Satellite Constraints on Arctic-region Airborne Particles

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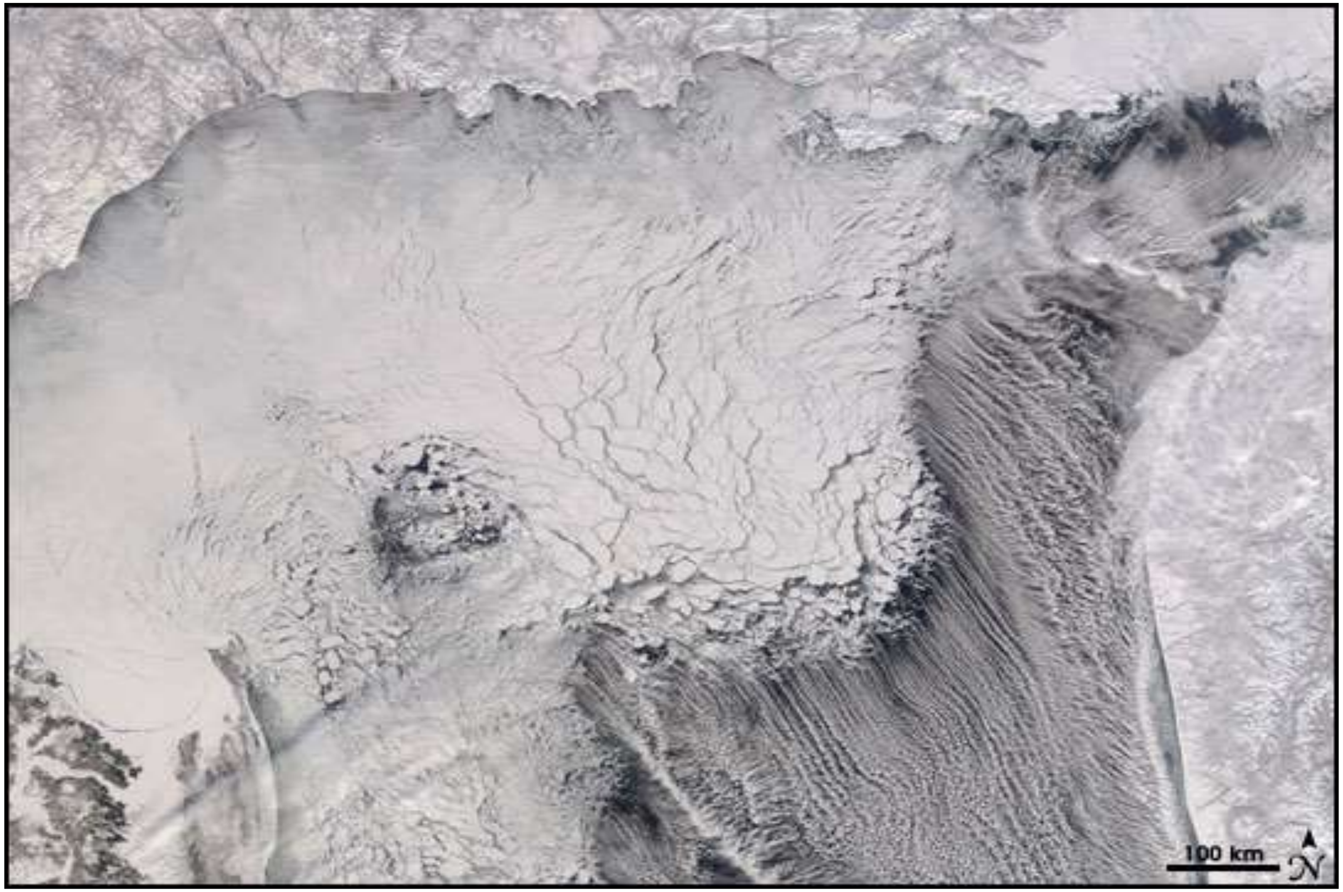


Sea of Okhotsk, MODIS image Feb. 6 , 2007, NASA Earth Observatory

Arctic Aerosol Remote Sensing Overview

• Aerosol remote sensing is especially ***challenging in the polar regions***, due to the combination of very bright surface, low sun angle, persistent cloud (including thin cirrus), and generally low aerosol optical depth (AOD). Some success in retrieving AOD over incomplete snow-covered surfaces has been achieved with passive imagers such as MISR.

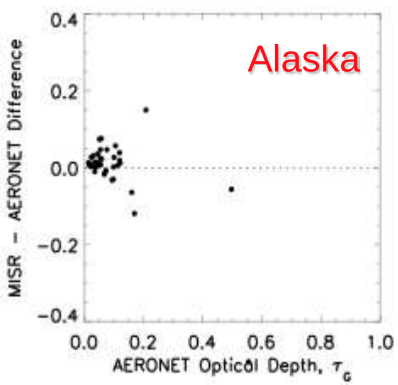
• Despite limited coverage, ***CALIPSO lidar*** is by far the most sensitive and is the best available space-based source of total-column and height-resolved Arctic aerosol observations, especially at night, when signal/noise is highest. The ***SAGE passive limb-sounders*** also provide height-resolved aerosol extinction profiles in the stratosphere and upper troposphere, again with very limited sampling. But results tend to be ***averaged*** over space and time.

• ***Passive imagers***, such as MODIS, MISR, and TOMS-OMI, provide broader spatial coverage on shorter timescales, making ***event-resolved studies*** possible. Such observations can be acquired reliably at lower latitudes, near the aerosol sources (mainly Boreal fires and pollution sites) where and when the surface is not snow-covered, and the AOD and sun elevation angle are higher. A promising approach to assessing high-latitude aerosol effects from passive imagers is to ***constrain chemical transport models with satellite observations at lower latitudes,*** *and use the models to simulate conditions in the Arctic*.

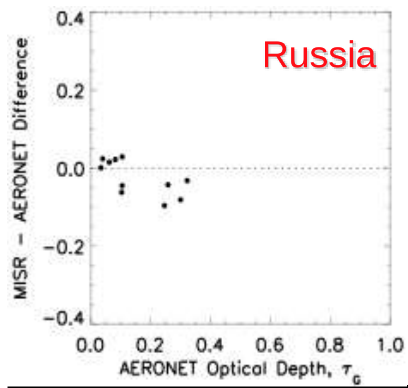
• Similarly, gas molecules such as ***CO and*** SO_2, mapped globally from space by AIRS, OMI, and other instruments, can serve as smoke and particle pollution tracers for constraining transport model simulations.

• Given the limitations of each approach, the ***combination of active and passive satellite measurements***, ***suborbital observations*** for validation and additional detail, ***and transport modeling*** constrained by observations, is required to complete the Arctic aerosol picture.

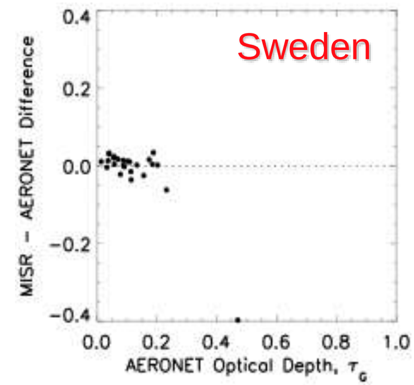
The Plusses and Minuses of Surface-based Sun Photometry



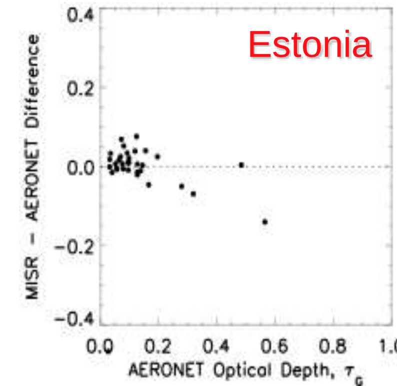
Bonanza Crk (64.7, -148.3)
7 years, 40 coincidences



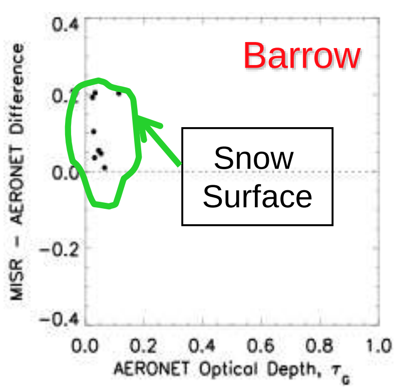
Yakutsk Ru (61.7, 129.4)
3 years, 12 coincidences



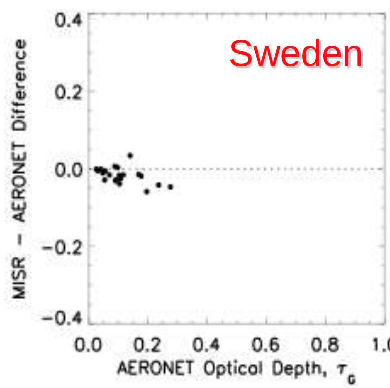
SMHI Swdn (58.6, 16.2)
3 years, 25 coincidences



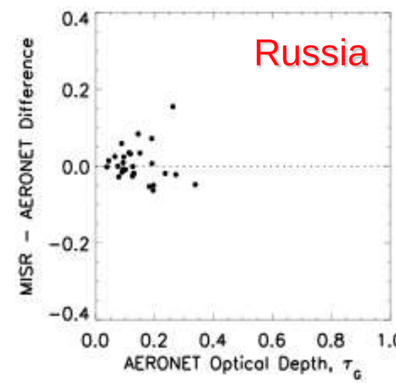
Toravere Estna (58.3, 26.5)
5 years, 34 coincidences



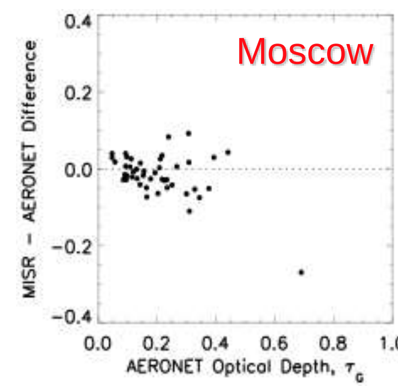
Barrow AK (71.3, -156.7)
5 years, 8 coincidences



Gotland Swdn (57.9, 19.0)
3 years, 21 coincidences



Tomsk Ru (56.5, 85.1.7)
5 years, 29 coincidences

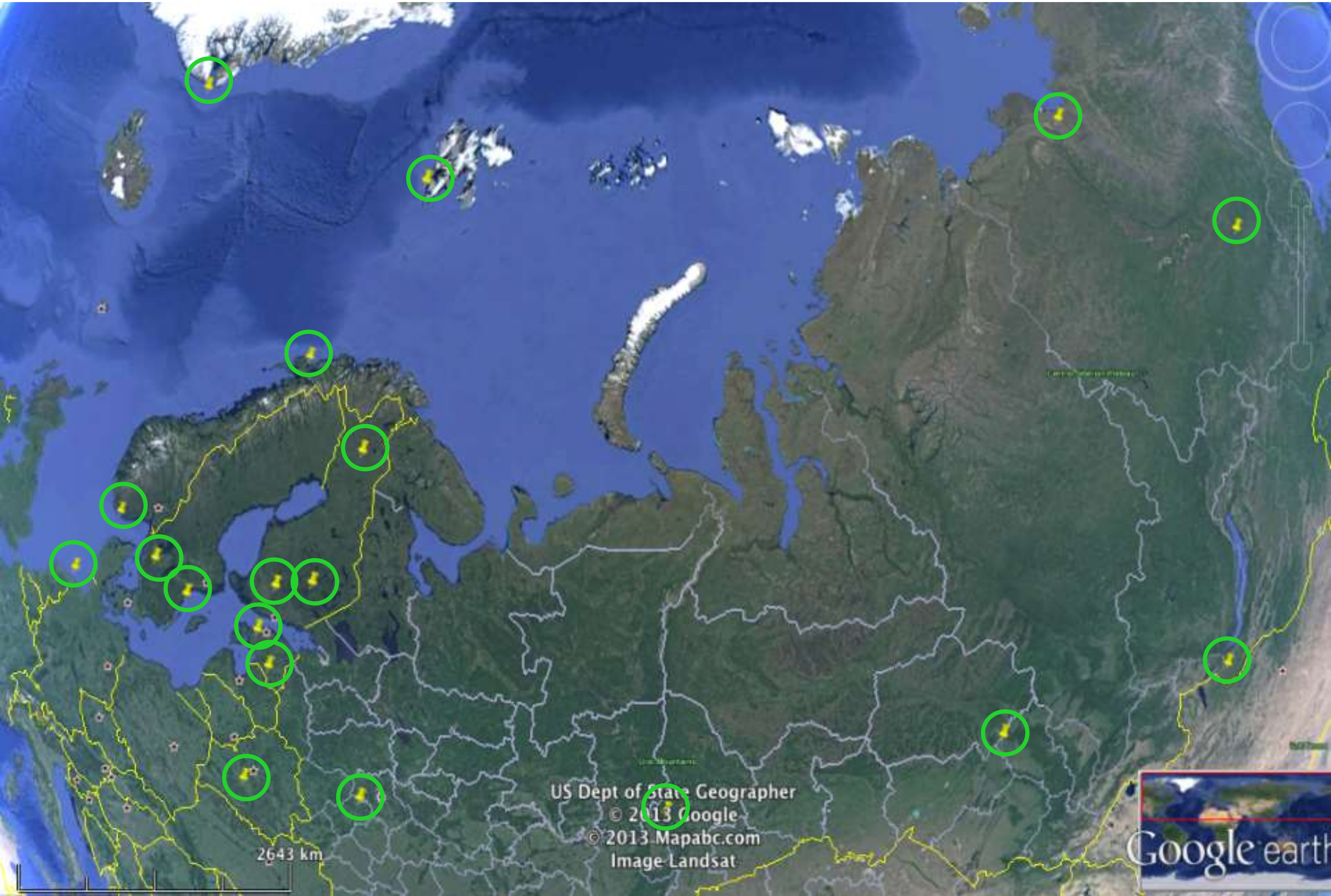


Moscow Ru (55.7, 37.5)
6 years, 46 coincidences

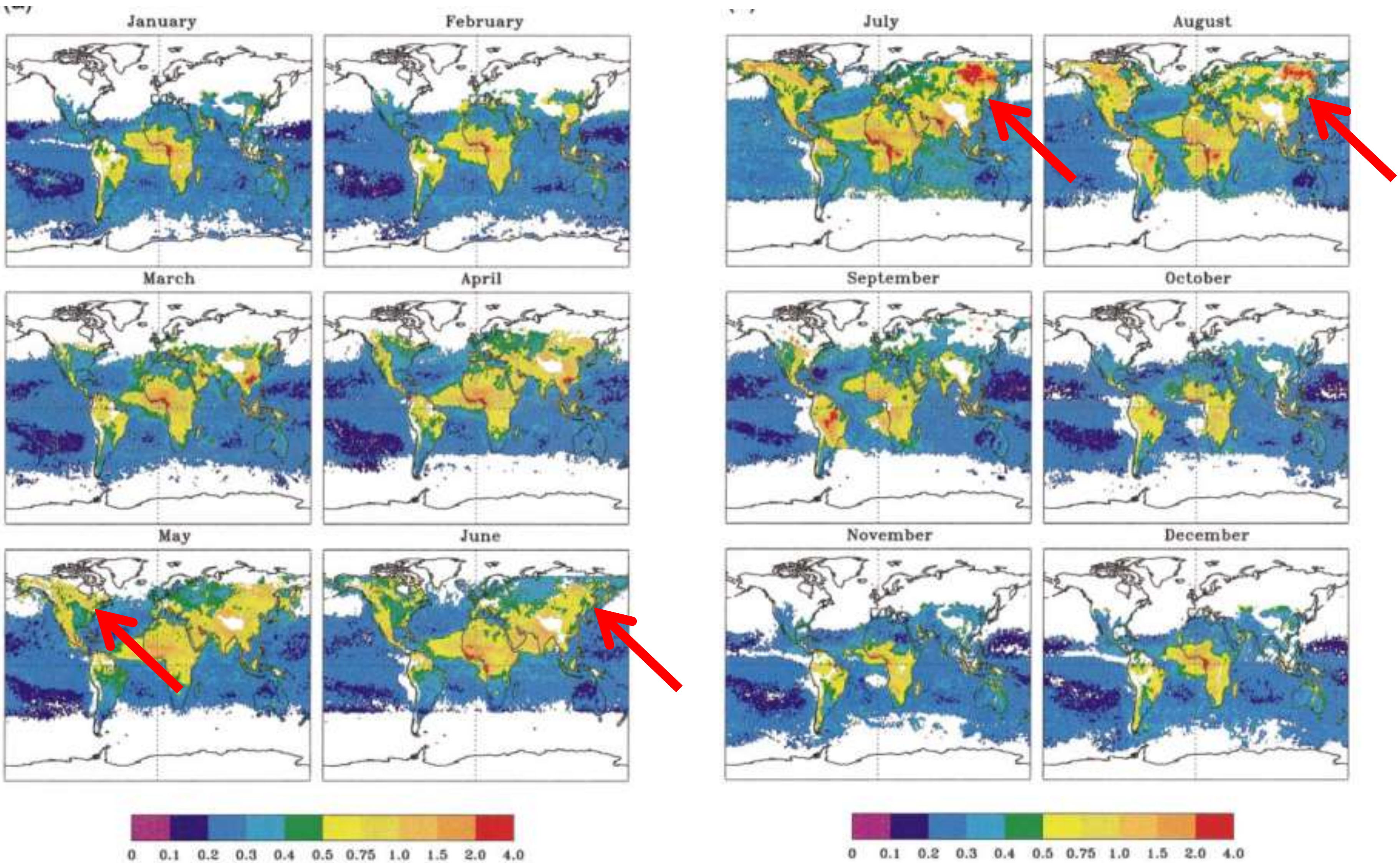
- Mid-visible **AOT's are generally <0.4**, and most are <~0.2
- Most AERONET sites are **snow-free** during operation; **only eight sites** north of 70˚N (in 2013)
- Persistent **cloudiness** limits coverage frequency (coincidences with MISR are shown)
- At latitudes **above around 70˚N**, **low sun angle** is an issue

AERONET Arctic Sites Reporting *Any* Data in 2013 (Approximate)

AERONET Arctic Sites Reporting *Any* Data in 2013 (Approximate)



1979-1991 Monthly Average Nimubs 7 TOMS Mid-visible AOD

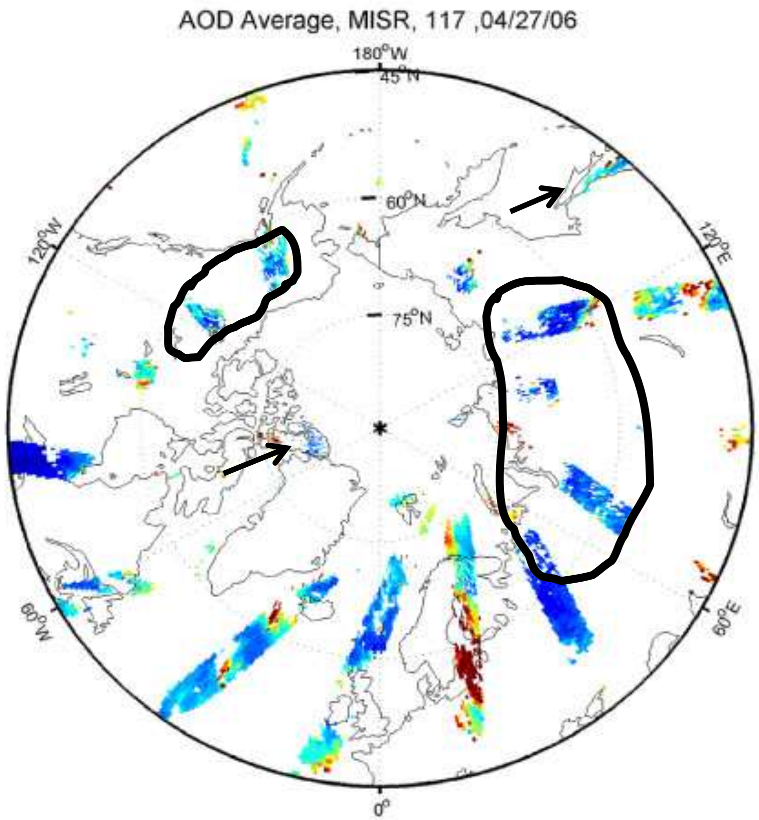


Passive Remote sensing (UV) constrains ***Sub-Arctic aerosol sources*** (wildfires, pollution)

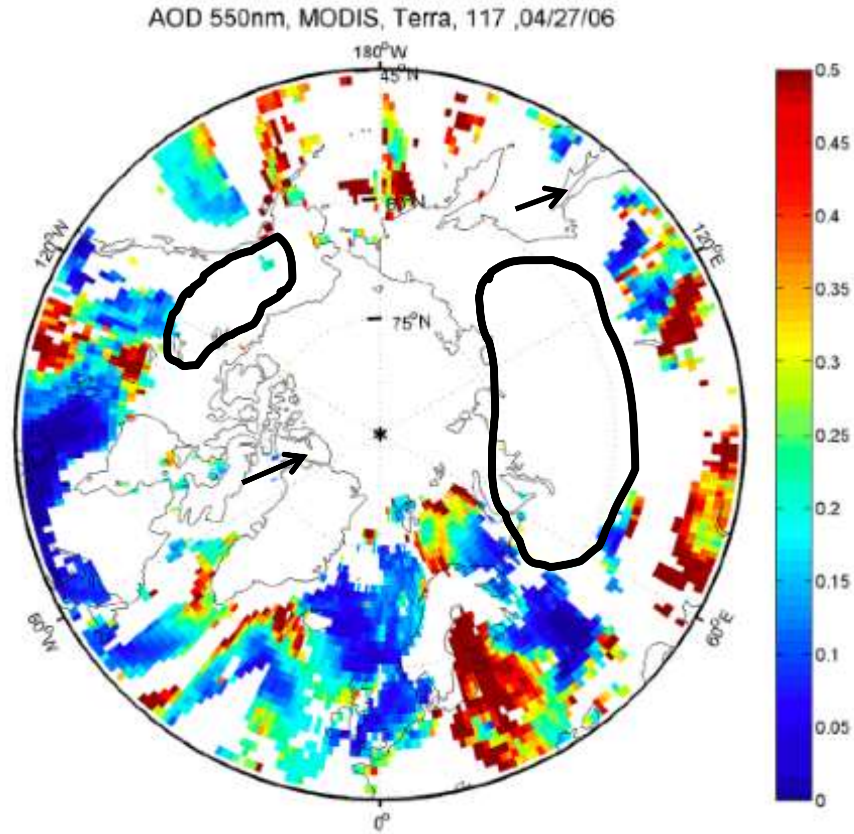
Torres et al., JAS 2002

MISR & MODIS High-latitude Aerosol Optical Depth Maps

Single-day mid-visible AOT observations *April 27, 2006*



MISR



MODIS

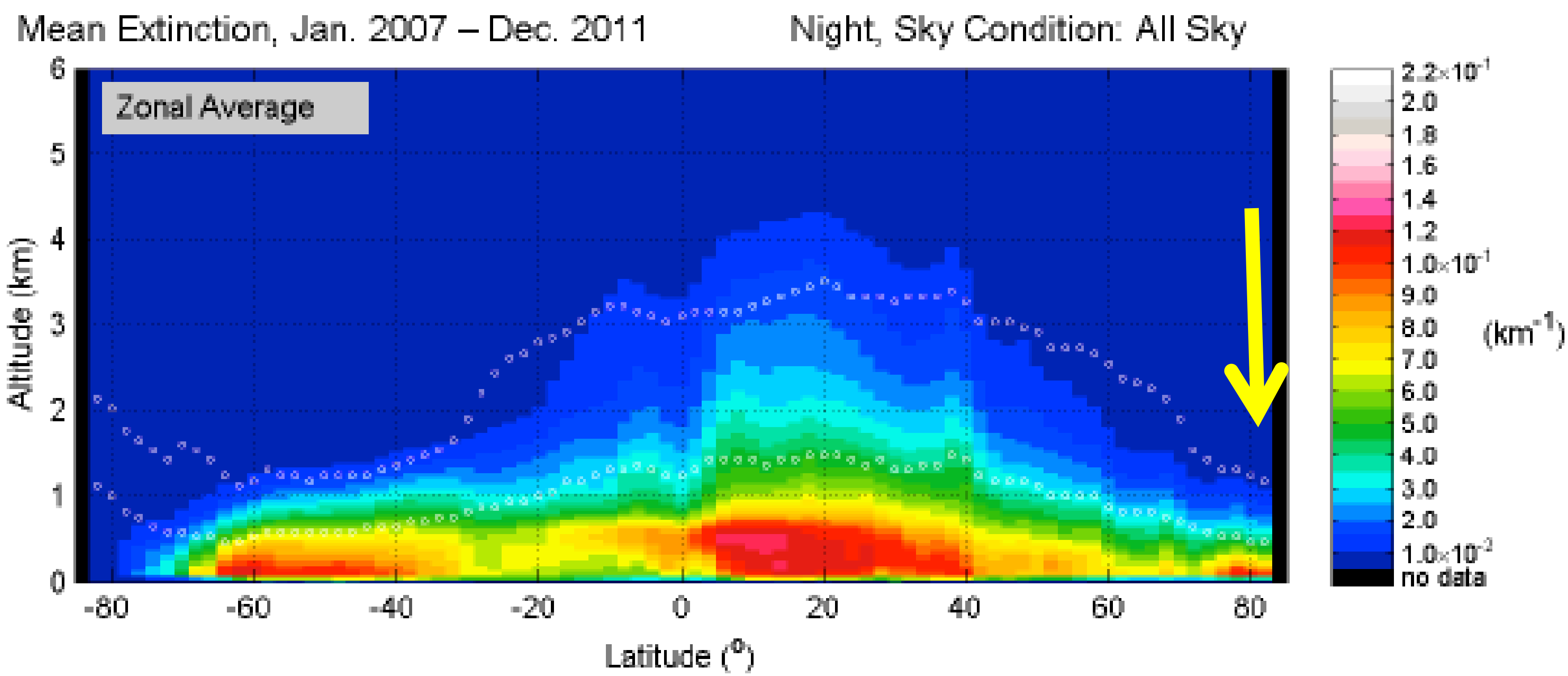
Complementary **Observations**:

MODIS provides large-swath **Coverage**

MISR fills in cloud-free **Continents**, **Nadir Glint** over water, some **Snow surfaces**

Data mapped by J. Redemann

Five-year, Zonal average CALIPSO 532 nm Aerosol Extinction

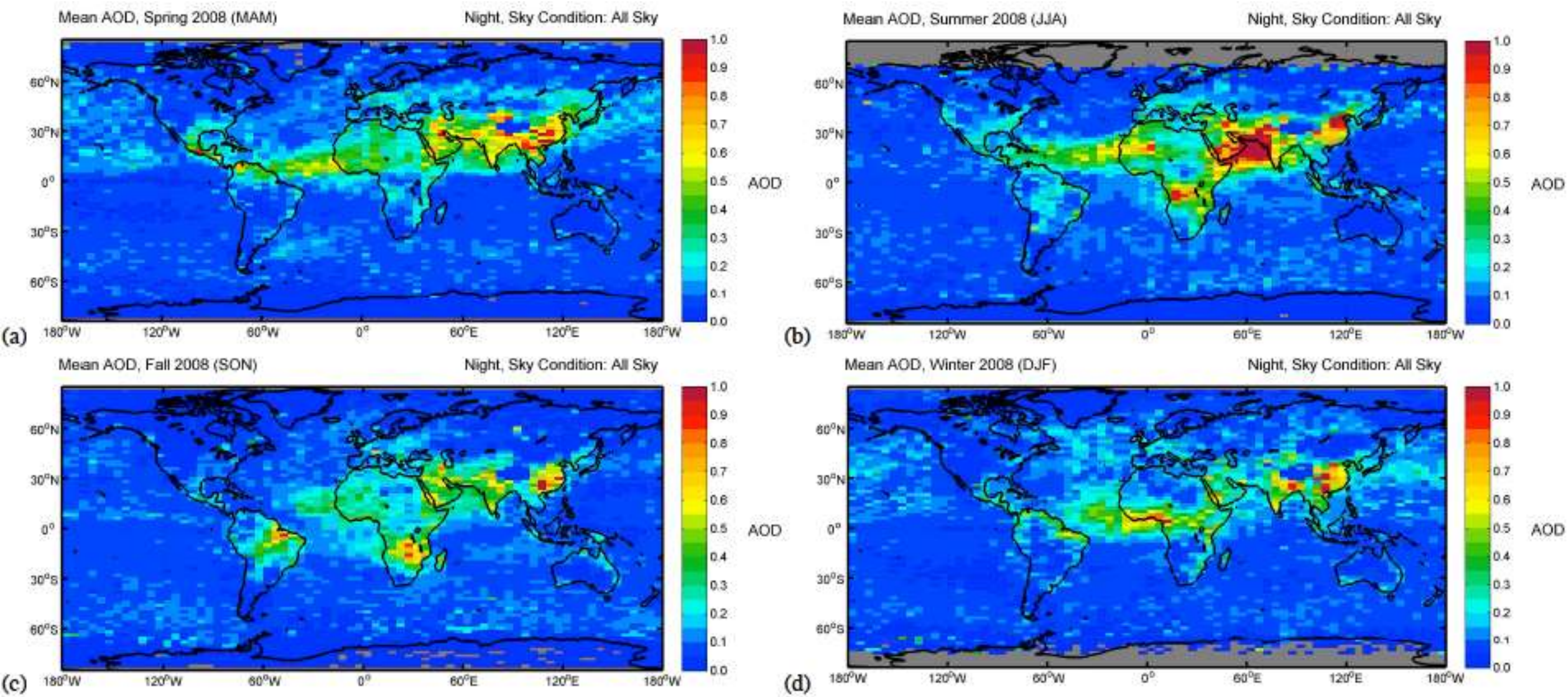


<u>Arctic</u>: On average, aerosol is concentrated ***Very Near-surface*** (~200 m)

- Due to low sampling frequency, ***much averaging*** is required
- For all but major aerosol events, need ***high nighttime signal/noise***

Winker et al., ACP 2013

Seasonal 2008 CALIPSO 532 nm Mean Aerosol Optical Depth



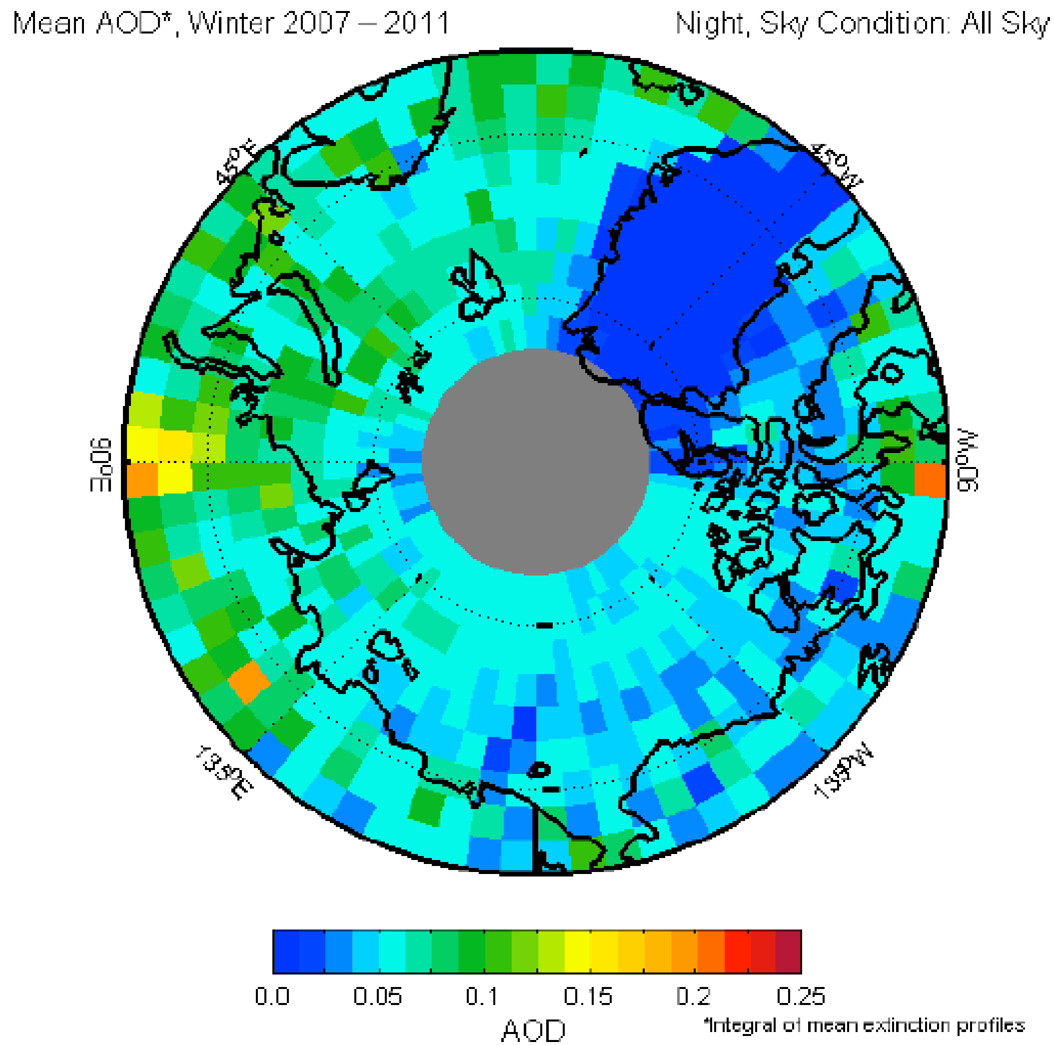
<u>Arctic</u>: Generally ***Low AOD*** (< 0.1)

High Arctic peak AOD ***Dec-March***; Low Arctic (60-70˚N) peak AOD in ***Summer***

High signal/noise at night [but no nighttime data during local summer]

Winker et al., ACP 2013

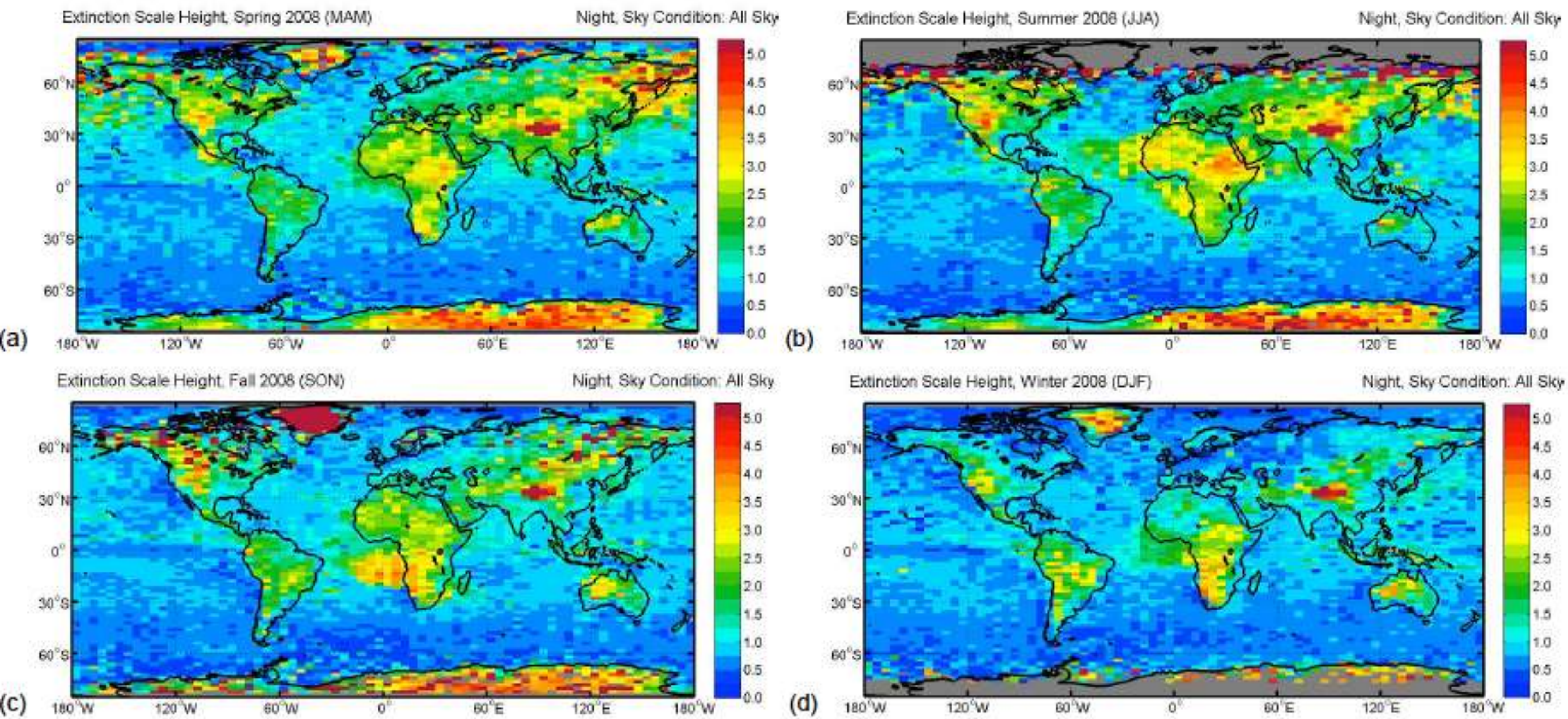
Winter 2007-2011 CALIPSO 532 nm Aerosol Optical Depth



Arctic AOD: ***Lowest over Greenland*** (< 0.02)
Highest over Russia (~0.2)

Winker et al., ACP 2013

Seasonal 2008 CALIPSO Aerosol Extinction Scale Height

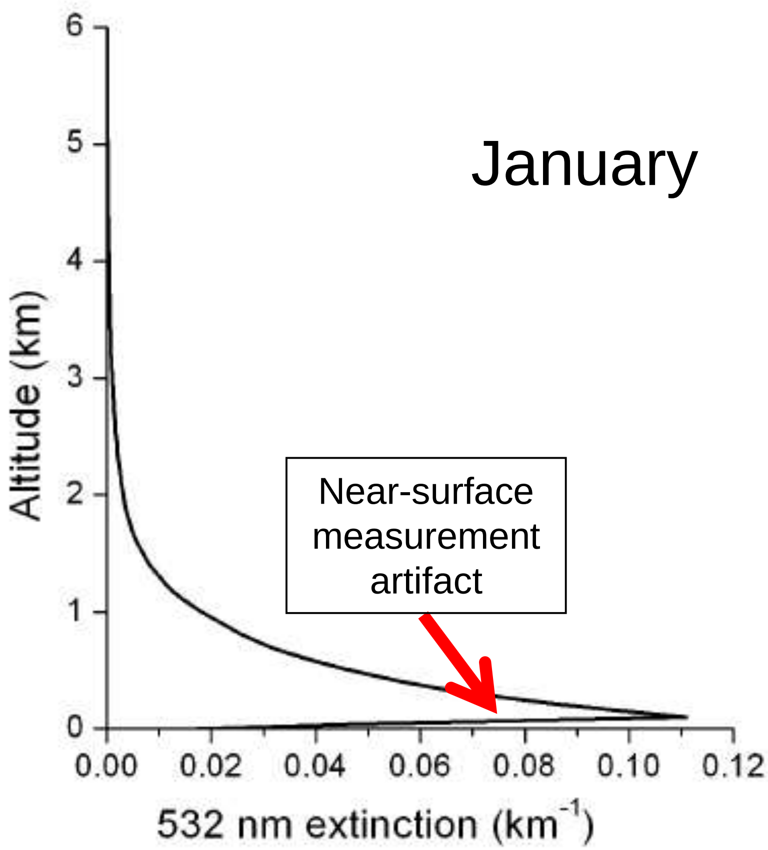


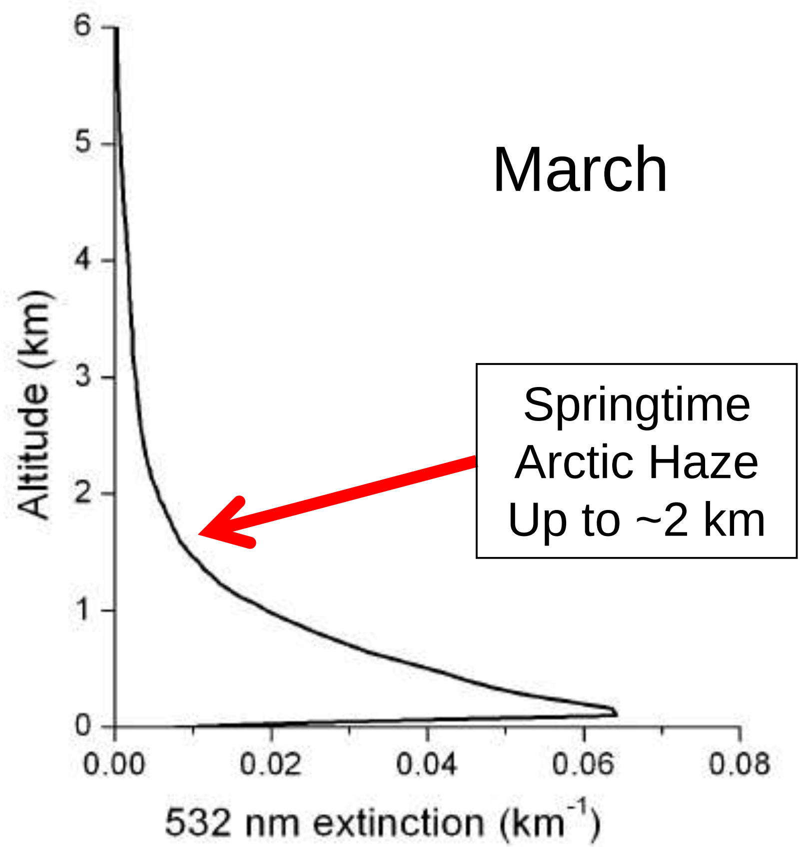
<u>**Arctic**</u>: ***Small*** scale-height (near-surface) over ocean; ***Larger*** scale-height over land
(Transport pathways play a role in this.)

Winker et al., ACP 2013

CALIPSO Mean 532 nm Aerosol Extinction Profile 2007-2011

61-82˚ N





Arctic: On average, aerosol is concentrated ***Very Near-surface*** (< 1 km)

Winker et al., ACP 2013

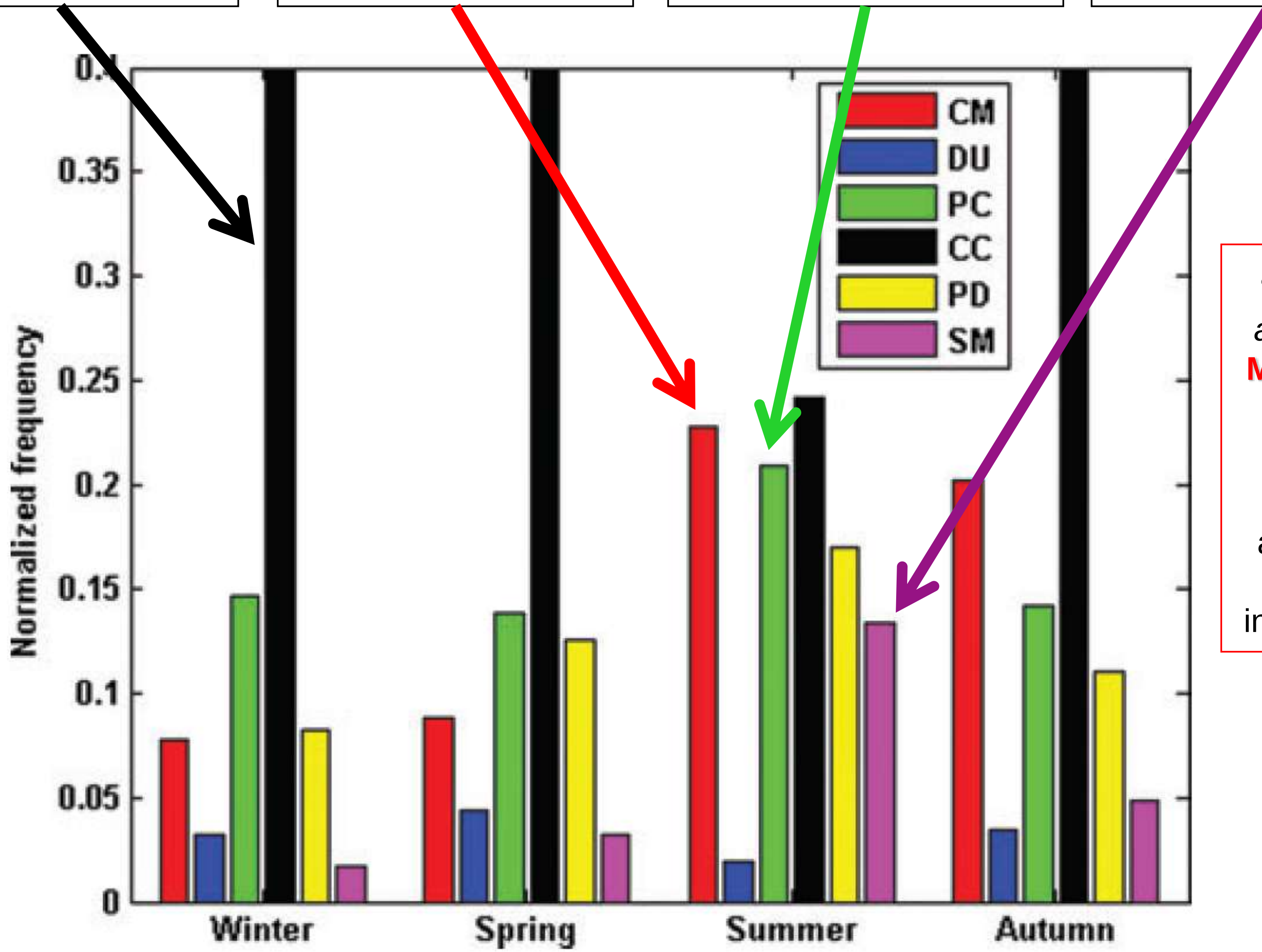
CALIPSO Aerosol "Types" by Season June 2006- May 2010

Clean Continental – The main Background

Clean Maritime – Summer & Autumn

Polluted Continental – All year – Summer peak

Smoke – Mainly in Summer

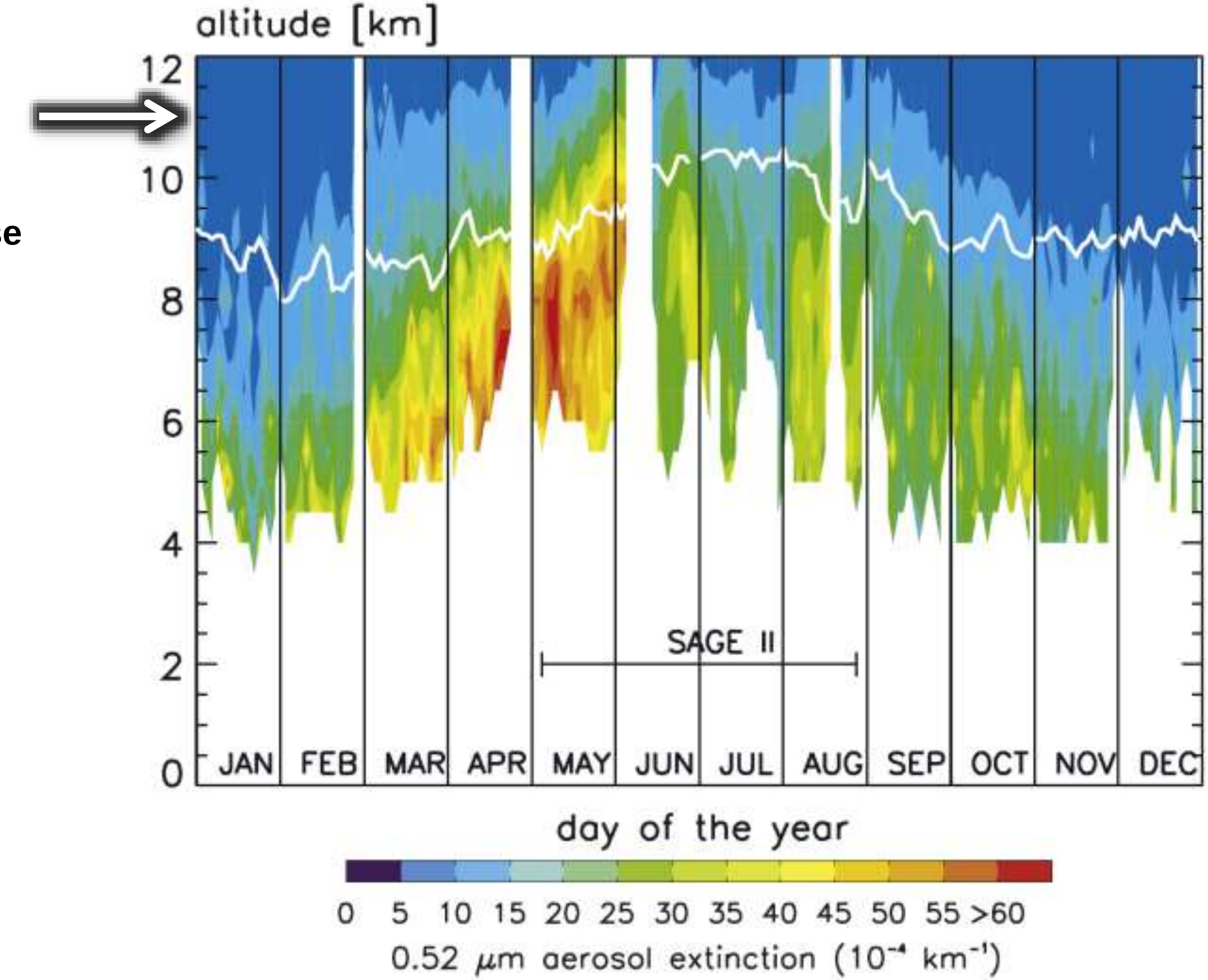


- *Di Pierro et al*. (2013) see **Maritime** peak in Winter
- **Polluted Continental** and **Polluted Dust** could include **Smoke**

Devasthale et al., Tellus 2011

Fifteen-year, Regional average SAGE 525 nm Aerosol Extinction

Tropopause



Averaged Daily:
1985-1990 &
1996-2004
60˚- 80˚ N

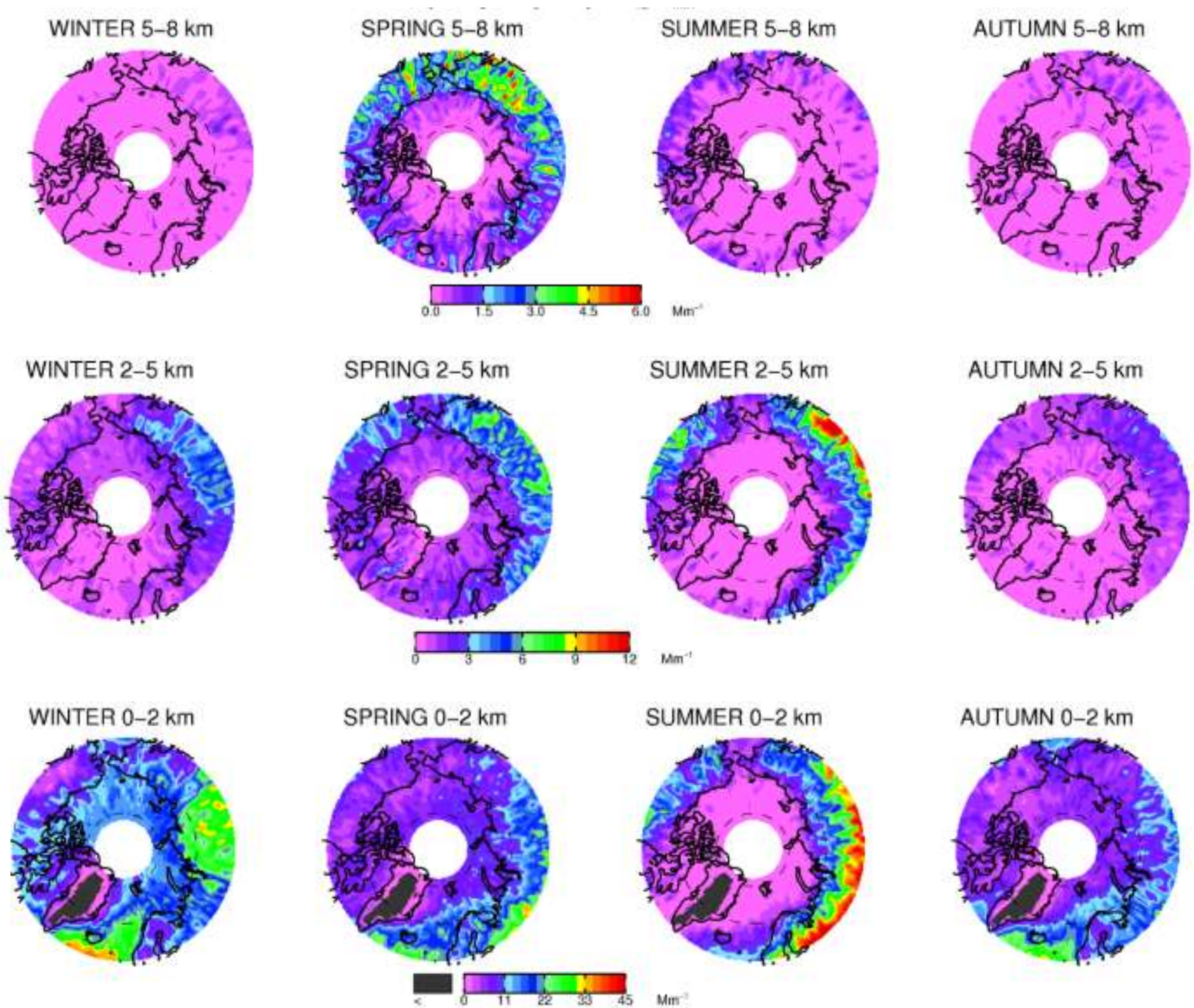
Sensitive to **thin, high-altitude** layers

"Color Ratio"
525/1020 nm
for particle size

Spring & Summer, & above ~4-6 km only; Extinction peak at the end of ***Spring***
Particle size decreases from ~0.35 to ~0.25 micron [Spring → Summer]

Treffeisen et al., JGR 2006

CALIPSO Layer-Resolved Seasonal Aerosol Extinction 2006-2012



Springtime high-altitude transport of Asian pollution & maybe dust (?) [But removal more rapid than in Winter]

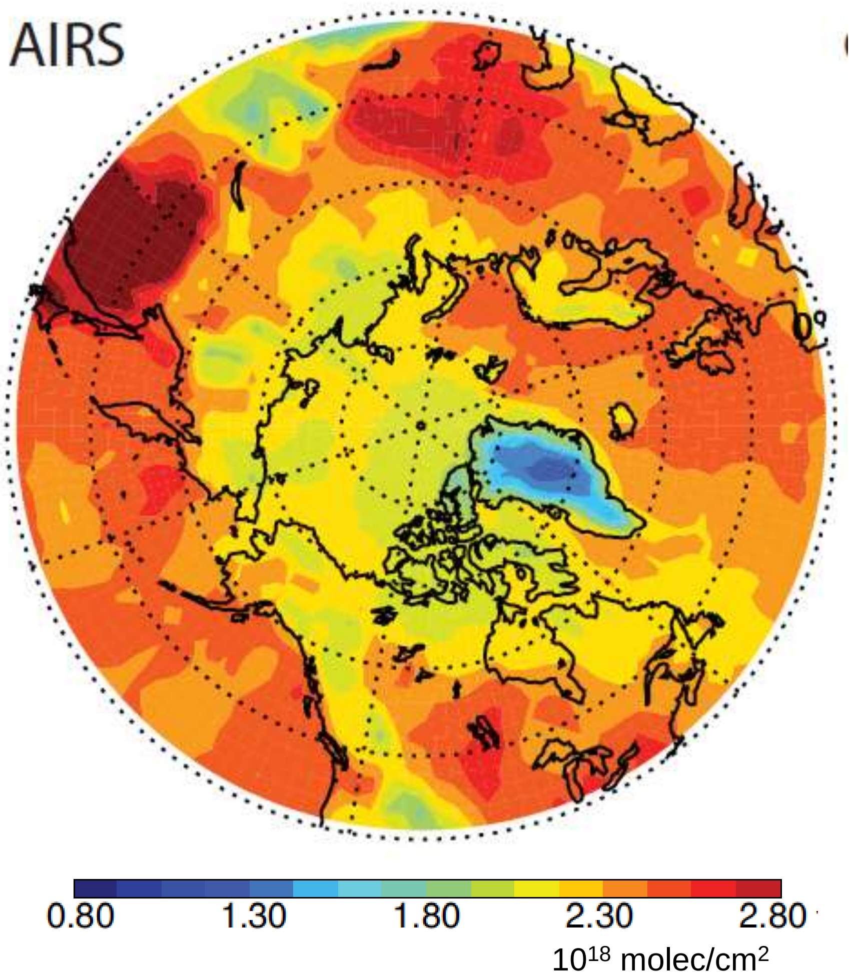
N Am & Siberia boreal ***fire smoke at mid-low altitude*** in Summer; annual low-Arctic AOD peak

Most high-Arctic transport is at low-altitude, in ***Winter***, and from Europe, W Siberia, N Atlantic [along isentropes]

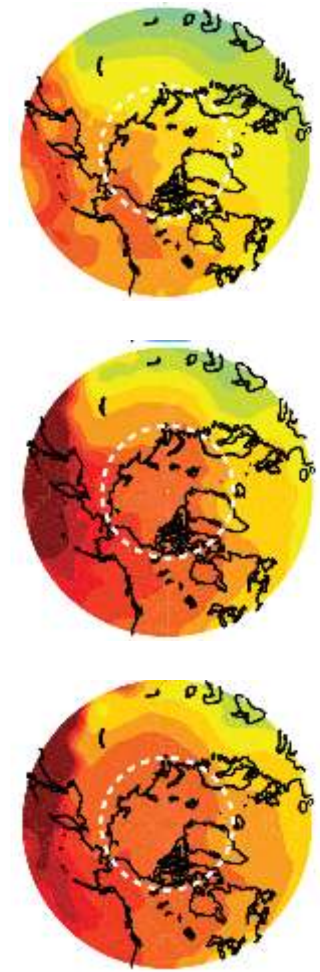
Also, ***inter-annual*** transport increases with positive ***NAO*** phase

Di Perro et al., ACP 2013

CO Column Abundance, April 2008
AIRS (IR) & GEOS-Chem Model



GEOS-Chem
Asian Anthropogenic Contribution to Arctic CO



5-10 km

2-5 km

0-2 km

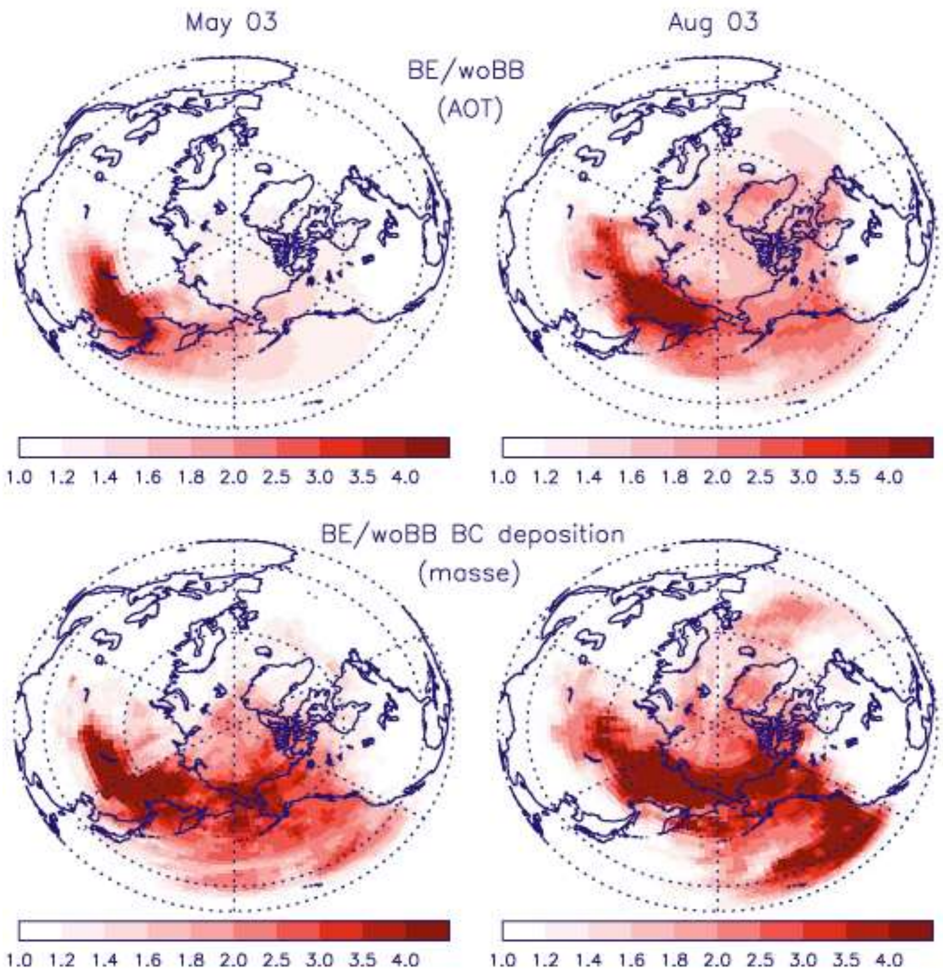
SE Asia is significant source of CO to the Arctic in Spring, a smoke/pollution tracer

Fisher et al., ACP 2010

Russian Biomass Burning Contribution Summer 2003
GEOS-Chem Model Constrained by Satellites

Monthly Mean Fractional AOD_{550} from Russian BB

Monthly Mean Black Carbon Wet Deposition Enhancement



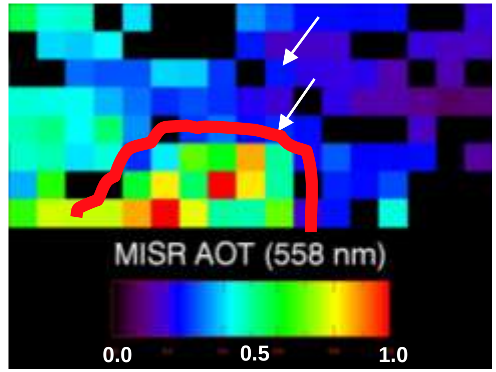
MOPITT CO
POLDER AOD
MODIS AOD
used to tune the model

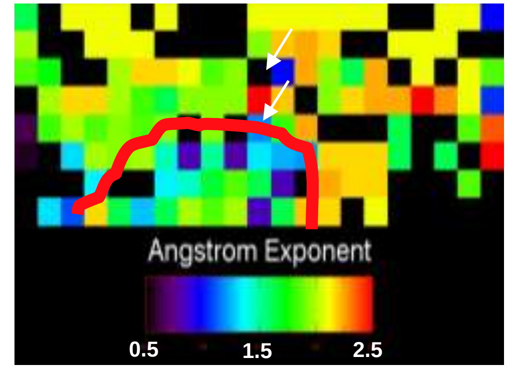
Model sources must be prescribed on a ***daily*** basis; ***injection height*** is key -- ***Passive Sensors*** are needed to provide adequate coverage

Generoso et al., JGR 2007

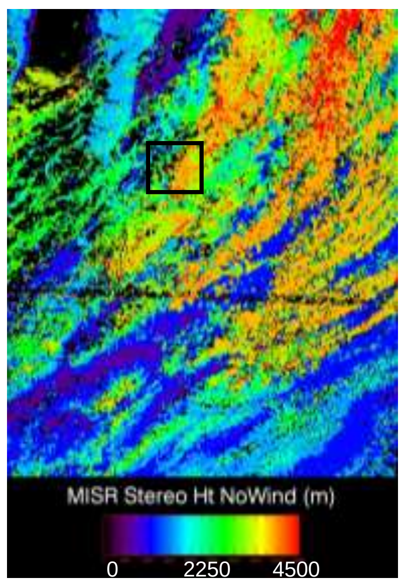
MISR maps of Boreal Fire Plume Height, Optical Depth, and Smoke Type

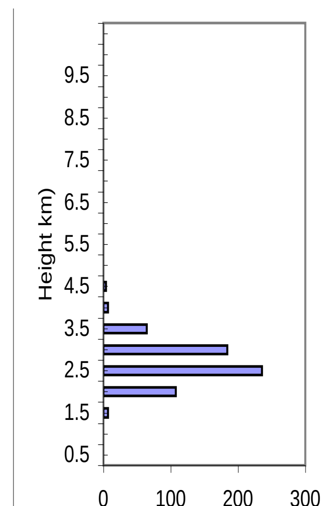
Alaska Wildfire July 02, 2004



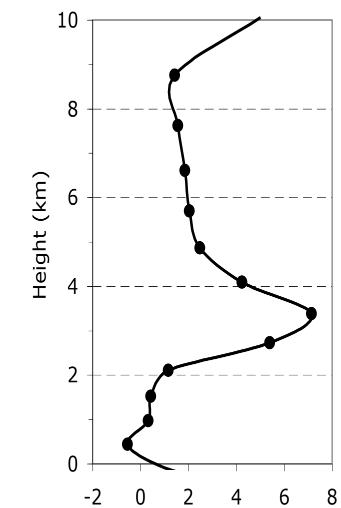


Siberian Wildfire June 11, 2003





Stereo-derived plume height

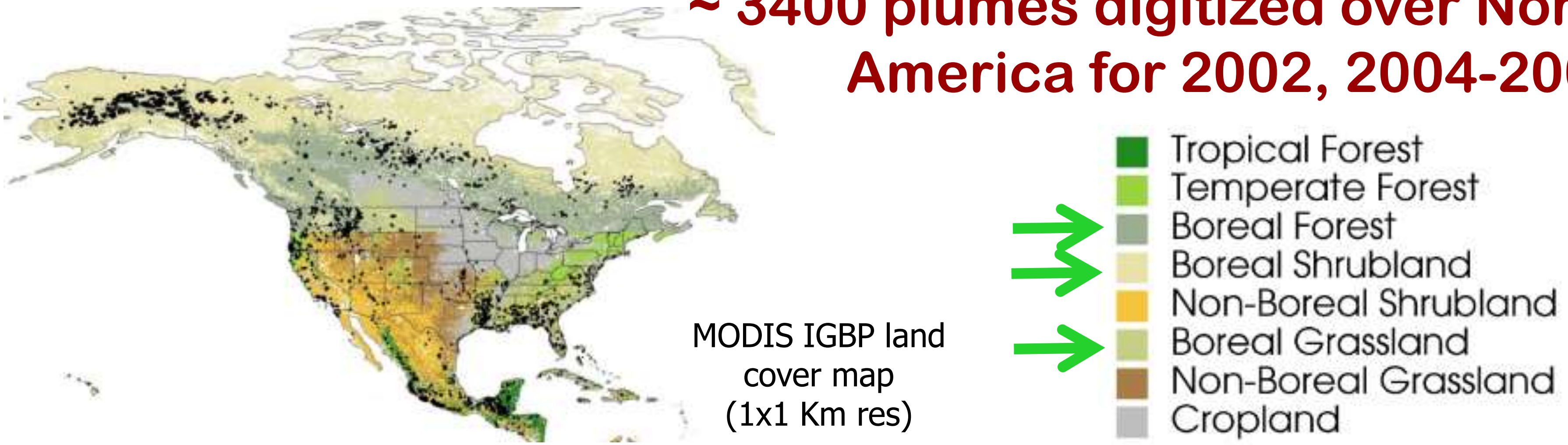


NCEP atm. stability profile

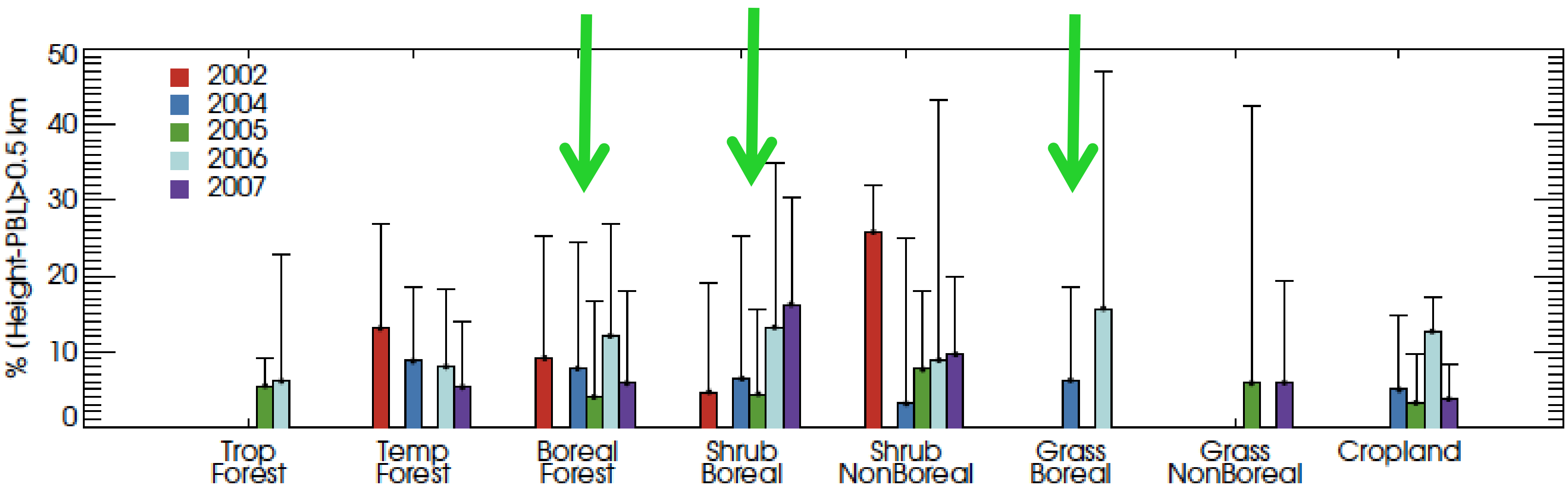
Kahn et al., JGR 2007

MISR N. America Plume *Injection Height* Climatology

~ 3400 plumes digitized over North America for 2002, 2004-2007



MODIS IGBP land cover map (1x1 Km res)

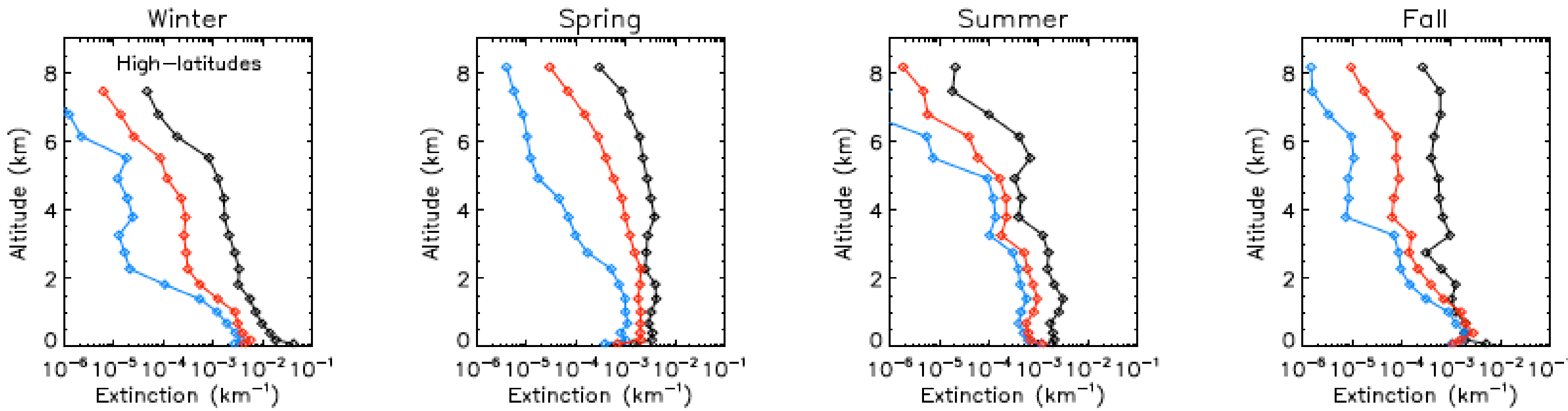


Percent of plumes >0.5 km ***above BL***, stratified by year and vegetation type

Val Martin et al. ACP 2010

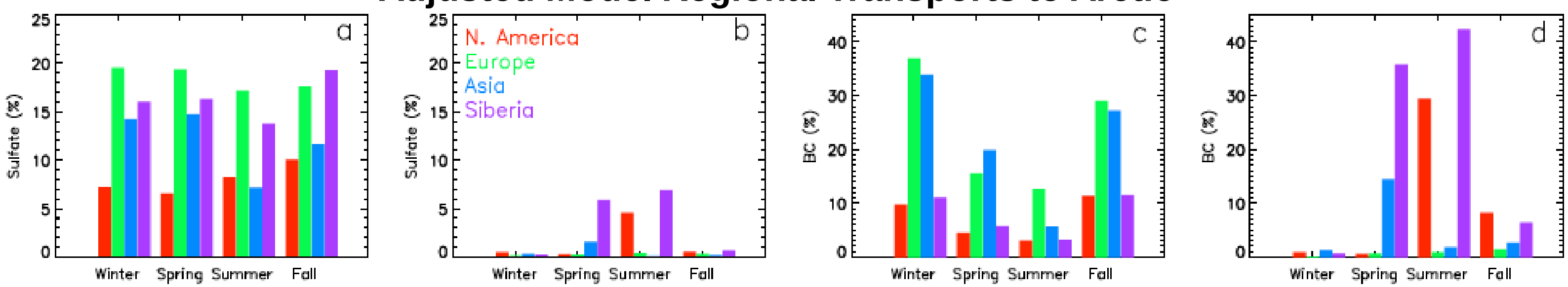
Aerosol Transport to the Arctic

ECHAM5 *Model* Constrained by *Satellite* + *Suborbital* Measurements



High-Latitude Vertical Profiles: **CALIPSO Lidar; Original Model; Adjusted Model**

Adjusted Model Regional Transports to Arctic



Anthropogenic Sulfate | **Wildfire Sulfate** | **Anthropogenic Black Carbon** | **Wildfire Black Carbon**

CALIPSO AOD + **ARCTAS** field data (BC, SO_2, SO_4^{2-}, CO) constraints reduce ***aerosol wet scavenging*** in the model

Bourgeois and Bey, JGR 2011