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Satellite-based estimates of surface water dynamics in the Congo River Basin

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ABSTRACT

In the Congo River Basin (CRB), due to the lack of contemporary *in situ* observations, there is a limited understanding of the large-scale variability of its present-day hydrologic components and their link with climate. In this context, remote sensing observations provide a unique opportunity to better characterize those dynamics. Analyzing the Global Inundation Extent Multi-Satellite (GIEMS) time series, we first show that surface water extent (SWE) exhibits marked seasonal patterns, well distributed along the major rivers and their tributaries, and with two annual maxima located: i) in the lakes region of the Lwalaba sub-basin and ii) in the “Cuvette Centrale”, including Tumba and Mai-Ndombe Lakes. At an interannual time scale, we show that SWE variability is influenced by ENSO and the Indian Ocean dipole events. We then estimate water level maps and surface water storage (SWS) in floodplains, lakes, rivers and wetlands of the CRB, over the period 2003–2007, using a multi-satellite approach, which combines the GIEMS dataset with the water level measurements derived from the ENVISAT altimeter heights. The mean annual variation in SWS in the CRB is 81 ± 24 km^3 and contributes to 19 ± 5% of the annual variations of GRACE-derived terrestrial water storage (33 ± 7% in the Middle Congo). It represents also ~6 ± 2% of the annual water volume that flows from the Congo River into the Atlantic Ocean.

1. Introduction

Despite its importance, the Congo River Basin (CRB, acronym glossary is given in Appendix A1), located in the central region of Africa, has not attracted as much attention among the climate and hydrology communities as has the Amazon Basin or other large rivers in the world (Alsdorf et al., 2016). Up to now, there is still an insufficient knowledge of the regional hydro-climatic characteristics and changes in this region, even though the CRB plays a crucial role at global and regional scales. Firstly, the CRB is remarkable as the second largest river system of the world in terms of both water discharge, with a mean annual flow of ~40,600 m^3/s, and drainage basin size (~3.7 × 10^6 km^2) (Laraque et al., 2001, 2009). It also plays a key role in the Earth system as one of the three main convective centers in the Tropics, with the Amazon River basin and the ‘maritime continent’ of Eastern Indian and western tropical Pacific Oceans (Hastenrath, 1985). Secondly, more than 80% of people in the CRB live exclusively on activities that are highly dependent on climate and water resource availability: fisheries, agriculture and livestock (Bele et al., 2010). In this region, the food production depends heavily on rain-fed agriculture, leading the population particularly vulnerable to food insecurity (Brown et al., 2014). Moreover, a couple of studies have shown that the CRB has already experienced changes in climate variability and in the hydrological system (Mahé and Olivry, 1999; Camberlin et al., 2001; Laraque et al., 2001; Samba et al., 2008; Samba and Nganga, 2012). Thirdly, about 50% of the CRB land area is covered by tropical forest (~190 10^6 ha, Verhegghen et al., 2012), representing about 18% of the world’s tropical forests (~1100 10^6 ha, Achard et al., 2002), and playing a crucial role as a sink of CO_2, storing about 50 billion tons of carbon (Verhegghen et al., 2012). In a recent study, Dargie et al., (2017) highlighted that the “Cuvette Centrale” peatland (Fig. 1) stores about 30 billion tons of carbon. This total amount of carbon is

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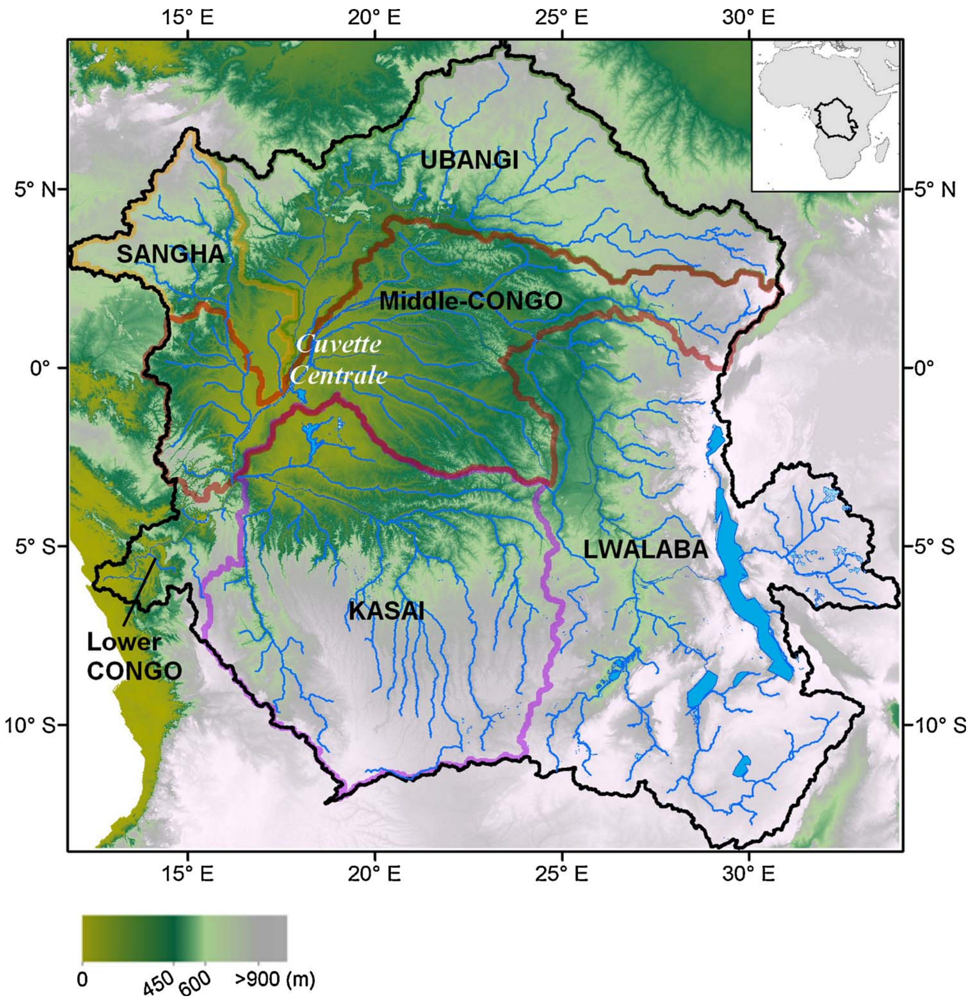

Fig. 1. The Congo River Basin: topography and the major sub-catchment areas.

equivalent to ~80 billion tons of CO_2 or about 2.3 years of current global anthropogenic emissions (~35 billion tons in 2015, Olivier et al., 2016). This stock is particularly vulnerable to land-use change and any future change in the water cycle. For all these reasons, there is an obvious need to better understand the CRB dynamic and to characterize its vulnerability to climate change and other crucial challenges. In particular, it is necessary to gain solid knowledge about the past and current hydro-climate processes of the CRB, in order to significantly reduce the uncertainties associated with future climate response under global warming. The limited understanding of the CRB's hydro-climate processes results mainly from the lack of *in situ* data availability: the network of stations, which data are publicly released, is sparse and poorly maintained, and it is substantially difficult of perform fieldwork, notably in the swamps. However, recent developments and improvements in remote sensing technology provide more observations than ever before (Alsdorf et al., 2007; Prigent et al., 2016) and allow us the unique opportunity to better understand the spatial and temporal variability of the CRB's hydro-climatic patterns.

In this study, our primary focus is on the CRB surface water (SW) dynamics, a key component of the land water budget equation. The SW, corresponding to water stored in rivers, lakes, wetlands, floodplains and in man-made reservoirs, is crucial to the survival of all living organisms, including humans and is a precious resource in term of biodiversity, ecology, water management and economy. Moreover, SW storage (SWS) plays a major role at all scales in the terrestrial water balance and in the Earth's climate system variability, through its interactions with the atmosphere and ocean. Up until now, the spatial and temporal dynamics of SW stored on the Earth's surface remains still largely unknown (Alsdorf et al., 2007). Since the last decades, progresses in satellite remote sensing are improving substantially our understanding of SW dynamics in the major river basins of the world. Among these derived-products, radar altimetry is providing since the early 1990s a monitoring of water levels variations of lakes, rivers, floodplains and reservoirs (Birkett, 1995; Crétaux and Birkett, 2006; Calmant et al., 2008). Additionally, it is possible to extract locally the extent of water bodies using satellite imagery, which, combined with altimetry data, enable the SWS estimation of lakes and reservoirs (Baup et al., 2014; Crétaux et al., 2016) and of floodplains (Frappart et al., 2005). More recently, merging information derived from active and passive microwave sensors and from optical data, the Global Inundation Extent from Multi-Satellite (GIEMS) dataset (Prigent et al., 2007; Papa et al., 2010; Prigent et al., 2016) offers unprecedented information on the variations of SW extent (SWE) at the global scale. The combination of GIEMS estimates with radar altimetry observations has further allowed the provision of spatio-temporal variations of SWS in large tropical river basins, such as the Amazon, Ganges–Brahmaputra and Orinoco basins (Frappart et al., 2008, 2010, 2012, 2015b; Papa et al., 2015). Recently, a few studies tried to understand the SW dynamics in the CRB using remote sensing and/or modeling (Rosenqvist and Birkett, 2002; Bwangoy et al., 2010; Jung et al., 2010; Beighley et al., 2011; Lee et al., 2011; Tshimanga et al., 2011; Tshimanga and Hughes, 2012; O'Loughlin et al., 2013; Becker et al., 2014; Betbeder et al., 2014; Lee et al., 2014, 2015). For instance, Rosenqvist and Birkett (2002) demonstrated that Synthetic Aperture Radar (SAR) image mosaics can be used to appraise the maximum extents of flooding in the CRB, but were not relevant to assess the SW dynamics and ranges of the variations.