European Geosciences Union
General Assembly 2012
Vienna, Austria : 22 – 27 April 2012

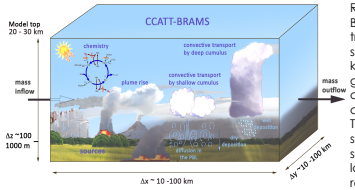
A fully coupled regional atmospheric numerical model for integrated air quality and weather forecasting

S. R. Freitas (1), K. M. Longo (2), V. Marecal (3), M. Pirre (4) , N. Rosario (2), M. Alonso (1), D. Moreira (1) and T. GMAI (1)

(1) INPE, CPTEC, Cachoeira Paulista - SP, Brazil (saulo.freitas@cptec.inpe.br), (2) INPE, CCST, Sao Jose dos Campos - SP, Brazil, (3) Meteo France, Toulouse, France, (4) CNRS, Orleans, France.

Abstract: A numerical modelling tool devoted to local and regional studies of atmospheric chemistry from surface to the lower stratosphere designed for both operational and research purposes will be presented. This model is based on the limited-area model CATT-BRAMS (Coupled Aerosol-Tracer Transport model to the Brazilian developments on the Regional Atmospheric Modeling System, Freitas et al. 2009, Longo et al. 2010) which is a meteorological model (BRAMS) including transport processes of gaseous and aerosols (CATT model). BRAMS is a version of the RAMS model (Walko et al. 2000) adapted to better represent tropical and subtropical processes and several new features. CATT-BRAMS has been used operationally at CPTEC (Brazilian Center for Weather Prediction and Climate Studies) since 2003 providing coupled weather and air quality forecast. In the Chemistry-CATT-BRAMS (called hereafter CCATT-BRAMS) a chemical module is fully coupled to the meteorological/tracer transport model CATT-BRAMS. This module includes gaseous chemistry, photochemistry, scavenging and dry deposition. The CCATT-BRAMS model takes advantages of the BRAMS specific development for the tropics/subtropics and of the recent availability of preprocessing tools for chemical mechanisms and of TUV codes for photolysis rates. Similarly to BRAMS this model is conceived to run for horizontal resolutions ranging from a few meters to more than a hundred kilometers depending on the chosen scientific objective. In the last decade CCATT-BRAMS has being broadly (or extensively) used for applications mainly over South America, with strong emphasis over the Amazonia area and the main South American megacities. An overview of the model development and main applications will be presented.

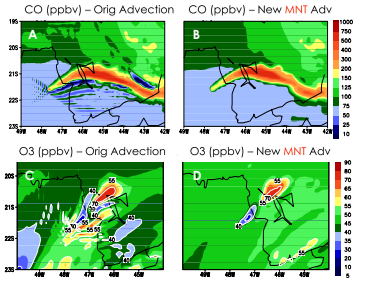
Short Description of CCATT-BRAMS



The Coupled Chemistry-Aerosol-Tracer Transport model to the Brazilian developments on the Regional Atmospheric Modeling System (CCATT-BRAMS) is presented. 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 (Madronich, 1990), FAST-JX (Wild et al., 2000) codes which are 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) (Djouad et al.,2002). For initial and boundary conditions, the system is able to be forced by large scale atmospheric-chemistry models analysis using a Newtonian relaxation scheme. Currently the system is able to assimilate MOCAGE (from Meteo-France) chemistry fields. Emissions are prescribed through a pre-processor for anthropogenic, biogenic, biomass burning, charcoal production, etc, using a set of published methodologies or inventories.

Impacts of a Monotonic Advection Scheme

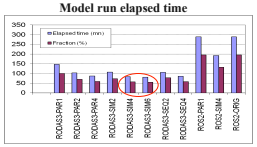
A horizontal view of the CO biomass burning plume as simulated by the original (non-monotonic) and a new monotonic (MNT, Walcek 2000) advection scheme implemented in CCATT-BRAMS is presented at Figure on the rights. The results refer to a height of 3.9 km. The horizontal distribution of CO simulated by the orig scheme (A) results in spurious oscillations with large under- and overshoots. On the other hand, the mnt advection (B) does not generate spurious oscillations and seems to produce much more realistic horizontal transport and tracer distribution patterns.



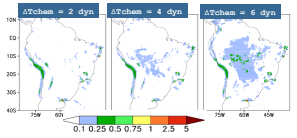
Panels C and D introduce a horizontal view of the ozone mass mixing ratio (ppbv) distribution as simulated by both schemes. The dipole pattern is evident. The simulation with the original scheme (C) seems to be unrealistic, with strong and spurious oscillations. The MNT one (D) produces more realistic patterns and well defined plume boundaries in terms of ozone.

The Chemistry Operator

The solver of the chemical mechanism is an implicit and multi-stage method proposed by Rosenbrock (1963). Currently are implemented ROS 2 (2nd order, 2 stages) and RODAS 3 (3rd order, 4 stages). The integration uses manual, splitting or dynamic chemistry integration timestep. The operator splitting used to solve the mass continuity equation may be defined as parallel, sequential and sequential symmetric allowing the chemistry integration to use larger timestep than dynamics and physics.



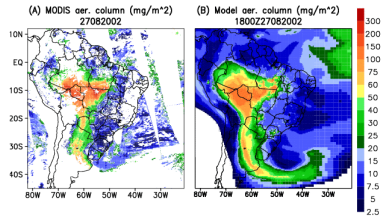
Exploring solvers and splitting operators



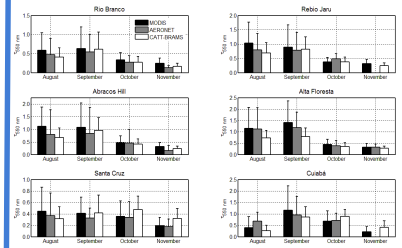
Surface O3 error (%):

- Time integration 120 h
- Rosenbrock of 3rd order
- Symmetric splitting using 2, 4 and 6 dynamic timesteps.

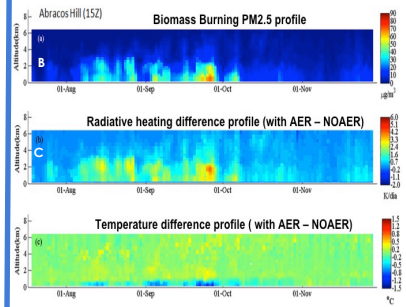
The Aerosol Model



The aerosol model is a simple mono-disperse for biomass burning and urban sources (aerosol model "MATRIX" is under implementation) and includes interaction with short and long wave radiation. The panel A of the figure on the left shows the river of smoke in terms of MODIS aerosol column (mg m-2) retrieval for 18 UTC 27 August 2002. Model results as a composite of the regional and large scale grids are shown in panel B. The pattern of the continental-scale smoke plume are clear in this image and depicts the smoke inflow areas from Africa, the outflow to the South Atlantic Ocean, as well as the emission sources from biomass burning regions. Also the modeled smoke pattern resembles very well the MODIS-retrieved pattern and indicates that the model dynamic works properly.



Model evaluation of the simulated aerosol optical depth (AOD, @ 550 nm) using AERONET data and MODIS retrieval is presented in the left figure. The evaluation is done using six AERONET sites of South America for August to November 2002. Mean value and standard deviation are shown. Note that model is able to represent the time variability and mean value of AOD is consistent with AERONET and MODIS. Also the standard deviation are in the same range.



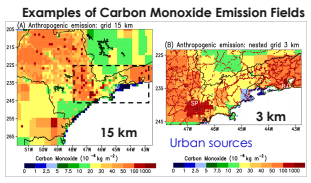
Impacts of the biomass burning aerosols on radiative transfer are showed on the left side. The panel A shows a time series of PM2.5 (μg/m³) from surface up to 6 km height at 15 UTC on the site Abracos Hill on the Southwestern of Amazon basin. Can be noted the polluted boundary layer with the smoke reaching levels up to 2.5 km and the low troposphere with values of PM2.5 between 10 and 30 μg/m³. The panel B shows the radiative heating difference between two simulations where a second one does not include the interaction between smoke and the radiation. Heating rates greater than 2 – 4 K/day are observed, with a cooling in the layers close to the surface. As a result, the layers above becomes 0.2 to 0.5 K warmer. The near surface layers becomes up to 1.5 K cooler. In that way, the presence of the biomass burning aerosol produced an atmosphere with stronger thermodynamic stability.

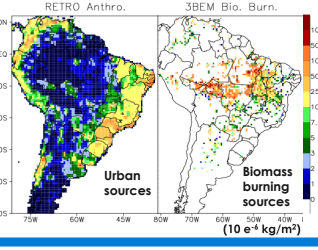
The Emission Tool PREP-CHEM-SRC

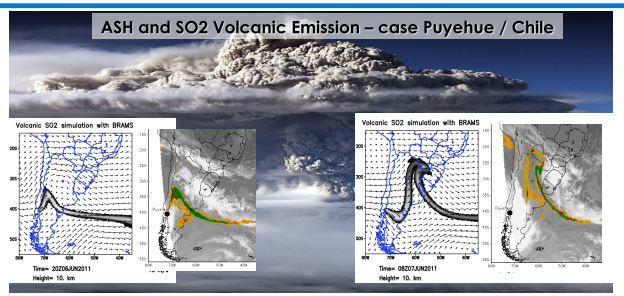
The preprocessor PREP-CHEM-SRC is used to produce emission fields (trace gases and aerosols) for CCATT-BRAMS. The considered emissions are from the most recent databases of urban/industrial, biogenic, biomass burning, volcanic, biofuel use and burning from agricultural waste sources. The follow inventories or data set are available MEGAN, EDGAR, RETRO, 3BEM, GFED, GOCART and an urban regional update for SA (Alonso et al 2010).

The preprocessor provides emission fields interpolated onto the transport model grid. Severa map projections can be chosen. The preprocesso is coded using Fortran90 and C and is driven by a *namelist* allowing the user to choose the type o emissions and the databases.

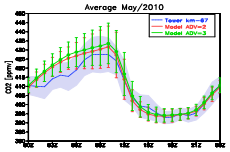
Biomass burning emissions is based on the Brazilian biomass burning emission model (3BEM) which estimate directly from satellite fire detections using a fire emission model. Up 100 of chemical species can be estimated. In this case, also parameters needed to drive an in-line 1-D cloud model is provided to determine the injection layer o emissions during the flame phase.





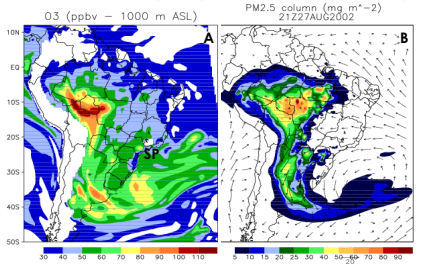


Coupling with the JULES surface scheme with CO2 biogenic fluxes



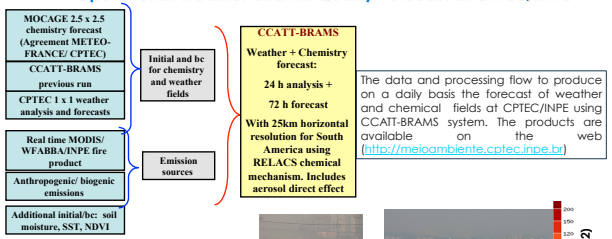
The figure on the left show the CO2 mixing ratio (ppmv) observed (blue) and simulated using the CCATT-BRAMS-JULES system (red and green). STD are also showed.

Ozone formation from biomass burning precursors and PM2.5: long range transport by low level jets

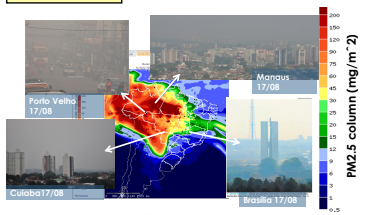


The figures on the left show a continental river of smoke crossing South America on the east side of the Andes Mountains on August 27, 2002. The figure (A) shows ozone (ppbv) and (B) particulate material column integrated (mg m-2). This smoke transport was detected by MODIS (not shown) and was enhanced by low level jets on east side of Andes mountains. The long range transport of tropospheric ozone and its precursors is evident showing that the biomass burning impacts also the air quality even on remote areas. The São Paulo megacity (SP) ozone plume is also shown invading normally clean areas westward.

Operational Weather and Air Quality Forecast at CPTEC/INPE



The data and processing flow to produce on a daily basis the forecast of weather and chemical fields at CPTEC/INPE using CCATT-BRAMS system. The products are available on the web (http://meioambiente.cptec.inpe.br)



An example of model output for 17 August 2010. Forecast of PM2.5 (mg/m²) column and the main urban areas in Amazon basin and central part of Brazil disturbed by the smoke from biomass burning.

Ongoing Work and Perspectives

The development of CCAT-BRAMS model has being pursuing a reliable regional atmospheric chemistry forecasting system for the South American continent. Operational since 2003, the model has been under continuous progress on chemistry, aerosols, physics and dynamics. Ongoing work implementation includes the MATRIX aerosol module, aqueous - chemistry phase, volcanoes applications, aerosol indirect effects and climate studies.

The 1st author acknowledges partial support of this work to CNPq (306340/2011-9) and FAPESP (2012/01659-3).