The Global Water Cycle: What are the Main Challenges?

Towards a Roadmap for Future Satellite Gravity Missions
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The Global Water Cycle: What are the Main Challenges?

What are some key issues that cannot be addressed without a next generation gravity mission?

- Is the global water cycle accelerating?
- Land contributions to global mean sea level rise
- Global freshwater availability and sustainability
- Emergence of long-term trends
- Enhanced space-time resolution for better utilization in hydrological applications

Is the global water cycle accelerating?

Water cycle acceleration

In a warming climate, we can expect more evaporation, and thus more precipitation and more runoff, i.e. bigger exchanges or more cycling of water in the water cycle

Models suggest and observations are beginning to indicate that the magnitude and frequency of hydrologic extremes of flooding and drought will also increase

GRACE is beginning to contribute to these studies: future missions can enhance spatial and temporal resolution of observations and provide the longer record required

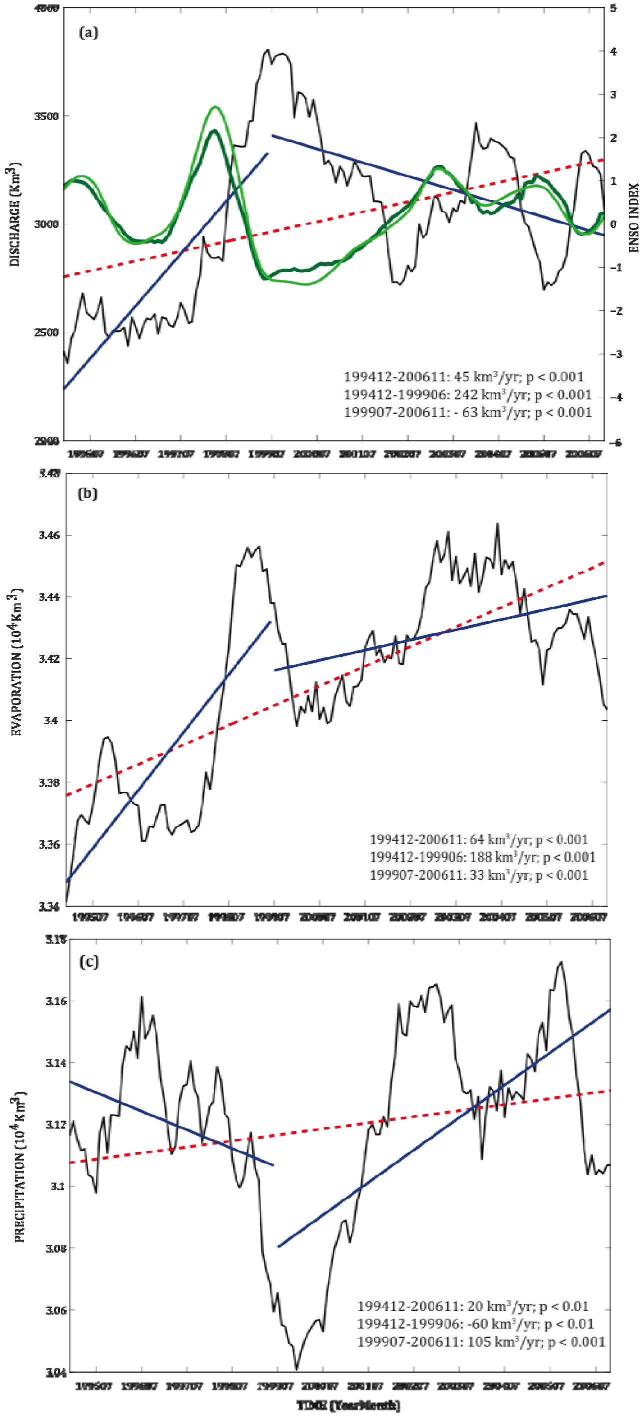
Is the global water cycle accelerating?

Is evapotranspiration increasing?

Rodell et al., 2004, Ramillien et al., 2006, Swenson and Wahr, 2006 and Seo et al., 2009 have all used GRACE estimate ET or P –E. With longer time series we can explore emerging trends in ET or P – E.

Is regional and global discharge increasing?

Syed et al., 2007 used GRACE data to show that Arctic discharge is bigger than could be estimated by traditional gauges, or was increasing, or both.



Syed et al. 2009

Recent work by Syed et al. 2009, shows that global freshwater discharge has been increasing over the period 1994-2006 at a rate of 45 km3/yr, largely in response to an increase of oceanic evaporation of 64 km3/yr

Estimates were based on global ocean mass balance. While not entirely GRACE based, ocean mass change is required and could be provided by a future gravity mission.

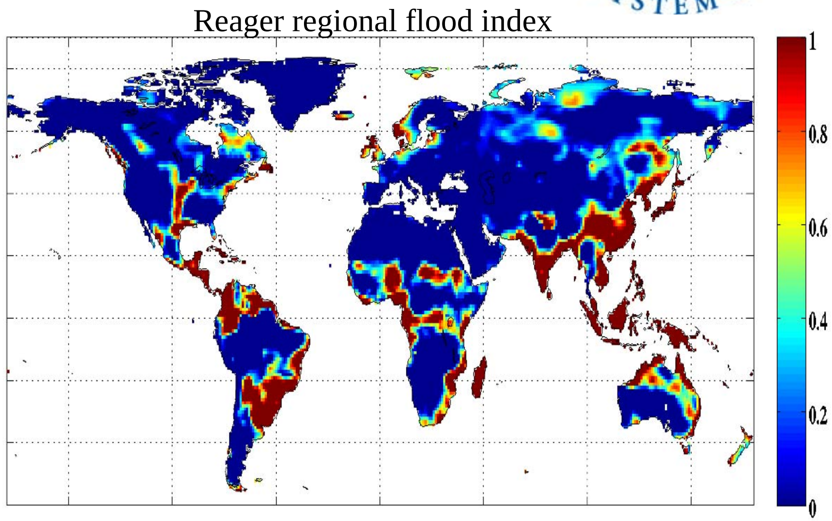
Is the global water cycle accelerating?

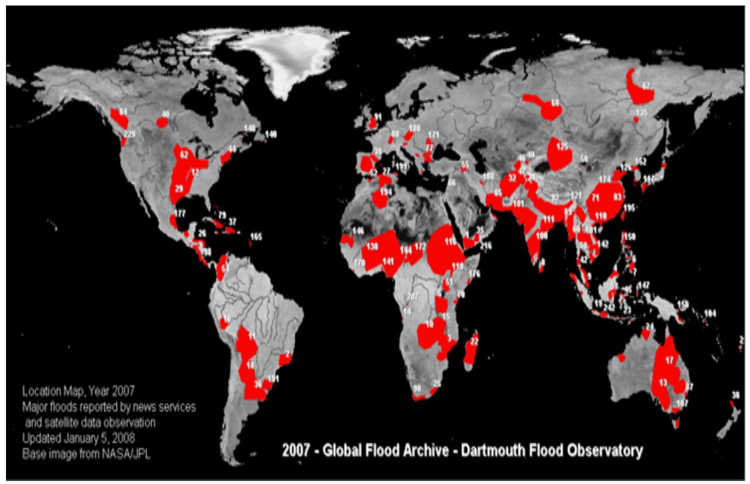
Are floods increasing?

Reager et al, 2009, proposed a GRACE-based regional flood index, which when extended in time, could provide insight into changing extremes

Is drought increasing?

Similarly, Anderson et al. 2005 and others have identified drought patterns in the GRACE data, which could provide long-term information on drought frequency





A comparison of the 2007 flood index maxima (*top*) and 2007 Dartmouth Flood Observatory reported floods (*bottom*).

Land contributions to global mean sea level rise

IPCC TAR, 2001, Church et al.

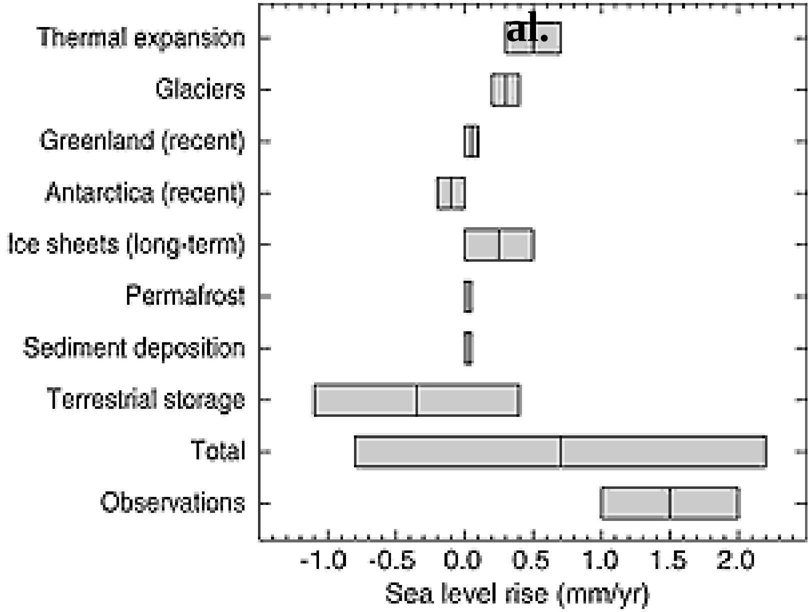


Figure 11.9: *Ranges of uncertainty for the average rate of sea level rise from 1910 to 1990 and the estimated contributions from different processes.*

IPCC FAR, 2007, Bindoff et al.

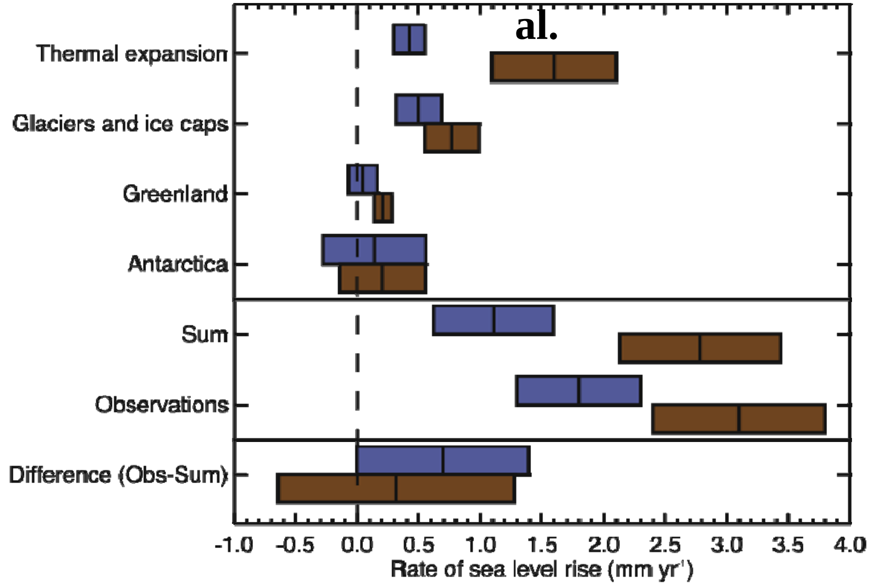


Figure 5.21. *Estimates of the various contributions to the budget of the global mean sea level change (upper four entries), the sum of these contributions and the observed rate of rise (middle two), and the observed rate minus the sum of contributions (lower), all for 1961 to 2003 (blue) and 1993 to 2003 (brown). The bars represent the 90% error range. For the sum, the error has been calculated as the square root of the sum of squared errors of the contributions. Likewise the errors of the sum and the observed rate have been combined to obtain the error for the difference.*

Land contributions to global mean sea level rise

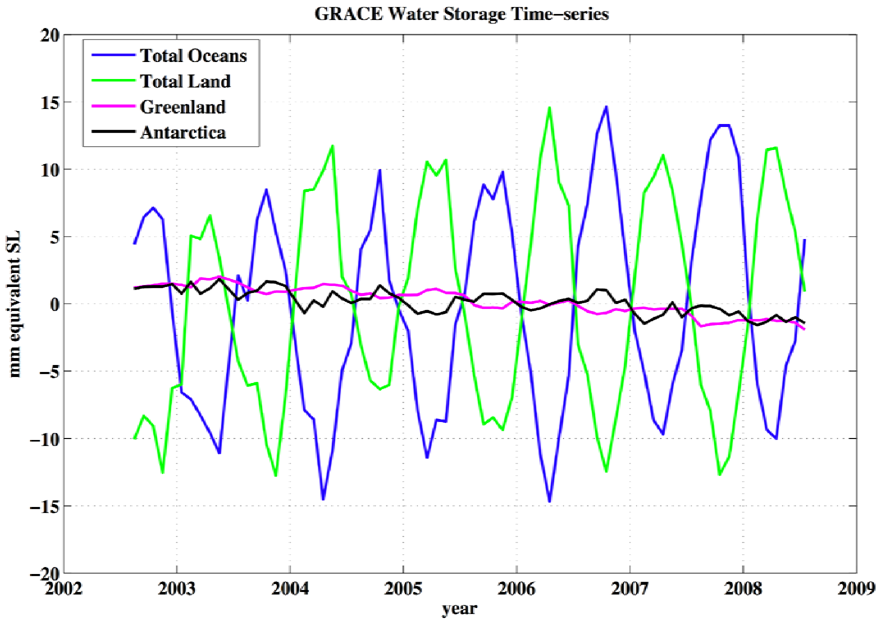
Message on land contributions continues to be mixed and highly uncertain

- IPCC splits into natural and anthropogenic and creates confusion
- Models are insufficient to address the question
- Chao et al., 2008, reservoir storage, -0.5 mm/yr
- Meier et al., 2007, alpine glaciers, + 1.1 mm/yr
- Ramillien et al, 2007, GRACE storage, +0.19 ± 0.06 mm/yr

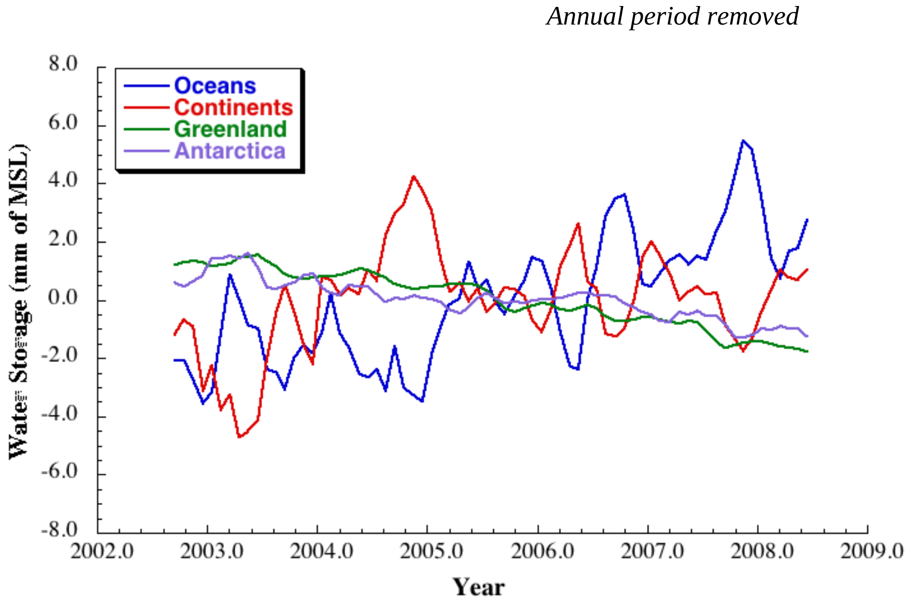
GRACE provides holistic estimate of land water storage change that includes all natural and anthropogenic sources

Land contributions to global mean sea level rise

Observing changes in global water storage using GRACE, 2002-2008



Annual period removed



Trends (mm/yr)

Ocean = 1.2± 0.4

Land = 0.3 ± 0.5

Greenland = -0.60 ± 0.1

Antarctica = -0.40 ± 0.2

- Balances within the uncertainty
- However, much room for improvement
- Need higher spatial resolution to resolve glaciers, reservoir contributions
- Need longer time series since interannual variation is large
- Important to know for mitigation and adaptation to sea level rise

Global freshwater availability and sustainability

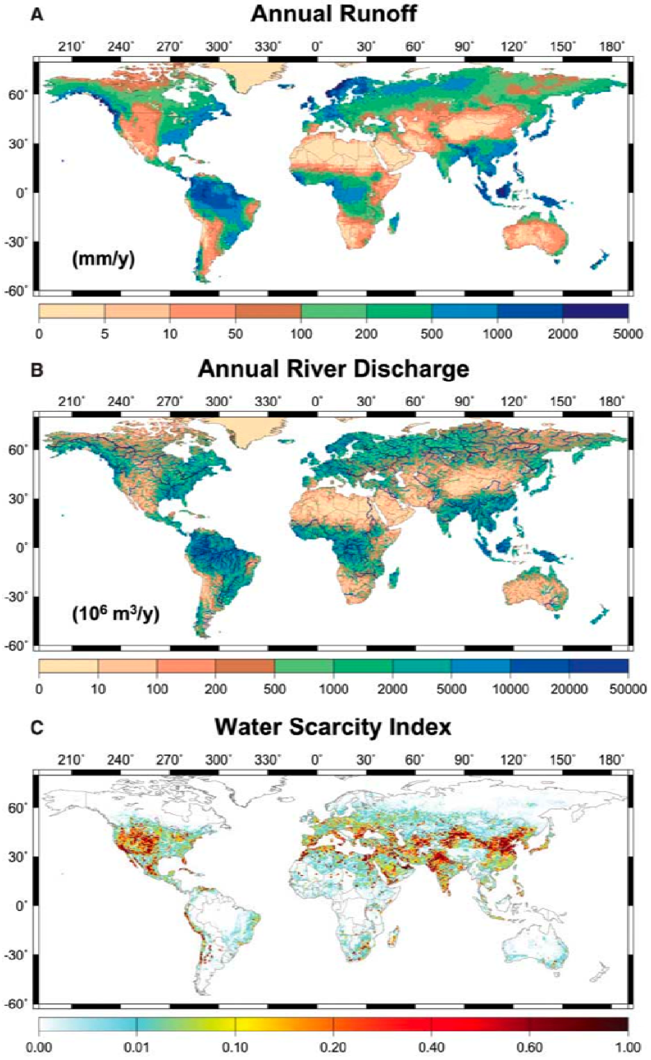


Fig. 2. Global distribution of (A) mean annual runoff (mm/year), (B) mean annual discharge (million m^3/year), and (C) water scarcity index *Rws* (3, 11). Water stress is higher for regions with larger *Rws*.

Oki and Kanae, 2008

Water scarcity indices, e.g. Vorosmarty et al., 2000, are important indices of future water availability.

Most, including the Oki and Kanae, 2008, version to the left, are based on surface water and exclude groundwater, so in fact the largest fraction of the global water supply unaccounted for

Global freshwater availability and sustainability

Global groundwater scarcity index by groundwater basin

•Groundwater recharge calculated from CLM 3.5

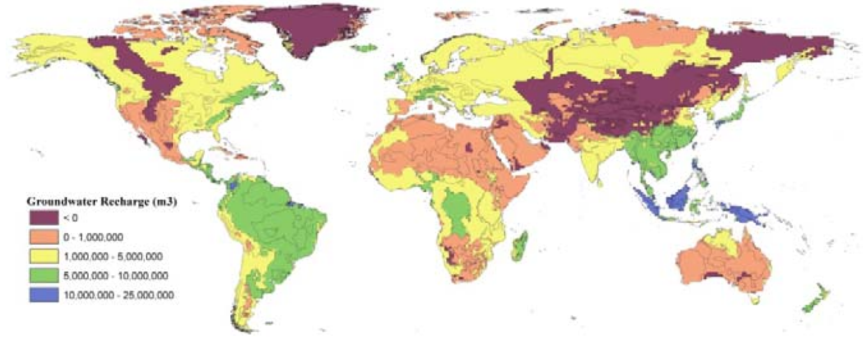
•Groundwater withdrawal calculated by multiplying high-resolution population data (as used in Vörösmarty study) with per capita withdrawal data from individual countries (from World Resource Institute)

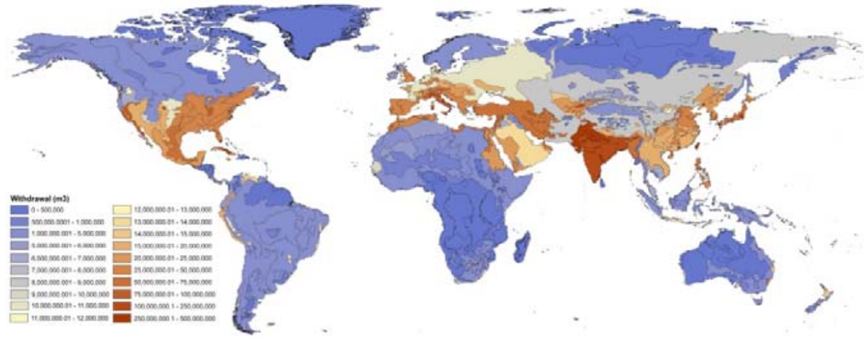
•Groundwater index calculated by dividing groundwater withdrawal by groundwater recharge

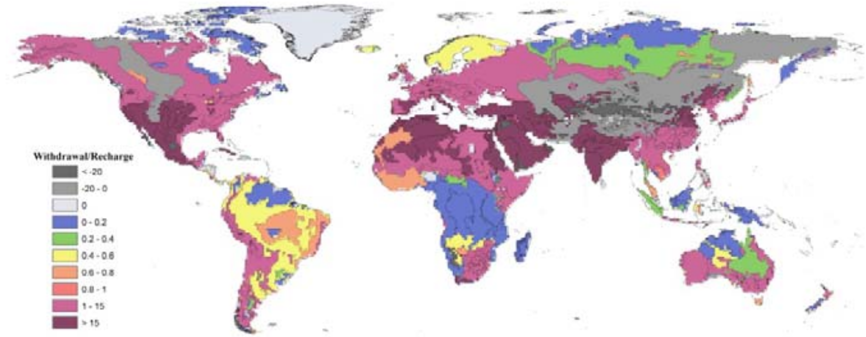
•Based on UN scale for water scarcity:

0.0-0.2 = Low scarcity
0.2-0.4 = Moderate scarcity
0.4-0.6 = High scarcity
0.6-0.8 = Severe scarcity
0.8-1.0 = Extremely severe scarcity

*Negative values represent areas where recharge is less than evapotranspiration







Voss et al., 2009

Global freshwater availability and sustainability

Conceptually, GRACE and future time-variable data can make a great contribution to stress indices. We know that GRACE can track total water and groundwater storage changes, so can contribute in many ways.

However, GRACE data not are very helpful due to its course spatial resolution, in particular relative to much higher resolution population data.

Gravity data have great potential for estimating water use, net groundwater recharge, virtual water, etc, but greater resolution required

Global freshwater availability and sustainability

- A key question for hydrologic research is ‘what is the space-time distribution of water and how will it change over the next century’

- There is a pressing need to quantify how much water is stored as ice, snow, surface water, soil moisture and groundwater; how this distribution varies in space; and how it varies on seasonal-to-decadal and longer timescales

- This will not be accomplished without a future gravity mission that can constrain total water storage changes, and that can be combined with advanced models and other sensors (SMOS, SMAP, SWOT, DESDynI, GPS, etc) to help disaggregate or decompose the signal into its components

- Water is the lifeblood of Earth, and GRACE time series, for the whole earth, for the continents, for river basins or for watersheds, should emerge as one of several critical indicators of regional health and sustainability

Emergence of long-term trends in water storage

Interannual variations and emerging trends from GRACE, 2003-2008