EGU General Assembly 2020

EGU2020-20485, updated on 19 Oct 2021
https://doi.org/10.5194/egusphere-egu2020-20485
EGU General Assembly 2020

Climate-groundwater dynamics inferred from GRACE and the role of hydraulic memory

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Groundwater is the largest store of freshwater on Earth after the cryosphere and provides a substantial proportion of the water used for domestic, irrigation and industrial purposes. Knowledge of the relationship between groundwater and climate is limited and undermined by the scale, duration, and accessibility of observations. Here we examine a 14-year period (2002-2016) of GRACE observations to investigate climate-groundwater dynamics of 14 tropical and sub-tropical aquifers selected from WHYMAP's 37 large aquifer systems of the world. GRACE-derived changes in groundwater storage resolved using GRACE JPL Mascons and the CLM Land Surface Model are related to precipitation time series and regional-scale hydrogeology. We show that aquifers in dryland environments exhibit long-term hydraulic memory through a strong correlation between groundwater storage changes and annual precipitation anomalies integrated over the time series; aquifers in humid environments show short-term memory through strong correlation with monthly precipitation. This classification is consistent with estimates of Groundwater Response Times calculated from the hydrogeological properties of each system, with long (short) hydraulic memory associated with slow (rapid) response times. The results suggest that groundwater systems in dryland environments may be less sensitive to seasonal climate variability but vulnerable to long-term trends from which they will be slow to recover. In contrast, aquifers in humid regions may be more sensitive to seasonal climate disturbances such as ENSO-related drought but may also be relatively quick to recover. Exceptions to this general pattern are traced to human interventions through groundwater abstraction. Hydraulic memory is an important factor in the management of groundwater resources, particularly under climate change.