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USING THE SUPER-PARAMETERIZATION CONCEPT TO INCLUDE THE SUB-GRID PLUME-RISE OF VEGETATION FIRES IN LOW RESOLUTION ATMOSPHERIC CHEMISTRY-TRANSPORT MODELS.

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1. ABSTRACT

We adopt the super-parameterization concept to include the vertical transport of hot gases and particles emitted from biomass burning in low resolution atmospheric-chemistry transport models. This sub-grid transport mechanism is simulated imbibing a 1D cloud resolving model with appropriate lower boundary condition in each column of the 3D host model. Through assimilation of remote sensing fire product, we recognize which column has fires, using a land use dataset appropriate fire properties are selected. The host model provides the environment condition and, finally, the plume rise is explicitly simulated. The final height of the plume is then used at the source emission field of the host model, releasing material emitted at flaming phase at this height. The simulation is carried out using the system CATT-BRAMS (Coupled Aerosol and Tracer Transport model to the Brazilian developments on the Regional Atmospheric Modeling System). We compare model results with 500 mb AIRS carbon monoxide (CO) data for September 2002 and show the huge impact that this mechanism has at the model performance.

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, 1991). 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, 1995**Erro! A origem da referência não foi encontrada.**). 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 despite of the continuous increasing of power computer capability, we still are far from to be able to run atmospheric models, including chemistry or not, taking account explicitly all relevant motion scales. In this way, the current chemistry models use several types of parameterizations in order to include the sub-grid transport and processes to resolve the mass continuity equation of the chemistry species. The most common sub-grid transport parameterizations include diffusion in the boundary layer and convective transport associated to the moist circulation. However for biomass burning emissions the strong updrafts associated to the initial buoyancy has a huge impact on tracer distribution through a direct and rapid transportation into the free troposphere as well as the stratosphere (Jost et al., 2004). This mechanism cannot be resolved explicitly by the current models and it is frequently ignored.

In this paper we describe the implementation of the plume-rise sub-grid transport term in the CATT-BRAMS model (Coupled Aerosol and Tracer Transport model to the Brazilian developments on the Regional Atmospheric Modeling System) using the super-parameterization concept (Grabowsky, 2001, Randall et al., 2003). CATT (Freitas et al., 2005) is a system designed to simulate and study the transport and processes associated to biomass burning emissions. It is an Eulerian transport model fully coupled to the Regional Atmospheric Modeling System – RAMS (Walko *et al.,* 2000). The tracer transport simulation is made simultaneously, or “on-line”, with the atmospheric state evolution.

3. METHODOLOGY

Biomass burning emits hot gases and particles which are transported upward due to positive buoyancy. The interaction between the smoke and the environment produces eddies that entrain colder environmental air into the smoke plume, which dilutes the plume and reduces buoyancy. The final height that the plume reaches is fairly controlled by the thermodynamic stability of the environment atmosphere. This mechanism has a strong

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impact on the pollutant dispersion since in the troposphere the pollutants are advected faster away from the source region. Also removal processes are more efficient in the PBL; when the pollutants are transported to the troposphere their residence time increases. In order to illustrate this mechanism, Figure 1 shows the plume rise associated to a deforestation fire on State of Rondônia, Brazil, during the SMOCC campaign.

Figure 1. Photograph of the smoke plume rise produced from a deforestation fire in Amazon basin.

The plume rise associated to the biomass burning is explicitly simulated using a simple one-dimensional time-dependent entrainment plume model. The equations are based on the first law of thermodynamics and the vertical equation of motion (Simpson and Wiggert, 1969). The **System of equations 1** introduces the 1-D cloud resolving model (CRM) designed for this task. Here ***w, T, r***$_v$ have the usual mean. Cloud microphysical calculations are based on Kessler (1969) parameterization for accretion and include ice formation according to Ogura and Takahashi (1971). Autoconversion is performed following Berry (1967) formulation. Entrainment of environmental air is taken to be proportional to the vertical velocity in the air, and the entrainment coefficient is based on the traditional approach $2\alpha R^{-1}$ where R stands for the radius of plume and $\alpha = 0.1$. Scalar fields are advected using a forward–upstream scheme of second-order, while for wind standard leapfrog-type scheme are used (Tremback *et al.*, 1987). The lower boundary condition for air parcel temperature and vertical velocity is given following Morton et al 1956 in terms of the heat flux (**E**) and plume area (***A***)**.** The upper boundary condition is defined by a Rayleigh friction layer with 60 s timescale, which relaxes wind and temperature toward the undisturbed reference state values. The model grid space resolution is 100 m with top at 20 km height. The model timestep is dynamically calculated following the Courant-Friedrich-Lewy stability criterion, not exceeding 5 seconds. The microphysics is resolved with time splitting (1/3 of dynamic timestep). Typically the steady state is reached within 50 minutes, being this number the upper limit of the time integration. The fire size is defined from remote sensing fire product and the heat flux is calculated according to the Table 1. The 1D plume model is embedded in a 3D model in the context of super-parameterization. In this technique, the 3D model feeds the plume model with the thermodynamical environment condition and the 1D model provides the final rise of the plume for the source emission field.

$$
\begin{cases}
\dfrac{\partial w}{\partial t} + w\dfrac{\partial w}{\partial z} = \gamma g B - \dfrac{2\alpha}{R} w^2 \\
\dfrac{\partial T}{\partial t} + w\dfrac{\partial T}{\partial z} = -w\dfrac{g}{c_p} - \dfrac{2\alpha}{R}\left|w\right|(T - T_e) + \\
\qquad + \left(\dfrac{\partial T}{\partial t}\right)_{microphysics} \\
\dfrac{\partial r_v}{\partial t} + w\dfrac{\partial r_v}{\partial z} = -\dfrac{2\alpha}{R}\left|w\right|(r_v - r_{ve}) + \\
\qquad + \left(\dfrac{\partial r_v}{\partial t}\right)_{microphysics}
\end{cases}
$$

System of equations 1. One-dimensional time-dependent entrainment plume model designed for simulate the smoke plume development.

The outline of this technique is:

- Use a 1D CRM embedded in each column of the large-scale atmospheric chemistry-transport model;
- Each grid box with fires, pass the large-scale condition of the host model to the 1D CRM;
- Resolve explicitly the motion of the plume;
- Return to the host model with the final rise of the plume (or the injection layer);
- Take account this plume rise at the source emission, releasing material emitted at flaming phase at this layer.

4. MODEL VALIDATION USING 2002 DRY SEASON DATA

Simulation for 2002 dry season was performed to compare model results with observed data.

Table 1. Lower and upper bounds for the heat flux (kW m^{-2})

Biome type	Lower bound kWm^{-2}	Upper bound kWm^{-2}
Tropical forest	30.	80.
Woody savanna - cerrado	4.4	23.
Pasture - grassland - cropland	3.3	

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 horizontal resolution of 35 km and covering 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 T126 analysis fields trough 4DDA technique. Two tracers was simulated, CO including plume rise sub grid transport and CO without this mechanism, both tracers were initialize with the same background values. Figure 2 shows the diurnal cycle of CO emitted by a source that includes the plume rise mechanism (c) and not (d). The time evolution of atmosphere stability can be envisioned at figure (a) and correspondent height of plume rise, the source emission, appears at figure (b). Without the plume rise, there is not CO above the mixed layer, figure (c). The CO distribution of figure (d) seems more realistic with a mixed layer polluted by emissions during the smoldering phase and the mean troposphere polluted by emission of the flaming phase.

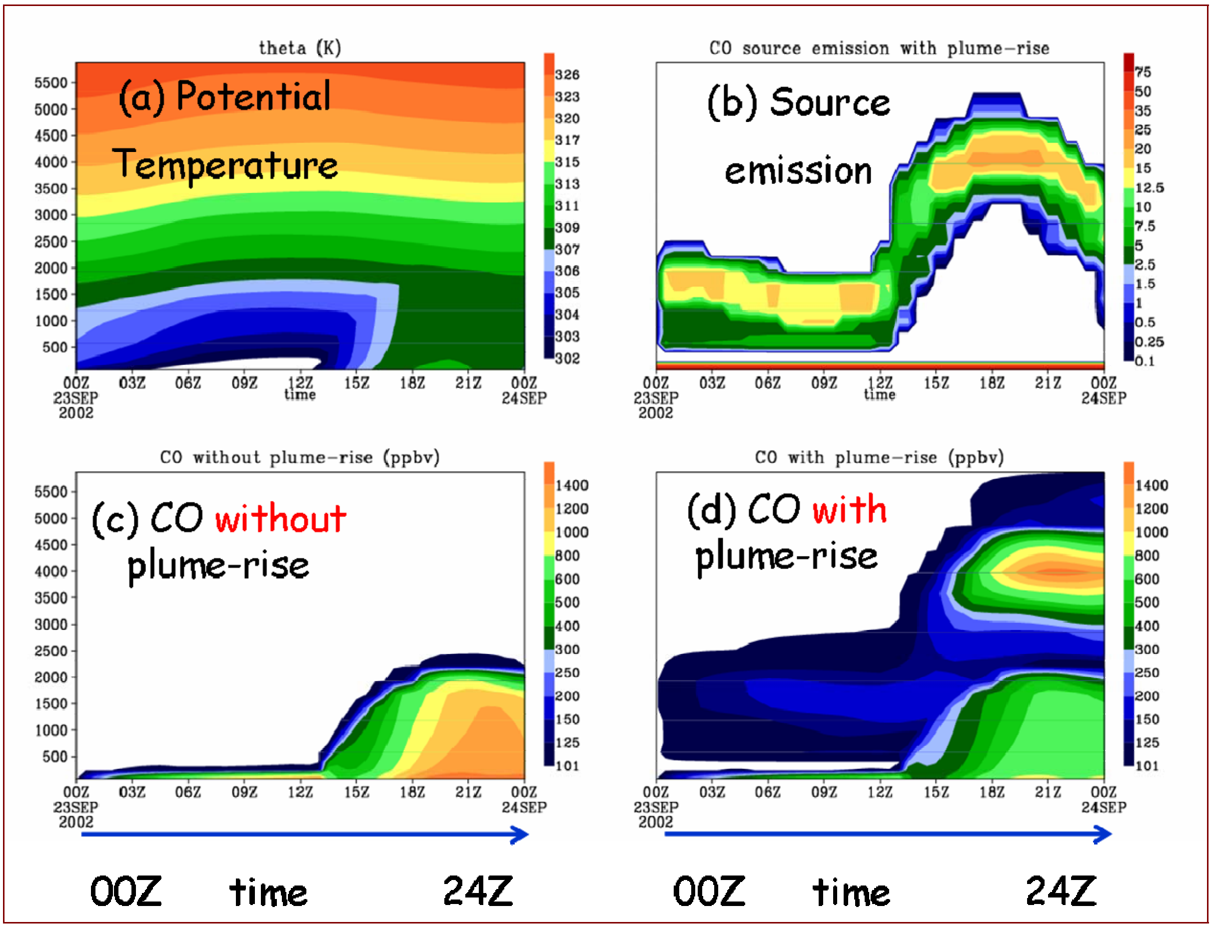

Figure 2. Diurnal cycle of the source emission with plume rise mechanism (b), the CO time evolution for a source emission without this mechanism (c) and with it (d).

Figure 3 shows model results for the both tracers defined above for 3 days of September 2002. CO at left side includes plume rise mechanism. At center appears CO at 500 mbar retrieval from AIRS (McMillan et al., 2005). Comparison with AIRS CO and CO without plume rise (right) demonstrated clearly the importance of this mechanism on simulation of CO at mean troposphere. Without the plume rise mechanism, the simulated mean troposphere over Amazon basin during the burning season is very clean, which situation is not in agreement with AIRS retrieval, for example.

5. CONCLUSIONS

We have shown the need to include the sub-grid transport associated to convection due the initial buoyancy of gases/aerosols emitted during vegetation fires. Model results indicated that this mechanism is of crucial importance for correct vertical mass distribution in the atmosphere.

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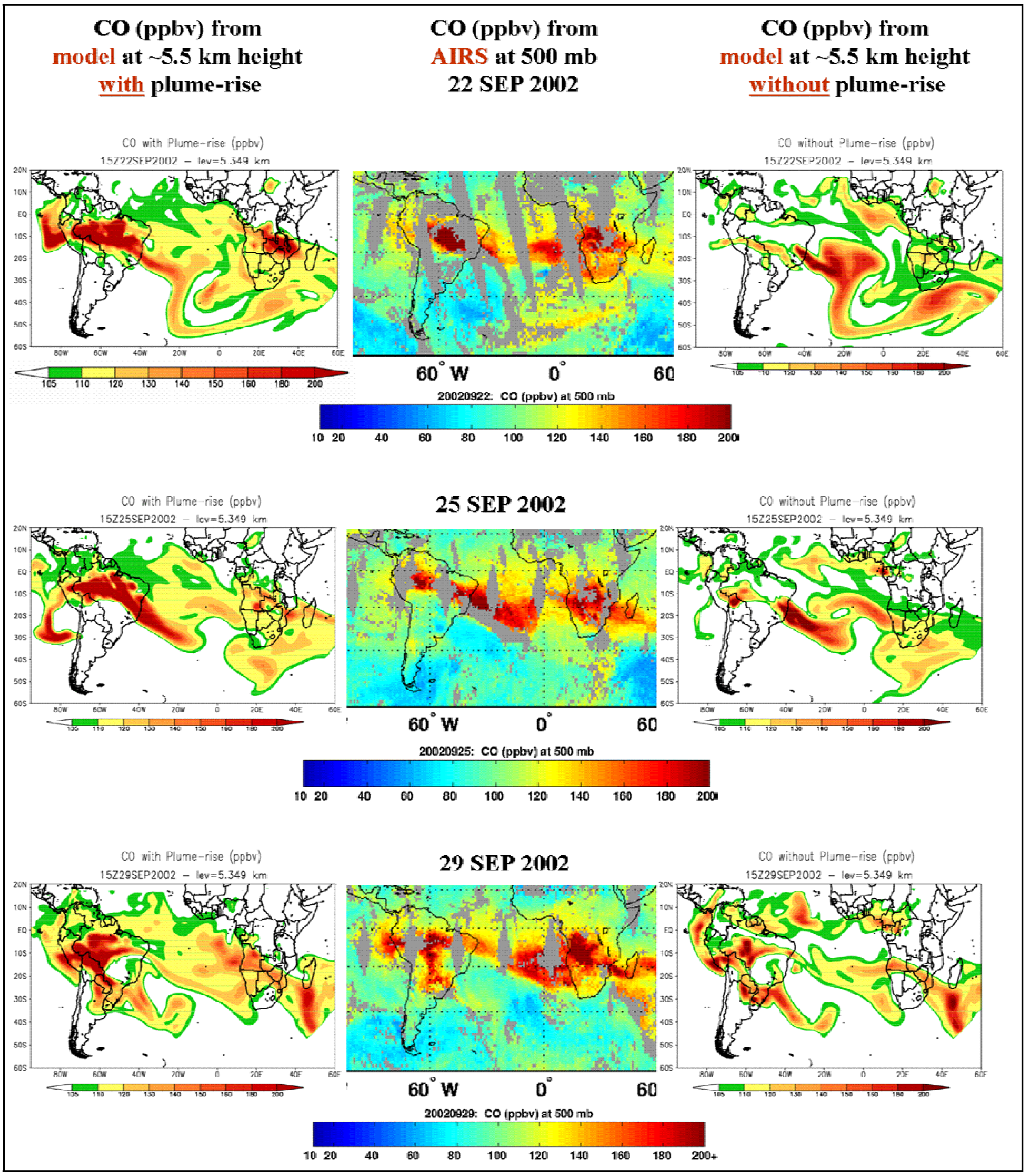

Figure 3. Model results at 5.5 km height for CO using plume-rise (left) and not (right) and AIRS daily global 500 mb CO retrievals from McMillan et al., 2005 (center).