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Potential of satellite rainfall products to predict Niger River flood events in Niamey

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ABSTRACT

A dramatic increase in the frequency and intensity of flood events in the city of Niamey, Niger, has been observed in the last decade. The Niger River exhibits a double outflow peak in Niamey. The first peak, is due to the rainfall occurring within about 500 km of Niamey. It has reached high values in recent years and caused four drastic flood events since 2000. This paper analyses the potential of satellite rainfall products combined with hydrological modelling to monitor these floods. The study focuses on the 125,000 km^2 area in the vicinity of Niamey, where local runoff supplies the first flood. Six rainfall products are tested : a gauge only product — the Climate Prediction Centre (CPC); two gauge adjusted satellite products — the Tropical Rainfall Measurement Mission (TRMM) Multi-Platform Analysis (TMPA 3B42v7) and the CPC regional product African Rainfall Estimate (RFE version 2); and three satellite only products, 3B42RT, the CPC Morphing method (CMORPH) and the Precipitation Estimation from Remotely Sensed Information using Artificial Neural Network (PERSIANN). The products are first inter-compared over the region of interest. Differences in terms of rainfall amount, number of rainy days, spacial extension of the rainfall events and frequency distribution of the rain rates are highlighted. The satellite only products provide more rain than the gauge adjusted ones. The hydrological model ISBA-TRIP is forced with the six products and the simulated discharge is analysed and compared with the discharge observed in Niamey over the period 2000 to 2013. The simulations based on the satellite only rainfall produce an excess in the discharge. For flood prediction, the problem can be overcome by a prior adjustment of the products – as done here with probability matching – or by analysing the simulated discharge in terms of percentile or anomaly. All tested products exhibit some skills in detecting the relatively heavy rainfall that preceded the flood and in predicting that the 95th percentile of the discharge (i.e., the flood alert level in Niamey) will be exceeded. These skills are however variable among products and the best overall results are obtained with the TMPA 3B42 products.

1. Introduction

Three recent floods on the Niger river have resulted in substantial damage in Niamey in 2010, (Sighomnou et al., 2010; Descroix et al., 2012), 2012 (Sighomnou, 2012; Sighomnou et al., 2013; OXFAM and ACTED report, 2012) and 2013 (Niger Basin Authority, ABN, website, http://www.abn.ne/), causing flooding, property damage and significant loss of life among people living near the river. These events have brought the attention of the media in a region traditionally known for its droughts rather than its floods. The analysis of these recent flood events has shown that they are related to a drastic change in the hydrological regime of the Niger basin in the region around Niamey (Descroix et al., 2012). Despite the severe droughts and a general decrease of the Niger river discharge (Albergel, 1987; Briquet et al., 1996; Mahé et al., 2003), the Niger River's right bank tributaries and other Sahelian rivers (Mahé et al., 2003, 2005; Descroix et al., 2009) have shown an increase in discharge, since the 1970s. This is attributed to changes in the runoff response of the watersheds (Albergel, 1987; Amani and Nguetora, 2002; Mahé and Paturel, 2009; Amogu et al., 2010) resulting from the droughts impact on vegetation cover, land cover clearing and subsequent increased soil crusting (Leblanc et al., 2008; Gardelle et al., 2010). The increase of runoff in the Niger River's right bank tributaries catchment resulted in a modification of the Niger river's regime near Niamey since the 80s, from a single to a double flood hydrograph (Amani and Nguetora, 2002; Descroix et al., 2012; Sighomnou et al., 2013). The first flood occurs during the rainy season and is a direct consequence of rainfall over the Niger River's right bank tributaries in the vicinity of Niamey. This first flood is now frequently more pronounced than the second one, and has caused four major flood events since 2000.

In addition to land-use changes, recent observations have raised the issue of a possible increase in extreme rainfall in the Sahel (Panthou et al., 2012, 2014). This could be the premises of an intensification of the hydrological cycle due to global warming (Giorgi et al., 2011) as

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already observed in other regions (Alpert, 2002). The risk of flood events is expected to increase if the land use changes continue, whether or not the increased frequency of rainfall extremes is confirmed. To reduce these risks, the flood genesis needs to be better understood and adequate monitoring systems need to be developed.

Currently, the monitoring of the flood risk in Niamey is based essentially on the surveillance of the river height upstream of Niamey. This is suitable for monitoring the second flood, which occurs between January and March, a few months after the end of the rainy season in Niamey. The first flood, which occurs in the heart of the rainy season is a more rapid phenomenon and is a consequence of runoff in the vicinity of Niamey. To predict this first flood the contributing rainfall must be precisely quantified. Given the relatively poor state of the operational gauge network in the area, satellite based rainfall is a very attractive alternative (Hossain et al., 2004). Further benefits of satellite rainfall estimates lie in their spatial and temporal resolutions (0.5°, 3 hourly or better) and in the near real-time availability of some products. However, as already discussed at length for radar based estimates (Berne and Krajewski, 2012 for a review), the potential benefit of high resolution may be outbalanced by the uncertainties and/or biases in the remotely sensed rainfall. These uncertainties and the way they might propagate in hydrological models (Hossain et al., 2004; Hong et al., 2006; Moradkhani et al., 2006; Nikolopoulos et al., 2010) need to be accounted for before any satellite rainfall product is considered for operational prediction.

Several recent works have evaluated satellite rainfall products over Africa based on gauges (Ali et al., 2005; Hughes, 2006; Roca et al., 2010; Jobard et al., 2011; Pierre et al., 2011; Habib et al., 2012; Thiemig et al., 2012; Gosset et al., 2013) and discussed their potential utility for the hydrological prediction of several African rivers (Nile tributaries — Artan et al., 2007; Gilgel Abay — Bitew and Gebremichael, 2011; Senegal river — Stisen and Sandholt, 2010; Volta and Baro-Akobo — Thiemig et al., 2013). Findings are consistent among these papers on the performance of some of the most commonly used product, in the Sahelian region. The products that do not ingest any gauge information – Precipitation estimation from Remotely Sensed Information using Artificial Neural Network (PERSIANN), Climate Prediction Centre (CPC) Morphing method (CMORPH) and Tropical Rain Measurement Mission (TRMM) Multi-platform Algorithm (TMPA, 3B42RT) – exhibit positive biases which may cause overestimation of the runoff and discharge when used in hydrological modelling (Thiemig et al., 2012; Gosset et al., 2013). Thiemig et al. (2013) have compared different methods for correcting the biases in the rainfall forcing, either by correcting the products themselves or by adjusting the model to the products (through recalibration for each type of rain forcing). The gauge adjusted products – TMPA 3B42v7 and the CPC regional product African Rainfall Estimate RFE2 – have generally low biases (at least at the monthly scale) but are not free of errors and may distort the spatial or frequency distribution of the rain rates (Gosset et al., 2013), with consequences for hydrology.

In this paper, we analyse the potential of six state of the art rainfall products combined with numerical modelling to analyse and assess the predictability of the Niger river first flood: a gauge only product (CPC), two gauge adjusted satellite products (3B42v7 and RFE2) and three satellite only products (3B42RT, CMORPH and PERSIANN). The study focuses on the ability of the model forced by satellite rainfall to reproduce the relatively high discharge levels encountered in recent years, and simulate the occurrence and length of floods.

Section 2 presents the hydrological context and the behaviour of the first flood observed in Niamey over the last 14 years. Section 3 describes the six rainfall products and compares some of their properties over the studied region. A bias-adjustment of the three products that do not ingest any gauge information is proposed. Section 4 presents the numerical modelling setup, based on the SURFEX platform (SURFace EXternalisée, in French) — ISBA (Interaction between Soil, Biosphere and Atmosphere) land surface model coupled with the TRIP (Trip Runoff Integrating Pathways) routing scheme. Section 5 discusses the simulation results. The discharges simulated with each rainfall product are compared with the observations over the period 2010–2013. The ability of the satellite forced simulations to reproduce the occurrence of the major floods of the period is quantified. The conclusions and perspective of this work are given in Section 6.

2. Hydrological context

The Niger River (Fig. 1) flows through a large part of West Africa. Its source is located in the humid mountainous Fouta Djallon area of Guinea. It initially flows northwards towards the Malian Sahel before turning south-eastwards towards Niamey and finishing its 4200 km long journey in Nigeria (Andersen et al., 2005; Ferry et al., 2012). An original feature of the Niger is its ‘inner delta’ (the light orange area in Fig. 1), which is characterized by a large lateral expansion of the river and large evaporation losses (Andersen et al., 2005). Around 60% of the inflow is lost in the Delta (Mahé et al., 2009).

Due to weakly connected drainage networks and aridity (so-called endorheism), most of the northern part of the basin does not contribute to the river flow. The river flow in Niamey originates from areas upstream the delta and from active tributaries downstream of the Niger–Mali border. As a consequence, the Niger River in Niamey exhibits two peaks (Fig. 2). The first peak occurs between August and September. It is due to the heavy monsoon rainfall occurring in August over the basins of three right bank tributaries (circled in Fig. 1): the Gorouol River (basin area 44,900 km^2), the Dargol (6940 km^2) and the Sirba (38,750 km^2). These ephemeral rivers (termed “koris”) and a series of smaller koris on both banks (27,020 km^2) define a contributing area of 117,610 km^2 (Descroix et al., 2012). The first flood is also named ‘red flood’ because of the colour of its sedimentary load. The second peak results from runoff during the rainy season (June–September) in the upper basin. The resulting flood wave is smoothed and delayed by routing through the Niger Inner Delta, and occurs in Niamey around January (Fig. 2). Because of it origin the second flood is also named the Guinean flood.

In the past, the two floods used to be merged into a single peak (Amani and Nguetora, 2002; Descroix et al., 2012), but since the 1970s, the first gradually became distinct from the second. Descroix et al. (2012) described this change with the poetic image: ‘the dromedary became a camel’. The first flood has intensified in the last decade because of the increase in runoff in the Sahelian zone (Albergel, 1987; Amani and Nguetora, 2002; Mahé et al., 2003, 2005; Mahé and Paturel, 2009; Amogu et al., 2010; Descroix et al., 2009, 2012).

As seen in Fig. 2, the two discharge peaks are lagged in time, and the delay between the two peaks makes it possible to study independently the local rapid Sahelian contributions and the slower signal due to the Guinean flood.

The threshold of 1700 m^3 s^{-1} (equivalent to a river height of 530 cm) is indicated in Fig. 2. According to the Niger Basin Authority (NBA or ABN in French), this is the critical height that triggers flooding. Since 2000 the discharge in Niamey exceeded this threshold during five years: 2006, 2003, 2010, 2012 and 2013 (Table 1). The most recent floods, 2010, 2012 and 2013 were exceptional in their intensity (maximum discharge rates between 1993 and 2429 m^3 s^{-1}) and/or their duration. These are three consecutive records for the first flood since the beginning of discharge observation in Niamey in 1920s. Note that the 2013 flood pattern differs from the other floods: the first flood is brief and intense, and the discharge minimum between the first and the second flood is the lowest of the studied period.

In order to distinguish which part of the first flood can be attributed to the three right bank and other local tributaries, and which part comes from the main course of the river (due to rainfall contribution in Mali) the discharge difference between Niamey and Ansongo is analysed.

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