Exploring the Frequency of Hydroclimate Extremes on the Niger River Using Monte Carlo Methods

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Motivation

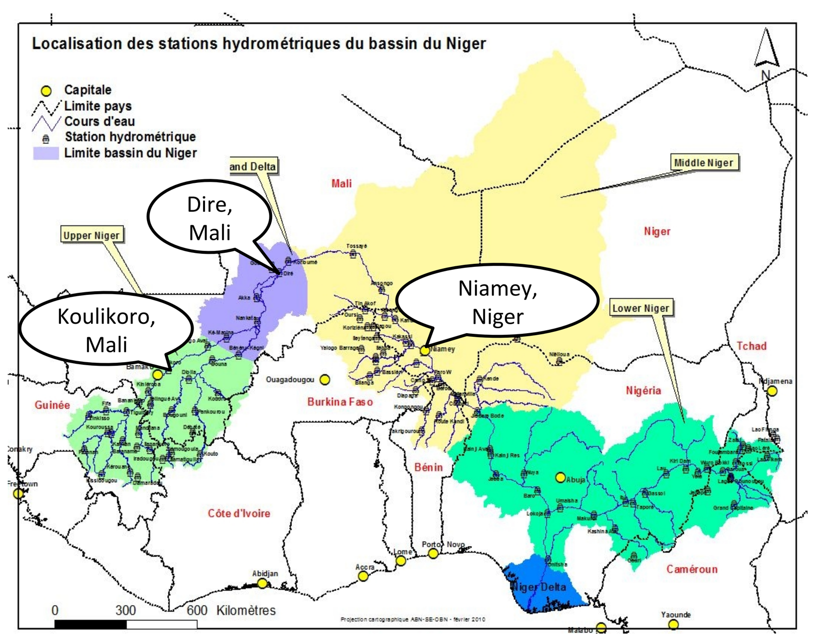
•Provide a historical overview of streamflow characteristics at three stations along the Niger River in West Africa from 1950-2009

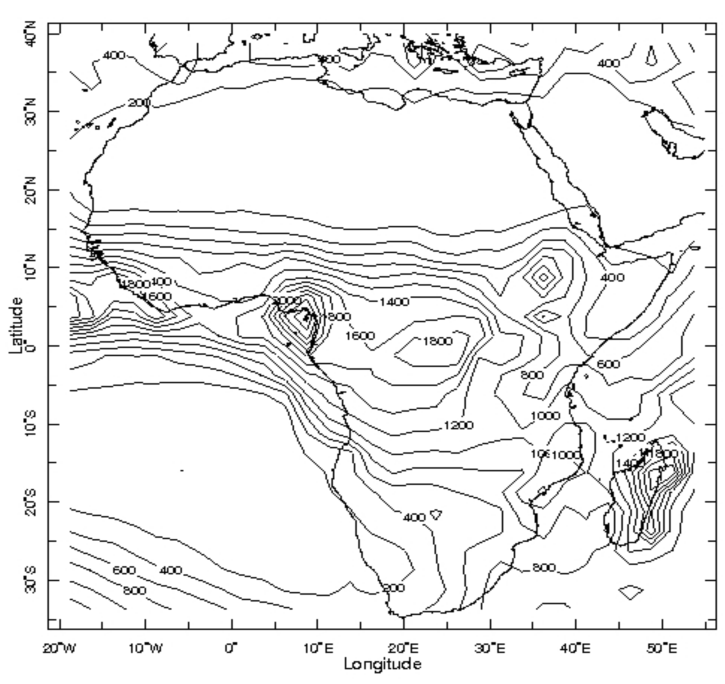
•Use statistical modeling and simulation approaches to understand and estimate changes in extreme hydroclimate event frequency, in the presence of global change (GC) and multidecadal variability (MDV) for the near-term future (2010-2040)

•Target risk management applications - notably index insurance

Data and Methods

- Monthly Rainfall data from the Global Historical Climate Network (GHCN)
- Daily Streamflow data from the Niger Basin Authority from Koulikoro, Mali (upper basin); Dire, Mali (inland delta); Niamey, Niger (middle basin)



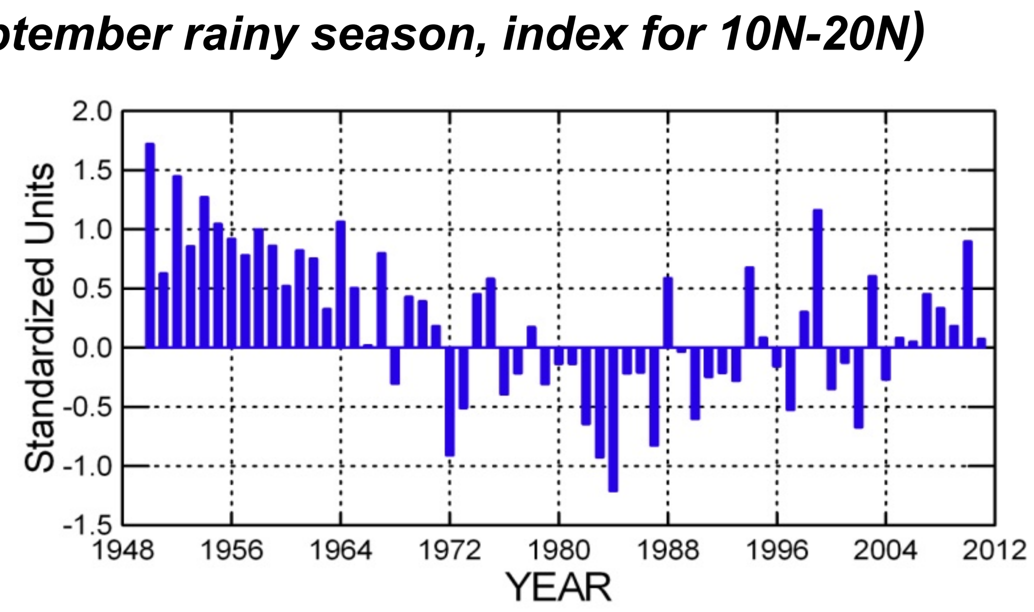


Historical Analysis

Sahel Rainfall (July-September rainy season, index for 10N-20N)

We divide the record into three periods or epochs:

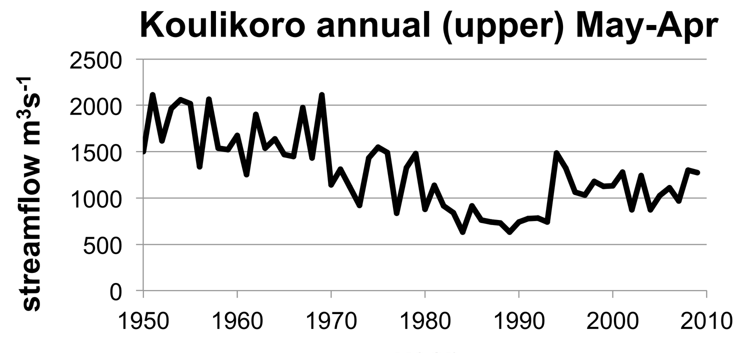
Wet Epoch 1950-1969 (P1)
Dry Epoch 1970-1993 (P2)
Wet Epoch 1994-2012 (P3)



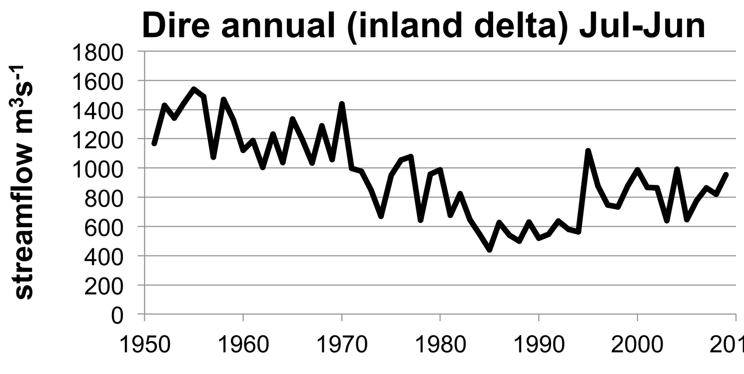
Hydrological Stations

The pattern in the streamflow record reflects the broader Sahel-wide changes in rainfall. The peak flood month for Koulikoro is September, for Dire is November and for Niamey is January.

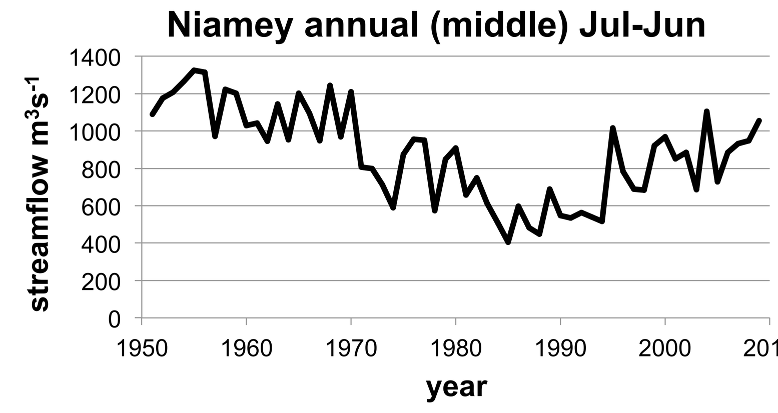
Koulikoro annual (upper) May-Apr



Dire annual (inland delta) Jul-Jun



Niamey annual (middle) Jul-Jun



Standard deviation, Skew and lag 1-year autocorrelation calculated for the three stations during 1950-2009, P1, P2, and P3 for the corresponding flood months.

Standard deviation (SD) and skew are computed from residuals from an 11 year running mean. The lag 1-year autocorrelation is calculated from a de-trended time series.

Skew is the 3rd central moment about the mean and the lag 1-year autocorrelation is a measure of MDV in the regional climate record.

Bold italicized values are statistically significant.

Streamflow m^3s^{-1}	Koulikoro	Dire	Niamey
1950-2009 SD	831	175	248
P1 SD	841	129	121
P2 SD	800	204	311
P3 SD	876	180	263

Skew	Koulikoro	Dire	Niamey
1950-2009 Skew	0.296	-0.096	-0.238
P1 Skew	***0.578***	***0.603***	0.347
P2 Skew	0.123	-0.033	-0.05
P3 Skew	0.163	-0.275	-0.401

Autocorrelation	Koulikoro	Dire	Niamey
1950-2009 autocorrelation	***0.315***	***0.516***	***0.665***

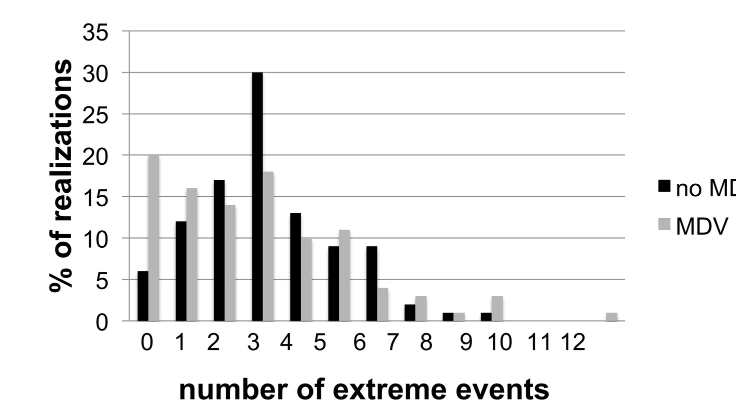
Statistical Simulation Experiments to Explore Changes in Extremes

Given the results of our analysis so far, we find no clear pattern in the response of the SD to epochal changes in mean precipitation. We also do not find a statistically significant skew across most station/epoch combinations. Consequently, in our simulation of the 2010-2040 period, we do not impose any systematic change to the SD and assume that our inter-annual values can be sampled from a normal distribution. However, given that there is a statistically significant lag-1 autocorrelation in the streamflow data, we do conduct simulations both including and not including multidecadal variability (MDV) simulated by a lag-1 autoregressive process.

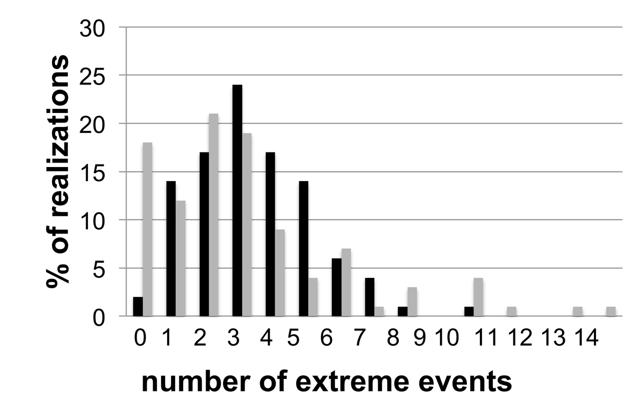
We explore the frequency of the 1 in 10 high flows and 1 in 10 low flows during the flood month based on the statistics of P3 for Koulikoro and Dire. In our baseline 30-year experiment, in which no trend is imposed on the mean streamflow, we compare the frequency of threshold crossing extremes with no MDV and with a lag-1 autocorrelation of 0.6 to represent the MDV. We expect an average of 3 threshold crossing extreme events in this baseline 30-year experiment.

1. Baseline Simulations (No Systematic Trend)

High Flow frequency



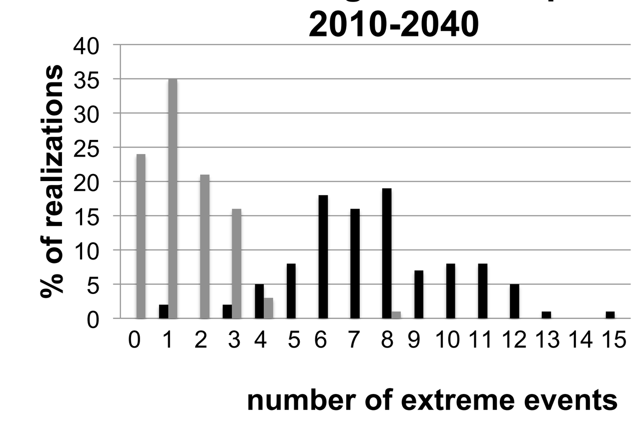
Low Flow frequency



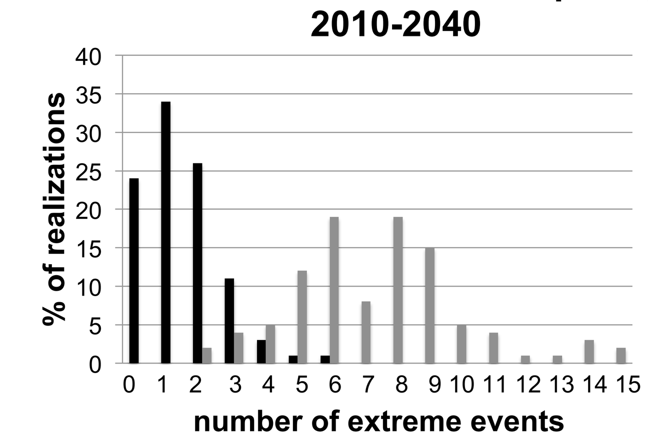
2. Simulations with a Systematic Trend (no MDV)

In this section, we simulate the frequency of 1 in 10 high flows and low flows for Koulikoro and Dire during 2010-2040 on the basis of a +20% trend in the mean streamflow ("wetter") and a -20% trend in the mean streamflow ("drier").

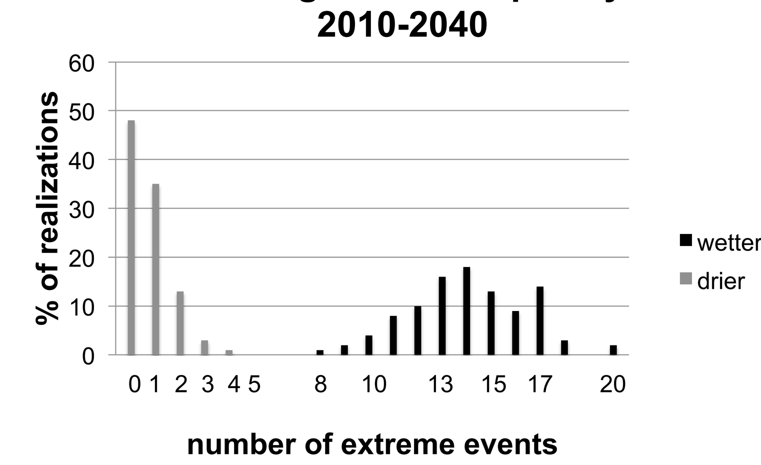
Koulikoro High Flow frequency 2010-2040



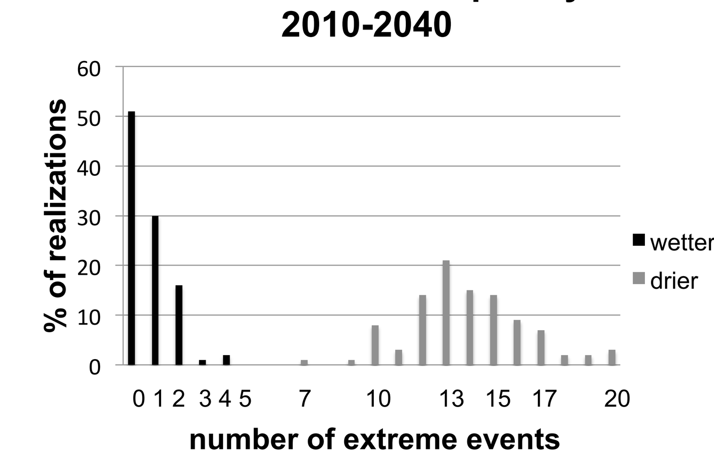
Koulikoro Low Flow Frequency 2010-2040



Dire High Flow Frequency 2010-2040



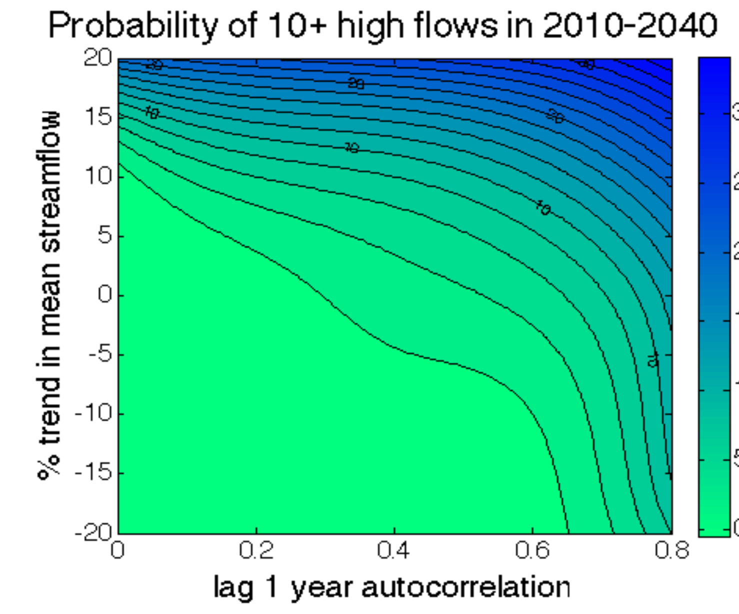
Dire Low Flow Frequency 2010-2040



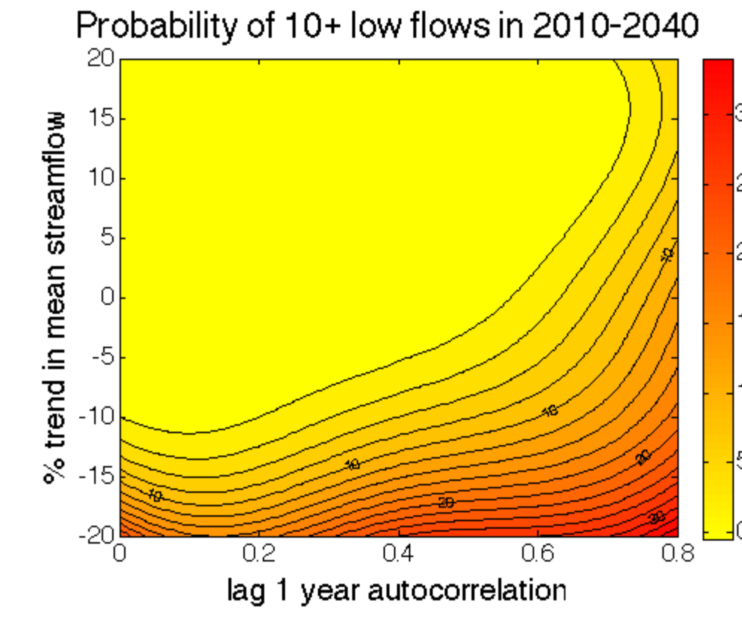
3. Simulations with Differing Magnitudes of Trend and MDV

Simulations are conducted exploring a range of trends in the mean streamflow from -20% to +20% and exploring a range of lag 1-year autocorrelation values from 0 to 0.8. The contour plots shown below represent the results for Koulikoro, again using 1 in 10 high and low flow definitions and statistics based on P3. The contour lines represent the % chance of 10 or more threshold crossing extremes in 2010-2040 with the given trend/MDV combination.

Probability of 10+ high flows in 2010-2040



Probability of 10+ low flows in 2010-2040



Conclusions

- In the observed record, the SD changes in the streamflow do not show a clear pattern in the epoch transitions – this is somewhat at odds with rainfall records and we may be seeing some increase in variability because of changes to the runoff coefficient due to land use change
- MDV has a clear impact on the spread of potential outcomes in baseline simulations
- In the experiment without MDV, Dire which has a smaller SD relative to the mean experiences more sensitivity to the frequency of extreme streamflow events
- In the experiment with MDV, both MDV and trend in the mean streamflow can significantly impact the probability of 10 or more extreme streamflow events in the 2010-2040 period – this can have significant human impacts and implications for adaptation strategy and potential.

Key References

• Paturel, J. E., M. Ouedraogo, E. Servat, G. Mahe, A. Dezetter, J. F. Boyer, 2003: The Concept of Rainfall and Streamflow Normals in West and Central Africa in a Context of Climatic Variability, *Hydrological Sciences*, **48**, pp. 125-137.

• M. N. Ward, A. Siebert, and O. Ndiaye 2012. "Decadal-to-Multidecadal Variation in Sahel Rainfall since 1950 and Associated Changes in the Frequency of Threshold---Crossing Seaonal Rainfall Totals", AMMA Conference, Toulouse, France, July 2012.

• Siebert, A. and M. N. Ward, 2011: Future Occurrence of Threshold-Crossing Seasonal Rainfall Totals: Methodology and Application to Sites in Africa, *Journal of Applied Meteorology and Climatology*, **50**, pp. 560-578.

• Zhang, X., F. W. Zwiers, and G. Li, 2004: Monte Carlo Experiments on the Detection of Trends in Extreme Values, *Journal of Climate*, **17**, pp. 1945-1952