A MESOSCALE AEROSOL VARIABILITY STUDY IN THE ASIAN OUTFLOW REGION IN SUPPORT OF CALIPSO VALIDATION

Jens Redemann(1), Theodore L. Anderson(2), Beat Schmid(3), Philip B. Russell(4)

(1)BAERI /NASA Ames, MS 245-5, Moffett Field, CA 94035, USA, E-mail: jredemann@mail.arc.nasa.gov
(2)University of Washington, Box 351640/408 ATG, Seattle, WA 98195, USA, E-mail: tadand@atmos.washington.edu
(3)BAERI /NASA Ames, MS 245-5, Moffett Field, CA 94035, USA, E-mail: bschmid@mail.arc.nasa.gov
(4)NASA Ames Research Center, Moffett Field, CA 94035, USA, E-mail: prussell@mail.arc.nasa.gov

ABSTRACT

The current low confidence in the estimates of aerosol–induced perturbations of Earth's radiation balance is caused by the highly non-uniform compositional, spatial and temporal distributions of tropospheric aerosols on a global scale owing to their heterogeneous sources and short lifetime. With the advent of active aerosol remote sensing from space (e.g., CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations [1]), there is potential for studying the vertical structure of aerosol properties with unprecedented spatial resolution. The CALIPSO measurements of aerosol backscatter, extinction and aerosol optical depth will require a careful and comprehensive validation exercise. Because of the small foot-print of individual lidar returns, there is a need to study the horizontal structure of aerosol properties to estimate the spatial scales which will allow meaningful comparisons of the space-borne lidar data and the suborbital validation measurements. In this paper, we examine the spatial variability of in situ measurements of dry aerosol scattering, dry aerosol absorption and ambient aerosol extinction at 550 nm collected aboard the NCAR C-130 aircraft in ACE-Asia (Aerosol Characterization Experiment – Asia, 2001), and compare it to the spatial variability of aerosol optical depth measured coincidentally with an airborne tracking sunphotometer. For the in situ parameters, the spatial variability of aerosol absorption on scales of up to 80 km is found to be larger than that of ambient scattering, which in turn is larger than the variability in dry scattering. The spatial variability of aerosol optical depth at 525 nm is shown to be comparable to the variability in ambient aerosol extinction, but it seems to become larger at scales between 80 and 200 km. However, data at spatial scales beyond 100 km in this study is sparse and may not be representative of the Asian outflow region.

1. INTRODUCTION

Over the last decade, the quantification of tropospheric aerosol abundance, composition and radiative impacts has become an important research endeavor. For the most part, the interest in tropospheric aerosols is derived from questions related to the global and local (instantaneous) radiative forcing of climate due to these aerosols.

One way to measure aerosol optical properties with high horizontal and vertical resolution is by means of lidar. Future estimates of aerosol radiative forcing will rely more heavily on lidar-derived measurements of aerosol extinction and backscatter, some of which will be taken by space-borne lidar systems, e.g., CALIPSO [1]. These space-borne measurements will have to be validated to maximize their importance for the study of aerosol-climate interactions. Validation of the CALIPSO measurements is envisioned to entail coincident, collocated measurements by airborne and ground-based lidar and sunphotometer systems, as well as airborne in situ measurements of aerosol optical properties. One of the biggest challenges in designing validation studies is to determine the temporal and spatial scales at which the satellite and the suborbital measurements are comparable.

In this paper we examine the spatial variability of in situ measurements of aerosol optical properties [2] collected aboard the NCAR C-130 aircraft in the ACE-Asia field experiment in April and May 2001 [3]. Coincident measurements of aerosol optical depth and columnar water vapor were carried out aboard the C-130 using the six-channel NASA Ames Airborne Tracking Sunphotometer, AATS-6 [4]. A comparison of the in situ derived ambient aerosol extinction at 550 nm and the aerosol extinction derived from AATS-6 measurements of AOD in vertical profiles showed good consistency between the two data sets [4]. The purpose of this paper is to compare the horizontal variability of the coincident in situ and AOD measurements aboard the same platform.

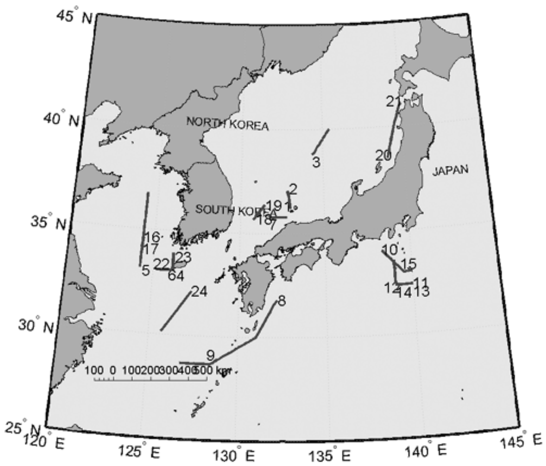

FIG. 1: A map of 24 low-level (below 100 m) flight legs of the NCAR-C130 aircraft in the ACE-Asia field experiment. The in situ and sunphotometer data from these flight legs were used in the spatial variability study presented here.

2. DATA SETS AND THEIR VARIABILITY

Aboard the NCAR C-130 in ACE-Asia, two integrating nephelometers (TSI Inc., Model 3563) measured integrated total scatter at 450, 550, and 700 nm wavelengths [5], while two Particle Soot Absorption Photometers (Radiance Research, Inc.) were used to measure light absorption by aerosols at 550 nm [6]. In conjunction with measurements of aerosol humidification, the data can be used to derive ambient aerosol extinction at 550 nm. The in situ measurements were taken at a temporal resolution of 2 s. However, because the flush time of the nephelometers is about 6 s, the in situ data were averaged to 10-s resolution to ensure the independence of consecutive data points. Because the goal of this study is to compare the in situ measurements to full-column AOD measurements we only considered flight legs with mean altitudes of less than 100 m.

In the 19 research flights of the C-130, a total of 44 flight legs were below 100 m. Because of non-deployment of AATS-6 in four of the 19 research flights as well as cloud coverage during some of the remaining 15 flights, only 24 of the 44 total flight legs that yielded in situ measurements also yielded full column AOD measurements. The AATS-6 measurements of AOD and columnar water vapor (CWV) are averaged and recorded at a temporal resolution of 3 s, which allows cloud screening of the actual transmission measurements taken at a frequency of 3 Hz.

Figure 1 shows the location of the 24 low-level flight legs for which coincident AATS-6 measurements of AOD exist. Figure 2 shows an example of the in situ

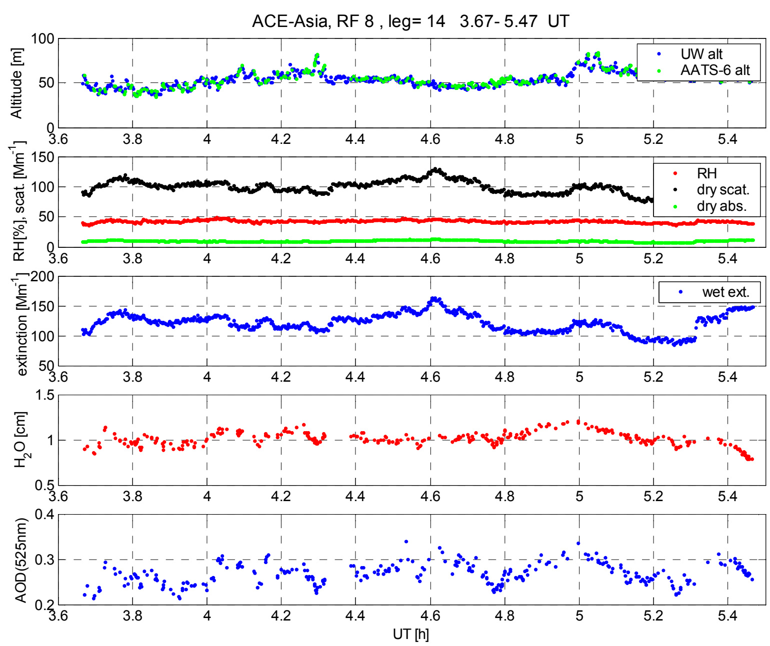

FIG. 2: Example of the aerosol in situ and aerosol optical depth measurements during a low-level leg of the NCAR C-130 aircraft in ACE-Asia on April,

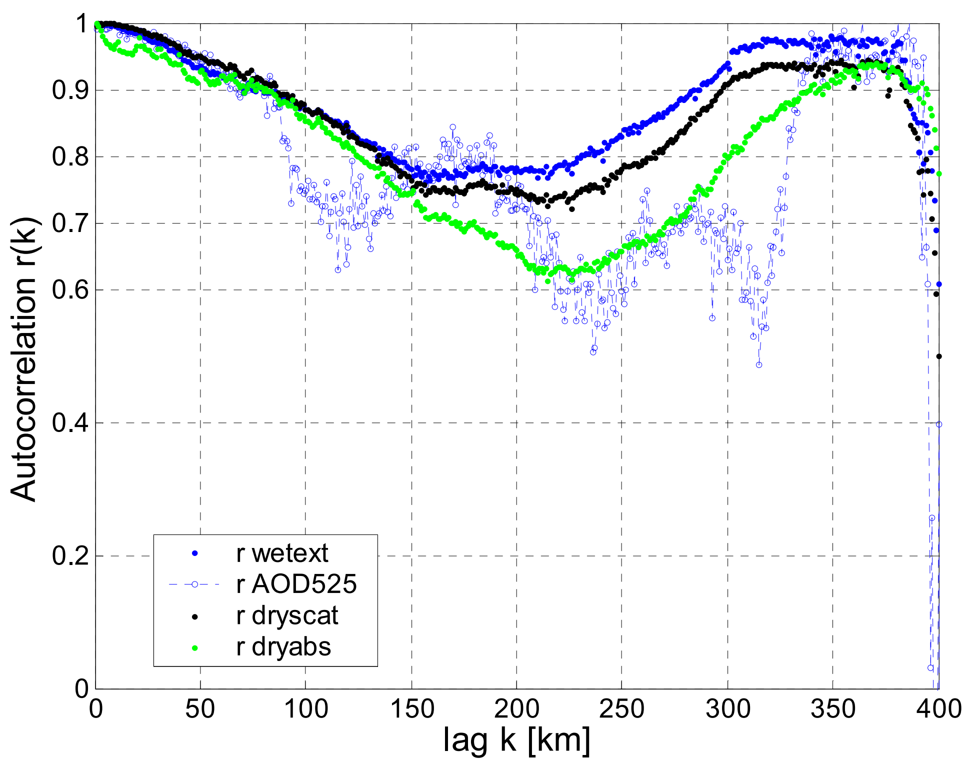

FIG. 3: Autocorrelation coefficient, *r(k)*, for four different variables measured coincidentally during 24 low-level flight legs of the NCAR C-130 in ACE-Asia, 2001.

and AATS-6 data collected during one of these flight legs. Data gaps in the AATS-6 data series around 4.35 UT are due to cloud obscurations of the instrument.

3. RESULTS AND DISCUSSION

As a measure of spatial variability of the data series from the 24 low-level flight legs we employ the auto-correlation coefficient as defined by [7]:

$$r(k) = \frac{\sum_{i}^{N}\left[(x_i - m_1)(x_{i+k} - m_2)\right]}{(N-1)s_1 s_2} \qquad (1)$$

where k is the separation, or lag, between a data pair x_i and x_{i+k}; m_1 and s_1 are the mean and standard deviation, respectively of all data points that are located $-k$ away from another data point and m_2 and s_2 are the mean and standard deviation of all data points $+k$ away from another data point.

Figure 3 shows the autocorrelation coefficient, *r(k)*, for the in situ measurements of dry absorption, dry scattering, the derived ambient extinction, and the sunphotometer measurements of AOD. Similarly, Table 1 gives the spatial lags in the various data sets that correspond to autocorrelations of 0.9 and 0.8, respectively.

On spatial scales of up to 80 km, the variability in absorption is largest (as indicated by the smallest autocorrelation) and the variability in the dry scattering measurements is the smallest. The variability in AOD on these scales is comparable to the variability in ambient extinction. On spatial scales beyond 200 km the autocorrelations seem to increase again for all quantities. It should be noted, however, that only 6 of the 24 flight legs considered extended beyond a horizontal distance of 200 km and that the autocorrelation analysis for such scales presented here is hence based on limited data. If found to be representative of aerosol properties in the Asian outflow region our analysis implies a correlation phenomenon with a spatial scale of about 300 km.

TABLE 1: Spatial lags [km] in the various data sets that correspond to autocorrelations of 0.9 and 0.8, respectively.

Autocorrelation → Type of data ↓	0.9	0.8
Dry absorption – 550 nm, in situ	73.2	124.5
Dry scattering – 550 nm, in situ	86.5	133.6
Derived ambient extinction – 550 nm, in situ	70.9	140.4
Aerosol optical depth, 525 nm, remote	74.9	91.7

With respect to satellite validation studies our analysis suggests a need for spatial proximity of within about 75 km between satellite and suborbital measurement in the Asian outflow regime if an autocorrelation beyond 0.9 is targeted.

4. REFERENCES

1. Winker, D. M., J.R. Pelon, and M.P. McCormick, The CALIPSO mission, spaceborne lidar for observation of aerosols and clouds, in *Lidar Remote Sensing for Industry and Environment Monitoring III. Proc. SPIE*, *4893*, 1-11, 2002.

2. Anderson, T.L., S.J. Masonis, D.S. Covert, N.C. Ahlquist, S.G. Howell, A.D. Clarke, and C.S. McNaughton, Variability of aerosol optical properties derived from in situ aircraft measurements during ACE-Asia, *J. Geophys. Res., 108* (D23), 8647, 2003a.

3. Huebert, B.J., T. Bates, P.B. Russell, G. Shi, Y.J. Kim, K. Kawamura, G. Carmichael, and T. Nakajima, An overview of ACE-Asia: Strategies for quantifying the relationships between Asian aerosols and their climatic impacts, *J. Geophys. Res., 108(D23)*, 8633, 2003.

4. Redemann J., S. Masonis, B. Schmid, T. Anderson, P. Russell, J. Livingston, O. Dubovik, A. Clarke, Clear-column closure studies of aerosols and water vapor aboard the NCAR C-130 in ACE-Asia, 2001, *J. Geophys. Res., 108* (D23), 8655, 2003.

5. Anderson, T.L., et al., Performance characteristics of a high-sensitivity, three-wavelength, total scatter/backscatter nephelometer, *J. Atmos. Oceanic Technol*., 13, 967-986, 1996.

6. Bond, T.C., T.L. Anderson, and D. Campbell, Calibration and intercomparison of filter-based measurements of visible light absorption by aerosols, *Aerosol Sci. and Tech., 30*, 582-600, 1999.

7. Anderson, T.L., R.J. Charlson, D.M. Winker, J.A. Ogren and K. Holmen, Mesoscale variations in tropospheric aerosols, *JAS*, 60, 119-136, 2003b.