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GRACE Groundwater Drought Index: Evaluation of California Central Valley groundwater drought

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ABSTRACT

Quantitative approaches to assess the complexity of groundwater drought are hindered by the lack of direct observations of groundwater over space and time. Here, we present an approach to evaluate groundwater drought occurrence based on observations from NASA's Gravity Recovery and Climate Experiment (GRACE) satellite mission. Normalized GRACE-derived groundwater storage deviations are shown to quantify groundwater storage deficits during the GRACE record, which we define as the GRACE Groundwater Drought Index (GGDI). As a case study, GGDI is applied over the Central Valley of California, a regional aquifer undergoing intensive human activities and subject to significant drought periods during the GRACE record. Relations between GGDI and other hydrological drought indices highlight our ability to capture drought delays unique to groundwater drought. Further, GGDI captures characteristics of groundwater drought that occur as a result of complex human activities and natural changes, thus presenting a framework to assess multi-driver groundwater drought characteristics.

1. Introduction and background

By the end of 2015, the prolonged and well-documented drought in California, recognized as starting in 2012 (Griffin and Anchukaitis, 2014), had reached historically unprecedented conditions. The Palmer Drought Stress Index (PDSI) (Palmer, 1965), a commonly used index to evaluate drought based on a simple water budget model (Alley, 1984), identified June and July of 2014 as having the two lowest indices in the Central Valley of California, where records date from 1900 to present, while the spring of 2015 exhibited PDSI values in the lowest 95% quantile (Fig. S1). Equally severe deficits were documented in the Standardized Precipitation Index (McKee et al., 1993) (Fig. S1). A comparison between drought indices and streamflow reconstruction further illustrates the historic nature of the drought, which potentially represents the worst California drought in the last 1200 years (Griffin and Anchukaitis, 2014). The prolonged drought, attributed to a persistent upper level weather dipole (Wang et al., 2014), resulted in a cascade of impacts affecting rangelands (Larsen et al., 2014), forests (Baguskas et al., 2014; Asner et al., 2016), agriculture and socioeconomics (Howitt et al., 2014) and groundwater (Faunt et al., 2015).

The term drought, used ambiguously above, refers to prolonged dryness manifesting itself in various water deficits including meteorological (precipitation), hydrological (streamflow), agricultural (soil moisture), socioeconomic and groundwater (Dracup et al., 1980; Mishra and Singh, 2010). Drought is largely driven by a change in climatic forcing, for example decreases in precipitation, which develop slowly and can last months to years (Tallaksen and van Lanen, 2004; Tallaksen et al., 2009). The lack of a formal definition of drought (Wilhite et al., 2007) combined with the difficulty in investigating its precursors have resulted in compartmentalized drought indices (for example, hydrological drought: PDSI; meteorological drought: SPI; groundwater drought: SGI (Bloomfield and Marchant, 2013)). Recent studies have sought to evaluate integrated drought indices (Hao and AghaKouchak, 2014; Hao et al., 2014; Ma et al., 2014). Thomas et al. (2014) developed a framework to evaluate a holistic drought characterization using data from the Gravity Recovery and Climate Experiment (GRACE) satellites, focusing on the total water storage deficits to characterize drought occurrence.

As the effect of drought cascades from meteorological to hydrological to agricultural drought, groundwater storage may be impacted

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