

Ice Production in Slightly Supercooled Arctic Stratiform Clouds as Observed by Ground-based Remote Sensors at ARM NSA Site

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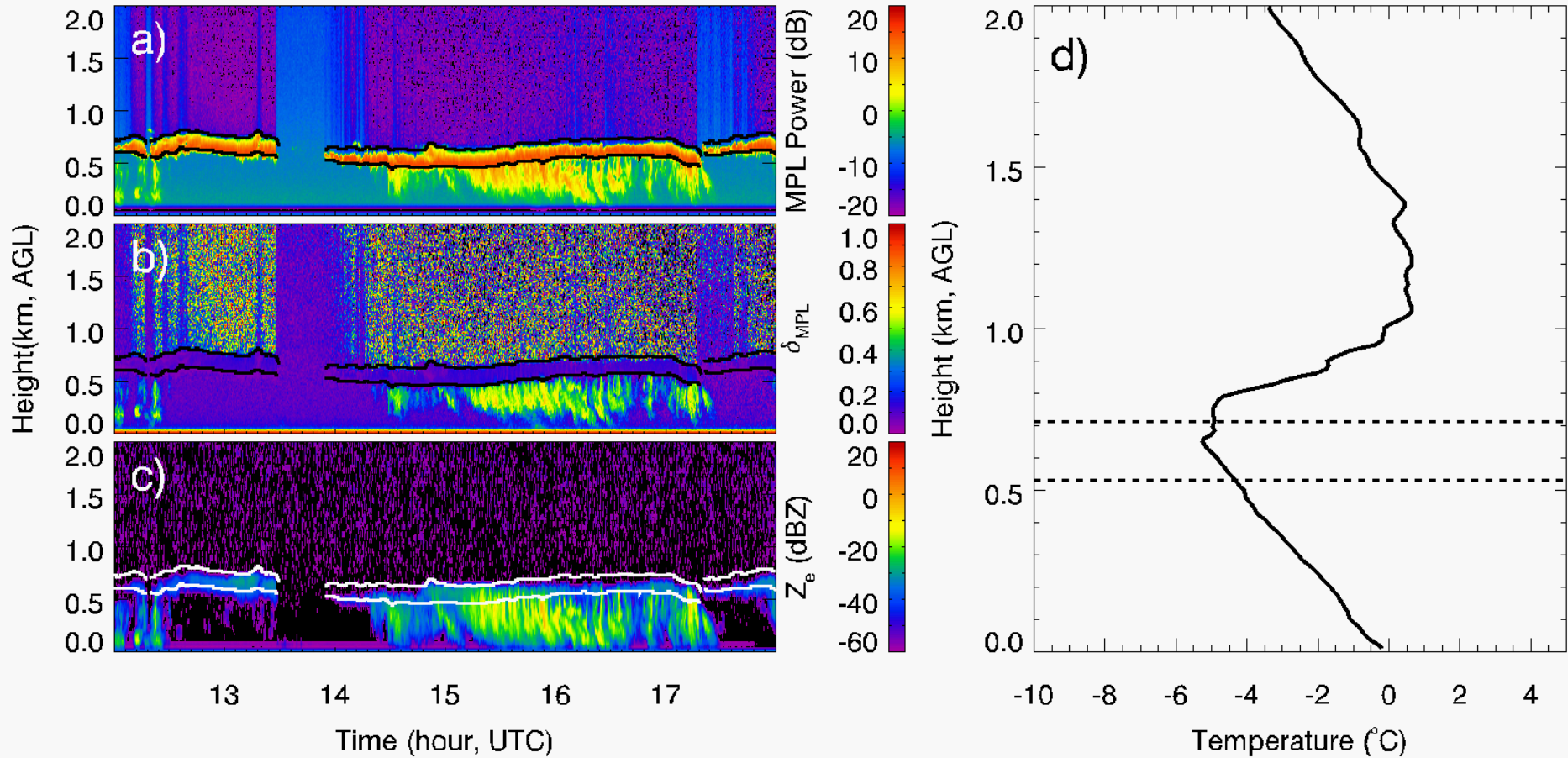
0316, 2017

Dataset

Instruments	Wavelength/ Frequency	Temporal/Vertical Resolution	Measured and/or Derived Quantities
“fast-switching” Micropulse lidar (MPL)	0.532 μm	10 sec / 15 m	Lidar backscattering, hybrid linear-circular depolarization ratio (δ_{MPL}) [<i>Flynn et al.</i> , 2007].
High Spectral Resolution Lidar (HSRL)	0.532 μm	30 sec / 30 m	Lidar backscattering, circular depolarization ratio (δ_{cir}) [<i>Eloranta</i> 2005].
The Ka-band ARM zenith radar (KAZR)	35 GHz	3.7 sec / 30 m	Radar reflectivity factor (Z_e), Doppler velocity [<i>Kollias et al.</i> , 2007].
Microwave radiometer (MWR)	23.8 and 31.4 GHz	20 sec / column integrated	Liquid water path (LWP) [<i>Turner et al.</i> , 2007].
Balloon-Borne sounding system (SONDE)		2 times per day / ~ 10 m	Atmospheric pressure and temperature profiles [<i>Troyan</i> 2011].

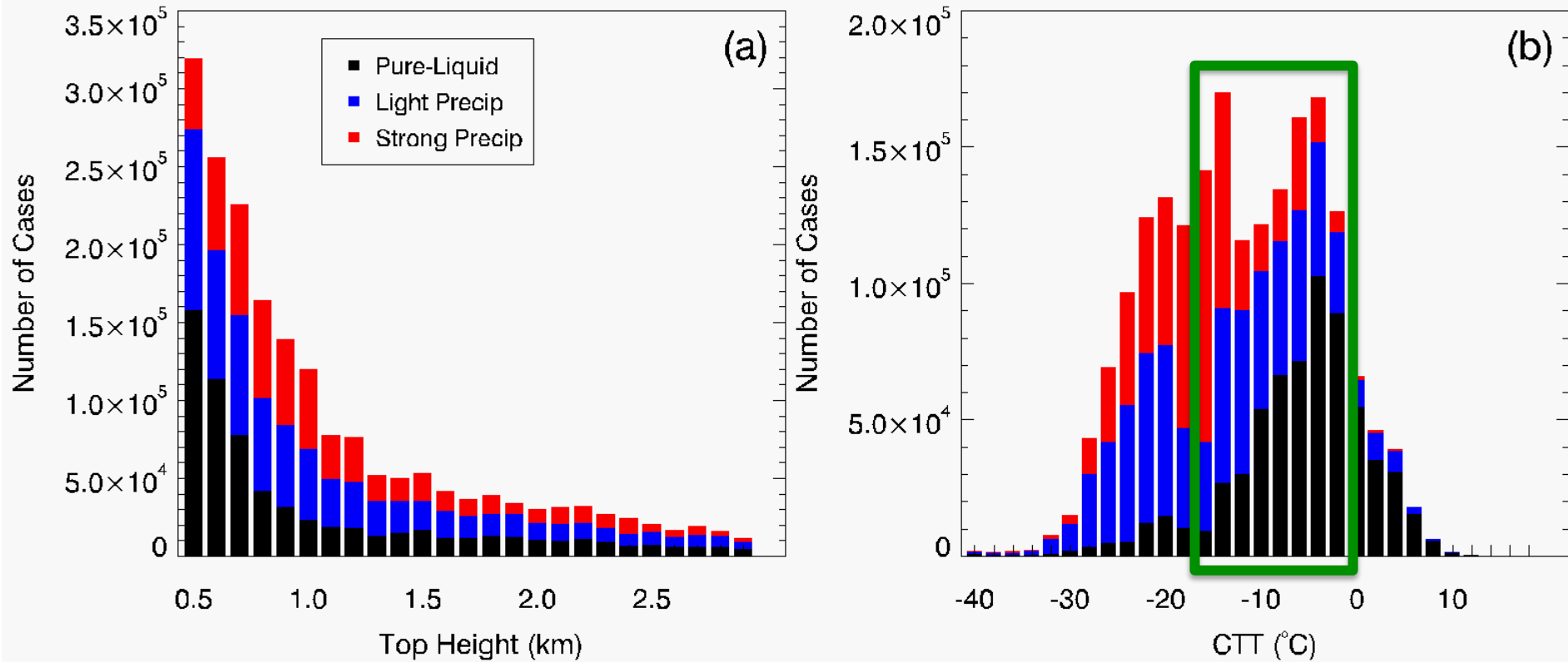
Four years of ground-based remote sensing measurements during 2011-2015 at NSA Utqiagvik (Barrow) site.

Observed Warm Ice Production



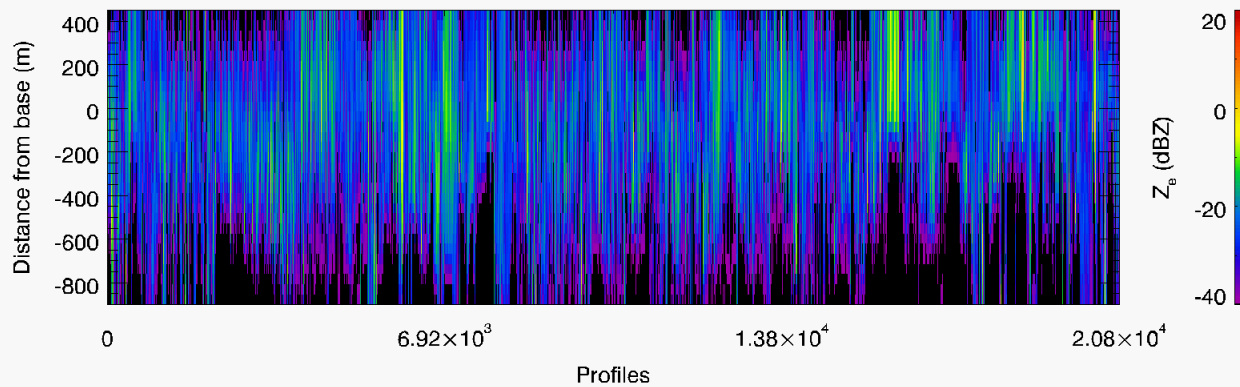
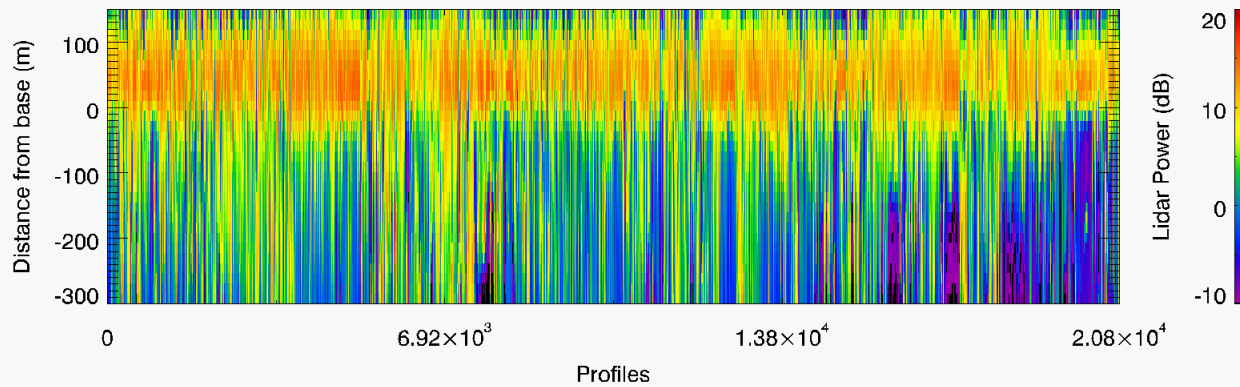
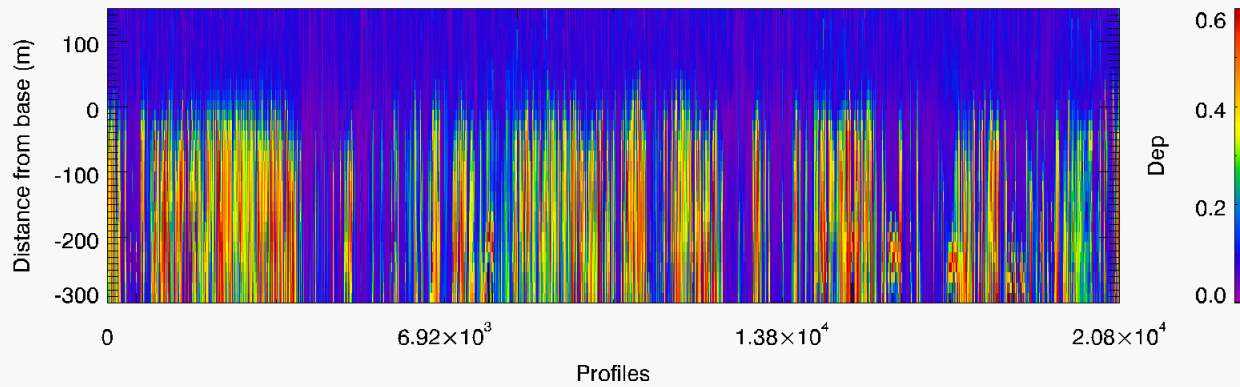
An example of ice producing cloud with top temperatures of ~ -5 °C at the ACRF NSA site on August 21st, 2013.

Stratiform Cloud Occurrence



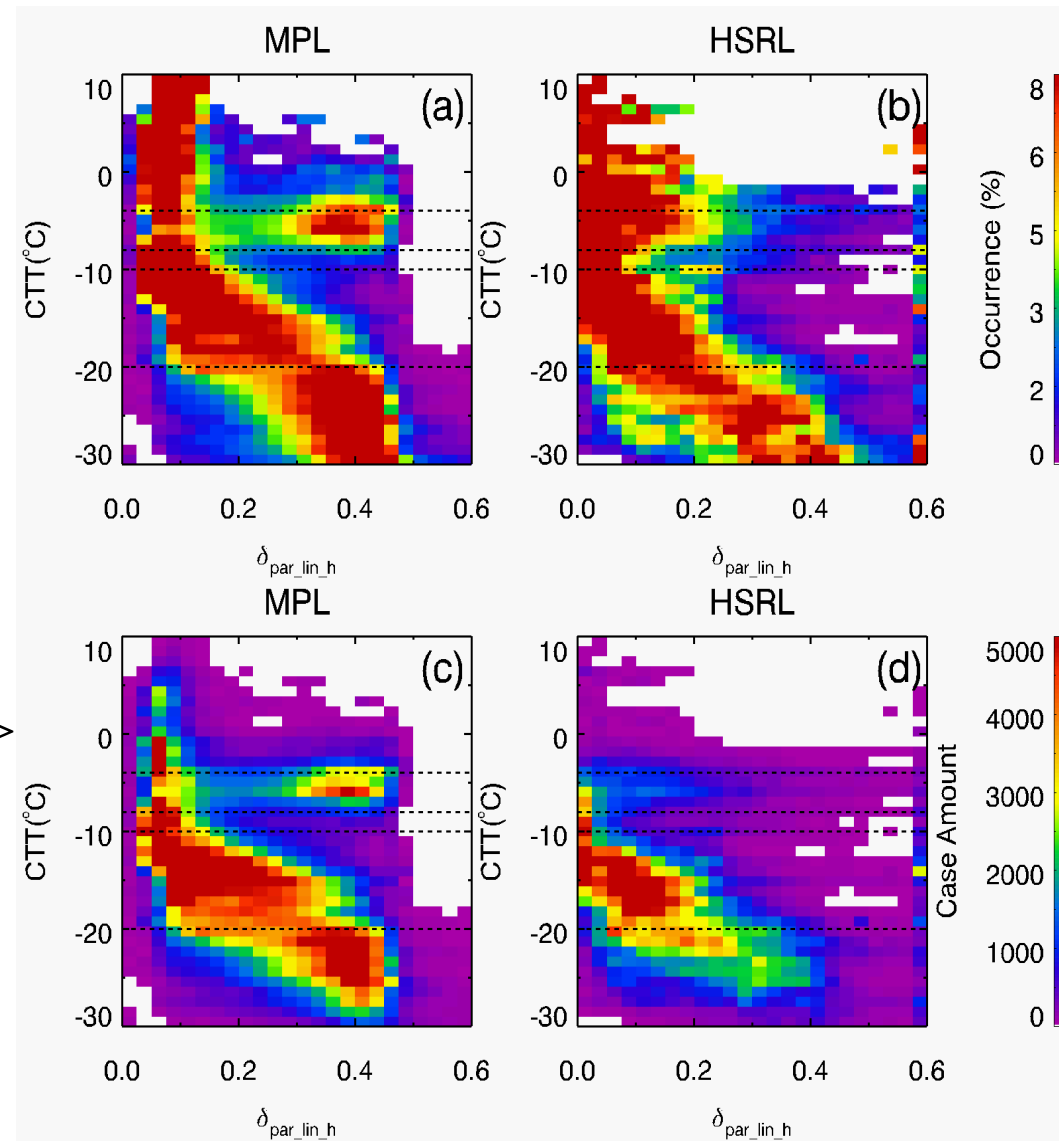
Pure-liquid ($Z_{e_h} < -40$ dBZ), weakly precipitating (-40 dBZ $< Z_{e_h} < -20$ dBZ), and strongly precipitating ($Z_{e_h} > -20$ dBZ) ASCs.

Ice Production at CTTs between -8- -4 °C



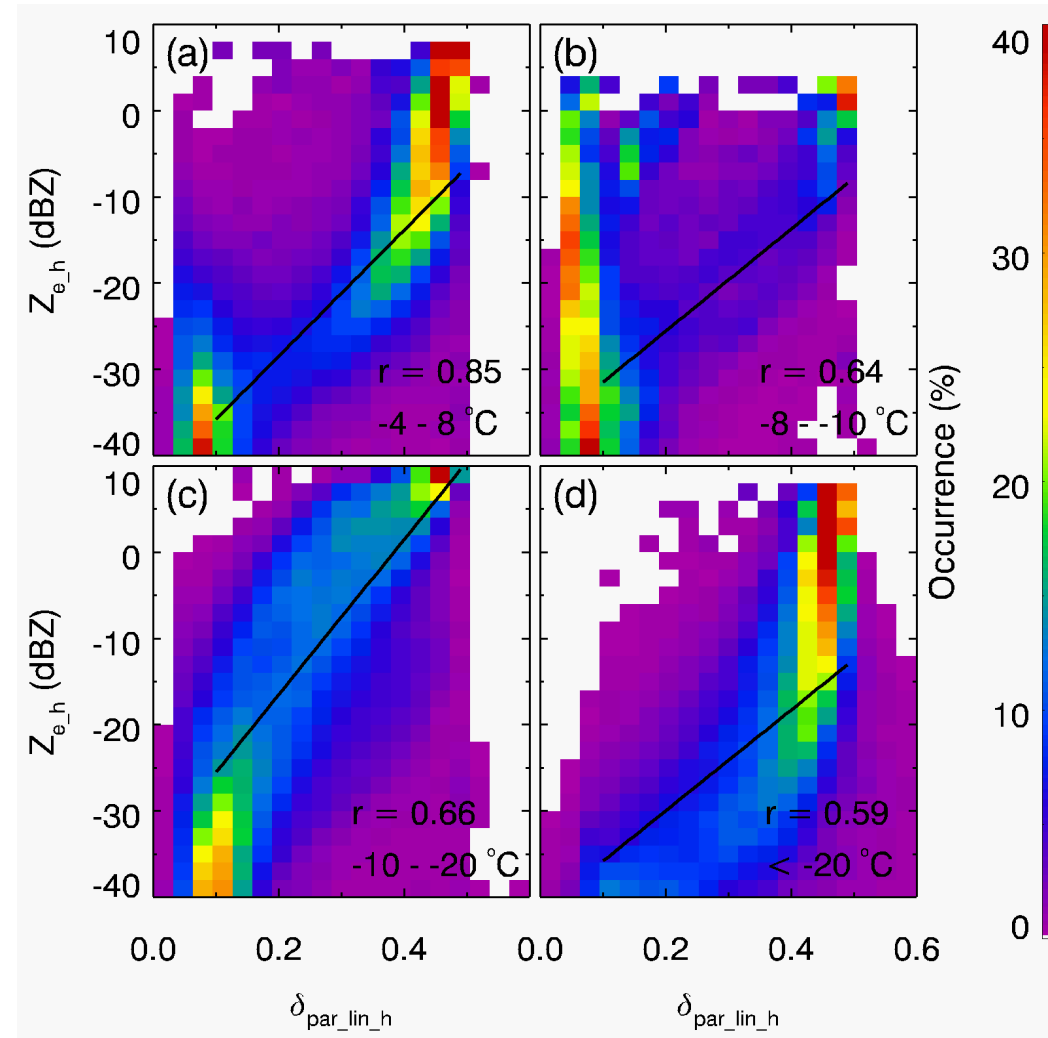
Ice Production in Slightly Supercooled Clouds

- Precipitating ($-40 \text{ dBZ} < Z_{e_h}$) stratiform clouds.
- $-8 - -4 \text{ }^\circ\text{C}$, large $\delta_{\text{par_lin_h}} \Rightarrow$ ice particle presence, columnar ice growth habit.
- $-10 - -8 \text{ }^\circ\text{C}$, small $\delta_{\text{par_lin_h}} \Rightarrow$ isometric ice growth habit.
- $-20 - -10 \text{ }^\circ\text{C}$, large $\delta_{\text{par_lin_h}} \Rightarrow$ planar ice crystal growth habit.
- $< -20 \text{ }^\circ\text{C}$, large $\delta_{\text{par_lin_h}} \Rightarrow$ polycrystalline ice crystals.



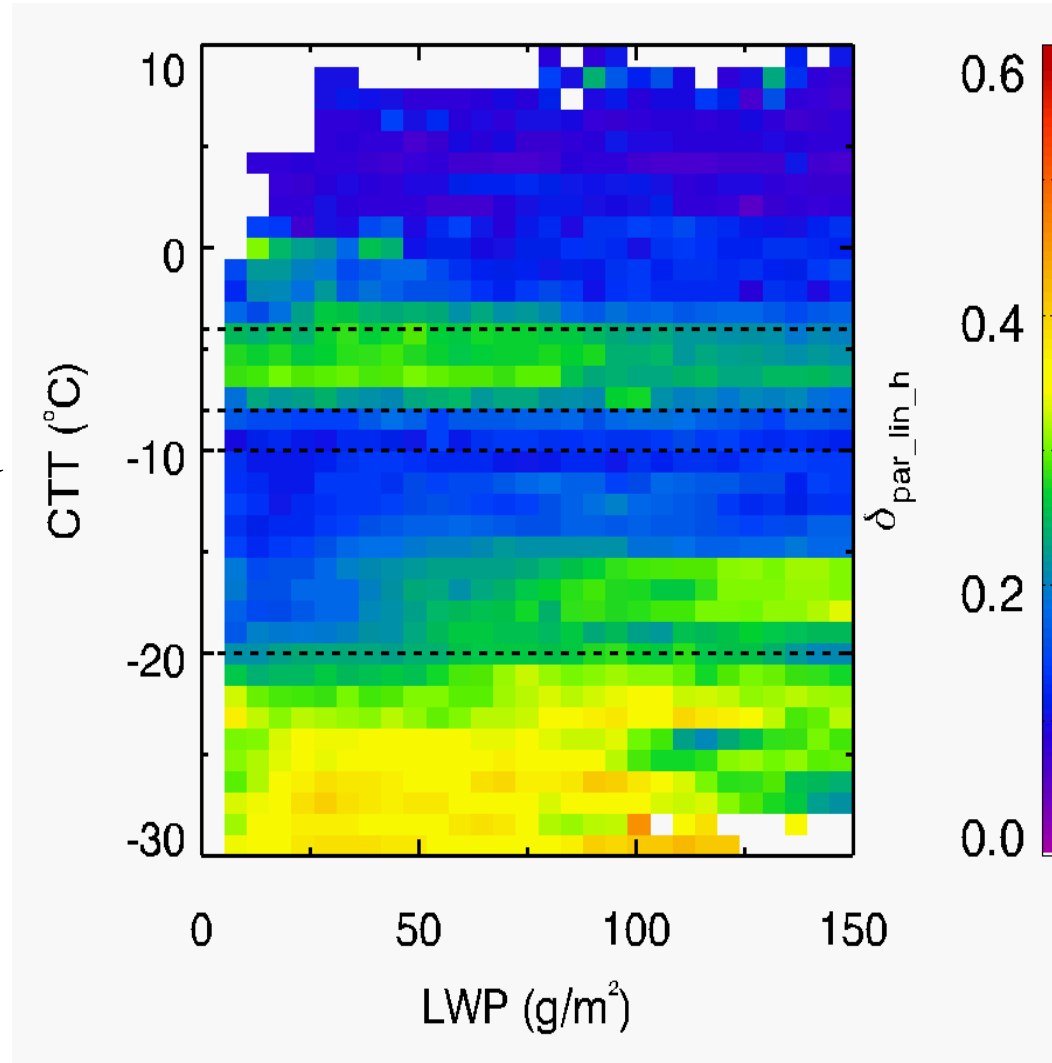
Ice Production in Slightly Supercooled Clouds

- $\delta_{\text{par_lin_h}}$ correlates well with $Z_{\text{e_h}}$ at each CTT range.
- $\delta_{\text{par_lin_h}}$ increases gradually as $Z_{\text{e_h}}$.
- Slopes of the $\delta_{\text{par_lin_h}}-Z_{\text{e_h}}$ relationship vary dramatically with CTT ranges.



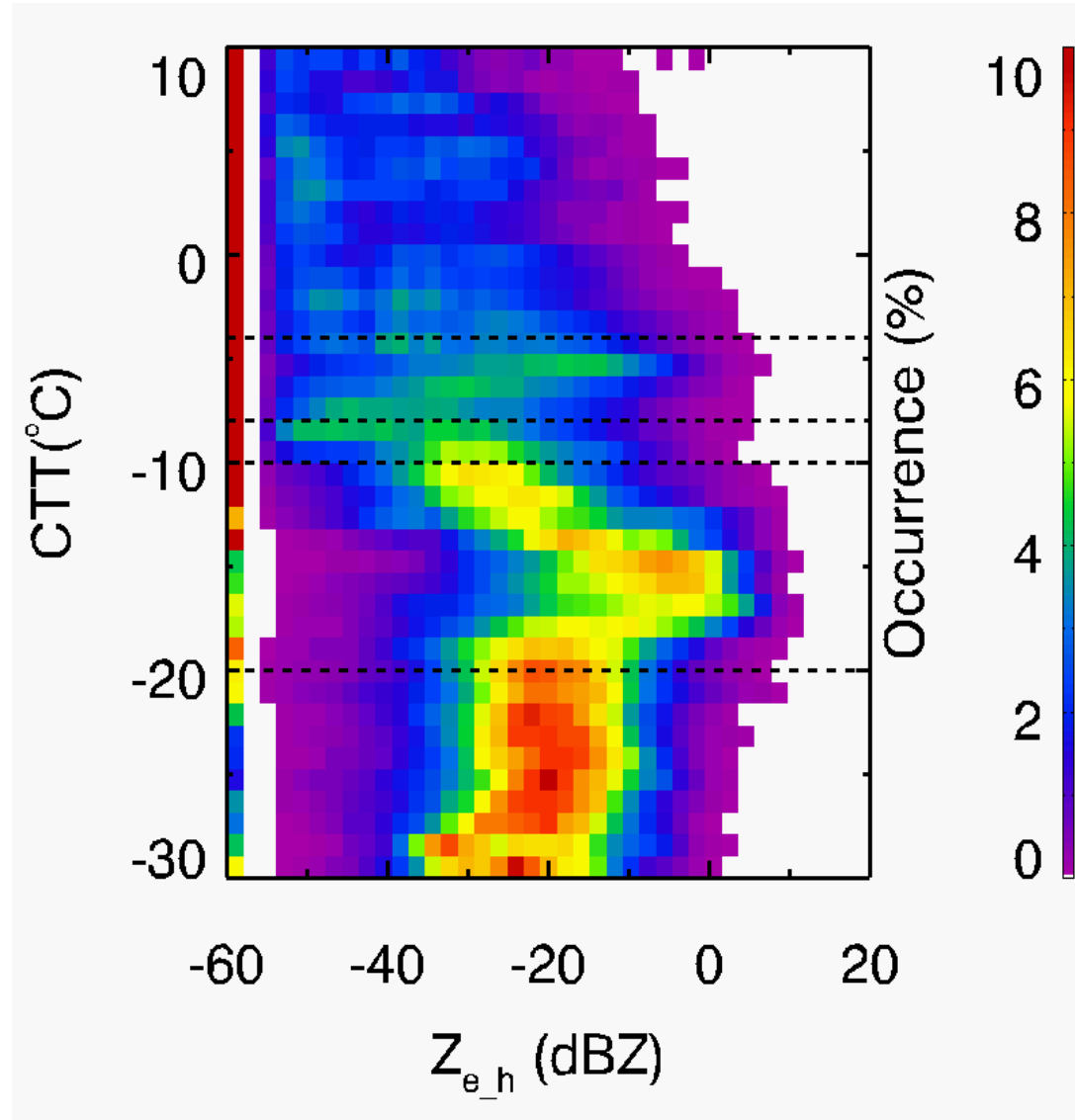
Ice Production in Slightly Supercooled Clouds

- -8 - -4 °C, $\delta_{\text{par_lin_h}}$ decrease with LWPs => more drizzle productions and/or increased riming?
- -10 - -8 °C, small $\delta_{\text{par_lin_h}}$ and do not change with LWPs .
- -20 - -10 °C, $\delta_{\text{par_lin_h}}$ increase with LWPs .
- < -20 °C, large $\delta_{\text{par_lin_h}}$ and do not change with LWPs.



Ice Production in Slightly Supercooled Clouds

- Two local maxima of Z_{e_h} at the CTTs of approximately $-6\text{ }^{\circ}\text{C}$ and $-15\text{ }^{\circ}\text{C}$.
- Two local minima at the CTTs of -10 and $-20\text{ }^{\circ}\text{C}$



Summary

- Ice crystal formations in slightly supercooled stratiform clouds as high as $-4\text{ }^{\circ}\text{C}$ are detected.
- For ice precipitating ASCs, lidar depolarization ratios correlate well with radar reflectivity, but the δ - Z_e relationship varies with temperature ranges.
- Radar Z_e and lidar δ observations are consistent with the laboratory-measured temperature-dependent ice growth habits.