VARIATIONS OF EAST AFRICAN CLIMATE DURING THE PAST TWO CENTURIES

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Abstract. The evidence on the climatic history of East Africa over the past two centuries comprises historical accounts of lake levels, observations and analyses of glacier variations, wind and current observations in the Indian Ocean, as well as raingauge measurements. East Africa experiences its rainy seasons in boreal spring and autumn, centered around April–May and October–November; the spring rains being more abundant and the autumn rains more variable. Rains tend to be abundant/deficient with slow/fast westerlies (UEQ) and Eastward Equatorial Jet (EEJ) in the upper hydrosphere of the equatorial Indian Ocean. A drastic climatic dislocation took place during the last two decades of the 19th century, manifest in a drop of lake levels, onset of glacier recession, and acceleration of UEQ and EEJ. The decades immediately preceding 1880 featured high lake stands, extensive glaciation, and slow UEQ and EEJ, as compared to the 20th century. The onset of glacier recession in East Africa after 1880 contrasts with a start of ice shrinkage in New Guinea and the Ecuadorian Andes around the middle of the 19th century. The regional circulation regime characterized by slow UEQ and EEJ in the decades prior to 1880 was conducive to extensive ice cover along with high lake stands in East Africa, and this may account for the onset of glacier recession much later than in the other mountain regions of the equatorial zone. The evolution of East African climate over the first half of the 19th century merits further exploration.

1. Introduction

Climatic change in East Africa caught the curiosity of the early explorers in the latter part of the 19th century, it recurrently continued to be a subject of investigations (reviews in Hastenrath, 1984, pp. 1–5, 42–134; Nicholson, 1998, 1999; Grove, 1996, 1998; Verschuren, 1996), and recently it has come into the focus of a long-term international field program (Johnson, 1993). Instrumental records are largely confined to the 20th century, and these have served to diagnose the circulation mechanisms of annual cycle and variability of climate. Reconstruction of the climatic history back into the 19th century has been based on much scarcer and largely indirect evidence. The purpose of the present paper is to sketch the status of research on the secular evolution of East African climate and, more importantly, to identify the frontiers of the present ignorance and the challenges that lie ahead.

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2. Evidence

Pertinent to this synopsis are raingauge and lake level measurements and historical accounts in East Africa, observations and analyses of glacier variations in the tropics at large, and ship observations of wind and currents in the Indian Ocean. Records of raingauge and lake level measurements are depicted and discussed in Hastenrath (1984, pp. 46–49), Nicholson (1996, 1998, 1999), Grove (1996, 1998) and Hastenrath et al. (1993). Historical accounts of lake levels (Sieger, 1887, 1888; Ravenstein, 1901; Hobley, 1914) have been appraised by various authors (Brückner, 1890; Academy of Sciences U.S.S.R., 1964; Grove et al., 1975; Hastenrath, 1984, pp. 42–49; Nicholson, 1998, 1999). Pertinent information on glacier variations in the global tropics is contained in Hope et al. (1976), Allison and Kruss (1977), Hastenrath (1981, 1984, 1997), Kruss (1983), and Hastenrath and Kruss (1992). Wind observations in the Indian Ocean stemming from the same source as in our atlas (Hastenrath and Lamb, 1979) are available in the COADS collection (Woodruff et al., 1987, 1993), and these are complemented by observations of surface currents (Hastenrath and Greischar, 1989, 199l; Hastenrath et al., 1993). An orientation on circulation and climate of East Africa and the Indian Ocean is provided in Hastenrath and Lamb (1979), Hastenrath et al. (1993), Beltrando and Camberlin (1993), Nicholson (1996), and Hastenrath (2000).

3. Twentieth Century

The sound observational basis in the 20th century has afforded insight into the circulation mechanisms of annual cycle, interannual, and longer-term variability (Hastenrath and Lamb, 1979; Hastenrath et al., 1993; Beltrando and Camberlin, 1993; Hastenrath, 1995, pp. 57–66, 2000; Nicholson, 1996). A brief summary of the most essential for the East African region must suffice here.

The annual cycle of circulation over the Indian Ocean basin is dominated by the alternation between the boreal winter monsoon winds blowing from South Asia into the southern hemisphere, and the boreal summer monsoon sweeping from the southern Indian Ocean into South Asia. Most pertinent for East Africa, however, are the monsoon transitions. East Africa experiences a rainy season between March and June, with its core around April–May. These rains are associated with the northward passage and eventual disintegration of the near-equatorial trough and embedded confluence zone. A second rainy season from September to December, but centered on October–November, is associated with the re-establishment and southward passage of the near-equatorial trough and concomitant wind confluence over the western Indian Ocean. The April–May rains are more abundant, and the October–November rains are more variable. Only during limited intervals in the monsoon transitions, namely in April–May and October–November, is the equatorial zone of the Indian Ocean swept by strong westerly winds, which then drive the

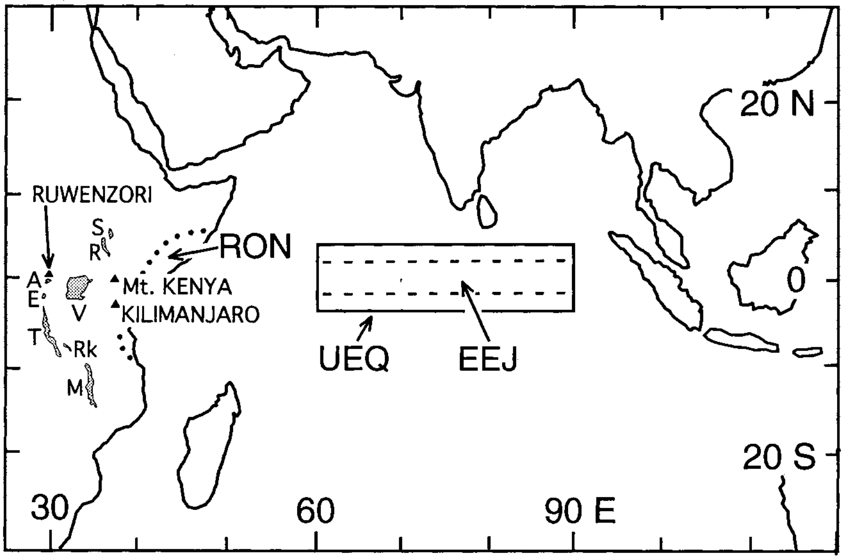

Figure 1. Orientation map. East African Lakes, from North to South: Stefanie S, Rudolf R., Albert A, Edward E, Victoria V, Tanganyika T, Rukwa Rk, Malawi M. Glaciated mountains: Kilimanjaro, Ruwenzori, Mount Kenya. Dotted line bounds area pertaining to rainfall index RON. Solid-line rectangle represents domain of the zonal wind index UEQ (4° N–4° S, 60–90° E. Within the area of UEQ, dashed lines bound the domain of the index of the Eastward Equatorial Jet EEJ (2° N–2° S, 60–90° E).

short-lived and intense Eastward Equatorial Jet in the upper hydrosphere (Wyrtki, 1973; Hastenrath and Lamb, 1979, charts 14–25; Hastenrath and Greischar, 1989, charts 154–165, 1991). The equatorial westerlies of October–November are a surface manifestation of a zonal-vertical circulation cell along the Indian Ocean Equator (Hastenrath, 2000).

Rains at the coast of equatorial East Africa tend to be deficient with fast westerlies and Eastward Equatorial Jet in the equatorial Indian Ocean. This relationship is particularly pronounced for the boreal autumn rainy season, and is captured by three compact indices (Hastenrath et al., 1993): RON is an index of the October–November rains at the coast of East Africa, UEQ is an index of the equatorial westerly winds, and EEJ is an index of the Eastward Equatorial Jet in the upper hydrosphere. The domains of these indices are shown in Figure 1, and their time series are plotted in Figure 2, along with the water level record from one lake (source: Hastenrath, 1984, p. 46) for comparison. For information on other East African Lakes refer to the previously cited literature (Hastenrath, 1984, pp. 46–49; Nicholson, 1998, 1999). Figure 3a serves to relate the short-lived and intense equatorial westerlies to the basin-wide October–November 1976–1995 mean surface wind pattern over the Indian Ocean. Over the period 1948–1987, RON has a correlation of –0.85 with UEQ, and of –0.61 with EEJ, and UEQ is correlated with EEJ at +0.76, all significant at the 1% level.

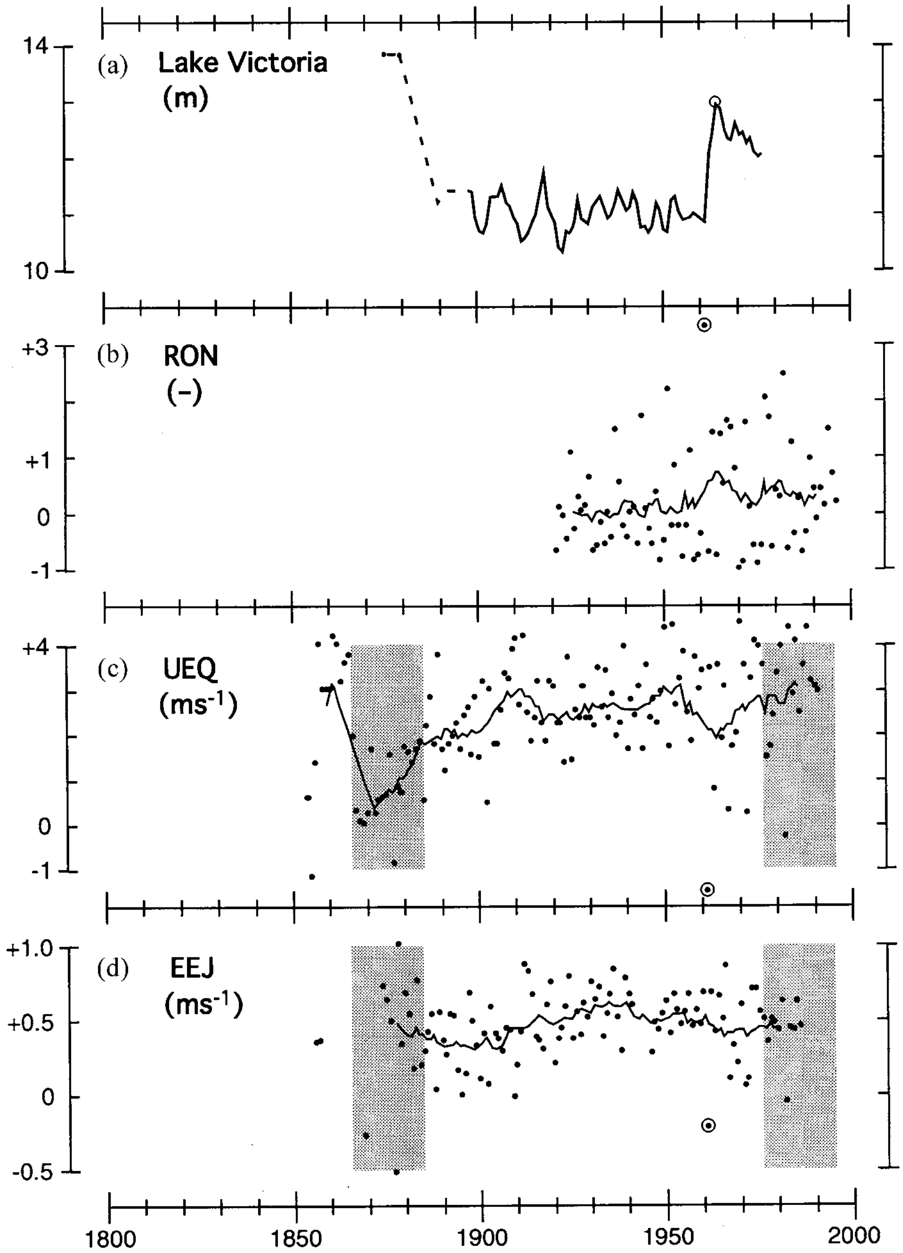

Figure 2. Time series plots of (a) water level of Lake Victoria, in m; (b) index RON of October-November rains at coast of East Africa, dimensionless; (c) index of westerlies over equatorial Indian Ocean UEQ, in ms^{-1}; (d) index of Eastward Equatorial Jet EEJ, in ms^{-1}. Thin solid lines in (b), (c), and (d) denote 11-year running means. Shading in (c) and (d) marks the periods 1866–1885 and 1976–1995 mapped in Figures 3a,b. In all four plots, open circle enclosing dot highlights the extreme conditions in 1961.

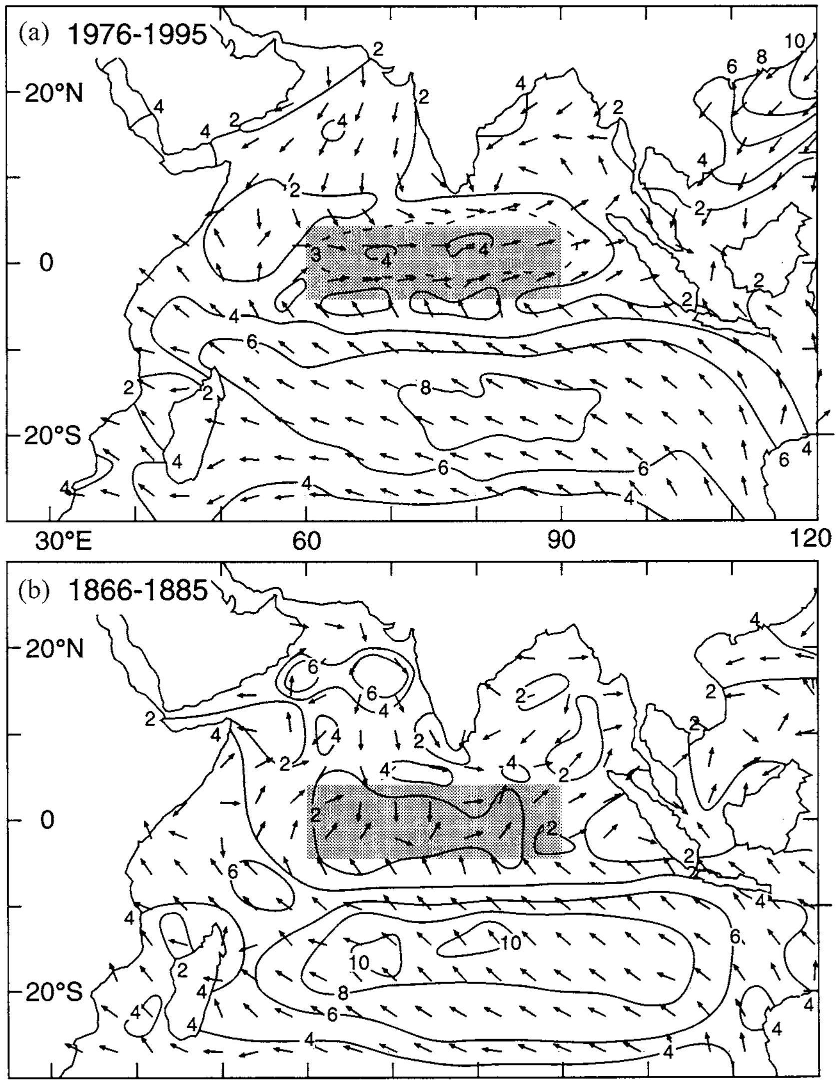

Figure 3. Maps of October–November surface wind field over Indian Ocean. Shading indicates the domain of the wind index UEQ (ref. Figures 1 and 2). Isotach spacing is 2 ms^{-1}, except for dashed line in equatorial region of map (a) denoting 3 ms^{-1}. (a) 1976–1995 mean. (b) 1866–1885 mean.

The history of climatic variability is in part depicted in Figure 2. The very considerable interannual variability of rainfall is largely dampened out in the lake level record, but even there the 1961 event stands out, with the typical symptoms of abundant precipitation, slow equatorial westerlies (UEQ) and weak Eastward Equatorial Jet (EEJ). Apart from the 1961 event of anomalously weak zonal circulation cell (Hastenrath, 2000) with weak equatorial westerlies (UEQ) and Eastward Equatorial Jet (EEJ), water levels varied comparatively little and stayed low through the 20th century. A drastic climatic dislocation is indicated for the last two decades of the 19th century, manifest in the abrupt drop of lake levels (Hastenrath, 1984, p. 46; Nicholson, 1998, 1999) and in the onset of glacier recession in East Africa (Hastenrath, 1984, pp. 42–134). This was forced by enhanced solar radiation due to diminished cloud cover accompanying the reduced precipitation; continuation of ice retreat beyond the early decades of the 20th century was favored by a warming trend (Kruss, 1983). Increasing atmospheric humidity accompanying the warming contributed to the accelerated ice wastage in the most recent decades of the 20th century (Hastenrath and Kruss, 1992).

4. Nineteenth Century

The lake and glacier evidence reviewed in the previous section indicates a drastic climatic dislocation within the last two decades of the 19th century, leading to the more uniform conditions of the 20th century. What are the characteristics of the immediately preceding climatic regime? Lake evidence (Hastenrath, 1984, pp. 46–49; Nicholson, 1998, 1999) indicates that water levels stood high, and the early explorers report a much greater extent of the mountain glaciers (Hastenrath, 1984, pp. 42–134). The circulation conditions are presented in Figures 3a,b and 2. In the boreal autumn rainy season of East Africa, during 1866–1885 (Figure 3b) as compared to the 20th century (Figure 3a), the tradewinds of the Southern Indian Ocean were much stronger and the equatorial westerlies weaker. Figure 2 further corroborates that in tune with the slower westerly winds the Eastward Equatorial Jet in the upper hydrosphere was also much weaker. From the 20th century experience, such circulation conditions are consistent with more abundant precipitation activity as borne out by the lake and glacier evidence.

This insight leads to the frontiers of present ignorance. Looking backward beyond about 1870, since when did the lakes stand high, since when was the mountain glaciation extensive, and, by inference, since when was the climate wet? Pertinent in this context are (a) the historical accounts of lake stands referred to above, (b) the time series of UEQ and EEJ plotted in Figue 2, and (c) information on glacier variations not only in East Africa but in the global tropics. These groups of evidence may be addressed in the following. (a) The early accounts on East African lakes (Sieger, 1887, 1888; Nicholson, 1998, 1999) offer tenuous indications of lower water levels before the middle of the 19th century. Nicholson (1999) presents reconstructions to that effect for Lakes Rukwa and Tanganyika (Figure 1), in particular. (b) Of the circulation indices (Figure 2), EEJ does not reach far enough back, while UEQ suggests faster equatorial westerlies before about 1860. These would be consistent with the notion of scarcer rainfall and hence lower lake levels. (c) While the East African glaciers clearly started to recede after 1880, it is not known when the era of extensive ice cover began. At this point, a comparison with the equatorial zone at large is in order. For the glaciers of equatorial New

Guinea, Hope et al. (1976) presented the field evidence, and on this basis Allison and Kruss (1977) applied numerical modeling of ice dynamics and retreat history to infer an onset of glacier recession around the middle of the 19th century. For the Ecuadorian Andes, the evaluation of early historical sources (Hastenrath, 1981, 1997) also yielded an onset of glacier retreat around the middle of the nineteenth century. In perspective then, the recession of glaciers in New Guinea and in the South American Andes apparently began early and around the same time, and the monotonic retreat continuing to the present may be seen in context with a secular warming trend. Contrasting with this pattern is only the behavior of the East African glaciers. Did they experience favorable climatic conditions for only a couple of decades preceding 1880? This would be compatible with the wind record and the accounts of lake levels. It would then seem that a merely regional evolution of circulation conditions may have been the cause for the glacier history of East Africa to be so different from the global tropics.

5. Conclusions

This note sought to place into context a diversity of evidence on the climatic evolution of East Africa over the past two centuries, and thereby to call attention to pending issues that may best be explored from a combination of field approaches. Pertinent are historical accounts of lake levels, observations on glacier variations and their analyses, long-term wind and surface current observations in the Indian Ocean, and raingauge measurements for the greater part of the 20th century. From the reasonably plentiful observations in the 20th century, a broad understanding has been reached of the circulation mechanisms operative in anuual cycle, interannual, and longer-term variability. Of greatest interest are the monsoon transitions, or the boreal spring and autumn rainy seasons of East Africa, centered around April–May and October–November. The April–May rains are more abundant and the October–November rains more variable. Only during these short intervals in the annual cycle is the equatorial zone of the Indian Ocean swept by strong westerly winds, which further drive the short-lived and intense Eastward Equatorial Jet in the upper hydrosphere. Rains at the coast of East Africa tend to be abundant/deficient with slow/fast equatorial westerlies and Eastward Equatorial Jet. The 1961 event combined the typical symptoms of abundant rainfall, slow equatorial westerlies and weak oceanic jet. Apart from this extreme event, water levels varied relatively little and stayed low through the 20th century.

Climatic change was concentrated in the last two decades of the 19th century, when the equatorial westerlies and associated oceanic jet accelerated, the lake levels dropped, and the mountain glaciers started to recede. For the couple of decades preceding 1880, the diversity of field evidence is mutually consistent regarding the climatic regime: lakes stood high, mountain glaciation was extensive, by inference precipitation abundant, and in accordance with this the equatorial westerlies and the oceanic jet were slow. This very regional circulation regime may account for the much later onset of ice recession in East Africa than in the mountains of New Guinea and the Ecuadorian Andes.

Evidence is tenuous regarding the beginning of this climatic regime in East Africa: ship observations are suggestive of faster equatorial westerlies before the middle of the 19th century, while data on ocean surface currents give out even earlier; there are indications of lower lake stands in the first half of the 19th century; and there is no pertinent glaciological information. When this regime of slow equatorial westerlies and oceanic jet, abundant precipitation, high lake stands, and extensive glaciation in East Africa began, and how the history of East African climate evolved over the first half of the 19th century, are issues that merit to be explored from a combination of field approaches.

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