DIRECT CLIMATIC FORCING DUE TO ATMOSPHERIC AEROSOLS FROM BIOMASS BURNING IN BRAZIL

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Abstract. *In this work, a box model was applied to estimate the aerosol direct radiative forcing (ADRF) due to biomass burning (BB) particulates measured in the Cerrado and in the Brazilian Amazon regions. In this paper, the data from the BB aerosols were obtained from the Smoke, Cloud, and Radiation – Brazil (SCAR-B) field project during a dry season in August and September, 1995 (Reid et al., 1998a). The scattering and absorption of the radiative fluxes were estimated based on measurements of important aerosol properties from the smoke plume produced by the burning of cerrado, pasture and primary rainforest. The ADRF was investigated for each aerosol component measured during in SCAR-B. The results for net radiative forcing at the Convective Boundary Layer (CBL) ranged from - 5.567 to – 20.523 Wm^{-2}. These results indicated that the net effect due to BB aerosols was the cooling of the local and regional climate system. Aerosol properties and the vertical profile of the atmosphere were important input parameters in determining the ADRF. However, in this study, aerosol concentration was the most important parameter that influenced the aerosol optical depth and consequently the ADRF from biomass smoke. The results also showed that "residue" aerosol was the most important aerosol component that influenced the light scattering.*

Keywords*: Atmospheric aerosols, direct radiative forcing, radiation models, Amazon Basin*

1. Introduction

Atmospheric aerosols may produce the cooling and warming of the Earth's system because of their capacity of scattering and absorbing a significant fraction of the incoming solar radiation. Aerosols may also warm the lower atmosphere by absorption and emission of thermal infrared radiation. The scattering and absorption of the solar and thermal infrared radiation causes what is called the aerosol direct radiative forcing (ADRF) on the climate system. However, the exact magnitude of the ADRF on climate has a large uncertainty. A large component of the uncertainty is due to the spatial and temporal variability in aerosol sources and distribution (Feczkó, et al., 2002). Uncertainties in quantifying direct forcing of aerosols also include their relative short-life in the troposphere (Schwartz, 1996) and inadequate knowledge of aerosol properties, such as optical properties and chemical composition (Reid et al., 2004). These uncertainties produce wide ranges of direct forcing values estimated by different approaches depending on the assumptions chosen.

Aerosol emissions from biomass smoke, associated with deforestation and clearing fires in the tropical regions, have important contribution on the balance of the surface-atmosphere system (Kaufman et al. 1998). In this work, the main goal was to characterize the influence of the different elemental composition of the biomass burning (BB) aerosols on the radiation budget in the Cerrado and in the Brazilian Amazon regions. Two simple box-models were applied in order to estimate the ADRF due to the scattering and absorption of the shortwave and longwave radiation. These models were based on the formulations proposed by Charlson et al. (1991) and Haywood and Shine (1995). The vertical aerosol optical depth was obtained at a height corresponding to that of a Convective Boundary Layer (CBL). Analyzes of the different aerosol properties in the calculation of the direct radiative forcing reflect the characteristics of the aerosol components from cerrado, pasture and primary forest. The aerosol properties were sampled from the SCAR-B experiments during the dry season, in August and September, 1995 (Reid et al., 1998a). These field experiments were performed in the vicinity of Cuiabá (state of Mato Grosso), Porto Velho (in the sate of Rondônia) and Marabá (in the state of Pará).

2. Estimating the Direct Effect of Aerosols

2.1. Influence on the direct effect due to scattering of the atmospheric aerosol

In order to estimate the ADRF effect due to light scattering, the modelling of scattering on the aerosol layer considers the following approximations: atmospheric aerosols are assumed to be nonabsorbing (single-scattering albedo of 1) and the optical depth, for most tropospheric conditions, it is usually considerably smaller than 1 (Seinfeld and Pandis, 1998). The aerosol direct effect due to scattering is calculated by the Charlson's formula (Charlson et al., 1991):

$$\Delta F_{sp}^{[\eta]} = -F_o T_a^2 (1-A_c)(1-R_s)^2 \overline{\beta} \tau_{sp}^{[\eta]} \quad (1)$$

where $\Delta F_{sp}^{[\eta]}$ (Wm^{-2}) is the radiative forcing due to the scattering by the [η] component of the aerosol; F_o is the incident solar flux (Wm^{-2}); T_a is the transmittance of atmosphere above the aerosol layer; A_c is the fraction of the surface covered by clouds and the factor $(1 - A_c)$ is introduced because the albedo enhancement due to aerosols is applicable only for cloud-free regions; R_s is the albedo of the underlying surface and the factor $(1 - R_s)^2$ takes into account multiple reflections between the surface and the aerosol layer; $\overline{\beta}$ is the fraction of average daily solar radiation scattered to space by the particle, averaged over the sunward hemisphere and $\tau_{sp}^{[\eta]}$ is the aerosol optical depth due to scattering for the [η] component of the aerosol. $\tau_{sp}^{[\eta]}$ may be obtained for the height of the CBL from integration of the light-scattered over the vertical extent (z) from the ground-level to the height of the Convective Boundary Layer:

$$\tau_{sp}^{[\eta]} = \int_0^H \sigma_{sp}^{[\eta]} \, dz \quad (2)$$

where $\sigma_{sp}^{[\eta]}$ is the aerosol mass scattering coefficient for the [η] component of the aerosol (m^{-1}). The scattering coefficient characterizes the scattering of light by airborne particles and is given by:

$$\sigma_{sp}^{[\eta]} = \alpha_{sp}^{[\eta]} m^{[\eta]} f(RH) \quad (3)$$

where $\alpha_{sp}^{[\eta]}$ is the particle light-scattering efficiency ($m^2\ g^{-1}$) and $m^{[\eta]}$ is aerosol mass concentration ($g\ m^{-3}$) for the [η] component of the aerosol and $f(RH)$ is the dimensionless hygroscopic growth factor (or humidification factor).

A critical physical characteristic of the soluble atmospheric particles is its hygroscopic behavior, because their influence in the size of the aerosols at ambient relative humidity. The f(RH) is given by:

$$f(RH) = \frac{\sigma_{sp}(\lambda, RH)}{\sigma_{sp}(RH_{ref})} \quad (4)$$

where σ_{sp} (λ, RH) is the ambient light scattering, generally at RH = 80%; $\sigma_{sp}(RH_{ref})$ is the dry light scattering, usually at RH < 35% (Reid et al., 2004).

2.2. Influence on the direct effect due to absorption of the atmospheric aerosol

The direct effect of the aerosol due to absorption can be estimated by the Haywood and Shine (1995) formulation, which given by:

$$\Delta F_{ap}^{[\eta]} = -F_o T_a^2 (1-A_c)\omega_o \overline{\beta} \tau_{ap}^{[\eta]} \left[(1-R_s)^2 - \frac{2R_s}{\overline{\beta}(\omega_o^{-1} - 1)} \right] \quad (5)$$

where $\Delta F_{ap}^{[\eta]}$ is the radiative forcing in the column owing to the absorption by the [η] component of the aerosol; ω_o is the single-scattering albedo; $\tau_{ap}^{[\eta]}$ is the aerosol optical depth due to light absorption for the [η] component of the aerosol and other parameters are the same as used previously. According Reid et al., (2004) the black carbon, the main constituent of soot, is only responsible for the light absorption of the particles. $\tau_{ap}^{[\eta]}$ may be obtained for the height of the CBL from integration of the light-absorption over the vertical extent (z) from the ground-level to the height of the CBL:

$$\tau_{ap}^{[\eta]} = \int_0^H \sigma_{ap}^{[\eta]} \, dz \quad (6)$$

where $\sigma_{ap}^{[\eta]}$ is the aerosol mass absorption coefficient of the black carbon aerosol (m^{-1}).

The mass absorption efficiency of the black carbon aerosol is given by:

$$\sigma_{ap}^{[\eta]} = \alpha_{ap}^{[\eta]} m^{[\eta]} \tag{7}$$

where $\alpha_{ap}^{[\eta]}$ is the particle light-absorption efficiency ($m^{-2}g^{-1}$) of the black carbon aerosol. In this case the hygroscopic growth factor for the absorption coefficient as it is close to 1 for all unsaturated conditions and consequently commonly neglected for smoke (Reid et al., 2004).

When is considered individual particles single-scattering albedo, ω_o, it is calculated by ratio between particle scattering and particle extinction. Single-scattering albedo can be obtained by combining measurements of the scattering and absorption coefficients according to:

$$\omega_o = \frac{\sigma_{sp}^{[\eta]}}{\sigma_{sp}^{[\eta]} + \sigma_{ap}^{[\eta]}} \tag{8}$$

2.3 Averaged up-scatter fraction

The aerosol direct radiative forcing is influenced by aerosol microphysics through the up-scatter fraction, β, which exhibits a dependence on particle size as a consequence of the particle size dependence of the phase function, i.e., the angular distribution of the scattered radiation (Schwartz, 1996). In this study the average up-scatter fraction was estimated from the backscatter ratio, $\beta(\cos\mu = 1)$ or simply $\beta(1)$, using the polynomial given by Anderson et al. (1999):

$$\overline{\beta} = 0.082 + 1.85\beta(1) - 2.97\beta(1)^2 \tag{9}$$

3. Experimental sites

The measurements reported in this work were performed during the SCAR-B experiment in the vicinity of Cuiabá (in the state of Mato Grosso, 16° S, 56° W), Porto Velho (in the sate of Rondônia, 9° S, 64° W) and Marabá (in the state of Pará, 5° S, 49° W) from August 23 to September 18, 1995 (Reid et al., 1998a). In SCAR-B the University of Washington (UW) Convair C-131A research aircraft was used to collected atmospheric aerosols from a wide variety of situation with regional hazes dominated by smokes. Cuiabá is located in the cerrado region, while Porto Velho and Marabá are located in the western and eastern regions of the Amazon Basin, respectively. The details of the experimental sites are described by Reid et al. (1998a).

4. Input Parameters

Cloud coverage: This study uses the measurements of the average cloud cover over Cuiabá (Local Haze, LH), Cuiabá (Aged Haze, AH), Porto Velho, and Marabá, that were performed out on aboard UW C-131A aircraft during the SCAR-B experiment, as shown in Tab. 1 (Reid et al., 1998a).

Height of atmospheric boundary layer: Table 1 shows the values of the height of the planetary boundary layer (PBL) that were available to the inversion height of the convective boundary layer (CBL) over Cuiabá, Porto Velho and Marabá during the SCAR-B experiment (Reid et al., 1998a). The atmospheric structures from the vertical profiles are also presented in Tab. 1.

Fractional transmittance and incident solar flux: In the present work, it was assumed the global mean value to the fractional transmittance above aerosol layer and incident flux solar on the aerosol layer, due to have no information about T_a and F_o in the Cerrado and in the Brazilian Amazon regions. The fractional transmittance of 0.87 above aerosol layer due to biomass burning aerosols was specified by IPCC (2001). The incident flux solar of 343 Wm^{-2} was obtained from literature (Seinfeld and Pandis, 1998).

Surface albedo: Surface albedo of 0.11 due to biomass burning aerosol over cerrado was reported by Guyon et al. (2003). In the Amazon Basin, forest and pasture the surface albedo was obtained during the Anglo-Brazilian Amazonian Climate Observation Study (ABRACOS) project, between 1991 and 1993 in the Jarú Biologic Reserve (10° 04' 55" S, 61° 55' 48" W), (Culf et al., 1995). Estimates values of the atmospheric transmittance, solar constant and mean surface albedo for forest and cerrado sites are given in Tab. 2.

Up-scatter ratio: In the present analyze, the up-scatter ratio values at a wavelength of 500mn measured during the SCAR-B experiment were reported by Reid et al. (1998a), as show in Tab. 3. The authors carried out measurements of the $\beta(1)$ from biomass burning aerosols with a three nephelometer (λ = 450, 550, 770 nm) aboard of UW C-131A aircraft.

Aerosol mass-scattering efficiency: Measurements of the particle mass-scattering efficiency, α_s, were carried out aboard of UW C-131A aircraft and also were obtained with a nepholometer (Reid et al., 1998a). Aerosol were sampled continuously through a pressure-regulated, isokinetic inlet and dried to a RH < 35%. Table 3 shows the values of the α_{sp} (λ = 550 nm) measurements in the vicinity of Cuiabá, Porto Velho and Marabá, during in SCAR-B.

Table 1. Meteorological conditions for seven vertical profiles obtained during flights of the UW C-131A aircraft in Regional Hazes in the Cerrado and in the Brazilian Amazon regions. Source: Reid et al. (1998a).

Parameter	Cuiabá	Cuiabá	Cuiabá (Aged)	Cuiabá (Aged)	Porto Velho	Porto Velho	Marabá
UW flight number	1692	1694	1696	1697	1700	1703	1712
1995	Aug. 23	Aug. 24	Aug. 30	Sept. 1	Sept. 5	Sept. 5	Sept. 17
UTC[(a)]	1630	1945	1500	1300	1945	1700	1500
Cloud type	clear	Ci	Ac	Ac	Cu	Cu	Cu
Cloud coverage, %	clear	thin	30-50	70-100	25	30	60
Optical depth at λ = 550 nm	~ 0.1	0.8	1.7	1.5	2.3	1.4	~ 0.3
Convective Boundary Layer							
Inversion height, km	2.3	2.7	3.5	3.9	3.8	4.1	2.1
Inversion pressure, hPa	757	718	650	622	629	~ 600	770
Inversion temp., ^oC	10	8	0	- 2	3.5	1	12
Inversion dew point, ^oC	- 1	- 1	- 3	- 4	- 10	- 3	11

(a) UTC (coordinated universal time)

Table 2 – Estimates of the values of several parameters in the evaluation of the aerosol direct radiative forcing.

PARAMETER	VALUE	REFERENCE
Atmospheric transmittance, T_a	0.87	IPCC (2001)
Solar constant, F_o	343 Wm^{-2}	Seinfeld and Pandis (1998)
Mean surface albedo for cerrado site[(a)], R_s	0.11	Guyon et al. (2003)
Mean surface albedo for forest site[(b)], R_s	0.133	Culf et al. (1995)

(a) R_s over Cuiabá and (b) R_s over Porto Velho and Marabá.

Aerosol mass-absorption efficiency: The values of the aerosol mass-absorption efficiency, α_{ap}, (λ = 550 nm), in Cuiabá (LH), Cuiabá (AH), Porto Velho and Marabá obtained during the SCAR-B experiment are given in Table 3 (Reid et al., 1998a). These values were used in this present study in order to obtain the aerosol mass-absorption coefficient of the black carbon aerosol.

Single-scattering albedo (SSA): The data of the single-scattering albedo, ω_o, for wavelength of 550 nm are given in Tab. (4).In SCAR-B, Reid et al. (1998a) found that there was a tendency for ω_o to increase with aged smoke.

Humidification factor: The hygroscopic growth factor was obtained from measurements carried out during the flights of the UW C-131A (Kotchenruther and Hobbs, 1998). The authors defined the *f* (RH) as the light-scattering coefficient for particles at 80% relative humidity (RH) divided by the light-scattering of dry particles at 30% RH. For smoke in Brazil, at a wavelength of 550nm, the ratio of the light-scattering coefficient at a RH of 80% to that at an RH of 30% ranged from 1.01 to 1.51 with an average value of 1.16. This study applied the same values of the humidification factor at RH = 80% measured during the SCAB-B experiment in Cuiabá (LH) and Cuiabá (AH). Table 4 shows the values of *f* (80%) at the Cuiabá, Porto Velho and Marabá due to biomass burning aerosols; in this case, the authors pointed out that average up-scatter fraction vary with RH.

Elemental concentrations: In SCAR-B, sixty-two 37 mm Teflon filters aboard the UW C-131A aircraft collected aerosols from biomass smoke in Cuiabá, Porto Velho and Marabá. The following ions elements were measured: Ca^{2+}, Cl^-, K^+, Mg^{2+}, Na^+, NH_4^+, NO_2^-, NO_3^-, $SO_4^=$, and $C_2O_4^=$ (oxalate). During the experiments, forty-one polycarbonate filters samples were collected simultaneously with Teflon filters. The polycarbonate filters were gravimetrically analyzed and then subjected to proton induced X ray emission (PIXE) spectroscopy to determine the concentrations of above cited elements. In the SCAR-B experiment, five different measurement techniques were used to measure black carbon (BC) content of the aerosol aboard the UW C-131A aircraft (Kaufman et al., 1998). The quality of the techniques that were applied to measure BC is described in detail by Reid et al. (1998b). The concentrations for all chemical species of the particles with aerodynamic diameter < 4 μm (PM_4) obtained in regional hazes during the SCAR-B experiment are shown in Tab. 5.

Table 3. Optical parameters of the biomass burning aerosols (Mean ± Standard Deviation) for Cuiabá (Local Haze), Cuiabá (Aged Haze), Porto Velho, and Marabá. Source: Reid et al. (1998a).

Parameter	Cuiabá (LH)	Cuiabá (AH)	Porto Velho	Marabá
α_{sp} (in $m^2\ g^{-1}$ at λ = 550 nm)	2.9±0.9	3.8±0.8	3.5±0.7	2.9±0.6
$\beta(1)$ (at λ = 550 nm)	0.15±0.02	0.12±0.01	0.11±0.01	0.13±0.01
α_{ap} (in $m^2\ g^{-1}$ at λ = 550 nm)	0.89±0.44	0.73±0.2	0.62±0.15	0.60±0.1
ω_o (at λ = 550 nm)	0.79±0.04	0.85±0.02	0.86±0.05	0.83±0.02

Table 4. Estimated values of *f*(RH) at RH = 80% during the SCAR-B experiment. Source: Reid et al. (1998a).

Site	*f* (80%)	$\beta(1)$ at 80% RH	$\overline{\beta}$ at 80% RH
Cuiabá	1.07	0.117	0.257
Porto Velho	1.10	0.102	0.237
Marabá	1.32	0.114	0.251

Table 5. Concentration of particles (PM_4) measured in regional hazes dominated by smoke from biomass burning over Cuiabá (LH), Cuiabá (AH), Porto Velho and Marabá during the SCAR-B experiment. Source: Reid et al., (1998a).

	Concentration of the biomass burning aerosol, PM_4 ($\mu g\ m^{-3}$)			
Element	**Cuiabá (LH)**	**Cuiabá (AH)**	**Porto Velho**	**Marabá**
Black Carbon	3.538	4.179	2.361	2.640
Ca^{2+}	0.199	0.072	0.126	0.198
Cl^-	0.053	0.007	0.084	0.264
K^+	0.650	1.144	0.801	0.759
Mg^{2+}	0.088	0.021	0.042	0.033
Na^+	0.044	0.072	0.169	0.264
NH_4^+	0.221	1.287	0.843	0.429
NO_3^-	0.663	1.144	0.506	0.363
$C_2O_4^=$	0.531	1.073	0.843	0.429
PO_4^-	0.004	0.007	0.008	–
$SO_4^=$	0.575	2.86	3.204	2.244
Fe	0.221	0.286	0.253	0.198
Residue[(a)]	37.277	58.702	32.800	24.981
Total	44.065	71.393	42.042	32.802
	Mass Apportionment, %			
Soil	10±6	8±4	12±8	12±15
Biogenic	7±3	1±1	4±6	5±3
Biomass burning	67±5	65±5	62±5	66±10
Residual	16±6	26±4	22±8	17±15

(a) The residue is the difference between the measured total aerosol mass (< 4 μm diameter) and that accounted for by the measured species; according Reid et al. (1998a) this aerosol is probably mostly organic.

5. Results and discussion

In order to quantify the direct effect of the biomass burning aerosol, it was required the magnitudes of the aerosol mass-scattering coefficient for the [η] component of the aerosol, aerosol mass-absorption coefficient of the black-carbon, aerosol optical depth due to light scattering for the [η] component of the aerosol, aerosol optical depth due to light absorption from black carbon aerosol and single scattering albedo.

5.1. Scattering and absorption coefficients

The aerosol mass-scattering coefficient for the [η] component of the aerosol, were estimated using the bulk parameterizations of the mass-scattering efficiency (λ = 550 nm), humidification factors, and concentration of the aerosol component, that were specified in Tab. 3, 4 and 5, respectively. The results of the calculated total aerosol mass-scattering coefficient, σ_{sp}, in Cuiabá (Aged Haze) was 53%, 56%, and 57% greater than calculated the total σ_{sp} in

Cuiabá (LH), Porto Velho and Marabá, respectively, as shows in Tab. 6. Value of *f*(80%) estimated during the SCAR-B experiment in Marabá was 19%, and 17% greater than the values of the estimated *f*(80%) in Cuiabá and Porto Velho, as shows in Tab. 4. The total BB aerosol concentrations measured in Cuiabá (AH) was 38%, 41%, and 54% greater than total BB aerosol concentrations measured in Cuiabá (LH), Porto Velho, and Marabá, as shows in Tab. 5. The influence of the measured α_{sp}, as shows in Tab. 2 during the SCAR-B experiment was small, due to this parameter not present greater difference between the values measured in the Cerrado and in the Brazilian Amazon regions. In this study, the results suggested that a reduction in aerosol emission has a significant influence in the magnitude of the mass-scattering coefficient.

The concentration of the "residue" aerosol comprised of 84.51% in Cuiabá (LH), 82.22% in Cuiabá (AH), 78.02 % in Porto Velho, and 76.16% in Marabá of the total aerosol concentration. It is important to note that the concentration of the aerosol "residue" was the most important parameter that influenced the aerosol mass-scattering in the CBL over Cerrado and Brazilian Amazon regions. Reid et al., (1998a) pointed out that "residue" aerosol was presumed to be mainly organic aerosols.

The σ_{ap}, was estimated through the use of the bulk parameterizations of the mass-absorption efficiency (λ = 550 nm), concentration of the black carbon, and calculated using the Eq. (8). The comparisons between the calculated σ_{ap} showed that in Cuiabá (AH) the magnitude of the calculated σ_{ap} was 57% and 54% greater than σ_{ap} calculated in Porto Velho and Marabá, respectively. In Cuiabá (LH) and Cuiabá (AH) the estimated values of the σ_{ap} no showed significant variability, 3.151×10^{-6} m^{-1} and 3.445×10^{-6} m^{-1}, respectively. In this case, the increase of concentration of the BB aerosol in Cuiabá (AH) was balanced by the increased of aerosol mass scattering efficiency on biomass smoke in Cuiabá (LH).

Table 6. Estimated values of aerosol mass-scattering coefficient depth due to light scattering of the [η] component of the biomass burning aerosols and aerosol absorption coefficient of the black carbon aerosol.

	Aerosol mass-scattering coefficient (m^{-1}) at λ = 550 nm			
Element (PM_4)	**Cuiabá (LH)**	**Cuiabá (AH)**	**Porto Velho**	**Marabá**
BC	1.098×10^{-5}	1.919×10^{-5}	9.090×10^{-6}	1.011×10^{-5}
Ca^{2+}	6.175×10^{-7}	2.907×10^{-7}	4.869×10^{-7}	7.579×10^{-7}
Cl^{-}	1.647×10^{-7}	2.907×10^{-8}	3.246×10^{-7}	1.011×10^{-6}
K^{+}	2.017×10^{-6}	4.652×10^{-6}	3.084×10^{-6}	2.905×10^{-6}
Mg^{2+}	2.744×10^{-7}	8.722×10^{-8}	1.623×10^{-7}	1.263×10^{-7}
Na^{+}	1.372×10^{-7}	2.907×10^{-7}	6.493×10^{-7}	1.011×10^{-6}
NH_4^{+}	6.861×10^{-7}	5.233×10^{-6}	3.246×10^{-6}	1.642×10^{-6}
NO_3^{-}	2.058×10^{-6}	4.652×10^{-6}	1.948×10^{-6}	1.390×10^{-6}
$C_2O_4^{=}$	1.647×10^{-6}	4.361×10^{-6}	3.246×10^{-6}	1.642×10^{-6}
PO_4^{-}	1.372×10^{-8}	2.907×10^{-8}	3.246×10^{-8}	–
$SO_4^{=}$	1.784×10^{-6}	1.163×10^{-5}	1.234×10^{-5}	8.590×10^{-6}
Fe	6.861×10^{-7}	1.163×10^{-6}	9.739×10^{-7}	7.579×10^{-7}
Residue	1.157×10^{-4}	2.387×10^{-4}	1.263×10^{-4}	9.563×10^{-5}
TOTAL	1.367×10^{-4}	2.903×10^{-4}	1.619×10^{-4}	1.256×10^{-4}
	Aerosol mass-absorption coefficient (m^{-1}) at λ = 550 nm			
BC	3.151×10^{-6}	3.445×10^{-6}	1.464×10^{-6}	1.584×10^{-6}

5.2. Optical depth of the aerosol layer due to light scattering and light absorption

The optical depth of the aerosol layer due to light scattering and light absorption, in the CBL were calculated using Eq. (2) and Eq. (7), respectively. The input parameters were the average values of height of the CBL in Cuiabá (Local Haze) of 2.5 km, Cuiabá (Aged Haze) of 3.7 km, Porto Velho of 3.95 km, and Marabá of 2.1 km measured during SCAR-B project and estimated values of the $\sigma_{sp}^{[\eta]}$ (λ = 550nm) and $\sigma_{ap}^{[\eta]}$(λ = 550nm) in this study, as show in Tab. 6.

The results showed that the estimated total aerosol optical depth (AOD) due to light scattering, τ_{sp}, from biomass burning aerosols in Cuiabá (AH) was 68%, 44%, 75% greater than estimated values of total τ_{sp} in Cuiabá (LH), Porto Velho and Marabá, respectively. The comparisons between the calculated aerosol optical depth due to light absorption, τ_{ap}, from black carbon aerosol showed that in Cuiabá (AH) the intensity of the τ_{ap} was 38%, 55% and 74% greater than calculated τ_{ap} in Cuiabá (LC), Porto Velho and Marabá, respectively. Then, these results suggested AOD was more influenced by the aerosol mass scattering and absorption coefficients than by the than by the height of the CBL.

Table 5 presents the concentration of the particles (PM_4) measured in local and regional hazes from biomass burning in the Cerrado and in the Brazilian Amazon regions, theses measurements showed that the "residue" aerosol have a larger contribution than other aerosols components on estimation of the σ_{ap} and consequently on the τ_{ap}. The contributions of the "residue" aerosol on estimated value of the τ_{ap} were 85% in Cuiabá (LH), 82% in Cuiabá (AH), 78% in Porto Velho and 76% in Marabá.

Table 7. Estimated values of the aerosol optical depth due to light scattering of the [η] component of the aerosol and light absorption due to black carbon aerosol in the Cerrado and in the Brazilian Amazon.

	Aerosol optical depth due to light scattering (at λ = 550 nm)			
Element (PM_4)	**Cuiabá (LH)**	**Cuiabá (AH)**	**Porto Velho**	**Marabá**
BC	2.475×10^{-2}	7.100×10^{-2}	3.591×10^{-2}	2.122×10^{-2}
Ca^{2+}	1.544×10^{-3}	1.076×10^{-3}	1.923×10^{-3}	1.592×10^{-3}
Cl^{-}	4.118×10^{-4}	1.076×10^{-4}	1.282×10^{-3}	2.122×10^{-3}
K^{+}	5.043×10^{-3}	1.721×10^{-2}	1.218×10^{-2}	6.101×10^{-3}
Mg^{2+}	6.860×10^{-3}	3.227×10^{-4}	6.411×10^{-4}	2.653×10^{-4}
Na^{+}	3.430×10^{-4}	1.076×10^{-3}	2.565×10^{-3}	2.122×10^{-3}
NH_4^{+}	1.715×10^{-3}	1.936×10^{-2}	1.282×10^{-2}	3.449×10^{-3}
NO_3^{-}	5.145×10^{-3}	1.721×10^{-2}	7.694×10^{-2}	2.918×10^{-3}
$C_2O_4^{=}$	4.118×10^{-3}	1.614×10^{-2}	1.282×10^{-2}	3.449×10^{-3}
PO_4^{-}	3.430×10^{-5}	1.076×10^{-4}	1.282×10^{-4}	–
$SO_4^{=}$	4.460×10^{-3}	4.303×10^{-2}	4.873×10^{-2}	1.804×10^{-2}
Fe	1.715×10^{-3}	4.303×10^{-3}	3.847×10^{-3}	1.592×10^{-3}
Residue	2.893×10^{-1}	8.832×10^{-1}	4.988×10^{-1}	2.008×10^{-1}
TOTAL	3.419×10^{-1}	1.074	6.394×10^{-1}	2.637×10^{-1}
	Aerosol optical depth due to light absorption (at λ = 550 nm)			
BC	7.875×10^{-3}	1.275×10^{-2}	5.782×10^{-3}	3.326×10^{-3}

5.3. Average up-scatter fraction

The values of the $\overline{\beta}$ in this study were calculated using the polynomial given by Anderson et al. (1999), Eq. (10). The results of the average up-scatter fraction were the following: in Cuiabá (Local) was 0.293; in Cuiabá (Aged) was 0.261; in Porto Velho was 0.250, and in Marabá was 0.272. Kotchenruther and Hobbs (1998) found values of average up-scatter fraction over Cuiabá, Porto Velho and Marabá of 0.257, 0.237, and 0.251, respectively, by using the Henyey-Greenstein phase function, these results of the average up-scatter fraction show good agreement with the values obtained in the present study.

5.4. Aerosol direct forcing due to light scattering and light absorption

The estimate of the ADRF for the height of the CBL due to light scattering and absorption from biomass burning aerosols over Cuiabá (LH), Cuiabá (AH), Porto Velho and Marabá, were obtained using Eq. (1) and Eq. (6), respectively. Inputs parameters used to calculate the $\Delta F_{sp}^{[\eta]}$ for the [η] component of the biomass burning aerosols and the $\Delta F_{ap}^{[\eta]}$ for the black carbon aerosol were specified in sections above. Table 8 shows the results of the $\Delta F_{sp}^{[\eta]}$ on local and regional scale for the [η] component of the biomass burning aerosols and $\Delta F_{ap}^{[\eta]}$ on local and regional scale for the black carbon aerosols.

The "residue" aerosol was the most important aerosol component that influenced the direct radiative forcing due to light scattering. Based on the calculation of total radiative forcing due to light scattering, ΔF_{sp}, the contribution of the aerosol "residue" comprise of 85% in Cuiabá (LH), 84% in Cuiabá (AH), 78% in Porto Velho and 76% in Marabá. These results may be attributed the elevated "residue" aerosol concentrations that were collected from biomass smoke episode in the Cerrado and in the Brazilian Amazon regions. The results showed that ADRF due to light scattering of the black aerosol in Cuiabá (LH), Cuiabá (AH), Porto Velho and Marabá was 42%, 23%, 89% and 93% greater than ADRF due to light absorption, respectively. Thus, the influence of black carbon aerosol in cooling the atmosphere was greater than their influence in warming the atmosphere. This contribution is largest in smoke plume produced by the

burning of pasture and primary forest than the burning of cerrado. Detailed information about the differences between burning in cerrado and rain forest may see in study performed out by Yamasoe et al. (2000).

The results of the ADRF showed that BB aerosols on local and regional scale in the Cerrado and in the Brazilian Amazon regions have a significant effect of cooling in the CBL, as shown in Tab. 8. This behaviour occurred due to the net radiative forcing (e.g. effect light scattering + effect light absorption) from BB aerosols presented a negative radiative forcing. It is important emphasize that light absorption from black carbon aerosol, which may be cause warming of the atmosphere, have a small influence on the total ADRF. Thus the ADRF in the CBL was dominated by light scattering. Despite of the small value of the total ADRF found in Marabá, in comparison with the values from the other sites, this value of the radiative forcing would have a significant influence on the regional climate system.

Table 8. Estimated local and regional values of the ADRF of the atmospheric boundary layer in the Cerrado and in the Brazilian Amazon regions.

	ADRF due to light scattering (Wm^{-2}) at λ = 550 nm			
Element (PM_4)	**Cuiabá (LH)**	**Cuiabá (AH)**	**Porto Velho**	**Marabá**
Black Carbon	- 1.657	- 1.429	- 1.270	- 0.451
Ca^{2+}	- 0.093	- 0.022	- 0.068	- 0.034
Cl^{-}	- 0.025	- 0.002	- 0.045	- 0.045
K^{+}	- 0.304	- 0.346	- 0.431	- 0.130
Mg^{2+}	- 0.041	- 0.006	- 0.023	- 0.006
Na^{+}	- 0.021	- 0.022	- 0.091	- 0.045
NH_4^{+}	- 0.104	- 0.390	- 0.454	- 0.073
NO_3^{-}	- 0.310	- 0.346	- 0.272	- 0.062
$C_2O_4^{=}$	- 0.248	- 0.325	- 0.454	- 0.073
PO_4^{-}	- 0.002	- 0.002	- 0.005	–
$SO_4^{=}$	- 0.269	- 0.866	- 1.724	- 0.383
Fe	- 0.104	- 0.087	- 0.136	- 0.034
Residue	- 17.413	- 17.776	- 17.644	- 4.263
Total ΔF_{sp}	- 20.590	- 21.620	- 22.615	- 5.598
	ADRF due to light absorption (Wm^{-2}) at λ = 550 nm			
BC	0.959	1.097	0.135	0.031
Total ΔF	- 19.631	- 20.523	- 22.480	- 5.567

6. Conclusion

This study has investigated the ADRF in the Cerrado and in the Brazilian Amazon regions. The box-models used were based on the aerosol properties and vertical profile of the CBL. In this study aerosol concentration was the main parameter that influenced net ADRF. Most of the aerosol composition consists of "residue" aerosol. This aerosol component has a significant impact on ADRF due to light scattering with a cooling tendency of the CBL. The radiative forcing by black carbon was characterized by low warming of the atmosphere in relation to the cooling of the atmosphere. This behaviour was more significantly in biomass smoke produce by burning in cerrado ecosystem than the burning in forest vegetations. Although there is a low warming caused by black carbons aerosol their effect on climate forcing is potentially important. Because an increase of the black carbon aerosol may result in heating of the atmosphere while reducing the solar irradiance at the ground, thereby altering the vertical temperature profile.

The results of the net radiative over CBL on regional scale was of – 20.523 Wm^{-2} in the Cerrado and ranged from – 5.567 to – 22.480 Wm^{-2} in the Brazilian Amazon. Christopher et al. (1998) estimated direct regional radiative forcing of the BB aerosols from smoke during the 1985 dry season. The authors used satellite data for more than 5×10^6 km^2 of the forest and cerrado regions over South America. They found that a net radiative of -25.6 Wm^{-2} and – 33.9 Wm^{-2} for cerrado and forest ecosystems, respectively. There is a considerable uncertainty between the results of the ADRF obtained in this study and by Christopher et al. (1998). This difference shows that it is necessary care in identifying and quantifying aerosols effects on climate system.

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9. Responsibility notice

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