Water Resources Variability in Africa during the XXth Century (Proceedings of the Abidjan'98 Conference held at Abidjan, Côte d'Ivoire, November 1998). IAHS Publ. no. 252, 1998.

Numerical simulations of intraseasonal, interannual and interdecadal climate variability over Africa

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Abstract This review underscores the importance of adopting a multi-pronged numerical modelling approach in investigating climate variability over such a vast continent as Africa. In particular, success is demonstrated of the ability of numerical models to simulate the African climate at the continental, regional, and catchment-scales. The prospects for applications of numerical simulation climate variations to resource management and decision-making are also explored.

INTRODUCTION

Droughts and floods in Africa have become a common feature. They rank among one of the most devastating natural tragedies in recorded human history and have claimed thousands of lives as well as causing massive population displacements and economic disruption. Although, major advances in understanding the nature and causes of these climatic events and their manifestations have been achieved during the past decade, a coherent picture that links the many factors which help to initiate, sustain and amplify them is still illusive. This review paper examines some of the recent studies based on a joint study between North Carolina State University, National Center for Atmospheric Research, and the University of Nairobi to clarify some of these issues.

CONTINENTAL CLIMATE VARIABILITY OVER AFRICA

The primary vehicle in this investigation is the standard NCAR CCM1 spectral GCM. The rhomboidal spectral truncation at wave number 15 (R15) is adopted. A historical overview of the CCM1-GCM is given by Williamson *et al.* (1987). Two model simulations are performed to study the sensitivity of the African continent seasonal and annual climate response to global-scale Sea Surface Temperature (SST) anomaly patterns. In the wet year case we set the global SST distribution in CCM1 for each calendar month to the corresponding 1950 SST conditions. The second simulation is based on the 1973 SST anomalies. In each run the model is integrated for ten years and the numerical integrations start from the same initial conditions where the orbital parameters required for computing the solar zenith angle and the initial conditions correspond to the middle of October. The Sahelian rainfall data used for the comparison with the model simulations was obtained from a historical raingauge station dataset archived at NCAR.

Results based on CCM1-GCM simulations

Nicholson (1987) has shown that the observed rainfall conditions in 1950 were characterized by wet conditions over the Sahelian zonal strip and Southern Africa,

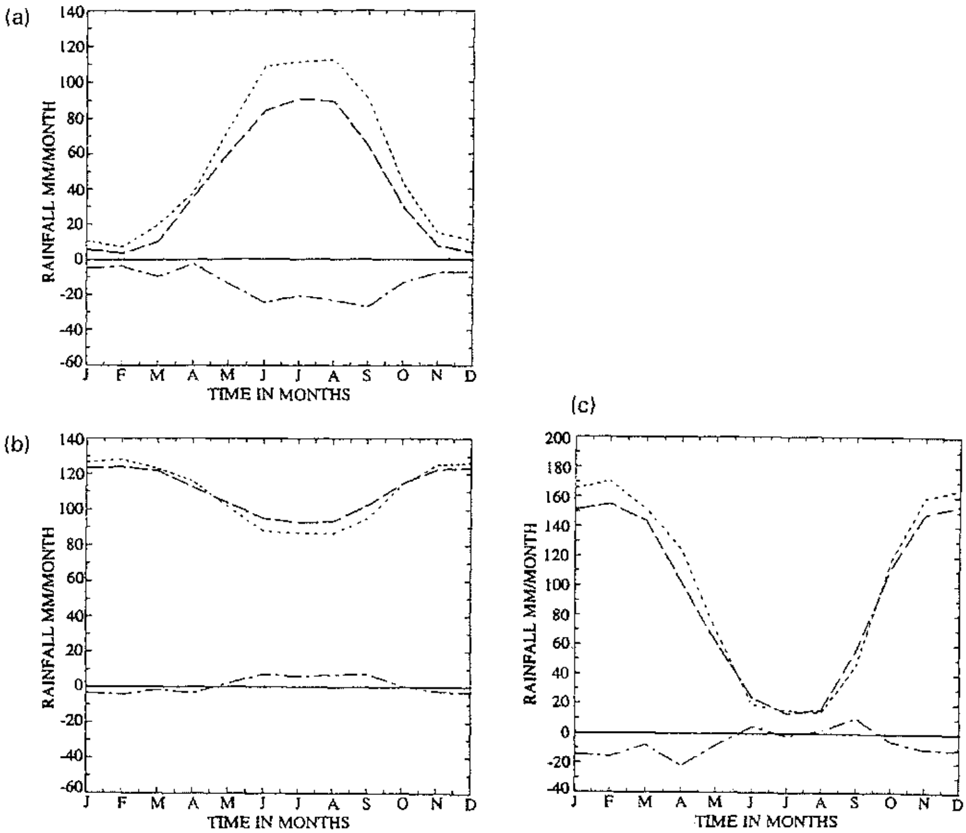

Fig. 1 NCAR CCM1 GCM simulated rainfall over (a) the Sahel (10°–20°N, 15°W–37°E), (b) equatorial Africa (10°S–10°N, 10°–30°E), (c) southern Africa (30°–15°S, 15°–35°E). Dotted (dashed) line represents the 1950 (1973) SST-forced GCM run. The dotted-dashed line style depicts the difference, 1973 minus 1950, model results.

but the equatorial zone was dominated by negative anomalies. By contrast the conditions in 1973 were characterized by the opposite phase of this continental rainfall anomaly pattern. The rainfall anomalies in 1950 and 1973 are representative of the decades of the 1950s and 1970s.

CCM1 successfully simulates the main features of the pattern reversal as the rainbelt moves across the continent during the course of the year (Fig. 1). Semazzi *et al.* (1996) have attributed this to the ability of the model to simulate the annual cycle oscillation realistically. Differences in the amplitude of the annual cycle signal rather than the phase changes appears to be more important in promoting the synchronous climatic conditions which prevailed in northern and southern Africa in 1950 and 1973.

During summer when the Sahelian region receives most of its rainfall, the model response to external SST anomaly forcing results is in reasonable agreement with the observations. Similar agreement between the model simulation and the observed rainfall is observed during winter when the rainfall belt is centred over Southern Africa. During spring and fall the model exhibits less agreement with observed data due to the deficient simulation of the semi-annual cycle. Inspection of the model's internal variability associated with each season yields valuable insight regarding the unique behaviour of the Sahelian climate. The Sahel exhibits virtually no internal variability, thus in distinct contrast from the rest of the continent. We believe that this could be part of the explanation why the Sahel responds more readily and uniquely to external forcing such as SST anomalies.

REGIONAL CLIMATE VARIABILITY OVER THE SAHEL IN WEST AFRICA

Based on simulations using the NASA Genesis version-2 GCM (Semazzi & Sun, 1997), a new hypothesis that accounts for the teleconnection between large scale SST anomaly forcing and the north/west African climate is proposed and tested. Results based on the NASA GCM indicate a distinct quasi-geostrophic windward-high and

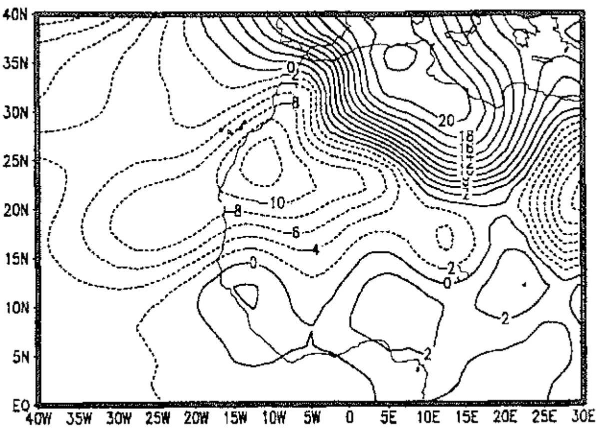

Fig. 2 Difference, NASA GEOS-1 GCM simulation, with minus without topography, JAS average geopotential height at 850 mb. Contour interval, 2 m.

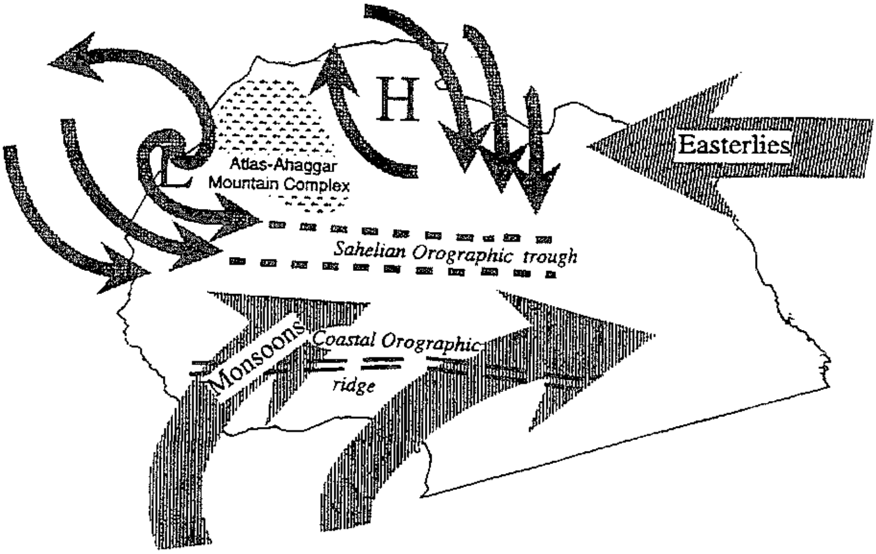

Fig. 3 Schematic figure showing the primary circulation features associated with the interaction between west African orographic forcing, the prevailing low-level easterly flow, and the southwesterly monsoon current.

lee-low pressure pattern generated as the easterly prevailing zonal flow crosses the Atlas-Ahaggar mountain range complex over north Africa (Fig. 2). The lee-low is located over the coastal region of the Sahel and is part of the orographic induced trough that extends across the continent in the zonal direction. During the years when cooler near-circumpolar northern hemispheric SSTs prevail, e.g. in 1973, the following sequence of climatic developments are deduced from the model simulations (Fig. 3); development of high pressure anomaly conditions over the northern hemisphere; a planetary-scale anticyclonic circulation pattern extending from 10°N

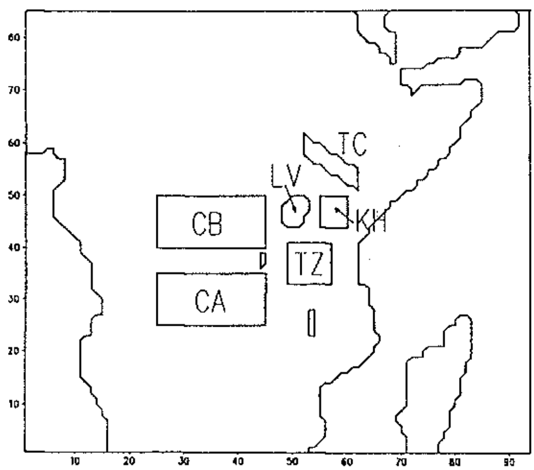

Fig. 4 Six climatic subregions used in the study: CB—Congo basin, CA—southern Congo and Angola plateau, LV—Lake Victoria, TC—Turkana Channel, KH—Kenya highlands, and TZ—Tanzania mainland.

to 40°N, with westerly anomalies over north Africa; weaker prevailing easterly zonal flow over north Africa across the Atlas-Ahaggar mountains; a weaker orographic induced lee-trough associated with the Atlas/Ahaggar mountain trough in the vicinity of western Sahel; weaker orographic induced low-level westerly zonal flow associated with the orographic lee-low; weaker transport of moisture from the mid-section of the Atlantic ocean into the interior of the Sahelian region; moisture and rainfall deficit over the Sahel.

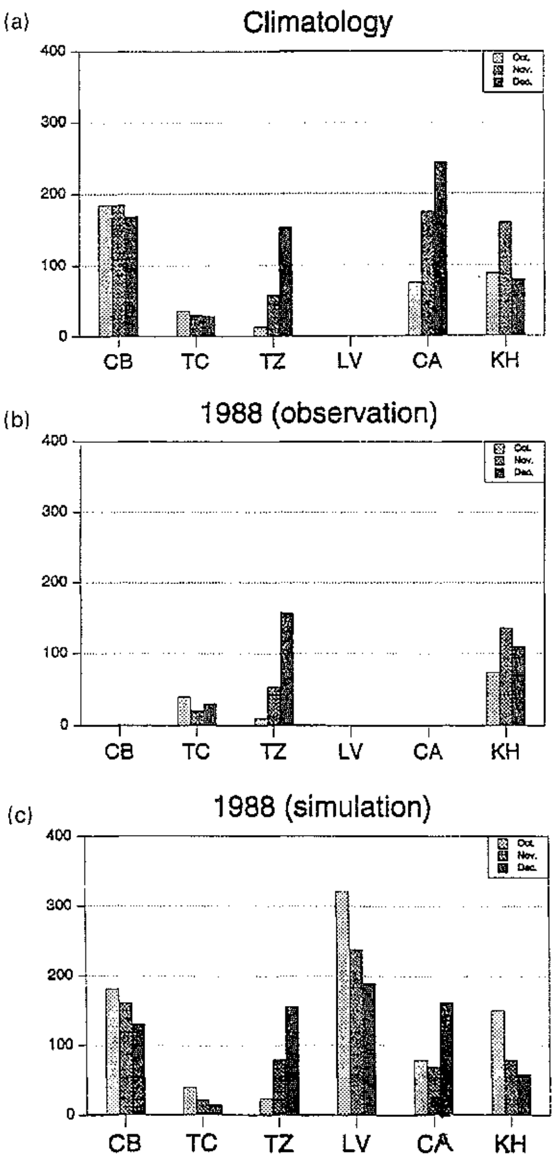

Fig. 5 Observed and simulated precipitation over the six study regions (see Fig. 4), from October to December 1988. (a) climatology, (b) observed, and (c) model simulation. Note that there are no observations for the CA, CB and LV regions. Units are mm.

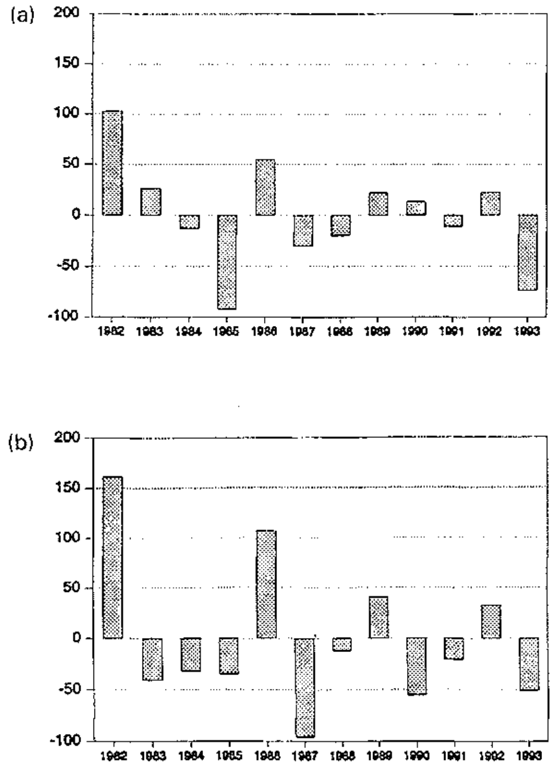

Fig. 6 Precipitation anomalies (1982–1993) based on the 12-year mean over Tanzania for the October–December season. (a) model simulation, and (b) observations. Units are mm.

CATCHMENT CLIMATE VARIABILITY OVER THE LAKE VICTORIA BASIN IN EASTERN AFRICA

Six sub-zones over eastern Africa are adopted for the evaluation of the model performance of the National Center for Atmospheric Research (NCAR) numerical Regional Climate Model (RegCM2) (Fig. 4). The model realistically reproduces the interseasonal (Fig. 5) and interannual variability (Fig. 6) of precipitation over the catchment areas of Lake Victoria. It simulates the large-scale characteristics over the region as well as the local features such as dominant precipitation maxima and the diurnal reversal in the lake/land breeze circulation over the lake. The simulated interannual variability of precipitation over the lake catchment is closely related to the warm El Niño events and the SST anomalies over the adjacent Indian and Atlantic oceans which agrees well with the observations.

Comparison of the simulations based on the one-dimension (1-D), in the standard version of RegCM2, and the new three-dimensional (3-D) lake model simulations (Fig. 7) clearly show the superiority of the 3-D formulation which produces much more realistic results. In particular, the 3-D model shows a surface temperature pattern indicative of dynamic mixing characterized by a swirl of warm water over the northern section of the lake. This pattern is not present in the 1-D model which is

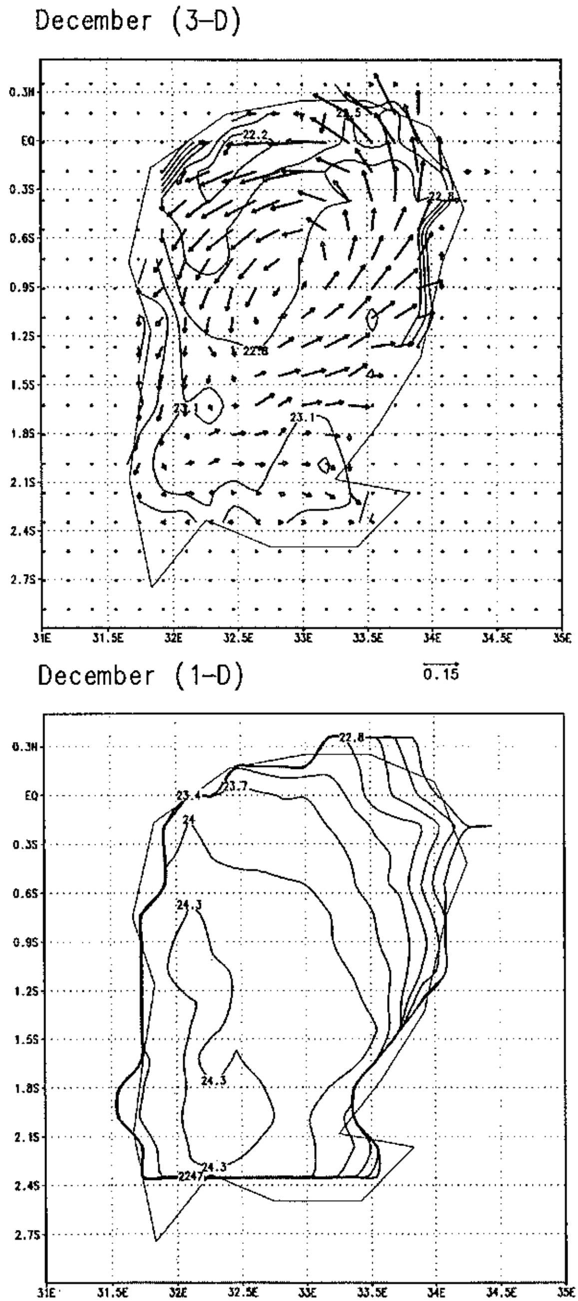

Fig. 7 Simulated December mean surface circulation (wind vectors) and temperature (contours) distributions over Lake Victoria: (*top*) based on a 3-D primitive-equation model of Lake Victoria, and (*bottom*), based on a 1-D thermal energy diffusion lake model (no dynamics) of Lake Victoria.

based on thermal diffusion only and no dynamics. These results underscore the need to proceed with the ongoing efforts to replace the 1-D formulation of the lake in RegCM2 by the new 3-D version.

Acknowledgements This research was supported by NSF under grant number ATM-9113511. We acknowledge the assistance provided by George Pouliot, Matayo Indeje, and Song Yi during the preparation of this paper. Indeje and Yi also made input based in their ongoing PhD theses work.

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