



Satellite Gravity Measurements and the Global Water Cycle

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GRACE

A Decade of Amazing Science



GRACE and Global Water Cycle

□ Hydrosphere

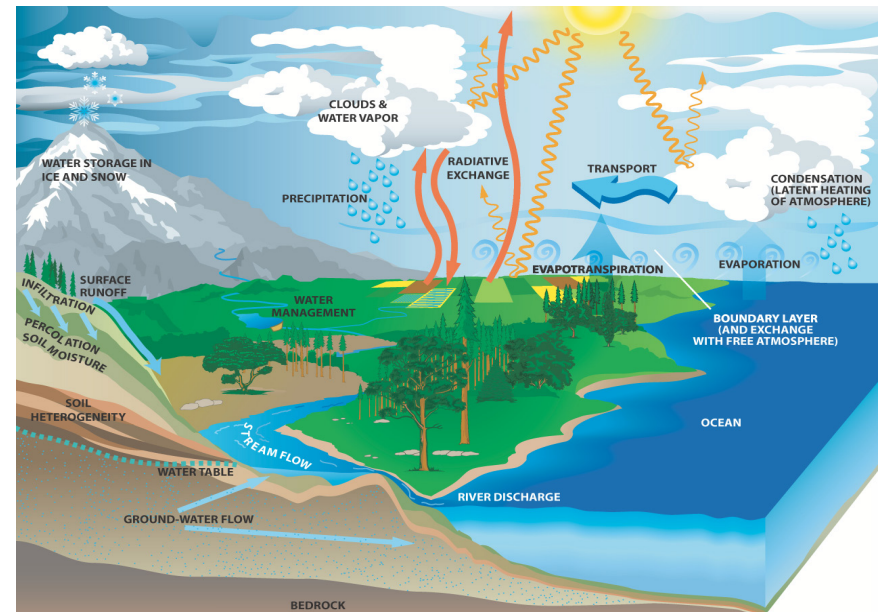
- Land water storage
- Precipitation
- Evapotranspiration
- Runoff
- Ground water
- Droughts
- Floods

□ Ocean

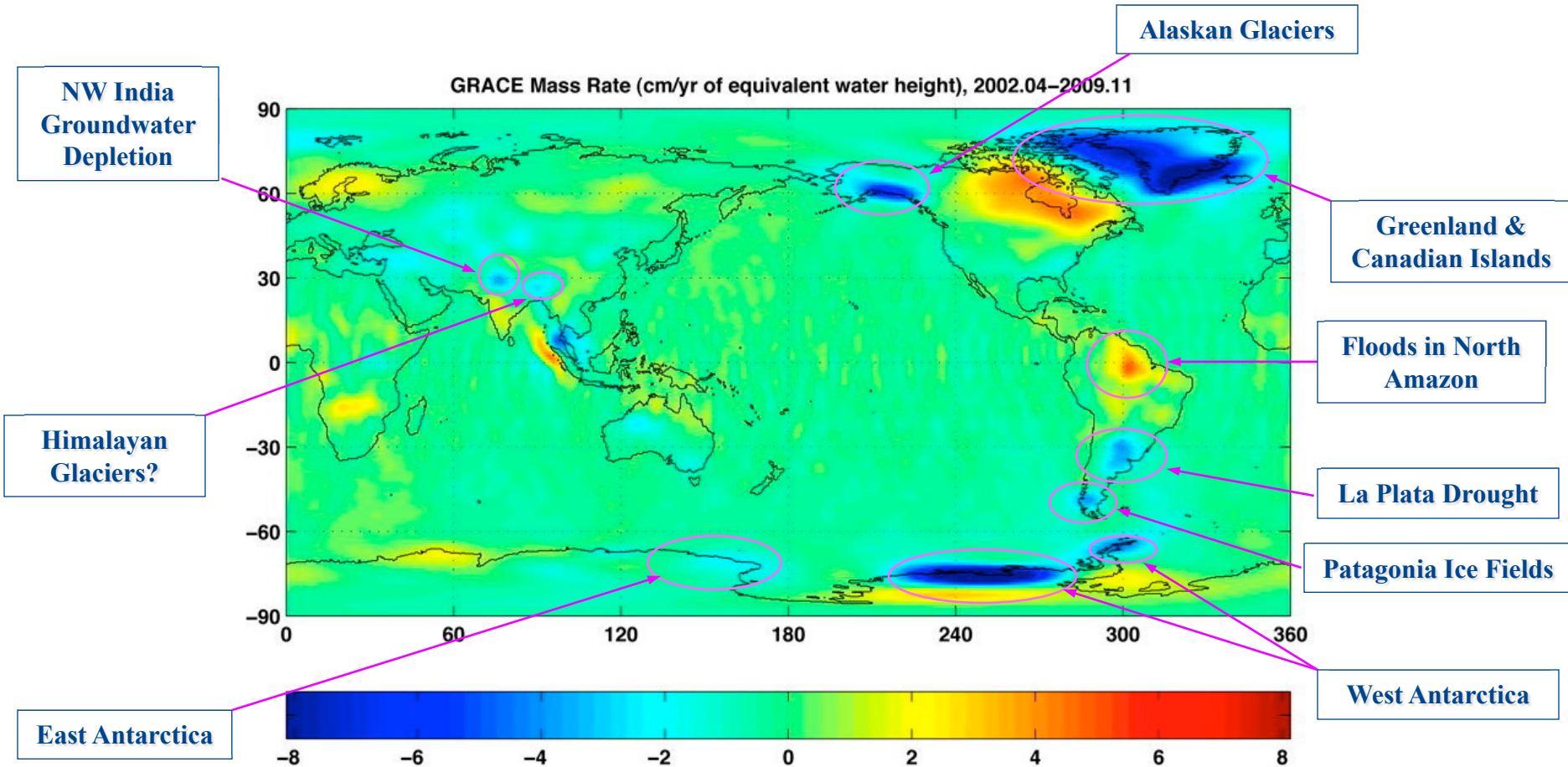
- Global sea level change
- Ocean heat content variation

□ Cryosphere

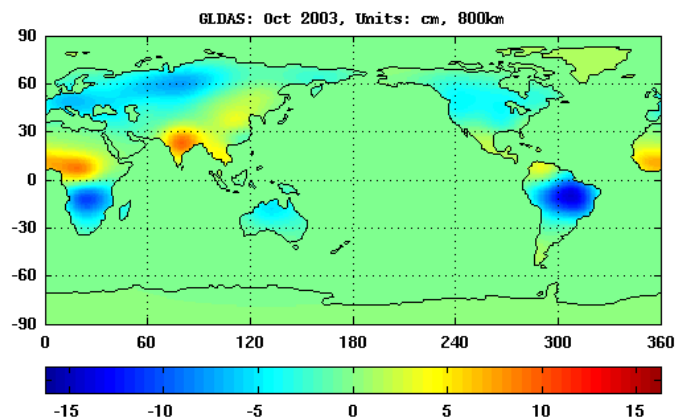
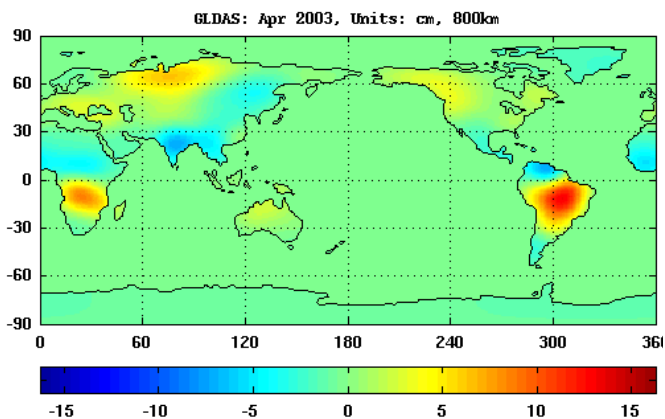
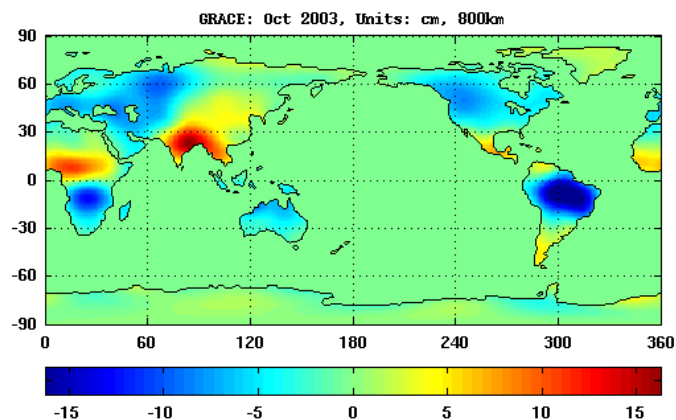
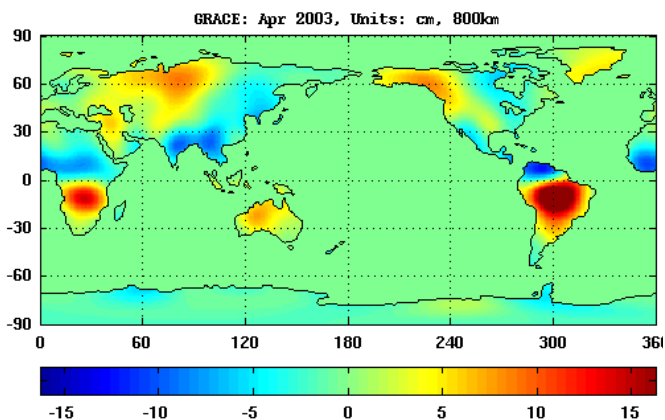
- Polar ice sheets mass balance
- Mountain glaciers mass balance



Global Long-Term Climate Change Signatures from GRACE

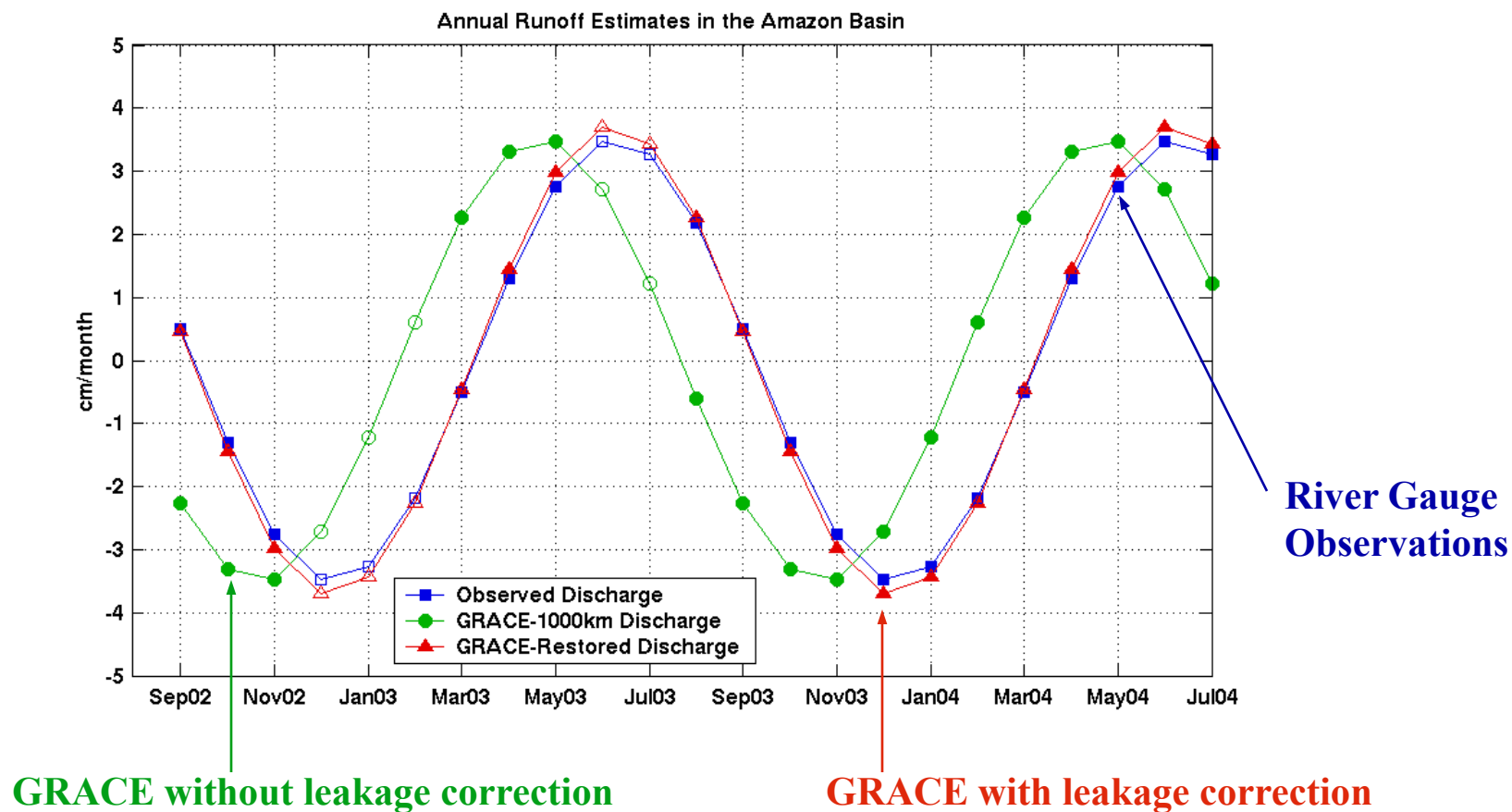


Terrestrial Water Storage Change from GRACE





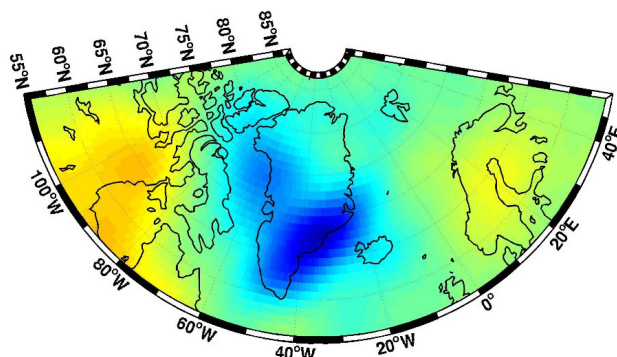
Annual River Runoff Estimates in Amazon



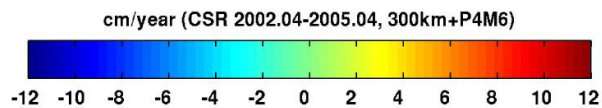
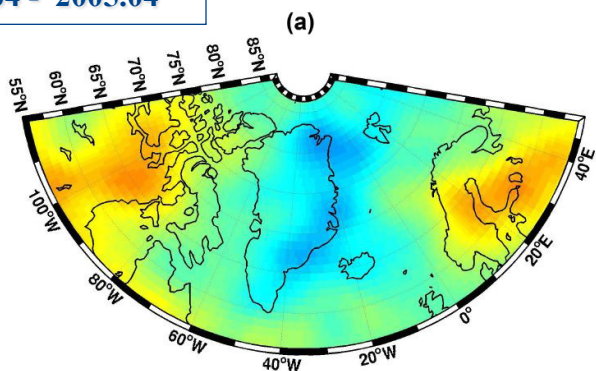


The Changing Climate & Greenland Ice Mass Change

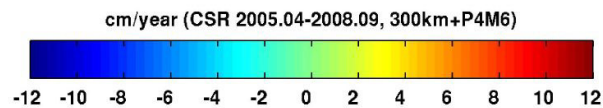
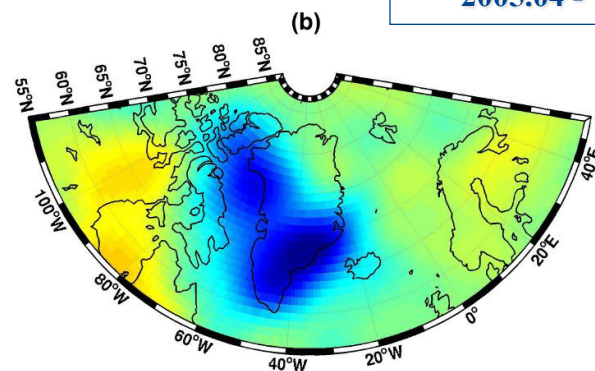
GRACE RL04 - 6.5 Years
2002.04 - 2008.09



RL04 - First 3 Years
2002.04 - 2005.04

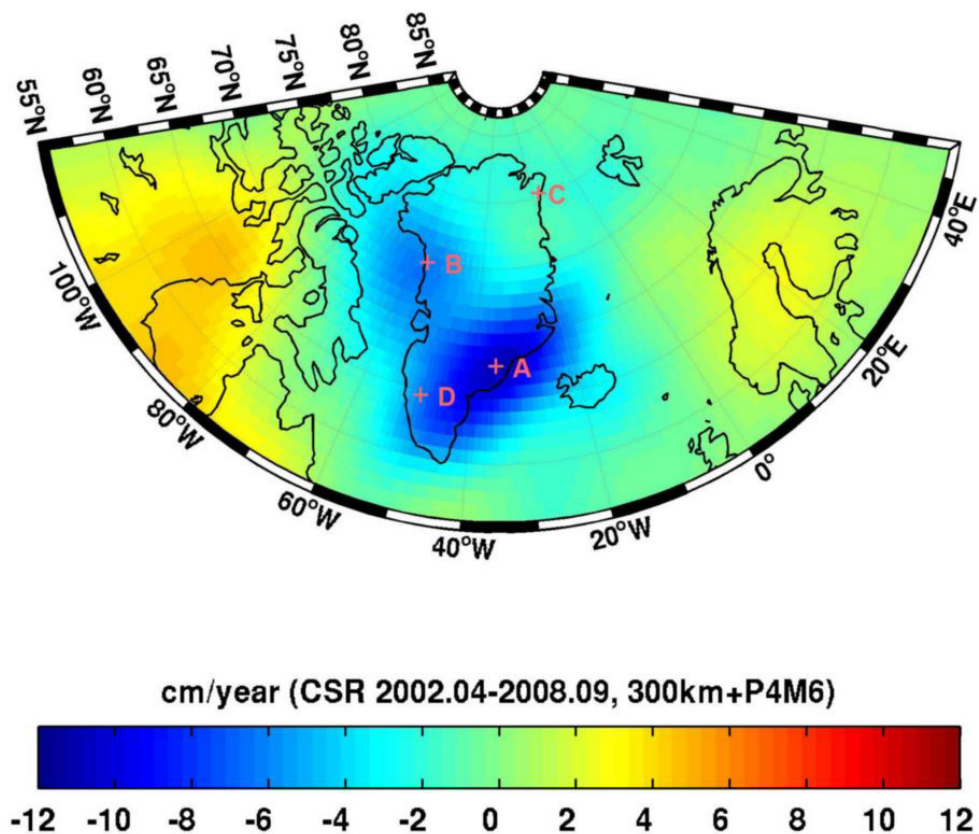


RL04 - Recent 3.5 Years
2005.04 - 2008.09



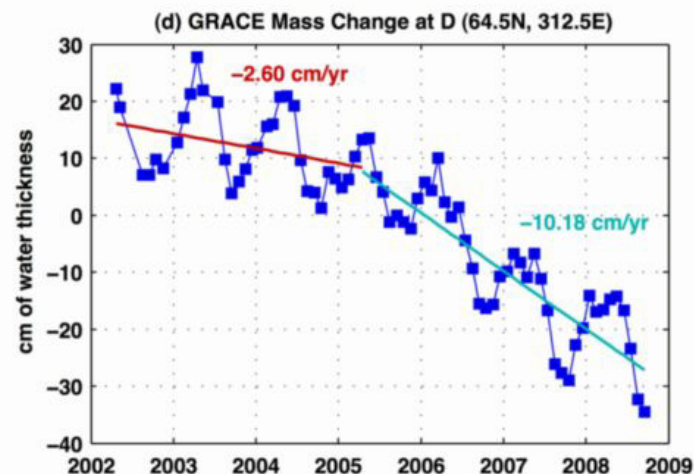
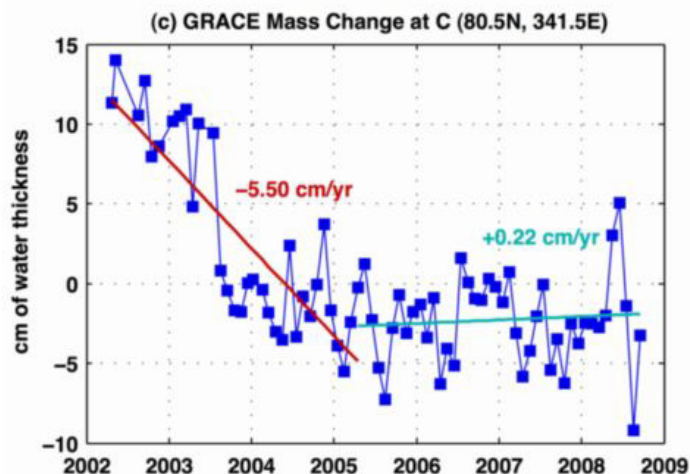
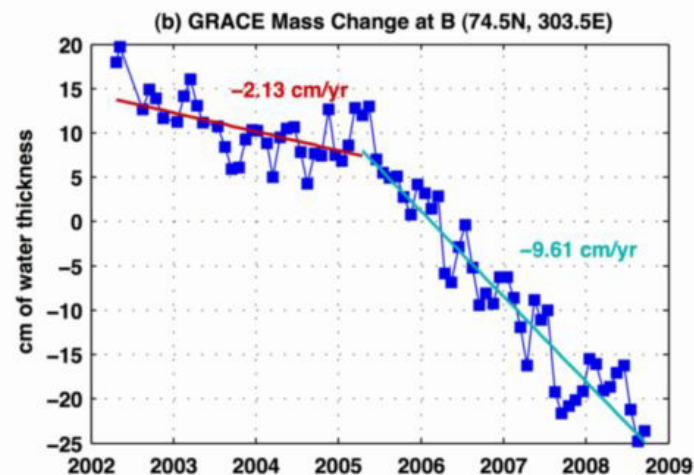
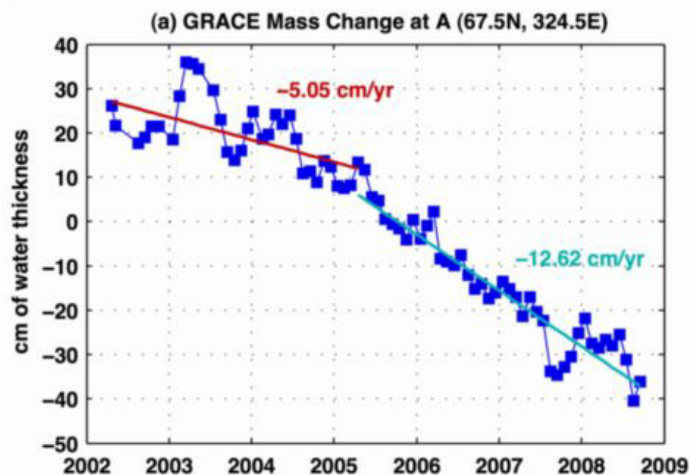


GRACE Time Series at 4 Selected Locations (A, B, C, D)





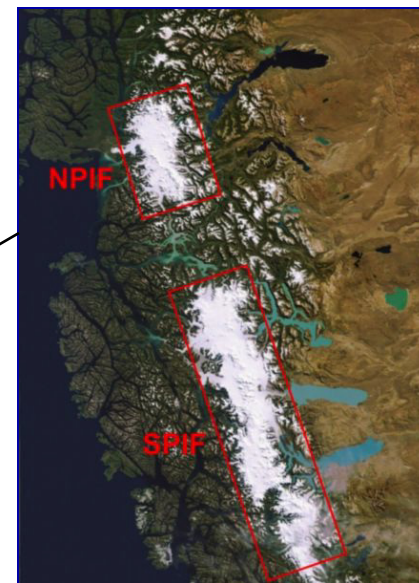
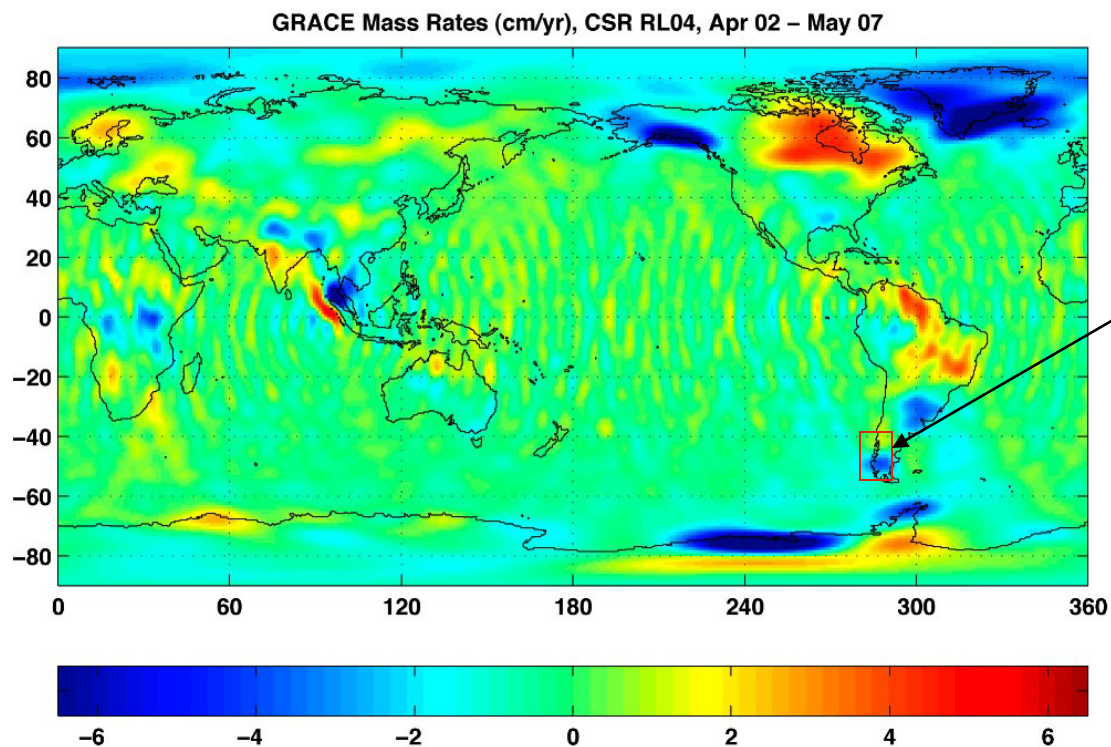
GRACE Time Series at 4 Selected Grids (A, B, C, D)



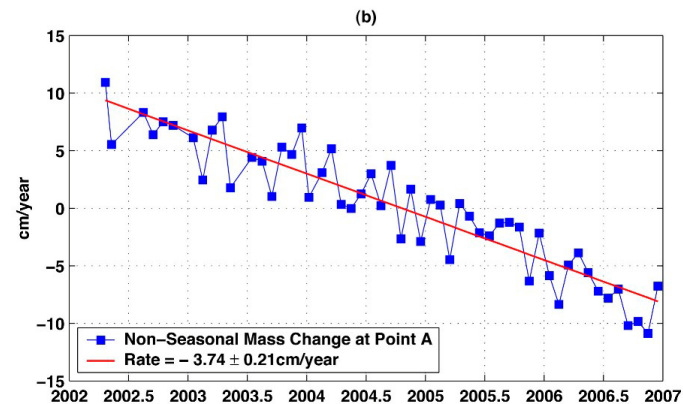
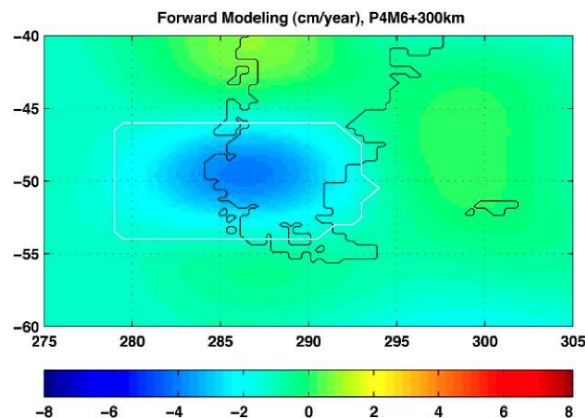
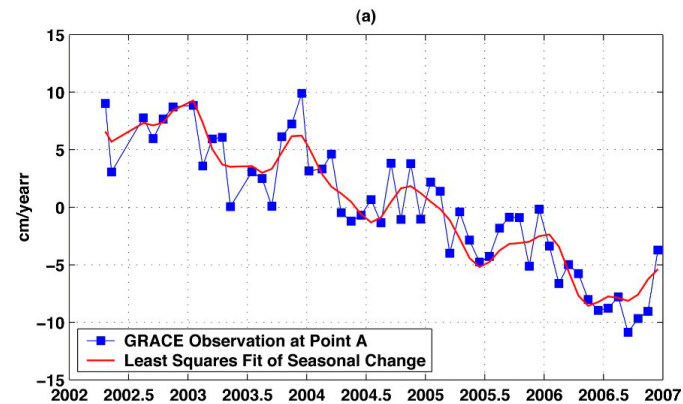
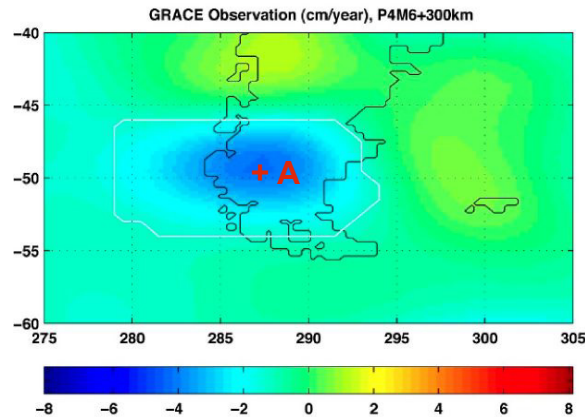


Ice Loss From Mountain Glaciers

Patagonia Ice Fields Melting From GRACE



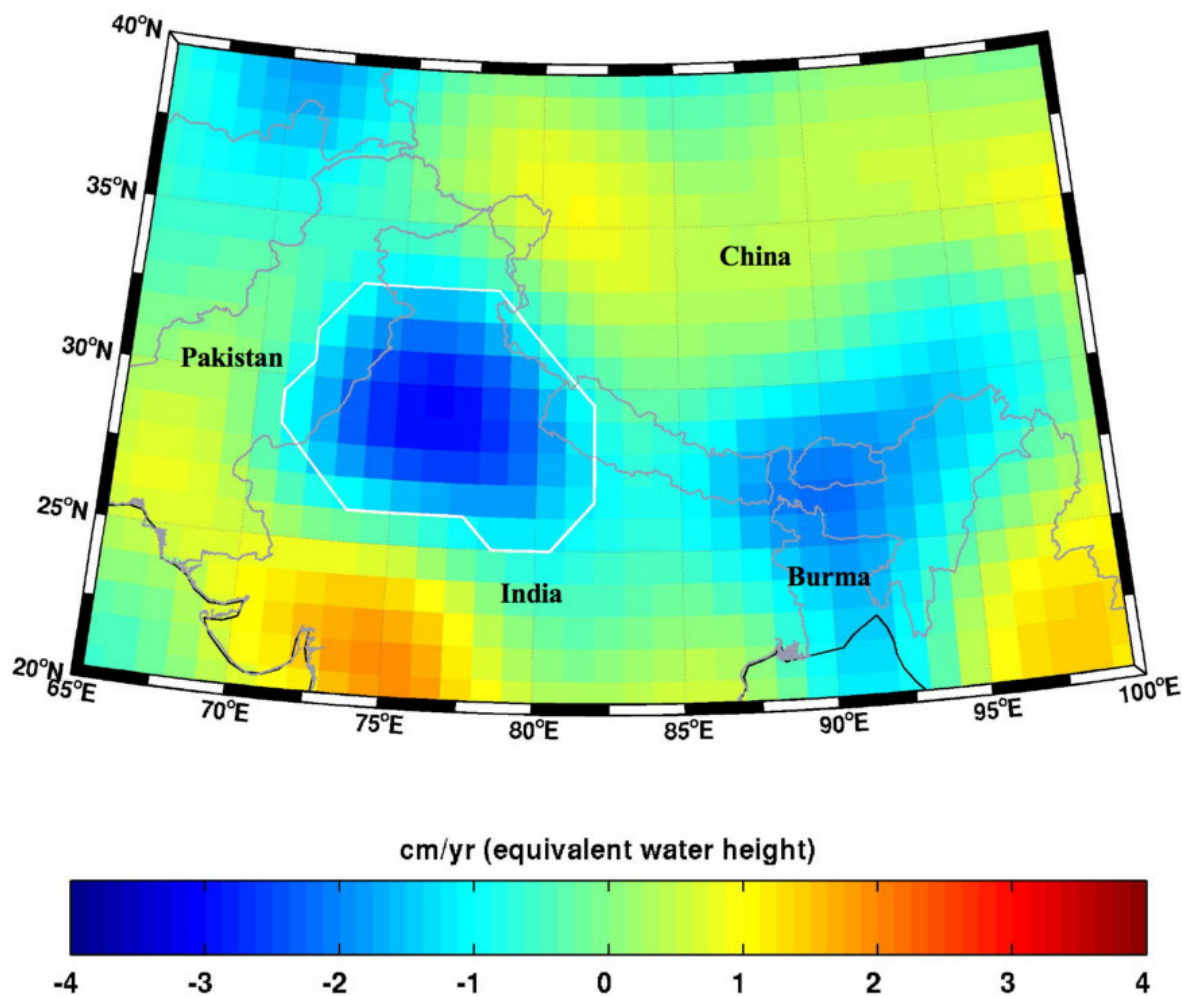
GRACE Observed Mass Rates in the PIF Region



GRACE estimated PIF ice melting rate based on forward modeling is 25.0 ± 9.2 km³/year, which is the first successful 'direct' measurement of PIF mass balance [Chen et al. 2007, GRL].

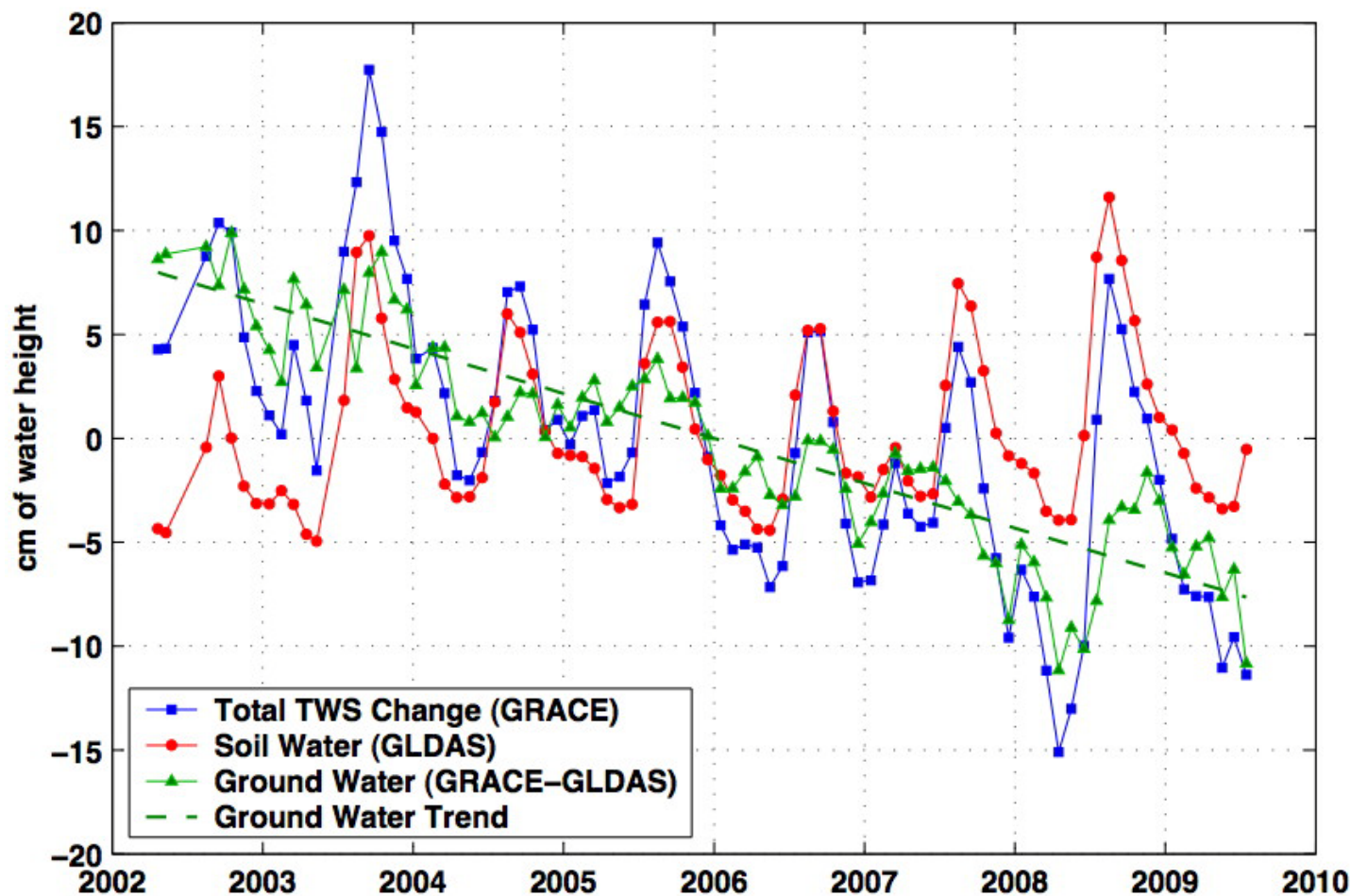


Groundwater Depletion From GRACE





Groundwater Depletion From GRACE





Challenges in Quantifying Ice Mass Balance of Asian High Mountains Glaciers

- Matsuo and Heki (2010, EPSL): -47 ± 12 Gt/yr
- Rodell et al. (2009, Nature): Assuming -13.4 Gt/yr (based on previous estimate for all the Himalayas glaciers during 1962–2004)
- Jacob et al. (2012, Nature): -4 ± 20 Gt/yr

Challenges?

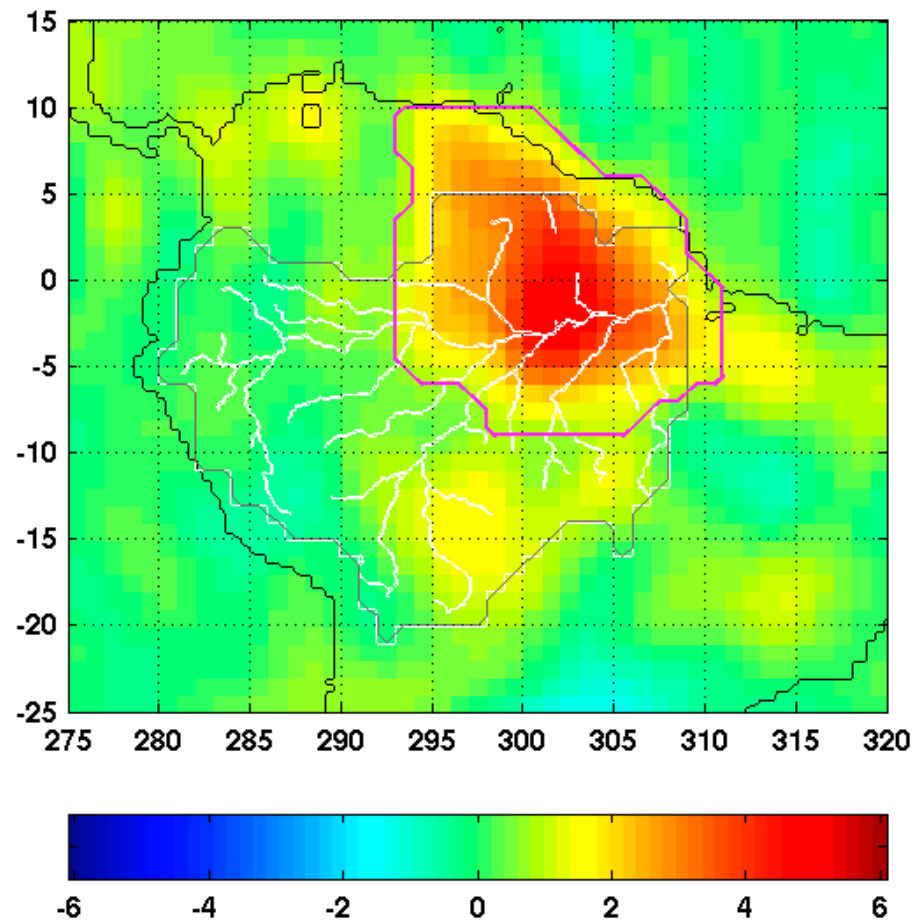
- ❑ “Fight” among land hydrology, glaciers and solid Earth
- ❑ Postglacial rebound (PGR) models
- ❑ Estimation methods
- ❑ Time spans
- ❑ Hydrological model uncertainty
 - ❑ GLDAS/Noha: 7 Gt/yr (2003-2010)
 - ❑ CLM4: 24 Gt/yr (2003 – 2010)



The 2009 Exceptional Flood in Lower Amazon



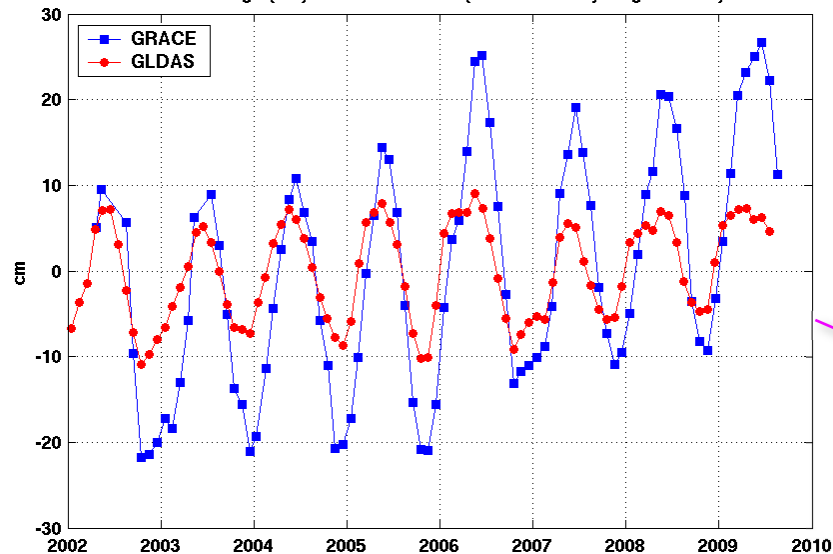
GRACE Mass Rate (2002.04 - 2009.08)



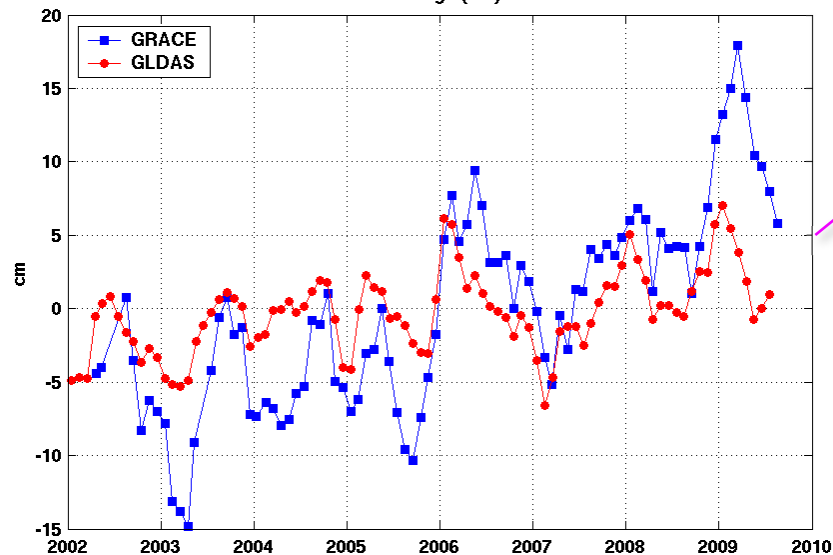
(Units: cm/year of equivalent water height)



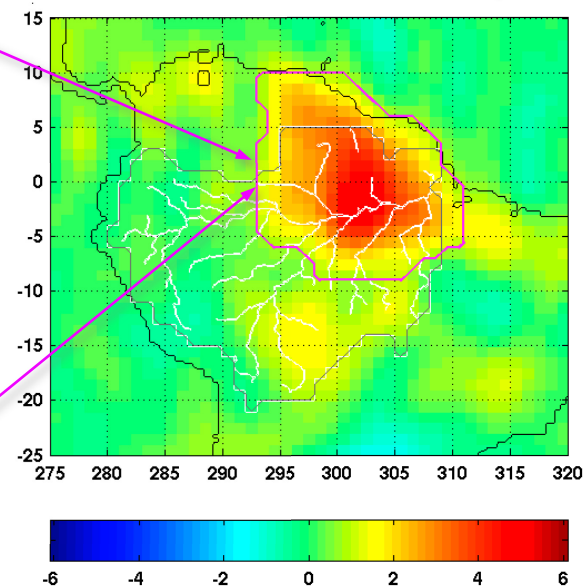
TWS change (cm) in North Amazon (area circled by magenta line)



Nonseasonal TWS change (cm) in North Amazon



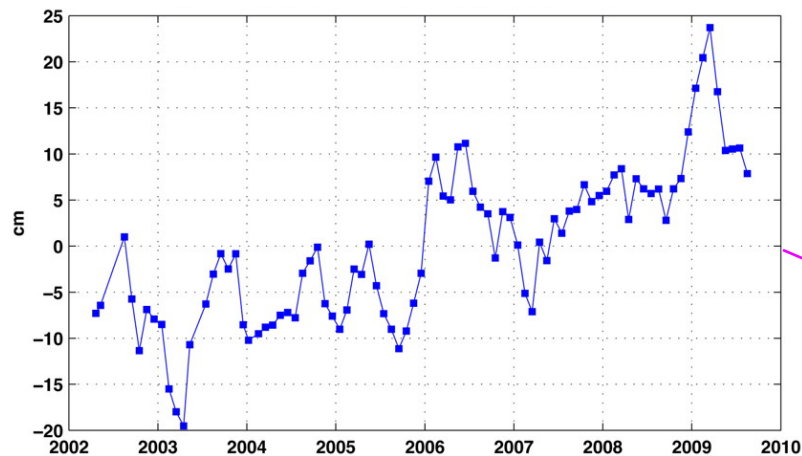
GRACE TWS Rate Map



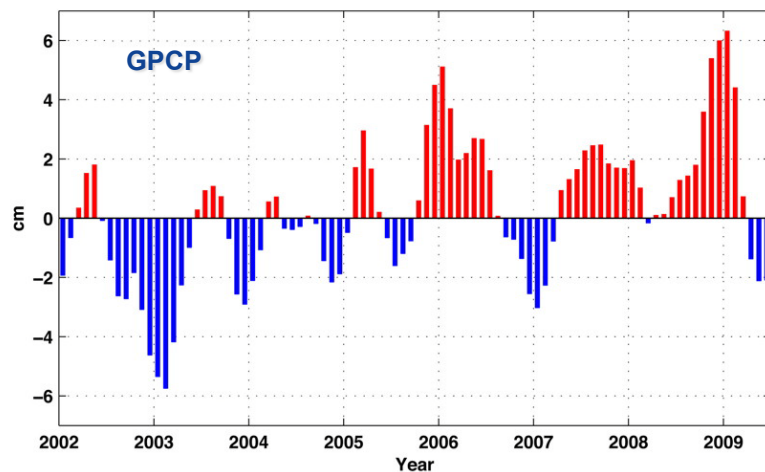
Units: cm/yr of water thickness



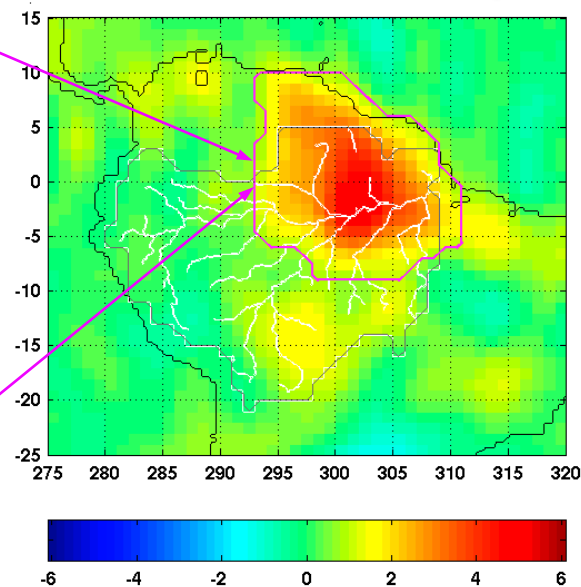
(a) GRACE TWS Change in Lower Amazon



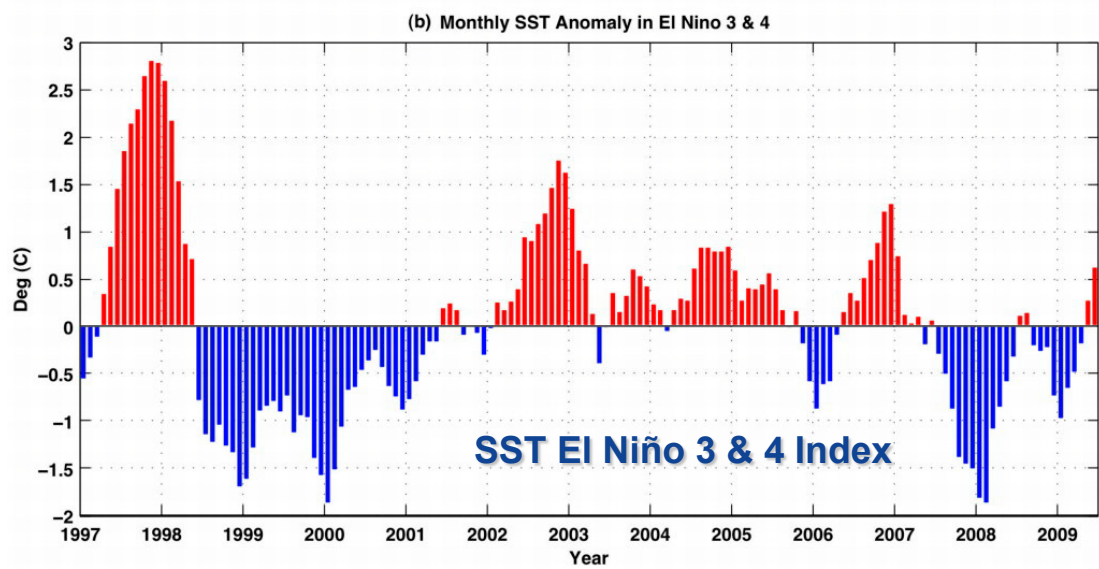
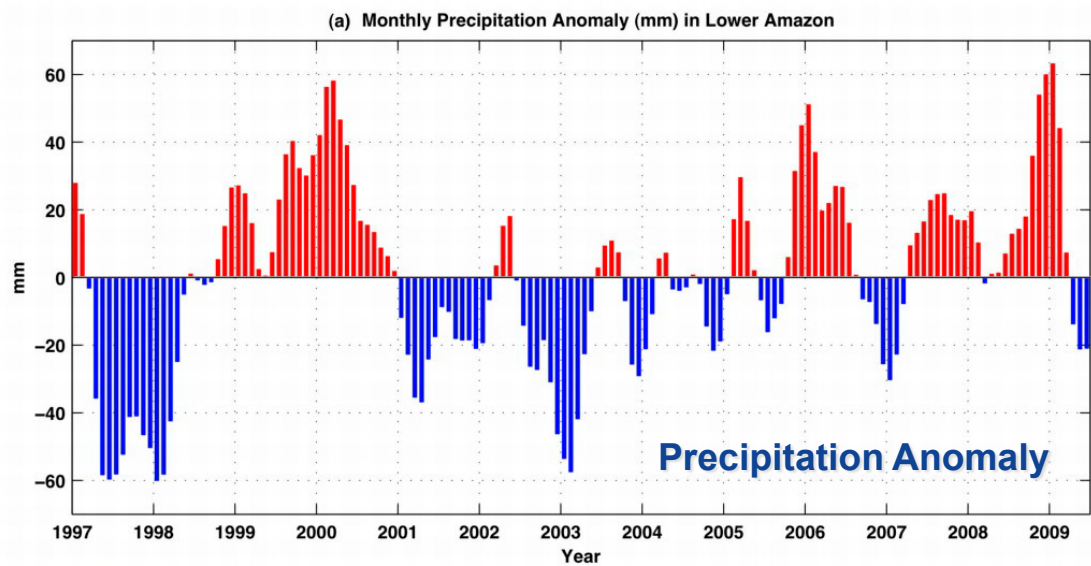
(b) Monthly Precipitation Anomalies in Lower Amazon



GRACE TWS Rate Map

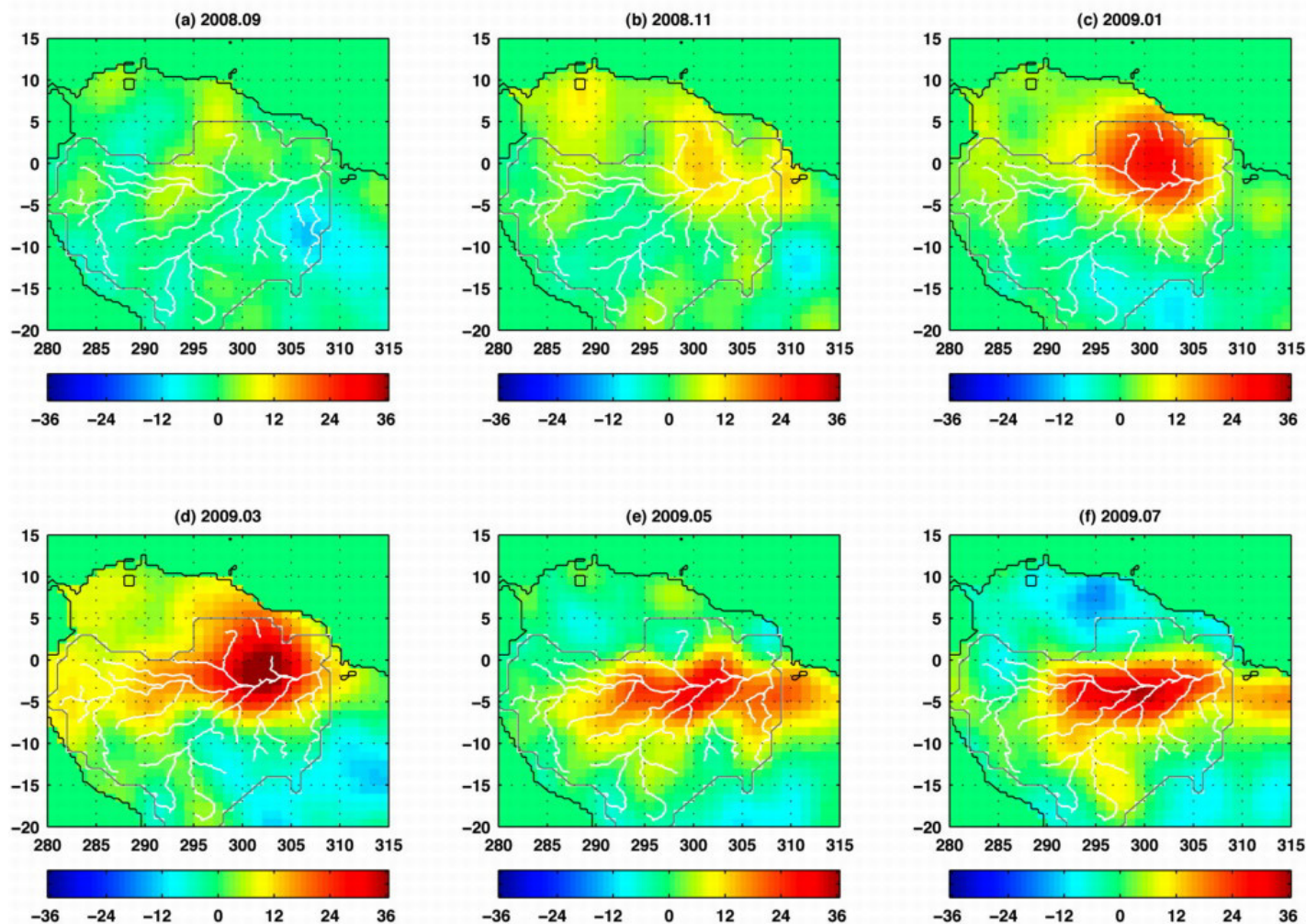


Units: cm/yr of water thickness





Development of the exceptional 2009 Amazon flood from GRACE



GRACE observed monthly TWS anomaly (seasonal signal is removed)

Main Conclusions



- ❑ **Satellite gravity measurements provide a unique means for monitoring large-scale water mass redistribution within the Earth system, including virtually all major components of the global water cycle.**
- ❑ **The 10 years of record of GRACE satellite gravity measurements provides a comprehensive global ‘survey’ of the climate system, and offers quantitative assessments of various important long-term climate change signals.**
- ❑ **Satellite gravimetry provides independent observations of mass variations in the Earth system, and can be used to validate related estimates from other remote sensing techniques and climate and land surface models.**
- ❑ **It remains a challenge for hydrologists and geodesists on how to correctly interpret GRACE observed TWS changes.**

A composite image of Earth from space, showing the Americas. Three satellites are depicted in orbit: a blue and yellow satellite on the left, a larger satellite with a large antenna on the top right, and a smaller satellite on the bottom left. The background is a starry space.

Thanks!

The Magic Blue Marble