INTERNATIONAL JOURNAL OF CLIMATOLOGY
Int. J. Climatol. **20**: 803–809 (2000)

SHORT COMMUNICATION

SEASONAL VARIATION OF THE RAINFALL OVER TAIWAN

MING-CHENG YEN[a] and TSING-CHANG CHEN[b,*]
[a] *Department of Atmospheric Science, National Central University, Chung Li, Taiwan*
[b] *Atmospheric Science Program, Department of Geological and Atmospheric Sciences, Iowa State University, Ames, IA, USA*

ABSTRACT

Two different approaches [empirical orthogonal function (EOF) analysis and rainfall regime identification] were applied to analyse the seasonal variation in Taiwan rainfall using 15 coastal stations administrated by the Central Weather Bureau of Taiwan, during the period 1981–1997. The major findings are as follows:

Using the EOF analysis, the major seasonal variations in Taiwan rainfall may be shown as a seasonal seesaw in rainfall between the southern and northern Taiwan modes following the alternation of the two East Asian monsoon components. The former mode is associated with the summer southwest monsoon, while the latter with the winter northeast monsoon.

Four (spring, summer, summer–fall and fall–winter) rainfall regimes are identified by the second approach: the four regimes cover northwest, southwest, east, and northeast Taiwan, respectively. The southern Taiwan mode is primarily formed by the second rainfall regime, while the northern Taiwan mode by the fourth. The seasonal variation in Taiwan rainfall is formed by the transition of these four rainfall regimes; this is reflected by a counter-clockwise rotation in these rainfall regimes around the island. Copyright © 2000 Royal Meteorological Society.

KEY WORDS: rainfall; seasonal variation; Taiwan

1. INTRODUCTION

As a subtropical island (22–25.5°N) within the western Pacific island chain, Taiwan experiences an annual variation in climate. This variation is established basically by the alternation of two monsoon components: the summer southwest monsoon and the winter northeast monsoon. Regardless of its size (about 150 km wide and 400 km long), this island has a complex geographic structure (which will be illustrated later in Figure 3) consisting of three major north–south oriented elements (the Chianan Plain in the west, the Central Mountain Range in the middle, and the narrow Hua-Tung Valley in the east), and two other small valleys (Taipei in the north and Lanyang in the northeast). The alternation of two monsoon components over Taiwan may simply form two separate rainy seasons: summer and winter. On the contrary, the complicated geographic structure of Taiwan results in a complex seasonal variation of rainfall in different regions across this island. The Central Weather Bureau (CWB) of Taiwan administrates 26 stations over Taiwan. Fifteen of these stations are located around the coastal zone of the island. Despite quality rainfall measurements being available for CWB stations, few attempts (e.g. Wang *et al.*, 1984) have been made to examine the seasonal variation in Taiwan rainfall in accordance with the transition of two monsoon seasons.

Recently, the Taiwan CWB made available to the authors the rainfall measurements at 26 stations for the period 1981–1997. An effort was made to explore the seasonal transition of rainfall in this sub-tropical island between the two monsoon components. This effort was performed with two diagnostic

* Correspondence to: Department of Atmospheric Sciences, National Central University, Chung Li, Taiwan 32054.

approaches: (i) the empirical orthogonal function (EOF) analysis and (ii) the rainfall regime identification using 15 coastal stations. The first approach was used to identify the two major rainfall regimes belonging to the summer and winter monsoons, respectively. The second approach is supplemented with a time station diagram of rainfall to illustrate the transition of these two major rainfall regimes. The purpose of this short note is to report the results obtained in this study with an emphasis on the interaction between the two monsoon components and the orography of Taiwan.

2. MONSOON TRANSITION

The low-level winds and rainfall in monsoon key regions are often used as indices of the monsoon evolution (e.g. Fein and Stephens, 1987). Thus, the alternation of the summer and winter monsoons in East Asia, along with the seasonal change in rainfall across Taiwan will be illustrated using these two variables.

According to Ramage (1971), a monsoon is defined as a circulation system with the reversal in wind direction of more than 120° once a year. As indicated by the seasonal mean streamline charts over East Asia (Figure 1(a) and (b)), southwesterlies in the summer yield to northeasterlies in the cold seasons. Since Taiwan is embedded in the East Asian monsoon system, the transition between the two monsoon components can be seen in the surface wind of reporting stations. Therefore, we select two stations:

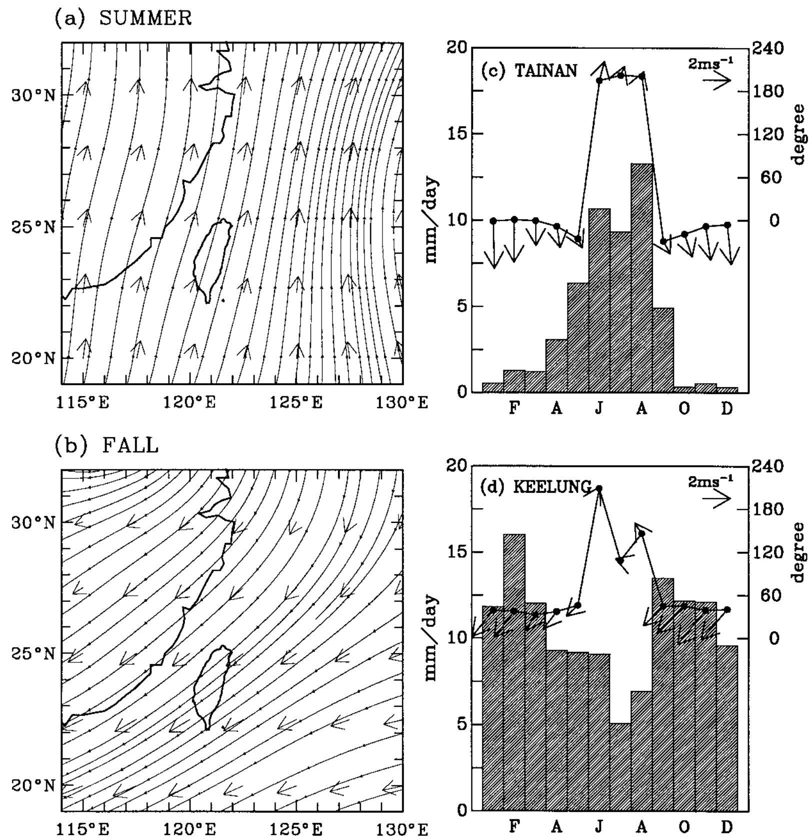

Figure 1. Seasonal mean 925-mb streamline charts (for the period 1981–1997) in (a) summer and (b) winter, and histograms of monthly mean rainfall (averaged over 1981–1997) at (c) Tainan (denoted by a dot in (a)) and (d) Keelung (denoted by a dot in (b)). The monthly mean surface wind vector and the wind direction (thin solid line) are also superimposed on the corresponding rainfall histogram. The phase of wind direction is defined clockwise with northerly at 0°

Tainan in southwest Taiwan (denoted by a dot in Figure 1(a)) and Keelung (denoted by a dot in Figure 1(b)) in north Taiwan. Vectors and directions (thin line) of monthly mean surface winds at these two stations are displayed in Figure 1(c) and (d), respectively. The onset of the Meiyü season generally occurs between 15 May and 31 May (e.g. Tao and Chen, 1987), when northeasterlies are reversed to southwesterlies. Because the monsoon northeasterlies are stronger in speed than the monsoon southwesterlies, it is not surprising to see that the monthly mean wind vectors at these two locations are still weak northeasterlies at Keelung and northwesterlies at Tainan in May. Based upon the direction of surface wind vectors, the transition from one monsoon to the other is relatively sudden. Inspection of the surface winds reveals that the southwest monsoon exists only during the summer seasons (May–August). In contrast, the northeast monsoon persists over the rest of the year. Regardless of its geographic complexity, the transition from one monsoon to the other over the entire island (as indicated by surface winds at the two stations) seems to be simultaneous.

Histograms of monthly mean rainfall at Tainan (southwest Taiwan) and Keelung (north Taiwan) are also displayed in Figure 1(c) and (d), respectively. Summer is the wettest season in southwestern Taiwan, although this is reversed over northern Taiwan. This opposite-phase seasonal variation in rainfall is relatively common to a number of regions in South and Southeast Asia (e.g. Nieuwolt, 1977). However, the interesting feature associated with the Taiwan rainfall is the existence of the opposite-phase seasonal variation between two regions of a moderate sized island, despite the uniform transition in the two monsoons over Taiwan.

3. SEASONAL VARIATION OF RAINFALL

As indicated by rainfall histograms at Tainan (Figure 1(c)) and Keelung (Figure 1(d)), the alternation of the two rainfall regimes is a result of the alternation in the northeast winter and the southwest summer monsoons with an apparent enhancing effect by the orography (outlined in Section 1). Of course it may not be completely legitimate to define two rainfall regions over all of Taiwan based on only two stations. The following questions are raised: (i) What is the geographic coverage of these two rainfall regimes, and (ii) how does the transition of two rainfall regimes behave following the alternation of the two monsoons? These questions will be answered by the following analyses: (i) the EOF analysis of rainfall, and (ii) the seasonal march of rainfall around the coastal zones of Taiwan. The EOF analysis provides a concise view of the major seasonal variation modes in Taiwan rainfall, while the second approach illustrates the transition between these seasonal variation modes. Results are reported in the following sections.

3.1. EOF analysis

After removing their annual mean values, the rainfall departures of all 15 CWB stations along the coastal zone are subjected to EOF analysis. Details concerning the EOF analysis are referred to Kutzback (1967). Displayed in Figure 2 are the eigencoefficient (C1 and C2) time series and eigenvectors (E1 and E2) of the first two principal eigenmodes. Based upon variance explained by these two eigenmodes (58% and 34.3%, respectively), the seasonal variation in Taiwan rainfall can almost be portrayed. The temporal variation of the Cs and the spatial structure of the Es reveal two distinct rainfall modes: *southern Taiwan* and *northern Taiwan* modes. Comparison between the C1 time series with the rainfall histogram of Tainan (Figure 1(c)) reveals that the summer monsoon rainfall in Taiwan is represented by the first eigenmode. In contrast, the comparison between the C2 time series and the Keelung rainfall histogram (Figure 1(d)) indicates that the autumn rainfall is represented by the second eigenmode.

Though the majority of the variance (92.3%) of seasonal rainfall variation over Taiwan is explained by the first two eigenmodes, two interesting features concerning Taiwan rainfall are missing

(i) The winter and spring rainfall are not represented by the first two eigenmodes, as indicated by the C1 and C2 time series.

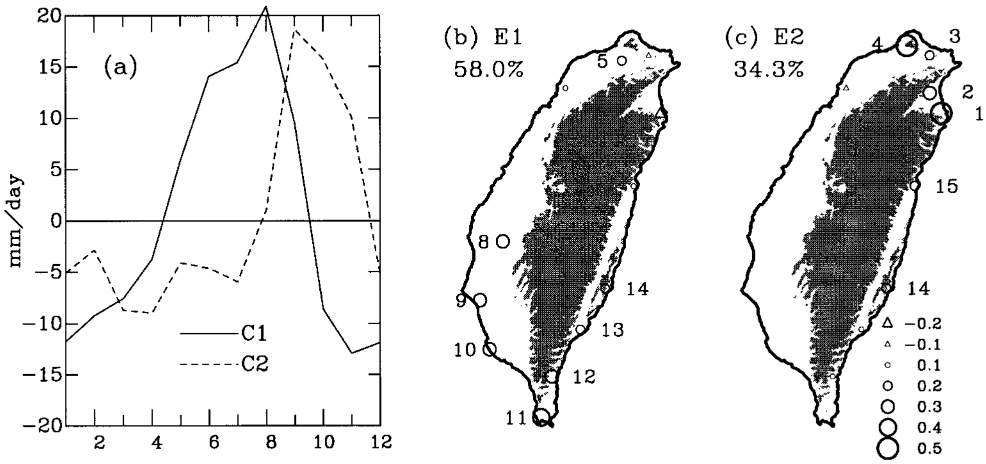

Figure 2. The first two principal eigenmodes of rainfall at 15 CWB stations (a) eigencoefficient time series are denoted by C1 (solid line) and C2 (dashed line), while eigenvectors are marked by open circles for positive anomalies and open triangles for negative anomalies in (b) E1 and (c) E2. The orography higher than 500 m is stippled. Locations of 15 CWB stations are shown in Figure 3, while those stations with values of eigenvector larger than 0.2 are marked by station numbers

(ii) Neither E1 nor E2 show any significant rainfall value for stations in northwestern or northeastern Taiwan.

As these two features of seasonal rainfall variations over Taiwan are missing, it becomes obvious that the winter and spring rainfall in northwestern and northeastern Taiwan (occurring between the two rainfall modes) is not represented by the first two eigenmodes. However, the rainfall in these regions during winter and spring may be regarded as the seasonal transition component between the southern and northern Taiwan modes.

3.2. Time station diagram of rainfall

Rainfall histograms of all 15 CWB stations are shown in Figure 3. Recall that the seasonal rainfall variations are opposite in phase between Tainan (southern Taiwan) and Keelung (northern Taiwan). Based upon the contrast of seasonal rainfall variations between these two stations, we number the CWB stations counter-clockwise, with Suao as Station 1 and Hualien as Station 15. Using the EOF analysis of Taiwan rainfall (Figure 2) as a reference, we separate the seasonal rainfall variation of this island into two regimes: (i) the cold-maximum rainfall regime, including Stations 1–4, and (ii) the warm-maximum rainfall regime, including Stations 5–15. Let us compare the rainfall histograms of 15 CWB stations (Figure 3) in further detail with the EOF analysis: a numerical value of 0.3 will be used as a criterion in determining whether the rainfall at a given station is a significant contributor to the eigenvector. With this criterion, we subjectively classify the following regimes based on the month of maximum rainfall occurrence:

(i) spring regime: Stations 5–7
(ii) summer regime: Stations 8–12 (coincident with E1)
(iii) summer–fall regime: Stations 13–15
(iv) fall–winter regime: Stations 14 (coincident with E2)

The seasonal march of Taiwan rainfall essentially follows the order of these four rainfall regimes. Regimes (i) and (iii) are the transition between those represented by eigenvectors 1 and 2.

As revealed by rainfall histograms in Figure 3, the transition of rainfall regimes in Taiwan is formed geographically by a counter-clockwise rotation in the four rainfall regimes around the island. It appears that rainfall regimes (ii) and (iv) following the alternation of the two monsoon components are created by

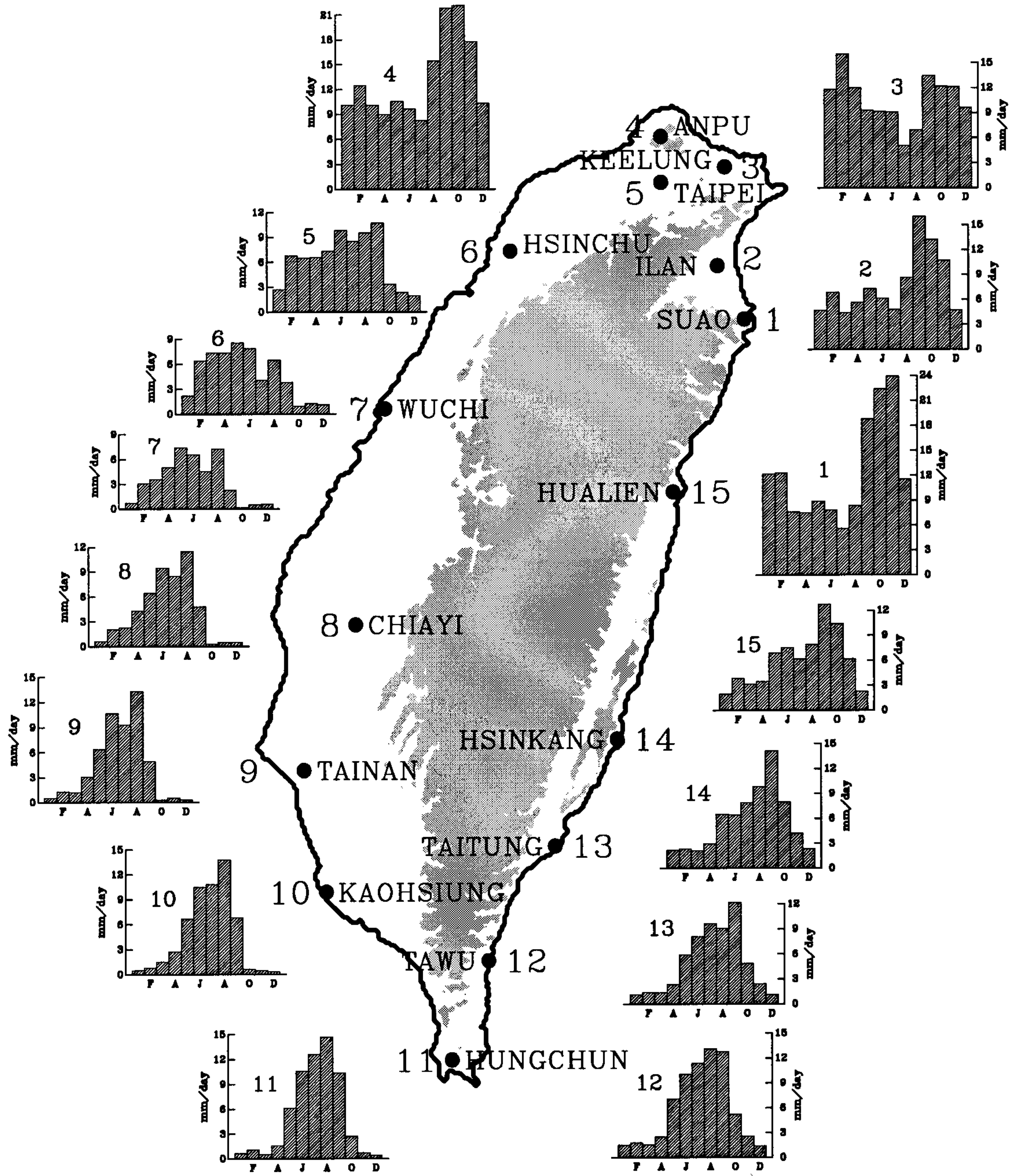

Figure 3. Rainfall histograms at all 15 CWB surface stations within the coastal zone around Taiwan. Every CWB station is numbered. The orography of Taiwan is stippled in the same way as Figure 2. The Taiwan geographic structure is formed by three major north–south oriented elements (the Chianan Plains in the west, including Stations 7–10; the Central Mountain Range in the middle; and the narrow Hua-Tung Valley in the east stretching southwestward from Station 15 to Station 3, and other two small valley (Taipei in the north, including Stations 3 and 5; and Lanyang in the northeast, including Stations 1 and 2)

the presence of the Central Mountain Range to form a complex seasonal march of rainfall around such a moderate sized sub-tropical island. However, in order to summarize concisely the counter-clockwise rotation of the four rainfall regimes over Taiwan, a time station diagram of rainfall is shown in Figure 4. The rotation of maximum rainfall occurrence around the island is in accordance with the seasonal

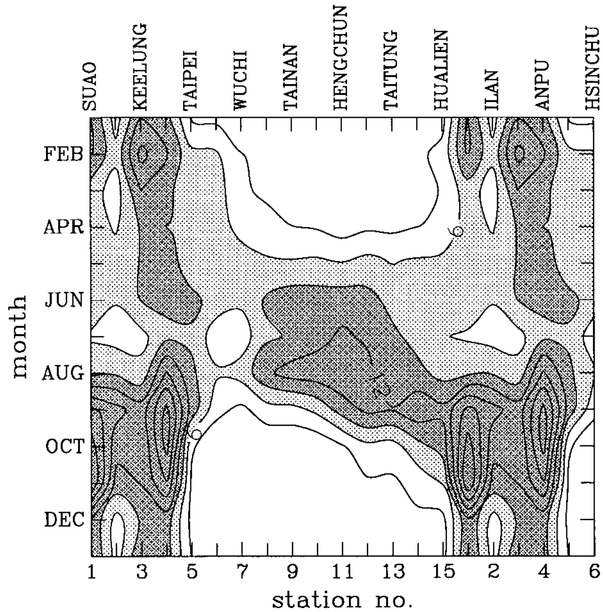

Figure 4. A long-term mean (1981–1997) time station diagram of rainfall for the 15 CWB stations shown in Figure 3. Values of monthly mean rainfall (P) are stippled in the following manner: 6 mm day$^{-1} \leq P \leq 9$ mm day^{-1} and 9 mm day$^{-1} \leq P$ are lightly and heavily stippled, respectively

rainfall march. This can be seen by observing the maximum rainfall values along the diagonal direction in this figure.

4. CONCLUDING REMARKS

Climatologically, the seasonal variation of climate over Taiwan, a sub-tropical island in East Asia (or the western North Pacific), is subjected to the alternation of two monsoon components: the summer southwest and winter northeast monsoon. Therefore, Taiwan rainfall should undergo a seasonal seesaw following the monsoon alternation. Actually, this simple hypothesis is complicated due to the presence of the north–south oriented Central Mountain Range. In other words, the basic seasonal variation of Taiwan rainfall between extreme climate conditions of the two monsoon components is essentially formed by a counter-clockwise rotation of four rainfall regimes around Taiwan over a 1-year cycle. In spite of the moderate geographic size of Taiwan, the seasonal variation in rainfall over this island interestingly exhibits a complicated, but orderly fashion due to its special geographic structure and the climatic influence by the two monsoon components.

A better understanding of the seasonal variations in Taiwan rainfall is certainly important to the planning of many human activities in this island, including agriculture, transportation, commerce, fishery, and so on. However, for climate research, the well-documented seasonal variation in Taiwan rainfall would facilitate an exploration into the interannual variation of regional rainfall and its physical link with the interannual variation of the large-scale circulation over the Asian monsoon region. Also, the four rainfall regions within Taiwan provide us with an excellent example for testing the orographic effect on regional climate simulations (e.g. Giorgi and Mearns 1991; McGregor 1997).

ACKNOWLEDGEMENTS

This study is partly supported by the NSF Grant ATM-9906454 of the USA and the NSC Grant 89-2111-M-008-033 of Taiwan. The authors thank Mrs Reatha Diedrichs for her typing support and Mr Seth Loyd for his editing assistance.

REFERENCES

Fein JS, Stephens PL. 1987. *Monsoons*. Wiley: New York.

Giorgi F, Mearns L. 1991. Approaches to the simulation of regional climate change: a review. *Research in Geophysics* **29**: 191–216.

Kutzback JE. 1967. Empirical eigenvectors of sea-level pressure, surface temperature, and prediction complexes over North America. *Journal of Applied Meteorology* **6**: 791–802.

McGregor JL. 1997. Regional climate modeling. *Meteorologic and Atmospheric Physics* **63**(1–2): 105–117.

Nieuwolt S. 1977. *Tropical Climatology*. Wiley: New York.

Ramage CS. 1971. *Monsoon Meteorology*. Academic Press: New York.

Tao S-Y, Chen L-S. 1987. A review of recent research on the East Asian summer monsoon in China. In *Monsoon Meteorology*, Chang CP, Krishnarnurti TN (eds). Oxford University Press: Oxford; 60–92.

Wang S-T, Cheng H, Chao Y-K. 1984. Natural seasons of the weather in the Taiwan area. *Atmospheric Science (Taiwan)* **11**: 101–120.

