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

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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

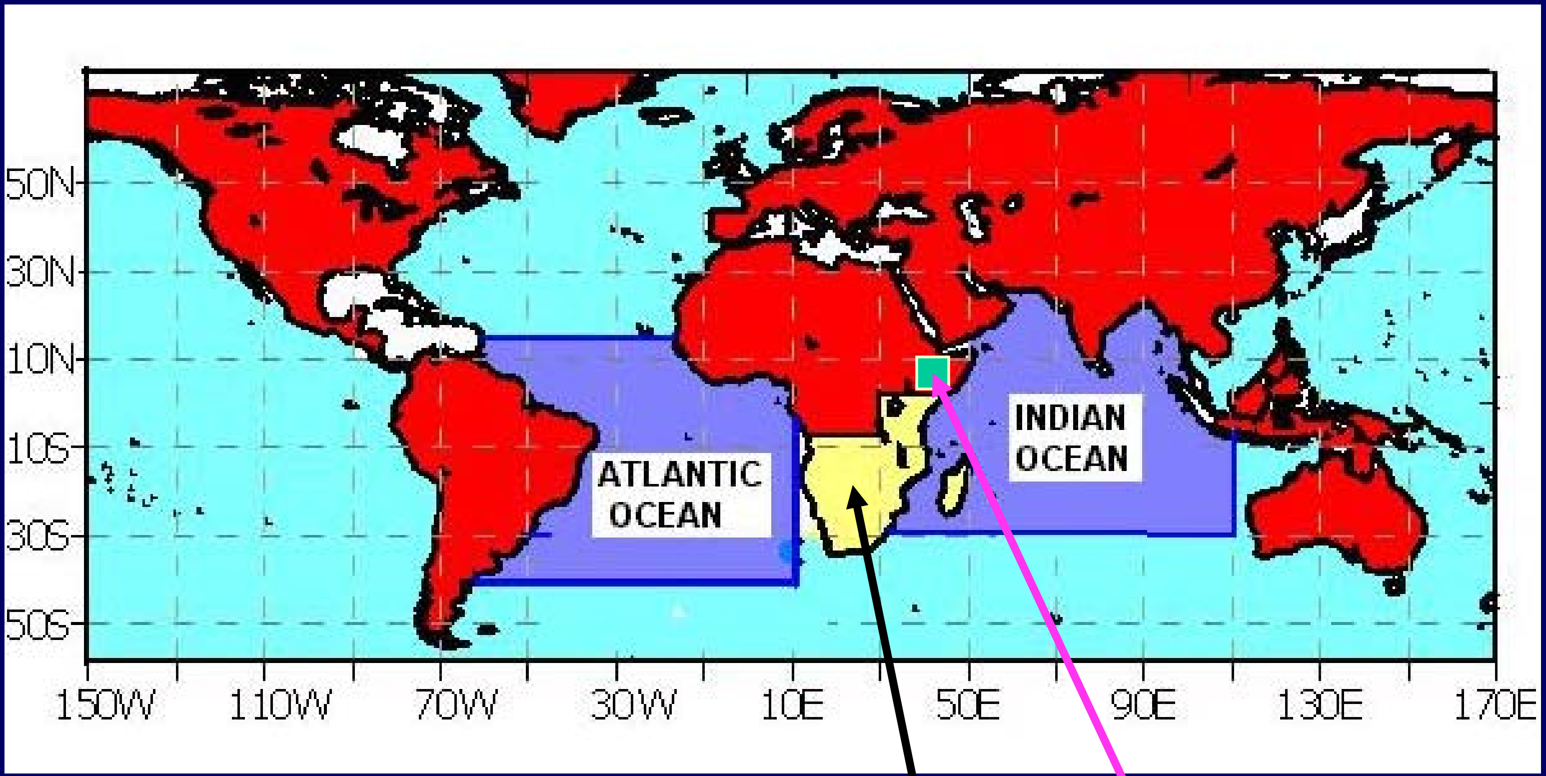
1. Understand the Non-stationarity and Nonlinearity of Climate process in Africa

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)

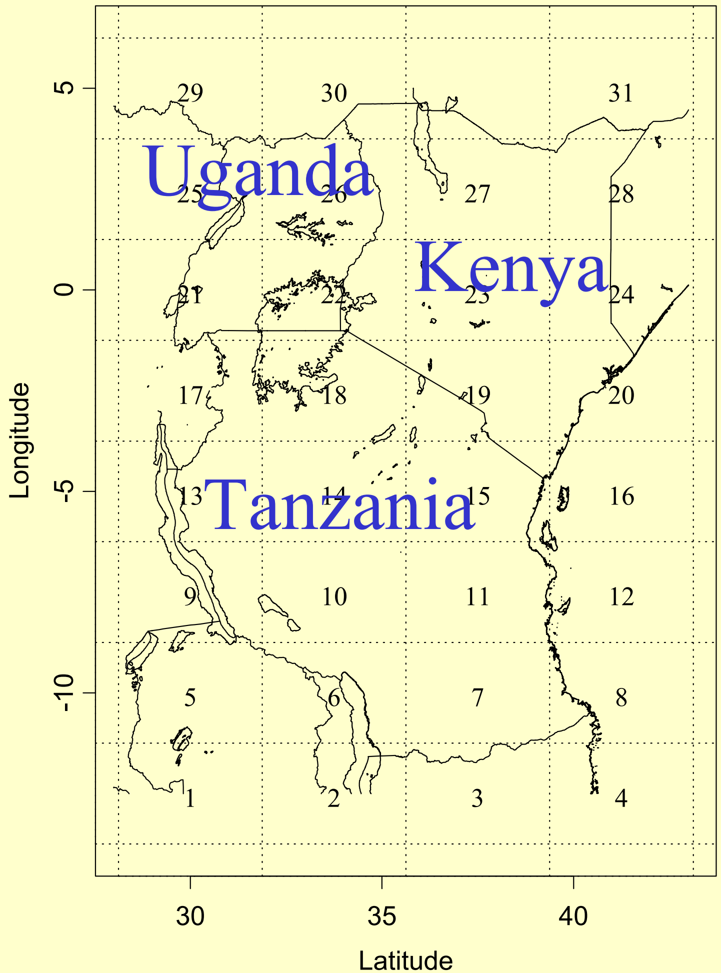
(b) Atlantic ocean(10°N-40°S,50°W10°E)

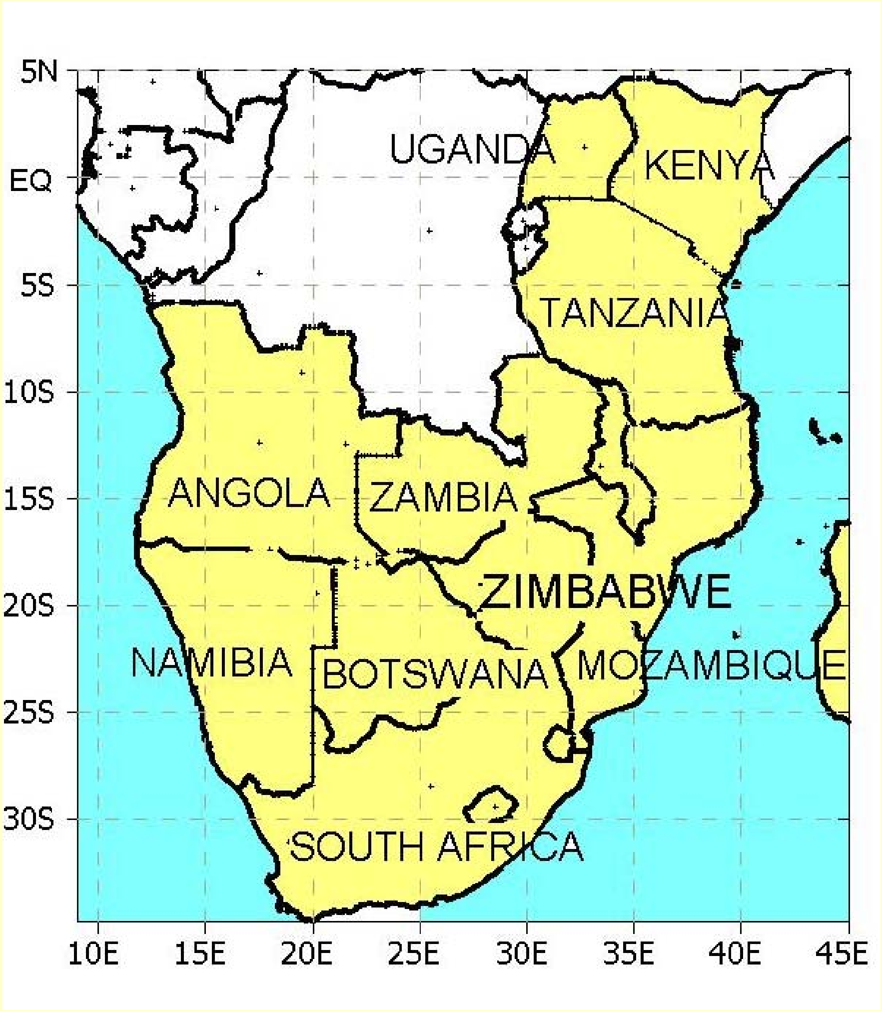
Precipitation (Predictand) of Southern & East Africa

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)

EAST AFRICA





SOUTHERN AFRICA

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)

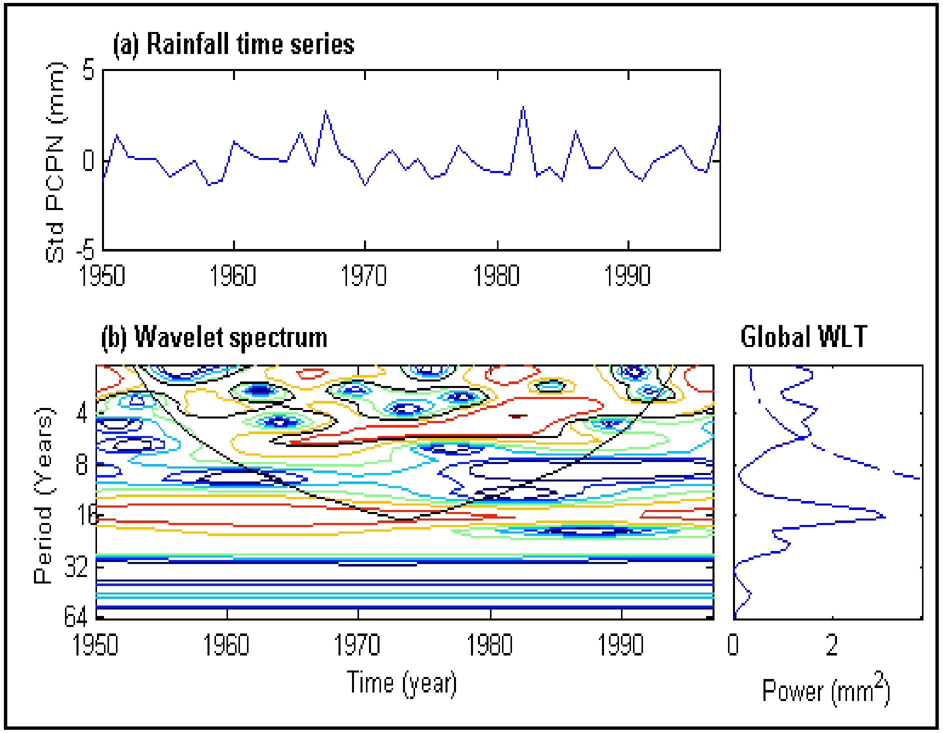
Identify Teleconnection Pattern by

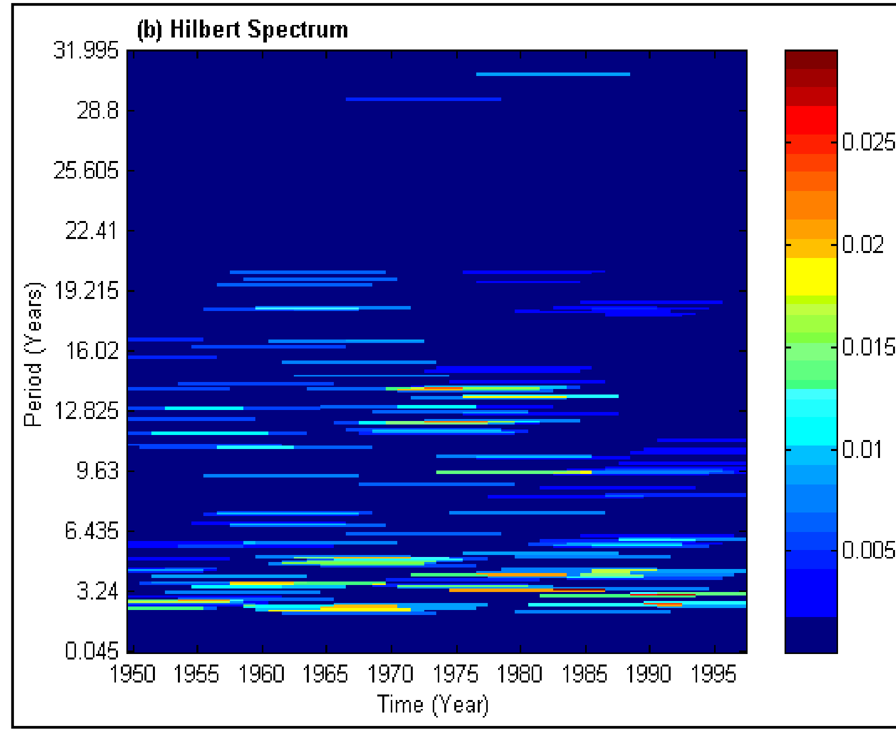
Wavelet based EOF (WEOF) or
Wavelet Principal Component Analysis (WLPCA)

Prediction Model

❖ Artificial Neural Network- Genetic Algorithm (ANN-GA)

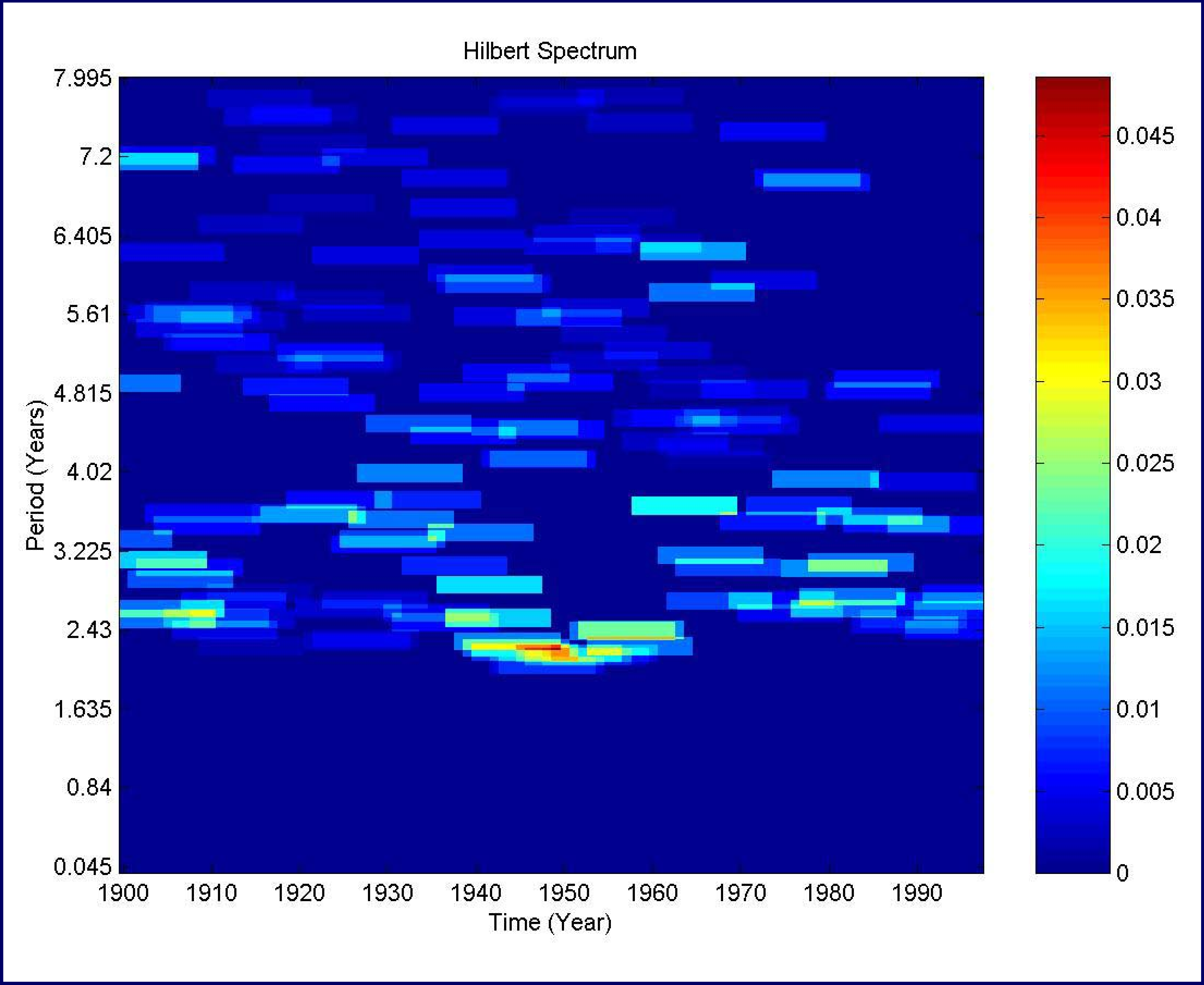
   * GA model biological evolution





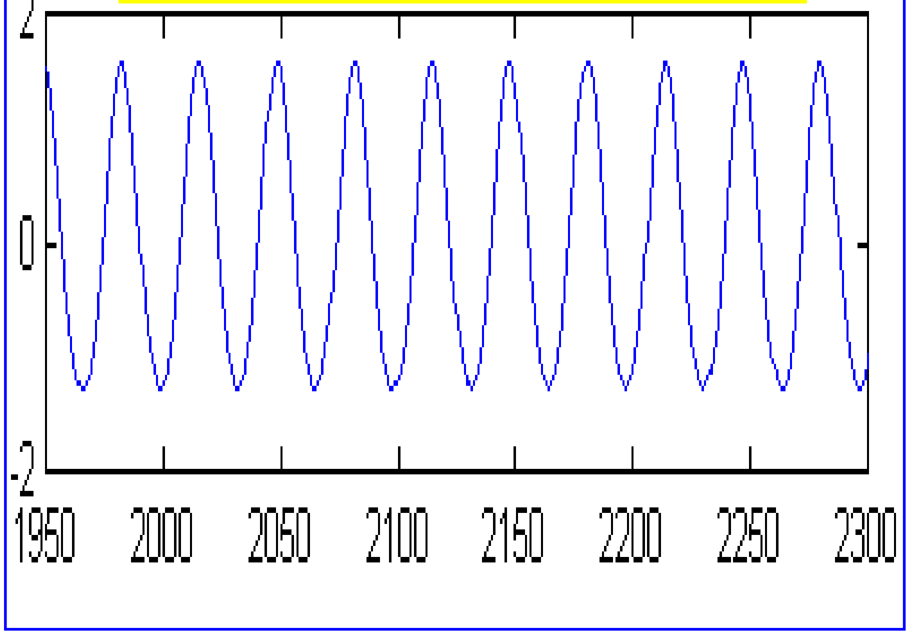
Wavelet Spectrum

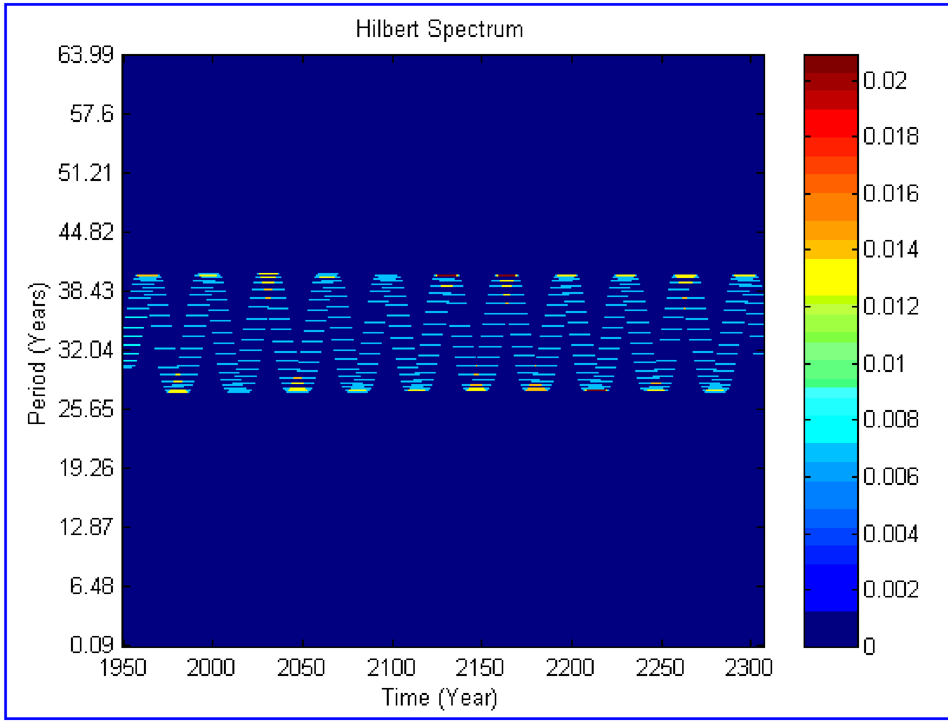
Hilbert Spectrum

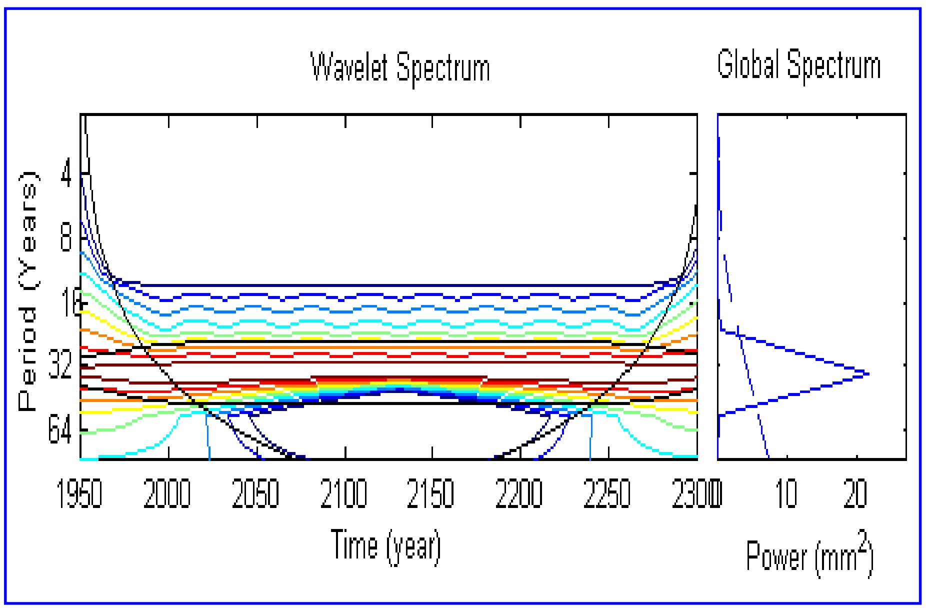


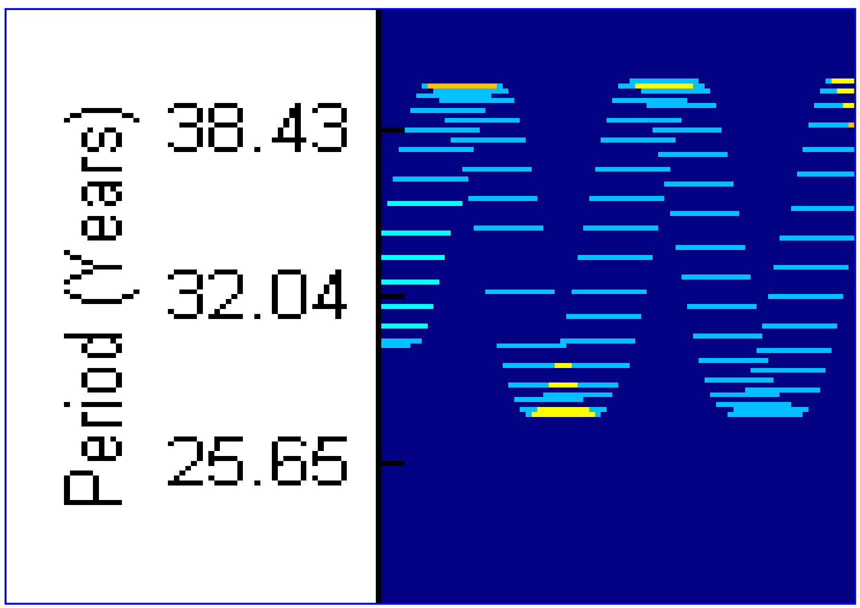
Hilbert Spectrum
Period (Years)
7.995
7.2
6.405
5.61
4.815
4.02
3.225
2.43
1.635
0.84
0.045
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
Time (Year)
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0

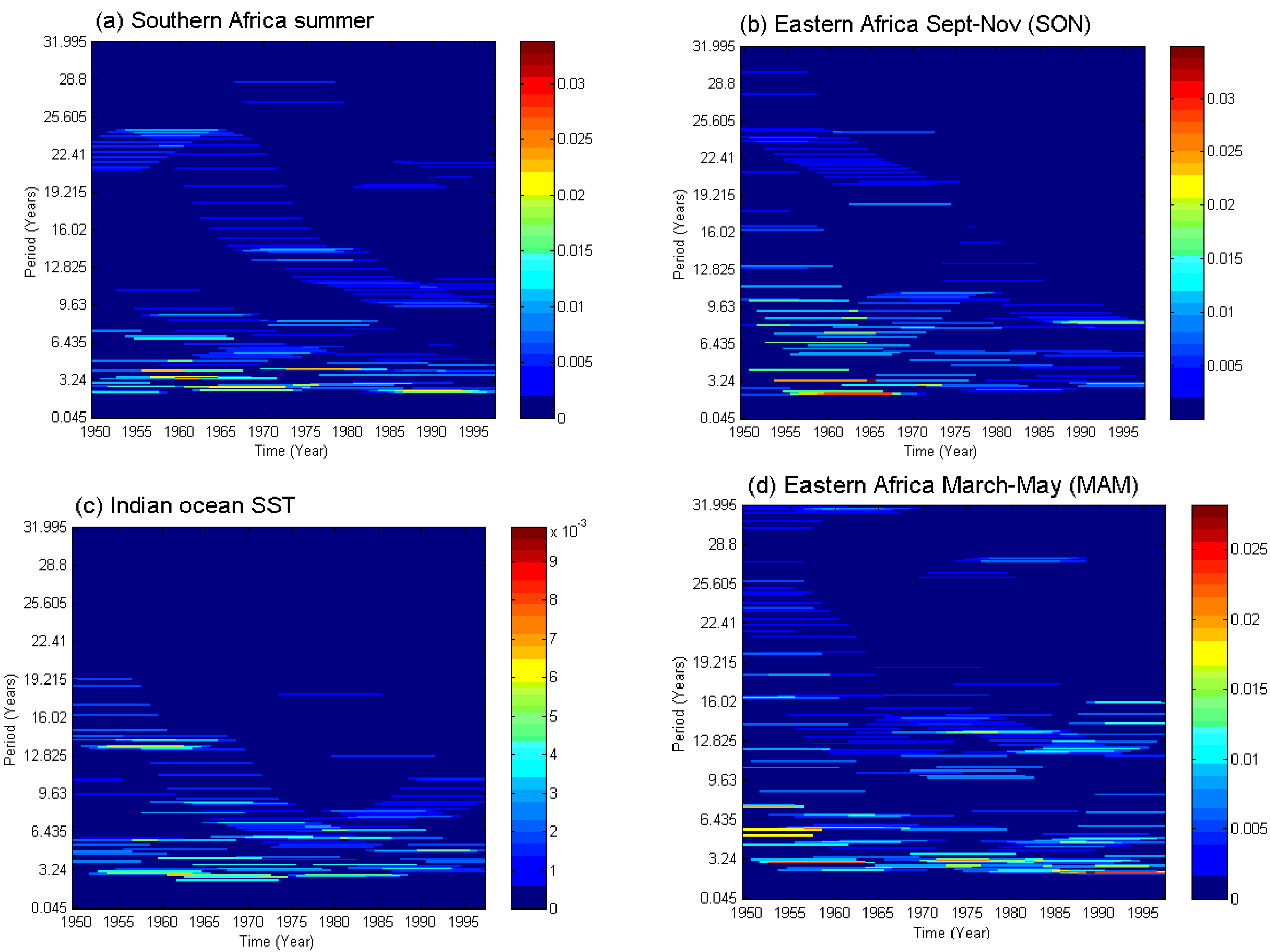
$$X(t) = \cos(\omega t + \varepsilon \sin \omega t)$$



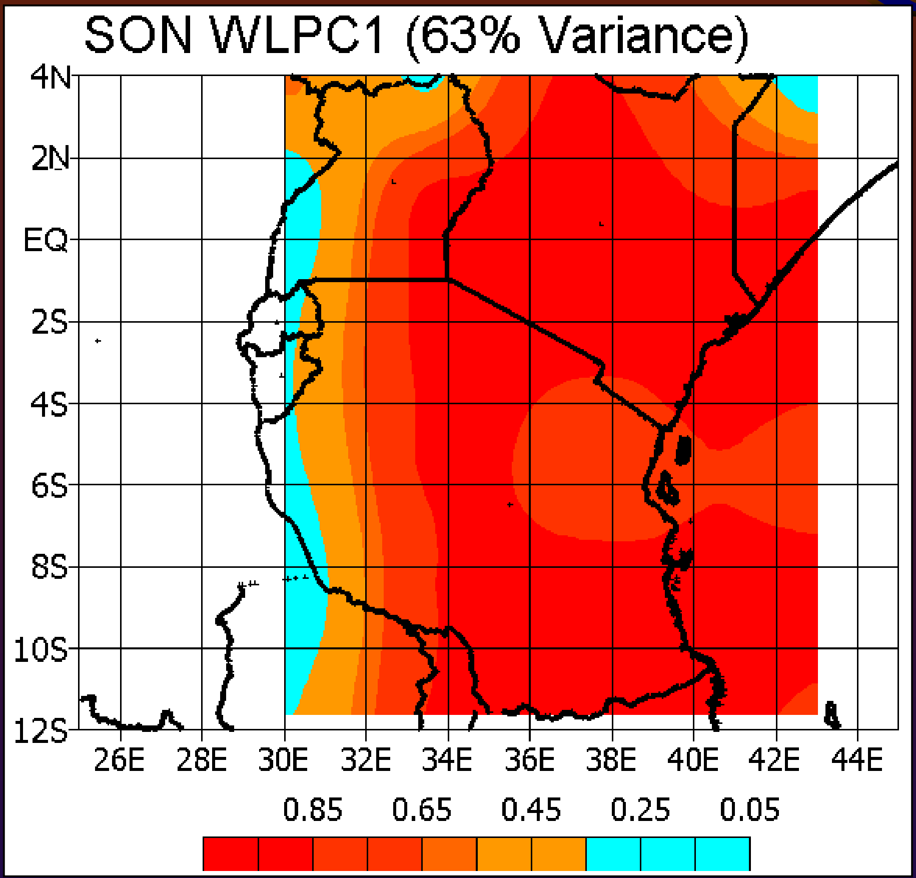


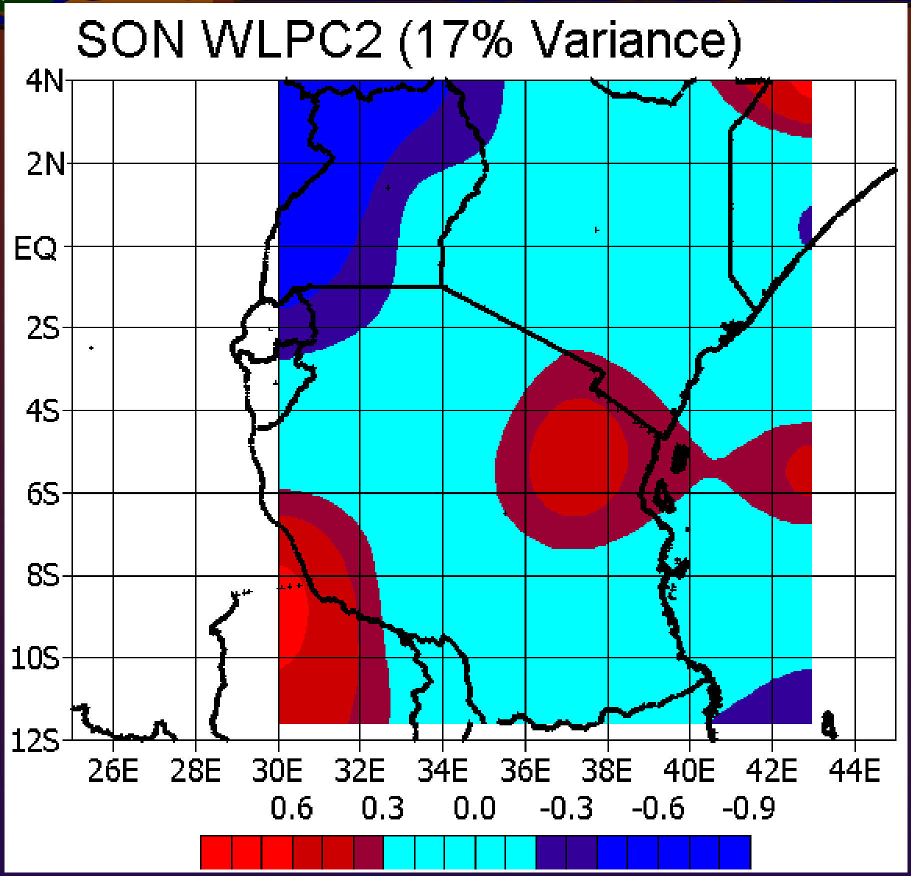





(a) Southern Africa summer
(b) Eastern Africa Sept-Nov (SON)
(c) Indian ocean SST
(d) Eastern Africa March-May (MAM)
Period (Years)
Time (Year)
31.995
28.8
25.605
22.41
19.215
16.02
12.825
9.63
6.435
3.24
0.045
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
0.03
0.025
0.02
0.015
0.01
0.005
0
x 10^-3
9
8
7
6
5
4
3
2
1

East Africa Rainfall: Spatial Modes 1 & 2



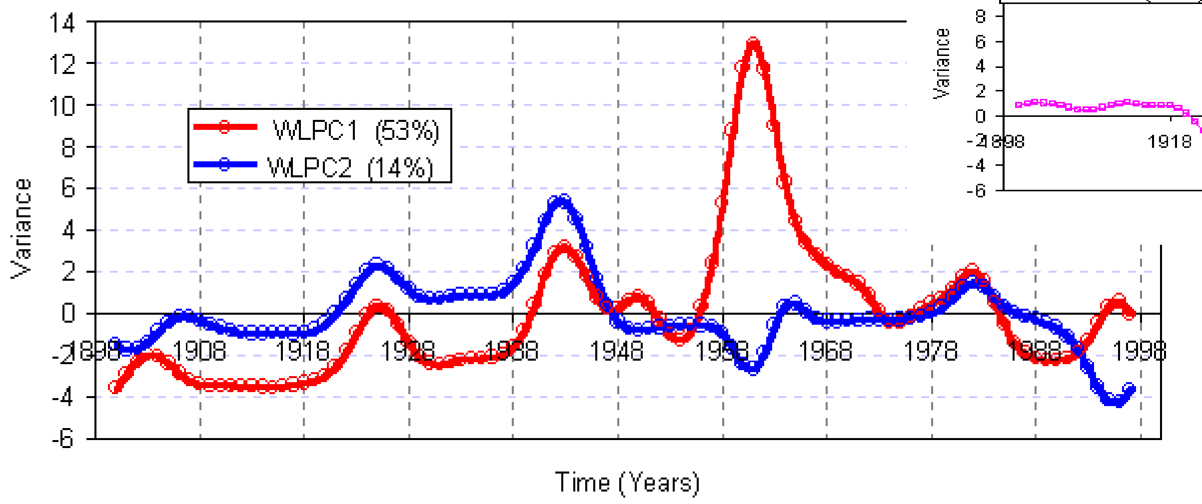


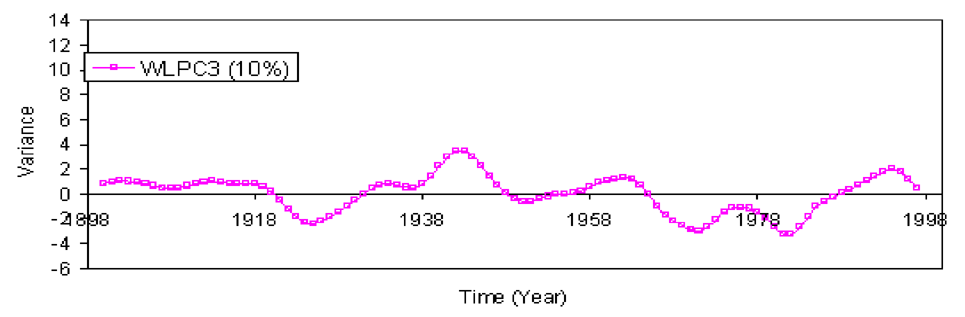
WEOF (WLPC) applied to 2.5° x 3.75° Scale-Averaged Wavelet Power (SAWP) or Frequency compacted energy variability

Pearson Correlations between WLPCs & individual SAWP

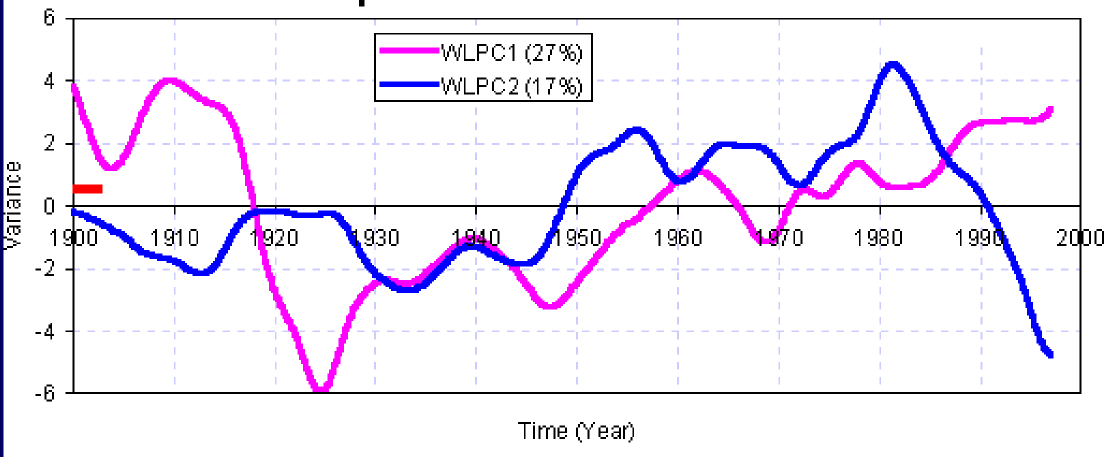
Wavelet Principal Components 1, 2 & 3

SON Temporal Modes

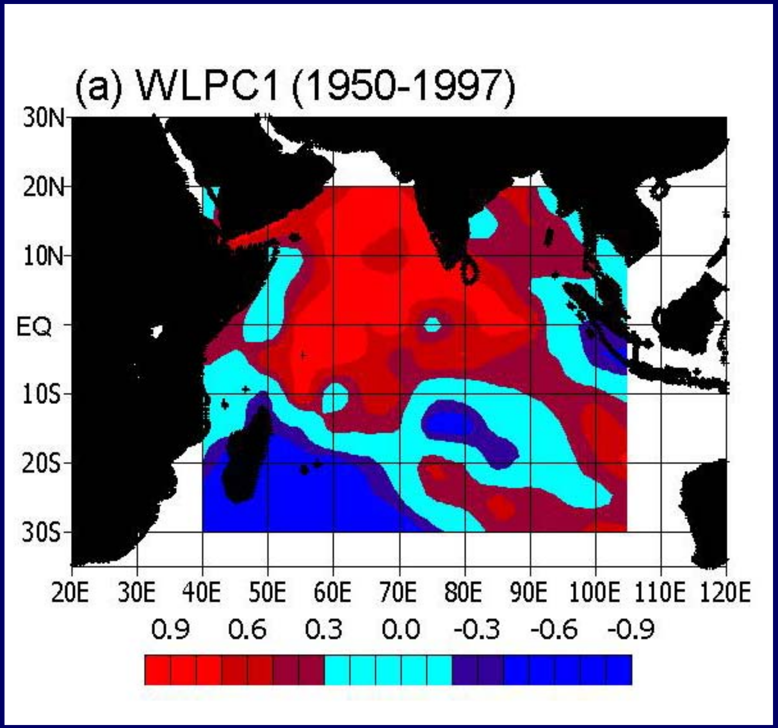


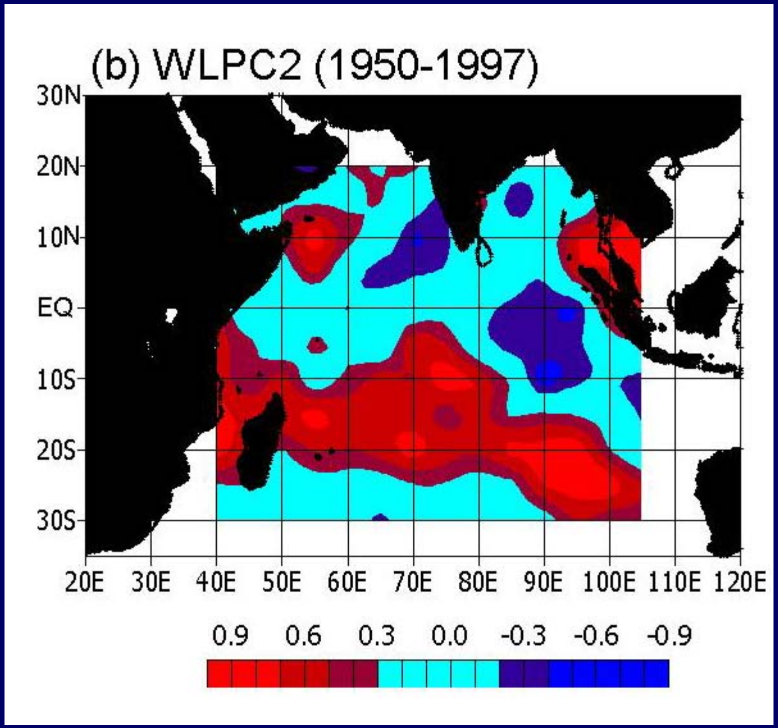


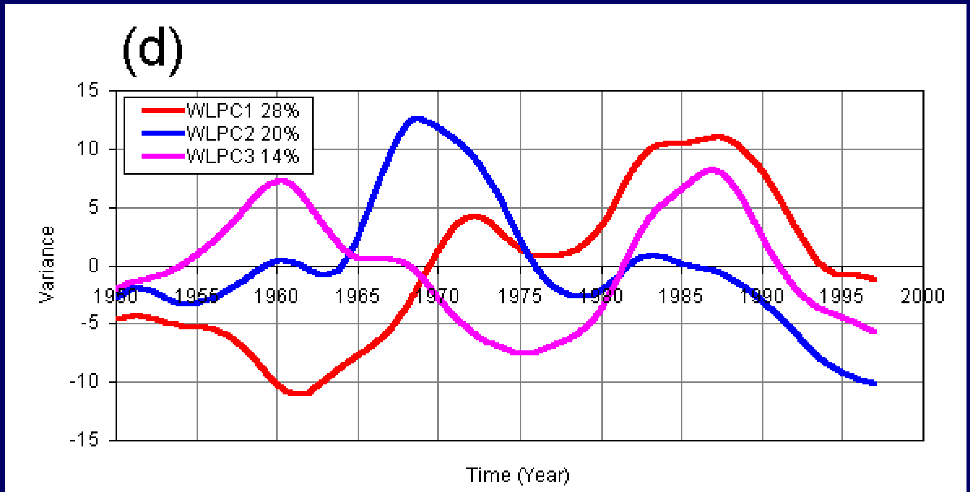
MAM Temporal Modes



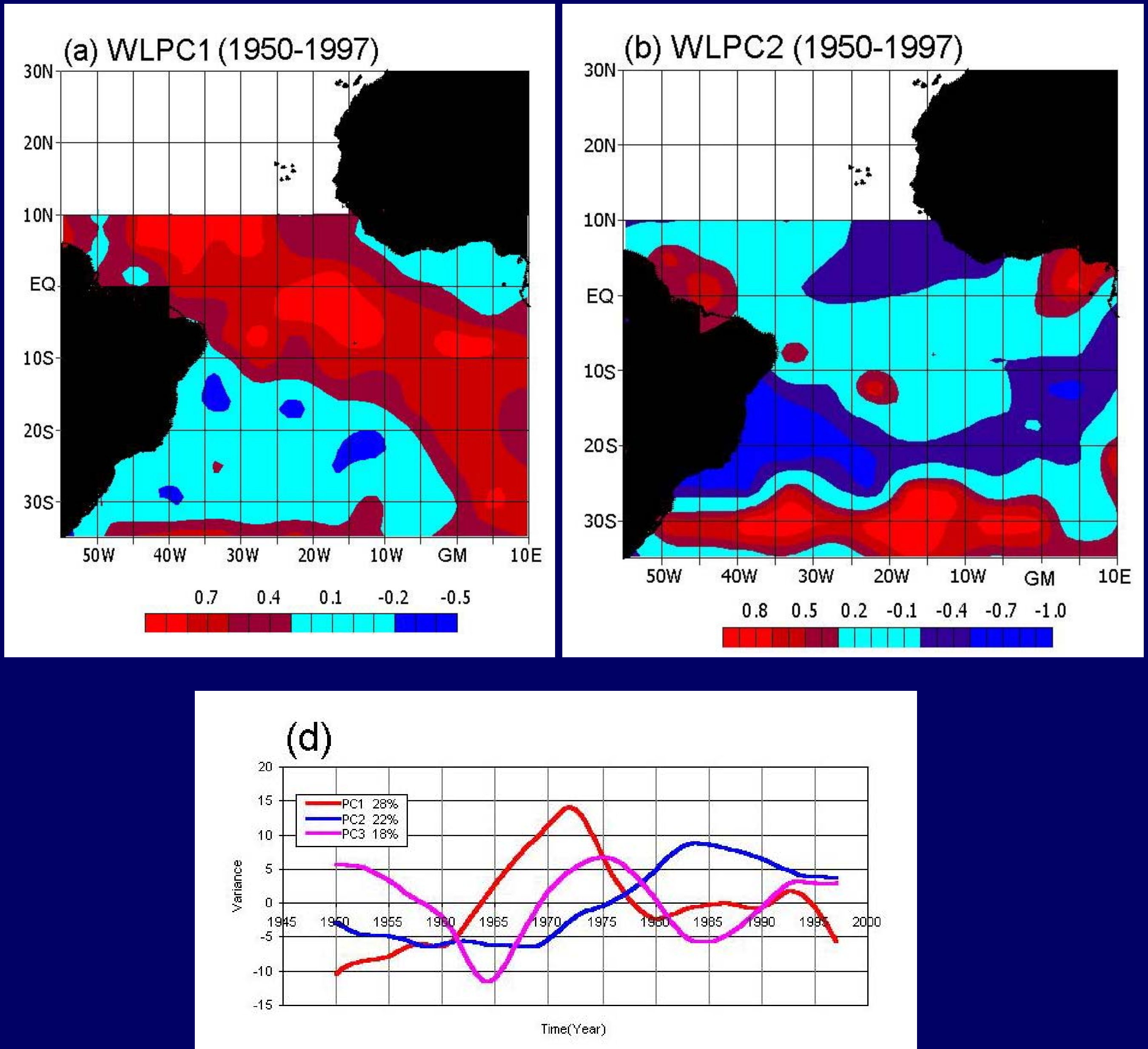
Modes of Variability (Indian Ocean)



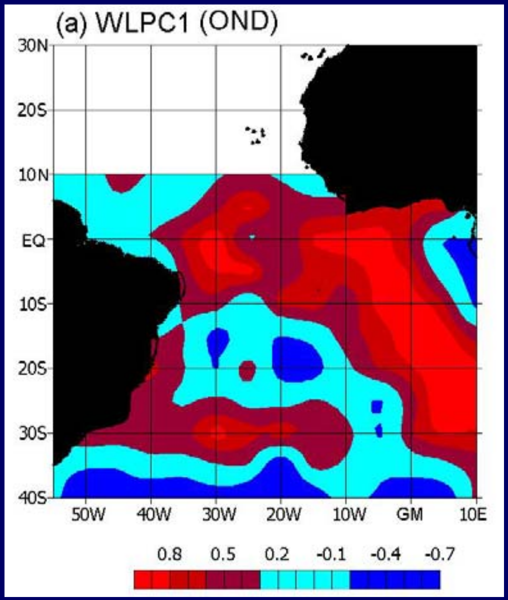


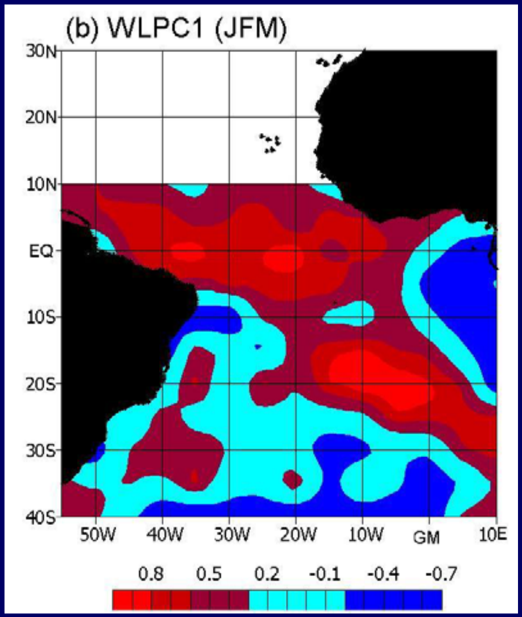


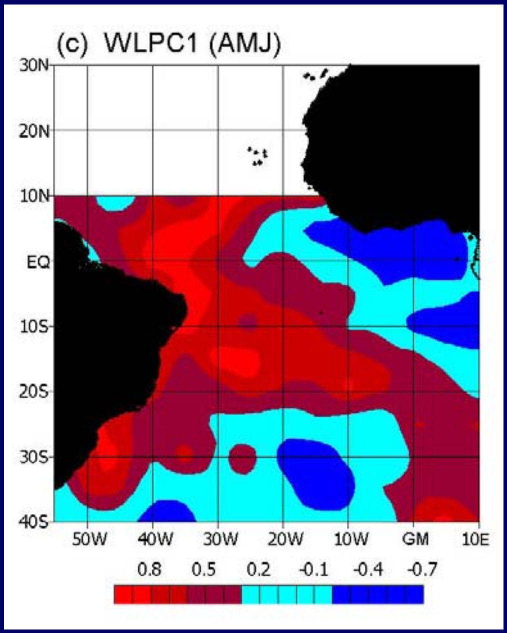
Modes of Variability (Atlantic ocean)

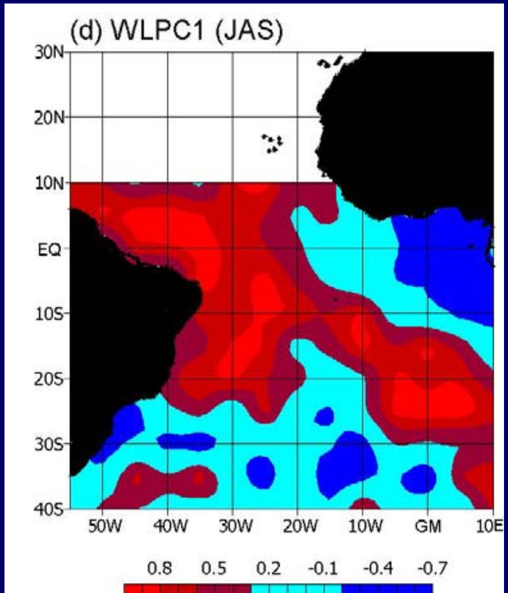


Modes of Variability (Atlantic ocean-Seasonal Variabilities)





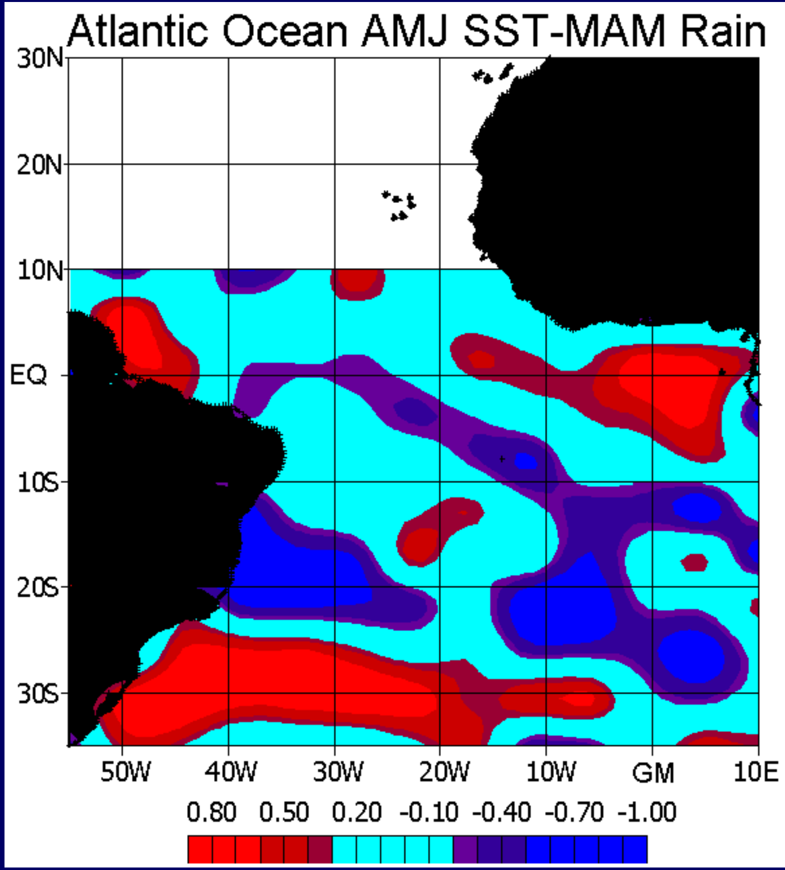


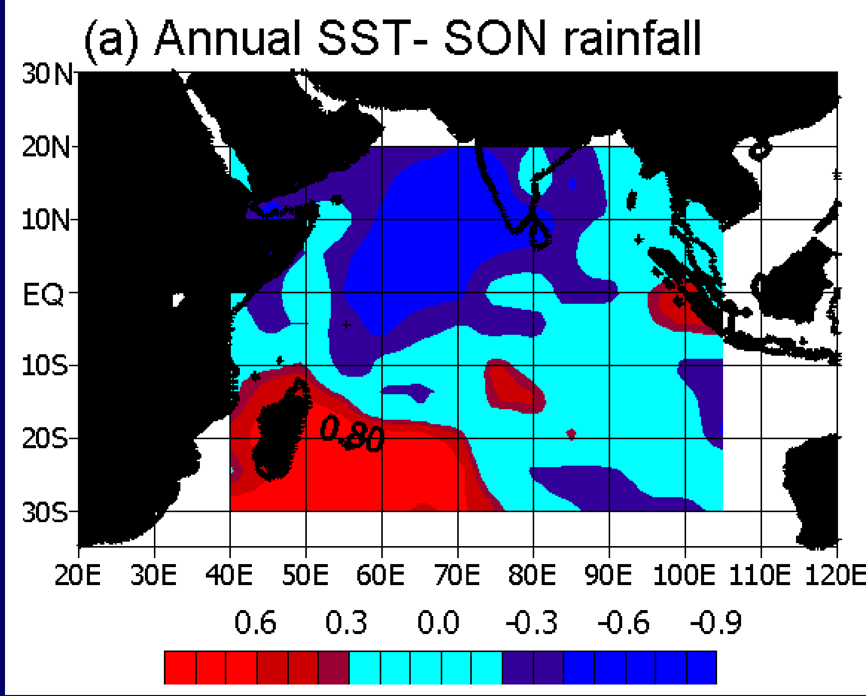


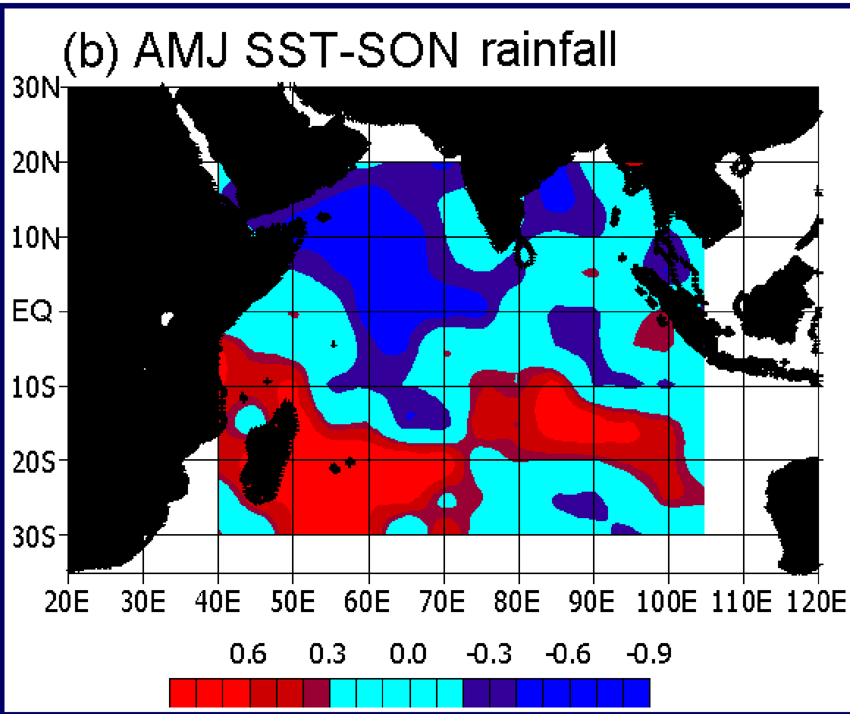
1. Seasonal variabilities migrate between Africa and S. America

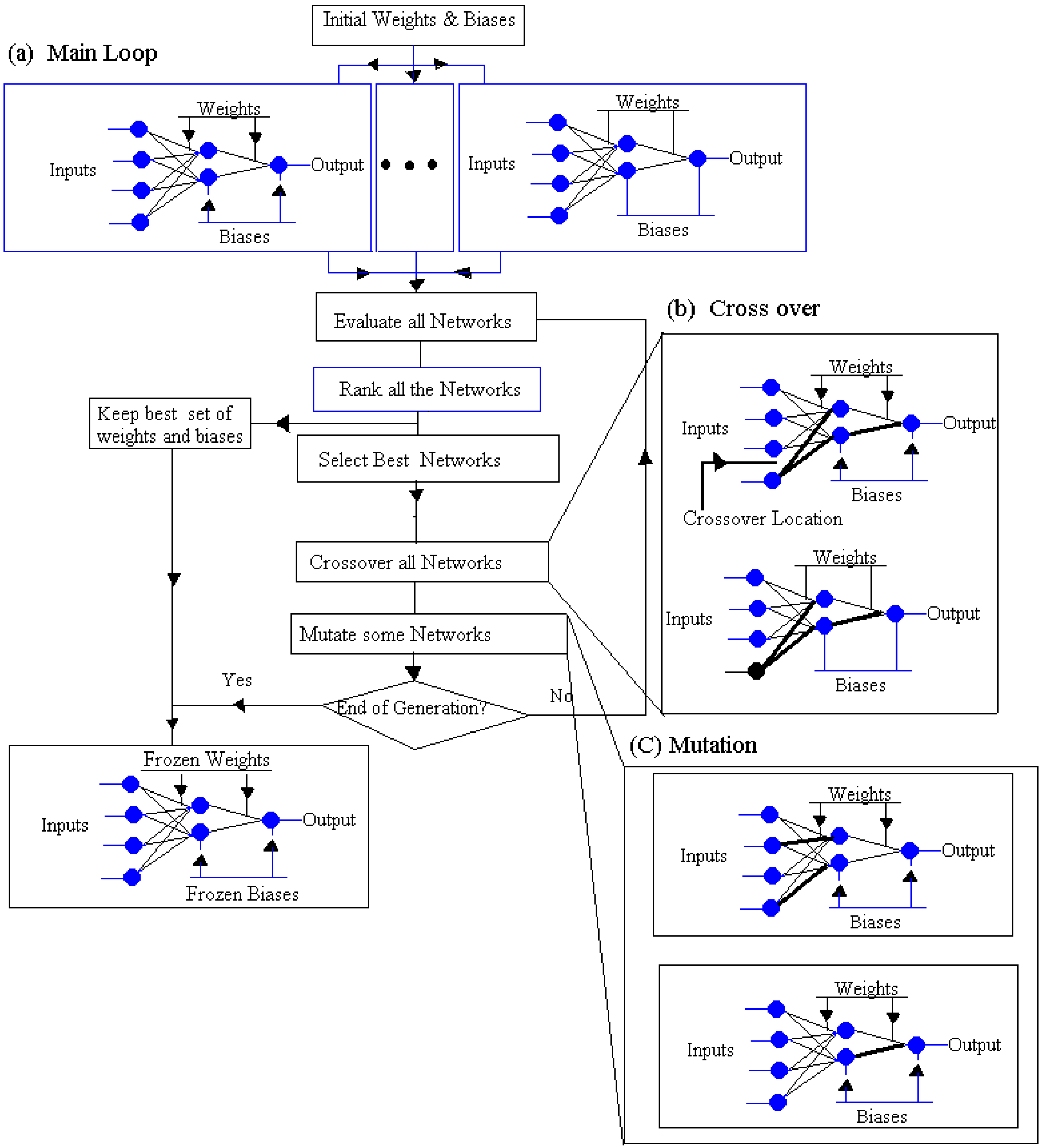
2. Strong links with coastal and near coastal area rainfall

Correlation between WLPCs of SON (MAM) Rainfall & each 5 x 5 grid box of Annual/AMJ SST in both oceans





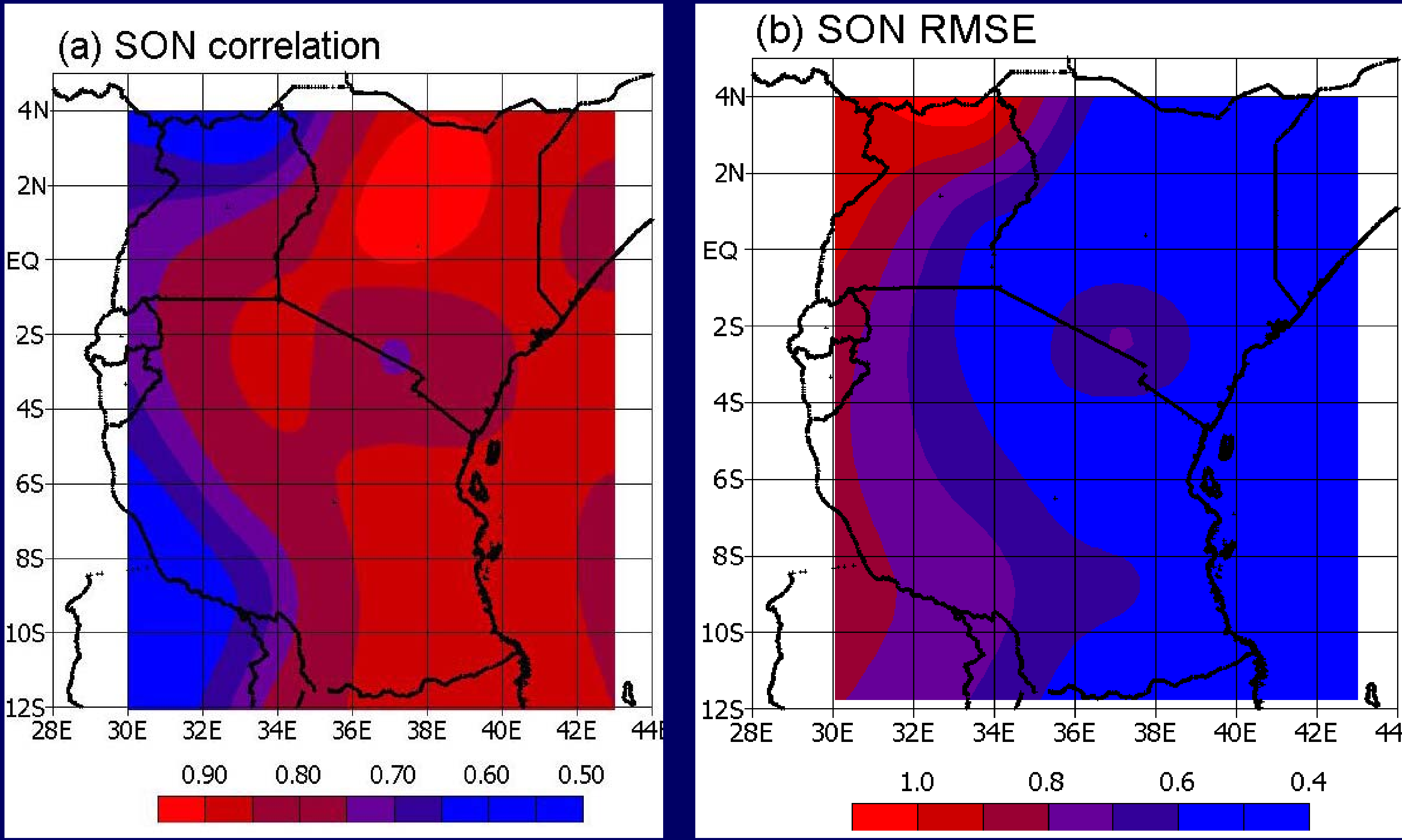




ANN-GA

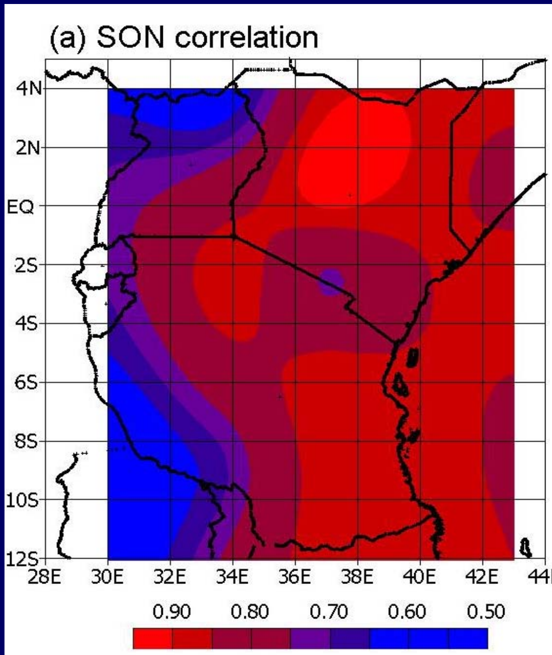
- 3-Layer ANN trained by Genetic Algorithm:
- (a) Main (Rank) – keep 80-90%
- (b) Cross Over – 100%
- (c) Mutation – 1%

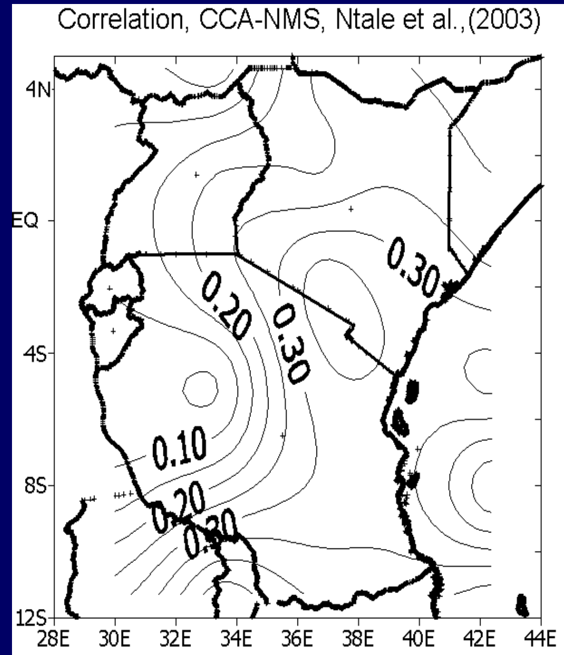
Predicted Rainfall 1987-1997

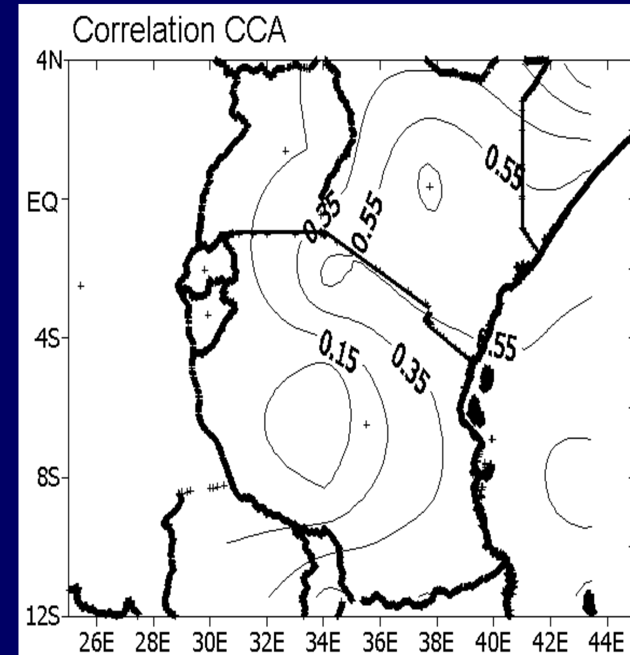


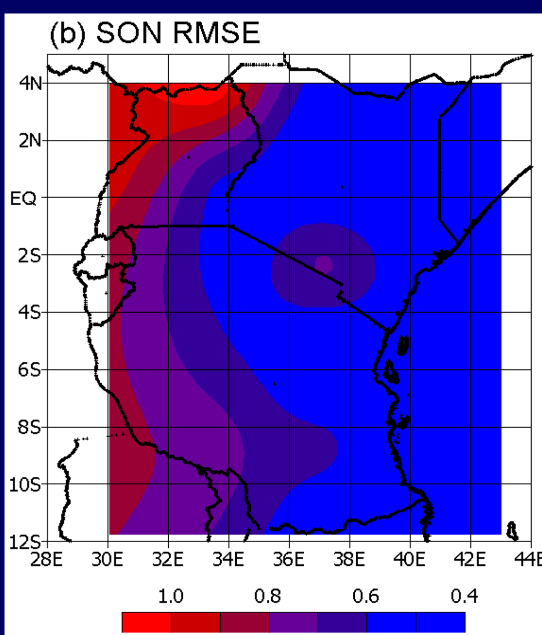
(1) Skill is high and structure follows I.D. signal (2) Confirms Signal ID by Wavelet and EMD-Hilbert based analysis (3) Predictor data is robust!

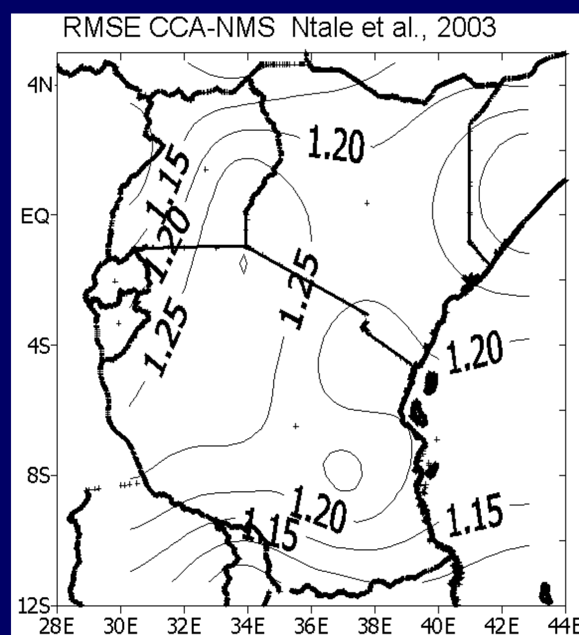
Comparison of prediction skill with Other Models

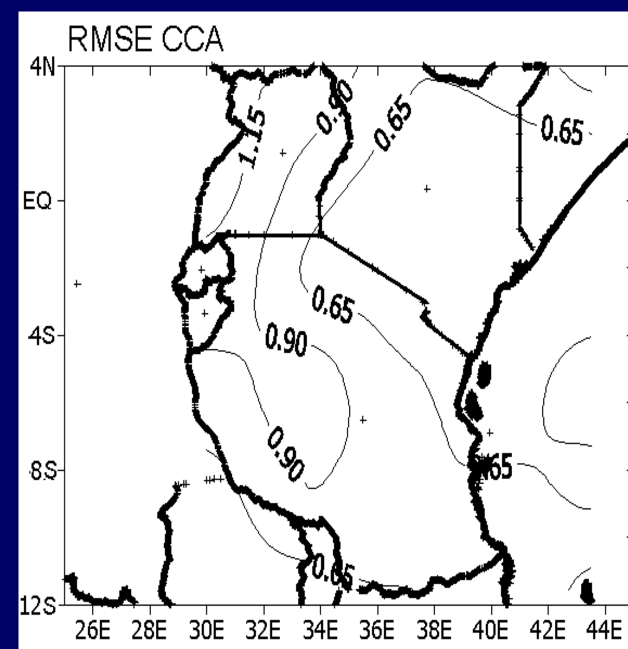


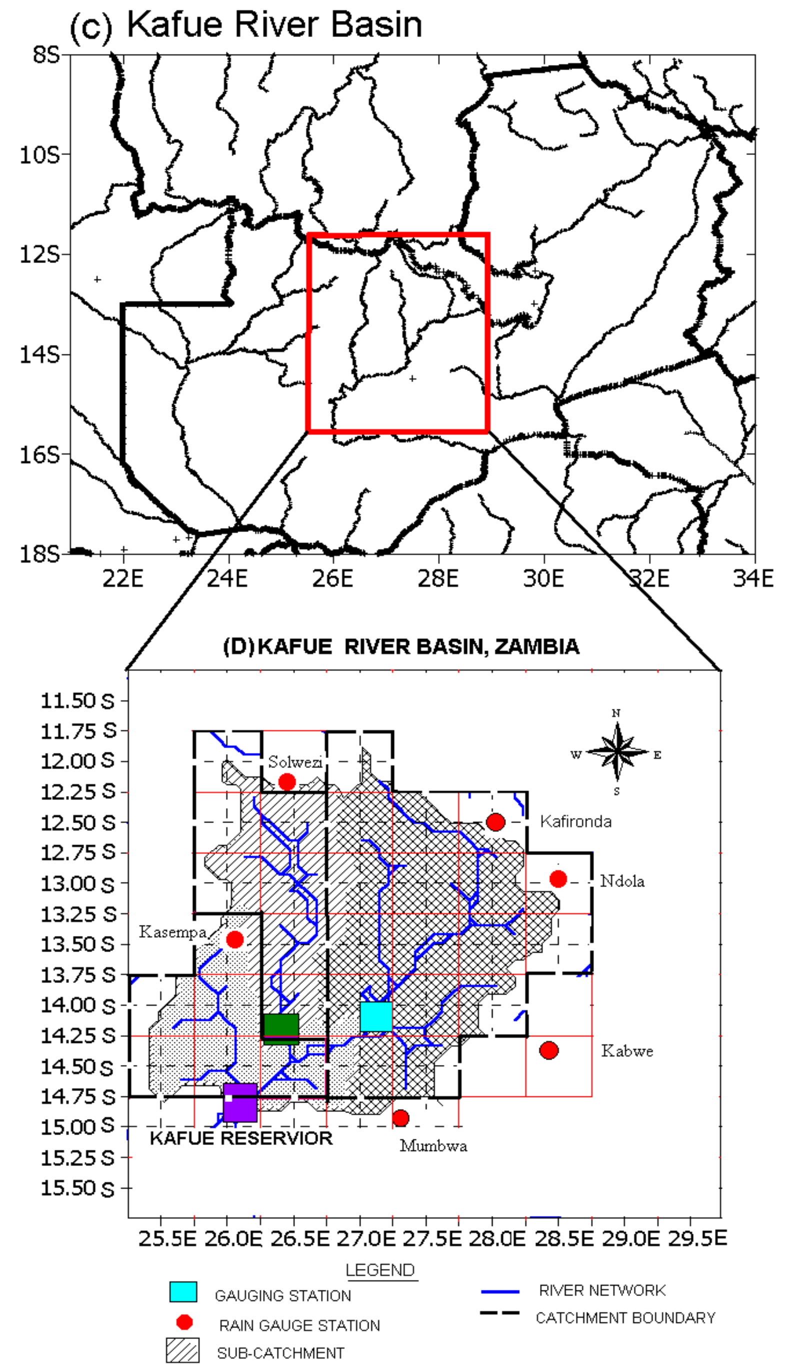


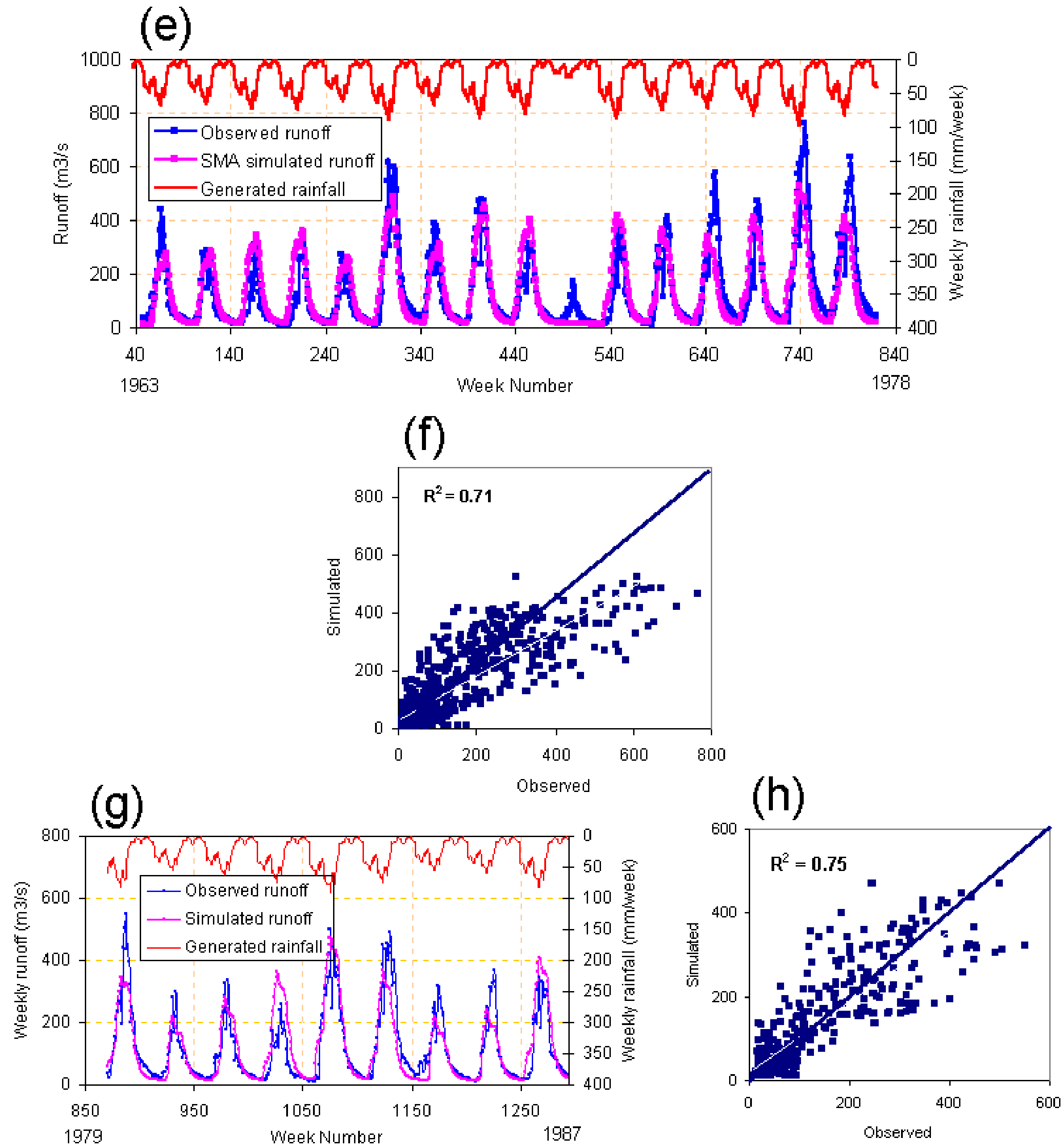









(c) Kafue River Basin
8S
10S
12S
14S
16S
18S
22E
24E
26E
28E
30E
32E
34E
(D) KAFUE RIVER BASIN, ZAMBIA
11.50 S
11.75 S
12.00 S
12.25 S
12.50 S
12.75 S
13.00 S
13.25 S
13.50 S
13.75 S
14.00 S
14.25 S
14.50 S
14.75 S
15.00 S
15.25 S
15.50 S
25.5E 26.0E 26.5E 27.0E 27.5E 28.0E 28.5E 29.0E 29.5E
N
W
E
S
Solwezi
Kafironda
Ndola
Kasempa
Kabwe
Mumbwa
KAFUE RESERVIOR
LEGEND
GAUGING STATION
RAIN GAUGE STATION
SUB-CATCHMENT
RIVER NETWORK
CATCHMENT BOUNDARY

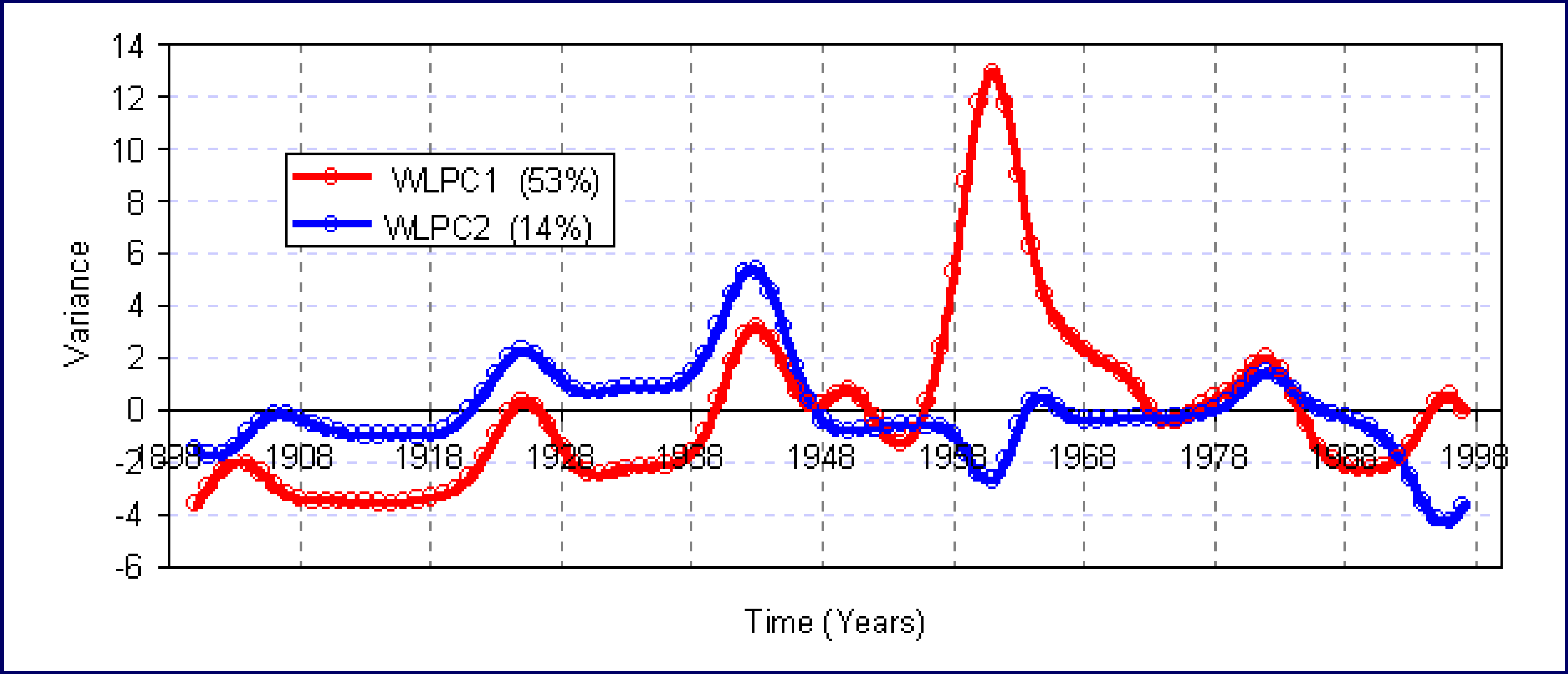


- simulated data (e) to (h)

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?



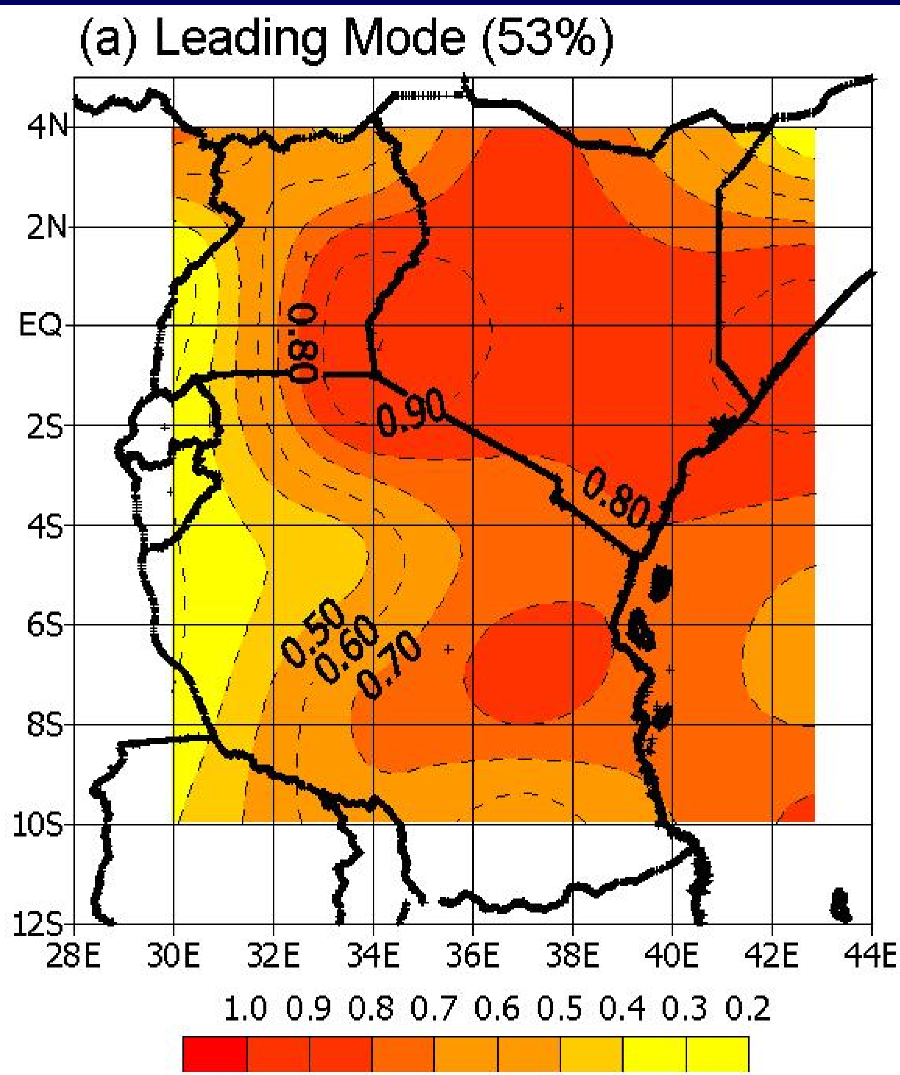
* Persistent 2 to 2.4-year: SST-rainfall, Good for prediction

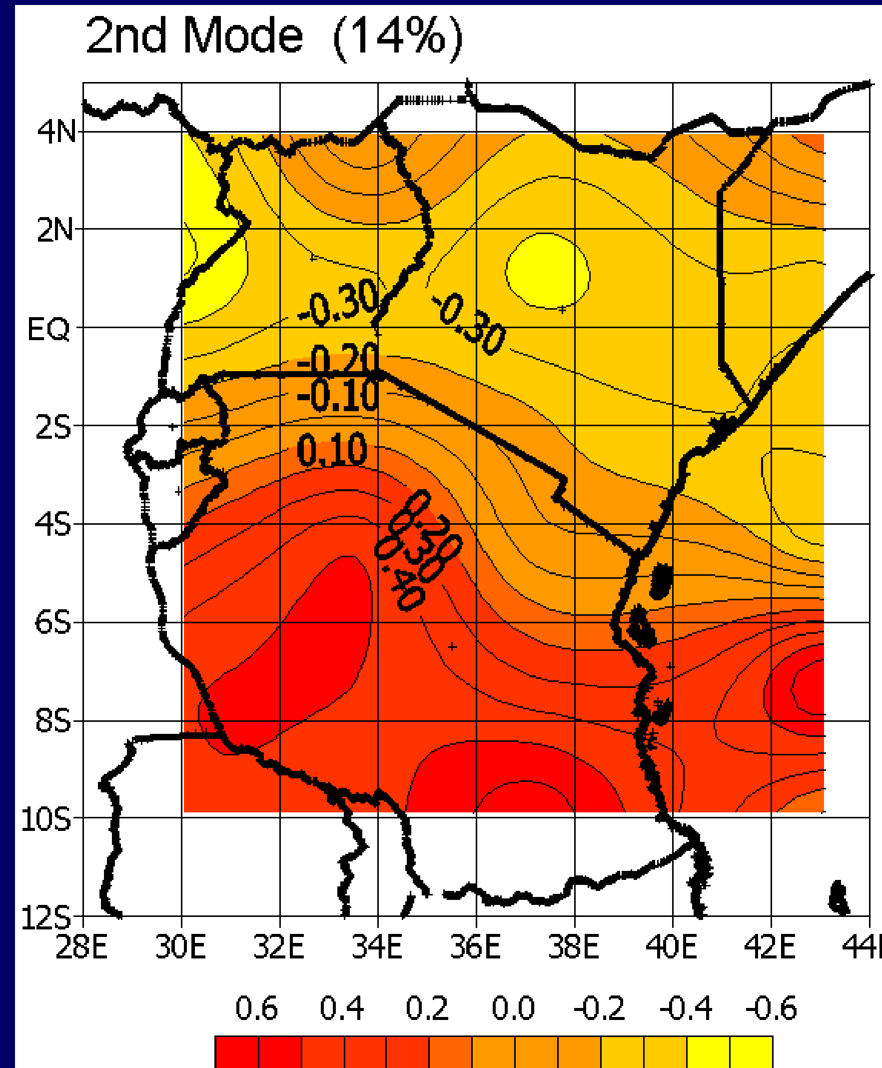
*2-2.4 cycle sign for drought : 1949, 1965-1997

*Quasi 20,100- year cycle: Good for long term planning

- Fourier Analysis in the 1970-1990, Tree ring, Temp, streamflow. Got the
- predictions wrong.

East Africa Rainfall: Spatial Modes 1 & 2





WEOF (WLPC) applied to 2.5° x 3.75° Scale-Averaged Wavele

Power (SAWP) or Frequency compacted energy variability

East Africa Rainfall: Spatial Mode 3

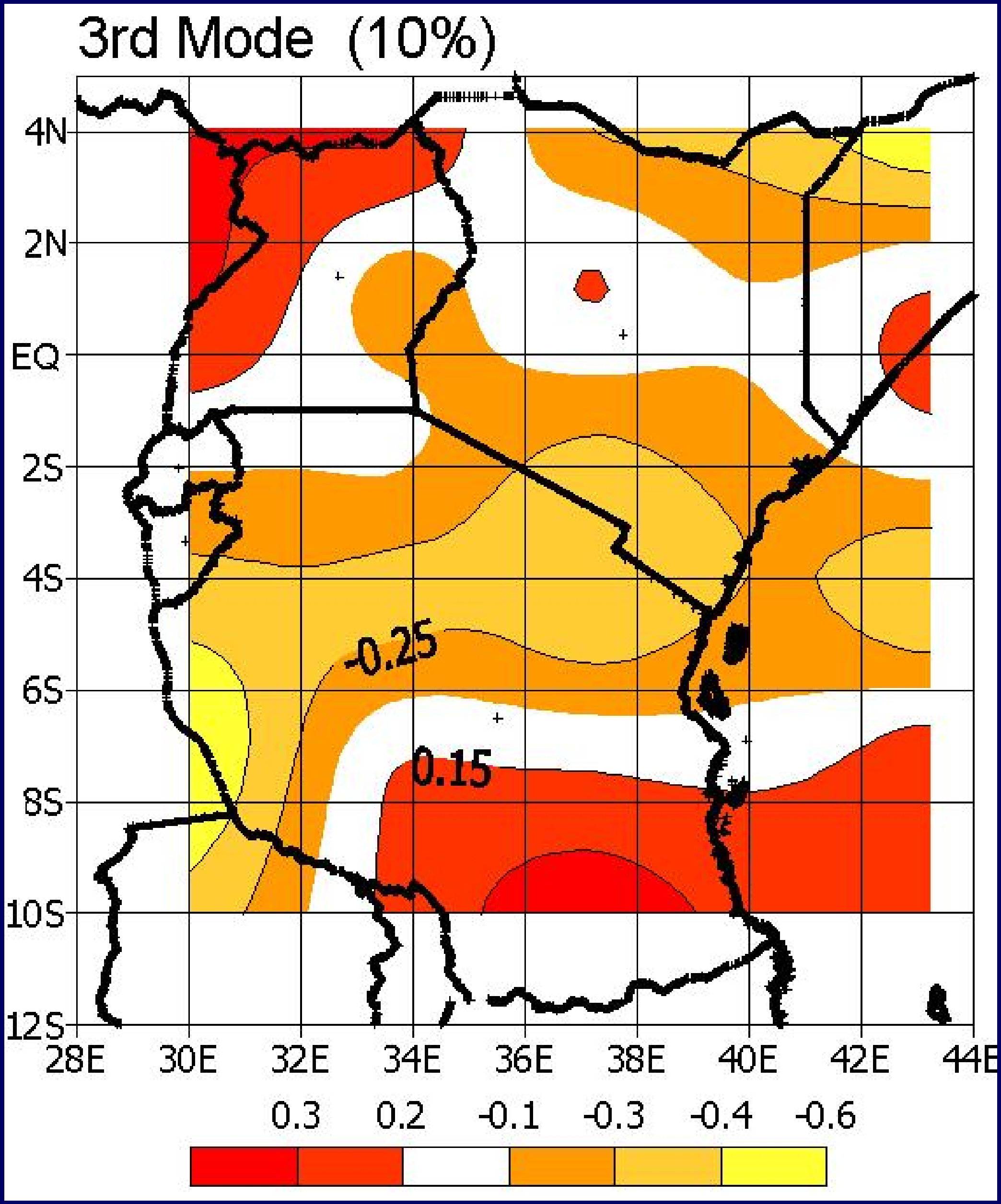


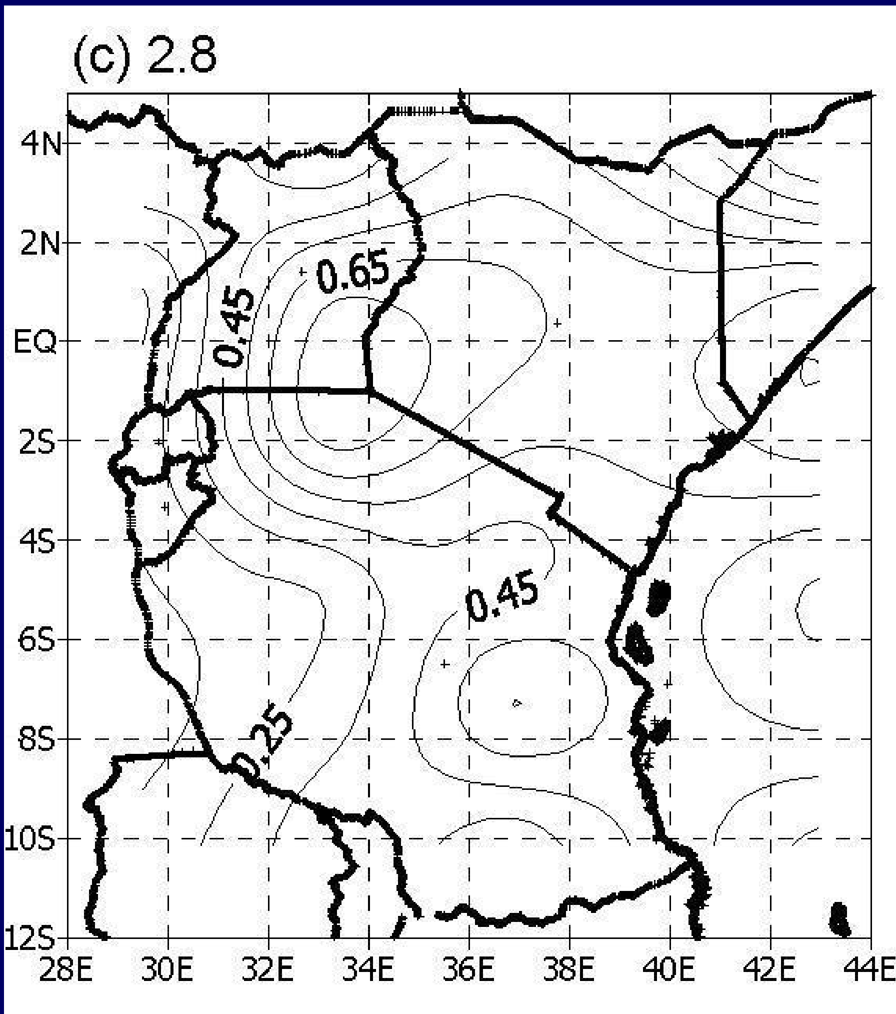
Table 1. Major Drought Episodes in East Africa in the 20th Century (Taken from Ntale 2001).

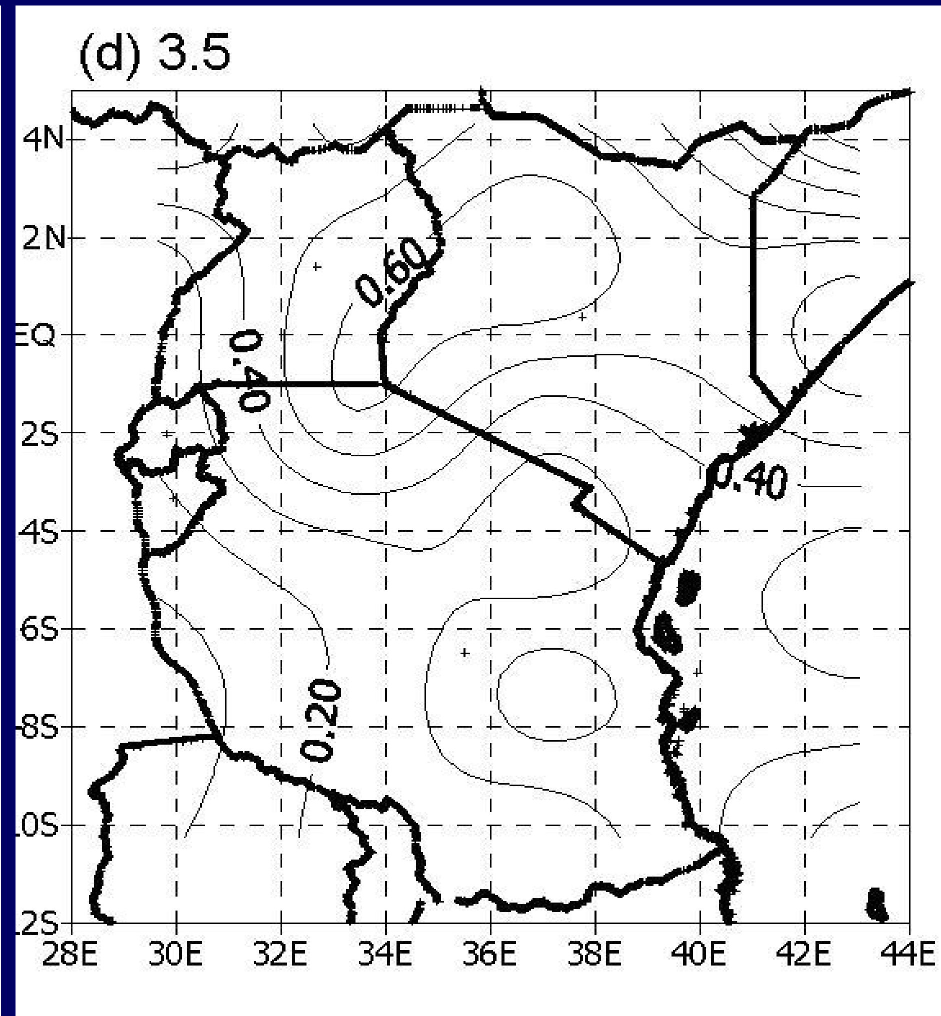
PERIOD	AREAS AFFECTED	COMMENTS
1899	Most parts of East Africa especially Kenya	Lake Stephanie dried up
1900	Central Tanzania	More than 60,000 died
1949	**Most of East Africa**, especially Sukuma District, central Tanzania	1.5 million cattle died or hastily slaughtered out of a population of 2.5 million
1965	Dry Belt of **Kenya**	260,00 people affected
1967 1971 1977	Karamoja, **Uganda** Wide spread in **Kenya** Wide spread in **Kenya**	25,000 people affected 1.5 million people affected In may, 100 people killed, 20,000 people affected
1979	Tukana District in **Kenya**	40,000 people affected
1979	North and NW **Uganda**	600,000 people affected
1984	Most of Kenya and Tanzania	Complete failure of long rains. Worst drought in Kenya in 40 years,
1984 1987	Arid district of **Kenya** Karamoja, **Uganda**	600,000 people affected 331,000 people affected
1988	NW Uganda	600,000 people affected
1990	North and NE arid districts of **Kenya**	1.2 million people affected. Worst maize crop in 10 years.
1991	North and NE arid districts of **Kenya**	2.7 million people affected. Worst maize crop in 105 years
1992	North and NE arid districts of **Kenya**	Continuing drought
1996/97	Central Tanzania	Late 1996, early 1997 Worst drought in 50 years. Cities face major shortages

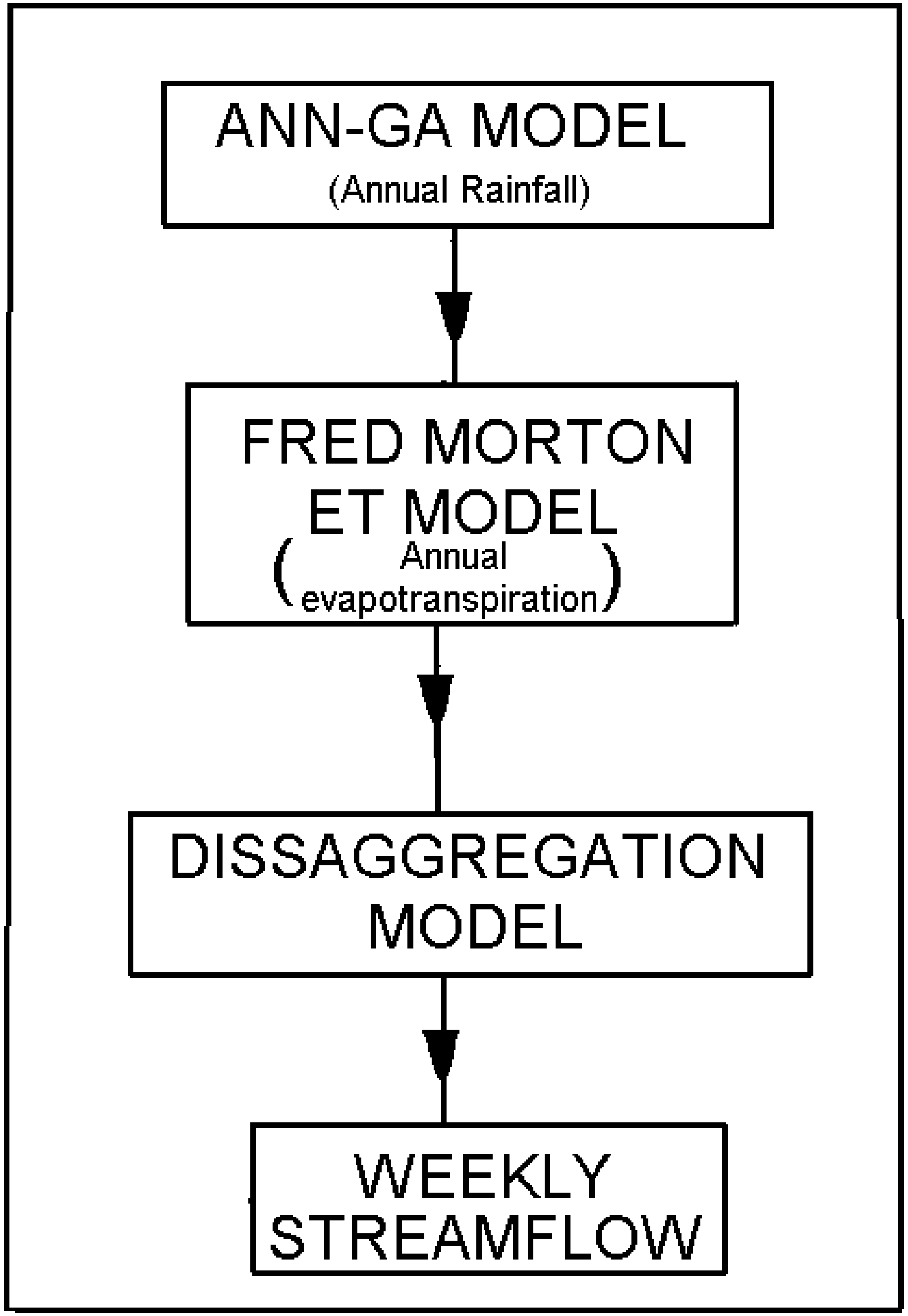
2002, Southern Africa, 15 Million Face Starvation

Spatial Variability of Frequency Modes

(2.8 & 3.5 year)



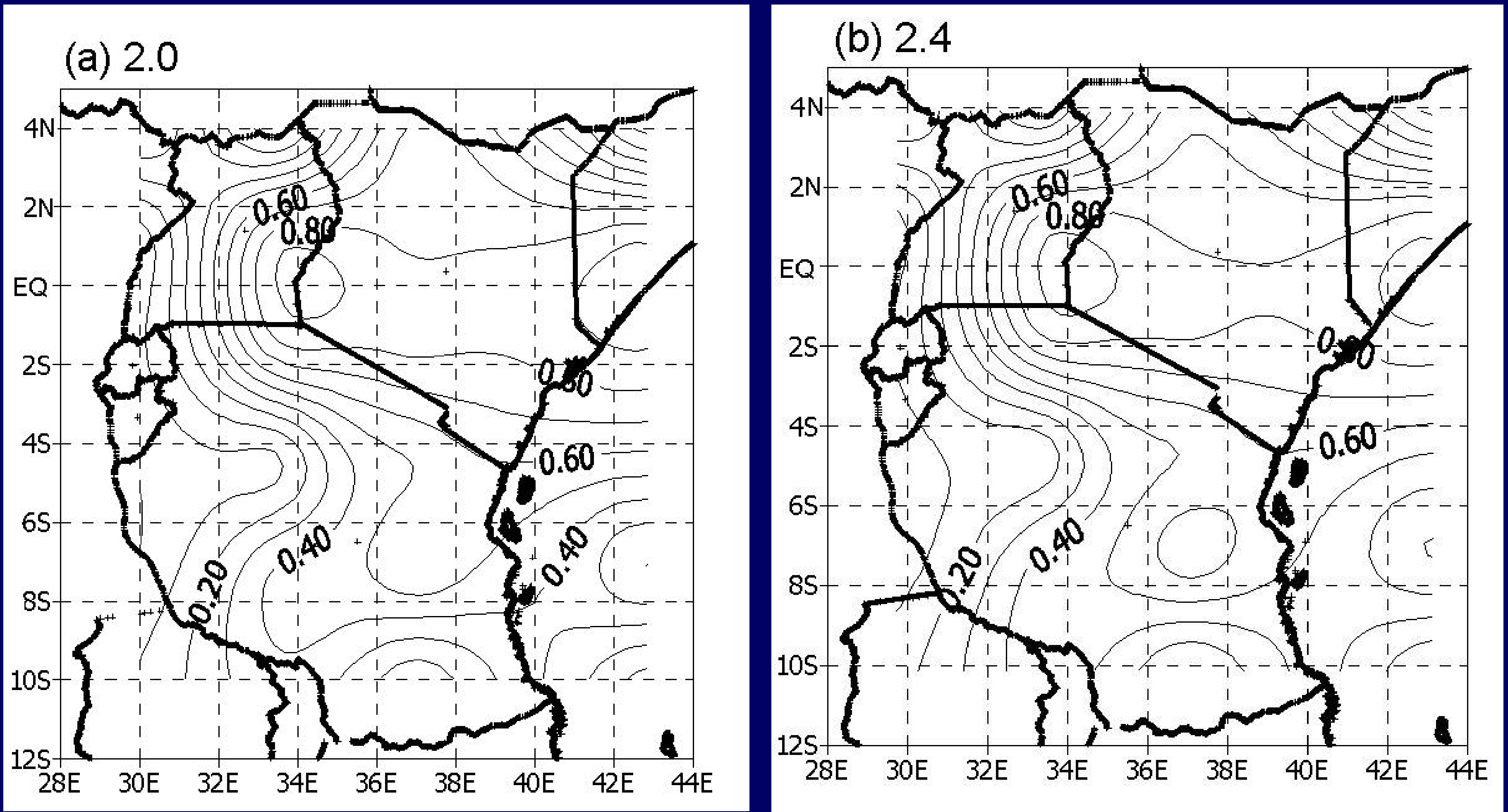




ANN-GA MODEL
(Annual Rainfall)
FRED MORTON
ET MODEL
(Annual evapotranspiration)
DISSAGGREGATION
MODEL
WEEKLY
STREAMFLOW

Spatial Variability of Frequency Modes

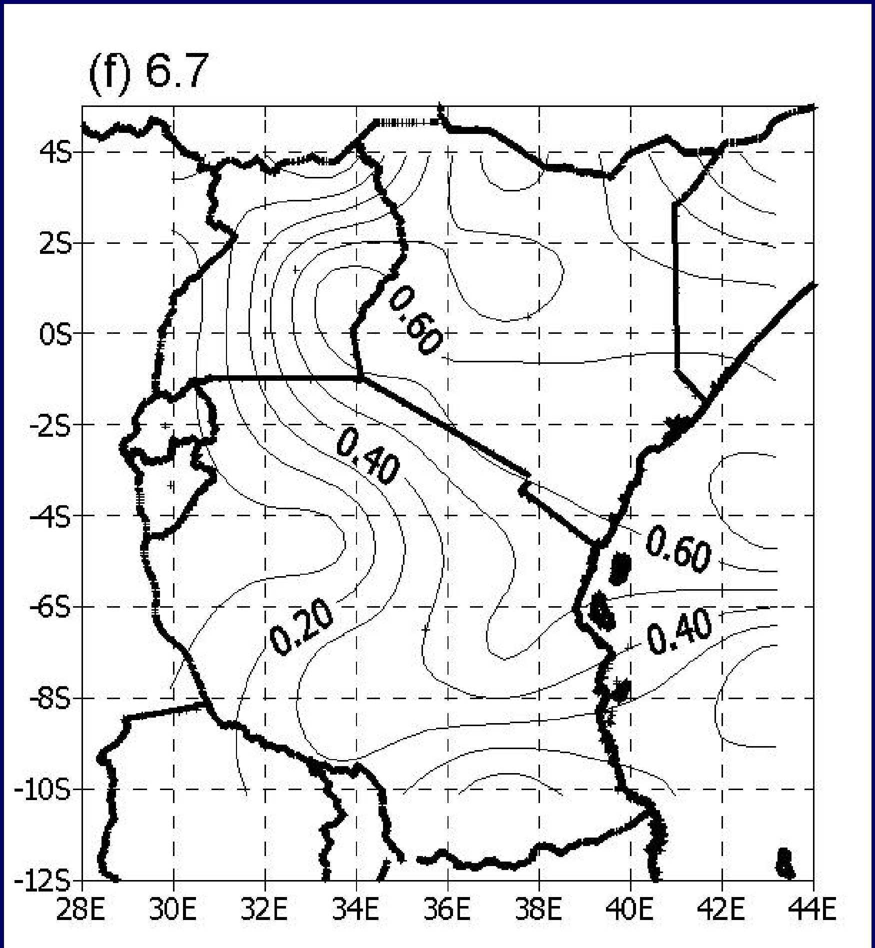
(2 and 2.4 year)

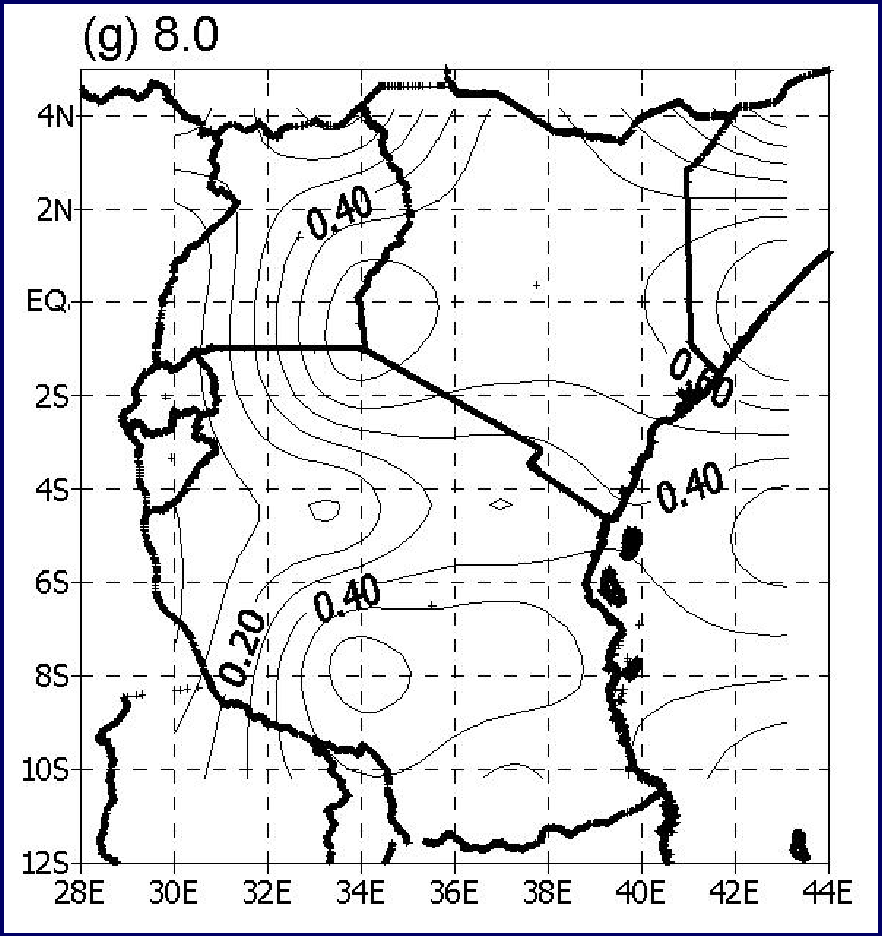


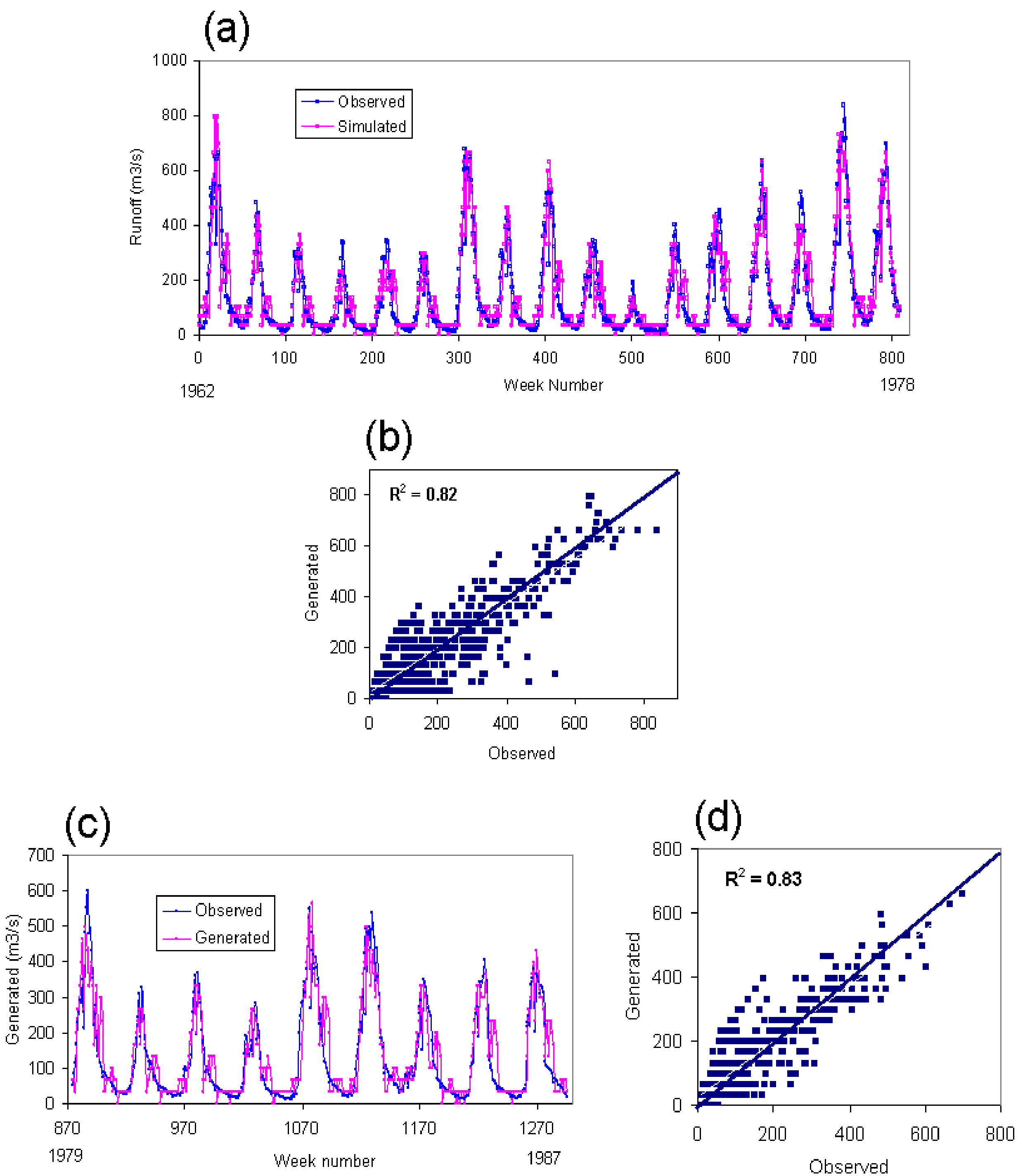
WEOF applied to 2-yr & 2.4 yr of wavelet spectra

Spatial Variability of Frequency Modes

(6.7 & 8 year)







- Statistically generated data (a) to (d)