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THE COUPLED AEROSOL AND TRACER TRANSPORT MODEL TO THE BRAZILIAN DEVELOPMENTS ON THE REGIONAL ATMOSPHERIC MODELING SYSTEM: VALIDATION USING DIRECT AND REMOTE SENSING OBSERVATIONS

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1. ABSTRACT

The atmospheric transport of biomass burning emissions is studied through a numerical simulation of the air mass motions using the CATT-BRAMS (Coupled Aerosol and Tracer Transport model to the Brazilian developments on the Regional Atmospheric Modeling System). CATT-BRAMS is an on-line transport model fully consistent with the simulated atmospheric dynamics. The sources emission from biomass burning and technological activities for several gases and aerosol may be defined from several published dataset and remote sensing. The mass concentration prognoses accounts also for convective transport by shallow and deep cumulus, wet and dry deposition and plume rise. Also, an additional radiation parameterization, which takes the interaction between aerosol particles and short and long wave radiation into account, was implemented. The model is applied for simulate carbon monoxide (CO) and particulate material PM2.5 transport during the SMOCC/RACCI campaign during the 2002 dry season. The model validation is presented with comparison of model results with remote sensing products and direct observations obtained during the SMOCC campaign.

2. INTRODUCTION

The high concentration of aerosol particles and trace gases observed in the Amazon and Central Brazilian atmosphere during the dry season is associated with intense anthropogenic biomass burning activity (vegetation fires, Andreae, [1]). Most of the particles are in the fine particle fraction of the size distribution, which can remain in the atmosphere for approximately a week (Kaufman, [2]). In addition to aerosol particles, biomass burning produces water vapor and carbon dioxide, and is a major source of other compounds such as carbon monoxide (CO), volatile organic compounds, nitrogen oxides (NO_x=NO+NO_2), and organic halogen compounds. In the presence of abundant solar radiation and high concentrations of NO_x, the oxidation of CO and hydrocarbons is followed by ozone (O_3) formation.

In GOES-8 visible imagery Prins *et al.* [3] have observed immense regional smoke plumes in South America covering an area of approximately 4 to 5 million km^2 during the biomass-burning season (Figure 1). Inhalable aerosol particles (d_p<10 μm) with concentrations as high as 400 μg m^{-3} have been measured near the surface level and the vertically integrated smoke aerosol optical thickness column rises as high as 4.0 (440 nm) in Central Brazil (Artaxo *et al.* [4], [5]; Echalar *et al.* **Erro! A origem da referência não foi encontrada.**).

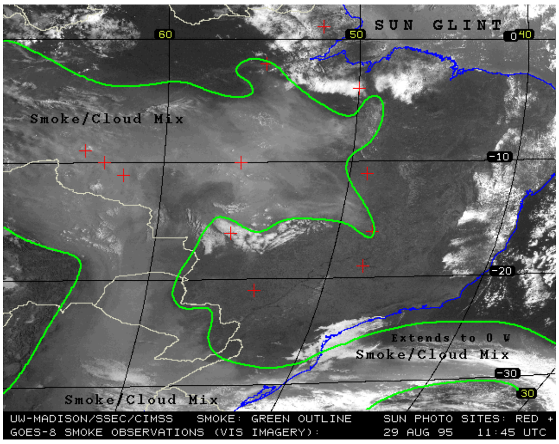

Figure 1. GOES-8 VIS 1145Z 29/08/1995. Smoke covers about 4 to 5 millions km^2 (Prins *et al.* [3]).

On a regional and global scale, a persistent and heavy smoke layer over an extensive tropical region may alter the radiation balance and hydrologic cycling. Modeling efforts of Jacobson [6] and Sato *et al.* **Erro! A origem da referência não foi encontrada.** have suggested that black-carbon radiative forcing could balance the cooling effects of the global anthropogenic sulfate emissions. The direct global radiative forcing of black-carbon is estimated to be 0.55 Wm^{-2}, corresponding to 1/3 of the CO_2 forcing. In terms of direct radiative forcing, this would elevate black-carbon to one of the most important elements in global warming, second only to CO_2 (Andreae [7]).

The presence of biomass burning particles in the atmosphere may also modify the solar radiative

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balance by changing cloud microphysics. These particles act as cloud condensation and ice nuclei, promoting changes in the cloud drops spectrum and so altering the cloud albedo and precipitation (Cotton and Pielke [9]; Rosenfeld [10]). This suggests that biomass burning effects may extrapolate from the local scale and be determinant in the pattern of planetary redistribution of energy from the tropics to medium and high latitudes via convective transport processes. Koren et al. [16] using satellite images of the Amazon rainforest suggested that smoke and cumulus clouds rarely occur together.

In this paper we describe the CATT-BRAMS model (Coupled Aerosol and Tracer Transport model to the Brazilian developments on the Regional Atmospheric Modeling System, Freitas et al., [15]) a system designed to simulate and study the transport and processes associated to biomass burning emissions. CATT is an Eulerian transport model fully coupled to the Regional Atmospheric Modeling System – RAMS (Walko *et al.* **[11]**). The tracer transport simulation is made simultaneously, or “on-line”, with the atmospheric state evolution. Also, an additional radiation parameterization, which takes the interaction between aerosol particles and short and long wave radiation into account, was implemented.

3. THE ATMOSPHERIC AND THE COUPLED EULERIAN TRACER TRANSPORT MODELS

3.1 BRAMS MODEL

BRAMS is based on the Regional Atmospheric Modeling System (Walko *et al.* [11]) 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 [12], 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 [13]). 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, [14]), another shallow cumulus scheme with thermical efficiency closure, soil moisture initialization (Gevaerd and Freitas, 2006, submitted), surface parameterization tailored for the tropics, etc. On the numerical and codification aspects, CATT-BRAMS had several optimizations in order to run faster on vector and scalar computers, including an optimization on parallelism for distributed computer clusters.

3.2 CATT EULERIAN MODEL

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, ***s*** (=ρ/ρ_{air}), is calculated using the mass conservation equation

$$\frac{\partial s}{\partial t} = \left(\frac{\partial s}{\partial t}\right)_{adv} + \left(\frac{\partial s}{\partial t}\right)_{\substack{PBL\\turb}} + \left(\frac{\partial s}{\partial t}\right)_{\substack{shallow\\conv}} + \left(\frac{\partial s}{\partial t}\right)_{\substack{deep\\conv}} + W_{PM2.5} + R + Q, \tag{1}$$

where the symbols are defined as follows:

- $\frac{\partial s}{\partial t}$, the local tendency,
- ***adv***, the grid-scale advection,
- ***PBL turb***, the sub-grid turbulent transport in the PBL,
- ***deep conv***, the sub-grid transport associated with the moist deep convection,
- ***shallow conv***, the sub-grid transport associated with the moist shallow convection,
- $W_{PM2.5}$, the convective wet removal for PM2.5 (particulate matter with d_p<2.5μm),
- ***R***, the sink term associated with generic dry removal and/or chemical transformation,
- ***Q***, the source emission associated with the biomass burning process.

Figure 2 illustrates some sub-grid processes simulated by CATT-BRAMS. The tracer mixing

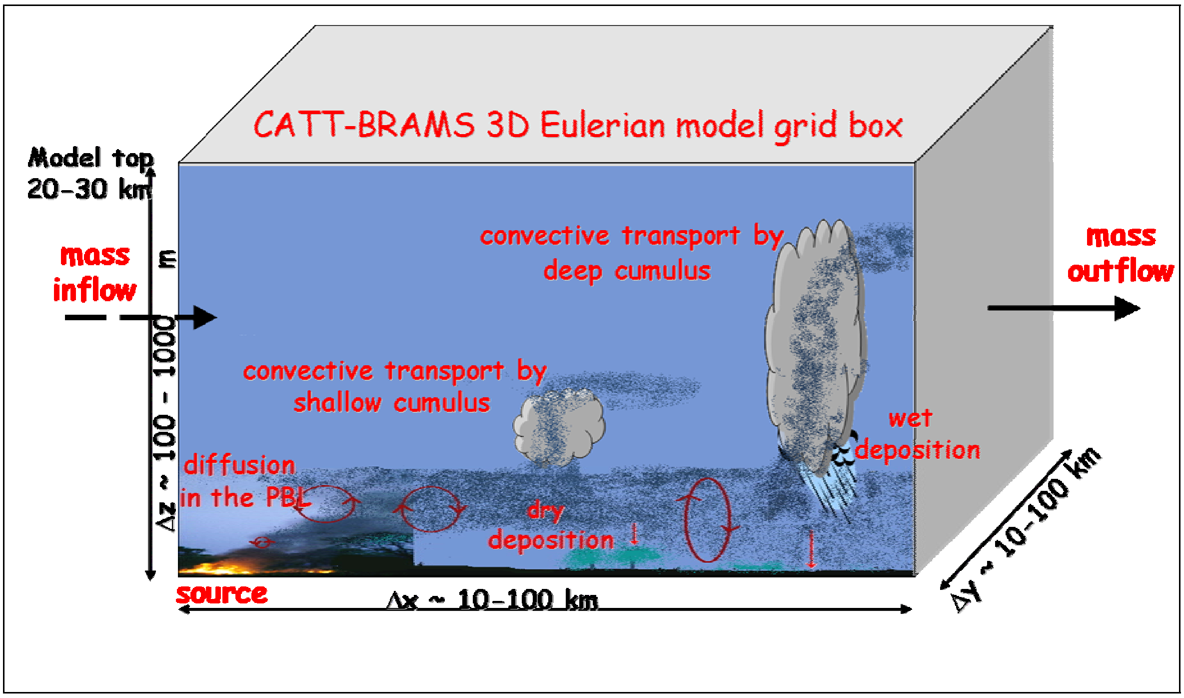

Figure 2. Some sub-grid processes involved in gases/aerosols transport and simulated by CATT-BRAMS system.

ratio is updated in time using the total tendency given by Eq. (1) and a constant inflow, variable outflow is applied as a tracer boundary condition.

4. MODEL VALIDATION USING 2002 DRY SEASON DATA

Simulation for 2002 dry season was performed to compare model results with observed data. The model configuration had 2 grids. The coarse grid had a horizontal resolution of 140 km covering the South American and African continents. Its main purpose was to simulate approximately the intermittent smoke inflow from the African fires to South America and to coordinate with and compare to the long-range transport of smoke from fires in South America to the Atlantic Ocean. The nested grid had a 35 km horizontal resolution and covered only South America. The vertical resolution for both grids was between 150 to 850 m, with the top of the model at 23 km (42 vertical levels). The time integration was 135 days, starting on 00Z 15 July 2002. For atmospheric initial and boundary condition we used the 6 hourly CPTEC (Center for Weather Prediction and Climate Studies-Brazil) global analysis T126 trough 4DDA technique. Two tracers was simulated, CO and particulate material with diameter less than 2.5 μm (PM2.5), with initial background values. The source emission estimation for the African and South American vegetation fires was prescribed using Freitas [17] technique. Here improved with updated emission factors and using a hybrid fire remote sensing database through combination of MODIS/AVHRR/GOES fire products.

Figure 3 shows an example of model output for particulate material with diameter les than 2.5 μm vertically integrated (mg m^{-2}) at 1800Z on 20 October 2002, streamlines are at 1.9 km height above surface. The red box defines the nested grid domain with 35 km resolution where is possible to visualize finer scales. Is evident the role of the anticyclonic circulation centered over the Atlantic Ocean, promoting the smoke exchange between South American and African continents, as well as a long range transport of biomass burning emissions. Figure 4 shows the MOPITT CO column (10^{18} mol/cm^2) monthly mean for September 2002, where can be observed a polluted troposphere due fire emissions on South American and African continents. The correspondent model result is showed at Figure 5. Model result compare very well with MOPITT estimation not only at space distribution as well as the values, in despite off a model misrepresentation at the southwest part of African continent and neighboring Atlantic ocean.

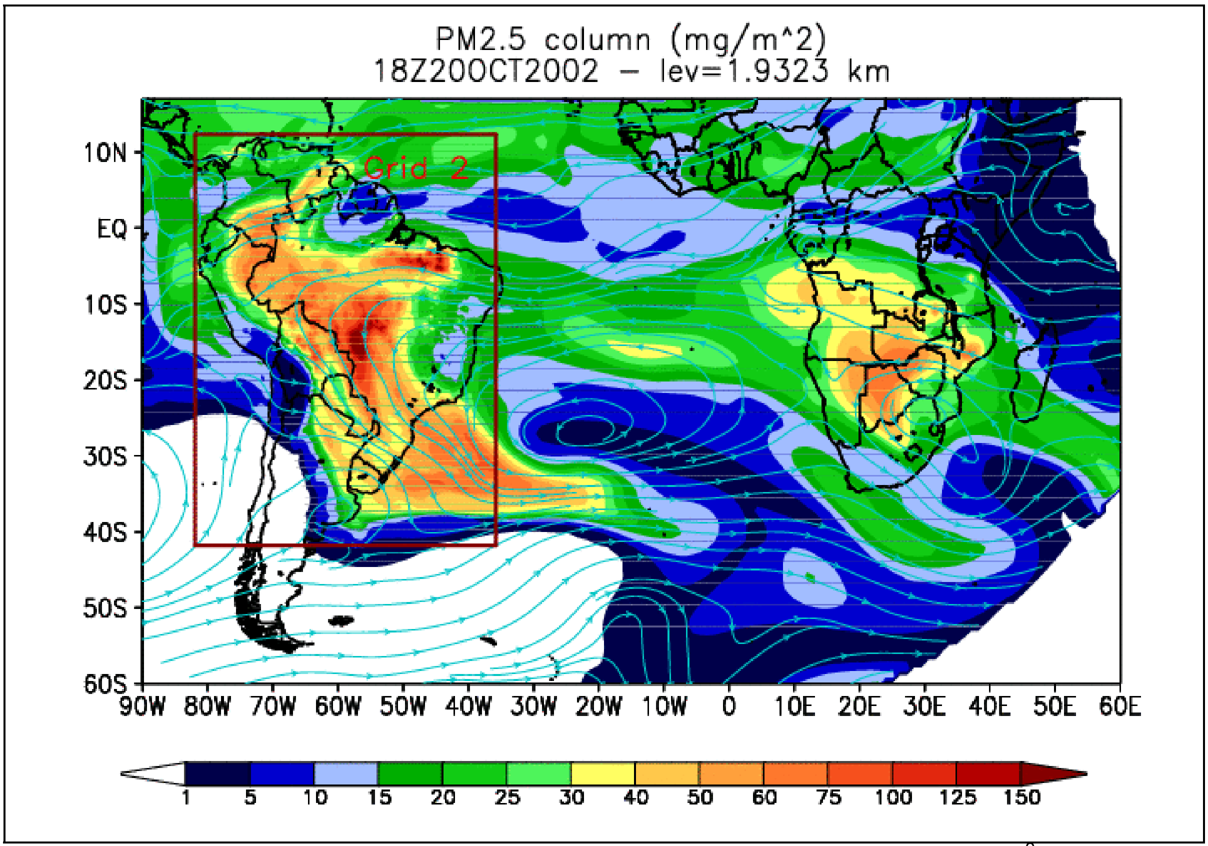

Figure 3. Particulate material with diameter les than 2.5 μm vertically integrated (mg m^{-2}). Model result for 1800Z 20/10/2002 at grids 1 e 2, the red box defines the domain of grid 2 with horizontal resolution of 35 km

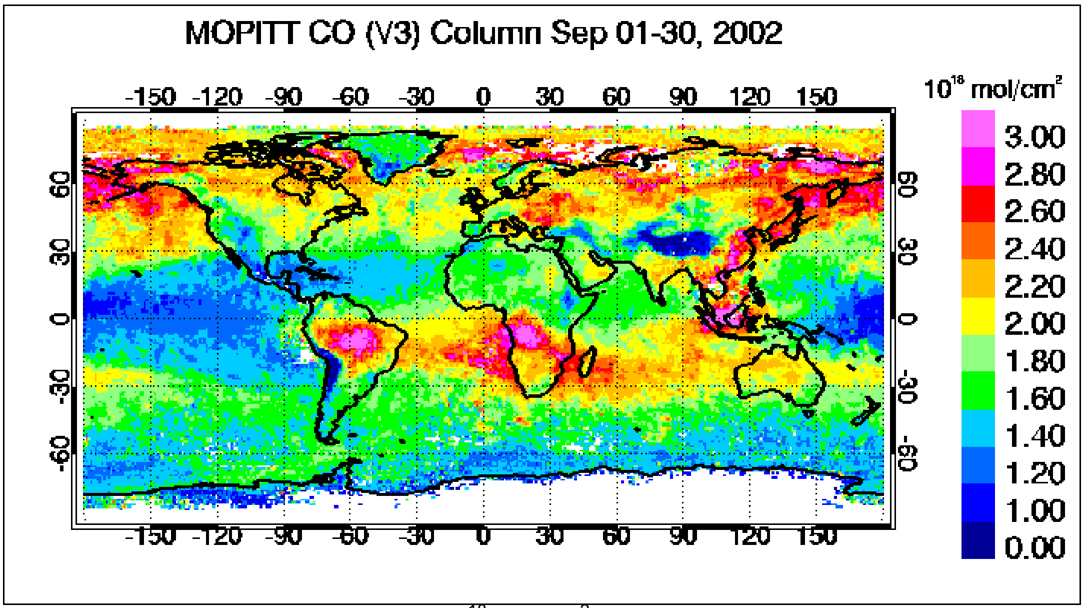

Figure 4. MOPITT CO column (10^{18} mol/cm^2) monthly mean for September 2002

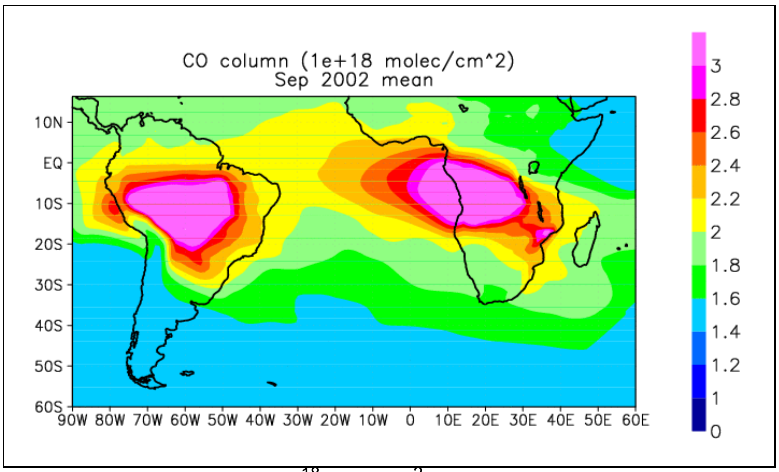

Figure 5. Model CO column (10^{18} mol/cm^2) monthly mean for September 2002

Carbon monoxide surface measurements were made at the ABRACOS pasture site, in the Rondônia state, during the SMOCC campaign from 10 September to 17 November 2002. Figure 6 shows a time series with a comparison of CO from the model and observed. During the SMOCC field campaign three very well characterized regimes of rainfall were observed. The period from 10 September to 8 October still shows the dry season characteristics with low precipitation rates and a high number of fires, not only in the Rondônia state but all over the Amazon basin and central Brazil. During this period, high values of CO were observed. The maximum values were as high as 4000 ppbv with the time series characterized by strong variability. This variability mainly indicates the proximity of fires to the measurement site; the plumes are intense and still have not been significantly dispersed. This may indicate that observation was not representative of the regional scale with impact at model performance; in despite of model values are in the standard error range.

Following this period, from 8 to 30 October there was an increase in precipitation and a consequent reduction in biomass burning. In Rondônia state the fires were rare but fires were still observed in the regional area. By the end of October the onset of the wet season drastically reduced the number of fire counts everywhere in South America. This pattern is clearly reflected in the surface level CO measurements performed in Rondônia and also in model results. For both periods, the model agreement is quite good.

The good performance of the model is also confirmed by comparison with aircraft profiles as showed by Figure 7 and Figure 8. Model could represent very well the mean CO profile from surface to the low troposphere (4 ~ 4.5 km height, the typical maximum altitude reached by SMOCC aircraft)

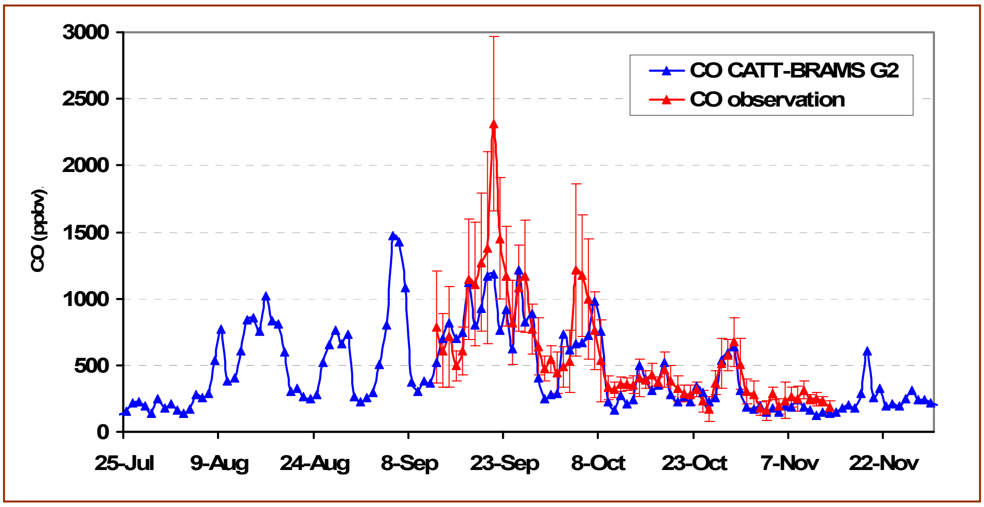

Figure 6. Time series with comparison between surface CO (ppbv) observed (red) and model (blue). The measurements were daily averaged and centered at 12Z. The error bars are the standard deviations of the mean values. The model results are presented as instantaneous values at 12Z.

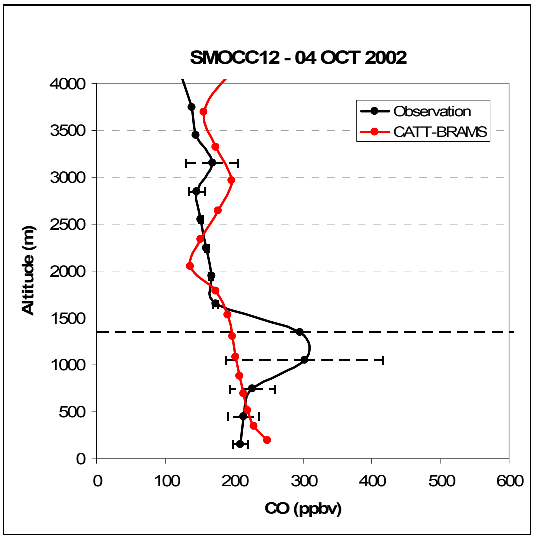

Figure 7. Comparison of CO from the model (red) and from aircraft observation (black, mean at space and time of the flight 12, standard deviation is also showed and).

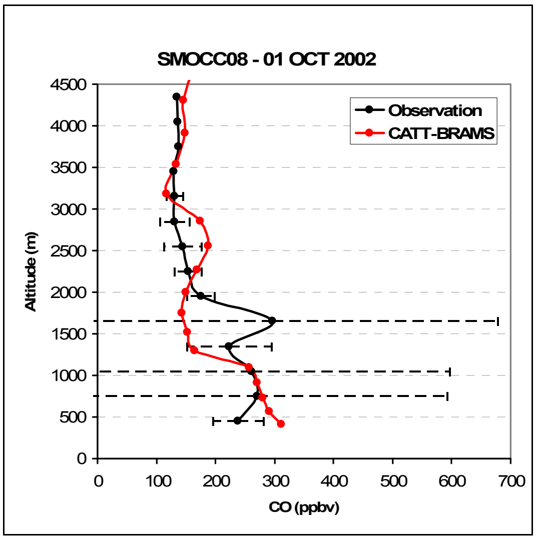

Figure 8. Comparison of CO from the model (red) and from aircraft observation (black, mean at space and time of the flight 08).

5. CONCLUSIONS

CATT-BRAMS model has been described; some validations were showed in this paper and point out the model capabilities. Additional validations are under work and will be present in future papers.

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