The purpose of this work was to investigate by aircraft the presence or absence of ice nucleus aerosols in the vicinity of mixed phase clouds in winter. Ice nuclei (IN) measurements were made in the context of a comprehensive aircraft investigation of the micro-structure of mixed phase clouds composed of ice particles and supercooled water drops in varying proportions. Such clouds form the basis for ice phase precipitation by the Bergeron-Findeisen process; they form the basis for processes for ice multiplication by the Hallett-Mossop process; they form the basis for cloud electrification by ice collision and bounce on growing graupel. From an important applied perspective, they provide an environment for aircraft icing whose severity relates to the drop and ice size distribution, the spatial distribution of regions of ice, mixed and supercooled cloud. Characterization of the concentrations of ice nuclei, as a function of temperature and saturation ratio, feeding different cloud regions in winter storm scenarios is critical to understanding the presence or absence of ice particles. Additional determination of ice nuclei chemical composition was made to give inference to their sources and scavenging properties. These measurements were part of a suite of measurements aboard the NCAR C-130 aircraft that were made to fully characterize the properties and formative nuclei concentrations of mixed phase clouds, including measurements of liquid and ice particle size and (for ice) habit distributions, nuclei for initiation of the cloud droplets (Cloud Condensation Nuclei, CCN), and Ultra Giant Nuclei (UGN) which may lead to supercooled drizzle. The aircraft study was conducted based out of NASA-Lewis in Cleveland, Ohio during November 2003. Since the project was closely associated with the AIRS-II international icing project (http://airs-icing.org/) many flights were conducted over and around the AIRS-II ground site in Montreal, Canada. Flights for cloud nuclei characterization were sometimes done in regions upstream of the expected cloud formation region, based on forward air mass trajectories, in the 24 hour period preceding cloud sampling.

All project objectives were met with varying degrees of success and analyses continue in collaboration with other investigators:

1) The CSU continuous flow diffusion chamber (CFDC) was installed on the NCAR C-130 aircraft for measurements during AIRS-II. Pre-study participation in the NCAR IDEAS-3 project facilitated readiness and permitted training of junior personnel in flight operations of instrumentation.

2) Clear air measurements of ice nuclei were made over a range of temperatures (-8 to -22°C) and for a spectrum of ice supersaturations relevant to mixed phase cloud formation.

3) Systems were constructed and employed in an attempt to keep sampled air and the contained particles at near ambient conditions, but at least at temperatures below 0°C.

4) Electron microscope grid collections were made of ice nuclei processed in the CFDC for analysis of their composition and morphology.

Figure 1 shows a schematic of sampling systems configured during IDEAS-3 for use during AIRS-2. The first added sampling strategy involved transfer and processing, as ice nuclei, the residual nuclei of evaporated cloud particles that were collected by a counterflow virtual impactor (Cynthia Twohy, Principal Investigator, Oregon State

University). This permitted meaningful sampling of ice nuclei during horizontal and vertical transects of cloud systems, in particular, examining cloud nuclei for the presence of immersion freezing nuclei. In sampling CVI cloud particle residuals, particles were always first exposed to strong warming and then drying to the lower relatively high water vapor mixing ratios present in the CVI sample stream. Connection to the CVI provided a 20 to 30 inertial enhancement factor for sampling particles remaining from cloud droplets and ice crystals, thereby providing added sensitivity to quite low IN concentrations.

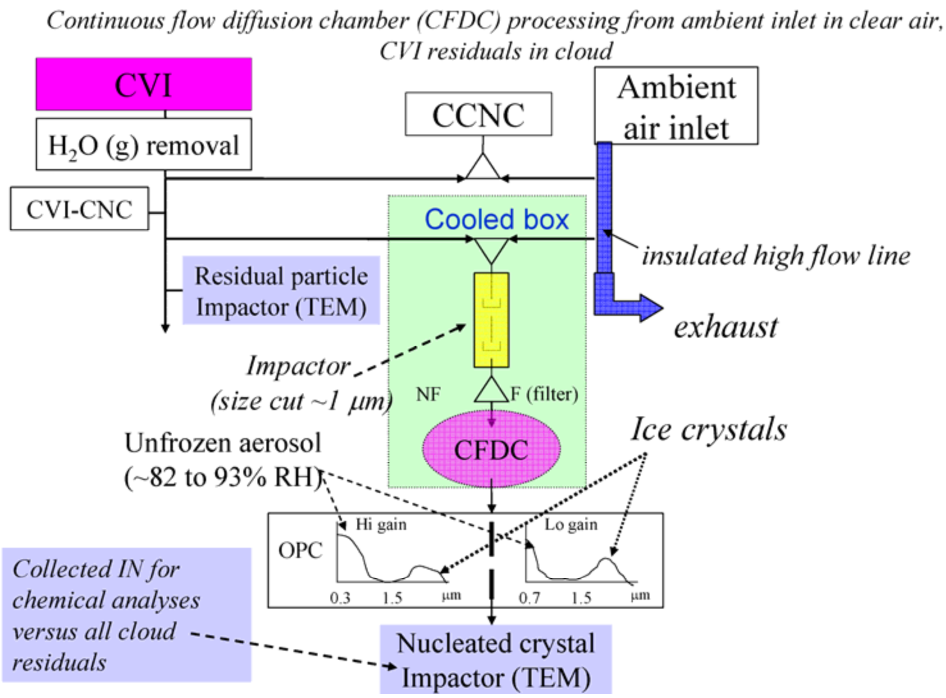

Figure 1. *Ice nuclei sampling for AIRS-2 included CFDC processing of ice nuclei from an ambient inlet during clear-air sampling and from cloud particle residuals collected via a CVI inlet during cloud passes. The Hudson CCN counter (CCNC) sampled in the same manner. In addition to measuring IN concentrations, the CFDC optical particle counter measured aerosol concentrations in 0.3 to 1 μm and 0.7 to 1 μm size ranges. Electron microscopy grids of IN were collected for comparison to cloud residual nuclei. Finally, attempts were made to keep the ambient air samples conditioned to ambient temperatures by insulating and force-cooling sample lines.*

As an additional sampling strategy, we explored for the first time was use of the aerosol size data that comes from the CFDC optical particle counter (OPC) that is used to identify, by size, nucleated ice crystals. A two-stage impactor preceded the CFDC chamber in order to remove particles above about 1 μm in size. Ice nuclei are identified as those particles remaining at sizes larger than 2 μm after passing through the CFDC growth section and following (liquid) evaporation section where the warm wall vapor source is removed and conditions relax to ice saturation. The OPC threshold size is about 0.3 microns on the highest signal gain channel. On a lower gain channel, the lower size detected was 0.7 microns. By switching between the two OPC channels, it was possible to simultaneously compare activated IN concentrations to the concentrations of particles between 0.3 or 0.7 to 1 microns. These aerosol sizes are the sizes at the relative humidity at the outlet of the CFDC. This relative humidity differs from the processing relative humidity in the CFDC (typically 95 to 105% with respect to water), ranging from 82 to 93% for the experimental temperatures used to process IN during the AIRS-2 study.

The work plan beyond data collection included:

1) Providing a final IN data set to other project investigators.

2) Performing composite analyses of IN concentrations and dependencies on temperature, humidity and other parameters for the project period.

3) Attending and present results at project science meetings, including one which took place during the 2004 International Conference on Clouds and Precipitation in Bologna, Italy and one in Mont Tremblant, Quebec (Fall 2004).

4) Collaborate with other project investigators on case study analyses and analyses of IN data on “trajectory” versus cloud flights in the context of other final data on aerosols, CCN, and cloud particle populations.

5) Collaborate with numerical modeling community. Informal discussions in this direction have been held with Dr. Roy Rasmussen of NCAR.

6) Prepare and submit one journal publication concerning ice nucleation in mixed phase clouds and collaborate with other investigators on scientific articles of broader scope.

A no-cost extension was requested at the end of the second year period in order to complete comprehensive data analyses and apply remaining funds toward publication of results. A final data set is available by request and individual requests for data have been met. Composite analyses have been advanced, as reflected in the findings. Results were incorporated into presentations at additional conferences, including the AGU 2004 Fall Meeting Special Session on “Tropospheric Aerosol Processes: The Physical and Chemical Aging of Aerosol Particles and Their Impacts”, which was organized by Dr. DeMott, at the AGU 2005 Fall Meeting Special Session on “Mixed-Phase Clouds and Their Impact on Weather and Climate,” at the DOE Atmospheric Radiation Measurement program Annual Science Team Meeting (2006), and at the 12th AMS Cloud Physics Conference (2006). Collaborations have been extended with other project investigators towards a publication that is nearly ready for submission. Modeling studies are still being pursued.