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THE SOUTH-EAST AUSTRALIA DROUGHT: POSSIBLE CAUSES

W Cai, T Cowan

The Drought

As we settle into winter the drought that has gripped much of southeast Australia (SEA) for the past decade shows no signs of breaking. The autumn months of 2008 brought little relief through much of southern Australia (excluding parts of Western Australia), with most rainfall totals between 40-60% of the long-term average. Across the Murray Darling Basin (MDB), arguably one of Australia's most vital economic resources, the 2008 autumn was the fourth driest on record. The combination of higher than normal temperatures and reduced rainfall since the middle of last century has meant that water availability in throughout the catchments of SEA has reached record lows. What factors are controlling this late autumn rainfall decline across SEA, and is climate change a major factor, or is it just long-term natural variability of the climate system? And what role does late autumn rainfall play in the current drought conditions, and how important is temperature?

Declining Autumn Rainfall Across Victoria

Since the 1950s much of southern and eastern Australia has exhibited strong rainfall reductions on a seasonal and regional basis. Winter rainfall across south-west Western Australia has decreased by about 12%, while summer rainfall in southern Queensland has also been trending downwards. Down in Victoria one can see a considerable decline in autumn rainfall, with 50% of the autumn reduction occurring in the month of May (Figure 1). Since 1990 only 5 out of the 19 May months have been above the 1961-1990 rainfall average. This is in contrast to the 13 years since 1990 that May rainfall has been well below average (between 25-75%). In the preceding forty years May rainfall showed a roughly even distribution.

This is a condensed version of two recent peer-reviewed papers by the CSIRO authors published by the American Geophysical Union journal, *Geophysical Research Letters*.

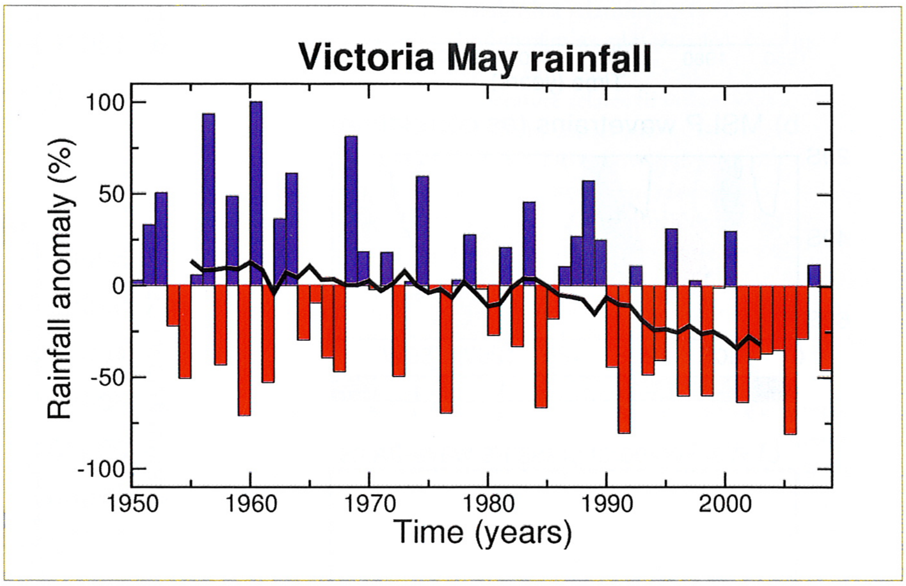

Figure 1. Percentage change in Victoria May rainfall from 1950-2008 (relative to the 1961-1990 average). Red (blue) bars indicate drier (wetter) than average, with an 11-yr running mean shown as a black line.

By using rainfall data from the Bureau of Meteorology, and climate data such as sea surface temperatures, sea level pressure and surface winds from a combination of observations and state-of-the-art climate models, we are able to study how the changing dynamics of the oceans surrounding Australia and the atmospheric conditions in the subtropics and mid-latitude regions are impacting on the autumn rainfall in Victoria. In terms of May rainfall we identified two sources of variability in the oceans that are conducive to good rainfall, one being the region north of Australia called the Indonesian Throughflow (which connects the Pacific to the Indian Ocean), and the other being the subtropical and mid-latitude Indian Ocean.

Western Pacific Ocean Influences

Higher sea surface temperatures in the Indonesian Throughflow region are associated with the familiar northwest cloud bands that help generate rainfall for much of central and south-eastern Australia. They typically occur during the southern rainy season from April – September. The temperature of this Throughflow surface water is strongly linked to an ocean-atmosphere feedback cycle known as the El Niño-Southern Oscillation (ENSO). A transition from an El Niño (which typically brings dry conditions to much of eastern Australia) to a La Niña (wetter conditions across eastern Australia) tends to be conducive to late autumn rainfall across northern Victoria, south-west New South Wales and eastern South Australia. From the mid-1970s onwards there have tended to be more El Niño events than La Niñas, which have also been more protracted in terms of duration. What this means is that the western Pacific Ocean, which is linked to late autumn rainfall across SEA, has tended be more El Niño-like, and spending less time transitioning to La Niña-like conditions. If one were to look at a time series of the Southern Oscillation Index (SOI) which is a measure of the surface pressure difference between Tahiti and Darwin (negative values indicate El Niño-like conditions in the western Pacific

Further declines in inflow across the MDB are likely.

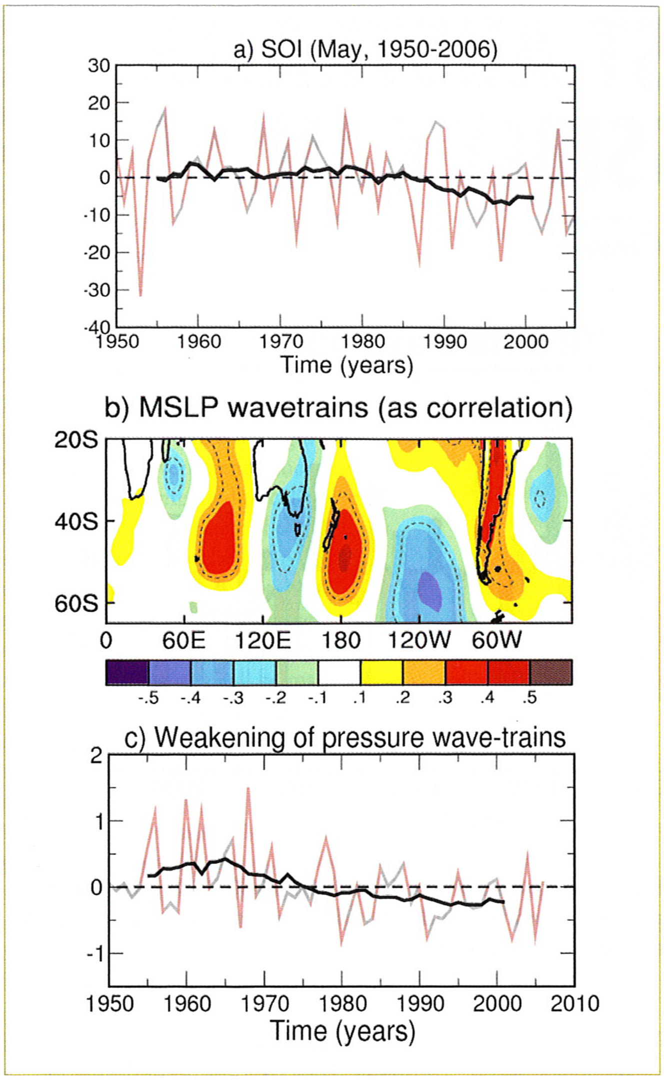

Figure 2. (a) A time-series of the SOI in May. The SOI is a measure of the surface pressure difference between Tahiti and Darwin. Negative (positive) values indicated El Niño (La Niña)-like conditions in the western Pacific Ocean. An 11-yr running mean is shown as a black line. (b) Correlation between an Indian Ocean sea surface temperature index and mean sea level pressure for May during 1950-2006 (red indicates high pressure associated with a heating in the mid-latitude Indian Ocean, whilst blue indicates lower pressure). Areas confined by dashed lines indicate correlations that are significant at the 95% confidence level. (c) Time series of 500 mb geopotential height empirical orthogonal function number 2. More negative values indicate a weakening of the pressure wave-trains emanating from the Indian Ocean.

Ocean), we can see that during May the SOI has been in decline since the 1980s (Figure 2a).

A shift toward a more El Niño-like state is consistent with other studies showing a global warming-induced weakening of the east-west atmospheric circulation pattern of the tropical Pacific Ocean, which is called the Walker Circulation.

Indian Ocean Influences

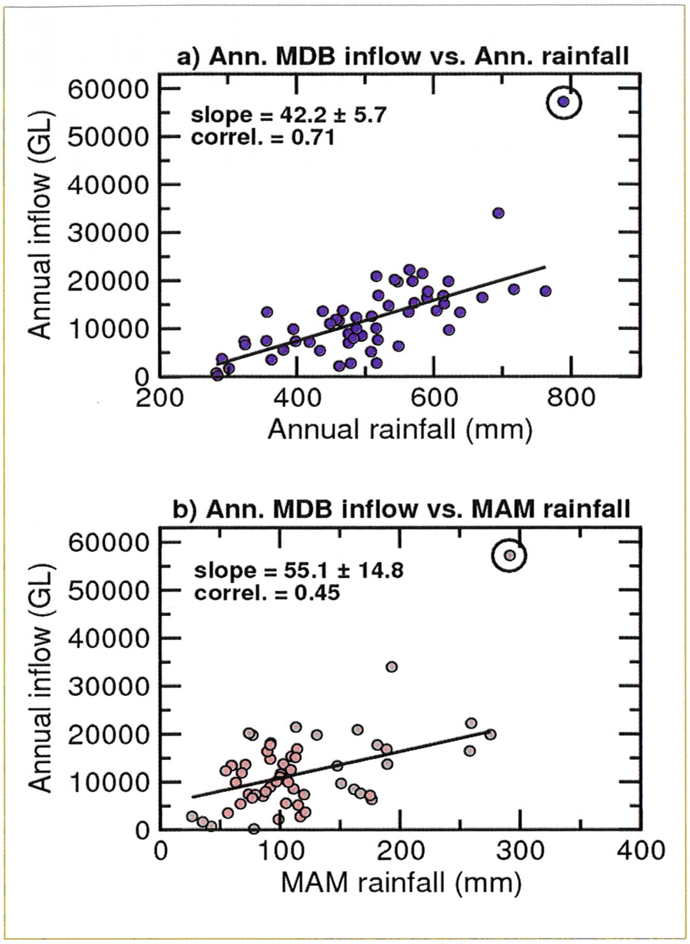

Figure 3. (a) Scatter diagram of annual-total rainfall versus annual-total inflow in the MDB. (b) Scatter diagram of autumn (March, April, May or MAM) rainfall versus annual-total inflow to the MDB. All data are linearly detrended, and the analysis is carried out without 1956 data (circled), which is considered an outlier. A correlation greater than 0.27 is significant at the 95% confidence level.

Across the other side of Australia the Indian Ocean is important in providing the means for rainfall generation for the southern regions of Victoria. Heating in the mid-latitude Indian Ocean generates downstream pressure wave-trains, or spatially alternating high and low pressure systems. These wave-trains show a strong coherence with low mean sea level pressure over southern Victoria in late autumn, thus providing the means for generating rainfall (Figure 2b, blue colour). Due to a basin-wide warming of the Indian Ocean, the sea surface temperature gradient between the subtropics and the mid-latitudes has reduced leading to a weakening of these pressure wave-trains (Figure 2c). This has led to a rise in sea level pressure over southern Victoria in May, and a subsequent reduction in rainfall. Through the comparison of observations with global climate models studies we have been able to show that the Indian Ocean warming is in part due to global warming. In fact the mid-latitudes of the Indian Ocean are some of the fastest warming oceans in the world (they have warmed by almost 1°C since 1950). Therefore, the fact that the weakening in the pressure wave-trains are linked to the long-term Indian Ocean warming suggests a component of climate change is active in the rainfall reduction over southern Victoria in late autumn.

Reduction of Inflow to the Murray-Darling Basin

Not only has rainfall across much of SEA been in decline since the 1950s, but inflows into Australia's longest river system, the

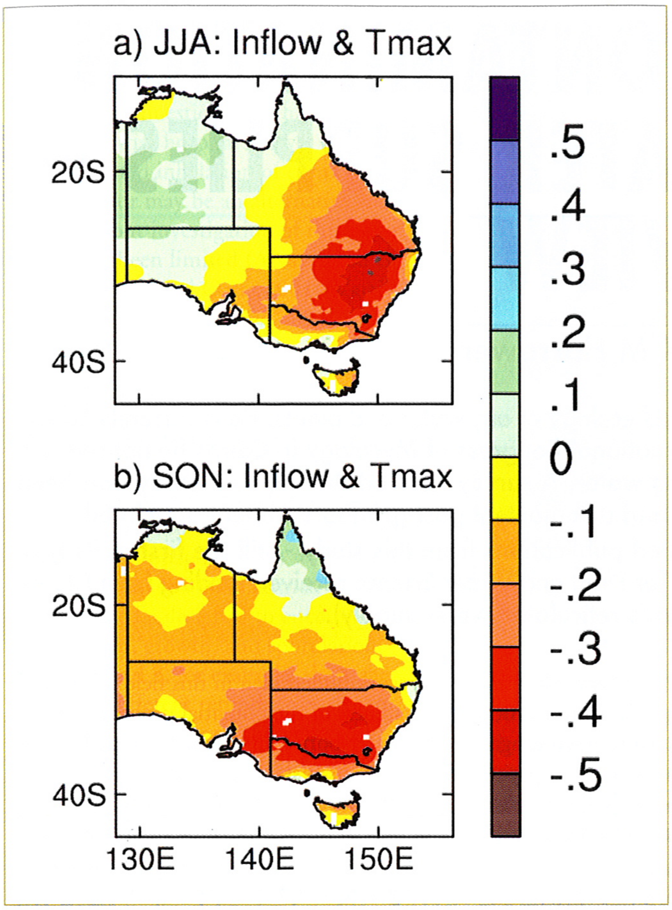

Figure 4. Maps of correlations between MDB residual total inflow and residual mean maximum temperature for (a) winter (June, July, August, or JJA) and (b) spring (September, October, November, or SON). All data are linearly detrended, and the analysis is carried out without 1956 data.

Murray-Darling, have also seen strong reductions. During the 1892-1902 Federation drought the average annual inflow into the MDB was 5400 GL yr^{-1} (1 GL = 10^9 litres). During the present drought (2000-2007) the average annual inflow was 4150 GL yr^{-1}, with a 12-month minimum of 770 GL yr^{-1} recorded for the 2006-2007 period (ending in March). Considering that rainfall during these two droughts was comparable, it raises some questions as to why our current drought seems to be more devastating than previous droughts, including the Federation drought. One difference is that the recent drought is hotter, with maximum temperatures in the order of 1°C higher than they were at the start of 20th Century.

Using data provided by the Murray-Darling Basin Commission we are able to look at how rainfall and temperatures are linked to inflow variability and long-term trends. Firstly, we were able to come up with a relationship between rainfall and inflow across the MDB. We found that on an annual basis the "conversion rate" between rainfall and inflow is 42 GL mm^{-1} (Figure 3a), whereas autumn rainfall has a conversion rate to annual inflow of 55 GL mm $^{-1}$ (Figure 3b). What this means is that autumn rainfall across the basin is important for the annual-inflow total.

By contrast, the autumn conversion rate to autumn inflow is low (6 GL mm^{-1}) indicating a soil "wetting mechanism" by autumn rain with delayed impacts on the proceeding seasons. We emphasise this feature because MDB rainfall experiences a greatest reduction in autumn, in the same vein as Victoria. However, this seasonality of rainfall reduction is not the only catalyst for the unprecedented inflow decline; it is a case of higher temperatures.

Impact of Rising Temperatures

Over the MDB variations in temperature and rainfall are not independent, as rainfall events tend to lower daily maximum temperatures. We can establish a relationship between fluctuations of inflow and maximum temperatures that are not related to rainfall (which we call residual Tmax). This gives us a clear picture of how temperature relates to inflow without the cooling influence of rainfall. In winter and spring there is a strong relationship between MDB inflow and residual Tmax (Figure 4). In these seasons an increase in maximum temperature is associated with a lower inflow across much of the MDB (shown in red in Figure 4). We are able to come up with a sensitivity factor of maximum temperature with inflow for these two seasons (in summer and autumn there is virtually no relationship between inflow and temperature, mainly due to low inflow).

The sensitivity of residual inflow to residual Tmax in winter and spring is statistically significant, at 319 GL °C^{-1} per month and 306 GL °C^{-1} per month, respectively, totalling to 1875 GL °C^{-1} for the two seasons. These results suggest that a rise of 1°C in maximum temperature reduces long-term average inflow by about 15%. The annual average temperature of the MDB has increased by about 0.9°C since 1950. This analysis is consistent with previous studies that suggest rising temperatures are exacerbating the impact of the present dry period.

The economic impacts of these declines in inflows also need to be considered. For example, with water at a price of 50¢ per 1000 litres, the direct economic loss is about $900M, however this does not include flow-on impacts.

The Future

If the relationship between temperature and inflow in winter and spring were to persist under a future climate, a 2°C increase by 2060 (based on current climate model projections) would reduce the inflow across the MDB to about 30% of the present day levels. The current batch of climate models also project a median annual rainfall reduction of between 5–15% by 2060 over the MDB. Taking the worse case scenario, a 15% rainfall decrease (or about 75 mm) would contribute to a 3150 GL reduction by 2060, or about 25% of the long-term average level.

So it seems likely that we will experience further declines in inflow across the MDB, as surface temperatures continue to climb and rainfall events dwindle. Further understanding of how climate change will impact future SEA autumn and winter rainfall awaits investigation, but for now the future is not bright.

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