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Barrow Black Carbon Source and Impact Study Final Campaign Report

July 2014

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Abstract

The goal of the Barrow Black Carbon Source and Impact campaign was to characterize the concentration and isotopic composition of carbonaceous atmospheric particulate matter (PM) at the Atmospheric Radiation Measurement (ARM) Climate Research Facility site in Barrow, Alaska. The carbonaceous component was characterized by measuring the organic and black carbon (OC and BC) components of the total PM. To facilitate complete characterization of the PM, filter-based collections were used, including a medium volume $PM_{2.5}$ sampler and a high volume PM_{10} sampler. Thirty-eight fine PM fractions ($PM_{2.5}$) and 49 coarse (PM_{10}) PM fractions were collected at weekly and bi-monthly intervals. The $PM_{2.5}$ sampler operated with minimal maintenance during the 12 month campaign. The PM_{10} sampler used for the Barrow Black Carbon Source and Impact (BBCSI) study used standard Tisch "hi-vol" motors that have a known lifetime of approximately 1 month under constant use; this necessitated monthly maintenance, and it is suggested that, for future deployment in the Arctic, the motors be upgraded to industrial blowers. The BBCSI sampling campaign successfully collected and archived 87 ambient atmospheric PM samples from Barrow, Alaska, from July 2012 to June 2013. Preliminary analysis of the OC and BC concentrations has been completed. This campaign confirmed known trends of high BC lasting from the winter through to spring haze periods and low BC concentrations in the summer. However, the annual OC concentrations had a very different seasonal pattern with the highest concentrations during the summer, lowest concentrations during the fall, and increased concentrations during the winter and spring (Figure 1).

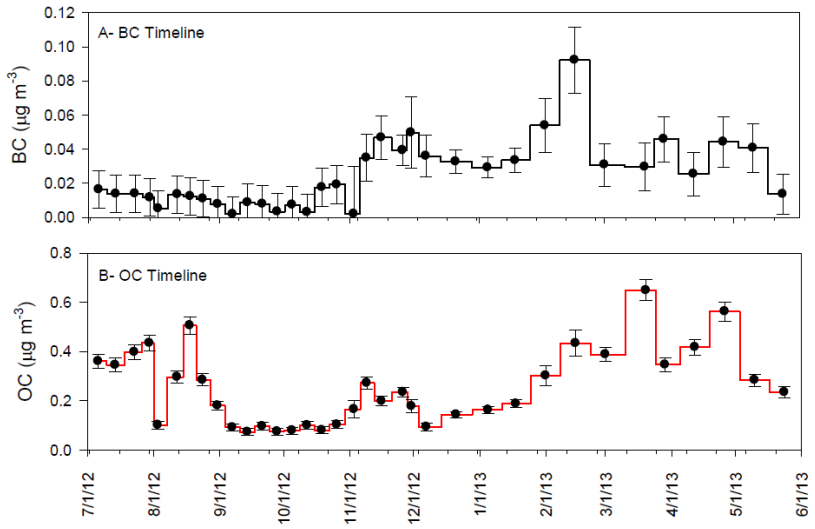

Figure 1. A – $PM_{2.5}$ black carbon concentration timeline from BBCSI field campaign; B – $PM_{2.5}$ organic carbon concentration timeline from the Barrow Black Carbon Source and Impact field campaign. Samples were taken at 1-week and 2-week intervals.

Preliminary radiocarbon source apportionment of BC and OC has been completed for the winter period. Winter results show that fossil sources of BC dominate the mid-winter Arctic BC burden (up to 72% fossil), while results for total carbon are relatively stable at 48% throughout the winter.

Acronyms, Abbreviations, and Definitions

ARM	Atmospheric Radiation Measurement
BBCSI	Barrow Black Carbon Source and Impact
BC	black carbon
NOAA	National Oceanic and Atmospheric Administration
NSA	North Slope of Alaska
OC	organic carbon
PM	particulate matter
$PM_{2.5}$	$PM_{2.5}$ is the designation for particles that less than 2.5 micrometers in diameter, which are considered to be "fine" particles. These particles are so small they can be detected only with an electron microscope. Sources of fine particles include all types of combustion, including motor vehicles, power plants, residential wood burning, forest fires, agricultural burning, and some industrial processes.
PM_{10}	PM_{10} is the designation for particles between 2.5 and 10 micrometers in diameter, which are considered to be "coarse." Sources of coarse particles include crushing or grinding operations, and dust stirred up by vehicles traveling on roads.

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1.0 Background

Two filter-based, particulate-matter (PM) samplers were deployed at the Atmospheric Radiation Measurement (ARM) Climate Research Facility site in Barrow, Alaska, from June 2012 to July 2013. The PM samplers were set up by researchers from Baylor University with the assistance of ARM field scientists and technicians. The Baylor researchers trained ARM site technicians in the operation and maintenance of the PM samplers. The PM samplers were operated for 1 year by ARM site technicians. The $PM_{2.5}$[1] sampler had 100% data coverage throughout the sampling campaign while the PM_{10}[2] sampler had an 80% data coverage rate for the length of the campaign. The $PM_{2.5}$ sampler motor was operated during the last week of sampling prior to instrument take-down. One of the major sampling time commitments for the onsite technicians was the regular maintenance required on the blower motors for the PM_{10} sampler. The motor on the PM_{10} sampler needed regular replacement (at minimum once per month) throughout the campaign. Motor failure sometimes occurred during severe weather, causing short-term loss of sampling coverage. After discussions with technicians, it has been determined that, to reduce maintenance requirements and to achieve higher data coverage, industrial-grade blowers will be used for the PM_{10} sampler in any future sampling campaigns in the Arctic. A seven-channel aethalometer also was onsite through September, but it was removed because of a technical malfunction. The aethalometer has been repaired and is now fully operational, and would be available for any future Arctic BC sampling.

2.0 Results

Following the filter collection in Barrow, the filters were shipped to Baylor University for offline analysis of OC and BC. The OC and BC concentrations were measured using a thermal optical transmission protocol for carbon measurement (Sunset Carbon Analyzer). The BC measured via the thermal optical transmission protocol would often be termed elemental carbon, but the more general BC term will be used here. Average PM_{10} OC and BC concentrations for spring, summer, winter, and fall at Barrow are presented below in Table 1.

Table 1. Seasonal averages of organic carbon and black carbon concentrations at Barrow, Alaska, during the sampling campaign

Seasonal Averages	OC ± Standard Deviation (ug/m^3)	BC ± Standard Deviation (ug/m^3)
Spring	0.084 ±0.009	0.039 ±0.007
Summer	0.38 ±0.04	0.01 ±0.02
Fall	0.13 ±0.01	0.029 ±0.007
Winter	0.43 ±0.03	0.07 ±0.01

[1] $PM_{2.5}$ is the designation for particles that less than 2.5 micrometers in diameter, which are considered to be "fine" particles. These particles are so small they can be detected only with an electron microscope. Sources of fine particles include all types of combustion, including motor vehicles, power plants, residential wood burning, forest fires, agricultural burning, and some industrial processes.

[2] PM_{10} is the designation for particles between 2.5 and 10 micrometers in diameter, which are considered to be "coarse." Sources of coarse particles include crushing or grinding operations, and dust stirred up by vehicles traveling on roads.

The distinct seasonal trends of elevated BC concentrations during the winter and spring demonstrated for the Barrow Black Carbon Source and Impact (BBCSI) campaign follow long-term seasonal trends for Arctic BC. This indicates the period from 2012 to 2013 is likely representative of long-term trends. The BBCSI campaign measurement of annual OC is unique as there is no long-term monitoring of OC at Barrow. Of note for the BBCSI campaign was high OC concentrations during the summer and winter months. To mitigate high concentrations of BC during the winter months, it is relevant to understand the contributions of different emission sources and different source regions to the total BC concentration. To address this question, radiocarbon analysis was used to quantify the contribution of fossil fuel combustion (fossil carbon) and biomass burning sources (contemporary carbon) to Arctic BC. To achieve this, the BC fraction of the PM_{10} samples was isolated from the OC fraction and subjected to radiocarbon analysis. Radiocarbon analysis has been completed for a subset of PM_{10} winter samples and a manuscript with details and results of this analysis is currently in process and will be submitted to a peer-reviewed journal in the early fall of 2014. Briefly, it was found that fossil carbon dominated Arctic BC in the mid-winter, while the contributions of fossil and contemporary carbon to BC are relatively even in the late winter. This study also highlights the importance of in-Arctic BC sources during the winter months. These results can be used to ground-truth emission inventories of Arctic BC sources, including gas flaring, residential burning, and spark-ignition engines (Stohl et al. 2013). Radiocarbon analysis for the full sampling period will be completed this year.

The abstract from the forthcoming manuscript is provided below:

"Black carbon is a major driver of climate change in the Arctic. Over the last century, the Arctic has undergone rapid warming at a rate almost twice that of the global mean. Accurate quantification of source contributions improves understanding of transport efficiencies of different emission sources (i.e. wildfires, fuel oil combustion and gas flares) from different source regions (i.e. Arctic vs. East Asia or North America). Here we present for the first time the split between fossil and contemporary biomass source contributions to atmospheric particulate black carbon and total carbon in the Arctic using radiocarbon abundance. We find that fossil fuel combustion dominates black carbon in mid-winter (ranging from 54 to 72%), while the fossil contribution for total carbon is relatively stable at 48 ±3%. These results can then be used to ground-truth molecular marker – chemical mass balance and emission inventory apportionment which implicate gas flaring, residential burning, and spark-ignition engines as major sources. Back trajectory analysis indicates two dominant source regions for this winter campaign, Northern Canada and Northern Russia. With intensifying Arctic oil exploration, shipping, and residential impacts, it is important to accurately quantify fossil and biomass source impacts to the aerosol burden in the Arctic."

3.0 Future Research Opportunities

Initial results from the BBCSI campaign inspire additional research questions:

- What are the year-to-year trends in fossil vs. biomass contributions to winter BC concentrations?
- What is the spatial variability in the sources of BC at for the North Slope of Alaska (NSA)?
- For the Arctic?

- What is the impact of emerging regional sources (oil and gas exploration and extraction) to the Arctic BC burden?

Additional sampling in the NSA is needed in order to determine the spatial extent, chemical composition, and year-to-year variability of Arctic carbonaceous PM. A combination of high-intensity, short-term campaigns, and longer-term monitoring and characterization are needed to answer these questions. A high-intensity summer campaign and a yearlong OC and BC monitoring campaign are described below as examples of studies attempting to address these ongoing questions.

Dr. Kerri Pratt (University of Michigan) and Dr. Rebecca Sheesley (Baylor University) are conducting summer sampling intensives at ARM sites in Barrow and Oliktok Point, Alaska, in 2015 and 2016 to characterize the local impacts and regional distribution of OC and BC. This field work is being funded by a National Oceanic and Atmospheric Administration (NOAA) grant (NOAA-OAR-CPO-2014-2003692), *Assessment of Atmospheric Aerosols Resulting from Oil and Gas Extraction Activities near the North Slope of Alaska* combined with an ARM field campaign. This project will allow for intensive sampling at Barrow and Oliktok Point for 1 month during the summers of 2015 and 2016. This intensive campaign combines the highly specific aerosol time-of-flight mass spectrometer, which gives number concentrations and chemical composition of individual particles, with filter sampling and offline chemical analysis and source apportionment of OC and BC. This sampling will enable further exploration of the high OC concentrations observed at Barrow during the first sampling campaign, specifically focusing on emerging regional sources, on the Arctic and NSA scales. Results from the sampling intensives will be compared to previous results from Barrow to determine if sources of OC are consistent from year-to-year and across the NSA.

Dr. Sheesley has submitted an ARM Climate Research Facility Field Campaign Proposal, *Multi-Faceted Approach to Characterizing Potential Radiative Forcing on the NSA using Two Coastal Sites*, which will exploit the ARM Mobile Facility–Aerosol Observing System deployment at Oliktok Point to more fully characterize sources and optical properties of OC and BC in the NSA. The proposed field campaign also will align with the NOAA 2015 to 2016 summer campaign to give an annual background to the intensive chemical characterization. Filter collection and offline radiocarbon source apportionment of BC and OC at Barrow and Oliktok Point would allow the two sites in the NSA to be included in the *Pan-Arctic ^{14}C-BC Observatory Program*, an international collaboration led by Stockholm University (Sweden) to combine circumpolar observations with transport modeling to explain BC sources and transport in the Arctic.

4.0 References

Stohl, A**,** Z Klimont, S Eckhardt, K Kupiainen, VP Shevchenko, VM Kopeikin, and AN Novigatsky. 2013. “Black carbon in the Arctic: The underestimated role of gas flaring and residential combustion emissions.” *Atmospheric Chemistry and Physics* 13:8833–8855. DOI:10.5194/acp-13-8833-2013.

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