Raindrop Measurements during Project Shower

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Abstract

Raindrop size distributions have been obtained on the island of Hawaii with filter papers and with a device called a drop recorder. The drop recorder automatically exposes a section of dyed paper tape to the rain at approximately two-minute intervals. The maximum sized drop found on each of the more than 4,000 samples has been plotted as a function of time. It is shown that a fair correlation exists between the maximum sized drop and rain intensity.

Over 300,000 drops $m^{-3} < 0.2$ mm diameter have been found in very light rains at altitudes of 5,500 feet on the volcanos of Mauna Kea and Mauna Loa.

1. Introduction

This paper will consist mainly of a presentation of the raindrop measurements made during Project Shower. There will be little emphasis on what the data might mean in terms of basic cloud physics processes or relationships between such important parameters as liquid water content, intensity of rainfall, and the median volume diameter. There are two reasons for this. First, a detailed study has already been made of the raindrop distributions (BLANCHARD, 1953) and what they might mean in terms of precipitation growth (WOODCOCK & BLANCHARD, 1955) in the very region covered by Project Shower. An analysis of the present data indicates no significant changes in the raindrop distributions and thus any further discussion along those lines is unnecessary. Secondly, it is felt that the data in the present form would be of great interest to others who may wish to make their own study of the Project Shower papers.

2. Methods of raindrop sampling

Two methods of obtaining raindrop size distribution were used throughout Project Shower. The first, the filter paper method, had been used successfully in earlier field trips to Hawaii (BLANCHARD, 1953). The second method, used for the first time in the present experiments, warrants some discussion in regard to its limitations.

This method utilizes an automatic portable device, called a drop recorder, that was designed to run off a 12 volt automobile battery. The sequence of operation of the drop recorder is as follows: At approximately two-minute intervals a sliding trap door at the top opens for a 2.7 second period. The raindrops that fall through the 33.2 cm² opening impinge on a methylene blue dye treated paper tape. A fine mesh wire screen around the opening prevents splash from the drops that strike in the immediate vicinity. During the two-minute interval between exposures a resistance wire heater dries the paper tape and the tape is advanced to a new exposure position. In this manner a drop recorder was run continuously for 15 hours collecting some 450 rain drop distribution samples. At the end of this time the battery voltage was still sufficient to give essentially the same operating characteristics as at the start. As a precaution, time marks were placed on the tape at various times during the daily runs. These times were later plotted versus length of tape exposed. The time of any particular sample was obtained from this calibration curve.

One would naturally have some doubt

Table 1. Filter papers, Hawaii 1954. At Club 299

Sample No.	Date	Time (Hawaiian Standard)	Position	Rainfall intensity mm hr⁻¹	Mass of Liquid water mg/m³ of air	Number			
						0.1	0.3	0.5	0.7
1	Oct. 25	0002	Club 299	19.4	1005	—	680	380	55
2	»	0004	»	23.2	1005	—	440	135	14
3	»	0008	»	26	1260	—	1,000	305	83
4	»	0010	»	6.35	410	680	620	225	200
5	»	0015	»	13.3	742	—	830	640	180
6	»	0017	»	16.5	774	650	890	590	155
7	»	0022	»	78	3550	132,000	31,000	890	420
8	»	0026	»	31.5	1490	10,300	4,000	870	215
9	»	0028	»	41.3	1950	—	3,650	390	55
10	Oct. 56	1049	2800′	0.95	157	3,950	5,500	760	110
11	»	1127.5	»	0.79	104	—	840	1080	105
12	»	1356	»	1.82	257	—	3,900	2400	220
13	»	1402	»	1.8	213	—	2,850	1500	215
14	»	1436	»	2.01	255	400	2,120	2400	315
15	»	1442.5	»	4.07	425	730	2,900	690	250
16	»	1525	»	4.96	427	—	610	1700	750
17	»	1536	»	1.47	190	—	3,400	1920	78
18	»	1551	»	0.42	99	5,700	6,000	98	
19	»	1629	»	0.68	129	6,000	5,200	700	
20	Nov. 2	1548	»	0.45	106	7,600	6,400	88	
21	»	1603	»	0.98	210	—	12,400	470	
22	»	1609	»	2.2	292	—	3,700	2850	260
23	»	1611.5	»	1.62	228	—	3,000	2580	78
24	»	1650	»	0.70	176	22,500	10,600	41	
25	»	1659	»	0.43	119	24.000	6,400		
26	»	1708	»	0.55	95	1,700	2,700	800	
27	»	1713	»	0.84	141	2,450	4,400	1080	10.5
28	»	1729	»	0.62	111	13,000	2,500	870	11.5
29	Nov. 6	1015	Club 299	16.3	1000	840	385	680	395
30	»	1020	»	14.7	916	1,850	600	385	104
31	Nov. 7	1156	2800′	8.6	550	1,850	530	—	170
32	»	1210	»	0.29	59	3,000	2,400	270	17
33	»	1217	»	4.8	386	970	970	430	620
34	»	1323	»	9.1	553	580	285	320	82
35	»	1332	»	13.6	920	770	114	128	200
36	»	1334	»	14.1	845	650	800	85	15
37	»	1356	»	1.13	153	395	5,000	490	112
38	»	1415	»	1.15	160	720	2,150	1700	50
39	Nov. 27	1128	*	29	1270	—	1,600	450	47
40	Nov. 29	0810	*	1.7	91	105	110	36	11
41	»	0833	*	0.94	55	152	39	43	13.5
42	»	0857	*	4.17	188	—	148	14	7
43	»	1550	4000′	0.28	51	3,100	1.950	290	
44	Nov. 30	1746	2000′	7	520	—	850	950	530
45	»	1750	»	3.2	247	—	79	410	305
46	»	1753	»	8.9	562	430	305	660	260
47	»	1756	»	0.76	100	—	1.240	890	124
48	»	1758	»	1.68	150	—	190	300	360
49	»	1803	»	1.23	120	265	910	440	215
50	Dec. 2	1658	2800′	0.89	131	1,450	2,200	1380	34
51	»	1704.5	»	34.6	1660	—	1,260	355	79
52	»	1713	»	14.9	893	610	1,150	490	34

and at various heights on the Saddle Road.

of drops m^{-3} within 0.2 mm size interval centered about indicated size (mm).

0.9	1.1	1.3	1.5	1.7	1.9	2.1	2.3	2.5	2.7	2.9	3.1	3.3	3.5	3.7
76	66	180	154	88	31	18								
65	141	105	22	61	44	53	28							
11	113	73	140	135	56	47	—	5.4						
133	183	100	34											
375	93	57	34	10.5	34	13.8	13.2	4.1						
230	70	87	12	16.5	10	9.7	14	13	—	—	4.1	4		
154	75	82	14.6	13.7	—	36	46	144	20.6	20.1	9.8	—	9.4	9.3
61	62	63	16.3	23	104	80	51	6.1						
65	56	130	225	95	75	84	46	10.8						
7.2														
72	8.8													
22.5														
11.5														
183	51	45	8.3											
12														
315	251	255	126	29										
290	480	137	130	16.7										
410	350	73	16											
400	100	—	6											
250	132	136	88	8.2										
740	560	117	40											
86	520	255	73	7.5										
70														
15.6														
110	62	64	82	83	49	40	25.5	6.1	5.9	—	5.4			
20.5	22.5	6.5	9.7	3.5	3.3	1.5	1.5							
22.5	18	2.2	3.1	5.7	1.7									
16.5	11	6.1	7.3	3.4	4.7	8.9	4.3	2.7	1.3	1.2				
360	130	65	29											
125	136	19												
245	225	9.1	41	45	7									
130	18.5													
22	44													
125	66	175	83	127	133	60	16							
69	295	230	150	34										

whether a sample obtained with an exposure area of only about 33 cm^2 would be representative. Now this area would be quite insufficient if exposures were made in thunderstorm or frontal type rains. In these rains the average maximum drop size of about 5 mm diameter would leave a 32 mm diameter spot on the tape. It is apparent that only 2 drops of this size could be collected without the occurrence of overlapping and splashing. However, in the typical Hawaiian orographic rains, the rain-

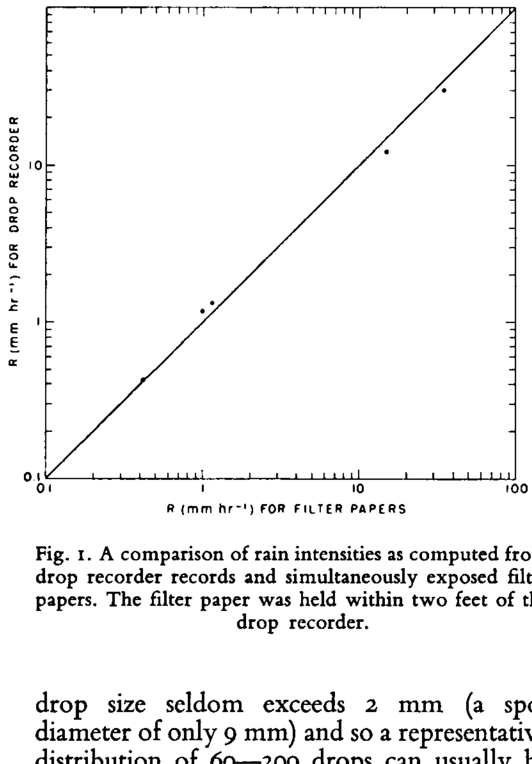

Fig. 1. A comparison of rain intensities as computed from drop recorder records and simultaneously exposed filter papers. The filter paper was held within two feet of the drop recorder.

drop size seldom exceeds 2 mm (a spot diameter of only 9 mm) and so a representative distribution of 60—200 drops can usually be obtained. With such a distribution the calculation of the rain intensity *R* is considered to be reasonably accurate. Several filter papers (each having an area over 7 times that of an exposure of the drop recorder) were simultaneously exposed alongside a drop recorder. The comparison of the calculated rain intensities is shown in fig. 1. In the earlier Hawaiian experiments (BLANCHARD, 1953) a good correlation was found between the rain intensity calculated from filter papers and that simultaneously measured with a 0.5 m^2 stainless steel funnel.

3. Filter paper samples

A very limited number of filter paper measurements of raindrop distribution were obtained. The filter paper technique was to be extensively used only on mechanical breakdown or other failure of the drop recorders. The data from the samples that were obtained are tabulated in table 1. All samples were obtained along the Saddle Road and thus the exact location may be found by noting from the table the elevation of the sampling position and then referring to the Location Map elsewhere in this volume to see where the road crosses this elevation contour.

It is perhaps pertinent to discuss briefly the samples and factors that may modify these rain distributions. Samples 1—9, obtained at Club 299, the base of operation of Project Shower, were made in heavy rain that covered the entire Hilo area. At the time of sampling the rain did not extend up into the saddle region between the volcanos. Indeed, the sky was relatively clear in that region and a downslope breeze existed. The maximum drop size, nearly 4 mm, is far larger than that usually found in the orographic rains that fall on the volcano slopes. The great numbers of drops in samples 7—8 in the 0.1 mm size range may be due, in part, to splash from large drops striking the flat roof of a building near the sampling region. The sampling point was about 20 feet horizontally and 8 feet vertically from the edge of the roof. With proper wind drift it is conceivable that some of the small drops counted on the filter paper originated on this roof.

Samples 39—43 were obtained in a Kona storm (SIMPSON, 1952) and thus are not representative of trade wind orographic rainfall.

4. Drop recorder measurements

Over 4,000 raindrop samples were obtained with three drop recorders which, on several occasions, ran simultaneously at various positions along the Saddle Road. As all these samples have not been evaluated, it was decided to present the maximum drop size found in each sample. It is felt that this would at least give an idea of how the raindrop distribution varied and would be a guide to those who wish to consider the maximum raindrop growth

Table 2. Drop Recorder Samples, Saddle Road, Hawaii, 2 December, 1954.

Sample No.	Time (Hawaiian Standard)	Height Above M. S. L.	Rainfall Intensity mm hr^{-1}	Mass of Liquid Water mg/m^3 of air	Number of drops per m^3 within 0.2 mm size interval centered about indicated size										
					0.1	0.3	0.5	0.7	0.9	1.1	1.3	1.5	1.7	1.9	2.1
1	0916.3	4120′	3.3	370	830	1,800	2900	470	123	26					
2	0918.3	»	3.3	320	830	765	1330	590	245	26					
3	0920.3	»	2.67	361	830	1,530	4800	117							
4	0922.4	»	2.2	332	11,300	7,400	2450	275							
5	0924.4	»	9.2	805	14,000	3,700	1470	1220	430	365					
6	0926.4	»	6.65	580	3,050	770	440	2050	154	77	46				
7	0928.7	»	5.05	524	4,700	2,000	2650	1050	278	26					
8	0930.8	»	8.05	668	8,300	2,380	440	980	650	205	22.5				
9	0948.3	2800′	0.4	65	2,250	1,800	438	38							
10	0950.7	»	0.32	50	730	850	550								
11	0952.7	»	0.13	36	7,500	1,900									
12	0954.8	»	5.3	358	*	570	275	195	154	155	114				
13	0956.7	»	15.9	910	*	—	55	38	123	335	320	122	18.6		
14	0958.9	»	16	946	*	—	109	155	92	417	298	143			
15	1001.2	»	5.83	357	*	*	109	195	61	232	45	20	18.5		
16	1003	»	19.1	1170	•	196	165	310	154	440	550	61			
17	1005.2	»	4.45	348	13,500	1,150	165	78	340	233					
18	1007.3	»	14.7	925	:	95	495	195	215	490	320	41			
19	1009.5	»	9.45	636	*	193	440	235	245	519	68	20			
20	1011.6	»	6	440	*	1,240	550	508	430	155	46				
21	1013.8	»	5.93	406	—	—	275	235	215	234	91				
22	1519	»	0.92	115	830	1,600	770	155	30						
23	1521	»	0.38	56	1,390	1,240	440	39							
24	1522.8	»	0.96	130	280	1,430	1310	115							
25	1525	»	0.53	83	280	1,620	880								
26	1526.8	»	0.19	34	—	1,330	220								
27	1537	»	1.57	175	2,800	480	880	580							
28	1539.6	»	0.14	26.2	2,500	850	165								
29	1633	»	3.7	408	13,800	7,200	1700	275	150	100					
30	1635	»	6.95	512	8,000	2,950	165	117	400	210	115				
31	1637	»	5.2	547	13,200	4,000	2200	940	310	52					
32	1639	»	19.9	1170	*	*	930	660	370	550	290	81			
33	1641.3	»	8.3	605	*	*	1200	470	340	205	115	20			
34	1643.5	»	25.2	1310	*	*	160	78	31	77	275	370	75	—	16.6
35	1645.3	»	7.9	490	9.700	2,400	—	39	31	490	115				
36	1647.5	»	3.4	286	4,700	1,600	110	310	370	77					
37	1649.4	»	3.7	331	22,500	3,850	220	235	155	155	22.6				
38	1651.4	»	21.5	1192	—	—	220	195	250	260	250	200	94		
39	1653.4	»	3.56	376	4,700	960	1150	1400	61						
40	1656	»	4.8	441	4,200	1,040	990	940	340	77					
41	1658	»	1.32	184	830	2,360	1800	155							
42	1700	»	1.55	205	1,400	960	2300	195							
43	1701.9	»	2.15	235	18,000	2,550	930	235	122	—	23				
44	1704	»	33.9	1712	*	*	—	156	92	180	300	223	138	71	16.5
45	1706	»	19.6	952	*	*	—	—	31	51	23	163	190	35	
46	1708.4	»	12.9	679	*	*	54	195	61	130	138	122	37	—	16.5
47	1710.4	»	28.6	1333	•	*	*	78	31	51	46	163	196	106	16.5
48	1712.4	»	12.2	806	*	*	—	218	272	310	387	252	41		
49	1714.5	»	7	532	14,800	3,600	330	430	340	102	113	20			
50	1716.4	»	4.9	412	11,300	2,550	550	630	92	180	46				
51	1718.6	»	4.85	475	8.700	3,900	1000	870	340	77					

* Splashing of large drops prevented accurate determination of raindrop concentration.

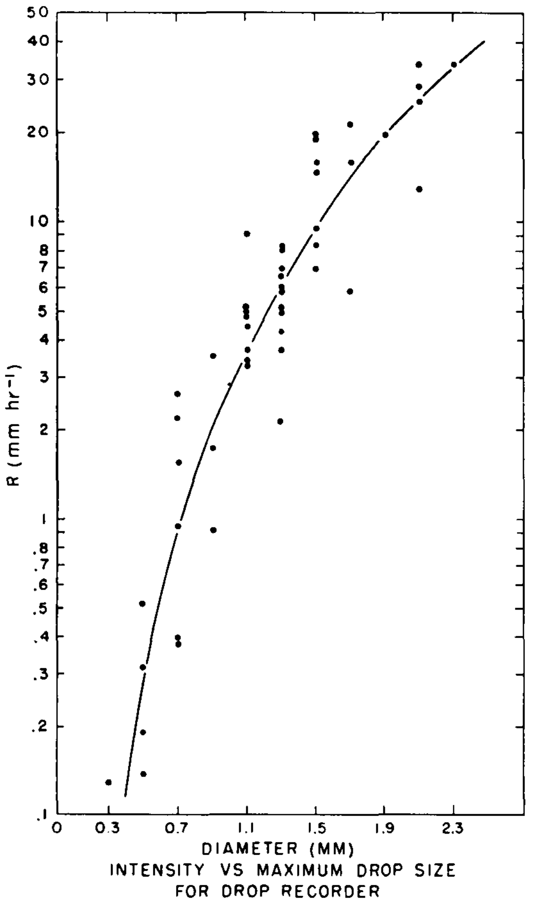

Fig. 2.

from the cloud drop spectra and liquid water contents presented elsewhere in this volume.

In addition to the above, one may use the maximum drop size to get a rough approximation to the rain intensity R. It is apparent that for a given maximum drop size R may vary considerably especially in transient conditions. Nevertheless the correlation is considerably better than that found in non-orographic rains. Fig. 2 shows this correlation for some samples obtained on 2 December at the 2,800 ft. station. Inasmuch as samples obtained on other days showed essentially the same correlation, it seems reasonable to assume that this may be regarded as typical of Hawaiian orographic rains.

Although extensive runs were made with the drop recorders on a total of 7 days, only 4 days have sufficient interest to be reported here. Figs. 3 a—3 e illustrate the variation of the largest drops as a function of time. These block type diagrams do not directly indicate the time of observation, but this is easily determined by remembering that a sample was obtained approximately every 2 minutes and that the vertical lines in the diagram occur at a time midway between adjacent samples.

It will be noticed that isolated points are often found where breaks occur in the block diagrams. Each point represents a sample which contained less than a total of ten drops. Thus,

Table 3. Drop Recorder Samples, Hawaii 1954.

Sample No.	Date	Time (Hawaiian Standard)	Position	Rainfall Rate mm hr⁻¹	Mass of liquid water mg/m³ of air	Number of drops m⁻³ within 20 micron size interval centered about indicated size (microns). 30	50	70
1	10/26/54	1707	5500′	0.129	99	38,800	77,000	34,000
2	»	1709	»	0.374	197	101,360	120,000	78,000
3	»	1711	»	0.171	118	91,650	95,000	76,000
4	»	1713	»	0.361	177	71,640	60,000	62,000
5	»	1715	»	0.177	118	52,220	56,000	34,000

Sample No.	Number of drops m⁻³ within 30 micron size interval centered about indicated size (microns) 90	110	130	150	170	190	210	230	250	270	290	310	330
1	33,000	27,500	25,200	9,400	2,550	985	365						
2	44,000	26,000	21,500	16,000	8,100	4,400	2,300	1,850	1,940	380	195	100	235
3	40,000	27,500	16,500	8,800	3,250	1,600	870	880	473	127			
4	37,000	22,500	17,000	13,000	8,000	5,500	2,740	1,620	1,570	400	320	350	
5	39,000	30,000	19,500	11,500	6,400	2,350	875	145	230				

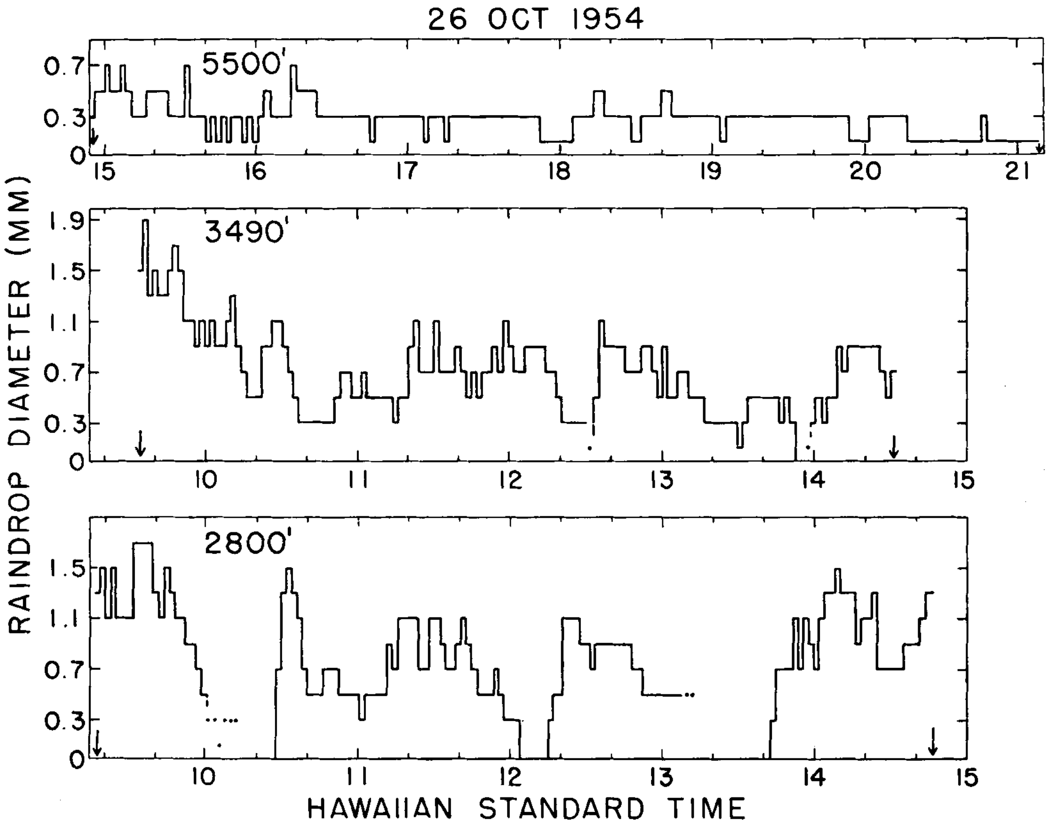

Fig. 3 a—3 e. The maximum drop diameter (± 0.1 mm) found on the drop recorder records plotted against time. See text for further information on the interpretation of this diagram.

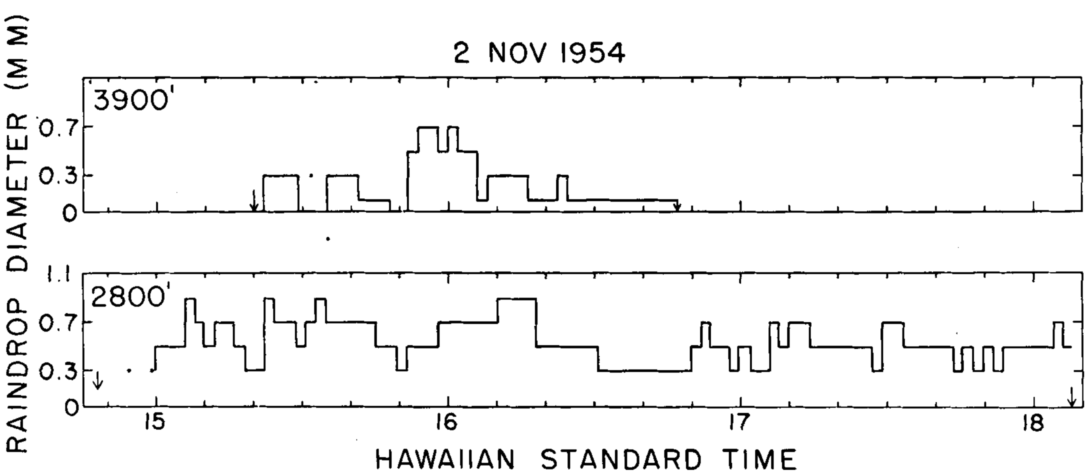

Fig. 3 b.

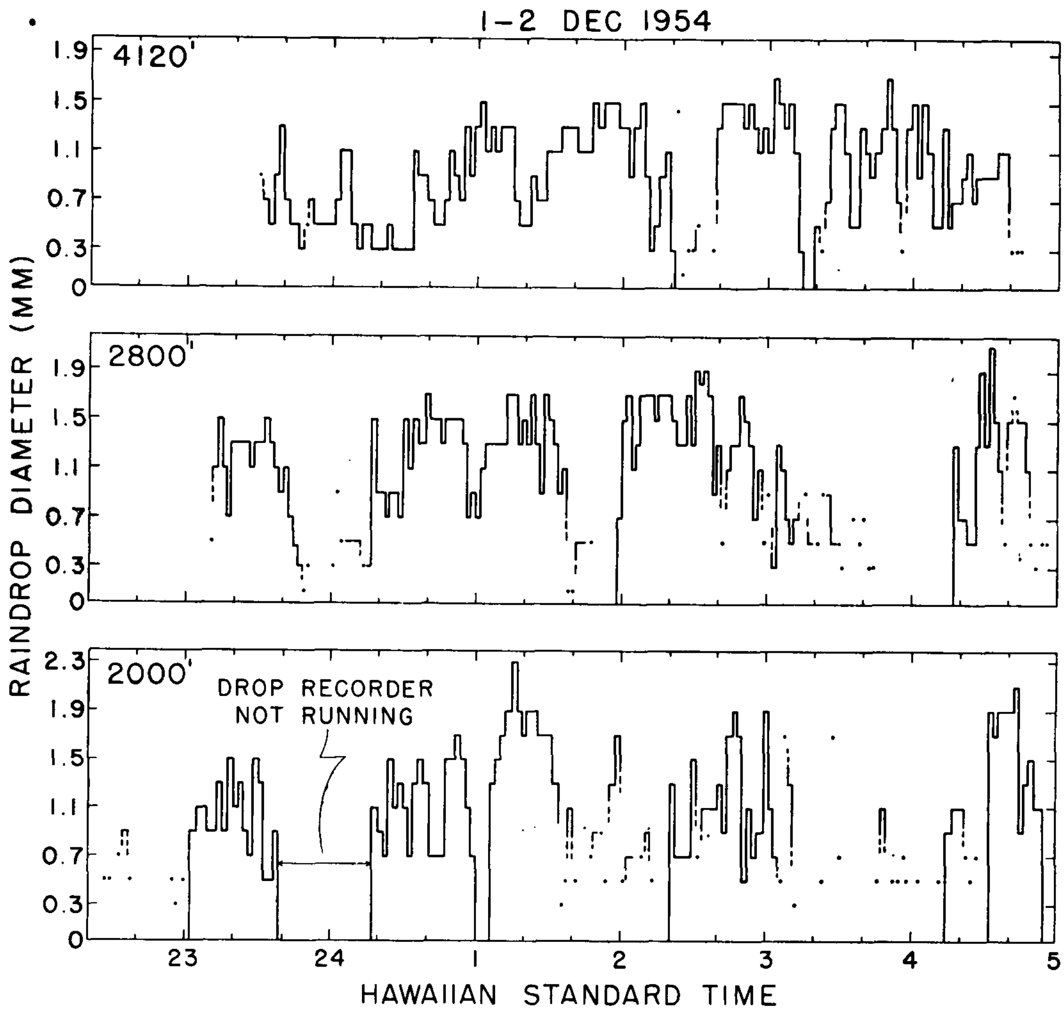

Fig. 3 c.

for example, at 2347 on 1 December at the 2,800 ft. station we find the last samples of a shower in which 10 or more drops were observed on a single exposure. The following 2 exposures, at about 2349 and 2351, showed less than 10 drops each. No rain was noticed on subsequent samples until 0001 when less than 10 drops were observed.

Near the beginning and end of the records of figs. 3a—3e (with the exception of the beginning of fig. 3c) a small arrow directed downward will be seen. This arrow points to the time at which the drop recorder was started or stopped as the case may be. In fig. 3c, the record of 1—2 December, all three recorders were set in operation at about 1800 on 1 December although no rain fell until about 2300.

The rains that fall at high levels on the volcano are often composed of many small drops that appear to be the winnowed remains of showers that began at lower levels. Such a case was found on 26 October when one of the drop recorders was in operation at the 5,500 ft. level. Examination of the samples revealed that a majority of the spots were less than 200 microns diameter which, from the calibration curve, indicated raindrops less than

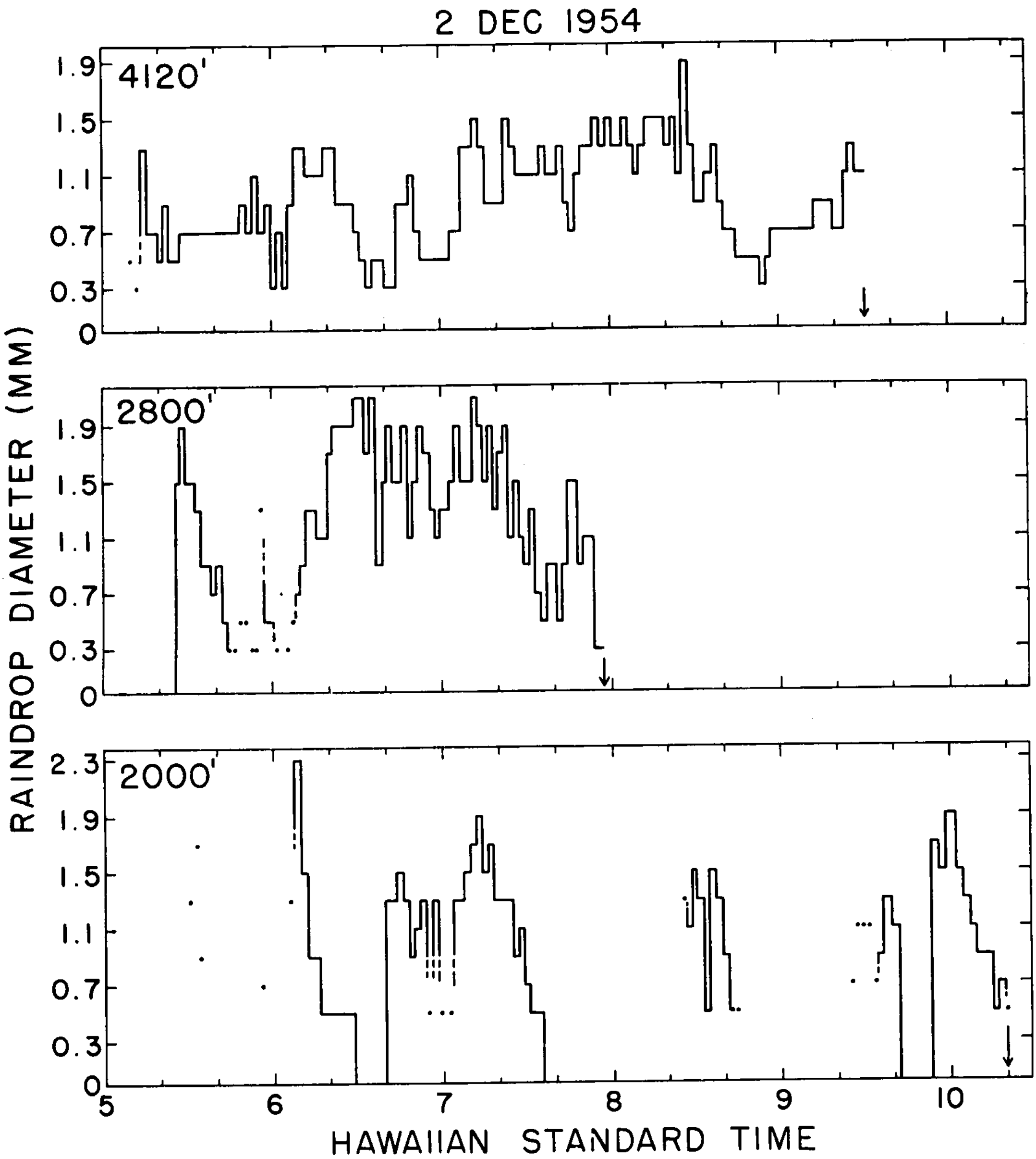

Fig. 3 c.

140 microns. A low power microscope was used for the size determination of the spots and from the subsequent count the data of table 3 were obtained. Here the number of drops per cubic meter are given for a 20 micron band width starting with the range 20—40 microns. Although the blue dye had been smoothly and fairly uniformly "buffed" into the recording paper it was sufficiently non-uniform to give, under the microscope, a "pebbly" appearance to the paper. This made it very difficult to get any accurate count of drops below 20 microns. It is believed that few were present. The number per cubic

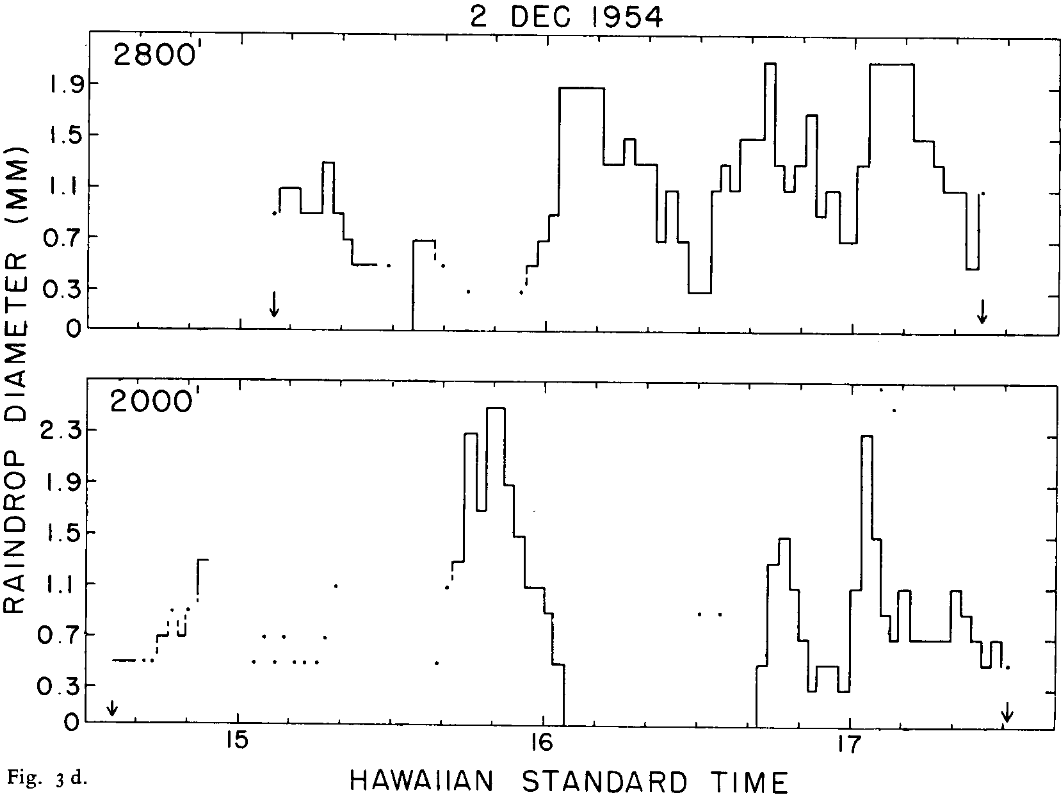
2 DEC 1954
2800'
2000'
RAINDROP DIAMETER (MM)
1.9
1.5
1.1
0.7
0.3
0
2.3
15
16
17
HAWAIIAN STANDARD TIME

Fig. 3 d.

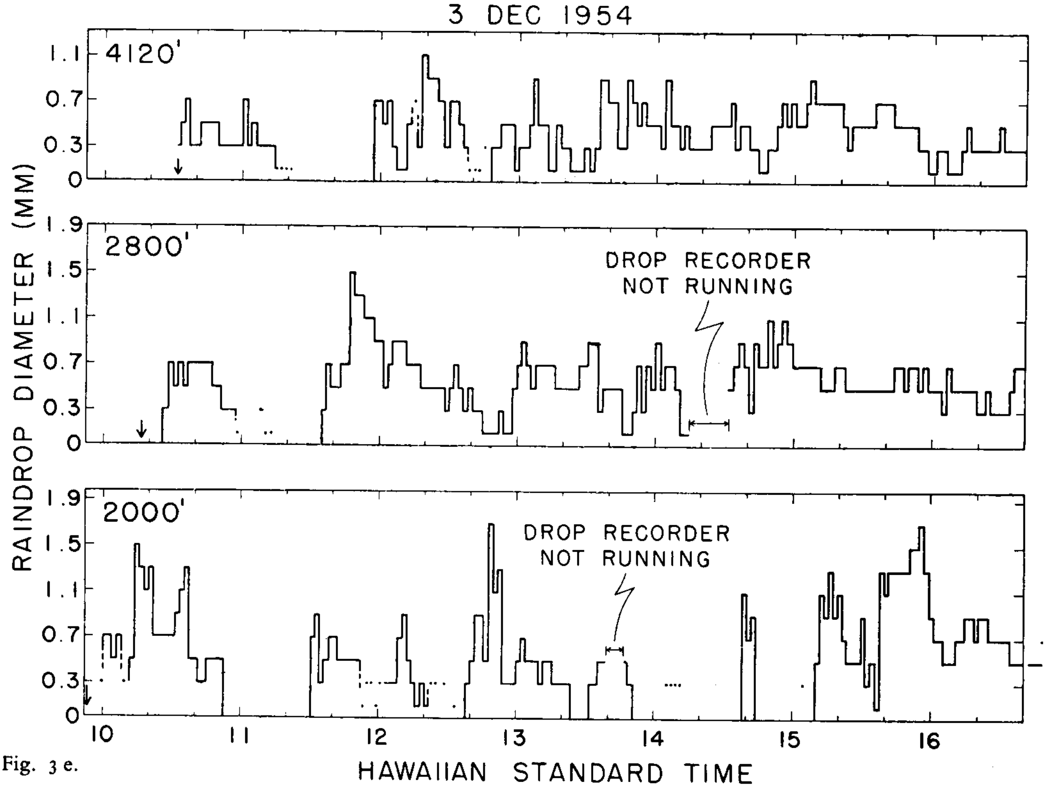
3 DEC 1954
4120'
2800'
2000'
RAINDROP DIAMETER (MM)
DROP RECORDER NOT RUNNING
DROP RECORDER NOT RUNNING
1.1
0.7
0.3
0
1.9
1.5
10
11
12
13
14
15
16
HAWAIIAN STANDARD TIME

Fig. 3 e.

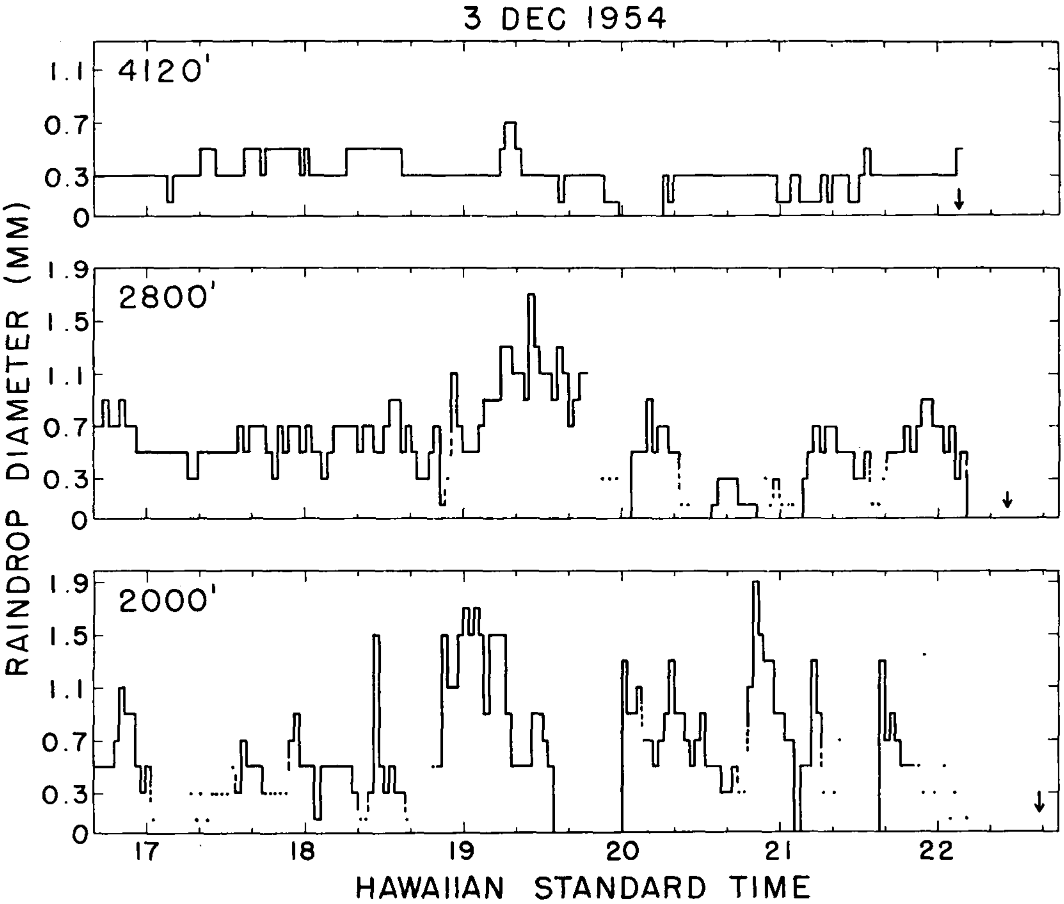

Fig. 3 e.

meter was less than the maximum value which was found at about 50 microns (see table 3). The results for five consecutive samples are given in table 3. These data were derived from the approximately 500 drops that were counted on each sample.

At the time of writing, these are the only high level samples that have been evaluated. Measurements made in prior years at this same location (BLANCHARD 1953) indicate that it is not uncommon to find more than 100,000 drops $m^{-3} < 0.2$ mm diameter. It was pointed out at that time that these counts were obtained with filter papers that tend to underestimate the actual count of drops < 0.2 mm. If the present drop recorders had been available it is likely that counts $> 300{,}000$ m^{-3} would have been obtained. Thus, it is the opinion of the writers that the distributions reported here are representative of the light rain that commonly falls at this altitude.

The complete evaluation of a number of the drop recorder samples has been made. Table 2 lists the drop distributions for 51 of the samples that were obtained on 2 December. Note the great number of drops $m^{-3} < 0.2$ mm diameter and the absence of any drops $>$ about 2 mm diameter.

5. Discussion

The drop recorder records indicate that the drop distributions are fluctuating and highly variable. A glance at fig. 3a—3e and table 2 shows that showers of one-half to one hours duration closely follow one another and appear to be superimposed on a background of light, nearly continuous rain. Some of the fluctuations in the rain are extremely light and probably would not be picked up by a standard recording rain gauge.

A characteristic common to many of the showers, and one that may be useful in the study of the mechanism of raindrop formation, is the rate of decrease of maximum drop size at the end of a shower. Examples of this may be found on fig. 3 c at the 2,000′ station at 0720 and 1000 and at the 2,800′ station at 2340 and 0540. The diameter of the maximum drop size undergoes a steady decrease at a rate of 0.07—0.1 mm per minute for a period of about 20 minutes. Two explanations for this have been considered (BLANCHARD, 1955), but neither has been satisfactory.

A detailed study of the drop distributions and their relationships with the rainwater chlorinity and the salt nucleus distribution is being carried out. This should supplement and carry further the ideas outlined in an earlier similar study (WOODCOCK & BLANCHARD, 1955).

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