Towards Deriving Temporal Sampling Requirements for Future Satellite Gravimetry Missions

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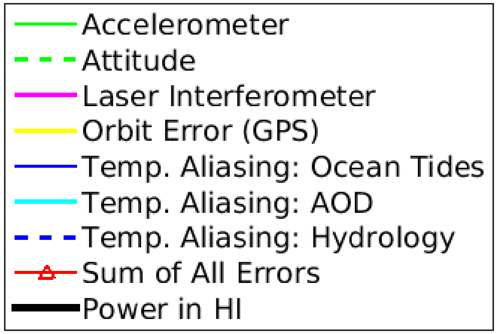
August 2, 2017
IAG-IASPEI Joint Scientific Assembly 2017
Kobe, Japan

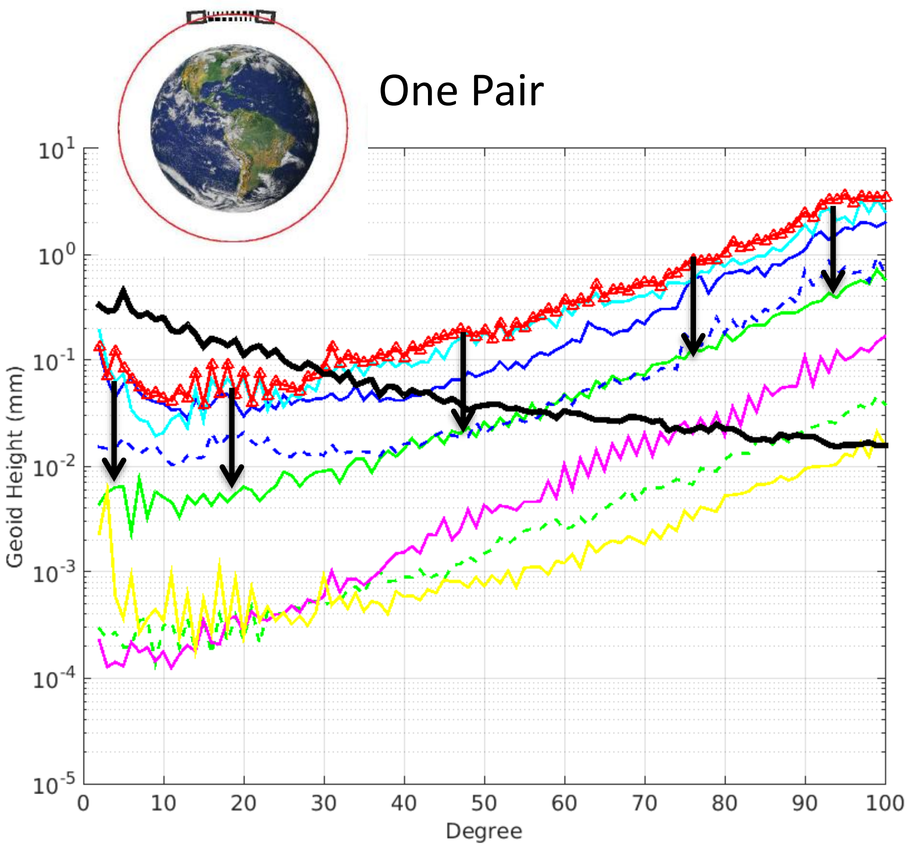
Simulation Results: **500 km altitude**, 300 km separation, GRACE-FO measurement errors

Temporal aliasing errors are dominant for single and dual-pair architectures

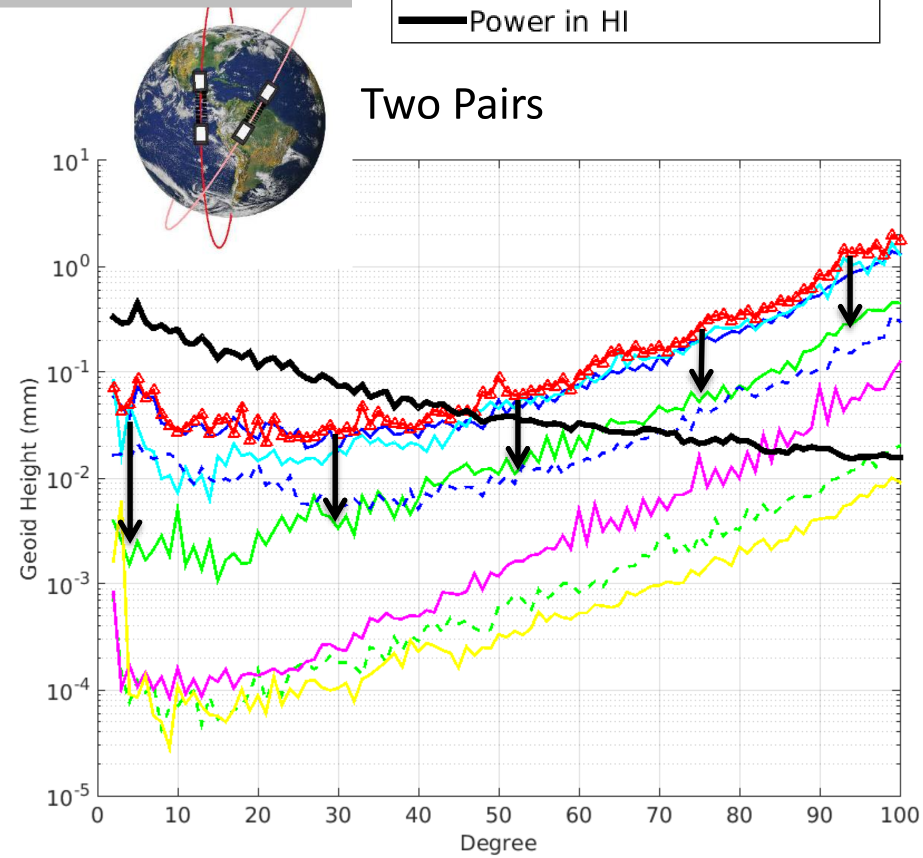
Can we reduce aliasing error to here?



One Pair



Two Pairs



How can we reduce temporal aliasing errors?

1) Improve background force models

2) Co-estimate parameters

3) Sample the gravity field more frequently

AOD aliasing errors are dominant at long wavelengths and 2-5 day timescales. This spectrum is directly observable using two pairs of LL-SST satellites

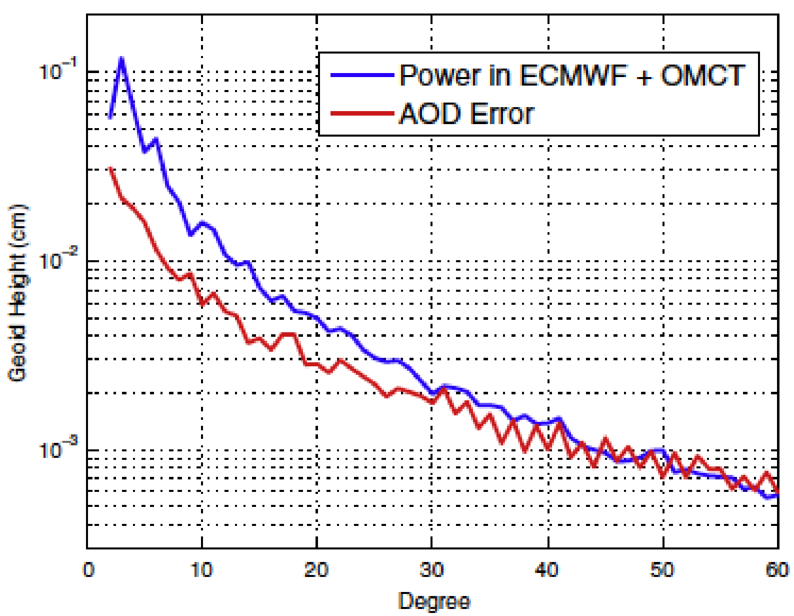


Fig. 2. Error in atmosphere and ocean models.

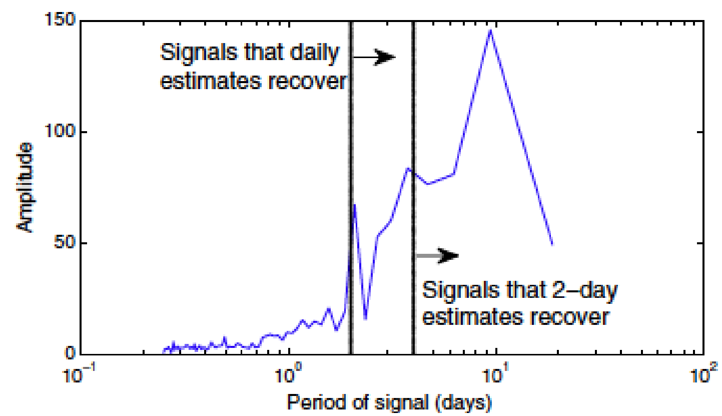


Fig. 4. Frequency content of the first mode of the AOD error displayed in Fig. 3.

Wiese et al., 2011a

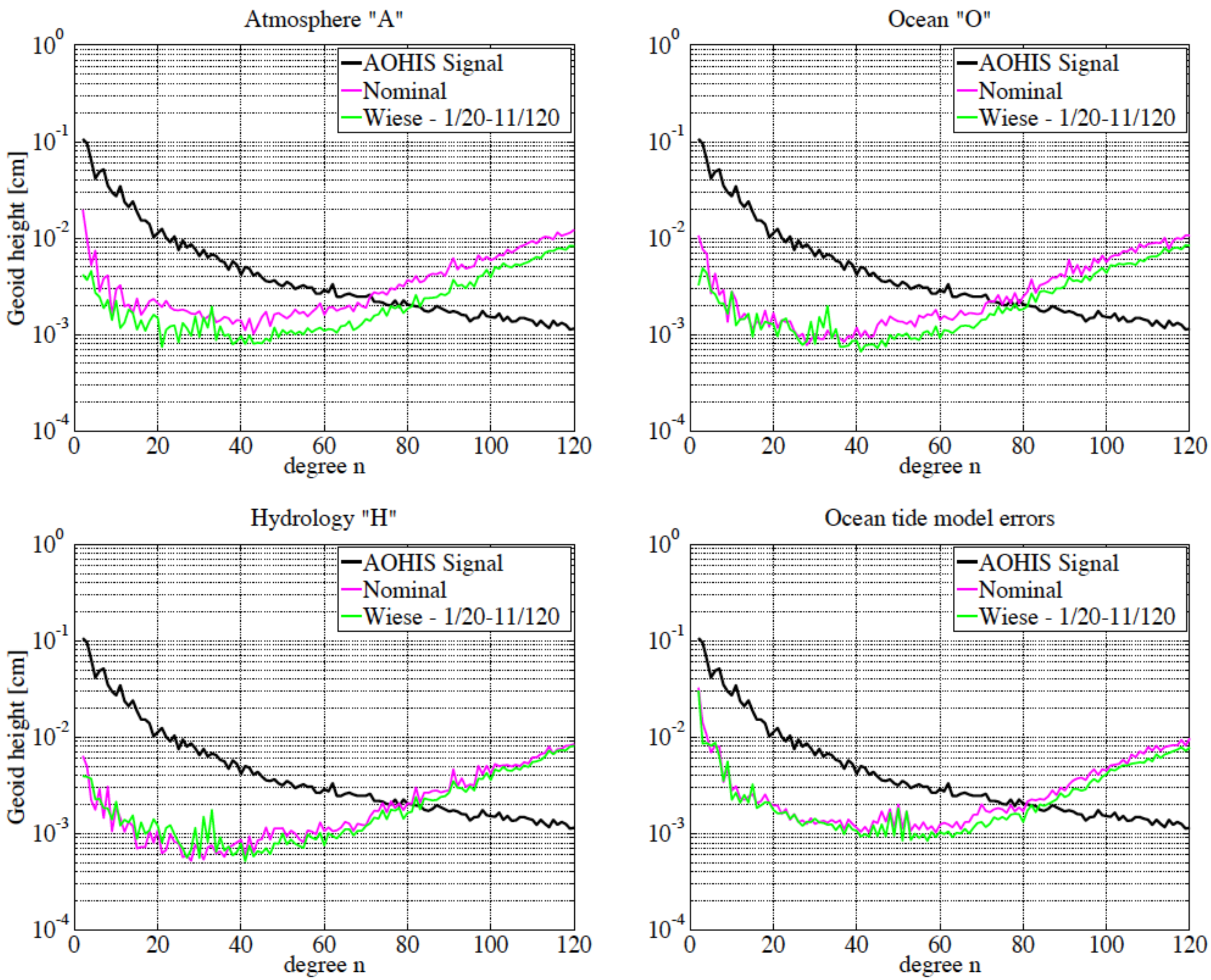


Figure 7.2.18: DDA in geoid heights of 11-day d/o 120 solutions of individual components inducing aliasing effects. Depicted are error curves of nominal and $\text{Wiese}_{1/20-11/120}$ solutions.

Daras, 2016

How can we reduce temporal aliasing errors?

1) Improve background force models
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Multi-pair LL-SST

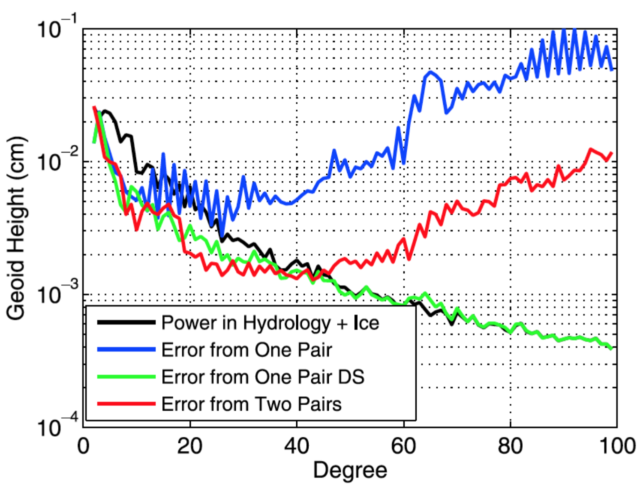


Figure 4. Geoid degree error for architectures consisting of one and two pairs of satellites.

Wiese et al., 2011b

Constellation of GNSS receivers

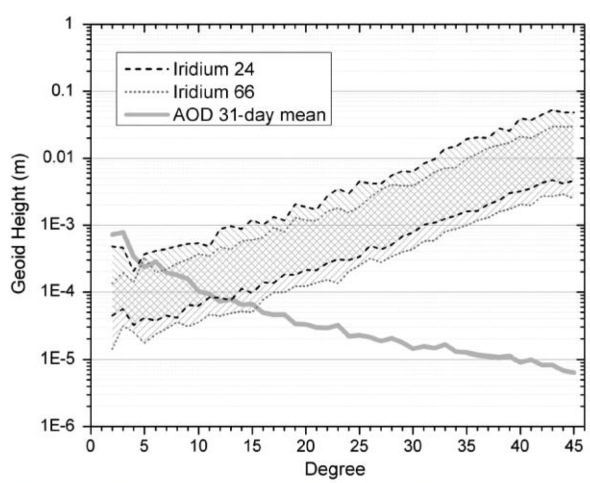
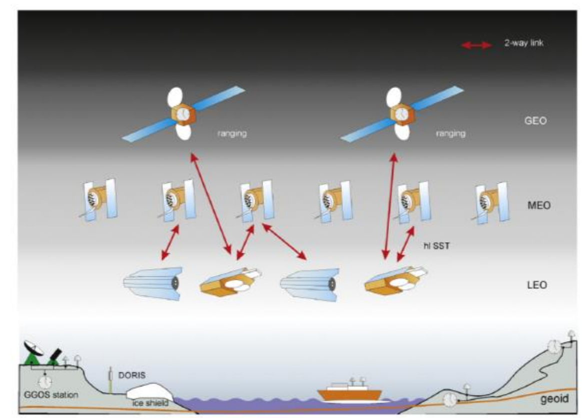


Fig. 6 Degree variances of the total error bands for the 31-day Iridium 24- and 66-satellite constellation simulations using assumptions for high and low measurement noise.

Gunter et al., 2011

GETRIS: HL-SST Concept



GETRIS constellation for gravity field recovery. The advantages can be seen in the LEO orbit which makes every mission he data link is also a high precision ranging link. This allows a continuous gravity field recovery with high temporal resolut

Hauk et al., 2016

Goal: Identify an observing system for which temporal aliasing errors are not the limiting source of error in recovering time variable gravity

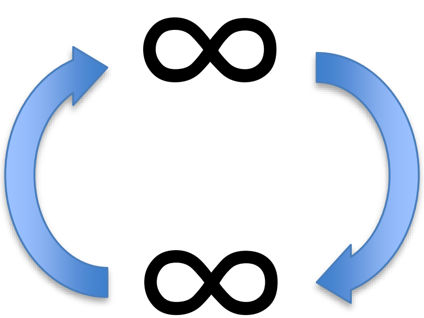
Select constellations of LL-SST, HL-SST, or GPS-receivers

↓

Run numerical simulations

↓

Analyze output



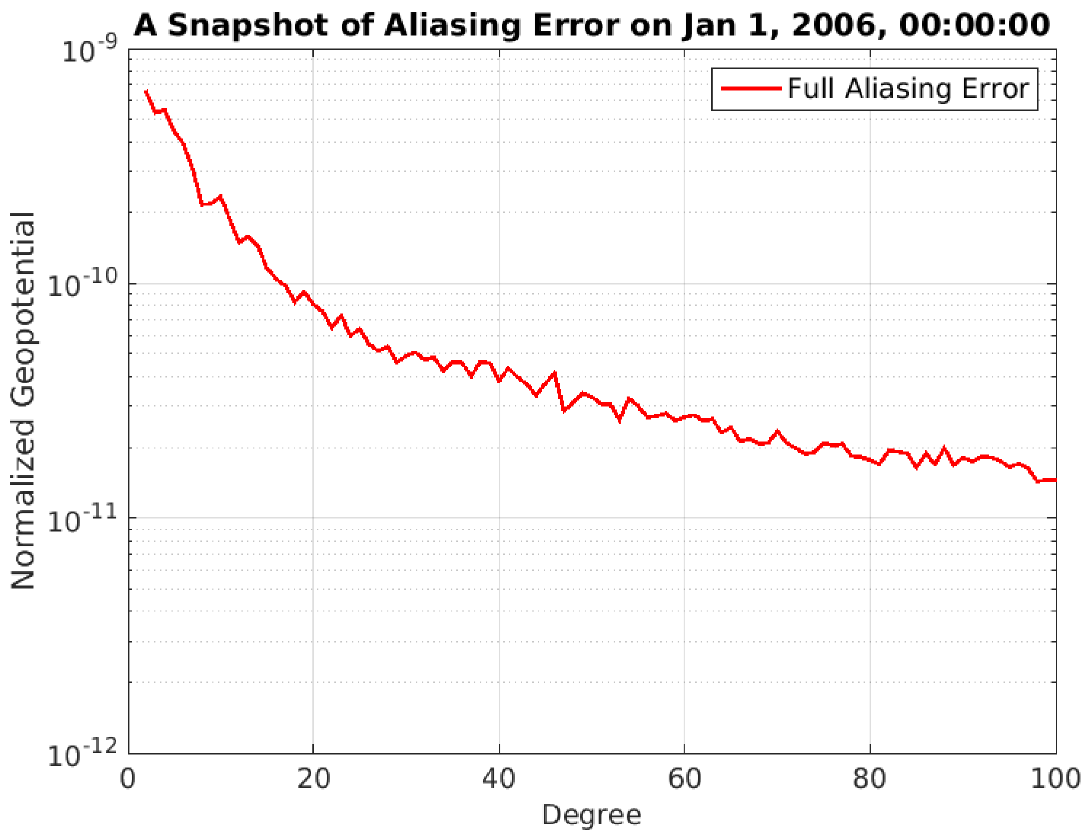
Assume we have an observing system that perfectly measures temporal gravity variations at specific spatial/temporal scales

↓

Modify our definition of temporal aliasing error to reflect this new knowledge

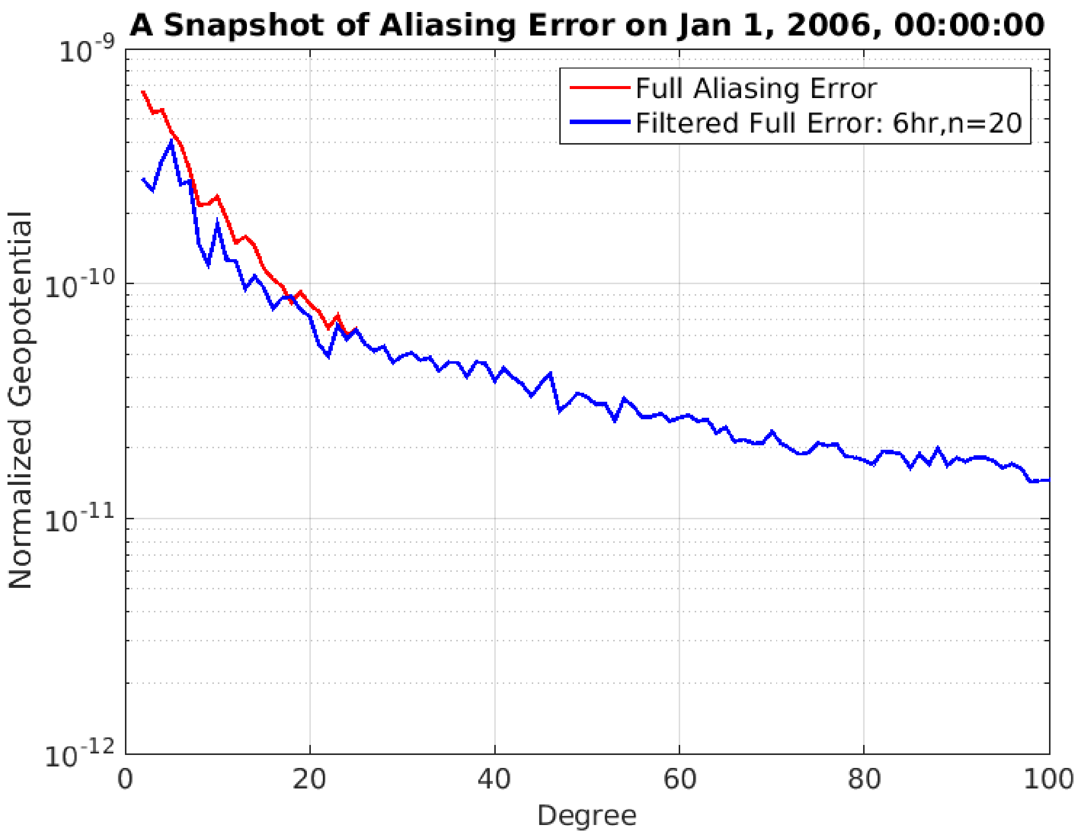
↓

Run numerical simulations with this modified aliasing error to ***understand the sensitivity of the gravity recovery process to the addition of new information***



	Truth Model	Nominal Model
Static Gravity Field	gif48	gif48
Ocean Tides	GOT4.7	FES04
Atmosphere/Ocean	"AO"	Aoerr+DEAL
Hydrology/Ice	"HI"	--

AOHIS 3-hr temporal res. *Dobslaw et al*. 2015



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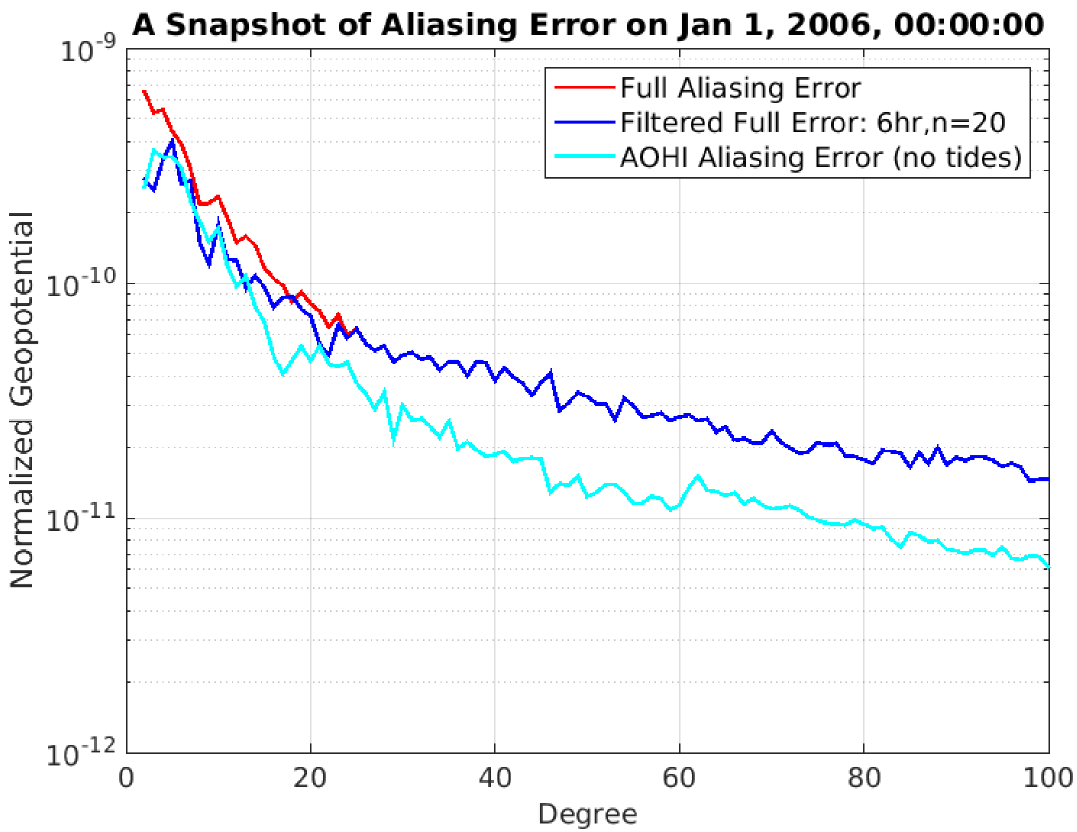

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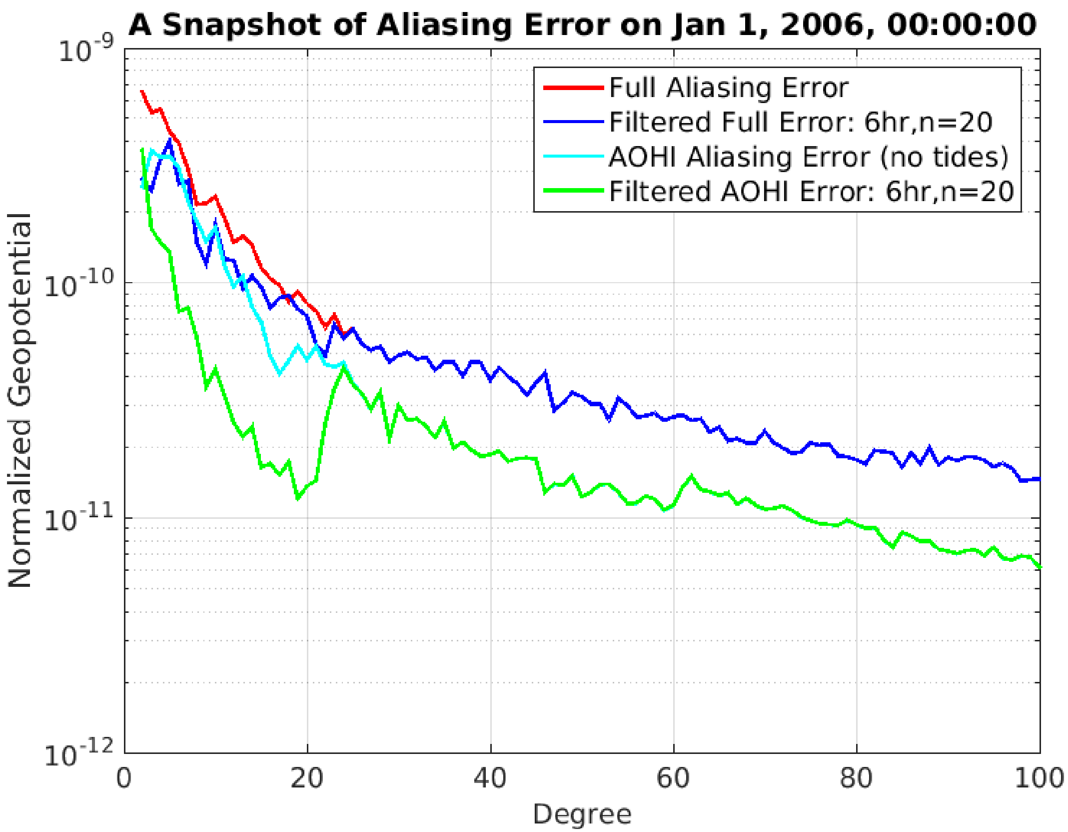

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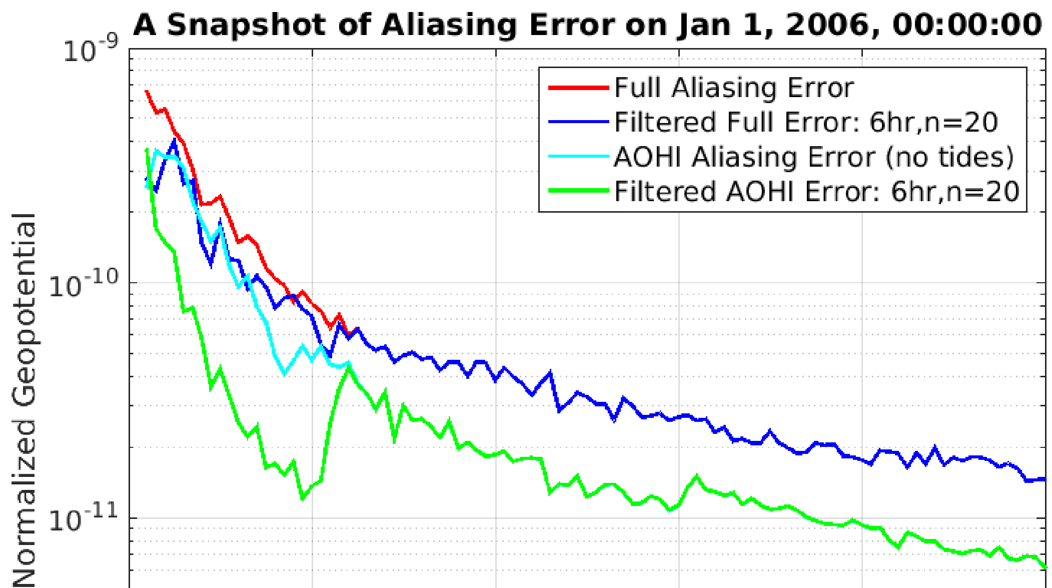

We assume that we have perfect knowledge of mass variations at time scales of **[6, 12, 24] hours** and at spatial scales of **n = [10, 20, 30]**.

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AOHIS 3-hr temporal res. *Dobslaw et al*. 2015

Simation Setup

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Ocean Tides	GOT4.7	FES04
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Hydrology/Ice	"HI"	--

AOHIS 3-hr temporal res. *Dobslaw et al*. 2015

- 29-day simulation
  - January 2006
- Mission Architectures
  - Single Polar Pair
  - Polar Pair + Lower Inclined Pair (72°)
- Altitudes
  - ~ 300, 500 km
- Separation Distance:
  - 300 km
- All satellites are in exact 29-day repeat orbits
- Simulation carried out to n = 100

Instrument noise models

- Laser (LRI) GRACE-FO Requirement
  - RMS of 10.88 nm/s
- Accelerometer GRACE-FO CBE

Alongtrack, Radial: $3.21\times10^{-11}\sqrt{1+\frac{.01}{f}+20f^4}$ m/s²/Hz$^{1/2}$

Crosstrack: $4.75\times10^{-10}\sqrt{1+\frac{.01}{f}+5\times10^{-4}f^4}$ m/s²/Hz$^{1/2}$

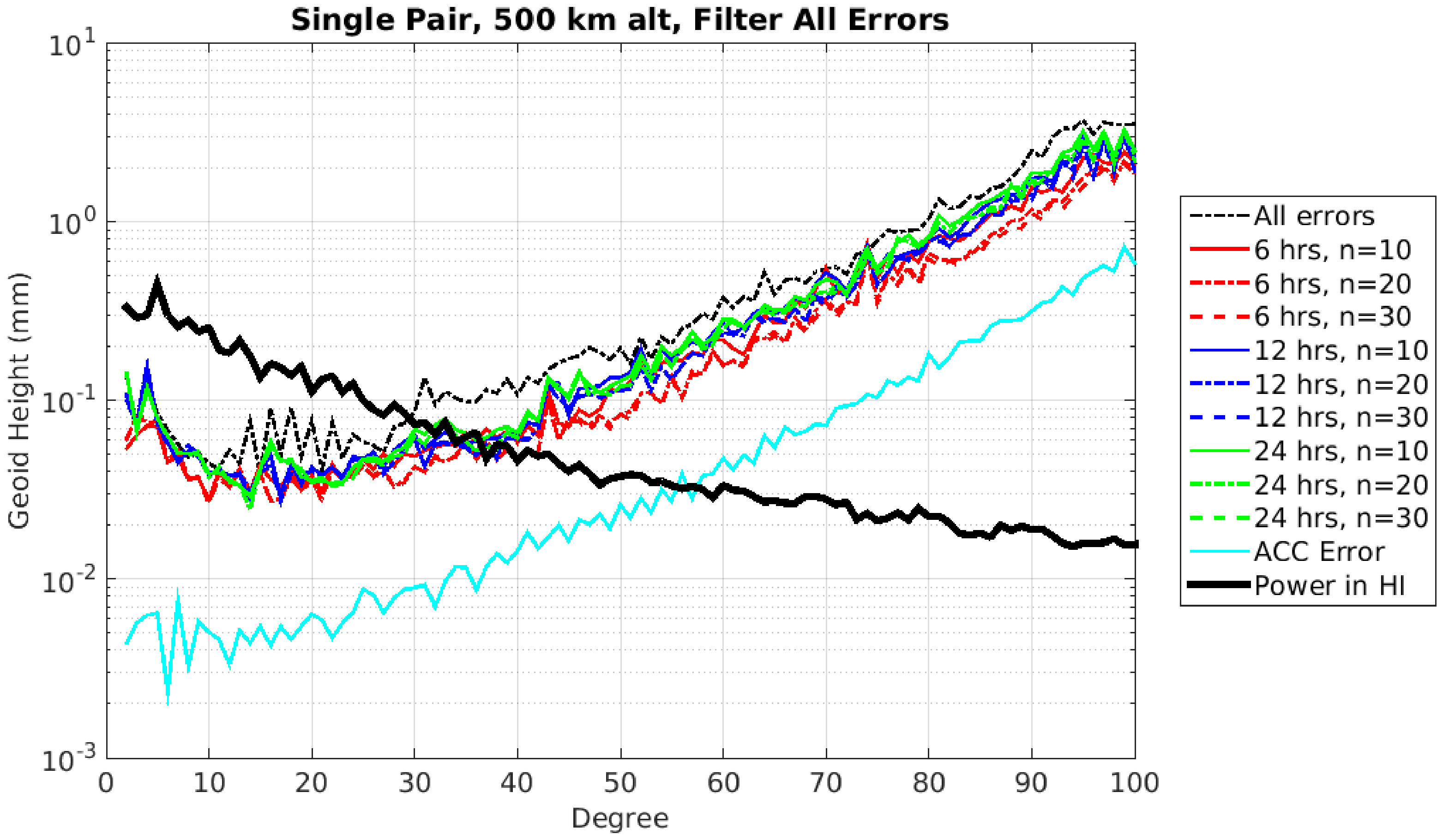
- Attitude GRACE-FO Requirement
  - Impacts ONLY accelerometer error, not MWI or LRI pointing

Pitch, Roll: 2.1×10^{-5} rad/Hz$^{1/2}$

Yaw: 1.7×10^{-4} rad/Hz$^{1/2}$

- GPS data is mimicked by using satellite positions as observables
  - 1 cm white noise in 3-axes is added

Architecture: One Pair
Altitude: 500 km
Aliasing: OT + AOHI



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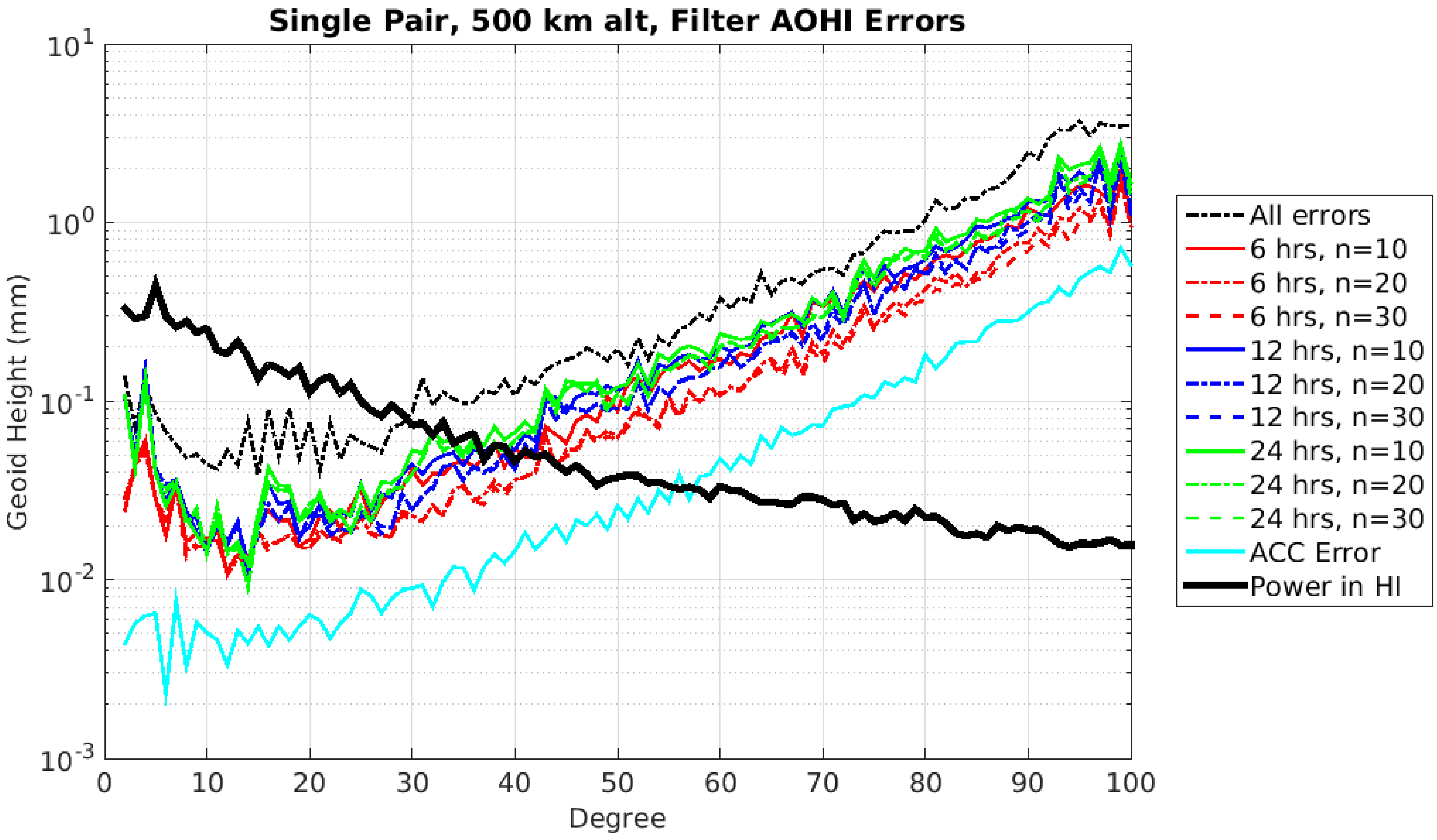

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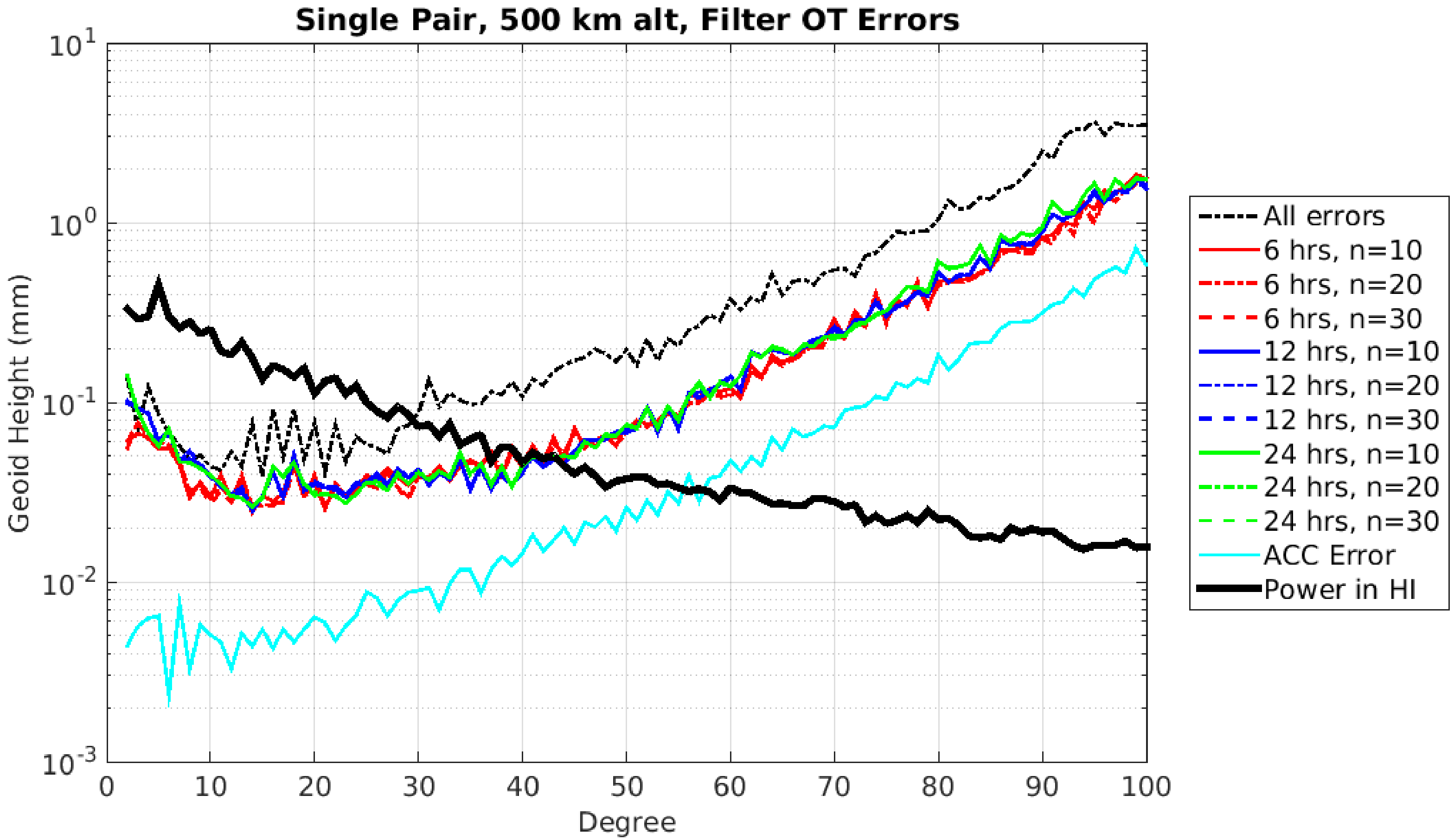
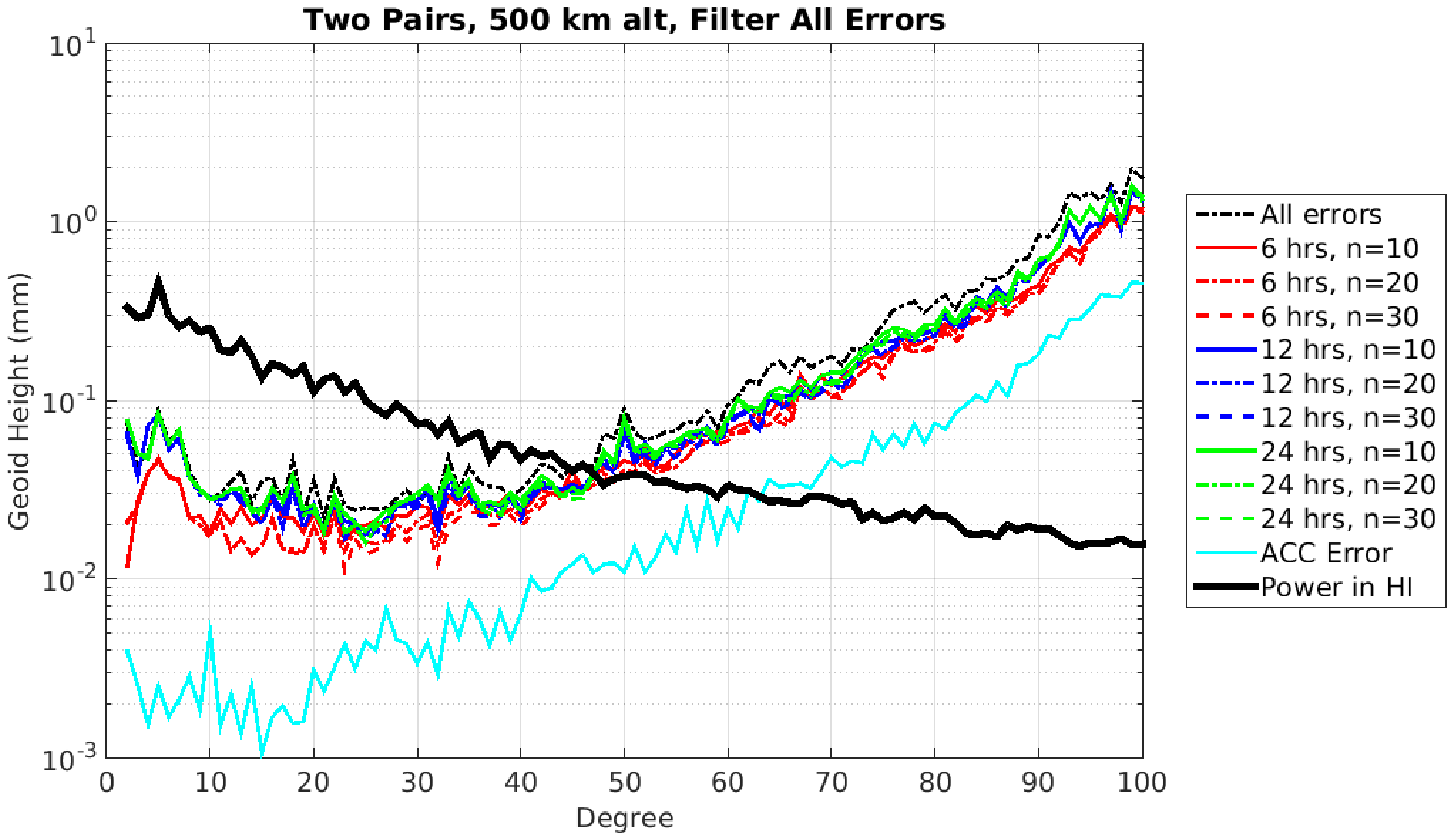


Architecture: Two Pairs
Altitude: 500 km
Aliasing: OT + AOHIS



Architecture: Two Pairs
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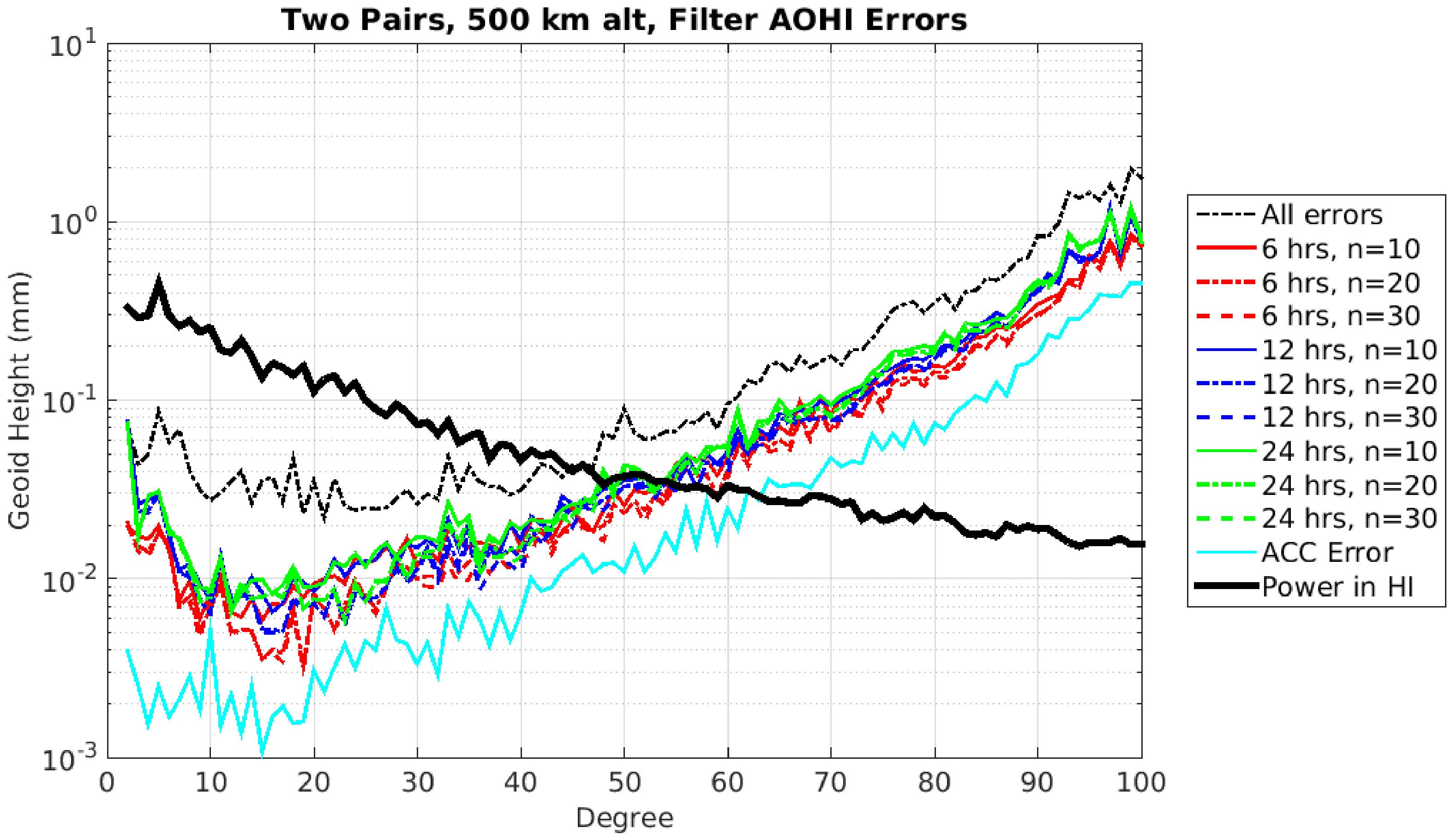
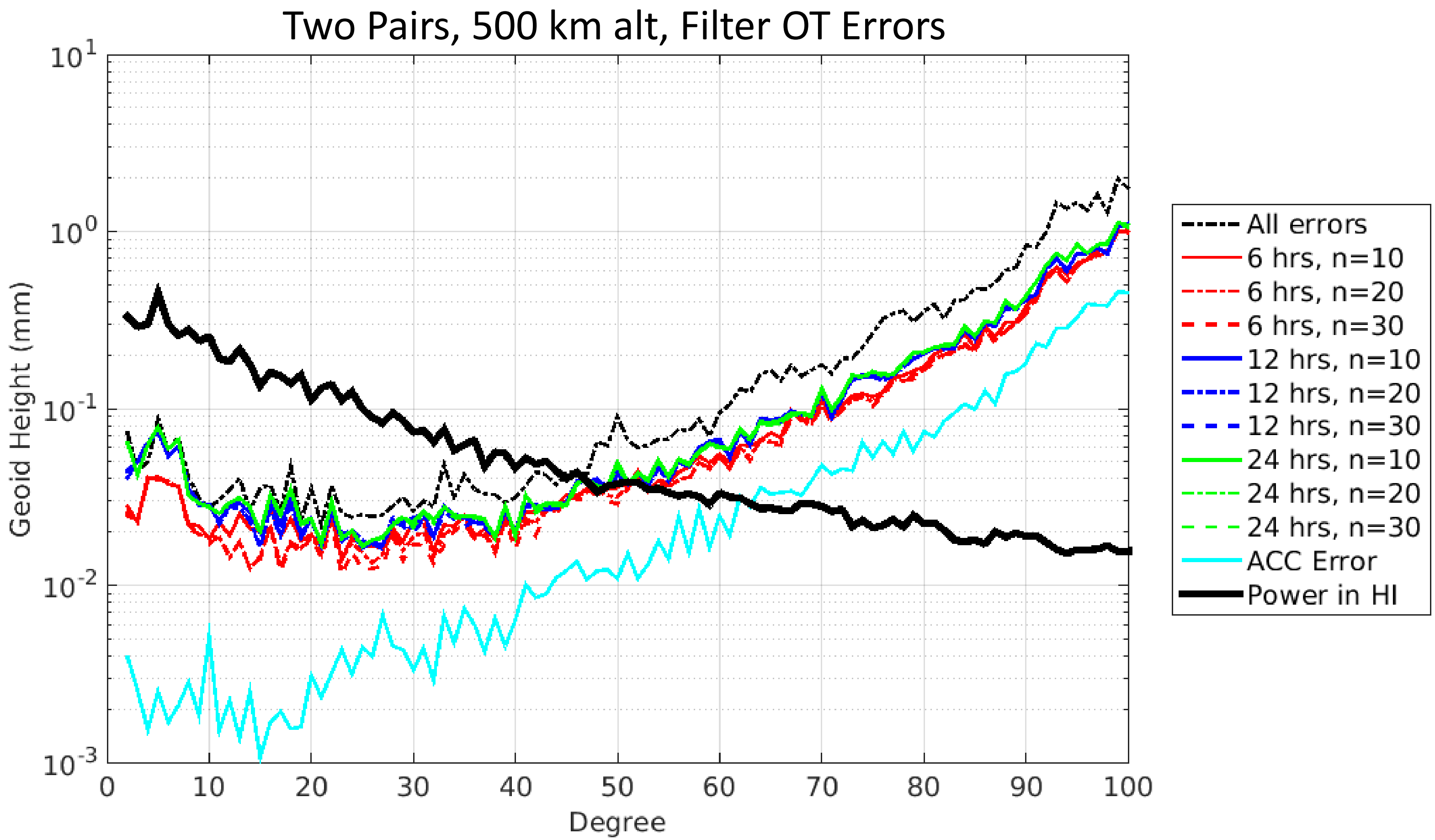
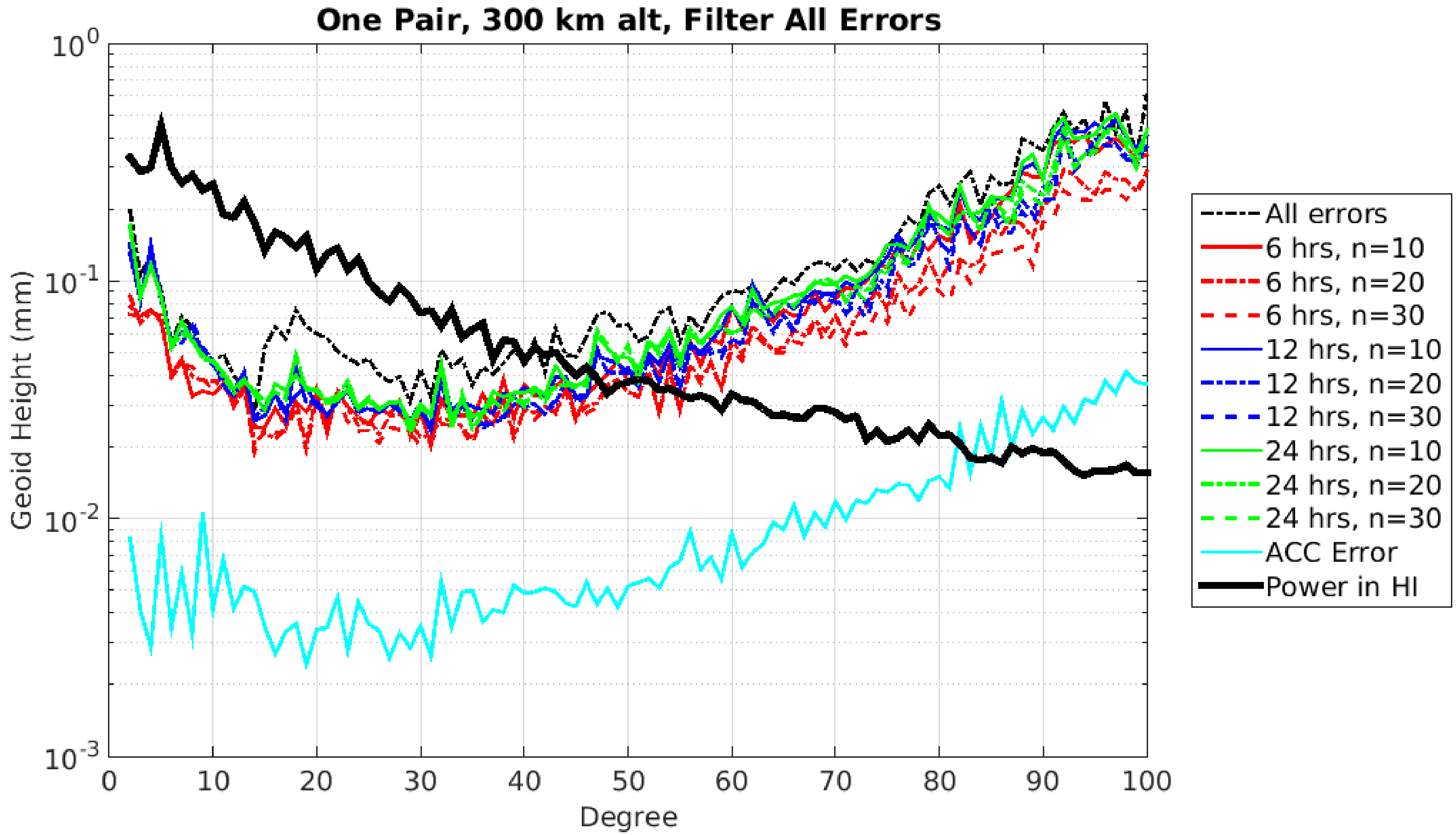


Architecture: Two Pairs
Altitude: 500 km
Aliasing: OT



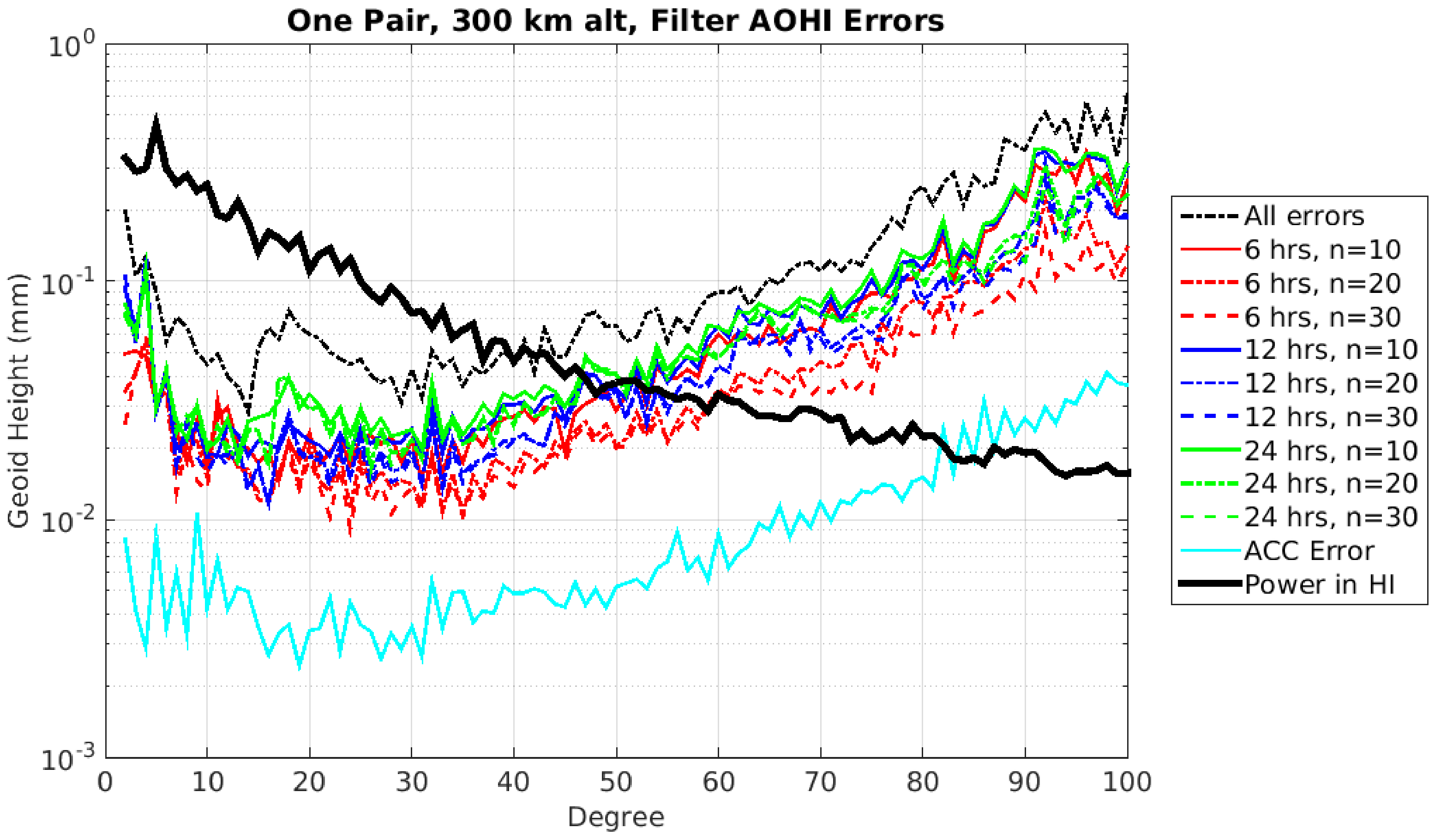
Architecture: One Pair
Altitude: 300 km
Aliasing: OT + AOHI



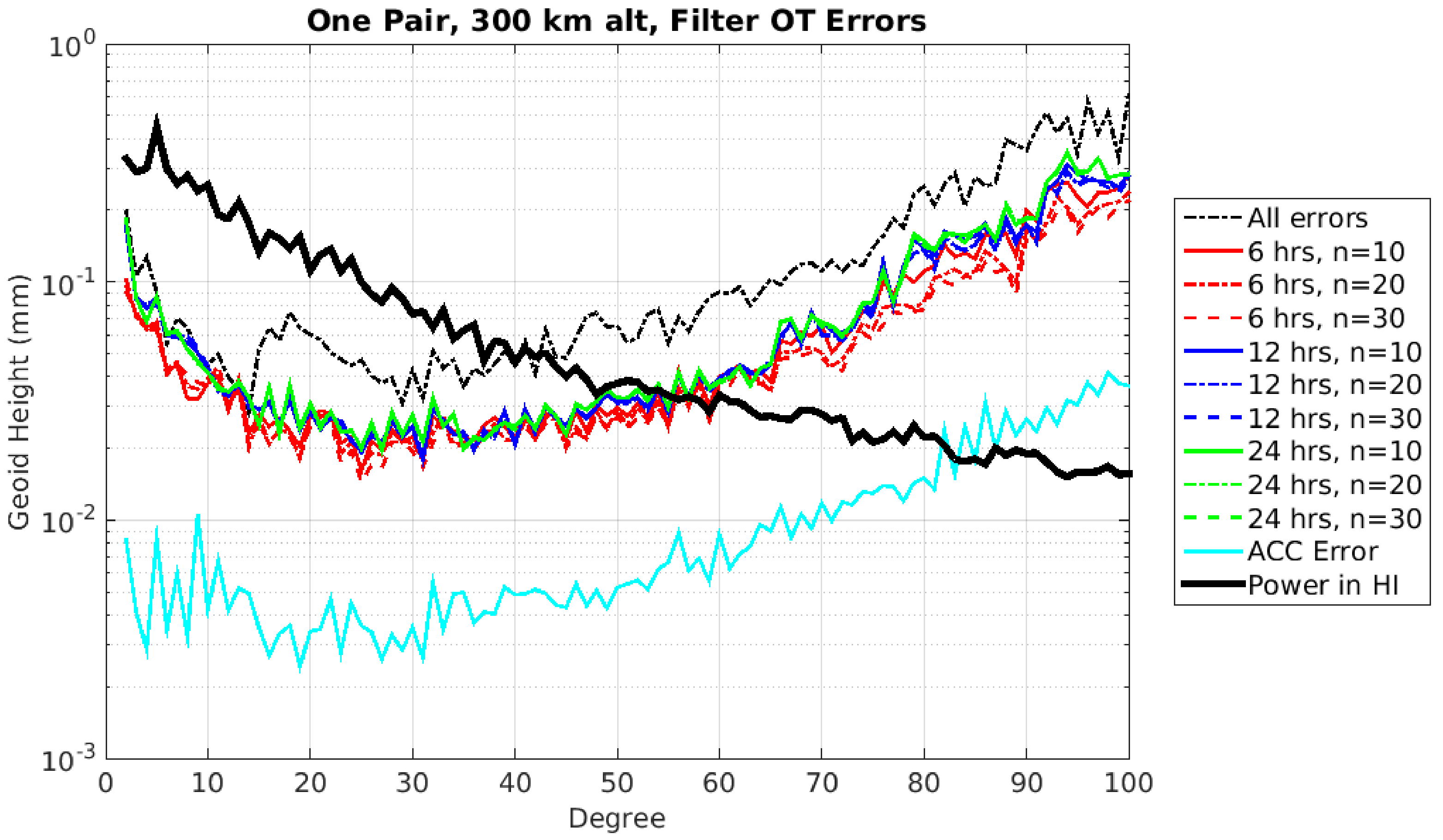
Architecture: One Pair

Altitude: 300 km

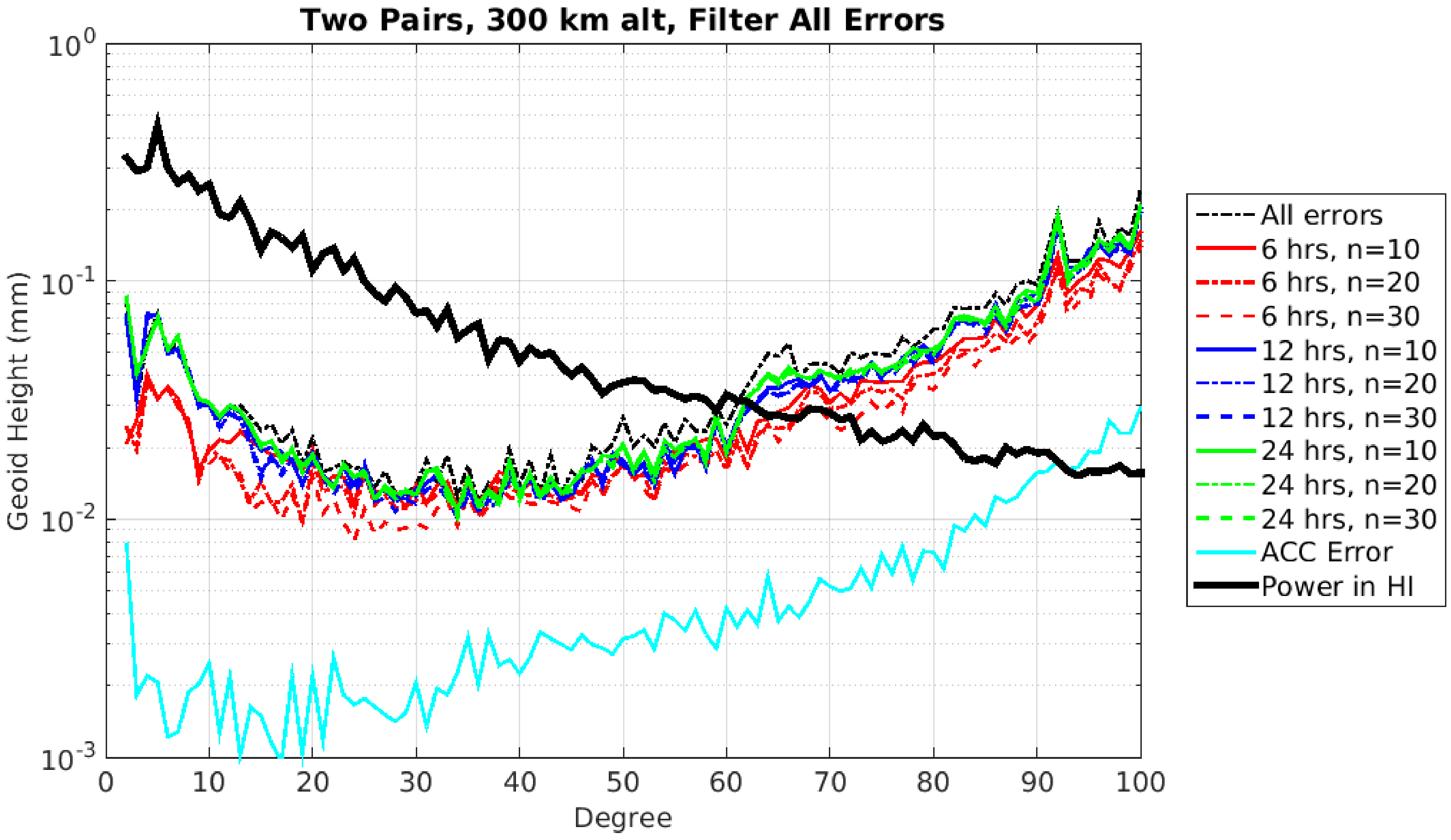
Aliasing: AOHI



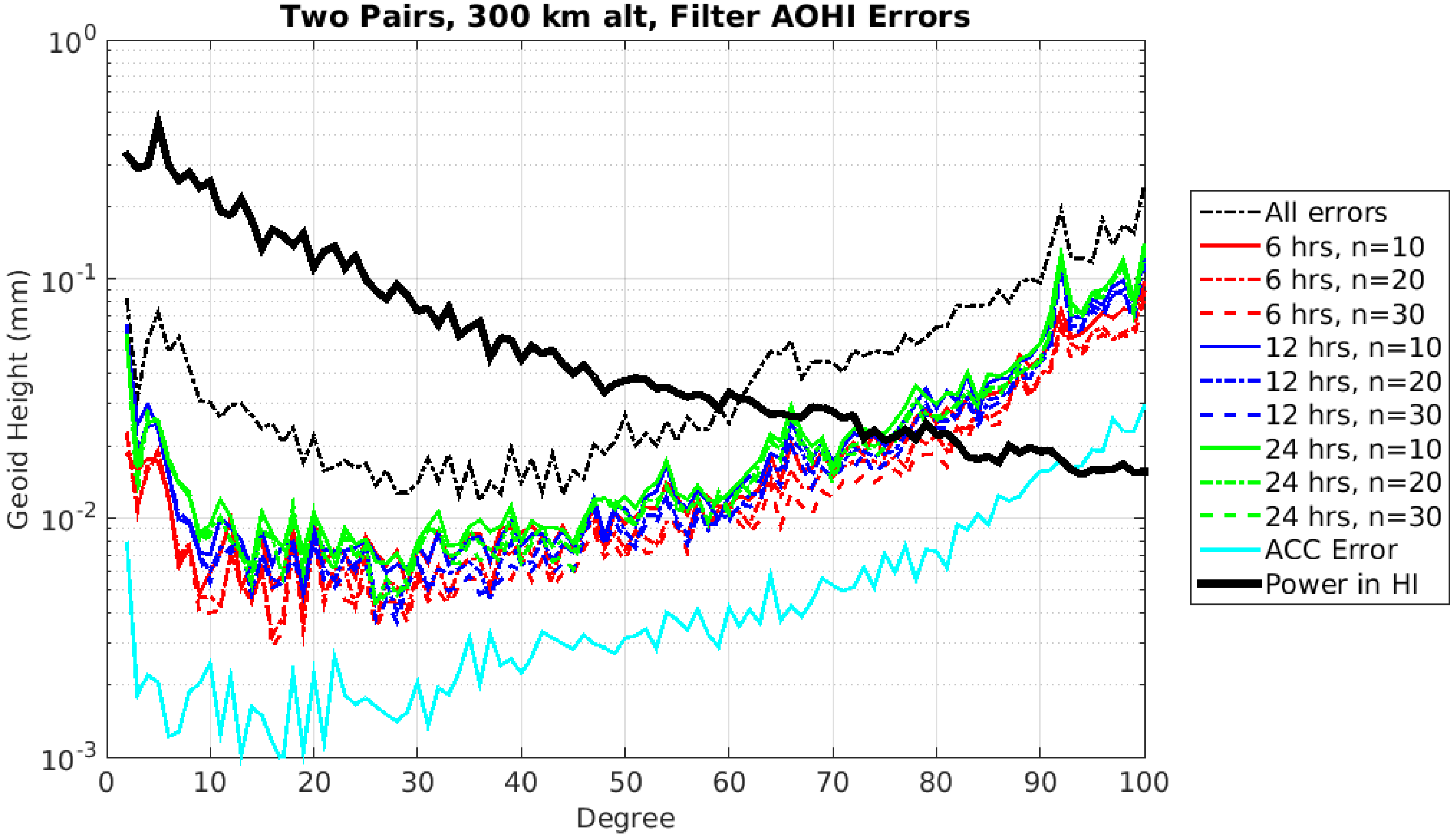
Architecture: One Pair
Altitude: 300 km
Aliasing: OT



Architecture: Two Pairs
Altitude: 300 km
Aliasing: OT + AOHI



Architecture: Two Pairs
Altitude: 300 km
Aliasing: AOHI



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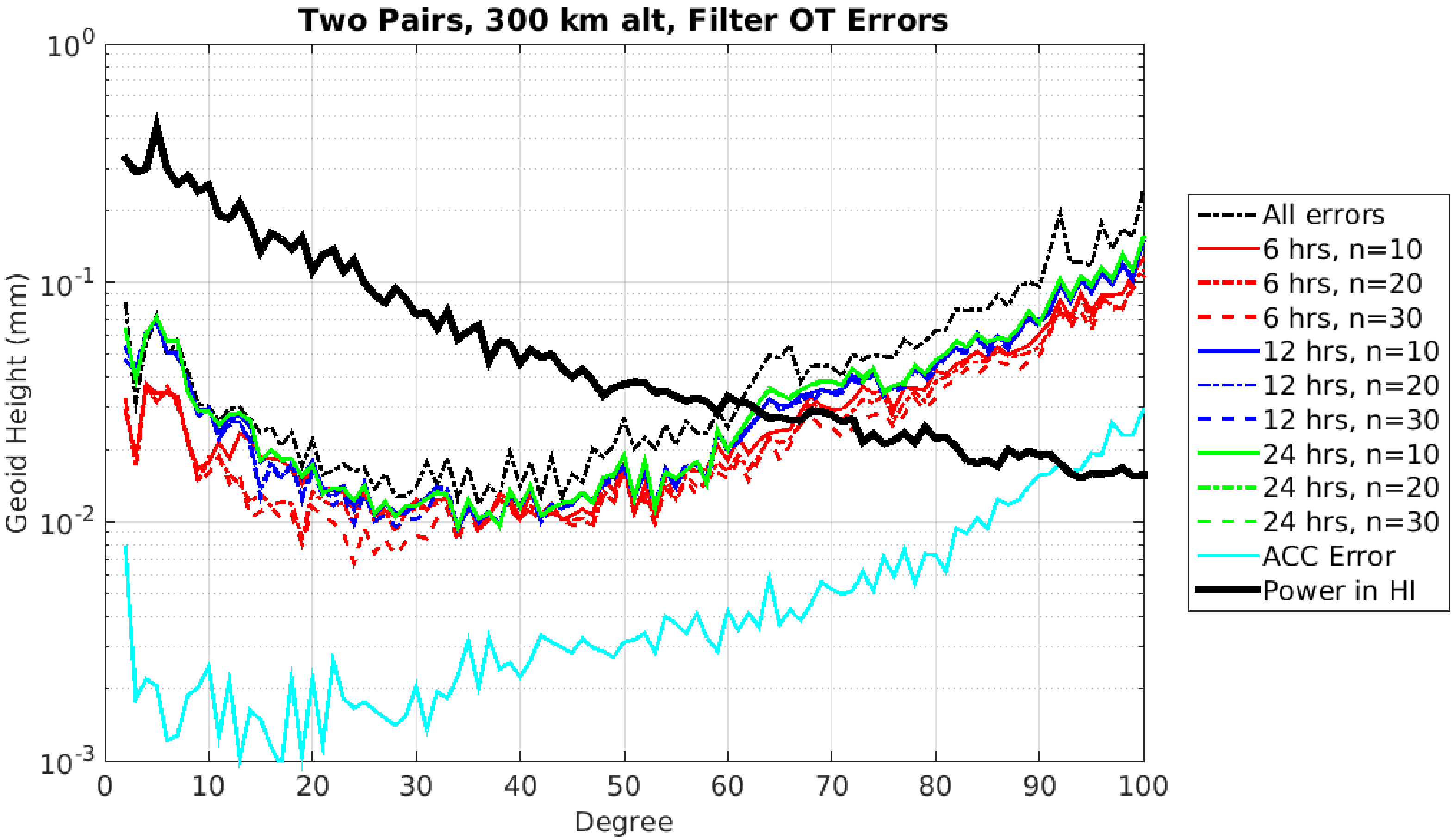
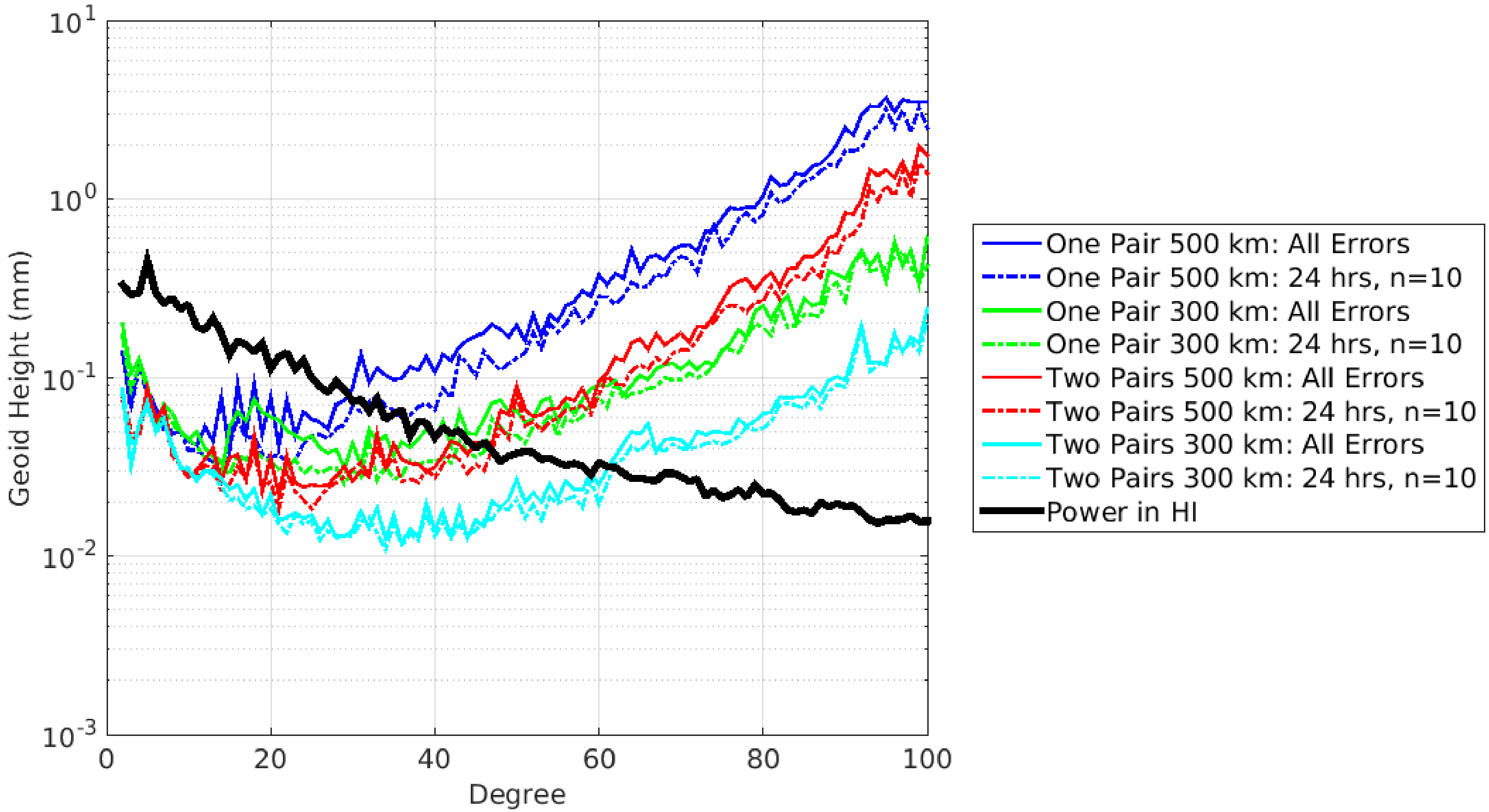
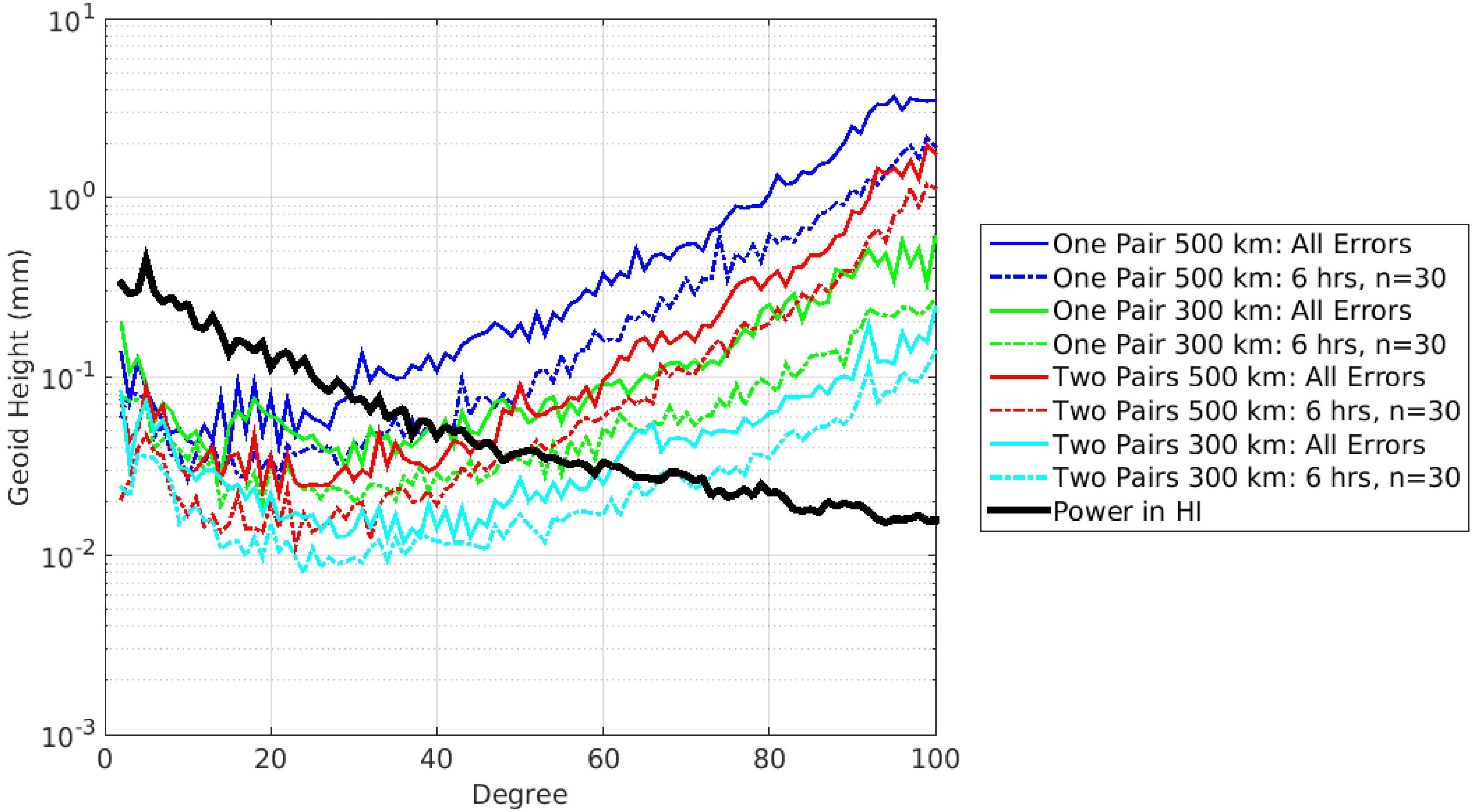
Altitude: 300 km
Aliasing: OT



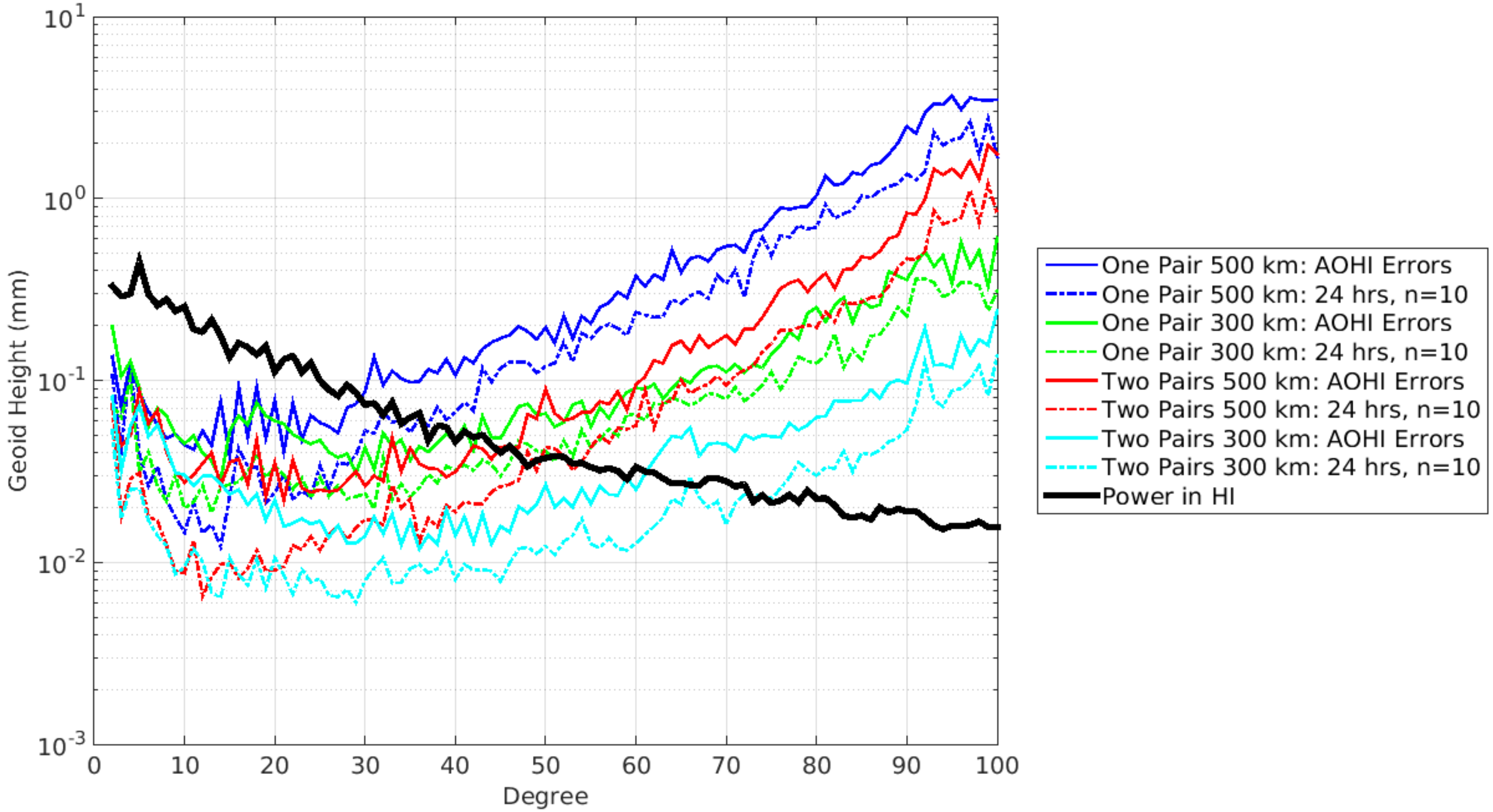
Summary: Daily 10 x 10



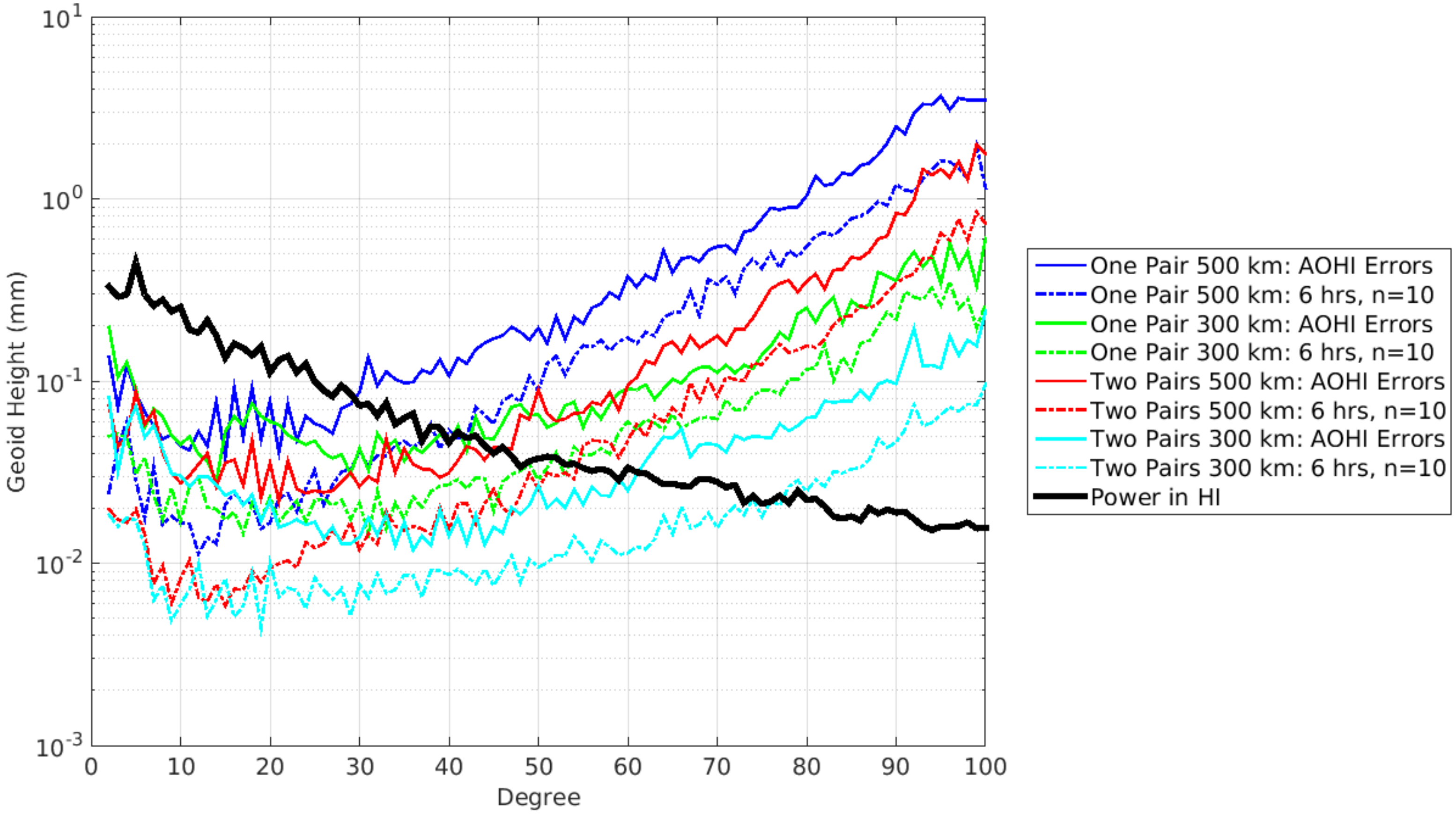
Summary: 6-hourly 30 x 30



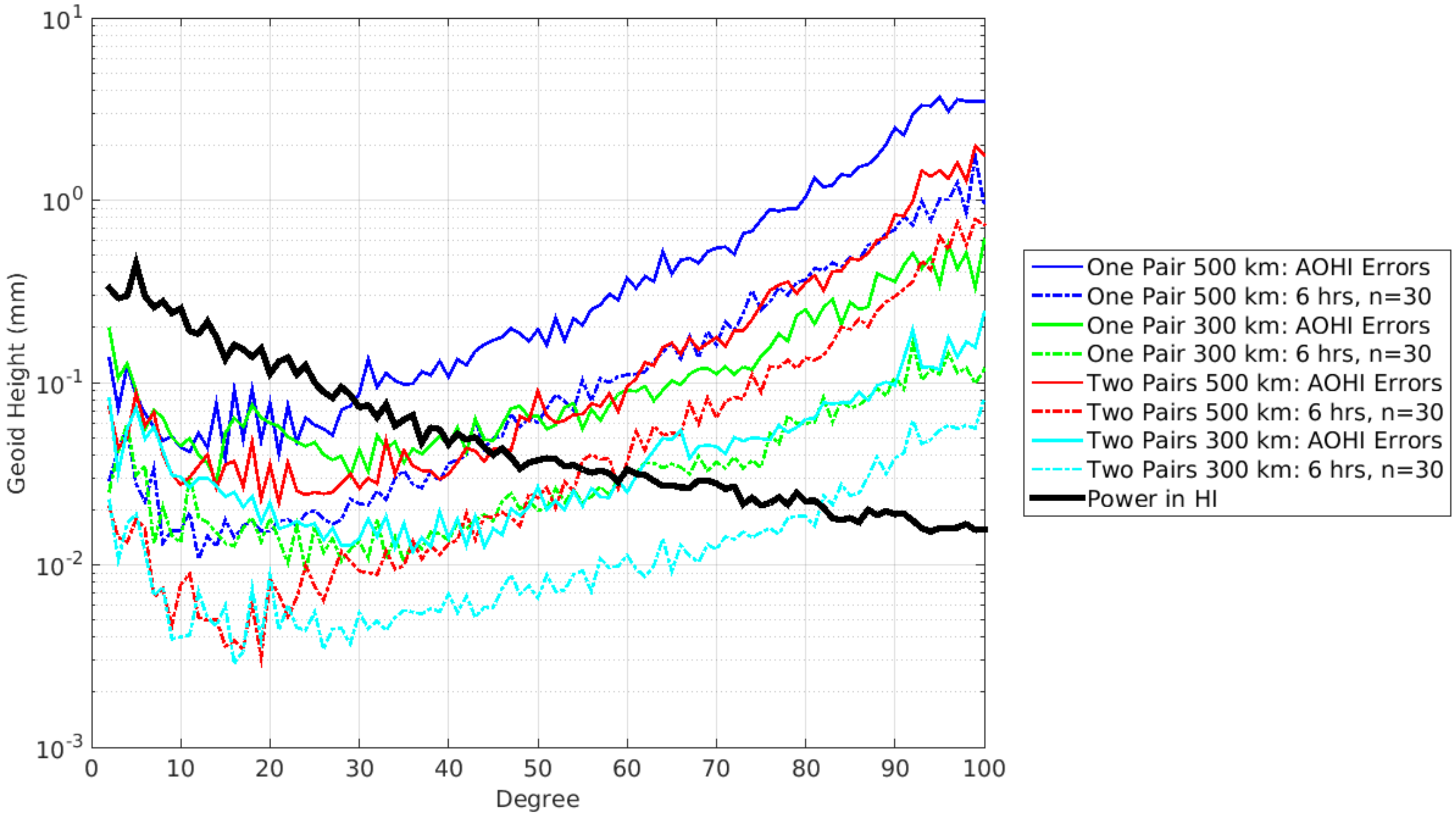
AOHI Errors Only: Daily 10 x 10



AOHI Errors Only: 6-hourly 10 x 10



AOHI Errors Only: 6-hourly 30 x 30



Summarizing Points

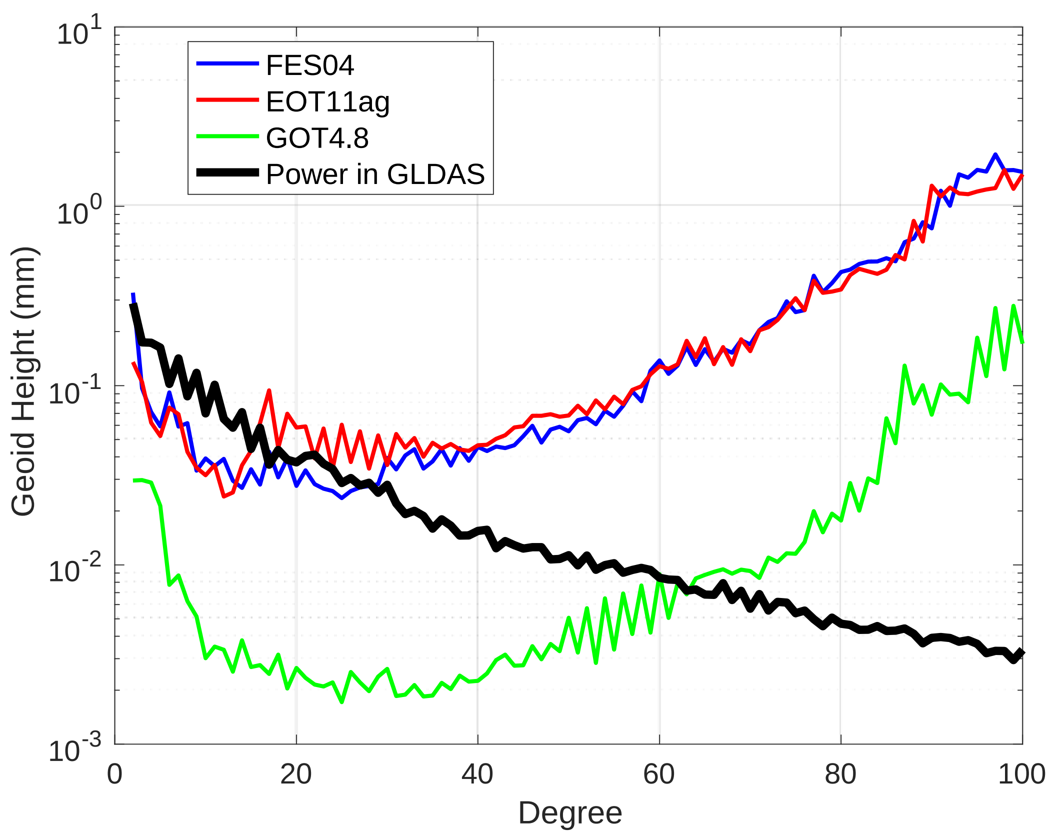
- Temporal aliasing errors at sub-daily time scales and small spatial scales are still dominant errors in the gravity recovery process
  - Large improvements in knowledge of high frequency mass variations at large spatial scales lead to small improvements in our ability to measure monthly mass variations at smaller spatial scales
- Ocean tide errors are less sensitive than AOD errors to spatial/temporal resolution of improvement in knowledge
  - This thought experiment was designed to target AOD aliasing error reduction more than ocean tide aliasing errors
  - Likely need to co-estimate ocean tides concurrently with the gravity field reduce aliasing error
- Two pairs of LL-SST satellites offer better performance than a single pair architecture augmented with an external observing system to capture 6-hourly, n = 30 (~670 km spatial res.) mass variations
  - Reduction of correlated error has a greater impact than reduction of temporal aliasing errors
- Speculative: Current level of performance of the accelerometers appears to be adequate for the foreseeable future, as aliasing errors will likely continue to dominate

Backup

Temporal Aliasing: Ocean Tides

Single Pair
500 km altitude
100 km separation

	Truth Model	Nominal Model
Static Gravity Field	gif48	gif48
Ocean Tides	GOT4.7	EOT11ag
		FES04
		GOT4.8
Atmosphere/Ocean (AOD)	AOD RL05	Dobslaw et al., 2016
		AOD RL04
		ECMWF + ECCO2
Hydrology	GLDAS	--



Takeaways

1) EOT11ag and FES04 provide comparable results. Slightly higher error in using EOT11ag for degrees 15 – 60.

2) Small differences between GOT4.7 and GOT4.8 (S2 constituent only) produce errors that exceed power in hydrology signal beyond degree 60.

Temporal Aliasing: Atmosphere/Ocean (AOD)

Single Pair
500 km altitude
100 km separation

	Truth Model	Nominal Model
Static Gravity Field	gif48	gif48
Ocean Tides	GOT4.7	EOT11ag
		FES04
		GOT4.8
Atmosphere/Ocean (AOD)	AOD RL05	Dobslaw et al., 2016
		AOD RL04
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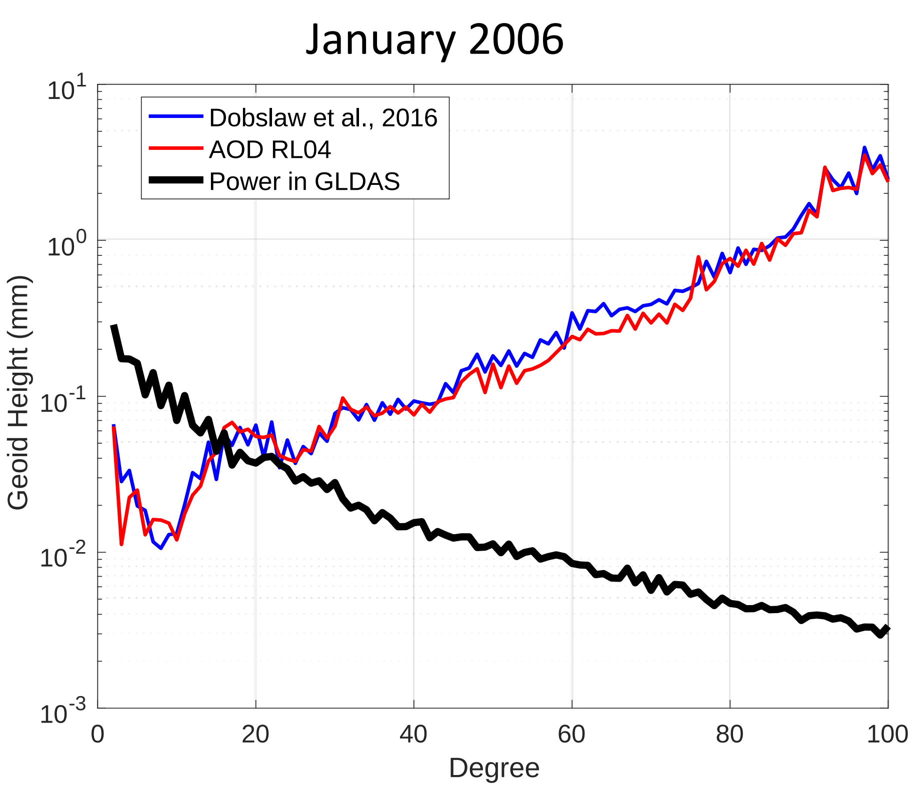

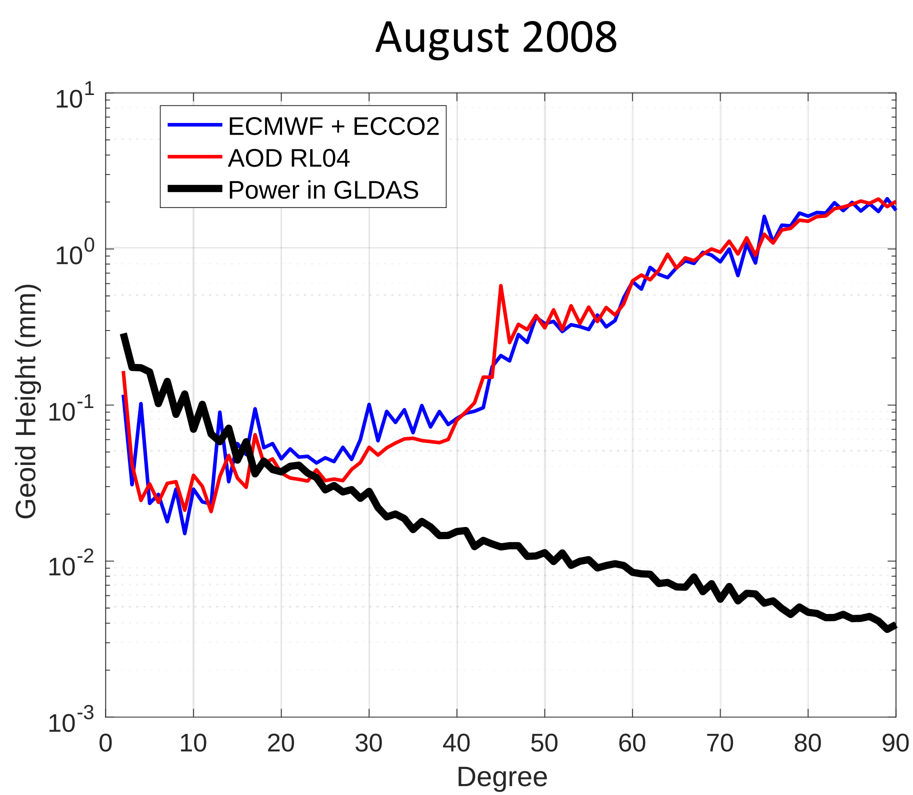

Problem Setup

- **Goal: Design an observing system for which temporal aliasing errors are not the limiting source of error in recovering time variable gravity**
- **Primary Science Question: How do the different spatio-temporal scales of temporal aliasing errors manifest in the gravity recovery process?**
- Rather than running simulations with N pairs of satellites, or N satellites with GPS receivers, we take a different approach
- We modify our definition of temporal aliasing errors, and reduce the error at various spatio-temporal scales to mimic the process of observing them.
- Then we understand how a dedicated single or dual-pair mission architecture could benefit from this added information by running a numerical simulations.