# Analyses and Modeling of Relationships Between Ice Nuclei Concentrations, Aerosol Concentrations, and Ice Crystal Number Concentrations in Clouds

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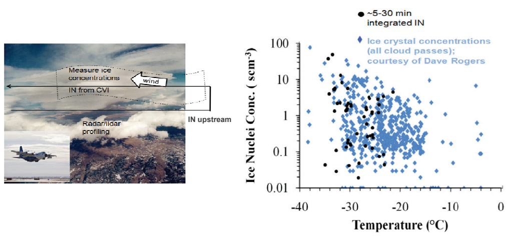
## Approach

Our approach uses combined data from multiple field studies in which measurements of the number concentrations of ice nuclei were made using the CSU continuous flow diffusion chamber; aerosol number concentrations (as a function of size) were obtained around clouds; and ice crystal number concentrations were obtained in clouds.

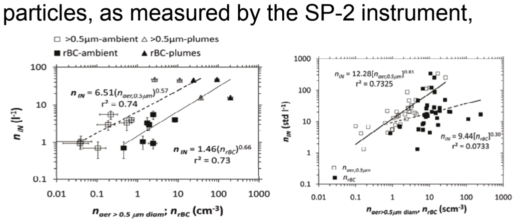
## Validation of IN-ice crystal relationships (ICE-L)

We studied IN-ice crystal concentration relationships in simple orographic wave clouds in the NSF ICE-L study The second panel shows the excellent correspondence between IN and ice crystal number concentrations for 7 cases, some fully described and also successfully modeled in Eidhammer et al. (2010).




## Composition

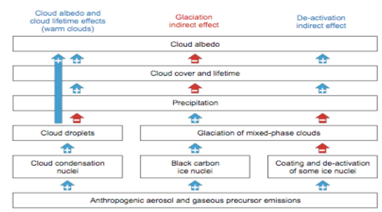
Some of our field studies have aerosol composition data that can be used to suggest linkages between particle type and ice nucleating activity. Below we show two preliminary findings from ICE-L (left) and PACDEX (right). The number concentrations of IN varied similarly to refractory black carbon (rBC) particles, as measured by the SP-2 instrument,




Variation of the number concentration of IN ($n_{IN}$) with number concentrations of particles larger than 0.5 µm ($n_{aer>0.5}$) and number concentrations of refractory black carbon particles ($n_{rBC}$) for ambient air and smoke plumes sampled in **ICE-L (left panel)** and for background conditions in **PACDEX (right panel)**.

## Motivation: Ice Indirect Effects

The formation of ice crystals in clouds is of vital importance in climate, as ice formation is one of the key processes initiating precipitation. Since ice nucleation is tied to the action of small numbers of specific aerosol particles (ice nuclei), natural and human impacts on the availability of IN can lead to alteration of the energy and hydrological cycles.

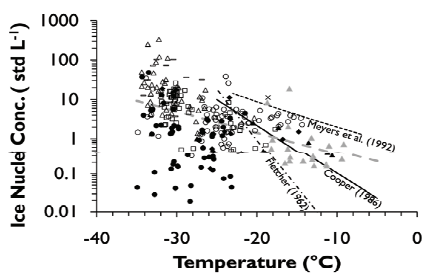



**Aerosol indirect effects in warm- and mixed-phase clouds** (Lohmann and Hoose, 2009)

Our project involves the **re-examination of field experiment data characterizing aerosols, ice nuclei, and ice formation in clouds.** The goals are, first, to determine if ice nuclei measurements predict ice formation in clouds, and second, to use the database of observations to derive improved parameterizations for predicting ice nuclei number concentrations.

## Proposed new parameterization

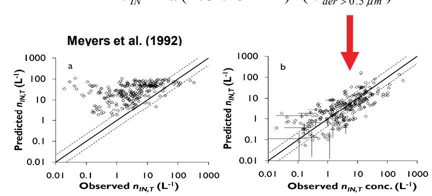
*[DeMott et al., 2010]*




We considered IN number concentrations active for T > -36°C and >100% RH (mixed-phase cloud conditions), ane data from 8 projects over 14 years. Superimposed are relationships predicted by prior proposed parameterizations, as driven by one independent variable, usually temperature. These formulations fail to capture the large variability of IN number concentrations at a single T.

We suggest using a power law dependence on temperature and number concentration of particles > 0.5 µm diameter:

$$n_{IN} = a(273.15 - T)^{b}(n_{aer>0.5\mu m})^{c(T)}$$




Much of the spread in the data shown above is due to IN source contribution variations; these are manifested as a strong link to the concentrations of particles having diameters > 0.5 µm (e.g., mineral dusts are major source of IN). Choosing $n_{aer>0.5\ \mu m}$ as an additional fit variable (along with T) reduces the variability by 2 orders of magnitude (63% of the points are predicted within a factor of 2).

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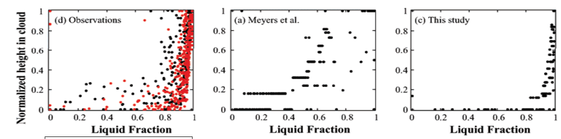
## Implementation in CAM3

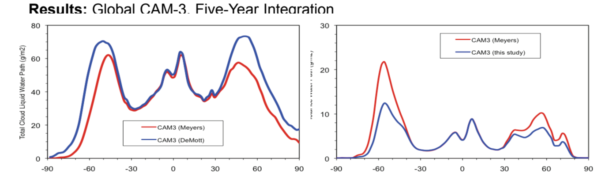
The new parameterization was implemented in the Community Atmospheric Model (CAM3) GCM with climatological aerosol fields and Liu et al. 2-moment microphysics. IN were predicted using either our new parameterization, or the standard option of Meyers et al. (1992). We ran both the single-column version to simulate Arctic clouds and the full global model.

**Results:** Mixed-Phase Arctic Cloud Experiment (October 9-10, 2004 single layer cloud)




Observed liquid water fraction as a function of height in cloud | Single column CAM3 with Liu et al. 2-moment microphys. + Meyers et al. IN | Single column CAM3 with Liu et al. 2-moment microphysics + new parameterization

**Results:** Global CAM-3, Five-Year Integration




Global model runs (five-year means): New treatment resulted in zonally-averaged increases (10-30 g m$^{-2}$) liquid water path (a) and decreases in ice water path up to 10 g m$^{-2}$ (b). We also found stronger (5-10 W m$^{-2}$ more negative) shortwave (SW) cloud forcing at storm track and higher latitudes, an increase in cloud cover by 5-10% at high latitudes, and global net forcing (SW + LW) decreased by 1.3 W m$^{-2}$.

## Summary and next steps

1) $n_{IN}$ relevant to mixed-phase clouds can be predicted (to first order) using: number concentrations of particles larger than ~0.5 µm and temperature.
2) More explicit treatment of ice nucleation mechanisms and of aerosol composition dependence will require long term measurement and validation efforts.
3) Global simulations suggest strong regional/seasonal influences of IN on cloud forcing and global net ~1 W m$^{-2}$ cooling per 1 order of magnitude $n_{IN}$ decrease.
4) Will compare ISDAC iIN measurements with our IN database, and simulate ISDAC clouds (using observed aerosols as input).

**References:**
**DeMott et al.**, 2010, Submitted to Proc. Natnl. Acad. Sci.; **Eidhammer et al.** 2010, Accepted to J. Atmos. Sci.; **Lohmann and Hoose**, 2009, Atmos. Chem. Phys.; **Liu et al.**, 2007, J. Climate 20: 4526-4547.