Examination of early echoes of developing convective storms

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Background

- Effective use of radar data in models in reducing spin-up time (e.g. Warn-on-Forecast) requires a good understanding of initial observed echoes and their associated processes.
- Many studies have investigated the impact of varying CCN concentrations on overall convective development and aerosol indirect effects.
- Previous studies of initial radar echoes of developing thunderstorms focused primarily on observations of the height of the first radar echo and rate of development. These studies generally only employed single-polarization radar data.
  - For studies employing dual-polarization radar, anomalously high-Z_{DR} early in storm lifecycle has been observed (Ilingworth et al. 1987; Knight et al. 2002; Knight 2006) but is poorly understood – a need for modeling studies was highlighted.
- Difficulties in early echo data collection remain.

The goal of this study is to investigate the effects of varying CCN concentration on initial polarimetric echo characteristics in developing storms.

Methodology

- The Hebrew University Cloud Model (HUCM), a non-hydrostatic 2-D model with rigorous spectral bin microphysics, was used to simulate strong convection from initiation:
  - Background sounding from a strong hailstorm that struck southwest Germany in 2006 was used to initialize the model
  - $\Delta x = 300$ m, $\Delta z = 100$ m, 1-min output
- Five CCN conditions that decrease exponentially with height were tested:
  - $CCN_{sfc} = 100$ cm^{-3}
  - $CCN_{sfc} = 500$ cm^{-3}
  - $CCN_{sfc} = 1000$ cm^{-3}
  - $CCN_{sfc} = 1500$ cm^{-3}
  - $CCN_{sfc} = 3000$ cm^{-3}
- Radar variables at each time step were computed using a polarimetric radar operator (Ryzhkov et al. 2011) at *S-band*.

Results

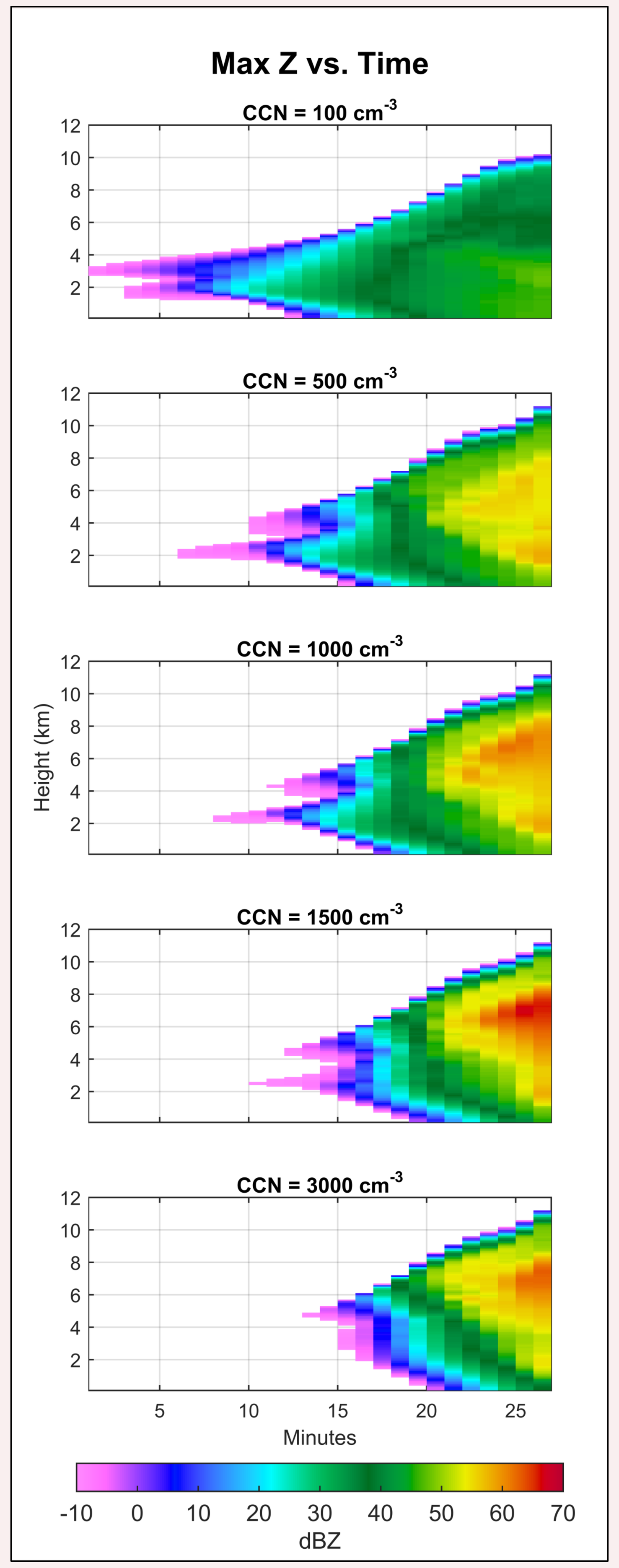

Figure 1: Time-height diagram of maximum reflectivity for five different CCN concentrations from the HUCM.

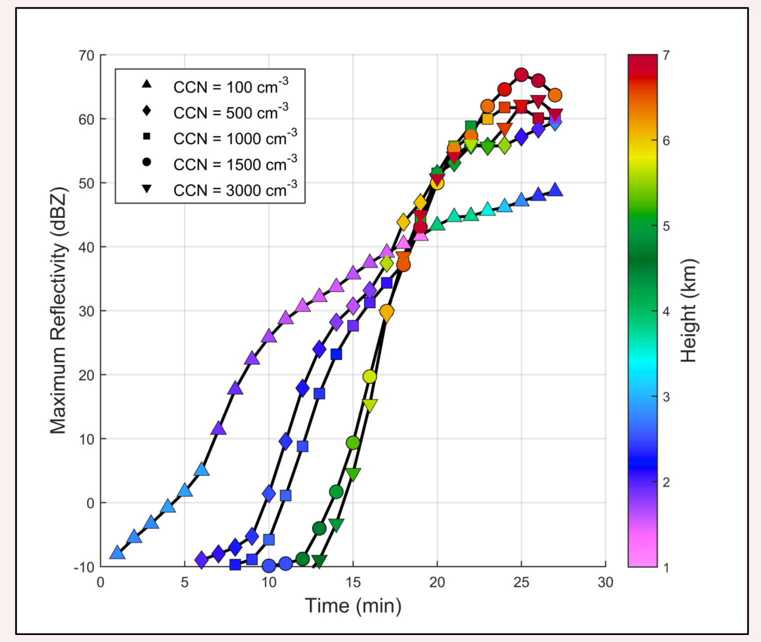

Figure 2: Maximum reflectivity vs. time for five different CCN concentrations from the HUCM, colored by the height at which the maximum reflectivity occurs.

- Initial precipitation formation is *delayed* by **12-14 minutes** between 100 cm^{-3} to 3000 cm^{-3} cases due to suppressed collision-coalescence processes, consistent with previous studies.
- As CCN concentration **increases**:
  - dZ_{max}/dt **increases**
  - height of Z_{max} **increases**
  - Z_{max} generally **increases**
- For *low CCN* cases, initial precipitation is warm rain just above cloud base (z = 1.5 – 3 km) that develops gradually.
- With increasing CCN, ice phases also begin to form causing initial bimodal Z distribution with respect to height.
- For *highest* CCN cases, graupel undergoes extremely rapid growth from accretion owing to a large excess of supercooled droplets making it above the freezing level and resulting in very high dZ_{max}/dt with little/no warm rain generation.

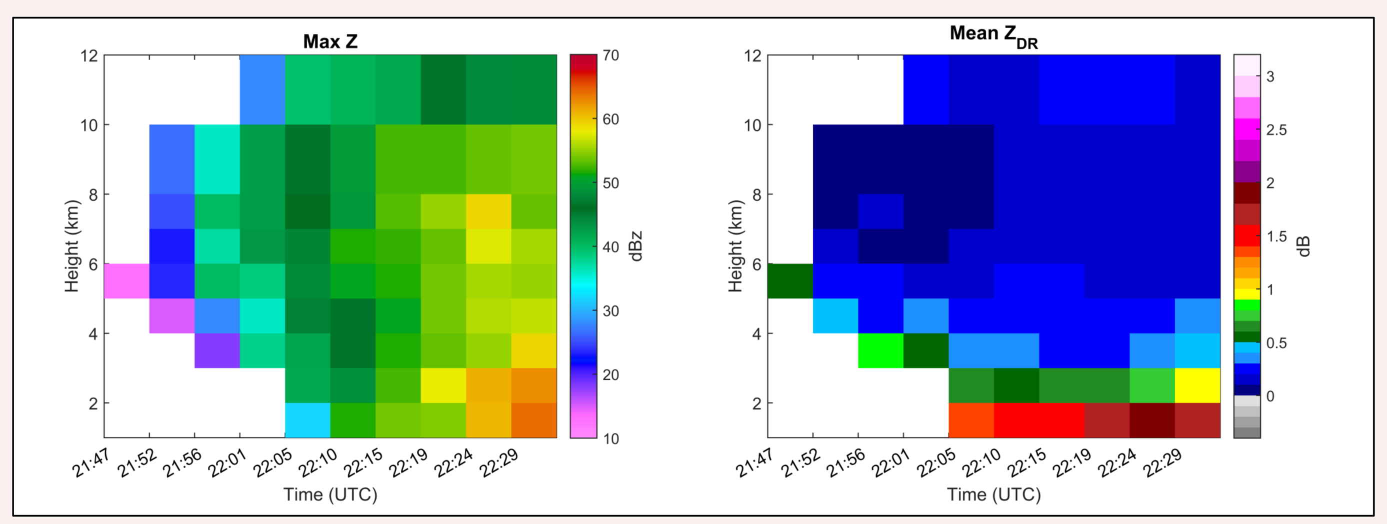

Figure 3: Time-height diagram of (left) maximum reflectivity and (right) mean differential reflectivity in a developing thunderstorm sampled by KOUN on 12 April 2014.

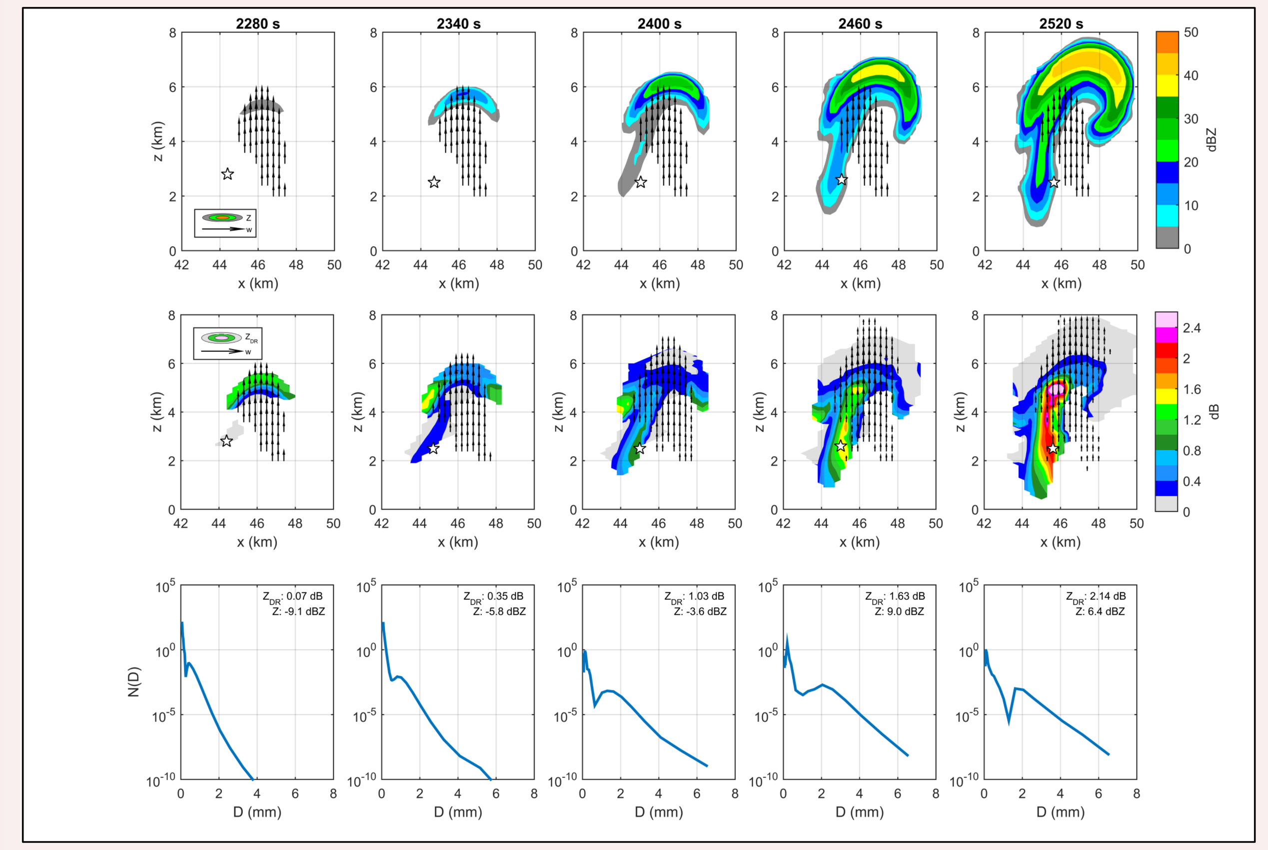

Figure 4: Cross-sections of Z (top), Z_{DR} (middle), and rain DSDs (bottom) at one-minute intervals in the developing stages of the storm with $CCN_{sfc} = 3000$ cm^{-3}. Vertical velocity > 5 m s^{-1} is shown by vectors. The rain DSDs are for the points denoted by stars on the Z_{DR} plots.

- Very early high-Z_{DR}/low-Z signature upwind of updraft and underneath high-Z region able to be reproduced *in high CCN cases.*
  - Consists of very low concentrations of large drops and is qualitatively very similar to those seen in Knight (2006).
  - Extremely anomalous Z_{DR} values (see Fig. 5).
  - Forms simultaneously through a large depth and only lasts for a few minutes before rain from ice phases begins to dominate.

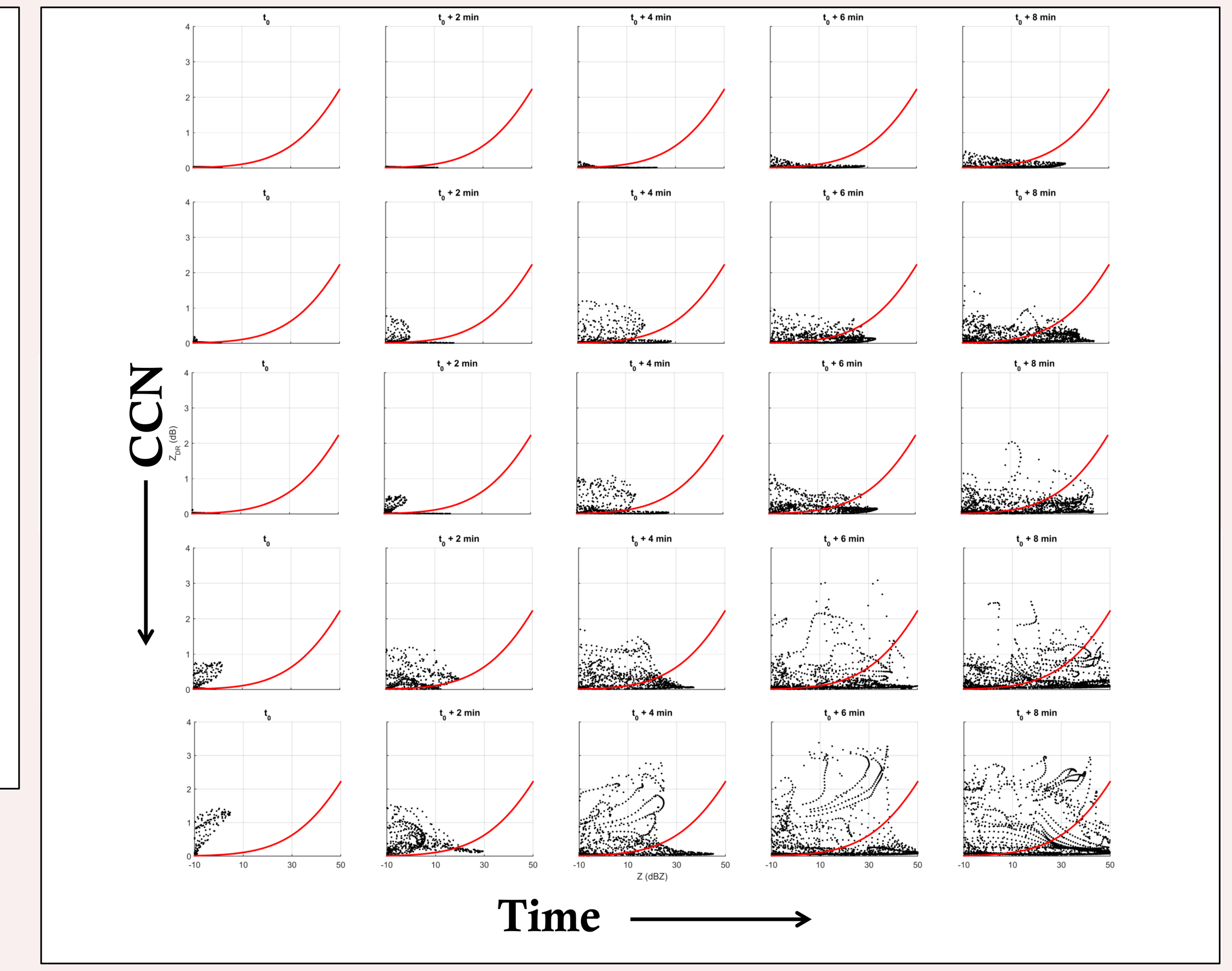

Figure 5: Scatterplots of Z vs. Z_{DR} at two-minute intervals for all five CCN cases. t_0 denotes the time in each case of the first occurrence of $Z \geq 0$ dBZ. The typical Z-Z_{DR} relation is shown in red and taken from Cao et al. (2008).

- Theory: Delayed warm rain processes in high CCN cases result in large availability of cloud drops for collection by a select few "lucky" drops resulting in extremely rapid coalescence.
- As CCN concentration increases, early values of Z_{DR} (with low Z) become increasingly high and widespread due to the aforementioned process despite much lower rain mass overall.

Summary and Future Work

- The polarimetric characteristics of initial echoes are strongly sensitive to initial CCN concentration.
  - Increasing CCN concentration delays precipitation and results in faster storm development at higher altitudes.
- Poorly understood early echo high-Z_{DR}/low-Z signature seen in previous observational studies has been reproduced and is a result of extremely rapid coalescence of a few large drops
- Early high Z_{DR} signature increases with increasing CCN.
- Ongoing work will continue to:
  - investigate the effect of varying environmental stability and moisture;
  - investigate the role of giant/ultragiant nuclei in determining early echo characteristics and possible role in early-Z_{DR} signature; and
  - collect observational data of early echoes using polarimetric KOUN.

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