The continuing decline in South-East Australian rainfall - Update to May 2009

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Introduction

Most of South-Eastern Australia (SEA) has seen reduced rainfall since the late 1990s (National Climate Centre – NCC-, 2008). Murphy and Timbal (2008) (hereafter, MT08) described the ongoing dry conditions across most of southern Australia to 2006 and its many impacts; of particular concern for water resource management agencies have been recent record low inflows or river run-offs into the Murray-Darling Basin (MDBA, 2009).

The South Eastern Australia Climate Initiative (SEACI) (Phase 1) was a 3 and half year research program (2006-2009) dedicated in part to understanding and attributing the on-going rainfall decline (SEACI, 2007) The SEACI research program is about to embark on a new 3 year phase (SEACI-2) with a stated aim: "*to enhance the understanding and improve predictions of the climate of south eastern Australia in order to better manage the impacts of climate change and variability across the region, with a focus on the impacts on water availability*". This note intends to contribute to the overall program goal by updating the description of the rainfall decline in SEA, its continuation since 2006 and changes in characteristics (i.e. magnitude, spatial extension and seasonality).

Worsening and broadening of the rainfall decline

By May 2006, rainfall deciles across the Australian continent since October 1996 (Fig. 1A) showed the clear emergence of a long-term rainfall deficit across SEA (within the area outlined by the black box: south of 33.5ºS and east of 135.5ºE). In a by–and-large wet decade across the Australian continent, it was a significant negative anomaly, on par with a similar anomaly in size and magnitude in south-eastern Queensland. Smaller negative anomalies were also emerging in the south-west of Western Australia (SWWA) and north-eastern Tasmania. MT08 reported that SEA was experiencing one of its worst protracted droughts on record, although it was not the driest decade. A larger rainfall deficit was observed during World War II (WWII), from 1936 to 1945.

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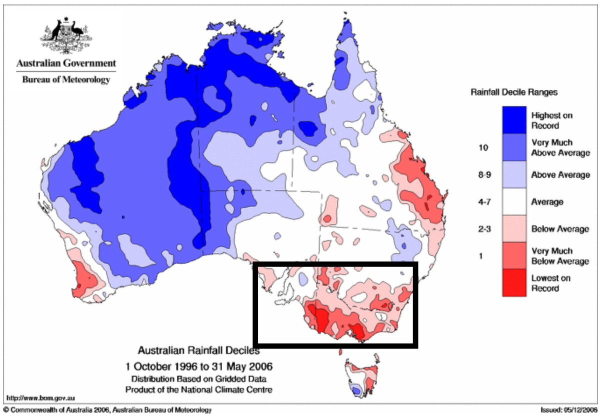

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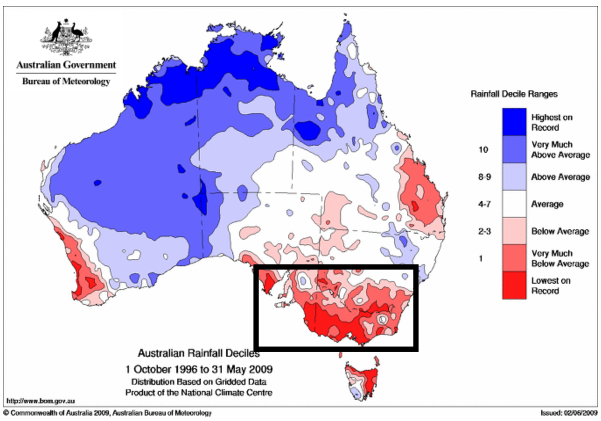

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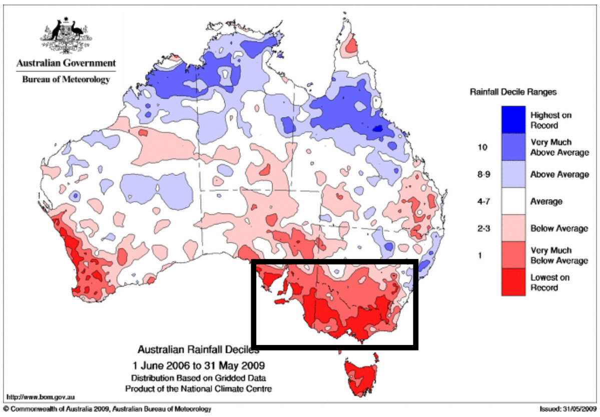

Figure 1: *Total rainfall deciles across the Australian continent for October 1996 to May 2006 (A), updated to May 2009 (B) and for the additional 3 years from June 2006 to May 2009 (C). Deciles are expressed using the long-term climatology from 1900 to 2009. The box used for SEA average is shown in black (Maps courtesy of the National Climate Centre).*

Fig.1B shows the same type of map except that it includes three more years and ends on 31 May 2009. The continent as a whole is still experiencing an above average rainfall period, but in general the areas suffering from long-term rainfall deficits have continued to be dryer than normal, displaying more severe anomalies. Arguably the situation in south-eastern Queensland is unchanged but the worsening is obvious across SEA and noticeable in the other southern dry regions (north and east of Tasmania and SWWA). The area under decile 1 now covers two thirds of the SEA box and the area affected by the largest rainfall anomalies on record has more then quadrupled. Seen in isolation, the latest 3 years (from June 2006 to May 2009, Fig. 1C), not surprisingly, were very dry across most of southern Australia and in particular SEA: rainfall in the lowest decile was recorded across most of the SEA box with about half recording the lowest 3-years total rainfall on record.

Within SEA, the spatial expansion between 2006 (Fig. 1A) and 2009 (Fig. 1B) of the area affected by record low rainfall includes the south western part of eastern Australia (SWEA), as identified in earlier studies by Timbal and Jones (2008) and Hope et al. (2009) but now also includes regions further east along the northern slope of the Great Dividing Range in eastern Victoria and southern New South Wales. The decile 1 rainfall area has extended from the south-west across two thirds of SEA, covering the entire Murray catchment (the Murray river and tributaries are shown on Fig. 4) and leaving only the north eastern corner with average rainfall and small pockets further south. Two small pockets showing no rainfall decline are worth mentioning: the southern part of the Mt Kosciusko National Park (in the lee of the main range) and an area north-east of Adelaide in the lee of the Southern Flinders Ranges. These two small regions in the lee of significant orographic features (which tends to enhance rainfall on the western slopes and decrease rainfall on the eastern sides in westerly flows) reinforces the impression that the highest rainfall decline is linked to a weakening of the dominant westerly flow as expected from a rainfall deficit whose temporal signature is scattered across the wet autumn/winter/spring months.

	Oct 96 - May 09		Jan 35 - Aug 47		1900-2008	
	Mean	σ	Mean	σ	Mean	σ
Annual	**503.6**	82.7	**511.7**	102.5	566.5	107.4
Autum	**99.7**	31.0	120.5	32.5	132.4	49.6

Table 1: *Means and standard deviation (σ) of annual an autumn rainfall (in mm) over SEA for the on-going drought (Oct 96 to May 09) and the WWII drought (January 1935 to August 1947) and the long-term mean (1900 to 2008). Bold figures are statistically different at the 95% level.*

As of May 2009, the twelve-and-a-half year rainfall average of 503.6$mm.year^{-1}$ (from October 1996) is now the lowest within the instrumental period; the previous lowest being 511.7$mm.year^{-1}$ before and during WWII (January 1935 to August 1947) (Table 1). It remains the case that the autumn rainfall decline is the most significant component of this decline: a 25% rainfall reduction from the long term mean (99.7 mm versus 132.4 mm) which accounts for just under 60% of the total rainfall decline and is significant at the 95% level. As noted in MT08, the strong autumn signature differs from the WWII protracted drought. Another difference is the very low inter-annual variability (σ = 82.7*mm* compared to 107.4*mm* for the long-term climatology versus 102.5*mm* during WWII). It was then suggested (MT08) that the absence of very wet years in the recent period, combined with the autumn signature and the on-going surface warming across SEA could have contributed to the significant consequences of the rainfall deficit in terms of river run-off across SEA compared to the WWII period.

Changes in seasonality of the rainfall decline

The autumn signature of the on-going protracted drought is still dominant with March, April and May recording the largest month by month anomalies in absolute values (Fig. 2A). However, an evolution is noticeable compared to the similar analysis in 2006 (Fig. 4 in MT08). There is now a continuum of 8 months from March to October showing a rainfall deficiency (outlined with an orange box). These 8 months include the entire wet season (May to October) where, over the 110 year long record period, 58% of the annual rainfall occurred. During the WWII period, there were also 8 continuous months with negative rainfall anomalies covering the wet season, but also extending into spring rather than earlier in autumn as in the current period (Fig. 2B).

Whereas MT08 did find a rainfall increase in June, this is not the case in the analysis we give here for two reasons. Firstly, we have updated the recent period to May 2009 and June rainfall in 2006-2008 was 25% lower than the long term average. Secondly, we have changed the reference period from the World Meteorological Organization (WMO) recommended standard 1961-90 to the entire high quality instrumental period, 1900-2009. It contributed to the June abnormality since June was not noticeably wetter during the wet 1961-1990 period. In addition, since the WMO standard was a very wet 30-year period, it gave an inflated perspective of the rainfall decline. Using the long-term climatology (1900 to 2009) as a reference period, the decline is not as large but is now seen in all months from March to October.

In terms of the seasonality of the rainfall decline, since 1996, 11 out 13 autumns have been drier than the long term average (including 2009), in contrast to 8 out of 12 winters and 6 out of 12 springs. Drier winters are equally distributed across the 12 years, although the last 3 winters (2006, 2007 and 2008) have all been below average and have contributed to the very large recent anomalies. But a drying trend in spring is now emerging with spring rainfall below the long term average 6 times during the last seven years (2002-2008).

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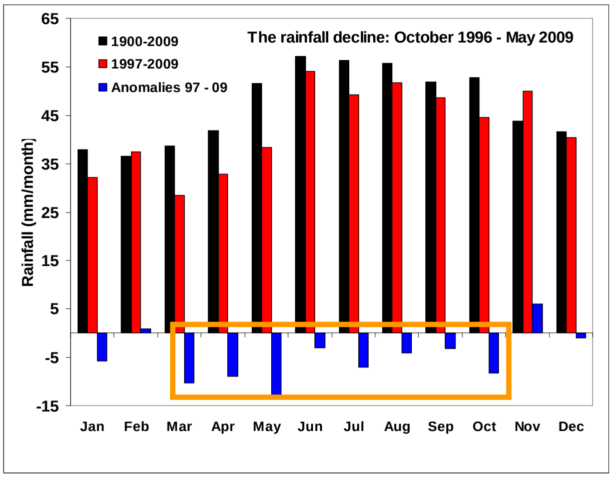

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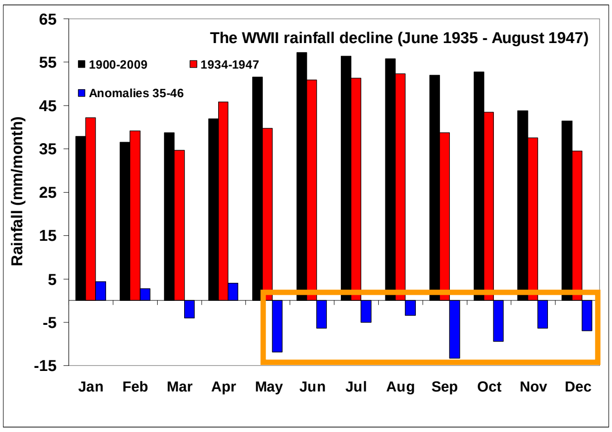
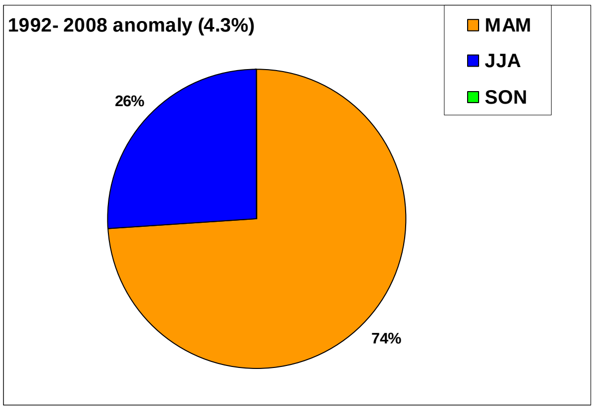
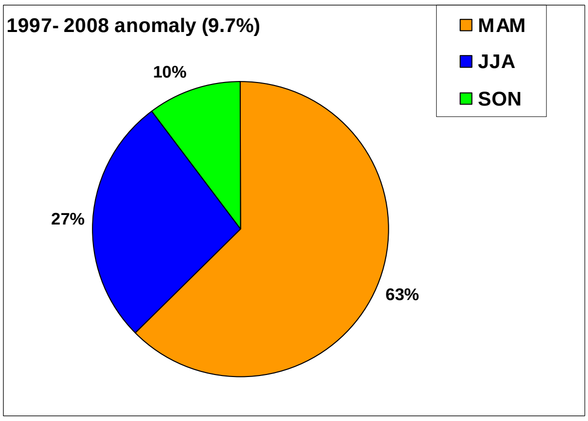
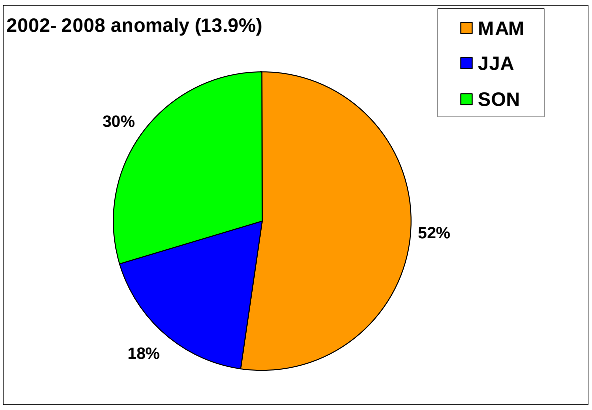


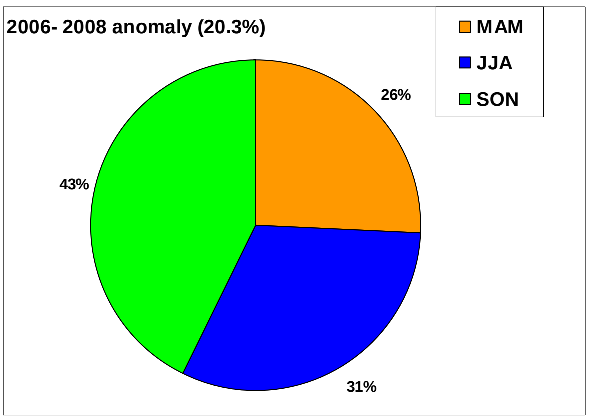
Figure 2: *Monthly mean SEA rainfall for the long-term climatology (black bars), for the on-going protracted drought (red bars in graph A) and during the World War II protracted drought (red bars in graph B); changes from the long term climatology are shown as blue bars. The continuous months with negative rainfall anomalies are outlined with orange boxes.*

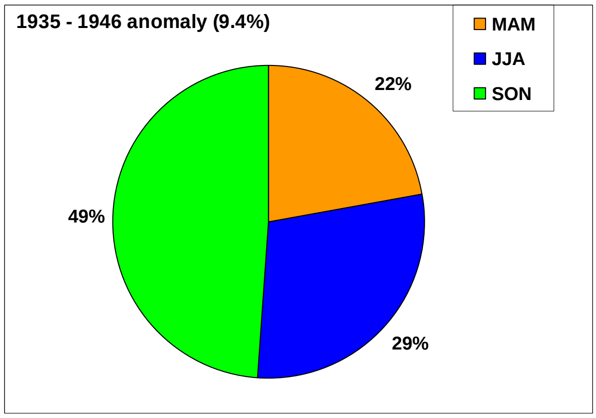
Splitting the rainfall decline across the 3 seasons which surround the winter half year (excluding summer when rainfall anomalies are small and inconsistent), the growing contribution to the decline from spring is evident (left column in Fig. 3).











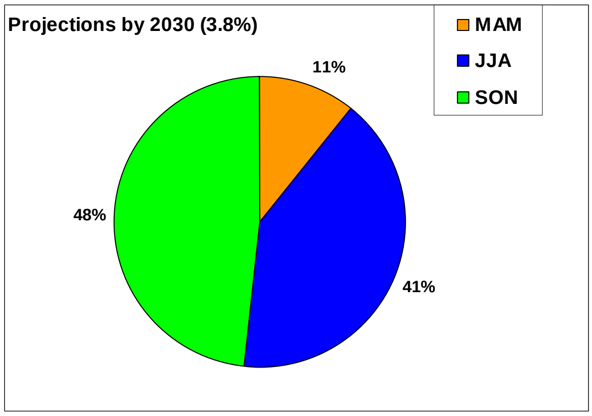


Figure 3: *Seasonal split of the rainfall anomalies for the on-going protracted drought, considered since 1992 (top left), since 1997 (second left), since 2002 (third left), during the last 3 years (bottom left), the WWII protracted drought (top right) and climate change future projections (bottom right). In all graphs, summer anomalies, either negative or positive, are omitted and percentages are based on the 3 seasons displayed. The annual rainfall anomalies (shown in the top left of each graph) includes all four seasons and are calculated from the long-term 1900-2008 mean, apart from the future projections which are based on the 1980-2000 reference period.*

A small but consistent rainfall decline can be traced as far back as 1992, when the autumn contribution (74%) dominates. For the period since 1997, the autumn contribution is still dominant (63%) but in the second half of that period it is somewhat less (52%) and only 26% over the last 3 years.

Note that this does not indicate a reduction of the autumn rainfall decline (it is -30.0*mm* during the 1992-2008 period, -32.7*mm* during the 1997-2008 period and -30.7*mm* during the 2006-2008 period), but simply that its relative contribution to the overall decline is less. Indeed, the overall annual rainfall decline has grown from -4.3% over the 17 years (starting in 1992) to -9.7% since 1997 and was -20.3% during the last three years – mainly as a result of declines in other seasons particularly spring (it was -5.4*mm* during the 1997-2008 period and -51.0*mm* during the 2006-2008 period). The split of the anomalies between the three seasons during 2006, 2007 and 2008 is similar to what was observed during WWII. It is also similar to the expected changes due to greenhouse gas emissions in the near future based on the IPCC-AR4 model using all emission scenarios available by 2030 for grid boxes covering SEA (CSIRO and BoM, 2007). Although the seasonality of the rainfall anomalies in the latest period resembles future projections of rainfall in SEA, the magnitude of the recent decline (about 20%) far exceed even the worse climate model projections (the median of the projections or "*best guess*" is a 3.8% decline by 2030 compared to the 1980-2000 reference period.

As part of the SEACI program, the role of key modes of variability in the on-going drought was evaluated, particularly those in tropical oceans: the El Niño Southern Oscillation (ENSO) in the Pacific and the Indian Ocean Dipole (IOD). Although, these modes are known to be important drivers of the Australian (including in SEA) climate (McBride and Nicholls, 1982; Nicholls, 1989), it was noted that their impact is very weak in autumn where nearly two thirds of the rainfall decline has occurred (Timbal and Murphy, 2007). Therefore both the ENSO and IOD drivers are unlikely to have contributed significantly to the rainfall decline up to 2006. On the contrary the rise of Mean Sea Level Pressure (MSLP) across southern Australia (Timbal and Hope, 2008) and in particular the intensification of the Sub-Tropical Ridge (STR) as diagnosed by Drosdowsky (2005) was found to be associated with a very sizeable part (about 70%) of the rainfall decline in SEA (Timbal et al., 2007). It is therefore noticeable that the area with the largest rainfall deficit (Fig. 1) coincides closely with the area showing the biggest negative influence of the STR intensity on rainfall (Fig. 4) thus strongly suggesting a role for the STR intensification on the on-going drought across SEA. Recent studies have noted global scale changes in the extent of the tropics, and the extent and intensity of the Hadley circulation. The tropics appear to be getting wetter over time (Allan and Soden, 2007), they appear to be expanding (Seidel et al., 2007), and the Hadley circulation also appears to be expanding (Lu et al., 2008). This suggests that the STR may be part of a much larger scale change in the global scale circulation, particularly as it provides a physical link between the decline in rainfall in SWWA and that now seen in SEA (Hope et al, 2009).

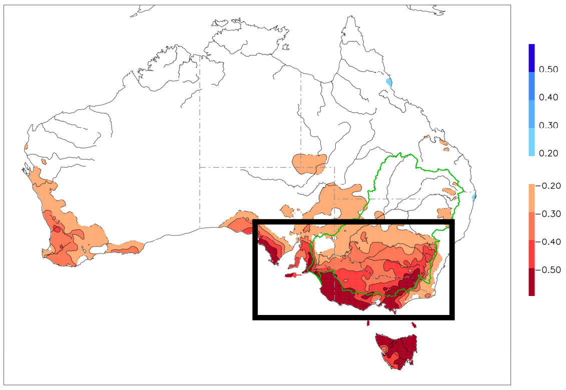


Figure 4: *Detrended correlations between the Sub-Tropical Ridge intensity and rainfall across Australia for all months, correlations significant at the 95% level and above are colour shaded.*

However, in light of the shift toward a larger spring rainfall anomaly in the last 3 years, a season where both ENSO and IOD are well formed with a sizeable influence on SEA rainfall (Timbal and Murphy, 2007), it is worth reviewing the recent phases of both modes of variability. Monthly normalised anomalies for ENSO indicators and the IOD Mode Index can be accessed from the BoM NCC web site: http://www.bom.gov.au/climate/enso/indices.shtml.

In the case of the tropical Pacific Ocean, the period from June 2006 to May 2009 comprised both positive and negative phases of ENSO with a weak El Niño event in 2006/07 followed by moderate La Niña event in 2007/08. A further negative La Niña-like anomaly followed in 2008/09. Overall, there has been no bias toward either phase. In addition, the 3 years rainfall decile map (Fig. 1C) is not consistent with the expected rainfall influence from either El Niño or

La Niña events across Australia: http://www.bom.gov.au/climate/enso/ensorain.comp.shtml. Therefore, it is unlikely that ENSO variability has contributed to the worsening of the drying trend in SEA.

In the case of the tropical Indian Ocean, the period from June 2006 to May 2009 was notable for a positive phase bias of the IOD. Three positive IOD events were recorded in that period; this is remarkable and only happens once before in the instrumental record at the end (1944, 1945 and 1946) of the WWII dry decade (Meyer et al., 2007). In addition, the 3 years rainfall decile map has some similarities in particular across Eastern Australia including SEA, with the known impact of IOD on Australian climate which peaks in late winter early spring (Fig. 5). This suggests that the Indian Ocean variability has likely contributed to the worsening of the rainfall decline during the last three years and in particular the additional shortfall in spring on top of the continuing autumn decline. This importance of the IOD on the observed SEA rainfall decline since 1997 should not be overestimated since it is limited to the latter part of the wet season (i.e. the spring contribution of the rainfall decline since 1997 is 10%, Fig. 3). However it is worth noting and monitoring since climate model future projected rainfall decline in SEA has a strong spring signature (Fig. 3).

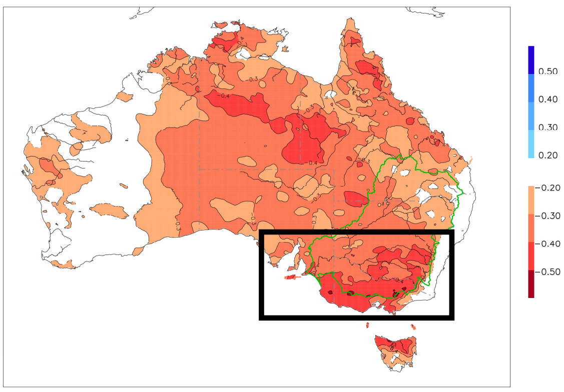


Figure 5: *Detrended ccorrelations between the Indian Ocean Dipole and rainfall across Australia for August to October, correlations significant at the 95% level and above are colour shaded.*

Beside tropical influences, the role of the Southern Annual Mode (SAM), the largest mode of variability in the southern hemisphere, is also worth monitoring. The influence of a positive phase of SAM on SEA rainfall is highly seasonal: positive in summer, negative in winter with no influence in autumn (Timbal et al., 2007). The lack of influence in autumn was pointed out as the main reason why SAM is unlikely to be an important contributor to the SEA rainfall decline (Timbal and Murphy, 2007), however that influence is worth monitoring since another study suggests that SAM is the main explanation for the southern Australia rainfall decline (Nicholls, 2009). Linear trends were calculated month by month (and for 3-month running means) from the Marshall (2003) index based on observed MSLP (http://www.nerc-bas.ac.uk/icd/gjma/sam.html) at selected stations and the Climate Prediction Centre (CPC) SAM index http://www.cpc.noaa.gov/products/precip/CWlink/daily_ao_index/aao/aao.shtml based on 700 hPa geopotential height (Fig. 6).

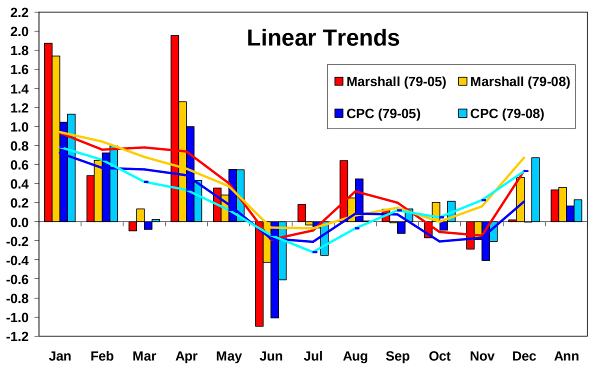


Figure 6: *Linear trends month by month (bars) and for 3-month running means (lines) using Marshall (red colors) and CPC (blue colors) SAM indices from 1979 to 2005 (dark colors) and from 1979 to 2008 (light colors).*

Linear trends are calculated since 1979 (the CPC calculation based on reanalyses are considered unreliable prior to the satellite era) to 2005 and have been updated to the end of 2008. The overall picture is unchanged, the largest trends are observed in summer and autumn (when upward trends should have a positive influence on SEA rainfall). In the season where SAM has a negative influence on SEA rainfall (June-July-August), there are no long-term trends in SAM. It is worth noting that individual months with the largest trends (either positive: April or negative: June) up to 2005 have seen these trends being reduced as more years are included. With time, some of the largest random anomalies inevitable with linear trends calculated month by month on short periods are being eroded. It is likely that the positive values of SAM indices in June in 2006, 2007 and 2008 which contributed to reduce the overall June trends also contributed to the dry months of June observed during these 3 years and discussed earlier. It is also interesting to note the emerging positive trend of the SAM in December (in both indices), which are consistent with the above average observed rainfall in December in 2007 and 2008 (but not in 2006 in the middle of an El Niño) and the positive influence of the positive phase of SAM in summer.

Conclusions

The long-term rainfall deficiency since October 1996 across South Eastern Australia (south of 33.5ºS and east of 135.5ºE) documented by MT08 was described as being severe but not unprecedented in the instrumental record. With an additional 3 years of below average rainfall, that statement is no longer true. The recent 12 year, 8 month period is the driest in the 110 years long record, surpassing the previous driest period during WWII. The spatial extent of the deficiency covers most of the south-western part of eastern Australia and extends along significant orographic features eastward and northward. The seasonal signature of the rainfall decline has also evolved. It remains dominated by a strong and highly significant autumn rainfall decline, but has been supplemented by recent declines in spring, particularly after 2002. The spring decline is the dominant feature of the very dry 2006-2008 period.

This change in the relative contributions by the autumn and spring seasons now more closely resembles the picture provided by climate model simulations of future changes due to enhanced greenhouse gases. However, the growing magnitude of the rainfall decline is far more severe than any of the IPCC-AR4 model projections except for the lowest deciles from the model uncertainty range, forced with the highest emission scenarios occurring later in the 21st century (2050 to 2070) (CSIRO and Bureau of Meteorology, 2007).

The most important characteristics of the on-going rainfall decline (spatial extension, intensification and change in seasonality) are well aligned with the recent evolution of the STR and its known influence on SEA rainfall. Other large-scale influences were briefly evaluated. It appears unlikely that the ENSO mode of variability has contributed to the worsening of the rainfall decline in the last 3 years. On the contrary, it appears likely that the Indian Ocean mode of variability (with three positive IODs in a row) may be linked to the strong spring signal in 2006-2008. However, that does not change the fact that the IOD is unlikely to be responsible for the largest component of the rainfall decline (the autumn part) and based on the limited evidence provided here, it is unclear whether the IOD is a contributor, or simply a covarying response to other factors. Finally, the long-term evolution of the SAM remains unlikely to explain the long-term decline in SEA due to the seasonal nature of the influence of SAM on SEA rainfall but its role (both positive or negative) is visible while updating month by month anomalies

One of the goals of the new SEACI program involves "*investigating the causes and impacts of climate change and climate variability across south eastern Australia*" This is now more relevant than ever, particularly as we are dealing with the worst rainfall deficit in the region within more than a century long instrumental record.

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