

Air Flow in the Central Valley of Maui, Hawaii¹

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ABSTRACT

Low-level winds in the central valley of the island of Maui were investigated in a field program during August 1976. Forty-one sites were occupied using three mobile stations during a period of persistent trade winds. Contemporaneous data from the Kahului Weather Service Office as well as other Hawaiian stations were collected to relate field observations to large-scale events. Streamline analyses reflect the diurnal variation of the low-level circulation which is profoundly influenced by Haleakala and West Maui volcanoes. The field survey was utilized in planning new fixed stations to monitor wind characteristics for wind power applications. Preliminary fixed station results are discussed. The importance of diurnal mesoscale patterns on wind power planning was emphasized.

1. Introduction

A revived interest in electric power generation by wind has stimulated studies of wind characteristics in areas that show potential for power generation. Owing to extreme vulnerability to interruption of fossil fuel supplies, the State of Hawaii is deeply involved in examination of the wind energy alternative.² Although small, the Hawaiian Islands possess a varied topography. Fifty percent of the land area lies above 600 m MSL (Blumenstock and Price, 1967). An analysis of wind power potential based on historical airport records such as done by Justus *et al.* (1976) for the continental United States would be misleading since all major long-record stations in Hawaii are airports near sea level. A variety of attempts have been made to model air flow over individual Hawaiian islands not including Maui (Lavoie, 1974; Hardy, 1976; Nickerson and Magaziner, 1976). Unfortunately, success has been elusive since ground-truth observations are inadequate. We have directed our efforts at remedying this deficiency, concentrating first on the properties of trade wind flow over the islands. Occurring approximately 70% of the year (Blumenstock and Price, 1967) the trades dominate Hawaiian weather and must prove a source of usable power if wind power is to be successfully exploited.

Our Maui field program had two purposes:

1) To define significant low-level flow features in the central valley by means of a brief and inexpensive

field program, testing *a priori* assumptions of topographic influences.

2) To use field results in siting a network of fixed stations for more rigorous evaluation of power generation potential and as a test of the accuracy of estimates made from the short-period survey.

Maui (Fig. 1) consists of two volcanoes connected by a broad, flat isthmus (central valley) planted in pineapple and sugar cane. Haleakala (Fig. 1) is much younger and less eroded than West Maui volcano and thus possesses the gentle slope characteristic of shield volcanoes (MacDonald and Abbott, 1970). During periods of northeasterly trade wind flow a subsidence inversion at 2 km (Leopold, 1948; Riehl *et al.*, 1951; Mordy and Eber, 1954; Lavoie, 1967, 1974) provides an effective upper lid and the central valley becomes a venturi. During the peak summer trade wind period, Kahului's July average speed of 7.1 m s^{-1} is 25% greater than other Hawaiian first-order stations (Department of Commerce, 1976).

Mesoscale circulations due to surface heating, especially on the slopes of Haleakala, complicate the simple venturi. Leopold (1949) demonstrated one mesoscale product of Haleakala, a cyclonic circulation cell which occurs at the intersection of the trade current diverted around the northern corner of the mountain with a lee side sea breeze.

The central valley is ideally suited for a field survey. The topography is relatively simple and a network of plantation roads in the isthmus and along the lower flank of Haleakala complements public thoroughfares providing ease of access to the study area. If a wind energy resource can be found in the central

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² The evaluation of wind energy potential depends considerably on engineering development of wind generators.

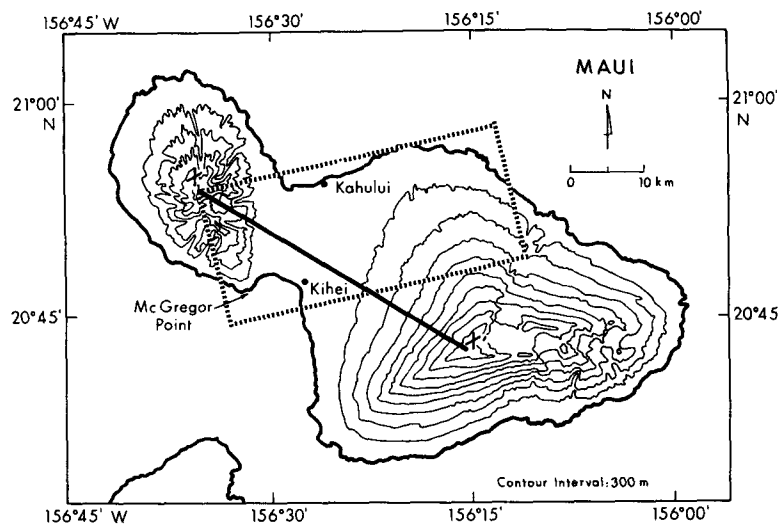


FIG. 1. Topographic map of the island of Maui featuring the rectangular area of the streamline analyses (Figs. 3-6), locations referred to in the text and a cross section from West Maui summit (X) to Haleakala (X').

valley, it would be juxtaposed with the population surrounding Kahului (Fig. 1).

2. Procedure

Between 7 and 26 August 1976 three mobile stations were deployed in the central valley. July and August represent the height of trade wind frequency and thus the highest probability of experiencing trade winds during field operations.

The stations are mounted on military surplus vans, each of which has one 9 m telescoping tower which can be rapidly erected through the center of the roof. The towers are guyed to the vans' roofs. A detachable bracket contains an integrating cup anemometer and wind vane.

Speed is recorded as an event (every 1.61 km) and direction continuously on the center pen of a spring-wound strip chart recorder. Prior to the elevation of the mast, directions were calibrated using a compass (magnetic declination over Maui is 11°15' east of true north). Thus each daily strip chart has its own direction calibration. Power to the anemometer electronics and vane potentiometer is supplied by an automobile battery. The overall system is inexpensive and reliable, if not sophisticated. Deployment of the system at a new site requires less than 1 h.

We stationed the vans at 41 sites during the field program (Fig. 2). Instruments were deployed and left unattended for 24 h at each site. If the trades failed, the stations were maintained *in situ* until favorable

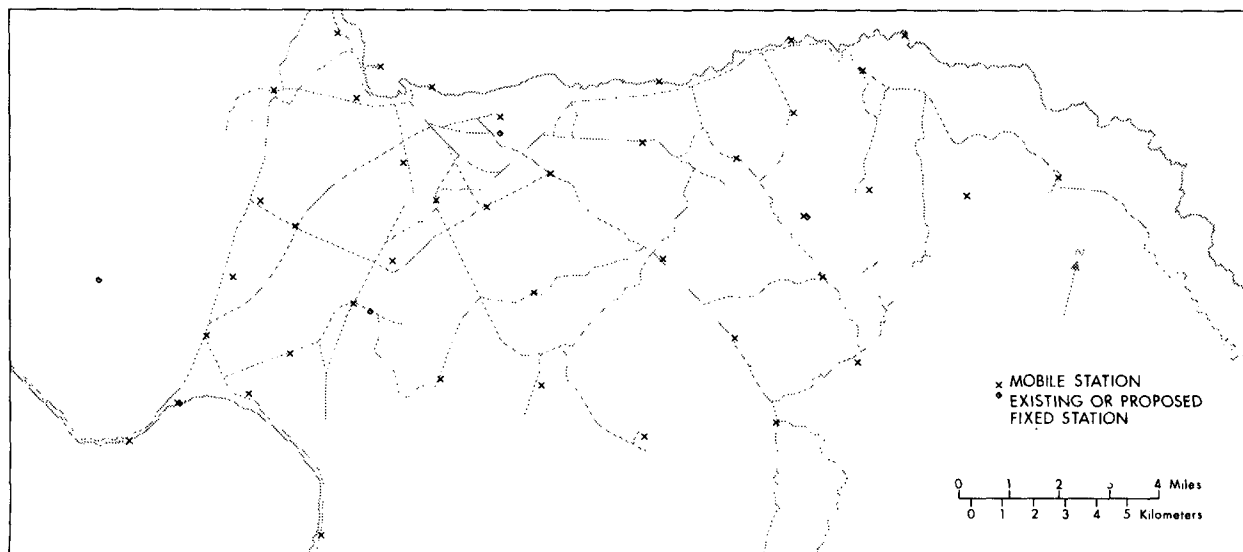


FIG. 2. Map of survey area featuring mobile station, proposed fixed station and the road network.

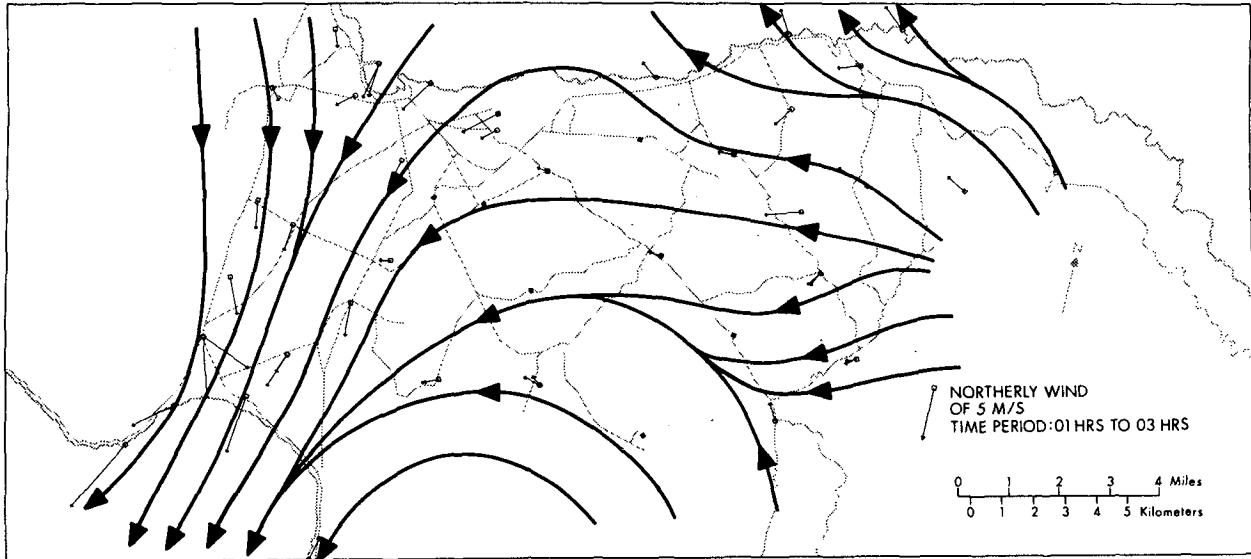


FIG. 3. Estimated average vector winds and streamlines for 0100 to 0400 LT. Multiple vectors indicate more than one day of observation.

winds returned. In this instance, we lost 16 and 17 August due to passage of a weakening tropical depression (remnants of Tropical Storm Gwen). A total of 1088 h of observations were obtained from the mobile platforms. In addition to these observations, contemporaneous data were obtained from a similar integrating anemometer at Kahului Weather Service Office (WSO). Additional observations were obtained from stations at Honolulu, Oahu and Lihue, Kauai. Pilot balloons, which are launched three times daily (0800, 1400 and 2000 LT³) at Kahului WSO, helped define the vertical wind structure.

3. Low-level wind fields

Since the Maui field survey operated over a limited period (coinciding, by choice, with optimum trade wind conditions), it is essential that the results be related to climatology. The only reference station available is the National Weather Service station at Kahului Airport. During the period of the survey Kahului winds were lighter than the 12-year mean (Table 1) although the steadiness (ratio of mean speed to resultant wind speed) was high as is characteristic of the trades.

In the absence of adequate energy storage, knowledge of diurnal cycles is essential to planning wind power applications. This is especially true in Hawaii where in the presence of persistent trade winds diurnal variations due to mesoscale processes dominate local weather. Hourly winds from field sites were combined with Kahului observations in a sequence of streamline analyses for the central valley (Figs. 3-6).

Wind directions (d) at the mobile stations have

been calculated as

$$d = \bar{d} + \sum_{i=1}^N (d_i - d'_i) / N,$$

where \bar{d} is the station mean direction, d_i the direction at the i th hour at a mobile station, d'_i the direction at Kahului WSO for that hour (mean for survey period) and N the number of hours sampled. Direction adjustments are based on the assumption that wind fields in the central valley respond systematically to direction shifts in trades.

Speed fields fluctuated considerably more than the direction fields. For that reason we have intentionally omitted adjusted isotach fields but have presented the raw mean speeds.

Because of the persistent trade winds during the period, we believe that we have depicted the essential features of trade wind flow in the central valley of Maui.

a. 0100-0400 LT (Fig. 3)

Downslope flow from Haleakala is evident in the eastern portion of the valley. Winds are generally

TABLE 1. Mean wind speeds and steadiness for first-order Hawaiian stations during the Maui field period (7-26 August 1976). Long-term mean is included for comparison.

Station	Mean 7-26 August (m s ⁻¹)	Long- term mean (m s ⁻¹)	(Years of record)	Percent steadiness
Lihue, Kauai	5.9	5.9	(26)	90.2
Honolulu, Oahu	6.3	6.4	(25)	91.5
Kahului, Maui	5.8	7.2	(12)	89.7
Hilo, Hawaii	3.0	3.2	(27)	12.5

³ Alaska Standard (150th meridian) Time.

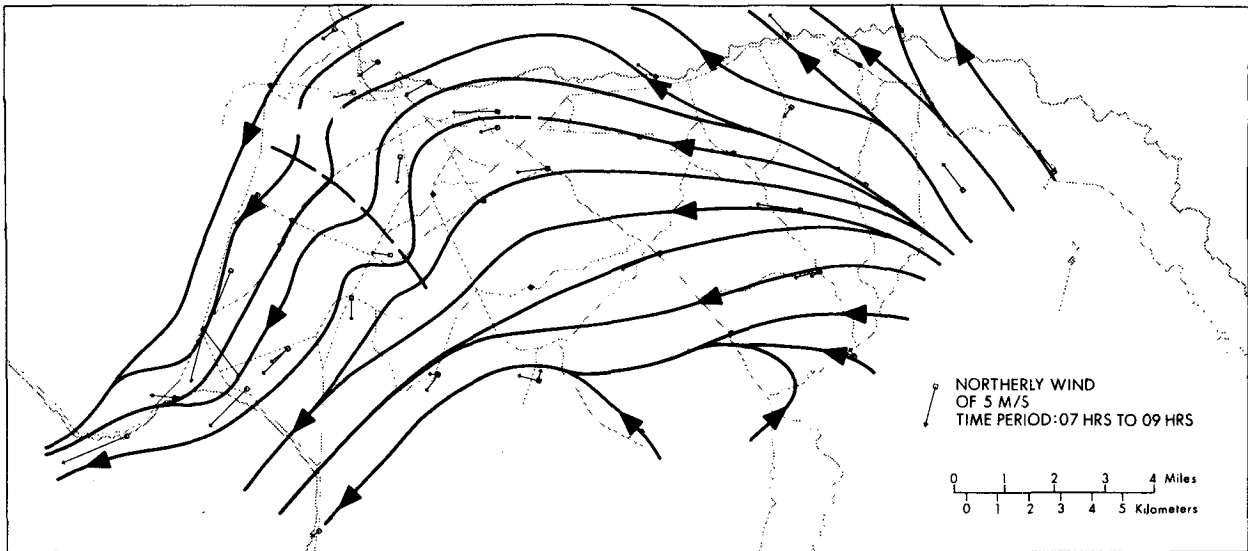


FIG. 4. As in Fig. 3 except for 0700 to 1000 LT.

light and offshore near the eastern coastal region. Drainage winds from West Maui are inconspicuous. In the leeward portion of the isthmus winds are fresh. McGregor Point (Fig. 1) experiences maximum wind strengths (15.4 m s^{-1}). Possible contributing factors are convergence of drainage flows with weakened trade winds leaving the valley.

b. 0700–1000 LT—immediately after sunrise (Fig. 4)

Winds strengthen and begin to shift to a more easterly direction in the eastern valley although some downslope components linger at higher elevations. As West Maui heats nearby winds turn slightly upslope.

Winds at McGregor Point slacken to 13 m s^{-1} as drainage winds disappear.

c. 1300–1600 LT (Fig. 5)

Northeasterly winds dominate the valley. Comparison with 12 h earlier reveals shifts of 30° on the northeast coast. Winds at Kahului and across the valley are at a diurnal maximum (Fig. 8) but at a minimum at McGregor Point. Sea breeze effects are evident along the southern coastline (e.g., Kihei, see Fig. 1). The Maui circulation cell (Leopold, 1949) lies south of the analyzed field but its presence may be inferred in the analysis.

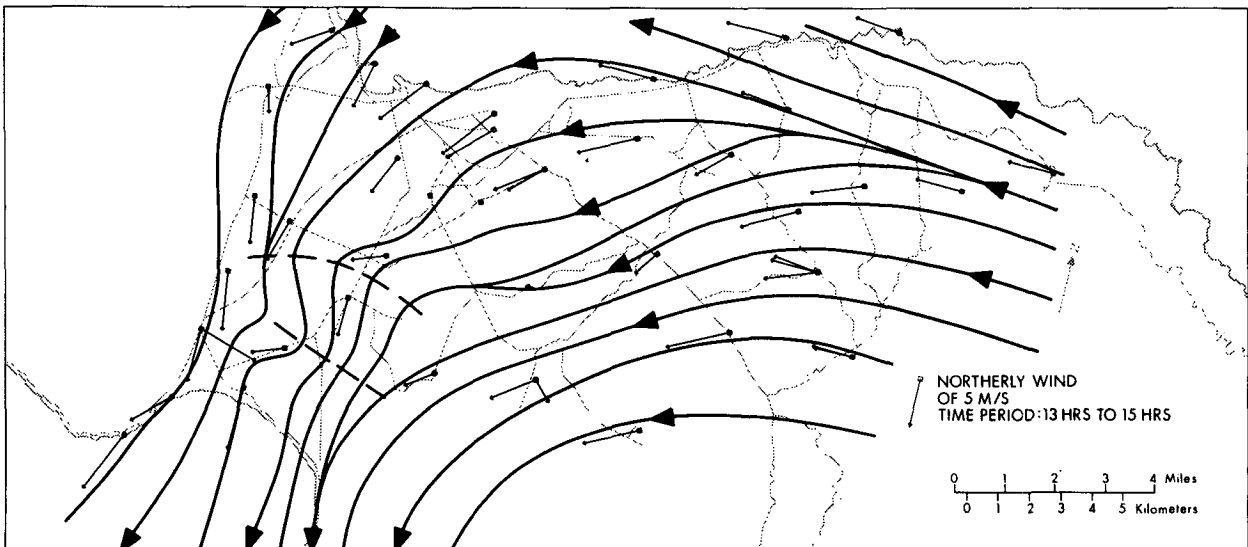


FIG. 5. As in Fig. 3 except for 1300 to 2200 LT.

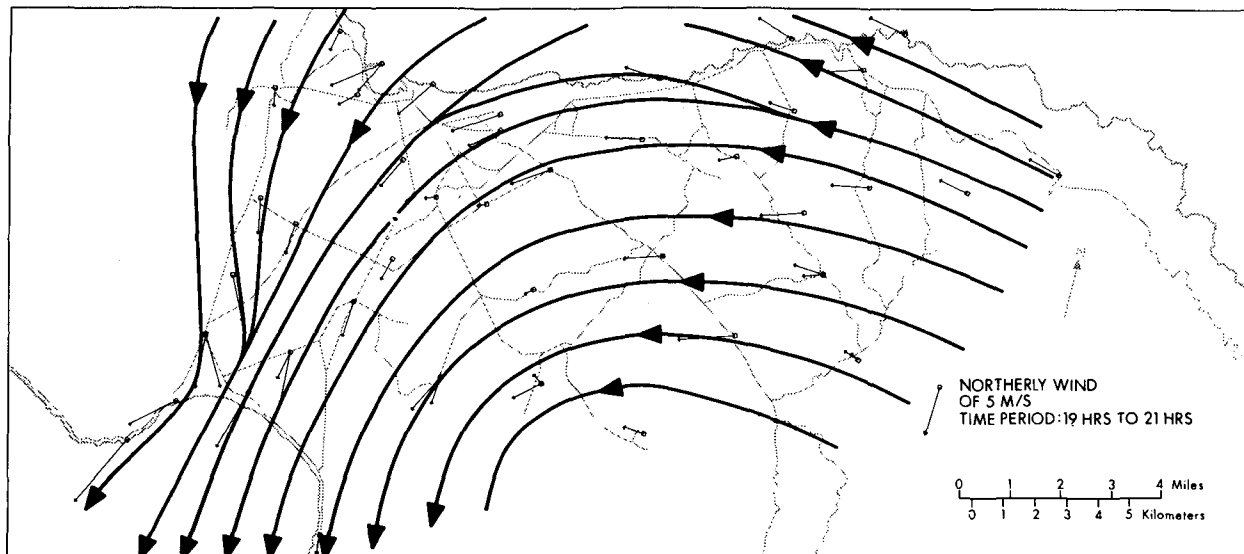


FIG. 6. As in Fig. 3 except for 1900 to 2200 LT.

d. 1900–2200 LT—immediately after sunset (Fig. 6)

Winds begin to slacken in the eastern valley. Along the upper slopes of Haleakala winds weaken and shift again to downslope. Maui energy demand peaks during these hours.

4. Discussion

Winds are stronger and more persistent in the leeward end of the valley than in the windward end. Over the same period McGregor Point averaged 13.7 m s^{-1} vs 7.0 at Kahului WSO (Fig. 7). Since power available varies as the cube of wind speed, the ratio of available power at McGregor Point to Kahului varies from 47.6 at 0800 to 1.8 at 1500. In Figs. 5 and 6 we see that in much of the survey area winds slackened immediately after sunset, the period of peak electric power demand (C. Higgins, personal communication). However, in 472 h of record at Kahului WSO the wind speed dropped below the 3.6 m s^{-1} cut-in speed of the NASA Plumbrook wind

mill for only 85 h (18% of the period). Most of these hours lay in the late evening and early morning, a slack period of power demand.

Two related diurnal mechanisms influence the Maui circulation. Haleakala and to a lesser extent West Maui produce diurnally varying mountain-valley circulations. Local circulations have been described for Mauna Loa (Mendonca and Iwaoka, 1969; Mendonca, 1969) and Mauna Kea (Morrison *et al.*, 1973), large (4000 m MSL) volcanoes on the island of Hawaii. Haleakala, while 1000 m lower in elevation, is nevertheless an immense structure.

Diurnal variations in low-level trades over open oceans are small (Riehl, 1954; Prüm, 1974) so the island must play a role. Considerable diurnal variation is evident in the Kahului surface wind strength (Fig. 8) as well as in the low-level winds measured by pilot balloons (Fig. 9). It is possible that turbulent mixing due to island heating may produce the afternoon acceleration of the winds in the lowest 250 m. An afternoon surface wind maximum is characteristic of continental stations but we have found similar afternoon trade wind maxima on leeward Oahu (Ramage *et al.*, 1977). National Weather Service personnel at Kahului (personal communication) have suspected that the subsiding component of Haleakala's thermally forced circulation may affect the pilot balloon winds over Maui. This may be the cause of the apparently spurious directions between 950 and 1330 m in the 1315 data (Fig. 9).

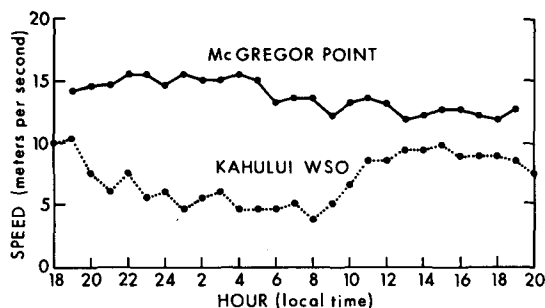


FIG. 7. Hourly wind speeds for McGregor Point (solid) and Kahului WSO (dotted) for the period 1800 LT 13 August to 2000 LT 14 August 1976.

5. Preliminary fixed station results

The results discussed above represent educated first guesses at wind characteristics in the central valley of Maui. The test of the veracity of the field

survey results lies in the development of long-term statistics at a number of points in the region. To this end we have incorporated survey results, with practical considerations to choose sites for installation of fixed measurement stations (Fig. 2). Of the five proposed sites one is Kahului WSO, one in the West Maui range has never been instrumented due to logistics problems, and a third at a harbor east of McGregor Point has only recently (August 1977) been instrumented in cooperation with the National Weather Service.

The remaining two sites have been operational since October 1976 and the preliminary results are discussed here to help evaluate the field survey estimates. The period of data record discussed *does not* include a summer trade wind season.

a. NOAA tower

The NOAA Data Operations Group maintain a tall tower at their Maui Field Station in Puunene 8 km northeast of McGregor Point. We instrumented this tower at the 9 and 26 m levels. The first nine month's data indicate that our field survey wind speeds for this region were considerably overestimated. We base this conclusion on the ratio of wind strengths between Kahului WSO and the tower as well as the actual mean speeds. At 26 m the mean speed was 5.2 m s^{-1} compared to 5.5 m s^{-1} at 6 m at the airport. Examination of direction traces at the NOAA tower revealed that there are considerable fluctuations throughout the day. This may indicate the boundary between the trade winds and the Haleakala sea breeze. This would displace both our boundary (Fig. 6) and Leopold's (1949) to the west.

b. Maunaolu College

Maunaolu College experienced strong winds during the field operations, is at a higher elevation (300 m MSL) than our other stations, lies in the eastern portion of the survey area, and is a possible site for alternate energy applications projects (Koide and Takahashi, 1977). A 15 m tower was erected. The nine-month mean (6.9 m s^{-1}) is within 3% of the field survey estimate based on ratios of Kahului and

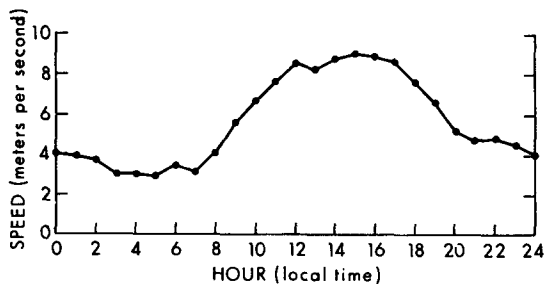


FIG. 8. Mean hourly wind speeds for Kahului WSO for the period 7-26 August 1976.

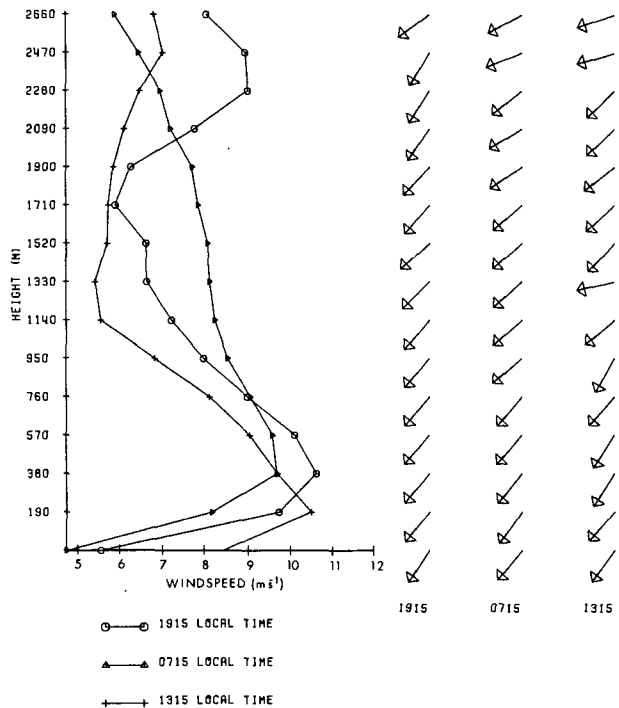


FIG. 9. Composite wind speeds and directions as functions of height for pilot balloon ascents at Kahului WSO for the period 7-26 August 1976. Mean height of trade inversion (based on Lihue, Kauai soundings) was 2 km for the period of the survey.

Maunaolu wind strengths once a $\frac{1}{6}$ power law correction is applied.

6. Conclusions

We have described an inexpensive field survey procedure for use in regions of persistent winds and relatively simple topography. We have been able to use the results of the field operation to prepare realistic analyses of the low-level wind fields in the central valley of Maui. The analyses confirm the existence of strong mesoscale influences due to Haleakala and West Maui volcanoes reflected in pronounced diurnal wind cycles. Preliminary results from fixed wind monitoring stations located on the basis of the survey results have caused adjustments in our derived wind fields at the intersection of the trade wind and the Haleakala sea breeze. As additional data accumulate we shall be able to further refine these estimates while collecting detailed data necessary for application to wind power generation. It should be emphasized that the procedures utilized in this effort may not work as well in areas of complex terrain and highly variable winds and that the field results represent "first guess" wind fields and not final results for applications planning.

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