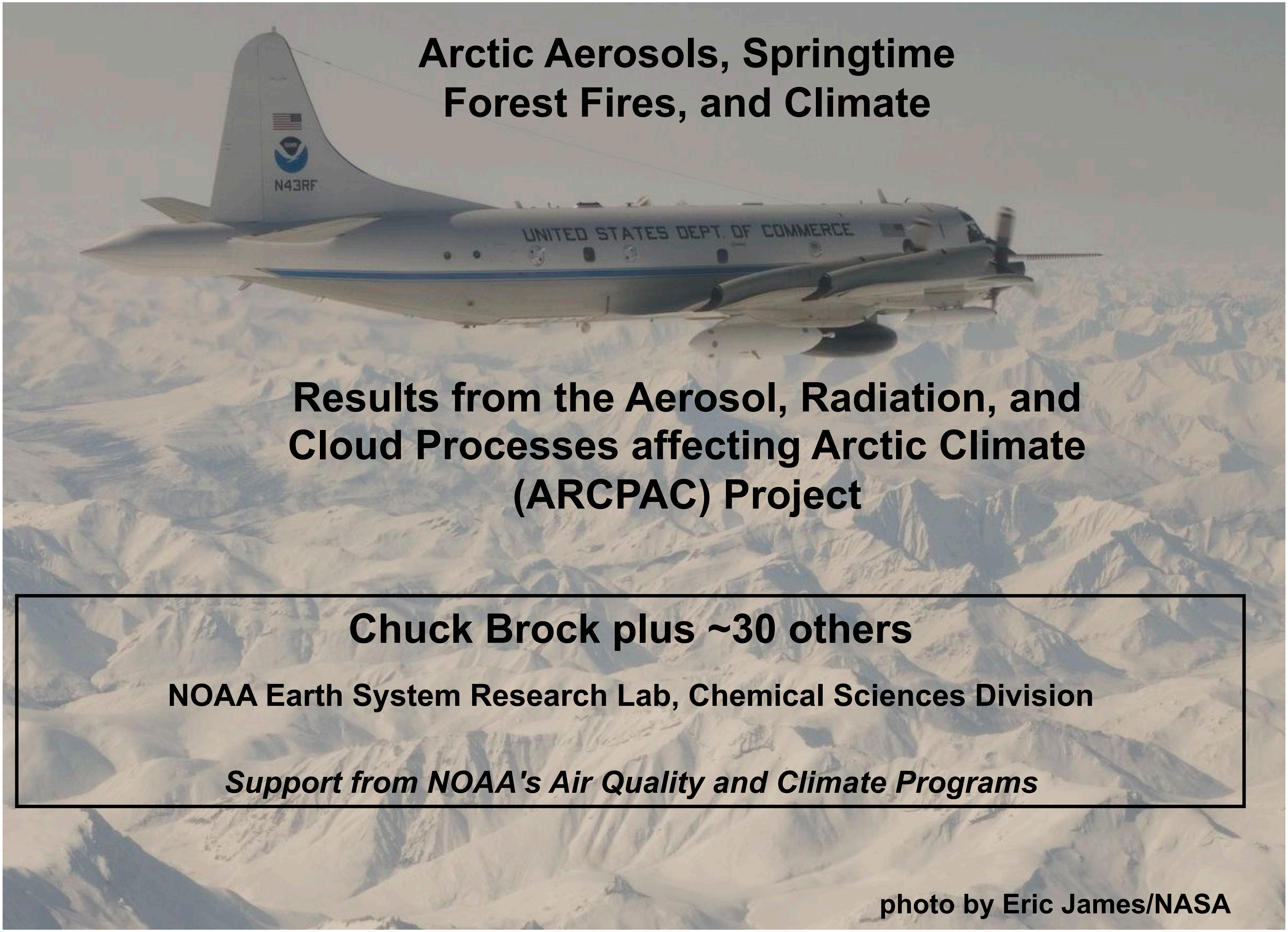
Arctic Aerosols, Springtime Forest Fires, and Climate



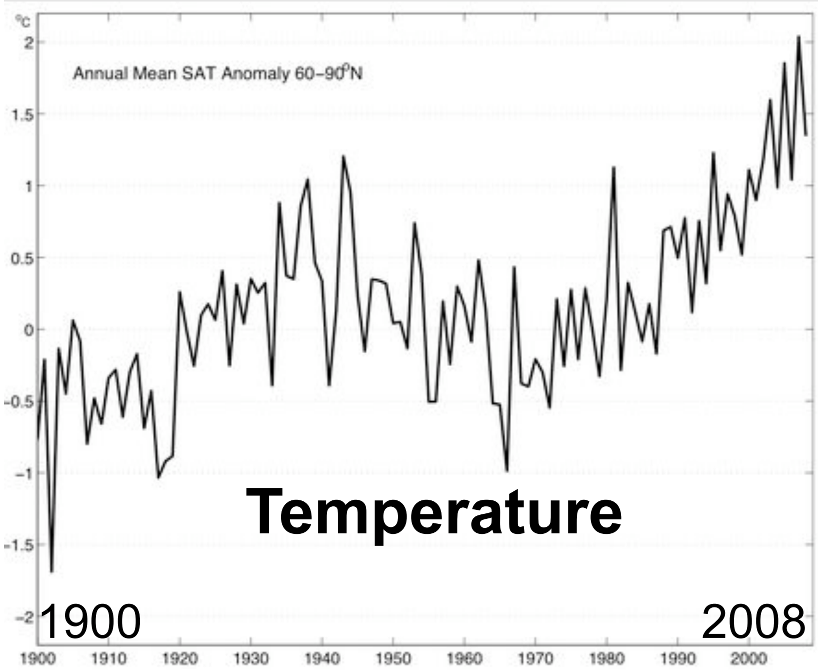
Results from the Aerosol, Radiation, and Cloud Processes affecting Arctic Climate (ARCPAC) Project

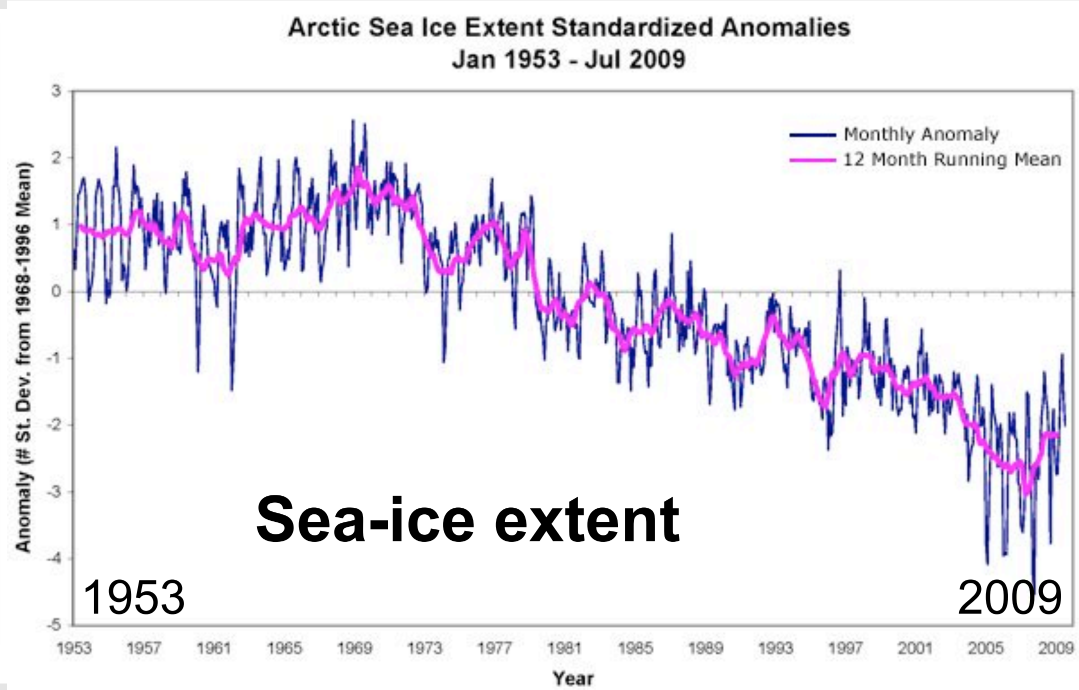
Chuck Brock plus ~30 others

NOAA Earth System Research Lab, Chemical Sciences Division

Support from NOAA's Air Quality and Climate Programs

photo by Eric James/NASA





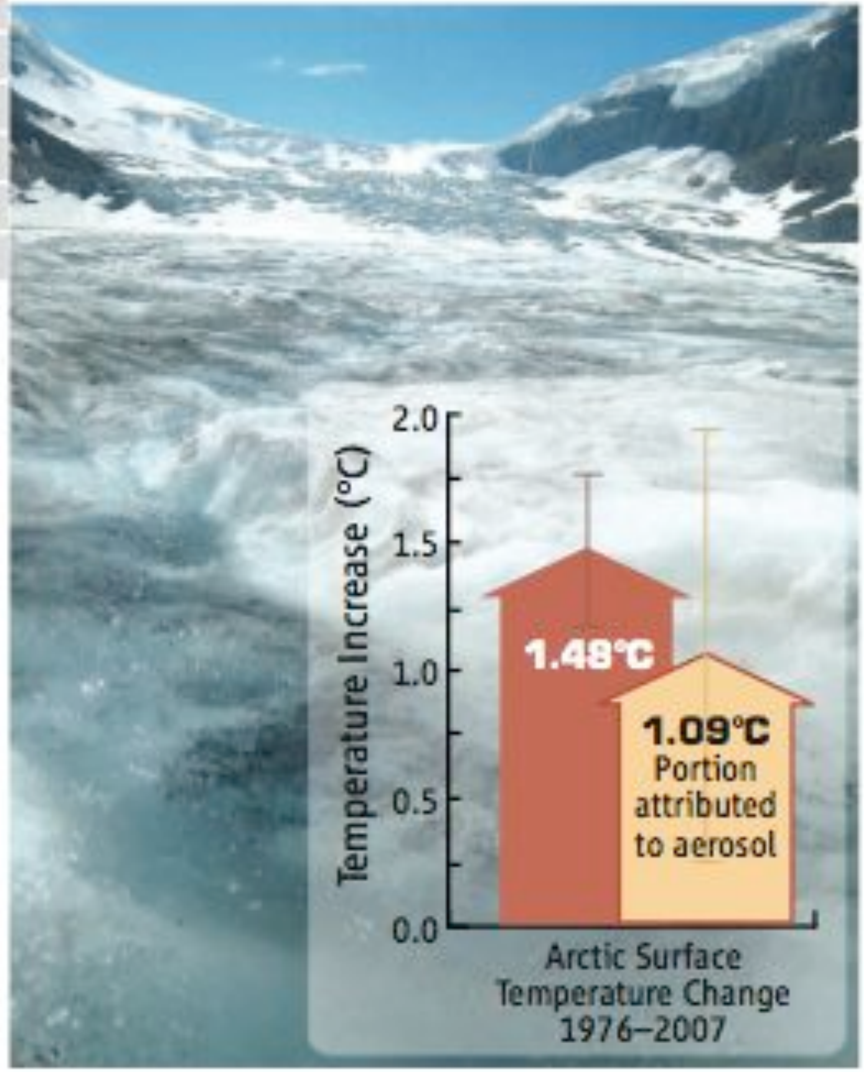
Concern is growing that aerosol particles are contributing to regional Actic warming by:

- **absorbing visible radiation**
- **enhancing snowmelt**
- **increasing cloud IR emissivity**

Are absorbing aerosols responsible for most of the Arctic warming?

"Climate response to regional radiative forcing during the twentieth century"

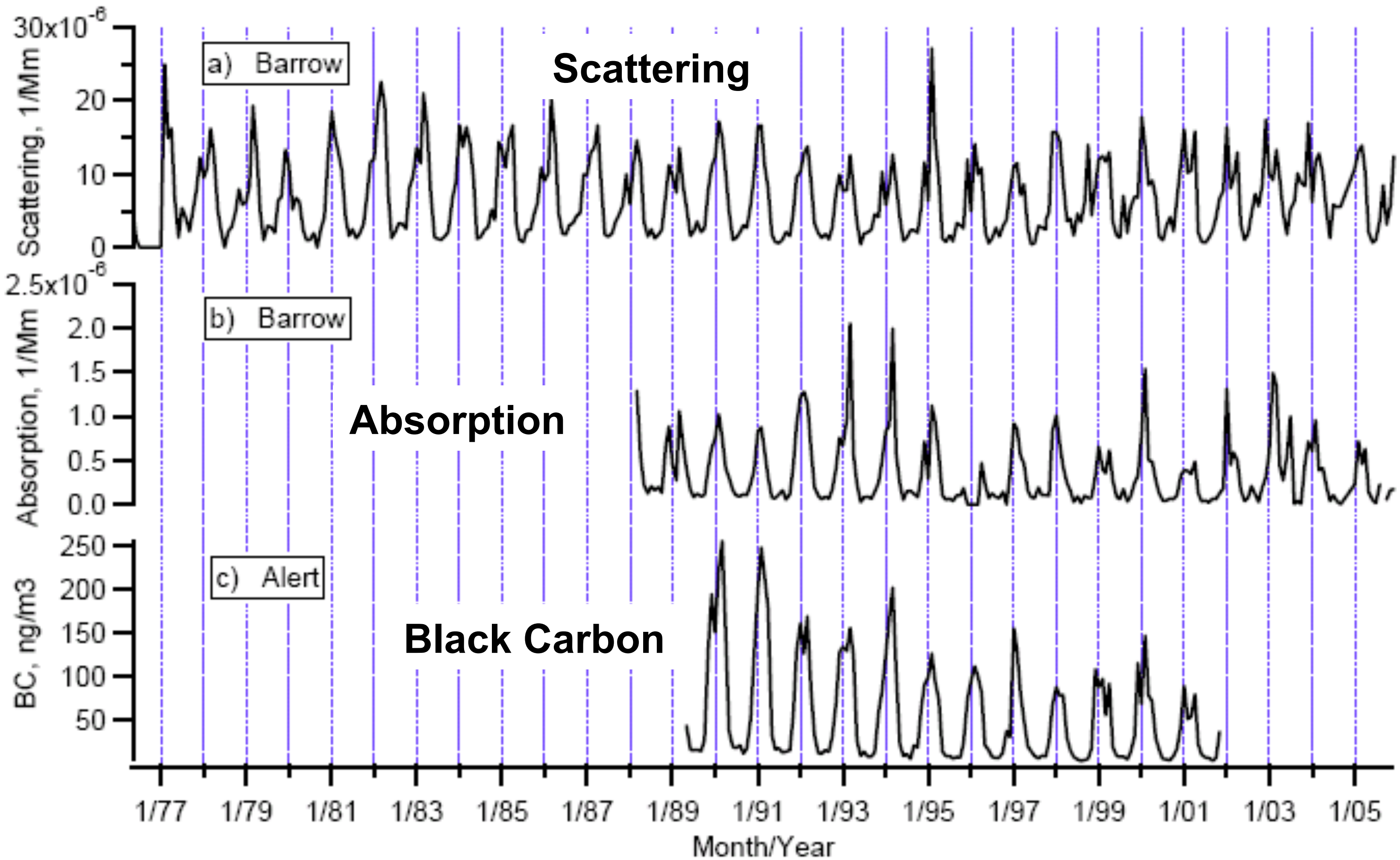
Drew Shindell and Greg Faluvegi in *Nature Geoscience*, 2009



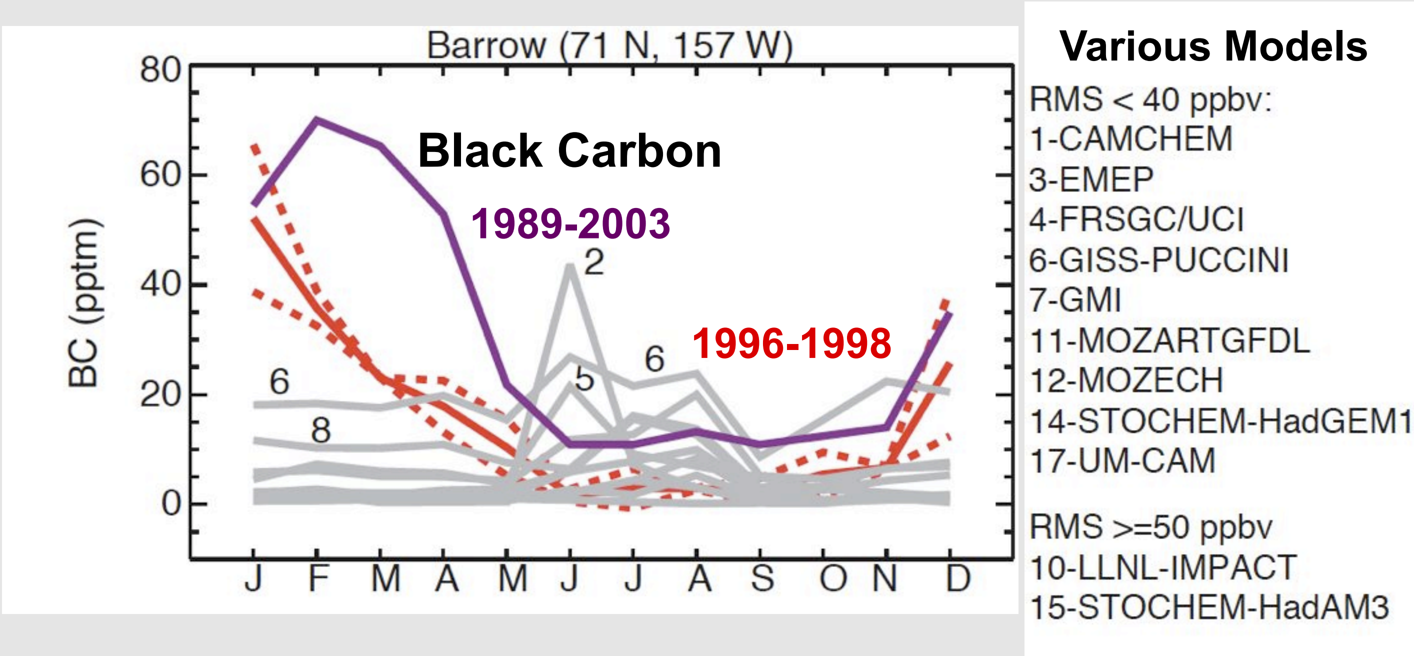
Black mark. A new analysis pins a significant portion of recent Arctic warming on soot (foreground).

The seasonal cycle in aerosol scattering and absorption

Do these models replicate observed concentrations?



Disagreements between Models and Measurements in Arctic



Shindell et al. ACP, 2008

- ***Most models do not show observed seasonal cycle in black carbon (soot)***

- ***Soot is a potent climate forcing agent; it enhances atmospheric heating, and snowmelt if deposited to surface***

Some specific ARCPAC goals

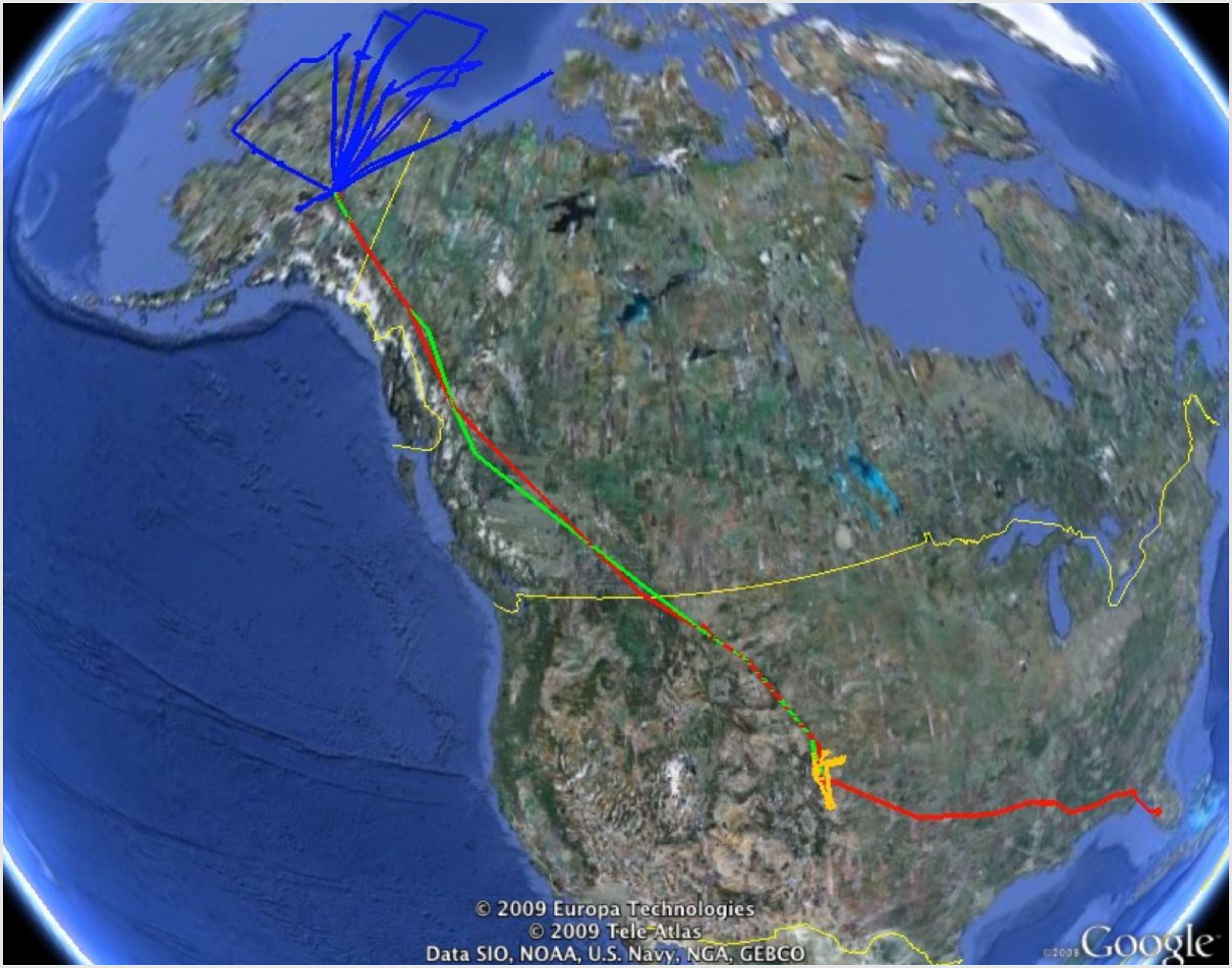
- **What are the optical properties of aerosol particles in the Arctic troposphere?**

- **How much black carbon is present, and from where does it come?**

- **What can we learn to constrain estimates of deposition to the snow surface?**

- **What are the direct radiative effects of absorbing and scattering aerosols in the Arctic?**

6 Arctic science flights; ~48 flight hours

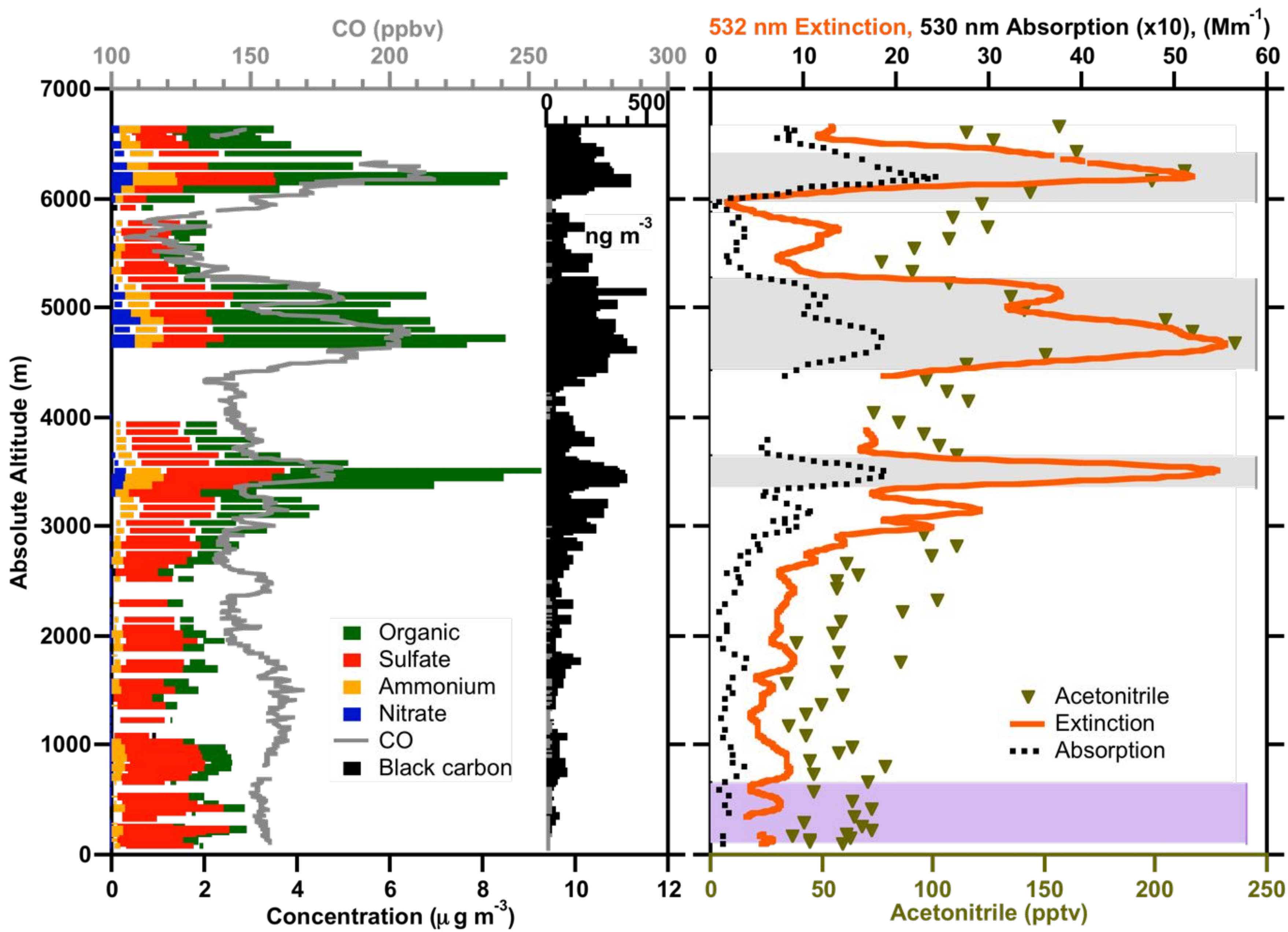


What did we see visually?
Aerosol layers over the Brooks Range; April 18th, 2008

D. Lack, NOAA and CIRES, Univ. of Colorado

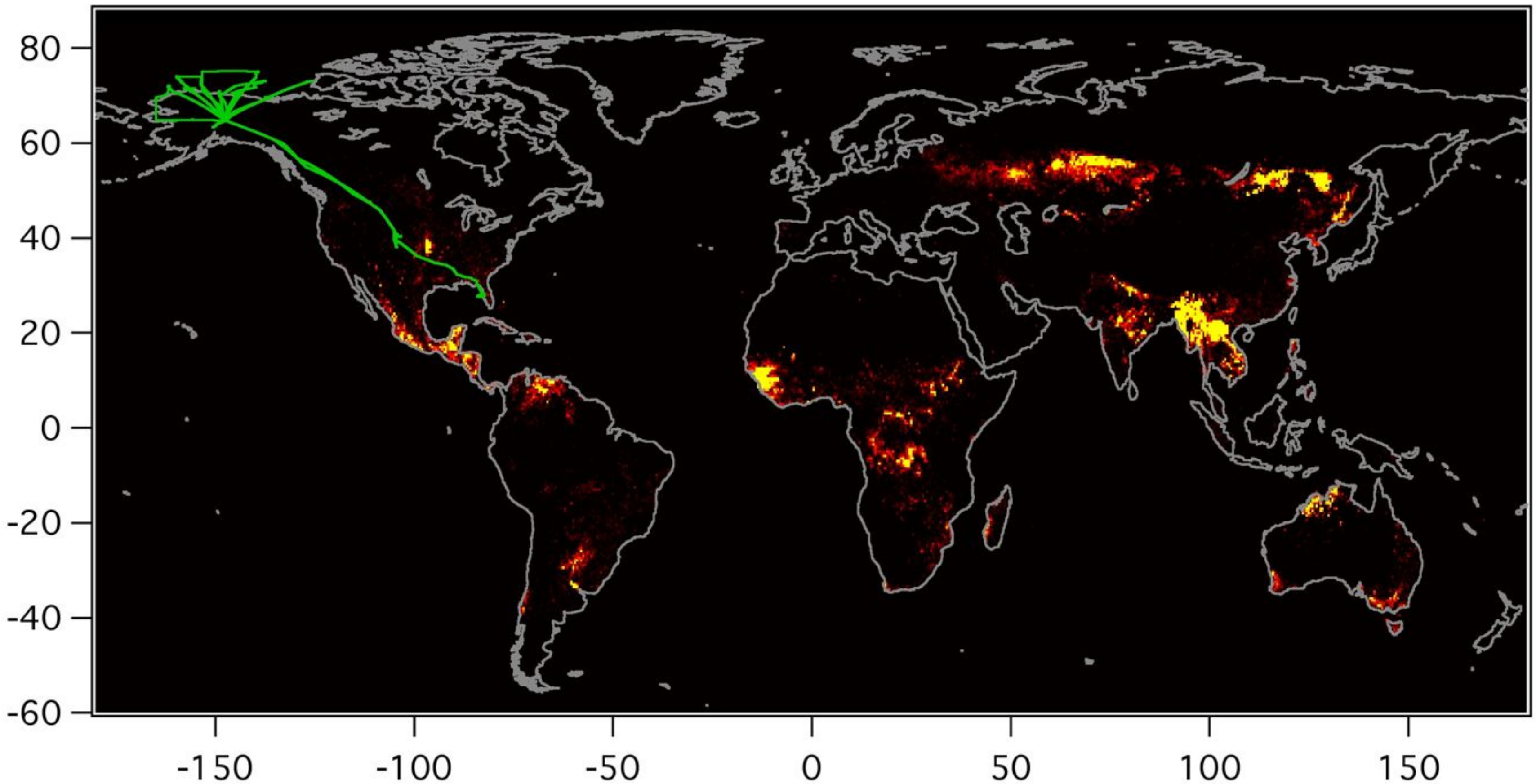
NASA P-3 from NOAA P-3
Aerosol layers over western Alaska; April 15th, 2008

D. Lack, NOAA and CIRES, Univ. of Colorado



CO (ppbv)
100
150
200
250
300
532 nm Extinction, 530 nm Absorption (x10), (Mm-1)
0
10
20
30
40
50
60
7000
6000
5000
4000
3000
2000
1000
0
Absolute Altitude (m)
0
500
ng m-3
Organic
Sulfate
Ammonium
Nitrate
CO
Black carbon
0
2
4
6
8
10
12
Concentration (µg m-3)
Acetonitrile
Extinction
Absorption
0
50
100
150
200
250
Acetonitrile (pptv)

MODIS fire counts and ARCPAC flight tracks



NOAA WP-3D flight
tracks April 2008

Warneke et al GRL 2009

Siberian fires in mid-April 2008

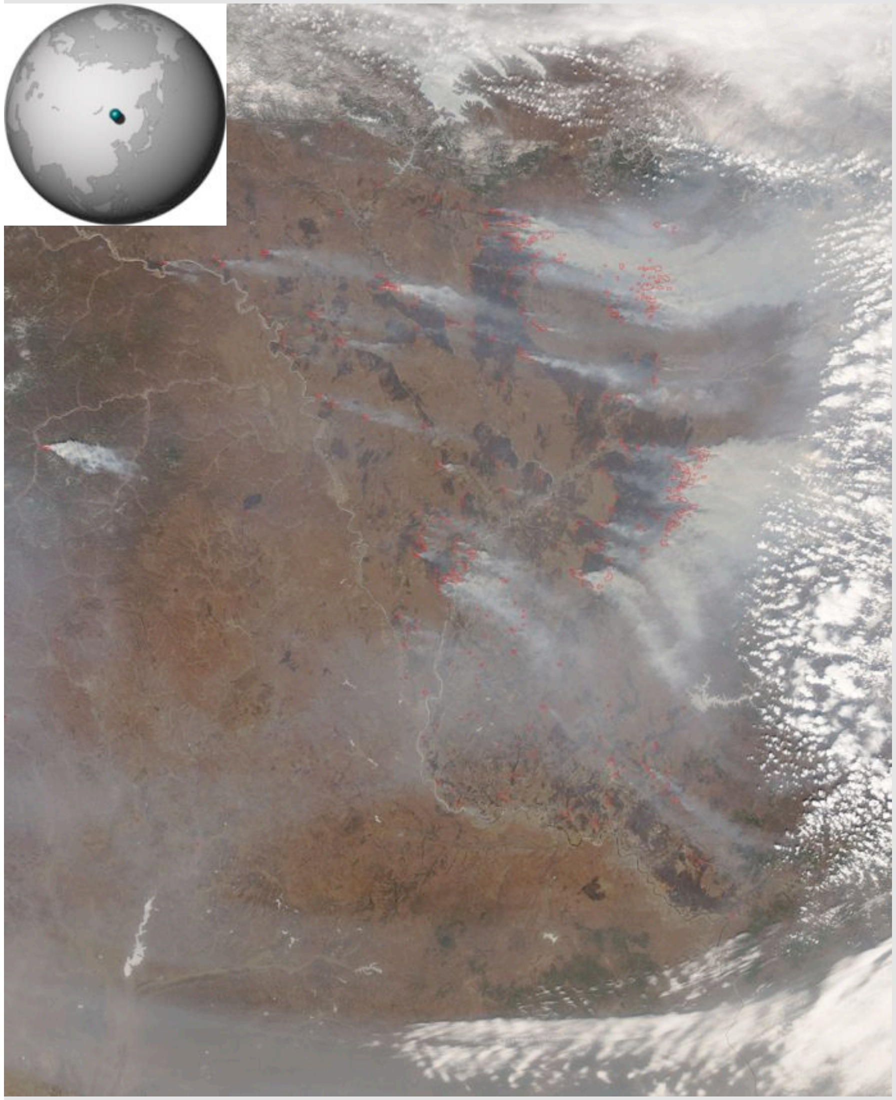
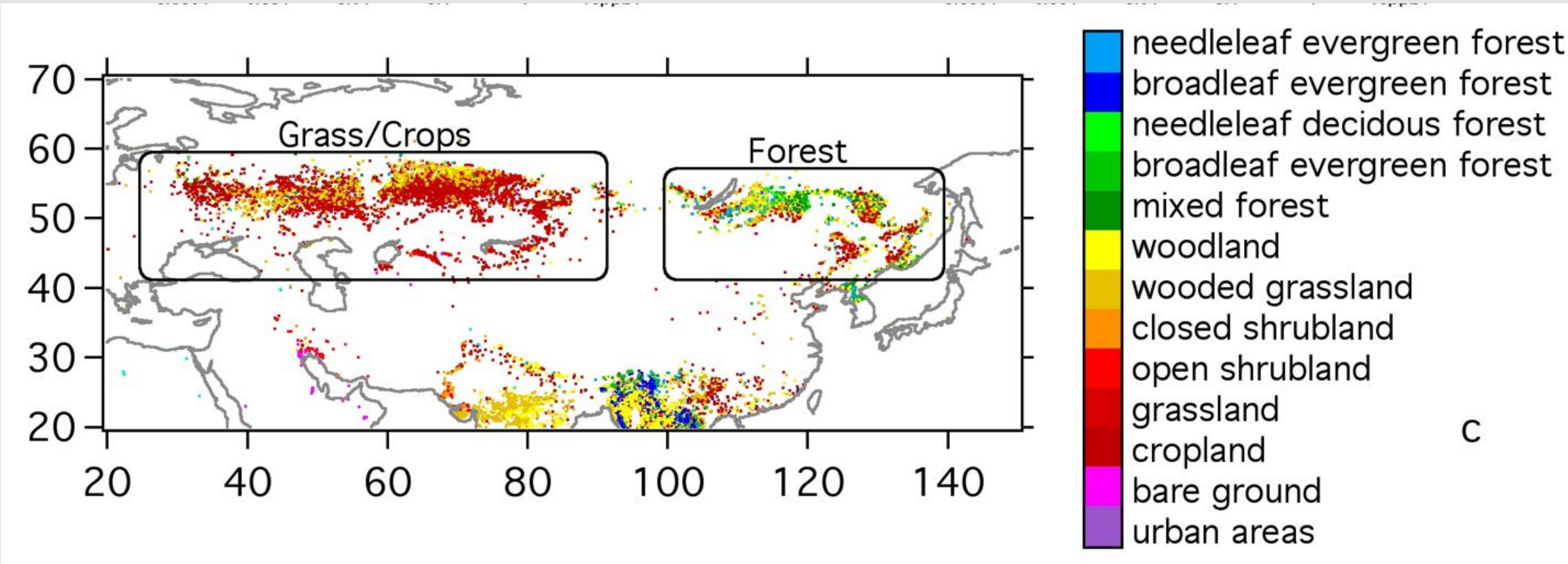


Photo of BB layer over Alaska's Brooks Range by Dan Lack

- MODIS satellite image of fires in Siberia
- Modest intensity, but widespread and fumigating
- Plumes observed in Alaska

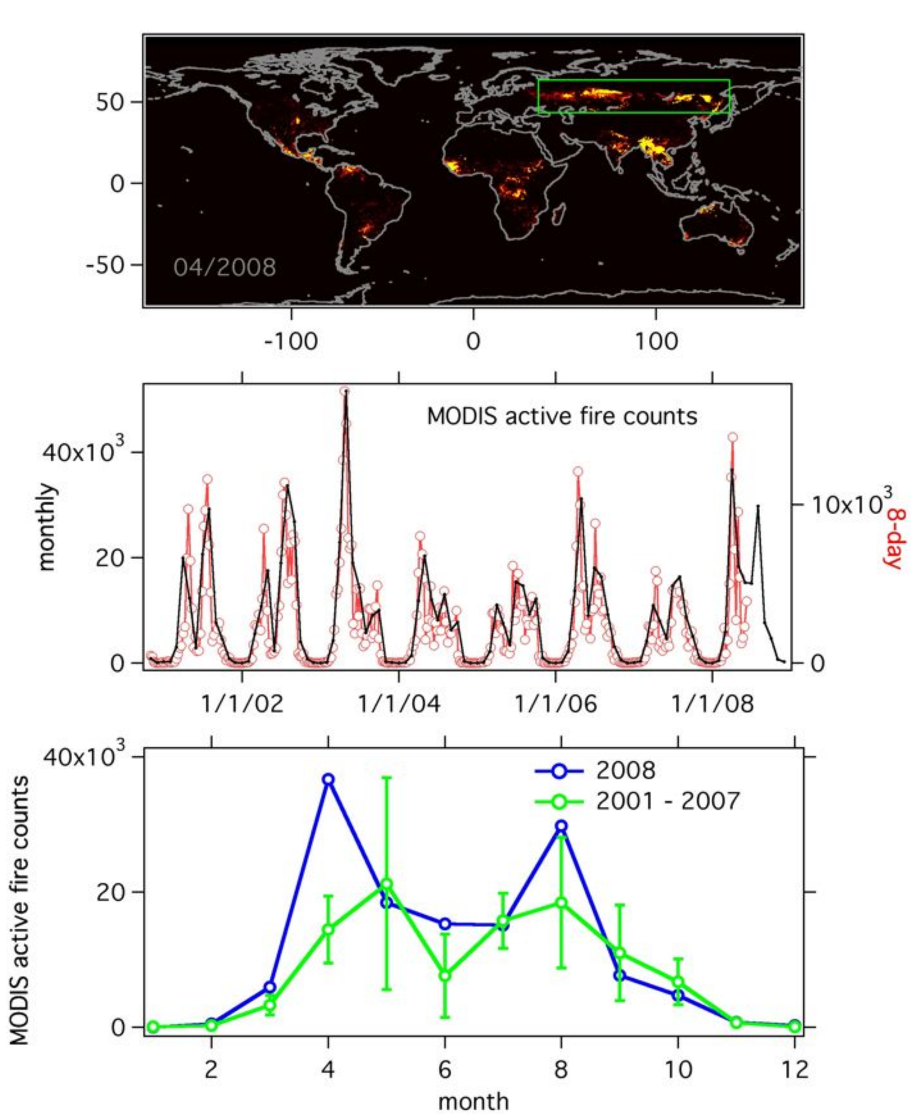
Two different source regions



- Fires mainly from SE Siberia (~80%) and Kazakhstan/Russia border area
- land cover data show different fuel types
- modest anthropogenic influence
- BB emissions Stohl et al.

Carsten Warneke & Jerome Brioude, CIRES/NOAA

Fires in 2008 versus previous years



Siberia + S. Russia/Kazakhstan fire counts

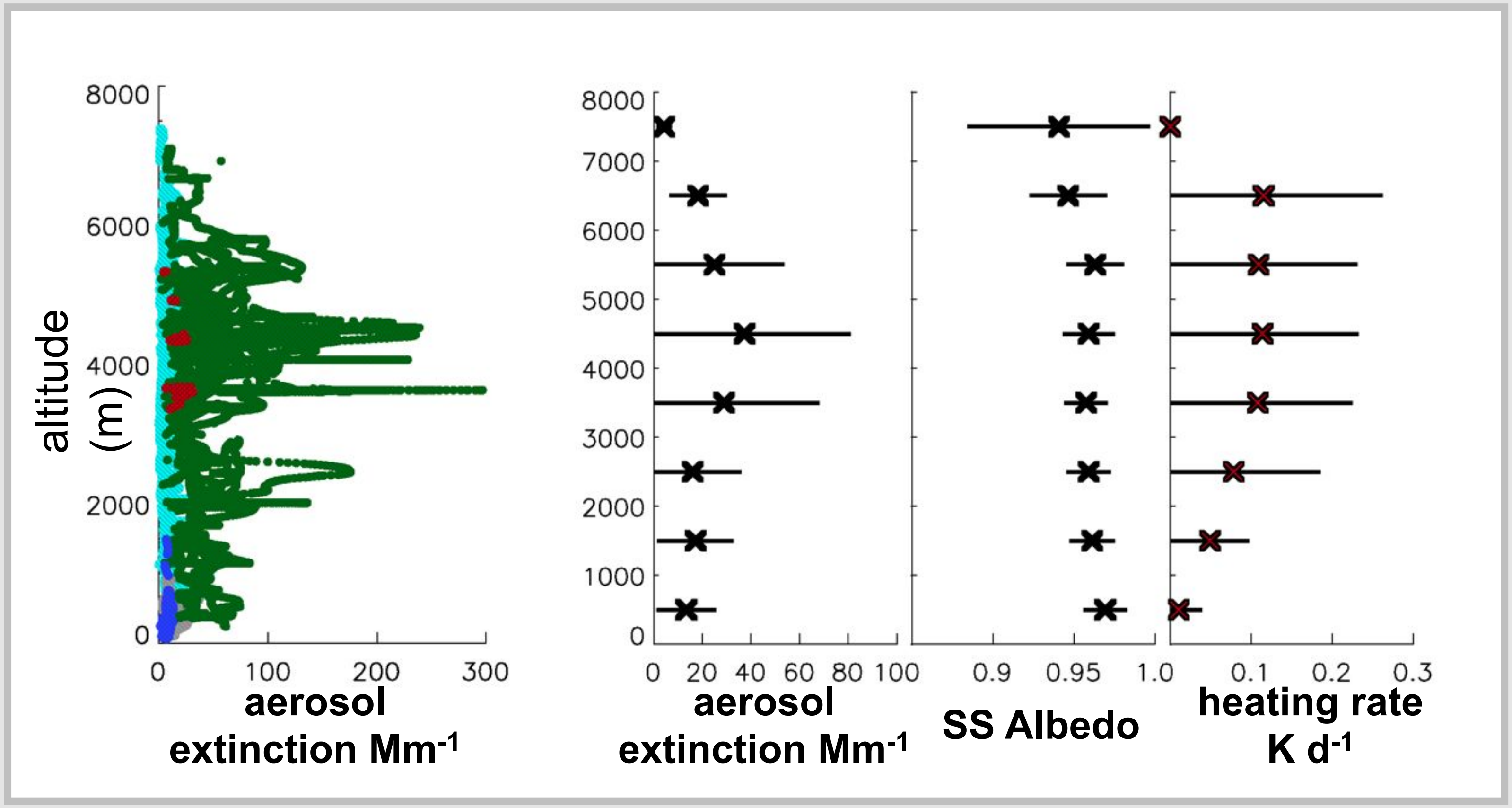
- **always large number of fires in April**
- **2008 twice as high as normal**
- **2008 very early fire season**
- **usually fire maximum in May**

•Transport model calculates that ~40% of aerosol in the Arctic in April comes from open fires from Southern Russia and SE Siberia

MODIS data from University of Maryland ftp server

Carsten Warneke, CIRES/NOAA

Heating calculated from observations (max possible at solar noon)



Allison McComiskey, CIRES/NOAA

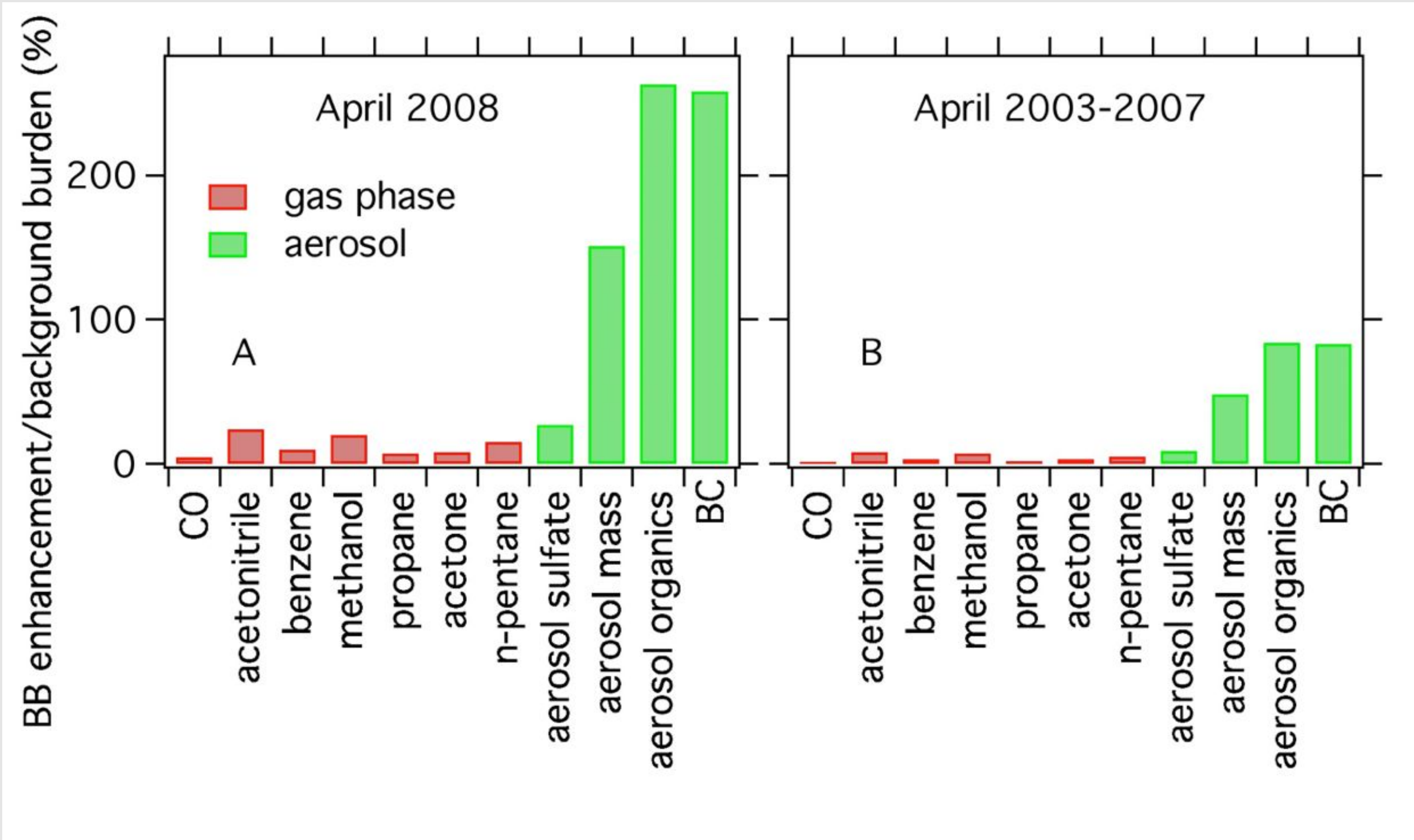
Summary

- ***Most climate models appear to underestimate the concentration of black carbon (soot) in the Arctic and struggle with seasonality***
- ***Layers of BB smoke mixed with fossil fuel pollution; layers cool the surface and heat the atmosphere modestly***
- ***Biomass burning an underappreciated annual source of springtime aerosols and gases to the Arctic; however,***
- ***Layers aloft decoupled from sea-ice surface layer over time scales investigated in ARCPAC***
- ***No evidence for removal of aerosol particles from fire plumes aloft to the snow surface***
- ***Evidence for some depositional losses in the shallow Arctic boundary layer over sea-ice (Spackman)***

[redacted]

April Arctic loading attributable to biomass burning

100% means BB = all other sources

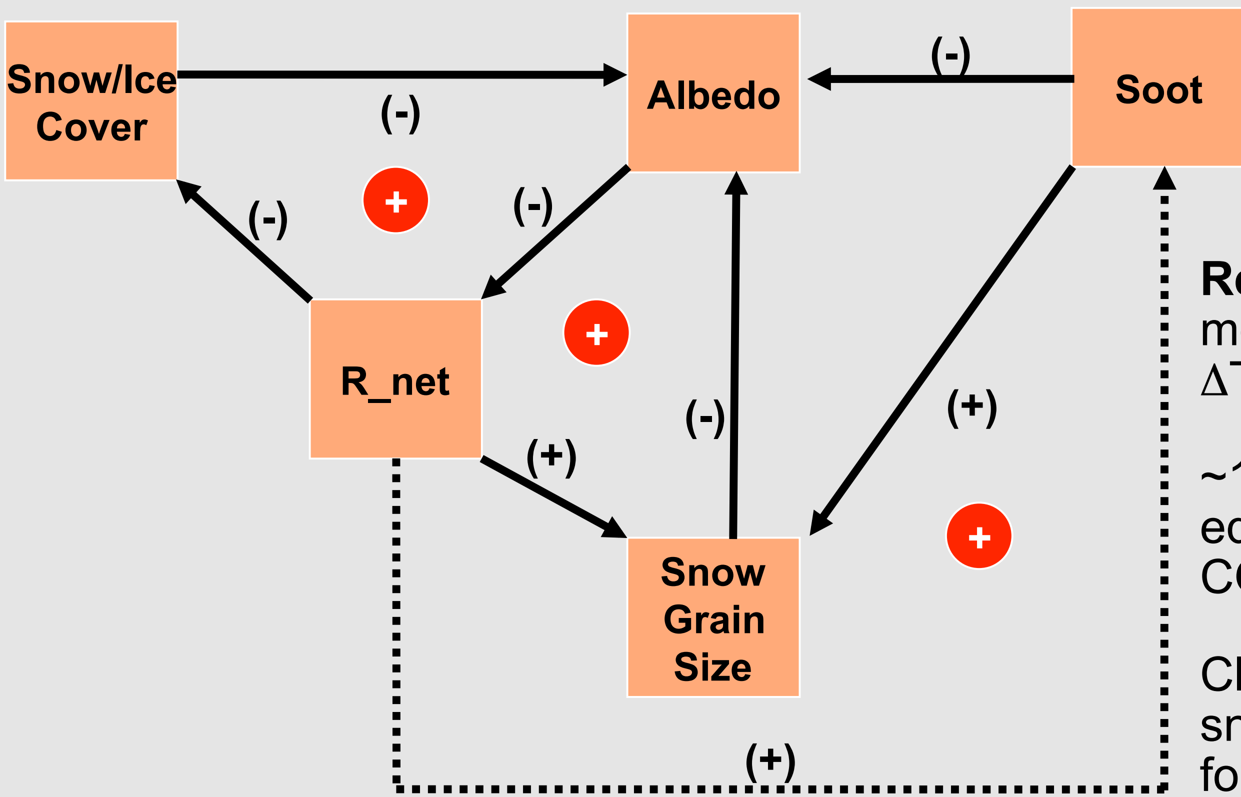


Warneke et al., 2009 GRL

Summary of radiative transfer calculations. . .

- Radiative transfer modeling begun, but not completed for range of SZA, surface albedos, etc.
- Densest smoke layers produce a local warming of <1 K/day under maximum solar conditions; average of ~0.1 K/day
- Effects of warming of the troposphere should be investigated
- Cooling at the surface is modest compared with other energy terms (sensible, latent heat)
- Forcing is sensitive to vertical distribution, single scatter albedo, and total optical depth
- Forcing calculated from Barrow observations appears reasonable despite these sensitivities; suggests ARCPAC observations are not grossly atypical

Black Carbon in Snow:
Multiple Positive Feedbacks



Concentration of hydrophobic and large impurities at the surface during melting**?**

Result: Forcing “Efficacy” more than 3x CO_2.
$\Delta T/W\ m^{-2}$

~1% change in snow albedo is equivalent to current industrial CO_2 radiative forcing

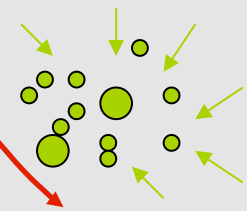
Climate forcing from soot in snow has similar magnitude to forcing from aerosol soot and brown carbon in the Arctic atmosphere

Flanner et al., JGR, 2007

Conceptual model (from ITCT) of particle removal

Lifting & scavenging remove most particles.
Insoluble gases (CO, acetonitrile) remain.

Aircraft measures insoluble gases, particles not removed, & particles formed from gas-phase oxidation and condensation.

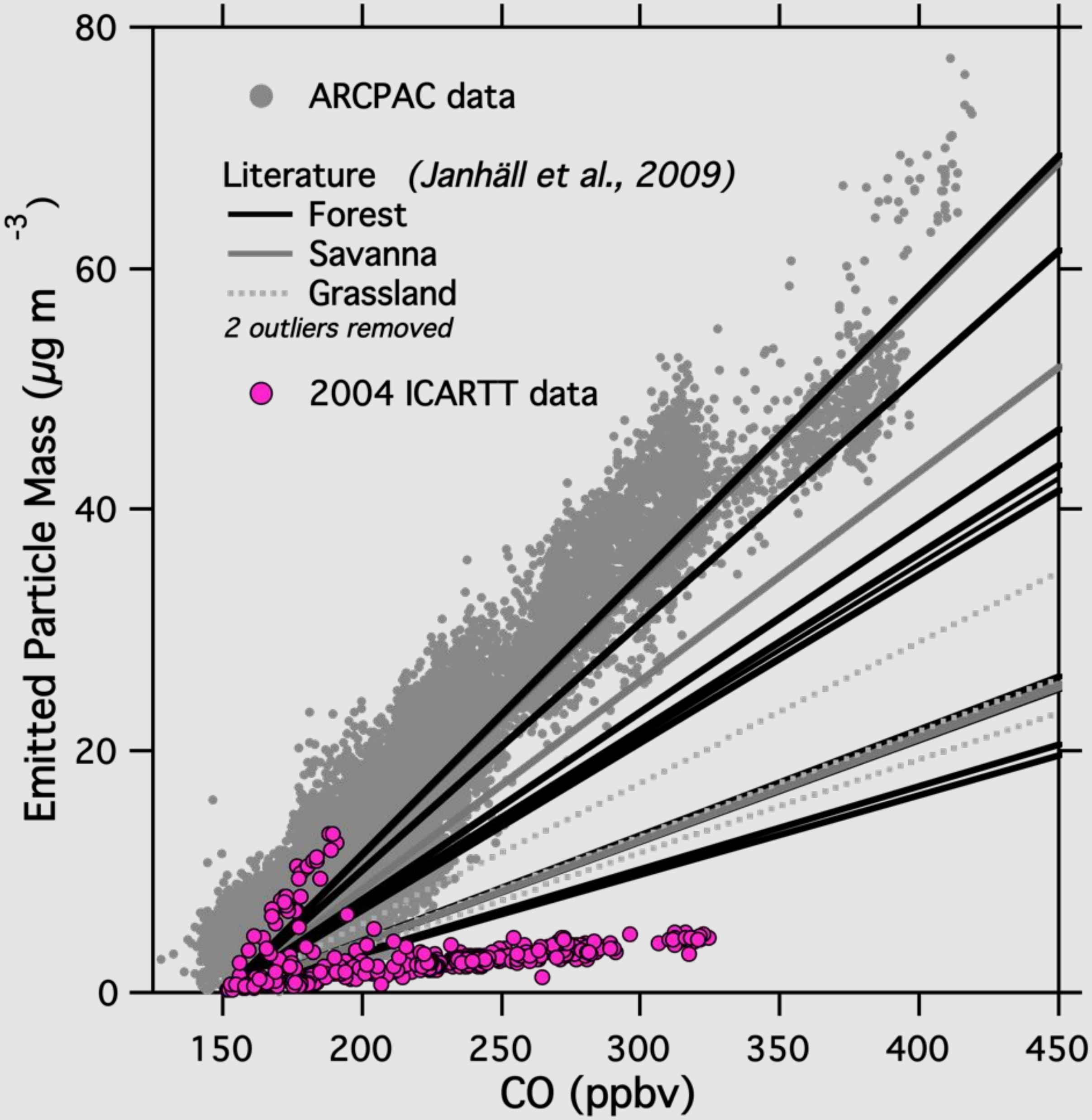


Transport & transformation:
$SO_2 \rightarrow SO_4^{=}$, $NO_x \rightarrow HNO_3$
& PAN, VOCs→SOA

~days to weeks

immediate to ~days

Fine Aerosol Mass vs. CO from ICARTT 2004 Alaskan Smoke



- **Smoke from Alaska measured near Maine in summer 2004**
- **One case of enhanced CO without much aerosol mass enhancement**
- **Acetic acid depleted**
- **Dew point lower**
- **Scavenging diagnosed (*de Gouw et al, JGR 2006*)**

Wollny