

## **2.d.9 Groundwater and Terrestrial Water Storage**

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Groundwater, soil moisture, surface water, snow, and ice are the components of terrestrial water storage (TWS). On multi-annual timescales groundwater typically controls TWS variability, except in permanently frozen regions (Li et al. 2015). Even on an annual basis TWS changes are a reasonable proxy for groundwater storage changes, the latter being insufficiently observed in most of the world. From 2002 to 2017 the Gravity Recovery and Climate Experiment (GRACE; Tapley et al. 2004) and since 2018 the GRACE Follow On (GRACE-FO) satellite missions have enabled estimation of TWS anomalies (departures from the long-term mean) based on precise observations of variations in Earth's gravity field. To bridge the 11-month gap between GRACE and GRACE-FO we make use of output from a land surface model that assimilates data from both missions (Li et al. 2019).

Plate 2.1 maps the changes in annual mean TWS between 2018 and 2019, as equivalent heights of water in centimeters, based on the data assimilation results. TWS changes reflect integrated hydrometeorological variations, including precipitation, solar radiation, air temperature, and other model forcings. Australia had its warmest year since recordkeeping began in 1910, and it was also a dry year everywhere save for the northeast of the country, contributing to notorious wildfire

damage (see Sidebar 7.X). Central Africa saw TWS gains following two dry years, while Angola and Zambia in southern Africa dried considerably. Conditions were mixed in South America, with drought accompanying heat across south-eastern Brazil, leading to TWS losses in that region, and TWS gains in many other parts of the continent. The effects of heavy precipitation and subsequent record spring and summer flooding in the midwestern United States can be seen in Plate 2.1, as well as a return to normal conditions after a particularly wet 2018 in the East. Near-record heat drove TWS losses across most of Europe despite near-normal precipitation. In Siberia and parts of southeastern Asia, drought caused water storage declines. TWS in Iraq and western Iran, on the other hand, was replenished by increased rainfall.

TWS changes in ice-covered regions have been dominated by ice sheet and glacier losses during the past two decades, to the point that annual hydroclimate must be interpreted from the GRACE and GRACE-FO observations with caution. Hence, TWS changes in Greenland, Antarctica, the gulf coast of Alaska, parts of Patagonia, and most polar islands are omitted here. Despite those omissions, ice losses continue to contribute to the high latitude trends (see Figure 2.d.9.1) and to the global mean, deseasonalized, monthly TWS anomaly time series (Figure 2.d.9.2). Drying across three continents centered near 15°S, as seen in Plate 2.1, is evident in Figure 2.d.9.1, as is wetting just north of that. Most of the NH resumed a long-term drying trend, and, overall, 2019 was near the lower end of the range of global mean TWS since 2002.

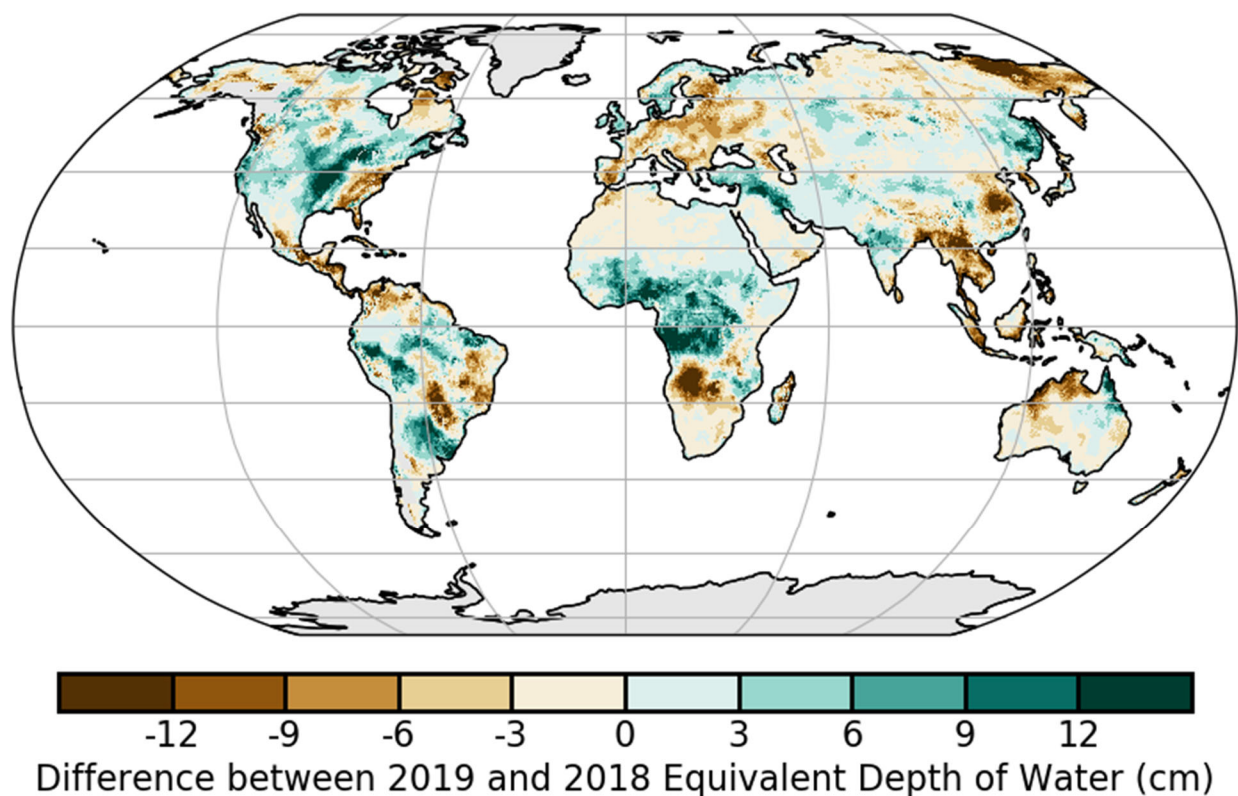


Plate 2.1. Changes in annual-mean terrestrial water storage (the sum of groundwater, soil water, surface water, snow, and ice, as an equivalent height of water in cm) between 2018 and 2019, based on output from a GRACE and GRACE-FO data assimilating land surface model. No data is shown over Greenland, Antarctica, the gulf coast of Alaska, parts of Patagonia, and most polar islands.

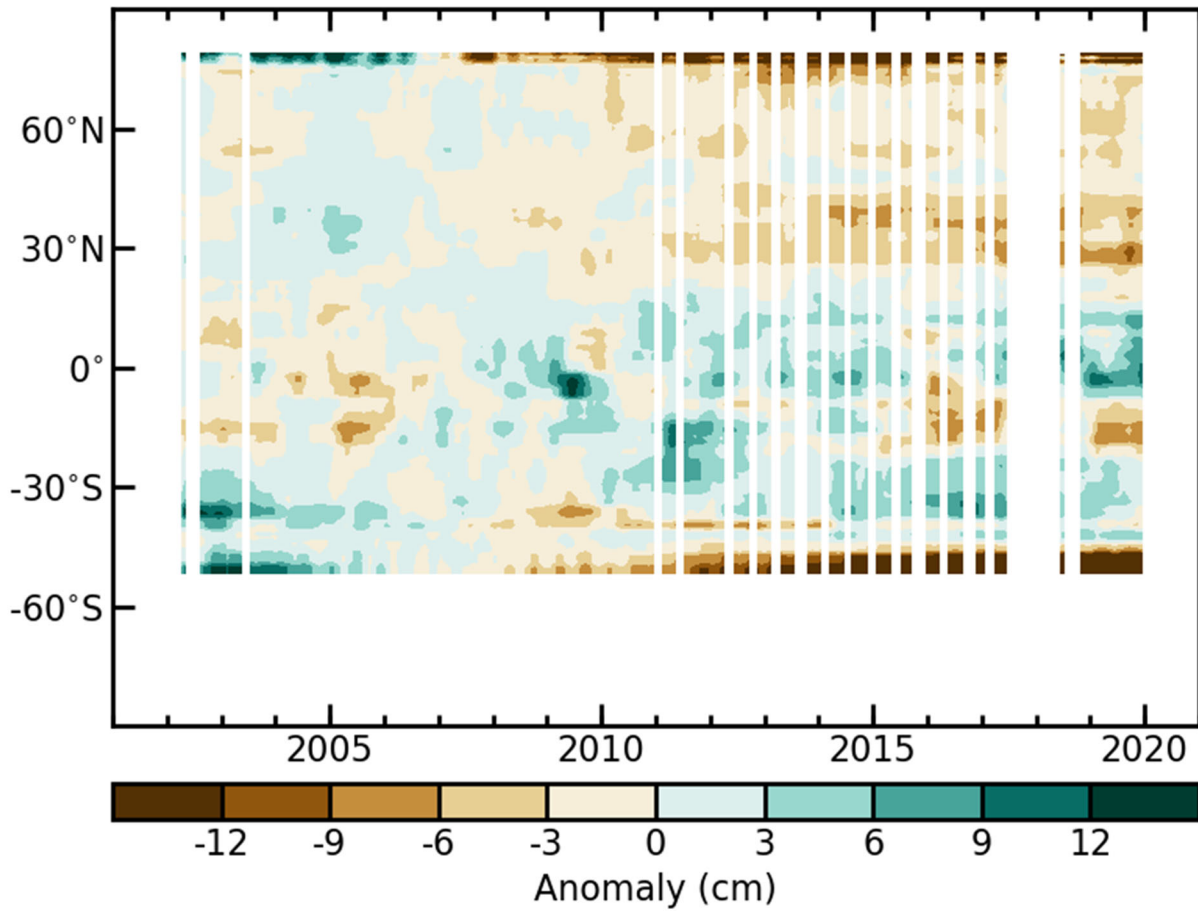


Figure 1.d.9.1. Zonal mean terrestrial water storage anomalies in cm equivalent height of water, based on observations from GRACE (through June 2017) and GRACE-FO (beginning June 2018), excluding the previously identified ice-covered regions. The anomalies are relative to a base period of 2005-10.

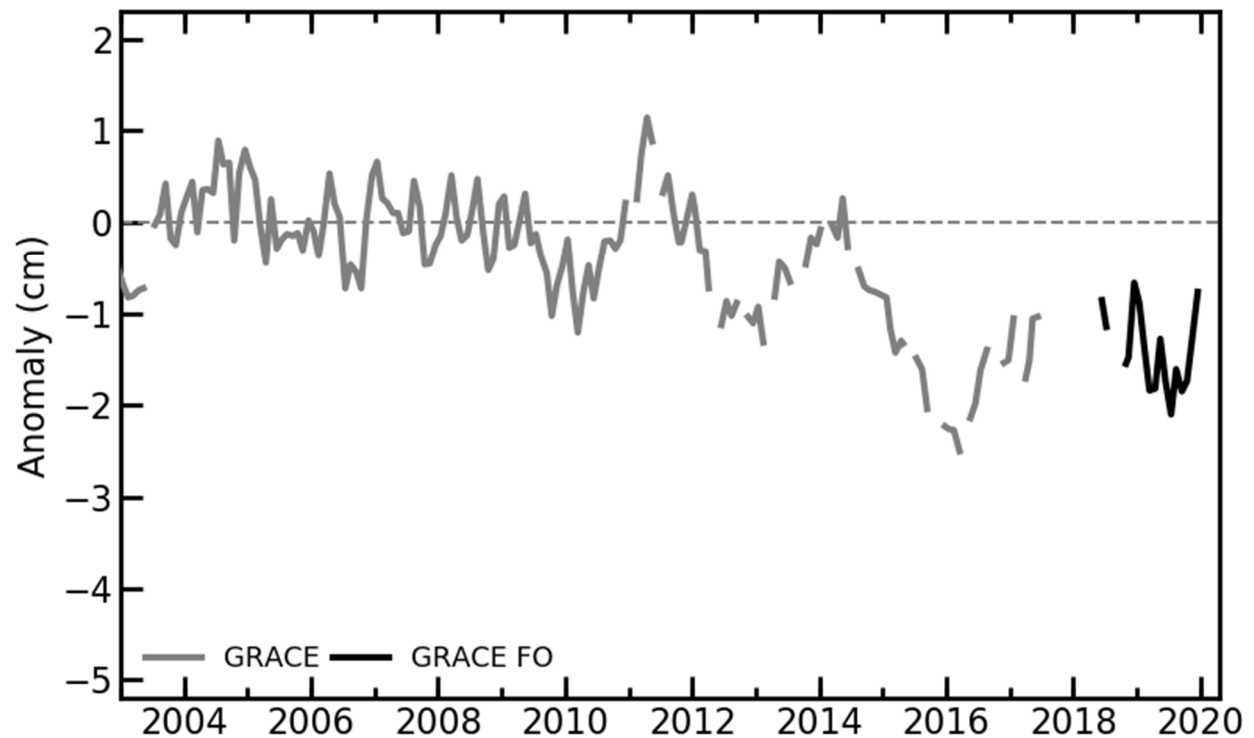


Figure 2.d.9.2. Global average terrestrial water storage anomalies, from GRACE and GRACE-FO, excluding the previously identified ice-covered regions, in cm equivalent height of water relative to a 2005-10 mean baseline.

### References

- Li, B., M. Rodell, and J.S. Famiglietti (2015), Groundwater variability across temporal and spatial scales in the central and northeastern U.S., *J. Hydrology*, 525, 769-780, doi:10.1016/j.jhydrol.2015.04.033.
- Li, B., M. Rodell, S.V. Kumar, H.K. Beaudoin, A. Getirana, B.F. Zaitchik, L.G. Goncalves, C. Cossetin, S. Bhanja, A. Mukherjee, S. Tian, N. Tangdamrongsab, D. Long, J. Nanteza, J. Lee, F. Policelli, I. B. Goni, D. Daira, M. Bila, G. de Lannoy, D. Mocko, and S. C. Steele-Dunne (2019),

Global GRACE data assimilation for groundwater and drought monitoring: advances and challenges, *Water Resour. Res.*, 55, doi:10.1029/2018WR024618.

Tapley, B. D., S. Bettadpur, J. C. Ries, P. F. Thompson, and M. M. Watkins (2004), GRACE measurements of mass variability in the Earth system, *Science*, 305, 503-505.

Watkins, M. M., D. N. Wiese, D.-N. Yuan, C. Boening, and F. W. Landerer (2015), Improved methods for observing Earth's time variable mass distribution with GRACE using spherical cap mascons, *J. Geophys. Res. Solid Earth*, 120, doi:10.1002/2014JB011547.