Model-based study of the role of rainfall and land use land cover in the changes in Niger Red floods occurrence and intensity in Niamey between 1953 and 2012

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Response to the review #2

First we would like to thank you for your comments which should help improving our manuscript.

Our objective in this paper is to understand the impact of rainfall variability on the Niger River regime in Niamey from 1953 to 2012, and to investigate the impact of other hydrological drivers that were reported to have changed on the studied period (such as LULC or drainage path and area).

Responses to major comments:

1. Response to the first comment relative to the high spatial and temporal variability in rainfall and its representation in the products and model. This is indeed a very good point in a region where most rainfall is from convective origin. First note that the sensitivity of the model to rainfall fine scale variability is discussed in the paper Casse et al. 2015 which covers the recent period (2000-2012) and studies the ability of satellite products and our model to reproduce the recent flood records.

- Concerning the hydrological model spatial resolution: the model grid resolution is indeed 0.5°, but the model includes a sub-grid parameterization of hydrology which includes spatial downscaling of rainfall. This was developed in order for some hydrological processes (such as infiltration excess runoff) to be present in the model even at relatively coarse resolution (and subsequent smoothing of the rain field). The sub-grid rainfall distribution is based on the scheme developed by Fan et al. (1996) and Peter-Lidard (1997). More details on the model can be found in Noilhan and Planton (1989), and about the sub-grid hydrology in Decharme and Douville (2005, 2007) (page 12050 line24-25). Previous work on the ISBA-TRIP model simulations of the Niger river discharge (Pedinotti et al, Casse et al. 2015, Casse and Gosset 2015) have shown that the model in its present resolution (and its subgrid hydrology) provides realistic discharge when forced with the rainfall products available and used for this study. Note also that in Casse et al, 2015 we have elaborated further on the sensitivity of the model output to rainfall spatio-temporal patterns. Another point is that we are looking at the daily discharge data, for a drainage area about 100 000km², and the processes are relatively smoothed out by the integration by the basin. If we were trying to characterize the hydrological response at small scale we will definitely be limited by the model/product. We will develop these points a bit more in the model description of the revised version.

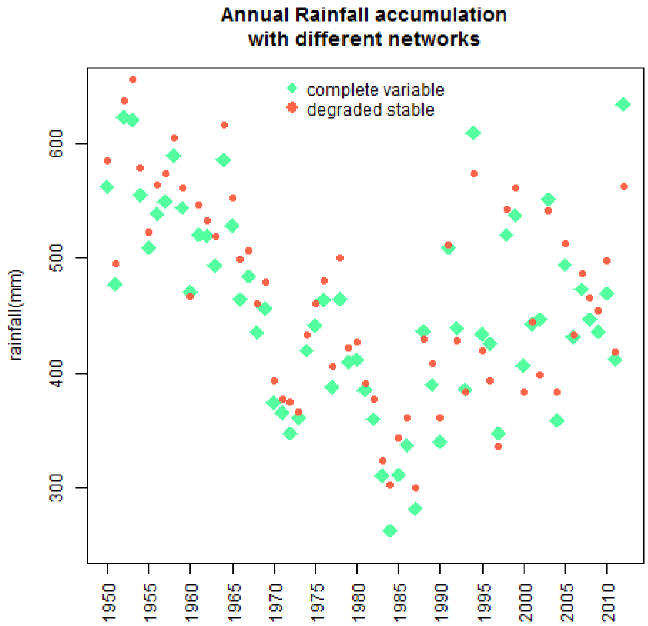
- Concerning rainfall spatial variability, we will also dwell more, in the revised version, on the appendix which provides an evaluation of the 3 products against a dense gauge network.

- Concerning rainfall time variability: The model time step for the forcing is 3h. As the rainfall products (PERSIANN-CDR, KRIG and CPC) are provided as daily accumulations, some basic temporal disaggregation is done, in order to represent the intense rainfall rates associated with convective rainfall. Based on dense gauges network (http://www.amma-catch.org/), and radar data from the observed region (http://meghatropiques.ipsl.polytechnique.fr/the-ouagadougou-super-site.html) and other work showing that daily rainfall is concentrated in few hours (Eldridge 1957, Rowell et Milford 1993) the daily rainfall accumulation is condensed in one 3h time step (between 16 and 19pm), as in Casse and Gosset 2015. This point will be explained in the revised version.

- The impact of rainfall products characteristics and differences on the simulation is briefly discussed in page 12057 lines 14-16. We did develop this point much more in Casse et al. (2015) where we highlighted the impact of the rainfall distribution (in space, time and intensity) on the hydrological modeling. Casse et al. 2015 provided an evaluation of the model and its ability to reproduce the recent (2010-2012) floods. The objective of the present manuscript is to use the model to study year to year variability and the relative differences in flood occurrence over a long period.

2. This is indeed a very good point. The products are not totally independent and rely on some common information. However, given the small number of gauges that common information is indeed limited and the various products algorithm use this information differently. As a matter of fact the appendix shows that the products are clearly different despite the common information; not only in terms of daily rainfall estimation but also in terms of rainfall distribution (in space, time and intensity). We will change "independent" for "different" in the revised version.

3. Response to the third comment on the possible effect of rain-gauge decrease on the climatic trend:
The trend in climatic evolution in Sahel since the 50's has been studied and documented by several authors. Our results are consistent with the overall literature. The purpose of this paper is not to demonstrate again the climatic evolution in Sahel but to illustrate its impact on the hydrological changes.
Anyway in order to answer your question about the possible effect of network changing density on the rainfall trend we did compute the long term series by using only 16 gauges for the whole period. The figure below (fig1) compares the annual rainfall accumulations with the originally used KRIG (green diamonds) and the degraded network with 16 gauges only (red circle). It can be seen that despite the differences the trend is very similar and the 3 main climatic periods (wet, dry, wetter again) are equally visible.



4. Response to the fourth comment relative to the discharge data quality:

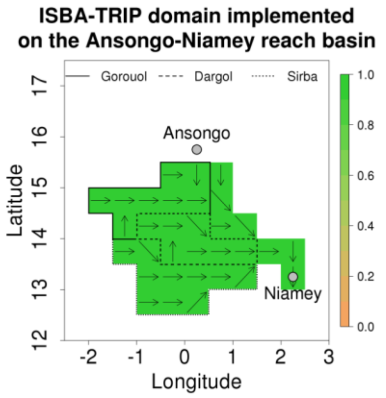
We commented on the discharge data quality and uncertainty in paragraph *2.2 Discharge Data* concerning the Red flood estimate, in a general way. To be more specific and answer your worries

- The Niamey station data is reliable. This station is in the capital city (and headquarters of the Niger Basin Agency), is well monitored and there is no missing data there. The rating curve is corrected regularly (and Doppler radar ADCP measurements have been done).
- The Ansongo station in Mali is less reliable (especially in the recent years because of the conflicts in Mali). The rating curve has not been updated recently and there is some missing data.

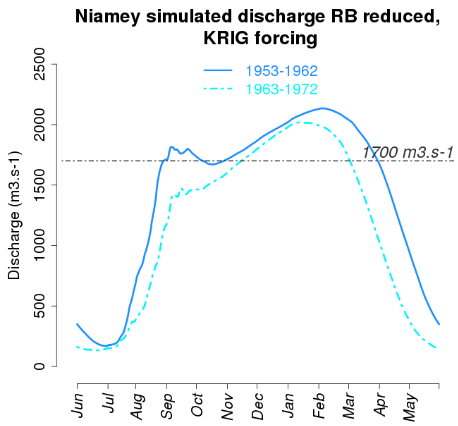
Note however that the comparisons between the simulated and observed discharge is done only for the Niamey station. The Ansongo data is used only either as a constraint to the model at the entry of the sub-basin or when computing the "red flood flow". As detailed in the text (page 12047 line 8 to 15) there is indeed some uncertainty in that estimate. Concerning the general question of data quality control, this is conducted in collaboration with ABN (Autorité du basin du Niger) which monitors, collects and provides the data.

5. Response to the fifth comment concerning the LULC:

We will integrate the following figure (fig2) to compare the map before and after vegetation and drainage area change:



We will also add the decadal evolution of the simulated discharge (fig3):



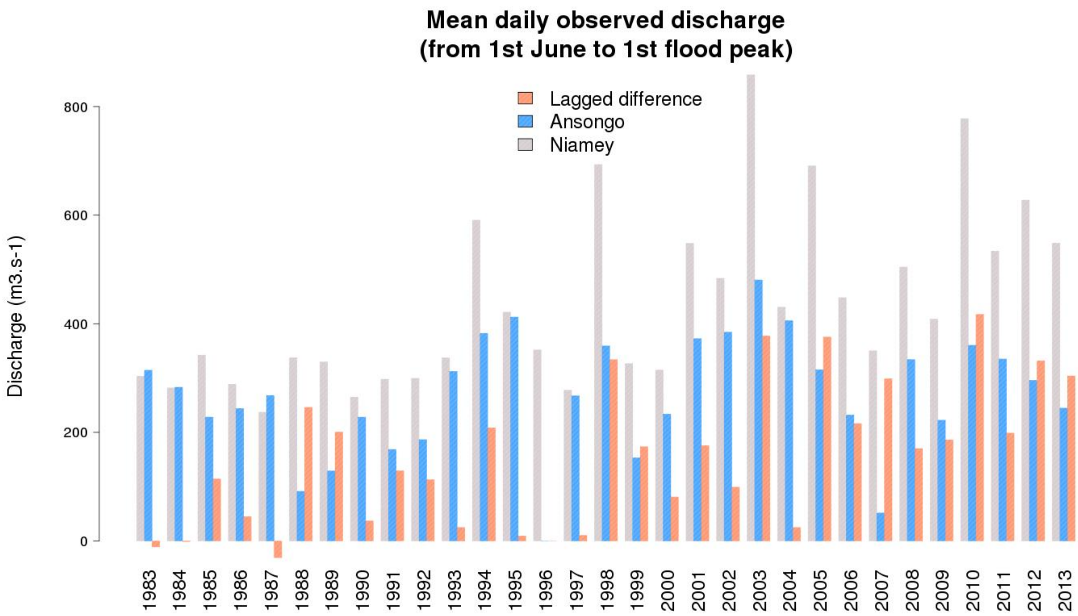
In addition we will discuss further in the final version the various sensitivity tests which have been done concerning vegetation/LULC changes. However due to the relatively simple representation of the vegetation in the model, the model is sensitive essentially to the cover percentage and not much to the details of the vegetation itself. The LULC changes as investigated here are not supposed to be a perfect representation of the real environment; they are a simplified representation of what has been observed: there was more vegetation and less bare soil in the 50's and 60's. Note that further investigations with a dedicated model and a more precise/realistic representation of vegetation are planned for the future.

Responses to minor edit:

-We will change Wester most for Westermost.

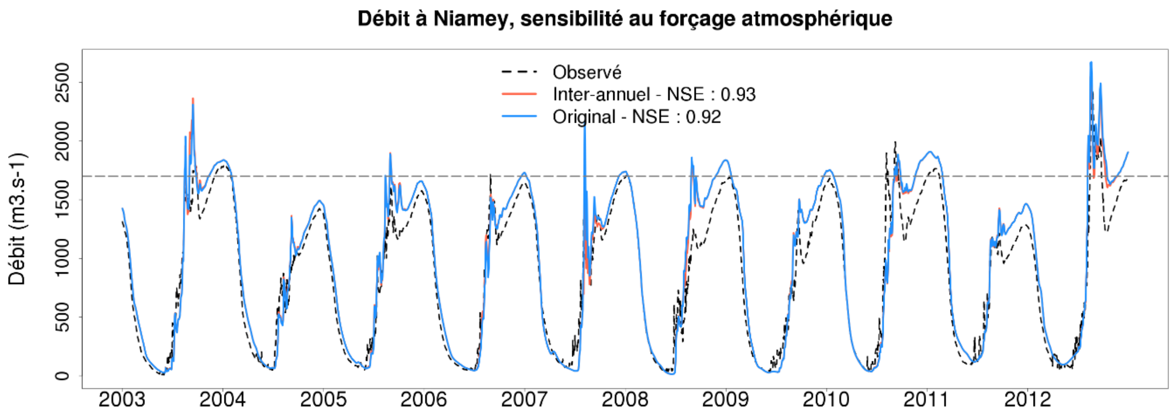
-We will not remove this sentence because we believe it is important to understand the Niamey hydrograph dynamic (and the point below).

- The contribution depends on the season and on the year. Before and after the rainy season the contribution of Ansongo to Niamey is mostly 100% (the discharge in Ansongo may be higher than in Niamey if evaporation/infiltration happens). During the rainy season –and the period of the red flood - the contribution varies from one year to another (see Casse and al. 2015). It depends on the Guinean flood dynamics and on the rainy season start date and intensity in the upper basin. (in addition, as discussed above there is the uncertainty in the Ansongo station data).
It is therefore difficult to give a rough estimation without further criteria. To give an answer, please see below (fig4) the mean daily discharge during the red flood rising flow period.



-WFDEI: Is one of the data set used by the CNRM (Centre National de Recherche Météorologique) the French Meteorological institute. There is also more information in Weedon et al. (2014, The WFDEI meteorological forcing data set: WATCH Forcing Data methodology applied to ERA-Interim reanalysis data, Water Resour. Res., 50, 7505-7514, doi: 10.1002/2014WR015638). We will include this new reference.

-By atmospheric forcing here, we mean atmospheric variables other than precipitation (page 12051 lines 9-11). The sensitivity tests to atmospheric forcing that are mentioned were done essentially to verify if climatological mean (for each day of the year) could be used for temperature/wind/solar radiation (etc.). They showed that using a climatological mean did not impact the results in terms of discharge during the flood period (which is what we are concentrating on here). This is illustrated below (fig5):



The figure above displays the daily observed discharge in Niamey between 2003 and 2012 (black dotted line), the grey dashed horizontal line is the inundation threshold ($1700m^3s^{-1}$). The coloured lines are for the simulated discharge: in blue with the original atmospheric forcing (and 3B2v7 TRMM rainfall), in red with an inter-annual mean of the daily atmospheric forcing (and 3B2v7 TRMM rainfall). The discharge is not sensitive to these changes in atmospheric forcing (pressure, temperature, radiation, wind).

We will mention these results more explicitly but do not believe the figure should be added.

- Captation of fig12 will be corrected.