Effects of Immersion Freezing on Simulations of Mixed-Phase Stratus Clouds (Theory and Results)

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Introduction

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

Cloud liquid water path, Case: b1
Introduction

Homogeneous Freezing (< -35°C) (Hagen et al., 1981; Jensen et al., 1998)

Splinter Ejection (> -8°C) (Heymsfield and Mossop, 1984)
Introduction

- Bigg (1980) observed sulfuric acid coating on aerosol particles during winter.
- Sulfuric coating is water soluble, transforming possible IN into CCN.
- 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.

From ground-based sensors:
- Large increases in IWC in updrafts
- Decrease in Liquid Fraction in updrafts

From in-situ measurements:
- Ice crystal concentrations strongly proportional to concentration of drops larger than 20 $\mu$m. (Rangno & Hobbs, 2001)
Immersion Freezing

Dynamical Alteration of Particle (Temperature, Concentration, etc.)
Immersion Freezing

Conceptual Model for Mixed-Phase Stratus

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Immersion Freezing

Dynamical Alteration of Particle (Temperature, Concentration, etc.)

**Graph**

- X-axis: Time (s)
- Y-axis: Concentration (#/L)

- Black line: Ice Particles
- Red markers: Ice Nuclei

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Immersion Freezing

NH₄HSO₄, Illite, 70% Soluble

Molality (mol/kg H₂O) vs. Drop Radius (µm)

- 0.001 mole/L

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Simulations

2-D Simulations for the SHEBA mixed-phase case

-- University of Wisconsin Non-Hydrostatic Modeling System (UW-NMS: Tripoli, 1992)

-- Advanced Microphysical Prediction System (AMPS: Hashino and Tripoli, 2007)
  - Size-resolved liquid and ice microphysics with diagnostic aerosol (IN and mixed).
  - Immersion freezing: Reisin (1996), and solubility effect from Diehl & Wurzler (2004)
  - CCN: 70% soluble NH$_4$HSO$_4$ mixed particle

-- Resolution: 200 m horizontal, 50 m + vertical
Simulations

Total Liquid Water Path

LIQUID | ICE
---|---
All Ice Processes
Immersion Only
Retrievals

10 minutes
360 minutes
720 minutes

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Simulations

Effect of Solution Concentration

From Hoffer (1961)

Fig. 5. Median droplet freezing temperature for droplets of different solute concentration (100-120 microns diameter).
Simulations

Effect of Solution Concentration

Total Water Path

Immersion Freezing Only
- 350/cc CCN
- No Sol. Effect

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Simulations

Effect of Solution Concentration

Total Water Path

Immersion Freezing Only
- 350/cc CCN
- No Sol. Effect
- 500/cc CCN
- No Sol. Effect
- 72.2/cc CCN
- No Sol. Effect

LWP (g/m^2)

Time (hrs.)
Summary

-- Understanding of ice nucleation mechanisms is key for understanding and modeling mixed-phase stratus lifetime.
-- Observation of IN involved with immersion freezing is uncertain at this time.
-- Simulations with only immersion freezing active produce approximately the correct amount of ice in high resolution simulation.
-- The freezing point depression due to presence of soluble material inside droplets significantly affects simulations, but pathways for these effects are not necessarily straightforward.