Use of a new aerosol-dependent ice nucleation parameterization for predicting ice nuclei and simulating mixed-phase clouds during ISDAC

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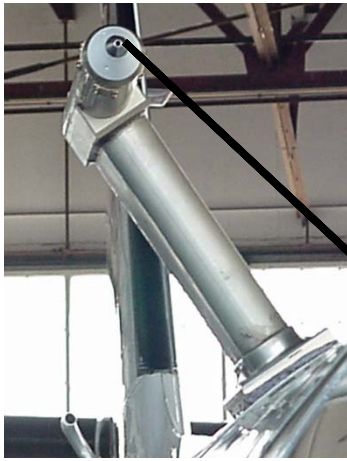
DOE-supported objectives

- Merge aerosol and ice nuclei (IN) data sets from multiple field programs toward a parameterization of ice nucleation as it depends on aerosols and thermodynamic conditions.
- Incorporate parameterization into models
- Compare and contrast IN predictions versus TAMU IN data collected during the Indirect and Semi-Direct Aerosol Campaign (ISDAC)

Sampling methods (CSU in various studies, TAMU in ISDAC)

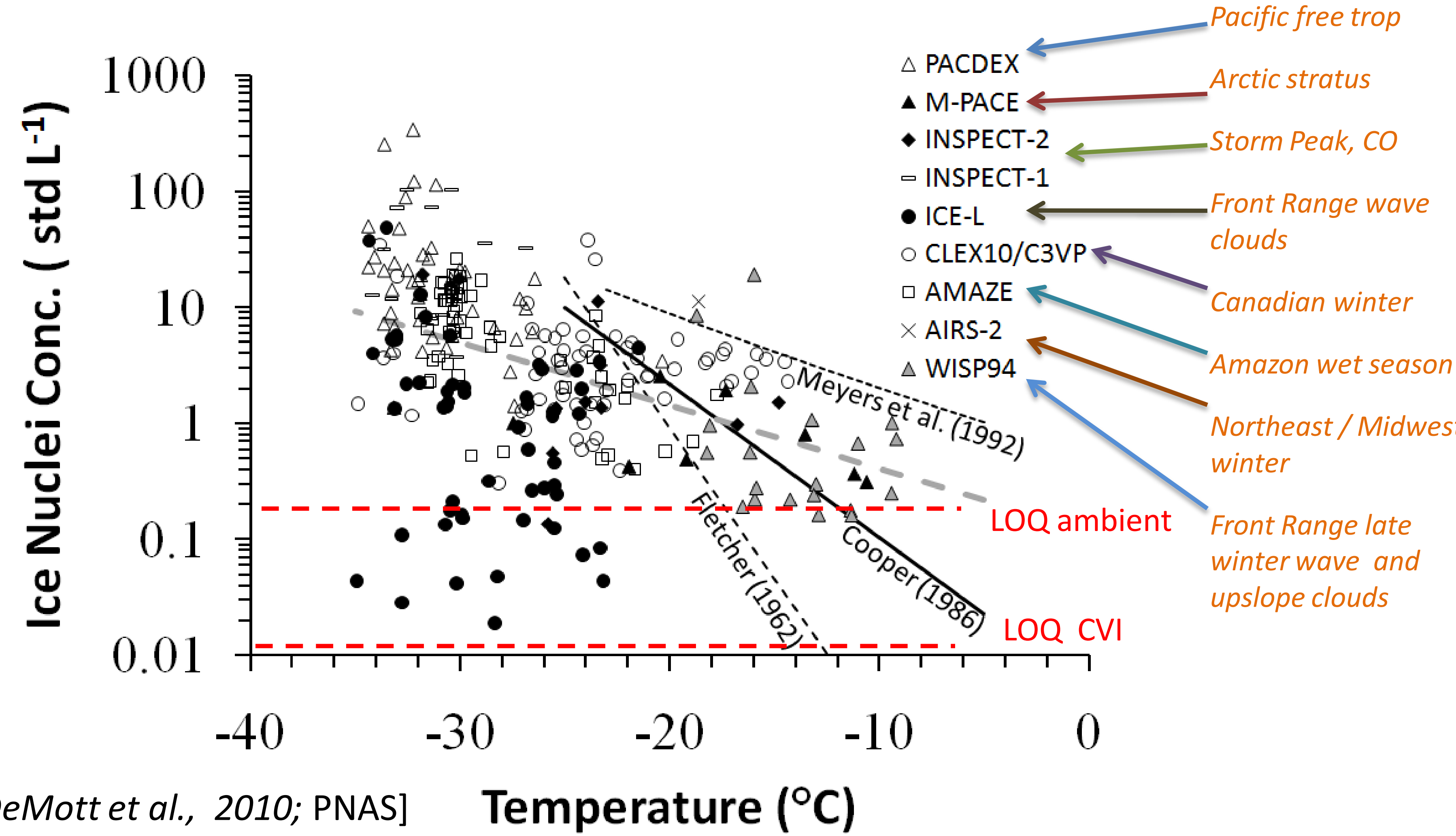


CVI inlet (aerosol from evaporated cloud particles when in clouds)

aircraft aerosol sample inlet

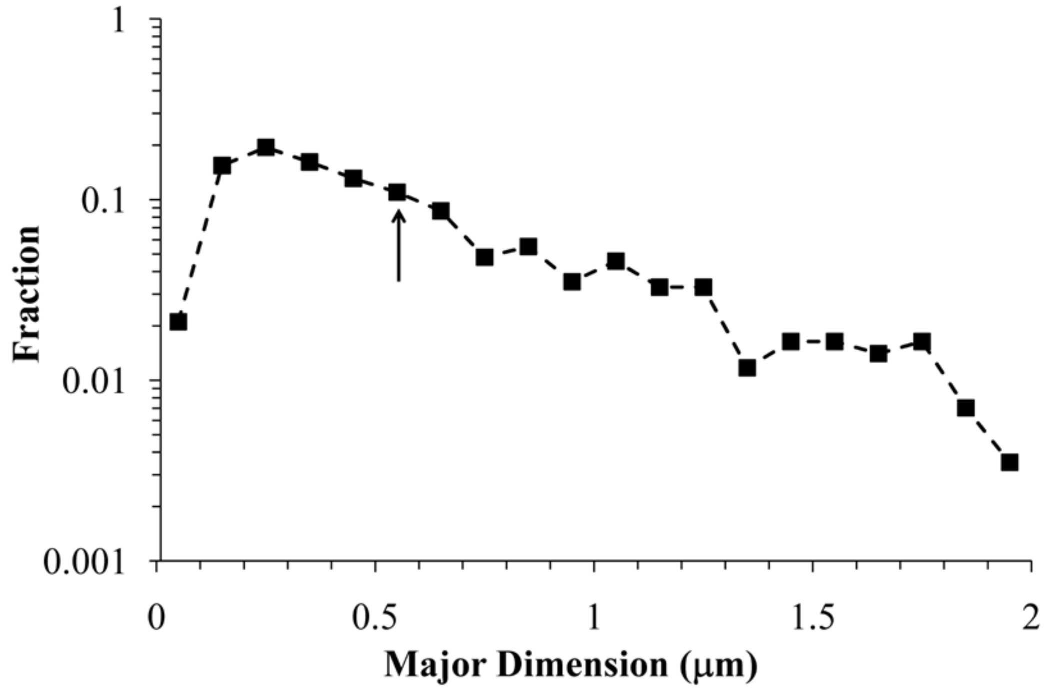
Continuous flow diffusion chamber (CFDC) in aircraft

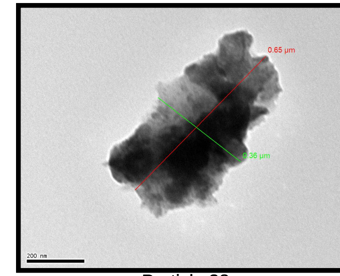
Ice nuclei concentrations (RH_w>100%) in projects over 14 years (292, 10-30 min. averages, coincident aerosol data)



[*DeMott et al., 2010;* PNAS]

Ice nuclei physical size from TEM analyses in several projects

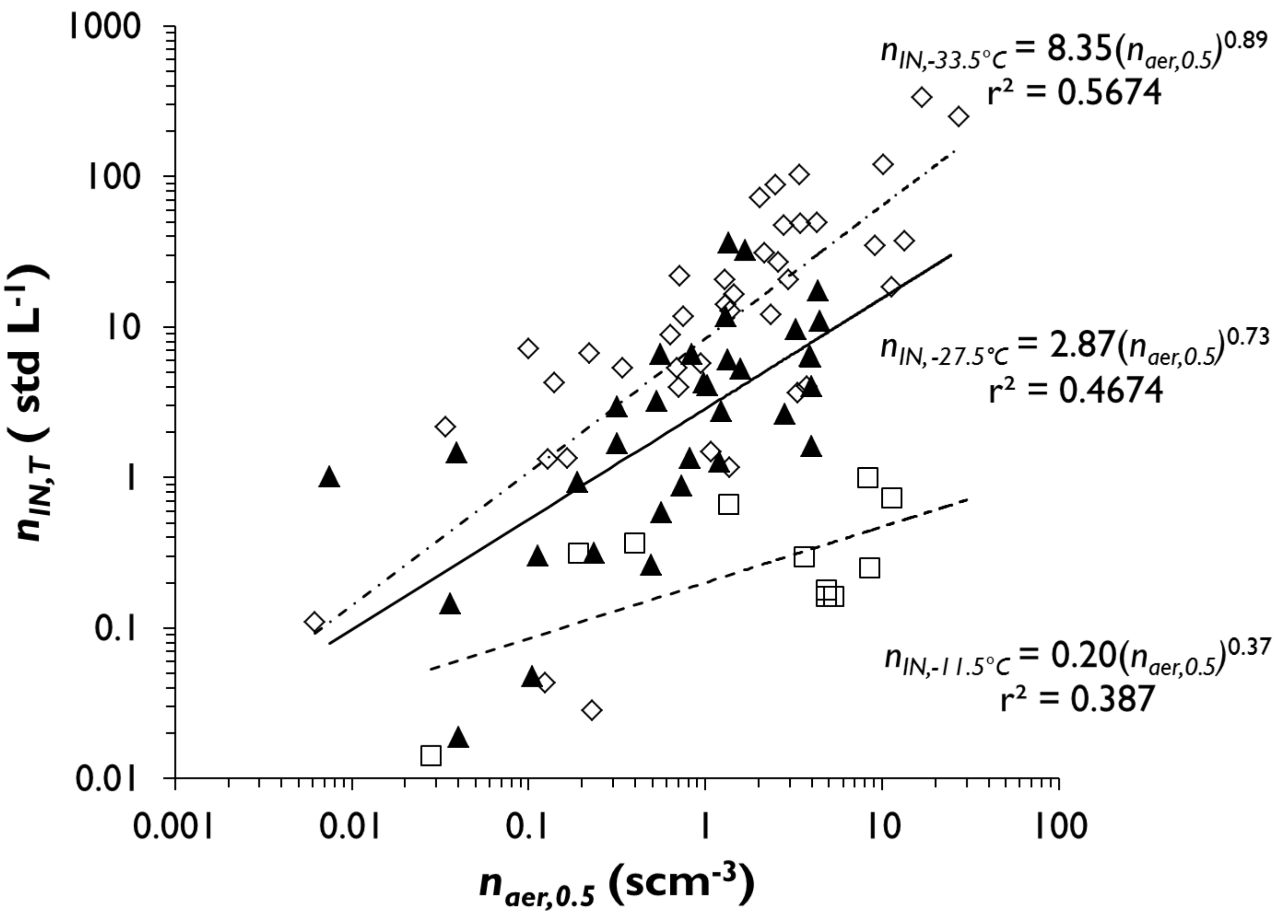




Particle 38

Alumina-silicate Mineral dust

Sensitivity to aerosol concentrations in narrow T ranges



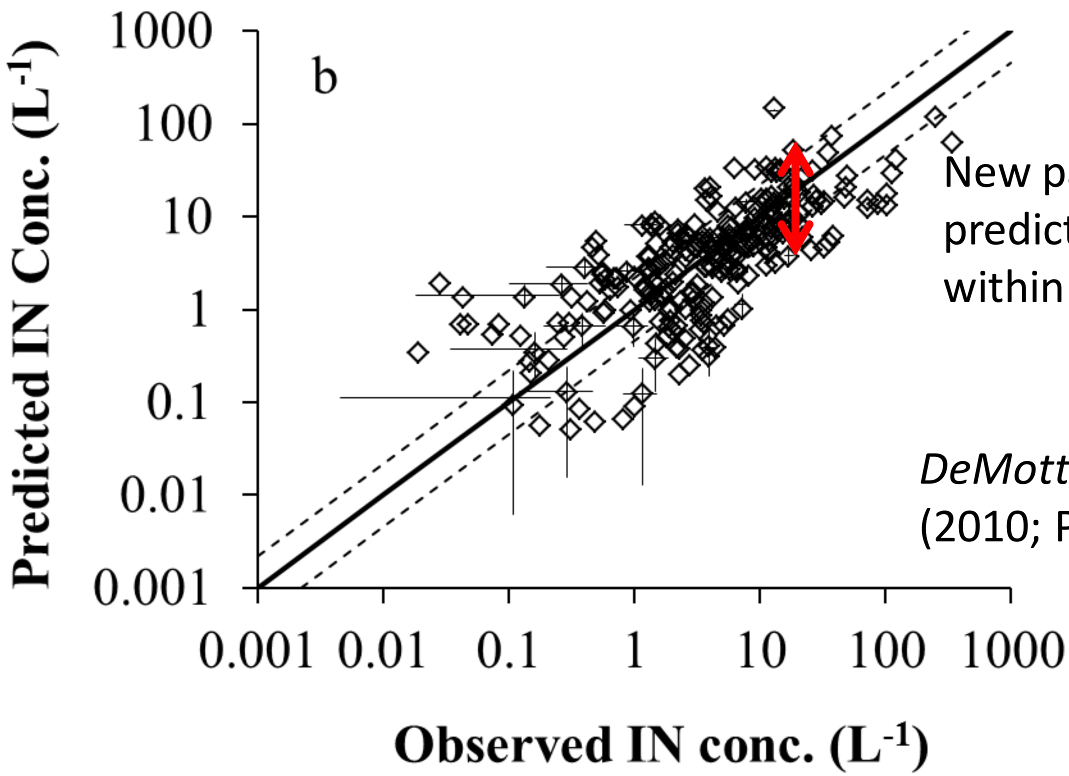
Parameterization of ice formation in mixed phase cloud acknowledges relation at any temperature with larger aerosol particles (DeMott et al. 2010, PNAS)

$$n_{IN,T_k} = a\left(273.16 - T_k\right)^b (n_{aer,0.5})^{(c(273.16 - T_k)+d)}$$

- a = 0.0000594, b = 3.33, c = 0.0264, d = 0.0033
- T_k is cloud temperature in degrees Kelvin
- $n_{aer,0.5}$ is the number concentration (scm^{-3}) of aerosol particles with diameters larger than 0.5 μm
- n_{IN} is ice nuclei number concentration (std L^{-1}) at T_k
- Ignores any IN dependence on supersaturation

Particle size and T parameterization reduces variability within ~1(O) magnitude, while T-only or S_i-only parameterizations produce large errors

$$n_{IN,T_k} = a\left(273.16 - T_k\right)^b \left(n_{aer,0.5}\right)^{\left(c\left(273.16 - T_k\right)+d\right)}$$

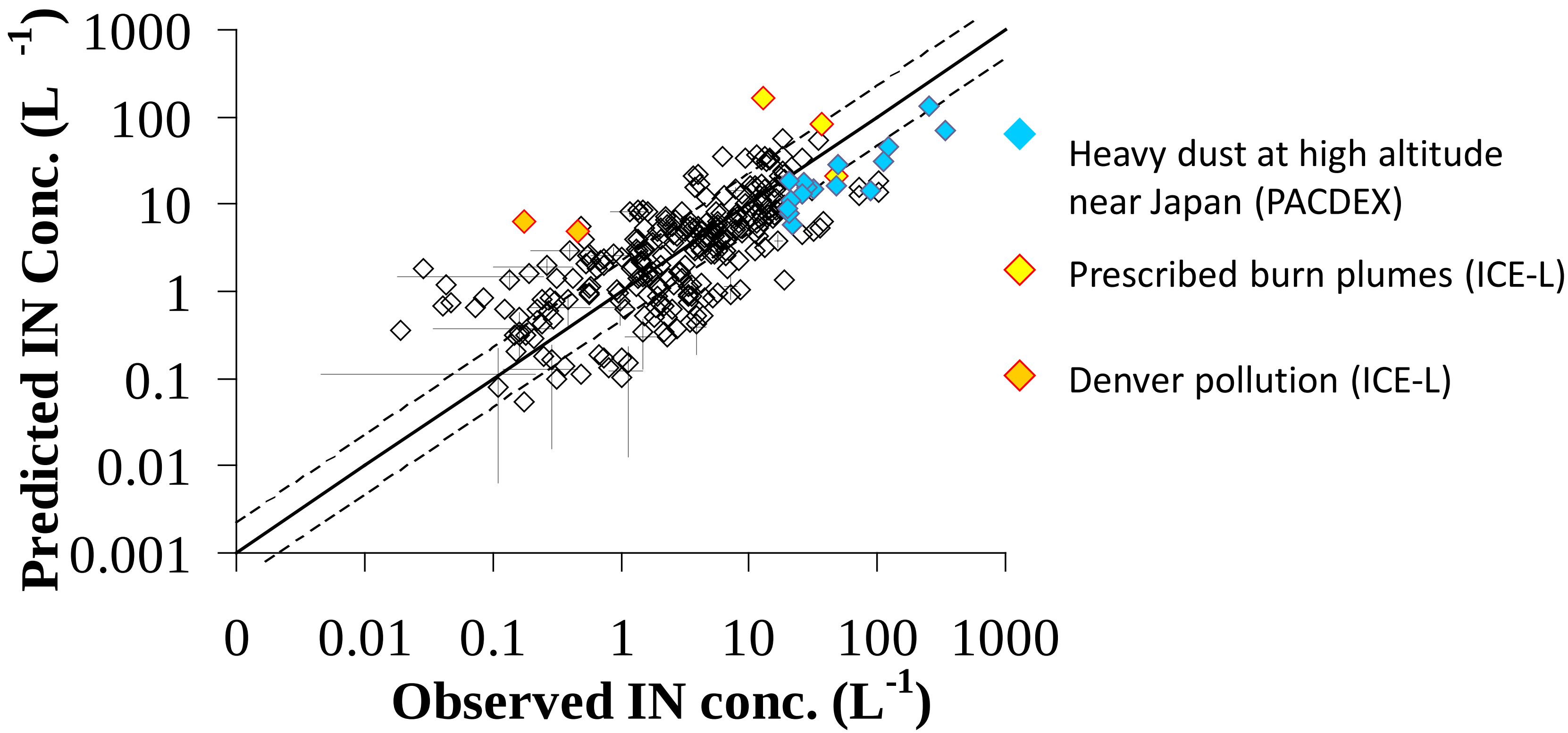


New parameterization predicts ~2/3 values within factor 2

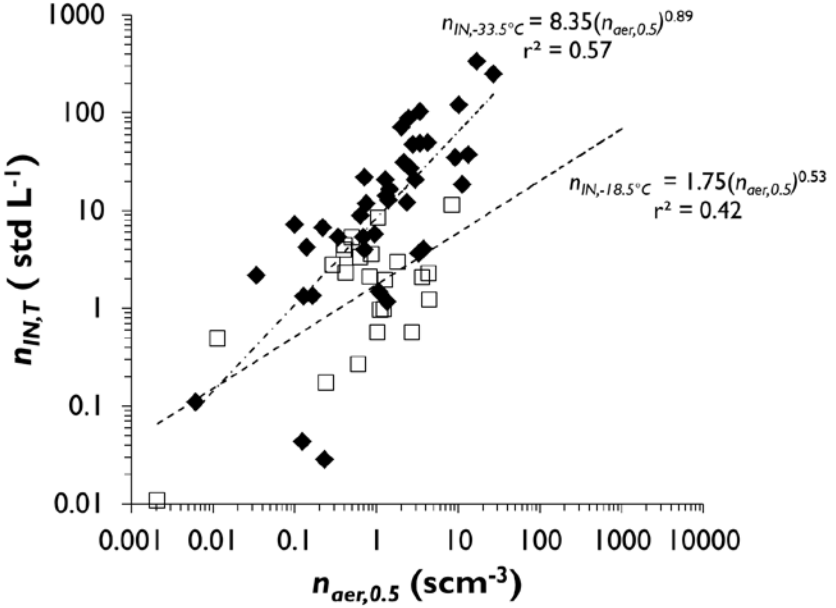
DeMott et al. (2010; PNAS)

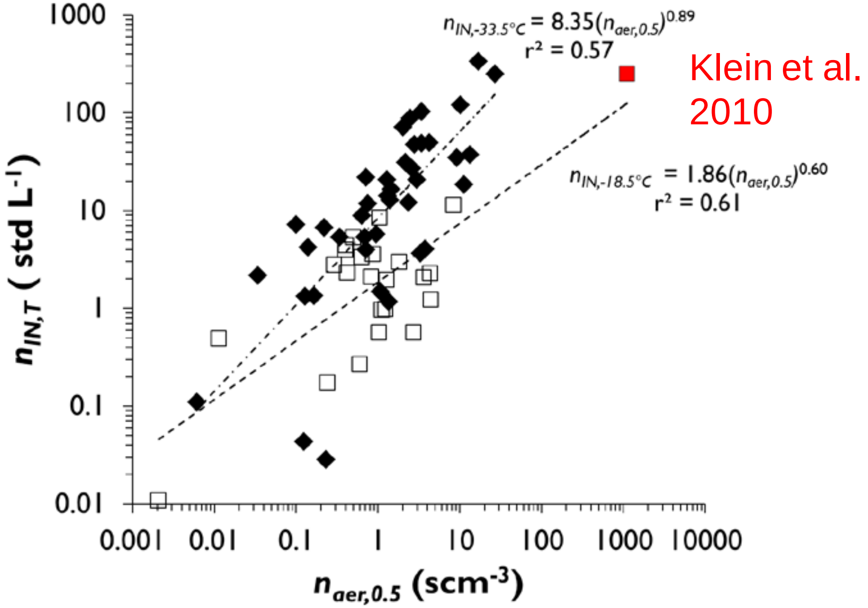
To be clear… chemistry or processing impacts on IN variability likely exist and require further research

Adapted from *DeMott et al.* (2010)



Strong needs for more data of high quality over a broader range of aerosol concentrations at warmer T

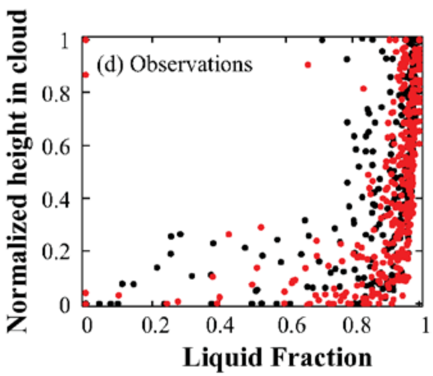




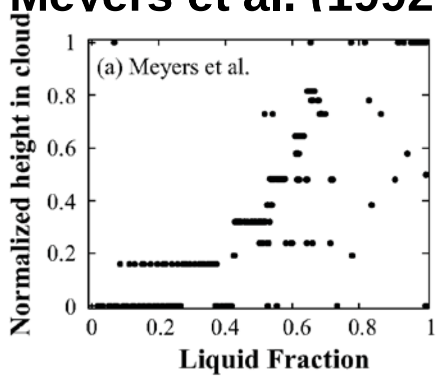
Implications for cloud modeling of aerosol-ice indirect effects in mixed-phase clouds

- PNAS: CAM-3 modeling → ~1 order [IN] ↓ = 1 W m^{-2} ↑ net cooling by clouds, and vice versa.
- M-PACE single layer Arctic stratus (Oct. 9-10, 2004) simulations with 2-moment microphysics

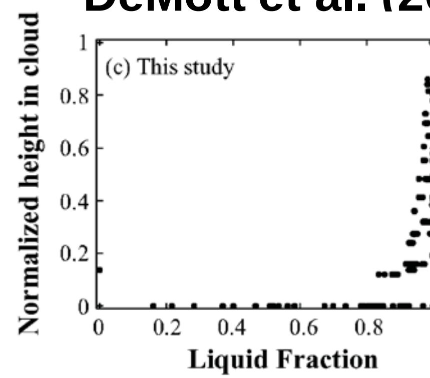
Cloud LW frac. Obs



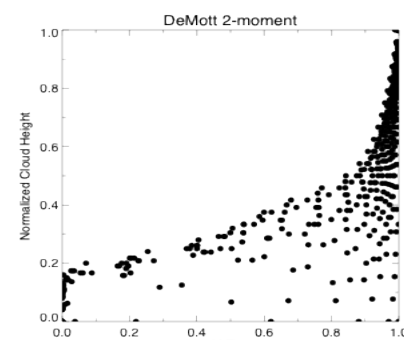
SCAM-3 w/ Meyers et al. (1992)



SCAM-3 w/ DeMott et al. (2010)

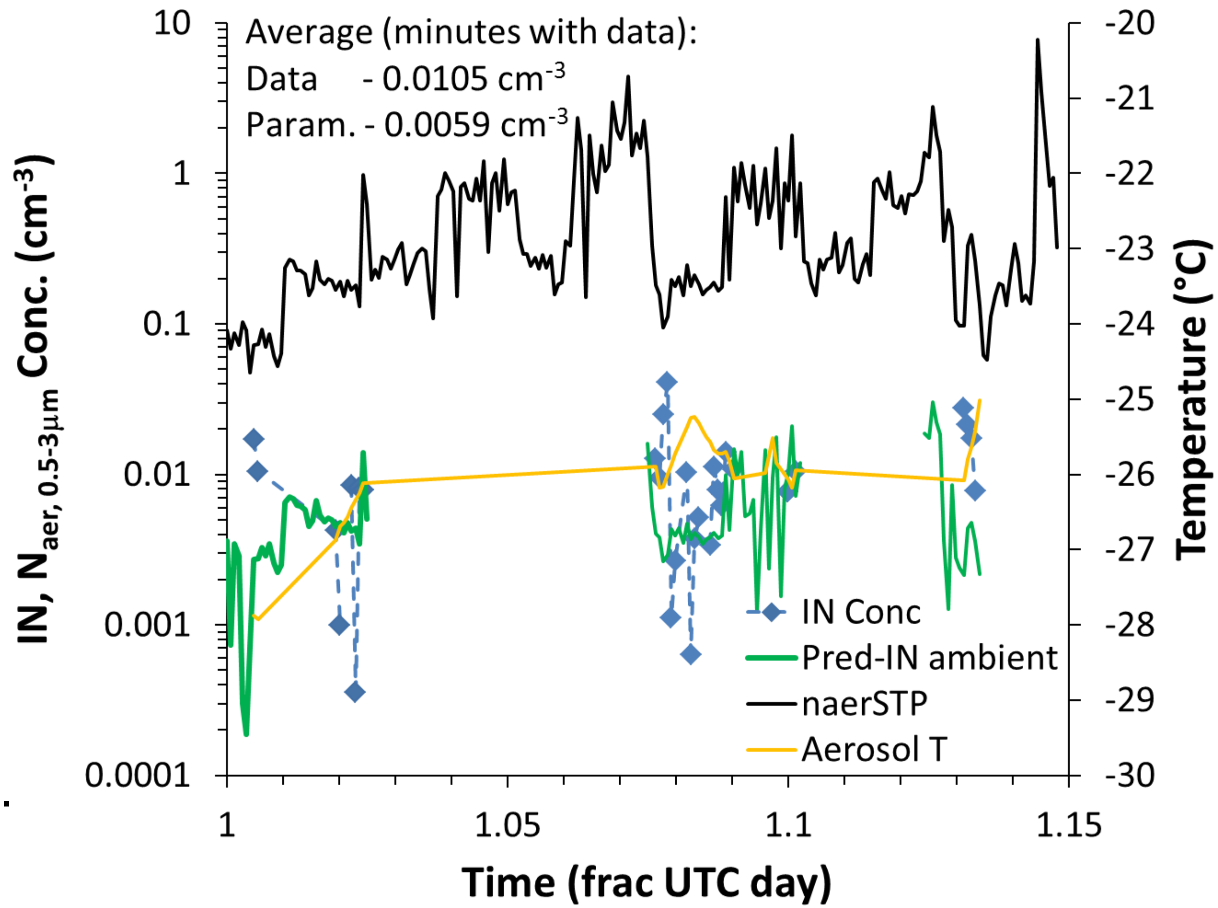


SAM (6.8.2) w/ DeMott et al. (2010), observed aerosols →



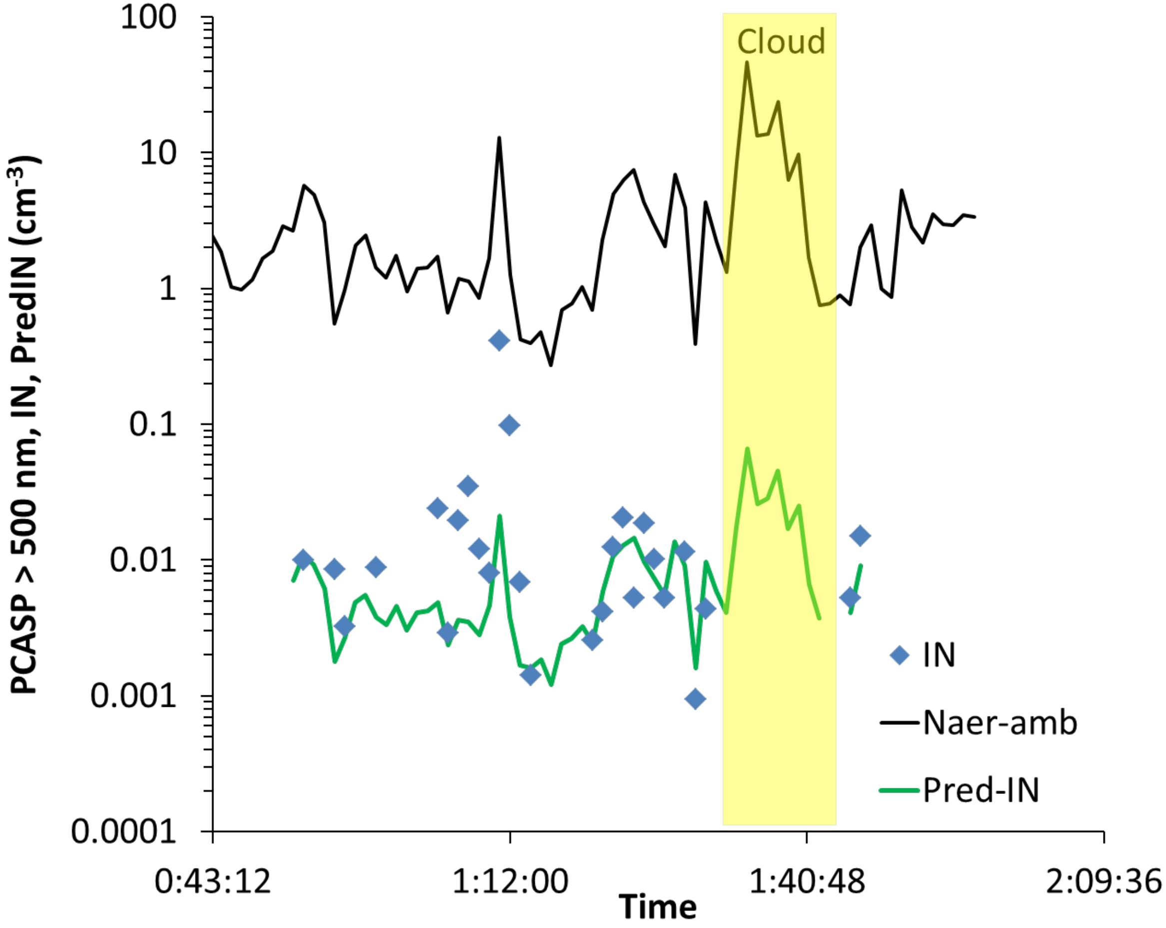
Use of ISDAC out-of-cloud PCASP number concentrations to predict IN number concentrations

Flight 31 (April 26, 2008) – 1 min IN for $RH_{TAMU\text{-}CFDC}$ > 101%

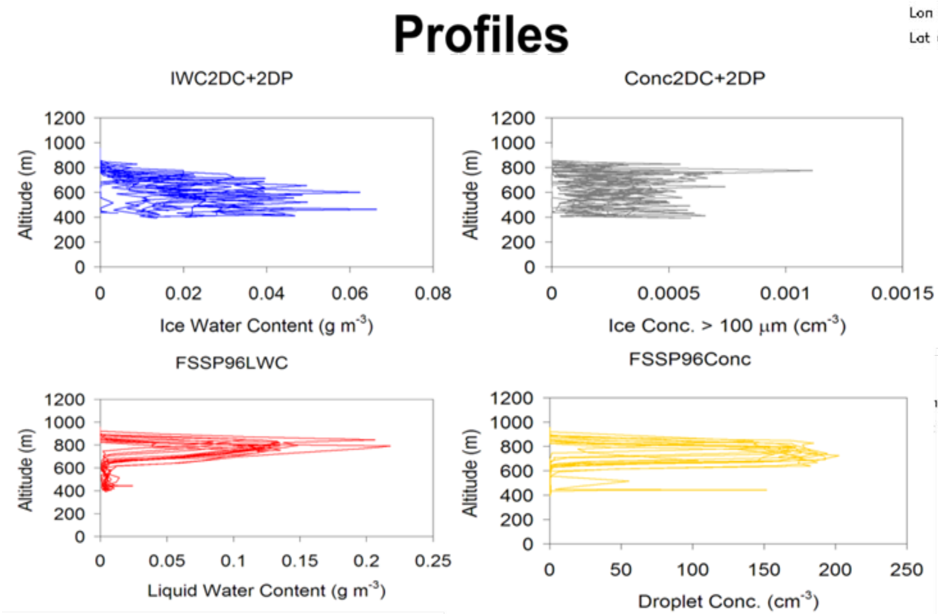


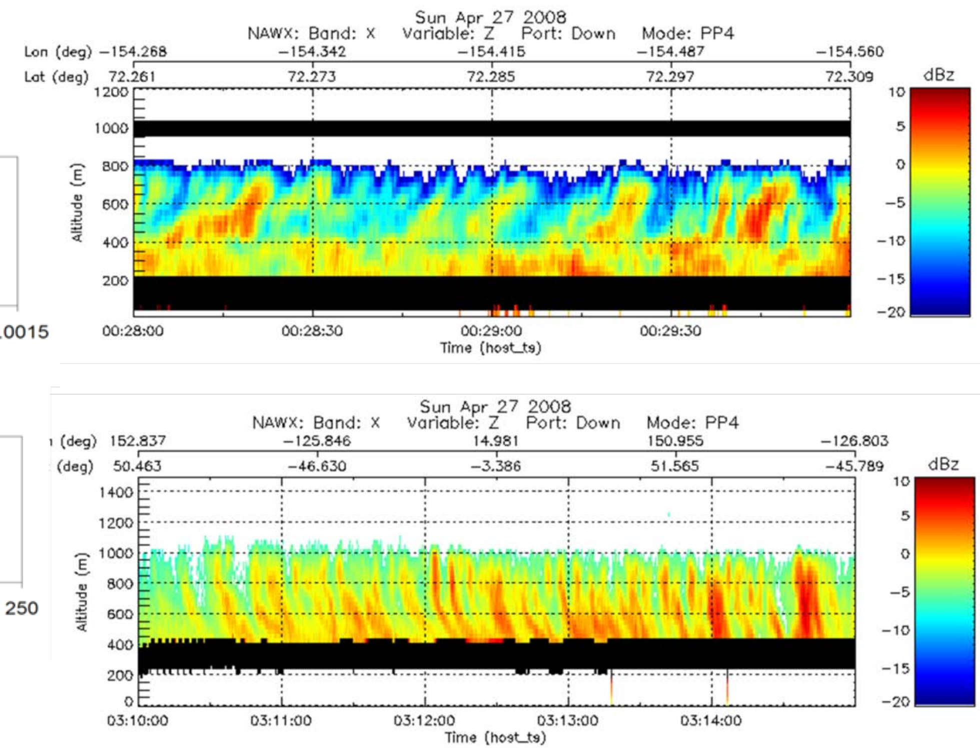
PCASP data courtesy of W. Strapp, P. Liu

ISDAC Flight 17



ISDAC Flight 31 (April 26, 2008) case study – single layer, upper region liquid dominant, lower region ice-dominated, precipitating ice at times





NAWX Airborne Radar Profiles courtesy of M. Wolde

Cloud data courtesy of W. Strapp, A. Korolev

N_1 = 206.9 cm^{-3}; N_2 = 8.5 cm^{-3}

s_1 = 1.50; s_2 = 2.45

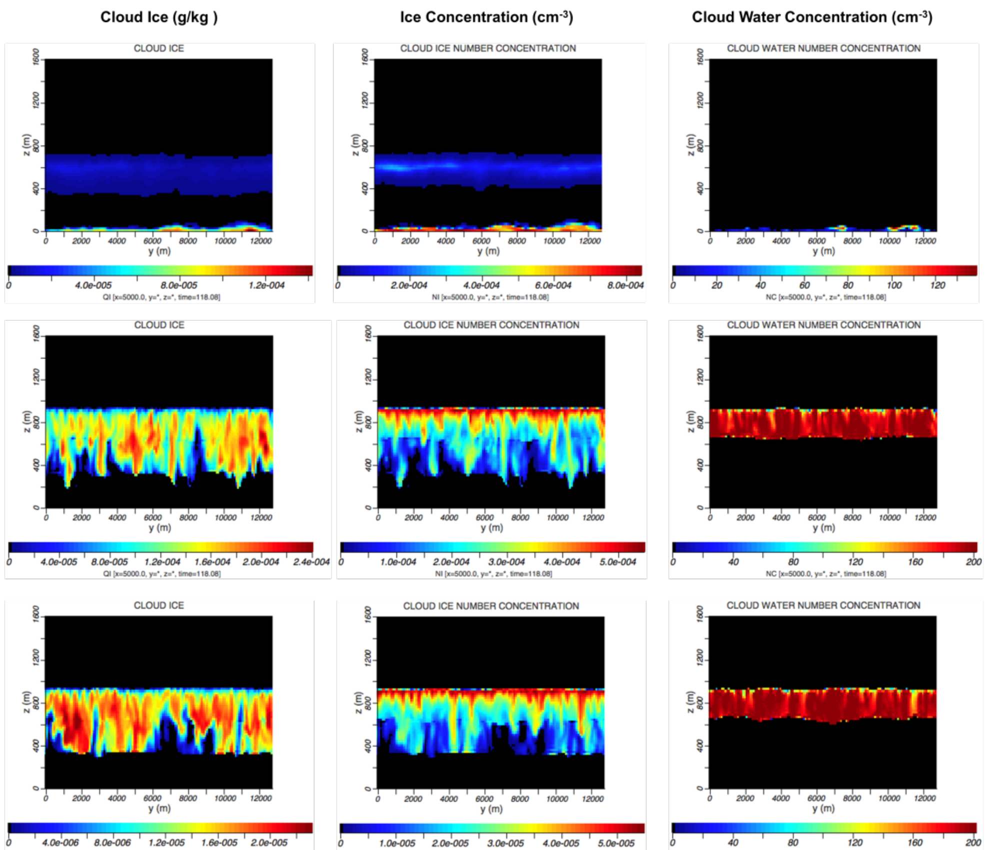
d_1 = 0.2 μm; d_2 = 0.7 μm

Acknowledgments to Mikhail Ovchinnikov, Michael Earle

Simulations and sensitivity studies using the System for Atmospheric Modeling (SAM v 6.8.2), Morrison 2-moment microphysics

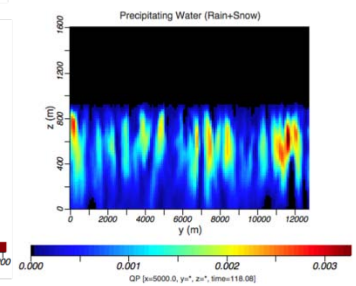
12-Hour Simulation Results

Rows: 10 x IN_D; IN_D (from DeMott et al. (2010)); 0.1 x IN_D



3-Dimensional data was examined with, and these plots produced from, ncBrowse: http://www.epic.noaa.gov/java/ncBrowse/

10 x IN_D: Early glaciation of cloud water and early precipitation



IN_D (from DeMott et al. (2010)): Ice conc. (0.2-0.3 L^{-1}) correct, and precipitation to surface

0.1 x IN_D: Ice conc. low by ~10; no precipitation to surface

Conclusions and outlook

- IN predicted by proposed parameterization linking to aerosols agrees within expectations with observed values during ISDAC – need to compile comprehensive comparison, and investigate discrepancies and possibly improve parameterization.
- Many characteristics of Flight 31 cloud case are well simulated using proposed IN parameterization – need further analyses of simulation details (cloud water and ice distributions) and comparison to remote sensing.
- Case shows strong sensitivity of clouds to ice formation process
- Simulate additional cases

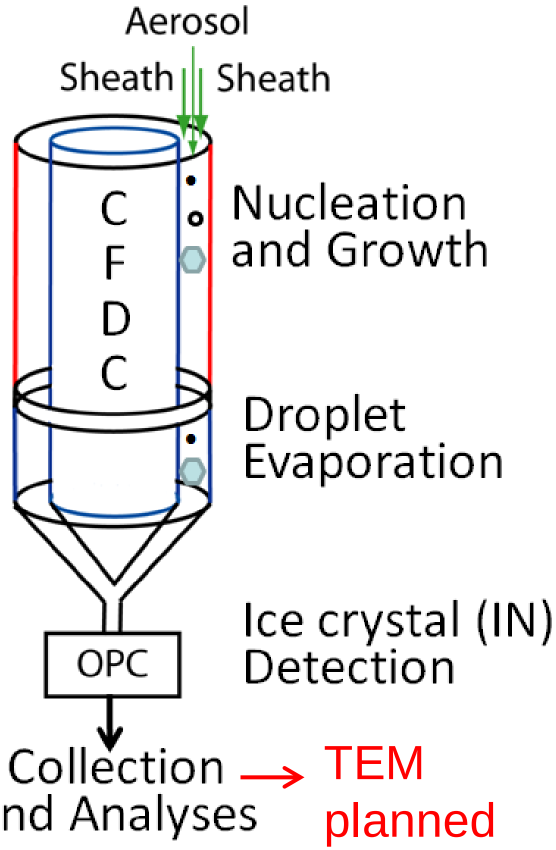
Extras just in case

How we measure IN in real-time - Continuous flow diffusion chamber (CFDC)

Pre-impactor (cut-size currently set to 1.5 μm)

Filter option

Small fraction of particles freeze at T, RH controlled by ice coated warm and cold walls



CFDC-1H

Total residence time ~7s

Rogers et al. (J. Atmos. Oceanic Technol., 2001)
Prenni et al. (Tellus, 2009)

Conceptual ice nucleation regimes/mechanisms and what a CFDC can measure