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# NUMERICAL SIMULATION OF BIOMASS BURNING EMISSIONS AND TRANSPORTATION DURING 1998 RORAIMA FIRES

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## 1. ABSTRACT

The atmospheric transport of carbon monoxide from the biomass burning was studied focusing on the on the role of deep convective systems on the 3D redistribution using the Eulerian approach for CO mixing ratio determination. The simulation was carried out using CATT-BRAMS (Coupled Aerosol and Tracer Transport model to the Brazilian developments on the Regional Atmospheric Modeling System). In this method, the mass conservation equation for CO is solved in-line with the atmospheric model equations. Source emissions of trace gases associated with biomass burning activities were parameterized and introduced in the model. The daily burned area estimate was obtained through a normalization of the total burned area using TOMS Aerosol Index. A convective parameterization with training capability was used in order to improve the representation of the involving deep convective systems in the model.

Model results were compared and validated with observational data collected during the LBA-CLAIRE-98 campaign. The numerical simulation was able to reproduce the observed CO profile and could explain the main transport mechanisms involved.

## 2. INTRODUCTION

During the first three months of 1998, an area of thousands of square kilometers in the Roraima Brazilian State (North Amazon), including savanna and forest areas, was affected by the hugest wild fire event ever occurred in Brazil (Shinabukuro et al., 2000).

A GOES-8 visible channel imagery of the North Amazon region for 16 March 1998 at 1145 UTC, had shown the smoke produced by the fires in Roraima and its southwest advection due the trade winds (Figure 1).

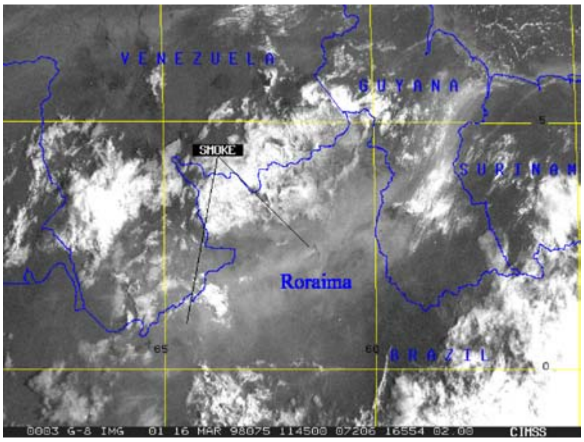

Figure 1: GOES-8 satellite image (visible channel) on 16 March 1998, 1145UTC.

Barbosa and Fernside (2000) had reported an accumulated precipitation of 30.6 mm between September 1997 and March 1998 in Boa Vista, capital of Roraima. This amount corresponds to only 8.7% of the historical mean for the period, which is 352 mm. The El Niño phenomena activity had favored this scenario of extreme drought, inducing a high subsidence over the North Amazon region, weakening the convective activity normally associated to the tropical instabilities and the Intertropical Convergence Zone (ITCZ).

Hot spots analysis from the ATSR World Fire Atlas (http://www.esa.int) over the North region of South America and Central America during March 1998 shows up the main areas of vegetation fires occurrence, with a highlight for the Northeast region of Roraima (**Figure 2**).

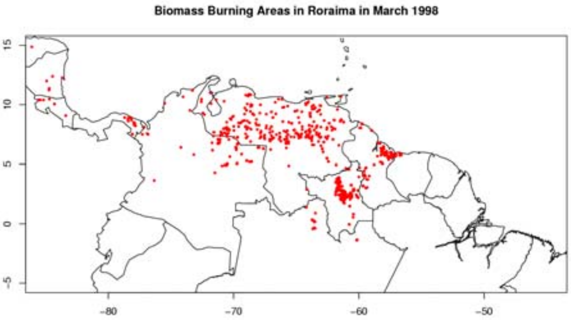

Figure 2: Fire pixels detected during March 1998 from ATSR.

According to Barbosa and Fearnside (2000) the vegetation fires between December 1997 and April 1998 affected a total area ranging between 38.114 e 40.678 km$^2$ , which corresponds to about 20% of the area of Roraima State. The bioma Cerrado was mainly affected with

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approximately 22.580 $km^2$ of burned area, while an area ranging between 11.394 and 13.928 $km^2$ of forest was destroyed.

The 1998 Roraima fires involved a total of 42.558 millions of tons of carbon. (Barbosa e Fearnside, 1999). From this total, 19.73 millions of tons were released by combustion, around 90% as $CO_2$; 22.33 were decomposed and 0.52 were deposited as charcoal.

The atmospheric chemistry experiment LBA-CLAIRE, during 19-29 March 1998, performed airborne trace gases and aerosol measurements. The 10 experiment missions take off from the International airport Zanderij (5ºN,55ºW) and flew over Suriname, Guiana and French Guiana. The flight duration was typically 3-4 hours reaching the maximum altitude of about 12 km. Figure 3 shows the LBA-CLAIRE flight number 8 trajectory on 26 March 1998, with altitudes over Suriname ranging from 9 to12 km between 19:30 e 22:30 UTC.

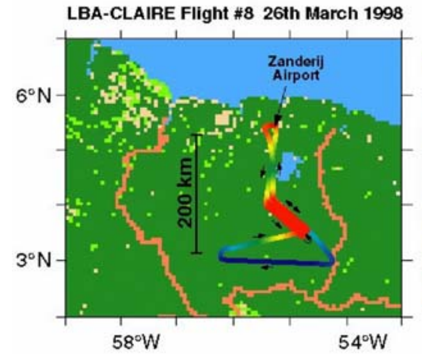


Figure 3: LBA-CLARE-98 flight number 08 trajectory.

During this flight an air mass layer with chemical composition typical of aged biomass burning smoke were detected at 9 to 12 km (Andreae et al., 2001). An enhancement of hydrocarbons, CO, $CO_2$, NO, $O_3$ and aerosol particles were observed (Figure 4).

The concentrations of CO and $CO_2$ produced during Biomass burning are usually well correlated (Andreae et al., 1996). According to Williams et al. (2001), the high correlation found between CO and $CO_2$ above 9 km on flight 08 was an indication that vegetation fires on remote areas could be responsible for the observed trace gases and aerosol enhancement. This conclusion is also leaned on the no observation of hot spots over Suriname on that period (Grégoire et al., 1998). Furthermore, the correlation found was typical of savannas vegetation fires (Andreae et al., 1996) and the air samples collected had elevated concentration of metilclorine and the absence of halocarbons of anthropogenic origin (Andreae et al., 2001). The polluted upper level layer found therefore could be related to the biomass burning events on Roraima. Bellow 8.5 km however the correlation between CO and $CO_2$ is low, suggesting the influence from air masses distinct from the on present at high levels.

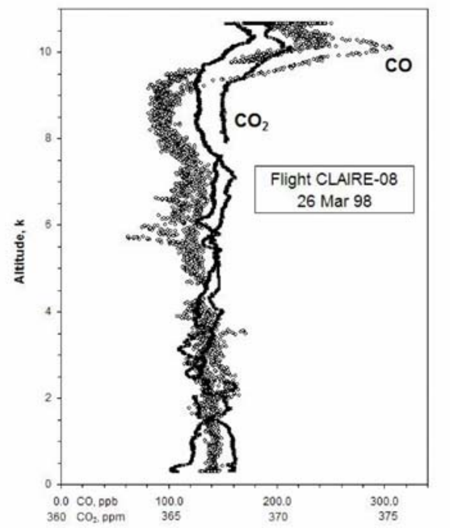


Figure 4: Vertical profile of CO and $CO_2$ measured during LBA-CLAIRE-98 flight 08.

concentration of metilclorine and the absence of halocarbons of anthropogenic origin (Andreae et al., 2001). The polluted upper level layer found therefore could be related to the biomass burning events on Roraima. Bellow 8.5 km however the correlation between CO and $CO_2$ is low, suggesting the influence from air masses distinct from the on present at high levels.

Freitas et al. (2000), using the convective trajectory technique, had shown that the origin of the high level air masses sampled during flight 08 could be explained by three consecutive processes: (a) advective transport by trade winds from the Roraima fires, (b) upward vertical transport by deep convective systems occurred Southwest of Amazonia and (c) advective transport following the upper level anti-cyclone to the Guiana and Suriname region (Figure 5). These processes can be visualized in the Figure 6.

A deep convective system West of Roraima was identified as the main responsible for the transport of pollutants from the low troposphere to the upper troposphere. This system building started at South of Venezuela at 18 March around 03:00Z. Afterwards, it propagated Southwest in the direction of Colombia and the Amazonas State, in Brazil, remaining active for about 24 hours (Figure 7).

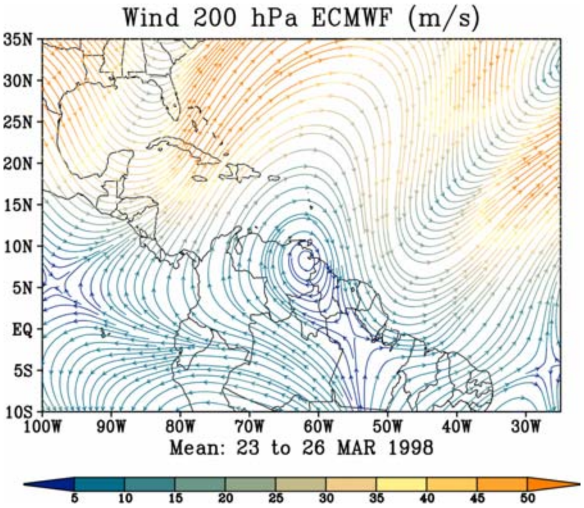


Figure 5: Mean wind field streamlines at 200hPa (from 23 to 26 March). Source: ECMWF.

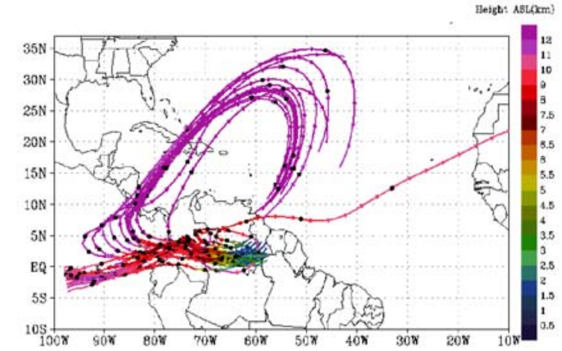
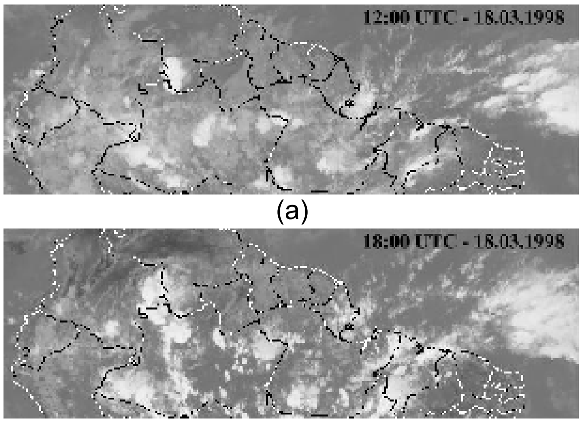


Figure 6: Convective air masses forward trajectories starting from Roraima on 16 March 1998 (Freitas et al., 2000).



(a)

(b)

Figure 7: GOES-8 visible images on 18 March at 12:00Z and 18:00Z.

## 3. THE ATMOSPHERIC AND THE COUPLED EULERIAN TRACER TRANSPORT MODELS

BRAMS is based on the Regional Atmospheric Modeling System (Walko *et al.* **Erro! A origem da referência não foi encontrada.**) version 5 with several new functionalities and parameterizations. RAMS is a numerical model designed to simulate atmospheric circulations at many scales. RAMS solves the fully compressible non-hydrostatic equations described by Tripoli and Cotton, 1982, and is equipped with a multiple grid nesting scheme which allows the model equations to be solved simultaneously on any number of interacting computational meshes of different spatial resolution. It has a sophisticated set of packages to simulate processes such as: radiative transfer, surface-air water, heat and momentum exchanges, turbulent planetary boundary layer transport and cloud microphysics. The initial conditions can be defined from various observational data sets that can be combined and processed with a mesoscale isentropic data analysis package (Tremback 1985). As for the boundary conditions, there is a 4DDA (four-dimensional data assimilation) scheme allowing the atmospheric fields to be nudged towards the large-scale data. BRAMS model introduces a ensemble version of deep and shallow cumulus schemes based on the mass flux approach (Grell and Devenyi, 2002), another shallow cumulus scheme with thermical efficiency closure, soil moisture initialization (Gevaerd and Freitas, 2006, submitted), surface parameterization tailored for the tropics, etc.

The training technique for the convective parameterization, based on Grell e Dévényi (2002) has been used. This scheme uses the flux mass concept with various types of closures, also using statistics techniques to obtain the mass flux. BRAMS model offers five different closures: grell (Grell, 1993), kain-fritsh (Kain e Fritsch, 1993), low level omega, moisture convergence e arakawa schubert (Arakawa e Schubert, 1974). Each closure refers to a set of conditions that activate or not the convection in each grid box. It is possible to obtain 15 members of the ensemble: five closures with 3 options of $cap_{maxs}$. In this way, one combines the best characteristics of each closure for the cumulus parameterization. The final precipitation field, or ensemble, would imbue the features of all of them according to the weight attributed to each one.

The radiation code used for short wave is described by Harrington (1997) and for long wave by Chen Cotton (1983). The model configuration has the horizontal resolution of 30 km and the minimal vertical resolution of 120 m for the first level and a ration of increment of 1.1 and the maximum of 750 m. The ECMWF atmospheric reanalysis was used and initial and boundary condition.

The atmospheric transport CATT-BRAMS (Coupled Aerosol and Tracer Transport model to the Brazilian developments on the Regional Atmospheric Modeling System) is an on-line transport model fully consistent with the simulated atmospheric dynamics. The model is fully described in Freitas et al., 2005. Briefly, CATT uses the BRAMS on-line tracer transport capability including several sub-grid transport processes and an emission model. The tracer mixing ratio is calculated using the mass conservation equation.

## 4. BIOMASS BURNING EMISSION ESTIMATION

The biomass burning emission estimation followed the approach described in Longo et al., this issue, is based on Freitas (1999), referred as Brazilian Fire Emission Model (BFEMO, Longo and Freitas, this issue), and also includes the EDGAR 3.2 CO from anthropogenic sources. The burned area per each fire was determined from a combination of the ATSR and TRMM fire pixels data, TOMS aerosol index and the the burned area discriminated by each bioma between December 1997 and April 1998 (Barbosa e Fearnside, 2000).

The total emission of CO and PM2.5 highlights the days 17, 21 and 23 of March as the ones with bigger release of trace gases and aerosol particles to the atmosphere. Only 23 March itself explain almost 40 Tg of CO and 3 Tg of PM2.5 (Figure 9).

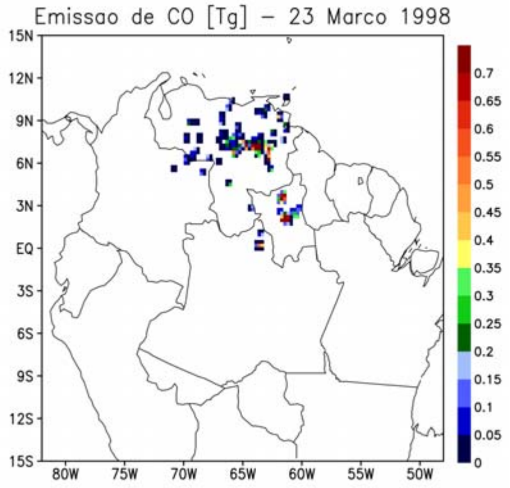


**Figure 8: Emission of CO (Tg) calculated for 23 March 1998.**

## 5. RESULTS

The precipitating convective systems modeled (Figure 10) are very close to the observation (Figure 7). Instability lines built up South Venezuela and its propagation to West is reproduced by the model at adequate local and time. Figure 11 shows the smoke plume (CO distribution) and the wind fields at about 12 km high on 26 March 1998 at 12:00Z, approximately time of the LBA-CLAIRE flight 08. The CO vertical profile from the model is compared with LBA-CLAIRE observation (Figure 12), where one can also see the model sensitivity to the chosen horizontal resolution. Only with a spatial resolution of 30 km was possible to reach a considerable degree of reproducibility of the observation, with the peak values between 300 and 350 ppbv.

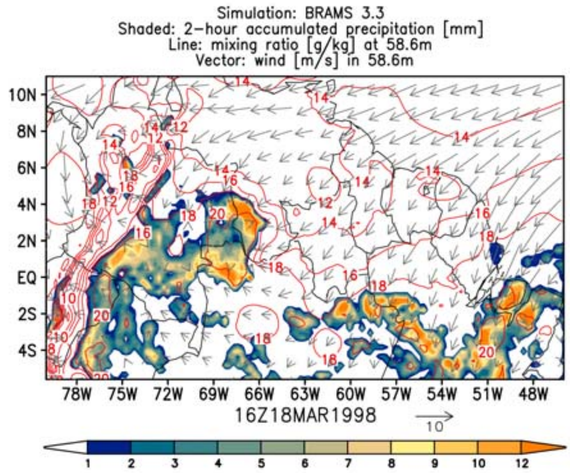


Figure 9: 2-hourly accumulated precipitation, winds and mixture rate from the model at 16:00 and 18:00 Z on 18 March 1998.

Figure 15 presents the vertical profiles of CO considering the convective transport (CO[CTC]), without convective transport (CO[STC]) and CO only from anthropogenic source (CO[ANT]). From the profile of anthropogenic CO one can see the major contribution of the biomass burning to the upper level polluted layer observed. The maximum of (CO[ANT]) indicated by the model in the upper levels did not reach 125 ppbv. This result is consistent with the observations of enhanced concentration of $CH_3CN$ e $CH_3Cl$, tracers of biomass burning activity, and low concentration of halocarbons from anthropogenic source.

Only the profile of (CO[CTC]) explains the concentration of CO observed, showing up the hole played by the deep convective system in the transport of pollutants process. Although the (CO[STC]) also presents a peak at upper levels, reaching almost 150 ppbv, this is explained by the vertical advection promoted by the wind fields not associated with cloud convection.

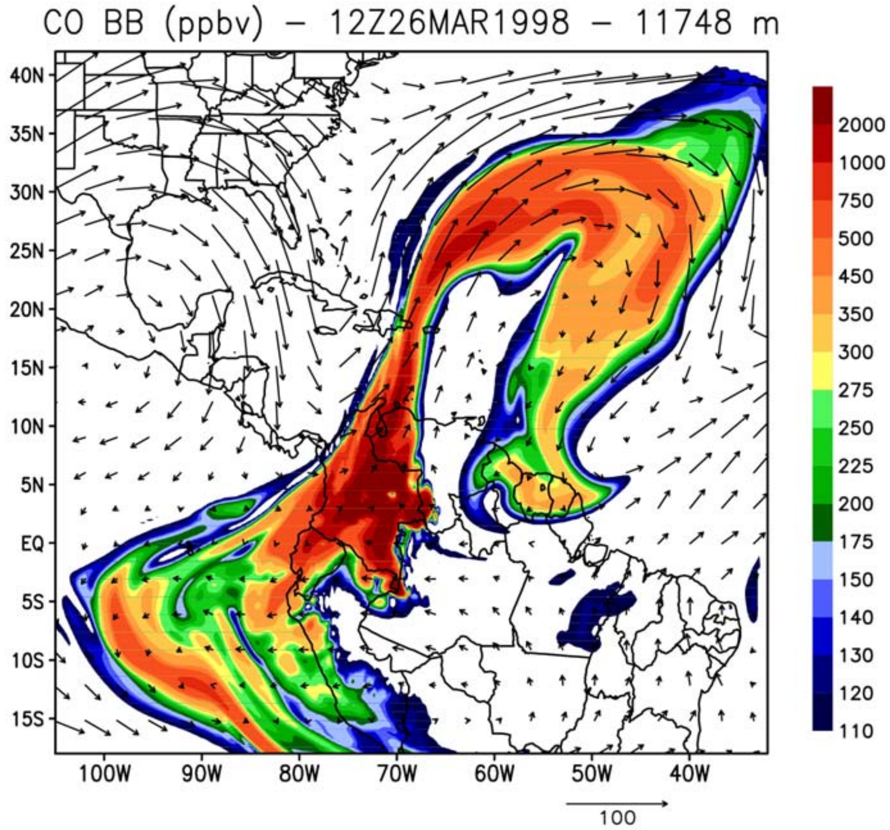


Figure 10: CO plume (ppbv) and wind field from the model at 11748 m.

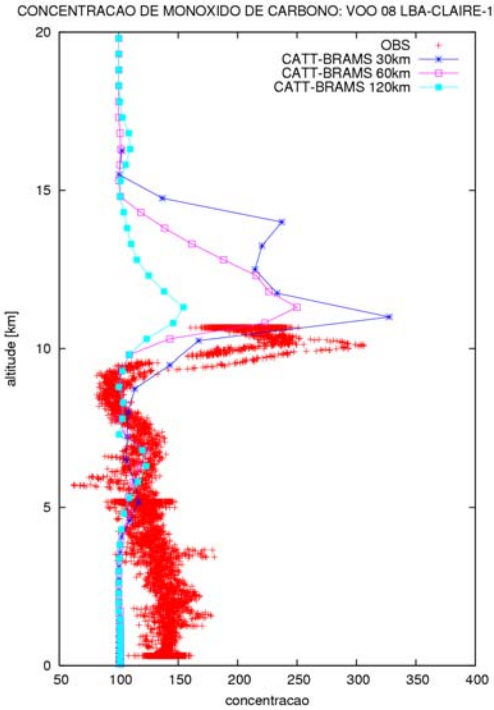


Figure 11: CO profile observed during the LBA-CLAIRE 98 (red) and the ones obtained by the model with different spatial resolution (4.6ºN;55.6ºW).

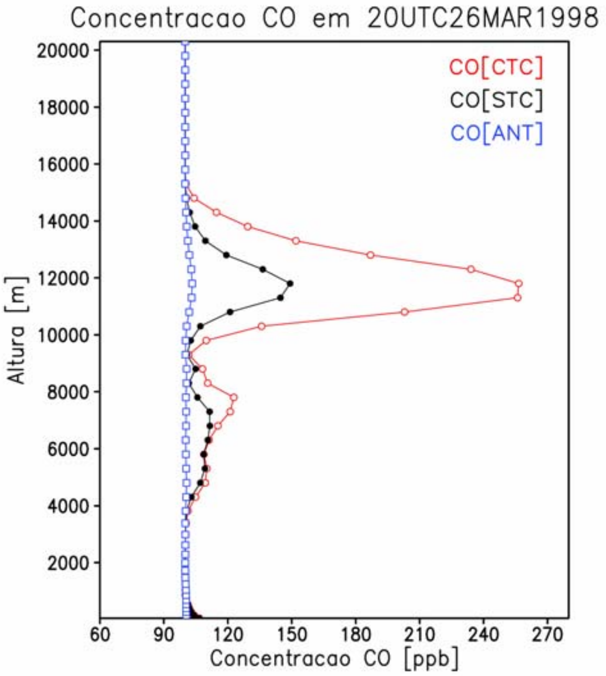


Figure 12: CO profiles from the model considering the convective transport (CO[CTC]),

without convective transport (CO[STC]) and CO only from anthropogenic source (CO[ANT]).

## 6. CONCLUSIONS

The CATT-BRAMS model allowed the prognoses of pollutants concentration in the study area with reasonable accuracy, reproducing the main features of the observed vertical profile of CO during LBA-CLAIRE, on 26 March 998.

It was demonstrated that the CO from anthropogenic source was insufficient to explain the observation. Being the model results consistent with the chemical composition of the upper level plume observed, typical of aged biomass burning smoke from savanna and forest fires.

The Eulerian analysis of the event occurred during the first month of 1998 have confirmed the previous Lagrangean studies.

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