Global Evaluation of Apparent Trends in Terrestrial Water Storage Observed by GRACE

Matt Rodell*, Jay Famiglietti, David Wiese, J.T. Reager, Hiroko Beaudoina, Felix Landerer, and Min-Hui Lo

*Hydrological Sciences Laboratory
NASA Goddard Space Flight Center
Gravity Recovery and Climate Experiment (GRACE) and GRACE Follow On

Aqua: MODIS, AMSR-E, etc.

GRACE: 2002-2017

GRACE FO: Scheduled to launch on 19 May 2018, aboard a SpaceEx Falcon 9 rocket

Conventional radiation-based remote sensing technologies cannot sense water below the first few centimeters of the snow-canopy-soil column. GRACE and GRACE FO are unique in their ability to monitor water at all levels, down to the deepest aquifer.
Linear rate of change of TWS (cm/yr) after first removing the seasonal cycle. Based on JPL GRACE Tellus mascon product*.  

Which apparent trends are caused by  
1. Natural interannual variability  
2. Water (mis)management  
3. Climate change  

https://grace.jpl.nasa.gov/data/get-data/jpl_global_mascons/
Natural Interannual Variability

Terrestrial Water Storage Trends, 2002-2016

Areas of increased TWS and precipitation

Areas of decreased TWS and precipitation

Percentage of Normal Precipitation, 2002-2016

Precipitation Trends, 2002-2016

Based on 1979-2016 data from the Global Precipitation Climatology Project version 2.3; Adler et al., 2016.
Water (Mis)Management

Terrestrial Water Storage Trends, 2002-2016

Percentage of Irrigated Area

Three Gorges and other reservoirs filling

Areas of intense agricultural irrigation and TWS decline

Areas of predicted precipitation increase and TWS increase

Areas of predicted precipitation decrease and TWS decline

Median climate model prediction of precipitation changes between 1986-2005 and 2081-2100, under the Representative Concentration Pathways 8.5 W/m² (RCP8.5; "business as usual") greenhouse gas emissions scenario from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report.
Declining TWS in Northwestern China
NW China Region TWS and Precipitation Time Series

194 mm/yr  Mean annual precipitation 1979-2015
213 mm/yr  Mean annual precipitation 2003-2015
+1 mm/yr   Linear precipitation trend 2003-2015

Drought is not a valid explanation for the observed trend

Data from the Global Precipitation Climatology Project (GPCP) v. 2.3 (Adler et al., 2016)
Northwestern China Region

Location of JPL mascons (641 & 726) in NW China

Glaciers

Desert
Northwestern China Region Glacier Melt

Tien Shan glacier loss estimates based on ICESat observations (2003 to 2009):
- $5.4 \pm 2.9 \text{ Gt/yr}$ (Farinotti et al. 2015)
- $7.5 \pm 3.4 \text{ Gt/yr}$ (Gardner et al. 2013)

TWS decline in the NW China region based on GRACE (2003-2009):
- $8.3 \pm 3.5 \text{ Gt/yr}$ (This study)

Our NW China region encompasses less than half of the area of glacier melt, which suggests that melting glaciers do not fully explain the observed mass loss.


Xinjiang province is one of the world’s largest producers of coal. Coal mining involves dewatering the aquifers that the mines intersect, such that consequent groundwater depletion is probable.

The NW China region lies within an internally draining basin. Water flowing from the region does not go far, yet GRACE detects no substantial TWS gains in adjacent regions.
Lakes into which the NW China region drains did not gain water during the study period.

Satellite altimetry data from the Global Reservoirs/Lakes (G-REALM) database.

“Since the mid-1980s, rain and snow have increased at the river’s headwaters in the Tian Shan mountains in western China’s Xinjiang Uygur Autonomous Region, Chinese data show. Yet in the past several years, the Ili’s flow has declined precipitously, says Murat Nurumbetov, a Kazhydromet engineer in Almaty. The ‘inescapable conclusion,’ he asserts, is that Xinjiang is drawing more heavily for irrigation, industrial use, and drinking water.”

In 2000, an artificial canal was dug as part of the Emergency Water Transfer Project (Tarim River Restoration Project) which diverted an average of 0.32 Gt/yr of water from Lake Bosten through the Kongqi River to the Tarim River, which supports irrigated agriculture and terminates in the desert.

Summary and Outlook

- GRACE (2002-2017) provided an unprecedented view of how water availability is changing around the world.

- We assessed 34 apparent trends and found
  - 12 caused by natural interannual variability
  - 14 probable or partial direct human impacts
  - 8 probable or possible climate change impacts

- During the study period all but one of the 34 regions lost or gained more water than the capacity of Lake Mead (32 Gt), the largest man-made reservoir in the U.S., and eleven lost or gained more than ten times that amount.

- One interesting region is in NW China, where glacier melt and groundwater withdrawals become surface waters, which are subsequently consumed by irrigated agriculture and evaporated from the desert floor, resulting in an observed 5.5 ±0.6 Gt/yr mass loss.

- A paper that describes the details of this study will appear online on May 16:

- GRACE Follow On is scheduled to launch on May 19!!!
Comparison of Trends in Three Mascon Products

NW China region linear trend estimates
-5.4 Gt/yr  JPL mascon (3°)  
-1.7 Gt/yr  GSFC mascon (1°)  

-2.2 Gt/yr  CSR mascon (1°)  
-2.8 Gt/yr  JPL mascon 200 km smoothed