Relation between hydro-climatic extremes and atmospheric circulation patterns in the Nile basin

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Introduction

• Extreme events are major concern to Africa
  – Floods and droughts

• Sensitive to rainfall variability => hydrological variability
  – Catchment selected => the Nile basin

• Research questions
  – Are these variability random or persistent in time?
  – Which periods show significant oscillation highs and lows?
  – Is it possible to find a link between extreme hydro-climatic events and large scale atmospheric variables?

• Sea Level Pressure fields => as indicator
• Hydro-climatic extremes => rainfall/river flow extremes
Data

- River flows
  - Major stations along the Nile river
- Rainfall
  - Gridded data (http://badc.nerc.ac.uk/data/cru/)
  - Station data
- Sea Level Pressure (SLP)
  - Tropical Atlantic Ocean (southern – northern)
  - Tropical Indian Ocean (southern – northern) (www.metoffice.gov.uk/hadobs)
- Southern Oscillation Index (SOI)
  - ENSO index (SLP difference in Pacific Ocean) (http://badc.nerc.ac.uk/data/cru/)

Annual & monthly
Study area and rainfall data coverage
Grids for SLP data

1. TNAO (0 - 20N, 60W - 10W)
2. TSAO (20S - 0, 50W - 15E)
3. TNIO (0 - 20N, 40E - 100E)
4. TSIO (20S - 0, 35E - 130E)
Method for Oscillation pattern analysis

- Empirical statistical analysis
  - To find (multi-) decadal oscillation patterns
- Calculating relative change in extreme values
  - Quantiles with the same return period
- Two time series are required
  - A reference period
    - The total observed time series
  - A block period
    - A subseries of the total time series
- A block period = 10 years
Anomaly computation

- If $i$ is a rank number, for $i = 1, 2, 3 ... n$
  - $X_1 \geq X_2 \geq X_3 \geq ... \geq X_n$ => the ranked extreme values

- Block period ($b$) & Total period ($t$)
  - Empirical return period ($R_b$) = $b/i$
  - Empirical return period ($R_t$) = $t/i$

- Quantiles for block & total period
  - $X(b), X(b/2), ... , X(b/i)$,
  - $X_r(t), X_r(t/2), ... , X_r(t/i)$.

- A relative change is the ratio of block period to total period quantiles
  $$\frac{X(b)}{X_r(t)}, \frac{X(b/2)}{X_r(t/2)}, ..., \frac{X(b/i)}{X_r(t/i)}$$
Anomaly computation

• Matching the return periods \( i^* = \frac{t}{b} \)
  
  - \( i^* \) – the rank number that corresponds to same return period as that of the block period quantile
  - \( i_b \) – the rank number of block period quantiles
  - \( t \) – total number of years of the time series
  - \( b \) – is the number of years in block period

• Anomaly of the block period (b)
  – Average of the most extreme events
  – 3 extreme values per year

• Sliding window approach – sliding by 1 year
  – To see the temporal variation of the anomaly
Monte Carlo confidence intervals

• To test statistical significance of the variation
  – Monte Carlo confidence intervals

• The null hypothesis
  – There is no persistence in time for the oscillation (no trends or multi-decadal oscillations)

• The nonparametric bootstrapping method
  – Empirical data => to generate random samples for each block
  – 1000 Monte Carlo runs executed
    • Generates 1000 possible anomaly factors

• The upper and lower limit of the confidence interval
  – Based on significance level of interest => 5%
Results and discussions

• The null hypothesis of no persistence in time (no trends) in the annual extreme river flow oscillations
  – Rejected
Main Nile and Blue Nile

- Annual time step results
  - 1930s – decreasing trend
  - 1940s to 1960s – increasing trend
  - 1960s to 1980s – decreasing trend
  - 1990s – increasing trend

- The 1980s – statistically significant oscillation lows
Blue Nile and Atbara

Sennar

Atbara

Rossier

Baheirdar

Change [%] vs Time [Year] for Blue Nile and Atbara with observed changes and confidence intervals.
White Nile

- 1940s – decreasing trend
- 1960s – increasing trend
- 1970s & 1980s – decreasing trend
- 1990s – increasing trend

• The 1960s – statistically significant oscillation highs
Rainfall Vs river flow

• Links between extremes were identified by looking pattern similarity
  • Similar patterns
    – rainfall & river flow
• Examples
  – Khartoum => Blue Nile
  – Malakal => White Nile
• Rainfall oscillations
  – Main driving factor for river flow oscillations
Rainfall Vs SLP difference

- Similarity between rainfall extremes in the Blue Nile and SLP difference of Tropical Atlantic Ocean
- Rainfall extremes have stronger relationship with SOI during less extreme rainfall periods (dry periods)
Seasonal scale

- **JJAS – Blue Nile (Main rainy season)**
- **Strong similarity between**
  - Rainfall over the Ethiopian highlands and flow at Khartoum
  - Rainfall extremes and TAO SLP difference during oscillations highs
  - Rainfall extremes and SOI during oscillations lows
Seasonal scale

- **OND – White Nile** (short rainy season)
- **Strong similarity of pattern between**
  - Rainfall extremes in Lake Kyoga region and TIO SLP difference
  - Rainfall extremes in Lake Victoria region during the 1960s and TIO SLP difference
- **Strong influence of Indian Ocean in OND season**
Seasonal scale

- **MAM – White Nile (Long rainy season)**
- **No pattern similarity between**
  - White Nile catchments and Indian ocean or Atlantic ocean
- **Rather the Sudan part of Blue Nile shows similar pattern with TAO SLP difference**
  - The SLP oscillations precede the rainfall oscillations
Summary

• Variability in rainfall/river flow extremes is not random
  – Oscillation patterns showed persistence in time

• Two patterns identified in the Nile basin
  1. Blue Nile, Atbara & Main Nile
  2. White Nile

• Periods with significant oscillation highs and lows identified according to the catchments
  – Significant oscillation lows
    • Late 1970s & beginning of the 1980s
    • Blue Nile, Atbara & Main Nile
  – Significant oscillation highs
    • Beginning of the 1960s
    • White Nile
Summary

• Possible links noticed between extreme hydro-climatic and atmospheric variables

• Blue Nile region
  – Relatively strong links in the JJAS & MAM seasons for high extremes with Tropical Atlantic Ocean
  – Strong similarity between SOI and less extreme rainfall periods

• White Nile region
  – Relatively strong links in the OND season with Tropical Indian Ocean
Conclusions

• **Blue Nile region**
  – Influenced by Tropical Atlantic Ocean during high extreme events
  – Higher influence of El Nino during less extreme events (dry periods)

• **White Nile region**
  – Influenced by Tropical Indian Ocean during the OND season

• **Main Nile**
  – Strongly linked with Blue Nile oscillation patterns, thus influenced by similar factors