The Eastern Cape drought

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Abstract

In recent years the Eastern Cape has experienced recurring drought with unfavourable impacts on agricultural production and water resources. Dam levels in early 1992 were 30% of capacity. Statistical analysis has demonstrated that drought recurs at intervals of 3,45 and 18,2 years, particularly when March rains fail to materialise. Regional analysis of cloudiness, surface and upper level winds, and sea surface temperatures exhibit distinctive patterns in drought years. Low-level winds sweep eastward bringing Karoo-like conditions to the Eastern Cape, in association with increased jet stream winds. Reduced cloudiness is noted in a NW-SE band extending from Namibia across the Eastern Cape watershed. To the south of Madagascar, the SW Indian Ocean anticyclone strengthens in drought years and increased trade winds cause the Agulhas Current to cool and recurve southwards near East London. Consequently sea surface temperatures to the south-west are 3°C cooler in dry years. The subtropical humid air mass over the Agulhas Current and north-eastern South Africa retreats eastward, and rainfall associated with cut-off lows and ridging anticyclones is limited over the Eastern Cape.

List of abbreviations

ECW – Eastern Cape Watershed
SST – Sea surface temperature
OLR – Outgoing longwave radiation
GIS – Geographic information system
SOI – Southern oscillation index

Introduction

The Eastern Cape Watershed (ECW, Fig. 1) has recently come under the influence of drought leading to a decline in the local economy through reduced agricultural productivity and a scarcity of water resources. The ECW is spread across a climatic transition zone: the west is dominated by mid-latitude, winter rainfall and the east by sub-tropical, summer rainfall. Mean annual rainfall ranges from 250 mm along the Karoo fringe at Jansenville to 450 mm in the east at Grahamstown (SA Weather Bureau, 1988). Mean annual evaporation (potential from class A-pan) is about 2 000 mm (SA Weather Bureau, 1986).

Following 18 months of below normal rainfall, dam levels at the end of 1991 were 30% of capacity (SA Weather Bureau Newsletter, 1991). Thus a study of the cycles of rainfall and the climatological mechanisms underlying drought in the ECW is overdue. Given the east-west gradient in the water deficit, it is hypothesised that drought results from an eastward encroachment of subsident dry air from the Karoo basin. Rainfall is dependent on instabilities in the mid-latitude westerlies in the transition seasons (Jackson and Tyson, 1971; Cowling, 1984; Preston-Whyte and Tyson, 1988). In drought years the meteorological processes sustaining cut-off low pressure systems (in autumn) and ridging anticyclones (in spring) over the southern escarpment are expected to be disrupted.

Climatic background

The ECW (Fig. 1) contains the Groot/Gamtoos, Sundays, Great Fish and Buffalo river systems, and extends from 31 to 34°S and 23 to 27°E. The coastline is convex and bends at an approximately 45° angle near Port Elizabeth. Alongshore winds which are characteristic of the area (Heydorn and Tinley, 1980; Hunter, 1987; Jury and Diab, 1990) diverge over the coastal plains. A feature of the adjacent SW Indian Ocean waters is the warm Agulhas Current which flows very near the coast at East London, but some 100 km seawards of Port Elizabeth (Jury et al., 1993). Subsident motions in the coastal zone which may dampen rainfall processes have been linked to atmospheric circulations off-shore over the Agulhas Current (Jury and Courtney, 1991). On the south-western flank of the ECW, a belt of steep coastal mountains to the east of George restricts the inland penetration of moisture.

The escarpment (indicated by the 1 000 m contour in Fig. 1) lies some 200 km from the coast near 22°E, creating the aforementioned Karoo basin where annual rainfall is less than 200 mm. In the east, the escarpment gradually converges towards the coast and is within 50 km at East London. There, the warm Agulhas Current supplies humid air which can be driven up the steep windward face of the escarpment, resulting in orographic rainfall with convective characteristics (maximum rate 90

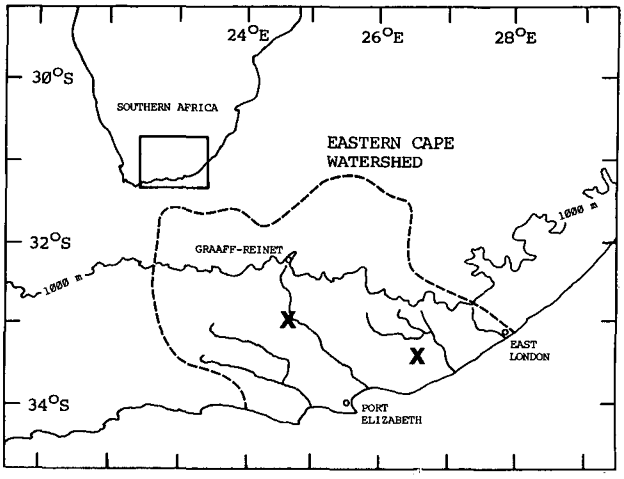

Figure 1
Location map of the Eastern Cape watershed (boundary dashed) showing rainfall stations with X symbols. The 1 000 m contour of the escarpment, major rivers and urban centres are shown

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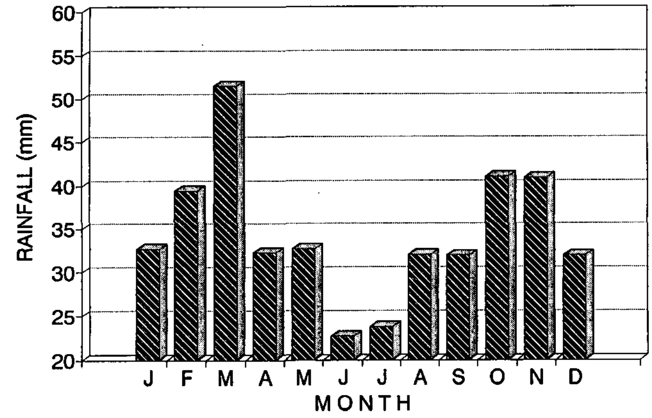

Figure 2
Seasonal trend of monthly rainfall (mm), based on stations shown in Fig. 1

TABLE 1
RECENT TRENDS IN RAINFALL IN THE ECW

Year	Port Elizabeth	Middleberg	Total
1977	699	435	1 134
1978	610	336	946
1979	608	310	918
1980	821	286	1 107
1981	897	453	1 350
1982	700	326	1 026
1983	421	283	704
1984	578	296	874
1985	526	342	868
1986	455	483	938
1987	572	255	827
1988	457	471	928
1989	286	478	764
1990	672	346	1 018
1991	331	363	694

mm/h). In the west, coastal sea temperatures are 5°C cooler, the slope to the interior escarpment is less and stratiform rainfall is more common (maximum rate 30 mm/h, SA Weather Bureau, 1983). The large-scale spatial distribution of moisture provides a sharp gradient: subtropical and humid to the north-east versus dry to the west (Taljaard, 1981) . In the vicinity of Cape Town, South Atlantic air subsides through the eastern limb of a semi-permanent marine anticyclone and vapour fluxes are diminished over the Benguela upwelling region (Hoflich, 1984) .

The seasonal trend in ECW rainfall is shown in Fig. 2. A bimodal distribution is noted, with peaks in March (52 mm) and October (41 mm). The driest months are centered on the winter solstice, while mid-summer rainfall is also limited. The bimodal seasonal distribution of rainfall highlights climatic processes and weather systems in the transition seasons as important determinants of rainfall cycles and drought. Here we focus on March when seasonal rainfall is highest. Drought may be defined as rainfall below -0,5 times the standard deviation for more than 9 consecutive months over a catchment area.

Data and methods

To quantify the cycles of drought and its underlying climatic forces, rainfall data were obtained from a number of stations within the ECW. Two stations (Jansenville and Grahamstown, shown by X symbols in Fig. 1) had continuous records dating to 1878 enabling long-term analyses of rainfall trends and cycles. Yearly standardised departures were calculated and a 5-point binomial filter was applied to smooth the year-to-year variability. A statistical periodogram and Fourier analysis package was used to discern cycles in the smoothed 100+ year time series. The current drought is not well represented in these filtered series, so a table of recent rainfall trends is provided for the Port Elizabeth (coastal) and Middleberg (interior) stations.

To understand the climatic processes associated with drought in the ECW, standardised departures of regional winds, sea surface temperature (SST), and outgoing longwave radiation data (OLR - a proxy for cloudiness) were processed. The data sets and the analysis procedure are described in Pathack (1993). Rainfall data for March were ranked and extreme years were chosen: dry - 1970, 1983, 1979 and wet - 1974, 1981, 1976. Once the groups were formed, standardised departures of the weather data in the domain 10 to 41°S, and 0 to 60°E were averaged to form composites of the 3 driest and 3 wettest March periods. The differences were then computed for interpretation. To assess the structure of the upper atmosphere, the westerly component of the wind was computed for dry and wet March periods.

Vegetation response to variations in rainfall is analysed using NOAA AVHRR normalised difference vegetation index data supplied by the IGBP World Data Centre in Boulder Colorado. Using a GIS based software system, the pattern of summer vegetation is analysed.

Results

Rainfall time series analysis

During 1991 little rain was experienced (Table 1) and dam levels dropped to 30%. Table 1 indicates that the current drought is more severe than the drought of 1982-1984. Rainfall for both stations in 1991 (694 mm) is the lowest of the recent decade. Coastal rainfall (Port Elizabeth) exhibits a downward trend in the recent decade and year-to-year changes tend to be out-of-phase

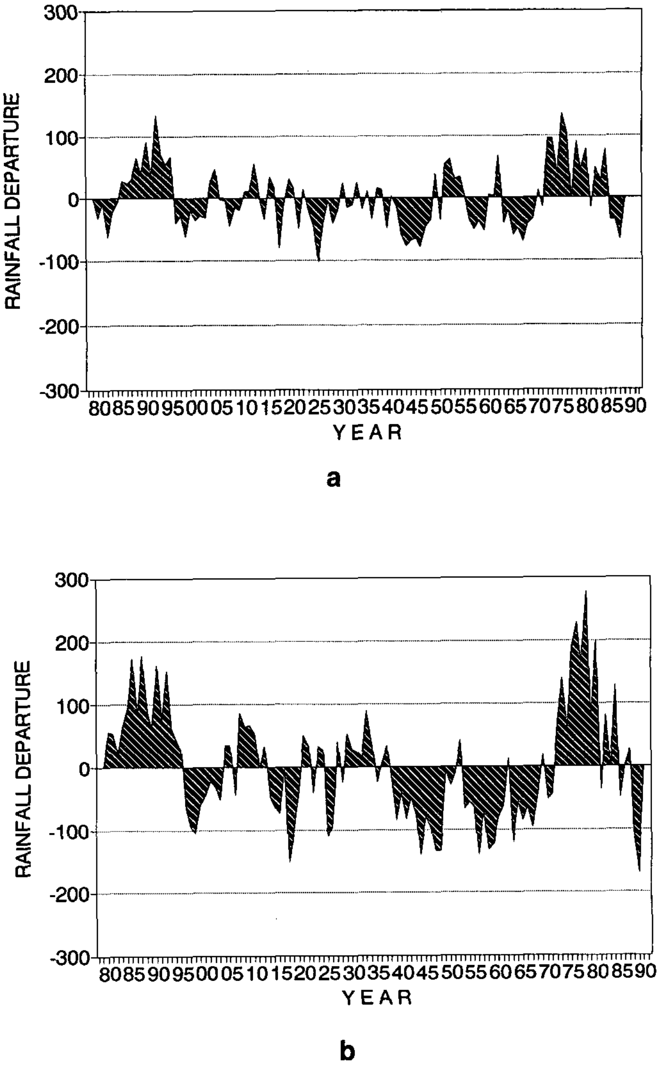

Figure 3
Long-term series of filtered annual standardised rainfall departures (x100) at Jansenville (a) and Grahamstown (b)

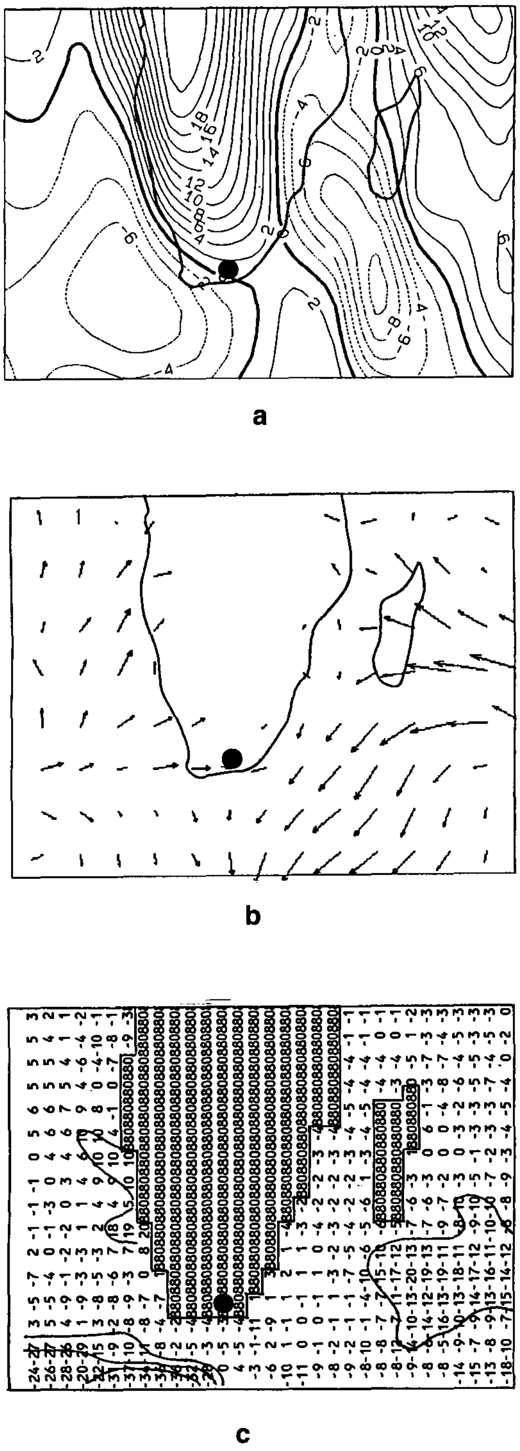

Figure 4
Dry-wet March differences for (a) OLR - proxy for cloudiness, (b) surface winds and (c) SST. OLR units = W/m², largest wind vector = 5 m/s, and SST units = °C x 10. ECW is shown by bold dot

with interior (Middleberg) rainfall, partially due to differing seasonal rainfall regimes. According to monthly data analysed by Jury and Levey (1993) the current drought started in April 1990 and continued unabated until October 1991. The most negative rainfall departures of the recent decade occurred in March and April 1991. It is useful to place the current problems in the context of long-term rainfall variability.

Figures 3a and b illustrate the cycle of above and below normal rainfall over the past century using annual standardised rainfall departures at Jansenville and Grahamstown. Significantly, no gradual trend is noted. The departures at Jansenville are less than Grahamstown, although good agreement is noted between the two records. Only two extended periods of significantly above normal rainfall can be seen, in the late 1880s and in the early 1970s. Hence dry spells are the norm. Prolonged droughts occurred irregularly before the turn of the century and again in the 1920s. Persistent drought characterises the 1940-1970 period. The most extensive period of flood (i.e. rainfall above +l times the standard deviation) is centered on 1974. Thereafter, the rainfall declines to its current dry state. Statistical analysis reveals that drought recurs at intervals of 18,2 years, in agreement with Tyson (1987). Another prominent cycle is found at 3,45 years. Correspondence between monthly ECW rainfall and the El Nino was tested using the southern oscillation index (SOI) and a correlation value of +0,33 was found at a lag of -12 months. Hence the SOI in the preceding year may provide some forecast guidance of seasonal rainfall departures. Other higher frequency cycles were found using monthly records and these are discussed in Jury and Levey (1993).

Regional climatic forcing of drought

Utilising the composite patterns for extreme dry and wet March periods, the difference fields may be analysed for OLR (inversely related to cloud depth), surface winds and SST. As the wet extreme is subtracted from the dry extreme, the patterns shown in Figs. 4a, b and c may be interpreted as drought anomalies. A feature of the OLR differences (Fig. 4a) is a NW-SE aligned positive anomaly (inferring dry weather) which lies across Namibia and, as expected, the ECW. It is suggested that autumn season drought in the ECW occurs in sympathy with drought across Namibia. The dry zone is "bracketed" by cloudy (negative OLR) areas over the oceans to the east and west. In Fig. 4 b surface winds are from the west over the Karoo and support the hypothesis of eastward advance of dry subsident air over the ECW. Surface wind anomalies in the SW Indian Ocean reflect an enhanced anticyclone, resulting in strengthened trade wind flow south of Madagascar. These winds are associated with below normal SST.

SST differences shown in Fig. 4c indicate cooling in drought years. A distinctive negative anomaly exceeding -3°C lies to the south-west in an area known as the Agulhas retroflection. Such a cooling results indirectly from the stronger north-easterly trade winds to the south of Madagascar (Fig. 4b) which are thought to cause the Agulhas Current to deflect southward near East London (VanBallegooyen et al., 1991). With a limited supply of warm Agulhas Current water, moisture fluxes to transient weather systems would be inhibited.

To understand the upper level structure of the atmosphere in drought conditions, the composite extremes for the westerly component of 200 hPa (12 km) winds are analysed. Figure 5a shows that upper westerlies are 4 to 6 m/s stronger in the mid-latitude and tropical zones in dry years. A subtropical trough (equatorward bulge of the westerlies identified by dashed line) is located over central Southern Africa, whereas in wet conditions the trough is located over the west coast and upper westerlies are slower.

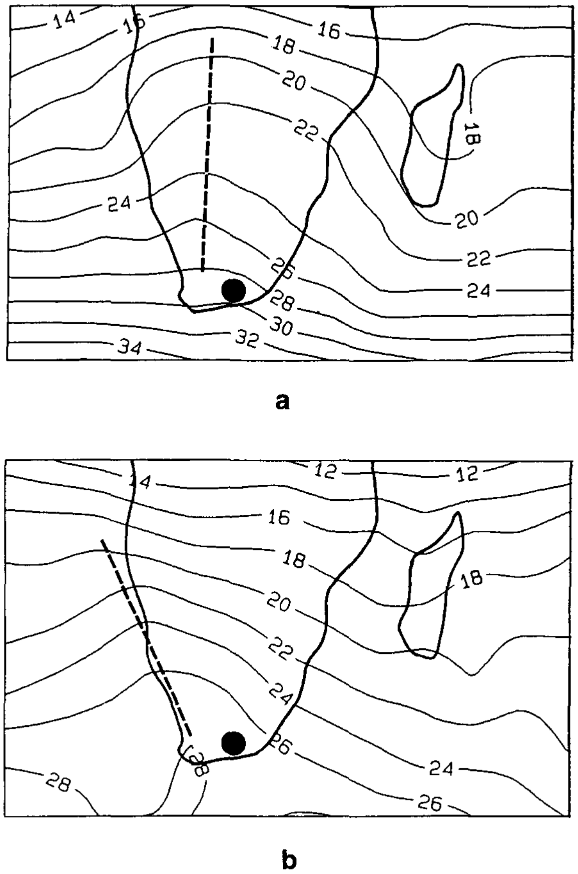

Figure 5
Upper 200 hPa zonal wind composite for (a) dry and (b) wet March periods. Units = m/s. Dashed line identifies trough axis

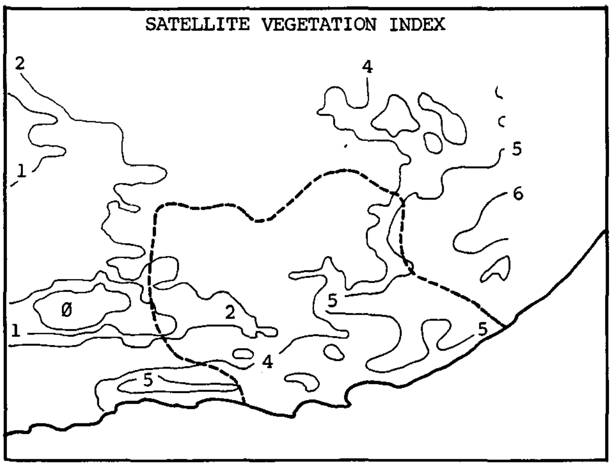

Figure 6
Satellite vegetation image composite map for a summer month showing relative photosynthetic density. Increasing numbers refer to healthy green vegetation growth. The domain is the same as Fig. 1

Discussion

The ECW has, in 1991-92, experienced deficiencies in water resources with impacts on agricultural production and the local economy. The watershed has seen periodic drought over the past century, most notably in the 1940-1970 period. A decade of exceptionally heavy rains in the 1970s was followed by a downward trend to the present day. The most recent drought commenced in mid-1990 and prevailed 18 months. In the context of the longer time series, however, the current drought is not unusual and much worse drought can be expected.

Analysis of mean annual data reveals that evaporation is 10 times greater than precipitation in the western part of the ECW on the fringe of the Karoo desert. The vegetation cover there is relatively sparse and chlorophyll-depleted as distinguished by the composite satellite image (Fig. 6). The eastward advection of dry Karoo air (from regions where vegetation levels are below 2 in Fig. 6) into the ECW is indicated for drought years by the surface wind anomaly pattern (Fig. 4b). Seasonal trends have illustrated the bimodal nature of rainfall (Fig. 2). Highest rainfall occurs in March with the advent of cut-off lows. Drought recurs at cycles of 3,45 and 18,2 years, partly in association with the southern oscillation (r = +0,33 one year earlier). This suggests that drought over the Eastern Cape interior may be sustained a couple of seasons after the decay of an El Nino event.

A feature inferred from the March drought composites is the tendency for the Agulhas Current to swing polewards further east than usual. In dry years SST in the retroflection are 3°C cooler than in wet years (Fig. 4c). A governing factor is the north-easterly wind anomaly in the upstream region of the SW Indian Ocean. Hence the humid, subtropical air mass providing input to rain-bearing weather systems may adjust to the underlying position of the warm Agulhas Current, retreating eastward in dry years.

The recent decline in coastal rainfall, embedded in the interplay of 3,45 and 18,2 year cycles, could point to a slight poleward shift of the subtropical/mid-latitude climatic boundary. As the westerlies retreat, winter rains along the southern fringe of the ECW may diminish. The demand for water resources in the ECW should be tailored to the trends in drought. It is anticipated that improved seasonal forecasts will flow from this research.

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