Ice Concentration Retrieval in Mixed-phase Stratiform Clouds (MSCs) Using Radar Reflectivity (Z_e) and 1-D Ice Growth Model

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Abstract: We develop an approach to retrieve the ice number concentration (*N_ice*) in MSCs by using Z_e measurements. A 1-D ice growth model is developed to calculate the ice diffusional growth and corresponding Z_e profile in MSCs. Combining modeled and observed Z_e provides *N_ice* estimations in MSCs with an uncertainty of a factor of 2, statistically.

1-D Ice Growth Model and Validations

- Ice particles are initiated at the top of supercooled liquid-dominated layer, grow large and fall out of the layer.
- Strong temperature dependence of ice growth habits.
- Only ice diffusional growth is considered.
- Terminal velocity (V_t) from Heymsfield and Westbrook (2010).
- Adaptive habit evolution method (Harrington et al., 2013).

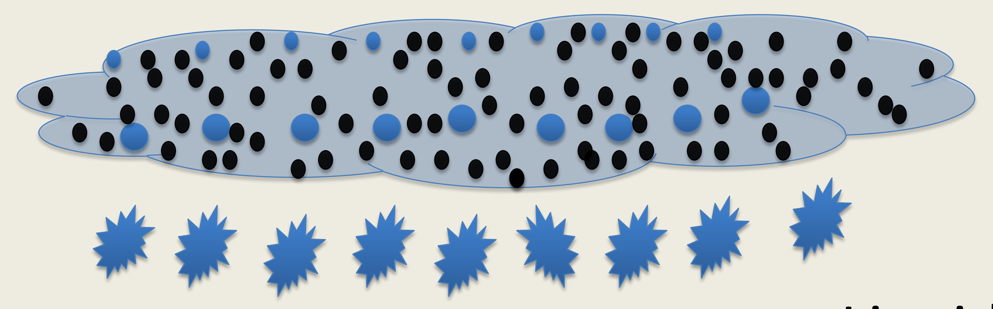

Fig 1. A conceptual model of ice growth in MSC.

• = Liquid
• = Ice

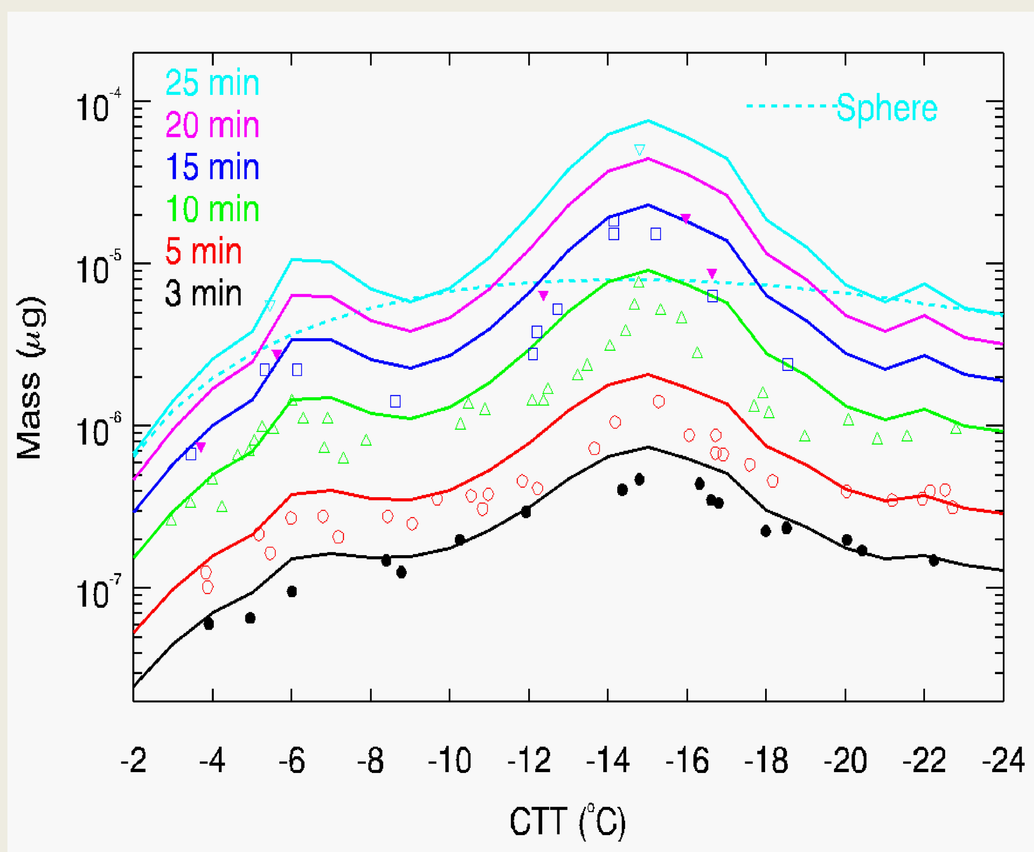

Fig 2. Ice Mass growth with time from 1-D ice growth model and cloud chamber measurements (Takahashi and Fukuta 1991, with different signs).

$$Z_{e\_n} = Z_e - Z_{e\_h0} = 10\log 10\left(\int_0^\infty f(D)D^6 \Big/ \int_0^\infty f(D_{h0})D_{h0}^6\right)$$

, Z_{e_h0} is reference Z_e at 200 m below top.

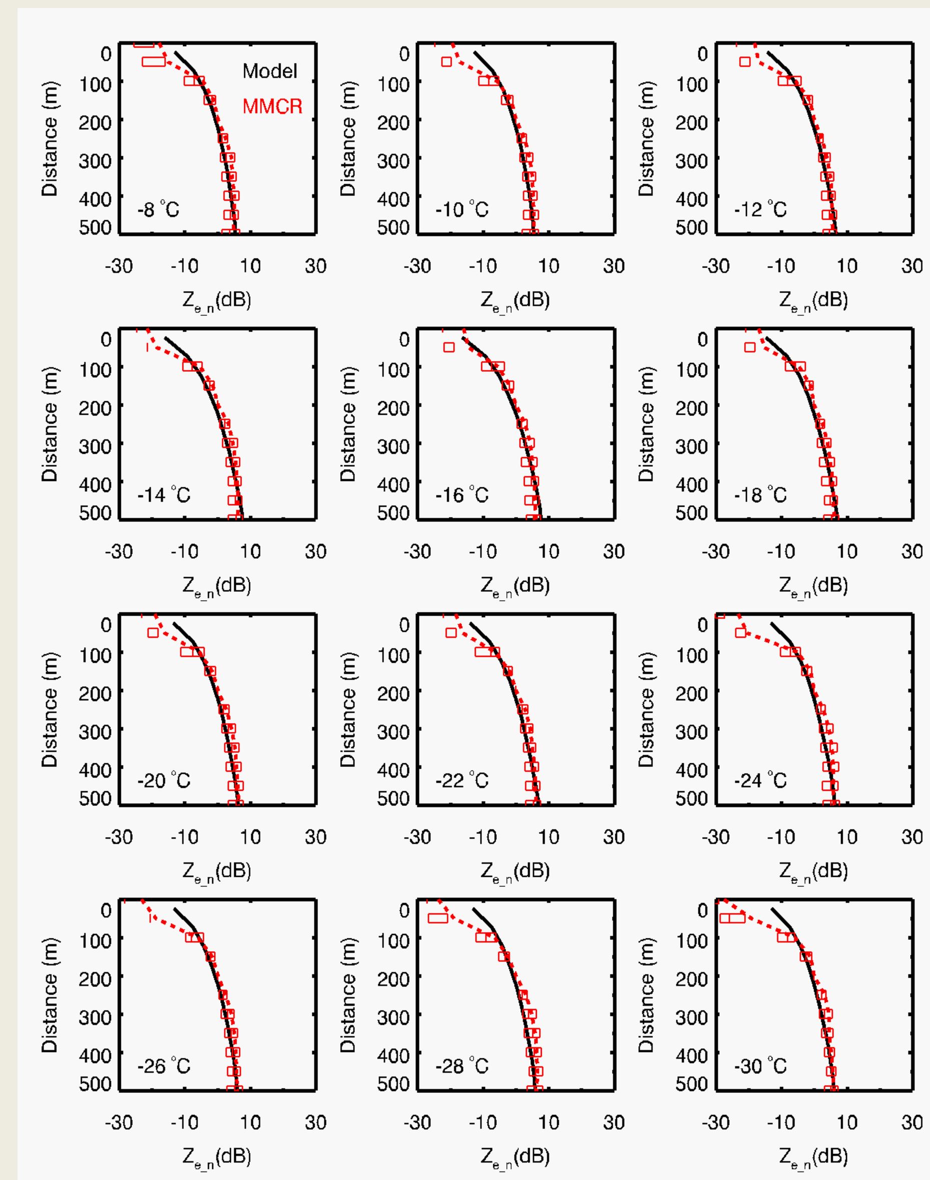

Fig 3. Z_{e_n} from 1-D ice growth model and 4 years of MMCR measurements of MSCs at NSA Barrow. Red boxes: 25%, 50%, and 75% of data.

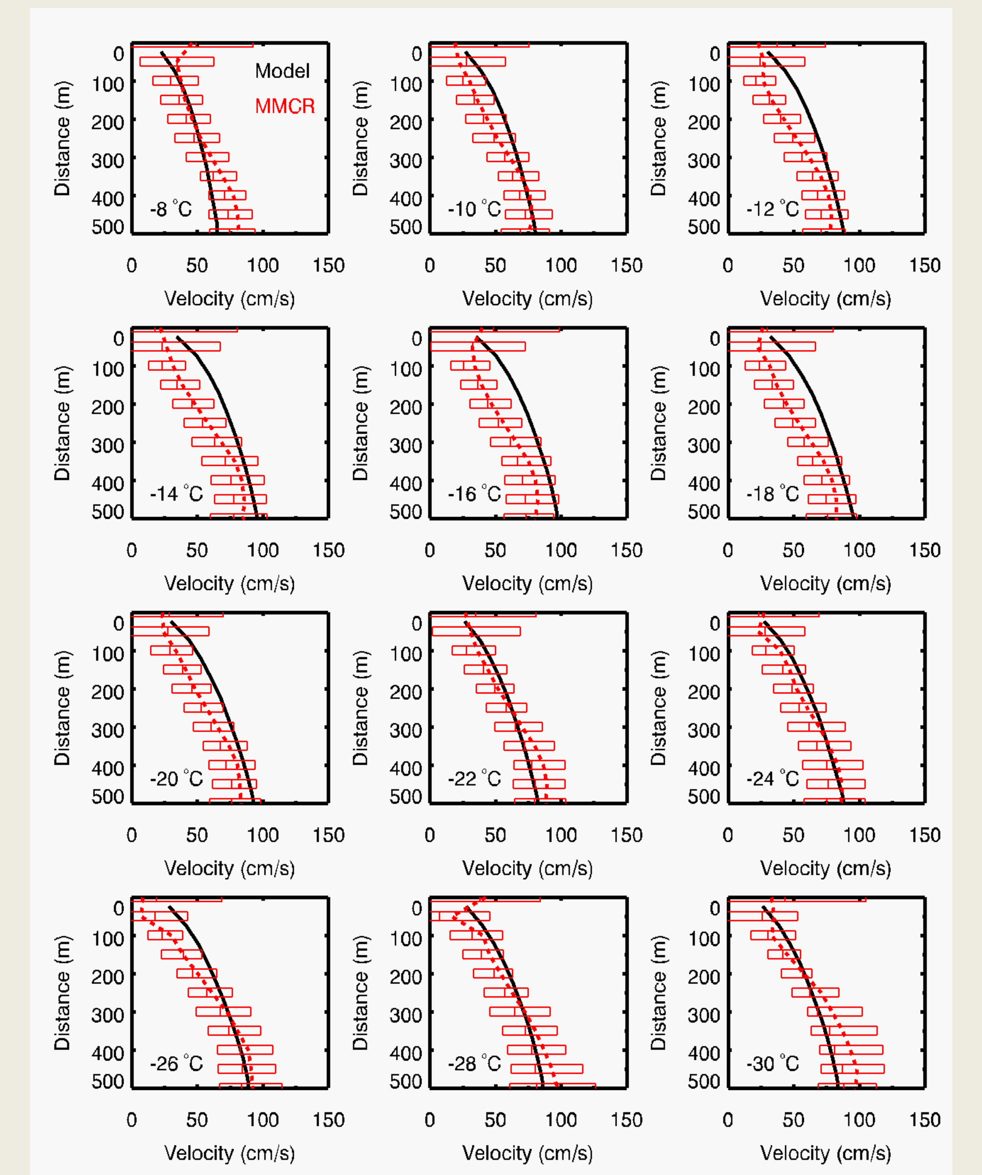

Fig 4. Same as Fig 3, except for Doppler velocity comparisons.

N_ice estimation and Validations

- In similar MSCs in terms of same CTT and LWP:

$$Z_e(dBZ) = 10\log 10(N\_ice * Z_{nor})$$

Z_{nor} is the radar reflectivity (mm^6/m^3) for normalized ice crystal size distribution.

- *N_ice* is the main cause for Z_e difference among similar MSCs (Zhang et al., 2012).
- $\mathbf{Z_{e\_layer}}$: mean Z_e between cloud top and 500 m below.

$$N\_ice = \frac{Z_{\_layer}(Obs)}{Z_{\_layer}(Model)}$$

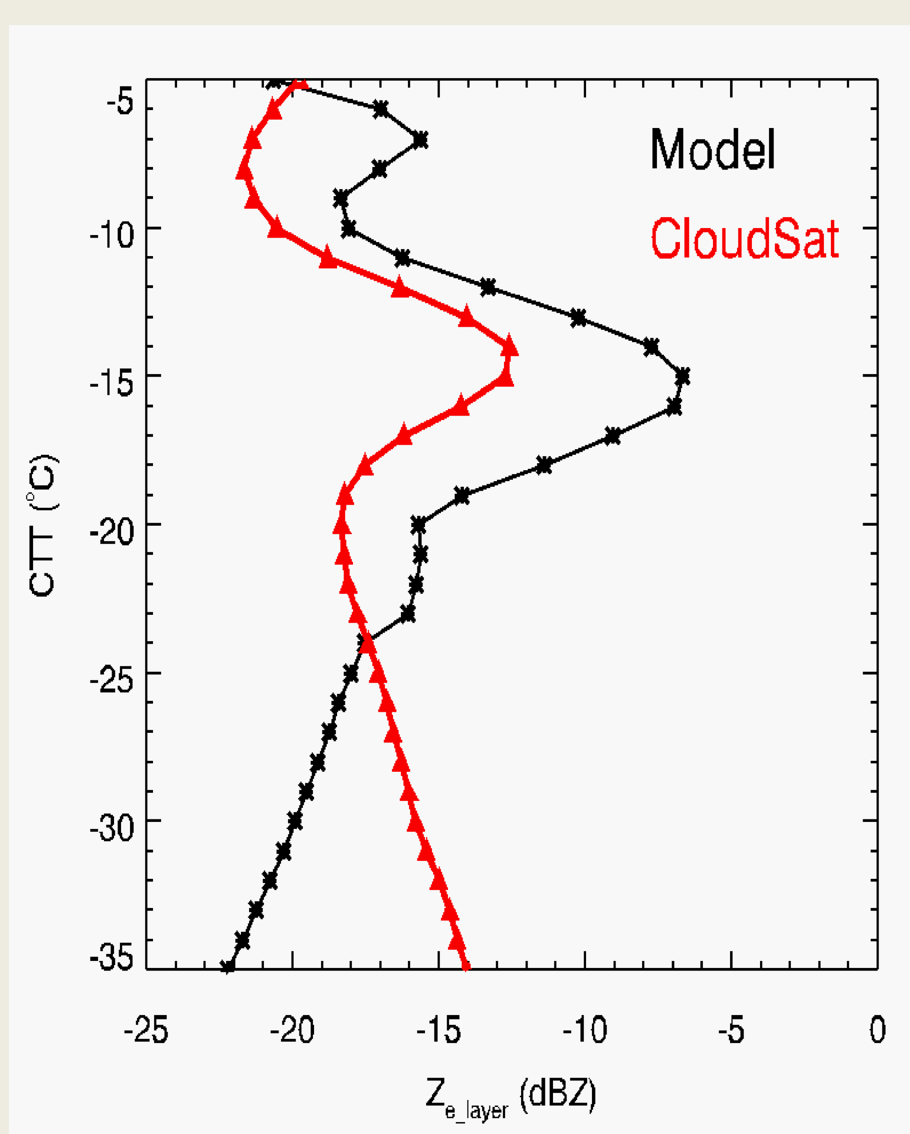

Fig 5. Calculated Z_{e_layer} from 1-D ice growth model (assuming *N_ice* of 1 L^{-1}) and 4 years of CloudSat measurements.

- The retrieved *N_ice* are within an uncertainty of a factor of 2 compared with *in situ* measurements, statistically.

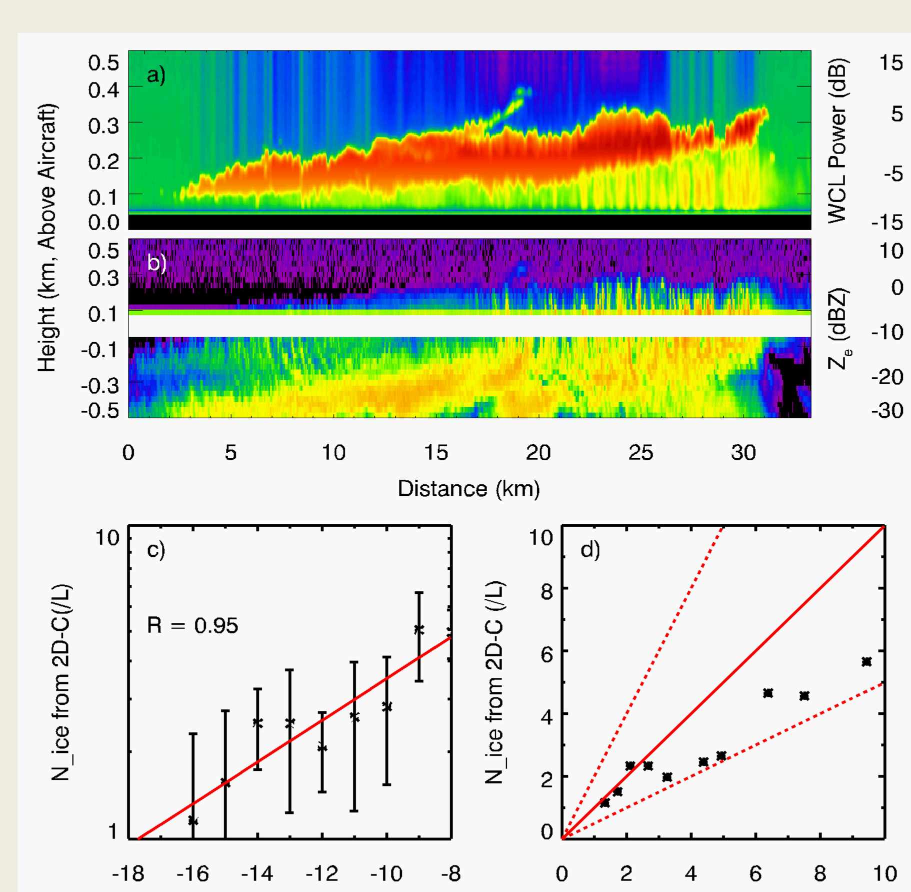

Fig 6. Dec 10th, 2007 during ICE-L. **a)** lidar backscattering; **b)** radar Z_e profiles; **c)** *in situ* 2D-C *N_ice* Vs. Z_{e_layer}, ; **d)** *N_ice* from *in situ* 2D-C and retrieval.

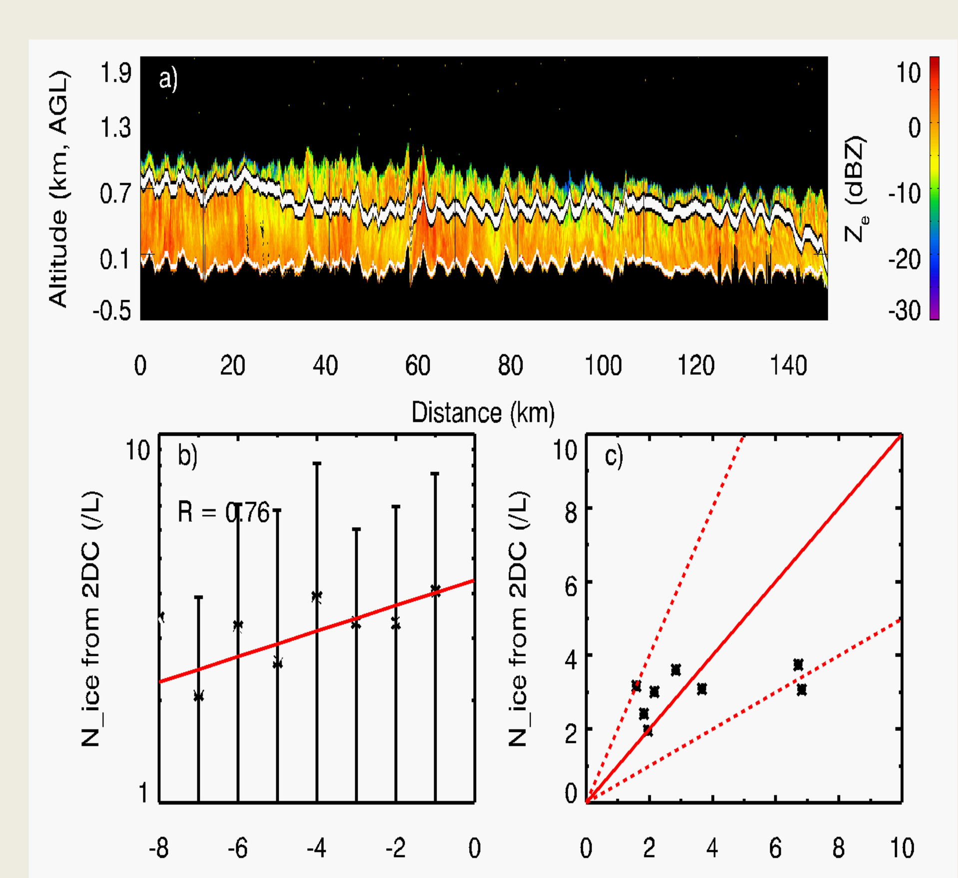

Fig 7. Same as for Fig 6, except for the case on Apr 8th, 2008 during ISDAC .

References

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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)**.