Quantifying the Dust Impacts on the Ice Generation in Supercooled Stratiform Clouds

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Motivations-1: The importance of heterogeneous ice generation

High impacts of IWPs on stratiform mixed-phase cloud radiative forcing
Results from multi-year results at the Barrow site.

DeMott et al. 2010

Big differences among many existing parameterizations!
—Which one is right?
Motivations-2: Heterogeneous ice generation strongly depend on aerosol types!

- Dust aerosols are effective and important ice nuclei (IN).
- Big uncertainties in our knowledge base about dust as IN.

The JJA dense dust occurrence based on CALIPSO observations

From Fig. 10a, Phillips et al. 2008, JAS.
Our Research Goals

• Using remote sensing to study ice generation in stratiform clouds
  – Ground-based observations at the Barrow site
  – Global Satellite observations

• Linking ice generation with aerosol properties
  – Dust

• Improve mixed-phase cloud parameterization
Distinct low liquid-ice mass partition during the spring time.
Spring time High Dust Occurrence is one of the potential reasons!

Based on 2007-2008
Dust Impacts from Satellite Observations

Use CloudSat radar and CALIPSO lidar measurements of mixed-phase altocumulus (Ac) to quantify dust impact on heterogeneous ice generation.

- CloudSat $\rightarrow$ ice properties.
- CALIPSO $\rightarrow$ liquid properties + nearby aerosol information.
- CloudSat $Z_e \rightarrow$ ice properties.

But, we have to use in situ measurements and modeling results to develop these new potentials.
The Similarity of Ice Crystal Size Distribution in Similar Mid-level Stratiform Clouds

Similar clouds in terms of cloud top temperature (CTT) and LWP.
Dusty Conditions

1. Clouds within a dense dust plume – *dusty*
2. Clouds over dust belt without clear dust layer – *non-dusty*
3. The same lat and lon zone in the southern hemisphere – *south*

The dusty case distribution (4-year CloudSat and CALIPSO data)
Dust impacts on heterogeneous ice generation

- Strong dust impacts on mixed-phase cloud occurrence, $Z_e$ maximum, and layer ice water path.
- For Ac clouds with similar properties, ice crystal generation and growth in them are similar.
- Thus, $Z_e$ differences among similar clouds in different regions reflect mainly ice number concentration differences.

The distribution of supercooled Ac as a function of CTT and $Z_{e\text{ max}}$ (500 m within cloud top) for dusty and non-dusty cases with maximum total attenuated backscattering (TAB) within 0.37-0.51 km$^{-1}$ sr$^{-1}$ (a, b, c); d) mixed-phase Ac fractions, e) mean $Z_{e\text{ max}}$, and f) IWP.
Regional Differences of the Dust Impact

(a) $Z_e_{\text{max}}$ differences between dusty, non-dusty and ‘South Regions’ MSCs in terms of CTT; (b) $Z_e_{\text{max}}$ differences between dusty and ‘South Regions’ MSCs for the four sub-regions.

8 dBZ $\rightarrow$ factor of $\sim 7$

5 dBZ Peak difference!
A simple ice growth model to establish $Z_e$-$N$ relationships

1. Given a cloud top temperature, a LWP, and turbulence features.
2. Ice crystals start near the cloud top, grow big and falls.
3. $Z_e$ profile as a function of distance from the cloud top.

A comparison of observed and modeled $Z_e$ profiles.
From Maximum $Z_e$ to Ice Number Concentration

Modeled $Z_e$ for 1 per liter ice concentration

Global Ac ice concentration within -7 and -38 degree.

See the Poster by Damao Zhang et al. for more details.
An in situ case for evaluation: -23 °C

- Collocated in situ and remote sensing observations indicate that ice number concentration (N) is a strong function of $Z_e$ max.
- Growth model estimated N agrees with observations within a factor of 2 statistically.
From maximum $Z_e$ to $N$ for ice in Stratiform Mixed-phase Clouds
Dust Impacts In the Context of Different Parameterizations

- Large variations in ice concentrations.
- Old parameterization generally overestimate ice concentrations.
- Need a better understanding of ice concentration variations in association with aerosol property variations!
Summary

1. Remote sensing (lidar and radar) measurements are capable to estimate ice crystal number concentration in mixed-phase altocumulus clouds with uncertainties about a factor of 2 (statistically).

2. Dust aerosols can enhance ice number concentration in mixed-phase altocumulus clouds by a factor 2 to 7.

3. Remote sensing offers a new opportunity to refine our knowledge of heterogeneous ice generation, and compliments with lab and field IN measurements.

4. Ongoing work:
   - to refine the growth model (see Zhang et al. Poster),
   - to link ice concentration variations with dust properties-size, source, and concentration (see our report during the ice nucleation section).
3-D cloud resolving model with an explicit bin microphysics (Fan et al. 2009)

The time evolution (12-hr) of model simulated clouds

The simple 1-D growth model performed quite well compared with 3-D CRM simulations.
An in situ case for evaluation: -15 °C