Analysis of Durban rainfall and Nile river flow 1871–1999

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With 7 Figures

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Summary

Climatic fluctuations across Africa are analysed from two century+ records of rainfall at Durban, South Africa and the Nile River flow in southern Egypt. A wavelet transform analysis is applied to the rainfall record to determine the strength of intra-seasonal to decadal rhythms. The annual cycle constitutes 33% of variability, whilst 2.3–4 year cycles account for 10% of the variance. A contingency analysis of flood events reveals a bimodal character with peaks in November and March. The Durban rainfall time series is compared with remote environmental variables. Close relationships are found with the meridional gradient of sea surface temperature in the Atlantic and the southern oscillation index. Comparisons are made between the southern summer rainfall at Durban (November–March) and northern summer Nile River flow (July–October). Cross-wavelet analysis of the two records indicates a matching of frequency in quasi-biennial and El Niño frequency bands. This suggests that the uptake of ‘teleconnections’ governing African climate occurs in a widespread manner.

1. Introduction

Recent studies of the African climate system suggest that some of the year-to-year variability may be widespread (Jury, 2000a). Ocean-atmosphere coupling over the tropical Atlantic, in response to El Niño (EN) phase, was found to induce common fluctuations of African rivers: the Nile, Congo, Niger and Zambezi. During high flow years, the upper level circulation becomes easterly over Africa, and dry conditions arise over South America (Amarasekara et al., 1997). Here the temporal nature of African climate variability is further explored using long-term data sets in northern (24° N) and southern (30° S) Africa.

Africa’s southeastern coast has a dense vegetation cover sustained by intermittent rains produced when humid air is drawn upslope from the nearby warm Agulhas Current (DeJager and Schulze, 1977; Walker, 1990; Jury et al., 1993). Mean annual rainfall is about 1 m at Durban – a large urban centre in South Africa requiring \(10^9\) m\(^3\) per year of water for consumption. Summer rains are produced when anticyclones ridge eastward along the coast, bringing southerly (onshore) winds (Diab et al., 1991; Miron and Tyson, 1984). Sea surface temperatures east of Durban act as climatic determinants and exhibit quasi-biennial (QB) frequencies Walker (1990).

Some 5000 km to the north of Durban lies the Nile River, draining the Ethiopian highlands (80%) and Sudan (20%). The Nile River flow has been extensively studied and linked with the global El Niño phenomenon (Bliss, 1925; Quinn, 1992; Eltahir, 1996). The correlation between the Nile flow and the Pacific Niño 3 sea surface temperature (SST) index in the period 1871–1997 is \(-0.54\) at zero lag (Eltahir and Wang, 1999). Warming in the equatorial eastern Pacific causes an indirect circulation and sinking motion over much of Africa, including the source of the Nile, suggesting that climatic influences are widespread.
In this study, we analyse long-term climate records for:

- Intra-seasonal to decadal variability,
- Extreme events and cross-spectral character,
- Relationships with remote climatic indices.

Our aim is to establish the historical context of climate variability in Africa, particularly its temporal character at two select points with long-term records.

2. Data and methods

2.1 Rainfall

Monthly rainfall data were obtained from the S A Weather Bureau for the period 1872 to 1999 – 128 years at the Durban Botanical Gardens (30° S, 31° E) located near the coast at an elevation of 91 m. Comparisons of monthly rainfall with adjacent stations yielded good agreement (< 10% departure each month) in periods of data overlap. Hence the long-term record could be accepted as accurate.

Many features of the Durban data are representative of a wider region according to principal component analysis (PCA) of summer rainfall anomaly maps. Although much of the rainfall is convective, the Durban results may be applicable to the eastern half of South Africa, encompassing the maize belt.

Monthly rainfall data were subjected to a contingency analysis to identify cases > 200 mm. A more detailed analysis of the temporal character of the Durban rainfall was achieved using the wavelet transform method described below. In addition, streamflow data for the Nile River for the period 1871–1997 was provided by Eltahir and Wang (1999).

2.2 River flow

To characterise the inter-annual variability of the Nile River, monthly streamflow data were obtained for a number of gauges along the river, including:

- Roseris, Ethiopia, 1914–1989 located at 11° N, 35° E
- Dongola, Sudan 1912–1973 located at 19° N, 31° E, and

The data are based on quality-checked hydrographic records, naturalized for known anthropogenic effects (e.g., dams built) based on estimated water use, and published in scientific reports. Following intercomparisons between gauges, peak flow values were retained and the cumulative naturalised flow was calculated for the July to November inflow season each year, to reconstruct the 127 year time series following procedures adopted by Eltahir and Wang (1999).

2.3 Wavelet transform

The time-frequency character of long-term climatic data is investigated using the Continuous Wavelet Transform (CWT) technique (Daubechies, 1992; Lau and Weng, 1995; Torrence and Compo, 1997; Mallat, 1998). The CWT is a mathematical tool which allows the decomposition of the signal \( x(t) \) in terms of elementary contributions called wavelets, which can be thought of as a packet of sine waves of varying amplitude and wavelength. These wavelets are described from a single function \( \psi \) by translations and dilatations:

\[
\psi_{b,a}(t) = \frac{1}{a} \psi \left( \frac{t - b}{a} \right) \tag{1}
\]

where \( a > 0 \) is the dilatation (scale) parameter and \( b \) is the translation (position) parameter. As the CWT is used to both filter and analyse the data, we have normalized by \( 1/a \) (Delprat et al., 1992). The CWT of the signal \( x(t) \) with the analysing wavelet \( \psi \) is the convolution of \( x(t) \) with a set of dilated and translated wavelets:

\[
W_x(b,a) = \frac{1}{a} \int_{-\infty}^{\infty} x(t) \psi^* \left( \frac{t - b}{a} \right) dt \tag{2}
\]

where \( ^* \) denotes the complex conjugate. The wavelet transform is continuous through variations imposed on \( a \) and \( b \). The CWT expands the time series \( x(t) \) into two-dimensional parameter space \( (b,a) \) and yields a measure of the relative amplitude of local spectral activity at scale \( a \) and time \( b \). The choice of wavelet \( \psi \) depends on the signal to be analysed. In our case, the signal is relatively well defined in frequency, so we select a wavelet that is localised in frequency space – the