Hydrological consistency in the Okavango basin: comparison between GRACE solutions, GPS records and hydrological modelling

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Abstract

In their 14 years of record, GRACE satellites revealed in austral Africa a broad area of major variations in the Earth's gravity field, located all over the Okavango-Zambezi basin. The GRACE signal not only shows a high annual amplitude, up to 50 cm of Equivalent Water Height (EWH), but also a pluri-annual trend with an increase until 2012 of about 50 cm of EWH and a dicrease since then. The comparison between the deformation of the Earth's surface modelled from this data set and the observed deformation of the surface measured from the geodetic network deployed in 2010 shows a strong correlation.

As in many other regions of high hydrological variations, this correlation allows the validation of the interpretation of the GRACE signal in terms of annual variation of EWH over the whole austral Africa. In this poorly monitored area, where almost no piezometric record is available, GRACE solutions now provide a reliable proxy for Terrestrial Water Storage (TWS). This proxy is then used to validate a hydrological model for the Okavango basin, a vital tool for the management of water ressources over the three developing countries hosting the basin.

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A major limitation of GRACE solutions is their spatial resolution of ~300 km. Despite its irregular and loose cover, the geodetic network can be in turn used to better constrain GRACE resolution. Most of the GRACE solutions distribute the variation of TWS all across the subcontinent. But the analysis of the spatial variability of the annual amplitude and phase in both horizontal and vertical displacement observed by the GPS stations allows to narrow the location of the main variation of TWS to the Upper Zambezi. This conclusion is corroborated by several geomorphological markers related to intense circulation of groundwater.

Regarding, the pluri-annual trend, GRACE solutions could be impacted more efficiently by processes in the deeper Earth such as an uplifting asthenosphere, which can similarly impact the GPS time series. This possibility calls into question the reliability of the satellites records to monitor TWS over several years. The shift in the regime of the hydrological basins, from recharge to discharge, is sometimes interpreted as a failure to disentangle geodynamic and a hydrological contributions. In the Okavango basin, the hydrological model, providing reliable simulations for the discharge of the river over the past 80 years of the corresponding hydrological chronicle, shows for TWS the same trends than the GRACE signal. The peak reached in TWS in 2012 is also revealed by the variations in the river discharge. As no major anthropogenic development occurred in the catchment area, GRACE satellites here actually managed to record the natural cyclic behavior of the hydrological system, predicted by modelling.
Finally, the geodetic network also allowed to reveal the very low rate of tectonic movements in the area. This contradicts the former geodynamic model in the region, predicting a strong deformation based on a supposed propagation of the African Rift Valley. A thorough review of the recent geophysical studies also highlights the very tectonically stable area. Thus, in case of a geodynamic contribution to the GRACE and GPS signals, this would remain far too moderate to be perceptible in the geodetic signals and GRACE solutions can be reliably inverted in EWH in the Upper Zambezi and Okavango basins.