The unusual rainfall and sea surface temperature characteristics in the South African region during the 1995/96 summer season

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Abstract

The 1995/96 summer season has been exceptional in the way that most South African regions experienced well above-normal rainfall conditions. These wet conditions were preceded by an abnormal lingering drought of almost five years. Water restrictions were applied due to prevalent dry conditions during the first few months of the 1995/96 summer season. December 1995 was characterised by the first occurrence of good precipitation which persisted for the remainder of the summer season. Apart from the good rainfall, an extensive region of well above-normal sea surface temperature (SST) anomalies rapidly developed during mid-December 1995 over the south-east Atlantic Ocean. The weekly variability of these SST anomalies as well as the concurrent South African rainfall patterns are explored. It becomes apparent that the well-defined warm SST region, which developed over the south-east Atlantic Ocean, may have resulted from the same atmospheric general circulation patterns which gave rise to the extremely high rainfall over South Africa.

Introduction

Synoptic patterns related to well-known floods and extremely high rainfall events over South Africa have been analysed and described in detail. Exceptionally high rainfall figures which resulted in widespread flooding over the central interior have been recorded during February 1988. This period was characterised by a strong inflow of humid air from the east, in the lower troposphere, with a persistent surface low-pressure system, associated with strong convergence over the northern parts of Botswana (Triegaardt, Van Heerden en Steyn, 1988). During September 1987 devastating heavy rains also fell over KwaZulu-Natal. The prevailing weather systems during this event included a cut-off low in the upper atmosphere accompanied by a strong surface high-pressure system that ridged across southern parts of the country and resulted in the inflow of humid air over the eastern escarpment (Triegaardt et al., 1988; Tennant and Van Heerden, 1994). Tropical cyclones in the Mozambique channel also contributed to well above-normal rainfall and floods over the eastern parts of KwaZulu-Natal as well as in the Limpopo valley (Alexander and Van Heerden, 1991).

The importance of links between the atmospheric general circulation and sea surface temperature (SST) fluctuations has become increasingly significant. Encouraging results were obtained from studies comparing regional SST anomalies with Southern African rainfall patterns.

Walker (1990) indicated that wet summer rainfall conditions over South Africa are usually associated with relatively high SSTs in the south-west Indian Ocean, west of the Agulhas Retroflection region (Walker, 1986) and adjacent to the west African coastline from 20 to 30°S. Principal component (PC) analysis by Mason et al. (1994) on late summer (January to March) regional SST anomalies for the period 1953 to 1989, showed an insignificant link between South African rainfall and the PC1 SST time series (Benguela region) which accounted for 17.3% of the total variance. The central south Atlantic Ocean, which accounted for only 7.4% of the total ocean variability (PC5 SST time series), appears to have the greatest effect on the South African rainfall limited to the southern Cape coastal regions (Mason et al., 1994). The importance of the phase of the Quasi Biennial Oscillation (QBO) (Lau and Shea, 1988) when comparing regional SST anomalies with Southern African rainfall has been demonstrated by Mason and Lindesay (1993), and Jury and Pathack (1993). Mechanisms linking above-normal SST anomalies over the central Indian Ocean with Southern African droughts has also been explored by Jury and Pathack (1991; 1993); Jury and Lutjeharms (1993); Landman (1995); Jury et al. (1996) and Tennant (1996).

Regional SST anomalies close to the coastline have been strongly correlated with the width of the continental shelf and adjacent coastal rainfall along the south-east coast of South Africa (Jury et al., 1993; Lutjeharms and De Ruijter, 1996). It was suggested by Brundrit and Shannon (1989) that above-normal SST anomalies in the south-east Atlantic Ocean may enhance the intensity of cold fronts sweeping over the Western Cape during winter months. Links between regional SST variability and South African rainfall are, however, not consistent, but complicated. This may be explained by the fact that regional SST anomalies in the vicinity of the South African coastline are located in relatively high latitude regions where local atmospheric responses become noticeably weaker (Webster, 1981; 1982).

In this paper the unusual rainfall and SST patterns that occurred in the Southern African region during the 1995/96 summer season, and particularly during December 1995, will be analysed and discussed. A distinctly strong high-pressure system, accompanied by abnormally strong easterly wind components in the vicinity of Cape Agulhas (Agenbag, 1996), developed south of the country during mid-December 1995. This high-pressure system, which contributed to anomalously high rainfall over the eastern parts of South Africa, may have also been responsible for the penetration of relatively warm ocean water towards the south-east Atlantic ocean (Walker, 1986; 1990) where SST anomalies as high as +4°C occurred.

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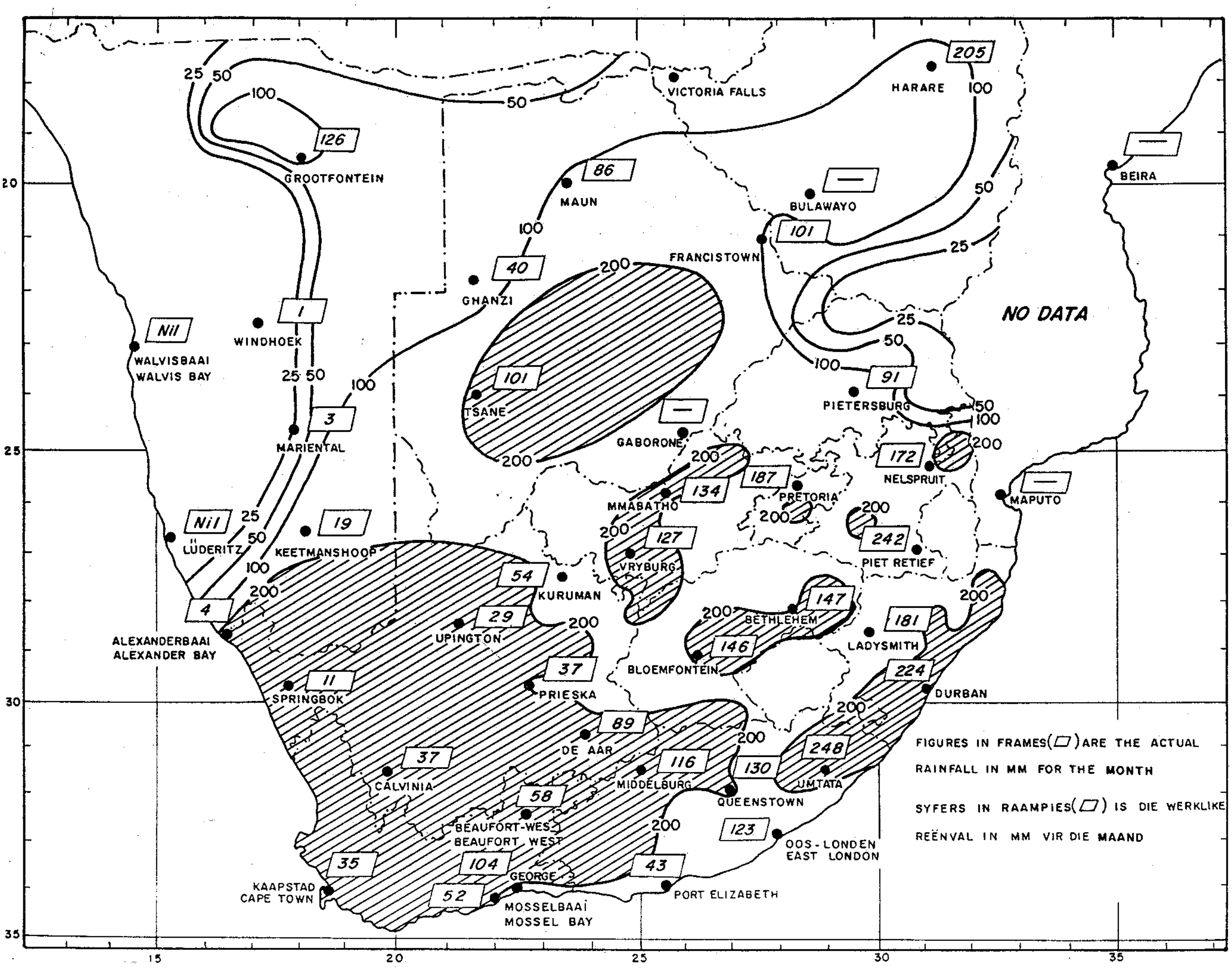

Figure 1

Rainfall (percentage of the normal) over South Africa for December 1995.
(Map: Directorate Climatology, South African Weather Bureau)

Data

Global monthly and weekly SST anomalies, for the period November 1995 to February 1996, were derived from a monthly high resolution (1° x 1°) global SST climatological profile as well as from monthly and weekly optimum interpolation SST fields provided by the National Meteorological Centre (NMC) (Reynolds, 1988; 1993; Reynolds and Smith, 1994). The weekly SST anomaly fields represent differences between both the weekly observed SST and weekly mean SST fields, which were linearly interpolated from the monthly SST climate data.

Observed rainfall data from approximately 400 rain gauges spread over South Africa, for the period November 1995 to February 1996, were interpolated to a grid field (Rautenbach, 1996) which covers the area 20° to 36°S and 13° to 34°E. The rainfall data were obtained from the Directorate Climatology of the South African Weather Bureau.

Rainfall

The 1995/96 summer season has been exceptional in many ways. Since mid-December 1995 onwards, extremely high rainfall figures were recorded over most of South Africa's summer rainfall region. What makes this season even more unique, was that it was preceded by an abnormal lingering drought of almost five years duration. Water restrictions were applied as a result of prevailing dry conditions during the first few months of 1995, when summer crops were severely affected.

With the exception of the far northern parts of the Northern Province, the entire country received rainfall in excess of 100% of the norm (Fig. 1) during December 1995. For large areas over the Western and Northern Cape, KwaZulu-Natal, Free State, Western Province, Gauteng and Mpumalanga rainfall figures were recorded which were even higher than 200% of the norm. During the same period most of the dams filled rapidly with water. Data from the Department of Water Affairs and Forestry (DWAF) indicates that the level of the Vaal Dam, for example, increased from 13% in mid-November 1995 to 100% in little more than five weeks (DWAF, weekly state of reservoirs). Extensive damage to property and crops was reported in KwaZulu-Natal, Gauteng and the Vaal River catchment area when dams overflowed and rivers flooded their banks.

According to the monthly newsletter of the South African Weather Bureau the highest total rainfall values on record was recorded during January 1996 at Durban (448 mm) and Woodbush east of Tzaneen (1 004 mm).

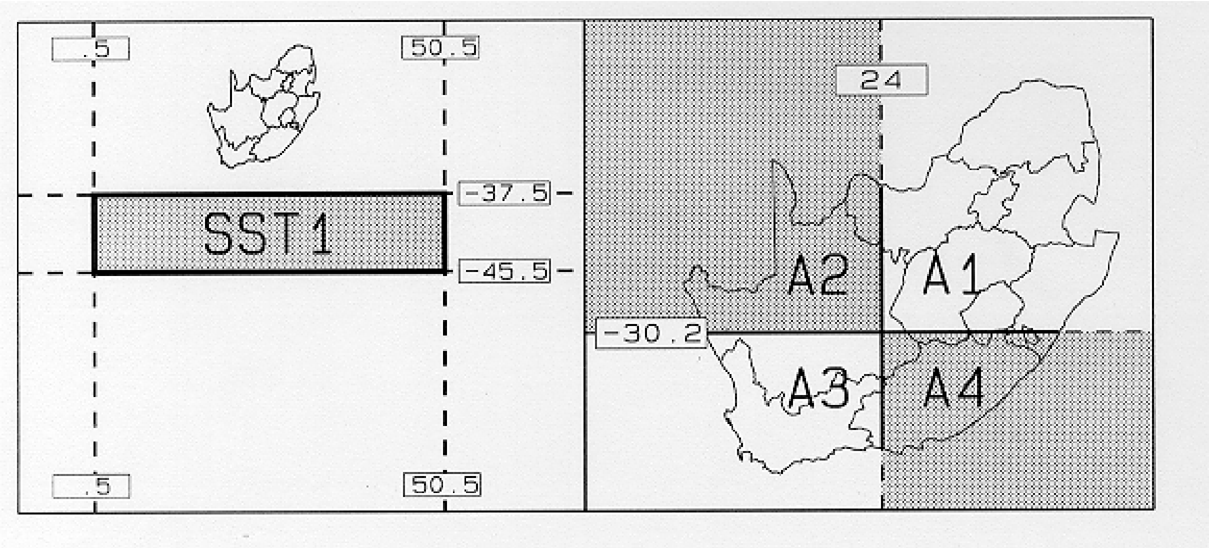

Figure 2
The explored SST domain (0.5°E to 50.5°E and 37.5°S to 45.5°S) relative to South Africa (left) as well as the four rainfall regions (A1, A2, A3, A4) over South Africa (right). The rainfall regions are separated by longitude 24°E and latitude 30.2°S.

TABLE 1
THE TEMPORAL DISTRIBUTION OF THE 15 CONSECUTIVE WEEKS USED IN ANALYSING THE MEAN SST AND TOTAL RAINFALL DATA FOR THE PERIOD 12 NOVEMBER 1995 TO 24 FEBRUARY 1996 (HIGH RAINFALL PERIODS ARE SHADED)

Week	Dates
Week **1**	12 Nov 1995 – 18 Nov 1995
Week **2**	19 Nov 1995 – 25 Nov 1995
Week **3**	26 Nov 1995 – 02 Dec 1995
Week **4**	03 Dec 1995 – 09 Dec 1995
Week **5**	10 Dec 1995 – 16 Dec 1995
Week **6**	17 Dec 1995 – 23 Dec 1995
Week **7**	24 Dec 1995 – 30 Dec 1995
Week **8**	31 Dec 1995 – 06 Jan 1996
Week **9**	07 Jan 1996 – 13 Jan 1996
Week **10**	14 Jan 1996 – 20 Jan 1996
Week **11**	21 Jan 1996 – 27 Jan 1996
Week **12**	28 Jan 1996 – 03 Feb 1996
Week **13**	04 Feb 1996 – 10 Feb 1996
Week **14**	11 Feb 1996 – 17 Feb 1996
Week **15**	18 Feb 1996 – 24 Feb 1996

In an effort to compare the rainfall of South Africa with regional weekly SST observations, the country was divided into four rainfall regions (A1, A2, A3, A4) separated by longitude 24°E and latitude 30.2°S as illustrated in Fig. 2. Although the spatial distribution of rainfall over these regions is not necessarily homogeneous, they nevertheless divide the country into a general summer rainfall section (A1 and A4), a winter rainfall section (A3 and A4) and a drier semi-desert section (A2). The weekly averages of the rainfall for the period 12 November 1995 to 18 February 1996 (Weeks 1 to 15 as listed in Table 1) are graphically displayed for each one of the four rainfall regions in the top diagram of Fig. 3. The rainfall extremes measured between 17 and 23 December 1995, as well as between 21 and 27 January 1996, are illustrated by the shaded blocks in Table 1. These rainfall events, which are also depicted by thick dashed vertical lines in Fig. 3, occurred predominantly over the summer rainfall region (A1 and A4).

During the period of investigation, the weekly rainfall variability (Fig. 3) from Regions A1, A3 and A4, followed the same general pattern, which emphasised the spatial extent of the consecutive rainfall events. The weekly rainfall variability over Region A2, however, differed slightly from the remaining three areas (A1, A3 and A4).

Synoptical diagnostic

Atmospheric circulation patterns were overwhelmingly tropical in nature during December 1995 and January 1996, with the inter-tropical convergence zone (ITCZ) reaching its most southern position during January 1996. On average December 1995 was characterised by exceptionally high sea-level pressure anomalies to the south of Southern Africa, with a persistent surface trough over the interior associated with a southward advection of moist tropical air (Fig. 4).

The atmospheric circulation for the first half of December 1995, however, was dominated by a surface trough over the interior, with cold front activity over the southern coastline between the 7th and 11th of the month. The third and last cold front of the month (15th and 16th) was succeeded by an extremely

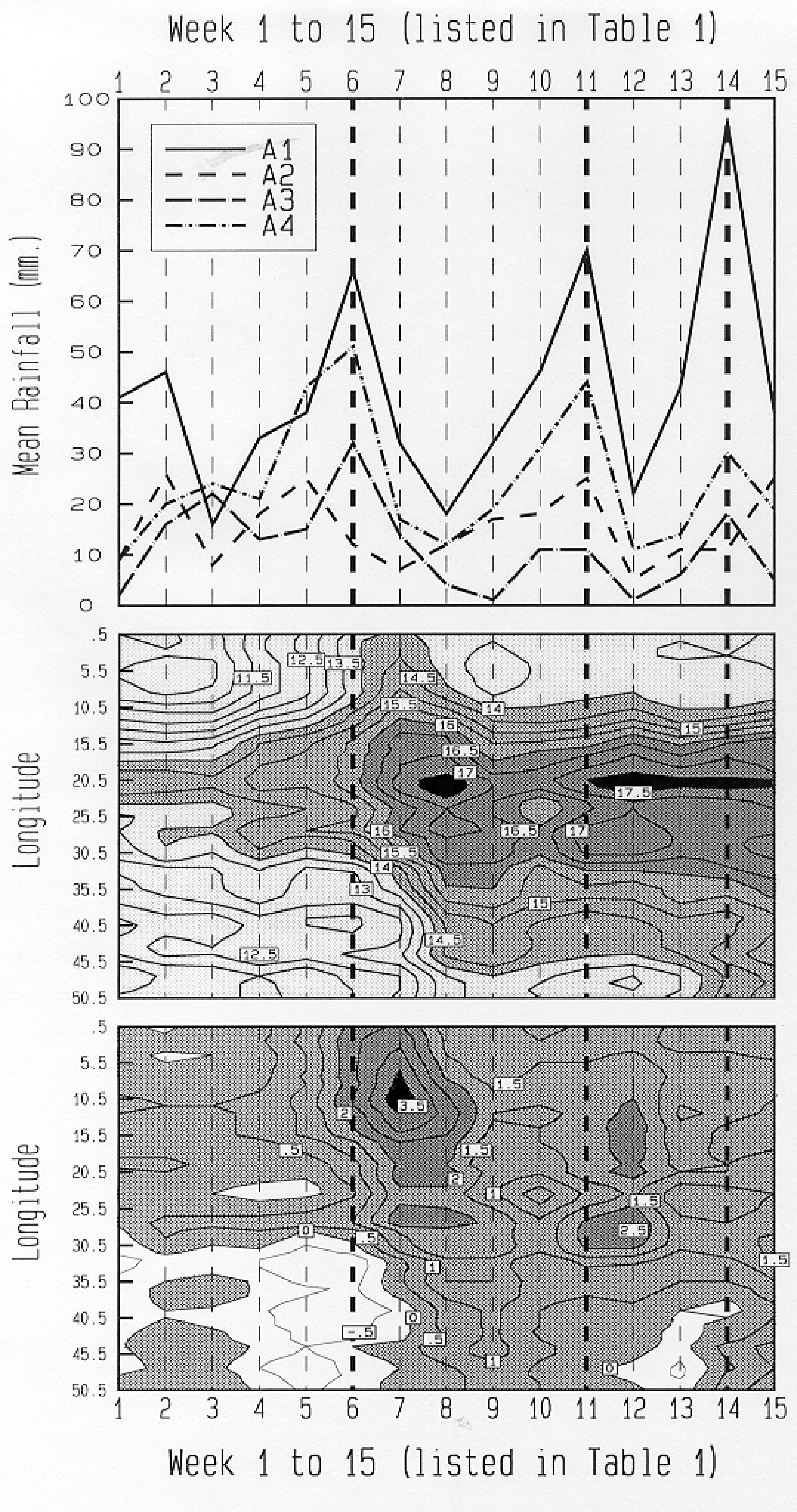

Figure 3

The time series of the total rainfall in mm. for regions (A1, A2, A3, A4) (top) as compared with time series of the longitudinal means of the observed SST values (middle) and SST anomalies (bottom), both in °C, over the SST1 region shown in Fig. 2. The temporal distributions of Weeks 1 to 15 are listed in Table 1.

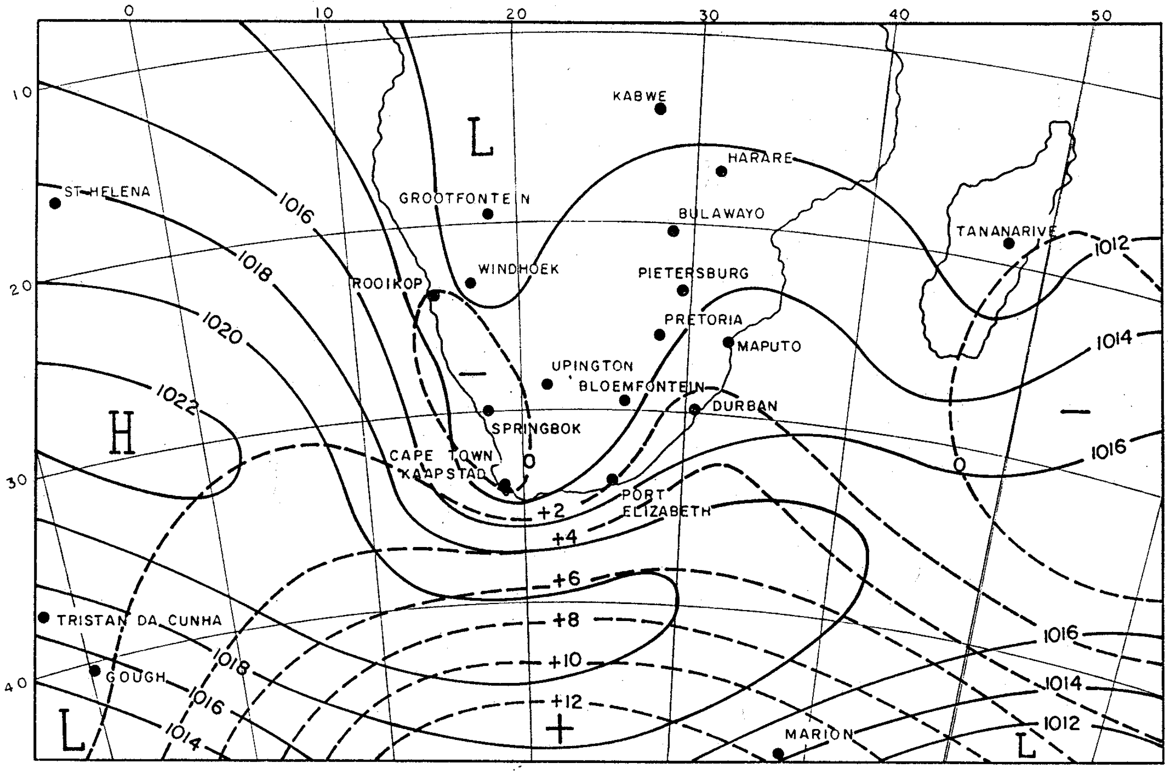

Figure 4

Mean sea-level (MSL) atmospheric pressure (solid isobars) and sea-level atmospheric pressure anomalies (dashed lines), both in hPa, for December 1995.
(Map: Directorate Climatology, South African Weather Bureau).

strong ridge of 1 032 hPa south of the country. As a result good rain fell over the central and eastern parts of South Africa. The deepening of a trough over the interior allowed the well-established ridge to persist south of the country and extensive showers were recorded between 17 and 23 December 1995. Between the 23rd and 25th a cut-off low-pressure system developed in the upper air over the Western Cape. Good rains were recorded as this trough progressed eastwards over the country.

During December 1995 extremely high sea-level pressure anomalies (a monthly average of +12 hPa) occurred over the ocean to the south of Southern Africa (Fig. 4). The mean sea-level (MSL) pressure measured at Marion Island during December 1995 (1013.9 hPa), was also the highest on record since 1950 (Information and Publications, South African Weather Bureau), and resulted in a very strong pressure gradient to the south of the country. The Cape Agulhas pressure index (Fig. 5) depicts the pressure difference between two points located at 35°S; 20°E and 40°S; 20°E, for the period 1981 to 1996 (Agenbag, 1996). Positive pressure indices denote predominantly easterly winds. The pressure index of +4.84 for December 1995, which is indicated by an arrow in Fig. 5, is obviously the highest calculated value since 1981, implying that exceptionally strong easterly winds prevailed south of the country during the second half of December 1995.

The MSL pressure over the entire Southern African region as far as 40°S was below-normal during January 1996. Some of the more notable synoptic events during this period was the tropical cyclone "Bonita", which moved from Madagascar to the northern parts of Mozambique between the 11th and the 15th of the month. Heavy rainfall that occurred between 25 and 27 January 1996 was caused by the deepening of a tropical low-pressure system and subsequent development of a strong cut-off low in the upper air over Botswana. A number of cold fronts moved across to the southern parts of the country during the first half of January 1996, with the second half of the month being characterised by surface high-pressure fluctuations in the southern region.

Regional ocean perturbations

The most comprehensive regional SST disturbance during December 1995, and probably also January 1996, was the intrusion of warmer ocean water into the south-east Atlantic ocean. This intrusion, which extended over a large area at 41°S and west of the 20°E longitude, is illustrated by the darkest shading in Fig. 6. The SST anomaly patterns for December 1995 (Fig. 6) correspond remarkably well with those in a similar map produced for April 1984 by Walker (1986).

The temporal SST variability around the 41°S latitude was explored by considering the longitudinal means of the observed and anomalous SST fields over a domain which extended over the area between 0.5°E to 50.5°E and between 37.5°S to 45.5°S. This domain is indicated by SST1 in Fig. 2. The time series of the longitudinal means of the observed and anomalous SST values for 15 consecutive weeks (from 12 November 1995 to 18 February 1996 or Week 1 to 15 as listed in Table 1) are displayed in the middle and bottom graphs of Fig. 3.

No notable SST disturbances were evident for the first five weeks of 1995 from 12 November to 16 December 1995 (Weeks 1 to 5 in Fig. 3). During this period small negative anomalies, in the order of -0.5°C, were measured over the south-west Indian

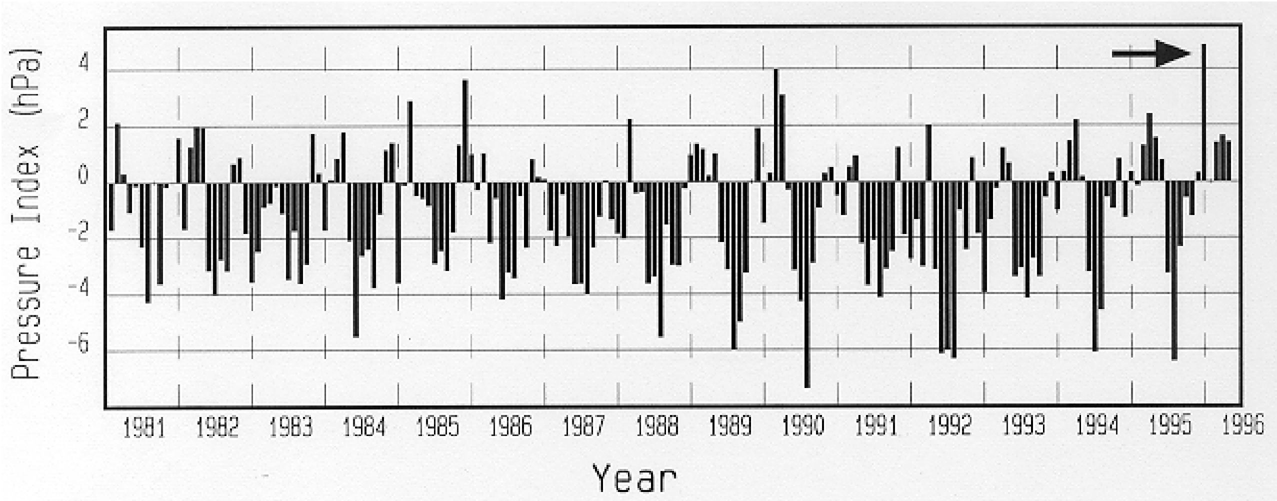

Figure 5

The Cape Agulhas Pressure index or the monthly mean sea-level (MSL) atmospheric pressure difference between two points located at 35° S; 20° E and 40° S; 20° E, for the period 1981-1996. Positive values denote predominantly easterly winds. (The data was obtained from the Sea Fisheries Research Institute, Rogge Bay, South Africa).

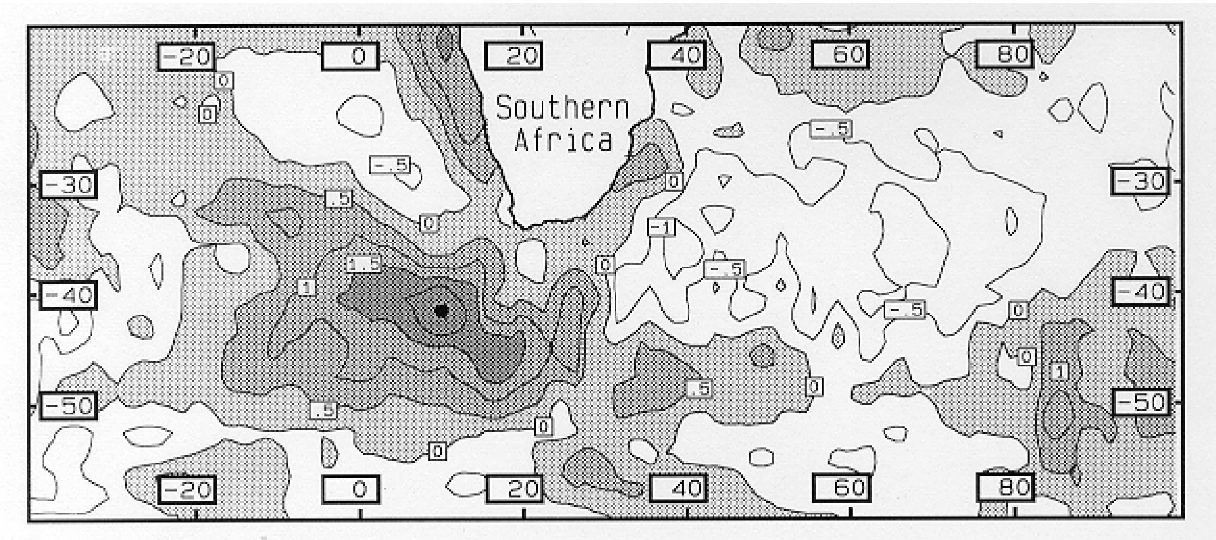

Figure 6

Mean sea surface temperature (SST) anomalies in ° C for December 1995. The above-normal SST region over the south-east Atlantic ocean is well defined by the darkest shaded area.

Ocean, while positive anomalies, similar in magnitude, also occurred over the south-east Atlantic Ocean. From 17 to 23 December 1995 (Week 6), SSTs increased over the south-east Atlantic Ocean and a significant anomaly of +4 °C developed at 10°E during the last week of December 1995 (Week 7). During the first week of January 1996 (Week 8), SSTs increased south of Southern Africa at 21° E to a maximum of 18°C. During the same period the SSTs showed a marginal increase over the south-west Indian Ocean. The two weeks between 7 to 20 January (Weeks 9 and 10) were characterised by a slight decrease in observed as well as anomalous SSTs over most of the SST1 region in Fig. 2. Although weaker than December, a second notable 2.5°C SST anomaly developed by the end of January (Week 12) over the south-east Atlantic Ocean as well as south of Southern Africa. The warm temperatures (18°C) which originated in the ocean during 25 January at 21°E persisted for the remainder of the period under consideration (Weeks 11 to 15).

Discussion

The frequency of extreme rainfall events over South Africa between Weeks 1 and 15, as listed in Table 1, compares considerably well with the frequency of the concurrent SST anomaly increases over the south-east Atlantic Ocean as well as SST increases at 20°E (Fig. 3).

The atmospheric mechanism responsible for the extreme rainfall event that appeared between 17 and 23 December 1995 (Week 6) was the Atlantic high-pressure system ridging in across the southern parts of the continent. This event was accompanied by the development of a deep cut-off low-pressure system in the upper atmosphere over the interior. An extremely strong stationary high-pressure system prevailed south of the country during the December rainfall event allowing strong easterly winds to persist to the south of the country. The rainfall between 21 and 27 January 1996 (Week 11) has been attributed to the development of a sequence of tropical low-pressure systems over the interior, while the second half of the month was characterised by more than one surface high-pressure intrusion to the south of the country. Both these rainfall events are depicted by thick dashed vertical lines in Fig. 3, which also illustrate that the high rainfall events were followed by above-normal SST anomalies over the south-east Atlantic Ocean with a time lag of about one week.

Walker (1986) found that similar SST anomaly patterns during April 1984 were preceded by the occurrence of abnormally high atmospheric pressure and strong easterly wind components south of the country. Walker (1990) also concluded that the penetration of warmer Agulhas current water into the south-east Atlantic Ocean depends on strong easterly wind forcing across the south-west Indian Ocean. The synoptical diagnostic for December 1995 revealed that the high rainfall events were in fact characterised by an abnormally strong surface high-pressure region, accompanied by a steep pressure gradient and therefore strong easterly winds over the ocean to the south of Southern Africa. There is good reason to believe that these atmospheric events may have contributed to an unusual westward penetration of the warm Agulhas Current waters into the south-east Atlantic Ocean. In support of this supposition, it was also found that the highest increase in observed SSTs occurred over a region south of Southern Africa (21° E) which extended west towards the south-east Atlantic Ocean (Fig. 3).

It has been postulated that an extreme westward penetration of warm Agulhas water into the South Atlantic could contribute to cyclogenesis or trough amplification, and in this manner, increase the likelihood of the formation of tropical low-pressure systems over Southern Africa (Walker, 1990). Atmospheric pressure patterns for January 1996 were indeed dominated by the formation of low-pressure systems over the interior. The links between warm SSTs in the south-east Atlantic Ocean and tropical lows over the interior could, however, not be confirmed as the major January rainfall event (Week 11) was preceded by a decreasing trend in observed as well as anomalous SSTs to the south of the country. The good rainfall, which occurred between 25 and 27 January 1996 (Week 11), was caused by the deepening of a tropical low-pressure system and subsequent development of a strong cut-off low in the upper air over Southern Africa. It is important to note that these tropical troughs appears to be the major summer rain-producing systems for South Africa (Harrison, 1984).

The moderate increase in SST anomalies over the south-east Atlantic Ocean during the end of January (Week 12) might be attributed to a concurrent increase in the frequency of high pressure systems to the south of the country.

Conclusions

The 1995/96 summer season has been exceptional in many ways. This season was not only preceded by an lingering drought (1990 to 1995), but was also characterised by extreme climatic events during December 1995 and January 1996. The MSL pressure of 1 013.9 hPa for December 1995 was the highest measured at Marion Island since 1950 (Fig. 4). The Cape Agulhas pressure index for December 1995, which reflects the pressure gradient south of Southern Africa, also had the highest calculated value since 1981. This means that exceptionally strong easterly winds prevailed south of the country during December 1995. In many regions the highest rainfall on record was recorded. During January 1996 Durban received 448 mm and Woodbush (east of Tzaneen) 1 004 mm (monthly newsletter of the South African Weather Bureau).

The extreme rainfall event which occurred during December 1995 (Fig. 3), was characterised by above-normal surface high-pressure regions and strong easterly winds south of the country, accompanied by the development of a cut-off low-pressure system in the upper atmosphere over the interior. This rainfall event was followed by the development of a significant above-normal SST anomaly over the south-east Atlantic Ocean.

The rainfall during January 1996 was modulated by a sequence of tropical low-pressure systems over the interior. A weak penetration of warm Agulhas water into the south-east Atlantic ocean probably resulted from an increase in the surface high-pressure frequency to the south of the continent.

Observed data illustrated a time lag of about one week between the extreme rainfall events (Weeks 6 and 11) and the occurrence of above-normal SST anomalies over the south-east Atlantic Ocean (Fig. 3). There is good reason to assume that these SST anomalies may have been caused by atmospheric circulation patterns induced by predominantly higher surface atmospheric pressures to the south of the country. According to previous findings (Walker, 1990) there is also an indication that complicated ocean-atmosphere interactions might have contributed to the evolution of a number of tropical lows over the interior, although it could not be clarified in this study. However, both the surface high-pressure systems over the southern ocean as well as the upper air tropical low-pressure systems can be linked to the occurrence of extreme SST and rainfall perturbations during the 1995/96 summer season. These results reconfirm the complex nature of links between regional SSTs and local atmospheric general circulation patterns. Future numerical model investigations are therefore recommended.

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