5A. 2 REAL TIME FORECAST OF TROPOSPHERIC OZONE AND SMOKE AEROSOL PRODUCED FROM VEGETATION FIRES EMISSIONS OVER SOUTH AMERICA

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ABSTRACT

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). In addition to aerosol particles (PM), 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 (NOx=NO+NO2), and organic halogen compounds. In the presence of abundant solar radiation and high concentrations of NOx, the oxidation of CO and hydrocarbons is followed by ozone (O_3) formation. The high levels of O_3 and PM induce several respiratory problems on the affect populated areas. PM has impact on weather modification by changing the energy budgets of the surface and troposphere, as well as the microphysical behavior of clouds, and consequently also their dynamics and precipitation efficiency. In this paper we describe a real time forecast of pyrogenic products over South America by using the Coupled Chemistry-Aerosol-Tracer Transport model to the Brazilian developments on the Regional Atmospheric Modeling System (CCATT-BRAMS). CCATT-BRAMS is an on-line transport model fully consistent with the simulated atmospheric dynamics and includes kinetic and photochemical reactions. The sub-grid transport parameterizations include diffusion in PBL, shallow and deep convection and plume rise for biomass burning emissions. The atmospheric model has a complex and state-of-art set of parameterizations to simulate surface-atmosphere exchanges, boundary layer development, cloud microphysics, radiative transfer, cumulus convection. Photolysis rates can either be used from LUT or calculated on-line using FAST-TUV which is fully coupled with the aerosol and microphysics modules. The system may be virtually configured with any desired chemical mechanism using a modified version of SPACK (Simplified Preprocessor for Atmospheric Chemical Kinetics). For initial and boundary conditions, the system is able to be nudged by large scale atmospheric-chemistry models analysis using a Newtonian relaxation scheme. Currently the system is able to assimilate MOCAGE (Meteo-France global chemistry model) fields. Emissions are prescribed through a pre-processor for anthropogenic, biogenic, biomass burning, etc, using a set of published methodologies or inventories. Fire emissions are updated on near real time and are spatially and temporally distributed according to the fire counts locations obtained by remote sensing (AVHRR, MODIS and GOES-12). An operational system has been implemented which produces daily 72-hours numerical forecast of CO, O_3, PM2.5 and NOx in addition to traditional meteorological fields. We present and discuss some important events of air pollution associated to vegetation fires captured by this operational system for the burning season of July-October 2009 over South America.

1 INTRODUCTION

Biomass burning (vegetation fires) is a major anthropogenic source of greenhouse gases, aerosols and pollutants to the atmosphere during the dry season (July to October) over South America (Andreae, 1991, Artaxo et al., 2002). Besides the contribution of greenhouse gases to the global warming, smoke aerosols have an impact on the radiative budget and

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cloud microphysics (Kaufman, 1995, Rosenfeld, 1999, Andreae et al., 2004) affecting the hydrologic cycle and boundary layer properties (Longo et al., 2006). In addition, smoke aerosols as well as ozone formation by biomass burning emission precursors are observed to frequently make the air quality of the neighbor areas even worst than for the South American Megacities, like São Paulo Metropolitan Region (Brazil Health 2006: an analysis of the health situation in Brazil, 2006, Artaxo et al., 2002). The emissions associated with several hundred of fires every day during the burning season and transported by the atmospheric motions, produces a huge plume of continental scale covering large areas around 4-5 10^6 km^2 of South America (Prins et al., 1998, Freitas et al., 2005).

2 METHODOLOGY

The operational air quality forecast system implemented at the Brazilian National Institute for Space Research is based on the CCATT-BRAMS model. This model is based on the previous version CATT-BRAMS (Freitas et al., 2009) and includes gas-phase chemistry. The CCATT-BRAMS system might be virtually configured with any chemical mechanism using a modified version of SPACK (Simplified Preprocessor for Atmospheric Chemical Kinetics, Djouad et al., 2002) pre-processor. The solver of the chemical mechanism is an implicit and multi-stage based on Rosenbrock's method (Hairer and Wanner, 1991). Currently are implemented ROS 2 (2nd order, 2 stages) and RODAS 3 (3rd order, 4 stages). The integration may use manual, splitting or dynamic time-step for the chemistry. The operator splitting used to solve the mass continuity equation may be defined as parallel, sequential and sequential symmetric. Photolysis rates are calculated on-line using FAST-TUV model. Dry deposition follows the resistance formulation and accounts for the aerodynamic, quasi-laminar layer and canopy resistances (Wesely, 1989, Seinfeld and Pandis, 1998). Wet deposition is parameterized following Berge (1993) for PM2.5, Henry's law for gaseous and is fully coupled with the convective scheme. In the case presented here, we used the Regional Atmospheric Chemistry Mechanism (RACM, Stockwell et al., 1997), with 70 species and 237 kinetic and photolysis reactions. Boundary condition for chemistry fields are provided by MOCAGE global chemistry forecast. The CPTEC/INPE analysis data provides initial and boundary conditions for the meteorological integration. Emission sources are defined for anthropogenic, biogenic and biomass burning as prescribed by RETRO (www.retro.enes.org), GEIA-POET (www.geiacenter.org) and 3BEM inventories, respectively. 3BEM is based on near real-time remote sensing fire products to determine fire emissions and plume rise characteristics (Freitas et al., 2007, Longo et al., 2007). CCATT is an Eulerian transport model fully coupled to BRAMS mesoscale model. The tracer transport simulation is made simultaneously, or "on-line", using exactly the same time-step as well as dynamical and physical parameterizations. The general mass continuity equation for tracers solved in the CCATT-BRAMS model is (in a form of tendency equation):

$$\frac{\partial \bar{s}}{\partial t} = \underbrace{\left(\frac{\partial s}{\partial t}\right)_{adv}}_{I} + \underbrace{\left(\frac{\partial s}{\partial t}\right)_{\substack{PBL\\diff}}}_{II} + \underbrace{\left(\frac{\partial s}{\partial t}\right)_{\substack{deep\\conv}}}_{III} + \underbrace{\left(\frac{\partial s}{\partial t}\right)_{\substack{shallow\\conv}}}_{IV} + \underbrace{\left(\frac{\partial s}{\partial t}\right)_{chem}}_{V} + \underbrace{W}_{VI} + \underbrace{R}_{VII} + \underbrace{Q_{pr}}_{VIII} + \underbrace{F}_{IX}$$

where $\bar{s}$ is the grid box mean tracer mixing ratio, term (I) represents the 3-d resolved transport term (advection by the mean wind), term (II) is the sub-grid scale diffusion in the PBL, terms (III) and (IV) are the sub-grid transport by deep and shallow convection, respectively. The term (V) accounts for the gas-phase chemistry. Term (VI) is the wet removal, term (VII) refers to the dry deposition applied to gases and aerosols particles, (VIII) is the source term that includes the plume rise mechanism associated with the vegetations fires (Freitas et al, 2006, 2007) and, finally, (IX) is the source term associated to anthropogenic and biogenic processes relevant for this forecast. Figure 1 illustrates the main sub-grid scale processes involved in the trace gas/aerosol transport, emission, deposition and photochemistry and simulated by this modeling system. Additionally, CCATT-BRAMS includes a radiation scheme that takes into account the interaction between aerosol particles and short and long wave radiation. A consistent description of the smoke and its interaction with short- and long-wave radiation make this model reliable for atmospheric feedback studies of the smoke aerosols (Longo et al., 2006).

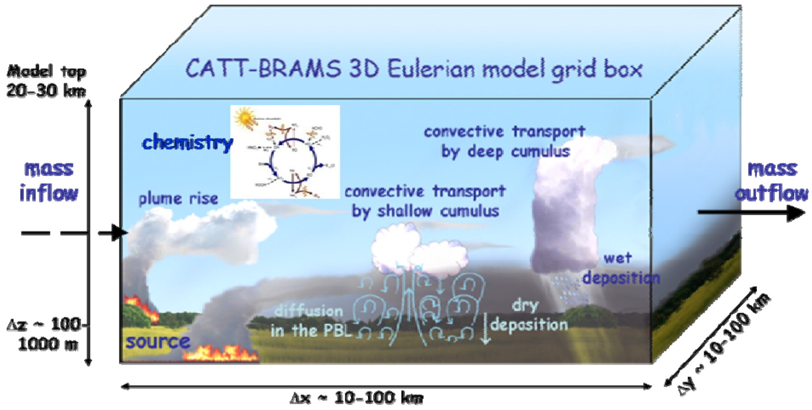

Figure 1 Several sub-grid processes involved in gases/aerosols transport, emission, deposition and photochemistry and simulated by CCATT-BRAMS system.

The operational system follows the scheme depicted in Figure 2. The fires observed by remote sensing on the previous day and the tracers concentration of the last run provide the source emission and the initial condition for the tracers. The CPTEC (Center for Weather Prediction and Climate Studies-Brazil) atmospheric and MOCAGE chemistry global analysis and forecast provide the initial and boundary conditions for the regional atmospheric model and chemistry fields using the 4DDA technique. The model configuration has 2 grids. The coarse grid has a horizontal resolution of 60 km covering the South and Central American continents. The nested grid has a 30 km horizontal resolution and covers mostly South America. The vertical resolution for both grids is between 100 to 850 m, with the top of the model at 21 km. Each time integration is 96 hours (with of 72 hours forecast).

3 CASES STUDIES

An example of performance of this operational system is showed at Figure 3. On April 2008, farmers of Argentina produced thousands of fires which generated enormous smoke plume (see Figure 3 B, MODIS visible image on 17/04/2008) that reached the city of Buenos Aires. The smoke caused a strong degradation of the local air quality (see Figure 3 C) and reduced the visibility. The Figure 3 A shows the real time forecast (initialized on 00UTC 16/04/2008) valid for 03UTC 17/04/2008 of the smoke plume invading the metropolitanean area of Buenos Airea. This example demonstrate the system skill on simulate, from a remote sensing fire product, the emissions, transport and forecast smoke aerosol and trace gases concentrations.

We also briefly discuss a current case occurred on 04/10/2009. Figure 4 introduces the real time fire location and pyrogenic CO emissions estimate generated by the forecast system. October marks the end of the dry season on South America, but still has a huge amount of fires burning large areas. From this figure, one can see fires burning vegetated areas of the arc of deforestation, but also fires inside of the Amazon basin, mainly around the main local roads and the Amazon River. Emission rates up 10^{-8} kg[CO] m^{-2} s^{-1} are estimated, mainly over dense forest areas. The left side of Figure 5 shows the emission rates of CO at levels ~ 6.7 km (up panel) and ~9.3 km (bottom panel) above local surface. This elevated emission is associated to its initial strong buoyancy provided by the fire heat flux during the flaming phase. The vertical level of the injection mass is determined by the plume rise model embedded in each column of the CCATT-BRAMS model (Freitas et al., 2006). On the right side of Figure 5, appears the forecast of NOx (ppbv) mixing ratio at level ~6.7 km and on 22 UTC 04/10/2009. This NOx is associated to the fires at North and Northeast part of Brazil, as reported previously, and are precursors of tropospheric ozone, as we will discuss below. The impact on air quality on surface level and at mean troposphere (~6.7 km) is demonstrated on Figure 6. The upper panels show the CO and O_3 mixing ratio (ppbv) on surface. The small CO plume that appears around latitude 23 S and longitude 46 W is associated to the Sao Paulo metropolitan area (SP) urban pollution. For ozone, biomass burning increases its value from typically background of 10 ppbv to up 70 ppbv. Is also evident the ozone plume formed from SP urban pollution. At the mean troposphere (~6.7 km above local surface, bottom panels), the smoke plume rise injected huge amount of CO and ozone precursors. The huge plume of ozone with maximum of 75 ppbv is transported to the northwest and to southeast by the trade winds at this level. This regional transport might have strong implications to the atmospheric chemistry composition of the receptors areas.

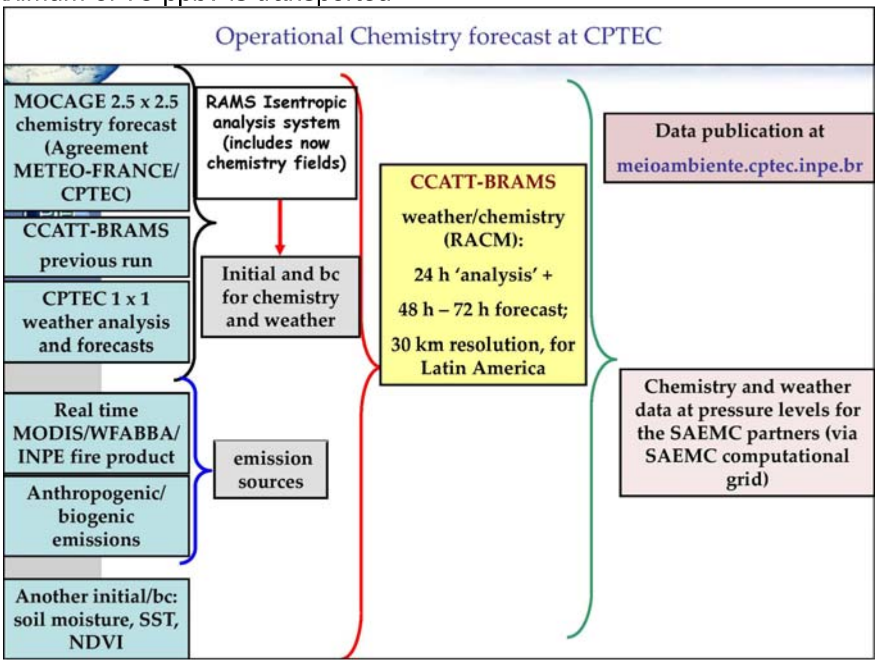

Figure 2. Chart describing the tools, models and data flux to produce the operational air quality forecast at the Brazilian Center for Weather Forecast and Climate Studies (http://meioambiente.cpte.inpe.br).

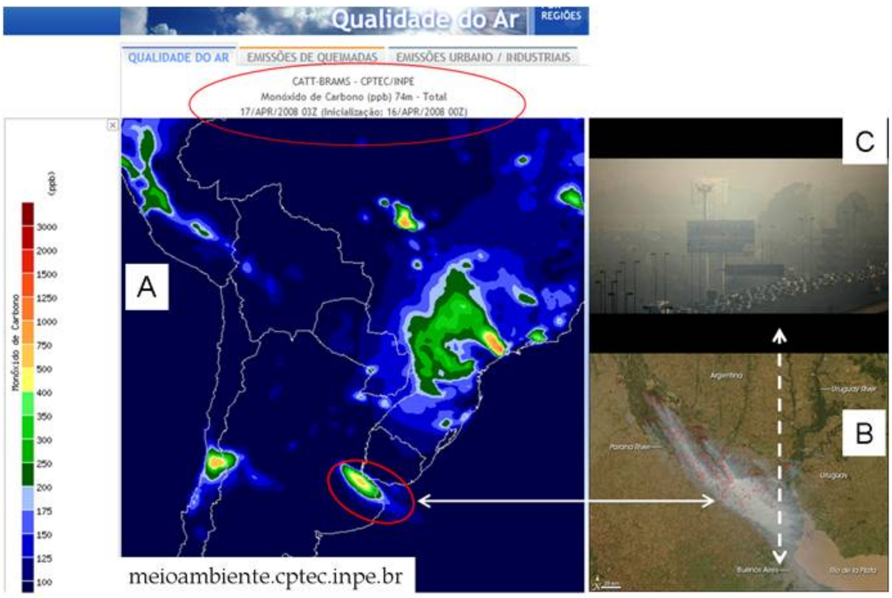

Figure 3. (A) Real time forecast of carbon monoxide over South America (valid for 03 UTC 17/04/2008) using CCATT-BRAMS at CPTEC/INPE/Brazil (http://meioambiente.cptec.inpe.br). (B) MODIS visible image for 17/04/2008. (C) Photopgraph of Buenos Aires on 17/04/2008.

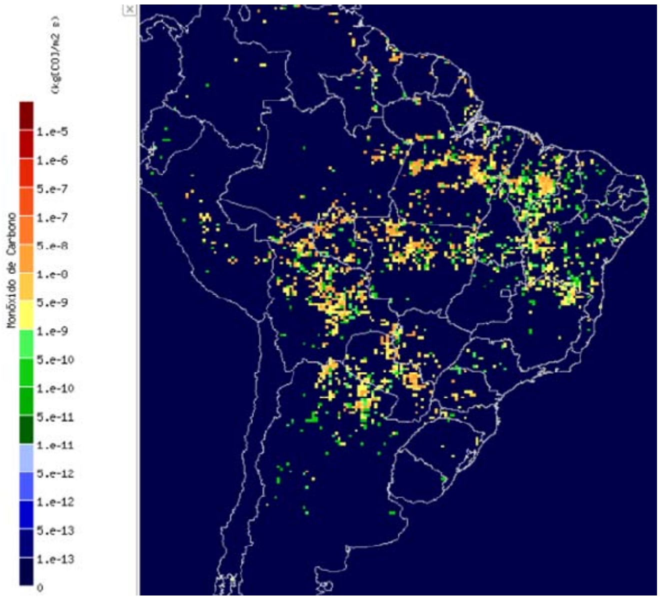

Figure 4. Real time fire location and carbon monoxide emission estimate (kg m^{-2} s^{-1}) for 04/10/2009**.**

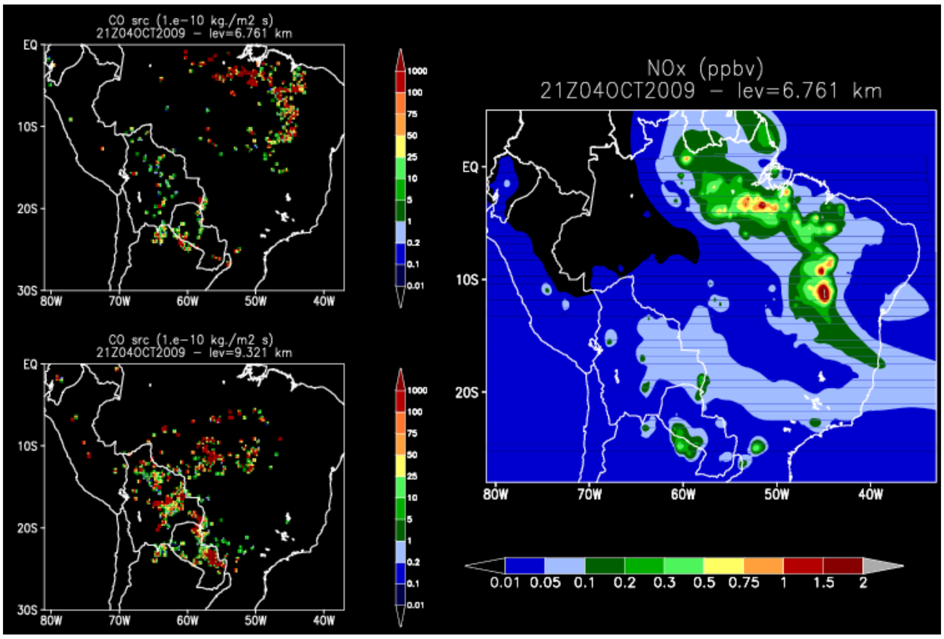

Figure 5. On the left side, elevated pyrogenic CO emissions estimated by using real time remote sensing fire products and a 1D plume rise model. On the right side, forecast of NOx mixing ratio at level ~ 6.7 km above local surface and on 21UTC 04/10/2009.

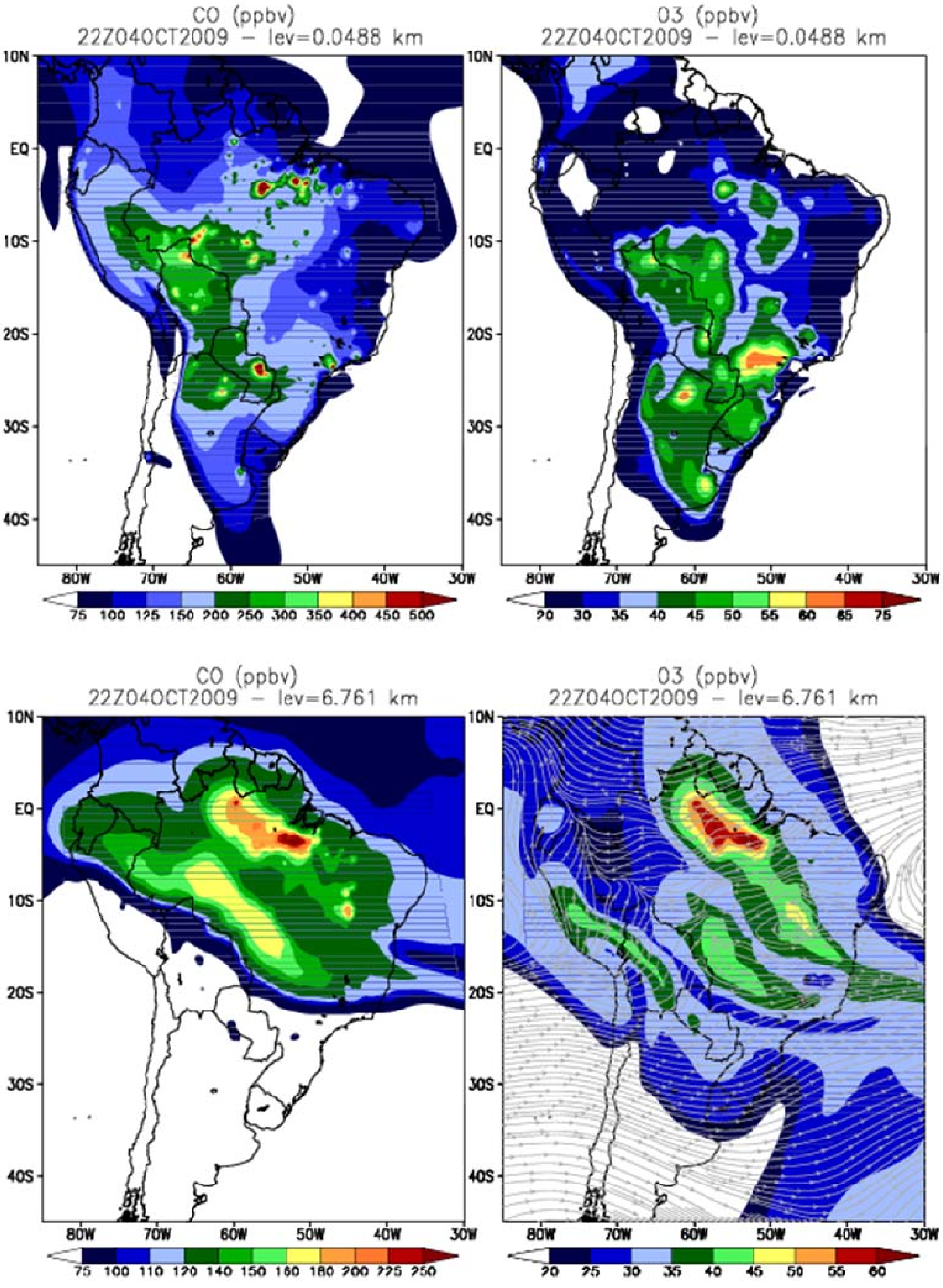

Figure 6. Upper panels: real time forecast of carbon monoxide (left) and ozone (right) mixing ratios (ppbv) on surface level for 22 UTC 04/10/2009. Bottom panels: the same but at the mean troposphere (~ 6.7 km above local surface).

4 CONCLUSIONS

We briefly describe a near real time air quality forecast system related to biomass burning on South America. This system, named CCATT-BRAMS, is an on-line Eulerian aerosol-chemistry model coupled to BRAMS atmospheric mesoscale model. Near real time fire emissions estimated is based on remote sensing fire products and provides not only the strength but location and timing as well. We have also discussed few cases of the model performance on simulating the evolution of the atmospheric chemistry composition on South America. In general, this system is a powerful tool in understanding the synoptic controls on the biomass burning plume transport and has demonstrated good prediction skills.

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