Aerosol Properties Across the North Slope of Alaska: Sources and Distributions from Utqiagvik (Barrow) to Oliktok Point

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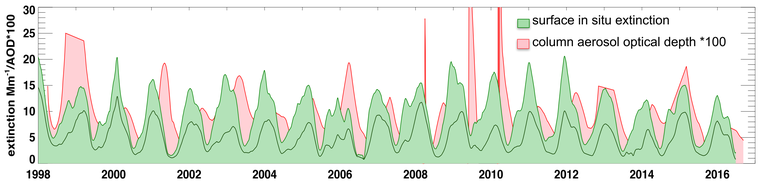
ASR Atmospheric System Research

ARM Atmospheric Radiation Measurement

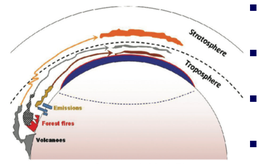
This research was supported by the Office of Biological and Environmental Research of the U.S. Department of Energy Atmospheric System Research Program Interagency Agreement No. DE-SC0013306 and DE-SC0014568 with data from the Atmospheric Radiation Measurement Climate Research Facility.

Motivation

Recent studies indicate that aerosol in the Arctic has appreciably offset greenhouse gas warming and sea ice loss (Najafi et al. 2015, Gagne et al. 2015); at the same time observations show a warming of the Arctic region that is still much greater than the global average due to Arctic Amplification mechanisms (Serreze and Barry 2011.) Air quality regulations are manifesting in declining aerosol burdens across the Arctic, so the rate of warming and sea ice loss may accelerate in the future. The radiative forcing potential of aerosol is dictated by the source and evolution after emission (Stone et al. 2014, right), so characterizing aerosol property distributions relative to source is essential for predicting future Arctic climate system responses to other anthropogenic changes.



Green: aerosol light extinction at 500 nm for particles < 10 μm measured in situ at the surface with a two month smoothing function; Dark Green line: extinction for particles < 1 μm ; Red: aerosol optical depth at 500 nm with a three month smoothing function. (in situ extinction from NOAA Barrow Observatory, DOE-ARM archived data; aerosol optical depth from DOE ARM MFRSR)



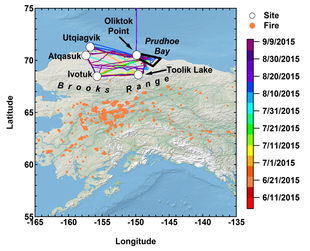
Stone et al. 2014, Elementa

- Arctic meteorology leads to stratification and *marked aerosol vertical structure*
- Vertical distribution of aerosol in Arctic is *source dependent* as illustrated in the graphic at left
- Source and evolution during transport controls *optical and cloud nucleating properties*
- Vertical structure of these properties dictates *aerosol-cloud interactions and heating rates*

Much of our knowledge of the seasonal cycle of Arctic aerosols comes from in situ measurements at the surface because: 1) they can be made continuously throughout the polar summer and winter and 2) detailed, continuous analyses for composition and source are possible (e.g., Quinn et al. 2008.) Radiometric observations have also been used to characterize Arctic aerosol in the column using aerosol optical depth (column extinction) and its wavelength dependence, the Angstrom exponent (e.g., Tomasi et al. 2015, Stone et al. 2014.) The plot at left reveals distinctly different seasonal cycles in aerosol measured at the surface versus column integrated measurements.

The ARM-ACME-V field campaign: June-Sept 2015

ARM Fifth Airborne Carbon Measurements



Aerosol properties including size distribution, number concentration (CPC), absorption and scattering, and black carbon (SP2) were measured in addition to gases, cloud properties, and atmospheric state across the North Slope between Oliktok Point and Utqiagvik.

Conclusions

We have examined persistent, seasonal differences in the horizontal and vertical distributions of aerosol properties that may alter our understanding of aerosol forcing, including their interactions with low clouds.

Our findings establish patterns of aerosol properties consistent with known sources and transport patterns across the North Slope:

- **more numerous, smaller particles surrounding Oliktok Point, likely from oil extraction activities;**
- **biomass burning aerosol aloft from regional- and long-range transport originating in Alaska and other boreal forests; and**
- **seasonal cycles of properties near the surface that reflect changing sources as surface cover and circulation pattern vary throughout the year.**

Prudhoe Bay as a source of small and numerous aerosol

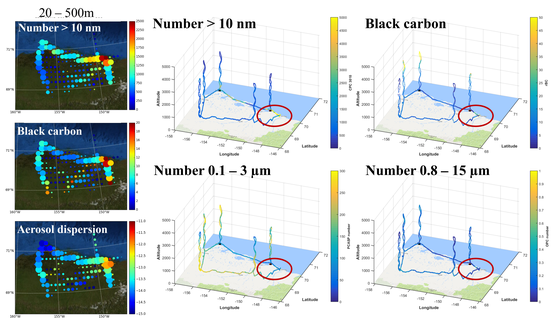
Prudhoe Bay aerosol emissions were persistent, localized, high in concentration, and relatively small in size.

High numbers near Prudhoe, particularly near ground below boundary layer, likely from local-regional oil extraction activities.

Prudhoe Bay is also source of black carbon.

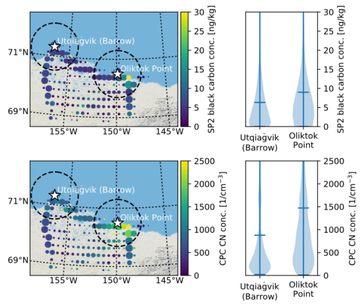
Simulations from HYSPLIT[1] show spatial dispersion of particles from Prudhoe Bay over the North Slope.

Prudhoe Bay aerosol emissions were persistent, localized, high in concentration, and relatively small in size.



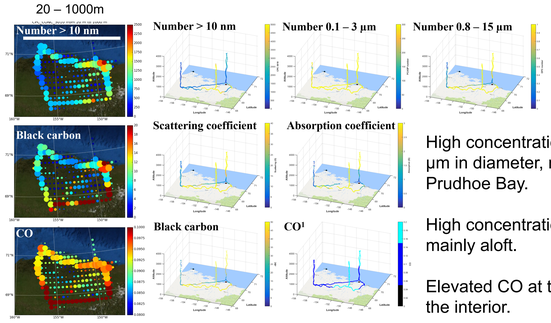
1. Draxler, R. R., NOAA Tech. Memo. ERL ARL-230, NOAA Air Resources Laboratory, Silver Spring, MD, 1999.

Non-cloudy observations below 400 m ASL from the 90 km areas surrounding both sites were analyzed to focus on local emission sources. Local maxima over Oliktok are evident in both black carbon and number concentration.



Higher altitudes and interior impacted by biomass burning

Almost all aerosol measurements were elevated during influence from fires.

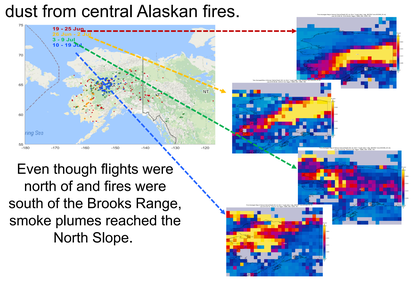


High concentrations of particles >10 μm in diameter, not as high as Prudhoe Bay.

High concentrations of black carbon, mainly aloft.

Elevated CO at the surface and aloft in the interior.

Satellite observations indicate high AOD and the presence of smoke and mineral dust from central Alaskan fires.

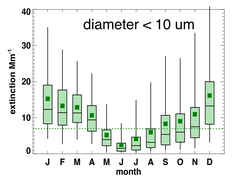


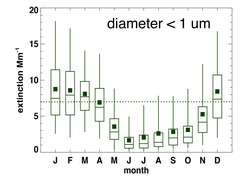
Even though flights were north of and fires were south of the Brooks Range, smoke plumes reached the North Slope.

Ground-based Aerosol Observations at Utqiagvik

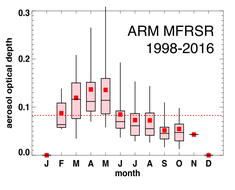
The seasonal cycles of aerosol properties are examined from 19 years of in situ and radiometric data

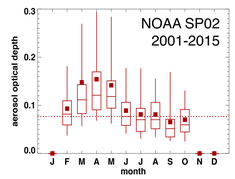
all aerosol properties at 550 nm unless otherwise specified



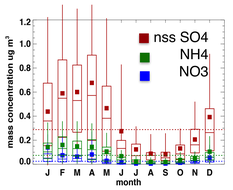


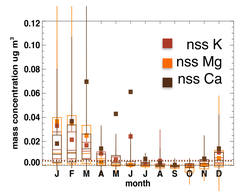
Supermicron and submicron extinction (550 nm) measured in situ at the surface both show typical Arctic haze seasonal cycles, with aerosol dispersing in early Spring with the breakup of the polar vortex.



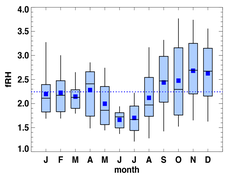


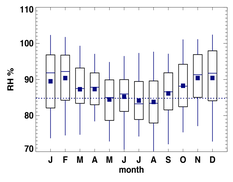
Aerosol optical depths (column extinction) show an increase in Spring (MAM) when surface extinction is declining.



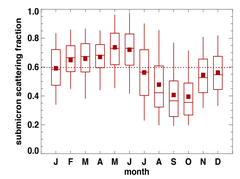


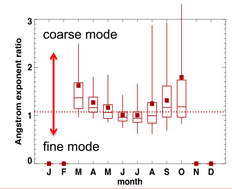
Ion chromatography shows aerosol compositions associated with haze, dust, and biomass burning follow seasonal haze cycles in the light extinction data. Dust and biomass burning aerosol do not appear to increase at the surface in late spring and early summer when aerosol optical depths (column extinction) are elevated.



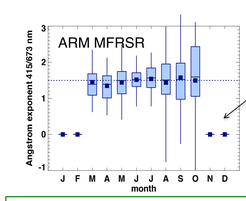


In situ aerosol measured at the surface is dried. Optical depths are measured at ambient conditions. A difference in the two measures occurs primarily from: 1) aerosol humidification (water uptake) differences, 2) aerosol aloft. Humidification factors (*f*RH) and RH% suggest that (1) is likely NOT the cause of the persistent difference seen in this data, regardless of likely large uncertainties in this data.



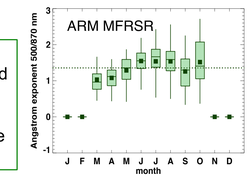


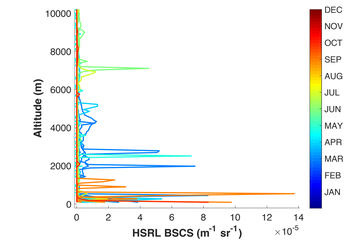
The submicron extinction fraction (<1um:<10um) extinction at the surface shows finer aerosol through mid-summer, then a distinct shift, likely due to local sea salt production. The ratio of the two Angstrom exponents at left reveals curvature in seasonality of the wavelength dependence of aerosol optical depth.



Angstrom exponents suggest that aerosol are shifted to finer effective sizes from Spring to Summer, with a coarse mode contributing more in the Fall and late Winter.

Data in winter months missing due to lack of sunlight. See 'Measurements' below

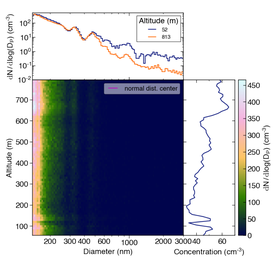




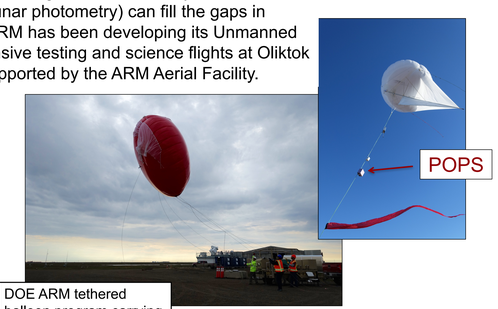
HSRL aerosol backscatter profiles from Utqiagvik from 2012-2016 are averaged monthly to show the seasonal distribution of elevated aerosol layers. The prevalence of enhanced layers aloft during the Spring and Summer (April – June) are consistent with surface in situ, ground-based radiometric, and aircraft profiles. These are likely regional- to long-range transport of biomass burning layers from boreal forest fires as indicated by many aircraft campaigns in the Arctic, including ACME-V at right.

DOE ARM UAS and TBS Programs: Measurements to Routinely Inform Aerosol Vertical Distributions Distributions

Sun photometers that provide aerosol optical depths can not provide information at night or under cloudy skies. In situ measurements on unmanned aerial systems (and other approaches such as Lunar photometry) can fill the gaps in observations of column aerosol properties throughout the polar annual cycle. ARM has been developing its Unmanned Aerial Systems and Tethered Balloon Systems (UAS/TBS) Programs with extensive testing and science flights at Oliktok Point in over the past two years. These flight include aerosol measurements supported by the ARM Aerial Facility.



Measurements of aerosol size distribution and number concentration from the Printed Optical Particle Spectrometer (POPS) mounted on the ARM Tethered Balloon System for 26 July 2016 are shown at left. Consistent with the ground-based and aircraft data presented here, aerosol loading is enhanced at higher altitudes in a layer distinct from the surface layer.



DOE ARM tethered balloon program carrying aerosol instrumentation during testing at OLI in the summer of 2016