

Exchanges

- Scientific Contributions -

Southern African rainfall - the role of the Indian and Pacific Oceans in HadAM3 idealised experiments*

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Background

The CLIVAR Africa Implementation Plan identifies three major questions concerning African climate. Of these, the first entails the causes of African climate variability and the second, the ability of current dynamical models to simulate this variability. In addition, the role of the ocean basins surrounding Africa in modulating climate separate from that of ENSO is emphasised. The importance of these questions lies in the need to develop our understanding of African climate and in enhancing seasonal forecasting potential.

Accordingly, we set out to identify the key sea surface temperature (SST) patterns and circulation mechanisms associated with southern African summer (JFM) rainfall variability, which are independent of ENSO. The work consists of an observed component (analysing Reynolds SSTs, Hulme rainfall, sea level pressure data (SLP) and reanalysis NCEP circulation fields), and a substantial set of idealised model experiments featuring HadAM3 forced with sea surface temperatures. Together

this work forms a large part of Anthony Preston's doctoral thesis.

Observed Relationships

While ENSO-southern African rainfall relationships have been studied in some detail, knowledge of non-ENSO related variability, though arguably as important, is less complete. Therefore we began by removing the ENSO (SOI) signal from all the observed and reanalysis data sets. There are several ways of doing this. We used linear regression, a simple technique that, although not perfect, has been applied for the same purpose in similar studies (e.g. Barreiro et al., 2002; Zhang et al., 1996). Regional indices of rainfall (rotated EOFs of JFM seasonal anomalies, 1959-1998) were calculated from the residuals of the ENSO-gridded rainfall linear relationship. This provided new regional rainfall time series independent of ENSO. Removing the ENSO signal in the same way from all remaining SST and circulation fields as well, we then regressed those fields onto the new rainfall time series. Figure 1 shows regions of significant correlation between the regional rainfall time series and the key fields of lower tropospheric moisture flux, specific humidity and sea level pressure (SLP). The most prominent feature in any part of the global circulation is a vorticity change in the Indian Ocean anticyclone. This leads to an enhanced (reduced) moisture flux over the eastern sea board of the sub-continent and attendant moisture flux convergence (divergence) over the southern African interior in wet (dry) years. In turn, the atmosphere is drier (more moist) over the Indian Ocean but more moist (drier) over southern Africa in wet (dry) years.

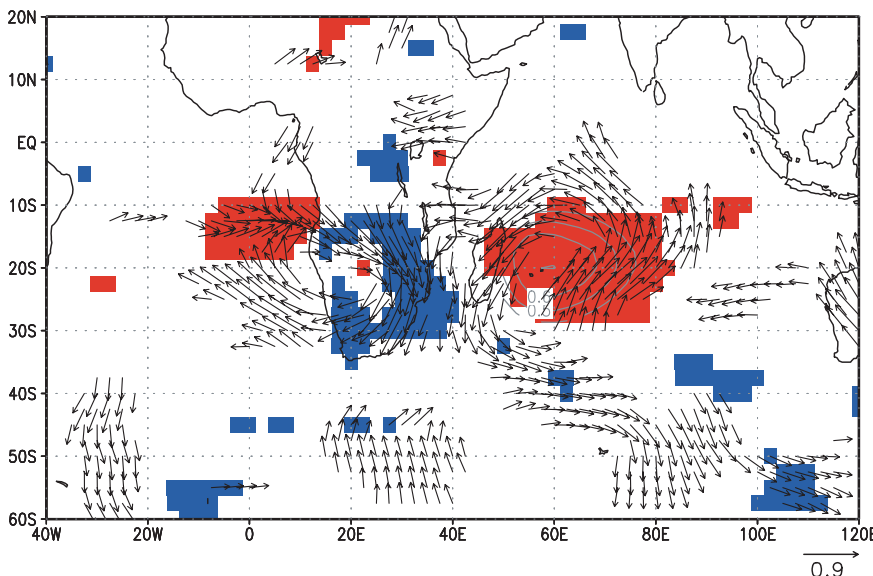


Figure 1: Correlations between non-ENSO related time series of southern African rainfall and non-ENSO related moisture flux at 700-hPa (vectors); specific humidity at 700-hPa (red shading = negative correlation, blue shading = positive correlation) and SLP (grey contours). Only statistically significant fields (0.05 level) are shown.

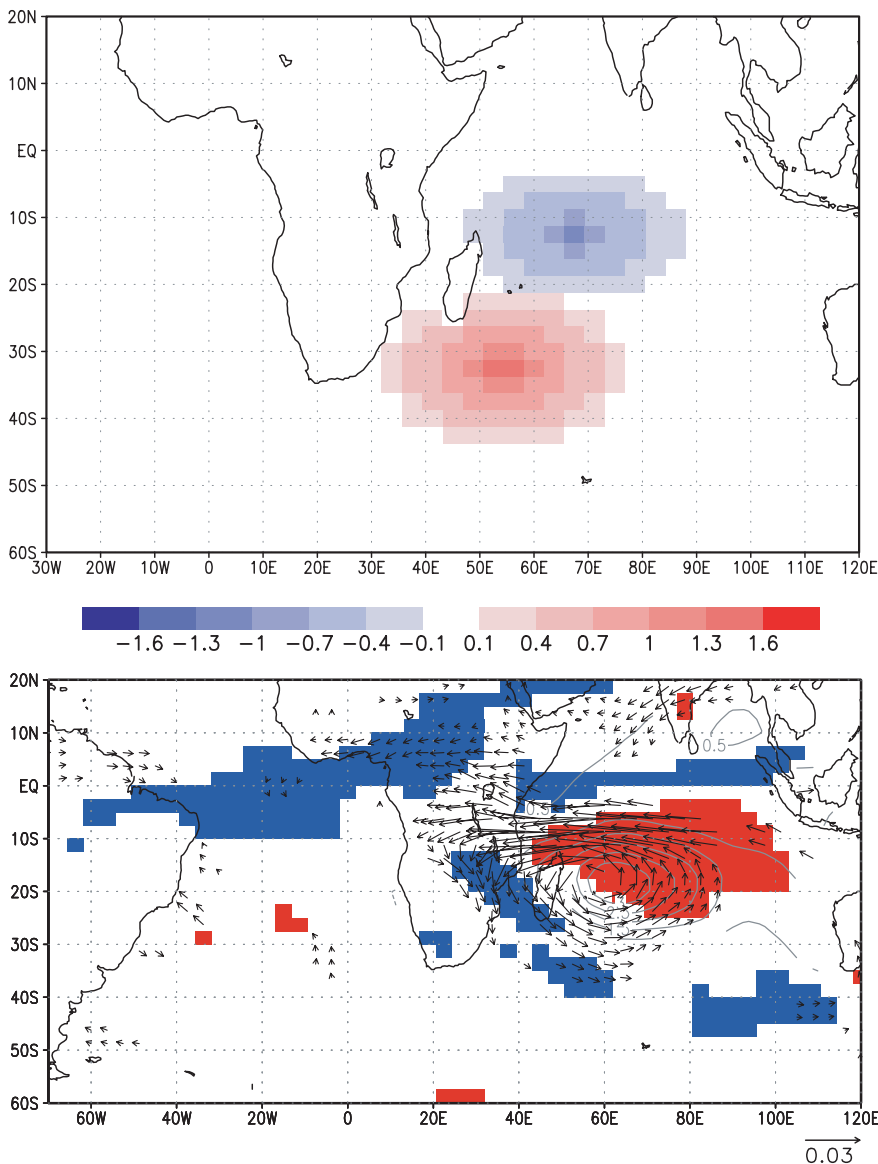


Figure 2a: Idealized sea surface temperature anomalies in °C associated with anomalously wet conditions over southern Africa in the austral summer. The patterns are linearly independent from ENSO.

Figure 2b: Circulation response (experiment minus control) in the Met Office, Hadley Centre model HadAM3 to the idealized sea surface temperature anomalies in Fig. 2a. Vectors are moisture flux anomalies at 700-hPa; shading represents lower specific humidity at 700-hPa (red) and higher specific humidity at 700-hPa (blue) and SLP (contours). Only statistically significant fields (0.05 level) are shown.

A coherent pattern of non-ENSO related SSTs accompanies these circulation anomalies. This features a modification of the SST gradient with warming in the south and cooling in the north of the south-west Indian Ocean (SWIO) in wet years whereas a modification with cooling in the south and warming in the north favours dry conditions (Preston et al., 2000).

Model Experimental Design

Are these SST patterns capable of forcing an Indian Ocean and southern African circulation response sufficient to induce significant rainfall anomalies? Do these anomalies resemble those in the observed (Figure 1)? Can this forcing pattern exert an influence in the absence of remote Pacific based forcing? To answer these questions, we set up a large number of idealised experiments using the AGCM HadAM3. Consistent with the observed fields, SST forcing was introduced in November, after which the pattern persisted until March. Integrations began from atmospheric states in equilibrium with climatological SSTs. The control experiment was forced with climatological SSTs. The experiment and control ensemble consisted of 10 runs (20 runs in total), each of the 10 runs differing only in terms of the initial atmospheric conditions.

The Indian Ocean SST Gradient

Experiment 1 was forced with warm SST anomalies in the south, and cool anomalies in the north of the SWIO (Figure 2a). The experiment minus control difference is shown in Figure 2b for JFM. The atmospheric response to these SST anomalies is a spin up of the Indian Ocean anticyclone, enhanced moisture flux across the African coastline through the lowest 3 km of the atmosphere, moisture flux convergence into the southernmost location of the ITCZ over Africa, and consequent enhanced convection. These features are similar to the observed fields shown in Figure 1, although the model clearly departs in details of the moisture flux convergence

over the subcontinent. A reversal of the SST gradient leads to a symmetrically opposite response in the atmosphere (not shown), as suggested by the observed correlation fields in Figure 1.

Are the negative and positive components of the modified SST gradient equally important in forcing the atmosphere? To answer this question, an additional series of 4 experiments (cooling southern SWIO, warming

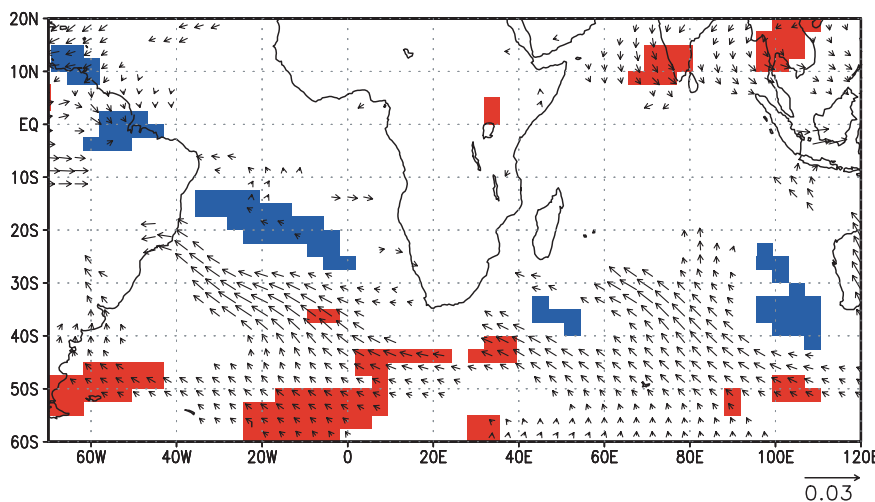


Figure 3: Circulation response in the UK Meteorological Office model HadAM3 to the idealised La Niña Pacific and Indian Ocean sea surface temperature anomalies. Vectors are moisture flux anomalies at 700-hPa; shading represents lower specific humidity at 700-hPa (red) and higher specific humidity at 700 hPa (blue) and contours show SLP. Only statistically significant fields (0.05 level) are shown.

southern SWIO, cooling northern SWIO, warming northern SWIO, as defined by the SST anomaly centres in Figure 2a) were run. It appears that the model is highly sensitive to changes in the northern part of the SWIO pattern (the northern lobe in Figure 2a), regardless of whether the SST anomalies forcing the model are positive or negative. In fact, the model response to forcing from the northern SWIO is very similar to the full modification of the gradient (e.g. as in Figure 2a). This suggests that the southern part of the SST pattern is unimportant in forcing the observed response evident in Figure 1. Model experiments with forcing from the southern SWIO only confirm this - the response being rather weak and localised above and immediately downwind of the local SST forcing. This may suggest that the southern component of the SST pattern is induced by the atmosphere in the observed data.

Indian and Pacific Ocean

Is the modification to the SST gradient in the SWIO shown in idealised form in Figure 2a a result of remote forcing from the Pacific? If we are to accept that linear regression removed the ENSO signal in the observed analysis adequately, then the answer is no. On the other hand, the SST gradient is well represented in 1974 and 1976, two La Niña years and two years in which rainfall in southern Africa was anomalously high.

A further set of experiments involving canonical ENSO (La Niña and El Niño) forcing were therefore conducted. In each of these experiments, Pacific only and Pacific and Indian Ocean forcing were prescribed (4 experiments in all). Figure 3 shows the model response to Pacific and Indian Ocean canonical La Niña forcing. Clearly the model is more sensitive to the patterns we identified as being separate from ENSO (e.g. Figure 2a) than it is to large scale and remote forcing.

Summary

In response to the CLIVAR Africa Implementation Plan, we have sought to better understand climate variability through the use of numerical models. In particular we have identified a non-ENSO related SST pattern, which exerts considerable influence on southern African rainfall. The presence of this pattern in various coupled model runs is discussed in another paper submitted to this issue of CLIVAR Exchanges by Matthew Swann and co-authors.

Acknowledgements

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