Possible mission architectures for a GRACE follow-on mission including a study on upgraded instrumentation suites, and multiple satellite pairs in moderately-inclined orbits

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Presentation outline

- Limitations of GRACE
- Simulation procedure
- GRACE Follow-On with upgraded technologies
- GRACE Follow-On with multiple satellite pairs
- Future work

Limitations of GRACE

- Instrument errors
  - Satellite-to-satellite ranging
  - Accelerometers
- Orbital altitude

GFO with upgraded technologies

- Temporal aliasing
  - Caused by under-sampling of the high-frequency changes in the gravity field

GFO with multiple satellite pairs

- Force model errors
  - Ocean and solid Earth tides
  - Atmospheric and non-tidal mass variations

Simulation procedure

- Goal: recover time-variable hydrological and ice mass variations in the presence of instrument and temporal aliasing errors
- Simulated error sources
  - Satellite-to-satellite range-rate errors
  - Removal of non-conservative forces
  - Satellite positioning errors
  - Imperfections in geophysical models (AOD & tides)

GFO with upgraded technologies

- Interferometric laser ranging system
  - Replaces the K-band microwave ranging system
  - Reduces error RMS from ~0.2 μ/s to ~0.6 nm/s
- Gravitational reference sensor (GRS)
  - Proof mass isolated within the body of the spacecraft
  - Micro-thrusting is used to maintain the position of satellite with respect to the proof mass resulting in a drag-free system
  - Reduces errors associated with on-board accelerometers
- Reduction in orbital altitude
  - Lower altitude satellites are more sensitive to higher spatial resolution features of gravity field
  - Would need to be accompanied by GRS to maintain orbital altitude

GFO with upgraded technologies

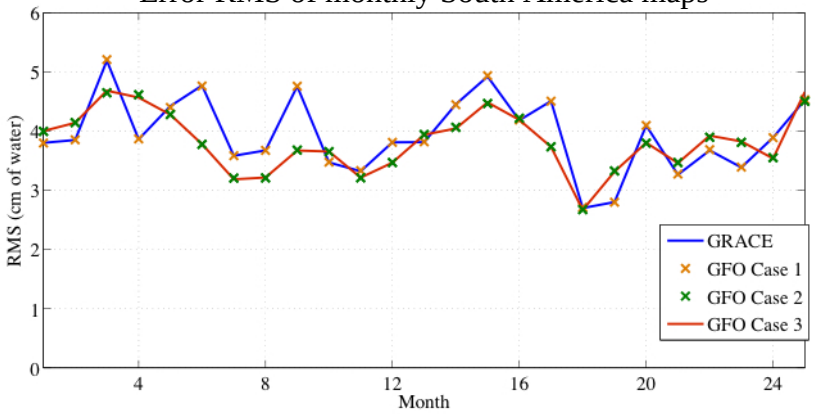
- Four different missions are simulated:
  GRACE and three possible GFO configurations

Mission	Altitude / satellite separation	Range-rate noise	Removal of non-conservative forces
GRACE	480 km / 220 km	K-band	Accelerometer
GFO Case 1	480 km / 220 km	Laser	Accelerometer
GFO Case 2	250 km / 50 km	K-band	GRS (drag-free)
GFO Case 3	250 km / 50 km	Laser	GRS (drag-free)

- GFO Case 3 is best-case scenario
- GFO Case 1 and Case 2 are “hybrid” missions
- Simulations estimate monthly regional mascon gravity estimates for South America and Greenland

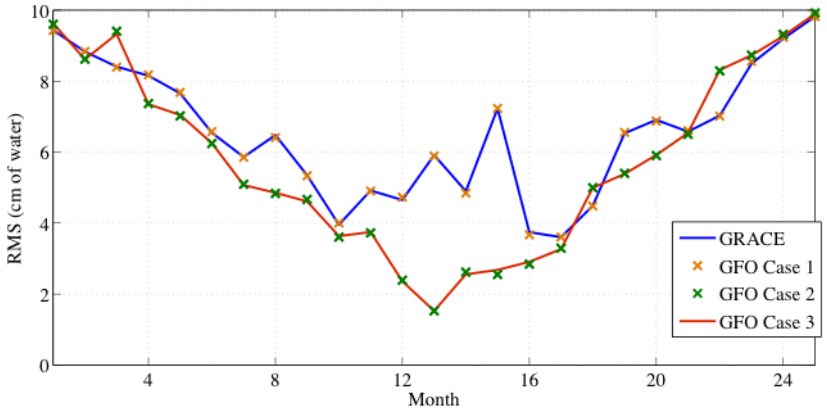
GFO with upgraded technologies

Error RMS of monthly South America maps



Mission Configuration	$\overline{\text{RMS}}$ (cm of water)
GRACE	3.95
GFO Case 1	3.95
GFO Case 2	3.81
GFO Case 3	3.82

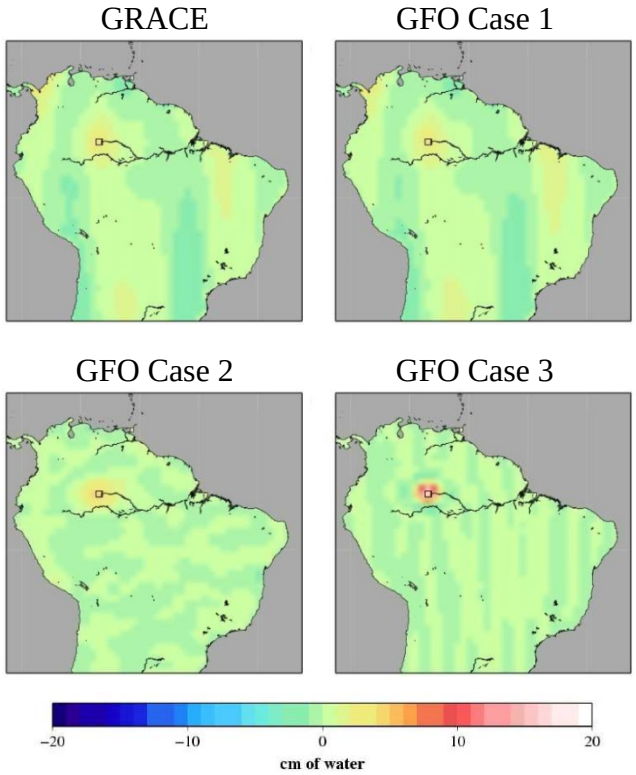
Error RMS of monthly Greenland maps

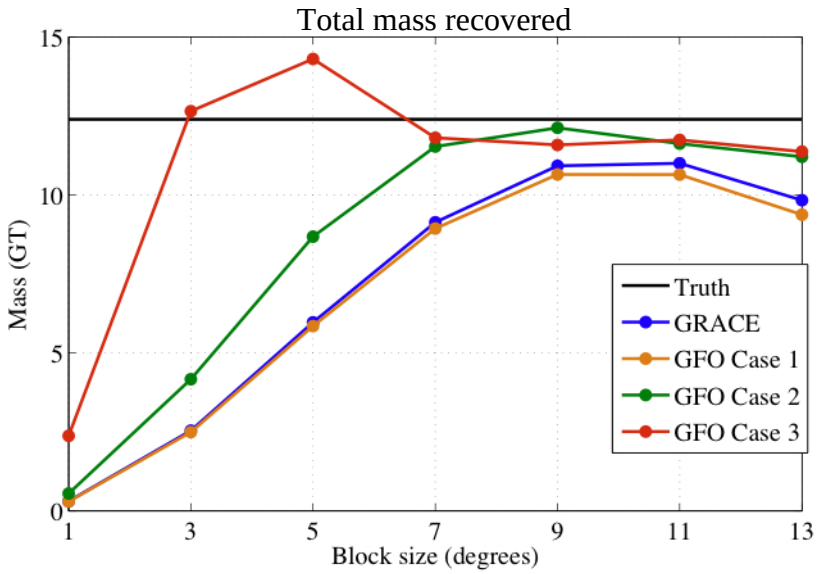


Mission Configuration	$\overline{\text{RMS}}$ (cm of water)
GRACE	6.59
GFO Case 1	6.59
GFO Case 2	5.78
GFO Case 3	5.78

GFO with upgraded technologies

- Spatial resolution study





GFO with multiple satellite pairs

- Reducing temporal aliasing errors
  - Improving atmosphere, ocean, and tide models
  - Co-estimating parameters (i.e. tidal coefficients)
  - Multiple satellite pairs

GFO with multiple satellite pairs

- Multiple satellite pair configurations

Lower inclined satellite pair + Polar satellite pair

Repeat Period (revs/ sidereal days)	Altitude (km)	Inclination (deg)
360/ 23	312	63
236/ 15	291	65
157/ 10	301	65

Repeat Period (revs/ sidereal days)	Altitude (km)	Inclination (deg)
79/ 5	312	90

Compare these to a single pair of polar satellites

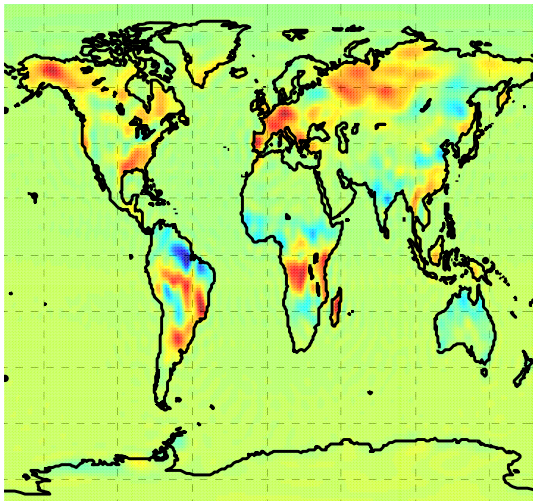
Repeat Period (revs/ sidereal days)	Altitude (km)	Inclination (deg)
363/ 23	317	90
238/ 15	293	90
159/ 10	283	90

GFO with multiple satellite pairs

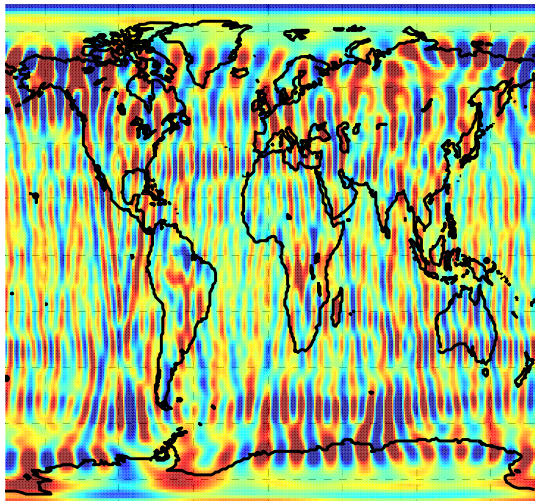
- Simulation setup
  - Satellites have laser interferometer and fly drag-free
  - AOD and tidal errors are included
  - Length of simulations: 10, 15, and 23 days
  - Spherical harmonics solved to degree and order 60
  - Low degree and order gravity fields can be estimated daily to correct the final multi-day solution (reduces the effect of temporal aliasing errors)

Results: plots in cm of water

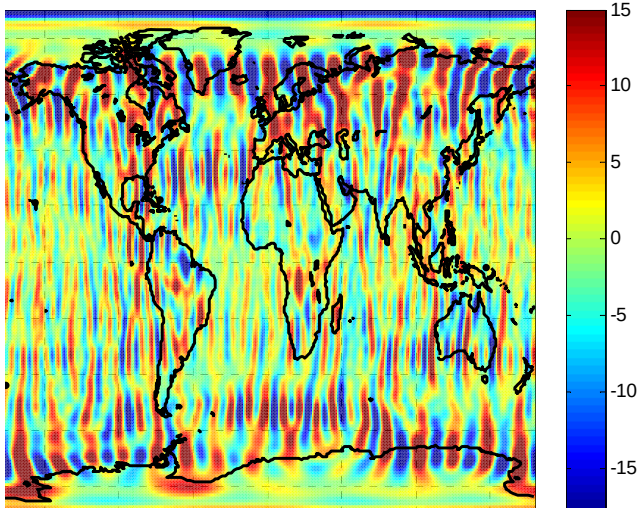
Truth



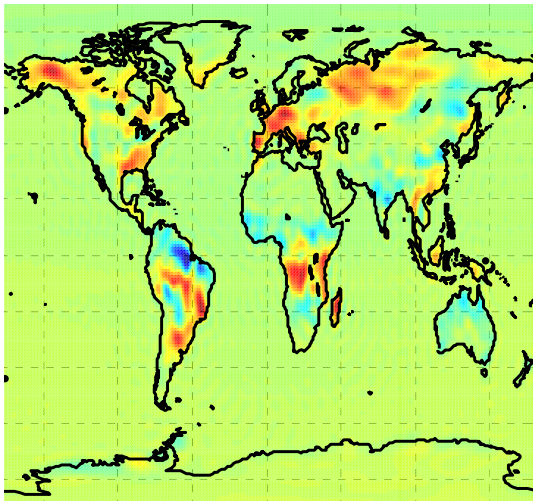
Single polar pair (15 day)



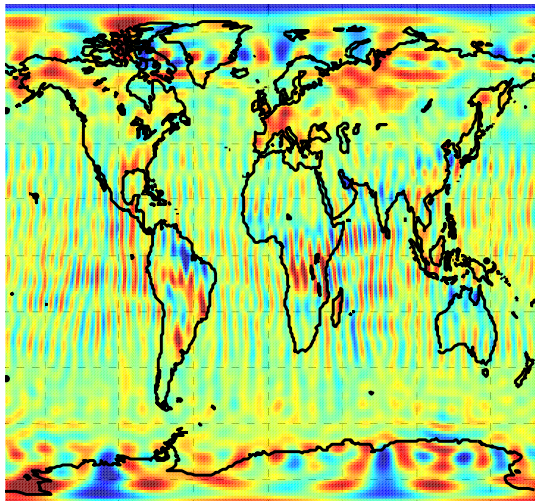
Single polar pair (15 day), estimate daily 10x10 fields



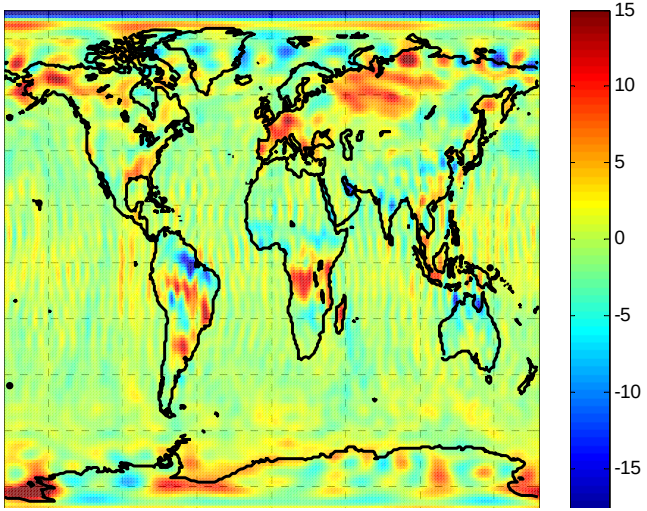
Truth



Multiple pairs (15 + 5 day)



Multiple pairs (15 + 5 day), estimate daily 20x20 field



GFO with multiple satellite pairs

- Comparison of performance for different configurations

Mission configuration		Hydrology error RMS (cm of water)	Ice mass error RMS (cm of water)
Single Polar Pair (estimating daily 10x10 fields)	10 day	11.3	8.3
	15 day	8.2	7.0
	23 day	7.6	6.2
Multiple Pairs (estimating daily 20x20 fields)	10 day + 5 day	2.6	5.2
	15 day + 5 day	1.9	4.9
	23 day + 5 day	2.2	6.3

Future work

- Increase fidelity of simulations to higher degree and order
- Further examine post-processing techniques such as Gaussian smoothing and de-striping
- Design more configurations and perform trade studies (different repeat periods, inclinations, formation types)
- Possible application of a global mascon estimation technique to achieve optimal solution with use of spatial constraints

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