The Creation of Specific Monsoon Indices for Borneo: RD1 and RD2[1]

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Abstract

Two main synoptic forces that govern the Southeast Asia region are the Asian Monsoon and ENSO. Many studies have been undertaken to established indices for these two large-scale circulations. Such indices will enable researchers to investigate empirical relationships between these two synoptic phenomena and the local climate of a particular region. However, all the monsoon indices that have been established so far are based on the geographical features of the south and east Asia. In order to deeply understand the local climate of Borneo – it is important to create specific indices that reflect the actual physical attributes of the region. RD1 and RD2 indices are aimed to achieve such deep understanding.

Introduction

[1] This research is part of the PhD thesis undertaken at Climatic Research Unit, University of East Anglia (United Kingdom) under the supervision of Prof. Phil Jones and Dr. Clare Goddess.

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There are two principal features of the large-scale circulation in Southeast Asia – namely the low frequency ENSO signals (2-7 years); and the seasonal monsoon modes fluctuating within the annual cycle. The main centre of action for the monsoon is the South China Sea within the area 2.5°-22.5°N and 102.5°E-122.5°E (Lu and Chan, 1999). However, the energy sources to stimulate the monsoonal flows originate from the mainland of the Asian continent (to the north), Indian Ocean (to the west), the Australian continent (to the south) and the western equatorial Pacific (to the east). ENSO, on the other hand, is a synoptic forcing that originates from the Pacific Ocean.

These two forces (i.e. the monsoon and ENSO) form and modulate the climate of Borneo (Sham Sani, 1984; Sirabaha, 1998). Therefore, in order to understand the local climate of Borneo – it is crucial to investigate how these two synoptic forces act and interact in forming large-scale circulation within the Southeast Asian region. Monsoon and ENSO are the most influential forces modulating surface climate in many part of the world (Nieuwolt, 1977; Das, 1986; Allan et al., 1996) – thus, many studies have been conducted to develop indices for both of these large-scale factors (e.g. Ropelewski and Jones, 1987; Barnston and Chelliah, 1997; Goswami et. al, 1998). The main purpose for such indices is to enable researchers to investigate empirical relationships between these two synoptic phenomena and the local climate of a particular region.

Monsoon

For the south Asian monsoon (also known as the Indian monsoon), which generally emphasizes summer rainfall, Lu and Chan (1999) identify two indices that have been successfully used to measure strong and weak monsoonal events. The first one is the all-Indian rainfall index (AIRI), which uses the precipitation average for June-September in subcontinental India (Krishnamurti, 1985). The other one is known as the WY index and is represented by the zonal wind shear between 850 and 200 hPa over Southeast Asia (Webster and Yang, 1992). Both of these indices have been improved in later work by Parthasarathy et al. (1995), and Goswami et al. (1998), and Wang and Fan (1999), respectively.

According to Lu and Chan (1999), the situation is more complicated in the case of the east and southeast Asia monsoon, which consists of three major airflows – (1) southwesterly flow (part of the Indian monsoon); (2) southeasterly flow (from the southwestern edge of the western Pacific sub-tropical high); and (3) the cross-equatorial flow over the southern part of the South China Sea (adjacent to Borneo). Whilst the summer monsoon is more dominant in the south Asia region (in terms of surface climate teleconnections – i.e. precipitation), the winter monsoon is stronger in the east and southeast Asia region (Lu and Chan, 1999; Lau et al., 2000). The monsoon in this region also shows a very distinctive wind component, which are southerly (northerly) during the boreal summer (winter).

The most well-known and widely accepted monsoon indices are listed in Appendix A. There are three issues/problems to be considered if these indices are to be used for Borneo:

(a) Most of the indices are specifically developed for either the south or east Asia regions. Ideally, as been pointed out by Wang and Fan (1999), any Asian monsoon index should be associated with the broad-scale flow of the Asian monsoon regions (this includes the Indian continent, Southeast Asia – both the mainland and the maritime continent, and East Asia). However, some researchers (e.g. Tao and Chen, 1987; Ding, 1994) stress that local manifestations can be significantly varied when the monsoon components move across different latitudes, land-sea contrast and topography.

(b) Most of the indices focus on the summer monsoon and they are based on the larger monsoon region (it normally includes both the southern and eastern part of Asia). According to Wu and Chan (1997), while the winter monsoon may be adequately represented by the planetary-scale flow, this may be questionable for the summer monsoon. Apparently, Borneo experiences equally noticeable effects during the winter and summer monsoon (Sham Sani, 1984). Therefore, a more local approach is required to find the best monsoon indices to diagnose the local climate of Borneo.

(c) All the existing indices are seasonal/annual measures except for the Unified Monsoon Indices by Lu and Chan (1999), which are calculated on a monthly basis for both monsoons. Therefore in most cases, correlation analysis could not be performed on monthly or daily values – thus, this will limit the investigation of the monsoon influences on precipitation/temperature on these time scales.

ENSO

ENSO indices are generally represented by two climatic variables – (a) the sea level pressure; and (b) sea surface temperature (SST). The well-established specific indices are listed in Table 2. Based on the published literature, it is clear that there is a consensus on what the most suitable ENSO indices are for Southeast Asia. In most of the previous studies (Quah, 1988; Cheang, 1993; Tangang, 2001; Caesar, 2002; Sirabaha, 2004), researchers have regarded the SOI (Southern Oscillation Index) and Niño-3.4 (SST anomaly for the Niño-3.4 region) as the best indices to be associated with Southeast Asia surface climate.

Table 1: Established ENSO Indices

Index	Climatic Variables	Description	Timescale
SOI	Sea level pressure (SLP)	SLP difference between Tahiti/Darwin	Monthly
Niño 1+2	Sea surface temperature (SST)	SST anomaly at the Niño-1 + 2 region	Monthly
Niño 3	Sea surface temperature (SST)	SST anomaly at the Niño-3 region	Monthly
Niño 3.4	Sea surface temperature (SST)	SST anomaly at the Niño-3.4 region	Monthly
Niño 4	Sea surface temperature (SST)	SST anomaly at the Niño-4 region	Monthly

Evaluation of established monsoon indices

The method used to evaluate the monsoon indices is a simple non-parametric correlation.[3] These indices will be correlated with surface variables of Borneo (i.e. precipitation and temperature) and also the well-established ENSO indices. There are two underlying characteristics of the monsoon phenomenon:

(a) The monsoon modulates the climate of Borneo on a seasonal basis (fluctuating within the 12-month annual cycle).

(b) The monsoon interacts with the ENSO signal, which is responsible to the occurrence of El Niño or La Niña events.

Using this knowledge, two criteria are identified to measure and justify the suitability of the monsoon indices – prior to the correlation analysis. The criteria are:

(b) The correlation between the monsoon indices and the surface variables (precipitation and temperature) must be convincing in both seasons (winter and summer monsoon). This serves as an indication of how reliable the indices are in capturing the seasonal variability.

[3] Correlation is a statistical technique meant to measure whether and how strongly pairs of variables are related. The measurement of correlation is expressed as a correlation coefficient (or "r"). These coefficients are normally reported as r = (a value between -1 and +1). If r is positive, it means that both variables move in the same direction. If r is negative it means that as one gets larger, the other gets smaller (or moving in the opposite direction).

(b) The correlation between the monsoon indices and ENSO indices (especially SOI and Niño3.4) must be highly significant. This measures the ability of the monsoon indices in phase-locking with the ENSO signals (the most prominent variability on multiyear timescales).

The results of the correlation analysis are shown in Figures 1 to 3. The following information serves as a guide for all the figures: (a) The thresholds of correlation coefficient values at 95% level of significance are 0.30 (for Monsoon-ENSO) and 0.34 (for Monsoon-Surface). The differences in threshold are due to the length of the data series: 42 years (1960-2001) for the monsoon and ENSO indices; and is only 34 years (1968-2001) for precipitation and temperatures; (b) Monsoon indices being evaluated are AIRI, RM2, WY, UMI1, UMI2 (see Table 1), and IOI (Indian Ocean Index), represented by the mean SST over Indian Ocean region bounded by 20° N–10° S and 50° E–100° E and computed in a 5° X 5° grid using the ship's observations archived by the National Data Centre of the India Meteorological Department (Tourre and White, 1994; 1996); (c) AIRI and WY are only available for the summer (SW) monsoon. Therefore, the correlation values for AIRI and WY during the winter (NE) monsoon are based on the seasonal values for the SW monsoon (i.e. with six month lag).

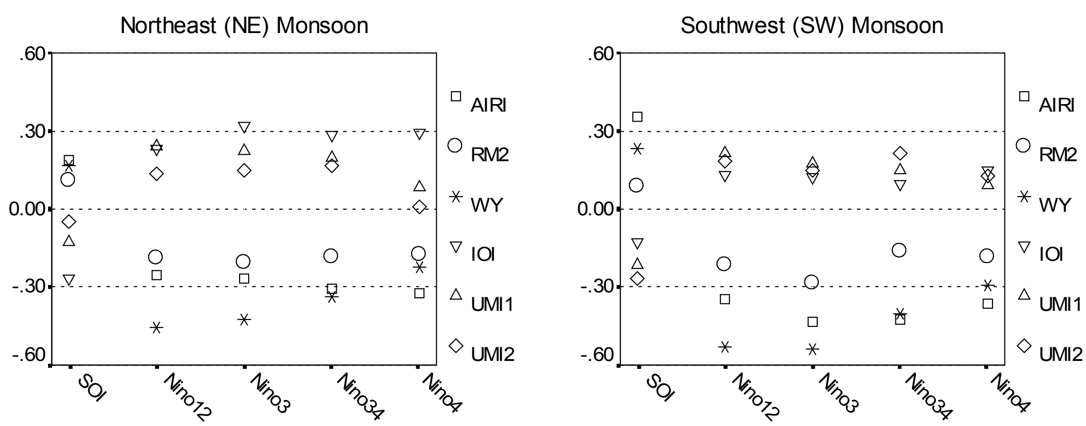

Figure 1: Correlation between selected monsoon indices (from previous studies) and well-established ENSO indices for two different monsoons

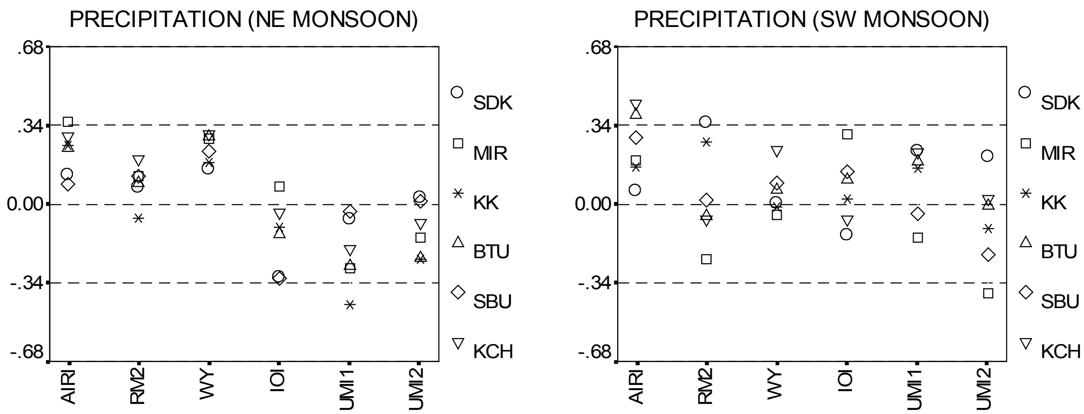

Figure 2: Correlation between selected monsoon indices (from previous studies) and precipitation at 6 key stations in Borneo for two different monsoons

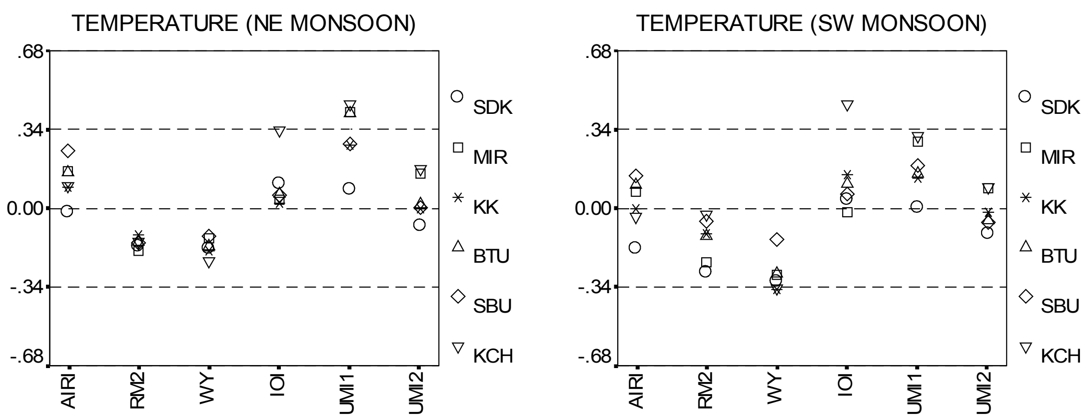

Figure 3: Correlation between selected monsoon indices (from previous studies) and temperature anomaly at 6 key stations in Borneo for two different monsoons

ENSO indices are SOI, Niño1+2, Niño3, Niño3.4 and Niño4 (see Table 1). Particular attention is given to SOI and Niño3.4, the two indices that are considered most representative of Borneo. Six key stations in Borneo are SDK (Sandakan – A1 climatic group), MIR (Miri – A1), KK (Kota Kinabalu – A2), BTU (Bintulu – B1), SBU (Sibu – B1) and KCH (Kuching – B1). In general, the chosen monsoon and ENSO indices are poorly correlated. During the winter (Northeast) monsoon, none of the indices is significantly correlated with SOI, and only WY (0.36) is statistically significant during the summer (Southwest) monsoon. As for the Niño3.4, AIRI (-0.31/-0.43) and WY (-0.34/-0.40) are significantly correlated in both seasons (winter/summer). However, all the other indices are statistically not significant.

The correlation with the surface climate of Borneo is also relatively poor. Only UMI1 shows significant correlation with more than one station (MIR, BTU, KCH) for temperature during the winter (Northeast) monsoon. The other indices have a maximum of only two stations significantly correlated in either case, with temperature or precipitation. However, none of the indices prove to be reliable for both surface variables (i.e. precipitation average and temperature anomaly) in both seasons (summer and winter).

Creation and evaluation of new monsoon indices

Upon evaluating several established monsoon indices used by previous studies (mostly using zonal and meridional upper wind shear at various gPh level), none of these indices establish convincing correlation with either the surface climate or the ENSO signals. In particular, most of the indices fail to establish reasonable teleconnections during the boreal winter – the season that supposedly manifests a stronger monsoon effect for Southeast Asia (as been reviewed by Sham Sani, 1984; Sirabaha, 1998; 2004). Therefore, it is appropriate, indeed essential, to create new indices using a more 'local approach' and focussing the centre of action within the region of Borneo (20°S-30°N; 75°E-140°E) itself. What is the justification for this new choice of so-called 'action centre'?

First, the main domain of action for the Southeast Asia Monsoon (SEAM) is between northern Australia and mainland Asia. Although there are various physical mechanisms that force the movement of the SEAM flow, the main source is the meridional thermal contrast between the northern and southern hemispheres (Lu and Chan, 1999). Since Borneo is located right on the equatorial line, the 20°S-30°N latitudinal ranges is appropriate. The second justification is to ensure consistency with the chosen synoptic window for all analyses in this thesis. Thus, this particular analysis will be empirically sounder when its results are associated with other findings in this research framework.

The synoptic variable used to create the new indices is sea level pressure (SLP). Most of the previous indices are based on upper level wind (at 1000, 850 and 250 hPa). This might be an appropriate approach to establish indices for the broader-scale monsoon region (i.e. the entire continent of South Asia or Far East Asia). However, for a smaller region like Borneo, the lower level wind is considered more effective (Sham Sani, 1973; Dale, 1959). There are two reasons why SLP is a better choice – (i) to shift the search for monsoon indices into a totally new perspective (so far, there is no established monsoon index based on sea level pressure); and (ii) SLP, being a lower level wind, has two advantages – not only the ability to reflect the large-scale signal, but also to capture the more local influences of geographical layout and land-sea distribution.

The SLP is derived from the gridded reanalysis data for the chosen window (20°S-30°N; 75°E-140°E – regarded as the monsoon action centre for Southeast Asia). Daily observations from 1960-2001 (42 years) with the grid resolution of 2.5° X 2.5° are used[4]. The two monsoon indices being created are named RD1 and RD2[5].

The first new index (RD1): SLP differences

Similar to the basic principle in creating the SOI, RD1 is a simple index using pressure differences between two identified points/areas. The two points identified are – (a) the northern latitude of 30°N; and (b) the southern latitude of 20°S. These are the starting latitudinal lines where the low-level wind changes its direction during the seasonal transition between winter and summer and vice versa (Sham Sani, 1984).

The daily values of RD1 are obtained from the differences between the averages of SLP values along the two latitudinal lines – 30°N and 20°S (27 grid-points of 2.5° X 2.5° in each line between the longitude 75°E-140°E). The can be represented mathematically as:

$$\text{RD1 Index} = \text{AVG}(\text{SLP}^{30°\text{N}})_{n=1,27} - \text{AVG}(\text{SLP}^{20°\text{S}})_{n=1,27}$$

Where,

$\text{SLP}^{30°\text{N}}$ is the averaged SLP values for 27 grid-points along the 30°N (latitude line)

$\text{SLP}^{20°\text{S}}$ is the averaged SLP values for 27 grid-points along the 20°S (latitude line)

The second new index (RD2): unrotated PC modes

This second index is more complex. RD2 values are obtained from the unrotated PC scores – the product of Principal Component Analysis (PCA) on the absolute measure of daily SLP from 1960-2001. The basic assumption in this process is that all the daily SLP gridded values at 567 grid points (evenly distributed over the chosen window) – could collectively represent the

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[4] The reanalysis data in common use are produced by the National Centers for Environmental Prediction and the National Center for Atmospheric Research (NCEP/NCAR) Reanalysis project (NCEP Reanalysis), and the European Centre for Medium Range Weather Forecasts (ECMWF). The reanalysis data chosen for this study are those produced by NCEP. Reanalysis data from this project have been used in previous studies for Southeast Asia (Caesar, 2002; Sirabaha, 2004).

[5] RD is chosen as the acronym for these new indices – which is the initial of the researcher.

monsoon mode on any particular day. The problem is, there are too many values to serve as diagnostic indices. PCA aims to reduce these variables and produce fewer significant modes, which should simplify the temporal variability. There are three important processes to achieve this goal using PCA:

- Reducing the 567 grid-point variables into fewer significant modes

- Combining the identified significant modes into one single monsoon index

- Calculating values to represent each day over the time series (these daily observations can then be converted into monthly, seasonally or annual values – depending on need)

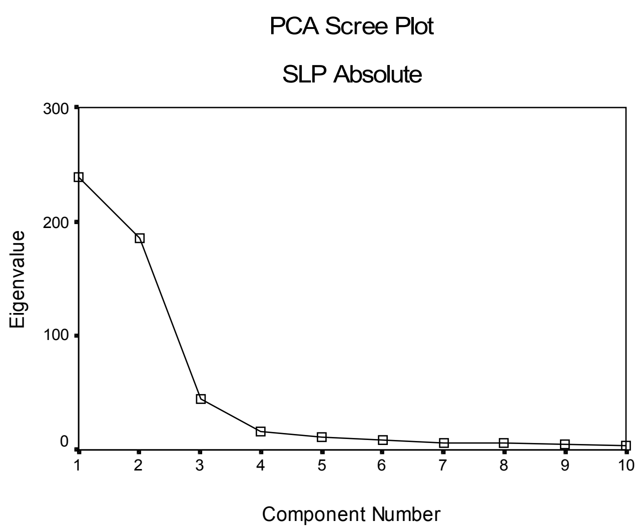

Figure 4: Scree Plot of the PCA

The core objectives neither include regionalisation nor map-pattern classification. Therefore, the most appropriate mode of decomposition is the P-mode (Yarnal, 1993). In this case, the PCA serves purely as a reduction process. Upon performing the PCA, it is found that there are four significant components that cumulatively describe a total variance of 86% (see Table 2). The criterion used to identify the significant modes is a Scree Plot (Cattell, 1966; Preisendorfer, 1988; Kostopoulou, 2004). The optimum number of PCs that should be retained is where the eigenvalue's plot bends (component number 4 in this case – see Figure 4).

Table 2: Percentage of variance explained by each PCA

	Unrotated Eigenvalues		
Retained PC	Total	% of Variance	% Cumulative
PC 1	239	42	42
PC 2	185	33	75
PC 3	45	8	83
PC 4	17	3	86

Each one of the retained components could, itself, serve as a monsoon index. However, the four components theoretically represent various physical features of the monsoon signals. Therefore, each one of them can only capture a certain fraction of the whole variability in the monsoonal flow. In order to obtain a more holistic and representative index, the calculation of the final value is done by averaging the score of all four retained components – and each component is weighted by its individual percentage of variance explained. The calculation is shown by the mathematical equation below:

RD2 Index $= [(PC_1 \bullet V_{\%1}) + (PC_2 \bullet V_{\%2}) + (PC_3 \bullet V_{\%3}) + (PC4_1 \bullet V_{\%4})] / 4$

Where;

PC is the component score of PC1, PC2, PC3 and PC4

$V_{\%}$ is the percentage of variance explained by PC1, PC2, PC3 and PC4 (see Table 3)

Evaluation of the new monsoon indices (RD1 and RD2)

These new indices will be tested as the basis of correlation performance with two other empirical climatic variables – namely the ENSO indices and the local climate (precipitation and temperature). The monthly/seasonal RD1/RD2 values that have been correlated with ENSO indices are the averaged values of all days in each month/season. These correlations are shown in Figure 5 (0.30 is the threshold for statistical significance at the 95% level). The correlations between surface climate (precipitation average and temperature anomaly) is shown in Figures 6 and 7 respectively (0.34 is the threshold for statistical significance at the 95% level).

In comparison with the previously established indices (Figures 1 to 3), the correlation results clearly indicate that these two new indices (RD1 and RD2) have shown far better performance (both with respect to local climate and ENSO indices). Based on overall correlation performance, it can be concluded that the best index from the previous indices (i.e. WY) is poorer than the worst of the newly created indices (i.e. RD1).

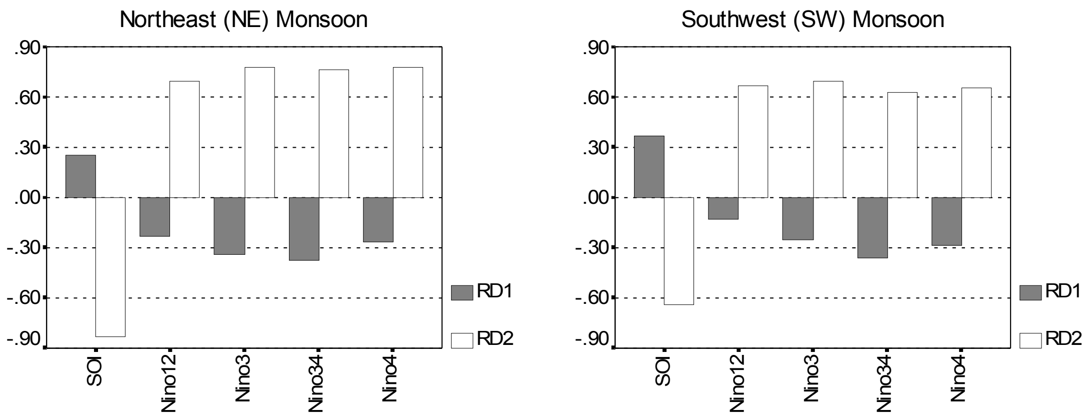

Figure 5: Correlation between RD1/RD2 and ENSO indices

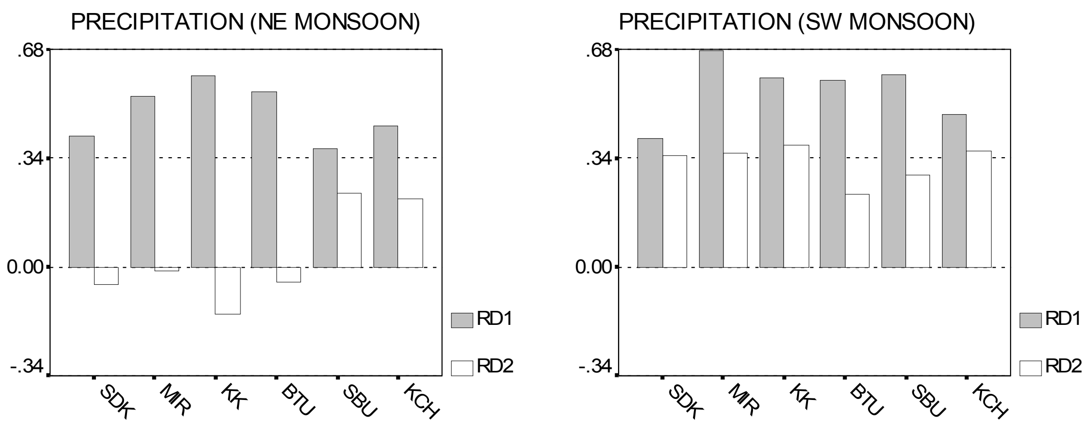

Figure 6: Correlation between RD1/RD2 indices and Borneo seasonal precipitation

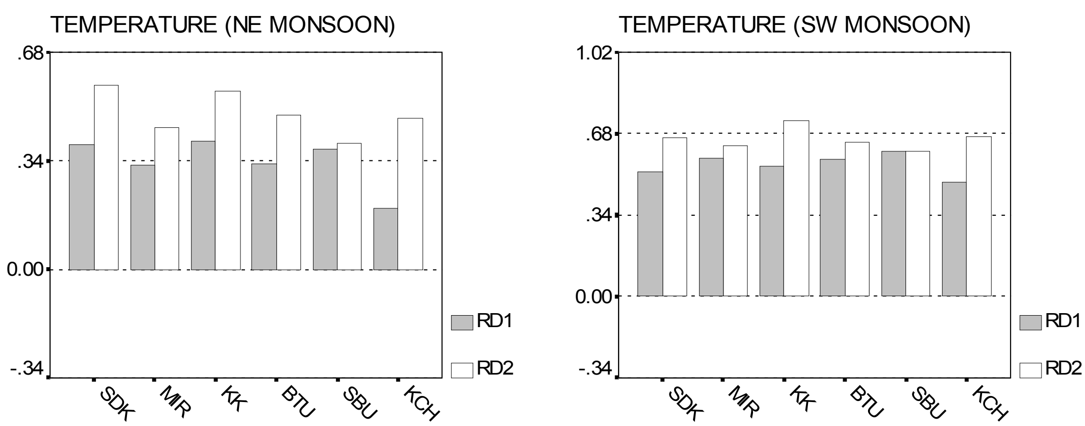

Figure 7: Correlation between RD1/RD2 indices and Borneo seasonal temperature anomaly

Of the two indices, RD1 is better correlated with precipitation; whereas RD2 is better correlated with temperature anomaly and the ENSO indices. Both indices also show much better association during the winter (NE) monsoon, as opposed to the previous indices – which are clearly biased to the summer monsoon. The results for RD1 and RD2 are summarised in Tables 3 and 4. The highest correlation between ENSO indices and the old monsoon indices (during the NE Monsoon) are: SOI – IOI (-0.27), Niño12 – WY (-0.46), Niño3 – WY (-0.42), Niño3.4 – WY (-0.34) and Niño4 – AIRI (-0.33. The highest correlation during the SW Monsoon are: SOI – AIRI (0.36), Niño12 – WY (-0.53), Niño3 – WY (-0.54), Niño3.4 – AIRI (-0.43) and Niño4 – AIRI (-0.36). RD2 proves to perform better than any of these monsoon indices (from previous studies).

Table 3: Correlation values for RD1/RD2 during the winter (NE) monsoon

3a Correlation coefficients with ENSO indices

	SOI	NIÑO12	NIÑO3	NIÑO34	NIÑO4
RD1	0.24	-0.23	-0.34*	-0.38*	-0.26
RD2	-0.84*	0.70*	0.78*	0.77*	0.78*

3b Correlation coefficients with precipitation

	SDK	MIR	KK	BTU	SBU	KCH
RD1	0.41*	0.53*	0.60*	0.55*	0.37*	0.44*
RD2	-0.05	-0.01	-0.15	-0.05	0.23	0.21

3c Correlation coefficients with temperature anomalies

	SDK	MIR	KK	BTU	SBU	KCH
RD1	0.39*	0.33	0.40*	0.33	0.38*	0.19
RD2	0.58*	0.45*	0.56*	0.49*	0.40*	0.47*

Values marked with (*) are statistically significant, at least, at the 95% level

Table 4: Correlation values for RD1/RD2 during the summer (SW) monsoon

4a Correlation coefficients with ENSO indices

	SOI	NIÑO12	NIÑO3	NIÑO34	NIÑO4
RD1	0.37*	-0.13	-0.25	-0.36*	-0.29
RD2	-0.64*	0.67*	0.70*	0.63*	0.66*

4b Correlation coefficients with precipitation

	SDK	MIR	KK	BTU	SBU	KCH
RD1	0.40*	0.68*	0.59*	0.58*	0.60*	0.48*
RD2	0.35*	0.35*	0.38*	0.23	0.29	0.36*

4c Correlation coefficients with temperature anomalies

	SDK	MIR	KK	BTU	SBU	KCH
RD1	0.52*	0.58*	0.54*	0.57*	0.61*	0.48*
RD2	0.66*	0.63*	0.73*	0.64*	0.61*	0.67*

Values marked with (*) are statistically significant, at least, at the 95% level

These new indices (RD1 and RD2) are also correlated fairly well with some of the previous monsoon indices, particularly the UMI1 and RM2 indices – as shown in Figure 8 (0.30 is the threshold for statistical significance at the 95% level).

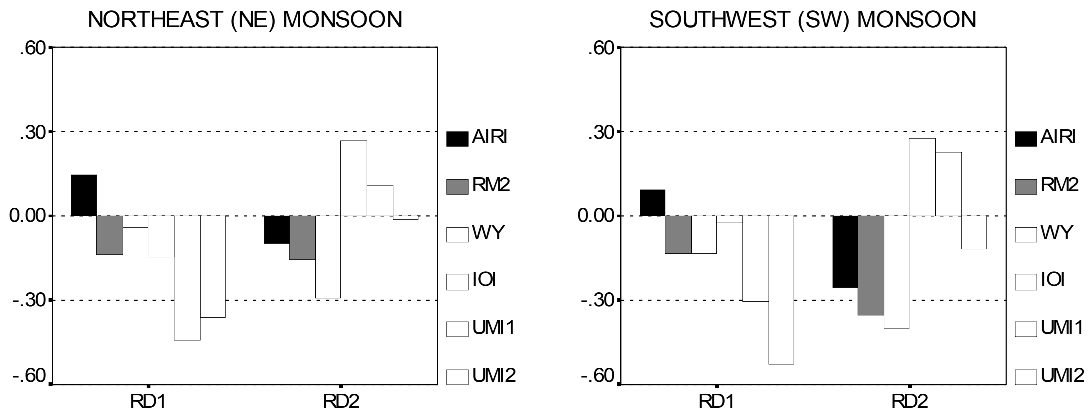

Figure 8: Correlation between RD1/RD2 and other monsoon indices

Conclusion

Two newly-created monsoon indices have been introduced – RD1 and RD2 (specifically created to suit the local climate of Borneo). The advantages of using these new indices are: (i) the indices are developed using lower level circulation (SLP) which is closely related to Borneo physical and geographical layout, instead of the upper level winds at geopotential heights of 200mb, 850mb and 1000mb (as with earlier indices); (ii) the indices are calculated on a daily timescale, which makes them flexible to be transformed into monthly or seasonal measures – depending on the purposes and aims of any analysis; (iii) the indices are shown to have stronger correlations with both the ENSO indices and local climatic variables (i.e. precipitation magnitude and temperature anomaly); and (iv) the indices exhibit reasonable correlations with other established monsoon indices – suggesting that the method used to develop these new indices has a sound theoretical foundation (i.e. consistent with previous studies).

Appendix A

List of well-established monsoon indices

Author	Index	Climatic variables used to establish indices	Monsoon region	Time-scale & Season
Webster and Yang (1992)	Webster and Yang Monsoon Index (WYI**)	The time-mean zonal wind (U) shear between 850 and 200 hPa (U850 – U200); averaged over south Asia from the equator to 20°N, and from 40°E to 110°E	Large-scale Asian monsoon region and South Asia region (excluding northern Bay of Bengal and a portion of south China)	Seasonal values for Summer Monsoon
Parthasarathy et al. (1995)	All Indian Rainfall Index (AIRI**)	Seasonally averaged rainfall over all Indian sub-divisions from June-September (1871 – 1995)	South Asia region (excluding northern Bay of Bengal and a portion of south China)	Seasonal values for Summer Monsoon
Goswami et al. (1998)	Monsoon Hadley Circulation index (MH)	The time-mean meridional wind (V) difference between 850 and 200 hPa (V850 – V200); averaged over the region of 10°N-30° N and 70°E-110°E	South Asia region (including northern Bay of Bengal and a portion of south China)	Seasonal values for Summer Monsoon
Wang and Fan (1999)	Convection Index (CI1 and CI2) Difference in Zonal (U) Wind (DU2)	CI1: negative outgoing longwave radiation (OLR) anomalies over the region of 10°N-25° N and 70°E-100°E CI1: negative OLR anomalies over the region of 10°N-25°N and 115°E-140°E DU2: meridional (U) wind difference at 850 hPa between region 5°-15°N; 90°E-130°E and region 22.5°-32.5°N; 110°E-140°E	CI1 for south Asian summer; CI2 and DU2 for southeast Asian summer monsoon	Seasonal values for Summer Monsoon
Lu and Chan (1999)	Unified Monsoon Index (UMI1**, UMI2**, UMI3)	UMI1: difference between meridional wind at 1000 hPa and 200 hPa (V1000 – V200) UMI2: the monthly average of meridional wind component at 1000 hPa UMI3: monthly average of meridional wind component at 200 hPa All calculations are over the region of South China Sea (2.5°-22.5°N; 102.5°E-122.5°E)	UMI1, UMI2 and UMI3 mainly for East Asia region	Monthly values for both monsoons (summer and winter)
Lau et al. (2000)	Regional Monsoon Index (RMI1 and RMI2**)	RMI1: the time-mean meridional wind (V) difference between 850 and 200 hPa (V850 – V200); averaged over the region of 10°N-30° N and 70°E-110°E RMI2: the time-mean zonal wind (U) at 200 hPa between region 40°N-50°N; 110°E-150°E and region 25°N-32.5°N; 110°E-150°E	RM1 for South Asia region and RM2 for East and Southeast Asia region	Seasonal values for Summer Monsoon

*Indices marked with ** are chosen in the comparison analysis in Section 6.3*

Bibliography

Allan, R.J., Lindesay, J.A., and Parker, D.E., 1996. 'El Niño Southern Oscillation and climatic variability', CSIRO Publishing: Collingwood, Victoria.

Barnston, A.G. and Chelliah, M., 1997. 'Documentation of a highly ENSO- related SST region in the equatorial Pacific'. *Atmosphere-Ocean*, 35, no.3, 367-383.

Caesar, J., 2002. 'The influence of sea surface temperature patterns on the winter monsoon over Southeast Asia'. PhD Thesis, University of East Anglia.

Cattell, R.B., 1966. 'The scree test for the number of factors'. *Multivariate Behavioral Research*, 1, 245-276.

Cheang, B.K., 1993. 'Interannual variability of monsoons in Malaysia and its relationship wit ENSO', *Proceedings of the Indian Academy of Science-Earth and Planetary Sciences*, 102, no.1, 219-239.

Cheang, B.K., 1993. 'Interannual Variability of Monsoons in Malaysia and its Relationship with ENSO'. *Proc.Indian Acad.Sci.(Earth Planet Sci.)* 102, 219-239. India.

Das, PK., 1962. Monsoons, Fifth WMO Lecture, WMO No. 613, World Meteorological Organisation, Geneva. 115 pp.

Davies T.D., Farmer, G. and Barthelmie R.J. 1990. 'Use of simple daily atmospheric

Ding, Y.H., 1990. 'Build-up, air mass transformation and propagation of Siberian high and its relations to cold surge in east Asia'. *Meteorological Atmospheric Physics*, 44, 281-292.

Ding, Y.H., 1994. 'Monsoon over China'. Kluver Academic Publishers, Dordrecht.

Goswami, B.N. and Wang, B., 2000. 'Commentary and analysis'. *Bulletin of the American Meteorological Society*, Vol. 81, No. 4, 821-824

Goswami, B.N., Krishnamurty, V. and Annamalai, H., 1999. 'A broad-scale circulation index for the interannual variability of the Indian summer monsoon', *Quarterly Journal for Royal Meteorological Siciety*, 125, 611-633.

Krishnamurti, T.N. Bedi, H.S. and Subramaniam, M.1989. 'The summer monsoon of 1987'. *Journal of Climate*, 2, 321-340.

Krishnamurti, T.N., 1971. 'Tropical east-west circulations during the northern summer'. *Journal of Atmospheric Science*, 28, 1342-1347.

Lau, K.-M., K.-M. Kim, and S.Yang, 2000. 'Dynamical and boundary forcing characteristics of regional components of the Asian summer monsoon'. *J. Climate*, 13, 2461-2482.

Lu, E. and Chan, C.L., 1999. 'A unified monsoon index for South China'. *Journal of Climate*, 12, 2375-2385.

Niewolt, S., 1977. Tropical climatology – an introduction to the climate of the low latitudes. John Willey & Sons, London.

Parthasarathy, B., Munot A.A., and Kotawale, D. R., 1995. 'Monthly and seasonal rainfall series for all-India homogenous regions and meteriological sub-divisions: 1871-1994'. Res. Rep. No. RR-065, Indian Institute of Tropical Meoeorology, Pune, India, 113pp.

Preisendorfer, P.W., 1988. Principal Components Analysis in Meteorology and Climatology. Elsevier, 425 pp.

Preisendorfer, P.W., Zwiers, F.W. and Barnett, T.P., 1981. 'Foundations of Principal Component Selection Rules'. *SIO Reference Series* 81-7, Scripps Institute of Oceanography, La Jolla, CA, 200pp.

Quah, L.C., 1988. 'ENSO and anti-ENSO Related Precipitation Response over Malaysian Region', *a working paper presented at the WMO/ASCA winter monsoon workshop*, Kuala Lumpur, 27 June-2 July 1988.

Ropelewski, C.F. and Jones, P.D., 1987. 'An extension of the Tahiti-Darwin Southern Oscillation Index'. *Monthly Weather Review*, 115, 2161-2165.

Sham Sani, 1984. Beberapa Aspek Iklim Negeri Sabah (Several Aspects of Climate in Sabah). Kajian Etnografi Sabah Jilid 8 (Enthnography Study of Sabah Volume 8). Bangi, Malaysia, Universiti Kebangsaan Malaysia – Yayasan Sabah.

Sirabaha, S. and Ceaser, J., 2000. Significance of the El Niño Southern Oscillation (ENSO) for Southeast Asia. *A paper presented at the Workshop on the Impact of El Niño-la Niña on Southeast Asia*, CERED, IGCN, APNGCR, UEA at Hanoi, Vietnam: 21-23 February 2000.

Sirabaha, S., 1998. The El Niño Southern Oscillation (ENSO) Impact on Interannual Rainfall Variability in Borneo Island. PhD Thesis, University of East Anglia.

Sirabaha, S., 2004. The Influence of El Niño Southern Oscillation on Climate in Southeast Asia. PhD Thesis, University of East Anglia.

Tangang, F., 1999. 'Empirical Orthogonal Function Analysis of Precipitation Anomaly in Malaysia. Malaysian'. *Journal of Analytical Sciences* 5, 155-165. Bangi, Universiti Kebangsaan Malaysia.

Tangang, F, 2001. 'Low Frequency and Quasi-Bienniel Oscillations in the Malaysian Precipitation Anomaly'. *International Journal of Climatology*, 21, 1199-1210

Tao, S.Y. and Chen, L.X., 1987. 'A review of recent research of the East Asian summer monsoon in China', *in Monsoon Meteorology*, Eds: C.P.Chnag and T.N Krishnamurti, Oxford University Press, 60-92.

Wang, B., and Z. Fan, 1999: 'Choice of South Asian monsoon indices'. *Bull. Amer. Meteor. Soc.* 80, 629-638.

Webster, P.J. and Yang, S., 1992. 'Monsoon and ENSO; selectively interactive system'. *Quarterly Journal of Royal Meteorological Society*, 118, 877-926.