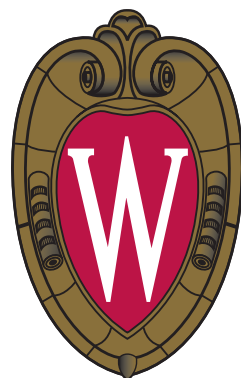


A Possible Role for Immersion Freezing in Mixed-phase Stratus Clouds

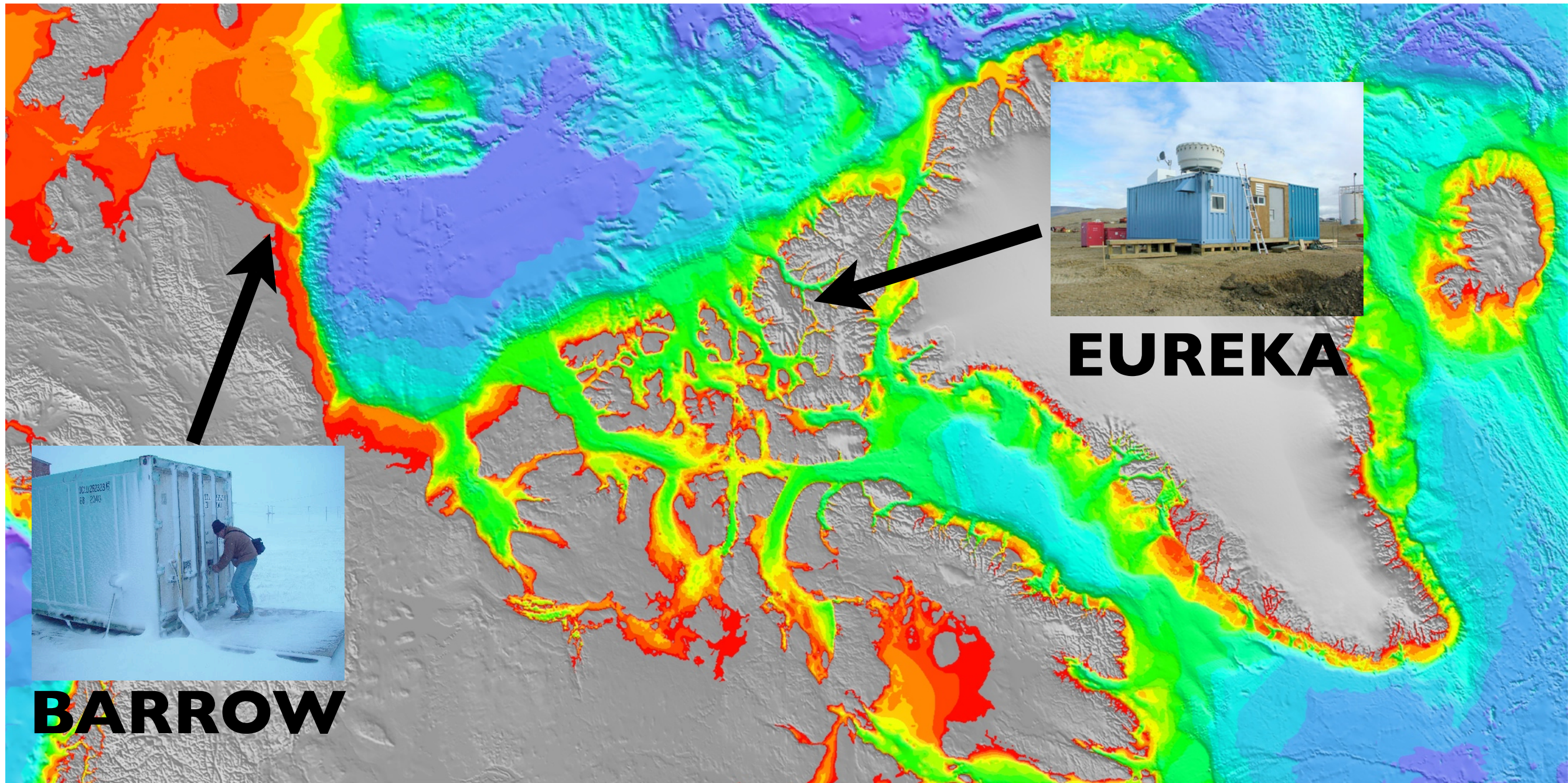
Gijs de Boer

T. Hashino, G.J. Tripoli, and E.W. Eloranta



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Introduction

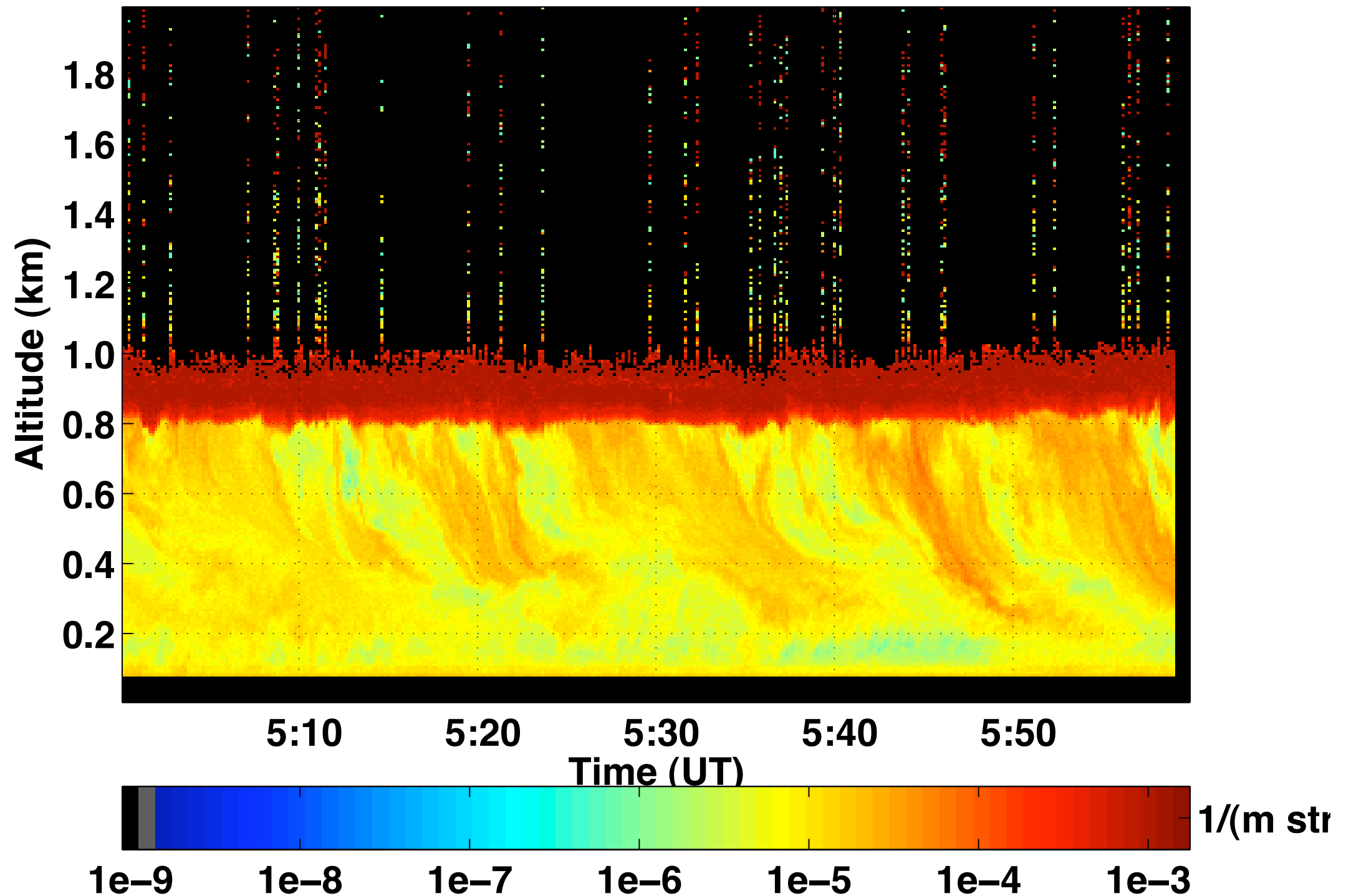


HSRL/MMCR combination

- Barrow (8/04-11/04) M-PACE (Verlinde, 2007)
- Eureka (8/06-Present) SEARCH

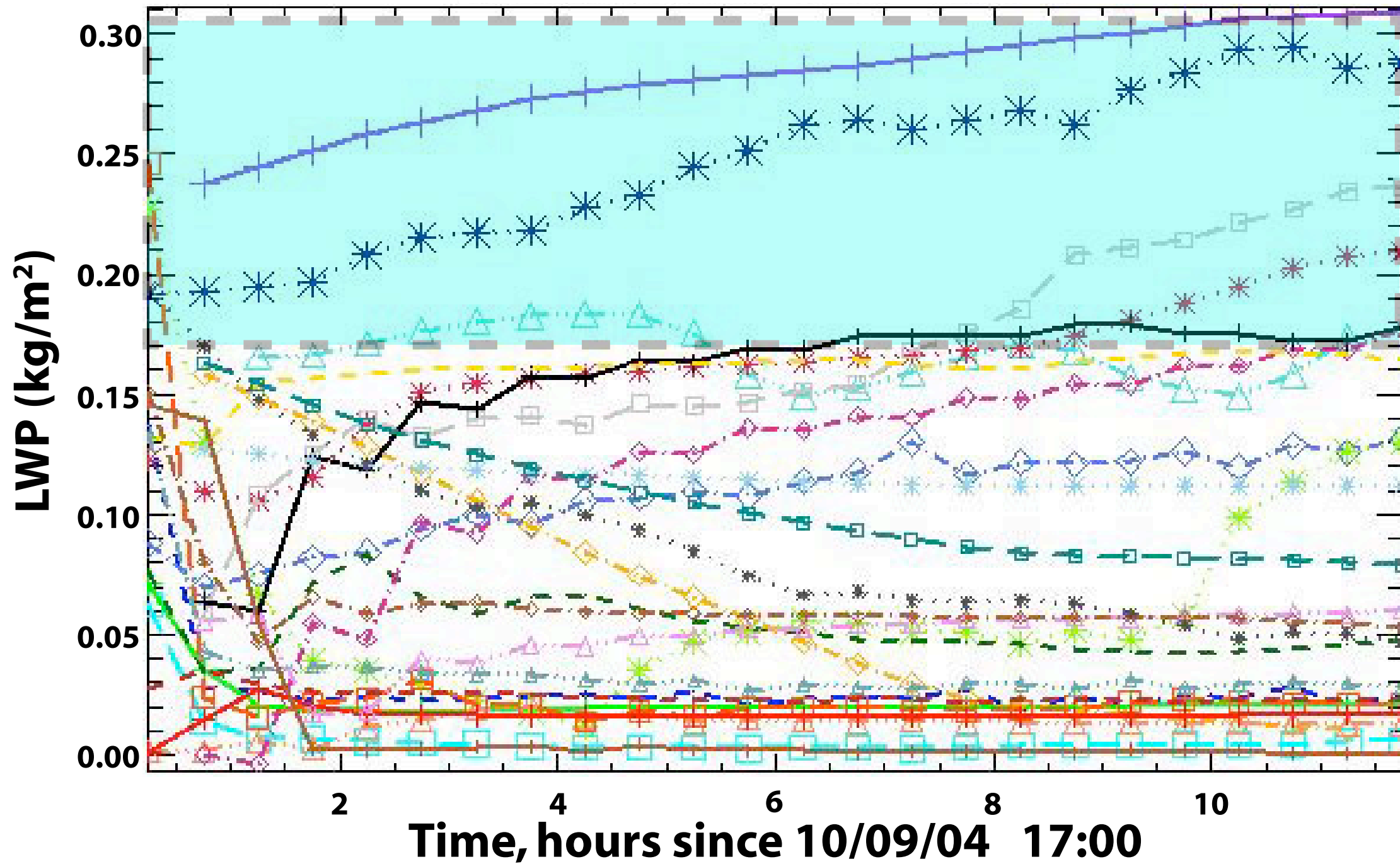
Introduction

Lidar backscatter cross section (Masked values shown in black and white)



Introduction

Cloud liquid water path, Case: b1



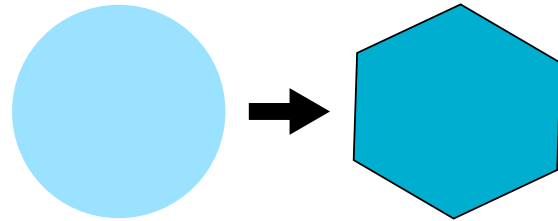
Data from Klein et al. (2008)

Ice Nucleation

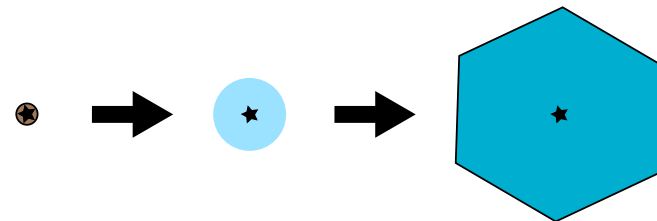
So, where does the ice come from?

- Primary Ice Formation (Pruppacher and Klett, 1997)

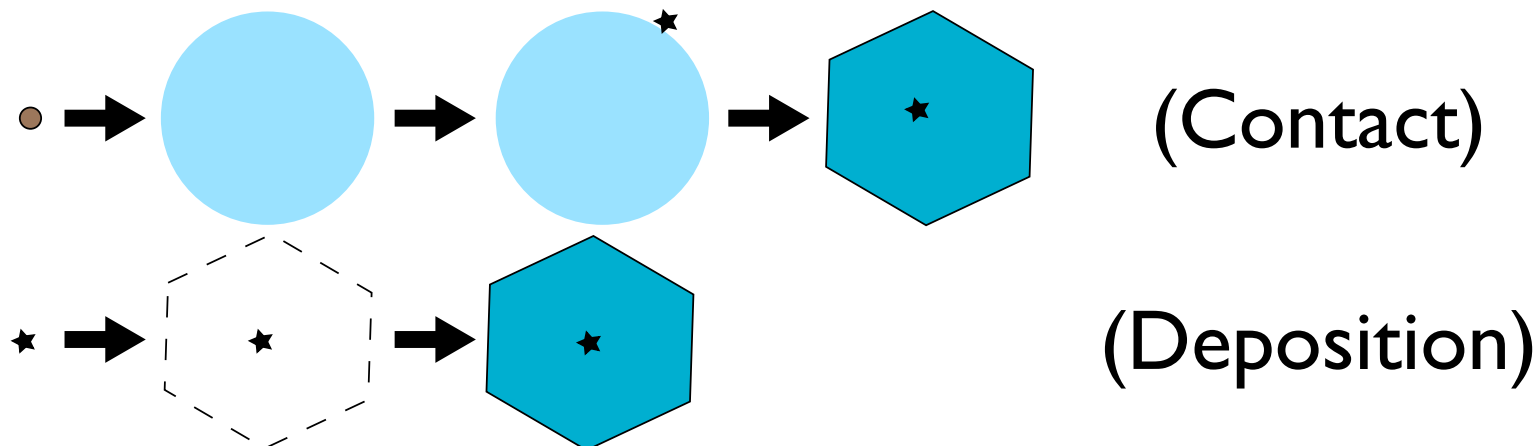
- Homogeneous nucleation



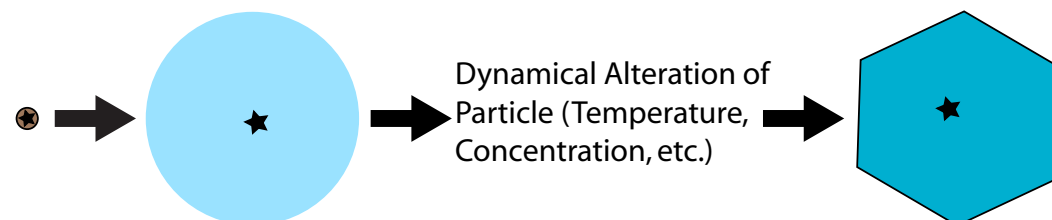
- Condensation nucleation



- Nucleation through free IN



- Immersion nucleation



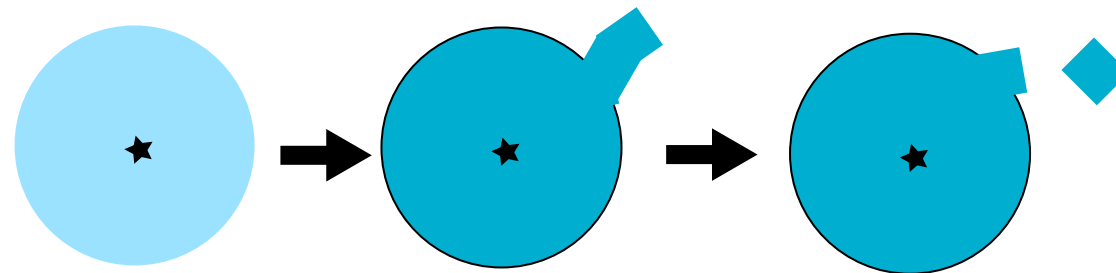
Ice Nucleation

So, where does the ice come from?

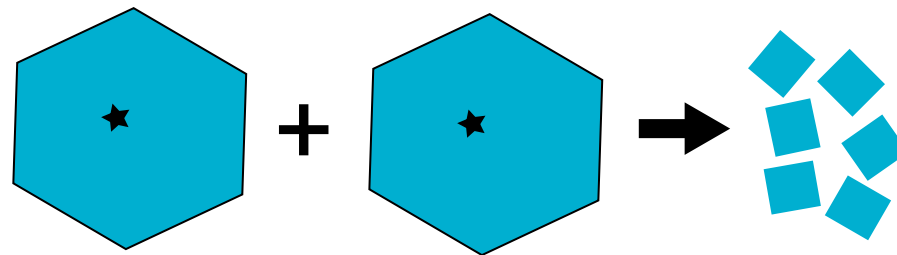
- **Secondary Ice Formation** (Pruppacher and Klett, 1997)

- Multiplication mechanisms

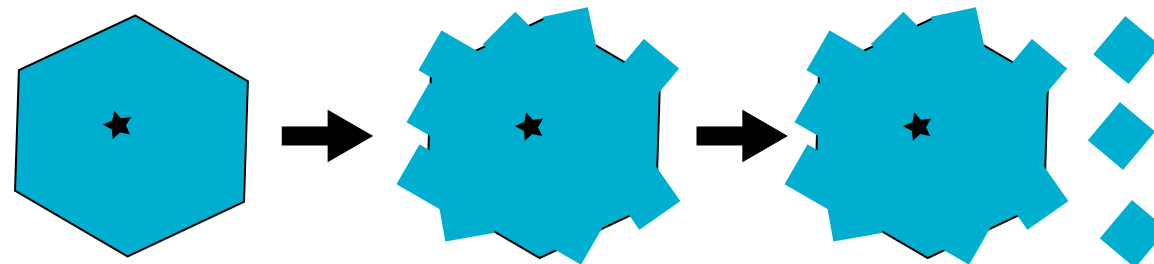
- Drop shattering:



- Ice-Ice Collisions:

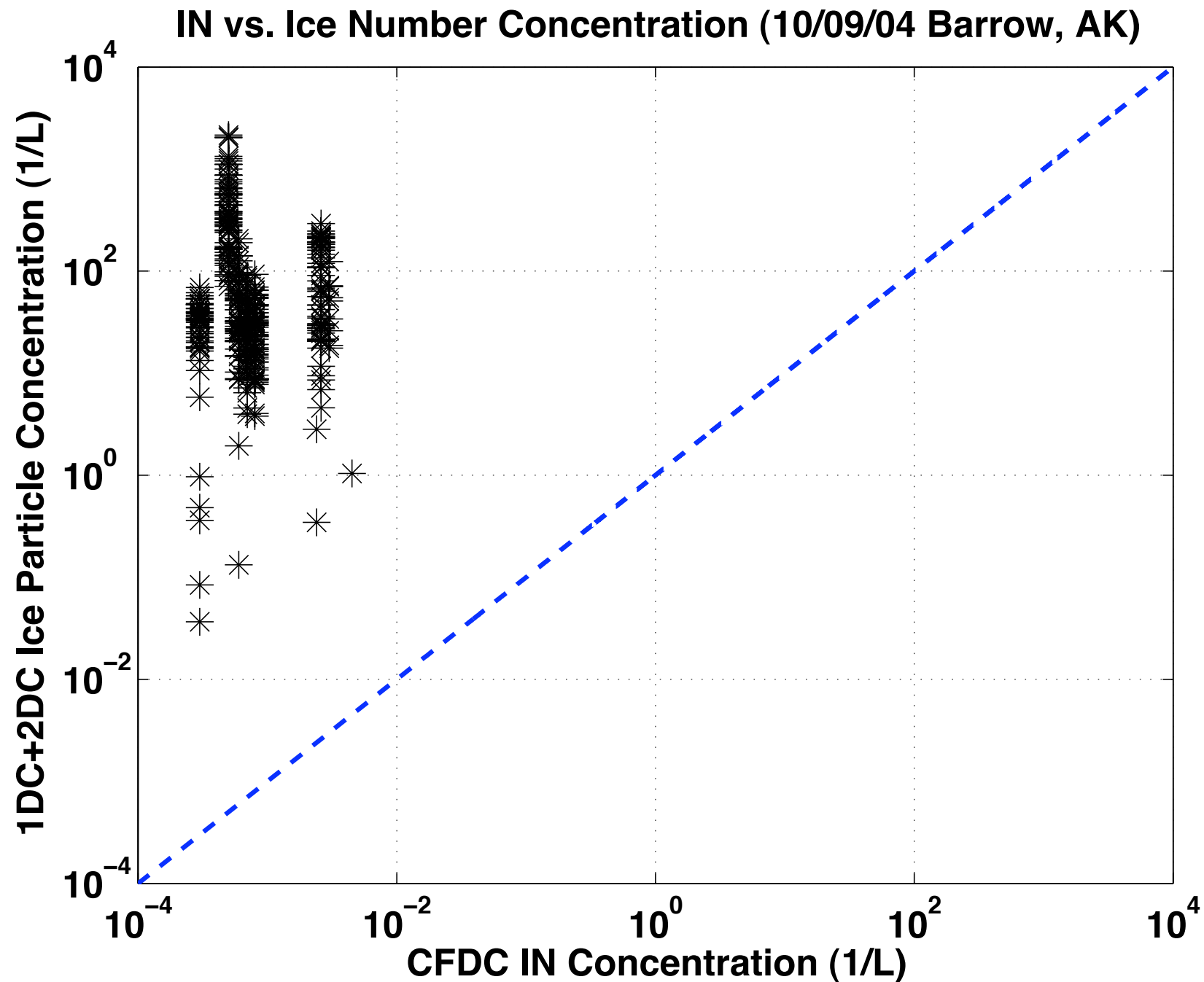


- Splinter ejection during riming (Hallett-Mossop, 1974)



Ice Nucleation

Ice concentrations often significantly exceed IN concentrations (Mossop, 1970; Beard, 1992)

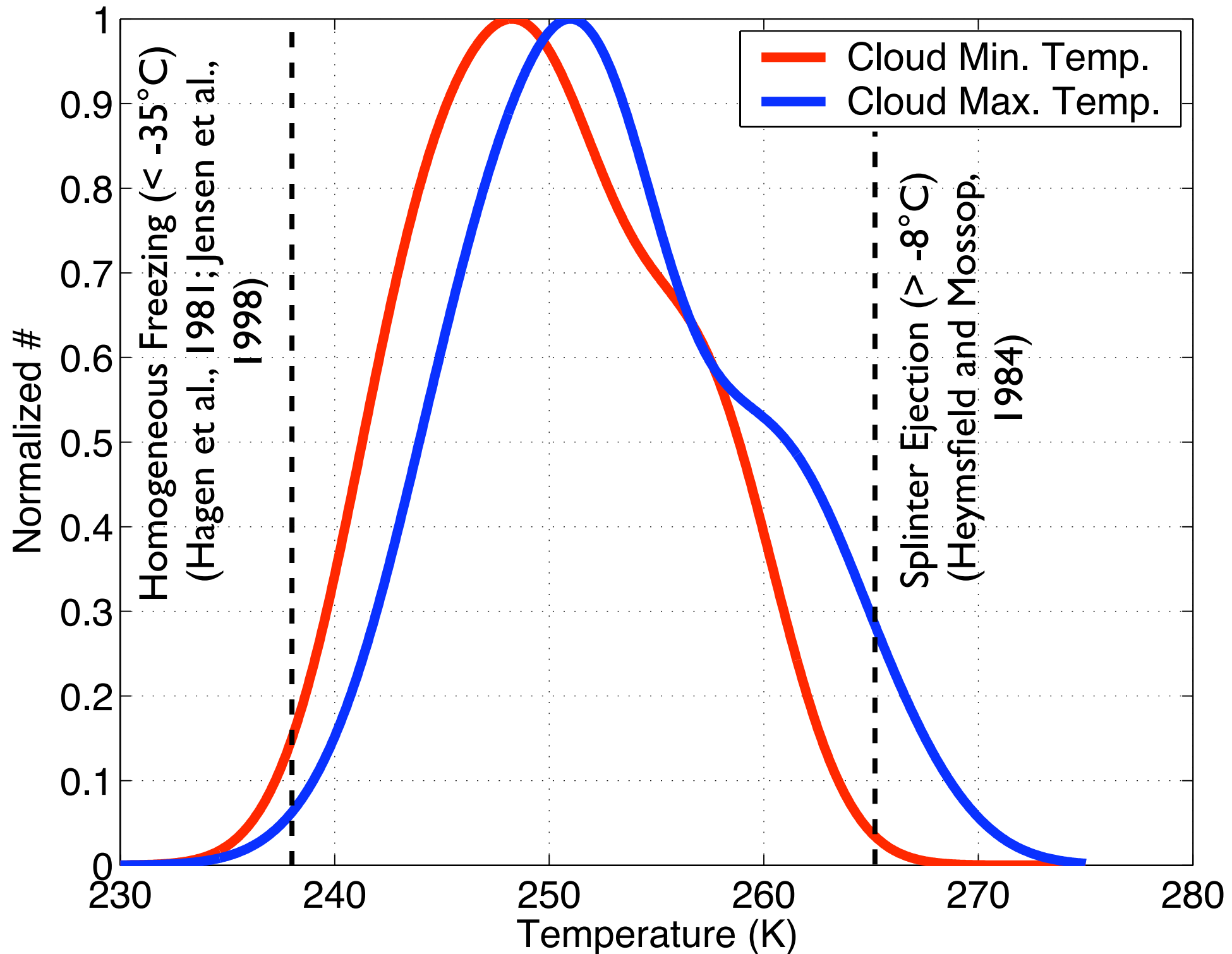


Data courtesy of Greg McFarquhar and Gong Zhang

Polar Cloud Working Group, 4th Pan-GCSS -- Toulouse, 2-6 June 2008

Ice Nucleation

So, where does the ice come from?



Immersion Freezing

What about immersion freezing?



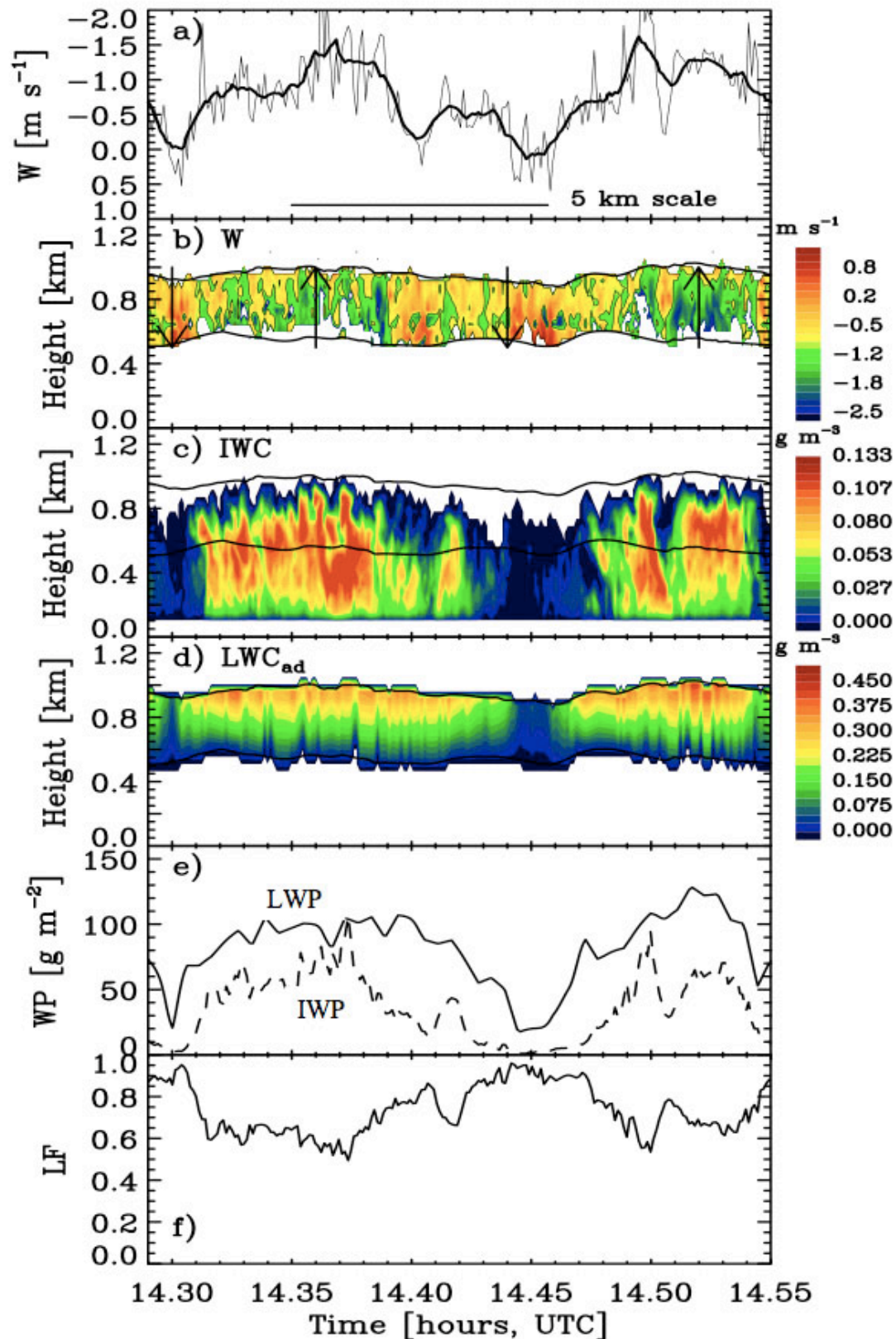
Image courtesy of J-P Blanchet

Some Observational Evidence

- Bigg (1980) observed sulfuric acid coating on aerosol particles during winter
- Reduced IN activity with coating confirmed by Bertram and Girard in laboratory
- Blanchet (2007) hypothesizes that sulfur coating is a result of sulfur emissions from Siberia, and that resulting particles in Arctic have reduced ice nucleating ability.

Immersion Freezing

What about immersion freezing?



Some Observational Evidence

From ground-based sensors:

- Large increases in IWC in updrafts
- Decrease in Liquid Fraction in updrafts

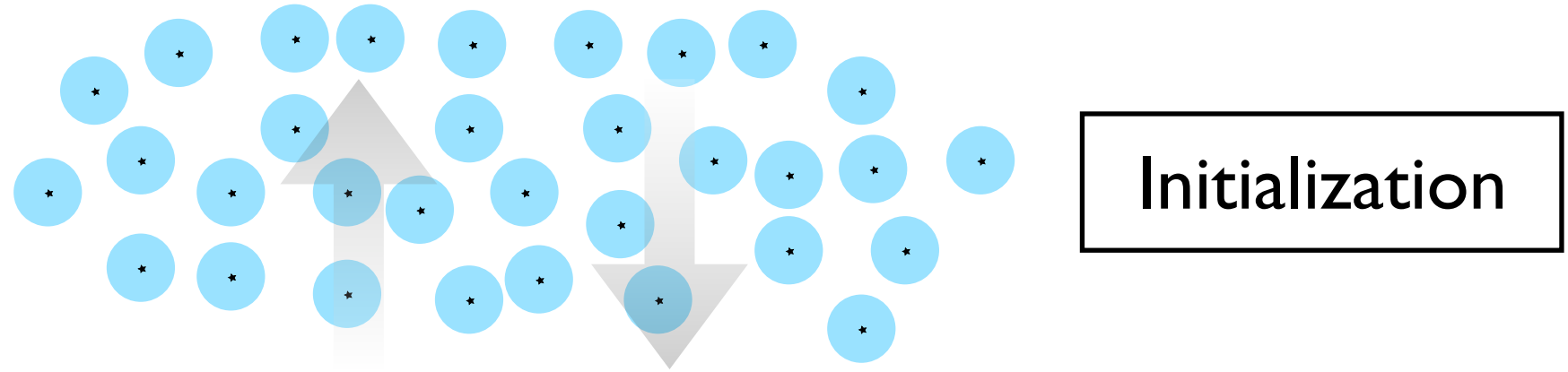
Figure courtesy of M. Shupe (NOAA)

From in-situ measurements:

- Ice crystal concentrations strongly proportional to concentration of drops larger than $20 \mu\text{m}$. (Rangno & Hobbs, 2001)

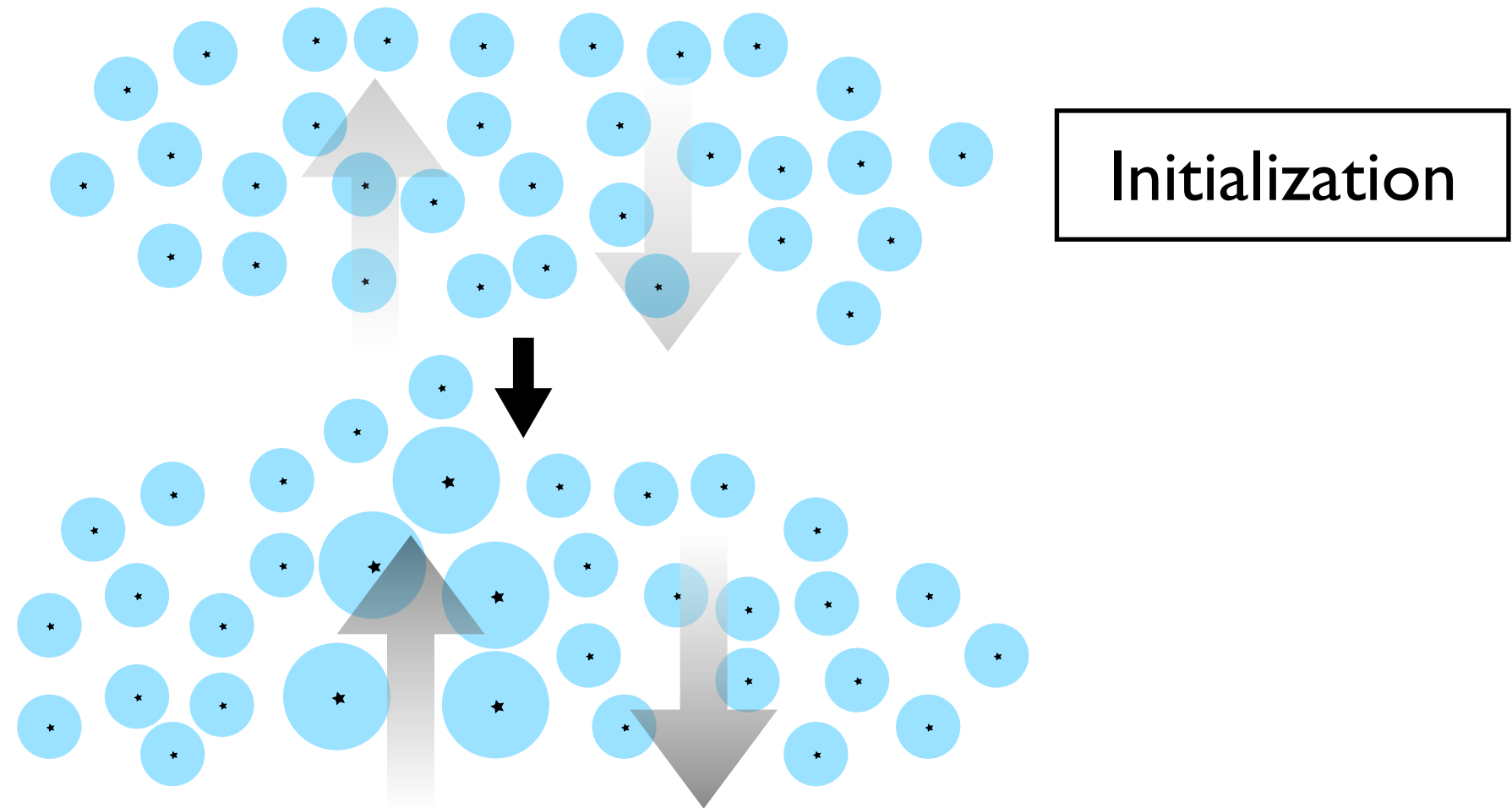
Immersion Freezing

Conceptual Model:



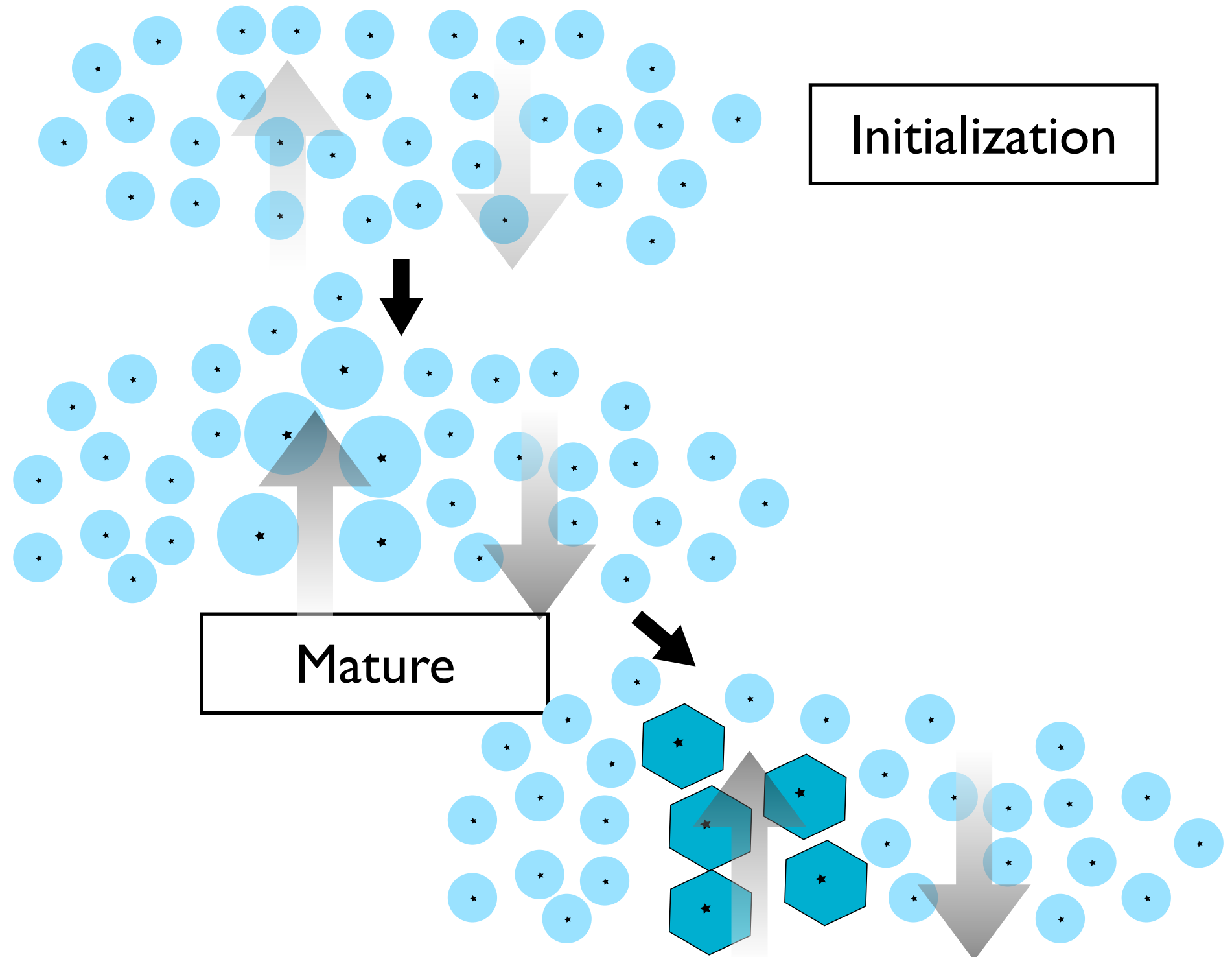
Immersion Freezing

Conceptual Model:



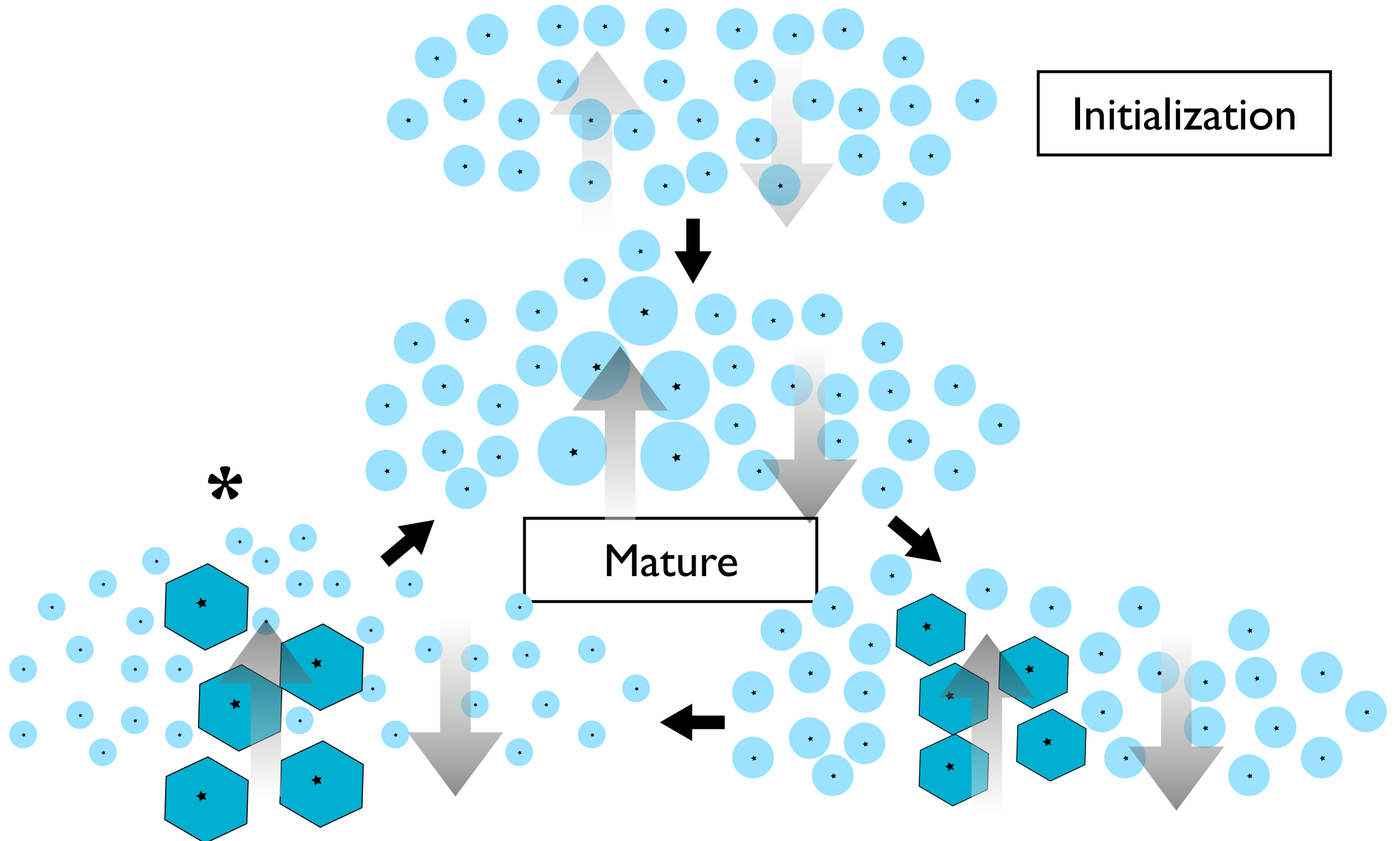
Immersion Freezing

Conceptual Model:



Immersion Freezing

Conceptual Model:

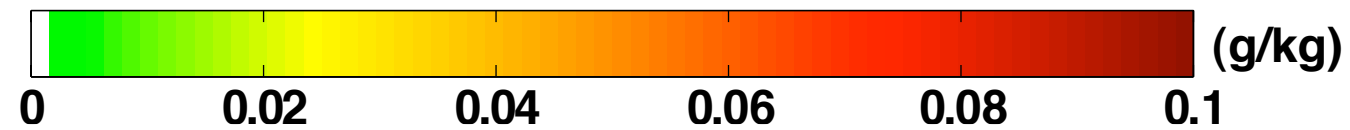
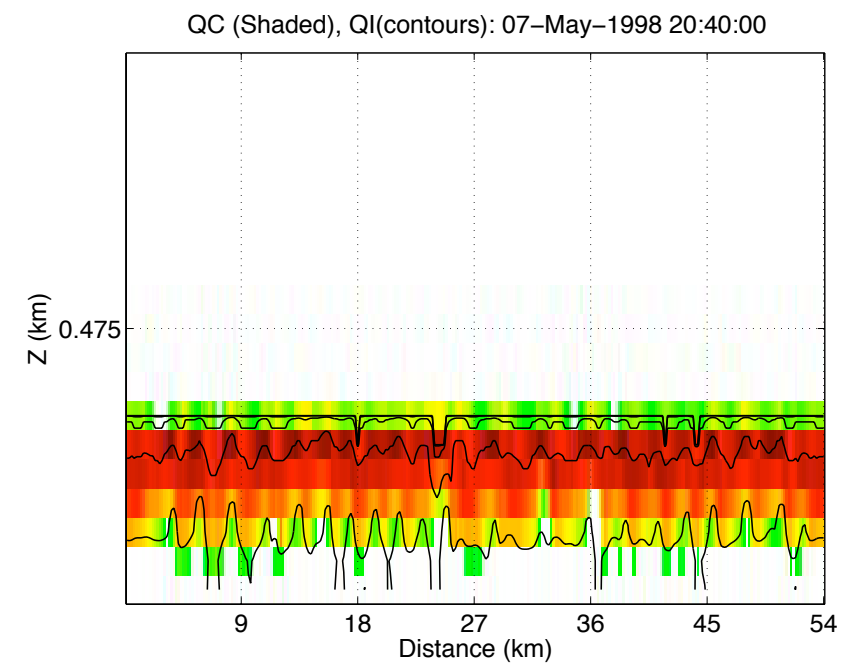
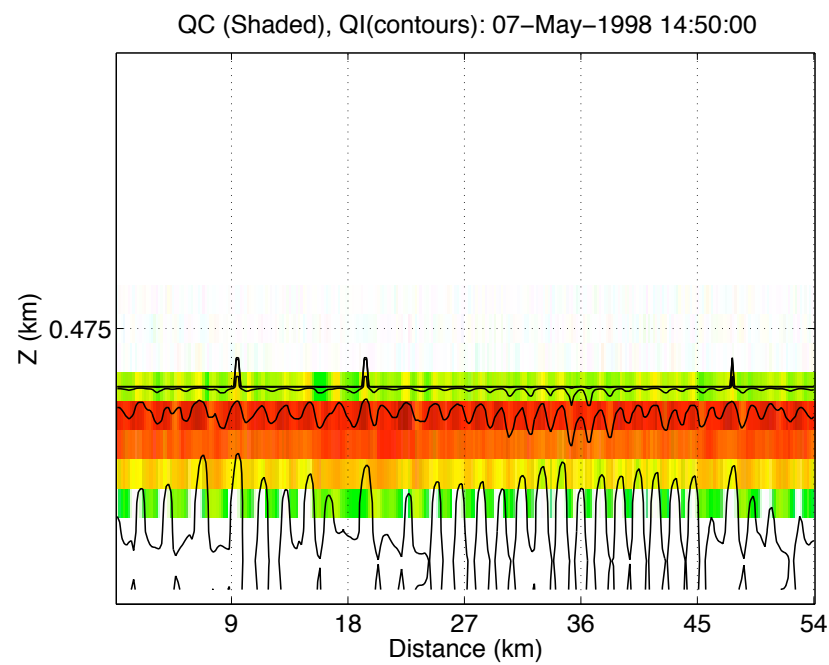
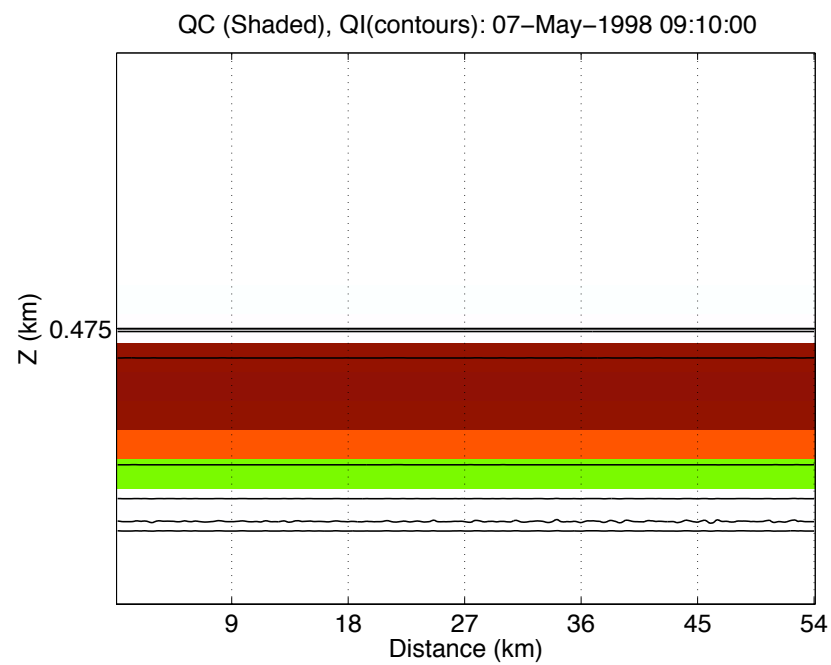
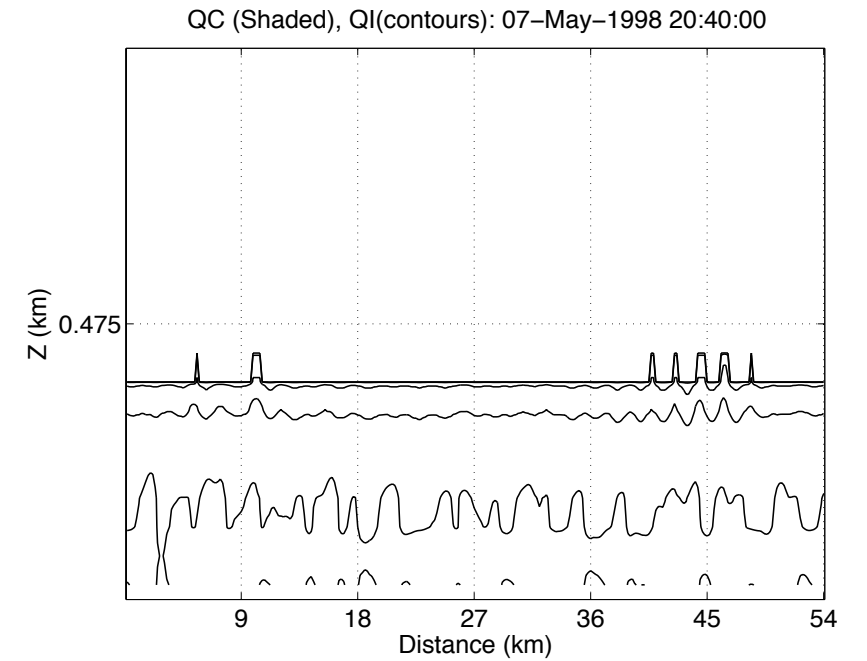
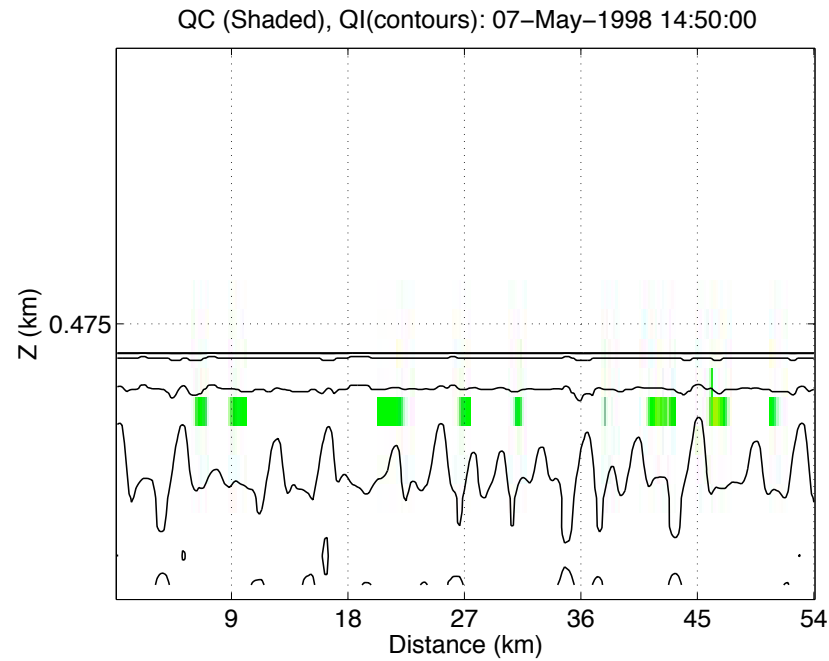
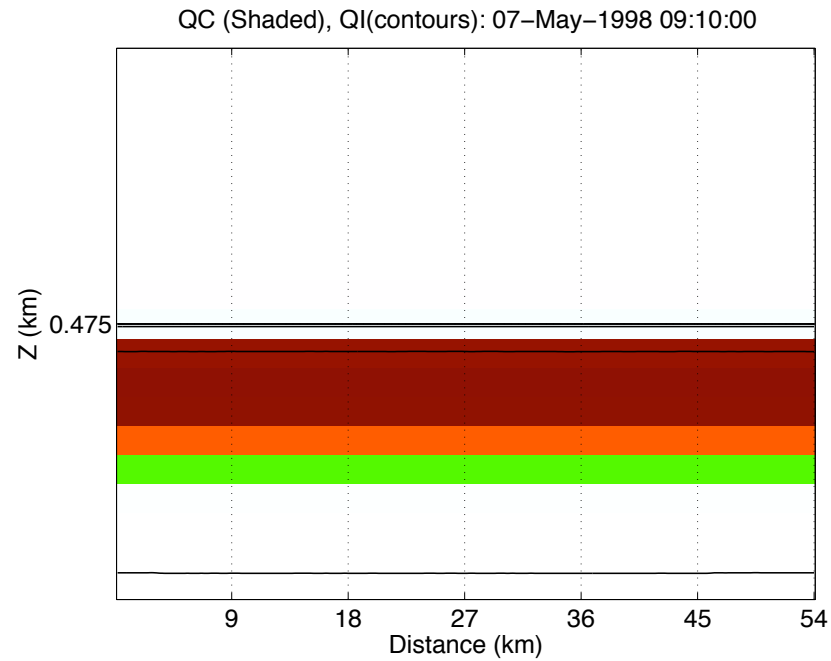


Simulation

t=10 min

t=350 min

t=700 min



Summary

- Nucleation of ice appears to control amount of liquid in mixed-phase stratus
- In-Situ and remotely-sensed observations provide evidence for possibility of immersion freezing
- Simulations reveal early hints at possibility of controlled nucleation through immersion freezing

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