GEOGRAFIA Online™ Malaysia Journal of Society and Space **3** (84 - 105)
 ISSN 2180-2491

Geografia
Malaysian Journal of Society and Space

Regional and temporal climatic classification for Borneo

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Abstract

This paper describes a regional and temporal climate classification which is an attempt to divide the Borneo region into several homogenous groups based on long-term average climatic behaviour. One the one hand, the method of the regional classification used is one where the result of the regional classification should not be affected by the changes in climate. On the other, the method of temporal classification adopted is to group each individual day into one of several identified modes. These modes, which will be changing on daily basis are described by specific spatial patterns of climatic variables (precipitation and temperature). Although these two regional and temporal classifications are created from different variables and different methods, they are mutually complementary and describe the local climate in Borneo. It was found that certain types of weather might be more associated with certain groups of climatic divisions. Thus while spatial climatic variations in Samarahan Climatic Group (B1) describe the unique pattern of weather Type 3 (Western Wet), those of Type 4 (Central Wet) and Type 5 (Eastern Wet) are more closely associated with the climate variability for Sepanggar (A1) and Sepilok (A2) groups.

Keywords: Borneo, climate classification, precipitation and temperature, regional climate classification, spatial patterns of climatic variables, temporal climate classification

Introduction

Why is climate classification needed? According to Virmani (1980), there are two basic functions of climate classification: firstly, to identify, organize and name climatic types in an orderly fashion and formulate relationships with surface climate variables; and secondly, to assist policy-makers in making decisions on climate-related socio-economic planning. Several classification models based on various approaches are found in the literature (e.g. de Martonne, 1926; Koppen, 1936; Hare, 1951; Thornwaite and Mather, 1955; Gadgil and Iyengar, 1980). To avoid misleading interpretation, it is important to realize that climatic classification is not an objective process, which could rigidly produce a single definitive solution. The result of any classification will differ depending on the choices of variables, methods, and data series. The subjectivity does not mean that a climate classification provides no benefit. As long as the classification process is coherent with pre-identified aims and purposes, it will be a useful exercise.

Regional classification is an attempt to spatially divide Borneo into several climatic divisions based on distinct surface climatic features. Temporal classification, on the other hand, is to identify the most significant weather features on daily basis – and classify all days into one of the identified modes. For a region like Borneo, where dependency on the agrarian economy is still vital, climate classification can be very useful. So far, no research of this kind has been conducted in Malaysia (or Borneo) at any level or scale. Therefore, establishing a specific scheme of climatic divisions and daily weather types will provide a new alternative for policy-makers in Borneo to assist in socio-economic planning. Conventionally, the most common option is to base it on political boundaries – which might not be suitable in most circumstances.

Regional classification

Regional classification is an attempt to classify Borneo into several climatic divisions using surface climate variables. Several stations in Borneo are selected for this analysis. These stations will be clustered together to form a set of climatic groups (based on similarity in surface characteristics). The only similar works that have been undertaken for this region are by Wyrtki (1956), Aldrian (1999, 2001) and Aldrian *et al.*, (2003). Wyrtki (1956) classified Indonesia into nine climatic regions based on precipitation patterns (using observed data). Aldrian (1999, 2001) made an attempt to improve Wyrtki's classification using data generated by ECMWF (European Centre for Medium-range Weather Forecasts) Reanalysis. Although these classifications had included Borneo, the spatial resolution was very coarse (i.e. all of Borneo was classified as D type). Thus, a more specific classification is needed for a better insight of spatial climate characteristics of Borneo.

Table 1. Selected stations for regional climate classification

Ref.	Stations	Political region	Daily observations	Monthly observations
TWU	Tawau	Sabah, Malaysia	1979 – 2001 (23 years)	1979 – 2001 (23 years)
SDK	Sandakan	Sabah, Malaysia	1968 – 2001 (34 years)	1960 – 2001 (42 years)
KDT	Kudat	Sabah, Malaysia	1983 – 2001 (19 years)	1983 – 2001 (19 years)
KK	Kota Kinabalu	Sabah, Malaysia	1968 – 2001 (34 years)	1960 – 2001 (42 years)
LBN	Labuan	Sabah, Malaysia	1979 – 2001 (23 years)	1979 – 2001 (23 years)
BRA	Brunei Airport	Brunei	1967 – 1999 (23 years)	1967 – 1999 (23 years)
MIR	Miri	Sarawak, Malaysia	1968 – 2001 (34 years)	1960 – 2001 (42 years)
BTU	Bintulu	Sarawak, Malaysia	1968 – 2001 (34 years)	1960 – 2001 (42 years)
SBU	Sibu	Sarawak, Malaysia	1968 – 2001 (34 years)	1962 – 2001 (40 years)
SAM	Sri Aman	Sarawak, Malaysia	1983 – 2001 (19 years)	1983 – 2001 (19 years)
KCH	Kuching	Sarawak, Malaysia	1968 – 2001 (34 years)	1960 – 2001 (42 years)
PTK	Pontianak	Sarawak, Malaysia	1961 – 1990 (30 years)	1960 – 1990 (31 years)
NGA	Ngapinoh	Sarawak, Malaysia	1983 – 1990 (8 years)	1960 – 1975 (16 years)
PBN	Pengkalan Bun	Kalimantan, Indonesia	1972 – 1990 (19 years)	1960 – 1986 (27 years)
PRYA	Pelangkaraya	Kalimantan, Indonesia	1969 – 1990 (22 years)	1969 – 1990 (22 years)
MTW	Muaratewe	Kalimantan, Indonesia	1961 – 1990 (30 years)	1960 – 1986 (27 years)
KBA	Kota Baru	Kalimantan, Indonesia	1962 – 1990 (29 years)	1960 – 1988 (29 years)
BPN	Balik Papan	Kalimantan, Indonesia	1960 – 1990 (31 years)	1960 – 1989 (30 years)
SMD	Samarinda	Kalimantan, Indonesia	1978 – 1990 (13 years)	1978 – 1990 (13 years)
TRK	Tarakan	Kalimantan, Indonesia	1960 – 1970 (11 years)	1960 – 1970 (11 years)

All these stations have both temperature and precipitation variables

Data (for regional classification)

In developing the regional classification, precipitation is the only surface variable that will be considered. This decision is reasonably acceptable due to the fact that rainfall variation is the most prominent and distinct feature of surface climate in Borneo. Twenty key stations (see Table 1) have been selected to produce the basic classification. The criteria for choosing these key stations are:

- The selected stations should geographically represent the key areas of Borneo
- The available data for each selected station are at least 8 years for daily observation and at least 10 years for monthly observations
- A common period (same period of observation for pairs of stations) between Sabah/Sarawak/Brunei and the Indonesian side (Kalimantan) is available
- Missing values (within the range of period for each station) are less than 60% of the entire data
- The first criterion is associated with sufficient data for determining spatial representativeness. The other three criteria are to ensure that the correlation matrix between all 20 stations is optimal and statistically reliable.

Methodology (for regional classification)

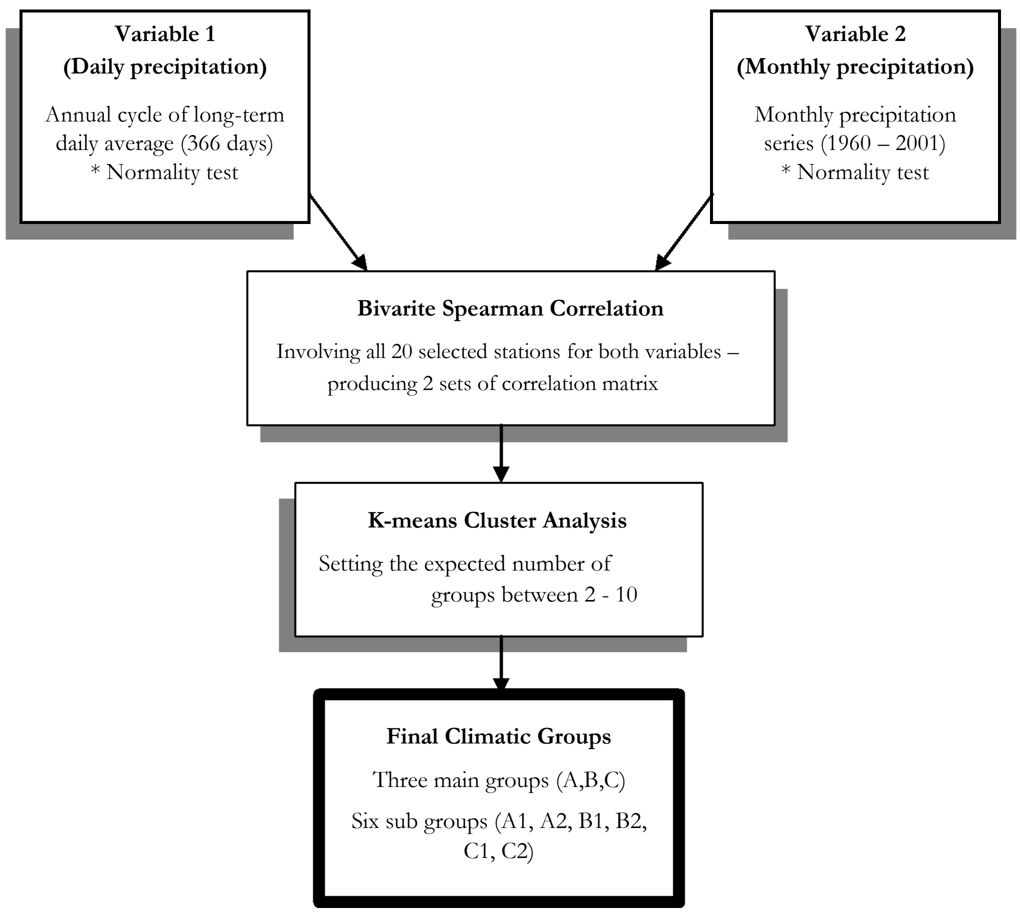

Figure 1. *Summary of regional classification procedures*

The main technique used to classify the stations into climatic groups is cluster analysis – using the K-means method. The precipitation data are first transformed into these two measures:

- Annual-cycle of long-term daily precipitation averages (366 days to include the leap year – 29th February)
- Series of monthly precipitation averages for each station (the data period is not identical for all stations and depending on the availability in the original data)

The consideration for choosing these two variables is because they are the main features of surface climatic fluctuation in Borneo (Sham Sani, 1984). The long-term daily precipitation averages (representing the seasonal scale) indicate the monsoon variability. The monthly series represents low-frequency climate variability that fluctuates on the time-scale of 3-5 years. This captures the signal of synoptic variability associated with El Niño Southern Oscillation (ENSO). By performing bivariate correlation between all of the 20 stations (conducted separately for each of the variables above), two sets of correlation matrices will be produced. For the first variable, which is the long-term daily average, a 5-day filter has been applied to enhance the Spearman Correlation coefficient with neighbouring cases. The final step is to assign each station into its respective group. This is done by K-means clustering technique using the correlation values produced in the previous steps (see Figure 1). K-Means methodology is a commonly used clustering technique. In this analysis the user starts with a collection of samples and attempts to group them into 'k' Number of Clusters based on certain specific distance measurements.

Results and discussions (for regional classification)

The results of the analysis are summarized in Tables 2 and 3. The dendogram for the cluster solution shows that the formation of clustered groups is optimal at the '3 clusters solution' (see Table 2) as almost half of the members for each group that formed at this solution remain in similar groups up to the '10 clusters solution' – the highest expected solution. At this level the following changes are observed – (a) 3 of the 7 original members in Group 1 eventually form another group; (b) 1 of the original 4 members in Group 2; and (c) 5 of the original 8 members in Group 3. The cluster agglomeration scheme (see Table 3) has further validated the initial conclusion derived from the dendogram table. The cluster coefficient shows a drastic increase from Stage 17 to the Stage 18 with more than 0.6 units of increments (5.14 to 5.80). This is the indication of where the optimal number of clusters formed (which is 3 main groups in this case). Therefore, based on the assumption that the optimal solution occurs at Stage 17 (refer to the agglomeration schedule – 'Final Cluster'), the retained final cluster solutions are 1 (Group A), 13 (Group B) and 18 (Group C). The initial members of the three main clusters are:

- Group A – KDT, SDK, KK, LBN, TWU, BRA, and MIR (7 stations)
- Group B – BTU, KCH, SBU, SAM, and PTK (5 stations)
- Group C – NGA, PBN, PRYA, MTW, BPN, KBA, SMD, and TRK (8 stations)

Table 2. Cluster dendogram table

	Cluster groups for each station in every step of the clustering analysis: based on the number of clusters formed (2 – 10 clusters)								
Station	10 clusters	9 clusters	8 clusters	7 clusters	6 clusters	5 clusters	4 clusters	3 clusters	2 clusters
1:KDT	1	1	1	1	1	1	1	1	1
2:SDK	1	1	1	1	1	1	1	1	1
3:KK	2	1	1	1	1	1	1	1	1
4:LBN	3	2	2	2	2	1	1	1	1
5:TWU	2	1	1	1	1	1	1	1	1
6:BRA	1	1	1	1	1	1	1	1	1
7:MIR	1	1	1	1	1	1	1	1	1
8:BTU	4	3	3	3	3	2	2	2	2
9:KCH	4	3	3	3	3	2	2	2	2
10:SBU	4	3	3	3	3	2	2	2	2
11:SAM	4	3	3	3	3	2	2	2	2
12:PTK	5	4	4	4	3	2	2	2	2
13:NGA	6	5	5	5	4	3	3	3	2
14:PBN	6	5	5	5	4	3	3	3	2
15:PRYA	6	5	5	5	4	3	3	3	2
16:MTW	7	6	6	6	5	4	3	3	2
17:BPN	8	7	7	5	4	3	3	3	2
18:KBA	9	8	8	7	6	5	4	3	2
19:SMD	10	9	6	6	5	4	3	3	2
20:TRK	10	9	6	6	5	4	3	3	2

Table 3. Cluster agglomeration schedule

Stage	Cluster 1	Cluster 2	Distance coeff.	Final Cluster	Stage by stage clustering process – combining the closest and most related
1	6	7	1.42	6	BRA > MIR
2	8	9	1.80	8	BTU > KCH
3	8	11	2.23	8	BTU > KCH > SAM
4	1	6	2.29	1	KDT > BRA > MIR
5	13	14	2.50	13	NGA > PBN
6	3	5	2.54	3	KK > TWU
7	1	2	2.99	1	KDT > BRA > MIR > SDK
8	8	10	3.19	8	BTU > KCH > SAM > SBU
9	19	20	3.34	19	SMD > TRK
10	13	15	3.61	13	NGA > PBN > PRYA
11	1	3	3.86	1	KDT > BRA > MIR > SDK > KK > TWU
12	16	19	3.88	16	MTW > SMD > TRK
13	13	17	4.15	13	NGA > PBN > PRYA > BPN
14	8	12	4.37	8	BTU > KCH > SAM > SBU > PTK
15	1	4	4.52	1	KDT > BRA > MIR > SDK > KK > TWU > LBN
16	13	16	4.83	13	NGA > PBN > PRYA > BPN > MTW > SMD > TRK
17	13	18	5.14 *	13	NGA > PBN > PRYA > BPN > MTW > SMD > TRK > KBA
18	8	13	5.80 *	8	BTU > KCH > SAM > SBU > PTK > NGA > PBN > PRYA > BPN > MTW > SMD > TRK
19	1	8	7.60	1	KDT > BRA > MIR > SDK > KK > TWU > LBN > BTU > KCH > SAM > SBU > PTK > NGA > PBN > PRYA > BPN > MTW > SMD > TRK > KBA

* The two values where the Cluster Distance Coefficient increase drastically from 5.14 to 5.80 (0.66 unit) and this indicates the formation of optimal cluster group (i.e. Cluster 1, 8 and 13). The complete members of each of the three cluster groups are shaded.

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In order to refine the classification, so that a more unique feature can be established, each one of the 3 main groups is further divided into 2 sub-groups. This is done by determining the degree of membership stability in the cluster dendogram and by analyzing the clustering steps in the agglomeration schedule. Two main features are evident:

- In terms of membership stability (up to 10 clusters) – (a) SDK, KDT, BRA and MIR are the most stable in group A (therefore they are the closest members within the group); (b) BTU, SBU, SAM and KCH are the most stable in group B; and (c) NGA, PBN and PRYA are the only members with high stability in group C.
- In terms of clustering steps – (a) KK, TWU and LBN are the last members formed in group A; (b) PTK for group B; and (c) BPN, MTW, SMD, TRK and KBA for group C.

These observations provide the basis for further separation between the cluster members. Therefore, the final subgroups can be classified as follows (A, B, C – and the most stable sub-group in each group will be further classified as 1 and 2):

GROUP	SUB-GROUP 1 (most stable)	SUB-GROUP 2 (less stable)
A	KDT, BRA, MIR, SDK	KK, TWU, LBN
B	BTU, KCH, SAM, SBU	PTK
C	NGA, PBN, PRYA	BPN, MTW, SMD, TRK, KBA

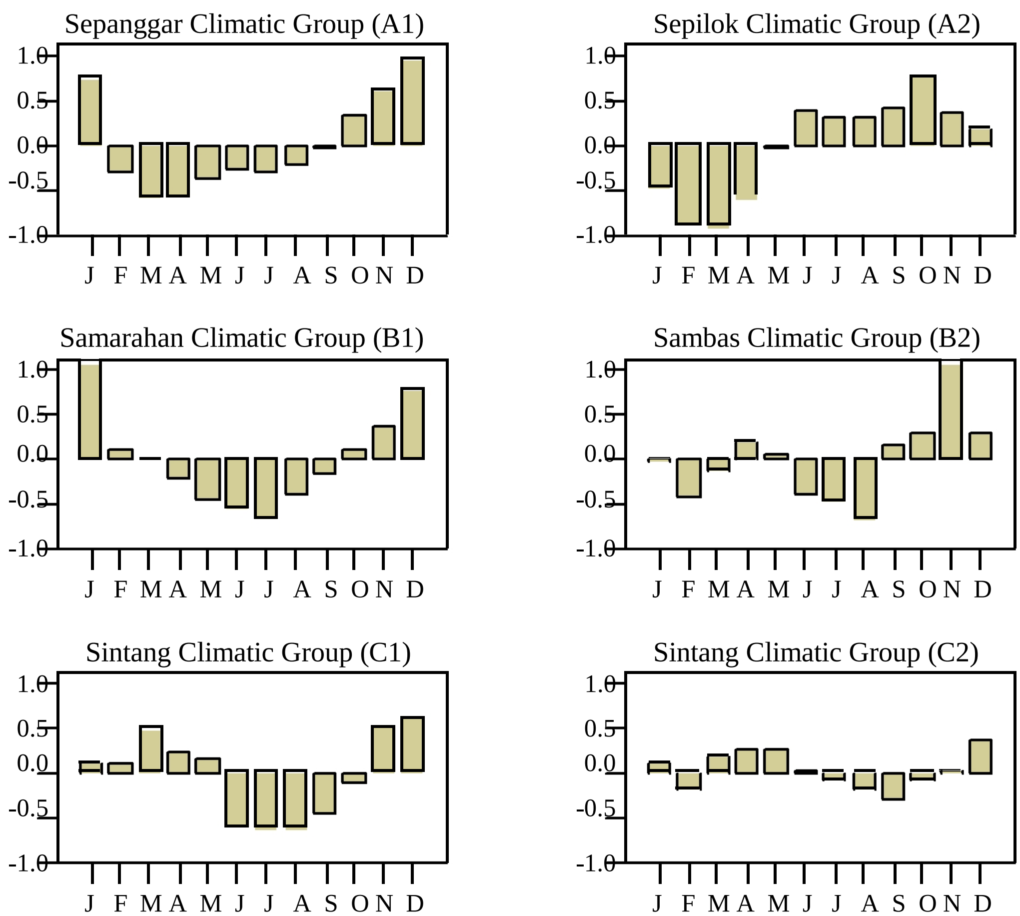

Figure 2a. *Normalized annual cycle (of precipitation) for six climatic groups in Borneo*

The K-means clustering procedure has successfully classified all the 20 selected stations into their respective groups. However, the total number of stations in Borneo with reasonable quality of monthly data is 29. It means that there are another nine unclassified stations. These are not included in the classification process due to the unavailability of reliable daily observations. To assign these 9 stations into an appropriate group (from the six established sub-groups), the comparison between normalized annual cycles has been performed. The steps taken are as follows:

- the monthly averages for all stations are normalized for the entire series.
- the long-term averages of the normalized monthly values for each station are calculated.
- the composite of normalized monthly values for each sub-group are plotted and then compared with the remaining nine individual unclassified stations.
- the comparison based on plots is then empirically validated by performing correlation analysis between normalized monthly precipitation for the individual stations and the composite values for each climatic groups.

Based on the annual cycle plot (see Figures 2a and 2b): BRS, BRL and BRL (all stations are in Brunei) have been assigned into sub-group A2; KPG into sub-group B2; BMS into sub-group C1; and the remaining 4 stations (all in Kalimantan – BTK, LIM, MAN and TSR) have been added into sub-group C2. To make this process (i.e. assigning the unclassified stations into their respective group) more objective, a correlation analysis of monthly precipitation time-series between all the identified climatic divisions (A, B, C) and the nine remaining stations is performed. Table 4 summarizes the results and the stations are assigned into their respective groups based on the highest value of correlation coefficients.

Table 4. Correlation values (for standardised precipitation) between the 9 unclassified stations with each climatic group

	Climatic group					
Station	A1	A2	B1	B2	C1	C2
BRS	0.71*	0.42	0.51	0.24	0.12	0.16
BRL	0.57*	0.37	0.44	0.22	0.15	0.26
BRK	0.71*	0.43	0.50	0.23	0.12	0.16
KPG	0.25	-0.08	0.47	0.50*	0.45	0.23
BMS	0.15	-0.21	0.49	0.16	0.50*	0.36
BTK	0.16	-0.13	0.43	0.26	0.45	0.50*
LIM	0.07	-0.02	0.24	0.22	0.31	0.47*
MAN	0.18	-0.11	0.29	0.08	0.35	0.47*
TSR	0.16	0.10	0.11	0.05	-0.07	0.21*

Values marked with (*) are the highest and all are statistically significant at the 95% level of confidence

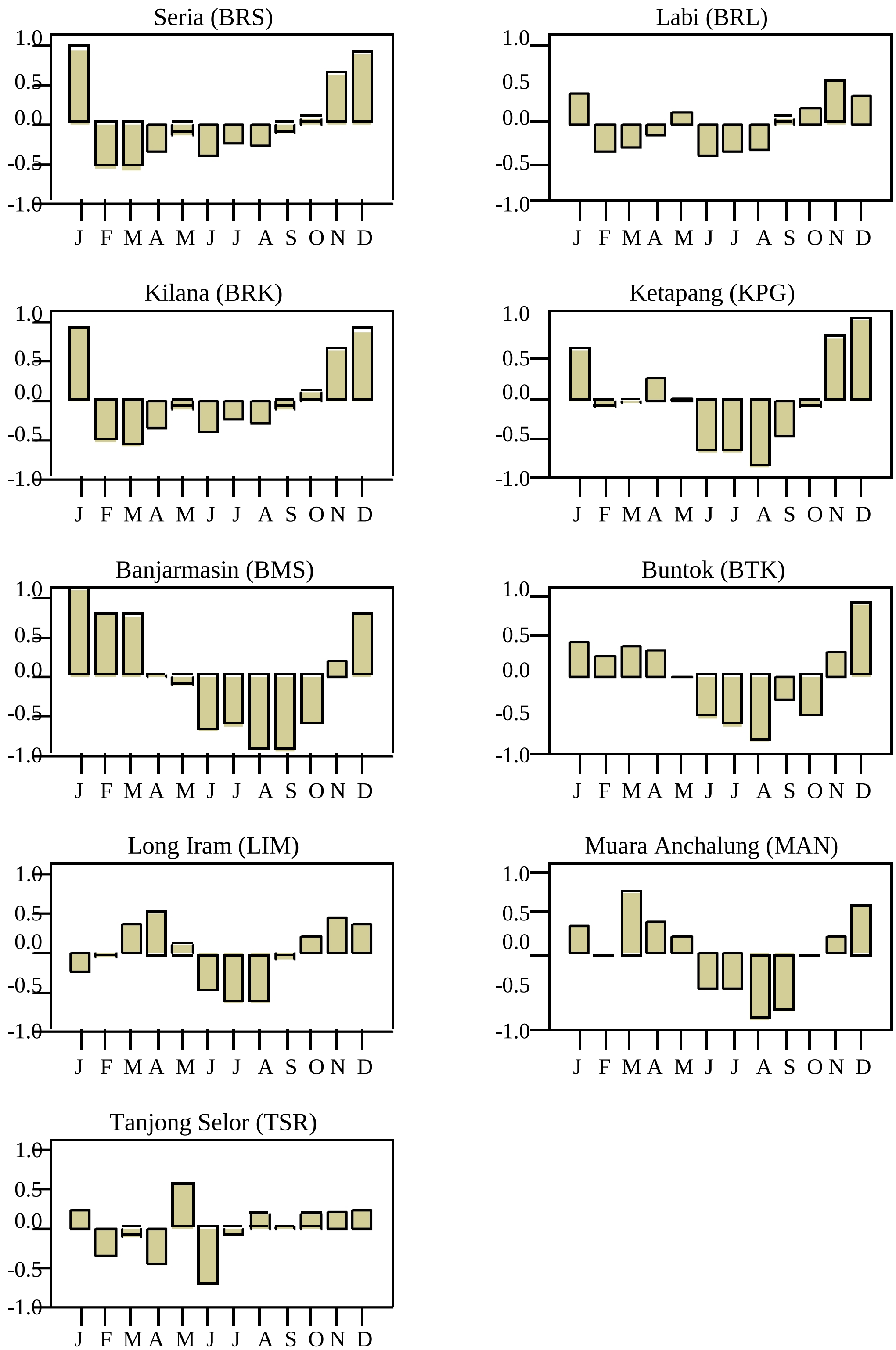

Figure 2b. *Normalized annual cycle (of precipitation) for nine unclassified stations in Borneo*

Regional classification: The conclusion

The limitations of this classification are mainly caused by the fact that they are subject to the availability of the basic data. The comparison of this Borneo classification with that of some other regions of the world reveals the following:

- The comparatively low number of active meteorological stations available in Borneo (the number of stations might be higher if it includes the stations which have been dormant since the 1960s and 1970s). The ratio between stations and the region sizes is 1 station per 25 thousands sq km. This ratio is at least 4 times lower than what is available in England, and three times lower when compared to Mexico (personal conclusion based on the number of active stations in both countries).
- In terms of geographical location, the stations are not ideally and evenly distributed. For example, Brunei which is almost 5 times smaller in size compared to Sabah, has four stations, that is, only one station less than the number of stations available in Sabah. Furthermore, twenty of the stations (or 60%) in Borneo are located in coastal areas, thus leaving only 9 stations to represent the whole interior of Borneo.

The final regional climatic groups for Borneo as mapped are shown in Figure 3. All 29 stations in Borneo have been grouped into their own cluster members. The boundary separating each group does not precisely represent the climatic regions. However, considering the data limitations, it provides a possible visual representation of how the different climate groups of Borneo is divided. Each of the climatic groups has been specially named after a selected place, which is located in its respective region. This will make it easier to discuss or to quote the climatic groups in the latter part of this thesis – by naming them with a specific reference, instead of the general term as in A1, A2, B1 and the like. The assigned names for each sub-group are as follows:

- A1 – Sepanggar climatic group (Sepanggar Bay is one of the many popular beaches around Kota Kinabalu)
- A2 – Sepilok climatic group (Sepilok is a rehabilitation centre for *orang utan*, and a main tourist attraction in Sandakan)
- B1 – Samarahan climatic group (Kota Samarahan is one of several small towns near Kuching, the Sarawak's capital city)
- B2 – Sambas climatic group (Sambas is a fishermen's settlement in the most northwestern part of Kalimantan)
- C1 – Sintang climatic group (Sintang is one of the very few meteorological stations located in the middle part of Borneo)
- C2 – Selor climatic group (Tanjong Selor is one of the meteorological stations located in the northeastern part of Kalimantan)

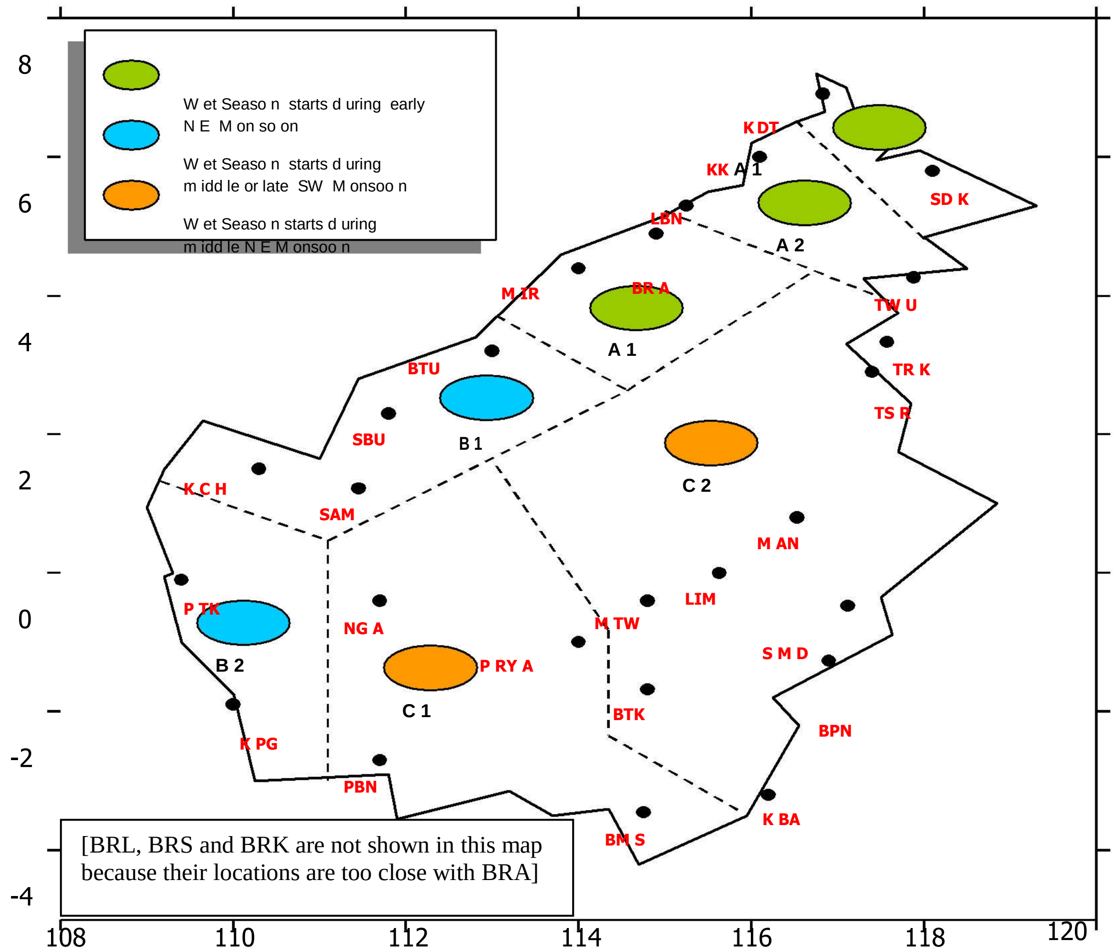

Figure 3. *Borneo climatic classification - the 29 main stations*

The next section discusses the climatic features that characterize each group and sub-group. our criteria were chosen to establish the characteristics. These are:

- **The duration of the wet season –** This is defined as the consecutive-six-month period with the highest amount of total precipitation. The period of six months was chosen to indicate a complete cycle of a season in order to be consistent with monsoon fluctuations in the region.
- **The degree of seasonality** – This refers to the ratio of total precipitation between the Northeast Monsoon (October – March) and the Southwest Monsoon (April – September). If the ratio is more than 1.2 but less than 1.5 (which indicates that total precipitation during the Northeast Monsoon are 20%-49% higher), the seasonality is considered moderate. If it is between 1.5 to less than 2.0, it is strong; and a value of more than 2.0 is regarded as very strong.
- **The occurrence of the three wettest and driest months** – This examines the monsoon season in which the three highest/lowest amounts of precipitation occur.
- **The number of absolute wet months –**This identifies how many absolute or average numbers of wet months occur at each station within each climatic group. An absolute wet month is defined for Borneo by referring to the months where the amount of rainfall exceeded more than 20% the monthly average of the entire region (more than 270 mm per-month). This criterion is different from the first one, which is only a relative measure of the 'wet season'.

The first two criteria serve as the two main factors which best identify the differences between the main groups A, B and C. The other two criteria are considered secondary in that they outline the unique features of the subgroups (the first and second variations). For instance, between A1 and A2. The summary of the characteristics is shown in Table 5.

Temporal classification data (for temporal classification)

Temporal classification for surface climate either for Malaysia, Borneo or Indonesia has never been done before although it has been applied for other regions (see for examples Mills, 1995; Christensen and Bryson, 1966). Thus, this part lacks relevant local references to previous studies. The methodology applied in this section is specially designed by the author exclusively for this task. The main aim of this temporal classification is to identify the most important modes that represent daily weather variability over Borneo. This method is an attempt to address the question of "how the spatial pattern of temperature and precipitation changes on daily basis?"

In other words, this classification analyzes the distribution of daily weather patterns that characterize Borneo's regional surface climate at the temporal scale. In order to precisely construct the significant modes, a number of stations with complete and overlapping data in terms of available variables and period of observation must be chosen to generate the patterns. The selected six stations are:

- KK (Kota Kinabalu), located on the west coast of Sabah,
- SDK (Sandakan), located on the east coast of Sabah,
- MIR (Miri), located on the northern part of Sarawak,
- BTU (Bintulu) and SBU (Sibu), both located in the interior part of Sarawak , and
- KCH (Kuching), located on the most western part of Sarawak.

These stations are selected because they have complete daily observation data for both precipitation and temperature that span a reasonably long period of 34 years, from 1968 to 2001 (see Table 1).

Table 5. Summary of characteristics for each climatic group

	SUMMARY OF UNIQUE FEATURES	MAIN CHARACTERISTICS		SECONDARY CHARACTERISTICS		
	Specific reference for each climatic zone Annual cycle feature and seasonality	Period of Wet Season	Degree of Seasonality	3 Wettest Months	3 Driest Months	Number of Absolute* Wet Months
A1	GA1: Sepanggar Climate Lowest precipitation occurs during monsoon transition from NE to SW; high precipitation in both monsoons Low degree of seasonality	Starts in Jun/Jul (middle SW) and extends up to Nov/Dec (middle NE)	Very weak less than 1.0	Aug – Nov (monsoon transition SW>NE)	Feb – April (monsoon transition NE>SW)	2 – 6 months (occur evenly in both NE and SW)
A2	GA2: Sepilok Climate Lowest precipitation occurs during monsoon transition from NE to SW; higher precipitation during NE Very strong degree of seasonality	Starts in Aug/Sep (late SW) and extends up to Jan/Feb (late/middle NE)	Moderate to very strong 1.2 – 2.5	Oct – Jan (NE)	Mac – May (monsoon transition NE>SW)	3 – 5 months (all occur during the NE)
B1	GB1: Samarahan Climate Lowest precipitation occurs during the late SW; and higher precipitation during NE Strong degree of seasonality	Starts in Oct (early NE) and extends up to Feb/Mac (late NE)	Moderate to strong 1.3 – 1.9	Dec – Feb (NE)	May – Aug (SW)	5 – 7 months (occur mostly during NE)
B2	GB2: Sambas Climate Lowest precipitation occurs during the late SW; peak amplitude of precipitation occurs twice – during SW and NE Moderate degree of seasonality	Starts in Nov (early NE) and extends up to Mac/April (end of NE)	Moderate 1.3 – 1.6	Oct – Jan (NE)	Jun – Aug (SW)	4 – 6 months (occur evenly in both NE and SW)
C1	GC1: Sintang Climate Lowest precipitation occurs during NE; peak amplitude occurs twice – during SW and NE Strong degree of seasonality	Starts in Oct (early NE) and extends up to Feb/Mac (late NE)	Moderate to very strong > 1.3 – 2.0	Dec – Mac (NE)	Jun – Sep (SW)	4 – 6 months (occur mostly during the NE)
C2	GC2: Selor Climate Lowest precipitation occurs during monsoon transition from SW to NE; peak amplitude occurs 3 times – during SW and NE Moderate degree of seasonality	Starts in Nov (early NE) and extends up to Mac/April (end of NE)	Weak to moderate 1.0 – 1.6	Jan – April (NE to early SW)	Jun – Aug (SW)	0 – 6 months (occur evenly in both NE and SW)

* Absolute Wet Months are referred to the actual number of months where the total precipitation is above the long-term average of all 29

Methodology (for temporal classification)

The method used in this temporal classification is Principal Components Analysis (PCA). The PCA is performed to reduce the dimension of the data, which consist of 34 years of daily observations for two surface variables (precipitation and temperature) at six stations. In this step, PCA will condense the information from these 12 variables into fewer variables, but still represent a large fraction of the original variance in the dataset. This is in contrast to the regional classification where the number of groups was not known prior to the classifying process. Using the number of retained components and the mathematical reasoning behind, the temporal classification can be objectively determined based on the number of modes that explain a significant amount of the total variance of Borneo's daily weather. In the next step, the component scores are utilised to classify all the days into their respective daily groups.

Two criteria are used to determine the number of components retained, namely, (i) the scree plot. and (ii) the percentage of variance explained. The scree plot from the first step (PCA data reduction) is shown in Figure 4, whereas the percentage of variance explained by each component is presented in Table 6. Based on these results, 4 components are retained which successfully describe at least one complete variable out of the 12, and fall within the range where the plot bends into a more straight line. The combined 4 components explain 65.3% of the overall variances in the dataset or almost 8 complete variables out of 12.

Table 6. Total of variance explained by the initial and rotated 4 retained components

PC	Initial Eigenvalues			Rotated Eigenvalues		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	4.2	34.9	34.9	3.8	31.8	31.8
2	1.5	12.1	47.0	1.5	12.6	44.4
3	1.2	9.7	56.6	1.4	11.4	55.8
4	1.0	8.7	65.3	1.1	9.5	65.3

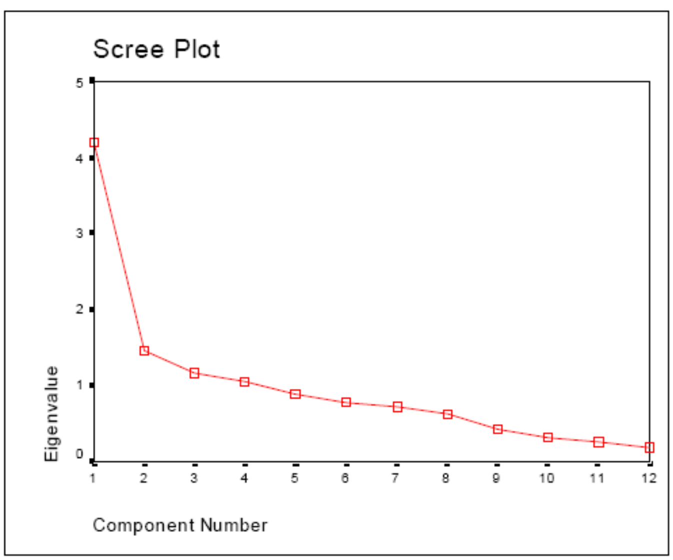

Figure 4. *Scree plot of the PCA of 12 local climate variables*

The 4 retained components were then rotated so that each of them will detect and represent the most prominent variance for a certain individual variable (or a certain group of variables). The assumption behind this rotation is that certain days can be significantly characterized by either temperature or precipitation anomaly (distinguished by climate variables). Similarly, there will also be several groups of days that can be characterized by distinct weather conditions in different part of Borneo (distinguished by stations). The detailed process of how the classification has been

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conducted is summarized in Figure 5 and outlined below:

- The 4 retained components will naturally provide 9 significant types of daily weather in Borneo. The first 8 types represent the high negative/positive scores where the thresholds chosen are +1.5 and –1.5. The ninth type is the unclassified days, in which none of the components score above +1.5 or below –1.5. This type is considered as the 'normal day' because the values of all the 12 variables are near to the long-term averages.
- The composites of each type are then created to determine the pattern of variance in precipitation and temperature, and how the variances change between the six stations.

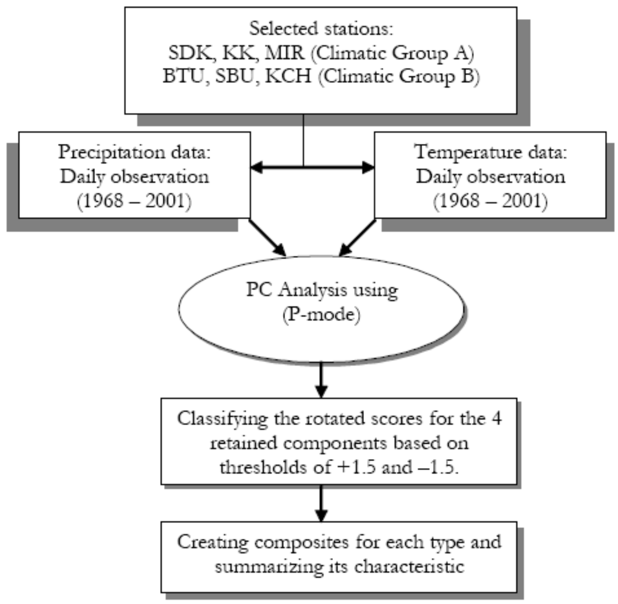


Figure 5. *Summary of the temporal classifying methodology*

Results and discussions (for temporal classification)

The anomaly composites for each weather type are created based on the types established by PC analysis (Table 7 and 8). In analyzing these composites, the concepts of 'normal', 'below' (<) and 'above' (>) normal are not used as a loose term, but rather defined by specific thresholds. For the precipitation analysis, 'below normal' refers to at least 50% less than the long-term average (~5 mm) rainfall amount. Similarly, the 'above normal' is used to describe a day with 50% more than the average rainfall amount (~15 mm). For the temperature, the thresholds used for significant anomalies are +0.5°C and –0.5°. All values in between these negative and positive thresholds are considered normal.

Table 7a. Precipitation anomaly (mm) in each Weather Type (WT)

W	SD				SB		
T	K	KK	MIR	BTU	U	KCH	
							Distinct feature
1	-4	-3	-3	-4	-3	-3	All stations are near normal
2	-5	-5	-5	-3	-5	-7	All stations are below normal (but not extreme)
3	-1	-4	2	18	37	40	Clear segregation between Sabah and Sarawak
4	0	34	40	26	2	-2	Positive extreme (> normal) in the central part
5	62	2	-1	0	0	2	Positive extreme (> normal) for east Sabah (SDK)
6	-1	3	0	-3	-3	-1	All stations are near normal
7	-5	36	-4	-9	-9	-11	Only KK shows positive extreme (> normal)
8	-6	-1	17	-4	1	-5	Only MIR shows positive extreme (> normal)

[X]=Wetter; [X]=Drier]

Table 7b. Temperature anomaly (°C) in each Weather Type (WT)

W	SD			SB		
T	K	KK	MIR	BTU	U	KCH	Distinct feature
1	0.1	0.1	0.1	0.0	0.1	0.1	All stations are near normal
2	1.3	1.6	1.6	1.7	1.7	1.6	Positive extreme for all stations
3	0.0	0.0	-0.1	-0.2	-0.7	-0.9	SBU and KCH less than normal
4	0.0	-0.5	-0.5	-0.4	-0.4	-0.5	All stations from KK to KCH are below normal
5	-1.0	-0.5	-0.3	-0.2	-0.1	-0.2	All station are within normal, except KK and SDK
6	-1.3	-1.6	-1.6	-1.6	-1.5	-1.2	Negative extreme for all stations
7	-0.4	-1.3	-0.6	0.0	0.7	1.1	Negative extreme for KK and positive for KCH
8	2.5	0.3	-0.3	-0.8	-1.3	-0.9	SDK is above normal; SBU/KCH are below normal

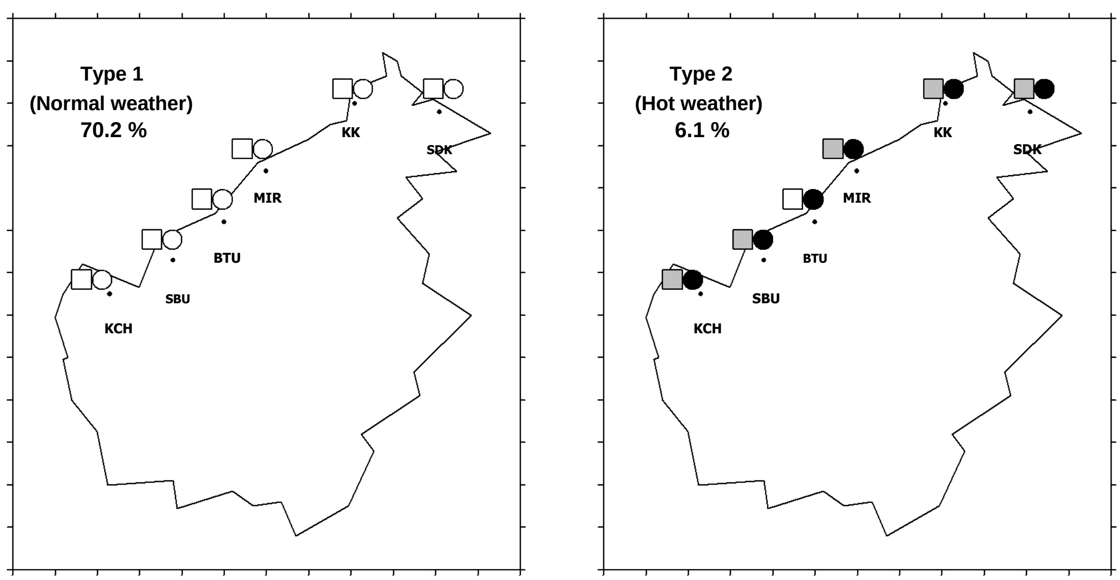
[X]=Cooler; [X]=Hotter]

Conclusion (for temporal classification)

The eight identified modes for daily weather in Borneo are mapped in Figure 6 and defined in Table 8. The first type (Normal weather) is a day considered to have ‘zero variance’ or insignificant anomaly for both precipitation and temperature. The other non-zero-variance types can be categorized into three main groups depending on which one of the two variables (temperature/precipitation) strongly characterizes their distinct features.

- Temperature Types: Type 2 (Hot weather) and Type 6 (Cool weather) are mainly characterized by positive or negative temperature anomalies.
- Precipitation Types: Type 3 (Western wet), Type 4 (Central wet) and Type 5 (Eastern wet) are best described by precipitation anomalies.
- Mixed Types: Type 7 (Various weather) and Type 8 (Mixed weather) is a combination of various climatic conditions (temperature/precipitation) throughout the region.

Type 1 (Normal weather), as expected, dominates the daily weather pattern of Borneo (see Table 8). 70.2% of the variance for the 34-year dataset is made of this type, totalling of 8712 days out from the overall of 12419 days. Accepting the fact that these normal days represent the long-term average of weather, it can be concluded that the probability for Borneo daily weather to differ from its normal condition (extreme weather) is only 29.8%. It is also important to note that Type 7 (Various weather) and Type 8 (Mixed weather) contribute only a combined total of only 0.6% of the variance. Therefore, from practical point of view, there are only five real important modes, namely Type 2, Type 3, Type 4, Type 5, and Type 6.



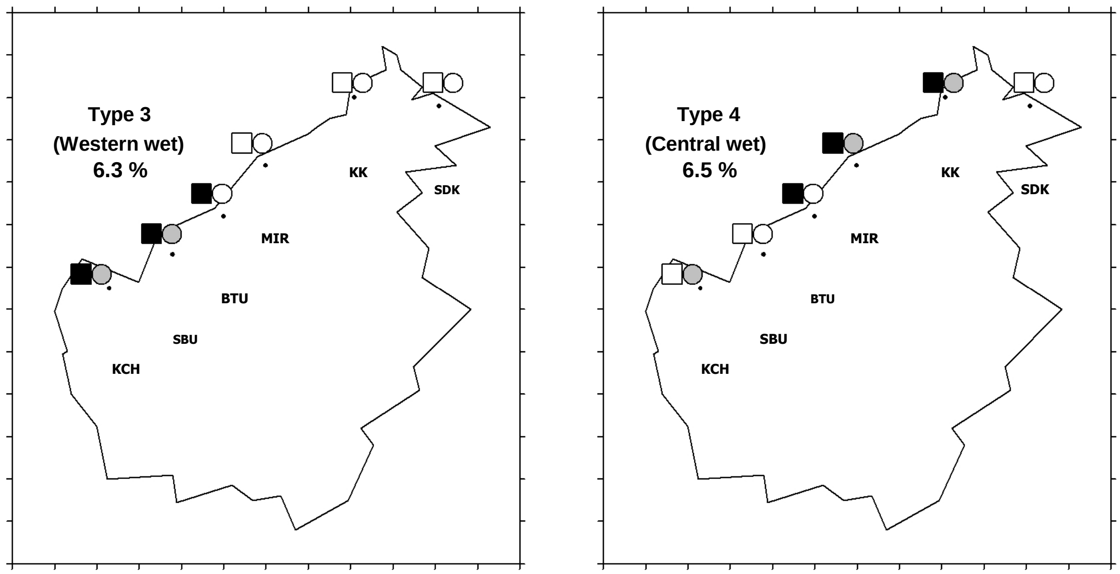
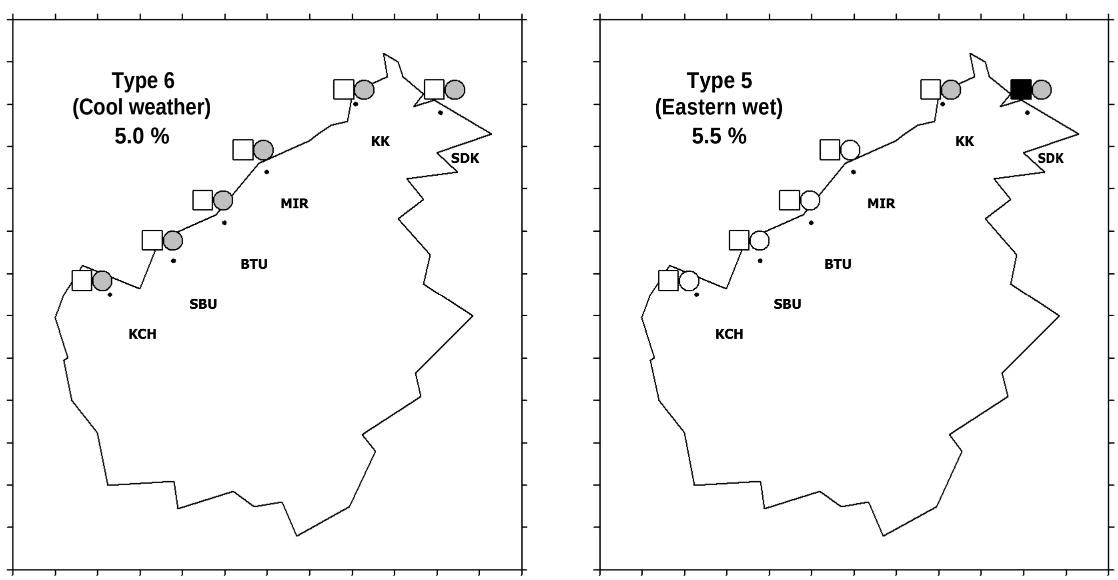


Figure 6a. *Spatial variation of temperature and precipitation for the eight significant weather types for Borneo [Type 1 – Type 4]*
(Percentage indicates the occurrence of the types subject to the overall period)

	Precipitation		Temperature
■	Above normal	●	Above normal
□	Within normal	○	Within normal
▩	Below normal	◍	Below normal



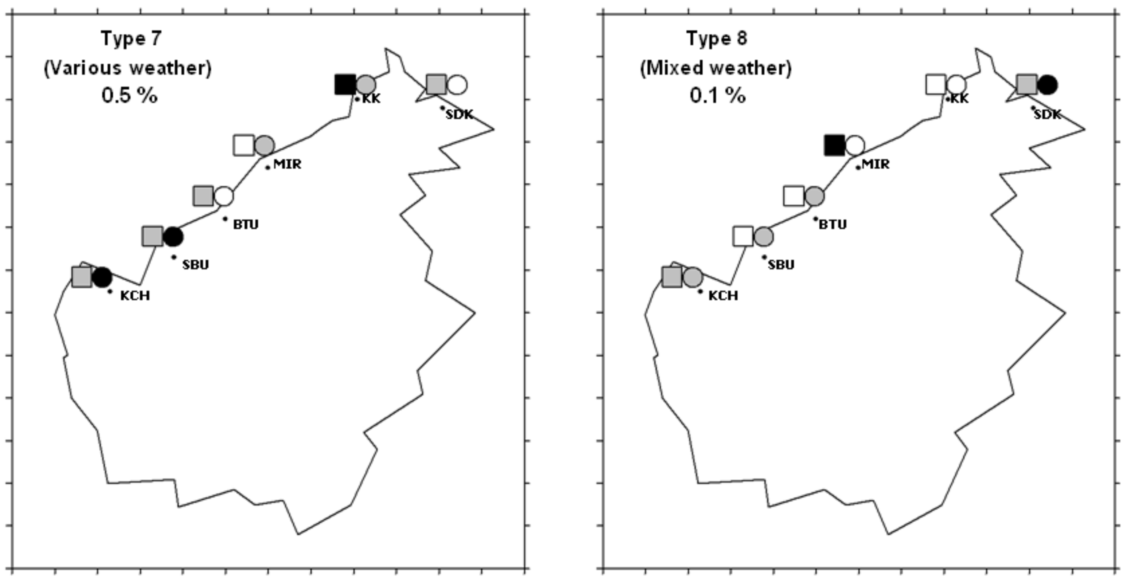


Figure 6b. *Spatial variation of temperature and precipitation for the eight significant weather types for Borneo [Type 5 – Type 8]*
(Percentage indicates the occurrence of the types subject to the overall period)

These types together comprise 29.2% of the overall variance. The most basic features of all the weather types are listed below:

- Type 1 (Normal weather): Both surface variables (temperature and precipitation) at all stations are within the normal range (≤ ± 4 mm/day for precipitation and ≤ ± 0.1°C for temperature).
- Type 2 (Hot weather): Precipitation is slightly below normal (by 4-7 mm/day) and temperature is extremely above normal (anomaly of more than 1.0□C) for all stations.
- Type 3 (Western wet): Precipitation is extremely above normal (anomaly of more than 18mm/day) for the southwestern part of Sarawak, from Bintulu to the far west of Kuching.
- Type 4 (Central Wet): Precipitation is extremely above normal (anomaly of more than 25mm/day) for the west coast of Borneo, from Kota Kinabalu and up to Bintulu.
- Type 5 (Eastern wet): Precipitation is extremely above normal (anomaly of more than 60mm/day) only for the east coast of Sabah (Sandakan).
- Type 6 (Cool weather): Temperature is extremely below normal (anomaly of more than 1.0°C) for all stations.
- Type 7 (Various weather): A very distinct mixture of various local conditions for both temperature and precipitation – rainfall is extremely below normal (anomaly of more than 50% less than average) for the southwestern part of Sarawak - from Bintulu up to Kuching; and only the west coast of Sabah (Kota Kinabalu) is above normal (anomaly of more than 35mm/day).
- Type 8 (Mixed weather): Mixture of various local conditions especially for temperature – very hot on the east coast of Sabah (Sandakan) and cold in the most western part of Sarawak (Kuching); for precipitation, significantly wet for Miri and dry for Sandakan and Kuching.

Table 8. Summary of the main daily weather types of Borneo

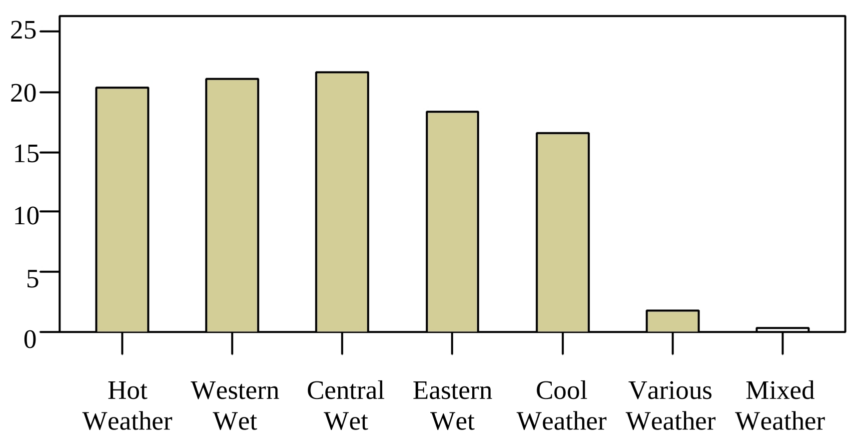
Original PC score	Weather type	Specific name	Number of occurrences	% of overall occurrences
Unclassified	Type 1	Normal weather	8712	70.2
PC1 > +1.5	Type 2	Hot weather	753	6.1
PC2 > +1.5	Type 3	Western wet	781	6.3
PC3 > +1.5	Type 4	Central wet	802	6.5
PC4 > +1.5	Type 5	Eastern wet	678	5.5
PC1 < -1.5	Type 6	Cool weather	616	5.0
PC2 < -1.5	Type 7	Various Weather	63	0.5
PC3 < -1.5	No type	Does not occur	0	0.0
PC4 < -1.5	Type 8	Mixed Weather	14	0.1

Based on 34-year data 1968-2001 (12419 days)

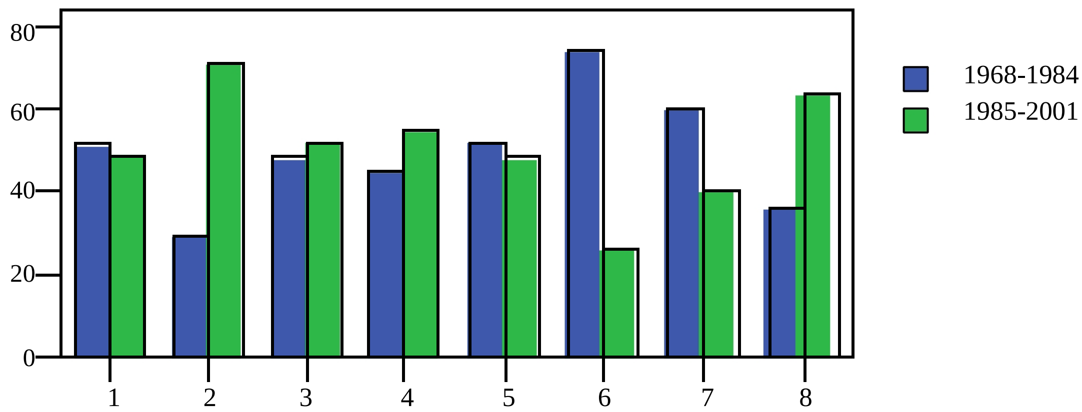
In further analysis, the probability of occurrence for each type is investigated by varying the seasonal and periodic factors (see Figure 7). The percentages of occurrence are compared between the Southwest and Northeast monsoons to determine which weather types are associated to which monsoons. The comparison is also made for two different periods (17-year each): (i) 1968 – 1984; and (ii) 1985 – 2001. This is to examine the consistency of occurrences of each type through time. The results of the comparison are shown in Table 9. The percentage values given in the table are the overall percentage of each type based on those two periods and two monsoon seasons. The T-test results are derived from the mean differences for each type based on the two comparison criteria. How is the T-test conducted?

Overall occurrences

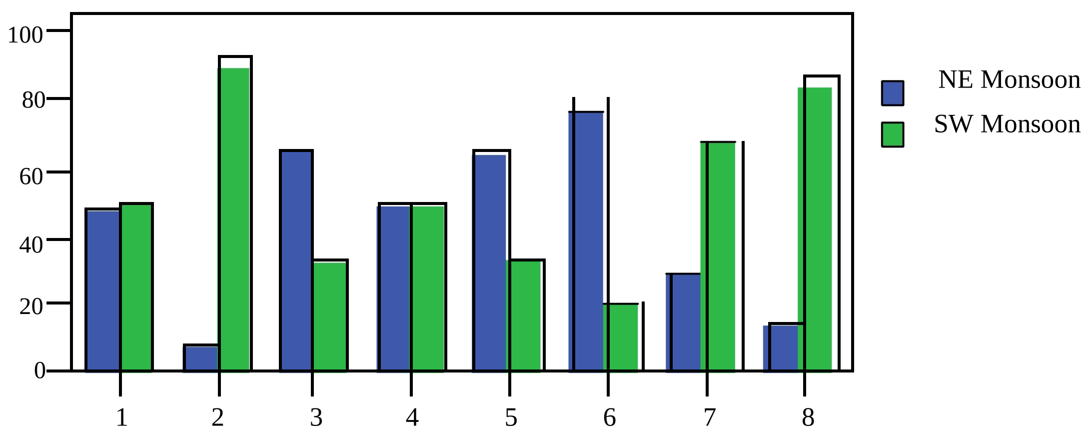
Normal Weather (Type 1) is accounted 72.2% of the days, and is not shown in this plot



Periodic comparison of 17 years (out of 34 years)



Seasonal comparison between NE and SW monsoons



Figures 7. *Histogram showing the percentages of occurrence for each weather type based on – (a) Overall occurrences; (b) Periodic comparison of 17 years (out of 34 years); and (c) Seasonal comparison between NE and SW monsoons*

Weather Types: 1 (Normal Weather), 2 (Hot Weather), 3 (Western Wet), 4 (Central Wet), 5 (Eastern Wet), 6 (Cool Weather), 7 (Various Weather) and 8 (Mixed Weather)

Table 9. Comparison of % occurrences based on different periods and seasons

Weather Type	1968-1984 (17 years)	1985-2001 (17 Years)	T-test Significance	Northeast Monsoon	Southwest Monsoon	T-test Significance
Type 1	51	49	NO	49	51	NO
Type 2	29	71	YES	8	92	YES
Type 3	48	52	NO	67	33	YES
Type 4	45	55	NO	50	50	NO
Type 5	52	48	NO	66	34	YES
Type 6	74	26	YES	79	21	YES
Type 7	60	40	NA	30	70	NA
Type 8	36	64	NA	14	86	NA

NA = T-test is not possible due to extremely low number of cases

There is no significant change for Type 1 (Normal weather) whether on a seasonal or a periodic basis (see Table 8). This normal type is distributed evenly during NE and SW monsoons; and its frequency of occurrence is consistent throughout the 34-year period. However, for the 7 other types. which contribute to the extreme variations in the local weather of Borneo. there are prominent differences in percentages of occurrence through time and season, which are summarized as below:

- Type 2 (Hot Weather): In this type The number of hot days has increased significantly in 1985-2001 compared to the period 1968-1984. It is also clear that this type of weather dominates the Southwest Monsoon with 92% of occurrence during this season. The changes in occurrence for Type 2 and Type 6 (as explained below) indicate a warming trend in Borneo.
- Type 3 (Western Wet): This type exhibits no significant changes on periodic basis. However, Type 3 occurs more during the Northeast Monsoon (67%) than the Southwest Monsoon. It means the western part of Borneo (Samarahan climatic group) does experience more wet days during the winter monsoon.
- Type 4 (Central Wet): This type denotes significant changes, either on a periodic or seasonal basis. In terms of occurrence, this type is the most consistent and not subject to change in times or seasons.
- Type 5 (Eastern Wet): This type represents significant changes on a periodic basis. It shares exactly the same nature as in Type 3 on seasonal scale. It occurs mostly during the Northeast Monsoon (66%).
- Type 6 (Cool Weather): This type is the mirror of Type 2. In the PC analysis, Type 6 (negative score) and Type 2 (positive score) are derived from the same component (PC1). Therefore, it is expected that Type 6 shows an opposite trend of occurrence compared to Type 2. Its occurrence has decreased significantly from 1968 to 2001, and has also been more dominant during the wet season (Northeast Monsoon).
- Type 7 (Various Weather): This type depicts a slight change on a periodic basis, but is not so prominent. However, it is clear that the probability of occurrence is higher during the dry season (Southwest Monsoon).
- Type 8 (Mixed Weather): This type shows significant differences both on periodic and seasonal time-scales. However, this trend might not be statistically convincing because the overall number of days (for this type) is comparatively very low (only 14 days). Thus, this low number of cases will hugely increase the possibility that any difference observed may be the result of a pure chance (as opposed to actual variance).

Main conclusion

A regional classification is an attempt to divide the region into several homogenous groups in terms of long-term average climatic behaviour (e.g. Meher-Homji, 1980). The result of the regional classification should not be affected by changes in analysis period. Temporal classification tries to group each individual day into several identified modes (e.g. Lamb, 1950; Karalis, 1969; Sheridan, 2002). These modes, which will be changing on daily basis, are described by specific spatial patterns of climatic variables, namely, precipitation and temperature.

Although these two classifications are created from different variables and different methods, they are mutually complementary to describe the behaviour of local climate in Borneo. Certain types of weather might be more associated with certain groups of climatic divisions. For instance, the spatial climatic variation in Samarahan Climatic Group (B1) describes the unique pattern of weather Type 3 (Western wet). Similarly, Type 4 (Central wet) and Type 5 (Eastern wet) are more closely associated with the variance in climate for Sepanggar (A1) and Sepilok (A2) groups. Three main climatic groups which had been refined into six sub-groups have been established to represent the Borneo region (see Table 10).

Table 10. Regional climatic groups of Borneo

Climatic group	Main characteristics
Group A Sepanggar (A1) – Sabah Sepilok (A2) – Sabah and Sarawak	Wet season starts during Southwest Monsoon and peak amplitude (high precipitation) occurs once during the Northwest Monsoon
Group B Samarahan (B1) – Sarawak Sambas (B2) – Kalimantan	Wet season starts during Northeast Monsoon and peak amplitude (high precipitation) occurs once during the Northwest Monsoon
Group C Sintang (C1) – Kalimantan Selor (C2) – Kalimantan	Wet season starts during Northeast Monsoon and peak amplitude (high precipitation) occurs more than once and during both monsoons

With respect to the temporal classification, eight local weather types, including the normal type with zero anomaly of precipitation and temperature, have been identified as the main variations of the Borneo daily climate (see Table 11).

Table 11. Daily weather types of Borneo

Weather type	Unique feature (subject to anomalies)
Type 1 (Normal weather)	Average temperature and precipitation for all stations. Equal number of occurrences when compared between the two periods (1968-1984 and 1985-2001) and the two monsoons (NE and SW Monsoons)
Type 2 (Hot weather)	High temperature for all stations. Approximately 71% of occurrences are in the second half of the period; and mostly during the SW Monsoon (92%)
Type 3 (Western wet)	High precipitation for B1 (Samarahan Group). No difference between the two periods, but on a seasonal basis more during NE Monsoon (67%)
Type 4 (Central wet)	High precipitation for coastal area from KK to BTU. No significant difference on periodic and seasonal basis
Type 5 (Eastern wet)	High precipitation for coastal areas of Sabah. Occurrences mostly during the NE Monsoon, but no difference on periodic basis.
Type 6 (Cool weather)	Low temperature for all stations. Approximately 74% of occurrences are in the first half of the period; and mostly during the NE Monsoon (79%).
Type 7 (Various weather)	Various surface conditions at some stations for both temperature and precipitation.
Type 8 (Mixed weather)	Various surface conditions at some stations especially for temperature.

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