Indirect and Semi-Direct Aerosol Campaign (ISDAC)

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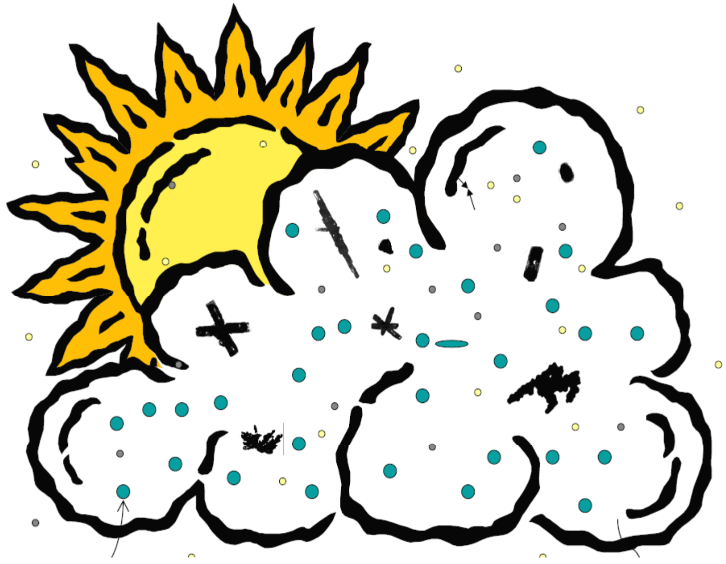
Modeling: Ann Fridlind , Xiaohong Liu, Shaocheng Xie



Barrow, Alaska

April 2008

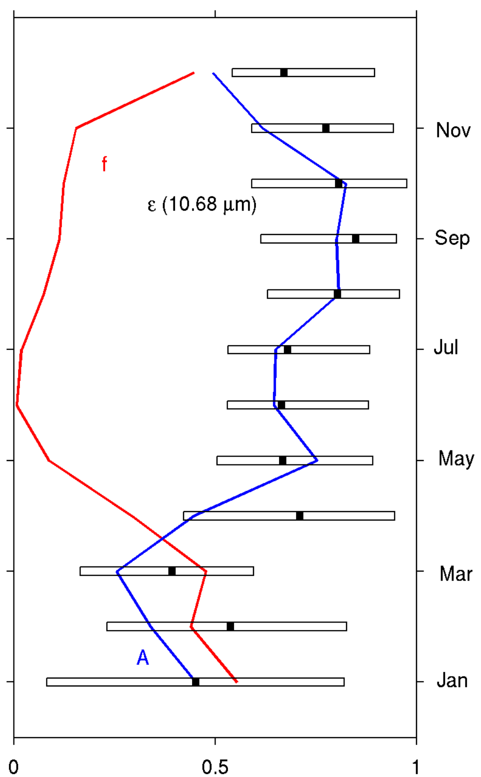
ARM

ASP

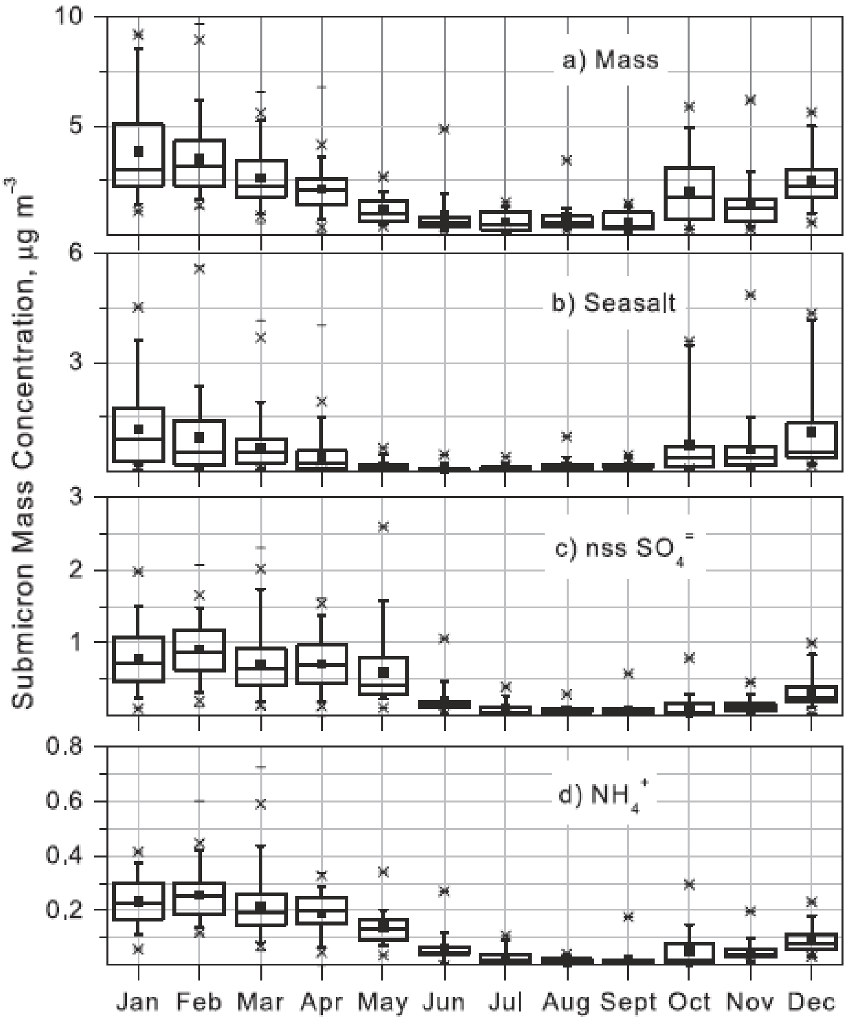
http://acrf-campaign.arm.gov/isdac/

Motivation

- Submicron arctic aerosol concentrations 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.*

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

Key Issues

- How do properties of the Arctic aerosol during April differ from those measured by the M-PACE during October?
- 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?
- 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?
- 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?
- 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?

ISDAC Key Issues

1. How do properties of the Arctic aerosol during April differ from those measured by the M-PACE during October?
2. 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?
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?
4. 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?

RISCAM Key Issues

- 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?
- 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?
- 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?
- What is the response of the effective radius to environmental aerosol loading for warm clouds in the Arctic?
- 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 aerosol 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?

3. 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, droplet dispersion, cloud optical depth, and longwave emissivity? How do these cloud properties depend on the degree of pollution?
- How do numbers of arctic IN vary as function of temperature and supersaturation, and how does this 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?

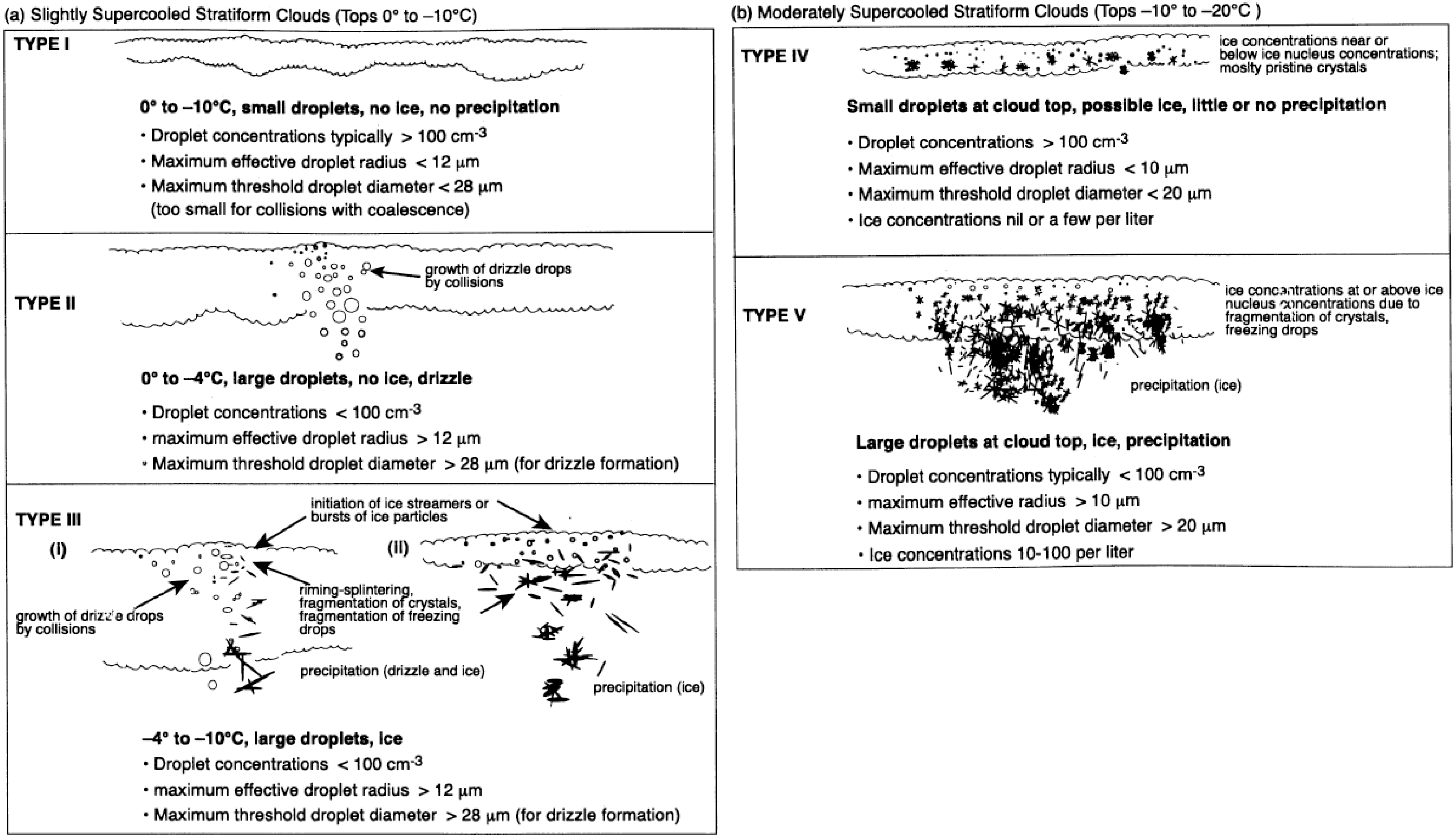
4. How well can cloud models and the cloud parameterizations used in climate models simulate the sensitivity of Arctic clouds and the surface energy budget to the differences in aerosol between April and October?

- 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?

5. 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?

Ice Formation Mechanisms (Rangno & Hobbs, 2001)



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

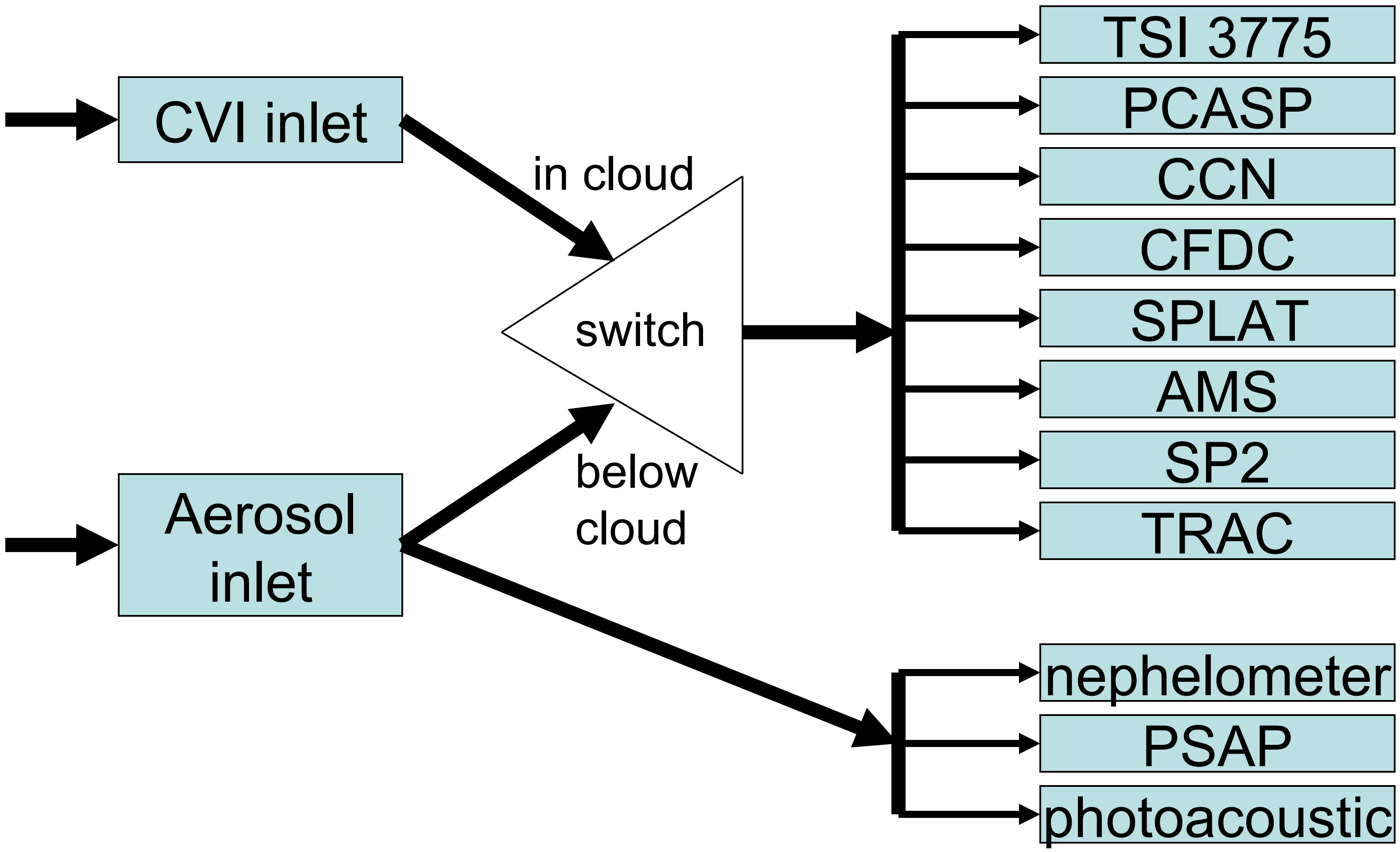
Instrument	**Measurements**
Atmospheric State	
3 Rosemont 102 probes	Temperature
NCAR reverse flow probe	Temperature
EG7G chilled mirror hygrometer	Humidity
LICOR LIC2G2	Water vapor and CO_2 mixing ratio
Rosemount 858 gust probe	Vertical velocity
Liquid/Super-cooled Liquid	
Rosemount icing (RICE) probe	Detects supercooled liquid
Vibrameter	Detects supercooled liquid
Nevzorov LWC/TWC probe	Liquid and total condensed water concentration
CSIRO King probe	Liquid water concentration
Cloud Microphysics	
DMT Cloud Spectrometer and Imager	Total water concentration
DMT Cloud, Aerosol and Precipitation Spectrometer	Temperature, liquid water and droplet number conc., cloud particle size distribution (0.5 ∠1500 μm)
SPEC Cloud Particle Imager	Cloud particle images (15 ∠2500 μm)
PMS FSSP-100X	Small particle spectrum (3 ∠45 μm)
PMS 2D2C	Imaging cloud particles (25 ∠800 μm)
SPEC 2DS	Cloud particle size distribution (50-1000 μm)
PMS 2DP	Imaging cloud particles (200 ∠6400 μm)
Korolev Cloud Extinction Meter	Cloud Extinction

Aerosol Instruments on Aircraft

Instrument	Measurement
Aerosol	
Condensation Nuclei Counter	Total particle concentration (> 3 nm)
PCASP / Ultra-High Sensitivity Aerosol Spectrometer	Aerosol size distribution (100-3000 nm)
DMT CCN counter	CCN concentration
Continuous Flow Diffusion Chamber	Ice nucleus concentration
PSAP	Optical absorption
Nephelometer	Optical scattering
3 laser photo-acoustic spectrometer	Aerosol absorption and scattering (405, 532 and 781 nm)
DMT Soot Photometer (SP2)*	Incandescent (black carbon) particle mass distribution
Aerosol Mass Spectrometer	Size-resolved aerosol composition (non-refractory)
Single particle laser ablation time of flight mass spectrometer*	Single particle size-resolved composition (refractory and non-refractory material)
Time-Resolved Aerosol Collector*	Time-resolved substrate for lab analysis (0.1 ∠7 µm)
Scanning Electron Microscope (linked with TRAC)*	Single aerosol particle analysis
Aerosol Sample Collection	
Aerosol inlet	Isokinetic aerosol inlet
Counter-flow Virtual Impactor	Separation of residual aerosol

* ASP support

Aerosol Instrument Configuration



Radiometers and Remote Sensing on Aircraft

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

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 μm
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 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

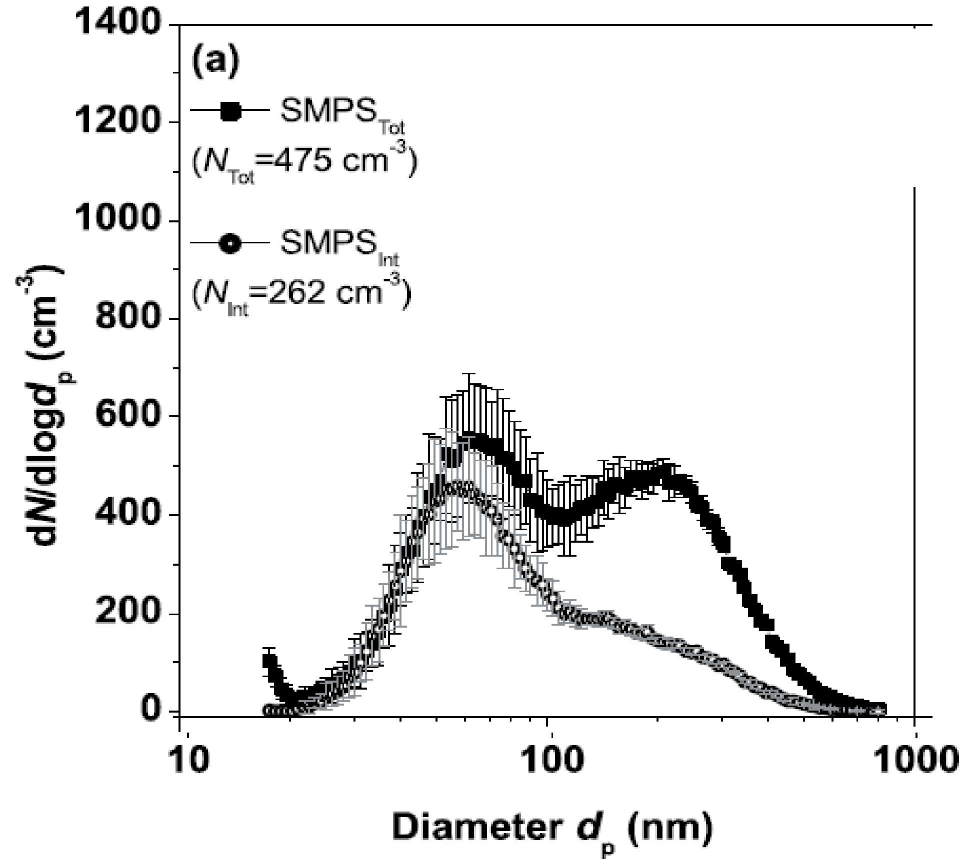
Experiment	Data Input	Validation Data
CCN closure	Aerosol size distribution Hygroscopicity distribution	CCN concentration
Droplet number closure	Aerosol size distribution, hygroscopicity distribution, vertical velocity	Droplet number concentration
Cloud water closure	Cloud particle size distribution	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
Aerosol scavenging	Same as for cloud modeling	Cloud-borne aerosol
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

Applications

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

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

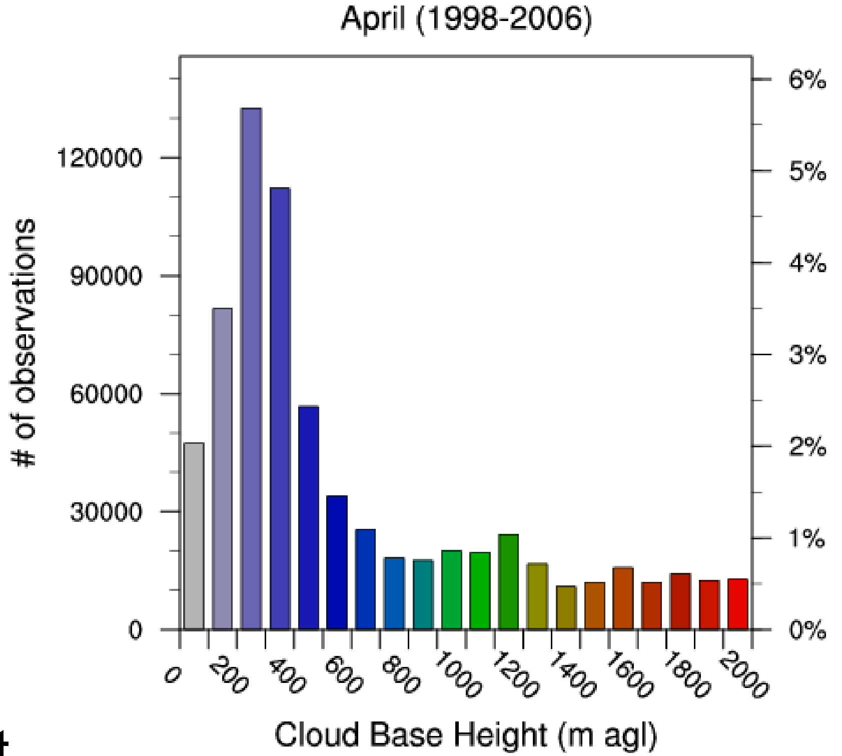
- Run with and without radiative heating by aerosol

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)



Questions?

Discussion Questions

- What lessons were learned from M-PACE that help us with planning ISDAC?
- What new or better measurements are needed?
  - Downward longwave
  - Surface temperature
- What science questions from M-PACE remain unanswered that can be answered by ISDAC?
  - Does drizzle suppression by pollution also inhibit crystal production by riming/splintering or freezing/shattering?
- What new questions can be answered by ISDAC?

Questions for Discussion

- Should instruments be eliminated or the experiment shortened if the U.S. $ continues to slide?
- Which instruments could be eliminated with the least impact on applications?
- Which applications should be eliminated if necessary?
- Given the instruments planned for the experiment, are there any valuable applications that have not been listed?