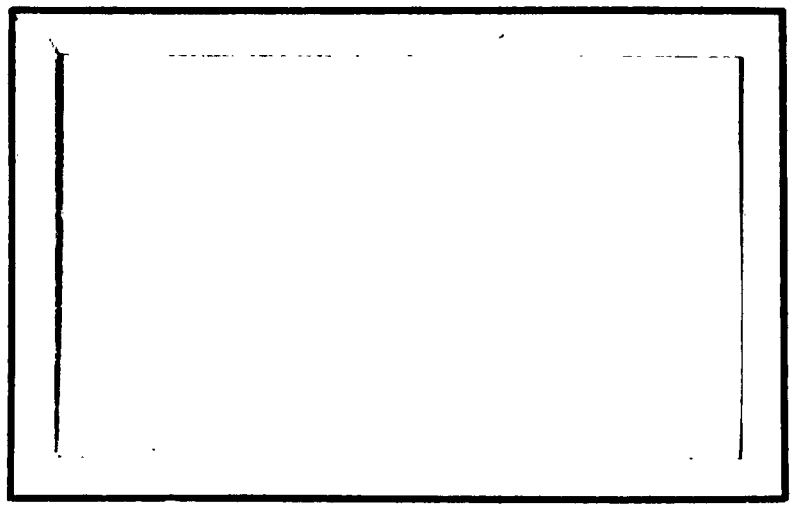
# WOODS HOLE OCEANOGRAPHIC INSTITUTION





WOODS HOLE, MASSACHUSETTS

WOODS HOLE OCEANOGRAPHIC INSTITUTION

Woods Hole, Massachusetts

Reference No. 52-34

# SEA-SALT NUCLEI STUDIES

conducted during the period

January 1, 1952 - March 31, 1952

Periodic Status Report No. 4
Submitted to Geophysics Branch, Office of Naval Research
Under Contract N6onr-27711 (NR-085-001)

April 1952

APPROVED FOR DISTRIBUTION _____
Director

The Contractor shall furnish the necessary personnel and facilities for and, in accordance with any instructions issued by the Scientific Officer or his authorized representative, shall conduct research on the practical aspects of atmospheric sea-salt nuclei, which shall include, but not necessarily be limited to, the following:

(1) role of atmospheric sea-salt nuclei in the formation of rain with emphasis upon the relationship between weight and number of nuclei and the occurrence of rain;

(2) distribution of airborne sea-salt as a factor in the corrosion of structual steels, the primary investigation to determine how far inland sea-salt is carried by the winds, and the rates at which it is deposited on exposed structures; and

(3) determination of the water vapor pressures over concentrated sea water at lower temperature, and the study of super saturation of droplets of concentrated sea water.

## Table of Contents

## PART I

### ATMOSPHERIC SALT IN HAWAII (A. H. Woodcock)

During this period A. H. Woodcock and D. C. Blanchard were in Hawaii, participating in the Cloud Physics Project of the Pineapple Research Institute, the Hawaiian Sugar Planter's Ass'n., the Territorial Cattlemen's Council, and the U. S. Weather Bureau.

As indicated in Periodic Status Report No. 3 (W.H.O.I. Reference No. 52-14) the tentative goals during this trip to Hawaii are as follows:

1. To collect further data concerning the relationship between the numbers of large salt particles in the air and the occurrence of rain on Oahu (see first results during June 1951, W.H.O.I. Reference No. 51-87).

2. To aid full-time members of the project in setting up a routine daily sampling of atmospheric salt with the objective of studying the long-term variations of the amounts of salt and of rainfall.

3. To make specific tests of the general relationship between atmospheric salt and rain drops, which was proposed in W.H.O.I. Reference No. 51-71. These tests will involve sampling airborne salt particles and at the same time and in the same area determining the size and chlorinity of rain drops at the base of rain-producing clouds.

4. To take part in seeding experiments in which water, sea water, salt or other finely divided particles will be introduced into warm trade wind cumulus clouds.

Airborne salt samples have now been taken during a total of thirty days in June and December 1951 and January and February 1952. Other data needed to relate the quantities of atmospheric salt present on these days to rainfall on Oahu are now being assembled and studied. This work will be reported at a later date.

Wind force during the thirty sampling days varied from one to seven. From the large number of salt-particle samples taken, variations in the distribution of salt with increasing wind force has been derived. Figure 1 shows smoothed distribution curves for wind forces 1 through 7, obtained at cloud levels in the trade winds of Hawaii. The line representing the distribution of salt at wind force 12 was derived from

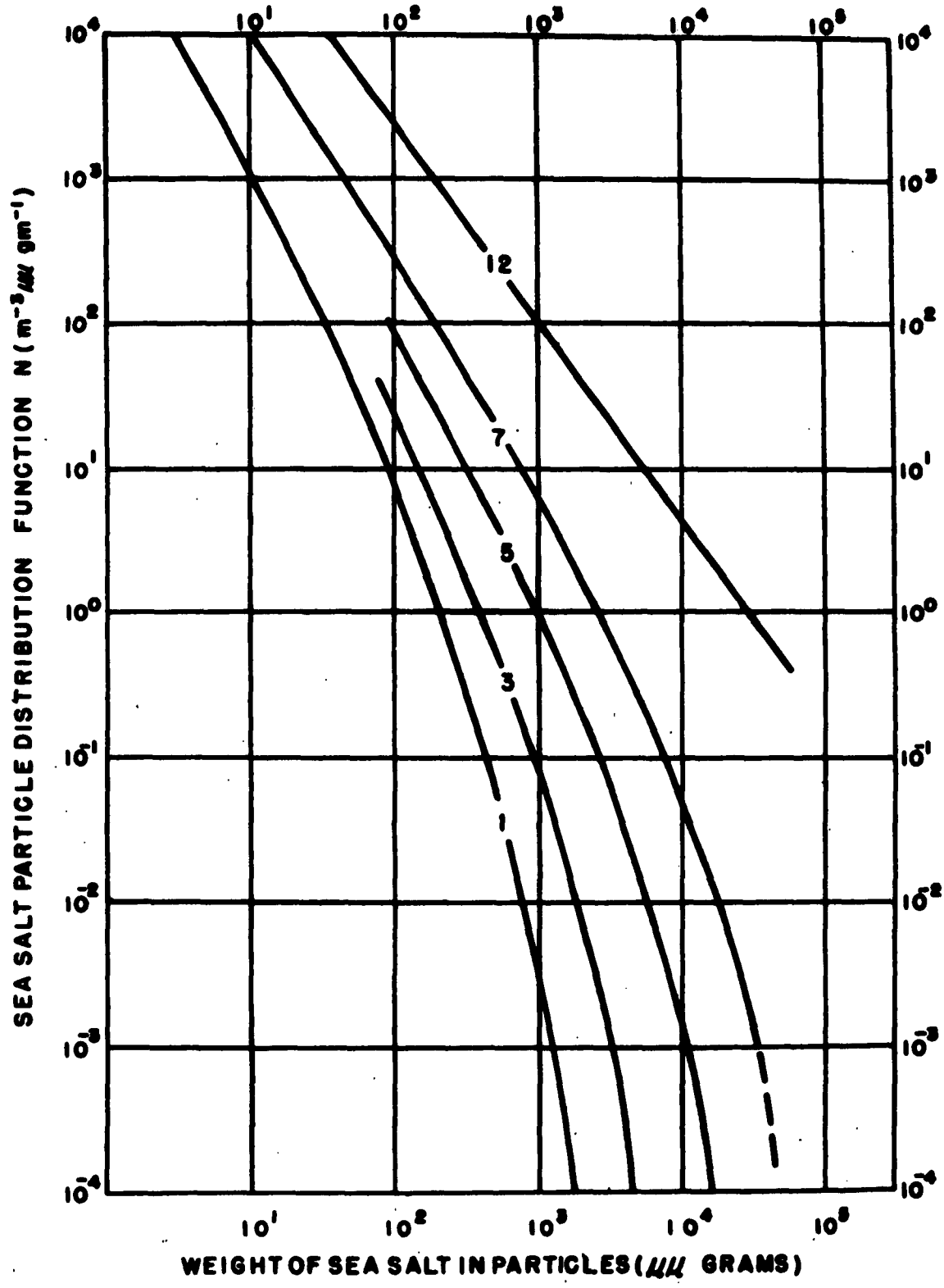



FIG. 1 Variations in the distribution of sea salt particles at cloud levels over the sea with increasing wind force (1 thru 7).

The distribution with force 12 wind was obtained in Florida, during a tropical storm.

samples taken nearer the sea surface during a tropical storm in southern Florida and is included here to suggest the probable maximum amount of salt to be expected in oceanic air over warm seas.

As will be seen later in this report, Figure 1 is useful in attempting to explain the chlorinity and the drop size distribution of local rains in terms of the number and size of the salt particles present at cloud levels. It is expected that the distributions shown on this figure will prove to be characteristic of trade wind areas similar to Hawaii. It would be very interesting to obtain distribution curves characteristic of winds over cold seas.

On one of the thirty sampling days salt particle measurements were made in the sub-cloud layer, the cloud layer and near the bottom of the trade wind inversion layer (see the study of other aspects of these layers by Riehl and others, 1951). Figure 2 shows a decreasing quantity of salt in ascending through these characteristic layers of the lower trade wind atmosphere. This decrease is somewhat comparable to that which occurs with decreasing winds at relatively constant level at the top of the sub-cloud layer (see Fig. 1). The distributions shown on Figure 2 were obtained on a day with force 3 winds. Later, we hope to sample salt in the three layers of the trades during higher winds. It is expected that the maximum range of distribution in the vertical will prove to be similar to that associated with changes in wind force (Fig. 1).

Figures 1 and 2 are important because they indicate the large differences in the salt-particle content of the ambient air in which local clouds form as the altitude is varied and as the wind force changes with time.

A filtering method of sampling airborne salt has been devised by the meteorology group and a routine daily measure of chlorides is being initiated. Our contribution to this work has so far been almost entirely advisory.

As mentioned in Periodic Status Report No. 3 (W.H.O.I. Reference No. 52-14), samples of rain were taken within clouds on a mountain side for the determination of drop size distributions and chlorinities at various rain intensities. It is necessary for our purposes to sample rains at cloud levels because of the evaporation and accretion processed which modify the chlorinity and intensity of rains as they fall from base to ground (see "Precipitation Studies" by D. C. Blanchard, Periodic Status Report No. 3 W.H.O.I. Reference No. 52-14).

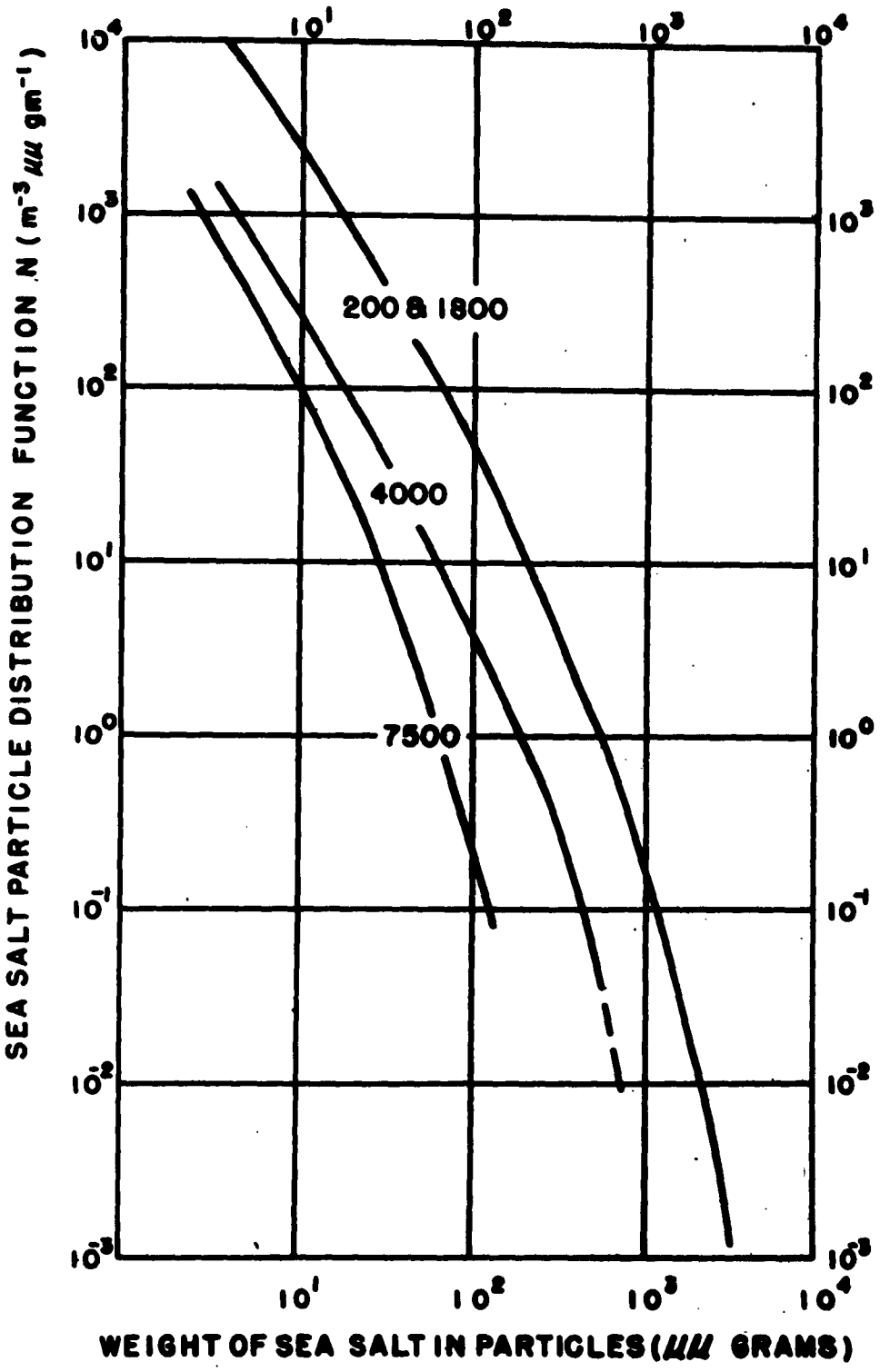



FIG. 2 Distribution of sea salt particles at various altitudes (200, 1800, 4000 and 7500 ft.) over the sea in the Hawaiian area. Wind force 3. Scattered cumulus clouds, with bases at 2100 ft. Base of trade-wind inversion at about 7000 ft.

The above chlorinity and drop distribution samples were taken in order to test the hypothesis proposed by Woodcock (1951) that the larger sea-salt particles in the air become rain drops in clouds. This hypothesis requires that the salt content of rain decrease with intensity and that the observed distribution of rain drop size at different rain intensities be similar to the size distribution of the atmosperhic salt particles at concentrations of salt and water similar to those actually measured in the rain waters concerned.

Figure 3 shows the measured chlorinity and rain intensity values derived from rain water samples taken during the same period of time as were the rain drop size samples (Fig. 4). These samples of rain are in each case regarded as inadequate, primarily because of the small number of observations represented at the higher rain intensities (see Figs. 3 and 4). However, the magnitude of the values given seem to support the hypothesis that each rain drop is formed on a large salt particle.

During the three-day period when the rain samples were taken, we were unable to make the airplane flights necessary to sample airborne salt and to estimate wind forces at sea. However, using the pibal wind speed observations at 3000 feet during this period (18 to 30 knots), an estimate of force 4 to 6 was obtained for winds over the sea. With this estimate of force, we can use the curves on Figure 1 which give the distribution of salt particles at these wind forces.

Assuming a salt particle distribution characteristic of force 4 winds (see Fig. 1), what concentrations of salt and water must be assumed in order to obtain rain drops of about the size and number actually sampled in the rain cloud (see Fig. 4)? Curve 4 on Figure 3 represents the salt concentrations necessarily assumed in deriving the computed rain drop distributions shown on Figure 5 from the salt particle distribution curve for force 4 winds (interpolated from Figure 1). Similarly, curve 6 on Figure 3 represents the salt concentrations necessarily assumed if the salt particle distribution with force 6 winds (interpolated from Figure 1) is used in deriving the computed rain drop distributions shown on Figure 5. These computations are similar to those already described in W.H.O.I. Technical Report No. 14, Reference No. 51-71, 1951.

It is very suggestive that the assumed distribution curves on Figure 3 lie mostly within the area of observed rain chlorinities and intensities, though it is somewhat disturbing that the salt content of the rains show no systematic variation

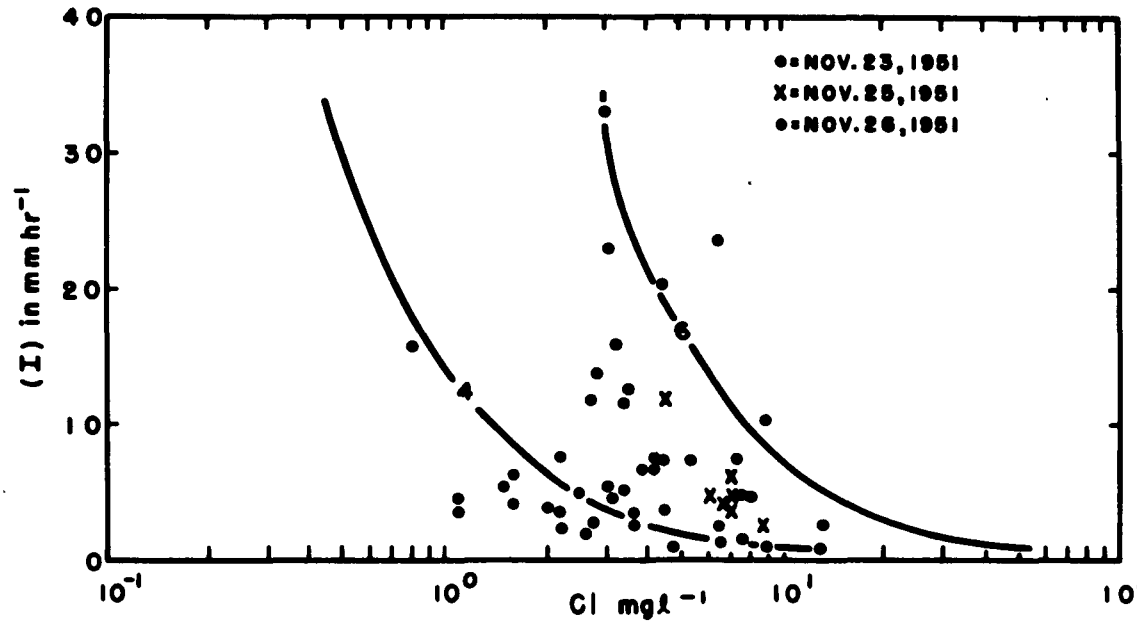



FIG. 3 In this figure, the symbols represent the chlorinities of rains of various intensities which were sampled within an orographic cloud at the 3000 ft. level on the windward slopes of a mountain.

The samples were taken between the hours of 1100 and 1600, during three days. The curved lines represent assumed variations of chlorinity with changing rain intensity at wind forces 4 and 6.

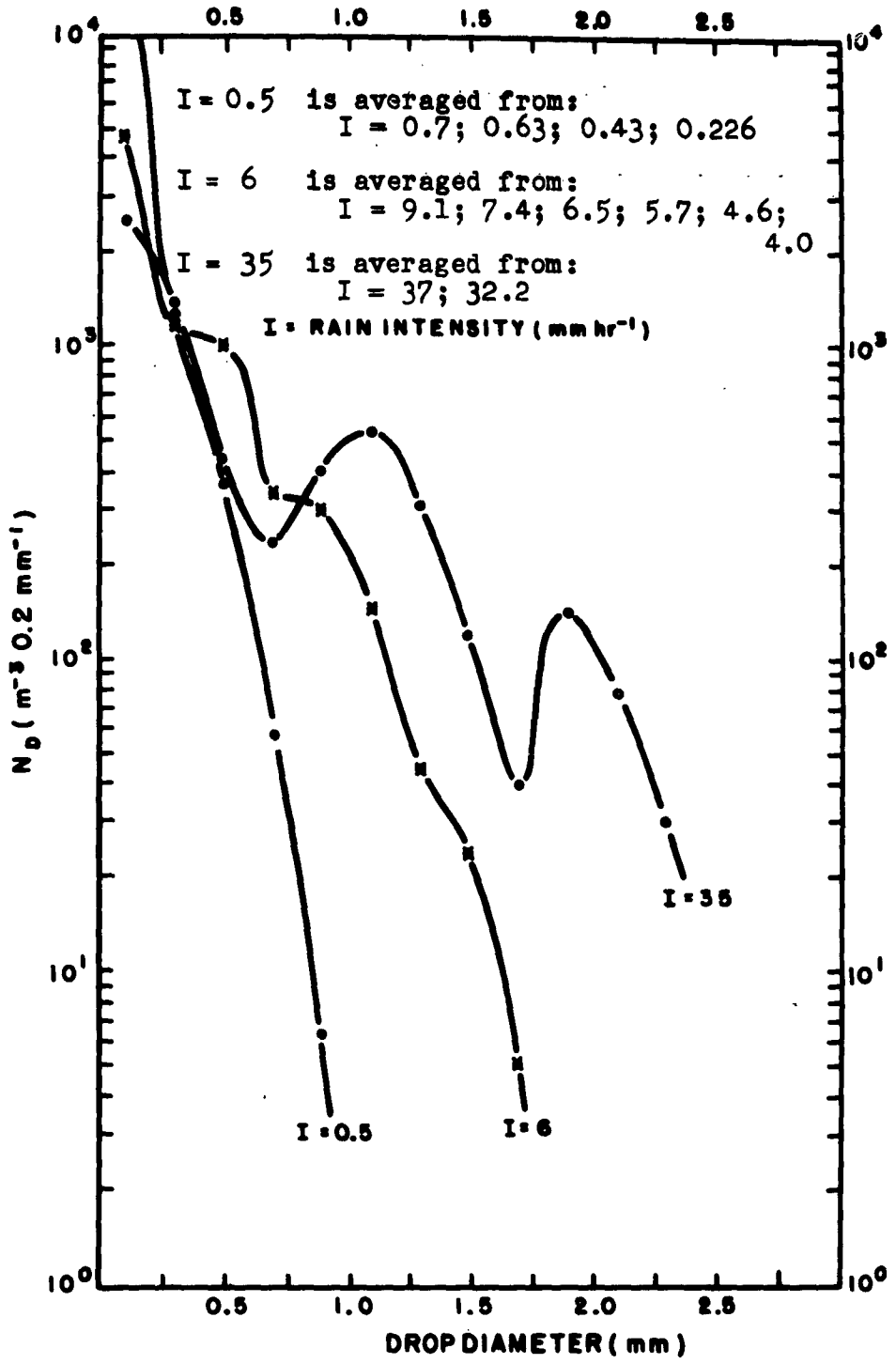



FIG. 4 Rain drop size distributions at averaged intensities. These values were derived from 12 filter-paper samples taken Nov.23, 25, and 26, 1951 in the clouds on a mountain slope.

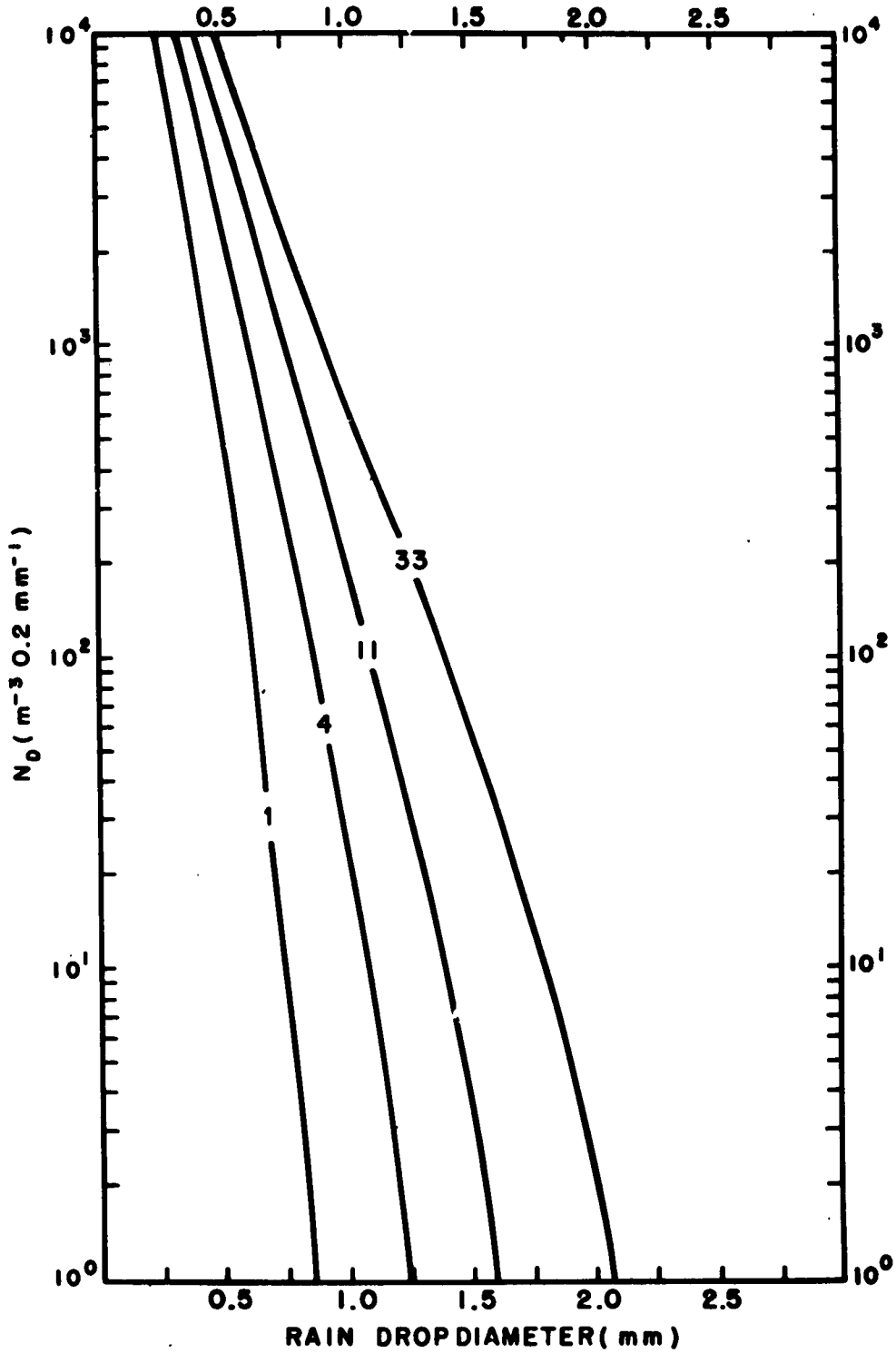



FIG. 5 Rain drop size distributions and rain intensities computed from the atmospheric salt particle distributions at wind forces 4 and 6 (interpolated from FIG. 1 ) using the salt concentrations given at similar intensities by curves 4 and 6 on FIG. 3.

with intensity, such as that given by the two curves. However, in orographic clouds, precipitation occurring before the cloud arrives at the sampling position would tend to lower the salt content of rains which subsequently fell from this cloud. Also, changes in rain intensity were observed during the time when the rain water samples were taken. These changes can also modify the intensity-chlorinity relationships.

The computed and measured values on Figures 3, 4 and 5 are tentatively regarded at this time as evidence that the larger sea-salt particles are the nucleus upon which rain drops form in warm clouds. Recent improvements in the methods of sampling rains for drop size distribution, for intensity and for chlorinity should remove much of the uncertainty in these measurements.

During March the project made a field trip to Hawaii to test the 10 cm portable radar equipment. It was found that the radar could track a spray plane into a cumulus cloud and then was able to indicate the growth and subsequent evaporation of the cloud of sea water spray drops released. No systematic attempt was made at this time to produce rain in the clouds.

On several airplane flights over the Big Island (Hawaii) samples were taken of airborne sea salt. A brief study of these samples suggests that the great mountains of Mauna Kea and Mauna Loa cause masses of air from above the inversion to be forced down into the cloud and sub-cloud levels.

## PART II

## PRECIPITATION STUDIES (D. C. Blanchard)

### A. The Transient Nature of Drop Size Distribution.

In the last Periodic Status Report, which covered the work from October 1, 1951 through December 31, 1951, the disadvantages of sampling rain several hundred meters beneath the cloud base were discussed. It was shown that the evaporation of the rain in the sub-cloud layer leads to erroneous drop size distributions and the accretion of atmospheric salt particles with rain gives increased values of Cl in the rain water. As both drop size distribution and rain water Cl content play an important role in the hypothesis that airborne salt particles are the nuclei for rain drops, it is necessary to eliminate or else evaluate the magnitude of these errors. The ever-changing atmospheric conditions make it extremely difficult to calculate these errors. Therefore, it becomes necessary to carry out the field measurements and observations at cloud base which means, of course, that the several hundred meters of sub-cloud fall is eliminated.

There is yet another reason why drop size determination should be made as near to the cloud base as possible. A given distribution of drops in a $m^{-3}$ at cloud base will be entirely different when these drops reach the ground. For example, suppose the drops in a $m^{-3}$ at cloud base range in size from 200 to 2000$\mu$. If it is 1000 m. to ground level, a fall time of about 2.5 minutes is required for the larger drops while the smaller drops will be 22.5 minutes and 890 meters behind. Thus, the distribution will be "spread out" and be transient for the first 22.5 minutes. At the end of this time a steady state condition will be established where the drop distribution is the same as that at cloud base. This, of course, is contingent on the fact that the drop size distribution at cloud level had reached and held the steady state during the preceding 22.5 minutes. Going to the actual case where drops of all sizes exist, the complexity of the transient state becomes apparent.

As the intensity in Hawaiian rains seldom remains constant for more than a few minutes at a time, drop distributions obtained far beneath cloud base cannot be representative of that at cloud level. It may be argued that even the distribution at cloud level is transient. This, admittedly, may often be true. However, the time required toreach the steady state is considerably less than at ground level.

These transient conditions in drop size distributions are naturally most noticeable in rains characterized by rapid changes in intensity. Eight measurements of drop size distribution made in the thunderstorm of February 11, 1952, at Honolulu, T. H., clearly show this effect. Figure 6, a plot of number of drops $m^{-3}$ $mm^{-1}$ spread in diameter, clearly indicates the relatively high numbers of large drops in the samples obtained in the first few minutes of the storm. These large drops of about 2.9 mm diameter, appeared nine minutes before any drops as small as 0.3 mm appeared. The absence of these small drops, which make up the majority of the total number of drops $< 1$ mm, is apparent in the three lower curves in Figure 6. It is reasonable to suppose that these three curves represent a highly transient condition; i.e., the time lapse of nine minutes until the first small drops appeared. If one assumes a fall distance of 700 m from cloud to ground (reasonable for Hawaiian clouds), it is found that the 0.3 mm drops will require 8.3 minutes more fall time than the 2.9 mm drops. The 8.3 minutes agrees with the observed time lapse of nine minutes before the occurrence of small drops.

Figure 7 further demonstrates the behavior of the transient drop size distributions. This is a plot of liquid water content, W, ($mm^3$ $m^{-3}$) against intensity. For a given liquid water

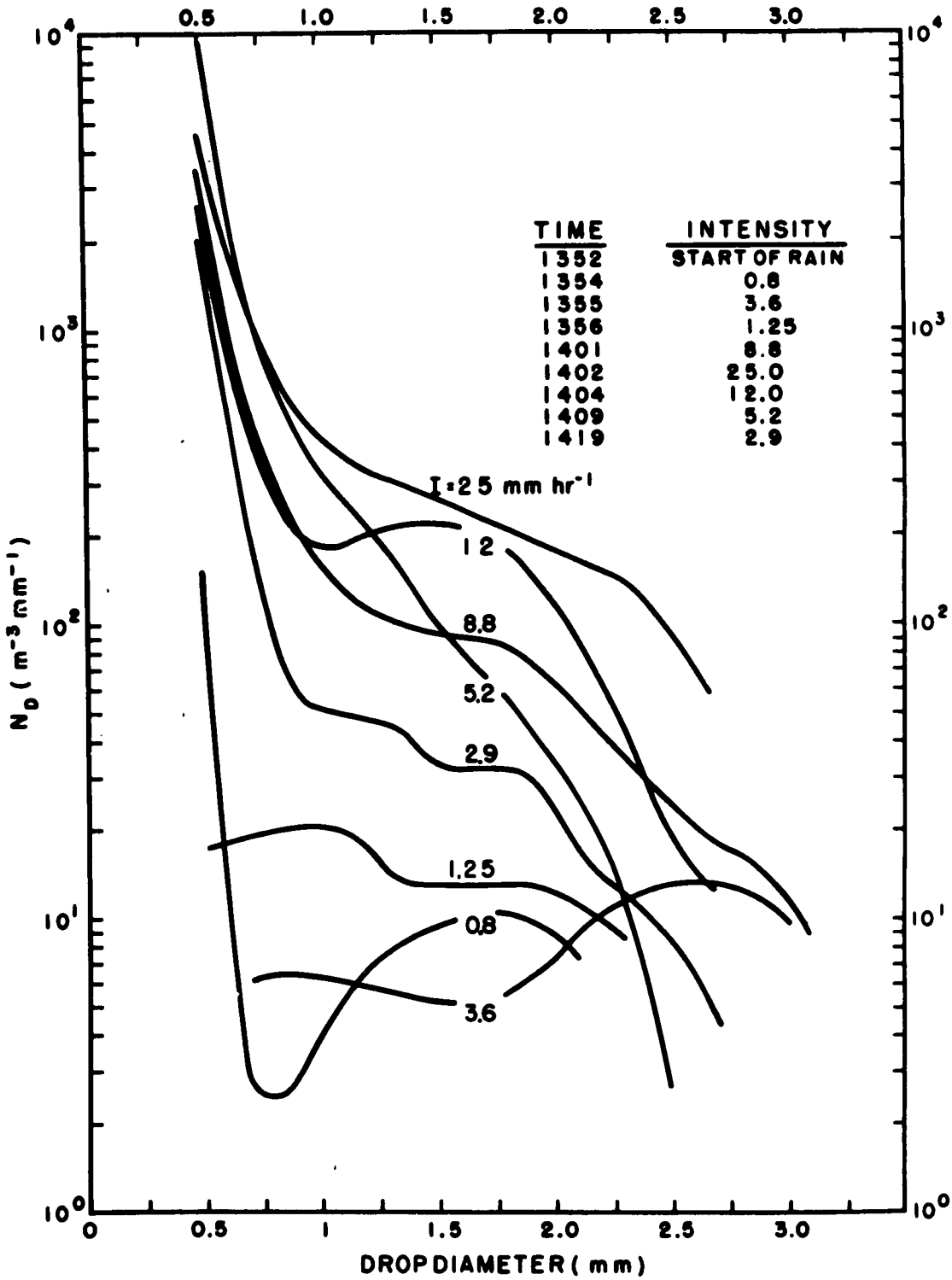



FIG. 6 Distribution function of drop sizes in thunderstorm of Feb. 11, 1952 at Honolulu, T.H.

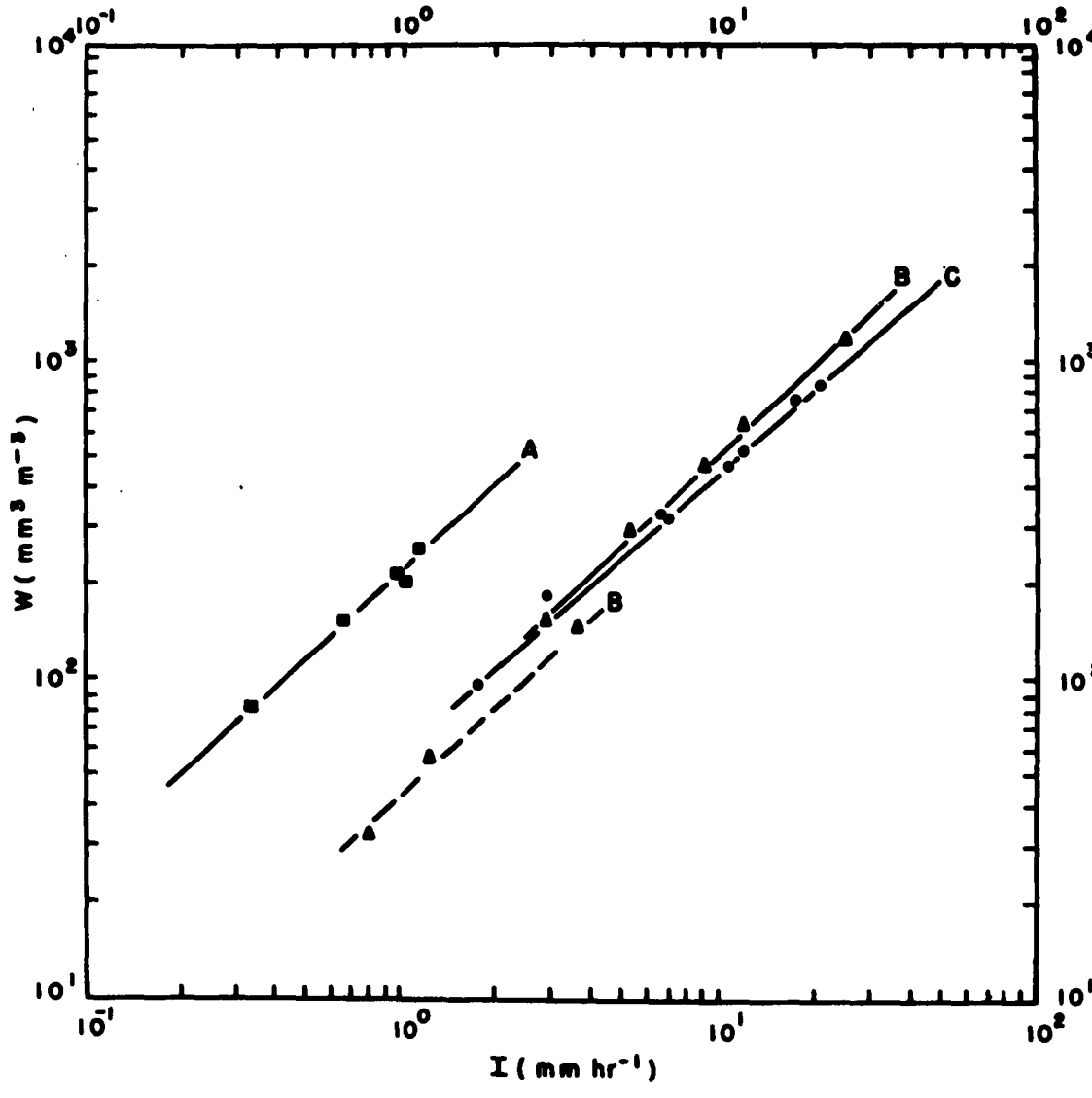



FIG. 7 A -- Sample obtained in orographic cloud on side of Mauna Kea; Mar. 1952.

B -- Sample obtained several hundred meters beneath base of thunderstorm at Honolulu; Feb. 11, 1952.

C -- Sample Obtained several hundred meters beneath base of Kona type storm at Honolulu; Jan. 19, 1952.

content the intensity will be a function of the size and number of drops in the distribution. For example, if a specified volume of water $m^{-3}$ is contained in drops of 2 mm it will fall much faster and, therefore, give a higher intensity of rainfall than the same volume of water in drops of 1 mm. Thus, the first three samples taken in the February 11 thunderstorm (the samples with a majority of large drops) show higher than average intensities for their indicated liquid water contents. These three samples, connected by the dotted line, are in direct contrast with the remaining five samples, which show a near linear (slope = 0.93) relationship and a relatively higher liquid water content.

B. Liquid Water Content as an Aid in Evaluating Drop Size Measurements

In the process of evaluating the data obtained from the filter papers, calculations were carried out to obtain the number of drops $m^{-3}$ for each 0.2 mm interval. From this it was a relatively easy step to arrive at the amount of liquid water per $m^{-3}$ expressed in $mm^3$. It was pointed out in the preceding section that non-representative or transient drop size distributions can be identified by means of a graph of liquid water vs. intensity. This type of graph has also proved useful in bringing out fundamental differences which exist in rains from various storms and different locations. Curves A and C of Figure 7 show the limiting values that have been found to date. It is indeed gratifying to find that different rains give unique W vs. I relationships. The only other data that could be found in the meteorological literature indicated that the W vs. I curve was the same, or nearly so, for all rains (Best, 1950). These data have been presented in the form of a single curve which is a composite of most of the published drop size distributions to date. This curve falls in the region of curves B and C of Figure 7. The fact that the present data show a variety of curves is in accordance with the idea that rain from warm clouds is, in part, a function of the size distribution of the initial hygroscopic nuclei which, in themselves, vary greatly both in size and number.

## PART III

## GROWTH RATE MEASUREMENTS (C. H. Keith)

During the past quarter an apparatus for the measurement of growth rates of salt nuclei has been constructed and some data have been obtained. Attempts have been made to correlate

this data with a modified form of the theoretical expression presented in the last Periodic Status Report (W.H.O.I. Reference No. 52-14). These met with no success and indicate that further data are needed to understand the processes taking place in the growth of atmospheric salt nuclei.

The apparatus constructed during the quarter is different from previous instruments used in salt nuclei studies, in that it overcomes the problem of changing the relative humidity around the salt nucleus by blowing air of a known constant humidity past the nucleus, rather than by introducing solutions of known vapor pressure near the drop and allowing the surrounding air to come to equilibrium with these solutions. A supply of air of known humidity is obtained by pumping room air at constant pressure through a two-leg system. One leg is a gas bubbler filled with warm water, the effect of this treatment being to supply air of 100% RH to a mixing chamber. The other leg consists of a needle valve and a drying tower, this leg also leads directly to the mixing chamber. By varying the needle valve setting air of any desired humidity can be obtained in the mixing chamber. This air is then led out through either a small chamber containing the salt nuclei suspended on spider webs or through a by-pass to a stationary psychrometer, and finally to a flow meter. The measuring chamber is mounted on a microscope stage to permit diameter measurements. Briefly, the method of measurement consists of measuring the humidity of the air stream with the by-pass open and the chamber filled with dry air, then switching to the chamber and obtaining drop diameter readings as a function of time. After the equilibrium diameter has been reached a flow measurement is taken (the purpose of this is to obtain a value of the velocity of air past the drop), and finally the system is switched back to the by-pass and a check on the humidity of the air stream is obtained.

The data obtained with this apparatus are as yet not very extensive, but in general indicate that the growth rate is primarily a function of drop size and relative humidity, as is expected. As yet not enough data have been collected to obtain an idea of the effect of velocity of air flow past the drop, or to obtain exact empirical relationships between the growth rate and the primary factors mentioned above. However, the curves seem to generally conform to the relationship

$$\log \frac{r_{eq} - r}{r_{eq} - r_o} = -Bt^{1/2}$$

$r$ = radius at time $t$
$r_{eq}$ = final radius, $t = \infty$
$r_o$ = initial radius, $t = 0$

where B is roughly a function of the humidity. Further data will clarify this empirical relationship especially if their

reliability is increased by repeated runs maintaining all factors constant. At present the limitations on this measurement are in the measurement of diameter and of humidity. The former can be improved by repeated runs, and the latter has been improved by substituting a thermocouple and recording potentiometer for thermometers in the measurement of the difference between the dry and wet bulb temperatures..

The theoretical expression outlined in the previous report has been modified to include heat effects, which are bound to be of greater importance than atmospheric diffusion and gives rise to an expression as follows:

$$\frac{h\ell M}{(1-h)RT_0^2}\, r_{eq}^2\, (A-A_0) - \left\{\frac{(1+h)}{(1-h)}\frac{\ell M}{2RT_0^2} + \frac{1}{T_0}\right\}\frac{r^2-r_0^2}{2} = \frac{\alpha}{\ell\rho_s}\, t$$

where $A = \frac{1}{6}\log_e \frac{f^2+f+1}{f^2-f+1} - \frac{1}{\sqrt{3}}\tan^{-1}\frac{2f+1}{\sqrt{3}}$

where $r$ = radius in $\mu$ at time $t$

$r_{eq}$ = radius at $t = \infty$ in $\mu$

$r_o$ = radius at $t = 0$ in $\mu$

$f = r/r_{eq}$

$h$ = relative humidity %/100

$\ell$ = heat of condensation at water vapor = 540 cal/gm

$M$ = molecular weight of $H_2O$ = 18 gm/mole.

$R$ = gas constant = 3 cal/mole. degree Kelvin

$T_o$ = initial temperature of drop and surroundings in degrees Kelvin

$\alpha$ = coefficient of heat conductivity in cal/cm sec°K

$\rho_s$ = density of solution $\cong$ 1 gm/cm$^3$

However, this expression gives rise to growth rate times of approximately 1 order of magnitude less than those experi-

mentally observed, and this discrepancy indicates either that some of the approximations used are invalid or that other processes are playing a dominant role.

REFERENCES

Best, A. C.: The size distribution of raindrops. Quarterly Journal of the Royal Met. Soc., 76, pp. 16-36, 1950.

Riehl, H., and others: The north-east trade of the Pacific Ocean. Quarterly Journal of the Royal Met. Soc., 77, pp. 598-626.

Woodcock, A. H.: Atmospheric salt particles and raindrops. Tech. Rept. No. 14, W.H.O.I. Ref. No. 51-71.