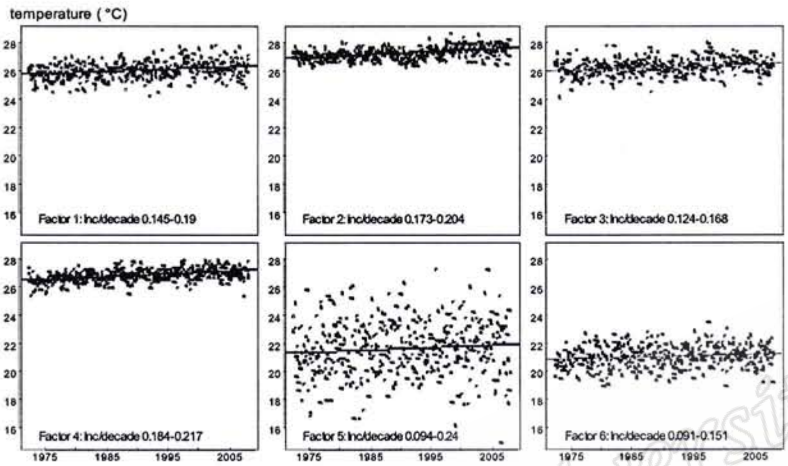

Figure 8. Temperature changes in regions defined by factors.

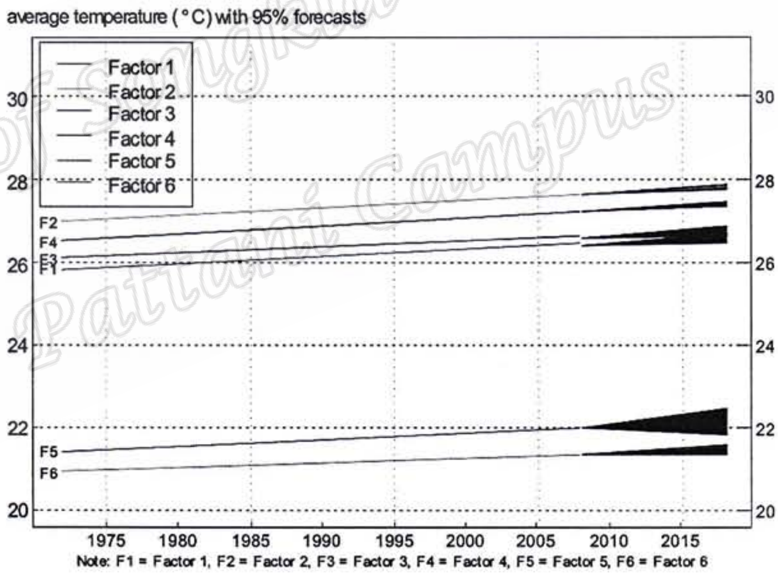

Figure 9. Temperature changes, with 95% confidence intervals, for the predicted temperature change in the next decade.

DISCUSSION

The average monthly temperatures in Southeast Asia from 1973 to 2008 were analyzed using various methods: a simple linear model, a multivariate linear regression model and factor analysis. A Linear model was fitted to the seasonally-adjusted temperatures using data collected from forty 10° by 10° grid-boxes, covering latitudes 25°S to 25°N and longitudes 75°E to 160°E. The temperatures were filtered by removing the auto-correlation using an AR(2) process. Because of correlations between residuals in adjoining grid-boxes (spatial correlation), factor analysis was used to classify filtered monthly temperatures in grid-boxes into six regions. Multivariate linear regression model was used to fit parameters for each factor. In the extended area covering latitudes 35°S to 25°N and longitudes 65°E to 160°E factor analysis could be classified by six similar regions, except some grid-boxes. A fit of trend of each region by simple linear model, showed that temperatures have increased gradually on average during 1973-2008. Simple linear regression models were also used to predict temperature in each region in the next decade (2009-18). Region 5 had the highest range of predicted temperatures with 0.7°C.

Future studies could investigate temperature changes over longer periods using linear spline models. Moreover, the study could be extended from Southeast Asia to other areas of the world.

ACKNOWLEDGEMENTS

We are grateful to Emeritus Prof. Don McNeil for supervising our research.

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Appendix II

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Spatial and Temporal Patterns of Temperature Change in Southeast Asia and Australia

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Abstract

In this study, we focus on surface temperature variation involving correlation in both time and space in Southeast Asia and Australia from 1973 to 2008. The area comprised 54 regions of 10° by 10° grid-boxes in latitudes 35°S to 25°N and longitudes 65°E to 160°E. The data were filtered with a second order autoregressive process to remove autocorrelations between temperature lags. Factor analysis was then used to account for spatial correlation between grid-boxes yielding six contiguous geographic regions. A fit of trend of each region by simple linear model showed that temperature averages in these six regions have increased gradually, ranging from 0.091 to 0.240°C per decade.

Keywords: Southeast Asia, climate change, time series analysis, spatial correlation, autocorrelations, factor analysis

1. Introduction

The climate over a period involves the averages of appropriate components of the weather over that period, together with the statistical variations of those system components (Houghton et al.1990).Hughes et al. (2006) studied the variations in the minimum/maximum temperatures of the Antarctic region using a multiple regression model with non-Gaussian correlated errors and linear auto-regressive moving average (ARMA) models with innovations. Griffiths et al. (2005) investigated extreme temperature changes in the Asia-Pacific region over the period 1961-2003, covering latitudes 46°N - 47°S and longitudes 80°E - 120°W. This study focused on the relationship between mean and extreme temperature in the Asia-Pacific region. Trends and relationships were calculated using linear regression and Pearson correlation analysis.

Climate change in Southeast Asia is expected to lead to significant variations in precipitation patterns. Climate change also has occurred at a regional level; for example, a broad range of climatological and geographic features exist within the Asia/Pacific region. All of India and Pakistan as well as much of western China is arid or semi-arid, and this sub region has warmed by approximately 0.1- 0.2°C per decade over the past 100 years (Preston et al. 2006). Southeast Asia is characterized by tropical rainforest and monsoon climates with high and constant rainfall (Cruz et al. 2007), and the upward trend of winter mean temperatures over 1954-2001 in the eastern region of Southeast Asia is 0.34°C per decade (Gong & Ho 2004).

Subsurface temperatures in four cities have been evaluated (Taniguchi et al. 2007).using nonlinearity to estimate the effects of surface warming due to urbanization and global warming, as well as the developmental stage of each city. Average surface temperature profiles in four Asian cities were compared. The magnitude of surface warming has been largest in Tokyo (2.8°C), followed by Seoul (2.5°C), Osaka (2.2°C), and Bangkok (1.8°C).

In Australia, trends in annual frequencies of extreme temperature events were examined, the result shows that the frequency of warm events has generally increased over at least the 1957 to 1996 period, whist the number of cool extremes has decreased (Collins et al.2000).

Temperature change in any large area is complex and varies considerably in both time and spatial correlation.Various statistical analyses have been used to model patterns of temperature change. For instance, Anisimov et al. (2007) investigated changes in air temperature in Russia. The spatial homogeneity of air temperature anomalies within each region were assessed through coefficients of correlation between the regionally averaged temperature time series and series at each station of this region, over the periods 1900-49 and 1950-2004. Portmanna RW et al.(2009) found that spatial variations in US temperature trends are linked to the hydrologic cycle. This study presents unique information on the seasonal and latitudinal structure of the linkage.Furthermore,

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sea surface temperatures of the North Atlantic Ocean during 1973-89 and 1990-2008 were described using auto-regression models, multivariate linear regression, factor analysis and spline linear models in conjunction with spatial correlation methods (McNeil & Chooprateep 2013). The temperatures in three regions which were identified by factor analysis were found to increase by approximately 0.13°C per decade in the first period and slightly over 0.40°C per decade in the second period.

The aim of this study is to investigate the trends and patterns in temperatures of a large specific region of Southeast Asia and Australia from 1973 to 2008. The selected region includes both land and sea, and temperature profiles of adjacent locations are correlated. Time series analyses use a simple linear model.

2. Methodology

The data were monthly temperatures in Southeast Asia and Australia for 5° by 5° latitude-longitude grid-boxes on the earth's surface were obtained from the Climate Research Unit (CRU, 2009), and described in detail by Brohan et al.(2006).The data from 1973 to 2008 were design of 10° by 10° grid-boxes using the average temperature.The data in the study area are located in latitude 35°S to 25°N and longitude 65°E to 160°E, and composed of Southeast Asian countries and Australia as shown in Figure 1.

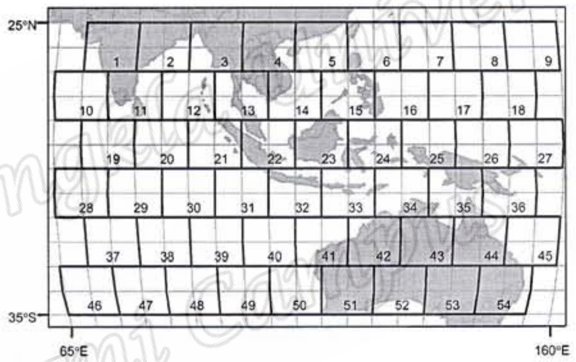

Figure 1. The study area

The data consist of 432 monthly temperatures and 54 grid-boxes. For each grid-box, temperatures were seasonally adjusted, seasonal variation was removed by subtracting the monthly average and then adding back the overall mean temperature. Simple linear model was used to fit these seasonally-adjusted temperatures (Figure 2), the model in this period takes the form

$$y_{it} = b_{0i} + b_{1i} d_t. \quad , \tag{1}$$

where y_{it} denotes the seasonally-adjusted temperature in grid-box i for month t and d_t denotes the time elapsed in decades since 1973, centred at the middle of the period, that is, $d_t = (t - n/2)/120$ for a period of n months,$b_{0i}$is the average temperature in grid-box i over the period, and b_{1i} is the estimated rate of increase in temperature per decade.

Time series data were considered, autoregressive (AR) models were used to account for the autocorrelations among the residuals from the fitted models. The average monthly temperature (y_{it}) in each grid-box was removed autocorrelations (AR) at lags 1 and 2 months and coefficients a_1 and a_2 are the estimated parameters of the model. The residuals (Z_{it}) from a second order AR model take the form (Chatfield 1996)

$$Z_{it} = y_{it} - a_1 y_{i,t-1} - a_2 y_{i,t-2} \quad , \tag{2}$$

Since there are six different sides of correlations in each box thus taking account of correlations. Factor analysis (Mardia et al. 1980) was applied to identify correlations between the filtered monthly temperatures in the 54 grid-boxes of each period. The factor model formulation with p factors, takes the form

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$$f_{ij} = \mu_j + \sum_{k=1}^{p} \lambda_j^{(k)} \emptyset^{(k)} \quad , \qquad (3)$$

where $f_{ij}$are adjusted temperatures in month i and grid-box j, μ_j is the mean temperature of variables in grid-box j, $\lambda_j^{(k)}$are the factor loadings at grid-box j on the k^{th} factor and $\emptyset^{(k)}$ are the common factors. All data analysis and graphical displays were carried out using R (R Developement Core Team, 2009).

3. Results

Separate linear models were fitted to the seasonally adjusted temperatures for each of the 54 grid-boxes of the study region. Figure 2 shows the temperature trends with fitted lines in each grid-box have increased over the 36-year-period.

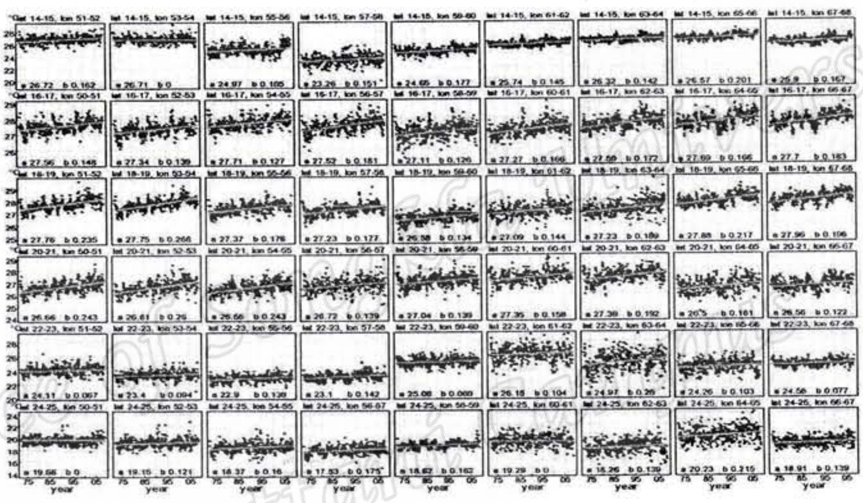

Figure 2. Temperature trends with fitted lines in 54 grid-boxes

The ACF plots in figure 4 show that all autocorrelations. To account for these significant autocorrelations, an autoregressive process of order two was fitted to the residuals from the linear regression model. The correlations in residuals from this fitted model are assumed to be stationary. Autocorrelations were accounted; an autoregressive process of order two was fitted to the residuals from the linear regression model. Figure 3 shows Autocorrelation function plot of the first grid-box is in left. The autocorrelations were removed from the filtering as shown in the right.

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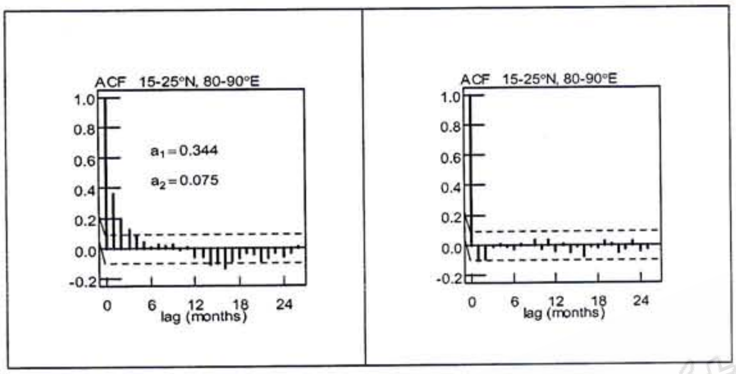

Figure 3. Autocorrelation function plots

After filtering, the factor analysis was applied to cluster 54 grid-box regions into six groups with different climate change patterns. In this case the variables are the filtered monthly temperatures within grid-boxes and the occasions are months. The correlation matrix is shown as a bubble plot, ordered by 6 factors in Figure 4. Of the 54 grid-boxes, 46 could be classified by factor analysis and combined into 6 factors (regions), which are displayed in Figure 5.

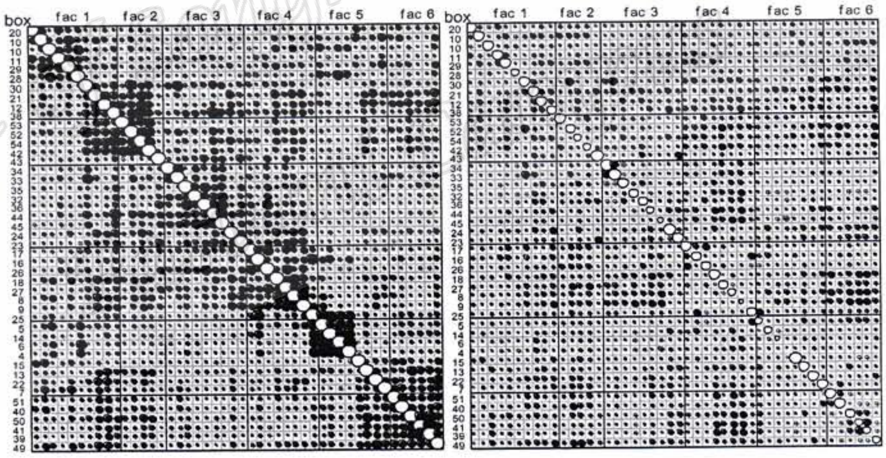

Figure 4. Bubble plots of correlations between filtered monthly temperatures in grid-boxes before (left) and after (right) fitting the factor model.

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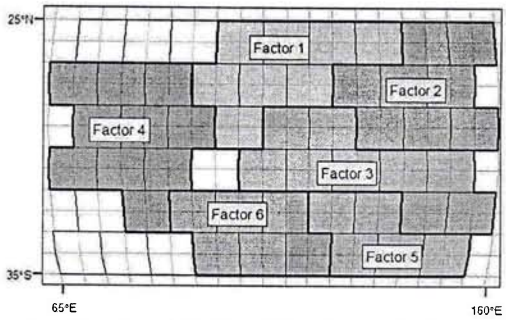

Figure 5. Adjacent grid-boxes were combined into six regions

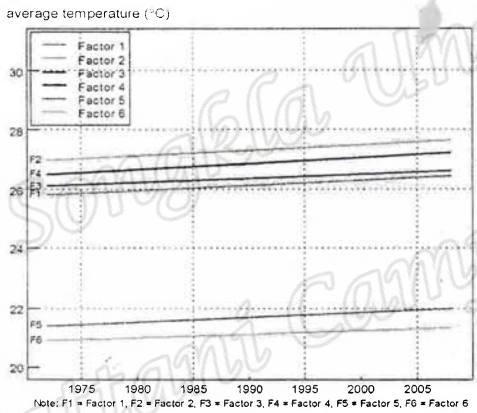

Figure 6. Six patterns of temperature change

Figure 6 shows that the temperatures increased for each factor, with increases ranging from 0.091 to 0.240°C per decade. Temperature increases are based on the linear regression model. The highest increase was in Factor 1 (Southern China, Vietnam, Cambodia, Thai, Laos, Malaysia, Singapore, Philippines) with 95% confidence interval 0.168±0.023°C per decade and the lowest increase was in Factor 6 (the West part of Australia) with 95% confidence interval 0.121±0.030°C per decade.

4. Discussion and Conclusions

This research analyses average monthly temperatures of a thirty-six-year period of the South-East Asia and Australia region, covering latitudes 35° S to 25°N and longitudes 75°E to 160°E. Various statistical methods were used including simple linear model, multivariate linear regression model and factor analysis. The linear model was fitted to the seasonally adjusted temperatures using data collected from fifty four of 10° by 10° grid-boxes. The temperatures were filtered by removing the autocorrelation using an AR(2) process. Because of spatial correlation in this study, factor analysis was used to classify filtered monthly temperatures in grid-boxes into six regions. Finally, a fit of trend of each region by simple linear model, which showed that temperatures have average increased gradually during 1973-2008. Future studies could be extended from this area to other areas.

5. Acknowledgements

We are grateful to Emeritus Prof. Don McNeil for his helpful suggestions.

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Appendix III

Surface air temperature changes from 1909 - 2008 in Southeast Asia assessed by factor analysis

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Abstract Monthly seasonally-adjusted surface temperature patterns in South-East Asia from 1909 to 2008 were studied. The area comprised 40 regions of 10° by 10° grid-boxes in latitudes 25°S to 25°N and longitudes 75°E to 160°E. Temperatures were studied for three overlapping 36 year periods; the first period: 1909‒1944, the second period: 1941-1976, and the third period, 1973‒2008. The data of each 36 year period were fitted to reduce autocorrelations at lags 1 and 2 months. Factor analysis was used to account for spatial correlation between grid-boxes giving six contiguous layer regions. Simple linear regression models were fitted to data within these larger regions. Temperatures were found to have increased in five from six regions over the first period with the increases ranging from 0.005 to 0.148°C per decade, in only three regions over the second period with the increases ranging from 0.008 to 0.150°C per decade and in six regions over the third period with the increases ranging from 0.082 to 0.222°C per decade.

1 Introduction

Warming of the climate system is evident from observations of increases in earth's surface temperatures. During the 20th century temperatures have increased by about 0.6°C with the 1990s being the warmest decade (Houghton et al. 2001). In the two 20-year periods of greatest warming of the 20th

century, from 1925 to 1944 and from 1978 to1997, global surface temperatures rose by 0.37°C and 0.32°C, respectively (Jones et al. 1999). Since 1850, the global surface temperature was the warmest during the twelve year period from 1995–2006. The linear warming trend over the last 50 years (0.13°C per decade) is nearly twice that for the last 100 years (Solomon et al. 2007).

Analysis of global surface temperature changes is not straightforward due to the correlation between adjacent areas in both space and time. Methods to analyze the temperatures changes have varied, such as detrended fluctuation analysis, correlations and first order auto-regressive models (Kiraly et al. 2006), maximum likelihood factor analysis (Lee et al. 2009), multivariate linear regression, factor analysis and spline linear models in conjunction with spatial correlation methods (McNeil and Chooprateep 2014). Among these methods, factor analysis is probably the least used method in climate research. It is a method used to analyze the structure of the interrelationships among a large number of variables by defining a set of common underlying dimensions, known as factors (Hair et al. 2009). This current study, factor analysis was used to explore the spatial and temporal patterns of temperature change in the Southeast Asia region. Southeast Asia is characterized by tropical rainforests and monsoon climates with high and constant rainfall (Cruz et al. 2007). The upward trend of winter mean temperatures over 1954–2001 in the eastern region of Southeast Asia was 0.34°C per decade (Gong and Ho 2004). In Southeast Asia from 1973 to 2008, the temperatures have increased ranging from 0.09 to 0.24°C per decade (Chooprateep and McNeil 2014). A longer period of observation should give more insight into how the temperatures have changed in Southeast Asia.

In this study, temperature patterns in three separate time periods covering a total of 100 years are described. The purpose of the study is to investigate the trends of temperature changes of a large region of Southeast Asia by considering three partially overlapping 36-year periods; 1909–1944, 1941–1976 and 1973–2008. Factor analysis is used to account for spatial correlations.

2 Data and Method

Monthly earth surface temperature anomalies in South-East Asia for a 100-year period (1909–2008) for 5° by 5° latitude-longitude grid boxes on the earth's surface were obtained from the Climate Research Unit (CRU 2009), and described in detail by Brohan et al (2006). A temperature anomaly is the difference between the long-term average temperature and the temperature that actually occurs. In this analysis, we added back the monthly average temperatures from 1961–1990 in each grid box to the temperature anomalies. Four grid boxes contained no temperature data and were combined with others to form larger 10° by 10° grid boxes. The data in the study area are located in latitude 25°S to 25°N and longitude 75°E to 160°E, and composed of all or part of the 11 Southeast Asian countries plus Northern Australia, Western India, Bangladesh, Nepal, Bhutan, Southern China, the Indian Ocean and the western part of the Pacific Ocean, as shown in Fig. 1.

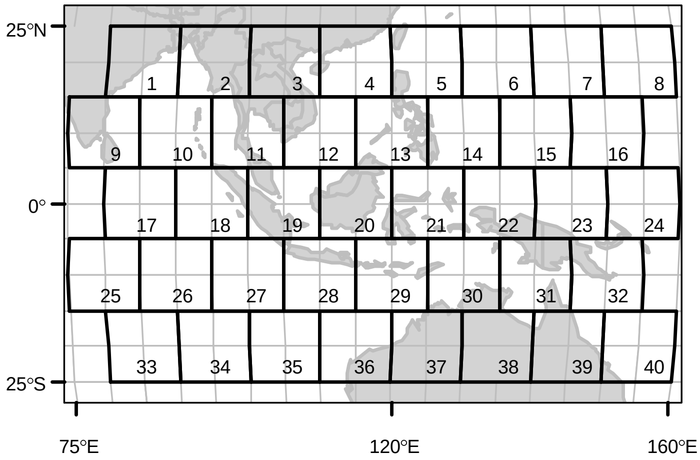


Fig. 1: The study region

For each 36-year period, the data consist of 432 monthly temperatures in 40 grid boxes. For each grid box the temperatures were seasonally adjusted, with seasonal variation being removed by subtracting the monthly average and then adding back the overall mean temperature. Simple linear regression models were then fit to the seasonally-adjusted temperatures for each period to estimate the 10-year changes in temperatures. The estimated signal for each model takes the form

$$y_{it} = b_{0i} + b_{1i} d_t \qquad (1)$$

where y_{it} denotes the seasonally-adjusted temperature in grid box i for month t and d_t denotes the time elapsed in decades since the beginning of each period (since1909 in the first period, since 1941 in the second period and since 1973 in the third period). The data were centred at the middle of each period, that is, $d_t = (t - n/2)/120$ for a period of n months, b_{0i} is the average temperature in grid box i over the period, and b_{1i} is the estimated rate of change in temperature per decade. The errors in the model are assumed to be independent and identically distributed normal random variables.

To assess the auto-correlations (AR) in the errors from the fitted models in each grid box, two-term auto-regressive models were fit to the residuals. Auto-correlation function plots were presented to describe the correlation between temperatures at different time lags. The residuals (Z_{it}) at lags 1 and 2 months take the form (Chatfield, 1996)

$$Z_{it} = y_{it} - a_1 y_{i,t-1} - a_2 y_{i,t-2} \qquad (2)$$

where $y_{it}, y_{i,t-1}, y_{i,t-2}$ denote seasonally-adjusted temperatures in grid box i at time t, $t - 1$ and $t - 2$, respectively. The Z_{it} are the filtered monthly temperatures. The parameters a_1 and a_2 are estimated by the model.

Finally, factor analysis was applied to identify correlations between the filtered monthly temperatures in the 40 grid boxes in each of the three time periods. The factor model formulation with p factors, takes the form

$$f_{ij} = \mu_j + \sum_{k=1}^{p} \lambda_j^{(k)} \emptyset^{(k)} \qquad (3)$$

where f_{ij} are the filtered temperatures in month i and grid box j, μ_j is the average temperature in grid box j, $\lambda_j^{(k)}$ are the factor loadings in grid box j on the k^{th} factor and $\emptyset^{(k)}$ are the common factors. Factor loadings are the correlation coefficients between the variables and factors.

All data analysis and graphical displays were carried out using the R language and environment (R Development Core Team 2009).

3 Results

Fig. 2 shows the trend of seasonally adjusted temperatures after fitting the linear regression models for each time period. The mean temperatures had a significant increase in the first and third 36-year periods, with correlations of 0.20 and 0.59, respectively, whilst a small increase over the second 36-year period was not significantly different from zero.

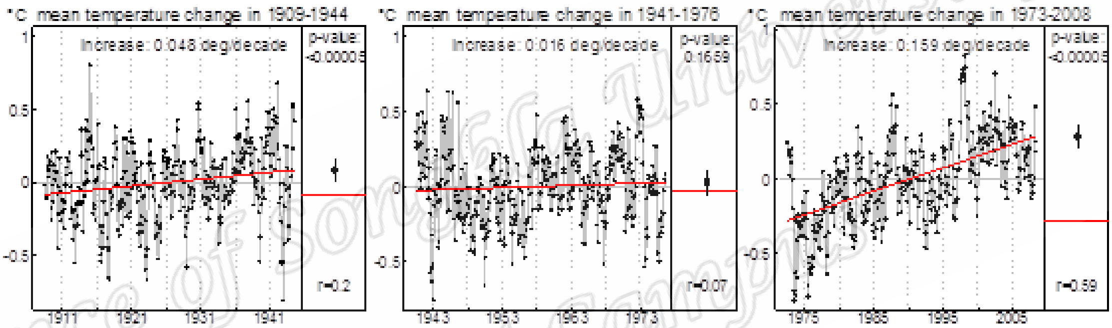


Fig. 2 Mean temperature changes using simple linear regression models for each period

Auto-correlation function plots describe the correlation between temperatures at different times, the correlations in residuals from the fitted models are assumed to be stationary. Auto-correlation function plots of grid box 15−25°N, 80−90°E (eastern part of India) in the first, second and third period are shown in Fig.3

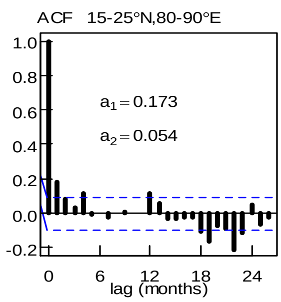
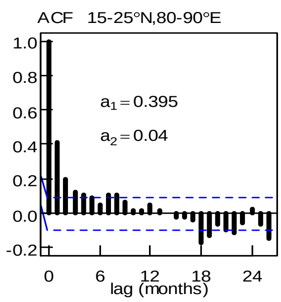
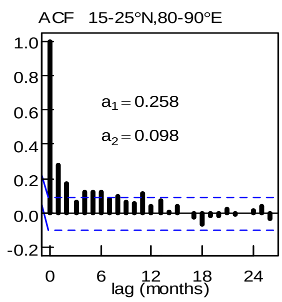
first period	second period	third period
		

Fig. 3 Auto-correlation function plots for grid box 15-25°N, 80-90°E in three periods. The dotted line represents the 95% confidence interval for zero correlation.

Fig.3 shows that there are significant auto-correlations for some time lags. An auto-regressive process of order two was fit to the temperature data to account for these significant auto-correlations. The average values of the two parameters (a_1 and a_2) in the two term auto-regressive models in the first period were 0.314 and 0.093; in the second period were 0.358 and 0.153 and in the third period were 0.494 and 0.107. Most of the auto-correlations were removed from the filtering in the first, second and third period as shown in Fig. 4.

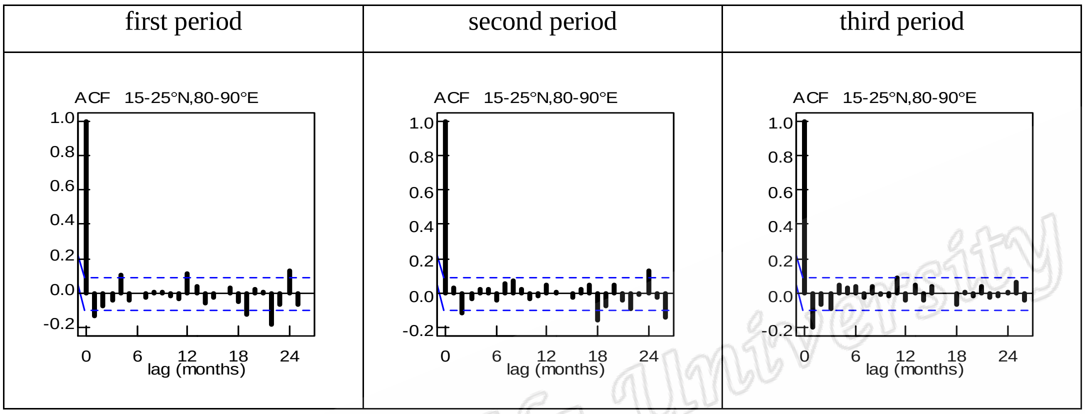


Fig. 4 Auto-correlation functions for the filtered residuals for grid box 15-25°N, 80-90°E in three periods. The dotted line represents the 95% confidence interval for a zero correlation.

After filtering, factor analysis was applied to the grid boxes for each time period resulting in six larger regions. Table 1 shows an example of factor loadings in the first period. High loadings (loadings > 0.30) have been highlighted with shading.

Table 1: Factor loadings in the first period

Grid Box	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Uniqueness
12	0.798		-0.130				0.434
11	0.715						0.559
19	0.631		0.137				0.540
4	0.616	-0.204			0.103		0.655
5	0.496			0.176		0.141	0.677
13	0.445	0.138	-0.155			0.190	0.728
10	0.414		0.197			-0.185	0.741
20	0.375	0.178				0.118	0.749
9	0.339		0.280				0.773
3	0.324	-0.109					0.897
31		0.786		0.227		-0.224	0.401
30	-0.158	0.717			0.110		0.406
29		0.565				0.211	0.582
21		0.370					0.839
28	0.216	0.304	0.145			0.191	0.670
26	-0.118		0.570				0.717
17			0.502			-0.398	0.672
27			0.463	-0.104			0.690
18	0.294		0.442			-0.408	0.596

Grid Box	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Uniqueness
34	-0.202		0.437	0.125	-0.103	0.124	0.778
25			0.428			-0.179	0.839
33	-0.172		0.395				0.850
35		-0.187	0.349			0.170	0.820
32	-0.117	**0.388**		0.634	-0.123		0.476
24		-0.170	0.167	0.595			0.631
40		0.220		0.568	0.111	-0.174	0.609
23		-0.190		0.434	0.104	0.139	0.747
38					0.932	0.176	0.132
39		0.222		0.172	0.680		0.355
37		0.157	0.168	-0.128	0.286	0.376	0.608
36	-0.143		0.202	-0.123	0.172	0.348	0.784
6	0.253					0.335	0.780
14	0.145				-0.131	0.322	0.832
15				0.238		0.226	0.867
7	0.104			0.191		0.153	0.906
16				0.298			0.901
22		0.113		0.197			0.932
8				0.125			0.972
2	0.230		0.149				0.891
1			0.142				0.954

Table 1 shows that in the period from 1909 to 1944, the six factors comprised 10, 5, 8, 4, 2 and 4 adjacent grid boxes, respectively. Grid box number 32 was a mixed factor since it loaded highly on Factors 2 and 4. In this period there were seven grid boxes having high uniqueness (≥ 0.867). In the second period, factor analysis also gave six factors of which 3 were mixed and 8 grid boxes had high uniqueness. In the third period, six factors were also observed, of which 5 grid boxes were mixed factors and 3 had high uniqueness.

Fig 5 shows the correlation matrix of the filtered temperatures between the grid boxes and the larger regions obtained from the factor analysis in the first, second, and third periods, respectively. High correlations (large dots) within each factor order by six factors (left) the factor model can reduce these correlations as show the correlation of residuals (right). Positive correlations are represented by *black dots*, whereas negative correlations by *red dots.* In each period, factor analysis divides the correlation of the filtered temperatures into six geographic regions. Similar temperature patterns were observed within each region, while different patterns were observed between regions. Thus, six different patterns of temperature changes were found in our study area.

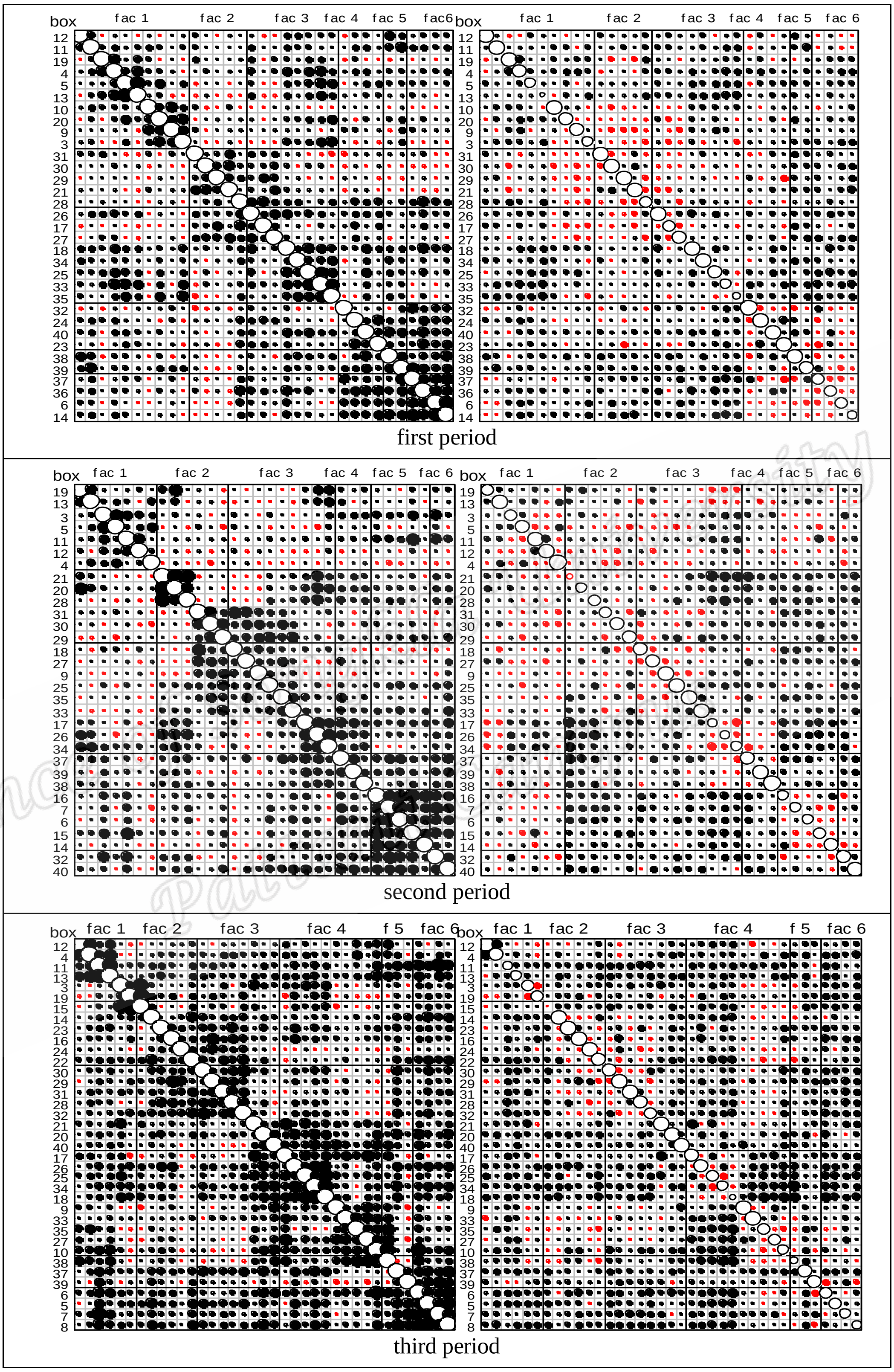


Fig. 5 Bubble plots of correlations between filtered monthly temperatures in grid boxes before (*left*) and after (*right*) fitting the factor model in three periods

From the factor analysis, 33, 32 and 37 of the 40 grid-boxes could be classified and combined into six regions in the first, second and third periods, respectively, as displayed in Fig.6. The factors identified from the factor analysis contained the mostly the same set of grid boxes across the three time periods. The first factor (Region 1) covered Southern China, Vietnam, Cambodia, Thailand, Laos, Malaysia, Singapore and Philippines. The second factor (Region 2) covered part of the Western Pacific Ocean only. The third factor (Region 3) covered Indonesia and Papua New Guinea. The fourth factor (Region 4) covered parts of the Indian Ocean only, the fifth factor (Region 5) covered Northern Australia, the sixth factor (Region 6) covered Pacific Ocean (North of Philippines).

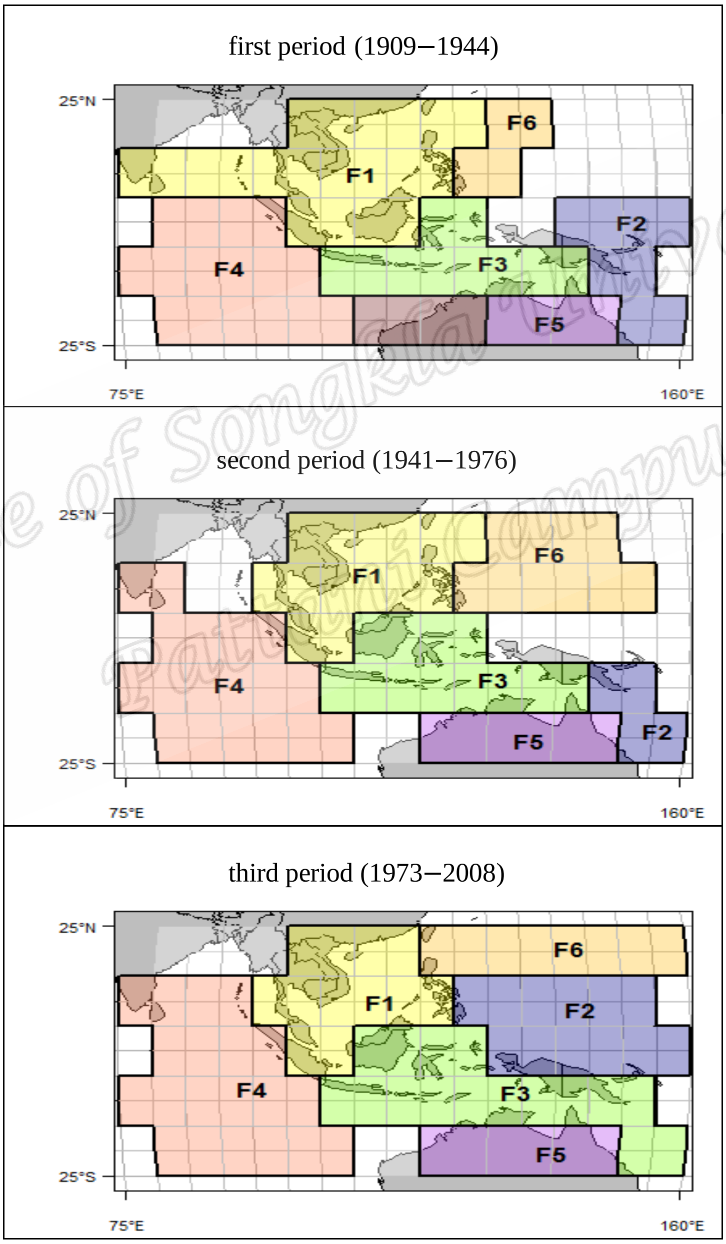


Fig. 6 The adjoining grid boxes after being combined into six regions in three periods

For each time period, factor analysis was used to identify spatial correlations between grid boxes. Most grid boxes were combined within the same factor, with the exception of some grid boxes in the Pacific Ocean located to the east of Indonesia. Due to the high variation of temperatures in this area, it is uncertain whether group inter-correlation exists among grid boxes to form factors, while some grid boxes moved to combine with other adjacent grid boxes.

The average temperatures in each of the six regions identified from the factor analysis were analysed using simple linear regression models. Estimated parameters with 95% confidence interval for each region in each of the three periods and comparisons of the change per decade are shown in Table 2.

Table 2 Temperature change per decade in three periods

Region	**first period (1909−1944)**	**second period (1941−1976)**	**third period (1973−2008)**
1 (F1)	0.082 $\pm$ 0.022	0.026 $\pm$ 0.029	0.174 $\pm$ 0.025
2 (F2)	0.115 $\pm$ 0.034	0.120 $\pm$ 0.031	0.187 $\pm$ 0.017
3 (F3)	0.036 $\pm$ 0.029	0.050 $\pm$ 0.027	0.151 $\pm$ 0.021
4 (F4)	0.028 $\pm$ 0.023	0.029 $\pm$ 0.021	0.178 $\pm$ 0.017
5 (F5)	0.070 $\pm$ 0.081	0.008 $\pm$ 0.073	0.152 $\pm$ 0.070
6 (F6)	0.067 $\pm$ 0.039	-0.041 $\pm$ 0.021	0.172 $\pm$ 0.014

In the first period, five regions were found to have a significant increasing linear trend: regions 1, 2, 3, 4 and 6 by approximately 0.08, 0.12, 0.04, 0.03 and 0.07°C, respectively. The average temperatures in Northern Australia did not change significantly. In the second period, average temperatures were found to increase significantly in three regions: regions 2, 3 and 4, by approximately 0.12, 0.05 and 0.03°C, respectively. The average temperatures of regions 1, 5 and 6 did not change significantly. In the third period, average temperatures in all six regions were found to increase significantly by approximately 0.17, 0.19, 0.15, 0.18, 0.15 and 0.17°C, respectively.

Over each of the three time periods, the average surface temperatures increased in the Western Pacific Ocean and Indonesia. Furthermore, in the third period, temperatures increased in all regions of Southeast Asia and Northern Australia ranging from 0.082−0.222°C per decade. The highest temperature change, from the second period to the third period, occurred in the Pacific Ocean north of Philippines, and was approximately 0.21°C per decade (range: -0.04 to 0.17).

4 Conclusion and discussion

In this study, surface temperature changes in Southeast Asia from 1909 to 2008 were separated into three overlapping, 36-year time periods. The average surface temperatures were analyzed separately in each period using time series analysis, simple linear regression, and factor analysis. The data consisted of forty 10° by 10° grid boxes, covering latitudes 25°S to 25°N and longitudes 75°E to 160°E. A linear model was used to examine the trend and pattern of the seasonally-adjusted temperatures. The temperatures were filtered with an AR(2) process to remove the auto-correlations between successive temperatures. Factor analysis was then used to classify these filtered monthly temperatures into six regions. A simple linear model was used to fit parameters for each factor.

Temperatures were found to have increased in five of the six regions over the first 36-year time period (with increases ranging from 0.005 to 0.148°C per decade), in three regions over the second time period (with increases ranging from 0.008 to 0.150°C per decade) and in all six regions over third time period (with increases ranging from 0.082 to 0.222 °C per decade). The result of the increases in temperatures in Southeast Asia in the third period is similar to the increase of the global surface temperature over the 1975–2005 period by about 0.2°C per decade (Hansen et al. 2006). In addition, Lean and Rind (2009) projected that global surface temperature would increase 0.15 $\pm$0.2°C per decade in the five years from 2009 to 2014, which was similar to the results in the third period in our study. From our study, the six patterns of temperature change which were grouped by factor analysis, especially over the third period, indicated increasing temperatures throughout much of this region.

In the tropical Pacific, trade winds blow from east to west. The winds push the sun-warmed surface water west, away from the South American coast, to a deep pool of warm water east of Indonesia. Along the South American coast, deep, cold water rises to the surface to replace the warm water being pushed west. As a result, the water in the eastern tropical Pacific is typically cool, while the western tropical Pacific, water is warmer. Multiple factors indicate that the Southeast Asia region possesses a high degree of vulnerability to climate changes such as, rainfall extremes, droughts, tropical cyclones and extreme tides. Such climatic impacts will severely threaten the livelihood of poor people living in rural areas with limited adaptive capacity. Many nations within the region struggle to cope with the current climate volatility (Preston et al. 2006).

Future studies could investigate the temperature changes in the same areas by separate land and sea surface temperatures. Moreover, other areas could be investigated using the methods in this study.

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