CHAPTER 3

Analysis of temperature change

This chapter consists of two main studies; fist investigating the temperature changes in Southeast Asia during 1973–2008 and second investigating the temperature changes in Southeast Asia during 1909 – 2008. The second study extended time from 36 year period to 100 years, broken into three overlapping 36-year periods.

3.1 Temperature changes in Southeast Asia during 1973–2008

Temperature changes in Southeast Asia from 1973 to 2008 were investigated first since it was the most recent period and contains the most complete data. The results presented in this chapter also appeared in Chooprateep and McNeil (2014a).

Time series

Using the basic methods of plotting the seasonally-adjusted temperatures against time with fitted model (Figure 3.1), the residuals were examined by box-plot and normal quantile plot (Figure 3.2-3.3).

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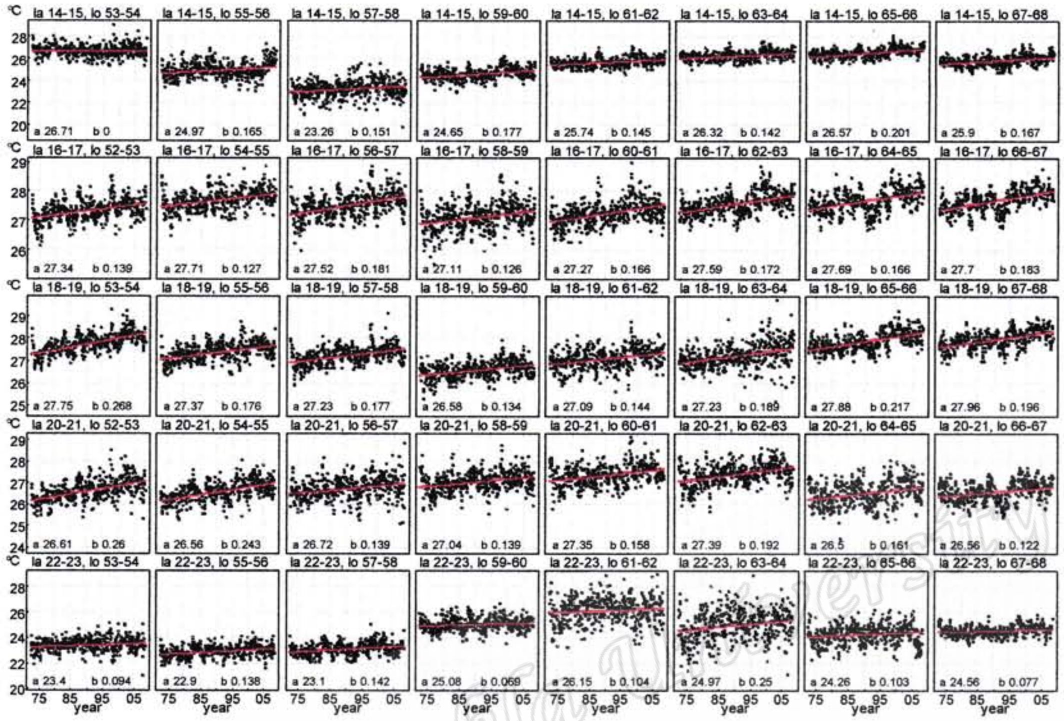

Figure 3.1 Time series plots with fitted linear models for period 1973-2008 for the 40 grid-boxes

Each graph in Figure 3.1 shows plots of average monthly temperatures versus months with a fitted line in each grid-box. Most of grid-boxes show the increasing trends, ranging from 0.00 to 0.27 °C per decade.

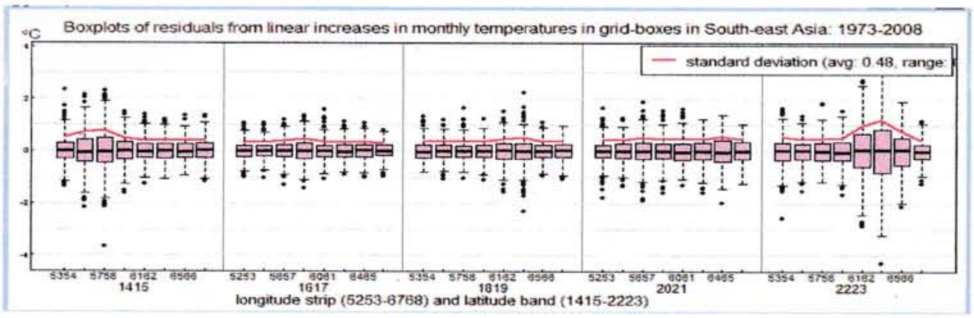

Figure 3.2 Box plots of residuals from fitted model

The residuals from fitted model in each grid-box were shown in each box plot. We have 5 panels which are broken down by latitudes. Some grid-boxes had a high dispersion of temperature (long dot line). For all grid-boxes combined, we examined

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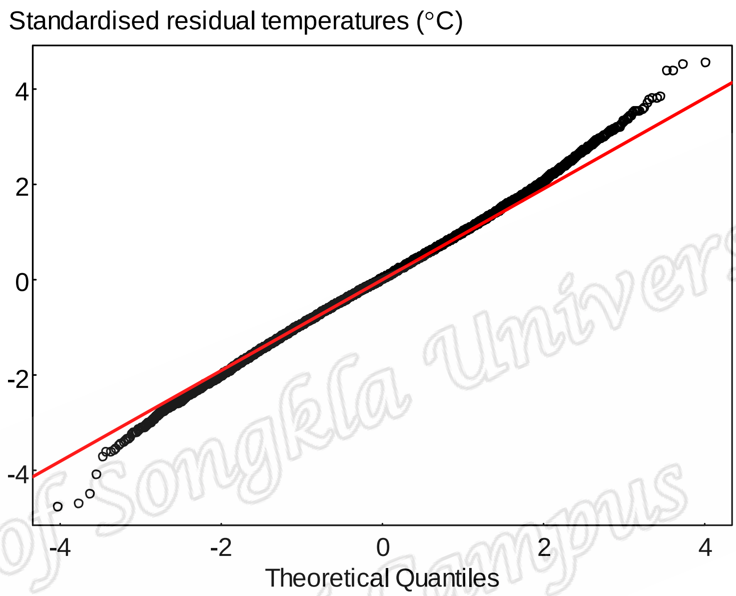
the distribution of residuals by normal quantile plot. Figure 3.3 showed the residuals stretched up and down from the normal line. That implies the residuals are not normally distributed. Although the residuals appear not normally distributed, we note



that these residuals have yet to take account of spatial correlation and temporal.

Figure 3.3 Normal quantile plot

Time correlation

Temperatures are time series data, the correlations between times were examined by plotting auto-correlation function as shown in Figure 3.4.

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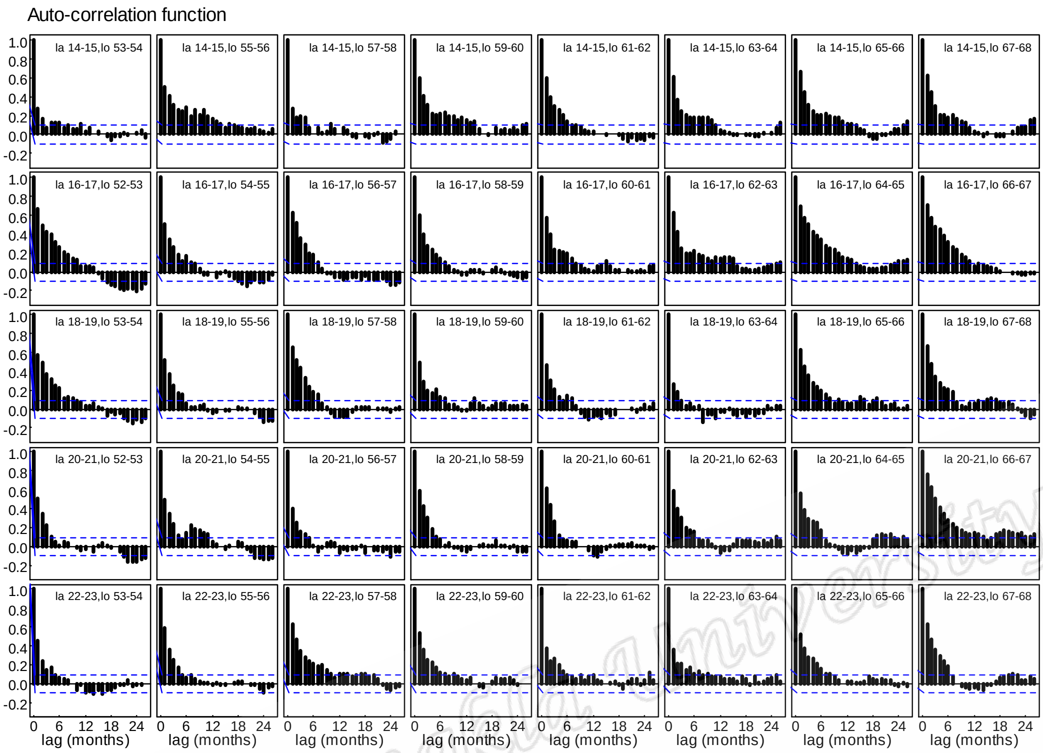

Figure 3.4 Auto-correlation function plots for the 40 grid-boxes.

A second order autoregressive model (AR) is fitted to the residuals from a fitted model. Then, the average monthly temperatures in each grid-box were filtered to remove auto-correlations by $Z_{it} = y_{it} - a_1 y_{i,t-1} - a_2 y_{i,t-2}$, where coefficients a_1 and a_2 are the average values of the two estimated parameters in the fitted 2-term autoregressive models (a_1 = 0.494 and a_2= 0.107) and Z_{it} are the filtered temperatures. The AR(2) residuals close to zero indicating no correlation between times as shown in Figure 3.5.

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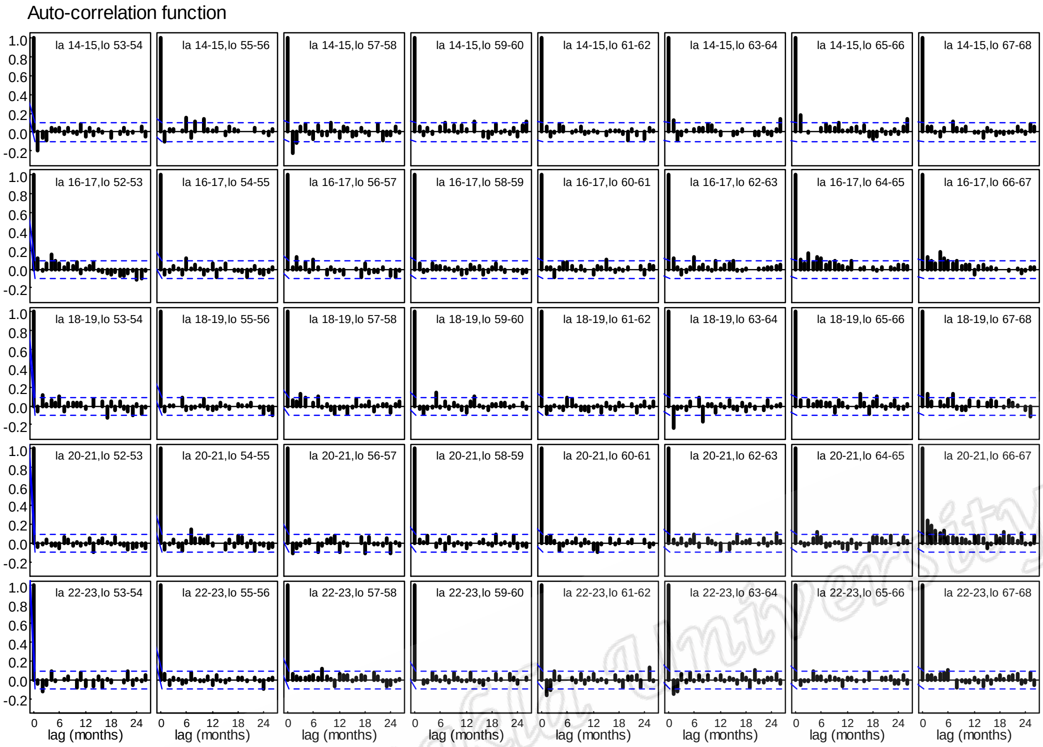

Figure 3.5 Auto-correlation function plots for the filtered residuals. The dotted line represents the 95% confidence interval for a zero correlation.

The filtered temperatures were clearly lower than the average monthly temperatures as shown in Figure 3.6 and would need to be rescaled accordingly to match the unfiltered data. Figure 3.6 demonstrates temperatures lower than temperatures in Figure 3.1 because auto-correlations have been removed. After removing auto-correlations, we accounted for spatial correlations as shown in Figure 3.7.

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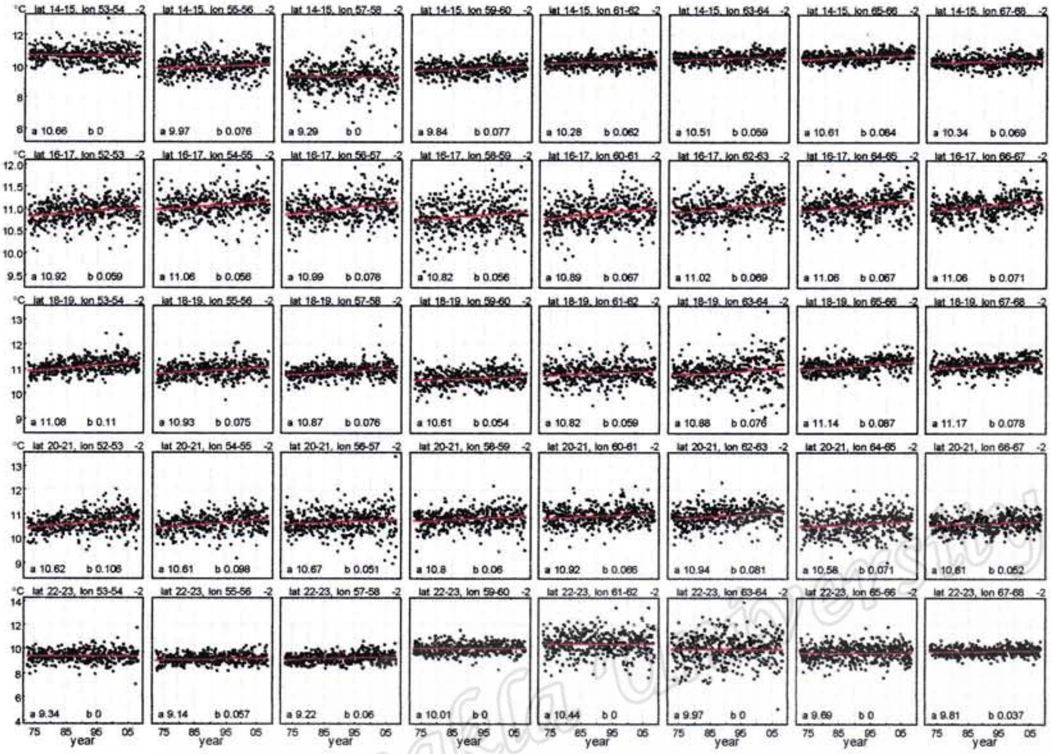

Figure 3.6 Filtered temperatures in 1973-2008

Spatial correlation

There are correlations between residual temperatures in adjoining grid-boxes in the region. These correlations displayed in bubble plots as shown in figure 3.7.

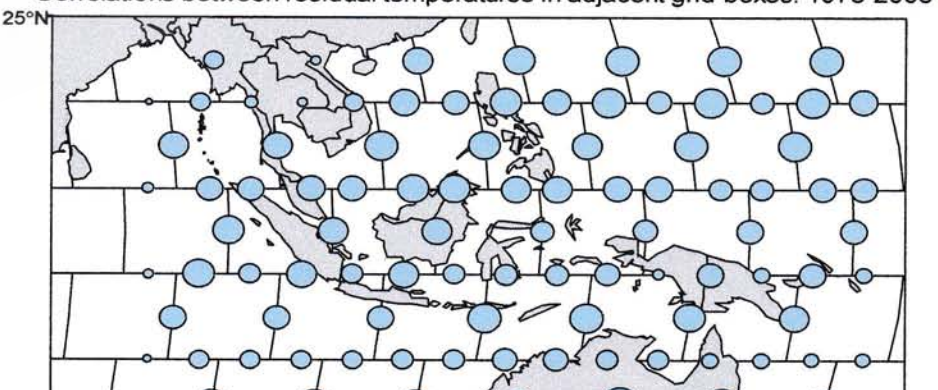

Figure 3.7 Spatial correlations of filtered residuals

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Figure 3.7 shows spatial correlations by the size of bubble charts, the bigger size means high correlation between adjacent grid-boxes. Each grid-box connected with each other by five different sides, the correlation coefficients among them are ranging from 0.003 to 0.781 and median 0.459.

Because of spatial correlations between adjacent grid-boxes, factor analysis was applied to identify correlations between the filtered monthly temperatures. Factor analysis (Promax method) used to classify grid-boxes to form a factor by maximizing the likelihood of the covariance matrix and minimizing the correlation between the factors for a specified number of factors. The results are considered by factor loadings greater than 0.3 for each factor. No variable is present in more than one factor. All variables except those with uniquenesses above 0.8 contribute to a factor as shown in Table 3.1.

Grid-Box	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Uniquenesses
	0.789	0.112					0.336
4	0.694			-0.115		0.278	0.444
11	0.626			0.278		-0.173	0.434
13	0.576	0.433					0.433
3	0.567	-0.153					0.697
19	0.378	-0.175	0.264	0.275			0.562
15		0.838	-0.217				0.371
14	**0.324**	0.676		-0.185		0.143	0.398
23	-0.100	0.640					0.557
16		0.630	-0.234				0.652
24		0.503		0.100		-0.108	0.748
22		0.359	0.131		-0.103		0.802
30		-0.132	0.894				0.288
29	0.123	-0.172	0.757				0.410
31	-0.151		0.674				0.558
28	0.175	-0.119	0.514				0.644
32	-0.193	**0.357**	0.410		-0.102		0.591
21	0.136	0.294	0.368	-0.146			0.682
20	**0.313**		0.333			-0.102	0.698
40		0.238	0.300				0.784
17				0.710			0.516
26				0.632			0.635
25				0.510			0.743
34				0.506			0.737

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Grid-Box	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Uniquenesses
18		-0.107	0.122	0.504			0.688
9	0.247	0.102	-0.236	0.460			0.681
33	-0.100			0.426			0.854
35				0.417			0.795
27			0.108	0.344		0.112	0.810
10	0.305		-0.130	0.307			0.764
38					1.009		0.005
37		-0.105			0.707		0.432
39		0.129	0.191		0.602	-0.100	0.540
6	0.118	0.104				0.761	0.318
5	**0.521**			-0.134		0.620	0.283
7	-0.132	0.111		0.127		0.595	0.567
8	-0.128	0.258				0.374	0.762
36		-0.105	0.110	0.141	0.163	0.148	0.884
2	0.165	0.122					0.950
1	0.119						0.973

Table 3.1: Results of the factor analysis with factor loadings

The 37 grid-boxes could be classified by factor analysis and given six groups of filtered temperatures comprising 6, 6, 8, 10, 3 and 4 of grid-boxes, respectively. There are 3 grid-boxes that have high uniqueness which were not combined with the other grid-boxes. The factor model can reduce these correlations as show in the correlation of the residuals in Figure 3.8.

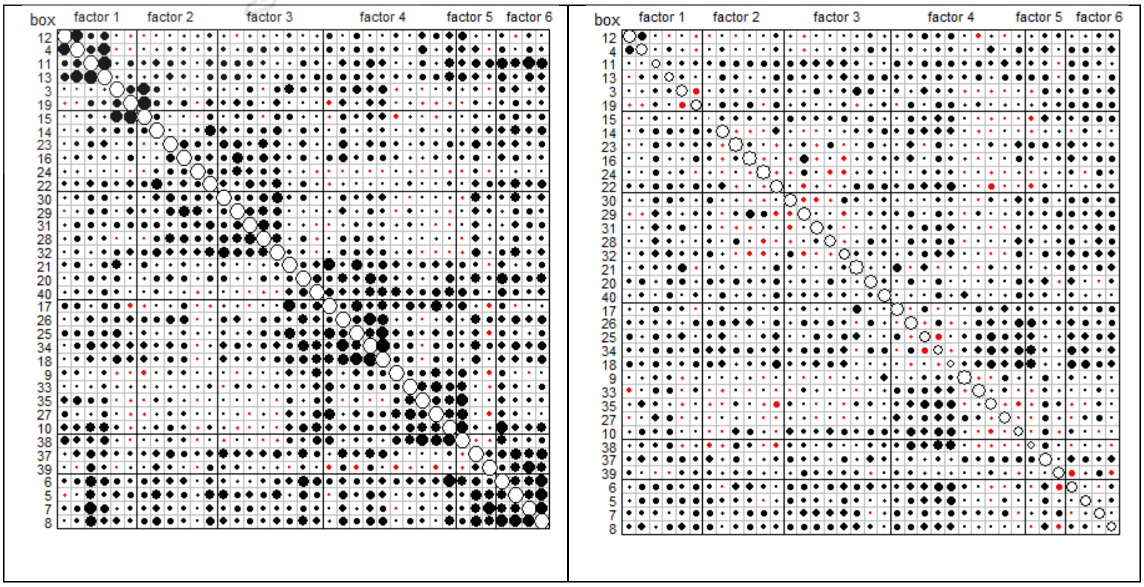

Figure 3.8 Bubble plots of correlations between filtered monthly temperatures in grid-boxes before (left) and after (right) fitting the factor model

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Figure 3.8 shows that the factor model has a largely reduced correlation between factors. The effect of the factor is significant in explaining the correlation between grid-boxes within the factor. Adjacent grid-boxes were combined into six regions as shown in Figure 3.9 (left).

Further exploration extended the area by 10° in each direction: north, south, east and west. This area comprised 70 regions of 10° by 10° grid-boxes. We found that the area in factor 2 and factor 6 were separated and factor 2 was split to the north and east sides as shown in Figure 3.9 (right). Therefore, the study area was extended only the south and west directions.

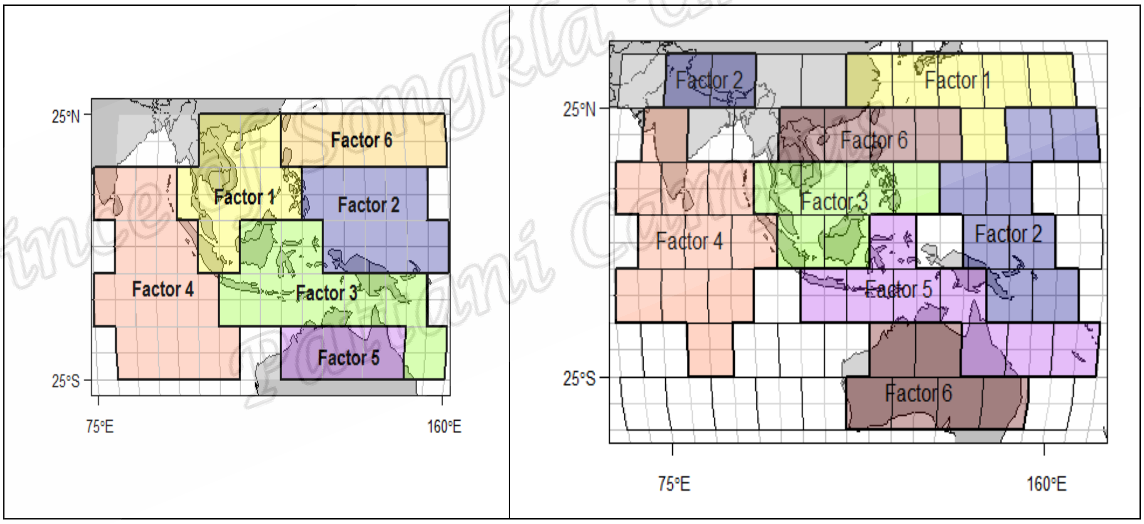

Figure 3.9 Six regions were combined by factor analysis (left) and the combined regions after extended the area for all directions (right), for comparison with the extended area

We investigated the area which was correlated in latitudes 35°S to 25°N and longitudes 65°E to 160°E, the results in this section also appeared in Chooprateep and McNeil (2014b). This area comprised 54 regions of 10° by 10° grid-boxes. The data in this area were analysed in the same methods, after filtering, the factor analysis was applied to cluster 54 grid-box regions into six groups with different temperature

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change patterns. Of the 54 grid-boxes, 46 could be classified by factor analysis and combined into 6 factors (regions) as shown in Figure 3.10. Each factor comprised the followings regions; Factor 1: Southern China, Vietnam, Cambodia, Thai, Laos, Malaysia, Singapore, Philippines. Factor 2: Western Pacific Ocean. Factor 3: Indonesia, Papua New Guinea. Factor 4: Southern India, Sri Lanka, Indian Ocean. Factor 5: Northern Australia. Factor 6: North-West Australia, Eastern Indian Ocean.

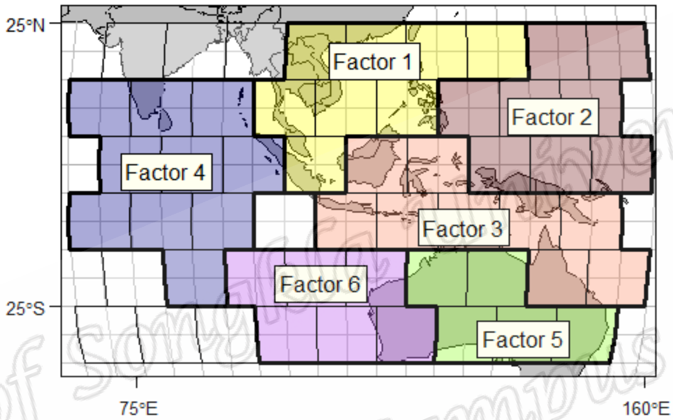

Figure 3.10 Six regions were combined by factor analysis

Temperature change and prediction

For the extended area, multivariate linear regression models were used to fit parameters for each factor. These models provide variance-covariance matrices of estimated temperature increases in adjoining grid-boxes of each factor. A simple linear regression model was used to analyse the average temperatures. Estimated parameters (b_0 and b_1) of the linear model in each factor are the average of y-intercepts and slopes based on grid-boxes of that factor's area.

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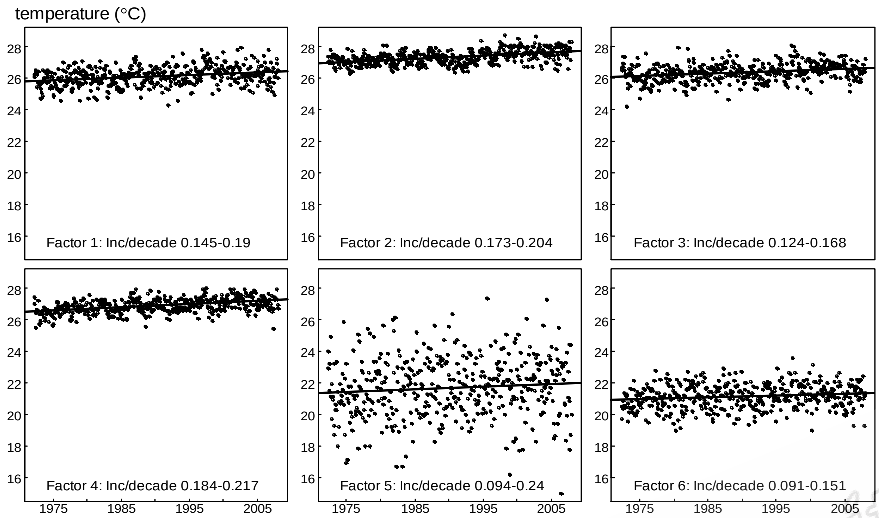

Figure 3.11 Temperature changes in regions defined by factors

The temperatures increased for each factor, with increases ranging from 0.091 to 0.240°C per decade. The highest increase was in Factor 4 (Indian Ocean) with 95% confidence interval 0.201$\pm$ 0.016°C per decade and the lowest increase was in Factor 6 (the West part of Australia) with 95% confidence interval 0.021$\pm$0.030°C per decade. Simple linear regression models were also used to predict temperature in each region in the next decade (2009-2018) in the same graph as shown in Figure 3.12.

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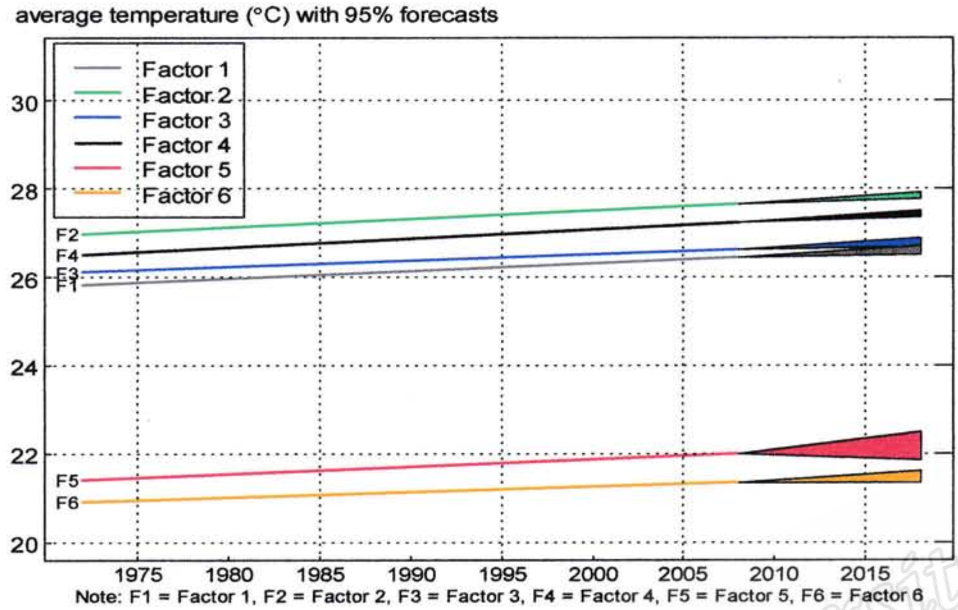

Figure 3.12 Temperature changes, with 95% confidence intervals for the predicted temperature change in the next decade

It is obvious that the average temperatures in factor 1, 2, 3, and 4 higher than 25 °C increased slightly from 1973 to 2008. Comparatively, the average temperatures in factor 5 and 6 around 21-22 °C increased slightly from 1973 to 2008. Factor 5 had the highest range of predicted temperatures with 0.7 °C.

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3.2 Temperature changes in Southeast Asia during 1909 – 2008

The final analysis was extended time from the 36 year period to 100 years in latitudes 25°S to 25°N and longitudes 75°E to 160°E. The extended time frame for the next study will be split into three 36 year periods. The temperatures at the end of each period might affect the temperature change in the future period. There is a three-year overlap at the end of period 1 and 2. The first, second and third periods are 1909-1944, 1941-1976, and 1973-2008 respectively.

Average time in each 36-year period

The average temperatures were fitted by a linear regression in each period. The result in Figure 3.13 shows that the mean temperatures had a significant increase in the first period (0.048°C per decade) and third period (0.159°C per decade), while the small increase over the second period was not significant different from zero. The coefficient correlations (r) between temperatures and times (months) in the first and third period were 0.20 and 0.59 respectively. There is an extreme increase in the third period.

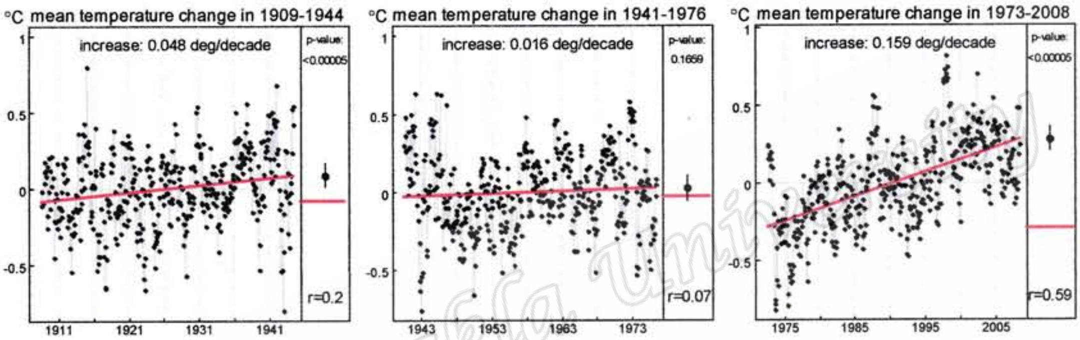

Figure 3.13 Mean temperature change of each period

For the first period (1909-1944) and second period (1941-1976), the data analysis was followed the steps as shown in Figure 2.3.

Time correlation

There are auto-correlations among residuals from the fitted model in each grid-box, AR(2) models are used to remove auto-correlations. The coefficients a_1 and a_2 of the two parameters in the AR(2) models are 0.314, 0.093 in the first period and 0.358, 0.153 in the second period respectively.

Spatial correlation

In each grid-box, then factor analysis was applied to identify correlations between the filtered monthly temperatures. There were 33, 32 and 37 of the 40 grid-boxes in the first, second and third period which could be classified and combined into 6 regions, as displayed in Figure 3.14. Most of the adjoining grid-boxes stayed in the same

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factor for three periods with the exceptions of some grid-boxes in the Pacific Ocean and east of Indonesia. Because of high variation of temperatures in this area, it is uncertain whether group inter-correlation exists among grid-boxes to form factors.

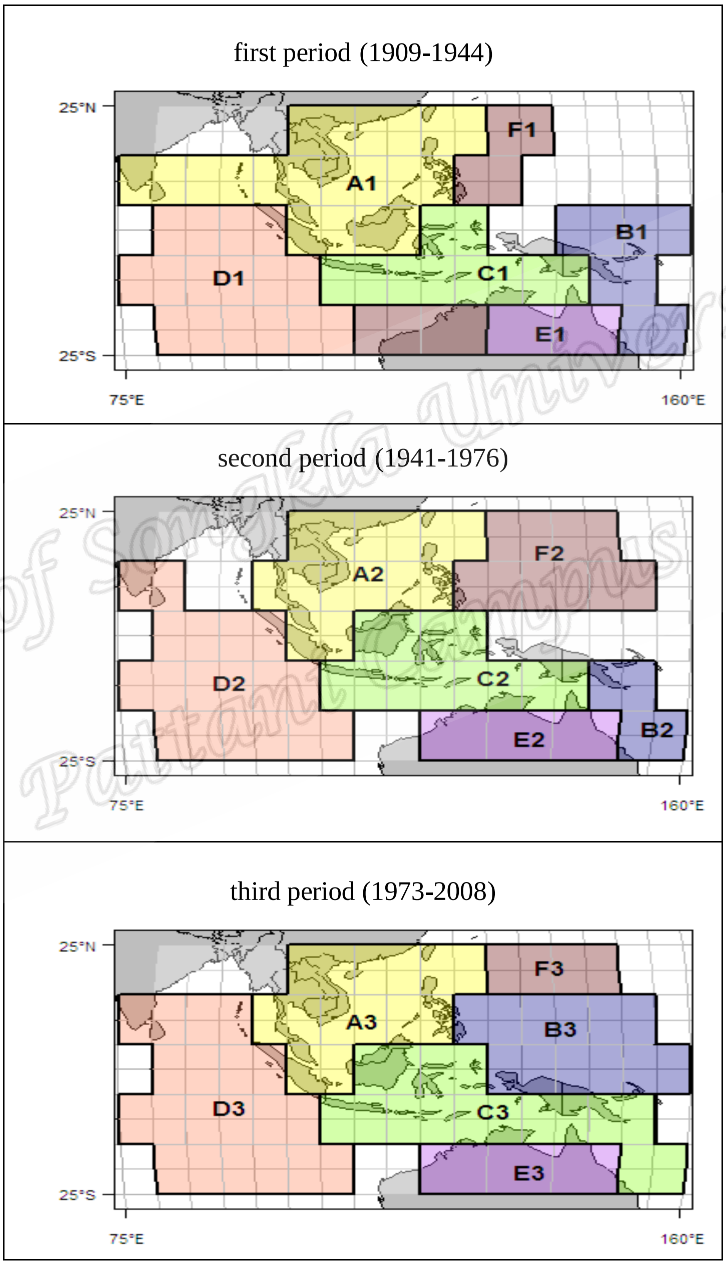

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Figure 3.14 The adjoining grid-boxes were combined into six regions in the first, second and third period.

Multivariate linear regression models were used to provide variance-covariance matrices of estimated temperature increases in adjoining grid-boxes of each factor. A simple linear regression model was used to analyse the average temperatures.
The results show the estimated parameters in each factor in each of the three periods and comparisons of the change per decade can be seen in Table 3.2.

Periods	Factor	Increase per decade	Increase per decade at the 95% CI
first period (1909-1944)	A1	0.082	0.060 - 0.104
	B1	0.115	0.081 - 0.148
	C1	0.036	0.007 - 0.065
	D1	0.028	0.005 - 0.051
	E1	0.070	- 0.010 - 0.151
	F1	0.067	0.028-0.106
second period (1941-1976)	A2	0.026	- 0.002 - 0.055
	B2	0.120	0.089 - 0.150
	C2	0.050	0.023 - 0.077
	D2	0.029	0.008 - 0.050
	E2	0.008	-0.065 - 0.081
	F2	-0.041	-0.062 - 0.020
third period (1973-2008)	A3	0.174	0.148 - 0.199
	B3	0.187	0.170 - 0.204
	C3	0.151	0.130 - 0.171
	D3	0.178	0.161 - 0.195
	E3	0.152	0.082 - 0.222
	F3	0.172	0.158 - 0.186

Table 3.2 The increase per decade in the first, second and third periods

Table 3.2 shows the temperature change of each period. Over the period 1909-1944, the average temperatures of five regions (A1, B1, C1, D1 and F1) were found to have a significant increasing linear trend. Over the period 1941-1976, the average temperatures of three regions (B2, C2 and D2) were found to increase significantly.

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Over the period 1973-2008, average temperatures in all six regions were found to increase significantly.

3.3 Conclusions

The average monthly temperatures in Southeast Asia during 1990-2008 were investigated. The long period time was separated into three time periods, 1909-1944, 1941-1976, and 1973-2008 respectively. In this study, the average temperature involving time and spatial correlation was focus upon. The following methods were used to analyse temperature data, (a) linear regression model (b) autoregressive model (c) factor analysis (d) multivariate linear regression model.

In each time period, factor analysis classified filtered temperatures into six regions. It was found that each region had a different temperature increase. In the first period, five regions had increased temperatures ranging from 0.005 to 0.148°C per decade. In the second period, three regions had increased temperatures ranging from 0.008 to 0.150°C per decade. In the third period, all six regions had increased temperatures ranging from 0.082-0.222 °C per decade. Over each of the three time periods, the average surface temperature was highly increased in the Western Pacific Ocean and Indonesia. The highest temperature change from the second period to the third period was in the Pacific Ocean near the north of Philippines, and was approximately 0.21°C per decade (from -0.04 to 0.17).

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