香港天文台
HONG KONG OBSERVATORY

Reprint 586

Regime Shift in Summer Rainfall in Southern China

Y.K. Leung & M.C. Wu

Seventh Joint Meeting of Seasonal Prediction on
East Asian Summer Monsoon, Nanjing, China, 11-13 May 2005

Regime Shift in Summer Rainfall in Southern China

LEUNG Yin Kong[1], WU Man Chi
Hong Kong Observatory
134A Nathan Road, Tsimshatsui, Hong Kong, China

1. Introduction

Interannual and interdecadal variations in summer rainfall over South China have been investigated by Chan and Zhou (2005) as well as others. However, variations in rainfall from the perspective of regime shift seems to have been less studied. A ‘regime shift’ is characterized by an abrupt transition from one quasi-steady climatic state to another, and its transition period is much shorter than the lengths of the individual epochs of each climatic state (Yasunak and Hanawn, 2002).

Using Principal Component Analysis (PCA) (Wilks, 1995) and Cumulative Summation (CuSum) analysis (Murodoch, 1979), this paper examines the regime shifts in rainfall in southern China between 1952 and 2003. Whether similar shifts are present in the South China Sea Summer Monsoon and the subtropical ridge, both of which greatly influence rainfall in southern China (Lu and Chan, 1999; Chang et al., 1999) are also examined.

Two regime shifts were identified in summer rainfall in southern China in this study. The first, occurring in the mid 1970s, coincided with a change in phase of the Pacific Decadal Oscillation (PDO) described by Mantua et al. (1997) and ushered in a dry spell.

The second regime shift occurred in the early 1990s, and coincided with a simultaneous regime shift in the South China Sea Monsoon as characterized by the summer Unified Monsoon Index (UMI) of Lu and Chan (1999). This regime shift ended the dry spell and marked the start of a wet spell.

---

[1] Leung Yin Kong, tel.: (852) 2926 3112, fax: (852) 2311 9448, email: jykleung@hko.gov.hk

The first regime shift and the dry phase were also found to coincide with a southward displacement of the latitudinal position of the subtropical ridge from its mean position. In contrast the second regime shift and the wet phase were found to coincide with a northward displacement of the subtropical ridge.

2. Data

52 years of rainfall data between 1952 and 2003 from Hong Kong, Macau, and Guangzhou, Shantou, Shaoguan, Meixian, Heyuan, Yangjiang and Zhanjiang in Guangdong are used to represent the rainfall in southern China. These stations are shown in Figure 1. The rainfall data for Hong Kong and Macau are obtained from the Hong Kong Observatory and Macao Meteorological and Geophysical Bureau respectively. Rainfall data for the seven stations in Guangdong are sourced from the National Climate Centre (NCC) of China Meteorological Administration (CMA).

Lu and Chan’s (1999) summer Unified Monsoon Index (UMI) for South China, defined as the JJA-averaged meridional wind at 1000 hPa averaged over the northern part of the South China Sea, 7.5°-20°N, 107.5°-120°E, is used to characterize the strength of the South China sea summer monsoon. UMI is computed from the United States National Centers for Environment Prediction-National Center for Atmospheric Research (NCEP-NCAR) re-analysis data (Kalnay et al., 1996).

The latitudinal position of the 500 hPa subtropical ridge can be represented by the subtropical high ridge-line index (SHI) which is available from NCC. SHI is defined as the mean latitude of the ridge-line of 5880 gpm contour in the region 110°-150°E and computed by averaging the values of latitude of the ridge-line at longitudes 110°E, 115°E, 120°E, 125°E, 130°E, 135°E, 140°E, 145°E and 150°E.

3. Methodology

PCA has the advantage of allowing the 52 years of rainfall observations at the nine stations to be reduced to a few major or principal components for analysis. When the data being subjected to PCA are observations over time at different stations, each principal component is represented by an eigenvector which reflects the regional variation in that component, and a time series which reflects the variation with time of that component. Details can be found, for example, in von Storch and Zwiers (1999), and Wilks (1995).

Following Murodoch (1979), the cumulative summation (CuSum) technique is used to detect the presence of regime shifts. At any given point in time, the CuSum is defined as the accumulating sum of anomalies (from the overall mean) of all preceding values. Regime shifts are represented by persistent and significant changes in slopes in the CuSum.

4. Results

The results of PCA show that the first principal component (PC1) accounted for 53% of the total variance (Figure 2a). The amount of variance explained decreases rapidly with the second (14%) and third (8%) principal components. Thus, information in the southern China rainfall field is contained largely in the first principal component (PC1). The eigenvector and time series associated with this principal component is taken to be representative of rainfall over southern China as a whole.

The elements of the eigenvector of PC1 is shown in Figure 2b. They are all positive and with similar magnitudes. This suggests that the regional variation in summer rainfall in southern China as characterized by PC1 is small.

Figure 3 shows the time series of PC1. Neither t-test nor the non-parametric Mann-Kendall test indicates any overall trends in this time series. However, changes in the mean state, i.e., regime shifts, does seem to have occurred around the mid-1970s, as well as around the early 1990s.

The presence of these regime shifts is confirmed by CuSum analysis (Figure 4). In this figure, there are apparently two significant changes in slope corresponding to the two major regime shifts. The first was in 1976/77 and marked the start of a dry phase. The second was in 1992/93 which put an end to the dry phase and ushered in a wet phase.

The first regime shift was associated with a change in the phase in the PDO (Chan and Zhou, 2005). In the mid-1970s, the PDO switched from a negative phase (the waters in the central North Pacific are warm, and the waters along the west coast of North America are cool) to a positive phase (the waters in the central North Pacific are cool, and the waters along the west coast of North America are warm). It has far-reaching consequences for large marine eco-system in the North Pacific (Mantua et al., 1997; Hare and Mantua, 2000).

The second regime shift coincided with a similar regime shift in the South China Sea Summer Monsoon. This is shown in the CuSum for the UMI (Figure 5). Possible regime shifts in the East Asian Monsoon, of which the South China Sea Monsoon is an important sub-component, have not been examined because none of the indices commonly used to characterize its strength had a statistically significant correlation (at 5% level) with PC1. The correlations of PC1 with the East Asian Summer Monsoon Index (EASMI, Zhang et al., 2000), South China Tropical Monsoon Index (STMI, Zhao et al., 1999), Western North Pacific Monsoon Index (WNPMI, Wang et al., 2001), and Regional Monsoon Index (RM2, Lau et al., 2000) are -0.17, -0.17, 0.11 and 0.09 respectively. UMI was found to correlate significantly (0.42) with PC1.

Likewise, Figure 5 shows that the average latitudinal positions of the subtropical ridge following the first and second regime shifts are 23.8°N and 24.9°N respectively against the 1952-2003 normal of 24.6°N. Thus, the dry phase is related to regime shift in the position of the subtropical ridge in the form of a southward displacement from its mean summer position, and the wet phase a northward displacement.

5. Conclusion

Two major regime shifts in the summer rainfall in southern China have been identified during the period 1952 to 2003. The first regime shift ushered in dry spell between the mid-1970s and early 1990s after which the second regime shift set in, and a relatively wet spell started.

Similar regime shifts after the mid-1970s are observed in the monsoon index as well as the position of the subtropical ridge indicating likely relationship among the three.

References

Chan, J.C.L., and W. Zhou, 2005: PDO, ENSO and the early summer monsoon rainfall over south China. *Geophysical Research Letter*, **32**, L08810, doi:10.1029/2004GL022015.

Chang, C.P., Yongsheng Zhang, and Tim Li, 1999: Interannual and Interdecadal Variations of the East Asian Summer Monsoon and Tropical pacific SSTs. Part I: Roles of the Subtropical Ridge. Journal of Climate, 13, 4310-4325.

Hare, Steven R., and Nathan J. Mantua, 2000: Empirical evidence for North Pacific regime shifts in 1977 and 1989. *Progress in Oceanography*, **47**, 193-145.

Kalnay, E., and Coauthors, 1996: The NCEP/NCAR 40-year reanalysis project. *Bulletin of American Meteorological Society*, **77**, 437-471.

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

Lu, E., and C.L. Chan, 1999: A Unified Monsoon Index for South China. *Journal of Climate*, **12**, 2375-2385.

Mantua, Nathan J., Steven R. Hare, Y. Zhang, J.M. Wallace, and R.C. Francis, 1997: A Pacific interdecadal climate oscillation with impacts on salmon production. *Bulletin of American Meteorological Society*, **78**, 1069-1079.

Murodoch, J., 1979: Control charts. Macmillian Press Ltd., London, United Kingdom.

Von Storch, Hans, and Francis W. Zwiers, 1999: *Statistical Analysis in Climate Research*. Cambridge University Press, 484 pp.

Wang, B., R. Wu, and K.M. Lau, 2001: Interannual variability of the Asian summer monsoon: contrasts between the Indian and the western North Pacific – East Asian monsoons. *Journal of Climate*, **15**, 4073-4090.

Wilks, Daniel S., 1995: *Statistical Methods in the Atmospheric Sciences*, *An Introduction*. Academic Press, 467pp.

Yasunaka Sayaka, and Kimio Hanawa, 2002: Regime shifts found in the Northern Hemisphere SST field. *Journal of the Meteorological Society of Japan*, Vol.**80**, No.1, 119-135.

Zhang, Q., L. Chen, S. Tao, and Y. Qiao, 2000: Definition and prediction of the East Asian monsoon, and the Asian atmospheric circulation. In *On the research of Short-Range Climate Prediction System in China*, Part 4: Formulation of Short-Range Climate Monitoring; Prediction; Operational Services System. Meteorological Press, 169-184 (In Chinese).

Zhao, H., X. Zhang, and Y. Ding, 1999: Zhongguo Xiaji Hanlao Ji Huan Jing Chang. Meteorological Press, 297 pp (In Chinese).

Figure 1. Locations of the nine rainfall stations in southern China used in this study.

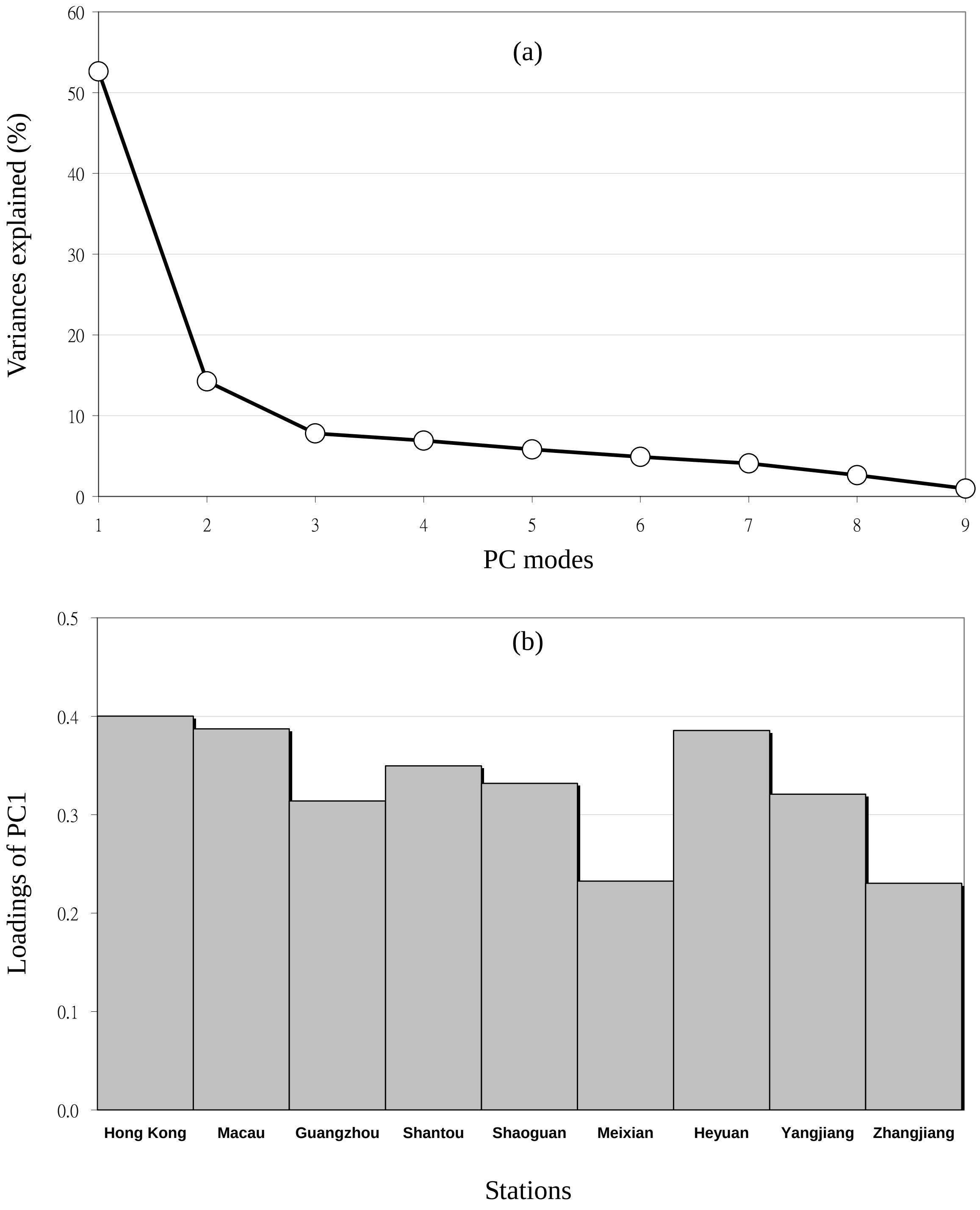

Figure 2. (a) Variances explained by each PC mode in PCA analysis. (b) Spatial loading of PC1 for the nine rainfall stations in Guangdong.

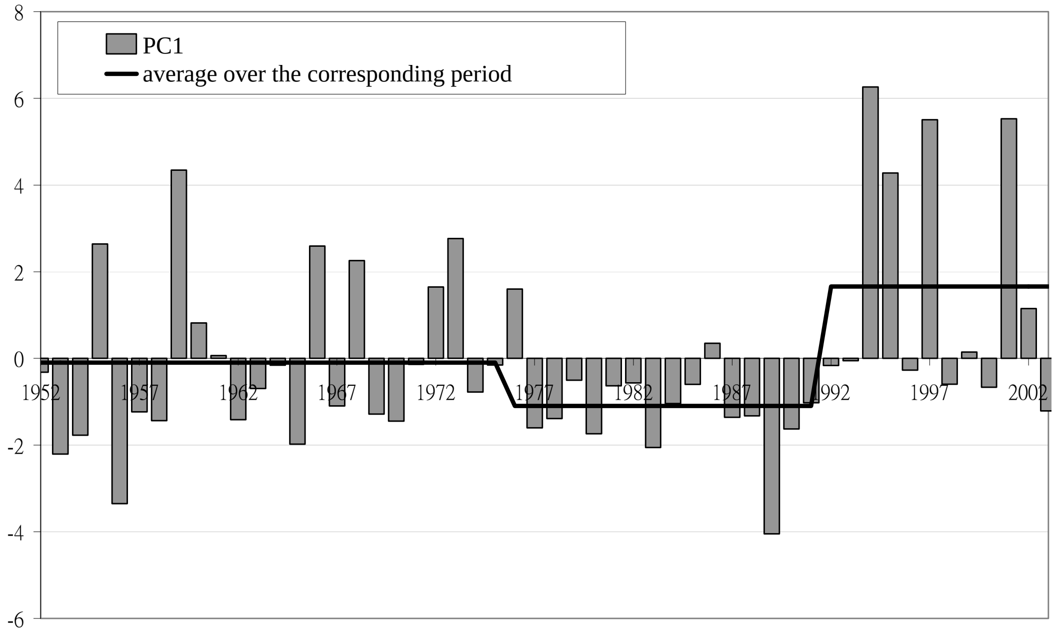

Figure 3. Histogram showing the temporal variation of PC1. The solid black line shows the mean states between 1952 and the mid-1970s, mid-1970s to early 1990s, and early 1990s to 2003.

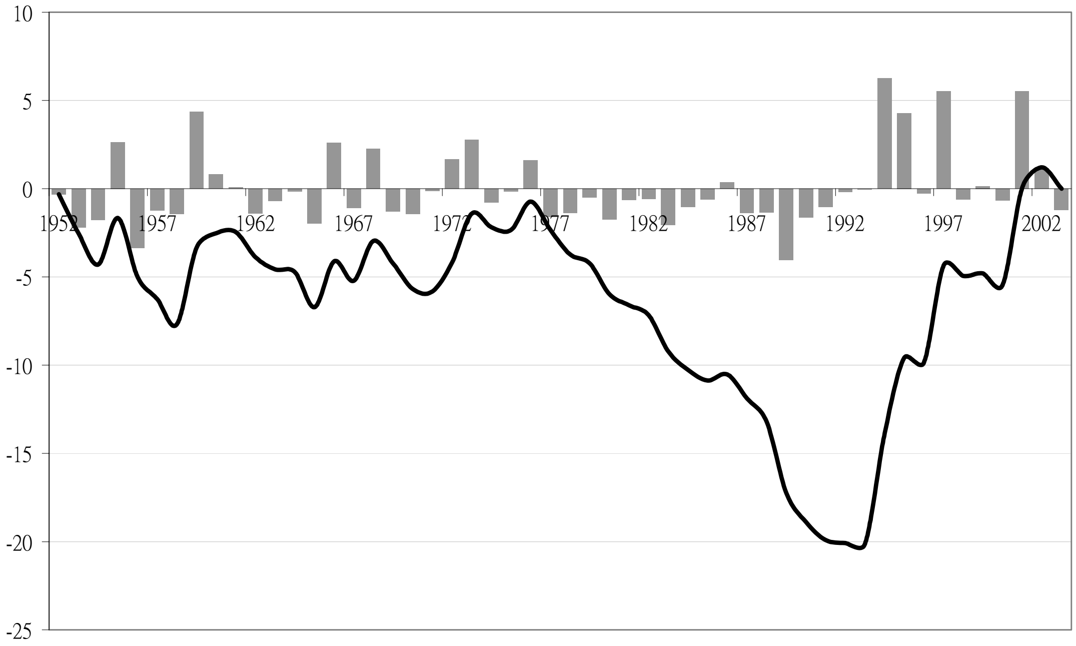

Figure 4. CuSum plot (black line) of PC1 superimpose on the historgram. Apparent change in slopes are noted by 1976/77 and 1992/93, which correspond to the year of regime shift.

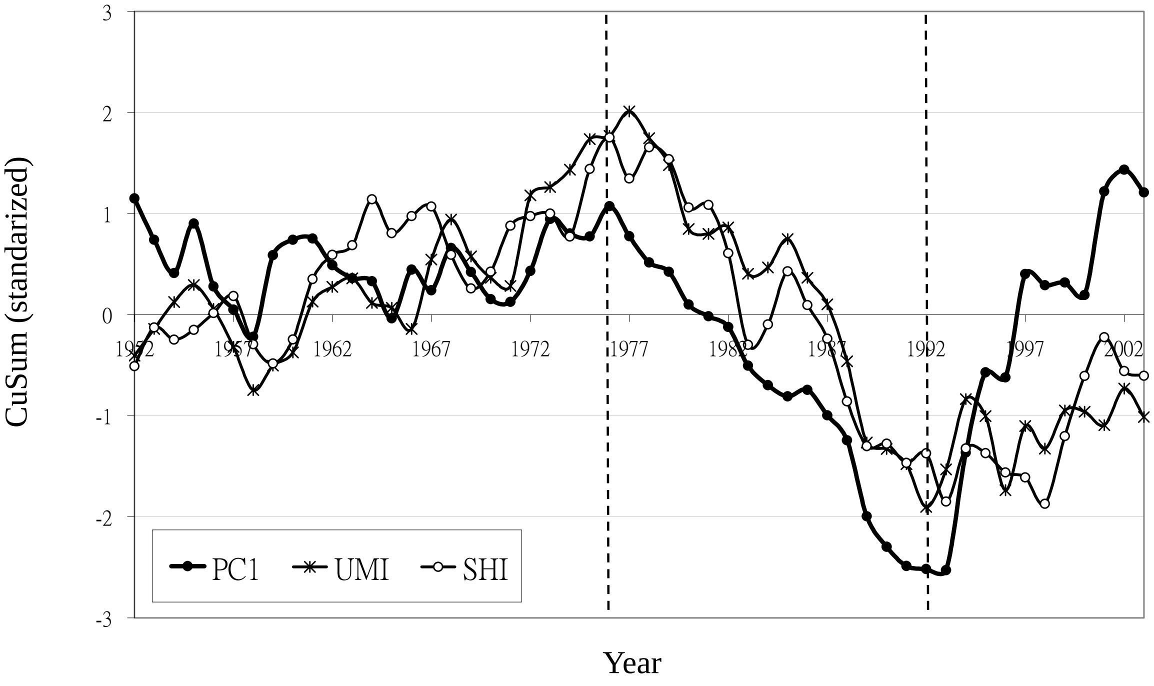

Figure 5. CuSum charts for PC1, UMI and SHI. Values for each time series are standardized for easily comparison. The two vertical dashed lines locate the years of regime shifts in mid-1970s and early 1990s.