Simulation study on future gravity missions with constellations and formations of small satellites

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Nikolas Pfaffenzeller, Roland Pail (Technical University of Munich), Tom Yunck (GeoOptics Inc.)

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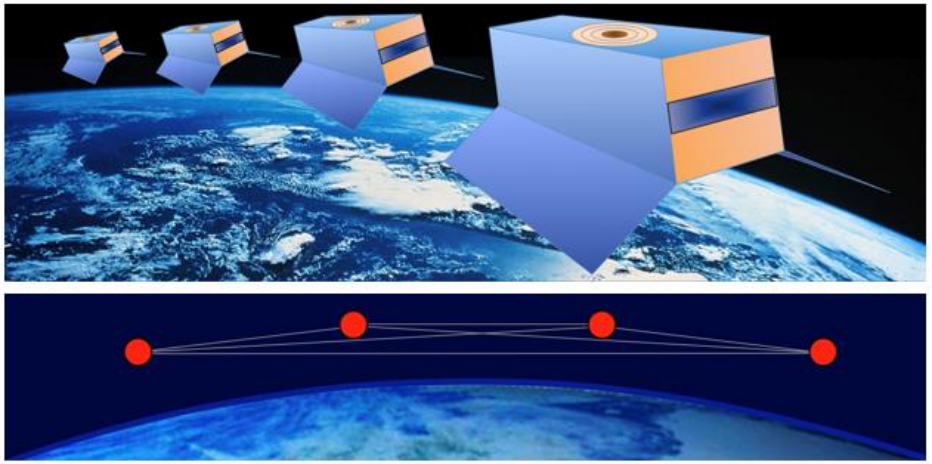
Motivation

- High costs for construction and launch of gravity field satellite missions
- Aims of NGGMs:
  - increase of spatio-temporal resolution
  - reduction of temporal aliasing
- Future concept with small satellites as proposed by Tom Yunck, 2019



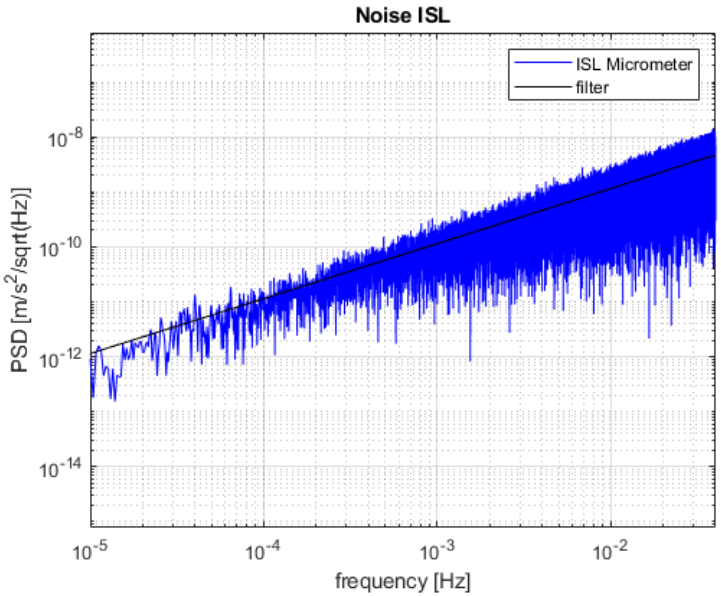
  - Yunck, T (2019), The Earth Gravitational Observatory: Smallsat constellation for multi-link low-low SST, Washington, DC.
  - Yunck, T, A Saltman, S Bettadpur, S Nerem, J Abel, M Widner, C Deccia, G Franklin (2019), The Earth Gravitational Observatory: Multisat clusters in chain formations, NASA Mass Change Workshop, Washington, DC

→ What is the impact of different satellite formations and constellations on gravity field solutions?

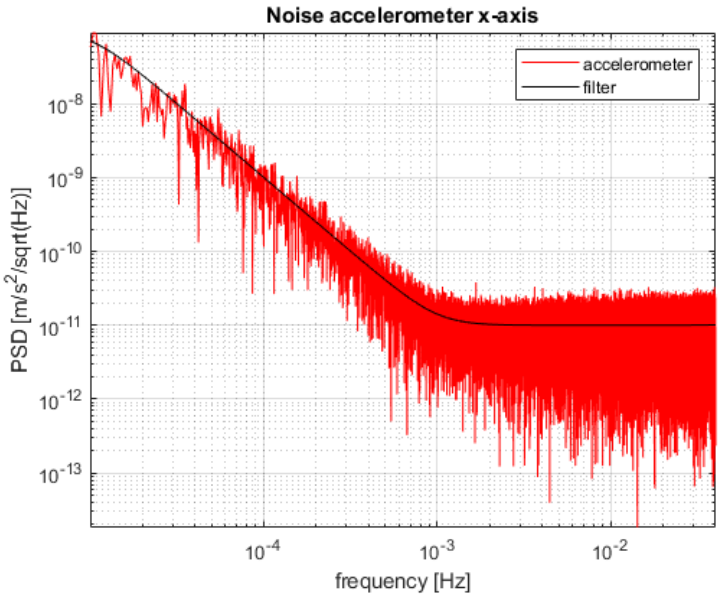
Gravity field processing

- Reduced scale numerical closed loop simulations
- Simulated Keplerian Orbits
- Simulated instrument errors

K-Band Microwave System
(single link measurement noise)



Accelerometers



- Pairwise links as input for the gravity field determination

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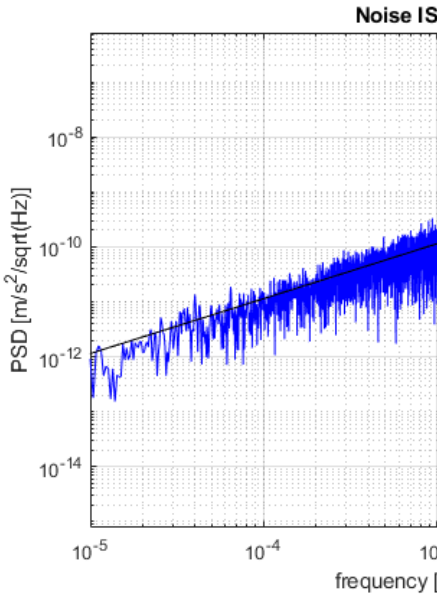
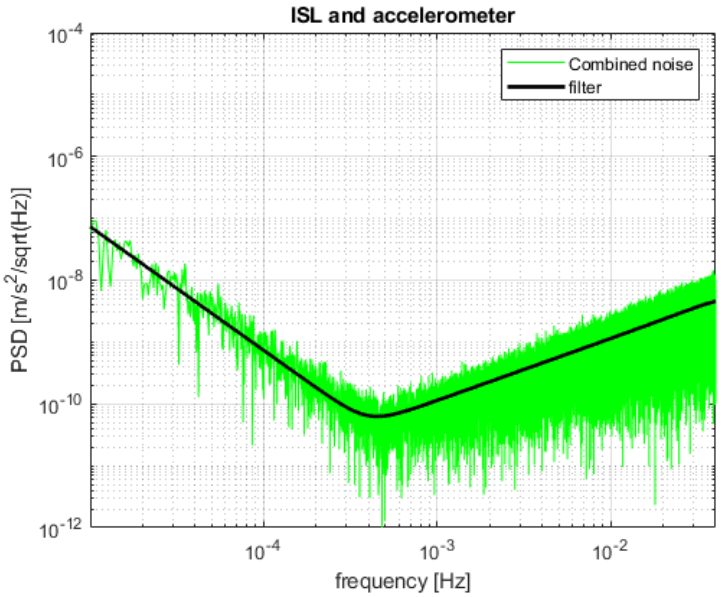
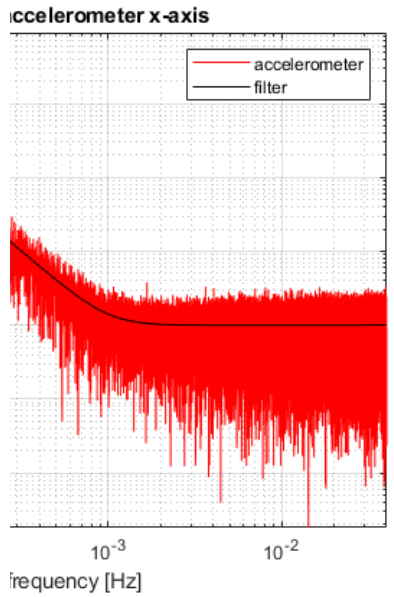






- Pairwise links as input for the gravity field determination

Simulations

Investigation period: 1 month

Variation of the

- Number of satellites
- Number of inter-satellite links (single, multi ISL)
- Orbit parameters
- Spacing of satellites (different at multi ISL)
- Input models

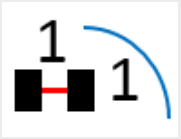
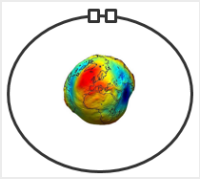
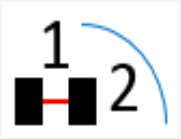
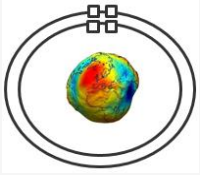
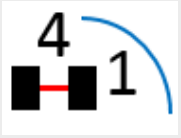
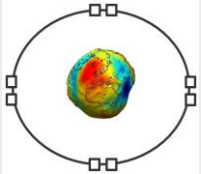
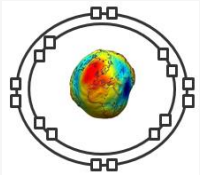
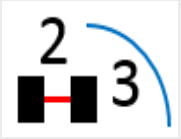
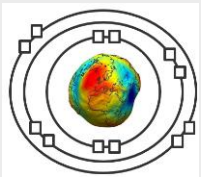
Single inter-satellite links = links between adjacent satellites (1-2, 2-3, …)
Multi inter-satellite links = links from each respective satellite to all other satellites

Static case: only instrument behaviour considered

Temporal case: additional HIS signal + errors of AO are considered

Ocean tides: additional model difference used as errors (FES2004 – EOT08a)

Configurations

case	Altitude [km]	Inclination [°]	Inital mean anomaly
	439	89	
	439 410	89 70	
	439	89	
	439 410	89 70	
	370 407 445	89 80 70	

X… number of satellite pairs per orbit
Y… number of orbits

- Repeat cycle: 17 days
- Inter-satellite distance: ~ 200 km
- Single inter-satellite link

Configurations

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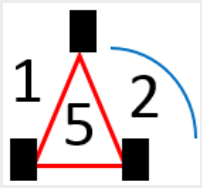
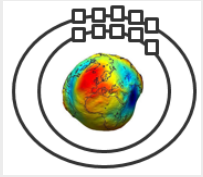
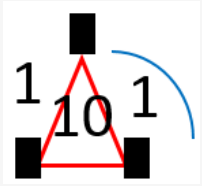
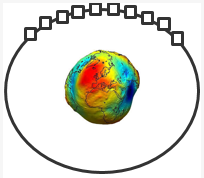
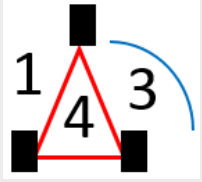
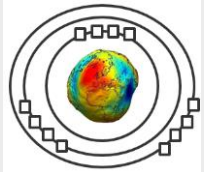
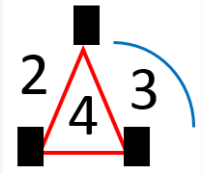
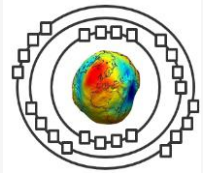
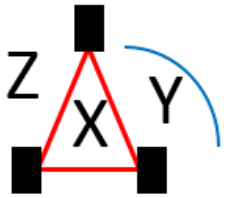
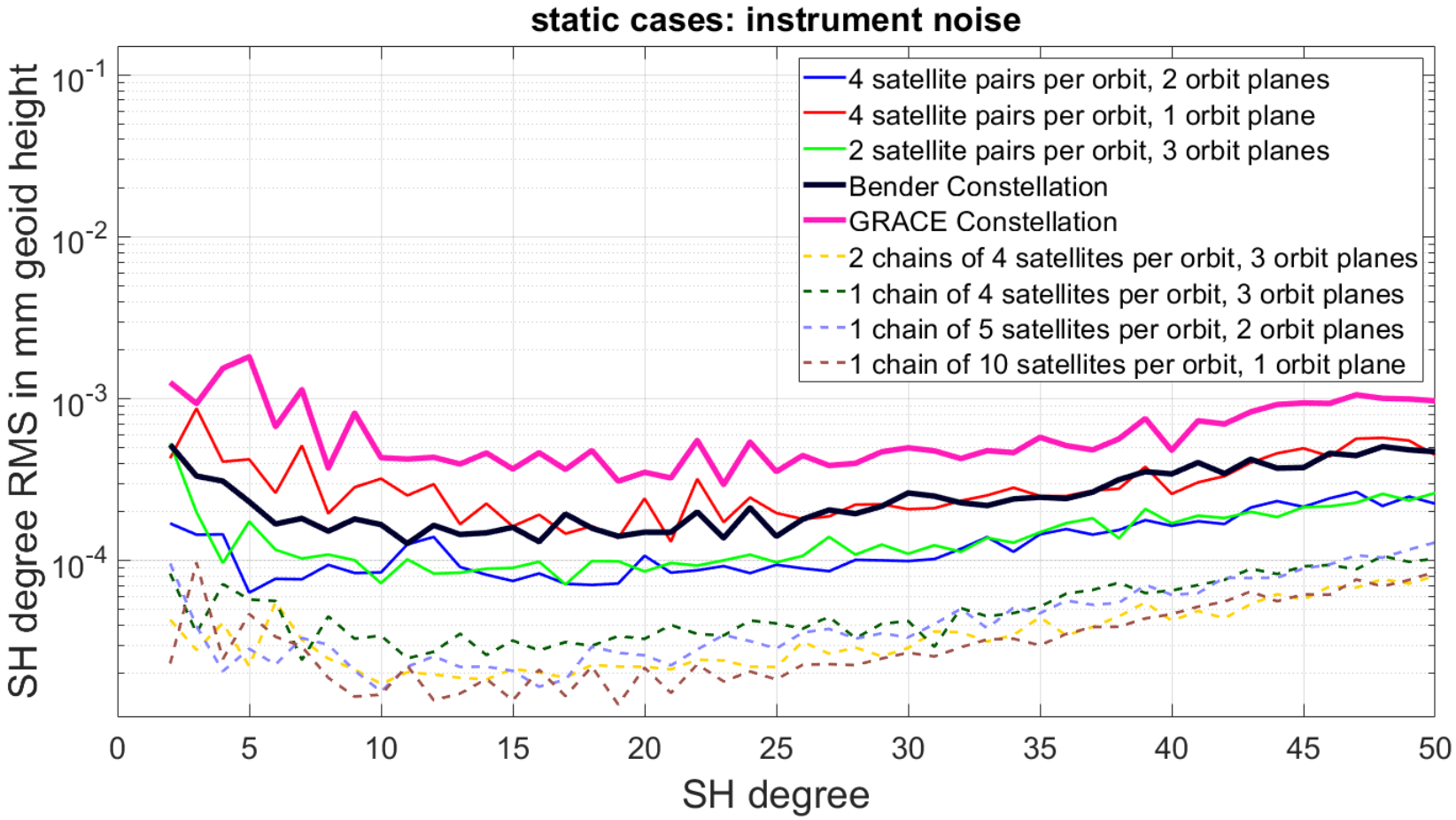
	439 410	89 70	
	439	89	
	370 407 445	89 80 70	
	370 407 445	89 80 70	



X… number of satellites forming a chain per orbit
Y… number of orbits
Z… number of chains per orbit

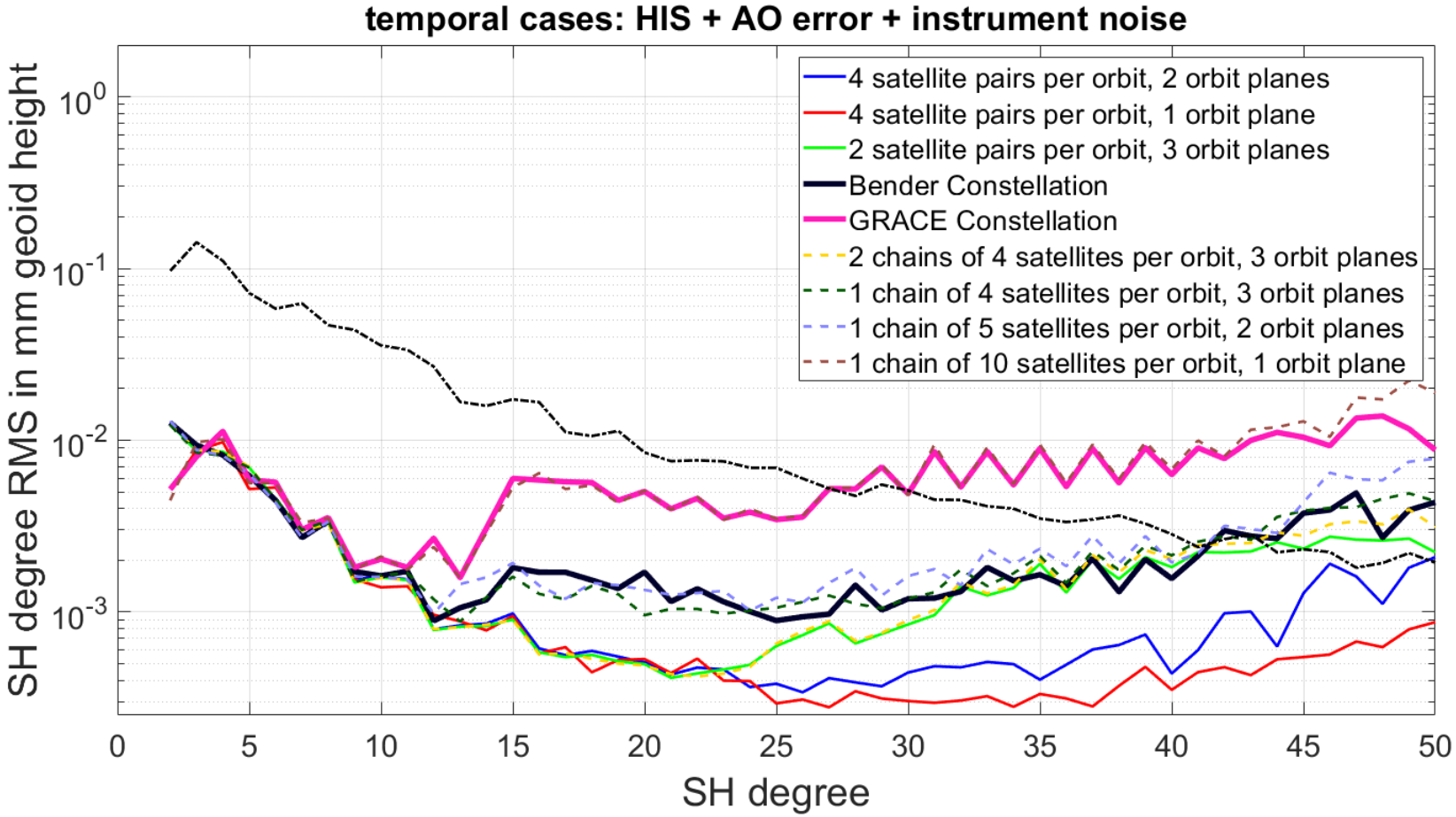
- Repeat cycle: 17 days
- Inter-satellite distance of neighboring satellites: ~ 200 km
- multi inter-satellite links

Simulation Results



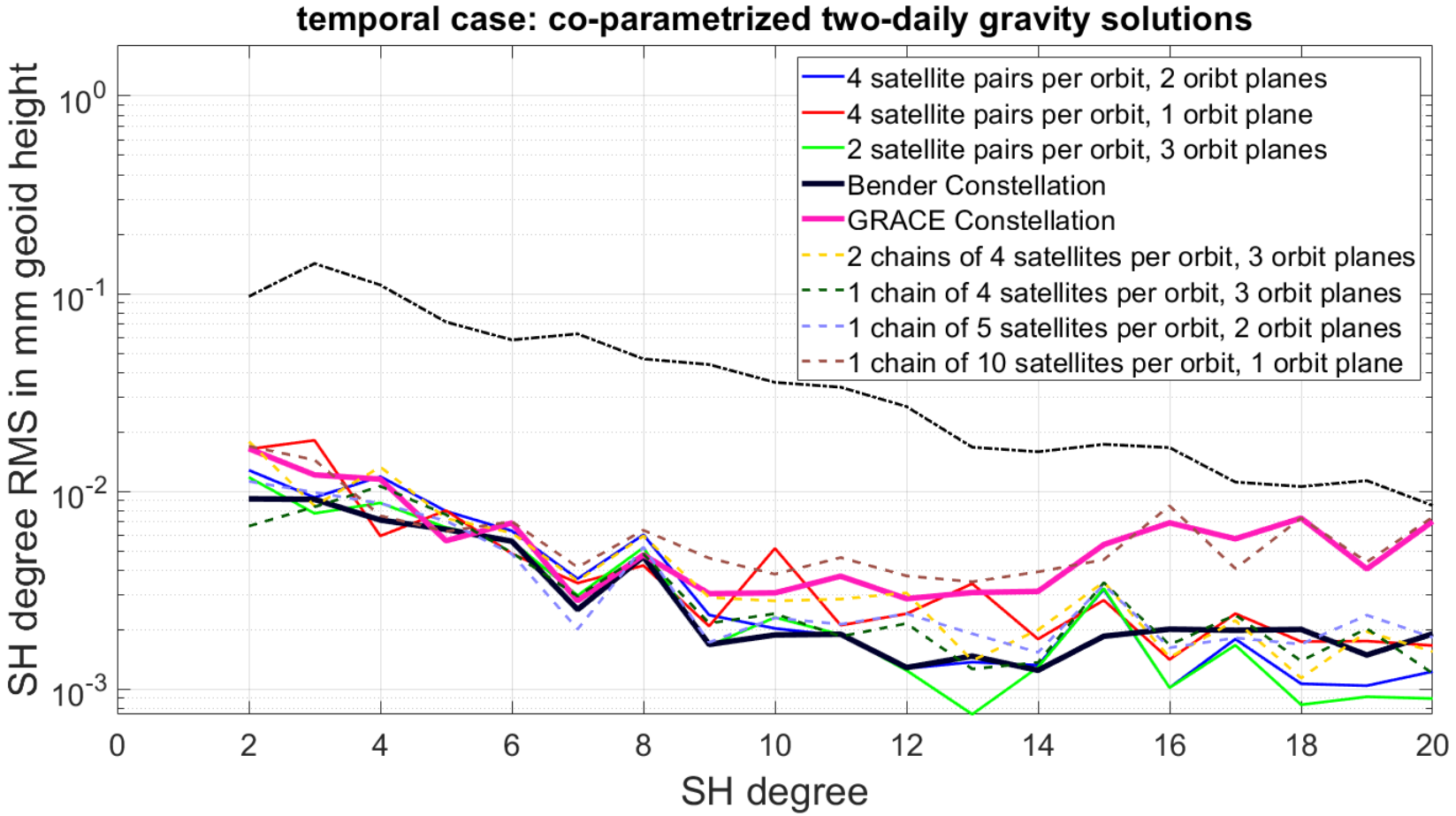
- Increased number of satellites and links → better performance

Simulation Results



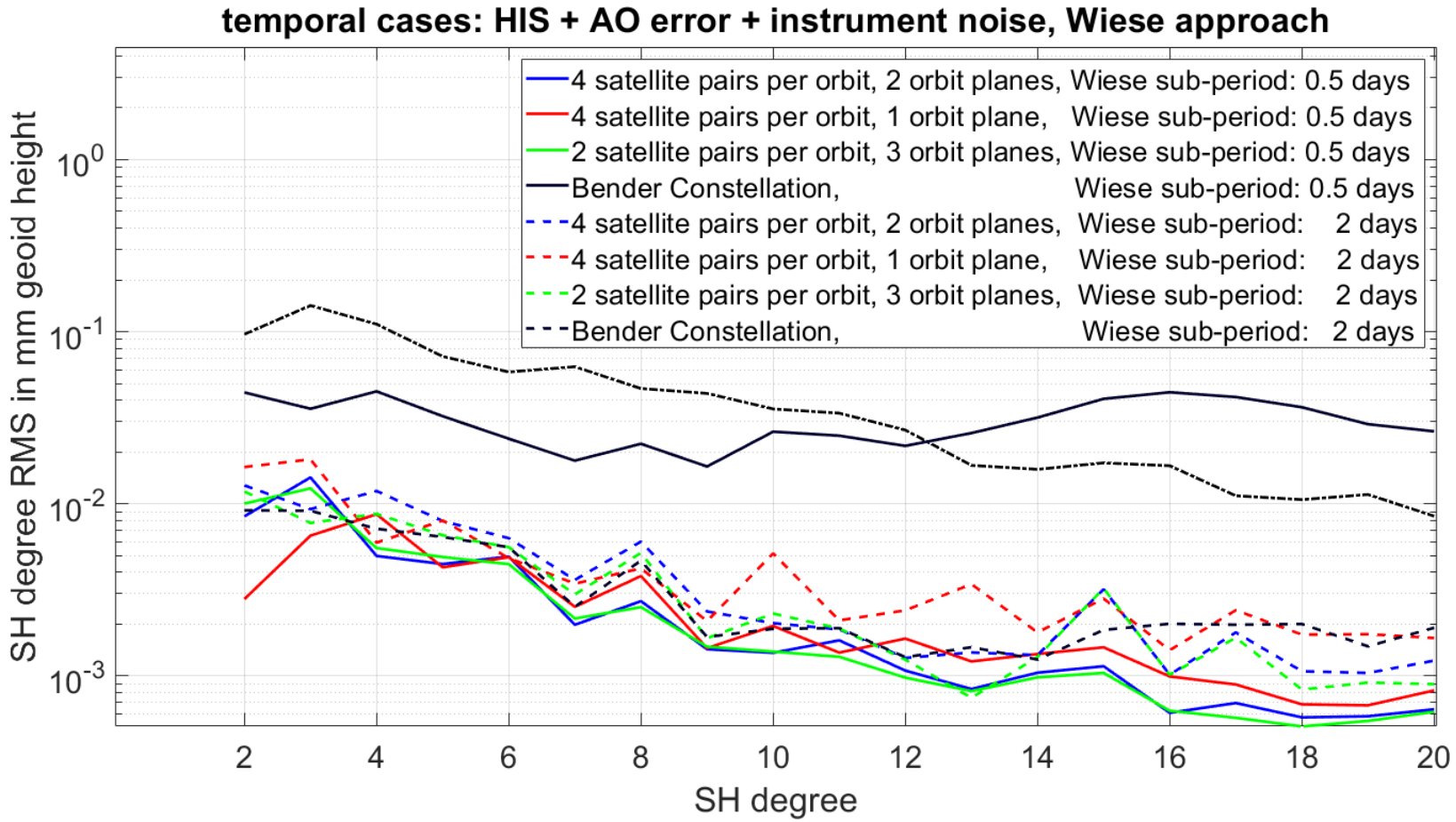
- Positive impact of a large number of links and satellites not valid anymore, but spatial distribution is more important

Simulation Results



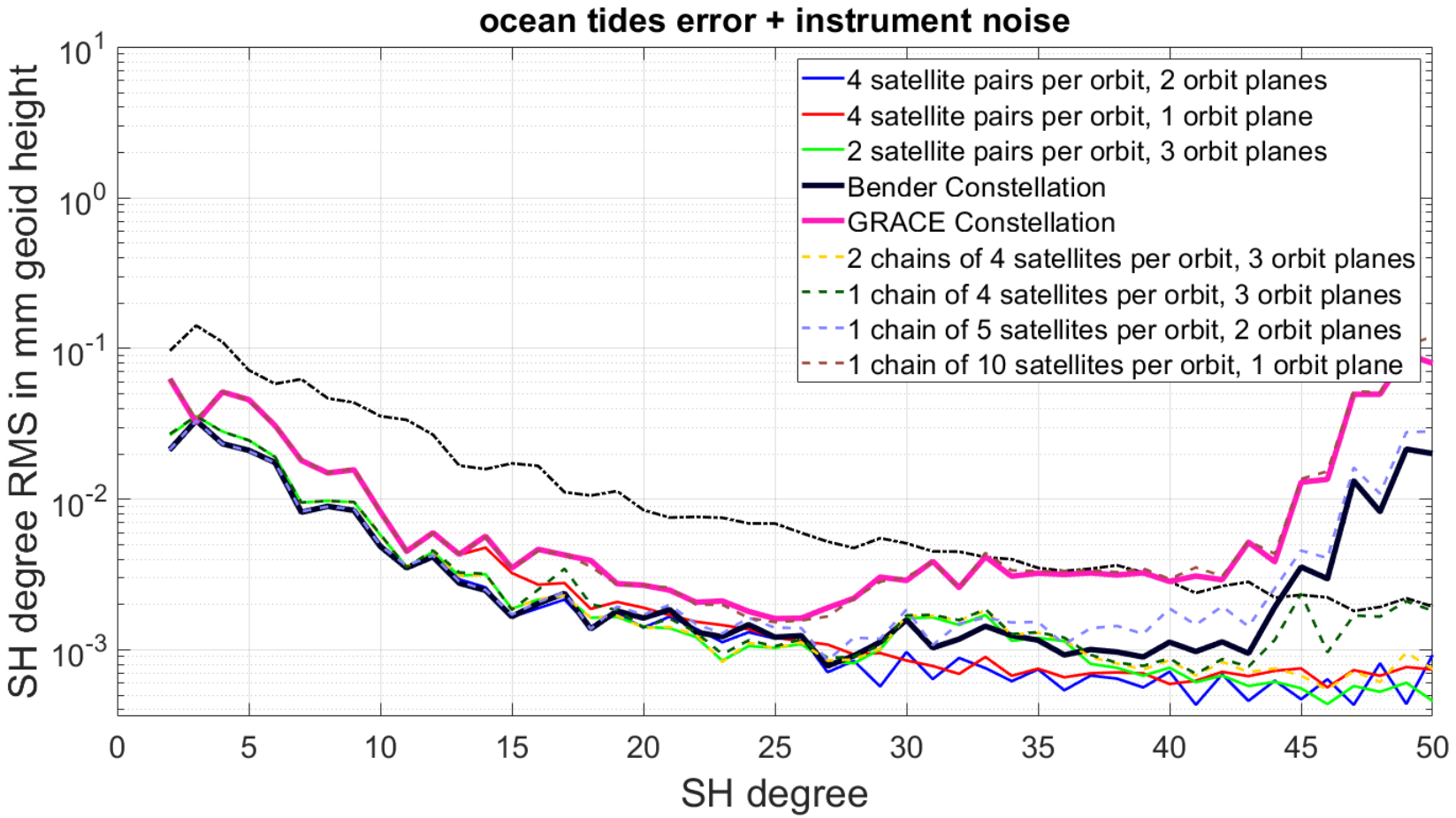
- Positive impact of a large number of links and satellites not valid anymore, but spatial distribution and number of orbit planes is more important

Simulation Results



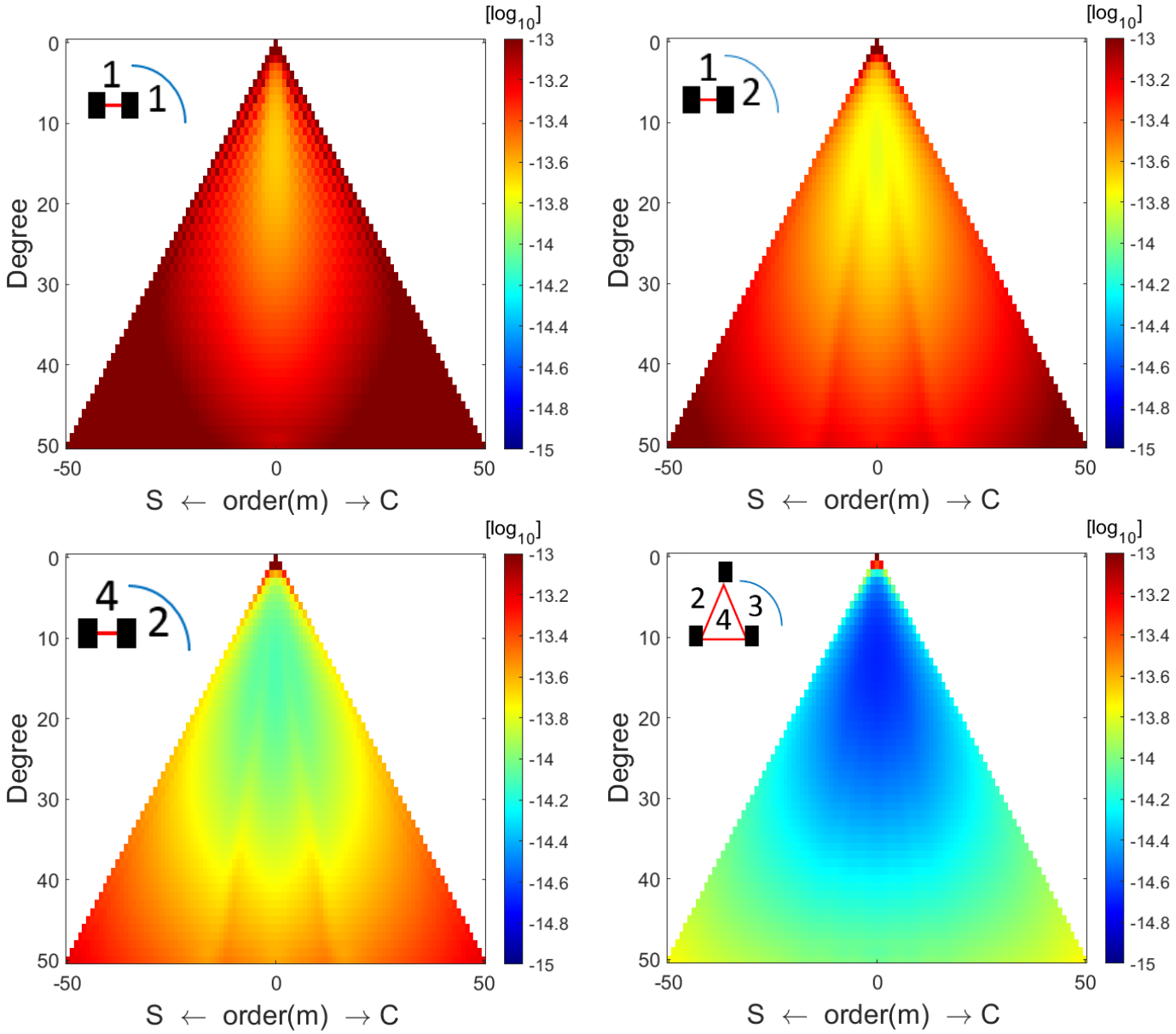
- For shorter sub-periods (e.g. 0,5 days) number of observations is more relevant than for longer sub-periods (e.g. 2 days) to achieve sufficient ground coverage (spatial resolution)

Simulation Results

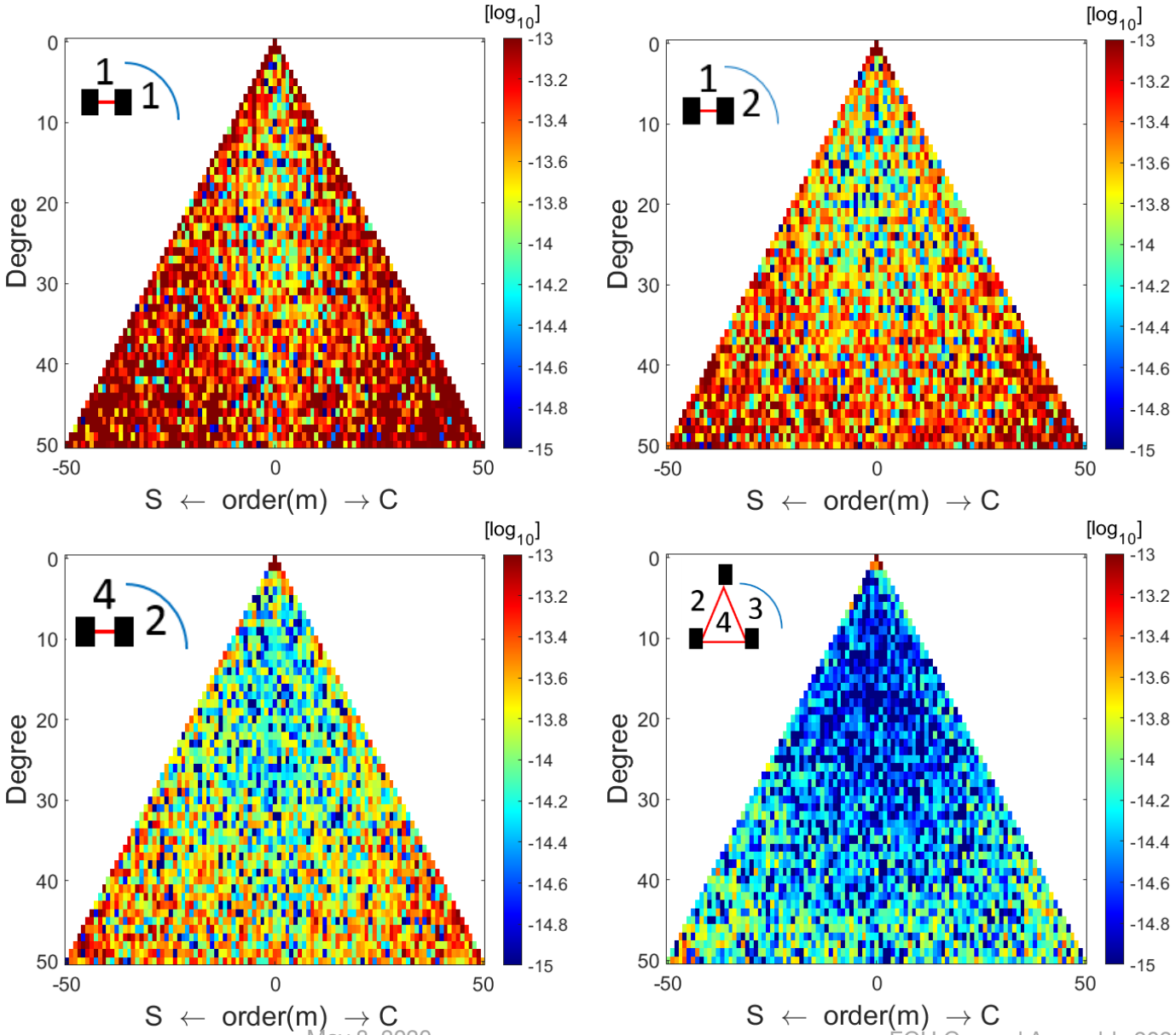


- Similar behaviour with ocean tides as temporal cases

Spherical harmonic coefficients – formal errors



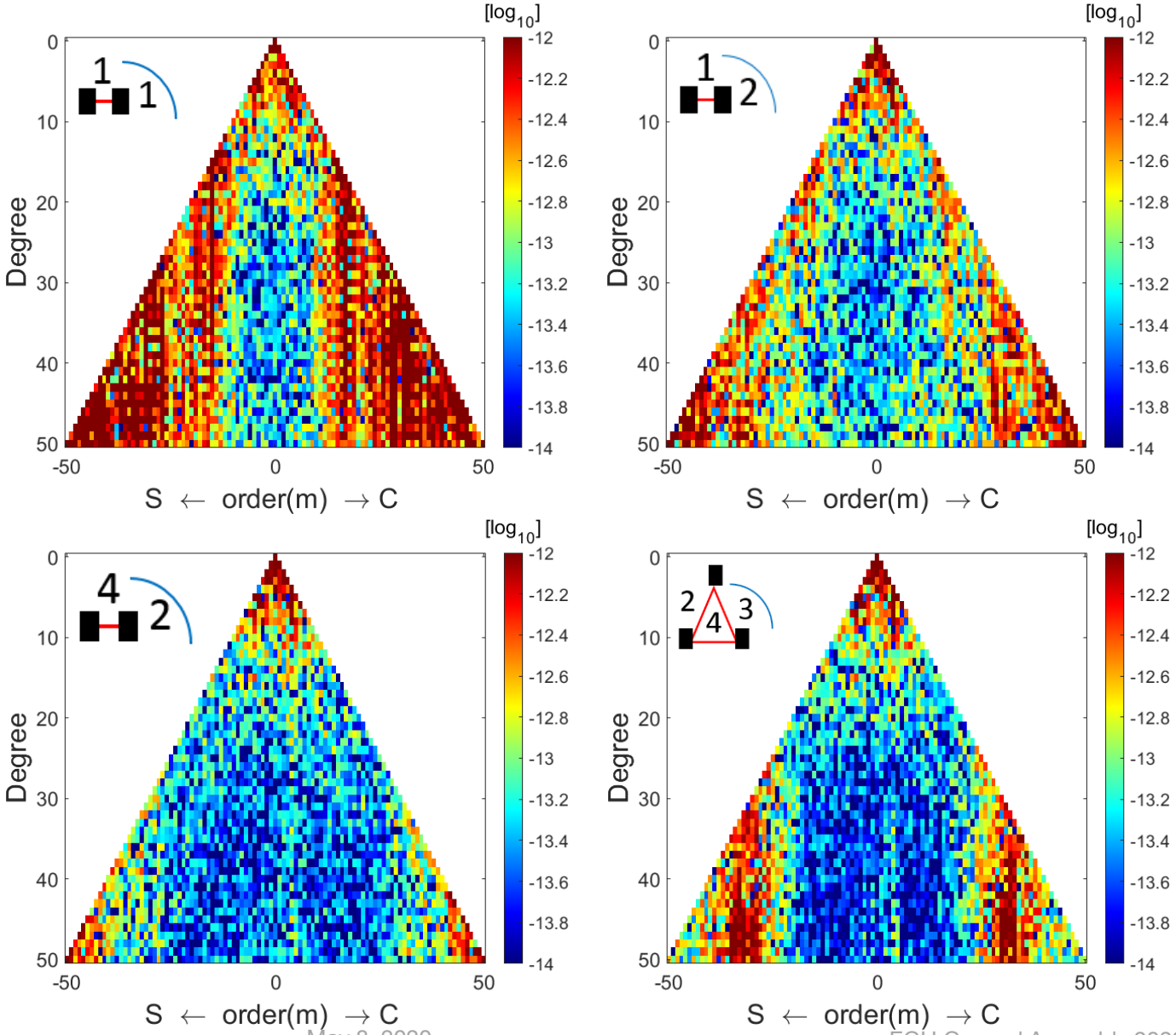
Spherical harmonic coefficients – static case



Formal errors and coefficients fit together

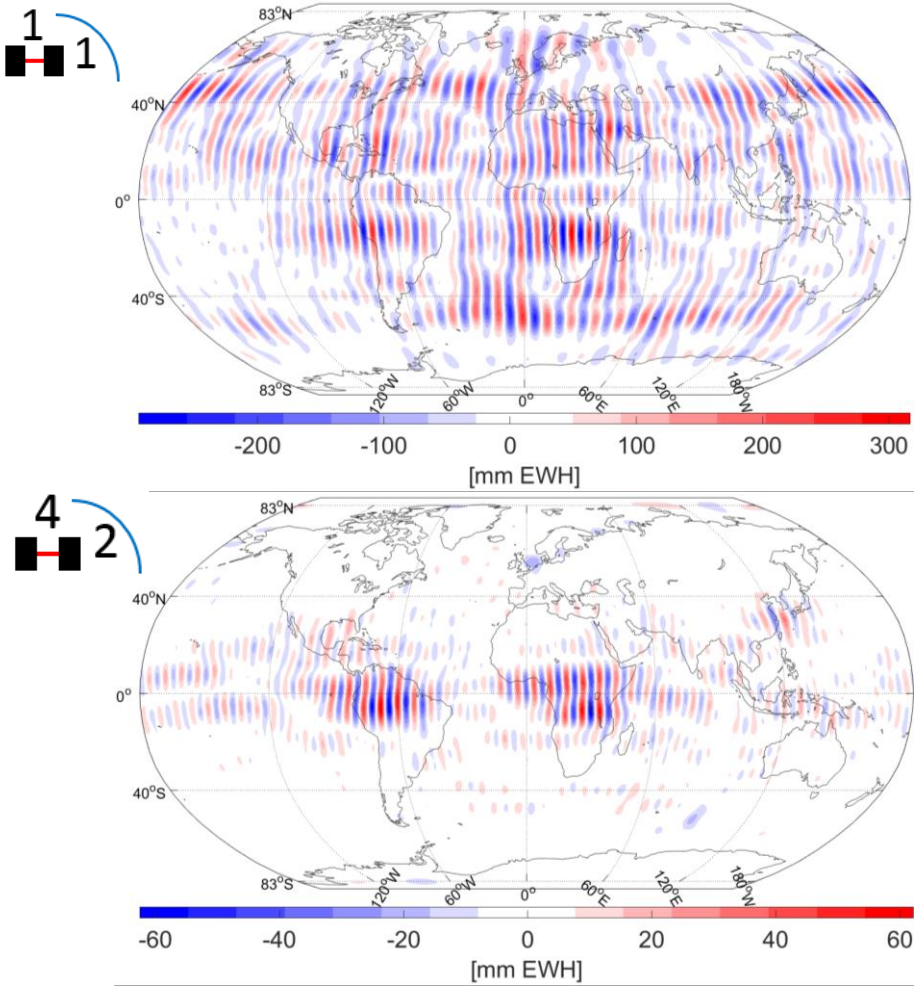
Lower impact of instrument errors in the constellation with satellite chains

Spherical harmonic coefficients – temporal case

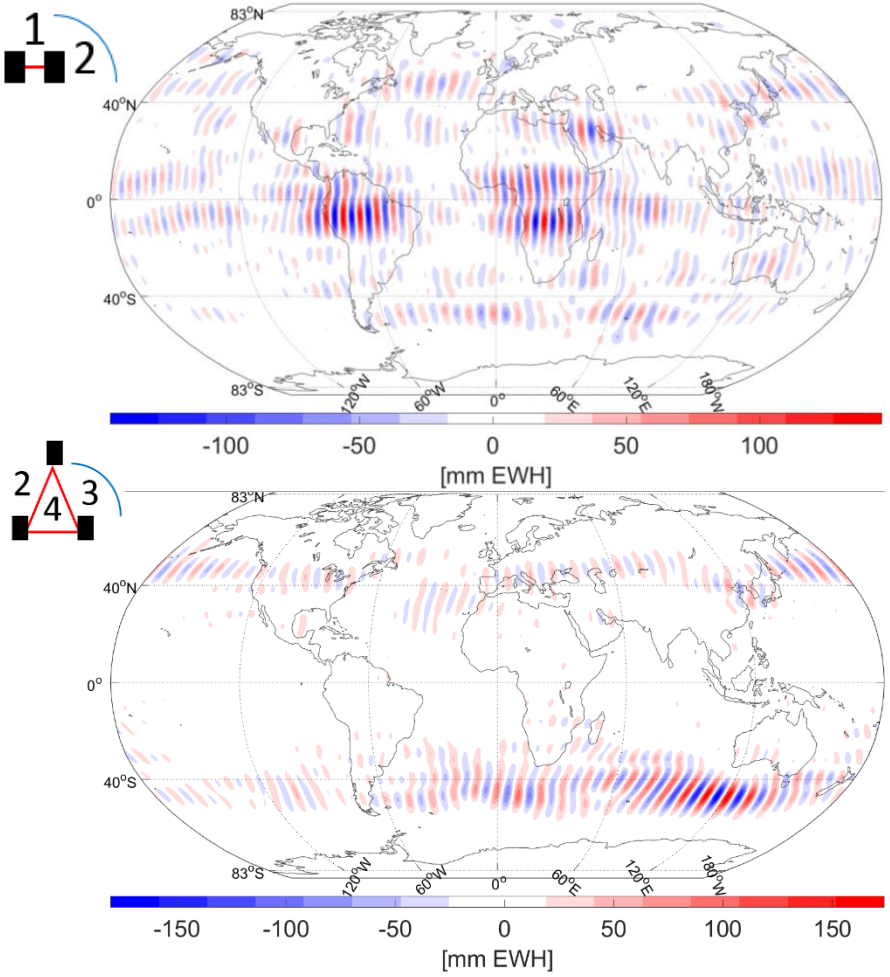


Higher coefficient differences to HIS signal in the constellation with satellite chains than in the multiple pair formation

Geoid map with time-variable gravity field signal



Striping pattern mostly eliminated



Slight reduction of temporal aliasing

Conclusions

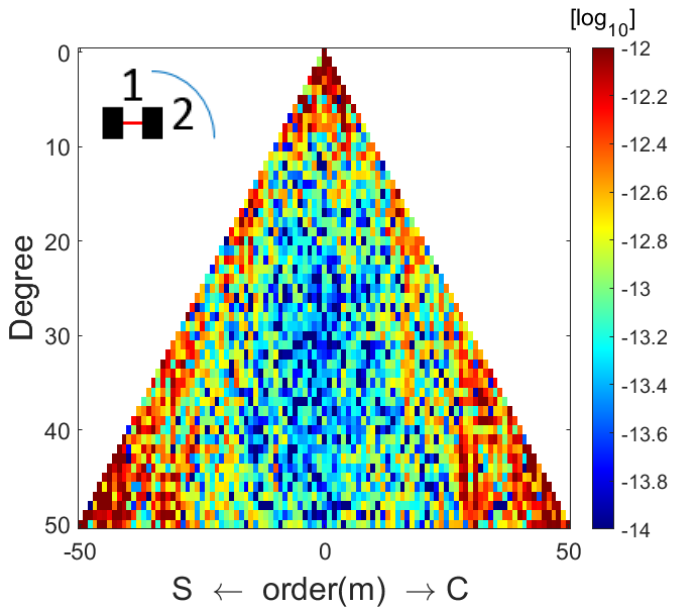
- Long satellite chains are not recommended, because they increase only redundancy (and thus reduce effect of instrument errors), but do not improve the dominating error source of temporal aliasing
- Spatial distribution of the satellite pairs more important than the amount of links (chains of satellites) for solutions with non-tidal variations
- Number of observations is primarily relevant to achieve sufficient spatial resolution in the case of short-term co-parameterization of non-tidal temporal gravity signals (Wiese approach)
- Very good performance of constellations with several pairs on the same orbit → further detailed studies necessary
- Constellations with high temporal resolution (either multiple satellite pairs or chains of satellites) achieve better results in ocean tides cases
- Further investigations:
  - co-parameterization of ocean tides → high potential due to multiple satellites and increased temporal resolution
  - updated link strategy for multi-satellite networks

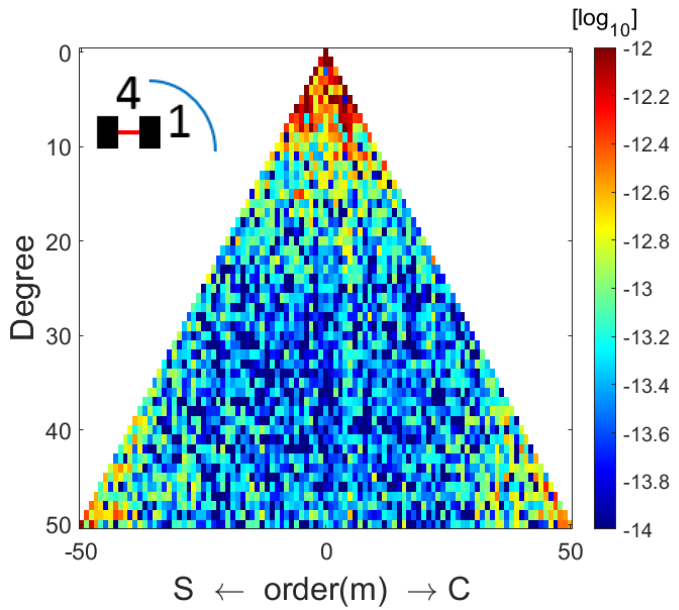
Literature

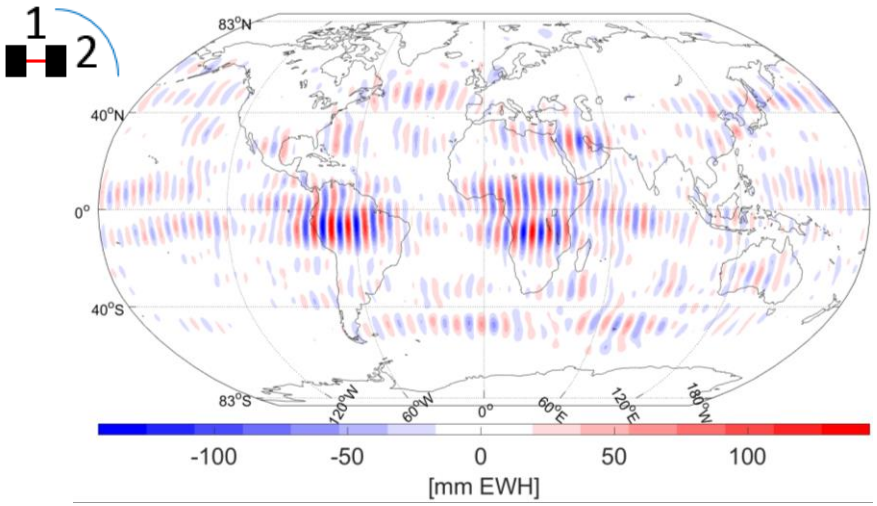
- Yunck, T (2019), The Earth Gravitational Observatory: Smallsat constellation for multi-link low-low SST, Washington, DC,
- Yunck, T, A Saltman, S Bettadpur, S Nerem, J Abel, M Widner, C Deccia, G Franklin (2019), The Earth Gravitational Observatory: Multisat clusters in chain formations, NASA Mass Change Workshop, Washington, DC

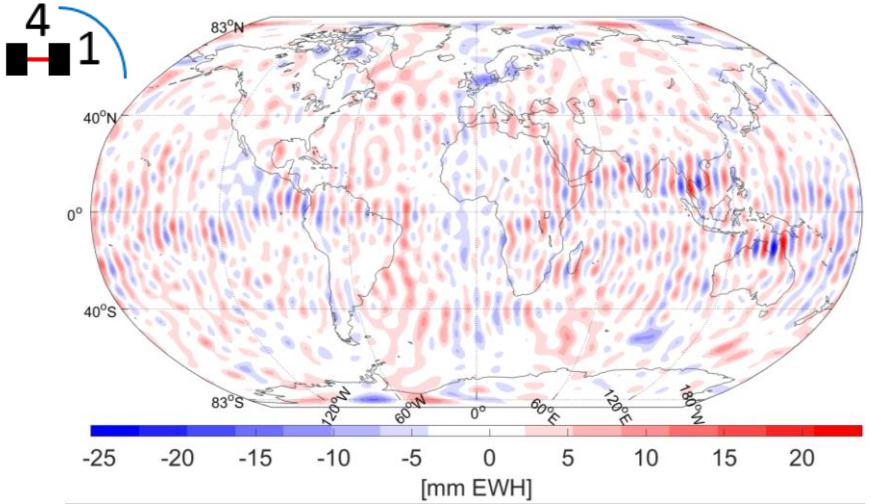
Backup Slides

Comparison Bender Constellation – multiple Pairs Constellation

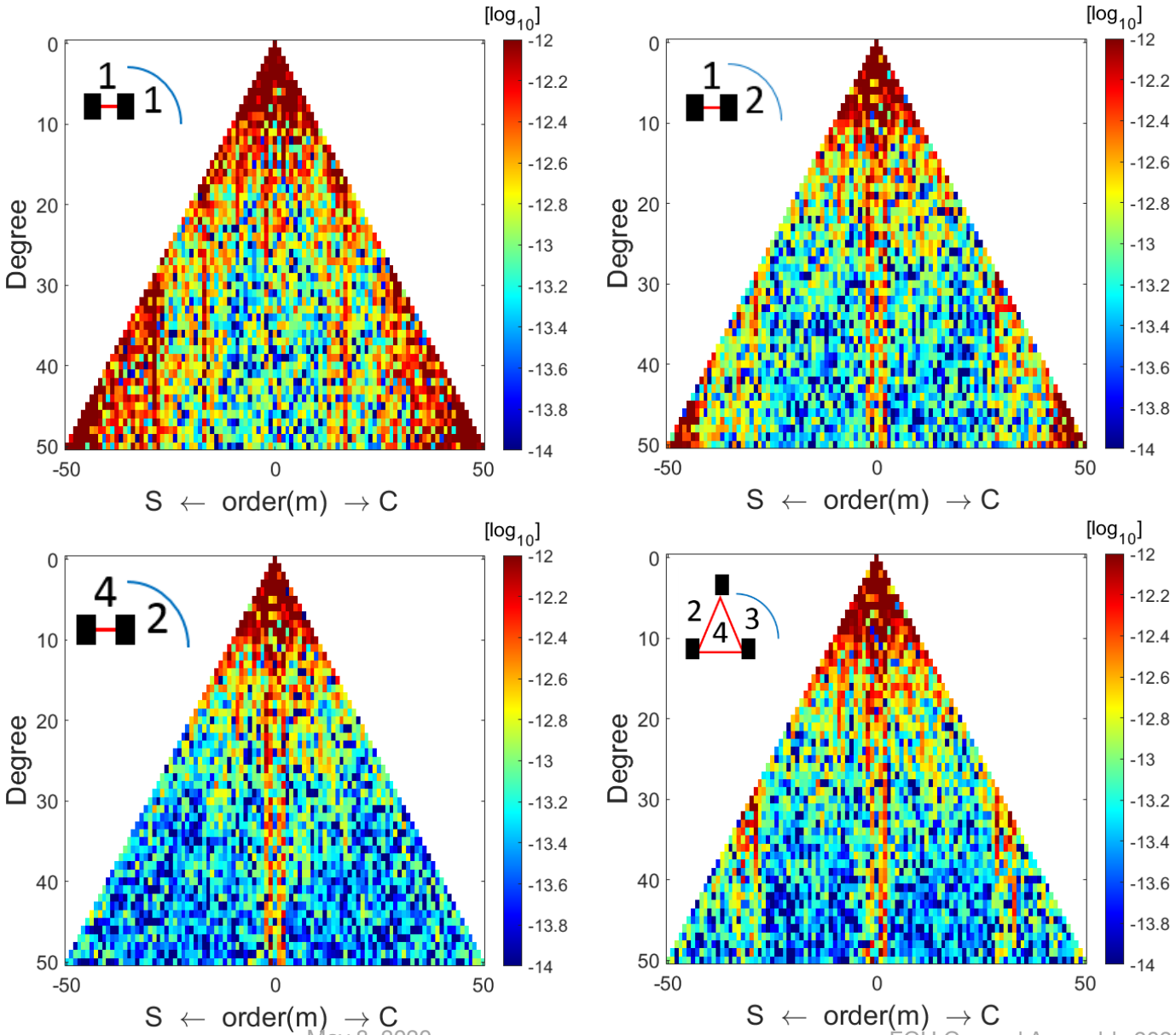








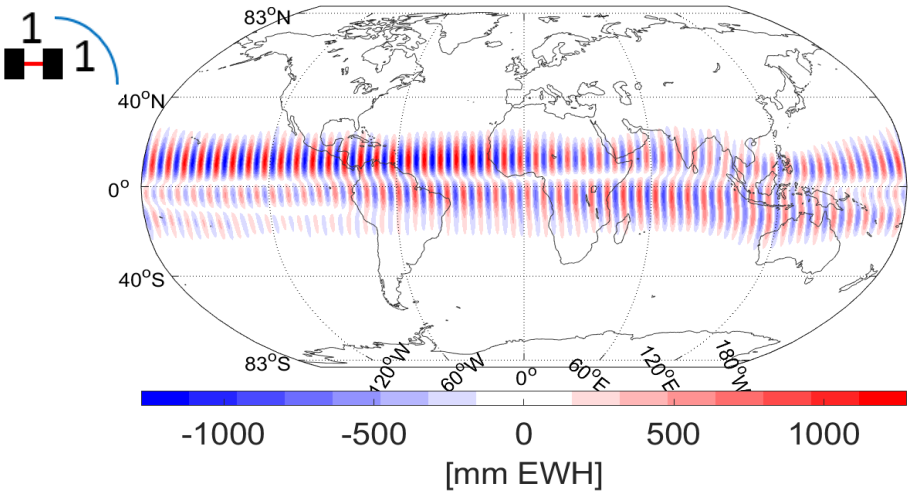
Spherical harmonic coefficients – ocean tides

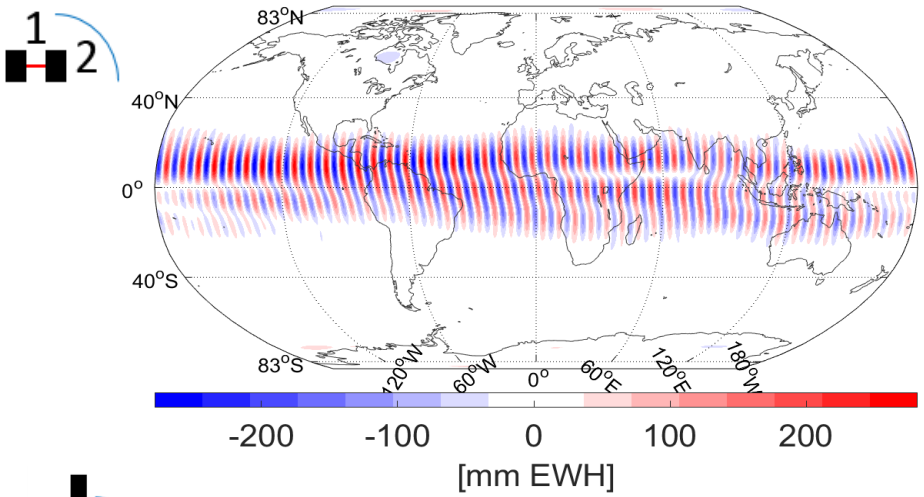


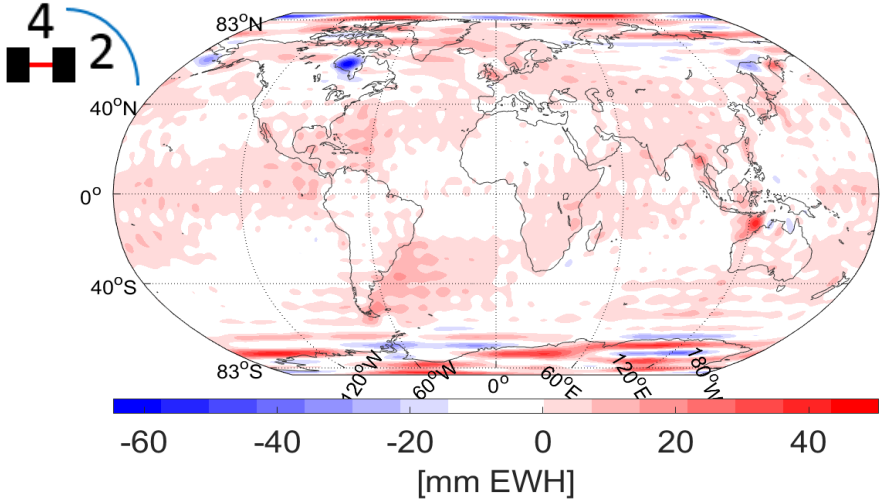
ocean tides errors in near zonal in all configurations apparent

Influence of ocean tides errors can be less decreasd by constellations compared to non-tidal components

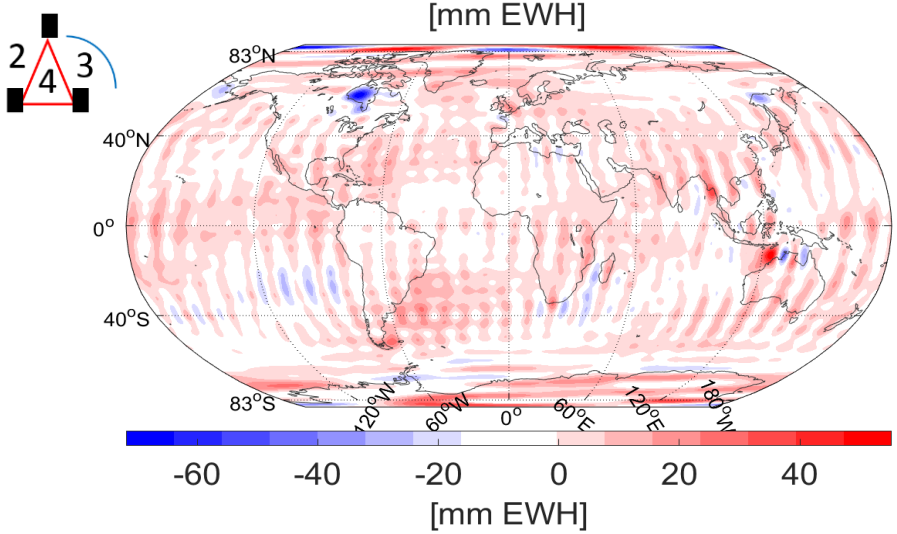
Geoid map with ocean tides signal







Striping pattern mostly eliminated



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