A.28 GRACE-FO SCIENCE TEAM

1. Scope of the Program

The Gravity Recovery and Climate Experiment Follow-On (GRACE-FO) twin satellites launched on a SpaceX Falcon 9 rocket from Vandenberg Air Force Base, sharing their ride into space with five Iridium NEXT communications satellites. The mission is a partnership between NASA and the German Research Centre for Geosciences (GFZ). GRACE-FO is a successor to the original GRACE mission, which operated from 2002 to 2017.

Like its predecessor, the two identical GRACE-FO satellites function as a single instrument. By tracking changes in their separation distance, the satellites are able to map regional gravity changes. A GPS system tracks each spacecraft's position relative to Earth's surface, and onboard accelerometers record forces on the spacecraft other than gravity, such as atmospheric drag and solar radiation. These data are combined to produce global monthly maps of the Earth's gravity and corresponding surface mass variations, which primarily reflect changes in the distribution of water mass in Earth's atmosphere, oceans, land and ice sheets. In addition, the experimental Laser Ranging Interferometer (LRI), designed to improve the precision of measuring the distance between the two spacecraft, is the first demonstration of laser interferometry between satellites. For more information about GRACE-FO, see: https://www.nasa.gov/gracefo and https://gracefo.jpl.nasa.gov/.

The GRACE mission launched March 17, 2002. Since 2010, GRACE operation teams have overcome numerous technical challenges and developed innovative methods to work around the limitations imposed by aging batteries and limited fuel availability for flight control. The mission ended on October 12, 2017, due to a battery cell failure on the GRACE-2 spacecraft, which reduced the satellite system power to an insufficient level and useful dual satellite science data were no longer viable. Over 4,300 peer-reviewed publications based on GRACE data have appeared during the mission's 15-year lifetime.

GRACE-FO will extend the GRACE data record for another five years and expand its legacy of scientific achievements. GRACE chronicled the ongoing loss of mass in the Greenland and Antarctic ice sheets and mountain glaciers. That wealth of data shed light on the key processes, short-term variability and long-term trends that impact sea level rise, improving sea level projections. The estimates of total water storage on land derived from GRACE data, from groundwater changes in deep aquifers to changes in soil moisture and surface water, have provided tools to measure the impact of droughts and monitor and forecast floods.

GRACE data have been used to infer changes in deep ocean currents, a driving force in climate. GRACE data have also been used to measure changes within the solid Earth itself, such as the response of Earth's crust to the retreat of glaciers after the last Ice Age, and the impact of large earthquakes.

The GRACE and GRACE-FO missions are responsive to NASA's Solid Earth Science Working Group Report *Living on a Restless Planet* (http://solidearth.jpl.nasa.gov/) that identifies the study of the dynamics of the Earth's gravity field as one of six significant

challenges for the next twenty-five years, as well as NASA's *Challenges and Opportunities for Research in ESI (CORE) Report* (2016) (http://go.nasa.gov/2hmZLQO). The scientific goals of the GRACE and GRACE-FO missions complement a number of international programs, including the World Ocean Circulation Experiment (WOCE), the Climate Variability Program (CLIVAR), and the Global Ocean Observing System (GOOS).

On January 5, 2018 the Committee on the Decadal Survey for Earth Science and Applications from Space (ESAS) of the National Academies of Sciences, Engineering and Medicine (NASEM) Space Studies Board, Division on Engineering and Physical Sciences released the 2017 Decadal Survey, "Thriving on Our Changing Planet: A Decadal Strategy for Earth Observations from Space." The 700-page document, among a broad set of recommendations, identifies five observation types to be continued by NASA, named Designated Observables (DO). Based on the GRACE science accomplishments, Mass Change is one of the five DOs. This perspective of the 2017 DS makes the bridging of GRACE and GRACE-FO mission data of the utmost priority.

The main focus of this program element is to engage the science community in developing methodologies that will enable the development of a continuous mass change measurement record among the GRACE and GRACE-FO observations. Of interest are proposals which also discuss the validation and verification of the proposed methodologies and merged data. Another high priority focus is data assimilation of GRACE and GRACE-FO data in a broad range of Earth System models and modeling systems. Proposals for data assimilation work should clearly identify the expected advances and qualify the benefits of the improved models.

This program element seeks proposals that will advance the development of new methods, algorithms, and models for the exploitation of gravity field observations to be made by GRACE, GRACE-FO, and future space-based gravity field missions for the broad spectrum of Earth system science challenges. This program element also seeks the development of techniques and algorithms capable of bridging gravity field observation across different gravity missions. Proposals are encouraged which are multidisciplinary in scope and which address the Earth System Science questions related to NASA's Strategic Goal 2.1 to "Advance Earth System Science to meet the challenges of climate and environmental change". (See A.1 The Earth Science Research Overview).

Due to the extreme sensitivity of the GRACE-FO measurement technique and its resolution, ground calibration of the mission is problematic. This program element, therefore, seeks proposals that provide predictive models for the static and time varying gravity field that can be verified through both ground and GRACE/GRACE-FO space-borne observations. This program element seeks improved models for the static gravity field and its short term and secular variations and their influence upon the terrestrial reference frame.

This program element seeks proposals for the identification and quantification of atmospheric, oceanographic, hydrospheric, cryospheric and solid Earth structure and dynamics manifested in the GRACE-FO observations. The analysis effort can include other data sources that complement the GRACE-FO measurements, such as Earth

rotation and temporal and static gravity field measurements and other innovative approaches, including the use of data from other satellite missions such as CHAllenging Minisatellite Payload (CHAMP) and Laser Geodynamics Satellite (LAGEOS) gravity, radar, and laser altimetry missions (Jason 1-3 and ICEsat and ICEsat2, and Shuttle Radar Topography Mission). Proposers are advised to limit their proposals involving GPS occultation to the improvement and/or validation of GRACE gravity field models only.

The focus of the proposals should be upon the GRACE and GRACE-FO data sets though multidisciplinary and multisensor studies as well as studies that will utilize the GRACE-like mission data base to develop new measurement strategies to improve measurements of the Earth's gravity field. In particular, NASA is interested in efforts to advance measurement concepts and algorithms that would utilize other NASA missions, as well as other observing systems, to enhance our understanding of the Earth System through improved accuracy and spatial resolution.

2. Programmatic Information

After the May 22, 2018 launch, ground stations acquired signals from both GRACE-FO spacecraft. Initial telemetry showed the satellites performing as expected. On July 19, 2018 after 56 days of successful operation, the Instrument Processing Unit (IPU-B) within the Microwave Instrument (MWI) on GRACE-FO Spacecraft #2 (GF2) failed to properly recover from a reboot and was powered down by the spacecraft due to a low current fault response. After a full investigation by an anomaly response team, the mission switched over to the redundant side of the MWI. The GRACE-FO K-band ranging (KBR) system has been fully operational since October 22, 2018. The Laser Ranging Interferometer (LRI) technology demonstration operated for a short period of time prior to the MWI IPU anomaly. The LRI resumed collecting data concurrently with data from the Microwave Instrument late in 2018. NASA will produce two 30-day gravity field maps prior to the official beginning of the science phase of the mission early in 2019.

In addition, NASA has approved extended science data operations for GRACE through September 30, 2019. The authoritative GRACE science data, covering the period from April 2002-September 2017, will result from a post-mission reprocessing to incorporate final calibrations. The data will be archived at NASA's Physical Oceanography Distributed Active Archive Center (PO.DAAC) and the GFZ Information System and Data Centre (ISDC) in Germany for use by the science community.

Four advanced gravity field missions have been launched since 2000. These missions include CHAMP (launched July 15, 2000), GRACE (launched March 17, 2002), ESA's Earth Explorer Gravity Field and Steady-State Ocean Circulation (GOCE) (launched March 17, 2009) and GRACE-FO. Proposers to this program element may consider the use of multiple satellite data sources and they are required to include GRACE and GRACE-FO data.

The investigators associated with the selected proposals will become members of the GRACE-FO science team for the term of their grants.

Continuation of studies funded by existing GRACE and GRACE-FO science team grants will be considered, but proposers are urged to describe accomplishments achieved and carefully articulate the progress to be made in the continuation efforts.

3. Summary of Key Information

Expected total program budget for new awards	~ $3M per year
Number of new awards pending adequate proposals of merit	~ 15 - 20
Maximum duration of awards	4 years
Due date for Notice of Intent to propose (NOI)	See Tables 2 and 3 of ROSES
Due date for proposals	See Tables 2 and 3 of ROSES
Planning date for start of investigation	6 months after proposal due date.
Page limit for the central Science-Technical-Management section of proposal	15 pp; see also Table 1 of ROSES *Summary of Solicitation* and the *NASA Guidebook for Proposers*
Relevance to NASA	This program is relevant to the Earth Science questions and goals in the NASA Science Plan. Proposals that are relevant to this program are, by definition, relevant to NASA.
General information and overview of this solicitation	See the *ROSES Summary of Solicitation*.
Detailed instructions for the preparation and submission of proposals	See the *NASA Guidebook for Proposers* at http://www.hq.nasa.gov/office/procurement/nraguidebook/.
Submission medium	Electronic proposal submission is required; no hard copy is permitted.
Web site for submission of proposal via NSPIRES	http://nspires.nasaprs.com/ (help desk available at nspires-help@nasaprs.com or (202) 479-9376)
Web site for submission of proposal via Grants.gov	http://grants.gov/ (help desk available at support@grants.gov or (800) 518-4726)
Funding opportunity number for downloading an application package from Grants.gov	NNH19ZDA001N-GRACEFO
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