NON-STATIONARY & NON-LINEAR ANALYSIS, & PREDICTION OF HYDROCLIMATIC VARIABLES OF AFRICA

Davison Mwale & Thian Yew Gan
Department of Civil & Environmental Engineering
University of Alberta, Edmonton
Statement of Problems

1. Climate Processes are non-stationary & nonlinear, occurrences of droughts & floods have been increasing in recent years
   (a) Southern Africa, in 2002 15 million people faced starvation
   (b) Canadian Prairies suffered droughts in 2001-2003

2. Popular Statistical Tools
   Canonical Correlation Analysis assumes Stationarity & Linearity
   There are rooms for improvement

3. Failure to Identify Relevant Predictor Fields
   Noise Reduction, increase Signal/Noise ratio
   Limit to relevant predictor fields increase prediction skill
RESEARCH OBJECTIVES

1. Understand the Non-stationarity and Nonlinearity of Climate process in Africa Temporal and Spatial Variability
   Changes of Oscillations in space, Time, Frequency

2. Enhance Prediction skill of seasonal Precipitation via nonlinear statistical model
DATA AND STUDY LOCATIONS

SST Predictor Fields:
(a) Indian ocean (40°E-110°E, 20°N-30°S)
(b) Atlantic ocean (10°N-40°S, 50°W-10°E)

Precipitation (Predictand) of Southern & East Africa
CASE EXAMPLE – East Africa (EA)

1. EA has two rainy seasons, September-November SON or **Short Rain** and MAM or **Long Rain**.
2. Major challenge: To predict the nature of this variability in EA rainfall over regional spatial scales, inter-annual to inter-decadal temporal scales.
3. Analyze unstable relationships between rainfall in EA & SST in Atlantic & Indian Oceans.
4. Using SST data identified in the teleconnections, predict SON & March-May (MAM) seasonal precipitation of East Africa (EA)
Raw Data

1. Monthly precipitation (1900-1997, 1950-1997), gridded at 2.5°x3.75° (East and southern Africa)

2. Monthly sea surface temperature SST (1950-1997), gridded 5°x5° (Indian and Atlantic ocean)
RESEARCH METHODOLOGY

I. Subject seasonal SST and rainfall to:

Data Decomposition

1. Wavelet Analysis & Hilbert Transform
   To analyse irregularly distributed events, non-stationary power over inter-annual to inter-decadal scales

Data Compression

1. Empirical Orthogonal Function (EOF)
2. Independent Component Analysis (ICA)

Identify Teleconnection Pattern by
Wavelet based EOF (WEOF) or
Wavelet Principal Component Analysis (WLPCA)

Prediction Model

- Artificial Neural Network- Genetic Algorithm (ANN-GA)
  * GA model biological evolution
Wavelet Spectrum

Hilbert Spectrum
$X(t) = \cos(\omega t + \varepsilon \sin \omega t)$
WEOF (WLPC) applied to 2.5° x 3.75° Scale-Averaged Wavelet Power (SAWP) or Frequency compacted energy variability Pearson Correlations between WLPCs & individual SAWP
Wavelet Principal Components 1, 2 & 3

SON Temporal Modes

MAM Temporal Modes
Modes of Variability (Indian Ocean)

(a) WLPC1 (1950-1997)

(b) WLPC2 (1950-1997)

(d)
Modes of Variability (Atlantic ocean)
Modes of Variability (Atlantic ocean-Seasonal Variabilities)

1. Seasonal variabilities migrate between Africa and S. America
2. Strong links with coastal and near coastal area rainfall
Correlation between WLPCs of SON (MAM) Rainfall & each 5 x 5 grid box of Annual/AMJ SST in both oceans.

(a) Annual SST- SON rainfall

(b) AMJ SST-SON rainfall
ANN-GA

- 3-Layer ANN trained by Genetic Algorithm:
  - (a) Main (Rank) – keep 80-90%
  - (b) Cross Over – 100%
  - (c) Mutation – 1%
(1) Skill is high and structure follows I.D. signal (2) Confirms Signal ID by Wavelet and EMD-Hilbert based analysis (3) Predictor data is robust!
Comparison of prediction skill with Other Models

(a) SON correlation

(b) SON RMSE


Correlation CCA

RMSE CCA-NMS, Ntale et al., 2003

RMSE CCA
simulated data (e) to (h)
**Observations and Conclusions**

- The present study demonstrated that non-stationary approaches to climate data analysis results in new insights in the variability of East Africa rainfall.
- Applying a non-linear statistical model, ANN-GA results in accurate seasonal prediction of East Africa rainfall.
- The predicted seasonal precipitation disaggregated to weekly precipitation, then used to drive a conceptual hydrologic model generally produced accurate basin streamflow for Kafue Basin in Zambia.
Significance of strong 2-2.4 & Quasi-20,100-year cycles?

* Persistent 2 to 2.4-year: SST-rainfall, Good for prediction
* 2-2.4 cycle sign for drought: 1949, 1965-1997
* Quasi 20,100-year cycle: Good for long term planning
WEOF (WLPC) applied to 2.5° x 3.75° Scale-Averaged Wavelet Power (SAWP) or Frequency compacted energy variability
East Africa Rainfall: Spatial Mode 3
## Table 1. Major Drought Episodes in East Africa in the 20th Century (Taken from Ntale 2001)

<table>
<thead>
<tr>
<th>PERIOD</th>
<th>AREAS AFFECTED</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1899</td>
<td>Most parts of East Africa especially Kenya</td>
<td>Lake Stephanie dried up</td>
</tr>
<tr>
<td>1900</td>
<td>Central Tanzania</td>
<td>More than 60,000 died</td>
</tr>
<tr>
<td>1949</td>
<td>Most of East Africa, especially Sukumaula District, central Tanzania</td>
<td>1.5 million cattle died or hastily slaughtered out of a population of 2.5 million</td>
</tr>
<tr>
<td>1965</td>
<td>Dry Belt of Kenya</td>
<td>260,000 people affected</td>
</tr>
<tr>
<td>1967</td>
<td>Karamoja, Uganda</td>
<td>25,000 people affected</td>
</tr>
<tr>
<td>1971</td>
<td>Wide spread in Kenya</td>
<td>1.5 million people affected</td>
</tr>
<tr>
<td>1977</td>
<td>Wide spread in Kenya</td>
<td>In May, 100 people killed, 20,000 people affected</td>
</tr>
<tr>
<td>1979</td>
<td>Tukana District in Kenya</td>
<td>40,000 people affected</td>
</tr>
<tr>
<td>1979</td>
<td>North and NW Uganda</td>
<td>600,000 people affected</td>
</tr>
<tr>
<td>1984</td>
<td>Most of Kenya and Tanzania</td>
<td>Complete failure of long rains. Worst drought in Kenya in 40 years</td>
</tr>
<tr>
<td>1984</td>
<td>Arid district of Kenya</td>
<td>600,000 people affected</td>
</tr>
<tr>
<td>1987</td>
<td>Karamoja, Uganda</td>
<td>331,000 people affected</td>
</tr>
<tr>
<td>1988</td>
<td>NW Uganda</td>
<td>600,000 people affected</td>
</tr>
<tr>
<td>1990</td>
<td>North and NE arid districts of Kenya</td>
<td>1.2 million people affected. Worst maize crop in 10 years</td>
</tr>
<tr>
<td>1991</td>
<td>North and NE arid districts of Kenya</td>
<td>2.7 million people affected. Worst maize crop in 105 years</td>
</tr>
<tr>
<td>1992</td>
<td>North and NE arid districts of Kenya</td>
<td>Continuing drought</td>
</tr>
<tr>
<td>1996/97</td>
<td>Central Tanzania</td>
<td>Late 1996, early 1997 Worst drought in 50 years. Cities face major shortages</td>
</tr>
</tbody>
</table>

**2002, Southern Africa, 15 Million Face Starvation**
Spatial Variability of Frequency Modes
(2.8 & 3.5 year)
ANN-GA MODEL
(Annual Rainfall)

FRED MORTON
ET MODEL
(Annual evapotranspiration)

DISSAGGREGATION MODEL

WEEKLY STREAMFLOW
Spatial Variability of Frequency Modes
(2 and 2.4 year)

WEOF applied to 2-yr & 2.4 yr of wavelet spectra
Spatial Variability of Frequency Modes
(6.7 & 8 year)
Statistically generated data (a) to (d)