Our changing view on the Earth: New perspectives and chances through GRACE, GRACE-FO, and beyond

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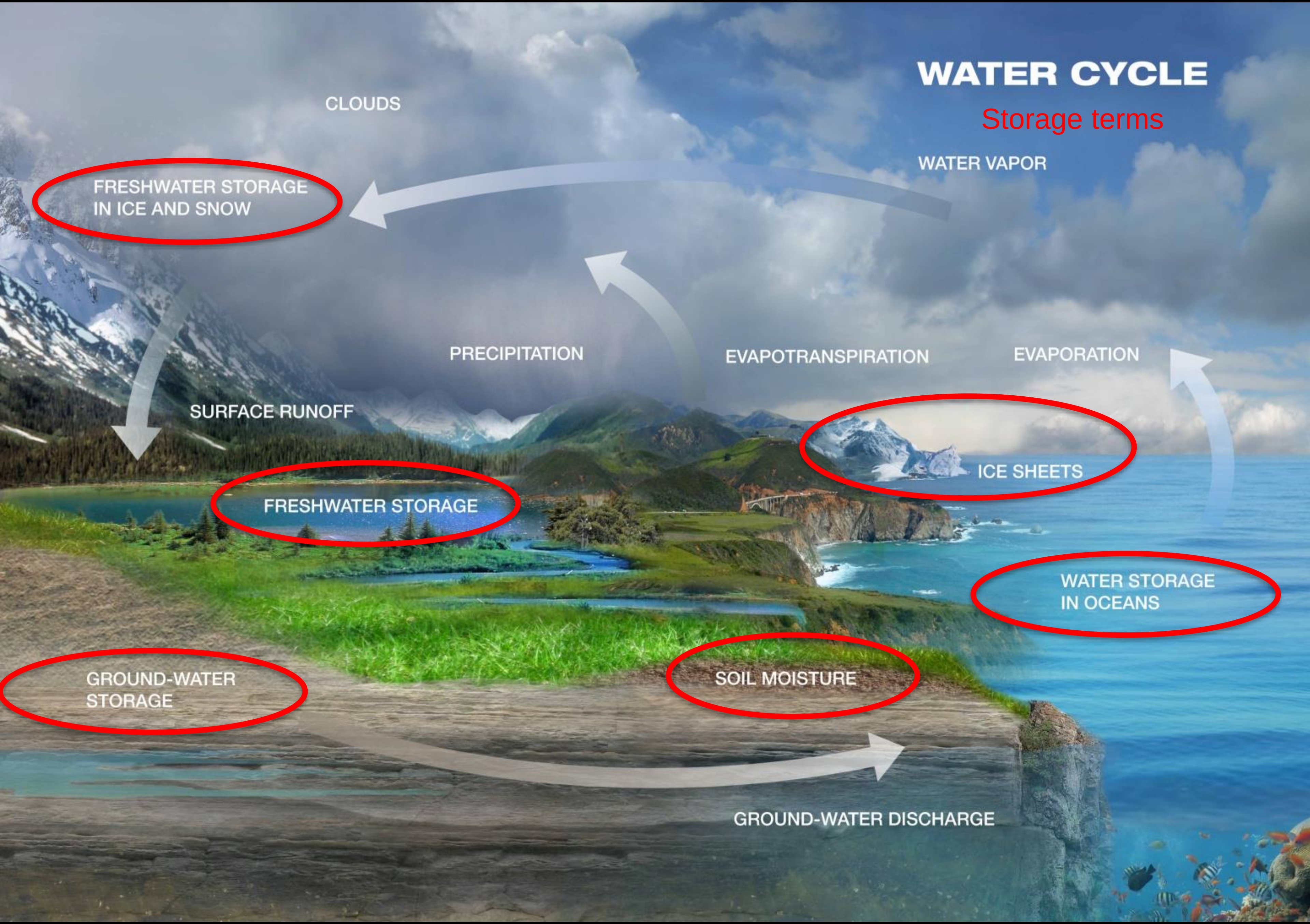
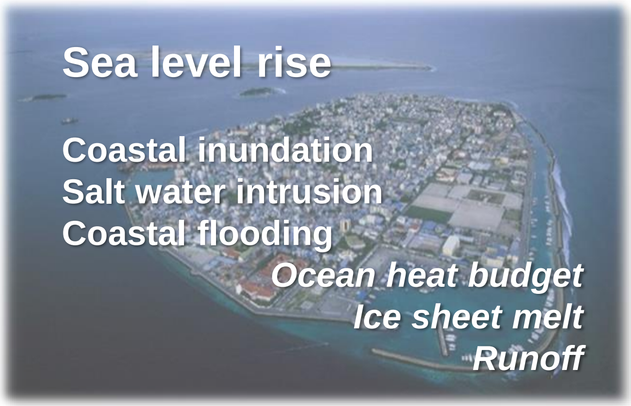
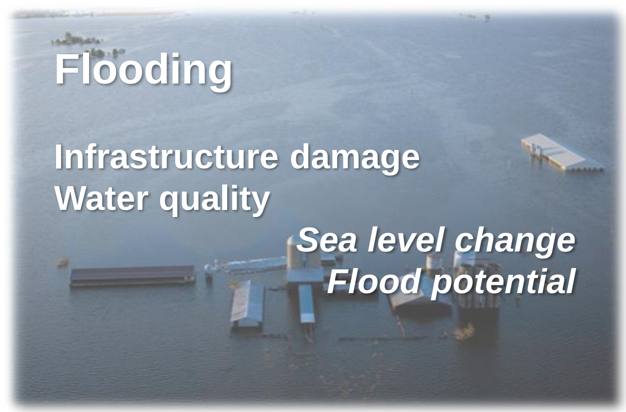
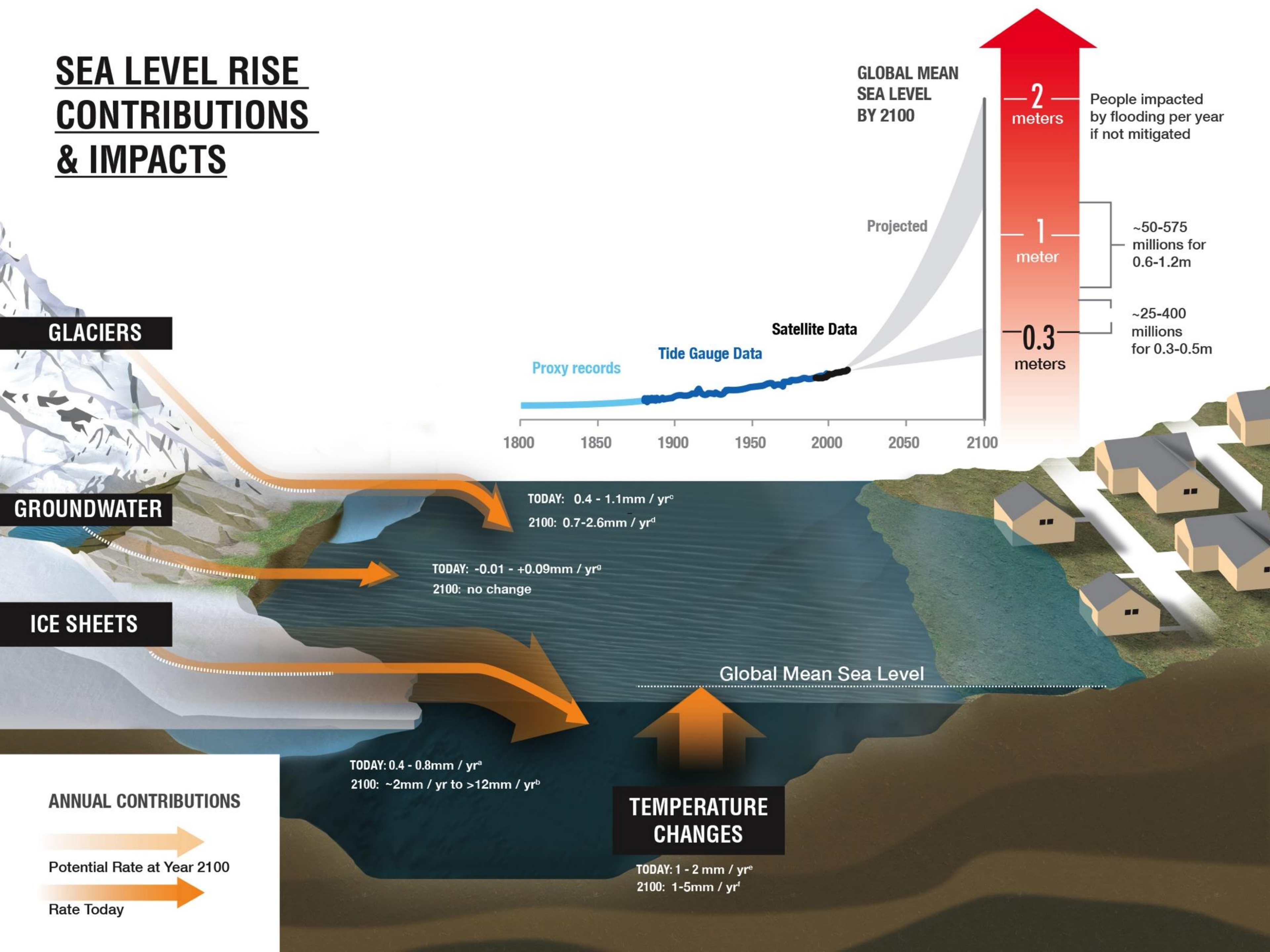

WATER CYCLE
Storage terms
CLOUDS
WATER VAPOR
FRESHWATER STORAGE IN ICE AND SNOW
PRECIPITATION
EVAPOTRANSPIRATION
EVAPORATION
SURFACE RUNOFF
ICE SHEETS
FRESHWATER STORAGE
WATER STORAGE IN OCEANS
GROUND-WATER STORAGE
SOIL MOISTURE
GROUND-WATER DISCHARGE

Humans affected by water

Water Availability and Quality and Impacts on Infrastructure






SEA LEVEL RISE CONTRIBUTIONS & IMPACTS
GLOBAL MEAN SEA LEVEL BY 2100
2 meters
People impacted by flooding per year if not mitigated
Projected
1 meter
~50-575 millions for 0.6-1.2m
~25-400 millions for 0.3-0.5m
0.3 meters
Satellite Data
Tide Gauge Data
Proxy records
1800
1850
1900
1950
2000
2050
2100
GLACIERS
TODAY: 0.4 - 1.1mm / yr[c]
2100: 0.7-2.6mm / yr[d]
GROUNDWATER
TODAY: -0.01 - +0.09mm / yr[g]
2100: no change
ICE SHEETS
TODAY: 0.4 - 0.8mm / yr[a]
2100: ~2mm / yr to >12mm / yr[b]
Global Mean Sea Level
TEMPERATURE CHANGES
TODAY: 1 - 2 mm / yr[e]
2100: 1-5mm / yr[f]
ANNUAL CONTRIBUTIONS
Potential Rate at Year 2100
Rate Today

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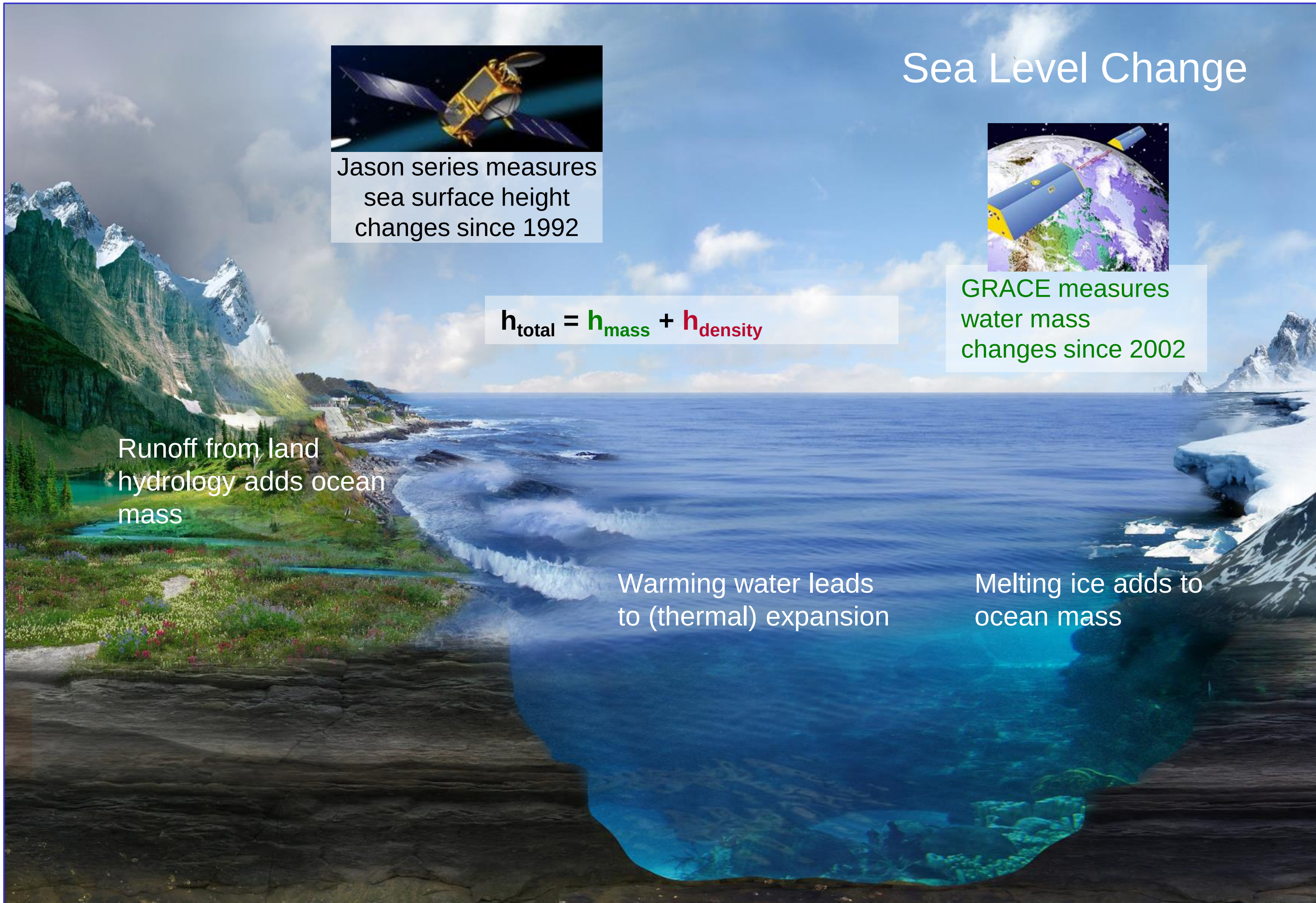
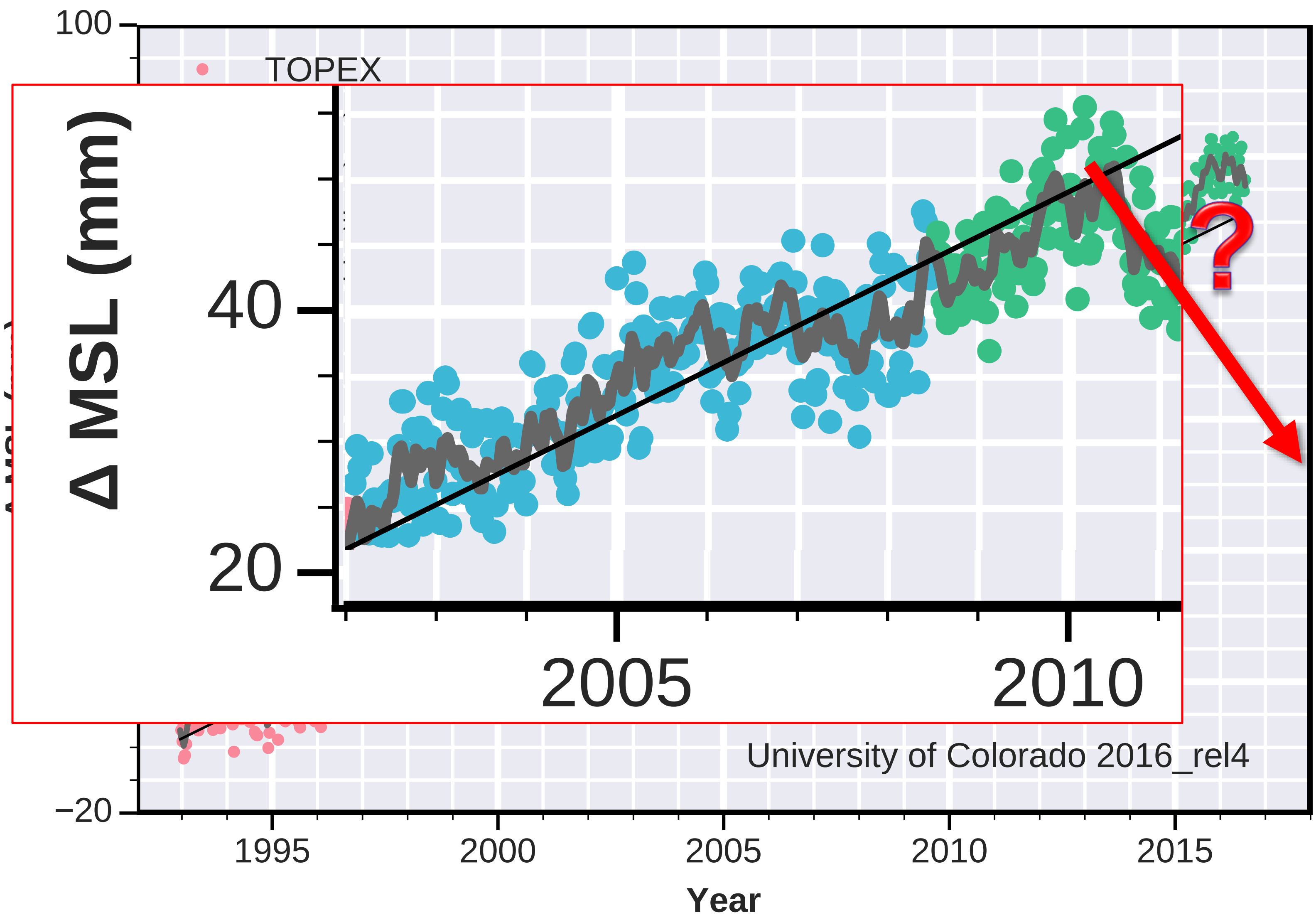
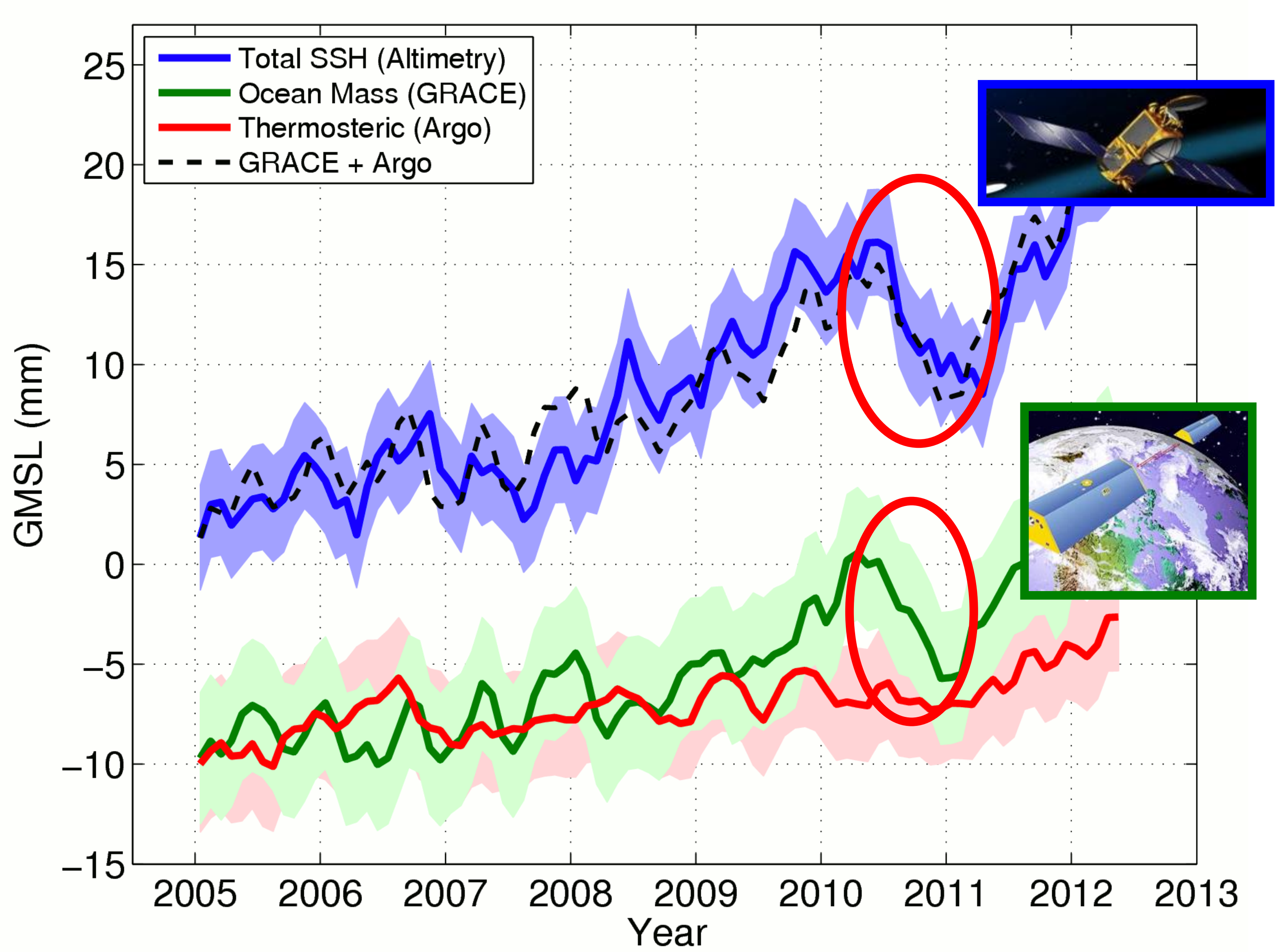
Causes and Observations of Sea Level Change



Altimetry observes sea level change since 1992



Using Multiple Satellites to “Track” Water



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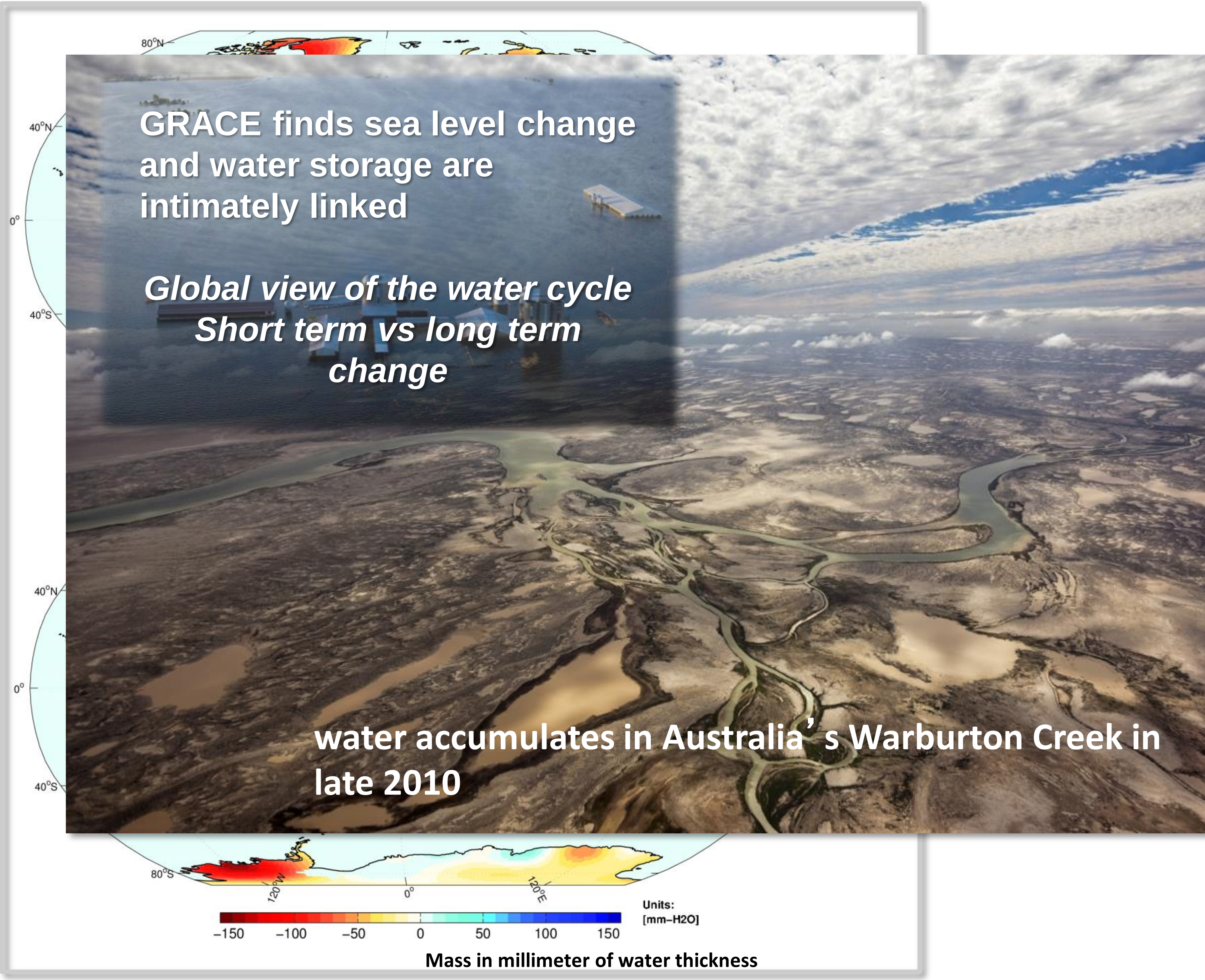
Terrestrial Water Storage in 2010 and 2011



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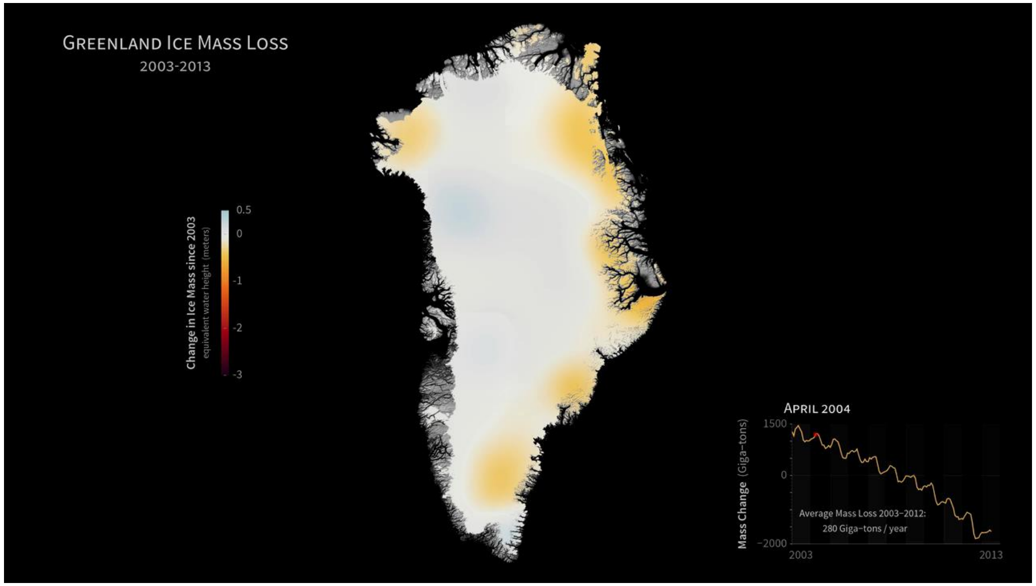
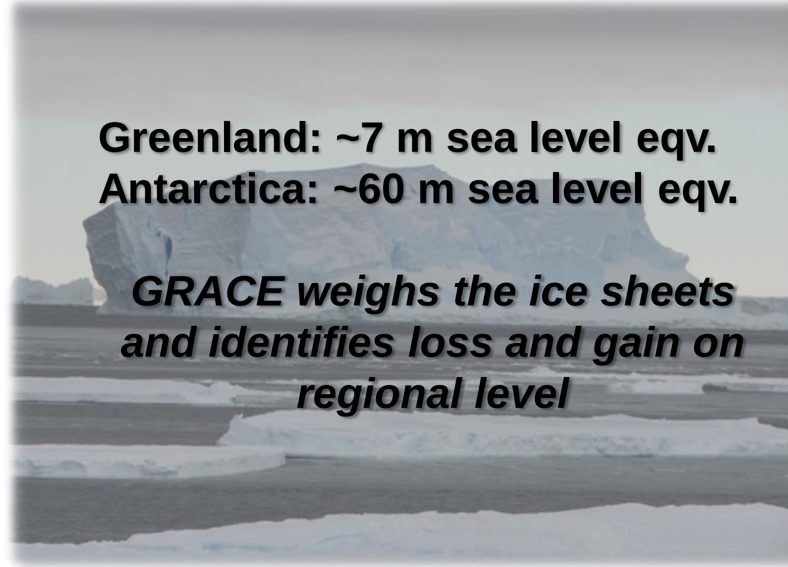
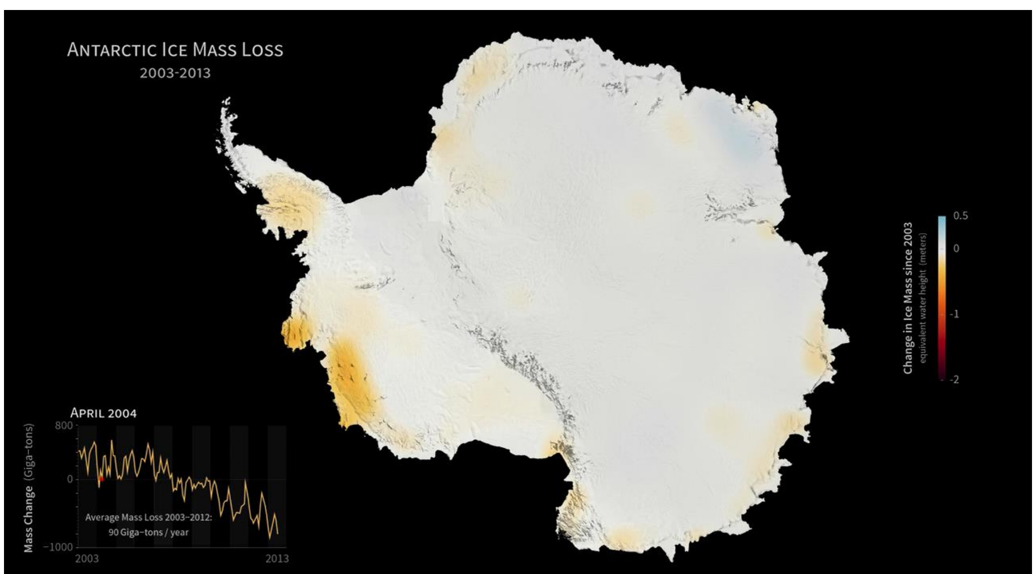
Ice Sheet Loss affecting sea level

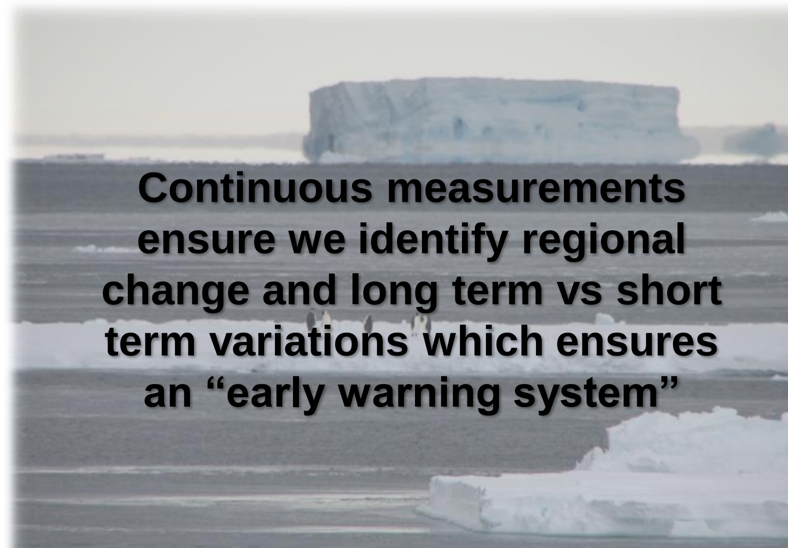




Greenland: ~7 m sea level eqv.
Antarctica: ~60 m sea level eqv.

GRACE weighs the ice sheets and identifies loss and gain on regional level





Continuous measurements ensure we identify regional change and long term vs short term variations which ensures an "early warning system"

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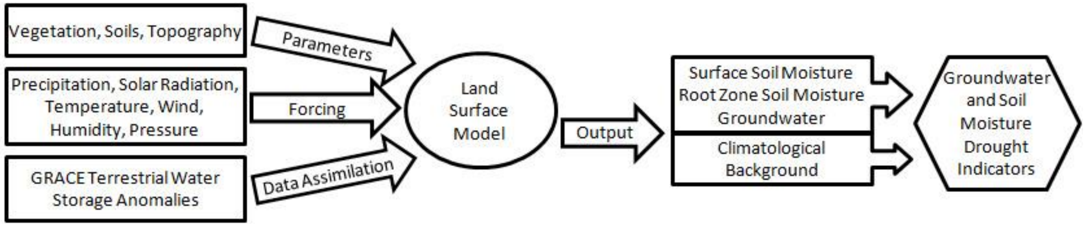
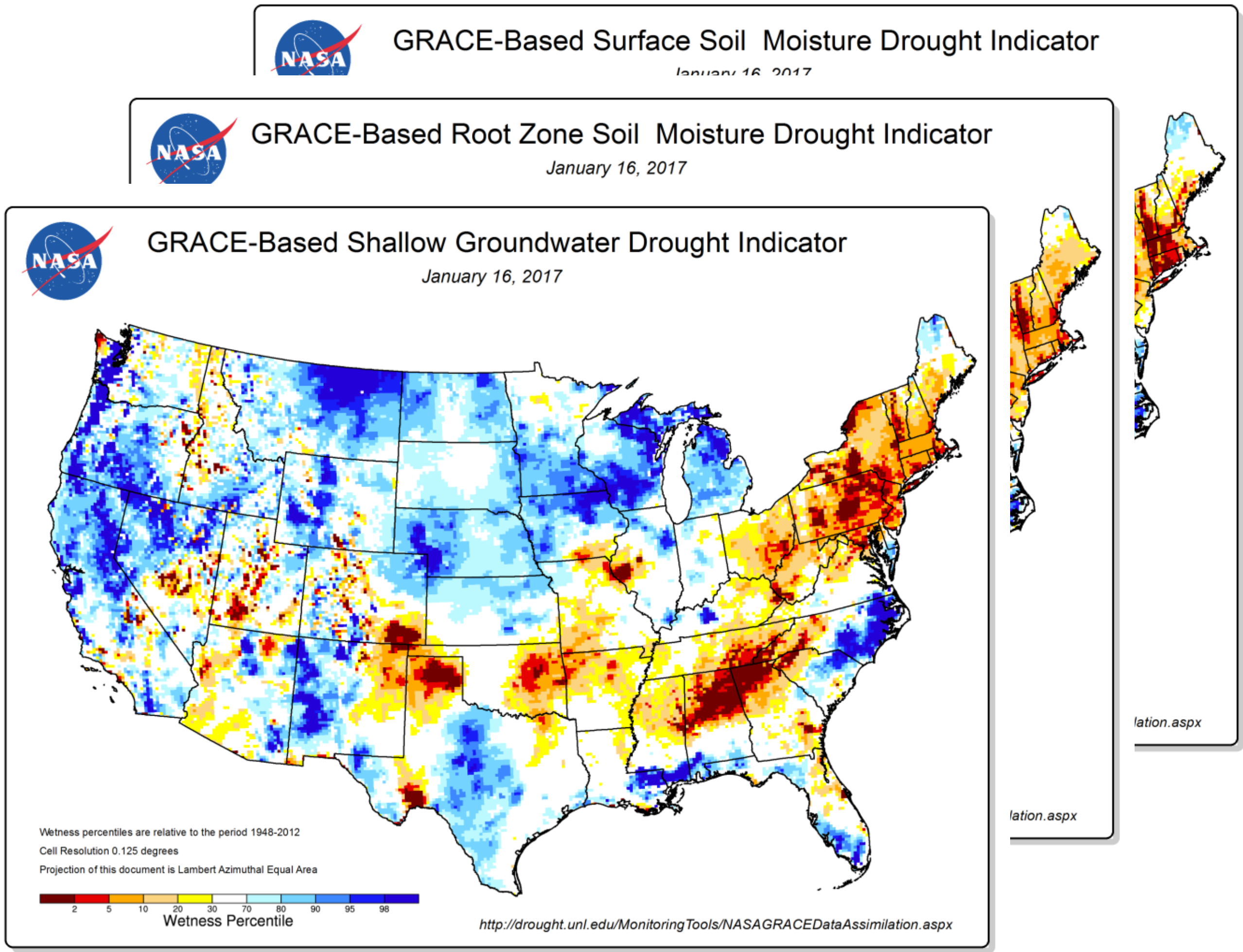
National Drought Monitor





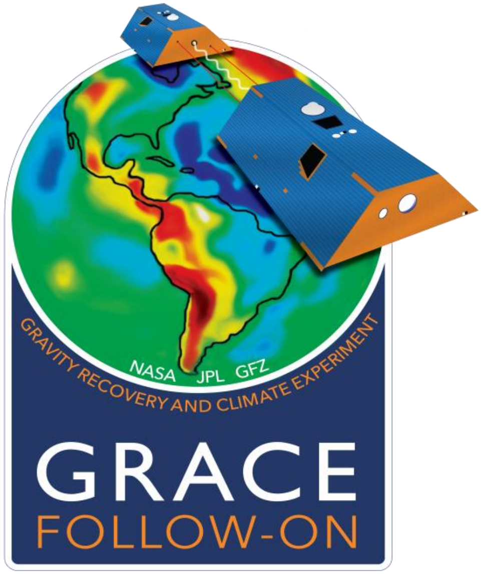
Weekly GRACE data assimilation for Soil Moisture and Groundwater Drought Indicators

Integral water storage provides insights into below-surface water reservoirs

California drought

GRACE Follow-on Project Overview

GRACE Follow-On

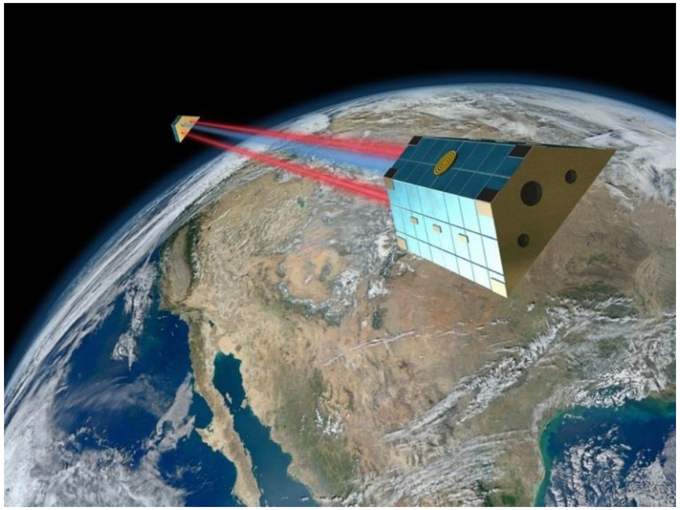


Salient Features

- *Implemented under US-German partnership*
- *Tech-Demo Laser Ranging Interferometer is Class D*
- *Follow-on to original GRACE Mission launched 2002*
- *Launch: **December 2017 on SpaceX Falcon 9***
- *Orbit: Near-circular Polar Orbit, 495 km altitude, 89º inclination*

Science

- *The GRACE-FO Mission will **continue and expand** upon the measurements initiated by the pathfinder GRACE Mission*
- *Will provide estimates of the **global high-resolution models of the Earth's gravity field for a period of up to five years** at a precision and temporal sampling equivalent to that achieved with GRACE.*
- *Will provide **QuickLook products for enhanced operational use** for water resource management*
- *The inter-satellite laser ranging interferometer will demonstrate satellite-to-satellite interferometry in low Earth orbit.*



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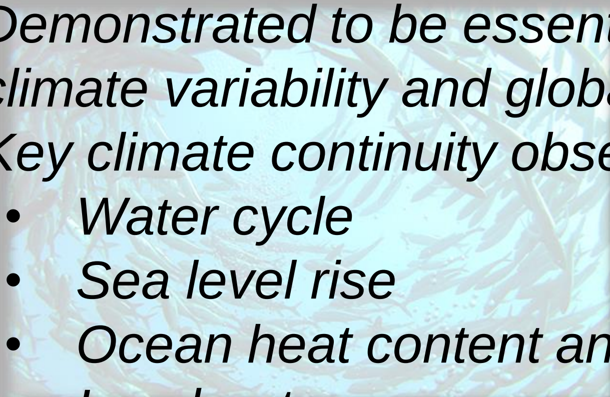
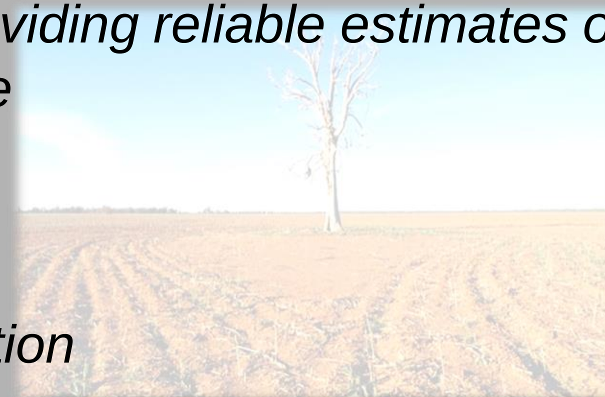
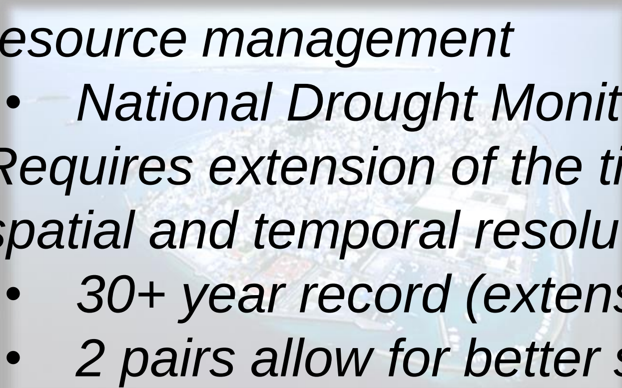
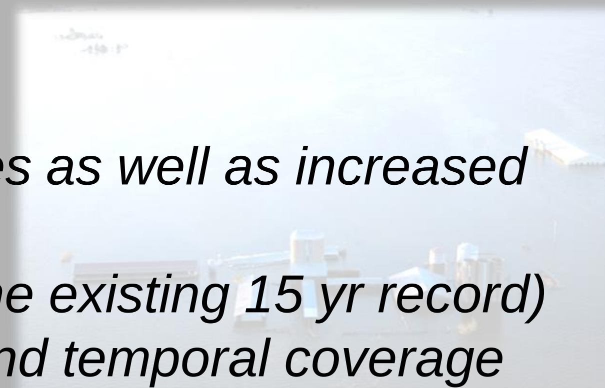
Future Opportunities

- *Demonstrated to be essential to providing reliable estimates of climate variability and global change*
- *Key climate continuity observation*
  - *Water cycle*
  - *Sea level rise*
  - *Ocean heat content and circulation*
  - *Ice sheets*
- *Demonstrated to be essential for near real time use for water resource management*
  - *National Drought Monitor*
- *Requires extension of the time series as well as increased spatial and temporal resolution*
  - *30+ year record (extension of the existing 15 yr record)*
  - *2 pairs allow for better spatial and temporal coverage*

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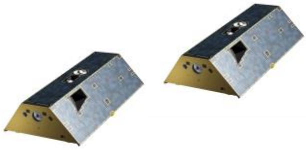
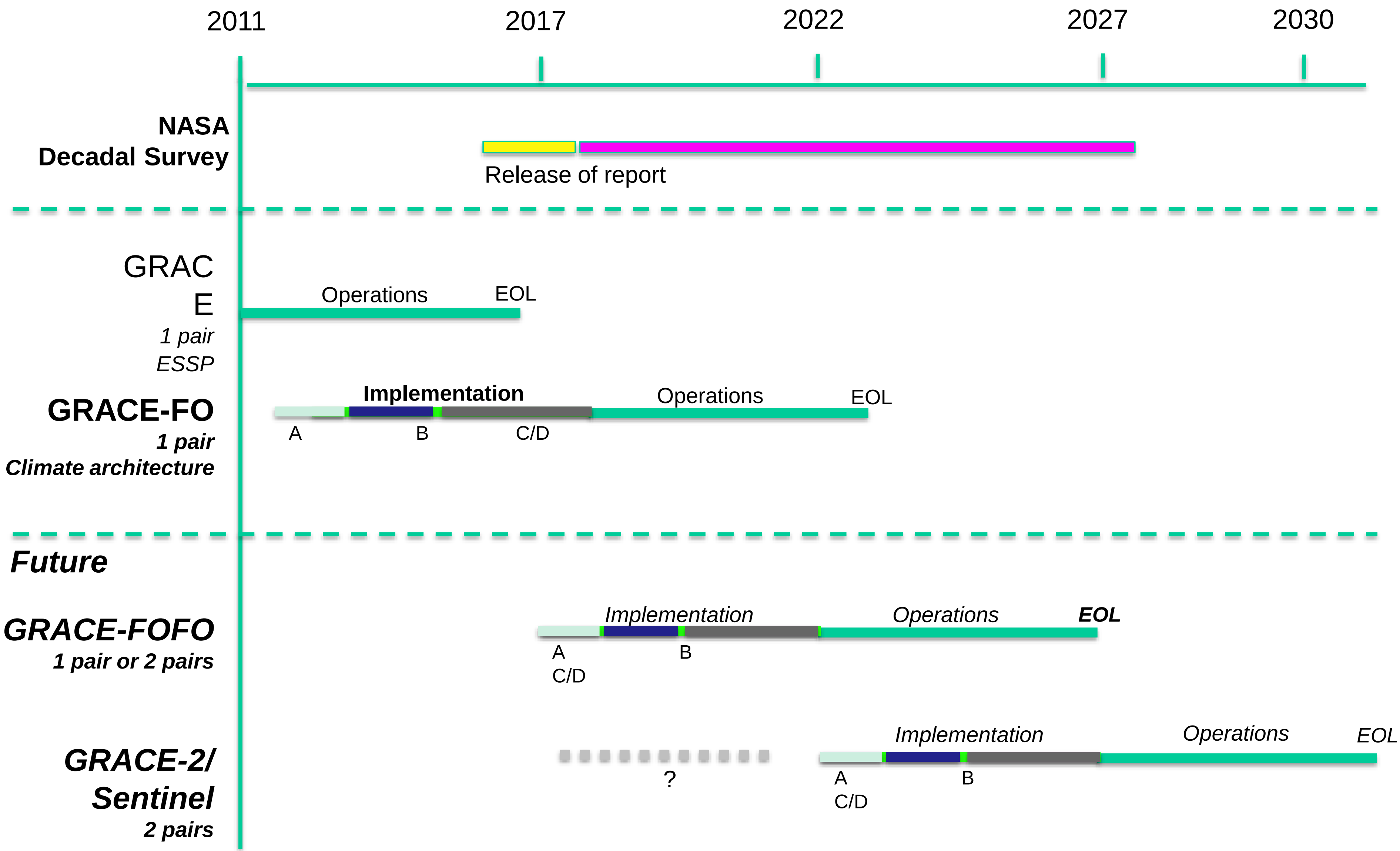
Continuity of mass transport measurements (gravity)





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BACK UP

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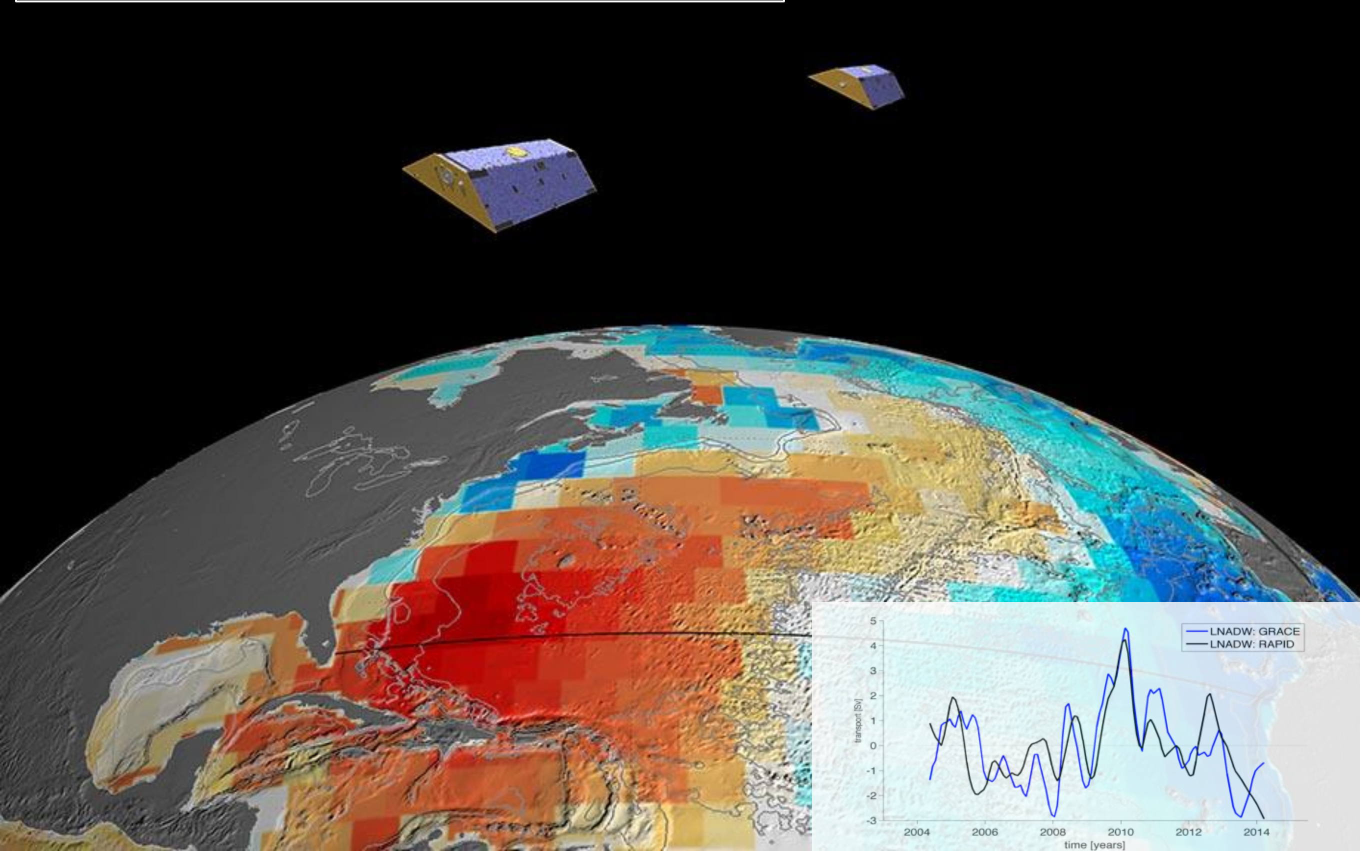
First detection of North Atlantic Meridional Overturning (AMOC) components with GRACE

The AMOC is an important component of the Earth's climate system: warm, salty water flows northward in the upper layers of the Atlantic, and colder water flows southward in the deep Atlantic.

Landerer, Wiese, Bentel, Boening, Watkins (2015), North Atlantic meridional overturning circulation variations from GRACE ocean bottom pressure anomalies, ***GRL.***

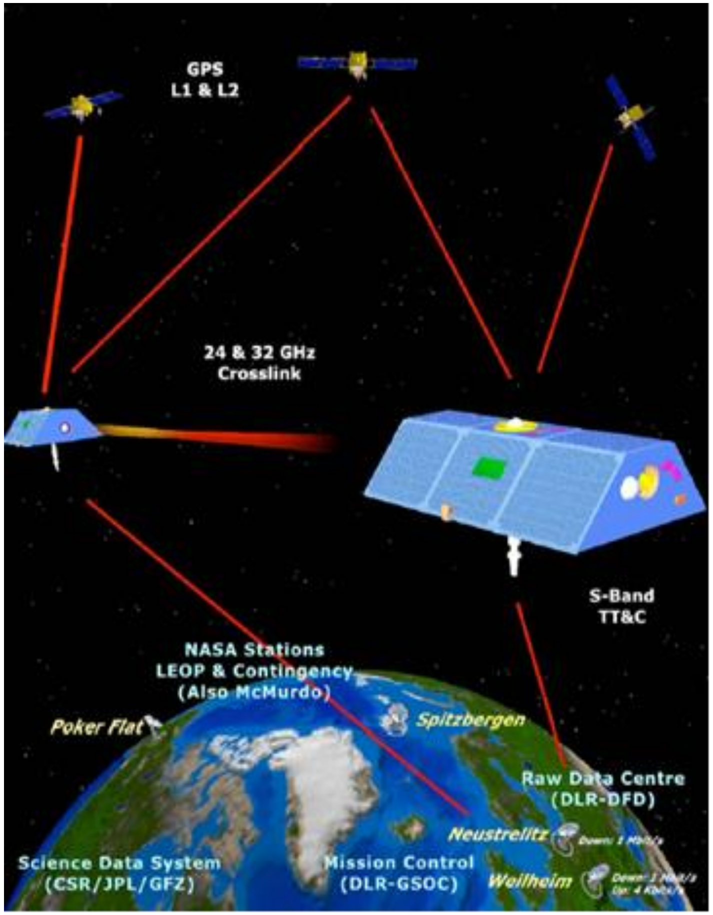


Main Results:

- New JPL GRACE mascon solution allows detection of basin-wide ocean volume transports
- observed prominent AMOC anomaly in winter of 2009/2010
- Will be used to address open science questions about AMOC dynamics
- Good agreement with in-situ observations at 26.5N suggest new applications of satellite gravimetry for long-term, global ocean circulation & climate monitoring

Project Overview

NASA – Mission Lead	**JPL** Project management, Science & Science processing, Mission Assurance, Spacecraft, Accelerometer, Microwave and Laser Ranging Instruments
Partners	**GFZ - German Research Centre for Geosciences** Science & science processing, Mission operations, Optical components of Laser Ranging Instrument, Launch Services with support from BMBF, BMWi, HGF, DLR
Risk Category	7120.5 Category 2; 8705.4 Payload Risk Class C (except for the LRI which is Risk Class D)
Launch	August 2017 on a contributed launch vehicle (Dnepr)
Orbit	Near-circular Polar Orbit, 490±10km altitude, 89º inclination
Lifetime	5 years baseline
Spacecraft	JPL Subcontract to Airbus Defence & Space (formerly Astrium), Germany
Instruments	Accelerometer – JPL Subcontract to ONERA, France Microwave Instrument– JPL in-house build Laser Ranging Interferometer – JPL and GFZ collaboration
Mission Ops	Operations contributed by GFZ via German Space Operations Center (GSOC)
Science Data	Science Data System (SDS) managed by JPL with centers at JPL, UT-CSR, GFZ. Data archived at PODACC.



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Moving Water and Climate

Land Hydrology:

- Water Balance:
  - Precipitation
  - Evaporation
  - Runoff
  - Snow
  - Groundwater

Oceans:

- Overturning Circulation
- Wind-driven currents
- Sea Level:
  - Mass vs. thermal
  - Planetary heat budget

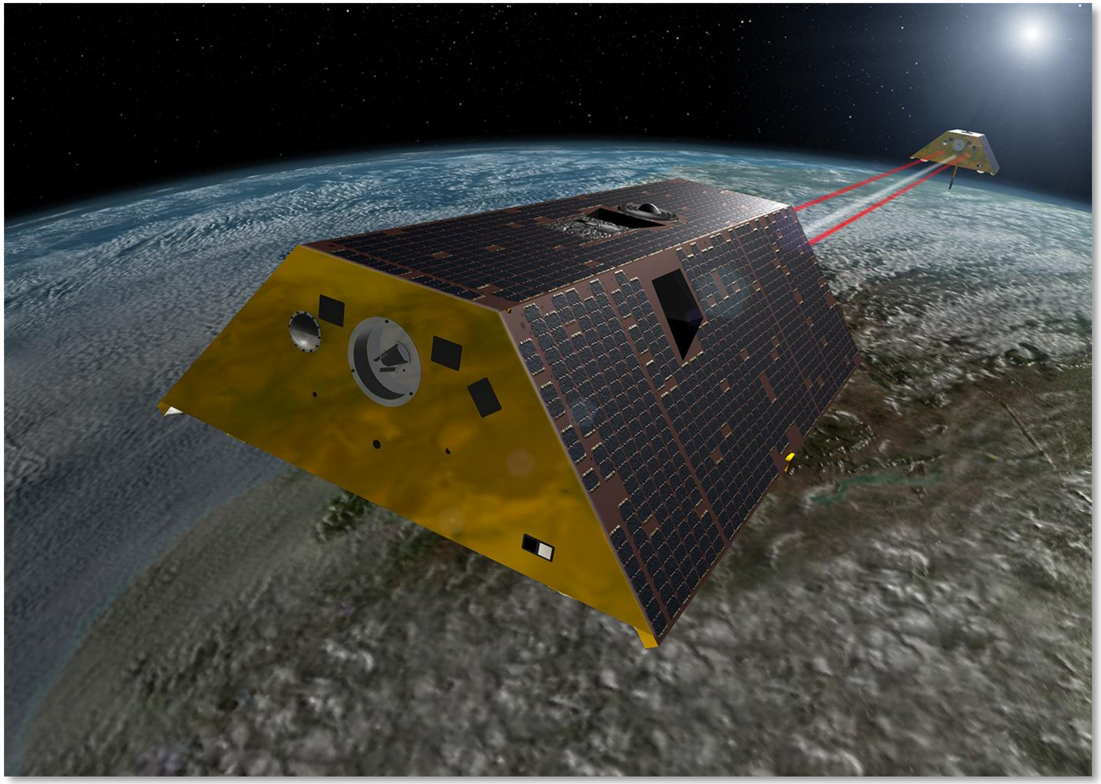
Land ice:

- Ice mass balance:
  - Surface mass balance
  - Discharge
- Gravitational effects on sea level

Outline (To be removed later)

- Importance of global view of water cycle (list of applications) – 1 slide
- Importance of total mass change vs. surface – 1 slide
- Example Topics:
  - Sea level: 6 slides
    - Short term fluctuations and connections to hydro
    - Long term change from Greenland and Antarctica
    - Implications: long and continuous time series needed
  - Hydro: 1 Slide
    - Quantifying drought and floods and groundwater in particular
    - Show California
    - Show drought monitor
    - Implications: constant monitoring needed, operational uses need near real-time data
  - Ocean: 1-2 slides
    - Overturning Circulation
    - Low SNR
    - Implications: more pairs decrease SNR
- Take-away slides: G-FO will continue climate record and improve operational use, G-FOFO and beyond will be important for climate applications and operational use (mentions options), more pairs better SNR – 2 slides

GRACE Follow On



Specs:

Quicklook Products: