Evaluation of Cloud Ice Microphysical Models with Habit Prediction Using Polarimetric Radar Observables

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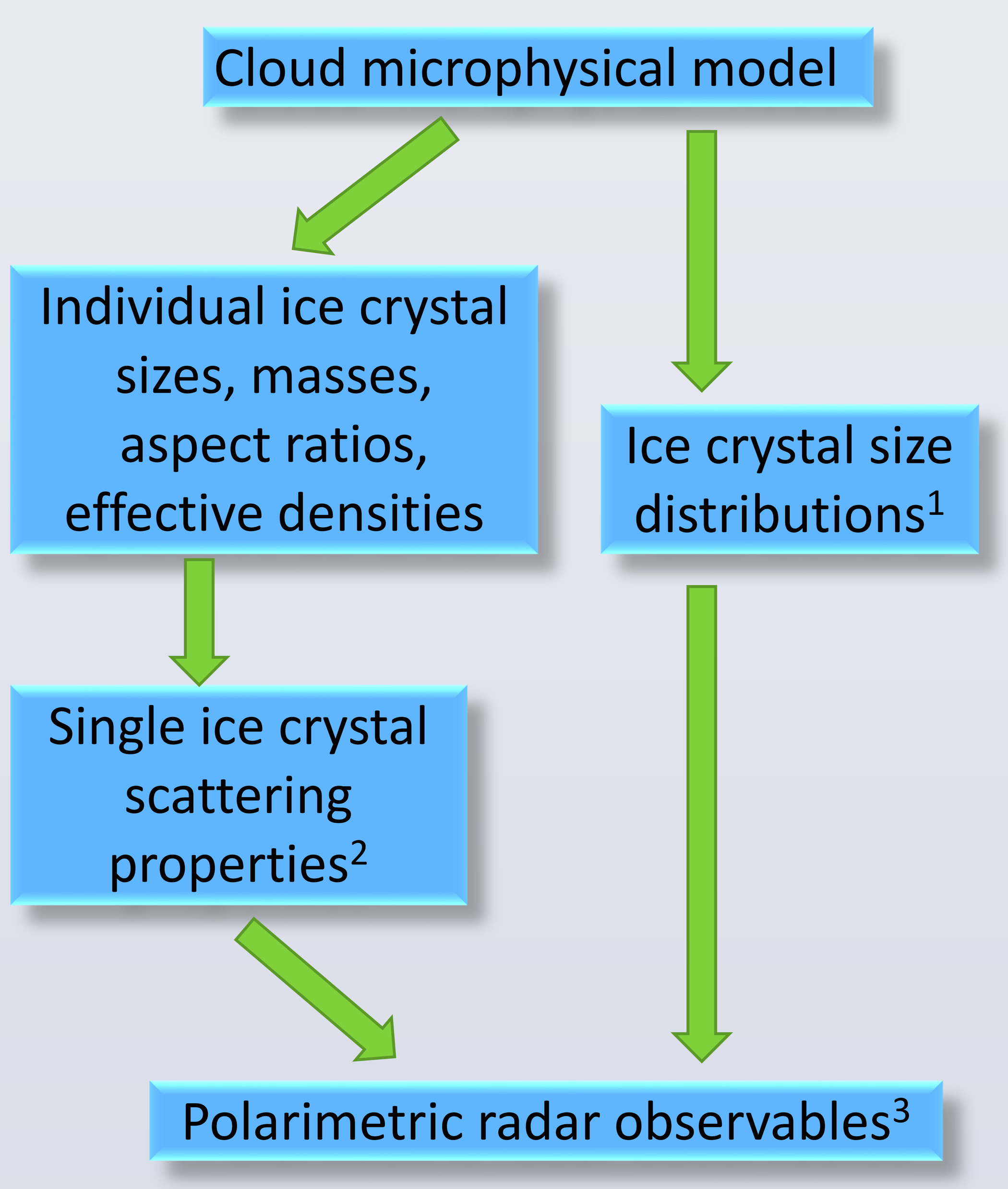
Introduction

- Ice particle scattering properties depend on their masses, sizes, and aspect ratios.
- In traditional cloud microphysical models ice crystal aspect ratios are fixed, leading to errors when simulating polarimetric radar observables using forward scattering models.
- The adaptive habit prediction model presented in Harrington and Sulia (2011) predicts the masses, maximum dimensions, densities and aspect ratios of ice crystals, which are necessary for simulating ice crystal scattering properties using forward scattering models.
- Such a microphysical model can be evaluated by comparing polarimetric radar observables calculated from it with real radar observations.

Work flow



1. Particle size distributions:
   - Provided by cloud microphysical model
2. Single scattering properties:
   - Backscattering cross section: σ
   - Amplitude scattering matrix: S
3. Polarimetric radar observables
   - Reflectivity at hh-polarization

$$Z_{\mathrm{hh}} = \frac{\lambda^4}{|K|^2\pi^5}\int_{D_{\min}}^{D_{\max}} \overline{\sigma_{\mathrm{hh}}(D)} N(D)dD \ \ (\mathrm{mm^6\ m^{-3}})$$

   - Reflectivity at hh-polarization

$$Z_{\mathrm{vv}} = \frac{\lambda^4}{|K|^2\pi^5}\int_{D_{\min}}^{D_{\max}} \overline{\sigma_{\mathrm{vv}}(D)} N(D)dD \ \ (\mathrm{mm^6\ m^{-3}})$$

   - Differential reflectivity

$$Z_{\mathrm{DR}} = 10\log_{10}\left(\frac{Z_{\mathrm{hh}}}{Z_{\mathrm{vv}}}\right) \ (\mathrm{dB})$$

   - Specific differential phase

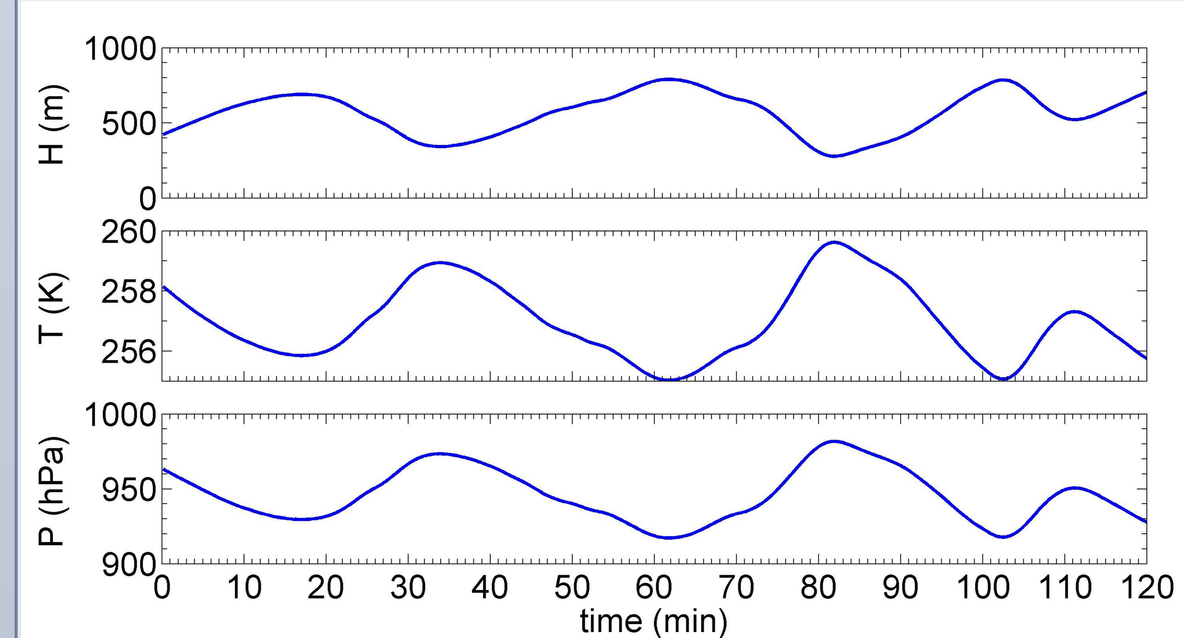
$$\mathrm{K_{DP}} = \int_{D_{\min}}^{D_{\max}} -10^{-3}\frac{180}{\pi}\frac{2\pi}{k^2}\mathrm{Im}\{\overline{S_{\mathrm{hh}}(D) - S_{\mathrm{vv}}(D)}\}N(D)dD \ \ (\mathrm{degree\ km^{-1}})$$

$(k=2\pi/\lambda)$

Cloud microphysical model

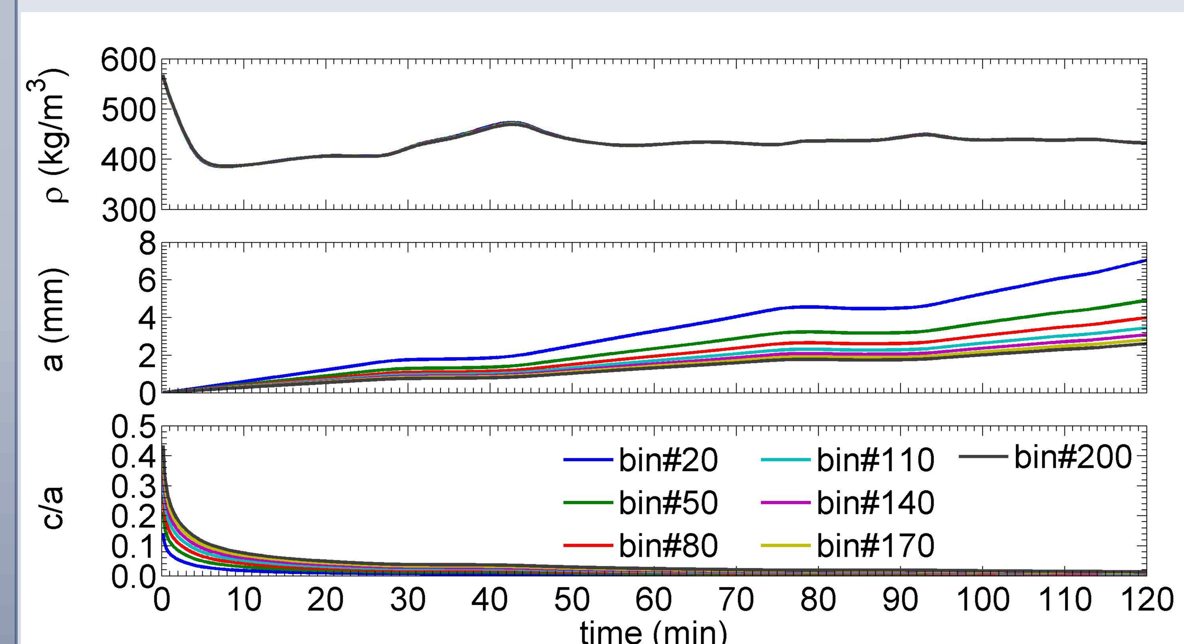
- A kinematic model incorporating the adaptive habit prediction model is used.
- Pressure field and flow field are obtained from a Large Eddy Simulation (LES) model.
- 2000 random air parcels at cloud base are selected at the beginning of the LES simulation. These 2000 parcels are tracked during the LES simulation.
- Initial temperatures of the parcels are set to -15 ℃. After that the temperatures of the parcels are determined under the adiabatic assumption.

Example: Height (H), pressure (P) and temperature (T) of one parcel trajectory



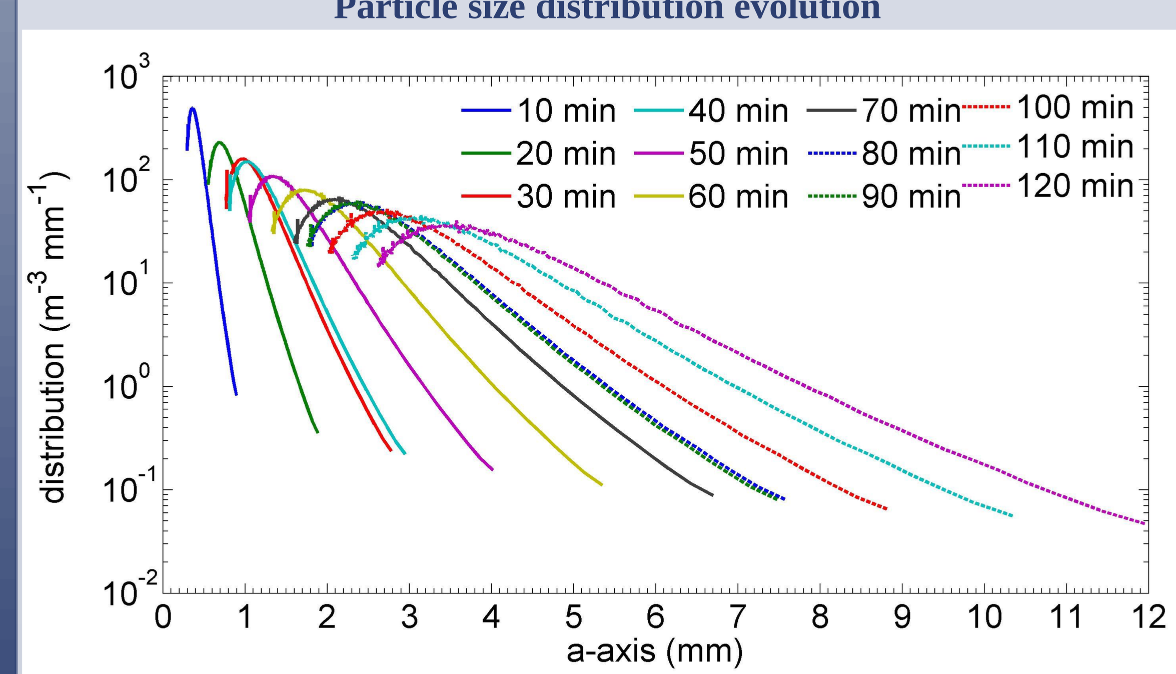
- Each air parcel has 200 liquid size bins and 200 ice size bins, both have Gamma-shaped particle size distributions initially. The a-axis (equatorial axis) and c-axis (axis of symmetry) of ice crystals can grow independently, allowing the aspect ratio to vary.

Effective density (ρ), a-axis length (a), aspect ratio (c/a) of 7 ice bins



- Particle size distributions change over time because the particles grow over time.

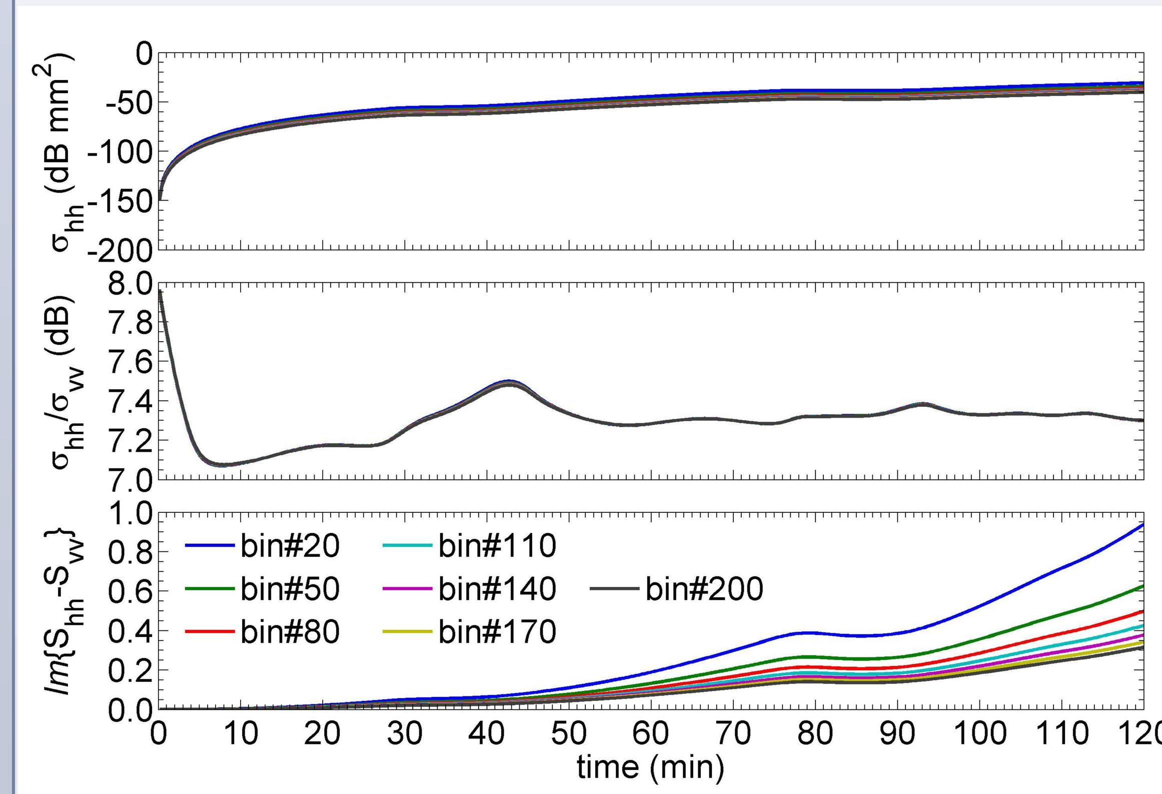
Particle size distribution evolution



Forward scattering model

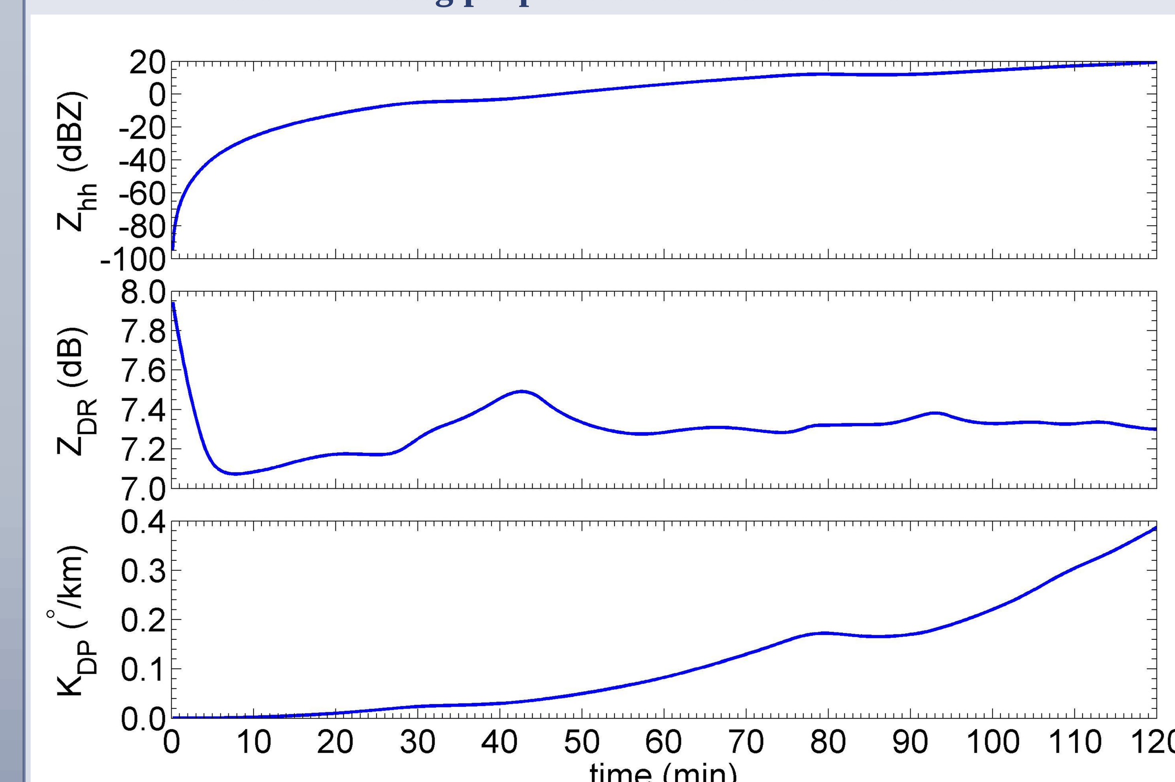
- An empirical single particle scattering model is developed based on the database built by Botta et al. (2013) with particle mass, maximum dimension, aspect ratio and effective density as predictor variables.

Single scattering properties at X-band side incidence



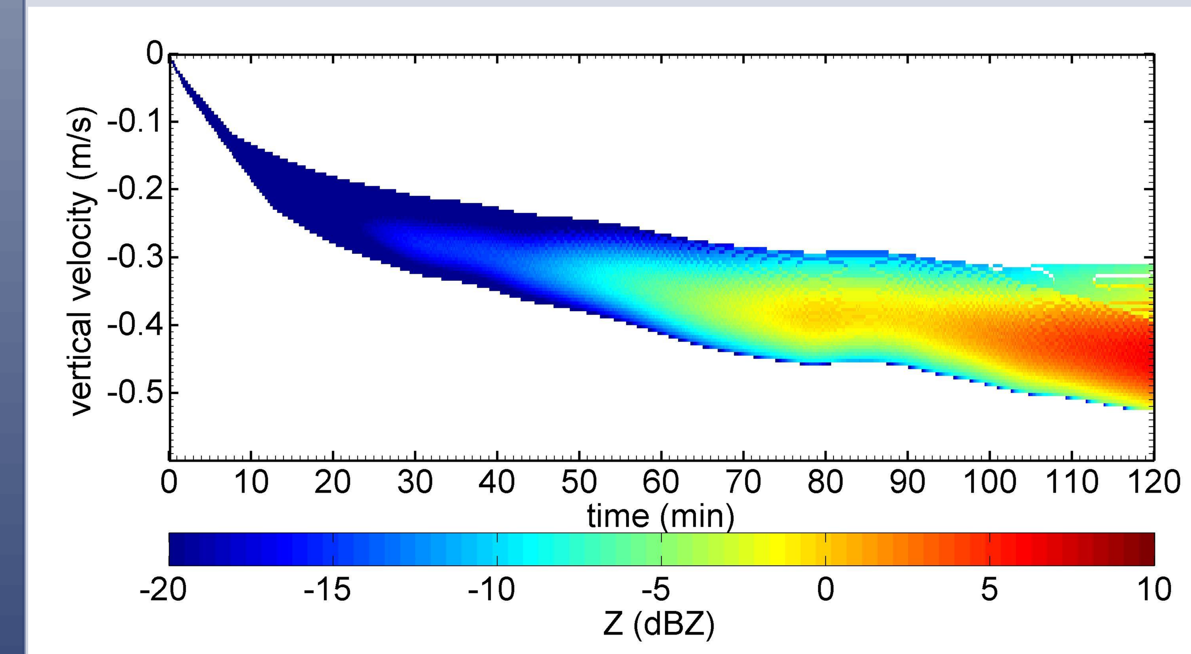
- Particle size distributions are used to calculate polarimetric radar observables.

Bulk Scattering properties at X-band side incidence



- Particle fall velocity can be used to simulate Doppler spectra.

Quite air vertical velocity spectra at X-band side incidence



Summary

- The adaptive habit prediction model predicts ice crystal masses, sizes, aspect ratios, and effective densities.
- These properties can be used to estimate single scattering properties of ice crystals, such as backscattering cross sections and amplitude scattering matrices.
- Combining the particle size distributions predicted by the adaptive habit model, polarimetric radar observables can be simulated.
- Using the particle fall speeds predicted by the adaptive habit model, Doppler radar spectra can be simulated.
- These polarimetric radar observables and Doppler radar spectra can be compared with real observations to evaluate the adaptive habit model.

Future work

- Extend the study to the adaptive habit model within a cloud resolving model.
- Evaluate adaptive habit model by comparing model-derived radar observables with radar observations from mixed-phase clouds in the Arctic.

References

Botta, G., K. Aydin, and J. Verlinde (2013), Variability in millimeter wave scattering properties of dendritic ice crystals, *J. Quant. Spectrosc. Radiat. Transf.*, *131*, 105–114, doi:10.1016/j.jqsrt.2013.05.009.

Sulia, K. J., and J. Y. Harrington (2011), Ice aspect ratio influences on mixed-phase clouds: Impacts on phase partitioning in parcel models, *J. Geophys. Res.*, *116*(D21), D21309, doi:10.1029/2011JD016298.

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