The coherent variability of African river flows: Composite climate structure and the Atlantic circulation

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Abstract

The composite structure of the ocean and atmosphere around Africa is studied in the context of river flow variability. Annual streamflows are analysed for the Blue and White Nile, Congo, Niger, Senegal, Zambezi, and Orange Rivers, and inflow to Lake Malawi. Spectral energy is concentrated in 6.6- and 2.4-year bands. The interannual variability of many river flows is significantly cross-correlated ($p < .05$) over the period 1950-1995, following removal of the mean trend. A combined river flow index indicates that flows were highest in 1961, 1962, 1968, 1977, 1978 and lowest in 1971, 1972, 1982, 1983, 1991.

Forming a composite of differences between high- and low-flow years, SST anomalies and other atmospheric fields are investigated to better understand climatic factors driving hydrological extremes. During high flows, NCEP reanalysis data reveal a composite La Nina event off Peru-Ecuador. SST patterns reveal an inter-hemispheric dipole in the Atlantic (eg. warm - north) and below normal SST in the west Indian Ocean during years with high flow. The equatorial east Atlantic undergoes warming through the 'composite year' in a manner consistent with its opposing response to the Indo-Pacific La Nina. Tropical upper winds are easterly and symmetrical about the equator, and may explain why inter-annual variability of river flows south of the equator are correlated with those of the north at 6-month lag. Low level westerly winds are greater during high flow years, particularly along the Guinea coast. Differences of OLR and upper velocity potential demonstrate two distinct centers of action either side of the tropical Atlantic. It is concluded that hydrological events over Africa and South America are sensitive to tropical Atlantic coupling with the global El Nino – Southern Oscillation signal.

Introduction

Ancient civilizations in Africa were dependent on a regular flow of water in the Nile, and in other major rivers: Niger, Congo, Senegal, Zambezi, and Orange; and the rift valley lakes: Victoria and Malawi. These water resources nurtured the evolution of man and enabled societal and economic advances. Their statistics are impressive: the Nile extends 6650 km in length, the Congo yields an annual runoff of 1 250 km^3, whilst the volume of Lake Malawi is 7200 km^3. However, Africa's rivers flow irregularly and fluctuations over millennia have occurred as a result of changes in the overlying monsoons.

Intra-decadal climate variability is pronounced along the margins between the tropics and the semi-arid African savanna (Nicholson,1981). Despite the risk of multi-year drought and flood, over 100 million people engage in agricultural activities there. Whilst the seasonal cycle of rainfall can be anticipated, runoff is such a small fraction of rainfall that vulnerability to climate impacts is high in Africa. Farquharson and Sutcliffe (1998) show that runoff is less than 10% of rainfall in areas where the seasonal total is less than one metre. In contemporary times, an explanation for the inter-annual fluctuation of African river flows has remained elusive (Servat et al., 1998). The flow of the Nile and Congo Rivers is influenced by the Pacific El Nino - Southern Oscillation (ENSO) phase (Amerasekara et al., 1997); so it is thought that further research on year-to-year changes in tropical climate may lead to a better understanding of hydrological extremes in Africa. Interaction between the regional circulation of the tropical Atlantic and convective patterns over the adjacent continents is the subject of this paper.

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The tropical Atlantic

The tropical Atlantic Ocean and its overlying atmosphere contain many similarities with the equatorial Pacific in terms of air-sea coupling processes. Although warm events similar to El Nino occur in the Atlantic, it is a narrower ocean basin and the continental influences of South America and Africa are more apparent. The asymmetry of the African landmass with respect to the adjacent ocean basin induces a north-south temperature gradient and a monsoon regime over the Gulf of Guinea. To the west, deep convection is confined to a narrow strip that spans the Atlantic Ocean with a northward tilt toward Africa (Servain et al., 1998). The inter-tropical convergence zone (ITCZ) over the east Atlantic experiences a seasonal migration, from 14°N in August to the equator in March. This region of moisture flux convergence and latent heating overlies higher sea surface temperature (SST). South of the equator south-easterly trades are strong and steady. Equatorial and coastal upwelling induces cooler SSTs and stratiform clouds there. In the Gulf of Guinea winds are more meridional and rotate clockwise becoming more westerly over Africa, in the process modulating inflow to continental rainfall regimes. Most of the tropical Atlantic gains heat radiatively and evaporation losses are found to be low (Hastenrath and Lamb, 1978). Cyclonic wind stress west of Angola produces an uplifted thermocline, which is sensitive to ocean-atmosphere coupling processes (Jury et al., 2000).

Studies of inter-annual climate variability have revealed two Atlantic modes: an equatorial ENSO-type every 2 to 5 years; and opposing sea surface temperature (SST) anomalies in northern and southern subtropics with a more decadal rhythm (Servain et al., 1998). Basin-scale winds and associated equatorial waves play a significant role in the generation of SST anomalies and coherent atmospheric responses and impacts (Nicholson and Entekhabi, 1987; Servain, 1991; Zebiak, 1993; D'Abreton and Lindesay, 1993; Curtis and Hastenrath, 1995; Mehta and Delworth, 1995;