Characteristics of climatic indicators and their influences on rainfall and temperature in the Murray-Darling Basin

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ABSTRACT

The association between climatic indices which are calculated on a monthly basis, including the El Niño Southern Oscillation (ENSO), and monthly rainfall and temperature in the Murray Darling Basin during the period 1960 to 2009 is investigated. The indices considered are El Niño 1+2, Niño 3, Niño 4, and Niño 3.4, Dipole Mode Index (DMI), North and Southern Atlantic Oscillation, Global tropics, Southern Annular Mode (SAM), Southern Oscillation Index (SOI), and Pacific Decadal Oscillation (PDO). A regression model with periodic functions is used to allow for seasonal variation, and the residuals are examined for evidence of non-stationarity over the study period. Generalized least squares is used to allow for the effect of autocorrelation when estimating the standard error of the regression parameters. Any estimated trend is removed from the residuals, which are then analyzed as a multivariate time series to highlight the dependence structure between indices. Correlograms suggested that the residuals of fitted ARMA (3,0,3) have significantly small autocorrelations, which is consistent with a realizations of white noise and cross-correlograms functions verify multivariate time series that cross correlogram of white noise approximately zero for all none zero lag by pre whitening method, which appears to be stationary process. A factor analysis model is also fitted, and possible interpretations of latent factors will be suggested.
Keywords: cross-correlogram, ENSO, generalized least squares,

1. **INTRODUCTION**

This poster paper proposes that the strong spatial and temporal variations of climate in the region of study are caused by the influences of synoptic systems. It is rational to examine relationships between climate indices and their influence on rainfall and temperature sequences in the Murray Darling Basin (MDB). Many studies have identified the relationship between Australian rainfall and the El Niño Southern Oscillation (ENSO) (Drosdowsky, 1993; McBride and Nicholls, 1983). Furthermore, changes in the Sea Surface Temperatures (SST) affect Australian rainfall (Zhang et al., 1997). The SST anomalous warming and cooling phases in the Pacific Ocean termed the Inter decade Pacific Oscillation (IPO) influences the ENSO phenomenon in Australia (Franks, 2002). Mantua et al. (1997) identified a multi-decadal persistence in the north Pacific sea surface temperatures, termed the Pacific Decadal Oscillation (PDO) The PDO index has been used in place of the IPO, as stronger relationships were found when using this index (Franks, 2002). The climatic variability in the Southern Hemisphere (SH) extra-tropics is measured by the Southern Annular Mode (SAM) that explains the greatest percentage of the variability. One objective of this paper is to present a regression based analysis to ascertain climatic indices, and to investigate their influence on rainfall and temperature sequences in the MDB.

2. AIMS

The recent variability of SST data has seen the development of indices based on more direct measures of temperature itself. The SST gradients have been indicating some uncertainty also to where exactly the ENSO process should be measured. More recently, another ENSO monitor called the multivariate ENSO index (MEI) has been developed (Wolter and Timlin, 1998). In this research several climatic indices are considered, for example, four climatic indices from the Pacific Ocean and three climatic indices from the Atlantic Ocean, Indian Ocean, Southern Annular Mode (SAM), SOI and PDO.

3. DATA

The rainfall and temperature data used in this research were obtained from the Australian Bureau of Meteorology (BOM, 2008). They were extracted from a 0.25° × 0.25° grid (BOM, 2008) for monthly rainfall and temperature from January 1957–December 2007. Sea-level pressure anomalies were derived from records over the Australian continent bounded by 110-160°E and 10-45°S over the period from 1957 to 2007 for each season and other pressure anomalies (e.g. monthly PDO, SOI) values were collected from the National Climate Centre of the Australian Bureau of Meteorology over the period 1957-2007. The weather station locations were selected because they recorded both rainfall and temperature data and had the highest BOM quality designation for both data series. The MEI in the Pacific Ocean, Atlantic Ocean, and Indian Ocean are defined in Table 1. The SST anomalies were derived from data available from Climate Prediction Centre (CPC) of the National Weather Service over the period 1950 to 2008. For the Dipole Mode Index (DMI) in the Indian Ocean, the SST anomalies were collected from the Japan Agency for Marine Earth Science and Technology (JAMSTEC) as derived by Kaplan et al. (1998) over the period from 1950 to 2008. The SAM data were collected from the Natural Environment Research Council, based on the British Antarctic Survey pressure anomalies derived by Marshall (2003) over the period 1957 to 2008. To facilitate time series analysis, the missing values were replaced by series' means, using SPSS version 17.

4. METHODS

There is a clear seasonal variation for at least some of the indices and in order to assess evidence of a trend, regression models are fitted with three periodic functions to allow for seasonal variation and linear and quadratic terms to allow for any trend. The general formula is given by.

$$Y_t = \beta_0 + \beta_1 C_1 + \beta_2 S_1 + \beta_3 C_2 + \beta_4 S_2 + \beta_5 C_3 + \beta_6 S_3 + \beta_7 (t - \bar{t}) + \beta_8 (t - \bar{t})^2 + \varepsilon_t \text{..eq.(1)}$$

Where t runs from 1 up to 608 and average t is 304.5, Y_t is climatic indicators and
$C_1 = \cos(2\pi t/12)$, $S_1 = \sin(2\pi t/12)$, $C_2 = \cos(2 \times 2\pi t/12)$, $S_2 = \sin(2 \times 2\pi t/12)$,
$C_3 = \cos(3 \times 2\pi t/12)$, $S_3 = \sin(3 \times 2\pi t/12)$,

An example of the fitted model is that for Nino1+2 shown below

$$\text{Nino } 1 + 2 = 23.12 + 0.0915\, C_1 + 2.8675\, S_1 - 0.2841\, C_2 + 0.09531\, S_2 - 0.0118\, C_3 - 0.0943\, S_3 + 0.00022\, (t - \bar{t}) - 0.0000018\, (t - \bar{t})^2$$

5. ANALYSIS AND DISCUSSION

5.1. DESEASONALIZED ASSESSMENT OF TREND

The result of fitting the regression model (equation 1) to the 11 climatic indices is summarized in Table 2. This is referred to as the deseasonalized – detrended time series.

Table 2: Assessment of climatic indicators

ENSO indices	NINO1.2	NINO3	NINO4	NINO3.4	NATL	SATL	TROP	DMI	PDO	SOI	SAM
Intercept	23.120	25.800	28.370	26.940	26.560	24.800	27.580	-0.004	0.218	-1.337	-0.122
Natural series Standard dev.	2.318	1.273	0.673	0.967	0.933	1.499	0.553	0.334	1.034	10.238	1.812
Deseasonalized Standard dev.	1.092	0.895	0.631	0.862	0.361	0.349	0.269	0.331	0.984	10.144	1.781
Co eff linear t	0.00022	0.00041	0.00070	0.00025	0.00058	0.00087	0.00091	0.00003	0.00157	-0.00724	0.00176
Est Standard error	0.00025	0.00021	0.00015	0.00020	0.00008	0.00008	0.00006	0.00008	0.00023	0.00236	0.00041
P-values	0.383	0.0484*	0.000***	0.2180	0.000***	0.000***	0.000***	0.679	0.000***	0.002**	0.000***
Co eff quadretic t	-0.0000019	0.0000005	0.0000036	0.0000023	0.0000051	-0.0000006	0.0000017	0.0000002	-0.0000047	0.0000064	0.0000001
Est Standard error	0.0000016	0.0000013	0.0000009	0.0000013	0.0000005	0.0000005	0.0000004	0.0000005	0.0000014	0.0000150	0.0000026
P-values	0.253	0.720	0.000***	0.068	0.000***	0.237	0.000***	0.723	0.001***	0.672	0.982
AR(1) coeff of residuals	0.902	0.922	0.937	0.936	0.88	0.849	0.936	0.736	0.807	0.636	0.208

*coefficients are statistically significant at the 5% level
**coefficients are statistically significant at the 1% level
*** coefficients are statistically significant at the 0.1% level

5.2. PREWHITENING WITH ARMA MODEL AND CROSS CORRELATIONS

In this section, we investigate the cross correlation between climatic indicators after removing trend and seasonal variation and allowing for correlation structure. This process is known as pre-whitening. In principle, the pre-whitened climatic indicator series are realisations of independent random variation and can therefore, be cross-correlated at one lag only

5.2.1. CORRELOGRAM AND CROSS CORRELATIONS

The pre-whitened series are considered as residuals of an independent sequence (discrete white noise). If we have two white noise sequences then by definition, the auto correlation function is 0 at all lags after than lag 0 when it is 1. The cross correlation between the two sequences can only be non-zero at a single value of lag k and if the white noise sequences are uncorrelated, the cross correlation is 0 at all lags. Therefore, for the pre-whitened time series, which we consider as realisations of white noise, we look for a single statistically significant cross correlation and note its lag. The cross correlations are shown in the Figure 3 and the maximum absolute values are presented in Table 4. In no case is there any evidence of one series leading or lagging another as the maximum cross correlations all occur at lag 0.

Table 3: Maximum absolute values of cross correlations

	NINO1.2	NINO3	NINO4	NINO3.4	NATL	SATL	TROP	DMI	PDO	SOI	SAM
NINO1.2	1.000										
NINO3	0.395 (0)	1.00									
NINO4	0.031(0)	0.201 (0)	1.00								
NINO3.4	0.088 (0)	0.766 (0)	0.510 (0)	1.00							
NATL	-0.024 (0)	0.003 (0)	0.049 (0)	0.025 (0)	1.00						
SATL	0.010 (0)	0.103 (0)	0.075 (0)	0.082 (0)	0.036 (0)	1.00					
TROP	0.365 (0)	0.673 (0)	0.532 (0)	0.673 (0)	0.127 (0)	0.301(0)	1.00				
DMI	0.098 (0)	0.71 (0)	-0.032 (0)	0.030 (0)	0.055 (0)	0.059 (0)	0.060 (0)	1.00			
PDO	0.092 (0)	0.040 (0)	-0.058 (0)	0.014 (0)	0.115 (0)	0.010 (0)	0.039 (0)	0.040 (0)	1.00		
SOI	-0.078 (0)	-0.035 (0)	-0.098 (0)	-0.084 (0)	-0.106 (0)	-0.003 (0)	-0.091 (0)	-0.081 (0)	-0.021 (0)	1.00	
SAM	-0.019 (0)	-0.027 (0)	-0.026 (0)	-0.043 (0)	-0.002 (0)	-0.079 (0)	-0.094 (0)	0.084 (0)	-0.021 (0)	-0.043 (0)	1.00

5.3. REGRESSION MODEL FOR RAINFALL AND TEMPERATURE SERIES

A regression model was fitted to determine whether the climatic indices and their interaction effects are significantly influencing the rainfall and temperature patterns in the MDB. A linear and quadratic term (mean adjusted) and a sinusoid of period one year were included in the regression model.

Table 4: Regression model fitted by individual CI for rainfall and temperature.

Rainfall model	Adelaide Airport		Broken hill		Canberra Airport		Hume dam		lake Victoria		Loxton		Melbourne Airport		Mildura Airport		Murray bridge		Sydney obs. Hill	
	std	R^2_{adj}	std	R^2_{adj}	std	R^2_{adj}	std	R^2_{adj}	std	R^2_{adj}	std	R^2_{adj}	std	R^2_{adj}	std	R^2_{adj}	std	R^2_{adj}	std	R^2_{adj}
Nino1+2	23.990	0.264	29.220	0.004	37.52	0.044	39.680	0.117	21.520	0.038	18.190	0.041	29.580	0.034	22.910	0.033	22.69	0.089	91.51	0.033
Nino3	24.000	0.264	28.970	0.020	37.22	0.060	39.390	0.130	21.510	0.038	18.140	0.046	29.470	0.041	22.940	0.031	22.69	0.089	91.40	0.035
Nino4	23.990	0.264	28.590	0.046	37.17	0.062	39.390	0.130	21.420	0.046	18.070	0.053	29.370	0.048	23.190	0.010	22.67	0.091	91.30	0.037
Nino34	23.990	0.264	28.680	0.040	37.13	0.064	39.280	0.135	21.470	0.042	18.090	0.051	29.400	0.046	23.050	0.021	22.69	0.089	91.34	0.037
N-Atl	24.020	0.262	29.240	0.002	37.65	0.038	39.990	0.104	21.590	0.031	18.200	0.040	29.580	0.034	23.080	0.018	22.69	0.089	91.49	0.034
S-Atl	24.010	0.263	29.250	0.002	37.66	0.037	39.960	0.105	21.500	0.039	18.110	0.049	29.500	0.039	23.060	0.020	22.64	0.093	91.14	0.041
G. tropi	24.030	0.262	29.030	0.016	37.51	0.045	39.680	0.117	21.560	0.034	18.170	0.043	29.630	0.031	22.950	0.029	22.69	0.089	91.49	0.033
DMI	23.780	0.277	29.240	0.002	37.28	0.056	39.320	0.133	21.480	0.041	18.090	0.051	29.540	0.037	23.190	0.009	22.6	0.096	91.50	0.033
PDO	24.030	0.261	29.150	0.008	37.65	0.037	39.990	0.103	21.550	0.035	18.200	0.040	29.620	0.032	23.260	0.004	22.65	0.092	91.40	0.036
SOI	23.730	0.280	28.400	0.059	36.49	0.096	38.500	0.169	21.040	0.080	17.830	0.079	29.440	0.043	22.730	0.049	22.67	0.090	90.94	0.045
SAM	24.010	0.263	29.040	0.016	37.31	0.055	39.970	0.104	21.470	0.041	18.180	0.042	29.400	0.046	23.130	0.015	22.65	0.092	90.36	0.057
Temp model	Adelaide Airport		Broken hill		Canberra Airport		Hume dam		lake Victoria		Loxton		Melbourne Airport		Mildura Airport		Murray bridge		Sydney obs. Hill	
	std	R^2_{adj}	std	R^2_{adj}	std	R^2_{adj}	std	R^2_{adj}	std	R^2_{adj}	std	R^2_{adj}	std	R^2_{adj}	std	R^2_{adj}	std	R^2_{adj}	std	R^2_{adj}
Nino1+2	2.581	0.879	4.809	0.131	2.315	0.904	1.629	0.940	3.430	0.552	1.484	0.933	2.634	0.893	1.531	0.937	1.893	0.828	91.510	0.033
Nino3	2.557	0.881	5.165	-0.002	2.288	0.907	1.643	0.939	3.427	0.553	1.491	0.932	2.627	0.894	1.541	0.936	1.891	0.829	91.400	0.035
Nino4	2.569	0.880	5.113	0.018	2.313	0.905	1.654	0.938	3.430	0.552	1.492	0.932	2.666	0.891	1.544	0.936	1.885	0.830	91.300	0.037
Nino34	2.560	0.881	5.106	0.020	2.296	0.906	1.651	0.938	3.427	0.553	1.492	0.932	2.647	0.892	1.544	0.936	1.888	0.829	91.340	0.037
N-Atl	2.531	0.884	4.894	0.100	2.347	0.902	1.645	0.939	3.425	0.554	1.487	0.932	2.670	0.891	1.540	0.936	1.883	0.830	91.490	0.034
S-Atl	2.550	0.882	4.884	0.104	2.349	0.902	1.655	0.938	3.429	0.552	1.492	0.932	2.685	0.889	1.544	0.936	1.885	0.830	91.140	0.041
G. tropi	2.473	0.889	5.137	0.008	2.317	0.904	1.654	0.938	3.430	0.552	1.488	0.932	2.663	0.891	1.543	0.936	1.867	0.833	91.490	0.033
DMI	2.538	0.883	5.160	0.000	2.319	0.904	1.627	0.940	3.430	0.552	1.473	0.934	2.648	0.892	1.527	0.937	1.887	0.829	91.500	0.033
PDO	2.581	0.879	5.141	0.007	2.352	0.901	1.655	0.938	3.422	0.554	1.492	0.932	2.680	0.890	1.544	0.936	1.888	0.829	91.400	0.036
SOI	2.578	0.879	5.166	-0.003	2.297	0.906	1.648	0.939	3.419	0.555	1.490	0.932	2.645	0.893	1.537	0.936	1.893	0.828	90.940	0.045
SAM	2.581	0.879	5.165	-0.002	2.310	0.905	1.654	0.938	3.425	0.554	1.483	0.933	2.663	0.891	1.537	0.936	1.893	0.828	90.360	0.057

From Table 4, the strongest influence of climatic indices on rainfall and temperature patterns will yield a minimum standard deviation (SD) and maximum adjusted R^2 in Table 5. This study suggested that the SOI is significantly the largest influence on rainfall and temperature patterns in the MDB and is well fitted according to the R^2 values from the regression model.

6. CONCLUSION

Statistical techniques were applied to assess the influences of climatic indices on rainfall and temperature patterns in the MDB areas and eastern Australia. This research provided evidence of seasonality. A deterministic trend and seasonal change in climatic indices series was highlighted by the various use regression models. Strategies were superimposed to detect the trend of influence of climatic indices on the SST and SLP in the Pacific and Atlantic Ocean. This study provided evidence of an increasing trend of influence in the Atlantic Ocean. Moreover, these indices are not significant influential on Australian rainfall and temperature patterns. The analytical evidence has shown that Australian rainfall and temperature subject to SOI and PDO influences. Furthermore, the consistent influence of SOI with PDO and their interaction effects was highly significant on Australian rainfall and temperature.

7. ACKNOWLEDGEMENTS

This study was funded by the Australian Research Council through grant DP0877707. Additional scholarship funding from the School of Advanced Studies Venice Foundation is also gratefully acknowledged.

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