Revisiting parameterizations of ice nucleation in cloud models

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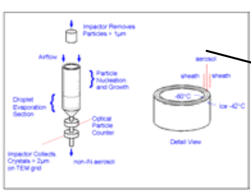
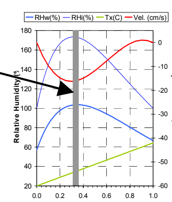
Motivation

Cloud resolving model studies have noted the sensitivity of simulation results to specification/formulation of ice formation processes. Parameterization of ice formation in cloud resolving models can take many forms of varying complexity, but it has been a number of years since recommendations have been made on the basis of actual ice nuclei data. Observations of heterogeneous ice nuclei have been made with the CSU continuous flow diffusion chamber for different locations and seasons over the past 12 years. This work in progress (at an early stage!) seeks to compile and document the state of our understanding of ice nuclei (IN) concentrations and to evaluate how simple or complex a description of ice formation in mixed phase clouds must be if one desires to predict ice initiation.

Methods

Continuous flow diffusion chamber (CFDC): At present, the only real-time measurement system for ice nuclei concentrations. The method used is to process a sample stream of aerosol particles from an inlet for constant temperature and relative humidity conditions in an ice-thermal diffusion chamber. Technique is sensitive to deposition, condensation and immersion freezing, and (at low temperatures) homogeneous freezing nucleation. Short time scale (~10s) neglects contact freezing nuclei. Focus here on the heterogeneous ice nuclei of relevance to mixed-phase clouds. All data sets will be reprocessed in exactly the same manner: data outside of clouds, concentrations at STP, same sample integration time interval and baseline procedures in every case, homogeneous freezing data excluded.

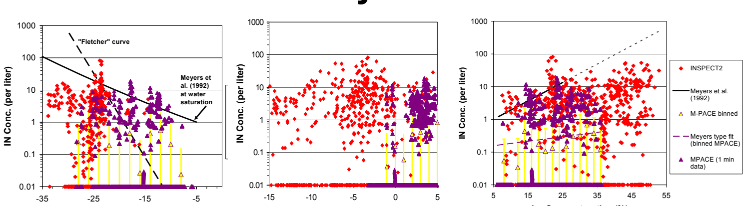




$-7 > T_{CFDC} > -60^{o}C$ $RH_{icesat} < RH_{CFDC} < 1.15*RH_{watsat}$

Projects under reanalyses: North Dakota Tracer Experiment: High Plains convection, Summer 1993; Winter Icing in Storms Project: Colorado stratiform clouds, Winter 1994; NASA-SUCCESS: High Plains spring cirrus, Spring 1996; FIRE-ACE/SHEBA Arctic, Spring1998; Ice Nuclei Spectroscopy studies: Colorado mountaintop site Fall 2001, Spring 2004; NASA CRYSTAL-FACE: subtropical convection and cirrus, Summer 2002; AIRS-2: Southeastern Canada mixed phase clouds, Fall 2004; M-PACE: mixed phase Arctic stratus, Fall 2004

Selected Preliminary Results

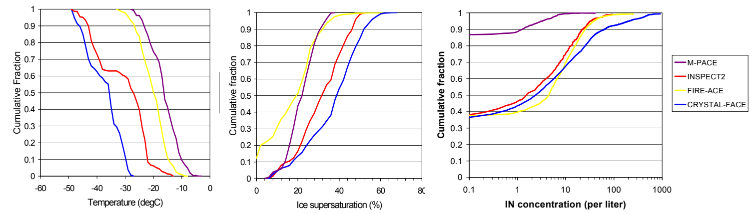


Examples from remote continental U.S. in Spring and Alaska in Fall:

1) Multivariate dependency on temperature and humidity apparent in all data sets.

2) Large variability. Asian dust impacts during INSPECT2.

3) Disagreement between observations and previous simplistic representations of IN concentration.

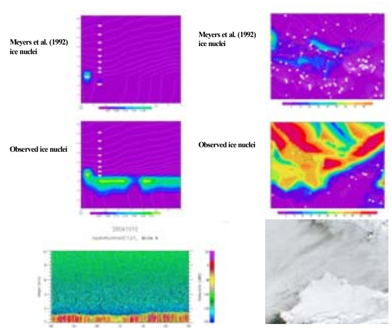


Cumulative frequency distributions of IN concentrations and processing conditions for four separate studies: These types of analyses can mask the multivariate dependencies. Nevertheless, note the general resemblance of two pairs of data sets for processing conditions (INSPECT2 and CRYSTAL-FACE; FIRE-ACE and M-PACE). The first pairing compares and contrasts Asian dust affected Western U.S. site in Spring versus Saharan dust affected site in Summer. The second pairing contrasts Arctic Spring and Fall.

1) Lower average IN concentrations are similar in CRYSTAL-FACE and INSPECT2, but stronger dust episodes typify South Florida region leading to larger percentage of higher IN concentrations.

2) Strong differences in IN concentration characterize the Fall versus Spring Arctic studies. Not only are IN lower in the Fall, but there are significant numbers of 1 minute (1 liter) samples (5 km paths) without any measurable IN. Do we need longer integration times for these samples or are some regions truly vacant of ice nuclei? How to quantify such things in models? Springtime Arctic IN are strongly affected by some combination of local sources and Asian dust transports.

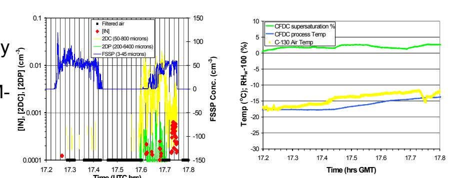
Strong sensitivity of Arctic clouds to IN: Observed IN improves CRM simulations of clouds in Fall season



Preliminary simulations with RAMS (courtesy of J. Harrington) demonstrate that the modified Meyers formulation derived from M-PACE data provided better cloud simulation versus the Meyers et al. (1992, J. Appl. Meteor.) curve, as indicated by liquid water parameters versus observations.

Possible direct evidence for spatial inhomogeneity of IN impacting spatial inhomogeneity of cloud ice

Data from NCAR C-130 aircraft near Montreal, Canada (Alliance Icing Research Study 2) on **November 14, 2003:** Nearby stratocumuli show strong contrast in ice crystal content. CFDC sampled the residual nuclei from cloud water and ice particles collected by a counterflow virtual impactor and processed these at the cloud temperature. IN are absent in cloud residuals in one case, but not in the other. An interpretation is that the presence of IN feeding cloud, most likely from above in this case, is a key factor in glaciation.



Conclusions and Future Directions

1) The variability of IN concentrations in time and space appears difficult, if not impossible, to capture using a single overarching functional dependence on temperature and relative humidity. I offer no solution or alternative at present.

2) Ultimately need an approach that ties ice nuclei to other aerosols in general (analyses not shown here).

3) We are simultaneously exploring, through laboratory studies of natural samples, to constrain the contributions of important global sources of ice nuclei for use in models that include aerosol species as prognostic variables.

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