Vertical and Spatial Profiling of Arctic BC on the North Slope of Alaska 2015: Comparison of Model and Observations

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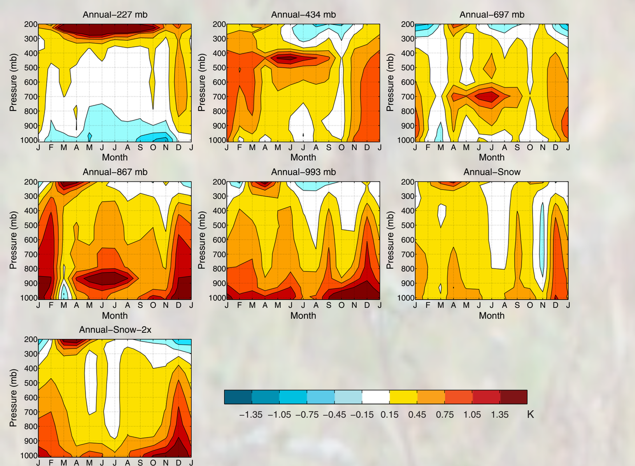
Abstract

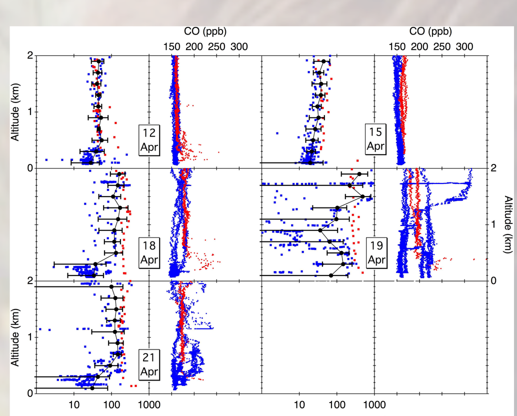
One of the major issues confronting aerosol climate simulations of the Arctic and Antarctic Cryospheres is the lack of detailed data on the vertical and spatial distribution of aerosols with which to test these models. This is due, in part, to the inherent difficulty of conducting such measurements in extreme environments. One class of under measured radiative forcing agents in the Polar Region is the absorbing aerosol – black carbon and brown carbon. In particular, vertical profile information of BC is critical in reducing uncertainty in model assessment of aerosol radiative impact at high latitudes.

During the summer of 2015, a Single-Particle Soot Photometer (SP2) was deployed aboard the DOE Gultstream-1 (G-1) aircraft to measure refractory BC (rBC) concentrations as part of the DOE-sponsored ACME-V (ARM Airborne Carbon Measurements) campaign. This campaign was conducted from June 1 through September 15 along the North Slope of Alaska. Flights started in Deadhorse (PASC) and was punctuated by vertical profiling over 5 sites (Atquasuk (PATQ), Barrow (NSA), Ivotuk, Oliktok (AMF), and Toolik). In addition to rBC, measurement of CO, CO_2 and CH_4 were also taken to provide information on the spatial and seasonal differences in GHG sources and how these sources correlate with BC. It is expected that the aerosol and gas phase measurement will provide an important dataset to assess the representativeness of ground sites at regional scales.

Introduction

Light absorbing aerosols are expected contribute to radiative forcing much as they do in the mid-latitudes – through atmospheric warming (direct effect) and alteration of cloud properties (semi-direct effect) collectively causing surface dimming and subsequent surface cooling. Such behavior has recently been predicted in a series of equilibrium climate simulations conducted by Flanner (2013). The figure on the left (Flanner 2013) displays the temperature profiles as a function of month for five different injection heights of BC. As is readily seen, the surface temperature response is seen to be sensitive to the BC vertical distribution.



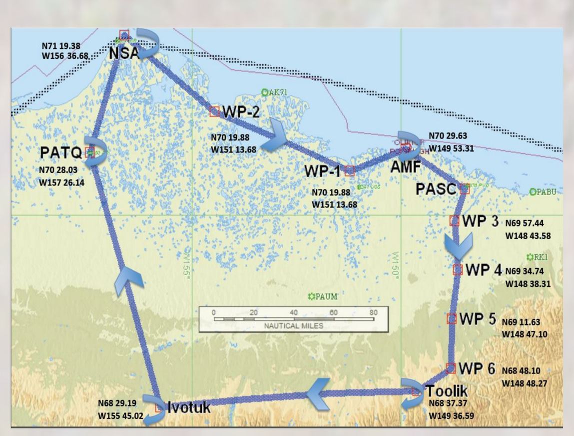


The figure on the upper right shows the vertical profiles of the rBC mass mixing ratio, and CO measured during the ARCPAC campaign (Spackman et al., 2010). The blue traces are for measurements conducted over ice and open leads while the red traces represent the ascent/descent around Fairbanks. The black line is the mean rBC profile for all the flights conducted during ARCPAC. A tendency for rBC concentrations to increase with altitude in the lower atmosphere is found, with some profiles exhibiting a loading maximum at altitudes of 3-4 kms.

ACME-V Field Campaign

The DOE-sponsored ACME-V field campaign, conducted along the North Slope of Alaska provides the opportunity to comparison observations with global climate model (CAM5) simulations to examine the ability of the model to capture observed monthly mean vertical profiles of BC and stratified aerosol layers. Additionally, armed with the observational data, radiative forcing calculations can be conducted to evaluate the impact on local energy balance due to uncertainty in simulated BC profiles during summer time over Arctic.

Shown on the right is the ACME-V flight track on conducted on June 7, 2015, where profile flights were conducted over 5 sites along the North Slope of Alaska (courtesy J. Hubbe (PNNL)).



Gultstream-1 (G-1) Platform

Aircraft Technical Information*

- **Length:** 19.4 m
- **Wingspan:** 23.9 m
- **Height:** 7.1 m
- **Cabin space:** 15.3 m^2
- **External probes (PMS cans):** 8
- **Maximum gross weight:** 16,330 kg
- **Maximum Endurance:** 9.5 hours
- **Maximum Range:** 4000 km
- **Endurance with full payload:** 4-5 hours
- **Crew capacity:** 7 max, 2 pilots + 3-5 scientists
- **Cabin payload:** 1,900 kg
- **Research Power:** 700A @ 28 VDC (incl. 85A @ 115 VAC, 60 Hz)
- **Ceiling:** 7.6 km

Courtesy: B. Schmid/PNNL

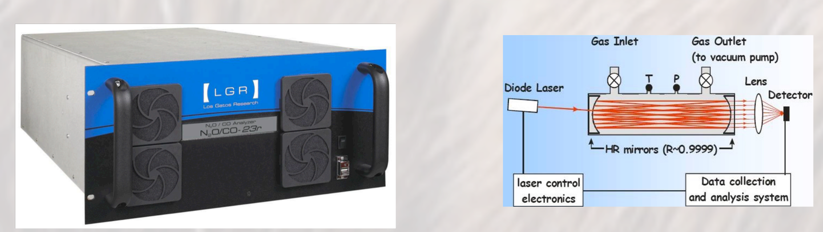
Instrumentation

Single Particle Soot Photometer (SP2)

Probe refractory black carbon (rBC) using laser-induced incandescence

- rBC mass loading; rBC size/mass distribution; rBC mixing state

CO, H_2O, N_2O Analyzer



Probe CO and N_2O using multipass white cell (NIR absorption)

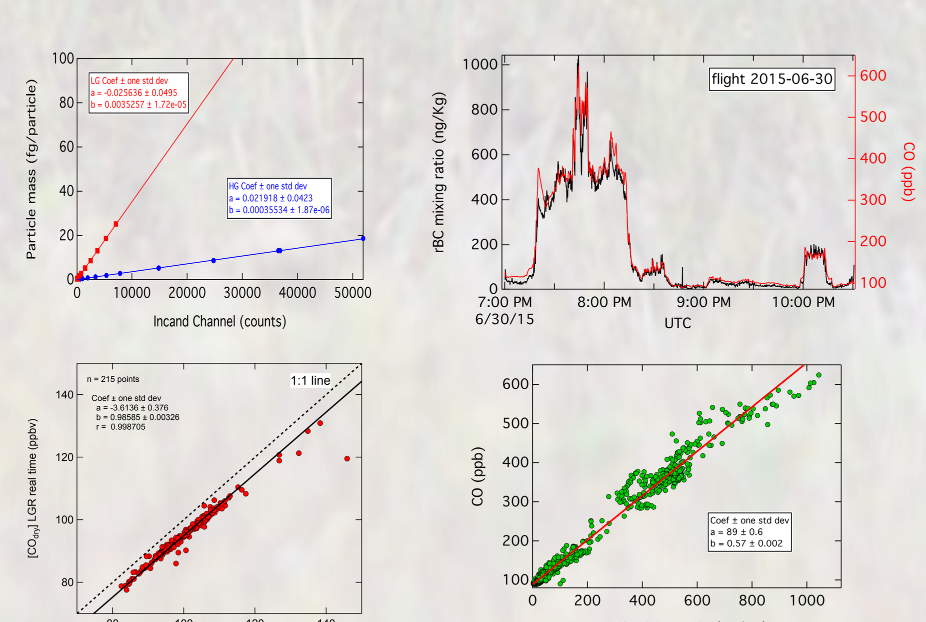
- CO and N_2O Calibration against 3-5 grab samples per flight
- CO and N_2O Precision: < 1 ppbV with ~10 sec time response

CO_2, CH_4, H_2O Analyzer

Probe CO_2, CH_4, and H2O using Cavity Ring-Down Spectroscopy (IR absorption)

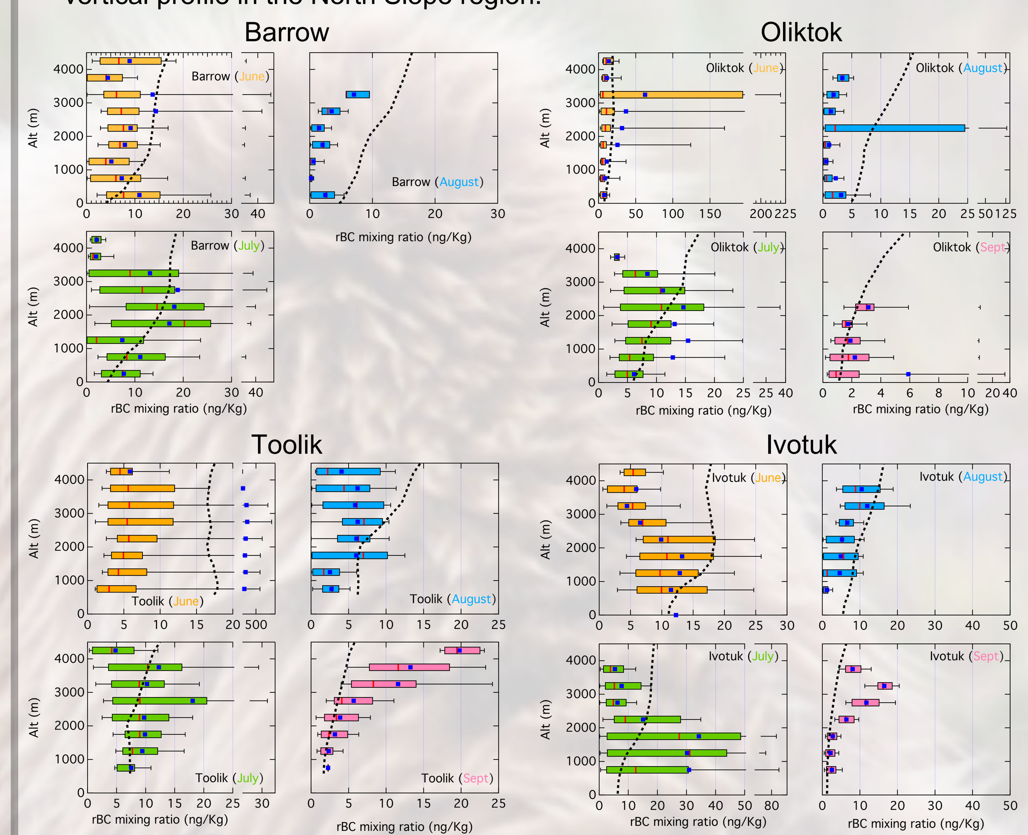
- Calibration against WMO standards
- Precision: < 0.2 ppm for CO_2; < 1 ppbv for CH_4

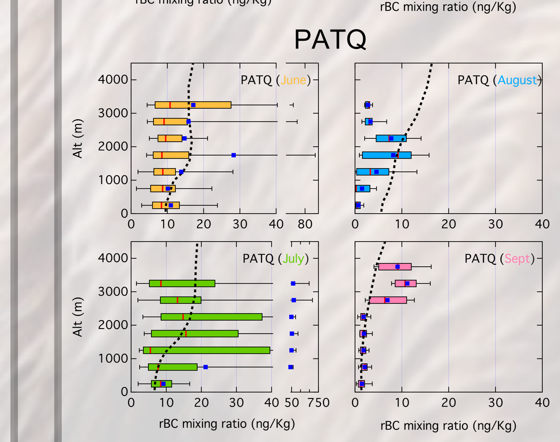
Example Data Streams and Selected Calibration plots



Profiling Statistics

ACME-V provided the opportunity to collect much needed statistics on the rBC vertical profile in the North Slope region.

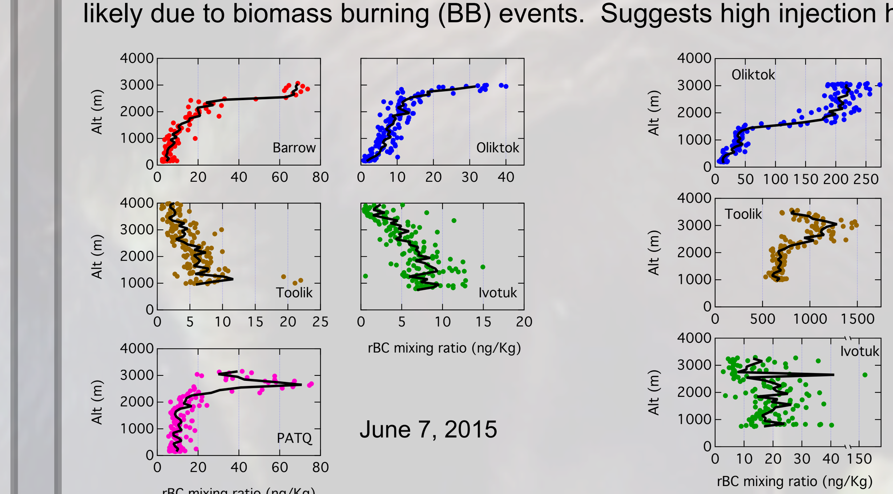




Box and whisker plots of the monthly median, means and 10, 25, 75, and 90 percentiles. Dotted line is CAM5 model based on 2011 inventory.

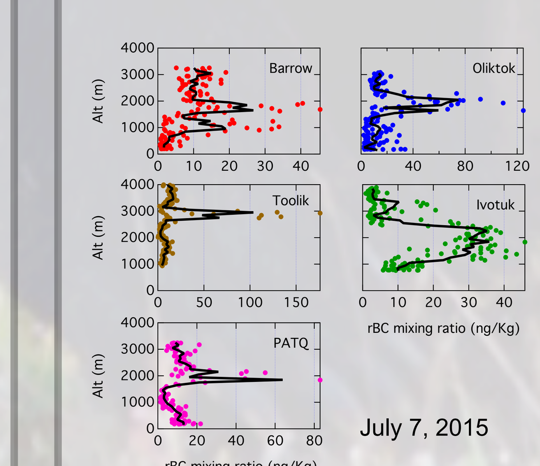
Observation-model agreement varies from very good: PATQ (June/July); Toolik (July); Barrow (July) to very poor [3x difference] Toolik (June & Sept); Barrow (Aug); Oliktok (Aug).

Several rBC profiles reveal the presence of pronounced aerosol stratification likely due to biomass burning (BB) events. Suggests high injection heights.



June 7, 2015

June 30, 2015



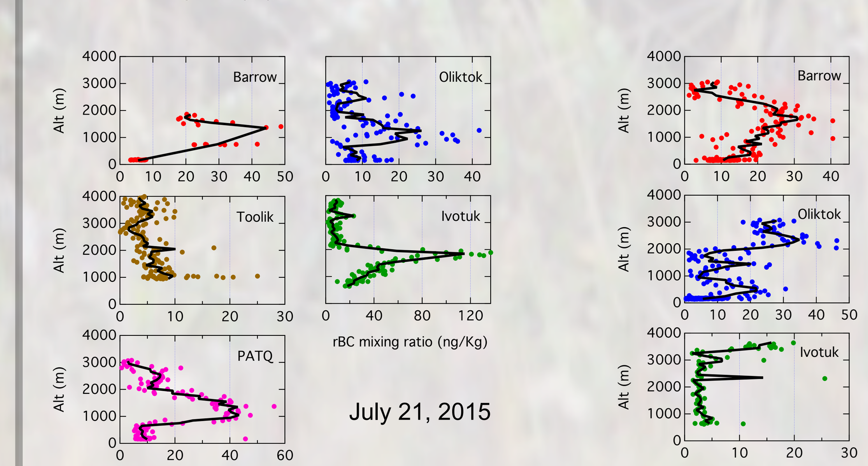
July 7, 2015

These events will drive the monthly mean rBC vertical distributions (shown above) if these events are frequent.

Day-to-day model-data comparison not shown here since model requires realistic fire emissions.

Vertical location of rBC likely indicate injection heights, and aging time

High rBC events may provide a good data set for studying BB aerosol properties over Arctic.

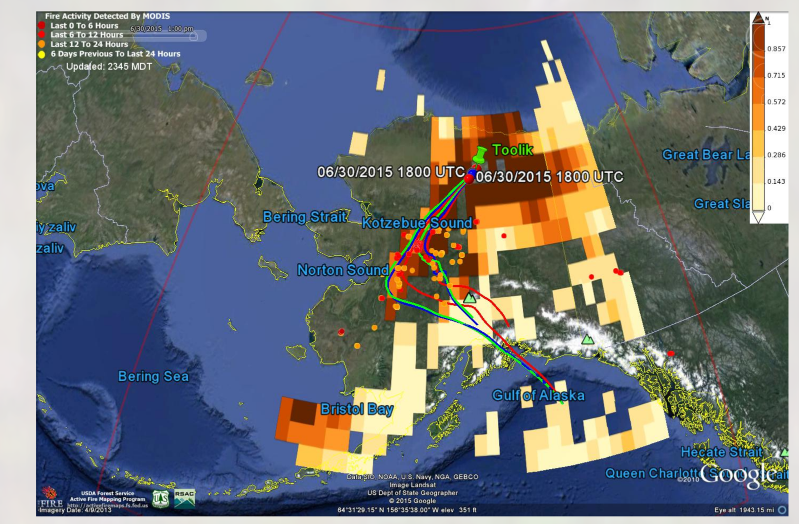


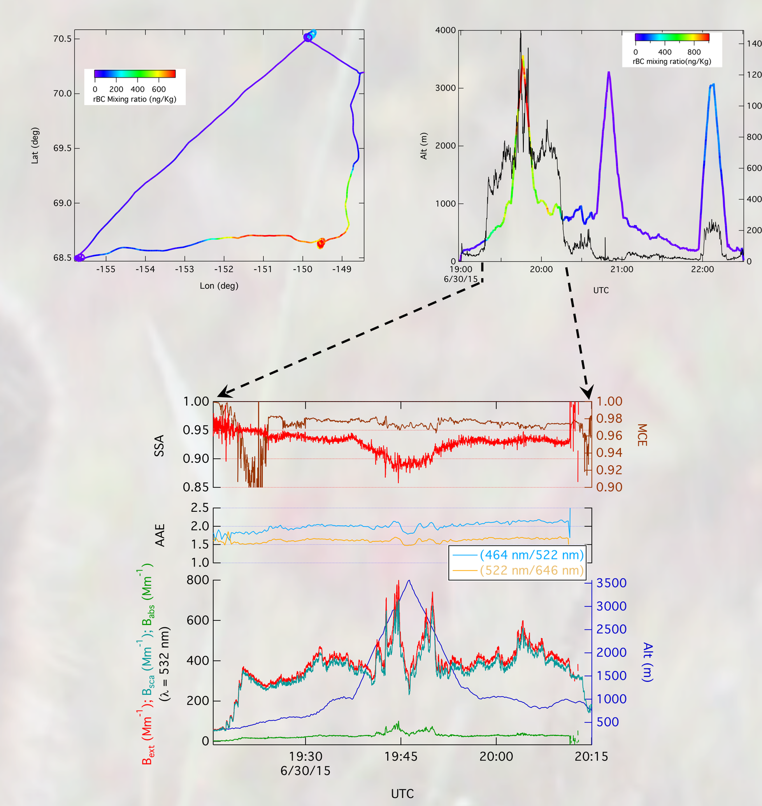
July 21, 2015

July 22, 2015

Biomass Burning Event (2015-06-30)

Fire activities and AOD at 550 nm from MODIS and back trajectory at 3000 m.





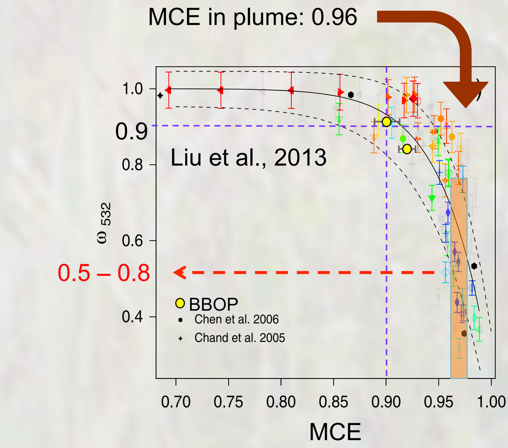
Modified Combustion Efficiency (MCE) is used as an index for the relative amount of flaming & smoldering combustion during a fire (Ward & Radke 1993)

$$MCE = \frac{\Delta CO_2}{\Delta CO_2 + \Delta CO}$$

MCE → 1: more flaming contribution

MCE = 0.8 – 0.9: more smoldering contribution

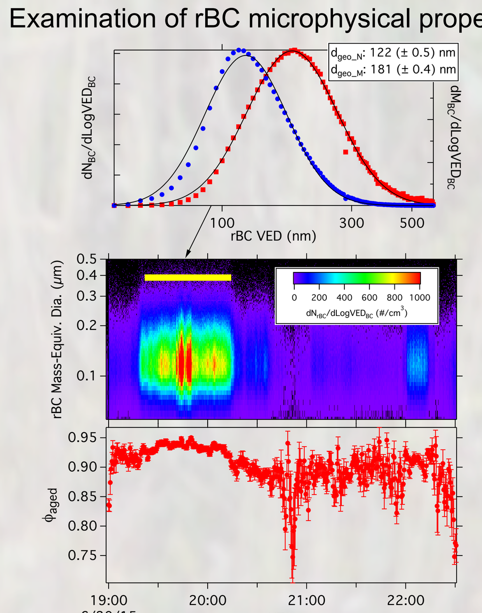
MCE in plume: 0.96



SSA_{MCE}: ~ 0.7 ± 0.06
SSA_{Obs}: 0.92 ± 0.04

Discrepancy between SSA_{obs} and SSA_{MCE} likely due to aging

Examination of rBC microphysical properties

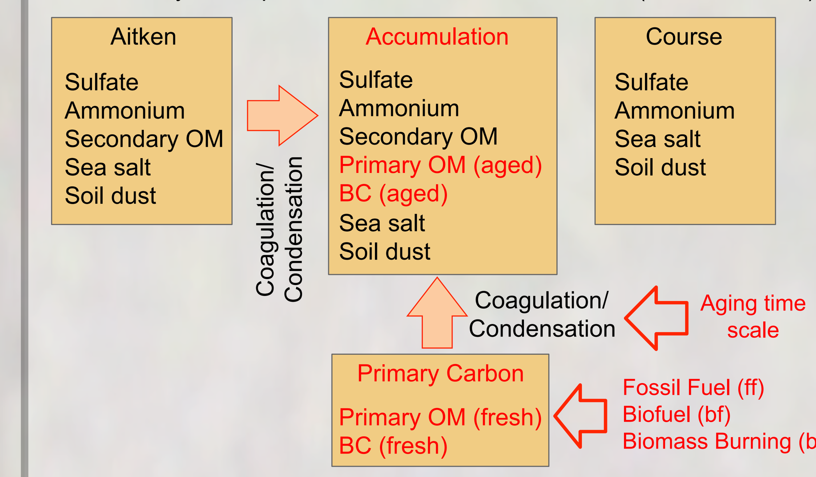


rBC biomass burning aerosol exhibit size mode of ~120 nm and mass mode of ~180 nm consistent with previous investigations.

Smoke plume is characterized by nearly 100% aged rBC particles consistent with the idea of rapid coating following particle generation.

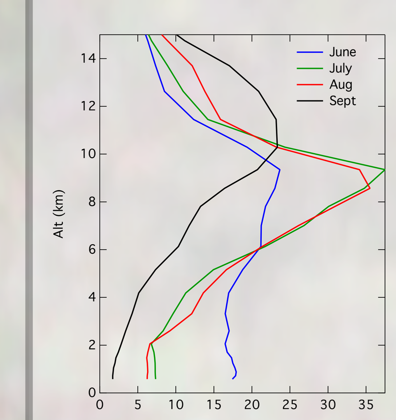
Climate Model Representation of BC profiles

Community Atmospheric Model with 4 aerosol modes (CAM5.3/MAM4)



CAM5.3/MAM4 is used to simulate BC distributions and radiative forcing over the Arctic

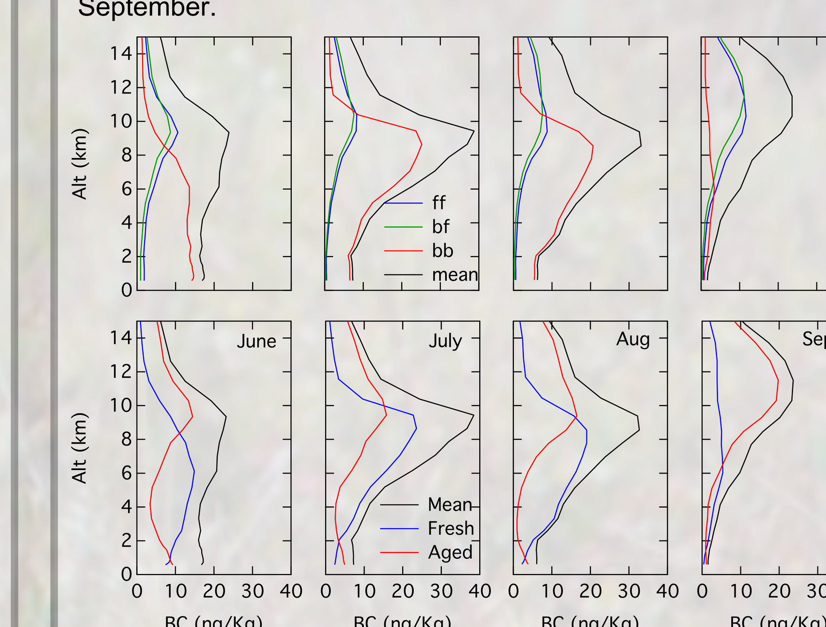
- Resolution: ~0.9°x1.25° horizontally and 30 vertical layers
- Fresh and aged BC mass mixing ratios
- BC fractions from fossil fuel, biomass burning and biofuel sources



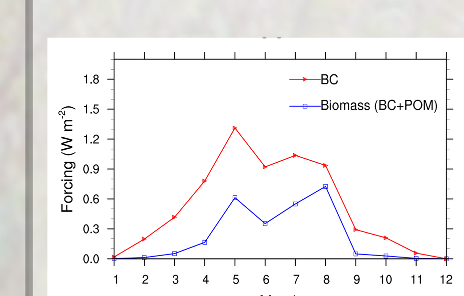
Seasonal variations in predicted monthly mean BC profiles are consistent with the observations (<5 km) at the Toolik site: BC concentrations peak in June and then gradually decrease

Also similar to the observed profiles, the modeled BC is well-mixed in June between surface and 5 km; and becomes more stratified later with aloft layers in the free troposphere

During the summer, over the **Toolik** site, BB is expected to be the predominate source of BC, while fossil fuel and biofuel are expected to become larger contributors to BC loadings in September.



Except for the boundary layer (<1 km) and above 9 km, fresh emitted aerosols are predicted to dominate the BC mass in the free troposphere and are most likely associated with BB sources.



From June to August, BC mainly from biomass burning is expected to induce a large positive radiative forcing of > +0.9 W m^{-2} over Arctic. It is very important to constrain the BC loadings and vertical distributions

Conclusion

- Vertical profiles of rBC were collected along the North Slope of Alaska as part of the DOE-ARM sponsored ACME-V campaign.
- Comparison of observed monthly means with model calculation (CAM5) reveals a range of agreement/disagreement.
- SSA_{MCE} – SSA_{obs} comparison for a biomass burning (BB) event suggest that BB aerosols were significantly aged by the time the plume reached the Toolik site.
- rBC data from this campaign will be available from the ARM website (http://www.arm.gov/campaigns/aaf2015abclp).

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References:

Flanner, M. G. (2013) *J. Geophys. Res. Atmos.*, 118, 1840
Spackman, J. R., et al.,. (2010) *ACP.*, 10, 9667–9680