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The Productiveness of Fog Precipitation in Relation to the Cloud Droplet Spectrum

JOHANNES GRUNOW

Deutscher Wetterdienst, Meteorological Observatory Hohenpeissenberg, Germany

*important comments re Camanchaca

Abstract—On Mount Hohenpeissenberg in Upper Bavaria (975 m NN) the atmospheric offer of fog precipitation is measured by a cylindric net of wires of 0.1 mm diameter, for which a nearly constant relation of deposit amount to wind velocity is found. The amount of deposited fog precipitation depends on (1) locality and exposition of the gage, and (2) weather situation. The efficiency of polar cold air, characterized by dominating small diameters of cloud droplets from 2 to 15 μ, is scanty. Increasing productiveness results, when maritime warm air masses from temperate or subtropical zones pass. The cloud droplet spectrum is then characterized by a broader range of 4 to 25 μ diameter, with a maximum frequency from 8 to 14 μ. The deposits are heaviest with amounts of 2 to 3 mm/hr when persistent cloud decks form on the windward side of the Alps. The air masses have then often degenerated by continental influence. The droplet spectrum indicates a wide range from 5 to 60 μ with a maximal frequent diameter of 12 to 18 μ.

Introduction—Cloud air streaming against an obstacle precipitates a part of cloud droplets. The deposit on trees is known as fog drip or in freezing weather is visible as rime. In flat land the fog deposits are just sufficient for wetting needles and leafage. But in mountain regions, which rise at times into the cloud space, and in coastal mist belts, where moist-warm air passes from sea to land, considerable amounts of additional water by fog drip can be expected.

Measuring method—The atmospheric potential of fog precipitation can be comparably measured with a specific fog gage as suggested by *Tabata* and coworkers [1955] for the research of sea fog on the coast of Hokkaido, Japan, and by the author [*Grunow*, 1952] for studying the productiveness of fog precipitation in mountain forests. Both types of fog collectors use the same principle, a system of wires. The Japanese pattern is that of a cylindrical wire screen; the German pattern that of a cylindrical wire net (Fig. 1). The effect of these gages is found in the theory of the dust filter derived by Albrecht. The amount M of deposit on cylinder, in case of the fog gages on each single wire, is given by

$$M = FvWtC$$

It depends on the diameter and length of the wires through the factor F, velocity of wind v, water content of fog W, time of deposit t, and an efficiency factor C which is influenced by the diameter of the wire, the diameter of droplets, and the wind velocity. The most favorable re-

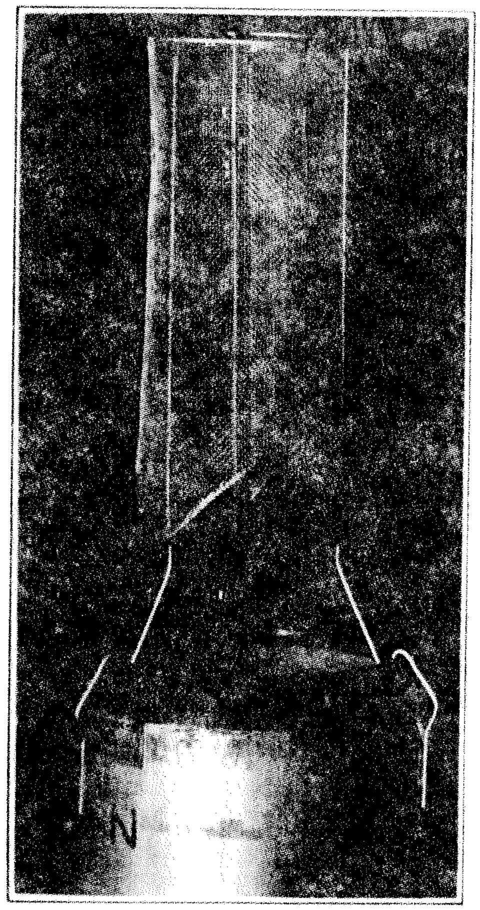

FIG. 1—View of the Hohenpeissenberg fog-collector; the cylindrical wire-net is mounted on a normal rain gage 10 cm in diameter

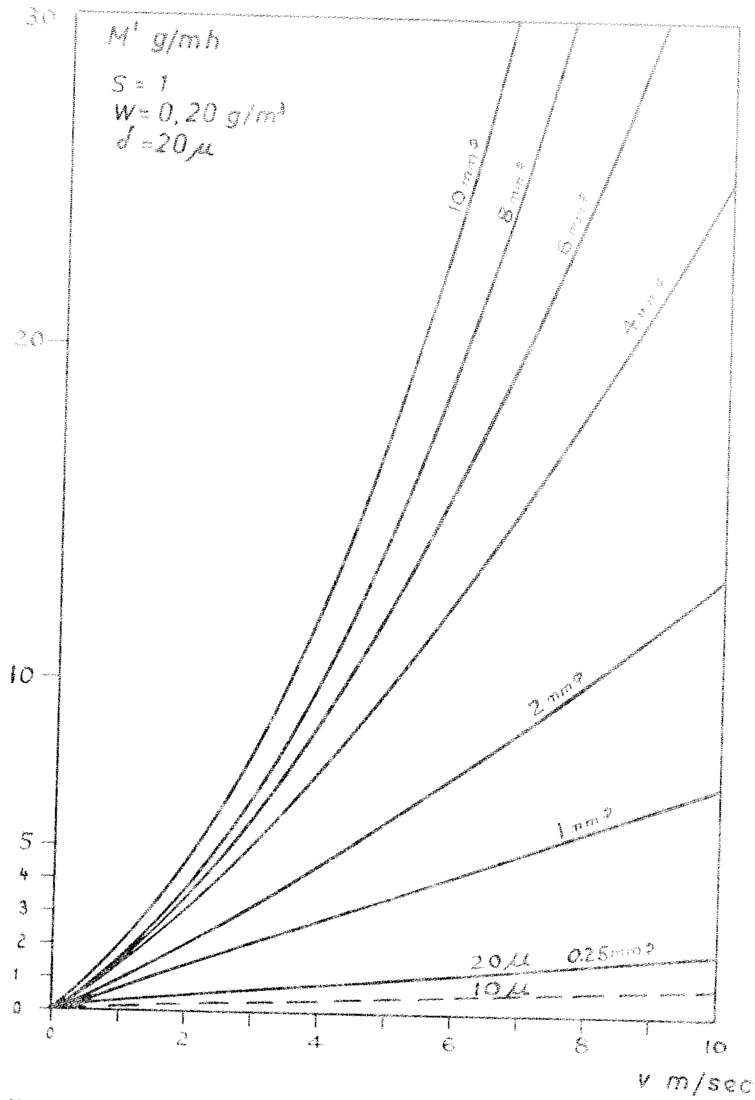

Fig. 2—Dependence of the amount of water deposit M' on the wind-velocity v, for various wire diameters at a cloud-droplet diameter of 20 μ

lation of fog droplet collection to possible amount in clouds is obtained when the diameter of the wire is a minimum. The condition of constant relation of deposit amount to wind velocity is nearly attained with wire-diameters of 0.1 mm (German pattern) and 0.12 mm (Japan pattern) (Fig. 2).

Factors influencing the amount of deposit—The amount of deposited fog precipitation, aside from the efficiency of the wire system, depends on (1) the locality and exposure of the gage, and (2) the weather situation. The locality factor is specified by the height above sea-level, the continentality (distance from sea), and the exposure to the fog-producing air currents, especially on windward slopes. These effects are demonstrated for several mountains of Germany in Figure 3 [*Grunow*, 1958]. The measurements on Table Mountain (Tfb) South Africa, very critically evaluated by *Nagel* [1956], showed rainfall of 1940 mm and additional fog precipitation amount of nearly 3300 mm in 1954. The fog precipitation was 170% of the rainfall.

Increasing amounts of fog precipitation are dependent on the weather situation. It is not only the direction and velocity of the depositing air current, but also the origin of the operating air mass, which influences the production of fog precipitation. The heaviest deposits occur where maritime warm air-masses from temperate or

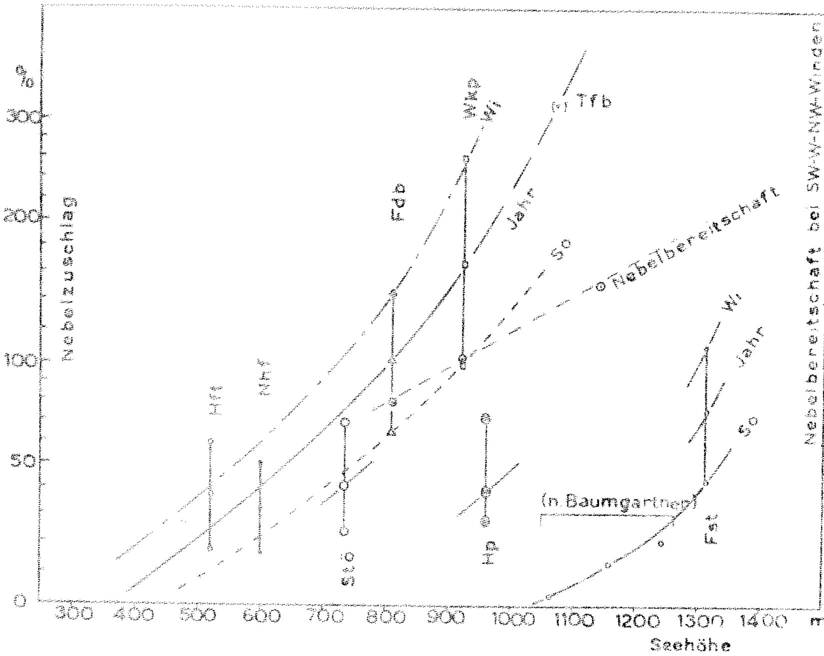

FIG. 3—Dependence of the excess of fog deposit on height above sea level and continentality

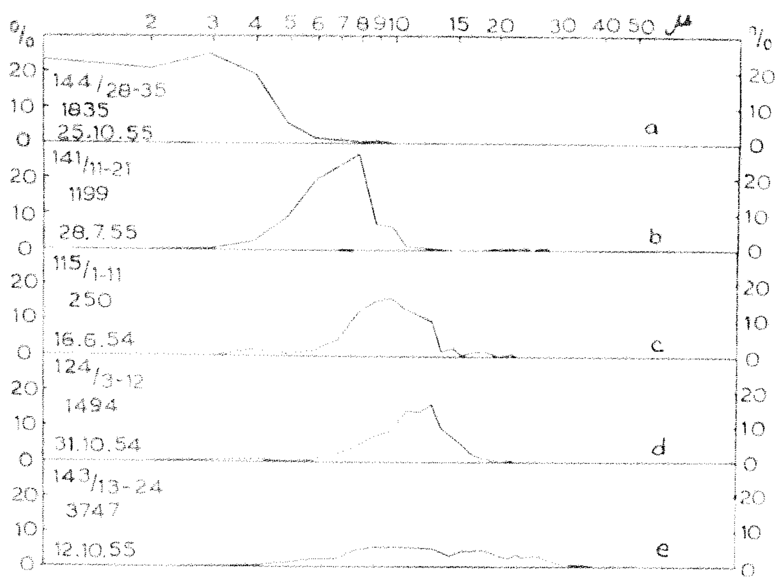

FIG. 4—Types of the cloud droplet spectrum in dependence on the origin of the depositing air mass

subtropical zones are in action, if a zonal circulation is predominant. The deposits are moderate or scanty, if the air masses originate in polar or arctic zones. This variable affects the value of W, the water content, of our formula.

Record of cloud-droplet spectrum—A relationship between the amount of deposit and the cloud-droplet spectrum was established using the record of the droplet spectrum of cloud air for different air masses. According to the method of *Diem* [1947] cloud droplets were collected between two oil layers of different viscosity, the upper being a thin film of paraffin oil placed above a base of heavier castor oil. The finding was immediately recorded by microphotography. The samples were taken under various fog situations, without any consideration of the deposited amount. Altogether 25 tests were evaluated, each consisted of an average of 12 samples with each several hundred or thousand droplets.

Types of droplet spectrum—The derived frequency distributions of droplet diameters can be classified according to the types of droplet spectrum, as seen in Figure 4. Each of these types presents obvious relations to the existing air mass and through it to the productiveness of fog precipitation. Polar cold air is characterized by dominating small diameters (Types a and b), in case of maritime origin, Type a with a range up to 10 to 12 μ and a remarkable part of diameters smaller than 2 μ; in case of continental origin Type b from 2 to 15 μ with a maximum number

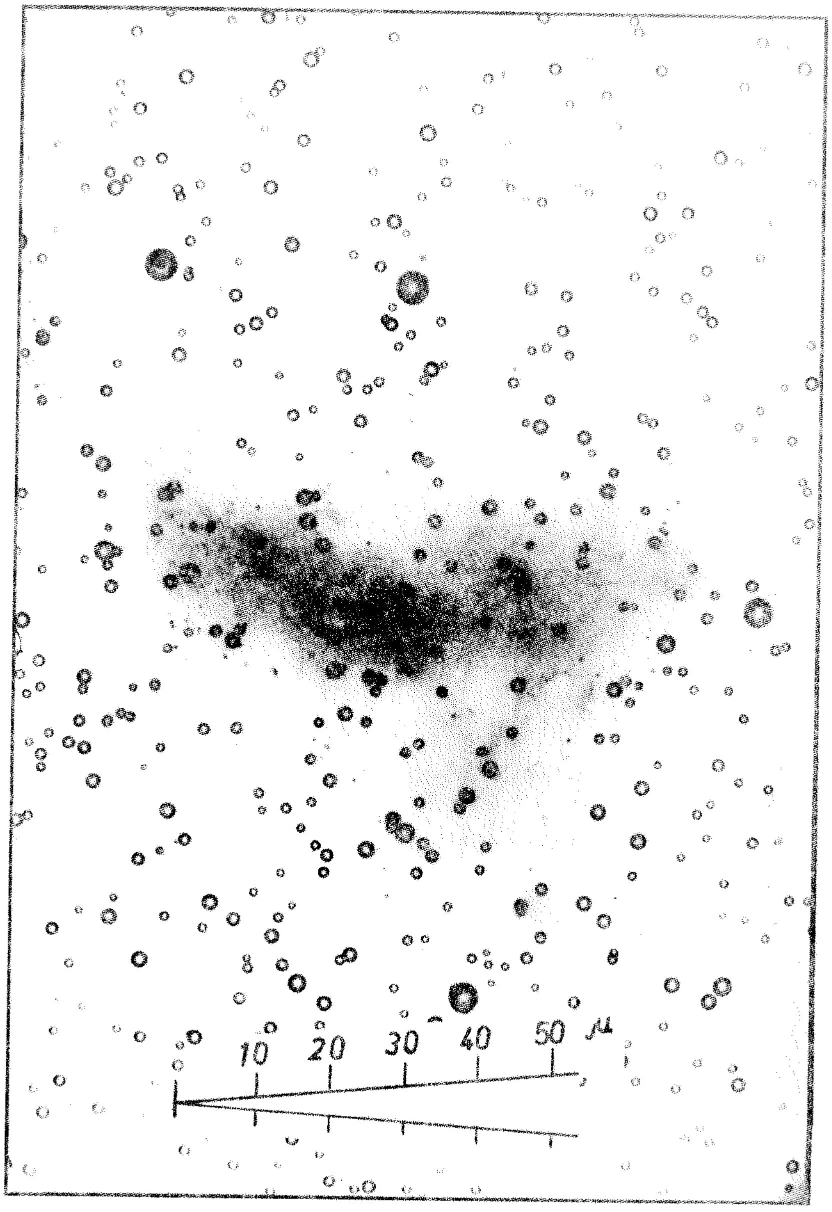

FIG. 5—Microphotographic record of cloud droplets from polar cold air; small amount of fog precipitation

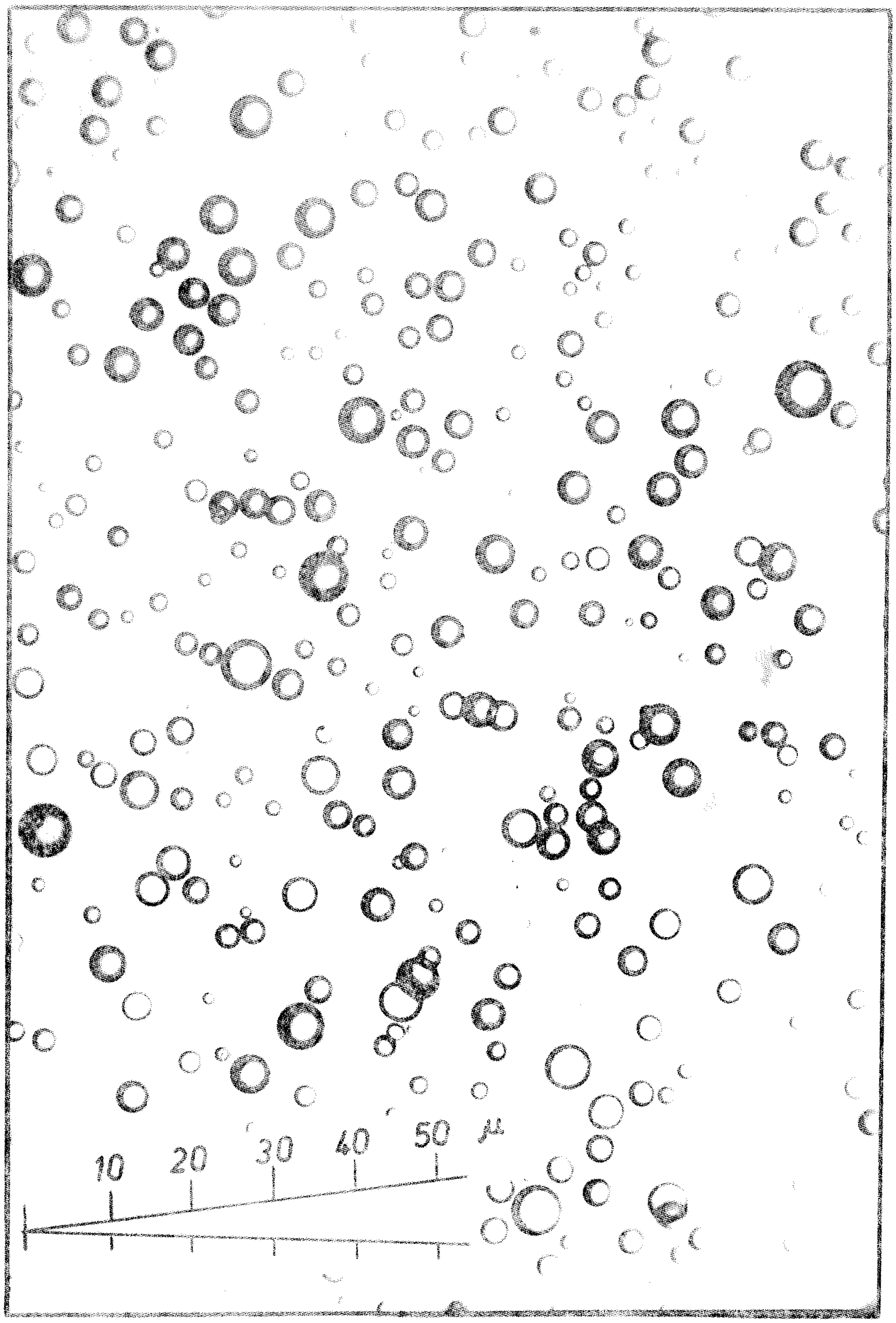

FIG. 6 Microphotographic record of cloud droplets from degenerated maritime subtropic air mass; heavy amount of fog precipitation

at 8 to 9 μ. The efficiency of fog precipitation is scanty. Types c and d are maritime warm air masses from moderate (Type c) or subtropical (Type d) zones. The droplet spectrum then indicates a broader range of 4 to 25 μ and a most frequent diameter of 8 to 11 μ. Fog precipitation becomes more and more productive. The deposits are heaviest with amounts of 2 to 3 mm/h in case of non-raining cloud decks formed on the windward side of the Alps. The air masses are often degenerated by continental influences and the droplet spectrum indicates a wide range from 5 to 60 μ with a maximum number at 12 to 18 μ. This result conforms with investigations of *Mahrous* [1954], who established the increase of droplet sizes as typical evidence of degeneration in the dense coastal fog in England. In the case of a narrow spectrum with smaller diameters of droplets a meridional circulation exists whereas the broad spectrum predominantly shows up with zonal circulation. Selected cases of these two types are demonstrated, with the microphotographic records of droplets in Figures 5 and 6.

Water content of samples—The different productiveness of these types of fog precipitation classified according to the droplet spectrum is easy to understand if the water content of each sample is calculated from the product $n \cdot \pi/6 \cdot D^3$. With increasing droplet diameter D the water content grows rapidly even if the concentration n of these droplets is small. Integrated over the whole spectrum, the results for the samples are:

Type	a	b	c	d	e
Total water content*	5	23	76	105	473

* Unit is $10^{-[illegible]}$ mm³.

Even this rough estimate indicates that the productiveness of fog deposit in case of a broad spectrum is a direct consequence of the microphysical structure of the clouds.

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Discussion

(Relating to the two immediately preceding papers)

Dr. C. E. Junge—Figure 3 of the paper just presented showed the increase of precipitation. This was the total increase plotted against area where there is no fog precipitation, is that right? You had figures of 200 to 300%.

Dr. J. Grunow—The figures represent only the additional fog precipitation amount deposited on the wire net of the gage at different mountain stations, without any consideration of rain or snow.

Dr. Junge—E. Eriksson, for instance, found that in Scandinavia the total amount of sea salt which is deposited from the atmosphere is approximately three times higher than can be accounted for by precipitation. The mountains in this area are often within clouds and the increase of precipitation by fog drip may be considerable and may explain the increase in sea salt deposit.

Dr. Grunow—At some places in higher altitudes, for instance, on the mountain station Wasserkuppe we have found the same result. The most interesting point where measurements were made with this type of gage, is Table Mountain in South Africa. In January 1955 the additional fog precipitation was tenfold the rain precipitation. In the annual average the unit with fog gage received four to fivefold the catch of the rain gage. According to the very critical evaluations of Nagel there was an assured excess of 1.7 fold of rain, derived only from days with fog without drizzle or rain. The best conditions for deposit are given if fresh maritime air masses are in action.

Dr. Junge—One more question: These 200 to 300% resulted from measurements with the wire screen. Did you make any estimates of how much the precipitation is increased by fog drip in a normal forest in a location similar to yours?

Dr. Grunow—In order to test the effective deposit on natural obstacles we have made measurements with a normal rain gage and with tubs under trees which acted as a natural fog meter, and in an open area with the fog gage, all at the same time. In case of fog without rain we found a reduction factor of 0.5 to 0.8 within the forests and of 3.2 on the edge of a forest. The reduction factors thus found depend on kind, form, and size of the trees and of the density of the woods. Therefore the reduction factor is only correct for the place at which these measurements are made.

Dr. H. Weickmann—You had pine trees?

Dr. Grunow—Yes.

Dr. Weickmann—They would have a higher collection efficiency than trees with leaves.

Dr. Grunow—The pine trees stand before our door. It is true, conifers have a higher efficiency than broad leafs, but more important is the situation of a forest in relation to the fog-bearing current of air. The highest amounts will be caught at the edge of the woods, but also within the forests a deposit of fog takes place. I remember, too, the work of Hori in Japan. He has also found considerable amounts within a forest.

Dr. W. E. Howell—With reference to your first paper, I recall that some time ago, C. K. Stidd (Cube-root-normal precipitation distributions, *Trans. Amer. Geophys. Union*, **34**, 31–35, 1953), when he was considering a possible representation of frequency distribution of rainfall amounts found zero, limited at dry stations for weekly or monthly rainfall amounts. Apparently there is a straight line relationship of the cube root of the fall amount broken down for very small amounts, and I presumed this was due to the fact that amounts less than one millimeter or at some stations less than one hundredth of an inch were not properly recorded. It occurs to me to wonder whether the measurement that you have made of the minute rainfall amounts would verify Stidd's presumptions that the cube root relationship holds down to very close to the zero line. I think it might be of interest of investigation.

Dr. Grunow—Thank you for this reference. In our further investigations we will investigate this relationship. I think this range of minute precipitation, although the monthly amount is not modified by this with regard to climatological and hydrologic applications, is worthy of consideration with respect both for theoretical and practical purposes, especially for agricultural meteorology and for artificial stimulation of rain.

Dr. B. J. Mason—When you are considering the collection efficiency of the fog catcher, do you regard this in terms of the collection efficiency of the individual wires?

Dr. Grunow—Yes.

Dr. Mason—When much fog is coming past the cylinder, do the pores, the spaces between the wires, become filled with water?

Dr. Grunow—In winter with riming, yes, but in summer we have found that is not of significance. This can be deduced from the nearly linear relationship between the amount deposited and the velocity of the wind.

Dr. Mason—Nagel in South Africa got rather unreasonable results because when he deduced the water content of the clouds from the collection efficiency of the single wire and the velocity of the cloud air which had gone by, he was out by a factor of 5 to 10, I think. This may have been because the spaces in between the wires were being filled. Then it is no longer possible to regard the cylinder as a number of individual wires. I would not say you should go so far as to regard it as a solid cylinder, but it may have approached that.

Dr. Grunow—Nagel assumed a water content of approximately 1 g/m^3, and this is a very high amount. The efficiency of a wire net cylinder is higher than that of a solid cylinder, because in the latter case, with increasing wind velocity, the current lines are more conducted around the profile. But the effect is less than the theoretical factor because some spaces will be closed by water. But, more important, the efficiency factor is nearly independent of wind velocity. We can observe the behavior of the cylinder in each weather situation because we have the instruments before our door, and we found that at low wind velocity there are no more spaces between the wires filled with water than at high velocity. However, measurements with our fog gage are proposed for determination not of the water content of clouds but of the additional fog precipitation, deposited in the same manner as by natural hindrances, and for this purpose we can use any efficiency factor.

Mr. Aldaz—At Mt. Washington Observatory we do some collection for the Atomic Energy Commission. We use a frame with no more than twenty bars, very solid and rigid, with diameters of the order of three millimeters, and we collected enormous amounts of water which reach the order of a quart, on many occasions, in about two hours. The frame is about two feet by one foot. The fog on Mt. Washington is sometimes very thick.

Dr. Woodman.—What we have just heard may have important applications to anyone who is interested in or in charge of conserving the water in regions where the mountains often reach into the base level of clouds. No trees should be cut from the tops of these mountains, because these trees are important collectors of otherwise unprecipitated water.

Dr. Bergeron.—I wonder if anybody of those present has visited that wonderful place on a small mountain in Portugal named Cintra*. It has a castle on top of it. On the top, which is small and isolated, one is in a tropical rain forest. One looks down on the desert toward Lisbon. Fog drip must be the explanation for its rich vegetation.

* Serra da Cintra, rugged mountain mass, north of Lisbon. Highest peak Cruz Alta (1772 ft); castle is Palacio da Pena.—Ed.

Geophysical Monograph Number 5

PHYSICS OF PRECIPITATION

PROCEEDINGS OF THE CLOUD PHYSICS CONFERENCE
WOODS HOLE, MASSACHUSETTS
June 3-5, 1959

Edited by
HELMUT WEICKMANN

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GEOPHYSICAL MONOGRAPH SERIES
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PUBLISHED by
AMERICAN GEOPHYSICAL UNION
OF THE
NATIONAL ACADEMY OF SCIENCES—
NATIONAL RESEARCH COUNCIL
Publication No. 746
1960