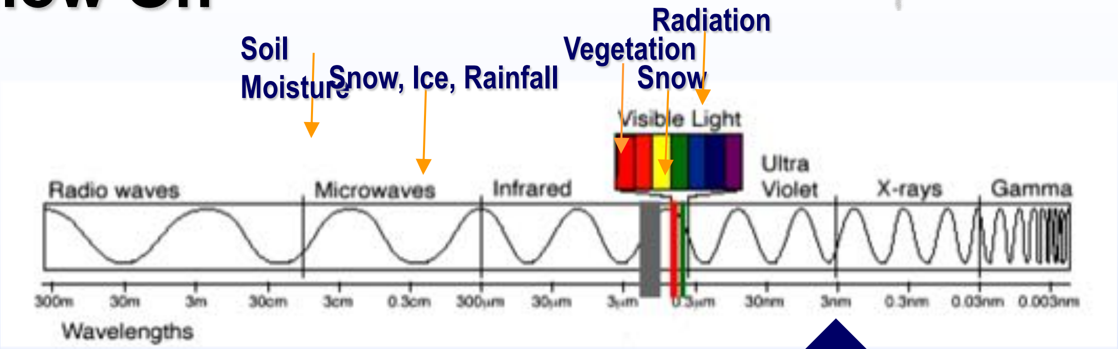
Global Evaluation of Apparent Trends in Terrestrial Water Storage Observed by GRACE

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

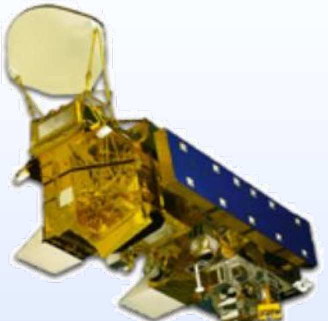
*Hydrological Sciences Laboratory
NASA Goddard Space Flight Center

Matthew.Rodell@nasa.gov

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

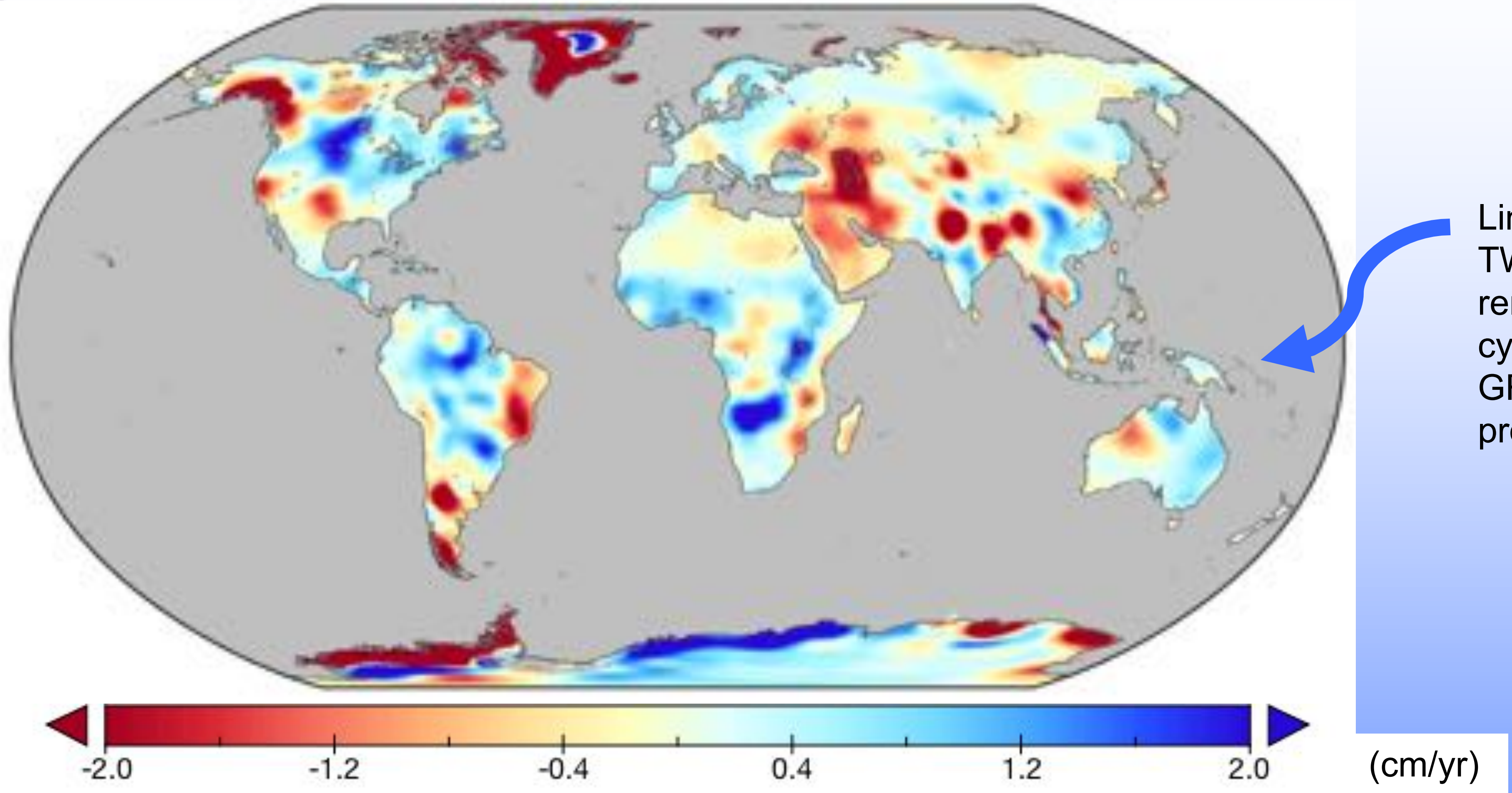
Conventional radiation-based remote sensing technologies cannot sense water below the first few centimeters of the snow-canopy-soil column

GRACE

GRACE and GRACE FO are unique in their ability to monitor water at all levels, down to the deepest aquifer

Matthew.Rodell@nasa.gov

Terrestrial Water Storage "Trends", 2002-2016



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

?

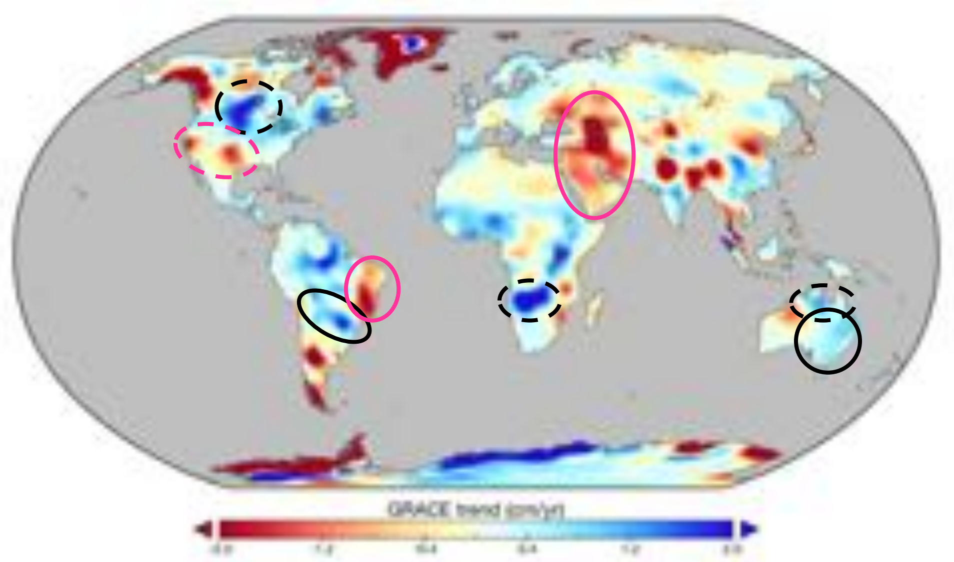
*Watkins, M. M., Wiese, D. N., Yuan, D. N., Boening, C. & Landerer, F. W., 2015: Improved methods for observing Earth's time variable mass distribution with GRACE using spherical cap mascons. J. Geophys. Res. Solid Earth 120, 2648-2671.

https://grace.jpl.nasa.gov/data/get-data/jpl_global_mascons/)

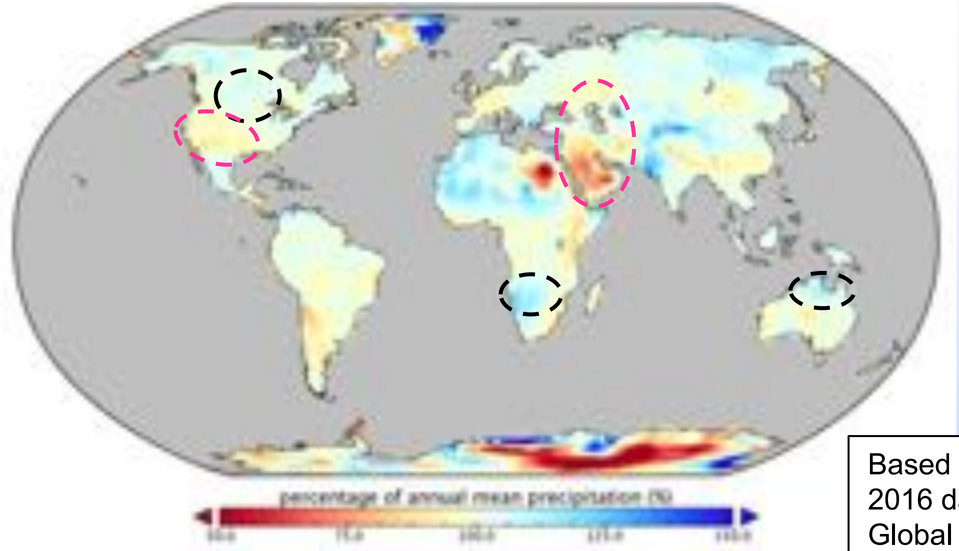
Matthew.Rodell@nasa.gov

Natural Interannual Variability

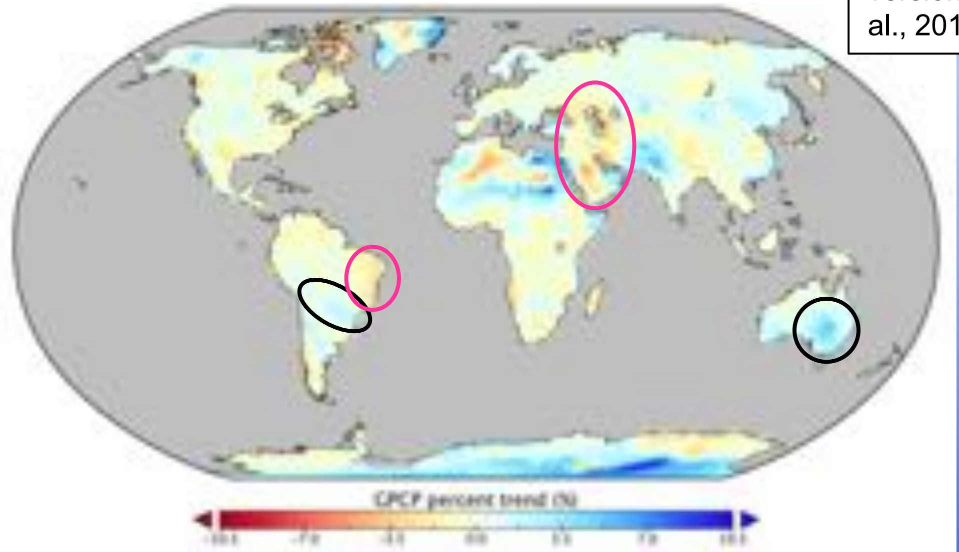
Terrestrial Water Storage Trends, 2002-2016



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.

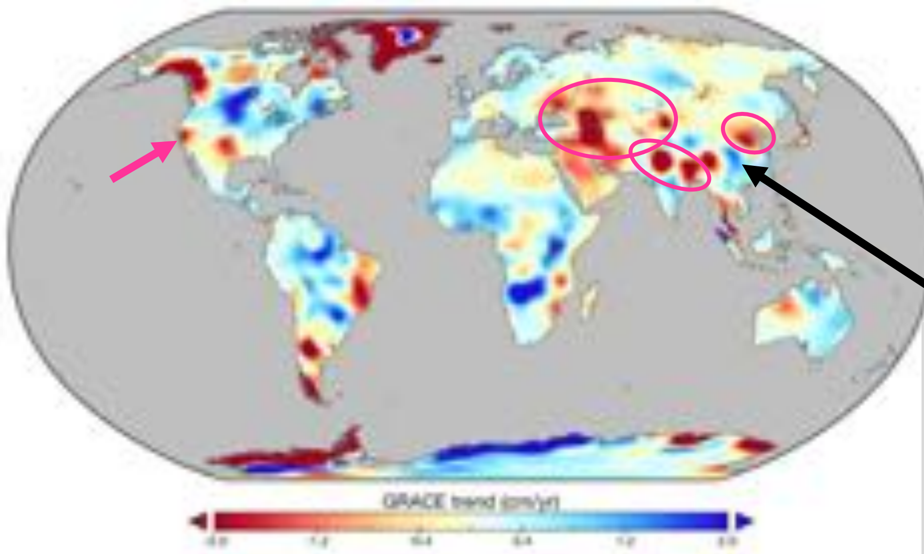
Areas of increased TWS and precipitation

Areas of decreased TWS and precipitation

Matthew.Rodell@nasa.gov

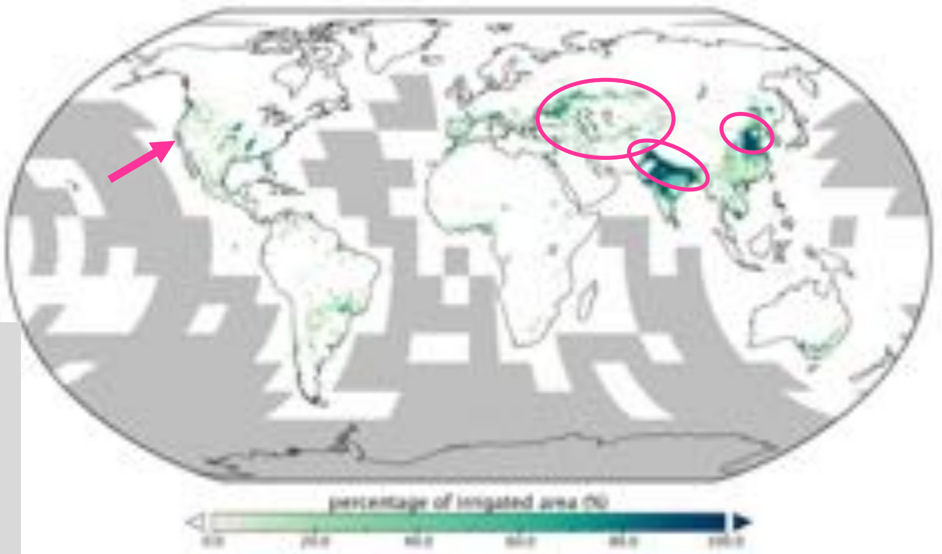
Water (Mis)Management

Terrestrial Water Storage Trends, 2002-2016



Three Gorges and other reservoirs filling

Percentage of Irrigated Area



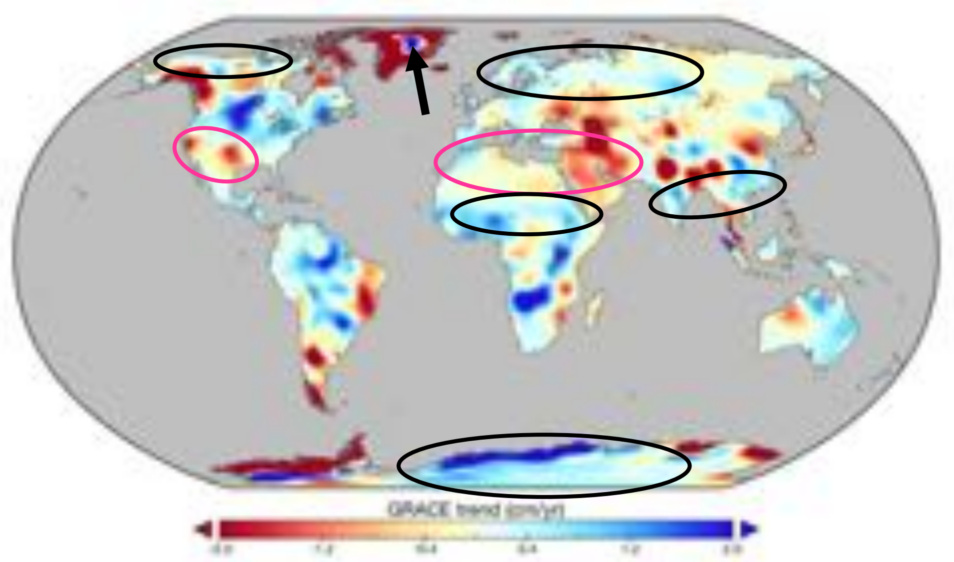
Areas of intense agricultural irrigation and TWS decline

Salmon, J. M., Friedl, M. A., Frolking, S., Wisser, D., & Douglas, E. M., 2015: Global rain fed, irrigated, and paddy croplands: A new high resolution map derived from remote sensing, crop inventories and climate data. *Int. J. Applied Earth Observation and Geoinformation* **38**, 321-334.

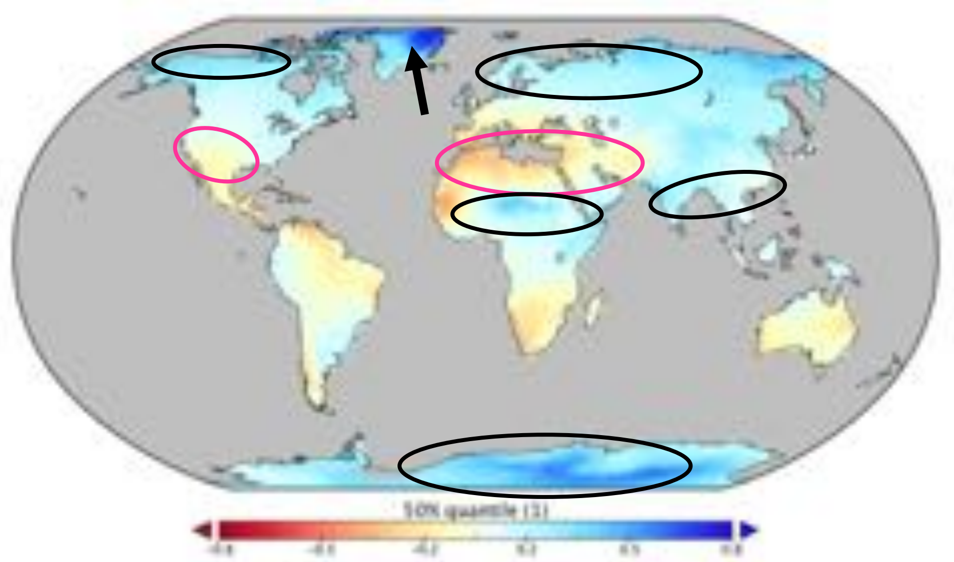
Matthew.Rodell@nasa.gov

Climate Change: Precipitation

Terrestrial Water Storage Trends, 2002-2016



RCP8.5 Predicted Increase in Precipitation



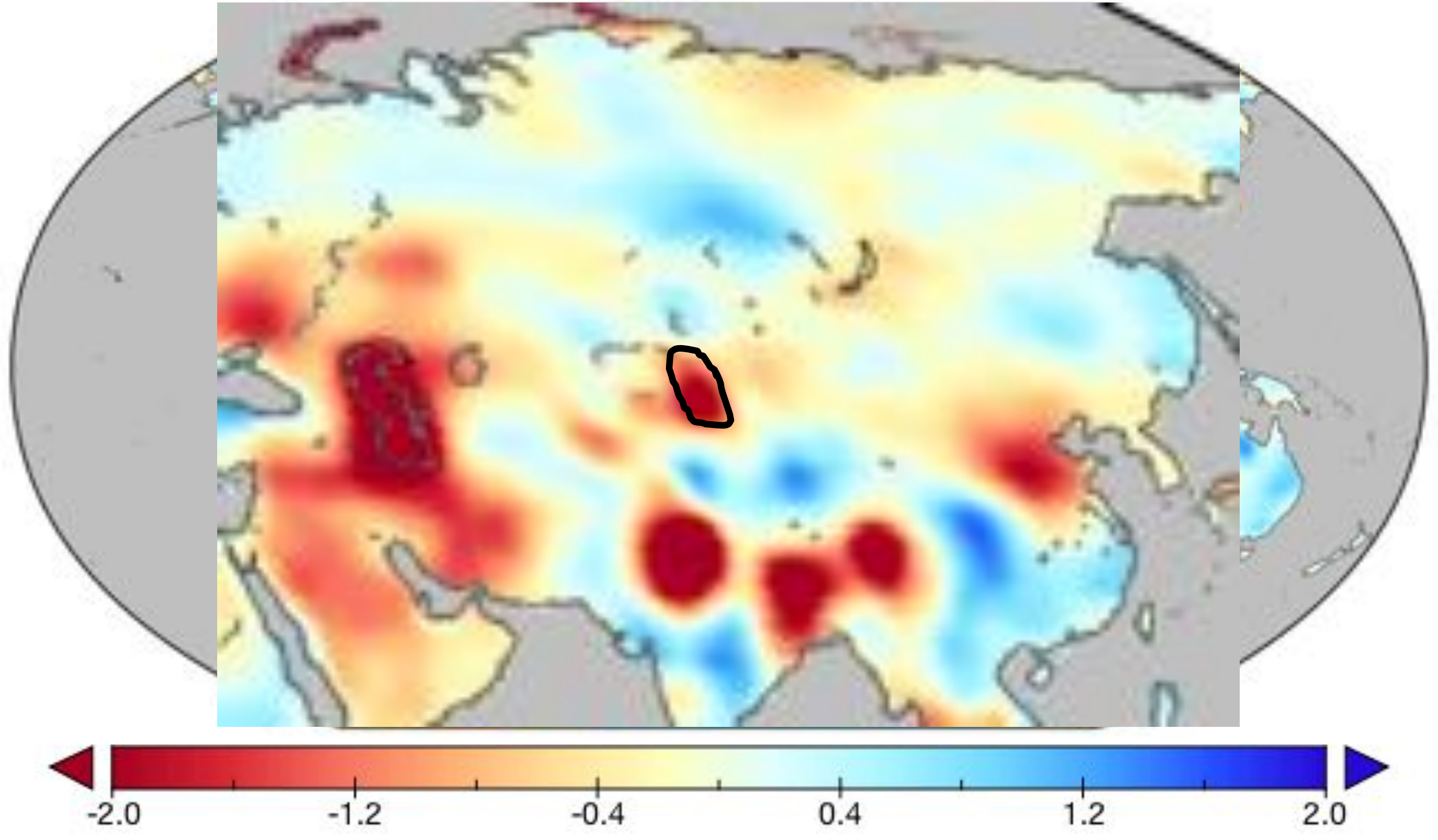
Areas of predicted precipitation increase and TWS increase

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

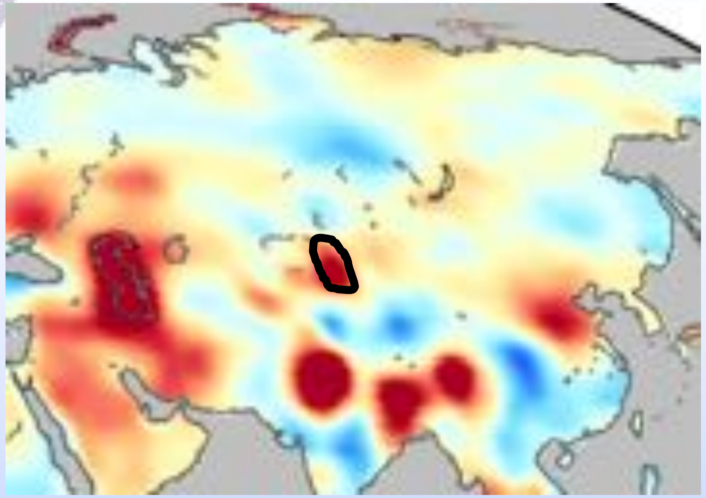
Matthew.Rodell@nasa.gov

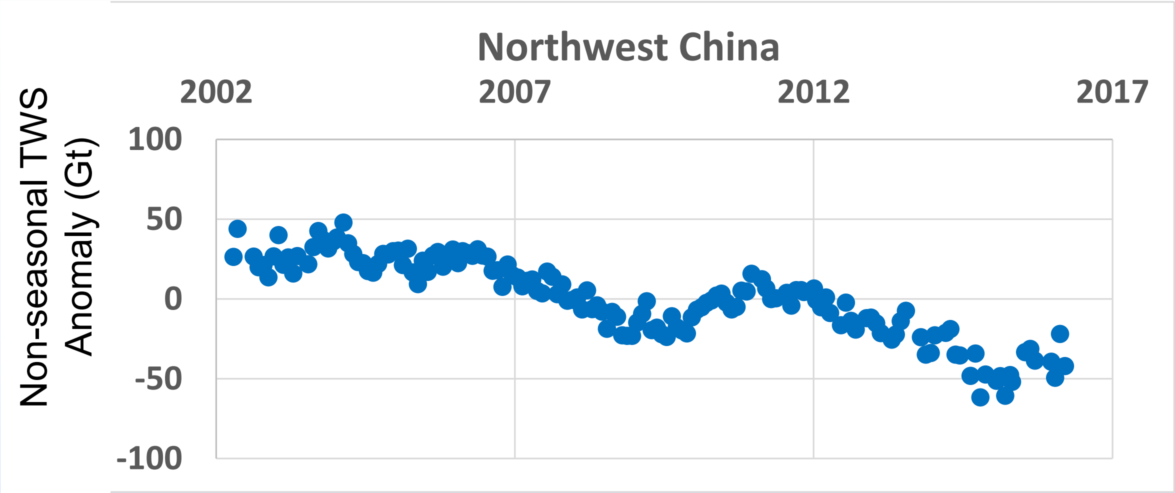
Declining TWS in Northwestern China

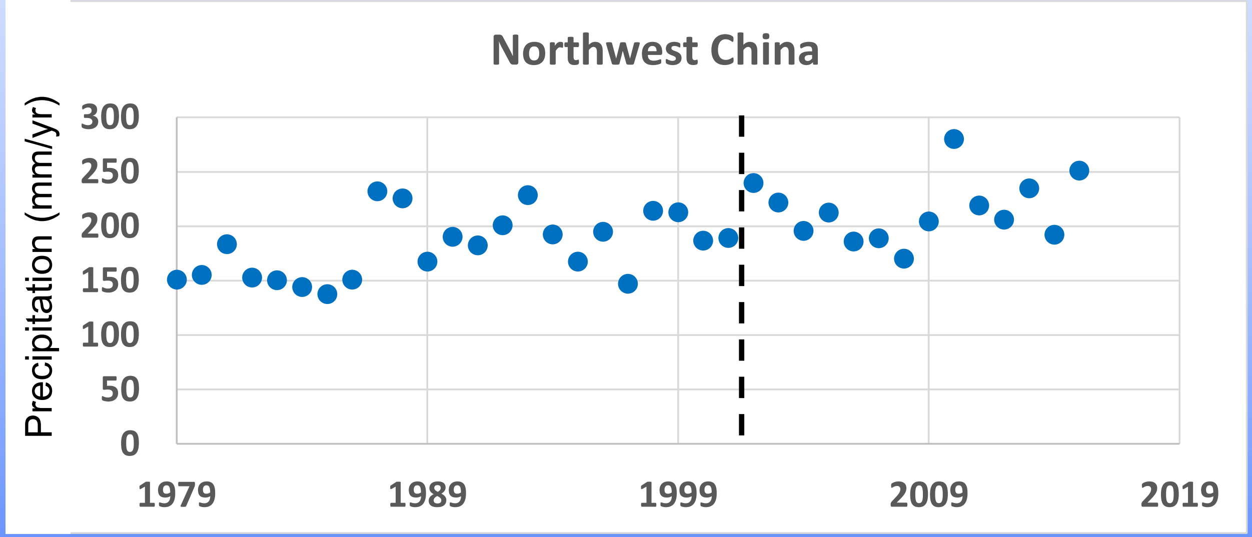


Matthew.Rodell@nasa.gov

NW China Region TWS and Precipitation Time Series







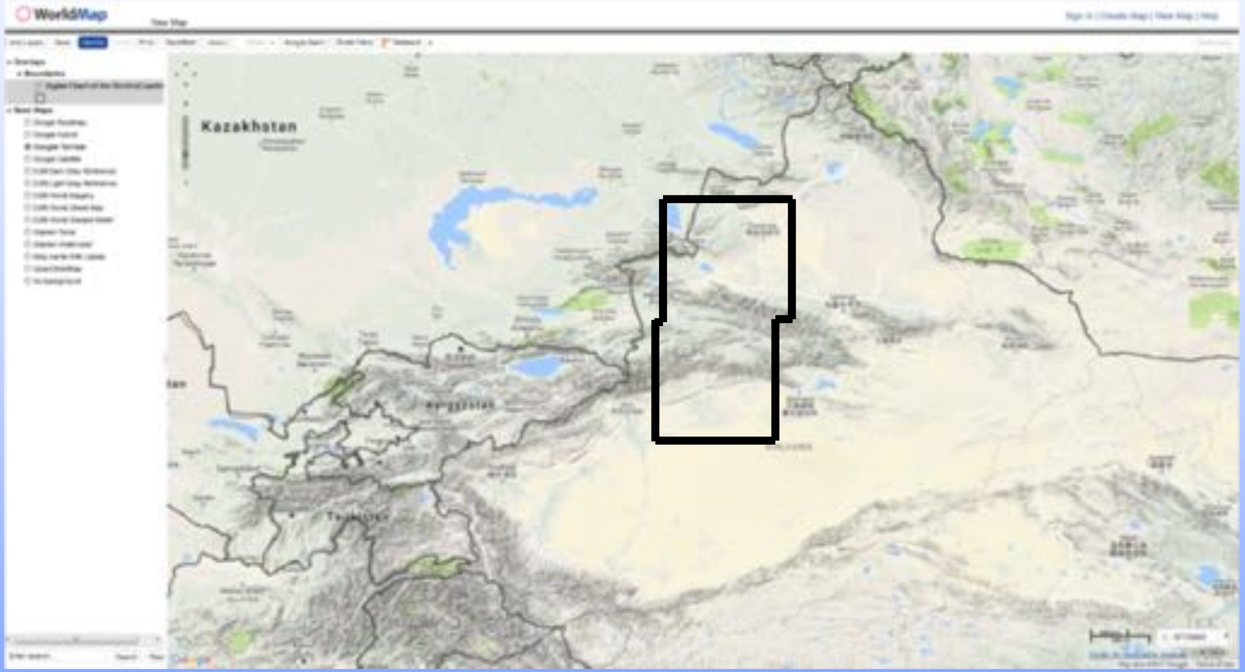
Data from the Global Precipitation Climatology Project (GPCP) v. 2.3 (Adler et al., 2016)

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

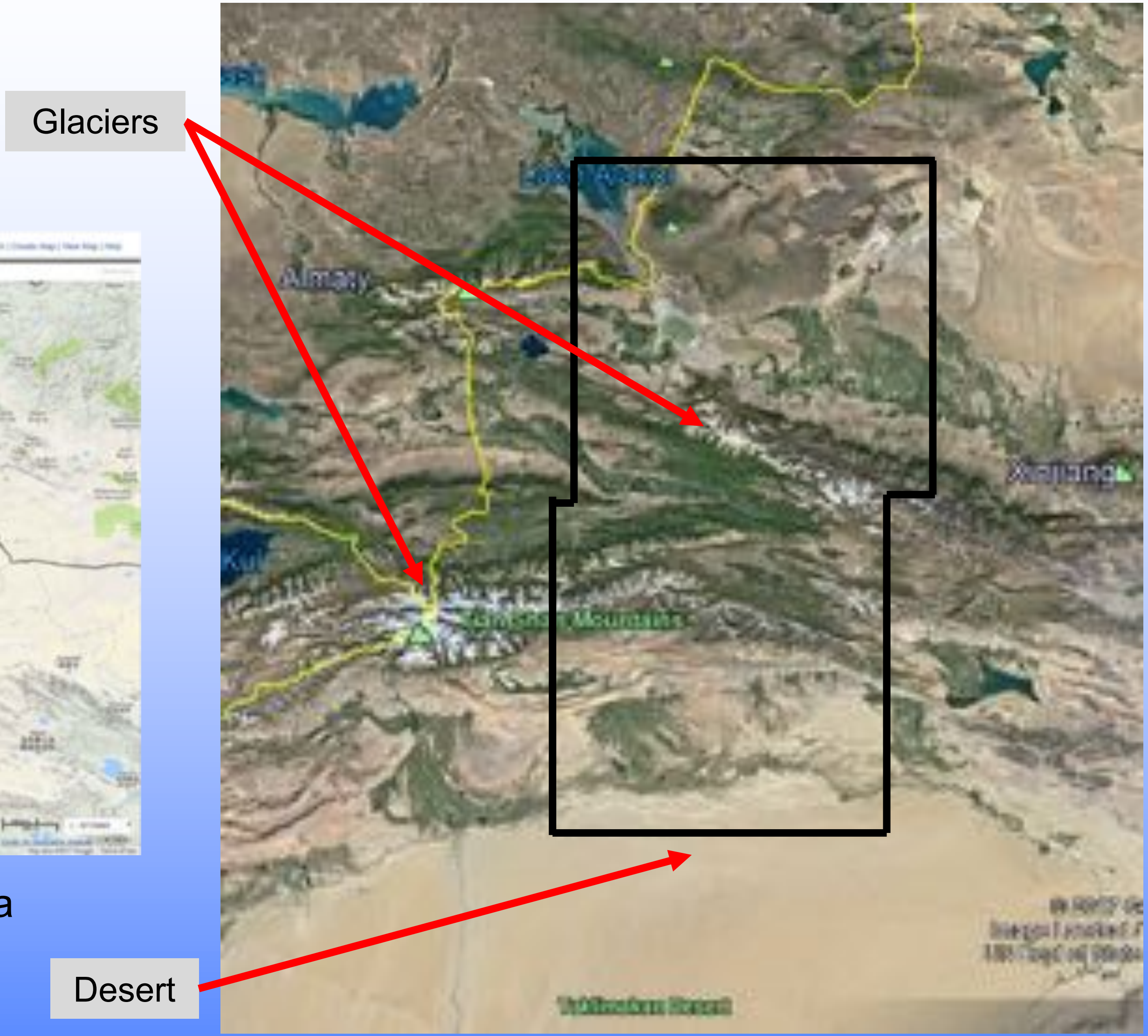
Drought is not a valid explanation for the observed trend

Matthew.Rodell@nasa.gov

Northwestern China Region



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



Glaciers

Desert

Matthew.Rodell@nasa.gov

Northwestern China Region Glacier Melt

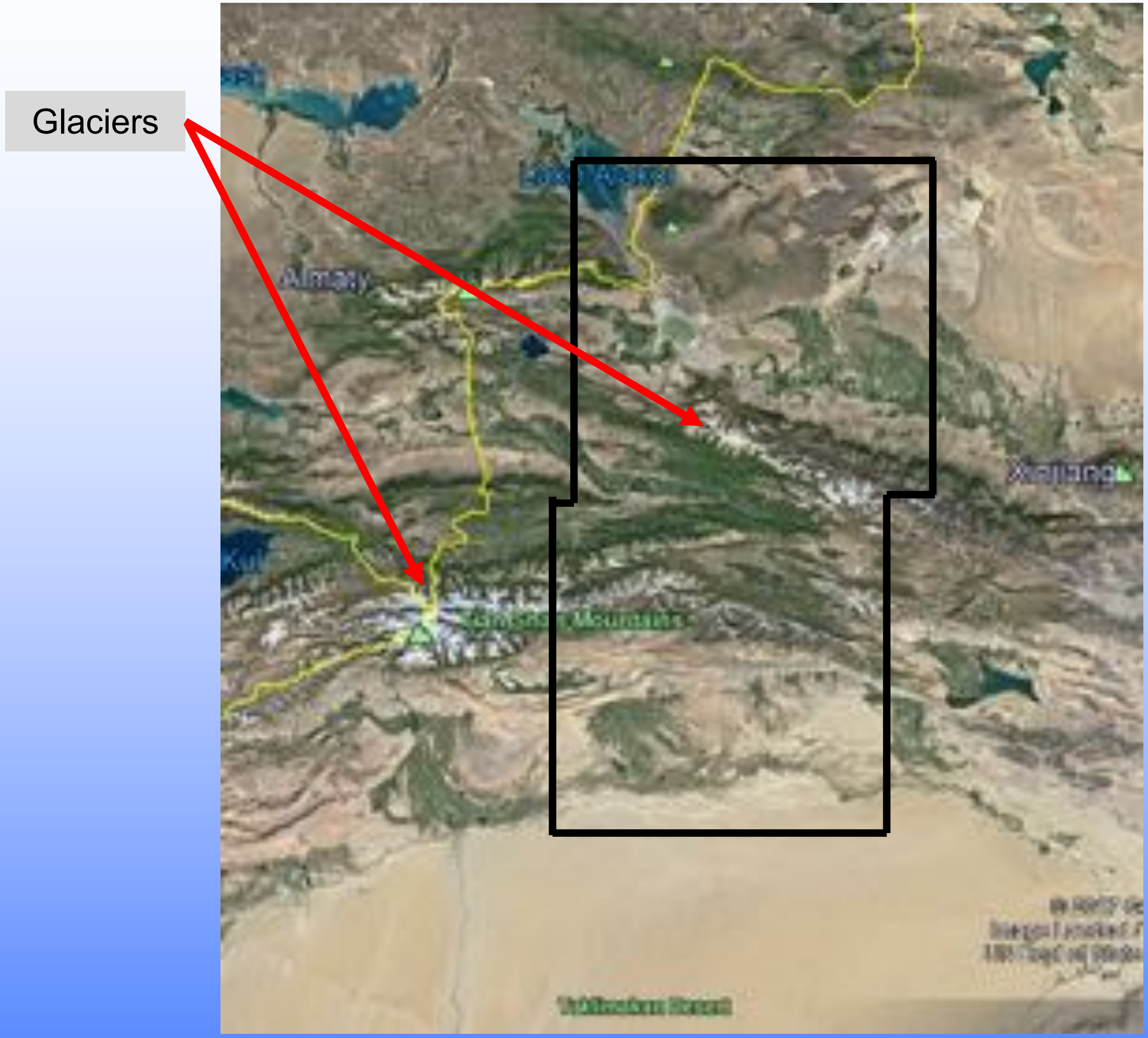
Tien Shan glacier loss estimates based on ICESat observations (2003 to 2009):

5.4 ±2.9 Gt/yr	*Farinotti et al. (2015)*
7.5 ±3.4 Gt/yr	*Gardner et al. (2013)*

TWS decline in the NW China region based on GRACE (2003-2009):

8.3±3.5 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.



Farinotti, D., Longuevergne, L., Moholdt, G., Duethmann, D., Mölg, T., Bolch, T., Vorogushyn, S., & Güntner, A., 2015: Substantial glacier mass loss in the Tien Shan over the past 50 years. *Nature Geoscience* **8**, 716-722.

Gardner, A. et al., 2013: A reconciled estimate of glacier contributions to sea level rise: 2003 to 2009. *Science* **340**, 852-857.

Matthew.Rodell@nasa.gov

Coal Mining in NW China

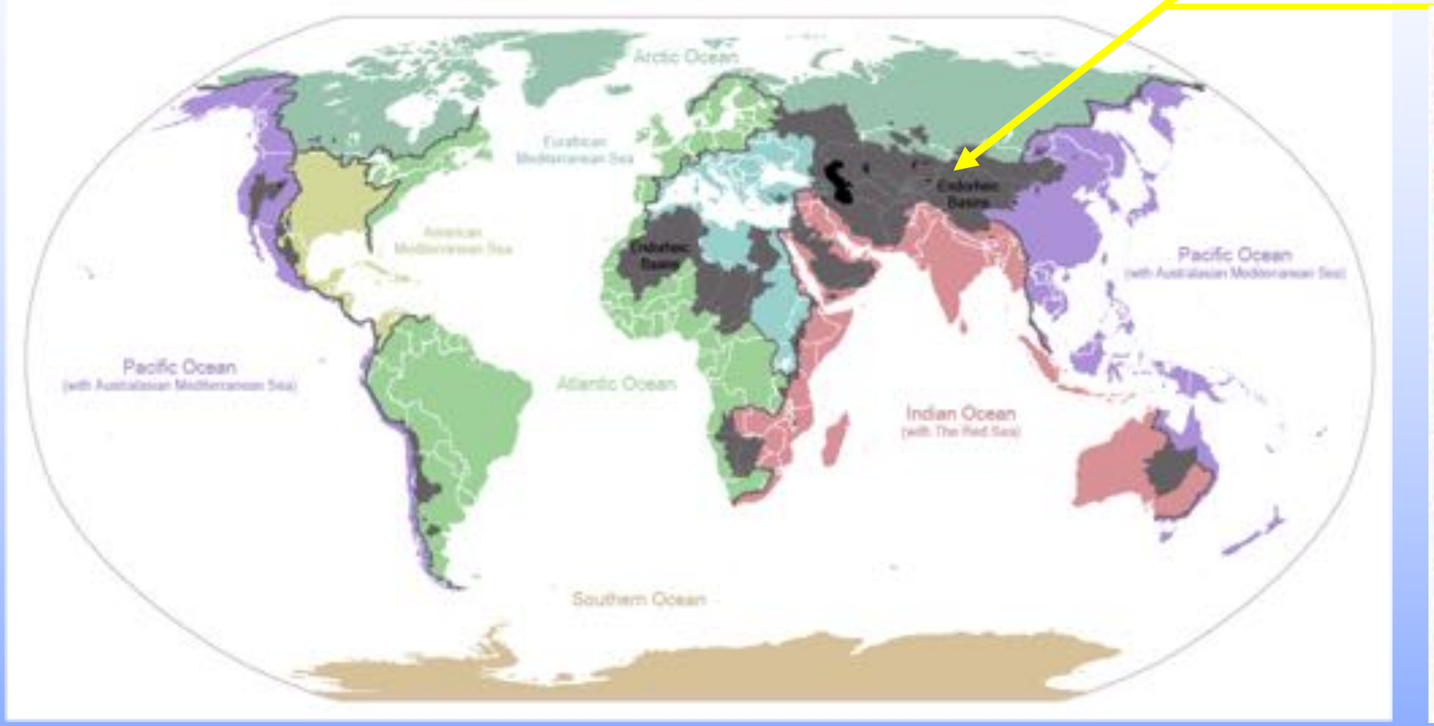
Tang, L. (2009). *Mapping the Energy Use in Xinjiang, Province of China*, Masters Thesis, Gavle University, Gavle, Sweden.

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.

Matthew.Rodell@nasa.gov

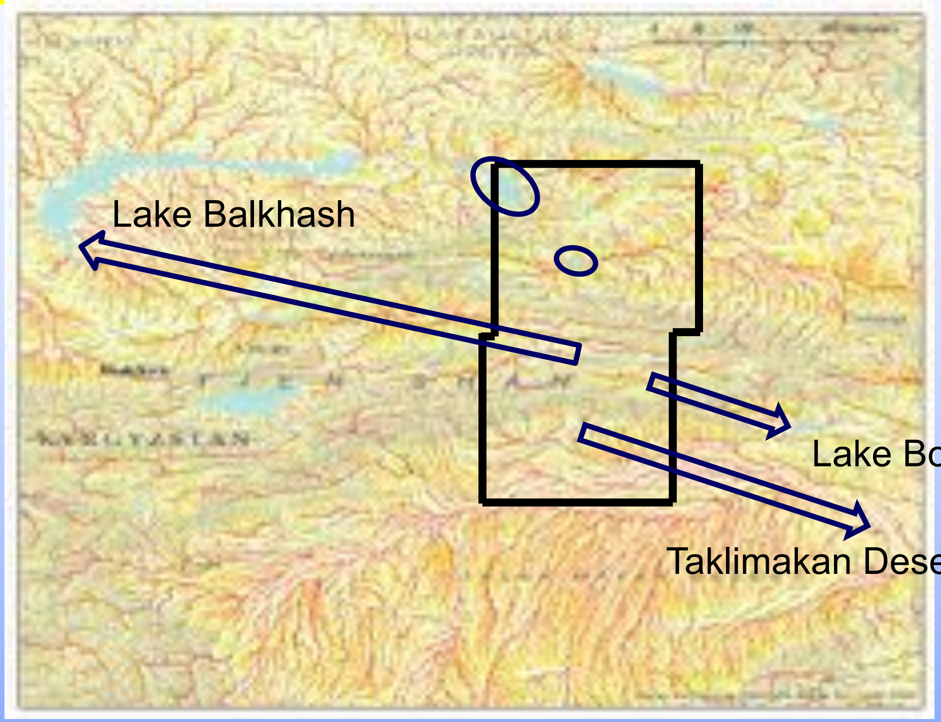
River Runoff from NW China Region

Global Drainage Basins



NW China Region

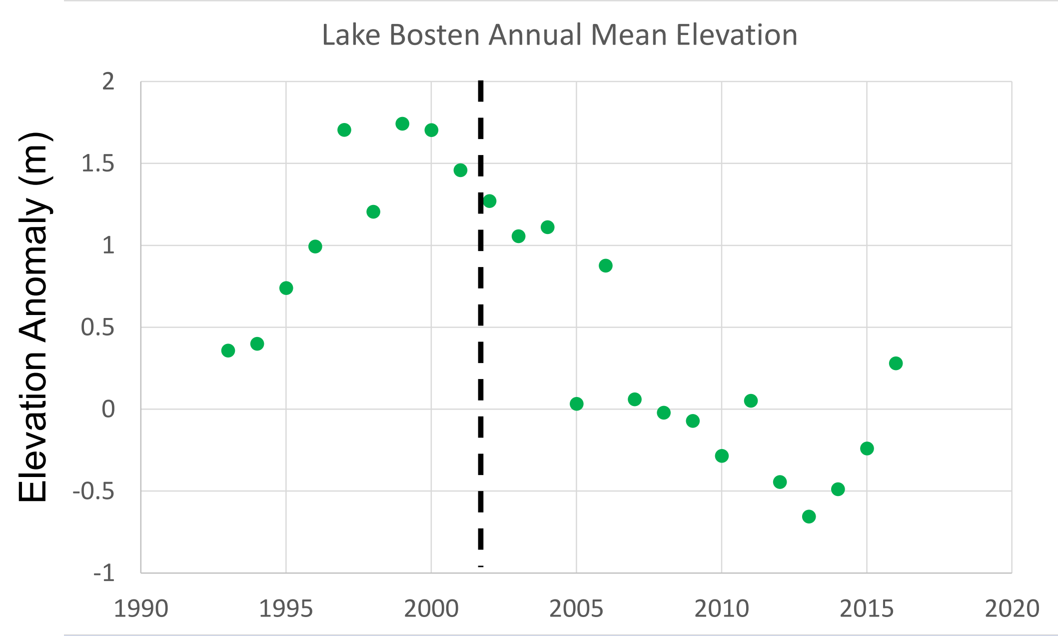
Stream and River Flow

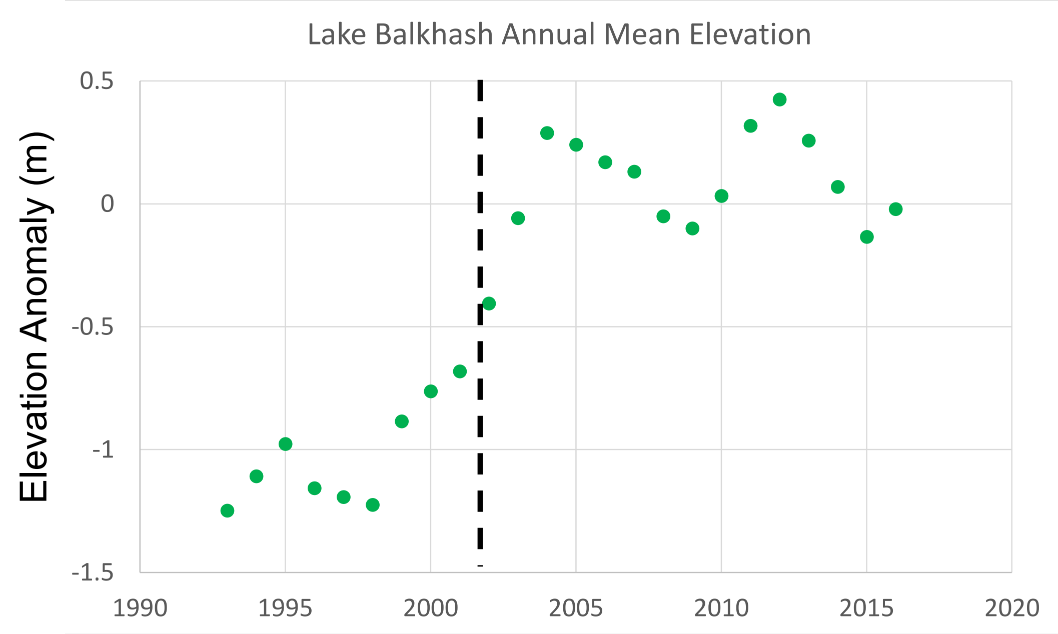


The NW China region lies within an internally draining basin. Water flowing from the region does not go far, yet GRACE detects no substantial TWS gains in adjacent regions.

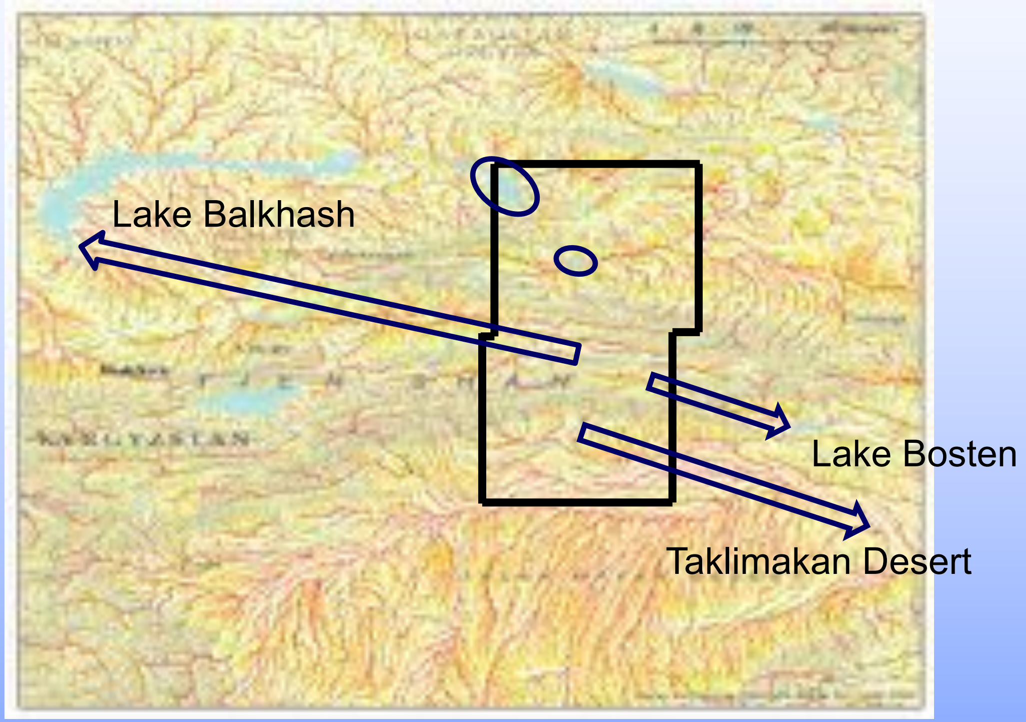
Matthew.Rodell@nasa.gov

Lake Elevation Time Series





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.

Birkett, C., Reynolds, C., Beckley, B., & Doorn, B., 2011: From research to operations: the USDA global reservoir and lake monitor. In *Coastal altimetry* (eds Vignudelli, S., Kostianoy, A. G., Cipollini, P., & Benveniste, J.), Springer, pp. 19-50.

Matthew.Rodell@nasa.gov

Water Use in NW China

Vulnerable watershed. Scientists predict that Balkhash will break up into several small lakes if inputs from the Ili River continue to decline.

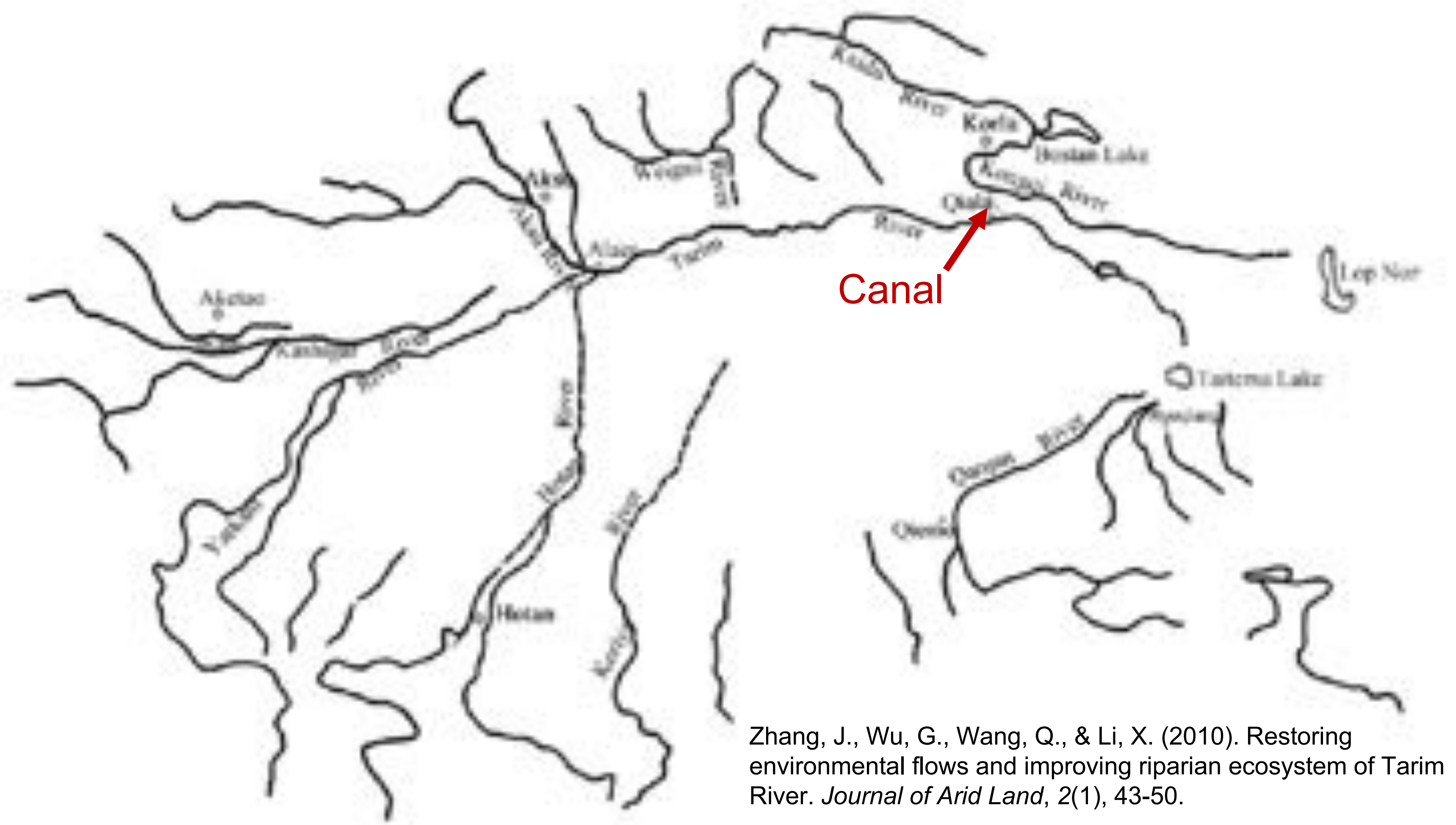
Seven percent of the NW China region is irrigated, and there is evidence that the irrigated area is increasing to support rapid population growth in Xinjiang Province.

Stone, R., 2012: For China and Kazakhstan, no meeting of the minds on water. *Science*, **337** (6093), 405-407.

“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.”

Matthew.Rodell@nasa.gov

Inter-basin Water Transfer from Lake Bosten



Zhang, J., Wu, G., Wang, Q., & Li, X. (2010). Restoring environmental flows and improving riparian ecosystem of Tarim River. *Journal of Arid Land*, *2*(1), 43-50.

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.

Matthew.Rodell@nasa.gov

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.

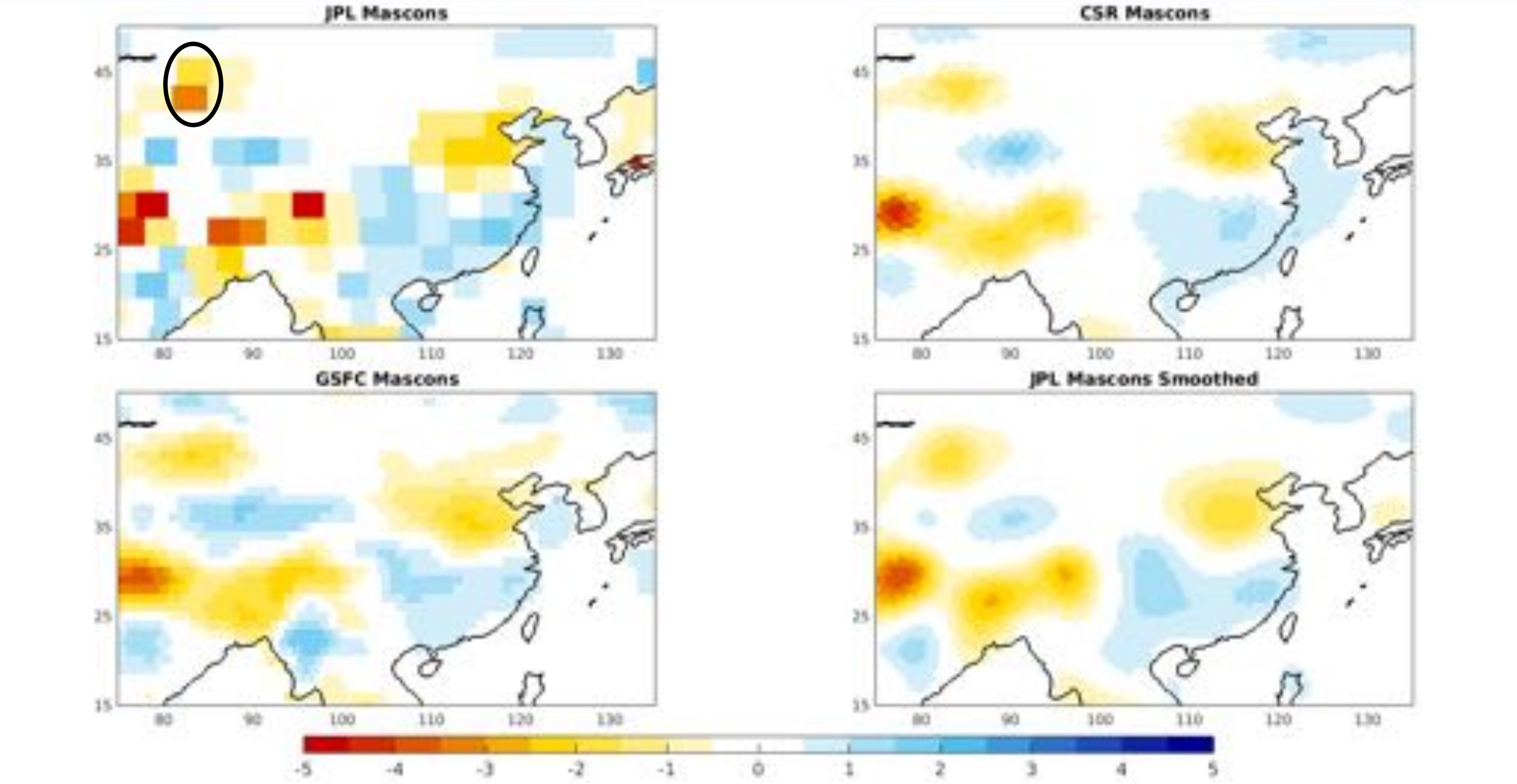
- A paper that describes the details of this study will appear online on May 16:

  Rodell, M., J.S. Famiglietti, D.N. Wiese, J.T. Reager, H.K. Beaudoing, F.W. Landerer, and M.-H. Lo, 2018: Emerging trends in global freshwater availability, *Nature*, in press.

- GRACE Follow On is scheduled to launch on May 19!!!

Matthew.Rodell@nasa.gov

Comparison of Trends in Three Mascon Products



Rate of Change of TWS (cm/yr)

NW China region linear trend estimates

-5.4 Gt/yr	JPL mascon (3°)	-2.2 Gt/yr	CSR mascon (1°)
-1.7 Gt/yr	GSFC mascon (1°)	-2.8 Gt/yr	JPL mascon 200 km smoothed

Matthew.Rodell@nasa.gov