

Climatology of Aerosol Optical Properties over the High Arctic

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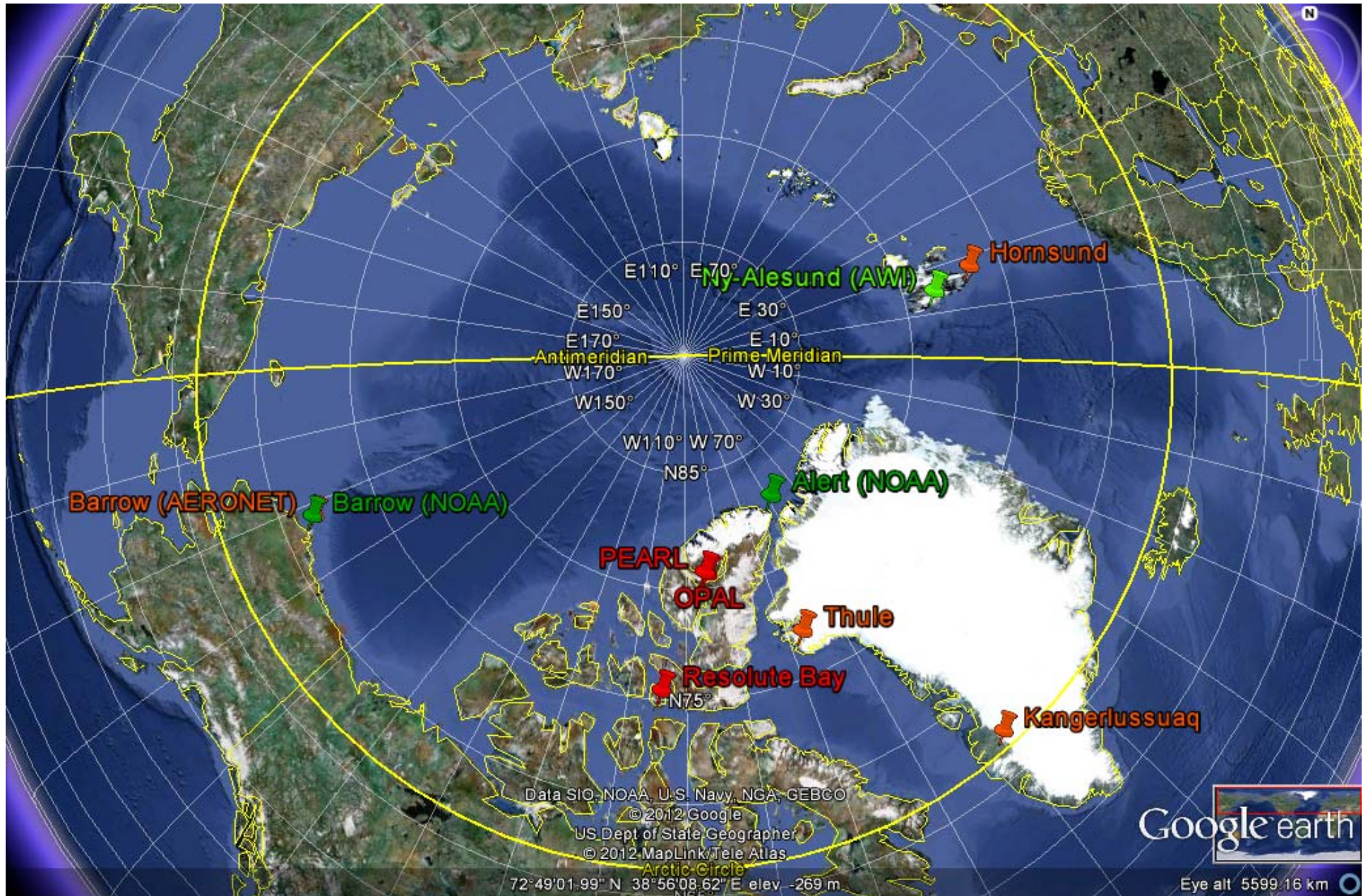
Introduction: Aerosols & Arctic Haze

- Aerosols affect the Earth's radiative balance through direct and indirect interactions with shortwave (SW) and longwave (LW) radiation at the top of the atmosphere, at the surface, as well as within the atmosphere by providing a radiative heating (or cooling) in the aerosol layers.
- Aerosols scatter (sulfates) and absorb (Soot/Black Carbon and Dust) the incoming solar radiation (Aerosol Direct Effect).
- Scattering aerosols reflect the incoming solar radiation resulting in atmospheric cooling. However, warming may result where the surface albedo is very high (Pueschel and Kinne, 1995) or if the sulfate is internally mixed with absorbing aerosols (Jacobson, 2001).
- Coarse mode aerosols such as mineral dust act like greenhouse gases by absorbing and emitting longwave (LW) radiation.
- Aerosols can influence the microphysical properties of clouds (Indirect aerosol effects) and thereby impacts the energy balance, precipitation, and the hydrological cycle. Depending on the composition and size, aerosols can serve as cloud condensation nuclei (CCN) or ice-forming nuclei (IN).
- Indirect effects of aerosols on cloud properties typically cause surface cooling (Quinn et al., 2008) but can also warm the surface through interactions with terrestrial (LW) radiation (Lubin and Vogelmann, 2006). The warming is expected to dominate during Arctic winter (Lubin and Vogelmann, 2007).

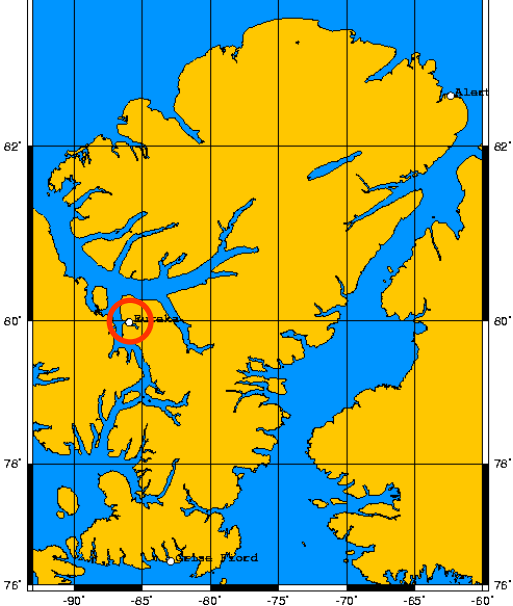
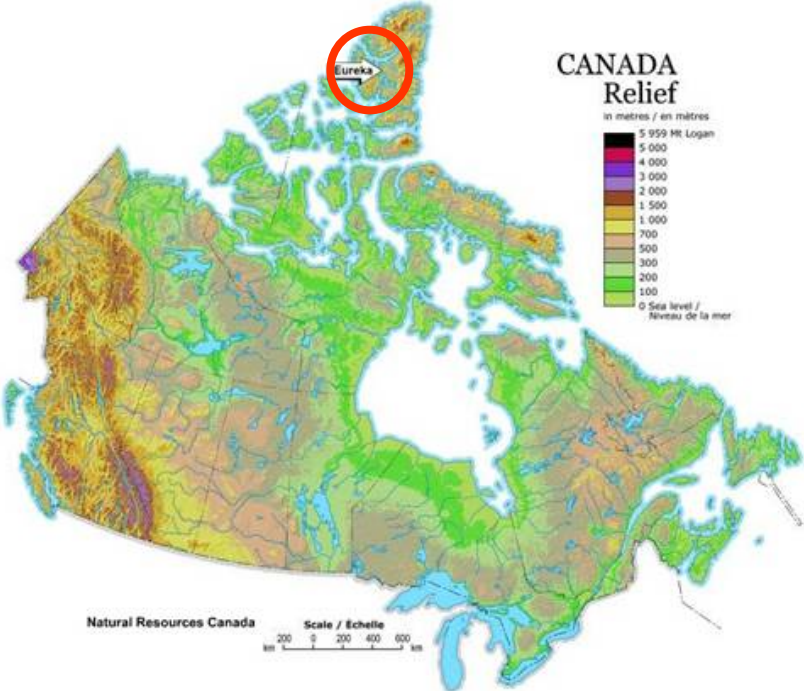
Introduction: Aerosols & Arctic Haze

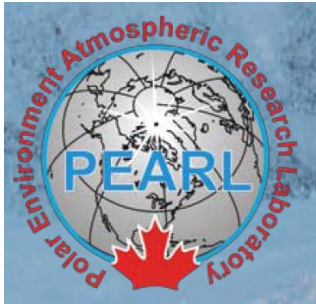
- Long-range transport of pollution from mid-latitudes is a major source of aerosols to the Arctic, with a winter-spring maximum known as Arctic haze (Quinn et al., 2009). High aerosol concentrations in the Arctic during winter-spring can be due to efficient transport from mid-latitudes, reduced vertical mixing, and lack of precipitation (Shaw, 1995; Quinn et al., 2007; Garrett et al., 2010).
- Unlike long-lived CO_2 , aerosols have an average lifetime in the atmosphere from days to weeks, but exhibit a somewhat longer lifetime in the Arctic.
- Absorption of solar radiation by aerosols in the atmosphere is enhanced by highly reflective snow- and ice-covered surfaces in the Arctic. Deposition of light-absorbing aerosols (such as Soot) on snow or ice can decrease the surface albedo.
- The shortwave (SW) component of the energy balance can be affected by light absorbing aerosols through the atmosphere and in the ice/snow surface.
- With respect to the longwave (LW) component, the aerosol effect in the Arctic differs from other regions because of the cold atmospheric temperatures, frequent occurrences of temperature inversion, and low water vapor content.
- The longwave (LW) radiation plays a particularly important role in the energy balance in the Arctic because of prolonged polar nights with little or no sunlight.
- Hygroscopic growth of particles leads to absorption of terrestrial radiation, inducing a direct warming effect that can be particularly efficient during polar night (Ritter et al., 2005).

High Arctic Sites



Eureka





PEARL



- PEARL - Polar Environmental Atmospheric Research Lab. It is operated by the Canadian Network for the Detection of Atmospheric Change (CANDAC).
- PEARL is located at Eureka, Nunavut (80N, 86W) on Ellesmere Island in Canada's high Arctic, 450 km north of Grise Fiord, the most northerly permanent settlement. PEARL is 1,100 km from the North Pole.
- ØPAL - Zero altitude Polar Atmosphere Laboratory. It is located about 15 km southeast of the PEARL ridge lab which is at an elevation of 610 m.

Instruments & Data used in this Study (Eureka)

Cimel Sun Photometer



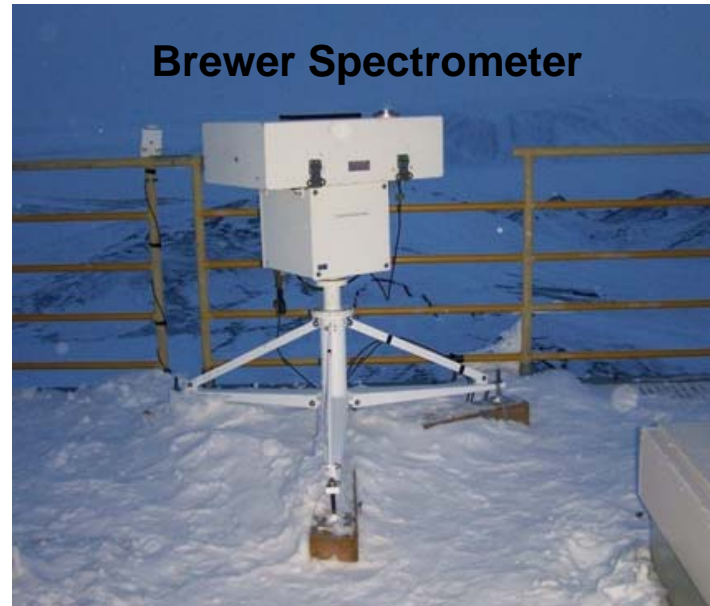
AHSRL



Bruker Fourier Transform Spectrometer



Brewer Spectrometer



Cimel Sun Photometer (AEROCAN / AERONET)



Aerosol optical properties:
Aerosol optical depth (AOD),
and Effective radius of the fine
& coarse mode.

The fine mode (τ_f & $r_{\text{eff},f}$) can typically be associated with forest or agriculture fire smoke, and pollution aerosols, while the coarse mode (τ_c & $r_{\text{eff},c}$) is an indicator of super-micron sized particulates such as dust, marine aerosols, and ice or water phase cloud particulates.



AERONET Data Display Interface **Version 2 Direct Sun Algorithm**

Level 1.0. Real Time Data.

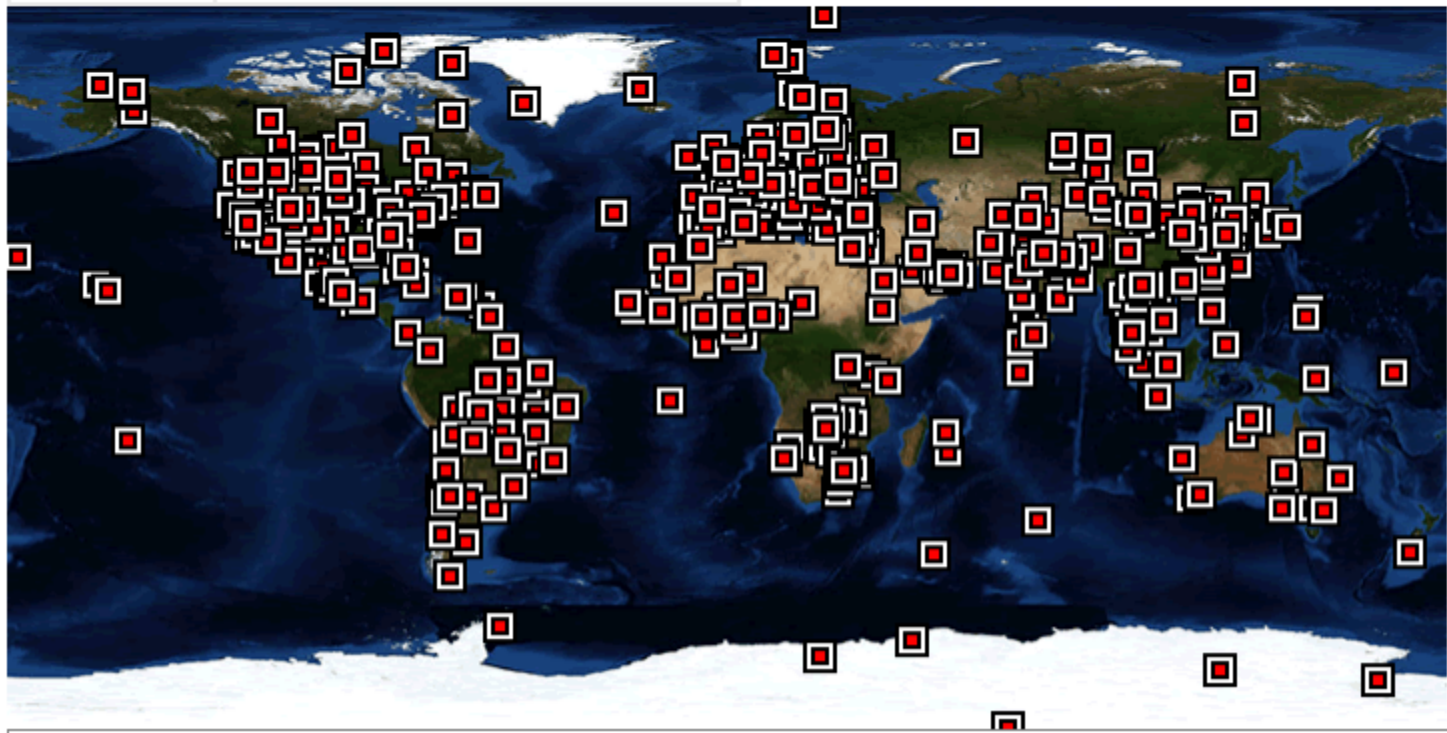
The following AERONET data are unscreened and may not have final calibration applied

[1993](#) [1994](#) [1995](#) [1996](#) [1997](#) [1998](#) [1999](#) [2000](#) [2001](#) [2002](#) [2003](#) [2004](#) [2005](#) [2006](#) [2007](#) [2008](#) [2009](#) [2010](#) [2011](#) [2012](#)

To zoom the map click on it.

[Back to World Map](#)

Total Data (Years):	<input checked="" type="radio"/> All	<input type="radio"/> >0.5	<input type="radio"/> >1	<input type="radio"/> >2	<input type="radio"/> >3	<input type="radio"/> >5	<input type="radio"/> >7
AOT Level	<input checked="" type="radio"/> Level 1.0	<input type="radio"/> Level 1.5	<input type="radio"/> Level 2.0				



AEROCAN (Canadian Sunphotometer Network)



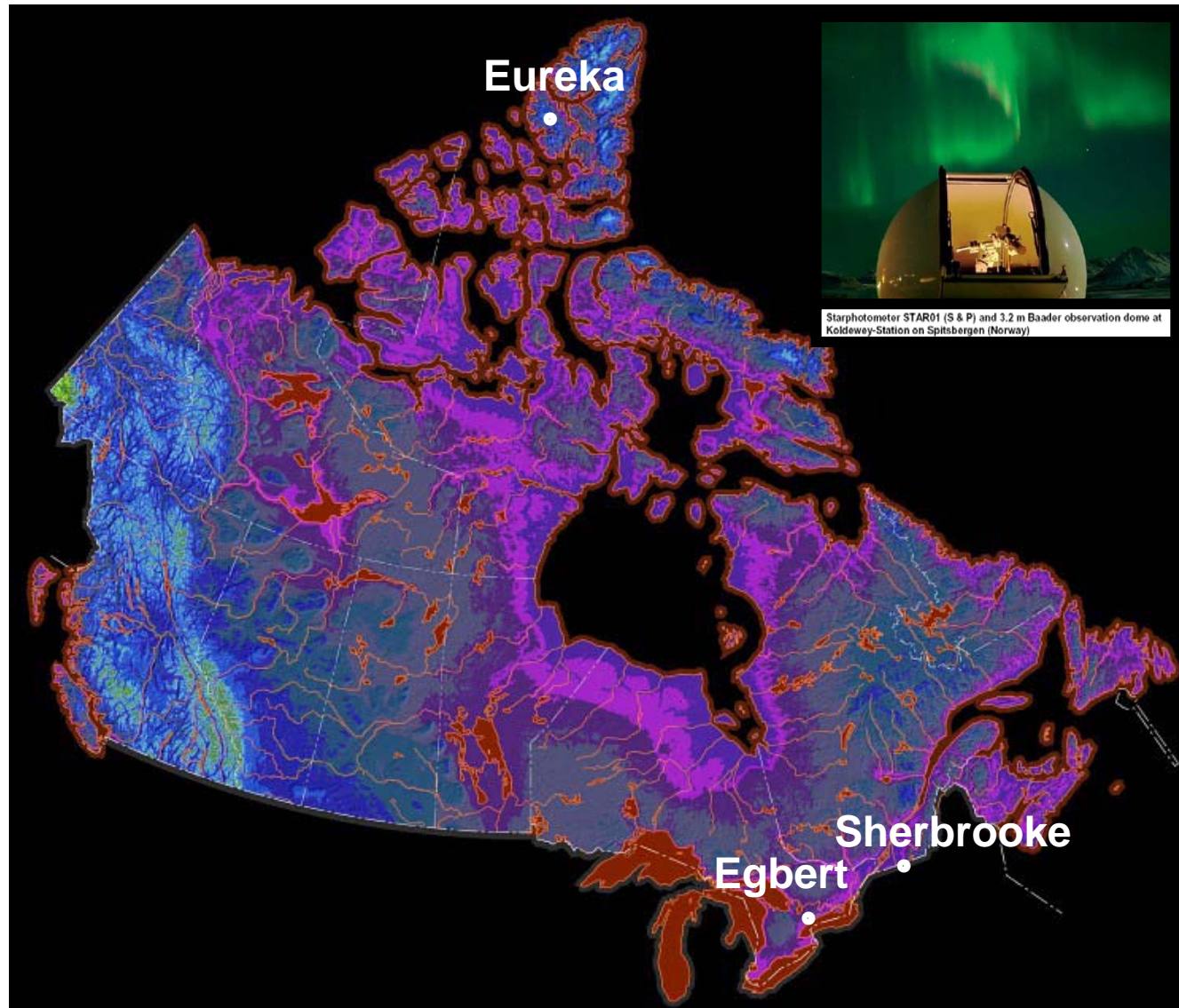
AERONET vs AEROCAN

AEROCAN is a full fledged sub-network of AERONET and benefits from all services that AERONET offers.

AEROCAN has a few unique features that go beyond AERONET protocols:

- All instruments use the high frequency, 3-minute mode (O'Neill mode).
- All data transmission is done using FTP.
- Complementary AOD processing chain in preparation for real time ingestion into an aerosol assimilation model (currently on hold).
- System wide display tools for real-time QA & troubleshooting.
- Separate prototype MySQL database for data QA (and science).
- Satellite calibration facility being developed (on hold with EC freezes).

AEROCAN* (Canadian Starphotometer Sites)



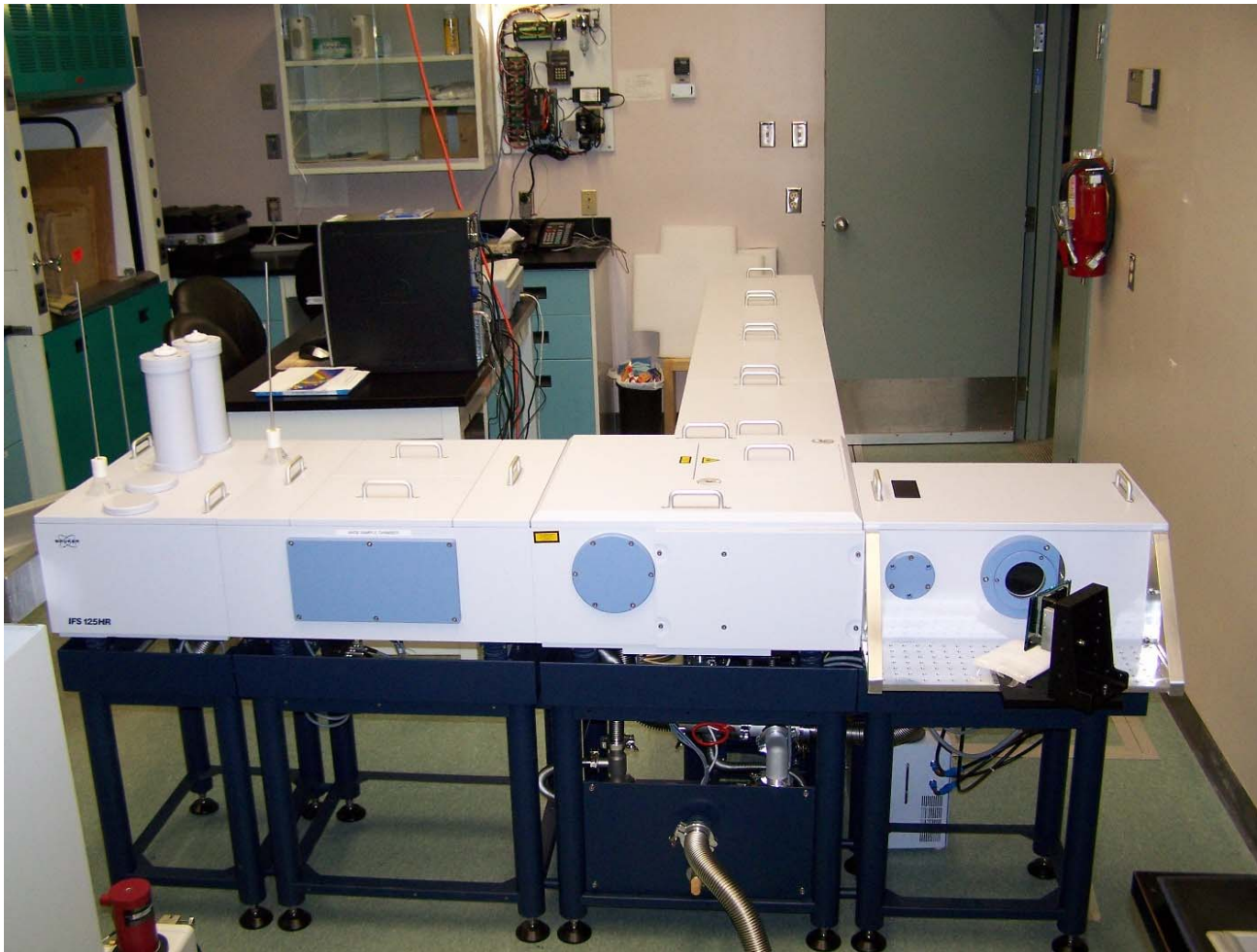
Arctic High Spectral Resolution Lidar (AHSRL)



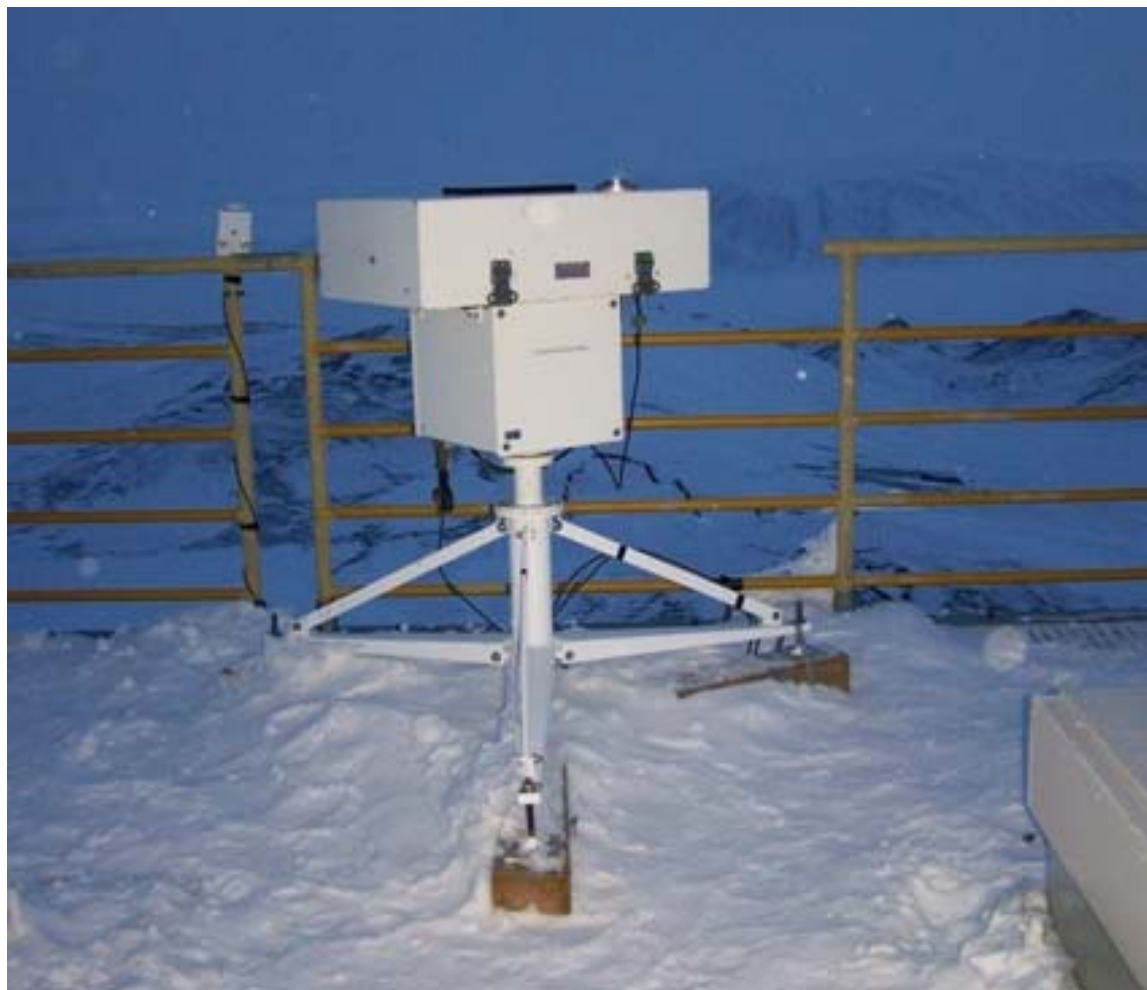
AHSRL measures the vertical profiles of backscatter coefficient (β) and depolarization ratio (δ)

The δ profiles permit one to distinguish between sub-micron smoke or pollution aerosols (low δ values) and irregularly shaped super-micron particles such as ice crystals and coarse mode aerosols such as dust (high δ values).

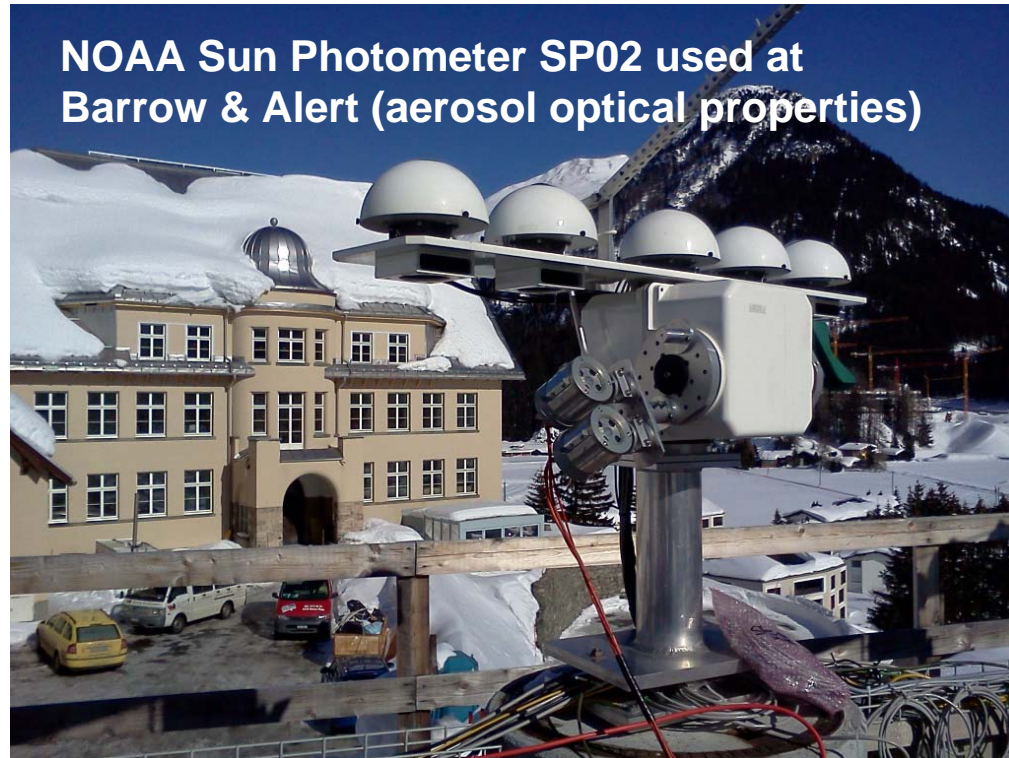
Bruker Fourier Transform Spectrometer (CO Column concentration)



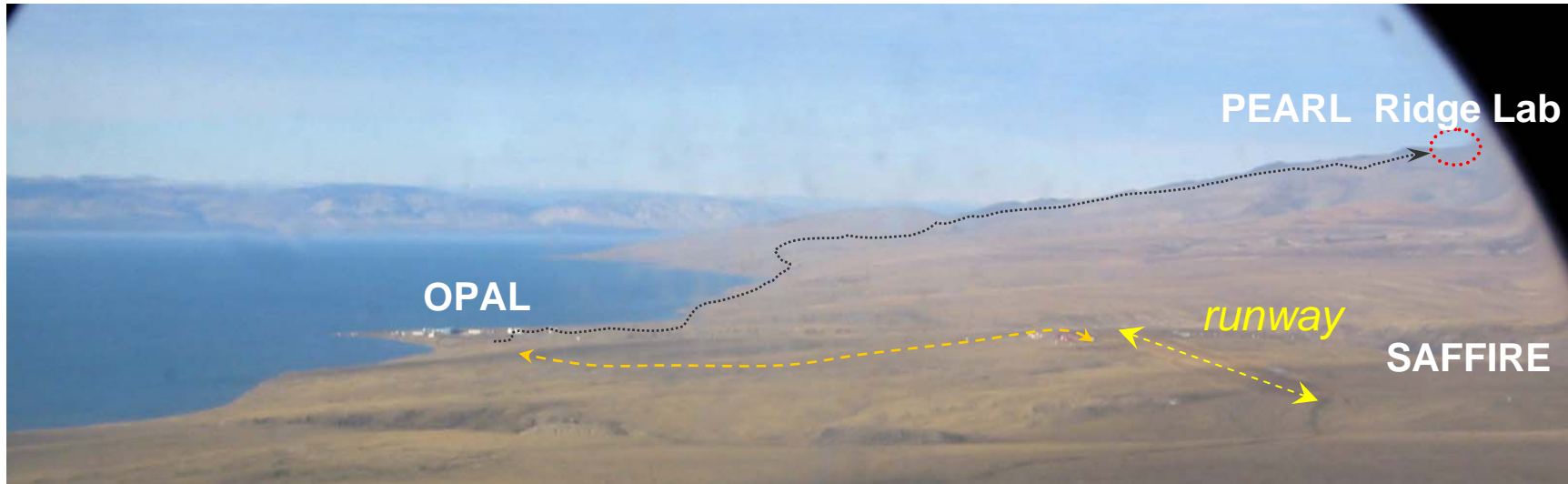
Brewer Spectrometer (SO₂)

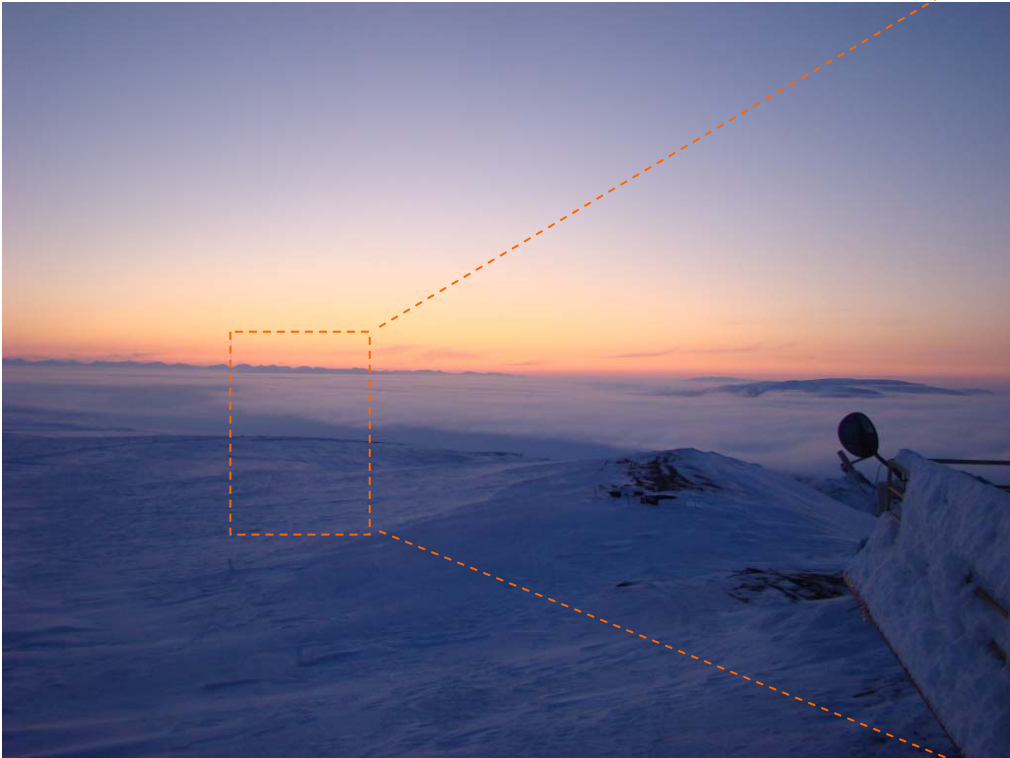


Instruments & Data used in this Study (Barrow & Alert)

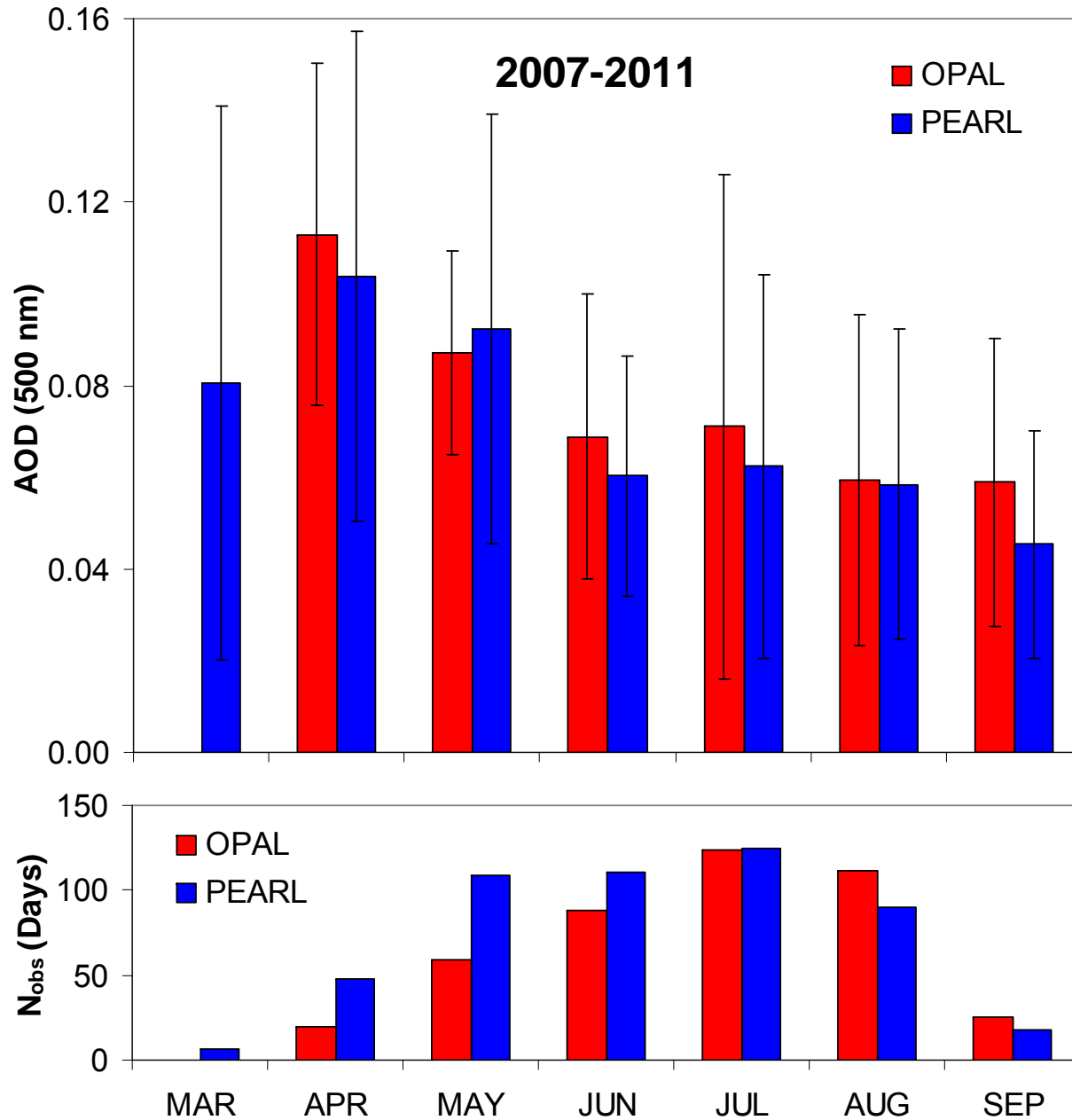


Sunphotometers installation in Eureka

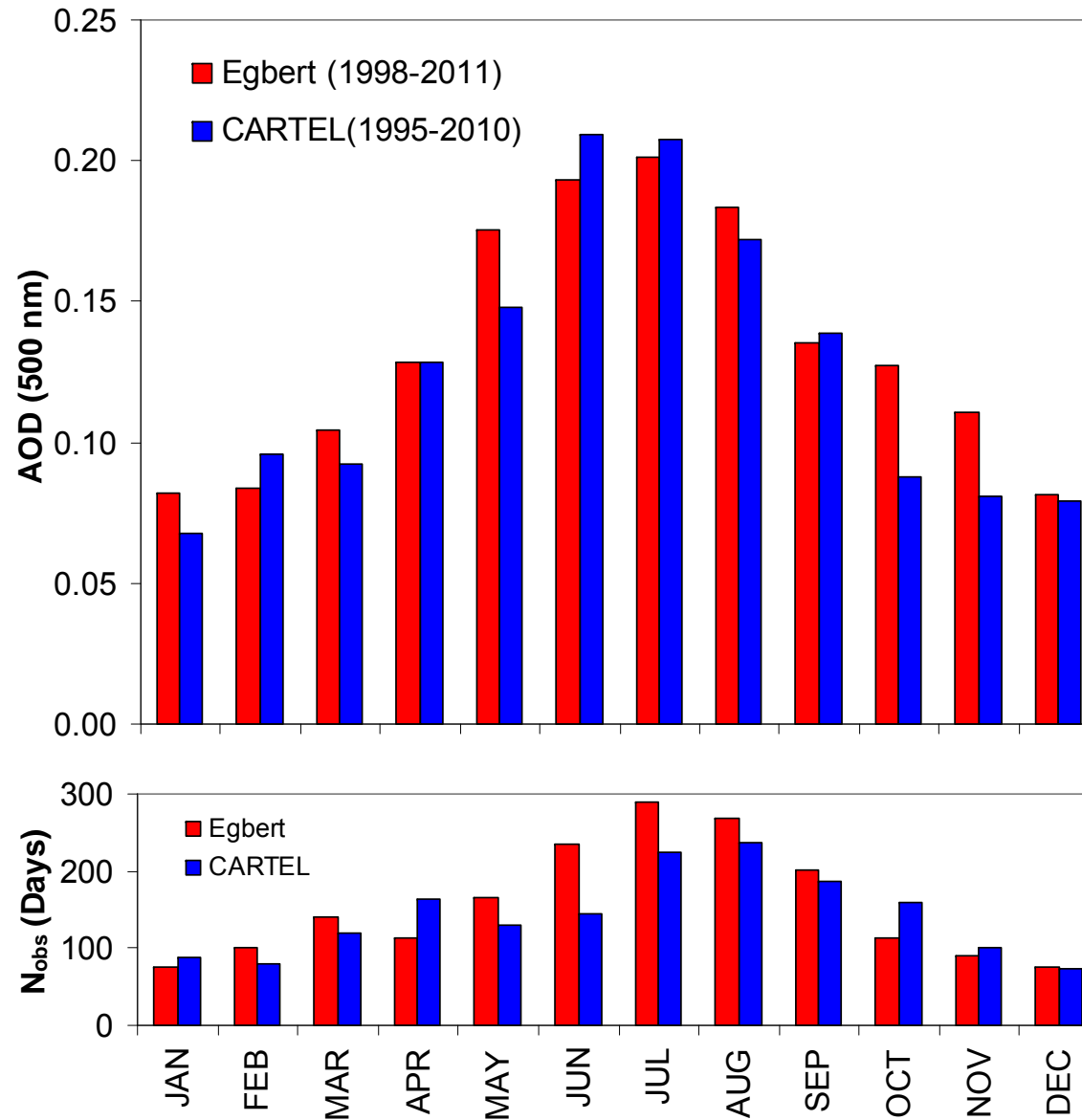




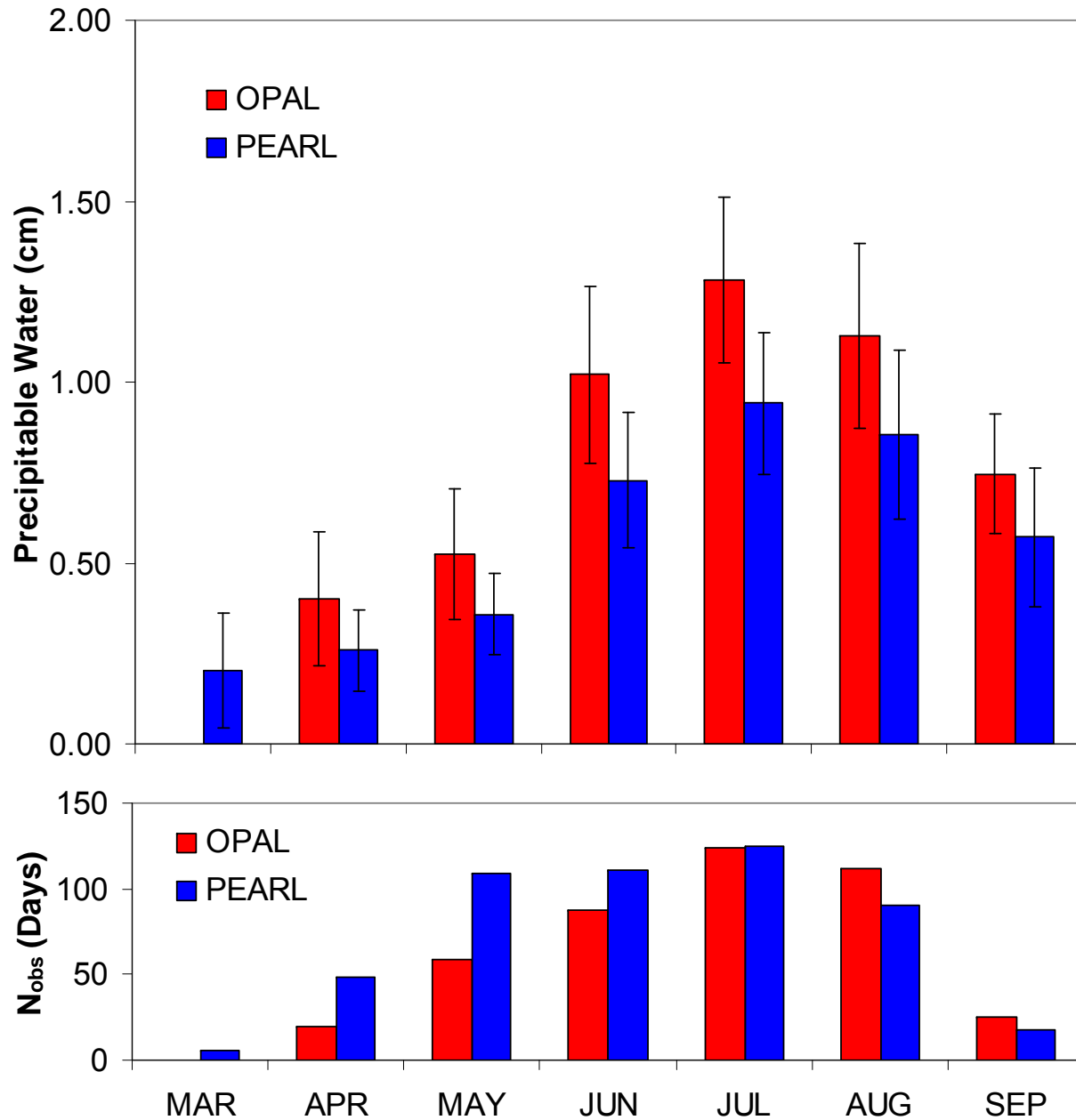
Eureka Aerosol Optical Depth Climatology



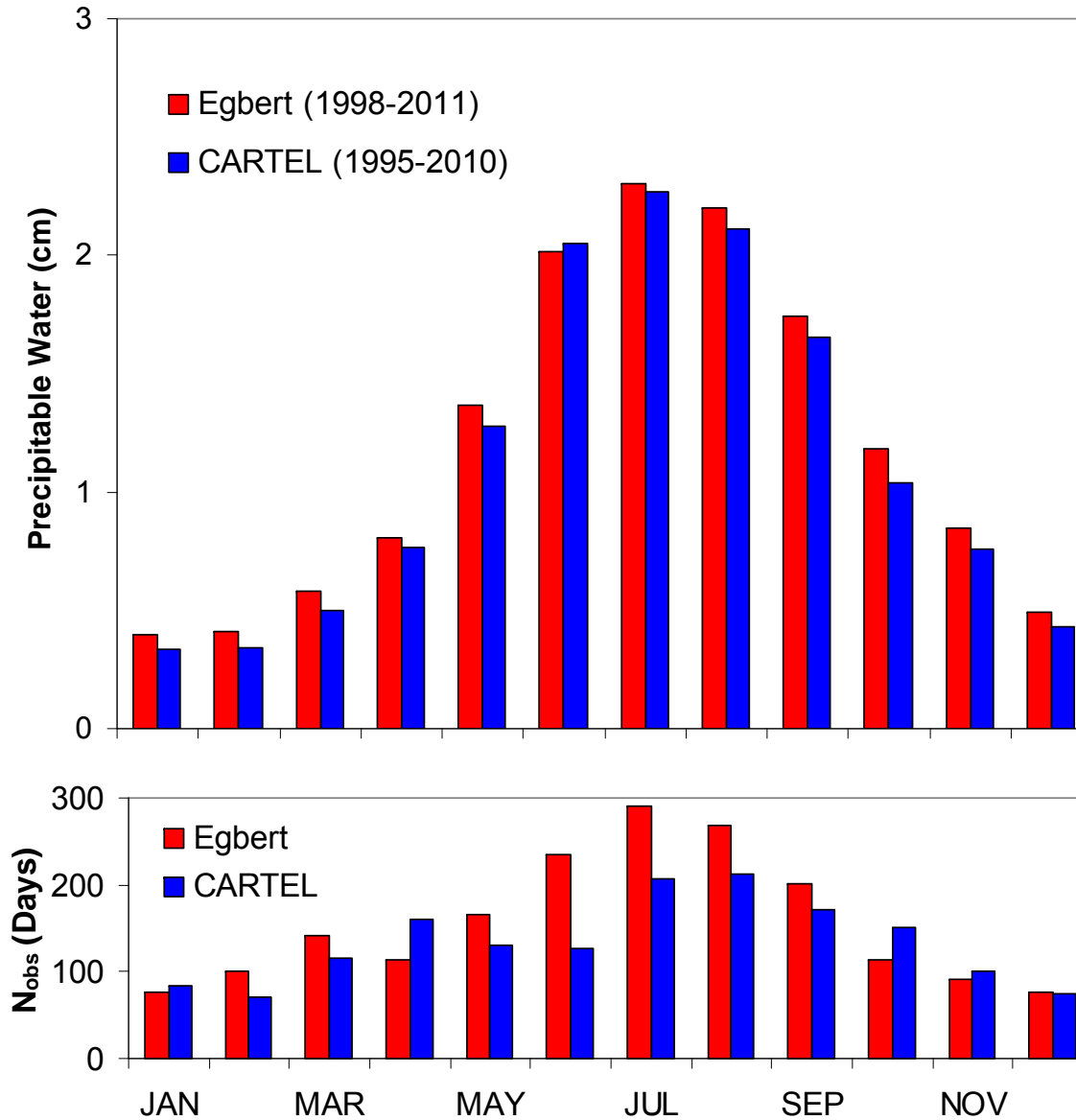
Mid-Latitude AOD Climatology



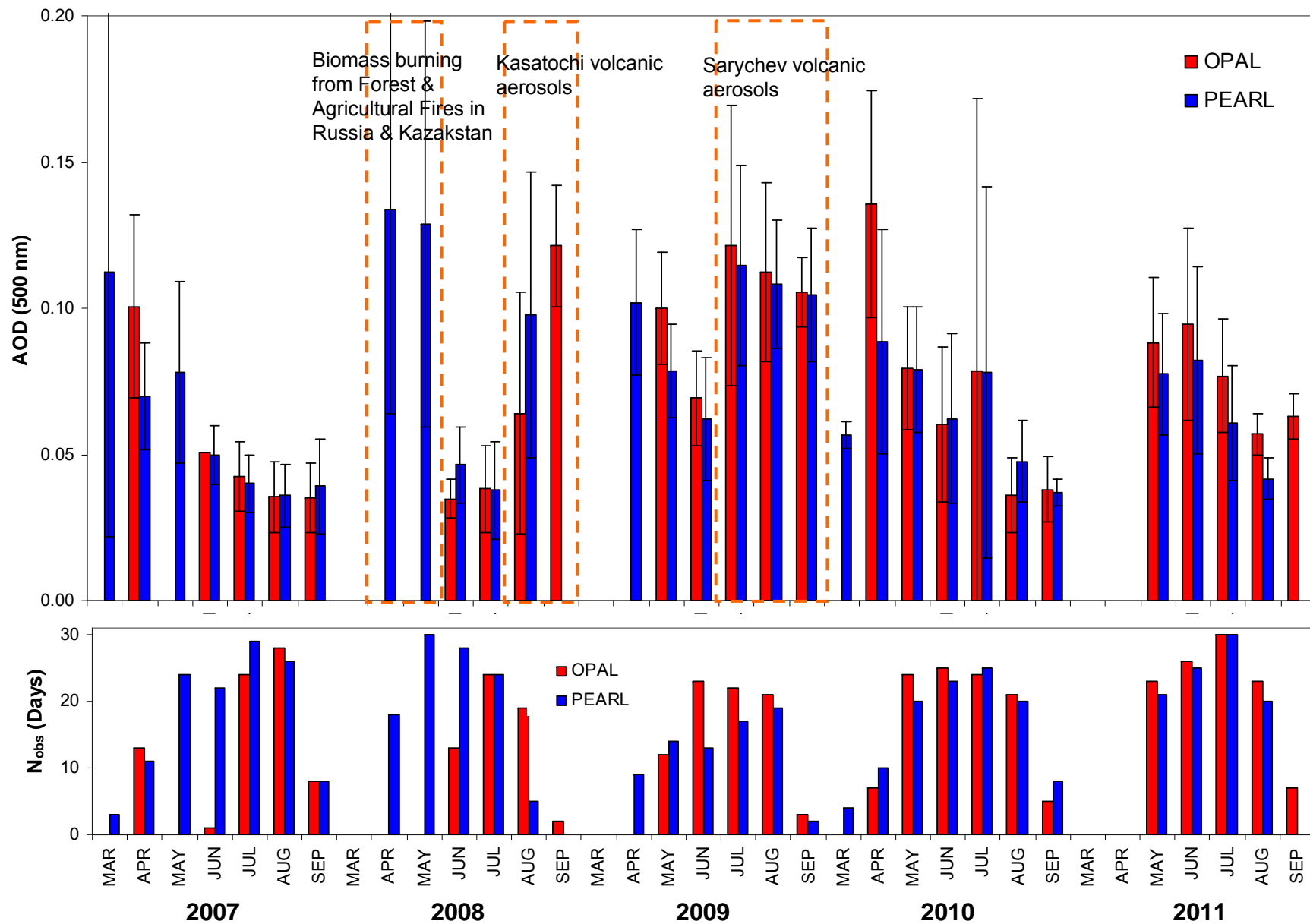
Eureka Precipitable Water Climatology



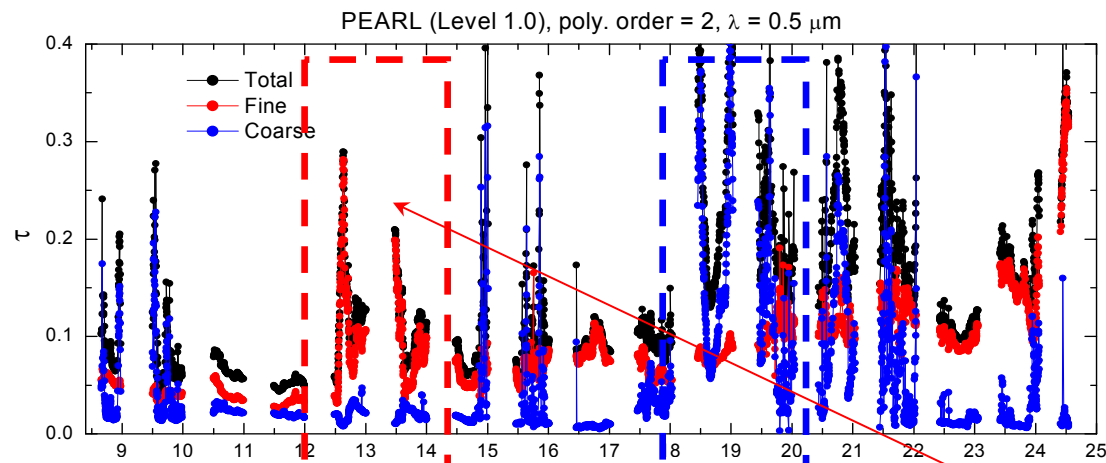
Mid-latitude Precipitable Water Climatology



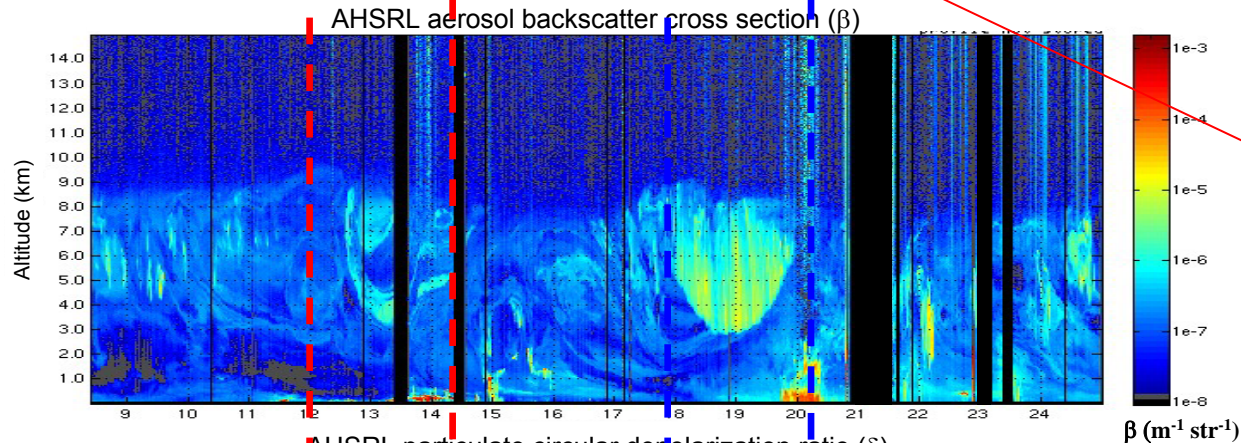
Seasonal and inter-annual variation of AOD over Eureka



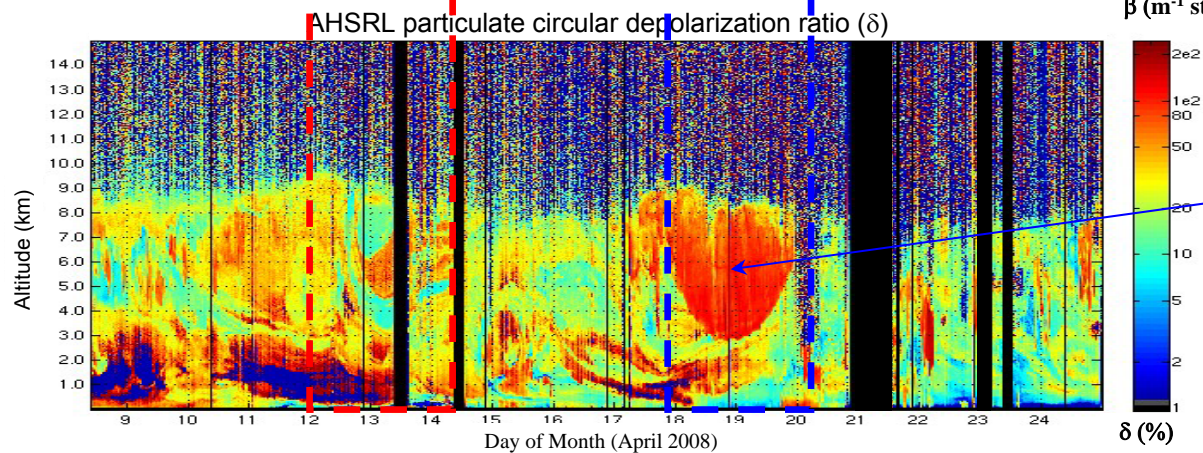
Biomass burning aerosols during Spring 2008 (ARCTAS)*



τ_f correlates well with β variations in the presence of small δ , while τ_c values correlate with β in the presence of large δ .

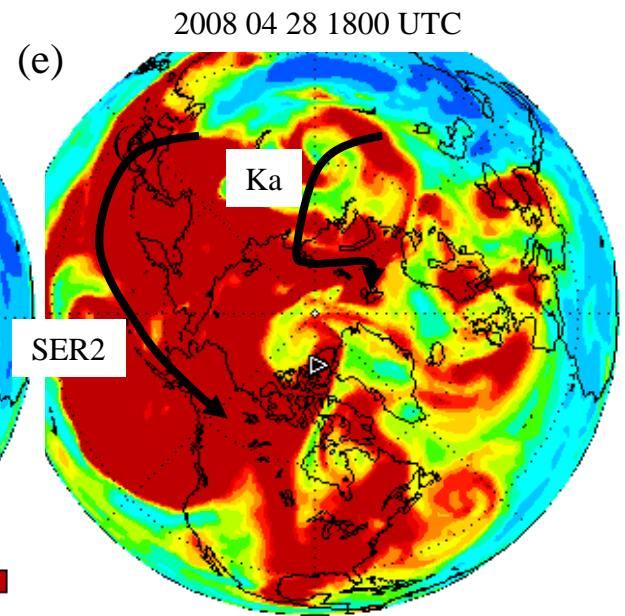
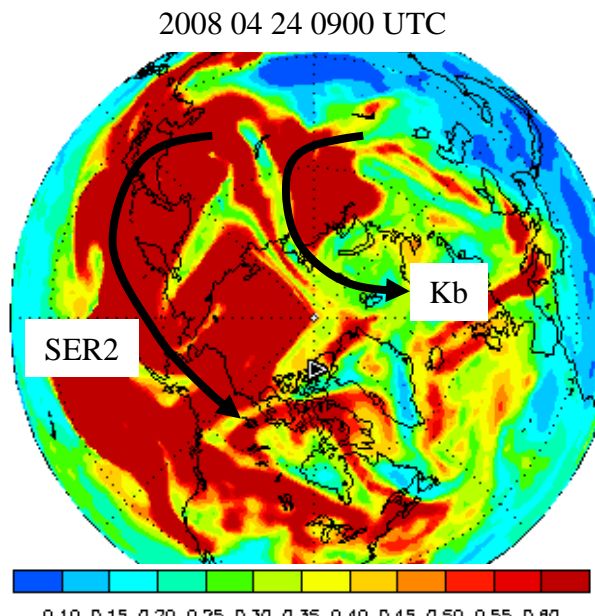
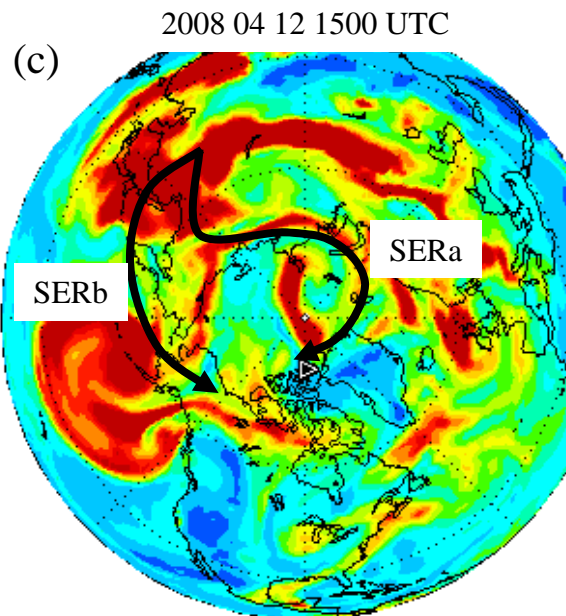
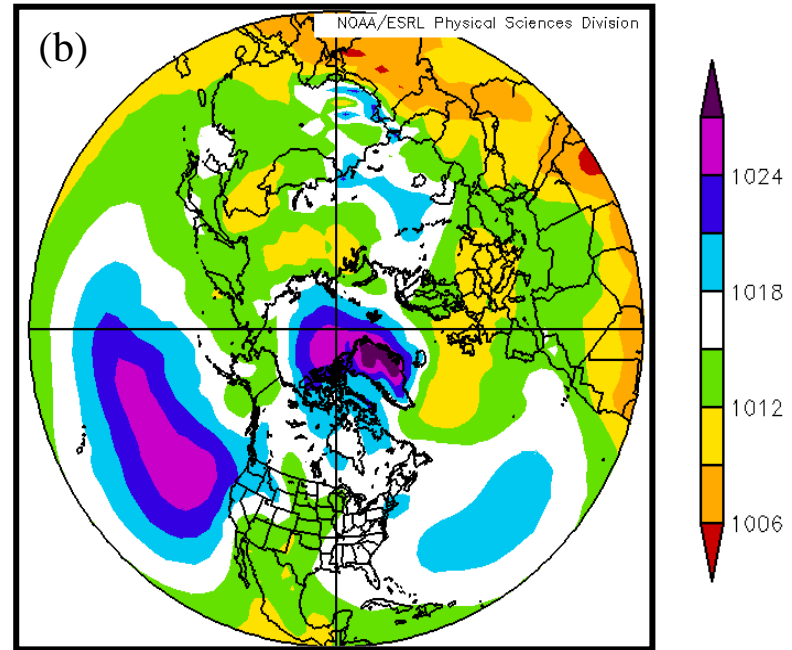
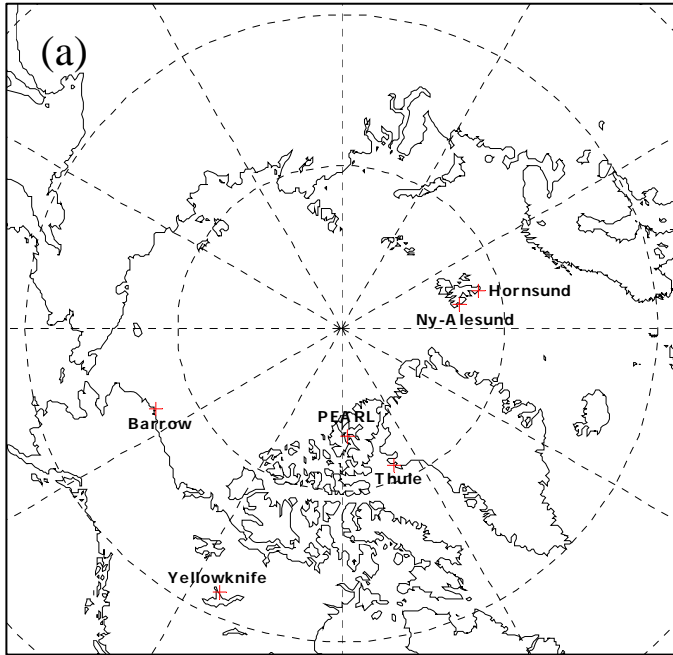


Fine mode aerosols were associated with biomass burning (agricultural and forest fires) from E/SW Russia & northern Kazakhstan.



Coarse - mode events were likely due to ice particles whose nucleation may have been associated with the presence of smoke, or possibly dust.

*Saha et al., GRL, 2010

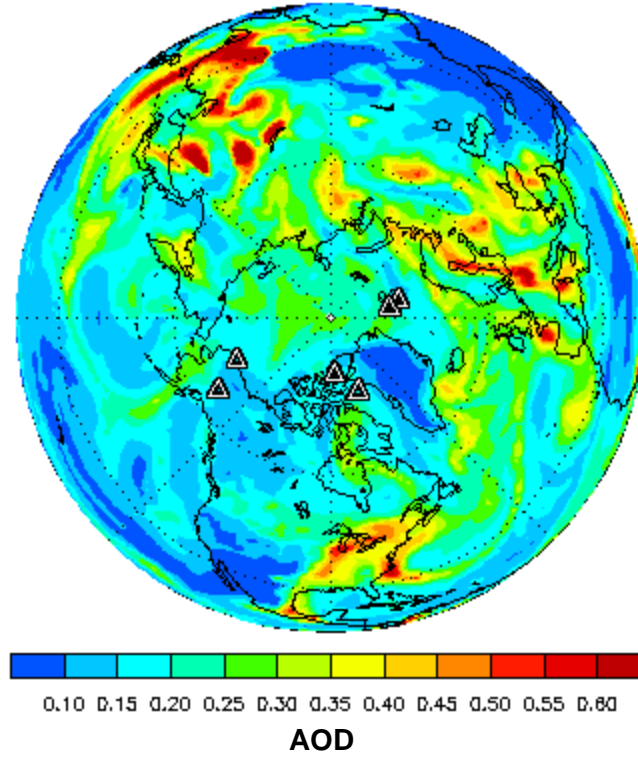


0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50 0.55 0.80

*Saha et al., GRL, 2010

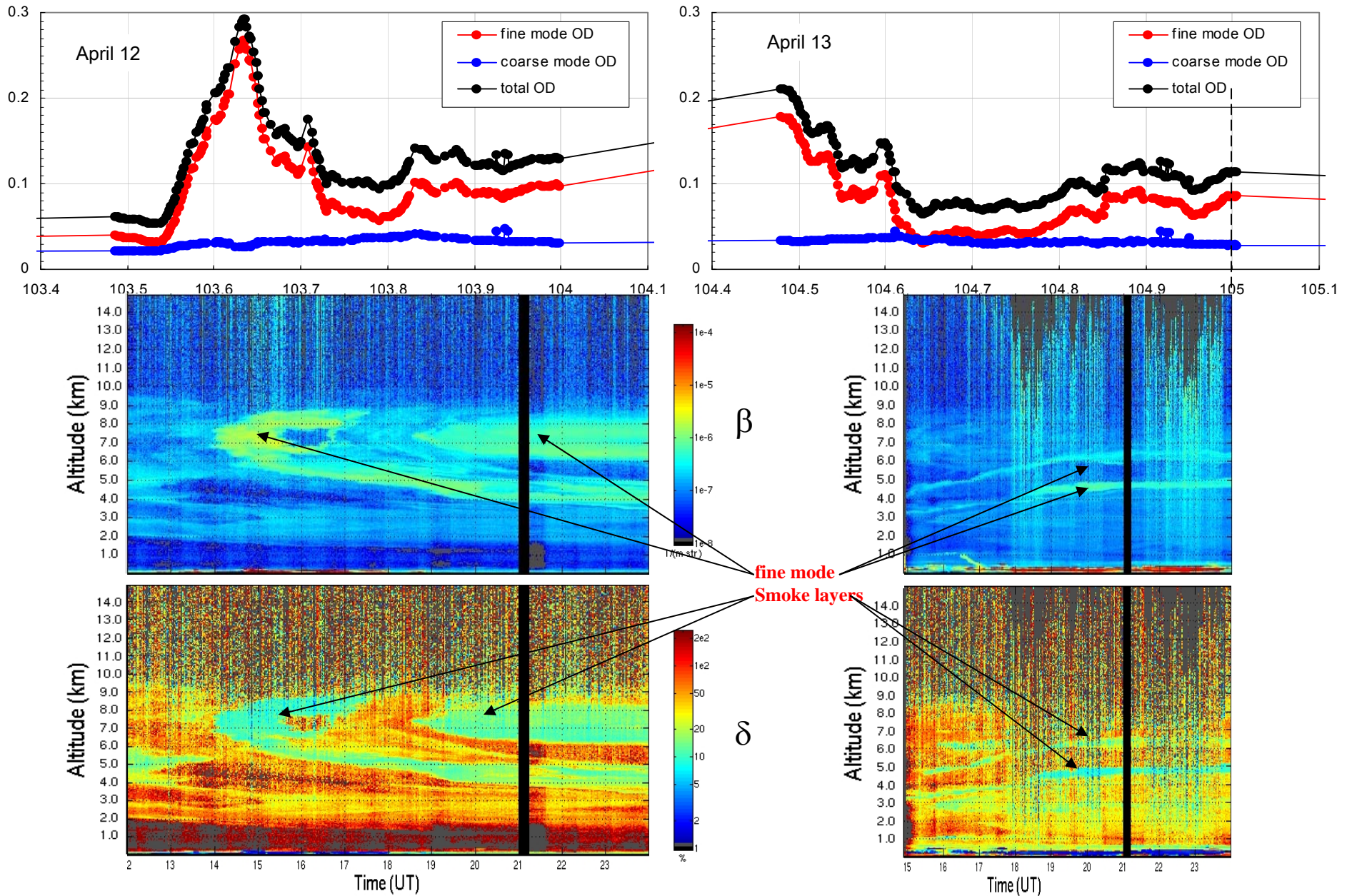
GEM-AQ AOD simulation for April 2008

GEM-AQ AOD 500 nm 2008 04 01 00:00 UTC



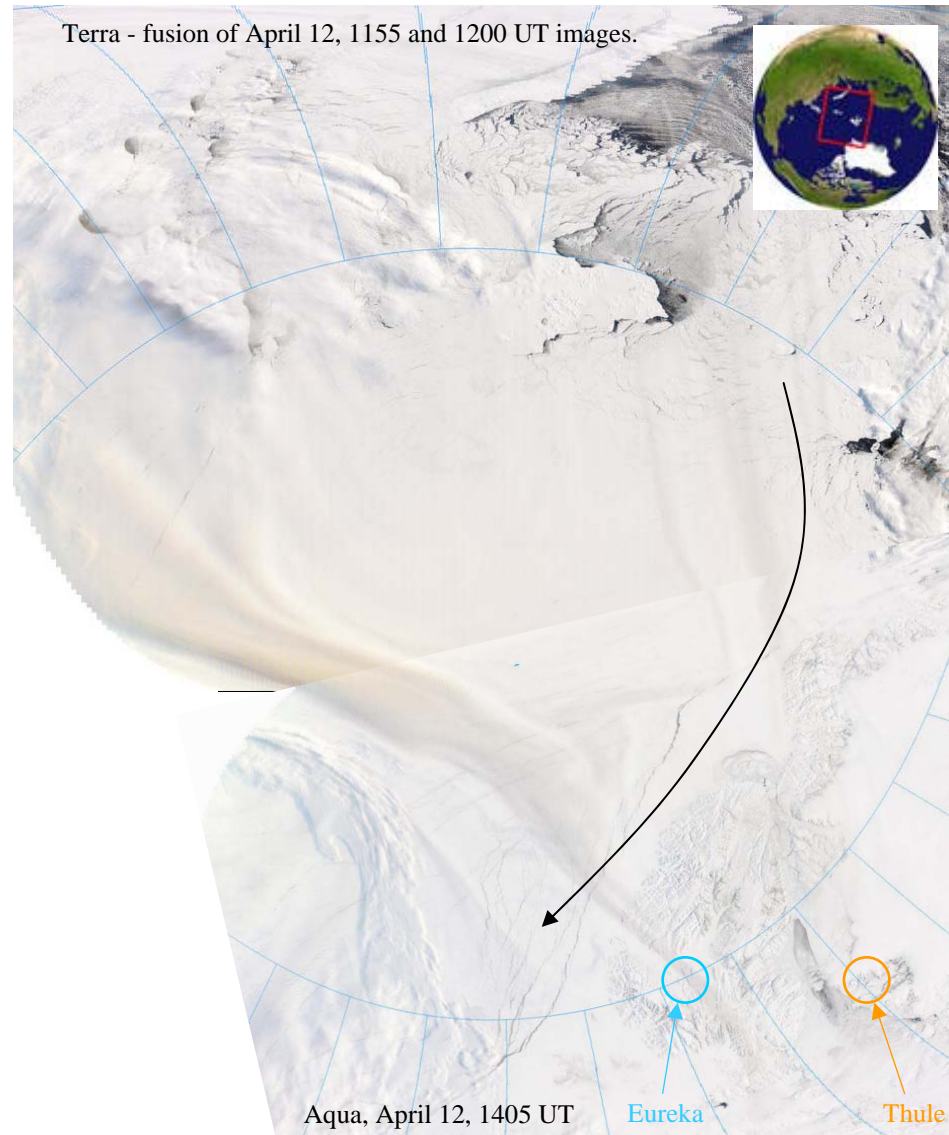
*Saha et al., GRL, 2010

Fine Mode (smoke) event of April 12-13 observed at Eureka



*Saha et al., GRL, 2010

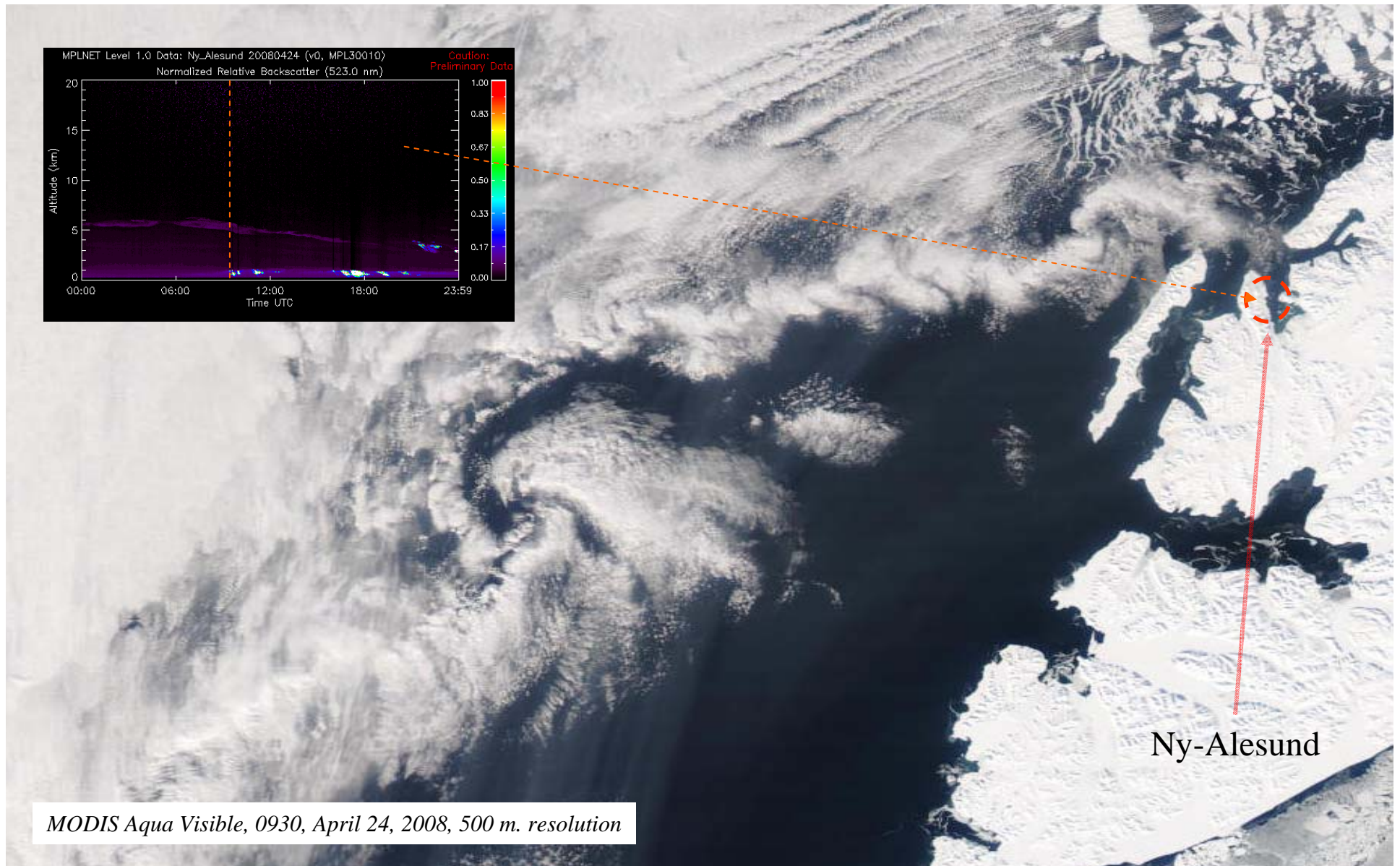
MODIS Imagery for April 12 Smoke Plume crossing Eureka



MODIS true color images (fusion of Terra and Aqua) showing the Pan-Arctic view of the April 12 plume crossing Eureka (part of the SERa plume movement).

*Saha et al., GRL, 2010

MODIS Imagery for April 24 Fine Mode Event at Ny-Alesund

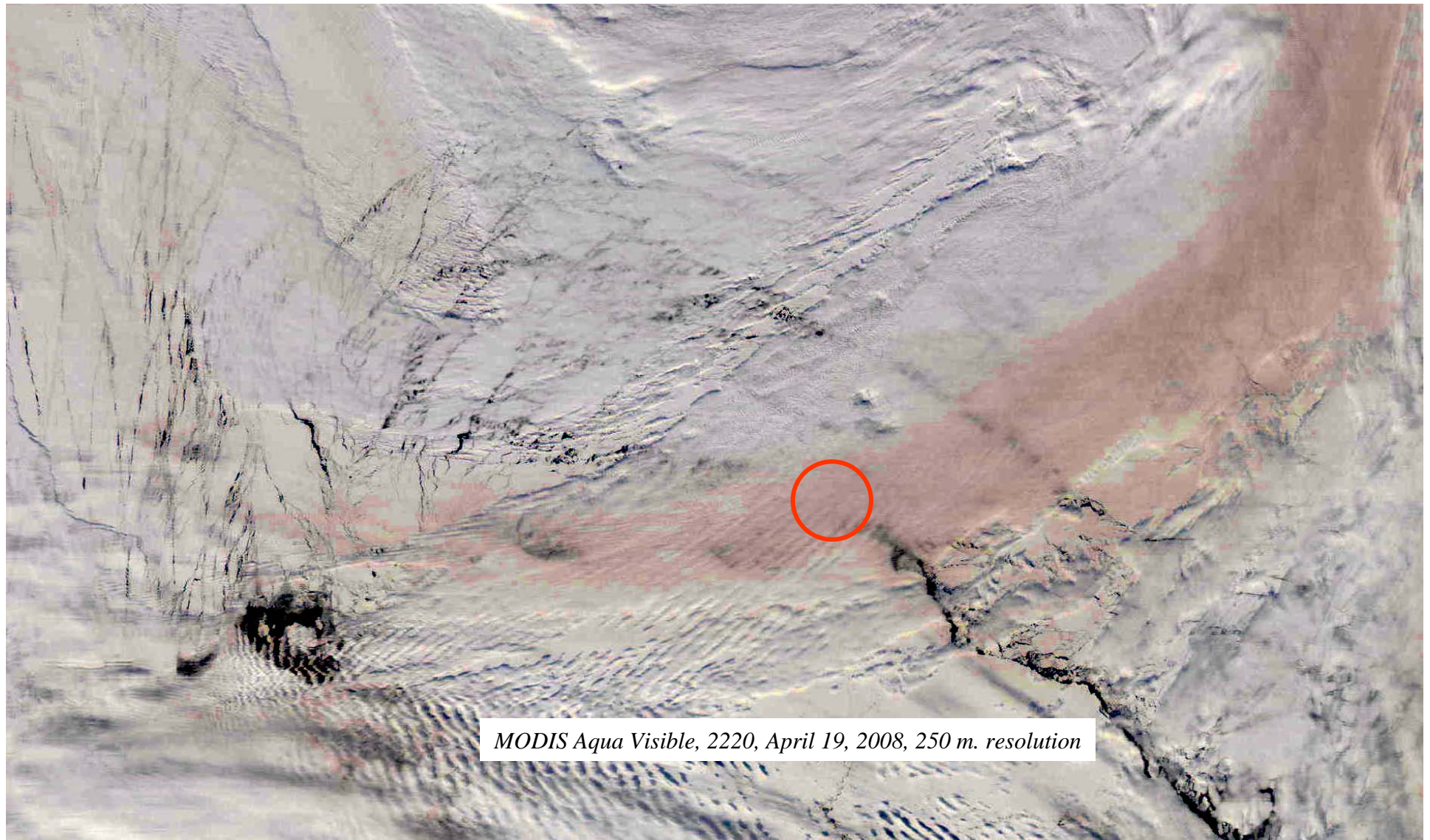


MODIS Aqua Visible, 0930, April 24, 2008, 500 m. resolution

Smoke surrounding Ny-Alesund (Kb event of April 24). While blinking between the Aqua visible (R,G, B = bands 1, 4, 3) and the Aqua SWIR image (R,G, B = bands 7, 2, 1), the fine-mode smoke largely disappears in the SWIR image over water.

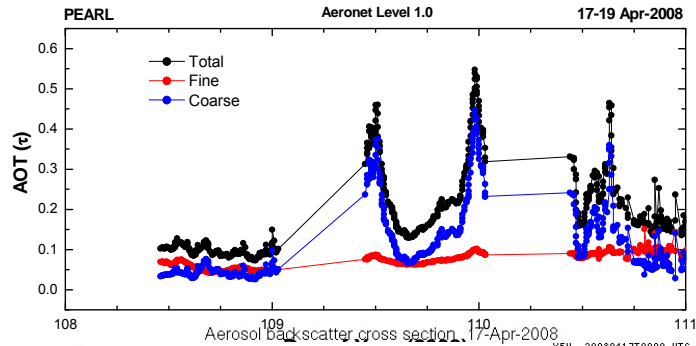
***Saha et al., GRL, 2010**

MODIS Imagery for April 19 Fine Mode Event at Barrow (Alaska)

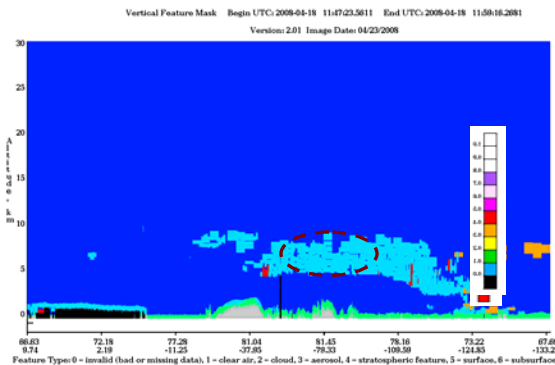
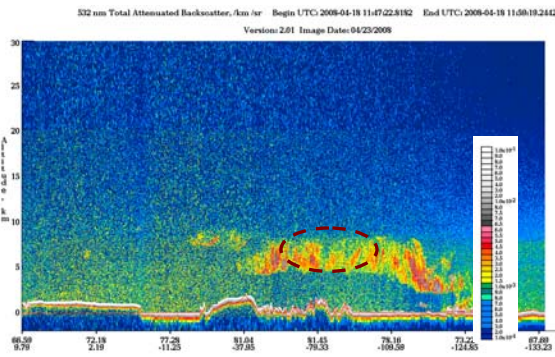
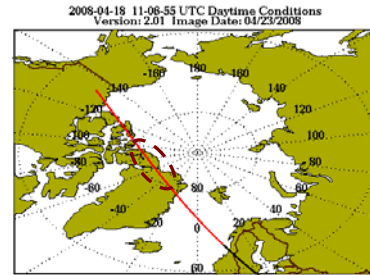


Smoke plume event at Barrow. The Aqua true-color image has been CMYK enhanced (linear stretch applied to the C, M, Y channels). The higher reflectivity of clouds versus snow indicates that the plume lies above a low-lying cloud. This was confirmed in comparisons with the HSRL data of Ferrare et al. (2009). The red circle indicates the position of Barrow. ***Saha et al., GRL, 2010**

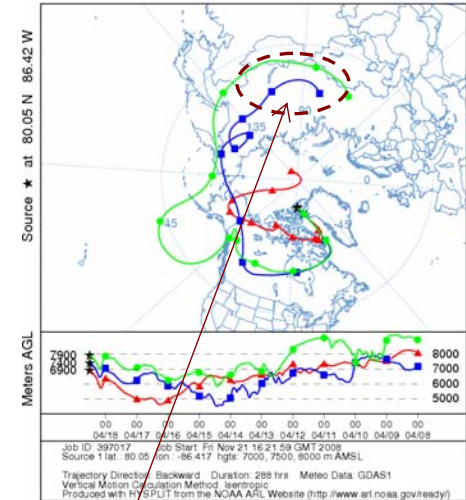
Coarse Mode Event observed at Eureka during April 17-19



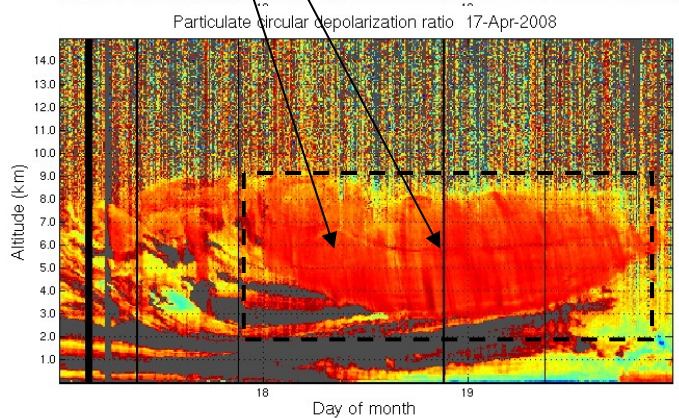
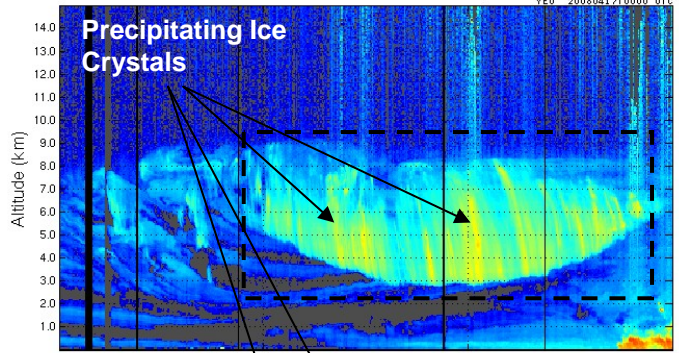
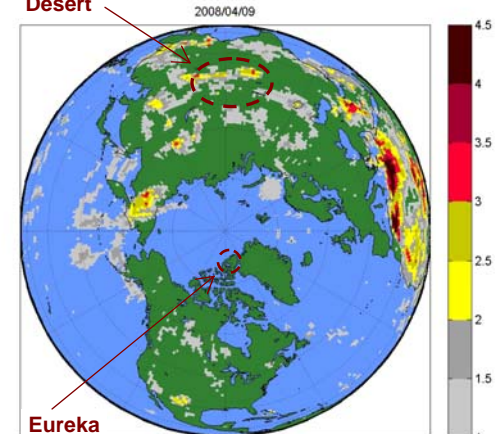
CALIOP profiles of Total Attenuated Backscatter and depolarization ratio



HYSPLIT Back Trajectories
NOAA HYSPLIT MODEL
Backward trajectories ending at 12 UTC 18 Apr 08
GDAS Meteorological Data

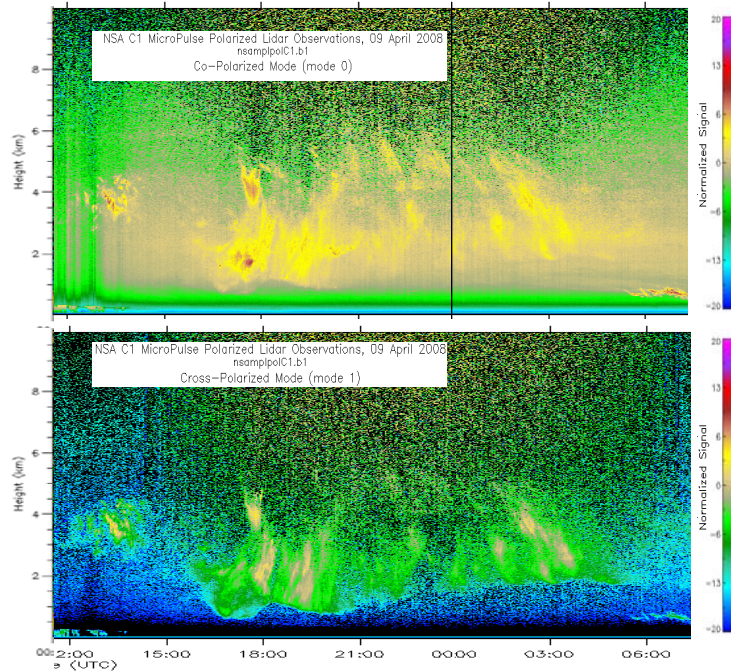
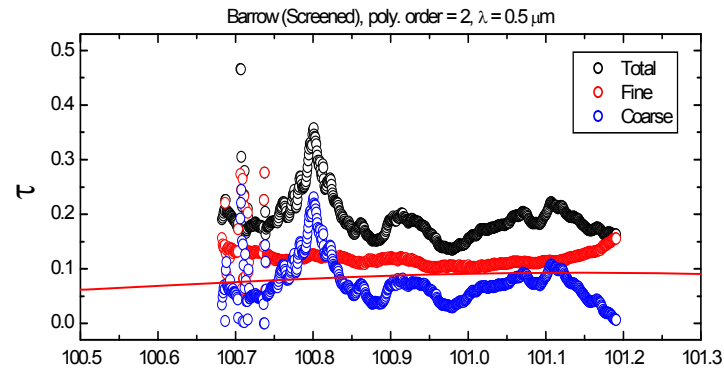


Gobi Desert OMI Aerosol Index



For this high δ event, τ_c varies in a low frequency (diurnal) fashion, unlike typical cloud effects whose high frequency τ_c excursions form the basis of most cloud screening algorithms. The smoke plume positions inferred from MODIS imagery and synoptic- dynamics combined with an analysis of the lidar / sunphotometry data and AOD simulations by Pierce et al. (2009) suggest that these features were a complex mixture of smoke and ice crystals and that the smoke particles (or possibly dust) might have acted as Ice Nuclei.

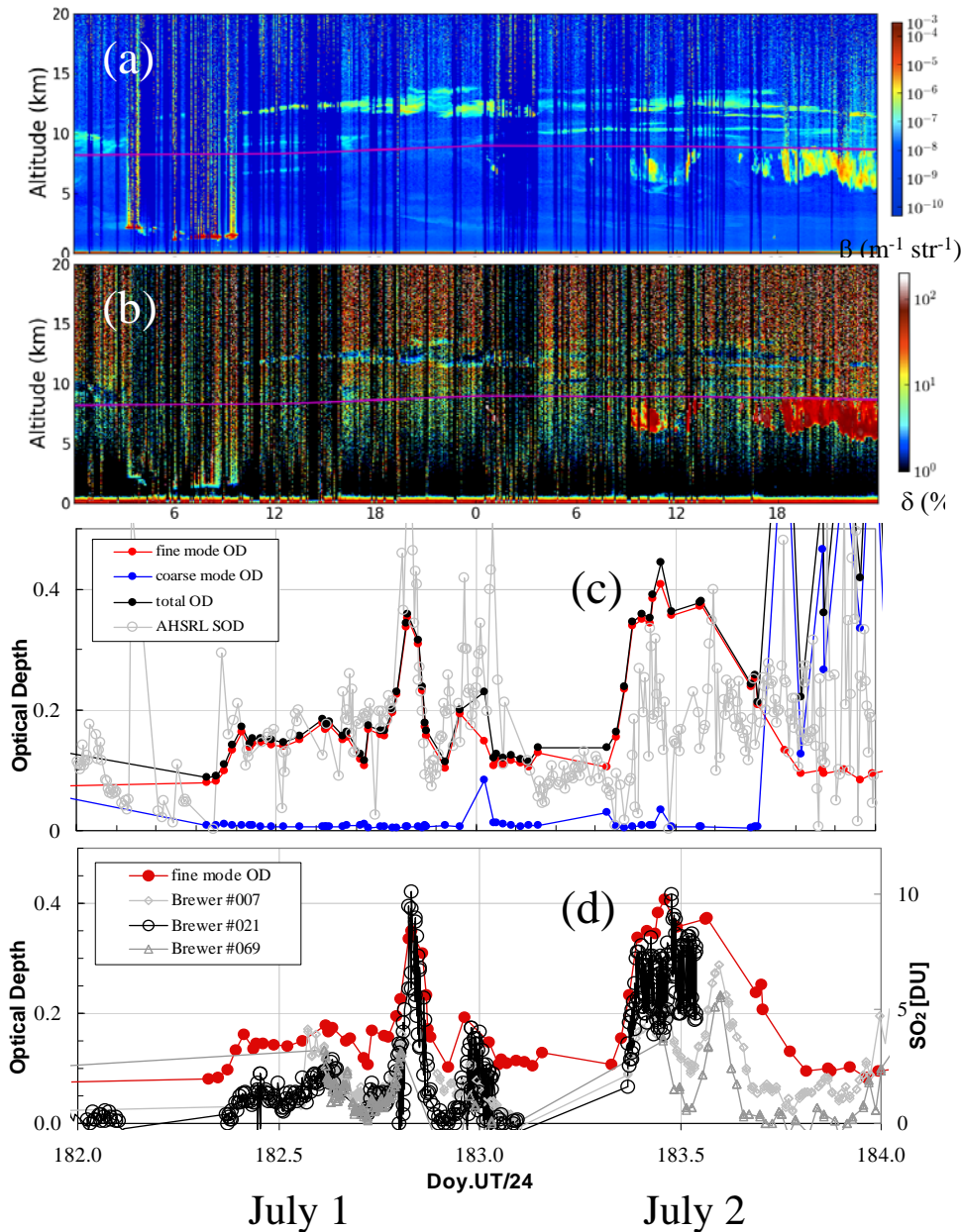
Coarse Mode Event observed at Barrow on April 9



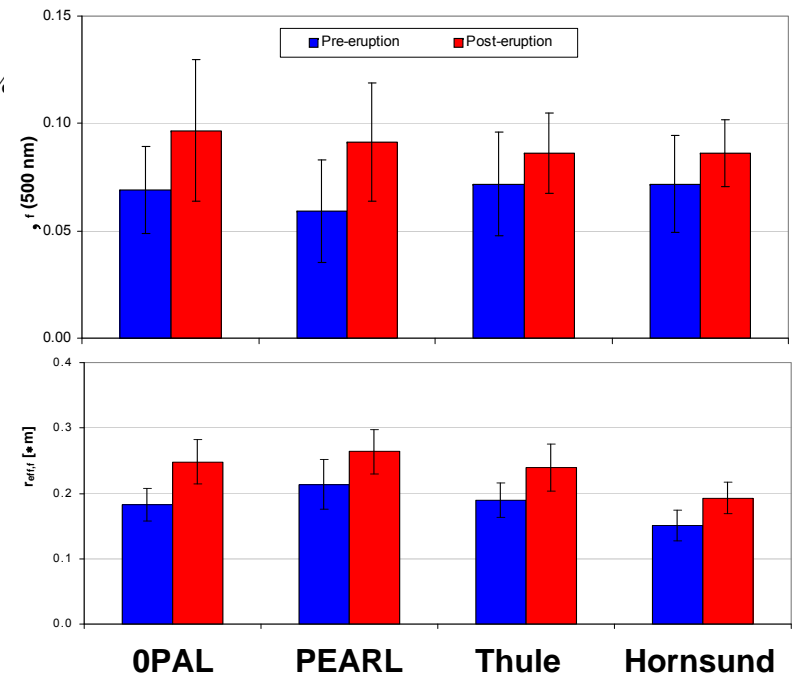
The AOD time series plot over Barrow on April 9 shows significant low-frequency τ_c variation with enhanced backscatter and high cross-polarization profiles. Using airborne lidar measurements acquired near Barrow on April 9, Ferrare et al. (2009) concluded that ice particles were making a significant contribution to the AOD.

***Saha et al., GRL, 2010**

Sarychev volcanic aerosols over the Arctic during Summer 2009*

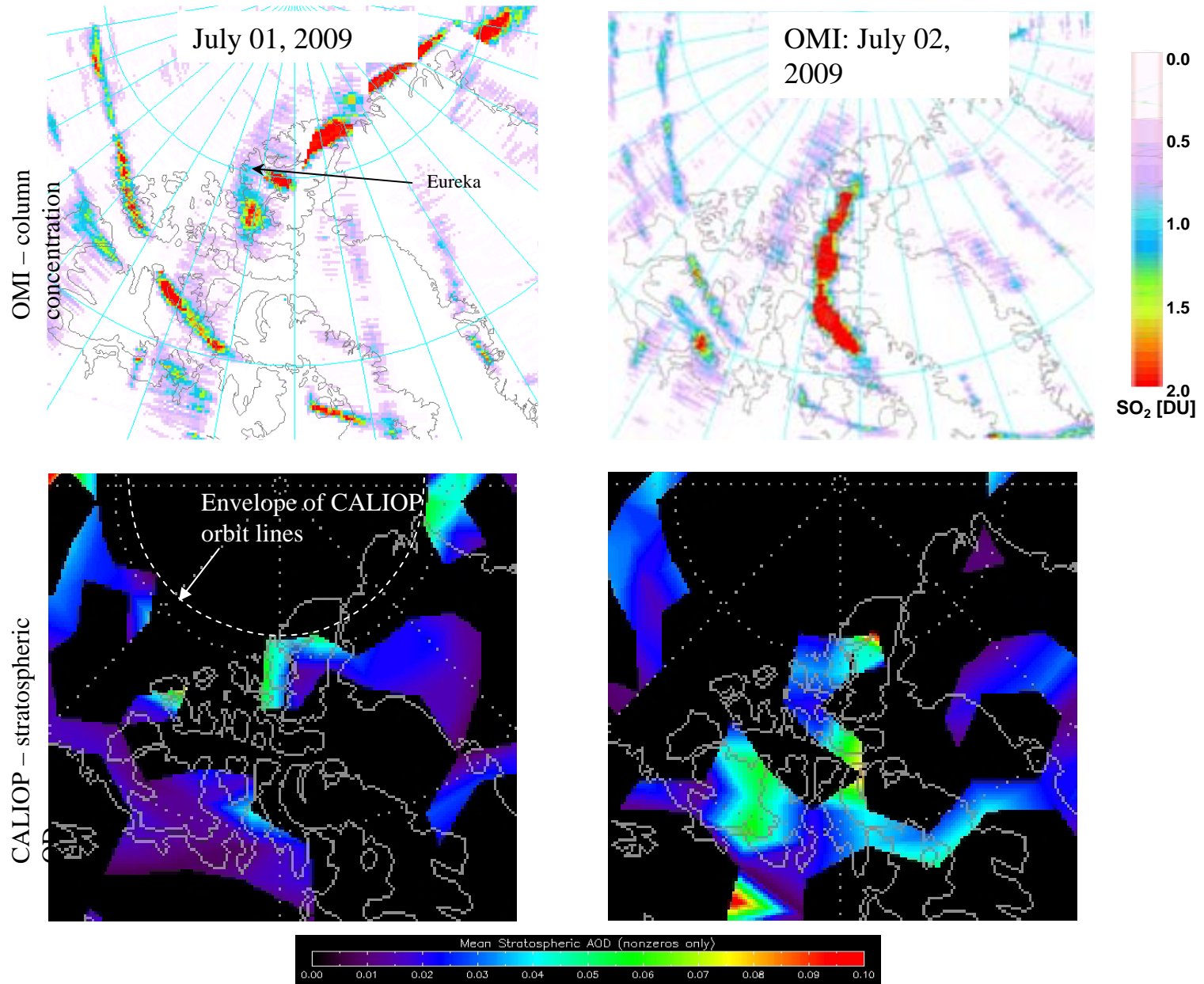


Pre- and post- SAT τ_{ff} and $r_{\text{eff},f}$ for four AEROCAN / AERONET high-Arctic stations



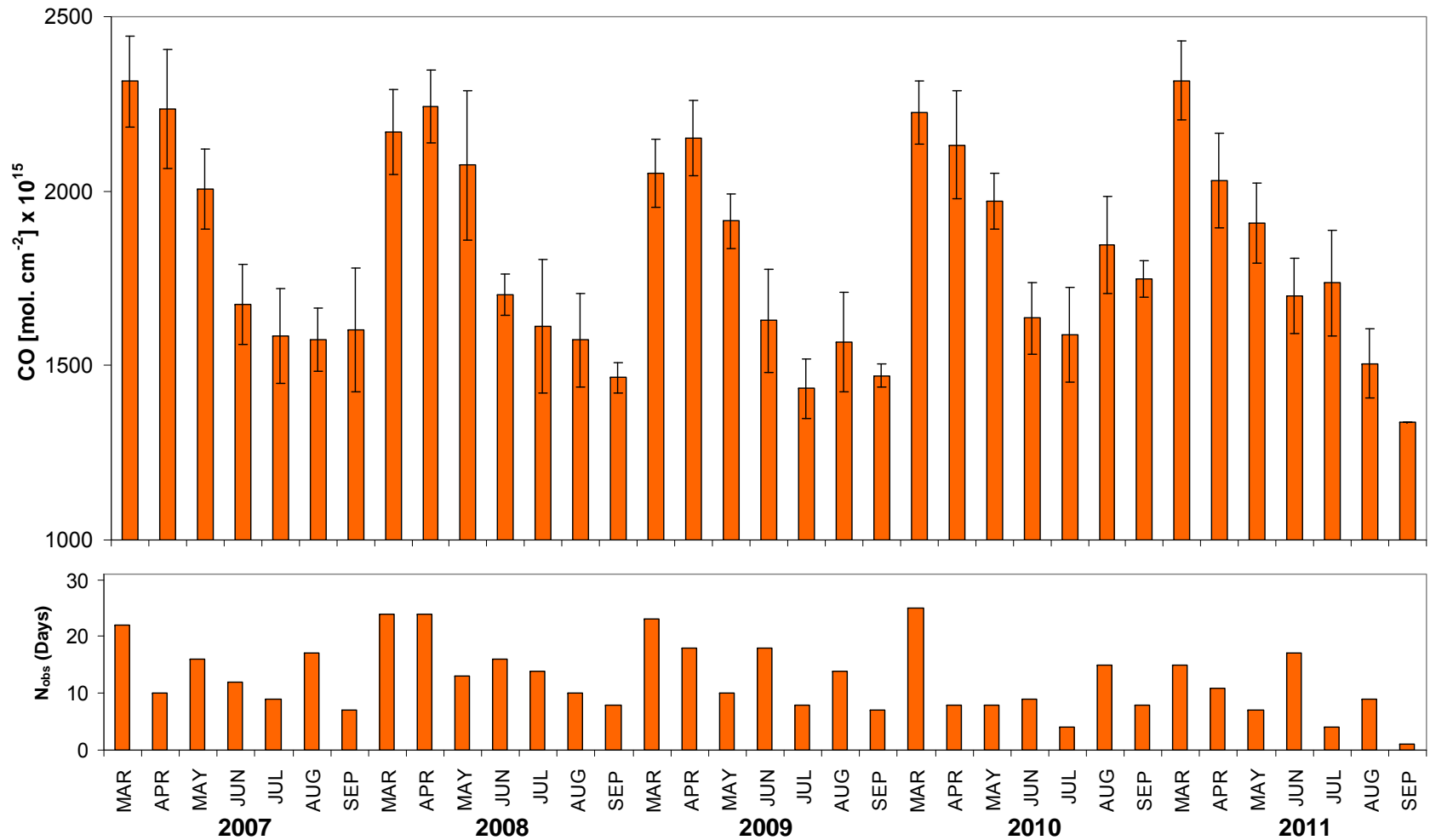
*O'Neill et al., JGR 2012

Illustration of Sarychev Plume (OMI SO₂ vs CALIOP SOD)



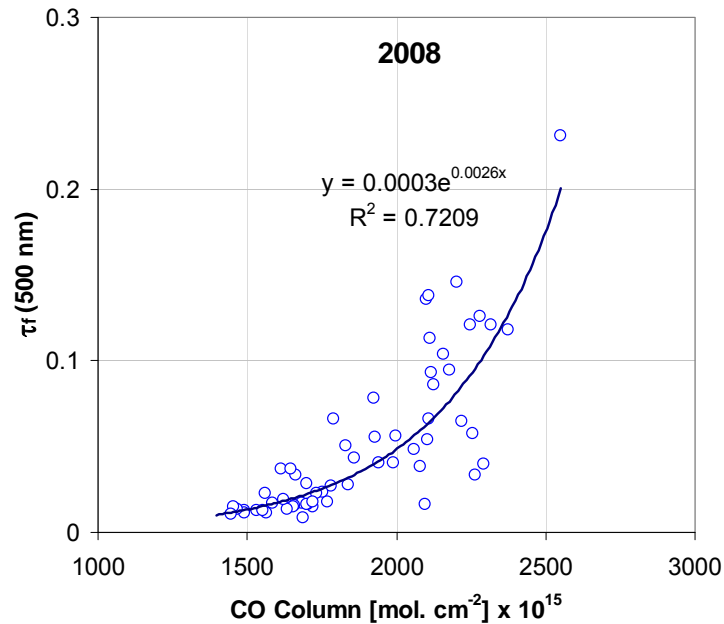
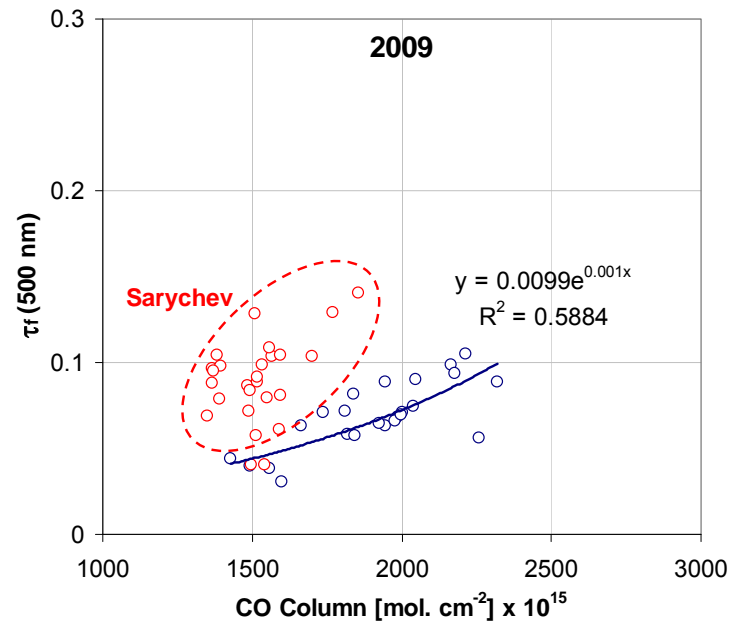
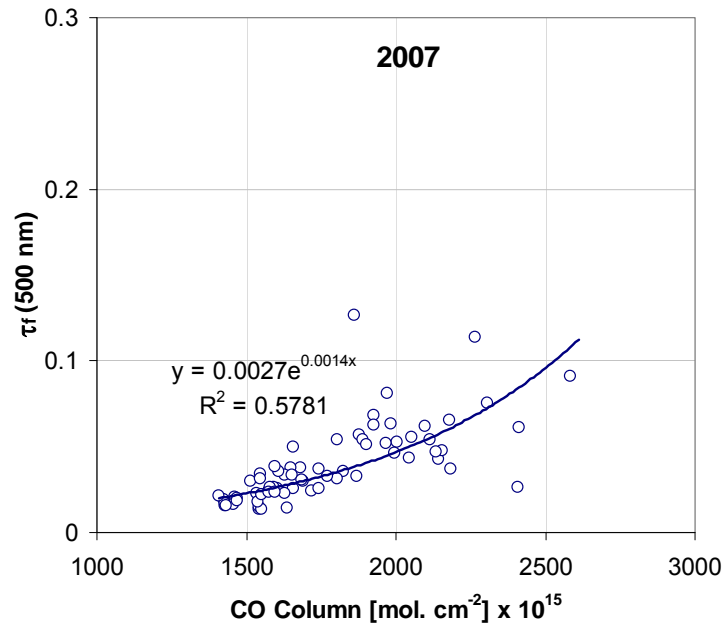
*O'Neill et al., JGR 2012

Variations of CO Total Column over Eureka



CO being a tracer of biomass, one would expect a degree of correlation with the fine mode aerosols that are also a primary product of biomass burning.

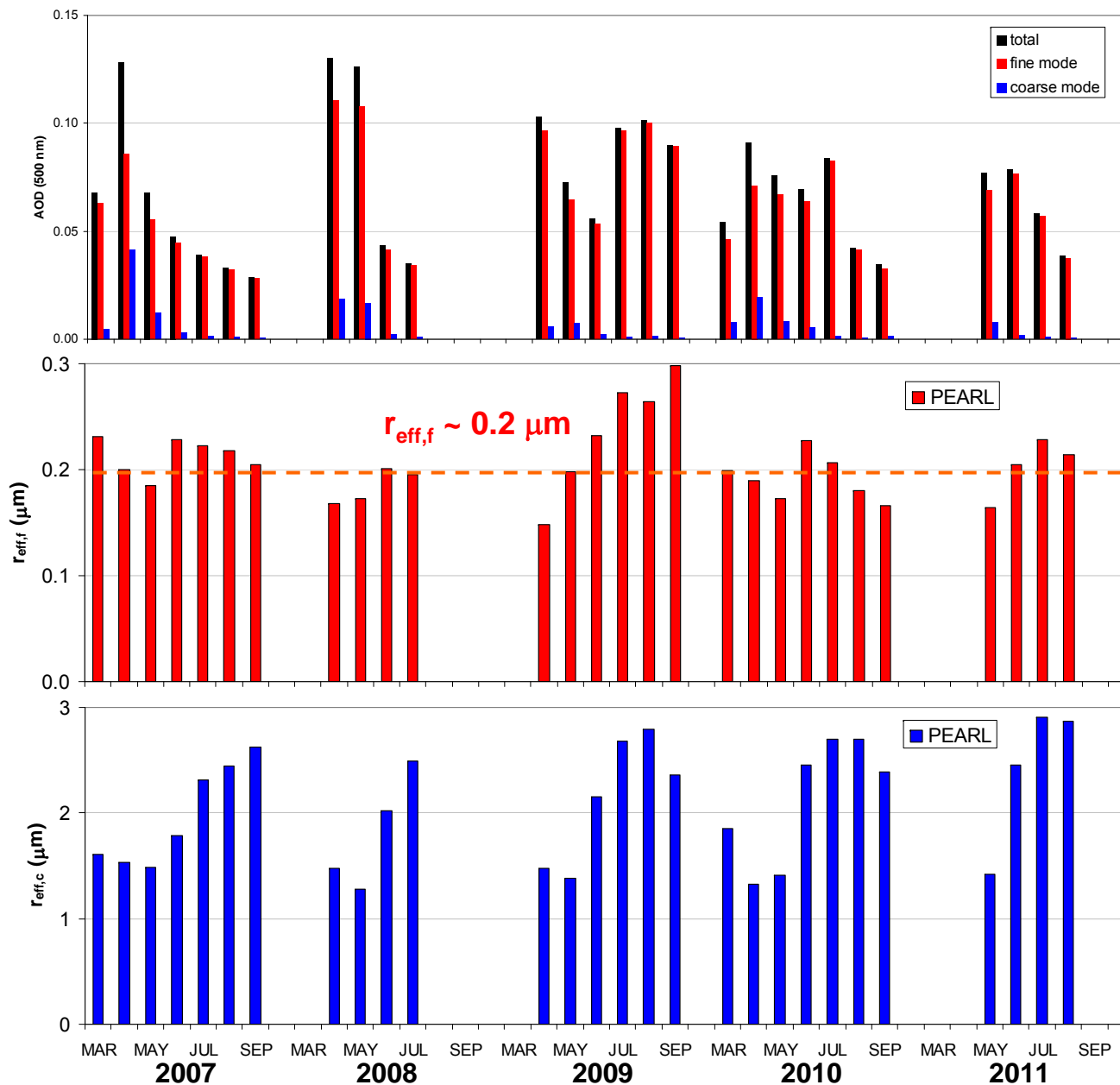
Fine Mode AOD vs CO



Shown in the figures are the variation of fine-mode AOD as a function of CO concentration for the three years of 2007, 2008 and 2009.

One can observe a moderate (2007), strong (2008) and insignificant (2009) correlation respectively for these three years. However if we separate out the Sarychev fine-mode AODs from the 2009 regression, we find a R^2 value that is comparable to the other two years.

Retrievals of fine & coarse mode AOD and Effective radius



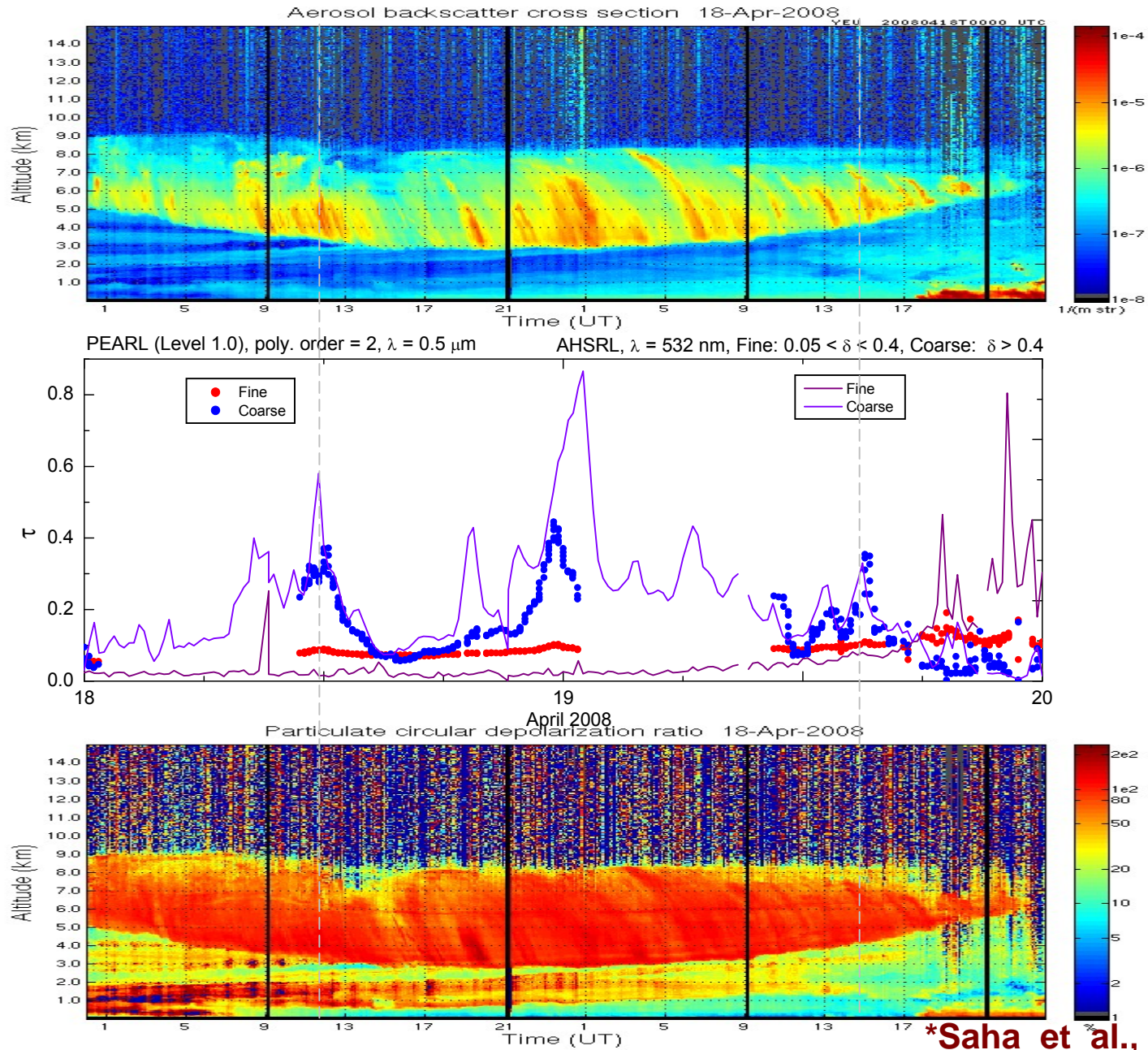
The fine-mode AOD shows the spring to summer decrease (confirms that the total AOD is fine-mode dominated).

The coarse mode AOD shows apparent springtime activity that could possibly be Asian Dust.

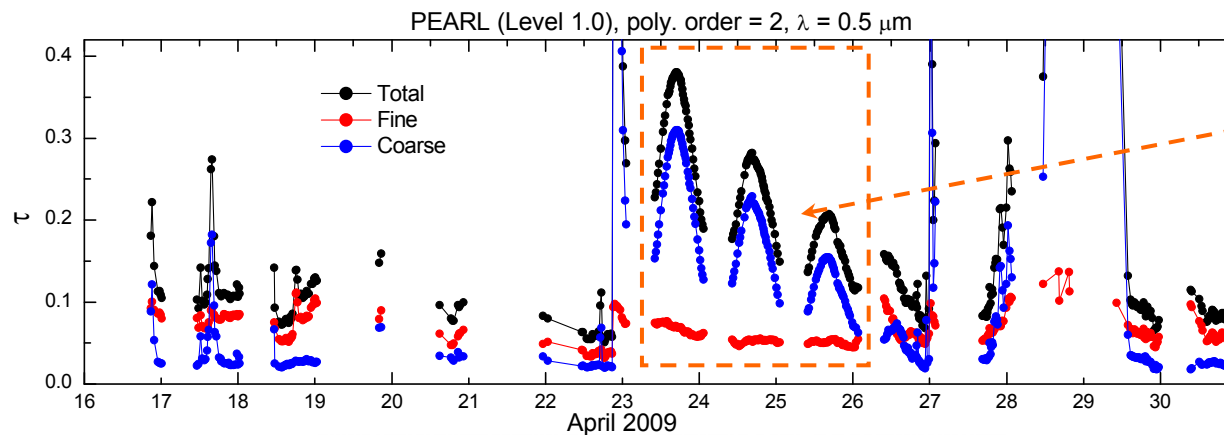
The fine-mode effective radius shows a relatively consistent variation except in 2009 where we know there was a strong Sarychev influence (O'Neill et al., 2012).

The coarse mode effective radius shows significant variations that could be real (possibly associated with marine aerosols) but which might, just as well, be associated with low-AOD retrieval artifacts.

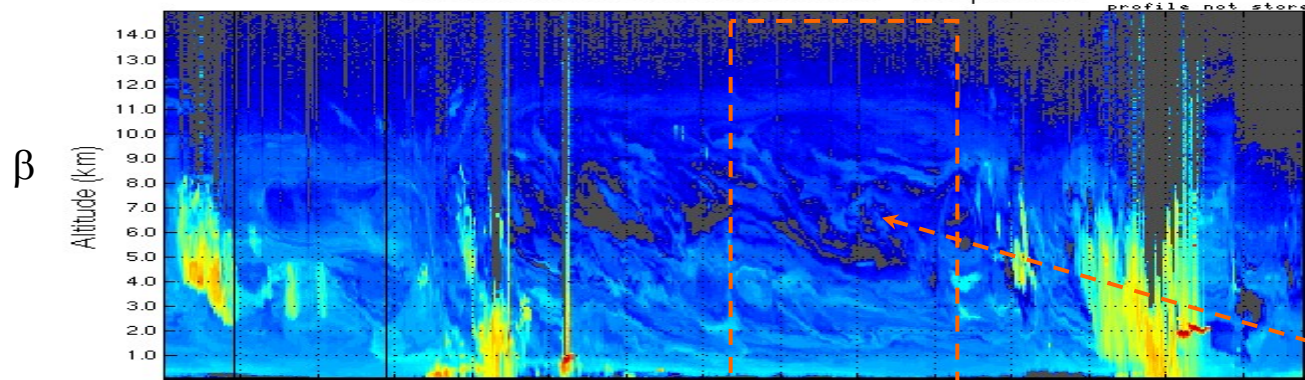
Coarse Mode Event (Nucleation of Smoke & Dust) during ARCTAS*



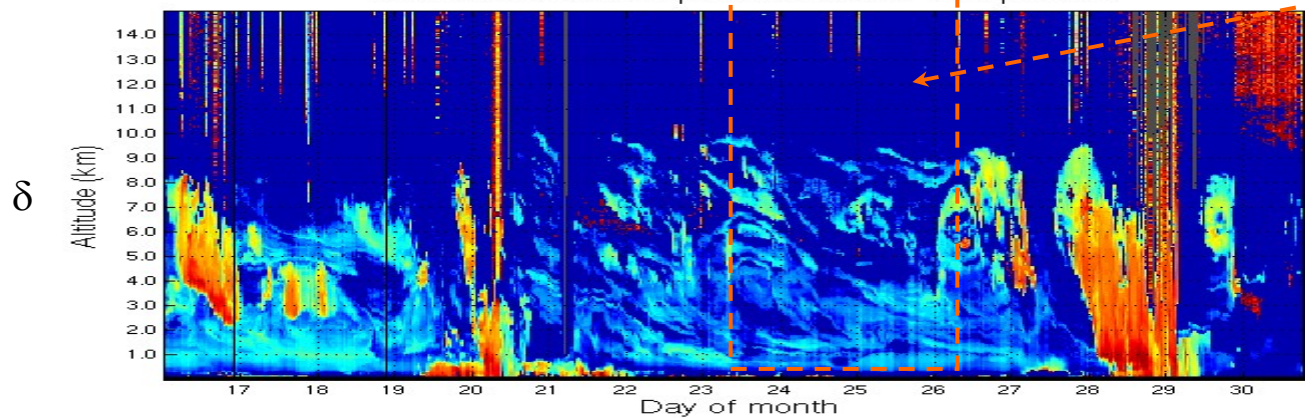
Coarse mode event at PEARL (Artifacts)



Suspicious coarse mode peaks possibly due to frost in the Cimel optics.



AHSRL does not show any coarse mode event



Frost Issues

Cimel Sunphotometer
Sept. 9, 2011



Cimel Sunphotometer
Sept. 22, 2009

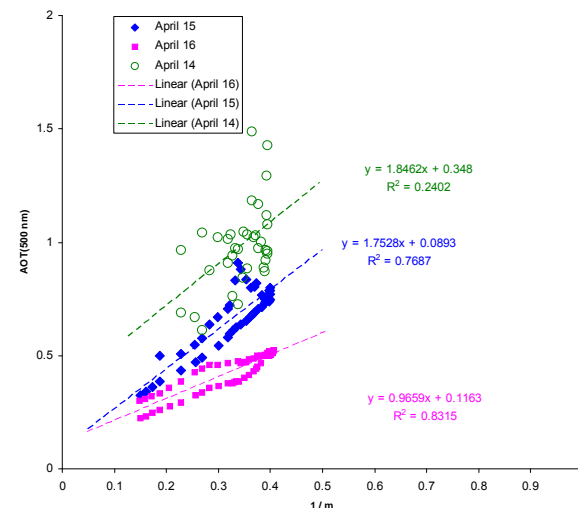
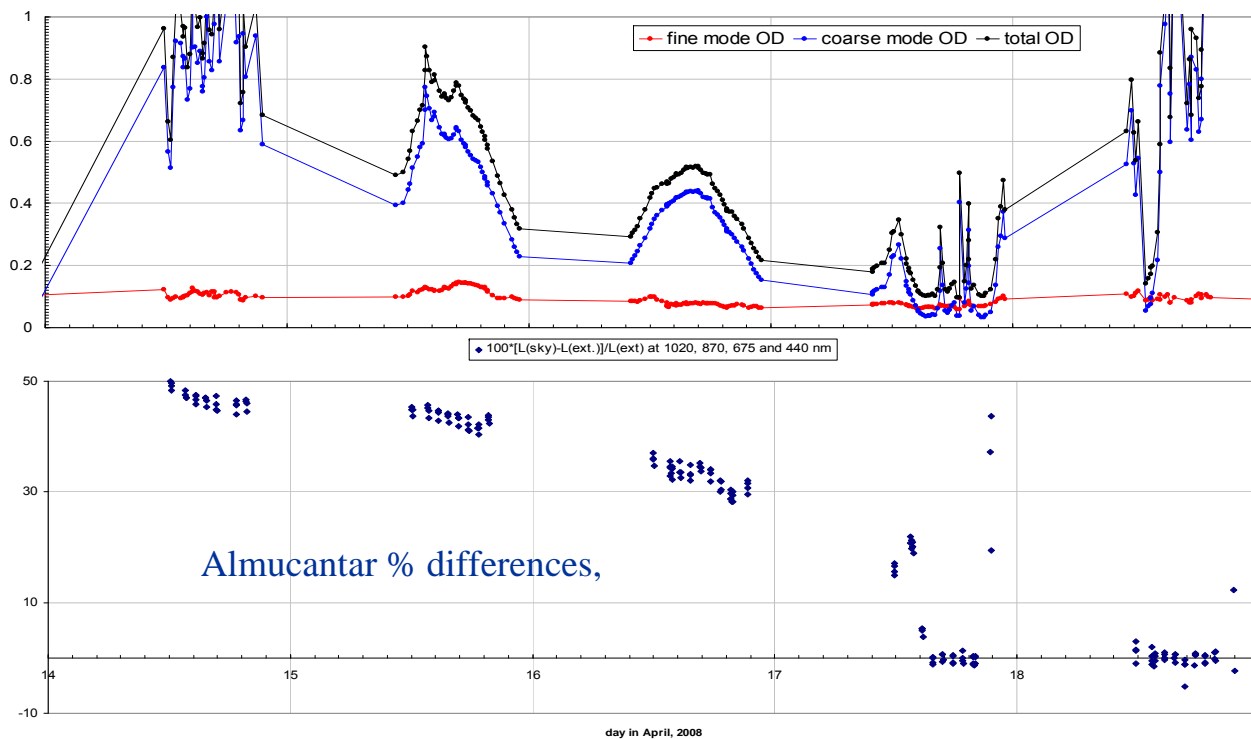


Star Photometer
Winter 2012



Coarse mode event at Thule (Artifacts)

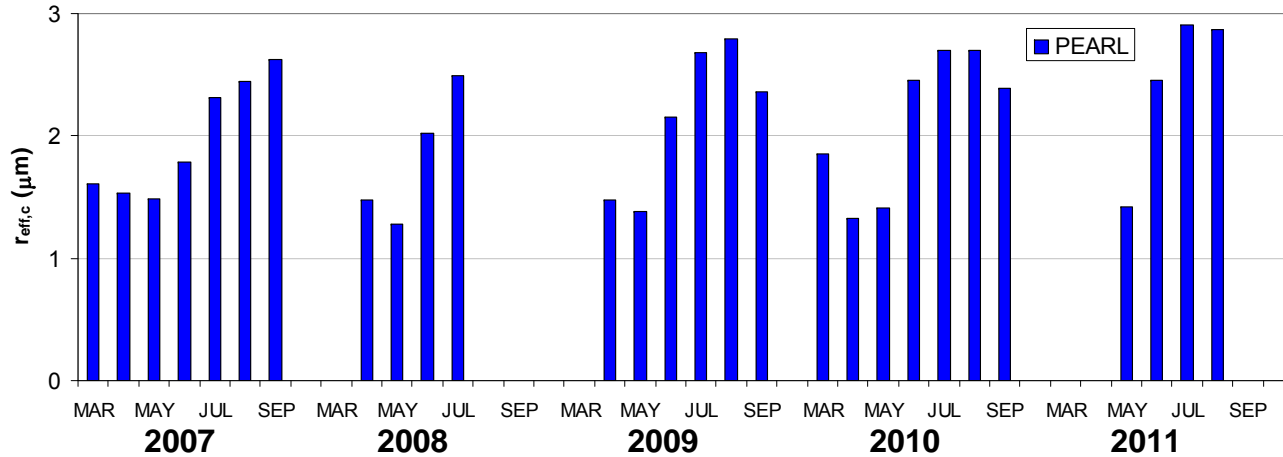
April 2008



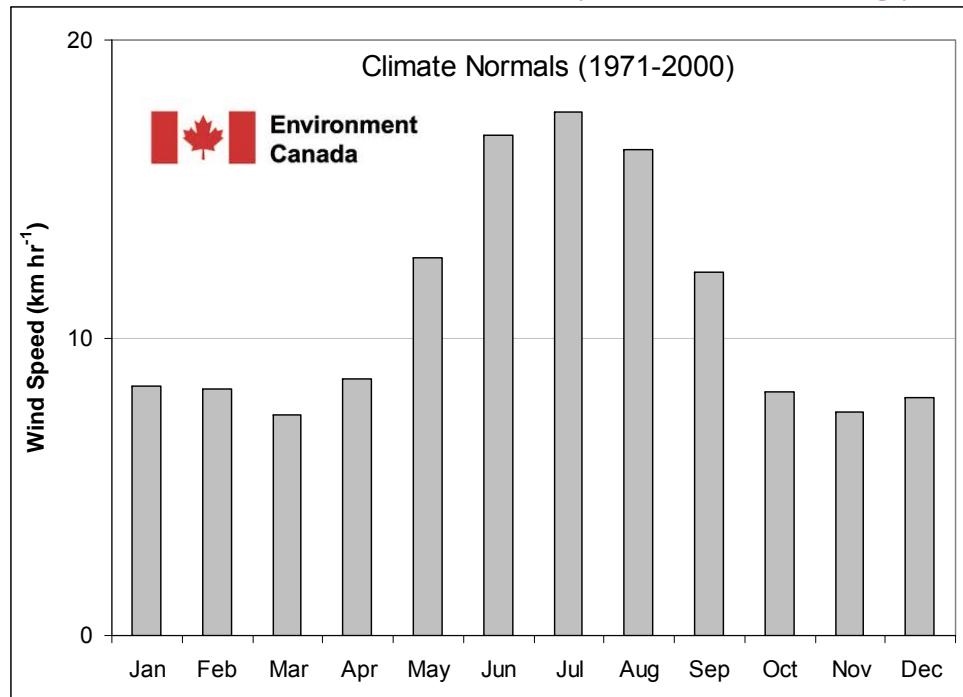
Computed AOT varies suspiciously as $1 / m$ (m - airmass)

Almicantar radiance differences at 6° azimuth should agree within 5%.

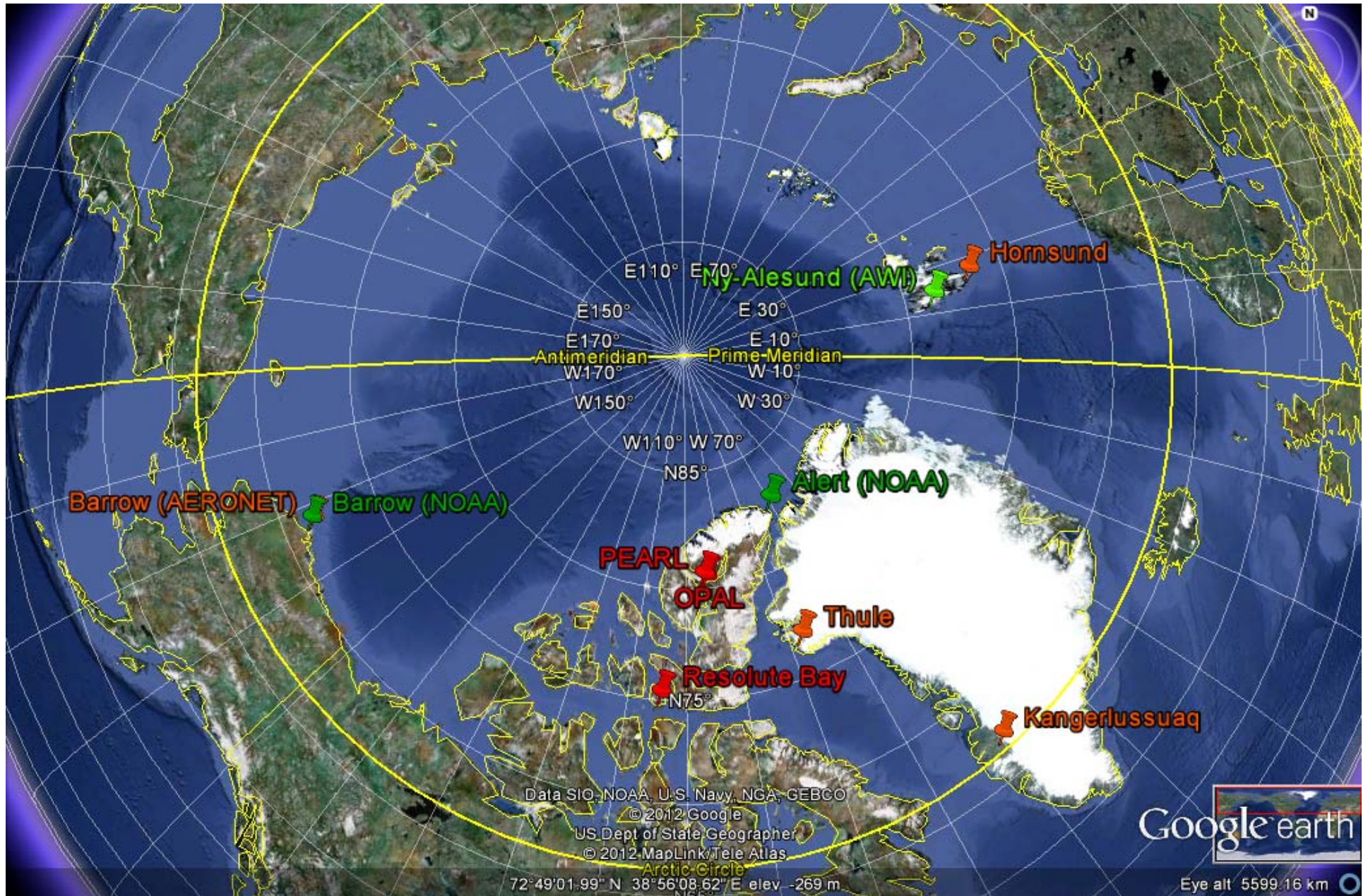
Coarse Mode Retrievals vs Wind speed (Eureka)



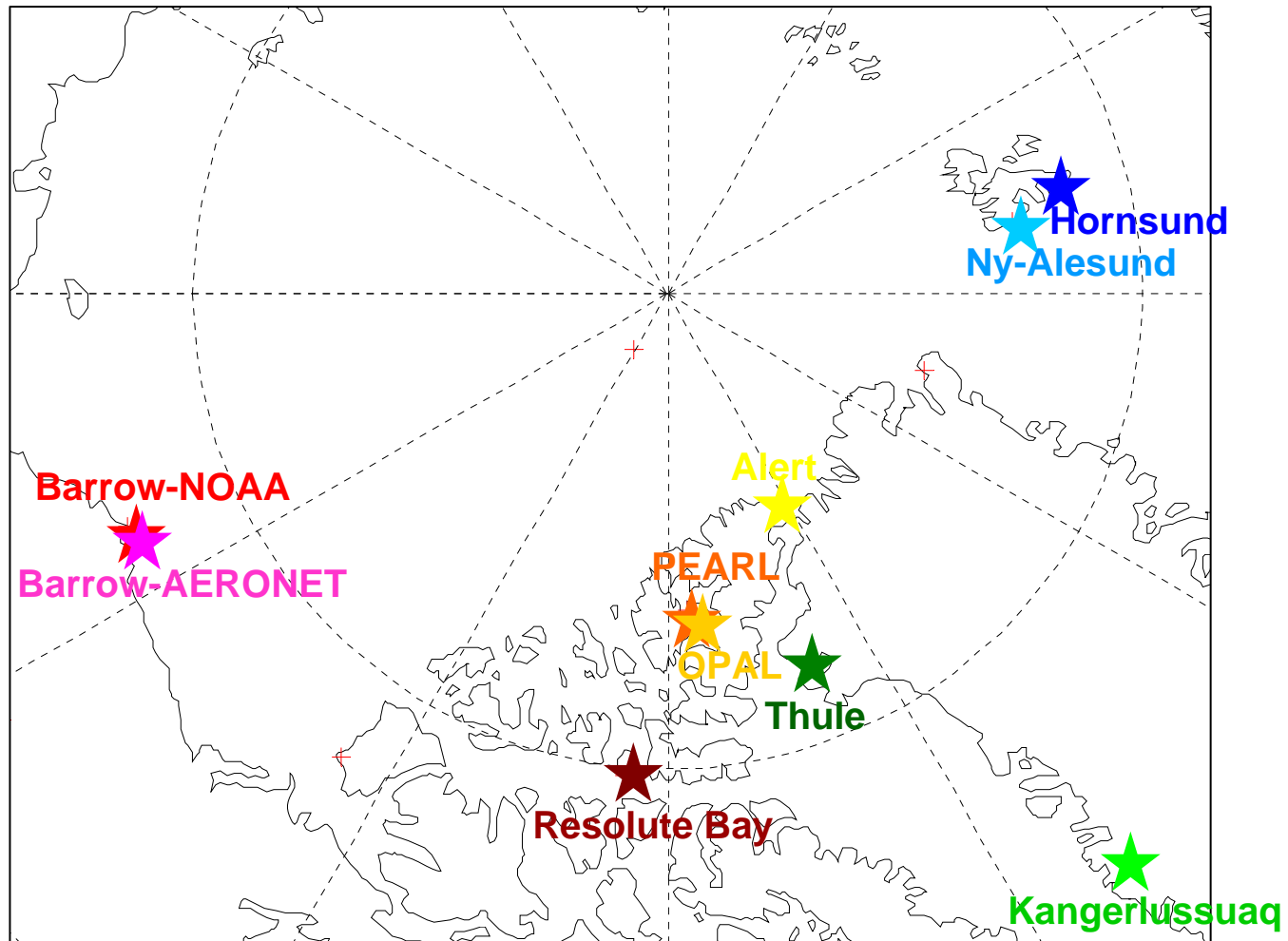
Eureka (OPAL) Wind Speed Climatology



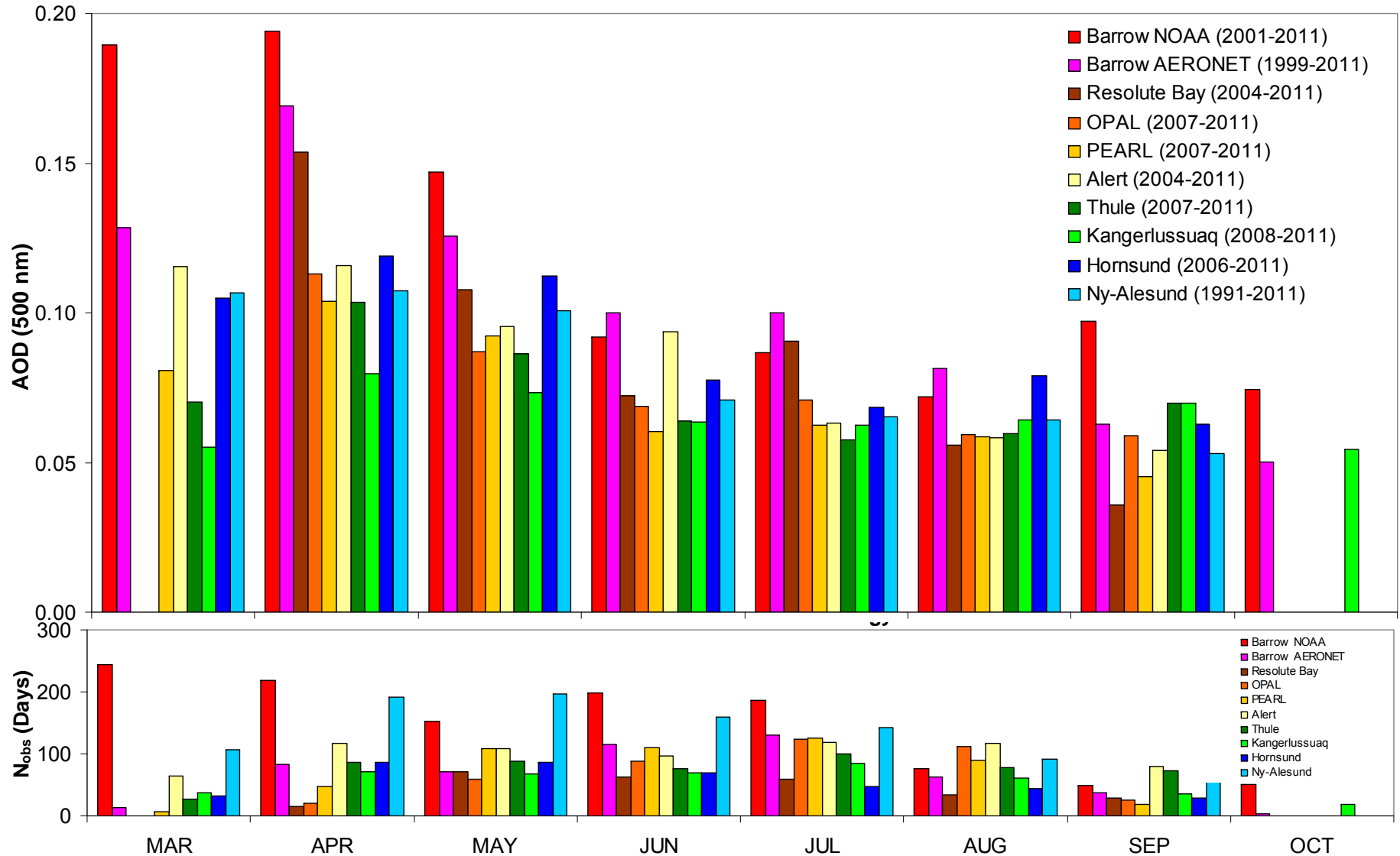
Sunphotometry at High Arctic Sites



Pan-Arctic sites for the AOD Climatology



Pan-Arctic AOD Climatology



AOD monthly climatology for an enhanced number of high Arctic stations on a pan-Arctic scale. It simultaneously shows the spring to summer decrease noted for Eureka as well as a west to east AOD decrease.

Summary & Conclusions

A multi-year AOD and effective radius climatology for the high Arctic showed a number of consistent features:

- ❖ Spring to summer decrease of fine-mode AOD (probably attributable to biomass burning and/or anthropogenic pollution).
- ❖ Significant correlation of fine mode AOD with CO concentration (which indicates a predominance of biomass burning aerosols throughout the entire year).
- ❖ West to east decrease in AOD on a pan-Arctic scale.

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A photograph of a sunset over a mountain range. The sun is a bright orange-red disk partially obscured by a layer of clouds or mist. The sky is a gradient of orange and yellow. The foreground is a dark, silhouetted mountain ridge.

Thanks for your attention!

Differential Sunphotometry at Eureka

