Atmospheric Sea-Salt Nuclei Data for Project Shower

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(Manuscript received July 18, 1957)

Abstract

This report presents, without discussion, extensive data on the distribution of sea-salt nuclei in Hawaii during the field activities of Project Shower. References to studies and digests of similar data from this region are given. It is pointed out that one of the major purposes of obtaining these data, simultaneously with the other data presented in this volume, was to test an hypothesis of raindrop formation by tracing the salts in the nuclei to the salts in solution in the raindrops. The reader is invited to use these data for this or other purposes.

During the field program of Project Shower in Hawaii an effort was made to measure those properties of the lower trade-wind atmosphere which were thought to be most significant in the formation of the orographic shower rains of the islands. In so doing it was expected that a final analysis of these measurements might reveal relationships useful in testing various hypotheses concerning the generation of these rains.

Among the properties of the trade winds thought to be important in (warm) shower rain formation is their salt-aerosol content. The purpose of this note is to present the salt nuclei observations made by the author (see Table I). The reader may thus study these data in relation to the other extensive Project Shower observations given here, and form or test his own ideas of shower rain or other meteorological processes.

Descriptions of the salt-particle sampling and measuring techniques used to obtain the data of Table I may be found in the meteorological literature (WOODCOCK and GIFFORD, 1949 and WOODCOCK, 1952). These methods have also been tested and used by other investigators (BOYCE, 1954, CROZIER, 1954, TWOMEY, 1954 and 1955).

Numerous measurements and studies of airborne sea salt in Hawaii have been made. They revealed great differences in the sizes and numbers of these particles which were associated with change in wind force, altitude, and location (WOODCOCK, 1953). These studies also suggested the existence of relationships between the amount of airborne salt nuclei and the total amount of rainfall (WOODCOCK and MORDY 1955 a), and between the weights of individual salt nuclei and the weight of salt in solution in raindrops (WOODCOCK and BLANCHARD 1955 b).

Additional discussion of methods and of the salt-sampling results given here seems unnecessary at this time, since it would be repetitious of material published in the journals cited above. However, a few comments about other factors pertinent to these results may be useful.

Table I seems to be the best form of presentation of the salt-particle data. From it one can readily derive graphically the many quantities concerning particle number and mass distribution.

Table 1. Sea-salt nuclei data presented as cumulative number of particles per cubic meter of air.
table, represent the lower limiting weight

Sample Number	Time LCT	Date 1954	Altitude feet	T_d	T_w	Cloud base altitude (feet)	Numbers of salt particles M^{-3} of air			
							0.17	4.4	20.6	56.1
1	1120	10-13	2,500	18.6	17.3	3,000	630,000	165,000	48,000	16,800
2	1206	10-16	2,200	19.1	17.7	2,500	335,741	119,741	38,741	9,741
3	1150	10-16	4,300	15.1	13.3	2,500	163,600	56,600	24,600	7,300
4	1045	10-18	500	24.1	20.0	2,200	608,436	140,436	45,436	19,436
5	1055	10-18	1,000	22.6	19.9	2,200	481,430	137,430	39,430	11,730
6	1037	10-18	2,000	20.1	18.1	2,200	511,630	180,630	64,630	20,130
7	1503	10-20	1,000	22.8	20.7	1,100	456,218	177,218	56,218	18,218
8	1430	10-21	1,000	23.4	20.9	2,000	1,656,976	366,976	97,967	36,976
9	1506	10-23	1,500	21.9	18.9	1,600	710,549	250,549	60,549	25,549
10	1220	10-26	500	24.2	20.8	2,000	2,134,500	394,500	80,550	33,550
11	1208	10-26	1,700	21.6	19.2	2,000	1,069,427	303,427	98,427	36,627
12	1515	10-30	2,600	19.6	15.8	(no cu)	1,040,000	137,000	33,000	7,400
13	1640	11- 2	1,500	21.8	20.0	1,850	2,180,000	410,000	103,856	34,856
14	1505	11- 6	700	24.0	21.6	1,000	1,280,000	160,000	28,532	11,532
15	1630	11- 6	3,000	19.6	17.8	1,000	440,000	48,000	3,000	
16	1610	11- 6	4,000	18.0	16.7	1,000	400,000	1,800	185	
17	1039	11- 7	1,300	22.5	20.4	1,650	1,072,800	376,800	72,800	23,800
18	1056	11- 7	3,000	19.1	16.8	1,650	265,520	78,520	17,020	4,720
19	1105	11- 7	4,500	16.6	14.4	1,650	224,020	66,020	9,420	1,720
20	1116	11- 7	6,000	15.0	10.3	1,650	34,540	8,140	640	
21	1448	11- 9	800	23.5	20.2	1,000	914,824	171,824	33,824	10,624
22	1513	11- 9	3,000	19.9	16.4	1,000	389,187	91,187	26,187	4,087
23	1527	11- 9	4,500	16.7	11.9	1,000	36,610	10,410	2,410	270
24	1634	11-14	1,500	21.6	19.5	1,200	425,769	132,769	39,769	5,769
25	1646	11-14	3,000	19.1	16.7	1,200	377,310	80,310	9,810	910
26	1709	11-14	4,500	16.8	15.0	1,200	86,240	15,940	1,140	
27	1521	11-22	500	24.6	20.7	2,300	1,184,972	220,972	62,972	17,972
28	1532	11-22	2,000	20.7	17.7	2,300	1,024,344	314,344	61,324	18,324
29	1550	11-22	4,100	16.6	14.5	2,300	553,750	193,750	35,750	11,350
30	1630	11-22	7,000	15.6	12.0	2,300	538,417	97,417	15,417	5,217
31	1630	11-22	7,500	14.2	10.9	2,300	463,467	90,467	16,467	5,167
32	1605	11-24	2,400	19.0	17.1	2,700	829,691	221,691	58,691	17,091
33	1557	11-24	4,000	16.4	12.9	2,700	844,410	189,410	54,410	13,310
34	1551	11-24	5,500	15.5	7.1	2,700	191,320	33,320	6,520	1,120
35	1521	11-24	6,300	—	—	2,700	10,390	2,290	690	
36	1600	11-25	1,500	21.2	17.6	3,000	3,200,000	540,000	115,000	30,000
37	1546	11-25	3,000	18.1	14.0	3,000	1,633,334	313,334	109,334	25,234
38	1539	11-25	5,500	13.1	10.3	3,000	790,850	120,850	15,250	5,350
39	1528	11-25	8,000	12.1	4.7	3,000	109,014	22,214	6,414	1,014
40	1658	11-26	1,500	20.6	16.7	3,200	2,500,000	490,000	160,000	35,000
41	1518	11-26	2,800	17.6	14.8	3,200	833,219	261,219	79,219	33,219
42	1529	11-26	4,500	15.1	10.7	3,200	1,779,550	279,550	45,550	15,950
43	1537	11-26	6,000	12.8	4.0	3,200	375,430	79,430	18,430	7,430
44	1549	11-26	8,000	9.7	1.7	3,200	39,280	5,780	980	190
45	1517	11-30	1,500	20.6	17.7	2,200	2,500,000	460,000	122,000	21,000
46	1423	11-30	2,000	19.8	17.1	2,200	2,057,576	592,576	174,576	59,576
47	1435	11-30	3,500	16.0	13.7	2,200	1,009,250	331,250	77,250	31,550
48	1442	11-30	5,000	13.8	10.5	2,200	1,404,070	234,070	41,070	19,070
49	1451	11-30	6,500	11.2	9.0	2,200	368,200	66,200	8,200	1,400
50	1505	11-30	8,000	10.6	4.7	2,200	53,220	8,220	820	
51	0827	12- 1	2,300	18.6	15.8	1,800	4,150,000	800,000	205,000	60,000
52	1440	12- 1	2,100	19.7	16.8	2,300	1,510,972	470,972	121,972	37,272
53	1448	12- 1	4,000	15.3	12.3	2,300	2,449,860	429,860	87,860	31,260
54	1457	12- 1	6,000	12.4	6.7	2,300	513,770	96,770	24,170	4,970
55	1509	12- 1	8,000	9.4	4.3	2,300	76,350	10,950	1,750	
56	1506	12- 2	500	22.3	18.7	2,100	4,000,000	710,000	148,000	28,000
57	1412	12- 2	2,000	19.3	16.0	2,100	2,433,925	433,925	138,925	72,425
58	1421	12- 2	3,500	16.5	13.7	2,100	1,937,710	167,710	43,710	9,710
59	1428	12- 2	5,000	13.0	9.9	2,100	1,579,970	209,970	44,970	10,970
60	1436	12- 2	6,500	11.6	8.3	2,100	33,040	5,040	640	
61	0827	12- 3	4,000	14.6	11.8	1,800	900,000	130,000	27,500	2,000
62	1334	12- 3	2,500	17.5	14.9	2,200	818,900	298,900	117,900	53,900
63	1345	12- 3	4,000	14.7	11.7	2,200	527,840	96,840	24,840	6,540
64	1356	12- 3	5,500	12.4	9.7	2,200	95,010	18,510	5,110	410
65	1402	12- 3	7,000	11.2	5.5	2,200	86,400	13,100	3,200	
66	0827	12- 5	500	22.1	18.4	2,000	1,400,000	290,000	78,000	11,500
67	0823	12- 5	3,000	17.2	14.2	2,000	730,000	175,000	17,000	

The nucleus weights, given at the tops of each of the columns of numbers on the right side of the in each weight-range category

having weight greater than that given at stop of each column (unit = 10^{-12} g)												
120	218	362	550	800	1120	1520	2000	2540	3200	4000	4900	5900
6,300	2,250	870	350	80								
4,841	2,821	1,651	981	501	251	81						
2,500	800	130	60	30	10							
9,236	5,036	2,636	1,036	236	76	16						
4,530	2,030	800	270									
8,130	2,530	910		360	177	52	11	3				
9,218	4,418	1,218	318									
20,076	10,076	6,126	3,636	2,026	1,316	780	481	292	172	100	43	13
11,149	5,649	2,389	1,149	549	219	118	59	21	7	2		
13,550	5,090	1,260										
11,227	4,357	1,587	897	457	227	116	54	24	10	3		
900												
11,856	3,956	2,216	1,321	696	293	119	41					
5,632	3,392	1,772	762	245	114	43	14					
7,000	1,760	770	300	90	40	17	6					
1,020	290											
580	90											
3,744	1,864	784	364	174	85	28	9					
1,247	247	67	14									
70												
1,769	359	169	69	20	5							
350	110											
8,872	4,072	2,092	1,042	297								
7,124	3,464	1,064	619	319	111	50	20					
2,450	650											
2,317	1,027	157										
2,767	997	247										
6,591	2,731	1,191	451	211	114	37	9					
5,110	1,370											
110												
2,900												
11,534	6,134	2,634	1,374	694	381	190	83	31	10			
2,350	870											
124												
11,019	4,819	2,399	1,089	449	222	80	20					
9,050	4,250	1,270										
2,830	1,120	280										
19,576	8,676	4,036	2,286	1,126	406	101						
9,350	4,980	1,660	660									
7,070	2,570	990	200									
5,000												
16,672	6,472	3,682	1,972	952	452	162	33					
15,660	7,560	4,390	2,090	630	210							
1,670	5,570	230										
34,925	15,425	8,245	5,215	3,485	2,425	1,545	835	415	135	54		
4,970	2,250	1,120	370									
3,470	1,370	510	170									
15,300												
2,340	570											

Thirty airplane flights were made in order to take the samples of sea-salt particles from which the data of Table I were derived. These samples were taken at various altitudes over the sea and a few miles east of the windward shore, near Hilo, Hawaii, using a light single-engine (Cessna 170) aircraft. Measurements of the salt-nuclei content of the trade-wind stream were thus made a short time before the air passed over the high-rainfall regions south and west of Hilo (see Location Map).

An effort was made to adjust the timing of the salt-nuclei sampling in the trade winds so that at least some of the rain subsequently sampled on the mountain side might come from approximately the same mass of air in which the salt nuclei were obtained. One of the major reasons for taking these samples of nuclei and rain was to attempt to trace the salt in the nuclei to the salt in solution in the raindrops, and thus to make further tests of the proposed salt nuclei-raindrop hypothesis.

With the exception of samples 30 and 31, all of the nuclei represented in Table I were sampled over the sea approximately along a line lying between positions 19° 52′ N, 154° 53′ W and 19° 40′ N, 154° 50′ W (see Map).

Samples 30 and 31 were taken over inland Hawaii, in the saddle between the mountains Mauna Loa and Mauna Kea. The altitude of the airplane was approximately 500 feet above the lava fields of the "saddle" when sample 30 was taken, and 1,000 feet in the case of sample 31. The flight line while sampling was between positions 19° 41′ N, 155° 25′ W and 19° 41′ N, 155° 30′ W.

In some cases, and for various reasons, the larger salt particles in the samples were not counted. Examples of these cases are samples 40, 56, 62, etc., Table I. In most cases, however, an effort was made to extend the "reading" of the sampling slides to the sparsely-distributed giant nuclei, which are present in numbers of tens or hundreds per cubic meter of air.

The wet-bulb and the dry-bulb temperatures given in Table I were measured from the aircraft at the time the salt nuclei samples were taken, using mercury thermometers manually exposed to the air stream. Thermometer error, tested with a U.S. Bureau of Standards thermometer, did not exceed .05° C, within the temperature ranges given. A small correction has been made for the temperature rise due to dynamic heating of the thermometers exposed at a flight speed of about 65 mph.

The altitudes given in Table I were taken from the airplane's altimeter. This instrument was adjusted, on each flight, to the pressure and altitude at the nearby Hilo Airport, and seemed reasonably accurate. For instance, by flying low over the cinder cone Puu Huluhulu in the "saddle" area (altitude 6,760 feet), the indicated altimeter altitude was found to be only 50 feet less than the correct value based upon a nearby geological survey "bench mark".

Cloud base altitudes listed in Table I are the minimum heights of the trade-wind cumulus measured by altimeter during the salt-sampling flights. Maximum cumulus cloud-base altitudes observed during the flights were often many hundreds of feet greater, indicating a very considerable variability in the condensation lifting level in one area during a short time interval.

The author is indebted to Mr. W. W. Stearns, pilot of Murray Air Ltd., Honolulu, whose interest in this study, punctuality and precision flying made the salt-nuclei sampling flights a pleasure as well as a success.

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