METHODOLOGICAL APPROACHES IN HAWAIIAN FOG RESEARCH

by

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FOG PRECIPITATION ALONG TOPO-CLIMATIC GRADIENTS
ON THE ISLAND OF HAWAII

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ABSTRACT

Recent studies have demonstrated the important moisture contribution from fog precipitation in mountain areas on the island of Hawaii. The present study investigates research methodologies useful in the study of Hawaiian upslope fog, including: (1) development of an improved fog gage; (2) development of indirect approximation methods for estimating average droplet sizes during precipitation episodes and separating fog and rainfall components; (3) establishment of an extensive fog sampling network on the island of Hawaii employing continuous recording equipment, for both rain, fog, and wind; (4) development of an original computer program for detailed temporal and spatial analysis of rain, fog, and wind parameters.

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INTRODUCTION

The objective of this paper is to assess a variety of methodological approaches for investigating the role and contribution of fog moisture in the water balance of mountain forest ecosystems on the island of Hawaii. Recent studies have demonstrated the important contribution of intercepted fog moisture on windward Mauna Loa; in the present study the research methodology employed in a more sophisticated analysis of fog is described and evaluated. The major goals in this study were to:

1. Test methods for droplet size determination in Hawaiian upslope fog
2. Develop a mechanical fog interceptor with geometrical properties that enable the clear separation of rain and fog components
3. Develop an accurate definition of a fog episode by separating fog from any nonvertical rainfall component, through an analysis of the physical relationships between rain inclination angle, wind speed, and droplet size
4. Compare the collection efficiency of the newly designed fog interceptor with that of the standard Grunow-type fog gage used in a number of previous studies
5. Devise an adequate sampling network, employing a combination of both automatic and manual equipment for evaluating the role of fog in both leeward and windward areas
6. Develop a computer program for reducing rain, fog, and wind data and for graphic display and statistical manipulation.

LITERATURE REVIEW

Fog has been variously defined in terms of visibility, droplet size, or formational characteristics. For the purposes of this discussion, we shall simply define fog as a cloud at ground level, with droplet sizes below 100 microns predominating.

There are basically two types of fogs: radiation and advection. Radiation fog is formed by radiational cooling to dew point of shallow layers of quiet humid air overlying a chilled surface. Advection fog is formed when moist air moves across a cold surface. Upslope fog, a type of advection fog, occurs in the Hawaiian Islands when warm tropical air ascends mountain slopes and cools to the saturation point at higher elevations.

Droplet size is an important factor in the "productivity", (i.e., water yield) of fog, and this variable is dependent largely on characteristics of the originating air mass. Fog that develops in continental source regions tends to have smaller droplets, higher concentrations, and a narrow size spectrum, while those originating in marine air generally have larger droplets and a wider size spectrum. Factors such as availability of moisture, type of cloud, availability and activity of condensation nuclei, age of the cloud, and the turbulent air motions all play a role in determining the growth of cloud droplets.

Nagel (1956) and List (1971) established the following arbitrary classes for distinguishing rain and fog from drizzle:

TABLE 1. ARBITRARY SIZE RANGE CLASSES FOR DISTINGUISHING RAIN AND FOG FROM DRIZZLE

CATEGORY	SIZE RANGE (NAGEL)	SIZE RANGE (LIST)
RAIN	200-600 microns	400-5000 microns
DRIZZLE	100-200 "	100-400 "
MIST	--	50-100 "
FOG	3-100 "	5-50 "
HAZE	0-3 "	--

Grunow (1960*b*), in his investigations into droplet size, found that fog formed in cold polar air is inefficient in producing large droplets, (diameters average 2 to 15 microns). In marine warm air masses, the cloud droplet spectrum was characterized by a broader range of 4 to 25 microns diameter, with a maximum frequency between 8 to 14 microns. Grunow found that the most productive fogs (2-3 mm/hr) occurred in nonraining cloud decks formed in degenerating marine air masses.

The effect of fog on vegetation was also investigated by Grunow (1960*a*), who found that minute precipitation played an important role as a water source for vegetation. The device which he used, the "Hohenpeissenberg Device", measures precipitation below the particle size which is needed to wet the standard rain gage. It was found in this study that nearly half of all rainfall fell into the category of minute precipitation.

Squires and Warner's (1957) study of the structure of orographic clouds on the slopes of Mauna Loa offers a partial explanation for the frequency of fog in the mountain areas of Hawaii. The average depth of orographic clouds decreases from about 1200 m at sea level to a depth of 600 m at inland elevations of 1800 m. There is a somewhat sharp transofrmation from a cumuliform structure near the ocean to a stratiform structure on the upper slopes. The general structure and shallow cloud depth would necessarily limit the growth of water droplets. The cloud droplet spectra obtained for low lying orographic clouds by Squires and Warner (1957) show a large quantity of droplets in the 12 to 18 micron range which Grunow (1960*b*, p. 115) considered optimum for interception by wire screens and trees in the forests of the windward Alps.

Nagel (1956) measured fog precipitation for a one-year period on Table Mountain, South Africa, using two rain gages, on equipped with a "fog catcher" made of wire mesh screen mounted on a standard 8-in. rain gage. Several problems were encountered, one being the air turbulence caused by the microtopography of the terrain, which made it difficult to obtain representative samples. However, Nagel pointed out that undisturbed airflow would also be difficult to measure because in an airstream with an upward directed component raindrops may move horizontally or upward. The fog precipitation for the one-year period was found to be 3299 mm, as compared with only 1940 mm, for rainfall.

On Lanaihale, on the island of Lanai, Hawaii, Ekern (1964) investigated the comparative efficiency of various fog collecting materials. He first constructed a harp patterned of vertical copper wires .01-in. diameter spaced .25 in. apart in a 37 x 37.5-in. frame. The harp was four feet off the ground, exposed adjacent to a tree, and kept oriented to the wind by use of a vane. The water collected was recorded in a standard 8-in. rain gage. Over a three year period, more than 1964 in. of water were collected by the harp while the standard rain gage caught only 104 in. (Ekern 1964, p. 420). After correction of the fog data to the unit vertical area of the rain gage, the fog interception was found to be 71 in., equal to 2/3 of the rainfall. Other materials were also tested for their interception efficiency. Air conditioning filters were found to be unsatisfactory; saran window screens retained water in the mesh and became impermeable to the wind. Vertical, louvered aluminum shade screens were found to be even more satisfactory than the harp, producing (per unit vertical area) 3.96 in. of water while the harp yielded 3.53 in., and the standard rain gage .99 in.

Fog and low lying clouds were investigated by Vogelman et al. (1968), on the slopes of the Green Mountains in Vermont. Three sampling sites were established at 540 m, 840 m, and 1080 m. Paired rain gages were used at each elevation, one unmodified and one with a double coil of aluminum wire screen set inside the gage and extending 16 cm above the top. Both of these gages were mounted on 6-ft wooden posts and set in the ground 5 feet apart in the center of clearings. Each week between 3 July 1967 and 27 August 1967 the water content was measured in millimeters. At 840 m, the screened rain gage gathered 5.0% more water than the unscreened rain gage while at 1080 m, the screened rain gage collected 66.8% more water than the unscreened gage.

Fog along an altitudinal gradient in the cloud forests of eastern Mexico was also investigated by Vogelman (1973). Fog interceptors were set up at various elevations ranging from 16 to 2425 meters. The gages were constructed from 1-liter oil cans. Some of the gages were fitted with a cylinder of aluminum window screen. In all 12 different stations were set up: 3 on the dry coastal plain, 7 in and near the rain forest, and 2 on the dry plateau above the cloud forest. During the dry season, fog interceptors produced 85.1% of rainfall at 1330 m and 102.9% of rainfall at 1898 m. However, Volgelman failed to reduce his data to unit vertical area equivalents, and percentage values reported are difficult to interpret.

Burton (1971) noted the capabilities of the giant redwood trees to gather water through interception of fog and low clouds and by absorption of this fog through the needles of the tree.

Juvik and Perreira (1974) in the pilot phase of an ongoing research program (of which this study is a part), set up fog interceptors at 4 different elevations on windward Mauna Loa: at 610 m, 1580 m, 2530 m, and 3415 m. These fog interceptors were constructed of aluminum louvered shade screens and were matched with corresponding 8-in. (20.32 cm) standard rain gages. They found that fog played an extremely important role, and that its relative contribution increased with elevation. At 2500 m, the fog intercepted (per unit vertical area) over a 7-month period equaled 65% of the direct rainfall. It was shown that with a simple set of regression equations one could predict fog interception as a function of rainfall and elevation. Juvik and Perreira also found that during summer drought periods the relative contribution of fog increased dramatically.

DROPLET SIZES

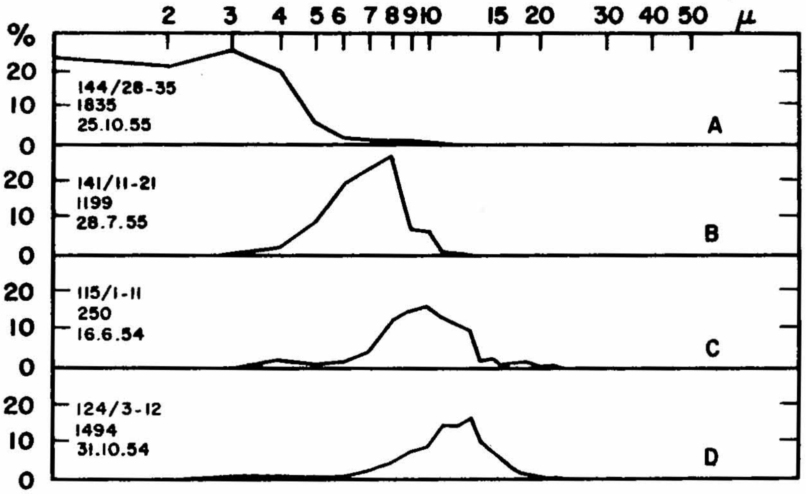
Droplet size is an extremely important parameter in any consideration of fog interception by either natural vegetation or artificial screens. The efficiency of fog interception is dependent on the interrelation of droplet size and the nature of the intercepting surface. As noted earlier, in Hawaii when ascending air is compressed between the rising mountain and the trade wind inversion, the cloud is transformed from cumuliform (with good vertical mixing) to stratiform, thinly layered with poor vertical mixing, and correspondingly smaller droplet sizes. Specific droplet information is particularly important in any consideration of large scale artificial screen catchment, because the collection efficiency of many materials may change under different droplet sizes.

Grunow (1960*b*) investigating fog droplet sizes in the Alps found that the air mass source region largely determined the nature of the droplet spectrum (Fig. 1). Polar continental air masses generally had much smaller droplet sizes than tropical maritime air.

Squires (1958) undertook airborn transects in the sampling of the cloud droplet spectrum on windward Mauna Loa. Figure 2 illustrates his findings of droplet sizes in orographic and stratus clouds. The decrease in droplet size for stratus is evident.

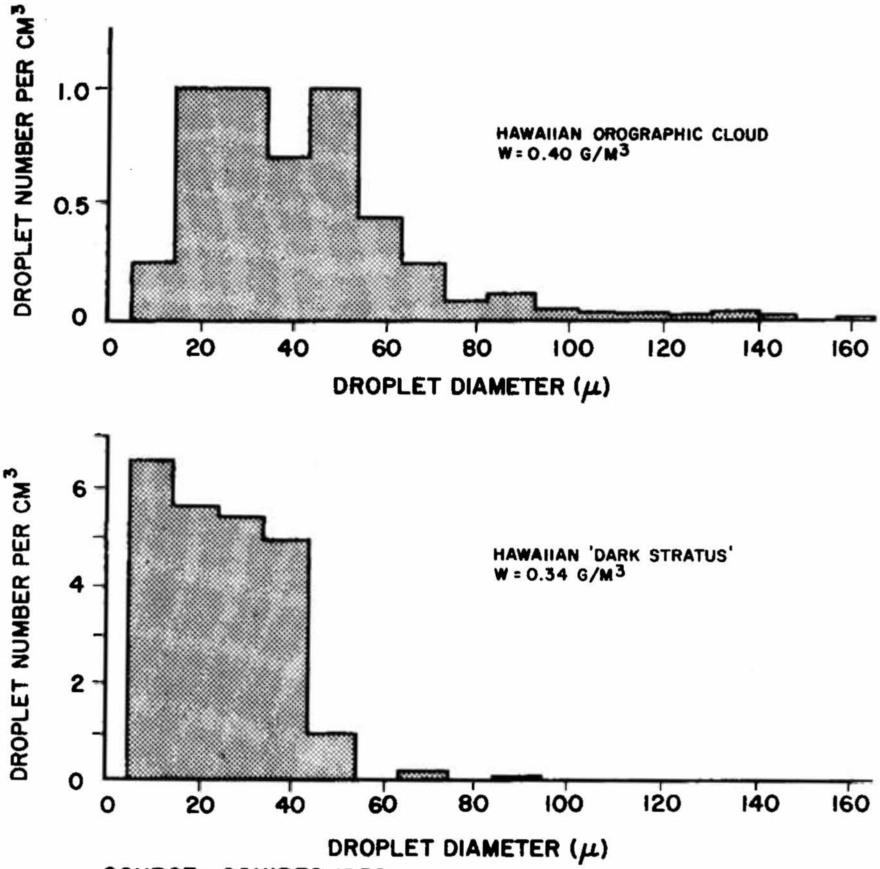
In the present study an analysis of ground level fog-cloud droplet size was undertaken at two locations on windward Mauna Loa: Hawaii Volcanoes National Park Headquarters (Sta. B-1), el. 1170 m, and Kulani Honor Camp (Sta. A-1), el. 1580 m (Fig. 3). The magnesium oxide method of drop size determination was utilized (May 1950). Microscope slides are exposed to burning magnesium and coated with a thin oxide layer. The slide is then exposed to fog for a specified period of time. Water droplets leave an impact crater in the magnesium oxide directly proportional to the actual droplet diameter. The impact crater diameters are then measured under a microscope and multiplied by a correction factor (0.75) to determine the droplet size (May 1950). Figure 4 presents a microphotograph of an exposed magnesium oxide coated slide. Typical fog droplet impact craters are shown in size relationships to a 1 mm raindrop.

Figure 5 illustrates the fog droplet spectra (averaged from several slide samples), for the two windward Mauna Loa locations. In comparing these results with those in Figures 1 and 2, our mean droplet sizes appear



SOURCE: GRUNOW 1960

FIGURE 1. FOG CLOUD DROPLET SPECTRUM AS A FUNCTION OF AIR MASS TYPE IN THE ALPS: (A-B) POLAR AIR; (C) MARITIME; (D) SUBTROPICAL MARITIME



SOURCE: SQUIRES 1958

FIGURE 2. AVERAGE DROPLET SPECTRA IN OROGRAPHIC AND STRATUS CLOUDS ON WINDWARD MAUNA LOA

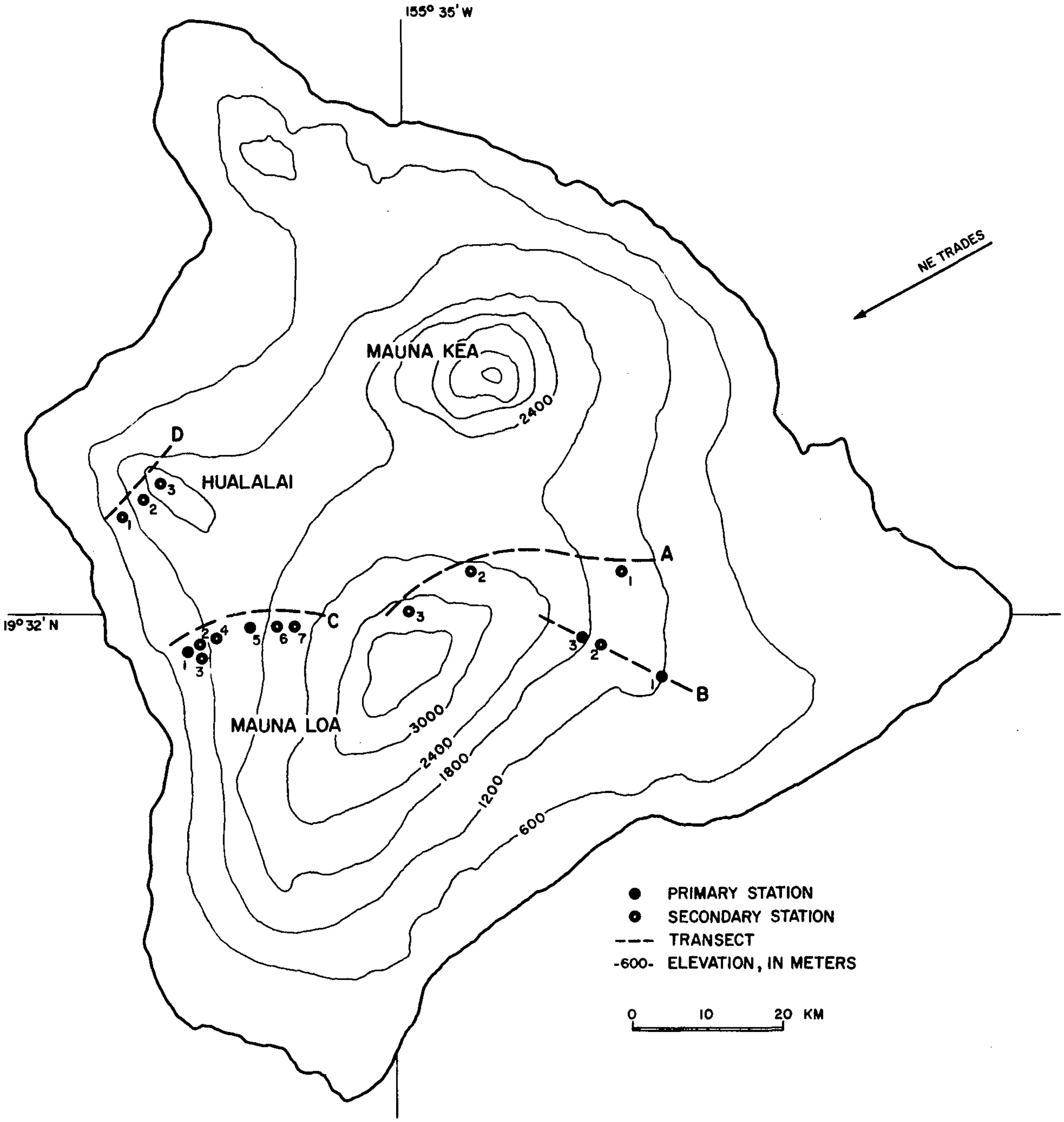


FIGURE 3. LOCATION OF FOG SAMPLING STATIONS ON THE ISLAND OF HAWAII

somewhat smaller, with the bulk of all droplets below 10 microns in diameter. The difference between our results and those in Figure 2 may in part be attributed to the differences in sampling height. Squires (1958) sampled at

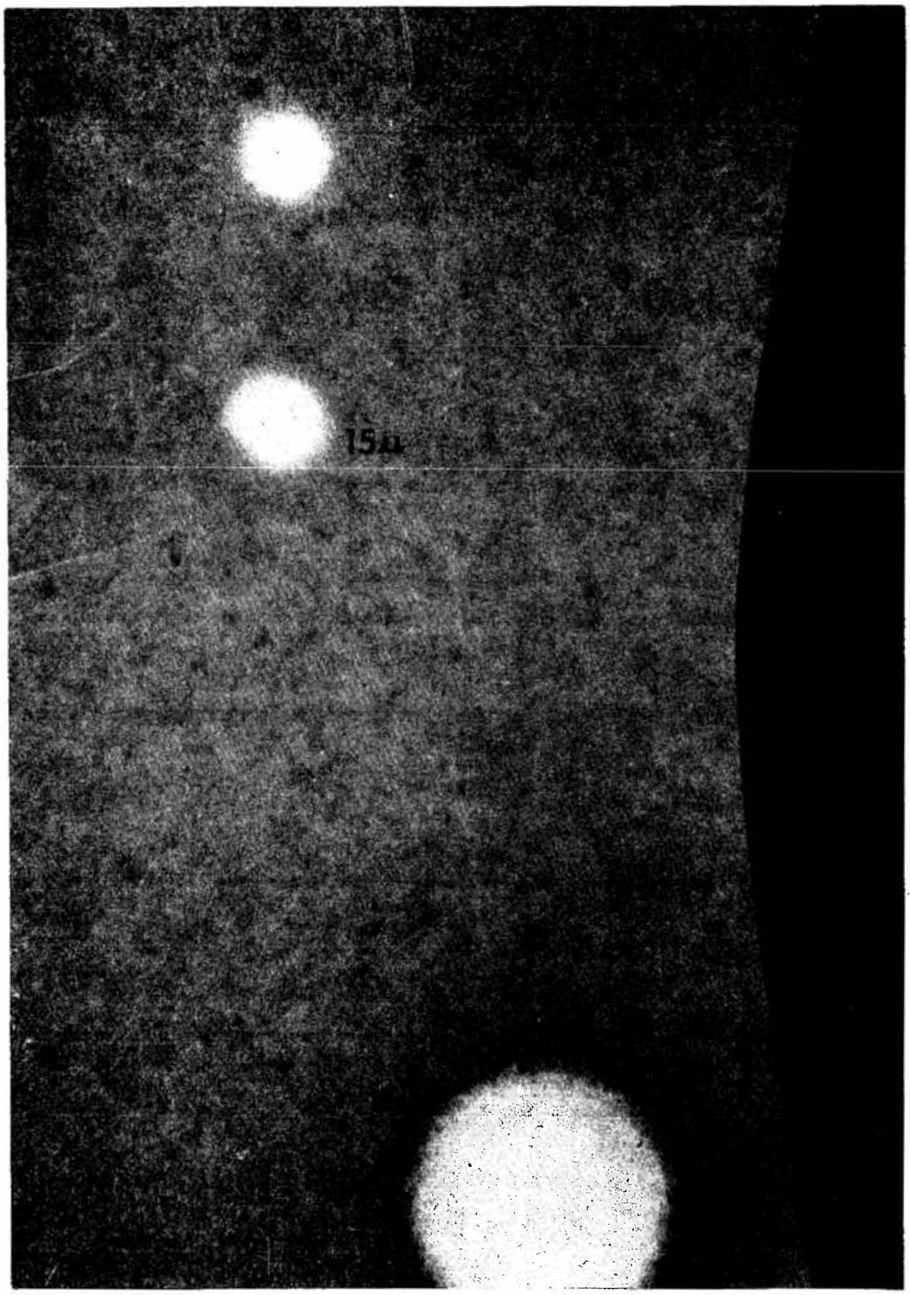
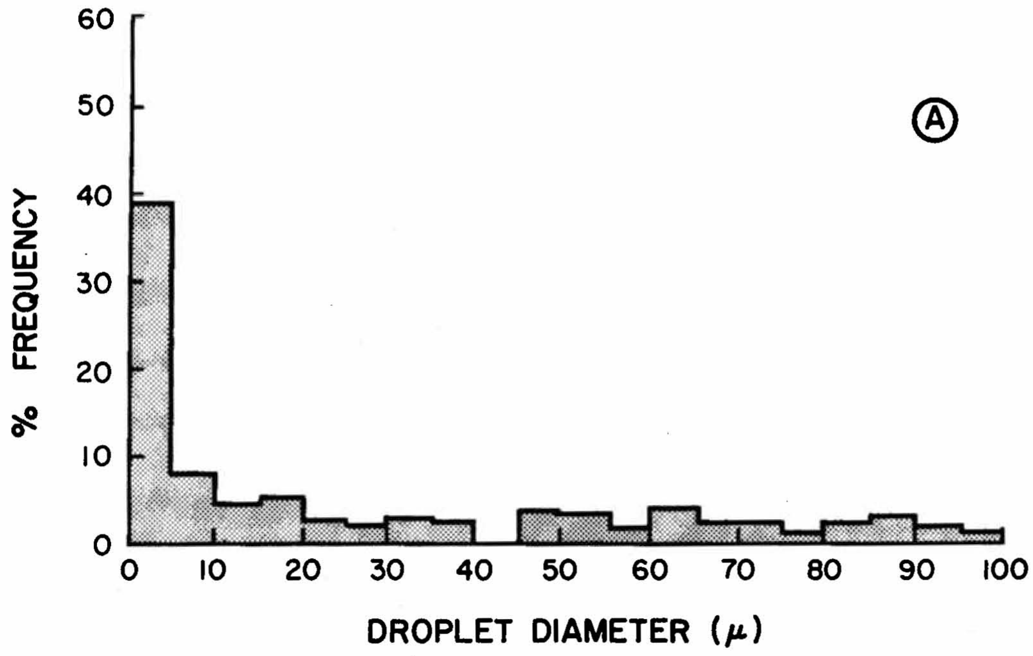


FIGURE 4. MICROPHOTOGRAPH OF FOG DROPLET IMPACT CRATERS ON MAGNESIUM OXIDE COATED SLIDE. TYPICAL FOG DROPLETS SHOWN IN RELATIONSHIP TO 1 mm, RAIN DROP (CHORD AT RIGHT)



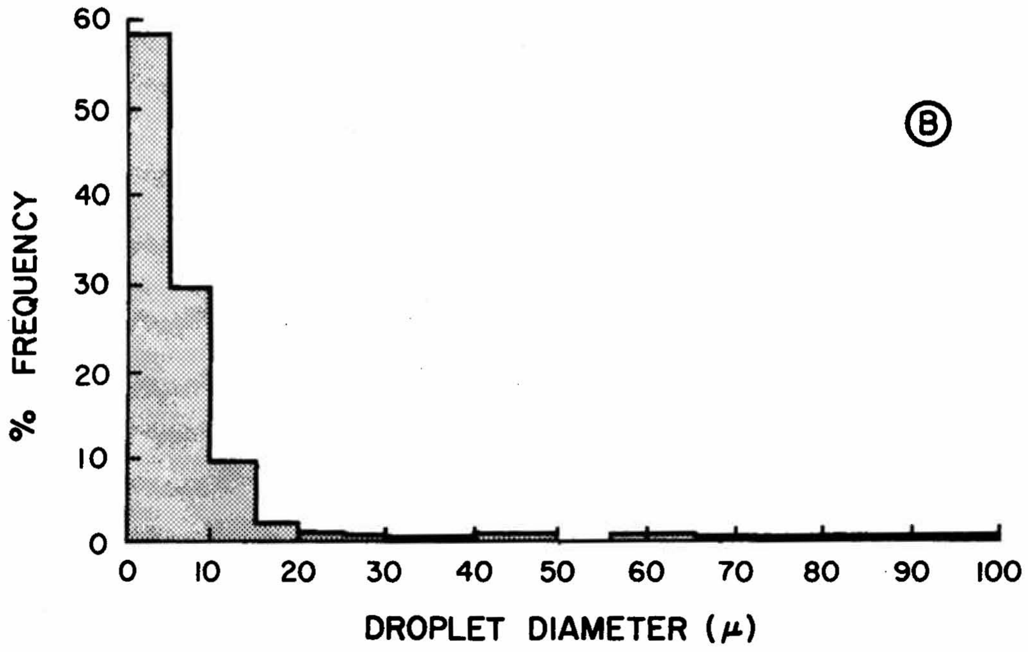


FIGURE 5. DROPLET SPECTRA FOR GROUND LEVEL UPSLOPE FOG ON WINDWARD MAUNA LOA: (A) KULANI HONOR CAMP, EL. 1580 m (AVERAGE OF 8 SAMPLES); (B) HAWAII VOLCANOES NATIONAL PARK HEADQUARTERS, EL. 1170 m (AVERAGE OF 5 SAMPLES)

1000 to 2000 feet (305 to 610 m) above the terrain. Samples taken in this study are at ground level, and perhaps represent an area at the very base of the cloud with poor droplet growth potential.

Regardless of the cause, the very small droplet sizes determined in this study help to further explain why simple rain gage data do not adequately portray the total moisture situation in mountain areas of Hawaii. Further, the designer of any artificial fog catchment system must be cognizant of the small droplet sizes in the choice of interception materials (see p. 16).

THE LOUVERED ALUMINUM SCREEN FOG GAGE

Ekern's (1964) detailed research on the comparative fog interception efficiency of various screen materials demonstrated the superior performance of wire harps and louvered aluminum shade screen. Typical wire mesh was found to be less satisfactory because of poorer drainage characteristics. Juvik and Perreira (1974) utilized louvered screen cylinders for fog catchment studies on Mauna Loa.

In the present study a gage similar to that developed by Juvik and Perreira was employed incorporating a number of design refinements based on field experiences with the earlier prototype. Figures 6 and 7 illustrate the louvered screen fog gage and the method of field mounting. The specific size dimensions of the gage are presented in Figure 8. A louvered screen cylinder (see Fig. 9 for screen detail) 12.7 cm in diameter and 40.6 cm in height was mounted into a stainless steel funnel with a diameter of 15.2 cm. This assembly was then supported on a tripod that placed the center of the screen cylinder at 3 m above the ground. Three meters was arbitrarily chosen to be representative of the mid-canopy height of subalpine scrub forests on the slopes of Mauna Kea and Mauna Loa, it was also considered that this height would minimize the effect of near surface vertical wind gradients. Companion wind measurements were also taken at 3 m. A flexible plastic tube drained the gage funnel into either a covered recording rain gage (at primary stations), or a covered, standard direct reading rain gage (at secondary stations). The louvered screen gage collected rainfall as well as horizontal traveling fog and moisture. The fog component may be derived from the difference between the louvered screen gage output, and that of a companion standard rain gage (with correction for differences in

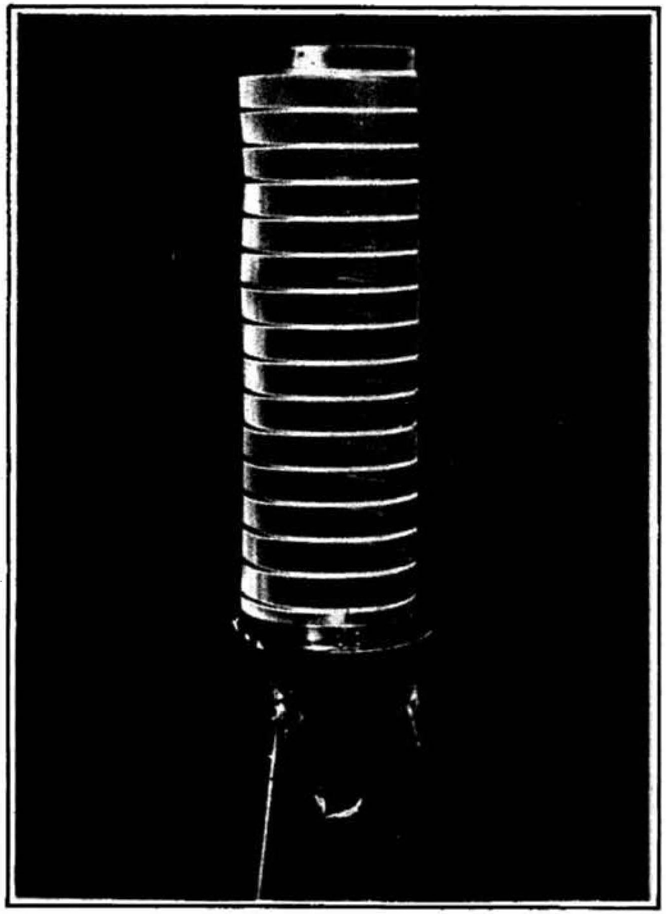


FIGURE 6. LOUVERED SCREEN FOG GAGE

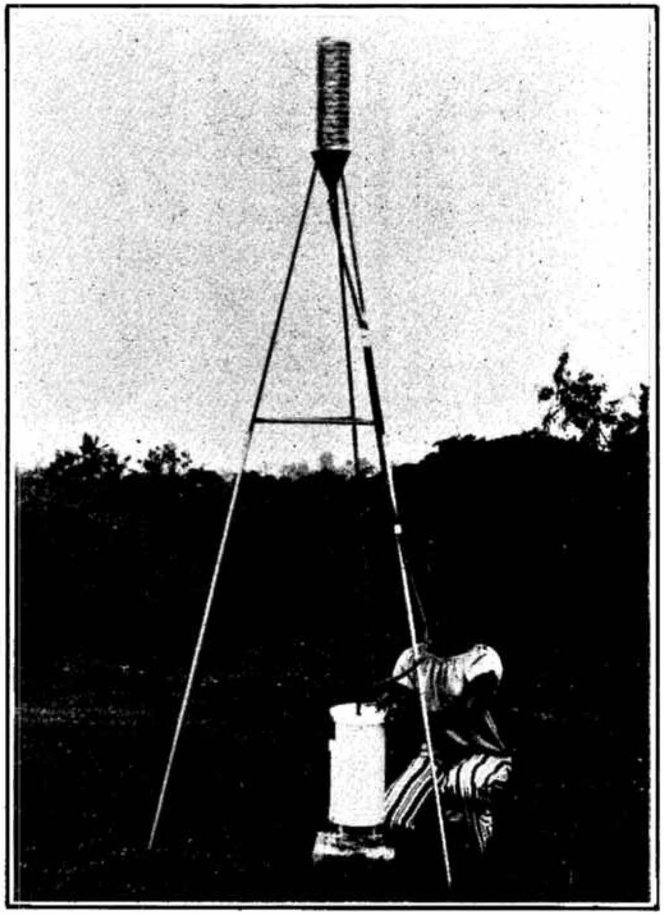


FIGURE 7. RECORDING FOG GAGE FIELD MOUNTED ON 3 m TRIPOD, DRAINING INTO TIPPING-BUCKET RAIN GAGE

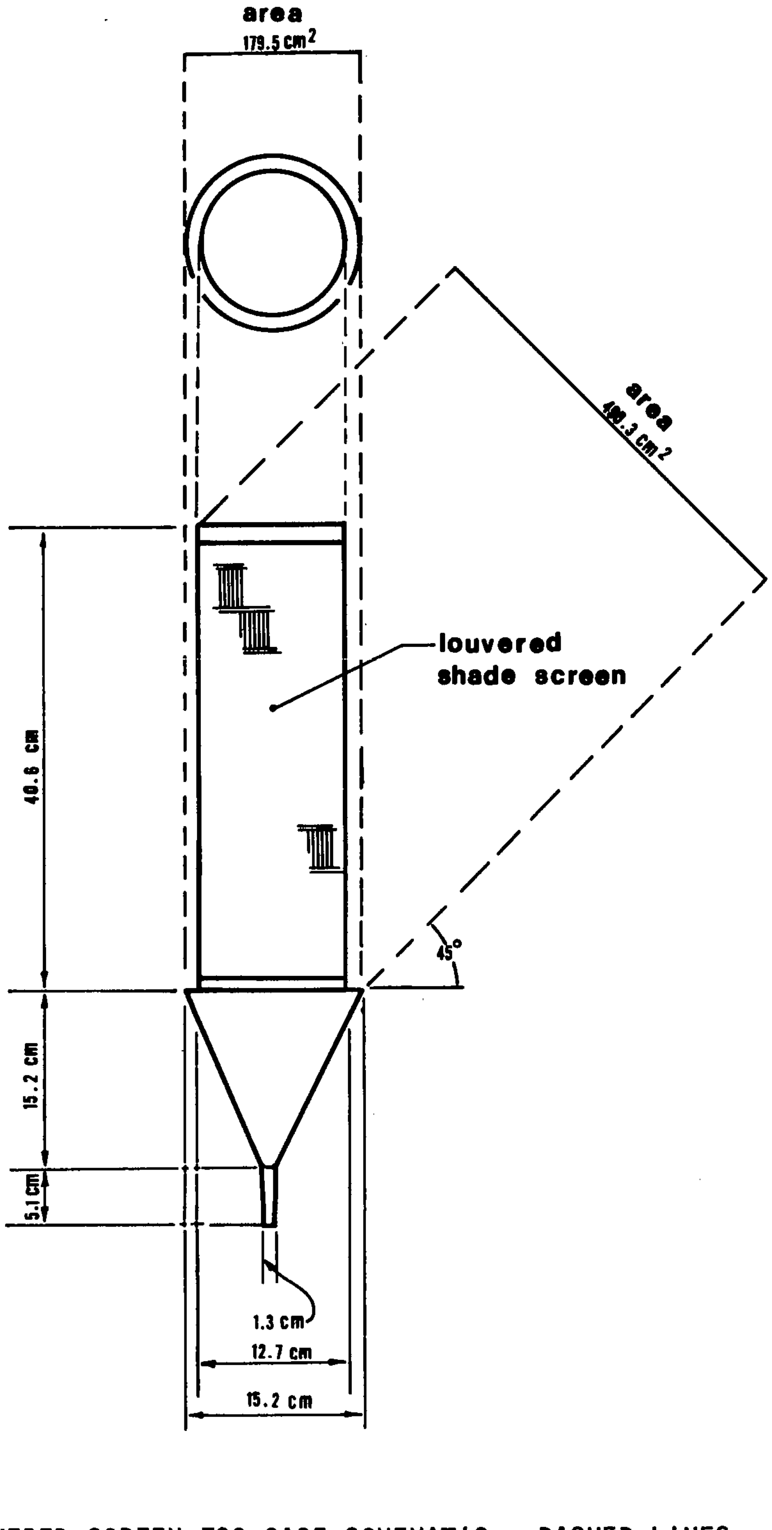


FIGURE 8. LOUVERED SCREEN FOG GAGE SCHEMATIC. DASHED LINES ILLUSTRATE CHANGE IN CATCHMENT AREA WITH CHANGE IN RAIN INCLINATION

catchment area). The interaction of rain and fog in the louvered screen gage is discussed in greater detail in a following section.

As Ekern (1964) demonstrated in his studies at Lanaihale, fog interception efficiency is largely dependent on the characteristics of the screen material used. In several previous studies on fog interception in South Africa (Nagel 1956), Europe (Grunow 1960*b*), and Mexico (Vogelman 1973), standard wire mesh screen gages of the Grunow type have been employed (Fig. 10).

In the present study, experiments were conducted to compare the collection efficiency of the Grunow type gage and the louvered screen gage. Weekly values of fog were computed on a "unit-area" basis for the two gages (because of different cylinder sizes) and plotted against the weekly rainfall. Based on a least square fit to the data, the louvered screen gage collected an average of 20% more fog than the Grunow gage.

NONVERTICAL RAINFALL AND THE LOUVERED SCREEN FOG GAGE: THE PROBLEM OF FOG DEFINITION

As discussed in the previous sections, the louvered screen fog gage collects rain as well as fog. However, simple subtraction of rainfall (collected in an adjacent rain gage) does not necessarily yield a true value for the measurement of fog if nonvertical rainfall has occurred during the sampling period. As illustrated in Figure 8 for rain-catching purposes the relative catchment area of the fog gage increases dramatically as the angle of incoming rain increases from vertical (i.e., from a catchment area of 179.5 cm^2 at vertical to 490.3 cm^2 at rain angle of 45°). Thus, during periods of nonvertical rainfall, the fog gage will record rain values substantially above a standard rain gage, even in the absence of fog, Figure 11 portrays the predicted relationship between the fog gage and standard rain gage as a function of rain inclination angle. For example, at a rain inclination of 45° the fog gage would be expected (on the basis of its geometry) to collect 2.1 times as much rain water as the standard rain gage. Conversely, if the fog gage (during a sampling period) records 5 times the precipitation of a standard rain gage, we must assume that the average inclination angle of incident precipitation exceeds 70° in order that this difference can occur.

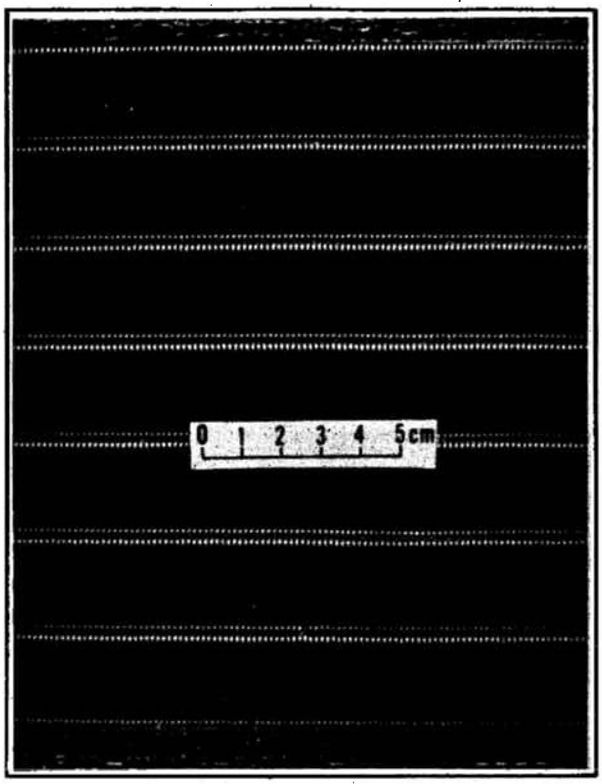


FIGURE 9. CLOSEUP OF LOUVERED ALUMINUM SHADE SCREEN

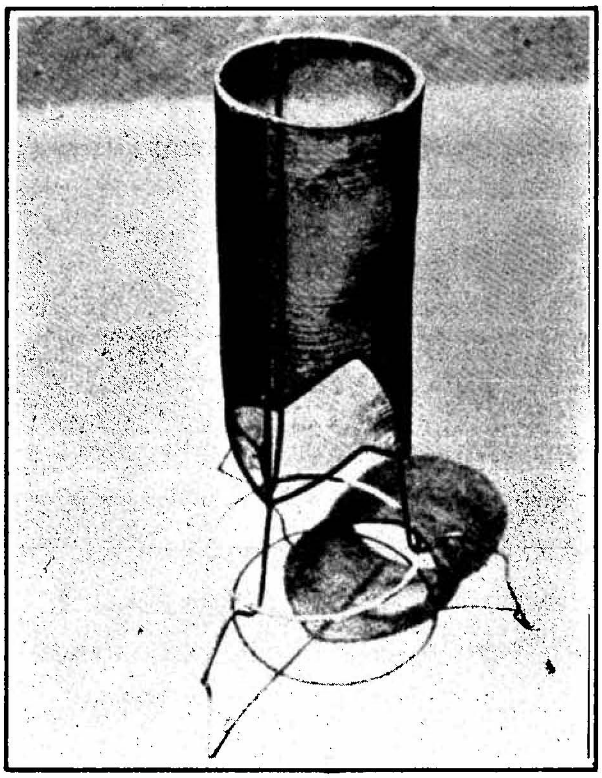


FIGURE 10. GRUNOW TYPE WIRE MESH FOG INTERCEPTOR

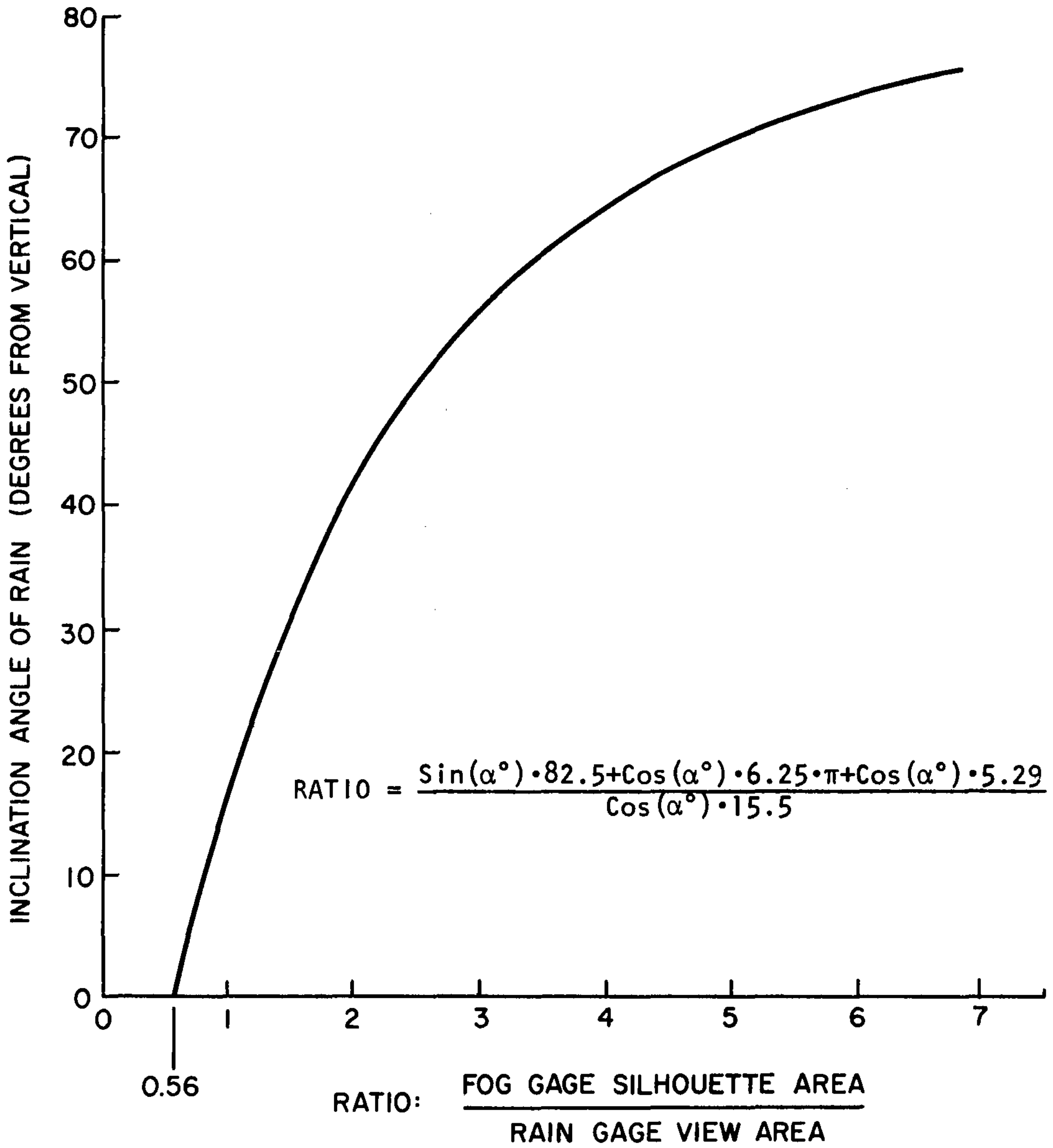
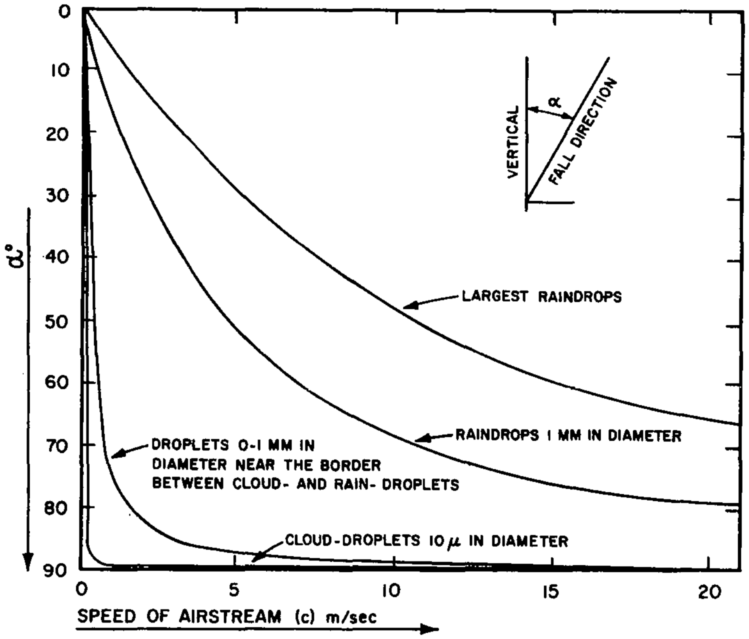


FIGURE 11. RELATIONSHIP BETWEEN FOG AND RAIN GAGE VIEW AREAS AND THE INCLINATION OF THE INCOMING RAIN

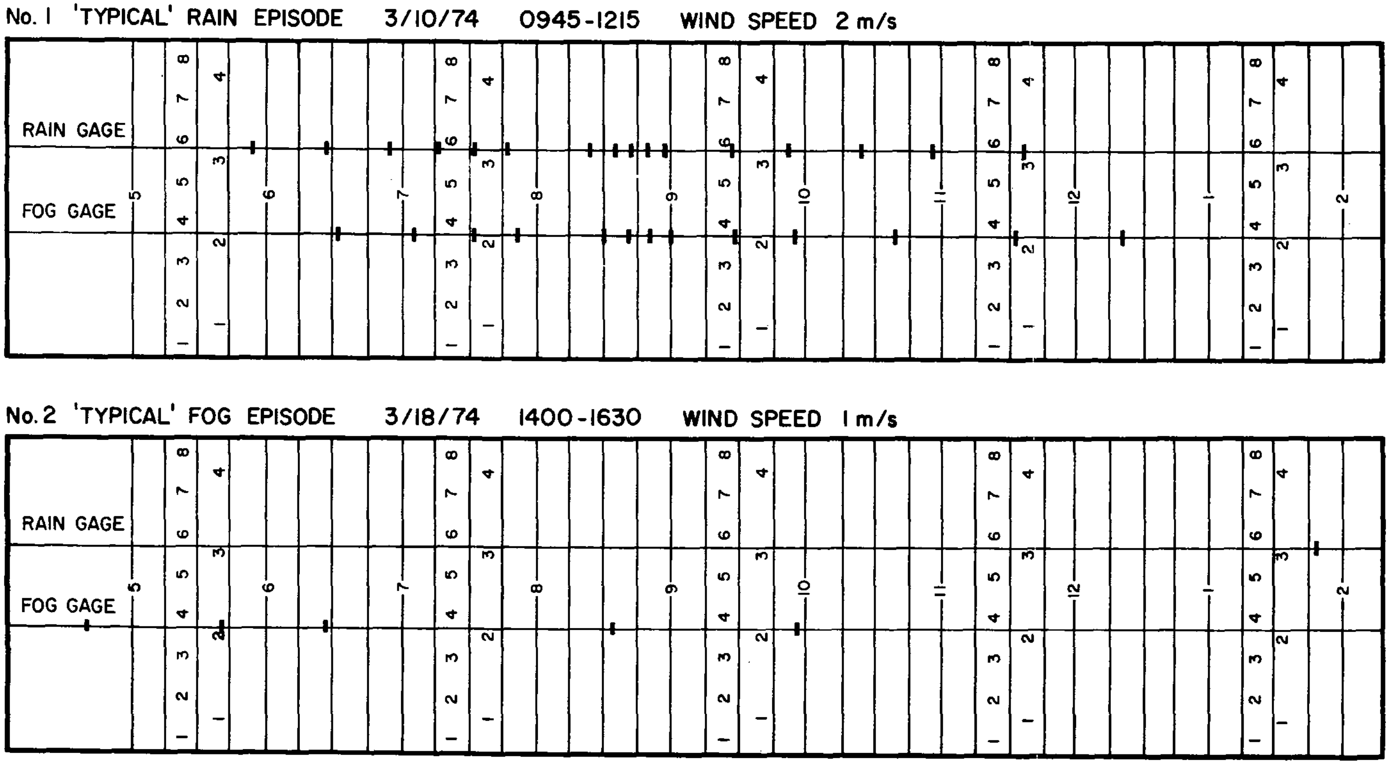
In the field monitoring program, neither the angle of rain inclination nor the average droplet sizes were directly measured. However, as Figure 12 illustrates, with the addition of wind speed, inclination angle and droplet size can be physically related. This relationship is important because, as noted above, greater water collection by the fog gage is not in itself proof of the presence of fog.



SOURCE: NAGEL 1956

FIGURE 12. PHYSICAL RELATIONSHIPS BETWEEN WIND SPEED, DROPLET INCLINATION, AND SIZE

With wind speed data, and using the relationships presented in Figures 11 and 12, it is possible to roughly approximate the average droplet size during any sample period. The data presented in Figure 13 can be used to illustrate the method for droplet size determination. The figure presents raw output from the tipping-bucket rain and fog gages at a primary station (B-3) on windward Mauna Loa (el. 2010 m). During episode No. 1, the fog gage tipped 13 times and the rain gage 16 times for a ratio of .81. Under vertical rainfall conditions a ratio of .56 would be expected since the fog gage has a cross sectional area equal to 56% of the rain gage. Plotting .81 in Figure 11 indicates that an inclination angle of roughly 8° is required to explain the measured ratio. If this value of 8° and the average wind speed for the period (2 m/sec) are then plotted in Figure 12, a drop size estimate



Episode	Gage	TIPS	mm	% of RAIN
No. 1	RAIN GAGE	16	4.06	——
No. 1	FOG GAGE	13	5.89	145.0
No. 2	RAIN GAGE	1	0.25	——
No. 2	FOG GAGE	5	2.26	900.0

FIGURE 13. COMPARISON OF TIPPING-BUCKET GAGE OUTPUT FOR TYPICAL RAIN AND FOG EPISODE ON WINDWARD MAUNA LOA

corresponding to "large size raindrops" results.

In episode No. 2 (Fig. 13) the ratio of fog to rain is 5.0 and plotting this in Figure 11 indicates an inclination angle of at least 70° to account for this ratio. Since the average wind speed during this period was only 1 m/sec and the inclination angle estimated at more than 70°, it is impossible for large raindrops to have been involved (Fig. 12). At a wind speed of 1 m/sec only drops smaller than 100 to 200 microns will fall at an angle exceeding 70°. Thus, it is possible to state with confidence that episode No. 2 represents a period of fog and mist rather than nonvertical "large drop" rainfall.

By programming the relationships presented in Figures 11 and 12 into data analysis computer programs, it is possible to delimit fog periods and separate these from nonvertical rainfall episodes, a refinement not attempted in previous fog studies.

FOG SAMPLING NETWORK

In an effort to monitor the contribution of fog precipitation in mountain areas on Hawaii, an extensive network of louvered screen fog gages were established on the island of Hawaii. While the present study is concerned primarily with research methodology rather than the analysis of field data, details of the fog monitoring program are presented here in the context of sampling methodology.

Two primary concerns dictated the development of the sampling network. First, sampling was largely restricted to windward and leeward mountain areas with relatively low direct rainfall, where it was hypothesized that the contribution of fog might represent a relatively large fraction of the total precipitation. Such areas represent the greatest potential for the development of large scale artificial fog catchment systems. Secondly, the accessibility problem was a prime consideration as much of the higher slopes of Mauna Loa are rugged, roadless lava lands. Sampling stations were necessarily restricted to areas with roads or jeep trail accesses.

Figure 3 identifies the location of fog sampling stations on the island of Hawaii. The major transects, A, B, and C (composed of 13 sampling stations), were oriented east-west on the slopes of Mauna Loa for comparative study of both windward and leeward fog conditions. Additional transects (D, E) were located on Hualalai Volcano above Kailua and in South Kona.

Primary station instrumentation included recording fog and rain gage (Weather Measure Corp. tipping-bucket gage No. 501) logged on multi-channel event recorders (Rustrak Model No. 292) (see Fig. 13 for typical recorder output). Wind speed and direction were monitored using a Field Recording Wind Set (R.M. Young Co. Model No. 6405). The standard setup for primary stations is illustrated in Figures 14 and 15. Secondary stations shown on the map in Figure 3 were equipped with manual reading rain and fog gages, and monitored at weekly intervals.

COMPUTER ANALYSIS PROGRAM

The fog analysis computer program (Appendix A) reduces 15-minute data samples of wind and precipitation parameters (compiled at primary recording stations) into a form useful for statistical manipulation and graphic display. The data summaries include hourly, daily, and total sample period averages for rain and fog precipitation, broken down into five categories: (1) periods with fog and rain, (2) periods with rain (irrespective of fog), (3) periods of fog (irrespective of rain), (4) periods of rain only, and (5) periods of fog only.

Analysis of the "rain only" and "fog only" episodes, in particular, is useful in characterizing precipitation episodes, both temporally and spatially. Figure 16 illustrates the temporal frequency of "fog only" episodes at two stations on windward Mauna Loa for a sample 15-day period. The striking difference between the two stations with respect to temporal occurrence of fog maxima is illustrative of the complex meteorology in mountain areas of Hawaii. Table 2 portrays the five rain and fog categories for this same sample period as a function of prevailing wind direction. As can be seen in the Table, during the sample period most rain and fog were associated with winds from the south and southeast in the case of Station No. B-3 while the pattern was more complex at Station No. B-1, where fog was derived primarily from the east and northeast. This sample period with a large southern wind component, represents a Kona strom situation (low pressure system between Hawaii and the subtropical high pressure cell to the north).

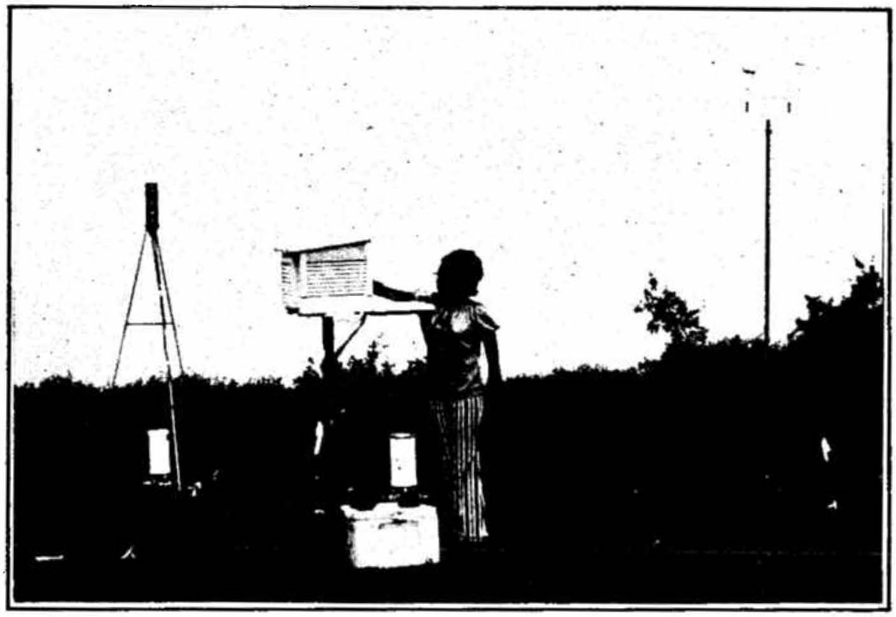


FIGURE 14. TYPICAL PRIMARY STATION WITH FULLY AUTOMATIC RECORDING EQUIPMENT OF FOG, RAIN, WIND SPEED, AND DIRECTION

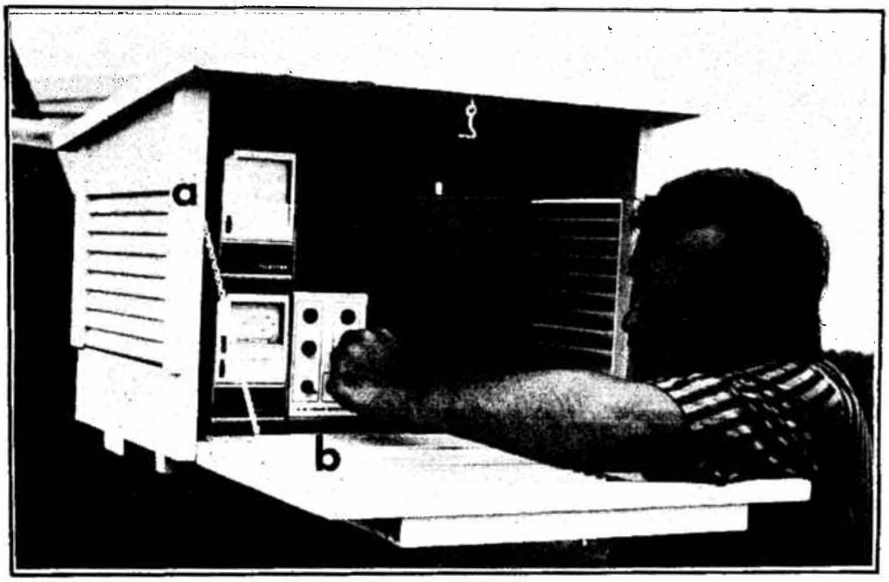


FIGURE 15. PRIMARY STATION INSTRUMENT SHELTER: (A) MULTI-CHANNEL TIPPING-BUCKET GAGE EVENT RECORDER; (B) WIND SPEED AND DIRECTION RECORDER

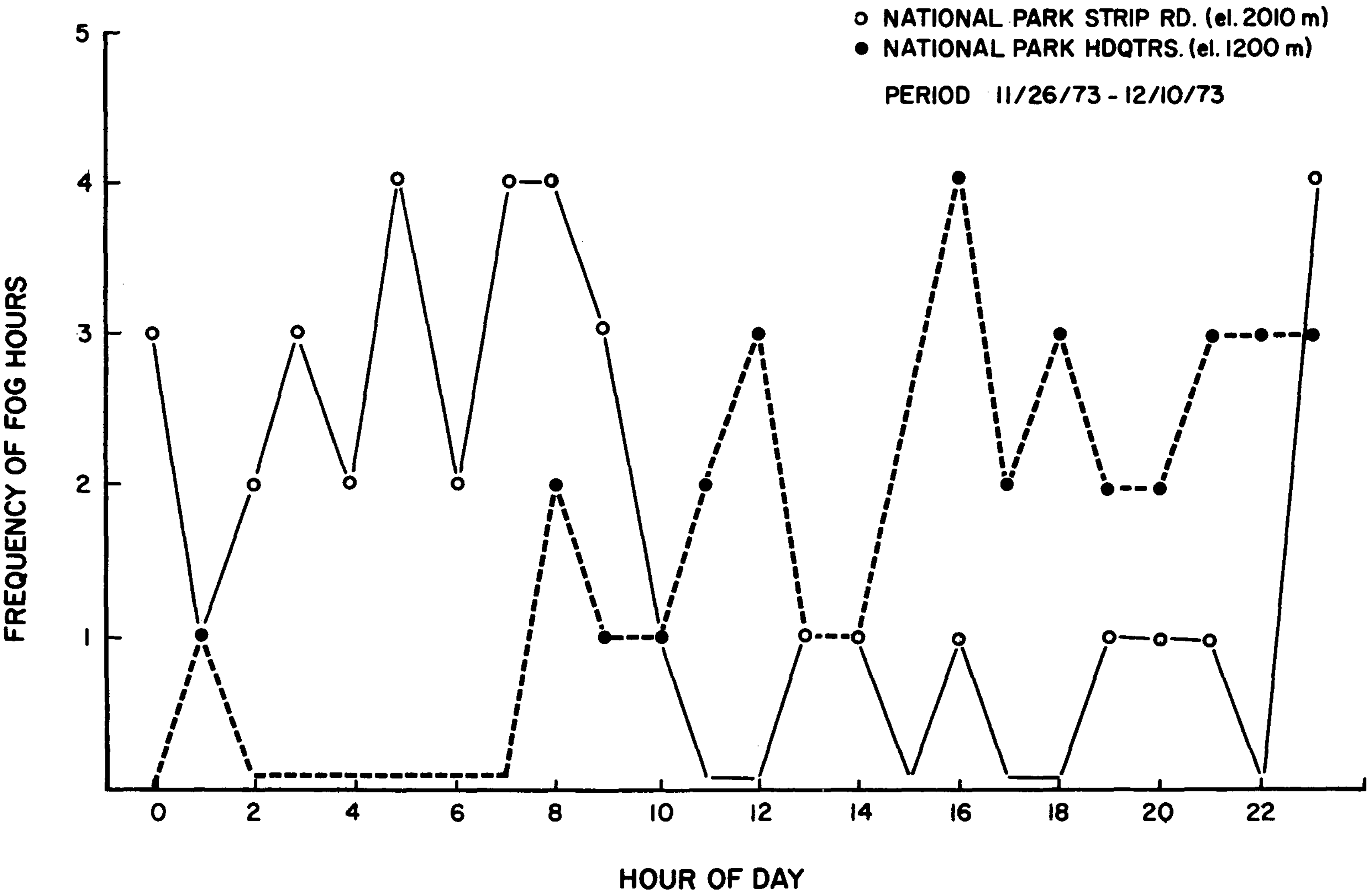


FIGURE 16. SAMPLES COMPUTER OUTPUT OF TEMPORAL FOG FREQUENCY FOR A 15 DAY PERIOD ON WINDWARD MAUNA LOA

TABLE 2. WIND DIRECTION CATEGORIES AGAINST 15 MIN. INTERVAL PERIODS OF RAIN AND FOG

	N	NE	E	SE	S	SW	W	NW	TOTAL NO. OF PERIODS
STATION NO. B-3 (NATIONAL PARK - STRIP RD.)									
FOG AND RAIN	2 (1%)	3 (1.5%)	6 (3.1%)	78 (40.8%)	89 (46.5%)	10 (5.2%)	1 (.52%)	2 (1%)	191
RAIN (IRRE-SPECTIVE FOG)	2 (.9%)	4 (1.9%)	6 (2.9%)	78 (38.8%)	96 (47.7%)	10 (4.9%)	1 (.49%)	4 (1.9%)	201
FOG (IRRE-SPECTIVE RAIN)	2 (.87%)	4 (1.7%)	8 (3.5%)	84 (36.8%)	112 (49.0%)	10 (4.3%)	1 (.43%)	7 (3.0%)	228
RAIN ONLY	Ø	1 (10.0%)	Ø	Ø	7 (70.0%)	Ø	Ø	2 (20.0%)	10
FOG ONLY	Ø	1 (2.7%)	2 (5.4%)	6 (16.2%)	23 (62.1%)	Ø	Ø	5 (13.5%)	37
STATION NO. B-1 (NATIONAL PARK HDQTRS.)									
FOG AND RAIN	1 (.46%)	7 (3.2%)	6 (2.7%)	103 (47.6%)	43 (20.0%)	21 (9.7%)	32 (14.8%)	3 (1.4%)	216
RAIN (IRRE-SPECTIVE FOG)	1 (.43%)	8 (3.5%)	6 (2.6%)	104 (45.6%)	47 (20.6%)	22 (9.6%)	37 (16.2%)	3 (1.3%)	228
FOG (IRRE-SPECTIVE RAIN)	1 (.39%)	17 (6.6%)	17 (6.6%)	104 (40.7%)	50 (19.6%)	27 (10.5%)	36 (14.1%)	3 (1.1%)	255
RAIN ONLY	Ø	1 (8.3%)	Ø	1 (8.3%)	4 (33.3%)	1 (8.3%)	5 (41.6%)	Ø	12
FOG ONLY	Ø	10 (25.6%)	11 (28.2%)	1 (2.5%)	7 (12.9%)	6 (15.3%)	4 (10.2%)	Ø	39

The computer analysis program summarizes the relationship between both wind direction and speed against precipitation episodes on an hourly, daily, and monthly basis. Knowledge of wind characteristics during precipitation episodes is particularly important to the possible future development of large scale fog catchment systems, insofar as catchment orientation could greatly influence the efficiency of water collection.

SUMMARY AND CONCLUSIONS

This study was undertaken with the objective of developing and field testing research methods and materials useful in a multi-faceted investigation of Hawaiian upslope fog.

Major accomplishments of the research included:

1. The development and field testing of an improved louvered screen fog gage.
2. The development of an approximation method for separating the contribution of nonvertical rainfall and fog, and estimating the average droplet sizes for precipitation episodes.
3. The establishment of an extensive fog sampling network on the island of Hawaii.
4. The development of a computer program for fog data analysis.

The present study has succeeded in its objective of developing useful research methods. The application of these research approaches during ongoing and future phases of the fog project should yield useful information on the water balance of mountain areas, and the feasibility of developing large scale artificial fog catchment systems in areas of chronic water shortage.

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APPENDIX

Fog Analysis Computer Program

```
          DIMENSION IM(4),RN(4),FG(4),WS(4),WD(4)
          DIMENSION RTOT(25),FTOT(25),R(25),F(25),AHS(25),HWS(25,SWS(25)
         1 IFRP(25),IRP(25),IFP(25),IRNLY(25)IFNLY(25),WN(25),JN(24),
         2 AR(25),AF(25),TR(25),WA(25),DUM(2)
          DIMENSION WSC(25,5),WDC(25,8),WDSC(25,5,8),I TFR(97,5)ISFR(6,5)
         1 IDFR(9,5),IWDS(25,5,8),ISC(25,5),IDC(25,8)IB(2010),B(1605)
          COMMON /RF/ IFRP,IRP,IFP,IRNLY,IFNLY,ITFR,ISFR,IDFR,IWDS,ISC,IDC,
          COMMON RTOT,FTOT,WA,R,F,AWS,HWS,SWS,WSC,WDC,WN,WDSC,AW,HW,SW,AR,
         1 AF,RTMP,FTMP
          EQUIVALENCE (IB(1),IFRP(1)),(B(1),RTOT(1))
          LOGICAL END, NEWSTA
          DATA END/.TRUE./, NEWSTA/.FALSE./
          DATA DATMIS/-0.00001/,DUM/2*-2./
          DATA D1,D2,D3,D4,D5,D6,D7,D8/23.,67.,112.,157.,202.,247.,292.,
         1 337./,S1,S2,S3,S4/1.,3.,5.,7./
          DATA IERR,IERRM/0,10/,WSMAX,LYR/29.,4/
C
  100     K = 0
          LOOP = C
  400     K = K+1
          IF(NEWSTA) GO TO 700
  500     READ 600, IS,IMON,IDY,IYR,IH,(IM(J),RN(J),FG(J),WS(J),WD(J),J=1,4)
  600     FORMAT(I1,2I2,I1,I2,4(I2,2F2.0,F3.1,F3.0,5X))
          IF((IS.EQ.0).AND.(IMON.EQ.0)) GO TO 5000
          IF((IS.LT.0).OR.(IMON.LT.1).OR.(IMON.GT.12).OR.(IDY.LT.1)
         1 .OR.(IDY.GT.31).OR.(IYR.LT.3).OR.(IYR.GT.LYR).OR.(IH.LT.0)
         2 .OR.(IH.GT.23)) GO TO 9600
          DO 650 I=1,4
          IF((IM(I).LT.O).OR.(IM(I).GT.45).OR.(RN(I).LT.O.).OR.(FG(I).LT.0.)
         1.OR.(WS(I).LT.0.).OR.(WS(I).GT.WSMAX).OR.(WD(I).LT.O.)
         2.OR.(WD(I).GT.360.)) GO TO 9600
  650     CONTINUE
          IH=IH + 1
          IF (K.EC.1) GO TO 700
          IF (IS.NE.ISL) GO TO 4900
          IF (IDY.NE.IDL .OR. IMON.NE.IML) GO TO 6100
          GO TO 1000
  700     ISL = IS
          IML = IMON
          IDL = IDY
          IYL = IYR
          IF(.NOT.(END)) GO TO 1000
          DO 800 I = I, 1605
          IB(I) = 0
          B(I) = C.
  800     CONTINUE
          DC 900 I =1606,2010
          IB(I) =0
  900     CONTINUE
          ISI = IS
```

```
      IMI = IMON
      IDI = IDY
      IYI = IYR
      NEWSTA = .FALSE.
      END =.FALSE.
C
 1000 DO 3500 I=1,4
      L = 0
      WS(I) = 0.4472 * WS(I)
      AWS(IH) = AWS(IH) + 0.25 * WS(1)
      IF((RN(I).EQ.0.).AND.(FG(I).EQ.0.)) GO TO 1300
      RTOT(IH) = RTOT(IH) + 0.254 * RN(I)
      FTOT(IH) = FTOT(IH) + 0.254 * FG(I)
      IF((RN(I).EQ.0.).OR.(FG(I).EQ.0.))GO TO 1100
      IFRP(IH) = IFRP(IH) + 1
      IRP(IH) = IRP(IH) + 1
      IFP(IH) = IFP(IH) + 1
      L = 1
      GO TO 1300
 1100 IF(FG(I).EQ.0.) GO TO 1200
      IFP(IH) = IFP(IH) + 1
      IFNLY(IH) = IFNLY(IH) + 1
      L = 3
      GO TO 1300
 1200 IRP(IH) = IRP(IH) + 1
      IRNLY(IH) = IRNLY(IH) + 1
      L = 2
 1300 IF(WS(I).LT.S1) GO TO 1700
      IF(WS(I).GT.S20 GO TO 1400
      NWSN = 2
      GO TO 1900
 1400 IF(WS(I).GT.S3) GO TO 1500
      NWSN = 3
      GO TO 1900
 1500 IF(WS(I).GT.S4) GO TO 1600
      MWSN = 4
      GO TO 1900
 1600 NWSN = 5
      GO TO 1900
 1700 NWSN = 1
 1900 IF(WD(I).GT.D4) GO TO 2300
      IF(WD(I).GT.D2) GO TO 2100
      IF(WD(I).LT.D1) GO TO 2000
      NWDN = 2
      GO TO 2800
 2000 NWDN = 1
      GO TO 2800
 2100 IF(WD(1).GT.D3) GO TO 2200
      NWCN = 3
      GO TO 2800
 2200 NWCN = 4
      GO TO 2800
 2300 IF(WD(I).GT.D6) GO TO 2500
      IF(WD(I).GT.D5) GO TO 2400
```

```
      NWDN = 5
      GO TO 2800
2400  NWDN = 6
      GO TO 2800
2500  IF(WD(I).GT.D7) GO TO 2600
      NWDN = 7
      GO TO 2800
2600  IF(WD(I).GT.D8) GO TO 2000
      NWDN = 8
2800  CONTINUE
      WSC(IH,NWSN) = WSC(IH,NWSN) + 25
      WDC(IH,NWDN) = WDC(IH,NWDN) + 25
      WDSC(IH,NWSN,NWDN) = WDSC(IH,NWSN,NWDN) + 25
      IF(L.EC.O) GO TO 3500
      IFM = 4*IH + I - 4
      IF(L.GT.1) GO TO 3000
      DO 2900 K = 1,3
      ITFR(IHM,K) = ITFR(IHM,K) + 1
      ISFR(NWSN,K) = ISFR(NWSN,K) + 1
      IDFR(NWDN,K) = IDFR(NWDN,K) + 1
2900  CONTINUE
      GO TO 3500
3000  DO 3100 K = L,5,2
      ITFR(IHM,K) = ITFR(IHM,K) + 1
      ISFR(NWSN,K) = ISFR(NWSN,K) + 1
      IDFR(NWDN,K) = IDFR(NWDN,K) + 1
3100  CONTINUE
3500  CONTINUE
      WA(IH) = WA(IH) + 1
      WN(IH) = WN(IH) + 1
      HWS(IH) = HWS(IH) + AMAX1(WS(1),WS(2),WS(3),WS(4))
      SWS(IH) = SWS(IH) + AMIN1(WS(1),WS(2),WS(3),WS(4))
      GO TO 400
4900  NEWSTA = .TRUE.
5000  IF(END) GO TO 9900
      END = .TRUE.
6100  DC 6200 I=1,24
      IF(WA(I).GT.O.) GO TO 6150
      RTOT(I) = DATMIS
      FTOT(I) = DATMIS
      GO TO 6200
6150  RTOT(25) = RTOT(25) + RTOT(I)
      FTOT(25) = FTOT(25) + FTOT(I)
      R(I) = R(I) + RTOT(I)
      F(I) = F(I) + FTOT(I)
6200  CONTINUE
      R(25) = R(25) + RTOT(I)
      F(25) = F(25) + FTOT(I)
      IF(LOOP.GT.O) GO TO 6500
      PRINT 6300,ISL
      PRINT 6400
6500  PRINT 6600,IML,IDL,IYL,RTOT,FTOT,
      IF(END) GO TO 7000
```

```
      DO 6800 I=I,75
6800  B(I) = 0
      LOOP = LOOP + 1
      K = 1
      GO TO 700
7000  Z = 24
      DO 5700 IT=1,
      W = WN(IT)
      IF(W.GT.O.) GO TO 5400
      Z = Z - 1
      R(IT) = DATMIS
      F(IT) = DATMIS
      AR(IT) = DATMIS
      AF(IT) = DATMIS
      AWS(IT) = DATMIS
      HWS(IT) = DATMIS
      SWS(IT) = DATMIS
      GO TO 5700
5400  AR(IT) = R(IT)/W
      AF(IT) = F(IT)/W
      RTMP = RTMP + AR(IT)
      FTMP = FTMP + AF(IT)
      AWS(IT) = AWS(IT) / W
      HWS(IT) = HWS(IT) / W
      SWS(IT) = SWS(IT) / W
      AW = AW + AWS(IT)
      HW = HW + HWS(IT)
      SW = SW + SWS(IT)
      DO 5500 I=1,5
      WSTMP = WSC(IT,I) / W
      ISC(IT,I) = WSTMP + 0.5
      WSC(25,I) = WSC(25,I) + WSTMP
5500  CONTINUE
      DC 5600 J=1,8
      WDTMP = WDC(IT,J) / W
      IDC(IT,J) = WDTMP + 0.5
      WDC(25,J) = WDC(25,J) + WDTMP
      DO 5600 I = 1,5
      WTMP = WDSC(IT,I,J) / W
      IWDS(IT,I,J) = WTMP + 0.5
      WDSC(25,I,J) = WDSC(25.I.J) + WTMP
5600  CONTINUE
5700  CONTINUE
      AR(25) = RTMP
      AF(250 = FTMP
      DO 5800 I=1,5
      ISC(25,I) = WSC(25,I) / Z + 0.5
5800  CONTINUE
      DO 5900 J=1,8
      IDC(25,J) = WDC(25,J) / Z + 0.5
      DO 5900 I=1,5
      IWDS(25,I,J) = WDSC(25,I,J) / + 0.5
5900  CONTINUE
```

```
      AWS(25) =  AW / Z
      HWS(25) =  HW / Z
      SWS(25) =  SW / Z
      DO 6000 I=1,5
      DO 6000 J=1,96
      ITFR(97,I) = ITFR(97,I) + ITFR(J,I)
6000  CONTINUE
      DO 6020 I=1,5
      DO 6020 J=1,5
      ISFR(6,I) = ISFR(6,I) + ISFR(J,I)
6020  CONTINUE
      DO 6040 I=I,5
      DO 6040 I=I,8
      IDFR(9,I) = IDFR(9,I) + IDFR(J,I)
6040  CONTINUE
      PRINT 7420
      PRINT 7200, IMI,IDI,IYI,IML,IDL,IYL,ISL
      PRINT 6400
      PRINT 7400 R,F
      PRINT 7410
      PRINT 7200, IMI,IDI,IYI,IML,IDL,IYL,ISL
      PRINT 6400
      PRINT 7400, AR,AF
      DO 7250 I=1,24
      JN(I) = I -1
7250  CONTINUE
      PRINT 7420
      PRINT 7200, IMI,IDI,IYI,IML,IDL,IYL,ISL
      PRINT 7440, (R(I),I=1,24, (F(I),I=,24)
      CALL HIST(R,F,24
      PRINT 7445, JN
      PRINT 7446
      PRINT 7460
      PRINT 7200, IMI,IDI,IYI,IML,IDL,IYL,ISL,
      PRINT 7440,(AR(I),I=1,24, (AF(I),I=1,24)
      CALL HIST(AR,AF,24)
      PRINT 7445, JN
      PRINT 7446
      DO 7300 I=1,24
      IFRP(25) = IFRP(25) + IFRP(I)
      IRP(25) = IRP(25) + IRP(I)
      IFP(25) = IFP(25) + IFP(I)
      IRNLY(25) = IRNLY(25) + IRNLY(I)
      IFNLY(25) = IFNLY(25) + IFNLY(I)
7300  CONTINUE
      PRINT 7450
      PRINT 7200, IMI,IDI,IYI,IML,IDL,IYL,ISL
      PRINT 6400
      PRINT 7500, IFRP,IRP,IFP,IRNLY,IFNLY
      PRINT 7600
      PRINT 7200, IMI,IDI,IYI,IML,IDL,IYL,ISL
      II = 1
      IN = 32
```

```
      DO 7850  MM=1,2
      PRINT 7700, JN(I),I=I,8
      PRINT 7800, ((ITFR(I,J),I=II,IN,J=5)
      II = II + 32
      IN = IN + 32
      DO 7850 I = 1,8
      JN(I) = JN(I) + 8
 7850 CONTINUE
      IN = IN + 1
      PRINT 7700, (JN(I),I=1,8
      PRINT 7880, ((ITFR(I,J),I=II,IN),J=1,5)
      DO 7910 I=1,24
      TR(I) = IFRP(I)
      R(I) = IRP(I)
      F(I) = IFP(I)
      AR(I) = IRNLY(I)
      AF(I) = IFNLY(I)
      JN(I) = I-1
 7910 CONTINUE
      PRINT 7930
      PRINT 7200, IMI,IDI,IYI,IML,IDL,IYL,ISL
      PRINT 7915, (IFRP(I), I=1,24
      CALL HIST(TR,DUM,24)
      PRINT 7445, JN
      PRINT 7940
      PRINT 7200, IMI,IDI,IYI,IML,IDL,IYL,ISL
      PRINT 7920, (IRP(I),I=1,24, (IFP(I),I=1,24
      CALL HIST(R,F,24)
      PRINT 7445, JN
      PRINT 7950
      PRINT 7960
      PRINT 7200, IMI,IDI,IYI,IML,IDL,IYL,ISL
      PRINT 7920, (IRNLY(I),I=1,24), IFNLY(I),I=1,24)
      CALL HIST(AR,AF,24)
      PRINT 7445, JN
      PRINT 7970
      PRINT 7900
      PRINT 7200, IMI,IDI,IYI,IML,IDL,IYL,ISL
      PRINT 8000, S1,S1,S2,S2,S3,S3,S4,S,4
      PRINT 8100, ISFR
      PRINT 8200
      PRINT 7200, IMI,IDI,IYI,IML,IDL,IYL,ISL
      PRINT 8300
      PRINT 8400, IDFR
      PRINT 8500
      PRINT 7200, IMI,IDI,IYI,IML,IDL,IYL,ISL
      PRINT 6400
      PRINT 8600, AWS,HWS,SWS
      PRINT 8700
      PRINT 7200, IMI,IDI,IYI,IML,IDL,IYL,ISL
      PRINT 6400
      PRINT 8800,S1,(ISC(I,1),I=1,25),S1,S2,(ISC(I,2),I=1,25),S2,S3,
     1  (ISC(I,3),I=1,25),S3,S4,(ISC(I,4),I=1,25),S4,(ISC(I,5),I=1,25)
```

```
      PRINT 8900
      PRINT 7200, IMI,IDI,IYI,IML,IDL,IYL,ISL
      PRINT 6400
      PRINT 9000, IDC
      PRINT 9100
      PRINT 7200, IMI,IDI,IYI,IML,IDL,IYL,ISL
      DO 9400 J=1,8
      IF(J.EC.C.5) PRINT 9300
      PRINT 6400
      IF(J.EQ.1) PRINT 9310
      IF(J.EQ.2) PRINT 9320
      IF(J.EQ.3) PRINT 9330
      IF(J.EQ.4) PRINT 9340
      IF(J.EQ.5) PRINT 9350
      IF(J.EQ.6) PRINT 9360
      IF(J.EQ.7) PRINT 9370
      IF(J.EQ.8) PRINT 9380
      PRINT 8800,S1,(IWDS(I,1,J),I=1,25),S1,S2,IWDS(I,2,J,I=1,25),S2,
     1  S3,(IWDS(I,3,J),I=1,25),S3,S4,(IWDS(I,4,J),I=1,25),S4,(IWDS(I,5,J
     2),I=1,25)
      PRINT 9300
 9400 CONTINUE
      PRINT 9500
      GO TO 100
 9600 IERR = IERR + 1
      PRINT 9610, IS,IMON,IDY,IYR,IH
      IF(IERR.NE.IERRM) GO TO 500
      PRINT 9620, IERR
 9900 PRINT 9990
      STOP
 6300 FORMAT(1H1,9X,'STATION NUMBER ',I1,' :',26X,'DAILY RAIN AND FOG B
     1Y HOURS (MM)',/'0 DATE',58X,'HOURS OF DAY')
 6400 FORMAT(1H,8X,'00  01  02  03  04  05  06  07  08  09  1
     10  11 12  13  14  15  16  17  18  19  20  21  22  23
     2  TOTAL')
 6600 FORMAT(IH-,I2,'-',12,'-7',I1/'  RAIN',24F5.1,F6.1/'0 FOG',24F5.
     11,F6.1)
 7200 FORMAT(IH+,70X,12,'-',12,'-7',I1,' TO ',12,'-',12,'-7',I1,
     1 ' AT STATION ',I1/)
 7400 FORMAT(1H-,' RAIN ',24F5.1,F6.0/1HO,' FOG ',24F5.1,F6.0)
 7410 FORMAT(IH-//31X,'HOURLY AVERAGE RAIN AND FOG FOR PERIOD')
 7420 FORMAT(IHI,29X,'RAIN AND FOG TOTALS BY HOURS FOR PERIOD')
 7440 FORMAT(IHC,2X,'MM RN',24F5.1/3X,'MM FG',24F5.1)
 7445 FORMAT(1H ,6X,24I5/63X,'HOURS OF DAY')
 7446 FORMAT(1H ,5X,'0 = RAIN (MM)'/6X,'X = FOG (MM)')
 7450 FORMAT(1H1/26X,'PERIODS OF RAIN AND FOG BY HOURS FOR PERIOD')
 7460 FORMAT(1H1,30X,'HOURLY AVERAGE RAIN AND FOG FOR PERIOD')
 7500 FORMAT('-R + F',24I5,17/'ORAIN ',24I5,17/OFOG  ',24I5,17/'OR ONLY
     1',I4,23I5,17/'OF ONLY',14,23I5,17)
 7600 FORMAT(1H-//18X,'PERIODS OF RAIN AND FOG BY QUARTER HOURS FOR PERI
     1OD')
 7700 FORMAT(IH ,8114,13X,'TOTAL')
```

```
348  7800  FORMAT(1H0,'RAIN + FOG ',8(413,2X)/'0 RAIN',5X,8(413,2X/'0 FOG'
          1,6X,8(413,2X/'0 RAIN ONLY ',8(413,2X)/'0 FOG ONLY ',8(413,2X)//)
349  7880  FORMAT(1H0,'RAIN + FOG ',8(413,2X),16/'0 RAIN',5X,8(413,2X),I6
          1 /'0 FOG',6X,8(413,2X,I6/'0 RAIN ONLY ',8(413,2X),I6,
          2 /'0 FOG ONLY  ',8(413,2x),16)
350  7900  FORMAT(1H1/5X,'WIND SPEED CATEGORIES AGAINST PERIODS OF RAIN AND F
          1OG FOR PERIOD')
351  7915  FORMAT(1H-,' FREQ  ',2415)
352  7920  FORMAT(1H0,'FREQ RN',I4,2315/' FREQ FG',14,2315).
353  7930  FORMAT(1H1,27X,'RAIN WITH FOG PERIODS BY HOURS FOR PERIOD')
354  7940  FORMAT(1H1,20X,'RAIN PERIODS AND FOR PERIODS BY HOURS FOR PERIOD')
355  7950  FORMAT(1H ,5X,'0 = RAIN PERIODS'/6X,'X = FOG PERIODS')
356  7960  FORMAT(1Hi,18X,'RAIN ONLY AND FOG ONLY PERIODS BY HOURS FOR PERIOD
          1')
357  7970  FORMAT(1H ,5X,'0 = RAIN ONLY PERIODS' 5X,'X = FOG ONLY PERIODS')
358  8000  FORMAT(1H0,29X,'WIND SPEED (M/S)'/1H0,14X,'0 -',F4.1  F5.1,'-',
          1 F4.1,  F5.1,'-',F4.1,  F5.1,'-',F4.1,3X,' ',F4.1,4X,'TOTALS')
359  8100  FORMAT(1H-,'RAIN AND FOG',16,  5110/'0  RAIN',6110/'0  FOG ',
          1  6110/'0 RAIN ONLY',18,5110/'0 FOG ONLY',19,5110)
360  8200  FORMAT(1H-////'0WIND DIRECTION CATEGORIES AGAINST PERIODS OF RAIN
          1AND FOG FOR PERIOD
361  8300  FORMAT(1H0,32X,'WIND DIRECTION'/1H0,18X,'N',4X,'NE',5X,'E',4X,'SE'
          1,5X,'S',4X,'SW',5X,'W',4X,'NW',3X,'TOTALS')
362  8400  FORMAT(1H-,'RAIN AND FOG ',816,18/'0  RAIN',5X,816,18/'0  FOG'
          1,6X,816,18/'0 RAIN ONLY  ',816,18/'0  FOG ONLY   ',816,18)
363  8500  FORMAT(1H-/////48X,'WIND SPEED FOR PERIOD')
364  8600  FORMAT(1H-,' MEAN ',24F5.1,F6.1/'OAV MAX',24F5.1,F6.1/'OAV MIN',
          1  24F5.1,F6.1)
365  8700  FORMAT(1H1/20X,'PERCENT WIND SPEED CATEGORIES BY HOURS FOR PERIOD'
          1)
366  8800  FORMAT(1H0,'0 -',F2.0,I4,2315,16/1H0,F3.1,'-',F2.0,14,2315,16,
          1  /1H0,F3.1,'-',F2.0,14,2315,16/1H0,F3.1,'-',F2.0,14,2315,16/1H0,
          2  ' ',F4.1,14,2315,16)
367  8900  FORMAT(1H-/////16X,'PERCENT WIND DIRECTION CATEGORIES BY HOURS FOR
          1 PERIOD')
368  9000  FORMAT(1H-,' N ',2415,16/'0 NE ',2415,I6/'0 E ',2415,16,
          1  /'0 SE ',2415,16/'0 S ',2415,16/'0 SW ',2415,16/'0 W ',
          2  2415,16/'0 NW ',2415,16)
369  9100  FORMAT(1H1, /6X,'WIND SPEED CATS AGAINST WIND DIRECTION CATS BY HO
          1URS FOR PERIOD')
370  9300  FORMAT(1H-)
371  9319  FORMAT(' NORTH')
372  9320  FORMAT(' NORTHEAST')
373  9330  FORMAT(' EAST')
374  9340  FORMAT(' SOUTHEAST')
375  9350  FORMAT(' SOUTH')
376  9360  FORMAT(' SOUTHWEST
377  9370  FORMAT(' WEST
378  9380  FORMAT(' NORTHWEST')
379  9500  FORMAT(1H+,'************  END OF PERIOD ANALYSIS  ************')
380  9610  FORMAT(1H-,20X,'ERROR IN DATA CARD -- ',I1,IX,12,'-',12,'-7',I1,
          1  1X,12,'00 -- DATA NOT USED'/)
381  9629  FORMAT(1H0,'EXECUTION HALTED ON ENCOUNTER OF',13,' DATA ERRORS'//)
382  9990  FORMAT(1H0,'END OF JOB')
383        END
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