Ice Concentration Retrieval in Stratiform Mixed-phase Clouds Using Cloud Radar Reflectivity Measurement and 1-D Ice Growth Model Simulations

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1. Motivations:

The simple ice generation and growth pattern in stratiform mixed-phase clouds (SMC) offers opportunities to use cloud radar reflectivity (Z_e) measurement to estimate the ice number concentration (N_ice). A 1-D ice growth model is developed to calculate ice diffusional growth along fall trajectory in SMCs. N_ice is retrieved by combining Z_e measurements and the 1-D ice growth model simulations. Validations of the retrieved N_ice with *in situ* measurement and a 3-D cloud-resolving models show that the retrieved N_ice are with in uncertainty of a factor of 2, statistically. The algorithms are applied to four-years of space-borne radar measurements to retrieve N_ice in mid-level SMCs globally.

2. Ice Growth Along Fall Trajectory in SMCs

- Ice crystals are initiated at the top of supercooled liquid-dominated layer, grow large and fall out of the layer.

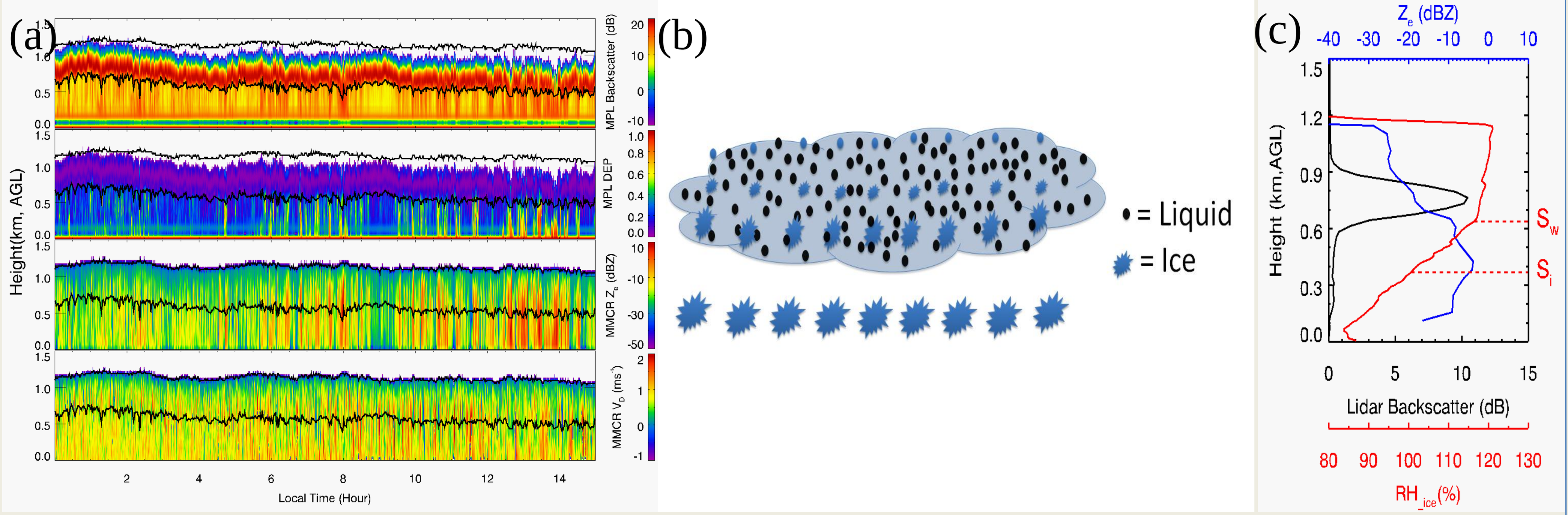

Fig 1. a) example of SMC system from ground-based remote sensing over ACRF NSA barrow site; b) a conceptual model of ice crystal growth along fall trajectory; c) MPL backscatter, MMCR Z_e and RH profiles.

3. Development and Validation of 1-D Ice Growth Model for

- Adaptive habit evolution for non-spherical ice crystal growth [Harrington et al., 2013].
- Terminal velocity (V_t) from Heymsfield and Westbrook [2010].
- Only ice diffusional growth is considered.

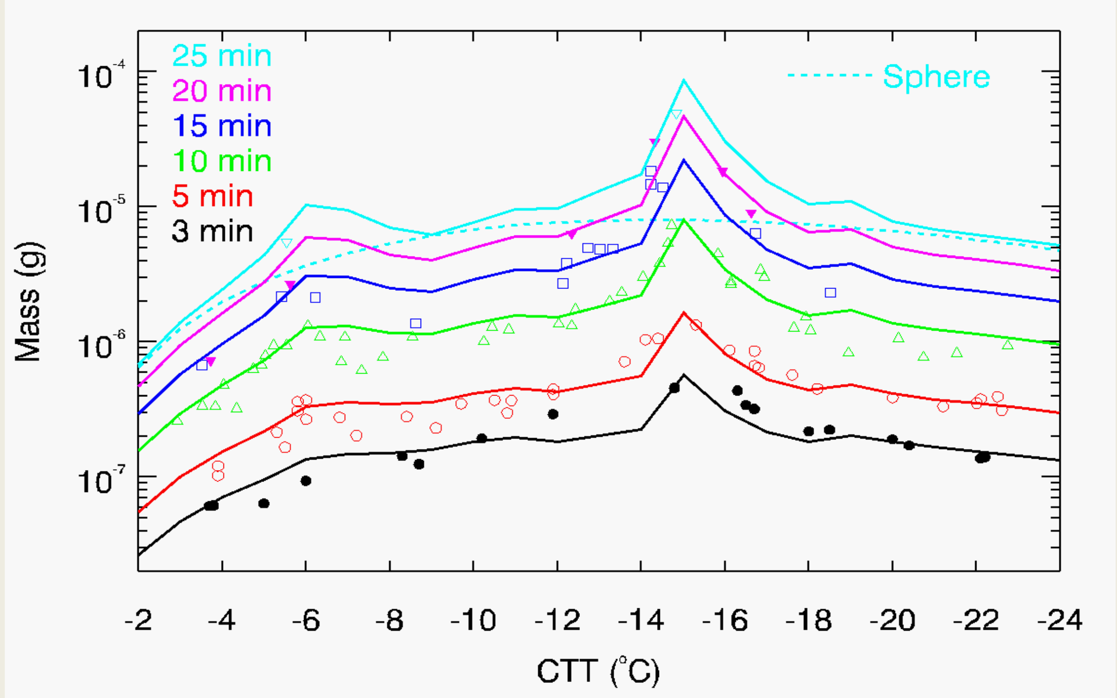

Fig 2. Ice mass growth using adaptive habit and spherical particles (dashed line) at different growth times. Laboratory wind tunnel measurements [Takahashi et al. 1991] are plotted with different signs.

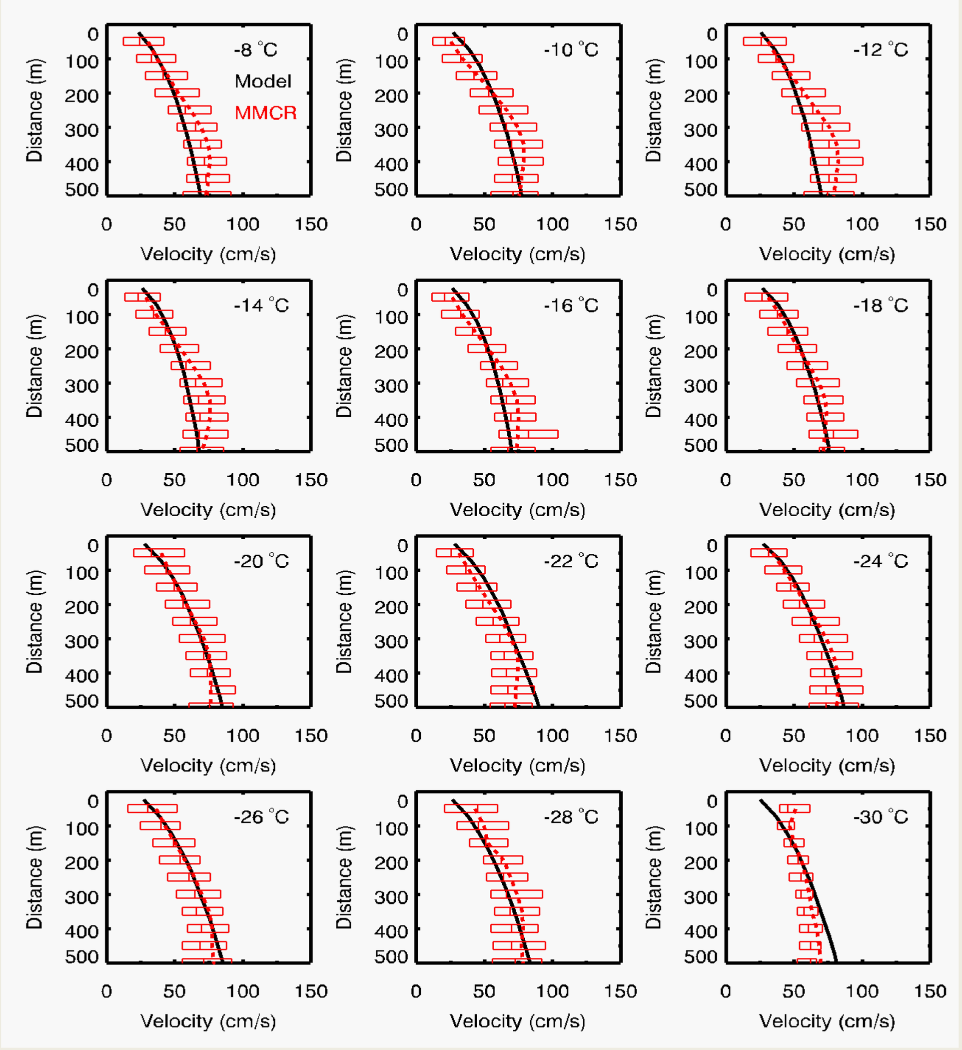

Fig 3. Comparison of V_t from 1-D ice growth model (black solid lines) with ARM NSA MMCR measurements (red dashed lines). Red boxes: 25%, 50%, and 75% of data.

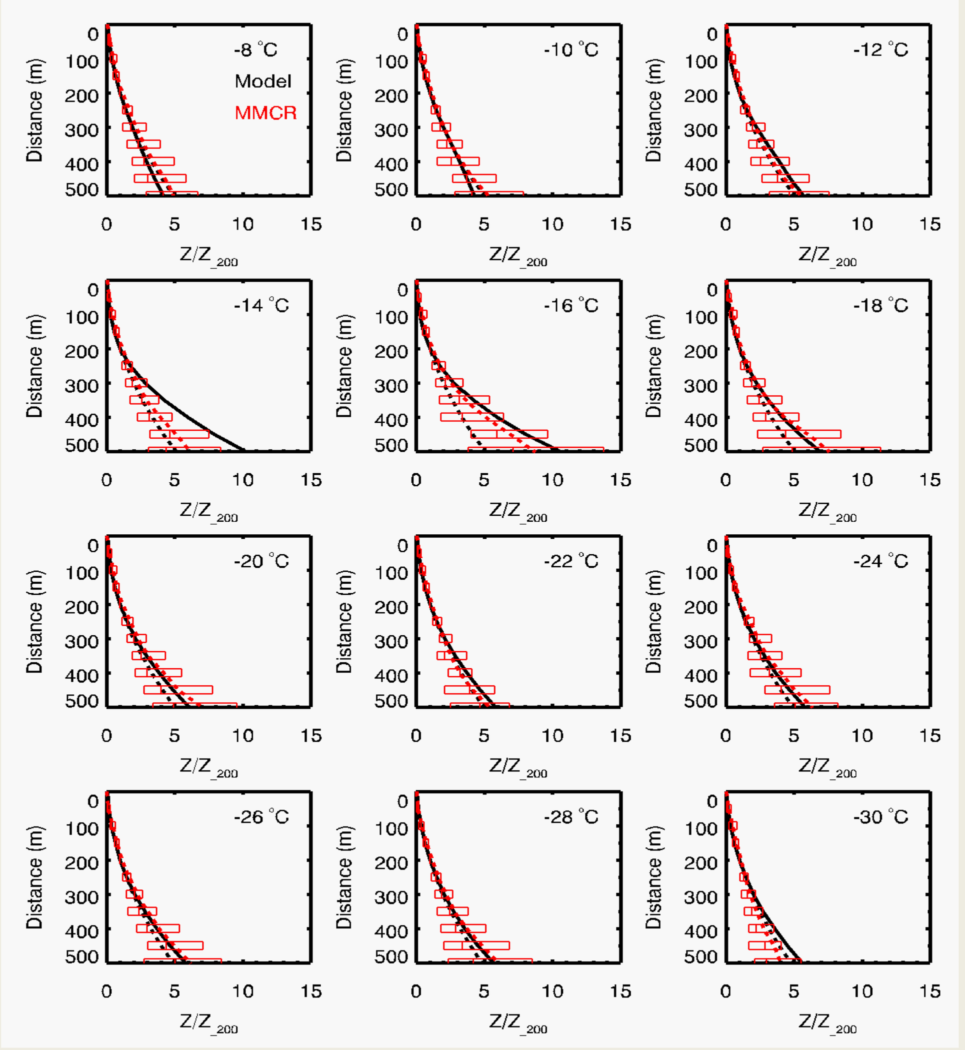

Fig 4. Comparison of Z/Z_{200} from 1-D ice growth model using adaptive ice habit (black solid lines) and spherical growth with MMCR measurements (red dashed lines).

4. N_ice Retrieval and Validations

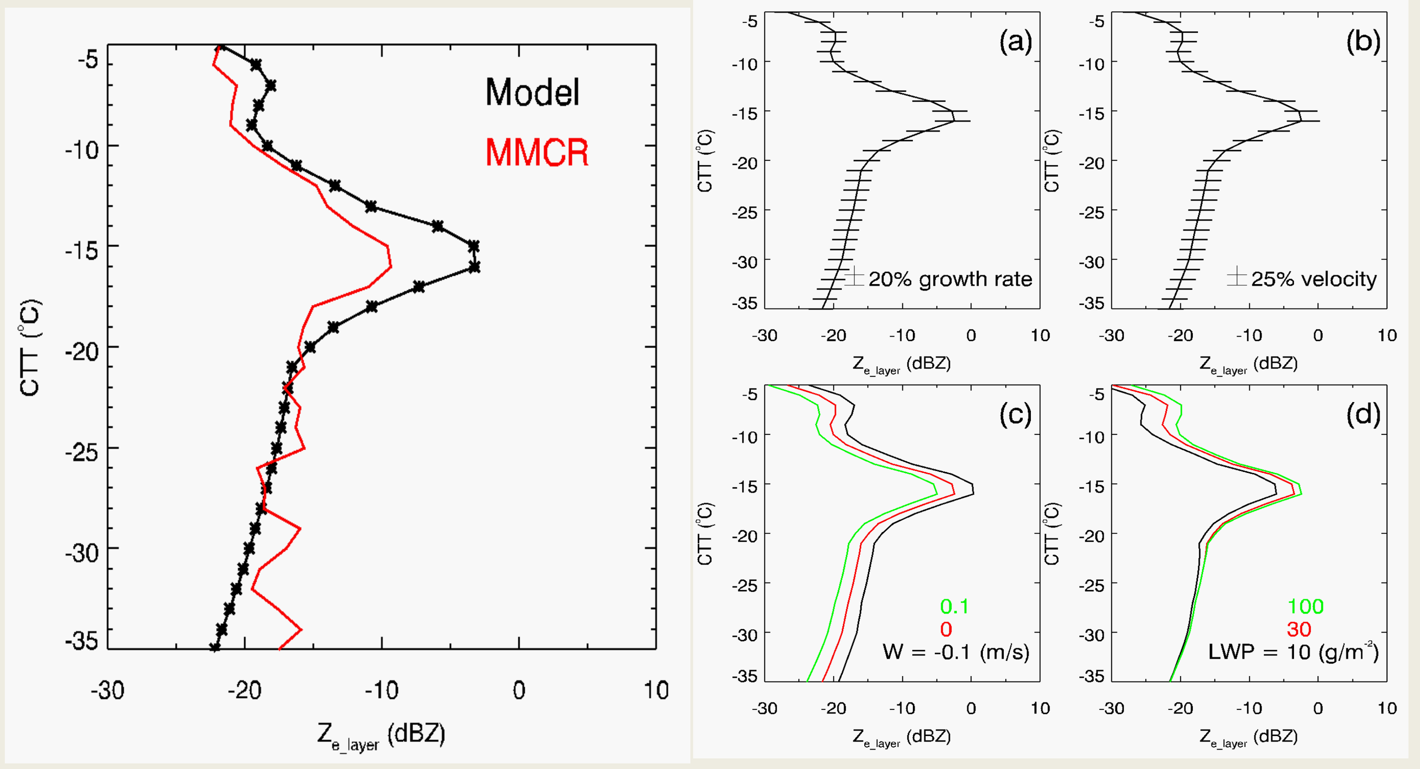

Fig 5. Left: calculated Z_{e_layer} from 1-D ice growth model and MMCR measurement. **Right:** sensitivity of Z_{e_layer} to: a) ±20% uncertainty in growth rate; b) ±25% uncertainty in V_t; c) different vertical air motion (w); d) different LWPs.

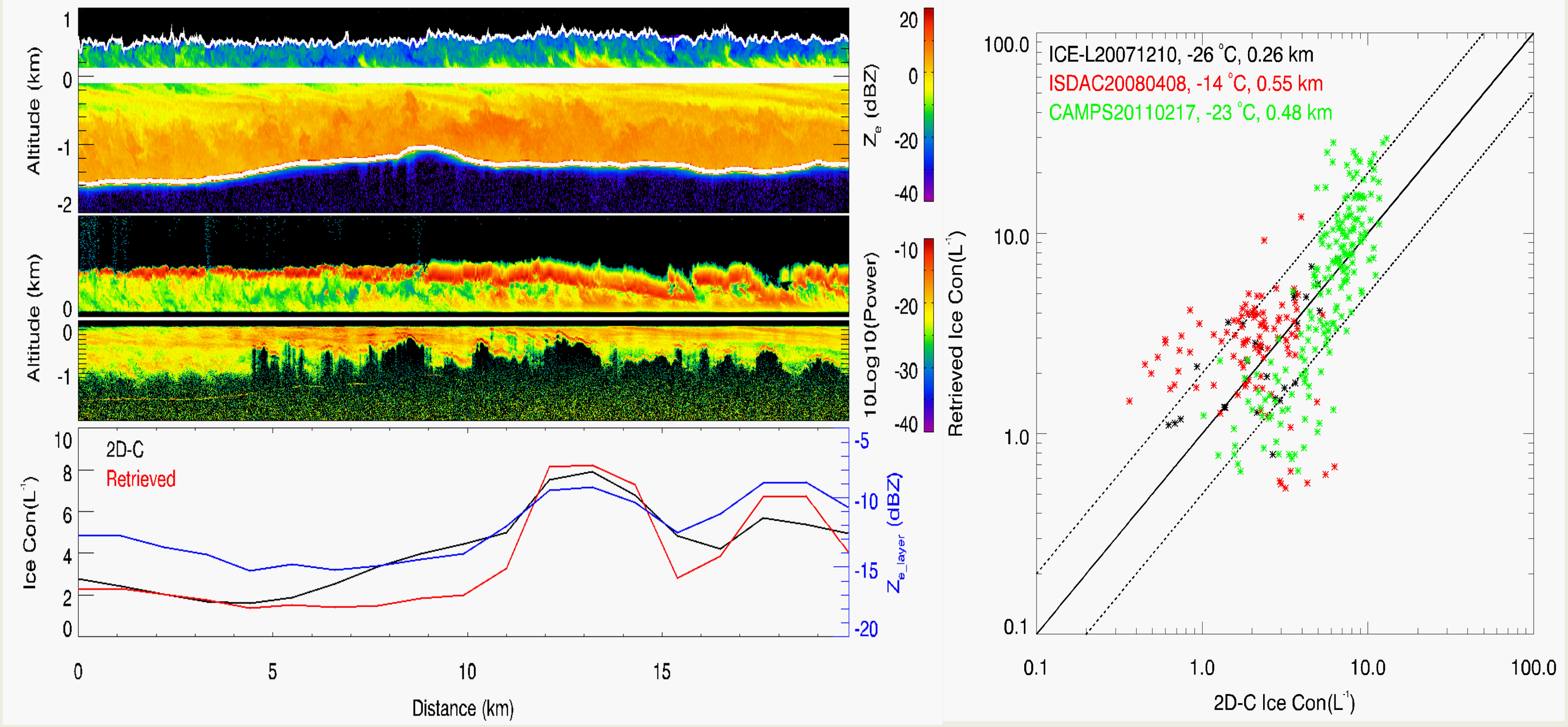

Fig 6. SMC detected during CAMPS on Feb 17th, 2011. a) WCR Z_e; b) WCL backscattering; c) 2D-C measured N_ice, WCR Z_{e_layer}, and retrieved N_ice; d) Comparisons of retrieved N_ice from ICE-L, ISDAC, and CAMPS (green).

- Z_{e_layer}: mean Z_e between cloud top and 500 m below.

$$N\_ice = \frac{Z_{\_layer}(Obs)}{Z_{\_layer}(Model, 1L^{-1})}$$

- The retrieved *N_ice* are within an uncertainty of a factor of 2, statistically.

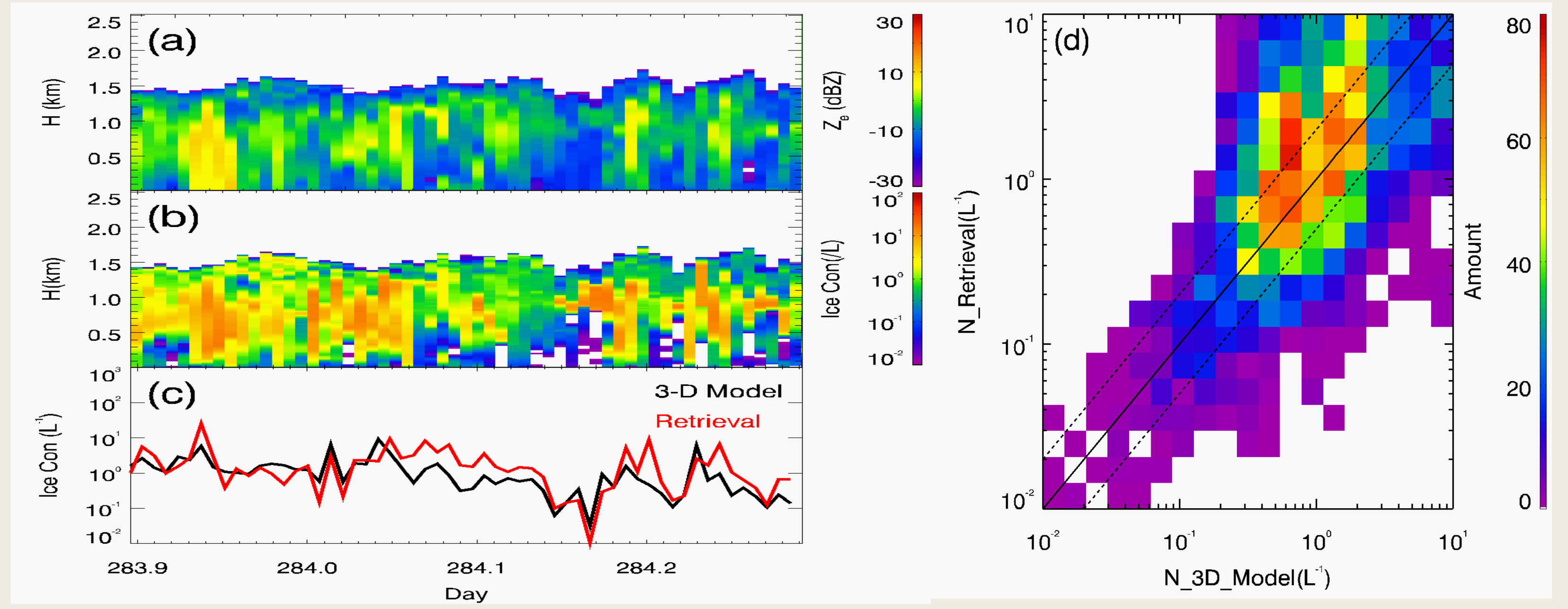

Fig 7. Comparison of retrieved N_ice with 3-D CRM simulations with bin microphysical schemes and radar simulator.

- Mid-level SMCs from four-yeas of collocated CALIPSO and CloudSat measurements.
- Steady increase of N_ice as CTT decreasing.
- Compare well with DeMott [2010]'s IN parameterization.

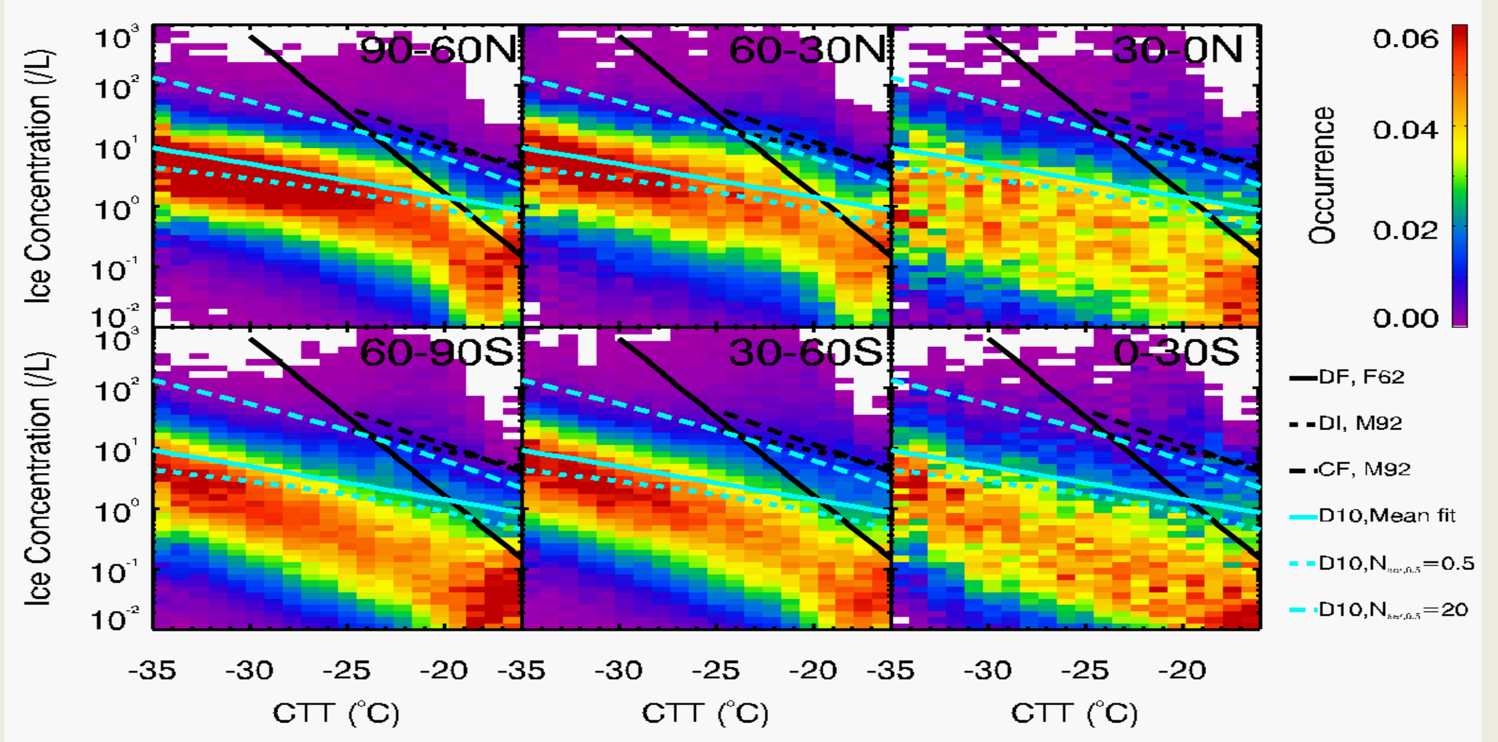

Fig 8: The occurrence of retrieved N_ice at each CTT for six latitude bands and comparison with IN parameterizations from previous studies. F62, M92, D10 refer to IN parameterizations from Fletcher (1962), Meyers et al. (1992) and DeMott et al. (2010),. $N_{aer,05}$ is coarse aerosol concentration, unit L^{-1}.

Reference: Harrington, J. Y., et al., (2013), A Method for Adaptive Habit Prediction in Bulk Microphysical Models. Part II: Parcel Model Corroboration, *J. Atmos. Sci.*, ***70*(2)**.