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SECULAR TRENDS OF HAWAIIAN RAINFALL

GONG-YUH LIN
California State University, Northridge

In past years studies in rainfall have found that abrupt rainfall decreases occurred at the end of the 19th century in the tropics and along the east coast of subtropics until the 1930's and 1940's at various stations (Kraus, 1955a, 1955b). In addition, studies by Arakawa (1956a, 1956b) indicate that an opposite condition occurred in the higher middle latitudes, that is, a wet period started around 1900 and terminated about 1930. These findings have been confirmed further by Lamb (1959, 1961, 1966) in his studies of the relationship between the general circulation and climatic variations. Lamb found that a dry period in the low latitudes and a wet period in the higher middle latitudes existed through the first three decades of this century as a result of unusual strengthening of the hemispheric westerlies.

Considerable efforts have been devoted to investigating the statistical characteristics of Hawaiian rainfall and their relationships to synoptic weather systems, general circulations, and topography. Yet, little attention has been paid to secular rainfall trends. Therefore, this paper aims to discuss secular rainfall variation in Hawaii and relate that variation to the general circulation in the light of findings by Kraus and Lamb regarding secular rainfall variations over many regions of the world.

METHOD

The residual mass curves of the annual rainfall for nine stations of Hawaii, where records from the turn of this century to 1971 are available, are plotted. The advantage in using the residual mass curve is that the fixed mean used for calculation need not be a true long-term average (Barnes, 1919). The curve shape is what is important. Periods with average rainfall above the selected mean are indicated by a rising or concave curve, whereas average rainfall below the selected mean is indicated 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 formula

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

where Y_i = 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 63 year period 1909-1971,

I = the year 1908.

REGIONALIZATION

The annual residual mass curves for the nine stations are shown in Figure 1. The vertical scale is adjusted for the convenience of map reproduction. Located in various sections of the island, these stations represent Hawaiian rainfall regimes well in

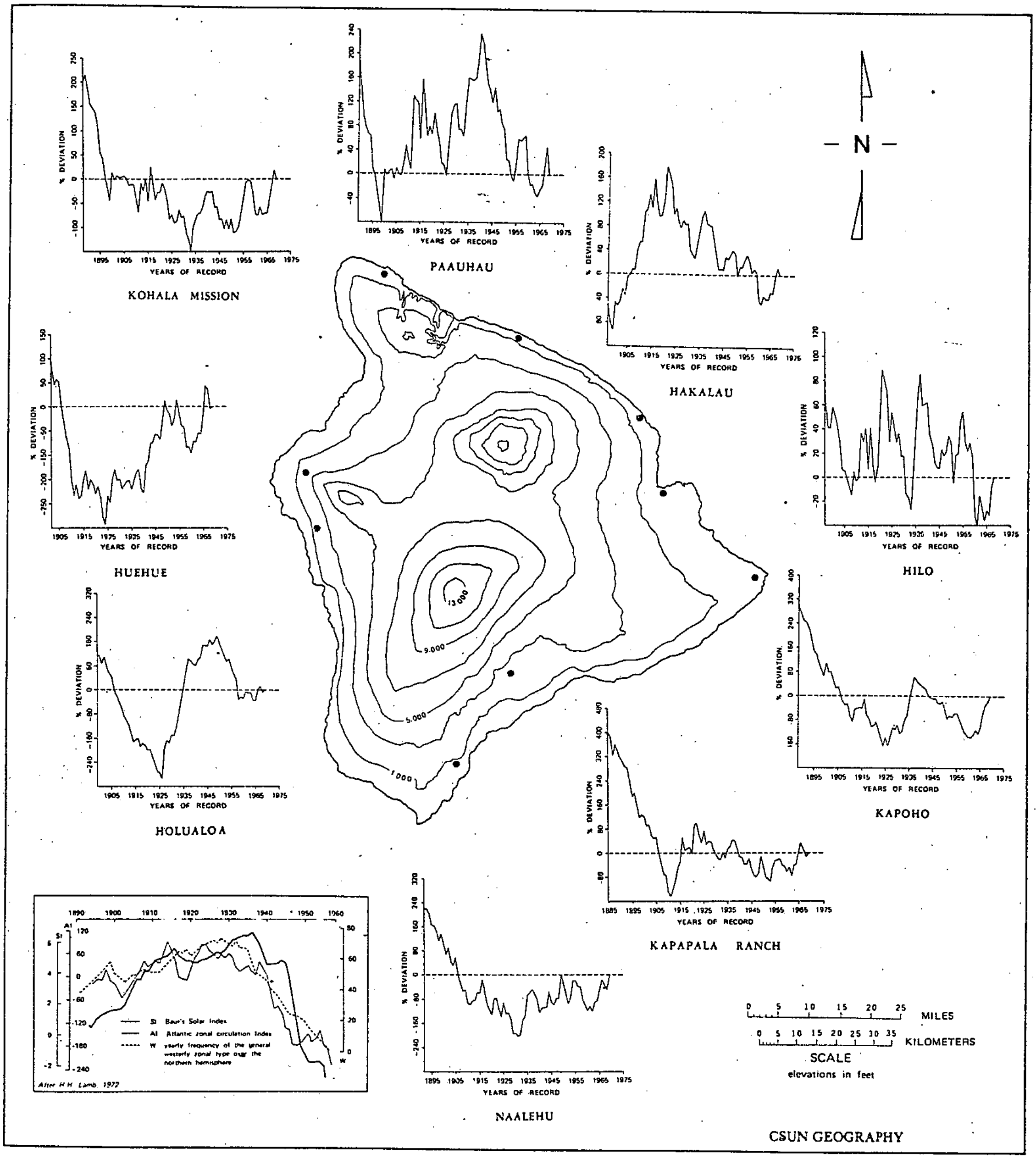

Fig. 1. Secular trends in Hawaiian rainfall.

terms of the seasonal variation. From the trends of the residual mass curves, three types of secular rainfall variation become apparent.

First, there is the windward type, which shows a dry period starting from the turn of this century to about 1940, and a wet period since. There were two rainfall peaks at about 1920 and 1940 (Paahau, Hakalau, and Hilo stations). Secondly, there is the leeward type, which shows a dry period starting from the turn of this century to about 1925 or 1935, and a wet period since (Kohola Mission, Huehue, Holualoa, and Naalehu stations). The third is the neutral-location type, which shows a dry period since the turn of this century without any distinct long wet period (Kapoho and Kapapala Ranch stations).

PHYSICAL CAUSES

Over various regions of the world, studies of secular rainfall variations indicate an association with the general circulation (Kraus, 1955a, 1955b; Lamb, 1966; Lin, 1973). The dry period during the first four decades of this century in the low latitudes was connected with the strengthening of the westerlies in the middle latitudes and the wet period since the 1940s has been attributable to the weakening of the westerlies in the same latitudes. The strength of the westerlies is usually expressed by a zonal index, which is the surface pressure difference between 35 and 55 degrees latitude (Rossby, 1939). Variation in the zonal index reflects the shift in the latitudinal distribution of the momentum rather than the change in the absolute value, owing to the conservative nature of the total momentum of the mid-troposphere westerlies for a given time (Namias, 1950). A low zonal index is evidenced by the strengthening of the westerlies in the subtropics which results in heavy rains in the low latitudes. By contrast, a high zonal index is associated with the strengthening of the westerlies in the middle latitudes and the weakening of the westerlies in the subtropics. Hence, the low latitudes experience dry weather.

Located in the tropical North Pacific, Hawaii is governed by the semi-permanent Pacific high pressure cells to the north and east. The island of Hawaii derives rainfall mainly from trade winds, Kona storms, and sea breezes. The trade wind rainfall is important in windward areas (the northeastern sector of the island). However, with the exception of the Kona areas (the western slope of the island), the other locations show that summer is a dry season when the trade winds dominate the island. A few Kona storms in winter may contribute a large proportion of rainfall to the island. Simpson (1952) stated, "Kona, meaning leeward, is used to describe the stormy condition in which the usually persistent trade winds are replaced by southerly winds and rain squalls." Kona storms are associated primarily with surface frontal activities or upper-level cyclones, and may contribute rainfall all over the island. However, Kona stations show a wet season in summer when Kona storms are virtually absent. Summer rainfall maxima at Kona stations are attributable to the shower activity associated with sea breezes in the daytime (Leopold, 1949).

It has been found that Hawaiian rainfall is related to the zonal index. Hawaiian rainfall decreased as the jet stream at 700 mb. migrated southward towards the islands (Yeh et al., 1951). The surface trade winds generally weaken as the 700mb. westerlies over them increased (Namias and Mordy, 1952). Consequently, a low zonal index with the strongest wind belt of the westerlies shifting toward the tropics reduces the trade wind rainfall over the island. This is reflected by the secular rainfall trend at Paahau, Hakalau, and Hilo. These stations show a pronounced wet period at the beginning of this century when the hemispheric westerlies reached an unusual strength. A dry period has started since the 1930's as the hemispheric westerlies have weakened. At Hakalau and Hilo, a short dry period between 1925 and 1930, and a wet period between 1935 and 1940 were evident. Rex (1971) has constructed January sea-level pressure anomaly patterns over the Pacific for these two periods. He concluded that the 1925-30 period favored light rains on windward locations and heavy rains on leeward locations, and the 1935-40 period favored just the reverse.

The leeward stations in general show a distinct dry period starting at the turn of this century and terminating around 1925 or 1935, and a wet period since. As mentioned before, the sea breeze is an important rain-producing mechanism over the leeward portions of the island. The sea breeze correlates inversely with the trade wind. Consequently, the leeward rainfall varies inversely with the strength of the easterlies, and directly with the intensity of the westerlies over the island (Solot, 1950). Secular rainfall trends at Kohola Mission and Naalehu well resemble each other despite the fact that the former is located in the northern end and the latter in the southern end of the island. Secular rainfall trends at these two stations indicate a strong inverse relation to secular trends of the strength and prevalence of the mid-latitude westerlies (Lamb, 1972; Fig. 1).

CONCLUSIONS

The purpose of this paper has been to uncover any possible relationship between the general circulation and secular rainfall variation in Hawaii. From the evidence presented some relationship does seem to exist. In Hawaii, secular rainfall variation is in accordance with the previous studies of Kraus and Lamb, indicating a relationship between secular rainfall variation in many regions of the world and the strength of the hemispheric westerlies. In Hawaii, the strengthening of the hemispheric westerlies has favored a wet period on windward locations and a dry period on leeward locations. By contrast, the weakening of the hemispheric westerlies has favored a dry period on windward locations and a wet period on leeward locations.

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REFERENCES CITED

Arakawa, H.,"On the Secular Variation of Annual Totals of Rainfall at Seoul from 1770 to 1944," *Archiv fur Meteorologie, Geophysik, und Bioklimatologie*, serie B, Vol. 7 (1956), pp. 205–211.

Arakawa, H., "Two Minima of the Average Rainfall at about the Turn of the Century and at about 1940 in the Far East," *Archiv fur Meteorologie, Geophysik, und Bioklimatologie*, serie B, Vol. 7 (1956), pp. 406–412.

Barnes, A. A., "Rainfall in England: The True Long-Average as Deduced from Symmetry," *Quarterly Journal of the Royal Meteorological Society*, Vol. 45 (1919), pp. 209–232.

Kraus, E. B., "Secular Changes of Tropical Rainfall Regimes," *Quarterly Journal of the Royal Meteorological Society*, Vol. 81 (1955), pp. 198–210.

Kraus, E. B., "Secular Changes of East Coast Rainfall Regimes," *Quarterly Journal of the Royal Meteorological Society*, Vol. 81 (1955), pp. 430–439.

Lamb, H. H. and A. I. Johnson, "Climatic Variation and Observed Changes in the General Circulation," *Geografiska Annaler*, Vol. 41 (1959), pp. 94–134.

Lamb, H. H. and A. I. Johnson, "Climatic Variation and Observed Changes in the General Circulation," *Geografiska Annaler*, Vol. 43 (1961), pp. 363–400.

Lamb, H. H., "Climate in the 1960's: Changes in the World's Wind Circulation Reflected in Prevailing Temperatures, Rainfall Patterns and Levels of the African Lakes," *Geographical Journal*, Vol. 132 (1966), pp. 183–212.

Lamb, H. H., *Climate: Present, Past and Future*, Vol. 1 (London: Methuen, 1972).

Leopold, L. B., "The Interaction of Trade Wind and Sea Breeze, Hawaii," *Journal of Meteorology*, Vol. 6 (1949), pp. 312–320.

Lin, G. Y., "Secular Variation of Rainfall Over the Island of Taiwan," *Proceedings*, Association of American Geographers, Vol. 5 (1973), pp. 144–147.

Namias, J., "The Index Cycle and its Role in the General Circulation," *Journal of Meteorology*, Vol. 7 (1950), pp. 130–139.

Namias, J. and W. A. Mordy, "The February Minimum in Hawaiian Rainfall as a Manifestation of the Primary Index-Cycle of the General Circulation," *Journal of Meteorology*, Vol. 9 (1952), pp. 180–186.

Rex, D. F., "Secular Trends in the Surface Pressure Distribution over the Pacific," *Symposium on Tropical Meteorology*, June 2-11, 1970, American Meteorological Society, pp. LV-1 to LV-5.

Rossby, C. G., "Relation between Variation in the Intensity of the Zonal Circulation of Atmosphere and the Displacements of the Semi-permanent Centers of Actions," *Journal of Marine Research*, Vol. 2 (1939), pp. 38–55.

Simpson, R. H., "Evolution of the Kona Storm, A sub-Tropical Cyclone," *Journal of Meteorology*, Vol. 9 (1952), pp. 24–35.

Solot, S. B., *Further Studies in Hawaiian Precipitation*, U.S. Weather Bureau Research Paper, No. 32 (1950).

Yeh, T. C. et al., "On the Relation Between the Circumpolar Westerly Current and Rainfall over the Hawaiian Islands," *Meteorological Monographs*, Vol. 1 (1951), pp. 47–55.