

Potential and limits of small satellite networks for temporal gravity field retrieval in the frame of the CubeGrav Project

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Nikolas Pfaffenzeller, Roland Pail (Technical University of Munich)

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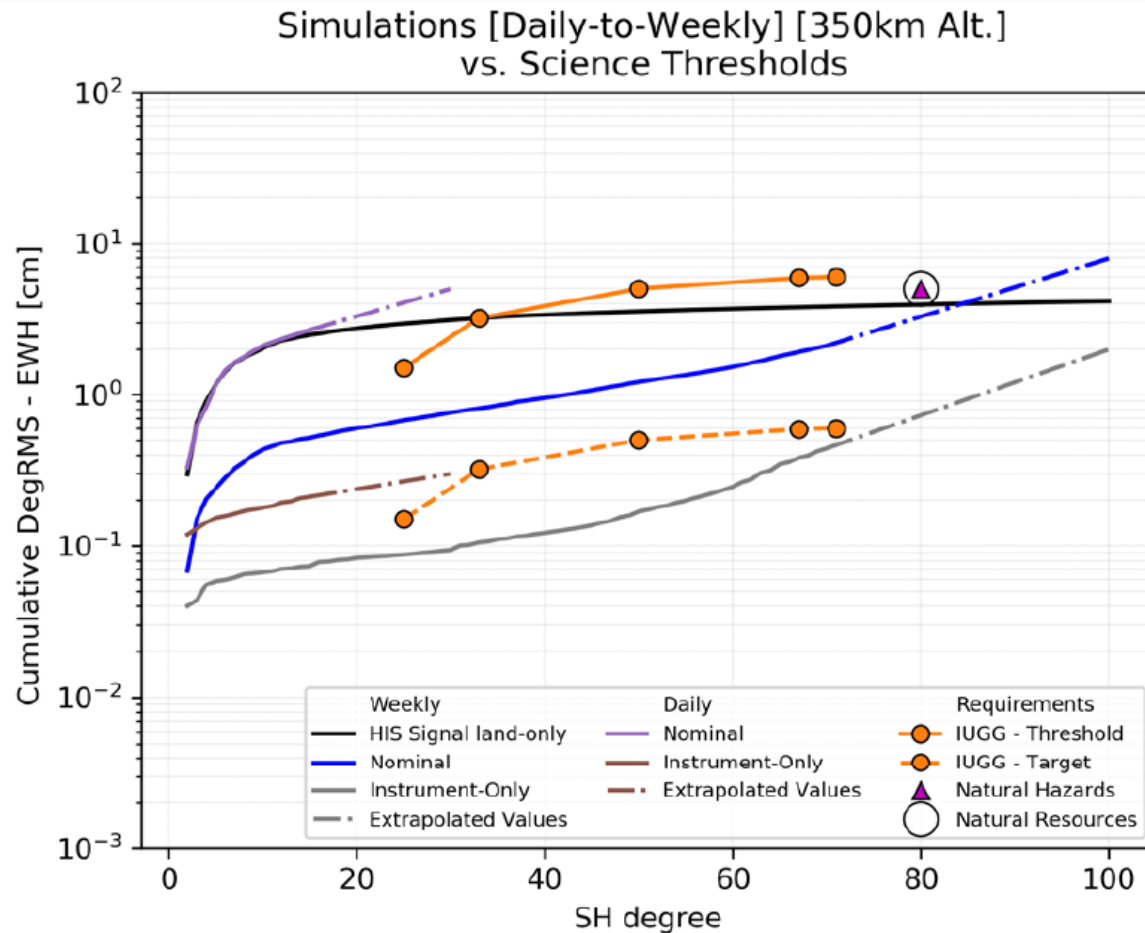
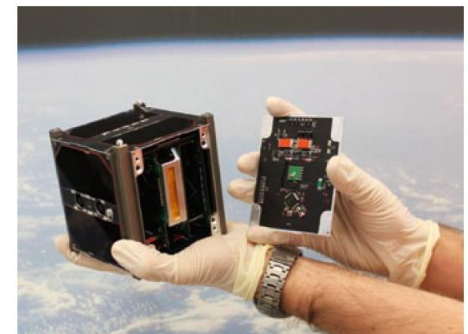


Figure 7. Cumulative errors of gravity field simulation vs. user and mission requirements expressed in EWH for daily-to-weekly time scales. The markers indicate specific target requirements.

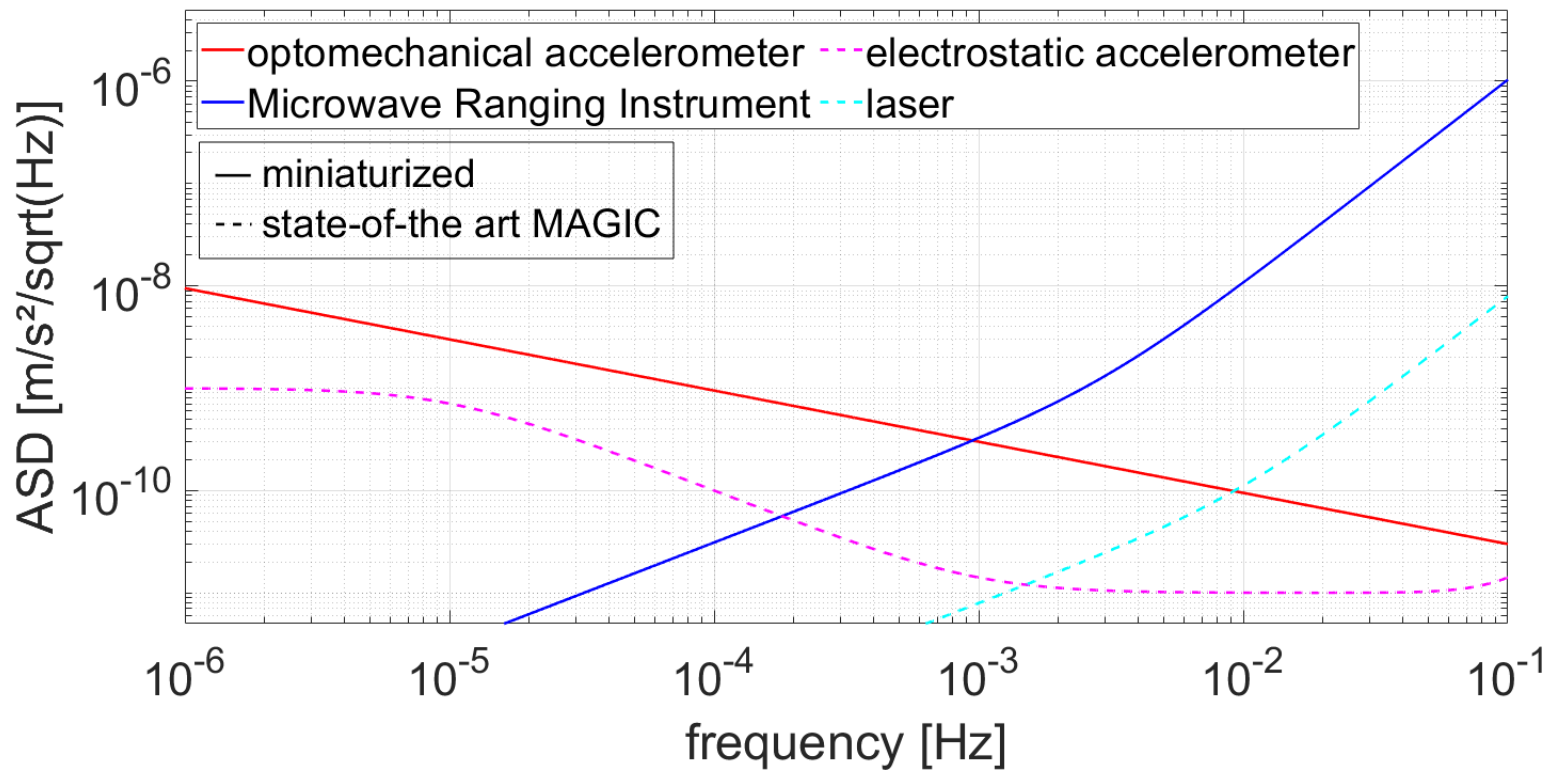
❑ Mission Requirement Document, MAGIC

- ❑ Science and User Needs on Gravity Field products not fulfilled with up-to-date gravity missions → Next Generation Gravity Mission (NGGM)
 - ❑ Project study „CubeGrav“ as mission concepts for NGGM with small satellites including potential analysis on
 - increase of spatio-temporal resolution
 - reduction of temporal aliasing
 - acceptable cost effort for dedicated mission
- What is the impact of different satellite formations and constellations on gravity field solutions?
- Focus on spatial coverage and temporal resolvability



- ❑ Full Scale Numerical Closed Loop Simulations
- ❑ Gravity Field processing pair-wise
- ❑ Two main gravity-relevant instruments considered:
 - Accelerometer:
 - Electrostatic Micro STAR (MAGIC) → state-of-the art NGGM
 - Optomechanical sensor (Hines et al. 2020) → miniaturized footprint: 48 mm x 92 mm, mass: 26 g, power: ca. 1 W
 - Inter-Satellite Ranging:
 - Laser (MAGIC) → state-of-the art NGGM
 - No miniaturized sensor available with $< 1 \mu\text{m}$
→ Assumption of future instrument with GRACE-FO K-Band Microwave Ranging System accuracy (Kornfeld et al. 2019)

instrument performances



- Higher performance of the state-of-the art instruments

Investigation period: 1 month

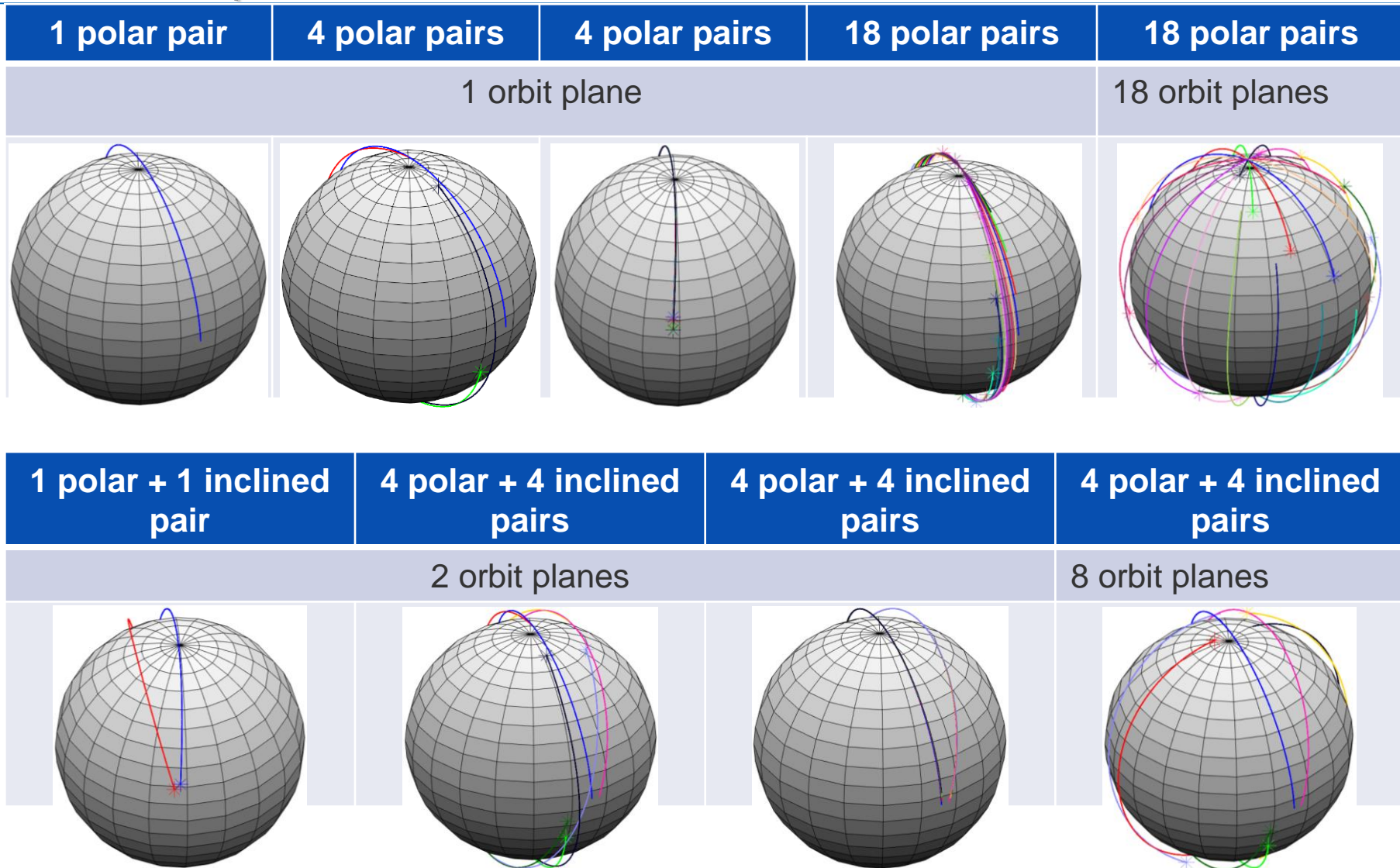
Inter-satellite distance: ~220 km

Retrieved Signal	Co-estimation of short periodic gravity fields		AO error	OT error
	approach	length		
HIS	-	-	yes	yes
AOHIS	„Wiese“ d/o 30 (Wiese et al. 20'11)	1 day, 12 h, 6h	-	yes

Orbits	Altitude [km]	Inclination [°]
Polar	463	89
Inclined	432	70

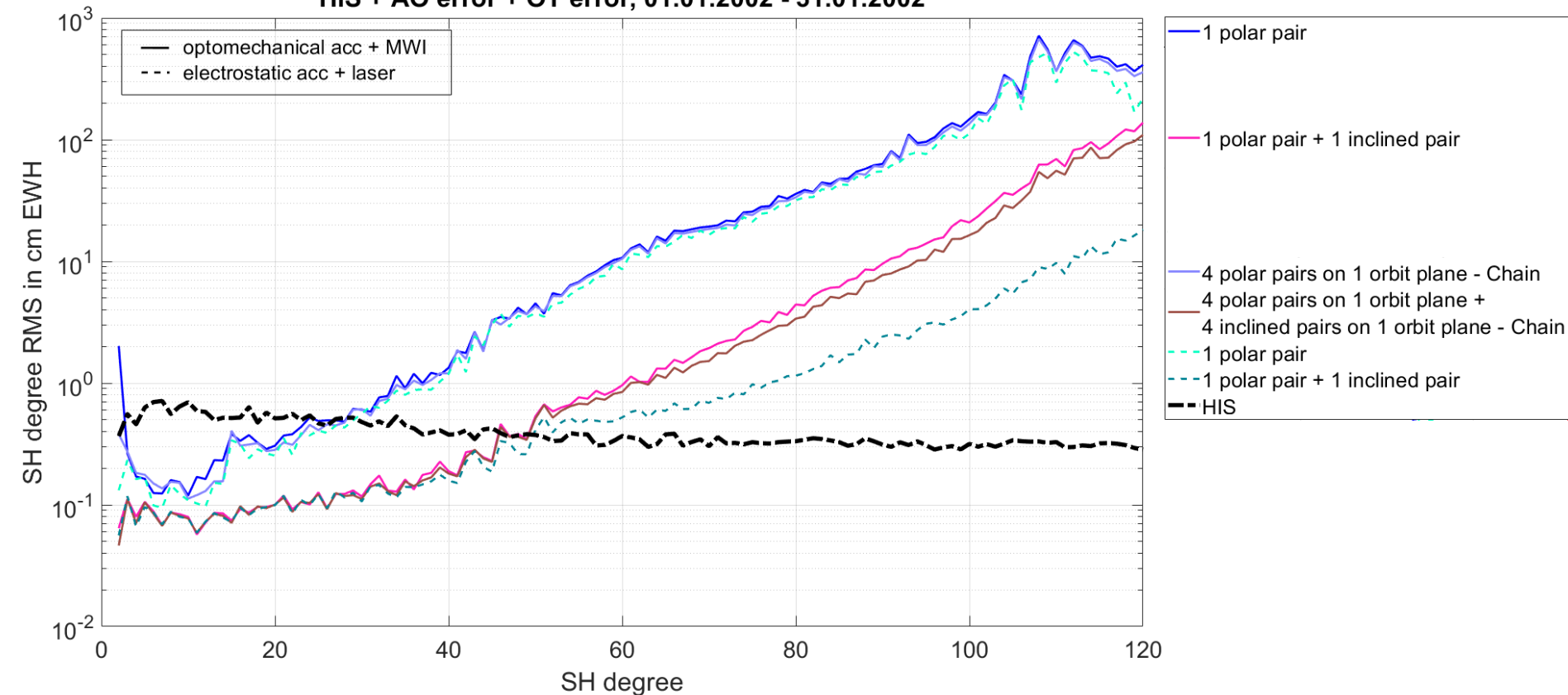
Orbital Parameters taken from MAGIC orbit set 3d_H (Massotti et al. 2021)

Orbital Setup



Simulation Results – monthly gravity field retrieval

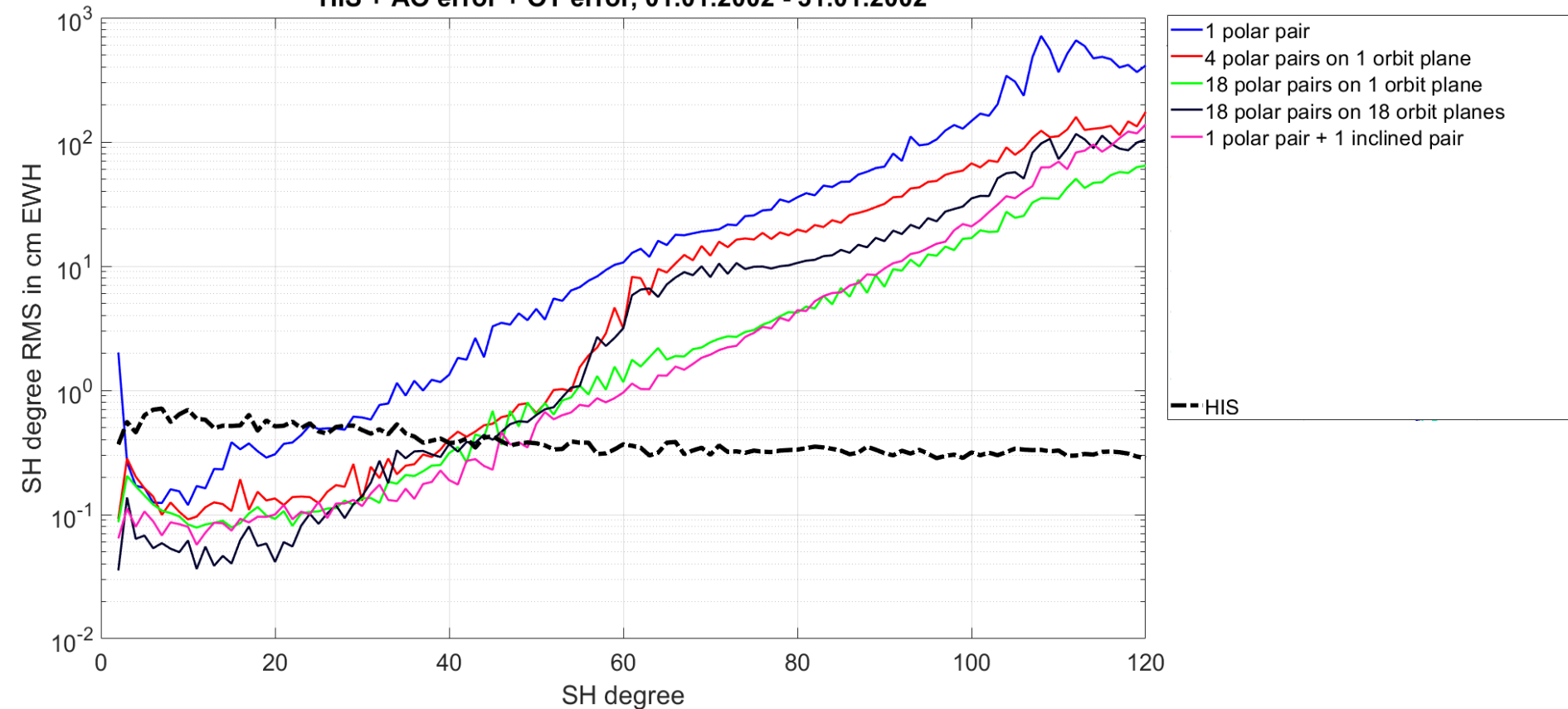
HIS + AO error + OT error, 01.01.2002 - 31.01.2002



- ❑ Similar performance with different instruments → temporal aliasing dominating gravity field
- ❑ Satellite chains increase only redundancy due to more provided observations but no better spatio-temporal resolution

Simulation Results – monthly gravity field retrieval

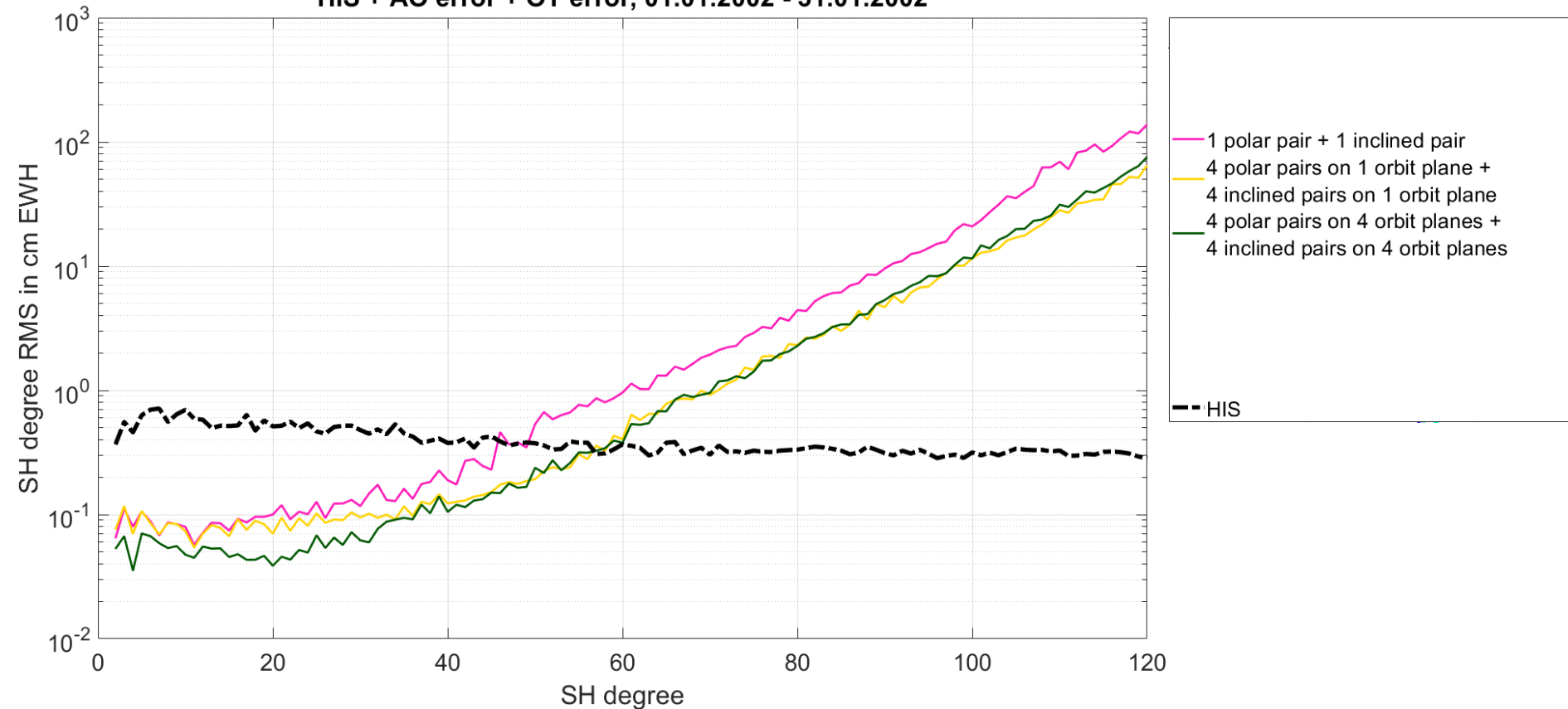
HIS + AO error + OT error, 01.01.2002 - 31.01.2002



- Increasing the number of polar satellite pairs improves performance and simultaneously decreases the added value from additional observations (for monthly retrieval!)

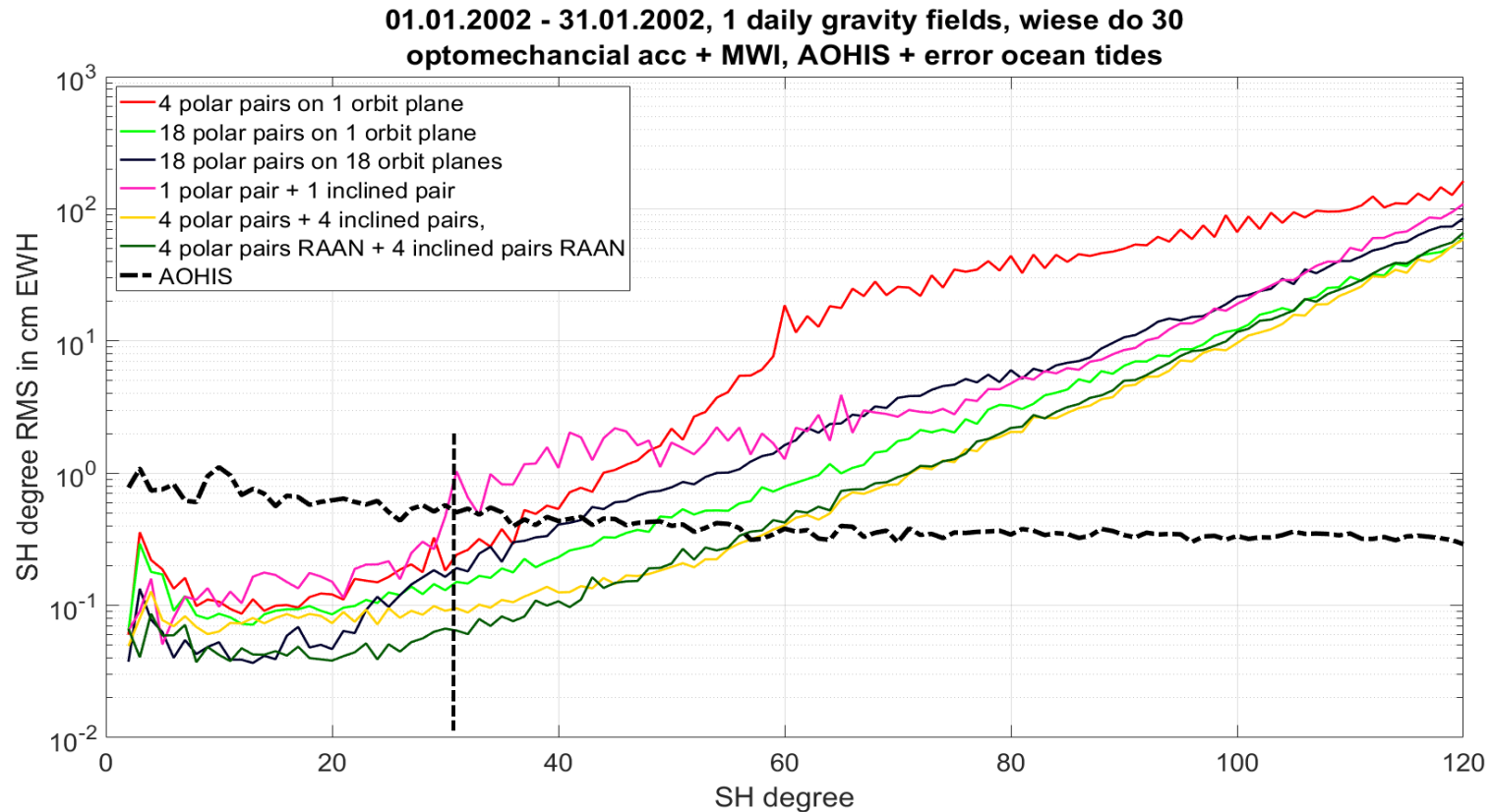
Simulation Results – monthly gravity field retrieval

HIS + AO error + OT error, 01.01.2002 - 31.01.2002



- ❑ Additional inclined satellite pairs improve the overall gravity solution
- ❑ Spatial distribution is of minor relevance for monthly field retrieval

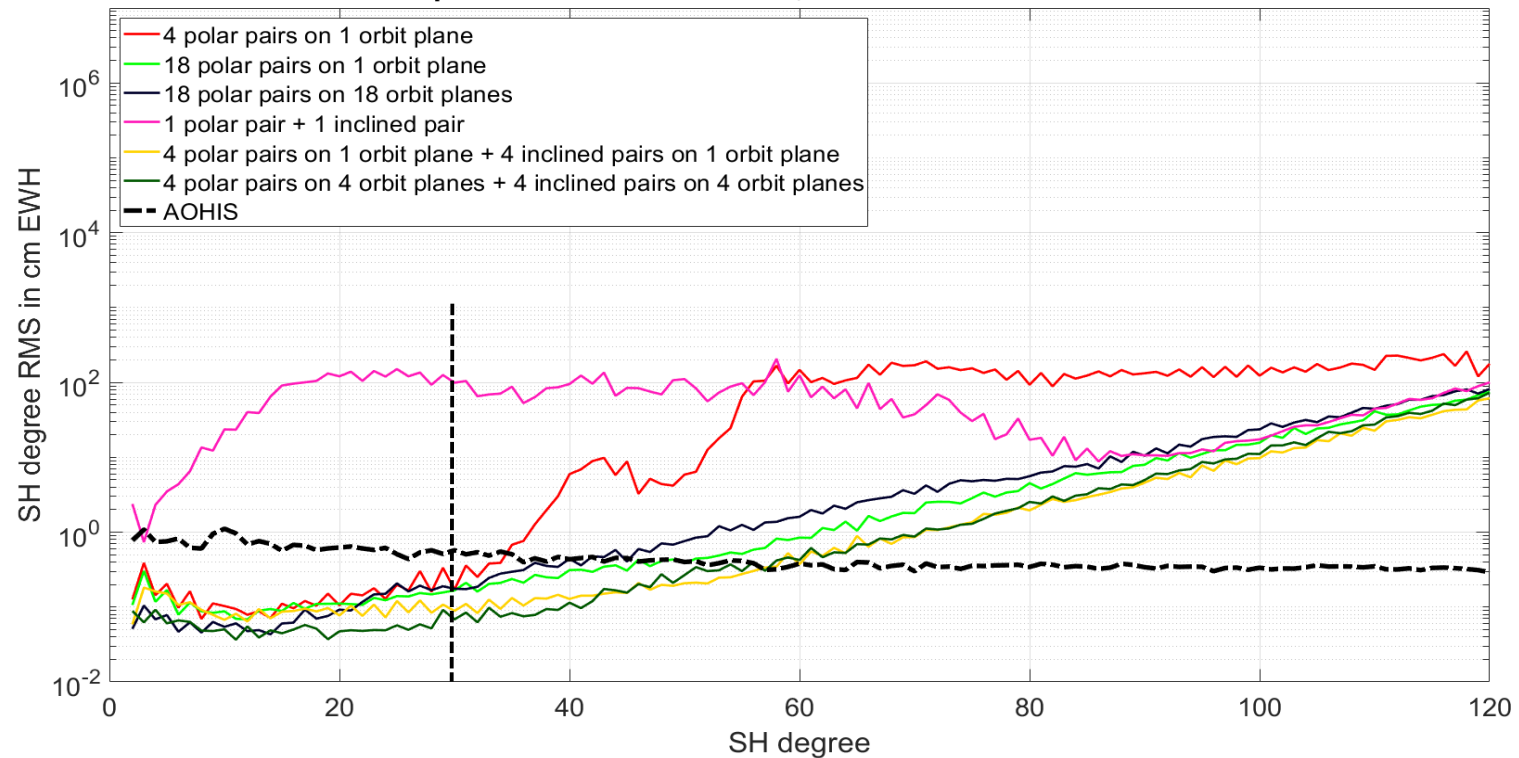
Simulation Results – Wiese approach – 1 daily co-estimation



- ❑ All scenarios are able to resolve 1-daily gravity fields
- ❑ Observations from inclined orbits and simultaneously a higher amount of satellites pairs perform the best

Simulation Results – Wiese approach – 12 h co-estimation

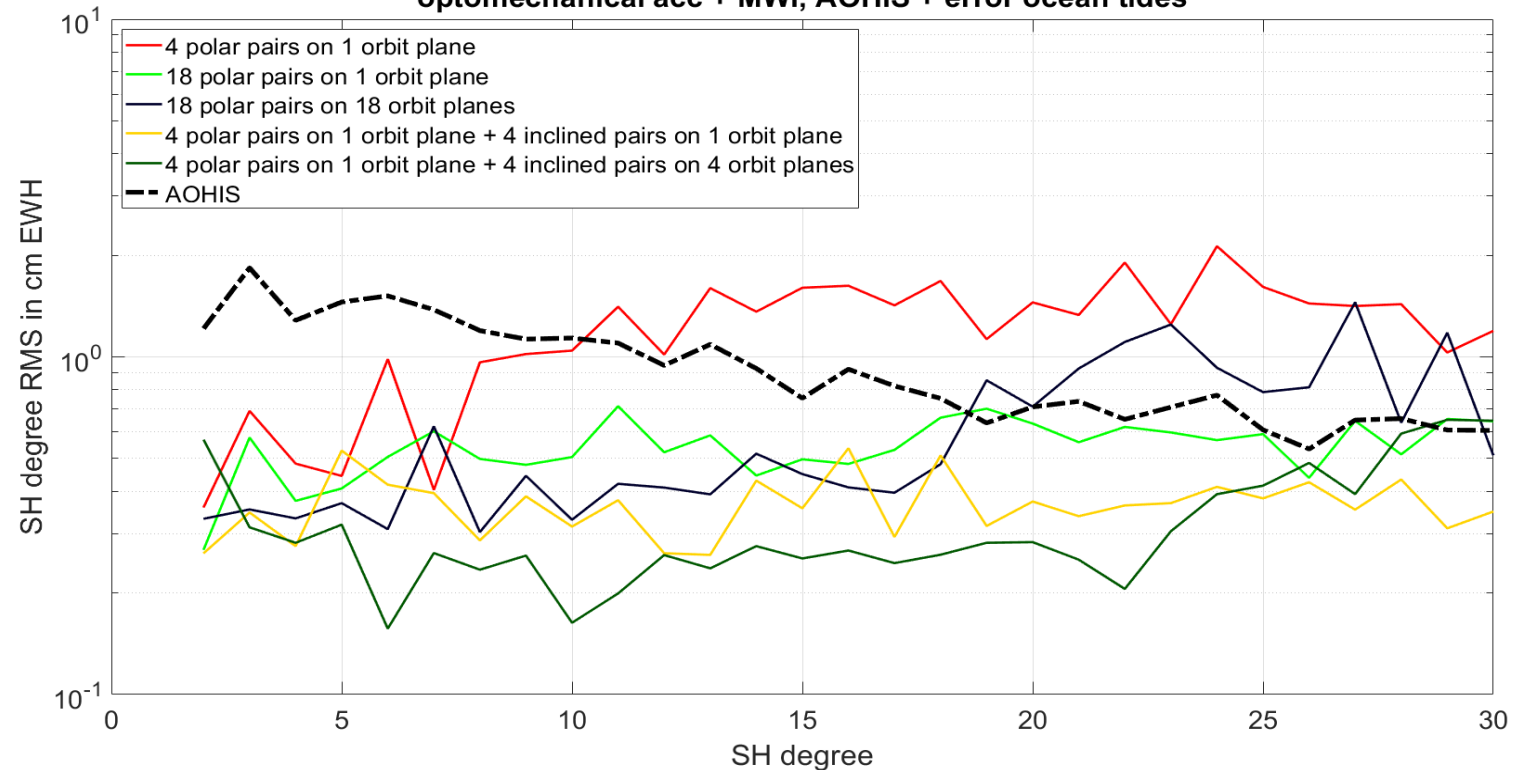
01.01.2002 - 31.01.2002, 12 hours gravity fields, wiese do 30
optomechanical acc + MWI, AOHIS + error ocean tides



- ❑ Configurations with limited spatial coverage are not able to co-estimate half-daily gravity fields and degrade the overall monthly solution

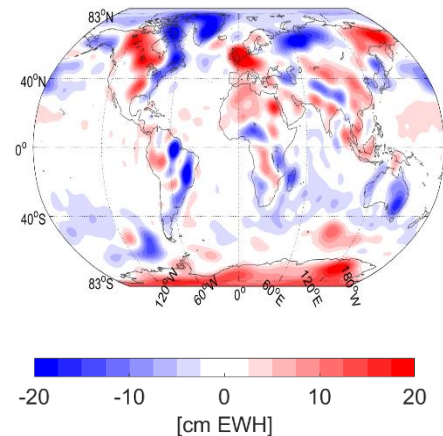
Simulation Results – Wiese approach – 12 h co-estimation

12:00 pm - 12:00 am on 01.01.2002, 12 hours gravity fields, wiese do 30
optomechanical acc + MWI, AOHIS + error ocean tides

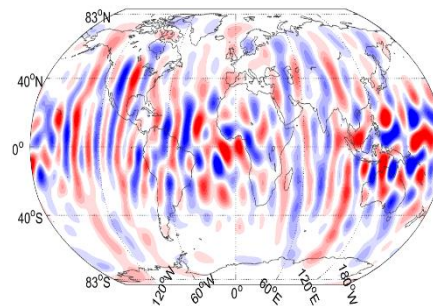


- ❑ Configurations with limited spatial coverage are not able to co-estimate half-daily gravity fields and degrade the overall monthly solution

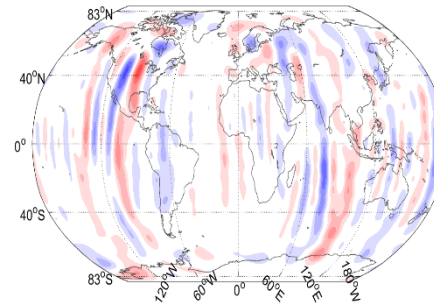
Global estimated half-daily Gravity Field Residuals from Simulations compared to AOHIS Signal in Equivalent Water Height (EWH) on 01.01.2002 12:00 h to 24:00 h



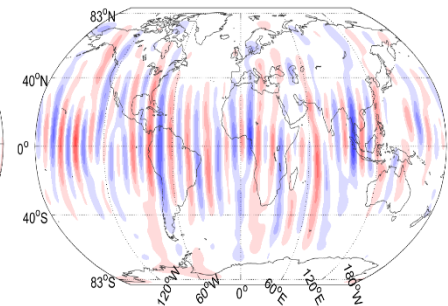
4 polar pairs



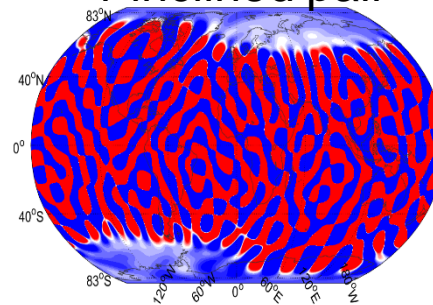
18 polar pairs



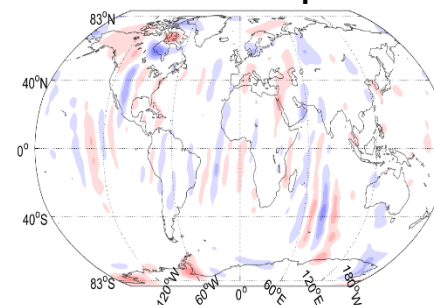
18 polar pairs
shift in RAAN



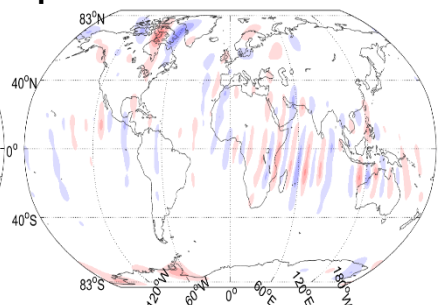
1 polar pair +
1 inclined pair



4 polar pairs +
4 inclined pairs



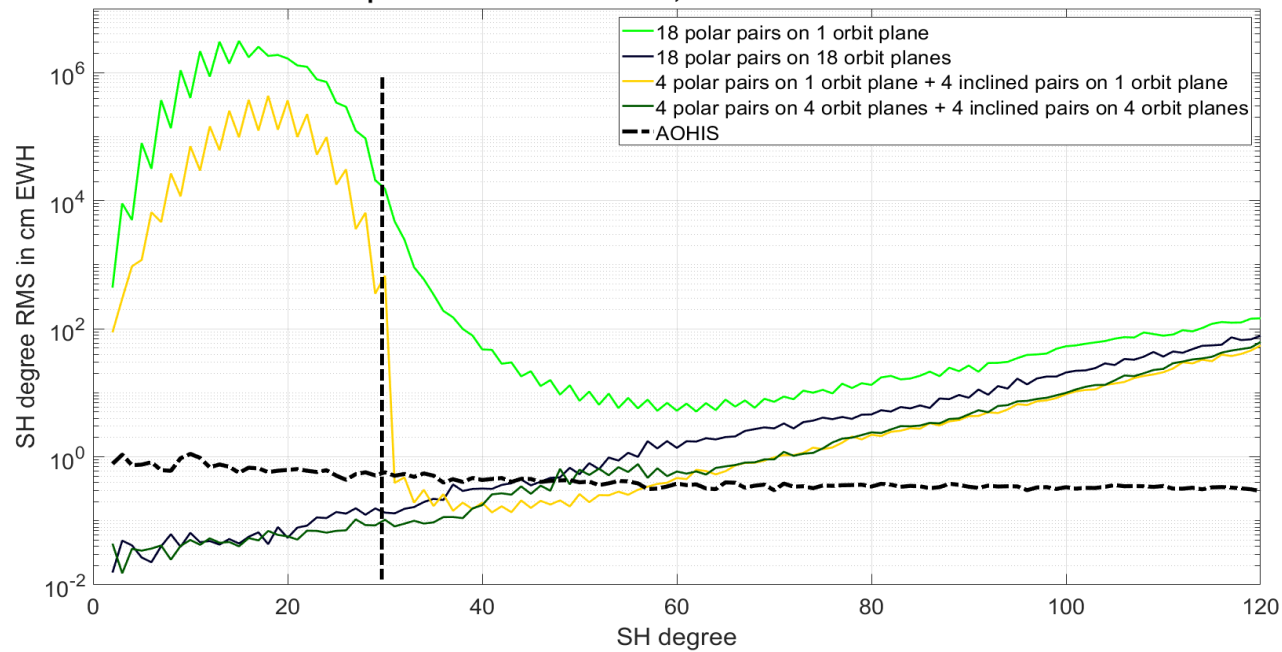
4 polar + 4 inclined
pair - shift in RAAN



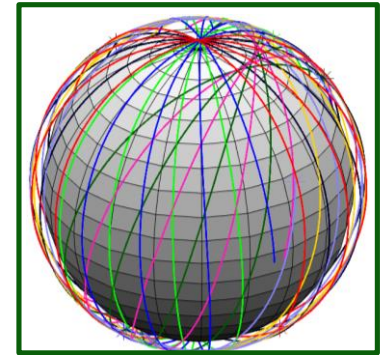
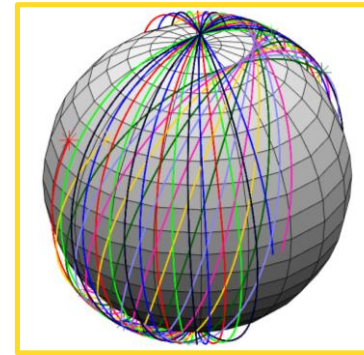
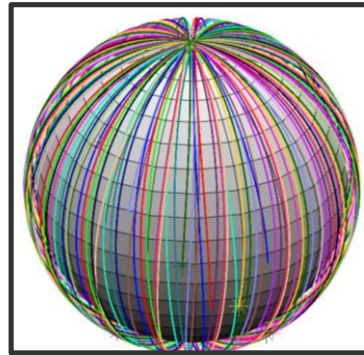
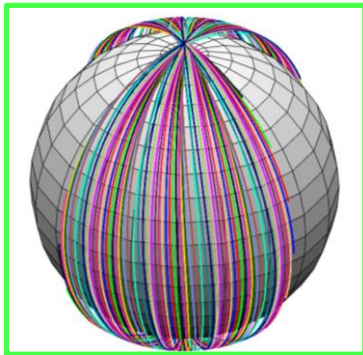
- ❑ Configurations with limited spatial coverage are not able to retrieve the 12 h AOHIS signal
- ❑ Reduction of striping pattern with inclined observations

Simulation Results – Wiese approach – 6 h co-estimation

01.01.2002 - 31.01.2002, 6 hours gravity fields, wiese do 30
optomechanical acc + MWI, AOHIS + error ocean tides



Ground track coverage after 6 hours:



- ❑ Miniaturized optomechanical accelerometer suitable for a potential CubeSat gravity mission but no candidate available for inter-satellite ranging with $< 1 \mu\text{m}$
- ❑ Co-estimation of short periodic (24 hours, 12 hours and 6 hours) stand-alone gravity fields
- ❑ Importance level of different criteria for NGGMs (application-dependent):
 - Added value ↓
 - Number of inter-satellite links
 - Number of satellite pairs
 - Spatial distribution of the satellites
 - Observations from different inclined orbits
- ❑ Further investigations:
 - Optimisation of ground track coverage with adapted orbits (sub-cycle)
 - What are potential candidates for ranging instruments?
→ Any ideas and suggestions are highly appreciated



- ❑ https://www.asi.it/wp-content/uploads/2021/03/MAGIC_NGGM_MCDO_MRD_v1_0-signed2.pdf (MRD MAGIC)
- ❑ Hines, Adam; Richardson, Logan; Wisniewski, Hayden; Guzman, Felipe (2020): Optomechanical Inertial Sensors. In: *Appl. Opt.* 59 (22), G167. DOI: 10.1364/AO.393061.
- ❑ Kornfeld, Richard P.; Arnold, Bradford W.; Gross, Michael A.; Dahya, Neil T.; Klipstein, William M.; Gath, Peter F.; Bettadpur, Srinivas (2019): GRACE-FO: The Gravity Recovery and Climate Experiment Follow-On Mission. In: *Journal of Spacecraft and Rockets* 56 (3), S. 931–951. DOI: 10.2514/1.A34326.
- ❑ Massotti, Luca; Siemes, Christian; March, Günther; Haagmans, Roger; Silvestrin, Pierluigi (2021): Next Generation Gravity Mission Elements of the Mass Change and Geoscience International Constellation: From Orbit Selection to Instrument and Mission Design. In: *Remote Sensing* 13 (19), S. 3935. DOI: 10.3390/rs13193935.

- ❑ Wiese, D. & Visser, Pieter & Nerem, Robert. (2011). Estimating low resolution gravity fields at short time intervals to reduce temporal aliasing errors. *Advances in Space Research - ADV SPACE RES.* 48. 1094-1107. [10.1016/j.asr.2011.05.027](https://doi.org/10.1016/j.asr.2011.05.027).