Mass Flux Measurements from the GRACE Mission

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WCRP OSC
Climate Research in Service to Society

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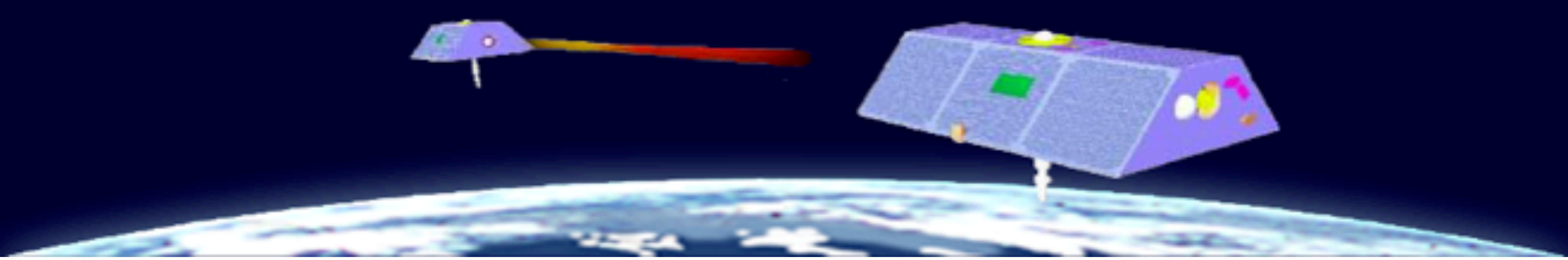


Objective

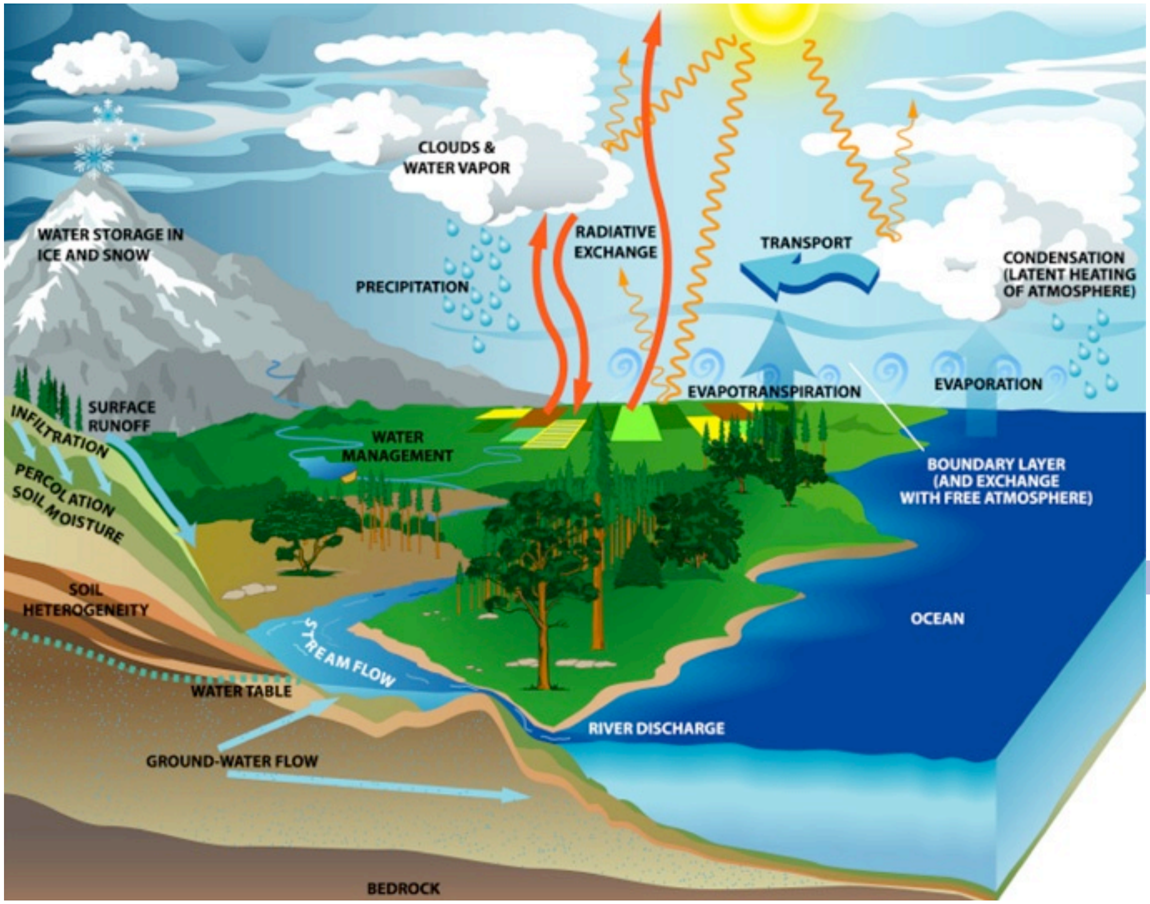
Describe the GRACE Mass Flux measurement

Discuss some of the applications of the measurement

Note it’s applicability as a climate data set

Discuss potential for continuing the measurements

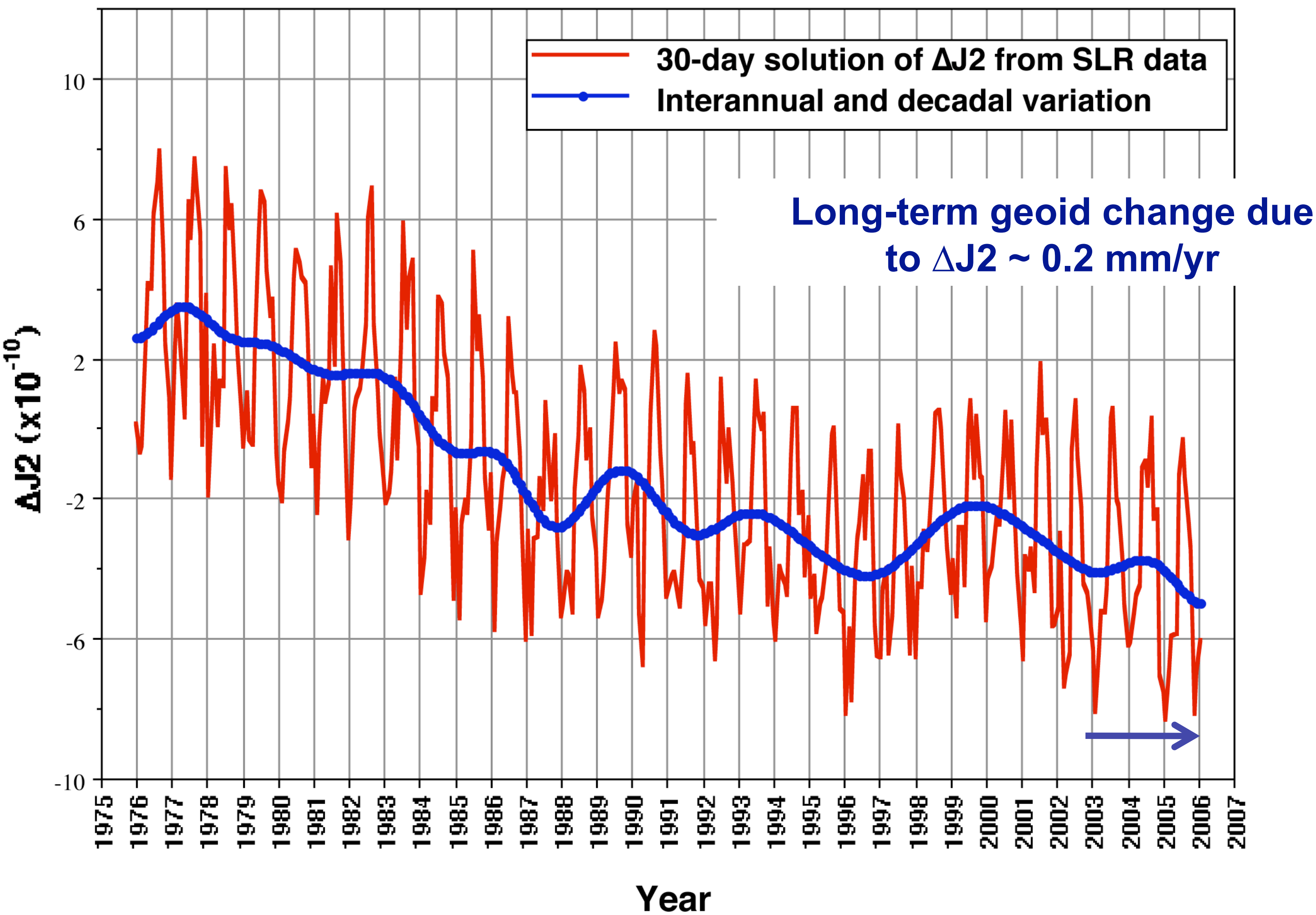
GRACE Observations and The Global Water Cycle



Global Gravity Measurements determine Mean Global Mass Distribution and the Temporal Variations which measure change in water mass of land and oceans

GRACE measures the change in all forms of the water stored on land after precipitation has been stored as snow, filtrated into the ground, evaporated or departed a basin as stream flow

Long Period and Annual Gravity Variations from SLR Data



The GRACE Mission

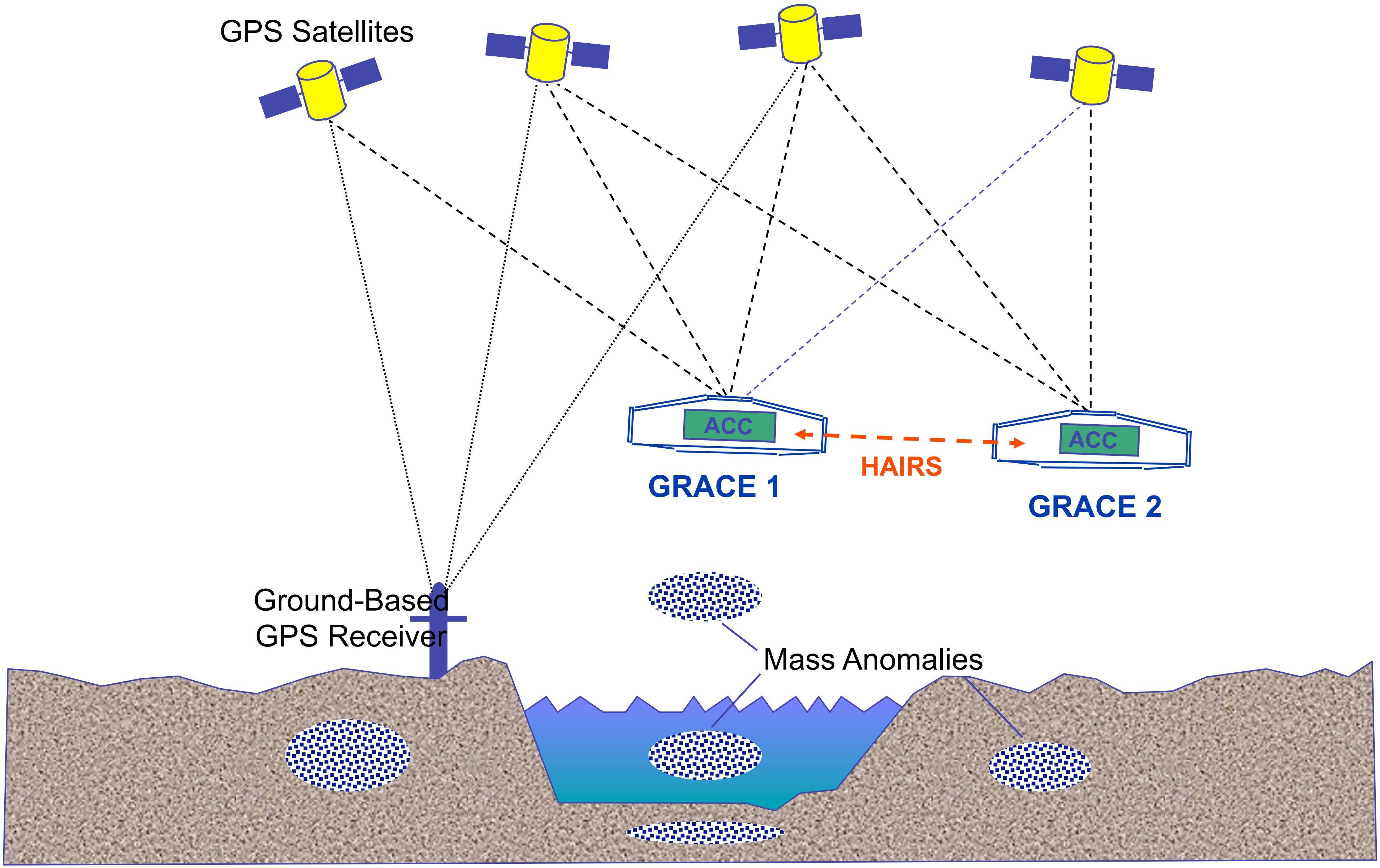
The Gravity Recovery and Climate Experiment (GRACE) is a joint *NASA and DLR mission* whose purpose is to improve our understanding of the Earth's dynamical system by *measuring the gravity signals associated with mass exchange between the Earth System components*.

The primary objectives are to accurately determine: 1) *the Earth's time-averaged gravity field* and 2) *it's temporal variations at monthly intervals*

The major time varying signal is due to water motion and the GRACE mission is providing a *continuous, global multi-year record of the seasonal mass transport between the oceans, land and atmosphere at inter-annual and decadal time scales.*

The objective of the GRACE mission is to *characterize the spatial and temporal variations in the Earth's mass transport, through accurate measurements of its gravity field.*

Grace Mission Concept



Grace Monthly Gravity Solution

Mean Apriori GEO

Time Variable Apriori Models
- Solid Earth Tide
- Ocean Tide
- Rotational Deformation
- Non-tidal Atmosphere+Ocean (AOD)

Corrections to Mean GEO

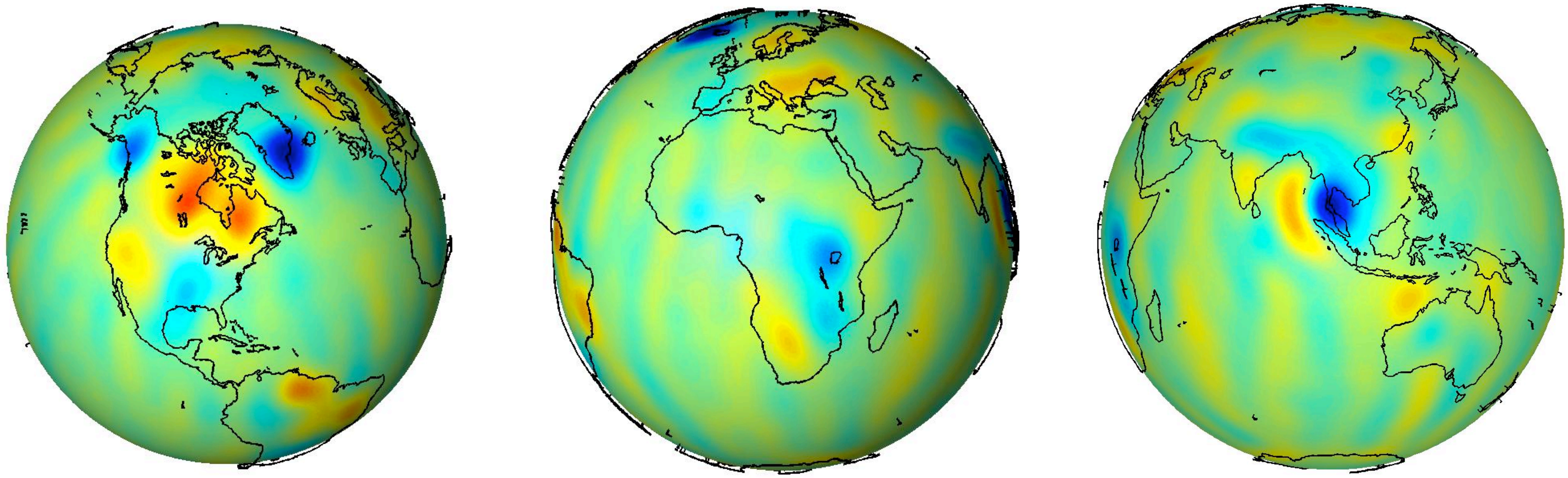
Signals in Estimate of GEO
- Continental hydrology
- Solid earth tide error
- Ocean tide error
- Rotational deformation error
- AOD error
- Mean model error

Data Processing Effects
- Instrument Measurement Noise
- Parameterization
- Aliasing of Short-period Variability
- Spacecraft events
- Ground track spacing
- Etc…

$$U_{ns}(r,\phi,\lambda,t) = \frac{\mu}{r}\sum_{n=2}^{\infty}\sum_{m=0}^{n}\left(\frac{R_e}{r}\right)^n \overline{P}_{nm}(sin\,\phi)\left(\overline{C}_{nm}(t)\,cos\,m\lambda + \overline{S}_{nm}(t)\,sin\,m\lambda\right)$$

Secular/Episodic Gravity Changes

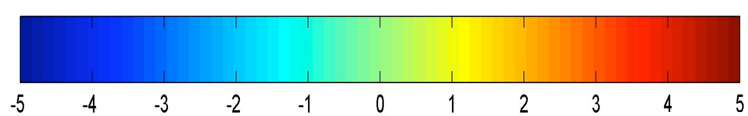
Difference of two 2-year means (2003-2004 and 2005-2006)
(degree/order 30 or ~700 km resolution)

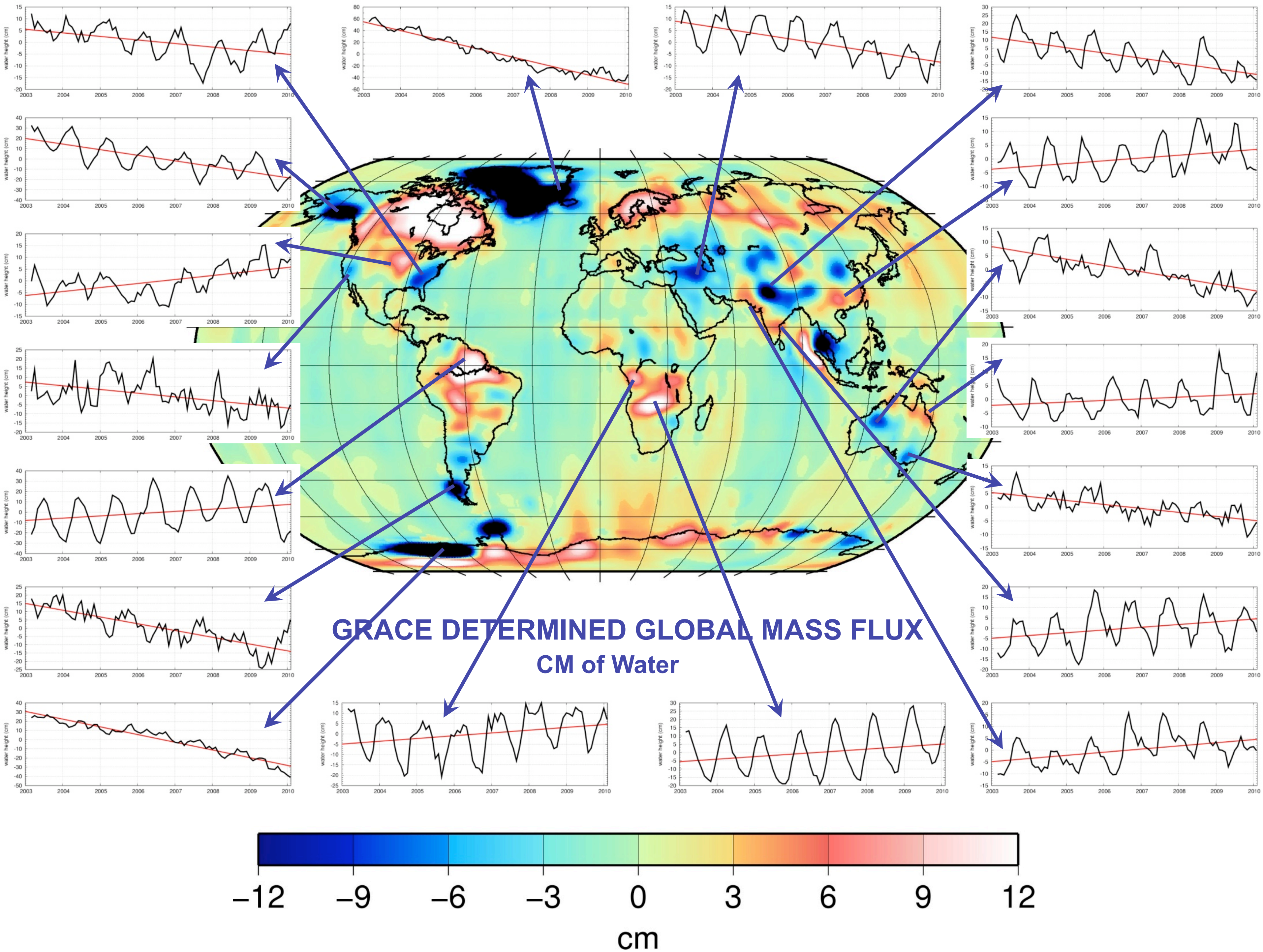


GIA over Canada; Greenland & Alaska ice mass losses

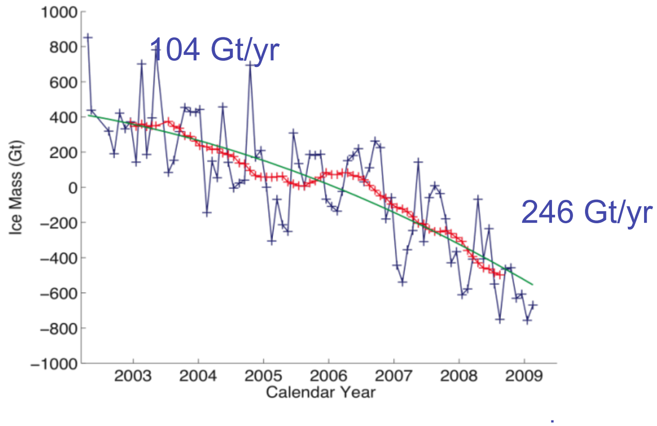
Lake Victoria basin mass loss

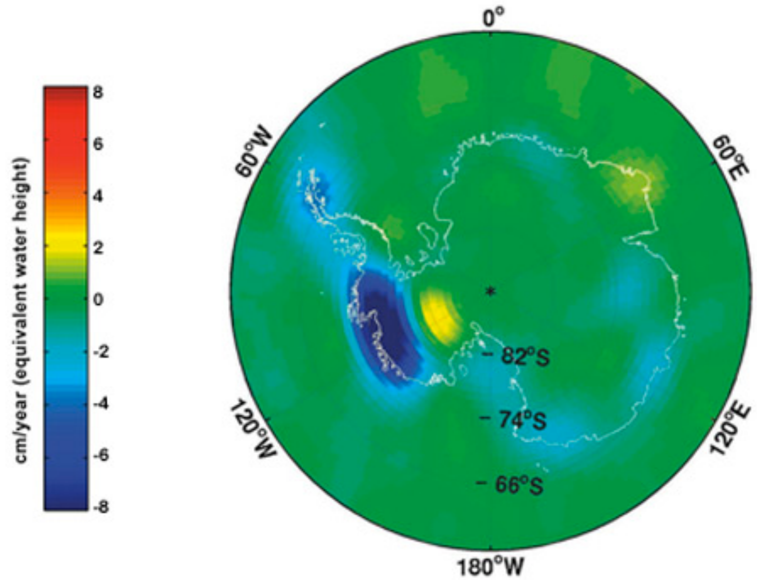
Sumatra-Andaman Earthquake

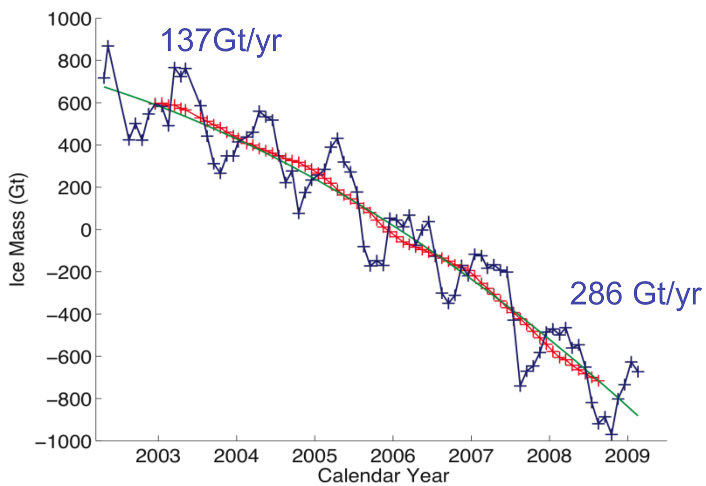


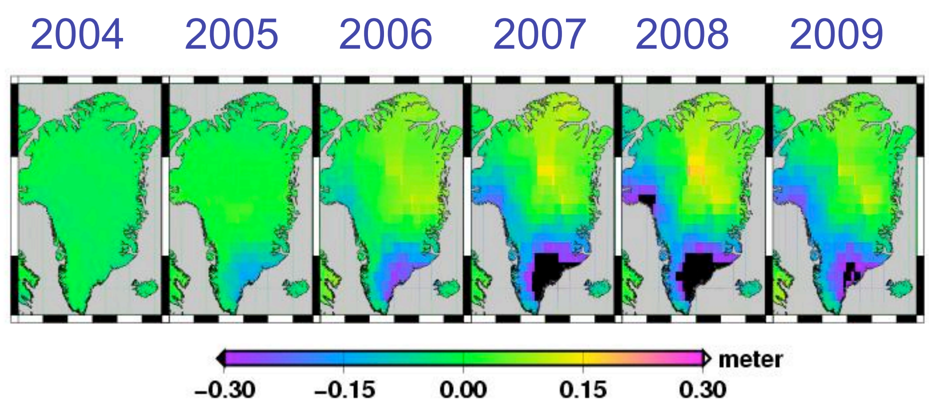

GRACE DETERMINED GLOBAL MASS FLUX
CM of Water
–12
–9
–6
–3
0
3
6
9
12
cm

Variability in Ice-Mass Change





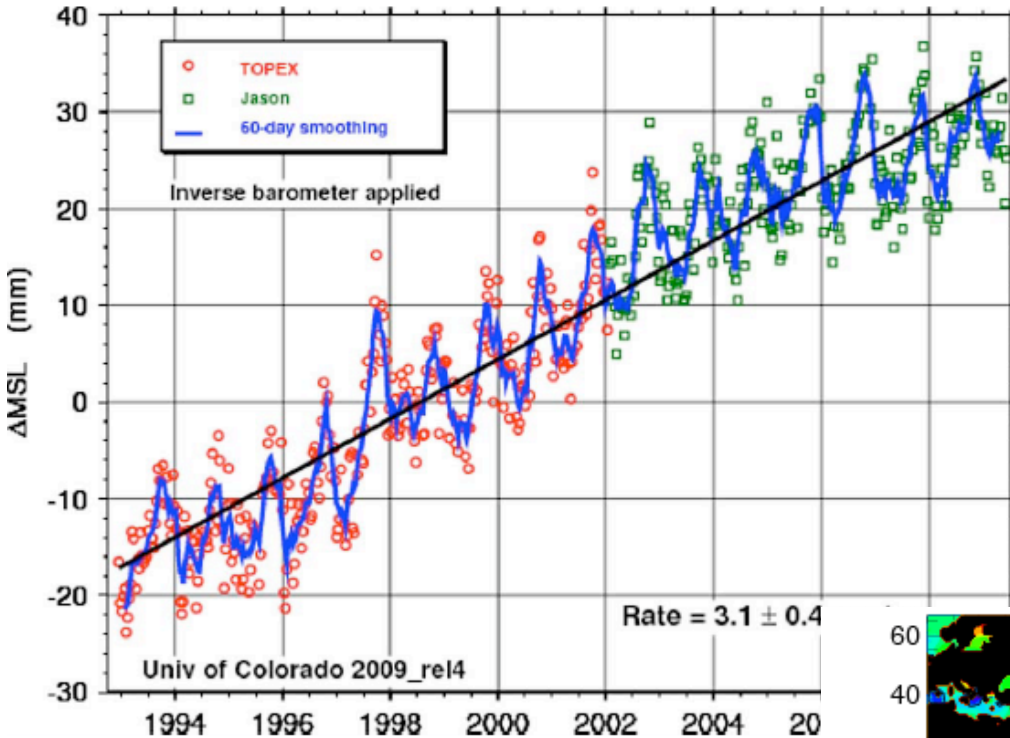


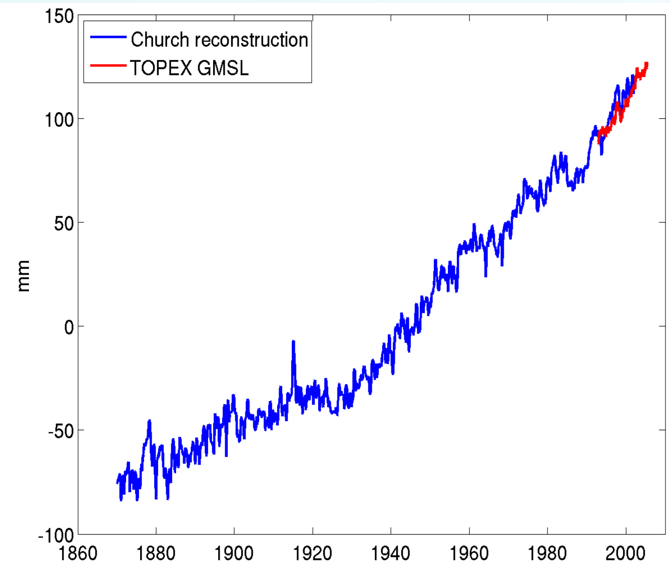


(from Velicogna et al, 2009)

From Watkins et al, 2009

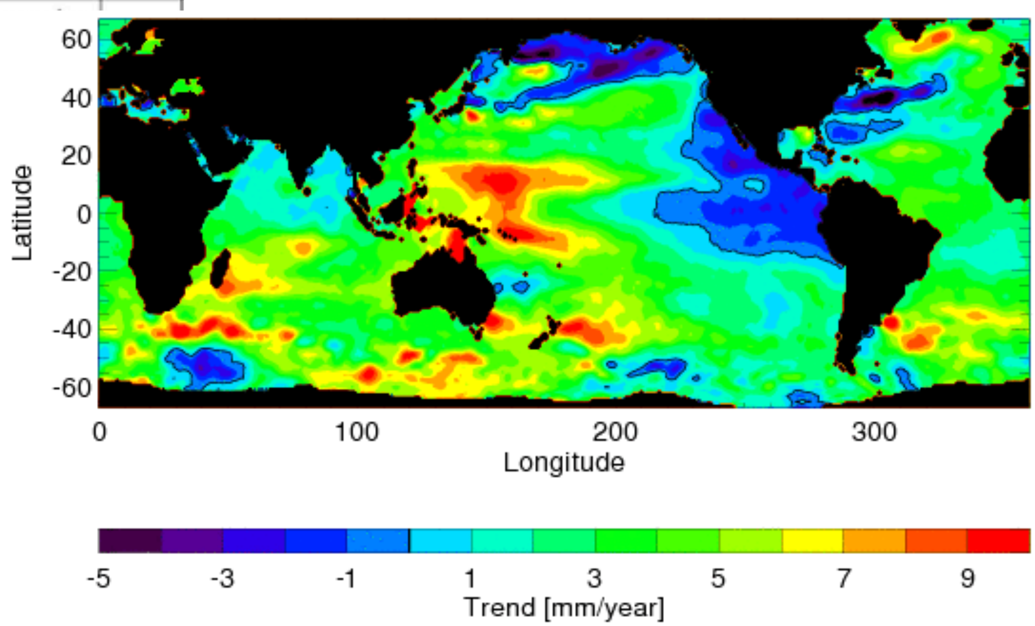
Sea Level Rise from Altimetry – 17 Year Trend



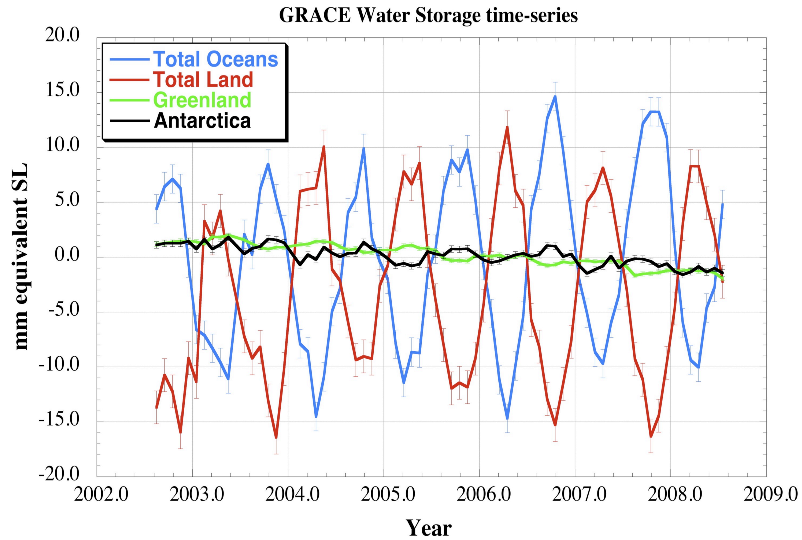


Global SL Rate = 3.1 ± 0.4 mm
(Nerem, 2009)

Global SL Trend Distribution
Courtesy Esselborn, GFZ



GRACE Mass Estimate



Trends (mm/yr)

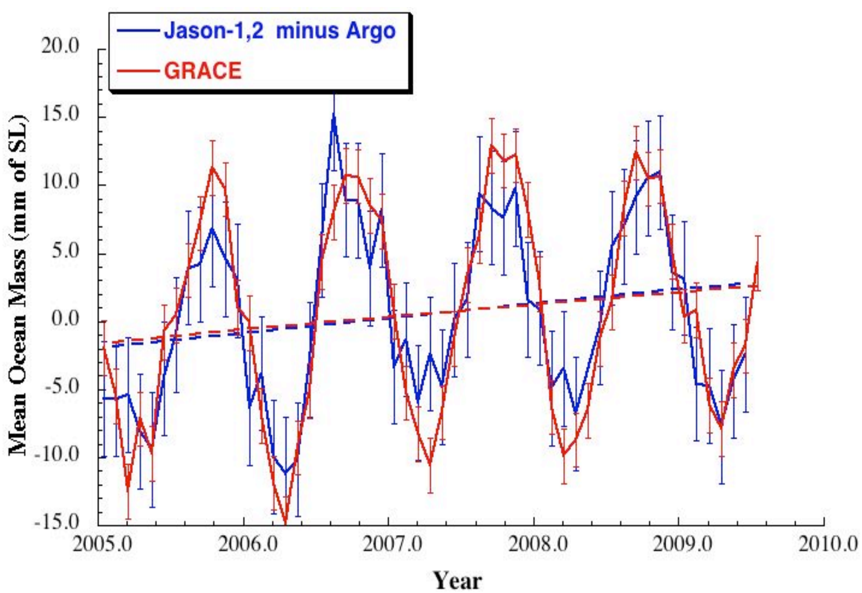
Ocean = 1.2± 0.3

Land = 0.3 ± 0.5

Greenland = -0.60 ± 0.1

Antarctica = -0.40 ± 0.2

Famiglietti, 2009



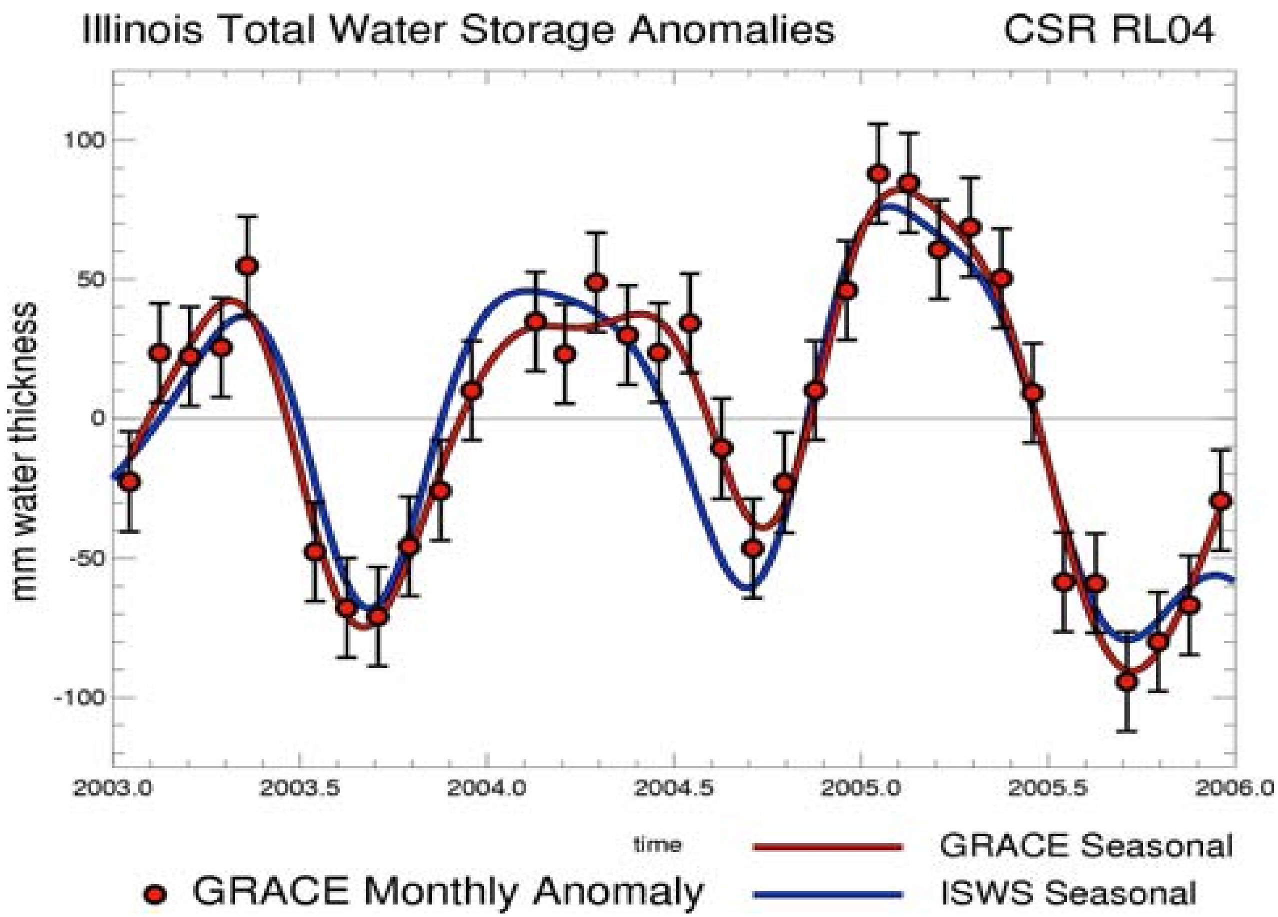
GRACE/Jason/Argo Closure

Grace Trend(2003-2009.5) = 1.3+/- 0.8 mm/yr

Chambers,, 2009

Groundwater Monitoring

Estimates match groundwater well measurements



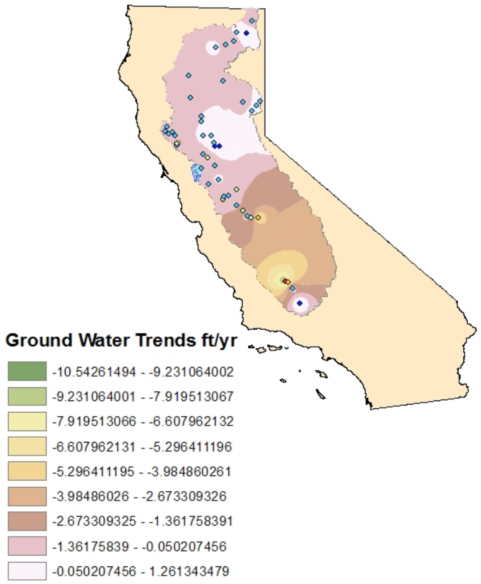
Swenson, 2007

Illinois

280,000 sq km

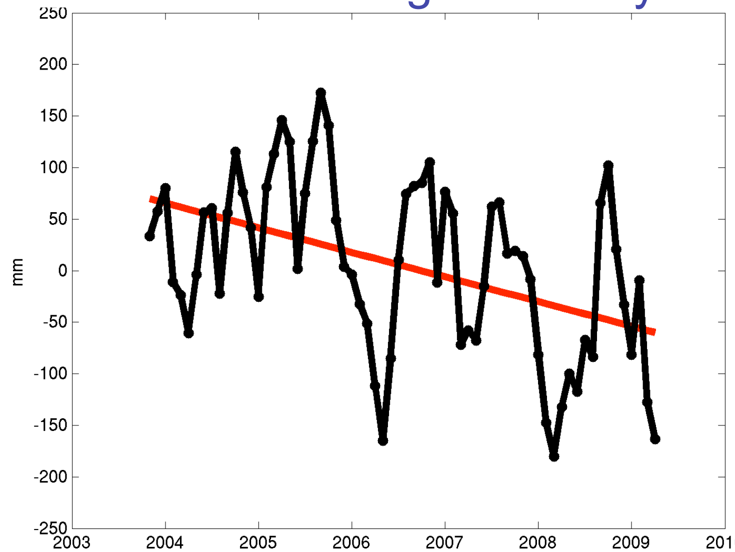
Method is applied in regions where groundwater is not well monitored, but depletion is likely: Africa, Middle East, etc.

GRACE DETECTS UNSUSTAINABLE GROUNDWATER LOSS



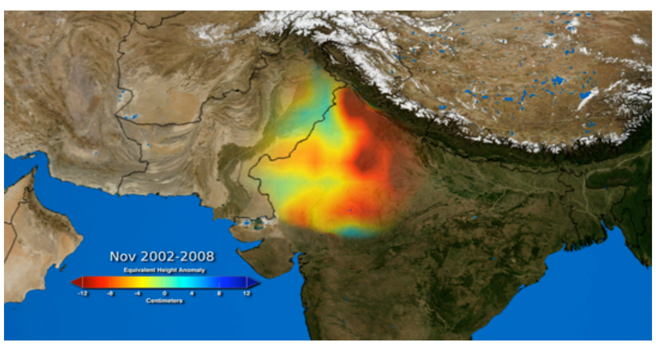
Observed trends in Sacramento and San Joaquin River basins in California. Sierra Nevada October, 2003 – March, 2009

Water Storage Anomaly

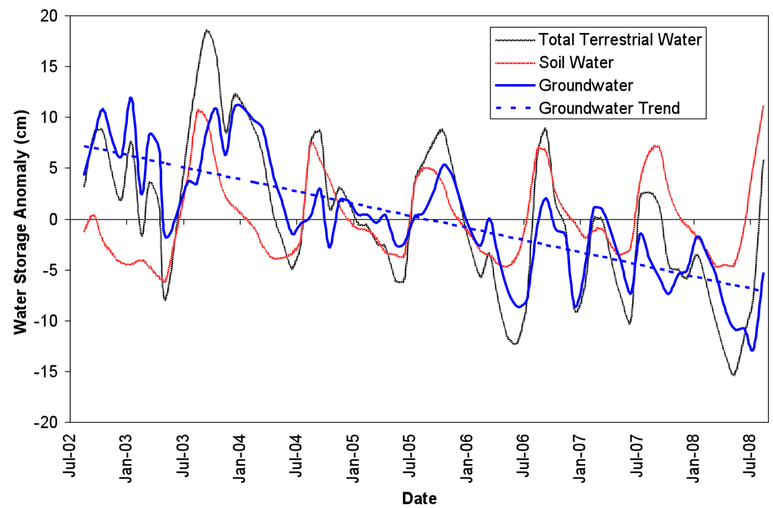


Drawdown by 31 km^3
(= 1 Lake Mead)
in 66 months

Famiglietti et al., 2009

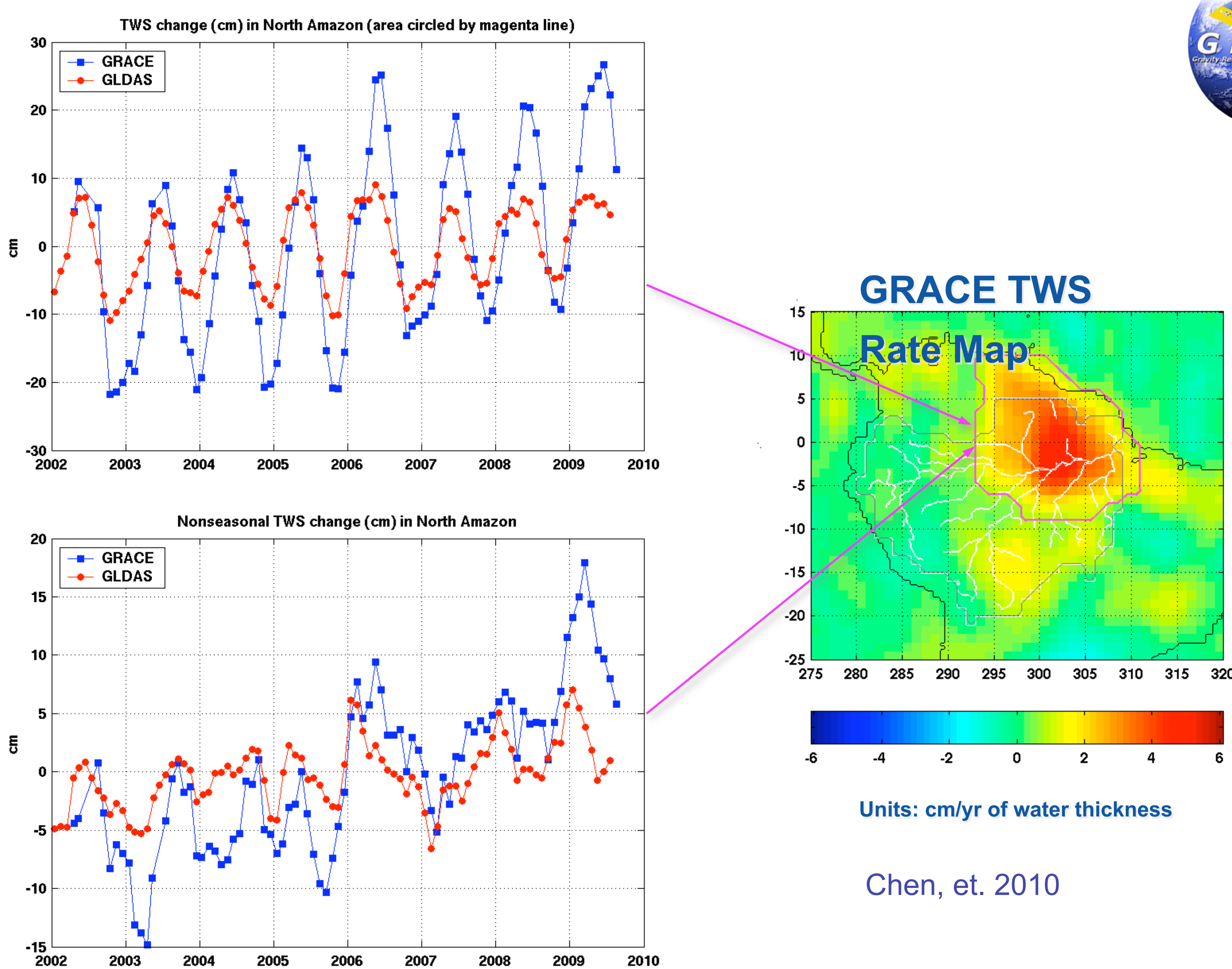


Pattern of groundwater depletion in NW India



Loss of 109 km^3
(3 Lake Meads)
over 72 months

Rodell et al., 2009



Units: cm/yr of water thickness

Chen, et. 2010

Model Assimilation

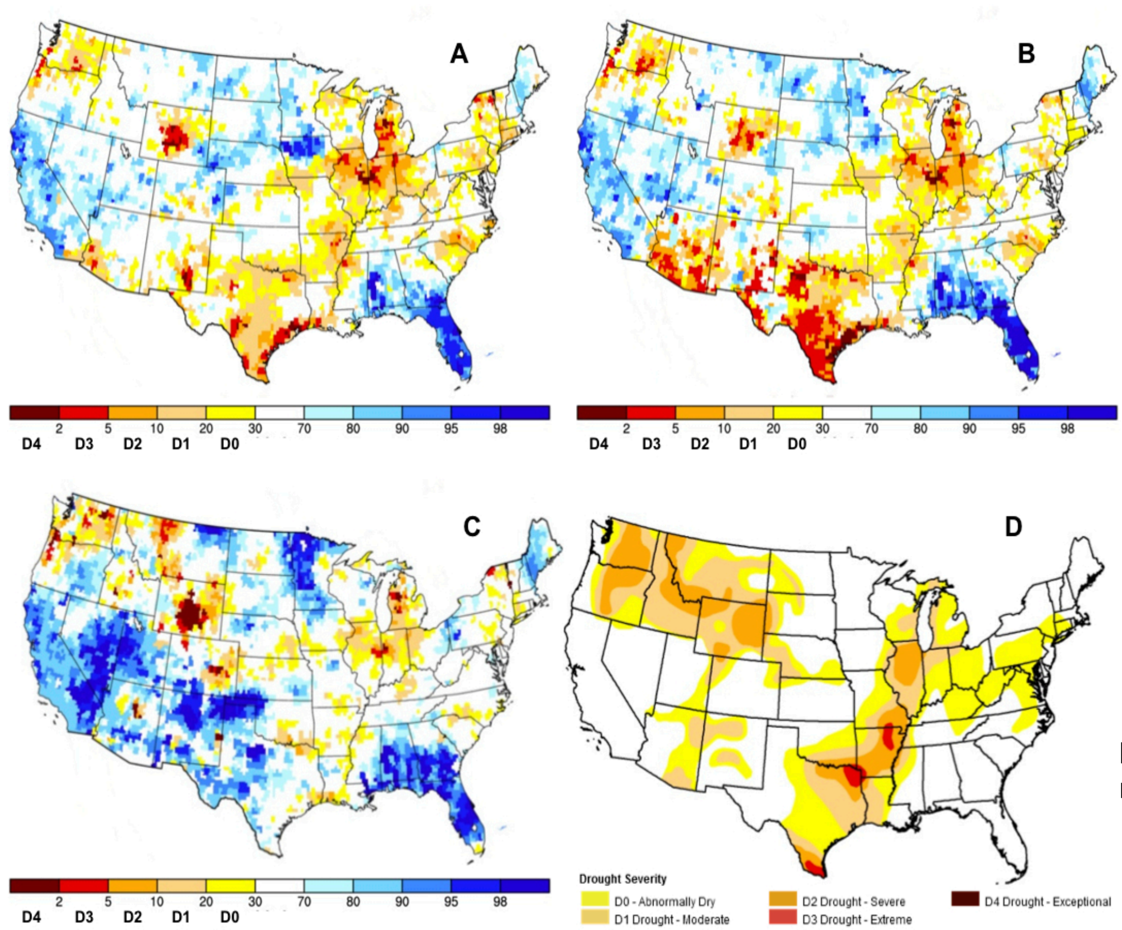
GRACE observations of the Earth's time-variable gravity field enable reliable detection of variations in total terrestrial water storage

- TWS is the sum of groundwater, soil moisture, snow, surface water, ice, and biomass.
- Enables closing the observational gap in monitoring regional to continental scale water storage changes on a systematic basis.
- Models provide enhanced spatial and temporal resolutio for the GRACE observations

Currently, a GRACE rapid response product is being produced on a daily basis tosupport near real time hydrology and natural hazard applications including drought, flooding and earth quake response

GRACE Indicators for Drought Monitor

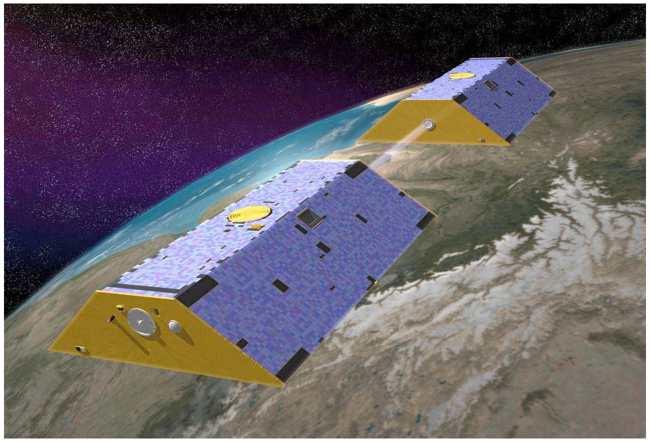
Surface Soil Moisture | Root Zone Soil Moisture



Groundwater | U.S. Drought Monitor Product

http://www.drought.unl.edu/dm/monitor.html

GRACE Mission Status Summary



GRACE data is producing excellent science

Time variable gravity effects enable new studies in Hydrology, Oceanography, Glaciology and Solid Earth Sciences

- Variety of disciplines involved (touches all NASA and DGF focus areas)
- Large number of "first-time" measurements

Enhanced Science with Mission Extension:

- Improved understanding of the climate system's secular, seasonal and inter-annual signals
- Scientific advances are expected from improved spatial-temporal resolution obtained with RL-05 gravity models

Mission Life

- Adequate satellite resources for continued mission
- Ageing components and single string operations are a concern
  - Battery Life is an evolving issue

Measurement Continuity Prospects

- NASA GRACE FO proposed in Presidents FY 2011 Budget
  - Proposed for Launch in 2017
- GFZ Proposal to BMBF FONA Program for German Funding

Issues for Overguide Budget:

- Battery Management to maximize mission life
- Development of Single Satellite Strategy for Bridging to GRACE FO
- Activities to improve the Science Yield

Orbit and Satellites

Launched: March 17, 2002

Over 9 years in orbit(3509 days)

Initial Altitude: 500 km

Current Altitude: ~456 km (-10 m/d)

Inclination: 89 deg

Eccentricity: ~0.001

Separation Distance: ~220 km

Currently 228 km(16 m/day)

Nominal Mission : 5 years

Non-Repeat Ground Track, Earth Pointed, 3-Axis Stable

Predicted Lifetime 2013

The Future of the GRACE Measurement

- The GRACE mission is unlikely to last until 2015
- Under the NRS ES Decadal Survey recommendations, a GRACE-II mission would be launched ~>2020. A significant gap would occur in the climate dataset.
- Science Community has expressed concern about the loss in measurement continuity.
- GRACE Follow-On was included as a Climate Continuity Mission in the FY 2011 Budget Initiative
  - Rapid response for data continuity by relying on the GRACE heritage
    - To be launched in 2016.
- There will likely be a gap in the GRACE and GRACE FO measurements

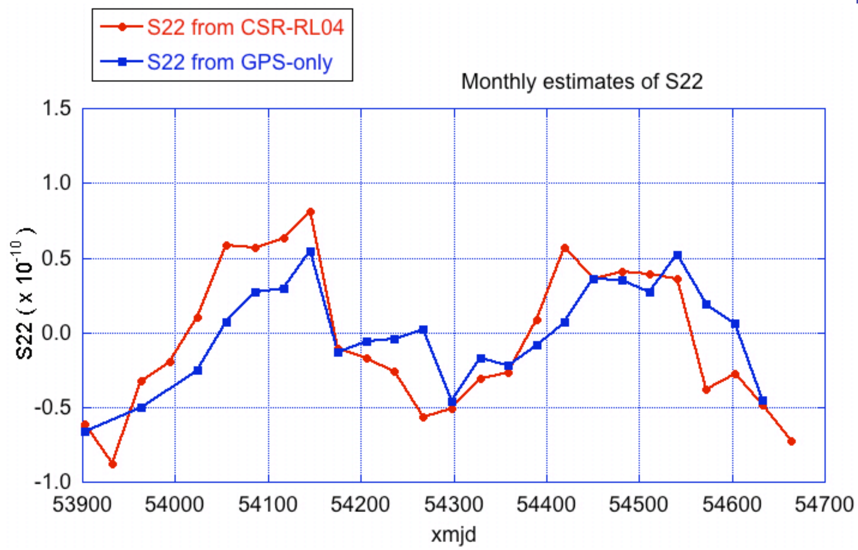
Science From Single GRACE Satellite

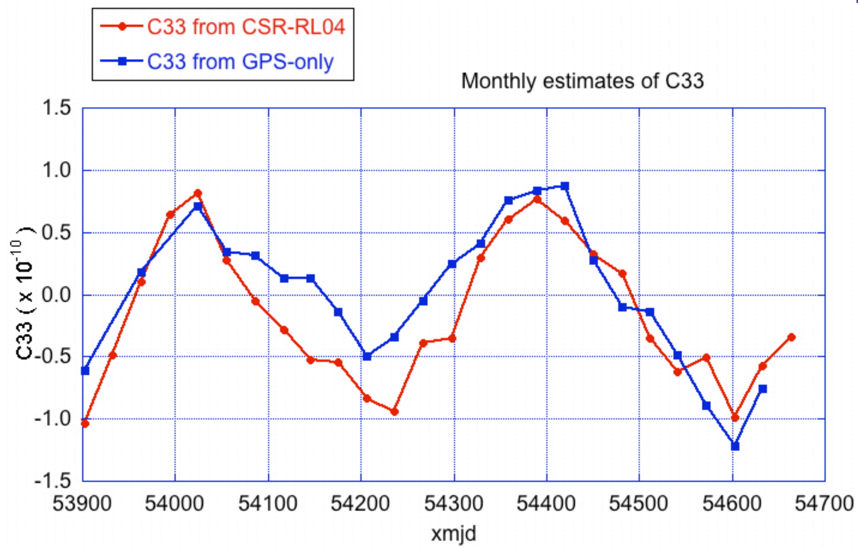
•Gravity Science:

- A single GRACE satellite, with operational GPS receiver, star-camera and accelerometer, can give time-variability of low-degree harmonics (see right).
- * Low degree field (5x5, perhaps more) should be determinable – some harmonics better than others. Best "science-use" approach is a subject for research.
- * Offers opportunity for direct inter-comparison between GRACE and GRACE-FO outcomes.

•Operations Scenario:

•Continuous operation of a GRACE satellite is not required to ensure science "continuity" – making for flexible operations scenario to ensure longevity. KBR will remain off, for power savings.





From Bettadpur,et al (WCRP, 2011)

Science Accomplishments

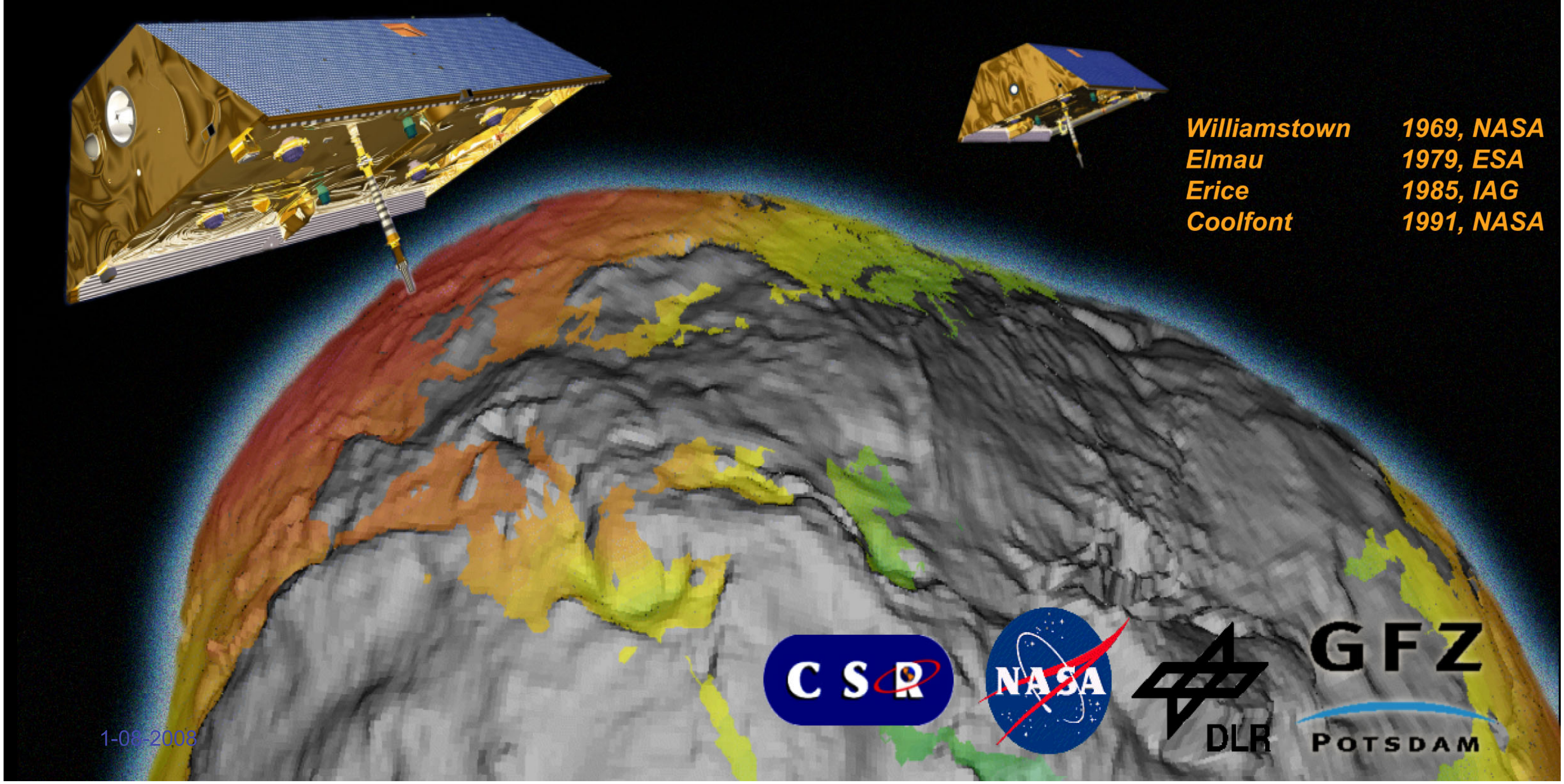
Some results from GRACE measurements of mass flux:

- Time variable gravity results provide unique insight into ice mass trends
  - Direct mass measurement of monthly mass change
  - Monthly measurement allows separation of trends and seasonal cycle
  - Complementary to altimetry and radar, which measure surface displacement and volume change
- Total water storage in major global river basins
  - Monthly coverage of every major basin, including Siberian/Arctic drainage basins
  - Integrated measurement of all forms of water storage: groundwater, soil moisture, surface water, and snow
  - Can be downscaled and decomposed via assimilation into land surface hydrology models for application to agriculture, water management, and climate monitoring
  - Constrains estimates of mass fluxes: precipitation, evapotranspiration, runoff
- Ocean Trends - Globally and regionally
  - Separation of mass and temperature components of sea-level change
  - Ocean bottom pressure change and inference of deep ocean currents
  - Trends in Arctic Ocean mass distribution revealing change in polar ocean circulation

GRACE

Gravity Recovery and Climate Experiment

A Response to over 3 Decades of Recommendations by the Scientific Community for a Dedicated Gravity Mission



Williamstown	*1969, NASA*
Elmau	*1979, ESA*
Erice	*1985, IAG*
Coolfont	*1991, NASA*

CSR NASA DLR GFZ POTSDAM

Progress in Mean Gravity Field Models