Indirect and Semi-Direct Aerosol Campaign (ISDAC)

The Influence of Arctic Aerosol on Clouds

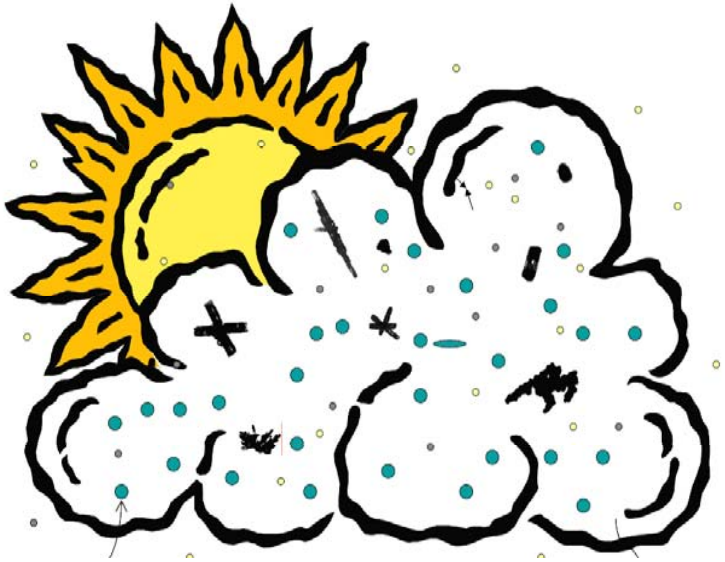
PIs: Steve Ghan, Greg McFarquhar, Hans Verlinde

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

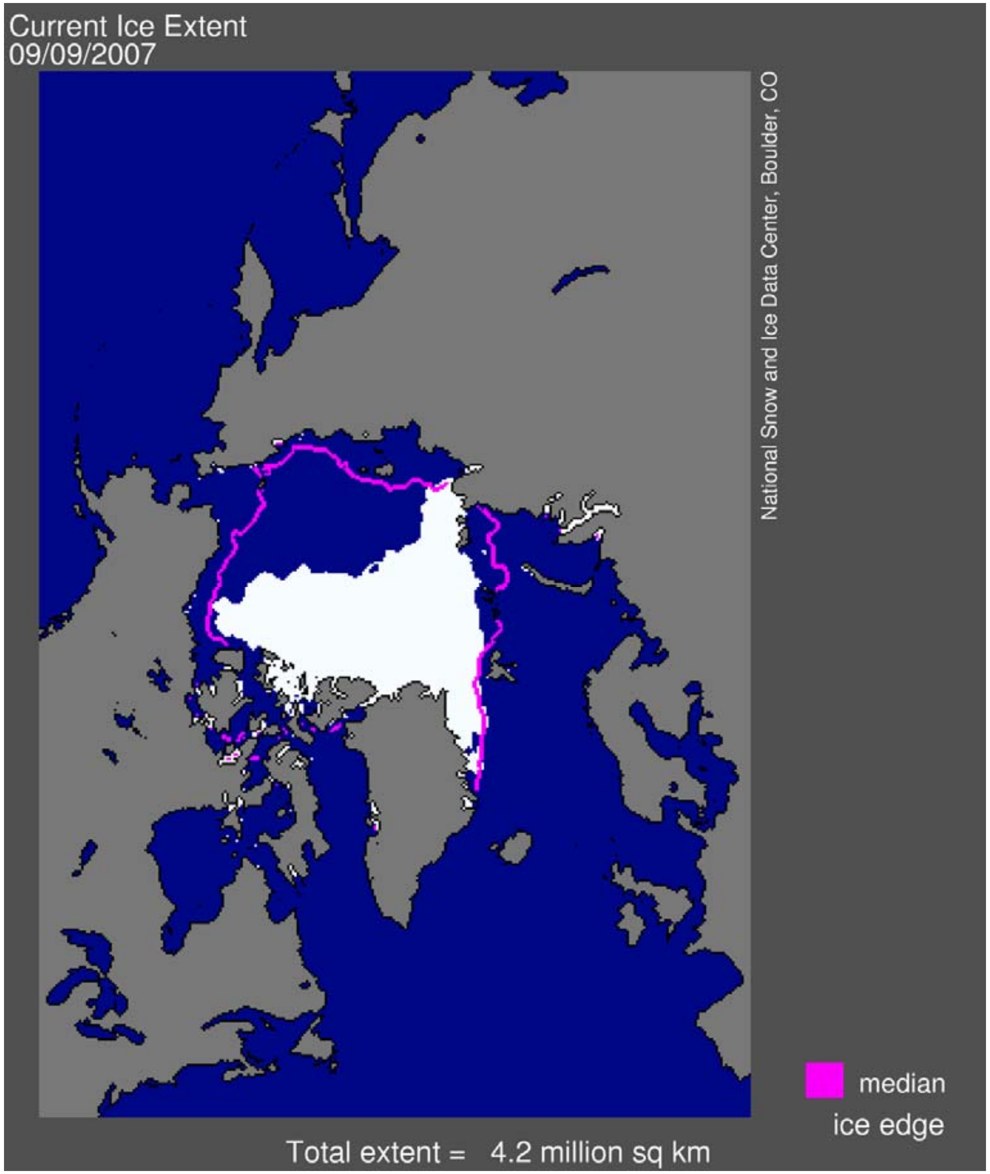


Barrow, Alaska

April 2008

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

Motivation

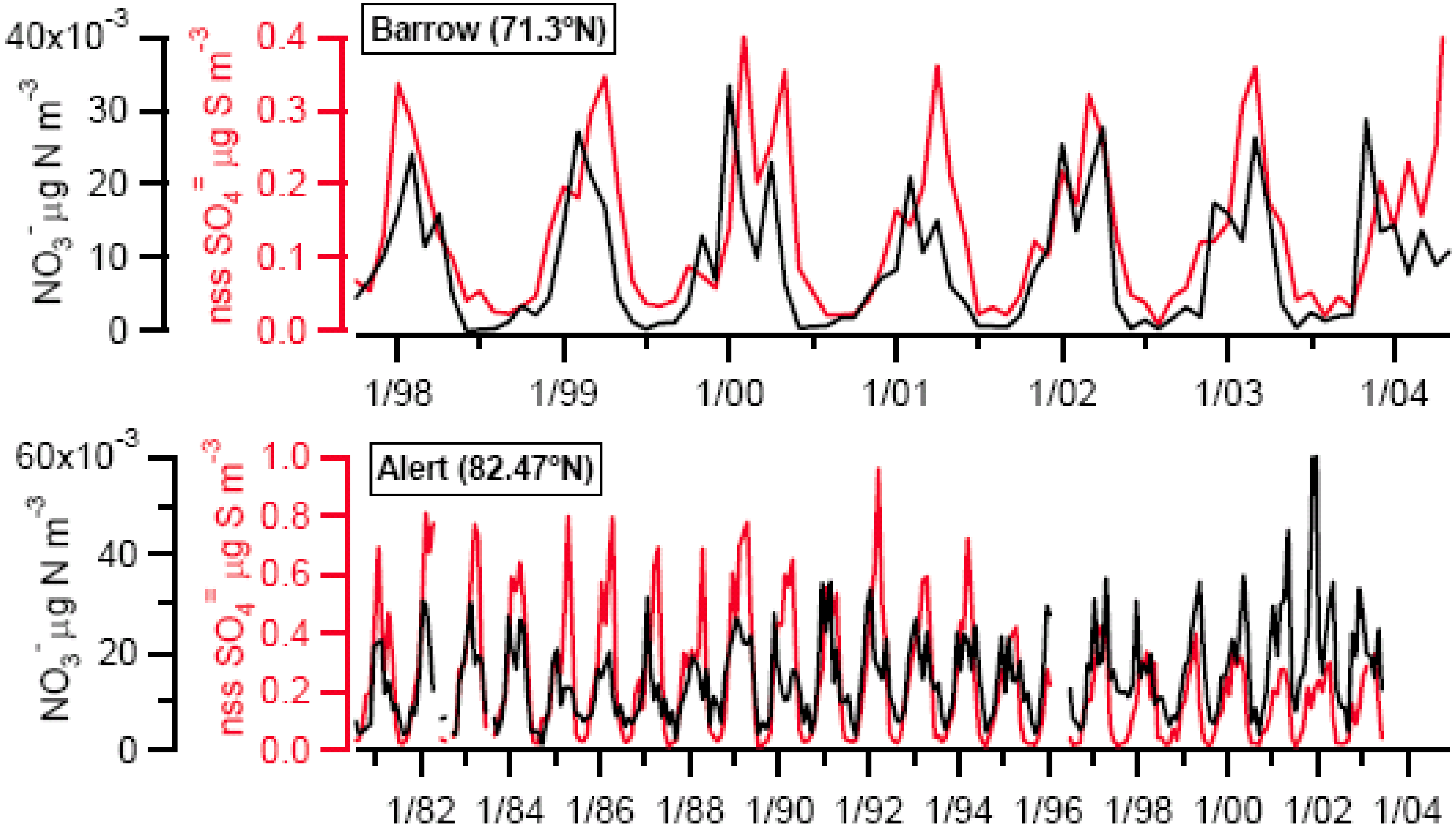


- Summertime Arctic sea ice has decreased dramatically in recent years, beyond climate model predictions.
- The Arctic is projected to be ice free during summer within 10-20 years.
- The role of clouds and aerosols in the loss of sea ice is not understood.

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



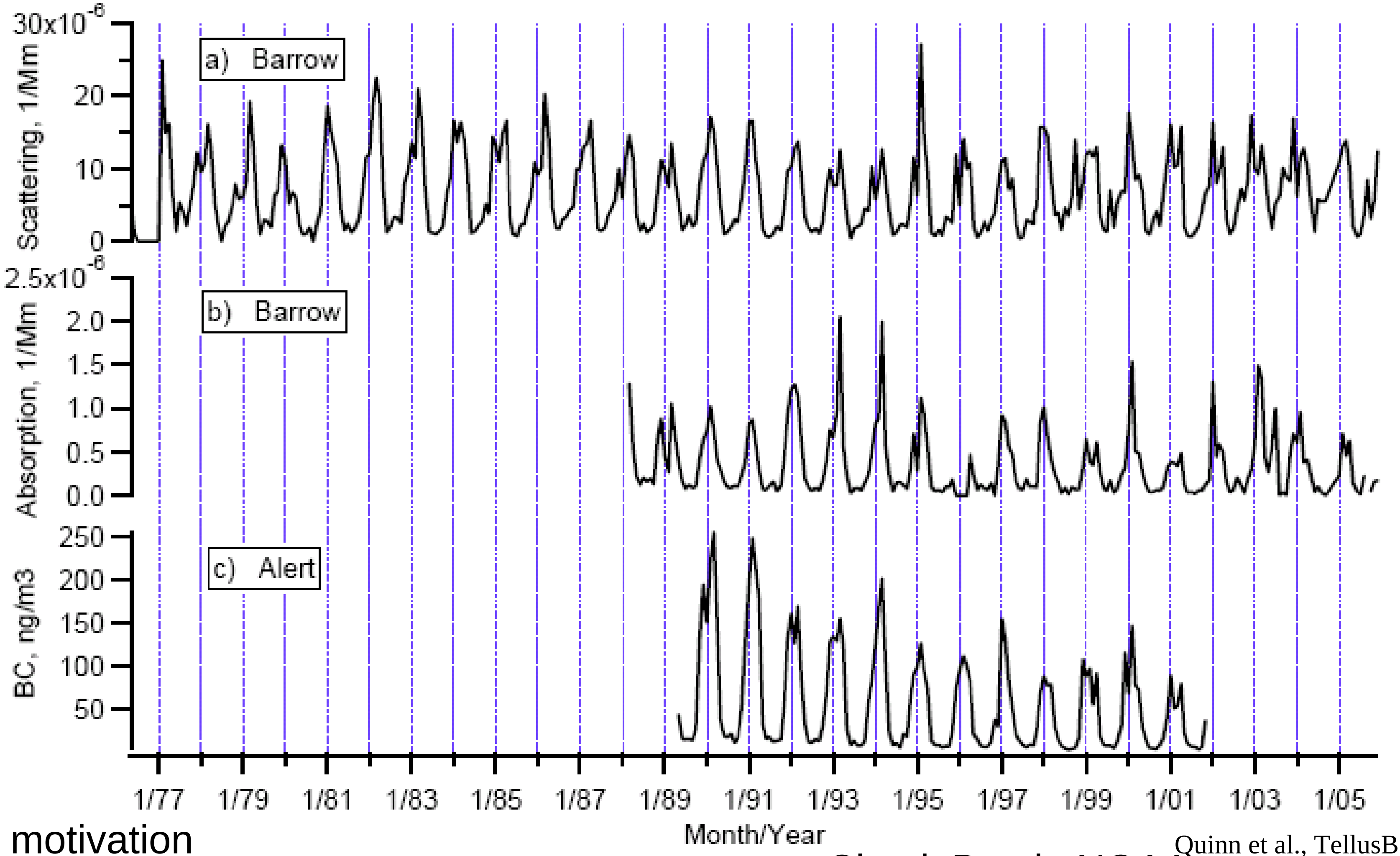
Quinn et al., *Tellus B, 2007*

motivation

Chuck Brock, NOAA

Similar annual cycle for scattering, absorption, black carbon

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



motivation

Quinn et al., TellusB, 2007.

Chuck Brock, NOAA

The Role of the Arctic Front

Arctic Monitoring and Assessment Programme, 2006

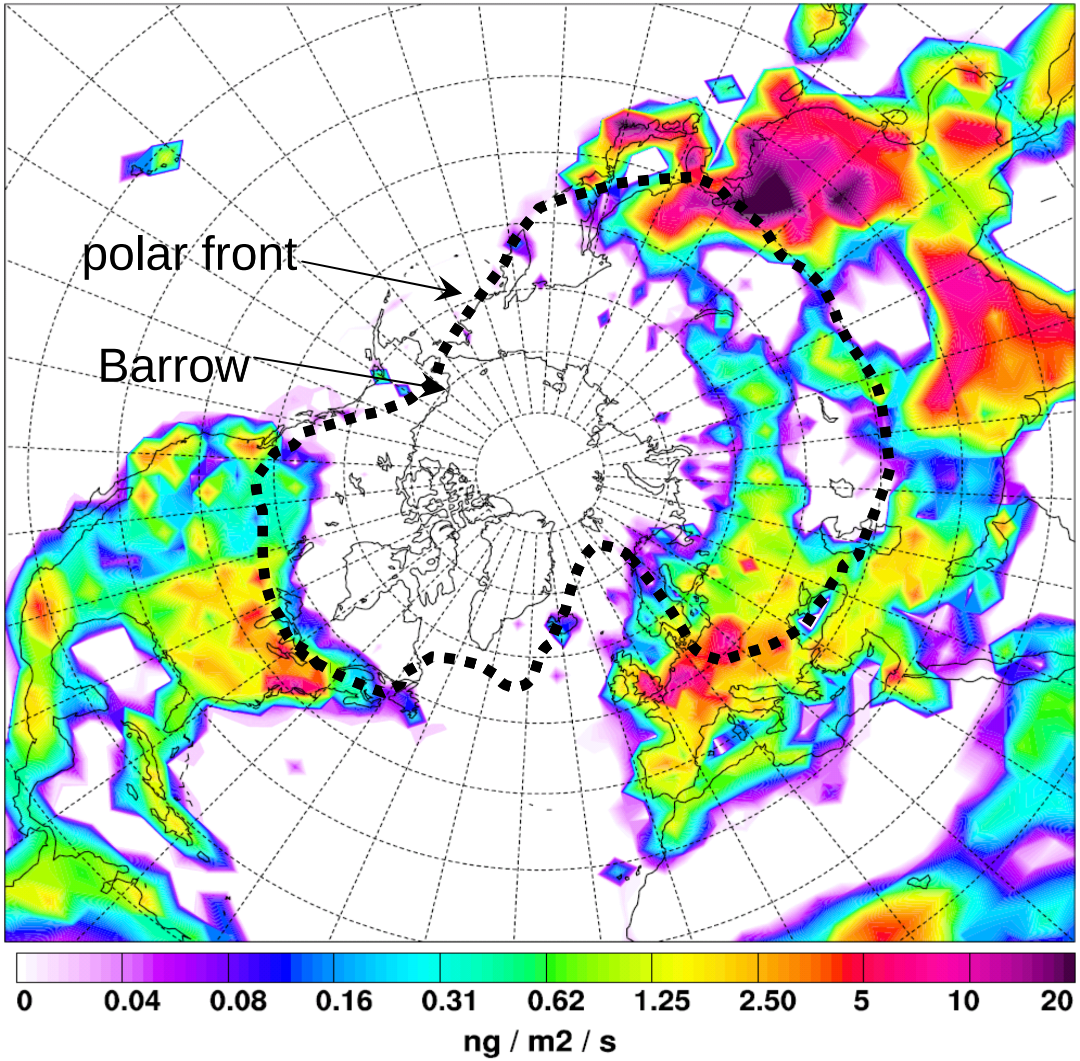
Sources for surface haze generally lie within the Arctic front

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

Chuck Brock, NOAA

motivation

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.

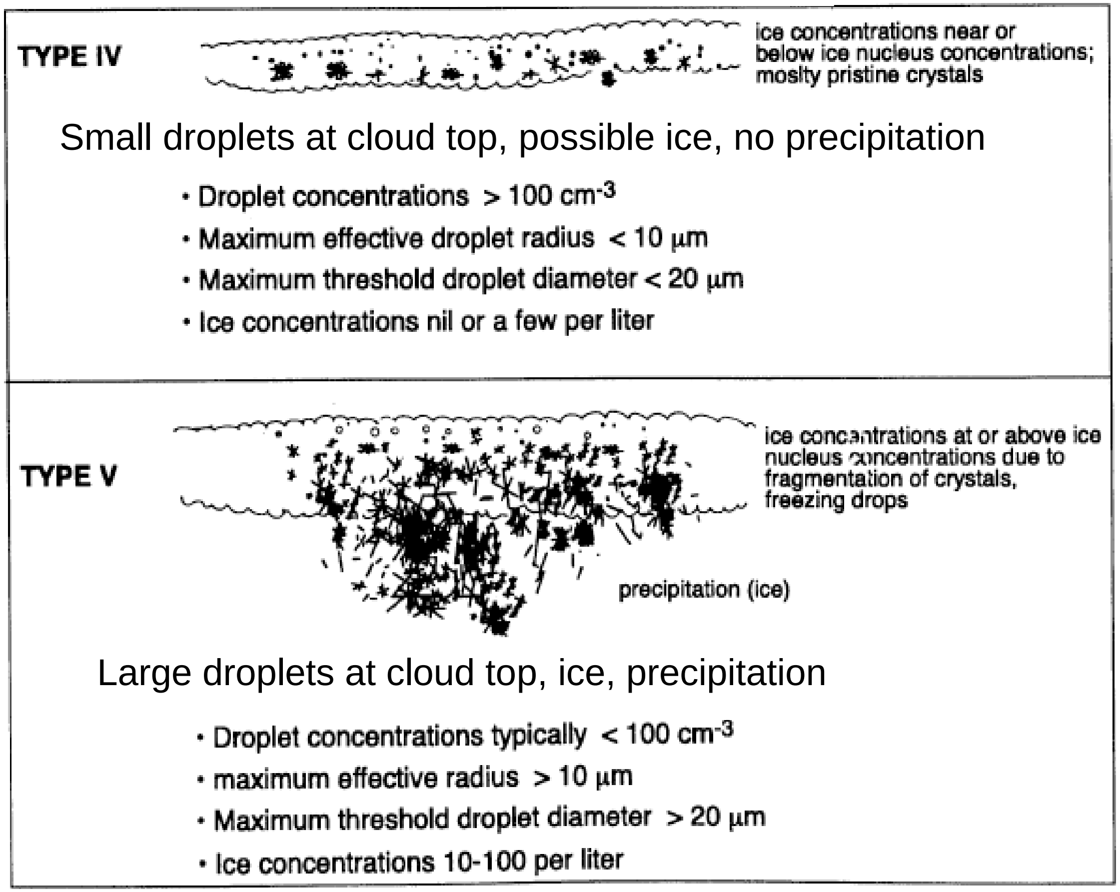
motivation

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.

Ice Formation Mechanisms: April vs October



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

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

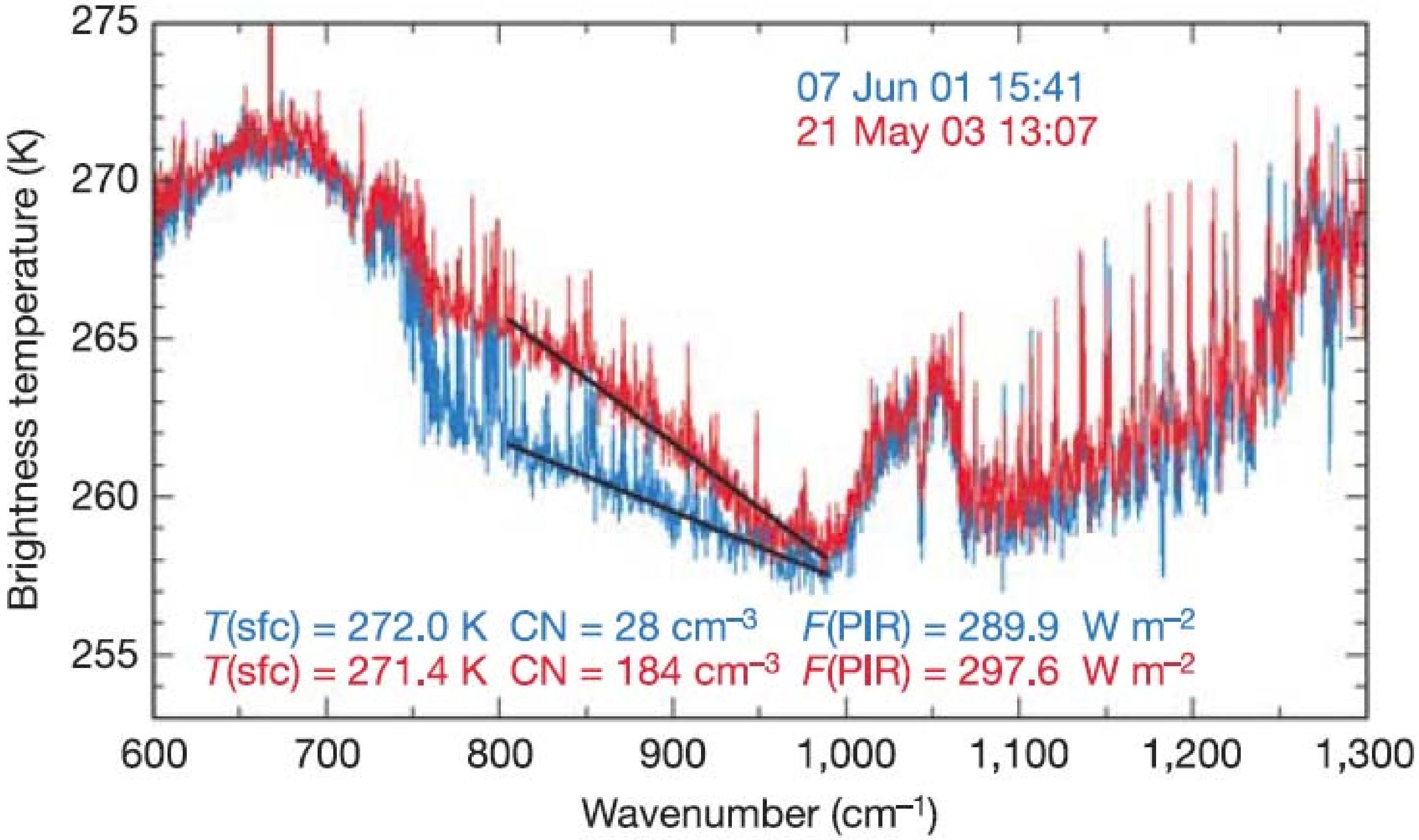
Rangno & Hobbs (2001)

Type IV conditions expected during ISDAC in April 2008.

Type V conditions encountered during M-PACE in October 2004.

motivation

A Longwave Aerosol Indirect Effect



Lubin & Vogelmann, Nature 2006

motivation

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

- Are CCN and IN concentrations 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. 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

Instruments on Aircraft

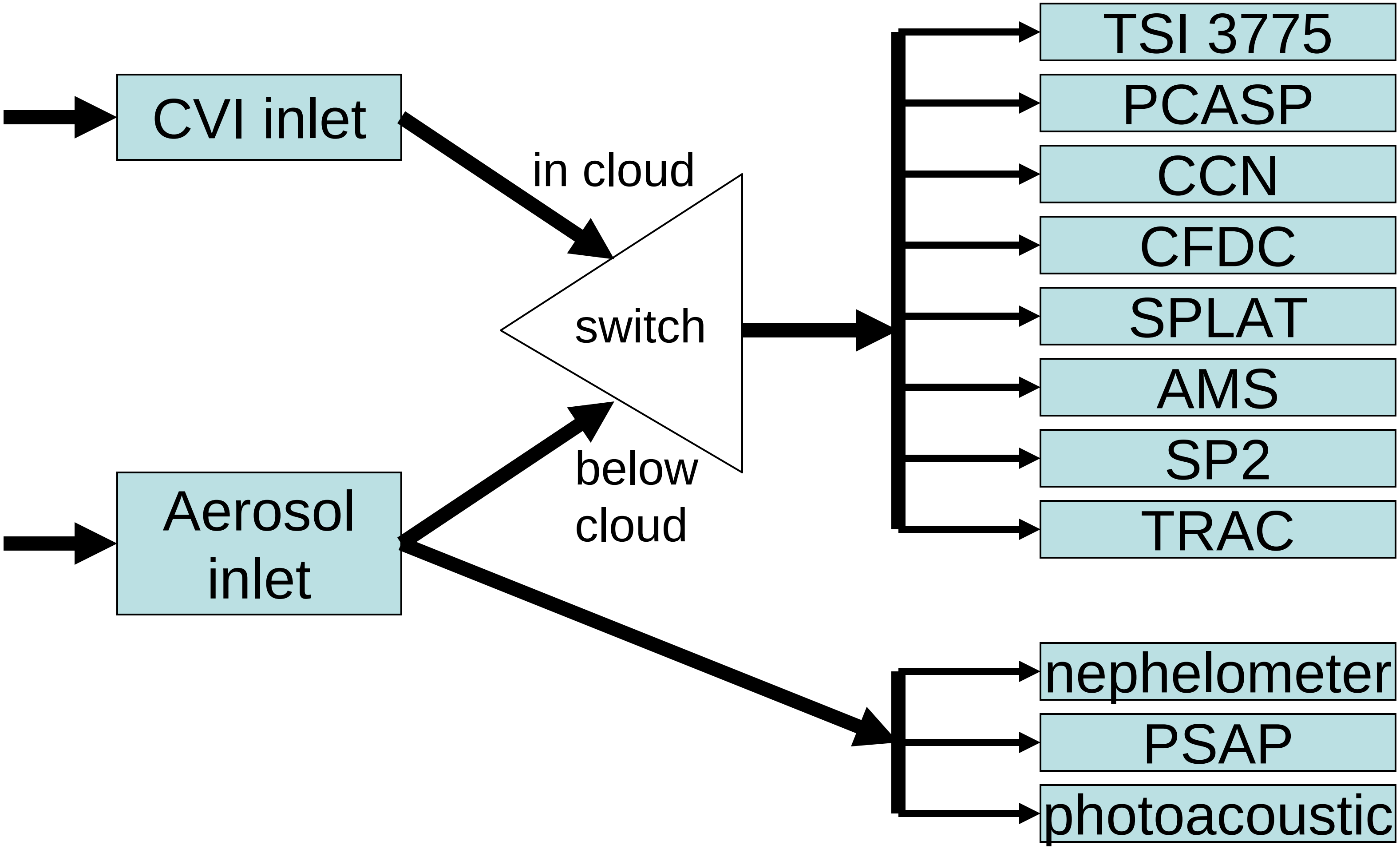
Instrument	Measurements	Investigator
Atmospheric State		
3 Rosemont 102 probes	Temperature	Mengistu Wolde
NCAR reverse flow probe	Temperature	Walter Strapp
EGG chilled mirror hygrometer	Humidity	Walter Strapp
LICOR	Water vapor and CO_2 mixing ratio	Mengistu Wolde
Rosemount 858 gust probe	Vertical velocity	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 Š 1500 µm)	Greg McFarquhar
SPEC Cloud Particle Imager	Cloud particle images (15 Š 2500 µm)	Greg McFarquhar Paul Lawson
PMS FSSP-100X	Small particle spectrum (3 Š 45 µm)	Walter Strapp
PMS 2D2C	Imaging cloud particles (25 Š 800 µm)	Walter Strapp
SPEC 2DS	Cloud particle size distribution (50-1000 µm)	Paul Lawson
PMS 2DP	Imaging cloud particles (200 Š 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**
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 Š 7 µm)**	**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



CVI inlet

in cloud

switch

below cloud

Aerosol inlet

TSI 3775

PCASP

CCN

CFDC

SPLAT

AMS

SP2

TRAC

nephelometer

PSAP

photoacoustic

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
W-band Doppler radar, dual polarization, up/down/side looking	radar cross section, hydrometeor type identification	Mengistu Wolde

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

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

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 ARCTAS (P-3 and B200)
  - NOAA ARCPAC (WP-3D)

Questions?