DROUGHT IN SOUTHERN AUSTRALIA: TRENDS, CAUSES, IMPACTS

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1. INTRODUCTION

Drought has become more frequent and intense over much of southern Australia in recent decades. Various possible causes of this change have been proposed including anthropogenic greenhouse gas emissions, stratospheric ozone declines, local and regional air pollution, changes in the Southern Annular Mode (SAM) or the Pacific Decadal Oscillation (PDO) or the Indian Ocean Dipole (IOD), shifts in the latitude of the subtropical ridge, and changes in regional sea surface temperatures. Some confusion about the "causes" of increased drought can arise because these "causes" might be *local* changes (eg., shift in latitude of the subtropical ridge), *intermediate* changes (eg., changes in the El Niño – Southern Oscillation, ENSO) which cause these local changes, or *ultimate* changes (eg., increased greenhouse gas concentrations) which may affect the changes in atmospheric modes such as ENSO. This paper focuses on the local and intermediate level of this stratification: what large-scale patterns or modes of climate variability are contributing to the recent decrease in Australian rainfall south of 30˚S)? In turn, such an approach may help determine the ultimate cause of the drought trend.

2. SOUTHERN AUSTRALIAN RAINFALL AND THE SUBTROPICAL RIDGE

The temporal variations of the mean latitude of the anticyclones that are a feature of the Australian region have been examined in a number of studies, most recently by Drosdowsky (2005), Larsen (2008), and Williams and Stone (2008). Drosdowsky (2005) used daily reanalysis data to construct a time series of the STR latitude over the east coast of Australia, whereas Larsen (2008) used the Hadley Centre high-quality global gridded mean sea level pressure data set, HadSLP2r, to construct a time series of the STR latitude over the longitudes 105-180˚E. Neither study found strong evidence of a trend in the STR latitude. Williams and Stone (2008) used three pressure data sets to calculate the latitude over the east coast, and reported that different trends (rarely statistically significant) were observed in different months, and that these trends also depended on the dataset used. They also reported statistically significant relationships with rainfall over parts of Australia, including southern Australia. This study extends these previous studies by developing a time series of monthly values of the latitude of the STR, averaged across Australian longitudes (105-155˚E), preparing a time series of the maximum pressure (hereafter referred to as "intensity") of the mean STR averaged across these longitudes, examining both variables for seasonally varying relationships with rainfall across southern Australia (south of 30˚S) and for seasonally varying trends, and using partial correlation to determine the relative roles of the latitude and intensity of the STR in explaining interannual variations and trends in southern Australian rainfall.

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Monthly values of the latitude and intensity (mean maximum pressure) of the subtropical ridge (STR), averaged across Australian longitudes (105-155˚E), from a high-quality global mean sea level pressure data set (HadSLP2r), were correlated with variations and trends in rainfall over southern Australia (south of 30˚S), for 1958-2005 (Larsen and Nicholls, 2009). Partial correlations show that in the cooler part of the year the intensity of the STR is the dominant factor causing rainfall variations (and correlations between latitude and rainfall are a by-product of the effect of intensity on both latitude and rainfall), whereas in summer the latitude of the STR is more important in determining southern Australian rainfall. The recent decline in southern Australian rainfall in recent decades (which has occurred principally in autumn) is related to a trend towards a more intense STR, rather than a trend in the latitude of the STR.

The relative strengths of the influence of latitude and intensity on the rain trends are illustrated in Figure 1, which shows the time series of the March-May total rainfall along with time series of the March-May average STR intensity and latitude. The strong trend towards increased intensity is clear, as is the negative relationship between intensity and rainfall (r = -0.46). Given this negative relationship, one should expect a decline in rainfall over the 1958-2005 period, associated with the strong trend to increased intensity. On the other hand, the figure reveals little evidence of a relationship between latitude and rainfall (r = -0.06), so even the weak trend of the STR towards higher latitudes did not contribute to the rainfall decline.

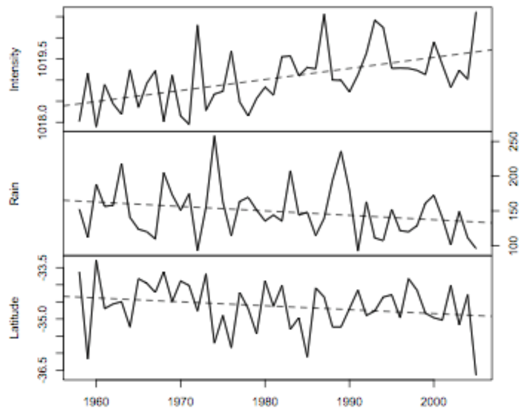

Figure 1. Time series of subtropical ridge intensity (top panel), rainfall (middle panel) and subtropical ridge latitude (bottom panel), for March-May. Dashed lines are linear trends.

3. REMOTE CAUSES OF THE SOUTHERN AUSTRALIAN RAINFALL DECLINE.

What are the more remote causes of this rainfall decline, ie what mode of climate variability is causing it (presumably through changing the intensity of the STR)? Sea surface temperatures around northern Australia are strongly correlated with southern Australian rainfall but the recent warming of the ocean should have led to increased rainfall if this was a primary cause of changes in rainfall, rather than the observed rainfall decline. The relationships between the rainfall and indices of several modes of the atmosphere/ocean system have been investigated to determine the *intermediate* cause of the rainfall decline. Indices of the modes that only use data remote from the Australian region are used to avoid the possibility that a relationship between the mode and Australian rainfall is simply reflecting the behaviour of “local” portions of the index. Thus a climate mode index that incorporates Australian pressure would likely be related to southern Australian rainfall, even if the remote parts of the mode were unrelated to Australian rainfall. Unless the remote contributions to the mode index were also related to Australian rainfall it seems physically unrealistic to consider that the mode, *per se*, was affecting Australian rainfall (rather than simply reflecting the influence of the local pressure changes on both rainfall and the index of the mode).

The southern Australian rainfall decline cannot be explained by a change in the behaviour of the El Niño – Southern Oscillation. Remote indices of this phenomenon (eg, NINO3 or Tahiti pressures) do not exhibit a trend over this period, even though pressures over Australia (and thus the Southern Oscillation Index, SOI) do exhibit a trend (Nicholls, 2008; see next section). Nor can the Indian Ocean Dipole be the cause of the rainfall decline since a remote index of the IOD (sea surface temperature in the western equatorial Indian Ocean) is not strongly correlated with Australian rainfall (on detrended data). The strong recent trend in the southern annular mode (SAM), on the other hand, appears to be able to account for much of the rainfall decline since its year-to-year variations (even measured with an index remote from the Australian continent) are correlated with year-to-year variations in southern Australian rainfall, and the sense of the correlation and the SAM trend would lead to a decline in rainfall (and an increase in pressure over Australia). The observed trend in SAM can reproduce over 70% of the observed rainfall trend.

4. TRENDS IN THE EL NINO – SOUTHERN OSCILLATION.

As noted above, trends in the El Niño – Southern Oscillation do not appear to be the likely cause of the decline in southern Australian rainfall. Trends in the seasonal and temporal behaviour of the over the period 1958-2007 were assessed using two indices of the phenomenon, NINO3.4 and a non-standardised Southern Oscillation Index (Nicholls, 2008). There was no evidence of trends in the variability or the persistence of the indices, nor in their seasonal patterns. There is a trend towards what might be considered more “El Niño - like” behaviour in the SOI (and more weakly in NINO3.4), but only through the period March-September and not in November-February, the season when El Niño and La Niña events typically peak. The trend in the SOI reflects only a trend in Darwin pressures, with no trend in Tahiti pressures (Figure 2). Apart from this trend, the temporal/seasonal nature of the El Niño – Southern Oscillation has been remarkably consistent through a period of strong global warming. Thus the trends in pressure over Australia cannot be simply identified as a trend in the El Niño – Southern Oscillation. They seem more likely attributable to another mechanism affecting only certain aspects of the ENSO system, and only at certain times of the year.

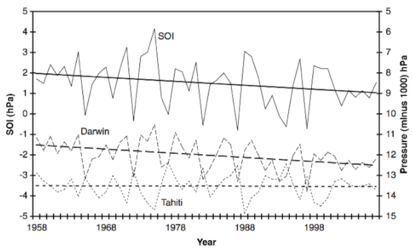

Figure 2. Time series of SOI (full line) and Darwin (dashed line) and Tahiti mean sea level pressure (dotted line), each averaged over April-September. Thick lines are linear trends.

5. CONCLUSIONS

The decline in southern Australian rainfall in recent decades is related to an increase in the intensity of the subtropical ridge, and is not the result of a shift in the latitude of the ridge. Trends in the El Niño – Southern Oscillation or the Indian Ocean Dipole are not the cause of the decline in rainfall (since ENSO indices remote from the Australian region have not exhibited any clear trend and remote indices of the IOD are not correlated with southern Australian rainfall variations from year-to-year). On the other hand, trends in the Southern Annular Mode do appear to be a plausible cause of the rainfall decline. These conclusions also apply separately to the rainfall declines in the southeast and southwest sub-regions. Recent trends in indices of the El Ninño – Southern Oscillation only occur in some ENSO indices, and even then only at certain times of the year. So the decline in rainfall cannot be ascribed, in any simplistic way, to increased frequency or intensity of the El Niño – Southern Oscillation.

6. REFERENCES

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