# P1.15 EVALUATION OF A RADAR HYDROMETEOR CLASSIFIER BY COMPARISON WITH IN SITU AIRCRAFT DATA

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## 1. Introduction

Intensive research over the last few decades with meteorological radars having a polarimetric capability has led to an emerging capability for identifying hydrometeor types remotely. Such work began with efforts to discriminate between hail and rain (e.g. Barge 1974); Jameson and Johnson (1990) summarize the early work. Several algorithms for inferring hydrometeor types from radar data have been developed (e.g. Höller et al. 1994; Matrosov et al. 1996; Vivekanandan et al. 1999; Zrnić and Ryzhkov 1999; Liu and Chandrasekar 2000; Straka et al. 2000). Most are based on calculations of the scattering properties of idealized model hydrometeors with limited comparisons with in situ observations of the particles. Like all remote sensing techniques, these algorithms need to be evaluated against extensive sets of in situ observations to validate and improve them. The work reported here examines samples of coordinated aircraft microphysics and polarimetric radar data from the Severe Storms Electrification and Precipitation Study (STEPS), a study of summer convective storms in the High Plains region of the U.S.A.

## 2. Matching of Observations

In concept one seeks aircraft and radar observations of the same population of hydrometeors to evaluate the algorithms. However, the sampling strategies and sampling volumes of aircraft sensors and radar differ markedly. Moreover, exactly collocated observations may not be useful for this purpose because the radar echo from the aircraft will contribute to the polarimetric observables and may invalidate the algorithms.

Thus, what is needed is the radar pixel which corresponds most closely in space and time to a given set of aircraft hydrometeor data (or vice versa), preferably without involving the aircraft echo. A computer algorithm to identify the appropriate "proximate pixels" from radar scan data and aircraft flight tracks has been developed by S. Goeke. This algorithm was applied to data from the S-Pol radar along the flight tracks of the T-28 from STEPS, to identify the corresponding data sets for this study.

Various other complications arise in the comparisons. The times of the aircraft samples in a radar pixel usually differ from that of the radar scan of that pixel. We focus on data within 2.5 minutes, which limits the number of aircraft particle data samples that could be matched to the radar pixels to less than half of the T-28 total for this storm. Due to the width of the radar beam, vertical gradients may mean that only ice particles are present in the upper part of the beam while melting or liquid particles occur lower down; the radar algorithm uses data which represent some kind of weighted sum for the whole radar contributing volume. The height of the aircraft penetration usually differs from that of the beam axis. The comparisons can also become erratic in regions with strong gradients when the "proximate pixel" algorithm shifts between neighboring pixels, or from one scan to another.

## 3. Analysis Procedure

With the matching radar pixels and aircraft data "points" thus identified, we examined the radar hydrometeor classification on a point-by-point basis. Attention has thus far been focused on mixed-phase regions and regions where transitions in the radar indications, say from graupel/rain to dry snow, occur. The particle images from such regions are examined to evaluate the radar classifications on either side of the transition and try to ascertain any corresponding change in the observed particle characteristics. The key radar variables listed in Table 1 are also studied for evidence of any distinct change that might be associated with the change in particle classification (since the classifier operates with fuzzy logic, the responsible changes in the radar signals may not be clearly evident). Consideration of the temperature, updraft speed, and cloud LWC in the sampled region helps in inferring the imaged particle types.

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| Table 1: Radar Variables of Special Interest | |
|---|---|
| $\Delta t$: | Time difference between aircraft sample and radar pixel |
| $P_{rx}$: | Crosspolar echo signal level |
| ZDR: | Differential reflectivity |
| $\rho_{HV}$: | Correlation between H and V echo components |

## 4. Data Examples

These examples are taken from the T-28 flight in the 29 June 2000 STEPS storm in northwest Kansas. The aircraft penetrated a severe storm that included an F1 tornado several times at the –6 to –10º C level.

### Graupel, but no rain

On a north-northwest heading generally close to the radial inbound direction toward the S-Pol radar, over a period of 3 min (about 18 km along the flight path) through updrafts up to 7 m $s^{-1}$, the aircraft encountered fairly steady graupel up to 5-6 mm in diameter, with an occasional larger particle (Figure 1). There was no sign of any raindrops in this interval, though a couple of possible frozen-drop images do appear.

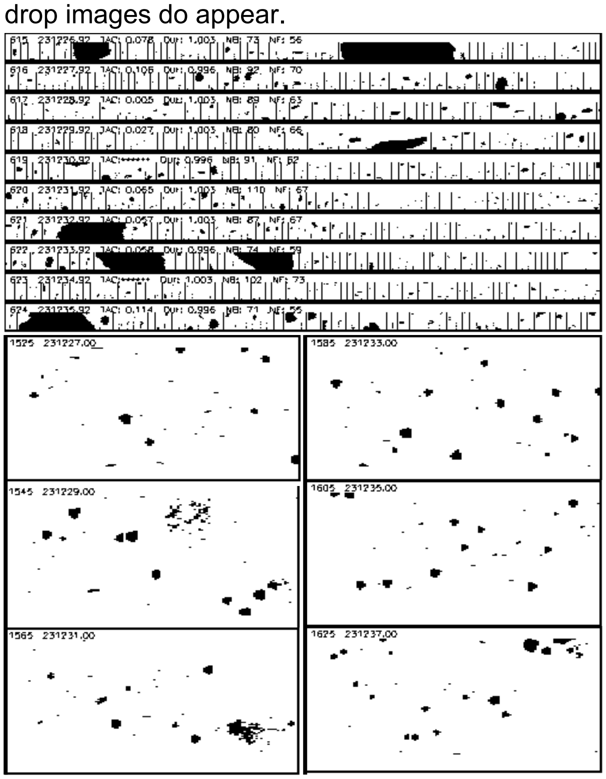

*Figure 1: Example particle images from radar pixels classified as "graupel/rain" or "graupel/small rain." Top: 2D-C probe images of graupel up to about 6 mm in diameter (vertical bars are 0.8 mm in height); no raindrops are evident in these images. Bottom: Every 20$^{th}$ HVPS image from the same region; size of largest particle is about 6 mm.*

During this period the corresponding radar pixels showed particle categories varying from "dry snow" to "graupel/small rain" to "graupel/rain." As noted, the image data show no sign of raindrops; with the sizable concentrations of small ice particles present any supercooled drops would not be expected to remain liquid for long. Neither would graupel of the observed sizes be expected to be in wet growth (which might appear to the radar as a liquid drop) in the observed cloud liquid water concentration (LWC) of around 1 g $m^{-3}$. The principal distinction between the "graupel/rain" and the "dry snow" pixels appears to be the generally smaller sizes of the ice particles in the latter cases.

### Hail and Rain/Hail

On a similar path nearly toward the S-Pol radar half an hour later, the T-28 encountered hail along the edge of an updraft and then some apparently liquid drops in the updraft itself (Figure 2). There were relatively few small ice particles in the updraft region, so the drops may have been carried up to the penetration level quickly enough not to have been frozen by the time of the T-28 encounter.

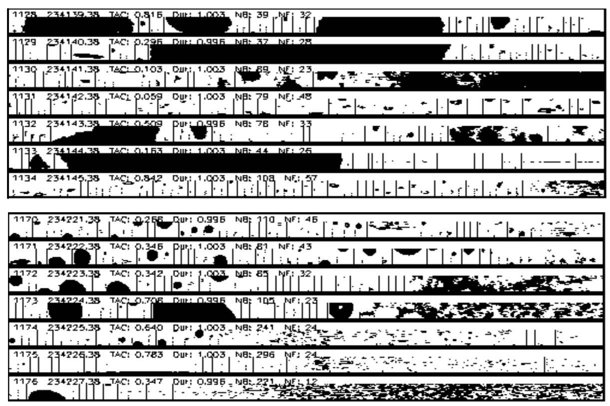

*Figure 2: Images from the 2D-C probe in (top) the center of a radar-identified "hail" region more than 5 km across (visible dimension of largest particle about 1.2 cm), and (bottom) the adjacent updraft region with drops up to about 3 mm in size.*

In this region, the radar classifier indicated "hail" first, then rain mixed with hail, then "graupel/small rain", and then "hail" again on the other side of the updraft (Figure 3). Values of ZDR up to 3 dB and specific differential phase up to 1 deg/km in the region where the lower images in Fig. 2 were obtained are consistent with the inference of liquid drops. While no rain was observed directly mixed with the hail, the proximity of the region with liquid drops makes it plausible that the radar beam encompassed both some of the hail and the nearby rain in the same contributing volume.

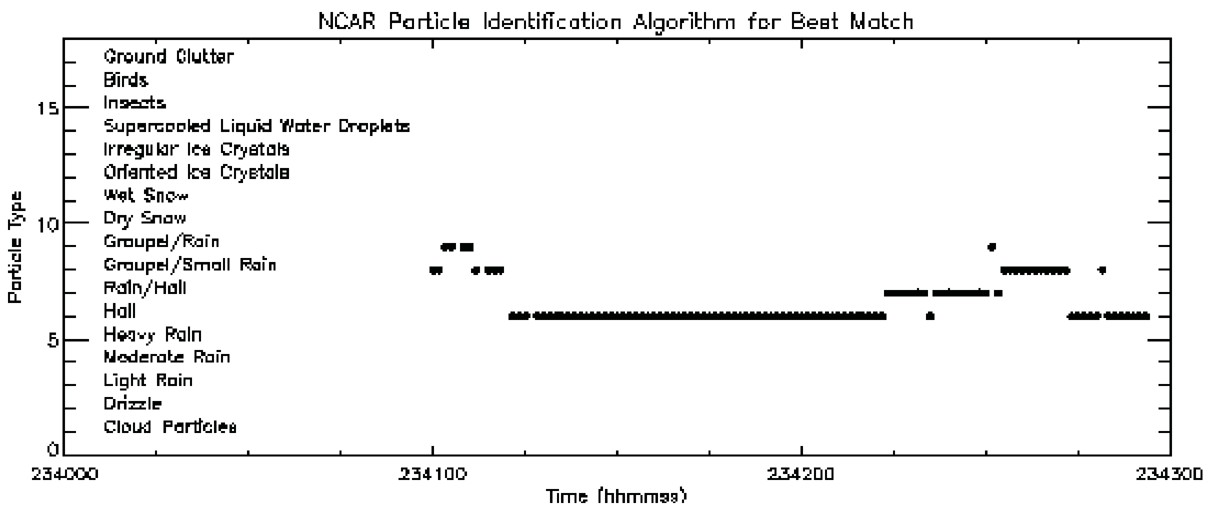


*Figure 3: Radar particle classifications for the period spanning the images in Fig. 2.*

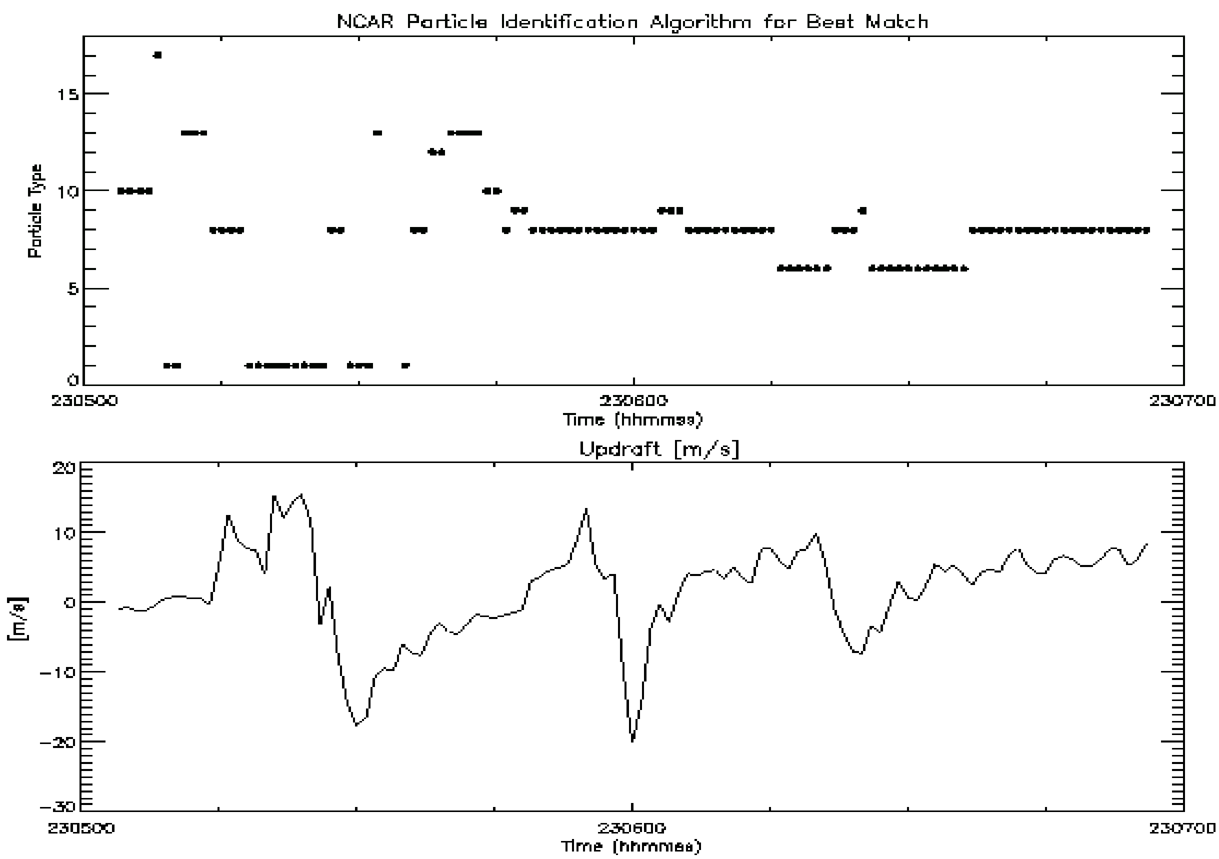


*Figure 4: (Top) The radar particle classifications for the weak-signal region corresponding to a fresh updraft/downdraft couplet on the north side of the storm, and the mature cell adjacent to the south. (Bottom) Updraft plot for the same time interval; the fresh couplet appears in the first 40 s of this plot, and the T-28 then entered the mature cell.*

**A weak signal situation**

During the penetration prior to the example shown in Fig. 1, the T-28 passed through a fresh updraft/downdraft couplet on the north side of the storm. At this time the aircraft was on a south-southeasterly heading about 40 km east of the radar. The updraft was a little over 1 km wide, with updraft speeds up to 15 m $s^{-1}$ and cloud LWC in excess of 2.5 g $m^{-3}$. The adjacent downdraft was narrower but also reached 15 m $s^{-1}$. Just a few submillimeter particles were observed on the T-28 instruments in this region. The weak echoes in this situation (compounded with the switching of the "proximate pixel" algorithm between two radar scans about 2 min apart) caused the classifier to vacillate among three or four categories (Figure 4). While most of those categories would be appropriate to a region of weak echoes, the suggestion of irregular ice particles and graupel/rain in the fresh updraft (around 230515 in the plot) is not very plausible.

In this situation the co-polar echo power for the scan closest in time to the aircraft penetration was generally less than –100 dBm. Thus the weaker cross-polar signal levels are near the system noise level, making the determination of variables like LDR or the channel cross-correlation subject to erratic variations. Such a situation with cross-polar signal levels too weak to yield valid data will arise when the co-polar signal itself becomes weak: in newly-developing echoes, around the periphery of stronger echo cores, and in storms at great distances from the radar.

## 5. Preliminary Findings

The analysis thus far has indicated several things:

1. The classifier indications of the presence of hail appear to be consistent with the in situ microphysics data.
2. While the aircraft data from the storm contain no direct examples of hail mixed with rain, the one extended interval with radar indications of a "rain/hail" mixture corresponds to a penetration with hail along the edge of an updraft and raindrops in the adjacent updraft region. Consideration of the beam geometry suggests that the radar inference was plausible for the situation that existed.
3. None of the extensive (nearly 400 s worth) aircraft data in the regions where the radar indicated a "graupel/rain", or "graupel/small rain", mixture showed any evidence of raindrops. The abundance of ice particles in those regions makes the survival of liquid drops unlikely in any case.
4. Situations with weak signal levels in the main (co-polar) channel, and correspondingly weaker cross-polar signals, cause difficulties for the classifier algorithm.

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