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SECULAR VARIATION OF RAINFALL OVER THE ISLAND OF TAIWAN

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ABSTRACT. Kraus's and Lamb's theory of the strength of Ferrel westerlies is employed as a possible explanation for the secular decline and rise of rainfall observed in Taiwan from 1900 to 1968. Four types of secular variation are identified within about seventy years of records. Even though combined effects of topographies and weather systems caused local variations, from approximately 1900 to 1930 a consistent secular decline in rainfall accompanied an increase in Ferrel westerly strength, and, from that time to 1968 a secular rise in rainfall accompanied a decline in Ferrel westerly strength.

Secular rainfall variations comprise a topic of interest to many scholars. Kraus (1955 a and b) found that an abrupt rainfall decrease occurred at the end of the 19th century in the tropics and along the east coast of the subtropics, e.g. the east coasts of North America and Australia. This dry condition terminated during the 1930's and 40's for different stations. In contrast, Arakawa (1956 a and b) pointed out that a wet period in the higher middle latitudes, e.g. China, Korea and Japan, commenced around 1900 and terminated about 1930. Both Kraus's and Arakawa's findings have been confirmed by Lamb (1959, 1961, 1966) in his sequential studies relating climatic variations to the general circulation. He found that the abnormal strengthening of the westerlies during the first 3 decades of this century caused a dry period in the low latitudes and a wet period in the higher middle latitudes.

Though neither Kraus nor Lamb studied the rainfall variation of Taiwan, located off China's southeast coast, a trend similar to those of eastern North America and Australia could be expected. In a detailed study of secular variation of precipitation over monsoon Asia, Yoshimura (1971) placed Taiwan in one single region in terms of the amplitude of the secular variation for January and two regions for July. However, the secular rainfall variation in Taiwan was more complicated than what Yoshimura stated. The complexity of the combined elements of varied landforms, transitional location between the large continent and ocean, and the peculiar monsoon and trade systems in the island created distinctive regional patterns of the secular rainfall variation. The purpose of this paper is thus to discuss the regionality of the secular rainfall variation in Taiwan and relate that variation to the general

circulation in order to see if there is a conformity with both Kraus's and Lamb's theory regarding the secular rainfall variation over many regions of the world.

METHOD

In general, there are two common methods used to study the secular rainfall variation, e.g. the moving average curve and the residual mass curve. Kraus (1955a) pointed out that the method of moving average suffered a disadvantage that a single extreme value might affect considerably the long-term mean. Grant (1952) also pointed out that the moving average process tended to shift the phase of some of the shorter fluctuations and resulted in a reverse trend of the original series.

In the current study, the residual mass curves of the annual rainfall for the seven stations of the island where records from the turn of this century to 1968 are available are plotted. One advantage of using residual mass curves is that the fixed mean used for calculation needs not be a true long-term average (Barnes, 1919). Attention is paid to the shape of the curve. A period with an average rainfall above the chosen mean is reflected by a rising or concave curve, whereas a period with an average rainfall below the chosen mean is reflected by a descending or convex curve. The residual mass is expressed in terms of the cumulative percentage deviation from the mean rainfall and is calculated by the following formula,

$$Yi = 100 \sum_{1}^{i}\left(\frac{Ri}{\bar{R}} - 1\right) - 100 \sum_{1}^{I}\left(\frac{Ri}{\bar{R}} - 1\right)$$

where Yi = the cumulative percentage deviation from the mean rainfall for the ith year
Ri = the rainfall for the ith year
$\bar{R}$ = the mean rainfall for the standard 60-year period 1909-1968
I = the year 1908

REGIONALIZATION

Figure 1 shows the annual residual mass curves for the seven stations. These are located in different sections of the island and well represent the Taiwan's rainfall regimes in terms of the seasonal variation. Four types of the secular rainfall variation can be easily identified by the trends of the residual mass curves. These are:

(1) The winter monsoon type, which shows a dry period between the turn of this century and the 1940's and a wet period since. The stations of Keelung and Hwalain belong to this type.

(2) The summer monsoon type, which shows a dry period from the late 1890's into the 1930's, a wet period between the 1930's and about 1960, and again a dry period since 1960. The stations of Hengchun, Tainan and Taichung belong to this type.

(3) The trade wind type, which shows rainfall peaks at 1918 and 1950, a trend similar to stations in the Pacific side of Japan (Sekiguti, 1964). The station of Taitung belongs to this type.

(4) The intermediate type, which shows no significant dry and wet periods. The station of Taipei belongs to this type.

PHYSICAL CAUSES

Both Kraus (1956 a and b) and Lamb (1966) found that secular rainfall variations over various regions of the world were connected with the general circulation. The dry period at the beginning of this century in the tropics and the subtropics was caused by the strengthening of Ferrel westerlies, culminating in about 1925. In contrast, the wet period after the 1940's was caused by the weakening of the westerlies in the middle latitudes. The strength of Ferrel westerlies was usually expressed by zonal index which was defined by Rossby (1939) as the surface pressure difference between 35 and 55 degree latitudes.

The island of Taiwan is located in the subtropics, which are characterized by increasing rainfall during periods of low zonal index when the belt of the strongest westerly wind is shifted toward the subtropics. Variation in the zonal index reflects the shift in the latitudinal distribution of the momentum rather than the change in the absolute value, because there is a conservative nature of the total momentum of the mid-troposphere westerlies for a given time (Namias, 1950). Both Liu (1966) and Wei (1968) pointed out that wet winter months in Taiwan were usually associated with a pronounced increase in the westerly wind speed at the 200 mb level. The wet period during the 1940's and 50's for all stations on the island was associated with the weakening of the westerlies observed by Girs (1963) and Lamb (1966).

It is interesting to note that the secular rainfall variation at the station of the trade wind type indicated a wet period starting at the turn of this

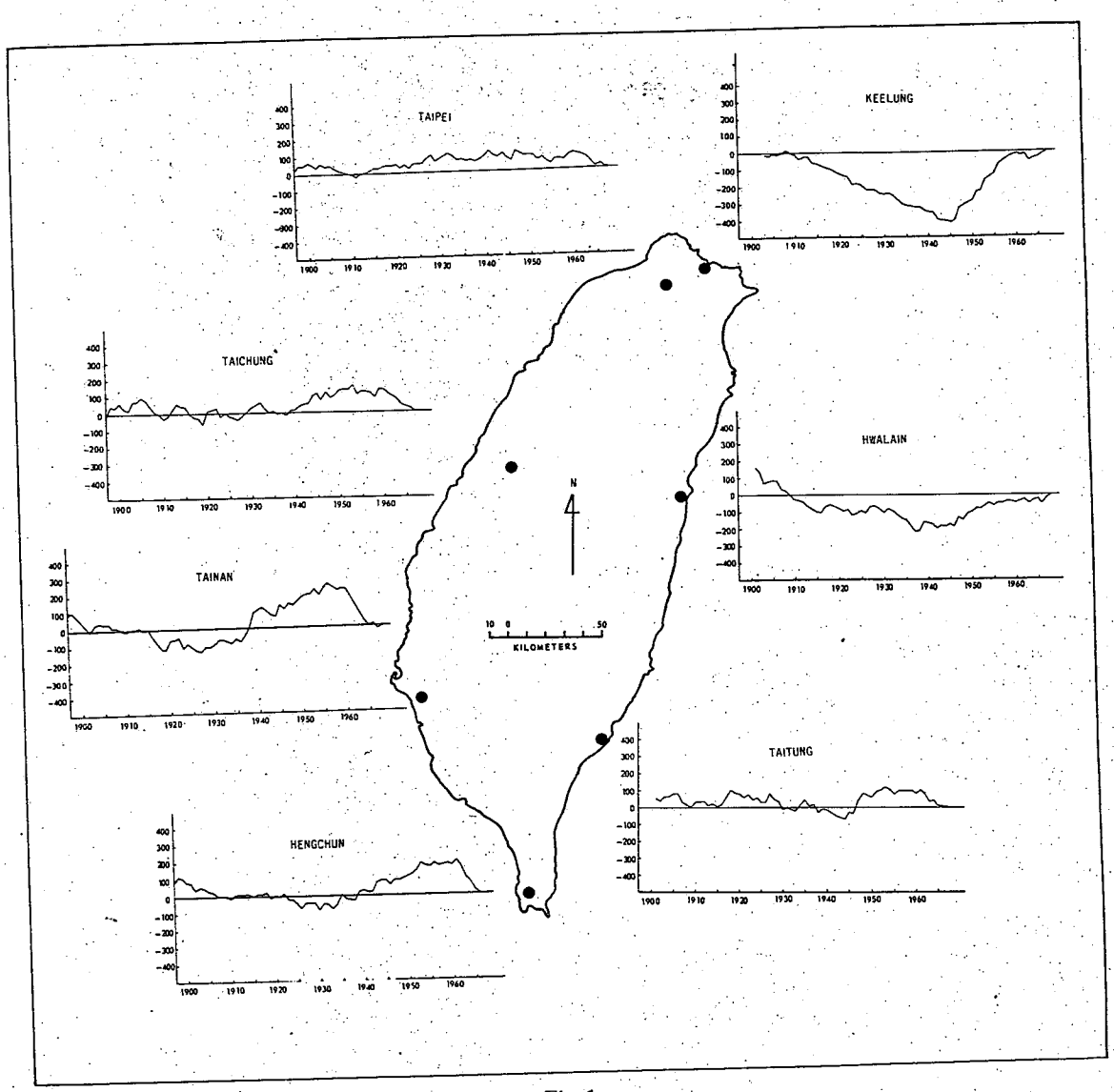

Fig. 1

century, a trend reverse that of the other stations. During periods of high zonal index, the North Pacific Anticyclone was well developed and extended westward over Taiwan. As a result, the easterly trades became strengthened and hence caused a large amount of rainfall in the windward station at Taitung. It is also interesting to note that the rainfall trend in the last decade (1960's) rose for the stations of the winter monsoon type and declined for those of the other types classified as before. Weather systems contributing various amounts of rainfall to the sections of the island during different seasons caused the regional divergence in secular rainfall variation. The main synoptic weather systems which contributed rainfall to the island of Taiwan were Siberia polar outbreaks, polar fronts and Taiwan lows in winter, and typhoons in summer. Several studies found that these weather disturbances were more active during periods of low zonal index in the northern hemisphere (Wei, 1968, 1969; S. T. Wang, 1970). Wei (1969) pointed out that in winter both polar fronts and Taiwan lows favored rainfall all over the island, whereas polar outbreaks favored rainfall only for the windward stations in the north and east portions of the island. The similar trend of rainfall increase in the 1950's for the stations of the winter monsoon type and the other stations

were associated with greater frequency of the Taiwan low. The Taiwan low is an extratropical cyclone formed over the sea surface in the vicinity of Taiwan. The frequency of the Taiwan low reached its maximum between 1951 and 1956 (Hsu, 1969; Wei, 1968). The reverse trend of rainfall between stations of the winter monsoon type and the other stations on the island in the last decade was in accord with less frequency of both the polar front and Taiwan low than the polar outbreak (Figure 2). The intrusion of the polar outbreak over Taiwan was usually associated with the presence of a 500 mb-level trough extending from the island of Sakhalin southwestward to the East China Sea, roughly along the 120° E longitude (S. T. Wang, 1958). In contrast, the Taiwan low occurred in association with the presence of a 500 mb-level trough over Manchuria and extended southward roughly along the 110° E longitude (P. Y. Wang, 1971; First Weather Wing, 1966). S. T. Wang (1970) pointed out that this trough was a secondary trough following the passage of the polar outbreak over China, and that the Taiwan low occurred most frequently at the time of the extremely low zonal index when intensive blocking highs occurred over the North Pacific Ocean and Western Siberia. The migration of the subtropical Bengal trough toward southeast China also favored the occurrence of the Taiwan low.

In summer, typhoons contributed a large percentage of rainfall to all the stations of the island. The frequency of typhoons which hit the island reached its maximum between 1959 and 1962 and tended to decrease thereafter (Wei, 1970; Liao, 1962). Wei (1970) pointed out that the displacement of the East Asiatic trough at the 500 mb level to the west of its normal position over the North Pacific, as well as the shrinking of the North Pacific Anticyclone at sea level, i.e. a low zonal index, favored the visiting of typhoons over Taiwan.

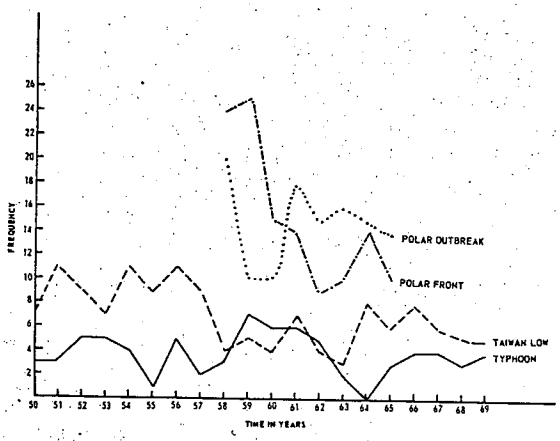

Fig. 2

CONCLUSIONS

Secular variation of rainfall in Taiwan is a part of a worldwide phenomenon and is in agreement with both Kraus's and Lamb's finding regarding the relationship between the secular rainfall variation in many regions of the world and the strength of the general circulation. Lamb (1966) pointed out that the rainfall trend of the world in the 1960's was a return to the pre-1900 situation rather than a continuation of the unique fluctuations in the 1920's and the 1940's. This was also confirmed by the reverse trend of rainfall in the 1960's between the stations of the winter monsoon type and the rest of the stations on the island of Taiwan, probably a similar condition to the pre-1900 period.

In general, the weakening of the westerlies was in association with the occurrence of the 500 mb-level trough over the coastal area of East Asia, roughly between the 110° E and 120° E longitudes. This upper level circulation pattern favored the occurrence of surface weather disturbances and hence increased rainfall over the island of Taiwan.

The spatial difference in secular variation of rainfall over the island was caused by the combined effect of different weather systems and topographies. Stations in the northern portion of the island derived their rainfall mostly from polar outbreaks. The North Pacific Anticyclone contributed most rainfall to the stations in the southeast portion of the island. Stations in the south and southwest of the island derived their rainfall mostly from typhoons in summer. Both winter and summer weather disturbances contributed almost equal amounts of rainfall to the stations in the northwestern portion of the island. Consequently, the seasonal rainfall variation in this region was more or less uniform and the secular rainfall variation did not show any significant fluctuations.

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BAHAMAN COASTAL DUNES

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ABSTRACT. Bahaman coastal dunes of Holocene age are well-represented on Cat Island, and four general dune types are identified as follows: 1) parabolic dunes, 2) massive ridge dunes, 3) beach-ridge dunes, and 4) mound dunes. All dunes are fossil landforms, except for the mound dunes of the Exuma Coast. All have been truncated to various degrees. Parabolic dunes and massive dune ridges were formed during two accretionary cycles related to falling sea-level, while beach-ridge dunes were formed during stages of beach accretion. Radiocarbon dates place the first phase of dune development at 3600 years B.P. and the second phase at approximately 2000 years B.P. Climatic changes associated with sea-level change are suggested as possible factors favoring dune development.

The prominent topographic features of many of the islands in the Bahamas are dunes of various types and ages. In the eastern Bahaman "Out Islands" and particularly on Cat Island, which is one of the larger islands along the eastern fringe of the Great Bahama Banks region, the bulk of the insular