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Examining water storage variations as a function of meteorology using GRACE and GLDAS

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The Upper East Region (UER) of Ghana, located between 10.2–11.2°N, 1.6°W–0.03°E, is characterised by a long dry season and annual floods that are exacerbated by the opening of the Bagre Dam in neighbouring Burkina Faso. The UER lies within the Volta Basin, which has been the subject of numerous hydrological studies. The basin spans several jurisdictions with varying meteorological conditions; thus, basin-wide studies may not truly reflect localised dynamics of water storage over the UER. Data from the Gravity Recovery and Climate Experiment (GRACE) mission and hydrological models, e.g., the Global Land Data Assimilation System (GLDAS), have been used for hydrological studies. Nonetheless, GRACE's resolution may restrict its application to large areas (≥150,000 km^2) or smaller areas with storage variations of ≥8 km^3, while GLDAS does not model surface water. With this in mind, this research evaluates GRACE and GLDAS for water storage analysis over the UER (~9000 km^2).

We used the latest mass concentration solution from the Centre for Space Research, GLDAS-NOAH, and the Global Precipitation Measurement (GPM) from April 2002 to June 2017. The long-term mean (2004–2009) was removed from GPM and NOAH. The GRACE time series was characterised by an increasing trend in terrestrial water storage anomalies (TWSA) (6.2 mm/yr), annual and semi-annual amplitudes of 99.4 mm and 10.5 mm, and annual and semi-annual phases of 39.1° and 13.6°, respectively. The minimum variation (-150.8 mm, -47.4 km^3) in TWSA occurred in May 2003, while the maximum (222.3 mm, 69.9 km^3) occurred in September 2012, both of which are during the rainy season. Rainfall anomalies showed a declining trend at a rate of 0.25 mm/yr. A Pearson correlation coefficient (r) between rainfall and TWSA revealed a low r = 0.30 (p-value << 0.01). Conversely, time-lagged r = 0.60, one and two months after rainfall. The largest (r = 0.66) occurred two months after rainfall. NOAH-based evapotranspiration anomalies (ETA) indicated a slow, but increasing, trend (0.4 mm/yr). Furthermore NOAH-derived TWSA underestimated storage, yielding a rate of decline of 2.1 mm/yr, which could be due to unmodelled surface water. However, NOAH-derived TWSA were comparatively strongly correlated with rainfall (r = 0.69 and 0.87 at lags 0 and 1). As rainfall is the only source of input to the water balance equation and as rates of ETA suggest conditions in the UER support water loss, these results may indicate a strong contribution to TWSA from the yet unmodelled water from the Bagre Dam.

This study was the first to investigate the impact of meteorological conditions on water availability in the UER using GRACE and GLDAS. The results show that GLDAS-NOAH underestimated storage, and that TWSA increased, although this increase is not entirely explained by rainfall. Subsequent experiments will incorporate the contribution of water from the Bagre Dam as well as other meteorological data (e.g., wind speed, humidity) to better explain the differences in those parameters and fully characterise the impact of meteorological conditions on water availability in the UER.