Satellite Constraints on Arctic-region Airborne Particles

Ralph Kahn
NASA Goddard Space Flight Center

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 SO₂**, 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.
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)
Passive Remote sensing (UV) constrains **Sub-Arctic aerosol sources** (wildfires, pollution)
Complementary Observations:

MODIS provides large-swath Coverage over water, some Snow surfaces
MISR fills in cloud-free Continents, Nadir Glint

Data mapped by J. Redemann
Arctic: 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
**Arctic**: 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]
Arctic AOD: **Lowest over Greenland** (<0.02)  
**Highest over Russia** (~0.2)
Arctic: *Small* scale-height (near-surface) over ocean; *Larger* scale-height over land (Transport pathways play a role in this.)
Arctic: On average, aerosol is concentrated Very Near-surface (< 1 km)
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
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]
**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*
SE Asia is a significant source of CO to the Arctic in Spring, a smoke/pollution tracer

Fisher et al., ACP 2010
Model sources must be prescribed on a **daily** basis; **injection height** is key -- **Passive Sensors** are needed to provide adequate coverage.
MISR maps of Boreal Fire Plume Height, Optical Depth, and Smoke Type

Alaska Wildfire  July 02, 2004

Siberian Wildfire  June 11, 2003

Kahn et al., JGR 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

CALIPSO AOD + ARCTAS field data (BC, SO₂, SO₄²⁻, CO) constraints reduce aerosol wet scavenging in the model

Bourgeois and Bey, JGR 2011