Capabilities and limits of Multi-satellite constellations and formations for temporal gravity field retrieval

May 24, 2022

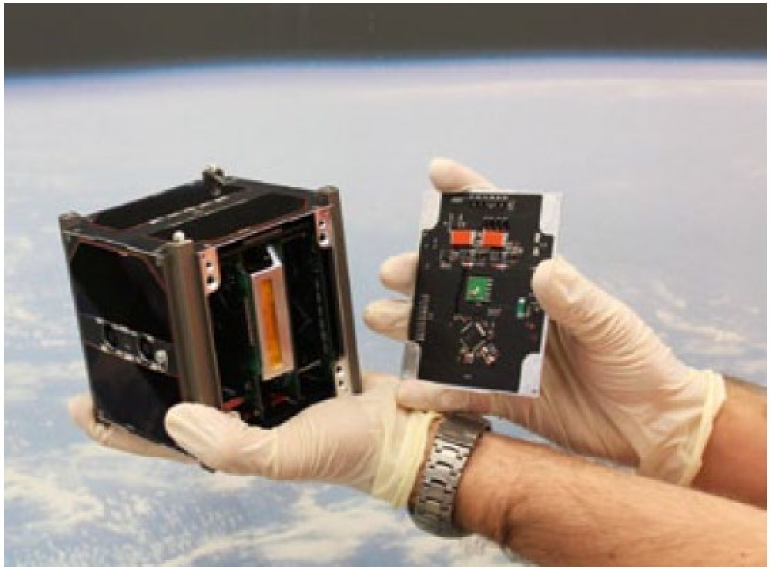
Nikolas Pfaffenzeller, Roland Pail (Technical University of Munich)

Living Planet Symposium 2022, Bonn

Motivation

- Science and User Needs not fulfilled with current gravity missions
  → new concepts beyond MAGIC for medium-term realization

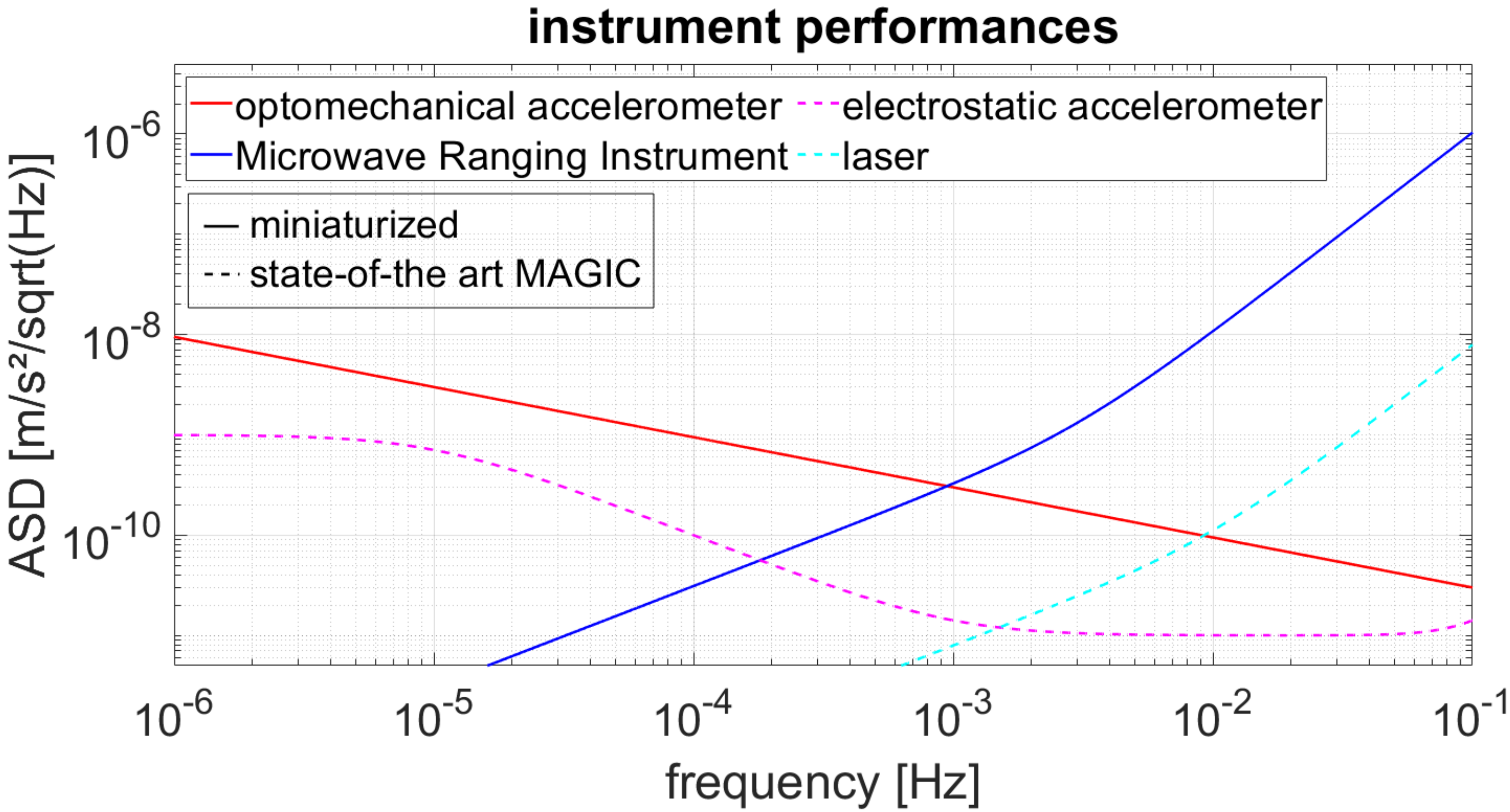
- Project study „CubeGrav“: investigate mission concepts with CubeSats, including analysis on
  - increase of spatio-temporal resolution
  - reduction of temporal aliasing
  - system design
  - reduced costs for dedicated mission



Simulation Environment

- Full Scale Numerical Closed Loop Simulations
- Satellite pairs (low-low tracking concept)
- Key payload:
  - Accelerometer:
    - Electrostatic Micro STAR (MAGIC) → state-of-the art NGGM (reference)
    - 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 µm → Assumption of future instrument with GRACE-FO K-Band Microwave Ranging System accuracy (Kornfeld et al. 2019)

Instrument Performance



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

Simulations

Investigation period: 1 month

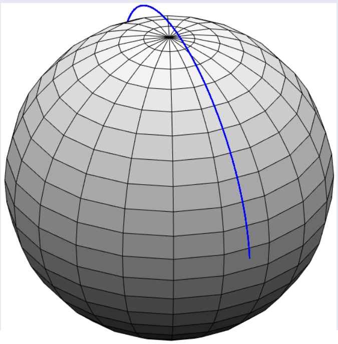
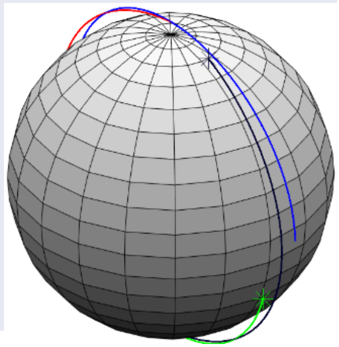
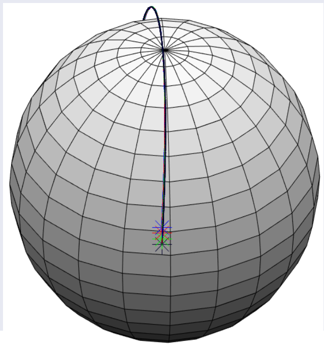
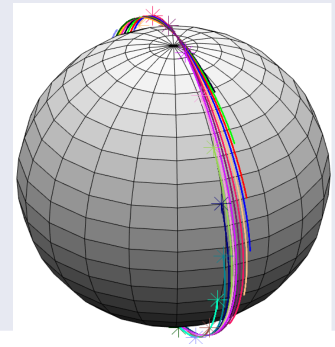
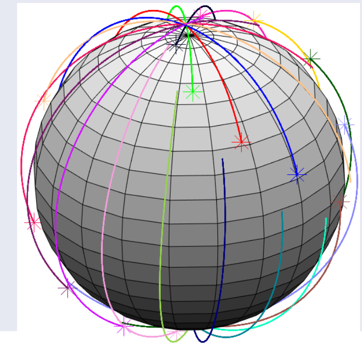
Inter-satellite distance: ~220 km

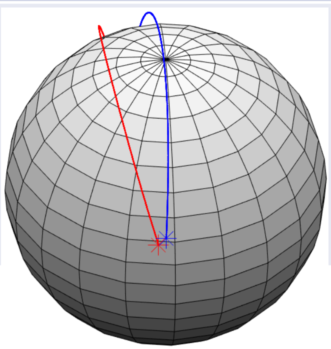
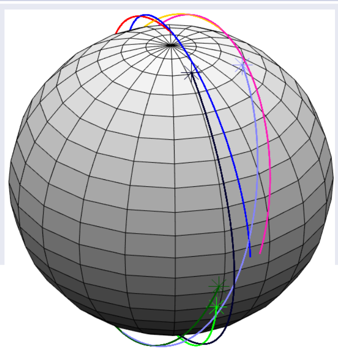
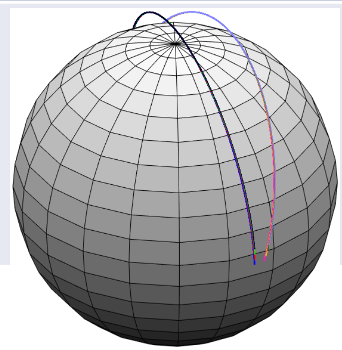
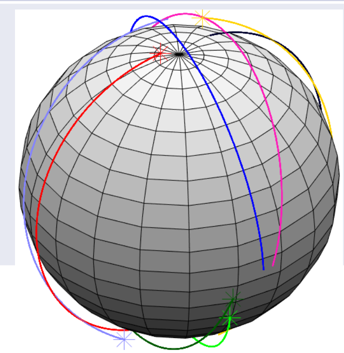
Retrieved Signal	Co-estimation of short periodic gravity fields		AO error	OT error
	approach	length		
HIS	-	-	yes	yes
AOHIS	„Wiese“ d/o 30 (Wiese et al. 2011)	1 day, 12 h, 6h	-	yes

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

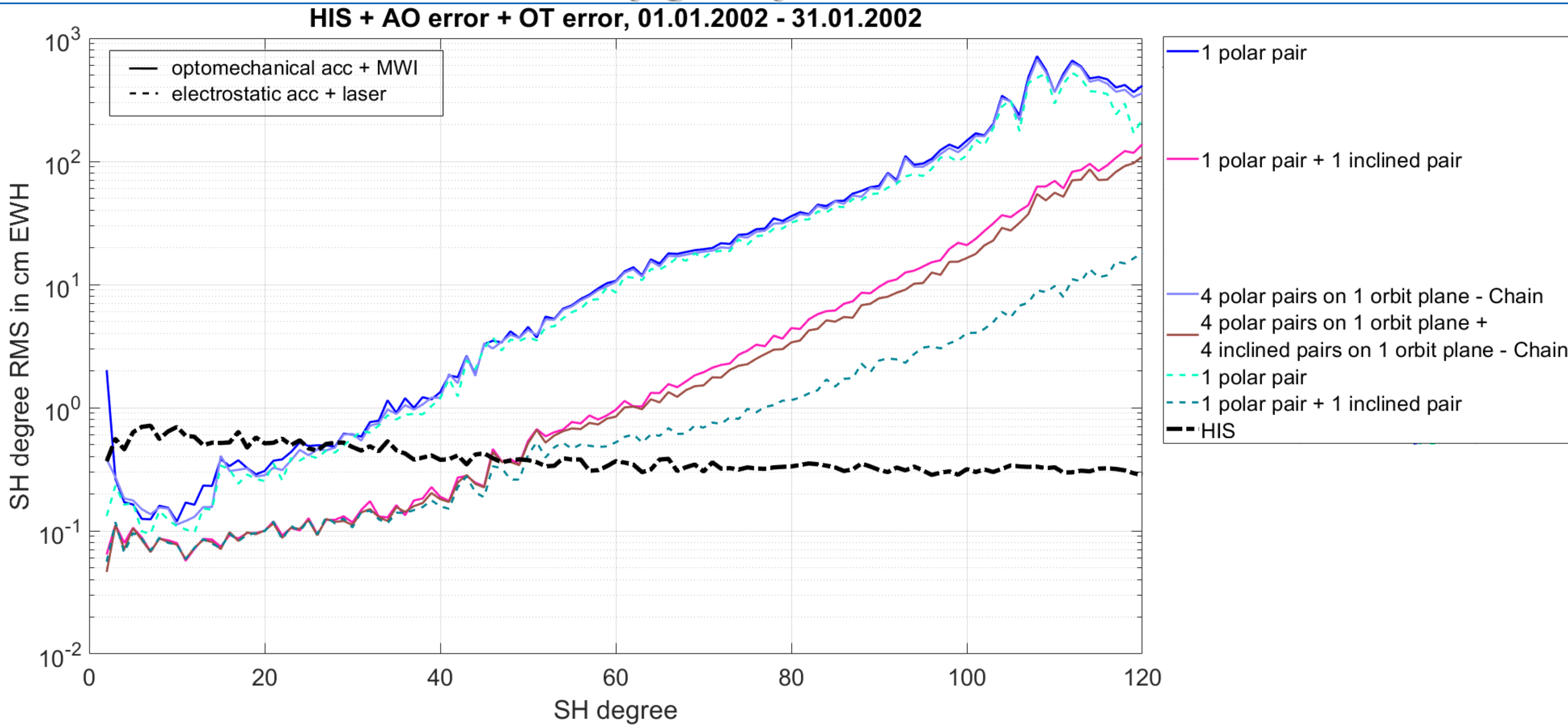
Orbital Parameters taken from MAGIC orbit set 3d_H (Massotti et al. 2021)

Orbital Setup

1 polar pair	4 polar pairs	4 polar pairs	18 polar pairs	18 polar pairs
1 orbit plane				18 orbit planes
				

1 polar + 1 inclined pair	4 polar + 4 inclined pairs	4 polar + 4 inclined pairs	4 polar + 4 inclined pairs
2 orbit planes			8 orbit planes
			

Simulation Results – monthly gravity field retrieval

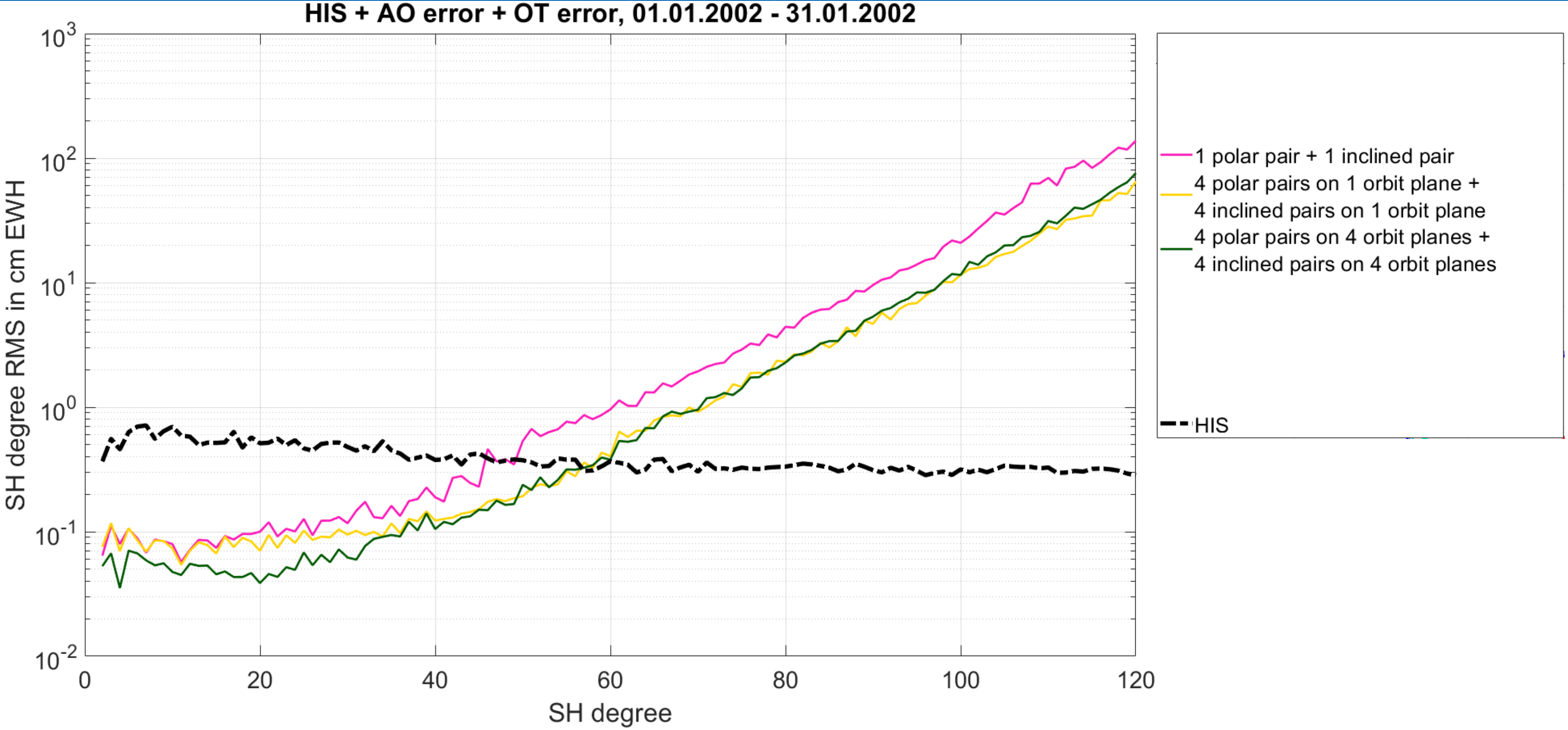


- Similar performance with different instruments → temporal aliasing dominating error contributor
- Satellite chains increase only redundancy due to larger number of observations, but no better spatial-temporal resolution

Simulation Results – monthly gravity field retrieval

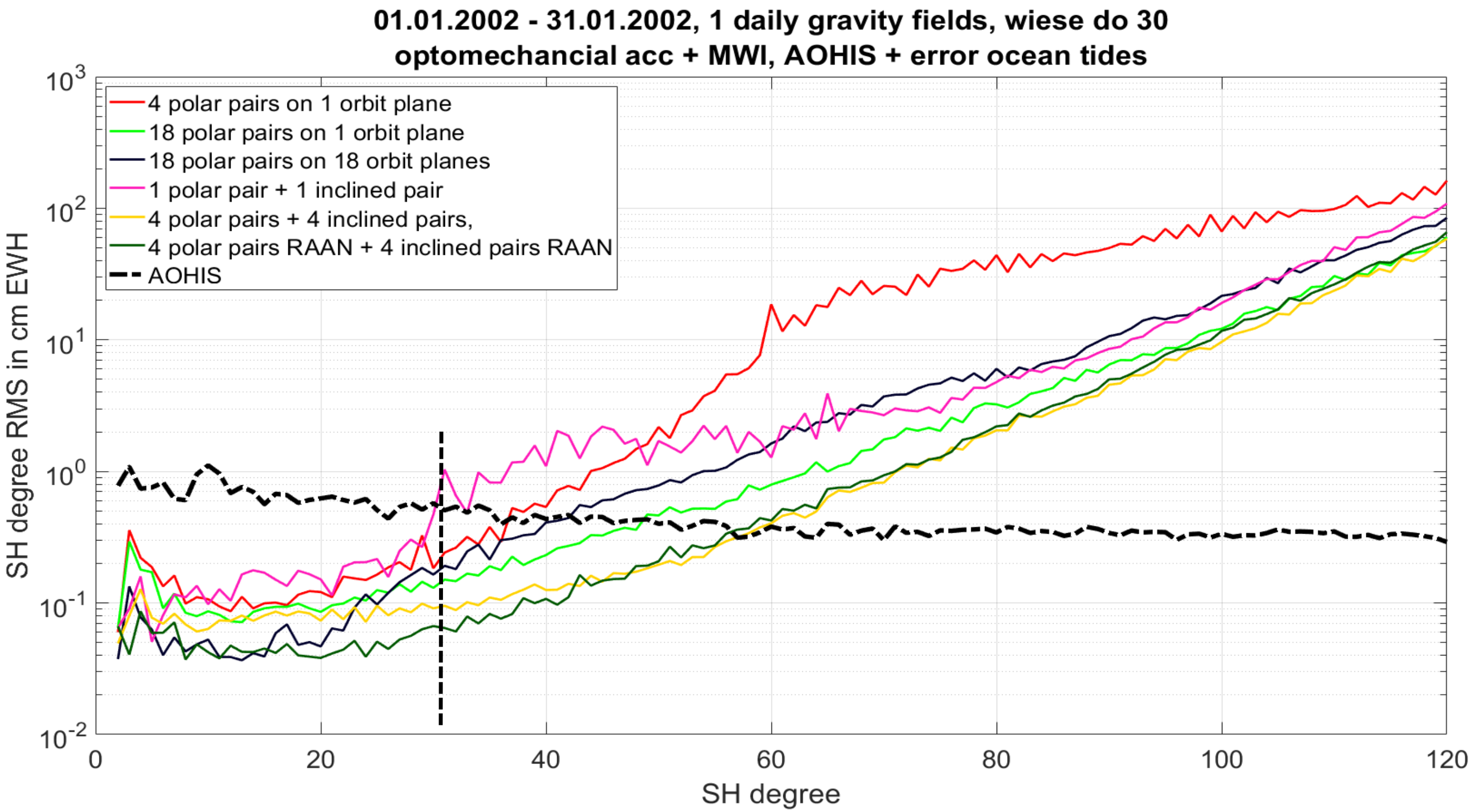
- Increasing the number of polar satellite pairs improves performance and simultaneously decreases the added value from additional observations (for monthly retrieval!)
- Performance of 18 polar pairs similar to 1 Bender double-pair

Simulation Results – monthly gravity field retrieval



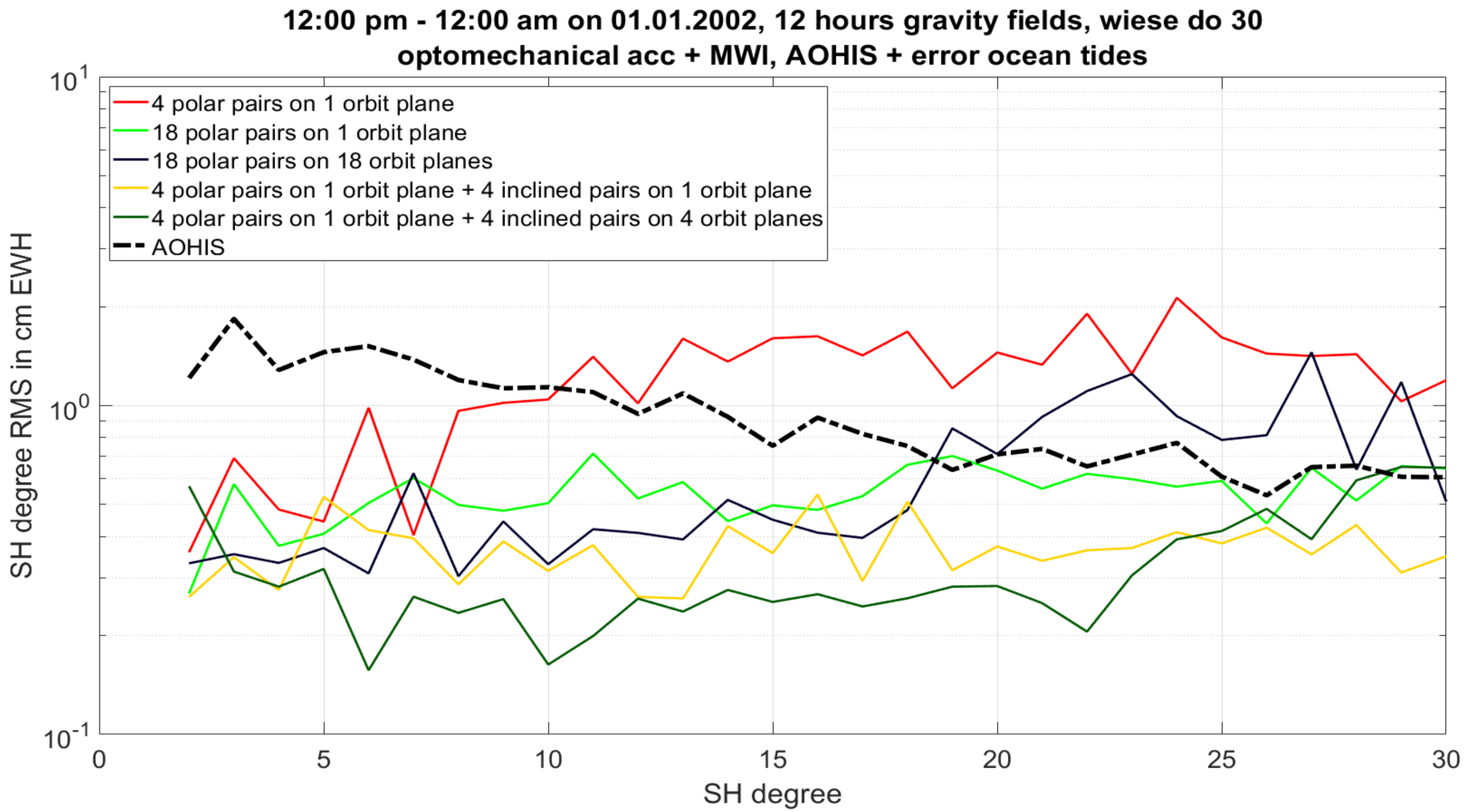
- Additional inclined satellite pairs improve the overall gravity solution
- Spatial distribution is of minor relevance for monthly field retrieval

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

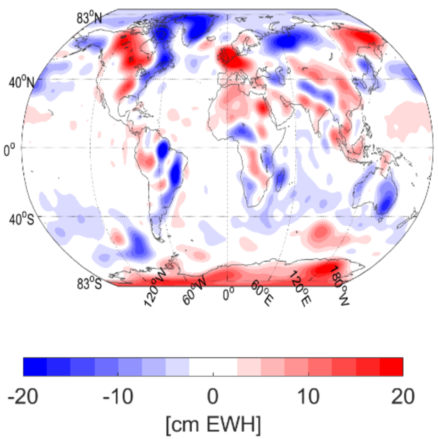
Simulation Results – Wiese approach – 12h co-estimation



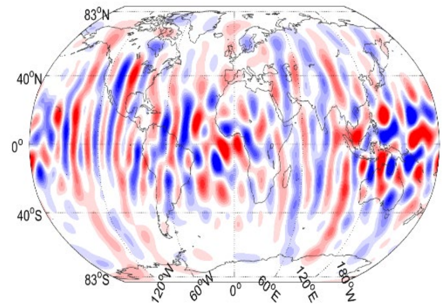
- Configurations with limited spatial coverage are not able to co-estimate half-daily gravity fields and degrade the overall monthly solution

Simulation Results – Wiese approach – 12 h co-estimation

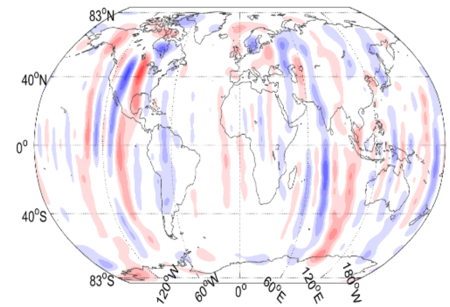
Global estimated half-daily Gravity Field Residuals from Simulations compared to AOHIS Signal in Equivalent Water Height (EWH) on 01.01.2002 12:00 h to 24:00 h



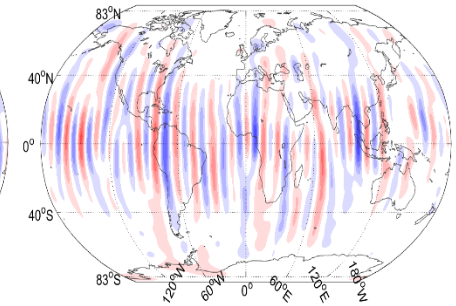
4 polar pairs



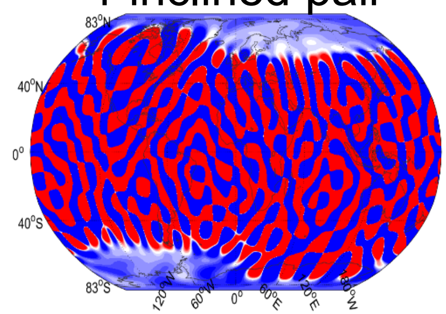
18 polar pairs



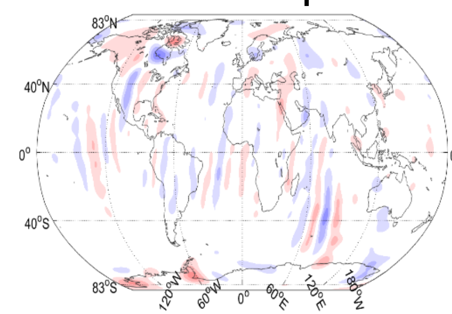
18 polar pairs shift in RAAN



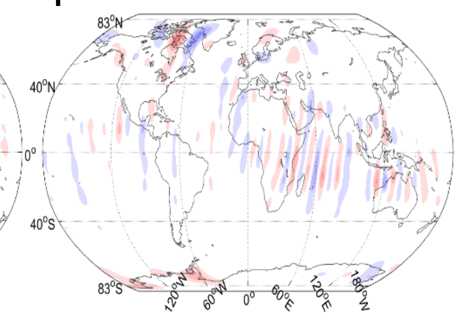
1 polar pair + 1 inclined pair



4 polar pairs + 4 inclined pairs

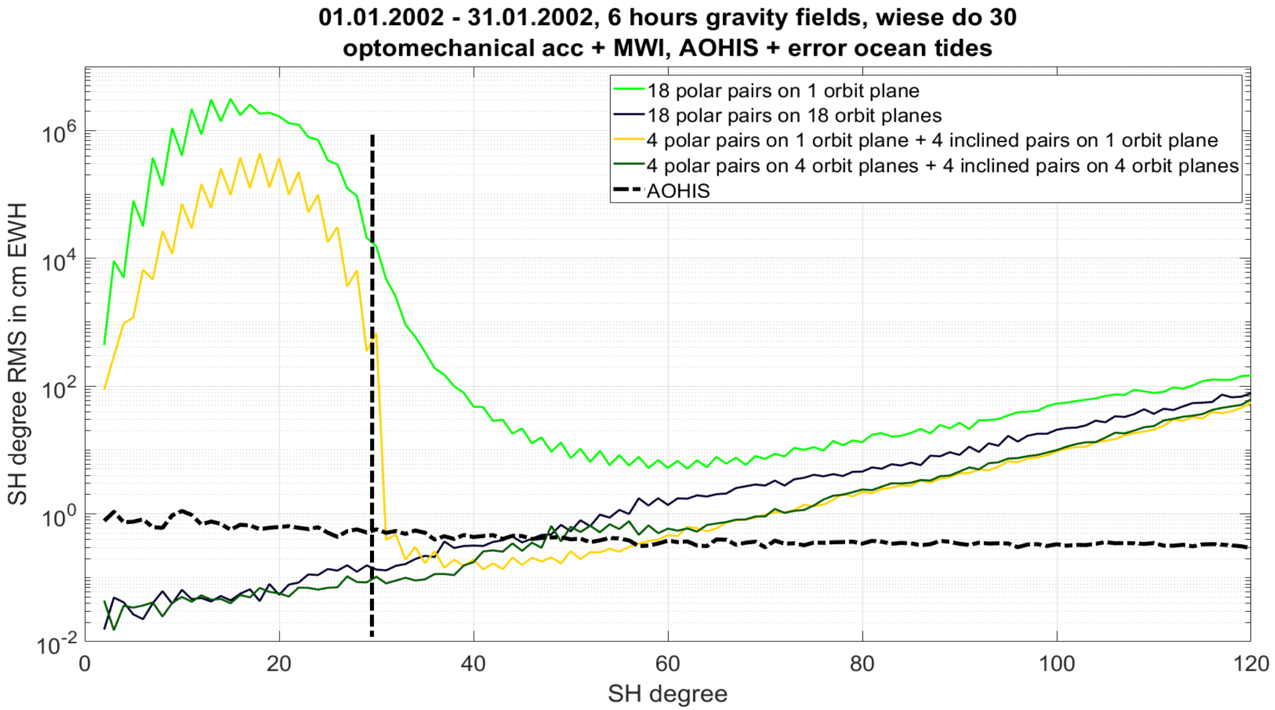


4 polar + 4 inclined pair - shift in RAAN

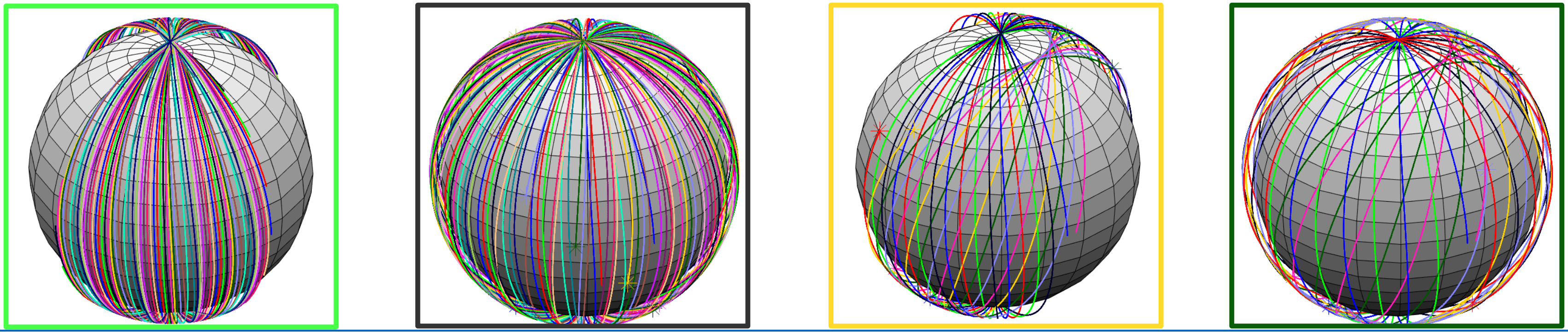


- Configurations with limited spatial coverage are not able to retrieve the 12 h AOHIS signal
- Reduction of striping pattern with inclinced observations

Simulation Results – Wiese approach – 6 h co-estimation



Ground track coverage after 6 hours:



Conclusions

- Miniaturized optomechanical accelerometer suitable for a potential CubeSat gravity mission, but no candidate available yet for inter-satellite ranging with < 1 µm
- Co-estimation of short-periodic (24 / 12 / 6 hours) stand-alone gravity fields
- Priorities (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:
  - Optimization of ground track coverage with adapted orbits (sub-cycle)
  - What are potential candidates for ranging instruments?
    → Any ideas and suggestions are highly appreciated

References

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