Indirect and Semi-Direct Aerosol Campaign (ISDAC)
The Influence of Arctic Aerosol on Clouds

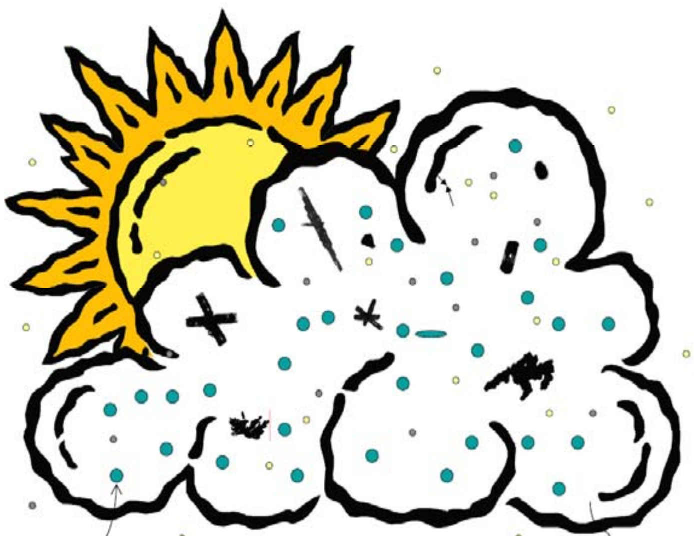
PIs: Greg McFarquhar, Steve Ghan, Hans Verlinde

ARM AVP: Beat Schmid, Greg McFarquhar, Jasin Tomlinson, John Hubbe, Debbie Ronfeld

In situ measurements: Sarah Brooks, Don Collins, Dan Cziczo, Manvendra Dubey, Ismail Gultepe, 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, David Mitchell, Rich Ferrare, Matthew Shupe, David Turner, Mengistu Wolde

Modeling: Mikhail Ovtchinnikov, Shaocheng Xie, Ann Fridlind , Xiaohong Liu



Barrow, Alaska April 2008

ARM

ASP

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

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Outline

- Motivation

  Arctic is warming much faster than models simulate.

- Key Questions

  Can aerosol-cloud-snow interactions resolve this issue?

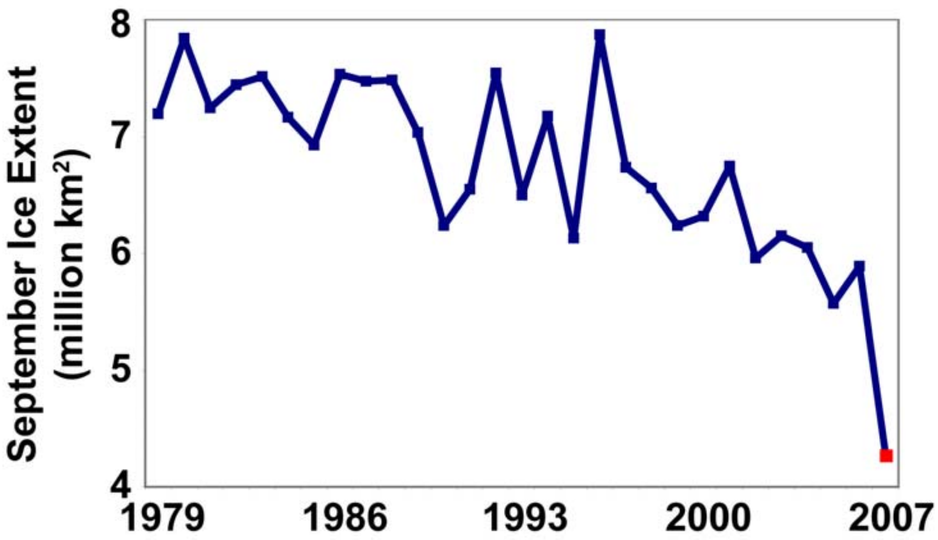
- ISDAC Observational Strategy

  State-of-art remote & in situ measurements of aerosol-cloud microphysics, chemistry and optical properties at and over NSA.

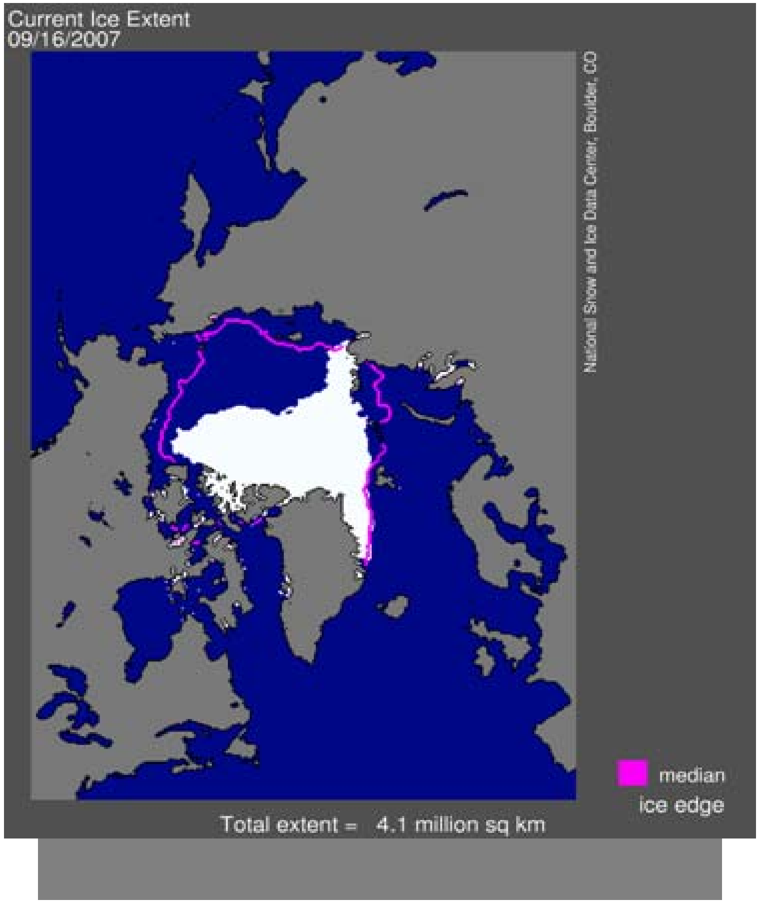
- First Results

  Aerosol measurements and cloud modeling

2007 Record Minimum Arctic Sea Ice Extent



September Arctic sea ice extent
(credit: NSIDC)



Credit: NSIDC

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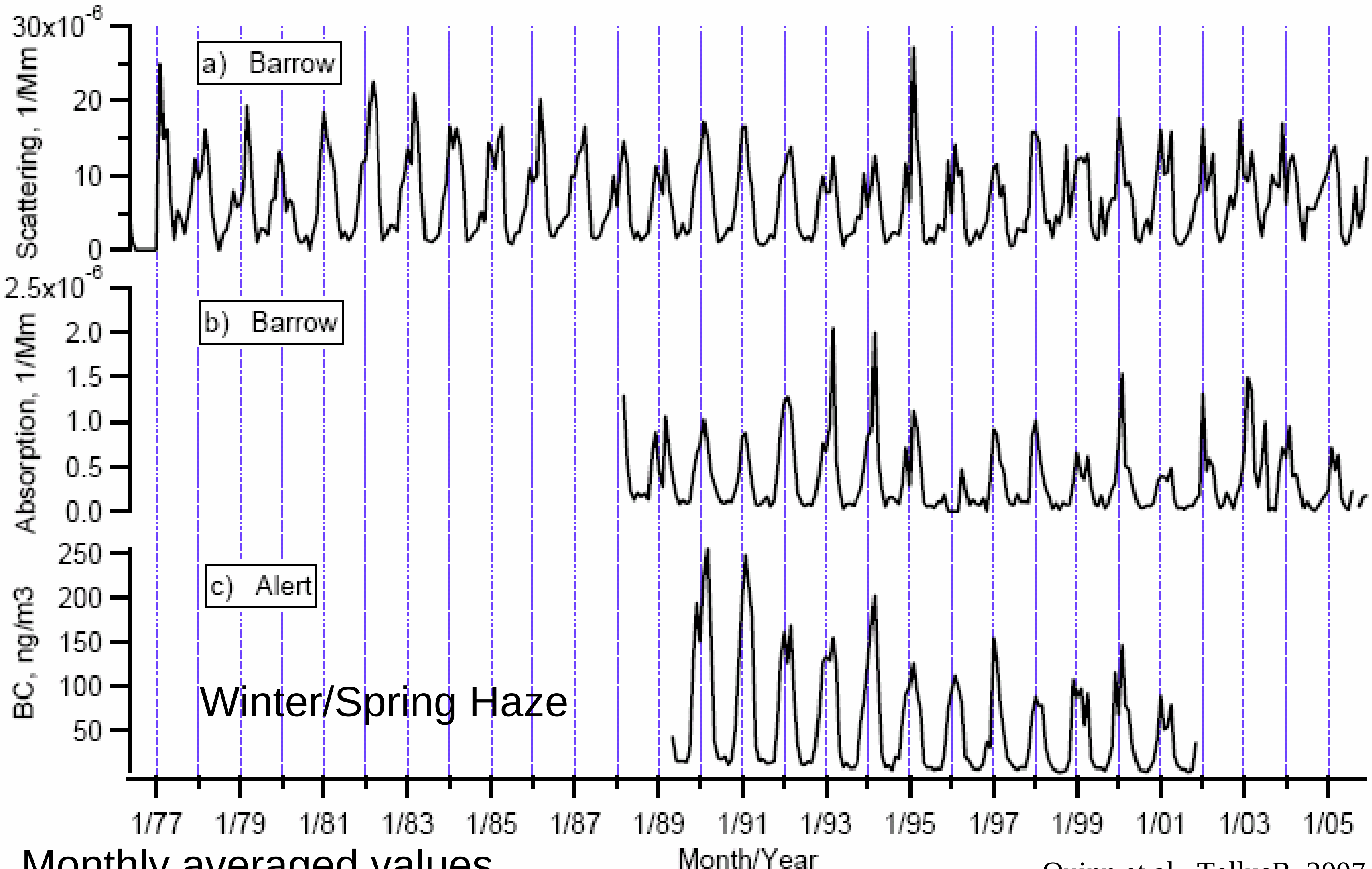
Arctic aerosol seasonal trends: Scattering, absorption, black carbon (surface/point data)

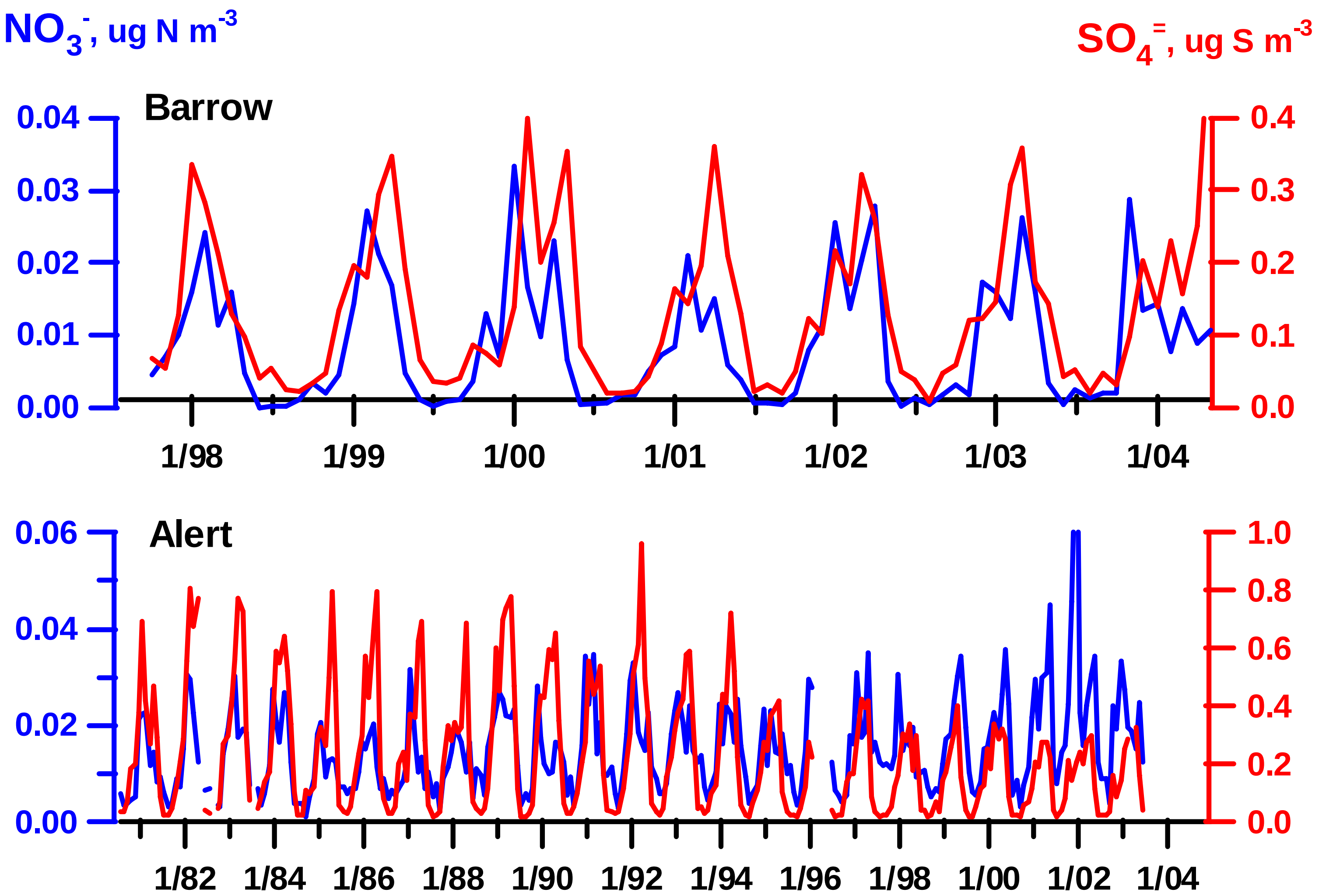


Monthly averaged values

Quinn et al., TellusB, 2007.

Seasonality of Arctic Haze

Winter/Spring Increase in Aerosol Nitrate and Sulfate



Quinn

Sources: **Diesel and gasoline engines** **Coal fired power plants**

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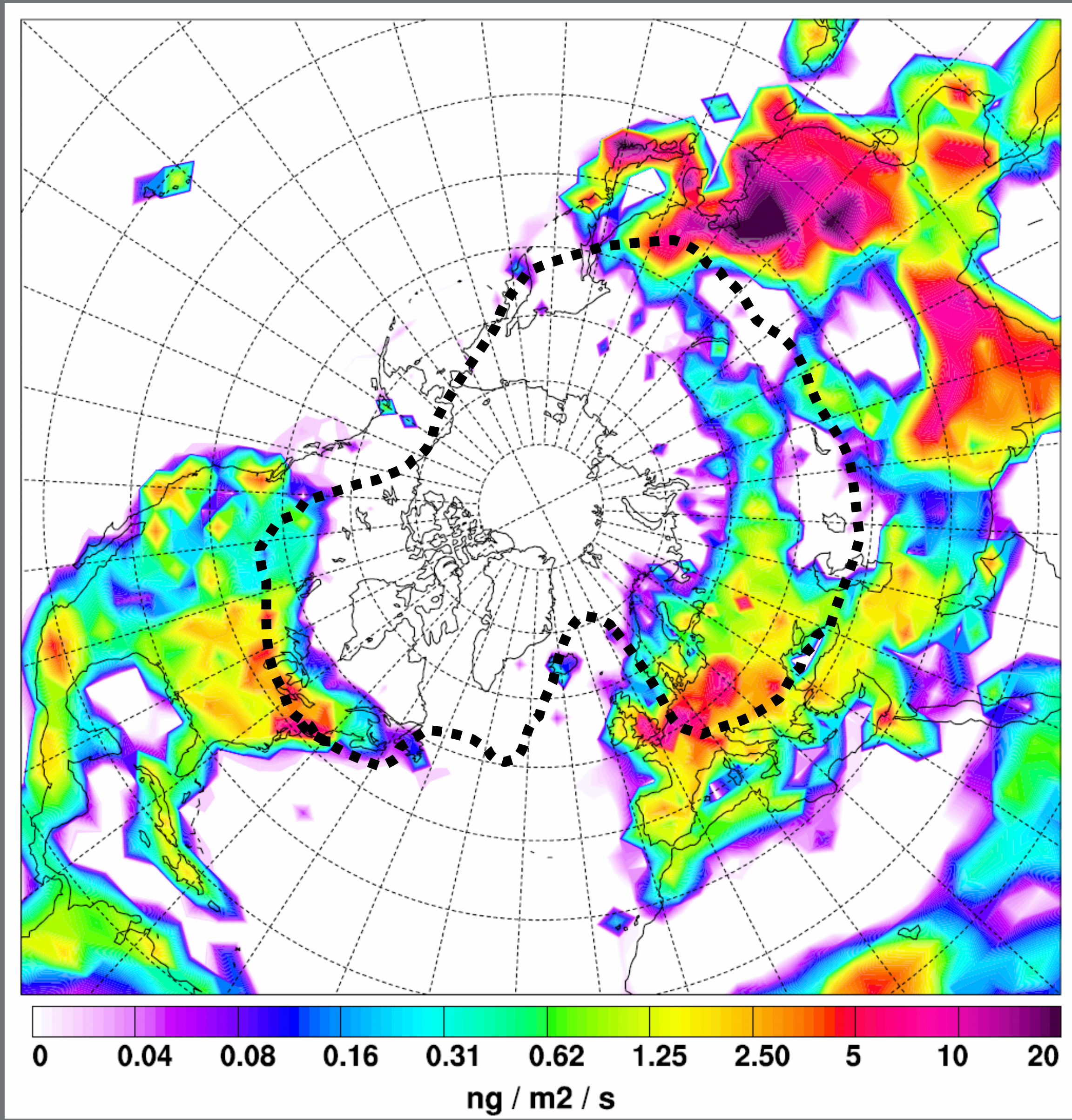

Anthropogenic sources of soot (industrial and biofuel)

Sources in northern Europe and NE China are consistently within or near the mean position of the Arctic front.

Stohl et al., 2006

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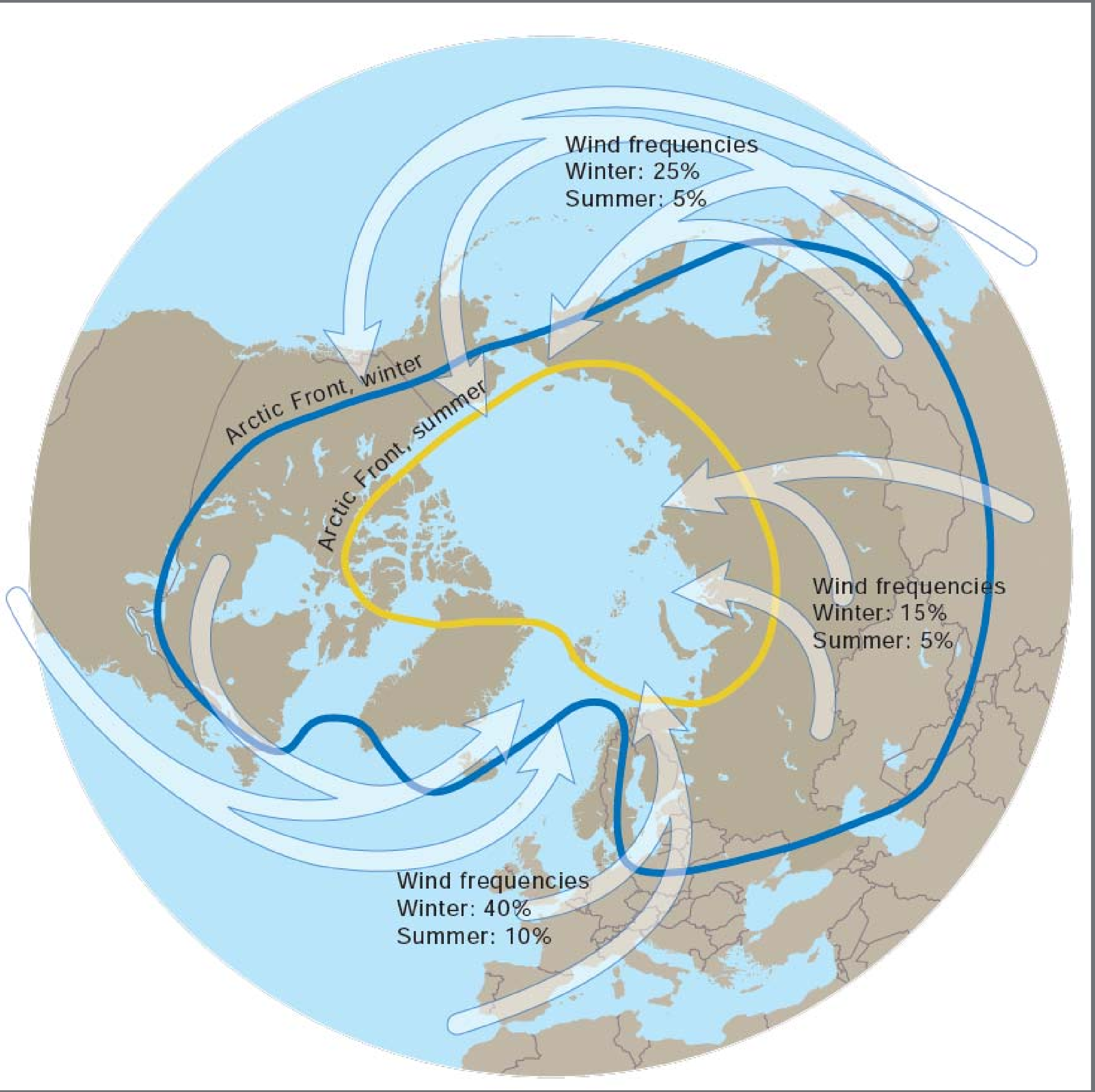

Sources for surface haze generally lie within the Arctic front

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

Arctic Monitoring and Assessment Programme, 2006

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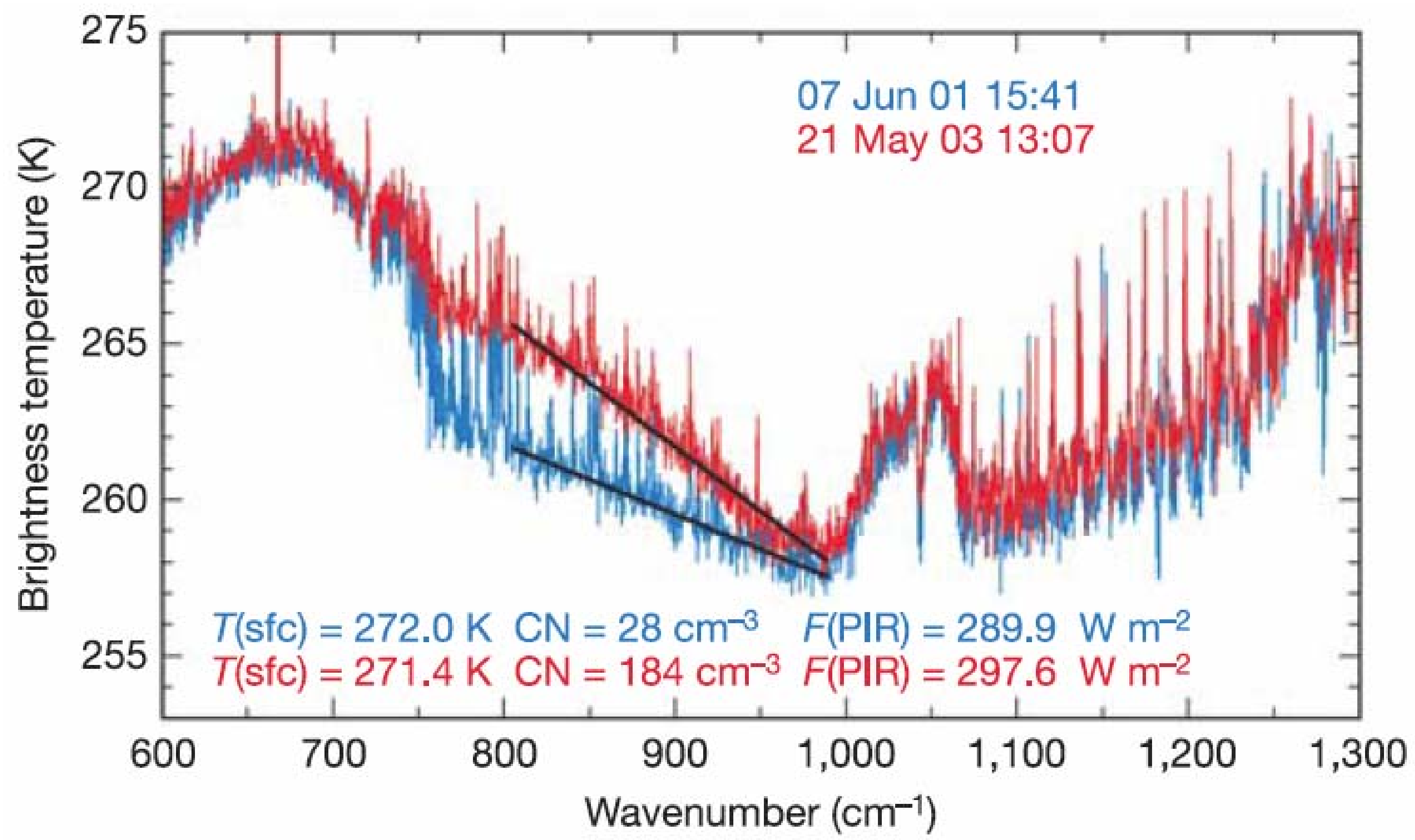
Long-wave Aerosol Indirect Effect
Observed at ARM NSA Barrow



Lubin & Vogelmann, Nature 2006

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ISDAC Motivation

- Most cloud-aerosol interactions studies on warm clouds.
- Interactions more complex for ice or mixed-phase clouds
- The Mixed-Phase Arctic Cloud Experiment at Barrow has provided new insights on ice clouds in clean conditions.
- Arctic air during April is more polluted than the air during M-PACE.
- This contrast provides an opportunity to
  - distinguish aerosol effects on clouds for clean & polluted conditions
  - evaluate surface-based retrievals of clouds and aerosol at Barrow
  - improve understanding of the scavenging of Arctic aerosol in spring
  - identify the chemical signature of ice nuclei in the Arctic

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 Observations (~42)

- temperature
- dew-point temperature
- total particle concentration
- aerosol size distribution (0.01-3 μm)
- size-resolved aerosol hygroscopicity (0.02-0.6 μm)
- cloud condensation nuclei concentration
- ice nuclei concentration
- single particle composition
- optical scattering by aerosol (neph/3-λ PA
- optical absorption by aerosol (PSAP/3-λ PA)
- vertical velocity
- cloud liquid water content
- total cloud water content
- cloud particle size distribution (0.5-2500 μm)
- cloud particle image (15-2500 μm)
- cloud extinction

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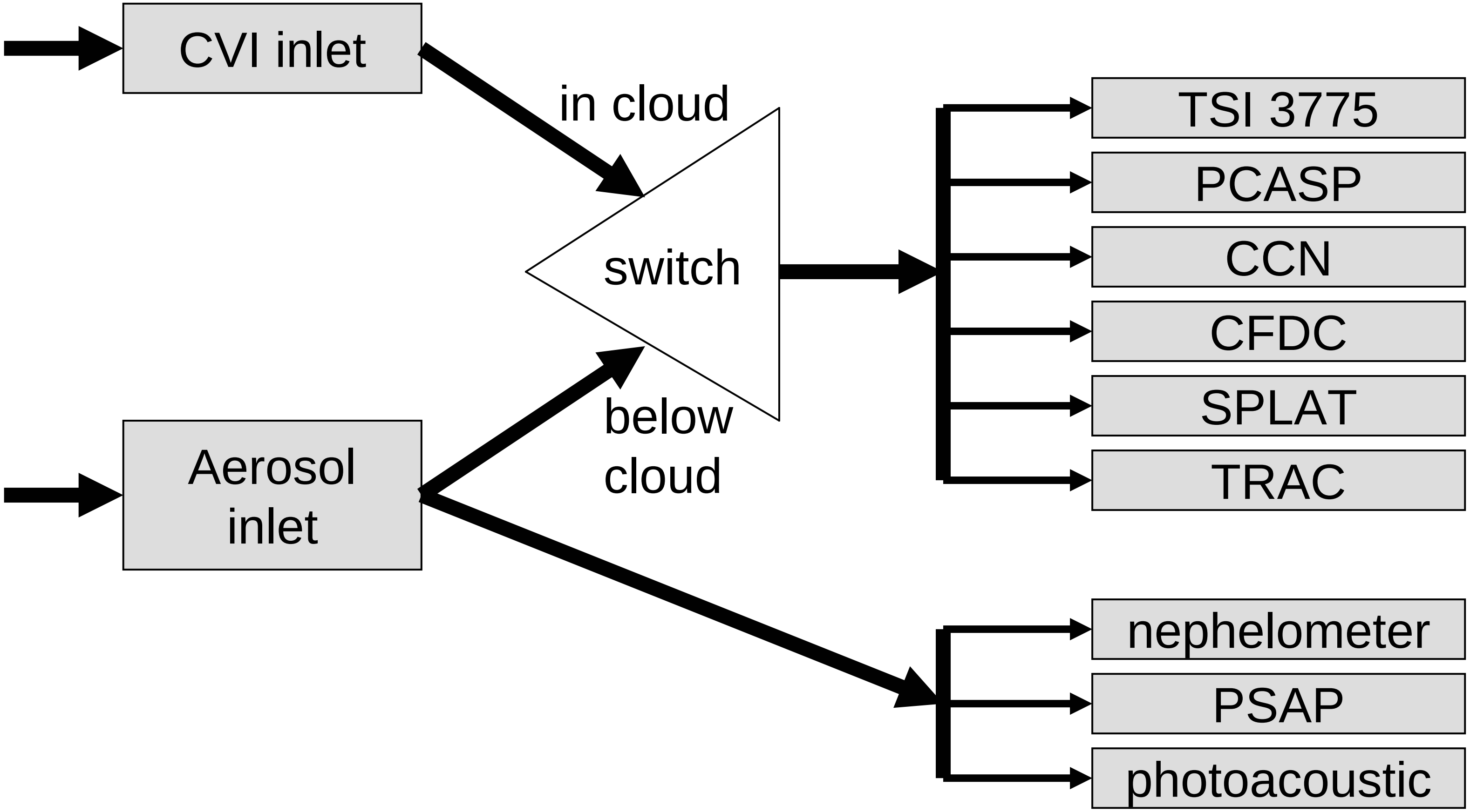
Aerosol Instrument Configuration



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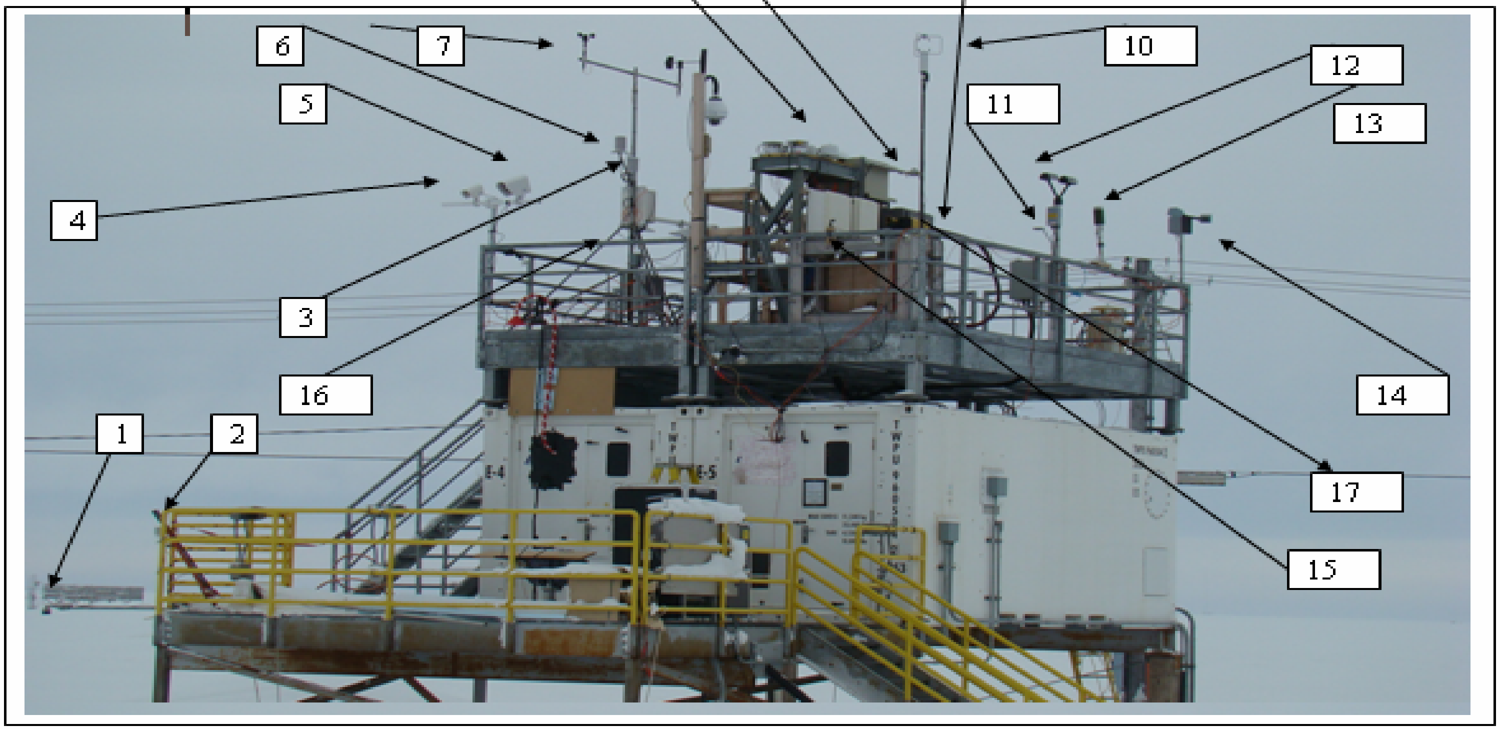
Enhanced Observations at Barrow SGP Site During ISDAC (Ismail Gultepe)

Environment Canada
Cloud Physics and Severe Weather
Research Section, Toronto

BARROW NSA SITE
I.GULTEPE
Ismail.gultepe@ec.gc.ca



1. Snow depth sensor
2. Temperature sensor
3. RH1 and T
4. Vaisala surface temperature
5. Vaisala water phase sensor
6. RH2 and T
7. Wind speed and direction
8. SW and IR fluxes
9. SPN1; cloud cover, direct and diffuse radiative fluxes
10. Turbulence measurements
11. Hot plate (TPS) precip sensor
12. Distrometer (precip rate/extinction)
13. CAP aerosol measurements
14. Sentry Vis sensor
15. DMIST Vis sensor/camera
16. Ice particle counter (IPC)
17. FMD droplet spectra
18. VRG101 precip instrument
19. FD12P precip and Vis sensor

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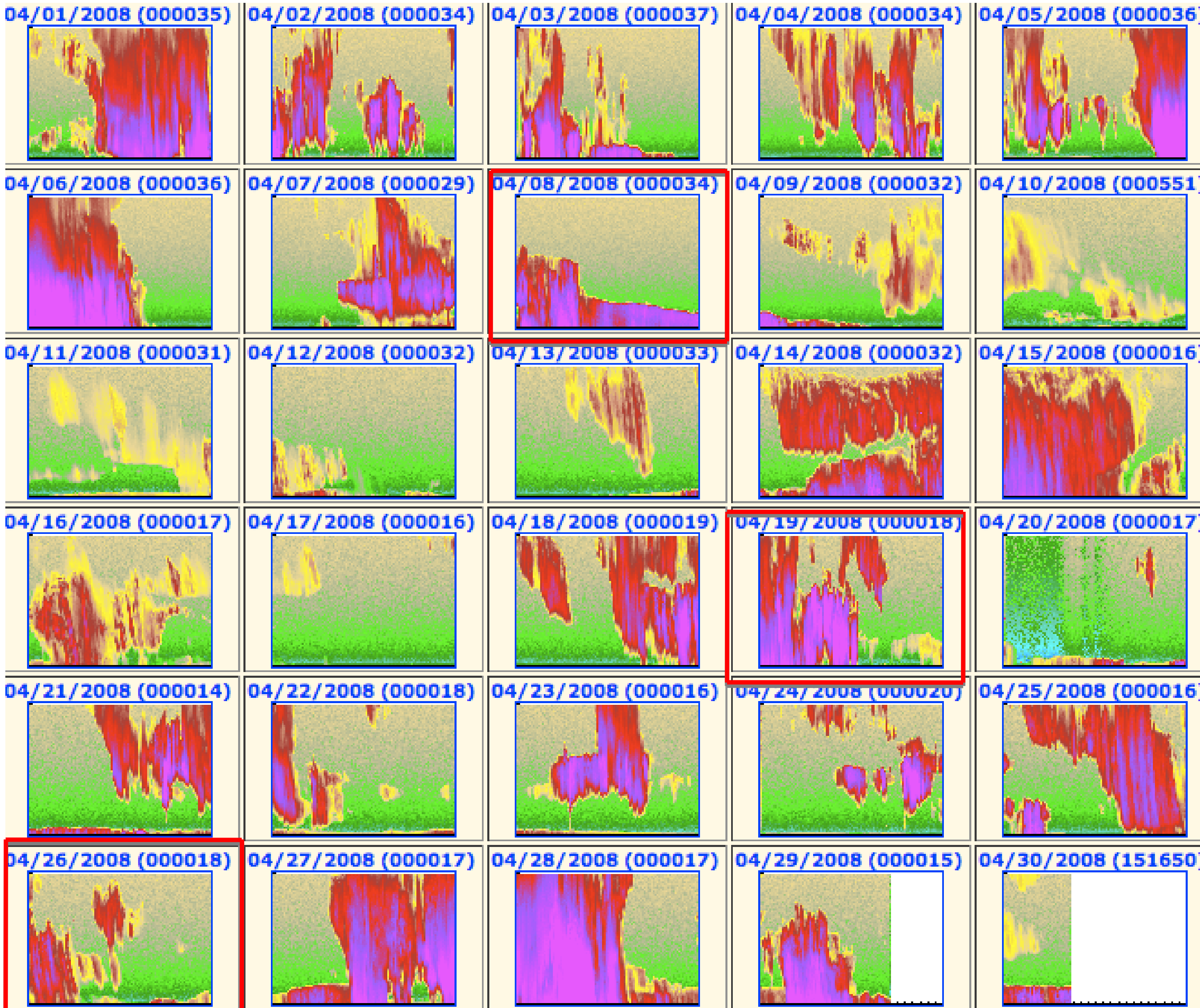
ISDAC Flights Summary

- 27 project sorties representing 103.6 hours of data on 12 different flight days
- Golden days with single-layer stratocumulus on 8 and 26 April when 3 sorties flown
- Heavily polluted day on 19 April
- Instrument performance for most part excellent

Applications

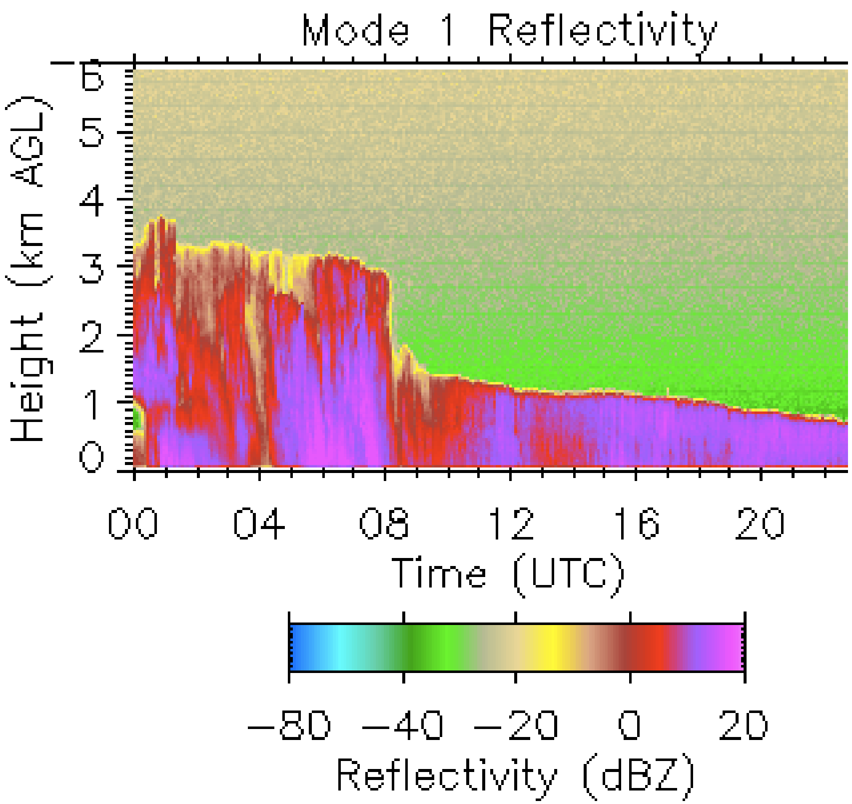
- CCN closure
- Droplet number closure
- Aerosol extinction closure
- Cloud extinction closure
- Cloud water closure
- Cloud modeling
- Semi-direct effect
- Crystal nucleation
- Aerosol extinction retrieval
- CCN retrieval
- MMCR retrievals
- MWR retrievals
- AERI retrievals
- ASD retrievals

Cloud Radar Reflectivity

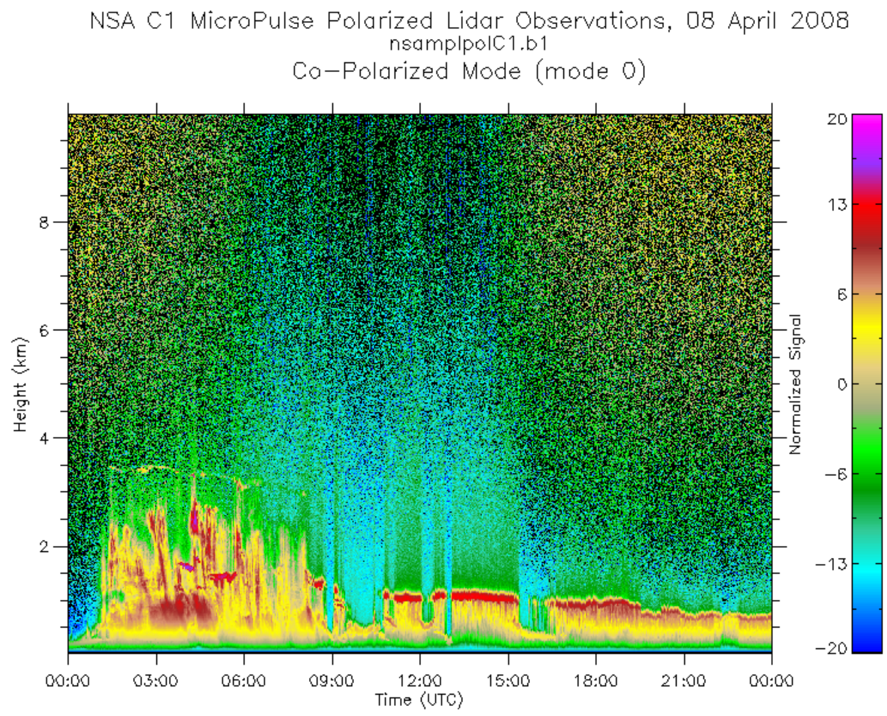


April 8

MMCR Reflectivity



MPL Co-Polarized Mode



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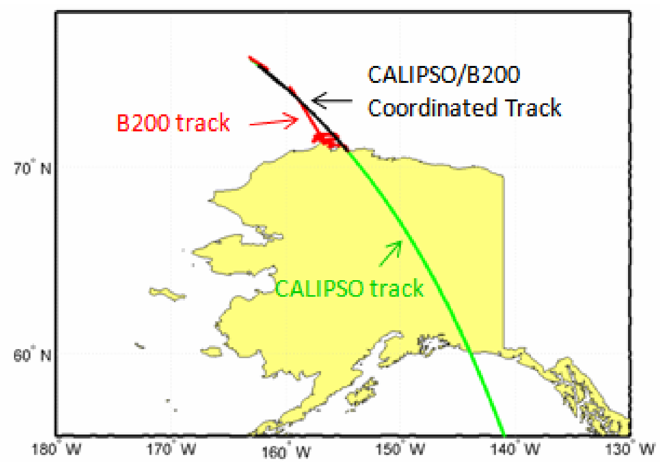
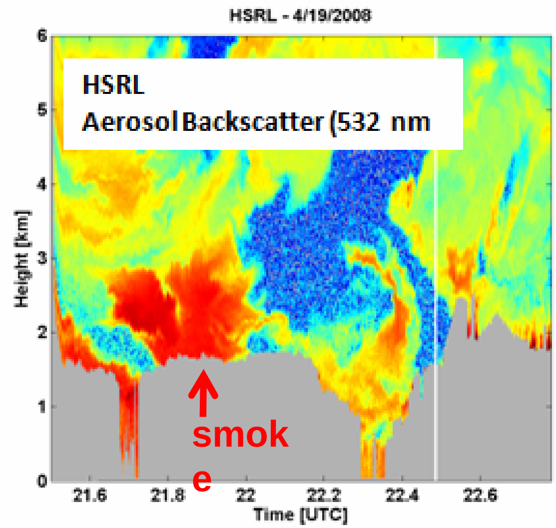
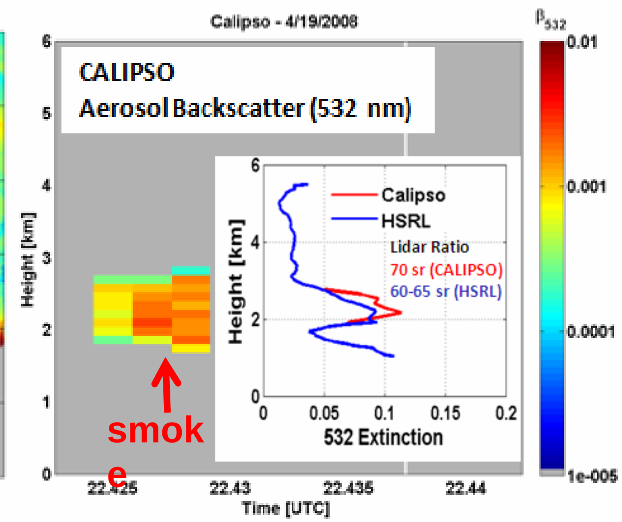
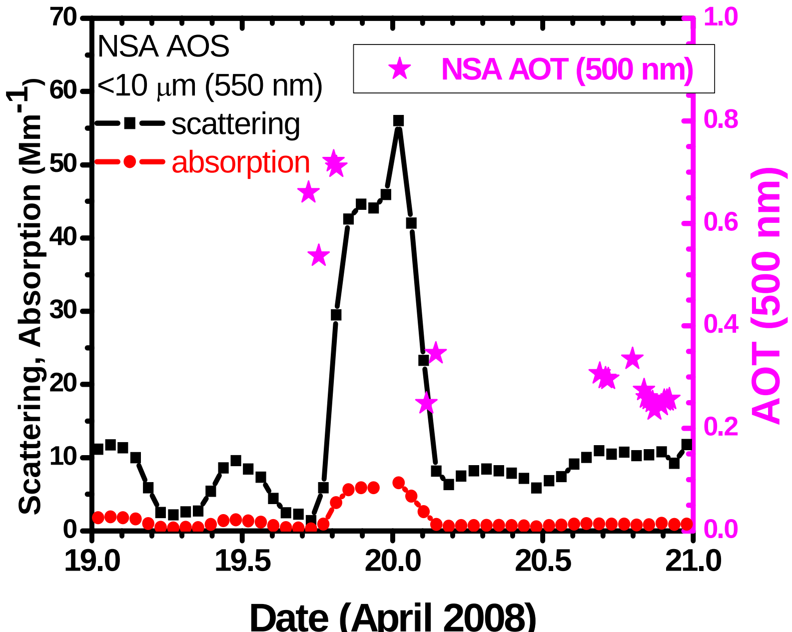
CALIPSO Validation During ARCTAS/ISDAC Example – April 19 – Siberian Forest Fire Smoke

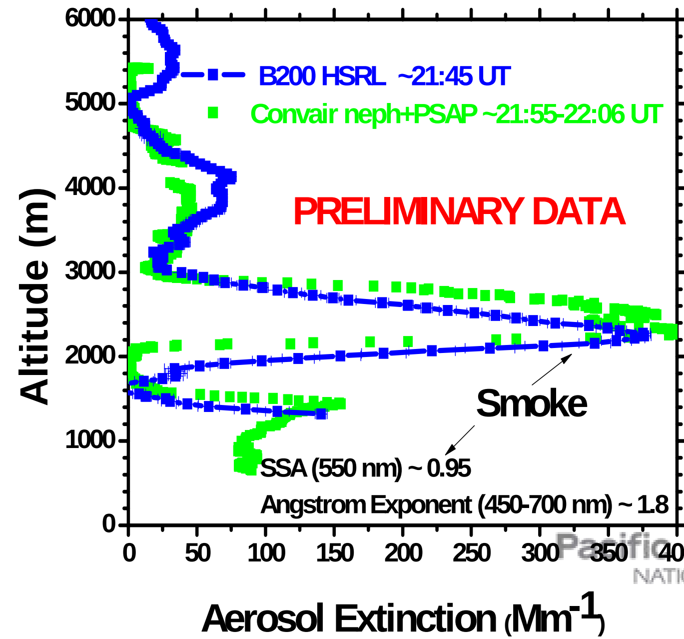
Rich Ferrare et al.



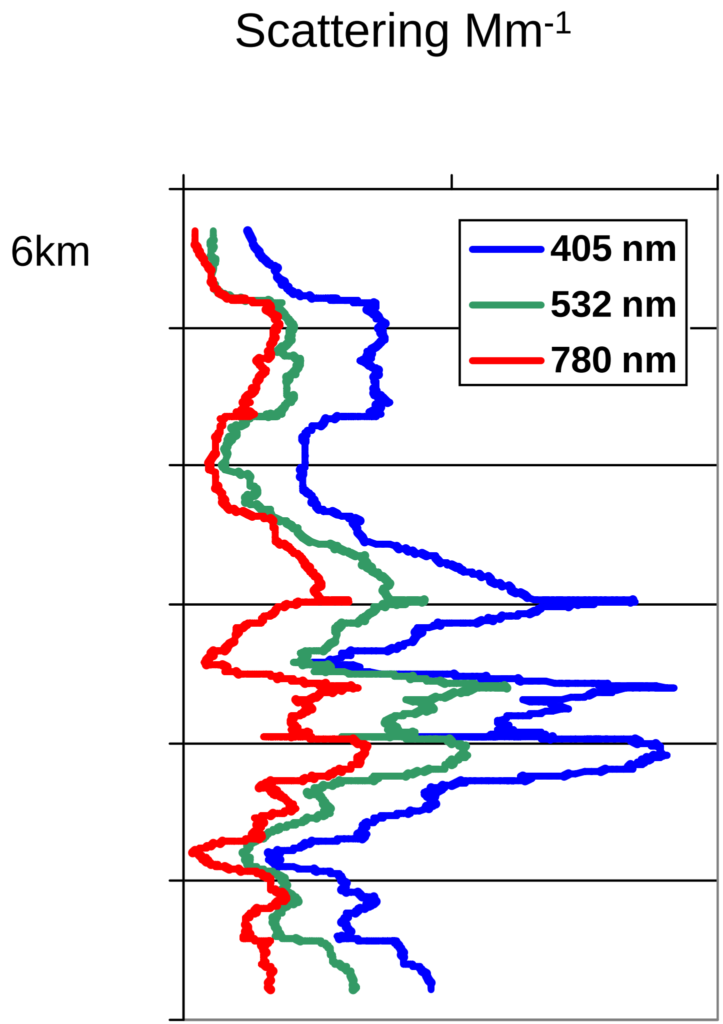


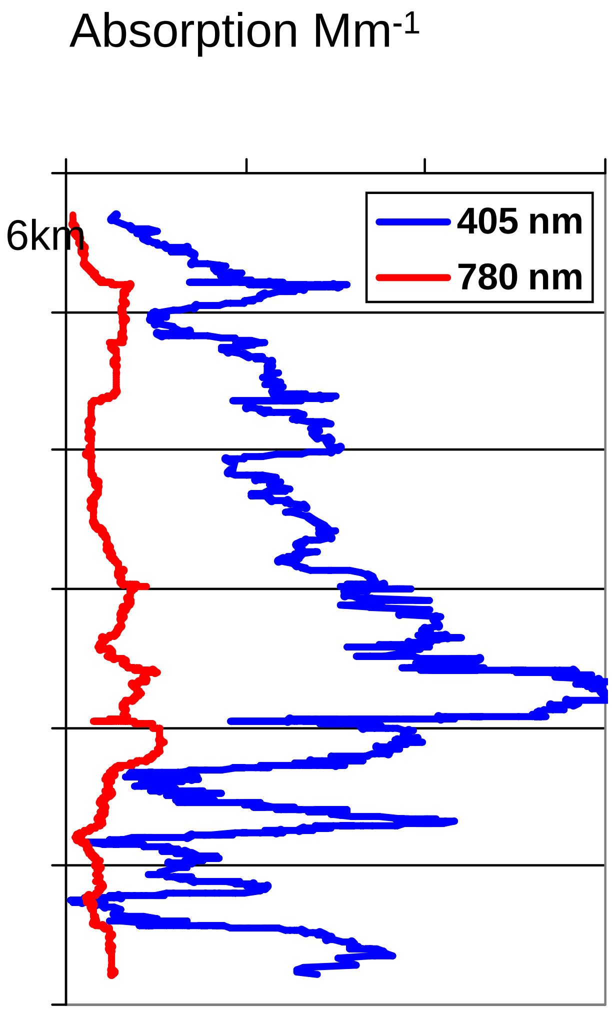






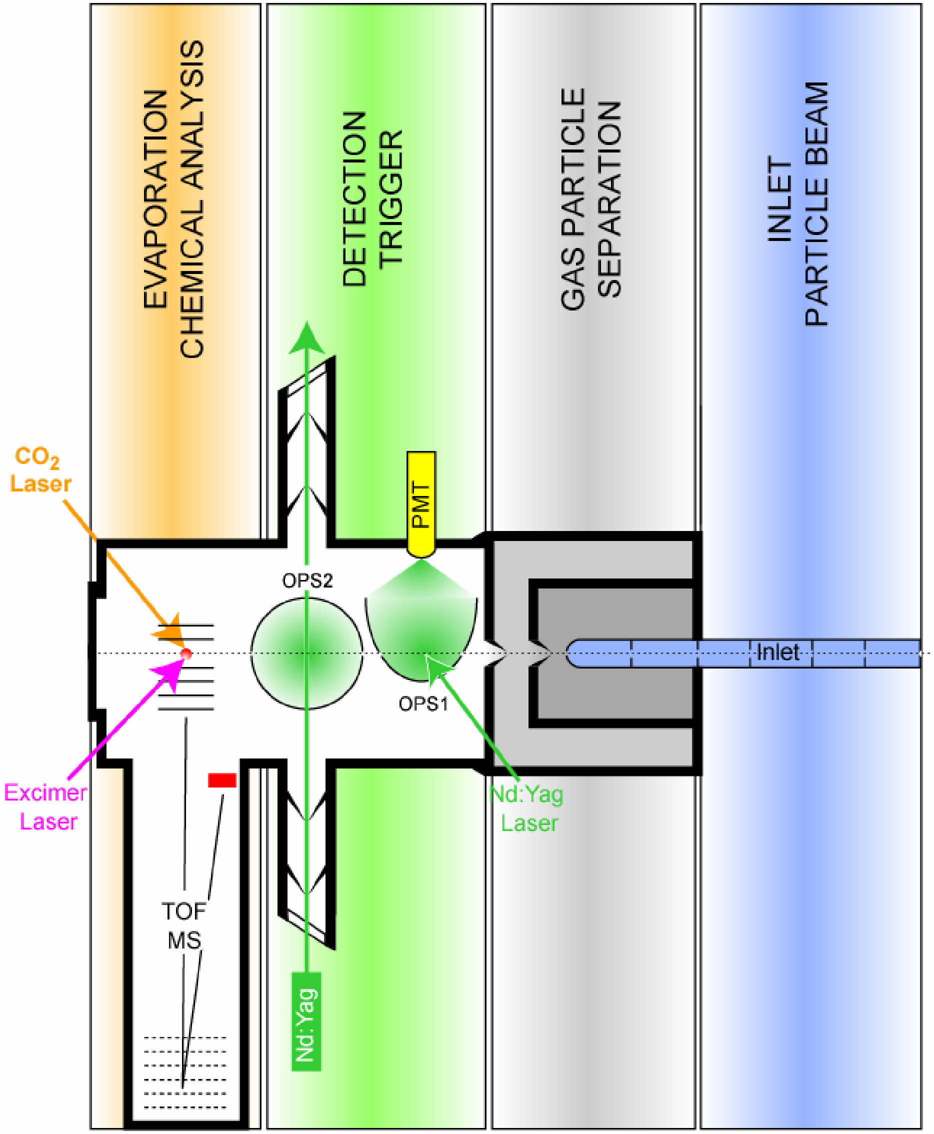
Los Alamos 3-Laser Photoacoustic Absorption and Scattering 405, 532, 781nm





Manvendra Dubey

SPLAT II: An Ultra-Sensitive, High-Precision Single Particle Mass Spectrometer



- Provides in *Real-time* the size and internal composition of individual 50 nm to 3 µm particles
- High sensitivity: detects 1p/sec for an aerosol sample of 1p/cm^3 with d>125 nm
- High sensitivity to small particles: detects 40% of 100 nm particles
- Sampling rate: sizes up to 500 p/sec, 100 of which are also chemically characterized
- Measures refractory and non-refractory aerosol fractions in each particle
- Measures aerodynamic size with better than 1% accuracy.
- Measured size and composition for 3 million particles during ISDAC

Alla Zelenyuk

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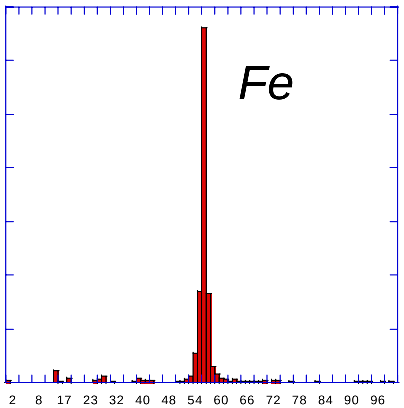
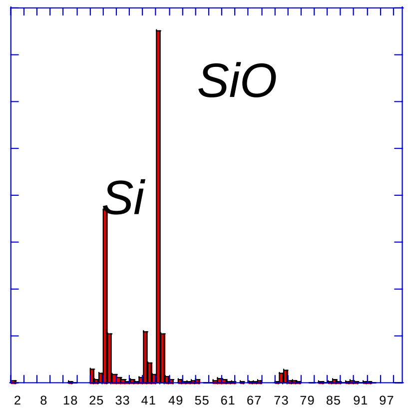
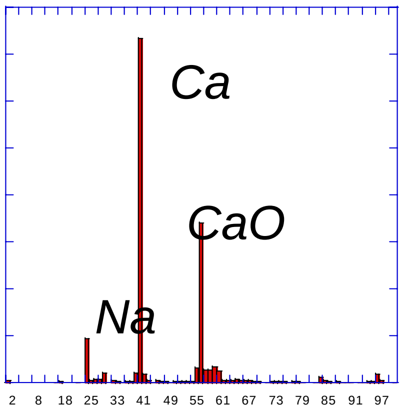
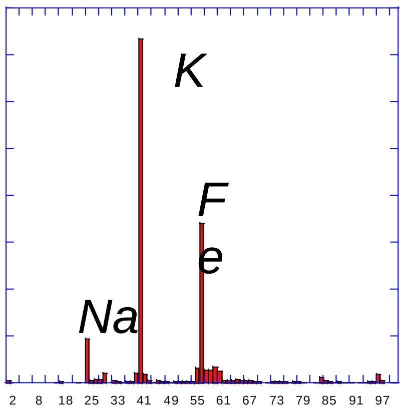
No artifacts of the CVI surface





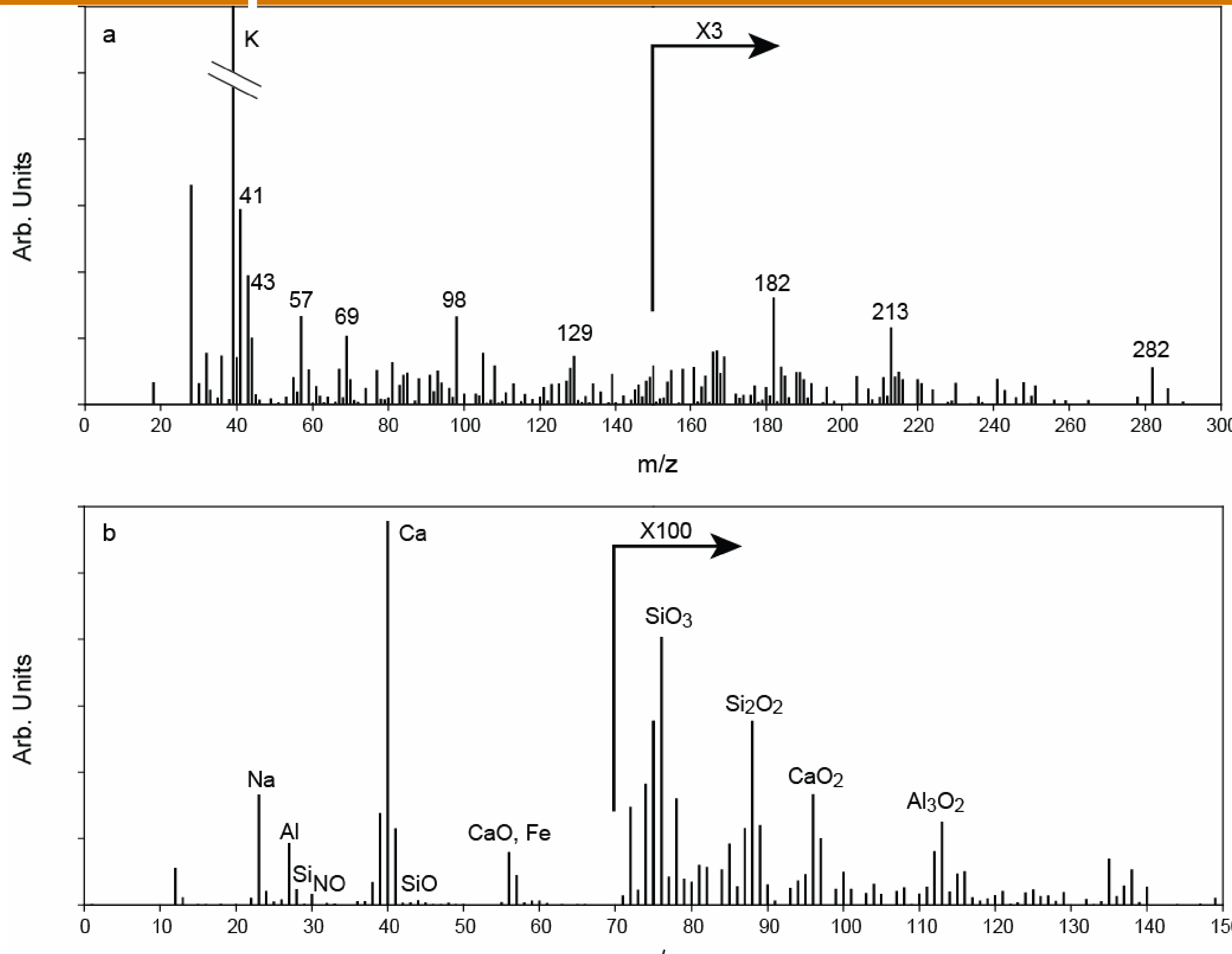




- No gold artifacts observed => either there is no sandblasting effect at the gold plated region or gold plating was effective in minimizing artifacts.
- 10% of the 406 residual particles on Flt 9 were Fe rich, and of those 41 particles only two showed signatures that might indicate stainless steel. The remaining Fe particles likely crystal residues.

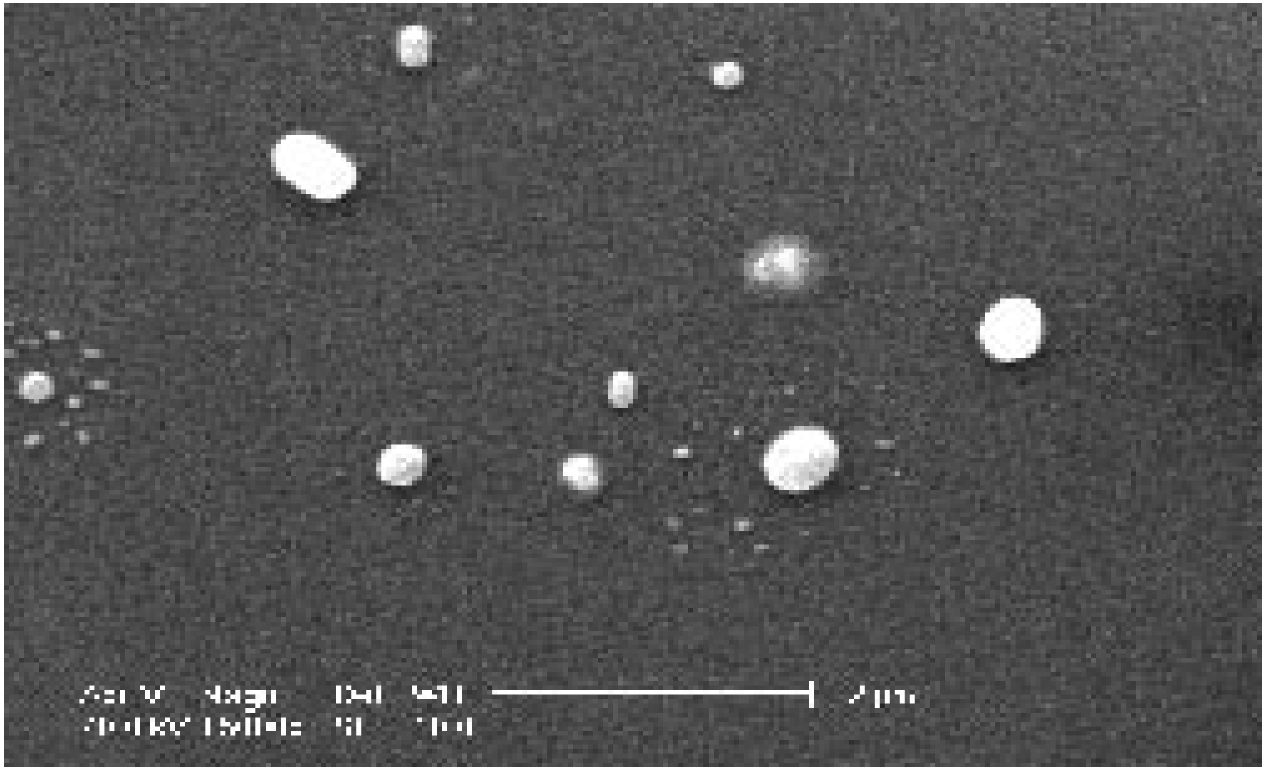
Alla Zelenyuk

Mass spectra of biomass burning particle and dust particle



Alla Zelenyuk

Samples from Time Resolved Aerosol Collector



Preliminary screening and analysis of images from the time-resolved aerosol collector indicate particles laden with carbon and sulfur. These data were obtained on April 8, 2008, a golden case.

Alex Laskin

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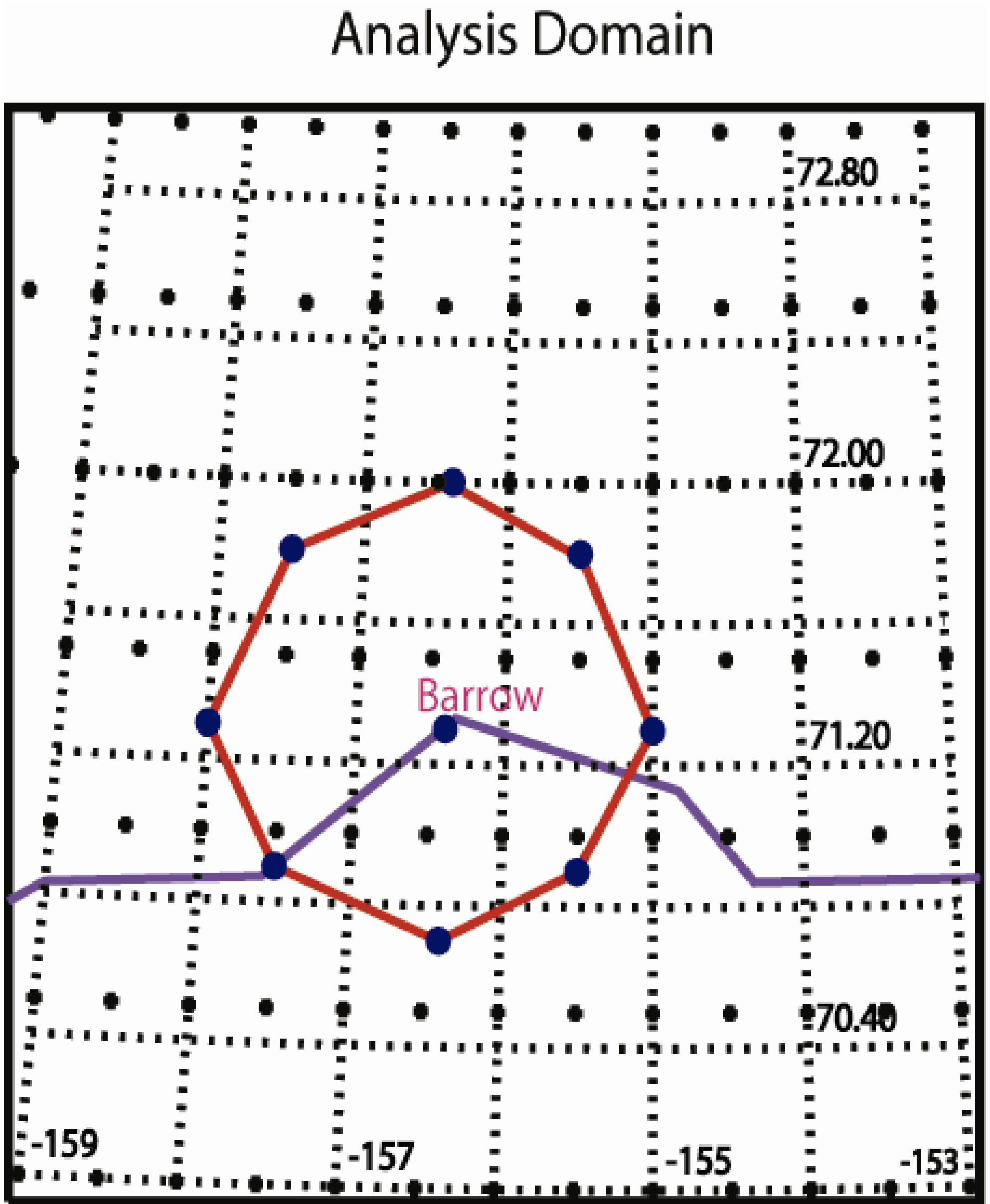
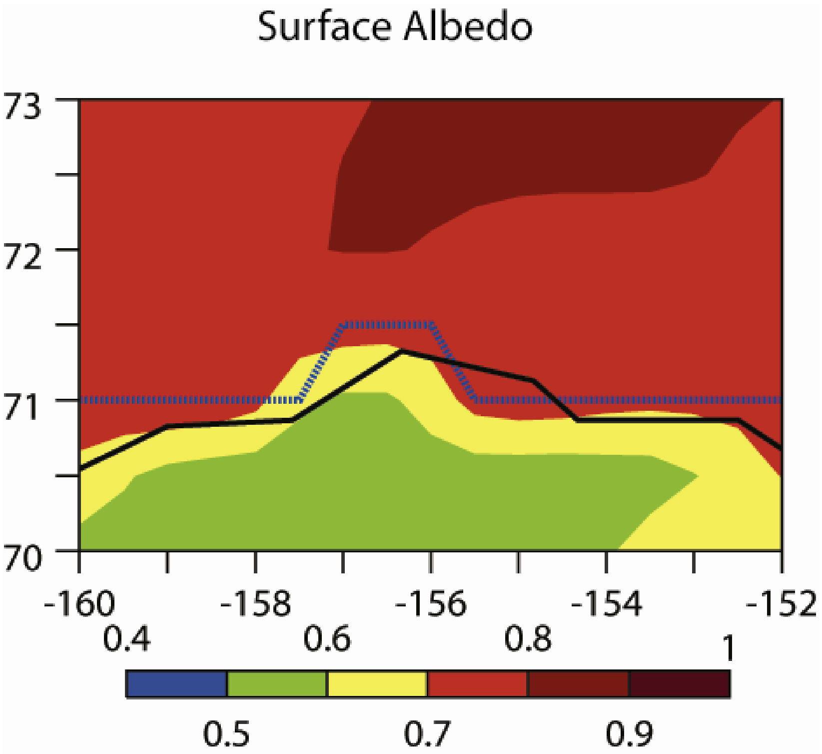
Modeling ISDAC Clouds





Shaocheng Xie

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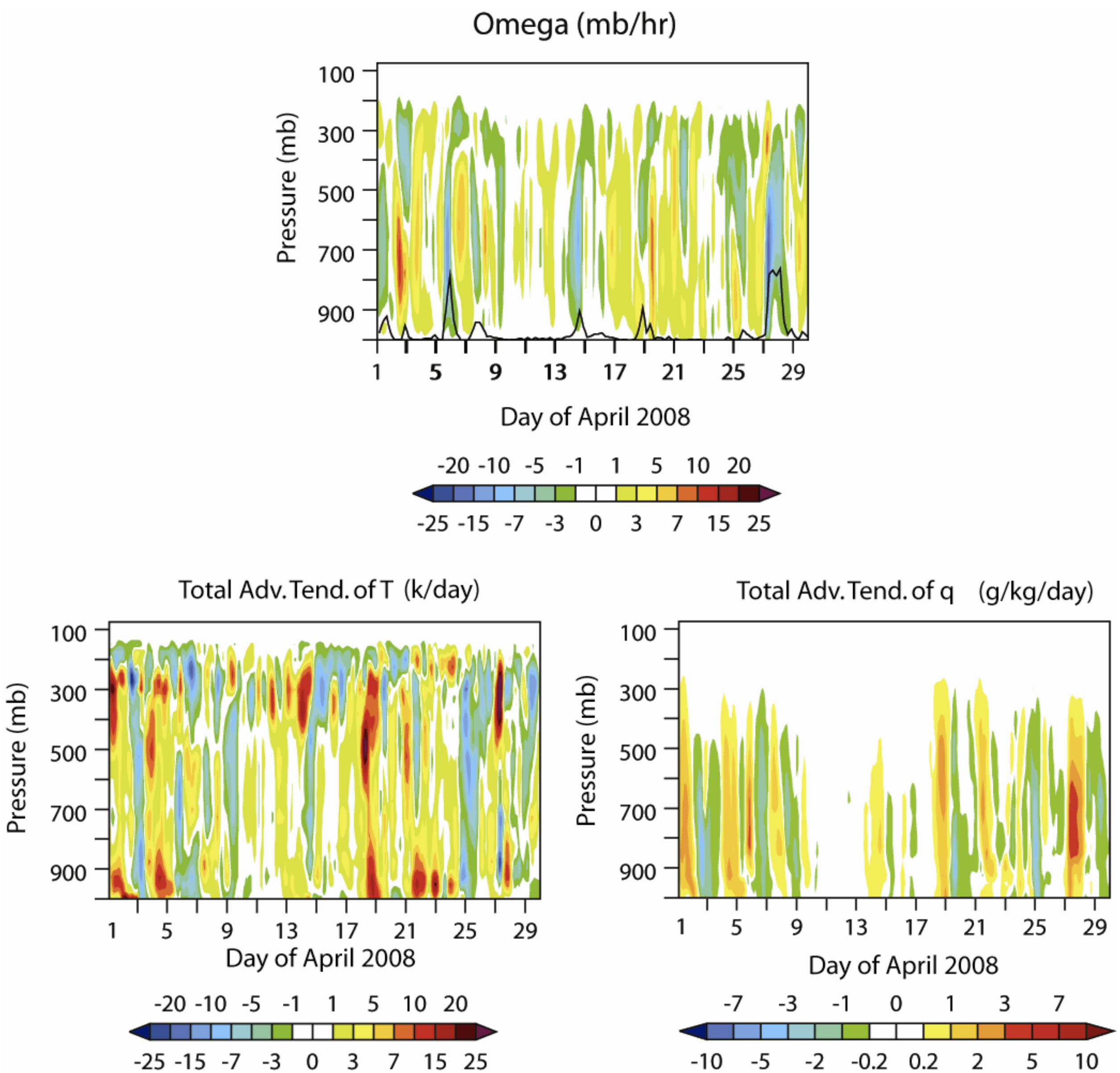
Forcing to Drive Cloud Models

Shaocheng Xie



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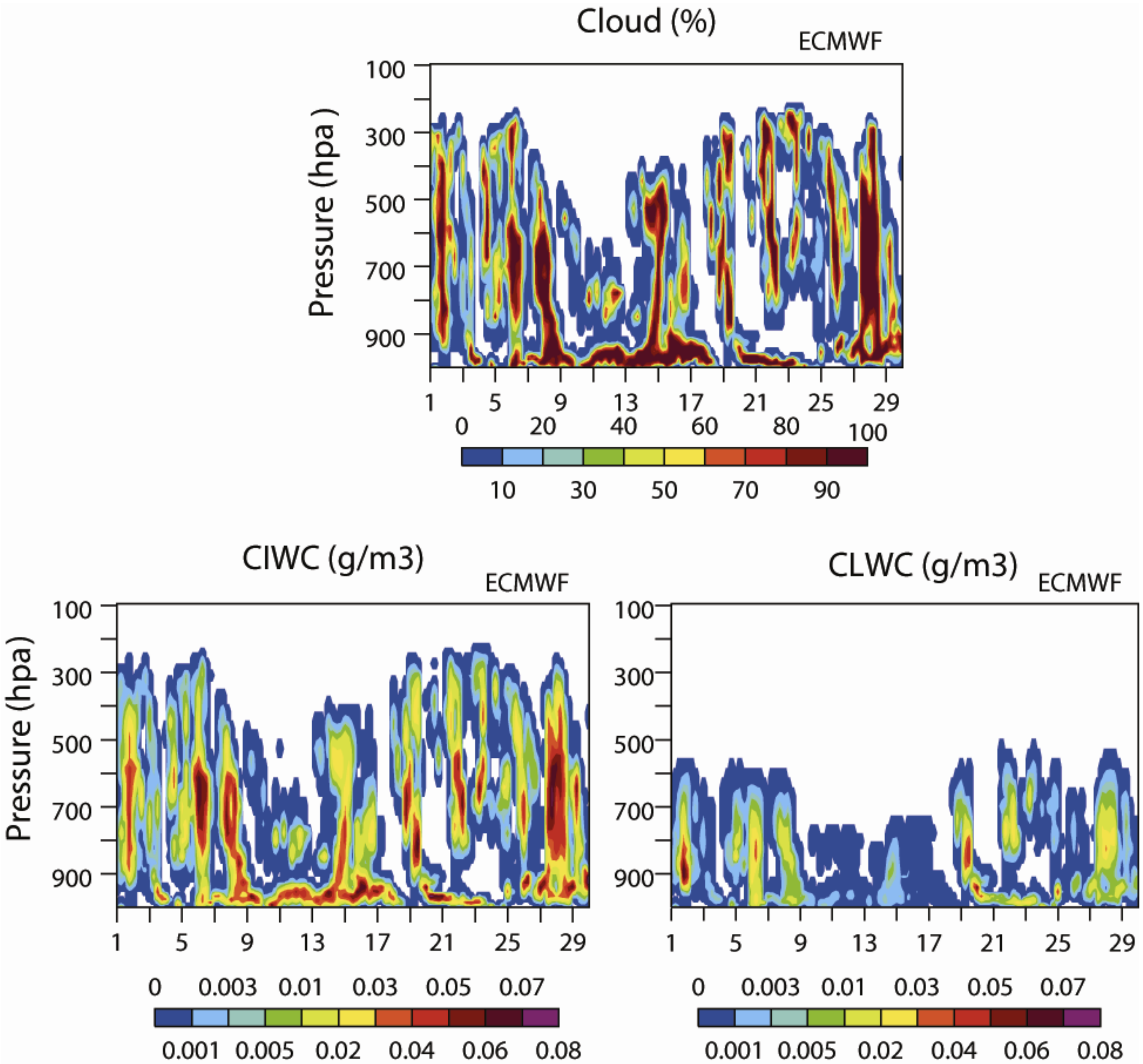
ECMWF Cloud Simulation



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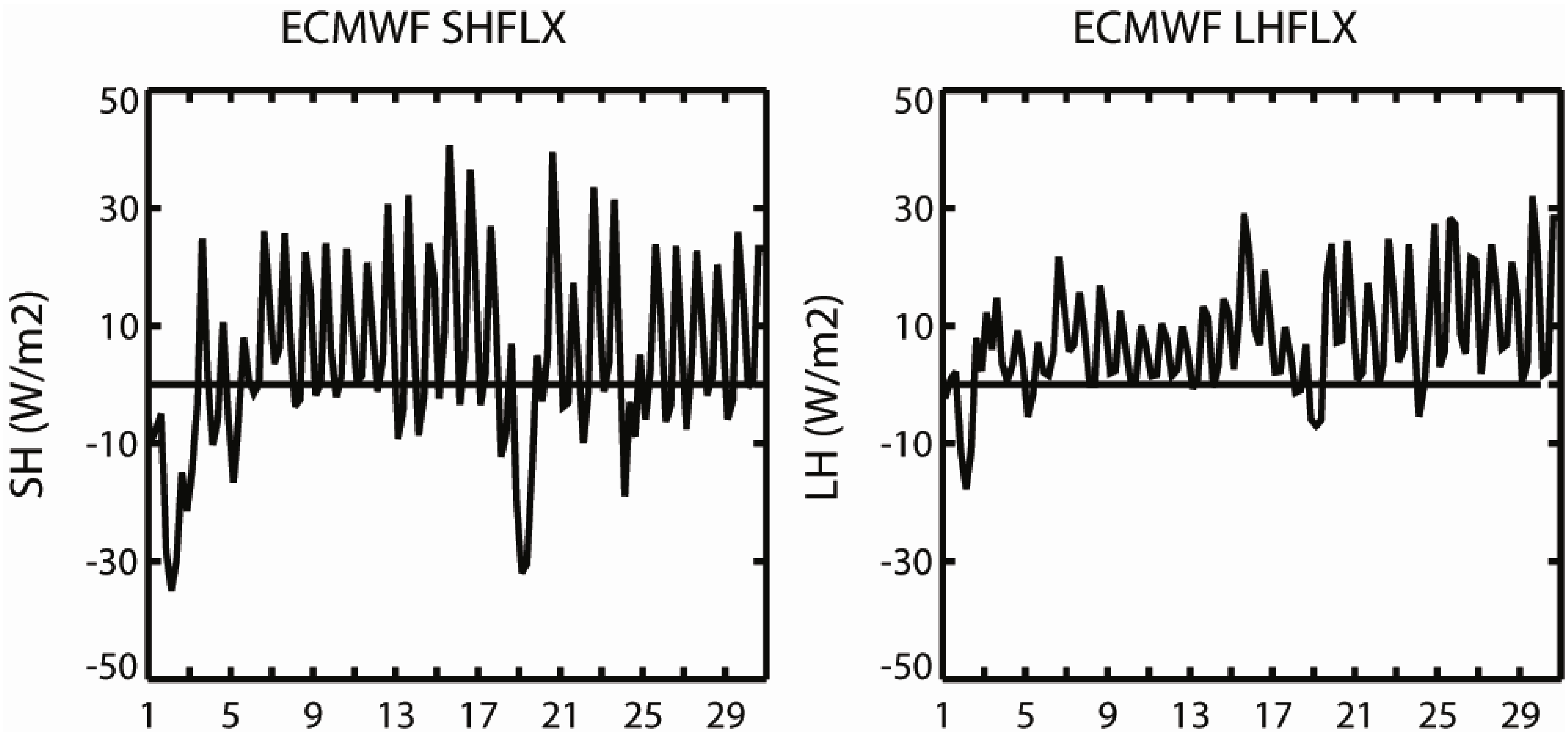
Surface Fluxes are Weak

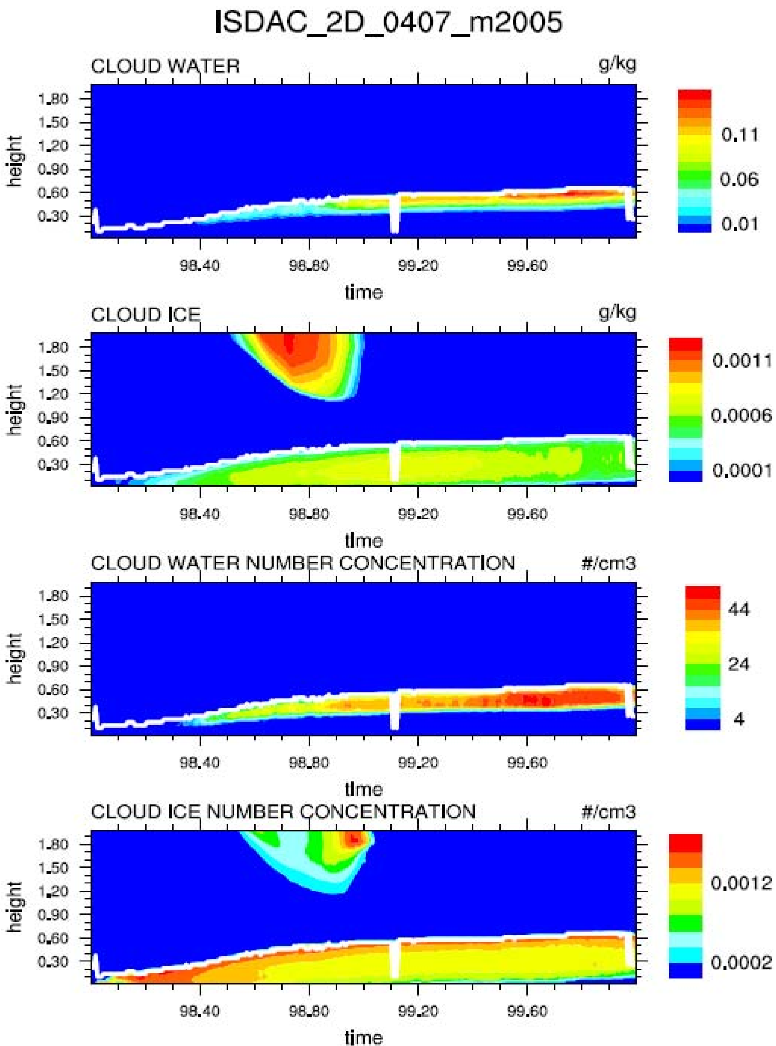
Shaocheng Xie



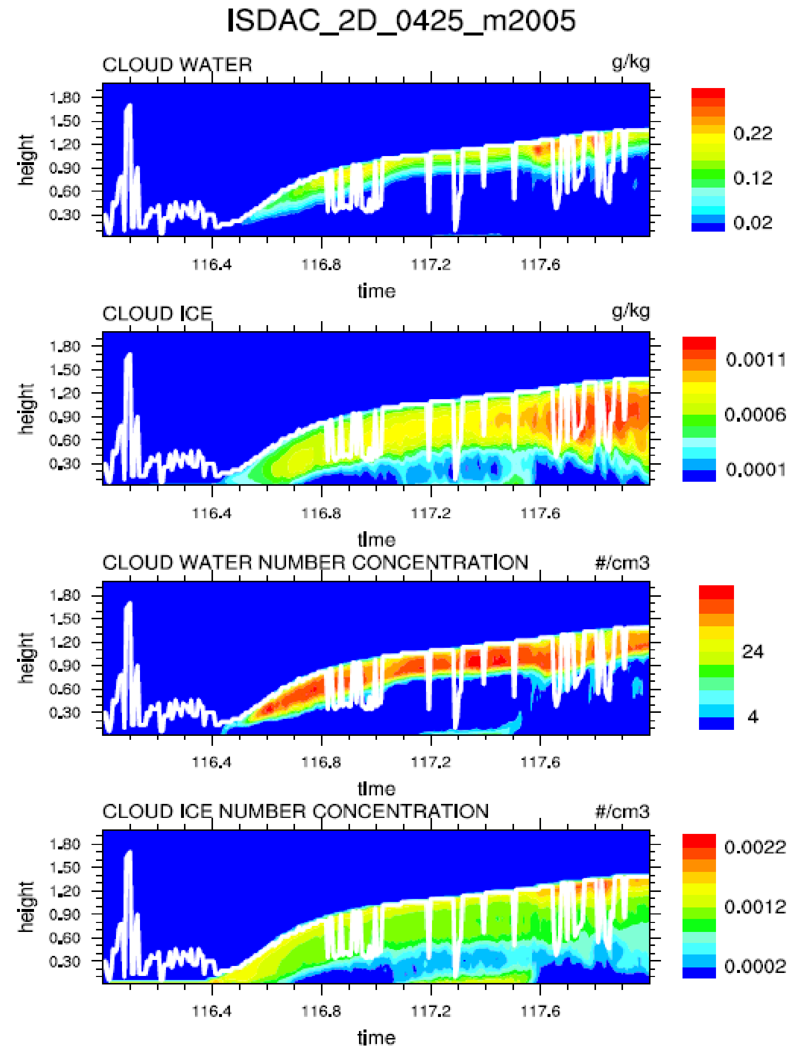
Simulation with Morrison microphysics

Mikhail Ovtchinnikov

April 8

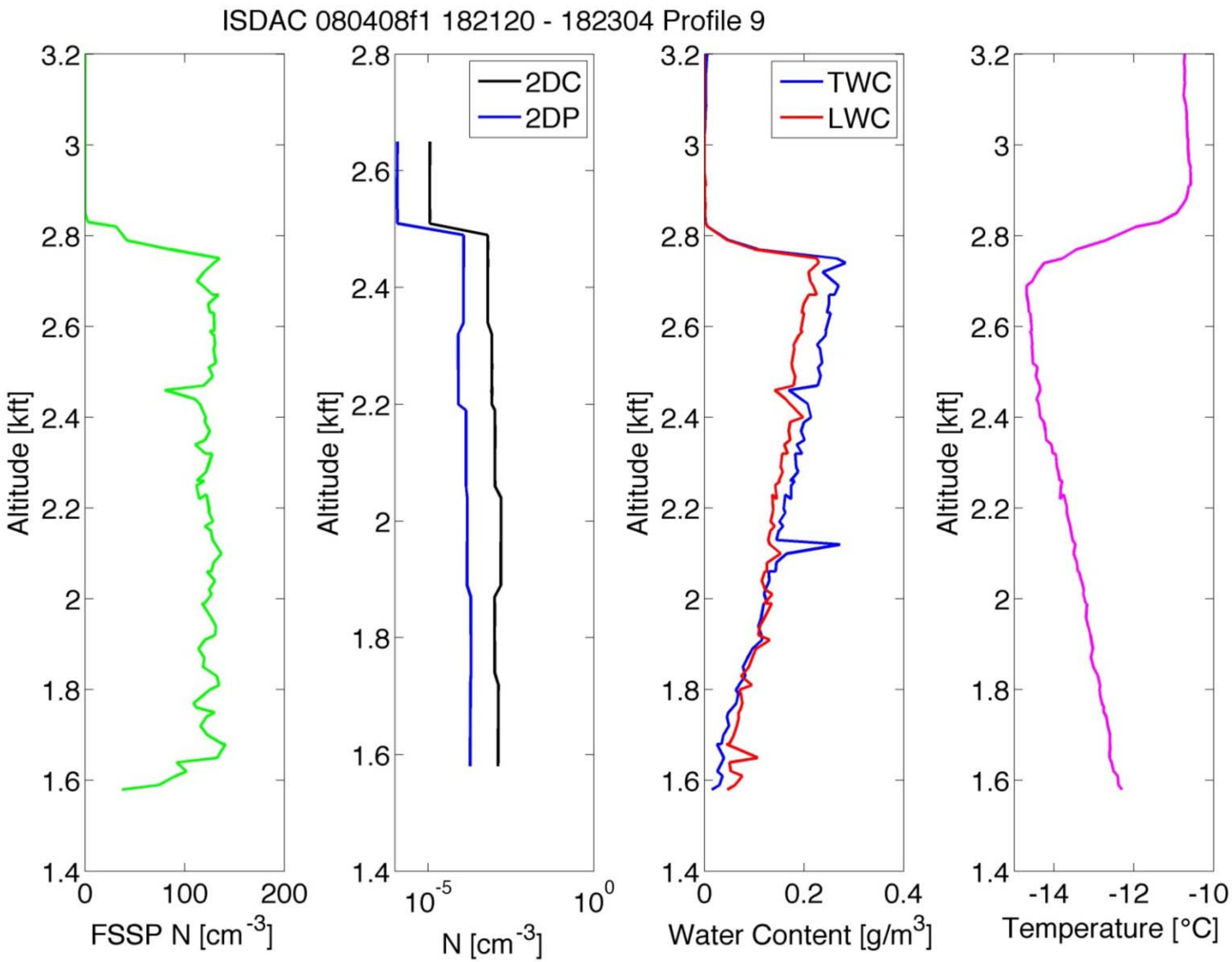


April 26



Vertical Profiles April 8

McFarquhar/Freer et al.



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ISDAC Summary

- Very rich aerosol/cloud data set collected, including (but not limited to) golden cases of single-layer stratus
- Sampled wide dynamic range of aerosols
- Data from comprehensive (~42) state of the art instruments link aerosol composition, cloud microphysics and optical properties for process level model development of Arctic clouds.
- Data will be useful for many applications, and should have great utility for modeling studies
- Data should be available in ARM archive

Overview

1. Types of observations (probes)
2. Golden days (April 8th, April 26th), heavily polluted day (April 19th) have been identified as priorities for first analysis
3. Flight profiles flown
4. Types of data available and preliminary analysis products

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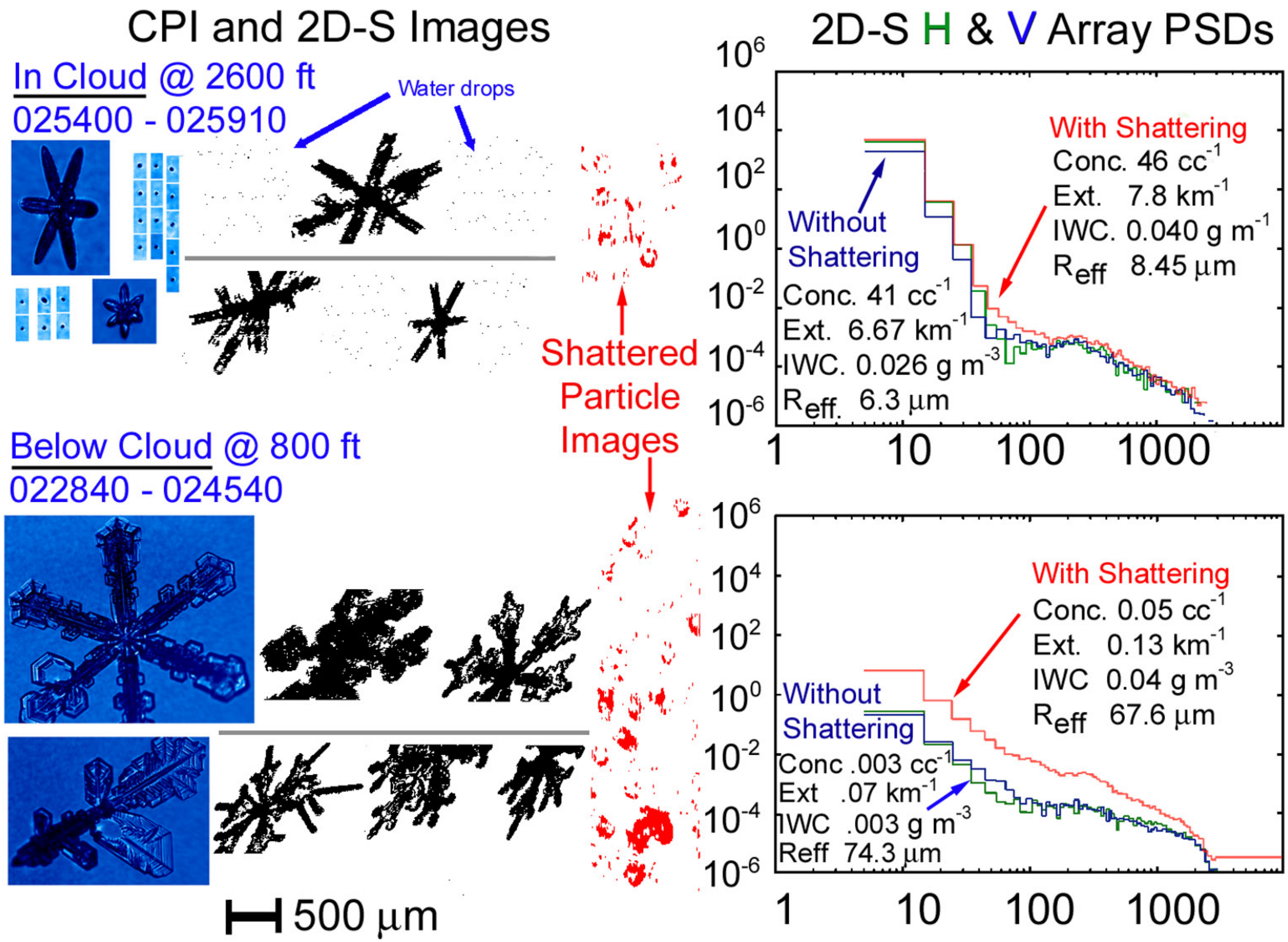
ISDAC Primary Observation Platform: Convair (National Research Council of Canada)

Equipped by Environment Canada, NRC, universities, and private companies with instruments to measure aerosol and cloud particles from 1 nm to > 10 mm

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 particles
- Bulk parameters
  - Bulk liquid water and total water
  - Bulk extinction
  - Flag for presence of supercooled water
- Redundancy key to microphysical measurements
  - Will be able to assess consistency & performance of multiple probes through closure tests (extinction & mass)
  - Will address question of crystal shattering and measurement of small crystals

Microphysical Properties with and Without Shattering (4-26-08)



Lawson et al.

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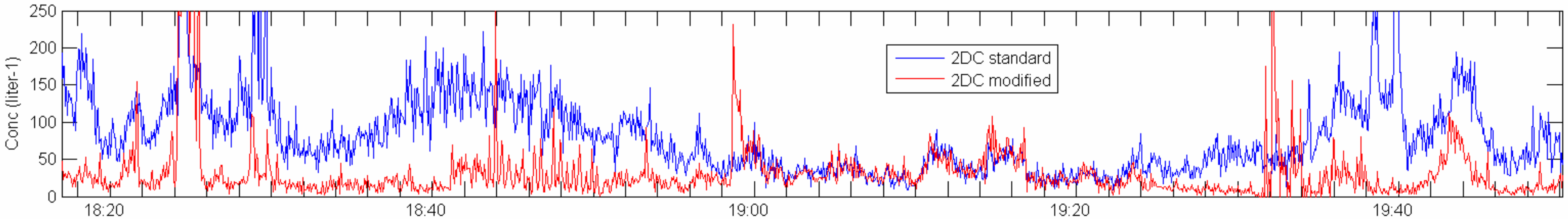
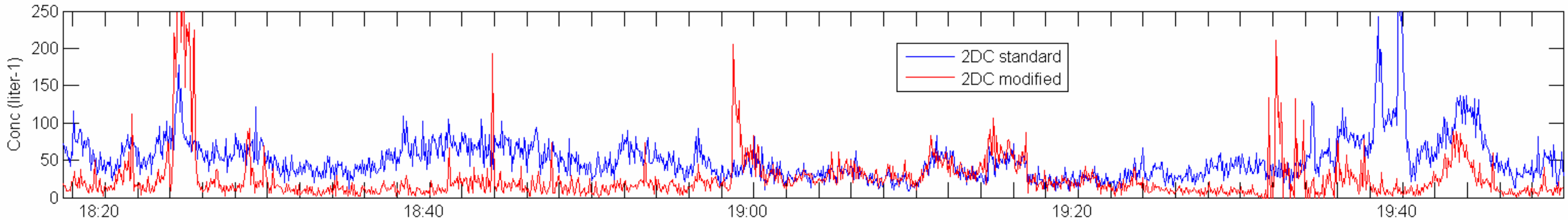
Standard and modified 2DC probes (Korolev)

Performance of modified probe (Korolev)

No corrections on shattering



After corrections



- Ice particle shattering with the standard OAP-2DC arms may result in the overestimation of the measured concentration ten fold or more.
- Existing correction algorithms are incapable of filtering out all shattering events.
- Modification of probe inlets seems to be the only solution for the shattering problem

Convair Was Equipped with Wide Range of Microphysical Probes

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Cloud Microphysics

DMT ConterFlow Virtual Impactor (CVI) for TWC	total water content	EC
DMT Cloud, Aerosol, and Precipitation Spectrometer (CAPS)	T, LWC, Nd, cloud size dist(0.5-1500 mm)	PNNL
SPEC Cloud Particle Imager (CPI)	cloud particle image (15-2500 mm)	PNNL
PMS FSSP-100X	small particle spectrum (3-45 um)	EC
PMS FSSP-100X	small particle spectrum (5-95 um)	EC
PMS 2D2C	imaging of cloud particles, nominally 25-800 um	EC
SPEC 2DS (10 micron config.)	cloud PSD 10-1280 um, orthogonal channels, and images	EC
PMS 2DP	imaging of cloud particles, nominally 200-6400 um	EC
DMT CDP	cloud droplets 2-50 um	DMT
Korolev cloud extinction meter	cloud extinction	EC
Plus two of the following PMS canister mounted probes		
PMS FSSP-300	large aerosol 0.3-20 um	EC
PMS FSSP-002	small particle spectrum (3-45 um)	EC
PMS 2DC-grey	grey-scale images of cloud particles, nominally 15-960 um	EC
DMT CIP	imaging of cloud particles, nominally 15-960 um	EC

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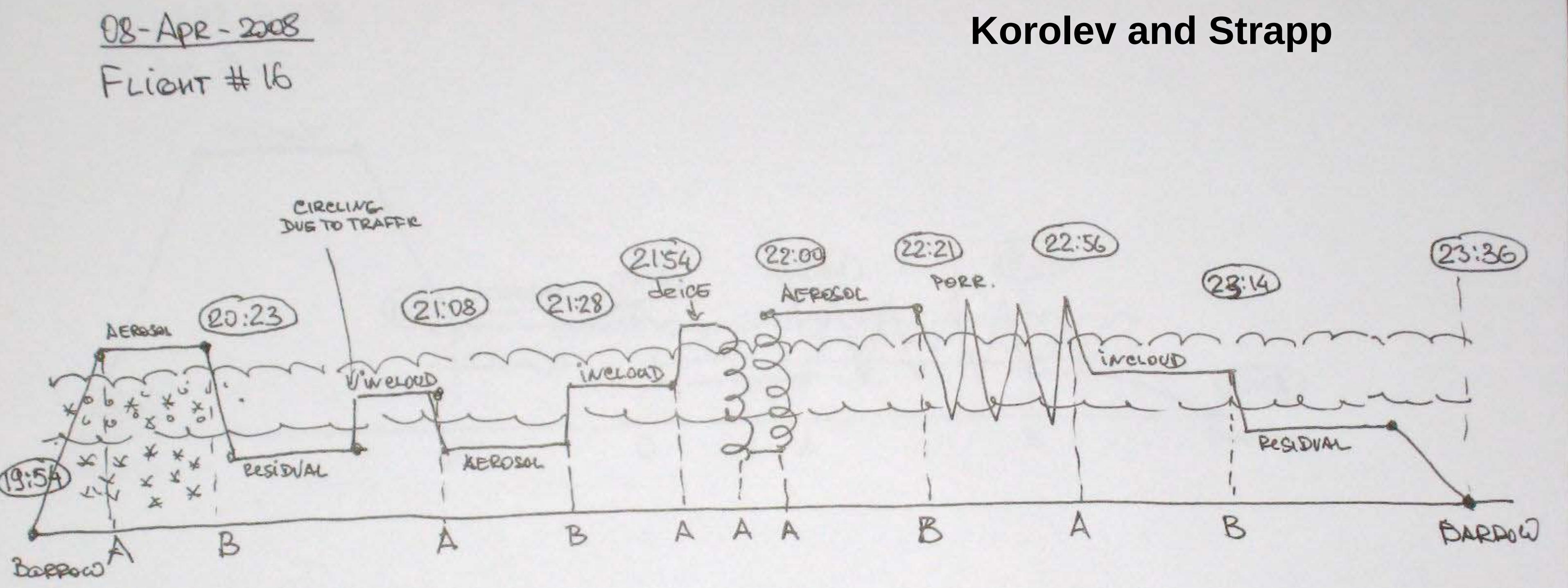
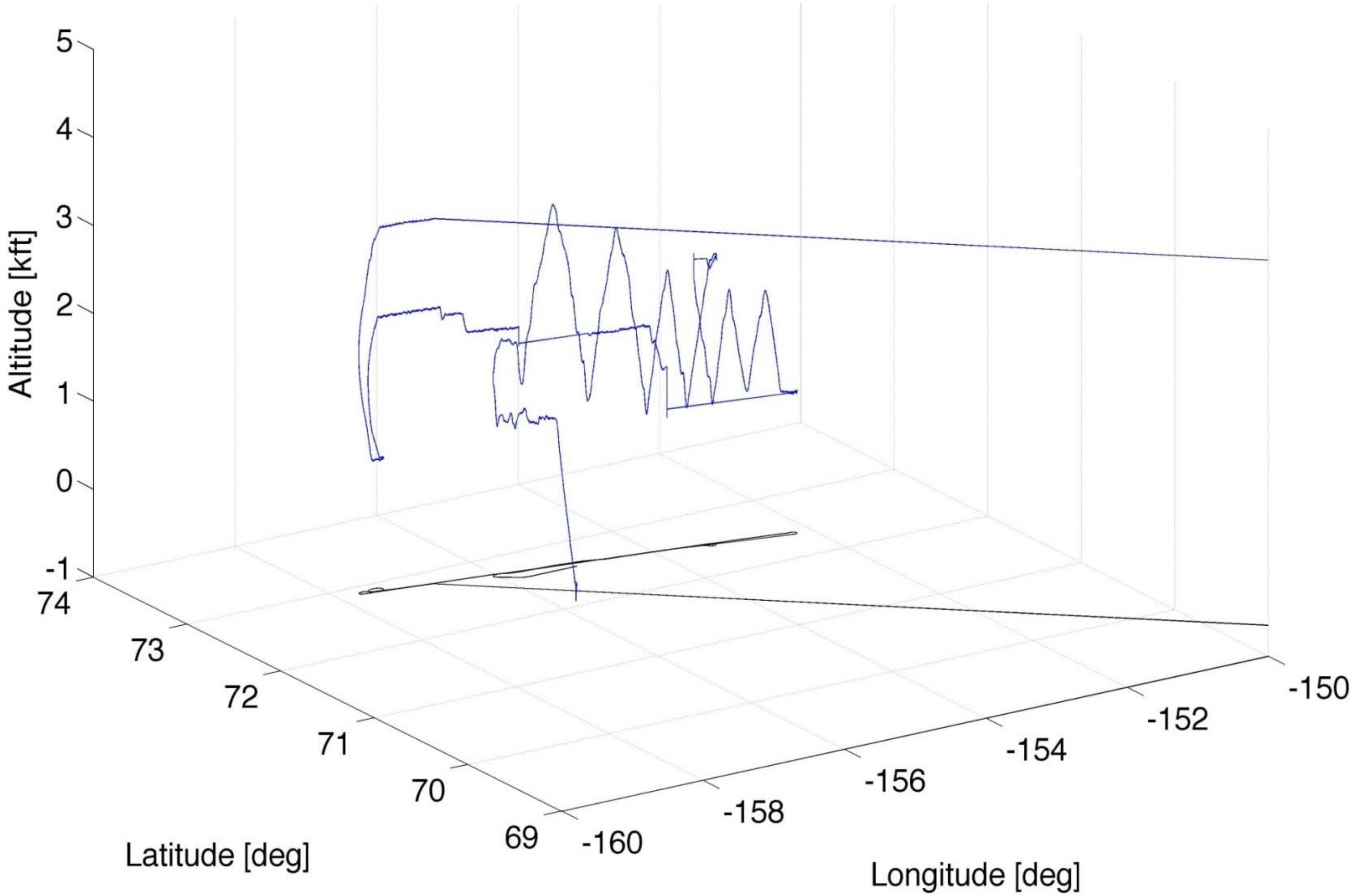
Korolev and Strapp



Flight profiles typically involved legs above and below cloud measuring both aerosols and residuals, and both porpoising and constant altitude flights through clouds

These flight profiles worked well on golden days (8 April and 26 April) where single layer clouds noted)

3-D Flight Profile Flown on 8 April Golden Day



Freer et al.

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April 8 flight track on google earth

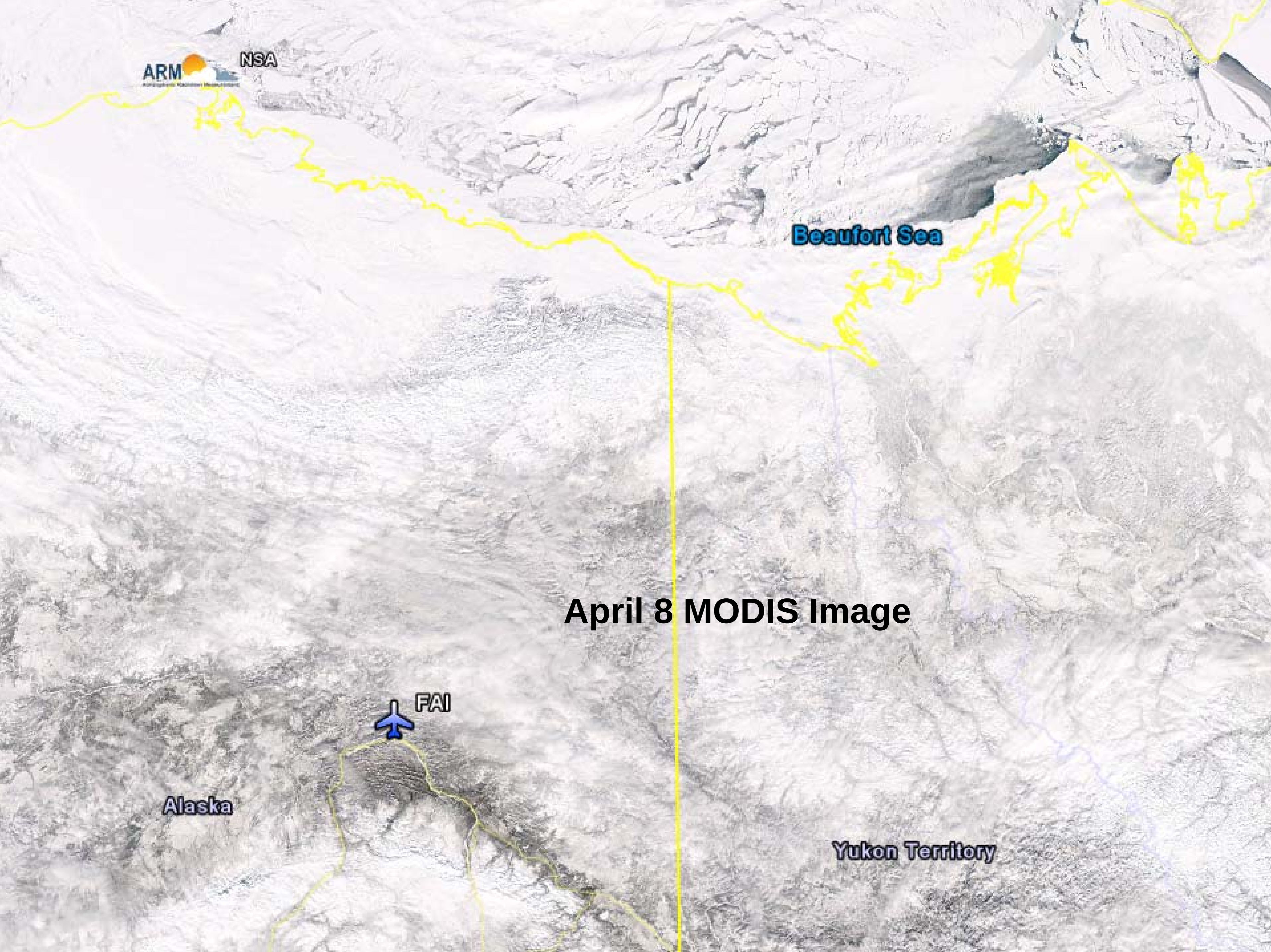
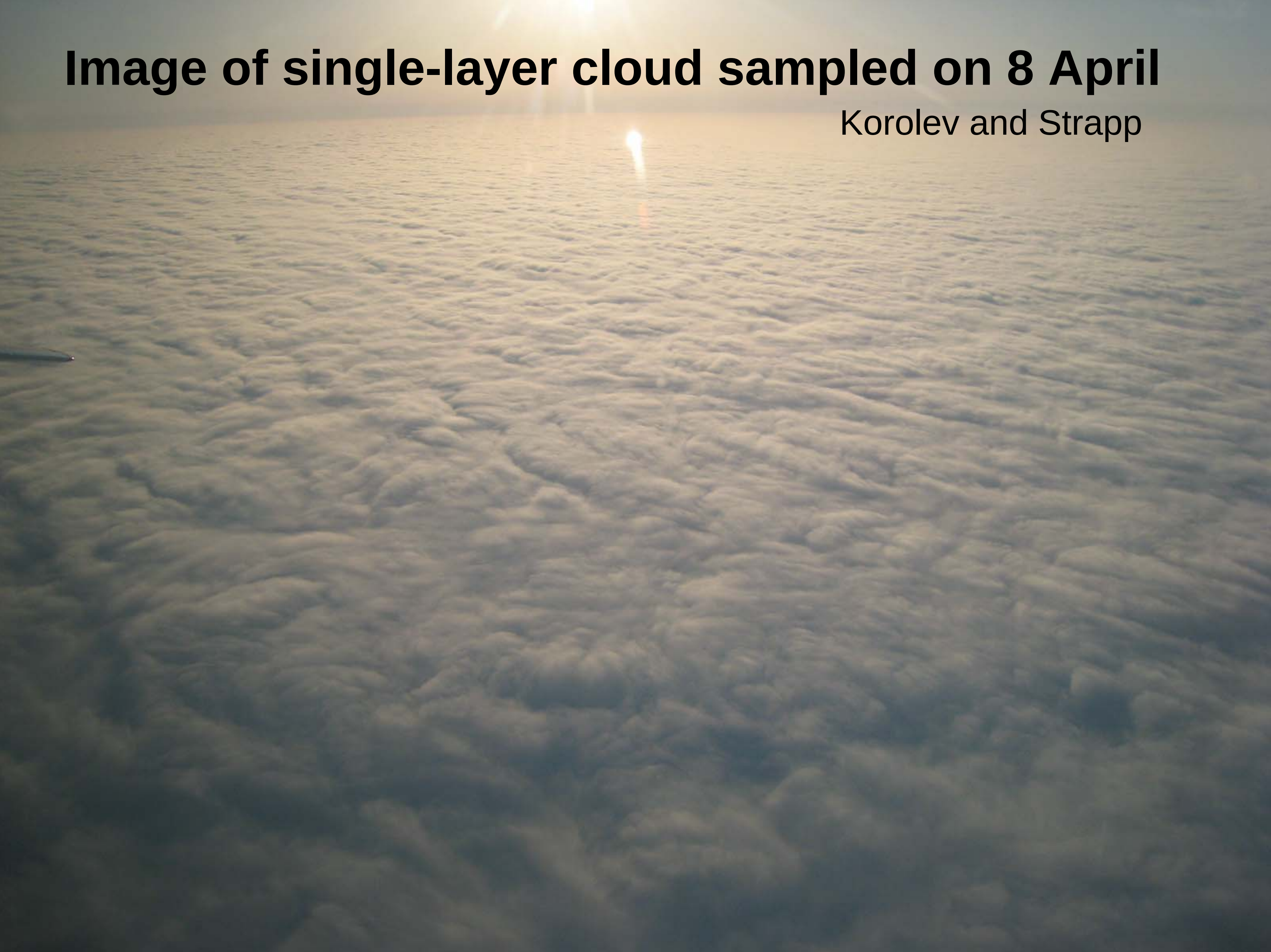

April 8 MODIS Image
ARM
NSA
Beaufort Sea
FAI
Alaska
Yukon Territory

Image of single-layer cloud sampled on 8 April

Korolev and Strapp

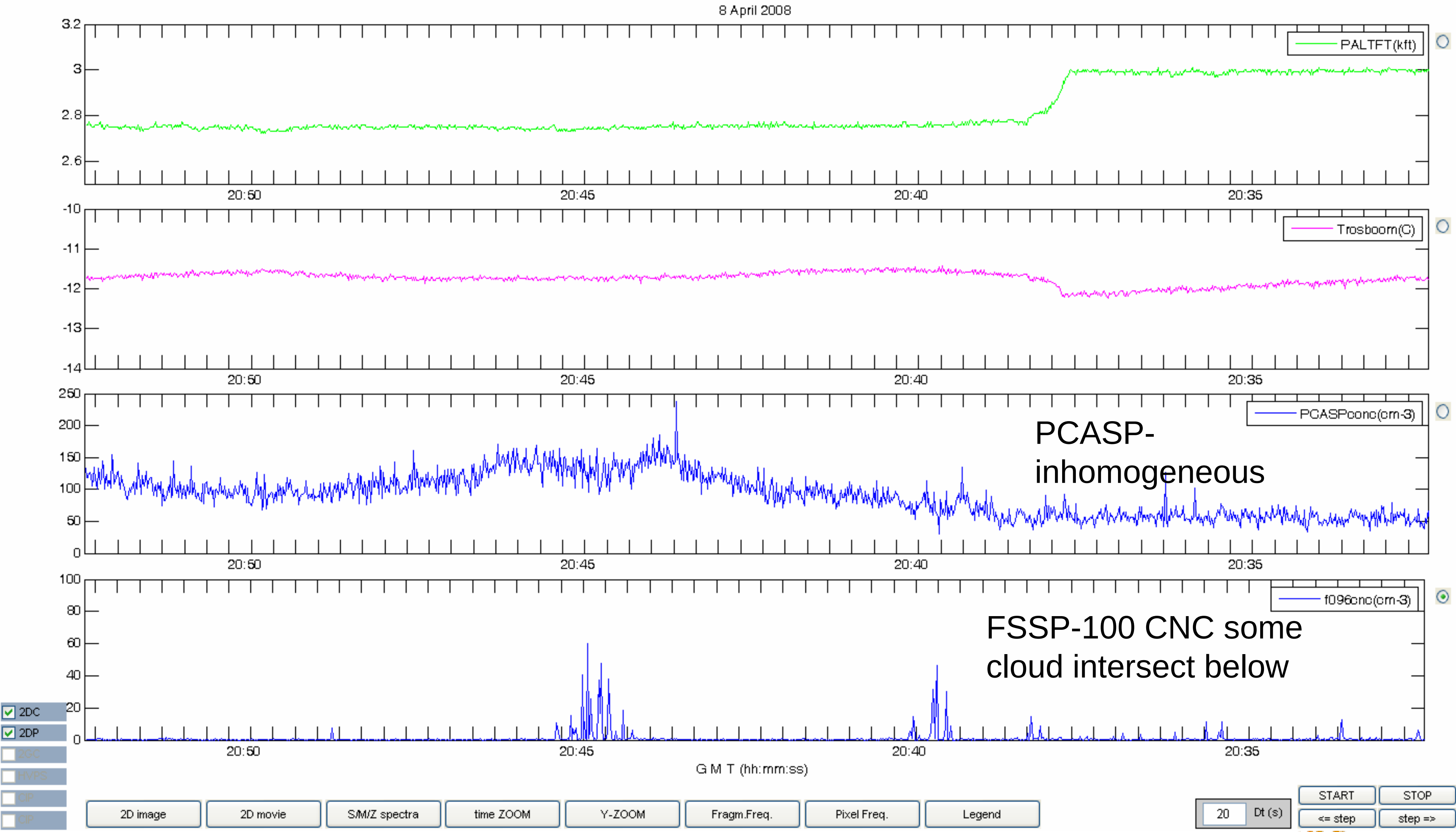


Below Cloud

Korolev and Strapp

A

B



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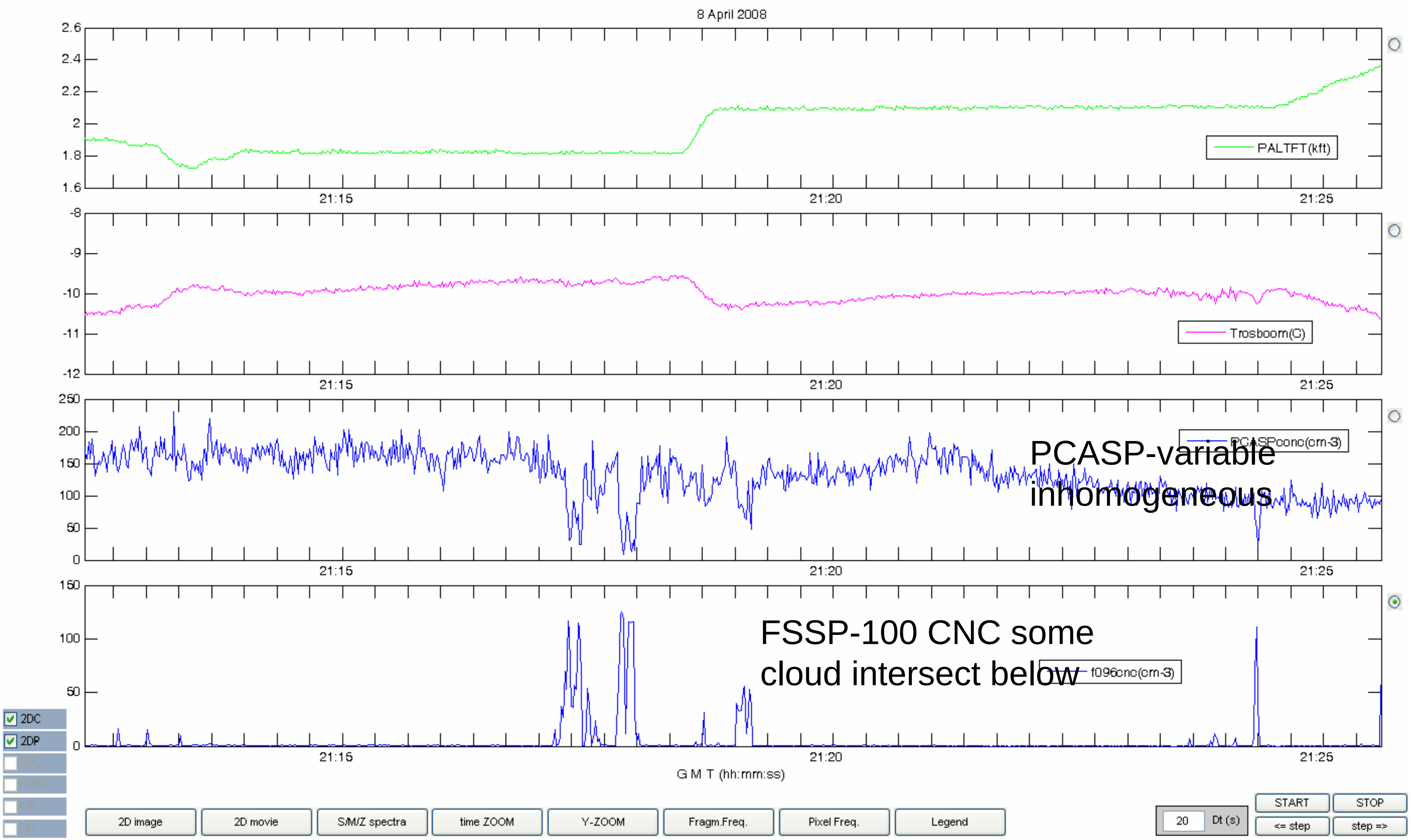
Below Cloud

Korolev and Strapp

A

B



Droplet closure studies with porpoise microphysics profiles

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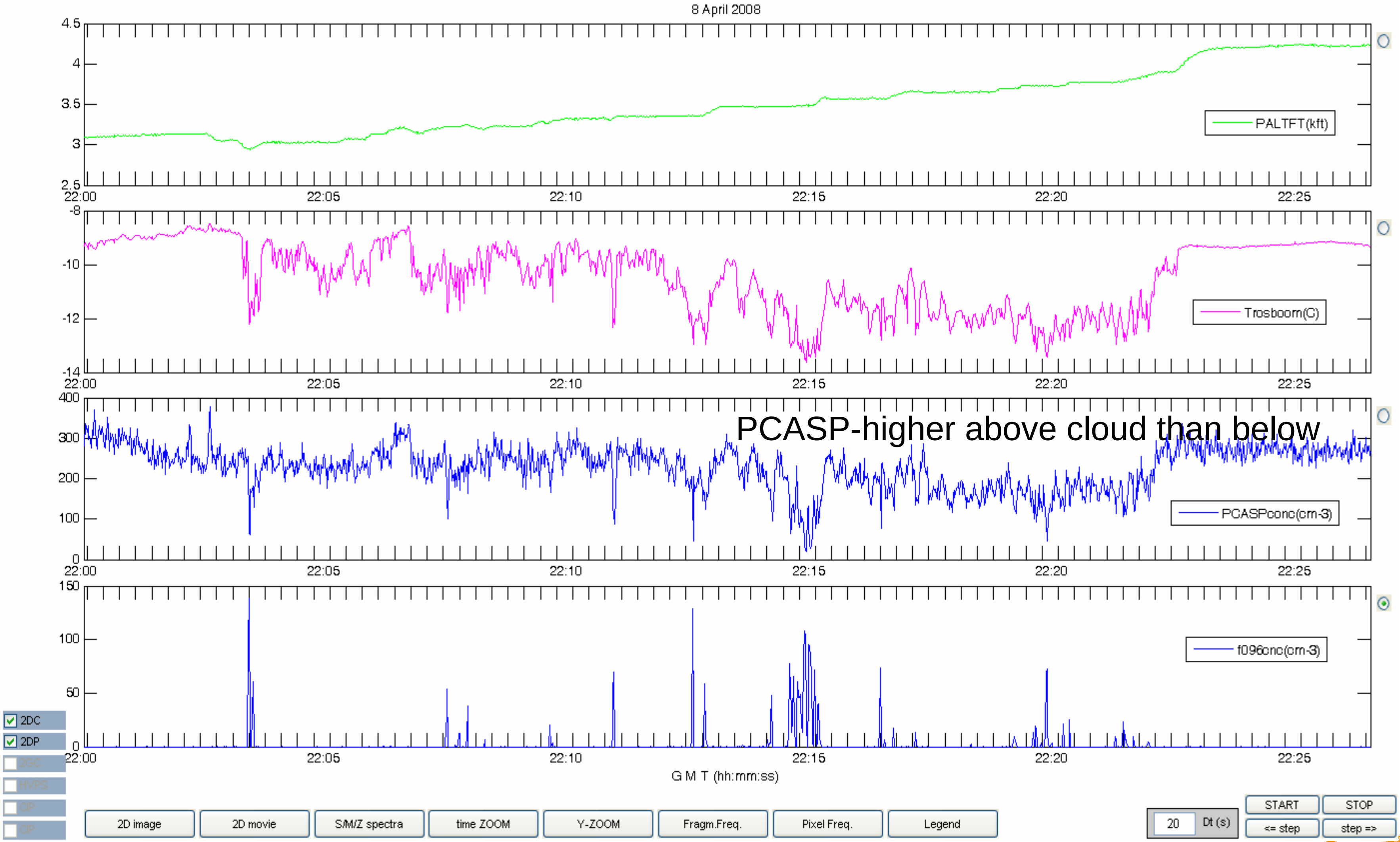
Above Cloud Top

Korolev and Strapp

A B



Aerosol-CCN/IN closure studies pollution aloft* vs below: Quantify by CRMs with well defined initial conditions and dynamics

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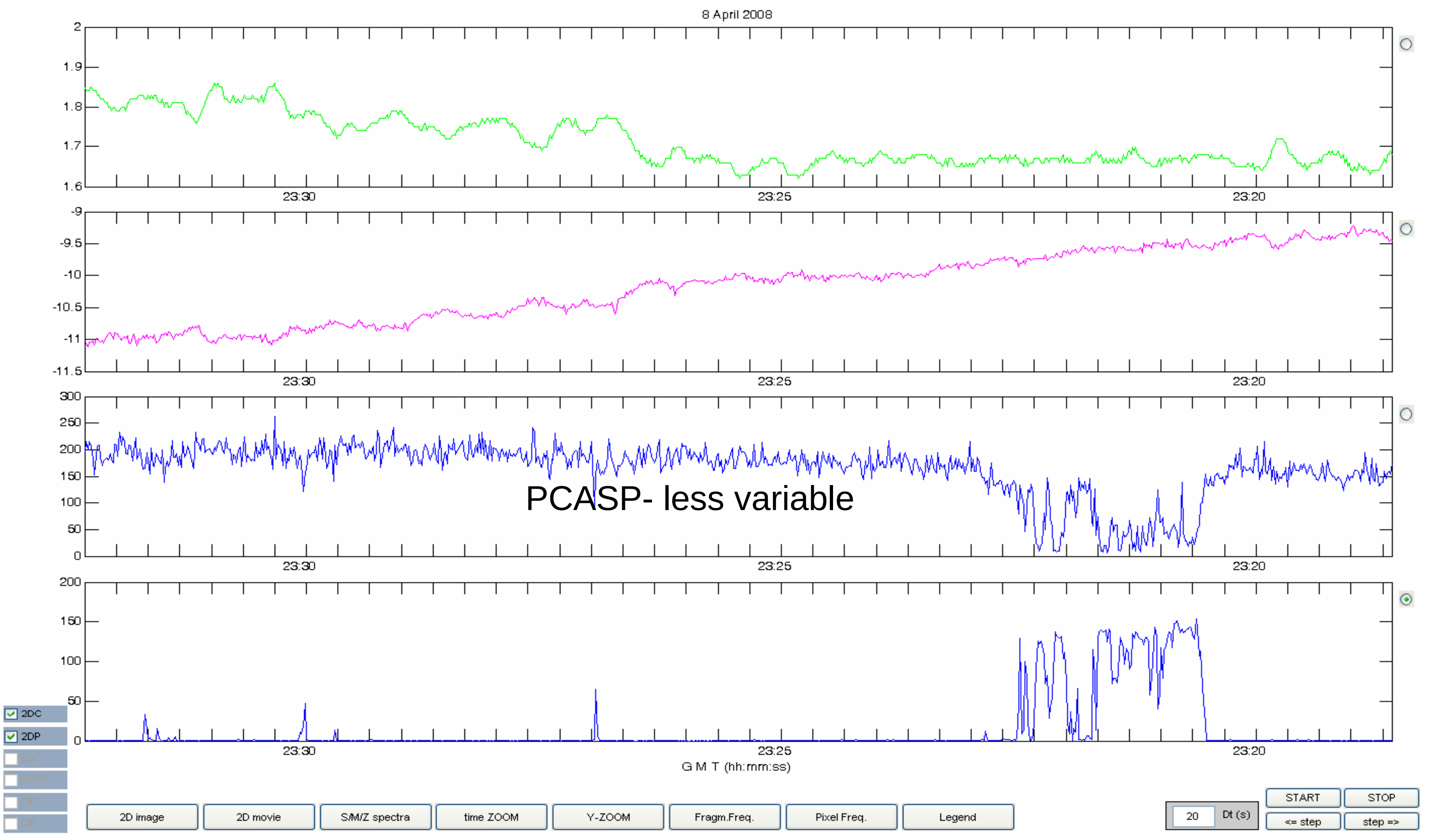
Below Cloud

Korolev and Strapp

A

B



Dynamics of large scale haze plumes: Core vs filaments vs cloud microphysics. Opportunity for Constrained LES Modeling!

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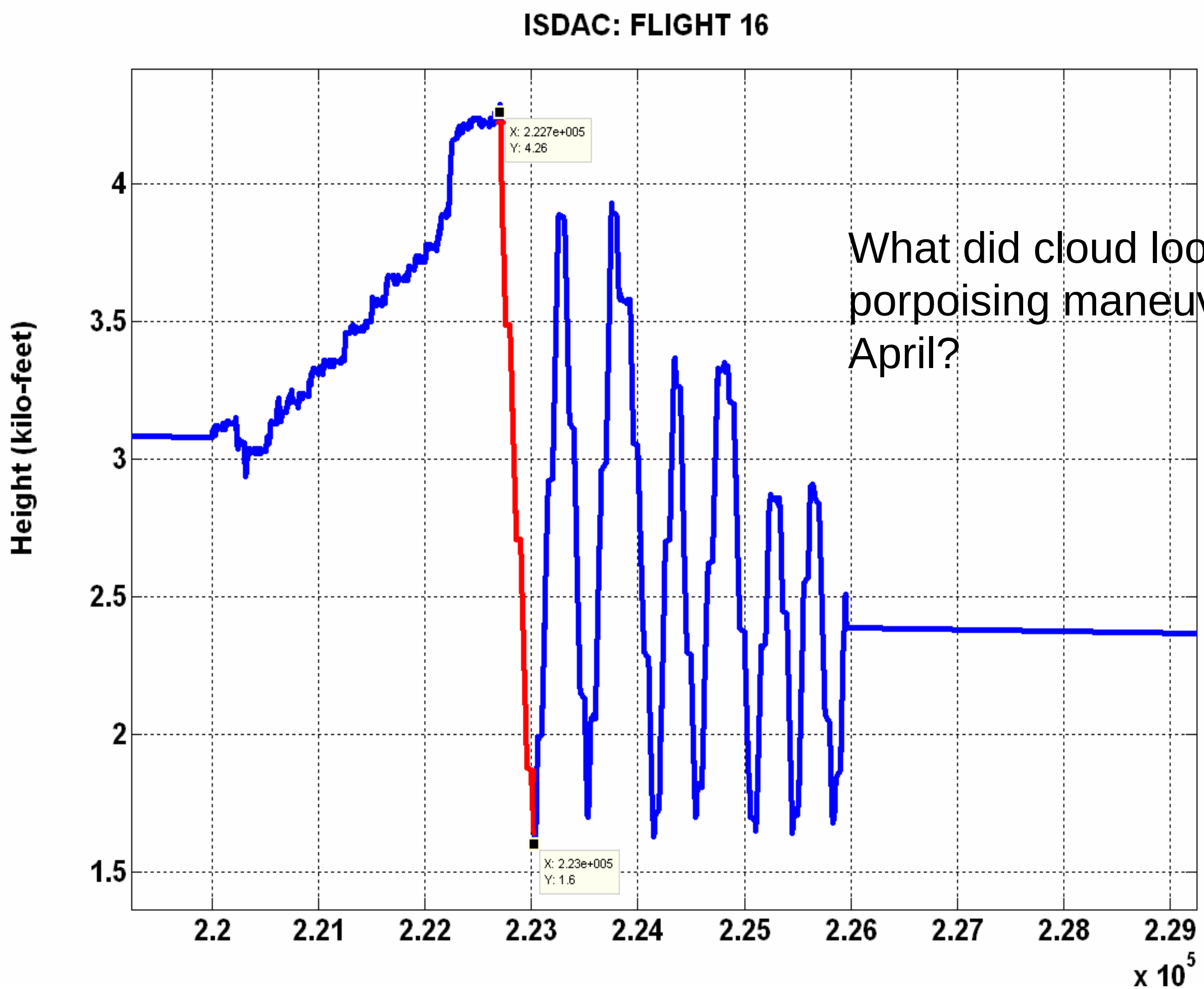
Height vs. Time (April 8) McFarquhar, Bae et al.



What did cloud look like during porpoising maneuvers on 8 April?

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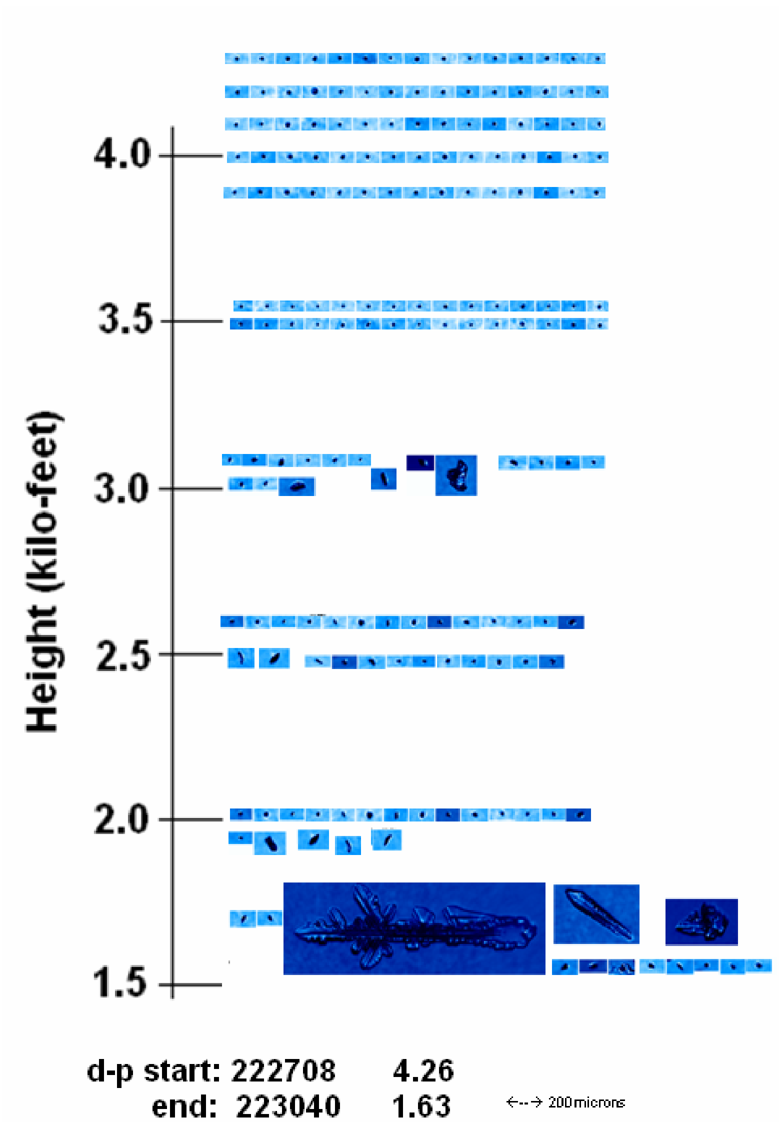
Select Particle Images as a Function of Height

McFarquhar, Bae et al.



CPI-Images

Small Spherical Supercooled Water

Interspersed with occasional ice particles

d-p: descent porpoise leg time height
a-p: ascent porpoise leg (hr:mm:sec) (kilo-feet)

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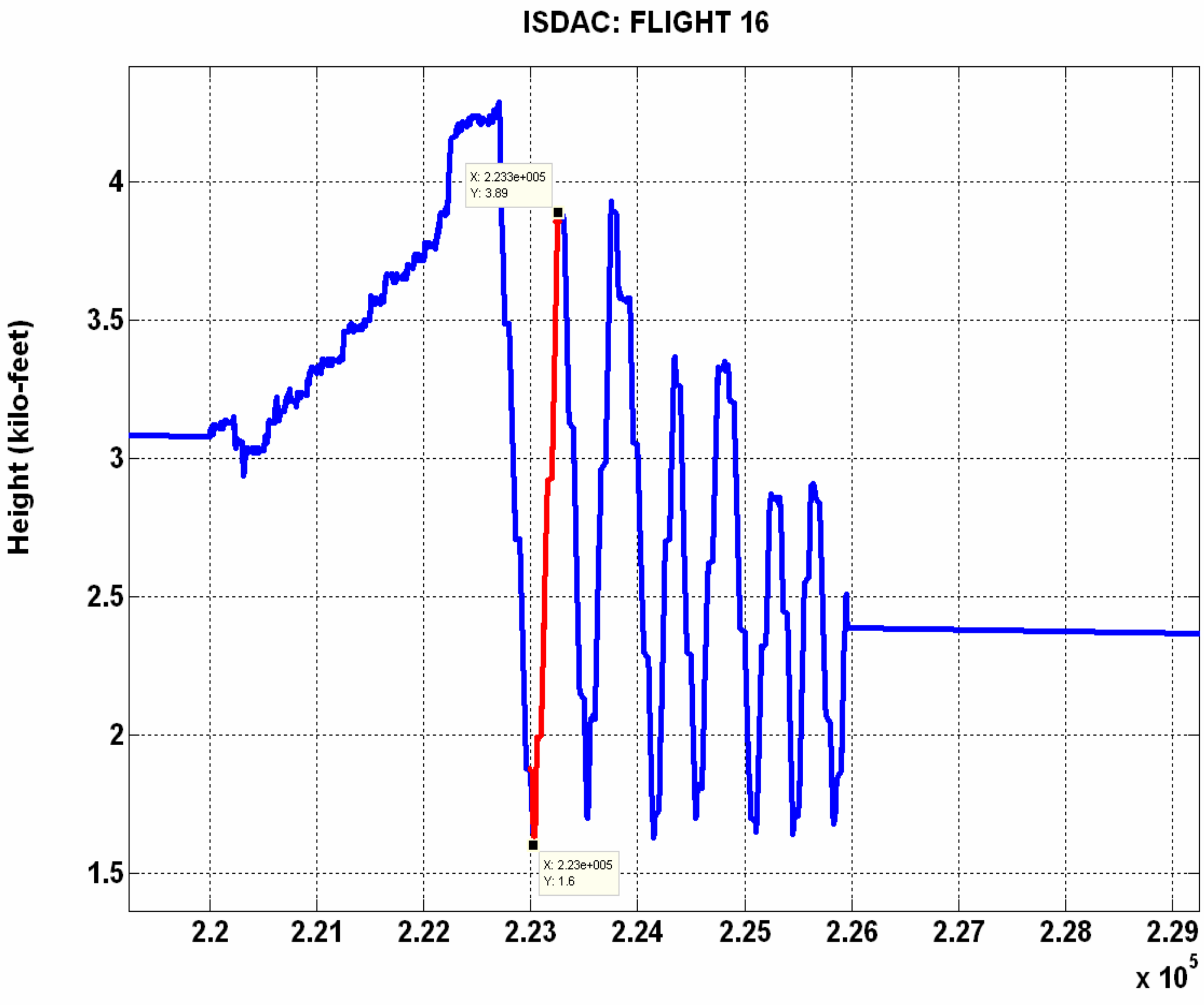
Height vs. Time (another porpoising leg)

McFarquhar, Bae et al.



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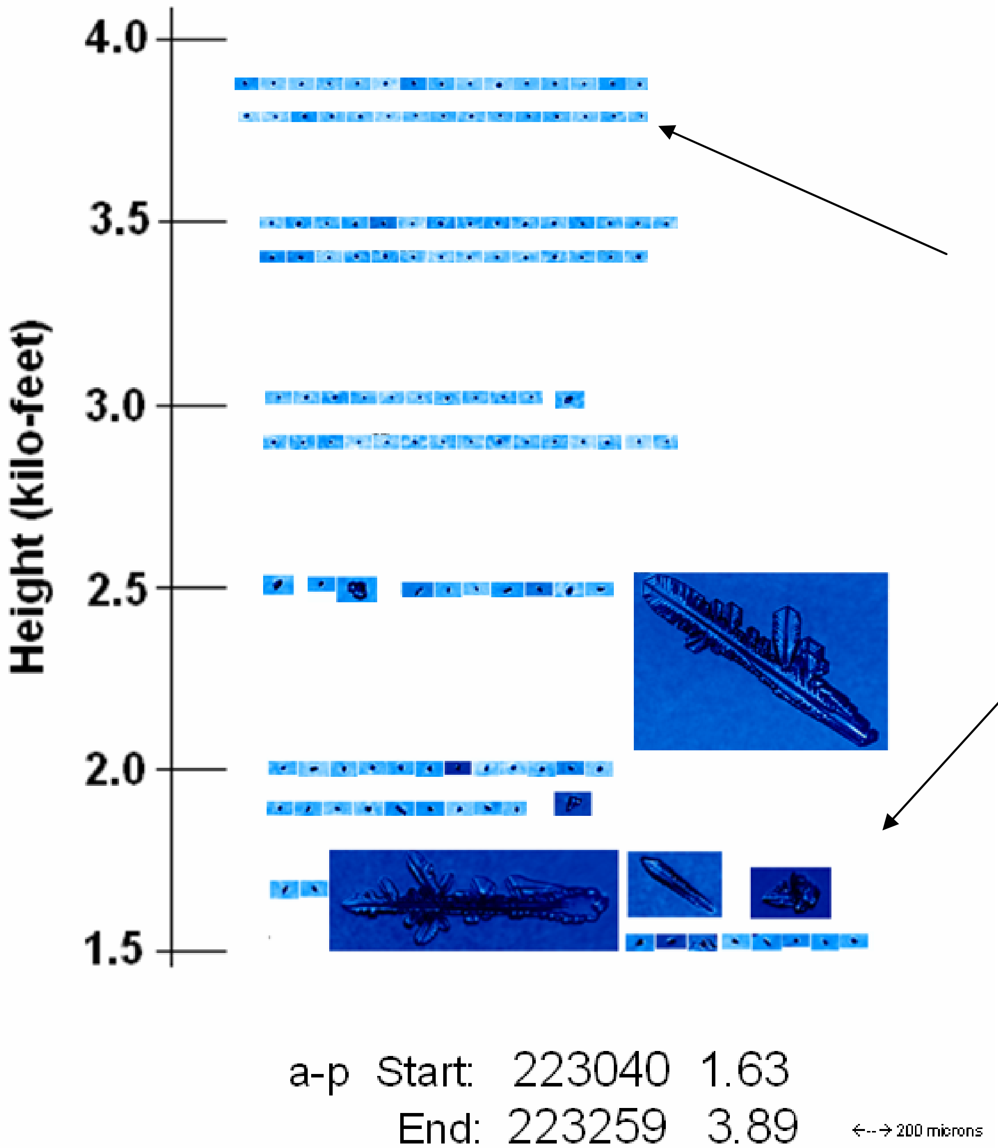
Select particle images as a function of height for the porpoising runs

McFarquhar, Bae et al.



CPI-Images

Small Spherical Supercooled Water

Interspersed with occasional ice particles

Spiral/porpoise profiles will provide statistical data sets for models

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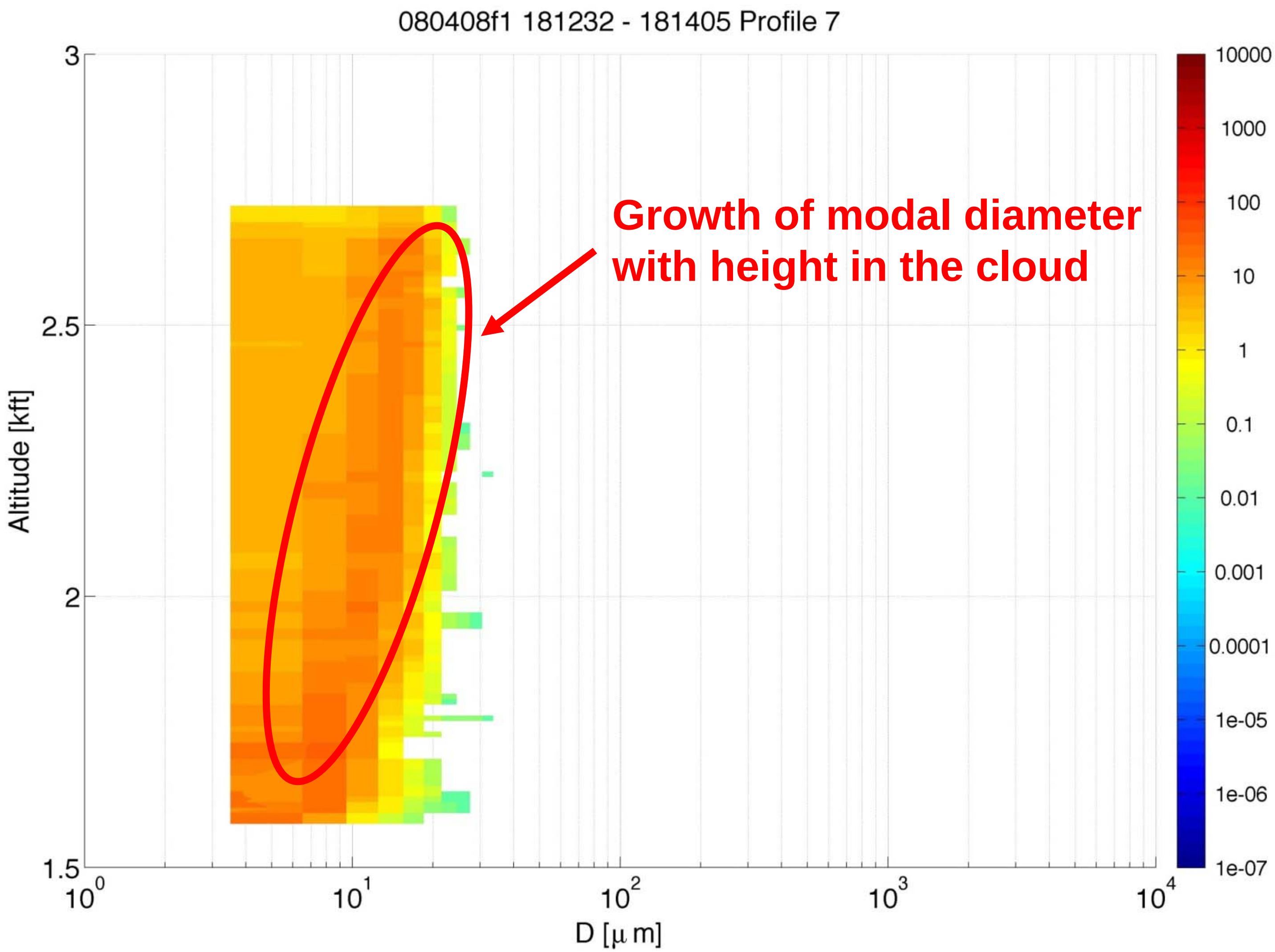
Evolution as Size Distributions as a Function of Altitude

McFarquhar, Freer et al.



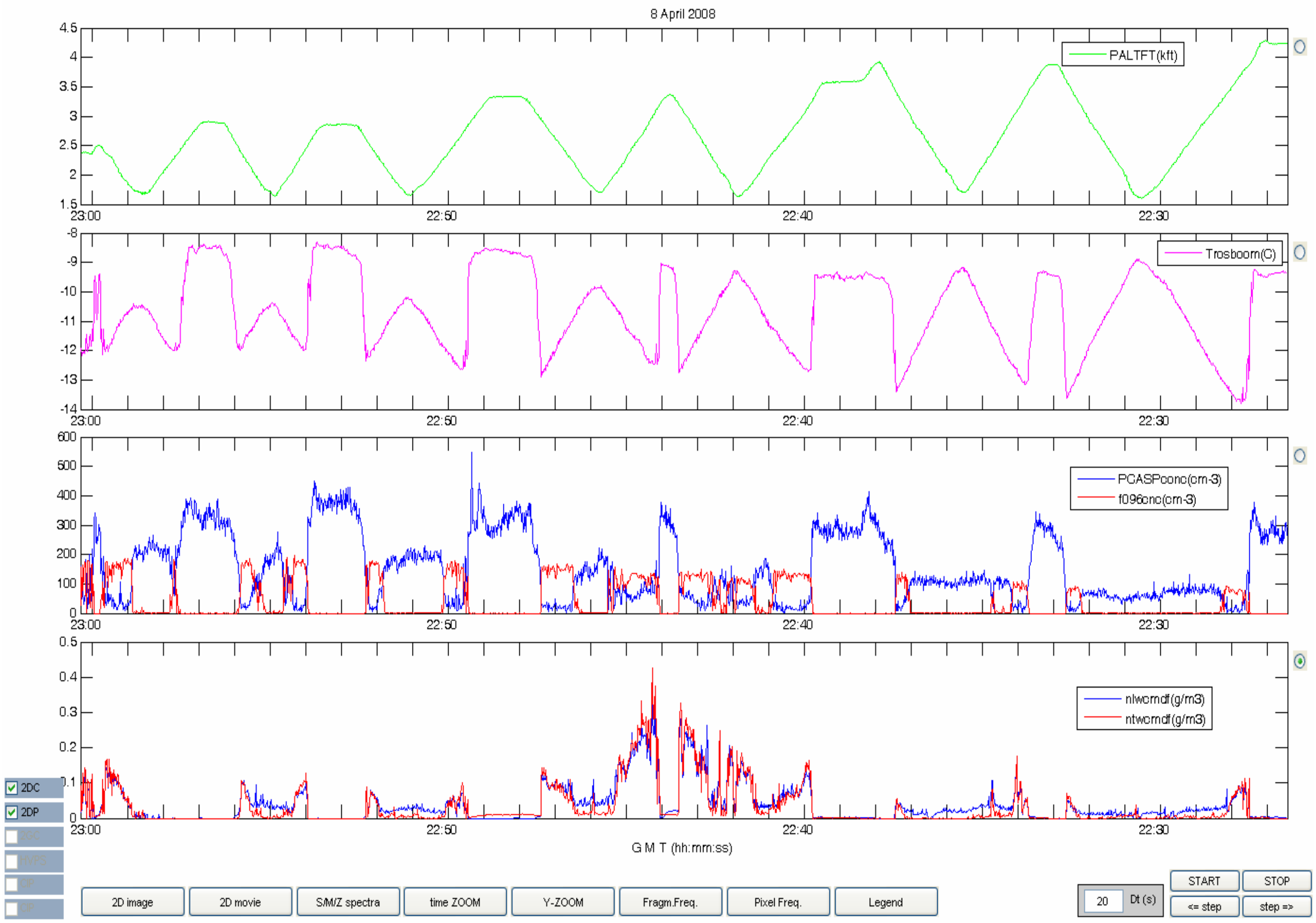
Profiles of Quantities through Porpoising Legs

Korolev and Strapp

A

Same for Porpoising, Cloud tops change but can be factored

B



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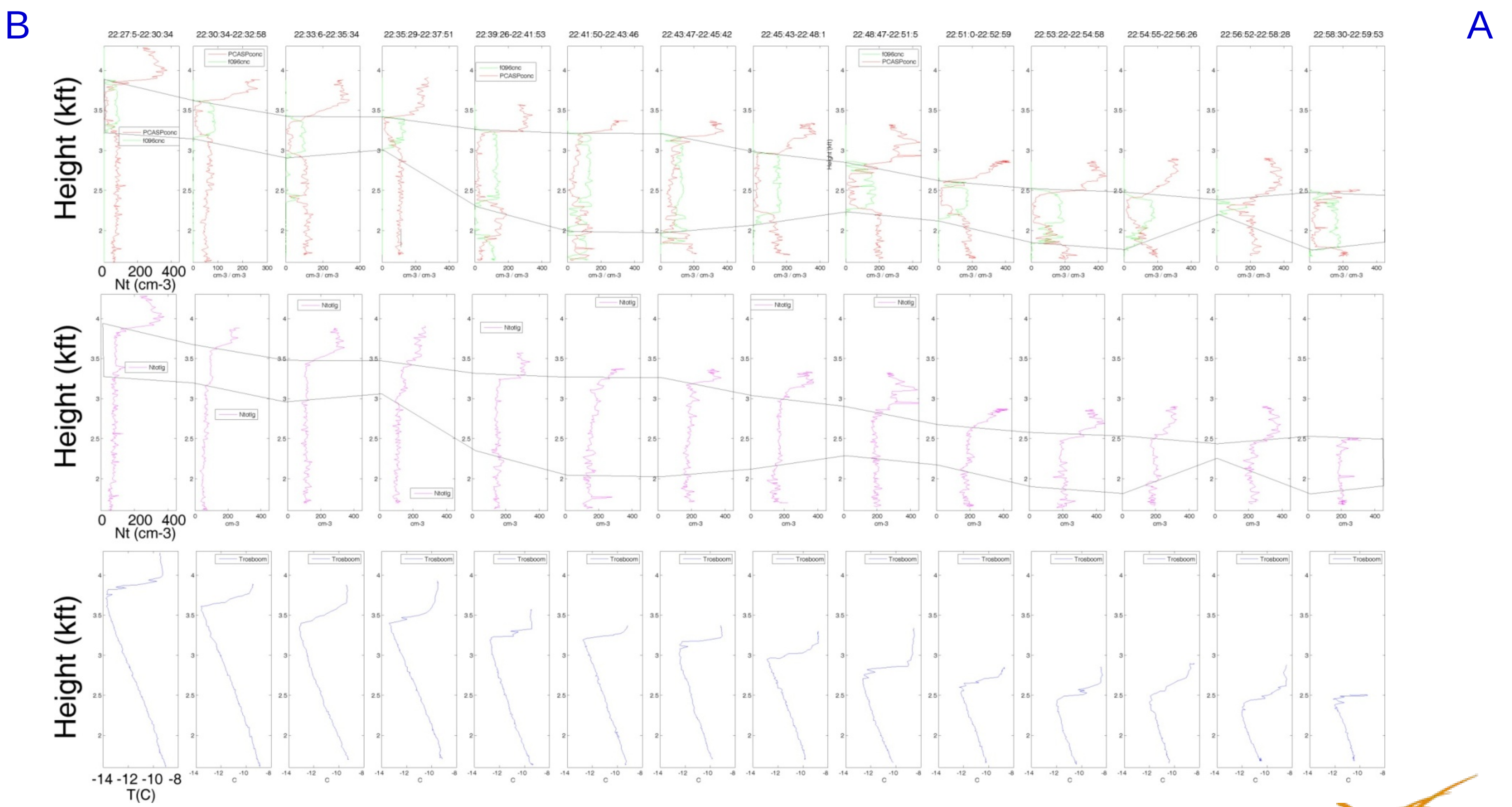
Porpoising maneuvers give information about horizontal & vertical variability of the cloud

Korolev and Strapp



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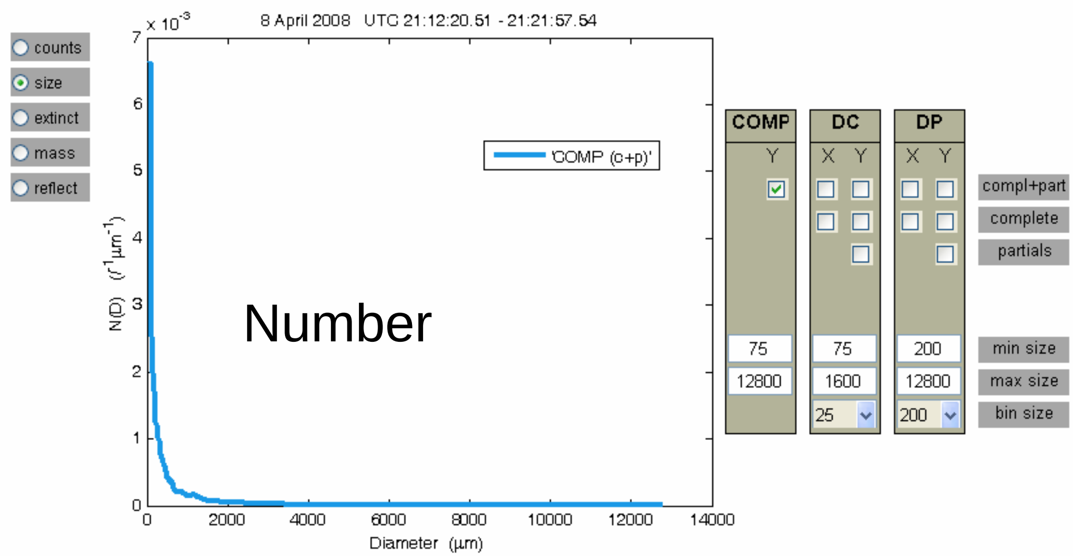
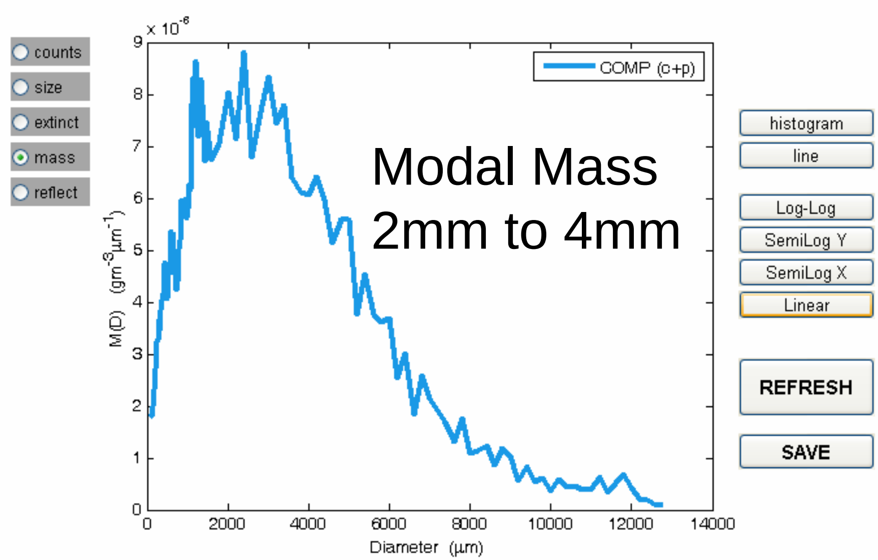
Integrated distributions of number and mass

Korolev and Strapp





9 minute average products for models

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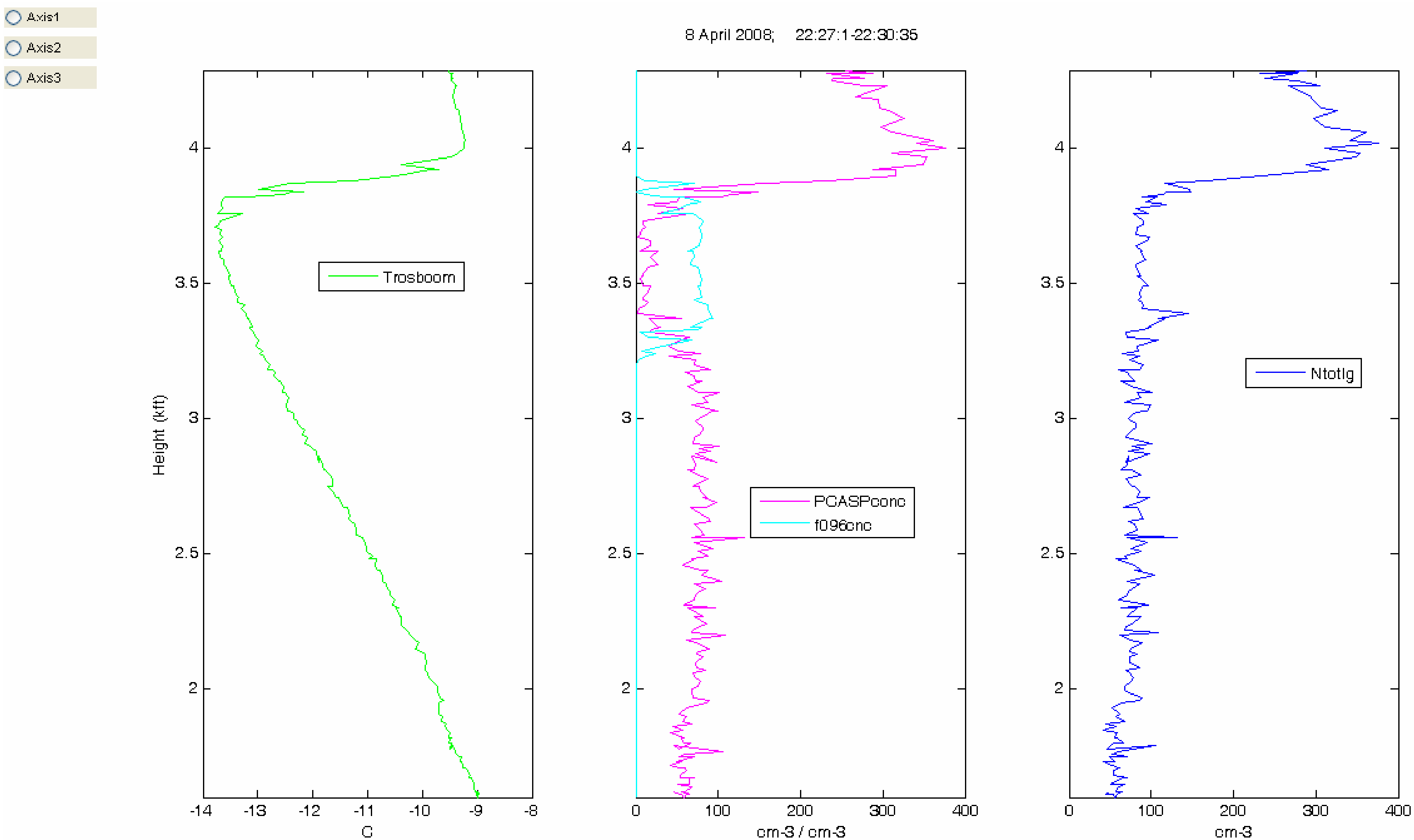
PCASP and FSSP Concentrations
(April 8, Porpoising)

Korolev and Strapp



Note: Vertical profiles are available for all the porpoising maneuvers

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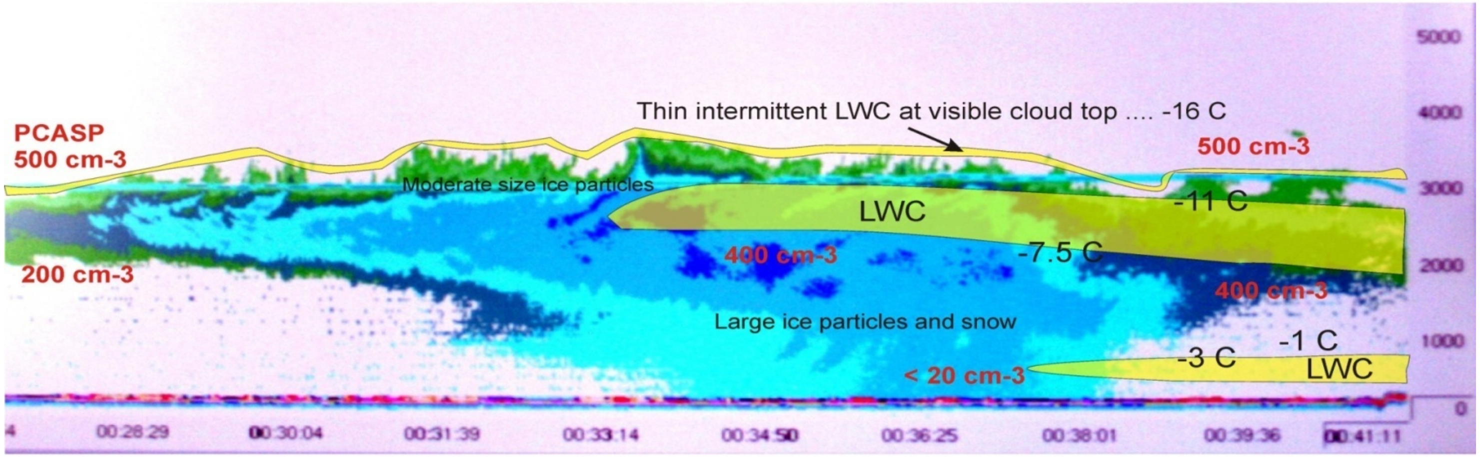
Conceptual Illustration of a Long-Lived Precipitation Area Imbedded in a Widespread Stratocumulus Deck (April 24, 2008)



- Cloud was situated to the east of Barrow, over an area of broken ice and open water.
- Visible cloud top was relatively flat and extended a great distance mainly to the north and east
- Radar reflectivities show vertical cross section of cloud ice particles from Ka radar
- Approximate area of liquid cloud shaded in yellow
- PCASP (0.13-3 um) aerosol number concentrations in red - moderate aerosol concs.
- Temperatures in black

Measurements made in this cloud:

- above cloud run 3900m
- below-liquid base CVI residual runs (2) 1800m
- below liquid base aerosol run 2100-1800 m
- porpoise run 3600-1800 m
- in-liquid cloud run 2450 m
- run below upper thin liquid top 3050 m
- low-level half-run 520m
- spiral up through main precipitation area, 520 - 3900 m
-

Strapp et al.

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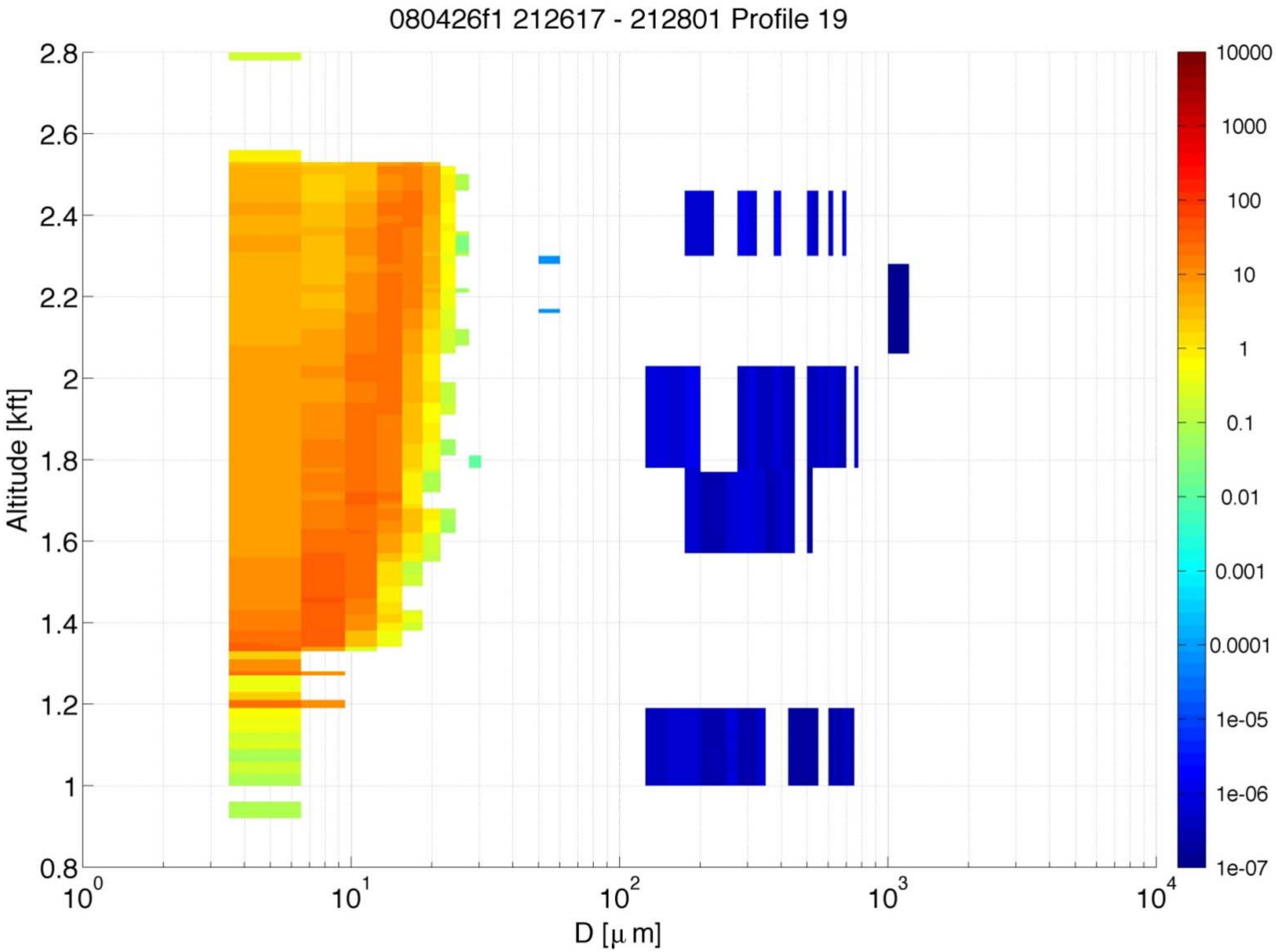
Size Distributions for Radar Imagery

McFarquhar/Freer et al.



Radar imagery helps put analysis of size distribution evolution in context of large-scale features and aerosol/residual observations made above and below cloud base; some larger crystals seen on 26th.

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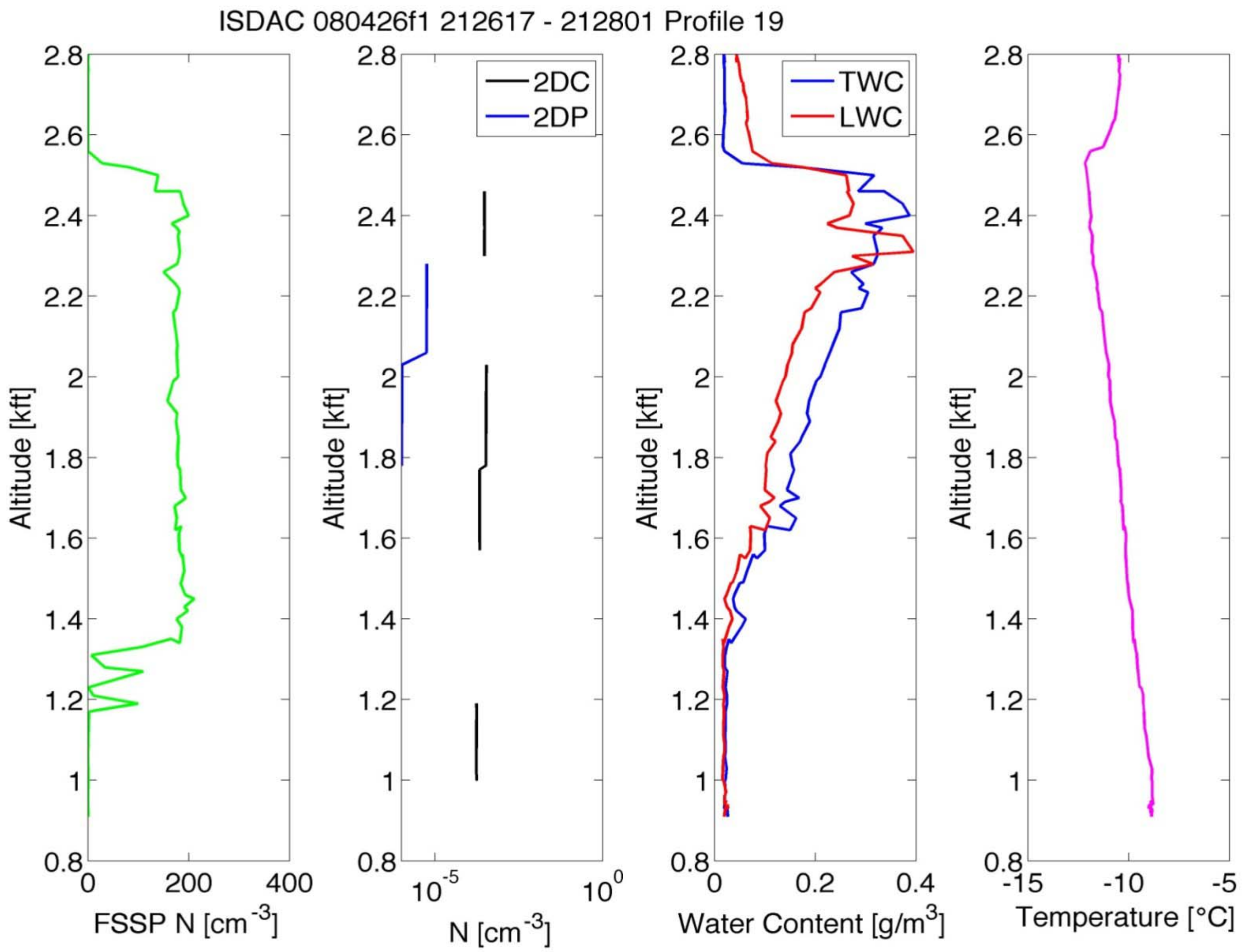
More examples of data that can be put in radar/aerosol context for 26 April

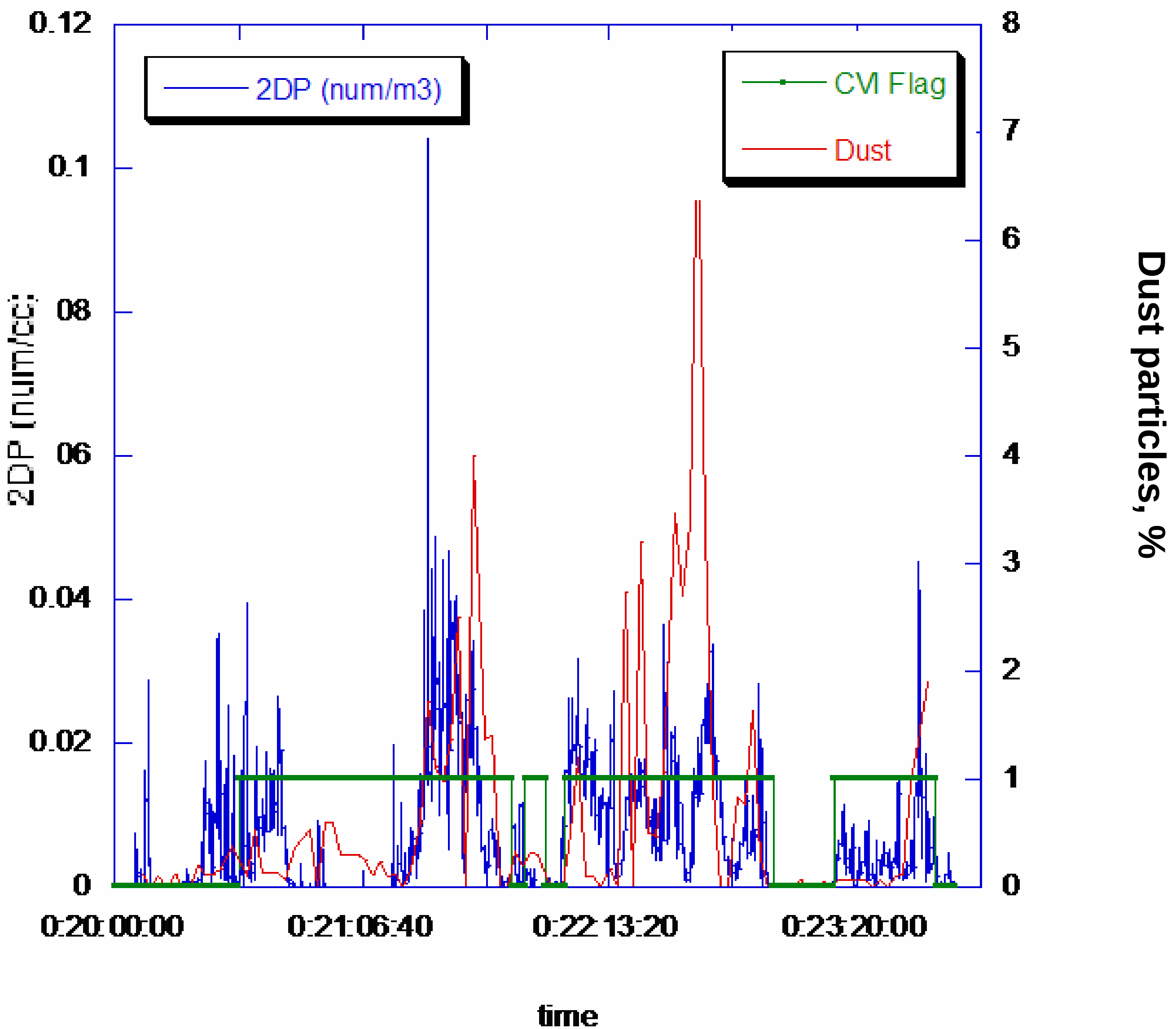
McFarquhar/Freer et al.



Chemistry: Ice Microphysics and Aerosol Optical Properties

- Alla Zelenyuk (PNNL)
- Claudio Mazzoleni and Manvendra Dubey (LANL)

Dust (SPLAT) correlation with ice crystal number (2-DP) April 1, Flight 09



Correlation between ice crystals number concentration measured by 2DP and fraction of particles characterized by SPLAT II and classified as dust.

(High CVI Flag value represents sampling through the CVI inlet)

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Pollution in Polar Regions
(ISDAC 19 April 2008, Large Haze Layers)

Layer of
Arctic Haze

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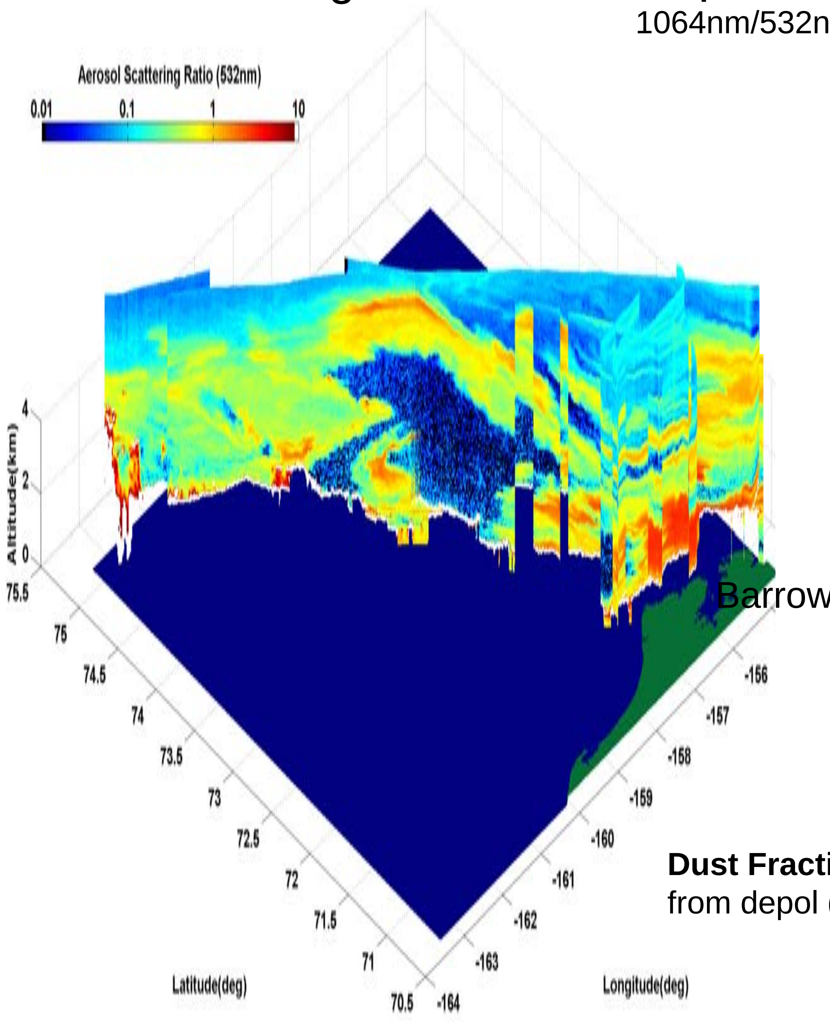
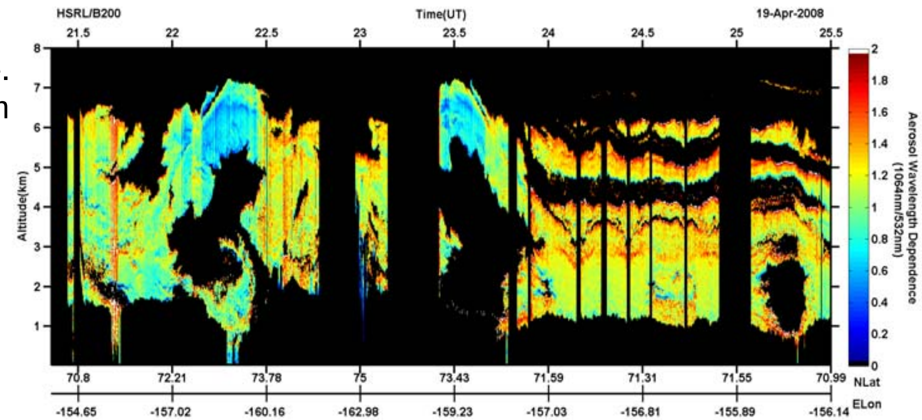
4/19 Pollution NASA B-200 Lidar Profiles

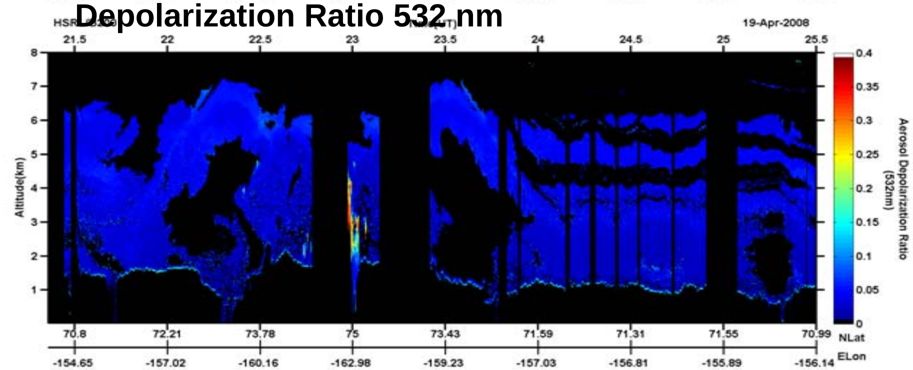
532nm Scattering Ratio



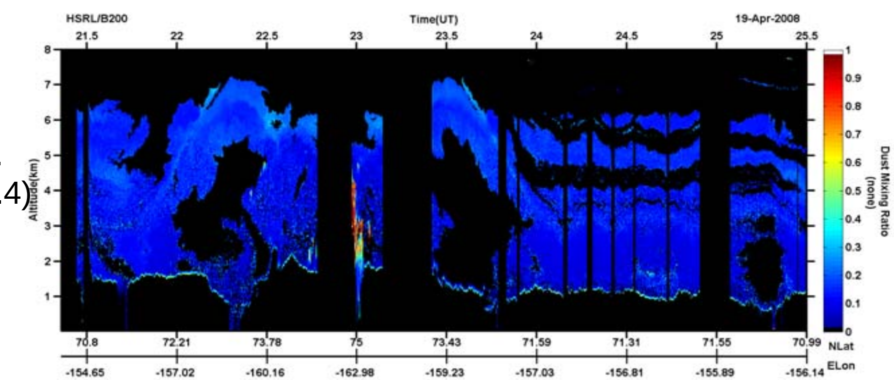
λ dependence.
1064nm/532nm



Depolarization Ratio 532 nm



Dust Fraction.
from depol (~0.4)



Ferrare