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Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Retrieving the hail size distribution from C-band radar Doppler spectra

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How can Doppler spectra from vertically pointing radars be exploited for deriving the hail size distribution (HSD), here: using DWD's birdbath scan?
How can multimodal Doppler spectra of hail and rain be processed?
Do major features of radar-retrieved HSDs agree with in situ observations?
Which hail size characteristics can be calculated from the radar-retrieved HSDs?
How well can exponential size distributions represent radar-retrieved HSDs?

Fig. 1: Hail supercell 10 min before passing over the DWD observatory Hohenpeißenberg on 30 April 2021. Red arrow indicates radar tower with DWD's C-band research radar.

Method for retrieving the hail size distribution (HSD)

Doppler spectra of hail (and rain)

Birdbath scan strategy and spectral postprocessing is based on Gergely et al. (2022), but clutter signal is not corrected (because clutter is not that significant in intense precipitation) and multiple precipitation modes, i.e. Doppler peaks, at each height are identified based on fixed power threshold (instead of adaptive algorithm, for speed and robustness) after Doppler spectra have been unfolded (semi-automated).

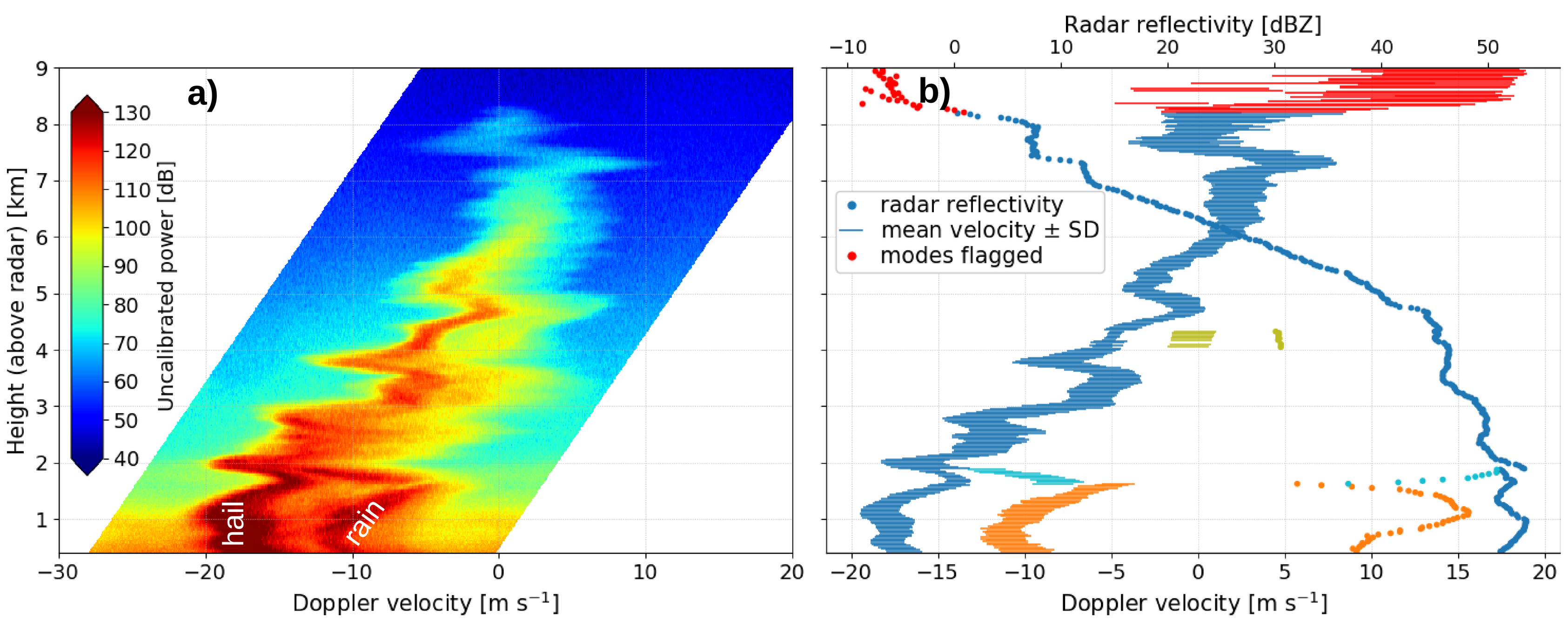


Fig. 2: (a) Profile of unfolded Doppler spectra recorded for the supercell shown in Fig. 1 while both hail and rain were observed at the ground. (b) Results of automated spectral postrprocessing and multimodal analysis, isolating individual precipitation modes. Dark blue and orange modes at ~ 0.4 to 1.4 km height indicate hail and rain, respectively.

Retrieval of HSD from near-surface Doppler spectra

Fundamental idea similar to Ulbrich (1974): (i) Convert Doppler velocities to hail sizes with previously determined hail size-to-fall-velocity relationships, (ii) determine the hailstone concentration in each spectral velocity bin, i.e. size bin, from the intensity of the radar signal. But, we separate hail mode from rain mode first, anchor the slow edge of the hail mode to the minimum hail size (here: 5 mm) and estimate the maximum hail size from the 'elbow' point and fast-falling tail of the hail mode. So far, only dry hail is included in the analysis (i.e. no liquid water in hail mode).

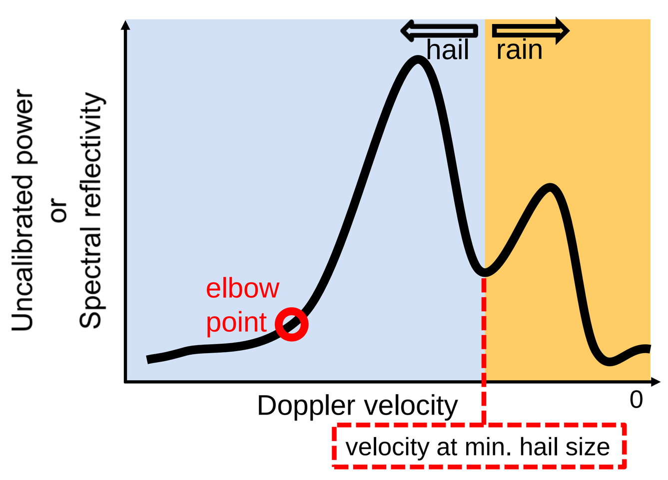
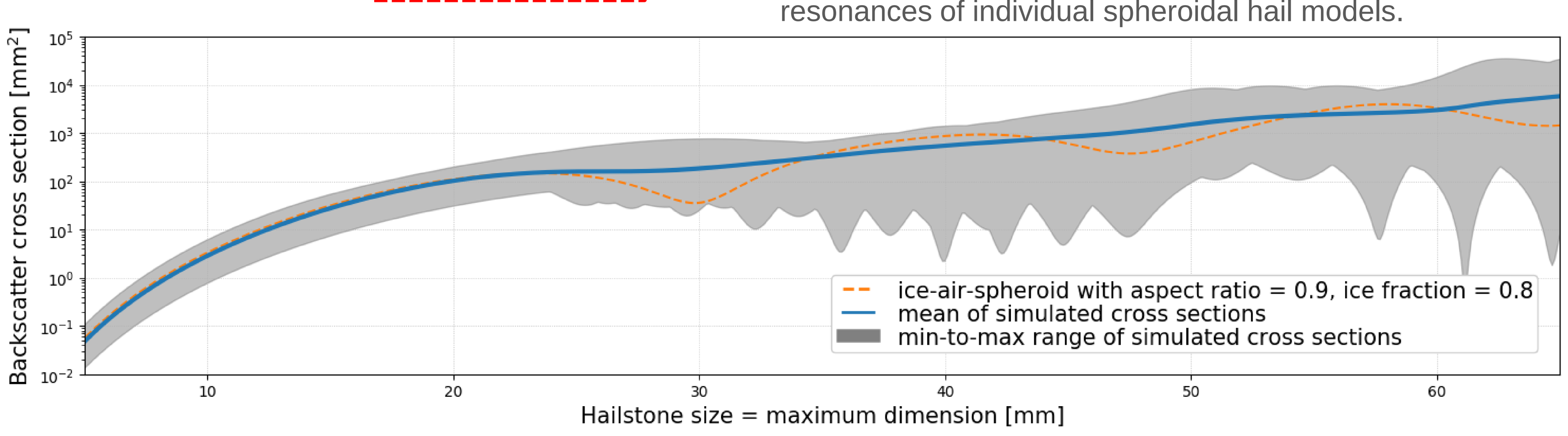


Fig. 3: Sketch of a bimodal Doppler spectrum at a height of about 0.7 km above the radar as shown in Fig. 2. Hail and rain modes are separated at the local minimum in Doppler power found between the two mode peaks.

Fig. 4: Summary of T-matrix scattering calculations for (dry) hail. The retrievals use the mean of all simulated cross sections for each hailstone size, which smoothes the strong resonances of individual spheroidal hail models.



HSD retrieval results

Radar-retrieved HSD vs. automatic hail sensor

HSDs derived from Doppler spectra show a plateau for small hailstones and then a rapid exponential decay (similar to in situ sensor), but also much higher (and more realistic based on manually sampled hailstones) maximum hailstone sizes and stronger exponential decay (i.e. higher slope parameters Λ). One critical difference is the much larger sampling volume of the radar measurements vs. in situ observations.

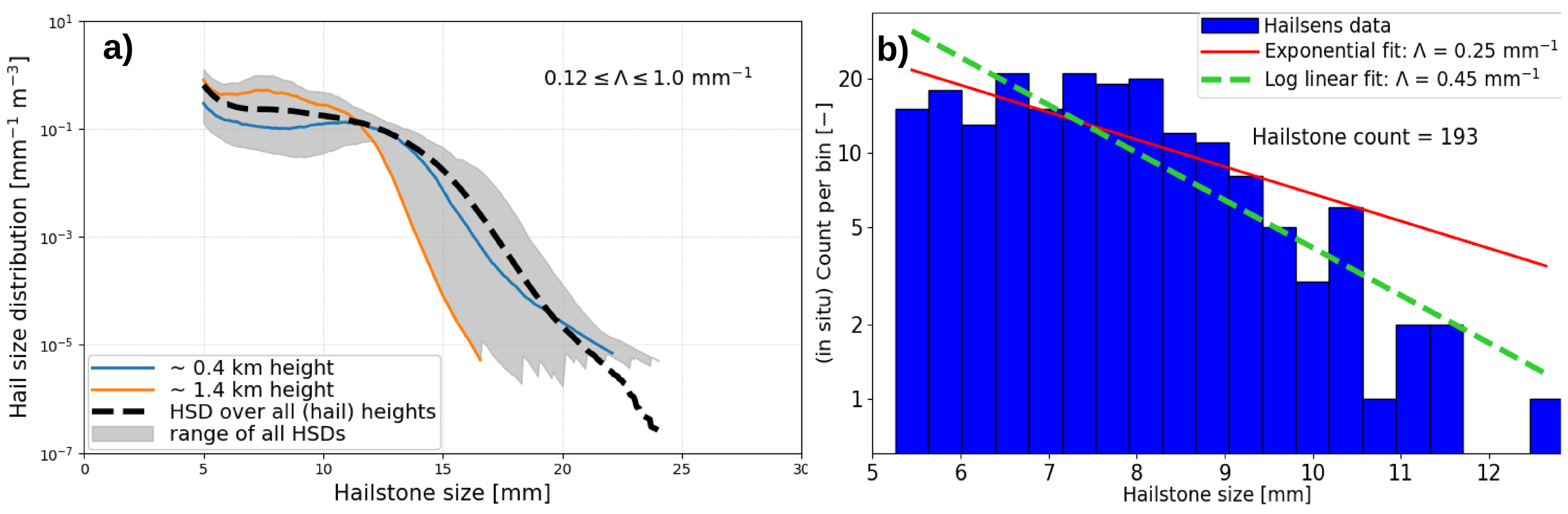


Fig. 5: (a) Hail size distributions retrieved from profile of Doppler spectra shown in Fig.2, with corresponding range of slope parameter Λ for fitted exponential size distributions. (b) In situ data from automatic hail sensor at the ground that estimates hailstone sizes from the impact energy of the hailstones on a plastic disc of 0.5 m diameter.

HSD characteristics and exponential fits

Characteristic hail properties can then be calculated from the full hail size distribution, both for spectral bin-by-bin radar retrievals and for fitted exponential distributions, e.g., number density, hail ice water content, atmospheric kinetic energy content E_kin at terminal fall velocity, hail rate, median mass diameter D_0, and energy-weighted mean diameter D_Ekin (e.g. Grieser and Hill, 2019).

a)

	Number density [m^{-3}]	Ice water content [g m^{-3}]	E_kin [J m^{-3}]	Hail rate [mm h^{-1}]	D_0 [mm]	D_Ekin [mm]
bin-by-bin retrieval	1.78	0.42	0.02	13.2	11.22	11.67
exp. fit logspace linear fit	3.88	0.36	0.01	8.98	7.31	8.98

b)

	Number density [m^{-3}]	Ice water content [g m^{-3}]	E_kin [J m^{-3}]	Hail rate [mm h^{-1}]	D_0 [mm]	D_Ekin [mm]
bias of fits [%]	106.8	-19.2	-47.0	-35.0	-34.6	-23.1

Fig. 6: (a) Average values of several characteristic hail properties calculated for the HSDs shown in Fig. 5a. (b) Mean percent difference (i.e. bias) for calculating the HSD characteristics for the fitted exponential size distributions instead of the bin-by-bin retrieved HSDs (with same minimum and maximum hail size).

Conclusions and outlook

- C-band radar Doppler spectra contain detailed information about HSDs
- If hail mode can be separated from rain and if hail microphysics (fall velocity, scattering properties) can be described adequately, characteristic hail properties can be estimated together with a detailed analysis of how the assumptions made for the HSD retrieval impact the retrieval results
- Next: How do results change if wet hail is included? Can the transition region between hail and rain modes be modeled more realistically?

References

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