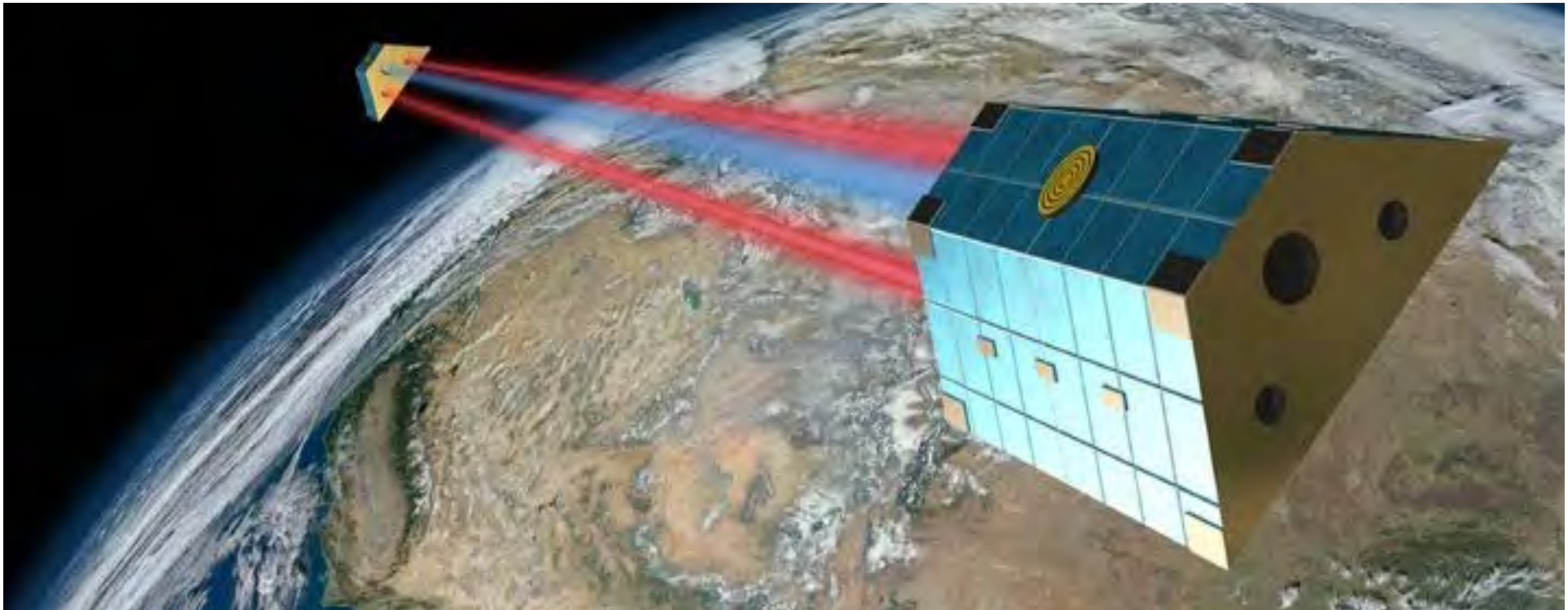


GRACE/GRACE-FO in the NASA Applied Sciences Program

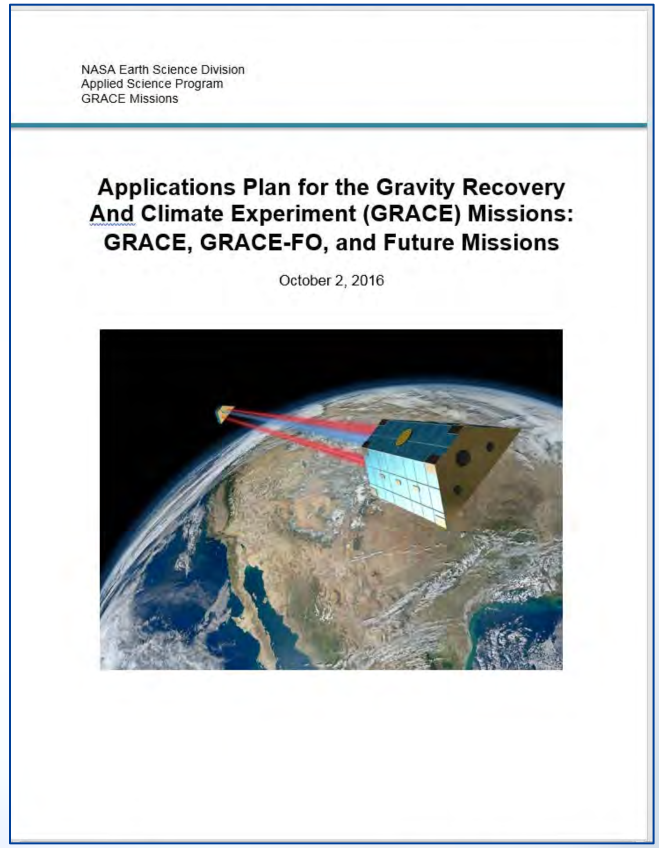
Brad Doorn, NASA HQ Program Sponsor

Deputy Program Applications Leads: Mike Jasinski, JT Reager, Margaret Srinivasan

GRACE Missions Application Plan

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.



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

Doorn et al., GSTM 2017

GRACE Application Focus Areas

Focus Areas:

- Water Resources
  drought monitoring, groundwater supply, flood potential,
- Climate
  groundwater as an indicator of climate variability and human impacts,
- Natural Disasters
  improved planning and mitigation activities,
- Surveying and Navigation
  decision support applications due to more accurate gravity fields.

Doorn et al., GSTM 2017

GRACE Applications Plan Initiatives

Initiatives:

- Foster an Applications Community of Practice
- GRACE Applications Working Group (GAWG)
- Communication Activities – Tutorials, workshops, Town Halls, webinars, conference special sessions, joint mission tutorials
- Identify and support sponsored GRACE applications research
- Seek opportunities in Capacity-Building Activities within NASA (ROSES, SERVIR, DEVELOP, etc.), US and internationally

Doorn et al., GSTM 2017

GRACE Applications Activities - 2017
GRACE Hydrology: Science Applications User Guidelines

GRACE Hydrology: Science User Guidelines Summary

For NASA's Gravity Recovery and Climate Experiment (GRACE) and GRACE Follow-on missions applications in the Hydrological Sciences

By JT Reager, GRACE-FO Science Team, GRACE-FO DPAs

The following information is intended to provide guidance and be a resource to users of GRACE data with respect to available data formats, and optimal approaches to the use of GRACE information and products. For more information on applied use of GRACE data and access to the GRACE Applications Plan, please visit grace.jpl.nasa.gov/applications.

Interpreting Terrestrial Water Storage Anomaly (TWSA): We assume that changes in the time-varying gravity field represent the movement of water mass over land, though this assumption should always be validated with ground data. Other signals, such as tectonics, can also influence the GRACE measurements. GRACE data represent the time varying gravity field, not the static gravity field, and as such should have no mean-value by definition. As with any time series, removing a record-length mean and then re-sampling could result in a new mean due to interannual variability. **The time-mean for the GRACE time series should be removed over whichever study period is being applied**.

3-degree native Spatial resolution: The resolution of the GRACE solution varies slightly with the version being used and the smoothing that is applied. However, GRACE gravity fields are typically solved to about 3 degrees latitude and longitude, and have no information beneath this resolution, independent of the resolution of the grid they are provided on. **Study areas beneath ~3 degrees latitude or 3 degrees longitude should not be considered for hydrology.** To be safe, a minimum study area of about 150,000 km^2 is best. Typically, these regions follow a natural hydrological boundary such as a river basin or an aquifer.

Non-uniform native Temporal Sampling: the GRACE gravity fields are solved for those time periods when data from enough orbits exist to create a global gravity field solution. This leads to non-uniform temporal discretization of the GRACE data products. **Be careful in comparing to other data sets that the GRACE data products do not represent a monthly mean, and are not uniformly spaced in time.** A time stamp is provided for each of the gravity fields in the data products.

Error handling: Error products are presented with each of the GRACE data products. Formal errors from two primary sources are calculated for spherical harmonic solutions: measurement and leakage errors. These errors should be added, and care should be taken that these errors can be spatially correlated for regional averaging (e.g. for a river basin). **Procedures and pseudo-code for averaging spatially-correlated errors are presented on the GRACE Tellus website.**

Available Data products: The GRACE "mascons" (3 arc-degree blocks covering the Earth's surface, each of which has a value of the estimation of mass concentration, or gravity field variation, in that area, e.g. RL05M) represent the state-of-the-art in the processing of the GRACE observations to minimize signal loss and leakage errors vs. spherical harmonic solutions. These should be used when possible, as they represent the lowest uncertainty solution for each 3-degree mascon (see Watkins et al., 2015 for validation). A coastal resolution improvement (CRI) filter is applied to coastal mascons to recover land signal from ocean-included mascons. **For hydrology applications, the CRI corrected data should be used.**

Scale-factors: Model-derived time-constant scale factors are presented with the data. These can be used to "downscale" the resolution of the GRACE observations to 0.5 degrees using prior information on signal spatial structure from a large-scale hydrology model. Note that caution should be applied in interpretation, as these models do not include groundwater pumping or other human-activity in their simulations. These scaled GRACE data are useful for studies of climate and hydrology at seasonal and interannual timescales, however, **GRACE data with scale factors applied should not be used for long-term groundwater studies or studies of human impacts in hydrology,** as they may misrepresent the spatial structure of water storage trends in certain regions. This is discussed further in Landerer and Swenson (2012).

Drafted by JT Reager, GRACE-FO Science Team & DPAs

Objectives

- GRACE data have many caveats in their application
- Users frequently misunderstand key characteristics of the GRACE data
- A simplified summary of major obstacles can make data application easier

Significance

- Will be reviewed by DPA team and GRACE applications working group
- Will be placed on GRACE Tellus website for easy visual reference before downloading
- Should eliminate some of the major issues with erroneous GRACE data use

Doorn et al., GSTM 2017

CUAHSI
universities allied for water research

GRACE Applications Activities - 2017

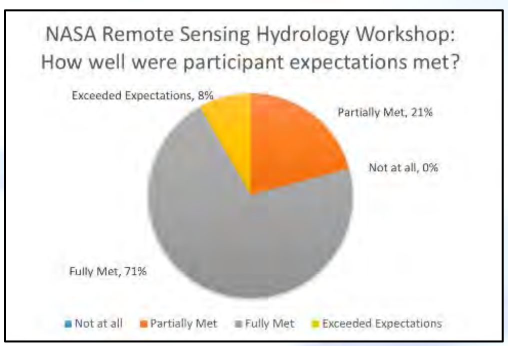
Remote Sensing Hydrology Training Workshop

2nd Annual CUAHSI*/NASA Remote Sensing Hydrology Training Workshop

April 4 – 6, 2017, Cambridge, MA

Workshop lead: JT Reager [john.reager@jpl.nasa.gov]

*Consortium of Universities for the Advancement of Hydrologic Science, Inc., https://www.cuahsi.org



Objectives

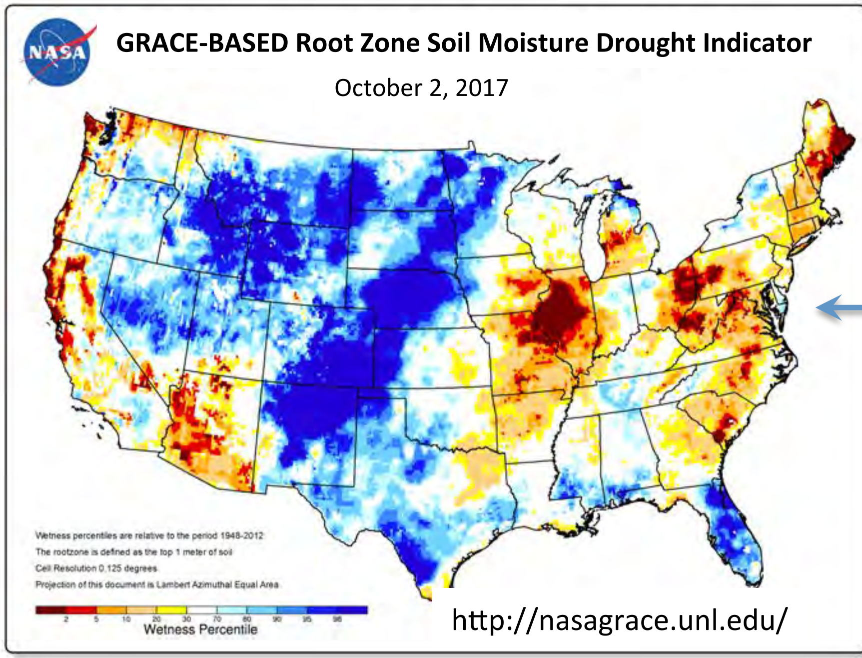
- Train 25 graduate students to use NASA hydrology products from GRACE, SMAP & SWOT
- Entrain user-base in academic community who will be future scientists, operational hydrologists, and water managers
- Instructor time and travel supported by GRACE DPA funds

Significance

- Huge demand: over 150 applicants for only 25 spots in the first week of registration!
- 79% of participants said their expectations were fully met or exceeded
- 88% of participants said they anticipate using these data in their research

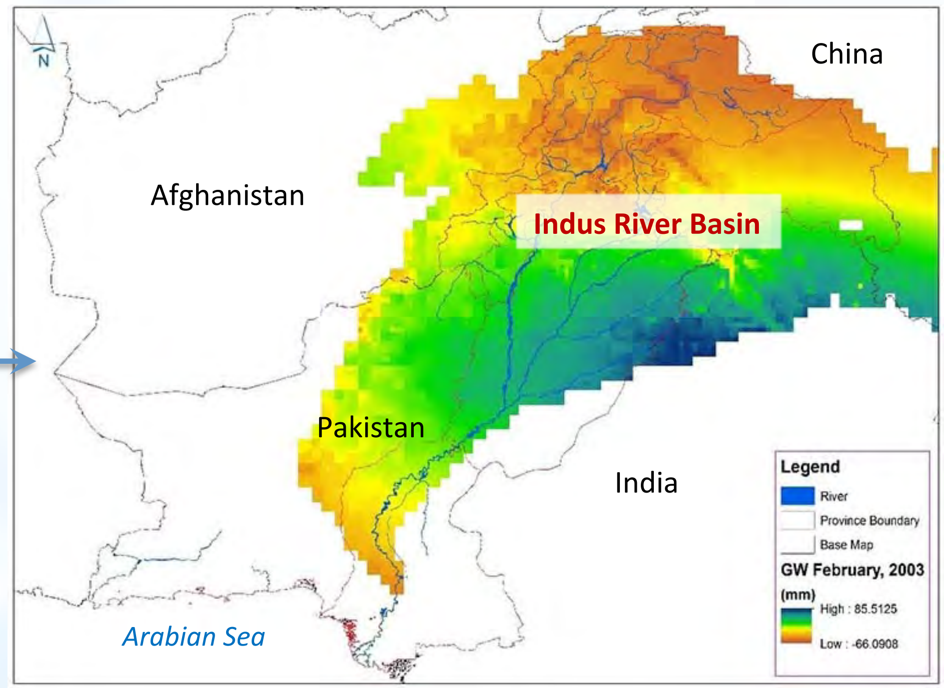
Doorn et al., GSTM 2017

Examples: GRACE Decision Support Applications



Groundwater and soil moisture drought indicators are generated each week, based on GRACE terrestrial water storage integrated with other observations and the Catchment land Surface Model. Drought indicators are expressed as a percentile showing the probability of occurrence within the period of record 1948 to present. Warm colors indicate dryer than normal; cool colors mean wetter than normal. Houborg et al., WRR 2012.

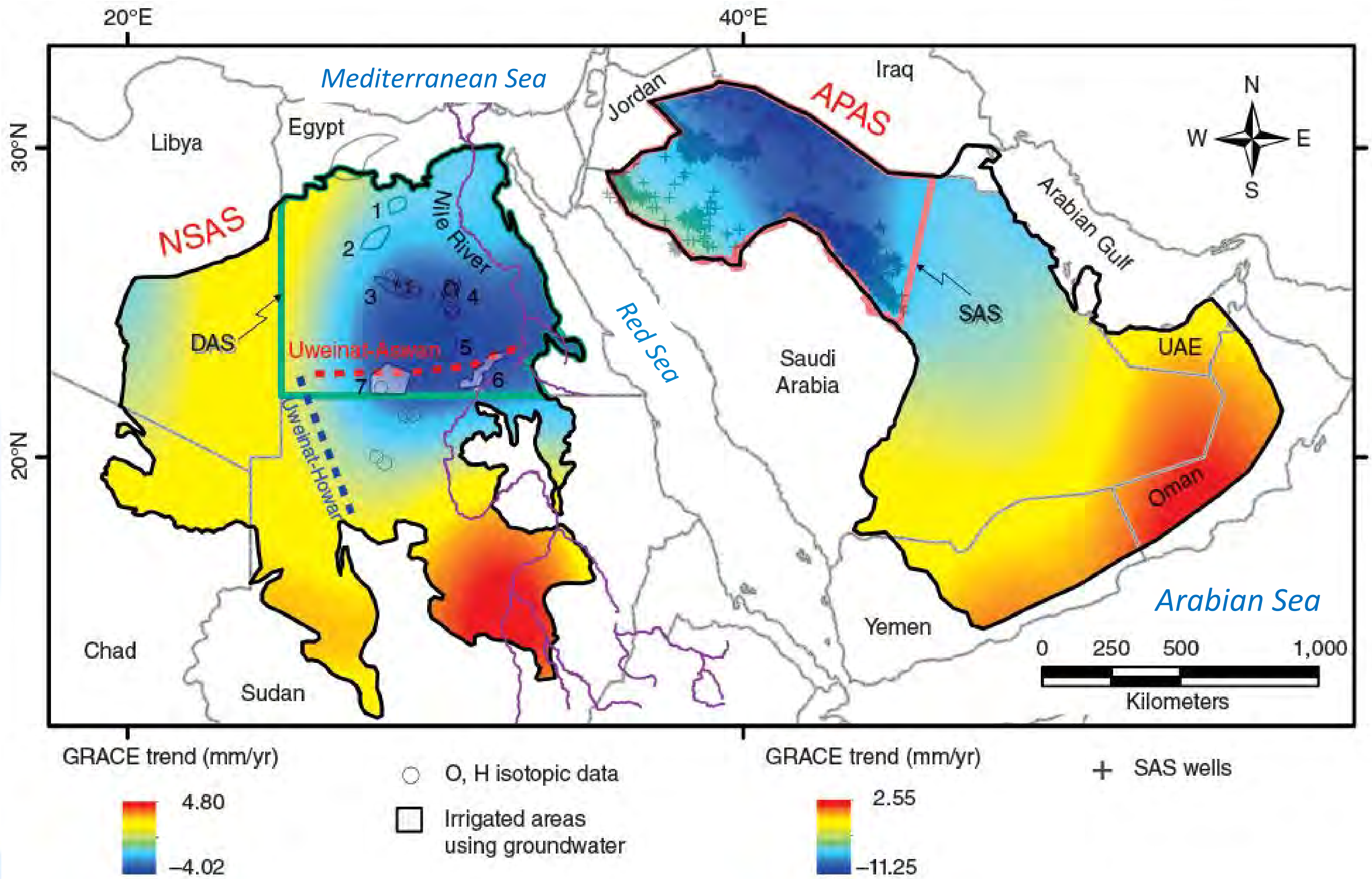
Indus Basin Monthly Groundwater Change



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 highlights areas where groundwater is replenished. Iqbal et al, 2016, Pakistan Council of Research in Water Resources

Doorn et al., GSTM 2017

Monitoring Fossil Aquifers for Sustainability

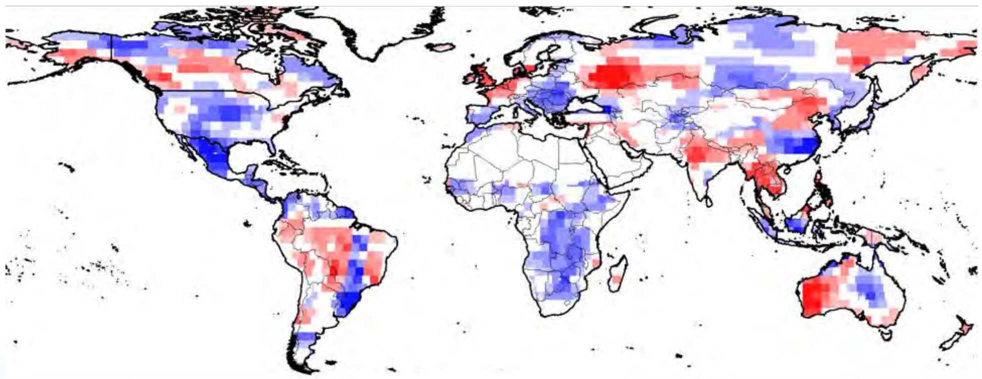


Linear trend over 2003-2012 in mm/yr from smoothed GRACE monthly solutions that span over the Nubian Sandstone (NSAS) and the Arabian Peninsula (APAS) aquifer systems. Sultan et al., 2015.

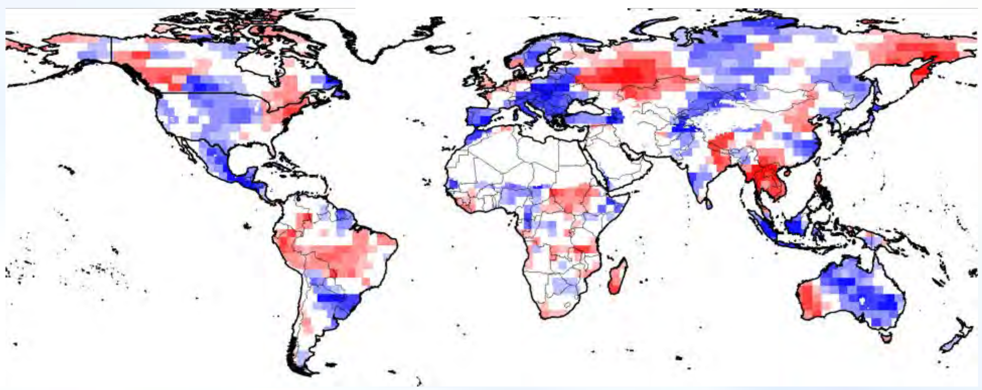
Doorn et al., GSTM 2017

Global GRACE Drought Severity Index

Mascon GRACE DSI



Palmer DSI



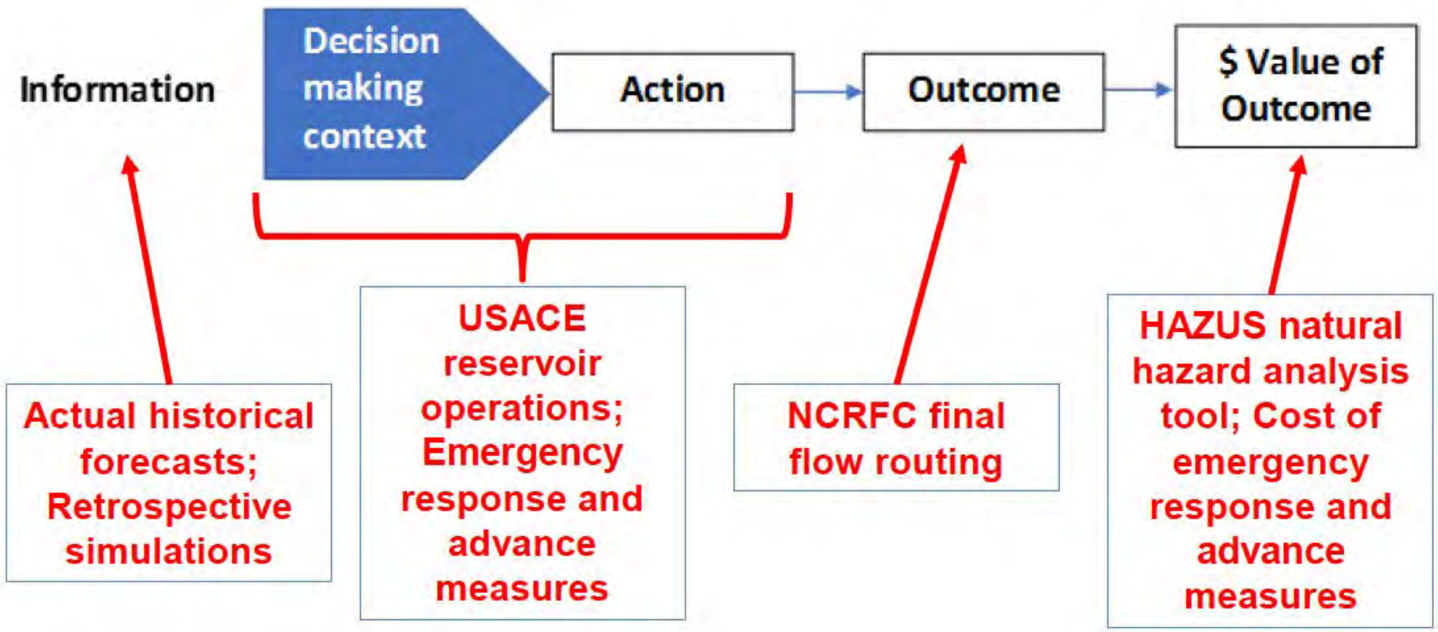
Typical comparison between GRACE-Drought Severity Index (DSI)
and Palmer Drought Severity Index PDSI (E.g. July 2010)

Zhao et al., JHM 2017

Doorn et al., GSTM 2017

GRACE Valuation Study*

Example 1: Integrating GRACE and GRACE Follow On data into river flow and flood forecasts



RFF

*Kuwayama, NASA Applied Sciences Water Resources Team Meeting, July 2017

Doorn et al., GSTM 2017

Application Goals for 2018 +

- Expand applications research
  - Participation by international, NGO, and Private communities
  - Strengthen links btw data products and decision support tools
  - build capacity for use, search and access of GRACE products
  - develop thematic GRACE application groups

- Assess benefits of using GRACE data in decision tools
  - compile list of GRACE applications by theme
  - quantify impacts of outcomes from current users ($ or other metrics)
  - review current applications projects; document lessons learned

- Highlight GRACE applications
  - encourage journal publications
  - host special session at one science/applications meeting per year

Doorn et al., GSTM 2017

GAWG Meeting

Wednesday, 11 October, 5-6 PM
Room; TBD

Agenda

Welcome and Introductions

Meeting Purpose

- -GRACE Data User Guidelines
- -Brainstorming - Moving Forward with the Applications Plan
- - Next steps – highlight recent research that should be harvested for applications potential

Next Meeting

Adjourn

Backup

Doorn et al., GSTM 2017

Doorn et al., GSTM 2017

GRACE Applications Working Group “GAWG”

- GAWG Makeup:
  - voluntary
  - w/diverse membership background,
  - GRACE experts and application stakeholders

- Possible areas to contribute:
  - Guidance on implementation of the Applications Plan,
  - Identification of potential GRACE applications,
  - Provide understanding on GRACE data products to users w/little remote sensing experience,
  - Participation in quarterly telecons, workshops, tutorials, and town halls at science meetings,
  - Identify key speakers, and suggest host institutions and venues,
  - Contact potential end-users and strategic partners, and facilitate collaboration w/ the GRACE/GRACE-FO Science Team and Project Office,
  - Contribute to GRACE applications manuscripts in peer-reviewed journals,

Doorn et al., GSTM 2017

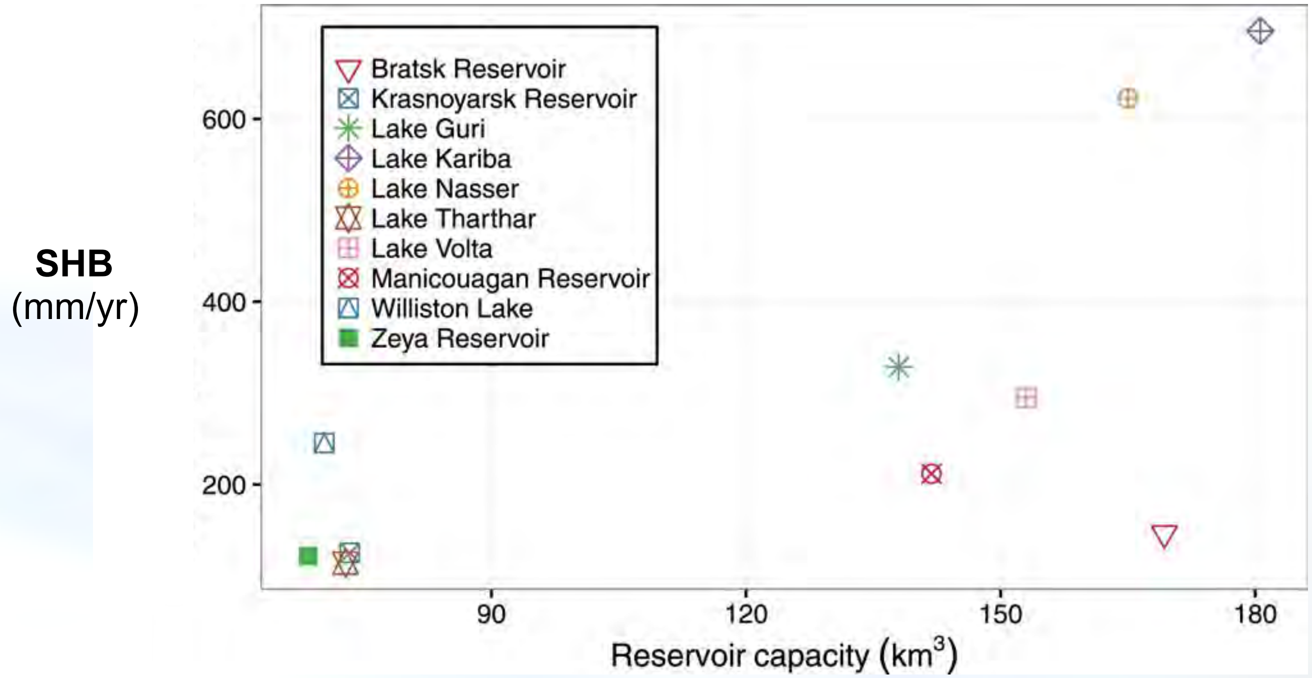
Timeline

Qrtr	2012-2015	2016	2017	2018	2019
1	Draft Applicatons Plan	Formulate GAWG Team	Annual User Workshop	Annual User Workshop	Annual User Workshop
	Web development		GAWG/EA Quarterly Call	GAWG/EA Quarterly Call	GAWG/EA Quarterly Call
			Draft Implementation Plan		
2	Draft Applications Plan	Mtg w/GRACE-FO Mission Proj Mngmt, JPL	GAWG/EA Quarterly Call	GAWG/EA Quarterly Call	GAWG/EA Quarterly Call
	GSA Mtg 2012; GEWEX Mtg, 2013	GAWG			
	AGU 2014;Texas Water Managers Mtg, 2014				
3	Present AP at 2015 GSTM, Austin	GAWG/Formal Invite/Telecom	GSTM, Austin	GSTM Potsdam	GSTM Austin
	First GAWG Mtg, GSTM, Austin	Present AP status, GSTM, Potsdam			
		Applications Session, GSTM, Potsdam			
4	AP Poster OSTM/Coast Alt Wkshp, Reston	AGU Presentation	AGU Town Hall	AGU GRACE Apl Sci Spec Sess	AMS GRACE Apl Sci Spec Sess
	Present at ICESat2 Apl Sci Wkshop, Denver	GAWG Telecom/Implementation Plan	GAWG/EA Quarterly Call	GAWG/EA Quarterly Call	GAWG/EA Quarterly Call
		Identify Early Adopters			
		Complete Applications Plan			

Doorn et al., GSTM 2017

GRACE-observed storage impact due to large reservoirs

Seasonal Hydrologic Buffer (SHB) - defined as the delay
in return of continental precipitation to atmosphere and ocean

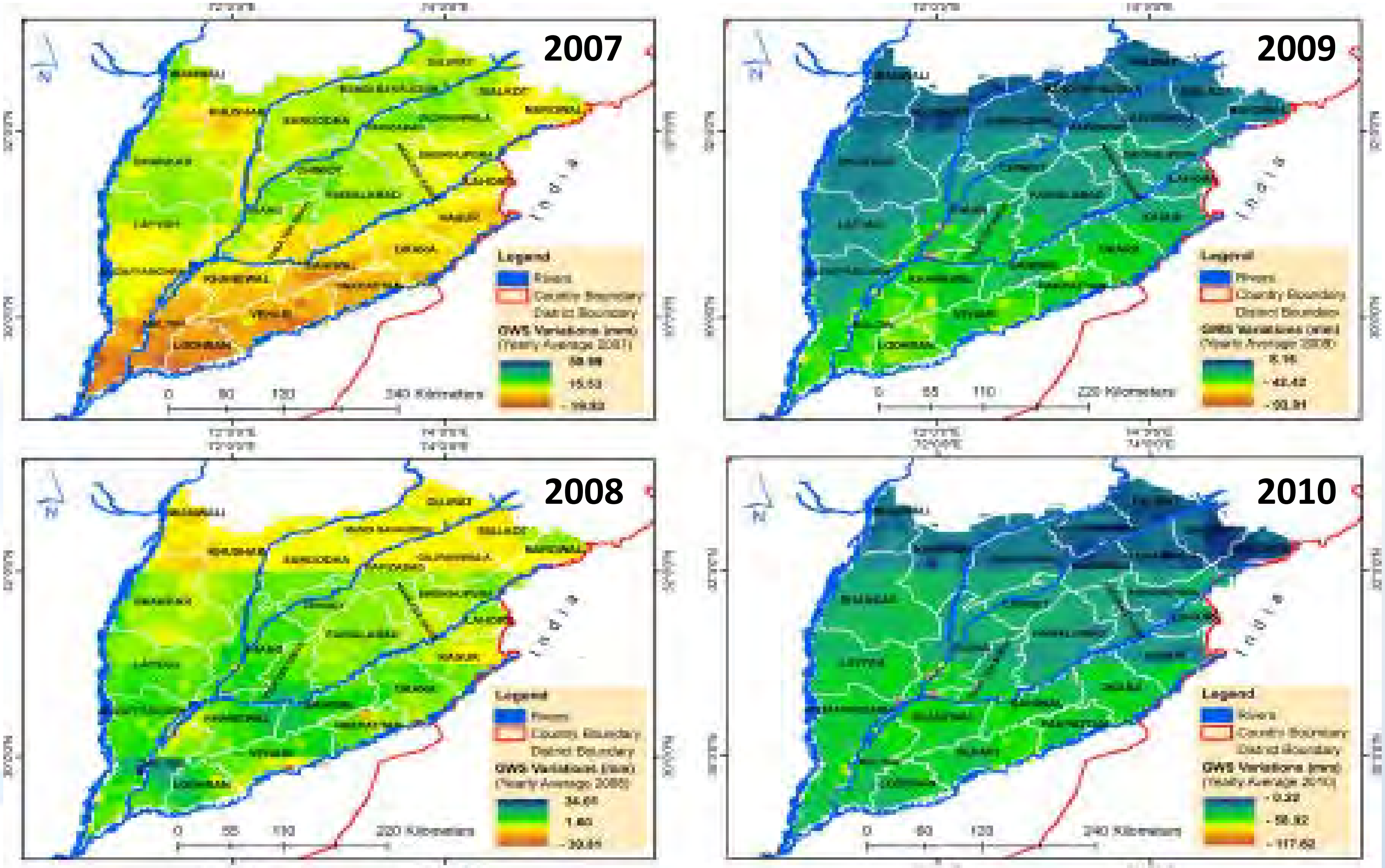


Positive correlation indicates that these large reservoirs have
a detectable contribution to GRACE-observed seasonal storage change.

Kuppel et al., Advances in Water Resources, 2017

Doorn et al., GSTM 2017

Indus Basin, Punjab Province, Annual Groundwater Change 2007-2010



Naveed Iqbal et al., Environ Monit Assess, 2017

Doorn et al., GSTM 2017

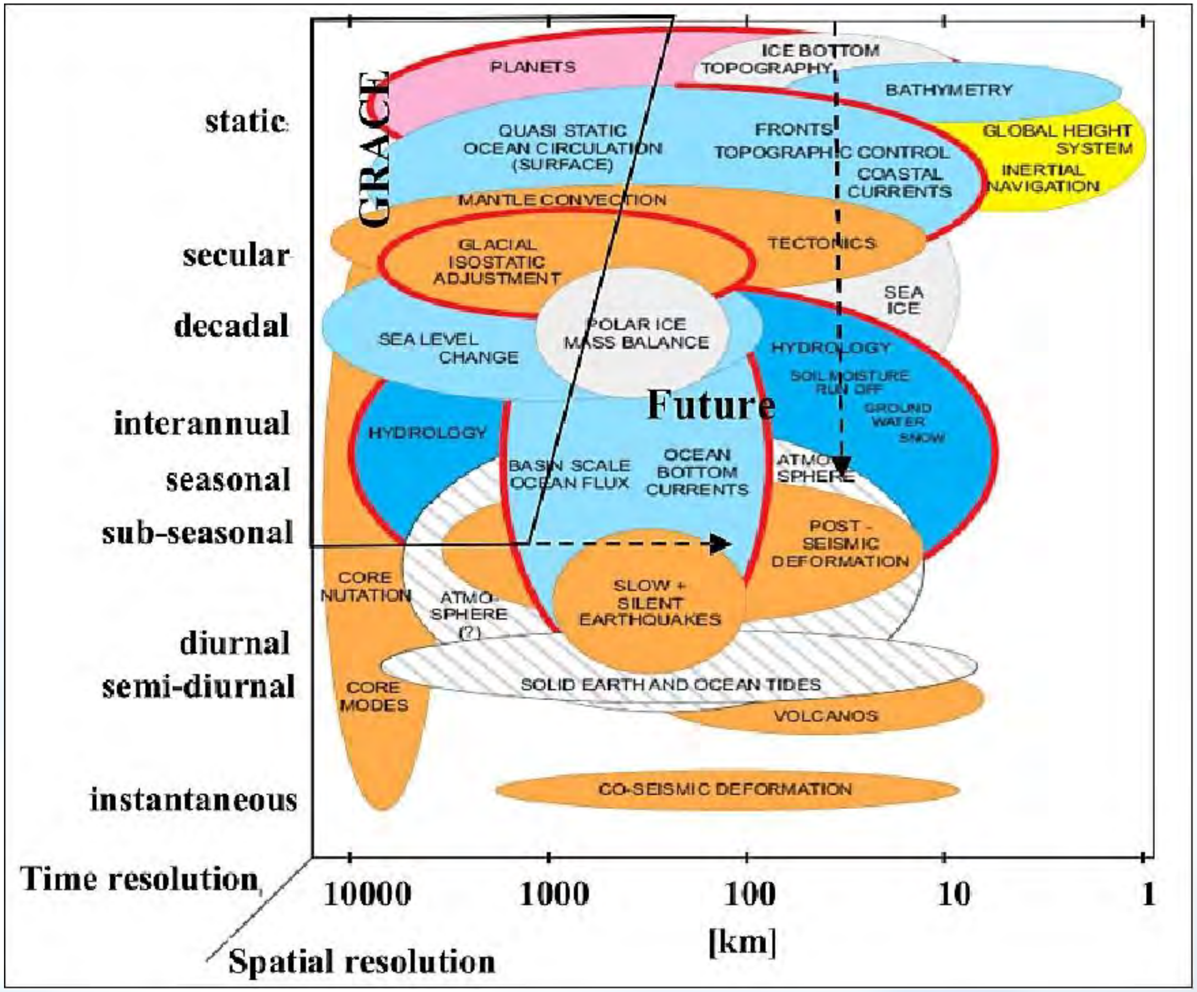
Oroville Lake, CA

July 2011

August 2014

Doorn et al., GSTM 2017

Sources of time variable gravity field sources



Time variable gravity field sources in terms of spatial resolution and time variability including GRACE sensitivity and goals for future gravity field missions (Gruber et al, 2011).

Doorn et al., GSTM 2017

GRACE Applications Activities
Next Steps

- **Finalize GRACE Hydrology: Science User Guidelines**
- **CUASHI follow-on**
- **Implementation**
- **Conference participation**
- **??**
- **GRACE Hydrology: Science User Guidelines Summary**
- **CUASHI follow-on**

Doorn et al., GSTM 2017