Indirect and Semi-Direct Aerosol Campaign (ISDAC)

The Influence of Arctic Aerosol on Clouds

PIs: Greg McFarquhar, Steve Ghan, Hans Verlinde
ARM AAF: Beat Schmid, Greg McFarquhar, John Hubbe, Debbie Ronfeld
In situ measurements: Sarah Brooks, Don Collins, Dan Czcico, 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
Why in Arctic?

- Arctic warming faster than models can simulate
- Stratiform clouds prevalent in Arctic
- Cloud feedbacks more important and poorly understood in Arctic compared to elsewhere
- 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 common in Arctic
  - Aerosols have strong seasonal cycle in Arctic to examine indirect effects
  - Unclear why mixed-phase clouds persist
M-PACE: Sept. 27 to Oct. 22 2004

Barrow

95 km

Atqasuk

267 km

Oliktok Point

360 km

Toolik Lake

201 km
Objective:
Collect focused set of observations to advance understanding of dynamical and microphysical processes in mixed-phase clouds, including radiative transfer through clouds.
Motivation: going beyond M-PACE

- Wanted similar & better data from ISDAC
  - to describe how differences between spring and fall arctic aerosols produce differences in cloud properties & surface energy balance
  - to make more comprehensive observations of aerosols and to fill in missing elements of M-PACE cloud observations (small ice)
1. How do properties of the Arctic aerosol during April differ from those measured by M-PACE during October?

2. To what extent do different properties of arctic aerosol during April produce differences in microphysical and macrophysical properties of clouds and the surface energy balance?

3. How well can cloud models and 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?
ISDACC Air Platform

Primary observation platform for ISDACC was National Research Council of Canada Convair

Equipped by Environment Canada, NRC, universities and private companies with 41 instruments to measure aerosol and cloud particles from 1 nm to > 10 mm in size
ISDAC Flight Operations

- 27 project sorties representing 103.6 hours of data on 12 different flight days
- Golden days with single-layer strato-cumulus on 8 and 26 April when 3 sorties flown; heavily polluted data on 19 April
What data did we get for ISDAC?

- Got 27 project sorties representing 103.6 hours of data on 12 different flight days
- Golden days with single-layer strato-cumulus on 8 and 26 April when 3 sorties flown; heavily polluted data on 19 April
Aerosol Instrument Configuration

CVI inlet

in cloud

switch

TSI 3775
UHSAS
CCN
CFDC
SPLAT
TRAC

Aerosol inlet

below cloud

nephelometer
PSAP
photoacoustic
What did we measure in cloud?

- **Size distributions:**
  - Forward scattering probes with and without shrouds, including those measuring interarrival times on some flights ($1 < D < 50 \, \mu m$)
  - Optical array probes covering complete range of particle sizes ($50 \, \mu m < D < 10 \, mm$)

- **High-resolution images of hydrometeors**

- **Bulk parameters**
  - Bulk liquid water and total water
  - Bulk extinction
  - Flag for presence of supercooled water

- **Redundancy key to microphysical measurements**
  - assess consistency & performance of multiple probes through closure tests (extinction & mass)
  - address question of crystal shattering and measurement of small crystals
Applications of ISDAC data

- CCN closure
- Droplet number closure
- Aerosol composition-microphysics-optics
- Cloud extinction closure
- Cloud water closure
- Cloud modeling
- Semi-direct effect
- Crystal nucleation
- Aerosol extinction retrieval
- CCN retrieval
- MMCR retrievals
- MWR retrievals
- AERI retrievals
- ASD retrievals
Applications of ISDAC data

- CCN closure
- Droplet number closure
- Aerosol composition-microphysics-optics
- Cloud extinction closure
- Cloud water closure
- Cloud modeling
- Semi-direct effect
- Crystal nucleation
- Aerosol extinction retrieval
- CCN retrieval
- MMCR retrievals
- MWR retrievals
- AERI retrievals
- ASD retrievals

In order to use ISDAC data for these applications, must quality control and understand nature of the measurements: thus far, many investigators have concentrated on this
Applications of ISDAC data

- CCN closure
- Droplet number closure
- Aerosol composition-microphysics-optics
- Cloud extinction closure
- Cloud water closure
- Cloud modeling
- Semi-direct effect
- Crystal nucleation
- Aerosol extinction retrieval
- CCN retrieval
- MMCR retrievals
- MWR retrievals
- AERI retrievals
- ASD retrievals

In order to use ISDAC data for these applications, must quality control and understand nature of the measurements: thus far, many investigators have concentrated on this. Integrated cloud product being developed to allow for easier use of data in investigations.
Image of single-layer cloud sampled on 8 April

Korolev and Strapp
Flight profiles involved legs above & below, and porpoises & constant altitude legs through clouds.

These flight profiles will permit investigation of cloud/aerosol interactions and are ideal for comparing against process-oriented modeling studies.
NRC NAX radar
X band radar Z and $V_d$ crossections
Constant SDs suggest nucleation throughout OR significant vertical mixing

26 April 2006, Flight #31

Alexei Korolev
Hi-res model with bin liquid/ice μphysics gives quasi steady mixed-phase single-layer (J. Fan)

Ice nucleation, constrained with $N_i = 4 \text{ l}^{-1}$, needed to maintain mixed-phase clouds
Future Modeling Studies

- Need quantitative comparison between model/observed cloud: dynamics & μphysics coupling stronger for ISDAC since reduced latent/sensible heat flux off ice-covered surface

- ISDAC/M-PACE boundary condition different
  → separate influence of bc & aerosols with:
  - M-PACE aerosol & bc
  - M-PACE aerosol & ISDAC bc
  - ISDAC aerosol & M-PACE bc
  - ISDAC aerosol & bc
How do enhanced aerosols affect cloud microphysics?

Does variation depend on IN or on changes in liquid drops associated with CCN, or secondary ice crystal production?

Chemistry of particles important
Research Progress

• **BAMS Science paper**

• **Special Issue planned for J. Geophys. Res.:**
  - Earle et al., Sulfate trend in the Arctic and its relationship to the Arctic particle size distribution
  - Shantz et al., Aerosol physical and chemical characteristics during clean and polluted episodes during ISDAC flights in Alaska
  - Gultepe, Aerosol and cloud effect on broadband fluxes based on in-situ measurements
  - Lubin, Effect of arctic cloud thermodynamic phase on spectral shortwave irradiance
  - Shupe et al., Comparison of cloud microphysics and dynamical-microphysical relationships between MPACE and ISDAC using ground based sensors
Research Progress

• **Special Issue planned for J. Geophys. Res.:**
  - Brooks et al., Ice nucleation as a function of aerosol source and composition
  - Avramov et al., Modeling study of ice formation closure during ISDAC
  - Solomon et al., WRF model studies comparing the cloud forcing mechanisms between MPACE and ISDAC
  - Ovchinnikov et al., Modeling aerosol effects in Arctic mixed-phase stratiform clouds
  - Fan et al., Representation of Arctic mixed-phase clouds and Wegener-Bergeron-Findeisen process
  - Liu et al., Testing cloud microphysics parameterization in CAM with ISDAC data in comparison with M-PACE
Summary

• Unique set of data acquired during MPACE/ISDAC
  – Useful for model and remote sensing evaluation, and for parameterization development
  – Making progress in understanding cloud and aerosol measurements
  – All data available on archive; derived products to follow

• Single-layer clouds have consistent structure
  – Ice occurs throughout cloud, with little evidence of height dependence
  – Vertical mixing driven by dynamics/turbulence
  – Ideal for hypothesis testing in modeling studies
Summary

• **Indirect/semi-direct aerosol effects**
  – Important to consider dynamical, mixing & turbulent processes when examining such effects
  – Future modeling/analysis/observational efforts needed to better understand these impacts
Opportunities

1. Test current understanding of droplet & crystal nucleation
2. Improve understanding of aerosol effects on lifecycle & radiative properties of mixed-phase clouds
3. Evaluate & improve representation of mixed- and ice-phase clouds in variety of cloud models
4. Test impact of isolated processes, such as droplet nucleation, on modeled fields
5. Test and improve remote sensing retrievals of cloud & aerosol properties from surface and space so that ISDAC observations can be extended to longer time period