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Raindrops from one Place are Different from Another Place

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Abstract
Marshall and Palmer (1948) [1], in a highly cited article, present their exponential general relation of;

$\Lambda = 41\ R^{-0.21}\ cm^{-1}$ where R is the rate of rainfall

$N_D = N_0\ e^{-\Lambda D}$ where D is diameter of raindrops.

When D = 0, $N_D = N_0$ and in this MP model, they find that $N_0 = 0.08\ cm^{-1}$. However, Jennings, for this paper, worked up the exact raindrop data in MP Fig. 2 and got.

$\Lambda = 41.1\ R^{-0.212}$ cm-1 (Jennings)

This is undersetandably very close to the MP result, but in an extended discussion in Pruppacher and Klett (1997) [2] pp. 30-38, it is remarked that N_0 can depend on R in the following way where (Sekhorn and Srivastava (1971)) [3] find.

$N_0 = 7 \times 10^3\ R^{0.37}\ m^{-3} mm^{-1}$ and $\Lambda = 3.8\ R^{-0.14}\ mm^{-1}$

Jennings got $N_0 = 0.0847\ cm^{-4}$ for Fig. 2 and keeps the accuracy because the data in MP Fig. 2 is linear above D = 1.5 mm raindrop size. Marshall and Palmer also note that the mass of rainwater can be calculated and correlated with the rate of rainfall R by the MP equation at the top here. At small raindrop size, there is devation from linearity of ln N_D versus D, which has a negative slope. In the MP paper, in Fig. 1, we note that the N_0 is not constant and applying Jennings formula above does not work.

Keywords: Raindrop Rate, Rate of Rainfall, Exponential Relation

Introduction

In modeling raindrops Marshall and Palmer came up with the ln N_D versus D fit that worked well for Figure 2 in their 1948 paper. However, in Pruppacher and Klett they say that a number of investigators have pointed out that N_0 is a function of R. Figure 1 in the Marshall and Palmer paper shows that this is so. For this paper, I used tracing paper and a Cartesian grid to get dln N_D/dD and N_0 for both figures. Figure 2 fits the exponential relation exactly but the author noticed that for Figure 1 there is no common N_0. In RESULTS the author will calculate N_0 according to Sekhorn and Srivastava's formula in ABSTRACT. N_0 for Figure 2 is more accureately $0.0847\ cm^{-4}$ and here the exponent and prefactor are in higher precision as the data fits the exponential relation well.

Results

The author got the slopes of the curves for Figure 1 and Figure 2 in Marshall and Palmer. Table 1 has the values of R, dln N_D/dD = $-\Lambda$, Λ, and $41.1\ R^{-0.212}\ cm^{-1}$. According to Jennings calculation in this paper on Figure 2, $\Lambda = 41.1\ R^{-0.212}\ cm^{-1}$.

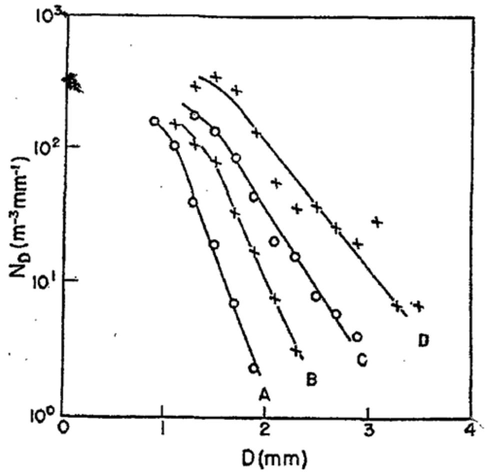

FIG. 1. Distribution of number versus diameter for raindrops recorded at Ottawa, summer 1946. Curve A is for rate of rainfall 1.0 mm hr⁻¹, curves B, C, D, for 2.8, 6.3, 23.0 mm hr⁻¹. $N_D \delta D$ is the number of drops per cubic meter, of diameter between D and $D + \delta D$ mm. Multiplication by 10^{-6} will convert N_D to the units of equation (2).

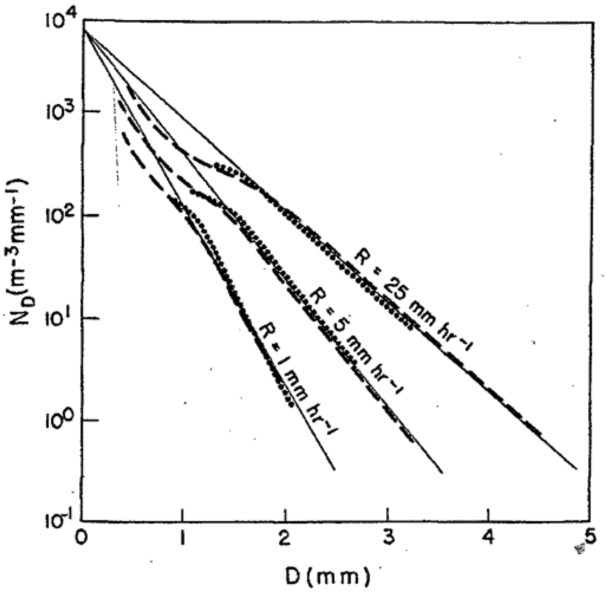

FIG. 2. Distribution function (solid straight lines) compared with results of Laws and Parsons (broken lines) and Ottawa observations (dotted lines).

Table 1

rate of rainfall	Marshall and Palmer	Figure 2	Jennings version of theory
R mm/hr	**$d\ln N_D/dD = -\Lambda$ cm^{-1} (data)**	**Λ cm^{-1} (data)**	**$41.1\ R^{-0.212} = \Lambda$ cm^{-1}**
1	- 41.054	41.05	41.1
5	- 28.962	29.0	29.2
25	- 20.979	20.98	20.8

Looking at Table 1 we can see that the exponential fit does well for its data. Pruppacher and Klett note, "more detailed studies...have demonstrated that the MP distribution is not sufficiently general to describe most observed spectra accurately." (page 34) In DISCUSSION the author will look at the N_0 for MP Figure 1. Copies of both of the MP figures are included here.

Discussion

We have to calculate the N_0 for R = 1, 2.8, 6.3, and 23.0 mm/hr rainfall rates in Figure 1 by reading the values off the graph. TABLE 2 has these numbers.

Table 2: Figure 1 – $N_0 = N_D$ intercept from the graph, Λ from reading the graph

R mm/hr	N_0 (m^{-3}mm^{-1})	Λ (cm^{-1}) data	$41.1\ R^{-0.212} = \Lambda$ theory	$N_0 = 7 \times 10^3\ R^{0.37}$ theory
1	17300	47.56	41.1	7000
2.8	19600	38.64	33.04	10250
6.3	7180	25.76	27.82	13830
23.0	7180	20.27	21.14	22330

This is from the actual numbers on the tracing paper and Marshall and Palmer have.

$$N_D = N_0 e^{-\Lambda D} \quad (1)$$

Taking the derivative with respect to D we have.

$$dN_D/dD = N_0 e^{-\Lambda D} (- \Lambda) \quad (2)$$

Then;

$$dN_D/dD = N_D (- \Lambda) \quad (3)$$

and forming the logarithm there obtains.

$$d\ln N_D/dD = - \Lambda \quad (4)$$

Now, in Figure 2 it is an exact fit for equation (4), but in Figure 1, N_0 varies. We saw how well Sekhorn and Srivastava's relation models Figure 1. Then we calculated the intercept on the N_D axis for the different R's according to Sekhorn and Srivastava and there is disagreement for Figure 1.

Conclusion

It is understandable that a simple exponential fit for the raindrops would give Marshall and Palmer's paper much notice. This subject is very important as rainfall needs to be understood.

Acknowledgement

One of the important physicists is André-Marie Ampère (1775–1836) who derived this preliminary equation that was used by James Clerk Maxwell to become one of Maxwell's four equations for electromagnetism.

$$\nabla \times \mathbf{B} = \mu_o \mathbf{J}$$

Maxwell added to Ampère's equation, and two of the others were from Carl Friedrich Gauss, with one from Michael Faraday. In addition, Ampère was a devout Catholic who prayed the Rosary. His name is one of the 72 names inscribed on the Eiffel Tower.

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