IAG Scientific Assembly 2025, Rimini

Joint orbit and gravity field determination from GPS carrier phase observations of Spire CubeSats

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

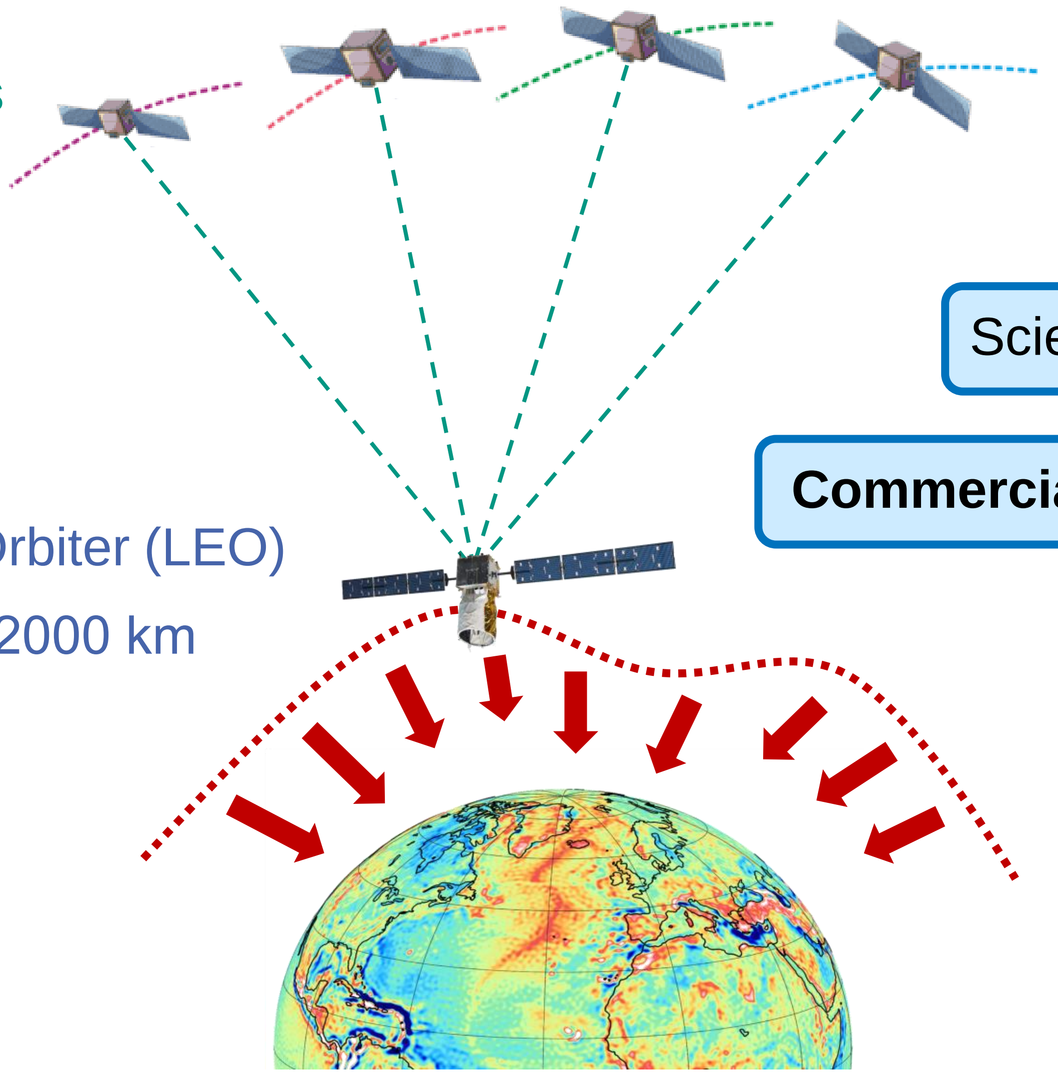
High-Low Satellite-to-Satellite-Tracking

GNSS satellites

~ 20.000 km

Low Earth Orbiter (LEO)

~ 200 – 2000 km

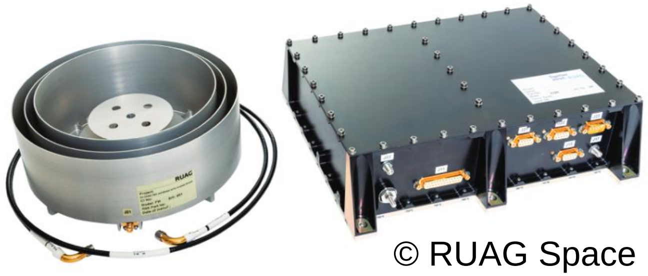


Scientific satellite missions

Scientific satellite constellations

Commercial mega-constellation

GNSS antenna and receiver



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Mega-constellations as gravity field sensors

Potential

Huge amount of observations

Faster global ground track coverage

Increased spatial-temporal resolution

Mega-constellations

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Limitations

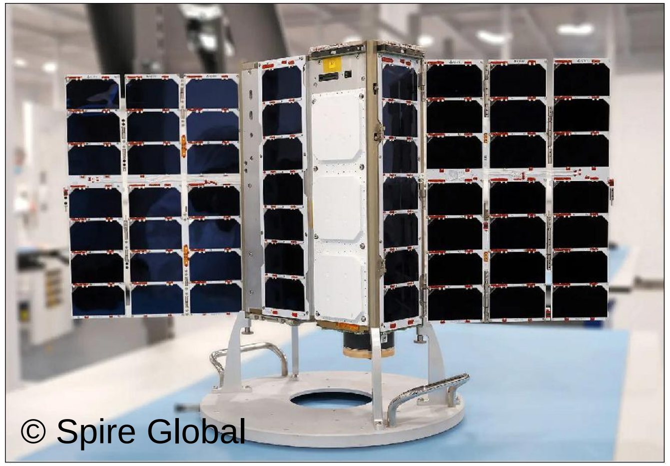
Restricted sensitivity (long-wavelength)

Dual-frequency GNSS receivers needed

Limited data access and quality

Commercial mega-constellations

- Spire Global constellation
  - More than 100 nano-satellites in low Earth orbit
  - CubeSats (standardized platform, low cost)
  - High-quality dual-frequency GNSS receivers
  - Different orbital characteristics (altitude, inclination)



10 x 10 x 34 cm, 4.7 kg

Data provision from 9 Spire CubeSats via ESA project (Third party mission)

Commercial mega-constellations

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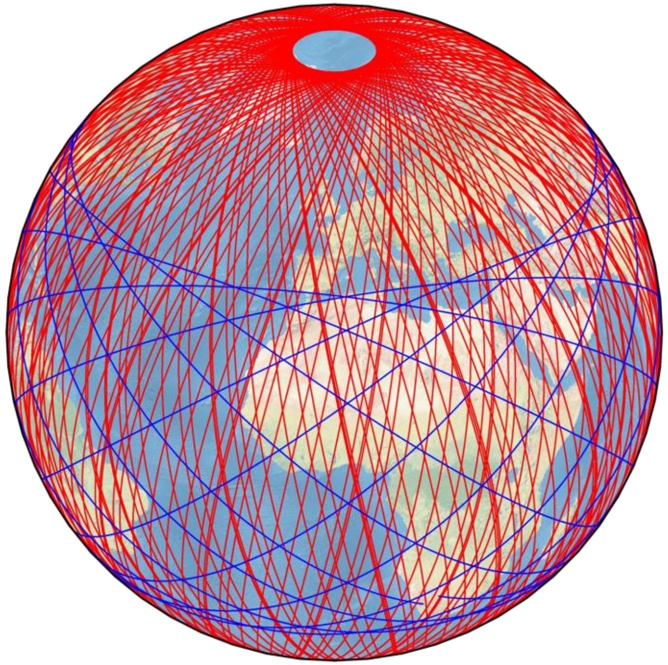
Data provision from 9 Spire CubeSats via ESA project (Third party mission)

Ground track coverage after one day

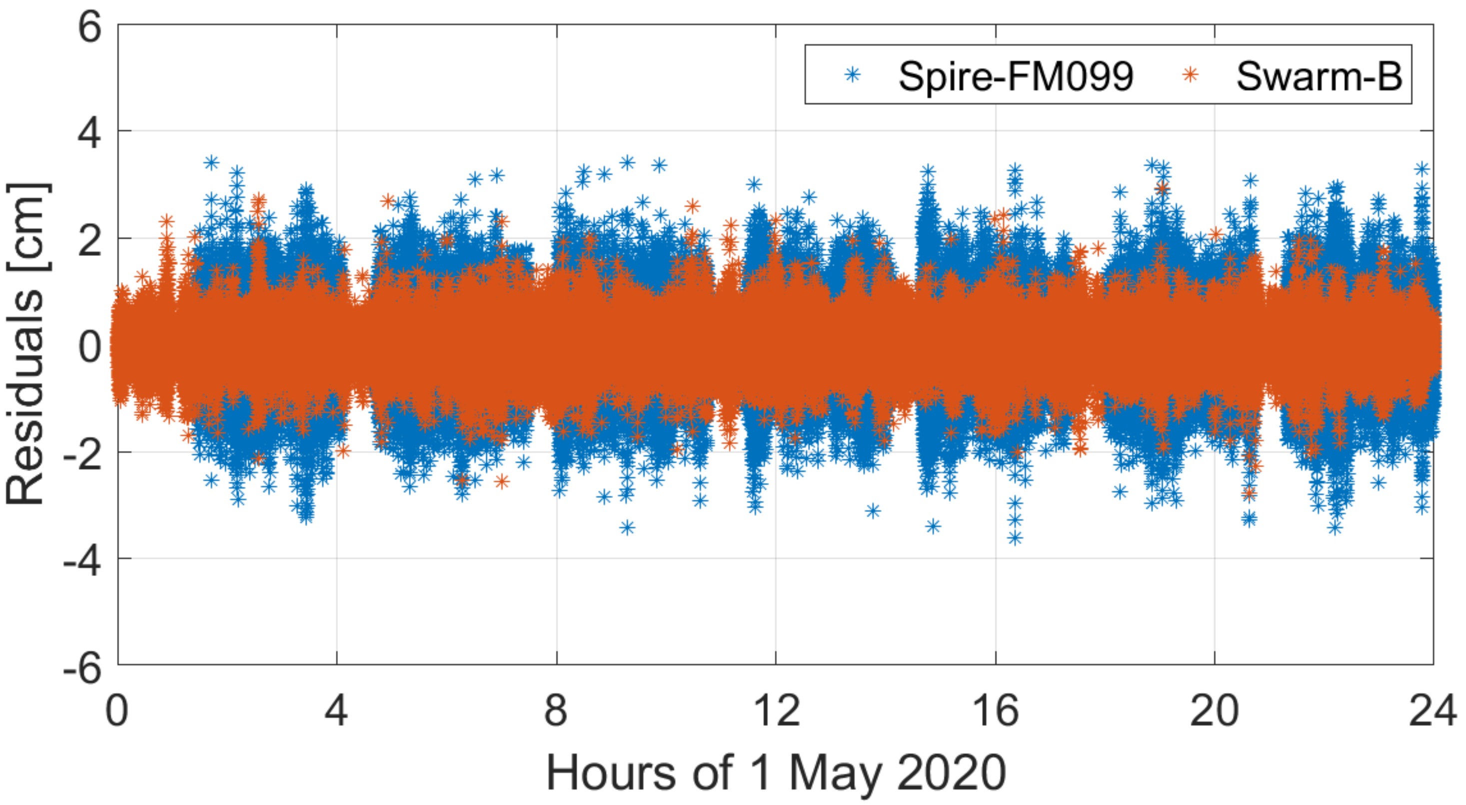


8 Sun-synchronous orbits

1 Low-inclined orbit (37°)

Quality of GPS data

- GPS carrier phase residuals of kinematic orbit determination



RMS: 0.82 cm

Factor
2−3

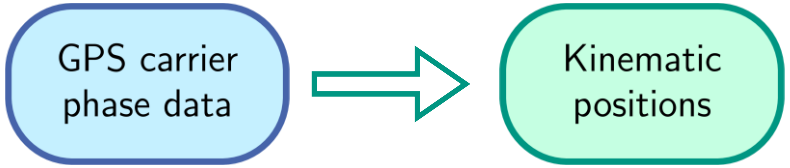
RMS: 0.36 cm

Gravity field recovery

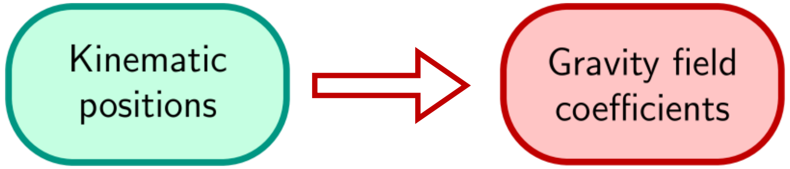
Celestial Mechanics Approach
Bernese GNSS Software

- Kinematic approach (KIN)

1) Precise orbit determination (POD)

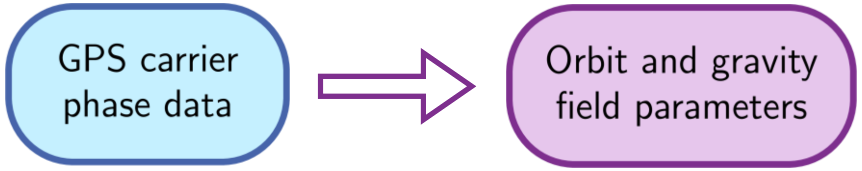


2) Gravity field recovery



- Phase approach (Phase)

Joint orbit and gravity field determination

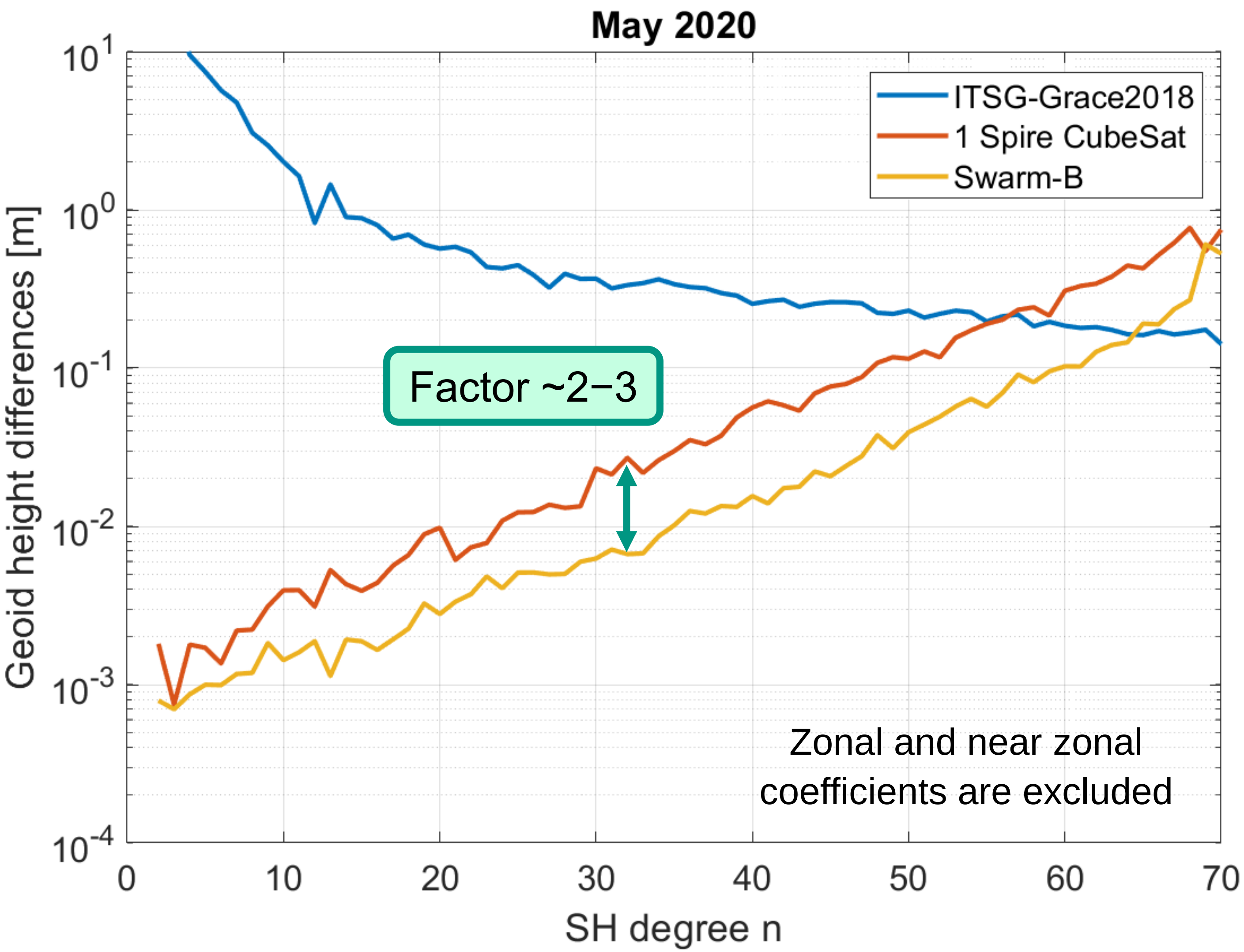


Kinematic approach

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

Spire

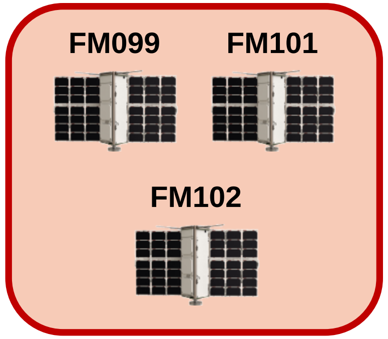
1 CubeSat



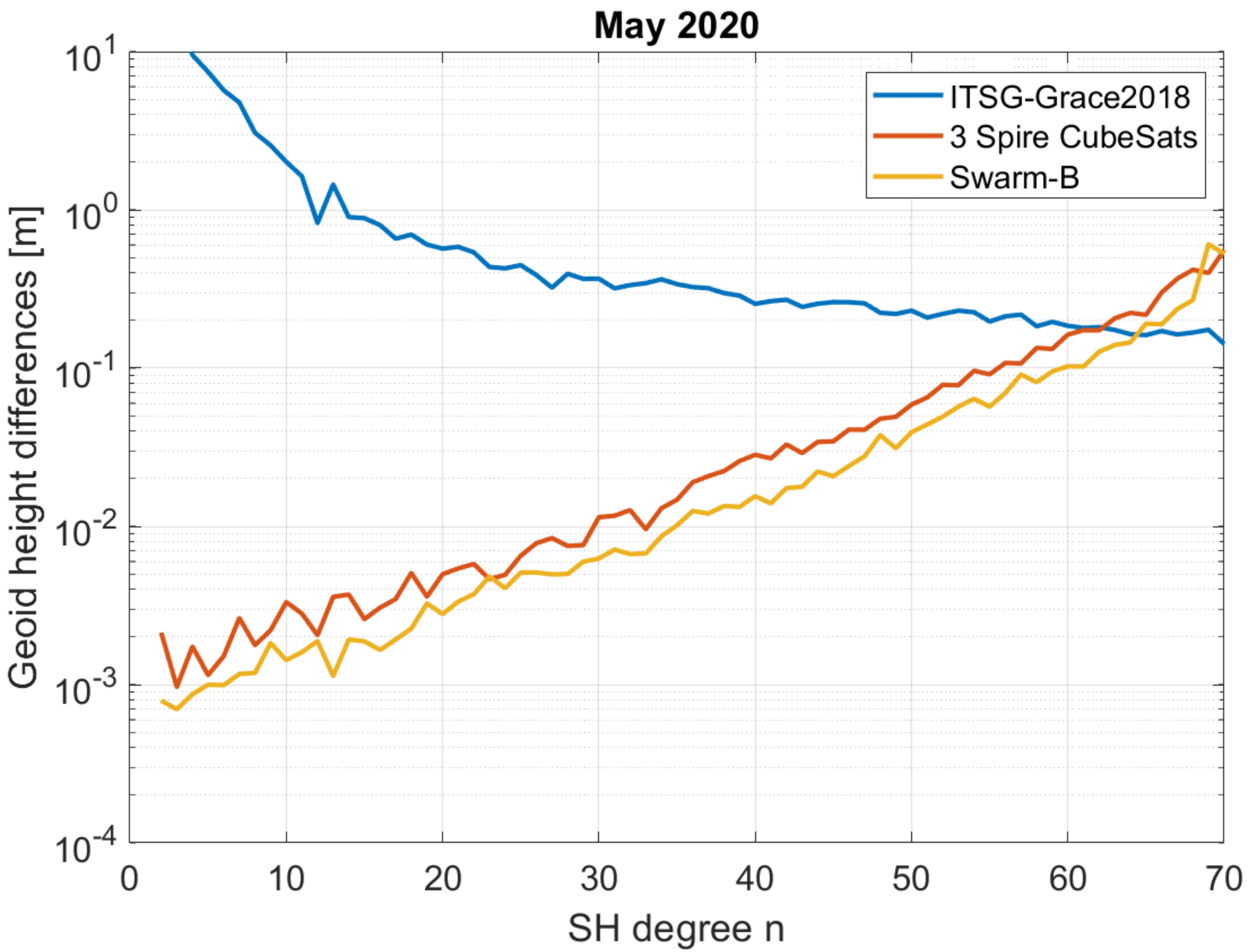
Swarm-B

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

Spire



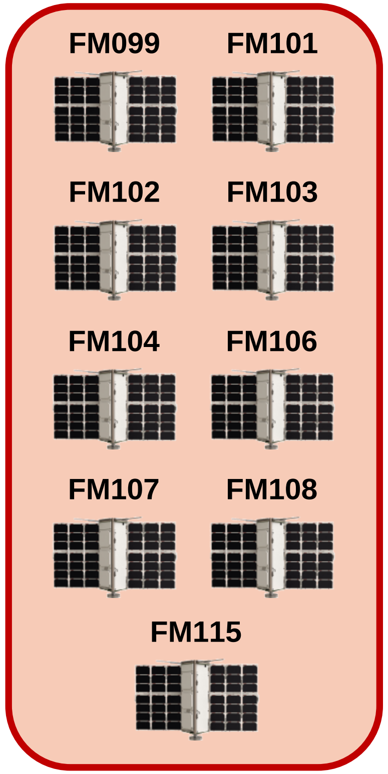
3 CubeSats



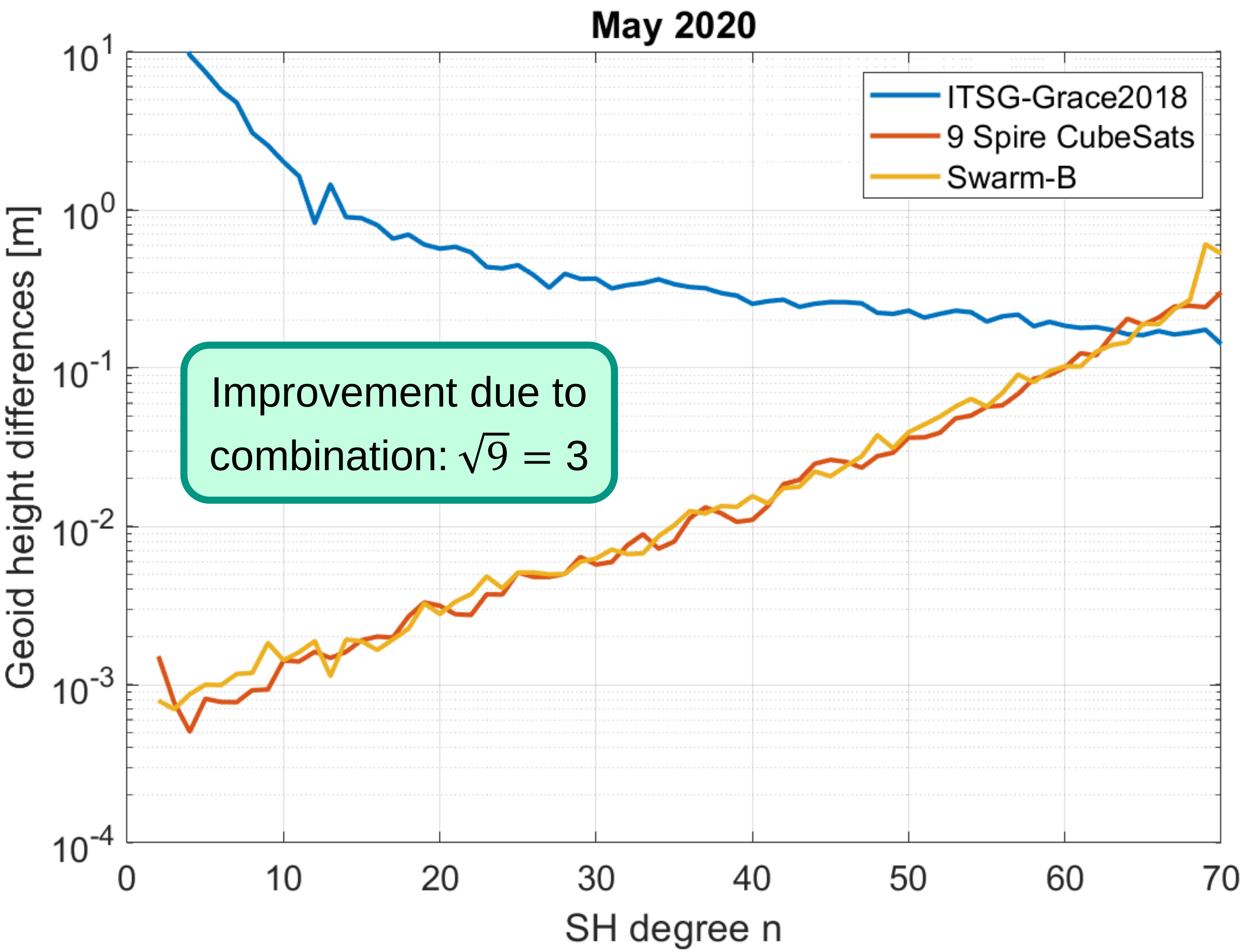
Swarm-B

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

Spire



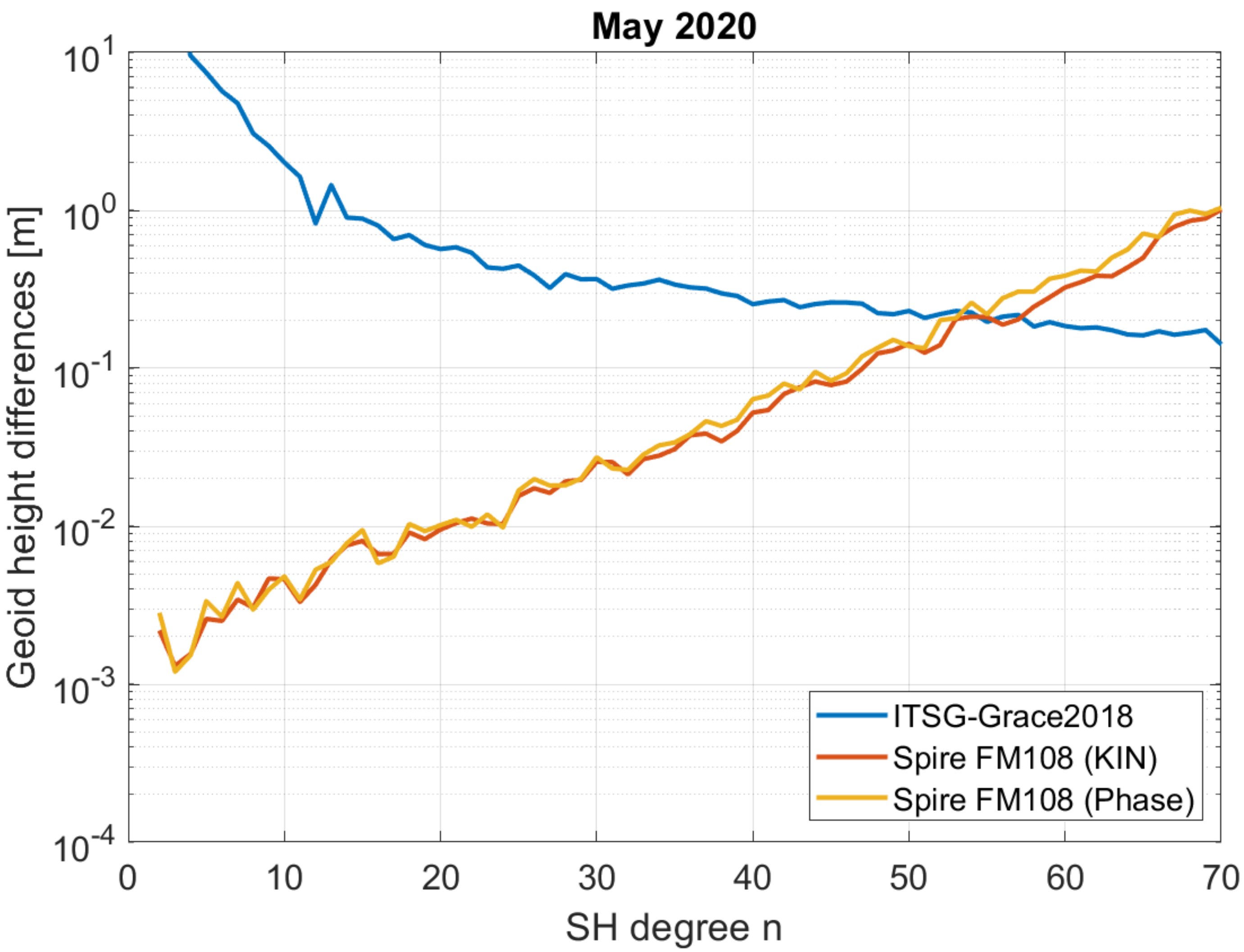
9 CubeSats



Swarm-B

Kinematic vs. phase approach

Kinematic and phase solutions (KIN vs. Phase)



Observation screening:

Both: iterative phase screening (POD)

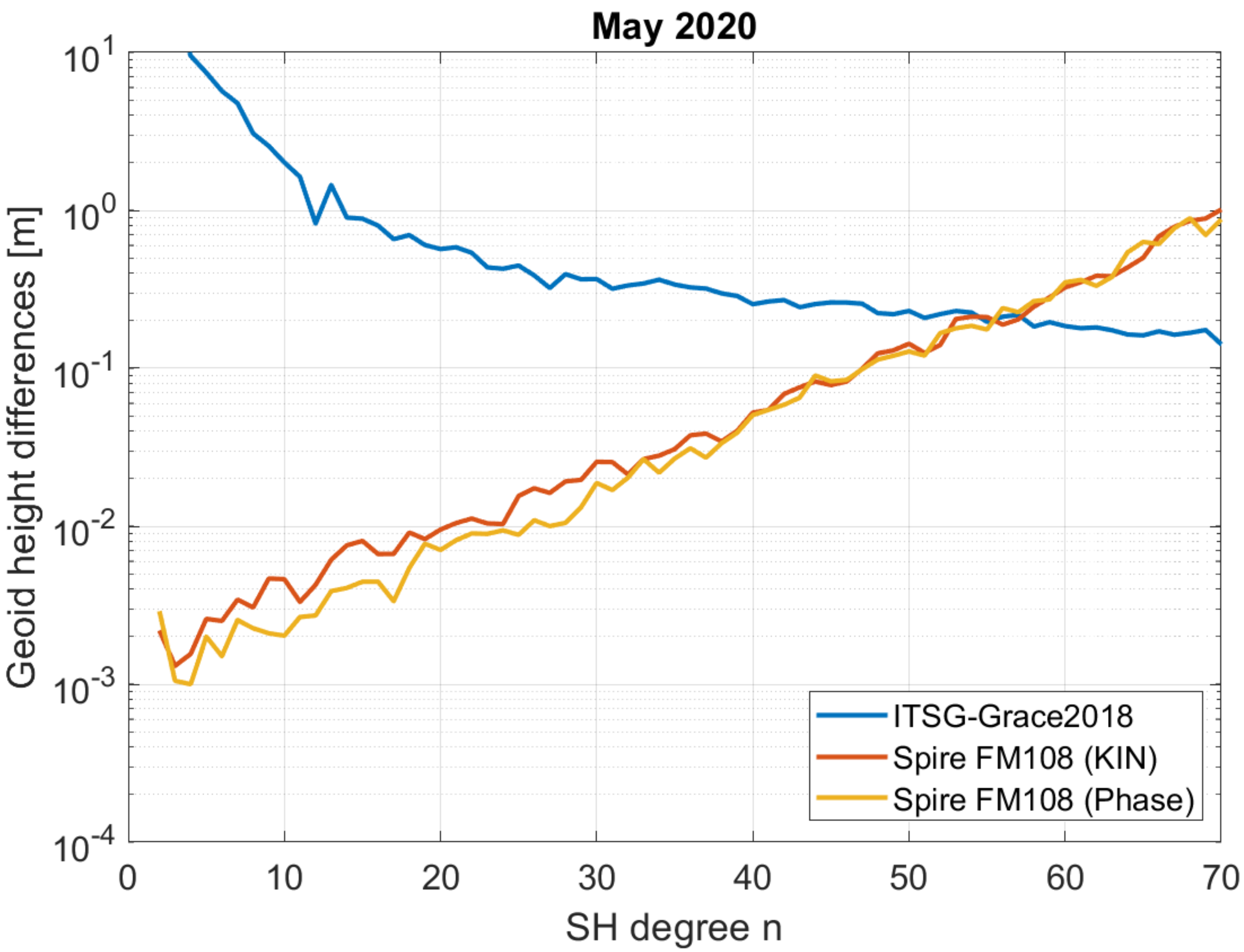
Kinematic positions

- Only epochs with sufficient GPS sat.
- Comparison to reduced-dynamic orbit

Phase observations

- No additional screening

Kinematic and phase solutions (KIN vs. Phase)



Observation screening:

Both: iterative phase screening (POD)

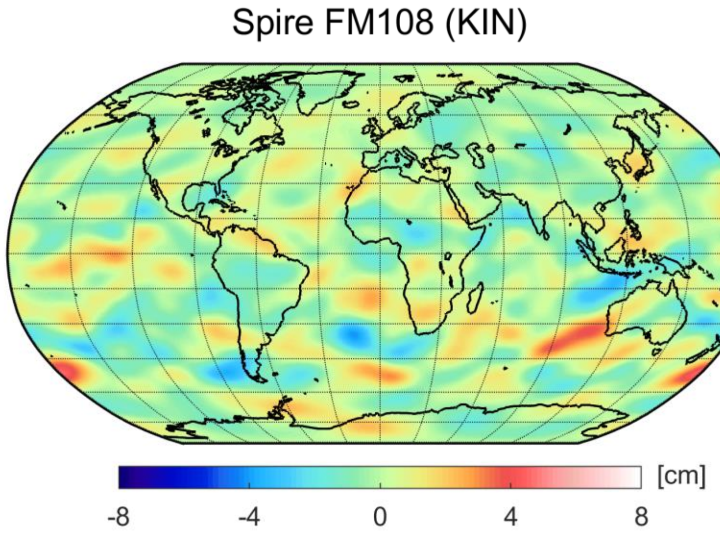
Kinematic positions

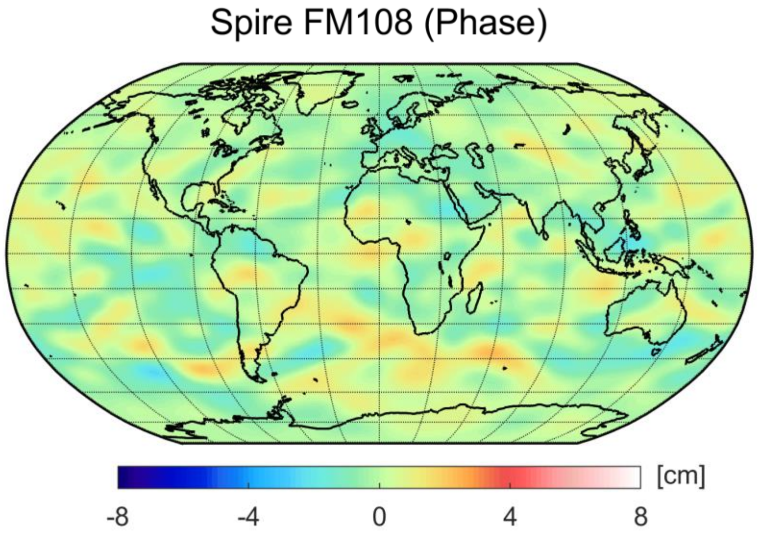
- Only epochs with sufficient GPS sat.
- Comparison to reduced-dynamic orbit

Phase observations

- Exclude phase residuals > 1.5 cm
- At least 50 observations per ambiguity

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





RMS [cm]	FM 099	FM 101	FM 102	FM 103	FM 104	FM 106	FM 107	FM 108
KIN	0.70	0.81	0.91	0.82	0.81	0.80	0.98	0.93
Phase	**0.64**	0.95	4.36	1.87	**0.79**	**0.61**	**0.70**	**0.64**

700 km Gauss filtered

Zonal and near zonal coefficients are excluded

Summary and outlook

Take home messages

1) GNSS data of Spire CubeSats allow to recover monthly gravity fields
2) Combinations of 9 CubeSats can reach a quality level comparable to Swarm-B
3) Solutions derived from GPS carrier phase observations show promising results
4) A suitable observation screening (or proper weighting) of Spire data is essential

Next steps

- Study time-variable gravity field signals (longer time series)
- Increase the temporal resolution (sub-monthly solutions)
- Improvement of the phase approach (e.g., advanced screening)

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