# Continuity of the GRACE FO Mass Change Measurement

Byron Tapley
UTCSR

**National Academies CESAS**

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Washington, DC

# Background

- GRACE FO Continuity has demanding challenges:
  - Establish a connection with GRACE
  - Last until a replacement mission can be implemented
  - Establish connection with the replacement mission
- These steps are necessary to ensure continuity of the 15 year Mass Change Measurement established by GRACE
- GRACE FO is just finishing it's proposed five year mission and is undergoing review for mission extension, so this is a good time to consider it's contributions and to look at the overall issues related to maintaining continuity of the Mass Change Measurement
- It has encountered problems with the loss of the accelerometer capability on one satellite and developing issues with thruster leaks
- In the following we will review some the recommendations for continuity, consider some of the contributions that are the basis of these recommendations, review some of the performance of GRACE FO and considering the challenges of a successful connection to a following mission
- NASA specific information on any issues related to the GRACE FO Mission can be obtained from Felix Landere, Project Scientist; or Rob Gaston, Project Manager.

# Gravity and Mass Change

The Earth's mass density varies as  geodetic *position* changes and as *time* changes

Mass has a gravitational effect.

As either position or time changes, the gravity signal varies.

Measurements that span the Earth,s surface allows determination of a model for the Earth's Gravity {Potential

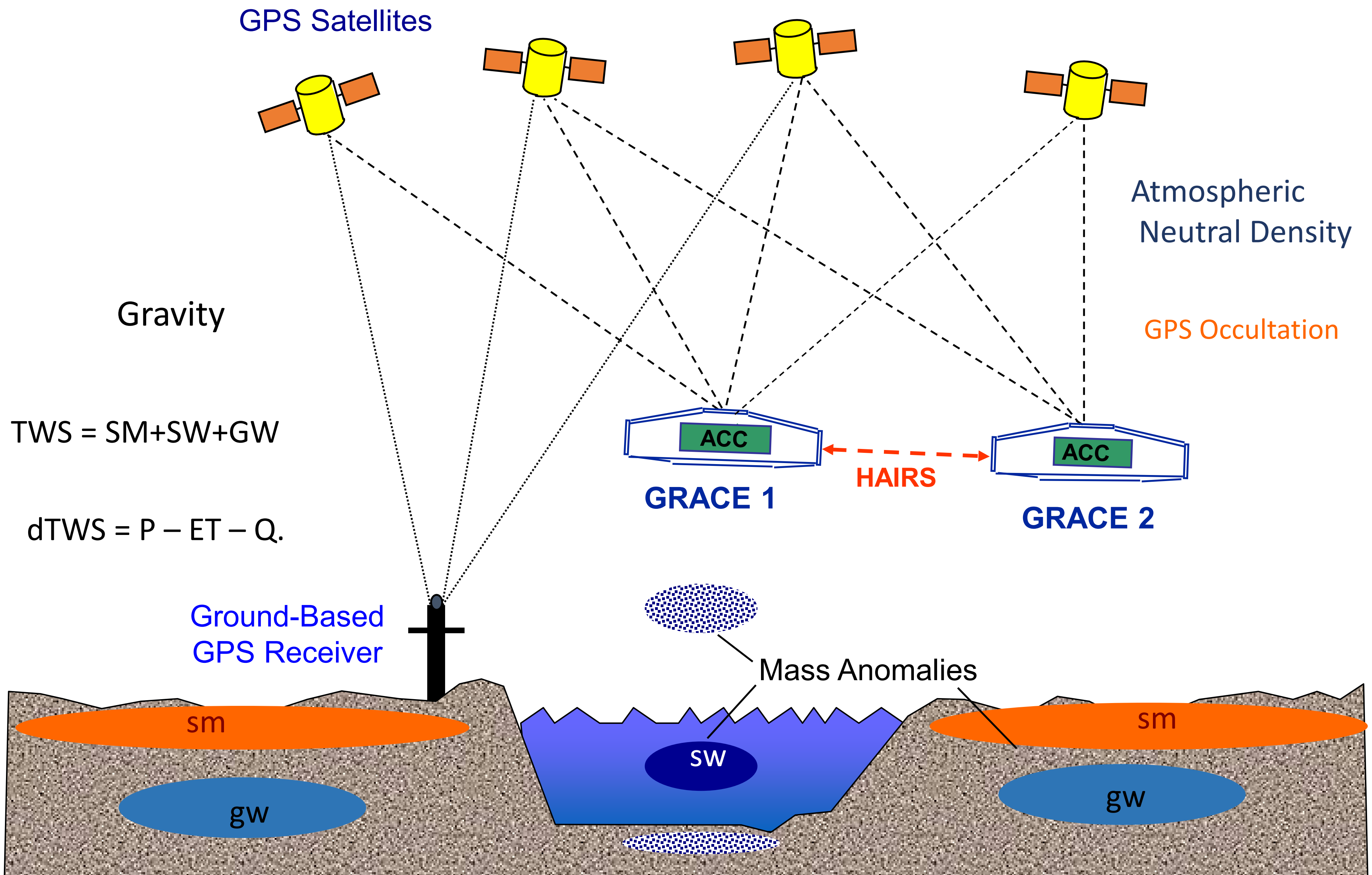
Repeated global measurements of gravity can be used to determine the spatial and temporal variations of the Earth System mass.

These gravity variations contain signals associated with the mass movement within and between the Earth System Components ( ocean, atmosphere, cryosphere, land surface and solid earth)

The gravity induced signal from mass variation is an an essential measurement for understanding the processes involved in Earth System Dynamics

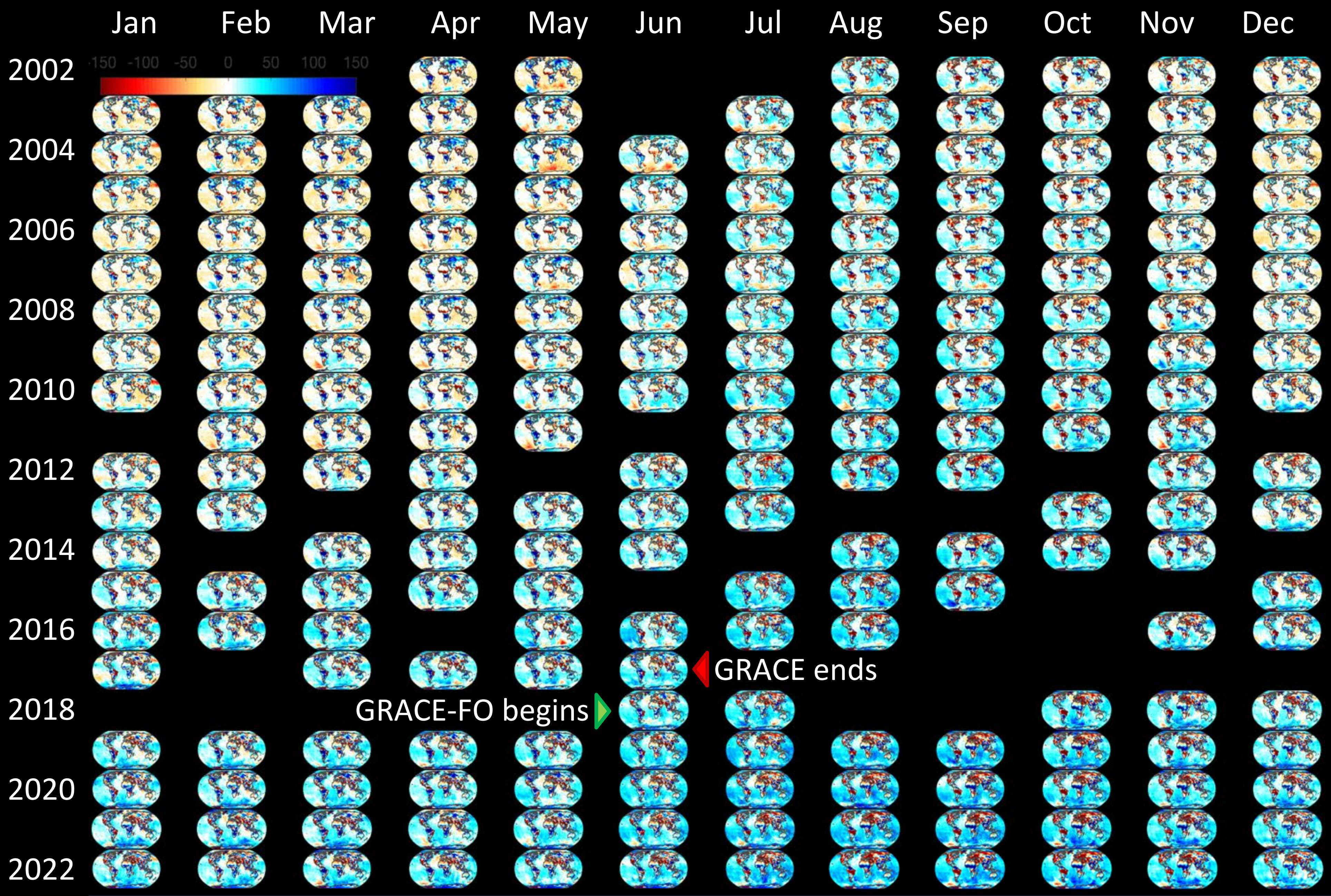
The GRACE Mission proposed to use this principle to better understand the Earth System Interactions

# Grace Mission Concept



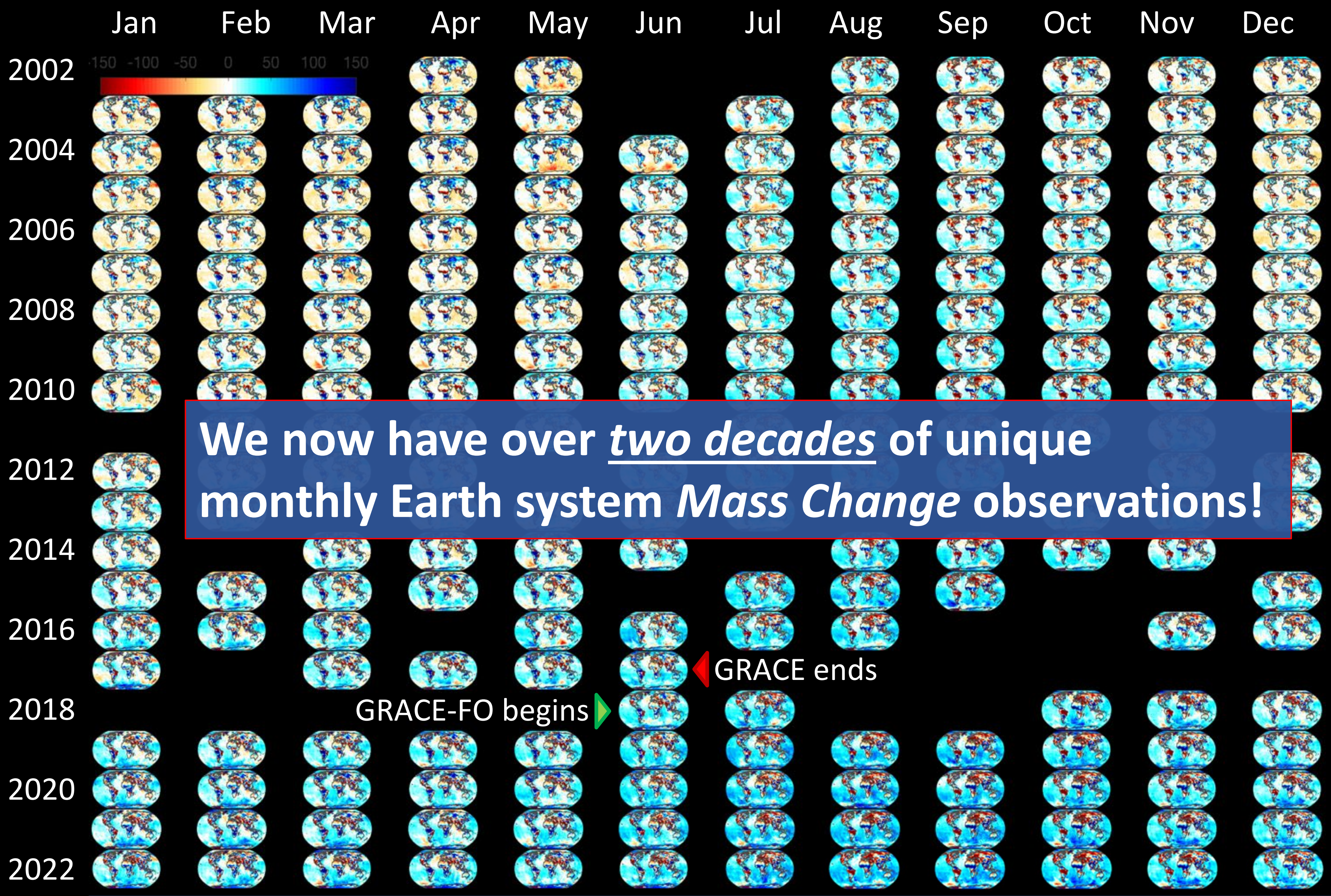
# GRACE and GRACE-FO: 20+ years of Amazing Discoveries





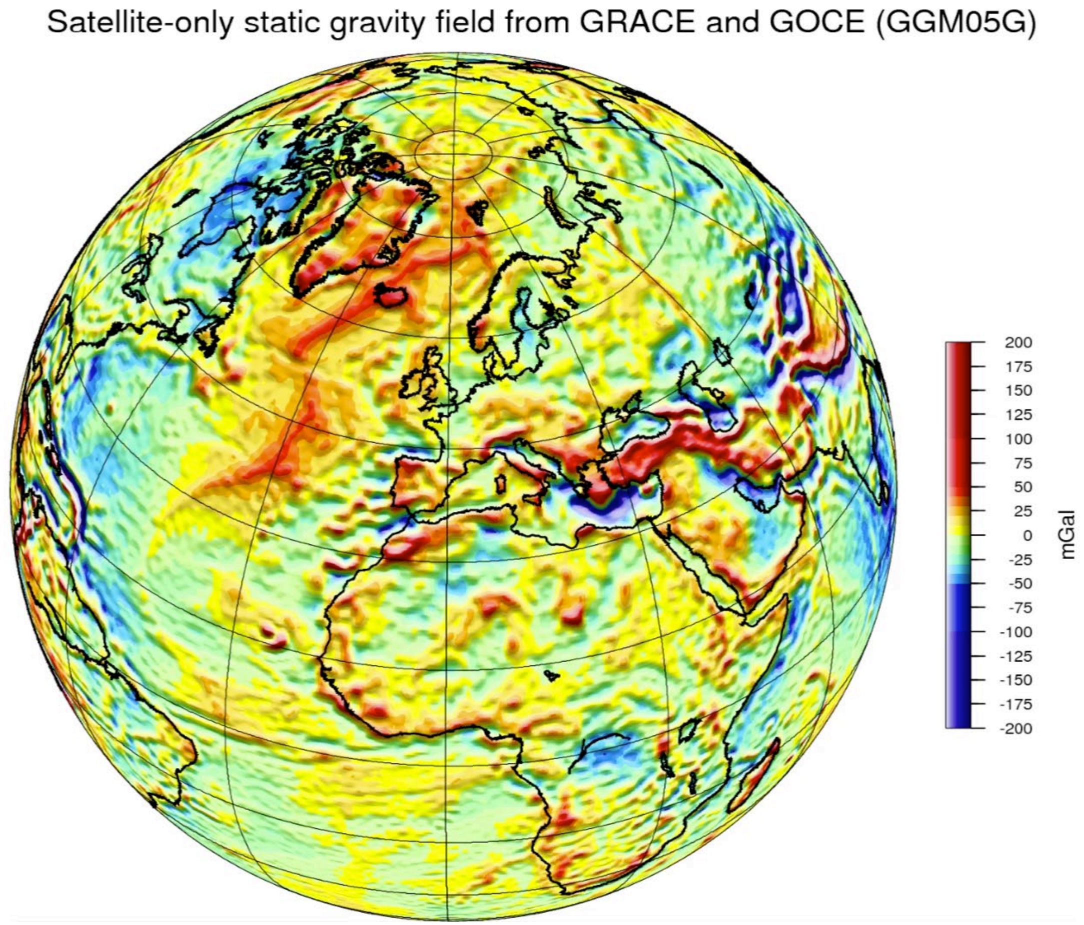
# GRACE and GRACE-FO: 20+ years of Amazing Discoveries

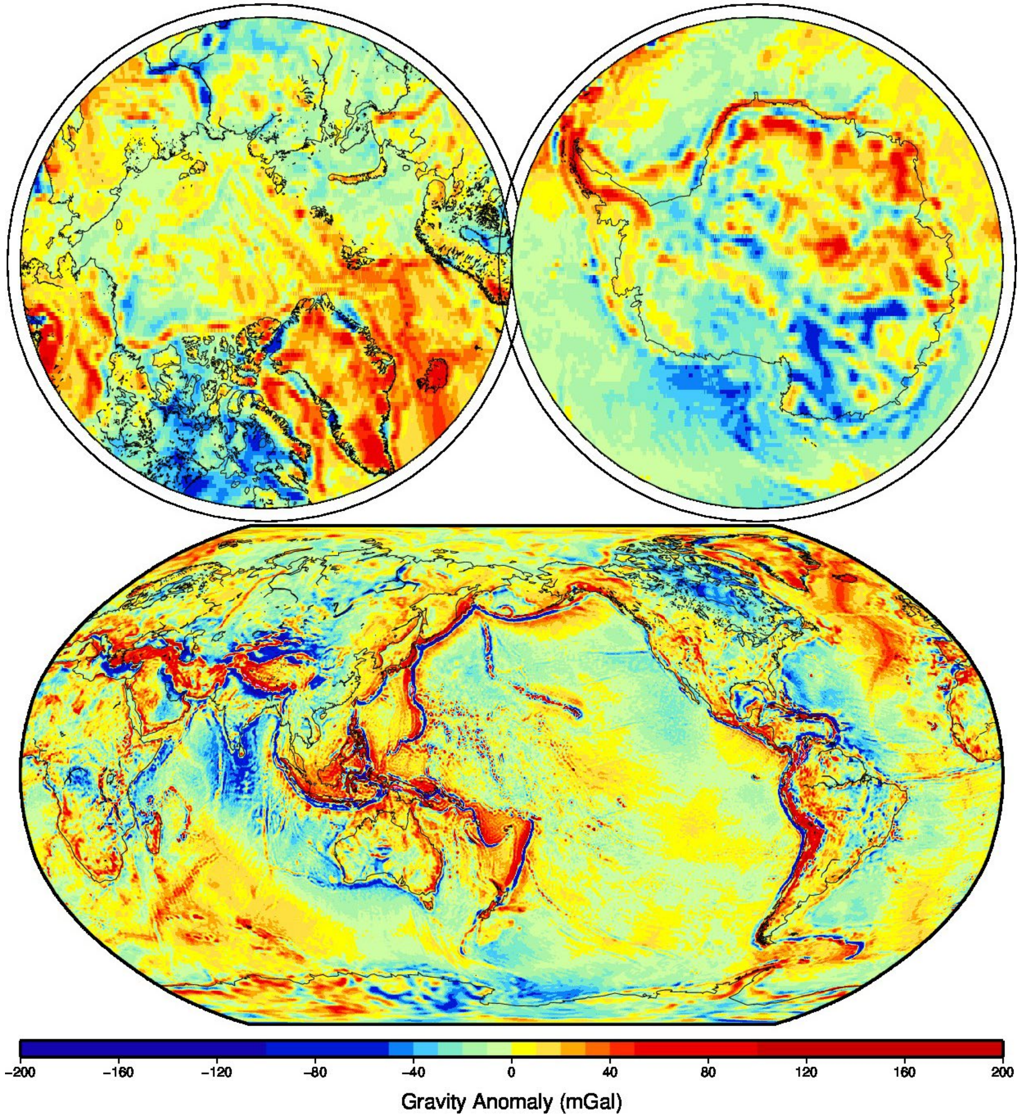
Jet Propulsion Laboratory
California Institute of Technology




**We now have over *two decades* of unique monthly Earth system *Mass Change* observations!**

# Mean Gravity Model




Gravity anomalies from GGM05C to degree/order 360 (no smoothing)

# Monthly Time Variable Models

GRACE data have significantly improved our understanding of the *global water cycle*, *mass and energy exchange* within and between the Earth System components, the *changes in ocean mass*, the changing *dynamics of polar ice caps* and *large continental aquifers* and improved the prospects for assimilation of mass change data into Earth System models.

<u>*Examples of applications include*</u>*:*

Earth system mass transport

Mass contribution to sea level change

Ocean heat storage

Surface and Deep Ocean Currents

Land surface ice sheet melt

Land surface TWS

Drought and flooding

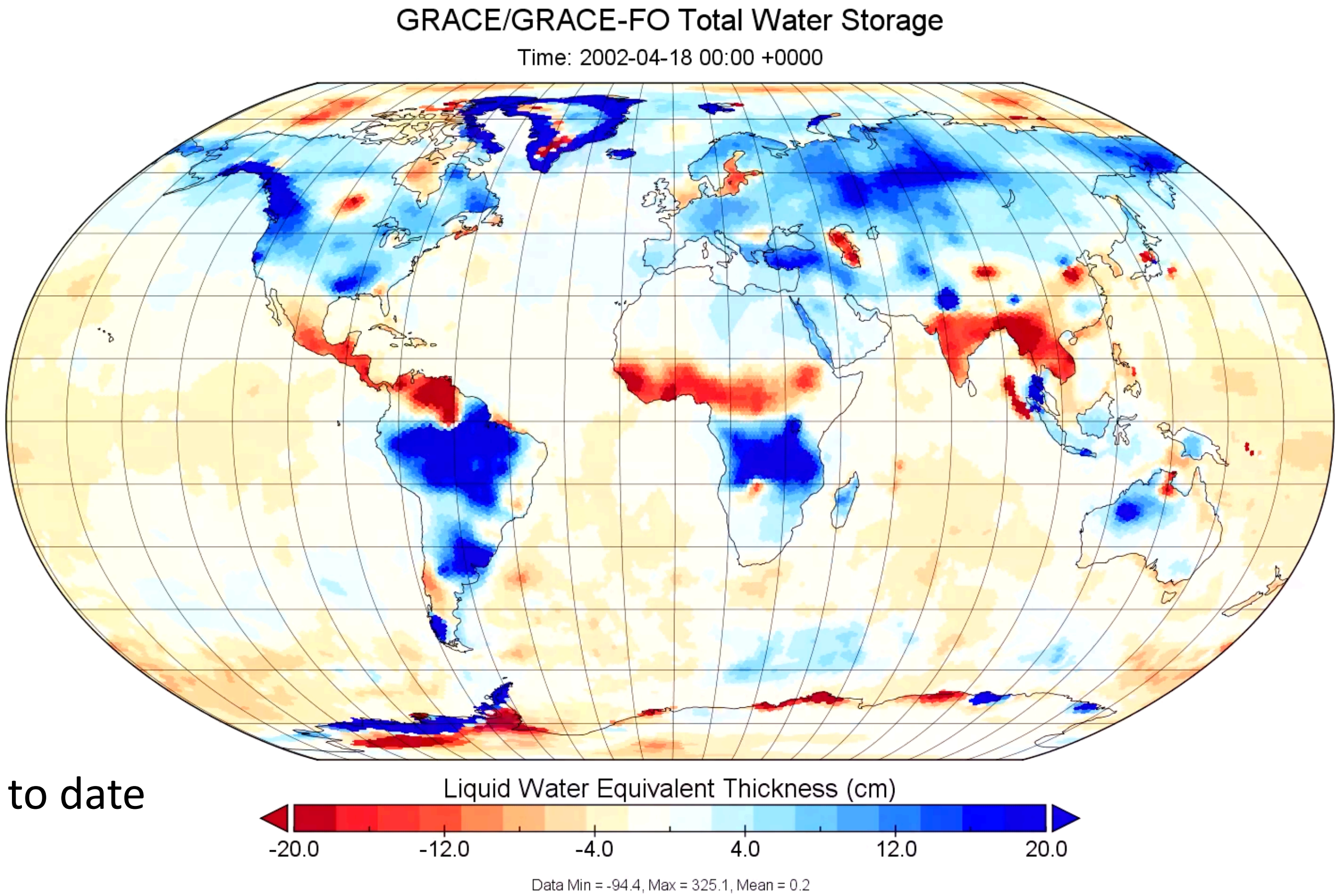
Water Availability Trends

Earthquake assessment

Modeling and assimilation

TWS Designated as an ECV

5600 Publications to date




Save, H., S. et al(2016), High resolution CSR GRACE RL05 mascons, J. Geophys. Res. Solid Earth, 121, doi:10.1002/2016JB01300

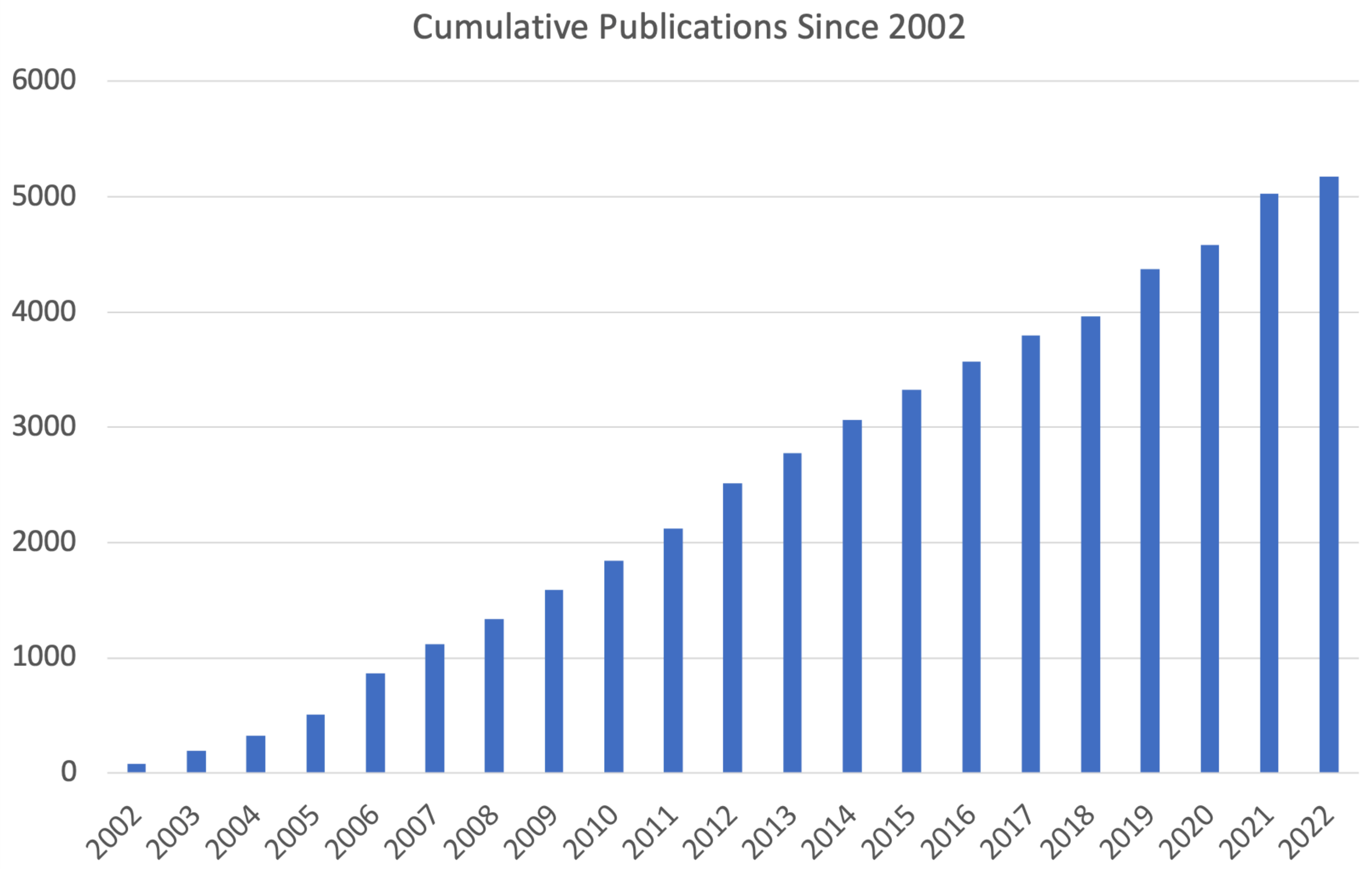
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

**Highlights:**

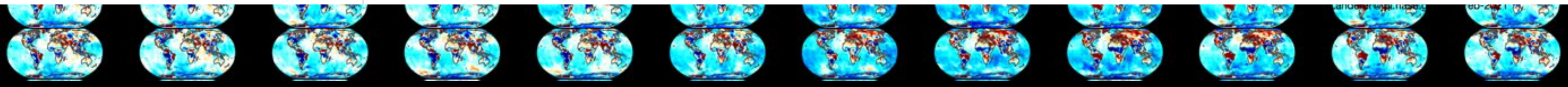
Publications: **5412**

**2nd most cited** NASA instrument/observable in the **IPCC AR6 report**

Terrestrial Water Storage (i.e., Mass Change) has recently been classified as a **GCOS Essential Climate Variable** and contributes to 14 of 54 additional GCOS Essential Climate Variables




2020



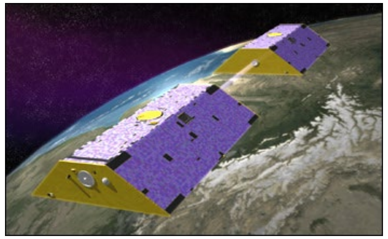
2022

# Mass Change Data Record: An established climate variable.

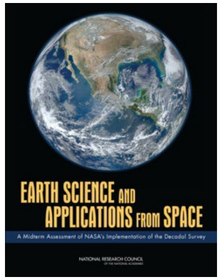
**2022: GCOS establishes Terrestrial Water Storage as an Essential Climate Variable; recommends urgent action to ensure continuity of gravity measurements**

2000 | 2010 | 2020

**1997**: Gravity Recovery and Climate Experiment (GRACE) selected under the NASA Earth System Science Pathfinder Program.

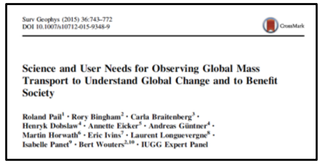


**2002**: Launch of GRACE




**2007**: Decadal Survey recommends a higher capability GRACE-II as a Tier-3 mission to continue observations from GRACE

**2010**: NASA Climate-Centric Architecture report recommends GRACE Follow-On as a gap-filler to continue observations between GRACE and GRACE-II



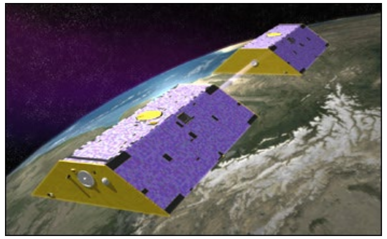

**2015**: IUGG Report on science and user needs for mass change to improve upon POR


**2016**: NASA/ESA IGSWG Report provides roadmap for 2-pair implementation to satisfy needs in IUGG report


**2017**: Decadal Survey recommends Mass Change as a Designated Observable to continue observations from GRACE-FO

**Continuity has been called for in three community reports: DS-2007, CCA-2010, DS-2017**

**Advances the goals of a broad community of the most important climate science and applications**



**2017**: GRACE End of Life

**2018**: Launch of GRACE-FO

**2002-2017, 2018 – present: GRACE and GRACE-FO Establish a Mass Change Climate Data Record**

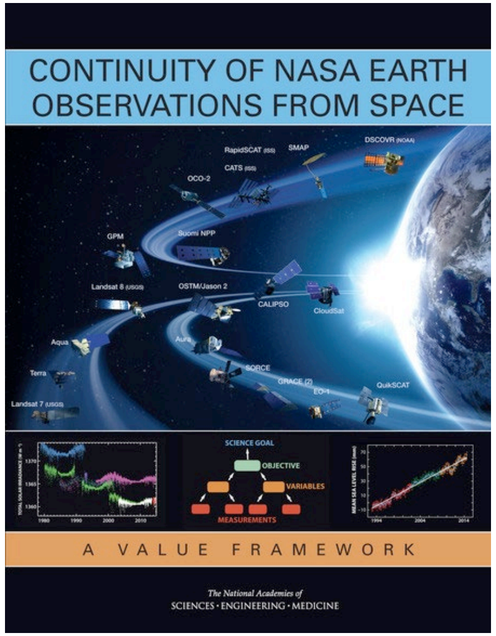
# The NASA 2010 Climate Centric Architecture

Climate Continuity Missions: The FY2011 budget request allowed NASA to address *important scientific needs for continuity of key climate observations*

- Includes a GRACE Follow-on mission (with a launch in 2016) to serve as a gap-filler between the operating GRACE and the recommended higher-capability GRACE-II Decadal Survey Tier 3 mission.


A following NRC Report, the 2016 NRC Climate Continuity Report, set requirements for selecting continuity missions.

- *Study was charged with looking at Continuity as a new element in the NASA Mission responsibilities.*
- *Defines Continuity in terms of a measurements ability to maintain consistent quality in the interpretation of scientific trends across the mission boundaries*
- ***Report underscores the problem with gaps in measurement record and encourages mission overlap***



# An internationally established and relied upon fundamental component of United Nations/ GCOS Essential Climate Variables (ECVs)

- **Satellite gravimetry missions provide critical ECVs data, uniquely monitoring sea level, terrestrial water storage (TWS) and ice sheets.**
    - TWS storage is now an official GCOS Essential Climate Variable (ECV)

- **Time-variable satellite gravimetry** is an effective way to measure TWS & groundwater globally
    - Could supersede or complement assessment of anthropogenic water use and groundwater monitoring
    - Could serve early warning systems for large-scale flood events or drought monitoring and forecasts.

- **With respect to "*gaps in satellite observations likely to occur in the near future*":**
    - "Urgent actions are needed to ensure continuity of …gravimetry missions …." [GCOS Implementation Plan, 2022]

# Recommendations from the 2017 Decadal Survey Report

- The Mass Change Measurement time series established by GRACE and GRACE FO is a very important component of the satellite remote sensed data set.
  - Measurements are deemed as Most Important in three of the six areas of interest
  - Hydrology, Climate and ESI Panels, along with the Global Water Cycle Panel, would use the MCM data to satisfy Most Important measurements objectives.
  - Change in Ocean mass, and it's role in the establishing the Ocean heat storage, Polar ice sheet mass and land surface total water storage were typical objectives where MCM measurements would be essential.
- The MCM should continue the GRACE FO series with accuracy comparable to the GRACE/ GRACE FO performance
- Measurement continuity is very important, so the MCM satellites should be launched to overlap with GRACE FO.
- Given the design maturity of the GRACE FO satellites, the mission cost should be comparable with the GRACE FO. The implementation cost assumes international participation in the mission implementation
- The primary deficiencies lie in the spatial and temporal resolution
- The technology challenge relates to deficiencies in spatial and temporal resolution and mission lifetime.

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# The Mass Change Observable

The Mass Change Targeted Observable(TO-9) corresponds to the movement of mass, whether it is moisture, groundwater, snow, ice, ocean water, and represents exchanges within and across elements of the Earth system. As such, the Mass Change Targeted Observable provides an integrated view of the entire physical Earth system, and allows the relating of changes in one system component to changes in another. By providing continuity of the GRACE measurement record, it addresses Most Important and Very Important objectives for three panels (Climate, Hydrology, and Solid Earth) and contributes to several integrating themes.

Mass Change Signals:

Groundwater

Surface Water

Soil Moisture

Glaciers & ice Sheets

Snow

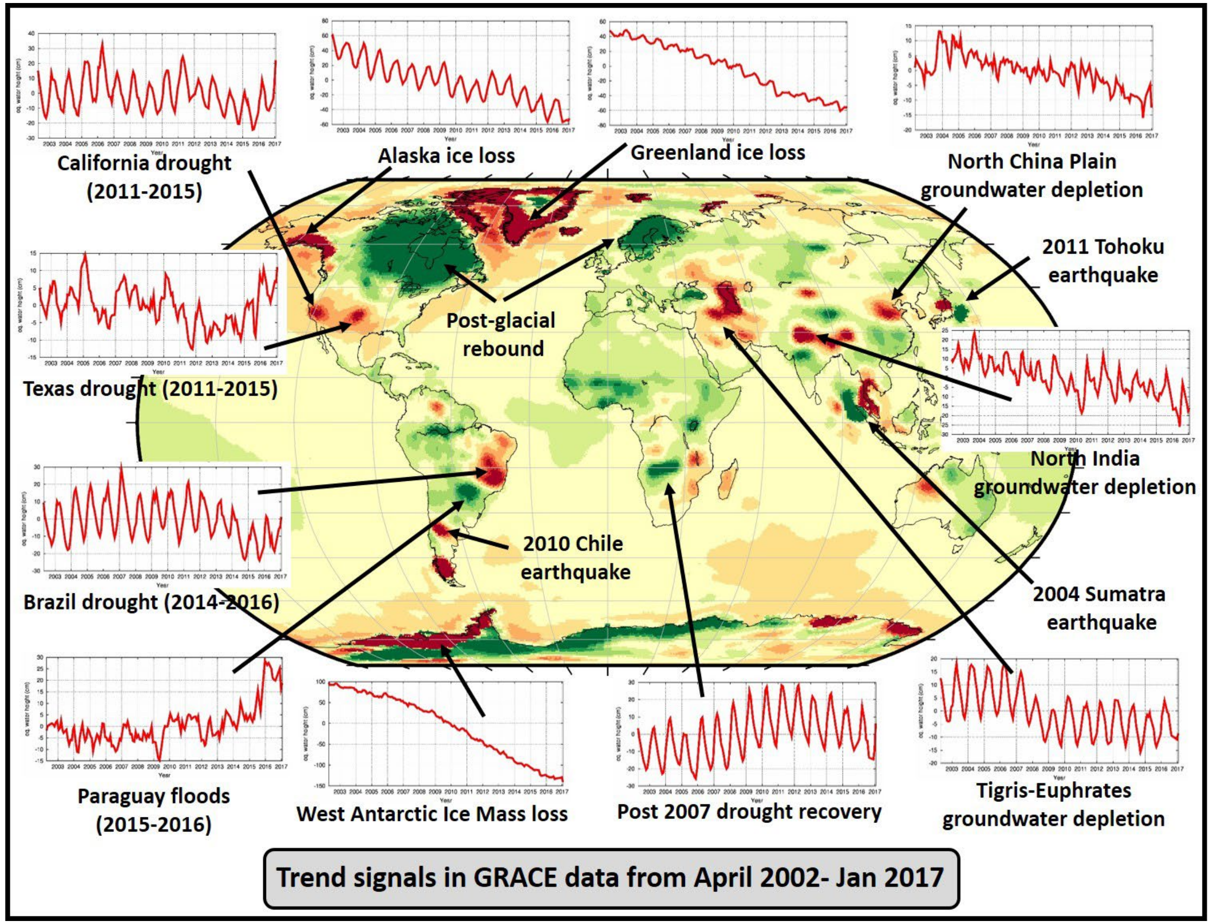
Permafrost

GIA

Subsidence

Earthquake

*Ocean Mass*




Trend signals in GRACE data from April 2002- Jan 2017

# NA 2017 ESAP Decadal Survey
# Box 4.7 The Need for Continuous Measurements

Satellite remote sensing measurements of Earth are used both for immediate applications and to establish long-term records that are essential for understanding Earth System behavior on longer time scales.

Two Targeted Observables (Mass Change and Surface Deformation and Change) are included in the Designated program element *specifically* to ensure continuity; several of the Targeted Observables listed in Table 3.6 (Greenhouse Gases, Ozone and Trace Gases, and others) are recommended for competition in the Earth System Explorer program element in part to provide continuity;

# The Need for Continuous Measurement

The need for a continuation of the Mass Change Measurements is a clear community priority, but *continuation does not necessarily satisfy the requirements for continuity.* Mission continuity has more demanding requirements

- Continuation
  - Measurement availability is primary requirement
  - Measurement quality should be maintained
  - Supports important application efforts, which would be impacted by nonavailability of the data
  - Supports important Earth System process studies

- Continuity
  - Calibrated and validated data of consistent quality
  - Validation of long term climate change trends
  - Assists with improving models and providing consistent multidecadal trends
  - Essential many Climate Change studies

# State of the Mass Change Measurement

The combined GRACE and GRACE-FO data record now covers the period from 04/2002 through 12/22, and has provided over 21 years of unique, global, month-to-month gravity and mass change observations that:

- Observe the mass movement within and between the Earth System components
- The data is used for science studies in Land Surface Hydrology, Oceanography and Cryology and for important applications in drought and water assessment and management and hazard assessment.
- Stimulated and support extensive interdisciplinary studies
- Produce science results that map directly onto 15 ESAS Earth Science objectives,
- 9 of which are in the very/most important category of the 2017 Earth Science and Applications from Space Decadal Survey report.

Over 5,600 papers have been published using the GRACE/GRACE FO data, and the data is the 2nd most cited NASA instrument/observable in the IPCC's 6th Assessment Report.

Important application of the data include international monitoring of land surface water availability and drought monitoring, and hazard assessment, including Earthquakes, flood prediction and assessment

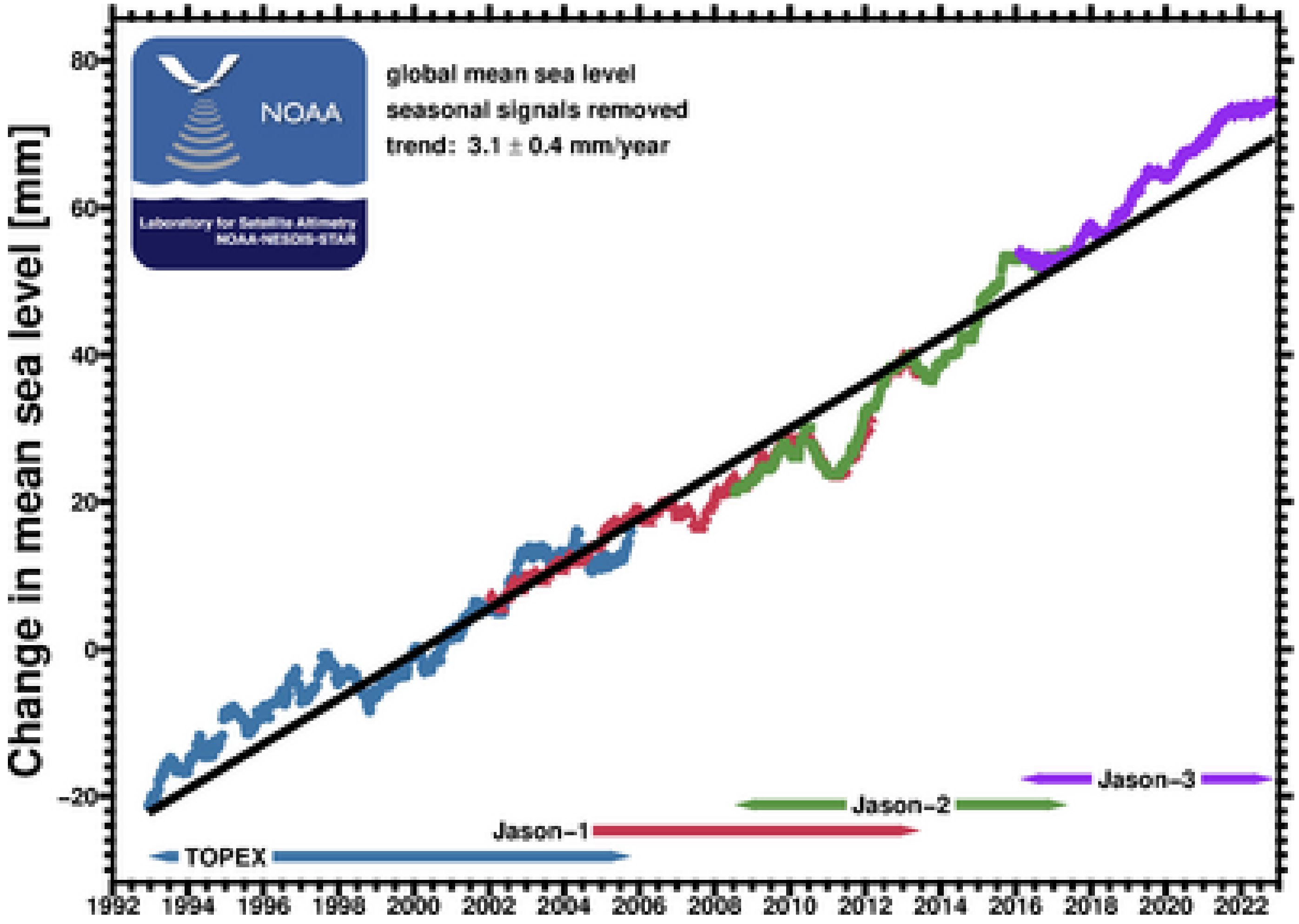
Extensive international use of the Mass Change Measurements contribute to the definition of 15 GCOS Essential Climate Variables.

The GRACE/GRACE FO Total Water Storage has been designated as a specific GCOS Essential Climate Variable

The 2017 ESAP Decadal Survey described the Mass Change Measurement as a "foundational measurement" and selected it as one of five measurements designated for implementation

# Some of the Science

# Global mean sea level from TOPEX/Poseidon, Jason-1,-2,-3




**A standard for Mission Continuity**

# Interpretation of Sea Level Change

From 2017  ESD Decadal Survey, p -3-34

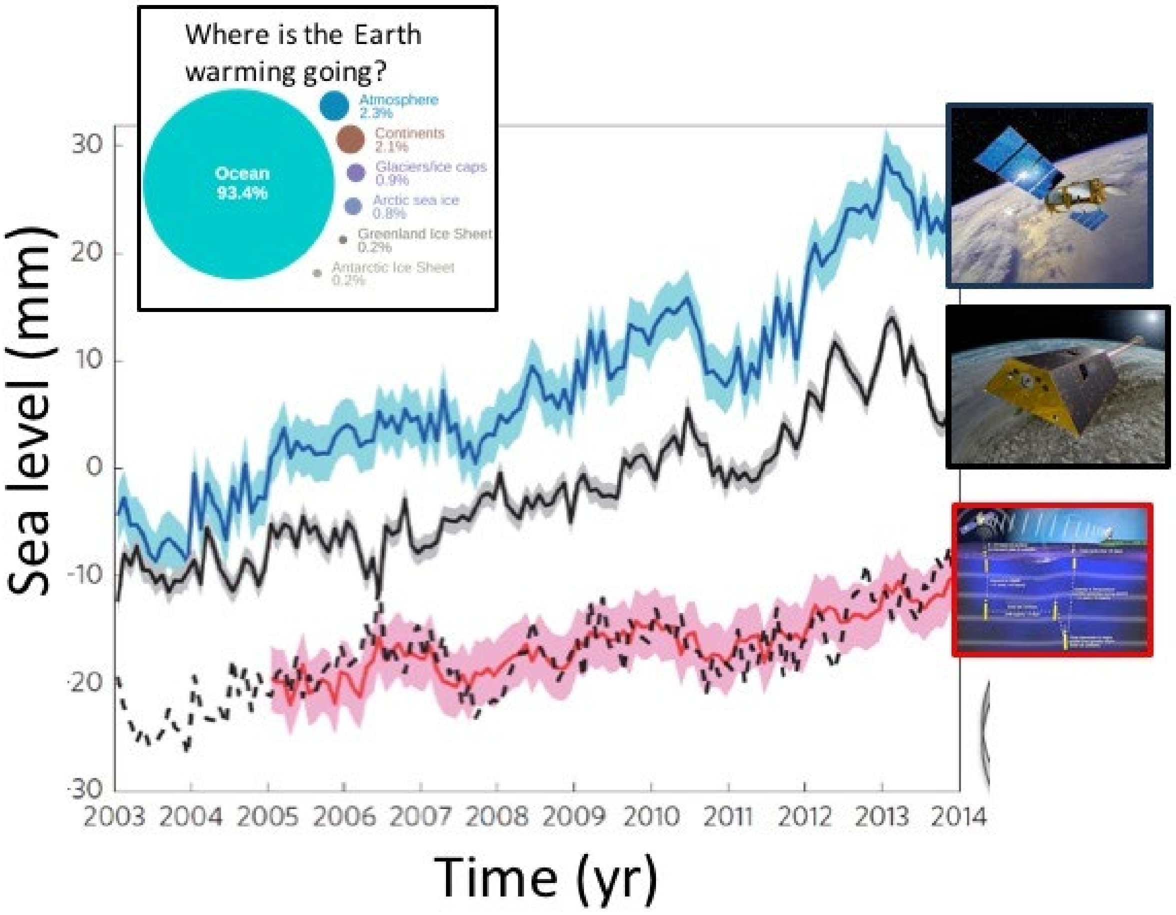



**FIGURE 3.8** More than 90% of the enhanced heating by greenhouse gases is being taken up by the oceans. This heating contributes a large fraction of the observed sea level rise. The global mean sea-level variations are observed variations by satellite altimetry (blue). The mass contributions from land sources (mostly ice sheets) are determined from GRACE data (solid black). The steric sea level rise component (thermal expansion) is the difference (dashed black curve) and is independently estimated based on in situ observations (red) limited to ocean depths up to 2000 m. These data suggest most heat uptake occurs over this depth of ocean (Llovel et al, 2014).

***Climate Variability and Change***        ***C-1 Sea Level Change***

The need to quantify the rates of sea-level change and its driving processes at global, regional, and local scales is of great importance as discussed by the Climate Panel. …. Gravity measurements provide critical information not only on the contributions of ice sheets and glacier systems to sea-level rise, but also changes and movement of mass throughout the Earth System (Box 3.7).

# Interpreting the Sea Level Budget

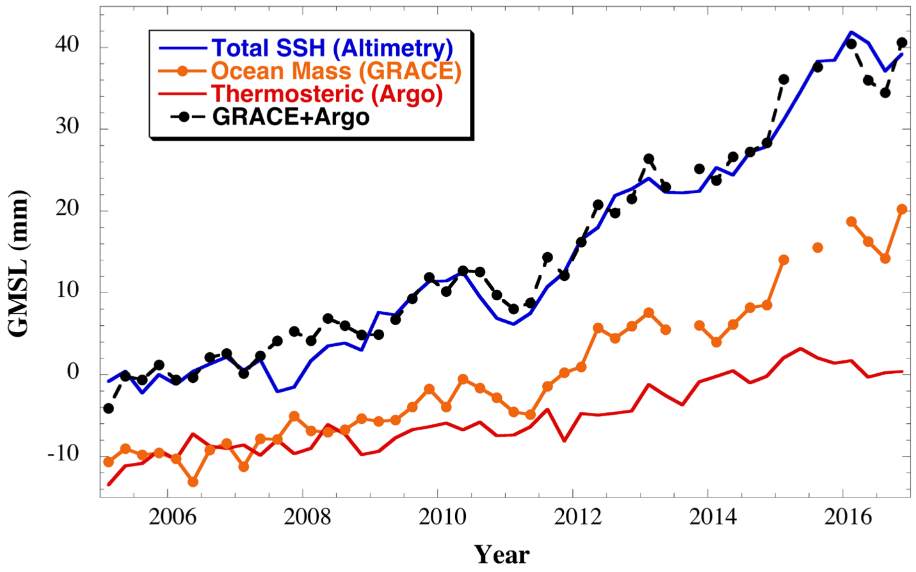
Trends

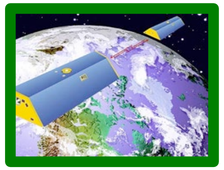
GRACE: 2.5 ± 0.4 mm/yr

Argo: 1.1 ± 0.1 mm/yr

Altimetry: 3.7 ± 0.6 mm/yr

G+A: 3.6 ± 0.4 mm/yr



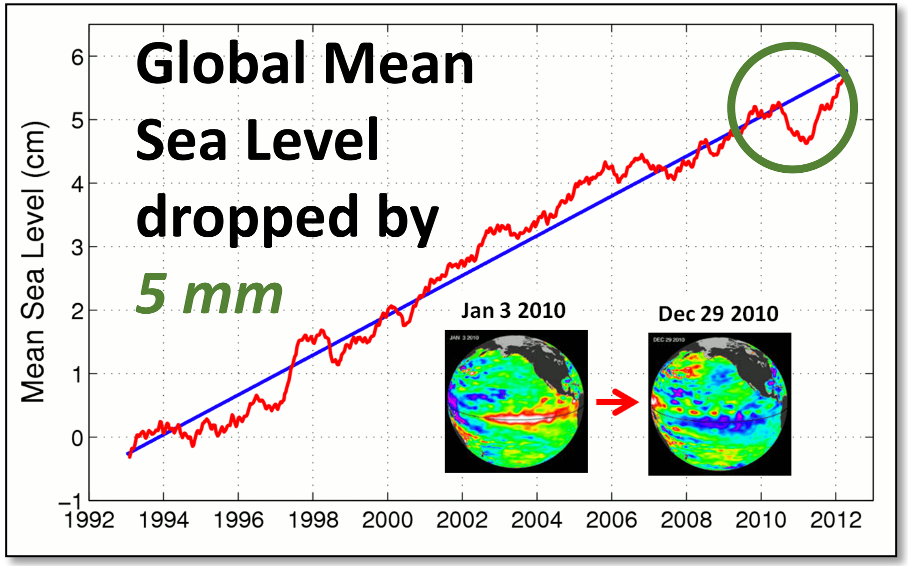



3-month averages, annual sinusoids removed. Error is 90% confidence and accounts for variance of residuals about fit, autocorrelation, and systematic errors for altimetry and GRACE.( Chambers, 2018)

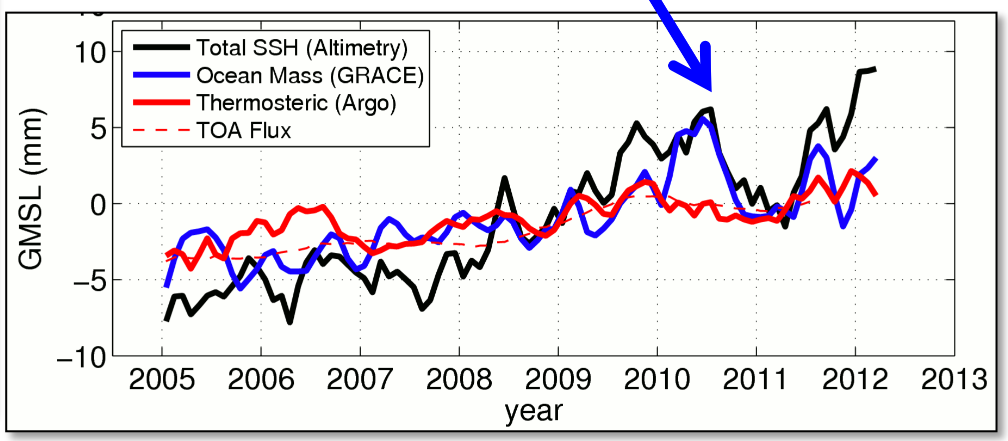
Acceleration ~ 0.084 ± 0.025 mm/y2, (Nerem, et al, 2018)

# Water Cycle – Interdisciplinary Research

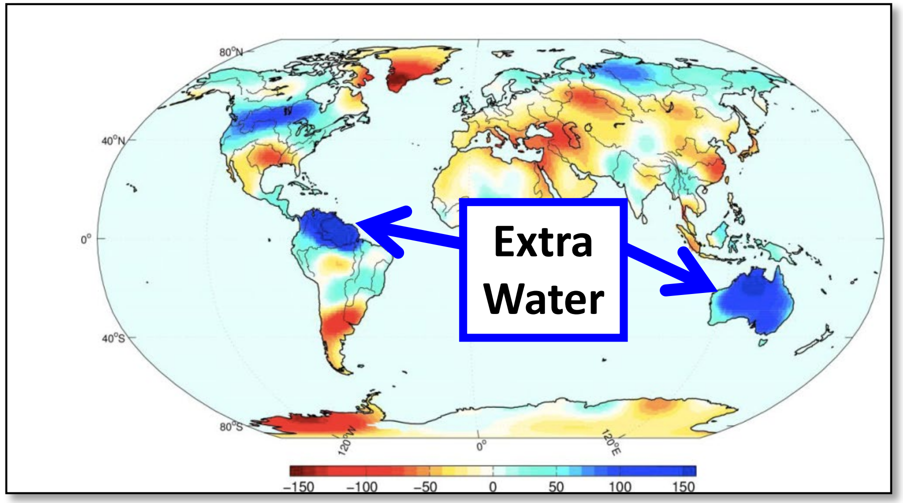
*The 2011 La Niña: So Strong, the Oceans Fell*




**Explained by missing *ocean mass***



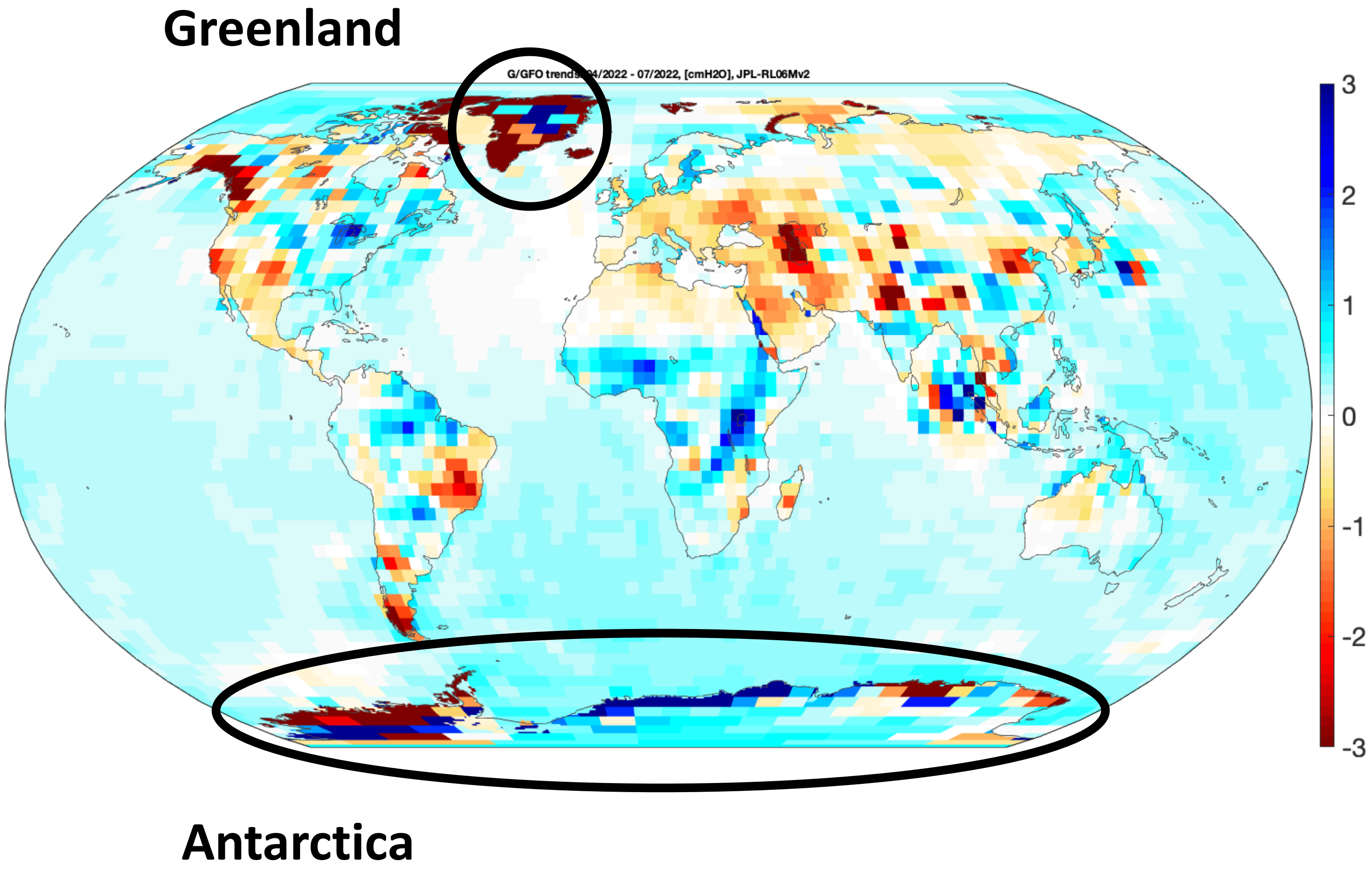

GRACE shows change in land water storage
from 2010 to 2011




1) **The problem:** *Projections* of how much the the GMSL will rise in the future *are highly uncertain*.
2) **What was done:** Combination of GRACE data, satellite altimetry and ARGO data used to explain sources of *sea level drop in 2010/11*
3) **Main findings:** GMSL drop was primarily caused by *freshwater exchange between ocean and land forced by strong La Nina event*.


*Boening, C., J. K. Willis, F. W. Landerer, R. S. Nerem, and J. Fasullo (2012), The 2011 La Niña: So strong, the oceans fell, Geophys. Res. Lett., 39, L19602, doi:10.1029/2012GL053055.*

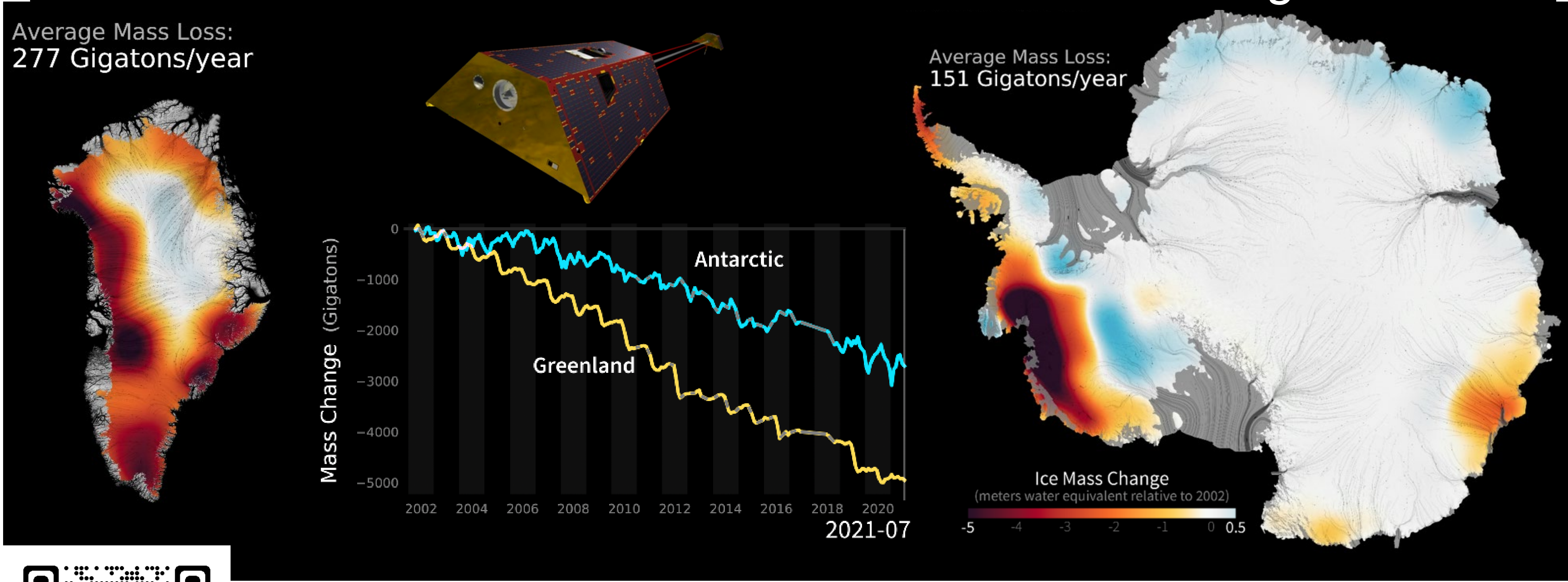
# Global Mass Change trends: 2002 - 2022




Units:
[cm-H2O / yr]

Data:
JPL Mascons

# **GRACE Follow-On:** Observations of *Ice Mass Change*



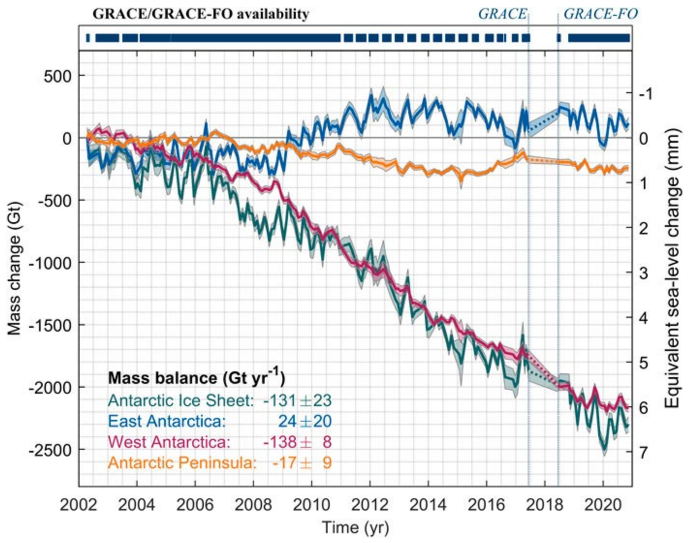

https://svs.gsfc.nasa.gov/31166

# Acceleration of Dynamic Ice Loss in Antarctica observed with GRACE-FO

Diener, et al., 2021, https://doi.org/10.3389/feart.2021.741789

The dynamic stability of the Antarctic Ice Sheet poses a large uncertainties for estimates of future global sea-level rise. Improving projections of the ice sheet evolution requires an understanding of the current trends and accelerations of ice mass changes from dynamics / discharge. GRACE/GRACE-FO data imply a mass loss acceleration of -5.3 Gt yr(-2) from discharge for the entire ice sheet from 2002-2020.

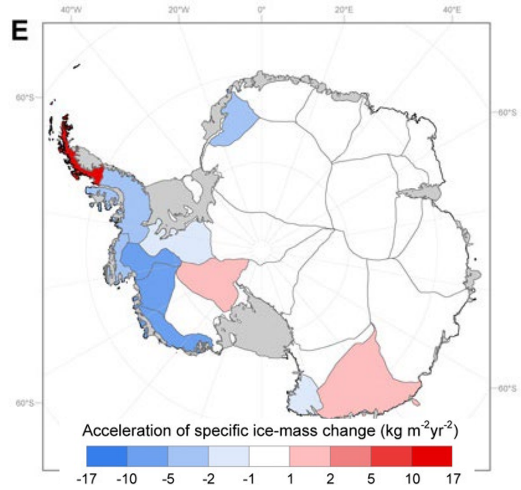
## Net Mass Changes:




Antarctic Ice Mass from from the GRACE and GRACE-FO missions. Equivalent sea-level contribution (right axis) is approximated as 1 mm sea-level rise for 360 Gt of ice mass loss.

## Acceleration of ice discharge :

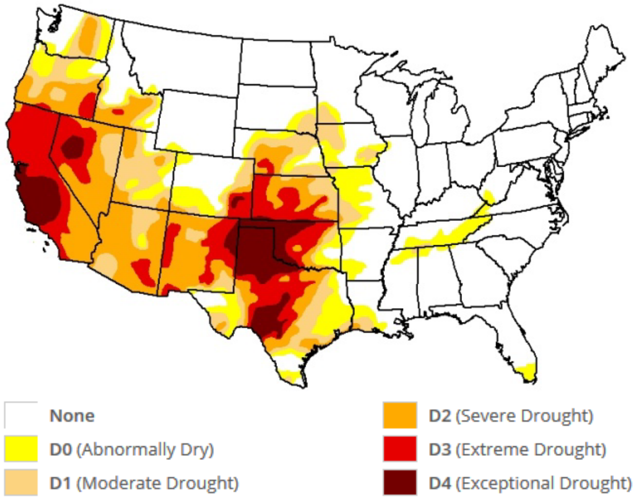
Ice-dynamic discharge can be derived by subtracting estimates of net snow accumulation from GRACE/GRACE-FO. After removal of these surface effects, GRACE/GRACE-FO data imply a discharge acceleration of -5.3 +/- 2.2 Gt yr(-2) for the entire ice sheet from 2002-2020, originating mainly in the Amundsen and Bellingshausen Sea Embayment regions (68%),



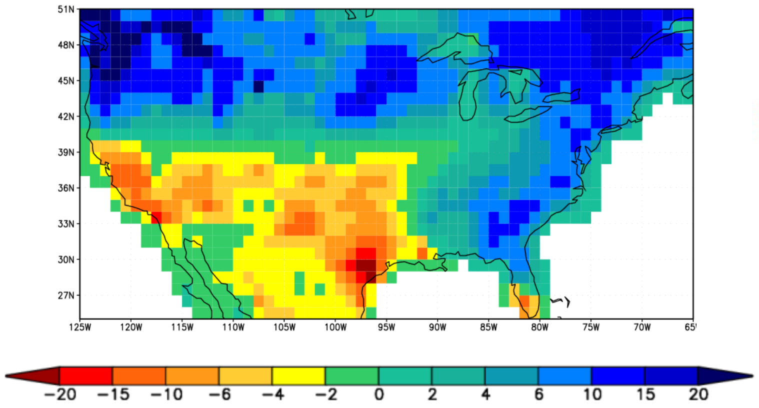

with additional significant contributions from Dronning Maud Land (18%) and the Filchner-Ronne Ice Shelf region (13%). If these rates and accelerations persisted, Antarctica would contribute 7.6 +/- 2.9 cm to global mean sea-level rise by the year 2100, more than two times the amount of 2.9 +/- 0.6 cm obtained by linear extrapolation of current GRACE/GRACE-FO mass loss trends.

# GRACE & GRACE-FO DA Based Wetness/Drought Indicators

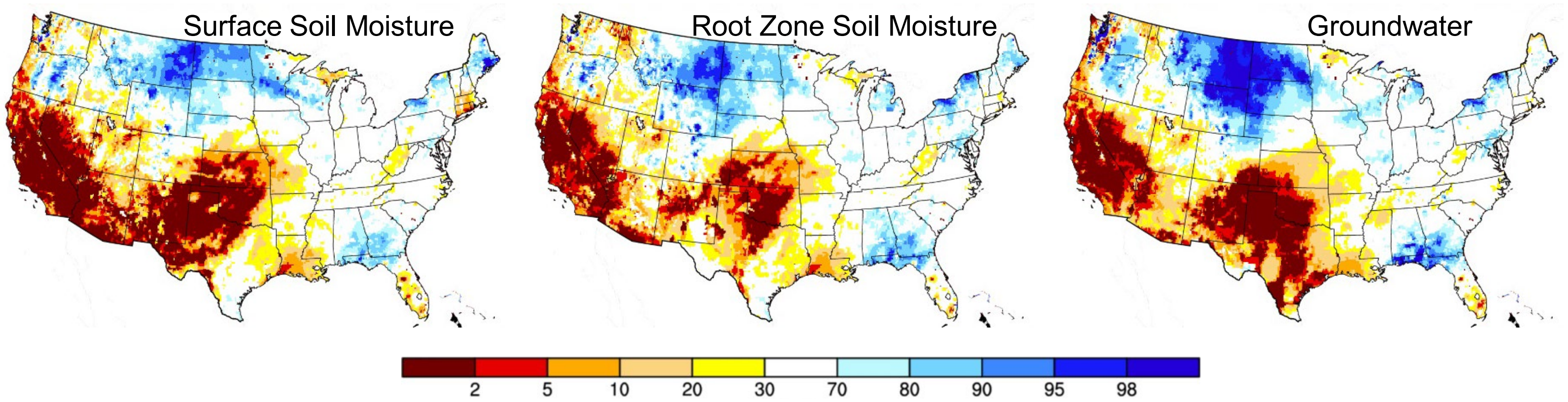
- 1948 to 2014 “open loop” (no data assimilation) LIS/Catchment LSM simulation provides background climatology
- 2002 to present, NLDAS2-forced, LIS/Catchment LSM simulation with GRACE & GRACE-FO DA, adjusted to be consistent with the background climatology using the overlapping period
- Groundwater and root zone and surface soil moisture outputs are converted to location and date-specific percentiles based on the CDF of the climatology
- Since 2011, weekly maps (below right) and data have been used by the authors of the U.S. Drought Monitor (right) and posted at http://nasagrace.unl.edu/




U.S. Drought Monitor for 20 May 2014, for comparison.




GRACE terrestrial water storage anomalies (cm equivalent height of water) for May 2014




Drought indicators from GRACE data assimilation (wetness percentiles relative to the period 1948-present) for 19 May 2014.

Houborg, R., M. Rodell, B. Li, R. Reichle, and B. Zaitchik (2012). Drought indicators based on model assimilated GRACE terrestrial water storage observations, *Wat. Resour. Res*, **48**, W07525.

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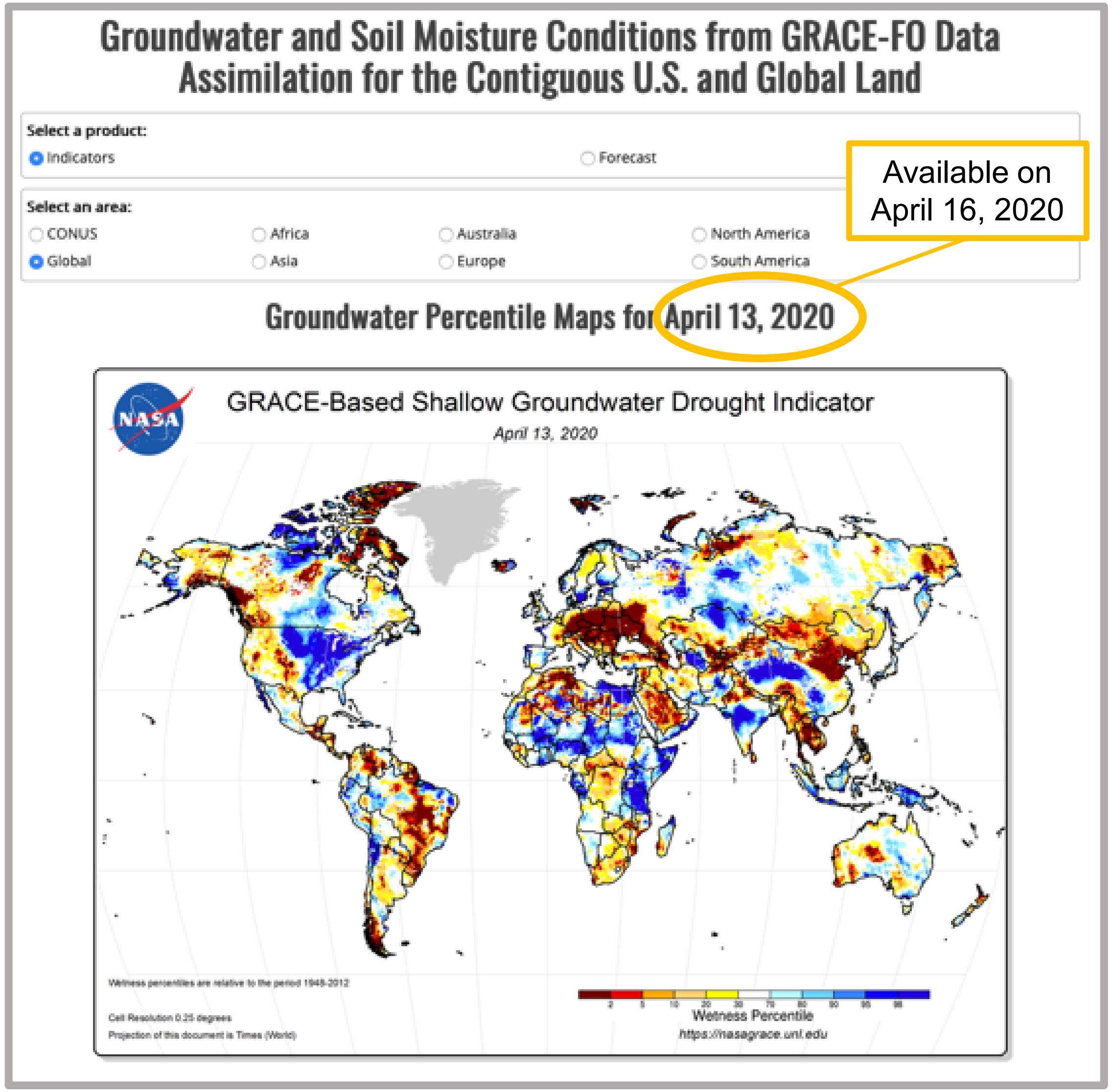
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

# First Global Groundwater Maps using GRACE-FO observations

Updated weekly for near real-time decision-making support




- NASA-GSFC is now generating weekly updates of **Groundwater and Soil Moisture Conditions** around the world that incorporate ***Mass Change Observations*** from the *GRACE-FO* satellites as a starting point.

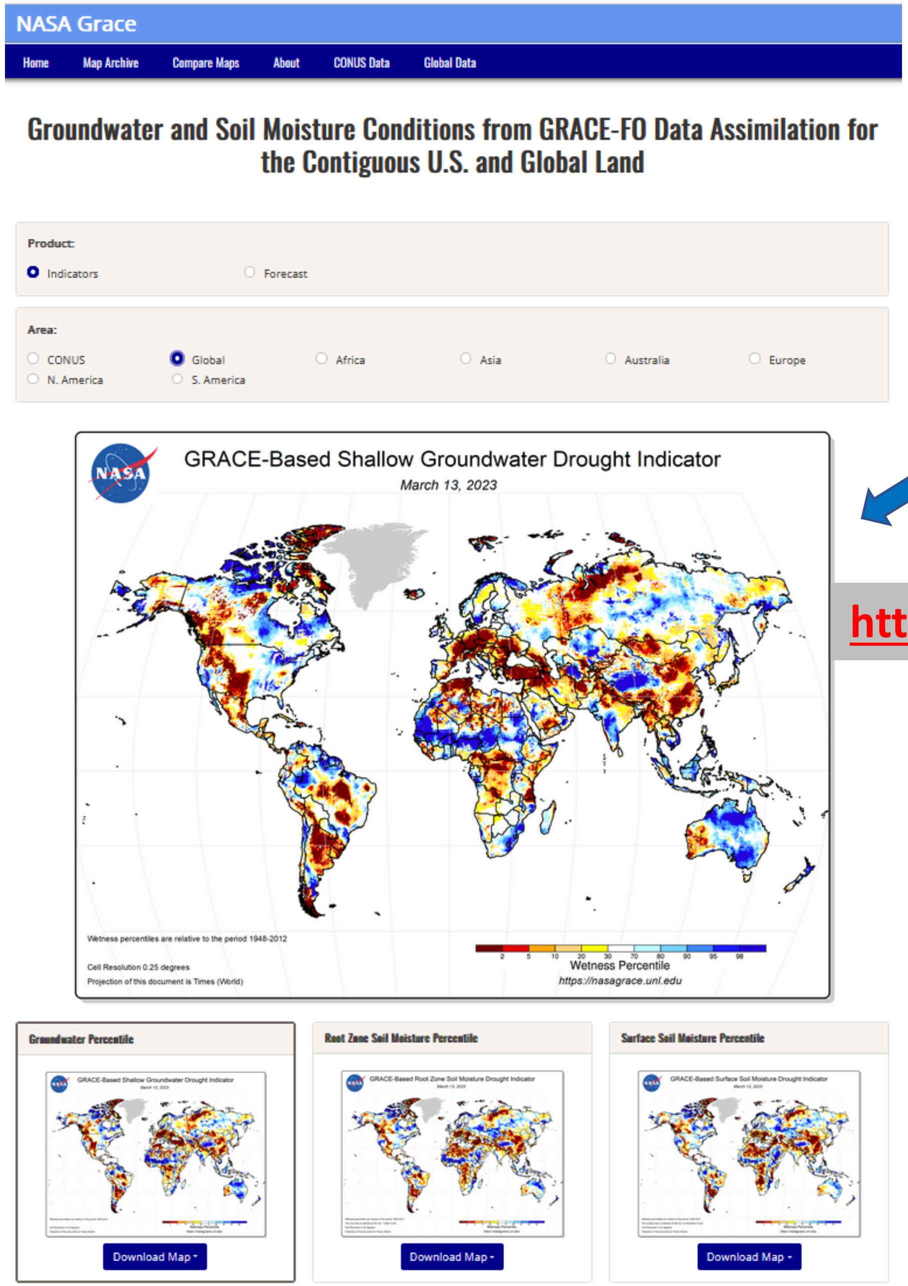
- The maps support management and decision-making by the USDA and FEMA, and soon by the U.S. Agency for International Development and the World Bank.

- New GRACE/GRACE-FO and hydrology assessments enable monitoring of both groundwater and extreme wetness and drought conditions globally in near-real time (<4 day lag) – these capabilities were severely lacking before.

https://nasagrace.unl.edu/

[Li et al. 2020]

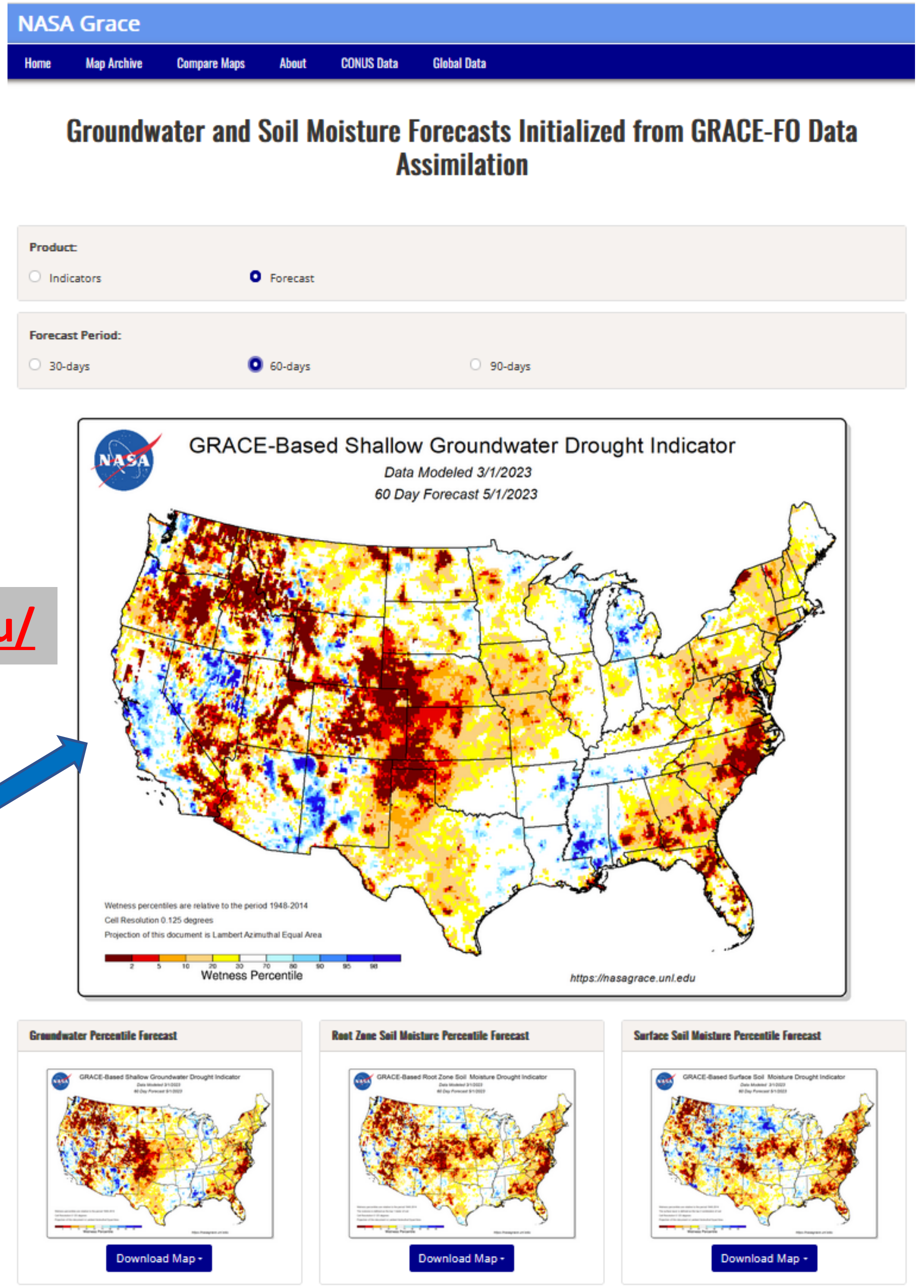
# GRACE-FO Data Assimilation Based Drought/Wetness Products

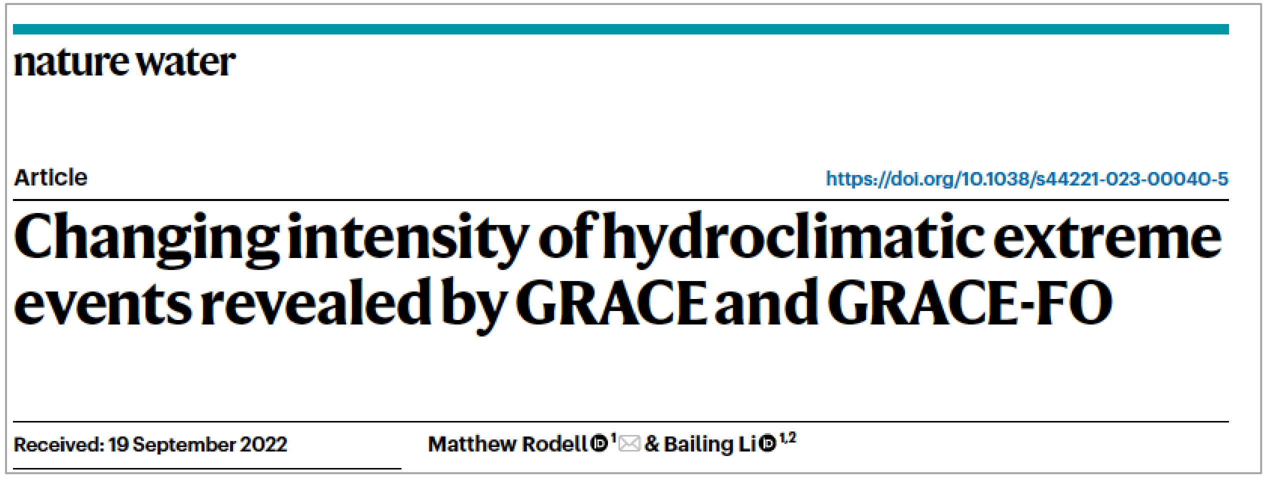



Weekly indicators

**https://nasagrace.unl.edu/**

30-90 Day forecasts





nature water

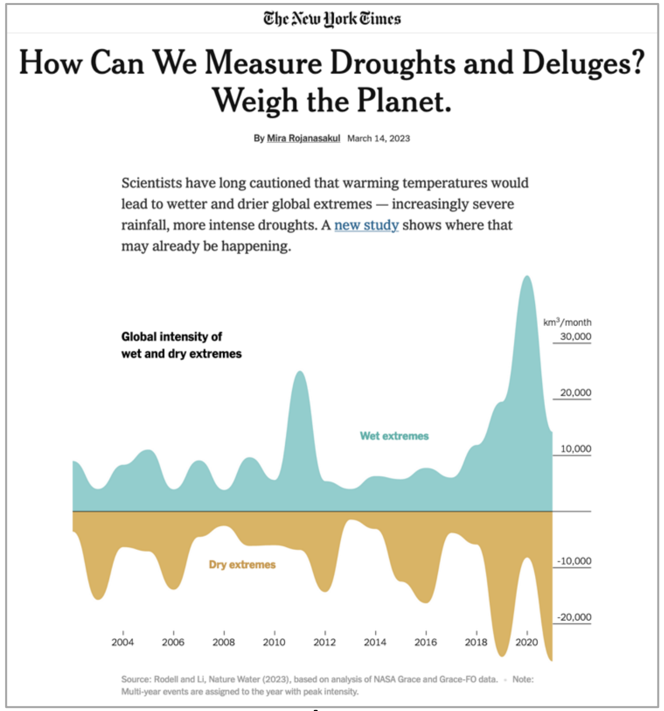
Article

https://doi.org/10.1038/s44221-023-00040-5

# Changing intensity of hydroclimatic extreme events revealed by GRACE and GRACE-FO

Received: 19 September 2022

Matthew Rodell[1] & Bailing Li[1,2]



The New York Times

## How Can We Measure Droughts and Deluges? Weigh the Planet.

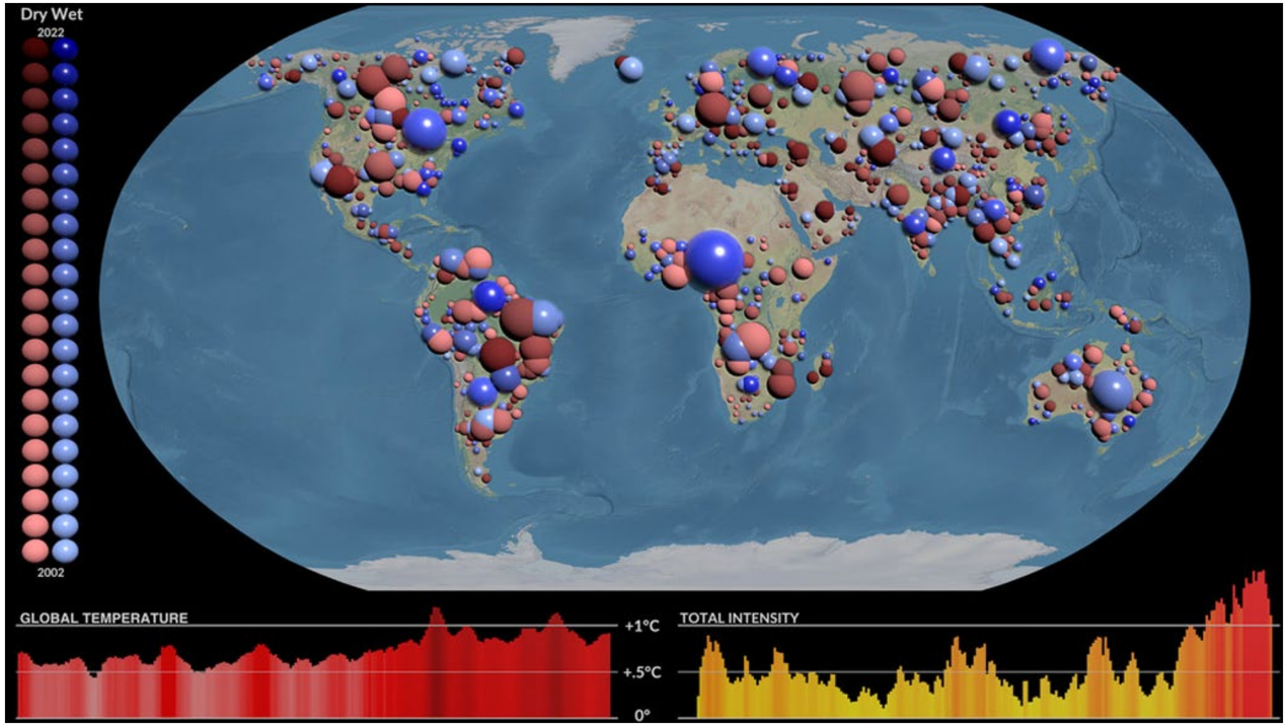
By Mira Rojanasakul March 14, 2023

Scientists have long cautioned that warming temperatures would lead to wetter and drier global extremes — increasingly severe rainfall, more intense droughts. A new study shows where that may already be happening.



Source: Rodell and Li, Nature Water (2023), based on analysis of NASA Grace and Grace-FO data. · Note: Multi-year events are assigned to the year with peak intensity.

NY Times, March 14, 2023




- Novel approach: terrestrial water storage observations from GRACE and GRACE-FO to delineate and characterize 1,056 extreme events during 2002–2021.
- Total intensity of extreme events was strongly correlated with global mean temperature, more so than with ENSO
- Implication: continued warming of the planet will cause more frequent, more severe, longer and/or larger droughts and pluvials.

# Status of GRACE-GRACE FO Continuity

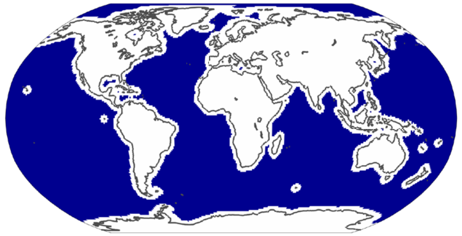
Current studies of science trends confirm that the GRACE FO performance is consistent with the GRACE performance during the nominal GRACE mission phase and exceeds it in the later uncontrolled temperature phase.

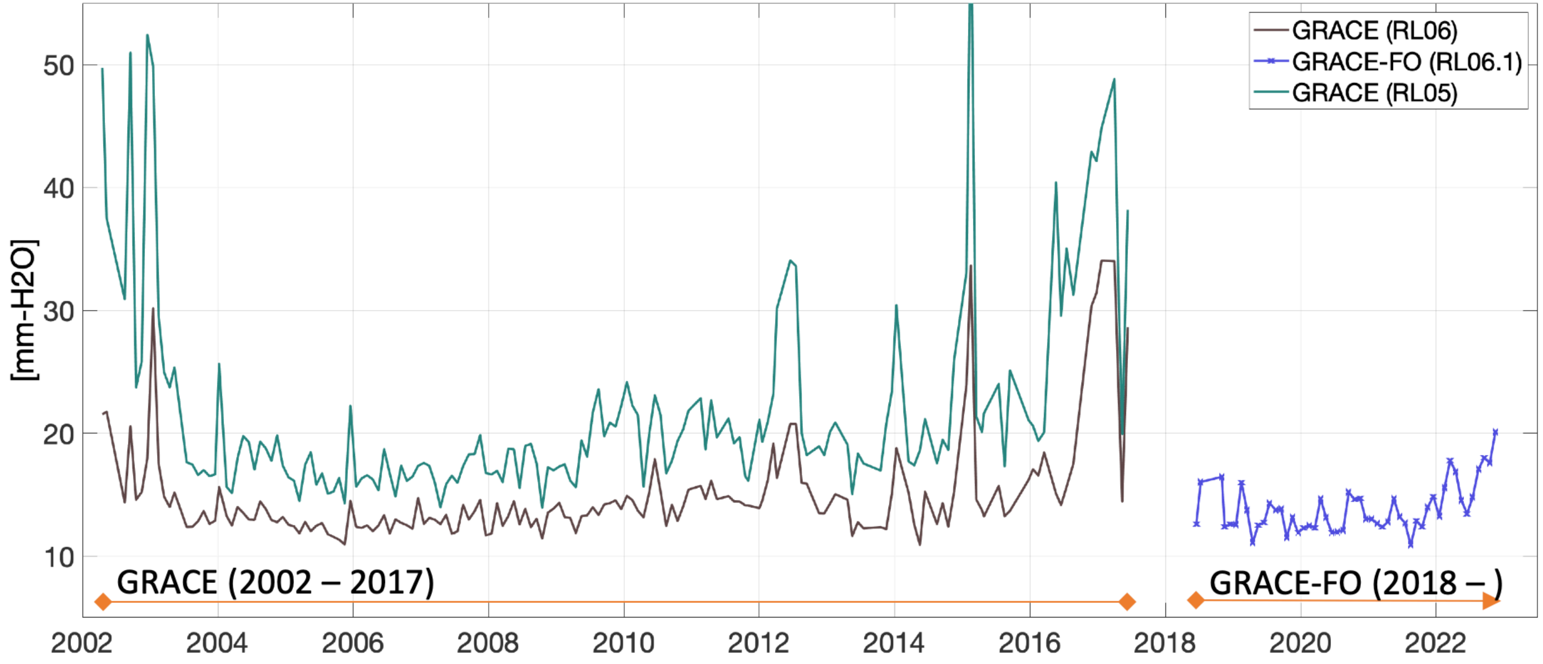
These studies conclude that the trends observed by GRACE can be related in a consistent and compatible manner to the trends observed by GRACE FO.

The GRACE FO results were obtained in a low solar activity period and the mission will operate in a less favorable environment during the remainder of the mission. Solar Cycle 25 activity has ramped up during the last year to F10.7 values that are higher than those encountered by GRACE during SC24.

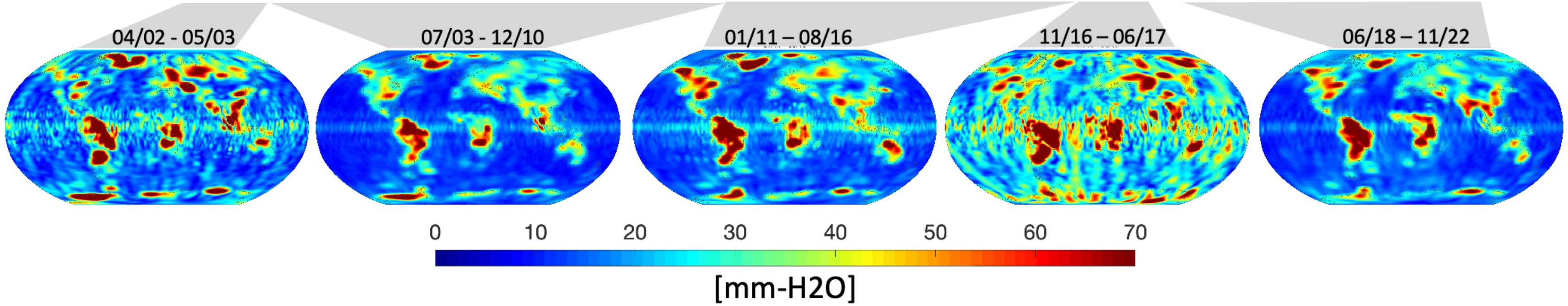
In the more active solar environment predicted during activity to establish continuity between GRACE FO and the MCM Mission, a challenging task will be encountered. Establishing continuity will be even more difficult if a mission gap occurs and this would support the need for a mission overlap between GRACE and GRACE FO.

# The Mass Change Record 2002-2022





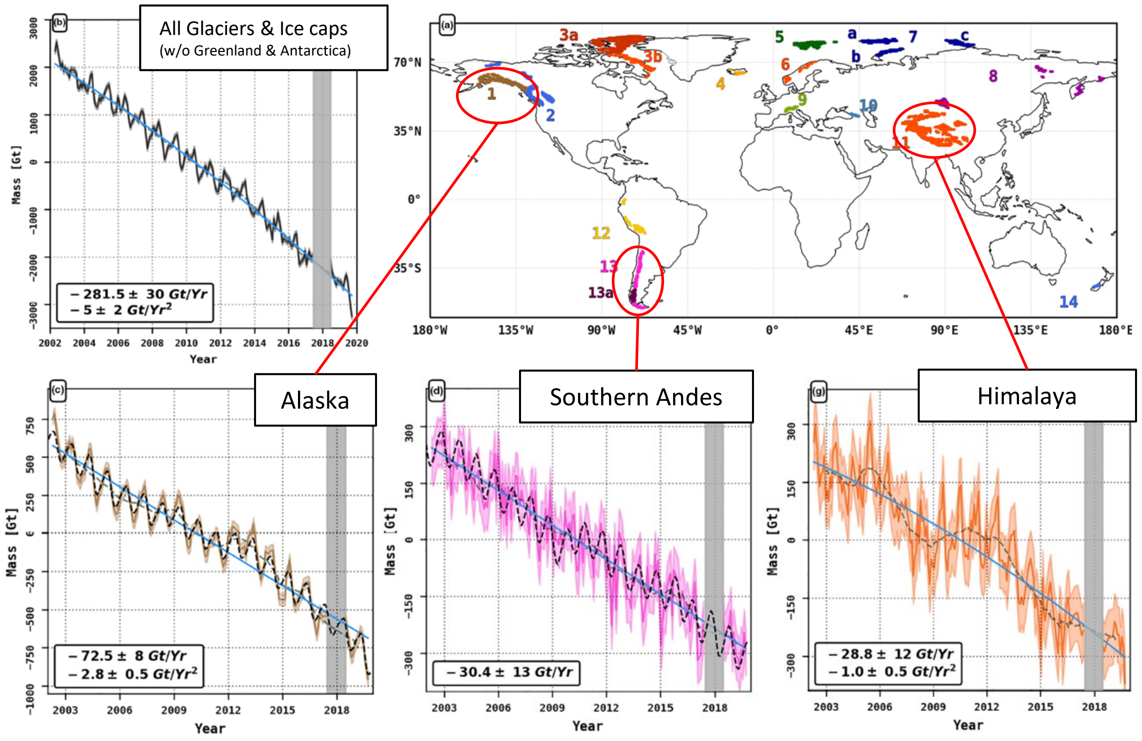

**<u>Ocean RMS:</u>**
Measure of error in the G/GFO monthly data




Error levels over the ***global ocean*** for **GRACE** and **GRACE-FO** are consistent across the 20+ year Mass Change data record.

Jet Propulsion Laboratory
California Institute of Technology

# GRACE & GRACE-FO satellites measure dwindling <u>total</u> glacier mass and freshwater reserves




Continuous monitoring of glaciers and ice caps with GRACE (2002-2017) and GRACE-FO (since 2018) has provided accurate measurements of global ice loss.

Glacier mass loss can affect freshwater resource management worldwide, in particular in the highly populated regions of High Mountain Asia and the Andes.

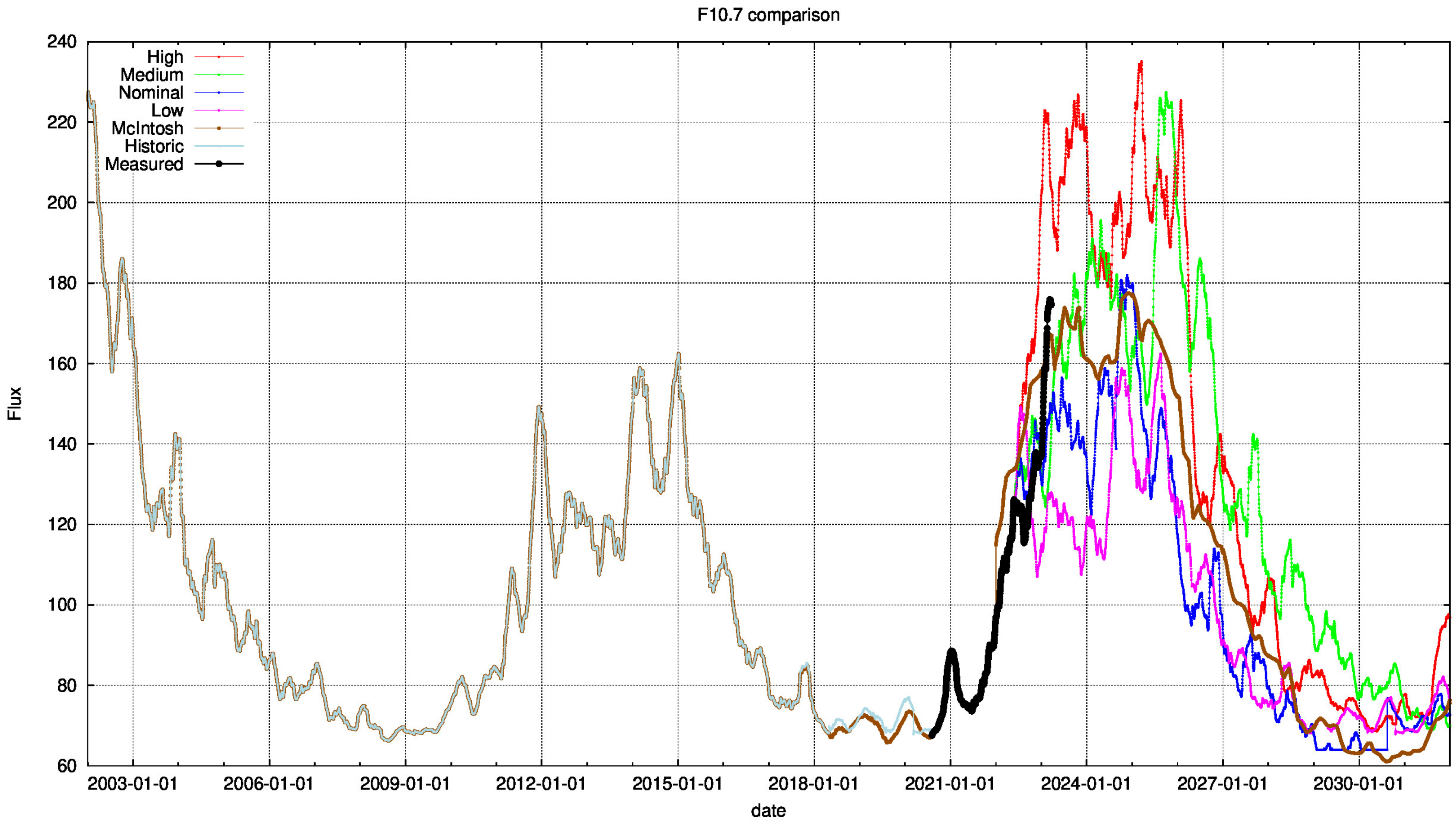
<u>Key Findings & Significance:</u>

- Glacier mass loss between 2002 and 2019 averaged 281.5 ±30 Gt/year (13 ±2 mm of global sea level rise).
- Significant acceleration in glacier mass loss of 50 ±20 Gt/yr per decade is occurring.
- The ice mass loss is most pronounced for Arctic glaciers (including Alaska) and glaciers in the Southern Andes and Himalaya.
- ***<u>Importantly:</u>*** Data continuity was confirmed between GRACE and GRACE-FO across the 11-month gap..

[Ciracì E., Velicogna I., Swenson S., Geophys. Res. Lett. 2020, https://doi.org/10.1029/2019GL086926]

# Outlook: Solar Cycle #25 continues to ramp up

- Progression & Prediction of solar cycle 25 is faster & stronger than initially predicted
- On trajectory to be of ***above-average*** strength (**McIntosh et al., 2020**)



# The GRACE FO Continuity Issues

The selection by GRACE FO in 2010 Climate Centric Architecture proposal to extend continuity of the MCM Measurement requires establishing connections between **GRACE and GRACE FO** and between **GRACE FO and MCM**

GRACE – GRACE FO Continuity issues

- Gap Between the Missions compounded by
  - Delayed lunch of GRACE FO
  - Lack of ACC availability of GRACE 2 ACC in late 2015 and 2017
  - Low altitude operation of GRACE
  - Degraded performance in GRACE FO ACC
- Connection aided by low solar activity interval

GRACE FO - Mass Change Mission continuity

- Possibility of a Gap between the missions
- Early termination of GRACE FO
  - Satellite component failure( Currently at end of nominal mission lifetime)
  - Atmospheric drag from high solar activity
  - Propellant expenditure from thruster leak
- Delayed launch date fof MCM
- Gap Between the GRACE FO and MCM Missions would involve
  - Low altitude operation of  GRACE FO
  - Degraded performance in GRACE FO ACC
  - Measurements in a high solar activity interval

# Summary of Current Concerns

- The GRACE FO Mission will likely end between 2028 and 2029
  - Cause for mission end will likely be propellent Expenditure due to leaking thrusters
  - Possible Drag Effects due to decreased Altitude and increased solar activity
- Multiple recommendations call for efforts to ensure Mass Change Measurement continuity
- Issue related to mission continuation
  - *Mission continuation is not necessarily mission continuity*
  - A gap between GRACE FO and the MCM impacts mission continuity
    - Multiple recommendations call for efforts to ensure record continuity
    - Concerns for both Science and Applications
  - Establishing Continuity over a break will be have an impact
    - Degraded ACC performance at low altitude will impact measurement accuracy
    - Extrapolation of science trends will be more difficult due to higher solar activity
    - In addition, a break raises the possibility of missing observations of unique events
  - Loss of Application data
    - TWS use for agricultural, water management and drought assessment purposes
    - Global Hazard Assessment including Earthquakes and Flooding
    - Weather Model Input from Occultation measurements
- Programmatic Issues
  - Mission concept and partnering has been successfully demonstrated by GRACE and GRACE FO
    - DLR funding for current proposed MCM mission expires in 2028
    - Using the proposed MCM partnering concept requires a 2028 launch

# Conclusion

GRACE-FO data continues the GRACE data record, and is producing excellent science and applications across all Earth system domains

For GRACE FO, the collection of high-yield gravity, mass change and GPS-RO, thermosphere observations

Improvements in data calibrations yields improved L-2/3/4 science data products

Comparison of Selected Science Trends across the GRACE and GRACE FO mission gap are consistent with continuity

Enabled by the mission gap occurring during minimal solar activity

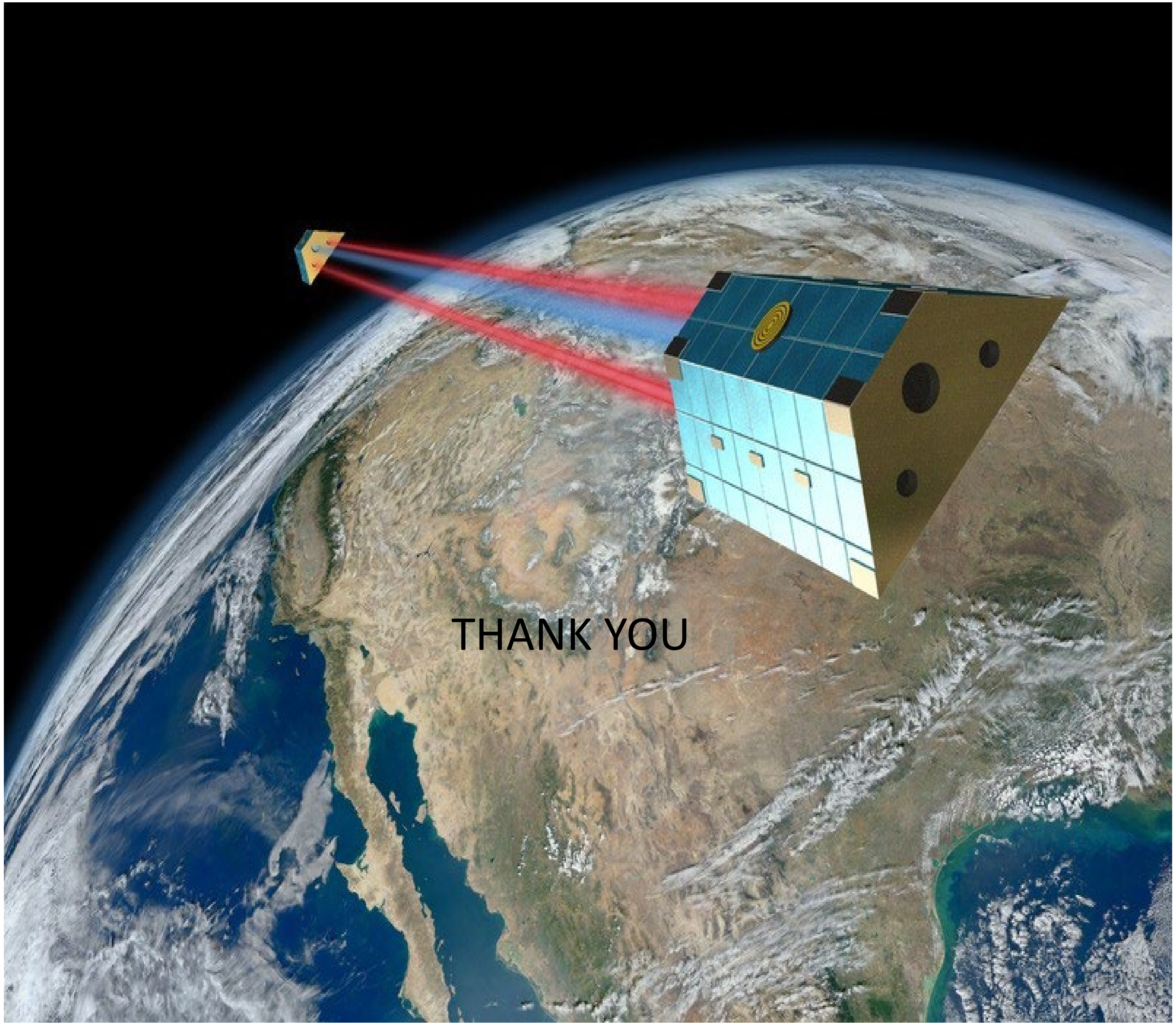
Future GRACE FO results will be obtained in a more challenging solar environment

Grace FO Lifetime is limited by a thruster leak that forecasts a mission end in 2028

Atmospheric Drag could end mission life as early as end of 2028

The mission is ending it’s nominal mission period and individual satellite component failure could occur at any point

A launch of the Mass Continuity Mission by 2028 would enable establishing continuity with GRACE FO and extending the, currently over two decade long, MCM record.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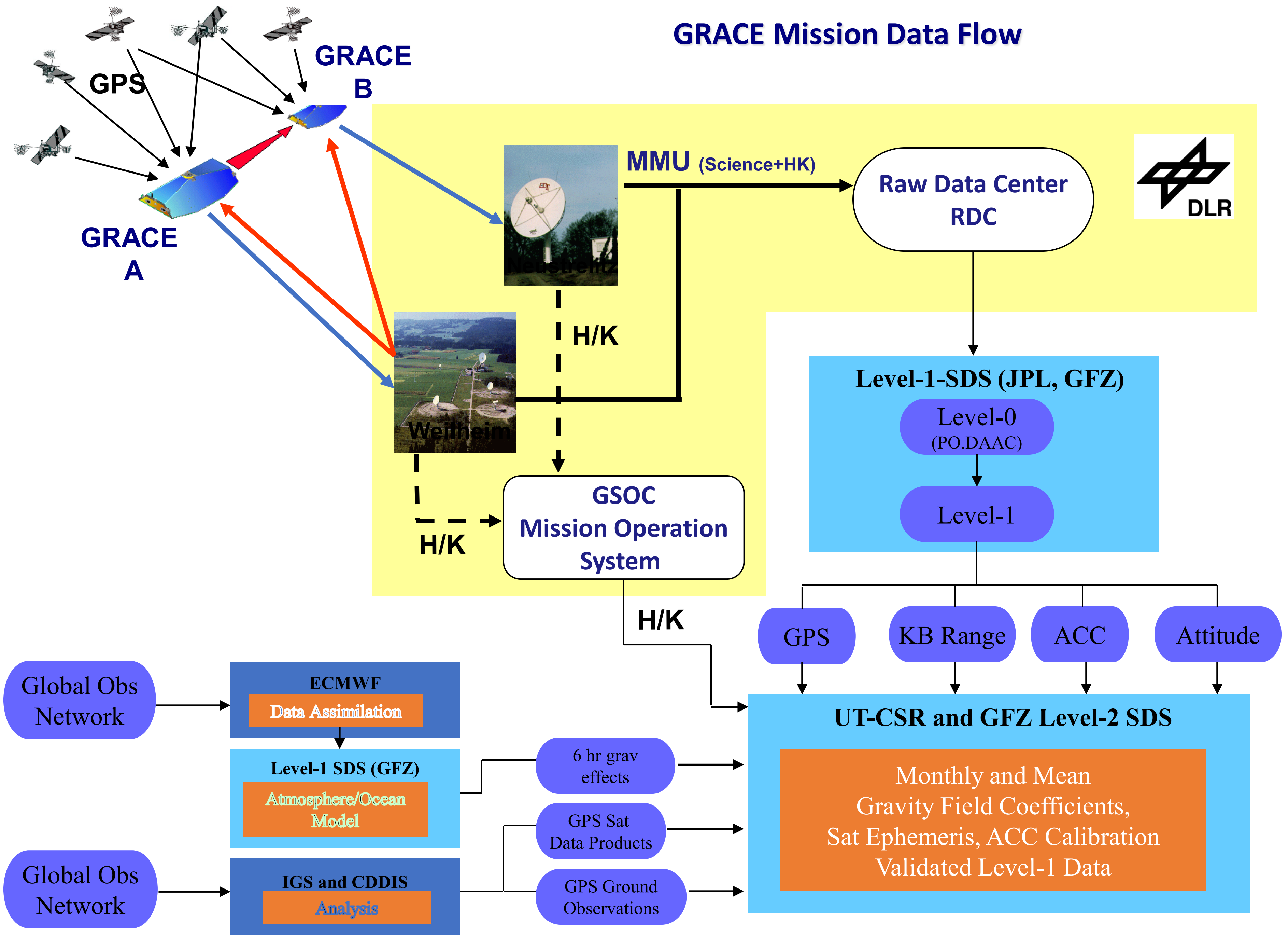
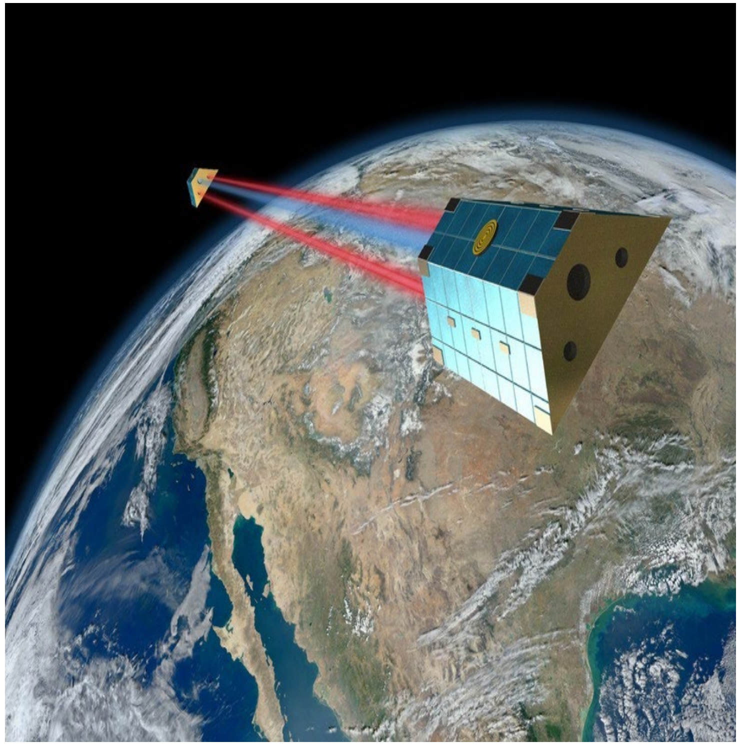

GRACE Mission Data Flow
GPS
GRACE B
GRACE A
MMU (Science+HK)
Raw Data Center
RDC
DLR
Weilheim
H/K
H/K
GSOC
Mission Operation
System
H/K
Level-1-SDS (JPL, GFZ)
Level-0
(PO.DAAC)
Level-1
GPS
KB Range
ACC
Attitude
UT-CSR and GFZ Level-2 SDS
Monthly and Mean
Gravity Field Coefficients,
Sat Ephemeris, ACC Calibration
Validated Level-1 Data
Global Obs
Network
ECMWF
Data Assimilation
Level-1 SDS (GFZ)
Atmosphere/Ocean
Model
6 hr grav
effects
GPS Sat
Data Products
GPS Ground
Observations
Global Obs
Network
IGS and CDDIS
Analysis

# The Gap Between GRACE and GRACE-FO



In 2010, NASA's Earth Science Division was assigned responsibility for maintaining continuity of a number of measurements deemed important to understanding the Earth system processes.

*Continuation of the time series of GRACE measurements was one of the specified observation sets and responsibility for extending the GRACE Mission's observation record of key earth system processes was assigned to GRACE-FO.*

Maintaining science quality data records requires that differences in science conclusions drawn from the two data sets be resolved as physical signals and cross calibration of the two data sets is a primary requirement. Overlap of the two missions would have enabled this calibration process.

*Final stage GRACE mission activity focused on minimizing the projected gap between the GRACE Mission End and the GRACE-FO Launch, but this was not achieved. An acceptable bridge for the gap between the two missions is needed.*

*The MCM implementation should attempt to ensure mission overlap.*