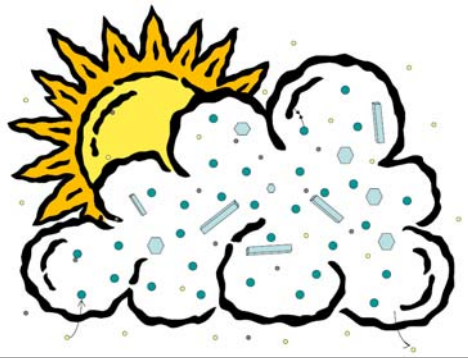
Indirect and Semi-Direct Aerosol Campaign

PI: Steve Ghan, Pacific Northwest National Laboratory

Co-I: Sarah Brooks, Don Collins, Connor Flynn, Ann Fridlind, Tim Garrett, John Hallett, John Hubbe, Greg Kok, Dan Lubin, Greg McFarquhar, David Mitchell, Mike Poellet, Matthew Shupe, David Turner, Hans Verlinde, Shaocheng Xie



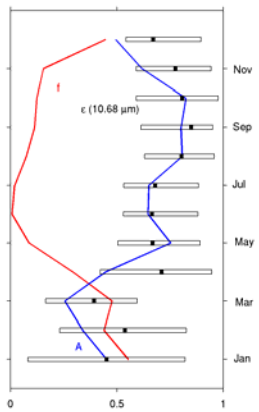
Barrow, Alaska

April 2008

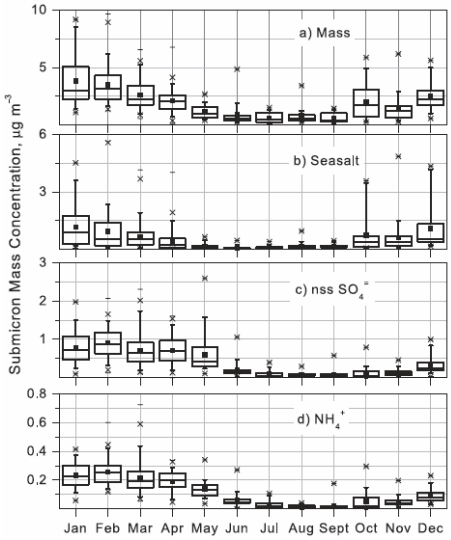
This experiment has been approved by the ARM program.

Motivation

•Submicron arctic aerosol concentrations & compositions vary widely with season



Garrett, T. J., and C. Zhao: Increased Arctic cloud longwave emissivity associated with pollution from mid-latitudes. *Nature, 2006.*



Quinn, P. K., T. L. Miller, T. S. Bates, J. A. Ogren, E. Andrews, and G. E. Shaw: A 3-year record of simultaneously measured aerosol chemical and optical properties at Barrow, Alaska. *J. Geophys. Res., 2002.*

Red line is polluted fraction; blue line is cloud coverage and quartile plots are emissivity; observations show that sea salt and sulfate dominate during the winter but large fraction of unknown residual mass during the summer; under the most polluted conditions the aerosol are predominantly composed of external mixtures of black carbon and sulfate, with internal mixing more common for background condition; a lot is unknown about the aerosol compositions and also how these vary with height

Why at NSA?

- Stratiform clouds more prevalent at NSA & they play important role in cloud feedbacks
- Large *arctic* climate sensitivity due to snow/ice albedo feedback and cloud feedbacks more important and more poorly understood in Arctic
- Most studies of cloud-aerosol interactions have focused on warm clouds
- Cloud-aerosol interactions more complex for ice or mixed-phase clouds
  - Glaciated & mixed-phase clouds more common at NSA than other sites
  - Aerosols have strong seasonal cycle at NSA so can look at indirect effects
- Colder & drier environment permits tests of radiative transfer codes

Key Issues

- How do properties of Arctic aerosol during April differ from those measured by M-PACE during October?
- To what extent do different properties of aerosol change cloud microphysical and macrophysical properties & surface energy balance?
  - Distinguish between aerosol effects in clean conditions observed during M-PACE & more polluted conditions expected in April
- How well can cloud models & cloud parameterizations used in climate models simulate sensitivity of Arctic clouds & surface energy budget to differences in aerosol between April and October?
- How well do surface measurements at NSA provide retrievals of aerosol, cloud, precipitation & radiative heating in Arctic

Aircraft Measurements: G-1/Citation/Falcon

- Temperature
- Humidity
- Total particle number
- Aerosol size distribution & hygroscopicity
- Cloud condensation & ice nuclei concentration
- Optical scattering and absorption
- Updraft velocity
- Cloud liquid water and ice water content
- Cloud droplet & crystal size distribution
- Cloud particle shape
- Cloud extinction

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 mm)
PMS PCASP-100X/DMT-SPP-200	aerosol size distribution (0.1-3 mm)
TDMA	Size-resolved aerosol hygroscopicity (0.015 - 0.6 mm)
DMT CCN counter	CCN concentration
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 mm)
DMT CSI	total condensed water concentration
T-probe	LWC, total condensed water concentration
SPEC CPI	cloud particle image 15-2500 mm
CIN	cloud extinction coefficient, asymmetry parameter

If we can also get the DOE Atmospheric Sciences Program to participate, we'd have two aircraft, one focusing on cloud, the other on aerosol. The aerosol aircraft would have a counter-flow virtual impactor, a CCN spectrometer, an Aerosol Mass Spectrometer, a PILS, and Time-Resolved Aerosol Collector for single particle analysis in the laboratory.

Surface Measurements

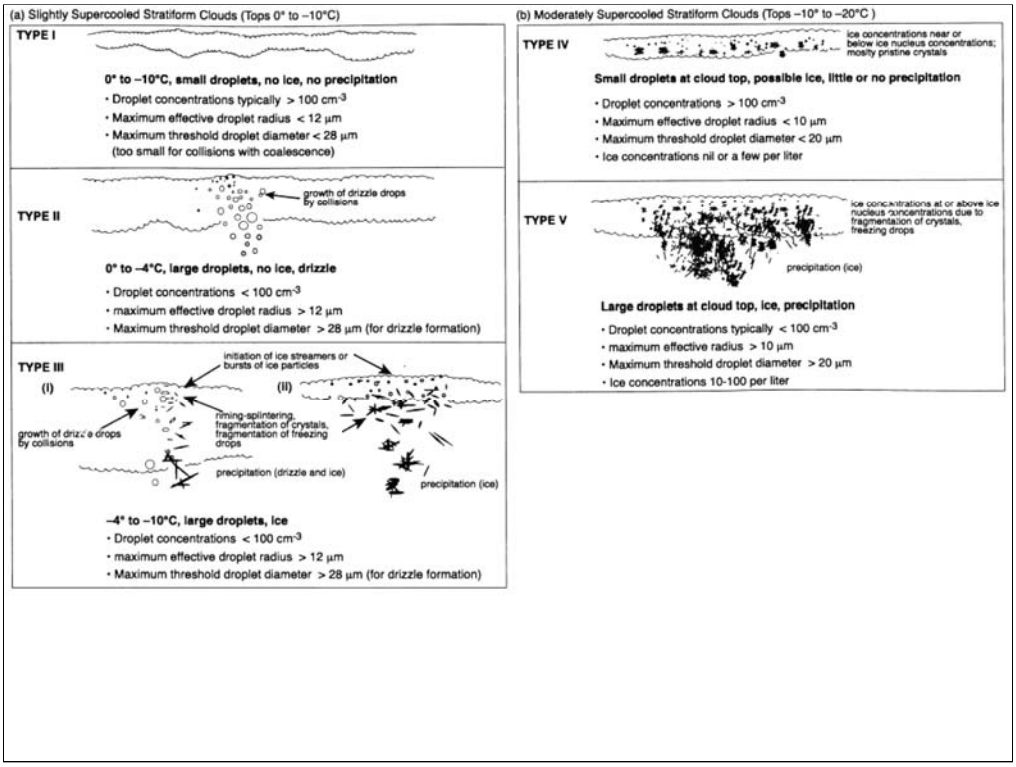
- Profiles of temperature, humidity and winds (radiosonde)
- Water vapor & liquid water path (microwave radiometer)
- Profiles of T, q, LWC, u, v, T_v (microwave & wind profiler)
- LWC & IWC profiles (radar)
- Aerosol backscatter & depolarization (lidar)
- AERI retrievals (T, q_v, WP, τ, r_e for water & ice)
- Aerosol t (radiometers and sun photometer)
- Downward & upward longwave & solar radiance
- Cloud base altitude (ceilometer)
- Precipitation (hot plate rain gauge) & Snow gauge
- Aerosol scattering & absorption as f(RH)
- Total particle number, accumulation mode number & CCN number
- Daily chemical analysis

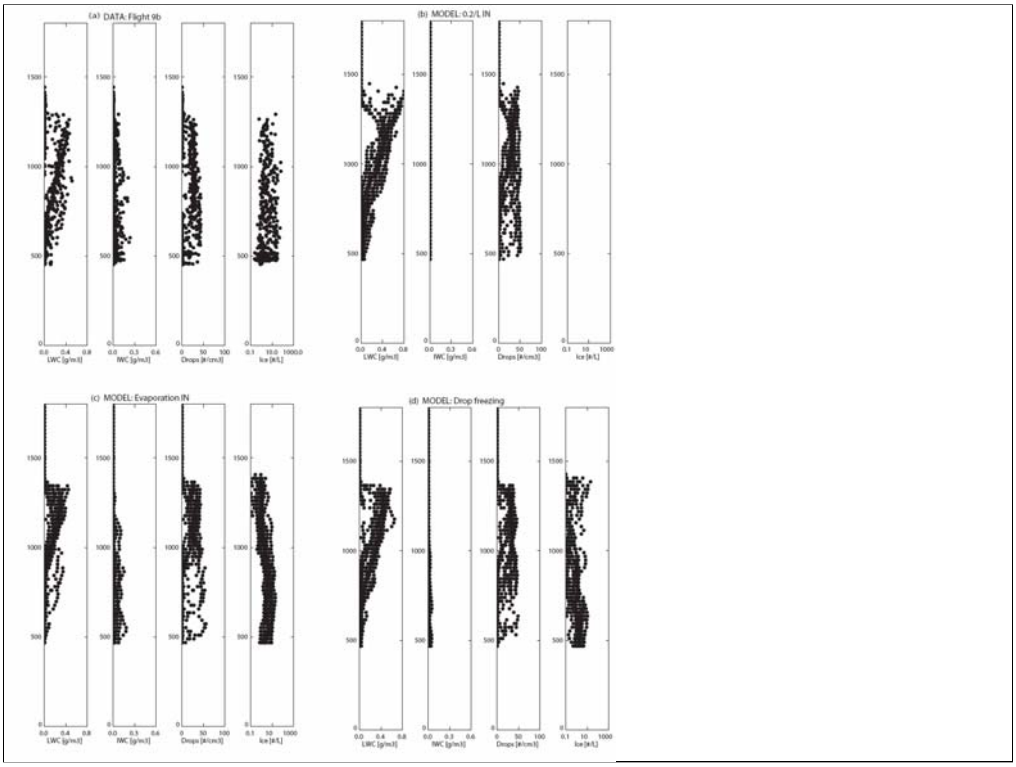
Applications

- CCN closure
- Droplet number closure
- Cloud water closure
- Cloud extinction closure
- CCN retrieval
- Cloud property retrievals
- Cloud modeling
- Semi-direct effect
- Relation between IN and ice crystal concentration

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 difference 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.


(a) Slightly Supercooled Stratiform Clouds (Tops 0° to −10°C)
TYPE I
0° to −10°C, 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
growth of drizzle drops by collisions
0° to −4°C, 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
(I)
(II)
initiation of ice streamers or bursts of ice particles
riming-splintering, fragmentation of crystals, fragmentation of freezing drops
growth of drizzle drops by collisions
precipitation (drizzle and ice)
precipitation (ice)
−4° to −10°C, large droplets, ice
• Droplet concentrations < 100 cm-3
• maximum effective droplet radius > 12 μm
• Maximum threshold droplet diameter > 28 μm (for drizzle formation)
(b) Moderately Supercooled Stratiform Clouds (Tops −10° to −20°C)
TYPE IV
ice concentrations near or below ice nucleus concentrations; mostly pristine crystals
Small droplets at cloud top, possible ice, little or 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
ice concentrations at or above ice nucleus concentrations due to fragmentation of crystals, freezing drops
precipitation (ice)
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


(a) DATA: Flight 9b
(b) MODEL: 0.2/L IN
(c) MODEL: Evaporation IN
(d) MODEL: Drop freezing
LWC [g/m3]
IWC [g/m3]
Drops [#/cm3]
Ice [#/L]

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

Applications

Experiment	Data Input	Validation Data
CCN closure	Aerosol size distribution 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 Hygroscopicity distribution IN(T,S_i) profile Meteorological profile, surface fluxes & large-scale forcing profiles	Cloud particle size distribution, LWC, IWC, temperature, humidity, cloud base, cloud phase, precipitation, cloud optical depth
Semi-direct effect	Aerosol size distribution Hygroscopicity distribution 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