Evolution of the 2002–2004 drought over northern South Africa and potential forcing mechanisms

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We consider the evolution of the 2003/04 summer drought over northern South Africa to wetter than average conditions by the end of the season. This season was neutral (that is, it did not coincide with either an El Niño or a La Niña event) and yet recorded well-below-average rainfall for at least the first four months of the summer (October–January) with a transition to above-average rainfall by March. Previous work investigating other neutral summers with significantly below-average rainfall over the region (1951/52, 1967/68, 1981/82) have indicated that, in contrast to El Niño dry summers, there are mid-latitude circulation anomalies south and southwest of South Africa that lead to an increase (decrease) in the advection of cool, dry (warm, moist) South Atlantic (South Indian) air masses over South Africa and hence dry conditions. It is shown that a similar situation occurred in October–December 2003 but these circulation anomalies started to break down in January 2004, resulting in a transition towards above average rainfall by the end of summer. Although the basic mechanism (modulated air mass advection) behind the early summer drought is clear, the mid-latitude circulation anomalies that lead to this situation for each significantly dry neutral summer (1951/52, 1967/68, 1981/82, 2003/04) are somewhat different. As a result, early identification of these patterns and potential forecasting of dry conditions prior to the start of summer is difficult.

Introduction

Northern South Africa is a summer rainfall region that is prone to significant flooding and drought disasters as well as extreme weather events.[1–3] With its large and poor rural population, many of whom are dependent on rain-fed agriculture, it is a region that is particularly vulnerable to extremes in weather and climate. In the last five years, the region has been subjected to flooding (particularly in the southern Kruger National Park and adjoining areas) in 2000 and an extended drought during 2002/04. It is the latter that is the focus of this study. The 2002/03 summer drought coincided with an El Niño event when one expects dry conditions over most of the summer rainfall region, particularly in the north and east.[4–6] Indeed, out of 10 strong El Niño events during 1921–2000, only the 1957/58 event was not associated with below-average rainfall in Limpopo province and neighbouring areas.[6] Conditions continued to be very dry in early summer (October–December, OND) 2003, despite there being no El Niño at the time, and then improved in January 2004 (Fig. 1). In February, the northern half of the province remained dry whereas the southern half recorded average or above-average rainfall; in March 2004, most of Limpopo province received above-average rains (particularly the east) (Fig. 1).

Limpopo province is also the centre of the 'drought corridor' defined[7] across 20–25°S in southern Africa. This 'drought corridor' not only experiences considerable interannual variability in summer rainfall but also frequently has rainy seasons in which half or more of the total December–February period is dry (that is, relatively few rainy days and some extended dry spells during the core summer rainy season).[7] Thus, dry conditions manifest themselves in Limpopo not just in reduced seasonal totals but also in an increase in the duration and severity of dry synoptic to intra-seasonal scale spells within the summer rainy season itself.

In a study of droughts over northeastern South Africa, including Limpopo province, it has been suggested[6] that those droughts that occur during non-El Niño years tend to be associated with significant mid-latitude circulation anomalies south or southwest of South Africa that result in the advection of relatively cool and dry South Atlantic air over South Africa. In this study, we investigated the evolution of the 2002/04 drought over the region in that context to determine the mechanisms responsible for the continuation of the drought into the non-El Niño summer (October–December 2003) and then the partial relief of these conditions in January–March (JFM) 2004. Note that 2003/04 was also a neutral summer (that is, neither El Niño nor La Niña). In so doing, we hope to shed further light on the regional circulation anomalies associated with drought episodes over South Africa, information that is needed if seasonal forecasting efforts over the country are to improve in accuracy.

Circulation anomalies associated with the summer 2002/03 drought and evolution towards the 2003/04 drought

As mentioned above, the summer 2002/03 drought took place during the mature phase of an El Niño event. High pressure anomalies (Fig. 2a) were evident during JFM 2003 over Australia, most of the South Indian Ocean and southern Africa, as expected for El Niño.[4,5,8] These acted to suppress convective rainfall over Limpopo province and neighbouring regions. On the hemispheric scale, a Rossby wave train was evident across the South Pacific and into the South Atlantic, the so-called Pacific South America (PSA) pattern,[8] again as expected for El Niño.[9,10] During AMJ 2003, the high pressure anomalies over South Africa strengthened, consistent with the continuing dry conditions and, on the hemispheric scale, the PSA pattern started to weaken with a transition towards a wavenumber 3 pattern in the southern mid-latitudes. The latter is characterized by three high and three low pressure anomalies evident around the hemisphere.

By the following winter (July–September, JAS), a strong wavenumber 3 pattern was evident over the mid-latitudes of the southern hemisphere, with a large cyclonic anomaly situated over South Africa and adjoining ocean areas to the south (Fig. 2a). When it occurs during the summer half of the year, this type of anomaly is characteristic of dry conditions over the summer rainfall region of South Africa, since it indicates increased advection of cool, dry South Atlantic air across the country.[6] As shown below, a cyclonic anomaly feature south or southwest of South Africa and associated advection of South Atlantic air across the country was present during OND 2003, thereby contributing to the drought. The following section discusses how these unfavourable conditions in the dry early

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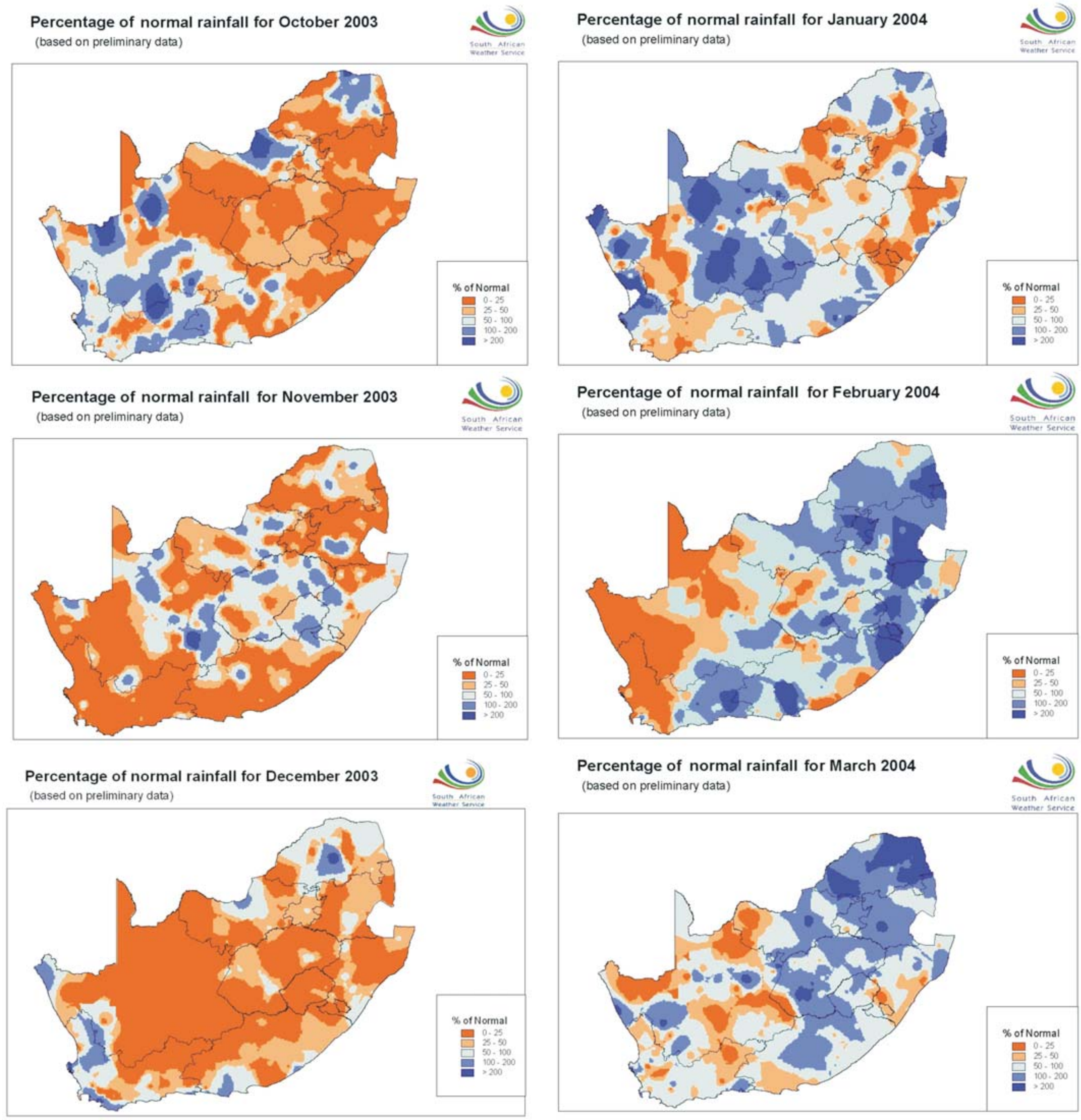

Fig. 1. Percentage of average rainfall recorded over South Africa for each month during the 2003/04 summer. Light blue and browns denote below-average rainfall, medium and dark blue signify above-average rainfall.

summer of OND 2003 evolved to the improved rainfall conditions in JFM 2004.

Circulation anomalies associated with the OND 2003 drought

Figure 2b shows 500-hPa geopotential height anomalies for each month of the OND 2003 period. For each month, a cyclonic anomaly was evident south or southwest of South Africa, with a high pressure anomaly extending over the country from the South Indian Ocean. These anomaly patterns have some similarities to circulation anomalies documented[6] during the severe non-El Niño summer droughts over northeastern South Africa (1951/52, 1967/68, 1981/82), in which a combination of a low pressure anomaly to the south or southwest together with high pressure anomalies over the land led to enhanced (reduced) advection of cool, dry (warm, moist) airmasses from the South East Atlantic (South West Indian) oceans. In a sense, the patterns displayed in Fig. 2b correspond to a circulation pattern that is more typical of winter with little opportunity for the development of easterly waves and lows over northern South Africa and neighbouring regions that is needed for good summer rains, either via organized tropical–extratropical cloudbands[11] or less organized thunderstorm systems. Consistent with the suggestion of a more winter-like circulation pattern over the South African region in OND 2003, Fig. 3 indicates that the subtropical jet was displaced northwards and strengthened during OND 2003.

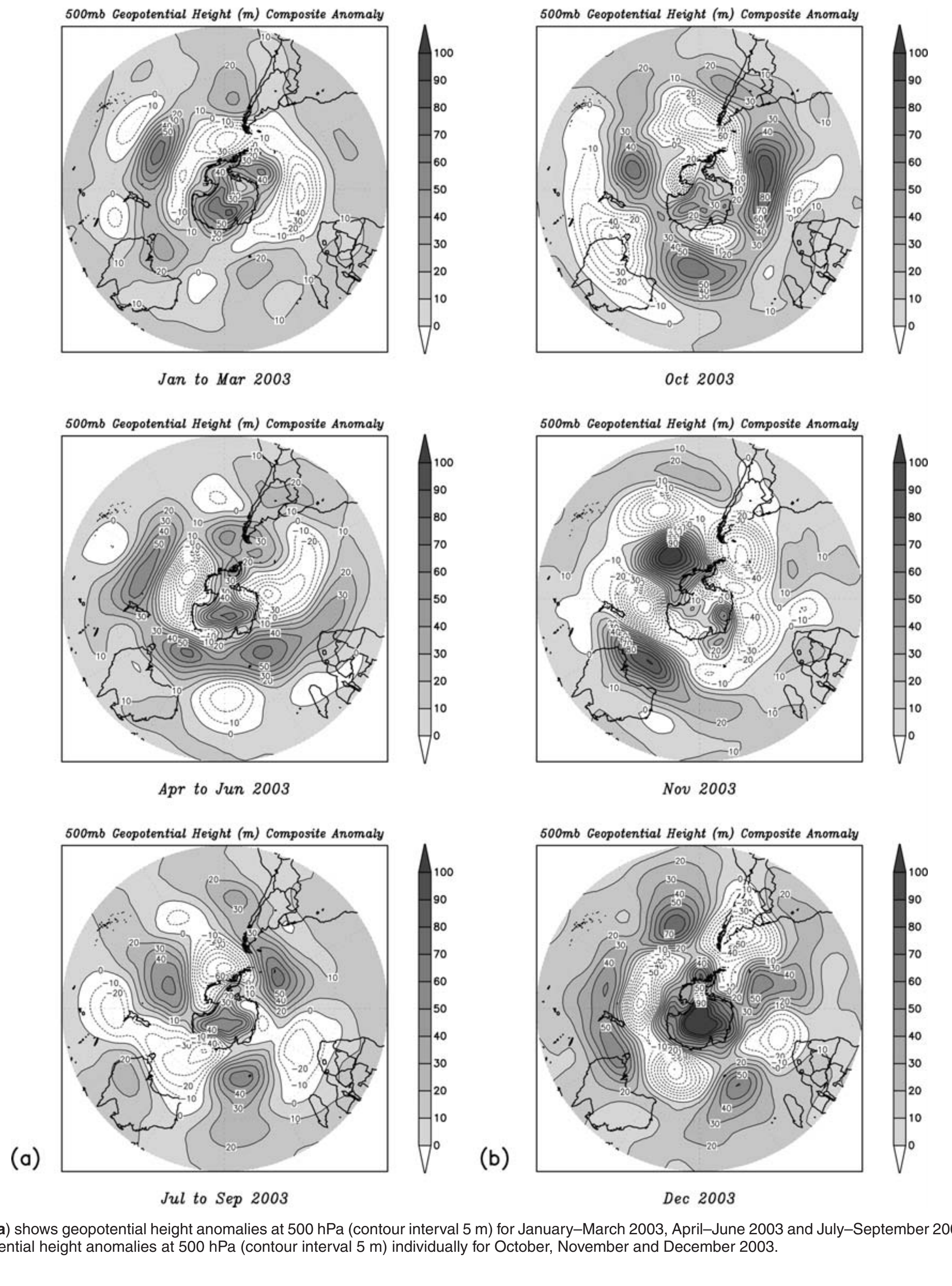

Fig. 2. Panel (**a**) shows geopotential height anomalies at 500 hPa (contour interval 5 m) for January–March 2003, April–June 2003 and July–September 2003. Panel (**b**) shows geopotential height anomalies at 500 hPa (contour interval 5 m) individually for October, November and December 2003.

On the hemispheric scale, Fig. 2b shows a wave 3 or 4 anomaly pattern for each month but with the ridges and troughs arranged such that they discourage the frontal activity needed to the southeast of South Africa for rain-producing cloudbands to form across the country. Compared with the JAS 2003 anomaly pattern, October and November 2003 suggest a slow westward planetary wave propagation of the main positive and negative height anomalies in the mid-latitudes.

The enhanced (weakened) advection of low-level airmasses from the South East Atlantic (South West Indian) oceans is confirmed in Fig. 4, which plots the zonal wind anomalies at the 850-hPa level, or just above the height of the interior plateau. With the exception of the KwaZulu-Natal coast and nearby ocean, positive (or westerly) anomalies are seen throughout South Africa and these extend into the Mozambique Channel and ocean east of Madagascar. A zonal wind transect along 35°E (not shown) indicates westerly (offshore) anomalies at the latitude band of Limpopo province and southern Mozambique that extend from the surface up to mid-levels. Furthermore, westerly anomalies exist entirely across the latitude band from southern Zimbabwe to south of South Africa at the 850-hPa level and above, confirming that the region corresponding to the interior plateau of South Africa and north into Zimbabwe was characterized by reduced inflow from the Mozambique Channel