National Aeronautics and Space Administration

New science capability in GRACE-like gravity missions with onboard gradiometers

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Program: FY22 SURP
Strategic Focus Area: Climate Science

Objectives:

- Develop the mathematical modeling framework and the measurement architecture necessary to exploit the extraordinary capability of cold atom technology for spaceborne gravity (and mass change) measurements with unprecedented resolution, accuracy, and flexibility

Background:

- Precision measurements of Earth's gravity field are critical to understanding our planet's mass transport and dynamic processes of the Earth system.
- Identification of new science enabled by the capability provided by the new measurement scheme is critical to further communicate to and advocate in the science community of the instrument concept.

Approaches and Results:

(a) Investigation of math and estimation models.
(b) Development of instrument error models compatible with practical or feasible cold-atom technology targets.
(c) Mapping between science outcomes and gravity measurement requirements.
(d) Development of practical flight mission and sampling scenario.
(e) Combination of outcomes from (a)-(d) into detailed numerical simulations to study the quality of the science benefits.

Year 1: We identified that a hybrid architecture of satellite-satellite tracking (SST) and a cross-track QGG (Fig. 1) would have significant benefit both in instrument implement and in gravity science.
Year 2: We systematically compared the instrument performance of different architectures (Fig. 2), and concluded that LRI and QGG complement each other and result in a much better instrument.
Year 3: We studied the aliasing effect due to fast gravity field variations that manifest themselves as measurement noise, and thus a realistic expectation from a gravity mission. Figure 3 shows noises with and without aliasing. While the instrument performance would be improved by about 10-fold in certain spatial scale, the science outcome would have much broader and significant impact.

Significance/Benefits to JPL and NASA:

- The concept of cold atom sensors for space applications has been acknowledged worldwide since our initial proposal.
- The proposed task will bridge the gap between instrument sensitivity and the science return, with feasible infusion paths to future missions.
- based on the results of the SURP project and the collaboration established, the joint team successfully submitted and won a proposal to the Instrument Incubator Program (IIP) sponsored by NASA Earth Science Technology Office.

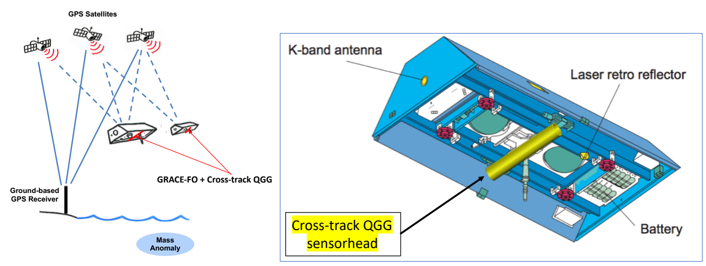
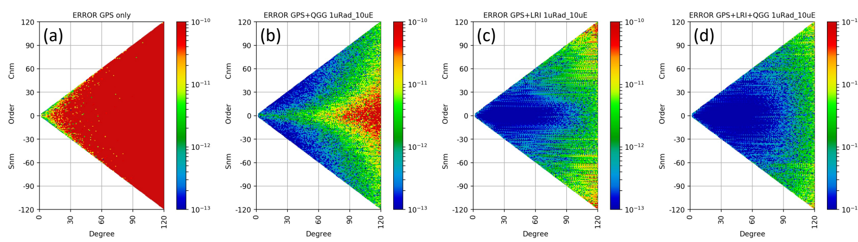


Figure 1. Left: Illustration of the hybrid configuration of GRACE-like satellite-to-satellite tracking configuration and onboard gravity gradiometer. Right: Notional fitting of gravity gradiometer to existing GRACE spacecraft.



With (GPS) **With (QGG+GPS)** **With (LRI+GPS)** **With (LRI+QGG+GPS)**

Figure 2. Instrument noise comparison of architectures. Red indicates higher degree-order noise in gravity field while blue lower noise. (b) represents a standalone QGG instrument. (c) is equivalent to GRACE-FO. (d) shows the proposed hybrid architecture.

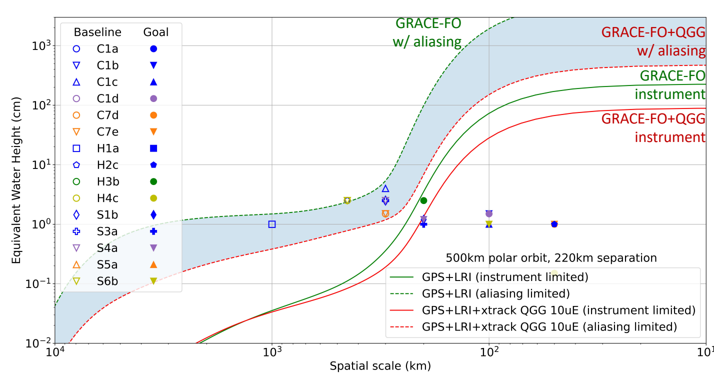


Figure 3. Performance comparison with the presence of aliasing. Symbols represent sensitivities required for the corresponding Mass Change Designated Observables.

Publications:

[1] Bettadpur, S., et al. "Hybrid SST and QGG configuration for Mitigation of Aliasing Error and Gravity Field Improvements A Simulation and Technical Trade Study", AGU Fall meeting, 2021.
[2] Rosen, M., et al. "Hybrid Architectures with Quantum Gravity Gradiometry and Satellite-to-Satellite Tracking for Spaceborne Mass Change Measurements - A Sensitivity and Performance Analysis", EGU, 2021.
[3] Bettadpur, S., et al. "Hybrid architectures with quantum gravity gradiometry and satellite-to-satellite tracking for spaceborne mass change measurements - A sensitivity and performance analysis", AGU Fall meeting, 2020.
[4] Rosen, M. D. (2021). Analysis of hybrid satellite-to-satellite tracking and quantum gravity gradiometry architecture for time-variable gravity sensing missions (MS thesis), permanent URL: https://repositories.lib.utexas.edu/handle/2152/87597.

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