Continuous Flow Ice Thermal Diffusion Chamber Measurements of Ice Nuclei in the Arctic

A.J. Prenni, P.J. DeMott, and S.M. Kreidenweis
Department of Atmospheric Science, Colorado State University
Fort Collins, Colorado

D.C. Rogers
National Center for Atmospheric Research
EOL/RAF
Broomfield, Colorado

Introduction

Mixed-phase stratus clouds are ubiquitous in the Arctic and play an important role in climate in this region. However, climate and regional models have generally proven unsuccessful at simulating arctic cloudiness, particularly during the colder months. Specifically, models tend to under-predict the amount of liquid water in mixed-phase clouds. This is problematic because cloud phase can greatly impact the radiative budget. The Mixed-Phase Arctic Cloud Experiment (M-PACE), conducted from late September through October near the ARM Climate Research Facility (ACRF) North Slope of Alaska (NSA) locale, focused on characterizing low-level, arctic stratus clouds. A major goal of the project was to determine why models tend to under-predict the amount of liquid in arctic mixed-phase clouds. To this end, measurements of cloud and aerosol properties were made by aircraft and a suite of remote sensing devices. Ice nuclei (IN) measurements were made using a continuous flow ice thermal diffusion chamber (CFDC) aboard the University of North Dakota Citation II aircraft. This instrument permits processing of aerosol particles at controlled temperatures and humidities sampled through an aircraft inlet in real time in and around cloud levels to determine IN concentrations (Rogers et al. 2001b). The CFDC is sensitive to all nucleation modes, except contact freezing, since the residence time is fairly short.

Results and Discussion

Figure 1 presents IN measurements from M-PACE. The data are presented as IN concentrations, binned as a function of processing supersaturation with respect to ice (Ssi). Shown in the figure are project average concentrations for the entire project, along with a best fit to the binned and weighted data using the functional form of Meyers et al. (1992). Immediately apparent from the figure is the large amount of scatter in the data, and the relatively weak dependence on processing Ssi. These averaged

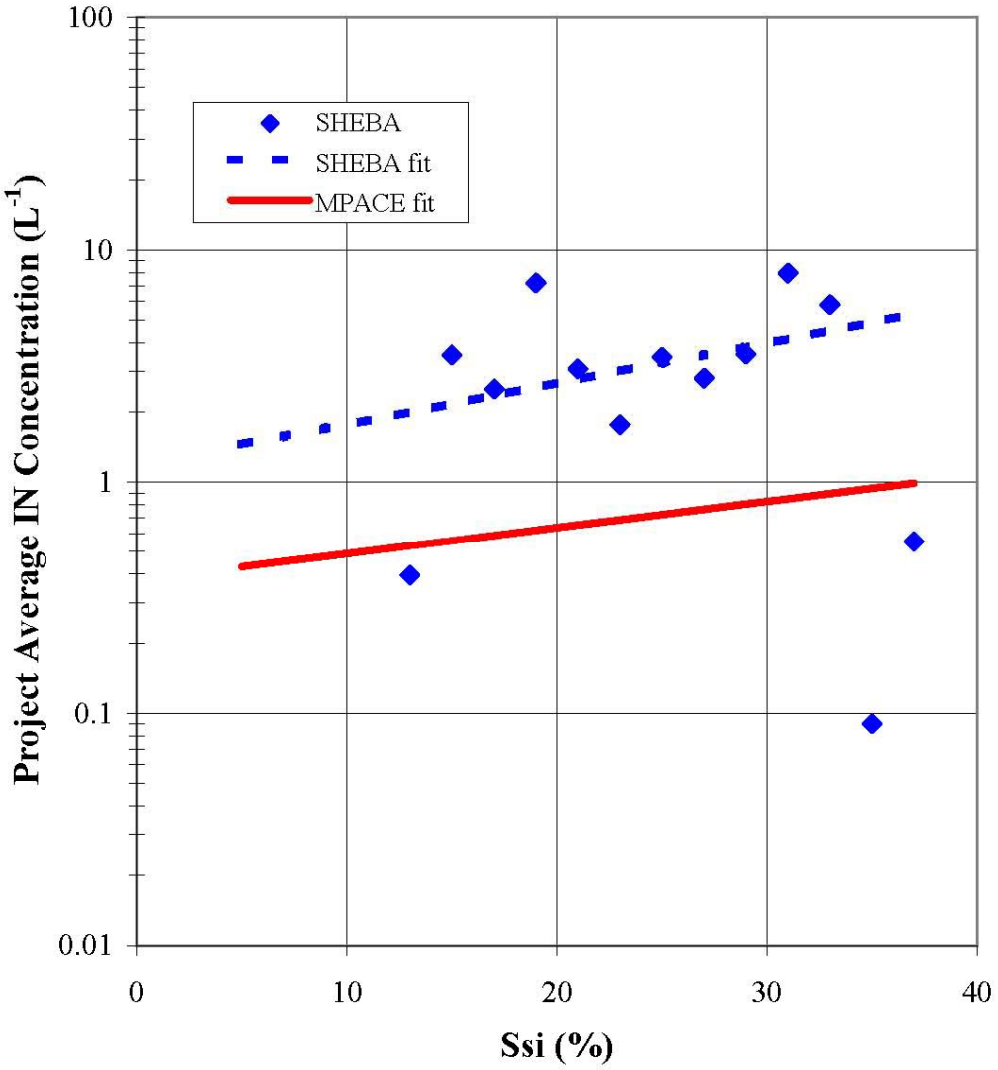

Figure 1. Project average IN concentrations as a function of processing supersaturation ice. Yellow triangles represent project average concentrations, along with a best fit to the binned and weighted data using the functional form of Meyers et al. (1992). The Meyers et al. (1992) parameterization, derived from mid-latitude data, is also shown.

concentrations include a substantial contribution from measurements for which no IN were detected. As such, this figure gives a good representation of the average IN concentrations during the project, but not necessarily the range of concentrations encountered during individual flights. Indeed, measured IN concentrations varied temporally and spatially by orders of magnitude for the same processing conditions. Also shown in Figure 1 is the IN parameterization of Meyers et al. (1992), used in many models. It is clear that the Meyers parameterization is not representative of average IN behavior

as assessed during M-PACE flights near lower-level arctic stratiform clouds, and its use will impair the ability to predict cloudiness and related radiative forcing in this region.

Measured IN concentrations also can be compared to cloud probe measurements. Figure 2 shows data from a short segment of the October 6 flight, in which the Citation ascended through a thin cloud, had a short leg above cloud, and then descended back into cloud. In this figure, measurements from the two-dimensional cloud (2DC) probe are used as a measure of ice concentration in the cloud; 2DC concentrations have been averaged over 60 seconds to make them directly comparable to the CFDC measurements, which are 60-second average values. As can be seen in the figure, for this flight leg IN concentrations measured above cloud approximate measured cloud-ice concentrations reasonably well, within a factor of two. However, IN concentrations often were dramatically different than those measured by the cloud probes. This was in part due to differences in CFDC processing conditions and ambient conditions. In some cases, the CFDC was operating at considerably warmer temperatures than was found in the cloud; for others, reduced IN values resulted if the instrument was operated below water saturation, so that condensation freezing nuclei were not measured. To date, we have only begun to explore relations between measured IN concentrations and measured cloud-ice. A comprehensive analysis is the subject of future work.

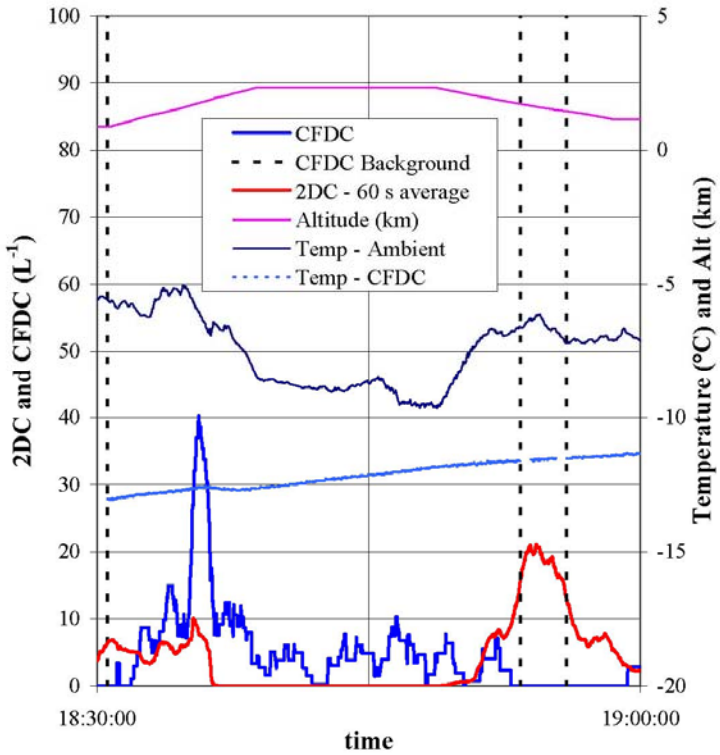

Figure 2. Comparison of IN concentrations measured above cloud with cloud-ice, as measured by the 2DC probe for a short flight leg on October 6. Also shown are ambient temperature and CFDC processing temperature and altitude. Time periods of filter measurements, taken to determine background counts in the CFDC, are indicated by the dashed black lines.

Aircraft CFDC measurements in the Arctic have been made in spring as part of Surface Heat Budget of the Arctic Ocean (SHEBA)/First ISCCP Regional Experiment-Aerosol Characterization Experiment (FIRE-ACE) (Rogers et al. 2001a). Here, we compare the M-PACE measurements to this springtime dataset to determine if there are measurable seasonal differences. The springtime IN data have been reprocessed to ensure equivalent treatment of the two datasets (data are limited to identical ranges of temperature and Ssw, background corrections are identical, and data are processed as 60-second running averages at STP). Results are shown in Figure 3 as a function of Ssi. The M-PACE are shown as the best fit from Figure 1. A fit to the SHEBA data is also included, in the functional form given by Meyers et al. (1992). From the figure, it is clear that springtime concentrations are enhanced relative to

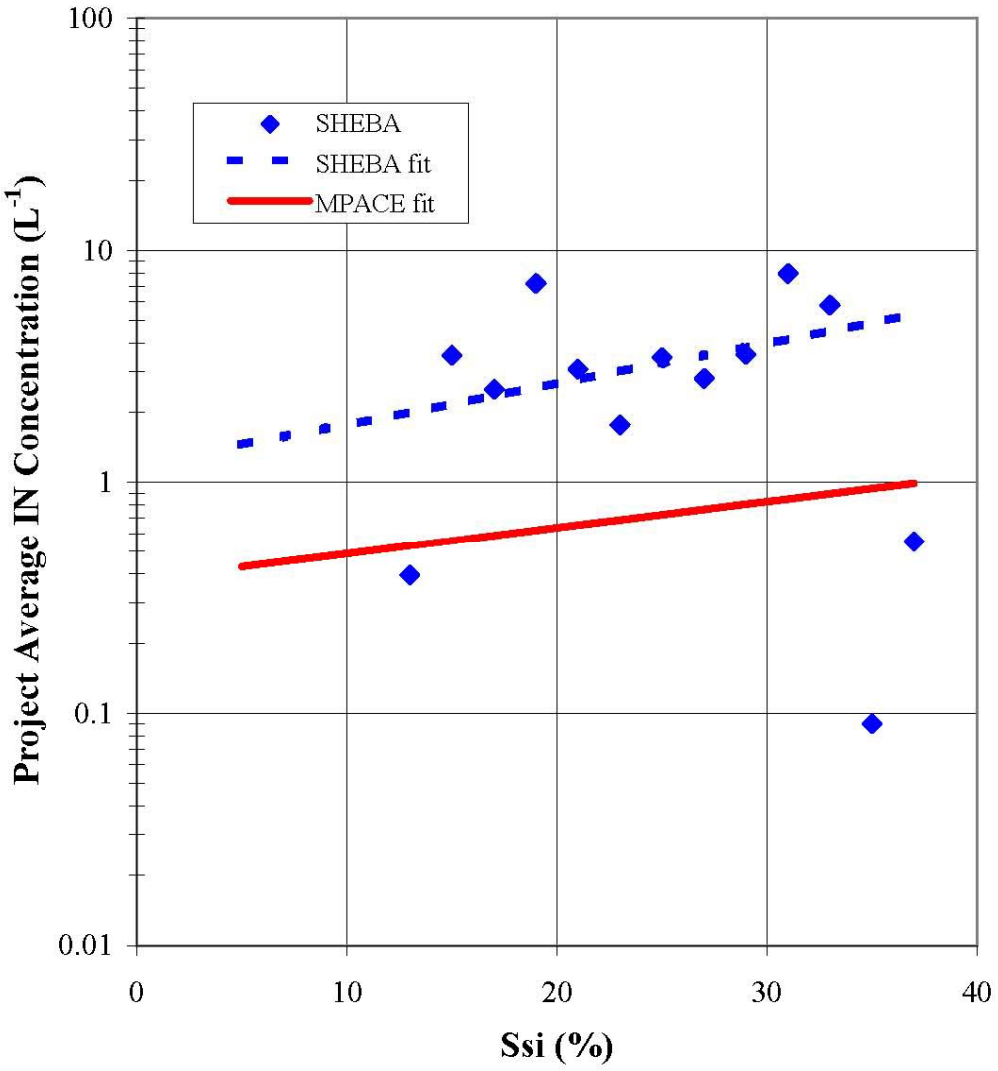

Figure 3. Comparison of project average IN concentrations from M-PACE in fall, shown as the best fit line from Figure 1, and SHEBA/FIRE-ACE during spring (blue diamonds; blue line best fit). Average IN concentrations during springtime are enhanced by about a factor of seven.

the measurements taken during fall, by about a factor of 7 based on the binned and weighted fits. These data suggest a seasonal dependence of IN, which may affect cloud processes. This is consistent with observations that cloud cover reaches a maximum in autumn (Intrieri et al. 2002), when ice phase process are less active. However, it should be noted that measurements taken during M-PACE focused on the area between Prudhoe Bay and Barrow, Alaska, with most measurements occurring over land or near the coast, while much of the springtime data was collected over the ocean, and that the open ocean (Bigg 1996) and open water leads (Rogers et al. 2001a) are potential IN sources. As such, the springtime data may have been affected by ocean sources which were not observed during M-PACE. More seasonal data are needed.

Contact

Anthony J. Prenni – email: prenni@lamar.colostate.edu. Phone: 907-491-8414.

References

Bigg, EK. 1996. "Ice forming nuclei in the high Arctic." *Tellus Series B-Chemical and Physical Meteorology* 48(2)223-233.

Intrieri, JM, MD Shupe, T Uttal, and BJ McCarty. 2002. "An annual cycle of Arctic cloud characteristics observed by radar and lidar at SHEBA." *Journal of Geophysical Research-Oceans* 107(C10), Article Number 8030.

Meyers, MP, PJ Demott, and WR Cotton. 1992. "New primary ice-nucleation parameterizations in an explicit cloud model." *Journal of Applied Meteorology* 31(7)708-721.

Rogers, DC, PJ DeMott, and SM Kreidenweis. 2001a. "Airborne measurements of troposheric ice-nucleating aerosol particles in the Arctic spring." *Journal of Geophysical Research-Atmospheres* 106(D14)15053-15063.

Rogers, DC, PJ DeMott, SM Kreidenweis, and Y. Chen. 2001b. "A continuous-flow diffusion chamber for airborne measurements of ice nuclei." *Journal of Atmospheric and Oceanic Technology* 18:725-741.