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Patterns of summer rainfall variability across tropical Australia - results from EOT analysis

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Abstract: EOT analysis provides for relatively simple, easily interpretable results when applied to rainfall data. Previous studies have applied this technique to Australian average annual rainfall data and identified dominant modes of variability, including long term trends. Here we use EOT analysis to identify modes of summer (November to April) average rainfall variability with a focus on recent decades. The dominant mode is centered over the Northern Territory but also encompasses much of the continent and represents a trend towards wetter conditions. The fourth mode is centered over Western Australia and although it also represents a significant trend towards wetter conditions, it is also linked to a drying trend over the eastern half of the continent. These trends are not related to changes in ENSO, but appear linked to a global pattern of changes in the hydrological cycle. Furthermore, even though these changes are not well simulated by existing climate models, the observed rainfall trends have occurred while global average temperatures have increased. Consequently, they may provide a more accurate indication of changes to be expected for this century if global warming continues.

Keywords: *Australian rainfall, empirical orthogonal teleconnections, trends, ENSO*

1. INTRODUCTION

Studies conducted over a decade ago noted increases in rainfall over parts of Australia (Hennessy et al., 1999; Suppiah and Hennessy, 1996; 1998) but concluded that any such trends were not statistically significant. More recent analyses have highlighted that some of these trends, particularly over the north and west of the continent, are highly unusual (Smith, 2004, Smith et al., 2008), but the reasons for them remain unclear. These trends, which are most evident post-1950, have occurred at the same time as global temperatures and Australian average temperatures have increased rapidly compared to the previous period, 1900-1950. However, at the same time, summer temperatures have decreased over the regions where rainfall has increased. This led Wardle and Smith (2004) to postulate that there may be a link between these changes whereby increasing surface temperatures over much of the continent drive a stronger summer or “monsoon-like” circulation, with increased rainfall, cloud cover and therefore cooler temperatures in the far north. Another hypothesis is that increased Asian aerosols may be implicated in disturbing the temperature gradient between Asia and Australia, leading to remote effects including an increase in rainfall over northern Australia (Rotstayn et al., 2007). Because Australian tropical rainfall is strongly influenced by ENSO (Smith et al., 2008) these trends may reflect a change in this phenomenon. Recently, Power and Smith (2007) noted unusually low values for the (June to December) Southern Oscillation Index (SOI), high values for mean sea-level pressure at Darwin, weak equatorial surface wind-stresses and the highest tropical sea-surface temperatures on record – all suggestive of a recent shift towards more El Nino-like conditions. However, these would imply drier, rather than wetter, conditions over time. Suppiah and Hennessy (1996, 1998) analysed daily rainfall records and showed that trends in total summer (November to April) rainfall over the period 1910-1990 tended to be accompanied by similar trends in the frequency of rainfall events. They noted that this tendency was consistent with the notion that a warmer atmosphere can hold more moisture and can lead to more intense events. These studies all point to the need to continue documenting and analyzing the trends to wetter conditions in the tropics, particularly if they represent the changes to be expected in a warmer world.

The Smith (2004) study employed Empirical Orthogonal Teleconnection patterns (EOTs) to analyze the all-Australia rainfall data. These proved useful in showing that much of the variance in all-Australian annual rainfall could be attributed to just two modes that cover much of central eastern Australia and central western Australia. Here we employ EOTs to analyze summer half-year rainfall data over Australia for the period 1901 to 2007 with an emphasis on better understanding the observed trends toward wetter conditions in the tropics.

2. EMPIRICAL ORTHOGONAL TELECONNECTION ANALYSIS

Empirical Orthogonal Teleconnection (EOT) analysis (van den Dool et al., 2000, Smith, 2004) offers several advantages over conventional EOF analysis. EOTs are constrained to be orthogonal in just one direction (time) rather than (as EOFs are constrained) two directions (space and time). As a result, EOTs provide a straightforward interpretation of patterns within data with a minimum of computation. Secondly, EOFs are designed to explain summed variance across spatial data whereas EOTs can be used to explain the simple sum over spatial data. This makes EOTs more suited to analyzing rainfall data where it can be more relevant to explain, for example, the all-Australian rainfall time series as opposed to all-Australian rainfall variance. Thirdly, EOFs can be regarded as an efficient means for compressing data at the expense of physical interpretation. In many applications, attempts to assist interpretation require the application of ‘rotation’. As van den Dool et al. (2000) noted, rotated EOFs can end up resembling EOTs – which are obtained at a fraction of the effort.

3. RAINFALL DATA

Smith et al. (2004) analyzed the Jeffrey et al. (2001) data set which was based on the careful interpolation of daily data amassed by the Bureau of Meteorology (BoM) and managed by the National Climate Centre. Here we make use of the updated high resolution (0.025^o by 0.025^o) BoM gridded data set which covers the period 1901 to 2007. We focus on the summer half year as represented by rainfall totals over the months November to April. The first period is November 1901 to April 1902 and the last period is November 2006 to April 2007, so the data encompass 106 seasons (1902 to 2007).

4. RESULTS

1901 – 2007

Figure 1 shows the first four EOT patterns for Australian summer-half year rainfall. The first pattern is centered over the Northern territory and explains 59% of the all-Australian summer rainfall time series. The second EOT is centered near Darwin, but covers much of Western Australia and the far northern regions including Cape York. This pattern is very similar to the long-term trend pattern in summer rainfall shown by Smith (2004, Figure 5) and explains 15% of the variance in the all-Australian summer time series. EOT 3 (11%) is centered over Eastern Australia while EOT4 (5%) is centered over Western Australia.

Figure 2 shows the time series of each of the EOTs while Table 1 summarizes some of the features associated with each. EOTs 1, 2 and 3 are significantly correlated (r =+0.32, +0.25 and +0.35 respectively) with the summer Southern Oscillation Index (SOI) values. Both EOT 1 and 2 reflect trends towards wetter conditions, over central and northern Australia, especially over the last 2 decades, while EOT3 reflects trends towards slightly drier conditions over south-eastern Australia. EOT4 suggests no significant trends over the far west of the continent.

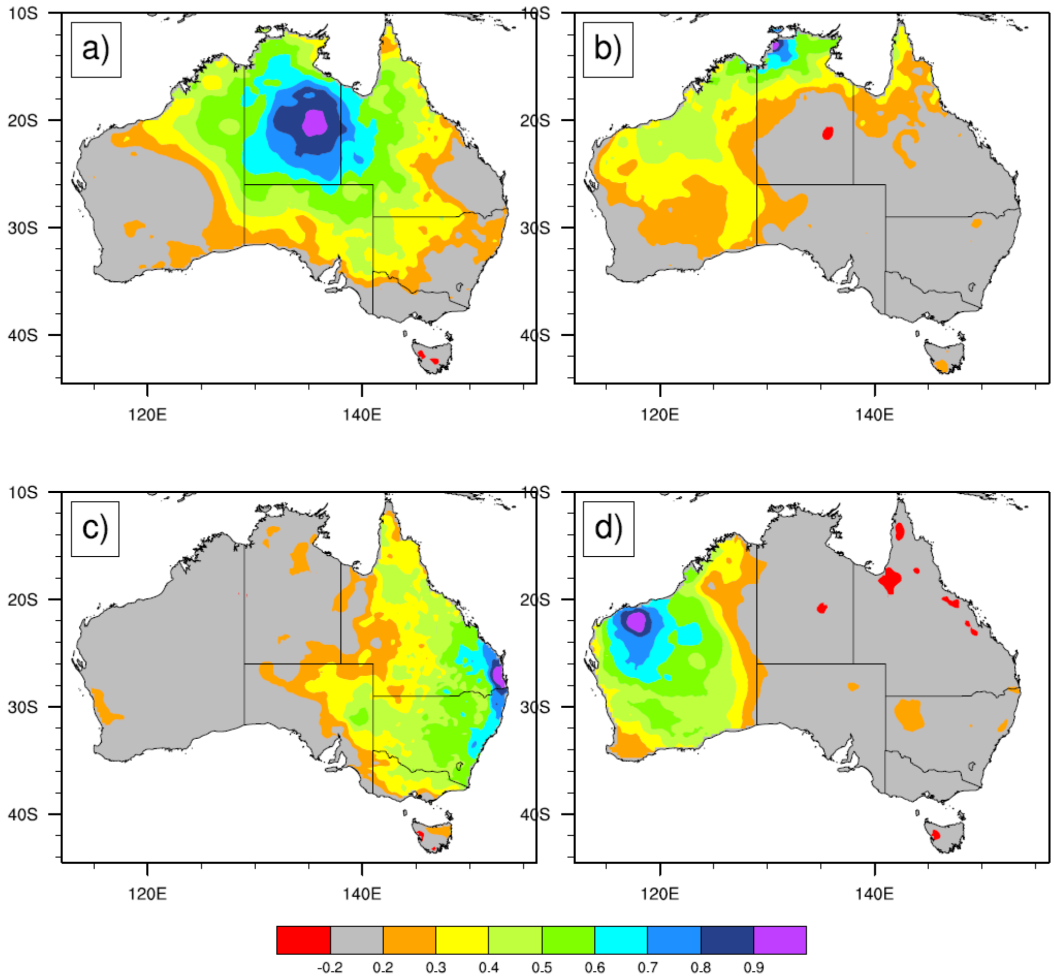

Figure 1. The first 4 EOT patterns (1901-2007): EOT 1 (a), EOT 2 (b), EOT 3 (c) and EOT 4 (d). In each case, the point where the correlation is unity marks the central location of the respective pattern.

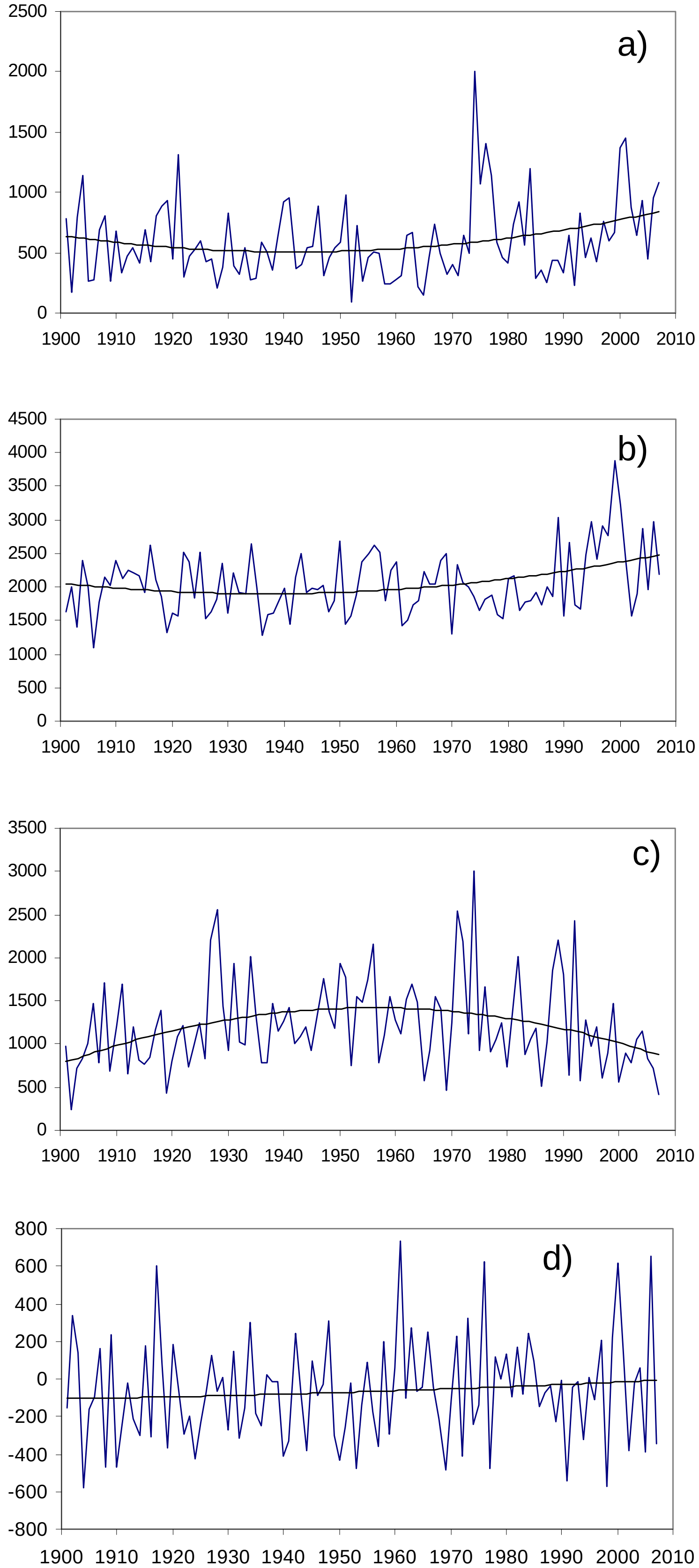

Figure 2. Time series for the first 4 EOTs (1901-2007): mode 1 (a), mode 2 (b), mode 3 (c) and mode 4 (d).The black curve represent a second order polynomial fit to the data.

1950-2007

The same EOT analysis has been repeated using just the data from 1950 onwards. Figure 3 shows the first 4 patterns, Figure 4 the associated time series, while Table 1 also summarizes some of their properties. It can be seen that the first pattern, again centered over the Northern Territory ("NT mode") is robust, since it is almost identical to that shown in Figure 1. This represents the strongest (but not the entire) impact of ENSO events on summer rainfall. EOT2, centered on Darwin ("D mode"), is similar to its counterpart in Figure 1, but differs in several respects. It captures more of the variability across Queensland and less of the variability over Western Australia. It is still strongly related to ENSO, but exhibits no significant long-term trends.

EOT3, centered more over NSW ("NSW mode") compared to its counterpart in Figure 1, is also related to ENSO events, but does not exhibit much of a significant long-term trend. Finally, EOT4, while also centered over Western Australia ("WA mode") is not strongly associated with ENSO, but does represent long-term trends in the data. It also appears to capture more of a decreasing trend across the eastern half compared to its counterpart.

The time series shown in Figure 4 include second-order polynomial fits to the data. The NT mode reflects wet events during the 1970's and in 2000 and 2001. Note that 2006 and 2007 also appear as relatively wet periods. The WA mode reflects the relatively wet years that occurred after 1994.

The interesting point here is that while Smith (2004) pointed to the unusual nature of increases in rainfall in the north and west of the continent up to the year 2002, it is apparent that relatively wet conditions have prevailed over the intervening 5 years. This suggests that, whatever, the causes, the trends in the data are now much more significant than previously estimated. The trend correlation coefficients for both the NT and WA modes are nominally significant at the 99% level.

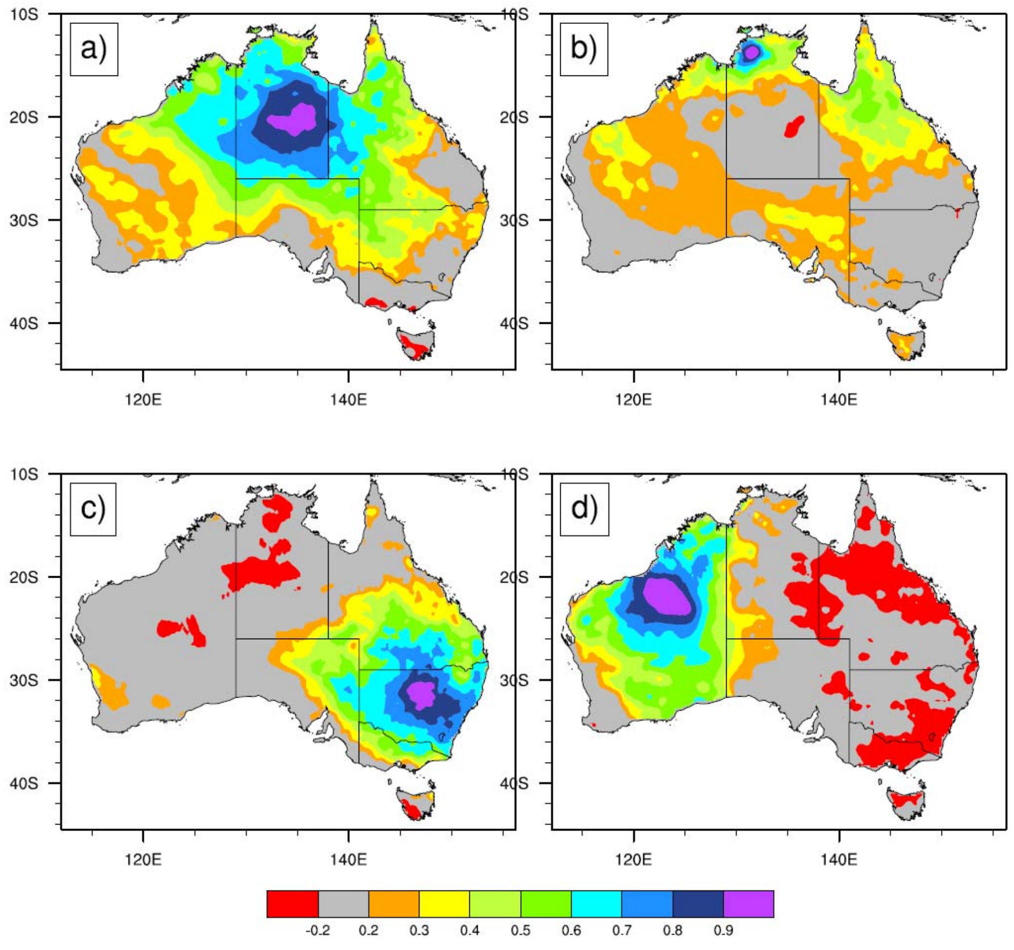

Figure 3. As for Figure 1 except the data correspond to the period (1950-2007).

5. DISCUSSION AND CONCLUSIONS

These findings reinforce the earlier findings of Smith (2004) where the recent trend towards wetter conditions in the north and west of the continent were first described as “unusual” in a historical context. This trend, particularly during the summer half of the year, has become more apparent according to the observations over the last 5 years (2003 to 2007). Both the first EOT (NT mode) and the fourth EOT (WA mode), indicate a significant increase in rainfall over time. Only the first EOT is related to ENSO which suggests that changes in ENSO are an unlikely explanation for the increases. Smith et al. (2008) noted that increases in summer season rainfall over Australia appeared to be the result of increases in intensity rather than duration of the rainy season. They also noted that ENSO events had more effect on the latter rather than the former. Furthermore, the fact that any trends in ENSO (Power and Smith, 2007) are towards more El Nino (or drier) conditions suggests another factor at play.

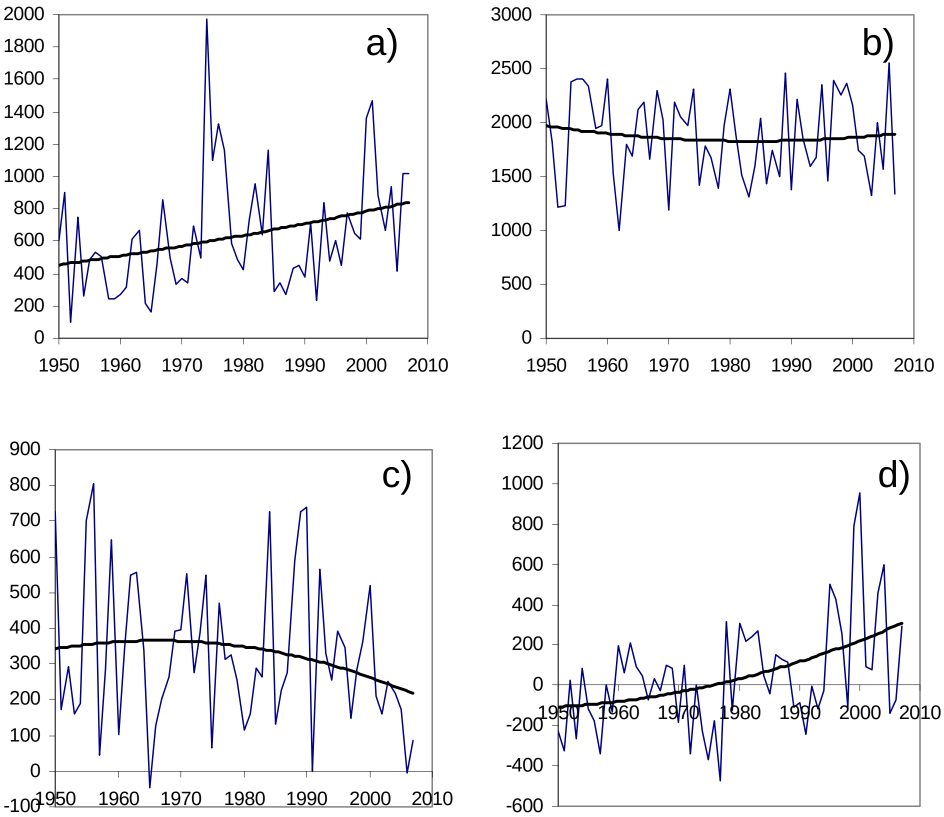

Figure 4. As for Figure 2 except the data correspond to the period 1950-2007: NT mode (a), D mode (b) NSW mode (c) and WA mode (d).

Table 1. Summary statistics for the first 4 EOTs using either raw or detrended data. r(SOI) represents the correlation with the Southern Oscillation Index (SOI) r(linear trend) is the correlation associated with a line of best fit to the time series.

1901-2007					1950-2007			
EOT	1	2	3	4	1	2	3	4
Raw data								
Variance	59%	15%	11%	5%	70%	14%	7%	3%
r (SOI)	0.32	0.25	0.35	0.16	.39	.32	.26	-.03
r (linear trend)	0.18	0.27	0.05	0.10	.31	.06	-0.18	.44

More recently, Allan and Soden (2007) have drawn attention to rising precipitation trends in the tropics, where air tends to ascend, and decreasing trends in regions where air tends to descend. They noted that these trends are much larger than can be simulated by climate models, and even larger than climate models predict for later this century. This raises the possibility that any such trends, including those detected over Australia and described here, are unrelated to the forcings (e.g. greenhouse gases) used to drive the climate models. Most likely, the models underestimate the climatic response to one or more of the forcings. However, the fact that these changes have occurred during a time when global average temperatures have risen, suggests (but is not proof of) a link with global warming – independent of any climate model results. If the link is real, then it is possible that the trends we see in rainfall may be a more reliable guide to the future than the model projections. In the case of Australia, this future may be one of much wetter conditions during summer in the north and west, but drier conditions in the far east. It is worth noting that this pattern is also seen in the rainfall totals for the latest wet season (October 2008 to March 2009).

In summary:

- The trend to wetter conditions over large parts of western and northern Australia during the summer half year is clearly evident
- The trend occurs over regions where ENSO both does, and does not have a significant influence. This further reinforces the fact that other factors are at work
- The pattern is part of an observed global signal involving increasing precipitation in the tropics
- Despite what climate models simulate, the observed trends may provide an indication of future conditions if global warming continues.

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