This report updates the report of findings given in the first and second annual reports. Quality ice nuclei data were collected over at least 38 hours during 11 of the research flights. These data have been processed, are supporting case study and long-term analyses, and are available to the community.

Observations and present conclusions from the study include:

1) ***The presence of ice in clouds is linked to the availability of IN***: Cloud particle residuals from sampling by the CVI were reprocessed by the CFDC to determine if the absence of cloud ice is associated with the absence of ice nuclei and vice versa. Our results show that IN are observed when clouds contain ice crystals (Figure 2) and IN are not present, at least within cloud droplets, when ice is not observed. This suggests that a primary ice nucleation process is involved in ice initiation. It could not be fully discerned whether absence or presence of ice were directly linked to absence or presence of IN in the air feeding clouds such as those shown in Figure 2, or if a time-dependent contact freezing process was involved. The balance of evidence in the case shown in Figure 1 supports the former hypothesis, as do other arguments presented by DeMott et al. (2006).

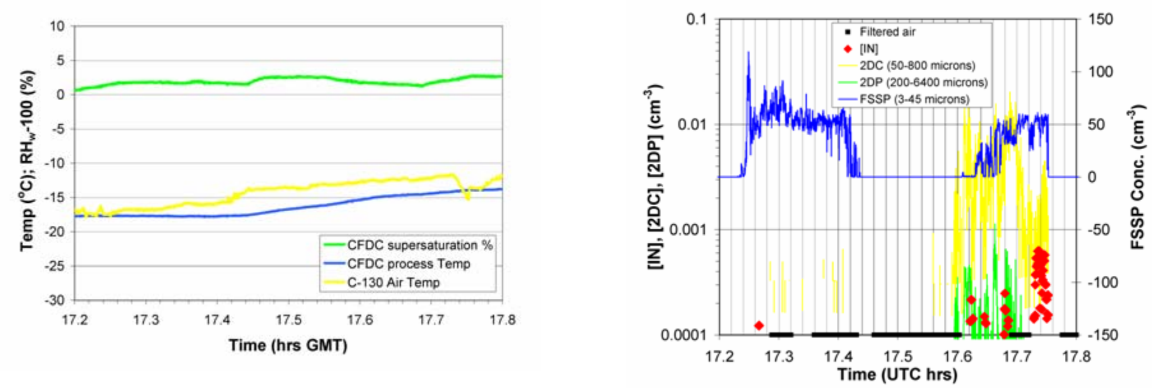

Figure 2. *Data from constant altitude flight (excepting ascent out of second cloud) through two lines of stratocumuli on 14 November 2003. CFDC temperature conditions were adjusted to attempt to mimic the ambient temperature conditions (left panel). The first cloud line had few or no apparent ice particles present. The second cloud contained verifiable ice particles, as indicated by the particle probe data (2D-C and 2D-P) shown in right panel). IN concentrations (right panel), sampled from CVI residuals in this case, were detectable only in cloud, as expected, and primarily only in the cloud that contained measurable ice concentrations. IN concentrations reported here are 1-minute values.*

2) ***A robust connection between IN and ice crystals concentrations in clouds is not generally observed:*** Such a connection would be supported by covariance of these two quantities. This is not clearly shown in Figure 2 except as the aircraft exited cloud top in a region without the presence of larger ice crystals. Figure 3 shows selected measurements of ice nuclei measured from cloud particle residuals versus ice crystal concentrations during a descent through a deep cloud system over Montreal on November 19, 2003. While IN concentrations generally trended with ice concentrations through the depth of the cloud, relatively close correspondence between IN and smaller ice crystal concentrations from the 2D-c probe was found only near cloud top. Thus, while the relative abundances of IN and ice crystals were found to vary qualitatively as expected for ice formation by primary nucleation, only in some cases or selective cloud regions was there quantitative agreement between IN and ice crystal concentrations. In the case shown in Figure 3, data exist to support to the existence of secondary ice formation processes due to the presence of cloud droplets in the 0 to -8°C cloud regime of the descent sounding, We can therefore speculate that the disparity between IN and ice crystal concentrations relates to secondary ice formation processes and perhaps the failure to resolve all ice formation processes in some cases, but this issue remains unresolved and requires further study.

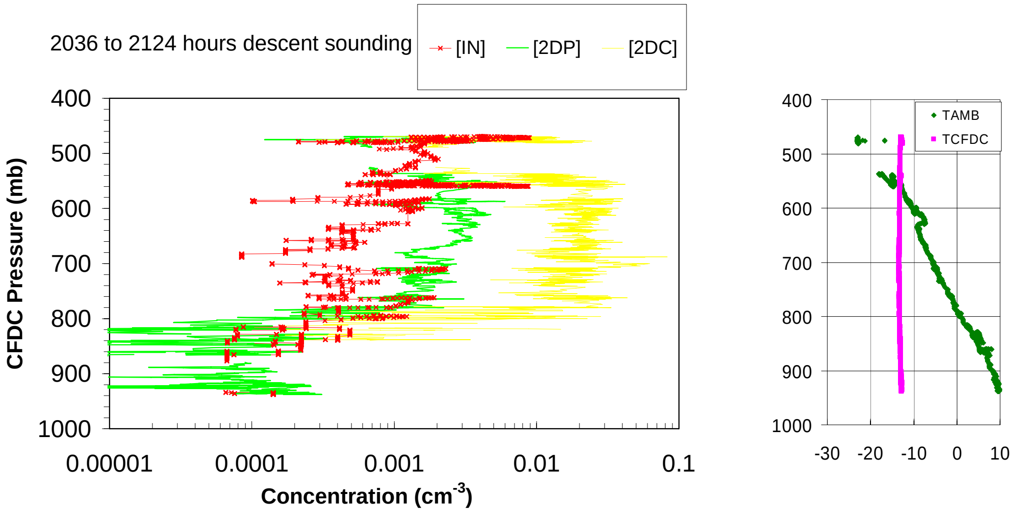

Figure 3. *Vertical profile of selected CFDC and C-130 data during sampling of deep cloud system over Montreal on November 19, 2003. The CFDC was connected inline with the CVI to process cloud particle residuals. Ice nuclei processing conditions were nearly constant at -12°C processing temperature and 100% relative humidity. IN concentrations are 30 s running mean values reported at 1 Hz. Zero values do not appear on the logarithmic scale.*

3) ***IN concentrations are often highly variable spatially within and around clouds and this variability is frequently reflected in and may relate to accumulation mode aerosol particle number concentrations:*** The spatial variability of IN, horizontally and vertically, is another factor clearly evident in Figure 3. The variability of aerosol concentrations for the same time period is shown in Figure 4, suggesting a direct relation between aerosols in the accumulation mode size ranges and IN concentrations in the supercooled cloudy air region. There is no relation between IN and total aerosol particle concentrations as indicated by the condensation nuclei concentrations measured by a CPC. These observations, which support results found nearly 40 years ago (Georgii and Kleinjung, 1967, *J. Rech. Atmos.*, **2**, 145-156) encouraged investigations of the generality of relations between aerosol and IN concentrations using data from a number of field studies supported by NSF and other agencies. A summary of some of these results are given in Figure 5. Comparisons are restricted to IN and aerosol concentrations at sizes larger than 0.5 μm, a size for which data is available from most studies.

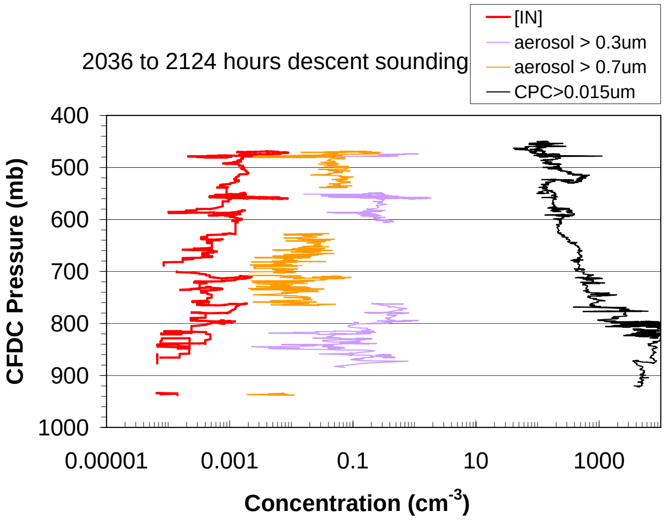

Figure 4. *Aerosol data from the same C-130 descent sounding profile as shown in Figure 2. Data from the CFDC OPC suggest correlations between accumulation mode aerosols (>0.3 μm and > 0.7 μm) and ice nuclei concentrations, but little correlation with total aerosol particles measured by condensation particle counter (CPC).*

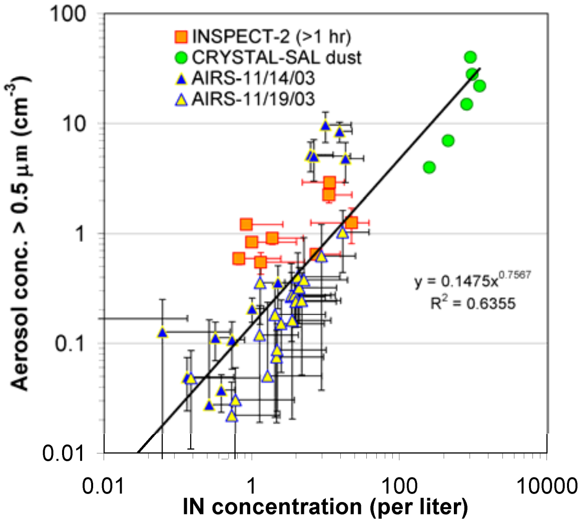

Figure 5. *Comparison between CFDC IN concentrations and aerosol concentrations at sizes above 0.5 μm in three different studies, including two days from the AIRS-2 project. Aerosol concentrations in AIRS-2 are from the CFDC OPC during sampling of CVI cloud particle residuals. Aerosol data in INSPECT-2, a mountain-top sampling study conducted in the Colorado Rockies during Spring 2004, are from optical and aerodynamic particle sizing instruments. Aerosol data from NASA CRYSTAL-FACE study sampling within Saharan Aerosol Layers (SAL) is from a Cloud and Aerosol Spectrometer (CAS). IN concentrations are irrespective of CFDC processing conditions, but all data are for temperatures warmer than -35°C. All IN data are 1 minute averages, except the INSPECT-2 data that is averaged over ~1 hour periods.*

Data are included for two days from AIRS-2 along with data from two studies that included higher IN concentrations due to the influence of desert dust particles, a key source of atmospheric IN. The other studies are the 2004 INSPECT-2 (Ice Nuclei SPECTroscopy-2) study, a Colorado mountaintop measurement study focused during the peak season (Spring) for Asian dust transports to the western United States and the 2002 NASA CRYSTAL-FACE (Cirrus Regional Study of Tropical Anvils and Cirrus Layers - Florida Area Cirrus Experiment) study. In the latter study, measurements were made directly within layers of high dust particle concentrations. Data in Figure 5 suggest a relatively strong and robust relationship between IN and larger aerosols particle concentrations, a relationship that reflects primary sources of IN and one that may be useful for numerical modeling applications. These investigations will continue, folding in data from other studies so that multivariate relations including temperature and/or supersaturation may be formulated.

4) Mineral dust particles are primary contributors to primary ice nuclei populations: Electron microscope morphological and chemical analyses of IN collected from the CFDC suggest that, as in other recent studies, mineral dust particles were predominant contributors to primary ice nuclei populations in the time frame and area of the AIRS-II study.

5) Project adds to composite analyses of 13 years of CFDC data: Retrospective analyses are underway to learn more about the dependencies of ice nuclei populations seasonally and by location. If mineral dusts are a strong influence on these populations, one should expect to see the influence of seasonal dust transport cycles and location with respect to dust transport pathways on ice nuclei concentrations. Figure 6 shows data collected around cloud levels at mostly below 8 km altitude from five selected studies, including the present AIRS-2 study (data through November 19, 2003). Data are selected due to the similar CFDC processing regimes and similar cloud temperatures of focus for the campaigns. The midlatitude data suggest strong differences seasonally, with the higher average IN concentrations in summer (North Dakota Tracer Experiment – NDTE1993) under moderate dust influences, somewhat lower IN concentrations and an increasing proportion of 1 minute samples indicating no IN during decreasing dust influences in Fall (AIRS-2), and much lower IN concentrations and more than 40% of 1-minute samples showing no IN in Winter (Winter Icing in Storms Project – WISP1994, over Colorado). A similar scenario exists in the Arctic, where very low IN concentrations exist already by October (Mixed-Phase Arctic Cloud Experiment – M-PACE in 2004), while Asian dust influences are strongly suggested by the IN distributions present in Alaska during Spring (FIRE Arctic Cloud Experiment/Sheba – FIRE-ACE in 1998). These analyses are continuing.

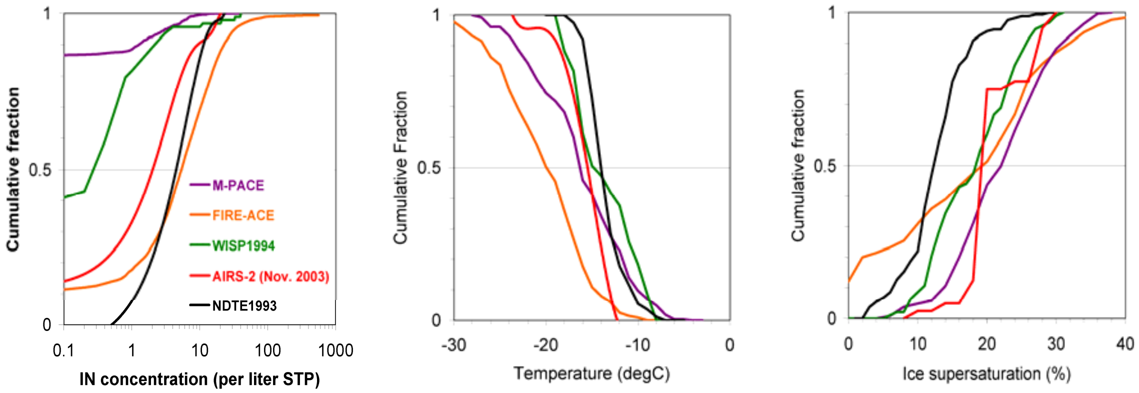

Figure 6. *Cumulative distributions of 1-minute averaged ice nuclei concentrations and CFDC processing conditions measured in five projects with relatively similar CFDC processing conditions. The projects shown were selected to represent Winter (WISP1994), Summer (NDTE1993) and Fall (AIRS-2) data collected near clouds at locations between 40 to 48º N latitude in North America, and Spring (FIRE-ACE) versus Fall (M-PACE) Alaskan Arctic data.*

6) Sampling IN into aircraft at ambient temperature and RH conditions will require a specialized exterior inlet: It was not possible, despite strong efforts made during the AIRS-2 study, to maintain the condition of sample air in order to investigate the potential effect of ice nuclei preactivation on detected IN concentrations. Compression (adiabatic) warming of air entering the outside aerosol inlet on the C-130 was a primary factor that could not be overcome. A specialized inlet will be necessary to address this issue in any future attempts to maintain sample temperature and relative humidity. The primary aerosol inlet used on the C-130 was also in a location that was apparently subject to thermal effects from a cabin exhaust vent. Additional sample warming of unidentified source occurred at times inside the aircraft cabin. Insulated sample lines also maintained a memory of thermal effects during aircraft ascent and descent. Active cooling systems in the vicinity of the CFDC rack were successful in maintaining precooling of sample air, had upstream conditioning succeeded, and these will be useful for future studies. The best conditioning achieved during the field study was to maintain air samples below 0 degrees C in some cases. Until an appropriate inlet is designed, the role of preactivation in cloud ice formation will remain unresolved.