Towards a Next Generation Gravity Field Mission

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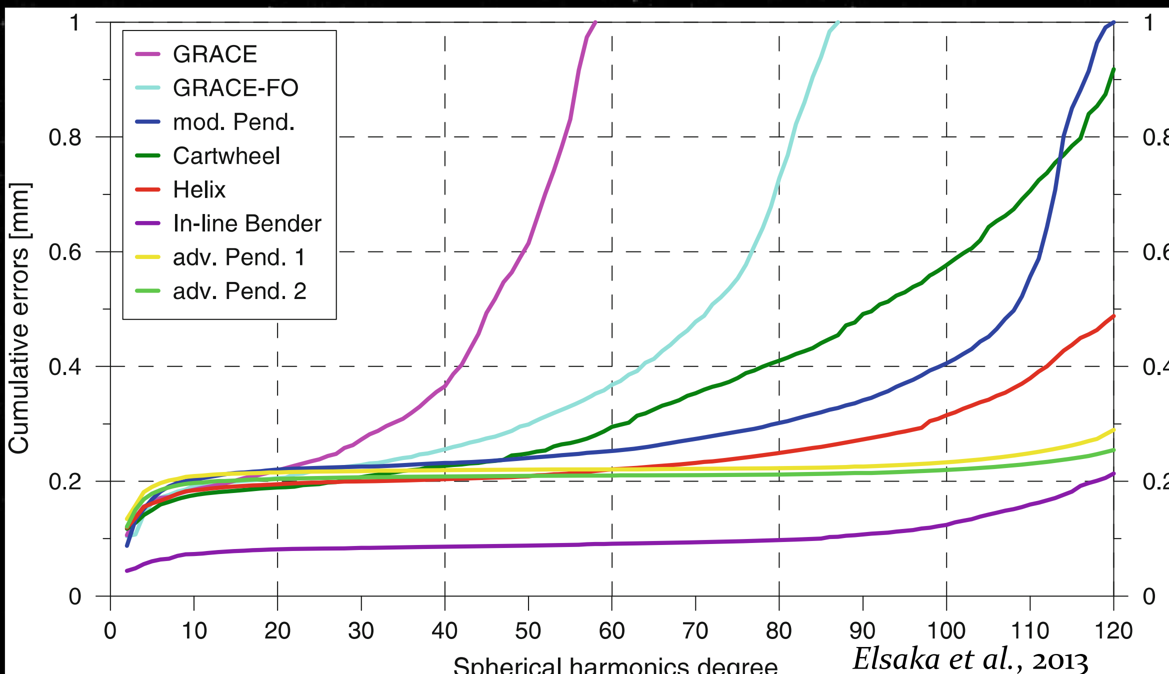
Background

- Community Workshops
  - April 2007: *Workshop on the Future of Satellite Gravimetry,* ESA-ESTEC, Netherlands
  - October 2009: *Towards a Roadmap for Future Satellite Gravity Missions,* TU Graz, Austria

- Main Outcome:
  - Short term: continue time series of gravity measurements (GRACE-FO)
  - Medium term: Next Generation Gravity Mission (NGGM) aka (GRACE 2), including constellations of low-low SST, laser interferometer, drag-free
  - Long term: alternative technologies (cold-atom gradiometry)

Primary Goal: Sustained, operational science monitoring of mass transport in the Earth system

What do we know?



Elsaka et al., 2013

Two satellite pairs has better performance than one-pair alternate formations (pendulum)

Pendulum formation is technologically more challenging

Motivating Questions:

1) What orbits optimize the return on science?
2) What measurement system is required to take advantage of a two-pair architecture?
3) What is the science benefit of two pairs relative to one pair?

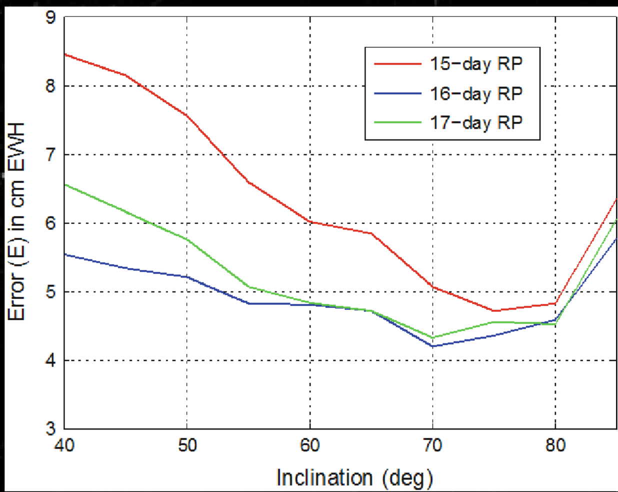
Dedicated studies on two-pair architectures

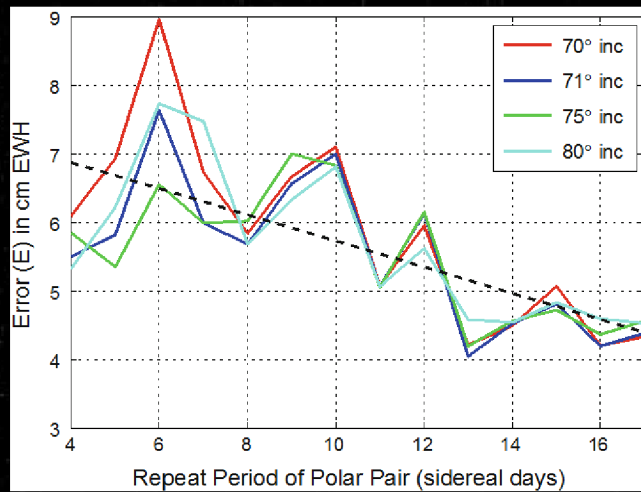
- Past Studies
    - Univ. of Colorado at Boulder, led by David Wiese, JPL
- Current Studies
    - NGGM-D, funded by DLR, led by Thomas Gruber, TUM
    - SC4MGV, funded by ESA, led by Nico Sneeuw, University of Stuttgart

Past Studies: Orbit design and data processing

J = AVG[Err(Ice) + Err(Hydro) + Err(Ocean)]

Orbit optimization performed using Monte-Carlo methods and high fidelity numerical simulations (*Wiese et al.*, 2012)





"Optimal" Architecture

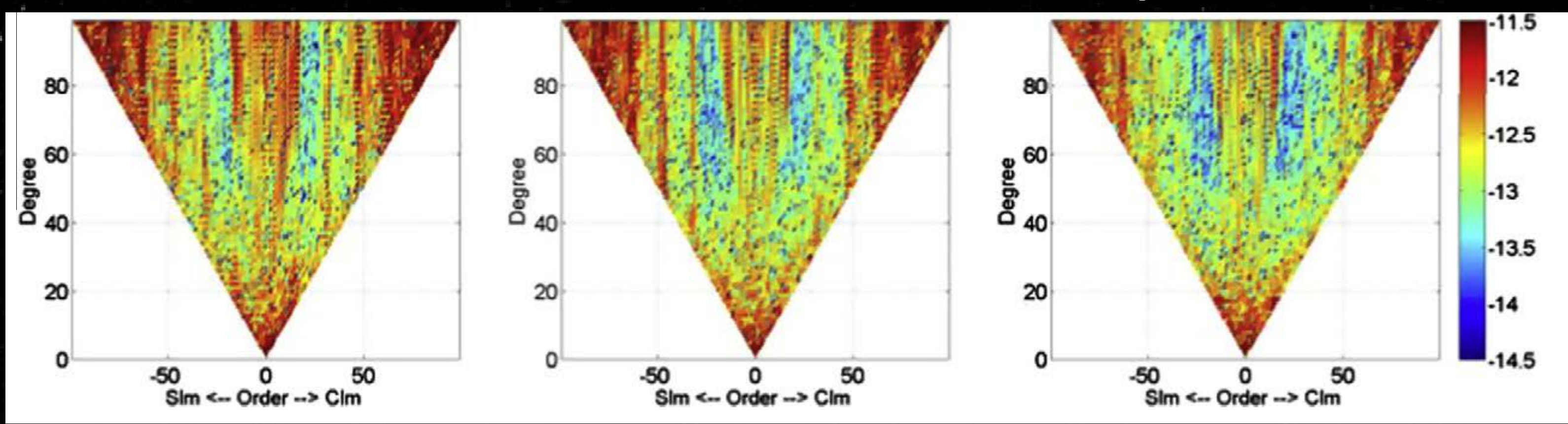
	RP	Inc	Alt
Pair 1	13 days	90°	320 km
Pair 2	13 days	72°	290 km

Error is minimized for:

1) Second pair inclination between 70°-75°
2) Repeat period of polar pair roughly equivalent to that of inclined pair

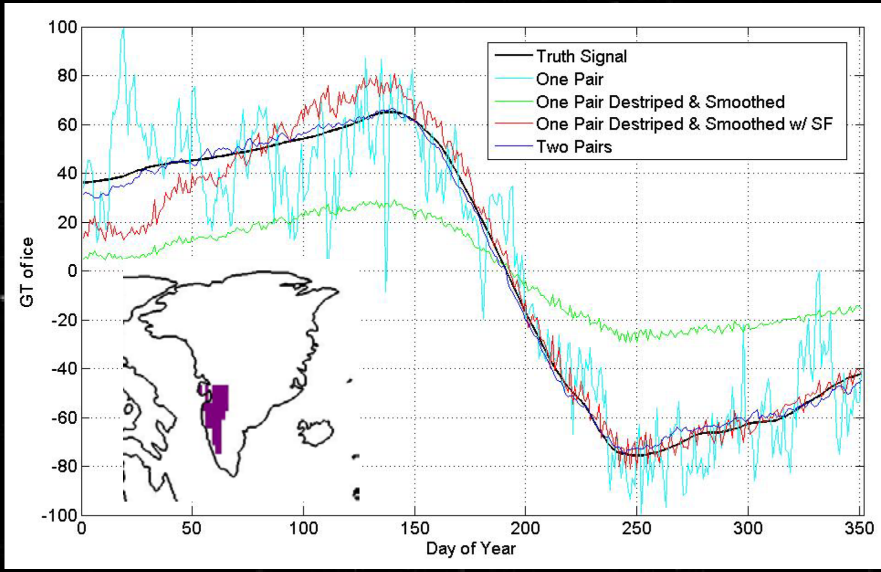
Two pair architecture allows for innovative data processing schemes to further reduce temporal aliasing errors (*Wiese et al.*, 2011a)

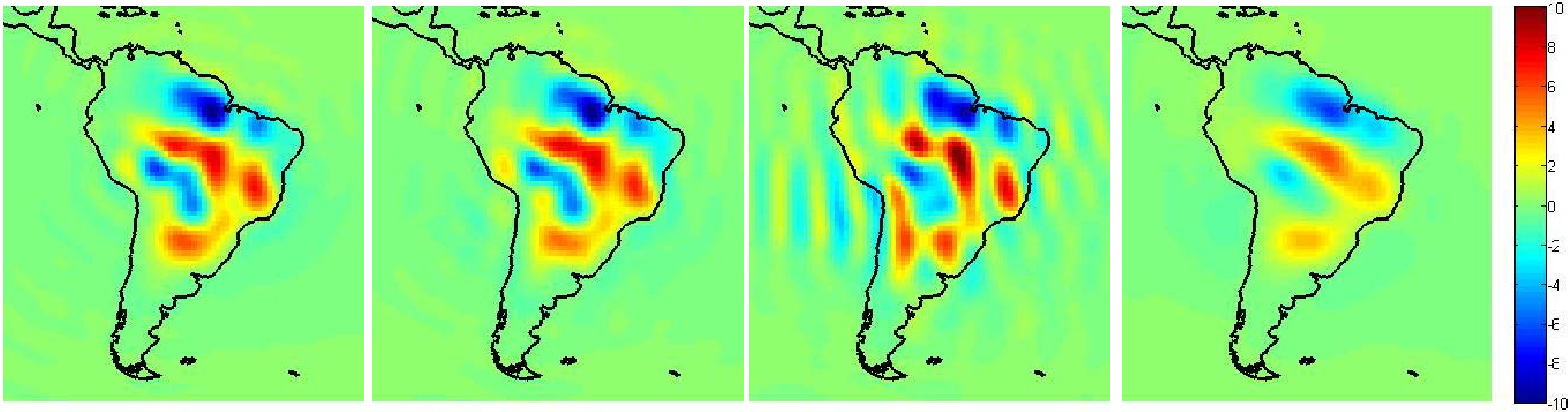
Regular processing | Daily 14 x 14 estimated | Daily 18 x 18 estimated



Past Studies: Expected Science Improvements (*Wiese et al.*, 2011b)

- Global Errors reduce by > 80%
- Error reduction for:
  - Hydrology Basins: 25%-40%
  - Greenland Basins: 55%-75%
  - Ocean Basins: 70%
  - Earthquakes: Greater SNR
- Improved temporal resolution
- Improved spatial resolution

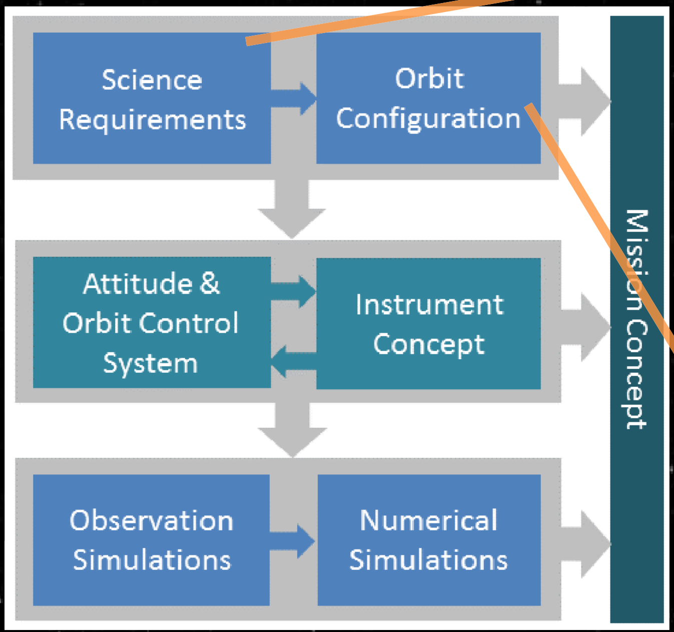


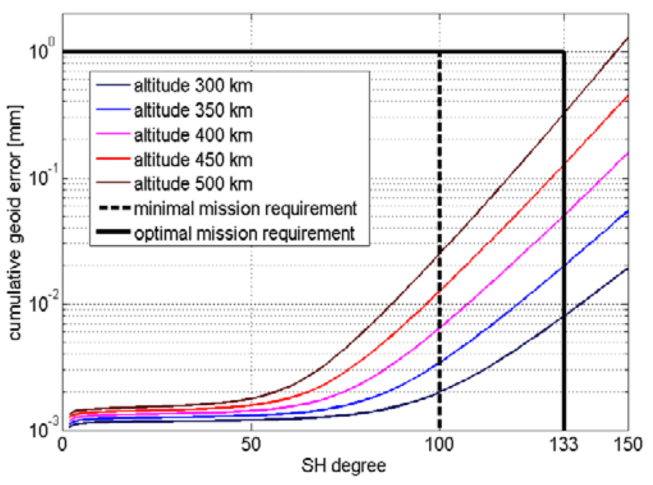


Truth | Two Pairs | One Pair | One Pair, Destriped & Smoothed (300 km)

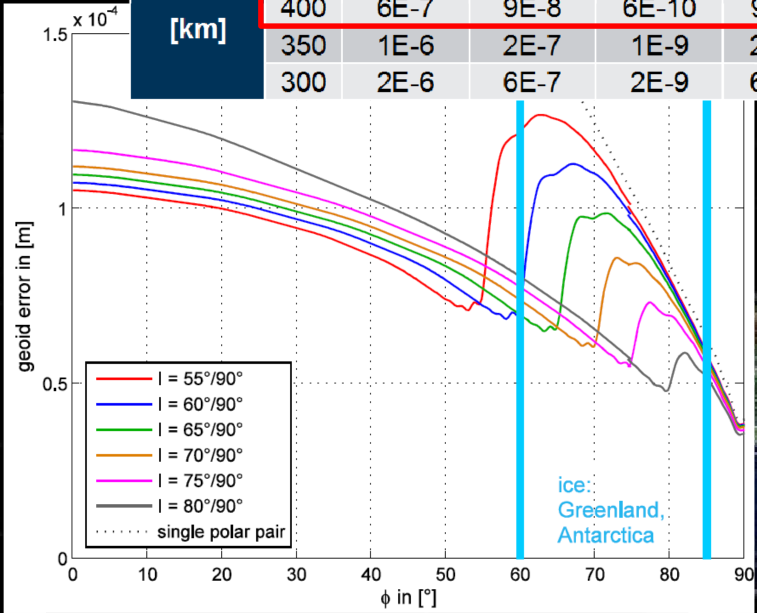
Current Studies: NGGM-D

- Minimum: 1 mm geoid error @ 200 km
- Optimum: 1 mm geoid error @ 150 km
- Weekly or shorter temporal resolution
- Mission duration of one decade





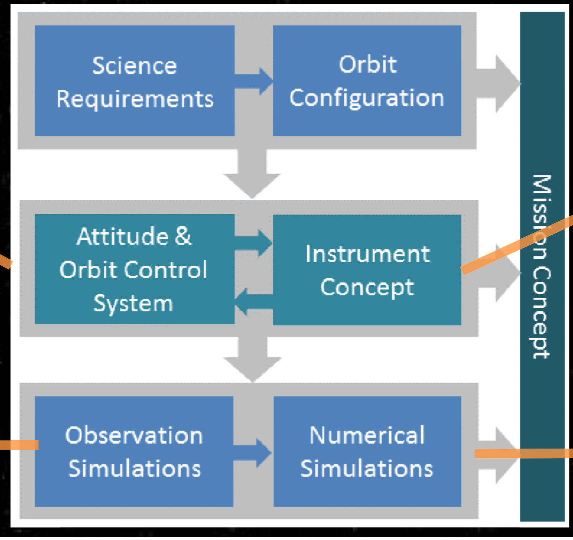
		SST [m]		ACC [m/s²]	
		Minimal	Optimal	Minimal	Optimal
Altitude [km]	500	1E-7	1E-8	1E-10	1E-11
	450	3E-7	4E-8	3E-10	4E-11
	400	6E-7	9E-8	6E-10	9E-11
	350	1E-6	2E-7	1E-9	2E-10
	300	2E-6	6E-7	2E-9	6E-10



- Double low-low SST pair
- Near polar (89.5 deg.) and inclined (70 deg.)
- 420 km altitude
- 100 km inter-satellite distance
- 31 day repeat cycle with 478 revolutions for the polar and 474 rev. for the inclined pair

Current Studies: NGGM-D

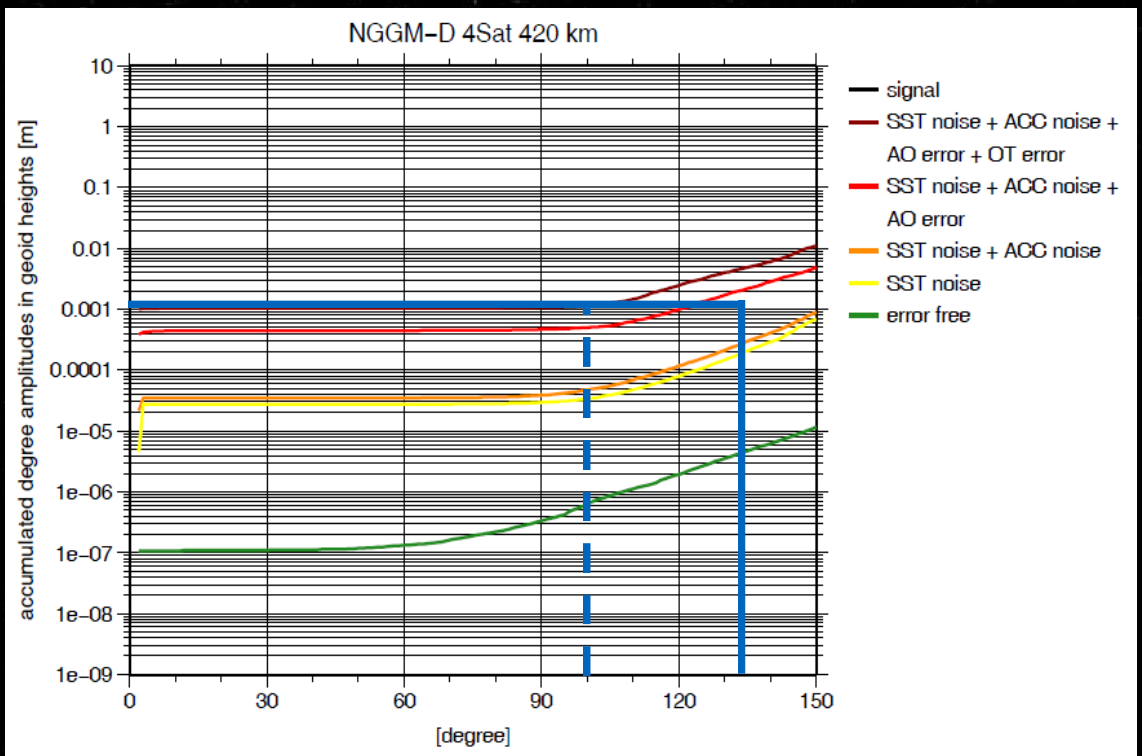
PMW cold gas thrusters
Magnetic torquers
Residual drag < 1E-8 m/s^2



ACC noise < 4E-11 m/s^2
Laser noise < 25 nm
Tone error requirements

Realistic orbits and observations
Realistic noise time series
Background model errors

Consistent independent solutions
Main error contribution: ocean tide model errors
1 mm cumulative geoid error @ 190 km
<u>Double pair better than single pair by a factor of 10</u>

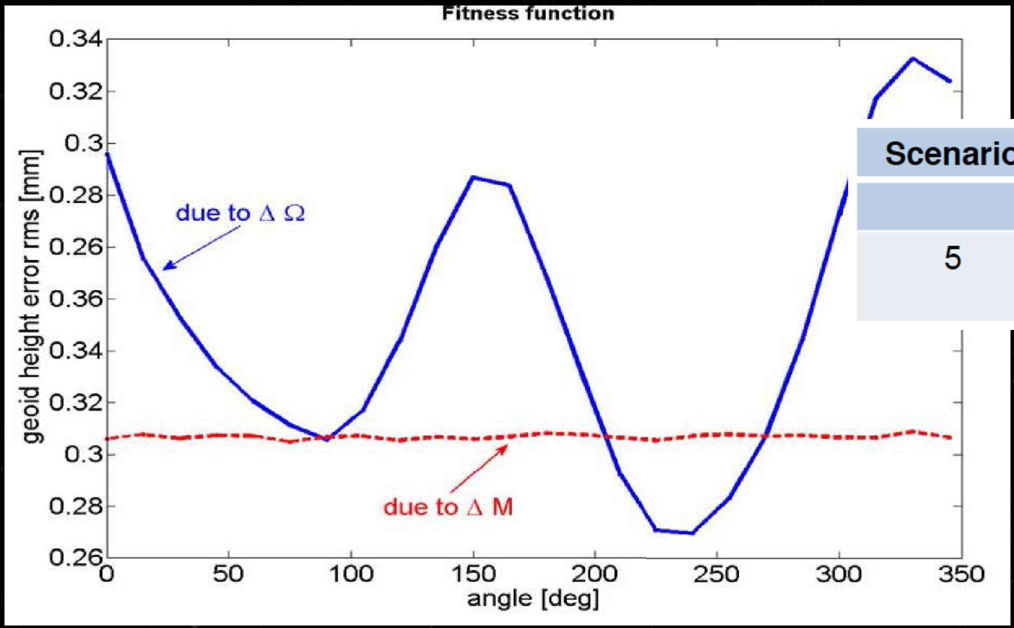


Current Studies: SC4MGV

Primary focus on two-pair constellation design and data processing schemes

- Use Genetic Algorithm (GA) to optimize the choice of orbits using Quick-look tool (no orbit integration), based on testing single (first) 10-day solution
- Massive numerical effort (3000 candidates)
- Free parameters include:
  - Repeat period of each satellite pair
  - Inclination of second pair between 65º-75º, 105º-115º
  - Right ascension and mean anomaly free to vary
  - Inter-satellite distance between 75 km - 100 km

In Progress!

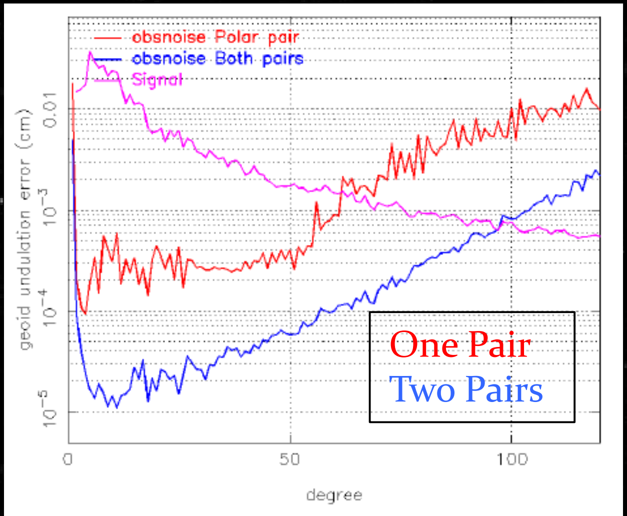


Current baseline scenario

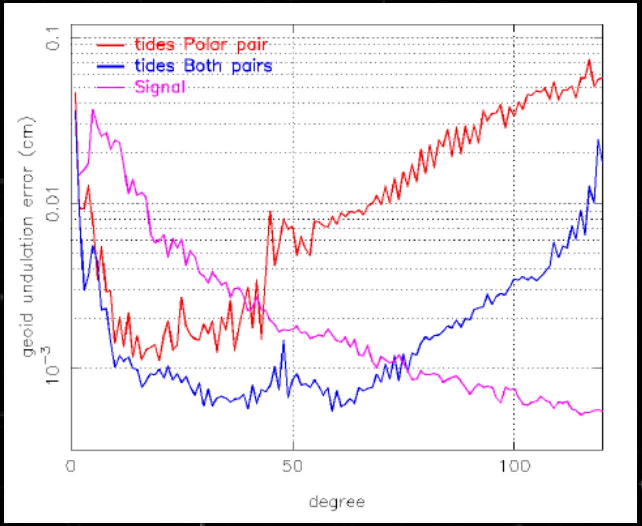
Scenario	β/α	inclination	altitude	Sub-cycle
	[rev./day]	[deg.]	[km]	[days]
5	172/11 460/29	92 115	361.9 342.5	3 7

Current Studies: SC4MGV

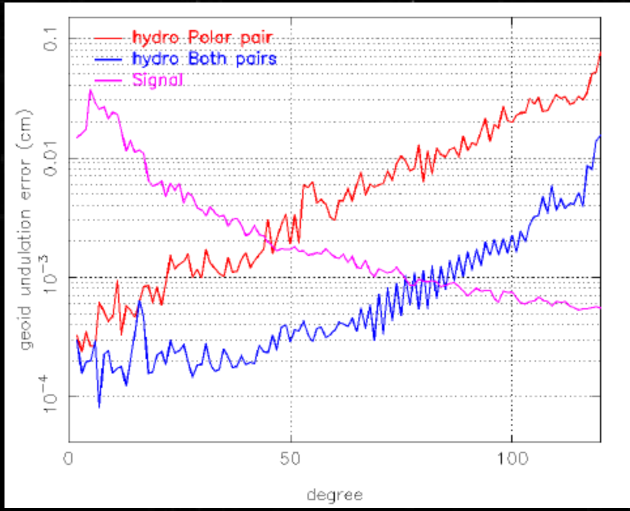
Observation Noise



Ocean Tide Aliasing



Hydrology Aliasing



Atmosphere/Ocean Aliasing

Conclusions (thus far):

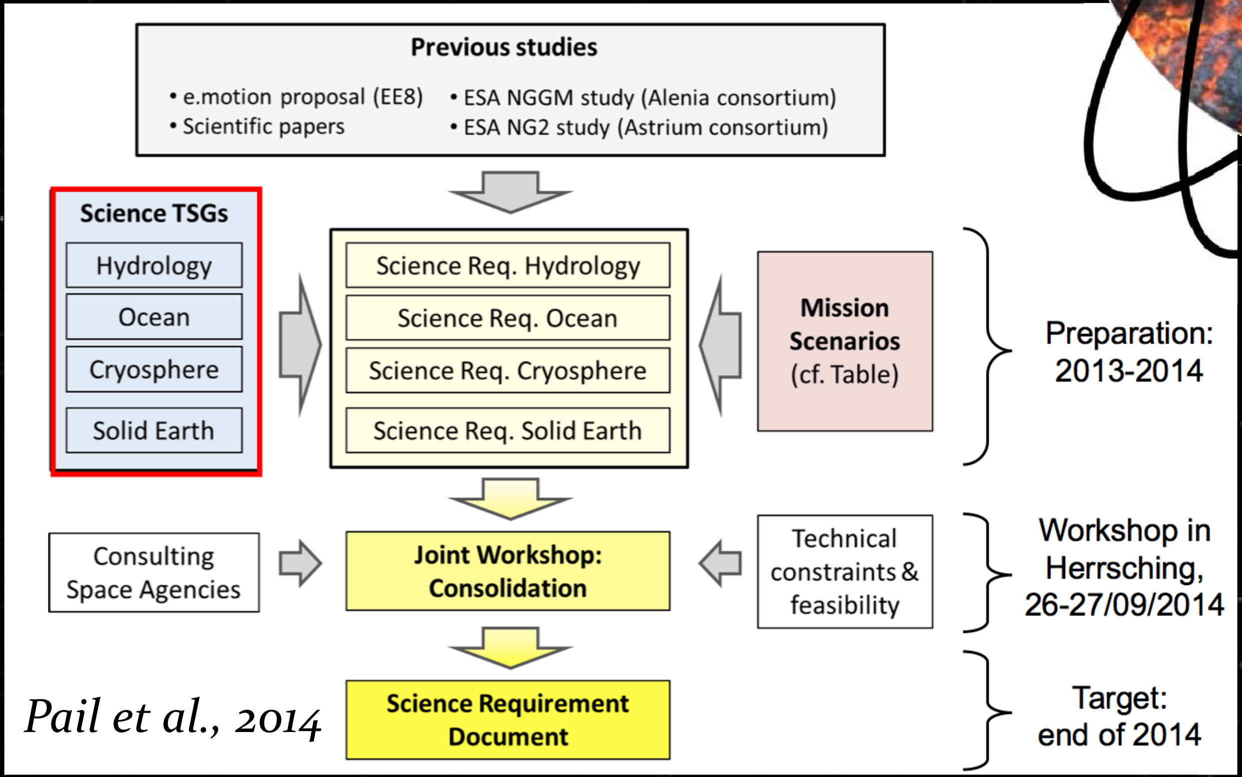
1) ACC noise is on par with temporal aliasing
2) Two pairs performs significantly better than one pair: error reduction of 70%

In Progress!

Where do we go from here?

Ongoing Activities

- "Consolidation of Science and User Requirements"
  - Initiated by GGOS, IAG, under the umbrella of IUGG
  - International participation led by Roland Pail (TU Munich)
- Expected Output
  - Consolidated Science and User Requirement Document
  - IUGG resolution to express need by user community



Pail et al., 2014

Ongoing Activities

- Interagency Gravity Satellite Working Group (IGSWG)
  - Joint collaboration between NASA/ESA formed in 2013
  - Many thanks to Roger Haagmans and John Labrecque for initiating

Name	Affiliation	Expertise Domain	
Srinivas Bettadpur	University of Texas, US	Gravity missions	NASA
Don Chambers	Univ. of South Florida, US	Oceanography	NASA
Michel Diament	INCU-CNRS, France	Geophysics	ESA
Thomas Gruber	TU Munich, DE	Gravity missions	ESA
Edward Hanna	Univ. of Sheffield, UK	Climate, Ice	ESA
Matt Rodell	GSFC, US	Hydrology	NASA
Pieter Visser	TU Delft, NL	Gravity missions	ESA
David Wiese	JPL, US	Gravity Missions	NASA

  - Goal: To provide findings to NASA and ESA on:
    - Science user requirements for a NGGM (input from IUGG study)
    - Compatibility of user requirements and expected mission performance (input from NGGM-D, SC4MGV, Univ. of Col., general literature)
    - Roadmap, including needed short-term studies
  - Document will be complete by next year

Outstanding Questions

- Orbit design
  - Synergies between orbit design with sub-cycles and data processing strategies to estimate gravity fields more frequently to reduce temporal aliasing errors
  - Overarching goal of *observing*, rather than *modeling* high frequency mass variations
- Removal of non-conservative forces
  - Inherent coupling between level of ACC error/drag-free system error with satellite altitude, mission lifetime, mission cost, and science outcomes which has not explicitly been characterized
- Definition of temporal aliasing errors
  - Does the choice of orbit/architecture ultimately depend on how we define temporal aliasing errors?
  - Is there a better definition for temporal aliasing errors?
  - What is the sensitivity of our analysis to the definition of temporal aliasing errors?

Thank You!

Questions?