How well do State-of-the-Art Techniques Measuring the Vertical Profile of Tropospheric Aerosol Extinction Compare?

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Introduction

In our current ARM Science Team funded effort we focus on the vertical profile of aerosol optical properties over the Southern Great Plains (SGP) Climate Research Facility (CRF). The effort makes use of the vast array of measurements obtained during the ARM Aerosol Intensive Operations Period (AIOP, May 2003). Dr. Richard Ferrare was the lead scientist for the AIOP. Dr. Schmid was the platform scientist for the CIRPAS Twin Otter (Bane et al. 2004), one of the two aircraft used during AIOP. Twin Otter data have been used in over 10 publications intended for the AIOP *Journal of Geophysical Research* special issue.

The May 2003 AIOP yielded one of the best measurement sets obtained to-date to assess our ability to measure the vertical profile of ambient aerosol extinction in the lower troposphere. This is because during one month, the heavily instrumented CIRPAS Twin Otter aircraft with well characterized aerosol sampling ability carrying well proven and new aerosol instrumentation, devoted most of the 60 available flight hours to flying vertical profiles over the heavily instrumented SGP CRF. This allowed us to compare vertical extinction profiles obtained from 6 different instruments: airborne Sun photometer (AATS-14), airborne nephelometer plus absorption photometer (PSAP), airborne cavity ring-down system (Cadenza), ground-based Raman lidar and 2 ground-based Micro-Pulse lidars. Detailed comparisons of the 6 methods have been submitted by Ferrare et al. (2005), Schmid et al. (2005), and Strawa et al. (2005). A summary is presented in Figure 1.

When compared to AATS-14, we find the aircraft in-situ extinction measurements to be biased low (0.002 – 0.004 Km^{-1} equivalent to 13-17% in the visible, or 45% in the near-infrared). We also find the low bias to increase with increasing wavelength.

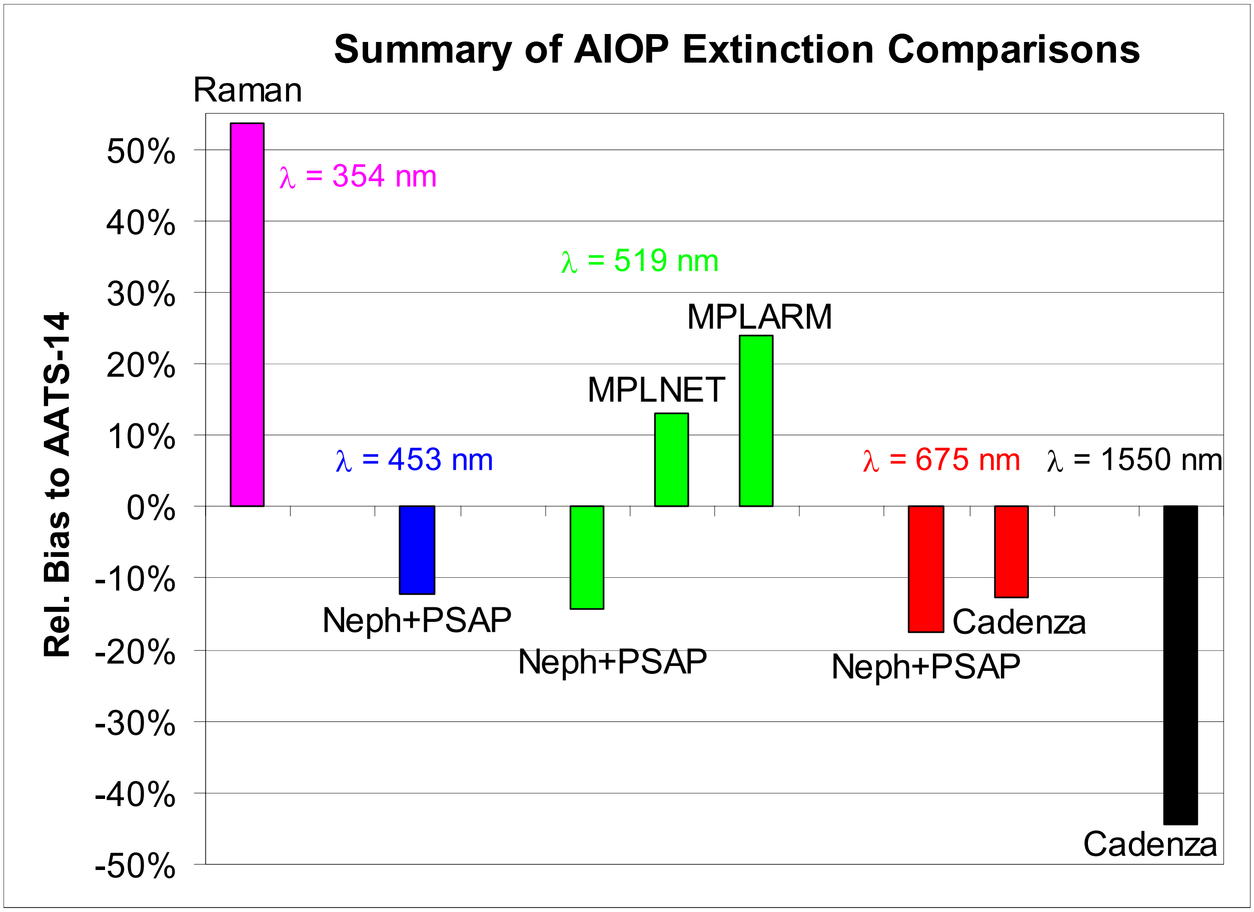

Figure 1. Relative bias of aerosol extinction derived from SGP Raman and Micro Pulse (MPLARM) lidars, NASA Micro Pulse Lidar (MPLNET) and aircraft in-situ measurements (Nephelometer+PSAP, Cadenza) with respect to AATS-14 (airborne sunphotometer), for 26 vertical profiles.

On the other hand, we find that with respect to AATS-14, the extinction values from all 3 lidars are biased high: Bias differences are 0.004 Km^{-1} (13%) and 0.007 Km^{-1} (24%) for the two elastic back-scatter lidars (MPLNET and MPLARM, λ=523 nm) and 0.029 Km^{-1} (54%) for the Raman lidar (λ=355 nm). Unfortunately, a gradual loss of the sensitivity of the Raman lidar starting about the end of 2001 went unnoticed until after AIOP. In an attempt to reduce or remove these adverse impacts, the automated Raman lidar algorithms (Turner et al. 2002) were modified (Ferrare et al. 2005) and the AIOP data were reprocessed. However, a positive bias (54%) remained. Differences were significantly less (~10%) for higher (0.15-0.3 km^{-1}) values of aerosol extinction; note also that the absolute differences between the lidar measurements of aerosol extinction and the other retrievals is about the same as found from previous comparisons between lidar and in situ measurements (Ferrare et al. 2005).

The overall trend found in AIOP, with lidar data yielding the largest extinction followed by airborne sunphotometry and aircraft in-situ measured values, is a typical result: Combining the results from AIOP with those from 5 previous field campaigns, we find airborne Nephelometer+PSAP measurements of layer aerosol optical depth to be consistently biased low (4 - 33%, average of 17%) when compared to airborne Sun photometer (AATS-6 or -14) values. In contrast, comparing extinction and optical depth vertical profiles from one of the AATS instruments with surface based or airborne lidars in 5 previous field campaigns results in no or small positive biases (i.e., lidar values larger than AATS values) (Schmid et al. 2005).

Strawa et al. (2005) and Schmid et al. (2005) find good to excellent agreement among the in-situ measurements, Cadenza and Nephelometer+PSAP at λ=675 nm, on the Twin Otter aircraft. This represents a very successful demonstration of the first airborne application of the cavity-ringdown method to measure aerosol extinction.

Hallar et al. (2005) have compared dry aerosol scattering measurements from the CIRPAS Twin Otter and the ARM routine light aircraft (Cessna C-172N; Andrews et al. 2004) in situ measurements for the formation flights performed during the AIOP. They found that averaged over all coordinated flight legs the Cessna scattering measurements (λ=530 nm) are lower than the Twin Otter measurements (Cessna/Twin Otter ratios of 0.928, 0.681 and 0.610 at blue green and red wavelengths, respectively) due to the fact that the Cessna samples the aerosol through an inlet with an aerodynamic size cut of 1 μm, while the Twin Otter inlet cut-off is ~8 μm. When an aerodynamic size cut of 1 μm was added to the Twin Otter sampling line during one of the formation flights, the corresponding ratios were 1.297, 0.973, and 0.925.

We also contributed to the following AIOP related submissions: Andrews et al. (2005) comparing methods for deriving aerosol asymmetry parameter, Feingold et al. (2005) performing aerosol indirect effect studies, Ricchiazzi et al. (2005) comparing aerosol optical properties obtained from in-situ measurements and retrieved from Sun and sky radiance observations, and Colarco et al. (in preparation, 2005) analyzing long-range transport of Siberian biomass burning aerosol observed over SGP during the AIOP.

The Planned Aerosol Lidar Validation Experiment (ALIVE)

The ACRF Raman Lidar started to operate at the SGP site in April 1997 as a turnkey, automated system for unattended, around-the-clock profiling of water vapor and aerosols with the goal of producing a 10-year climate data record (Turner et al. 2001, 2002). The AIOP validation results revealed that an unnoticed loss of sensitivity of the Raman lidar had occurred leading up to AIOP resulting in a high bias in derived aerosol extinction (54%, 0.029 km^{-1} with respect to AATS-14).

However, major modifications made to the Raman lidar in 2004 (after AIOP) have dramatically improved the system's sensitivity. Further validation of ACRF Raman Lidar is therefore crucial to test the integrity of the entire Raman lidar aerosol extinction record. The hypothesis to be tested is that for the periods not affected by lower sensitivity the ACRF Raman Lidar can measure aerosol extinction profiles at 355 nm with systematic uncertainties not exceeding the range of 15-20%, or 0.025 km^{-1}, whichever is larger. In addition to the Raman Lidar at SGP, ARM uses Micro-Pulse Lidars (MPL) at all of its ACRFs including the ARM Mobile Facility. ARM has only very recently developed algorithms to retrieve aerosol extinction from its MPLs. The β-version of the retrieval has been validated using data from AIOP. The ARM SGP MPL was found to have a high bias of 24% (with respect to AATS-14). Further validation with a larger data set is highly desirable.

We will perform the simultaneous validation of aerosol extinction profiles obtained from the Raman and Micro Pulse Lidars using the NASA Ames Airborne Tracking 14-channel Sun photometer (AATS-14). The extinction profiles obtained from AATS-14 flown aboard a profiling aircraft are increasingly viewed as a standard to which other methods are compared (Hegg et al. 1997; Collins et al. 2000; Ferrare et al. 2000; Hartley et al. 2000; Livingston et al. 2000; Redemann et al. 2000; Schmid et al. 2000; Welton et al. 2000; McGill et al. 2002; Wang et al. 2002; Kaufmann et al. 2003; Magi et al. 2003; Murayama et al. 2003; Redemann et al. 2003; Schmid et al. 2003a, b; Magi et al. 2005; Ferrare et al. 2005; Schmid et al. 2005; Strawa et al. 2005).

During ALIVE (planned for September 11-22, 2005) AATS-14 will obtain extinction vertical profiles aboard the Sky Research Jetstream 31 aircraft during spiral ascents and descents over the SGP ACRF (~20 flight hours, profiles 300 - 23'000 ft altitude, see Figure 2).

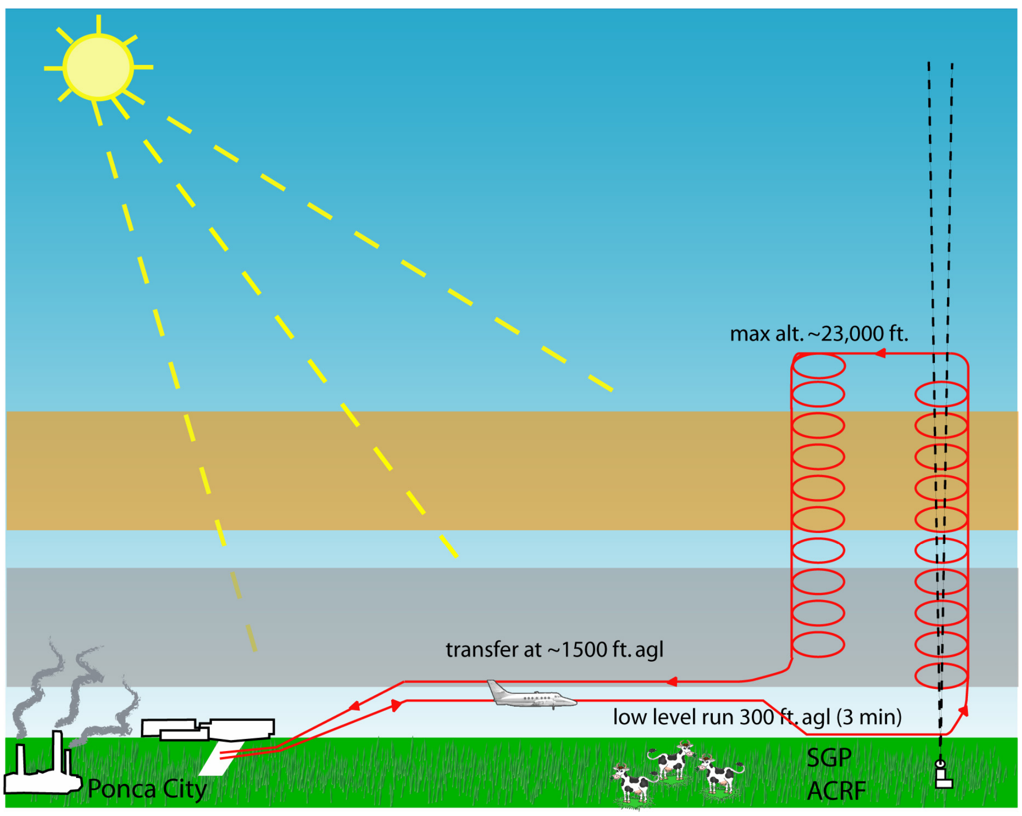

Figure 2. Typical flight pattern for lidar validation flight originating from Ponca City, Oklahoma with vertical profiles centered over the SGP ACRF.

The NASA Research Scanning Polarimeter (RSP) will be operated as a piggy-back instrument aboard the Jetstream (at no cost to ARM). The RSP will provide multi-spectral measurements of the upwelling polarization and radiance (Cairns et al. 1999).

Added benefit can be obtained by coordinating the proposed validation flights with the ARM In-situ Aerosol Profile (IAP) aircraft (as done in the 2003 Aerosol IOP). These measurements will help evaluate the IAP measurements after the IAP instruments are moved to a new aircraft.

In addition, we are also exploring the possibility of coordinated flights with h a NASA funded Lear Jet carrying the NASA Langley High Spectral Resolution Lidar (HSRL), Hyperspectral Polarimeter for Aerosol Retrievals (HySPAR), Langley Airborne A-band Spectrometer (all downward looking).

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Acknowledgment

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