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FOG DROP MEASUREMENTS AT BARROW, ALASKA

Motoi Kumai, et al

Cold Regions Research and Engineering Laboratory

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CONDUCTED FOR
ADVANCED RESEARCH PROJECTS AGENCY
ARPA ORDER 1615
AND
U.S. ARMY MATERIEL COMMAND
BY

CORPS OF ENGINEERS, U.S. ARMY
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HANOVER, NEW HAMPSHIRE

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

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PREFACE

These studies were conducted as part of the Arctic Surface Effect Vehicle Program conducted for the Advanced Research Projects Agency by the U.S. Army Cold Regions Research and Engineering Laboratory (USA CRREL) under ARPA order 1615. The work was partially funded by the U.S. Army Materiel Command under DA Project 1T061102B52A, Work Unit 003.

Field work and report preparation were accomplished by Dr. Motoi Kumai, Physicist, Research Division, and laboratory work was assisted by SP5 R.F. Glienna, USA CRREL. Significant contributions were made to the project at Barrow by Mr. T. Thompson, Mr. C.S. Morris, Mr. L.L. Warnke, Mr. D.J. Schneider and Mr. Kehoe of the Applied Physics Laboratory, Johns Hopkins University.

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13. ABSTRACT

Arctic fog droplets were sampled on chloride-sensitive gelatin-coated glass slides at Point Barrow, Alaska, in the summer of 1971. The collection efficiency of the fog droplets was determined. About 20,000 fog drop radii were measured. The results of analysis of the concentration and the size distribution of fog drops are presented in the form of tables and photomicrographs. It is shown that the concentration and the size distribution changed rapidly with time and space; the drop radii ranged widely between 3.3 and 65 μ; the mean radius was 10 μ; the maximum concentration was 24 drops/cm^3 and the liquid water content was 0.09 g/m^3 at a visibility of 250 m. Calculations were made of the attenuation by fog at wavelengths of 0.571 and 1.06 μ for the observed size distributions and concentrations of fog drops.

14. KEY WORDS

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INTRODUCTION

Summer fog at Barrow is a marine fog which forms in the Arctic Sea and moves onto the land. For years, weather data have been collected at many locations in the Arctic, but arctic fog drop measurements are rare. The concentration and size distribution of arctic marine fog droplets were measured in 1964 at Point Barrow, Alaska (Kumai 1965), as part of a study of fog formation in the summer Arctic Sea, an area of very low air pollution. Fog drop nuclei were identified using an electron diffraction method. The results showed that 91% of the nuclei were sea salt particles.

This paper describes the sampling and analysis of arctic fog at Barrow, Alaska, during summer 1971. The object of the research was to obtain the mean concentration and the size distribution of fog droplets between a radar site and its targets and between a laser and its targets, and from these data to calculate the attenuation coefficient for wavelengths of 0.57 μ and 1.06 μ. During the fog drop sampling, the backscattering of a 1.06-μ laser beam and a 94-GHz radar beam from sea ice obstacles and from their standard targets was measured by the Applied Physics Laboratory of Johns Hopkins University for use in developing an obstacle avoidance system for arctic surface effect vehicles.

METHODS

Fog drop samplers

A satisfactory fog drop sampler should:

1. Accommodate drops ranging from a few microns to a few hundred microns in radius.
2. Provide the size distribution of drops over distances of 150 to 450 m within fog.
3. Provide enough samples to adequately represent the fog structure.
4. Have a precision of 10% or better.

The direct method of fog drop sampling is to collect the drops on a substrate using an impactor. Samplers of this type include a three-slide collector (Brown and Willett 1955) and a cloud drop sampler for aircraft (Squires and Gillespie 1952, Jiusto 1965). These instruments satisfied their design objectives and have been utilized to accumulate valuable information on cloud physics, but for various reasons they were not considered suitable for our particular experiments. Therefore, we attempted to find a sampling device specifically suited to our requirements.

For the first tests at Barrow we used a two-stage impactor containing slides precoated with silicone oil or gelatin to collect fog drops or replicas. A 100-cm^3 volume of air was taken into the impactor, and only a few drops were observed in the field under an optical microscope. No drops were found in the second stage, showing a 100% collection efficiency for the first stage. We repeated this method several times with the same results. Since a thousand drops were needed to determine size distribution over the desired distance, it was concluded that the two-stage impactor was too inefficient for use in a fog of low concentration.

During this early sampling a good collection of fog drops was found on the upwind side of the shaft of an anemometer being used to measure the wind speed and thus the length of the airstream being sampled. This observation led to the adoption of a method in which a slide precoated with a gelatin film was cut into 5-mm-wide, 30-mm-long strips and attached to the upwind side of the anemometer shaft. This method was used for the remainder of the tests.

Fog drop replication

One of the materials used for the replication of fog drops is gelatin. A 20% (by weight) solution of gelatin in warm distilled water is prepared, applied to a microscope slide and allowed to dry (Jiusto 1965). In the present experiments a gelatin reagent film containing colloidally dispersed red silver dichromate was used for drop replication and also for chloride identification of sea salt nuclei larger than 10^{-12} g (Farlow 1957, Kumai 1965).

A droplet impacting on the gelatin film dissolves some of the gelatin and leaves a trace after it evaporates. The drop replica resembles a round crater when viewed under an optical microscope with oblique illumination or under a phase contrast microscope. The evaporation of water drops of about 0.2 mm radius was observed under an optical microscope. The radii of the drops on the film were found to coincide with the radii of the replicas. The contact angles of the drops on this film, measured from photomicrographs of side views of the drops, were found to average about 35°. When a contact angle of 35.7° was made by the drops with the film, it was calculated that one-half the radii of the convex-shaped drops on the film was equal to the radii of the drops before contact with the film. The radii of the replicas can be determined down to 1 μ. The time for replication is very short for a small drop. Multiple impacts of drops on the same area are generally distinguishable as overlapping replicas.

EXPERIMENTS

Experimental set-up

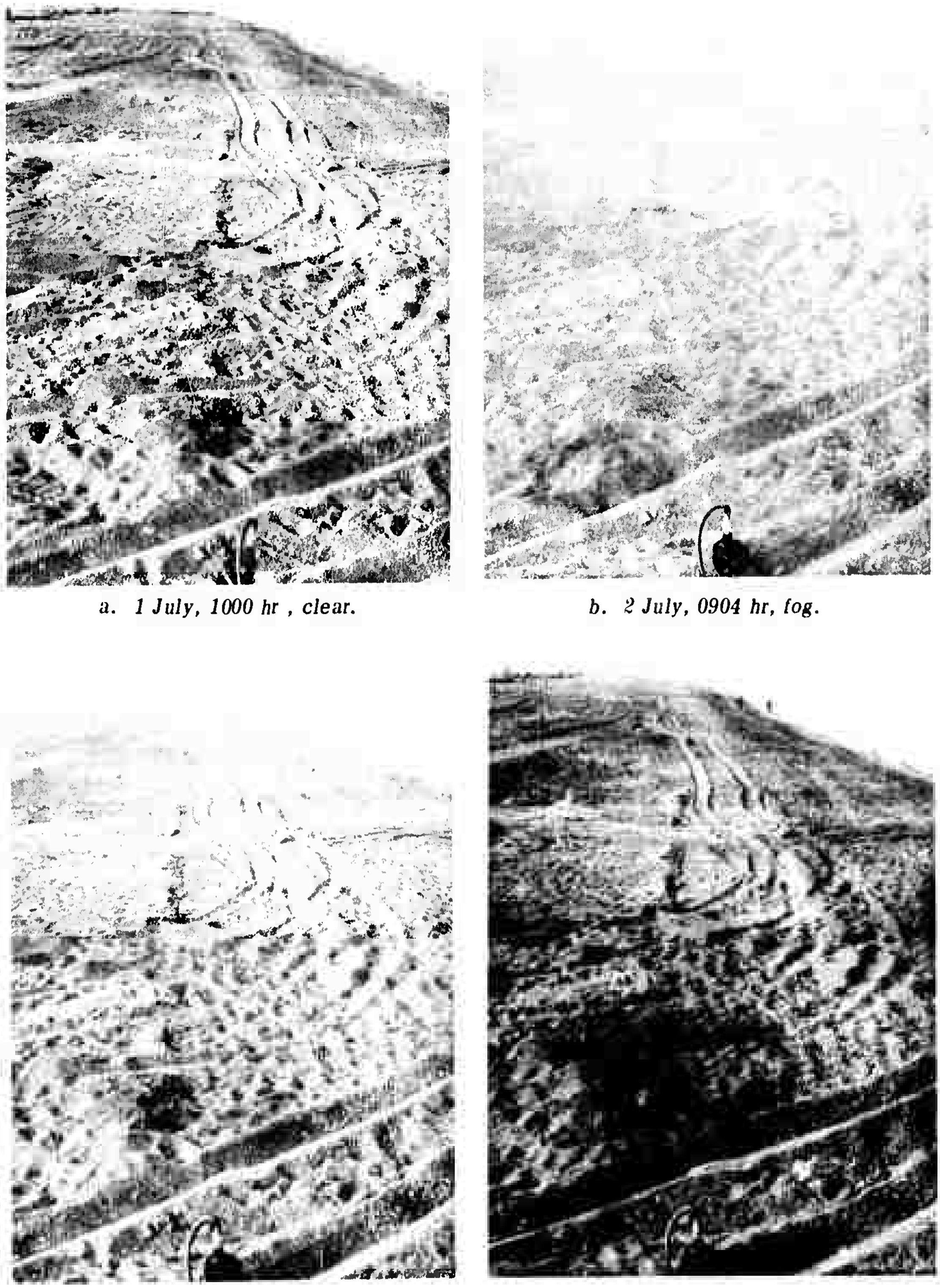
The sampling took place on the coast of the Arctic Sea near Barrow, about 1.5 km northwest of the U.S. Naval Arctic Research Laboratory. Dense fog is formed here in the summer by the advection of moist air over broken sea ice; the fog then moves inland. In June, July and August, dense fog that lowers visibility to less than 1.6 km (1 mile) occurs over 50 hours each month. The maximum average is 84 hours in June at Barrow (10-year weather records).

A wanigan was set up as a base for observation, preparation and photomicroscopy (Fig. 1). Fog drops were collected on the upwind side of the wanigan. For visibility observation and photography, flags were lined up along the beach at 30.5-m (100-ft) intervals (Fig. 2). A small laser target was set up 152.4 m (500 ft) from the wanigan, and a large target at 228.6 m (750 ft). A small target for radar was set up at 304.8 m (1000 ft), and a large one at 457.2 m (1500 ft). The radar (94 GHz) and laser (1.06 μ) equipment was set up on the second level of the wanigan to measure attenuation due to fog.

a. 29 June 1971 (fog).

b. 27 June 1971 (clear).

Figure 1. Radar target and observation wanigan.



a. 1 July, 1000 hr , clear.

b. 2 July, 0904 hr, fog.

c. 2 July, 0953 hr, fog.

d. 2 July, 1020 hr. clearing.

Figure 2. Views from the observation wanigan.

Fog drop collections

Fog drops were collected on a slide coated with chloride-sensitive gelatin film attached to the shaft of the anemometer. Since the fog drop concentrations on the slide had to be fairly dense but without agglomeration the time of exposure to the airstream was calculated beforehand. The length and volume of the airstream sampled were calculated from the wind speed, the time of exposure to the wind, and the film area. The drop collection efficiency was determined for drop radii, wind speeds, density and viscosity of the air, and film width, using the theoretical consideration of Langmuir and Blodgett (1946). Thus the average concentrations and size distributions of fog drops between radar and laser sites and their targets were determined.

RESULTS AND DISCUSSION

Measurements of fog drop radii

A dense fog covered the Barrow area from 1900 hr on 29 June to 0930 on the 30th. Twelve samples of advection fog drops were collected on precoated gelatin films 1.5 m above the beach. The air temperature was 1°C and the wind velocity was between 1.5 and 4.5 m/sec. At 0820 on 2 July a bank of advection fog was observed over the Arctic Sea to the north. This fog bank invaded the area around 0840 (Fig. 2d). During the fog,samples were taken between 0900 and 1019. The air temperature was 0°C and the wind speed was between 1.4 m/sec and 2.0 m/sec.

Fog drop collection and weather data are shown in Table I. In this sampling the time of the film's exposure to the airstream was 30 or 60 seconds, and the length of the airstream was between 85 and 275 m. These samples gave a mean concentration and size distribution for the time and space desired. Photomicrographs of the samples were taken for size measurements under an optical microscope with oblique illumination and were enlarged by a factor of 100 (Fig. 3). The size of

Table I. Fog drop collection and meteorological data.

Film exposed to airstreams for 30 sec (Specimens 1 and 12) or 60 sec (all others).

Specimen	*Time (AST)*	*Airstream length (m)*	*Wind speed (m/sec)*
30 June (Temp 1°C, R.H. 98%, and wind NE)			
1	0010	145	4.8
2	0020	275	4.5
3	0040	270	4.5
4	0045	269	4.5
5	0050	128	2.1
6	0053	125	2.1
7	0057	119	2.0
8	0110	121	2.0
9	0115	117	2.0
10	0120	118	2.0
11	0125	121	2.0
12	0915	106	3.5
2 July (Temp 0°C, R.H. 96%, and wind N)			
13	0900	119	2.0
14	0905	107	1.8
15	0923	97	1.6
16	0932	116	1.9
17	0941	85	1.4
18	0950	97	1.5
19	1003	91	1.4
20	1019	219	1.6

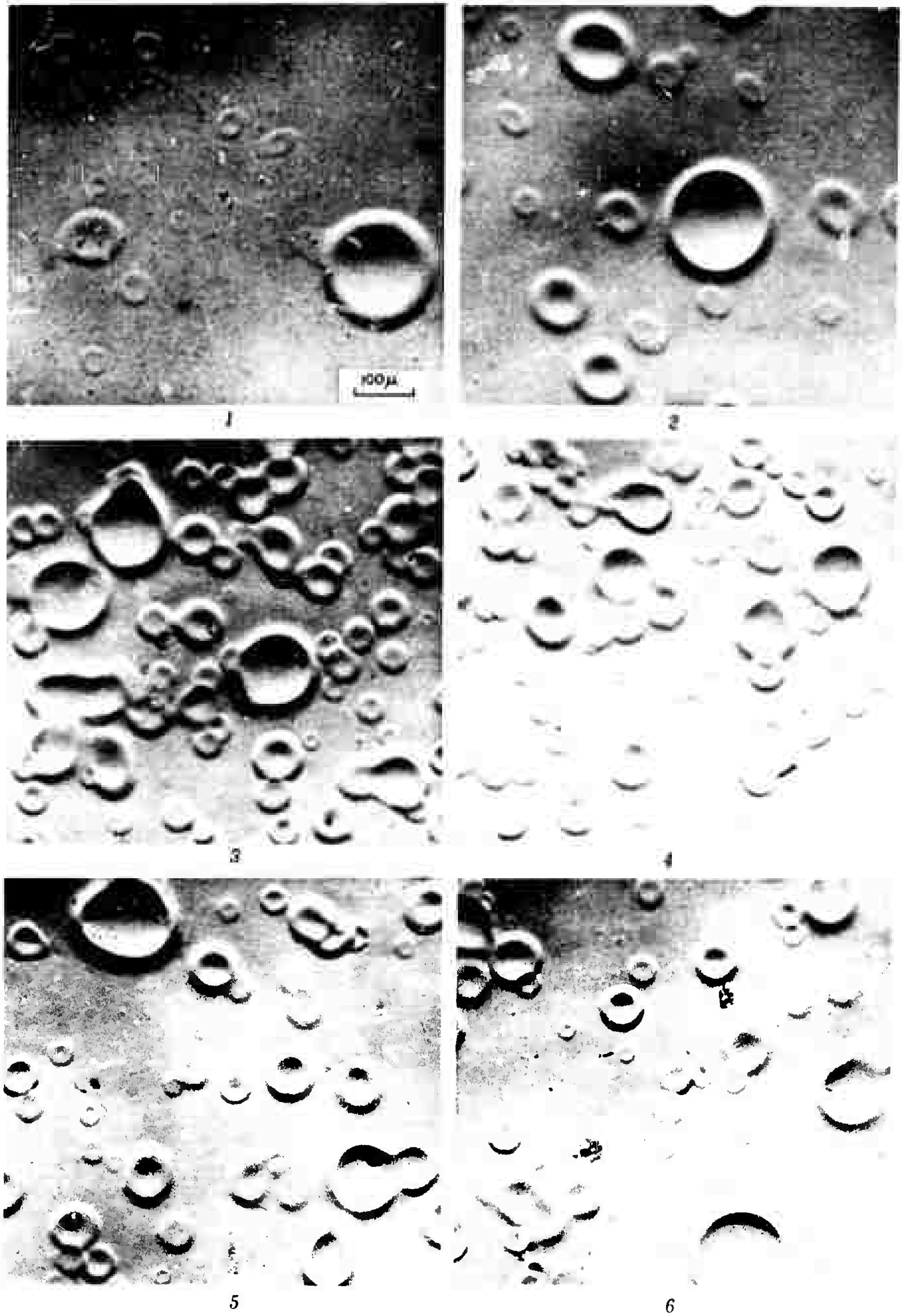


Figure 3. Fog drop prints on chloride-sensitive gelatin-coated glass slides.

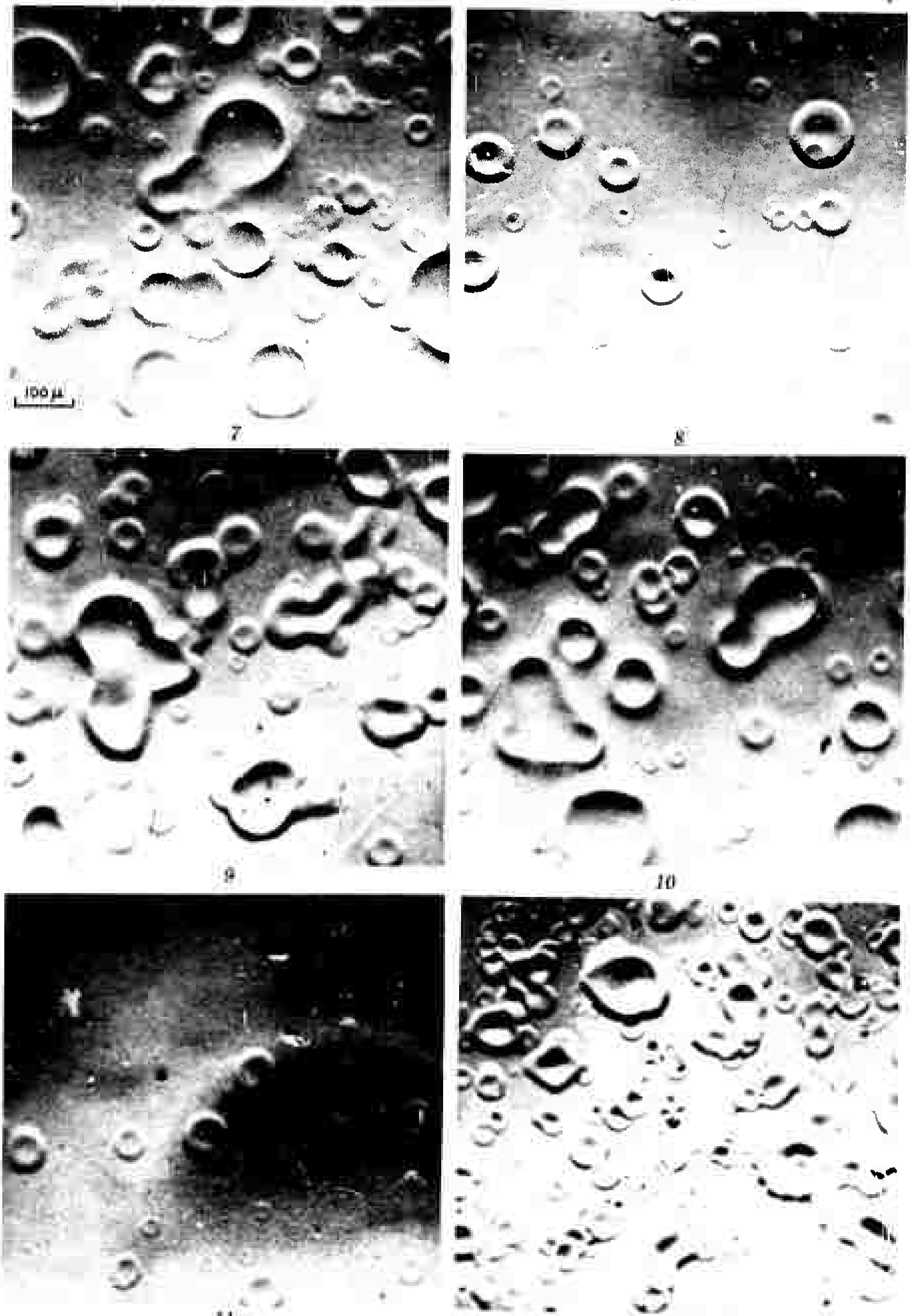


Figure 3. (Cont'd).

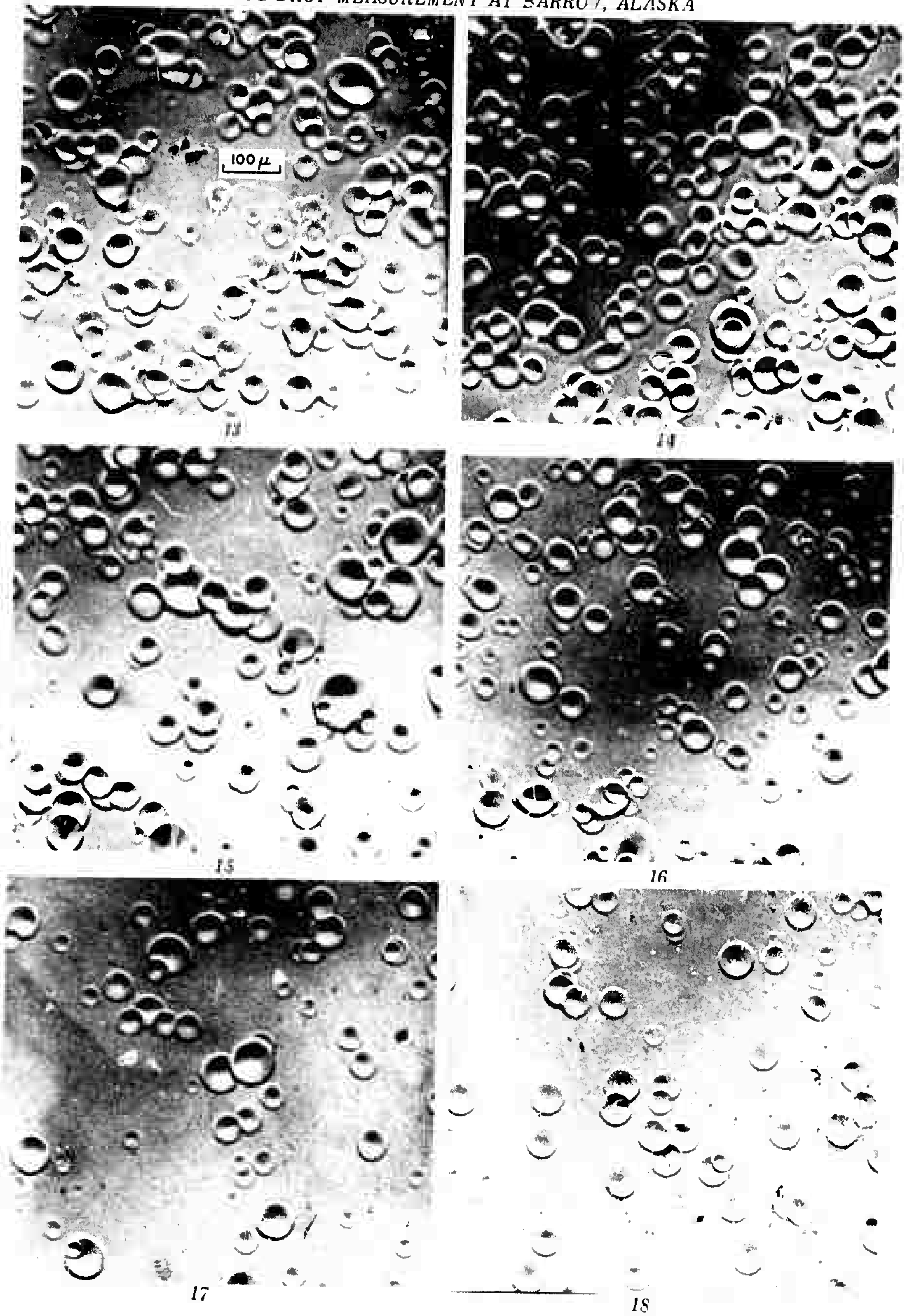
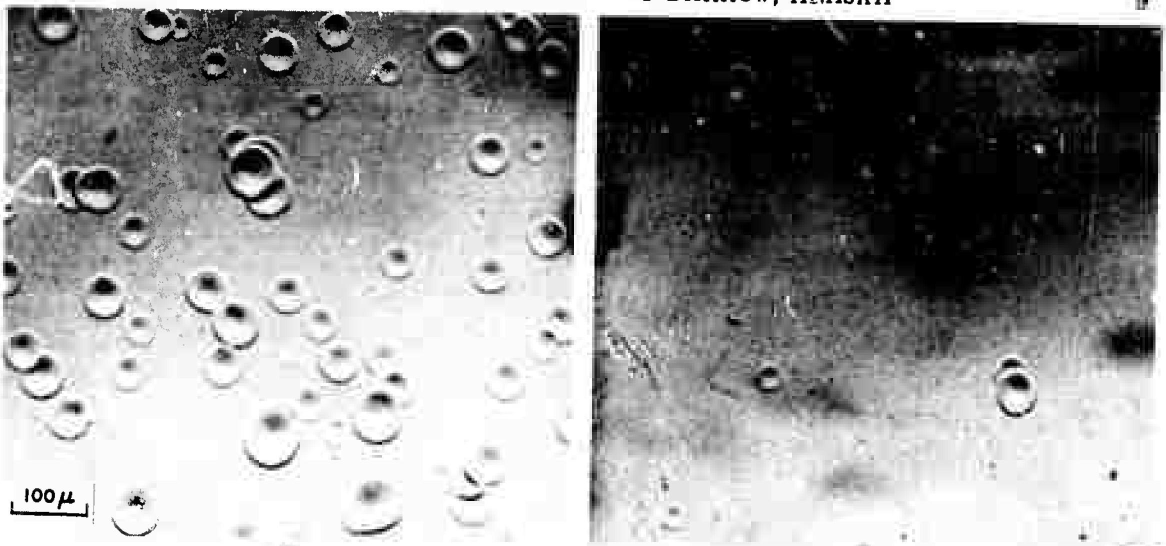


Figure 3 (Cont'd) Fog drop prints on chloride-sensitive gelatin-coated glass slides



19 20

Figure 3. (Cont'd).

the fog drop prints in the photomicrographs was measured with a Leitz particle analyzer which can measure print diameters from 1.2 to 27.7 mm. The size range is divided into 48 units. The diameter of the actual drop can be obtained by taking half the diameter of the print in the photomicrograph (Jiusto 1965). The range of drop radii was 3.3 to 65 μ, and the width of the division (Δr) was 1.3 μ. About one thousand drop prints were measured for each specimen to determine the size distribution. The true size distribution is obtained by making adjustments for collection efficiency.

Collection efficiency

Langmuir and Blodgett (1946) described the water drop collection efficiency of differently shaped collectors in the case of potential flow. The collection efficiency of a narrow flat plate (ribbon shape) is applicable to our experiments. The value of collection efficiency is a function of slide film width and given environmental conditions. Dimensionless parameters ϕ and K are as follows:

$$\phi = \frac{18 \rho_a^2 C}{\eta \rho_s} \nu$$

$$K = \frac{2 \rho_s \nu}{9 \eta C} r^2$$

in which

ν = wind velocity (cm/sec)

r = radius of fog drop (cm)

ρ_a = 0.001275 g/cm³, density of air (0°C, 1000 mb)

ρ_s = 1 g/cm³, density of fog drop

η = 1.718×10^{-4} g/cm sec, viscosity of air (0°C, 1000 mb)

C = 0.25 cm, half width of slide collector.

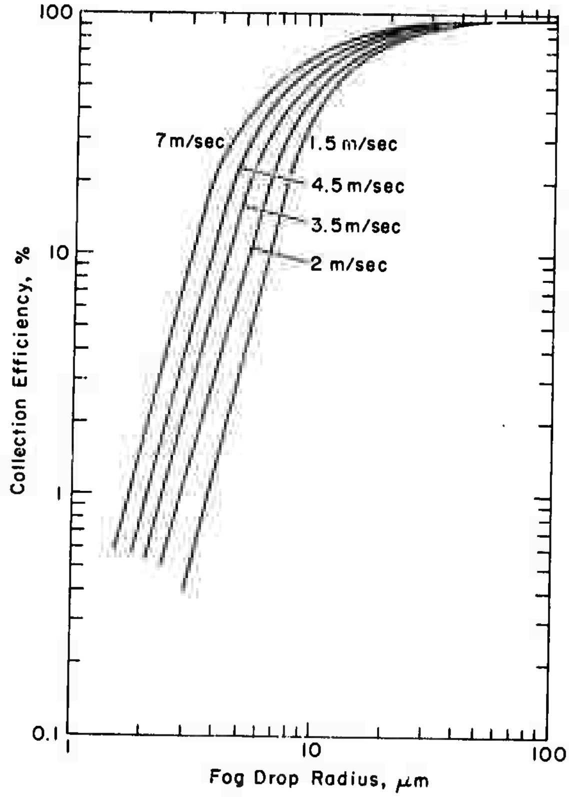


Figure 4. Fog drop collection efficiency.

The collection efficiency E (%) for various wind velocities and drop radii at an air temperature of 0°C and an atmospheric pressure of 1000 mb is shown in Figure 4. The collection efficiency for minute droplets is extremely small; therefore collection of a large number of drops is required for each sampling. In these experiments, over 10^3 drops were collected for each specimen. The smallest drop radius was 3.3 μ. The collection efficiency for the smallest drops was 0.6% for a wind velocity of 1.5 m/sec, 1.6% for 2 m/sec, 3.2% for 3.5 m/sec, 6% for 4.5 m/sec, and 14% for 7 m/sec. The largest drop radius was 65 μ and its collection efficiency was 95% for a wind velocity of 1.5 m/sec, and 98% for 7 m/sec.

Size distribution

$n_0(r)$ is the number of drops having radius r on a slide of known area, as shown in Table II. $E(r)$ is the collection efficiency for drops of radius r for a given wind velocity. $n_0(r)/E(r)$ is the number of fog drops having radius r on a given area on the slide corrected by the collection efficiency for a given wind velocity. $n(r)$, the percentage of fog drops having radius r, corrected for the collection efficiency, is expressed as follows:

$$n(r) = \frac{n_0(r)}{E(r)} \times \frac{100}{N}$$

in which

$$N = \sum_{0}^{r_i} \frac{n_0(r_i)}{E(r_i)} .$$

Table II. Fog drop size distribution

Drop radius (μ)	Specimen 1 (no.)	2 (no.)	3 (no.)	4 (no.)	5 (no.)	6 (no.)	7 (no.)	8 (no.)	9 (no.)	10 (no.)	11 (no.)	12 (no.)	13 (no.)	14 (no.)	15 (no.)	16 (no.)	17 (no.)	18 (no.)	19 (no.)	20 (no.)
2.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.5	0	0	12	12	9	9	7	14	12	11	6	24	5	11	4	15	4	3	4	0
4.8	0	2	19	31	12	9	12	27	25	22	21	43	16	39	21	41	23	10	4	2
6.1	0	5	47	65	48	39	26	120	42	46	56	112	46	63	31	123	54	36	19	3
7.4	3	24	69	82	49	81	46	127	52	51	90	184	85	95	94	224	123	81	32	10
8.7	8	38	98	114	109	101	87	167	106	88	87	171	146	135	120	214	160	171	78	7
10.0	9	84	114	104	113	102	105	116	112	113	89	150	221	130	140	131	143	154	66	7
11.3	15	83	113	95	123	133	132	107	159	112	92	135	216	213	163	104	134	201	98	4
12.6	20	107	109	110	114	113	114	86	121	111	48	108	197	180	194	77	76	198	90	5
13.9	17	85	101	83	100	90	108	57	111	81	31	64	140	119	182	55	28	101	81	
15.2	9	70	84	84	89	81	93	47	69	85	32	39	59	51	106	20	20	36	34	
16.5	14	66	70	58	66	81	65	35	67	54	20	25	14	16	29	8	9	11	10	
17.8	6	58	58	39	46	34	57	20	46	48	19	16	4	8	17	5	3	6	10	
19.1	7	66	25	30	24	42	45	9	36	36	6	5	3	4	12	5	4	0		
20.4	5	45	24	29	37	23	39	9	26	30	2	3	4	4	7	2	2	1		
21.7	0	31	17	21	26	35	30	5	28	23	2	3	0	0	1	0		1		
23.0	1	20	14	9	8	17	18	6	15	27		0	1	0	1	0				
24.3	2	23	3	8	10	9	12	2	11	15		1	0	1	0	0				
25.6		14	10	10	10	6	11	3	10	15		0	1		1	0				
26.9		4	6	8	2	6	7	0	9	2		0			0	1				
28.2		9	3	7	5	2	13	0	4	7		0			0					
29.5		4	2	5	7	2	9	1	13	3		0			1					
30.8		3	2	1	3	3	8		8	2		0			0					
32.1		3	0	1	2	3	3		4	3		0			1					
33.4		1	2	2	1	4	1		2	5		0			0					
34.7		0	0	2	0	2	6		1	2		1			1					
36.0		0	0	2	3	1	1		1	1										
37.3		1	1	0	3	1	5		3	0										
38.6		1	0	0	4	3	0		3	0										
39.9		1	0	1	1	1	0		1	0										
41.2		0	0		0	0	1		2	1										
42.5		3	0		0	1	2		0	0										
43.8		1	1		0	1	2		0	0										
45.1		0	1		0	0	0		0	1										
46.4		0			0	0	1		0	0										
47.7		1			0	0	1		0	1										
49.0		1			1	0	1		0	1										
50.3		0				0	0		0	1										
51.6		0				1	1		0											
52.9		0				0	2		1											
54.2		0				0	0													
55.5		0				1	0													
56.8		0					1													
58.1		0																		
59.4		0																		
60.7		1																		
62.0		0																		
63.3		0																		
64.6		1																		
Total	116	856	1005	1013	1025	1037	1072	958	1100	998	601	1084	1158	1069	1126	1025	783	1010	526	38

Table III. Fog-drop size distribution corrected for collection efficiency.

Drop radius (μ)	Specimen 1 (%)	2 (%)	3 (%)	4 (%)	5 (%)	6 (%)	7 (%)	8 (%)	9 (%)	10 (%)	11 (%)	12 (%)	13 (%)	14 (%)	15 (%)	16 (%)	17 (%)	18 (%)	19 (%)	20 (%)
2.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.5	0	0	9.3	8.94	18.5	18.6	15.2	22.1	21.1	21.2	20.6	23.2	9.3	17.4	12.32	20.4	12.5	10.8	25.[illegible]	0
4.8	0	0.7	4.6	7.1	7.0	5.3	7.4	12.2	12.5	12.1	22.1	8.3	8.5	17.6	19.89	15.9	22.0	11.1	7.7	34.96
6.1	0	1.0	6.8	9.0	8.6	7.0	4.9	16.5	6.4	7.71	20.7	12.37	7.5	8.6	11.85	14.5	18.2	14.0	12.9	18.42
7.4	3.9	3.8	7.9	9.0	5.6	9.3	5.6	11.2	5.1	5.47	12.3	14.5	8.8	8.3	11.58	16.9	15.3	11.7	8.0	22.73
8.7	8.4	5.3	9.9	10.91	10.1	9.5	8.6	12.0	8.5	7.71	7.02	11.4	11.6	9.7	8.67	13.2	11.7	14.5	11.5	9.35
10.0	8.4	10.9	10.6	9.24	9.1	8.3	8.9	7.2	7.7	8.51	5.54	9.0	16.2	8.1	7.84	6.9	8.1	10.1	7.5	7.23
11.3	13.6	10.2	9.9	7.93	8.9	9.6	10.1	5.9	9.8	7.55	4.85	7.7	14.1	11.8	7.72	4.95	6.4	11.1	9.4	3.50
12.6	17.5	12.6	9.3	8.83	7.4	7.4	7.9	4.3	6.7	6.78	2.22	5.8	11.7	9.0	8.08	3.32	3.2	9.66	7.5	3.86
13.9	14.3	10.5	8.1	6.32	6.1	5.5	7.2	2.7	5.8	4.67	1.34	3.2	7.8	5.6	7.1	2.23	1.1	4.61	6.4	
15.2	7.1	7.7	6.6	6.26	5.2	4.8	5.8	2.1	3.5	4.67	1.32	1.9	3.1	2.3	3.94	0.79	0.7	1.56	2.6	
16.5	11.0	7.0	5.3	4.23	3.7	4.6	3.9	1.5	3.2	2.85	0.77	1.2	0.7	0.7	1.01	0.3	0.3	0.45	0.7	
17.8	4.5	6.0	4.3	2.74	2.5	1.8	3.3	0.83	2.1	2.43	0.71	0.7	0.2	0.3	0.57	0.19	0.1	0.24	0.65	
19.1	5.2	6.8	1.8	2.08	1.3	2.2	2.5	0.37	1.6	1.77	0.22	0.2	0.1	0.16	0.39	0.16	0.1	0		
20.4	3.9	5.7	1.7	2.03	1.9	1.2	2.1	0.36	1.1	1.46	0.07	0.1	0.2	0.16	0.22	0.05	0.06	0.04		
21.7	0	3.1	1.2	1.43	1.32	1.8	1.6	0.19	1.2	1.08	0.07	0.1	0	0	0.03	0		0.04		
23.0	0.65	2.0	0.9	0.6	0.39	0.85	0.95	0.23	0.63	1.27		0	0.03	0	0.03	0				
24.3	1.3	2.3	0.2	0.54	0.49	0.44	0.6	0.075	0.46	0.69		0.03	0	0.03	0	0				
25.6		1.4	0.6	0.66	0.48	0.29	0.56	0.11	0.41	0.69		0	0.03		0.03	0				
26.9		0.35	0.4	0.52	0.096	0.29	0.35	0	0.37	0.09		0			0	0.03				
28.2		0.87	0.2	0.46	0.24	0.095	0.65	0	0.16	0.31		0			0					
29.5		0.35	0.1	0.32	0.33	0.094	0.43	0.036	0.52	0.13		0			0.03					
30.8		0.26	0.1	0.07	0.07	0.14	0.39		0.32	0.08		0			0					
32.1		0.26	0	0.07	0.092	0.14	0.13		0.16	0.13		0			0.03					
33.4		0.09	0.1	0.12	0.046	0.18	0.04		0.078	0.21		0			0					
34.7		0	0	0.12	0	0.091	0.3		0.039	0.08		0.03			0.03					
36.0		0	0	0.12	0.14	0.045	0.04		0.039	0.04										
37.3		0.09	0.06	0	0.14	0.045	0.22		0.12	0										
38.6		0.09	0	0	0.18	0.14	0		0.12	0										
39.9		0.09	0	0.07	0.045	0.045	0		0.038	0										
41.2		0.09	0		0	0	0.04		0.076	0.04										
42.5		0.09	0		0	0.045	0.09		0	0										
43.8		0.09	0.06		0	0.045	0.09		0	0										
45.1		0	0.06		0	0	0		0	0.04										
46.4		0			0	0	0.04		0	0										
47.7		0.09			0	0	0.04		0	0.04										
49.0		0.09			0.044	0	0.04		0	0.04										
50.3		0				0	0		0	0.04										
51.6		0				0.044	0		0											
52.9		0				0	0.09		0.037											
54.2		0				0														
55.5		0				0.043														
56.8		0																		
58.1		0																		
59.4		0																		
60.7		0.09																		
62.0		0																		
63.3		0																		
64.6		0.09																		
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Thus, the size distribution of the 20 specimens of fog drops was obtained, as shown in Table III. These specimens show a characteristic wide range of size distribution, especially for specimens 2-10, collected during a fog of long duration.

Liquid water content

The area concentration of fog drops can be obtained from photomicrographs like those shown in Figure 3. It is necessary to correct the area concentration for the collection efficiency as determined by the drop radius and air velocity. The volume concentration of the drops can be obtained from the area concentration and the length of airstream sampled. The liquid water content (LWC) can be computed from the drop radius r_i and the concentration n_i:

$$LWC = \frac{4\pi}{3} \rho \sum_{i=0}^{\infty} n_i r_i^3$$

where ρ is the density of the water drop. The mean radius, drop radius range, and the most frequently occurring radius of the Barrow fog drops are given in Table IV.

Table IV. Characteristics of summer fog at Barrow, Alaska.

Specimen	Concentration (drops/cm^3)	LWC (g/m^3)	Drop radius (μ) Range	Mean	Most frequent
1	0.5	0.006	6.8-24.9	13.6	12.6
2	0.4	0.009	4.2-65.4	15.0	12.6
3	2.7	0.028	3.3-45.8	11.2	10.0
4	2.5	0.026	3.3-40.5	10.9	8.7
5	4.9	0.083	3.3-49.7	13.5	3.5
6	6.5	0.12	3.3-56.2	13.5	3.5
7	5.2	0.071	3.3-57.5	11.2	3.5
8	4.6	0.032	3.3-30.2	10.4	3.5
9	8.2	0.15	3.3-53.6	13.7	3.5
10	7.4	0.070	3.3-50.3	9.6	3.5
11	4.1	0.009	3.3-22.3	6.7	4.8
12	19.6	0.065	3.3-35.3	7.7	3.5
13	14.0	0.067	3.3-26.2	9.3	4.8
14	24.2	0.089	3.3-24.9	8.1	4.8
15	21.1	0.089	3.3-35.4	8.3	3.5
16	18.6	0.043	3.3-27.5	7.0	4.8
17	14.7	0.033	3.3-21.0	7.1	7.4
18	13.9	0.050	3.3-22.4	8.4	8.7
19	9.5	0.034	3.3-18.4	7.9	3.5
20	0.4	0.0007	4.2-13.2	6.9	4.8
Mean	9.2	.054	3.6-36.0	10.0	5.8

Attenuation coefficients

The optical properties of fog can be determined from the Mie theory of scattering. The Mie theory is an exact theory for a monochromatic wave which impinges upon a fog drop of any known size and index of refraction. The magnitude of the spectral attenuation coefficient b depends upon the wavelength of the light and the size distribution, concentration, and complex index of refraction of the fog drops:

$$b = \sum_{r_{min}}^{r_{max}} n(r)\ \delta r \pi r^2\ K_{ext}\ (x,m)\ \ [\text{meter}^{-1}]$$

$$m = n - ik$$

where:

$n(r)$ = the number of fog drops per unit volume per δr radius interval

x = $2\pi r/\lambda$, drop size parameter

m = complex index of refraction

n = real part of the refraction index

k = imaginary part of the refraction index

K_{ext} = total extinction cross section.

The K_{ext} values are obtained for complex indices of refraction m and drop size parameters x (Penndorf and Goldberg 1956, Twomey and Howell 1965, Irvine and Pollack 1968).

Optical attenuation coefficients were computed for the observed Barrow fog for optical wavelengths of 0.571 μ and 1.06 μ using the Mie theory. The calculations were made for the concentrations shown in Table IV and the size distributions shown in Table III. The attenuation coefficients b (m^{-1}) of the Barrow fogs are presented in Table V. The optical wavelengths of 0.571 μ and 1.06 μ are those corresponding to atmospheric windows. The attenuation coefficients for 0.571 μ wavelength were found to be smaller than those for 1.06 μ wavelength.

Table V. Attenuation coefficients and visual ranges of summer fog at Barrow, Alaska.

Specimen	*Attenuation coefficient*		Visual range
	$b(m^{-1})$ for 0.571 μ	$b(m^{-1})$ for 1.06 μ	m (for 0.571 μ)
1	6.20×10^{-4}	6.44×10^{-4}	4830
2	6.41×10^{-4}	6.66×10^{-4}	4670
3	2.62×10^{-3}	2.71×10^{-3}	1145
4	2.38×10^{-3}	2.45×10^{-3}	1260
5	4.19×10^{-3}	4.40×10^{-3}	715
6	5.73×10^{-3}	5.90×10^{-3}	520
7	5.66×10^{-3}	5.69×10^{-3}	530
8	2.10×10^{-3}	2.19×10^{-3}	1425
9	6.73×10^{-3}	6.91×10^{-3}	445
10	6.05×10^{-3}	6.21×10^{-3}	495
11	1.44×10^{-3}	1.50×10^{-3}	2085
12	9.08×10^{-3}	9.49×10^{-3}	330
13	8.78×10^{-3}	9.24×10^{-3}	340
14	1.21×10^{-2}	1.28×10^{-2}	245
15	1.15×10^{-2}	1.21×10^{-2}	260
16	6.96×10^{-3}	7.30×10^{-3}	430
17	5.47×10^{-3}	5.74×10^{-3}	550
18	7.19×10^{-3}	7.59×10^{-3}	415
19	4.56×10^{-3}	4.88×10^{-3}	655
20	1.37×10^{-4}	1.45×10^{-4}	21915

The visual range is defined as the distance V_m at which the threshold contrast is 5%:

$$\exp(-b V_m) = 0.05$$

$$V_m = \frac{2.996}{b}$$

where b is the attenuation coefficient of the atmosphere at the time and place. The calculated visual ranges for the Barrow fogs are presented in Table V. The values of the visual range calculated at a threshold contrast of 5% were closer to the observed visibility than those at a threshold contrast of 2%.

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