# Indirect and Semi-Direct Aerosol Campaign (ISDAC)

## The Influence of Arctic Aerosol on Clouds

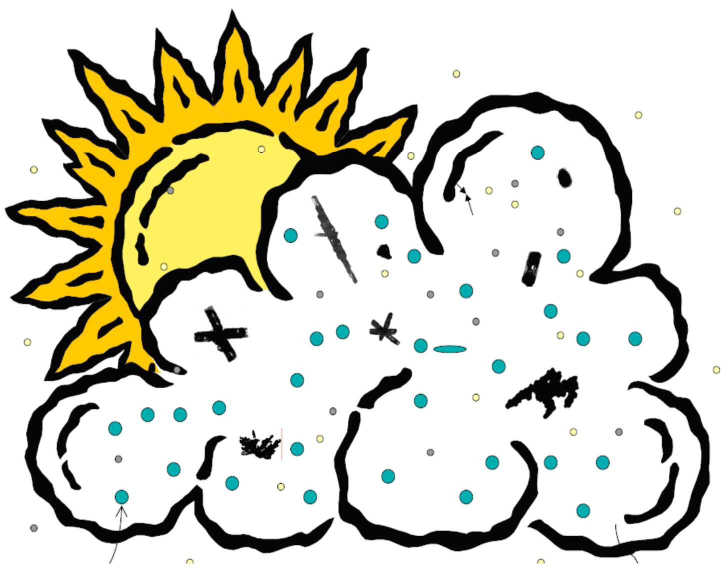
PIs: Steve Ghan, Greg McFarquhar, Hans Verlinde

ARM AVP: Beat Schmid, Greg McFarquhar, John Hubbe, Debbie Ronfeld

In situ measurements: Sarah Brooks, Don Collins, Dan Cziczo, Manvendra Dubey, Greg Kok, Alexei Korolev, Alex Laskin, Paul Lawson, Peter Liu, Claudio Mazzoleni, Ann-Marie McDonald, Greg McFarquhar, Walter Strapp, Alla Zelenyuk

Retrievals: Connor Flynn, Dan Lubin, Mengistu Wolde, David Mitchell, Matthew Shupe, David Turner

Modeling: Ann Fridlind , Xiaohong Liu, Shaocheng Xie



Barrow, Alaska

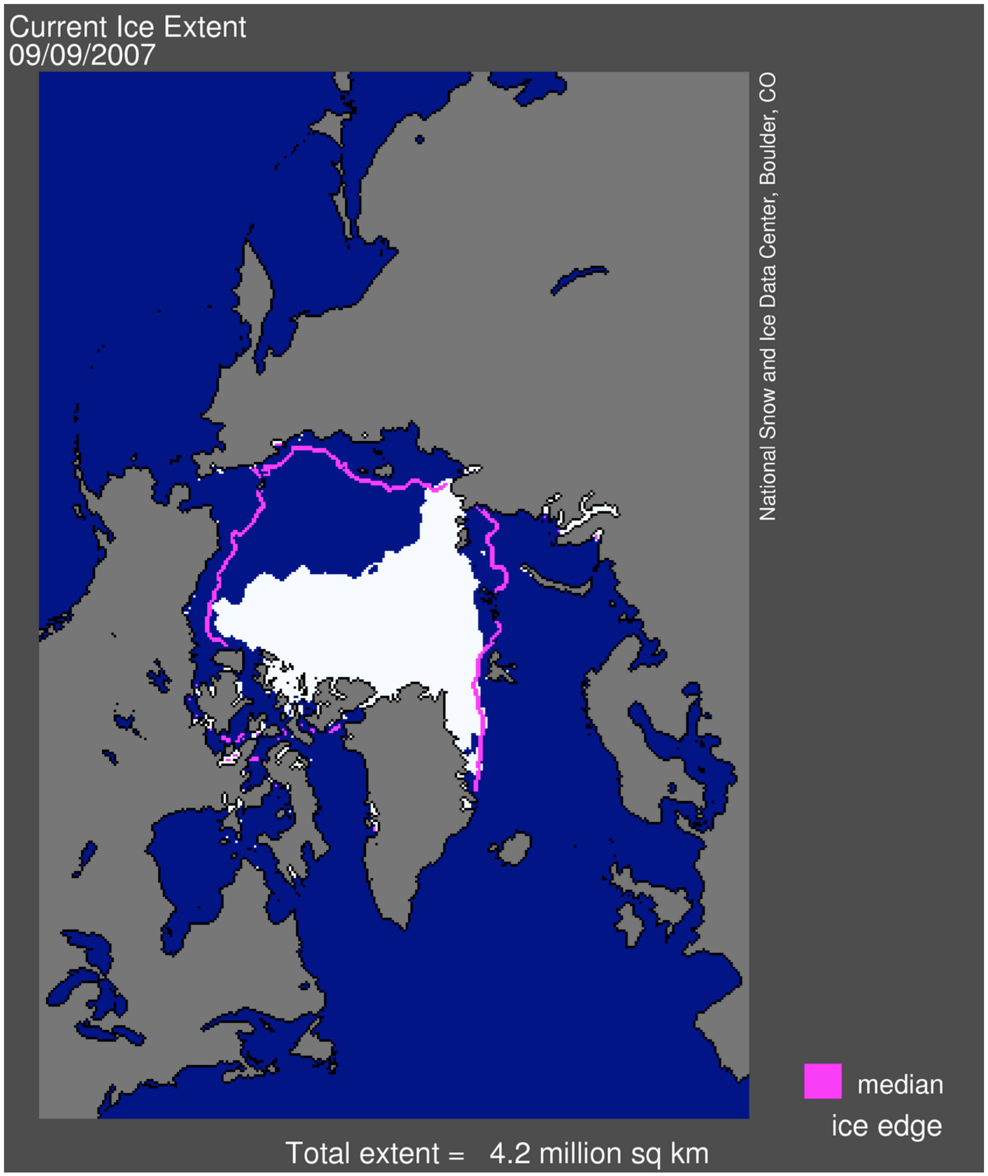
April 2008

http://acrf-campaign.arm.gov/isdac/

# Outline

- Motivation
- Key Questions
- Measurements
- Applications

# Motivation

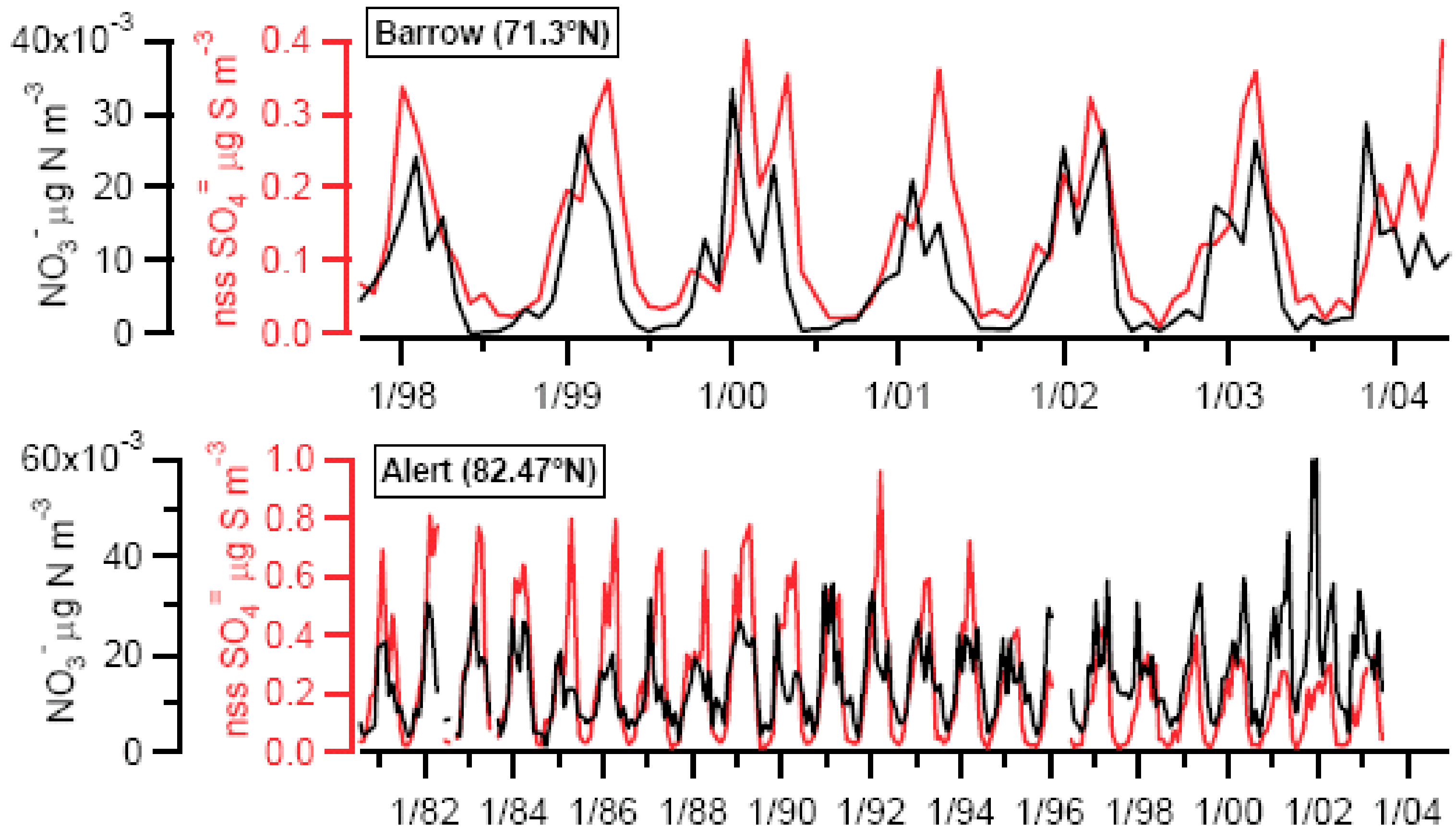



- Summertime Arctic sea ice has decreased dramatically in recent years, beyond climate model predictions.
- The Arctic is projected to be ice free during summer within 10-20 years.
- The role of clouds and aerosols in the loss of sea ice is not understood.

Chuck Brock, NOAA

# Submicron arctic aerosol concentrations vary widely with season

- Peak in late winter/early spring
- Haze spans the Arctic poleward of the Arctic front
- Mostly sulfate, but unknown contributions from organic and dust



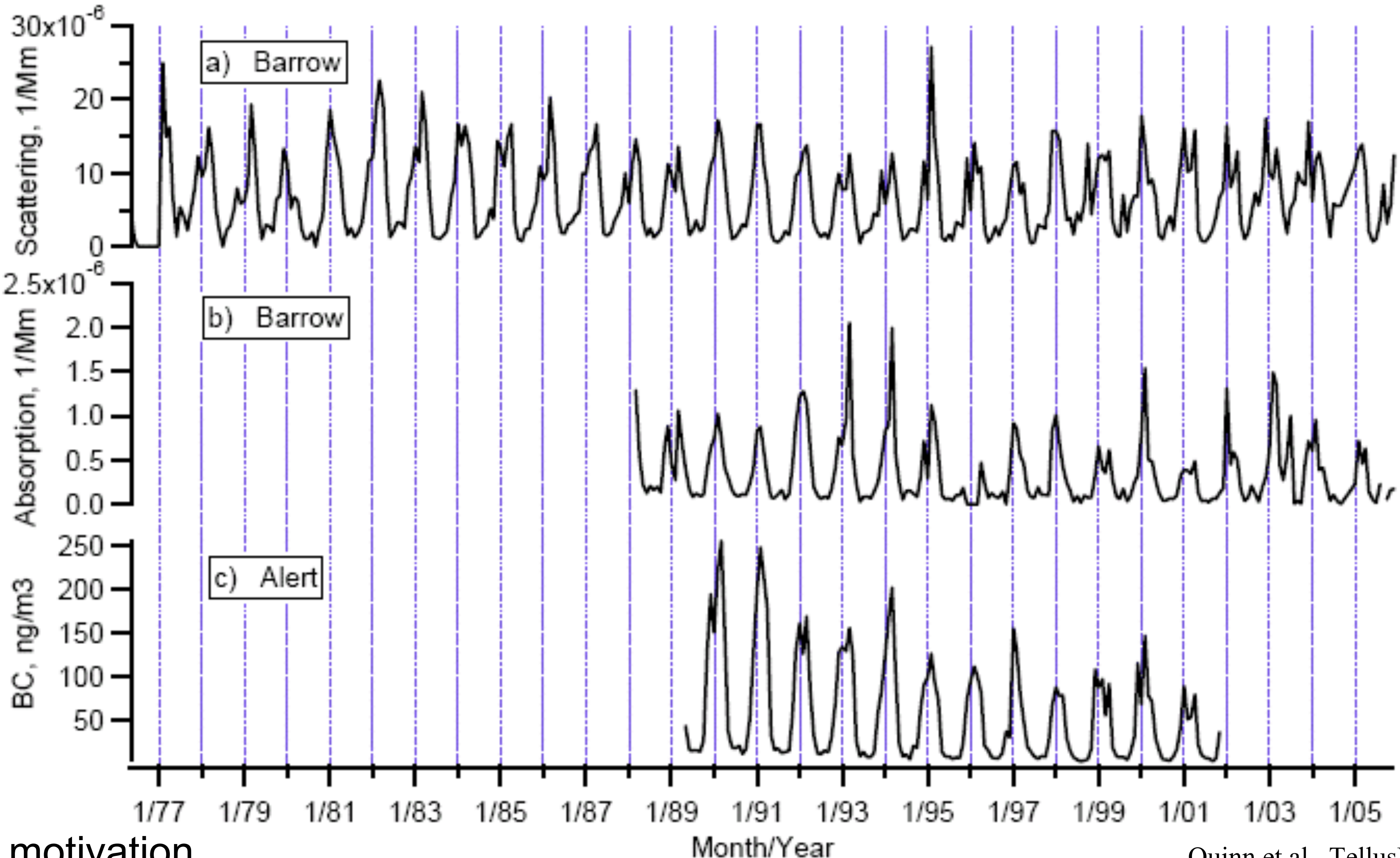

Quinn et al., *Tellus B, 2007*

motivation

Chuck Brock, NOAA

# Similar annual cycle for scattering, absorption, black carbon

Decrease in black carbon and absorption due to decline of Soviet emissions?




Quinn et al., TellusB, 2007.

motivation

Chuck Brock, NOAA

# The Role of the Arctic Front


*Arctic Monitoring and Assessment Programme, 2006*

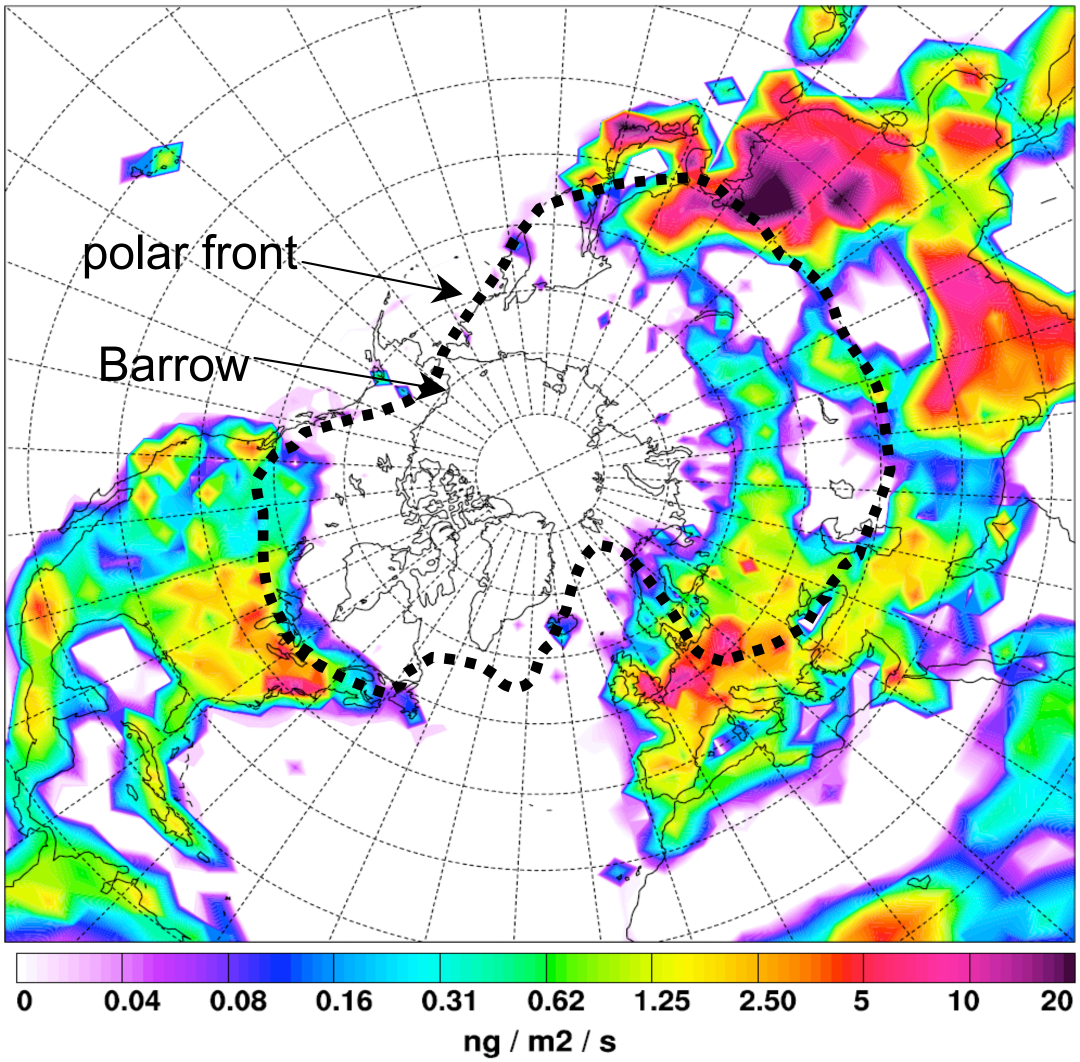
**Sources for surface haze generally lie within the Arctic front**

**Layers aloft may have sources further south (if they can survive cross-front processes)**

motivation

Chuck Brock, NOAA

# Anthropogenic sources of soot (industrial and biofuel)




*Stohl et al., 2006*

**Sources in NE Europe and NE China are consistently within or near the mean position of the Arctic front.**

motivation

Chuck Brock, NOAA

# Motivation

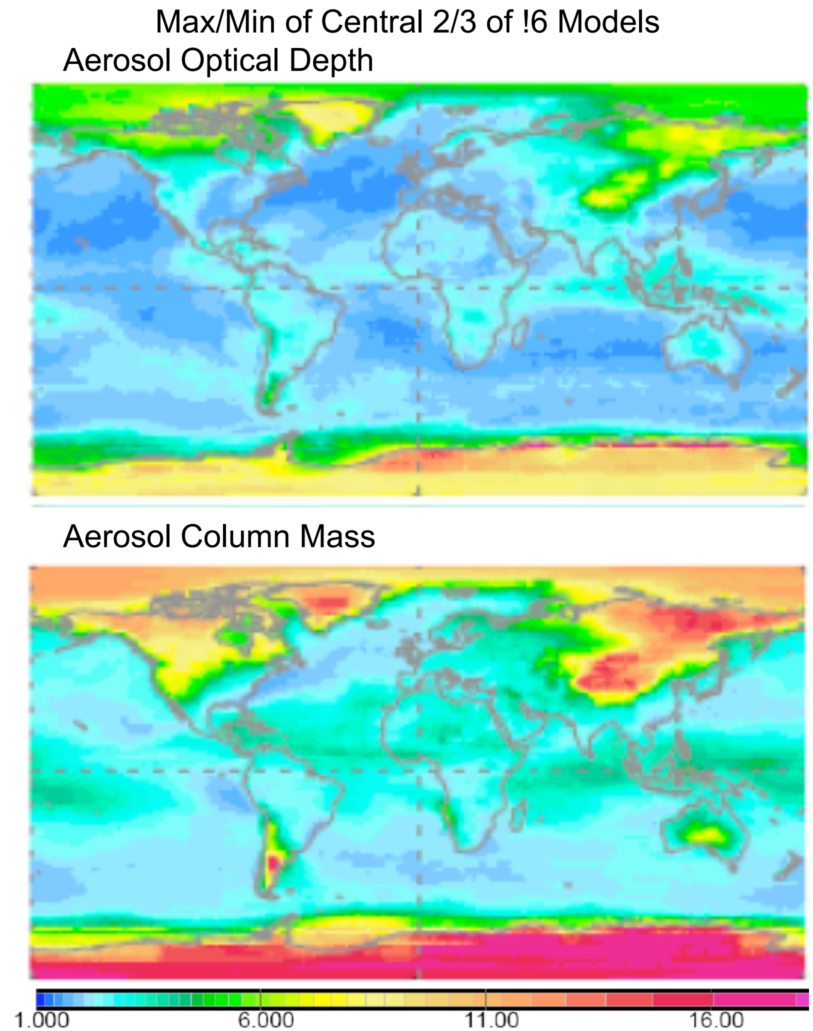
- The ARM Program established a permanent site at the North Slope of Alaska for several reasons:
  - Climate models suggest a large *arctic* climate sensitivity due to snow/ice albedo feedback. Snow and sea ice melt each year at the NSA. ARM measurements there could improve understanding of snow and ice albedo feedbacks and how they interact with clouds.
  - The atmosphere at the NSA is colder and drier than at the other ACRF sites, thus permitting important tests of radiative transfer codes using surface-based measurements.
  - Of the three permanent ACRF sites, stratiform clouds are most prevalent at the NSA. Stratiform clouds play important roles in cloud feedback.
  - Glaciated and mixed-phase clouds are common at the NSA, so that studies of glaciation are more convenient at the NSA than at the other sites.
  - Aerosols have a strong seasonal cycle at the NSA. This permits studies of both direct and indirect effects of aerosols.

# ISDAC Motivation

- Most studies of cloud-aerosol interactions have focused on warm clouds.
- Cloud-aerosol interactions are much more complex for ice or mixed-phase clouds than for warm clouds.
- The Mixed-Phase Arctic Cloud Experiment at the ARM site in Barrow has provided new insight into these interactions.
- The arctic air during April is expected to be much more polluted than the air during M-PACE.
- This contrast provides an opportunity to
  - distinguish between aerosol effects on arctic clouds under clean and polluted conditions
  - evaluate surface-based retrievals of clouds and aerosol at Barrow
  - improve understanding of the scavenging of arctic aerosol during spring
  - identify the chemical signature of ice nuclei in the arctic

# Aerosol Models Have Particular Trouble Simulating Aerosol Beyond the Polar Front

- Most of the relative uncertainty in simulated aerosol optical depth and mass loading is in polar regions.
- Most Arctic aerosol comes from midlatitude sources.
- Uncertainty in the treatment of transport is unlikely to cause a 10-fold uncertainty.
- Such uncertainty is probably due to the treatment of scavenging by clouds.

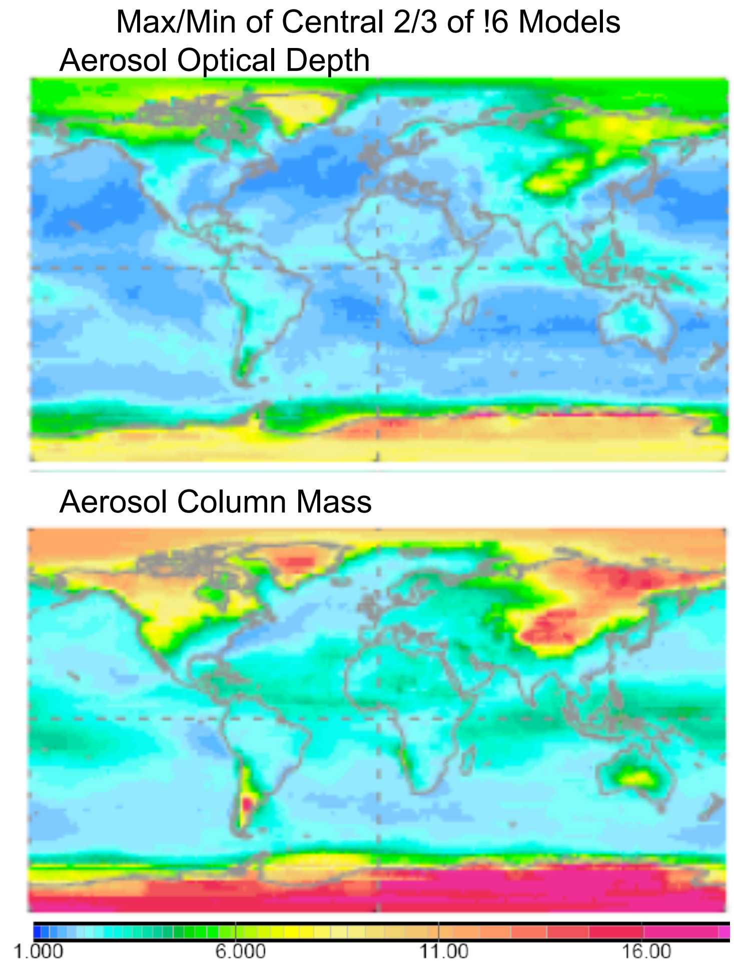



Kinne et al., An AeroCom initial assessment. *Atmos. Chem. & Phys.*, 2006.

motivation

# Aerosol Scavenging is Highly Uncertain

- Most of the relative uncertainty in simulated aerosol optical depth and mass loading is in polar regions.
- Most arctic aerosol comes from midlatitude sources.
- The treatment of transport is unlikely to cause a 10-fold uncertainty.
- Such uncertainty is probably due to the treatment of scavenging by clouds.




Kinne et al., An AeroCom initial assessment. *Atmos. Chem. & Phys.*, 2006.

# Ice Formation Mechanisms: April vs October

**TYPE IV**


Small droplets at cloud top, possible ice, no precipitation

- Droplet concentrations > 100 $cm^{-3}$
- Maximum effective droplet radius < 10 μm
- Maximum threshold droplet diameter < 20 μm
- Ice concentrations nil or a few per liter

**TYPE V**


Large droplets at cloud top, ice, precipitation

- Droplet concentrations typically < 100 $cm^{-3}$
- maximum effective radius > 10 μm
- Maximum threshold droplet diameter > 20 μm
- Ice concentrations 10-100 per liter

Rangno & Hobbs (2001)

Type IV conditions expected during April.

Type V conditions encountered during October.

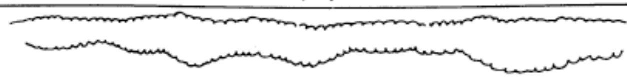
motivation

# Ice Formation Mechanisms

Slightly Supercooled Stratiform Clouds (Tops 0 to -10 C)

s -10 to -20 C)

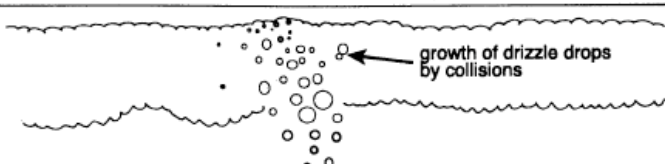
**TYPE I**



0 to -10C, small droplets, no ice, no precipitation

- Droplet concentrations typically > 100 cm$^{-3}$
- Maximum effective droplet radius < 12 μm
- Maximum threshold droplet diameter < 28 μm (too small for collisions with coalescence)

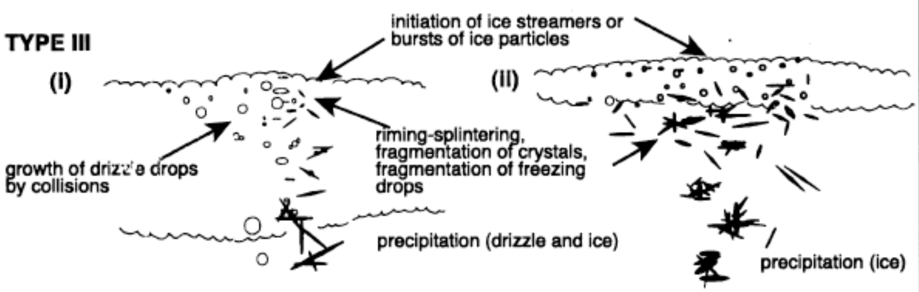
**TYPE II**




0 to -4C, large droplets, no ice, drizzle

- Droplet concentrations < 100 cm$^{-3}$
- maximum effective droplet radius > 12 μm
- Maximum threshold droplet diameter > 28 μm (for drizzle formation)

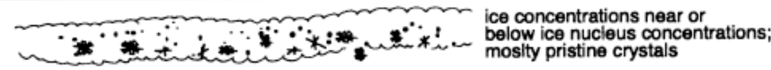
**TYPE III**




-4 to -10C, large droplets, ice

- Droplet concentrations < 100 cm$^{-3}$
- maximum effective droplet radius > 12 μm
- Maximum threshold droplet diameter > 28 μm (for drizzle formation)

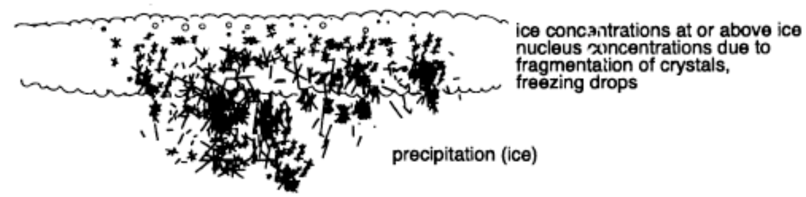
**TYPE IV**




Small droplets at cloud top, possible ice, no precipitation

- Droplet concentrations > 100 cm$^{-3}$
- Maximum effective droplet radius < 10 μm
- Maximum threshold droplet diameter < 20 μm
- Ice concentrations nil or a few per liter

**TYPE V**




Large droplets at cloud top, ice, precipitation

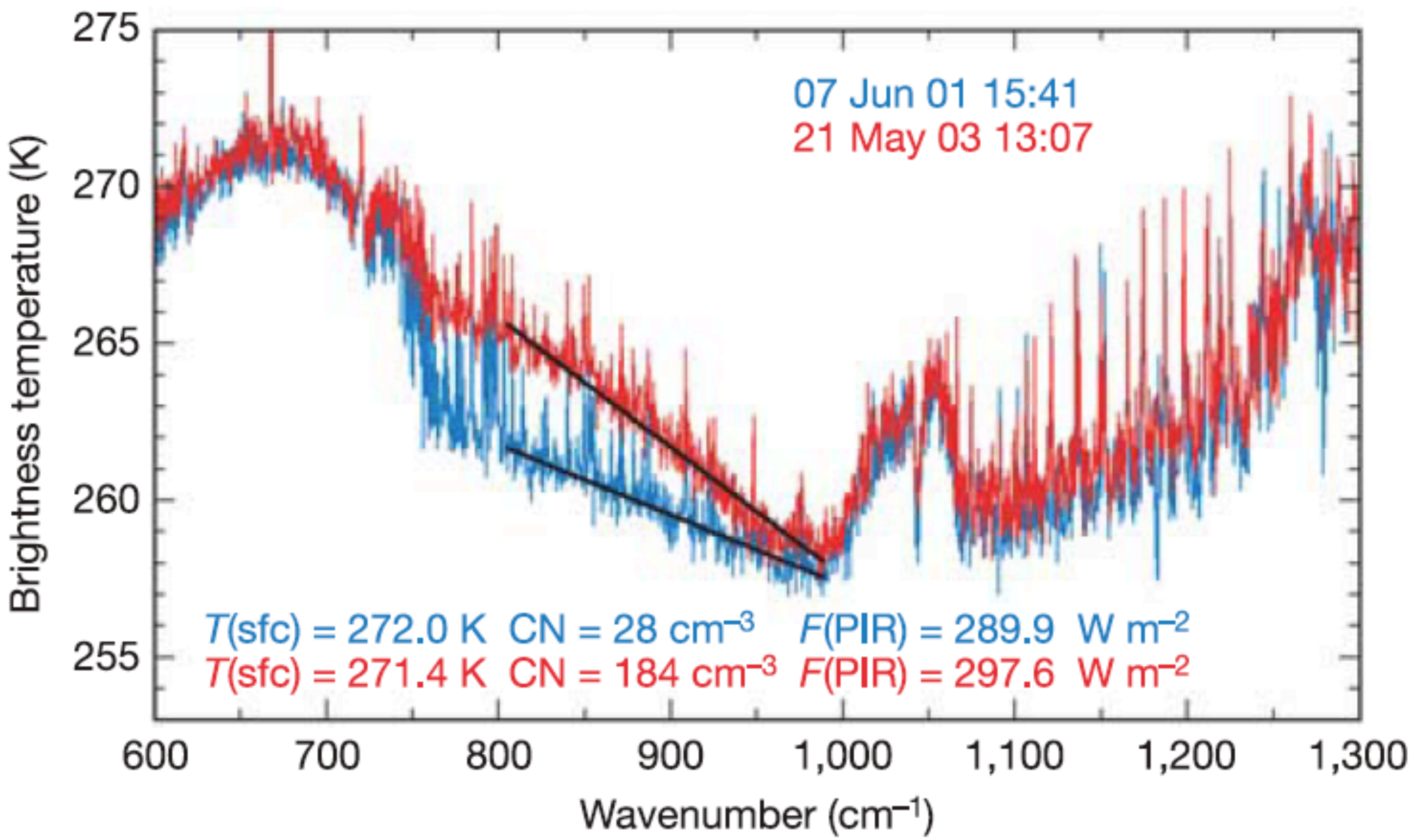
- Droplet concentrations typically < 100 cm$^{-3}$
- maximum effective radius > 10 μm
- Maximum threshold droplet diameter > 20 μm
- Ice concentrations 10-100 per liter

Type V conditions were encountered during M-PACE. Type IV conditions are expected during ISDAC.

motivation

Rangno & Hobbs (2001)

# A Longwave Aerosol Indirect Effect




motivation

Lubin & Vogelmann, Nature 2006

# Key Issues

1. How do properties of the Arctic aerosol during April differ from those measured by the M-PACE during October?
2. Which processes produce the strong seasonality of the Arctic aerosol? How well can aerosol models simulate the processes that produce the strong seasonality in the Arctic aerosol?
3. To what extent do the different properties of the Arctic aerosol during April produce differences in the microphysical and macrophysical properties of clouds and the surface energy balance?
4. How well can cloud models and the cloud parameterizations used in climate models simulate the sensitivity of Arctic clouds and the surface energy budget to the differences in aerosol between April and October?
5. How well can long-term surface-based measurements at the ACRF Barrow site provide retrievals of aerosol, cloud, precipitation and radiative heating in the Arctic?

# Key Questions

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objectives

# RISCAM Key Issues

1. What is the uncertainty in cloud properties and the associated long wave (nighttime) heating rate profiles derived from ground-based and satellite remote sensor retrieval algorithms?
2. To what extent do surface measurements of aerosol number concentrations, size distribution, and cloud-nucleating properties represent the properties of particles entering clouds at cloud base, and how does the measured cloud droplet concentration (size resolved) at the base of the (liquid) cloud correspond to the aerosol distributions?
3. What is the spatial variability of aerosol, cloud microphysical properties and vertical velocities, and how does this variability depend on microphysical properties, cloud type and synoptic classification? What is the evolving role of aerosol in the seasonal variability of cloud properties?
4. What is the response of the effective radius to environmental aerosol loading for warm clouds in the Arctic?
5. What are the surface spectral albedos and their variability over land?

# *1. How do properties of the Arctic aerosol during April differ from those measured during M-PACE in October?*

- Are CCN and IN concentration in the Arctic higher during April than in October?
- What are the physical and chemical properties, including degree of internal mixing, of the arctic CCN and IN during April?
- How do the vertical distributions of the aerosol during April differ from those during October?

# *2. Which processes produce the strong seasonality of the Arctic aerosol?*

- Which processes contribute to the scavenging of arctic aerosol during spring?
- How well can aerosol models simulate the processes that produce the strong seasonality in the Arctic aerosol?

# *2. To what extent do the different properties of the Arctic aerosol during April produce differences in clouds?*

- Do the more polluted conditions during April in the Arctic enhance droplet number, crystal number, cloud optical depth, and longwave emissivity?
- How does the measured variation of Arctic IN with temperature and supersaturation compare against parameterizations used in models?
- Does glaciation enhancement by increased IN dominate glaciation suppression by droplet size reduction associated with increased CCN?
- What is the relationship between IN and ice crystal number and what role does ice multiplication play in determining ice crystal number concentration?
- How do differences in large-scale meteorological forcing and surface conditions affect how cloud properties differ in the polluted April compared with October?
- What role does aerosol absorption of sunlight play in the dissipation of springtime arctic clouds?

## *3. How well can cloud models and the cloud parameterizations used in climate models simulate the sensitivity of Arctic clouds and the surface energy budget to the differences in aerosol between April and October?*

- Can cloud models and parameterizations simulate the seasonal differences in the droplet number, crystal number, glaciation, riming, droplet dispersion, cloud optical depth, and longwave emissivity in the Arctic?
- Can models and parameterizations successfully simulate the partitioning of cloud water and cloud ice in arctic clouds and the longevity of springtime arctic clouds?

## *4. How well can long-term surface-based measurements at the ACRF NSA locale provide retrievals of aerosol, cloud, precipitation, and radiative heating during April in the Arctic?*

- How does the performance of these retrievals depend on stratification, cloud thickness, and cloud phase?

# Science of Opportunity

- Small ice crystal issue
- Long-lived mixed phase clouds
- CloudSat and Calipso validation

# Aircraft Instruments and Measurements

| Instrument | Measurements |
|---|---|
| Rosemont 102 Probe | temperature |
| Chilled mirror, Lyman-alpha hygrometers | dew-point temperature |
| Counterflow Virtual Impactor (ASP) | cloud-borne aerosol |
| Condensation Particle Counter | total particle concentration (d> 3 nm) |
| DMA, PCASP | aerosol size distribution (d 0.01-3 μm) |
| HTDMA | size-resolved aerosol hygroscopicity (d 0.015 - 0.6 μm) |
| DMT CCN counter | CCN concentration (one S) |
| CCN spectrometer (ASP) | CCN spectrum |
| CFDC | IN concentration |
| Aerosol Mass Spectrometer (ASP) | Size-resolved volatile composition |
| Single Particle Mass Spectrometer (ASP) | Single particle composition |
| Single Particle Soot Photometer (ASP) | Refractory particle mass distribution (d>100 nm) |
| Time-Resolved Aerosol Collector / CCSEM/EDX (ASP) | Single particle chemical composition and mixing state |
| PSAP, nephelometer | optical absorption, scattering |
| Gust probe | updraft velocity |
| Gerber probe | LWC |
| DMT CAPS | temperature, LWC, cloud particle size dist (d 0.5-1500 μm) |
| DMT CSI | total condensed water concentration |
| T-probe | LWC, total condensed water concentration |
| SPEC CPI | cloud particle image (d 15-2500 μm) |
| Cloud Integrating Nephelometer | cloud extinction coefficient, asymmetry parameter |

# Instruments on Aircraft

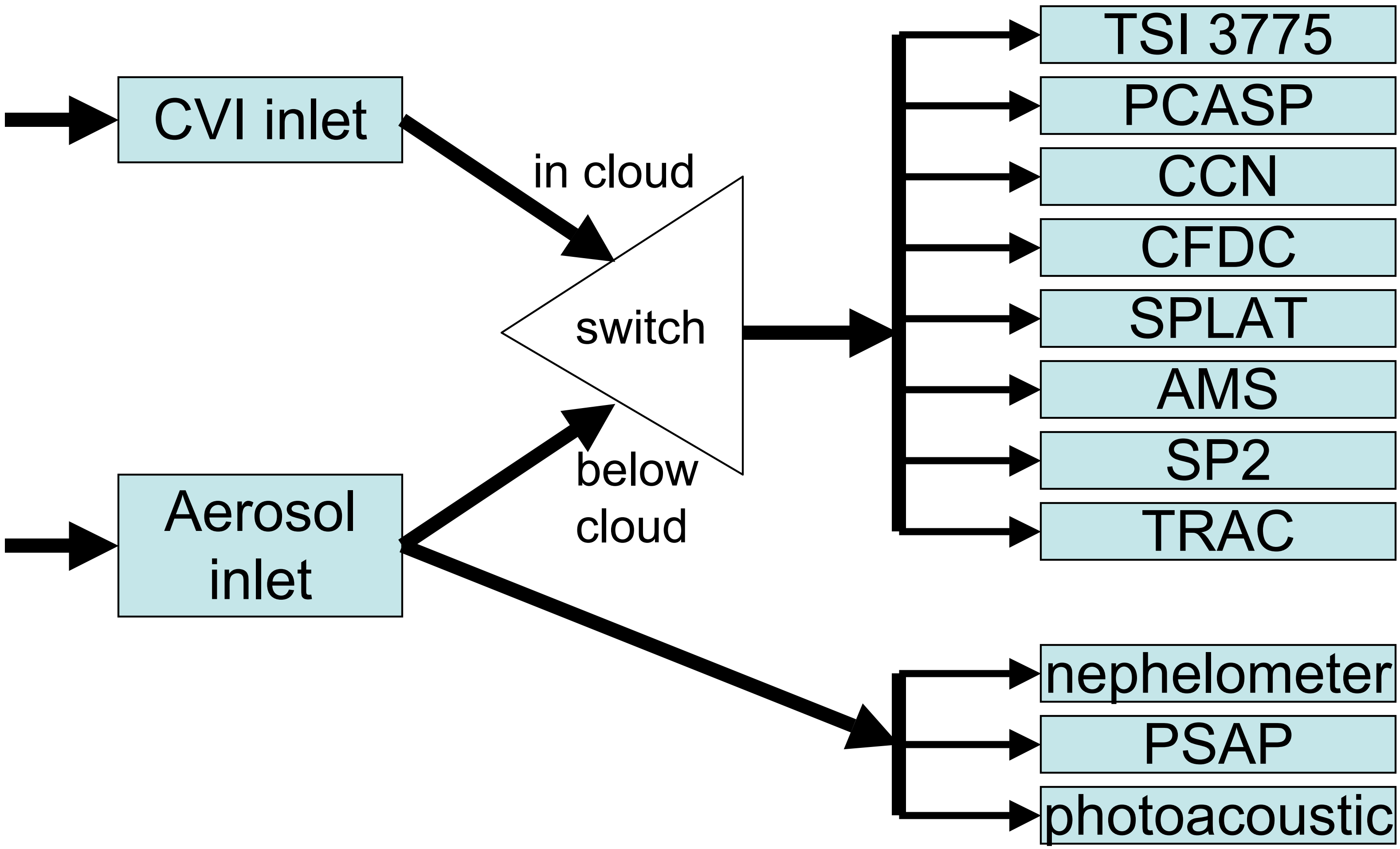
| Instrument | Measurements | Investigator |
|---|---|---|
| | **Atmospheric State** | |
| 3 Rosemont 102 probes | Temperature | Mengistu Wolde |
| NCAR reverse flow probe | Temperature | Walter Strapp |
| EG7G chilled mirror hygrometer | Humidity | Walter Strapp |
| LICOR LIC2G2 | Water vapor and $CO_2$ mixing ratio | Mengistu Wolde |
| Rosemount 858 gust probe | Vertical velocity | Mengistu Wolde |
| | **Liquid/Super-cooled Liquid** | |
| Rosemount icing (RICE) probe | Detects supercooled liquid | Walter Strapp |
| Vibrameter | Detects supercooled liquid | S. Cober |
| Nevzorov LWC/TWC probe | Liquid and total condensed water concentration | Alexei Korolev |
| PMS CSIRO King probe | Liquid water concentration | Walter Strapp |
| | **Cloud Microphysics** | |
| DMT Counterflow Virtual Impactor | Total water concentration | Walter Strapp |
| DMT Cloud, Aerosol and Precipitation Spectrometer | T, liquid water and $N_d$, cloud particle size distribution (0.5 – 1500 μm) | Greg McFarquhar |
| SPEC Cloud Particle Imager | Cloud particle images (15 – 2500 μm) | Greg McFarquhar<br>Paul Lawson |
| PMS FSSP-100X | Small particle spectrum (3 – 45 μm) | Walter Strapp |
| PMS 2D2C | Imaging cloud particles (25 – 800 μm) | Walter Strapp |
| SPEC 2DS | Cloud particle size distribution (50-1000 μm) | Paul Lawson |
| PMS 2DP | Imaging cloud particles (200 – 6400 μm) | Walter Strapp |
| DMT CDP | Cloud droplets (2-50 μm) | Greg Kok |
| Korolev Cloud Extinction Meter | Cloud Extinction | Alexi Korolev |

# Aerosol Instruments on Aircraft

| Instrument | Measurement | Investigator |
|---|---|---|
| | Aerosol | |
| Condensation Nuclei Counter (TSI 3775) | Total particle concentration (> 3 nm) | Peter Liu |
| Ultra High Sensitivity Aerosol Spectrometer (UHSAS) | Aerosol size distribution (100-3000 nm) | Peter Liu |
| DMT CCN counter | CCN concentration | Alex Laskin |
| Continuous Flow Diffusion Chamber | Ice nucleus concentration | Sarah Brooks |
| Radiance Particle/Soot Absorption Photometer (PSAP) | Optical absorption | John Ogren |
| Nephelometer | Optical scattering | John Ogren |
| 3 laser photo-acoustic spectrometer (PAS) | Aerosol absorption and scattering (405, 532 and 781 nm) | Manvendra Dubey |
| DMT Single Particle Soot Photometer (SP2) | Incandescent (black carbon) particle mass distribution | Greg Kok |
| Single Particle Laser Ablation Time of flight mass spectrometer (SPLAT) | Single particle size-resolved composition (refractory and non-refractory material) | Alla Zelenyuk |
| Time-Resolved Aerosol Collector (TRAC) | Time-resolved substrate for lab analysis (0.1 – 7 $\mu$m) | Alex Laskin |
| | Aerosol Sample Collection | |
| Aerosol inlet | Isokinetic aerosol inlet | Peter Liu |
| Counter-flow Virtual Impactor | Separation of residual aerosol | Ann-Marie McDonald |

ASP support

# Aerosol Instrument Configuration



# Radiometers and Remote Sensing on Aircraft

| Instrument | Measurement | Investigator |
|---|---|---|
| **Radiometers** | | |
| Infrared Thermometer | Cloud emissivity; Nadir view, narrow field of view | Walter Strapp |
| Broadband visible radiometers | Hemispheric radiometers, zenith and nadir | Chuck Long |
| Broadband Pyrgeometers | Hemispheric infrared fluxes, zenith and nadir view | Chuck Long |
| **Remote Sensing** | | |
| ProSensing up-looking G-band radiometer | Water vapor and liquid water path above aircraft | Mengistu Wolde |
| Ka-band up/down looking radar | Radar cross sections | Walter Strapp |
| X-band/W-band Doppler radar, dual polarization, up/down/side looking | radar cross sections, hydrometeor type identification | Mengistu Wolde |

# ARM Aircraft Measurements

| Instrument | Measurements |
|---|---|
| Rosemont 102 Probe | temperature |
| Chilled mirror hygrometer | dew-point temperature |
| Lyman-alpha hygrometer | dew-point temperature |
| TSI 3025 | total particle concentration (> 3 nm) |
| DMA | aerosol size distribution (0.01-0.75 μm) |
| PCASP | aerosol size distribution (0.1-3 μm) |
| HTDMA | size-resolved aerosol hygroscopicity (0.015 - 0.6 μm) |
| DMT CCN counter | CCN concentration (one S) |
| CFDC | IN concentration |
| PSAP | optical absorption |
| Nephelometer | optical scattering |
| Gust probe | updraft velocity |
| Gerber probe | LWC |
| DMT CAPS | temperature, LWC, cloud particle size dist (0.5-1500 μm) |
| DMT CSI | total condensed water concentration |
| T-probe | LWC, total condensed water concentration |
| SPEC CPI | cloud particle image 15-2500 μm |
| Cloud Integrating Nephelometer | cloud extinction coefficient, asymmetry parameter |

# Key ARM Aircraft Measurements

| Instrument | Measurements |
| --- | --- |
| TSI 3025 | total particle concentration (> 3 nm) |
| DMA | aerosol size distribution (0.01-0.75 mm) |
| PCASP | aerosol size distribution (0.1-3 mm) |
| HTDMA | Size-resolved aerosol hygroscopicity (0.015 - 0.6 mm) |
| DMT CCN counter | CCN concentration (one S) |
| CFDC | IN concentration |
| PSAP, photo-acoustic | optical absorption |
| Gust probe | updraft velocity |
| DMT CAPS | temperature, LWC, cloud particle size dist (0.5-1500 mm) |
| DMT CSI | total condensed water concentration |
| SPEC CPI | cloud particle image 15-2500 mm |
| CIN | cloud extinction coefficient, asymmetry parameter |

# Surface Measurements

| Instrument | Measurement | Location |
|---|---|---|
| Radiosonde | Temperature, humidity, winds profiles | ACRF Barrow |
| Microwave radiometer | Water vapor path, liquid water path | ACRF Barrow, Atqasuk |
| Microwave radiometer profiler | Temperature, humidity, LWC profile | ACRF Barrow |
| 915 MHz radar wind profiler/RASS | Winds, virtual temperature profile | ACRF Barrow |
| Vaisala ceilometer | Cloud base altitude | ACRF Barrow , Atqasuk |
| AERI | Temperature, humidity profiles, water path, optical depth, and effective radius of the ice and water component of mixed-phase clouds | ACRF Barrow |
| Cimel sunphotometer | Aerosol optical depth | ACRF Barrow |
| MFRSR | Aerosol optical depth multiple wavelengths | ACRF Barrow , Atqasuk |
| NIMFR | Aerosol optical depth | ACRF Barrow |
| Upviewing radiometers | Downward longwave, solar radiance | ACRF Barrow , Atqasuk |
| Downviewing radiometers | Upward longwave, solar radiance | ACRF Barrow , Atqasuk |
| **Spectroradiometer** | **Cloud optical depth, effective radius** | **ACRF Barrow** |
| Hotplate rain gauge | Precipitation | ACRF Barrow , Atqasuk |
| Humidified nephelometer | Aerosol scattering as f(RH) | CMDL Barrow |
| PSAP | Aerosol absorption | CMDL Barrow |
| Condensation nuclei counter | Total particle number | CMDL Barrow |
| PCASP | Accumulation mode size distribution | CMDL Barrow |
| CCN | CCN concentration (one supersaturation at a time) | CMDL Barrow |
| Daily chemical analysis | Submicron mass, ion concentration | CMDL Barrow |
| Snow gauge | Snowfall | CMDL Barrow |

# Surface Measurements

| **Instrument** | **Measurements** |
|---|---|
| Radiosonde | Temperature, humidity, winds profiles |
| Microwave radiometer | Water vapor path, liquid water path |
| Microwave radiometer profiler | Temperature, humidity, LWC profile |
| 915 MHz radar wind profiler/RASS | Winds, virtual temperature profile |
| Vaisala Ceilometer | Cloud base altitude |
| Millimeter cloud radar | Cloud liquid water, cloud ice content profiles |
| Micropulse lidar (polarized) | Aerosol backscatter profile, depolarization ratio |
| AERI | Temperature, humidity profiles, water path, optical depth, and effective radius of the ice and water component of mixed-phase clouds |
| Cimel sunphotometer | Aerosol optical depth |
| Multi-Filter Shadowband Radiometer | Aerosol optical depth at multiple wavelengths cloud optical depth, cloud fraction |
| **Humidified Tandem DMA** | **Size distribution of aerosol number & hygroscopicity** |
| **ASD spectroradiometer** | **Cloud optical depth, effective radius** |
| Normal incidence multifilter radiometer | Aerosol optical depth |
| Upviewing radiometers | Downward longwave, solar irradiance |
| Downviewing radiometers | Upward longwave, solar irradiance |
| Hotplate rain gauge | Precipitation |

# ASP Instruments and Measurements

| Instrument | Measurement |
|---|---|
| Counterflow Virtual Impactor | Cloud-borne aerosol |
| Scanning Mobility Particle Sizer | Aerosol size distribution 3-1000 nm |
| PCASP | Aerosol size distribution 0.1-3 $\mu m$ |
| TSI 3010, 3025A | Total aerosol number |
| DRI CCN Spectrometer | CCN spectrum |
| Particle-in-Liquid System | Particle ionic composition |
| Aerosol Mass Spectrometer | Size-resolved composition |
| Time-Resolved Aerosol Collector / CCSEM/EDX | Single particle chemical composition and mixing state |
| DRI Photoacoustic | Aerosol absorption |

# Applications

| Experiment | Input Data | Validation data | Lead |
|---|---|---|---|
| CCN closure | Aerosol size distribution | CCN concentration | Don Collins |
| | Hygroscopicity size dist | | |
| Droplet number closure | Aerosol size distribution | Droplet number concentration | Steve Ghan |
| | Hygroscopicity size dist | | |
| | Vertical velocity | | |
| Cloud water closure | Cloud particle size distribution | Total water content (TWC) | Greg McFarquhar |
| Cloud extinction closure | Cloud particle size distribution | Cloud extinction | Greg McFarquhar |
| Aerosol extinction closure | Aerosol size distribution<br>Aerosol composition | Aerosol extinction | Claudio Mazzoleni |
| Cloud modeling | Aerosol size distribution | Cloud particle size distribution | Ann Fridlind |
| | Hygroscopicity size dist | Liquid water content (LWC) | |
| | Ice Nuclei conc (T,S) | TWC | |
| | Downward longwave at top | | |
| | u,v, T, q | precipitation | |
| | Surface fluxes & large-scale forcing profiles | Cloud extinction | |
| Semi-direct effect | Same as for cloud modeling, plus the following | Same as for cloud modeling | Ann Fridlind |
| | Aerosol absorption | | |
| | Aerosol scattering | | |
| Ice crystal nucleation | Size-resolved composition of residual aerosol | IN(T,S) | Sarah Brooks |
| Relation between IN and ice crystal concentration | $IN(T,S_i)$ | Crystal size and habit | Greg McFarquhar |
| | temperature | Cloud particle size distribution | |
| | humidity | | |
| | water-ice interface | | |

# Retrieval Applications

| Experiment | Input Data | Validation Data | Lead |
|---|---|---|---|
| Aerosol extinction retrieval | Aerosol attenuated backscatter | Aerosol scattering | Connor Flynn |
| | | Aerosol absorption | |
| CCN retrieval | Aerosol backscatter | CCN | Steve Ghan |
| | Aerosol scattering | | |
| | Relative humidity | | |
| | Surface CCN | | |
| | humidification function | | |
| MMCR retrievals | Radar reflectivity | LWC | Matthew Shupe |
| | | TWC | |
| MWR retrievals | Microwave radiance | LWC | Dave Turner |
| AERI retrievals | Infrared radiance spectrum | TWC | Dave Turner |
| | | LWP | |
| | | Cloud particle size distribution | |
| | | Cloud extinction | |
| ASD retrievals | Solar radiance spectrum | Same as for AERI | Dan Lubin & Andrew Vogelmann |
| MFRSR retrievals | Direct and diffuse radiance at multiple wavelengths | Aerosol scattering and absorption | Qilong Min |
| BBHRP | Vertical profiles of cloud properties, T, q | Net longwave irradiance profile | Eli Mlawer |
| Full Flux Analysis | Surface direct and diffuse SW and LW radiance, temperature | Cloud optical depth | Chuck Long |

# Applications

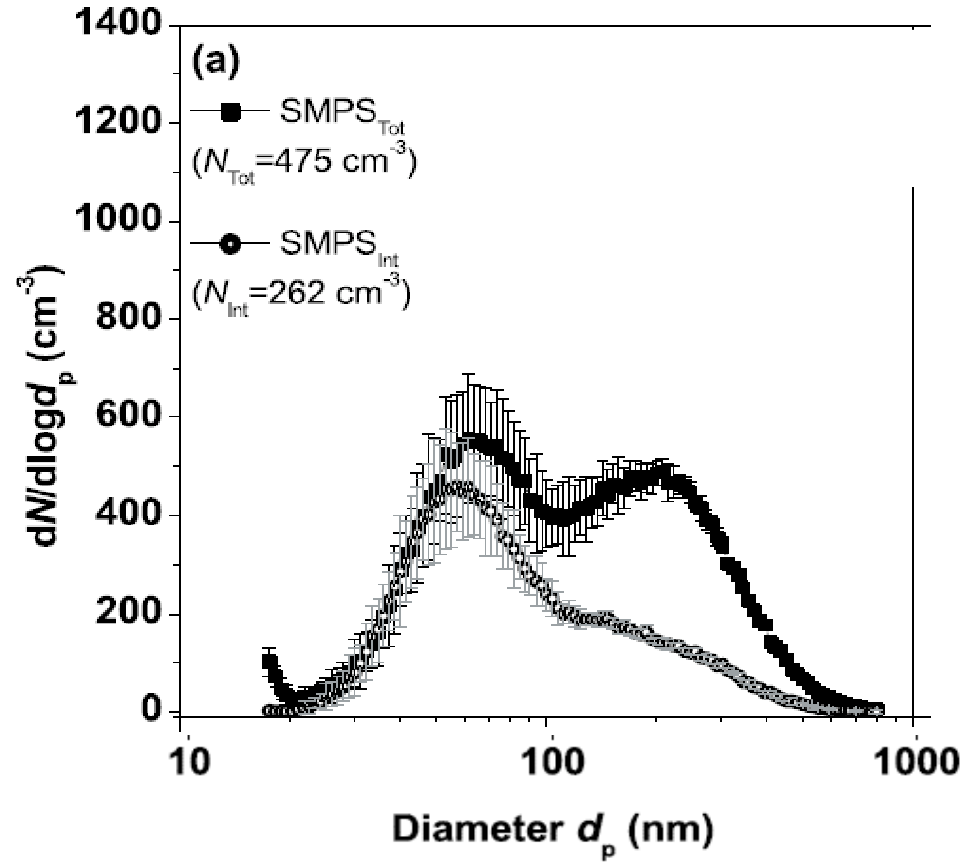
| Experiment | Data Input | Validation Data |
|---|---|---|
| CCN closure | Aerosol size distribution<br>Hygroscopicity distribution | CCN concentration |
| Droplet number closure | Aerosol size distribution, hygroscopicity distribution, vertical velocity | Droplet number concentration |
| Cloud water closure | Cloud particle size distribution | Total condensed water content |
| Cloud extinction closure | Cloud particle size distribution | Cloud extinction and optical depth |
| CCN retrieval | Aerosol backscatter, scattering and relative humidity profile, surface CCN and humidification function | CCN concentration |
| Cloud property retrievals | Radar, lidar, AERI and microwave radiometer measurements, ASD spectroradiometer | Aircraft measurements of cloud particle size, LWC, IWC, phase and optical depth |
| Cloud modeling | Aerosol size distribution profile<br>Hygroscopicity distribution<br>$IN(T,S_i)$ profile<br>Meteorological profile, surface fluxes & large-scale forcing profiles | Cloud particle size distribution, LWC, IWC, temperature, humidity, cloud base, cloud phase, precipitation, cloud optical depth |
| Aerosol scavenging | Same as for cloud modeling | Cloud-borne aerosol |
| Semi-direct effect | Aerosol size distribution<br>Hygroscopicity distribution<br>$IN(T,S_i)$ profile, aerosol absorption | |
| Relation between IN and ice crystal concentration | $IN(T,S_i)$ in clear air input to a cloud, humidity and temperature profiles, Ice crystal shape & size distribution, observations of water-ice interface | Crystal habits compared against expected habits (lab experiments) from T, $S_i$ to assess primary and secondary nucleation mechanisms |

# Applications

- CCN closure
- Droplet number closure
- IN closure
- Crystal number closure
- Cloud water closure
- Cloud extinction closure
- Aerosol extinction closure
- Cloud modeling
- Semi-direct effect
- Aerosol and cloud retrievals

# Aerosol Scavenging

- Two conditions for wet scavenging of aerosol:
  - Attachment to hydrometeor
  - Precipitation of hydrometeor
- Evaluate first condition by comparing simulated and observed partitioning of aerosol between interstitial and cloud-borne
- Evaluate second by comparing simulated and observed hydrometeor size distribution and precipitation rate




Henning, Bojinski, Diehl, Ghan, Nyeki, Weingartner, Wurzler,and Baltensperger: Aerosol partitioning in natural mixed-phase clouds. GRL 2004.

# Cloud Modeling: M-PACE vs ISDAC

- ISDAC and M-PACE boundary conditions are likely to be very different because of the much more extensive ocean water during M-PACE
- Separate influence of different boundary conditions from different aerosol by performing four simulations:
  - M-PACE aerosol and boundary conditions
  - M-PACE aerosol and ISDAC boundary conditions
  - ISDAC aerosol and M-PACE boundary conditions
  - ISDAC aerosol and boundary conditions.

# Cloud Modeling: Semi-Direct Effect

- Run with and without radiative heating by aerosol

# Deployment

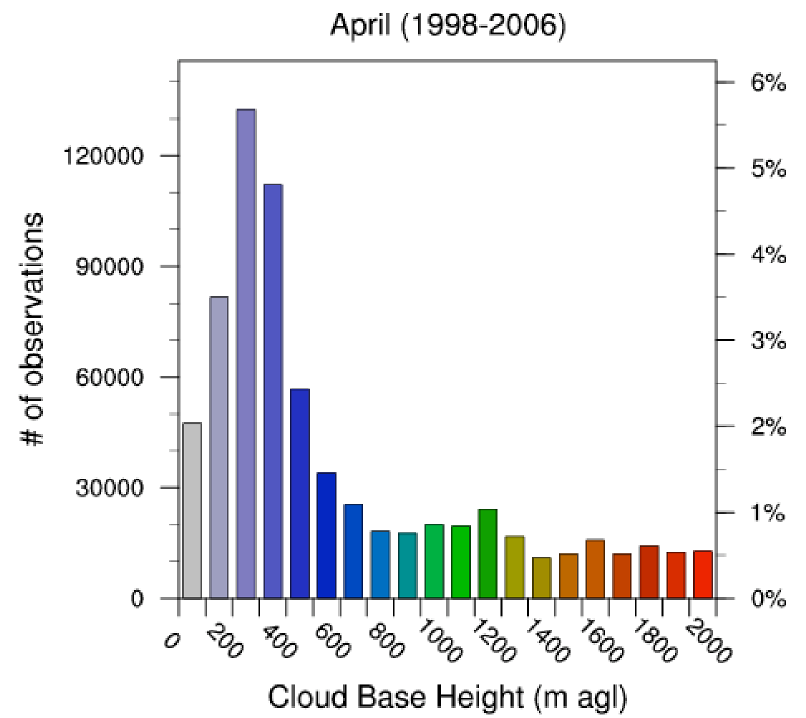
- Instruments mounted on Canadian National Research Council Convair-580 aircraft
- 11 sorties out of Fairbanks during period April 1- 30
- Each sortie 8.5 research flight hrs: fly to Barrow, sample, refuel, sample, return to Fairbanks
- Total of 94 research flight hours

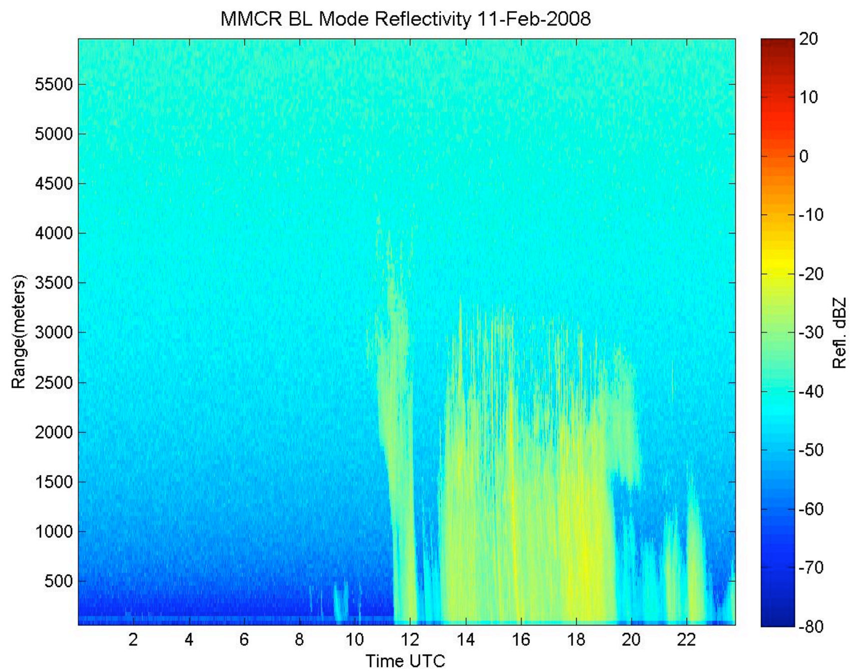
# Flight Patterns

- Horizontal transects
  - above, below or between cloud
  - in cloud
- Spiral profiling
- Missed approaches at Barrow airport
- Porpoising
- Coordination with other aircraft (NASA DC-8, P-3 and B200, NOAA WP-3D)

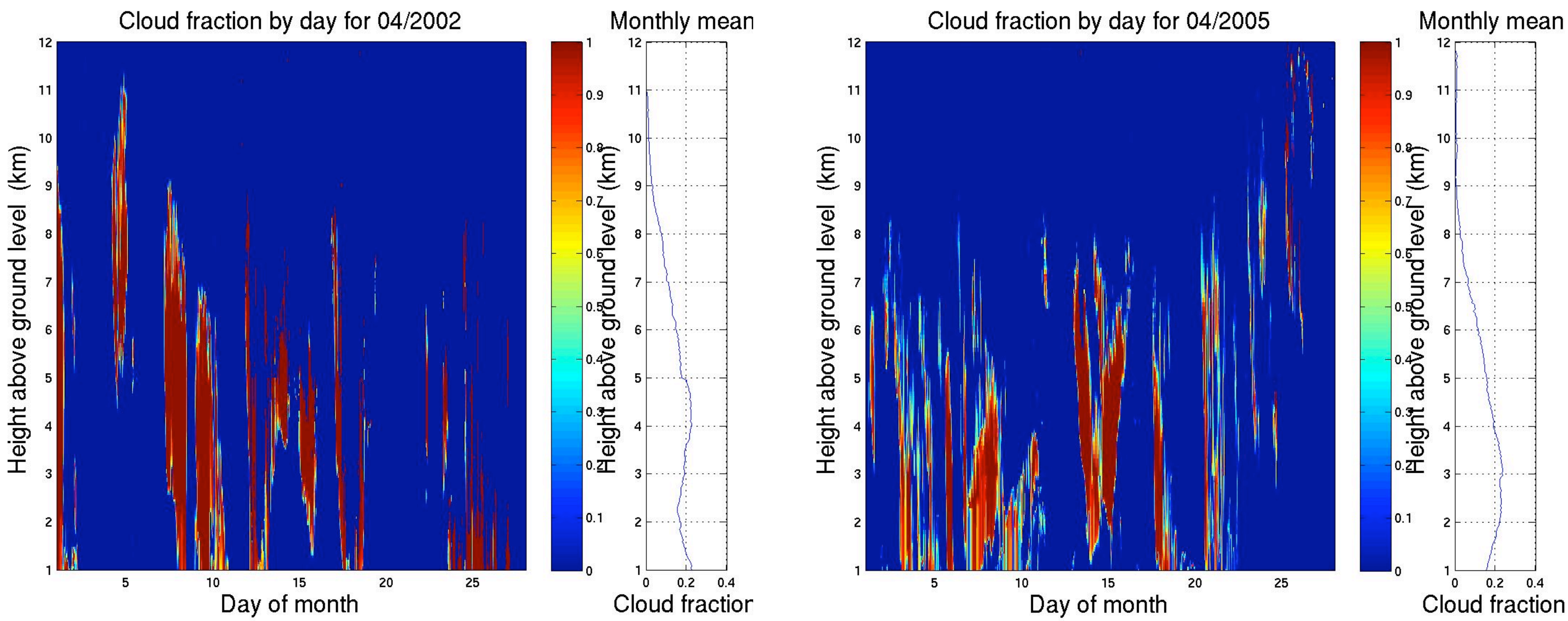
# Sampling Issues

- Low cloud
  - Missed approach limits sampling below cloud
- Icing
  - sample aerosol before entering liquid cloud
- Sampling statistics
  - 10 minutes aerosol outside cloud
  - > 30 minutes inside glaciated cloud for SPLAT & AMS



# Cloud Frequency




Questions?