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Global water storage trends as observed from the GRACE/-FO G3P product

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With time series ranging over more than twenty years, terrestrial water storage (TWS) variations observed by the Gravity Recovery and Climate Experiment (GRACE, 2002-2017) and GRACE-Follow-On (GRACE-FO, since 2018) missions are providing unique insights into hydrological dynamics, on a global scale. TWS encompasses changes in all water storage compartments, from soil moisture, surface water storage, snow and ice, to groundwater. GFZ operationally provides monthly TWS grids via the GravIS portal (Gravity Information Service, gravis.gfz.de).

Within the G3P project, GFZ recently released a global gravity-based product that includes both TWS variations and also groundwater storage (GWS) variations. GWS is calculated by subtracting the aggregated and filtered storage contributions of the other water storage components, from GRACE/-FO TWS. A challenge for both TWS and GWS is the separation of long-term trends (e.g., resulting from regional human activities and climate change) from stochastic variations as attributable to natural climate variability ("climate noise").

To address this challenge, we introduce an unsupervised trend analysis framework that uses power-law noise models to account for long-range memory in the hydrological time series under investigation. This approach requires minimal assumptions about the underlying processes and provides a robust method for separating long-term trends from stochastic variability. By addressing the limitations of existing methods, such as underestimated uncertainties and simplified noise representations, our framework allows for accurate quantification of trend magnitudes and of their significance. Firstly, this is confirmed for TWS, by comparing reported trends to our detected trends. Concerning the GWS product, we observe that anthropogenic depletion of groundwater is a primary driver of freshwater decline. Furthermore, we reveal previously unobserved trends, including increasing groundwater levels in parts of Africa and declining trends in central and eastern Europe. We also demonstrate how the presented method identifies potential false-positive trends, which enhances the reliability of trend detection. This

scalable approach for trend analyses is currently extended to integrate uncertainties that arise from measurement system uncertainties, enhancing its applicability to other essential climate variables.