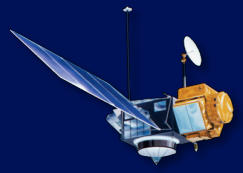


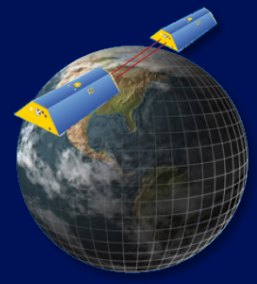
GRACE Satellite Gravity Measurements and Geophysical Applications

Jianli Chen

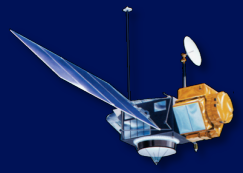
（陈剑利）

Ph.D., Senior Research Scientist

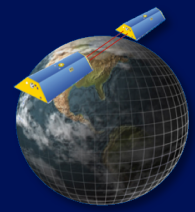
Center for Space Research, University of Texas at Austin



2014 SEOGC Summer School 07/14-07/19, Shanghai

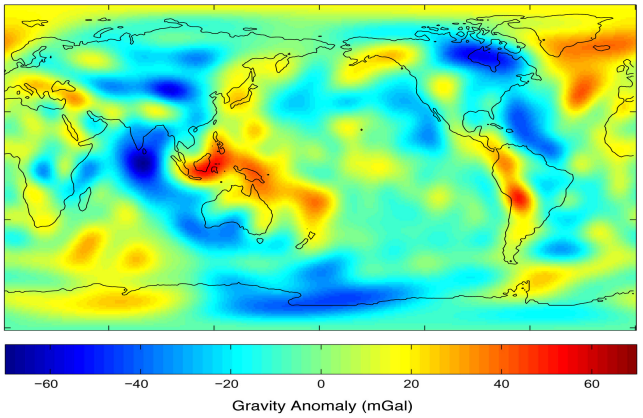


GRACE Satellite Gravity Measurements and Geophysical Applications

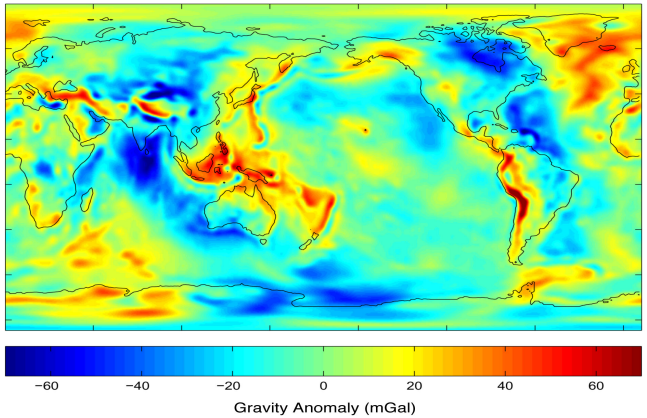


Progress in Gravity Field Resolutions

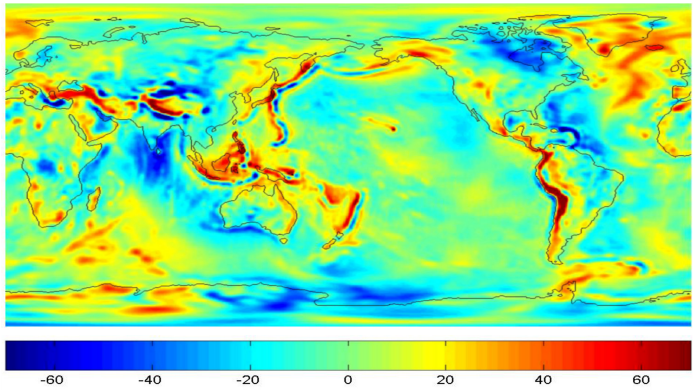
Decades of tracking to geodetic satellites



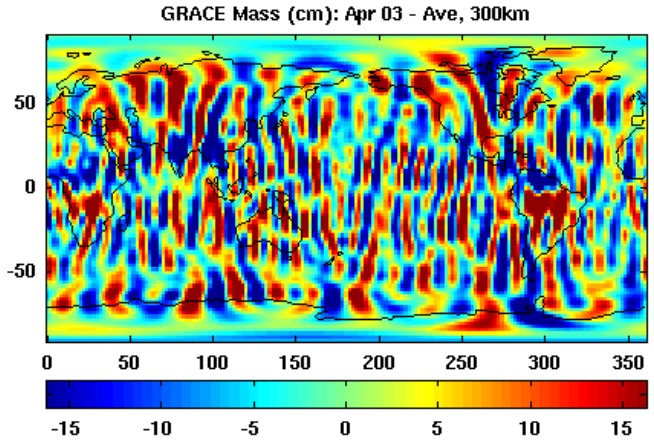
111 days of GRACE data

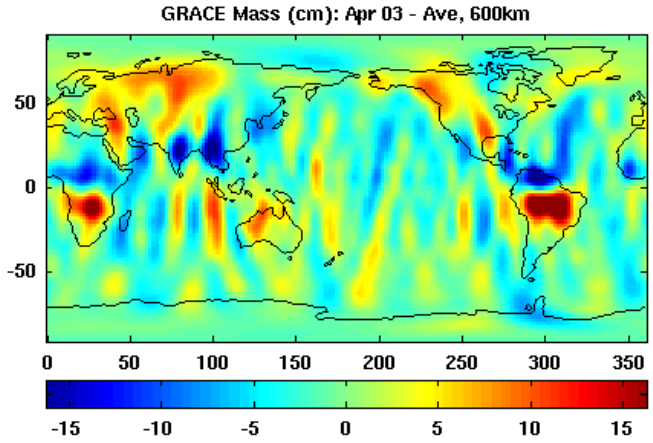


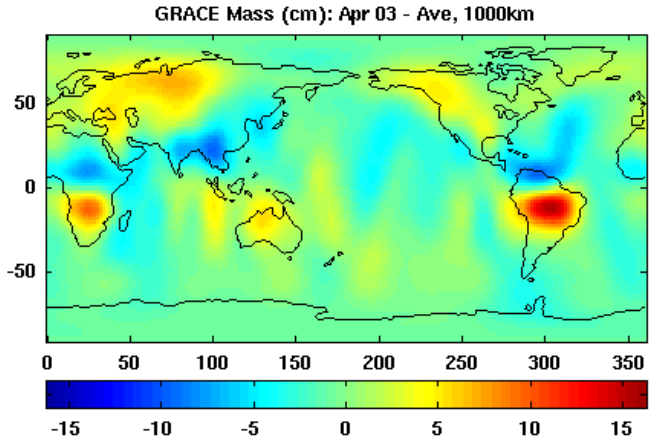
13 months of GRACE data

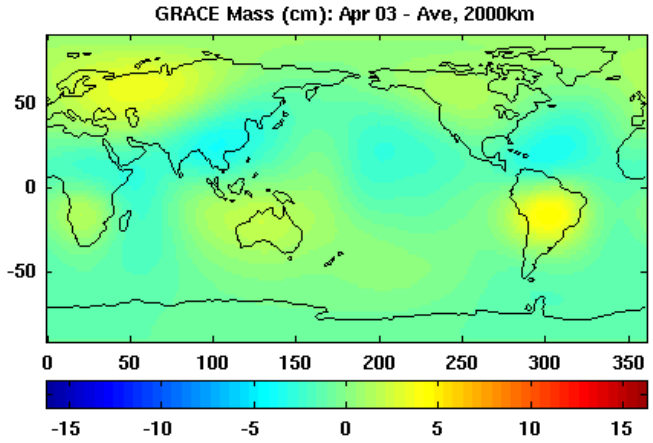


Challenges of GRACE Data Processing

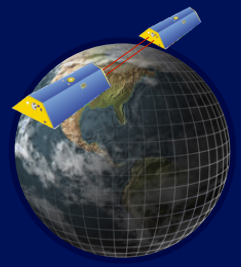






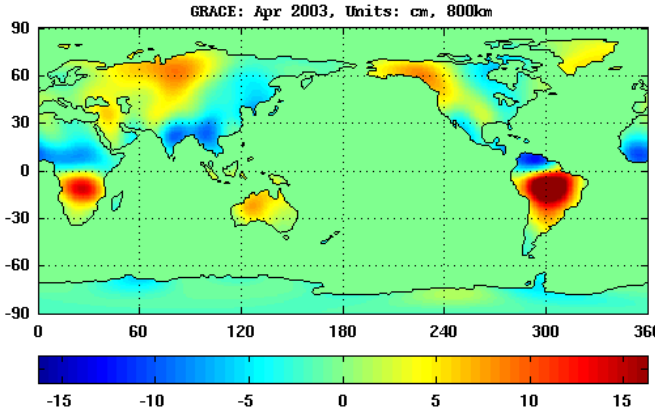


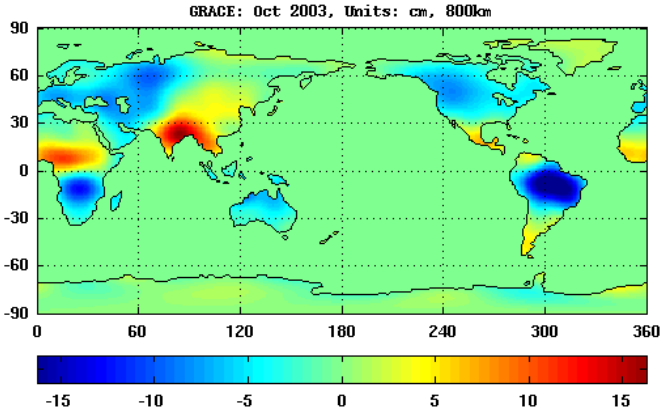
GRACE and Global Climate Change

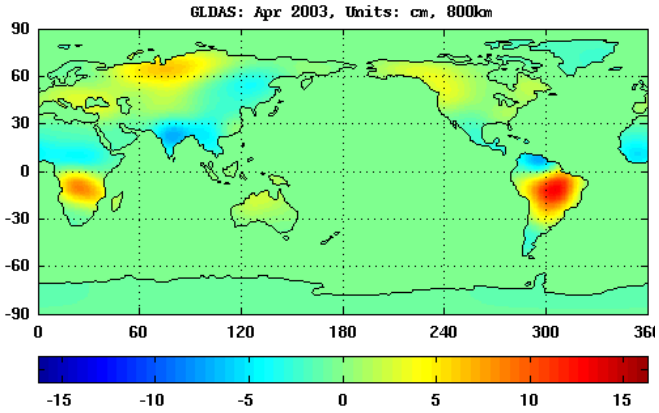


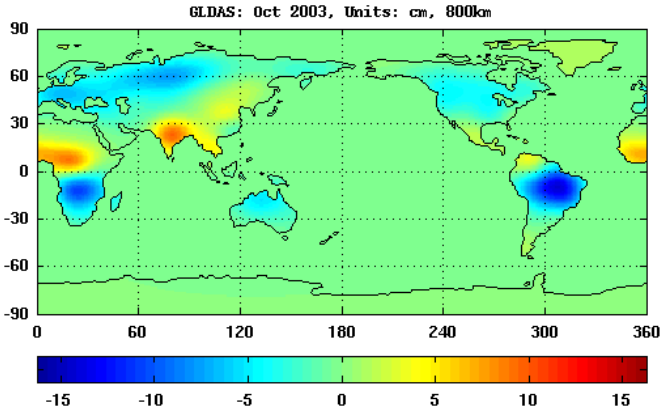
- Hydrosphere
  - Land water storage
  - Precipitation
  - Evapotranspiration
  - Runoff
  - Ground water
  - Droughts
  - Floodings
- Ocean
  - Global sea level change
  - Ocean heat content variation
- Cryosphere
  - Polar ice sheets mass balance
  - Mountain glaciers mass balance

Global Water Storage Change from GRACE

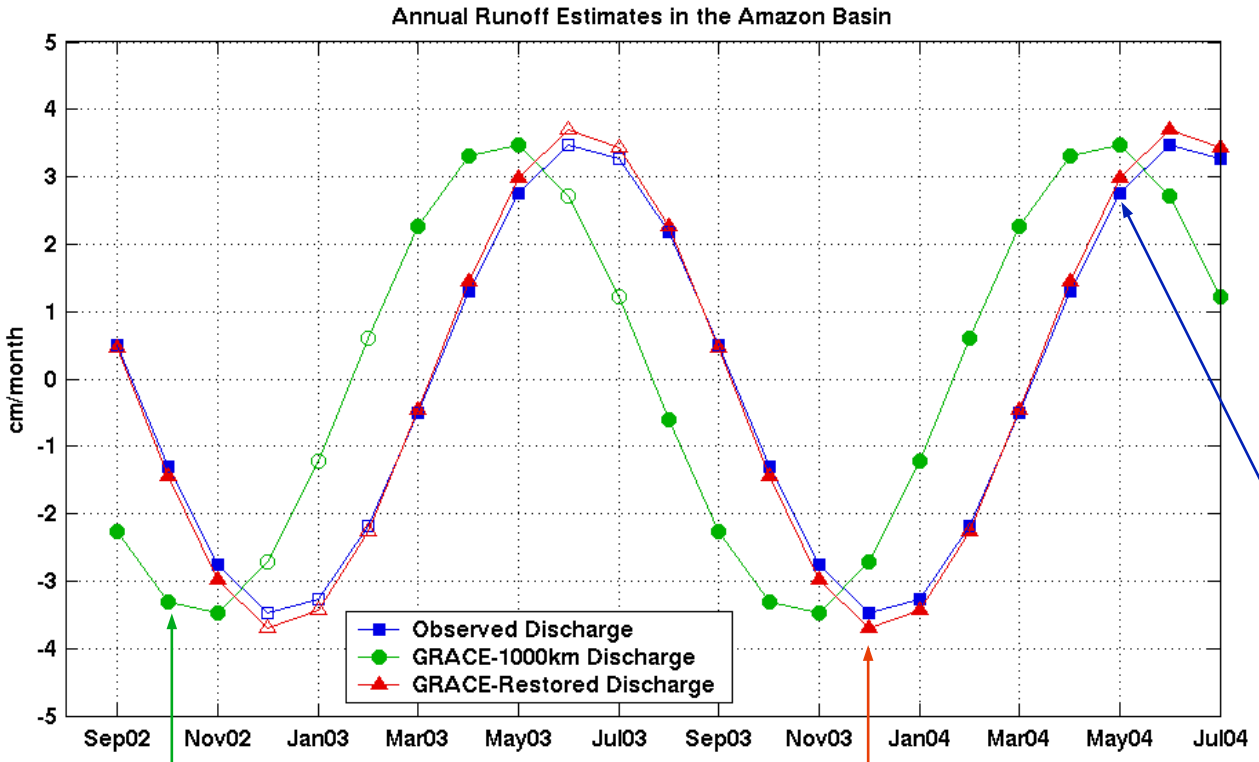








Annual Runoff Estimates in Amazon Basin

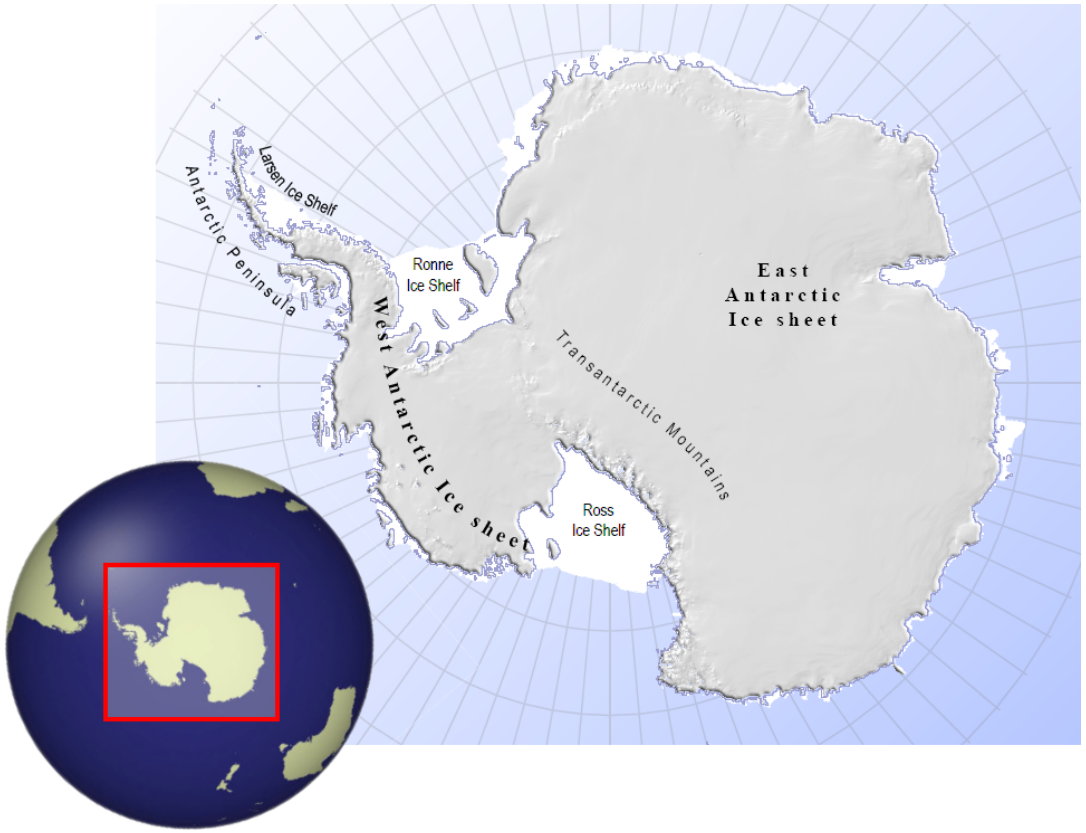


River Gauge Observations

GRACE without leakage correction

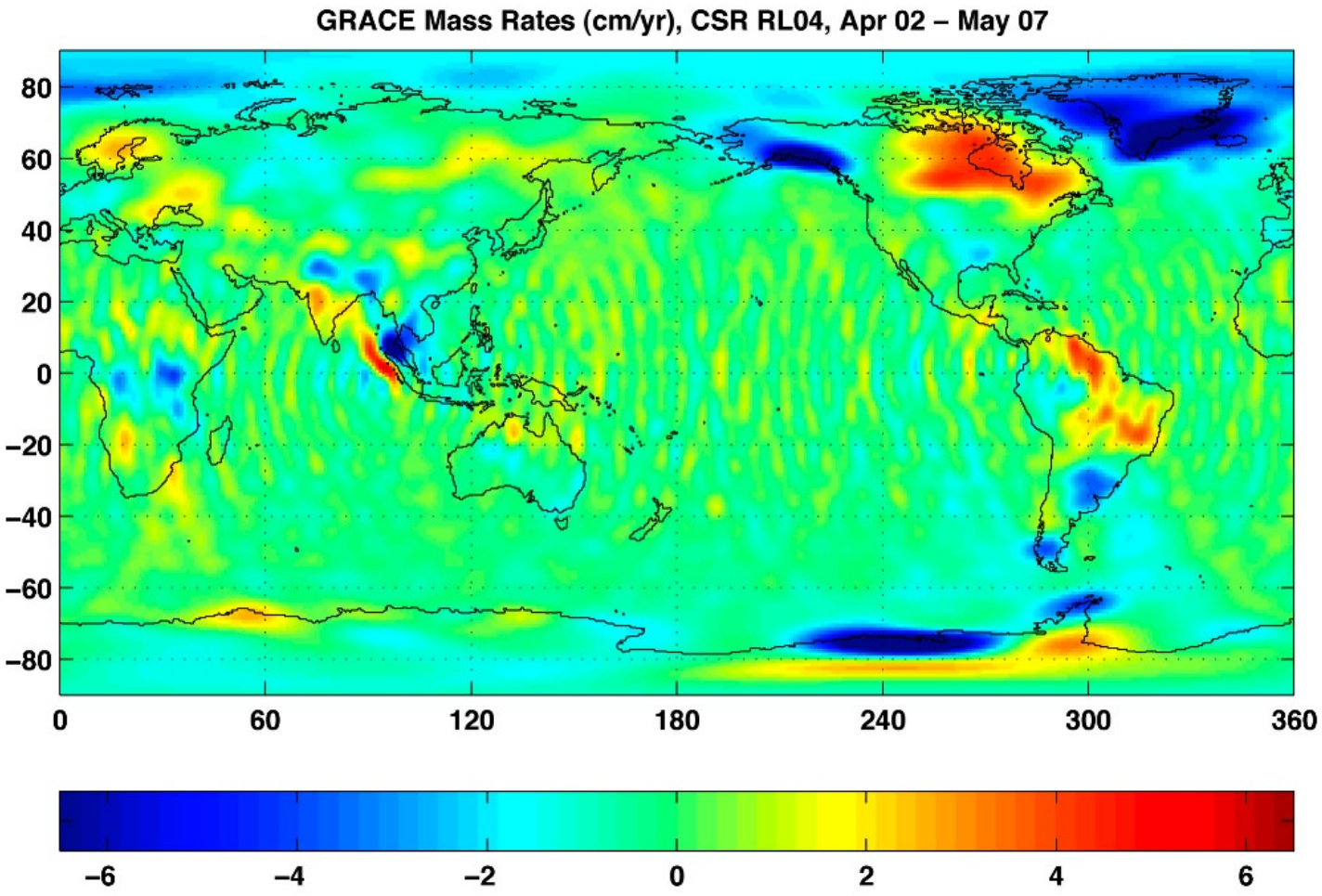
GRACE with leakage correction

Antarctic Ice Sheet Mass Balance From GRACE



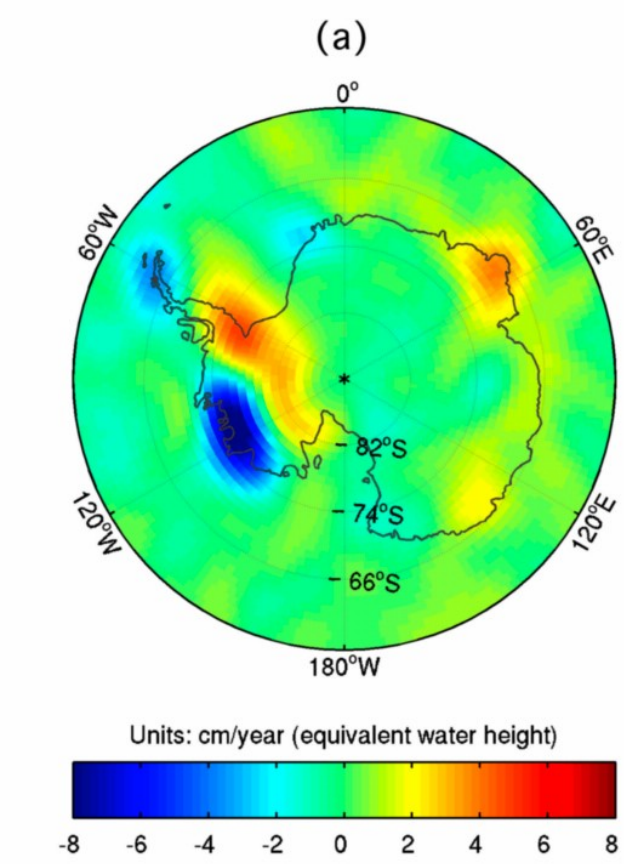
The Antarctic ice sheet has a total area of ~ 14,000,000 km^2 and averaged ice sheet thickness of ~ 2.16 km, accounts for 90% of the world's ice and 75% of the world's fresh water resources, and has the potential to raise the global sea level by over 70 meters if completely melt.

Global long-term mass change rates from GRACE

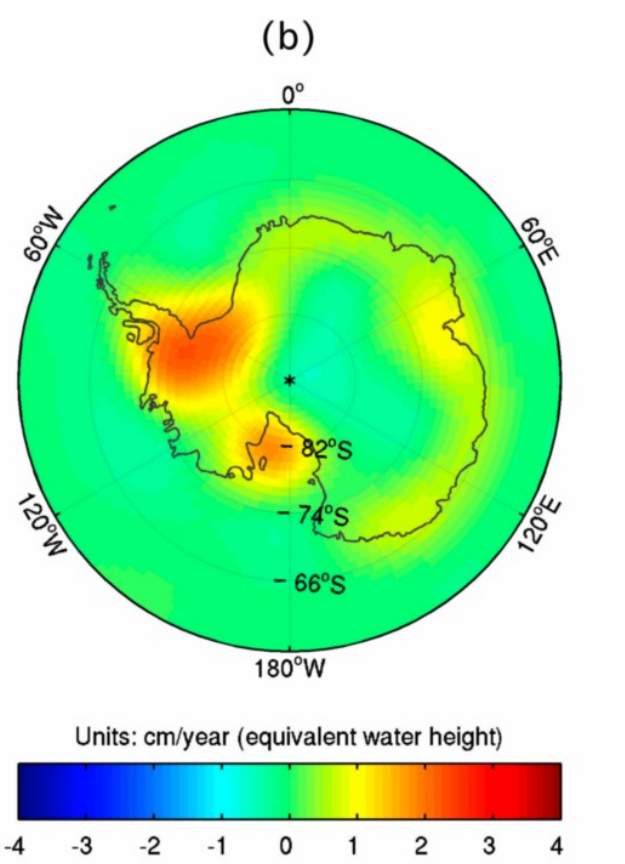


Based on 58 CSR RL04 monthly gravity solutions from April 2002 to May 2007.

GRACE-observed mass change rates (in cm/year of water height) over Antarctica, P4M6 + 300 km Gaussian smoothing.

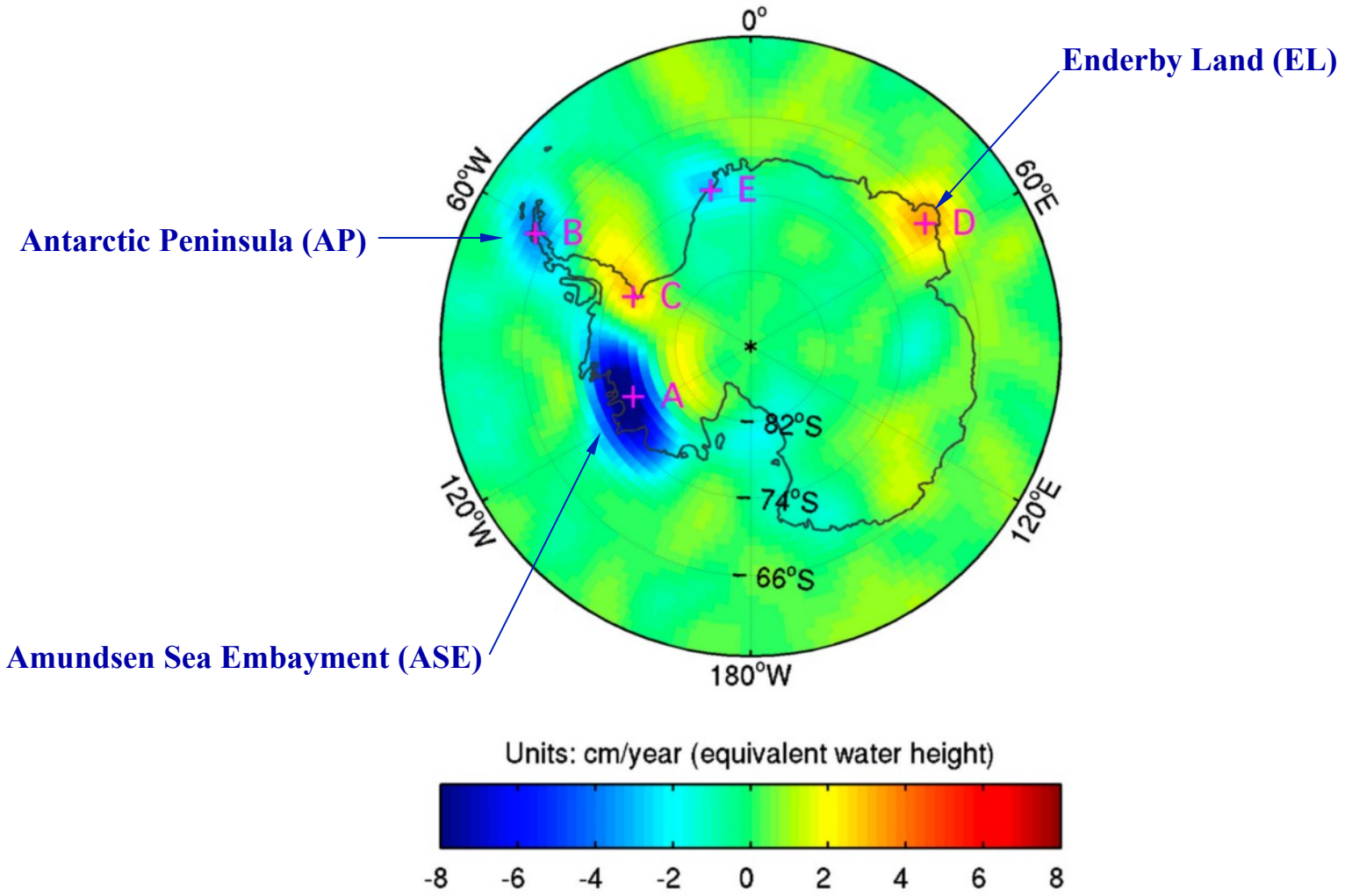


PGR effects (in mass equivalent) over Antarctica from the IJ05 PGR model, P4M6 + 300 km Gaussian smoothing.



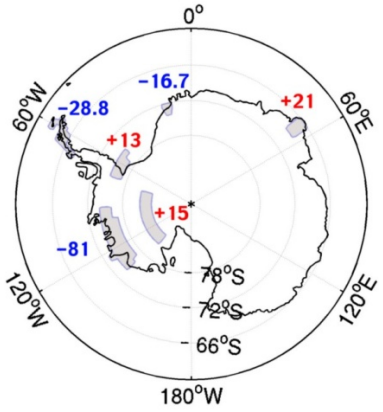
(Please note the different color scales, ± 8 vs. ± 4.)

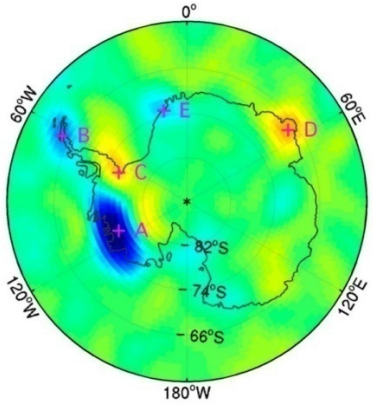
Antarctic long-term ice mass change rates (GRACE - PGR)



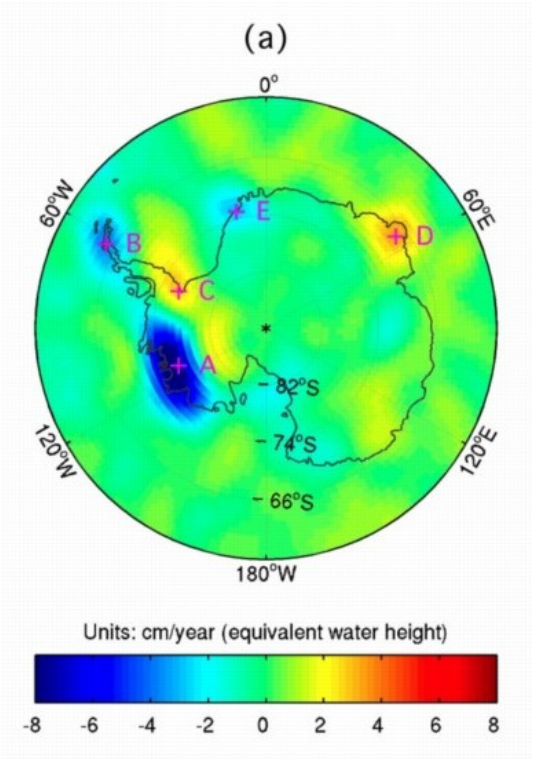
Forward Modeling

- **Step-1:** To choose six regions (shaded) where GRACE data show prominent signals. In each region (on 1° x 1° grid), a trial mass rate (in units of km^3/yr) is distributed uniformly. The remainder of the grid (outside Antarctica) retains GRACE mass rates. Therefore, spatial leakage from the 6 regions to areas outside Antarctica should be evident when comparing the model and GRACE rate maps. This is a variation of the forward modeling technique in our previous studies.
- **Step-2:** To convert the constructed mass rate grids into spherical harmonics.
- **Step-3:** To replicate procedures (used to transform GRACE data) to compute surface mass changes (no degree-1 terms, same truncation and same 2-steps filtering, …).
- **Step-4:** To adjust model rates and region shapes until there is general agreement with the GRACE map. As a final constraint, we force model integrated mass rate for each region (sum over grid points with cosine of latitude weights within boundaries where magnitude exceeds 1 cm/year) to agree with the GRACE map.

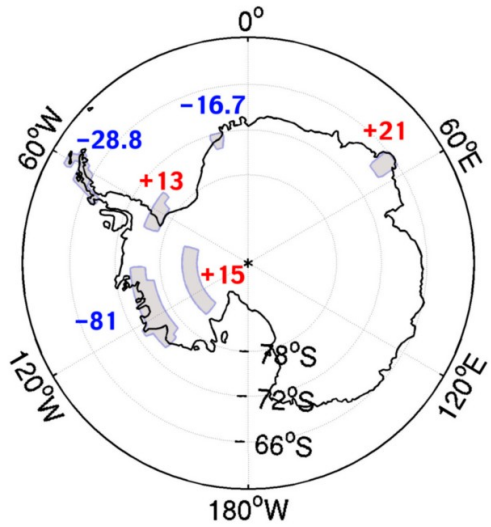




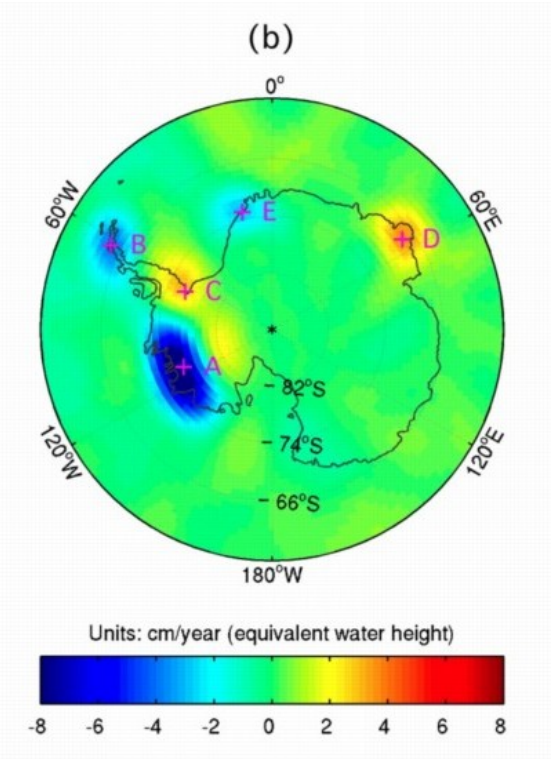
GRACE Observations (GRACE-PGR)



Modeling Scheme

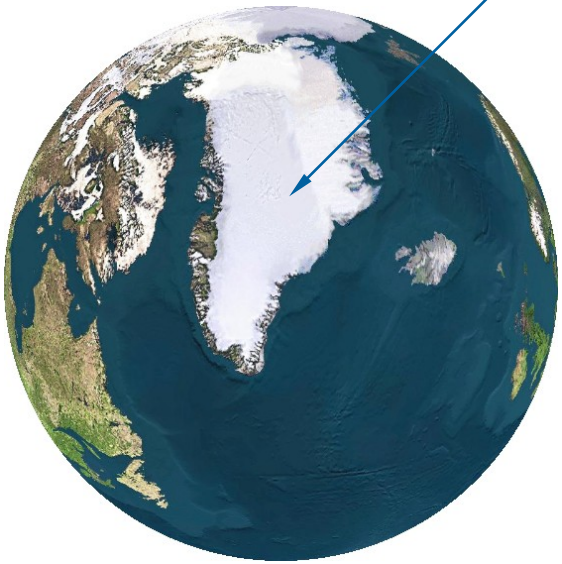


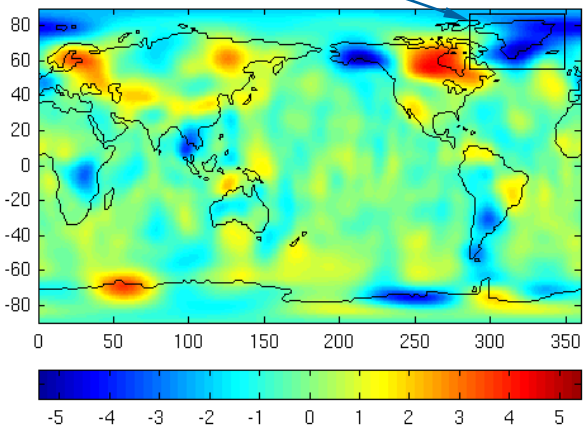
Forward Modeling Estimates



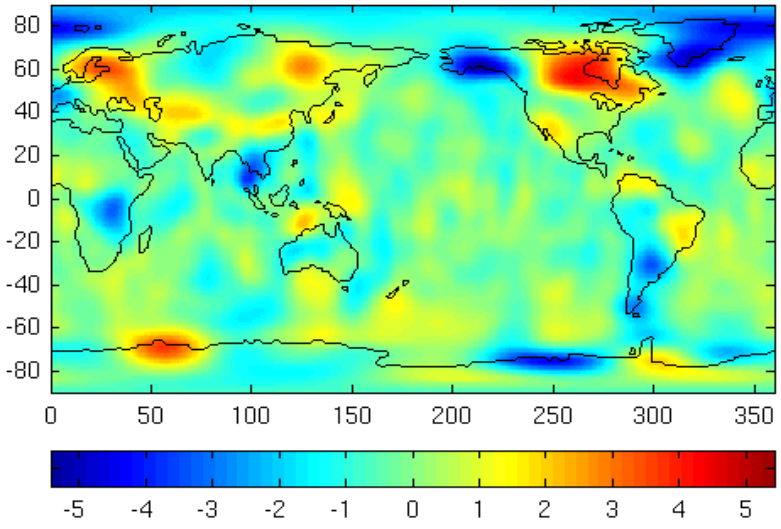
Climate Change and Greenland Ice Loss

Greenland Ice Sheet

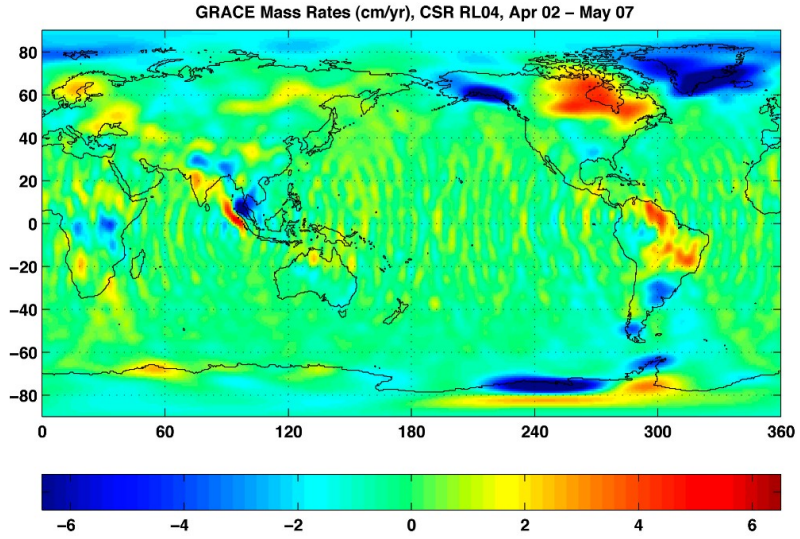




The Changing Climate & Greenland Ice Mass Change



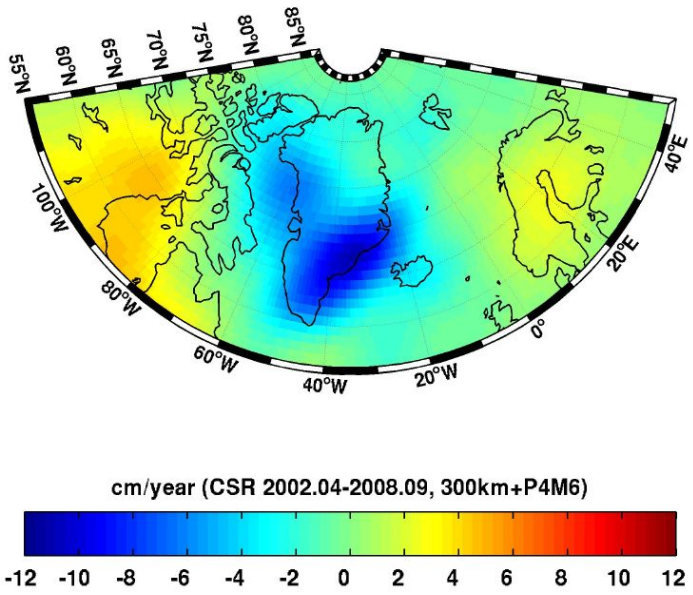
RL01 - 3.5 Years
(Apr 2002 - Nov 2005)



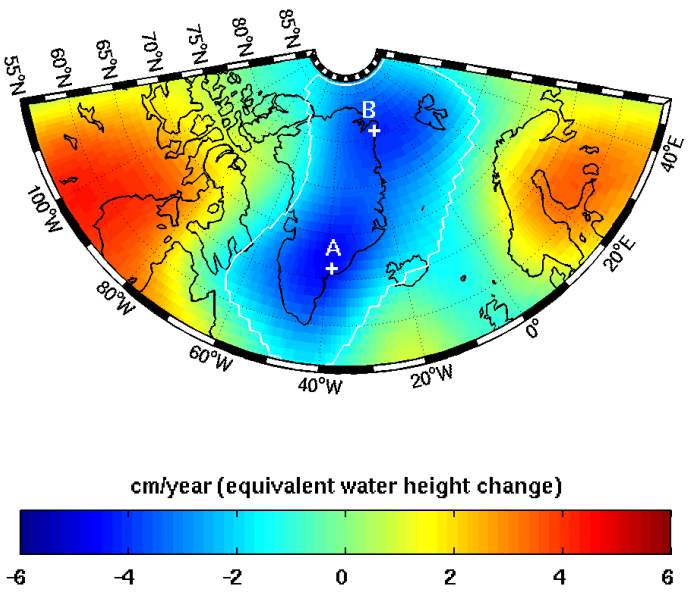
RL04 - 5 Years
(Apr 2002 - May 2007)

The Changing Climate & Greenland Ice Mass Change

GRACE RL04 - 6.5 Years
2002.04 - 2008.09

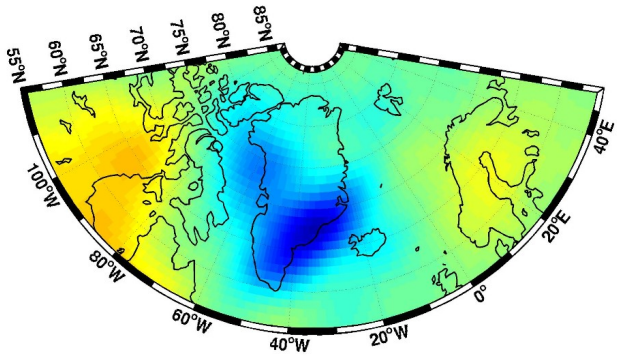


GRACE RL01 - 3.5 Years
2002.04 - 2005.11

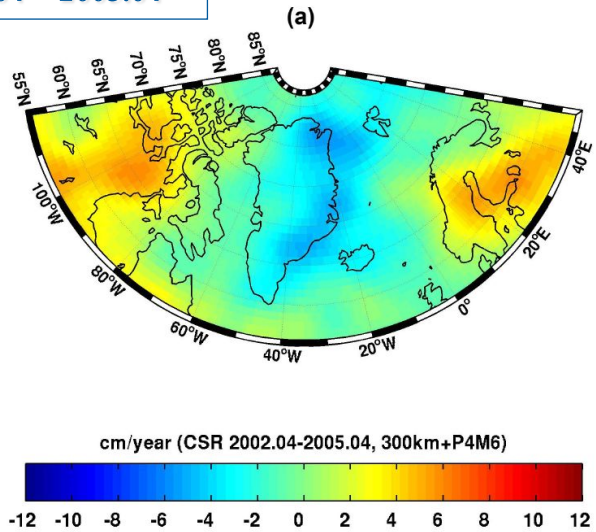


The Changing Climate & Greenland Ice Mass Change

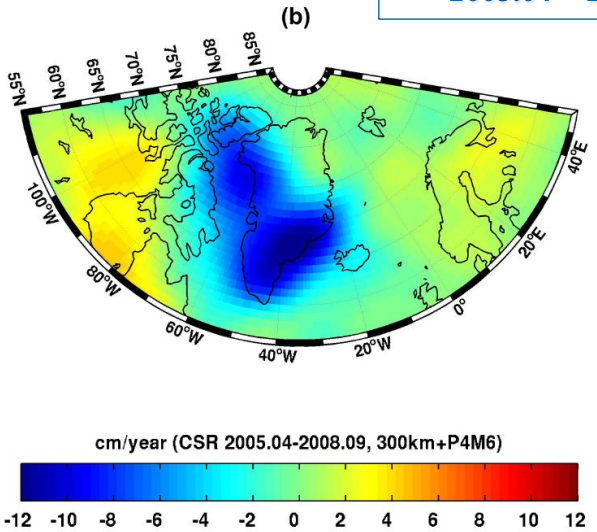
GRACE RL04 - 6.5 Years
2002.04 - 2008.09



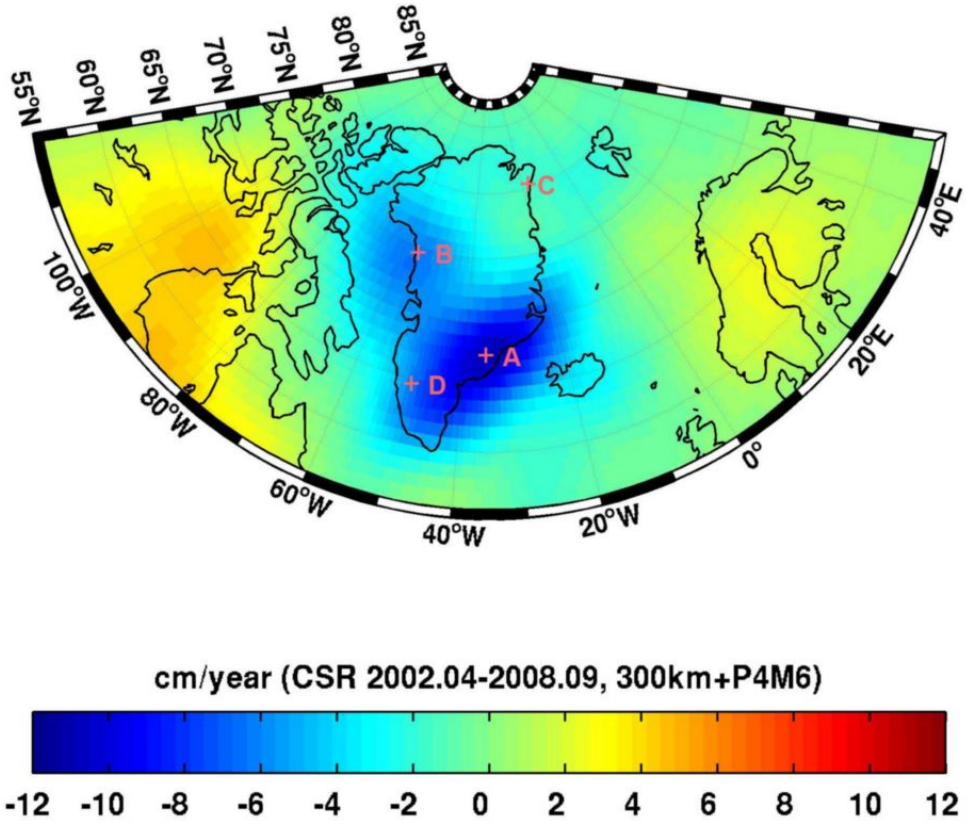
RL04 - First 3 Years
2002.04 - 2005.04



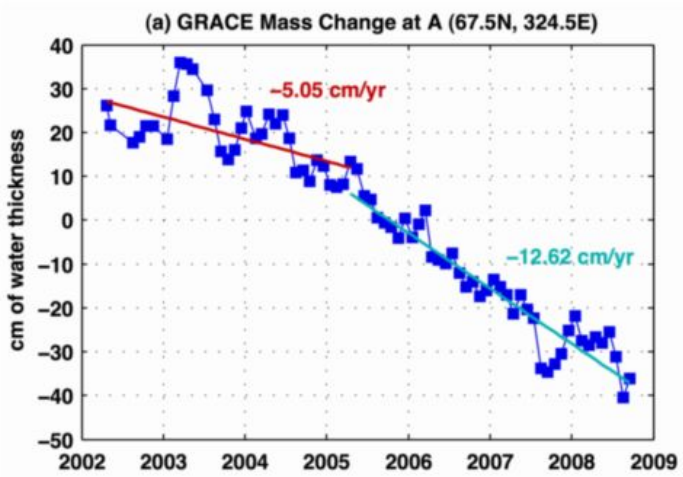
RL04 - Recent 3.5 Years
2005.04 - 2008.09

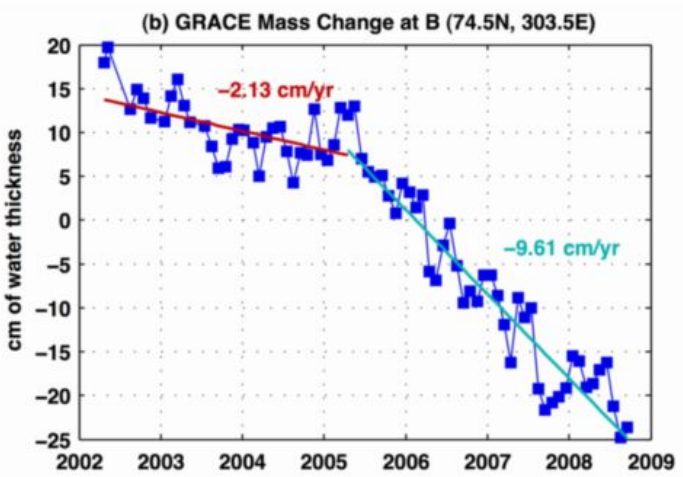


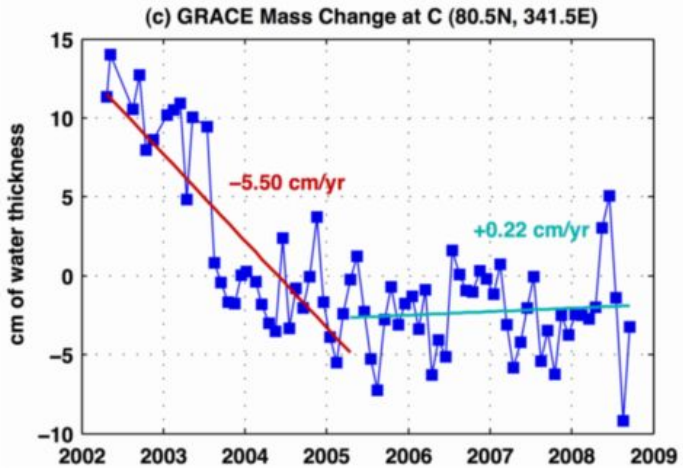
GRACE Time Series at 4 Selected Locations (A, B, C, D)

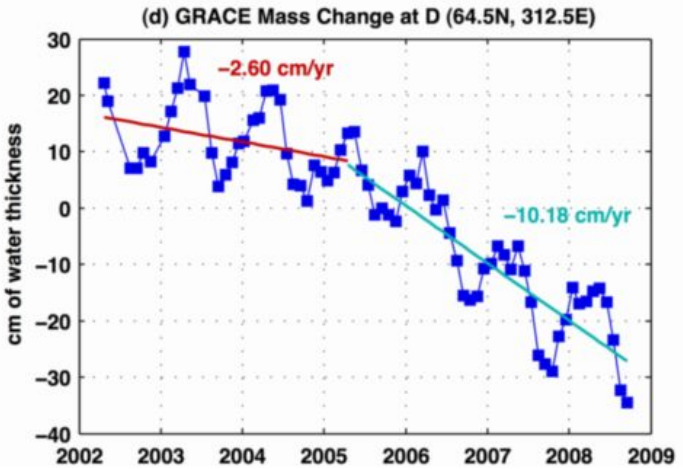


GRACE Time Series at 4 Selected Grids (A, B, C, D)

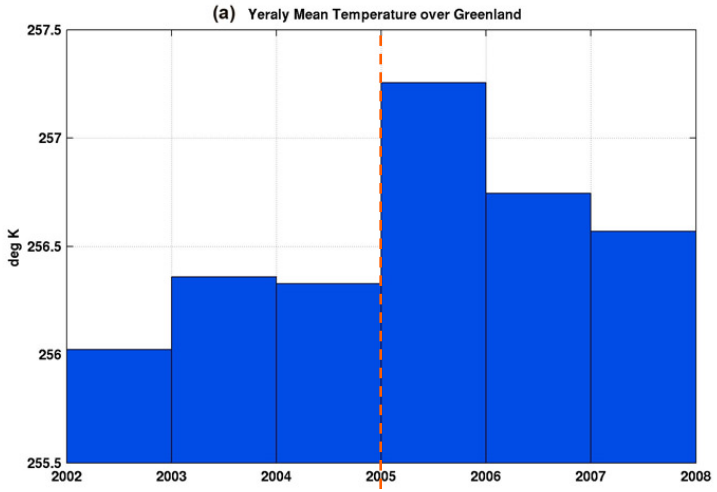




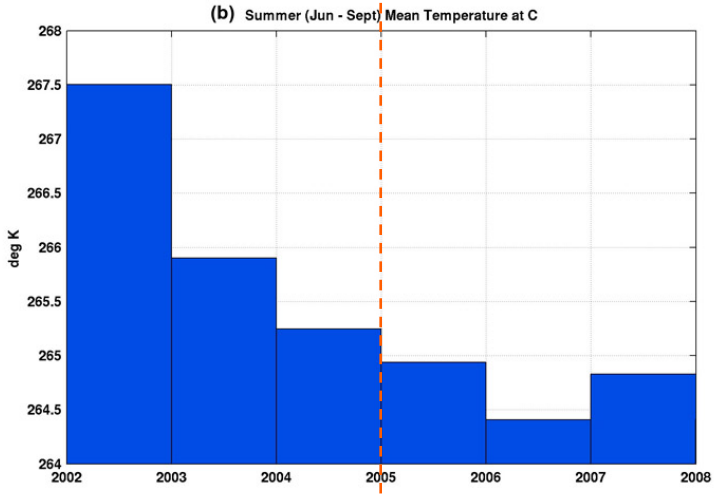




The Changing Climate in Greenland



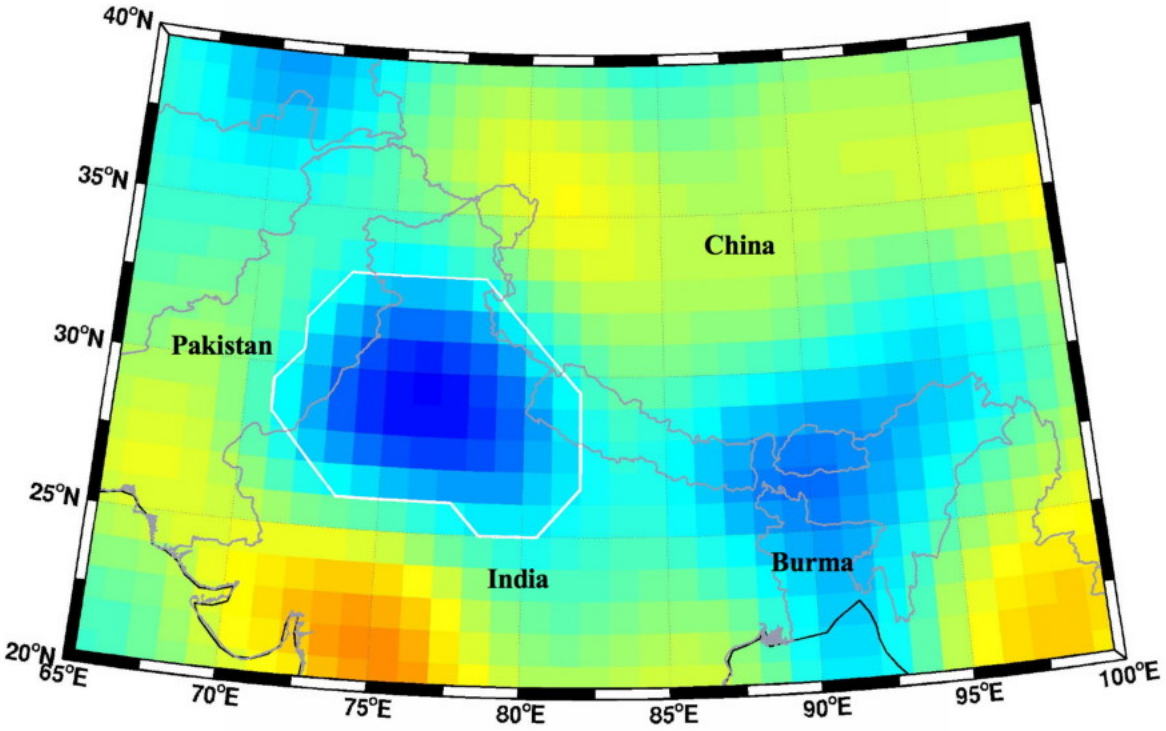
Yearly Mean Temperature (2m) Over Greenland



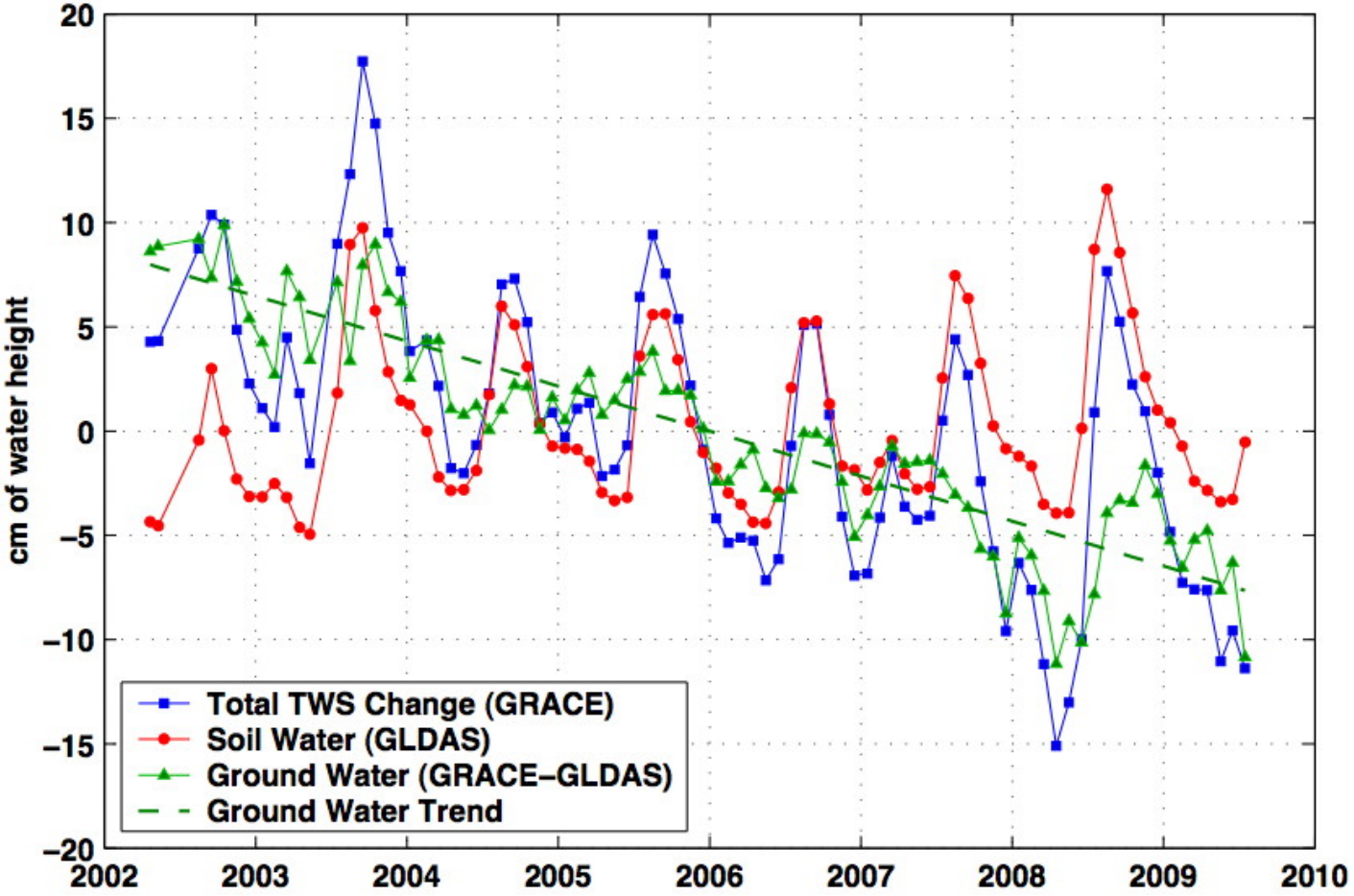
Summer (Jun - Sept) Mean Temperature (2m) at Point C

2005

Excessive Groundwater Depletion in Northwest India

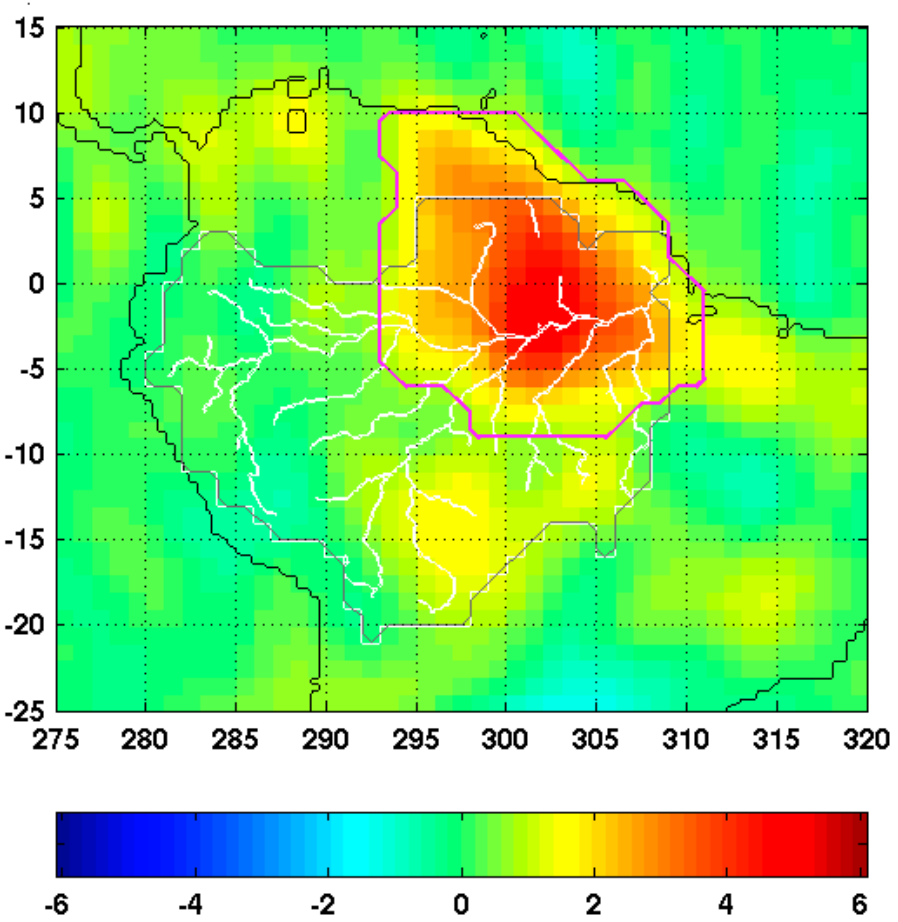


Excessive Groundwater Depletion in Northwest India

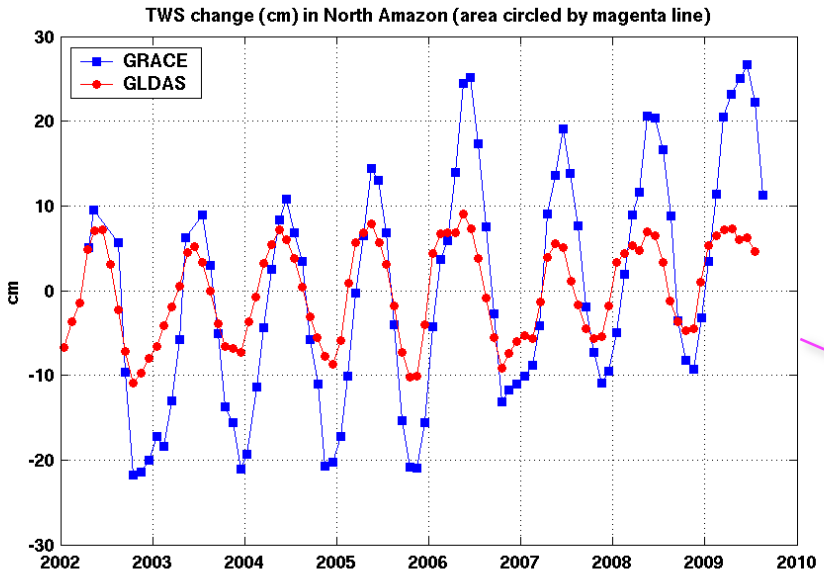


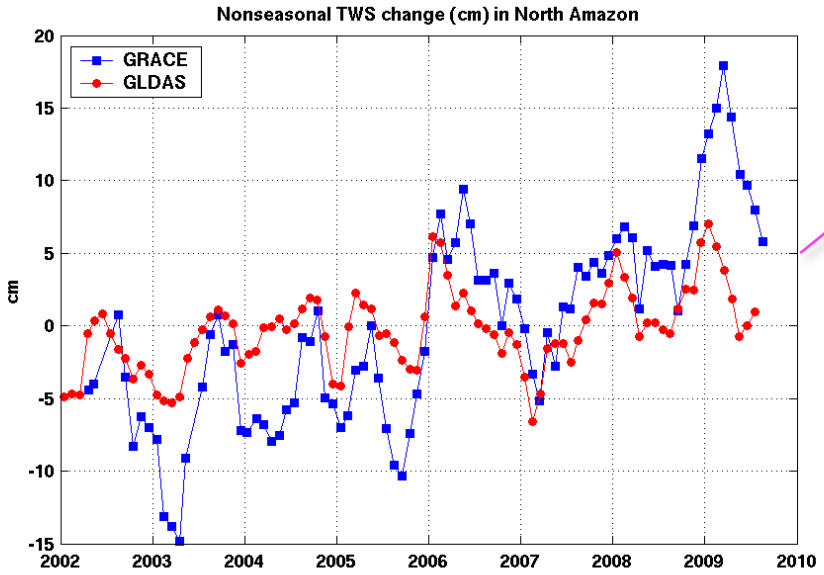
The 2009 Exceptional Flood in Lower Amazon

GRACE Mass Rate (2002.04 - 2009.08)

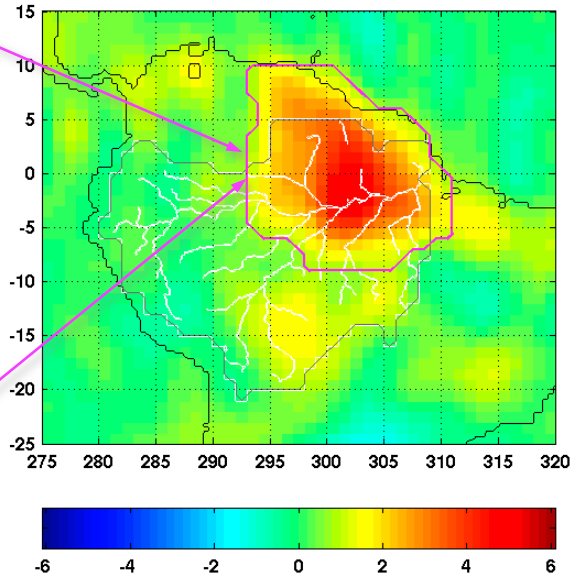


(Units: cm/year of equivalent water height)

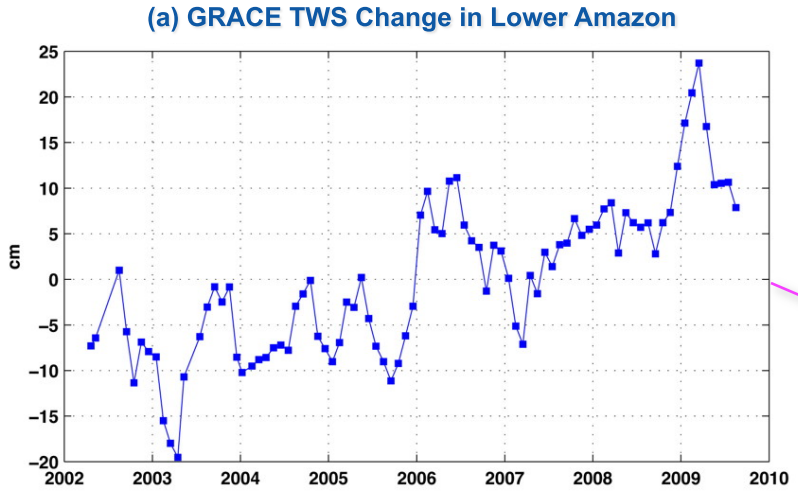


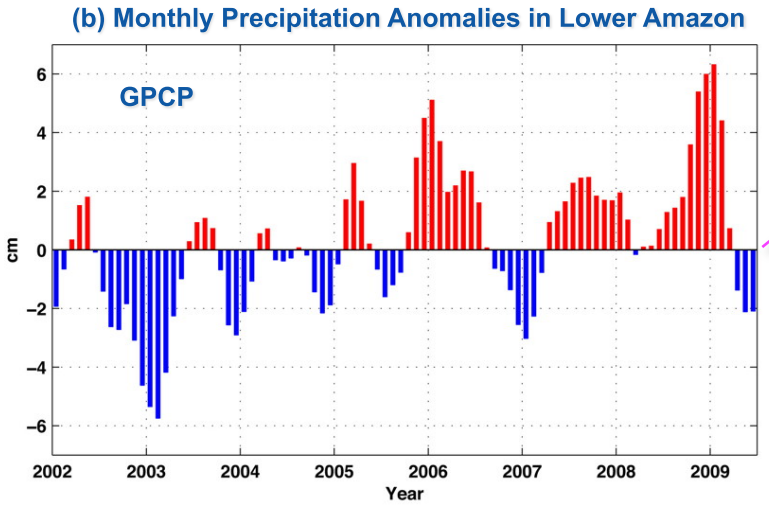


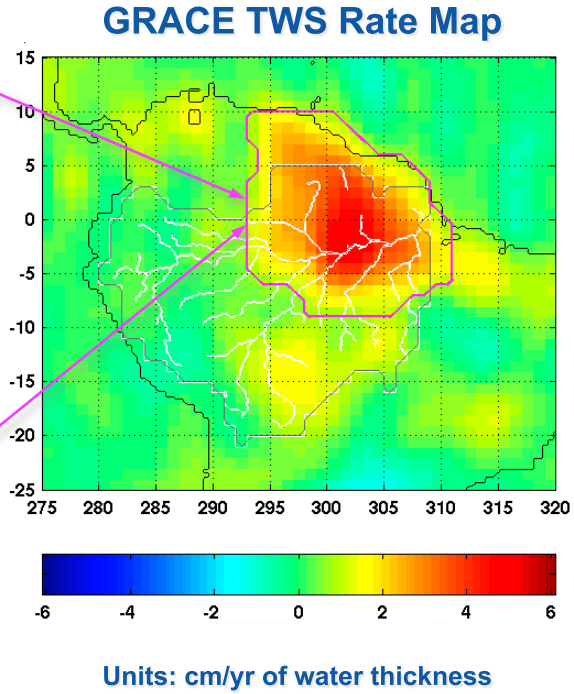
GRACE TWS Rate Map

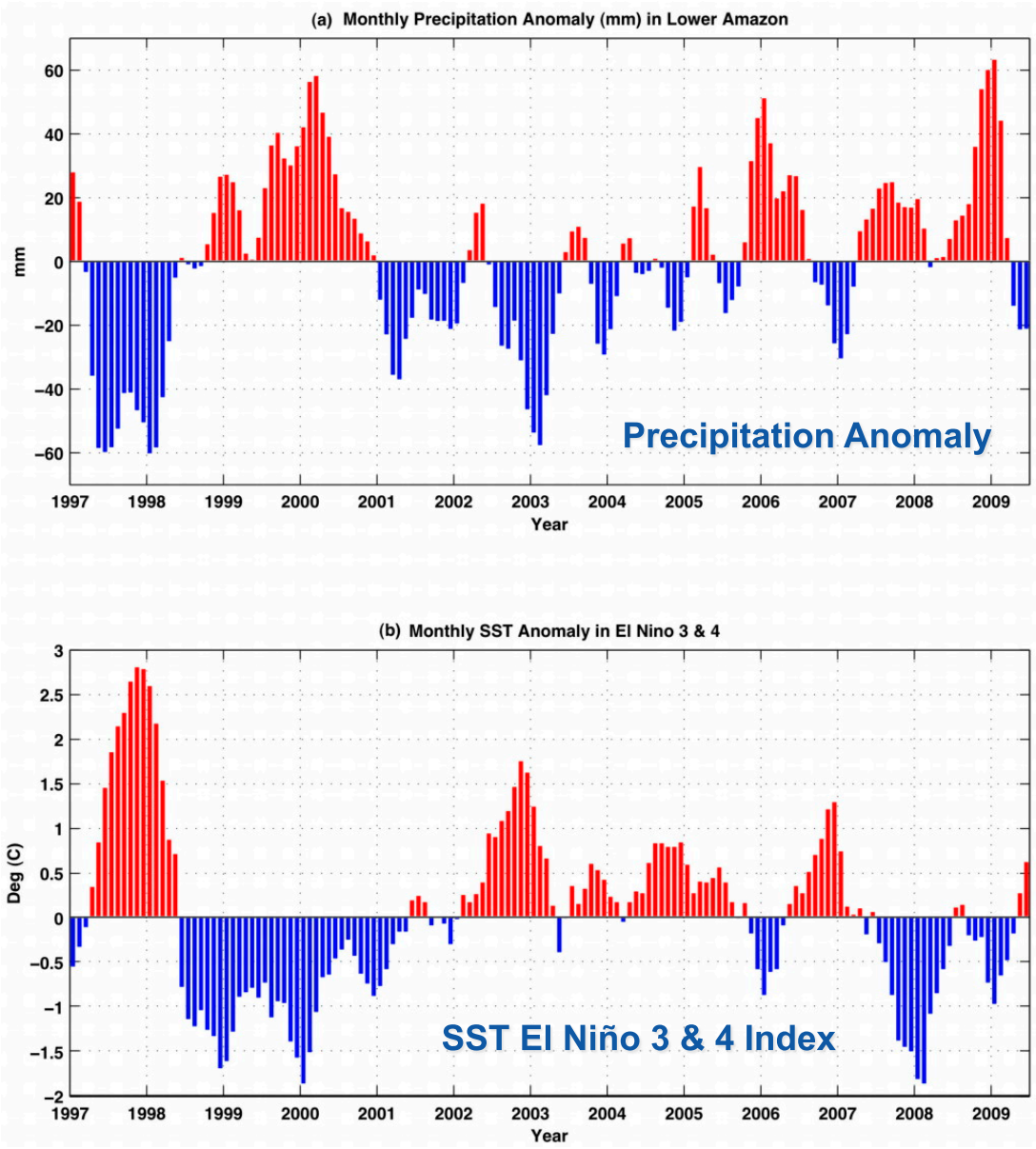


Units: cm/yr of water thickness

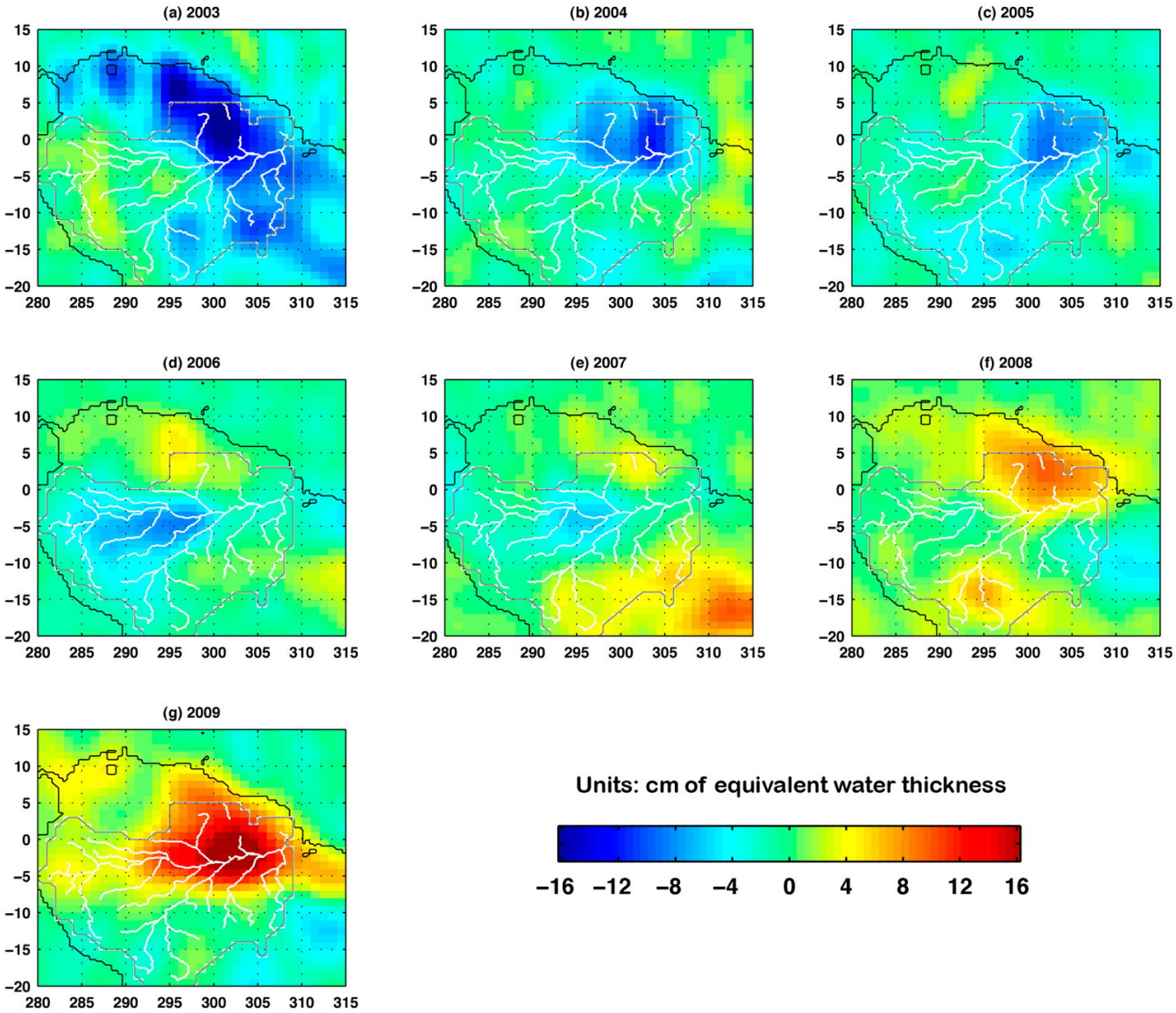

(a) GRACE TWS Change in Lower Amazon
cm
25
20
15
10
5
0
−5
−10
−15
−20
2002
2003
2004
2005
2006
2007
2008
2009
2010


(b) Monthly Precipitation Anomalies in Lower Amazon
GPCP
cm
6
4
2
0
−2
−4
−6
2002
2003
2004
2005
2006
2007
2008
2009
Year

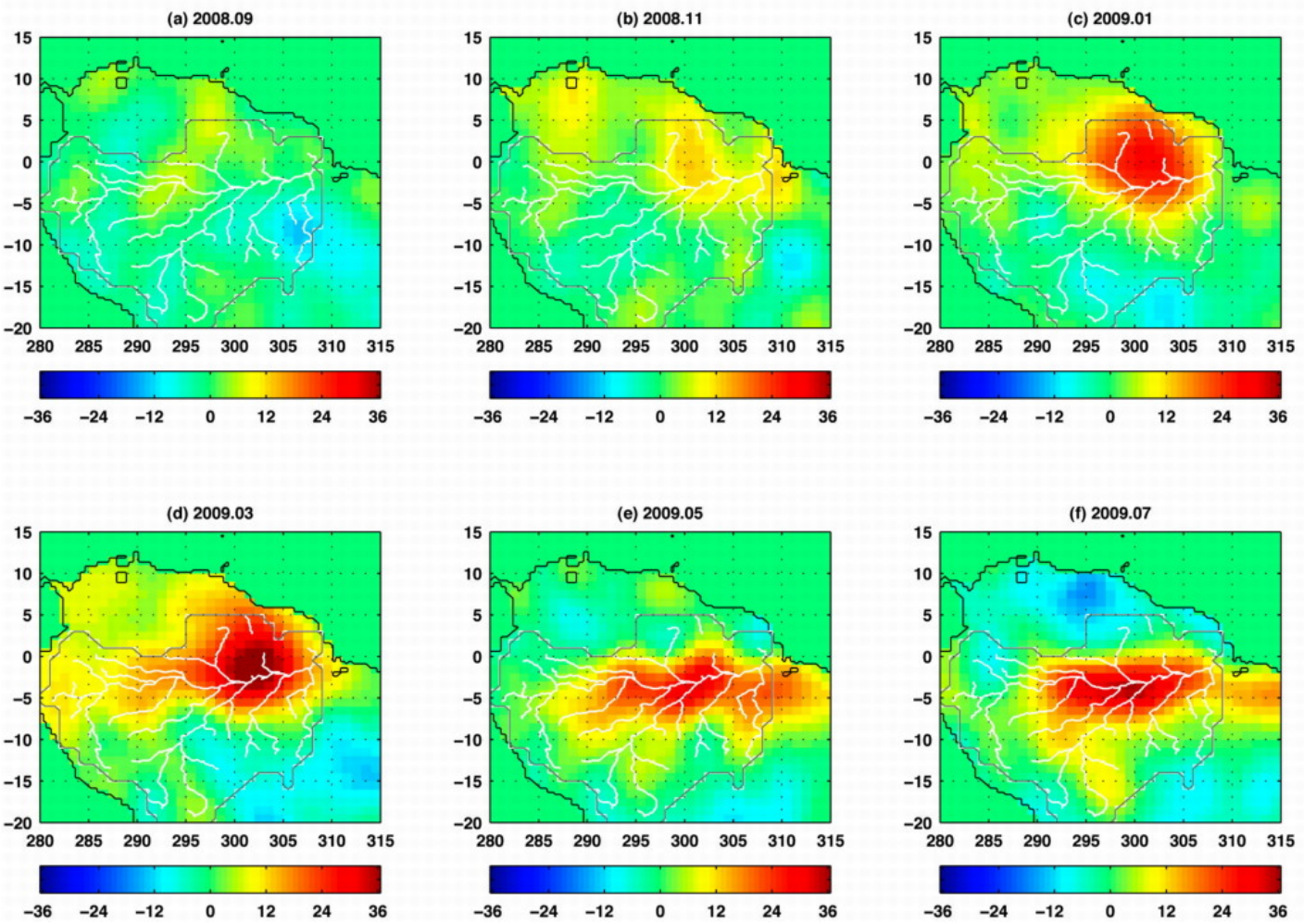

GRACE TWS Rate Map
15
10
5
0
-5
-10
-15
-20
-25
275
280
285
290
295
300
305
310
315
320
-6
-4
-2
0
2
4
6
Units: cm/yr of water thickness


(a) Monthly Precipitation Anomaly (mm) in Lower Amazon
mm
Year
Precipitation Anomaly
(b) Monthly SST Anomaly in El Nino 3 & 4
Deg (C)
Year
SST El Niño 3 & 4 Index

GRACE Yearly TWS change (Yearly = Average from July of the previous year through June)

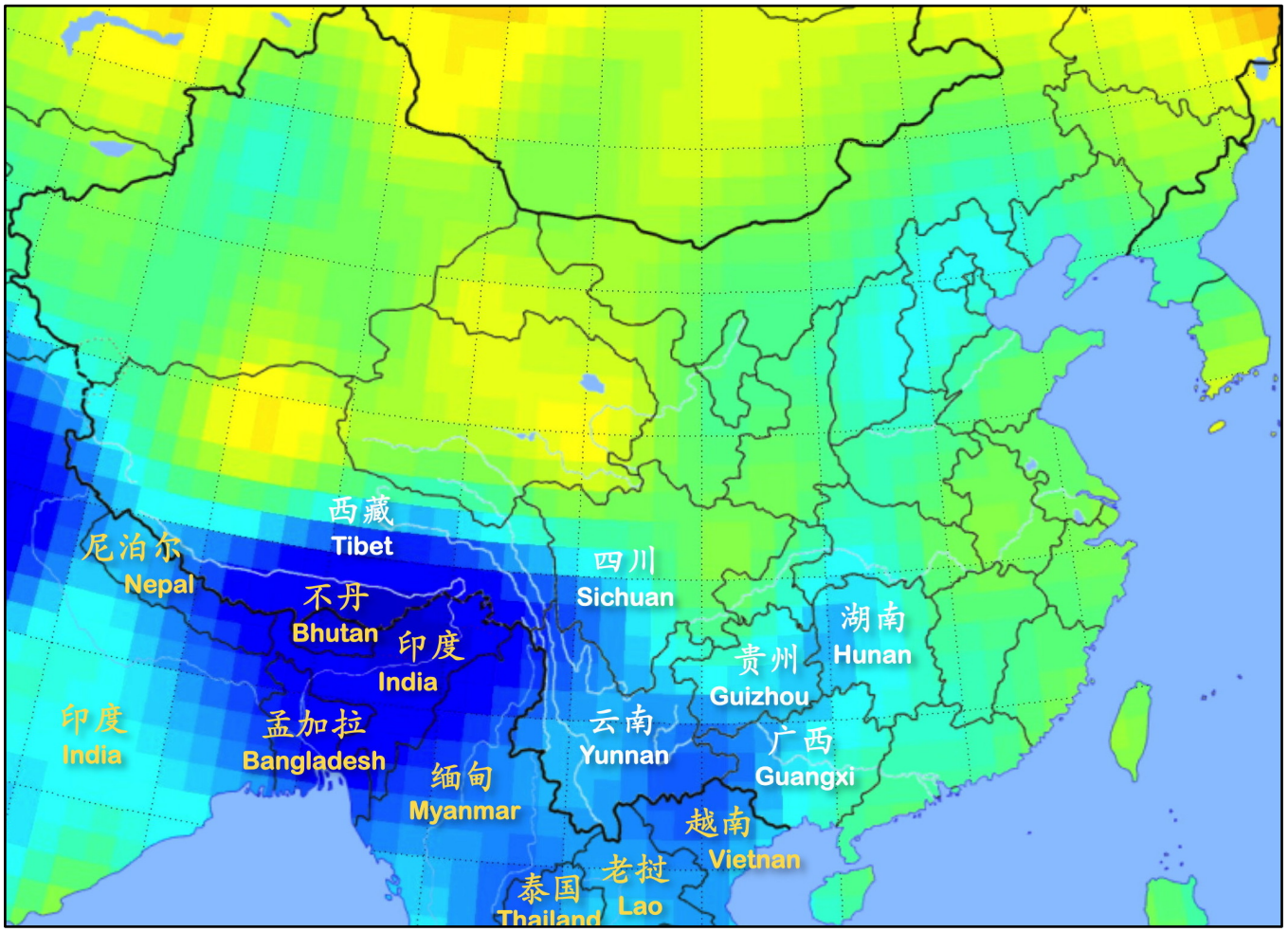


Development of the exceptional 2009 Amazon flood from GRACE



GRACE observed monthly TWS anomaly (seasonal signal is removed)

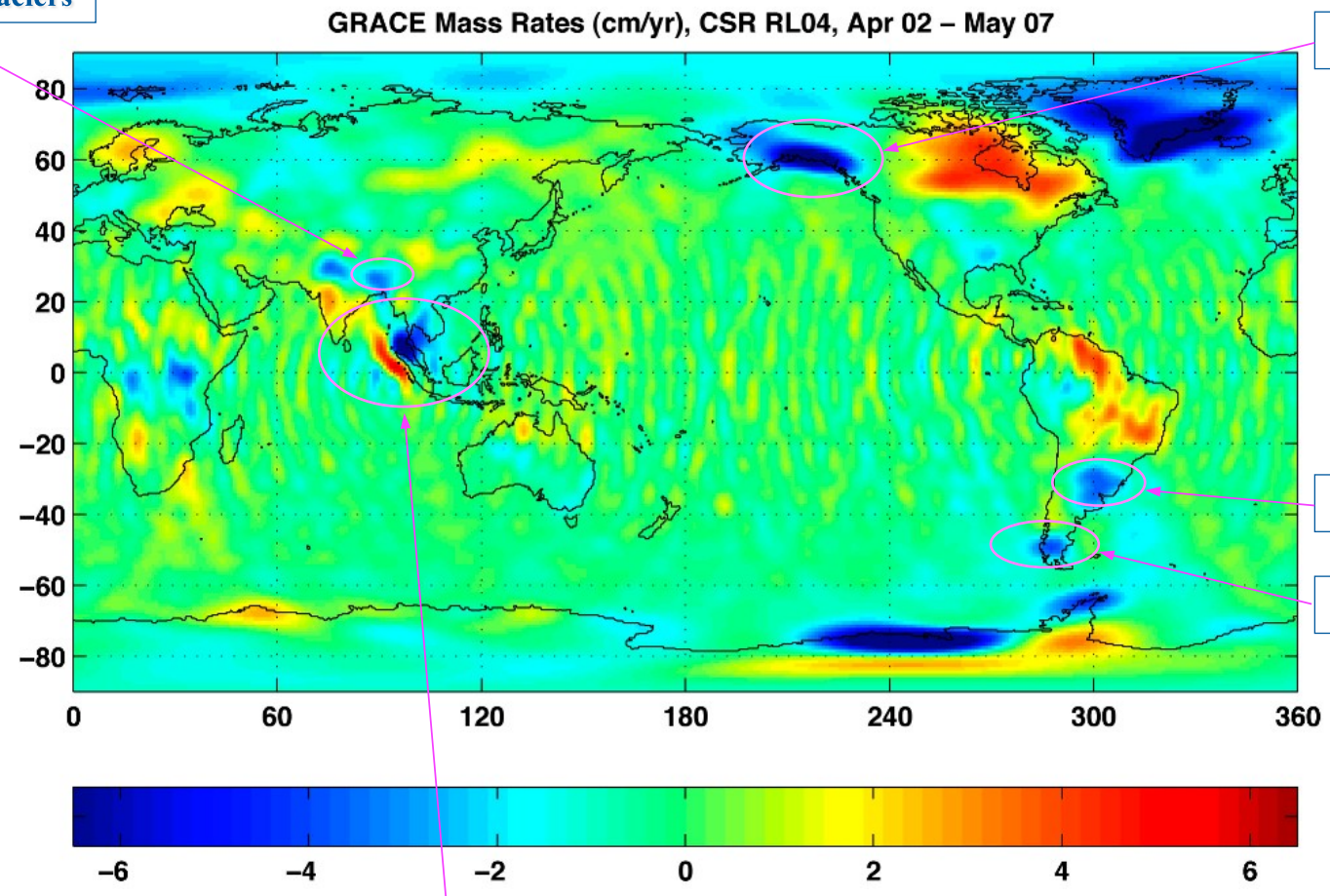
The 2010 Severe Drought in Southeast Asia (GRACE 2010.01)



Units: cm (equivalent water thickness)

-24 -18 -12 -6 0 6 12 18 24

Any other applications of GRACE?



Himalaya Glaciers

Alaskan Glaciers

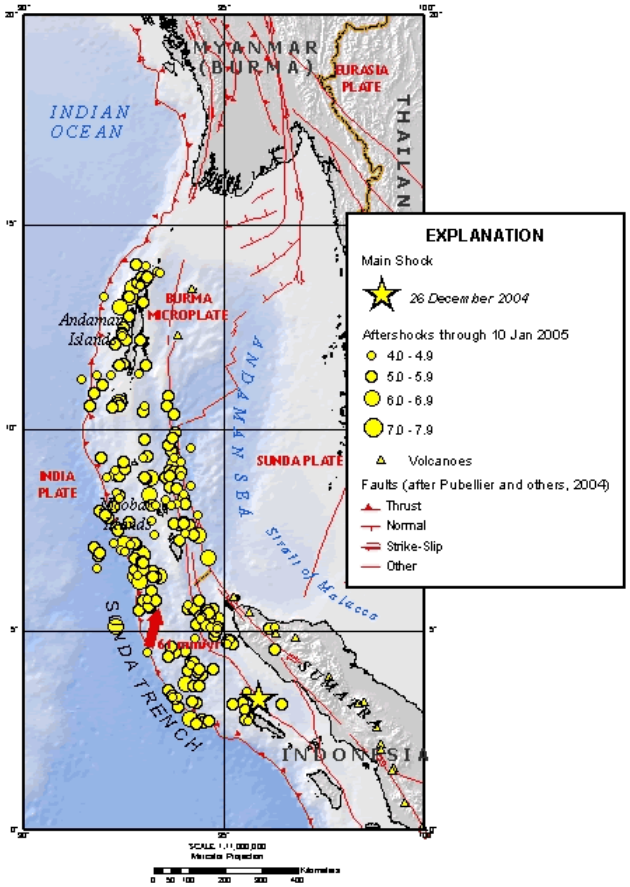
La Plata Basin

Patagonia Ice Fields

Sumatra-Andaman Earthquake

GRACE Other Applications - Coseismic & Postseismic Deformation

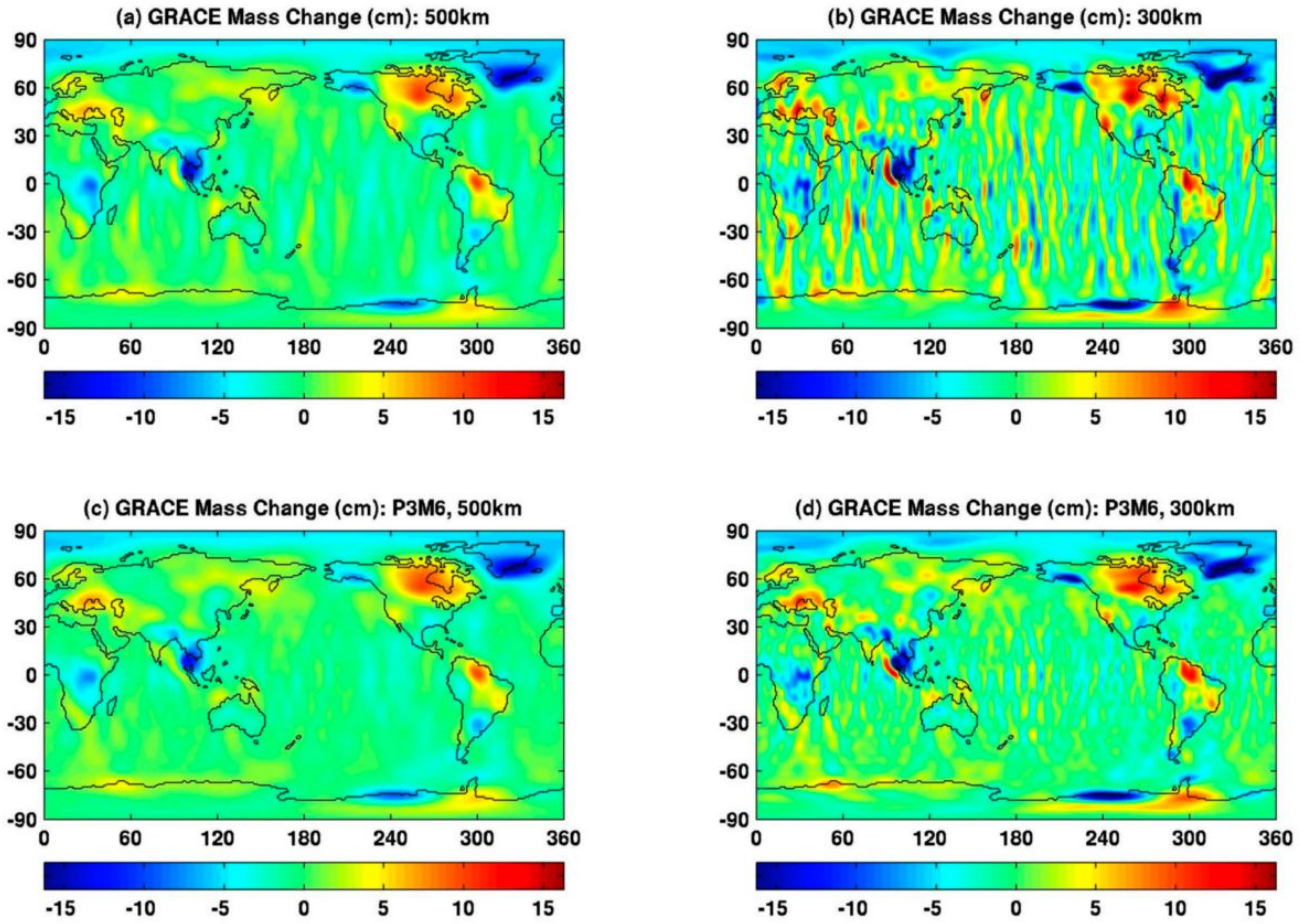
- The Sumatra-Andaman earthquake (Mw=9.1) on December 26, 2004, the 2nd largest in modern history.
- Special processing of GRACE range rate data (Han et al. 2006) revealed co-seismic gravity changes .
- Examine GRACE RL04 spherical harmonic products for evidence of coseismic change.
- RL04 time series may be examined for postseismic deformation.



GRACE Data and Processing

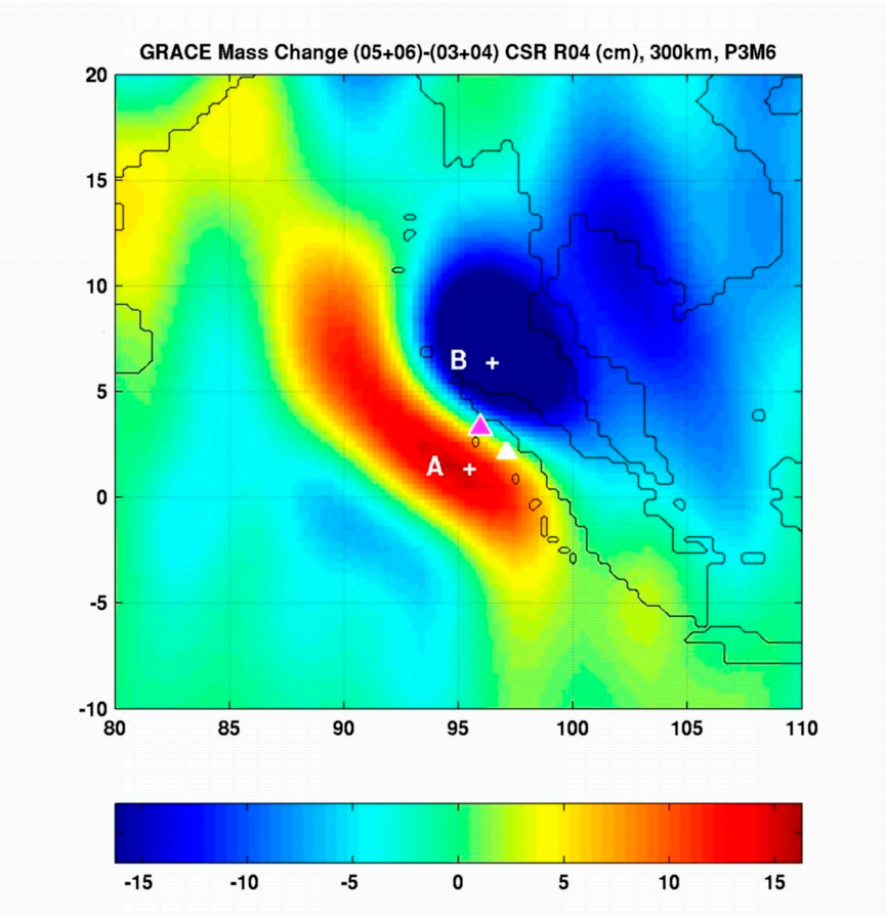
- **CSR GRACE RL04 solutions**
  - April 2002 through February 2007 (updated to January 2009);
  - 55 (or 79) monthly solutions, up to degree & order 60
- **Applied Filters**
  - De-correlation filtering [Swenson and Wahr, 2006]
  - 300 km Gaussian smoothing
- **Coseismic Change**
  - [mean of (2005 + 2006)] ***minus*** [mean of (2003 + 2004)] ;
  - 21 solutions in each mean;
    - (2003 + 2004): Jan. 2003 - Nov. 2004;
    - (2005 + 2006): Jan. 2005 - Sept. 2006; (Dec. 2004 excluded);
- **Postseismic Change**
  - Use entire 55 (or 79) point time series;
  - Examine pre-seismic and post-seismic periods

GRACE-observed mass change: [mean of 2005+2006] - [mean of 2003+2004]

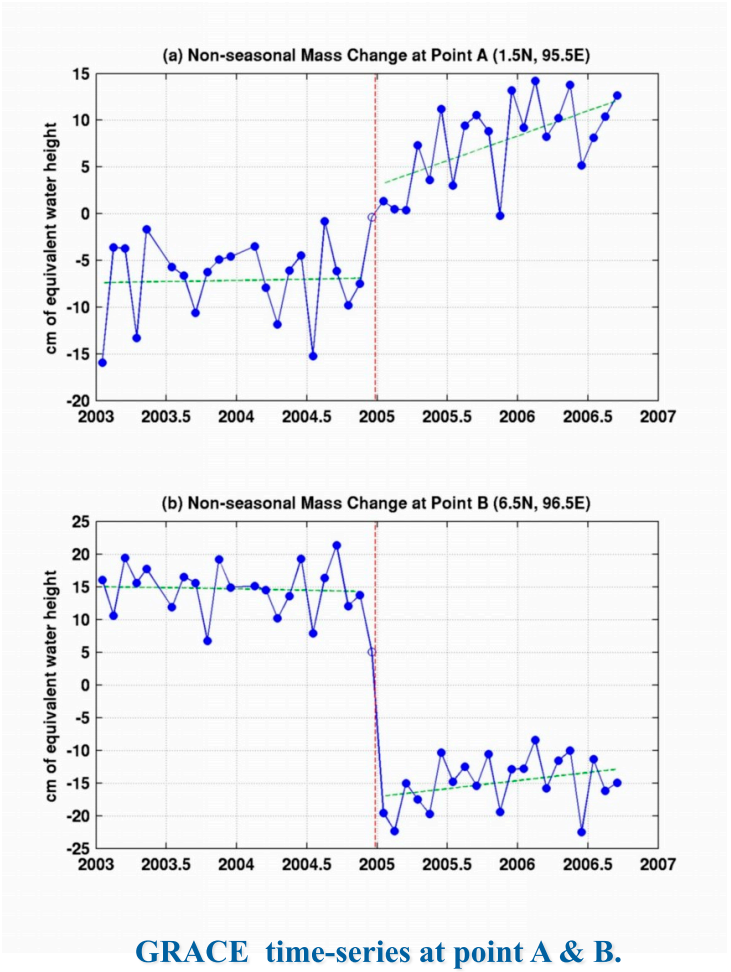


From 4 different filtering schemes (in cm of equivalent water thickness change).

Coseismic Deformation Estimate
(cm water equivalent mass change)



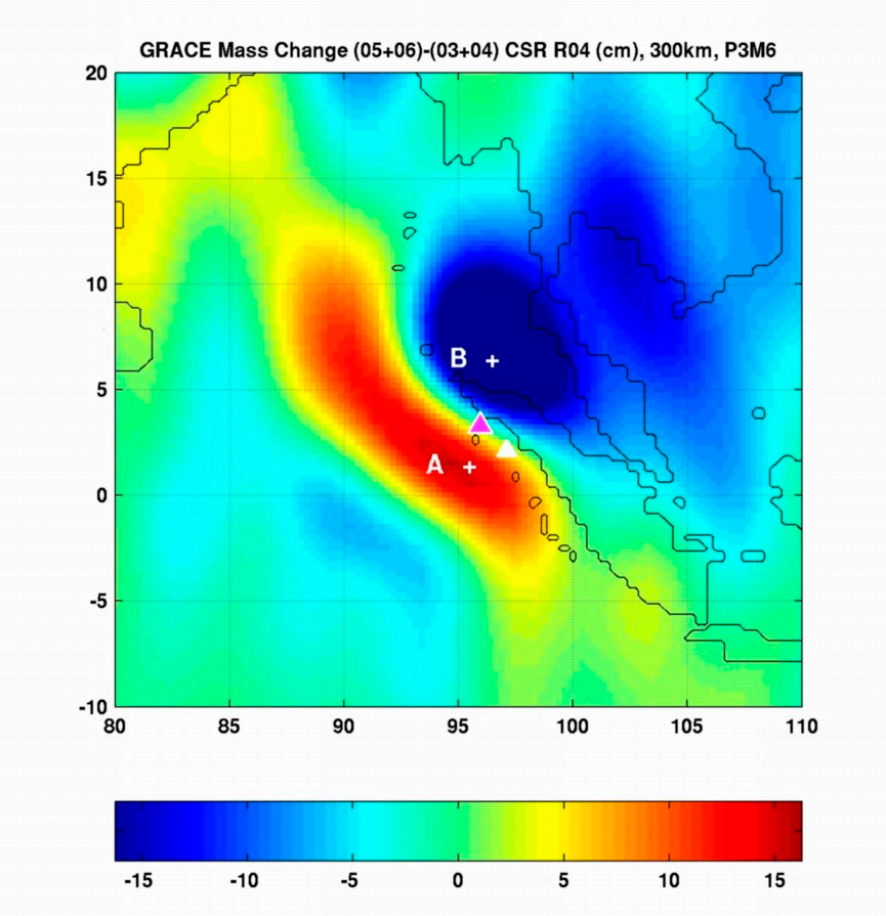
Epicenters of Sumatra-Andaman (Mw=9.1) and Nias (Mw=8.7) earthquakes are marked by pink and white triangles.



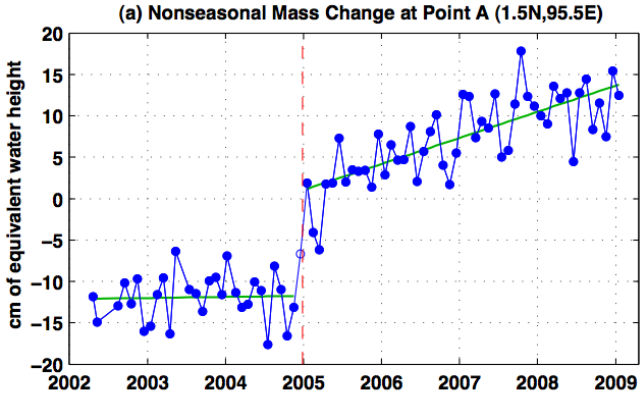
GRACE time-series at point A & B.

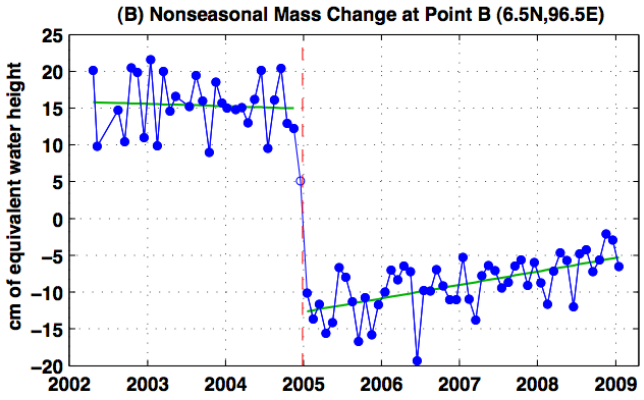
Chen et al., GRACE Detects Coseismic and Postseismic Deformation from the Sumatra-Andaman Earthquake, Geophys. Res. Lett., 34 (13), L13302 10.1029/2007GL030356, 2007.

Coseismic Deformation Estimate
(cm water equivalent mass change)

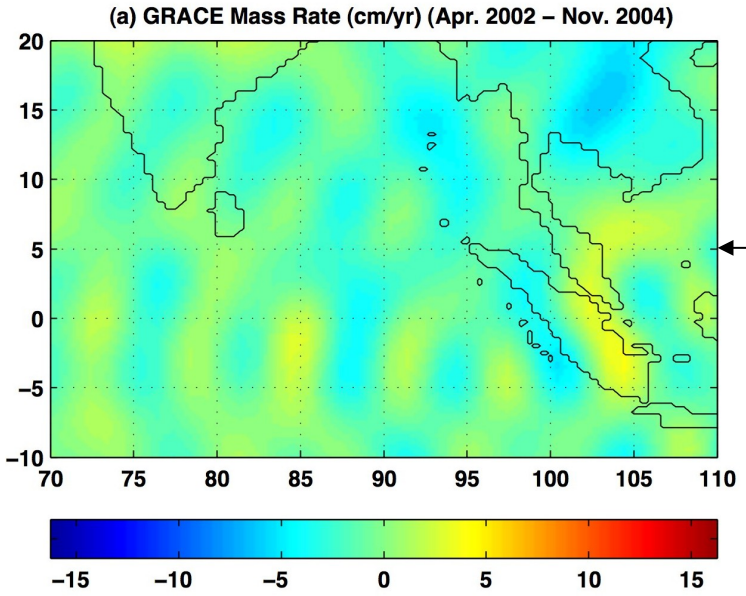


Epicenters of Sumatra-Andaman (Mw=9.1) and Nias (Mw=8.7) earthquakes are marked by pink and white triangles.

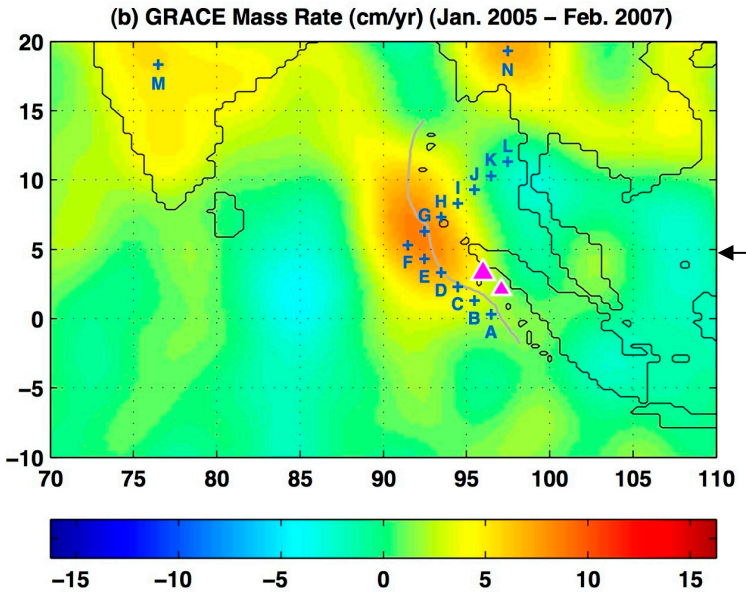




Extended GRACE time-series at point A & B.

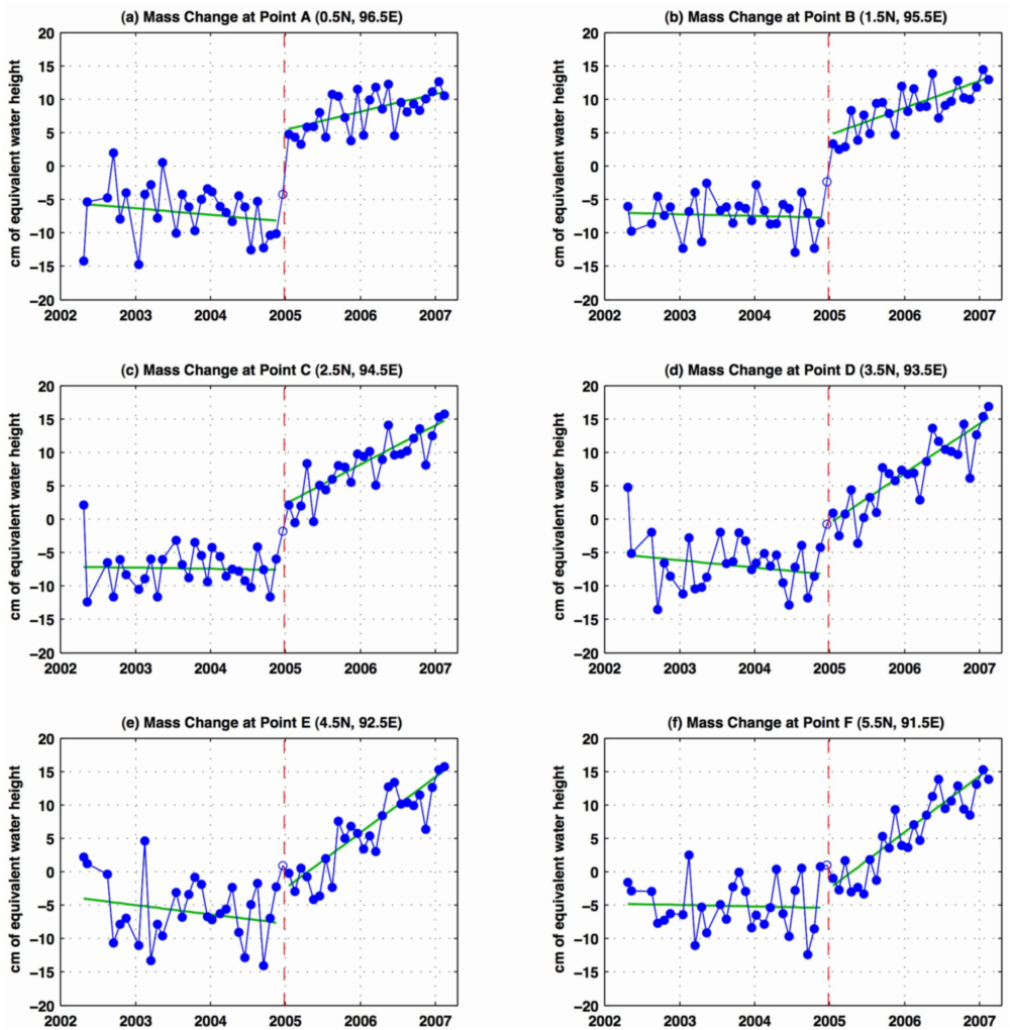


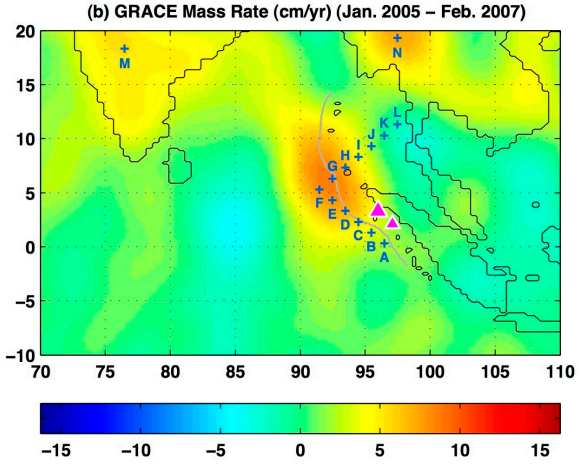
Preseismic Mass Rate Map



Postseismic Mass Rate Map

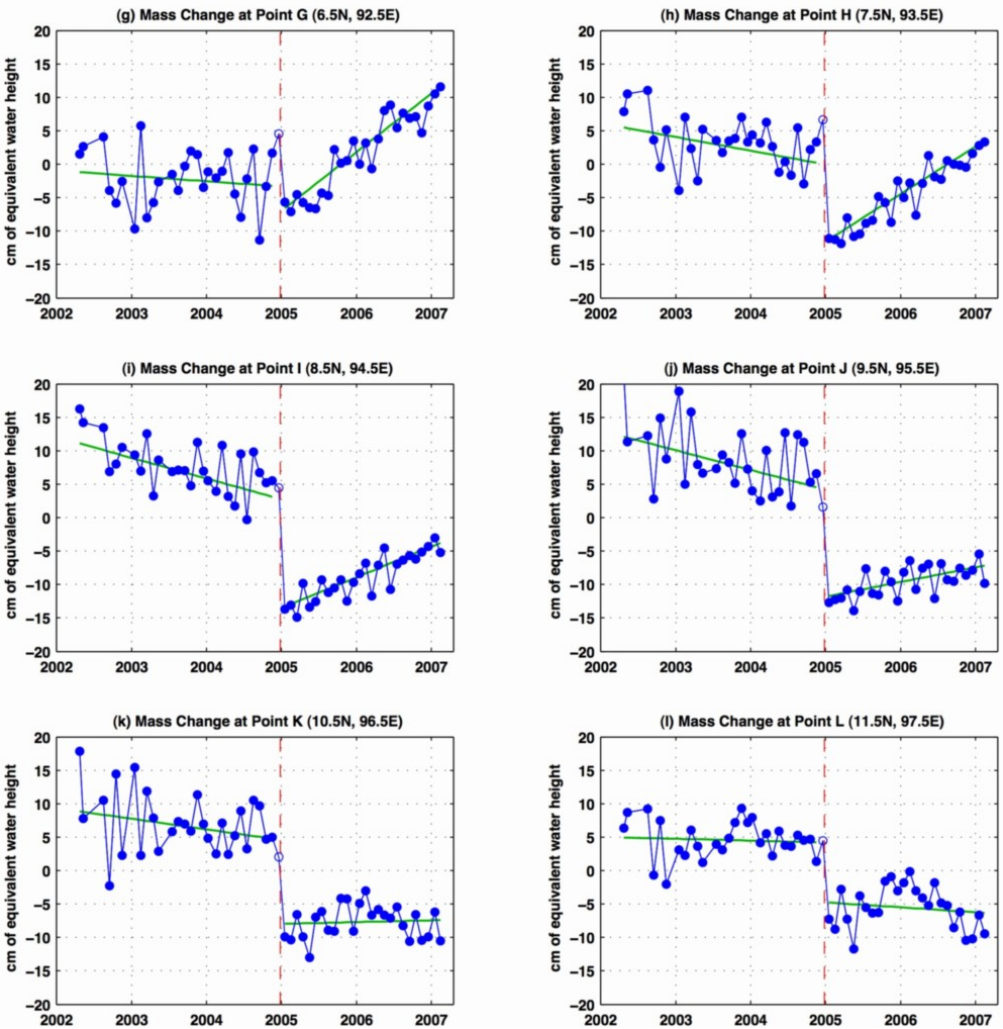
Mass Rate Time Series at Points A-F

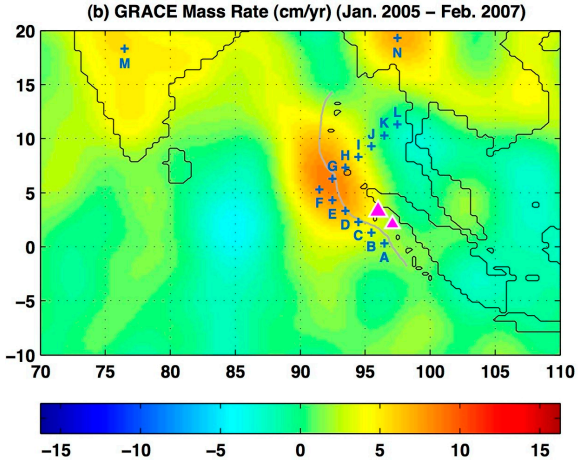




At points in uplift zone.

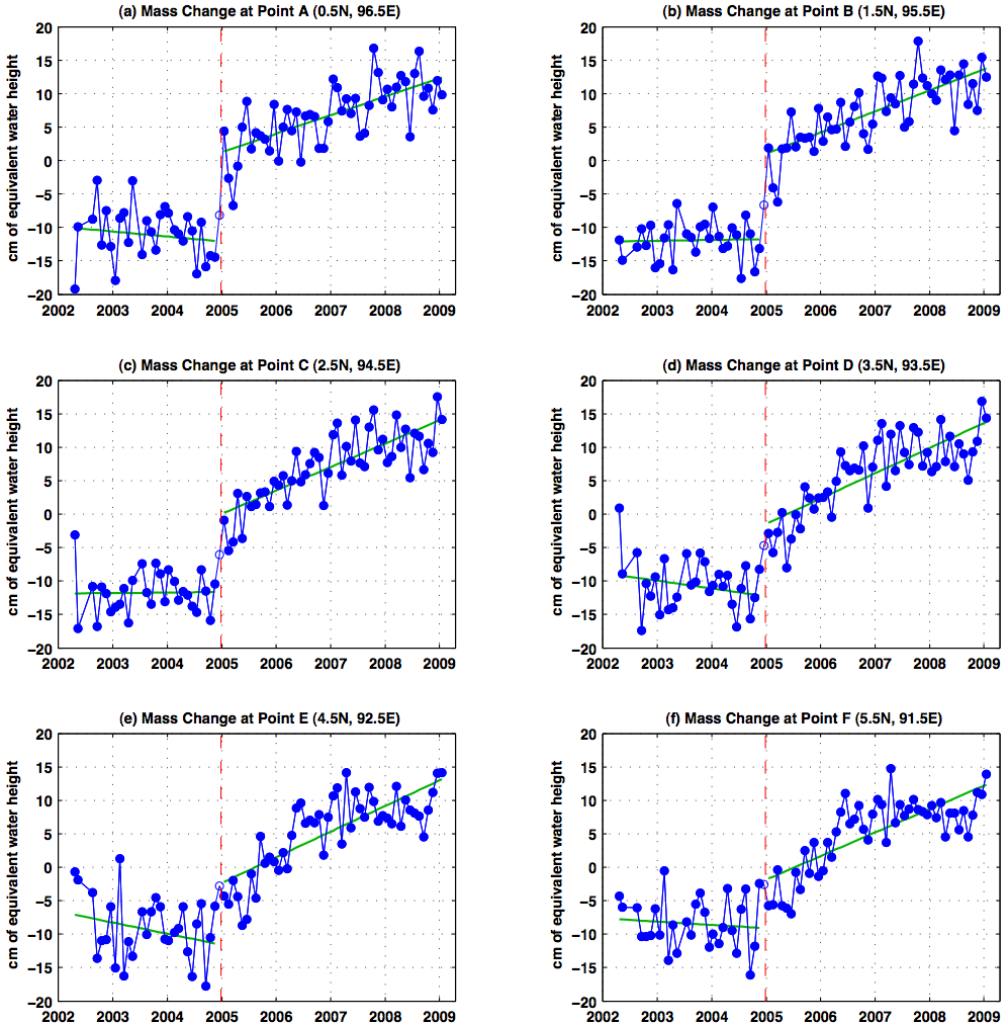
Postseismic Mass Rates at Points G-L

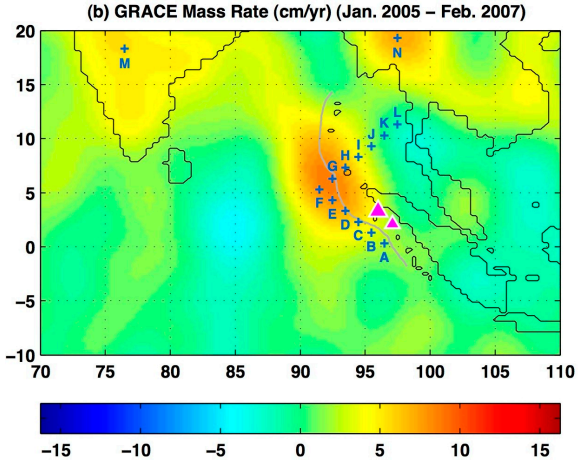




At points in subduction zone.

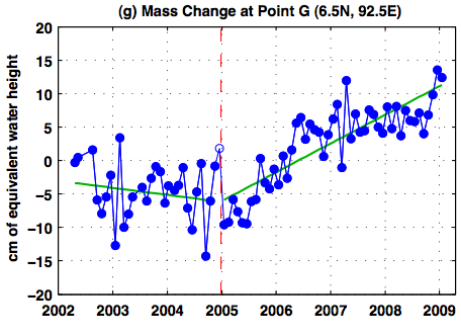
Mass Rate Time Series at Points A-F

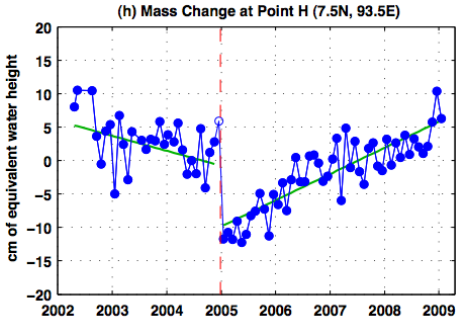


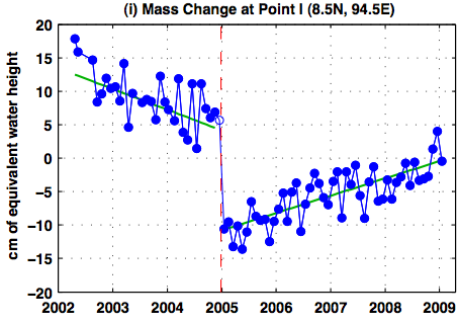


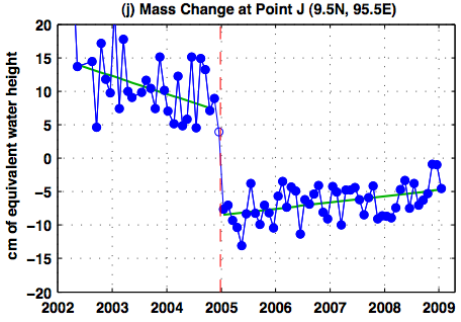
At points in uplift zone with extended GRACE time series.

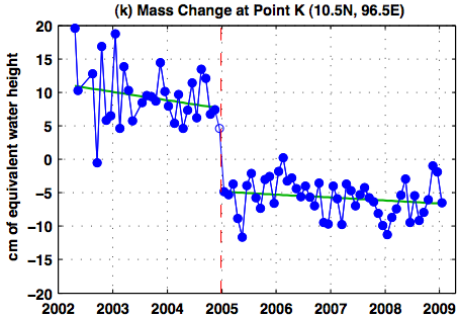
Postseismic Mass Rates at Points G-L

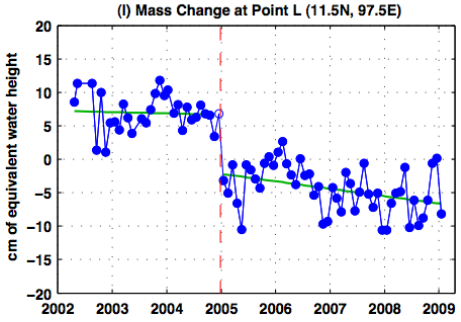


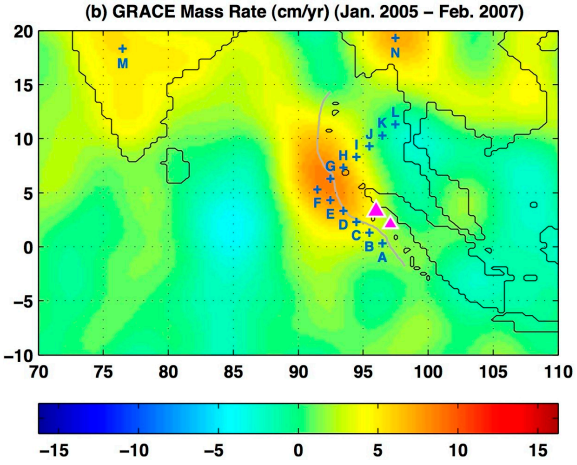












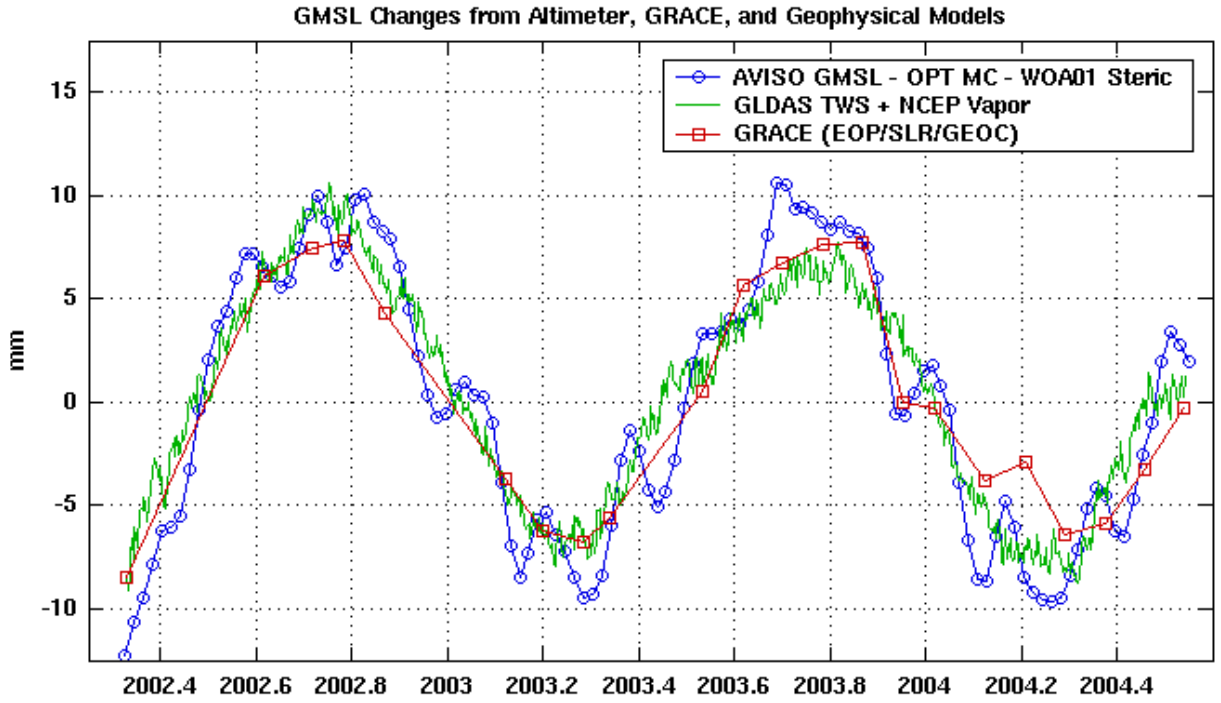
At points in subduction zone with extended GRACE time series.

Conclusions (co- & postseismic deformation)

- GRACE RL04 gravity data are of sufficient spatial resolution to capture mass redistribution of Sumatra-Andaman earthquake.
- After appropriate filtering, RL04 data clearly delineate effects of the rupture, extending over 1800 km, consistent with previous GRACE estimates, deformation model estimates and other geodetic measurements.
- RL04 time series show steady mass increase, presumably related to post-seismic uplift, equivalent to ~ 8 cm/year of water mass in a broad region northwest of the epicenter centered on the Andaman-Sunda fault zone.
- Time series of gravity change (mass rates) provide a new coseismic/postseismic measure of major earthquakes.
- Mass rate estimates (for tectonic, seismic and other non-climate studies) may be contaminated by interannual variability in regions with large seasonal signals

GRACE Other Applications - Sea Level Change

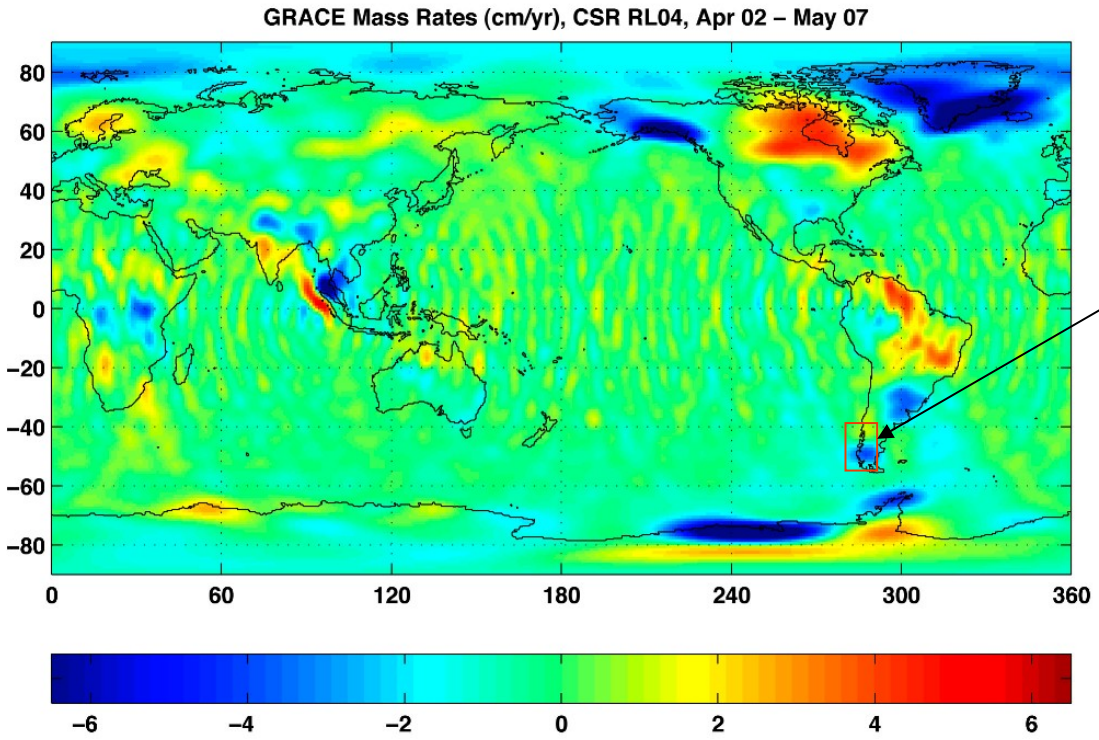
Global Non-Steric Sea Level Change From GRACE

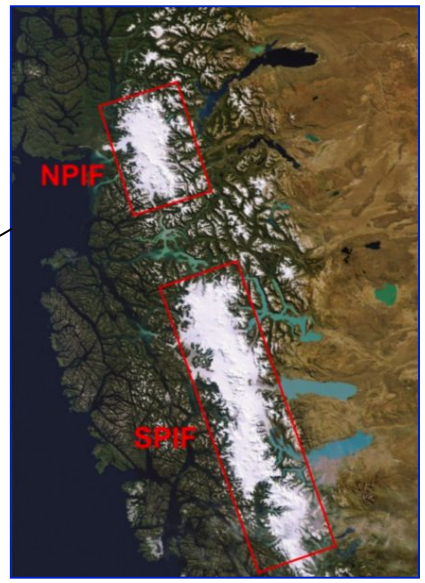


(See Chen et al. 2005 (JOG, Vol. 79, No. 9, 532-539) for details.)

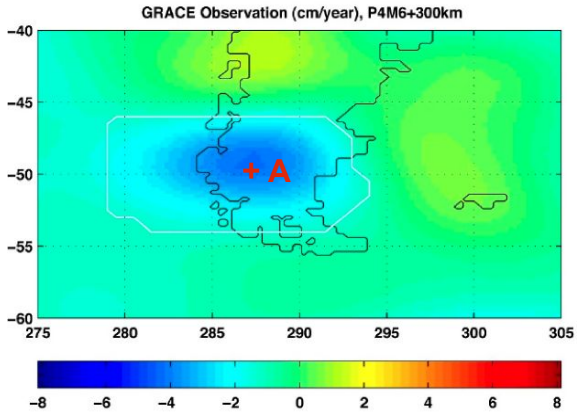
GRACE Other Applications - Mountain Glaciers

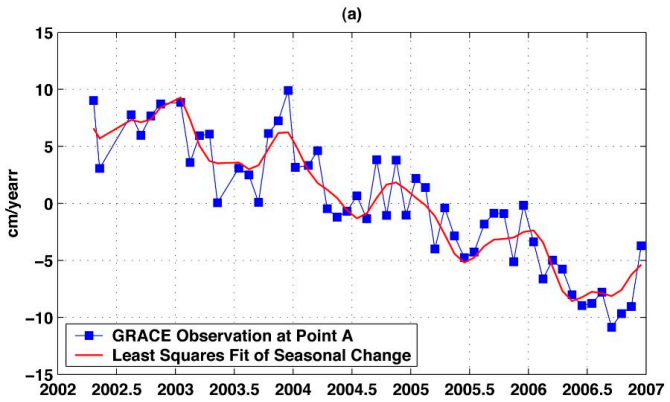
Patagonia Ice Fields Melting From GRACE

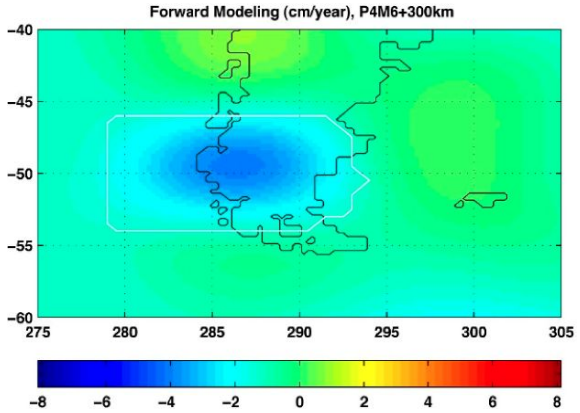


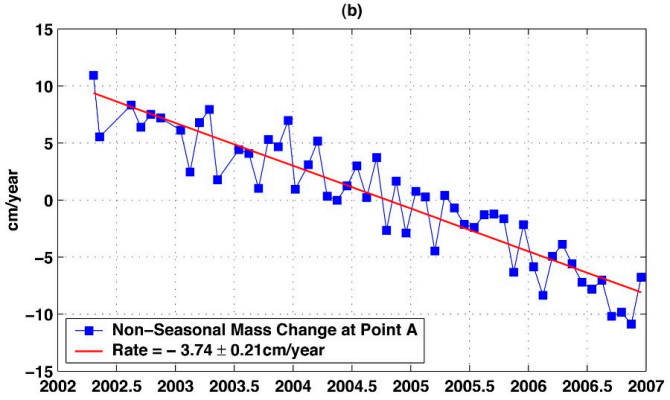


GRACE Observed Mass Rates in the PIF Region









GRACE estimated PIF ice melting rate based on forward modeling is 25.0 ± 9.2 km^3/year - first successful 'direct' measurement of PIF mass balance of recent years [Chen et al. 2007, GRL].


Thanks!
The Magic Blue Marble