NOTES AND CORRESPONDENCE

Diagnostic Studies of Two Contrasting Rainfall Episodes in Hawaii: Dry 1981 and Wet 1982

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ABSTRACT

The circulation features that accompanied the dry January/February of 1981 and the wet January/February of 1982 in Hawaii are compared. The results indicate that surface and upper-air circulation features are very distinct during these two winter months with contrasting rainfall extremes. Four major synoptic patterns (frontal, kona, trade, and ridge) that influence Hawaiian rainfall have been described. The Kona storm pattern contributes to most of the rainfall in wet 1982, followed by the frontal pattern. No kona storm days occurred during dry 1981, and the rainfalls on frontal days in dry 1981 were less than half of those in wet 1982. The trade wind and ridge patterns are not important for rainfall either in dry 1981 or wet 1982. A possible relationship between the PNA pattern and rainfall anomalies during these two non-ENSO winter months is suggested.

1. Introduction

Hawaii experienced large interannual rainfall variability in the early 1980s (Chu 1989). A severe and persistent drought in 1981 (Haraguchi 1981) was followed by excessive rainfall in 1982 and a prolonged drought in 1983/1984. Deficient rainfall episodes in Hawaii tend to follow the occurrence of the El Niño–Southern Oscillation (ENSO) phenomenon (Meisner 1976; Horel and Wallace 1981; Lyons 1982; Ropelewski and Halpert 1987; Chu 1989; Cayan and Peterson 1989), but the late 1980 drought that persisted through a large portion of 1981 occurred in the absence of an apparent ENSO phenomenon. To understand the large interannual variability that occurred between dry 1981 and wet 1982, this study investigated the circulation features associated with two contrasting rainfall episodes.

2. Data

The data used in this study included 1) daily surface winds and precipitation from National Weather Service first-order stations at Lihue and Honolulu in Hawaii (Fig. 1); 2) monthly mean ship observations over the North Pacific from NOAA's Comprehensive Ocean–Atmosphere Data Set (COADS) and interim COADS; 3) daily upper-air analyses of wind velocity and geopotential height on 2.5° latitude–longitude grids at 850 and 200 hPa obtained from European Centre for Medium Range Weather Forecasts; 4) twice-daily synoptic charts analyzed at the National Weather Service Forecast Office in Honolulu; and 5) GOES satellite pictures.

3. Background information

Yeh et al. (1951) classified synoptic flows associated with Hawaiian rainfall into various types. More recently, Lyons (1982) noted that the major wintertime synoptic-flow patterns affecting Hawaii are, in decreasing order of importance, the trade wind, the southwest wind, and the midlatitude frontal rainband. Accordingly, a subjective classification of these three patterns and a fourth unrelated one, ridge, was made based on surface charts, satellite images, and daily surface records.

For simplicity, the midlatitude frontal rainband pattern will be referred to as the frontal pattern. A frontal day occurred when the winds at Lihue and Honolulu were between 140° and 260° and a cold front was identified immediately to the west of Kauai (Fig. 2a). Frontal passages generally bring light to moderate precipitation to the Hawaiian Islands. Not all fronts moved past Kauai and Oahu; many either dissipated or passed well to the north of the islands. The southwest wind

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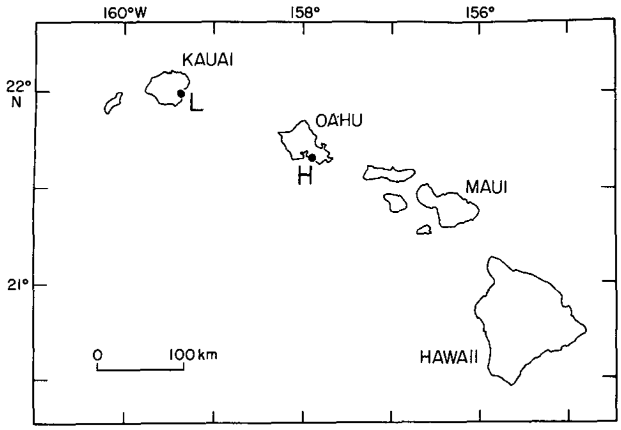

FIG. 1. Map of the major Hawaiian Islands. Lihue and Honolulu are indicated by capital letters L and H, respectively.

pattern is a manifestation of a subtropical cyclonic circulation often produced by a large-amplitude trough in the polar westerlies (Simpson 1952; Ramage 1962). This type of subtropical cyclone is locally termed a "kona storm" which can last for days or weeks without weakening and can occasionally bring flooding to the islands. A kona storm day occurred when Hawaii appeared to be under the influence of the circulation of a subtropical cutoff or closed low pressure center (Fig. 2b). This type of storm is typically a nonfrontal low pressure system within 1500 km of the islands, and it appears on satellite images as large, quasi-stationary, commalike cloud bands or masses with deep convection and rain to the east of the storm center. A trade-wind day occurred when Lihue and Honolulu were located south of the subtropical high pressure ridge and a northeasterly flow (30° to 90°) persisted over the islands (Fig. 2c). Climatologically, the resulting moist trade winds provide the most important source of water in the islands (Yeh et al. 1951; Lyons 1982). The ridge pattern occurred when the islands were zonally sandwiched between two subtropical anticyclones and the subtropical ridge axis was near the islands (Fig. 2d). Under this condition, land and sea breezes, along with their attendant convection, provide the source of rainfall to the islands; this flow pattern, however, is usually characterized by low rainfall.

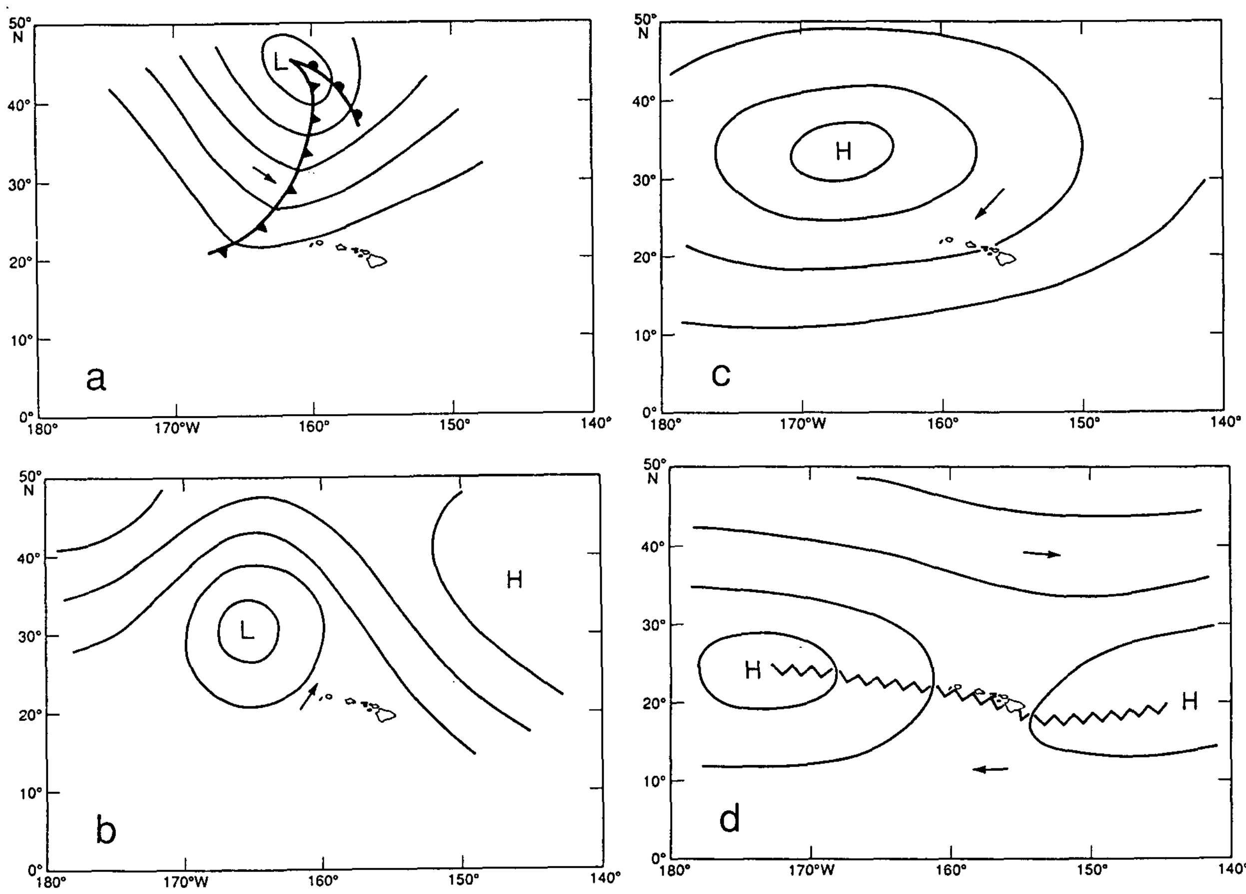

FIG. 2. Schematics showing various synoptic patterns that produce winter rainfall in Hawaii: (a) frontal; (b) kona storm; (c) trade wind; and (d) ridge. Wind directions are indicated by arrows. In (d), the zigzag denotes the ridge axis.

4. Surface circulation and statistics of synoptic patterns

Anomaly maps[1] of surface winds at the peak rainy season (January/February) during the dry and wet episodes in Hawaii are presented. In January/February 1981 (hereafter referred to as JF81), a band of enhanced westerly anomalies is seen to the north of Hawaii (Fig. 3a). Northeast trade winds become stronger to the south of Hawaii. For January/February 1982 (hereafter referred to as JF82), the midlatitude eastern North Pacific is marked by strong easterly anomalies (Fig. 3b). Southerly anomalies are found to the east and northwesterly anomalies to the west of the islands. Thus, an anomalous cyclonic circulation prevails in the vicinity of the islands during the wet episode, a pattern almost opposite to that of dry JF81.

Wet episodes are usually made up of alternating short periods of dry and wet spells. This observation raises a question as to whether monthly or bimonthly data can properly resolve these weather regimes. Nevertheless, kona storms are conspicuous and quasi-stationary synoptic features in the eastern subtropics of the North Pacific. By examining the daily synoptic surface charts and satellite pictures, we noted that three cyclonic systems stalled near the islands in JF82. Hence, the anomalous cyclonic circulation in the eastern subtropical Pacific, as reflected from bimonthly charts, is a manifestation of long-lived kona storms.

Statistics compiled from daily surface data are shown in Table 1. The analyses for Lihue and Honolulu are similar in many respects. Total rainfall in JF81 was much below normal. There was a lack of kona storm days at both stations. The frontal, trade wind, and ridge patterns produced only meager rainfall in JF81.

In contrast, rainfall totals in JF82 were much above normal (Table 1). The Kona storm pattern was the main contributor to rainfall totals during this wet episode, followed by the frontal pattern. Also notable in Table 1 is the fact that the trade wind pattern in both years was not a big producer of rainfall at either station, which is in contrast to climatologies (Yeh et al. 1951; Lyons 1982). If the statistics of the frequency of occurrence for Lihue and Honolulu are combined, then kona days increased dramatically (0 to 31) from JF81 to JF82 at the expense of three other patterns, particularly of trade wind days (41 to 22).

5. Upper-air circulation and synoptic patterns

The distribution of geopotential heights at 850 hPa over the North Pacific during JF81 is shown in Fig.

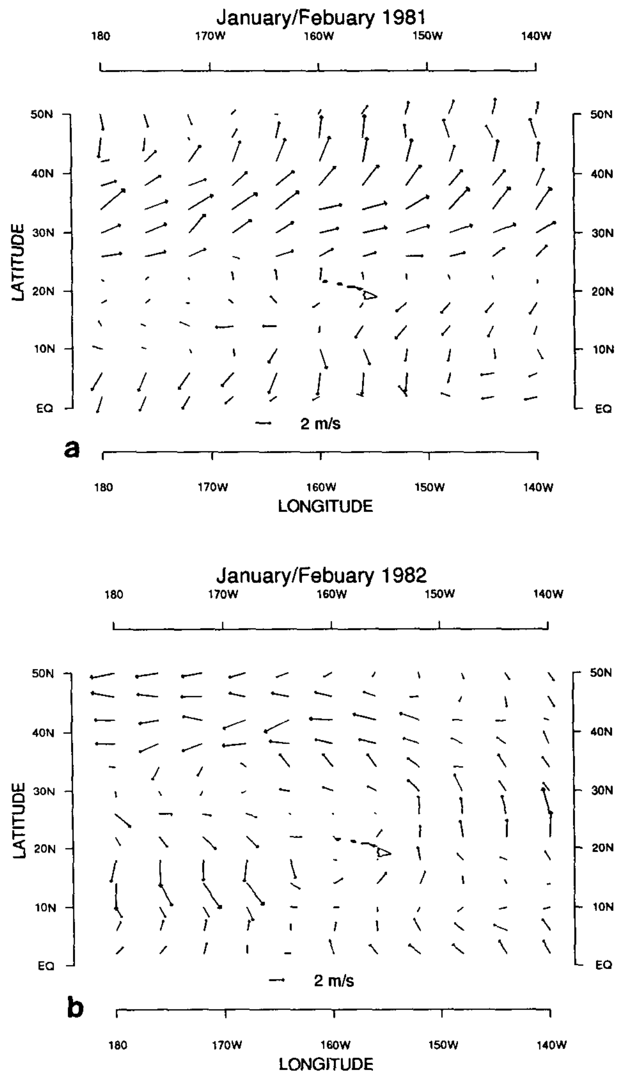

FIG. 3. Surface vector wind anomalies in the eastern North Pacific for (a) January/February 1981 and (b) January/February 1982. Anomalies are departures from 1951–1987 mean.

4a. Hawaii is located near the center of an elongated subtropical ridge that extends westward across the Pacific, and the axis of the ridge is just north of the islands. Within the center of the ridge, air subsides and warms adiabatically, producing a tendency for high temperature and low humidity throughout most of the lower and middle troposphere. Hence, although the number of the trade wind days in dry 1981 is nearly double that observed in wet 1982 at both Lihue and Honolulu (Table 1), the trade wind pattern accounted for only a little more rain in JF81 than in JF82. The axis of the subtropical ridge was just south of the islands in JF82, and the intensity of the subtropical ridge was less in JF82 than in JF81 (Fig. 4b). Moreover, the ridge during

[1] Anomaly is understood as the difference between individual bimonthly values and the corresponding long-term bimonthly mean, which is determined from the ship records covering the period 1951–1987.

TABLE 1. Statistics of the total number of days and rainfall (inches) associated with four major synoptic patterns (frontal, kona, trade, and ridge) in Hawaii. Data are based upon daily records at Lihue and Honolulu for January/February 1981 and 1982, denoted as JF81 and JF82, respectively. The percentage of rainfall, for each pattern, of the bimonthly rainfall (% tot), bimonthly rainfall totals (total rain), the long-term average bimonthly rainfall (avg rain), and the number of frontal passages (front pass) are also shown. Because of rounding, the sum of the percentage of rainfall, for each pattern, of the bimonthly rainfall (% tot) does not necessarily equal 100%.

Month	Front pass	Front days	Rain	% tot	Kona days	Rain	% tot	Trade days	Rain	% tot	Ridge days	Rain	% tot	Total rain	Avg rain
Lihue															
JF81	4	18	1.49	49.0	0	0	0	19	1.42	46.7	22	0.13	4.3	3.04	9.92
JF82	4	16	3.33	17.4	16	14.39	75.3	10	0.81	4.2	17	0.59	3.1	19.12	9.92
Honolulu															
JF81	4	17	1.08	60.7	0	0	0	22	0.55	30.9	20	0.15	8.4	1.78	6.51
JF82	4	15	5.47	36.5	15	8.26	55.1	12	0.48	3.2	17	0.77	5.1	14.98	6.51

JF82 was divided into two cells, one in the western North Pacific and the other in the eastern North Pacific. Hawaii was situated on the western flank of the eastern subtropical high and experienced moist southwesterly flows throughout the period. This flow pattern is not conducive to trade wind rainfall and may account for the extremely low frequency of trade wind days in JF82 (Table 1). Also, there were fewer ridge days in JF82.

At 200 hPa, the negative anomaly center during JF81 was found over the Aleutians (Fig. 5a). Farther south, positive height anomalies dominated the Hawaiian Is-

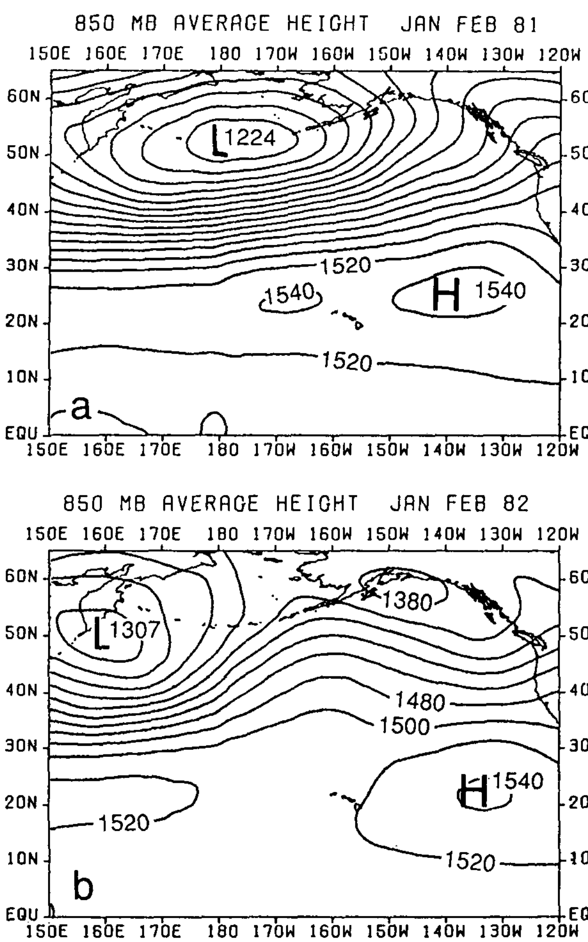

FIG. 4. 850-hPa geopotential height for (a) January/February 1981 and (b) January/February 1982. Contour interval is 20 gpm.

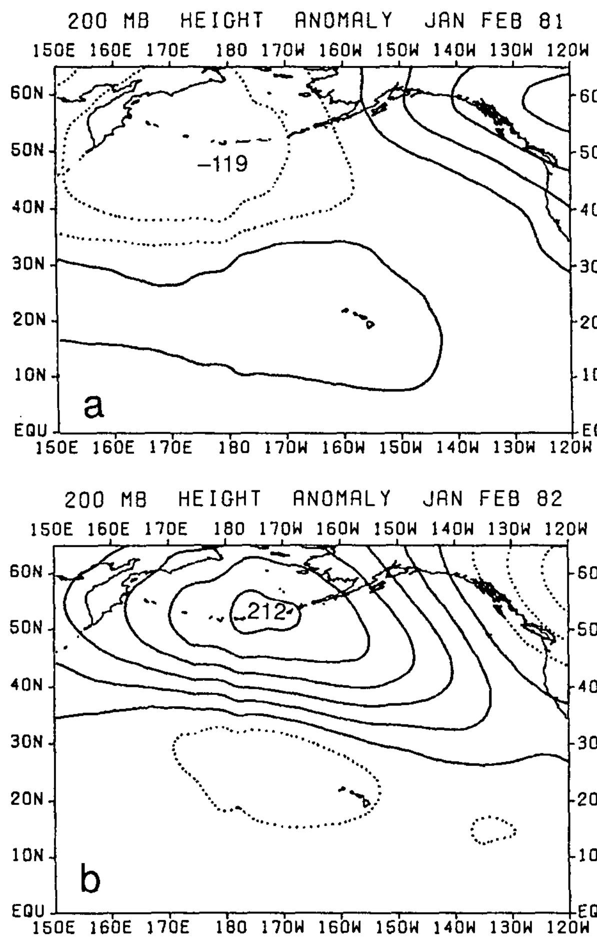

FIG. 5. 200-hPa geopotential height anomaly for (a) January/February 1981 and (b) January/February 1982. Areas of negative anomalies are shown as dashed lines. Contour interval is 40 gpm. The anomaly is departure from 1979–1987 mean.

lands. Taylor (1984) noted that this positive height anomaly pattern reflects an intensification and eastward displacement of the western North Pacific subtropical ridge. The upper-air circulation features presented in Figs. 4a and 5a do not favor the development of kona storms and suggest that the midlatitude storm track (i.e., fronts) is displaced farther poleward and eastward of Hawaii. Thus, although frontal days dominated the rainfall during JF81, the total rainfall was far less than normal due to the lack of upper-level support (Table 1). During JF82, large positive height anomalies were found over the Aleutian Islands, and negative height anomalies were found over Hawaii at 200 hPa (Fig. 5b). The weaker-than-normal subtropical ridge over the North Pacific allowed more transient wave disturbances to penetrate southward, producing more rain over the islands (Table 1). For instance, 16 (15) kona storm days were observed at Lihue (Honolulu) during JF82. These storms provided the primary rainfall to the islands during this period.

During JF81, the jet stream core at 200 hPa, defined as an area with speed greater than 40 m s^{-1}, extended to the north of the islands (Fig. 6a). Hawaii was located near the right exit region of the jet core, a region climatologically associated with upper-level convergence and midtropospheric subsidence (e.g., Reiter 1969). During JF82, the jet stream core remained mainly to the west of the date line and Hawaii was farther away from the jet core (Fig. 6b). The resulting upper-level divergence over Hawaii is climatologically conducive to enhanced wave activity and synoptic-scale cyclonic activity.

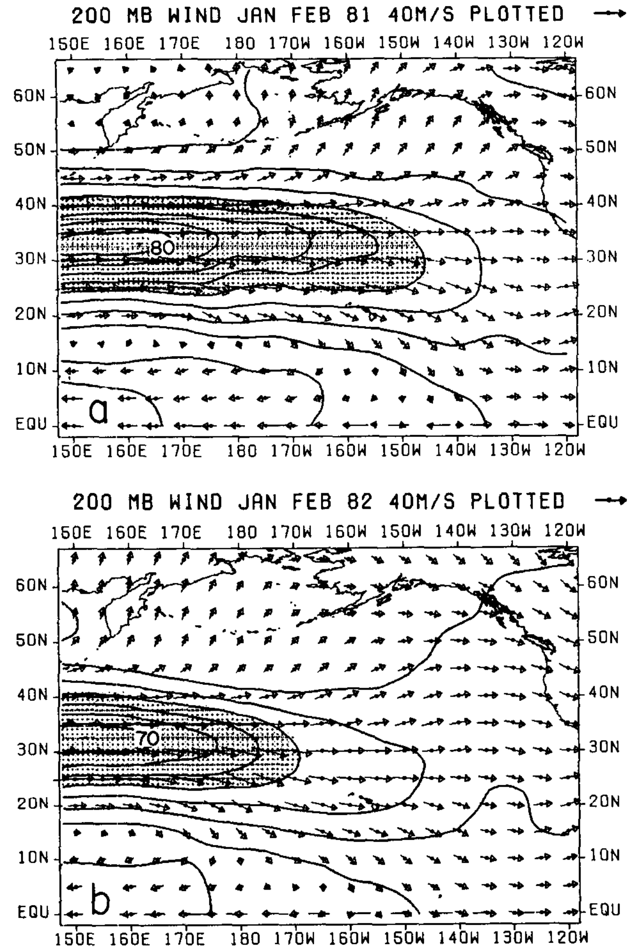

FIG. 6. 200-hPa wind field for (a) January/February 1981 and (b) January/February 1982. Isotach interval is 10 m s^{-1}. Area with wind speed greater than 40 m s^{-1} is shaded.

6. Discussion and summary

Our case study focused on circulation features that affected two contrasting rainfall episodes in Hawaii during non-ENSO winter months. The dry JF81, corresponding to the positive phase of the Pacific/North American (PNA) teleconnection pattern (Wallace and Gutzler 1981), is characterized by an anomalous anticyclonic circulation at the surface and by an extensive subtropical high pressure ridge in the lower troposphere. At 200 hPa, the westerly jet stream over the central and eastern North Pacific is enhanced, and Hawaii is located near the right-front quadrant of the jet core.

The wet JF82 corresponded to the negative phase of the PNA pattern. An anomalously strong cyclonic circulation, characteristic of kona storms, prevailed throughout Hawaii and over the region between the midlatitudes and the subtropics. At 850 hPa, Hawaii experienced moist equatorial flow. At 200 hPa, the jet stream over the eastern North Pacific was weaker than normal and did not extend as far eastward.

A large portion of the rainfall during JF82 was contributed by the quasi-stationary kona storms, and to a lesser extent by frontal precipitation bands. The kona storm pattern was completely absent during JF81. For both dry and wet episodes, rainfall resulting from the trade wind and ridge patterns was minimal. As two years of contrasting wintertime rainfall episodes are characterized by an opposite polarity of the PNA pattern, it is hypothesized that the PNA pattern acted as a large-scale control on the presence (or absence) of transient synoptic activities (e.g., kona storms, fronts) for modulating rainfall anomalies in Hawaii. However, because only two cases of extreme rainfall events were studied, these results should be considered preliminary in nature and may not necessarily be applied to other extreme rainfall episodes.

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