**ENSO-like decadal variability and South African rainfall**

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1. Introduction

[2] Joint EOF and multitaper method singular value decomposition (MTM-SVD) analyses of 1871–1998 global sea surface temperature (SST) and mean sea level pressure (MSLP) data indicate the existence of ‘ENSO-like’ patterns on various decadal to multidecadal timescales [Allan, 2000]. These show significant signals outside the tropical Indo-Pacific, and it is conceivable that they may influence rainfall in areas remote to ENSO impacts like South Africa. The existence of prominent southern African decadal rainfall variability has long been known [e.g., Tyson et al., 1975] but the mechanisms are unclear. Here, links between South African decadal scale rainfall variability for summer and winter rainfall patterns and ‘ENSO-like’ decadal patterns are explored.

[3] The premise is that the various decadal to multidecadal ENSO-like modes which have significant expression in the Indian Ocean/southern African region [Allan, 2000], move in and out of phase with each other through time, sometimes reinforcing the impact on rainfall on each scale and sometimes opposing each other. Thus a simple linear combination of the various modes may help explain the observed low frequency variability in South African rainfall.

2. Methods and data

[5] A winter and a summer rainfall series for 1900–1998 are respectively formed by spatially averaging the New et al. [2000] gridded rainfall over 17°–21°E, 32°–34°S for each May–September and over 25°–31°E, 22°–32°S for each October–March. This has been extended to 2001 using South African Weather Service data. A seven point running mean is then applied to each series to bring out the decadal scale signals of interest and yields a record from 1903 to 1998.

[6] The resulting decadal rainfall variability is then compared with the time series of the joint leading SST-MSLP seasonal EOF derived by Allan [2000] for various decadal to multidecadal bands. This approach is somewhat similar to that of Holland et al. [1999] who derived global low pass filtered SST EOFs and then regressed these series against the leading EOF of sub-Saharan African summer rainfall. The bands shown in Allan [2000] and applied here were obtained after Chebyshev filtering the global UKMO GISST3 and GMSLP 2.1f data in various near-decadal bands of 9–13 years, 13–18 and 18–39 years. These three leading EOF series are referred to as EOF1, EOF2 and EOF3 below. The particular bands were determined from significant signals in the MTM (frequency domain specific) SVD localised variance spectrum of the joint SST and MSLP data [Mann and Park, 1996].

3. Results

[7] When positive, the spatial pattern of the leading EOF on each band shows a broad warm tongue over the central to eastern Pacific, warming over the tropical Indian Ocean but cooling over the South West Indian Ocean. The MSLP EOF shows a large area of higher pressure extending out from Australia across the Indian Ocean and Africa and lower pressure over most of the Pacific. This type of SST and MSLP pattern typically leads to dry conditions over South Africa [Jury and Parthack, 1991; Reason and Mulenga, 1999] because it favours the offshore shift of the ascending branch of the local Walker circulation. Hence one expects decreased (increased) rain when the EOF timeseries is positive (negative). Note that this pattern is the leading EOF on interannual, decadal and longer scales. The various modes move in and out of phase with each other through the record so that sometimes the ‘ENSO-like’ pattern and its impacts are re-inforced on the different bands while at other times, they are out of phase and hence weakened. Thus some linear combination of the different decadal EOFs may be more successful at representing decadal scale rainfall variability than a single band.

[8] The simplest linear combination is one in which each of the bands that do contribute, does so equally; i.e., a simple average. Not all of the bands may contribute of course. Thus, it was found that the average of summer EOF1 and 3 (9–13 and 18–39 year bands) was quite successful in inversely tracking summer rainfall smoothed with a 7 point running mean (Figure 1). The correlation coefficient for this series with the rainfall record is −0.40 but this increases considerably to −0.53 if the last two years (1997 and
1998) are removed. These values are statistically significant at the 95% level after re-calculating the degrees of freedom to allow for the filtering. We justify removing the 1997–8 smoothed rainfall since both are directly influenced by the raw data for 2000, a highly anomalously wet year with devastating floods in the region. The fit shown in Figure 1 is not improved by a multiple linear regression (correlation coefficient $-0.41$ or $-0.53$ if the last two years are removed).

[9] Folland et al. [1999] found strongest correlation between the 4th EOF of low pass filtered global SST and the leading EOF of sub-Saharan African January–March rainfall. This SST EOF also shows an "ENSO-like" pattern over the tropical Pacific and Indian Oceans except that largest weights are in the central rather than the eastern Pacific as occurs for our EOFs 1–3. Figure 1 suggests that the weakest association between the rainfall and EOFs 1 & 3 series occurs for 1938–1954. The 1938/9 and 1942/3 La Niñas and 1940–42 protracted El Niños had a relatively strong impact on South African rainfall. This fact together with these three events occurring one after the other (i.e. large interannual variability relative to the smoother decadal variability) may explain why the association in Figure 1 is weakest for 1938–1954.

[10] In the southwest, cold fronts and to lesser extent cut-off lows are important and one might expect a less robust relationship than for the summer rainfall region where tropical influences are greater. Nevertheless, it was found that the simple average of winter EOF2 and 3 (13–18 and 18–39 year bands) gave good results up until 1982 with winter EOF1 working better after that date (Figure 2). The apparent "jump" around 1980 in the Figure 2 smoothed series results from 1980 and 1982 being particularly dry followed by 1983 being well above average and subsequent winters almost always wetter than average. Around 1980 is also when the nature of the semiannual oscillation in the Southern Hemisphere and SST variability in the tropical Pacific changed [Hurrell and van Loon, 1994]. These authors note a change in the circumpolar trough and upper level vortex after the late 1970s.

Figure 1. Normalized South African summer (Oct–Mar) rainfall anomalies averaged over 25–31°E, 22–32°S (solid) and the average of the leading joint SST-MSLP EOFs on the 9–13 and 18–39 year bands (dash) plotted for 1903–1998.

Figure 2. Normalized South African winter (May–Sep) rainfall anomalies averaged over 17–21°E, 32–34°S plotted as solid for 1903–1998 and a series (dashed curve) formed by the average of the leading joint SST-MSLP EOFs on the 13–18 and 18–39 year bands (1903–1982) and the leading joint SST-MSLP EOF on the 9–13 year band (1983–1998).

Figure 3. 500 hPa geopotential height anomalies (m) composited for the (a) wet 1970–1977 and (b) dry 1978–1984 summer seasons using NCEP re-analysis data [Kalnay et al., 1996].
Such changes would be expected to influence midlatitude cyclone activity and hence winter rainfall. Correlating the EOF series plotted in Figure 2 with that of winter rainfall (1903–1998) produced $r = -0.47$, again significant at the 95% level. This can be improved to $-0.52$ using the multiple linear regression formula $0.09*\text{EOF}_1 + 0.61*\text{EOF}_2 + 0.60*\text{EOF}_3$ for the 1900–1982 period and EOF1 after 1982.

4. Potential Mechanisms

[11] Figures 1–2 suggest that the region experiences wet and dry spells on near-decadal scales. One simple way of considering potential mechanisms is to examine composite anomalies of various circulation fields for particular wet and dry spells based on the raw rainfall data.

[12] The 1970–1977 period was particularly wet over the summer rainfall region and composites for that spell are contrasted with those for the adjoining dry spell of 1978–1984. Low (high) pressure anomalies over southern Africa and the Indian Ocean/Australian region characteristic of a La Niña (El Niño) pattern occur during the wet (dry) spell (Figure 3). SST anomalies reflect these ENSO tendencies although both spells show warmer conditions over the adjacent South West Indian Ocean. However, low level wind anomalies are onshore (offshore) (Figure 4) during the...

Figure 4. As for Fig. 3 except surface wind composite for wet minus dry spell (0.5 m/s contour).

Figure 5. 500 hPa geopotential height anomalies (m) composited for the (a) dry 1958-1971 and (b) wet 1981–1994 winter seasons using NCEP re-analysis data [Kalnay et al., 1996].

Figure 6. As for Fig. 5 except latitude-height section of zonal wind (m/s) sliced along 15°E or just upstream of the winter rainfall region.
wet (dry) spell reflecting a strengthening (weakening) of the mean flow and increased (decreased) advection of moist marine air over eastern South Africa. Low level divergence fields indicate relative convergence (divergence) of this moisture over eastern South Africa during the wet (dry) spell. Low level cyclonic (anticyclonic) vorticity anomalies occur over low latitude southern Africa during the wet (dry) spell thereby favouring (discouraging) tropical convection and rainfall.

For the winter region, contrast the 1958–1971 dry spell with the 1981–1994 wet spell. In the Atlantic/African sector, the circumpolar trough and subtropical high pressure belt weaken during 1958–1971 (Figure 5a) with the reverse for 1981–1994 (Figure 5b). During the dry (wet) spell, the westerly jet shifts north and strengthens as in Figure 6a (shifts south and strengthens above and south of the region – Figure 6b). Also during 1958–1971, there is less precipitable water in the atmosphere upstream of the region, decreased 1000–500 hPa thickness implying a colder and drier atmosphere and divergent low level flow in the region all implying less rainfall. Roughly the reverse patterns were found for 1981–1994. Consistent with the ‘ENSO-like’ decadal pattern, SST is warmer (cooler) than average near South Africa during the wet (dry) spell. These circulation and SST changes are favourable for increased frequency and more intense midlatitude systems in the region during the wet spell and the reverse during the dry spell.

5. Concluding remarks

[14] SST-MSLP EOF modes on decadal to multidecadal scales display ‘ENSO-like’ patterns [Allan, 2000] and one might expect that the associated circulation could influence rainfall in regions that are significantly impacted by ENSO. South Africa is such a region and it has been shown that simple linear combinations of the ‘ENSO-like’ EOF pattern derived for 9–13, 13–18 and 18–39 year bands correlate significantly with 7 year running mean rainfall for both the southwestern winter rainfall region and the north and eastern summer rainfall region. These results are consistent with global maps of correlations between seasonal rainfall and the bandpass filtered EOF time series shown in Allan [2000].

[15] For the southwest, composites of wet and dry spells suggest that the potential mechanism involves changes in the strength and position of the westerly jet which impacts on the track, intensity and frequency of midlatitude frontal systems that bring most of the rainfall. For the summer rainfall region, where convection and tropical influences are more important, there are changes in SST and regional circulation, which imply changes in the advection of moist marine air over eastern and northern South Africa.

[16] South Africa and neighbouring countries are prone to devastating flood and drought events, e.g., the 2000 flooding over northeastern South Africa and Mozambique. These events develop within a slowly varying background of longer term modes dominated by ‘ENSO-like’ patterns on various decadal to multidecadal scales that move in and out of phase with each other, thereby strengthening or weakening the local impacts. Climate prediction is a high priority in the South African region with its large and vulnerable rural subsistence population. The results presented here indicate that it may well be possible to improve the predictability of decadal scale rainfall variability in the region.


References


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