On the Size Distribution of Raindrops in Hurricane Ginger

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ABSTRACT

Airborne foil impactor measurements in Atlantic Hurricane Ginger (1971) show a raindrop size spectrum which is well represented by an exponential relation of the Marshall-Palmer type. No difference was observed between the spectral characteristics of the rainbands and those of the eyewall, but some dependence of the slope-rainfall rate relation on rainwater content was noted.

1. Introduction

Hurricane Ginger, an Atlantic hurricane of the 1971 season, was an atypical storm. It remained at hurricane strength for 20 days while looping about the Atlantic in a most peculiar way (Simpson and Hope, 1972: Frank, 1972). Its longevity and frequent proximity to suitable staging locations enabled Project Stormfury to monitor the storm with numerous aircraft penetrations and even to conduct two seeding experiments (Hawkins *et al.*, 1972). Raindrop spectra were obtained using an aluminum foil impactor aboard seven of these flights. These sampled several parts of the life cycle of the storm as shown in Fig. 1. Each foil flight was at about 5,000 ft where the ambient temperature was 17±1C. The DC-6 aircraft maintained a true airspeed of 200±10 kt.

2. Data reduction

The foil from the impactor was photographed using a technique similar to that of Merceret (1973a) and the

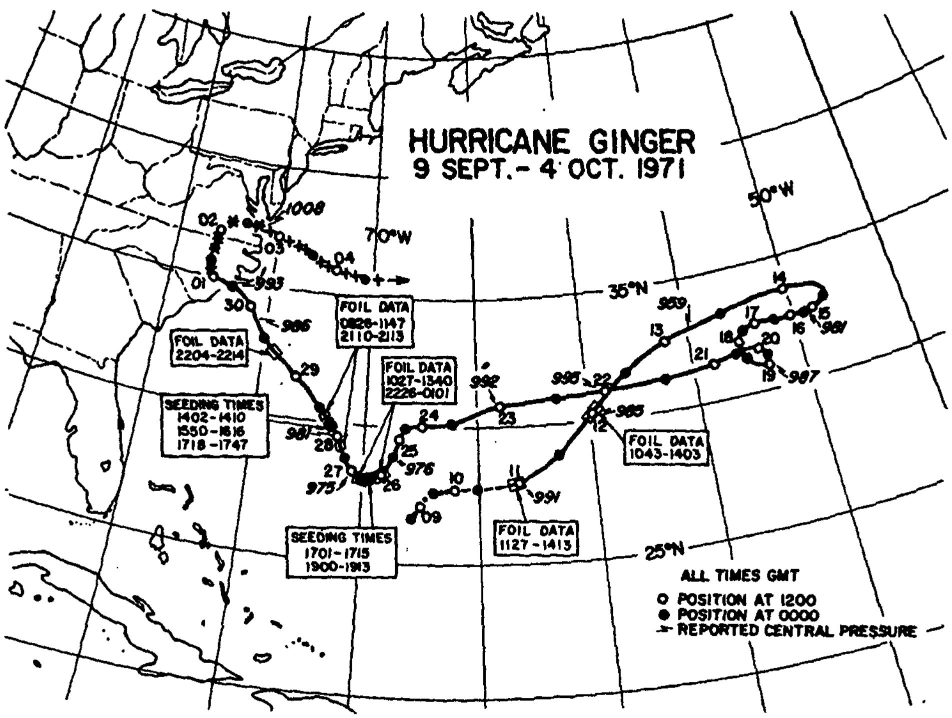

FIG. 1. The track of Hurricane Ginger.

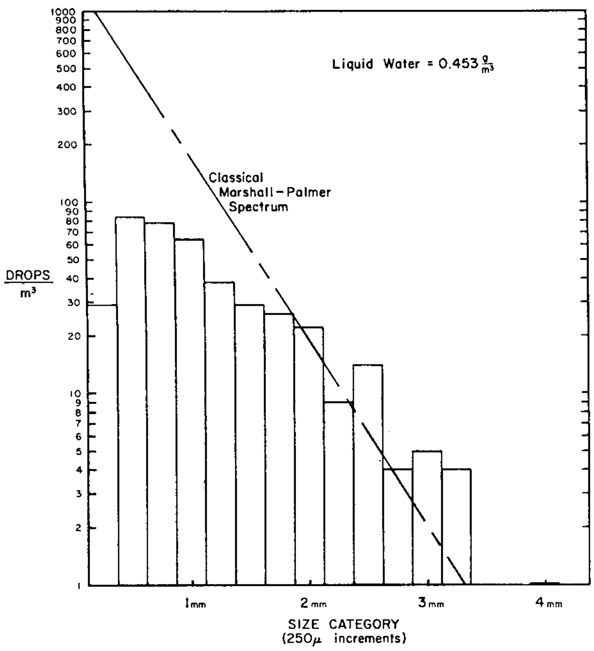

FIG. 2. Typical small water content spectrum.

drop size distributions determined from the photographs by counting the number of 250 μm lines (caused by grooves 250 μm apart on the impactor drum) in each image. A size calibration based on the work of Schecter and Russ (1970) is included in the computation of rainwater content and spectra. The sample sizes were selected large enough to satisfy the criteria of Cornford (1967, 1968a, 1968b) for statistical reliability yet small enough to represent a meteorologically homogeneous region of the storm. The average sample represented a volume of about 0.5 m^3 of air and contained more than 500 droplets.

The data were stratified by rainwater content computed from the samples to determine whether the shape of the spectrum was dependent upon the quantity of liquid water present. Data from the relatively weak eyewall (eight sets) were initially processed apart from those from the rainbands (168 sets), but the rainwater content and spectral parameters differed between the two kinds of environments by less than 15% of their standard deviations. As a result, the data have been combined to increase the overall sample size slightly. Similarly, data from the two flights following seedings were first processed apart but as indicated by Hawkins *et al.*, little or no effect was expected because of the diffuse nature of the storm and the weak character of the eyewall. We observed no effect and these data were also combined with the rest.

Four least squares fits to the exponential form $N_D = N_0 e^{-\lambda D}$, suggested by Marshall and Palmer (1948), were created. Types 1 and 2 constrained the intercept, N_0, to that found by Marshall and Palmer while types 3 and 4 fit both the slope, λ, and intercept as free parameters. Types 1 and 3 minimized the squared deviation along the drop count, N_D, axis while types 2 and 4 minimized it along the size, D, axis. The reason for generating four fits has been given in detail by Merceret (1973b) and will only be summarized here. The intercept of an unconstrained fit is most strongly influenced by the small sized droplet concentration, but most of the physically interesting quantities are governed by the concentrations of the larger droplets and thus critically dependent on the slope of the distribution. For example, the liquid water content is proportional to $N_0\lambda^{-4}$ and the radar reflectivity is proportional to $N_0\lambda^{-7}$. Since the slope of a least squares fit depends somewhat on which variable is treated as the dependent variable, the analyst should tell his reader which choice he has made or, better, present both results. Constraining the intercept also affects the computed slope and, as the data indicate, may lead to a more consistant relation between the slope and physical quantities such as the rainfall rate. Hence all four kinds of fits are used in this paper.

3. Results

The exponential model well fit the data from Hurricane Ginger. For both large rainwater content regions (≥ 1.0 g/m^3) and small rainwater content regions (<1.0 g/m^3), the correlation coefficient to the exponential form averaged 0.87 with a standard deviation of 0.1. Typical spectra are presented in Figs. 2 and 3.

Marshall and Palmer found the slope of the distribution to be related to the rainfall rate, R, by

$$\lambda\ (\mathrm{cm}^{-1}) = 41R^{-0.21} \quad \text{for } R \text{ in mm/hr.}$$

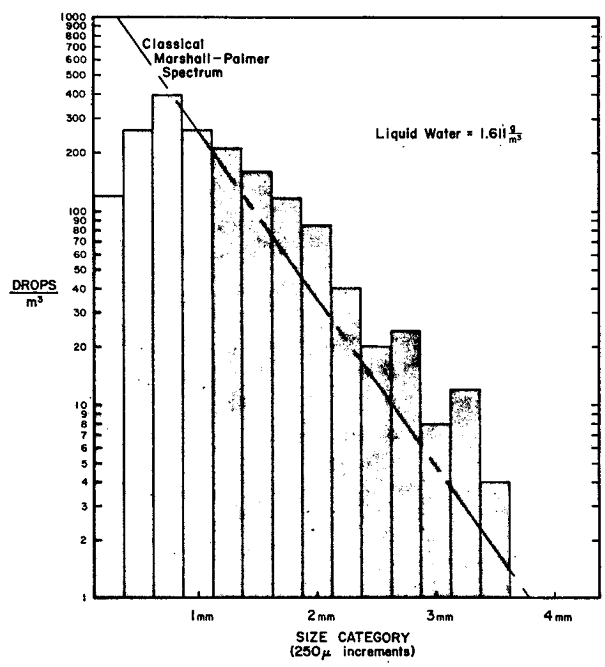

FIG. 3. Typical large water content spectrum.

The results from Ginger do not differ greatly from that relation, except for the unconstrained fits at low rainwater content as shown in Table 1. The rainfall rates were computed from the drop size spectra using the volume and terminal velocity of drops in each size category. The correlation coefficients are given in parentheses.

The intercepts of the free fits average within a factor of 2 of the classical value as shown in Table 2.

The mean rainwater content of the samples under 1 g/m³ was 0.43 with a standard deviation of 0.25 g/m³. For the large water content samples the mean was 2.07±1.24 g/m³.

For the low liquid sets the volume mean diameter of the droplets was 904±281 μm while for the larger water content sets it was 1374±195 μm. The volume median diameter always ran 1.5±0.2 times as large as the volume mean diameter.

4. Conclusions

The Marshall-Palmer representation of droplet size spectra has traditionally been found applicable to surface raindrop distributions in extratropical weather systems. It is interesting to find that airborne measurements show the Marshall-Palmer form is also a good model for the spectra from tropical Hurricane Ginger. If rainfall rates are to be computed from the slope of the distribution, the slope of the constrained fits gives more constant results. For droplets smaller than one millimeter, the exponential form overestimates the number of droplets in a given size category. While Ginger was an unusual storm, these data may be sufficient justification for using the Marshall-Palmer model for the raindrop size spectrum in tropical storms until further measurements are accumulated.

TABLE 1. λ-R relationship in Hurricane Ginger.

Fit type	<1.0 g/m³ (139 samples)	≥1.0 g/m³ (37 samples)
1	$42R^{-0.20}$ (0.97)	$46R^{-0.23}$ (0.97)
2	$44R^{-0.18}$ (0.92)	$49R^{-0.23}$ (0.95)
3	$47R^{-0.44}$ (0.81)	$31R^{-0.23}$ (0.43)
4	$53R^{-0.33}$ (0.78)	$40R^{-0.22}$ (0.46)

TABLE 2. Mean ratio of free fit intercept (N_0) to that of Marshall and Palmer.

Fit type	<1.0 g/m³	≥1.0 g/m³
3	1.47	0.34
4	2.10	0.51

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