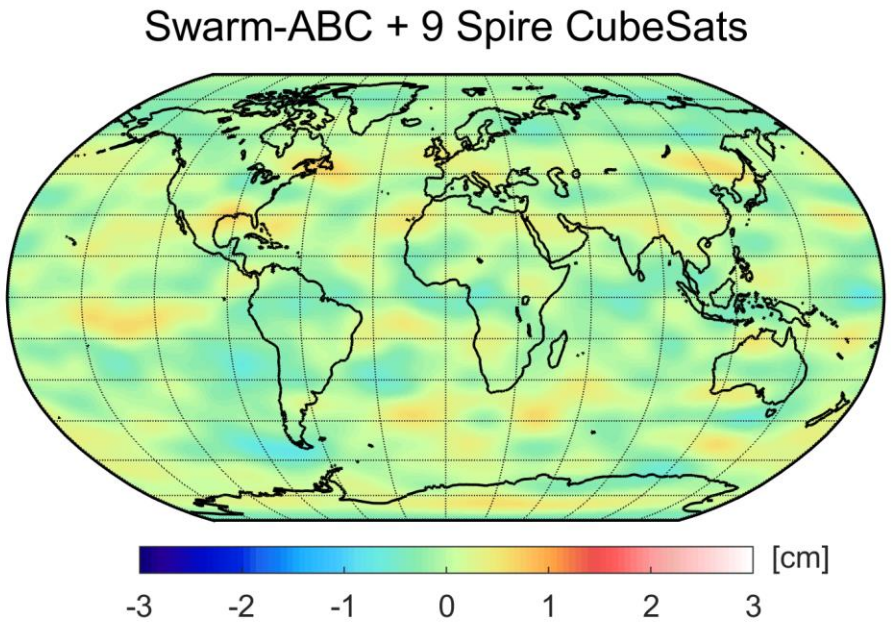


RMS improvement: ~ 10%

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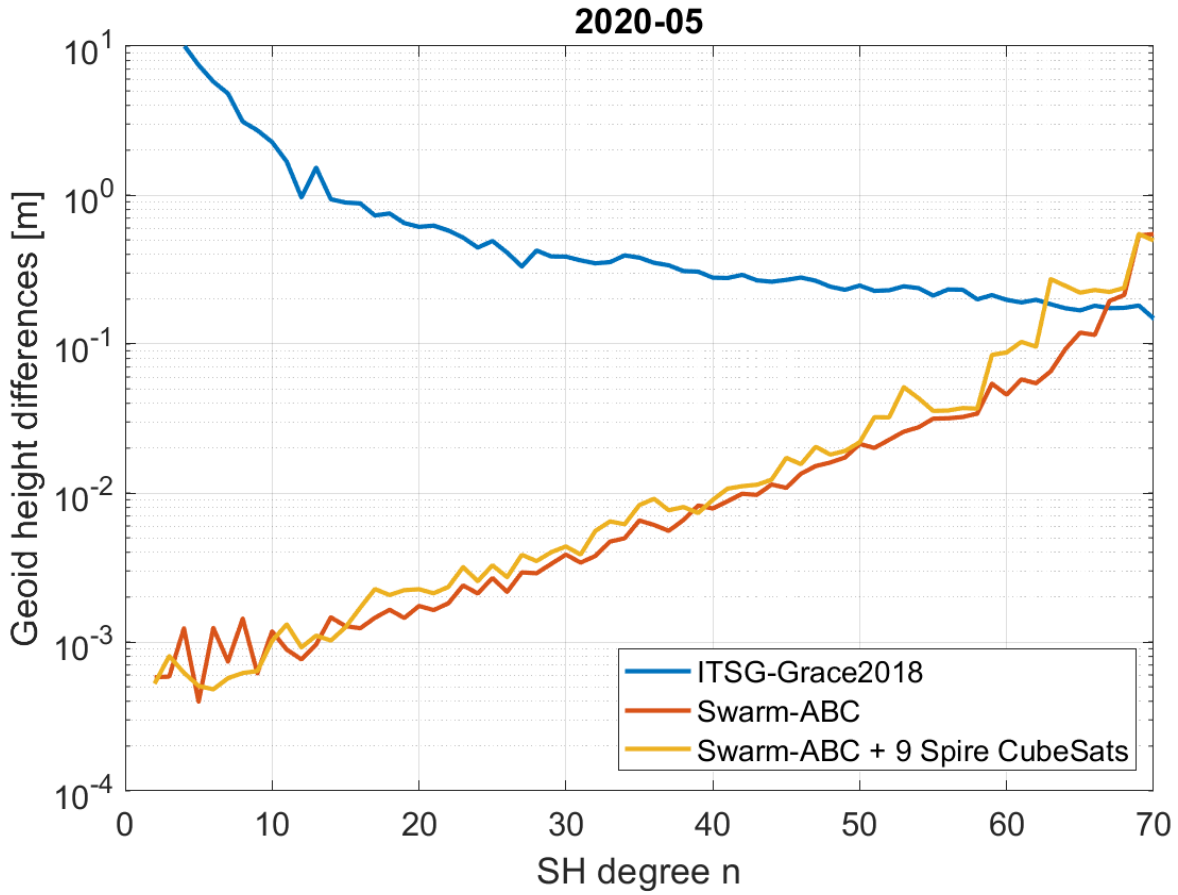


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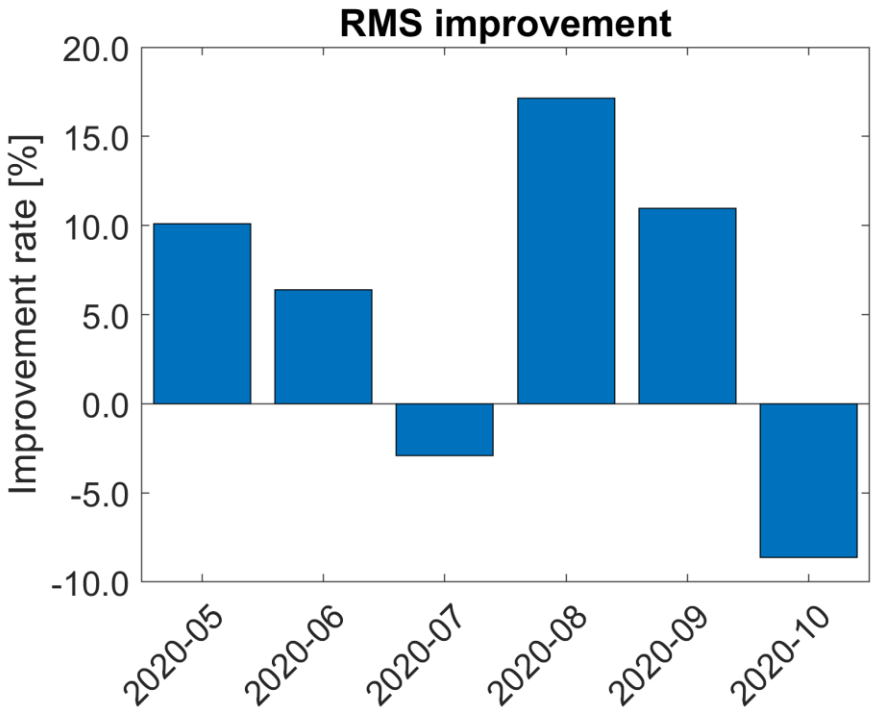


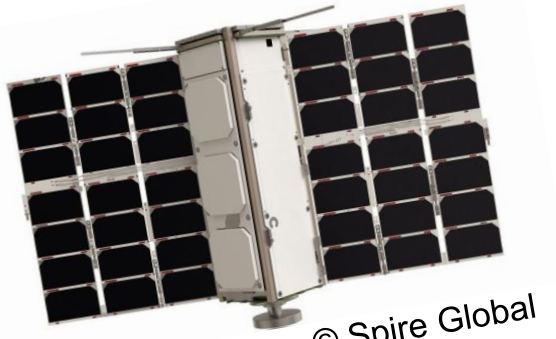
# Summary and outlook

## 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

Contact: grombein@kit.edu

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

# References

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