

ISDAC Flight Planning Document

S.J. Ghan
G. McFarquhar
A. Korolev
P. Liu
W. Strapp
H. Verlinde
M. Wolde

April 2008

Work supported by the U.S. Department of Energy,
Office of Science, Office of Biological and Environmental Research

DISCLAIMER

This report was prepared as an account of work sponsored by the U.S. Government. Neither the United States nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. Government or any agency thereof.

Contents

1.	Introduction.....	1
2.	Flight Planning and Mission Execution	1
2.1	Briefing and Planning Schedule	2
3.	Generic Flight Profiles	3
3.1	Flights in the Vicinity of Barrow.....	3
3.1.1	Spiral Profiles over the ACRF Site at Barrow.....	4
3.1.2	Legs Flown at Constant Horizontal Altitude Within Clouds	5
3.1.3	Legs Flown at Constant Horizontal Altitude Outside of Clouds.....	5
3.1.4	Missed Approaches at Barrow Airport.....	6
3.1.5	Porpoising Maneuvers.....	6
3.2	Flight Patterns Flown During Transits Between Barrow and Fairbanks.....	7
3.2.1	Legs Flown at Constant Horizontal Altitude Within Clouds	7
3.2.2	Legs Flown at Constant Horizontal Altitude Outside of Clouds.....	8
3.2.3	Porpoising Maneuvers.....	8
3.3	Coordinated Flights with Other Aircraft	8
3.3.1	A-train Evaluation Legs	9
3.3.2	Comparison of Cloud/Aerosol Data with NOAA WP-3D	9
3.3.3	Comparison of Cloud/Aerosol Data with NASA DC8.....	9
3.3.4	Coordinated Flights Between Convair and B200.....	9
3.3.5	Coordinated Flights Between Convair and NASA P-3B	10
4.	Cloud Mission Profiles.....	10
4.1	Identifying Thermodynamical Conditions for Maintaining Mixed-Phase Clouds	10
4.2	Statistical Characterization of Microphysics and Thermodynamics of Mixed-Phase Clouds.....	12
4.3	Ground-based Remote Sensing Validation	13
4.4	Remote Sensing Validation – CloudSat and CALIPSO.....	15
4.5	Instrumentation Studies.....	16
4.6	Small Particles in Mixed-Phase and Ice Clouds.....	18
4.7	Spatial Scale of Mixed-Phase Cloud Variability.....	20

4.8 Cloud Extinction Closure 21

4.9 Cloud Water Closure 22

4.10 Scale Dependency of Ice Crystal Number Concentration for Cloud-Climate Modeling
Applications: Emphasis on Dynamics 22

4.11 Cloud Cover Parameterizations 23

4.12 Ice Fog Microphysics and Extinction: Emphasis for In Situ Validations 24

5. Aerosol or Aerosol-Cloud Science Objectives 25

5.1 CCN Closure 25

5.2 Droplet Number Closure 25

5.3 Cloud Modeling 26

5.4 Semi-Direct Effect 27

5.5 Ice Crystal Nucleation 27

5.6 Relation Between IN and Ice Crystal Concentration 28

5.7 Aerosol Extinction Retrieval 29

5.8 CCN Retrieval 29

5.9 Ice Crystal Nucleation Parameterizations and Dehydration Processes 30

5.10 Long Range Transport of Pollutants to the Arctic Troposphere 31

5.11 Cloud Processing of Hg in the Arctic Troposphere 31

5.12 Aerosol Optical Closure in the Arctic Troposphere 32

5.13 Contributions to CCN Closure Studies and Aerosol Activation Studies 32

Figures

1. Proposed flight pattern for the Convair-580 to study turbulence and microphysics of
mixed-phase clouds 12

1. Introduction

This document outlines flight profiles to be flown by the National Research Council of Canada Convair during the Indirect and Semi-Direct Aerosol Campaign (ISDAC). This flight planning document complements the ISDAC Science Overview Document (SOD) that describes the scientific justification for ISDAC and the principal science questions it is addressing.

Section 2 summarizes the operations plan that governs the timing for the weather briefings and go/no-go decisions in the field. The roles of the planning and management teams also are described. Section 3 describes the basic flight profiles and the meteorological conditions in which they will be flown. The flight descriptions are arranged in sub-sections according to the location where they will be flown:

1) describes missions or components of missions in the vicinity of Barrow; 2) describes components of missions during transits to and from Barrow; and 3) describes coordinated flying with other aircraft in the vicinity of Fairbanks or Barrow. The approximate number of each flight profile needed to adequately address ISDAC science goals also is estimated. Section 4 summarizes the science questions that will be addressed with each of the flight scenarios and identifies the key instrumentation needed for each. Section 5 provides a mission “scorecard” that we can use in the field to track which science goals have been addressed during which flight profile.

2. Flight Planning and Mission Execution

Proper execution of the flight plans will require careful planning and implementation in the field. This task will be especially daunting given the complex environment of the Arctic and the physical separation of project participants between Barrow, Fairbanks, and possibly other locations. In the following paragraphs, we outline the general flight planning and mission execution approach that will be followed during the experiment.

It is important that the flight planning process for ISDAC be as open as possible. However, flight profiles will be recommended by a small group of individuals with the discussion facilitated by the AVP chief scientist, Greg McFarquhar, who is also a Co-PI for ISDAC and the Aerial Vehicles Program (AVP) technical director, Beat Schmid. In addition to Greg McFarquhar and Beat Schmid, the flight decision-making group will include the following people: Steven Ghan (ISDAC PI), Hans Verlinde (North Slope of Alaska [NSA] Site Scientist), John Hubbe (Pacific Northwest National Laboratory), Walter Strapp and/or Alexei Korolev (Environment Canada) and Mengistu Wolde (National Research Council [NRC] Environment Canada [EC]).

The meteorological conditions will be reviewed the day prior to a mission by the flight decision-making group, with an objective to determine whether the air crew will be on-call for a flight the next day, and to provide a first cut flight plan for the mission. A decision to alert the flight crew to prepare for a flight will be made at an early meteorological briefing on flight-day, utilizing the most up to date measurements from the Atmospheric Radiation Measurement (ARM) Climate Research Facility (ACRF) site. The flight plan will be modified, if appropriate, to reflect recent conditions over the site, and a briefing of the NRC pilots will be then given by the NRC/EC flight director. Takeoff will be no earlier than two hours after this meeting, so there will be significant time to follow the weather and issue a final ‘go/no-go’ decision to the NRC/EC flight director approximately 30 minutes before takeoff. After the first flight, the NRC/EC flight director will contact the flight decision-making group in Fairbanks from the ground in Barrow for further guidance for the second mission.

The NRC/EC flight director will be briefed carefully by the flight decision-making group before the flight on the highest priority objectives of the day, and will thereafter have authority to make common-sense modifications to the flight plan based on real cloud conditions observed in the air, and any operational/instrument issues that might affect the data set.

Forecasting support will be provided by the NSA Site Scientist Team from Penn State. They will lead the weather briefings and discussions that are summarized in Section 2.1. The instrument mentors will be responsible for the calibration of their instrument, integration with the platform, operation during the campaign, removal of the instrument from the platform, data processing, and data archiving.

2.1 Briefing and Planning Schedule

It is anticipated that the following schedule will be followed:

- 20:00 Meteorological briefing for flight decision-making group; if next day is suitable, preliminary flight plan produced. This meeting may be cancelled if flights are clearly not expected the next day.
- 06:00 Meteorological briefing for flight decision-making group; official flight plan produced;
- 07:00 Alert all flight crew and instrument support of possible flight; brief NRC pilots on expected mission profile; pull aircraft out of hangar
- 07:15 All crew and support on aircraft preparing for mission
- 09:00 Doors closed, all non-crew members off the aircraft – final ‘go/no-go’ decision from flight decision-making group
- 09:30 Takeoff Fairbanks
- 11:15 Commence measurements over ACRF site
- 13:15 Landing Barrow after flight #1
- 13:45 NRC/EC flight director contacts flight decision-making group in Fairbanks for guidance on second flight
- 14:00 Doors closed
- 14:30 Takeoff Barrow for flight #2
- 14:40 Start measurements over ACRF site
- 17:30 Start transit back to Fairbanks
- 19:15 Land Fairbanks.

The above schedule requires a crew day of a little over 12 hours, the maximum recommended crew-day for the NRC pilots. In this regard, there will be little opportunity to extend the period on the ground at Barrow to wait for more favorable cloud conditions.

3. Generic Flight Profiles

There are basically three different locations/conditions in which the Convair will be flown during ISDAC: 1) missions or components of missions in the vicinity of Barrow; 2) components of missions during transits between Barrow and Fairbanks; and 3) coordinated flying with other aircraft in the vicinity of Barrow or Fairbanks. The different flight scenarios are described separately for each. Each mission during ISDAC will include combinations of the flight profiles that are described below.

3.1 Flights in the Vicinity of Barrow

When the Convair is operating in the vicinity of Barrow, the following flight profiles will be flown:

1. Spiral profiles over the ACRF site at Barrow
2. Legs flown at constant horizontal altitude within clouds
3. Legs flown at constant horizontal altitude outside of clouds
4. Missed approaches at the Barrow airport
5. Porpoising maneuvers (i.e., ramped ascents and descents).

These flight profiles are described separately below. Discussions will take place the day before each mission to determine what combination of these profiles will be put together on the same flight day.

The following rules will apply to the minimum altitudes that the aircraft may be flown at under the conditions noted below:

- **For flights over the ACRF site:** In Visual Flight Ruler (VFR), (non-cloudy) conditions, the minimum flight altitude, when pilots agree that conditions of the day are adequate (based on visibility, surface wind, surface texture, cloud-base height and texture, ambient lighting texture, set against pilots' familiarity with the area and/or route) would be 500 feet above ground (assuming that the immediate area around the Barrow site has no population or buildups) and otherwise 1000 feet above ground. In Instrument Flight Ruler (IFR), (cloudy) conditions, the minimum altitude will be the Minimum Safe Altitude (MSA) for Barrow Airport (as yet not determined due to unavailability of the Barrow Airport approach charts, but the MSA would not be lower than 1600 feet above mean sea/level (AMSL), based on examination of air route planning charts and could quite possibly be higher). Missed approaches into Barrow airport could get us lower in the vicinity of the airport, but not over the Barrow site. In some cloud-base conditions, it might be possible to proceed VFR, after establishing visual conditions on an approach to the Barrow Airport and cancelling IFR, to and over the Barrow site or offshore, and operate as low as 500 feet, as long as the pilots feels that the conditions of the day are adequate (as described above).
- **For flights between Deadhorse and Barrow and Any Other Low-Level Flights Offshore:** In VFR conditions, flights could be conducted at 500 feet, if the pilots agree that the conditions of the day are adequate (see above for the influencing factors) and possibly lower, again depending upon conditions. In IFR conditions, the lowest level flight altitude offshore (at least five nautical miles [nmiles] offshore at all times) would be 1500 feet above the sea surface. In IFR conditions, the lowest flight altitude for the overland route between Deadhorse and Barrow would be 2000 feet AMSL for the

direction of flight, 3000 feet for Barrow to Deadhorse, using the low frequency (LF)/ mandatory frequency (MF) air route G16 over land (a 30-degree dogleg). The minimum IFR altitude for the direct Deadhorse to Barrow route would be 6000 feet MSL.

3.1.1 Spiral Profiles over the ACRF Site at Barrow

Many ISDAC science goals require profiles of atmospheric parameters over the ACRF's remote sensing site at Barrow (71.75°N, 151 W). Because observations of aerosols require horizontally long level legs, the spiral profiles will concentrate on the acquisition of in situ cloud observations. Thus, the location of clouds (particularly horizontally extensive boundary layer clouds such as stratus, stratocumulus, altocumulus and altostratus) will dictate the altitude ranges of the spirals. For ISDAC, the meteorological conditions will impact the timing of the profile (as is typical for a field project). However, deviations from the predetermined profiles will be made when hazardous flight conditions exist or due to aircraft control restrictions. Because of the ubiquitous nature of clouds over Barrow, we anticipate clouds will be present typically over the NSA.

The lower and upper altitude of the spirals cannot be determined a priori, because it is dictated by the altitudes of cloud layers. The location of the cloud layers will be determined from onboard radar or visual observations or from the remote sensors at the ACRF NSA site. Then, the spirals should be conducted ideally between an altitude 100 m below cloud base to 100 m above the highest layer of horizontally extensive clouds (e.g., 100 m above stratus, stratocumulus, altocumulus or altostratus, but spirals will not continue to cirrus altitudes). The profiles should be flown in an Eulerian fashion (i.e., centered over the fixed location of the Barrow site) rather than a Lagrangian fashion (i.e., advecting with the background wind). The rate of ascent or descent should be between 2 to 4 m s⁻¹ depending on the thickness of the cloud so that the ascent/descent lasts between 5 to 10 minutes. The radius of curvature should be as tight as possible and one edge of the spiral should be centered over the ACRF NSA site; the other edge of the spiral should be in the downwind direction so that the cloud is sampled in situ after it passes over the NSA site. The profiles can be flown in either an ascending or descending fashion. It does not matter whether the spirals are flown in clockwise or counter-clockwise fashion.

In the event that air traffic control restrictions make it impossible to fly these spirals directly over the Barrow site, the spirals can be flown in a cloudy region directly downwind of the NSA site (ideally we do not want to fly upwind because we do not want to seed the cloud before it is remotely sensed by the ground-based equipment, but it is possible to fly the spirals upwind if that is where the clouds are). As noted above, the minimum altitude for spirals will be about 1600 feet above ground in cloudy conditions over the ACRF site, or 1500 feet MSL offshore. A missed approach into Barrow airport would be required to profile lower.

Because acquisition of in situ cloud data during these profiles are central to many of the ISDAC objectives, we would like to fly as many of these profiles as possible (at least two during each flight) in the widest variety of meteorological conditions possible.

3.1.2 Legs Flown at Constant Horizontal Altitude Within Clouds

Some level legs will be flown through clouds at a constant altitude to acquire information on the horizontal variability of cloud properties and to provide sufficient sampling of residual aerosol behind the counterflow virtual impactor (CVI). These legs can either be at a single horizontal altitude or at a series of altitudes in a stair-step pattern of ascending or descending altitude. The first legs should be flown through layers dominated by ice water so that samples of ice crystal residuals can be collected behind the CVI before ice potentially clogs the inlet. It will be especially useful to collect data at altitudes that are anticipated to have the highest liquid water contents (these altitudes being determined from earlier stair-step patterns, spiral profiles, or in absence of other information just below cloud top). During the project, legs should be flown in both the along-wind and cross-wind directions (or alternatively, along-coast and cross-coast) to give a better measurement of the spatial distribution of the cloud microphysical properties and to help remove or characterize the effects of land versus ocean (ice/leads); the meteorological conditions will dictate what type of horizontal legs are flown on an individual day. Some legs should be preferentially flown downwind of the ACRF site so that the in situ data are collected after the cloud layer has been remotely sensed by the ACRF site to avoid seeding effects. The legs should be 10 to 15 km (2 to 3 minutes long) to provide adequate sampling of the residual particles behind the CVI. When legs are flown at several altitudes, the first leg should be ~ 100 m above cloud top. Subsequent legs should be conducted at vertical steps of 50 to 150 meters depending on the depth of the cloud. The transition from one altitude to another one should be conducted along enroute descent with the vertical speed approximately 3m/s to 5m/s. The last horizontal leg is conducted near the level of sublimation of ice particles, identified from the onboard radar, or if the precipitations fall to the ground, then at the lowest allowed altitude, or no lower than 300 to 600 meters (depending on temperature) below the cloud base of the mixed-phase layer. It is also possible to conduct the stair-step pattern starting at the bottom and working to the top of the cloud.

Additional horizontal legs are needed that are oriented perpendicular to the coastline. The Convair should start at Barrow and fly 50 km at a constant altitude north perpendicular to the coastline in order to sample the gradient of cloud properties. These flight profiles are especially desirable later in the project when the ice has moved away from the coast (we expect larger gradients then). The inward and outward flights should be conducted at alternate altitudes (one 100 to 200 m below cloud base and another at mid-level) to get information on the gradient of cloud properties at multiple levels. One such leg should be flown when the sea ice is at the coast as a baseline. Once the ice has moved further from the coast, multiple such legs are desired to determine statistically how cloud properties vary with distance away from the coast. The position of the sea ice will be monitored both from visual observations from the Convair flight scientist and from any remote sensing data available.

3.1.3 Legs Flown at Constant Horizontal Altitude Outside of Clouds

Some legs need to be flown above and below clouds to sample key atmospheric properties that cannot be well measured inside clouds (and also to determine what these quantities are outside of clouds). These quantities include aerosols, ice nuclei, humidity, temperature, and spectral radiance. The orientation of these legs with respect to the surface site is not as important as for the cloud legs. However, the legs are envisioned to be between 60 to 75 km long (10 to 15 minutes long) because longer time periods are required for measuring the cloud condensation nuclei (CCN) concentrations; the lines for the CCN

observations do not necessarily have to be straight legs but should be flown at a single altitude. Measurements of aerosols in stably stratified layers and especially below the cloud are required to meet the science objectives. Horizontal legs over water or a flat surface also are required for the radar calibration maneuvers. Because the minimum altitudes over land are high, it is possible that the data acquired will be biased to oceanic regions; however, such legs are the only possible way of obtaining aerosols under clouds.

Additional horizontal legs are needed that are oriented perpendicular to the coastline. The Convair should start at Barrow and fly 75 to 100 km at a constant altitude below the cloud base north perpendicular to the coastline in order to sample the gradient of aerosols, humidity, and temperature. These flight profiles are especially desirable later in the project when the ice has moved away from the coast (we expect larger gradients then). The flight inward could be conducted at an altitude above the cloud top. One such leg should be flown when the sea ice is at the coast as a baseline. Once the ice has moved further from the coast, multiple such legs are desired to statistically determine how aerosols and humidity vary with distance away from the coast in a variety of meteorological conditions.

These legs through clear air generally should precede flight profiles (spiral or horizontal legs) through clouds so that the effects of icing on the aerosol sampled through the aerosol inlet are minimized.

3.1.4 Missed Approaches at Barrow Airport

When the spiral profiles or horizontal legs below clouds cannot be flown over Barrow because the cloud base is too low, missed approaches should be flown at the Barrow airport to gain information on the vertical structure of the clouds and aerosol. Although it is recognized that the conduct of the missed approaches may be in large pre-determined by air traffic control (ATC), there are certain features desired if operationally possible. The missed approach should start at the lowest altitude sampled during the other flight profiles (typically the lowest altitude that is allowed for flight away from the airport, i.e., 500 m) and continue down to the lowest possible altitude that can be flown safely (i.e., we want to get a complete profile including the cloud and below the cloud to the surface because we want to sample the aerosol and the precipitation falling from the cloud and reaching the ground). The descent rate for the missed approach should be approximately 2 m s^{-1} to match the climb/descent rate of the spiral profiles (or whatever aircraft operations dictate). The length of the missed approach is set according to the descent rate and altitude at which the missed approach starts.

The missed approaches should be flown on all operation days when a low cloud base precludes the spiral profiles from reaching at least 100 m below the cloud base. At least one, and preferably two, missed approaches should be completed on each such day so that we obtain a vertical profile of the cloud and aerosol properties covering their entire depth. In the event that the missed approaches take longer than about 20-30 minutes (i.e., the aircraft is vectored a long way from the air field), we will have to restrict ourselves to one missed approach per flight leg.

3.1.5 Porpoising Maneuvers (i.e., ramped ascents and descents)

In some cases it may be desirable to fly a series of ramped ascents and descents through the cloud to sample the vertical and horizontal structure of the cloud and other parameters in cases where spirals

cannot be flown. Here, we envision porpoising from above the cloud to as close to ground as possible to sample the horizontal and vertical variability (descend at a rate of approximately 5 m s^{-1}). The length of the porpoising leg should be long enough so that we get at least one combination of ramped ascent and descent throughout the cloud.

3.2 Flight Patterns Flown During Transits Between Barrow and Fairbanks

The Convair will be transiting either to or from Barrow when it is not operating in the vicinity of Barrow or flying coordinated legs with other aircraft (however, these flight profiles could be flown outside the vicinity of Barrow even if the Convair was not transiting to or from Barrow). The following flight profiles will be flown during the transit legs from Barrow to Fairbanks (the Convair will fly straight to Barrow from Fairbanks to maximize time on station so such patterns are not envisioned during the transit from Fairbanks):

1. Legs flown at constant horizontal altitude in clouds
2. Legs flown at constant horizontal altitude outside of clouds
3. Porpoising maneuvers (i.e., ramped ascents and descents)
4. A-train evaluation legs.

It should also be emphasized that measurements during the transit must be evaluated carefully to ensure that the mission objectives over the ACRF site are not compromised. For example, excess airframe icing will negatively affect later measurements, and could delay a second flight. Excessive times at low altitudes or altitude changes could lengthen the mission, which would reduce the time for sampling in the vicinity of Barrow. Transit time from Fairbanks to Barrow is assumed to be approximately 1.75 hours, and should not be lengthened without the agreement of the flight decision-making group. These flight profiles are described separately below.

3.2.1 Legs Flown at Constant Horizontal Altitude Within Clouds

Some level legs will be flown through the cloud at a constant altitude to acquire information on the horizontal variability of cloud properties and to provide sufficient sampling of residual aerosol behind the CVI. These legs can either be flown at a single horizontal altitude or at a series of altitudes in a stair-step pattern of ascending or descending altitudes during the flights between Barrow and Fairbanks. The first legs should be flown through layers dominated by ice water so that samples of ice crystal residuals can be collected behind the CVI before it becomes clogged with ice. It will be especially useful to collect data at altitudes that are anticipated to have the highest liquid water contents (these altitudes being determined from earlier stair-step patterns, spiral profiles, or in absence of other information just below cloud top). The runs in a supercooled liquid cloud should be restricted to the return transit because, if a lot of icing occurs on the first transit, it could impact other parts of the mission over Barrow.

The orientation of the legs is dictated by the closest route between Fairbanks and Barrow to minimize the transit time. The legs will be most useful on the north side of the mountains where legs can be flown in horizontally extended boundary layer stratus, stratocumulus, altostratus, or altocumulus. When legs are flown at several altitudes, the first leg should be $\sim 100 \text{ m}$ above cloud top (see flight pattern 3.2.2 below). Subsequent legs should be conducted at vertical steps of 50 to 150 meters depending on the depth of the

cloud with each leg approximately 3 minutes long (10 to 15 km) to provide adequate sampling of the residual particles behind the CVI. The transition from one altitude to another one should be conducted along enroute descent with the vertical speed approximately 3m/s to 5m/s and after the descent another 3 minutes should be flown at constant altitude. The last horizontal leg is conducted near the level of sublimation of ice particles, identified from the onboard radar, or if the precipitations fall to the ground, then at the lowest allowed altitude, or no lower than 300 to 600 m (depending on temperature) below the cloud base of the mixed-phase layer. It is also possible to conduct the stair-step pattern starting at the bottom and working to the top of the cloud. During the flight, the onboard scientists should note the approximate altitude of a layer with the largest supercooled water contents. After the series of altitudes are flown, a longer leg of approximately 10 minutes (30 km) should be flown in this layer, making note that the instruments are not icing up.

3.2.2 Legs Flown at Constant Horizontal Altitude Outside of Clouds

Some legs need to be flown above and below clouds to sample key atmospheric properties that cannot be well measured inside the cloud (and also to determine what these quantities are outside of the cloud). These quantities include aerosols, ice nuclei, humidity, temperature and spectral radiance. During the transits, time should be spent measuring atmospheric quantities both in stratified layers and below the cloud. These legs are envisioned to be between 60 and 75 km long (10 to 15 minutes long) because longer time periods are required for measuring the CCN concentration. Measurements of aerosols in stably stratified layers and especially below the cloud are required to meet the science objectives. These legs generally should precede legs through the cloud to minimize the effects of icing on the aerosol inlet. It is also noted that below-cloud runs will generally not be possible during transit unless they are immediately after the Barrow measurements on the second flight, or if the cloud is an elevated layer. As previously mentioned, the Convair cannot transit at low altitudes for significant periods of time in order to maximize the on-station time over Barrow.

3.2.3 Porpoising Maneuvers (i.e., ramped ascents and descents)

To provide a survey of the vertical structure of the atmosphere while enroute between Fairbanks and Barrow, it will be useful to fly a series of ramped ascents and descents through the atmosphere to sample the vertical and horizontal structure of the cloud and aerosol. Here, we envision porpoising from above the cloud to as close to ground as possible to sample the horizontal and vertical variability (descend at a rate of approximately 5 m s⁻¹). A series of porpoising legs can be flown during the transit legs. In addition, as previously mentioned, these porpoising maneuvers will be flown only if there is sufficient flight time, because porpoising uses a lot of fuel and thereby limits on-station time. These maneuvers may be possible on the return transit to Fairbanks, if time permits.

3.3 Coordinated Flights with Other Aircraft

We will fly coordinated with other aircraft ((NASA P-3B, DC8 and B200, NOAA WP-3D) and fly satellite evaluation legs to answer relevant science questions. In this section, the relevant coordinated flight profiles are listed.

3.3.1 A-train Evaluation Legs

There are several overpasses of the A-train on a leg that roughly passes between Barrow and Fairbanks, with overpass times approximately between 1400 and 1430 local time (Optimal overpass days are April 1, 3, 10, 12, 17, and 19, with April 5, 8, and 21 also representing possibilities). On these legs, the Convair will either fly a straight line leg above, below or within the cloud or a spiral descent over the NSA Barrow site (depending on which product/retrieval is deemed most suitable for evaluation given the cloud conditions) at the time of the overpass. If a straight leg is flown, it would be flown at the same orientation as the overpass line and would be approximately 15 minutes long to get sufficient sampling of clouds/aerosols. The spiral descent/ascent would be at a rate between 2 to 4 m s⁻¹ so that the boundary layer cloud could be sampled in approximately 15 minutes. It is expected that these evaluation legs will be flown in coordination with other aircraft, as outlined in subsequent coordinated profiles.

3.3.2 Comparison of Cloud/Aerosol Data with NOAA WP-3D

These comparisons will be conducted in the vicinity of Barrow or the Beaufort Sea where there are no obstruction hazards or near the base at Fairbanks. Legs will be flown at a constant altitude either inside of the cloud (for cloud microphysics comparisons) or outside of the cloud (for aerosol comparisons). Two waypoints will be identified (preferably in direction parallel to wind, or parallel or perpendicular to the coastline) and the Convair and NOAA WP-3D will alternately fly these way points, with the planes separated by ATC. Once the first aircraft has completed a constant altitude leg, it will ascend to higher altitude after which time the second aircraft will complete the leg at the altitude previously occupied by the first aircraft. This will be repeated for a series of different altitudes. Because of horizontal inhomogeneities in clouds especially and because the different aircraft can never sample the exact same cloud element, the coordination described above should be sufficient to intercompare many aspects of instrument performance (e.g., the impact of shattering producing small crystals, cloud mass and extinction closure, etc.). It is also proposed to perform precision instrument approaches slantwise through cloud layers, for example to Barrow, again separated by ATC.

3.3.3 Comparison of Cloud/Aerosol Data with NASA DC8

We will use similar intercomparisons as outlined in 3.3.2 above. There will be a particular focus on performing these intercomparisons in clouds.

3.3.4 Coordinated Flights Between Convair and B200

We will fly coordinated flights during the A-train overpasses described above with the B200 flying at 28,000 feet, well above the location of the Convair. On other flights in the vicinity of Barrow, the Convair and B200 will coordinate with the Convair and the Barrow flying the same legs (with the same way points) with the B200 at 28,000 feet and the Convair either within, above, or below the cloud. When the Convair is executing spiral ascents/descents over Barrow, the B200 can fly figure 8 flight patterns centered over the location of the spiral ascent/descent. For flights not in the vicinity of Barrow, the Convair and B200 can still fly coordinated, but the Convair will be flying along a single transect towards/from Fairbanks.

3.3.5 Coordinated Flights Between Convair and NASA P-3B

Because the NASA P-3 has instruments for measuring the broadband solar albedo, the infrared irradiance of clouds, and the solar spectral flux radiometer (SSFR) for retrieving optical thickness and effective radius, the coordinated flying between the NASA P-3B and Convair is envisioned to be similar to that described in 3.3.4 where the NASA P-3B is well above the cloud and the Convair either just above the cloud, within the cloud, or below the cloud. In addition, the NASA P-3B also will fly just above the cloud to measure the aerosol optical depth above the cloud and to get the aerosol optical depth between the cloud top and the altitude where the SSFR does its cloud retrieval measurements. When the NASA P-3B is flying just above the cloud and in coordination with the Convair, the Convair will ideally complete its above cloud leg and then when it descends to within the cloud, the NASA P-3B will start its above cloud leg, the separation between aircraft being dictated by air traffic control. Alternatively, the Convair would complete its above cloud leg after the NASA P-3B has finished its just above cloud leg; however, the first scenario is preferable so that the Convair can make its above-cloud measurements before the aerosol inlet is potentially clogged up by supercooled water.

In the event that any coordination is required to intercompare in situ observations, the coordination would follow that outlined in 3.3.2 above.

4. Cloud Mission Profiles

4.1 Identifying Thermodynamical Conditions for Maintaining Mixed-Phase Clouds

Point of Contact: Alexei Korolev

Science Motivation/Hypothesis: The main objective is to study the conditions required for maintaining long-lived mixed-phase clouds. Mixed-phase clouds are considered to be condensationally unstable and are eventually expected to turn into ice-only clouds. However, the observation of long-lived mixed-phase stratiform cloud layers conflicts with this theoretical proposition. Recent theoretical analyses (Korolev and Field 2007) have proposed the necessary and sufficient conditions required for the dynamic forcing, which may result in indefinite maintenance of mixed-phase stratiform cloud layers. The study of the mixed-phase maintenance will be conducted through the measurements of microphysical and thermodynamical properties of mixed-phase long-living cloud layers and deep ice clouds and its following comparisons with the theoretically estimated conditions required to maintain mixed phase.

Measurement Objectives: To address the objective posed above, the microphysical and thermodynamical characterization of the cloud layer should be conducted above, inside, and below the mixed-phase layer. The underneath characterization should be extended a few hundred meters below the cloud base. The mission will require both in situ measurements and airborne remote sensing. The key measurements to meet this objective are:

- In situ microphysics: droplet and ice particle size distributions, ice water content (IWC), liquid water content (LWC), extinction coefficient, onboard radar.
- Thermodynamics: turbulent fluctuations, water vapor, temperature, wind speed and wind direction.

The measurements of vertical turbulent fluctuations are critically important for these measurements. The measurements of turbulence should be conducted along horizontal flight legs.

General Aircraft Flight Profiles:

Option 1 (long-living mixed-phase layer): Typically long-living (more than 2-3 hours) mixed-phase layers are represented by horizontally extended boundary layer *St*, *Sc* or midlevel *As*, *Ac*. After identifying this layer from visual and onboard radar observation, the aircrew initiates along wind straight horizontal legs, 10-15km (2-3min) long, stacked at several altitudes. The first leg is conducted approximately a hundred meters above the cloud top. The following legs should be conducted with vertical steps 50 to 150 meters, depending on the depth of the cloud. The transition from one altitude to another one should be conducted along enroute descent with the vertical speed approximately 3m/s to 5m/s. The last horizontal leg is conducted near the level of sublimation of ice particles, identified from the onboard radar, or if the precipitations fall to the ground, then at the lowest allowed altitude, or no lower than 300 to 600 meters (depending on temperature) below the cloud base of the mixed-phase layer. After the last leg the aircraft performs enroute (preferred) or spiral ascent to the cloud top. The estimated time to accomplish one cycle is 30-45 min depending on the cloud depth.

Option 2 (embedded mixed phase layers): Embedded mixed-phase layers typically occur in deep *Cs-Ns* or *As-Ns* associated with frontal systems. Identifying the embedded mixed-phase clouds from the onboard radar is not always successful. However, they can be easily detected during a vertical sounding. After identifying the mixed-phase layer should proceed with the flight pattern in Option 1. The number of the flight legs below the base of the mixed-phase layer should be limited to five with the vertical step 100 meters. The estimated time to accomplish one cycle is 30-45 min depending on the cloud depth.

Option 3 (ice clouds): After identifying a continuous deep ($\Delta Z > 1\text{km}$) ice cloud from the onboard radar, perform straight legs stacked at 5 altitudes with the vertical step 100 meters. The estimated time to accomplish one cycle: 30min depending on the cloud depth.

It is preferable that these flights be conducted over the ACRF site so that additional measurements of turbulence can be obtained from the ARM cloud radar. This would also be advantageous for evaluating the cloud radar vertical velocity measurements. However, these flight patterns also can be done elsewhere if conditions are appropriate provided horizontal legs of a few minutes long (to get measurements of turbulence) can be made inside and underneath a mixed-phase layer.

Repetitions Necessary:

Ideally 2-3 repetitions for options 1 and 2.

Weather Conditions:

Frontal cloud systems.

Synergy with Other Missions:

- Ground-based remote sensing validation
- Statistical characterization of mixed-phase clouds.

Critical Instruments:

Nevzorov LWC/total water content (TWC) probe, cloud spectrometer impactor (CSI), forward scattering spectrometer probe (FSSP), optical array probe (OAP)-two-dimensional cloud (2DC), OAP-2DP, Rosemount icing detector (RICE), Extinction probe, Licor, Rosemount 858, Ka-band radar.

Flight Profile: See Sections 3.1.3 and 3.2.1.

Reference:

Korolev, AV, and PR Field. 2007. “The effect of dynamics on the formation of mixed phase clouds (theoretical consideration).” *J.Atmos.Sci.*, in press.

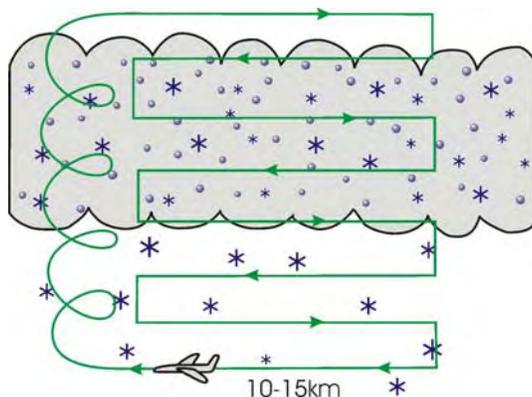


Figure 1. Proposed flight pattern for the Convair-580 to study turbulence and microphysics of mixed-phase clouds.

4.2 Statistical Characterization of Microphysics and Thermodynamics of Mixed-Phase Clouds

Points of Contact: Alexei Korolev, Walter Strapp, Hans Verlinde, and Greg McFarquhar

Science Motivation: Characterize microphysical and thermodynamical properties of mixed-phase clouds. Identify differences in occurrences of mixed-phase clouds in the Arctic (from the present study) and midlatitude clouds (Korolev et al. 2003; Korolev and Isaac 2006). Determine the spatial variability of cloud microphysical properties and vertical velocities, and determine how the variability depends on cloud type and synoptic classification. The main targets are (1) statistical characteristics of the liquid water fraction, (2) statistical characterization of relative humidity, (3) statistical characterization of the extinction coefficient in clouds with the different phase composition, (4) statistical characterization of the total water contents, (5) statistical characterization of the total number of droplets, total number of ice crystals and effective radii of water droplets and ice crystals, (6) statistical characterization of different parameters that describe the shapes of the size distributions, and (7) statistical characterization of vertical velocities. After obtaining these data, there will be an attempt made to relate the spatial variability of the cloud microphysical quantities and vertical velocities to the cloud type and synoptic classification and to determine the evolving role of aerosol in the variability of cloud properties.

Measurement Objectives: Vertical profiles of clouds over the ACRF NSA site as well as clouds encountered during transit flights between Fairbanks and Barrow suits this objective well. In situ microphysics, dynamics, radiation and thermodynamics, particle size distribution, TWC, LWC, IWC, extinction/integrated cross-sectional area, vertical motion, turbulence, and water vapor will be sampled. Radars will operate in side-looking mode to provide horizontal context when acquiring measurements in the vicinity of Barrow.

General Aircraft Flight Profiles:

Option 1 (transit flights): After takeoff, identify from the onboard radar the altitude and boundaries of clouds, if they exist. Conduct enroute repeated ascents and descents through the identified cloud layer. The vertical velocity of the aircraft during profiling should not exceed 5m/s, and horizontal velocity should not be more than 100m/s. If level legs are conducted in the vicinity of Barrow, each leg should ideally be followed by a spiral to document the microphysical properties in the cloud.

Option 2 (vicinity or over the ACRF NSA site): After identifying coordinates and altitude of a cloud from the ground-based and/or onboard radar and/or satellite imagery perform a spiral sounding through the whole cloud layer.

Repetitions Necessary:

Ideally 2 repetitions for options 1 and 2.

Weather Conditions:

Frontal cloud systems.

Synergy with Other Missions:

- Ground-based remote sensing validation
- CloudSat, Cloud Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) validation.

Critical Instruments:

Nevzorov LWC/TWC probe, CSI, King probe, RICE, Extinction probe, Licor, Ka-band radar

Flight Profile: See Sections 3.1.1 and 3.2.1.

References:

Korolev, AV, GA Isaac, S Cober, JW Strapp, and J Hallett. 2003. "Microphysical characterization of mixed-phase clouds." *Q. J. Roy. Meteor. Soc.*, **129**, 39-66.

Korolev, AV, and GA Isaac. 2006. "Relative humidity in liquid, mixed phase and ice clouds." *J.Atmos.Sci.*, **63**, 2865-2880.

4.3 Ground-based Remote Sensing Validation

Points of Contact: Greg McFarquhar, Hans Verlinde and Steve Ghan

Science Motivation/Hypothesis: Evaluate/verify/intercompare the retrieval of vertical profiles of cloud microphysical properties from ground-based remote sensors with direct in situ measurements of the retrieved quantities. The primary goal of this mission objective is to assess the uncertainty of cloud properties derived from retrieval algorithms (microphysics and radiative) from ground-based remote sensors including the broadband heating rate profile (BBHRP) algorithms. Other objectives include the development of empirical relationships (i.e., mass- and area-dimensional relationships in cirrus) that are needed in these algorithms and to characterize the spatial variability of cloud microphysical quantities.

Measurement Objectives: Profiles of in situ microphysics measurements of ice crystal and liquid size and shape distributions, and bulk measurements such as ice water content, liquid water content, total water content, integrated cross-sectional area and extinction in the vicinity of the ground site are needed. Profiles of radiation, thermodynamics, vertical motion, turbulence, water vapor and radiation also required. These in situ measurements are required over the ACRF site, although occasional porpoising legs along CloudSat legs will meet satellite remote sensing requirements. Remotely sensed radar reflectivity and Doppler velocity (if available), lidar backscatter, upwelling and/or downwelling radiative quantities such as flux and narrowband measurements are required in vicinity of the ground site.

General Aircraft Flight Profiles:

In situ aircraft will spiral up/down over Barrow (Eulerian) and then fly a series of level legs (approximately 50 km) centered at the location of the ground site where the legs would be made at the cloud top, and then descend into 3 or 4 more levels with legs either with/against ambient wind (exact locations and levels should include mid-cloud and near base, but exact altitudes chosen depending on clouds observed on particular day); following stair-step pattern, in situ aircraft will fly 3-4 Eulerian spirals to determine how much cloud properties over the ground site are changing with time.

Repetitions Necessary:

Need at least two flights specifically dedicated to this objective where three to four spirals and at least one stepped profile is executed during each flight.

Weather Conditions:

Ideally we want to sample clouds with a variety of structures and phases (including single-layer boundary layer clouds and clouds occurring in multiple layers, especially those with mixed-phases). Ideally this flight plan will be done in clouds without a complex horizontal structure so that it is easier to relate the in situ observations to the radar observations by considering advection terms. For clouds with a complex horizontal structure, the observations are still useful because it contributes to the development of a statistical database for comparing in situ observations with remote sensing retrievals and does not bias the statistics of such comparisons to cases with simpler horizontal structures.

Synergy with Other Missions:

- Small particles
- Instrument Intercomparison.

Critical Instruments:

Cloud aerosol precipitation spectrometer (CAPS), CVI, cloud particle imager (CPI), FSSP-100, 2DC, 2DP, 2DS, Extinctionmeter, cloud droplet probe (CDP), (convection inhibition [CIN]).

4.4 Remote Sensing Validation – CloudSat and CALIPSO

Points of Contact: Walter Strapp, Alexei Korolev, David Hudak, Howard Barker, and Peter Liu

Experimental Objective: Compare measurements from Convair cloud and aerosol in situ and remote sensing instrumentation to CloudSat and CALIPSO

Science Motivation/Hypothesis: In the spring of 2006, the CloudSat W-band radar and the CALIPSO lidar were launched into space to join an existing train of satellites with an array of instruments designed to make global measurements of the atmosphere, including clouds and aerosols. The remote sensing and in situ instruments on the Convair-580 aircraft are highly suited for making validation measurements of the satellite mounted CloudSat W-band radar and CALIPSO lidar. Data products provided by the CloudSat and CALIPSO satellites include profiles of liquid water and ice water, cloud base and cloud top, and effective radius of particles. Several airborne measurement programs have already been performed to compare to CloudSat and CALIPSO data products, including a study of winter clouds in the winter of 2006/2007 in Ontario using the Convair-580 aircraft. The ISDAC offers a unique opportunity to extend this effort in arctic clouds and aerosol layers.

Measurement Objective: The CloudSat and CALIPSO satellite will pass over the Alaska area several times per week, providing vertical cross sections of radar reflectivity at 94 GHz, and lidar backscatter ratios at two wavelengths. Several data products are provided by the CloudSat/CALIPSO data processing group. The Convair-580 has the opportunity to validate the gross features of the CloudSat W-band radar using its own more sensitive W-band/X-band radar, and its Ka-band radar. Perhaps more importantly, it possesses sophisticated instrumentation such as bulk LWC, IWC, and TWC measurements, and particle spectrometers, to validate CloudSat and CALIPSO algorithms describing the properties of clouds and aerosol layers.

Flight Profiles:

The ISDAC flight programs will include routine 1.75-hour transit flights back and forth between Barrow and Fairbanks. If properly timed, these transit flights can be used to make valuable validation measurements for CloudSat. Two simple flight patterns are suggested. In the first case (Type 1), there will be a minimum impact on ISDAC other than the coordination of transit flight time and some additional transit time in order to transit to the CloudSat flight track. In the second case, a one-hour addition to the transit is used to study a feature along the line.

Type 1: Transit between Fairbanks and Barrow will be timed so that a the Convair-580 aircraft can pick up the CloudSat track shortly after takeoff, and run an appropriate length of the track between Barrow and Fairbanks coincident at some point with the overpass of the satellite. This would be a direct transit down the line with no reversal of course. Depending on the cloud conditions, the aircraft may on some occasions fly above or below the cloud to get good remote sensing comparisons or, on other occasions, fly in the cloud to get in situ validation data. The aircraft may porpoise through the cloud layer depth to

get validation of vertical profiles, or occasionally remain near the cloud top to get validation of effective radius measurements. The flight director likely would make this decision based on pre-flight guidance, and on real-time measurements taken onboard the aircraft. The same flight plan could be done without clouds to measure aerosol layers for comparison to CALIPSO. This flight plan would add approximately 0.5 hours to the standard Fairbanks-Barrow transit.

Type II: The Convair-580 aircraft would again pick up the CloudSat track shortly after takeoff. In this case, an interesting cloud feature along the line with a scale size of about 40 nmiles would be identified by pre-flight weather guidance, and the takeoff time would be chosen so as to be at that location on the CloudSat track approximately 30 minutes before the overpass. The aircraft would then probe this 40 nmile section of the track for 30 minutes prior to until 30 minutes after the overpass, performing in situ profiles and down-the-track legs. Some adjustment of the aircraft track may be performed to account for cloud translation. This flight plan would add approximately 1-1.75 hours to the standard Fairbanks-Barrow transit.

Repetitions Necessary:

As often as the ISDAC PIs can accommodate. This is an opportunity to take advantage of flight time that may not otherwise provide any scientific value.

Weather Conditions:

Ideally, moderately shallow (1-2 km) liquid, mixed-phase or glaciated cloud layers, with both sub-Cloudsat and above-CloudSat minimum detectable reflectivity (-28 dBZ), and with cloud bases higher than the minimum IFR enroute altitude. In the case of CALIPSO validation, mid-level cirrus layers, and visible pollution layers would be most interesting. Relatively stratiform cloud or aerosol layers would be preferable to highly variable layers.

4.5 Instrumentation Studies

Points of Contact: Walter Strapp, Alexei Korolev, and Greg McFarquhar

Experimental Objective: To improve our understanding of cloud measurement accuracy using measurements during transit flights.

Science Motivation/Hypothesis: Many of the science questions we seek to address with ISDAC data are dependent on knowledge of the bulk and size-resolved cloud properties measured with in situ aircraft probes. In spite of new advances in instrumentation over the past decade, many of the same problems plaguing older instrumentation remain, and new problems continue to be discovered. Furthermore, the uncertainty, precision, and statistical representativeness of these measurements are substantial and difficult to establish. Whereas many old instruments have been characterized extensively and weaknesses documented, the performance of many new instruments has not had the benefit of similar characterization and documentation. Some of these problems, such as the accuracy of small ice particle measurements and the accurate separation of liquid and ice particles in mixed-phase clouds, limit our ability to make progress on fundamental issues dependent on knowledge of cloud microphysical properties. Thus, it is highly desirable that data be acquired in a variety of cloud conditions so that the performance and derived

quantities of a variety of probes can be tested. In this way, it is hoped that some uncertainties and better understanding of the measurements used to answer the other science questions will be obtained.

Measurement Objective: The Convair-580 aircraft will carry a complement of both well-characterized older technology instruments, and lesser characterized newer instruments with presumed superior performance in some areas. Some instruments will be modified specifically to mitigate certain problems such as shattering of ice particles and contamination of measurements by subsequent measurement of shatter debris. A variety of hot wire probes and a counterflow virtual impactor will all measure cloud total water content, providing an array of measurements to provide comparative performance data. A variety of small particle imaging probes will provide the same type of comparative performance data to assess the improvements provided by the newer technologies, thereby helping to provide information on the accuracy of past measurements with older probes.

Most ISDAC flights will provide a certain amount of instrument comparison data. However, the specific science objectives of the missions may not offer the flexibility for optimum flight patterns for instrument studies. In this mission, it is proposed to take advantage of uncommitted portions of transit flights between Barrow and Fairbanks to do instrument-specific performance studies.

The primary goal of this experiment is to intercompare size-resolved concentrations and bulk moments of the size distributions (e.g., ice and water mass contents) measured by a variety of probes on the aircraft. The specific science questions we seek to address with this objective are

1. How do measurements of concentrations of small ice crystals (with maximum dimensions less than 100 μm) vary between different probes in a range of conditions (can we fly at a range of true air speeds)?
2. What is the impact of shattering on tubes of some of the in situ particle samplers and how does this vary with varying conditions and true air speed?
3. How much do concentrations/mass contents vary between probes operating in similar size ranges (especially as a function of phase of the cloud)?

Flight Profiles:

The objective would be to use uncommitted portions of transit flights between Fairbanks and Barrow to perform instrument performance testing. The onboard radar can be used to identify interesting cloud layers to perform such testing, or alternatively onboard observers may identify interesting cloud layers by eye. The aircraft would be directed to perform appropriate maneuvers for the specific instrument tests (e.g., porpoises through cloud depths or straight and level runs through cloud, speed runs, pitch and yaw excursions etc.). If time permits, and if particularly favorable cloud conditions are encountered for such performance testing, the direct transit may be interrupted to linger in the area to prolong the testing before resuming direct transit to the destination. Ideally these flights also will be flown in conjunction with ground-site measurements or satellite overpasses to allow further comparison with retrieval products.

Repetitions Necessary:

As often as the ISDAC Pis can accommodate. The intercomparisons between Fairbanks and Barrow represent an opportunity to take advantage of flight time that may not otherwise provide any scientific value.

Weather Conditions:

Currently, this is being proposed mainly for cloud studies. For each instrument sub-experiment, suitable weather conditions may vary. It is likely that a series of sub-experiments could be devised that would make use of almost any cloud conditions. Similar experiments should be designed for aerosol instrumentation. Several (>2) reasonable events should be observed during the experiment. In particular, we should try to repeat measurements in clouds with varying extinction coefficients, with varying phases and with varying structures (e.g., single-layer versus multi-layer clouds); two different altitudes should be sampled for each event.

Synergy with Other Missions:

- Ground-based validation
- Small particle measurements
- A-Train algorithm validation.

Critical Instruments:

FSSPs, CDP, CAPS, CSI, Nevzorov LWC/TWC, Water Vapor, CPI, , 2D-S, particle measuring system (PMS) 2D probes, Korolev extinction probe, CIN.

4.6 Small Particles in Mixed-Phase and Ice Clouds

Points of Contact: Greg McFarquhar, Alexei Korolev, and Walter Strapp

Science Motivation/Hypothesis: The number concentrations of small ice crystals, with maximum dimensions less than approximately 100 μm , in mixed-phase clouds and in ice clouds, are very poorly known because conventional in situ microphysical probes do not measure well these small crystals at typical aircraft speeds. Past studies have reached contradictory conclusions on the importance of these small crystals to total number concentration, projected area, extinction and mass of clouds. This is one of the key unknown questions in cloud microphysics. These small crystals have unknown effects on microphysical properties, such as ice crystal effective radius and mass-weighted fall speeds, and on radiation and hence are represented poorly in parameterizations for large-scale models. Assumptions in some ground-based and satellite retrievals also rely on assumptions about typical numbers of small ice crystals that have not been well validated. The primary objective of this mission is to characterize the number of small particles (maximum dimensions less than approximately 100 μm) that occur in mixed-phase and ice-phase clouds and to determine whether or not past measurements of high small ice crystal concentrations are instrument related (e.g., it has been hypothesized that artificially high concentrations of small crystals may be associated with shattering of large ice crystals on some probe tips). As a secondary objective, it will be examined if the role of small ice crystals is related to the location of the measurements (altitude, phase, liquid water fraction, temperature, humidity, etc.).

Measurement Objective: To address the role of small ice crystals in microphysical and radiative properties, it is important to acquire in situ measurements of ice crystal size distributions covering the complete range of possible particle sizes, measurements of bulk properties of the size distribution (e.g., mass content, extinction/integrated cross-sectional area) obtained independently from measurements of

the size distributions and preferably coincident retrievals of these bulk quantities from ground-based or satellite instruments. Observations should be obtained in ice-, mixed- and even liquid-phase clouds to test the performance of the probes. The key measurements needed to meet this objective are:

- In situ measurements of particle-size distributions covering the complete range of possible ice crystal sizes (CDP, CAS, FSSP, 2DS, 2DC, 2DP)
- Measurements from forward scattering probes both with and without protruding inlets and shrouds (CDP, CAS and FSSP)
- High-resolution images of ice crystals to help identify particle habits (CPI, CAPS, 2DC, 2DP), information helpful for deriving estimates of total mass content and bulk extinction optical depth from the in situ size distributions
- In situ measurements of extinction optical depth derived from extinction meter
- In situ measurements of total mass content derived from CVI probe
- Remotely sensed extinction optical depth from lidar backscatter (either airborne or ground-based) and if possible, upwelling and/or downwelling radiative quantities such as flux and narrowband measurements
- Flown in conjunction with Terra and/or Aqua MODIS, if possible, for additional comparisons with satellite retrievals or in conjunction with measurements made at the ground-based sites.

General Aircraft Flight Profiles:

In situ aircraft (Convair) flies either level legs, porpoises, or spirals to obtain good data base in variety of conditions from all the probes coordinated lidar backscatter measurements from NSA.

If lidar from ground-based site used for lidar backscatter, an approximately 5- to 10-minute leg (60-100 km) should be flown with/against ambient wind over ground-based site; altitudes of cirrus can be radioed to Proteus pilot to help select the flight altitudes especially if thin cirrus layer present:

- If coordination with Terra/Aqua possible, two end-points for run selected such that flight leg is flown parallel to overpass of satellite and 10 to 15 minute leg will be flown in this orientation
- Observations in variety of phases (liquid-, mixed- and ice-) required throughout the campaign.

Repetitions Necessary:

- Several repetitions (10 to 20 representative samples) should be made because this is a crucial question in cloud and radiation physics, comparisons made with ground-based lidar.
- Range of phases and cloud conditions should be sampled.
- Observations can be acquired as component of other missions.

Weather Conditions:

- Ideal situation would be uniform thin cirrus in a single layer.
- Both thin and thick cirrus layers should be sampled.

Synergy with Other Missions:

- Ground-based validation
- A-Train algorithm validation
- In situ probe intercomparison.

Critical Instrumentation:

CAPS, CVI, CPI, FSSP-100, 2DC, 2DP, 2DS, Extinction meter, CDP, (CIN).

4.7 Spatial Scale of Mixed-Phase Cloud Variability

Point of Contact: Greg McFarquhar

Science Motivation/Hypothesis: Many past studies have suggested that mixed-phase clouds consist of a clustering of phases, whereby there are packets of liquid and ice that appear with very small spatial scales between them. Although the existence of such clusters has been established, the nature of the mixing between the clusters or the spatial scales of the clusters have not been well established.

Measurement Objective: To address the spatial scales of these clusters and the nature of the mixing between water and ice in mixed-phase clouds, it is important to fly horizontal legs in mixed-phase clouds at a variety of altitudes. Further, it is needed to make these observations in both multi-layer and single-layer clouds to determine the degree to which seeding from upper layers affect the mixing of phases in the lower layer clouds. The key measurements needed to meet this objective are:

- In situ measurements of particle size distributions covering the complete range of possible ice crystal sizes (CDP, CAS, FSSP, 2DS, 2DC, 2DP)
- Measurements from forward scattering probes both with and without protruding inlets and shrouds (CDP, CAS and FSSP)
- High-resolution images of ice crystals to help identify particle habits (CPI, CAPS, 2DC, 2DP), information helpful for deriving estimates of total mass content and bulk extinction optical depth from the in situ size distributions
- In situ measurements of extinction optical depth derived from extinction meter
- In situ measurements of total mass content derived from cloud spectrometer and impactor (CVI) probe.

The frequency of the measurements required for this objective would be approximately 10 Hz for the synchronous probes.

General Aircraft Flight Profiles:

- In situ aircraft (Convair) flies level legs in a variety of conditions with mixed-phase clouds to characterize the clustering, spatial scaling and mixture of the phases.

- Ideally, some of the horizontal legs should be flown perpendicular to the coastline (e.g., 50 km) to determine what the gradient of cloud properties along the coastline is. (Mixed-Phase Arctic Experiment [MPACE] observations and modeling studies have suggested that this is an important factor to consider, especially when the ice moves away from the coastline later in the spring.)
- Flights should also be conducted in both cross-wind and along-wind directions.
- If coordination with Terra/Aqua possible, two end-points for run selected such that flight leg is flown parallel to overpass of satellite and 10- to 15-minute leg will be flown in this orientation.
- Observations in variety of phases (liquid-, mixed- and ice-) are required throughout the campaign.

Repetitions Necessary:

- Several repetitions (10 to 20 representative samples) should be made to try and better understand this spatial scaling.
- Range of phases and cloud conditions sampled.
- Observations can be acquired as component of other missions.

Weather Conditions:

- Ideal situation would be mixed-phase clouds, both occurring in a vertically continuous layer and in multiple layers.
- Sample at a variety of altitudes and layers within the clouds.

Synergy with Other Missions:

- Ground-based validation
- A-Train algorithm validation
- In situ probe intercomparison.

Critical Instrumentation:

CAPS, CVI, CPI, FSSP-100, 2DC, 2DP, 2DS, Extinction meter, CDP, (CIN).

4.8 Cloud Extinction Closure.

Points of Contact: Greg McFarquhar and Alexei Korolev

Science Motivation: Cloud extinction closure consists of comparing the measured cloud extinction with that calculated from Mie or other theories using the measured size distribution of cloud particle number and shape. This provides a test of Mie and other theories for warm, ice, and mixed-phase conditions. Cloud extinction closure rarely has been achieved.

Measurement Objective: Sample the cloud in stratified layers known to be warm, ice, or mixed-phase. Critical measurements include cloud extinction, cloud particle size distribution 0.5-5000 microns, cloud particle shape 100-1000 microns. Perform separate closure for warm, ice, and mixed-phase conditions.

General Aircraft Flight Profiles: See Sections 3.1.1, 3.1.4, 3.1.5, 3.2.1, and 3.2.3.
Horizontal track or spirals through multiple levels of cloud for 5-10 minutes each.

Repetitions Necessary: 3.

Weather Conditions:
Stratiform cloud is preferred.

Synergy with Other Flight Objectives:
Can be combined with cloud modeling and with ice nucleation objectives. Strong connection with cloud water closure.

Critical Instrumentation:
CAPS-CAS, CAPS-CIP, 2DS, 2DP, CIN, 2DC, extinction meter.

4.9 Cloud Water Closure.

Points of Contact: Greg McFarquhar, Alexei Korolev, and Walter Strapp

Science Motivation: Cloud water closure consists of comparing the measured bulk cloud water with the cloud water calculated from the integration over the measured cloud particle size distribution. This provides an important check on our cloud particle and bulk measurements.

Measurement Objective: Sample the cloud in stratified layers known to be warm, ice, or mixed-phase. Critical measurements include total water content, cloud particle size distribution 0.5-5000 microns, cloud particle shape 100-1000 microns. Perform separate closure for warm, ice, and mixed-phase conditions.

General Aircraft Flight Profiles:
Horizontal track through multiple levels of cloud for 5-10 minutes each.

Repetitions Necessary: 3.

Weather Conditions:
Stratiform cloud is preferred.

Synergy with Other Flight Objectives:
Can be combined with cloud modeling and with ice nucleation objectives. Strong connection with cloud extinction closure.

Critical Instrumentation:
CAPS-CAS, CDP, FSSPs, CAPS-CIP, 2DS, 2D2-C, 2DP, CVI, Nevzorov LWC/TWC, PMS King.

4.10 Scale Dependency of Ice Crystal Number Concentration for Cloud-Climate Modeling Applications: Emphasis on Dynamics

Points of Contact: Ismail Gultepe, Eric Girard, George Isaac, and Peter Liu

Science Motivation: Earlier work by Gultepe et al (2001) suggested that small particle concentration is important to obtain various physical/dynamical parameterizations and to understand relationships between Ni and dynamical/thermodynamical parameters (e.g., vertical air motion, Rhi, and T). Without the knowledge of small Ni, e.g., particles size less than 100 micron, earlier parameterizations used in literature become not applicable for climate/cloud studies. Development of scale-dependent Ni parameterizations is needed for applications related to various cloud systems.

Measurement Objectives: Aircraft flight patterns should represent various meteorological events from a few hundred meters up to 100 km. To obtain statistically significant microphysical parameters, constant flight legs should not be less than 30 km (5 min duration). Flights should be done at various T and RH levels, and specifically for $T < -20\text{C}$ within the cloud.

General Aircraft Flight Profiles

- Constant altitude level flights over 30 to 50 km length stack up within the cloud. At least 4 legs within the cloud; 1 close to base within the cloud, 1-2 within the cloud, 1 close to cloud top.
- Eulerian spirals over the Barrow site for vertical variability in the related parameters. In ideal case, before and after the constant flight legs.
- Clear air segments (30-50 km) above, below, and around the cloud system if it is possible.
- If an ice fog forms over the NSA site, lowest flight levels or missed-approach flight patterns will be useful for intercomparisons. In this case, a few flight legs at the lowest level (300 feet) are considered to be important.

Synergy with Other Missions: Small particles, scale effects, Ni parameterizations.

Weather conditions: boundary layer (BL) clouds, ice clouds, clouds over ocean and land, shear/turbulent environments.

Critical Instruments: (DMT) CVI, FSSP-100, FSSP-300, 2DC, 2DS, CIP, extinction meter, passive cavity aerosol spectrometer probe (PCASP), relative humidity (RH), T, and Rosemount radom probe wind measurements.

Reference

Gulpepe, I, GA Isaac, and SG Cober. 2001. "Ice crystal number concentration versus temperature." *Int. J. Climatology.*, **21**, 1281-1302.

4.11 Cloud Cover Parameterizations

Points of Contact: Ismail Gulpepe, George Isaac, and Eric Girard

Science Motivation: Cloud cover parameterizations include large uncertainties; 1% change in cloud cover can balance greenhouse warming effect. With new data sets, we will analyze the Ni, TWC, IWC, and Nd for various thermodynamical conditions and develop a cloud cover parameterization for modeling applications.

Measurement Objectives: Longer flight legs are better for cloud cover (Cr) parameterization. For this reason, various cloud microphysical parameters will be included from the flight legs. Measurements from the transit flights can be very applicable for parameterization development.

General Aircraft Flight Profiles

Overall, longer constant flight legs during the project are suggested for data collection. There are no specific criteria to fly into the clouds.

Synergy with Other Missions: Small particles, scale effects, cloud cover, IWC and TWC.

Weather Conditions:

Mixes of various cloud types are needed for the analysis. Flights should not be done always for a specific cloud type.

Critical instruments:

Nevezorov probes, FSSP-100, FSSP-300, 2DC, 2DP, 2DS, CIP, extinction meter, RH, T.

4.12 Ice Fog Microphysics and Extinction: Emphasis for In Situ Validations

Point of contact: Ismail Gultepe, Peter Liu, Eric Girard, and George Isaac

Science Motivation: Ice fog microphysical and extinction measurements are important for various applications: 1) cloud-climate studies, 2) aviation applications, 3) nucleation, and 3) validation of aircraft in situ based measurements and analyzing the results. Ice fog is a cloud at the surface with no main dynamical disturbance. For this reason, various measurements at the surface will be used for parameterization development and in situ validation.

Measurement Objectives: Measurements at the surface will be done by the various instruments for ice particles and extinction measurements, and also at the higher levels (e.g. 300 m) by aircraft in situ instruments. At the surface, measurements will be continuous during the entire month of April. If aircraft flies into higher levels of ice fog, measurements can be tested against each other.

General Aircraft Flight Profiles

- Flight segments (5-30 km) below the fog top height (~200 m), and around the fog system, if possible.
- If an ice fog forms over the NSA site, the lowest flight levels or missed-approach flight patterns (as low as possible) will be useful for intercomparisons. In this case, a few flight legs at the lowest level (300 feet) are considered to be very important.

Synergy with Other Missions: Visibility, extinction, small particles, nucleation, Ni parameterizations.

Weather Conditions: BL ice clouds, high-level ice clouds, clouds over ocean and land.

Critical Instruments: DMT CVI, FSSP-100, FSSP-300, 2DC, 2DDS, CIP, extinction meter, RH, T, and Rosemount radom probe wind measurements, ultra-high sensitivity aerosol spectrometer (UHSAS) PCASP, single particle laser ablation time-of-flight (SPLAT) mass spectrometer, continuous flow

diffusion chamber (CFDC), aerodyne mass spectrometer (AMS) and various precipitation, extinction, and ice microphysical measurements.

5. Aerosol or Aerosol-Cloud Science Objectives

5.1 CCN Closure

Points of Contact: Steve Ghan, Don Collins, and Peter Liu

Science Motivation: CCN closure consists of comparing the measured CCN concentration with the concentration calculated from the Kohler theory using measurements of size distributions of the aerosol number and either composition or hygroscopicity. This comparison provides a test of the Kohler theory and of our ability to measure CCN. CCN closure has been achieved only recently due to advances in aerosol measurement technology, but has never been achieved in the Arctic. The relatively polluted conditions expected during April above Barrow suggests that CCN closure can be achieved. This experiment is compromised by the absence of a differential mobility analyzer (DMA) or humidified tandem differential mobility analyzer (HTDMA) on the aircraft. These instruments are on the ground, which provides size and hygroscopicity measurements below clouds under all conditions except fog, but not necessarily near the cloud base and within 500 m of the aircraft measurements only for missed approaches.

Measurement Objectives: Sample the aerosol in stratified layers below cloud layers. Critical measurements include CCN at a single supersaturation (0.2%), size distribution of aerosol number (100-1000 nm), and hygroscopicity (50-500 nm).

General Aircraft Flight Profiles: See Sections 3.1.3, 3.1.4, and 3.2.2. Long horizontal tracks through homogenous aerosol layers below clouds with 10 minutes sampling time.

Repetitions Necessary: 3.

Weather Conditions: Cloud-free layers.

Synergy with Other Flight Objectives: Can be combined with any objective requiring hygroscopicity measurements below clouds, such as droplet number closure or cloud modeling.

Critical Instrumentation: CCN, DMA, HTDMA, PCASP.

5.2 Droplet Number Closure

Points of Contact: Steve Ghan and Hans Verlinde

To what extent do measurements at the surface of aerosol number concentrations, size distribution, and cloud-nucleating properties represent the properties of particles entering clouds at the cloud base, and how does the measured cloud droplet concentration (size resolved) at the base of the (liquid) cloud correspond to the aerosol distributions? What is the response of the effective radius to environmental aerosol loading for warm clouds in the Arctic?

Droplet number closure consists of comparing the measured droplet number with that estimated from dynamic Kohler theory using measured updraft velocity and size distributions of measured aerosol number and hygroscopicity. This comparison provides a test of our understanding of the droplet nucleation process. Closure has been achieved only recently due to improvements in aerosol measurement technology, and has never been achieved in the Arctic. Closure will be challenging for ISDAC because of the weak updrafts expected in the stratified clouds.

Measurement Objective: Sample the aerosol in stratified layers below the clouds. Sample droplet number and updraft velocity in lower part of the cloud. Critical measurements include size distribution of aerosol number (50-1000 nm) and hygroscopicity (50-500 nm), droplet number and updraft velocity. Aerosol characterization, including total aerosol number concentration, cloud condensation, and ice nucleus concentrations. Vertical air motion, turbulence, and water vapor. Below and above cloud layers. During these flight legs radars will look alternatively up/down into the cloud layer.

General Aircraft Flight Profiles: See Sections 3.1.3 and 3.2.2.

Long horizontal tracks through homogenous aerosol layers below clouds with at least 10 minutes sampling time followed by either a horizontal track just above cloud base or a spiral to document the microphysical properties in the cloud.

Repetitions Necessary: 3.

Weather Conditions: Stratocumulus is preferred for stronger updrafts.

Synergy with Other Flight Objectives: Can be combined with cloud modeling objective.

Critical Instrumentation: DMA, HTDMA, PCASP, gust probe, CAPS-CAS.

5.3 Cloud Modeling

Points of Contact: Steve Ghan and Ann Fridlind

Science Motivation: Cloud modeling consists of comparing measured clouds with clouds simulated by a numerical cloud model using measured aerosol and boundary conditions. This is the ultimate test of our understanding of clouds and their sensitivity to aerosols because it allows the clouds and circulation to respond to the aerosol. A variety of numerical experiments are needed to isolate differences between clouds during ISDAC and M-PACE because of differences in aerosol and boundary conditions.

Measurement Objective: Critical measurements include downward longwave at a level above all clouds of interest, precipitation at the surface, and vertical profiles of cloud particle size distribution (0.5-5000 micron), liquid water content, ice water content, and cloud extinction, size distribution of aerosol number (10-3000 nm) and hygroscopicity (50-500 nm) below the cloud, $IN(T,S_i)$. Also needed are vertical profiles of u,v , T , q and their horizontal advective tendency, surface temperature, and surface fluxes of sensible and latent heat; these can come from European Centre for Medium-Range Weather Forecasts (ECMWF) analyses.

General Aircraft Flight Profiles: If possible, a 10-minute horizontal leg below the cloud; if not, a 1-minute sample on a missed approach to the Barrow airport to get CCN concentration at one supersaturation. Follow this with 1-minute horizontal legs between and above cloud layers, then descend in vertical spirals above Barrow to sample clouds.

Repetitions Necessary: 10.

Weather Conditions: Any type of cloud with top below 3 km.

Synergy with Other Flight Objectives:

Strong connection to semi-direct objective. Most closure studies can be performed along with this experiment.

Critical Instrumentation: PCASP, HTDMA, CCN, CFDC, pyrgeometer, CSI, Nevzorov, King probe, CAPS-CAS, CAPS-CIP, 2DS, 2DP, cloud extinction probe.

5.4 Semi-Direct Effect

Points of Contact: Steve Ghan and Ann Fridlind

Science Motivation: An additional mechanism for aerosol effects on clouds is through the radiative heating produced by absorption of sunlight. Although the sun is near the horizon at Barrow in April, it may shine long enough to produce a significant semi-direct impact on the energy balance by heating the air sufficiently to burn off clouds. This experiment is an extension of the cloud modeling experiment, adding the radiative heating by the aerosol.

Measurement Objective: Measure vertical profiles of absorption by aerosol at visible wavelengths.

General Aircraft Flight Profiles: Vertical spirals through clear air if possible.

Repetitions Necessary: 10.

Weather Conditions: All cloud types with tops below 3 km.

Synergy with other Flight Objectives: Strong connection to cloud modeling experiment.

Critical Instrumentation: As needed for cloud modeling, plus PSAP and photoacoustic.

5.5 Ice Crystal Nucleation

Point of Contact: Sarah Brooks

Science Motivation: Much is unknown about the composition and size of ice nuclei, particularly in the Arctic. IN concentrations were measured during M-PACE, and were found to be rarely at detectable levels. Although we expect higher aerosol mass concentrations during ISDAC, we don't know if IN

concentrations will be higher. If they are, we need to know why. This experiment will determine the composition of the ice nuclei by examining the residual aerosol behind a CVI.

Measurement Objective: Given the much larger number concentrations of CCN versus IN, it is important to be sure that cloud water does not “contaminate” the ice crystals we wish to sample. Conditionally sample clouds dominated by ice by using measured total water and liquid water to identify ice clouds and icing probes to identify supercooled water. Sample aerosol behind CVI, using single particle mass spectrometer (SPLAT), aerosol mass spectrometer (AMS), and single particle soot photometer (SP2).

General Aircraft Flight Profiles: Horizontal legs through stratified ice clouds.

Repetitions Necessary: 10.

Weather Conditions: Stratiform completely glaciated cloud layers.

Synergy with Other Flight Objectives: Can be combined with cloud closure experiments. Strong connection to next experiment.

Critical Instrumentation: RICE, Nevzorov, CVI, SPLAT, AMS, SP2.

5.6 Relation Between IN and Ice Crystal Concentration

Point of Contact: Greg McFarquhar

Science Motivation: M-PACE has shown that ice crystal number concentrations can far exceed the measured IN concentrations for measured temperature and supersaturations. However, the IN concentrations were near the detection limit for the CFDC. If IN concentrations are higher during ISDAC, the relationship could be examined with more confidence. Secondary production of ice crystals is expected to be less important for ISDAC than it was for M-PACE, so we expect better agreement between IN and N_i measurements for ISDAC.

Measurement Objective: Measurements of T, S_i , IN(T, S_i) below and above ice clouds, crystal number within stratified ice clouds.

General Aircraft Flight Profiles: Horizontal legs of 15 minutes below, above, and lastly within ice clouds.

Repetitions Necessary: 10.

Weather Conditions: Stratiform ice clouds.

Synergy with other Flight Objectives: Strong connection to previous experiment.

Critical Instrumentation: Rosemont, LICOR, CFDC, SPEC CPI, CAPS-CAS, CAPS-CIP, 2DS, 2DP.

5.7 Aerosol Extinction Retrieval

Points of Contact: Steve Ghan and Connor Flynn

Science Motivation: Evaluate the conditions in which the micropulse lidar (MPL) retrieval of aerosol extinction works and when it does not.

Measurement Objective: Vertical profiles of measured aerosol scattering and absorption in clear air.

General Aircraft Flight Profiles: Vertical spirals directly over ACRF site.

Repetitions Necessary: 5.

Weather Conditions: Clear column over ACRF site.

Synergy with Other Flight Objectives: Strong connection to CCN retrieval.

Critical Instrumentation: Nephelometer, PSAP, photoacoustic.

5.8 CCN Retrieval

Point of Contact: Steve Ghan

Science Motivation: Evaluate the conditions in which the surface-based retrieval of CCN (Ghan and Collins, 2004; Ghan et al., 2006) works and when it does not.

Measurement Objective: Measurements of CCN concentration and aerosol size distribution at multiple levels above the ACRF site.

General Aircraft Flight Profiles: Stacked horizontal legs of 1 minute each over the ACRF site.

Repetitions Necessary: 5.

Weather Conditions: clear above ACRF site.

Synergy with Other Flight Objectives: Strong connection to extinction retrieval.

Critical Instrumentation: CCN, DMA, PCASP, HTDMA.

References:

Ghan, SJ, and DR Collins. 2004. "Use of in situ data to test a Raman lidar-based cloud condensation nuclei remote sensing method." *J. Atmos. & Ocean. Technol.*, **21**: 387-394.

Ghan, S, TA Rissman, R Elleman, RA Ferrare, DD Turner, C Flynn, J Wang, J Ogren, J Hudson, H Jonsson, T VanReken, RC Flagan, and JH Seinfeld. 2006. "Use of in situ cloud condensation nuclei, extinction, and aerosol size distribution measurements to test a method for retrieving cloud condensation nuclei profiles from surface measurements." *Journal of Geophysical Research.*, **111**.

5.9 Ice Crystal Nucleation Parameterizations and Dehydration Processes

Points of contact: Ismail Gultepe, Peter Liu, Eric Girard, George Isaac

Science Motivation: Ice crystal number concentrations versus ice nuclei and total aerosol number concentrations will be analyzed and parameterized, if a relationship exists. There are different processes for ice nucleation (e.g. homogeneous and heterogeneous nucleation processes). Various in situ aerosol measurements (SPLAT, AMS and SP-2) can help us better understand both refractory and non-refractory characteristics of ice nuclei. These results will be used in the Canadian Global Environmental Multiscale (GEM) model to study semi-direct effect and indirect effect of aerosols.

Measurement objectives: This will be specifically for ice cloud conditions, representing various cloud systems. Measurements need to be done both within and outside of the cloud at various T and RH conditions.

General Aircraft Flight Profiles:

- Constant altitude level flights over 50 km length stack up (separated at 300 m at least) within the cloud. At least 4 legs within the cloud; and 1 close to base within the cloud, 1-2 within the cloud, 1 close to the cloud top.
- Lagrangian Spirals in clear air and within the cloud.
- In ideal case, before and after the constant flight legs.
- Clear air segments (30-50 km) above, below, and around the cloud system if it is possible.
- If an ice fog forms over the NSA site, the lowest flight levels or missed-approach flight patterns will be useful for intercomparisons. In this case, a few flight legs at the lowest level (300 feet) are considered to be very important.

Synergy with Other Missions: Small particles, Nucleation, Scale effects, Ni parameterizations.

Weather Conditions: BL ice clouds, high level ice clouds, clouds over ocean and land, shear/turbulent environments.

Critical Instruments: DMT CVI, FSSP-100, FSSP-300, 2DC, 2DS, CIP, extinction meter, RH, T, and Rosemount Radom probe wind measurements, PCASP, UHSAS, SPLAT, CDFC, AMS, SP-2. Since we are flying in clouds, we will also be using the CVI (not the DMT CVI) to look at the residue from ice crystals.

5.10 Long Range Transport of Pollutants to the Arctic Troposphere

Points of Contact: Shao-Meng Li, Richard Leaitch, Anne Marie Macdonald, Kurt Anlauf, Walter Strapp, and Peter Liu

Science Objective: The primary scientific objective will be the long range transport of pollutants to the Arctic, the cloud processing of pollutants in the Arctic, aerosol optical closure, contributions to CCN closure, and contributions to the overall ISDAC scientific objectives.

Measurement Objectives: To investigate long range transport of pollutants from lower latitudes to the Arctic.

General Aircraft Flight Profiles: a series of vertical profile measurements from surface to 20 kft, ascending or descending over Barrow/Fairbanks.

Repetitions Necessary: yes.

Weather Conditions: Clear sky preferred.

Synergy with Other Missions: Impact of long range transport on the Arctic chemistry including aerosols; results complement those of the other missions.

Critical Instruments: CO, Hg, O₃ (gaseous pollutants), AMS, SP2 (aerosol pollutants), UHSAS (particle number size distribution), CPC (aerosol number concentration).

5.11 Cloud Processing of Hg in the Arctic Troposphere

Points of Contact: Shao-Meng Li, Richard Leaitch, Anne Marie Macdonald, Kurt Anlauf, Walter Strapp, and Peter Liu

Science Objective: The primary scientific objective will be the long-range transport of pollutants to the Arctic, the cloud processing of pollutants in the Arctic, aerosol optical closure, contributions to CCN closure, and contributions to the overall ISDAC scientific objectives.

Measurement Objectives: To understand the potential effects of clouds (liquid and solid phase clouds) on the transformation of Hg in the atmosphere.

General Aircraft Flight Profiles:

- Pre-cloud (cloud base) air Hg and CO measurements
- In-cloud interstitial Hg and CO vertical profiles
- LWC and cloud droplet size distribution vertical profiles
- Updraft velocity measurements at the cloud base and in the cloud.

Repetitions Necessary: yes.

Weather Conditions: Cloudy situation, both liquid phase and solid phase clouds.

Synergy with Other Missions: The flight plan will be the same as those planned for other ISDAC missions; no separate flights are needed.

Critical Instruments: Hg(g), CO (gaseous pollutants), Nevzorov probe (LWC), FSSP100 (cloud droplet size distribution), 3-D wind (updraft velocity measurements).

5.12 Aerosol Optical Closure in the Arctic Troposphere

Points of Contact: Shao-Meng Li, Richard Leaitch, Anne Marie Macdonald, Kurt Anlauf, Walter Strapp, and Peter Liu

Science Objective: The primary scientific objective will be the long range transport of pollutants to the Arctic, the cloud processing of pollutants in the Arctic, aerosol optical closure, contributions to CCN closure, and contributions to the overall ISDAC scientific objectives.

Measurement Objectives: To characterize optical property closure of aerosols in the Arctic.

General Flight Plans: No specific plans needed.

Repetitions Necessary: yes.

Weather Conditions: Clear sky preferred.

Synergy with Other Missions: The objectives will be completed while other missions are carried out; no specific mission flights are necessary for these objectives.

Critical Instruments: PSAP (absorption), Nephelometer (scattering), UHSAS/FSSP300 (aerosol number size distribution), AMS/SP2 (aerosol chemistry size distribution), SPLAT (size distribution of aerosol dust components), CPC (aerosol number concentration).

5.13 Contributions to CCN Closure Studies and Aerosol Activation Studies

Points of Contact: Shao-Meng Li, Richard Leaitch, Anne Marie Macdonald, Kurt Anlauf, Walter Strapp, and Peter Liu

Science Objective: The primary scientific objective will be the long-range transport of pollutants to the Arctic, the cloud processing of pollutants in the Arctic, aerosol optical closure, contributions to CCN closure, and contributions to the overall ISDAC scientific objectives.

Measurement Objectives: To make critical measurements necessary to complete CCN closure studies in clear air, and complete studies on aerosol activation in clouds.

General Flight Plans: Profiles in clear air, pre-cloud (at cloud base), in cloud measurements coupling to CVI.

Repetitions Necessary: yes.

Weather Conditions: Stratus clouds.

Synergy with Other Missions: These objectives are already incorporated in the main missions of the ISDAC program.

Critical Instruments: UHSAS and PCASP-100x (aerosol number size distribution), AMS (aerosol chemical size distribution) on ambient or after CVI, SP2 (size distributed soot carbon), SPLAT (size distribution of aerosol dust components) and CCN.