Black Carbon Shootout: Instrument Intercomparison

T. Shingler[1,2], R. H. Moore[1], C. E. Robinson[1,3], E. L. Winstead[1,3], M. A. Shook[1,3], E. C. Crosbie[1,2], L. D. Ziemba[1], K. L. Thornhill[1,3], B. E. Anderson[1]

[1]Science Directorate, NASA Langley Research Center, Hampton, VA., USA

[2]Universities Space Research Association (USRA), Columbia, MD., USA

[3]Science Systems and Applications, Inc. (SSAI), Hampton, VA., USA

Background

The U.S. NASA Langley Aerosol Research Group (LARGE) has been providing BC based measurements and engine emission factors for over 15 years in a variety of airborne and ground based field campaigns, and laboratory studies. These data are made available to the general public and must be of the highest quality to enable assessments and prediction of environmental impacts related to changing technology and emission patterns. Studies are needed to more firmly establish the accuracy and precision of these measurements and to resolve observed differences between techniques in similar test venues. In support of this goal, a multi-part, laboratory-, and field-based intercomparison of instruments, called the Black Carbon Shootout (BCS) has been performed.

Experimental

The instruments used in the BCS intercomparison include filter-based EC/OC (Sunset Labs), a Micro Soot Sensor Plus (MSS+; AVL), two Laser Induced Incandescence (standard sensitivity: LII-300; high-sensitivity: LII-300-HS; Artium Technologies) instruments, and a novel Differential Photoacoustic Spectrophotometer (DPAS; Aerodyne Research). Supporting instrumentation includes two CPCs (non-thermal denuded and thermal denuded), a long-SMPS, and a nano-SMPS. The DPAS instrument contains two photoacoustic cells in series, separated by a particulate filter, using a 532 nm 200 mW DPSS laser.

A MiniCAST (Jing Ltd.) was used as to produce a controlled combustion particle source. Initial instrument calibrations were performed using the MiniCAST operating under conditions generating particles with an EC/TC ratio of 0.91. The MiniCAST $N_{2,mix}$ flow was then adjusted between 0 and 300 mlpm to generate particles containing increased organic content (EC/TC ratios between 0.48-0.91) and sampled through a dilution chamber as described in Figure 1.

Atomized solutions of Fullerene, Nigrosin Dye, and Aquadag were also sampled. Samples were also collected behind the NASA Falcon aircraft at varying thrust settings (% N1) and multiple dilution ratios.

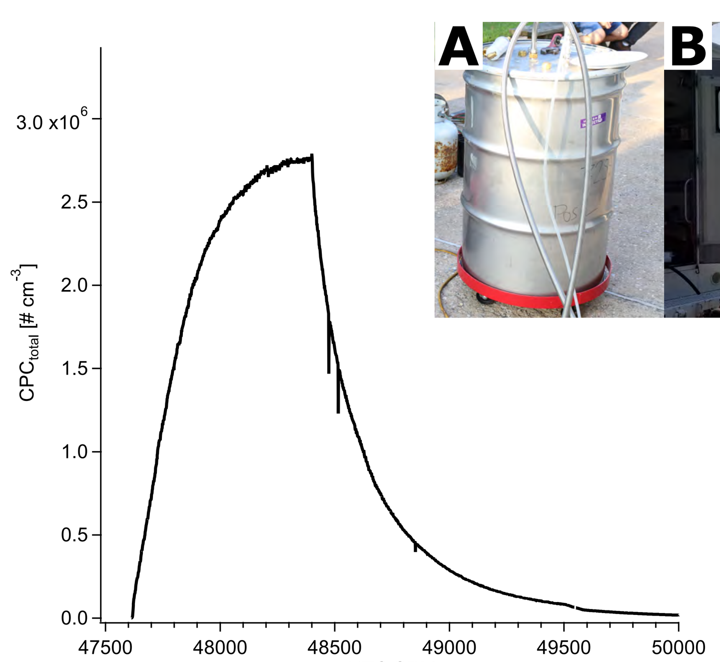


Figure 1. A stainless steel 55 gallon drum (inset A) was used as a dilution chamber to generate concentration gradients for each of the MiniCAST combustion conditions in the lab. The NASA Falcon is shown in inset B. A sampling inlet is just out of view on the right.

Results

Using a MiniCAST for a combustion source, mass concentration was calculated from integrated EC mass on an EC/OC filter and total sample volume. This mass concentration was then used to correct measurements from individual BC instruments sampling concurrently. MiniCAST was operated at $Air_{Dil.}$ = 20 lpm, $N_{2,quench}$ = 7.5 lpm, $Air_{oxi.}$ = 1.5 lpm, $N_{2,mix}$ = 0 mlpm, and C_3H_8 = 60 mlpm. Linear correction factors of 1.0063, 1.6302, and 1.1229 were applied for the LII-300, MSS+, and DPAS, respectively. The LII-300-HS was not available during this sampling period.

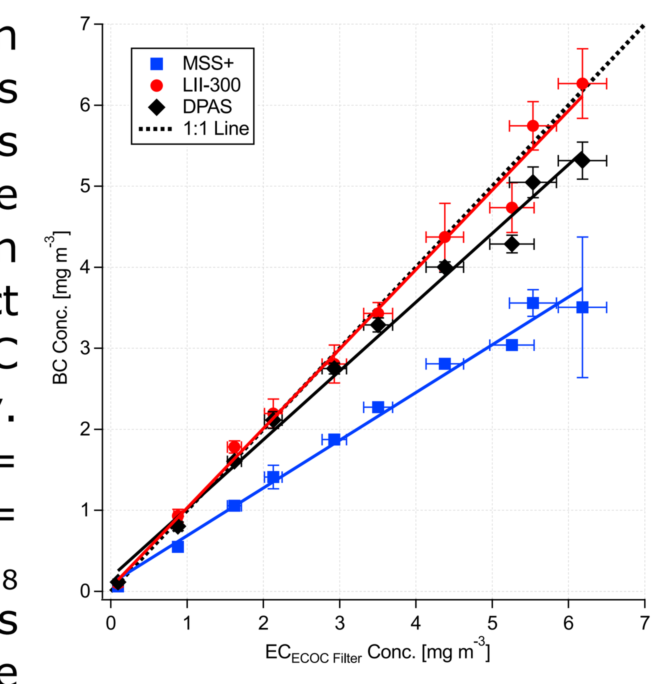


Figure 2. Instrument calibration to EC from a filter collection. All samples collected at 0.91 EC/TC. Note: LII-300-HS not available here.

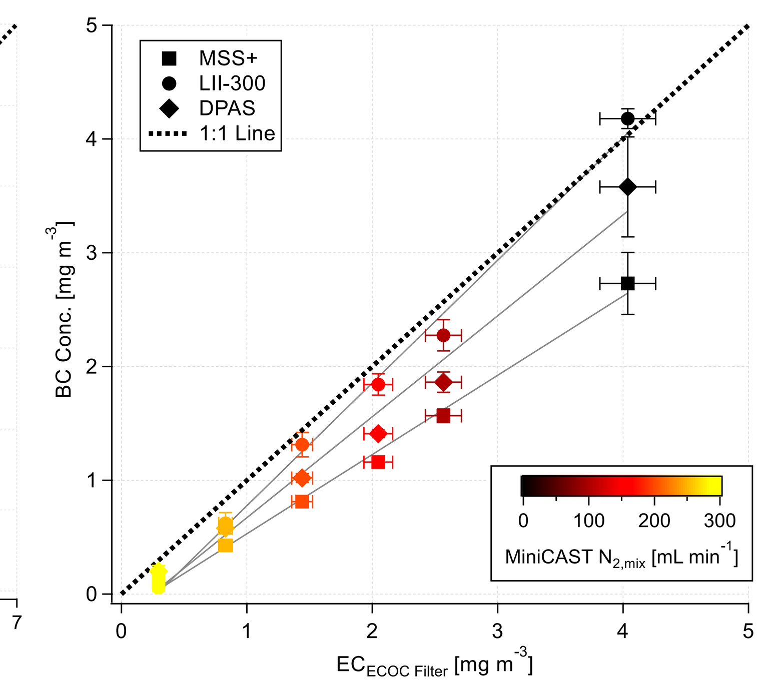


Figure 3. Instrument comparison to EC from a filter collection at varying EC/TC ratios.

The MiniCAST was then operated with increasing $N_{2,mix}$ flow rates from 0 to 300 mlpm and sampled through the stainless steel dilution barrel. The instruments agree well at higher EC/TC ratios with only the lowest EC/TC ratio (0.48) having significant disagreement in all instruments. Interesting stratification in response to varying EC/TC ratios in the LII-300-HS is seen. Additional work is still necessary to fully understand the high sensitivity LII-300-HS unit.

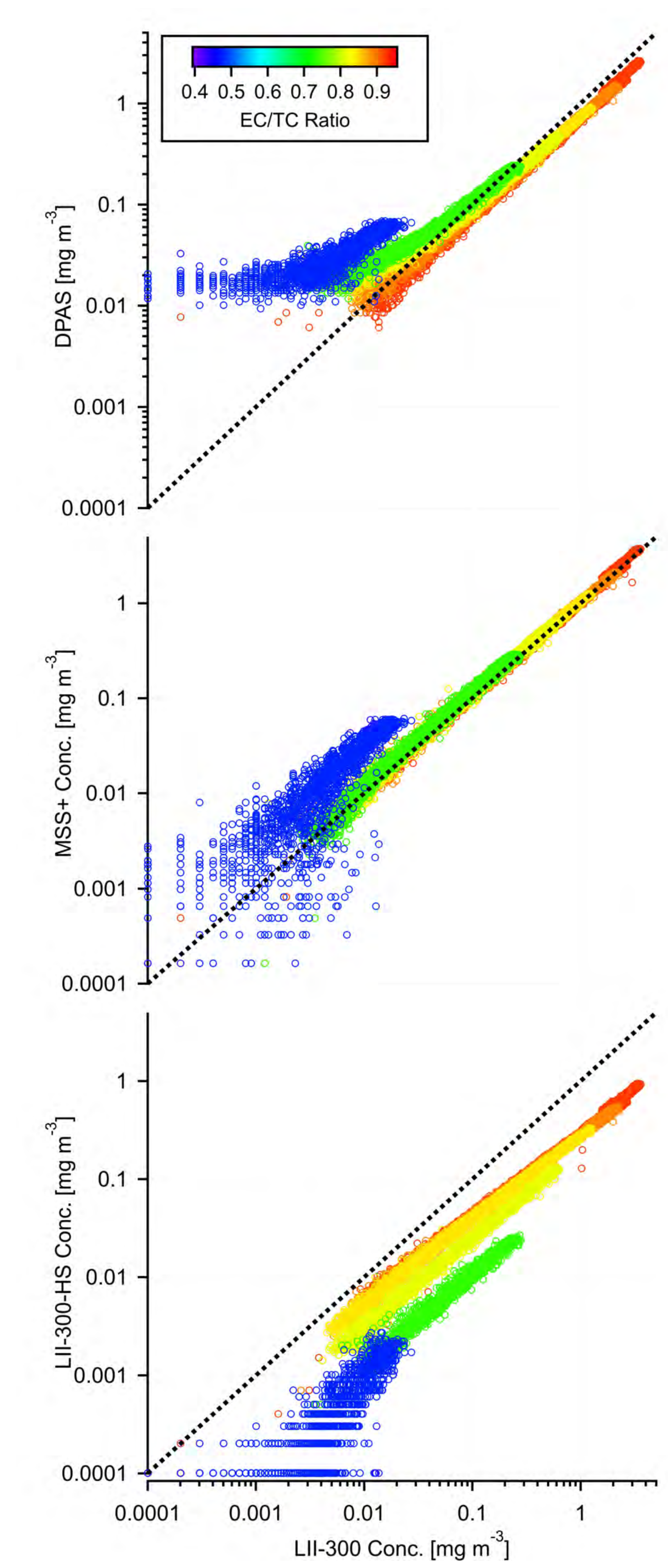


Figure 4. Measurement comparison using MiniCAST dilution runs at varying $N_{2,mix}$ flow rates (resulting in changes in EC/TC ratio).

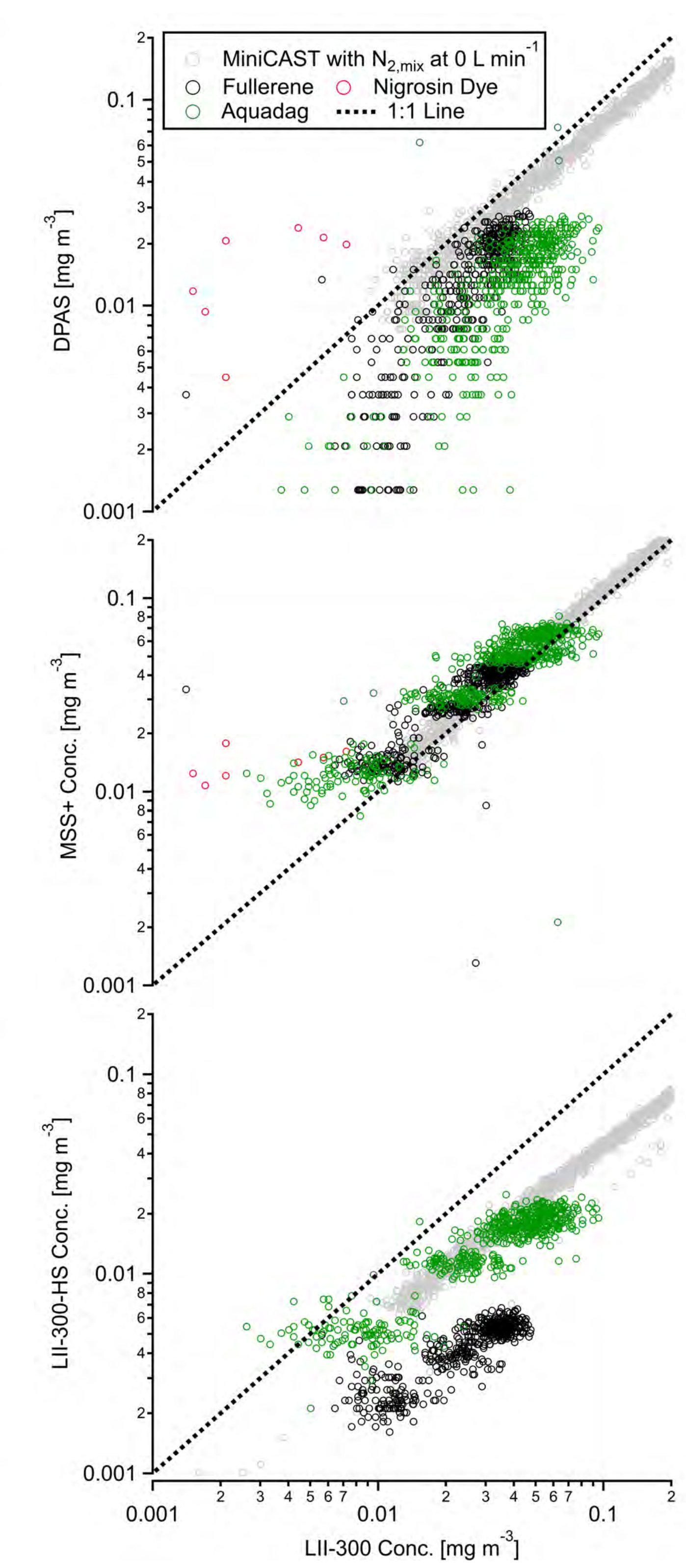


Figure 5. Measurement comparison using atomized solutions of Fullerene, Nigrosin Dye, and Aquadag.

Changes in particle size are a likely contributor to measurement disagreement between instruments. Previous work has shown that soot mode diameter decreases in the MiniCAST with increasing $N_{2,mix}$ flow rate (Moore et al., 2014), from ~110 nm at 0 mlpm to ~40 nm at 300 mlpm. Additionally, atomized solutions of the absorbing compounds Fullerene, Nigrosin Dye, and Aquadag were also compared. As shown in Figure 6, Nigrosin dye is detectable by the photoacoustic instruments but not the LII-300. Atomized solutions were not sampled through the dilution barrel.

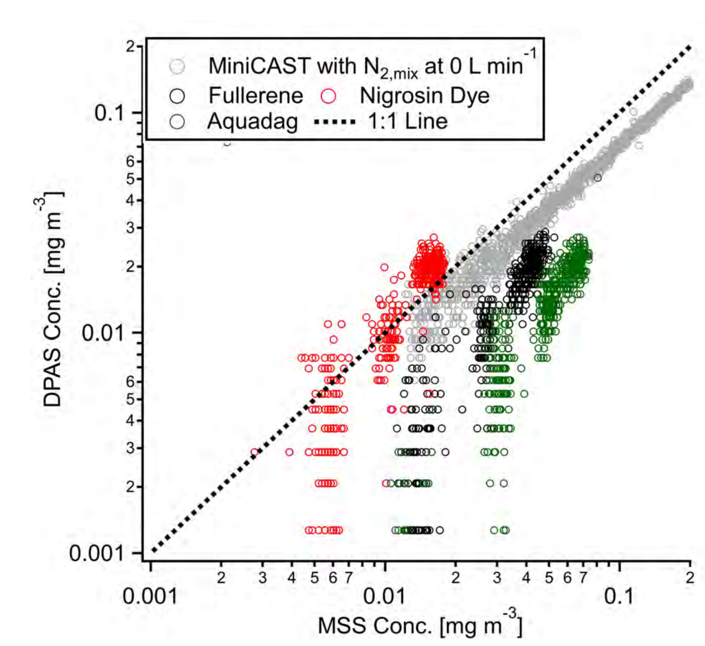
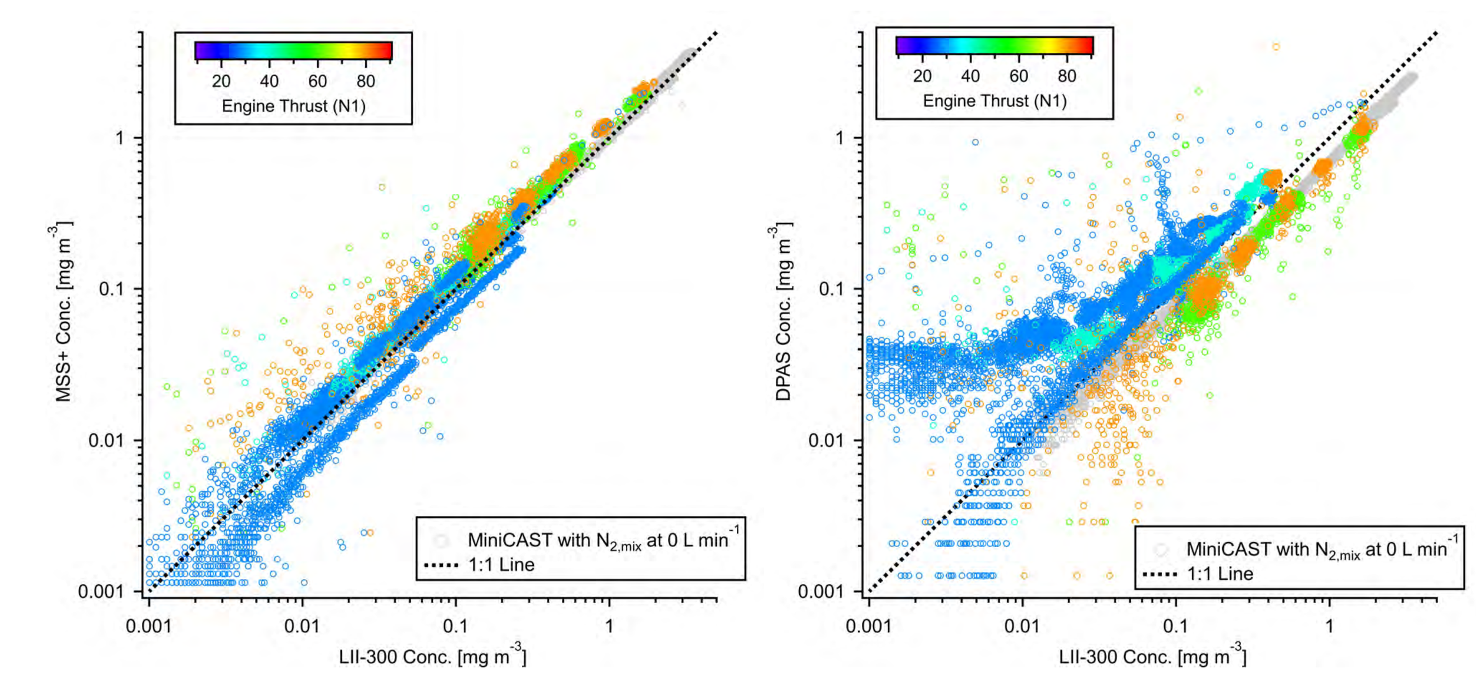


Figure 6. Measurement comparison between the DPAS and MSS using atomized solutions of Fullerene, Nigrosin Dye, and Aquadag.

The instruments were loaded into the LARGE research van with a sampling inlet line positioned approximately 5 meters from the exit plane of a NASA Falcon engine running at thrust settings (% N1) between 20-80%. A filtered dilution line was added to the sample line and multiple dilution flows were used to generate a range of sampling concentrations. The LII-300 and MSS+ are in reasonable agreement under all conditions sampled. The agreement between the LII-300 and the DPAS is of interest in that the the lower engine thrust settings are typically overestimated in the DPAS and limited by the overall LLOQ at a 1 hz sampling rate.

Concurrently collected EC/OC filter samples indicate average EC/TC ratios of 0.30, 0.53, 0.55, and 0.64 for 20, 40, 60, and 80% N1, respectively. The LII-300-HS was not available during sampling behind the Falcon aircraft.



Figures 7 and 8. Soot measurements by the MSS+ (left) and DPAS (right) collected concurrently behind the NASA Falcon aircraft at varying engine thrust settings are compared to the LII-300. Concentration gradient controlled by a filtered dilution line.

Conclusions

- Novel DPAS instrument capable of producing BC measurements in agreement with the LII-300 and MSS+ for combustion generated soot; higher LLOQ at 1hz than the MSS+ and LII-300 instruments.

- Instruments agree well at high EC/TC ratios for combustion generated soot. Atomized solutions are less agreeable.

- High-sensitivity LII-300 may be more sensitive to interference from increased organic content.

Future Work

Additional analysis of LII-300, MSS+, and DPAS in conjunction with the PSAP, TAP, CAPS PM_{ex}, and PASS3 will be completed. Concurrent sampling from additional sources, including sampling behind a runway at a regional airport and along a busy highway will be included.

References

Moore, R.H. et al. (2014) *Aerosol Sci. Tech.*, 48:5, 467-479, DOI: 10.1080/02786826.2014.890694