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Terrestrial water storage changes over the Pearl River Basin from GRACE and connections with Pacific climate variability

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ABSTRACT

Time-variable gravity data from the Gravity Recovery and Climate Experiment (GRACE) satellite mission are used to study terrestrial water storage (TWS) changes over the Pearl River Basin (PRB) for the period 2003–Nov. 2014. TWS estimates from GRACE generally show good agreement with those from two hydrological models GLDAS and WGHM. But they show different capability of detecting significant TWS changes over the PRB. Among them, WGHM is likely to underestimate the seasonal variability of TWS, while GRACE detects long-term water depletions over the upper PRB as was done by hydrological models, and observes significant water increases around the Longtan Reservoir (LTR) due to water impoundment. The heavy drought in 2011 caused by the persistent precipitation deficit has resulted in extreme low surface runoff and water level of the LTR. Moreover, large variability of summer and autumn precipitation may easily trigger floods and droughts in the rainy season in the PRB, especially for summer, as a high correlation of 0.89 was found between precipitation and surface runoff. Generally, the PRB TWS was negatively correlated with El Niño-Southern Oscillation (ENSO) events. However, the modulation of the Pacific Decadal Oscillation (PDO) may impact this relationship, and the significant TWS anomaly was likely to occur in the peak of PDO phase as they agree well in both of the magnitude and timing of peaks. This indicates that GRACE-based TWS could be a valuable parameter for studying climatic influences in the PRB.

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1. Introduction

The Pearl River is the third largest river in terms of drainage area and has the second largest streamflow in China. Due to its importance to the social-economic development of China, many studies [1–9] have been conducted for water security concerns in the Pearl River Basin (PRB), e.g., rainfall regimes, drought and wetness, evapotranspiration, atmospheric water vapor, water discharge and sediment load. Among them, Zhang et al. [3] found that the PRB trends to be dryer in the rainy season and wetter in winter, and moisture content is one among many factors acting on the dry or wet conditions of the basin. Moreover, increased rainfall variability and frequencies of extremely high/low rainfall events related to the weakening Asian monsoon [4] as well as the frequencies of short wet periods with increased total amount of precipitation [1] potentially increase the risk of floods and droughts over the PRB. Furthermore, decreasing evapotranspiration result mainly from increasing aerosol and intensifying urbanization may weaken the hydrological cycle in the basin [2]. These studies have been valuable for the characterization of the PRB's hydrological regime. However, recent strong anthropogenic influences, such as damming effects by the Longtan Reservoir (LTR), have significantly impacted the hydrological cycle of the PRB [8]. In addition, the upper and mid-PRB is formed primarily by a karst geological environment with strong heterogeneities [10,11], making it a great challenge to monitor and simulate water variations in these areas. Therefore, a combination of precipitation and other datasets (e.g., satellite observations and hydrological models) would be beneficial for a more comprehensive analysis.

The twin Gravity Recovery and Climate Experiment (GRACE) satellite mission, a project jointly sponsored by the National Aeronautics and Space Administration (NASA) and the German Aerospace Center (DLR), was launched in March 17, 2002. The spatial-temporal change of the Earth gravity fields mapped by the GRACE satellite provides information directly related to the mass redistribution at or near the surface of the Earth, e.g., changes in terrestrial water storage (TWS), ocean, polar ice sheets and mountain glaciers [12]. Particularly, hydrological applications would be the largest contribution of GRACE among many related studies [13] since TWS changes associated to climate variability and change play a crucial role in regional and global hydrological cycles and water management. GRACE-derived TWS changes, including changes in surface water, soil moisture, groundwater, snow and ice, have been widely used to investigate water balance in many river basins, especially for drought and flood assessment. Examples include the Amazon Basin [14,15], the Yangtze River Basin [16,17], the Mississippi River Basin [18], the Murray Darling Basin [19] and the Nile Basin [20].

In the present study, GRACE-based TWS, in combination with precipitation and in situ water level data of the LTR, along with outputs from two hydrological models: the Global Land Data Assimilation System (GLDAS) and the WaterGAP Global Hydrology Model (WGHM) are used to investigate water variations over the PRB. Possible teleconnections with Pacific climate variability are analyzed by using indices of El Niño-Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO). The objective of this study is to assess the related impacts of human intervention and climate variability on water resources within the PRB.

2. Study region

The PRB ranges from 97°39′E–117°18′E and 3°41′N–29°15′N with an area of ~442,000 km^2 located in China (Fig. 1). In addition to the uneven spatio-temporal precipitation distribution, approximately 80% of the total discharge concentrates in the rainy season (April–September) [4]. The climate is mainly influenced by the eastern Asian monsoon and typhoons as well as the topographic features [9]. Many dams (data available at http://www.fao.org/nr/water/aquastat/dams/index.stm) have been built for irrigation and hydroelectricity. Among them, the LTR which is the second largest dam in China, was built at the midstream of the PRB, Guangxi Province. At its first stage of water impoundment from September 2006 to the end of 2009, the water level reached 375 m with a total storage capacity of 16.2 km^3. This artificial water impoundment has strongly influenced water variations in the PRB [8].

3. Data and methods

3.1. GRACE data

The latest release of CSR RL 05, GFZ RL 05a and GRGS RL03 data for the period 2003 to Nov. 2014 were used to derive TWS for the PRB. GRGS is a regularized solution and no further filtering is required [21]. Both of the CSR and GFZ data were processed following the methods of [22] to obtain monthly TWS anomalies. Firstly, degree-2 zonal C20 time series were replaced by analyzed Satellite Laser Ranging (SLR) data [23]. A hybrid filtering scheme combined de-correlation filter P3M6 [24] and 300 km Fan filter was then employed to reduce noise [25]. A regional scaling factor of 1.48 computed by applying the same filtering techniques (except for de-correlation) to GLDAS-based TWS [26] was obtained to recover the lost signal due to truncation of the gravity coefficients and filtering for both of CSR and GFZ TWS. This scaling factor is close to the value of 1.35 derived from the Community Land Model v4.0 provided by the GRACE Tellus