UNCLASSIFIED

Photoacoustic Observations of Aerosols Aloft Alaska: Quantification of Arctic Direct Radiative Forcing

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ARM-SGP '09

'08 China Olympics Plume Study

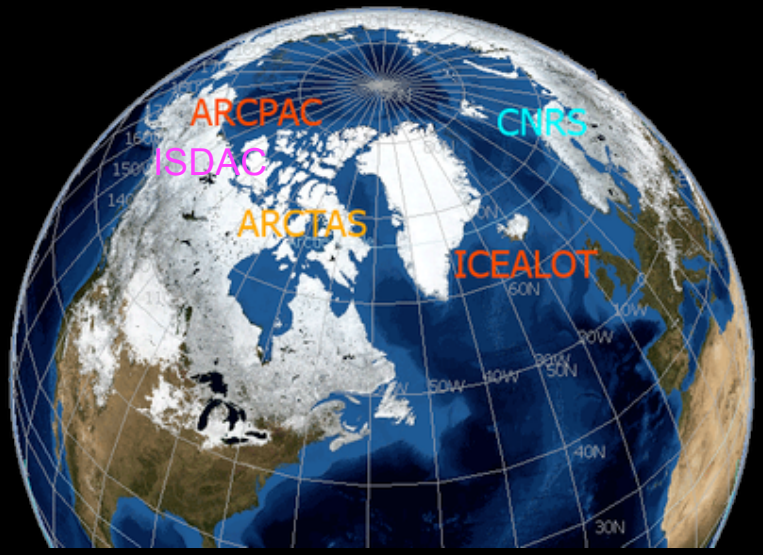
Earth & Environmental Sciences

ARM Aerosol and Cloud Working Group Nov 12 2008

Preamble: Arctic is Canary in Climate Change Mine

- From Detection-Attribution to Solution-Action
- Must Act: Headed to ~10 W/m^2 forcing in 2100, inertia
- Socio-technological actions (Speed, Scale, Urgency, Cost) need
  - **MONITOR PACE OF ARCTIC CHANGE: ICE FREE TIPPING POINT**
  - **PRECISE GLOBAL CLIMATE SENSITIVITY, $d(\Delta T_s)/d(F_{aer+GHG})$**
- Outstanding Issues:
  - **MODELS UNDERPREDICT RATE OF ARCTIC ICE RETREAT**
  - **CLIMATE SENSITIVITY** is ill constrained (Uncertainty x 2-4)

Concerted Multi-Agency Field Campaigns Concluded the International Polar Year April 2008



Polar Study using Aircraft, Remote Sensing, Surface Measurements and Models, of Climate, Chemistry, Aerosols, and Transport

By over 285 scientists from DOE, NOAA, NASA and Europe

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http://www.polarcat.no/, http://acrf-campaign.arm.gov/isdac/ http://www.esrl.noaa.gov/csd/arcpac/, http://www.espo.nasa.gov/arctas/

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Indirect & Semi-Direct Aerosol Campaign ISDAC: The Influence of Arctic Aerosol on Clouds

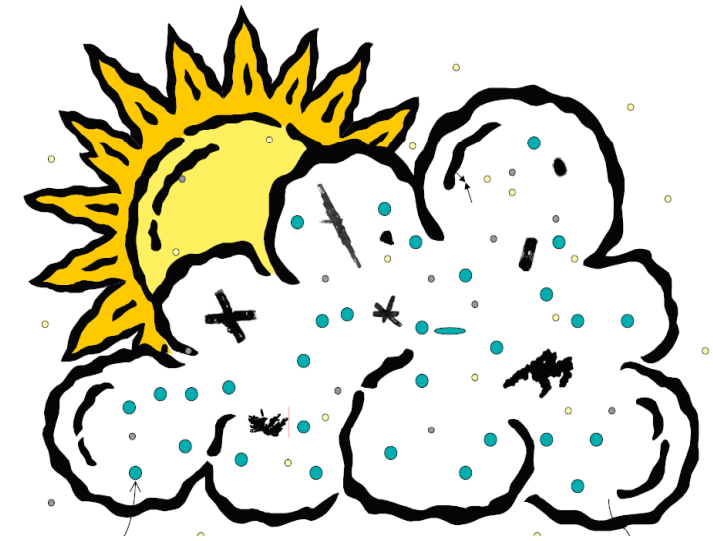
PIs: Greg McFarquhar, Steve Ghan, Hans Verlinde

ARM AVP: Beat Schmid, Greg McFarquhar, 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/

Outline

- Motivation

  Arctic is warming much faster than models simulate.

- Key Questions

  Are aerosol-cloud-snow-ice forcings feedbacks responsible?

- ISDAC Observational Strategy

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

- Fresh Results to Guide Modelers: Dialogue

  Improve Arctic aerosol-cloud-radiation treatments.

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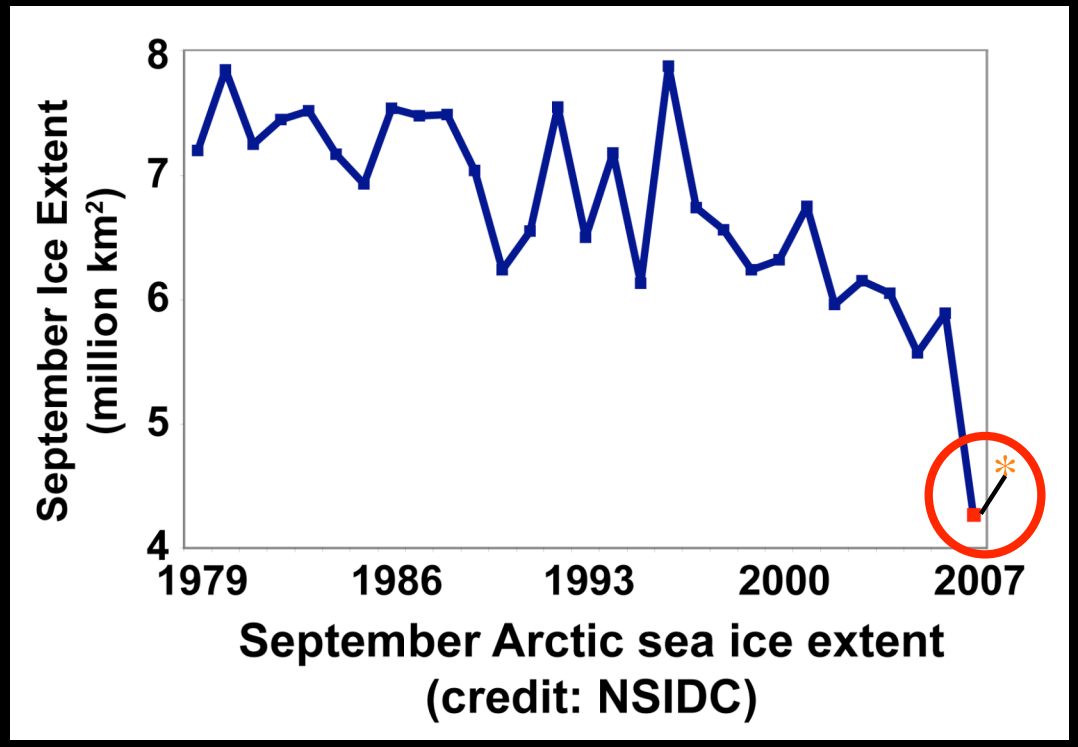
2007-08 Record Minima in Sept. Arctic Sea Ice Extent



Additional open ocean = Texas + Alaska

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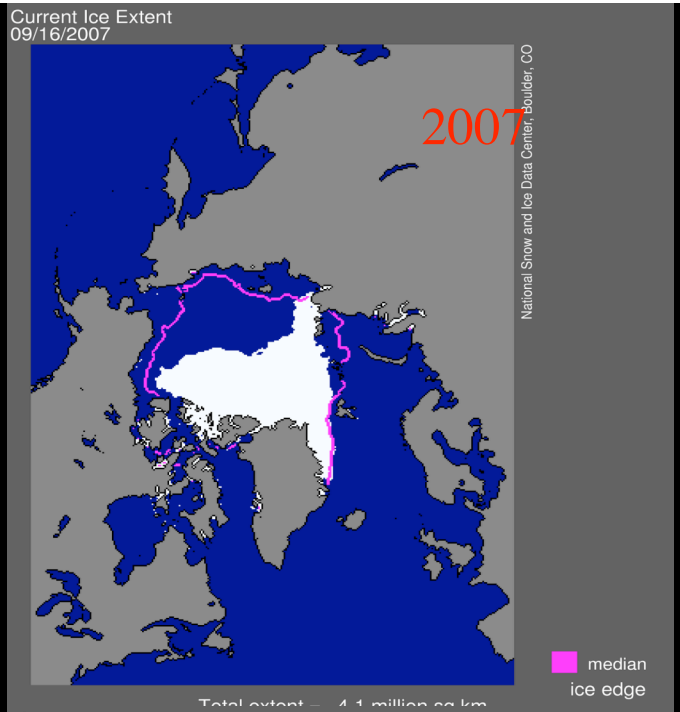
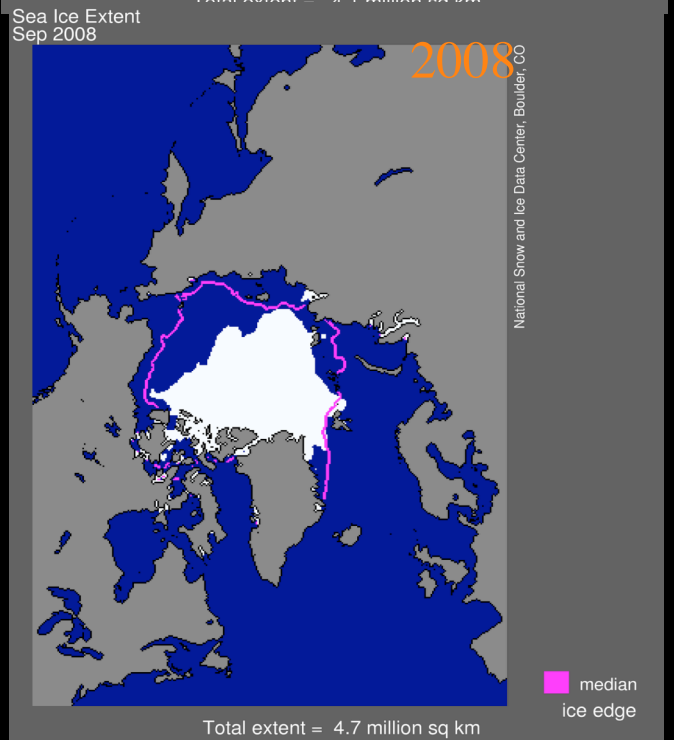
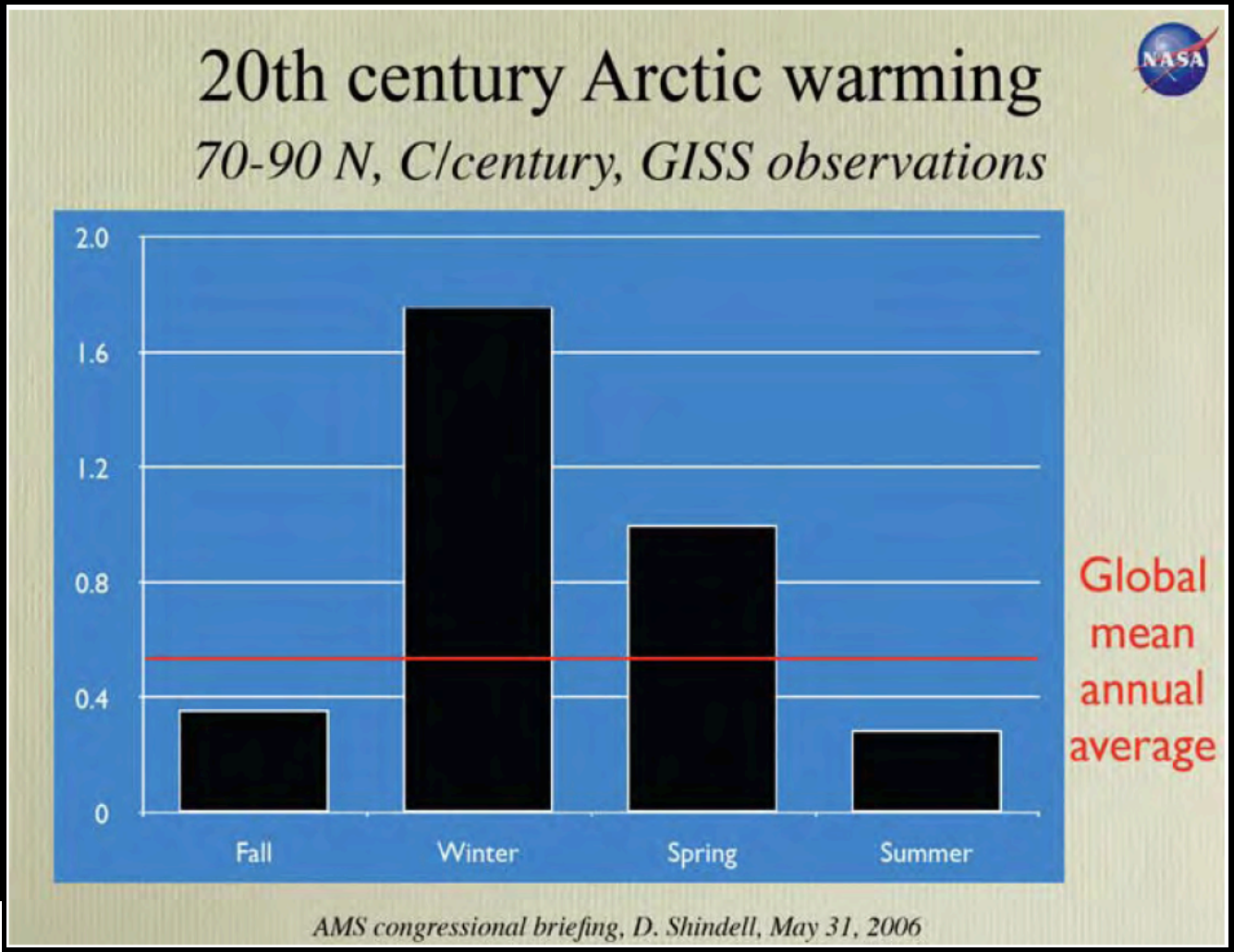




Arctic warmed more than global mean in spring & winter



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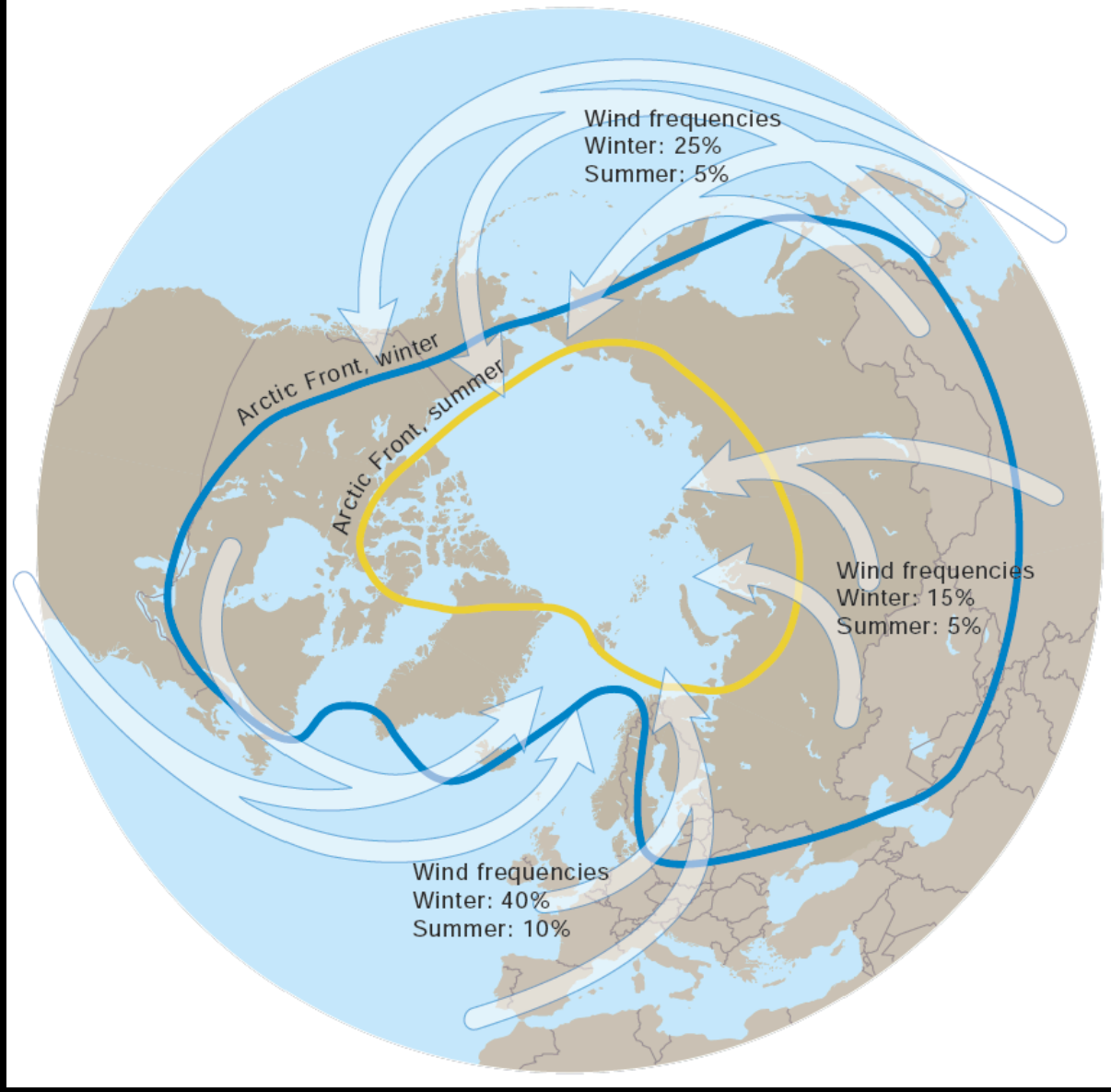

Sources for surface haze generally lie within the Arctic front

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

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Arctic Monitoring and Assessment Programme, 2006

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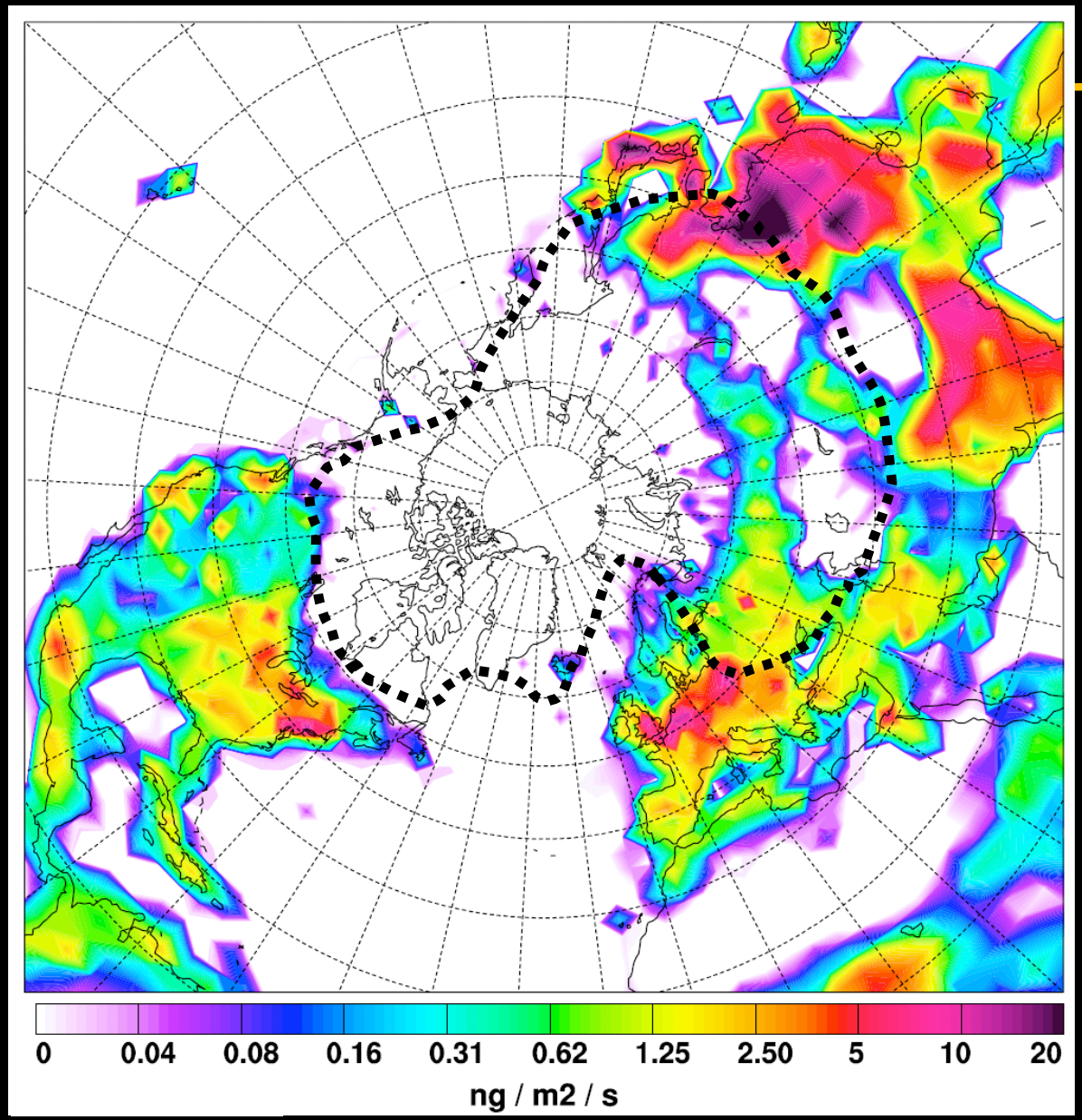

Anthropogenic sources of soot (industrial and biofuel)

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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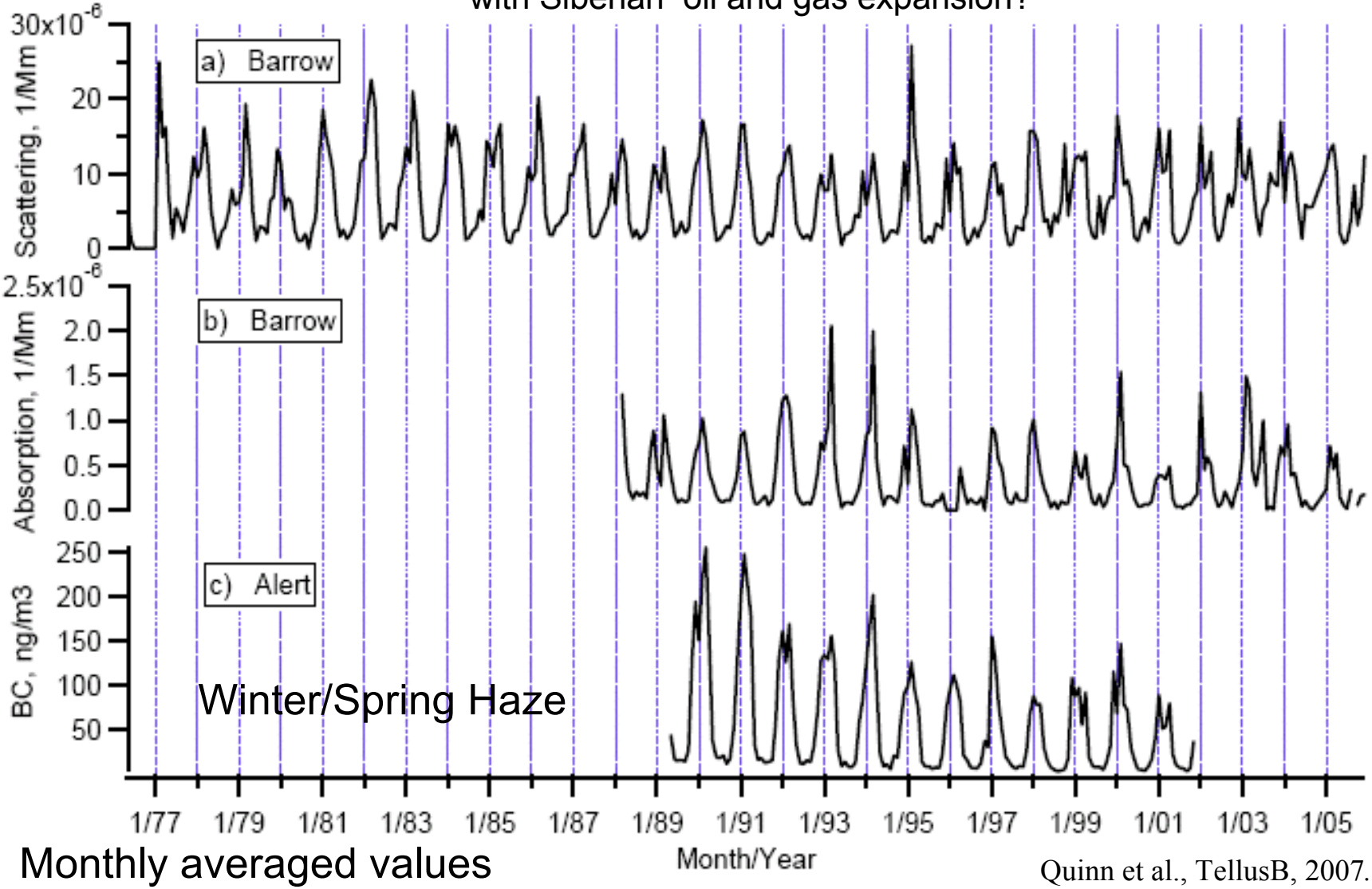
Arctic seasonal cycle trends: Aerosol scattering, absorption, black carbon (surface/point data)

Decrease in black carbon and absorption due to decline of Soviet emissions? Will this continue with Siberian oil and gas expansion?

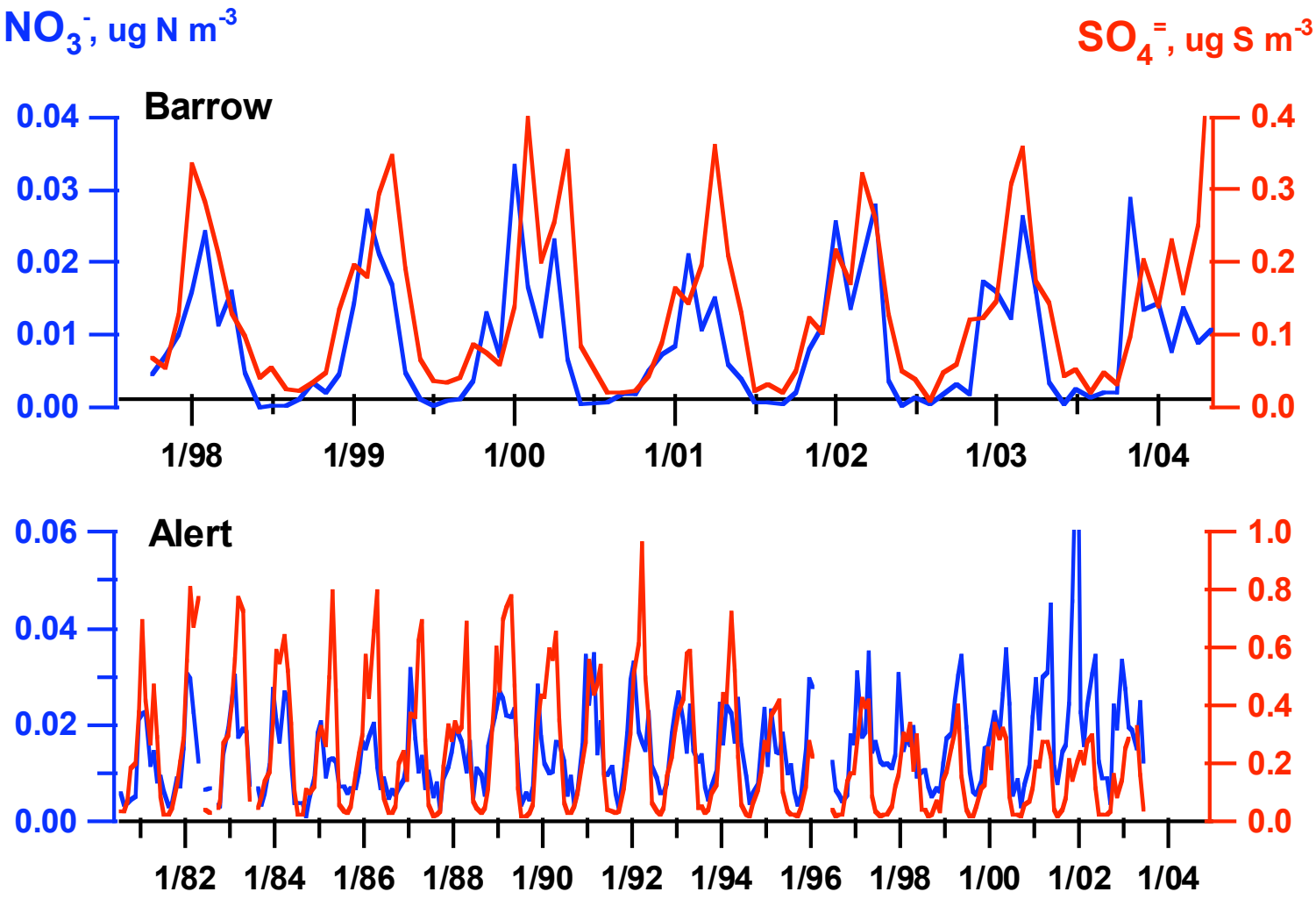


Monthly averaged values

Quinn et al., TellusB, 2007.

Seasonality of Arctic Haze

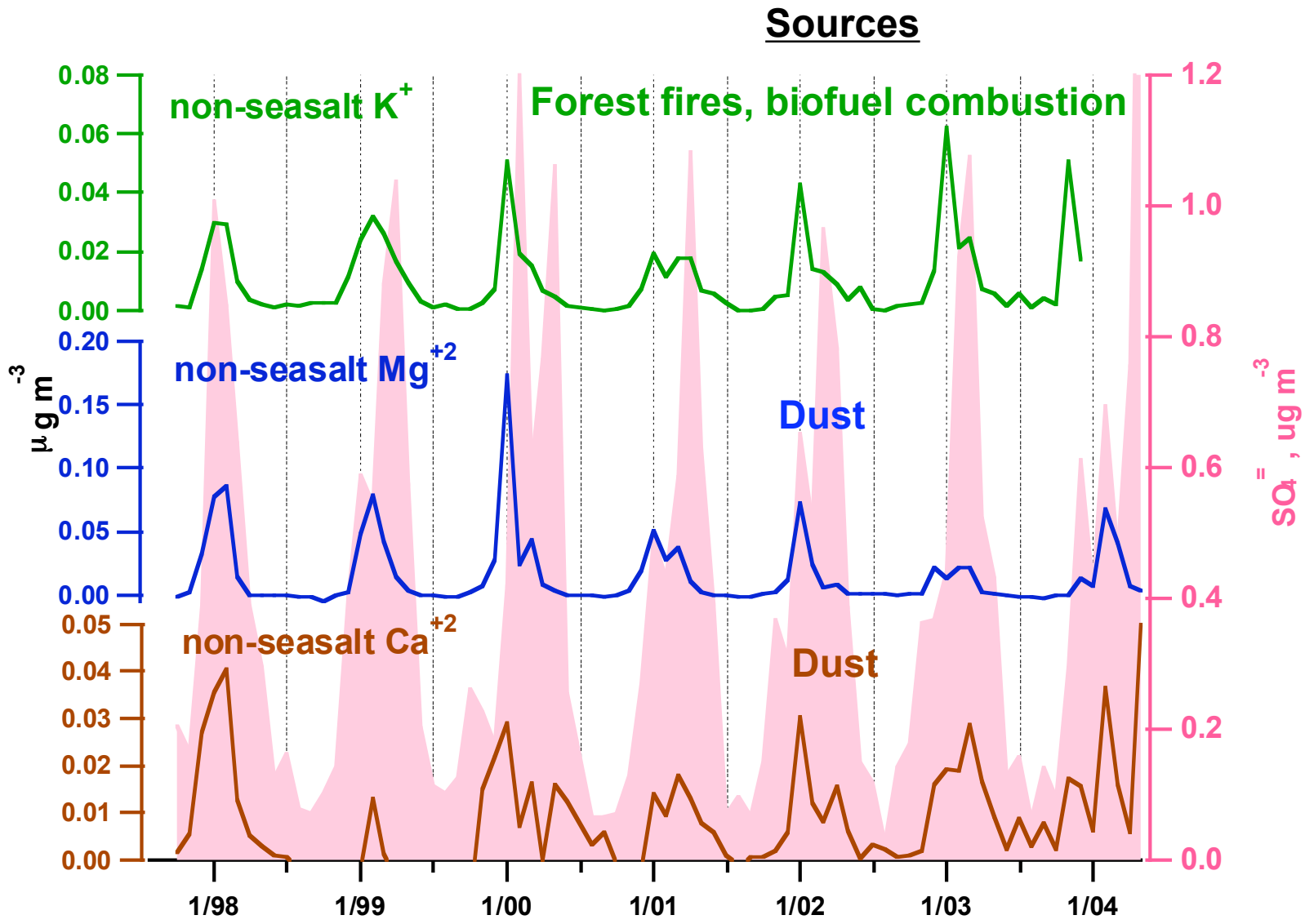
Winter/Spring Increase in Aerosol Nitrate and Sulfate (Surface/Point)

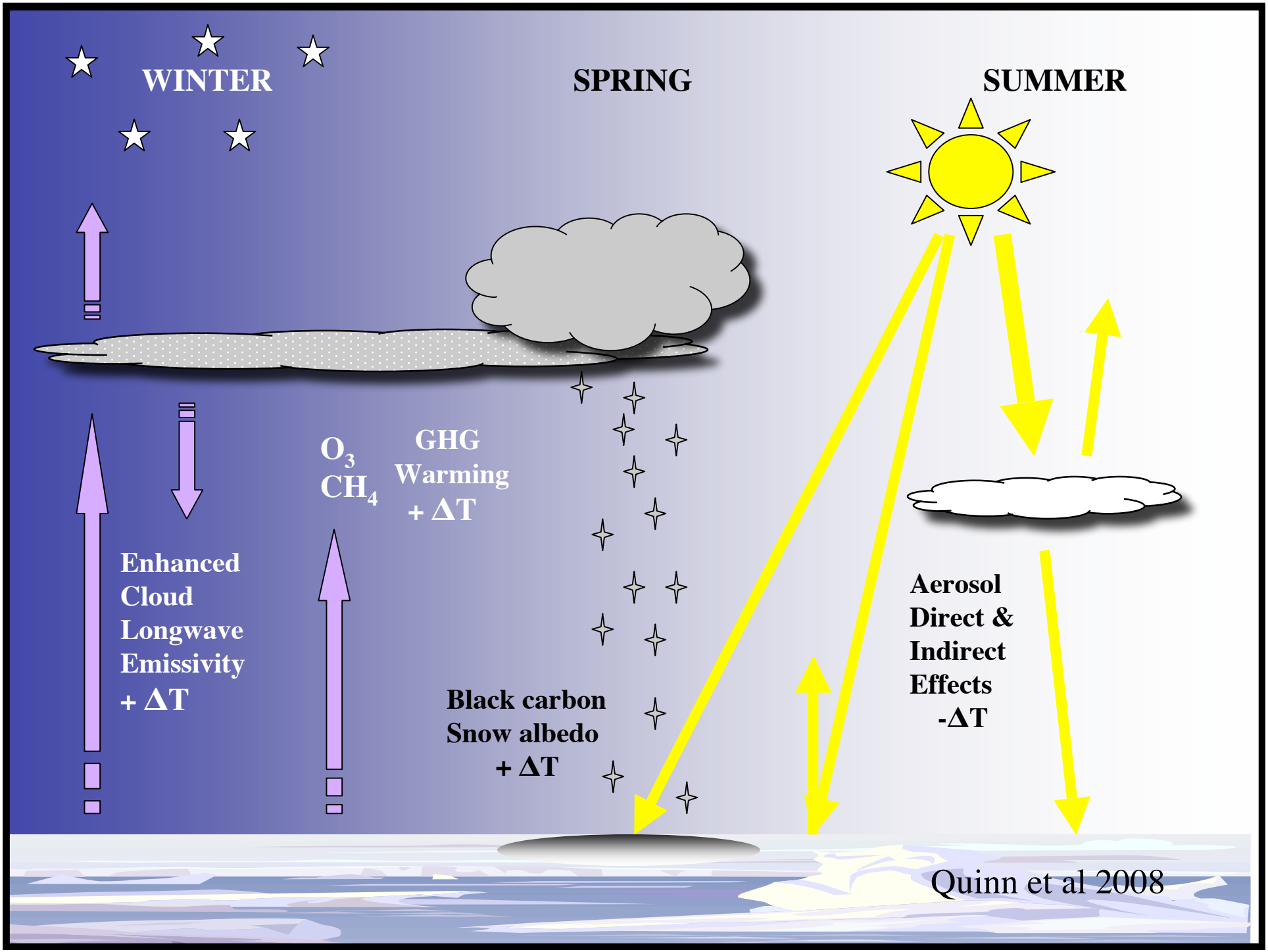


Sources: Diesel and gasoline engines Coal fired power plants

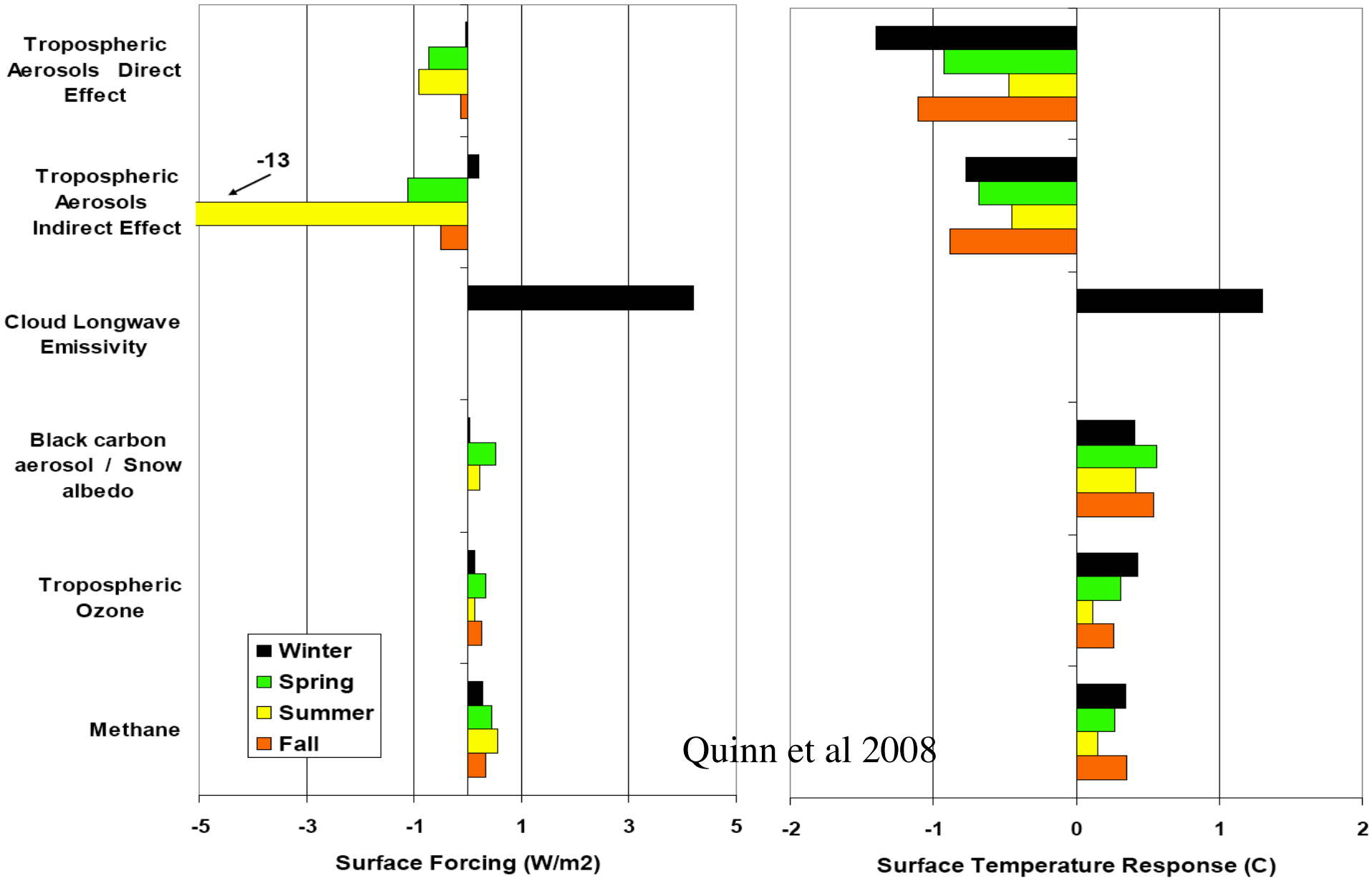
Seasonality of Arctic Haze: Fires/Biomass Burn

Winter/Spring Increase in Aerosol Potassium, Magnesium, and Calcium



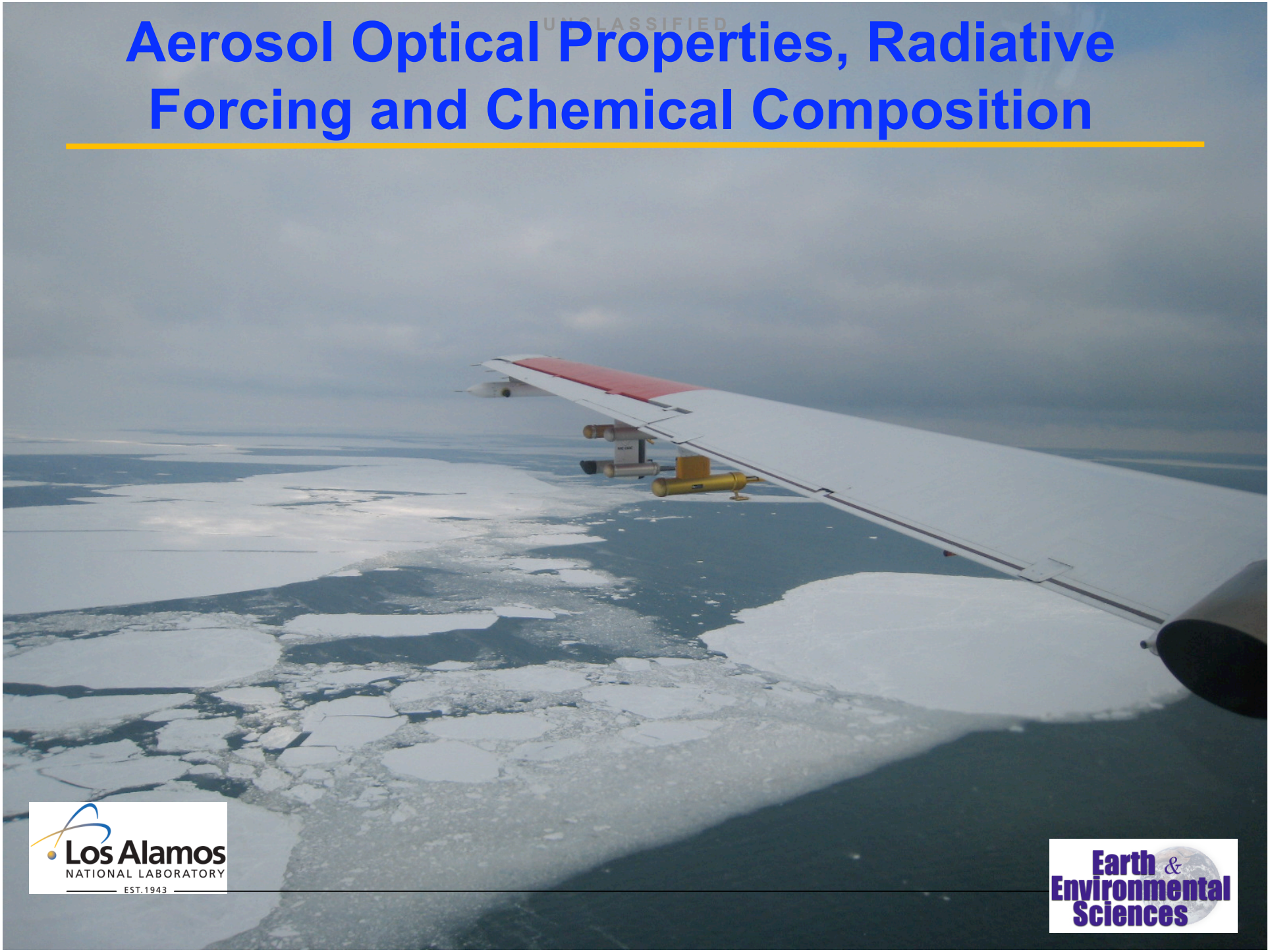

WINTER
SPRING
SUMMER
Enhanced
Cloud
Longwave
Emissivity
+ ΔT
O3
CH4
GHG
Warming
+ ΔT
Black carbon
Snow albedo
+ ΔT
Aerosol
Direct &
Indirect
Effects
-ΔT
Quinn et al 2008

Arctic Surface Forcing & Warming (GISS Model)



Quinn et al 2008

Aerosol Optical Properties, Radiative Forcing and Chemical Composition



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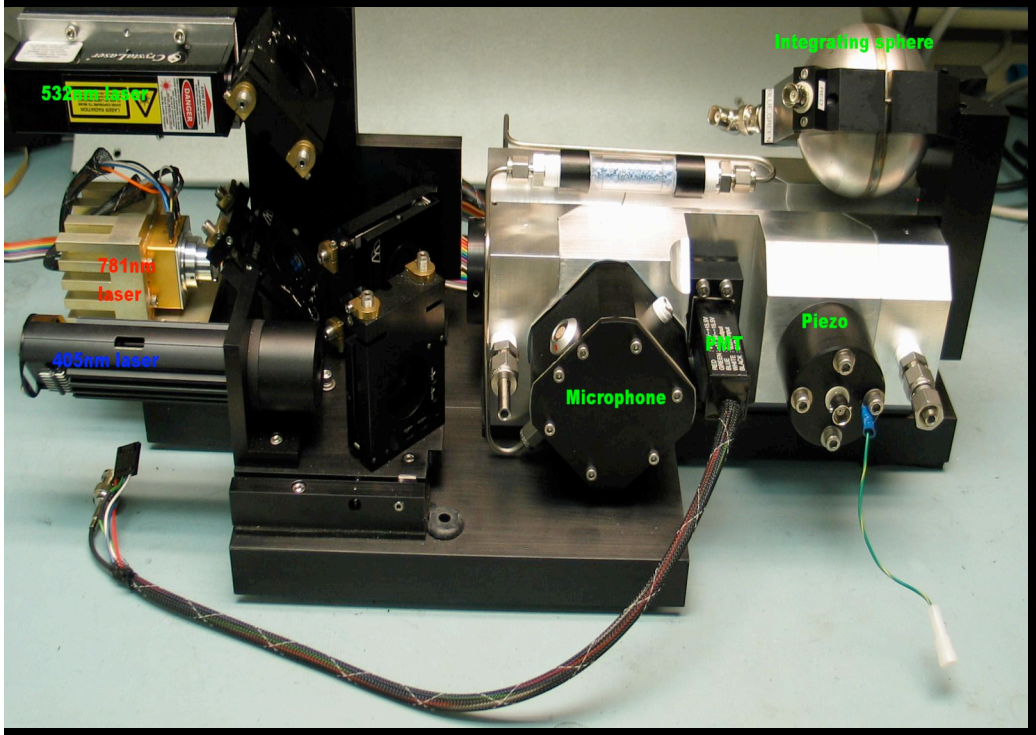
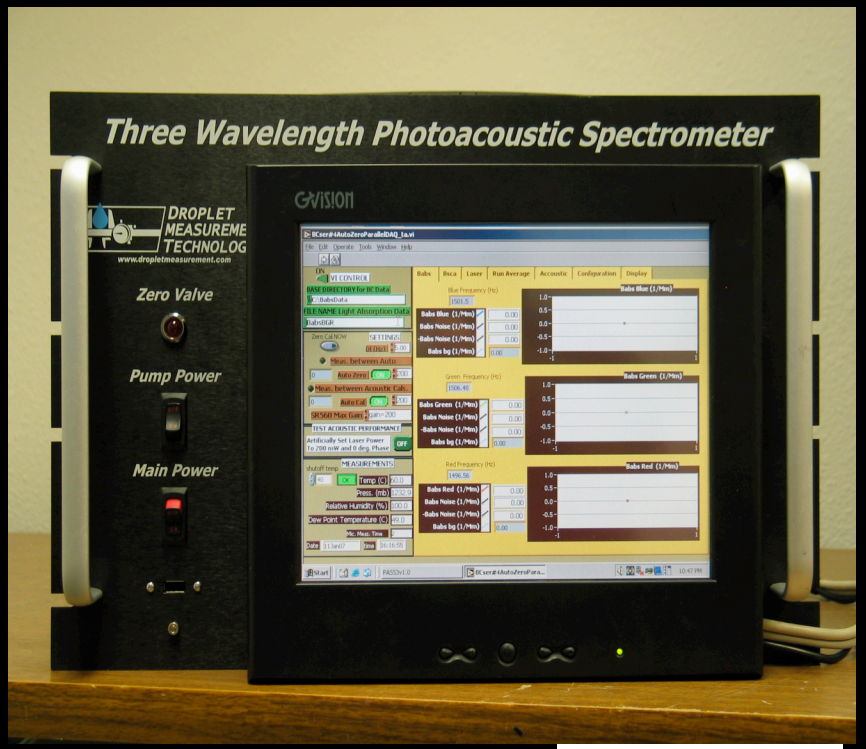
Los Alamos 3-Laser Photoacoustic Absorption and Scattering 405, 532, 781nm

- Can discriminate soot, dust and sulfate.
- How dark (warming) or light (cooling) are aerosols?
- What aerosols are good ice nuclei (dust, organics)?
- Do cloud processes darken aerosols as they deposit on snow?





Satellite Retrievals → Global Assimilation → Regional Prediction → Validation

RAQMS Realtime Air Quality Modeling System

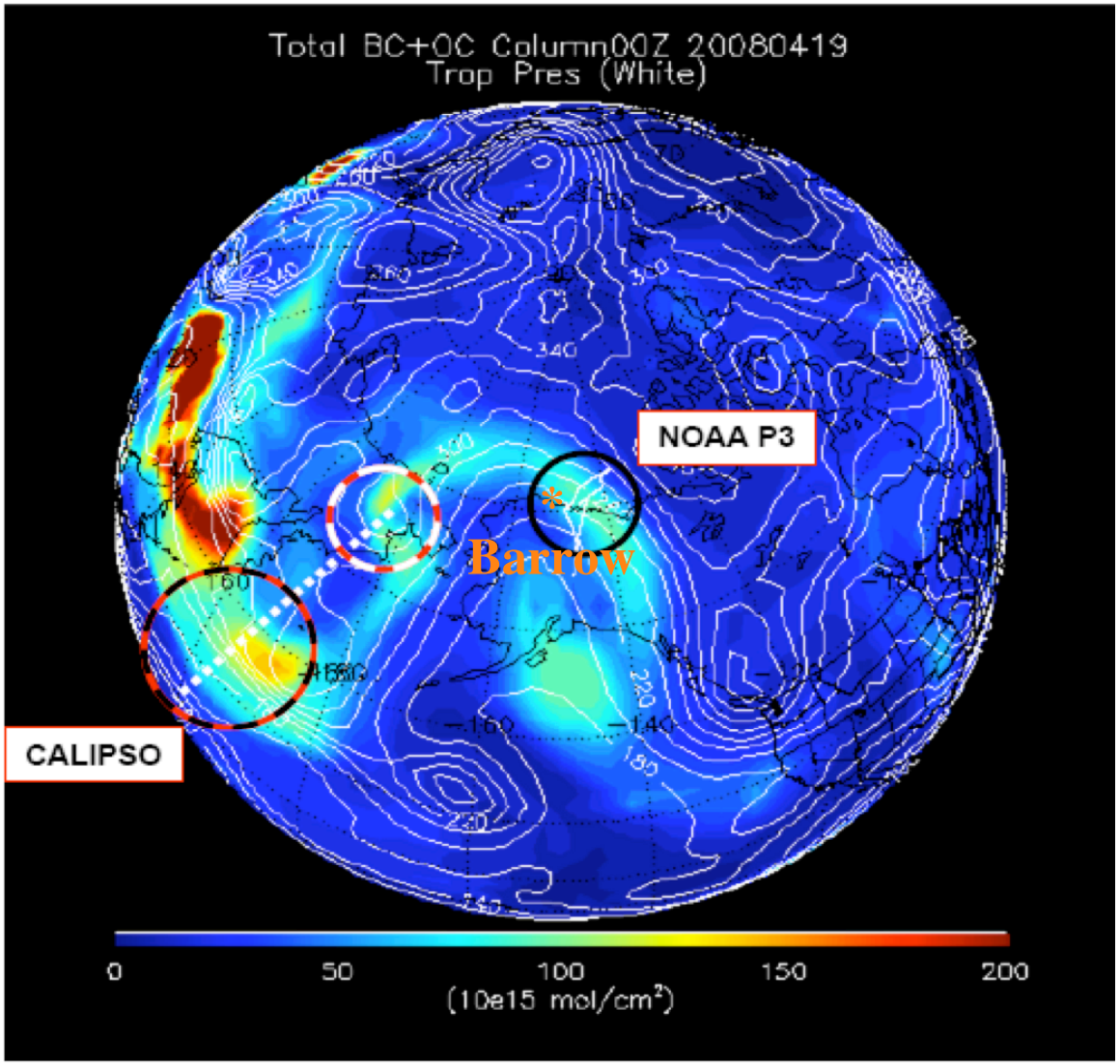
April 19, 2008 BC+OC

RAQMS total column BC+OC (x1015 mol/cm2) analysis at 00Z on April 19th, 2008.

The tropopause pressure is contoured.

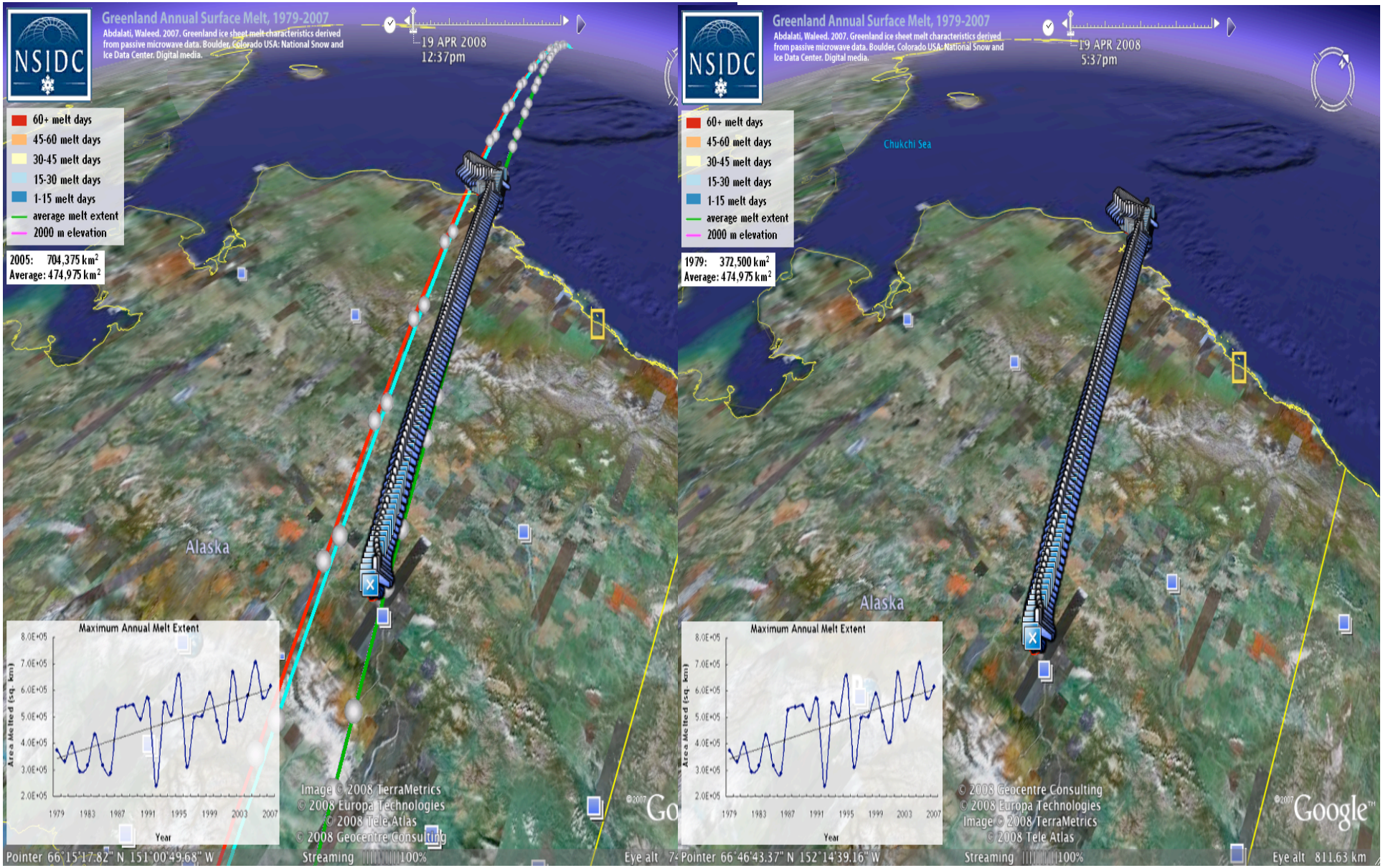
The location of the 15:17:11Z April 18th, 2008 CALIPSO Track is shown as a bold dotted line.

The flight track of the NOAA P3, which sampled the predicted biomass burning plume is also shown off the Northern coast of Alaska.



Brad Pierce, NOAA

C-580 Flight: 19th April 2009, 11.30am – 8.30pm

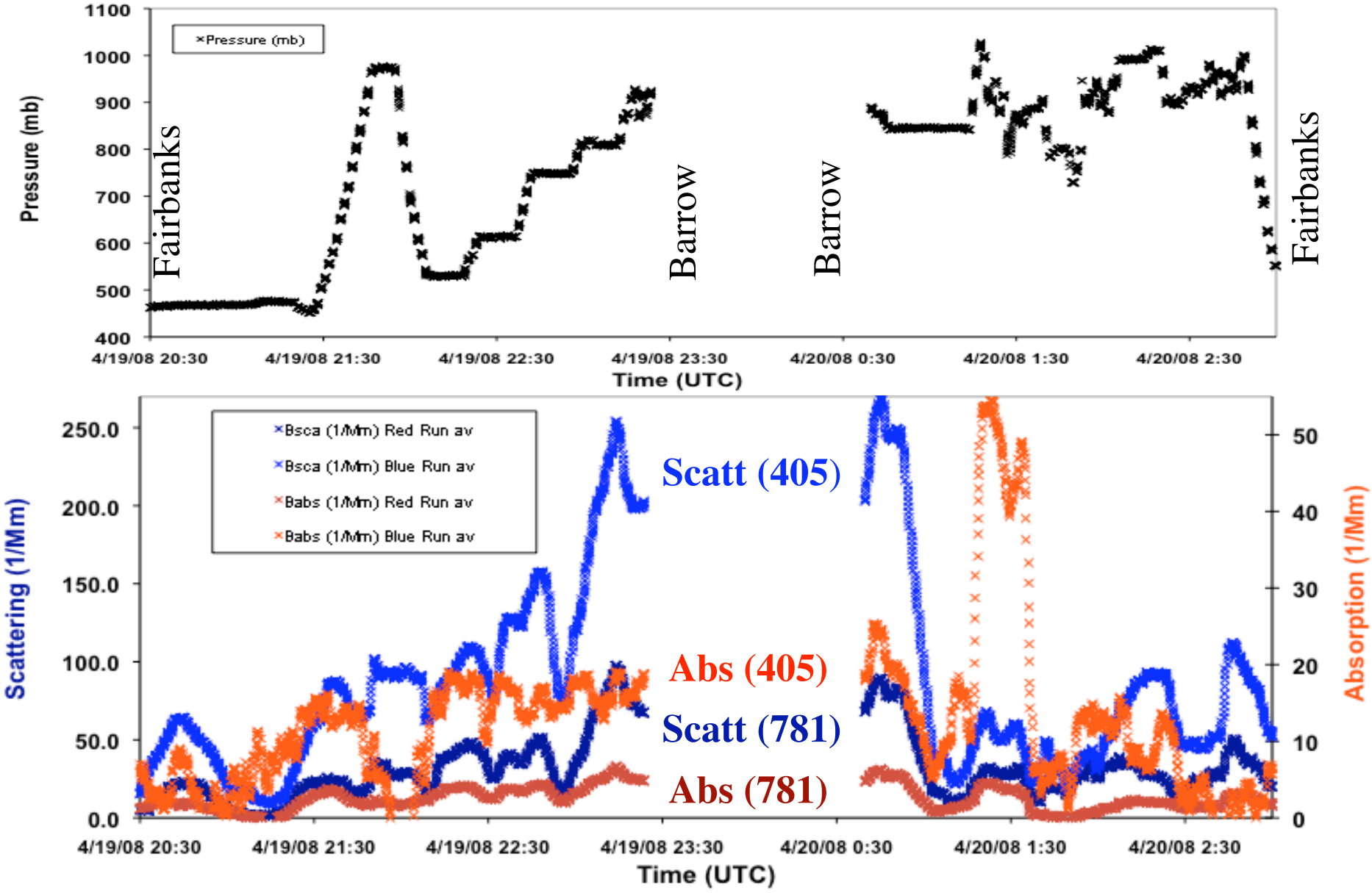


Large Pollution in Polar Regions

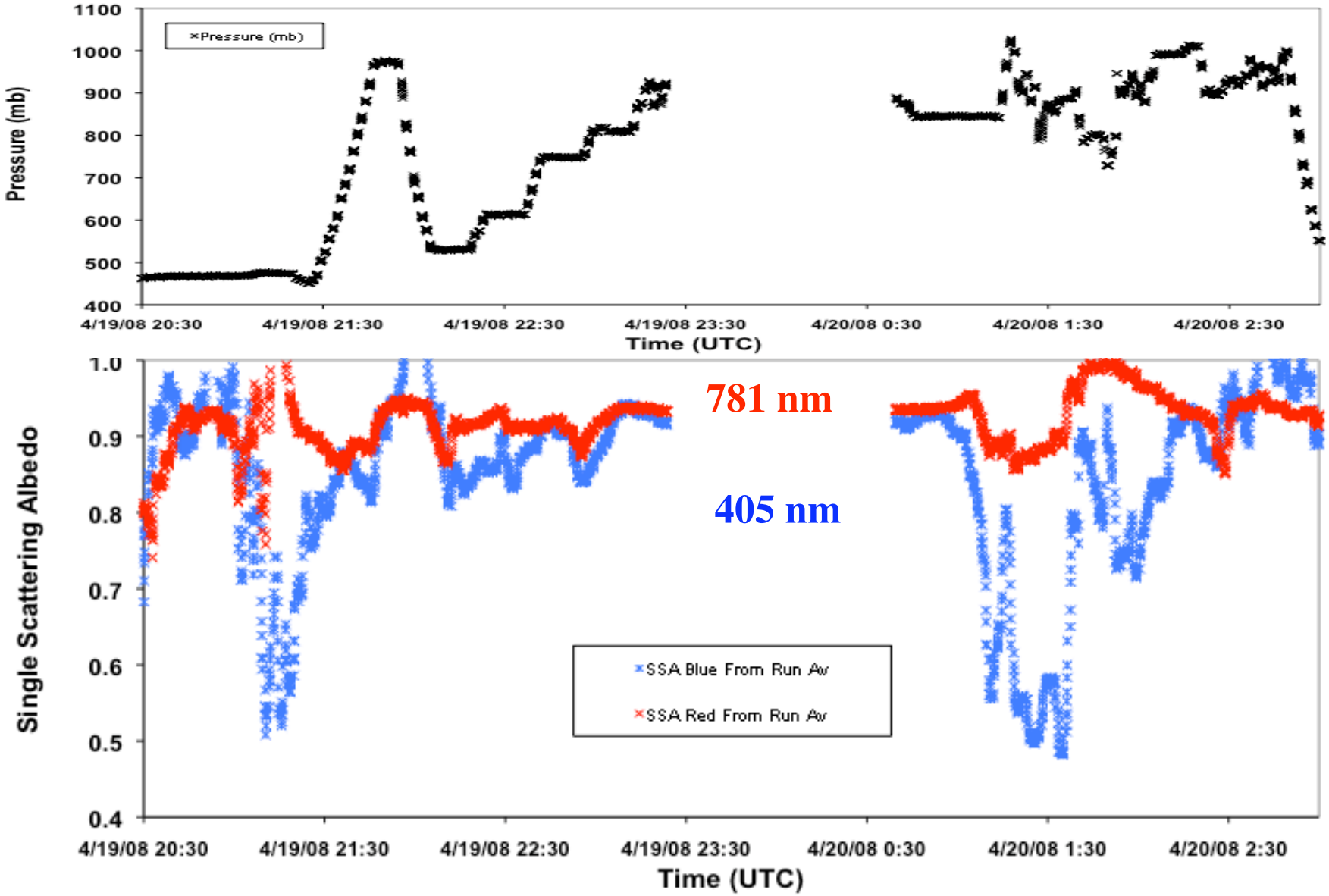
(ISDAC 19 April 2008)

Layer of Arctic Haze

Flight Track Optical Properties: Time Series

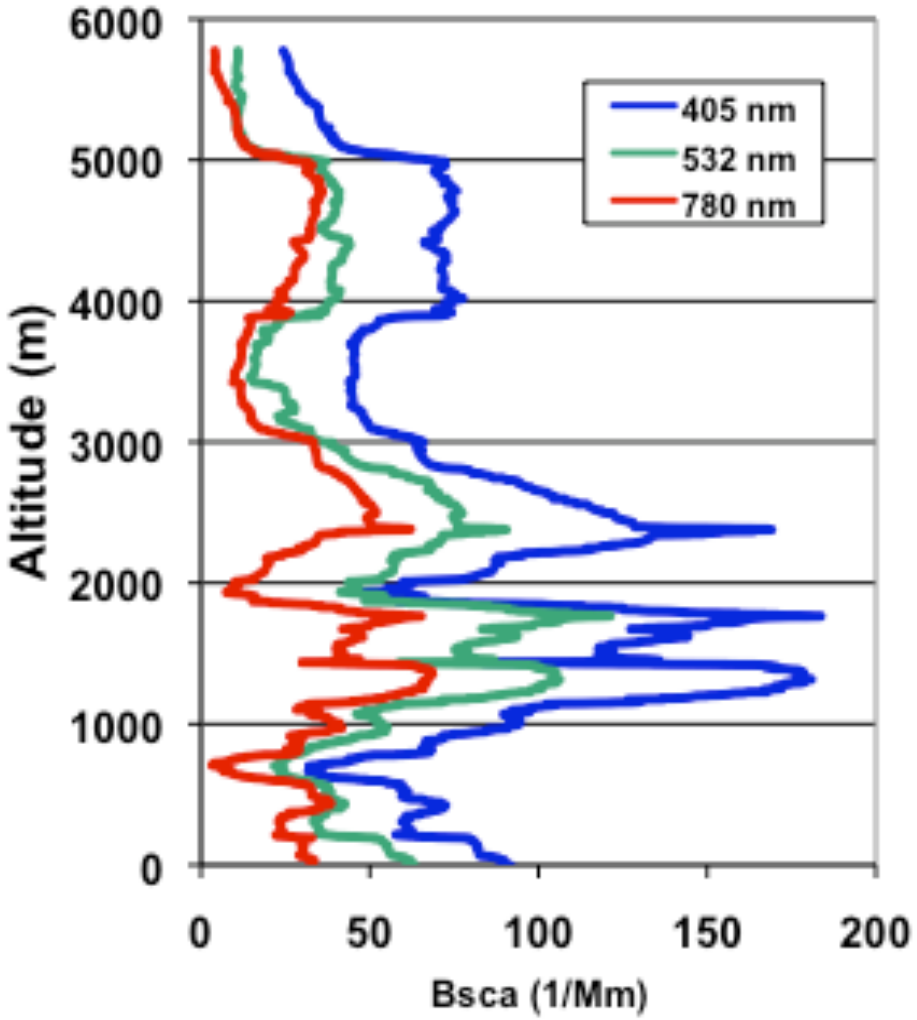


Flight Track Single Scatter Albedo: Time Series

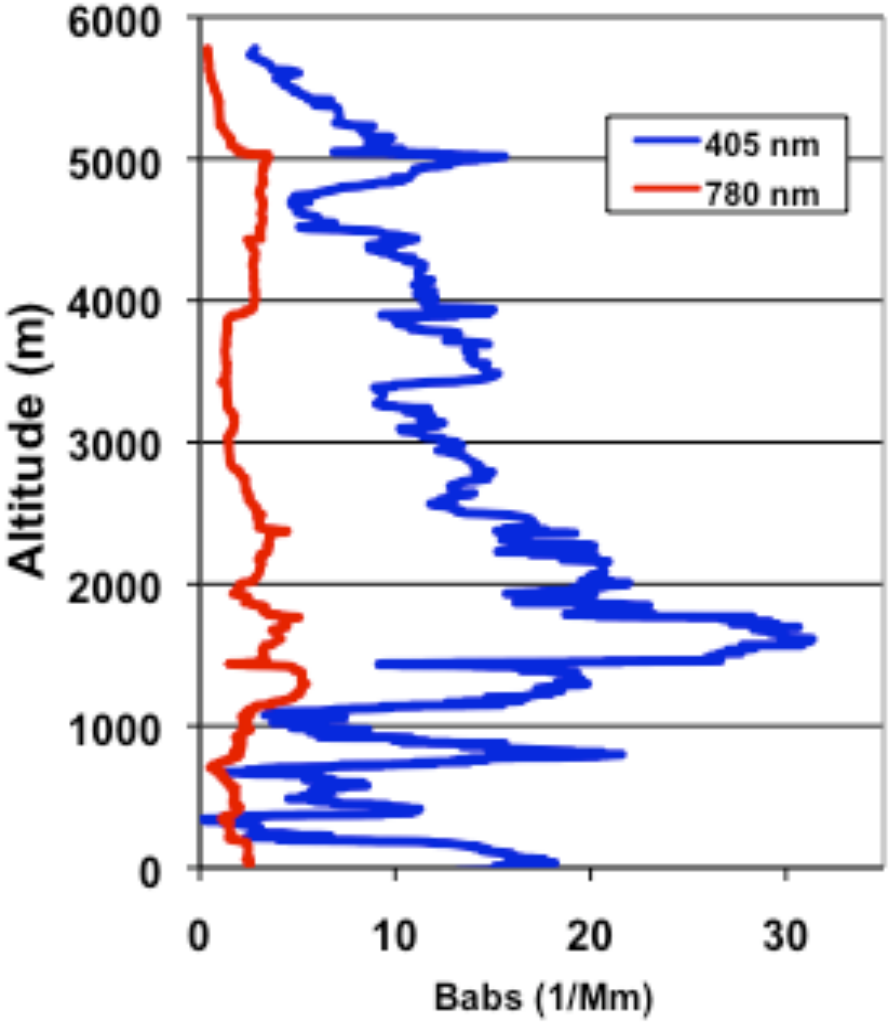


Pollution Layers: Soot, OC, Dust, Sulfate

Scattering Mm^{-1}

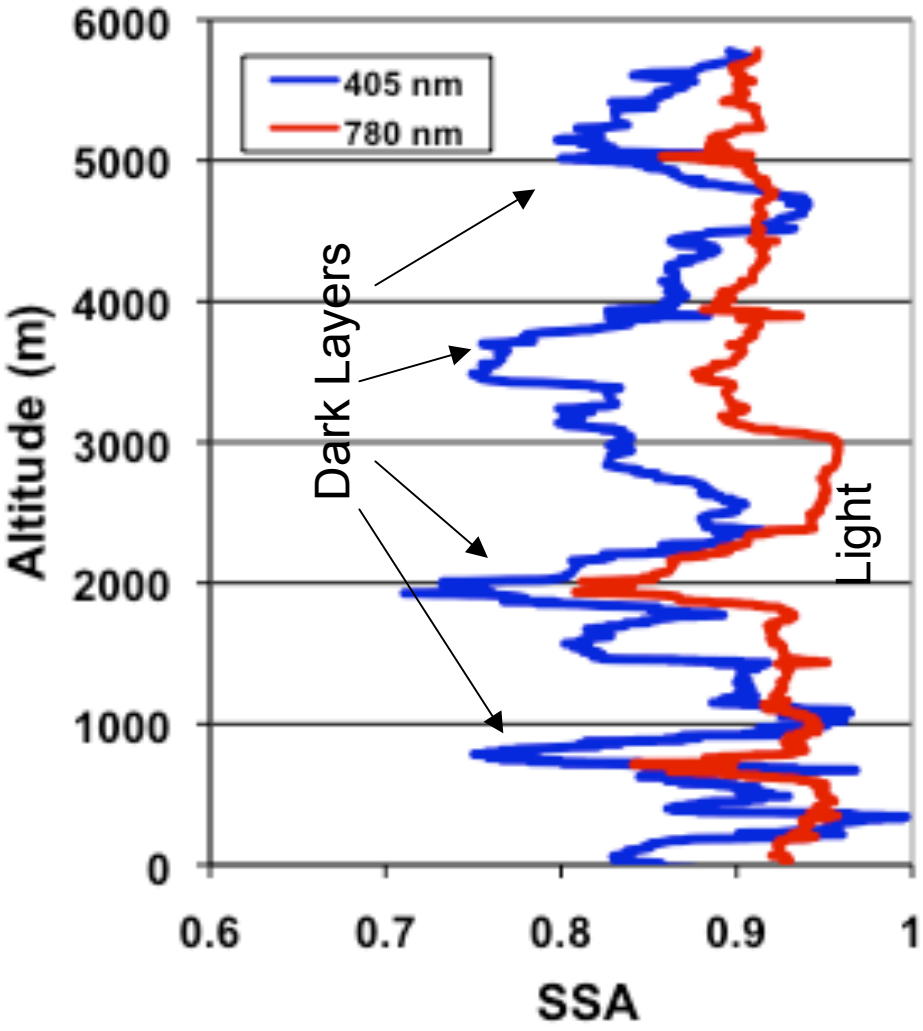


Absorption Mm^{-1}

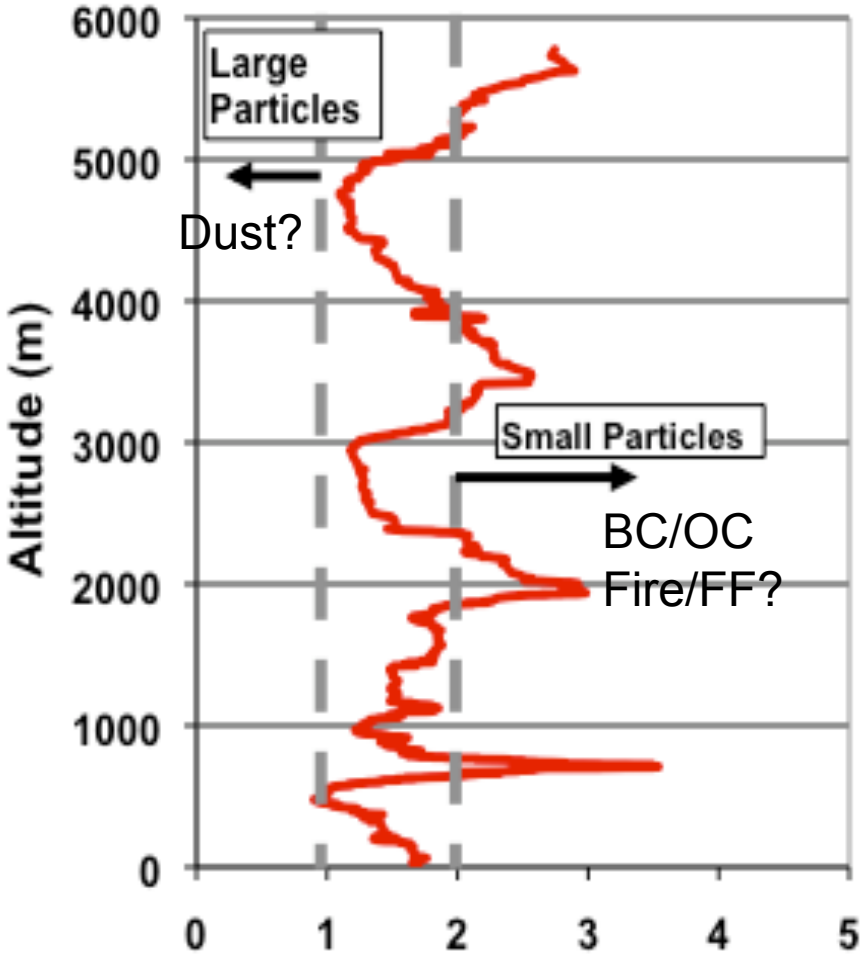


Pollution Layers: Soot, OC, Dust, Sulfate

Single Scatter Albedo [S/(S+A)]

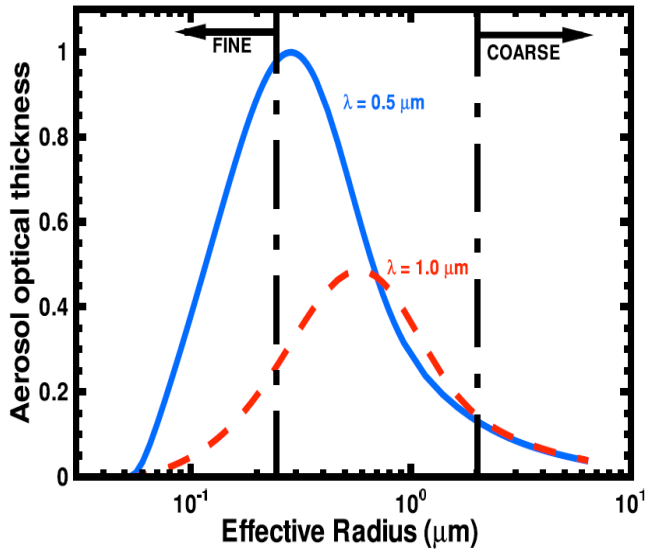


Angstrom Coeffn

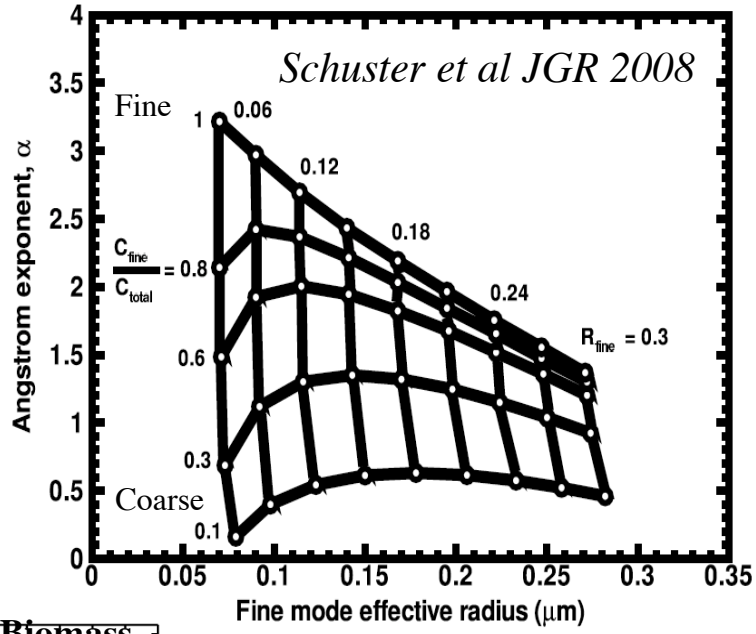


$\alpha = -\ln(Ext_{780}/Ext_{405})/\ln(780/405)$

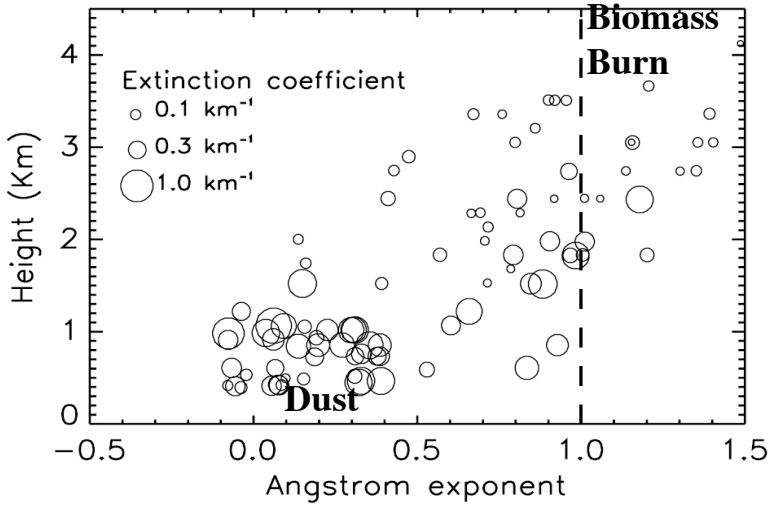
Coarse (Dust) + Fine (BC): Angstrom Exp.



Bimodal Mie Theory



Field Data
West Africa
DABEX



Johnson et al JGR 2008

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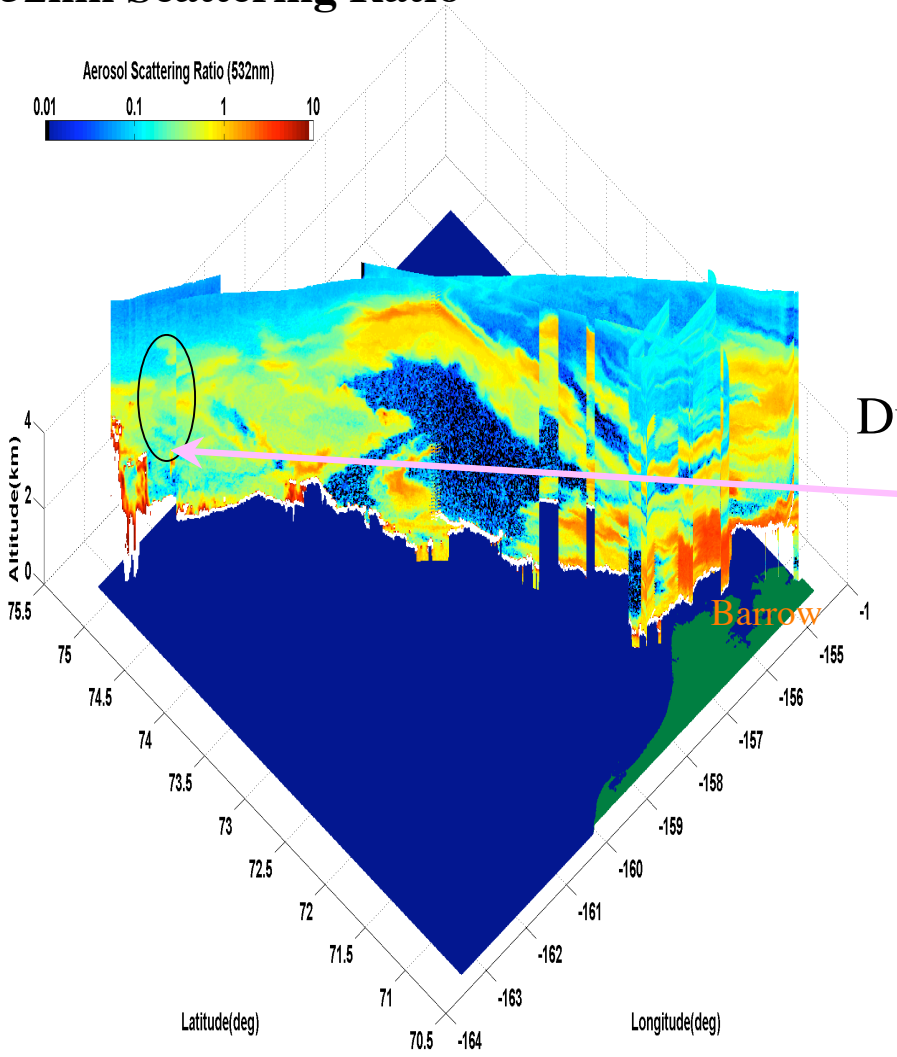
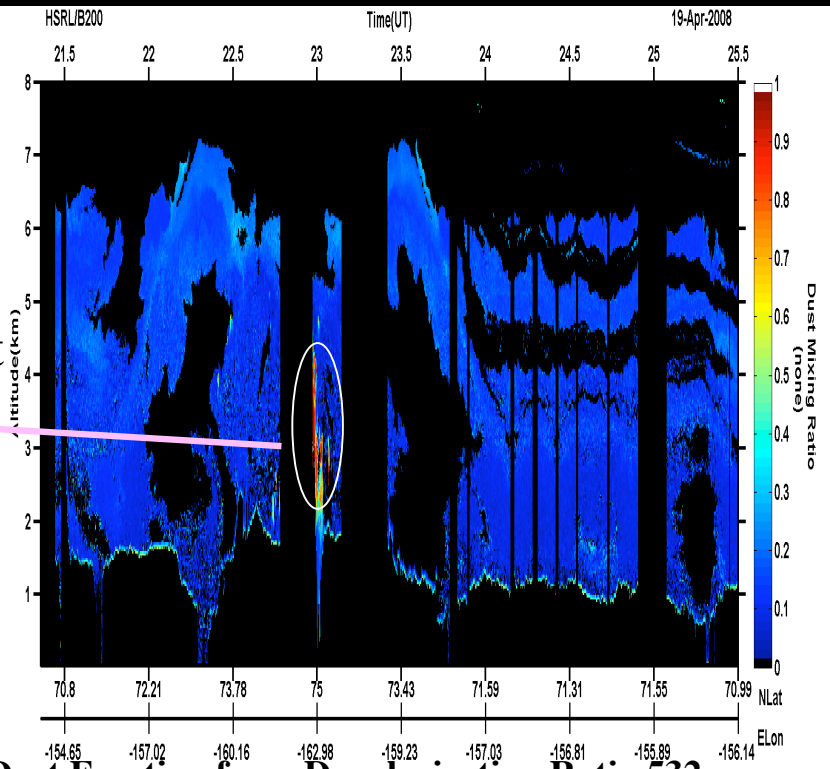
4/19 Pollution NASA HSRL/B-200 Lidar Profiles: Depolarization Derived Dust

532nm Scattering Ratio



Dust



Dust Fraction from Depolarization Ratio 532 nm

Ferrare et al

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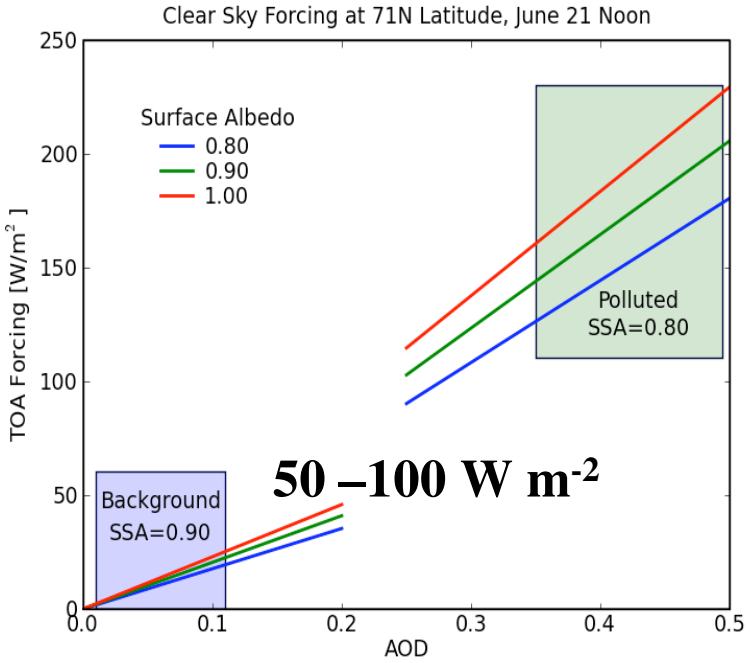
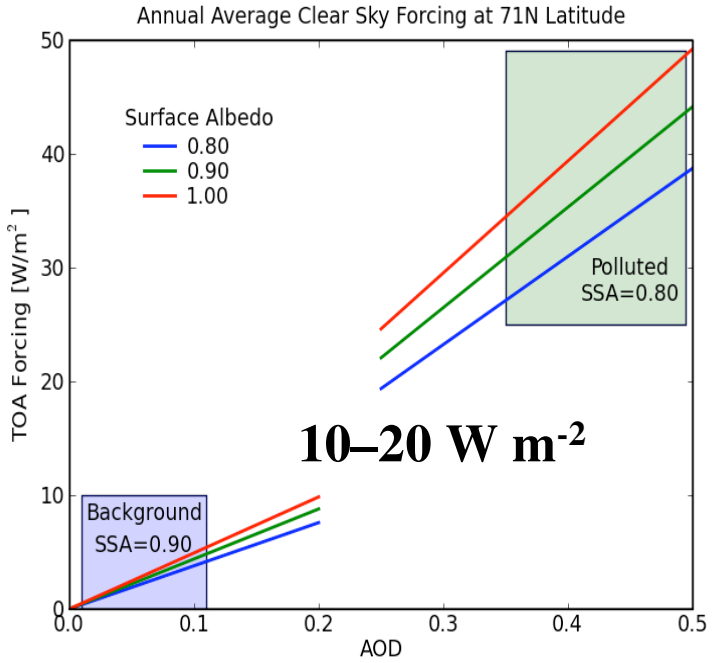
What is clear sky TOA radiative forcing of Arctic Pollution?

S = Solar constant
T = Transmission
N = Cloudiness
g = Asymm Param
w = Single Scatt. Albedo
a = Surface albedo
τ= Aerosol Optical Depth

- **Chylek GRL, 1995**

$$\Delta F = -\frac{S}{4} T^2 (1-N)\,\tau\,[(1-a)^2(1-g)\omega - 4a(1-\omega)]$$

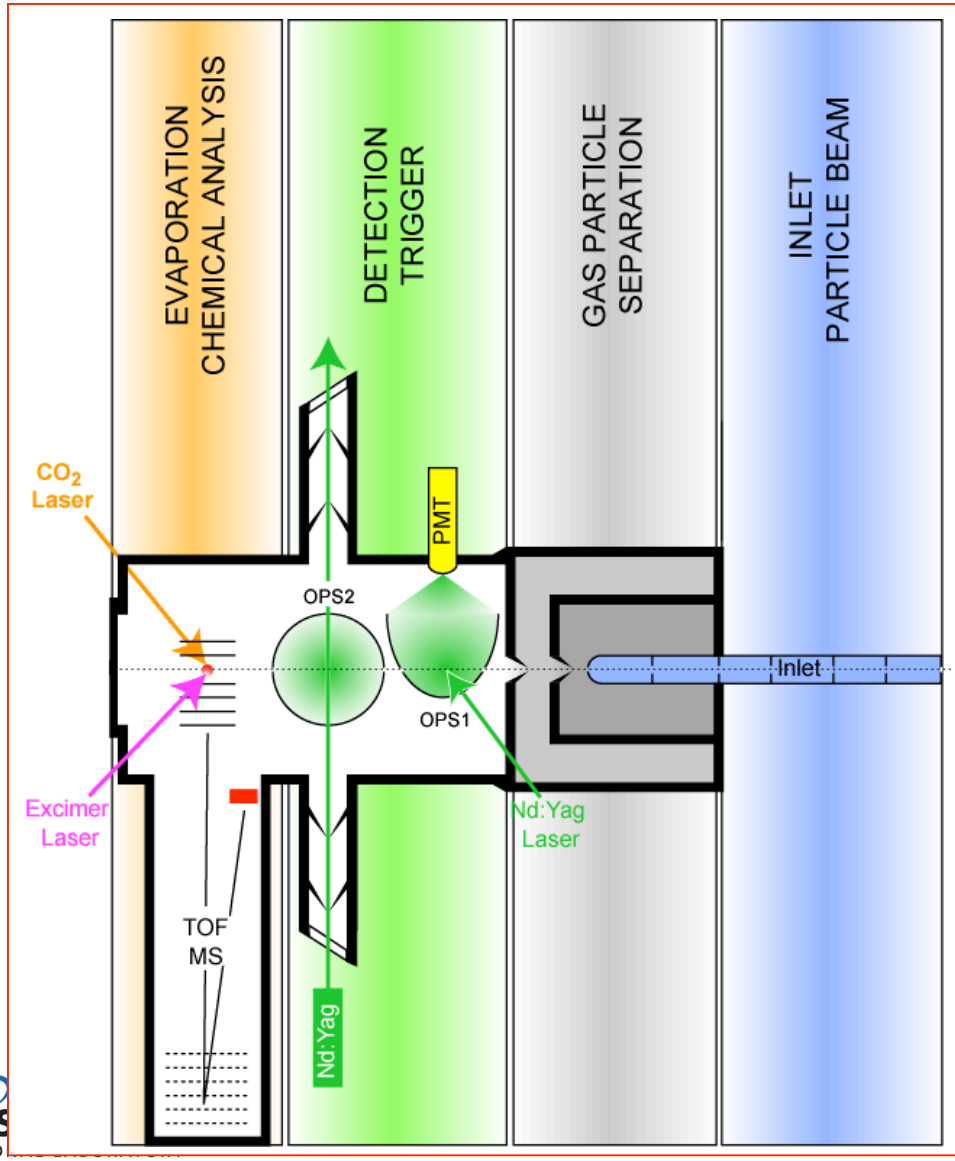




Model-GISS: 0.92 Wm^{-2} (Spring), 0.3 Wm^{-2} (Annual) *Quinn et al ACP 2008*

Pollution (Fires, dust, industrial) events cause transient direct forcings that can last for 10-20 days and are orders of magnitude larger than the mean Arctic aerosol and GHG forcing and can be highly variable.

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

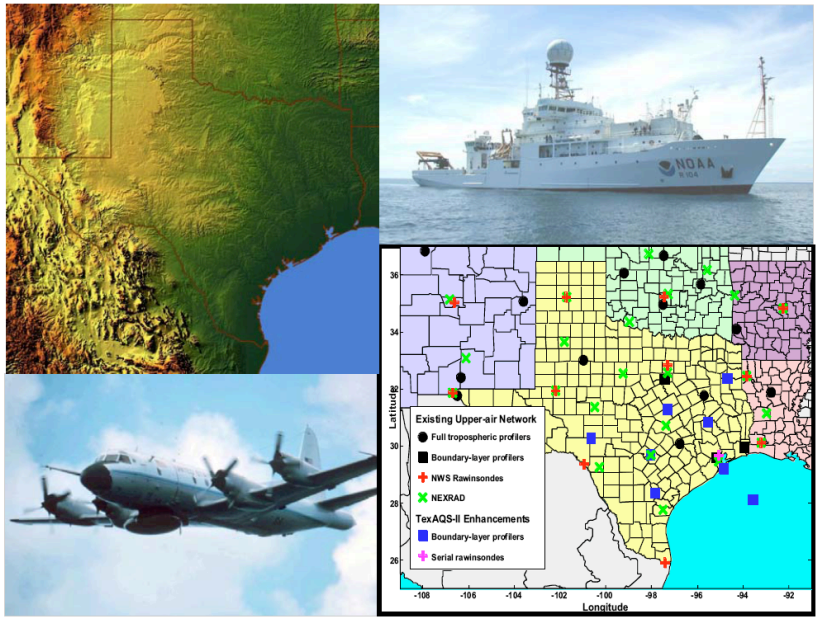
Conclusions

- Arctic haze optical properties consistent with layers of aged biomass, dust and sulfate, which are dynamically mixed in a complex manner
- Imply large TOA forcing above Arctic ice/snow
- Verify with mass spectrometer (SPLAT)
- Impacts on ice nucleation and soot deposition

GoMACCS/TEXAQS Houston Aug/Sep 06

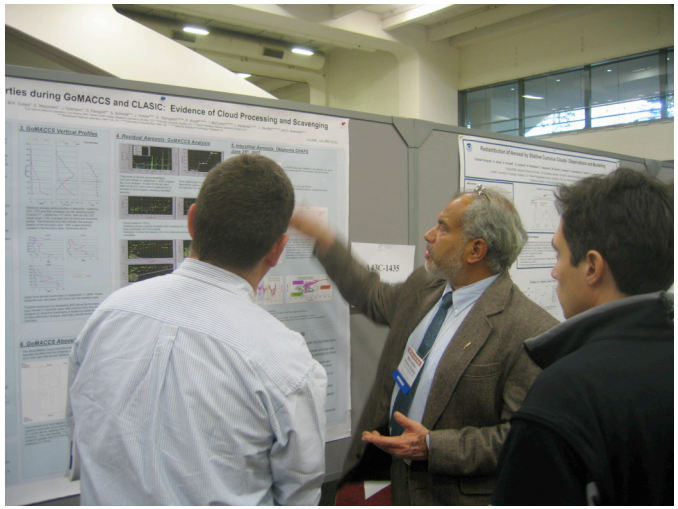
2006 TEXAQS/GoMACCS

Science and Implementation Plan



Combining Climate Change and Air Quality Research

March 2005



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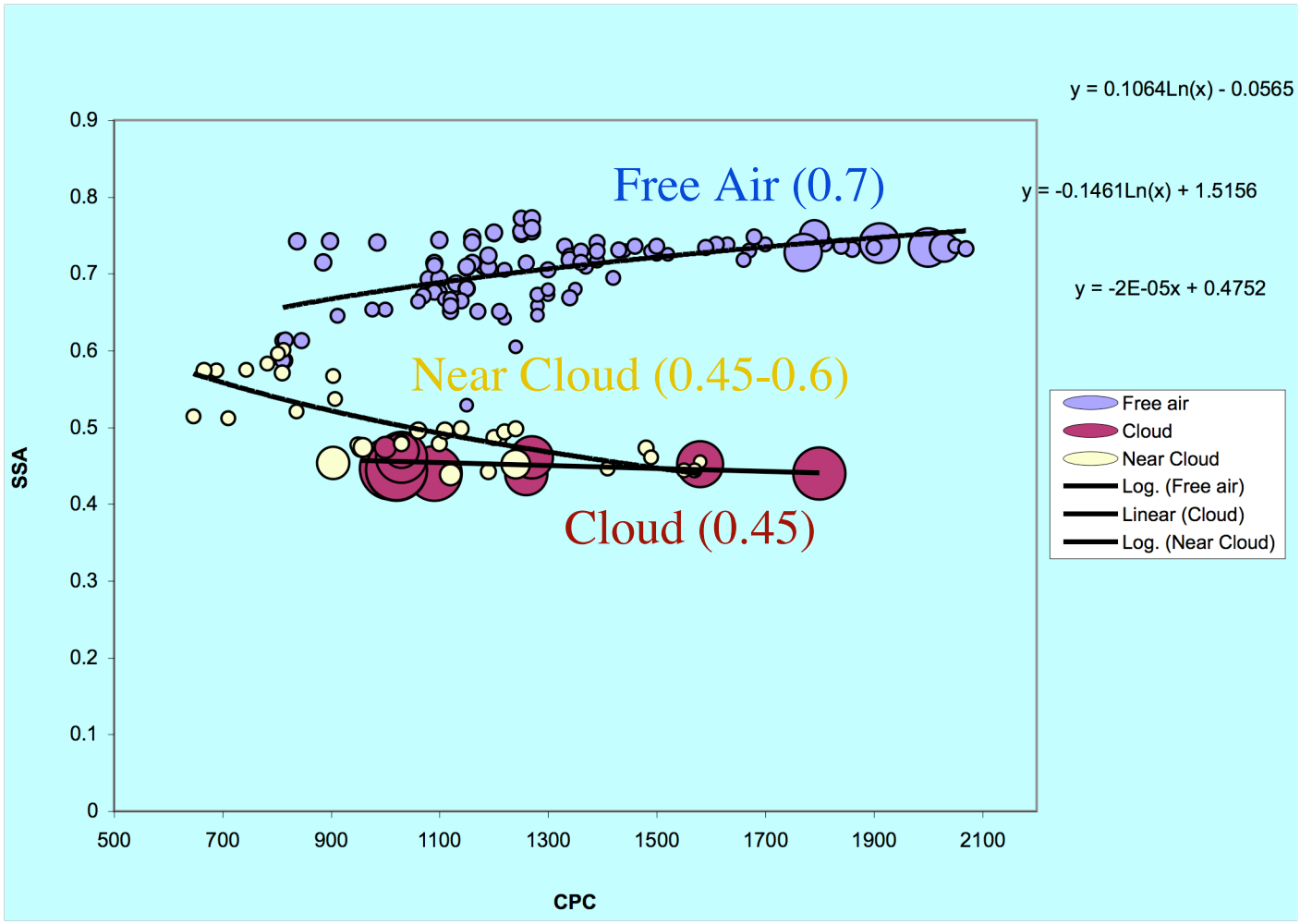
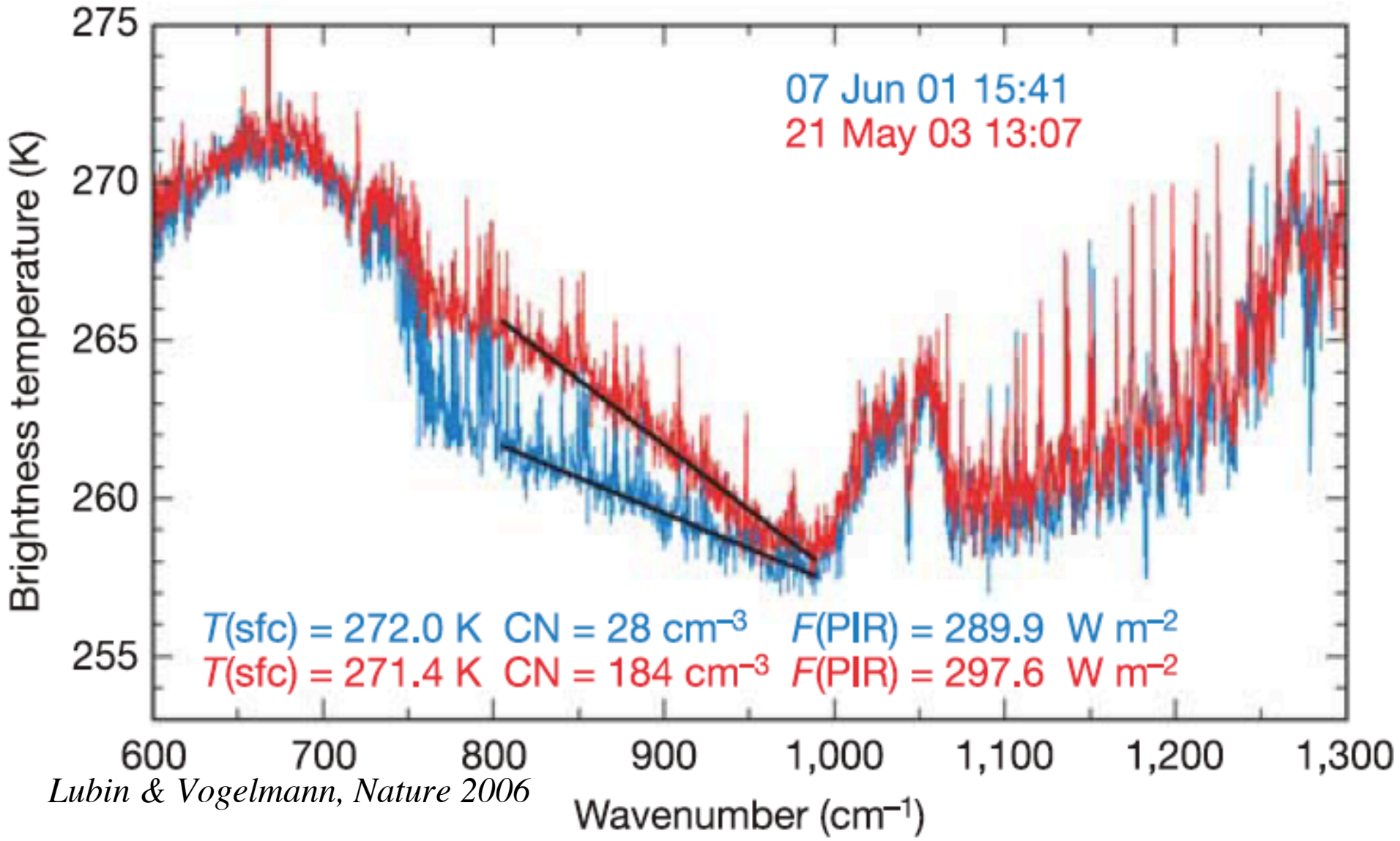
Clouds can darken aerosols if they are not aged enough to be internally mixed: Dynamics, Microphysics or Chemistry?



SSA

CPC

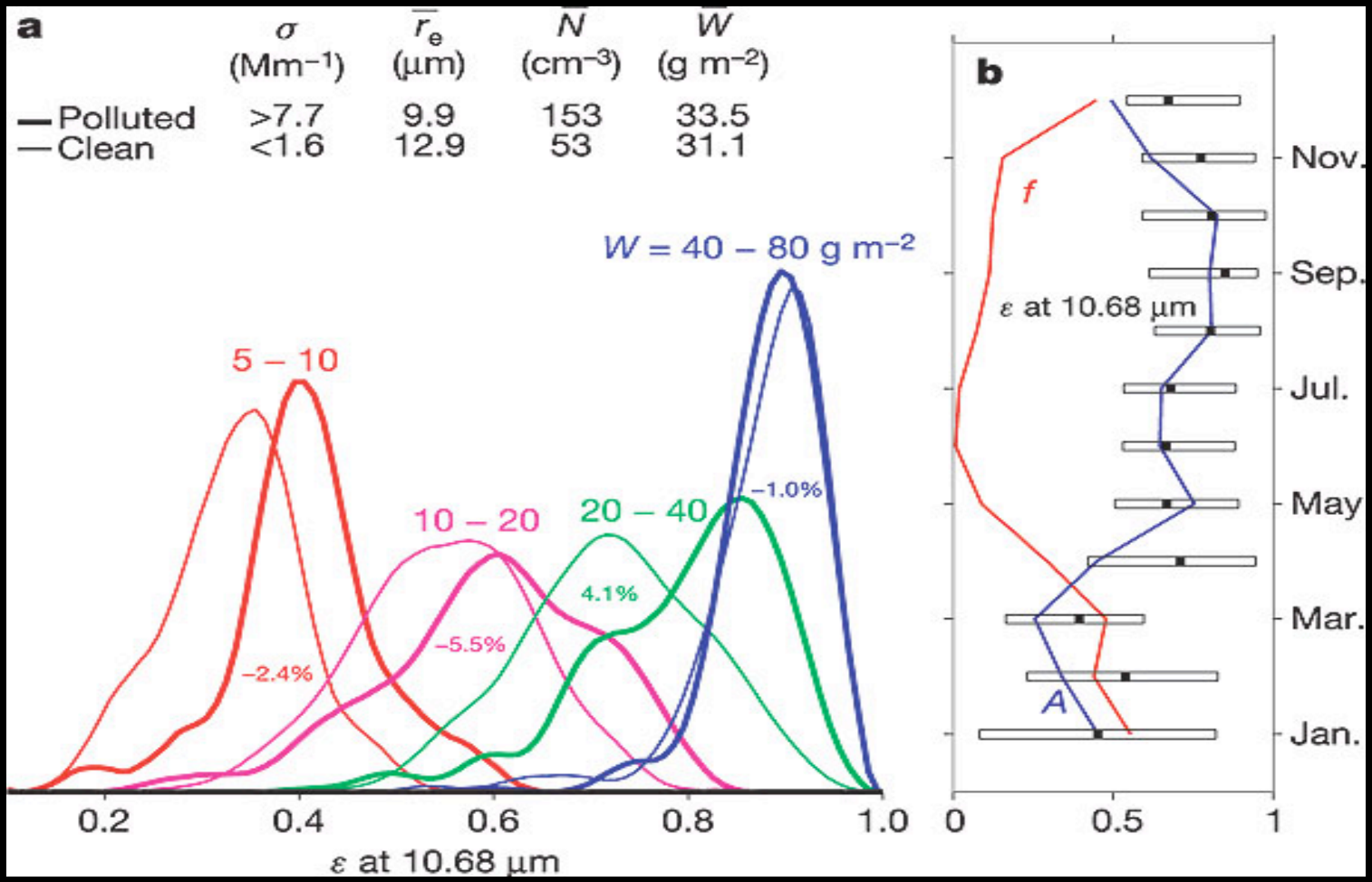
Long-wave Aerosol Indirect Effect: Observed at ARM NSA Barrow



Lubin & Vogelmann, Nature 2006

Arctic cloud longwave emissivity increase by pollution

*Garrett Nature 2006, 4 years ARM data at Barrow**



Where thin water clouds and pollution are coincident, there is an increase in cloud longwave emissivity. Warming under cloudy skies ~5 W m^{-2}, 1.5 °C