Simulating drought in Southern Africa using sea surface temperature variations

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Abstract

Changes in atmospheric circulation that produce droughts over South Africa are briefly reviewed, as too are the links between regions of homogeneous sea surface temperature variation in the oceans around Southern Africa and their correlation with rainfall over South Africa. Thereafter sea surface temperature anomaly fields known to be linked to the occurrence of droughts are used to initialise the 4-level CSIRO general circulation climate model to simulate drought over South Africa. Model results are compared with previously developed hypotheses concerning ocean-atmosphere interactions in the region and are shown to be consistent with observations in many important respects.

Introduction

The variability of South Africa's climate has been extensively investigated for many years. A detailed review and synthesis of the characteristics and mechanisms of the variability, particularly that of rainfall is available (Tyson, 1986). Variability may be ascribed to, changing synoptic conditions and pressure patterns from scales of a few days to seasons and extended spells of years. Variations in the tropical easterlies and their attendant disturbances exert an important controlling influence on South African rainfall (Tyson, 1984; Harrison, 1984; 1986; Jury and Pathack, 1991; Jury et al., 1991). Likewise, the importance of the El Niño-Southern Oscillation phenomenon (ENSO) in modulating the variability of South African rainfall has been demonstrated (Harrison, 1986; Lindesay, 1986,1988; Van Heerdenetal., 1988; Mason and Lindesay, 1993). Changes in the wave configuration and frequency of westerly Rossby waves are other factors of fundamental importance in controlling the variability of rainfall south of about 20°S over the subcontinent (Tyson, 1981; Steyn, 1984; Harrison, 1986; Jury and Levey, 1993). Over the last few years increasing recognition has been given to the importance of sea surface temperature changes in regulating the atmospheric circulation and rainfall over Southern Africa (Gillooly and Walker, 1984; Walker and Mey, 1986; Nicholson, 1986, 1989; Nicholson and Entekhabi, 1987; Walker, 1989,1990; Mey et al, 1990; Walker and Lindesay, 1989;Brundrit and Shannon, 1989). The most recent and detailed treatment of this subject has been Mason's principal components analysis of Atlantic and Indian Ocean sea surface temperatures and the linking of changes in these to rainfall variability over South Africa (Mason, 1992, 1993 a,b).

In this paper the latest findings on how sea surface temperatures in the oceans adjacent to Southern Africa affect South African rainfall will be reviewed. In addition, simulations using the Australian 4-level, mixed layer (slab ocean) CSIRO general circulation climate model, initialised with regional sea surface temperature anomalies associated with late summer (January to March) drought over Southern Africa, will be presented and compared with observations and previously developed ideas.

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Links between regional sea surface temperatures and South African rainfall

Previous research has shown that during periods of within-season drought, as well as during dry spells extending over years, pressure throughout the atmosphere over Southern Africa tends to rise, while falling to the south and south-west (Miron and Tyson, 1984). At the same time anomalous divergence and subsidence occur over the subcontinent (Tyson, 1986). Upper-level standing waves in the westerlies are displaced eastward with the preferential locality for the occurrence of trough lines shifting from the west to the east coast region, or even out to sea to the east of Natal (Steyn, 1984; Harrison, 1984; Tyson, 1986; Jury and Levey, 1993). At the same time tropical easterly flow weakens (Tyson, 1981; Harrison, 1986; Jury and Pathack, 1991; Jury et al., 1991), tropical-temperate troughs occur further to the east (Harrison, 1984,1986; Lindesay, 1988; Jury and Levey, 1993), the locus of occurrence of cloud bands associated with tropical- temperate troughs moves eastward off the continent and over the western Indian Ocean (Harrison, 1986; Lindesay, 1988), the westerlies strengthen south of Africa (Harrison, 1986; Jury and Levey, 1993), particularly in the vicinity of Marion Island (Harrison, 1986), and tracks of weaker mid-latitude storms shift northward (Harrison, 1986; Tyson, 1986). These changes are illustrated schematically in Figs. Land 2.

Sea surface temperatures around South Africa vary characteristically during dry summers in a pattern first identified by Walker (Walker, 1990) (Fig. 3). Principal components analysis (Mason, 1992; 1993 a,b) reveals that the pattern of warming and cooling of the oceans around South Africa (Fig. 4) is more complicated than shown by Walker. Eight principal components have been found to explain 75% of the sea surface temperature variability over the period 1910 to 1989 (Table 1). The effect of this variability on South African rainfall is, however, complicated. Those areas of the ocean in which the greatest variability in sea surface temperature occurs do not necessarily have the greatest effect on rainfall, if any effect at all. An example is the Benguela system (PC 1) which explains most ocean temperature variability (17,3%). In some areas of the Northern Transvaal the system appears to explain up to 16% of the rainfall variability when the effect of the Quasi Biennial Oscillation (QBO) is ignored and up to 49% when the QBO is in its easterly phase. (The QBO (having a periodicity of around 2 years) is associated with the periodic reversal from easterly to westerly of equatorial stratospheric winds in the region