

Using an Unmanned Aircraft to Observe Black Carbon Aerosols During a Prescribed Fire at the RxCADRE Campaign

Tara L. Craft, Catherine F. Cahill, and Gregory W. Walker

Abstract - Black carbon (BC) aerosols impact the earth's climate by absorbing solar radiation in the atmosphere and depositing on ice surfaces and lowering the albedo of those surfaces. Black carbon aerosols have been widely studied; however, using small unmanned aircraft systems (UAS) for the airborne study of the vertical and horizontal concentrations of BC is new territory. Using UAS to study BC poses some challenges due to size and weight restrictions of the aircraft, as well as issues that arise when adapting ground based instrumentation for use on different aircraft. University of Alaska Fairbanks researchers successfully integrated and flew a microAeth AE-51 on a Boeing ScanEagle to measure the concentration of BC and other absorbing and scattering particles during a prescribed fire experiment, RxCADRE, conducted at Eglin AFB, FL, during October and November 2012. The microAeth successfully collected black carbon aerosols in the smoke plume when the Boeing ScanEagle UAS encountered the plume.

Index Terms - Black Carbon, Fire, Smoke, RxCADRE, UAS

I. Introduction

Atmospheric aerosols influence global climate by absorbing and scattering long and short-wave radiation. The absorbing and

scattering of radiation can cause warming or cooling of the atmosphere in the regions impacted by the aerosol. Black carbon (BC) is a primary aerosol, emitted directly at the source from incomplete combustion processes, such as fossil fuel and biomass burning, and is a major contributor to radiative forcing. Much atmospheric BC is of anthropogenic origin [1], but wildfires account for at least 40% of global black carbon production [2]. When BC is deposited onto surfaces, such as snow and ice, the albedo of the Earth's surface decreases, causing a decrease in reflected solar radiation and an increase in absorbed solar radiation that leads to melting of the snow and ice around deposited particles as the dark BC particles absorb the solar radiation, heat up, and melt the snow and ice around them. General circulation models (GCMs) suggest that the reduction of sea ice and snow albedo by BC is three times as effective as CO₂ forcing for global average surface warming [3].

There is currently a wide range of sensors that allow for the measurement of aerosols, in particular; BC. There is not, however, a wide range of sensors that allow for the airborne measurement of BC aerosols using small unmanned aircraft systems (UAS). Currently, the aerosol measuring capabilities on small UAS is limited to non-existent due to payload weight and size restrictions. The successful adaptation and

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Tara L. Craft is a Master's Candidate at the University of Alaska Fairbanks, Department of Chemistry and Biochemistry, Fairbanks, AK 99775 USA (email: tcraft2@alaska.edu).

Catherine F. Cahill is a professor of chemistry at the University of Alaska Fairbanks, Department of Chemistry and Biochemistry, and Geophysical Institute, Fairbanks, AK 99705 USA (email: cfcahill@alaska.edu).

Gregory Walker is the Chief Technical Officer and Founding Director of the Alaska Center for Unmanned Aircraft Systems Integration at the Geophysical Institute of the University of Alaska Fairbanks, Fairbanks, AK 99775 USA (email: gregory.walker@gi.alaska.edu).

integration of ground-based aerosol sensors on UAS will allow for more understanding of the spatial and temporal distribution of aerosol mass concentration, composition, and size. This paper will discuss the successful integration of a micro-aethalometer, an instrument that measures BC, onto a University of Alaska Fairbanks (UAF) UAS during a 2012 field campaign, RxCADRE (Prescribed Fire Combustion-Atmospheric Dynamic Research Experiments), at Eglin Air Force Base, Florida.

II. Methods

Between October 31st and November 6th 2012, scientists from the University of Alaska Fairbanks used ground-based instrumentation to collect aerosols in the plumes created by 4 different prescribed burns during the RxCADRE experiment. There were three small plot burns (Picture 1) approximately 5 to 10 acres each, as well as one large plot burn (Picture 1) approximately 1600 acres. The small and large plots uniformly contained grass fuels. Aerosols from the small plot burns were only collected by ground-based sensors due to the short duration of the burn and the high flight altitude of the UAF Boeing ScanEagle, which was above the low smoke plume.



Fig. 1. The left image shows the layout of the small-burn plots (S5-S3). The right image shows the layout of the large plot (B-70) in relation to the small plots.

During the large plot burn, there were 6 aircraft, from multiple institutions, orbiting simultaneously over the plot and providing an excellent demonstration of airspace deconfliction. There were two manned aircraft (Cessna 206, and Piper Navajo fitted with a WASP sensor), and four unmanned aerial systems (2-G2Rs, an Aeryon Scout, and a

Boeing ScanEagle), collecting different sets of data during the prescribed burn.

Unmanned Aircraft System

The UAS platform for the aerosol instrumentation was a Boeing ScanEagle [4] from UAF. The ScanEagle is an autonomous aircraft that is launched from a trailer mounted, Mark 4 launcher, and is typically used for surveillance purposes. The ScanEagle has the following dimensions: 5.6 ft. (1.71 m) L x 10.2 ft. (3.11 m) W (wingspan). This UAS can weigh between 30.9 lb. (empty structure) and 48.5 lb. (max takeoff weight) and has a fuel engine. It can fly for over 24 hours and up to 19,500 feet (5,950 m). The horizontal speed maximum is 80 knots and typical cruise speeds are between 50 and 60 knots (25.7 m/s and 30.9 m/s, respectively).

Instrumentation

The instrument used to record the BC concentration was the microAethalometer (microAeth) manufactured by Aethlabs in San Francisco [5]. The microAeth provides real-time analysis by continuously measuring the absorption and scattering of transmitted light an aerosol deposits on a T60 Teflon-coated borosilicate glass fiber filter. Two microAeths were used at RxCADRE: the first is a single wavelength (AE-51) and that measures optically absorbing particles at 880 nm, which is interpreted as the concentration of BC; and the second microAeth (AE-52) is a multi-wavelength sensor and that measures both absorbing and scattering (UVPM) particles at 880 nm and 370 nm, respectively. The 370 nm is interpreted as an indicator of aromatic organic compounds like those found in tobacco smoke, wood, and biomass burning smoke. Both microAeths have a preferred measurement range of 0 to 1 mg BC m⁻³, with a measurement precision ±0.1 µg BC m⁻³. The microAeths weigh approximately 0.62 lbs (280 g) and have the following dimensions: 4.6 in (117 mm) L x 2.6 in (66 mm) W x 1.5 in (38 mm) D. Both instruments were designed for ground-based operation and the main goal of

the UAF scientists participating in the campaign was to adapt one of the microAeths, the AE-51, for use on the Boeing ScanEagle.

Advantages and Disadvantages of using UAS

There are many advantages to using a UAS instead of a manned aircraft. A UAS can fly in hazardous areas and collect real-time air samples without putting humans at risk. They are less expensive than manned aircraft and less expensive to maintain in the long-term. The UAS is more maneuverable and can have longer dwell times than manned aircraft, meaning it can stay in the air longer than manned aircraft. Aircraft pilots can only fly for a certain amount of time before they need to take a mandatory rest period. Unmanned aerial systems can stay airborne as long as their fuel will allow.

While there are many advantages to using a UAS, there are some disadvantages as well. The FAA (Federal Aviation Administration) has tighter regulations for using a UAS versus a manned aircraft. In some cases, the FAA needs to be contacted years in advance of the UAS flight. Typically the UAS platform is smaller than a manned aircraft so the payload weight and size capabilities are more restricted. Filter saturation for onboard sensors is also an issue, especially if the sensor needs to have filter strips changed periodically. If the filter changing is autonomous then the UAS can stay airborne until the end of sampling. If the filter needs to be changed manually; either the aircraft needs to return to base during sampling for a filter change, or the instrument does not collect samples for the entire duration of the flight.

III. Results

The two-wavelength microAeth (AE-52) mounted on a 1.3 m ladder (Pic. 2), collected smoke absorption data for the three small-burn plots (S5, S4, and S3) on November 1st, 2012 (Fig. 1). The ladder was positioned in the expected paths of the smoke plumes from each fire. Due to the variability of the winds, the

microAeth was not in the center of the plume for all three fires. The ladder was moved between the S5 and S4 fires, fires 1 and 2 respectively, to maximize the smoke collected by the microAeth. During the S4 fire, oversaturation was reached, as indicated by the arrow in Fig. 1. After oversaturation occurs, the instrument only responds to large changes in concentrations impacting the filter. There is minimal data from fire S3 because the wind blew most of the smoke plume to the west of the microAeth, not because the sampler was oversaturated.

During the fires, there is a larger signal in the 880 nm wavelength of the microAeth than the 370 nm wavelength because the smoke plume contained many light-scattering particles in addition to the highly absorbing black carbon particles identified by the 370 nm wavelength absorption and the 880 nm wavelength is sensitive to both types of particles. The observed peak height difference between the two wavelengths therefore correlates to how much organic carbon is in the sample. This result implies that over half of the particulate matter in the smoke plume is organic matter produced by the incomplete combustion of the fires' fuels.



Pic. 2. Instrumentation setup for small plot burns (S5-S3). Both the DustTrak (left) and the microAeth (right) were collecting smoke samples for all three small burns. The ladder was 1.3 meters high.

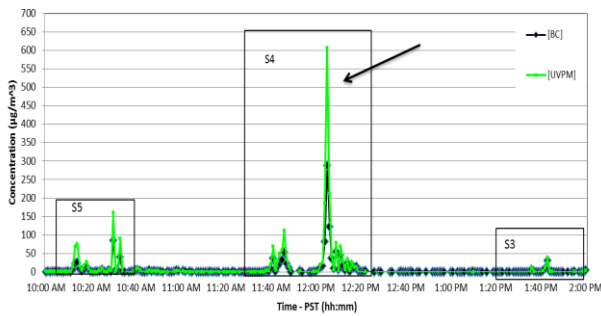


Fig. 1. Ground based instrument data from the AE-52 (multi-wavelength microAeth). The black arrow on the graph is showing where oversaturation occurred.

Fig. 2 shows the results from the DustTrak [6] collected during the three small plot burns. TSI measures respiratory (RESP) size fractions as $PM_{4.0}$. Fig. 2 shows most of the collected particles are very fine, mostly in the $PM_{1.0}$ range. This shows that these aerosols are very near the point of combustion and brand new. The same pattern is observed, as in Fig. 1, but the concentrations vary because: PM_{10} includes $PM_{4.0}$ which includes $PM_{2.5}$ which includes $PM_{1.0}$. Just focusing on the 2 mg m^{-3} recorded for $PM_{1.0}$, there is a trend at each size fraction, the same peak can be seen at each size fraction indicating all of collected particulates are really small ($PM_{1.0}$) which is consistent with a fresh, hot burn. Another important feature of Fig. 2; the concentrations are recorded in mg m^{-3} which leads to the conclusion, the microAeth is underestimating the amount of particulate generated by the fire, since the microAeth is getting oversaturated at 0.6 mg m^{-3} whereas the DustTrak is recording up to 2 mg m^{-3} .

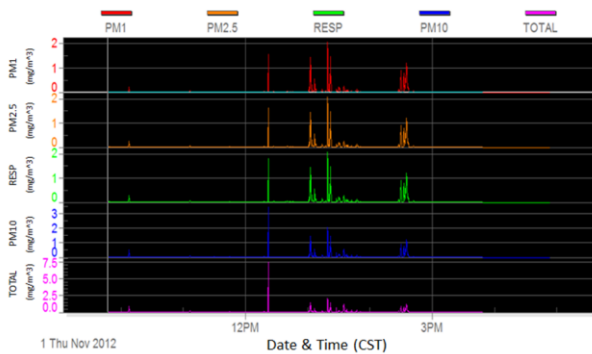


Fig. 2. Data from the TSI DustTrak for the small plot burns on November 2nd, 2012.

We were successful in mounting the one-wavelength microAeth (AE-51) onto a Boeing ScanEagle aircraft (Pic. 3 and 4) for the large plot burn (plot B-70) on November 2nd, 2012. The microAeth was placed in the back of the fuselage in front of the fuel compartment. The inlet tube for the instrument stuck 1.3 cm out of the bottom of the aircraft and created a straight path from outside the airframe into the instrument. This was the first integration of an Aethlabs microAeth on an unmanned aircraft.



Pic. 3. Photo showing the placement of the microAeth (AE-51) in the fuselage compartment of the Boeing ScanEagle. The AE-51 was positioned in the back of the fuselage and held in place by Velcro. Weight and balance adjustments were made after the integration.



Pic. 4. Photo showing the position of the inlet tube for the AE-51 (circled in white). The inlet stuck out of the bottom of the fuselage through one of the holes where an extra screw was used. The inlet only extended 1.3 cm from the fuselage to minimize the effect of wind on the inlet tube shape and orientation.

The ScanEagle was launched at 8:40 am CST and flown just under 9 kilometers to the region of the large plot burn. The ScanEagle flew in circular pattern 500 m above the prescribed burn to observe the burn and its smoke plume

from 360 degrees around the fire. It orbited for 5.5 hours until the prescribed burn was completed and it returned home to land at 2:30 pm CST.

Figure 3 shows the concentration of black carbon aerosols collected by the microAeth during the flight over the large plot burn. The smoke plume reached the ScanEagle altitude at 1:04 pm CST as shown by the increase in black carbon concentration in Figure 3. The magnitude of the peaks in Figure 3 are smaller than Figure 1 because for the small burns (Fig. 1) the microAeth was ground-based, right in the line of the smoke for the majority of the burns. During the large burn (Fig. 3), the smoke was mostly below our instrument as the ScanEagle was orbiting the plot. The peaks at 8:38 am and 2:15 pm CST are the result of exhaust and generator emissions at the unmanned aircraft staging platform.

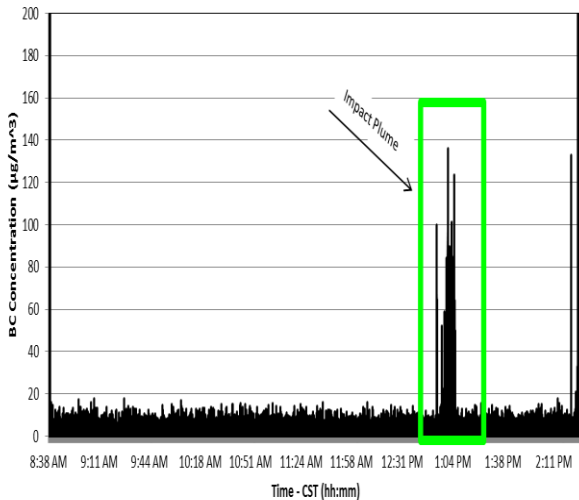


Fig. 3. Data collected from the airborne micro-aethalometer (AE-51) over the large plot burn. The green box shows the instrument successfully collected data when it impacted the plume.

IV. Conclusions

The RxCADRE campaign, from October 31 and November 6th 2012, was an opportunity to incorporate a ground-based micro-aethalometer on a Boeing ScanEagle. During the campaign, 4 grass plots were burned (Picture 1). Ground-based sensors (microAeth

and DustTrak) were collecting smoke particulate data during the small-burn plots (S5-S3). Comparing the ground based instruments (Fig. 1 and 2); there is an underestimation of the particulate concentration being recorded by the AE-52. The DustTrak helps to confirm this point because there is a difference in magnitude of 1000 between the concentrations recorded by both instruments; the AE-52 was recording in micrograms whereas the DustTrak was recording in milligrams. During the large-burn plot (B-70), there was a successful integration and flight of a one-wavelength microAeth onto the ScanEagle by scientists at the University of Alaska Fairbanks. Having the BC sensor onboard allowed for airborne measurements within the smoke plume. Fig. 3 proves the integration was successful, showing the large uptake of BC aerosols when the plume was impacted at 1:04 pm CST.

There is work that still needs to be completed in this emerging field. Laboratory work will help to troubleshoot the microAeth so there is a better understanding of how quickly the microAeth responds when it encounters an aerosol plume. Also, in the laboratory, aerosols of known composition will be generated using the aerosol generator and optical particle counter to help calibrate the microAeth. Currently, it is believed that the concentration range measurable by the microAeth is 0-1 mg BC m⁻³, but the true limits of the sensor need to be tested to determine how sensitive the microAeth is to various aerosol compositions and concentrations. An optical particle counter will give an aerosol size distribution that will allow knowledge of what sized aerosols may be lost during sampling. The integration of the microAeth on different aircraft is another major goal, so the sensor can become a standardly-used instrument for UAS-based BC measurements around the world.

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