2.d.8 Groundwater and terrestrial water storage—M. Rodell and D. N. Wiese

Terrestrial Water Storage (TWS; the sum of groundwater, soil moisture, surface water, snow, and ice) reached 20-year highs or lows in several regions in 2022. Changes in mean annual TWS between 2022 and 2021 are plotted in Plate 2.1 as equivalent heights of water (cm). Drought and heat continued to affect southern Europe in 2022, with TWS reaching 20-year lows in the Danube River basin and in the Alps. Drought in western Iran also worsened with another year of large TWS losses (some >9 cm). Above-normal precipitation provided some relief to western Russia, but TWS remained below average. Large increases in TWS (some >12 cm) were seen in Southeast Asia, due in part to the heaviest rain in 60 years falling in southern China in June and Typhoon Noru causing flooding in Vietnam and Laos in September (see section 7g for details). TWS in central and southern India approached 20-year highs as well. Extreme drought struck the Yangtze River basin in the summer of 2022, causing the river to reach record low levels and severely depressing TWS in the region. Southeastern Australia had a very wet year, with multiple episodes of extreme rain and flooding contributing to 20-year high TWS in the Murray-Darling River basin by the end of the year. Conversely, north-central Australia became notably drier (section 7h4). Wet weather caused TWS increases in the northern portion of sub-Saharan Africa and in South Africa, with the latter experiencing record-breaking rainfall in April. Drought affected a large area of south-central Africa centered on Lake Tanganyika, diminishing TWS, yet TWS remained above normal in almost all of sub-Saharan Africa. In North America, dry weather caused TWS declines up and down the U.S. Central Plains, while previously elevated TWS dropped closer to normal levels in the eastern United States. As a result, TWS in the Mississippi River basin dropped to a 20-year low, as water levels in October in the lower Mississippi River itself were the lowest since at least 1988. TWS in the southwestern United

States was nearly unchanged from the low levels in that region in 2021. TWS increased in south-central Canada and decreased in north-central Canada. In South America, eastern Brazil gained a huge amount of water, exceeding 12 cm over a large area, while northern Brazil added to already elevated TWS levels. Much of the western half of the continent's TWS experienced declines due to subpar rainfall.

Figures 2.d.8.1 and 2.d.8.2 depict zonal mean and global mean TWS anomalies, respectively, since April 2002 after removing the seasonal cycle. Data gaps occur during the interim between the GRACE and GRACE-FO missions and when onboard instruments were shut down for various reasons. In addition to excluding from these averages TWS declines associated with ice sheet and glacier losses in Antarctica, Greenland, the Gulf Coast of Alaska, and polar islands (as per Rodell and Wiese 2022), more areas where glacier ablation caused long-term trends in High Mountain Asia, western Canada, and in the southern Andes were also excluded this year. Most notably, 2022 witnessed intensification of both a dry zone between about 25°N and 45°N and a wet zone between about 8°S and 15°N (Fig. 2.d.8.1). The former is attributable to TWS declines in the central and eastern United States, southern Europe, the Caspian Sea and adjacent lands, and eastern China. The latter was caused by TWS gains in eastern Brazil, northern sub-Saharan Africa, southern India, and southeastern Asia. South of that zone of wetness, dryness that began in 2019 or earlier appears to be abating, also owing to TWS gains in eastern Brazil. At the global scale (Fig. 2.d.8.2), TWS, excluding ice sheets and glaciers, fluctuated by about 1 cm throughout the year, remaining stable with respect to 2021 and somewhat low overall.

TWS is a useful indicator of hydroclimatic variability because it reflects the integrated effects of weather over months to years. Groundwater and terrestrial water storage are not well monitored at regional and larger scales using conventional approaches, but the Gravity Recovery and Climate Experiment (GRACE) and GRACE Follow-On (GRACE-FO) satellite missions have provided global, monthly time series of TWS anomalies (departures from the long-term mean) since 2002 (Tapley et al. 2004; Landerer et al. 2020). On a monthly scale, uncertainties are typically around 1 cm–2 cm equivalent height of water over a 500,000 km^2 region at midlatitudes (Wiese et al. 2016). Groundwater typically dominates the interannual variations in TWS except in the wet tropics (dominated by surface water) and high latitude and alpine regions (dominated by ice and snow; Getirana et al. 2017).

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Figures

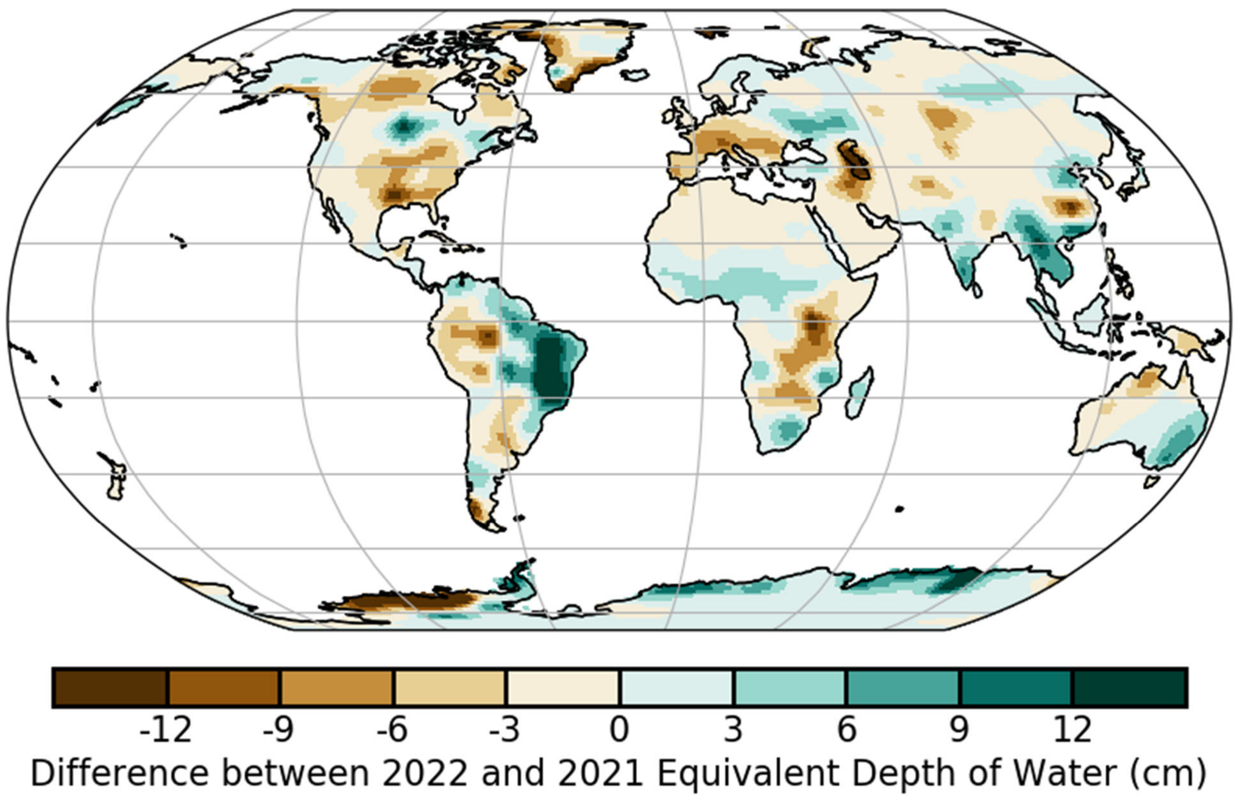

Plate 1. Changes in annual-mean terrestrial water storage (the sum of groundwater, soil water, surface water, snow, and ice, as an equivalent height of water in cm) between 2022 and 2021, based on gravity observations from the GRACE and GRACE-FO satellite missions.

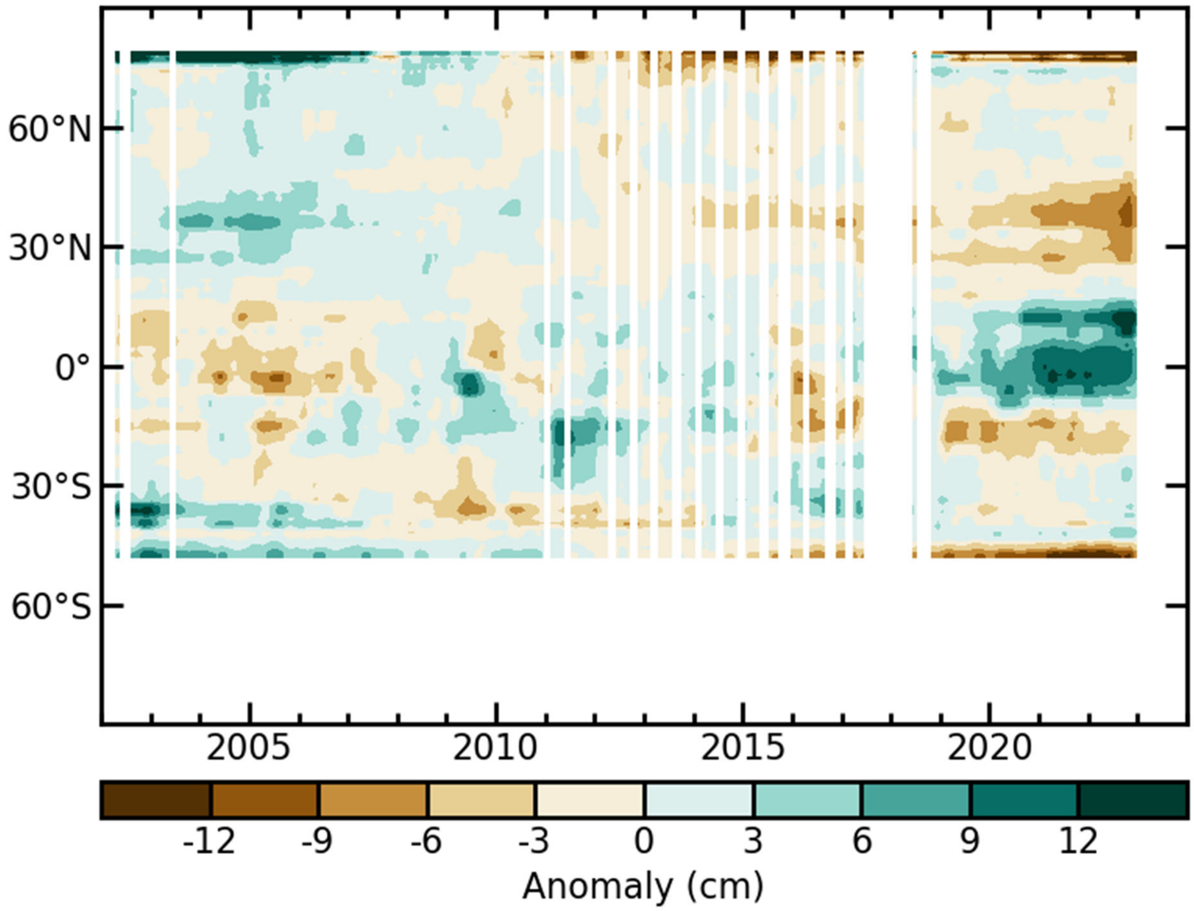

Figure 1. Zonal means of monthly terrestrial water storage anomalies, excluding those in Antarctica, Greenland, the gulf coast of Alaska, polar islands, and major glacier systems, in cm equivalent height of water, based on gravity observations from GRACE and GRACE-FO. The anomalies are relative to a base period of 2003-2020.

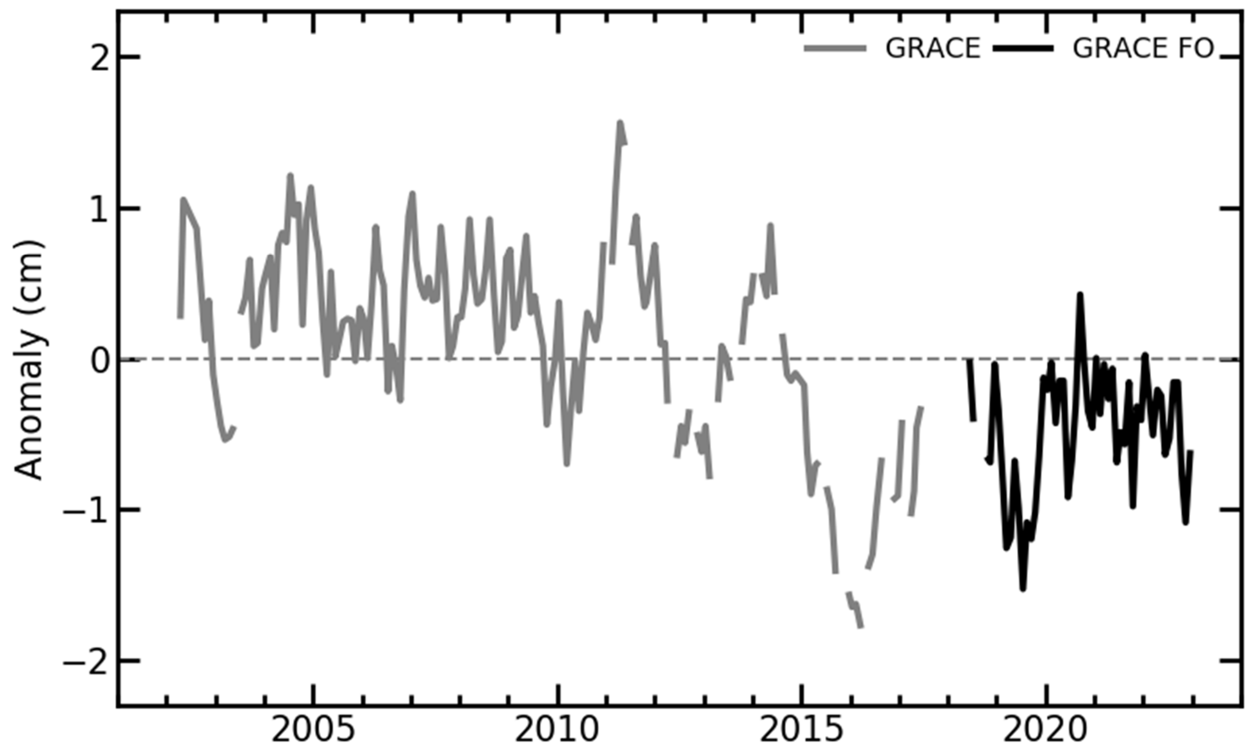

Figure 2. Global average terrestrial water storage anomalies from GRACE (gray) and GRACE-FO (black), in cm equivalent height of water, relative to a 2003-2020 mean baseline.

Datasets used and their URLs

JPL GRACE Mascon Ocean, Ice, and Hydrology Equivalent Water Height RL06 CRI Filtered Version 03. https://podaac.jpl.nasa.gov/dataset/TELLUS_GRAC-GRFO_MASCON_CRI_GRID_RL06.1_V3