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Recent Climate History of Hawaii[1]

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ABSTRACT: The recent energy and synoptic climate of Hawaii is examined in this article. The results indicate trends in the energy climate, increasing temperature and decreasing solar radiation, though no evidence is found of trends or cycles in the synoptic climatic elements, rainfall and sea level pressure.

THIS ARTICLE PRESENTS a brief discussion and analysis of the climate in Hawaii since scientific weather observations began in the nineteenth century.

WEATHER OBSERVATIONS

Some of the earliest meteorological observations in Hawaii were reported by Lt. Charles Wilkes, who, while in command of the U.S. Exploring Expedition, spent the winter of 1840–1841 in the islands. Wilkes' visit to the islands, just 62 years after their discovery by Captain Cook, appears to have coincided with blustery weather. He found the daytime winds "blow with great strength" though "the nights are calm and beautiful" (Wilkes 1851). Wilkes added a postscript to his assessment of the nocturnal weather, however. On an expedition to the summit of Mauna Loa, Wilkes' party measured 457 mm (18 in.) of snow, experienced gales from the southwest gusting up to 21 m/sec (47 mph), and recorded temperatures as low as −7.8°C (18°F). On huddling in camp near the summit, Wilkes later wrote, "the howling wind ... rendered the hours of darkness truly awful" (Wilkes 1970).

Wilkes reported the mean annual temperature at Honolulu to be 24.3°C (75.8°F) based on several years of measurements, near the long-term mean of 23.9°C. He also listed rainfall totals of 536 mm (21.1 in.) during 1837 and 1189 mm (46.8 in.) for 1838. The 1838 value is one of the highest annual rainfall totals ever recorded in Honolulu. Mean barometric pressure was 1015 mb (29.973 in. mercury) during his stay, near the long-term mean for September through April of 1016 mb. Sea surface temperatures averaged 26.4°C (79.5°F), which, if accurate, would be unusually warm (Wilkes 1851).

In the late nineteenth century, weather observations became more common as agricultural interests grew, and finally the newly established Climatological Office for the then Territory of Hawaii began publishing records in 1905. By 1985 nearly 2000 climatological stations had been established and maintained at one time or another, giving Hawaii one of the densest climate monitoring networks in the world (Giambelluca et al. 1986).

To illustrate the history of the general climate during this century, weather data are graphed in Figures 1 and 2. The data are separated into climatic elements related to the energy balance, radiation and temperature, and climate elements that indicate synoptic conditions, rainfall and sea level pressure. The air temperature curve was compiled by taking the average of three windward sites at Lihue, Kauai (State ID: 1020.1, National Oceanic and Atmospheric Administration (NOAA) ID: 5580); Hana, Maui (State ID: 355.0; NOAA ID: 1125); and Hilo, Hawaii (State ID: 87.0; NOAA ID: 1492) (all data from NOAA's Climatological Data for the States). Only windward sites were used in the temperature curve, because these sites are less affected by daytime land heating and thus more accurately represent the oceanic climate. The data since 1950 represent airport records adjusted to town sites by comparing overlapping per-

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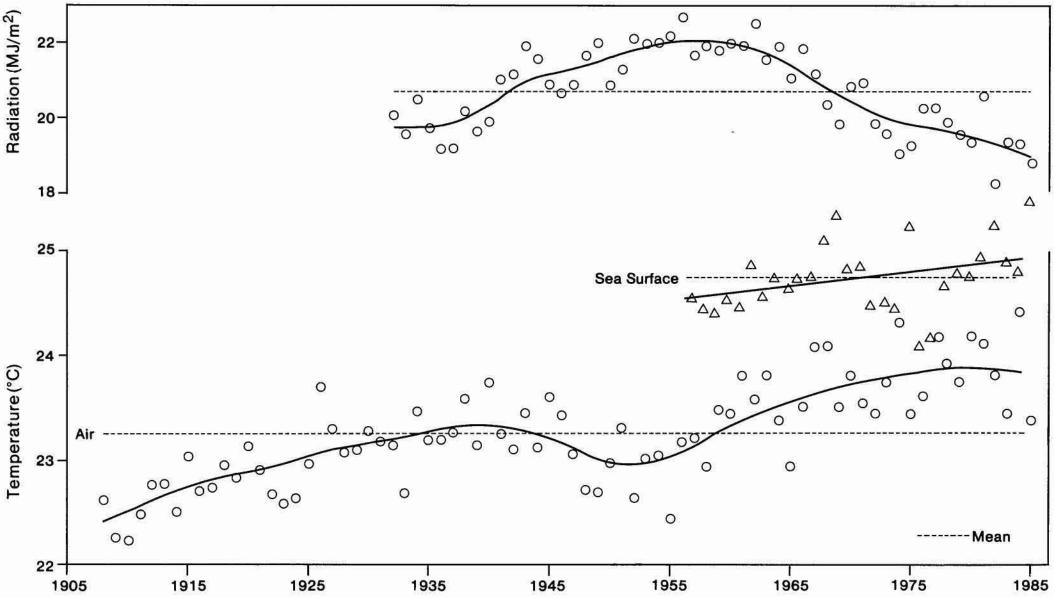

FIGURE 1. Historical energy climate. Data are discussed in the text. The reciprocal relationship between temperature and radiation may indicate that cloudiness acts as a negative feedback agent to temperature fluctuations in the north-central Pacific. (o symbols indicate global radiation and air temperature. △ symbols indicate sea surface temperature.)

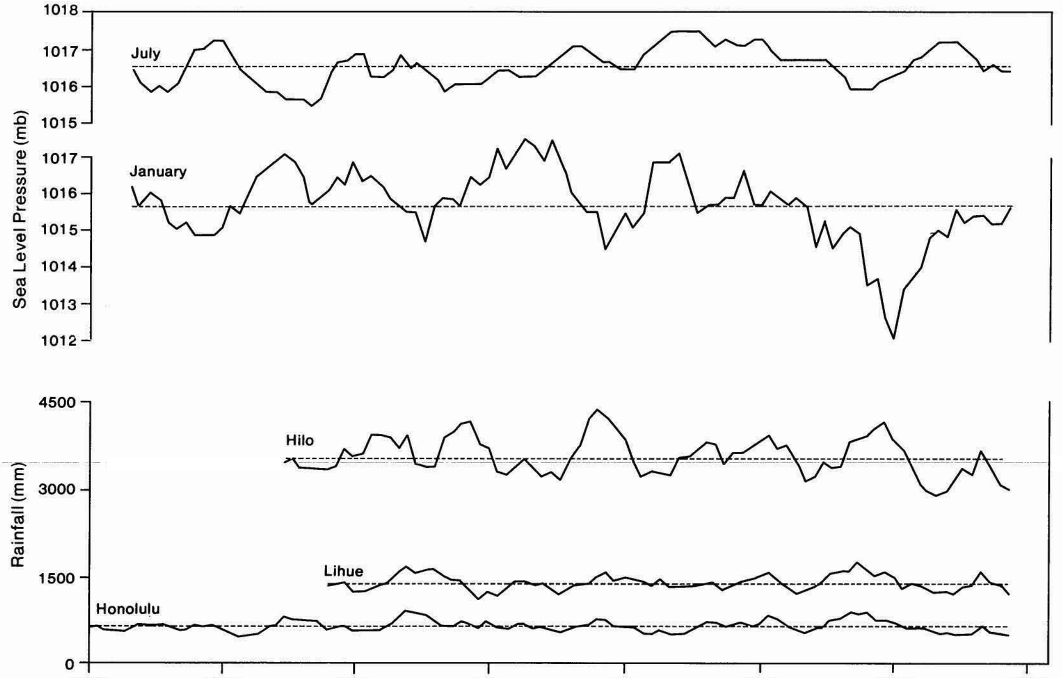

FIGURE 2. Historical synoptic climate indicators. Data are discussed in the text. Cycles and trends appear absent in the data, although rainfall variations are generally in phase at the leeward, windward, and intermediate sites.

iods. Accordingly, the following corrections were applied to the post-1950 airport records: Lihue: −0.6°C, Hana: −0.2°C, Hilo, +0.1°C. Possible sources of variation in these records are discussed by Hoyt and Siquig (1982). The sea surface temperature (SST) curve has been derived from weekly sea surface temperature measurements collected off Koko Head, Oahu. These data are discussed in Seckel and Young (1977). Solar radiation has been measured in Honolulu since 1932, first at the Hawaiian Sugar Planters' Association's Makaki Substation (State ID: 707.0), and, since 1976, at the University of Hawaii (these data are discussed by Ekern 1982). The rainfall data (from Lihue, Hilo, and Honolulu; State ID: 703.0; NOAA ID: 1919) and sea level pressure data (from Honolulu) have been smoothed by calculating 5-year running mean values; that is, a value plotted for a given year represents the average of that year's measurements plus the two previous and two successive year's measurements (data from NOAA's Climatological Data for the States and the World Meteorological Organization's World Weather Records). The quality of the rainfall data are discussed by Giambelluca et al. (1986).

THE ENERGY CLIMATE

Climatic time series data are generally analyzed by looking for trends and cycles in the individual climatic elements and for relationships between these elements. An analysis of the recent energy climate depicted in Figure 1 is particularly interesting. Air temperatures rose from the beginning of the century until about 1940, declined to 1955, and then resumed the upward trend. In support of the recent warming trend, sea surface temperatures, taken off Koko Head, Oahu, have risen about 0.4°C since 1955. The local temperature record matches global temperature trends except for the period of 1955–1975 when global temperatures remained fairly constant (Jones et al. 1986). The few years of temperature data reported by Wilkes indicate a warmer period in the 1830s. This is supported in part by the apparent high measured SST. Global temperatures of the period were markedly lower, however. In fact, 1800–1850 was a time of maxima in Alpine glaciation and Icelandic sea ice (Lamb 1977).

The cause of the temperature trend is largely a matter of speculation. Possible explanations might be a change in atmospheric circulation or warming by greenhouse gases, such as carbon dioxide and methane. Wentworth (1949) reported a significant easterly shift in the tradewinds over Hawaiian waters between 1910 and 1940 followed by a return to more northerly winds through 1946, corresponding nicely to the temperature curve. An analysis of local winds since 1946 shows no continuation of this trend, but a study of winds over the entire Pacific Ocean (Whysall et al. 1987) indicates a slight easterly shift in the tradewinds over the past 30 years. An easterly shift in the tradewinds would increase the southerly component of the North Equatorial Current and bring warm equatorial water into the region. Seasonal cycles in the North Equatorial Current and associated forcing mechanisms are discussed by Wyrtki (1974) and White (1977), though no trends are evident between 1950 and 1970. Namias (1969), however, reported warmer than normal SSTs for much of the north-central Pacific between 1954 and 1967. This study also suggests an abrupt increase in SST in the fall of 1961, associated with an anomalously strong north Pacific high-pressure ridge. This jump corresponds closely with the temperature data given in Figure 1.

As another possible mechanism for the observed warming trend in Hawaii, it is particularly appropriate to consider greenhouse gases in light of the importance of Mauna Loa Observatory in documenting the steady rise in atmospheric carbon dioxide. Although the magnitude of the overall temperature increase since 1908 exceeds most predictions for carbon dioxide-induced warming, increased longwave radiation trapping likely contributes to the trend.

In opposition to the temperature trend, measured solar radiation in Honolulu rose until the mid-1950s and has since declined by nearly 0.5% per year. The general shape of the radiation curve is supported by solar radiation measurements at Mauna Loa Observatory and by many agricultural solar radiation stations throughout the state. Hours of bright sunshine [which has been used in other climate history analyses (Angell et al. 1984, Changnon 1981)], recorded at Honolulu Airport since 1905, also support the long-term solar radiation trend. These corroborating data indicate that the observed trend has not been confined to the Honolulu site, but is a statewide phenomenon.

The observation that the radiation trend in Hawaii tends to oppose the temperature trend has important implications for global climatic change. A major question in climatology today is whether temperature increases due to greenhouse gases will be offset by feedback mechanisms. It has been suggested that the Earth might maintain thermeostasis, or constant temperature, by regulating its solar energy receipt through changes in cloud cover (Charlson et al. 1987). Since clouds are highly reflective of solar radiation, an increase in cloud cover would reduce the solar energy absorbed by the Earth, which would presumably have a cooling effect. In Hawaii, as trends in atmospheric transmissivity have not been reported (Mendonca et al. 1978), the recent decrease in solar radiation at the surface must be due to an increase in average cloud cover. This suggests that, in the Hawaiian Islands area at least, cloud cover does indeed appear to increase in a warmer atmosphere and thus may act as a negative feedback agent to temperature fluctuations. Similar observations have been reported for Europe, India, and the United States (Henderson-Sellers 1987). Of course, it is possible that the temperature and radiation trends are unrelated; the decrease in solar radiation could be due to a change in global circulation patterns, for example. Or the increase in temperature could be a delayed thermal lag response to high solar radiation in the middle of the century.

SYNOPTIC WEATHER INDICATORS

Unlike the energy climate elements, the synoptic weather indicators, rainfall and atmospheric pressure, show no apparent trends in the record. A time series analysis reveals that strong cyclic patterns are also absent. The apparent absence of trends and cycles in the record makes the job of the weatherperson, who is called upon to predict tomorrow's weather, or even next year's, doubly difficult. Recent efforts at weather prediction have moved away from searching for cycles and have concentrated on global weather events, such as El Niño, as precursors to Hawaiian weather patterns.

The smoothed rainfall records for a windward (Hilo), leeward (Honolulu), and intermediate (Lihue) site generally fluctuate about the mean in phase, particularly for Lihue and Honolulu. This suggests common mechanisms for variation, such as the frequency of fronts and upper troughs in winter. Although the amplitude of yearly fluctuations in rainfall is greatest at the wet windward site, as a percentage of the average value, variability is greater at the drier sites. The coefficient of variation for annual totals of rainfall at Honolulu is 35%, at Lihue 25%, and at Hilo 21%. Rainfall is one of the most variable climate elements. By contrast, the coefficient of variation for the annual Honolulu solar radiation totals is just 5%, for temperatures at Hilo, Lihue, Hana, and Honolulu is between 2% and 3.5%, and for summer and winter sea level pressure is less than 0.2%.

The mean in annual rainfall appears stable for all three stations, an indication that long-term trends are absent for Hawaiian rainfall. In a similar analysis using many more rainfall stations around the state, Woodcock and Jones (1970) found evidence of a slight, though not statistically significant, decline in rainfall between 1910 and 1960. Despite the absence of strong rainfall trends, it has been noted that drought years tend to be clustered.

As with rainfall, sea level atmospheric pressure levels fluctuate evenly about a steady mean value. The variation in January pressures, subject to winter storms and pressure troughs, is much greater than in July when a strong Pacific high-pressure cell is established to the north and tradewinds dominate. It is interesting to note that the dips and peaks in

January and pressure generally oppose annual rainfall at Hilo.

CONCLUSIONS

Since Wilkes' visit to the islands in the mid-1800s, the study of Hawaiian weather has grown enormously. The network of climate stations in the islands is one of the densest in the world, particularly the rain gauge network. This reflects the importance of weather in the daily life of modern Hawaii. The value of local weather measurements can be easily illustrated by noting that most of the climate data gathered in Hawaii are collected by the private sector, and, in particular, by agricultural concerns.

An understanding of the past climate may offer clues to what we might expect in the future. It appears that annual rainfall is not predictable by statistical methods, and thus, as has happened in the past, the State of Hawaii will be forced to handle drought periods in response to, rather than in accurate anticipation of, the event. Temperature trends are more clear. The climate is warming. Although this has little influence on local weather, global warming may affect Hawaii. An increase in Earth's temperature would cause the expansion of seawater and a corresponding rise in sea level in Hawaii. Two studies on the phenomena predict a 70-cm rise within the next 40–100 years. If this happens, few near-shore structures will be endangered, but Hawaii could face changes in beaches and reefs, increased flooding at the lower reaches of streams, and a decrease in water quality in the lowest-lying areas of the aquifer (Moberly and Mackenzie 1985).

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