Reply[1]

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Passarelli has commented on our paper (Houze *et al.*, 1979) in which we presented evidence from airborne measurements obtained during the CYCLES PROJECT that the precipitation particles in frontal clouds tend to be exponentially distributed in size and that the parameters of the distribution (N_0 and λ) show systematic variations with temperature (T). We welcome the opportunity to discuss our results further in light of Passarelli's comments.

Passarelli is interested in whether N_0 and λ in our data obey an equilibrium relationship suggested by his theoretical work, *viz.*,

$$N_0 = C\lambda^3, \qquad (1)$$

where C depends on snowfall type, temperature lapse rate and vertical air motion (Passarelli, 1978a). Comparison of Figs. 4 and 5 in our paper shows that our observations tend toward an exponential relationship between N_0 and λ (since both $\log N_0$ and $\log\lambda$ are linearly related to T). Algebraic elimination of T from the best-fit lines shown in these figures leads to an exponential relationship between N_0 and λ, specifically, $N_0 \propto \lambda^{1.6}$.

Thus, although an exponential relationship is indicated, it does not have the exponent of 3 predicted by (1). To investigate the relationship further we have plotted N_0 and λ from our data in log-log format in Fig. 1. Values of N_0 and λ for spectra sampled below the melting level are not included in this plot since Passarelli's theory applies only to snow. The best-fit line to the data, which is shown in Fig. 1, was obtained by the method of least squares; it has a slope of 1.3, again indicating an exponent of less than the equilibrium value of 3 predicted by Passarelli's theory.

These results do not, however, invalidate Passarelli's theory since there is considerable scatter in the data points in Fig. 1 (the correlation coefficient is only 0.64), and the slope obtained from the best-fit line in Fig. 1 is an *a posteriori* result.

Scatter in our datum points can be expected from Passarelli's theory since the value of C in Eq. (1) varies according to *in situ* conditions. Passarelli (1978b,c) describes two sets of data in which N_0 and λ fit closely exponential relationships of the form (1).

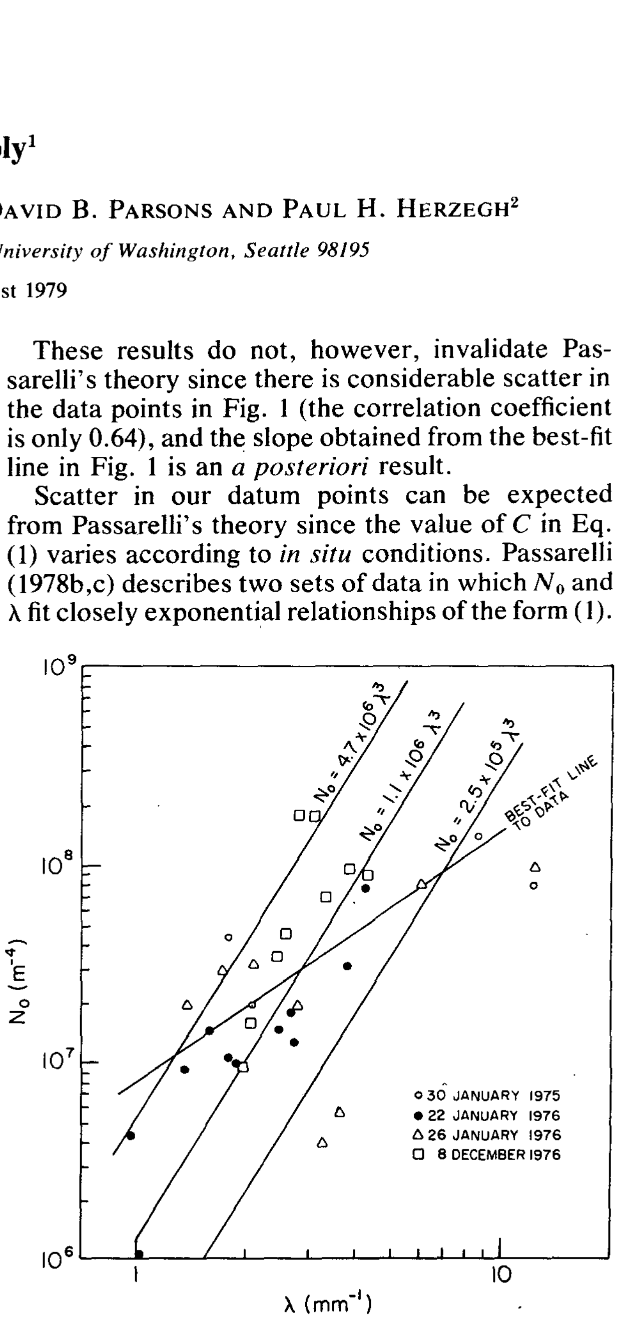

FIG. 1. Relationships between particle-size spectrum parameters N_0 and λ from CYCLES data. Passarelli's theoretical equilibrium relationship, $N_0 = C\lambda^3$, is shown for three values of C corresponding to the mean and standard deviation of the observed distribution of $\log C$. The best-fit line was obtained by the method of least squares.

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His data, however, were obtained with a primarily vertical sampling strategy, evidently aimed at obtaining a set of points (N_0,λ) closely related in time and space, especially in the vertical. In this case, C was nearly constant and all of the sampled spectra obeyed the same equilibrium relation. In our data set, the samples were not obtained during ascents or descents, but rather along horizontal traverses at various heights in various parts of cyclonic storms. Our samples are thus highly independent, whereas Passarelli's are highly dependent. Since the storms we studied show considerable inhomogeneity in their cloud and precipitation patterns (Hobbs, 1978), the value of C can be expected to vary from one independent sample to the next.

In view of the fact that scatter in our data is predicted by Passarelli's theory, we can test whether or not the pattern of scatter shown by the datum points in Fig. 1 is consistent with the theory. More specifically, we test our data against the *a priori* hypothesis that our samples of particle size spectra were drawn from a population of spectra governed by Passarelli's equilibrium relationship (1), with the corollary that the scatter in Fig. 1 is associated with sampling and therefore with different values for C. By application of the chi-square test for goodness of fit, we find that the distribution of log$C$ given by application of (1) to our data points in Fig. 1 is not significantly different from a normal distribution of log$C$ with a mean and standard deviation estimated by our points (we found a value for chi-square of 12.1 for 13 degrees of freedom). The equilibrium curves of $N_0 = C\lambda^3$ corresponding to the mean and standard deviation values of the hypothesized normal distribution of log$C$ are shown in Fig. 1. The two outer curves, corresponding to the positive and negative standard deviations, encompass a range of values of C from 2.5×10^5 to 4.7×10^6 m^{-4} mm^3. The tendency of our data to cluster within these limits is evident. In addition, we note that Passarelli's (1978b,c) data give values of $C = 3.6 \times 10^5$ and 3.7×10^6 m^{-4} mm^3, which also lie within these limits.

In summary, we conclude that our data, as well as Passarelli's, could have been drawn from a population of particle size spectra governed by the equilibrium relationship (1). Thus, the data are consistent with his theory. However, it should be kept in mind that, while the data are not inconsistent with his theory, neither do they confirm it. In fact, objective best-fits to our data suggest (*a posteriori*) exponents for λ in (1) in the range 1.3–1.6. Hence, caution should be exercised in applying the equilibrium theory until more data and theoretical investigations are completed.

As to whether riming plays a significant role in spectral broadening, we note that our statement, quoted by Passarelli, was meant to be general, not ruling out any possible collectional process. Passarelli's contention that riming has *no* effect on spectral broadening is correct only if the collection efficiency is a constant.

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