2nd INTERNATIONAL FORUM ON RAIN ENHANCEMENT SCIENCE

Secondary Ice Production in Cumulus Clouds

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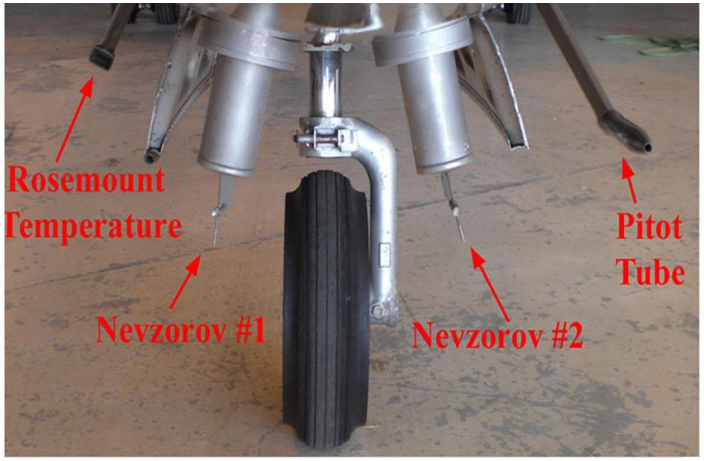
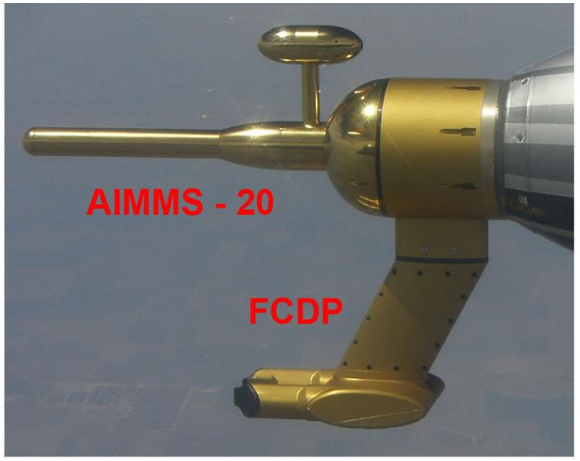
UNITED FOR WATER SECURITY

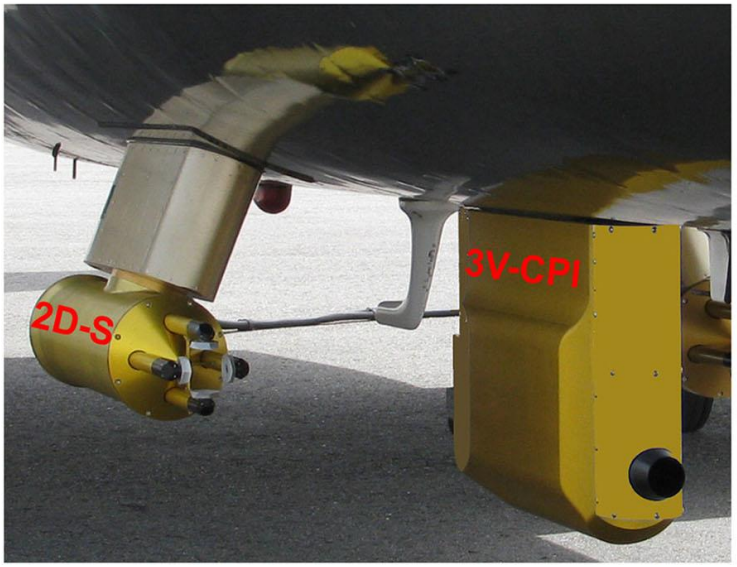
برنامج الإمارات لبحوث علوم الاستمطار
UAE Research Program for Rain Enhancement Science

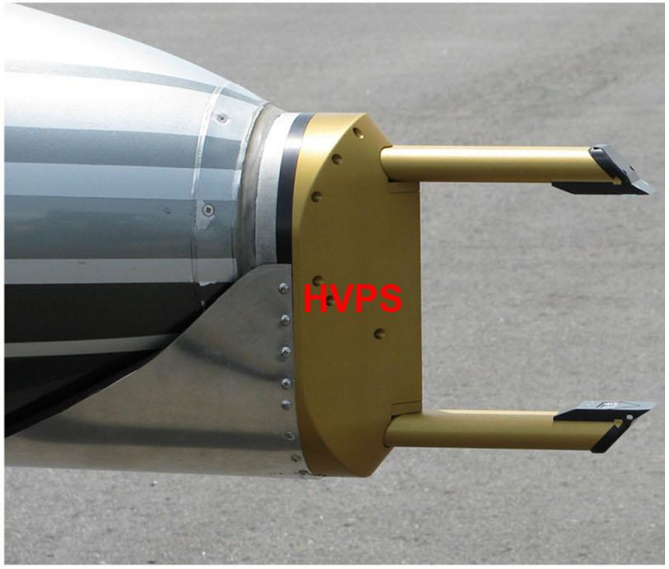
SPEC Learjet Research Aircraft

Learjet is Equipped with State-of-the-Art Microphysics and Air Motion Instrumentation







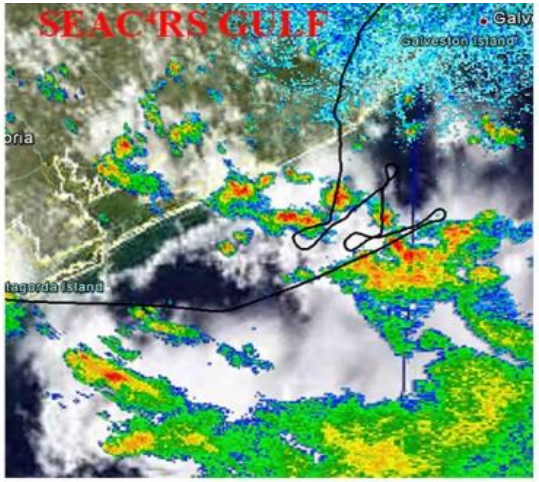


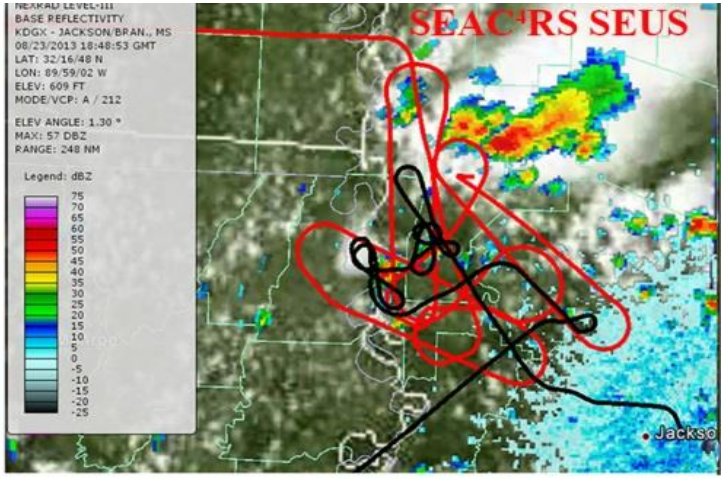
Learjet Participation in ICE-T, SEAC^{4}RS, Navy Icing and UAEREP Field Campaigns

Learjet made 137 Cumulus Cloud Penetrations in ICE-T (2011), 84 Penetrations in SEAC^{4}RS (2013), 90 Penetrations in Navy Icing (2014) and 108 Penetrations in UAEREP (2017)

The Principal Role of the Learjet was to Penetrate new, Growing Turrets in the Region from -5°C to -10°C to Search for Ice Initiation, and then Climb with the Developing Turret up to -35 °C to Document Ice Development.

Learjet Flight Tracks





Hypothesis

Cumulus clouds that produce (~ millimeter-diameter) Supercooled Large Drops (SLDs) in sufficient concentrations rapidly glaciate via a Secondary Ice Process in the cloud region -5 °C > T > ~ -15 °C. Rapid glaciation can lead to enhanced precipitation.

Cumulus clouds that produce only small diameter (< ~ 50 μm) drops do not generate secondary ice and substantial SLW is carried well above the –15 °C level.

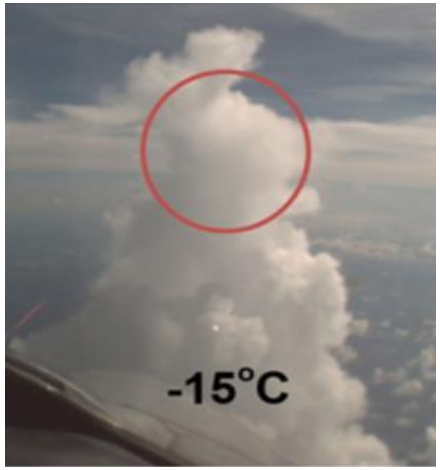
Some Cumulus clouds that do NOT naturally produce SLDs may be stimulated via hygroscopic seeding to enhance the coalescence process and produce SLDs.

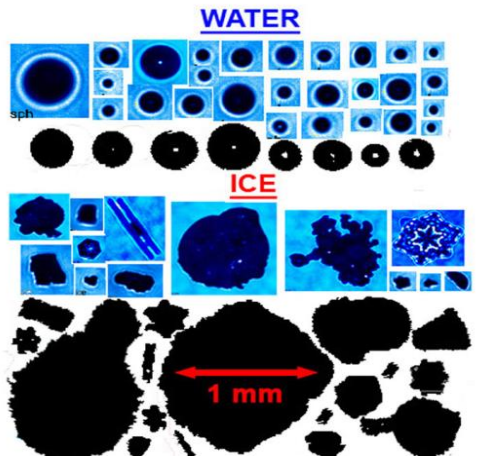
Question

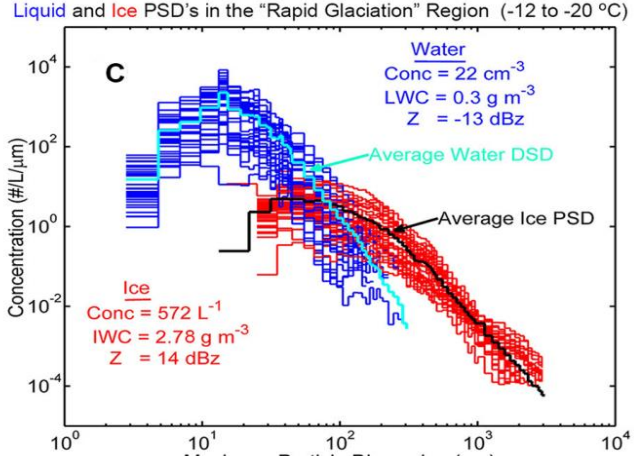
What are the characteristics of clouds that can be potentially stimulated to produce SLDs?

Rapid glaciation via Secondary Ice Production in (ICE-T) Tropical Clouds

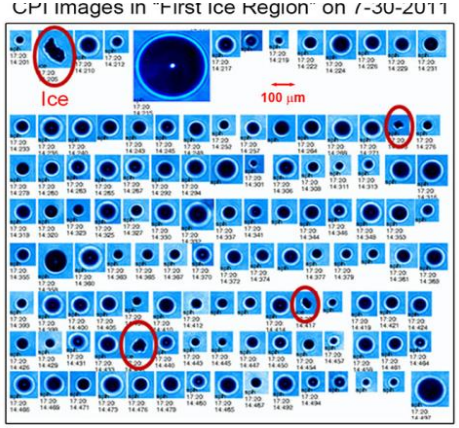
Rapid Glaciation

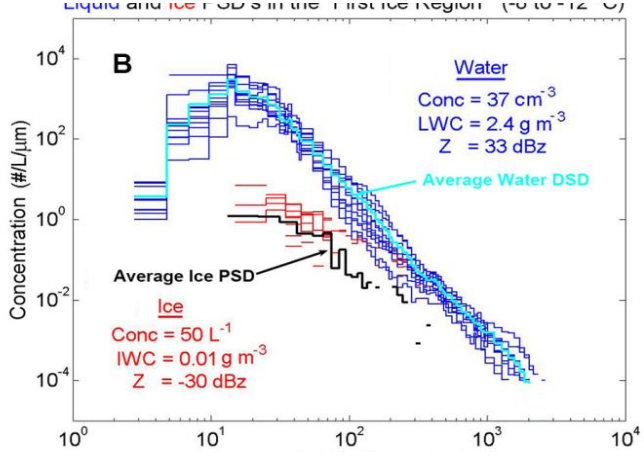




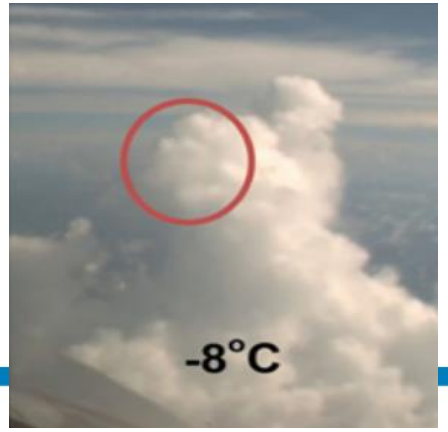


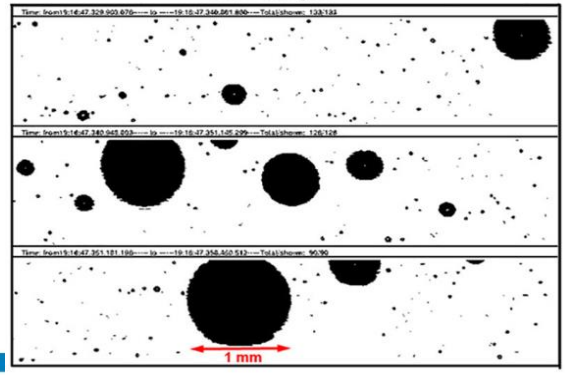
First Ice

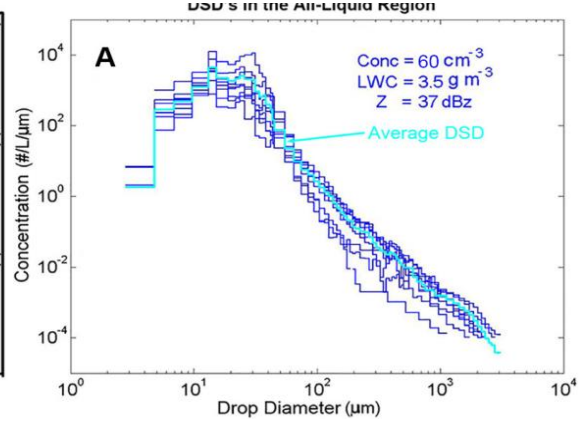




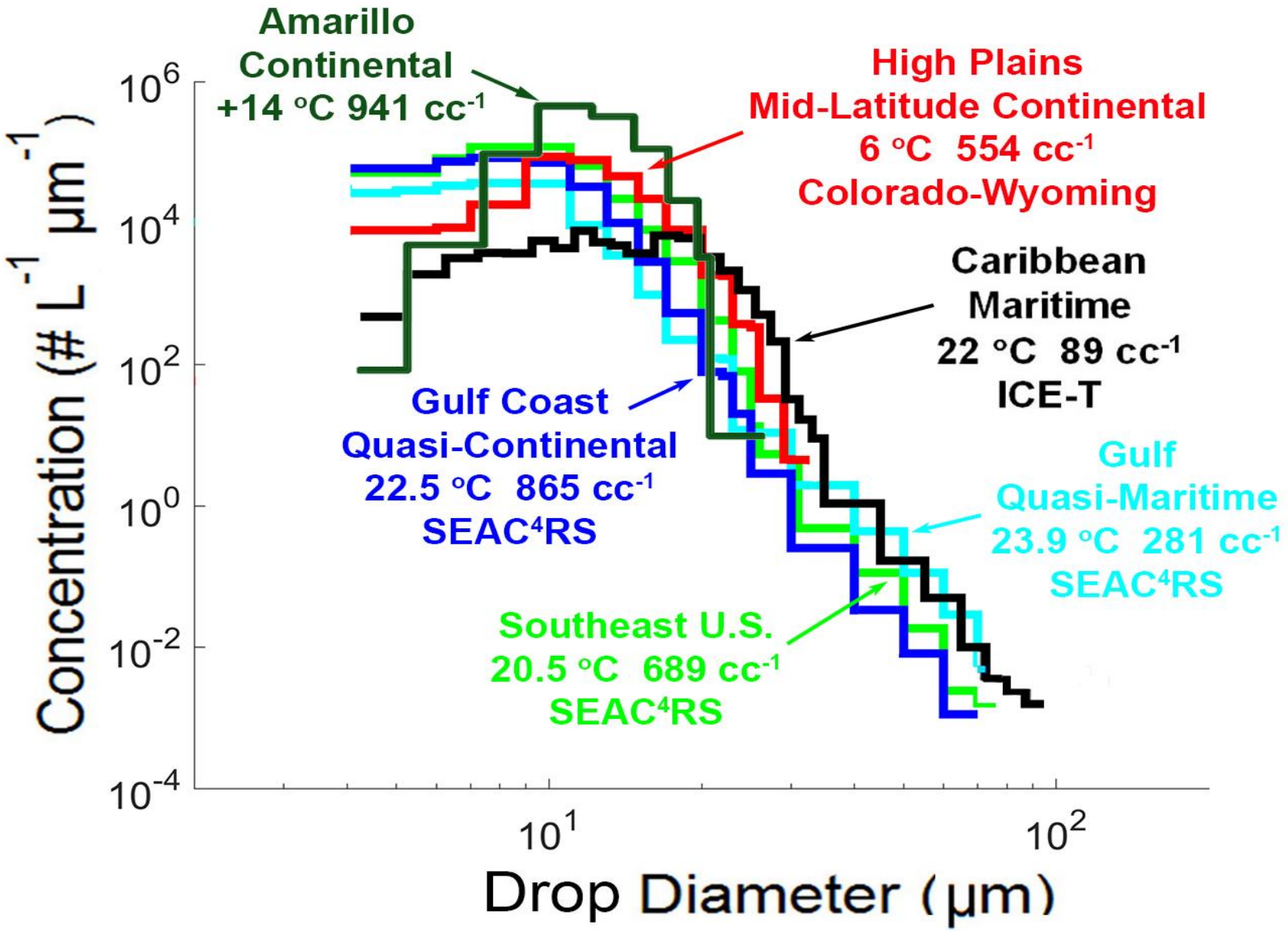
All Liquid with SLDs



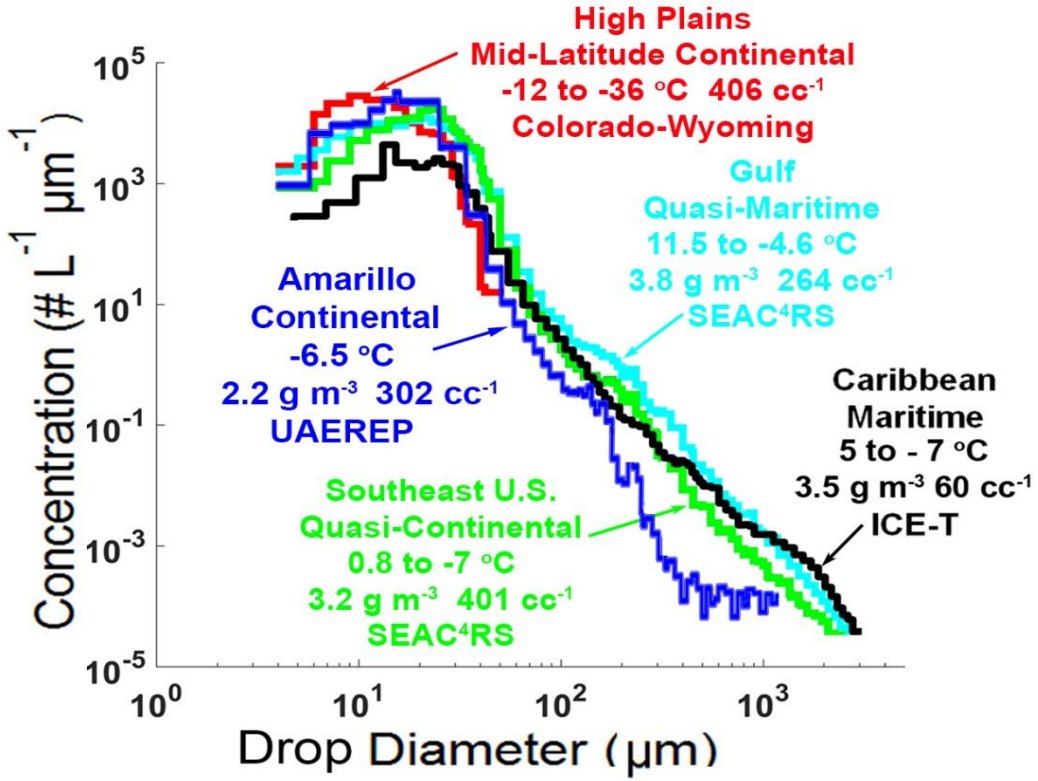


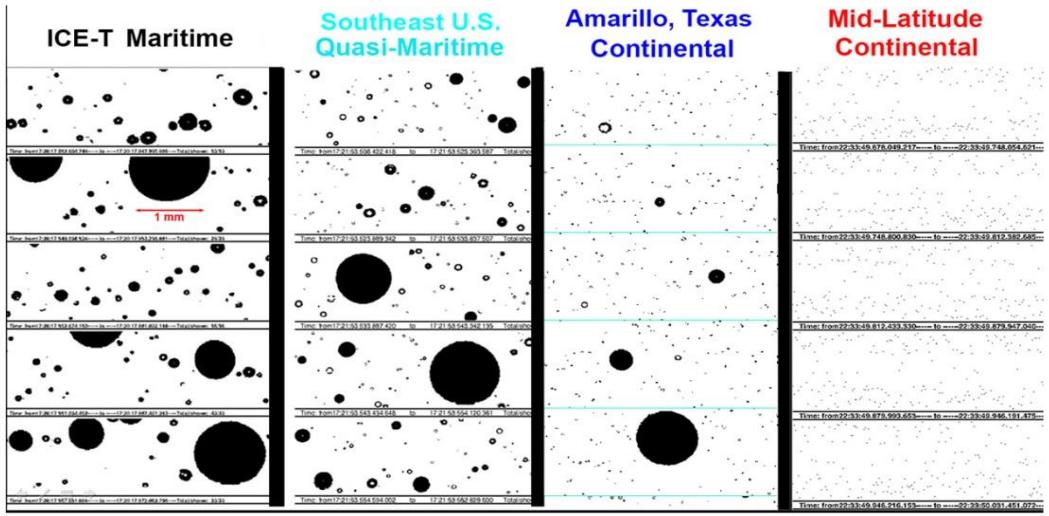


Cloud Base Drop Size Distributions as a Function of Cloud Base Temperature

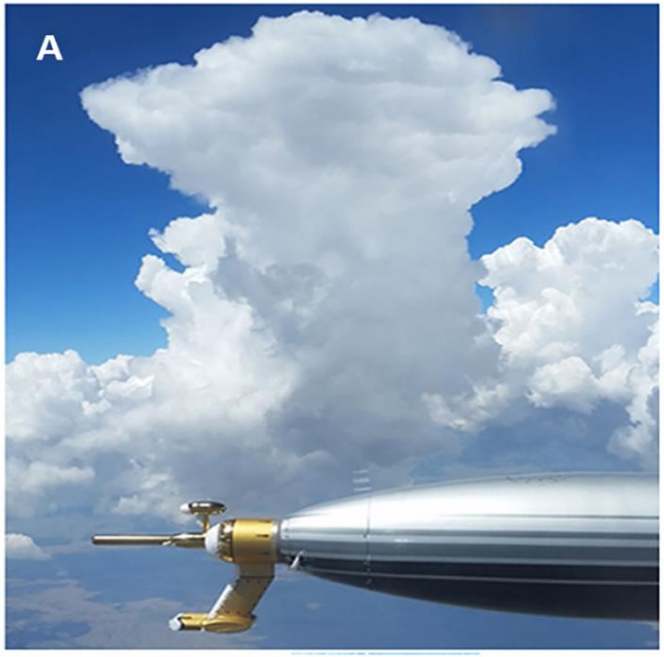


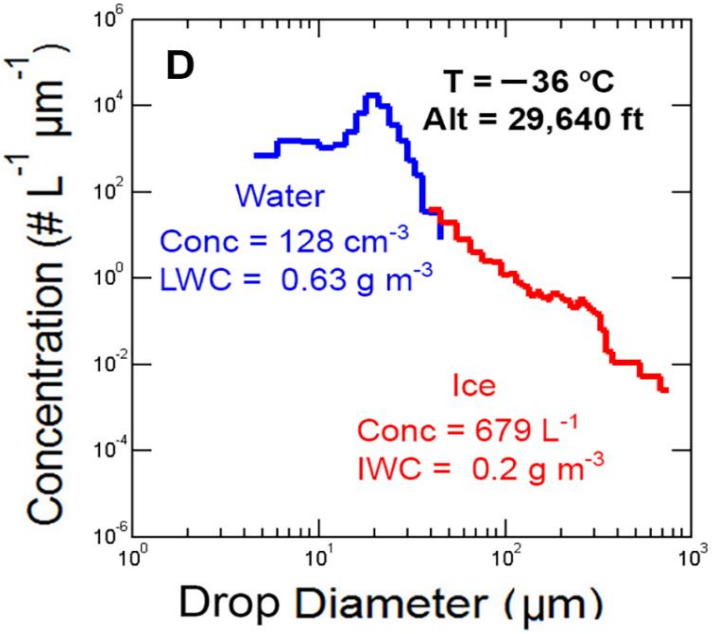
Drop Size Distributions in All-Liquid Cloud Regions

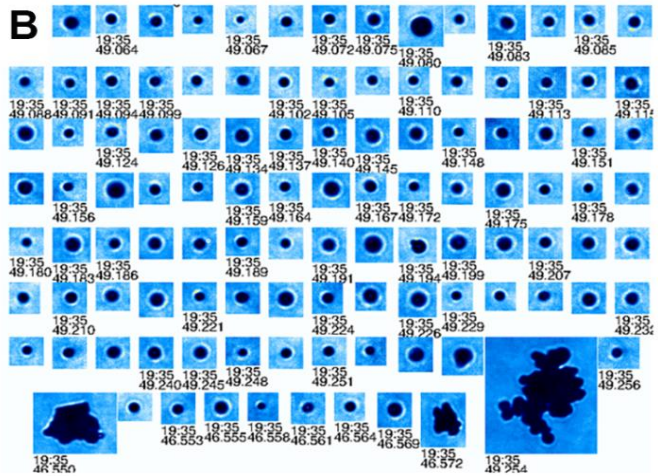




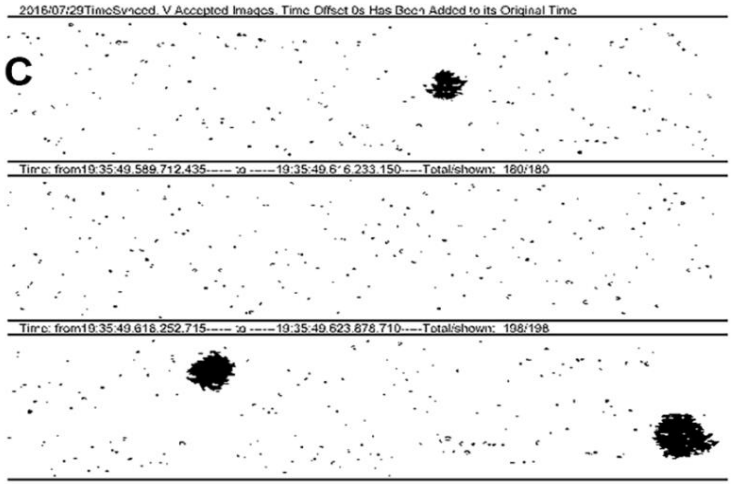
Supercooled Small Liquid Drops at -36 °C In Wyoming







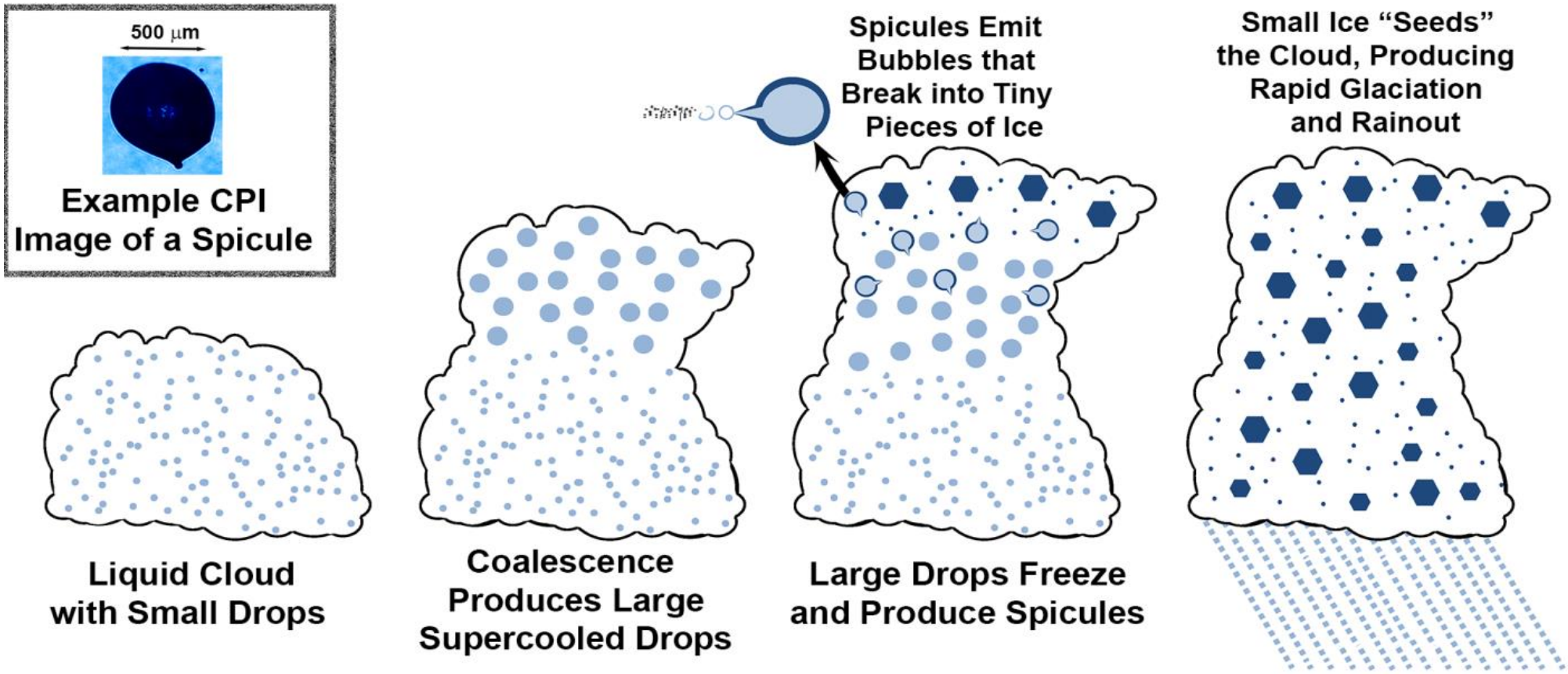
3V-CPI Images 200 µm



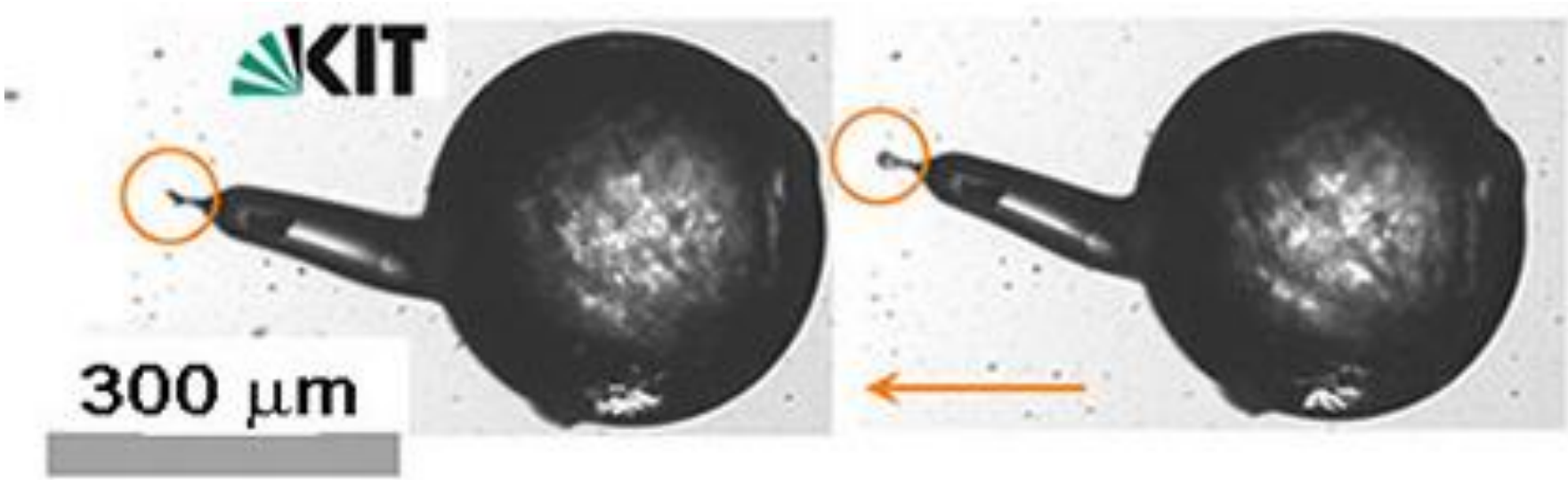
2D-S Images 1 mm

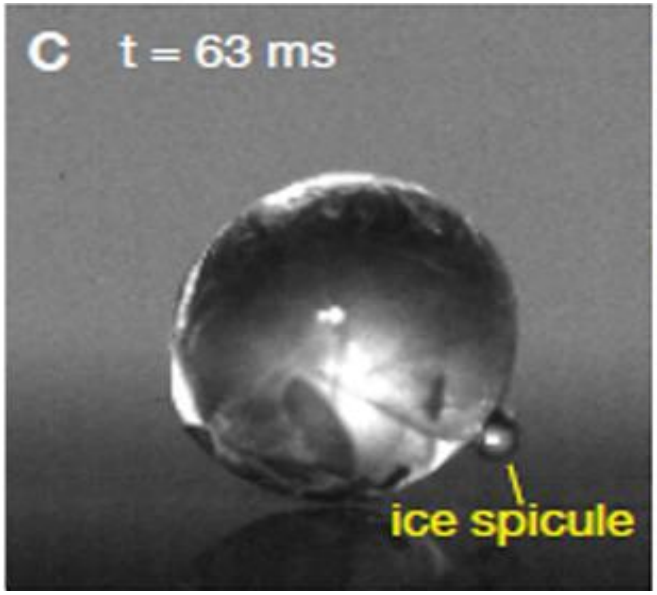
Why is there a correlation with SLDs and Secondary Ice Production?

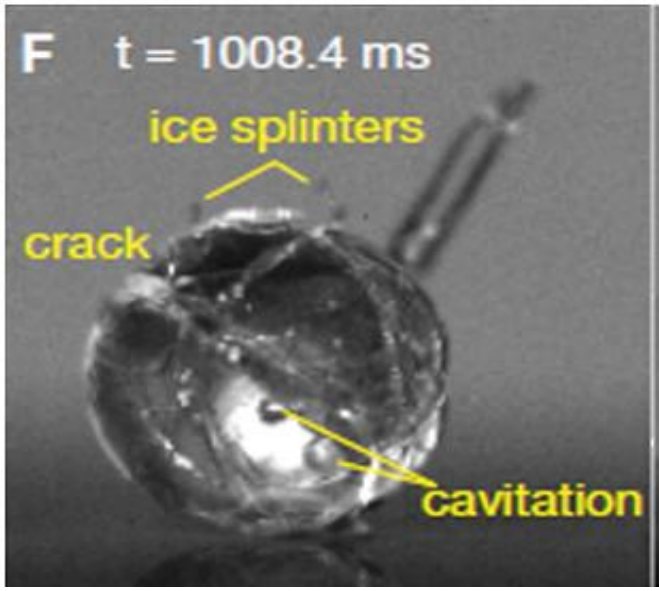
Cartoon Illustrating Secondary Ice Process in Clouds that Produce Supercooled Large Drops

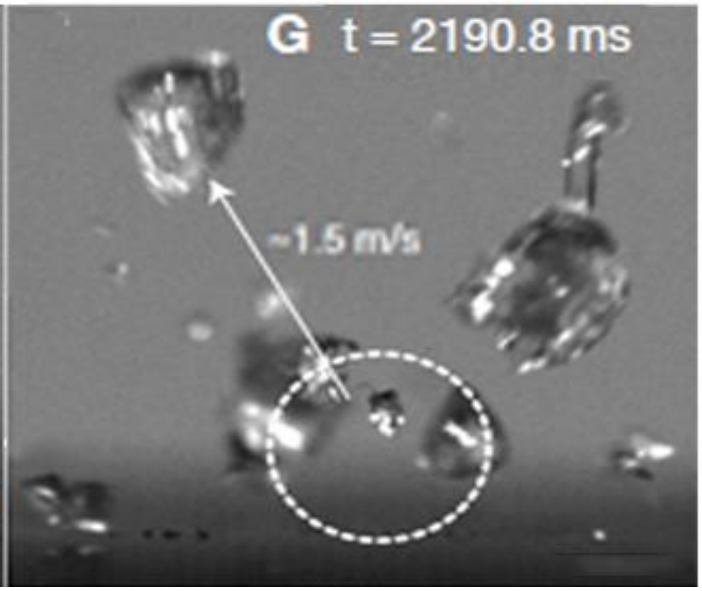


Laboratory Work of Leisner et al. (2014) and Wildeman (2017)







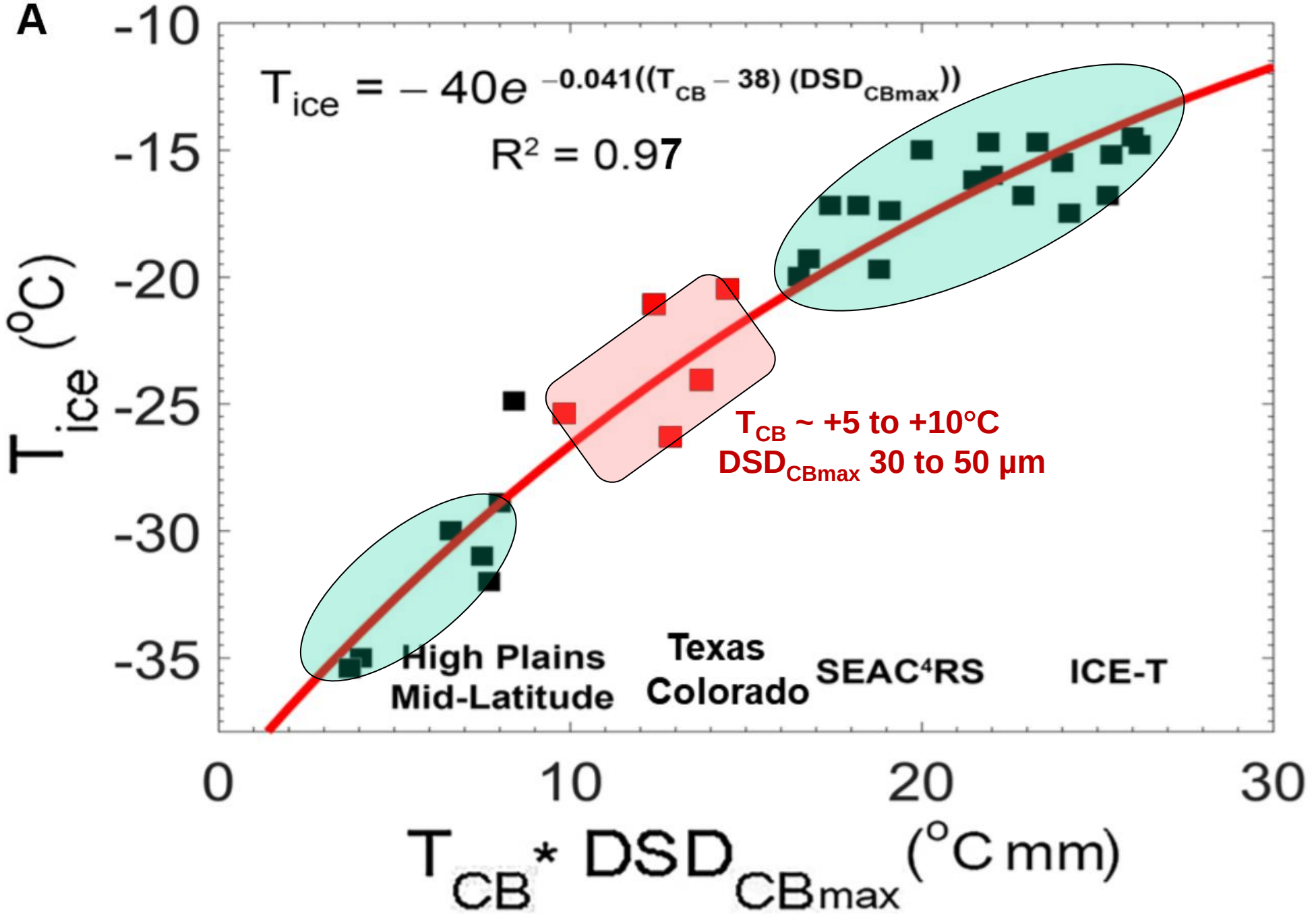


What is the Connection of Secondary Ice Production to Weather Modification?

- In some cumulus clouds it may be possible to simulate the coalescence process (by hygroscopic seeding at cloud base) to produce SLDs that would not be produced naturally.

- Freezing SLDs can fracture and emit small ice that will rapidly freeze other SLDs due to differential fall velocities.

- This will lead to an "Avalanche" process that rapidly glaciates the cloud (i.e., akin to glacionic seeding the entire supercooled updraft in a few minutes), with the possibility of enhancing rainfall.


A
$T_{ice} = -40e^{-0.041((T_{CB} - 38)(DSD_{CBmax}))}$
$R^2 = 0.97$
T_{CB} ~ +5 to +10°C
DSD_{CBmax} 30 to 50 µm
High Plains
Mid-Latitude
Texas
Colorado
SEAC⁴RS
ICE-T
-10
-15
-20
-25
-30
-35
T_{ice} (°C)
0
10
20
30
$T_{CB} * DSD_{CBmax}$ (°C mm)

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Thank You!