Optical Properties of the 1997 Smoke Event at the ARM Tropical Western Pacific Site

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Introduction

Drought conditions and population pressures in Indonesia and surrounding areas in the Tropical Western Pacific (TWP) sparked massive biomass burning episodes during September-November of 1997. Some of this smoke advected over the Manus Island Atmospheric Radiation Measurement (ARM) TWP site. Analysis of smoke-related aerosol is of interest. Smoke aerosol from biomass burning is thought to be a major source of absorbing aerosol in the atmosphere and is also significant for atmospheric chemistry. The complement of radiation and remote sensing measurements at the TWP ARM site provides a potentially valuable data set for understanding the radiative properties of smoke aerosol. It is also important to understand the perturbation that the smoke aerosol introduces to the standard data set. In this paper we present an initial analysis of the 1997 smoke haze events.

The TWP data set includes measurement of the aerosol optical thickness from spectral solar photometeric measurements and measurement of the hemispheric shortwave flux at the surface. These are basic data with which to study aerosol radiative effects. Full knowledge of aerosol distributions is difficult to obtain by passive sensing alone. In particular for absorbing aerosol the vertical distribution is needed to understand the aerosol transport and heating rates associated with aerosol absorption.

The micropulse lidar (MPL) deployed at ARM sites provides a detailed picture of the vertical structure of boundary layer and elevated dust or smoke plume aerosols (Spinhirne 1993). MPL is an eye-safe, ground-based, zenith pointing instrument capable of full-time, long-term unattended operation at 523 nm. MPLs are deployed at all three current ARM sites.

The MPL data analysis includes instrument correction and backscatter analysis techniques to detect cloud boundaries and analyze vertical aerosol structures. A summary of MPL applications is found in Hlavka et al. (1997). For this paper, a time history of MPL data was analyzed from July through September 1997 and combined with spectral photometer data from the multifilter rotating shadowband radiometer (MFRSR) and the Downwelling Radiation Instrumentation (SKYRAD) at the ARM TWP site at Manus, Papua New Guinea.

Data Analysis and Results

Vertical profiles of processed MPL data show the chronology and vertical distribution of this advection. Figure 1 displays a 1-week image of MPL signal profiles showing aerosol loading during and just prior to the initial smoke event in September 1997.

MPL case studies were calibrated with the MFRSR to develop aerosol optical depth and aerosol extinction cross section values of the smoke layer at various times during the episodes. Based on a procedure by Spinhirne et al. (1980), a differential equation has been developed which, when integrated vertically through the lidar profile, relates atmospheric attenuation to an integration of the received signal return. It includes a separation of aerosol and molecular scattering terms. For the MPL data, which is all vertically pointing, the basic procedure is one of calibration

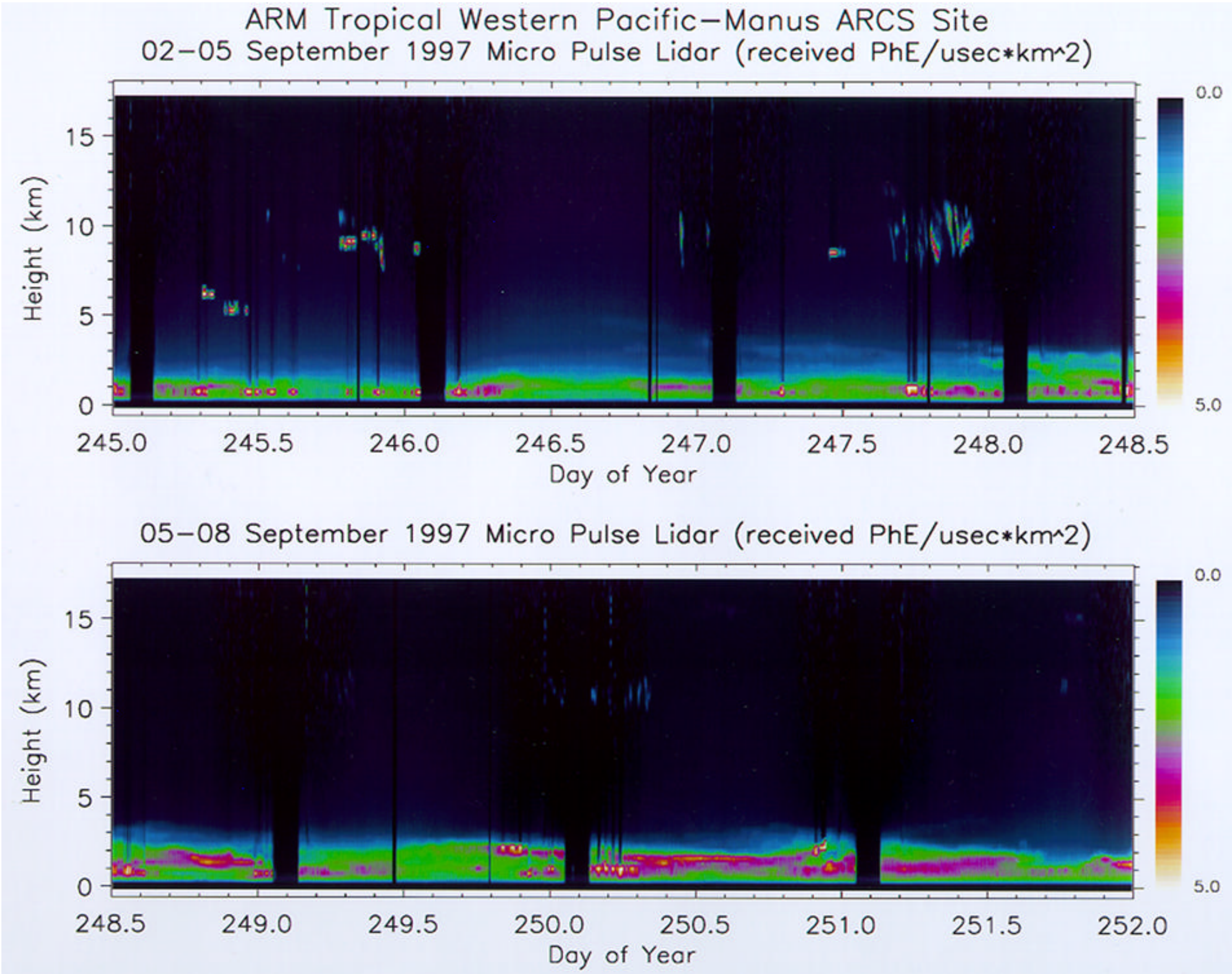

Figure 1. One week time series image of MPL vertical profiles showing increase in aerosol loading over time in the lowest three kilometers during moderate smoke event. (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/spinhirne-98.pdf*.)

and subsequent normalization of signals to the molecular scattering cross section in the upper troposphere. By reference to the calibration, the optical thickness for the boundary layer aerosol can be directly derived from the MPL data alone. Figure 2 shows average aerosol profiles calculated from 90-minute time periods based on MPL backscatter and MFRSR aerosol optical depth calculations.

A time history of the link between MPL integrated backscatter, shortwave flux measurements, and aerosol optical depths during cloud-cleared periods is plotted in Figure 3. The smoke haze only appears episodically on several days toward the end of the period shown. MPL aerosol optical depths in this plot were calculated based on a fixed calibration of a smoke-free day with the MFRSR. The MFRSR optical depths that were available were the result of Langley plot analysis for afternoon data. As seen in Figure 1, an error from temporal inhomogeniety of the aerosol loading was possible. Disagreement between the MPL and MFRSR optical depths is in fact correlated with the apparent temporal variability. It may be noted that there is a large increase in the ratio of the optical thickness to the integrated backscatter cross section on several days (251, 254, and 257 or September 8, 11, and 14). These days have high optical thickness and correspond to days when smoke aerosol were present. The change in the ratio indicates there has been a strong effect of attenuation on the received lidar signal.

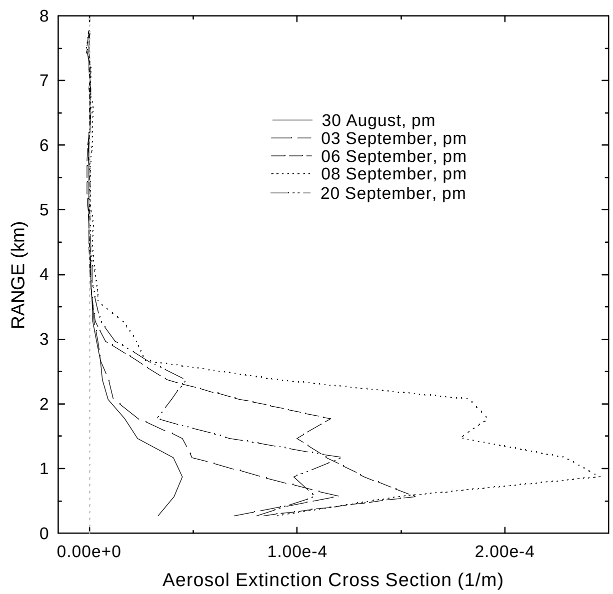

Figure 2. Aerosol extinction profiles calculated from 90-minute periods at the TWP site in 1997.

The effect of the smoke and haze on the surface shortwave flux is seen in Figure 3 and emphasized in Table 1. The drop in surface shortwave flux during smoke haze periods was observed to be around 100 w/m^2. The level of observed aerosol influence on the surface shortwave flux may be compared to calculations. The calculations were obtained from the ARM CAGEX group (Charlock and Alberta 1996) employing a code by Fu and Liou (1992). In Table 2 are found values determined by applying radiative transfer calculations using several levels of aerosol absorption and various optical depths. The observations compared best to the radiative transfer results when the model used absorbing aerosols as input. In this calculation, the absorbing aerosol correspond to an urban aerosol model with a 2 µm particle size and the strongly absorbing aerosol to an urban model with 8 µm particle size.

Table 1. TWP observations.

Day	τ(MPL)	F↓(w/m^2)
September 3 (246)	0.12	598
September 10 (253)	0.10	610
Smoke - September 8 (251)	0.62	525
Smoke - September 11 (254)	0.73	480

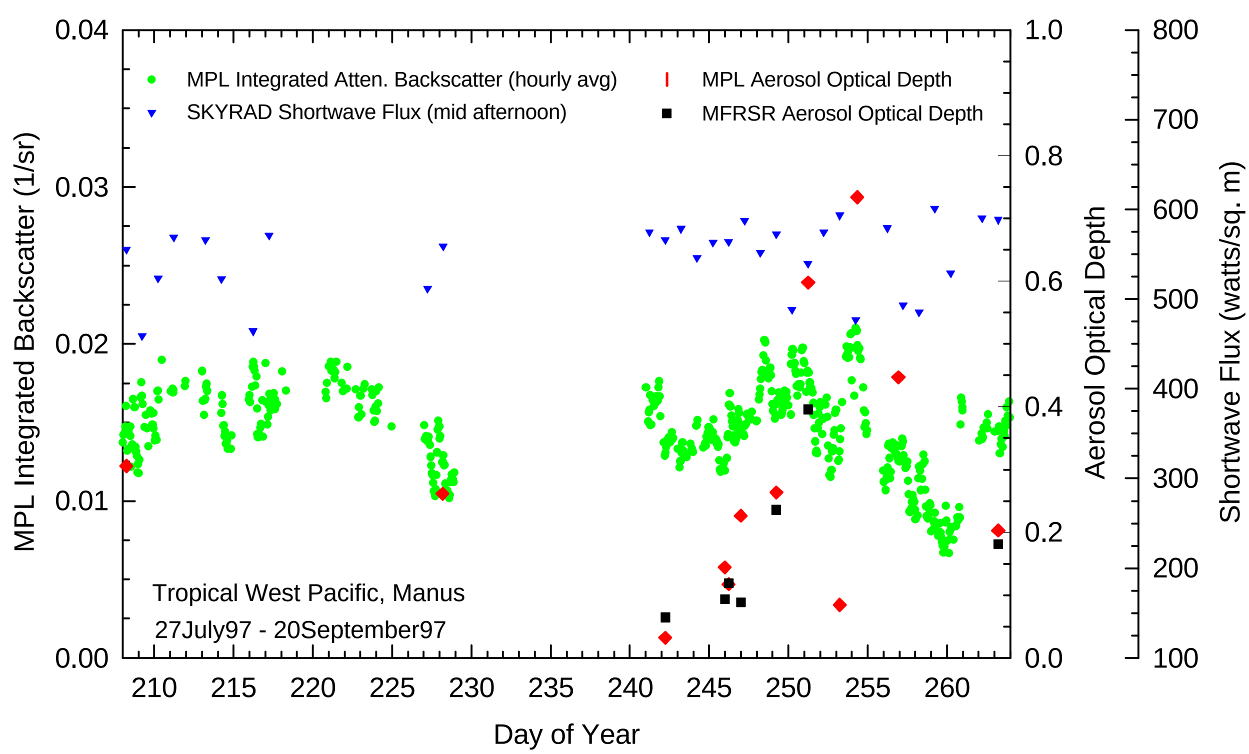

Figure 3. Cloud-cleared optical and radiation measurements at the TWP site from July to September 1997. (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/spinhirne-98.pdf*.)

Table 2. Modeled F↓(w/m^2) [cos θ_z = 0.6]

Aerosol Model: τ	Low Absorbing (Marine aerosol)	Moderately Absorbing	Strongly Absorbing
0.1	610	594	582
0.2	603	567	545
0.4	585	516	477
0.6	568	469	418
0.8	552	426	370

Summary

Significant smoke and haze episodes occurred at the ARM TWP site in September through November 1997. Aerosol optical depths increased to 0.6-0.8 during smoke haze episodes. The aerosols show significant absorbing characteristics. Based on these case studies, preliminary aerosol shortwave forcing from smoke haze is around -100 w/sq. m. The level of aerosol absorption would correspond to a shortwave radiative forcing of 3-4 degree/day throughout the boundary layer. Evidence from aerosol extinction profiles and MPL signal images show that the planetary boundary layer height increased 1 km to 2 km during the smoke haze episodes, but transport to the upper troposphere was not seen.

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