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TRANSTEC EDITORIAL

TESTING A SMOKE AEROSOL OPTICAL MODEL: CUIABA 1995, A CASE STUDY

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1. INTRODUCTION

Aerosols from biomass burning sources in the tropical regions of the globe play a significant role in the earth's energy balance (IPCC, 1994). Recent model studies incorporating sulfate aerosols demonstrate that the direct aerosol forcing, in part, counters warming by greenhouse gases over the industrial regions of the Northern Hemisphere (Mitchell et al., 1995). These models do not include biomass burning aerosol, but the observed extent, duration and concentration of biomass burning aerosols suggest that the direct effect of these aerosols on global climate may be of the same magnitude as the sulfate aerosol of northern mid-latitudes. In addition because of their hygroscopicity, biomass burning aerosol acting as cloud condensation nuclei may play a significant role in modifying cloud properties and affecting the energy balance indirectly (Twomey, 1984, Kaufman and Nakajima, 1993). There remains large uncertainties in estimating the aerosol effect on climate. (IPCC, 1994). Observations and modeling of the physical and radiative properties of aerosols are the first step to narrowing those uncertainties.

A network of ground-based sun/sky radiometers have been deployed in the Amazon Basin of Brazil during the burning seasons from 1993-1995 (Holben et al , 1996). These instruments use sun measurements to derive spectral optical thickness and total column precipitable water vapor, and also invert sky measurements to obtain volume size distribution and phase function. Previously using only two Cerrado stations that collected data in 1993 (Brasilia and Cuiaba) a preliminary model of smoke optical properties was constructed (Remer et al, 1996).

In this study we construct an optical model using the full three year data set that includes additional Cerrado stations as well as sites near the deforestation zone. The additional data permits a calculation of the uncertainties in the physical and optical parameters of the smoke model. The model is tested against similar data measured in Cuiaba during the 1995 burning season that was purposely withheld from the original data base in order to achieve an independent testbed.

2. THE MODEL

The sky radiances from each symmetrical almucantar are inverted to achieve aerosol volume size distribution (Nakajima et al, 1983). The Nakajima et al. (1983) inversion does not represent the correct size distribution for small particles due to assumptions at the lower size limit of the inversion. The volume of small particles is adjusted by assuming that these particles can be represented by a single lognormal and matching the optical properties calculated by the inversion with the optical properties of a lognormal size distribution in a look-up table (Remer et al., 1997).

Data collected in 1993 include a mode centered near 0.55 μm that represents the stratospheric aerosol created by the Mount Pinatubo eruption. Data from 1994 and 1995 do not include this mode. In this study, all 1993 data has had the stratospheric mode subtracted from each mean volume size distribution. The adjusted volume size distributions are sorted and ordered according to increasing aerosol optical thickness at 670 nm. Each 5-10 size distributions are averaged to give the mean size distribution for a particular aerosol optical thickness. The data from the forest sites and the Cerrado sites were analyzed separately. The volume size distributions reveal a bi-modal distribution. Figure 1 shows the mean size distributions ordered according to optical thickness for the Cerrado sites.

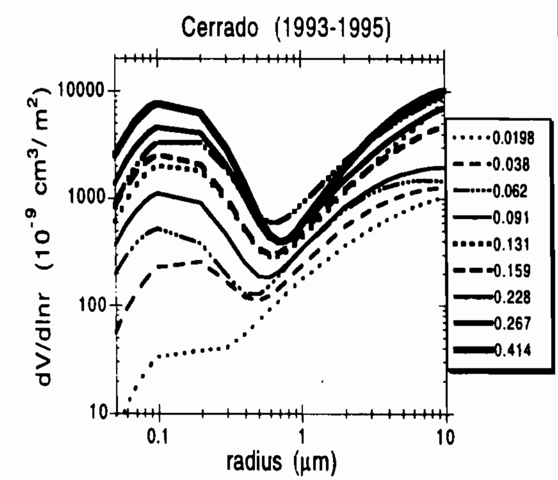

Fig. 1 Corrected mean size distributions for Cerrado sites for full data base.

The accumulation mode and coarse mode are then fit as lognormals according to the equation

$$\frac{dV}{d\ln r} = V_o \exp\left[-\frac{\left(\ln\left(\frac{r}{r_m}\right)\right)^2}{2\sigma^2}\right]$$

where dV/dlnr is the volume, Vo is the amplitude, r_m is the volume modal radius and σ is the standard deviation of the natural logarithm of the radius. The parameters of the lognormal fits along with the uncertainties in the fits for the two modes are given in Table 1 and shown graphically in Figs. 2 and 3. The uncertainties are much larger in the coarse mode than the accumulation mode and also larger for the forest sites than the Cerrado sites.

Table 1. Lognormal parameters and uncertainties for the Cerrado sites, the forest sites and also the parameters from the original analysis of the 1993 Cerrado sites.

	accumulation	coarse
Cerrado Vo	$f_1(\tau)$	$f_5(\tau)$
Cerrado r_m (µm)	0.132±0.014	11.5±14
Cerrado σ	0.60±0.04	1.26±0.23
Forest Vo	$f_2(\tau)$ $\tau<0.20$ $f_3(\tau)$ $\tau\geq0.20$	4800±1010
Forest r_m (µm)	$f_4(\tau)$ $\tau<0.20$ 0.145±0.025 $\tau\geq0.20$	9.0±24
Forest σ	0.60±0.09	1.20±0.30
1993 Vo	0-25,000	2200-9000
1993 r_m (µm)	0.130	5.6-21.2
1993 σ	0.50	0.7-1.2

$f_1(\tau) = -580+20700\tau$
$f_2(\tau) = 350+9500\tau$
$f_3(\tau) = -2070+21300\tau$
$f_4(\tau) = 0.074+0.358\tau$
$f_5(\tau) = 1030+27300\tau$

The accumulation mode particle size (r_m) is remarkably consistent in each data set and from one data set to the next This is especially true for the Cerrado sites. On the other hand, σ has increased from 0.50 in 1993 to 0.60 in the full 3-year data set. The parameters for the accumulation mode are taken from the look-up table during the correction of size distribution for small particles. The look-up table is incremented by Δr_m=0.005 and $\Delta\sigma$=0.10. This resolution may be inadequate to properly resolve σ.

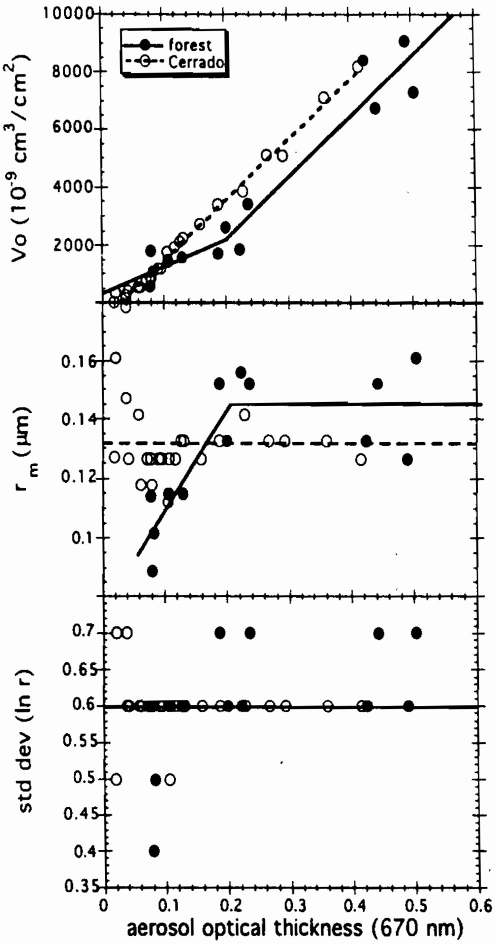

Fig. 2 Accumulation mode lognormal parameters as function of aerosol optical thickness at 670 nm.

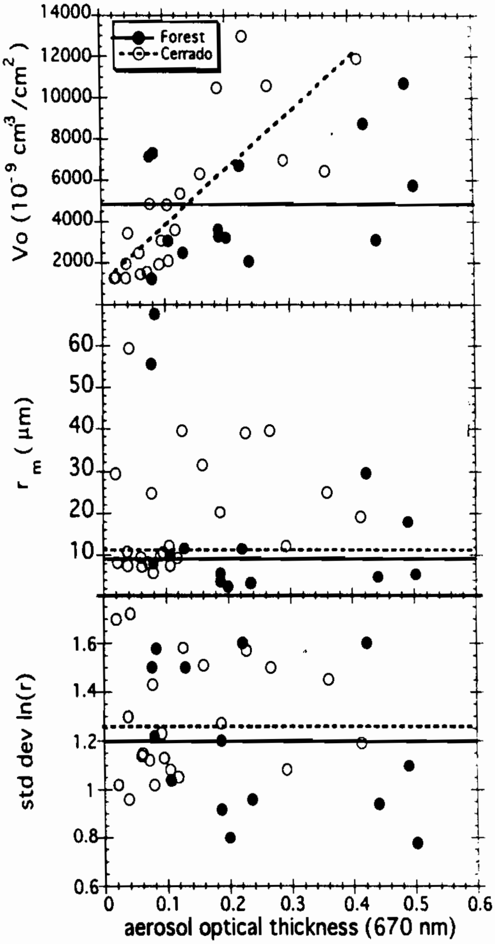

Fig. 3 Coarse mode lognormal parameters as function of aerosol optical thickness at 670 nm

3. CUIABA 1995

There were 27 almucantar inversions achieved from 22 Aug. through 14 Nov. 1995. These data represent aerosol conditions ranging from optical thicknesses at 670 nm of 0.09 to 1.11, and originate from a variety of locations according to trajectory analysis. The retrieved phase functions from the Cuiaba data set were sorted according to aerosol optical thickness and averaged for every three size distributions. Fig. 4 shows how well the model predicts the phase functions observed at Cuiaba. The model phase functions are calculated using Mie scattering code (Dave and Gazdag, 1970).

4. DISCUSSION

There is insignificant difference in

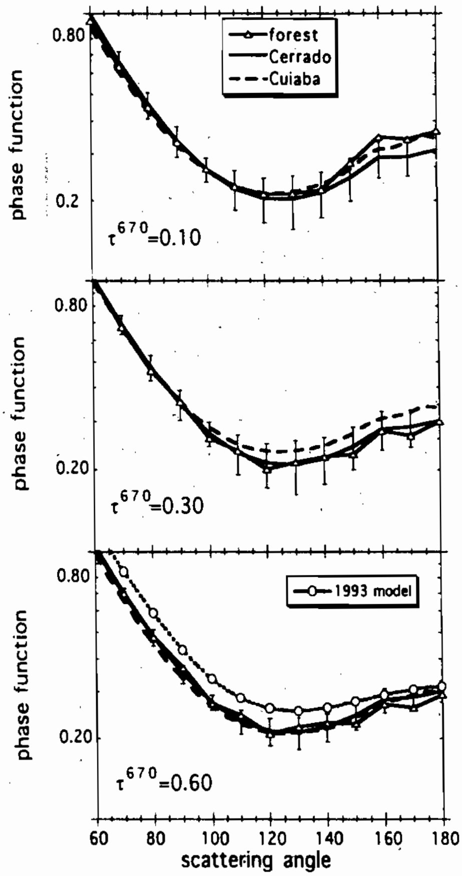

Fig. 4 Aerosol phase function calculated for the forest and Cerrado models with the error bars representing the uncertainty in the Cerrado model. Also plotted is Cuiaba 1995 and the phase function from the original 1993 model at τ=0.60.

optical properties of the forest and Cerrado models and both are able to predict the phase function of the Cuiaba 1995 data. This is because of the consistency in the parameters of the accumulation mode that dominates the aerosol optical properties. The model of the coarse mode is less certain.

The new models, calculated from the three year data base, better predict the phase function at Cuiaba than the original model calculated from only the 1993 data. The optically important difference between the 1993 and present models is the accumulation mode σ. The $\Delta\sigma$ of 0.10 is sufficient to create the difference in phase functions seen at higher optical thicknesses.

7. TRAJECTORY ANALYSIS

Back trajectories were run in 5x5 clusters within a 2.5 by 2.5 degree grid around Cuiaba using the NASA/GSFC isentropic trajectory model (Schoeberl et al., 1992).. NCEP analyses were used to drive the model. The 37 days of calculated back trajectories were separated into seven categories. Figure 5 shows an example from each of the categories. The seven categories were found to have significantly different mean values of optical thickness, precipitable water vapor and Angstrom coefficient as measured by the sun radiometer at Cuiaba.

The trajectories were superimposed on INPE published maps of weekly fire counts. The number of fires encountered by an air parcel on its journey to Cuiaba was noted and the mean calculated for each trajectory category. There is a strong correlation between number of fires encountered and optical thickness at Cuiaba (Fig. 6). The volume size distributions (Fig. 7) and resulting aerosol phase functions (Fig. 8) vary systematically depending on category of trajectory. The accumulation mode shows a degree of variability unexpected from previous analyses. In previous analyses we sorted the data by optical thickness, not air mass origin. Possibly, averaging within optical thickness groups smears any signal of size variability.

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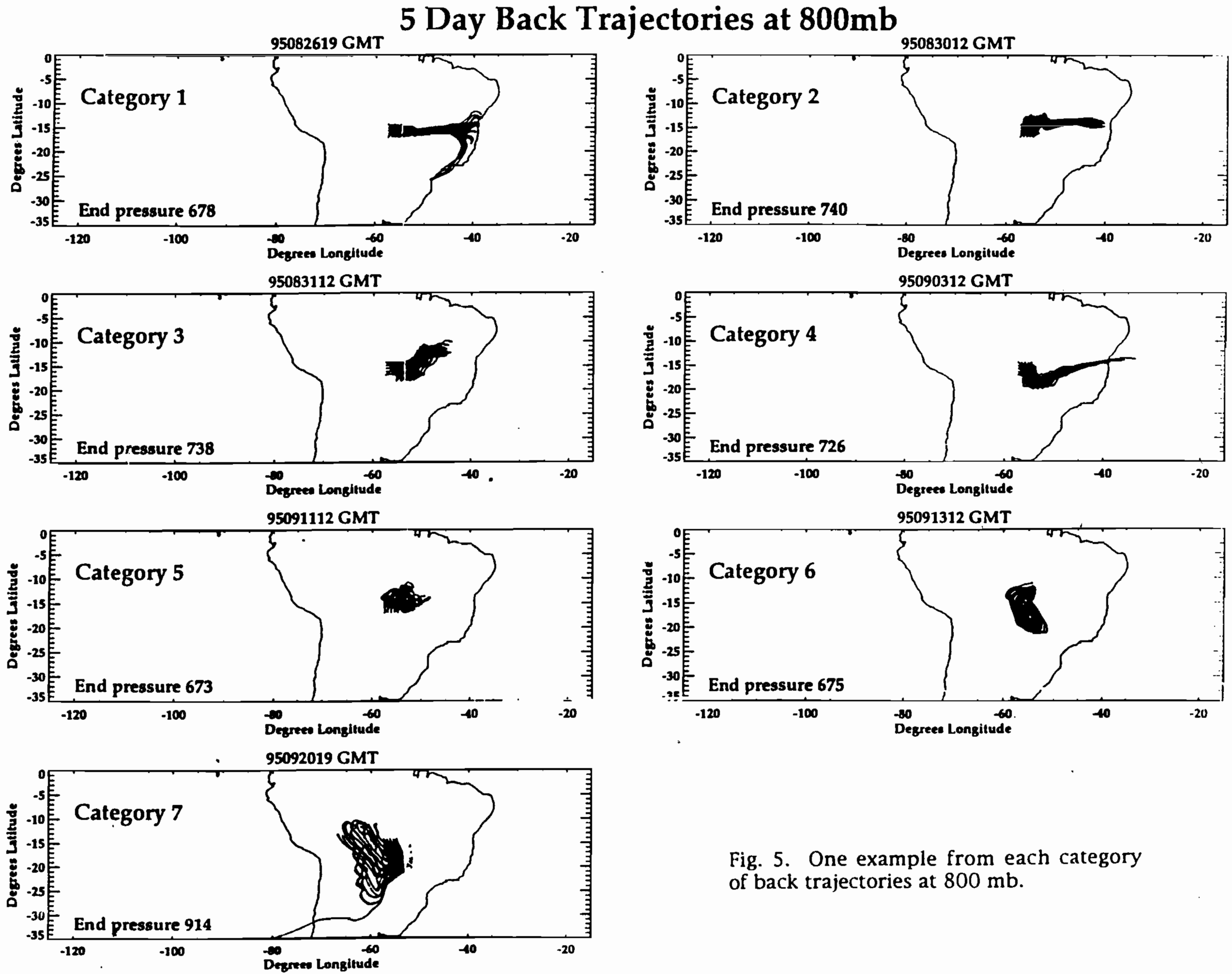

Fig. 5. One example from each category of back trajectories at 800 mb.

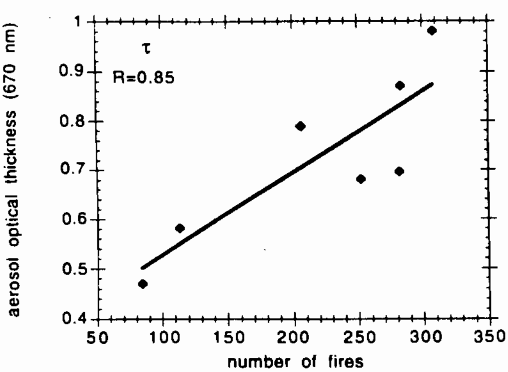

Fig. 6 Mean category optical thickness as a function of the number of fires encountered on a 5-day journey to Cuiaba.

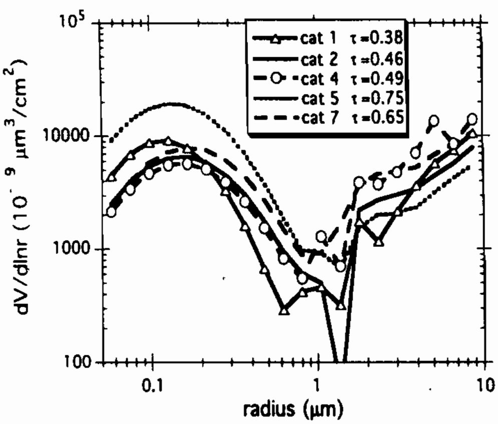

Fig. 7 Mean category volume size distributions, inverted from sky radiance data. Shown are the mean category optical thicknesses, calculated from the sun data, but measured at the time the sky radiances were measured.

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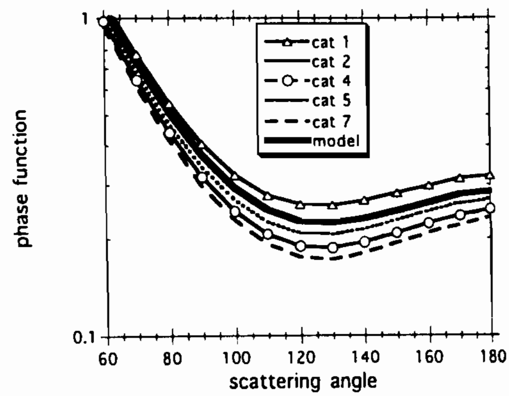

Fig. 8 Phase functions calculated from the accumulation modes of the volume size distributions for each category and for the model constructed from the three year data base.

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