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North Slope of Alaska Black Carbon Loadings and Mixing State for MOSAiC Field Campaign Report

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July 2021

ARM

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Executive Summary

The Arctic represents a unique region to study global climate change in that it exhibits pronounced sensitivity towards aerosol radiative forcing, referred to as arctic amplification. Of the aerosol species that are expected to contribute to this aerosol forcing, black carbon (BC) is arguably at the top of the list. Black carbon has this distinction because it exerts two radiative forcing influences that can be characterized as atmospheric and non-atmospheric. As an atmospheric forcer, BC behaves much as it does in the mid-latitudes – through the direct effect and semi-direct effects – collectively causing surface dimming with subsequent surface cooling and mid-altitude warming affecting cloud cover. As a terrestrial forcer, which is unique to the cryosphere, the deposition of BC on the surface can readily decrease polar surface albedo that, in turn, can activate a positive feedback wherein the increased surface absorption leads to further snow melt causing still further reduction in surface albedo.

The single-particle soot photometer (SP2) was deployed from December 2019-October 2020 at the National Oceanic and Atmospheric Administration (NOAA) Observatory at Utqiaġvik (formerly Barrow) on the North Slope of Alaska (NSA). The single-particle soot photometer (SP2) was operated locally by NOAA staff and collected data for >85% of the deployment. Black carbon mass loading exhibited a seasonal trend wherein the BC concentrations were highest in January to April (~ 20 ng/m^3), punctuated with episodic events characterized by BC mass loading in excess of 100 ng/m^3 and had a low of ~ < 2 ng/m^3 during June and July. These short-duration, high-mass loadings observed during late July to August are tentatively ascribed to contributions from biomass burning.

The archived North Slope of Alaska (NSA) data set contains 1-minute-averaged mass loadings and the BC number size distribution.

Acronyms and Abbreviations

ACT	Atmospheric Community Toolkit
ARM	Atmospheric Radiation Measurement
BC	black carbon
DOE	U.S. Department of Energy
GMD	geometric mean diameter
MOSAiC	Multidisciplinary drifting Observatory for the Study of Arctic Climate
NOAA	National Oceanic and Atmospheric Administration
NSA	North Slope of Alaska
PSI	Paul Scherrer Institute
PSL	polystyrene spheres
rBC	refractory black carbon
SP2	single-particle soot photometer

Contents

Figures

1.0 Background

The Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) field campaign took place during the 2019-2020 winter and entailed interdisciplinary measurements of the atmosphere, sea ice, upper ocean, and biosphere in a concerted effort to better quantify and understand the rapid changes taking place in this region. A central feature of this study was connecting the measurements conducted aboard the *Polarstern* ice-breaker observatory with a distributed network of measurements across the Arctic Circle with the goal of acquiring data that can be used to characterize the spatial variability in this region on grid-box scales. As captured in Figure 1, 12 sites were identified as part of this measurement (including the *Polarstern* observatory). Figure 1 also reveals that only a portion of the measurement network would be sampling for black carbon, depicted by the red squares. To help provide a more complete spatial coverage of refractory black carbon (rBC) loading, an SP2 was deployed at Utqiaġvik from December 2019 through October 2021. This deployment thereby provided an additional rBC measurement at a location that, in combination with the other SP2 sites, helped MOSAiC meet its science objectives by extending the rBC measurements spatially across the Arctic to enable a more optimized use of models designed at a grid-box scale +/- 15-40 km.

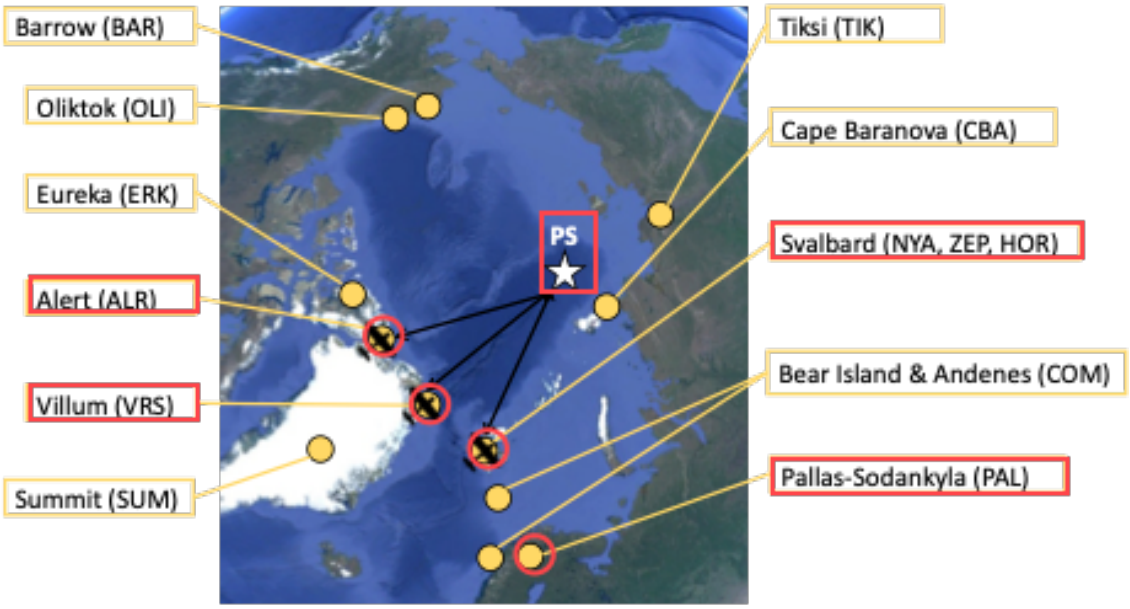

Figure 1. A network of 12 ground sites around the Arctic Circle plus the aircraft used collectively to provide spatial variability of various aerosol properties. Of the 12 ground sites, only 5, signified by the red boxes/symbols, measured refractory black carbon using the particle-resolved SP2: Polarstern, Alert, Villum, Pallas-Sodankyla, Svalbard. Graphic courtesy of M. Zanatta (AWI).

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2.0 Notable Events or Highlights

This pilot deployment of the SP2 during MOSAiC at the NSA site provided the opportunity of testing protocols for consideration of closer U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) user facility-NOAA collaboration and a more comprehensive aerosol measurement suite at Utqiaġvik in the future. NOAA has recently completed construction of a new observatory that will provide state-of -the-art space intended for cooperative science across agencies and universities.

In addition to the DOE-NOAA collaboration, this deployment also represented the first use of the Python-based data reduction ingest developed from the Atmospheric Community Toolkit (ACT) and subsequently through the ARM ENG00004151.

3.0 Lessons Learned

No instrument failures occurred during the campaign. Three data interruptions are noted (7/31-8/3; 8/11-14, and 8/28-31).

4.0 Results

Since this campaign supported MOSAiC and data analysis has recently begun, only a brief summary of the data collected is presented here.

4.1 Calibration

The incandescence channel of the SP2, used to detect refractory black carbon (rBC) was calibrated using Aquadag, while the scattering channel was calibrated using polystyrene spheres (PSL). Figure 2 shows the calibration plots for both the high-gain and low-gain incandescence and scattering channels.

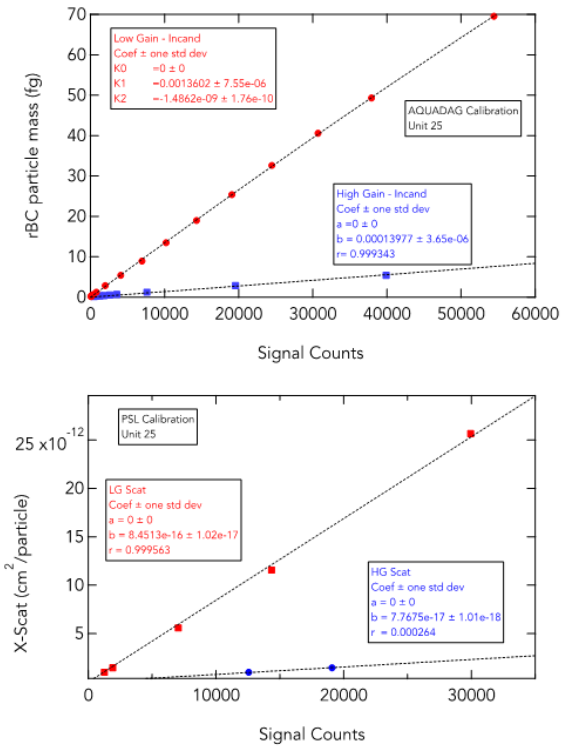

Figure 2. Calibration plots for the incandescence channel (upper panel) and the scattering channel (lower panel). Aquadag was used as the incandescence calibration material, but the coefficients were adjusted by a factor of 1.3 to give a fullerene-equivalent calibration plot. See text for more details on the fullerene-Aquadag calibration.

In the SP2 community, two calibration materials are used: Aquadag and fullerene soot. Figure 3 shows the difference in incandescence signal as a function of particle mass for these two calibration materials.

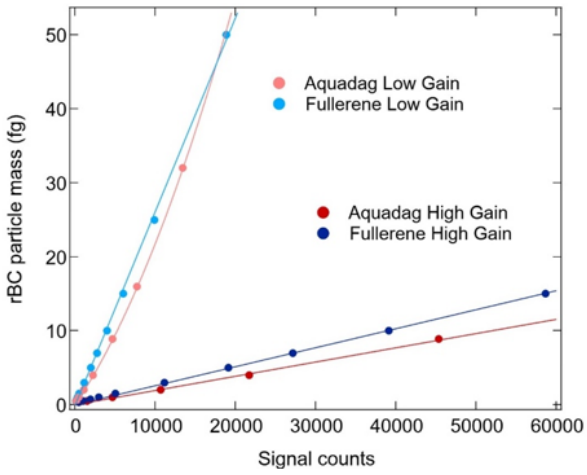

Figure 3. SP2 calibration curves for fullerene soot (blue traces) and Aquadag (red traces). This calibration plot shows that for a given particle mass, the laser-induced incandescence signal for Aquadag is larger than that observed for fullerene.

Use of Aquadag is driven mainly by its ease to use and absence of variability among differing production lots. However, fullerene soot is a more appealing calibration material because it has a similar structure (Baumgardner et al. 2012) and generates an incandescence signal per particle mass very similar to that observed for ambient soot (Laborde et al. 2012). Aquadag, in contrast, has a very different structure than ambient soot, and particle incandescence for a given Aquadag mass differs from that observed for ambient soot. For this reason, the SP2 community has adopted fullerene soot as the preferred calibration material and, in those instances when Aquadag is used to calibrate the SP2, the derived Aquadag calibration is adjusted to give a fullerene-equivalent calibration.

The impact of these two-calibration standard is readily appreciated by comparison of derived rBC mass loadings and number size distributions using in the two calibration materials. The calibrations shown in Figure 3 were used to analyze the ambient data taken at Paul Scherrer Institute (PSI) before the MOSAiC SP2 intercomparison workshop held in May 2019.

The rBC mass concentration time series collected on May 18 and 19, 2019 and determined using calibration with fullerene soot and with Aquadag are shown in the left panel of Figure 4. The fullerene soot calibration reported about 30% more rBC mass than the Aquadag calibration. Likewise, the rBC mass distribution on May 18, 2019 determined with fullerene soot and Aquadag together with their lognormal fits (right panel in Figure 4) revealed that the fullerene soot calibration gave an amplitude that is about 30% higher than that derived using the Aquadag calibration. The geometric mean diameter (GMD) determined with fullerene soot is 20 nm more than the GMD determined with Aquadag.

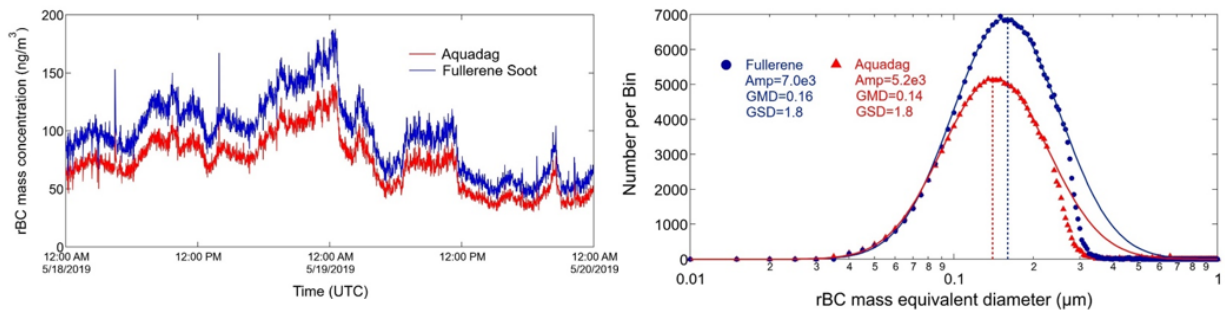

Figure 4. Examples of derived refractory black carbon (rBC) mass loading (left plot) using Aquadag (red trace) and fullerene (blue trace) calibrants. The plot on the right shows how the two different calibration materials impact the derived rBC size distribution. Data shown here was collected during the pre-MOSAiC SP2 intercomparison held at the Paul Scherrer Institute in May 2019.

As highlighted above, the SP2 community has generally agreed to reference reported rBC mass to fullerene, thereby necessitating a correction factor for Aquadag-based calibrations. Figure 5 shows a correlation plot between a fullerene and Aquadag calibration from which a correction factor of 1.3 is derived.

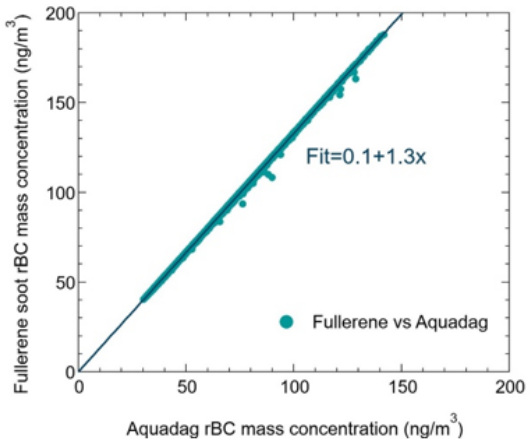

Figure 5. Correlation plot of derived rBC mass concentrations using Fullerene soot and Aquadag as calibration materials. The slope gives the correction factor to adjust the derive a fullerene-equivalent calibration from an Aquadag calibration.

Application of this correction factor brings the Aquadag-based rBC mass loadings and number size distributions in agreement with that derived using the fullerene as the calibration material (Figure 6).

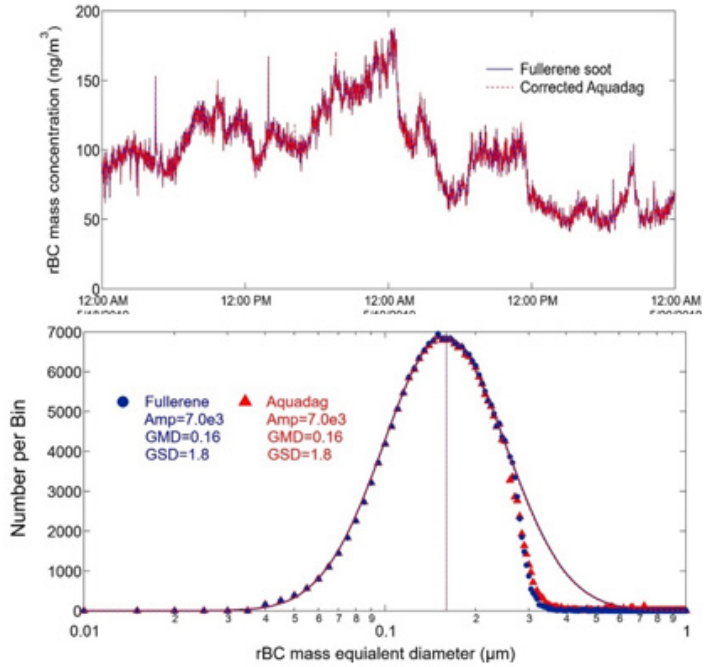

Figure 6. Application of the correction factor to the Aquadag calibration coefficients is seen to bring agreement with the fullerene-based calibration.

4.2 Refractory Black Carbon Mass Loading at Utqiaġvik

Shown in Figure 7 is the rBC concentration, ng/m^3, from January 2021 to October 2021. There is a distinct variation in the black carbon loading where the highest background levels are found from January to April which is then followed by very low background concentrations that are punctuated with very high

concentrations. These short-duration, high-concentration events are believed to be due to regional or long-range transported smoke plumes from wildfires. The observed seasonal trends are consistent with those reported by others (Barrett et al. 2017, Gogoi et al. 2016).

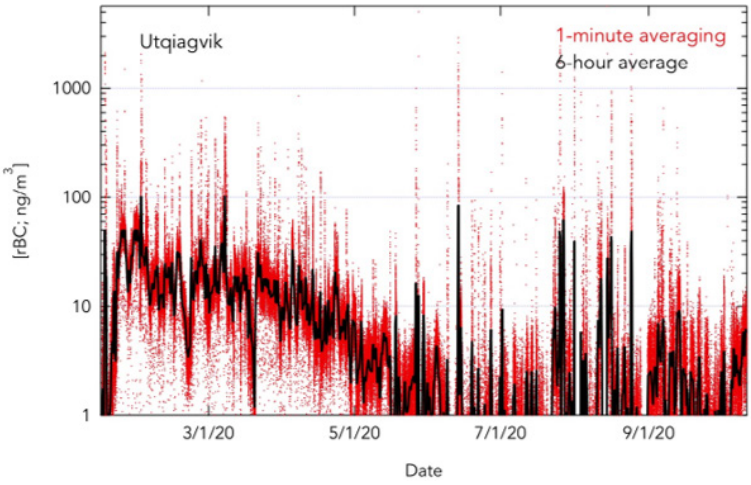

Figure 7. Refractory black carbon (rBC) mass loading measured at Utqiaġvik. Red dots represent 1-minute average, and the black trace is a 6-hour boxcar average.

Figure 8 shows the variation of the rBC number size distribution over the same sampling window shown for the black carbon loading.

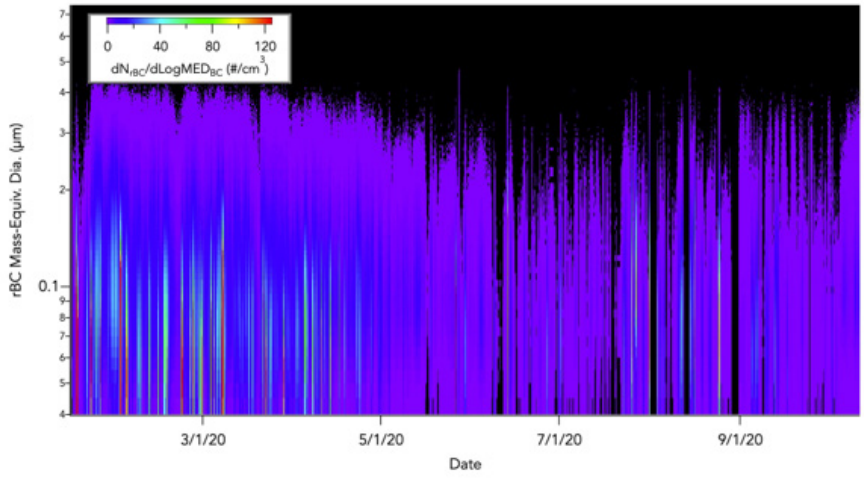

Figure 8. Refractory black carbon (rBC) size distribution. Size data is a 6-hour running average.

5.0 References

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