Indirect and Semi-Direct Aerosol Campaign (ISDAC)

The Influence of Arctic Aerosol on Clouds

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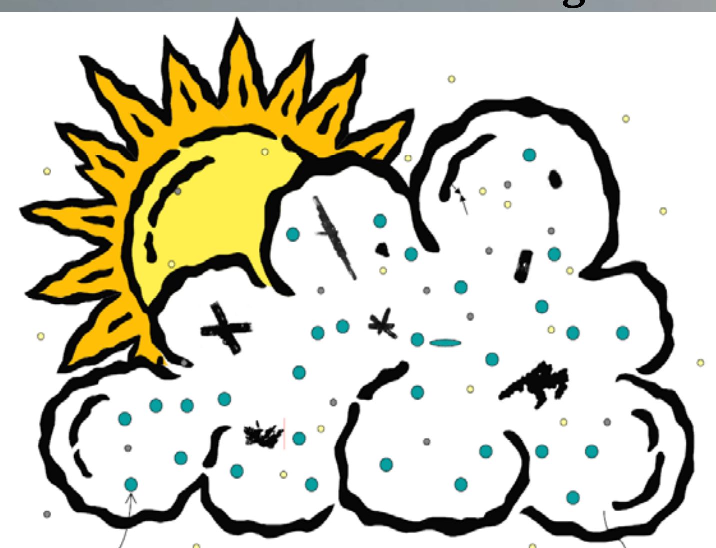

Barrow, Alaska April 2008

ARM

ASP

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

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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)

Key ISDAC Issues

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?

ISDAC Air Platform

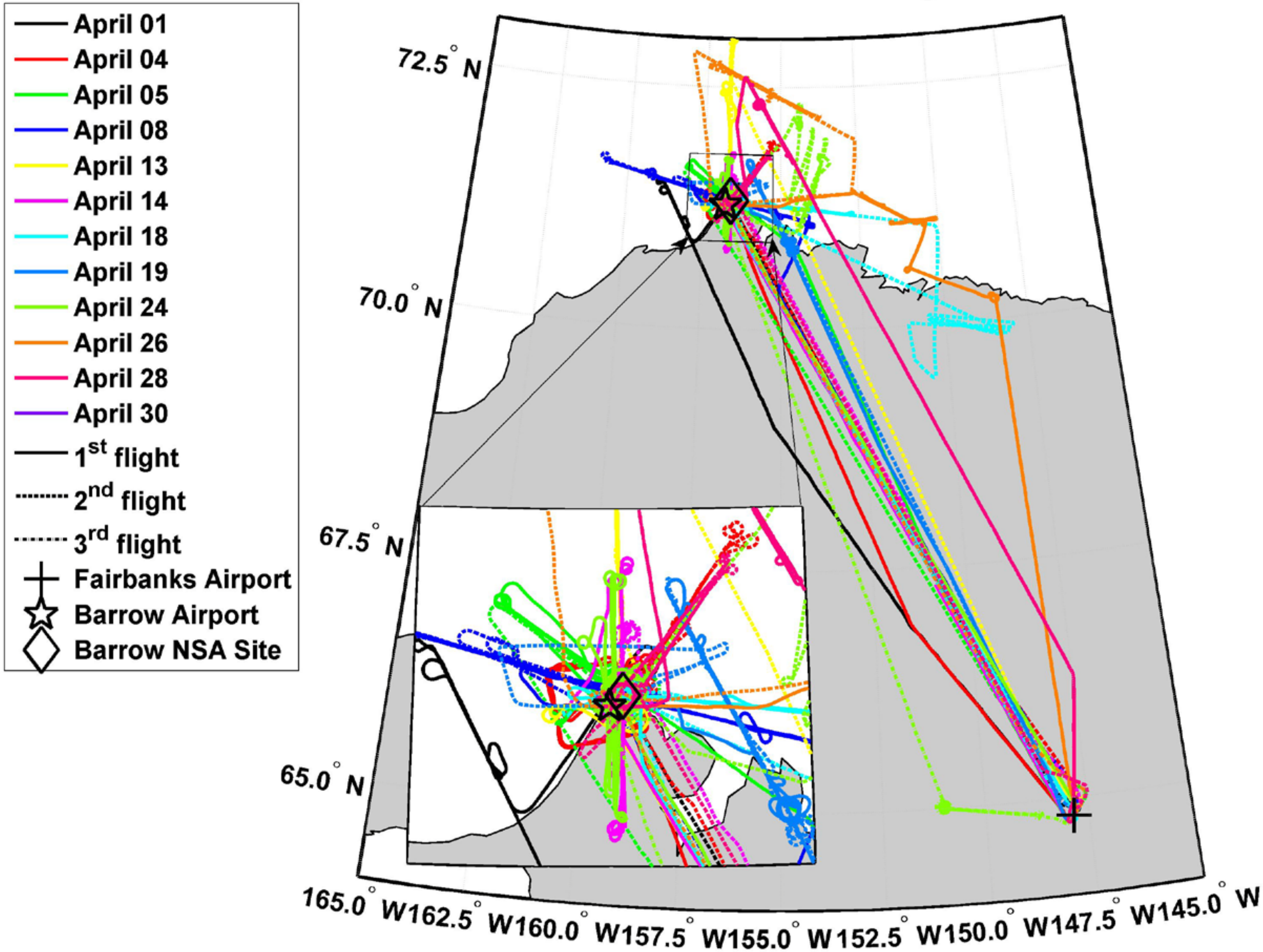
Primary observation platform for ISDAC was National Research Council of Canada Convair

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

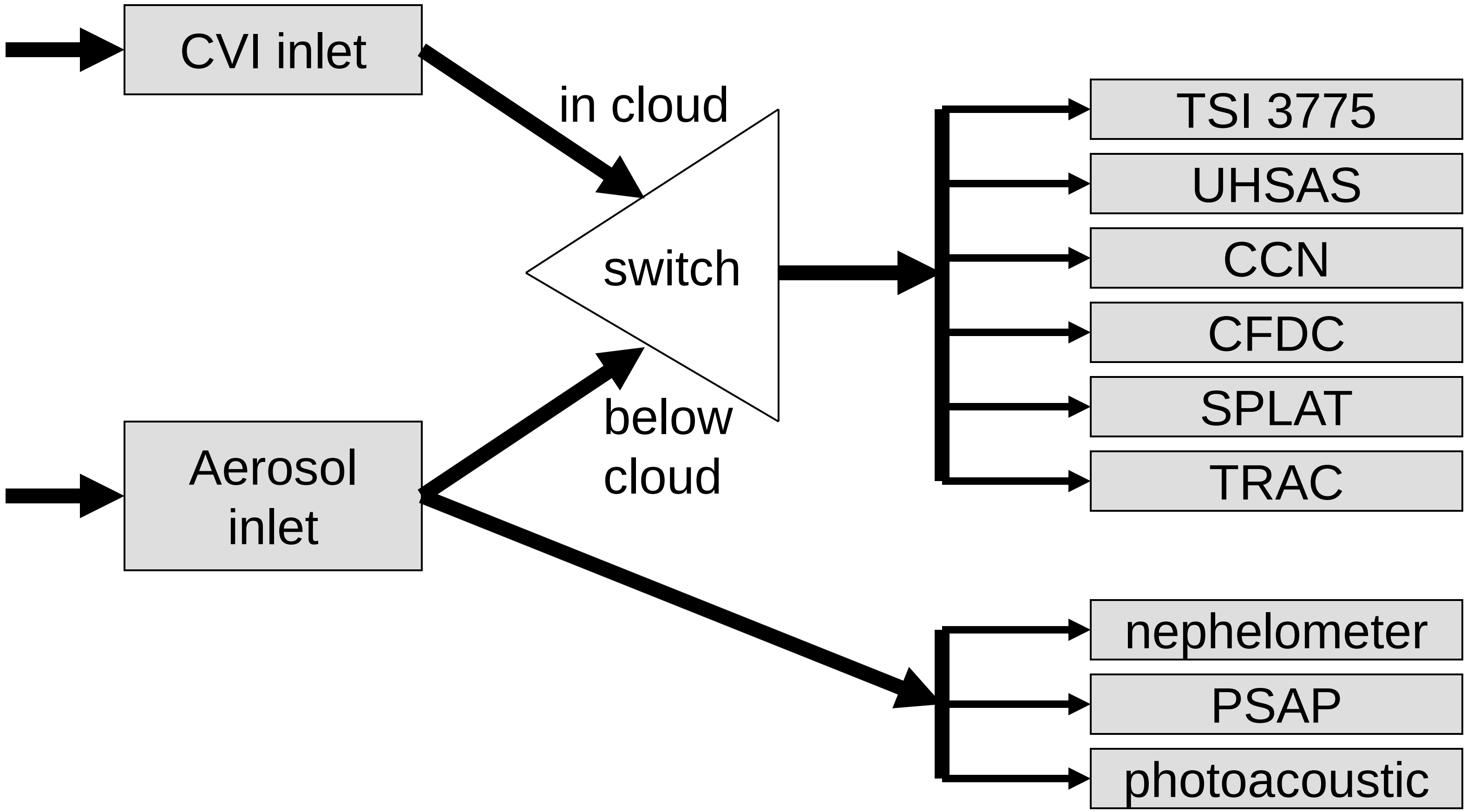
ISDAC Flight Operations

- 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

Track of all ISDAC flights



Aerosol Instrument Configuration



Pacific Northwest
NATIONAL LABORATORY

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 μm)
  - Optical array probes covering complete range of particle sizes (50 μm < 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

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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

Image of single-layer cloud sampled on 8 April

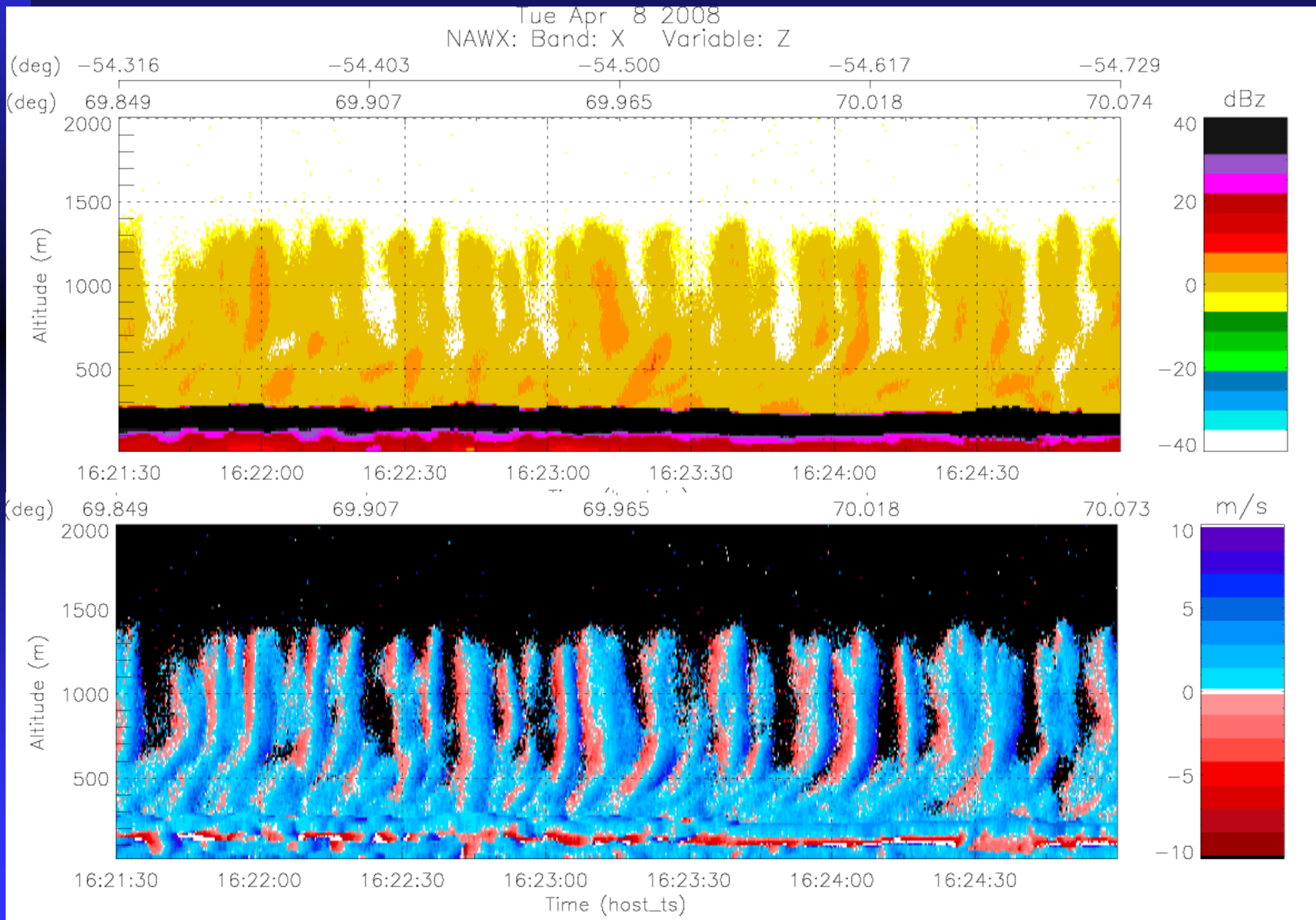
Flight profiles involved legs above & below, and porpoises & constant altitude legs through clouds

These flight profiles will permit investigation of cloud/aerosol interactions and are ideal for comparing against process-oriented modeling studies

Korolev and Strapp

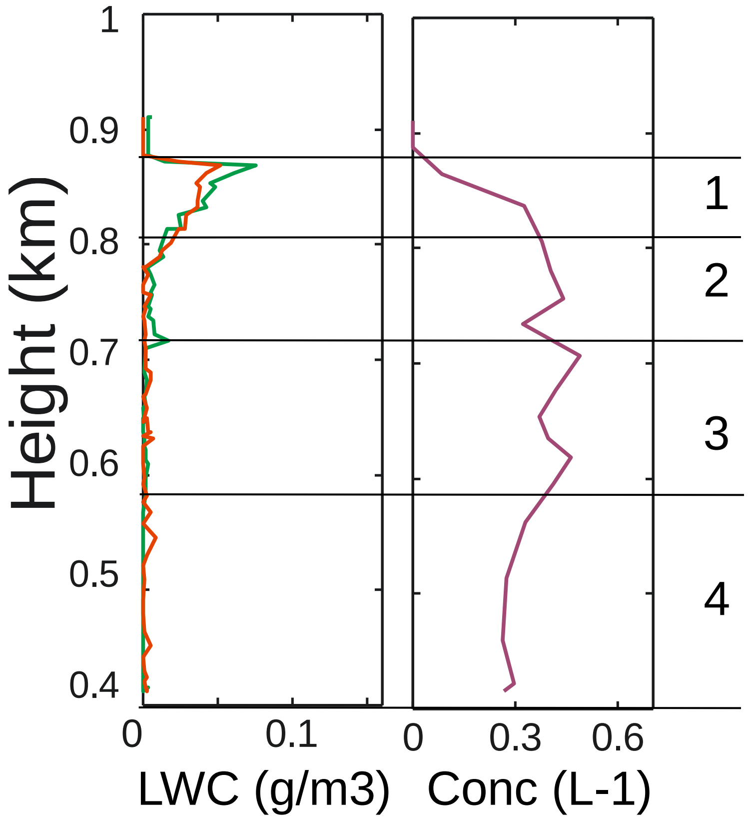
NRC NAX radar

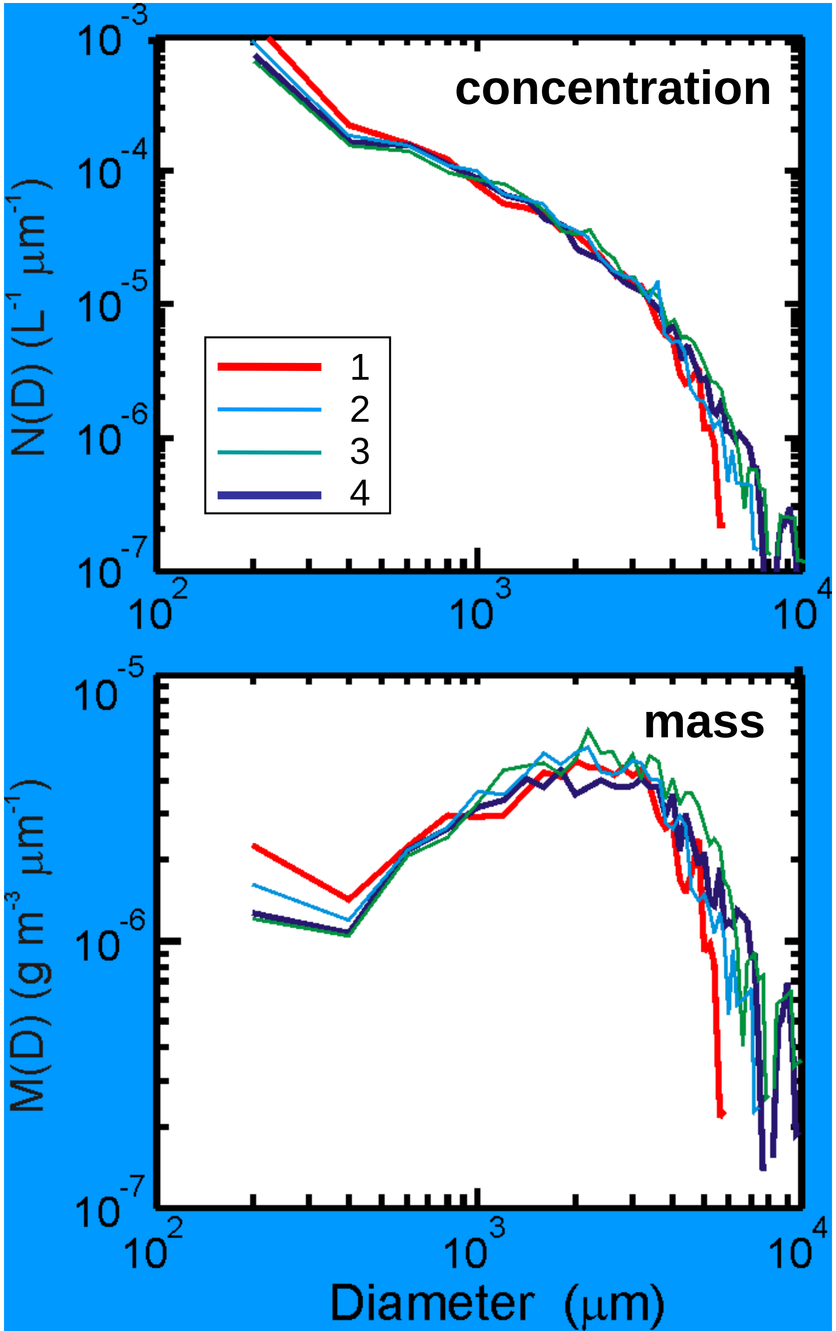
X band radar Z and V_d crossections



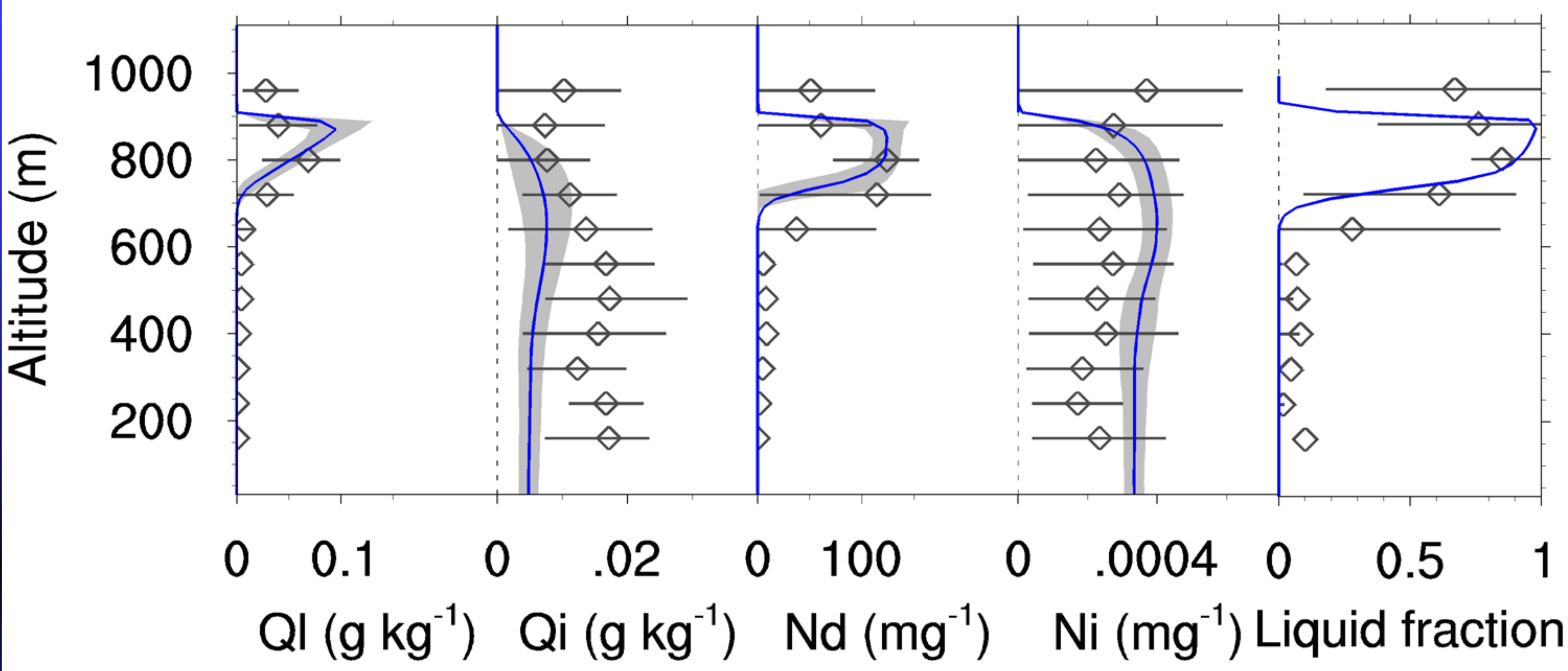
Alexei Korolev

26 April 2006, Flight #31





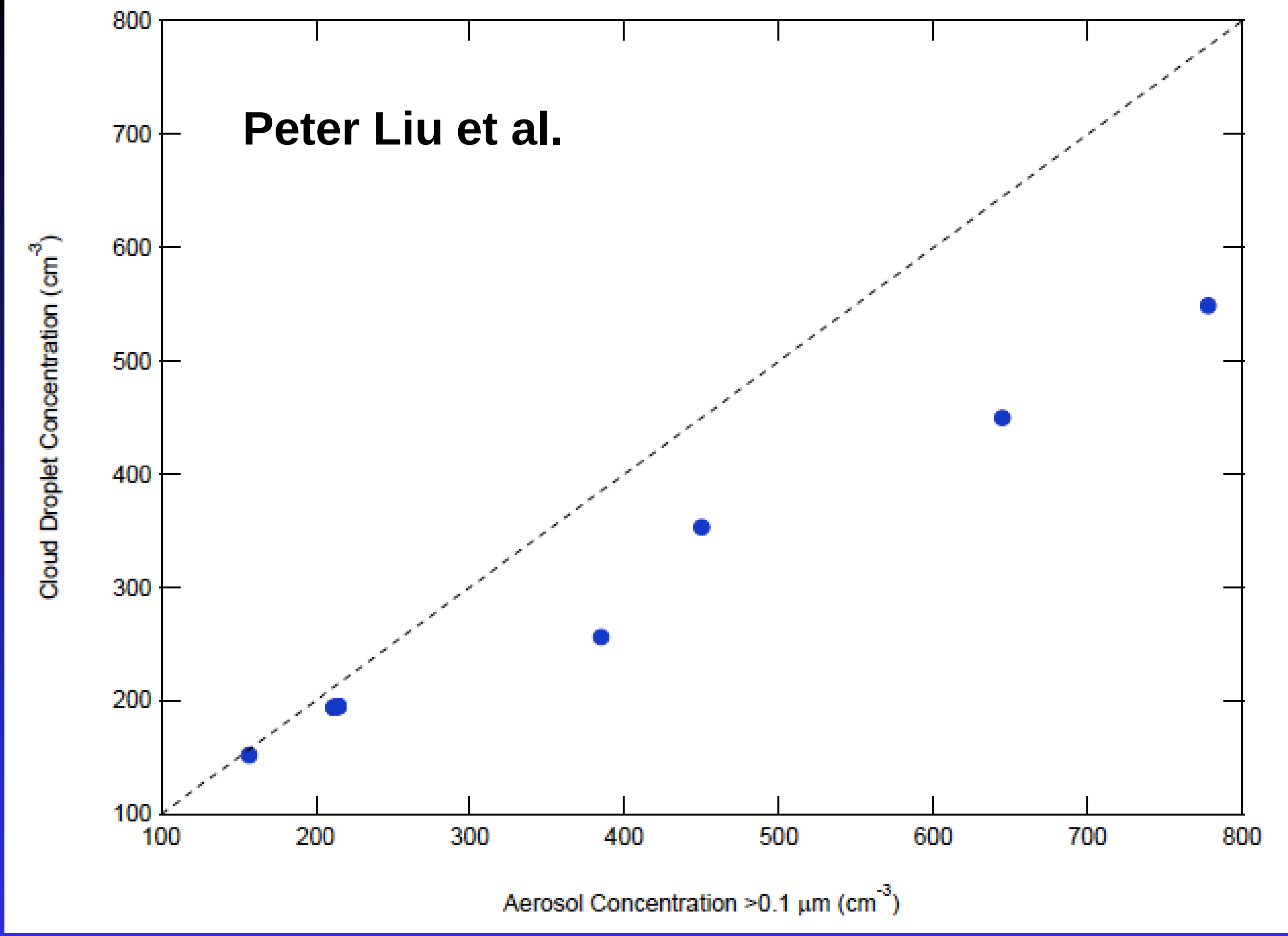
Constant SDs suggest nucleation throughout OR significant vertical mixing



- **Hi-res model with bin liquid/ice μphysics gives quasi steady mixed-phase single-layer (J. Fan)**
- **Ice nucleation, constrained with $N_i = 4\ l^{-1}$, 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 µphysics?
- 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**
  - McFarquhar et al., The Indirect and Semi-Direct Aerosol Campaign: The impact of arctic aerosols on clouds, Bull. Amer. Meteor. Soc., In press (Dec. 2010)
- **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 epsidoes 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**