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Full Paper

Trends in maximum temperatures in Australia from 1990 to 2012

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Abstract: This study uses statistical methods to analyse climatic variations of air surface temperatures in Australia between 1990 and 2012. Maximum monthly temperature data were obtained from the Australian Bureau of Meteorology. Monthly maximum temperatures, collected from 81 stations in Australia over a period of 23 years, were analysed to determine the variation trends. The data from each station were adjusted for seasonal effects, and then further autocorrelations were removed by using a second-order autoregressive process. In the next step, factor analysis was employed to account for spatial correlations and group all stations into five regions, namely south-east, central-north, central-east, central-west and central regions. A simple linear regression model was then fitted to the data within each region. The average maximum temperatures trended higher in the south-east and central-west regions, with temperatures increasing between 0.071 - 0.559 ˚C per decade. In contrast, those in the central-north region decreased from 0.004 to 0.314 ˚C per decade while the central and central-east regions showed insignificant increase in temperature.

Keywords: Australia, maximum temperatures, spatial correlation, autocorrelation, factor analysis, linear regression model

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INTRODUCTION

Over the last few decades, many studies have researched air surface temperature changes using a variety of approaches such as variation models and cause-and-effect studies. The variation models involved many methods including computer simulation and statistical techniques. For example, Lean and Rind [1] used multiple linear regression analysis to decompose monthly mean surface temperature anomalies since 1980 into four components (global scale). Anisimov et al. [2] investigated temperature changes in Russia during 1900-1949 using coefficients of correlation, linear regression and time series.

Several methodologies have been used to analyse variations in temperatures, including statistical methods for analysing spatial and temporal variations in temperature. Jones et al. [3] investigated the surface air temperatures in both the southern and northern hemispheres over the past 150 years by using linear trends; the two 20-year periods of greatest warming over this period were 1925-1944 and 1978-1997 when global surface temperatures increased 0.37 and 0.32 ˚C respectively. In addition, McNeil and Chooprateep [4] studied the sea surface temperatures of North Atlantic Ocean between 1973 - 2008 by using a spline linear regression model with one knot. The temperature was found to increase by approximately 0.13 ˚C per decade during 1973-1989 and in two of three larger regions it was found to increase by 0.40 ˚C per decade during 1990-2008.

In several studies temperatures were analysed using time series models. For instance, Hughes et al. [5] analysed the variations in the minimum/maximum temperatures of the Antarctic region using a multiple regression model with non-Gaussian correlated errors and linear autoregressive moving average models. Chooprateep and McNeil [6] analysed average monthly temperatures in South-east Asia using linear regression, second-order autoregressive (AR2) and factor analysis models. They found that average temperatures increased by 0.082 - 0.222 ˚C per decade during 1973-2008. For daily data with high variations in the long period during 1970-2012 in Australia, the average daily maximum temperatures were fitted by a sixth-order polynomial regression model [7].

Many researchers have examined climate change both on global scale and specific areas for several decades and reported changes in the average temperature, minimum temperature and maximum temperature. In previous research [8] the solar radiation and cloud cover in Australia were studied, which we expected might be correlated with maximum temperatures. Thus, we were interested in maximum temperatures in this region. In this study we have investigated the trends and patterns of maximum temperature changes over Australia using monthly maximum temperature observations between 1990 - 2012. These were analysed graphically and with different statistical models.

METHODS

Monthly maximum air surface temperatures during 1990-2012 were collected from 81 reporting stations with less than ten per cent missing data. These stations cover all parts of Australia (Figure 1). The data were obtained from the Australian Bureau of Meteorology [9].

In this study the missing data were interpolated using multiple linear regression method to estimate two coefficients of which the month and year are predictable variables. The 276 monthly temperatures from each station were seasonally adjusted. Seasonal variations were removed by subtracting the average of monthly maximum temperatures from the temperature database for each station over the observed period (23 years) and then adding back the overall mean temperatures.

Using a simple linear regression to fit these seasonally-adjusted temperatures, the model takes the form $y_{it} = b_{0i} + b_{1i}d_t$, where y_{it} denotes the seasonally-adjusted temperature in station i for month t, d_t denotes the time elapsed in decades since 1990, b_{0i} is the average temperature at station i over the observed period, and b_{1i} is the estimated rate of increase in temperature per decade. The data were centred in the middle of time, i.e. $d_t = (t–n/2)/120$ for a period of n months. The model assumes that errors are independent and normally distributed. For the assumption of independent errors, a second-order autoregressive model was fitted to the residuals from the fitted model [10]. Then the average monthly temperatures at each station were filtered to remove autocorrelations by $Z_{it} = y_{it} -$

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$a_1 y_{i,t-1} - a_2 y_{i,t-2}$, where coefficients a_1 and a_2 are the average values of the two estimated parameters in the fitted 2-term autoregressive models and Z_{it} are the filtered temperatures.

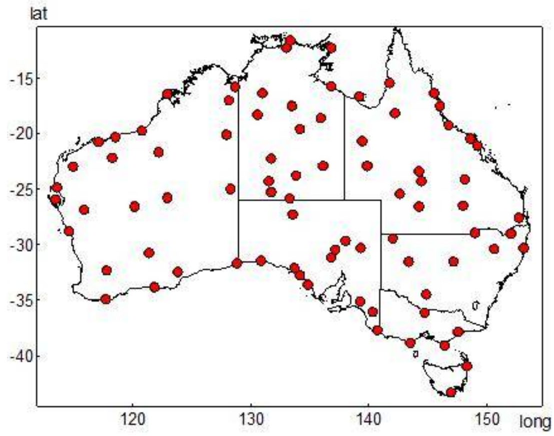

Figure 1. Location of 81 stations in the study

Finally, factor analysis [11] was applied to identify spatial correlations. The factor model formulation with m common factors, involving a weighted sum of factors to the data, is of the form $y_{ij} = \mu_j + \sum_{k=1}^{m} \lambda_j^{(k)} \emptyset_i^{(k)}$, where y_{ij} are variables in factor j and time i, μ_j are constants, $\lambda_j^{(k)}$ are termed loading factors and $\emptyset_i^{(k)}$ are common factors. This method classified the 81 stations into five geographical groups. We used the covariance matrix of estimated slopes in the simple regression model to fit the factor model. Data analysis and graphical displays were carried out using R program [12].

RESULTS AND DISCUSSION

The maximum monthly temperatures from 1990-2012 at five selected stations (Victoria River Downs, Balgo Hills, Watarrka, Dover and Kowarryarma Airport) were plotted and shown in Figure 2. This graph shows the seasonal effect of each month during the study period. For each station, seasonal variations were subsequently removed from maximum temperatures; then a simple linear regression was fitted to the seasonally-adjusted maximum temperatures. The maximum monthly temperatures adjusted for seasonal effects from five selected stations are shown in Figure 3.

In Figure 3 two regression coefficients (constant b_0 and slope b_1) capture the rate of increase in temperatures per decade. For example, Dover is modelled using $y = 16.42 + 0.196d_t$, where y is the average seasonally adjusted maximum temperature and d_t is the time (decade). The increase in temperature per decade can be described and compared among stations. For example, of five selected stations: Dover, Watarrka, Victoria River Downs, Balgo Hills and Kowanyama Airport, the average seasonally adjusted maximum temperatures increased significantly in Dover, decreased significantly in Watarrka, and were unchanged in Victoria River Downs, Balgo Hills and Kowanyama Airport. For each station, the correlation between temperatures at different times was described by an autocorrelation function (ACF).

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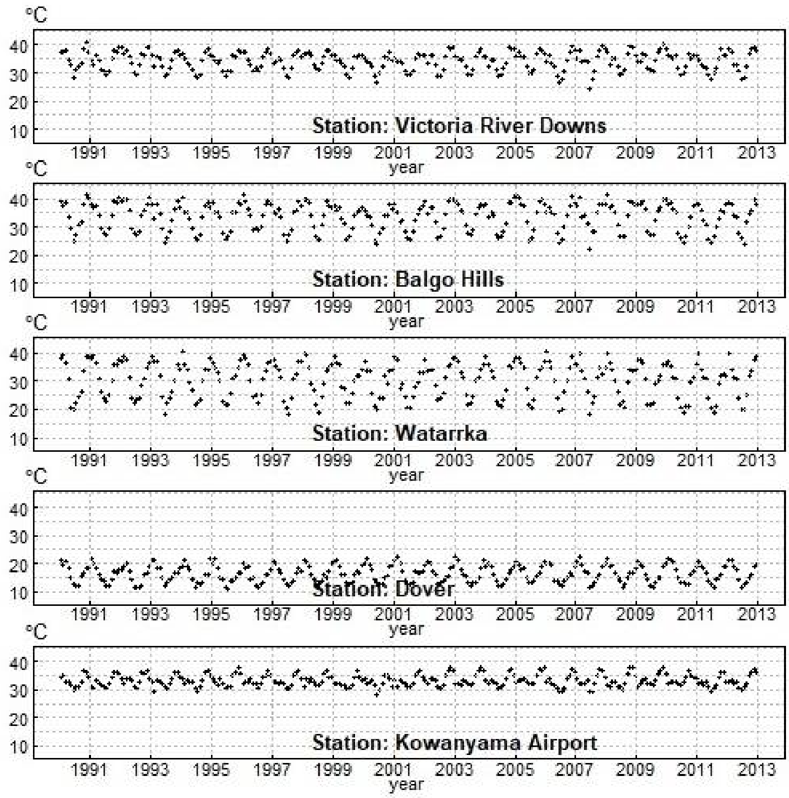

Figure 2. Maximum monthly temperatures at five stations during 1990-2012

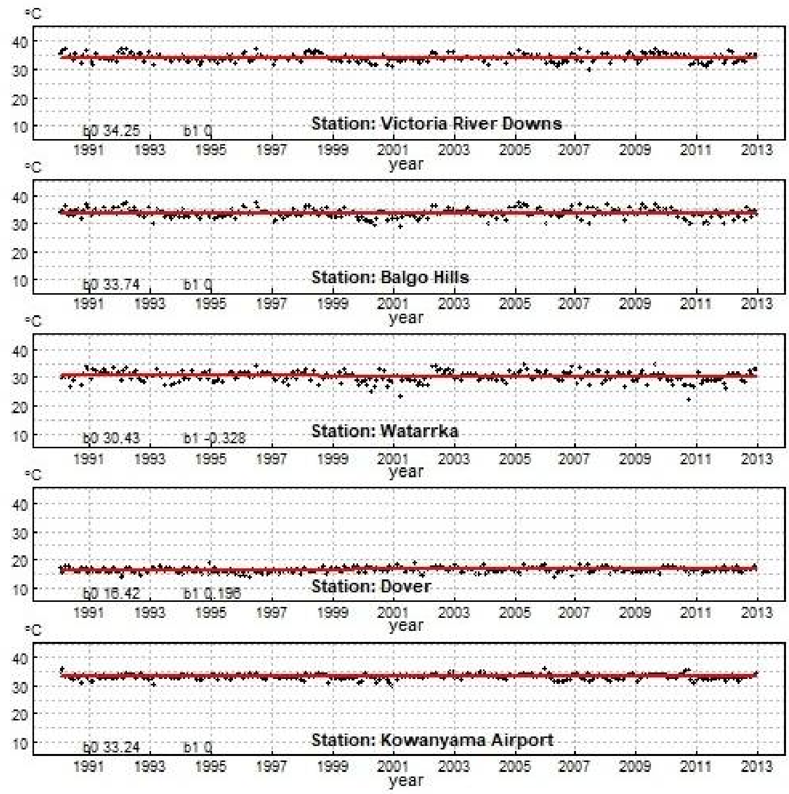

Figure 3. Average seasonally adjusted monthly temperatures from five selected stations during 1990-2012

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The ACF plots in Figure 4 show that the autocorrelations of residuals are significant and positive up to lag 5 and 7 at the Victoria River Downs and Balgo Hills station respectively. To account for these significant autocorrelations, an AR(2) model was fitted to the residuals from the simple linear regression model. Most of the autocorrelations were removed by the autocorrelation structure as shown in Figure 5, as evidenced by the filtered residuals being not different from zero. For each station, the average values of the two parameters (in the fitted 2-term autoregressive models) are a_1 = 0.280 and a_2 = 0.111.

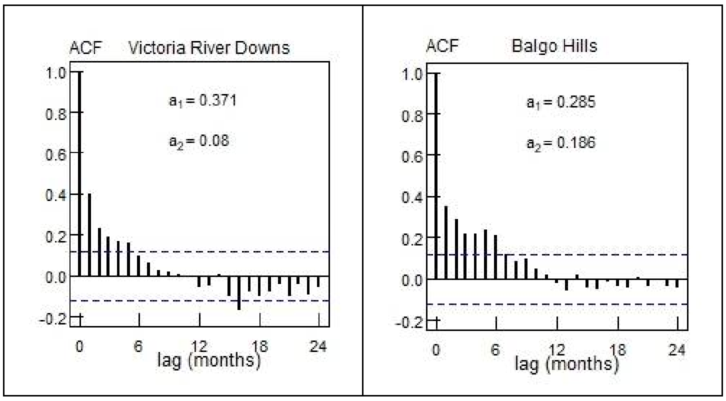

Figure 4. ACF plots for two selected stations

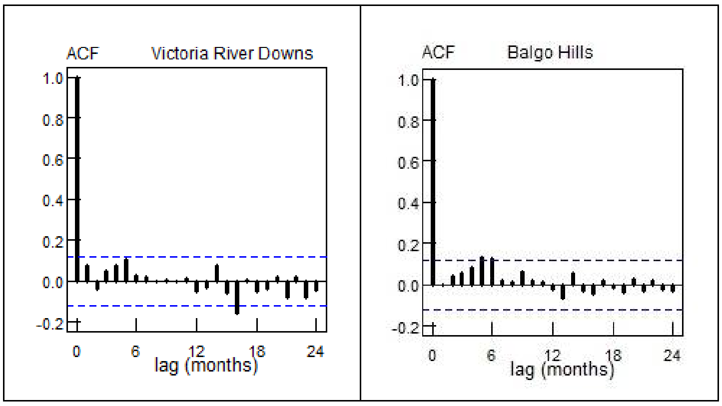

Figure 5. ACFs for filtered residuals of two selected stations

The correlations between the filtered monthly temperatures were then classified using factor analysis with promax rotation. For each factor, factor loadings greater than 0.333 were identified, as explained in Tabachnick and Fiddell [13]. The stations were classified into five factors, with their factor loadings as shown in Table 1.

Table 1 shows that there are three stations with factor loadings less than 0.333 and uniqueness greater than 0.75: Denham (a6044), Geraldton Airport Comparison (a8051) and Carnarvon Airport (a6011). High uniqueness values with small loadings indicate that the three stations are not correlated with other stations; thus, we eliminate those three stations (a6044, a8051, a6011). Seventy-eight stations are classified into five groups geographically: south-east (SE: Factor 1), central-north (CN: Factor 2), central-east (CE: Factor 3), central-west (CW: Factor 4) and central (C: Factor 5), as shown in Figure 6.

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Table 1. Results of factor analysis with factor loadings

Station ID	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Uniqueness	Group
a26021	1.077	0.193	-0.181	-0.149		0.138	
a25507	1.06	0.17	-0.163	-0.119		0.094	
a24521	1.011	0.116				0.09	
a90015	0.969	0.147		-0.191	-0.125	0.317	
a18079	0.92		-0.145			0.18	
a18069	0.887					0.287	
a80015	0.886					0.225	
a18012	0.862				0.127	0.196	
a85096	0.857				-0.115	0.359	
a85279	0.834		0.137		-0.13	0.372	
a94020	0.823	0.158			-0.211	0.47	SE
a75031	0.772		0.132		0.176	0.199	
a92045	0.72				-0.244	0.551	
a16001	0.71				0.4	0.1	
a18106	0.661			0.141	0.125	0.356	
a16065	0.618	-0.13	0.117		0.449	0.123	
a11003	0.55			0.262		0.425	
a46043	0.524	-0.116	0.338		0.34	0.191	
a17031	0.516	-0.162	0.183		0.503	0.109	
a17099	0.488		0.263		0.464	0.142	
a14825	0.137	0.932	-0.126			0.169	
a14840		0.919	-0.124		0.14	0.145	
a15131	0.101	0.876				0.232	
a2056		0.867	-0.201	0.158	0.121	0.267	
a2032		0.848	-0.173	0.202	0.174	0.224	
a15085		0.82				0.201	
a15135		0.804			0.28	0.131	
a14703		0.801			-0.101	0.348	
a14042	0.137	0.726				0.537	
a14508		0.722				0.529	CN
a29012		0.694	0.311	-0.135	-0.142	0.323	
a29127		0.638	0.397			0.218	
a29038	0.207	0.633	0.252	-0.129	-0.281	0.502	
a13007		0.62	-0.155	0.308	0.462	0.188	
a3057		0.604	-0.128	0.479		0.459	
a29039	0.128	0.557	0.198		-0.157	0.627	
a14401		0.554			-0.133	0.745	
a31037	-0.267	0.503	0.117	-0.118		0.554	
a32025	-0.225	0.464	0.179			0.615	
a43020			0.951			0.133	
a36026		0.185	0.88			0.116	
a36031		0.243	0.863		-0.11	0.137	CE
a35065	-0.17	0.108	0.859			0.239	
a40004	-0.256	-0.109	0.859	0.123		0.379	

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Table 1 (Continued).

Station ID	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Uniqueness	Group
a52020	0.109	-0.156	0.846			0.26	CE
a45015	0.105		0.833		0.184	0.102	
a56032		-0.146	0.809			0.411	
a38024		0.119	0.774		0.147	0.144	
a54003	0.233	-0.165	0.745	0.116		0.304	
a59040	-0.106		0.679	0.118		0.594	
a33247	-0.335	0.3	0.564			0.428	
a51039	0.3	-0.242	0.562		0.227	0.304	
a38003		0.345	0.532		0.203	0.257	
a32040	-0.177	0.41	0.511		-0.153	0.474	
a33119	-0.329	0.273	0.495	-0.113		0.502	
a46037	0.356	-0.129	0.441		0.439	0.161	
a6072	-0.123	-0.113	0.114	0.919		0.25	CW
a5026	-0.231	0.177		0.879	0.225	0.177	
a6099				0.86	-0.13	0.368	
a4035	-0.133	0.216		0.857		0.257	
a4032		0.194		0.784		0.332	
a13012				0.781	0.253	0.236	
a12038	0.151			0.741		0.293	
a4019		0.215		0.708	0.108	0.382	
a10536		-0.127		0.706	-0.265	0.486	
a13030	-0.23	0.216	-0.165	0.696	0.493	0.167	
a13015	-0.121		-0.101	0.669	0.476	0.236	
a11017	0.227			0.644		0.414	
a9789	0.288			0.557	-0.176	0.505	
a9741	0.22	-0.123		0.425	-0.22	0.695	
a15511					0.883	0.082	C
a15603	0.168				0.822	0.102	
a15652		0.164			0.788	0.197	
a13017				0.326	0.77	0.124	
a15590		0.259			0.755	0.115	
a16085	0.168		0.101		0.691	0.27	
a15528		0.42			0.617	0.259	
a15602	0.137	0.361	0.249		0.463	0.261	
a6044		-0.239	0.107	0.24	-0.308	0.817	Cut off
a8051		-0.223		0.328	-0.312	0.777	
a6011	0.101	-0.269	0.158	0.304	-0.312	0.767	

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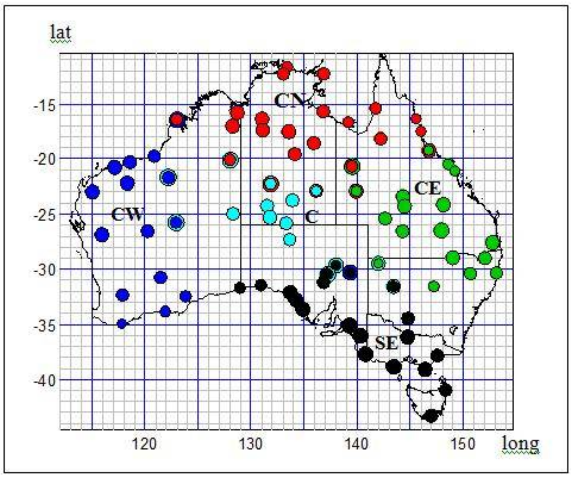

Figure 6. Five groups of stations classified by factor analysis

For each factor, a simple linear regression model was used to fit the average temperatures of the stations in that factor. The estimated regions, constants (y-intercept) and slopes with 95% confidence level are shown in Table 2. The 95% confidence interval for each region is used to determine whether the trend of maximum temperature increase or decrease is statistically significant. If the 95% confidence interval of maximum temperature does not include 0, the trend neither increases nor decreases.

Table 2. Estimated regions, constants and increases in temperature per decade

Region	Constant	Increase in temperature per decade (˚C) (95% confidence interval)
South-east	22.20	0.358 ± 0.201
Central-north	32.75	-0.159 ± 0.155
Central-east	27.99	0.036 ± 0.190
Central-west	29.03	0.276 ± 0.206
Central	29.88	-0.078 ± 0.271

Table 2 also shows that the maximum temperature per decade increased significantly by approximately 0.36 and 0.28 ˚C in the south-east and central-west regions respectively but decreased significantly by approximately 0.16 ˚C in the central-north while it was unchanged in the central and central-east. The 95% confidence intervals of temperature change per decade in the south-east, central-north and central-west were 0.157 to 0.559 ˚C, -0.314 to -0.004 ˚C and 0.070 to 0.482 ˚C respectively.

Figure 7 shows trends of temperature in the five regions; the CN region is tropical and has the highest maximum temperatures of more than 30 ˚C, while the C, CW and CE regions have medium maximum temperatures of not more than 30 ˚C. In contrast, the SE region has the lowest maximum temperatures (lower than 25 ˚C).

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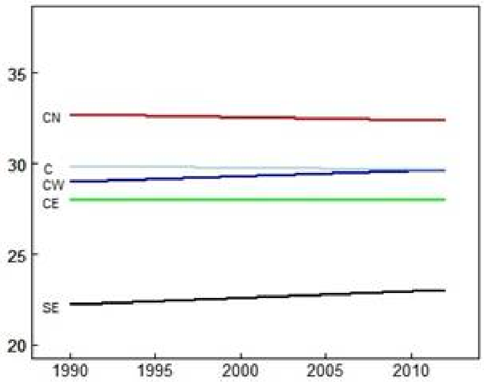

Figure 7. Average maximum temperature trends in each region

Several factors likely contribute to the temperature increase in the south-east and central-west regions. The rising temperature trends in Australia are associated with increases in the intensity of heating events. Heat from the surrounding oceans influences Australia's climate. The warmer ocean surface temperatures in the western Pacific Ocean caused by La Niña events bring less extreme maximum temperatures but more prolonged heat waves to Australia [14]. In the summers of 1982-83 and 2002-03, El Niño events showed a statistically significant increase in temperature and decrease in rainfall in eastern Australia [14]. Heat waves have increased in frequency and duration in Australia since 1974 [14]. In southern and eastern Australia, the longer fire season from December to February increased temperatures and created droughts [14]. Especially in south-eastern Australia, droughts have been occurring since 1973 with critical increased temperatures during 2002-03 [15]. Most regions in Australia have four seasons in a year: summer, autumn, winter and spring. Only the central-north of Australia, which is in the tropical zone, has just two seasons: the wet season and the dry season. Thus, the weather in the central-north is different from other regions: the maximum temperatures during 1990-2012 have decreased but there is no evidence of decreasing maximum temperatures in other regions.

Furthermore, maximum temperatures have been linked to solar radiation and cloud cover in Australia [8]. This study has found that the maximum temperatures during 1990-2012 were inversely proportional to the percentages of estimated cloud cover which were studied in the same period [8]. Maximum temperatures in the south-east region tended to be lowest at the highest cloud cover period. Similarly, maximum temperatures in the central-north region were highest when cloud cover in this region was lowest [8].

CONCLUSIONS

This study has employed second-order autoregressive model to remove the seasonal component of the maximum temperatures in Australia from 1990 to 2012. Factor analysis was used to classify spatial correlations of the seventy-eight stations into five regions, and simple linear regression model was used to estimate the rate of temperature increase per decade for each region.

The average maximum temperature in the south-east region was found to increase by 0.157-0.559 °C per decade while in the central-west region it increased by 0.071-0.482 °C per decade. In contrast, the average maximum temperature in the central-north region decreased by 0.004-0.314 °C per decade and there was no evidence of average maximum temperature increase in the central and central-east regions.

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