After more than half a century of work on radar QPE it is good to go back to fundamentals. Half a century is a long time and questioning ourselves on progress to date is needed. The purpose of this presentation is to spur discussion.

1. Stratiform versus convective rain

Over a number of years a terminology and a number of concepts that were used originally as a first step in formulating a problem became broadly accepted and acquired an established status not compatible with their lack of precision. One such concept is “stratiform” precipitation as opposed to “convective” precipitation. The characteristics of precipitation from these two ill-defined categories are supposed to be well differentiated and it is broadly believed that distinct Z-R relationships for the two will lead to an improvement in radar QPE. However, microphysics in stratiform precipitation falling from an anvil of a convective cell and in stratiform precipitation resulting from a large scale uplifting should be expected to be quite different. The two do not deserve to go under the same name of “stratiform” unless we do not pretend to give a quantifying meaning to the term. Some examples, given in Figures 1a, 1b, and 1c illustrate this.

There is a great deal of variability in the microphysical processes in widespread non strongly cellular precipitation that lead to variability in Z-R relationships.

In passing, these examples also illustrate well another nonsense statement: variability of the drop size distribution is unimportant.

2. Z-R relationships

As mentioned, variability in the Z-R relationship is far from negligible. Adding polarization diversity is an excellent choice in terms of data quality in general and will palliate this problem, at least at short ranges and at S-band and X-band. At C-band the benefits of polarimetry for Z-R relationships appear to be less clear.

Adaptive Z-R relationships are needed that go beyond the stratiform-convective division. Most of the variability is in the so-called stratiform precipitation. Whether adaptable Z-R relationships will be derived from polarimetry or by some stratification of precipitation type, the stochastic nature of the problem must be acknowledged. Because of this, the correlation structure of the Z-R variability becomes a precondition for an efficient use of adaptable relationships. That is, we must know what is the time-space domain for which using of a single Z-R relationship will result in errors below a predetermined value. The less space-time resolution we require the more tractable the problem becomes.

In relation to this we should note another broadly assumed truth that is questionable: due to the non-linearity in the in Z-R relationship the transformation of Z into R should be made as early as possible. However, if bent brackets denote space average and an overbar denotes a time average:

\[ \langle Z \rangle = \int D^6 N(D) dD = \int D^6 \langle N(D) \rangle dD \]

and

\[ \langle R \rangle = \int D^{3.67} N(D) dD = \int D^{3.67} \langle N(D) \rangle dD \]

That is, averages of rain rate are related to averages of reflectivity through the average of the drop size distribution. We should expect the latter to have less time-space variability than the instantaneous DSD and have longer time-space decorrelation values. This will minimize the errors associated with the variability. Thus, the transformation from Z to R should be done at the last stage possible compatible with the resolution required for a particular application.

By requiring less we may deliver better products.

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Fig. 1a- A two-hour period of “stratiform” precipitation during an extra-tropical transition. In these situations the exponents in the Z-R relationships are close to convective cases as shown by the disdrometric relationship in the right panel.

Fig. 1b- A more typical period of summer “stratiform” rain during a large scale uplifting.

Fig. 1c- The profile of reflectivity as seen by a vertically pointing radar (left) shows two distinctive periods that would be defined as “stratiform” (dash-dot period) and “convective” (dash period) by any commonly used criteria. On the right the two Z-R relationships are shown to be in practice indistinguishable.
3. The Vertical Profile of Reflectivity

Another much used ambiguous concept is “The Vertical Profile of Reflectivity”. Of course, we can measure reflectivity as a function of height but this does not necessarily define an object we are entitled to denote as VPR. Figure 2 shows a time height profile of reflectivity in a situation where trails can be well differentiated. In these trails the larger particles are to the left of each trail. In a continuous precipitation at each level there is a mixture of particles coming from different origins and having undergone different histories. It is clear that the VPR has no well-defined physical meaning. It is naïve to expect the VPR to contain information that can be used to deterministically extrapolate a measurement aloft to ground.

Figure 3 shows an observed set of profiles and illustrates how rapidly information on reflectivity at one height becomes fuzzy when we use it as information on precipitation intensity at another height. It is clear that the vertical profile of reflectivity is a probabilistic concept and must be used as such. An example of a climatological probabilistic VPR is given in Fig. 4, where the lines are iso-probabilities of having a given reflectivity on the x-axis at the y-axis height. Thus, an equiprobability climatological VPR correction (by probability matching) for an observation of 17.5 dBZ at 1 km above the bright band peak corresponds to a reflectivity of 25 dBZ one kilometer below the peak. A correction with the mean profile gives 23 dBZ at -1km. Perhaps a better climatological correction can be obtained by conditioning the statistics to observed values. Figure 5 shows the mean profiles stratified in 2 dB intervals at 1 km above the BB peak. For the same observation of 17.5 dBZ at 1 km the extrapolation to -1 km now gives 27 dBZ, that is, a 4 dB difference with respect to a climatological average profile.

Using climatological VPR corrections is like using a climatological Z-R relationship. It is acceptable if large errors are tolerable.

The alternative is an adaptable VPR correction, necessary for QPE if Q stands for quantitative (as opposed to qualitative). However, to derive a VPR that is representative of a situation (that is, a time-space interval) we must first quantify the time-space variability of the VPR. This can be formulated as: given a measured value at a point in the volume scan at ranges long enough so that the ground values are not seen, what is the optimal time-space domain at short ranges that will give us the VPR profile that will minimize the residual errors after the VPR correction. For this we must know the time-space correlation structure of the values at ground given the value measured at the particular height. Or, in other words what is the decorrelation time and decorrelation distance of the residual errors after a particular VPR correction. Moreover, since this variability is very large we must condition the statistics to some obvious parameters that determine the change of reflectivity in height and its variability. All this is not easy, but absolutely necessary.

In fact, the two main problems in radar QPE, the correction for the vertical profile of reflectivity and the adjustment of the Z-R relationship require similar approach and may benefit by stratification by the same parameters, namely height of the bright band (which we use to some extent); depth of precipitation; profile of vertical air motion; hodograph.

4. Adjustment by gages

What is the purpose of gage adjustment? Correct for the residual variabiliy of the VPR before or after some mean correction was applied? Correct for the variability of the Z-R relationships? Calibrate the radar? Or sweep under the rug all the shortcomings of the system?

Depending on our objectives different requirements are needed, all related with the space-time variability of the uncertainties in QPE. The spacing of raingages and their spatial coverage must be matched to the decorrelation distance of the residuals of the Z-R relationship used and the residual of errors after VPR correction. The fact that both may be correlated makes the problem more interesting.

A cluster of gages within a domain smaller than the decorrelation distance of residuals will adjust radar to this particular domain but will result in large biases outside.

The success in gage adjustment depends on the success in understanding the VPR correction and the adjustment of the Z-R relationship and the structure of the residual uncertainties. And I don’t know of any shortcut!

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Fig. 2- This time-height profile illustrates that through horizontal drift and size sorting the precipitation at a given height is composed of particles having very different microphysical history.

Fig. 3- The left figure illustrates the variability in VPR encountered in any situation defined by tens of minutes and tens of kilometers. This leads to the rapid decorrelation of reflectivity in height: for a distribution of ±1 dB at any level there is a five-fold broader distribution at one kilometer apart.

Fig. 4- Probabilistic VPR

Fig. 5- Mean climatological profiles stratified at 1 km above the BB every 2 dB from 12 to 30 dBZ