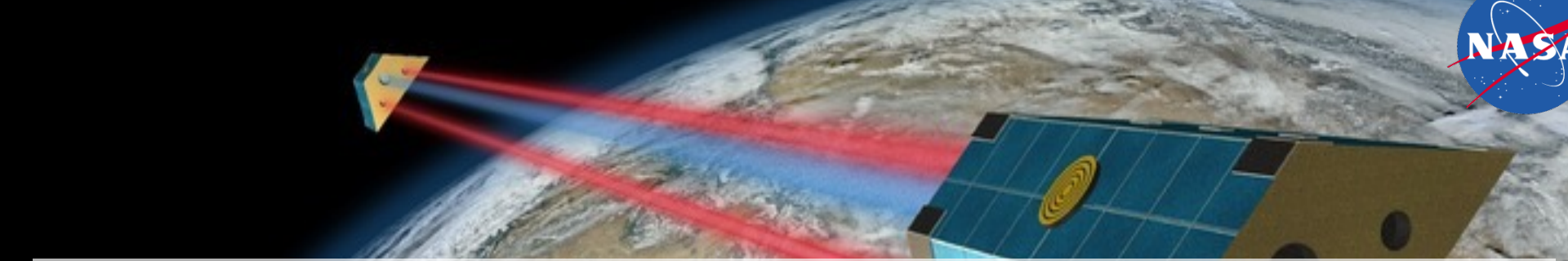


GRACE/GRACE-FO in the NASA Applied Sciences Program

JT Reager[1], GRACE Deputy Program Applications Lead
Michael Jasinski[2], GRACE Deputy Program Applications Lead
Margaret Srinivasan[1], GRACE Asst Deputy Program Appl Lead
Brad Doorn[3], NASA HQ Program Applications Lead

[1]Jet Propulsion Laboratory, California Institute of Technology
[2]Goddard Space Flight Center
[3]NASA

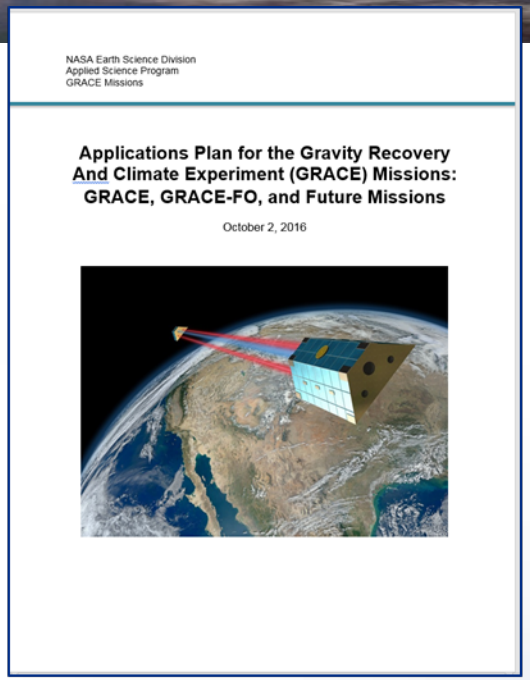
GRACE-FO Science Team Meeting, October 9-11, 2018

Applied Sciences Objectives for GRACE-FO

Objectives:

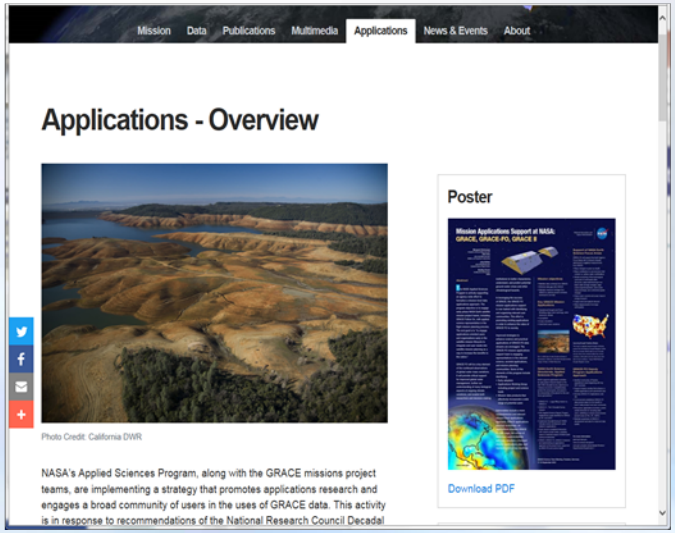
- Increase awareness of GRACE missions science data to applications community
- Engage potential GRACE data users including the international community,
- Promote understanding of GRACE products to new end users & understand their requirements,
- Facilitate exchange of ideas/expertise btw GRACE scientists and current & potential application,
- Approach strategic government and private partners interested in bringing their own resources.

https://grace.jpl.nasa.gov/applications/overview/


NASA Earth Science Division
Applied Science Program
GRACE Missions

Applications Plan for the Gravity Recovery And Climate Experiment (GRACE) Missions: GRACE, GRACE-FO, and Future Missions

October 2, 2016



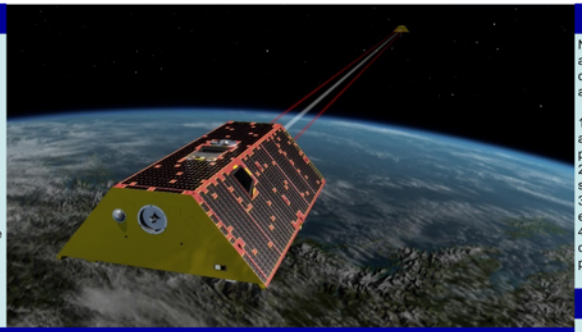
GRACE Summary Poster

Applied Sciences Goals, Activities and Societal Benefits of the Gravity Recovery and Climate Experiment Follow-On Mission (GRACE-FO)

Abstract

GRACE-FO, the follow-on mission to the highly successful GRACE mission (2002-2017), consists of twin satellites separated about 200 km that make detailed measurements of Earth's gravity field. When made in conjunction with other data and models, they provide estimates of terrestrial water storage change, ice-mass variations, ocean bottom pressure changes and sea-level variations. GRACE-FO, scheduled for launch in 2018, is functionally identical to GRACE except that it includes an experimental laser ranging instrument that will provide more accurate gravity measurements compared to GRACE.

During pre-launch phases, the NASA Applied Sciences Program in Water Resources has continued to develop a formalized GRACE-FO Applications effort to encourage incorporation of GRACE and GRACE-FO observations into Earth System models for operational uses. The overarching purpose is to discover and demonstrate innovative uses and practical benefits of GRACE science data and technology. The goal is to promote the use of satellite data by public and private organizations to help support decision-making activities and services, and to enable them to envision possible applications as a way to increase the societal benefits of GRACE.



Applied Sciences Objectives

The overall objectives are:

i) Enhance GRACE-FO applications research through identifying and supporting relevant evolving societal needs in the areas of policy making, resource management and disaster response,
ii) Increase GRACE-FO collaborations through raising mission awareness and fostering partnerships with organizations that provide complementary resources and extend the mission's reach,
iii) Accelerate continued and new use of the data by ensuring that GRACE missions plan and support applications goals in parallel with science goals.

Specific objectives are to:
i) Promote the use and understanding of GRACE-FO products to the community of end-users and decision makers that are interested in using the missions' data products in their application,
ii) Facilitate contact, information exchange and collaborations feedback among GRACE-FO and various user communities.
iii) Promote communication strategies to target and support user community. requirements.

Application Science Activities

Specific GRACE Applications activities include:

i) Increase awareness of GRACE/GRACE-FO missions and data products through outreach workshops, tutorials, and town halls.
ii) Identify and engage a diverse applications community of potential GRACE-FO data users.
iii) Facilitate understanding and use of available GRACE-FO data products through communication with GRACE-FO project scientists.
iv) Share knowledge and experience through the formulation of a GRACE-FO Applications Team that includes a working group and an application user community.
v) Engage strategic government and private partners interested in bringing their own resources. The goal is to continue to build on the current GRACE applications community and their broad support.
vi) Capacity building for the U.S. and the international community.
vii) Writing of a GRACE-FO Science and User Guide to facilitate user understanding and selection of GRACE-FO data products.

Applications Focus Areas

GRACE-FO science data offer the potential to improve decision-making across many application areas. Opportunities are currently envisioned in the areas of water resources including surface and groundwater, weather and climate, natural disasters and surveying and navigation, although others exist.

Water Resources - Seasonal and interannual changes in water availability including water stored in surface waters, groundwater, and snow and ice can be quantified using GRACE. Hence GRACE missions have the potential to inform water resources decision-making related to surface and groundwater management, and snow and streamflow quantification, flooding preparedness, drought mitigation, irrigation management, food security and agricultural management, among others.

Too much or too little water can have huge impacts on people around the world. The agricultural community, wildfire managers and other decision-makers will use GRACE-FO data provide weekly National Drought Monitor weekly maps.

Enhanced Prediction Skills for Weather and Climate - By providing GPS radio-occultation measurements daily, coupled with an improved understanding of the global water cycle, data from GRACE-FO will help advance Earth system analysis and weather and climate forecast modeling.

Improved Predictions of Flood Potential - GRACE-FO will provide a means to observe monthly variations in total water storage within large river basins. The terrestrial water storage signal defines the time-variable ability of land to absorb water. Water storage from GRACE-FO may allow users to assess the predisposition of a river basin to flooding months in advance.

Sea Level Change Prediction and Ocean Current Monitoring - Data from GRACE-FO will allow scientists and decision makers monitor sea level and determine—in conjunction with other observations—how much of the change is due to warming, ice melting or runoff from land. Ocean bottom pressure measurements from GRACE-FO will also enable the tracking of deep ocean current changes.

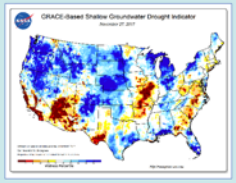
Surveying and Navigation- GRACE-FO improved capability has potential applications that rely on accurate gravity fields as in surveying and navigation.

Capacity Building

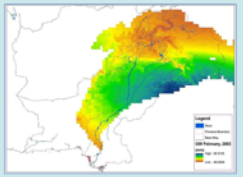
NASA defines capacity building as activities that strengthen or contribute to the U.S. and developing world capacity to use NASA Earth observations data/products in decision making, including human, scientific, technological, organization, institutional, and resource-based capacities. Activities include:

1. Applied Remote Sensing Training (ARSET): increases utility of NASA Earth science and model data by providing training to decision makers and applied science professionals in water resources and air quality areas.
2. DEVELOP: supports young and transitioning professionals in working on applied science projects with NASA science advisors and end users.
3. Gulf of Mexico Initiative (GOMI): addresses coastal management issues and enhance the ecological and economic health of the Gulf region.
4. SERVIR: provides Earth observation data and science applications to help developing regions improve their environmental decision making through a partnership with the U.S. Agency for International Development (USAID).

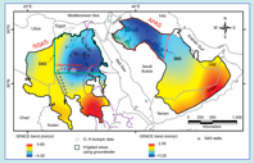
Examples of GRACE Applications



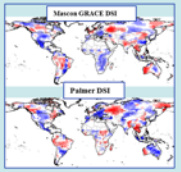
U.S. Groundwater and Soil Moisture Conditions from GRACE Data Assimilation. http://drought.unl.edu/MonitoringTools/NASAGRACEDataAssimilation.aspx Houborg et al. 2012.



Pakistan water managers used GRACE data to produce monthly groundwater changes in the Indus River Basin. Orange and yellow indicates areas where groundwater is depleted; blue and green areas where groundwater is replenished. Iqbal et al, 2016.



Monitoring fossil aquifers for sustainability-- Linear trend over 2003-2012 in mm/yr from smoothed GRACE monthly solutions that span over the Nubian Sandstone (NSAS) and the Arabian Peninsula (APAS) aquifer systems. Sultan et al., 2015.



Global GRACE Drought Severity Index - Typical comparison between GRACE-Drought Severity Index (DSI) and Palmer Drought Severity Index PDSI (E.g. July 2010) Zhao et al., JHM 2017.

Contacts

Bradley Doorn, Program Manager for Water Resources, NASA Science Mission Directorate
Deputy Program Assistants: Michael Jasinski, Hydrological Sciences Lab, NASA GSFC;
JT Reager, Cal Tech/Jet Propulsion Lab; Margaret Srinivasan, Cal Tech/Jet Propulsion Lab

Current Main Areas of GRACE Applications

E.g. GRACE-Related Special Sessions at Conferences

AGU Fall 2017 Mtg, New Orleans: Four sessions, 37 GRACE presentations

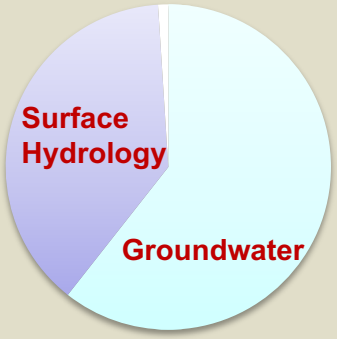
- Applications of GRACE, Models, and Monitoring for Water Resources Assessment (I,II,III)
- Large Scale Modeling and RS of Water Cycle for Better Human Water Management

AMS 2018 Annual Mtg, Austin: Five sessions, 12 GRACE presentations

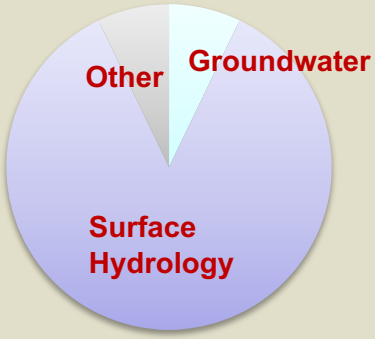
- Drought Analysis and Prediction
- Advances in the Application of Land Surface Observations and Land Data Assimilation
- Land Surface - Atmosphere Interaction
- Multi-processes Analysis and Modeling, and Product Application in Arid and Semiarid Regions
- NASA Earth Observation Systems and Applications for Health and Air Quality Models and Decision

Topic Distribution:

AGU



AMS



Post Launch Goals

Develop Closer Partnership with the GRACE-FO Project Office

- Identify applications goals that complement Project goals
- Leverage NASA Applied Sciences Program (e.g. outreach, training, workshops, data user guides)

Expand Applications Research

- Define management decisions made from GRACE groundwater information
- Define non-hydrology applications
- Expand applied research themes
  - Demonstrate application for disaster case: E.g. flood/drought, earthquake
  - Climate change/sea level rise
  - Data assimilation within regional or global atmospheric models
  - Navigation & surveying
  - Solid earth/earthquakes

GRACE Project Brochure

Applications in GRACE Project Brochure !

Table of Contents

Applications and Benefits to Society

Among the applications of GRACE-FO mission data are improvements to our understanding and forecasting of freshwater availability, droughts, agricultural resources, sea level rise, climate change and solid Earth changes. Data from GRACE-FO—along with information from other Earth-observing satellites and airborne missions, combined with ground-based data—will lead to advances in Earth system science for years to come.

Monitoring Freshwater Resources

Water resource managers rely on accurate estimates of underground water storage like those provided by GRACE and soon GRACE-FO to monitor freshwater resources necessary for human activities including public consumption, irrigation and sanitation—among other uses.

Enhanced Prediction Skills for Weather and Climate

By providing GPS radio-occultation measurements daily, coupled with an improved understanding of the global water cycle, data from GRACE-FO will help advance Earth system analysis and weather and climate forecast modeling.

Improved Forecasting for Drought and Flood Risk

Too much or too little water can have huge impacts on people around the world. The agricultural community, wildfire managers and other decision-makers will use GRACE-FO data to provide weekly maps of drought risk.

Enhanced Prediction of Flood Potential

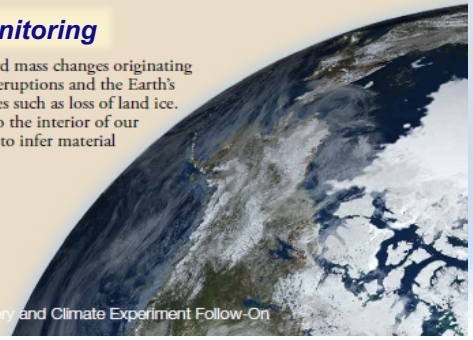
GRACE-FO will provide a means to observe monthly variations in total water storage within large river basins. The terrestrial water storage signal defines the time-variable ability of land to absorb and process water, and accounts for the water beneath the surface. Water storage information from GRACE-FO will allow users to assess the predisposition of a river basin to flooding as much as 5–11 months in advance.

Improved Sea Level Change Prediction and Ocean Current Monitoring

Data from GRACE-FO will allow scientists to keep a close eye on sea level and determine—in conjunction with other observations—how much of the change is due to warming, ice melting or runoff from land. Ocean bottom pressure measurements from GRACE-FO will also enable the tracking of deep ocean current changes.

Better Solid Earth Monitoring

Data from GRACE-FO will also record mass changes originating from earthquakes, tsunamis, volcanic eruptions and the Earth's crust as it adjusts to other mass changes such as loss of land ice. This effectively provides a window into the interior of our planet, and gives researchers new data to infer material properties deep below the surface.



Post Launch Goals for 2018+ (cont'd)

Build Capacity for Use, Search and Access of GRACE Products

- Outreach, training, SERVIR, DEVELOP, ARSET
- Continue GRACE Applications Website
- Complete users guide and lessons learned

Assess impacts of using GRACE data in decision tools

- Quantify impacts of outcomes from current users ($$ or lives saved?)

Highlight GRACE Applications Research

- Continue to maintain GRACE Applications Website
- Encourage journal publications
- Host special session at one science/applications meeting per year

Post Launch Goals for 2018+ (cont'd)

DLR – Understand DLR applied research needs.

Highlight GRACE Applications Research

- NCAR NSF funded to incorporate GRACE within CLM to calibrate model almost an operational activity
- **Brigit Scanlon**, UT, Austin – improvement of climate models using GRACE
- **Matt Rodell,** GSFC – Western Water Office, GRACE assimilated into land surface model
- **Hyongki Lee,** U. Houston – Monitoring Surface Water Storage Changes over the Lower Mekong with Multiple Satellite Techniques Towards Sustainable Water Management
- **Venkat Lakshmi** – Evaluation of Risk and Capacity Development for Two Indian River Basins

Highlights of Recent GRACE Applications

GRACE Applications Research

- NCAR NSF funded to incorporate GRACE within CLM to calibrate model
  almost an operational activity
- Brigit Scanlon, UT, Austin – improvement of climate models using GRACE
- Matt Rodell, Western Water Office, GRACE assimilated into land surface model

First GRACE Data Assimilation-Based Global Wetness/Drought Maps

M. Rodell, B. Li, H.K. Beaudoing, A. Getirana, and B. Zaitchik

Highlight:

- Global maps of wetness/drought conditions in surface and root zone soil layers and shallow groundwater are now being produced on a weekly basis.
- The maps are based on the integration of GRACE terrestrial water storage and other observation-based datasets within a sophisticated model of land surface processes.
- GRACE Follow On data will be integrated when they become available.
- The maps will soon be distributed through the online portal at the National Drought Mitigation Center, http://drought.unl.edu/.

Relevance:

- Drought and wetness monitoring data are valuable to water resources managers, drought specialists, disaster aid agencies, and agricultural interests, among others.
- At present, routine global drought indicator maps are scarce, and none assess groundwater conditions.
- These new products make use of and enhance the value of observations from NASA's GRACE and (in 2018) GRACE Follow On missions.
- The products were developed at NASA/GSFC with funding from NASA's Terrestrial Hydrology Program.

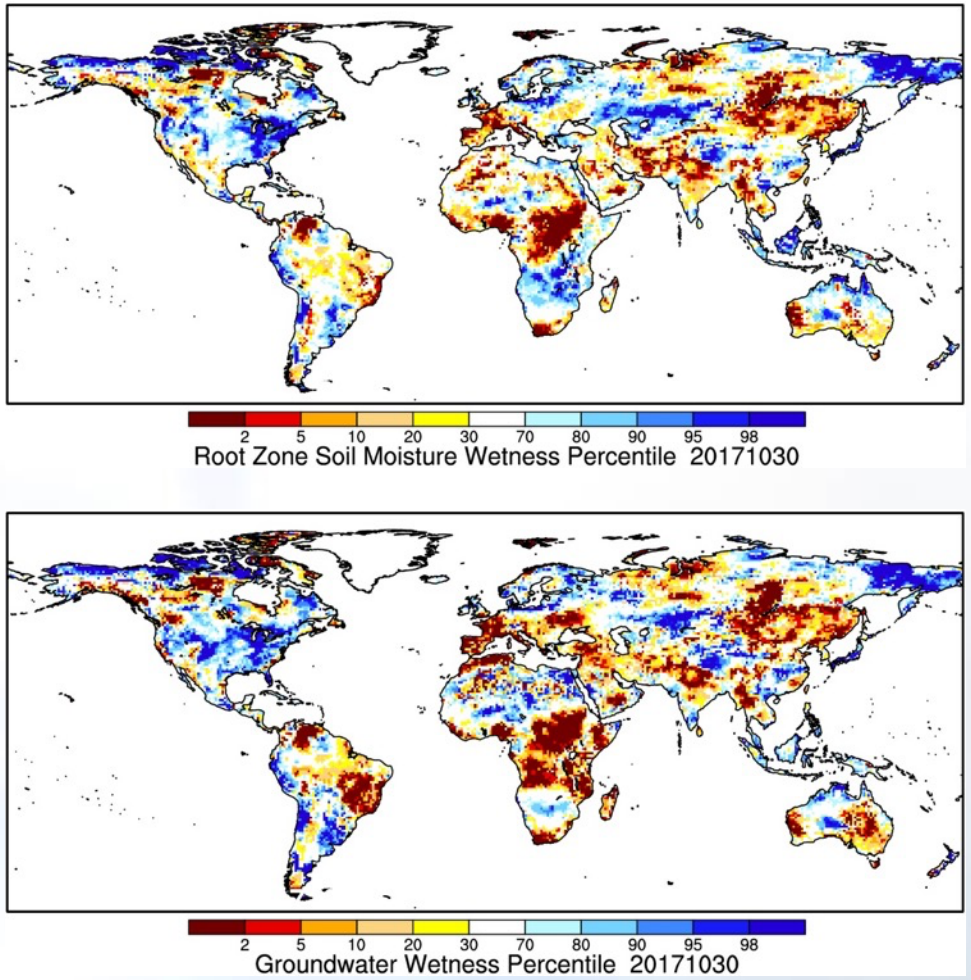
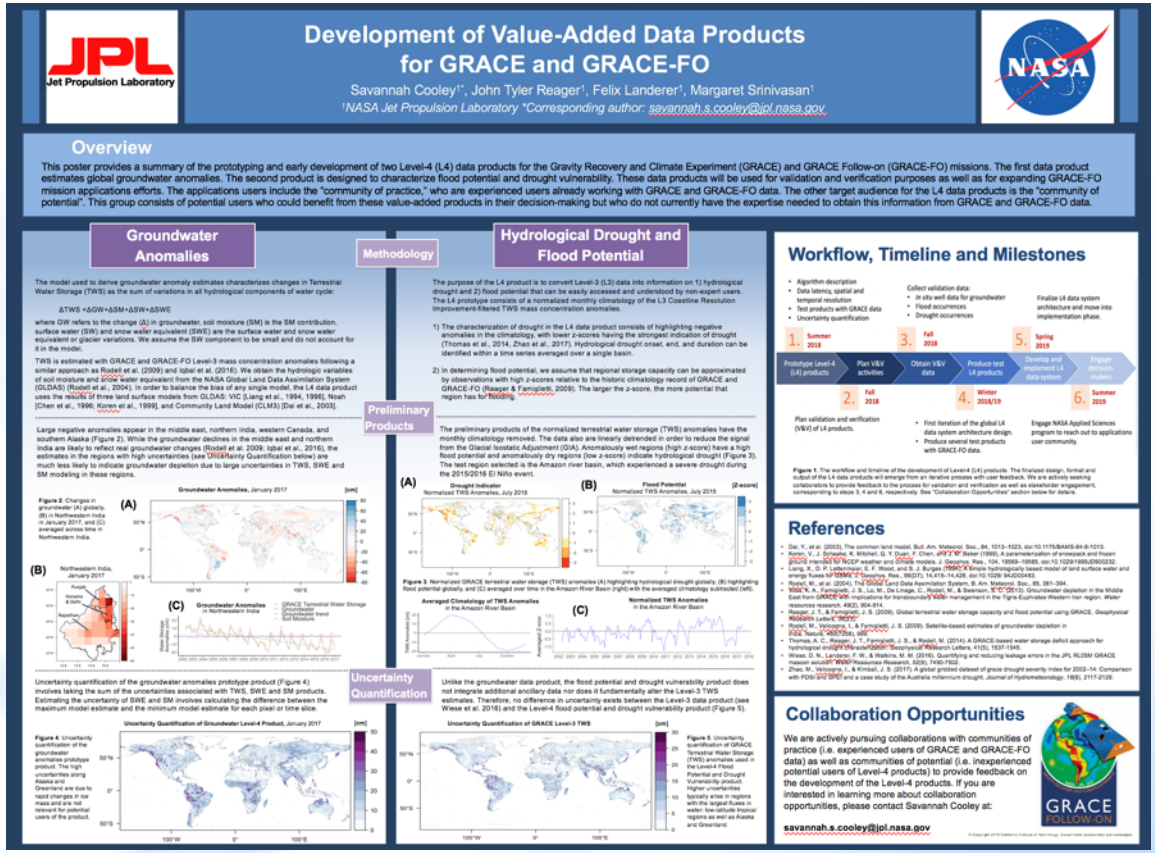


Figure 1: Root zone soil moisture (top) and shallow groundwater (bottom) drought/wetness indicators for 30 October 2017. Units are wetness percentiles relative to seasonal conditions at each location during the period 1948-present. For example, a grid pixel in the 5th percentile has been dryer than present in only 5% of past Octobers. Greenland has been masked out.

Level 4 Products

JPL Efforts

- Value-added products (Cooley presentation @ GAWG, Thu.)



Development of Value-Added Data Products for GRACE and GRACE-FO

Savannah Cooley[1*], John Tyler Reager[1], Felix Landerer[1], Margaret Srinivasan[1]

[1]NASA Jet Propulsion Laboratory *Corresponding author: savannah.s.cooley@jpl.nasa.gov

Overview

This poster provides a summary of the prototyping and early development of two Level-4 (L4) data products for the Gravity Recovery and Climate Experiment (GRACE) and GRACE Follow-on (GRACE-FO) missions. The first data product estimates global groundwater anomalies. The second product is designed to characterize flood potential and drought vulnerability. These data products will be used for validation and verification purposes as well as for expanding GRACE-FO mission applications efforts. The applications users include the "community of practice," who are experienced users already working with GRACE and GRACE-FO data. The other target audience for the L4 data products is the "community of potential". This group consists of potential users who could benefit from these value-added products in their decision-making but who do not currently have the expertise needed to obtain this information from GRACE and GRACE-FO data.

Groundwater Anomalies

Methodology

Hydrological Drought and Flood Potential

Preliminary Products

Uncertainty Quantification

Workflow, Timeline and Milestones

References

Collaboration Opportunities

We are actively pursuing collaborations with communities of practice (i.e. experienced users of GRACE and GRACE-FO data) as well as communities of potential (i.e. inexperienced potential users of Level-4 products) to provide feedback on the development of the Level-4 products. If you are interested in learning more about collaboration opportunities, please contact Savannah Cooley at:

savannah.s.cooley@jpl.nasa.gov

See Cooley et al, poster GSTM-2018-16

Upcoming Meetings

American Water Resources Assciation, Baltimore, MD

- Chairing Special Session Wed, Nov 7: *"Improving Water Resources Decision Support Using Satellite-based Earth Observations and Hydrologic Data Assimilation Systems"*
- Invited Presentation on GRACE Applications

American Geophysical Union Fall Mtg, Washington DC

- Co-Chairing Special Session Friday, December 14

"Remote Sensing Applications for Water Resources Management, Including Droughts, Floods, and Associated Water Cycle Extremes"

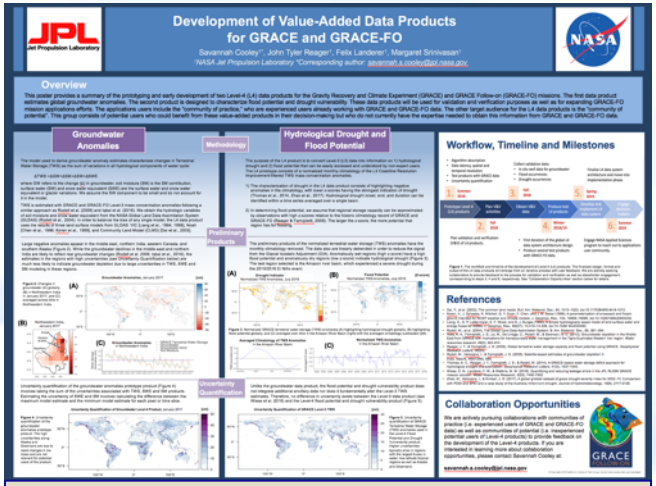
Very large number of Abstracts, also invited talks by L. Friedl (NASA Applications overview) and Tom Wagner (per ICESat2)

CUAHSI, TBD

- Training focus for graduate students,
- GRACE/GRACE-FO, other hydrology remote sensing assets

GRACE/GRACE-FO Applications

See Srinivasan et al, poster GSTM-2018-76



See Cooley et al, poster GSTM-2018-16

GRACE-FO Applications Working Group Meeting

Thursday, 11 October

Time: 17:00-18:30

Location: Room H-VR1 (near plenary room)

DISCUSSION TOPICS:

User Resources:

–GRACE User Guideline update

–L4 Data products – Cooley presentation

–Training; ARSET

GRACE Applications portfolio:

–Low latency 3-day product

Also, see GRACE Applications posters

Thank you