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Research papers

GRACE reveals depletion of water storage in northwestern South America between ENSO extremes

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ABSTRACT

Dynamics of terrestrial water storage are determinant for many natural and social phenomena, with implications for water security and environmental sustainability. Here we use 2002–2017 data from the Gravity Recovery and Climate Experiment (GRACE) to study these dynamics in the Magdalena-Cauca river basin in northwestern South America. Through comparison with water balance-based estimates we assess the performance of multiple GRACE products in representing water storage dynamics in the basin, identifying the Mascon product from the Jet Propulsion Laboratory as the best suited for further analysis. We then investigate the existence of long term trends and show that terrestrial water storage in general and groundwater storage in particular have been gradually depleting in the basin since around the end of 2010. GRACE data reveal that this trend is not uniform across the basin but exhibits a clear-cut pattern in which the water depletion rate is more pronounced in the lower parts of the basin than it is in the upper basin. We explore the mechanisms behind the identified temporal trends and spatial patterns and show that water storage depletion largely coincides with a period between the La Niña and El Niño extreme phases of ENSO. Likewise, the pronounced contrast between depletion rates in the lower and higher parts of the basin largely coincides with marked biophysical differences between these regions, including the presence of major wetland systems in the lowlands, and the highlands of the Andean mountains.

1. Introduction

Many natural and social phenomena depend on the dynamics of terrestrial water storage, which plays a major role in the Earth's climate system through its effect on the global water, energy, and biogeochemical cycles (Famiglietti, 2004; Huang et al., 2013; Long et al., 2017; Yang et al., 2017; Salazar et al., 2018). The dynamics of terrestrial water storage are, however, sensitive to global change and understanding how and why these dynamics are changing in different regions of the world is critical to water resources management in river basins and the assessing of present and future water security (Voss et al., 2013; Long et al., 2014); and is recognized as a fundamental problem of the hydrological sciences in the Panta Rhei context (Montanari et al., 2013; Rodriguez et al., 2018).

A first order explanation of these dynamics is given by the water balance equation,

$$\frac{dS}{dt} = P - E - Q, \tag{1}$$

which, for a river basin, determines that temporal variations in terrestrial water storage (dS/dt) depend on the differences between input fluxes of precipitation (P) and output fluxes of evapotranspiration (E) and river discharge (Q). Here S includes all components of water storage at the surface (e.g. water bodies, soil moisture, and snow) and beneath it (groundwater).

Estimation of dS/dt for any given region is challenging, especially when hydrological data is scarce or unavailable (e.g., Voss et al., 2013; Ouma et al., 2015; Hassan and Jin, 2016). Monitoring wells provide precise but generally scattered (in space and time) data of groundwater level that can be used to estimate variations in groundwater storage (e.g., Nanteza et al., 2016; Huang et al., 2013). Observations of soil moisture, snow, and surface water provide additional means to directly estimate different components of total water storage. The water balance equation (Eq. (1)) allows for the estimation of dS/dt indirectly through estimates of fluxes P, E, and Q. Though this is not trivial for large river basins, it can be accomplished through combining multiple observational techniques (e.g. gauging networks and remote sensing) and

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