South Eastern Australian
Climate initiative

Project 1.1.1

Observed variability in the climate of south-eastern Australian and its relation to large-scale features

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In order to characterise large-scale influences on the climate of South-Eastern Australia (SEA) a number of indices were computed. SEA is defined as the spatial average of gridded data from the National Climate Centre of the Bureau of Meteorology below the 33ºS line. For rainfall data are available from 1901 to 2006, and for temperature (Tmax and Tmin) from 1950 to 2006.

A series of indices were explored to analyse the impact of ENSO (Niño 3, Niño 4, Niño 3.4, the SOI), all indices show similar behaviour and results are presented for Niño 3.4 (central Pacific, 170°W-120°W) constructed using Sea Surface Temperature (SST) anomalies from Smith and Reynolds (2004) reconstruction version 2. Similarly indices were constructed using the same SST database for the Indian Ocean: one for the Indonesia-Indian Equatorial Ocean (120°-130°E, 10°S-0°N) and one for the north-west shelf (100°-130°E, 20°S-5°S), only results for the latter are presented as both indices yield similar results. In addition, an index for the Southern Annular Mode was used: the Marshall (2003) SAM index that is calculated from station pressure observations, covering 1958-2005.

Finally, many of the influences of the climate indices in SEA come about through modulations of the atmospheric circulation, this was quantify computing a Mean Sea Level Pressure (MSLP) index for SEA (from 140°E to 150°E and from 33°S to 40°S) using gridded HadSLP2 data with 5° resolution from 1850 to 2004 (Allan and Anselm, 2006). In order to remove this indirect influence we have calculated a time series of SEA rainfall with the time series of rainfall regressed on the MSLP time series. The rainfall residual time series is therefore uncorrelated with SEA MSLP.

Significance of the correlations obtained was assessed using the method described by Power et al. (1998). The method takes into account the autocorrelations of the time series. Generally the autocorrelations at 1 month lag were very small for most indices (only for the SST-based indices were they greater than 0.1), and so the impact of these autocorrelations was minimal. When we talk of significant correlations we mean that the correlations are deemed to be significantly different from zero at the 90% significance level (in bold in Table 1) and very significant (at the 99% level, in red in the following table).

Autumn	Tmax	Tmin	Rain	R-f(P)
MSLP SEA	**0.40**	**-0.24**	**-0.29**	
Niño 3.4	0.09	**-0.23**	-0.07	0.04
NWS	**0.28**	0.11	0.07	**0.19**
SAM	-0.06	-0.02	-0.02	0.09
Tasman	**0.32**	**0.49**	**0.25**	**0.27**

Winter	Tmax	Tmin	Rain	R-f(P)
MSLP SEA	**0.54**	**-0.44**	**-0.74**	
Niño 3.4	0.18	**-0.23**	**-0.21**	-0.04
NWS	0.08	**0.41**	**0.30**	**0.32**
SAM	-0.01	**-0.31**	**-0.27**	0.17
Tasman	**0.39**	**0.30**	0.07	**0.22**

Spring	Tmax	Tmin	Rain	R-f(P)
MSLP SEA	**0.46**	**0.29**	**-0.39**	
Niño 3.4	**0.37**	-0.11	**-0.39**	**-0.26**
NWS	0.00	**0.34**	**0.26**	**0.19**
SAM	-0.20	**0.28**	**0.31**	**0.47**
Tasman	**0.40**	**0.60**	0.16	**0.22**

Summer	Tmax	Tmin	Rain	R-f(P)
MSLP SEA	0.14	**0.34**	0.14	
Niño 3.4	0.14	-0.04	**-0.19**	**-0.26**
NWS	**0.24**	0.19	-0.09	-0.13
SAM	0.02	**0.30**	**0.31**	**0.27**
Tasman	**0.43**	**0.55**	**0.19**	**0.19**

Table 1: *Correlation between SE of Australia mean Tmax, Tmin, Rainfall and a rainfall residual (with the relationship to Mean Sea Level Pressure removed) and a range of climate indices for the four calendar seasons. The climate indices are: MSLP above the SE of Australia, ENSO index (Niño 3.4 SST anomalies), an index of the Indian Ocean variability (SST anomalies over the North-West shelf), the Southern Annular Mode index and neighbouring SST anomalies in the Tasman Sea. Note: Red figures indicate significance above the 99% level and bold figures above the 90% level.*

The main findings are:

- Local MSLP has the greatest influence of all indices; apart in summer where it is mostly negligible (except for Tmin) and will not be discussed further. Local MSLP has a negative influence on rainfall which is strongest in the heart of winter (e.g. rainfall is associated with low pressure systems) and a positive influence on maximum temperature (e.g. higher temperature associated with highs). The influence on minimal temperature is more complex and swaps sign between autumn and winter where high MSLP means clear sky and colder night-time temperature and spring and summer were the relationship become positive due to the influence of Tmax (Power *et al*., 1999).

- ENSO-related correlations are at the strongest in spring and generally highest for rainfall and Tmax. Highest correlation is -0.39 between Niño 3.4 and SEA-mean rainfall in spring. It reaches 0.50 with the SOI, but still only explains 25% of variance. This confirms that SEA is not the Australian region the most affected by ENSO (Nicholls, 1989). The strong relationship with rainfall in spring is strongly reduced when the influence of local MSLP is removed, thus confirming that the influence of ENSO on SEA rainfall is through large-scale circulation changes.

- Indian Ocean SSTs are related to rainfall and Tmin in winter and in spring as well, but the signal is weaker. Interestingly the relationship with rainfall is only reduced, slightly, in spring when the influence of local MSLP is removed but it remains unchanged in winter and in autumn it increases and becomes significant. It suggests that the influence of the warm SST along the North-West coast of Australia is felt in SEA by other mechanisms than circulations changes, *e.g.* moisture fluxes.

- The Southern Annular Mode (SAM) index correlates significantly in all seasons except autumn. The SAM modulates SEA rainfall in winter where the negative correlation indicates that the southward contraction of storm track leads to less rain. The opposite is true in spring and summer where there is more rain with southward storm track (Hendon *et al*., 2007). The signature for Tmin is similar and there is no influence on Tmax. The impact of the SAM is expected to come about through circulation changes. However, when the effect of MSLP is removed the correlation between the SAM and SEA rainfall in winter changes sign, and in spring it is much stronger, thus suggesting that the direct influence of SAM on SEA rainfall is stronger due to some changes in the flows but is reduced by the concomitant impact on regional MSLP.

- The strongest influence of neighbouring Tasman Sea SSTs is seen on temperature: Tmax in winter and Tmin in spring-summer-autumn. The only significant correlation with rainfall is in autumn (0.25). Interestingly, when the impact of MSLP is removed, the relationship with rainfall is always stronger, albeit still modest, and becomes significant in all seasons.

In light of this analysis, it is hard to explain the decline of rainfall in SEA. Most of this decline has occurred in autumn since 1991 (Murphy and Timbal, 2007). The only climate indices that are closely related to autumn rainfall are local MSLP and SSTs. Although, it is known that MSLP in SEA has increase in the last 20 years thus forcing the rainfall decline. On the contrary, the Tasman Sea SST correlations are independent of MSLP but are positive and since the Tasman Sea has been one of the fastest warming parts of the ocean it is unlikely to explain the rainfall decline in autumn, if anything it has possibly acted to reduce the rainfall decline.

One plausible explanation is that the SEA as defined earlier is affected by several influences which might differs from one part of the region to another.

In order to investigate this further, we have split the rainfall in SEA in four sub-regions covering SEA and matching those uncovered through rotated EOF analysis by Drosdowsky and Chambers

(2001). We have chosen to calculate the average monthly-mean rainfall for two stations in each region that capture the spatial variability of these rainfall patterns. High quality rainfall stations were used. Maps of the correlation between these time series and the monthly gridded HQ rainfall analyses over the period 1948-2005 are shown in Figure 1. Areas where the correlations explain more than 20% total variance are shaded and show the main centres of action of these patterns of rainfall variability. They match very well four of the rotated EOFs from Drosdowsky and Chambers (2001): number 1 (Fig. 1 top left based on rainfall at Peak Hill and Bingara), number 2 (Fig. 1 top right, based on rainfall at Murray-Bridge and Orroroo), number 5 (Fig. 1 bottom left, based on rainfall at Meredith and Yan Yean) and number 8 (Fig. bottom right, based on rainfall at Thargomindah and White cliffs).

The four patterns generally do not overlap and cover most of the SEA. The mean monthly rainfall of each pair of stations was averaged to give a time series of a regional rainfall index.

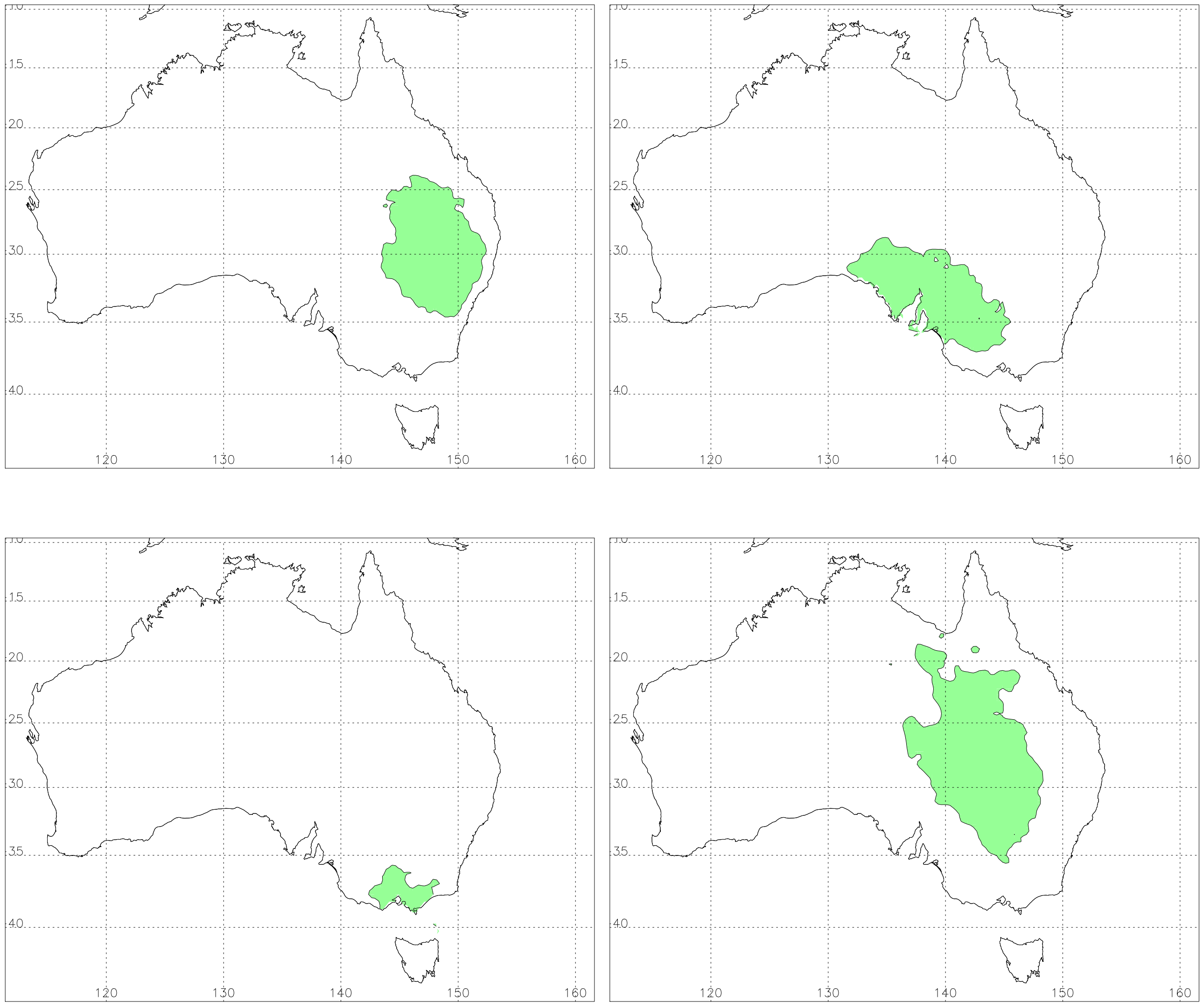

Figure 1: *4 rainfall patterns covering SEA (see text for details on their calculation) and refer in the following analysis as: Eastern (top left), North-West Cloud Band (NWCB) (top right), Victoria (bottom left), Central (bottom right).*

Some interesting regional features emerge (Table 2). The influence of the Indian Ocean in winter appears to be largest in NWCB region and non existent in the Victoria region, however no clear differences appears in autumn. The strong influence on ENSO in spring does not reach the NWCB region and in winter it contracts to the Eastern region. The influence of SAM in winter is limited to the Victoria region and change signs further north (in agreement with Hendon et al., 2007). The influence of the Tasman Sea is felt mostly in the Eastern and Central regions, it changes signs for the Victoria region in winter and spring.

Overall, the influence of the various large-scale mode of variability appears to vary from one part of the SEA region to another. However, in autumn where most of the rainfall decline occurred in the last 15 years, no particular influences appear to dominate. In fact, this is often the season where the correlations are often the weakest and least contrasted between the sub-regions.

There is a hint that the warming of the tropical central Pacific (Niño 4 SST anomalies, no necessarily related to a trend in ENSO but simply the global warming of the ocean) and the rises of MSLP above SEA may have contributed to the autumn rainfall decline. The negative correlation are indicative as well as the spatial patterns with stronger correlation for the NWCB and Victoria regions where the overall rainfall decline is the largest in SEA.

Based on this analysis alone, it is not possible to clearly and definitely attribute the autumn rainfall decline in SEA on the basis of naturally occurring large-scale modes of variability.

Autumn	NWCB	Victoria	Eastern	Central
MSLP SEA	**-0.33**	**-0.43**	-0.17	-0.17
Niño 4	**-0.35**	**-0.30**	-0.16	**-0.37**
Ind. Ocean	0.00	-0.13	0.12	-0.19
SAM	0.04	-0.01	-0.01	0.05
Tasman	0.18	0.08	0.21	0.21

Winter	NWCB	Victoria	Eastern	Central
MSLP SEA	**-0.65**	**-0.49**	**-0.25**	**-0.23**
Niño 4	0.05	-0.15	**-0.46**	**-0.29**
Ind. Ocean	**0.55**	0.08	**0.40**	**0.48**
SAM	-0.13	**-0.30**	0.14	0.13
Tasman	0.15	-0.12	0.19	**0.29**

Spring	NWCB	Victoria	Eastern	Central
MSLP SEA	**-0.24**	**-0.37**	0.05	-0.04
Niño 4	-0.14	**-0.45**	**-0.46**	**-0.43**
Ind. Ocean	0.15	0.16	0.22	0.20
SAM	0.18	0.13	**0.33**	**0.29**
Tasman	0.04	-0.17	**0.31**	**0.24**

Summer	NWCB	Victoria	Eastern	Central
MSLP SEA	**0.32**	0.11	0.06	0.18
Niño 4	0.03	-0.04	-0.15	**-0.33**
Ind. Ocean	-0.13	0.01	-0.10	**-0.26**
SAM	0.17	0.16	0.22	**0.29**
Tasman	0.09	0.08	**0.39**	0.18

Table 2: *Correlation between SE of Australia mean Tmax, Tmin, Rainfall and a rainfall residual (with the relationship to Mean Sea Level Pressure removed) and a range of climate indices for the four calendar seasons. The climate indices are: MSLP above the SE of Australia, ENSO index (Niño 3.4 SST anomalies), an index of the Indian Ocean variability (SST anomalies over the North-West shelf), the Southern Annular Mode index and neighbouring SST anomalies in the Tasman Sea. Note: Red figures indicate significance above the 99% level and bold figures above the 90% level.*

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