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Circulation mechanisms of climate anomalies in East Africa and the equatorial Indian Ocean

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Abstract

The “Short Rains” at the coast of equatorial East Africa, concentrated around October–November, are highly variable and have an extremely tight concurrent correlation with the westerlies over the central equatorial Indian Ocean. The equatorial westerlies drive the Wyrtki Jet in the upper ocean and enhance the westward temperature gradient, and they are the surface manifestation of a powerful zonal-vertical circulation cell along the Indian Ocean Equator at this time of the year. With a strong equatorial circulation cell, the enhanced subsidence and cool surface waters in the West serve to reduce the rainfall over East Africa, and conversely the enhanced ascending motion and warm waters in the East favor precipitation in Indonesia. In the interannual variability over the second half of the 20th century, the years 1961, 1994 and 1997 stand out with particularly weak westerlies over the central equatorial Indian Ocean and disastrous floods in East Africa. At longer time scales, there is evidence of an enhancement of the equatorial westerlies accompanying the drop of lake levels and onset of glacier recession in East Africa in the last two decades of the 19th century. Despite the tight concurrent correlations, the prospects for seasonal forecasting are modest. Predictability decreased from the 1958–1977 to the 1978–1997 period, although the boreal autumn equatorial zonal circulation cell remained strong throughout.

Keywords: Climatology; Circulation; Rainfall; Anomalies; Circulation mechanisms; Climate anomalies

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1. Introduction

East Africa experiences its rainy seasons during the transitions between the winter and summer monsoons, when the confluence between the airstreams from the two hemispheres is closest to the Equator. The boreal autumn rains, or "Short Rains", are particularly variable, and circulation anomalies in that season have led to disastrous floods repeatedly over the past half-century. Thus, the extreme event of 1961 (Thompson and Mörth, 1965; Lamb, 1966; Hastenrath, 1984, pp. 42–49; Reverdin et al., 1986; Flohn, 1987; Kapala et al., 1994) caused a drastic rise of the levels of East African lakes, which took years to subside. Similar more recent extreme anomalies include 1994 and 1997 (Birkett et al., 1999; Behera et al., 1999; Webster et al., 1999; Latif et al., 1999). On the scale of many decades, an extremely tight correlation was found between the surface westerlies over the central equatorial Indian Ocean and the East African "Short Rains" (Hastenrath et al., 1993). Interest in the climate of the equatorial Indian Ocean and East Africa has increased in recent years, with attention to processes in the upper ocean (Anderson, 1999; Lau and Nath, 2004) and seasonal forecasting (Mutai et al., 1998; Mutai and Ward, 2000; Philippon et al., 2002; Black et al., 2003; Clark et al., 2003; Hastenrath et al., 2004).

With focus on the October–November core of the East African "Short Rains" the present paper shall review circulation processes operative in the interannual and longer term variability of precipitation in equatorial East Africa. Section 2 describes the literature sources and pertinent datasets, Sections 3 and 4 examine the dynamics of the wind field in the context of the annual cycle, Sections 5 and 6 discuss interannual and longer term variability of circulation and climate, Section 7 addresses the challenge of climate prediction, and some reflections are offered in the closing Section 8.

2. Data and literature reference

The present brief synthesis draws on a sequence of studies (Hastenrath et al., 1993, 2004; Hastenrath, 2000, 2001; Hastenrath and Polzin, 2003, 2004, 2005), which had as basis the Comprehensive Ocean–Atmosphere Data Set (COADS) of long-term ship observations (Woodruff et al., 1987, 1993), the National Center for Environmental Prediction-National Center for Atmospheric Research Reanalysis (NCEP-NCAR) (Kalnay et al., 1996; Kistler et al., 2001) global upper-air fields and ensembles of long-term raingauge stations. Information was in part compacted into indicative indices, as detailed in the caption to Fig. 1. The October–November rainfall is captured by the index RON (rain, October-November) for East Africa and SJB (Sumatra, Java, Borneo) for Indonesia. These index series were compiled as "all-station average normalized departures" using the procedure first introduced by Hastenrath (1976). The index RON is based on seven stations at the coast of East Africa and the index SJB on eight stations in Indonesia. The measurements are complete over the entire 1958–1997 period, except for some missing station values in 1997 in East Africa.

3. Annual cycle

The annual cycle of atmospheric and oceanic circulation has been comprehensively documented in atlases and textbooks (Hastenrath et al., 1989; Hastenrath, 1985, pp. 56–64; Hastenrath, 1995a, pp. 57–66). Some essentials are compacted here in Figs. 2 and 3. The basin-wide surface wind field is dominated by the alternation between the boreal winter (Fig. 2a) and summer monsoons (Fig. 2c). In winter flow from South Asia recurves near the Equator to meet the South