Improving the Representation of Snow Crystal Properties within a Single-Moment Microphysics Scheme

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Background

- High resolution forecast models are increasingly reliant upon bulk water microphysics schemes.
- Predict cloud constituents and precipitation rather than their net effects.
- Dilemma:
  - Many schemes available.
  - Numerous assumptions required.
  - Validation is difficult, requiring direct measurement or remote sensing.

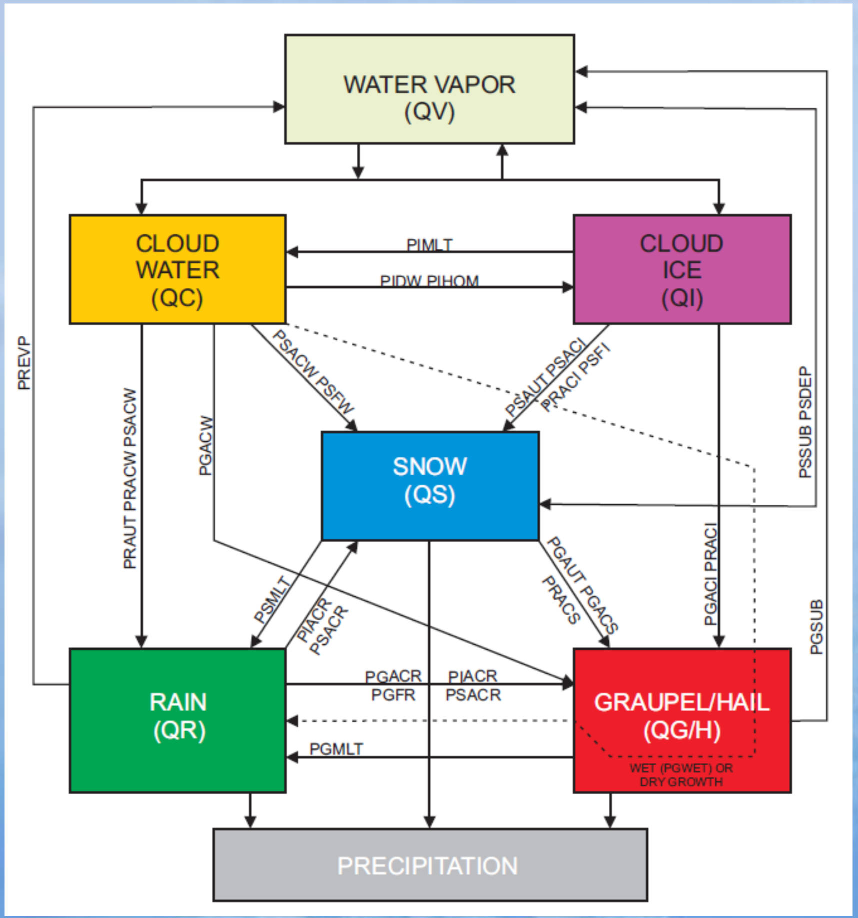


Figure 1. Example flow chart of hydrometeor classes and their related processes, adapted from Lin et al. (1983).

Approach and Methods

- Perform a high resolution (1 km) simulation of a synoptic-scale snowfall event observed during the Canadian CloudSat/CALIPSO Validation Project (C3VP).
- Compare simulated snow crystal properties and size distributions to field campaign measurements.
- Adjust model assumptions based upon observations.
- Data Sources:
  - Size distribution parameters
  - King City radar (C-band)
  - CloudSat radar (W-band)
  - Crystal terminal velocities.

WRF Simulation + NASA Goddard Scheme

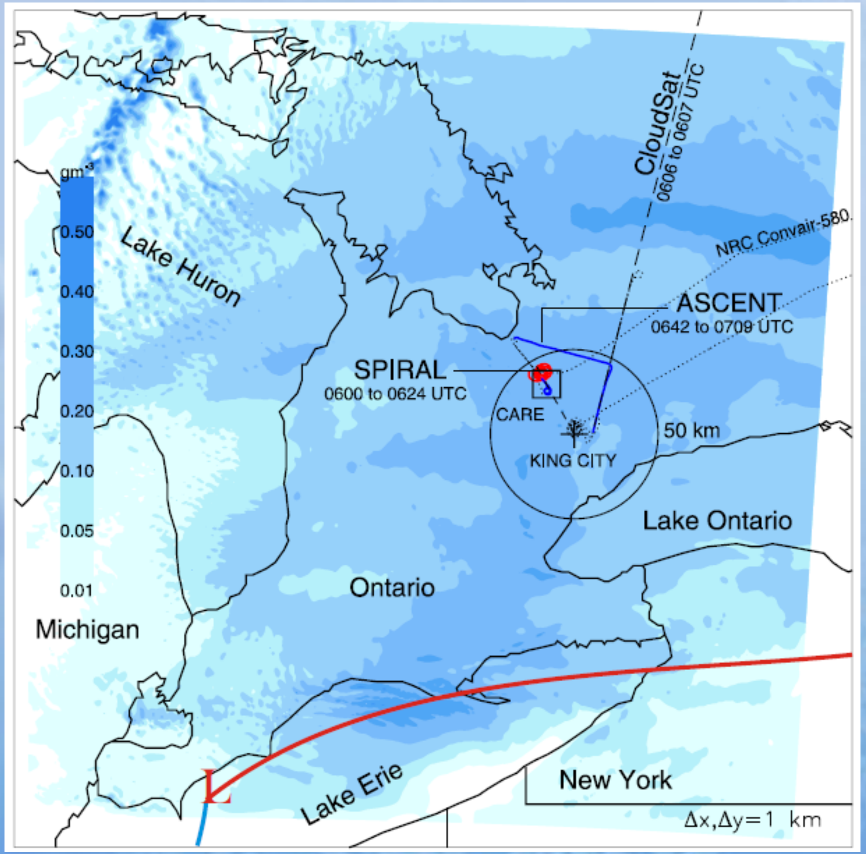
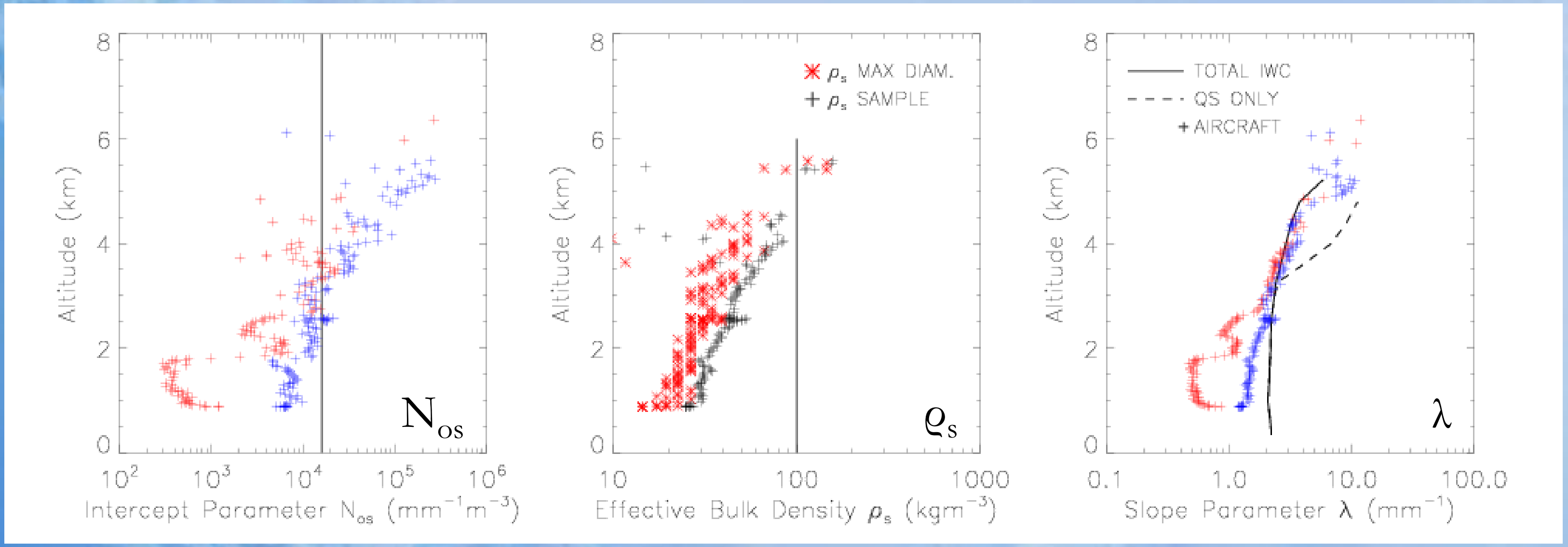


Figure 2. Snow content from the lowest model vertical level of a high resolution WRF simulation of the 22 January 2007 synoptic-scale snowfall event (shaded), along with frontal boundaries and C3VP observational data sets.

Size Distribution and Density



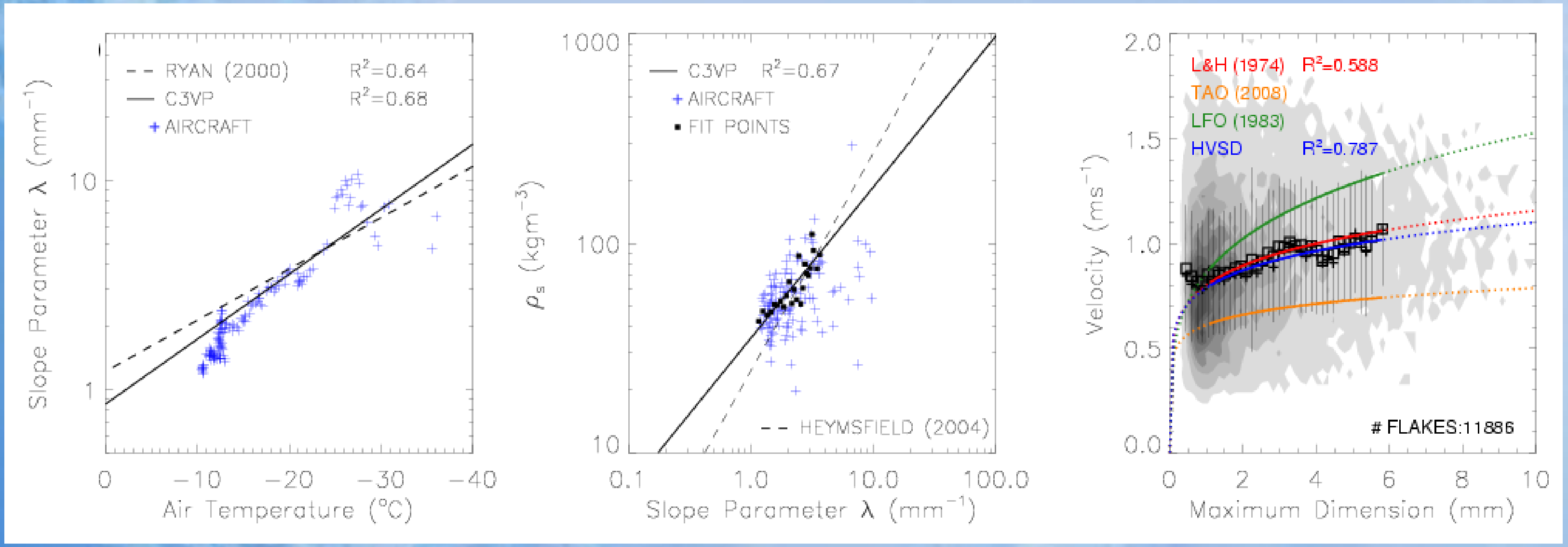
The use of a fixed distribution intercept fails to represent vertical variability within aircraft sampled profiles.

The constant value assigned to the snow bulk density does not allow for a decrease between cloud top and cloud base.

Combined, these errors fail to represent the steady decrease in mean crystal size, equal to 1/λ.

$$\lambda = \left(\frac{\pi \rho_s N_{os}}{q_s \rho_a}\right)^{\frac{1}{4}}$$

Parameterization by λ(T), ρ(λ)



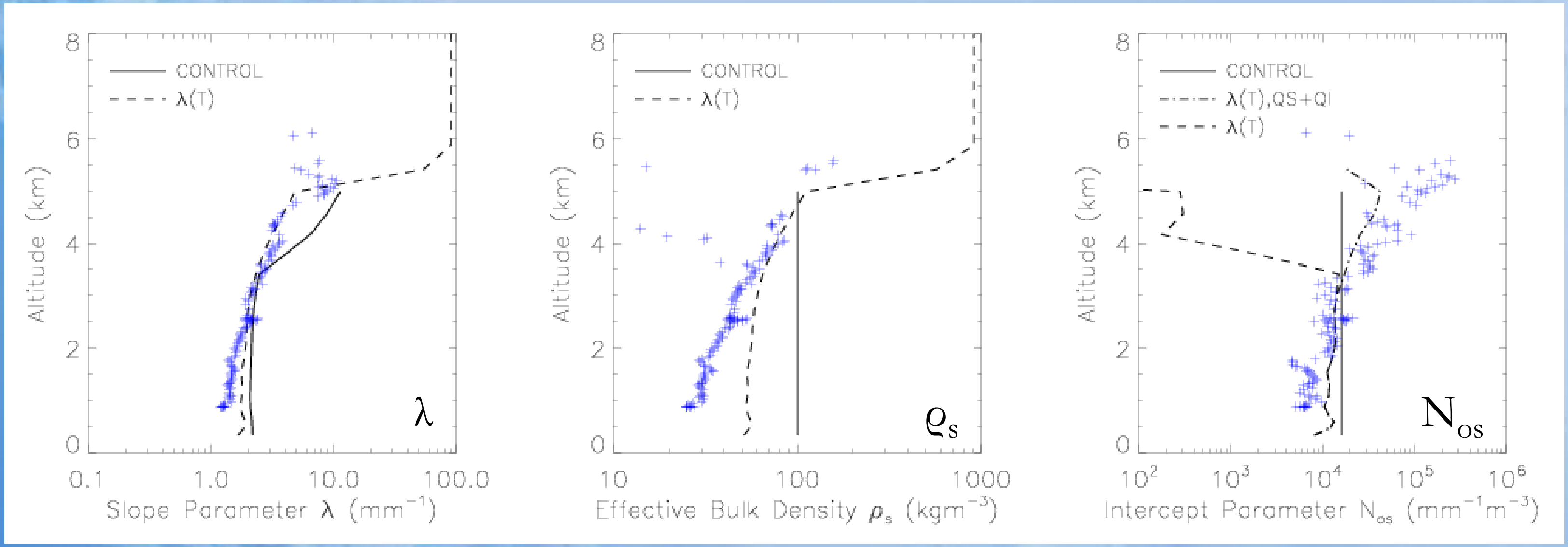
Parameterize the distribution as λ(T), following Ryan (2000), with equation adjusted to fit C3VP data sets.

Parameterize the bulk density as ρ(λ), following Heymsfield et al. (2004), using mean values of the observed ρ in small increments of λ.

Adjust the power-law relationship for diameter and fall speed to match observations of aggregates at the surface.

$V(D) = aD^b$

Parameterization by λ(T), ρ(λ)



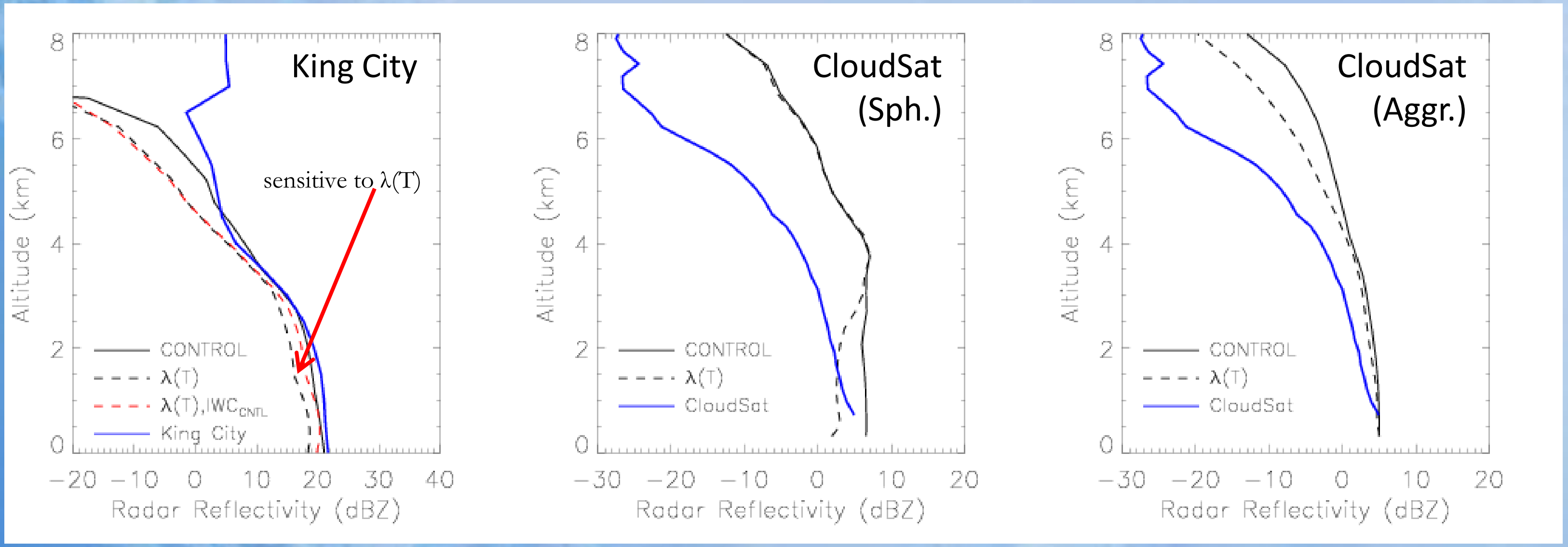
Some improvement in representing vertical variability, but limited success where temperature profile is nearly isothermal.

Improvement over a fixed value approach, but success is limited by the narrow range of λ(T) below 3 km.

Improved the vertical profile of the simulated distribution intercept.

Not shown: Slight increase (decrease) in precipitation rate (ice water content)

Radar Comparisons



Comparing median profiles of simulated reflectivity against observations, λ(T) reproduces the general profile but is sensitive to inversions.

Increasing the mean size of aggregates leads to a decrease in simulated dBZ, due to Mie resonance effects, despite a better fit to observed distributions.

Simulation of CloudSat reflectivity from complex aggregate shapes improves the fit, but neither scheme represents the lapse rate of dBZ below 3 km.

Column Integrated Parameters

- Hypothesis:
  - As an alternative, develop a column integrated value to use in parameterization.
  - Avoid complexity of the temperature profile while tracking location in the vertical column.
- Selection of “excess vapor path”, or column integral of vapor mass beyond ice saturation.
  - Crystal habit sensitive to EVP, could later provide “habit prediction” in a more involved scheme.
- Caveat:
  - Depends upon accurate portrayal of water vapor profile and will be sensitive to an accurate simulation of cloud depth.

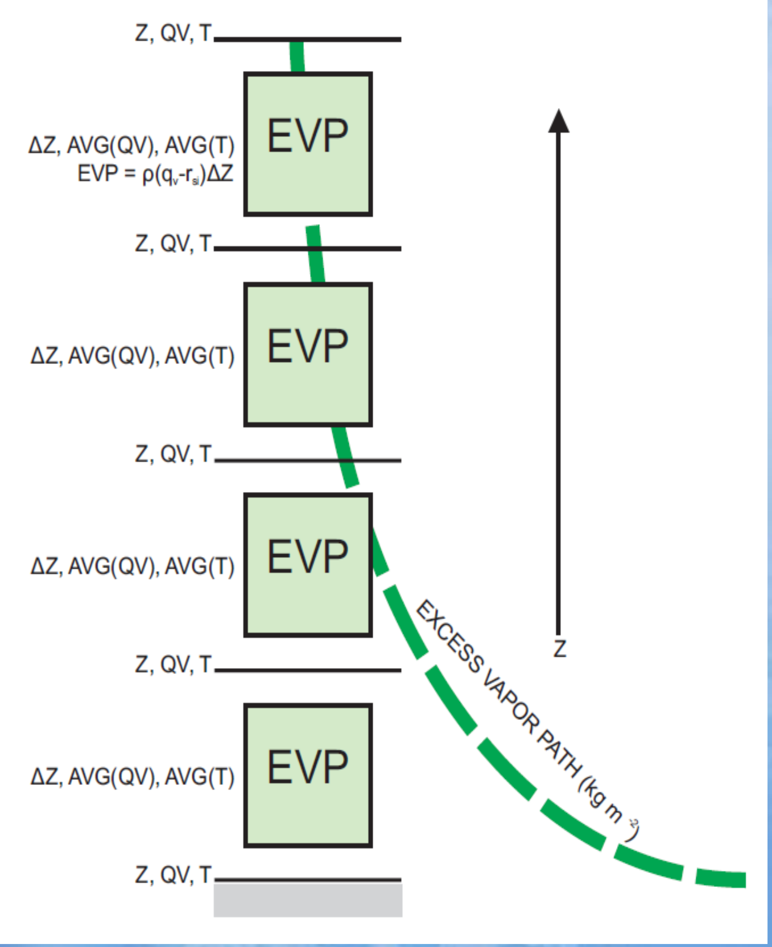
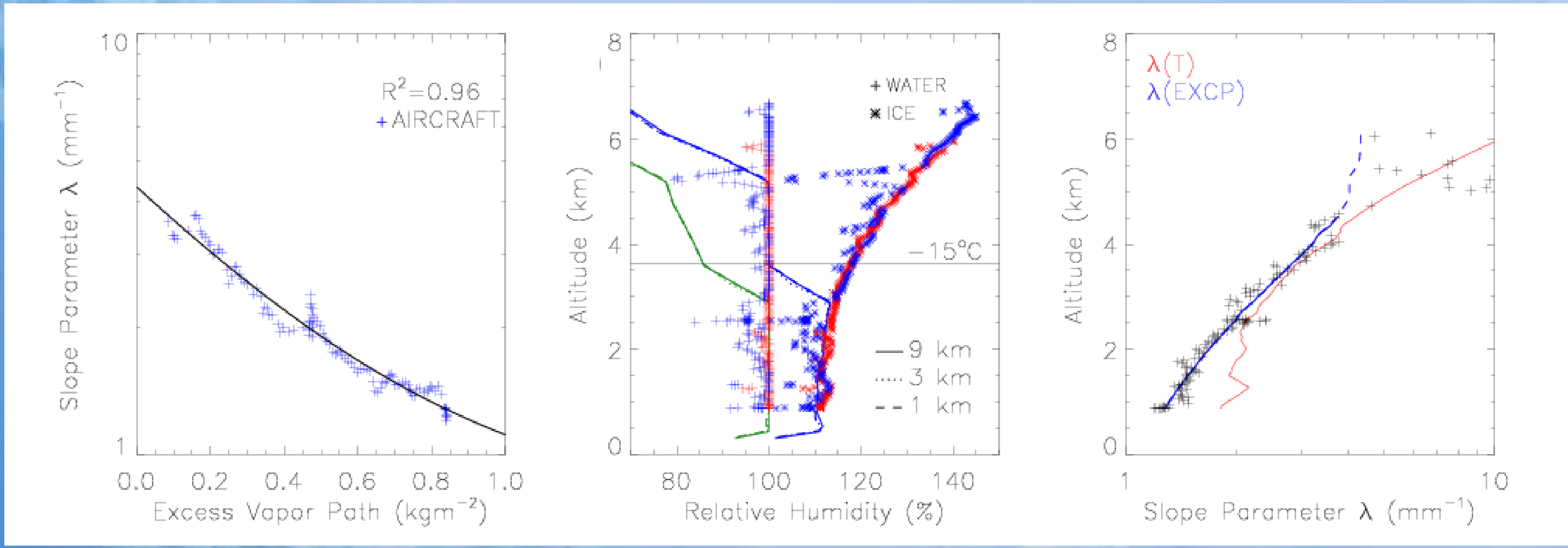


Figure 3. Methodology for estimating EVP/EXCP from aircraft data or output from a weather forecast model.

Column Integrated Parameters

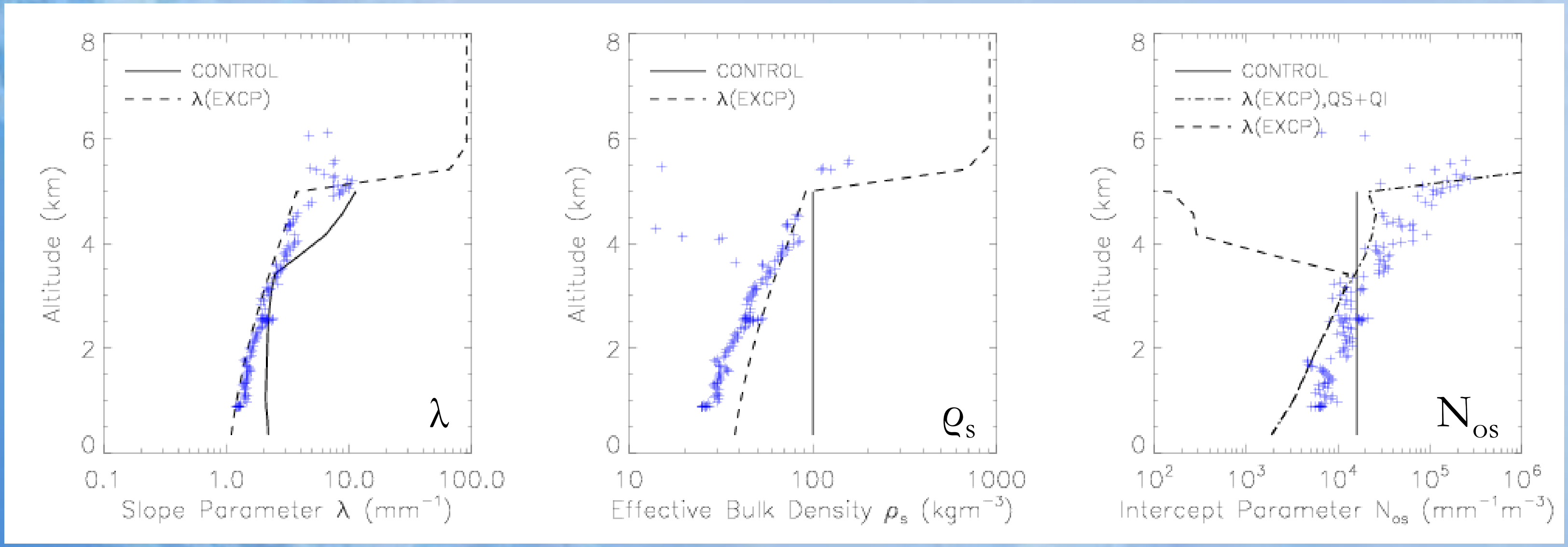


Develop a new relationship between the slope parameter and excess vapor path, λ(EXCP), while retaining ρ(λ).

Integrate EXCP where simulated ice water content exceeds 0.01 gm^{-3}, assuming saturation with respect to water to match observations.

This improves the representation of the distribution slope in regions where the temperature profile is complex or isothermal.

Column Integrated Parameters

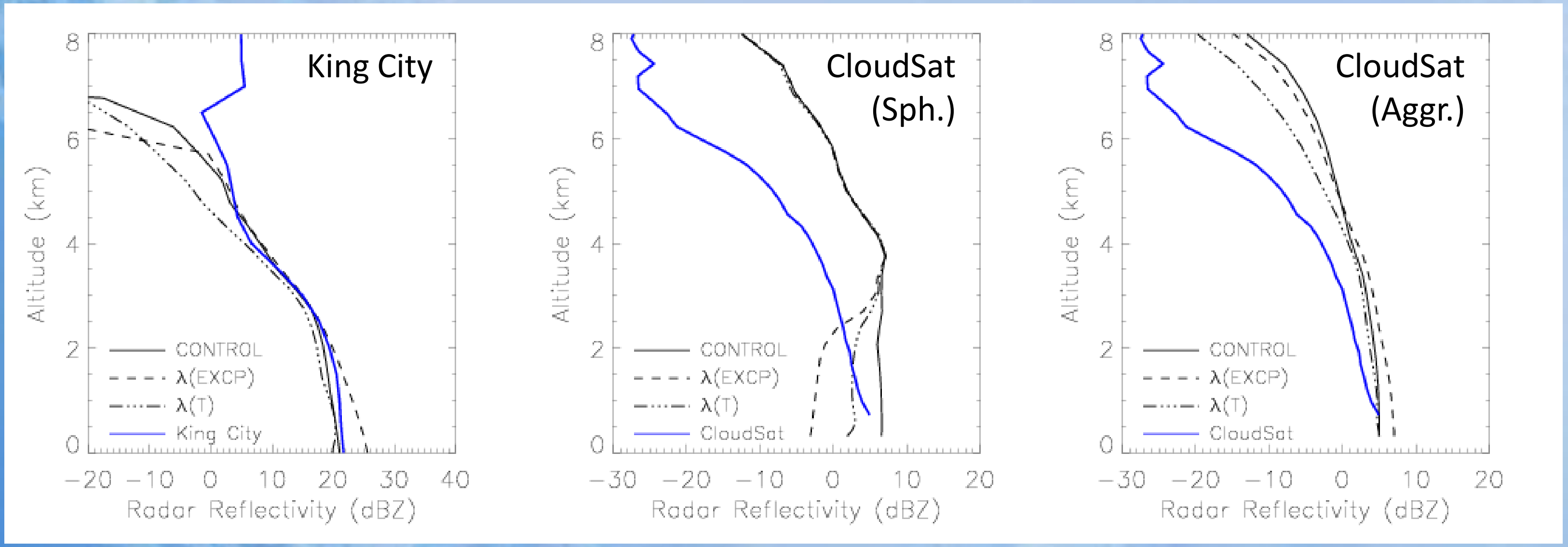


Continuous decrease in the distribution slope, since the excess vapor path continues to increase with cloud depth. Improved fit to variability in height.

Broadened range of bulk densities, with fit to observations limited by the strength of the best-fit ρ(λ) relation.

Continues the improvement upon the fixed value approach, but values of the intercept are consistently underestimated.

Radar Comparisons



Use of λ(EXCP) maintains a reasonable fit to King City radar observations, except for an overestimate in the lowest 2 km.

The column integrated approach will produce a larger mean size near cloud base, which further degrades the fit from Mie spheres.

The use of EXCP avoids the stagnation of mean aggregate size at low levels in λ(T) and continues the dBZ increase toward the surface, observed by CloudSat.

Summary

- The assumptions of a single-moment microphysics scheme (NASA Goddard) were evaluated using a variety of surface, aircraft and radar data sets.

- Fixed distribution intercepts and snow bulk densities fail to represent the vertical variability and diversity of crystal populations for this event.

- Temperature-based equations have merit, but they can be adversely affected by complex temperature profiles that are inverted or isothermal.

- Column-based approaches can mitigate complex profiles of temperature but are restricted by the ability of the model to represent cloud depth.

- Spheres are insufficient for use in CloudSat reflectivity comparisons due to Mie resonance, but reasonable for Rayleigh scattering applications.

- Microphysics schemes will benefit from a greater range of snow crystal characteristics to accommodate naturally occurring diversity.

Questions?

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