MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

Real time forecast of tropospheric ozone and smoke aerosol produced from vegetation fires over South America

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Grupo de Modelagem da Atmosfera e Interfaces
Modeling of the Atmosphere and its Interfaces Group

Ministério da Ciência e Tecnologia

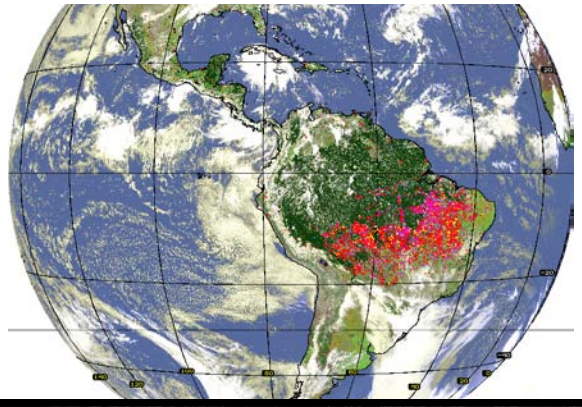
GOVERNO FEDERAL BRASIL PAÍS RICO É PAÍS SEM POBREZA

Motivation

Megacities – South America (urban pollution)

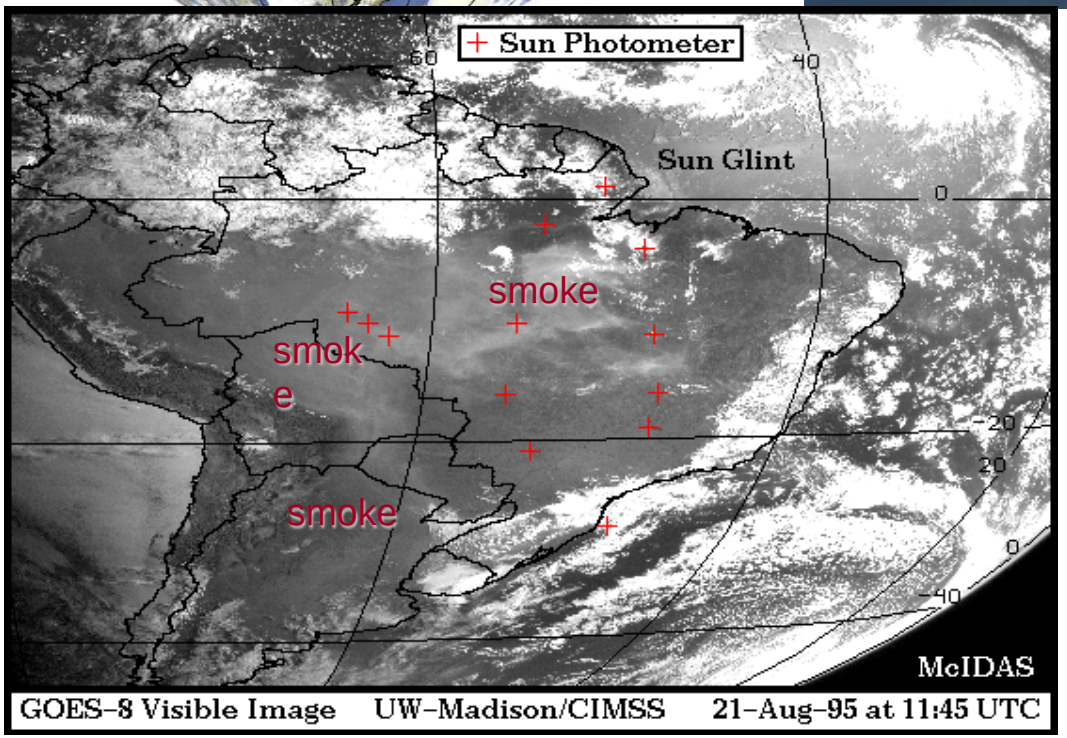
Biomass Burning Emissions

> 5000 fires
GOES-8 WF_ABBA



Local smoke plume
(deforestation fires)

(picture from M. Andreae)

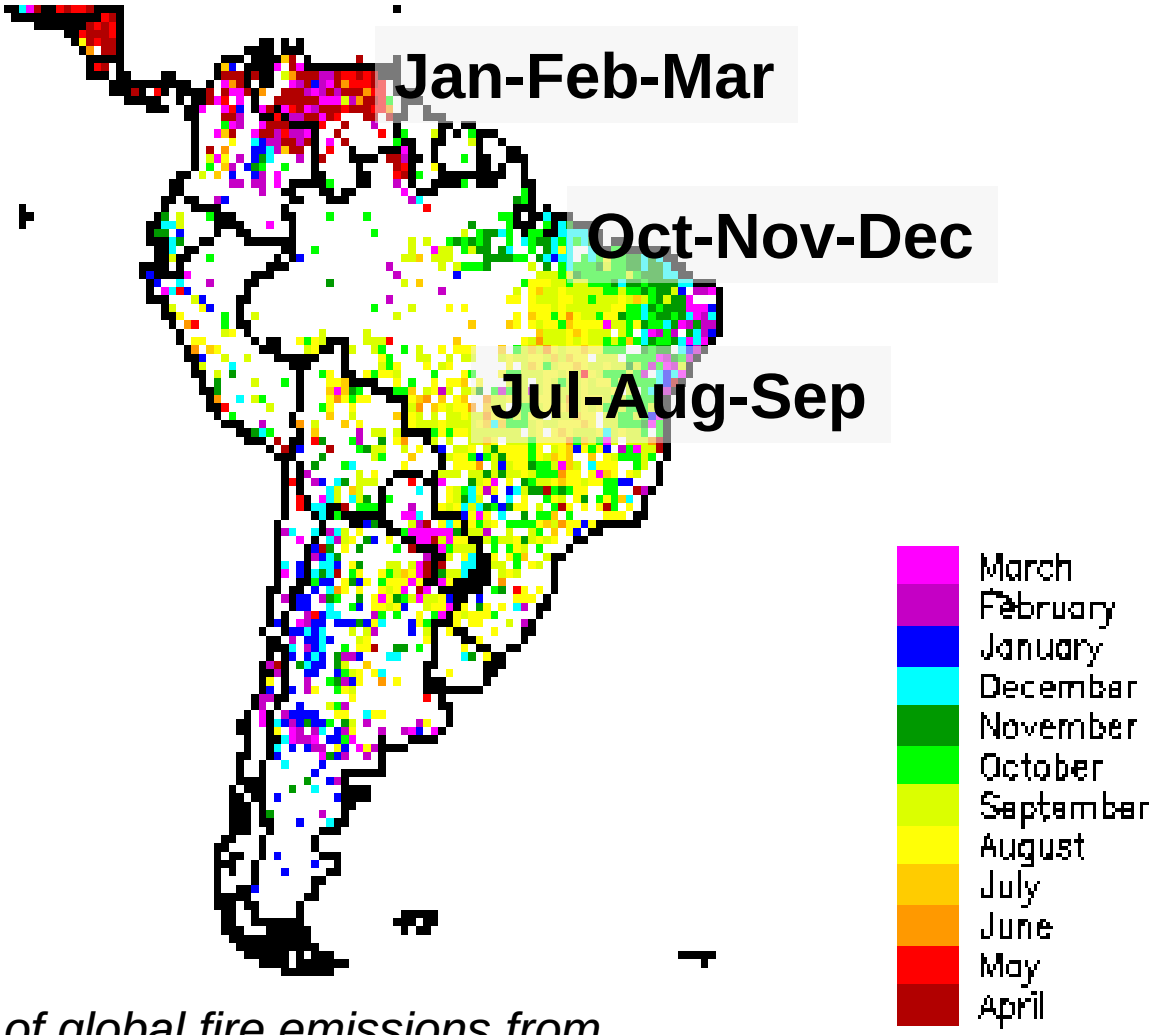


Regional smoke plume

~5 millions km^2

(Prins et al. 1998)

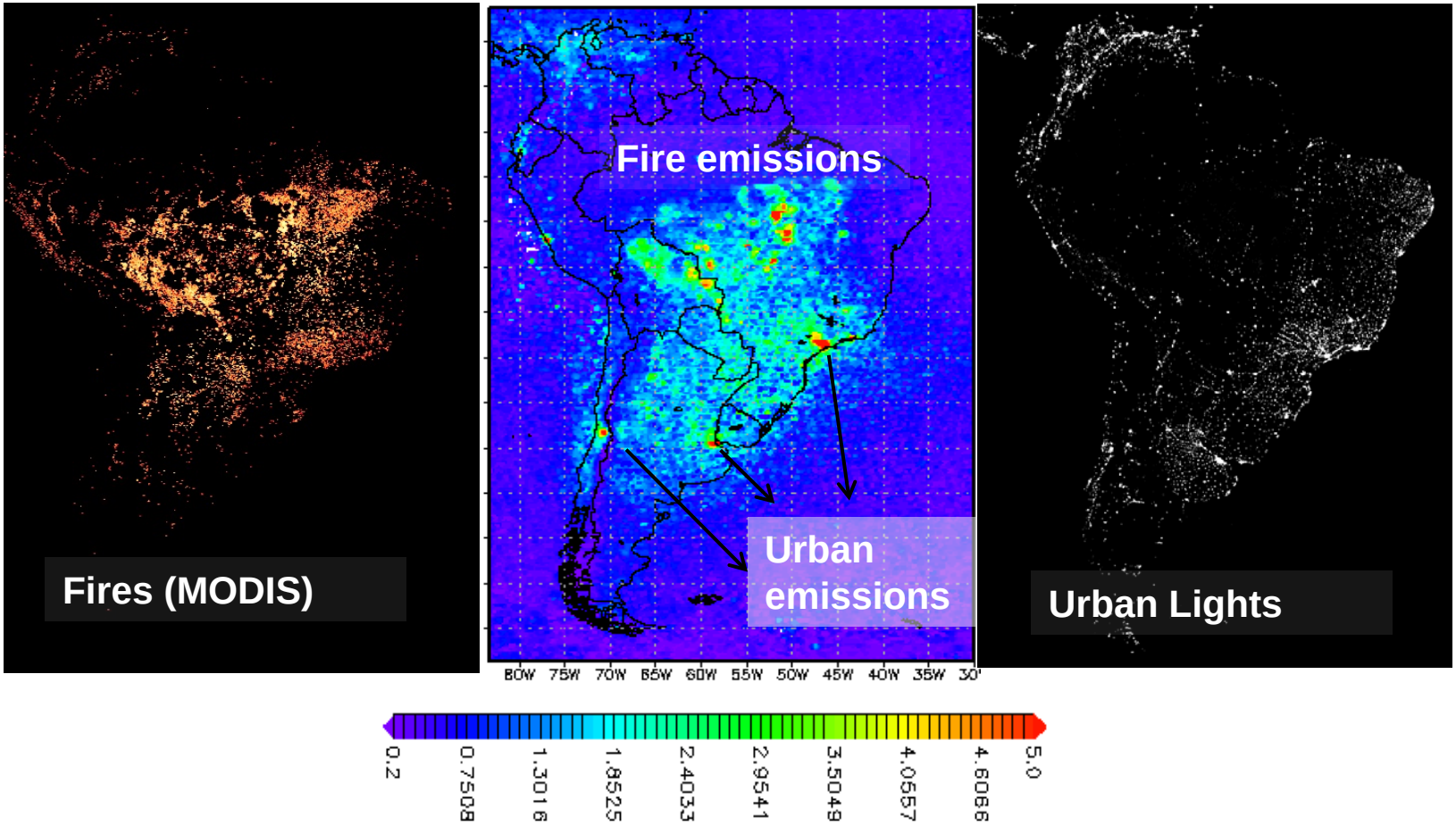
Monthly occurrence of Biomass Burning in South America



Monthly occurrence of global fire emissions from April 1992 to March 1993, source: Dwyer et al., 1999 (adapted).

Deforestation drivers in Amazon

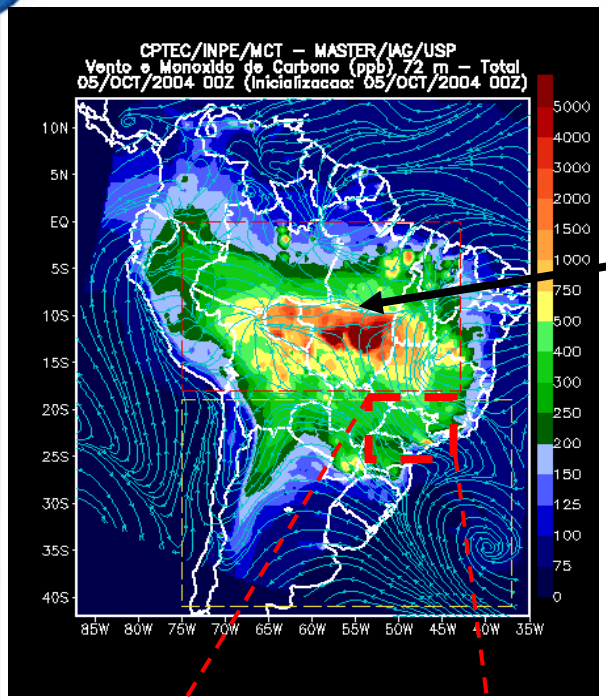
NO_2 Tropospheric column : Biomass Burning X Urban emissions



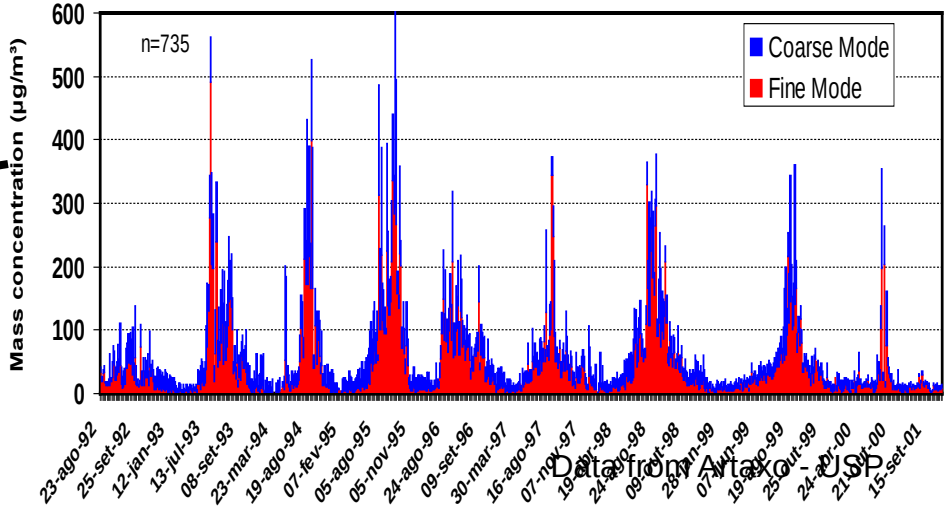
01-31 Aug 2010 Aura OMI

(10^{15} molec/cm^2)

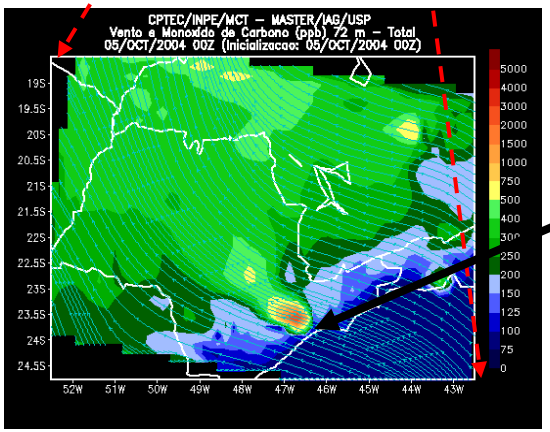
Biomass burning versus urban pollution

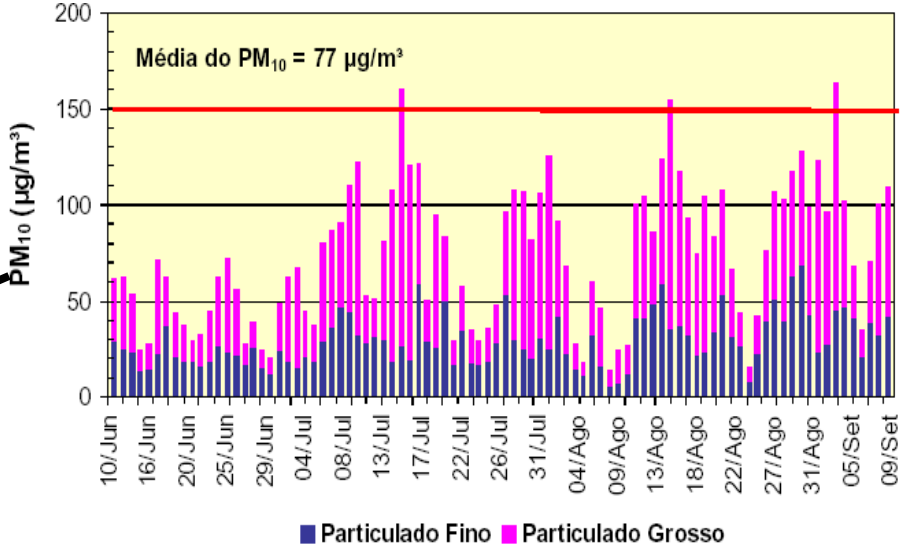


Alta Floresta - 1992-2001 Aerosol mass concentration



Data from Artaxo - USP

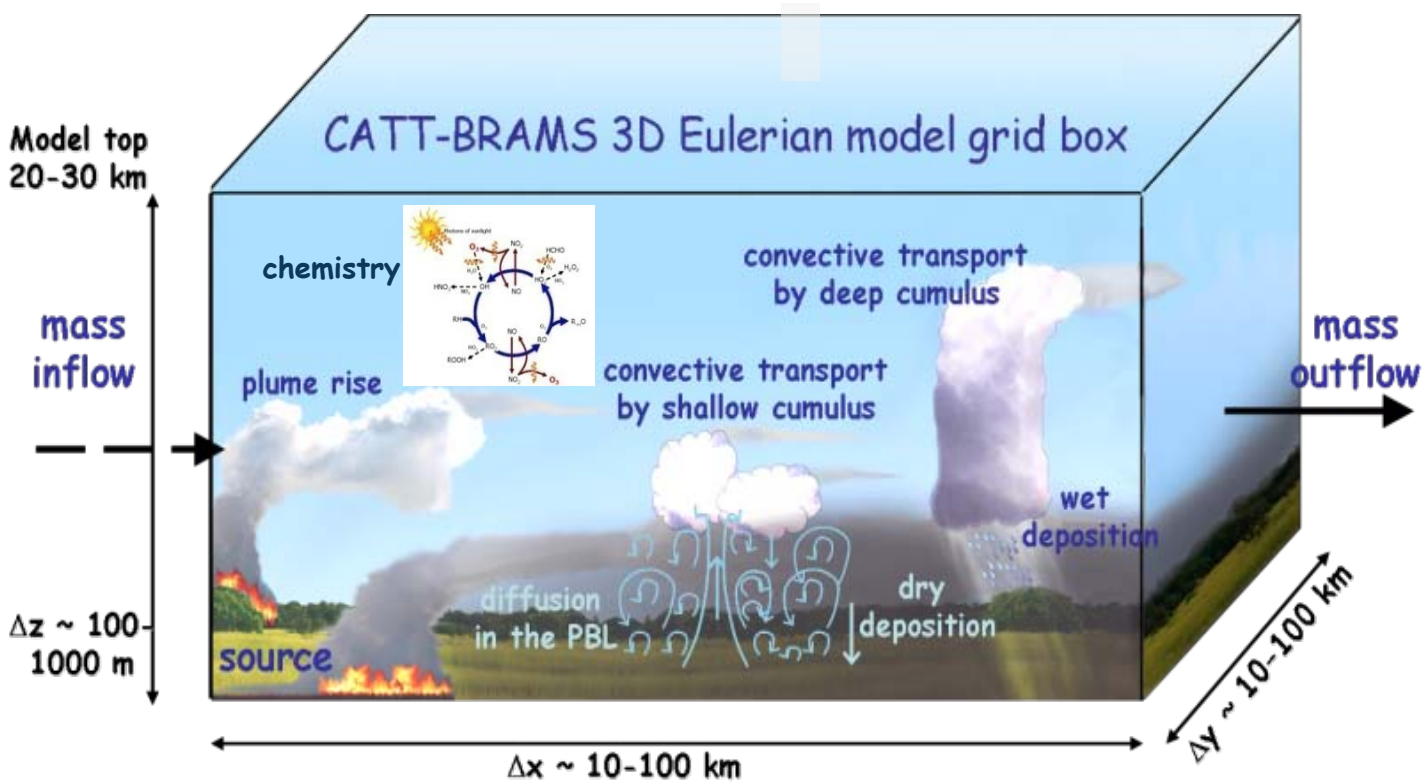




São Paulo - winter 1997 Aerosol mass concentration

Numerical Modeling

Coupled Chemistry-Aerosol-Tracer Transport model to the Brazilian developments on the RAMS: CCATT-BRAMS



On-line approach

Freitas et al., 2005, 2009, Longo et al., 2006, 2010

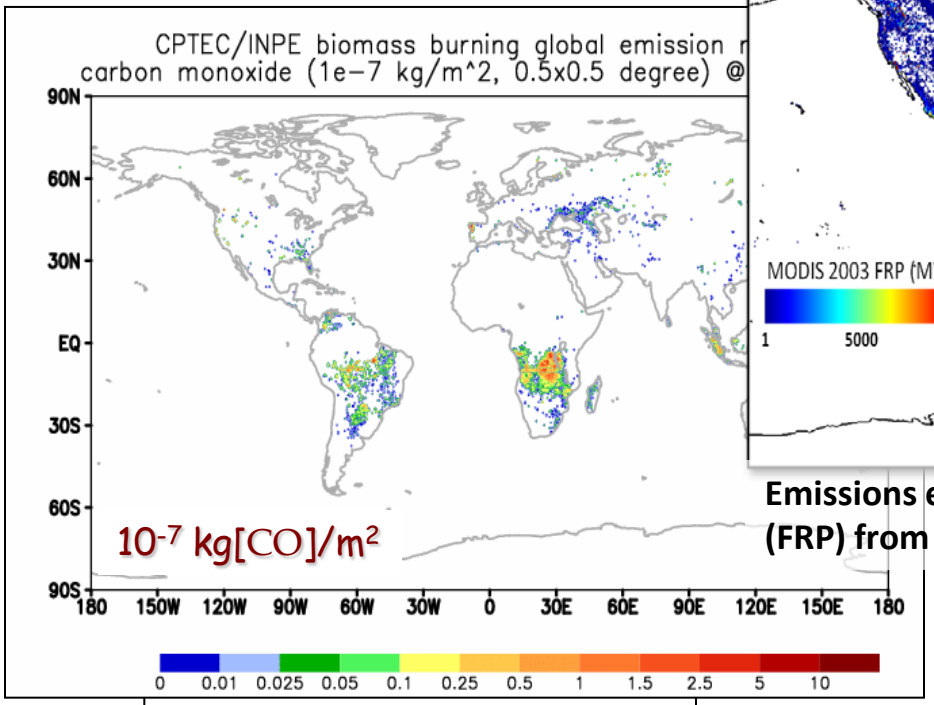
Coupled Chemistry-Aerosol-Tracer Transport model to the Brazilian developments on the RAMS:

CCATT-BRAMS	FORMULATION
Dynamics	Non-hydrostatic / time-split compressible (RAMS/CSU)
Advection	Monotonic (Walcek 2000, Freitas et al. 2011)
Sub-grid scale convective transport/ wet deposition	Coupled to Grell and Deveny (2002) cumulus scheme – (deep / shallow)
PBL Turbulence	Several, normally M&Y 2.5
Dry deposition	Resistance approach coupled with surface scheme/PBL
Emissions	MEGAN, EDGAR, RETRO, 3BEM, GFED, GOCART, Volcanoes. Urban regional update for SA (Alonso et al 2010).
Plume rise – Veg. Fires	1-D in-line cloud model forced by heat flux / fire size (Freitas et al., 2007/2010)
Gas-Phase Chemistry	SPACK pre-processor (RACM, RELACS, CB07, etc) (Longo et al., 2011)
Photolysis	LUT, FAST-JX, FAST-TUV(in-line, aerosol and clouds effects)
Boundary condition	MOCAGE global chemistry model
Aerosol with direct effect on radiation	Simple mono-disperse for biomass burning/urban (aerosol model "MATRIX" is under implementation) (Longo et al 2006, Rosário et al., 2011)

Biomass Burning Emissions Estimation

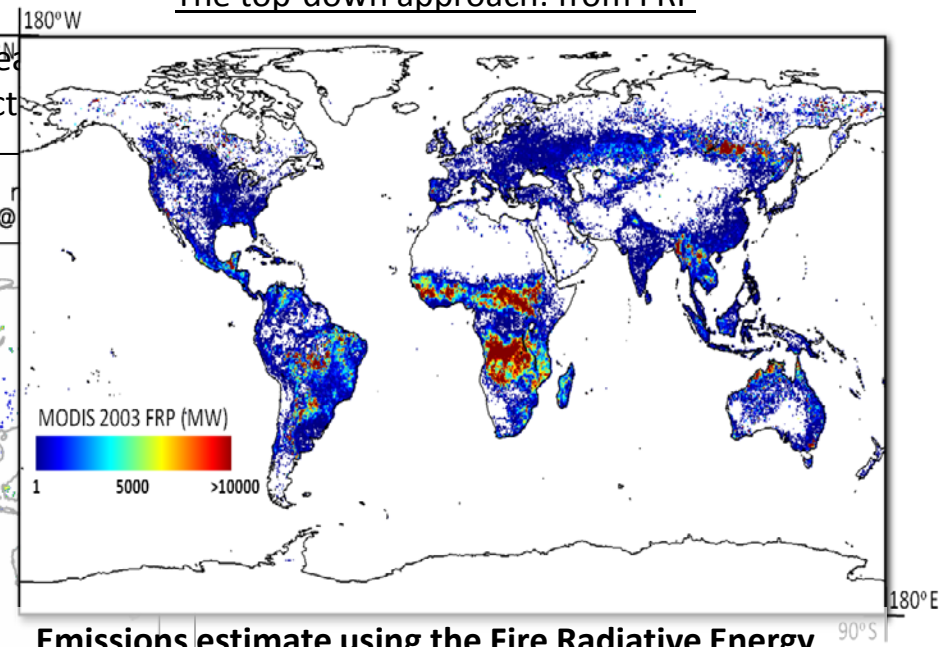
Brazilian Biomass Burning Emission Model (3BEM)

The bottom-up approach: fire size/burnt area
carbon density, emission and combustion fact



$$M_{[\eta]} = \alpha_{veg} . \beta_{veg} . Ef_{veg}^{[\eta]} . a_{fire},$$

The top-down approach: from FRP



Emissions estimate using the Fire Radiative Energy (FRP) from MODIS, GOES and SEVIRI sensors.

Pereira et al., 2009

Freitas et al., 2005, Longo et al., 2010

Including the sub-grid scale smoke plume rise mechanism (inspired on the "*super-parameterization*" concept)

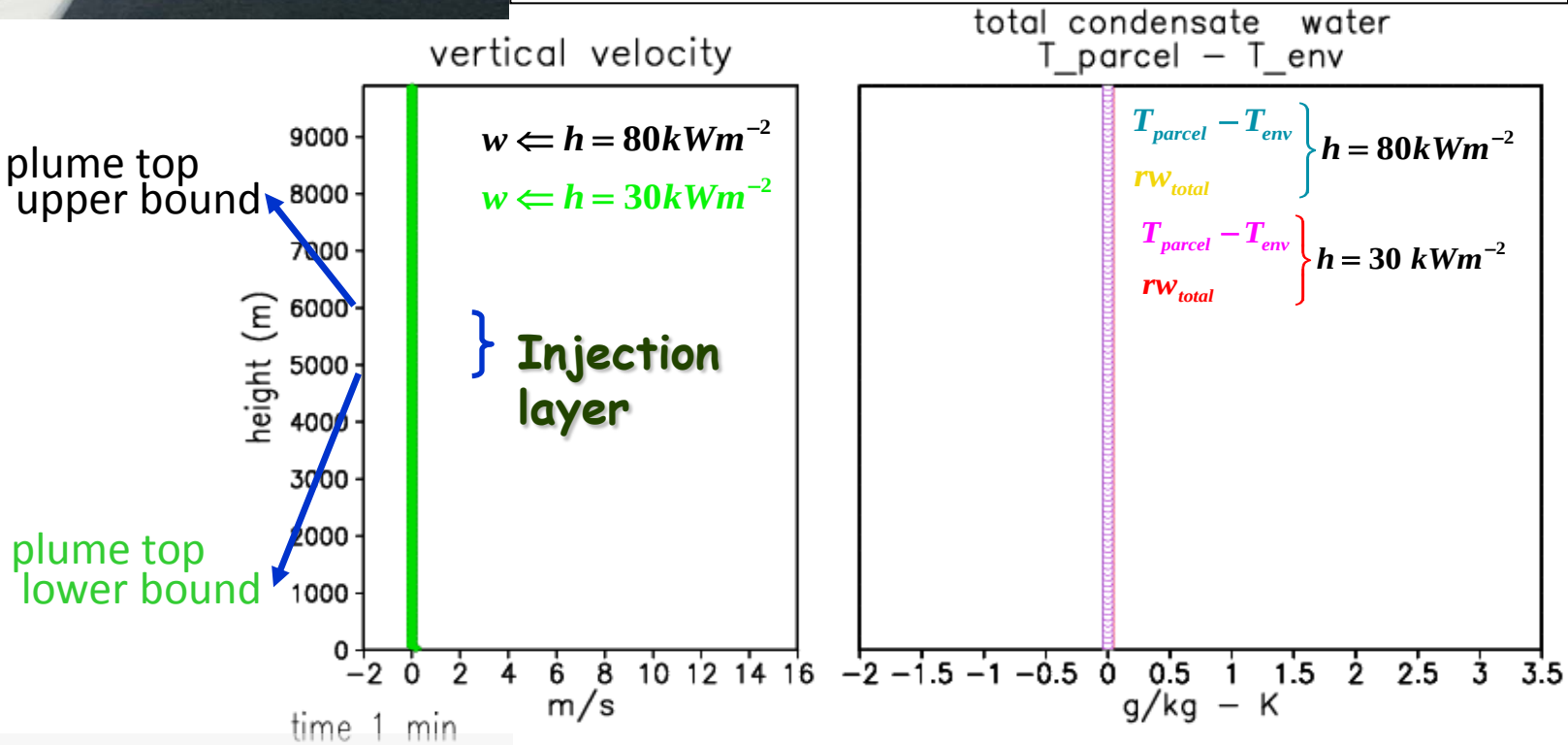
1D plume-rise model for vegetation fires

Biome: Forest

Time duration: 50 mn

Fire size: 20 ha

Heat flux: 80 kWm^{-2} / 30 kWm^{-2}



Freitas et al., 2006, 2007, 2010

In-line 1D pyro-cloud to estimate the injection layer

- Advantages:
  - Physical based formulation
  - Uses the actual atmospheric stability (hourly, diurnal, seasonal variability)
  - Includes the ambient wind interaction with the smoke plume (dilution, momentum exchange, bent-over)
  - Account for the cloud microphysics additional buoyancy (increase the final height)
- Disadvantages or requirements
  - Needs fire size***
  - Needs heat flux from fire***

*** some groups (INPE, KCL, Harvard) are working on using remote sensing data to supply these information.

Emission Fields Preprocessor

Geosci. Model Dev., 4, 419–433, 2011
www.geosci-model-dev.net/4/419/2011/
doi:10.5194/gmd-4-419-2011
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Geoscientific Model Development

PREP-CHEM-SRC – 1.0: a preprocessor of trace gas and aerosol emission fields for regional and global atmospheric chemistry models

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[3]Laboratoire de Physique et Chimie de l'Environnement et de l'Espace, CNRS-Université d'Orléans, Orléans, France
[4]Centre National de Recherches Météorologique/Groupe d'étude de l'Atmosphère Météorologique, Météo-France and CNRS, Toulouse, France
[5]Cooperative Institute for Research in Environmental Sciences (CIRES) and NOAA Earth Systems Research Laboratory (ESRL), USA

Received: 24 May 2010 – Published in Geosci. Model Dev. Discuss.: 23 June 2010
Revised: 12 April 2011 – Accepted: 5 May 2011 – Published: 10 May 2011

Abstract. The preprocessor PREP-CHEM-SRC presented in the paper is a comprehensive tool aiming at preparing emission fields of trace gases and aerosols for use in atmospheric-chemistry transport models. The considered emissions are from the most recent databases of urban/industrial, biogenic, biomass burning, volcanic, biofuel use and burning from agricultural waste sources. For biomass burning, emissions for the mass continuity equation (MCE), which are crucial needed information for these numerical studies. To provide this information, several international programs and groups have been developing emission inventories of the most relevant primary atmospheric trace gases and aerosols. For example, we can cite the Global Fire Emissions Database (GFED, van der Werf et al., 2006) for biomass burning and

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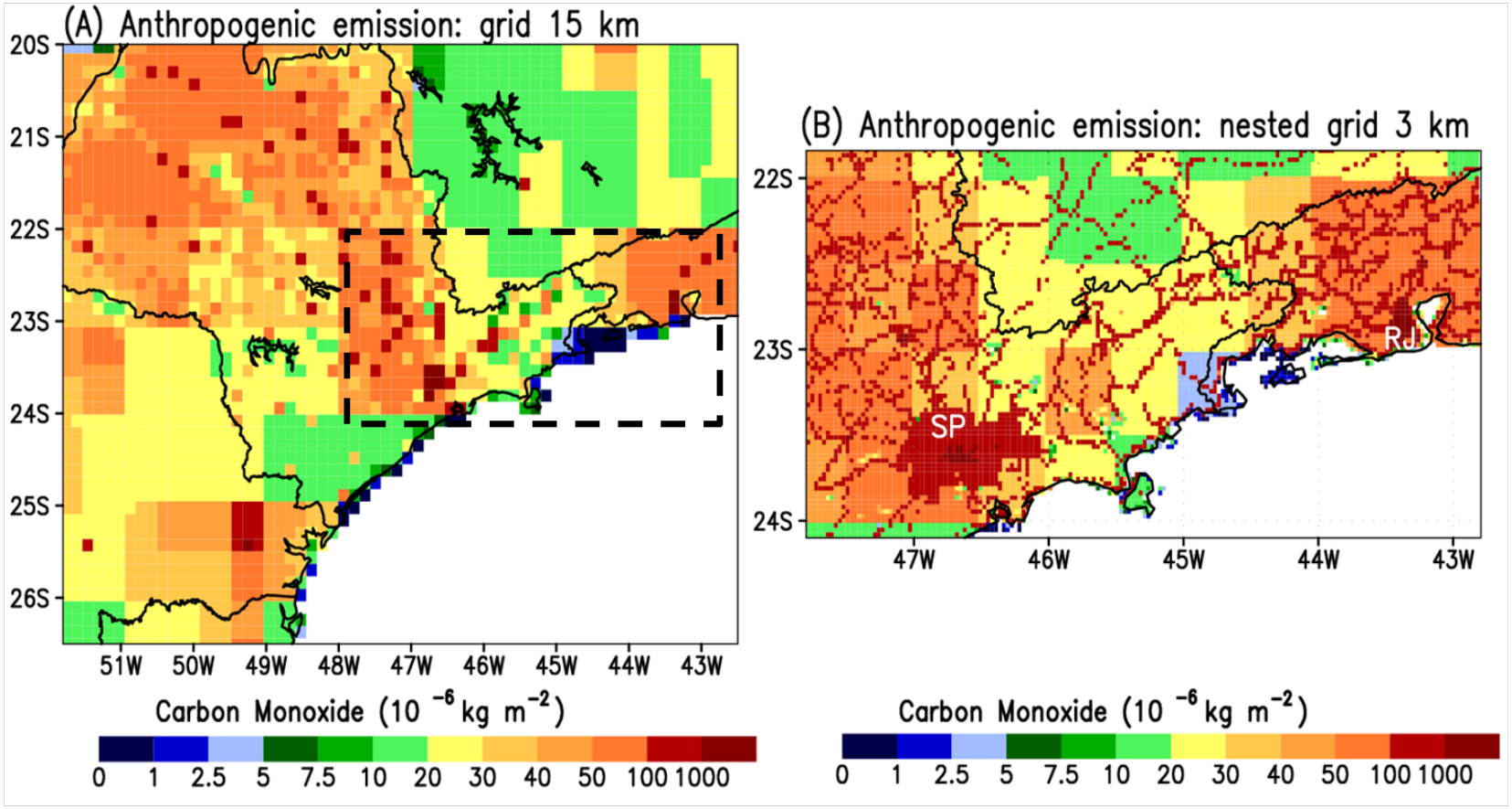
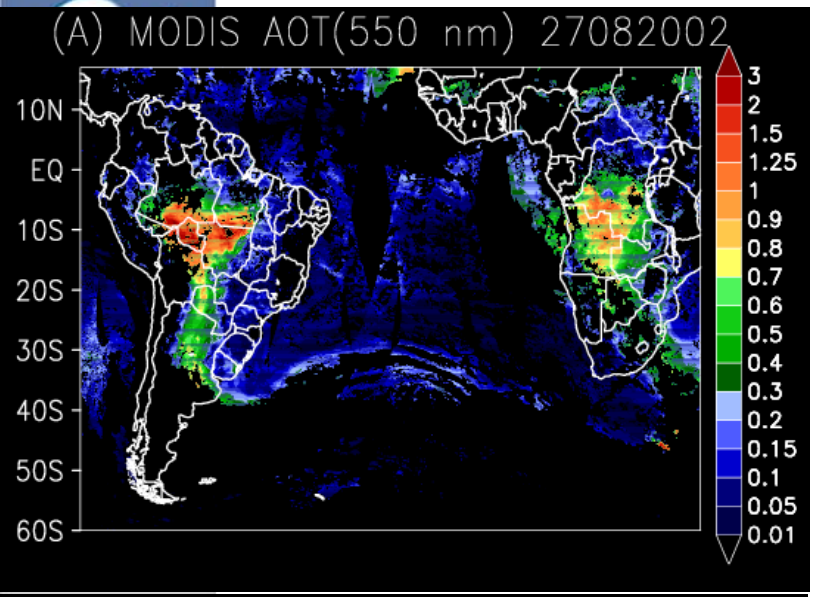
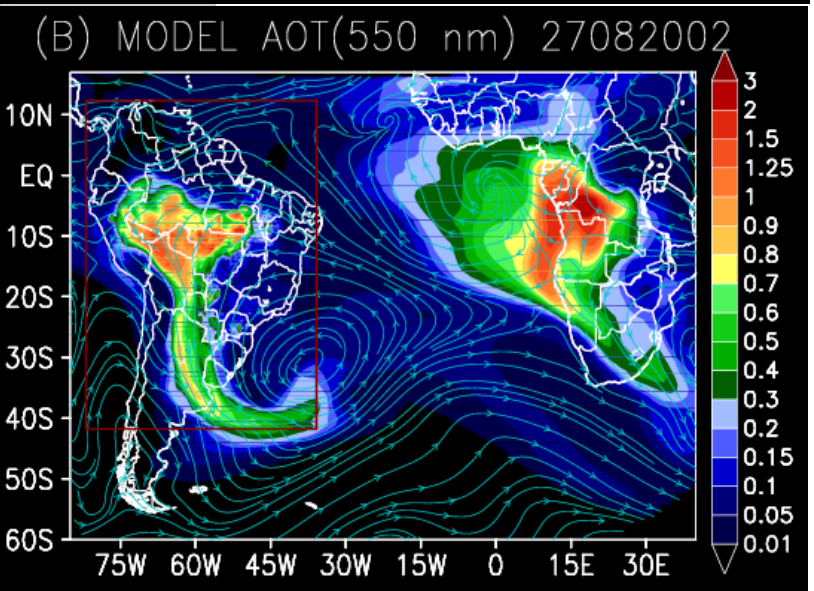
Global - Regional – Local Emissions Inventories : Provided by the PREP-CHEM-SRC System



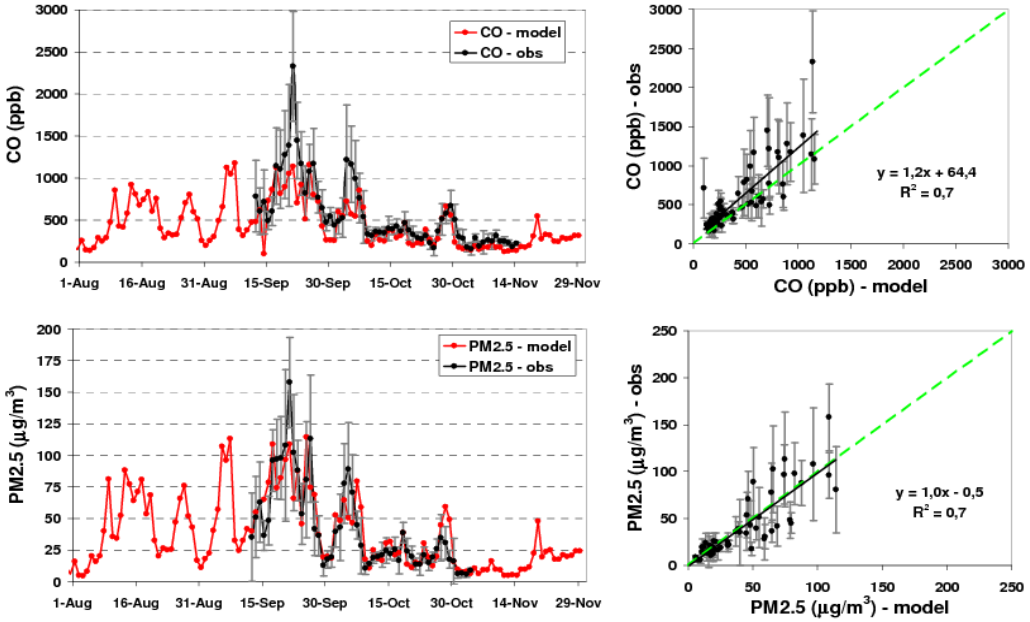
Freitas et al., 2010/2011, Alonso et al., 2010

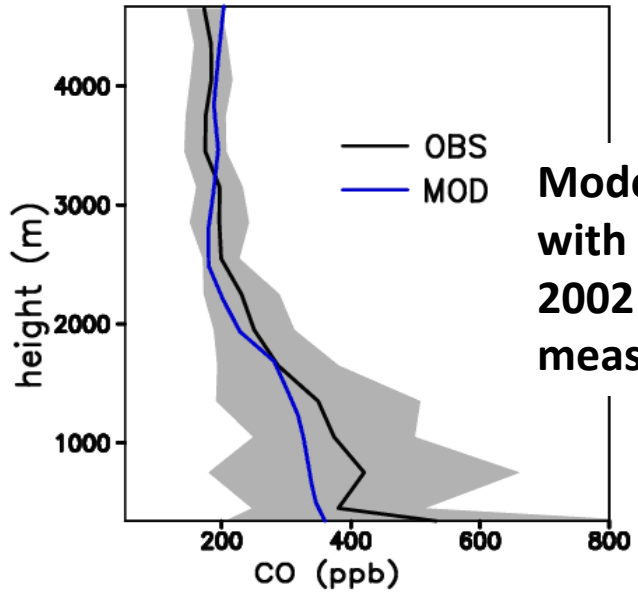
Aerosol Optical Depth (550 nm) : MODIS x MODEL





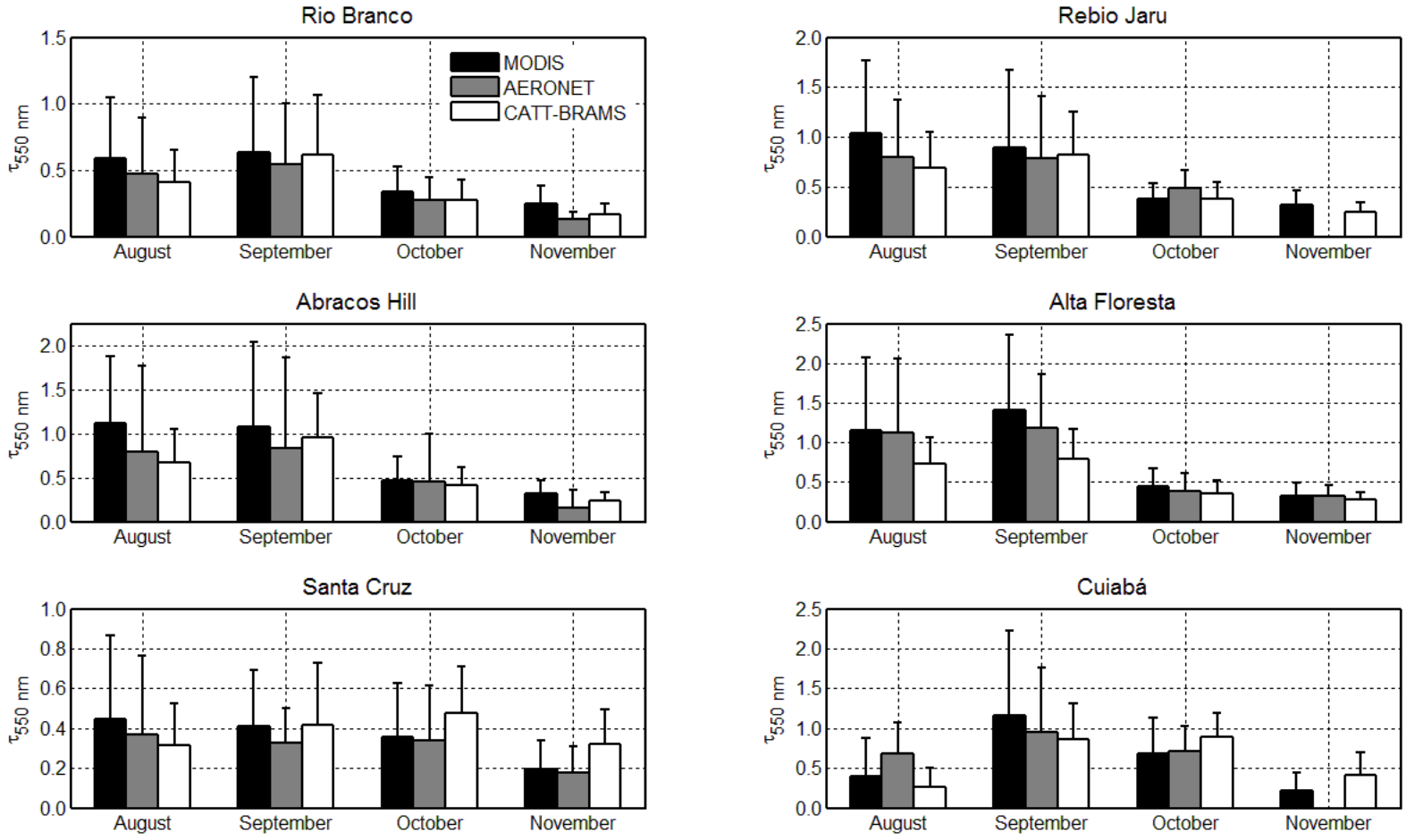
Model evaluation with SMOCC/RaCCI 2002 using near surface measurements (CO and PM2.5)





Model evaluation with SMOCC/RaCCI 2002 with airborne measurements (CO)

CATT-BRAMS Aerosol Optical Depth



Southern of the Amazon basin and Cerrado:

Monthly average

The operational system

Operational Weather and Air Quality Forecast at CPTEC/INPE

MOCAGE 2.5 x 2.5 chemistry forecast (Agreement METEO-FRANCE/ CPTEC)

CCATT-BRAMS previous run

CPTEC 1 x 1 weather analysis and forecasts

RAMS Isentropic analysis system (includes now chemistry fields)

Initial and bc for chemistry and weather fields

Real time MODIS/WFABBA /INPE fire product

Anthropogenic/ biogenic emissions

Additional initial/bc: soil moisture, SST, NDVI

Emission sources

CCATT-BRAMS

weather/chemistry (RELACS):

24 h pre-forecast+

72 h forecast

25 km resolution for South America

Data available on daily basis at

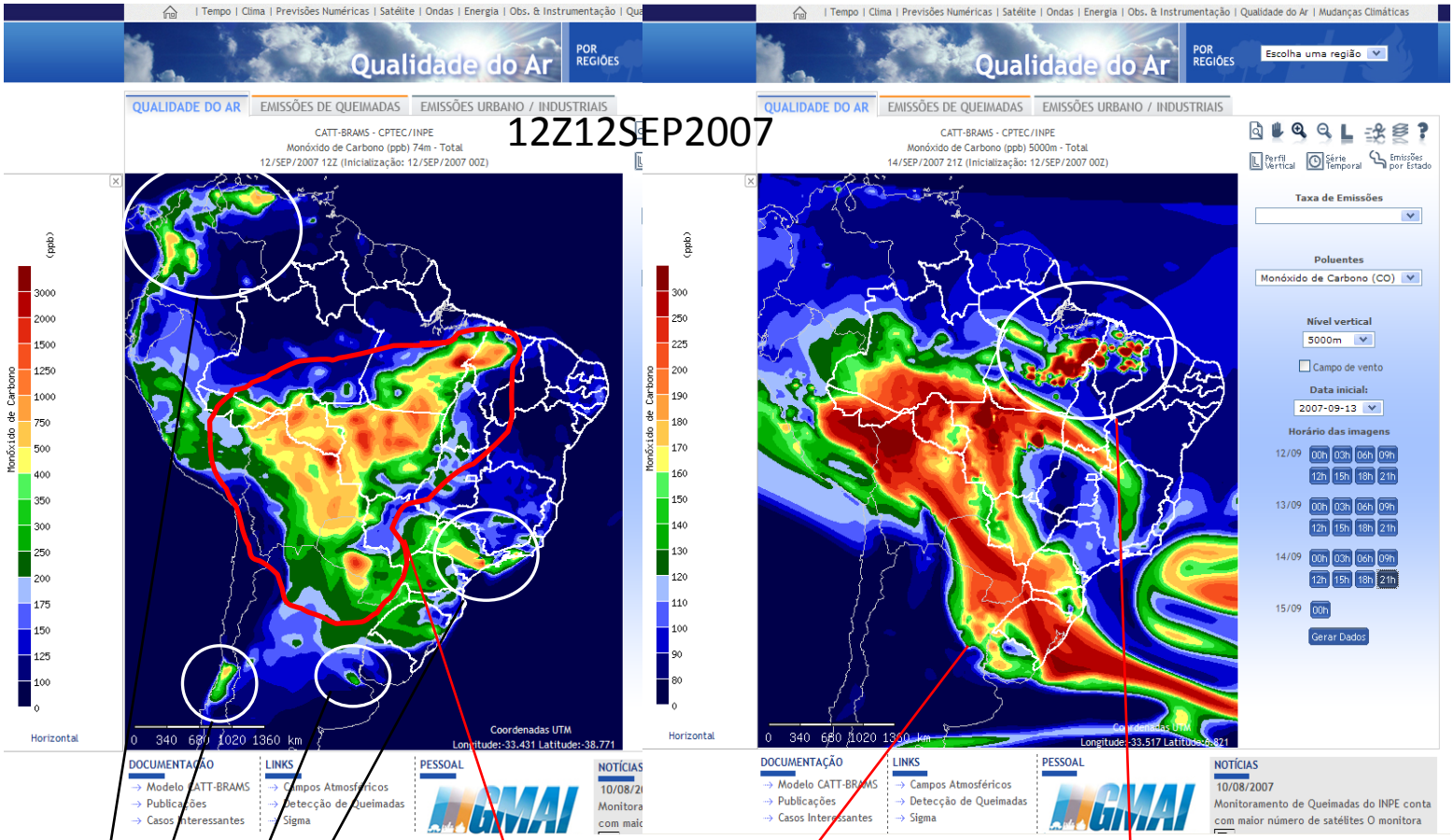
http://meioambiente.cptec.inpe.br

Real Time Air Quality Forecast for South America:

http://meioambiente.cptec.inpe.br

Surface level CO (ppbv)

500 hPa CO (ppbv)



12Z12SEP2007

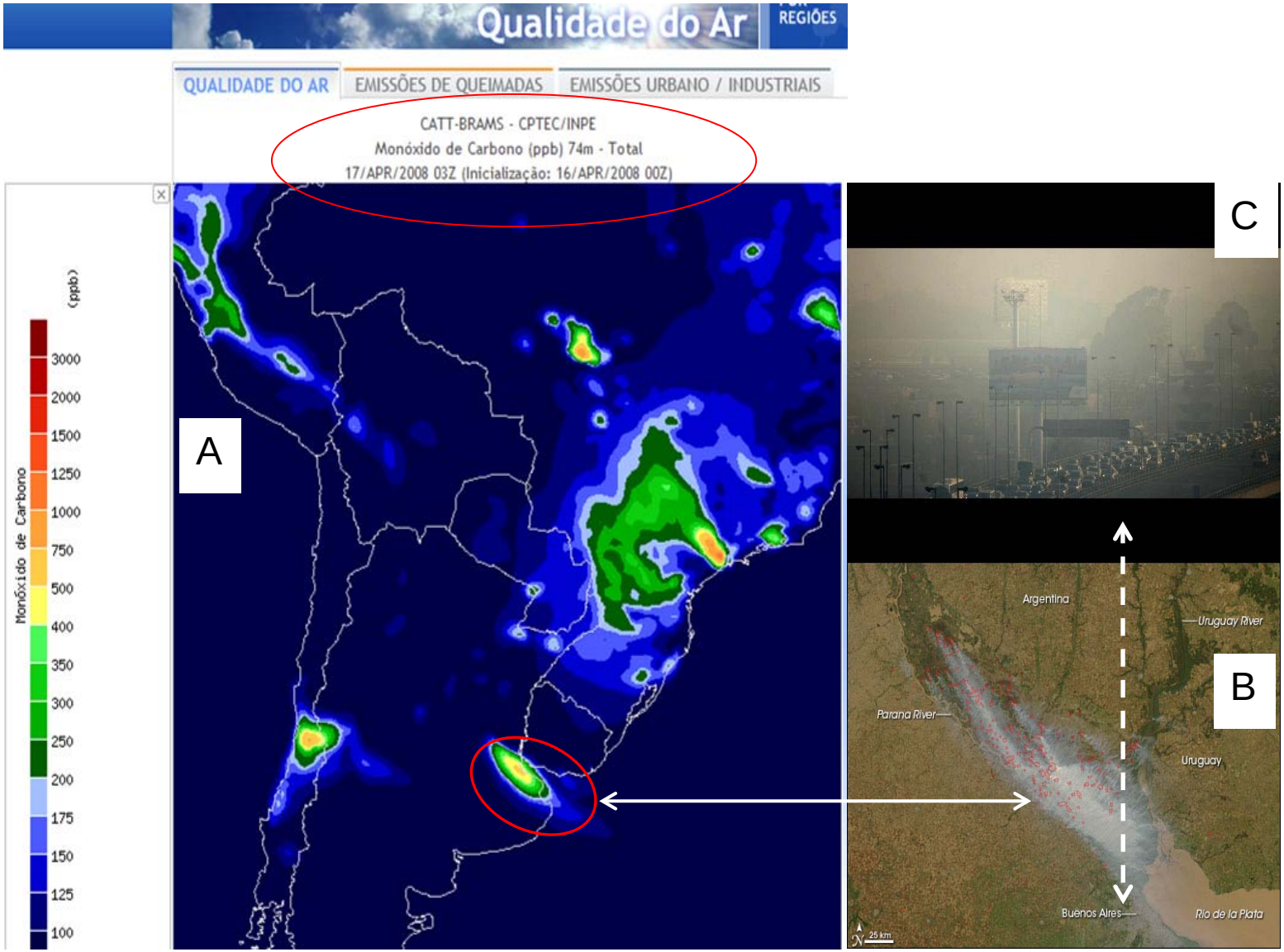
Mega Cities pollution

Old biomass burning pollution plumes

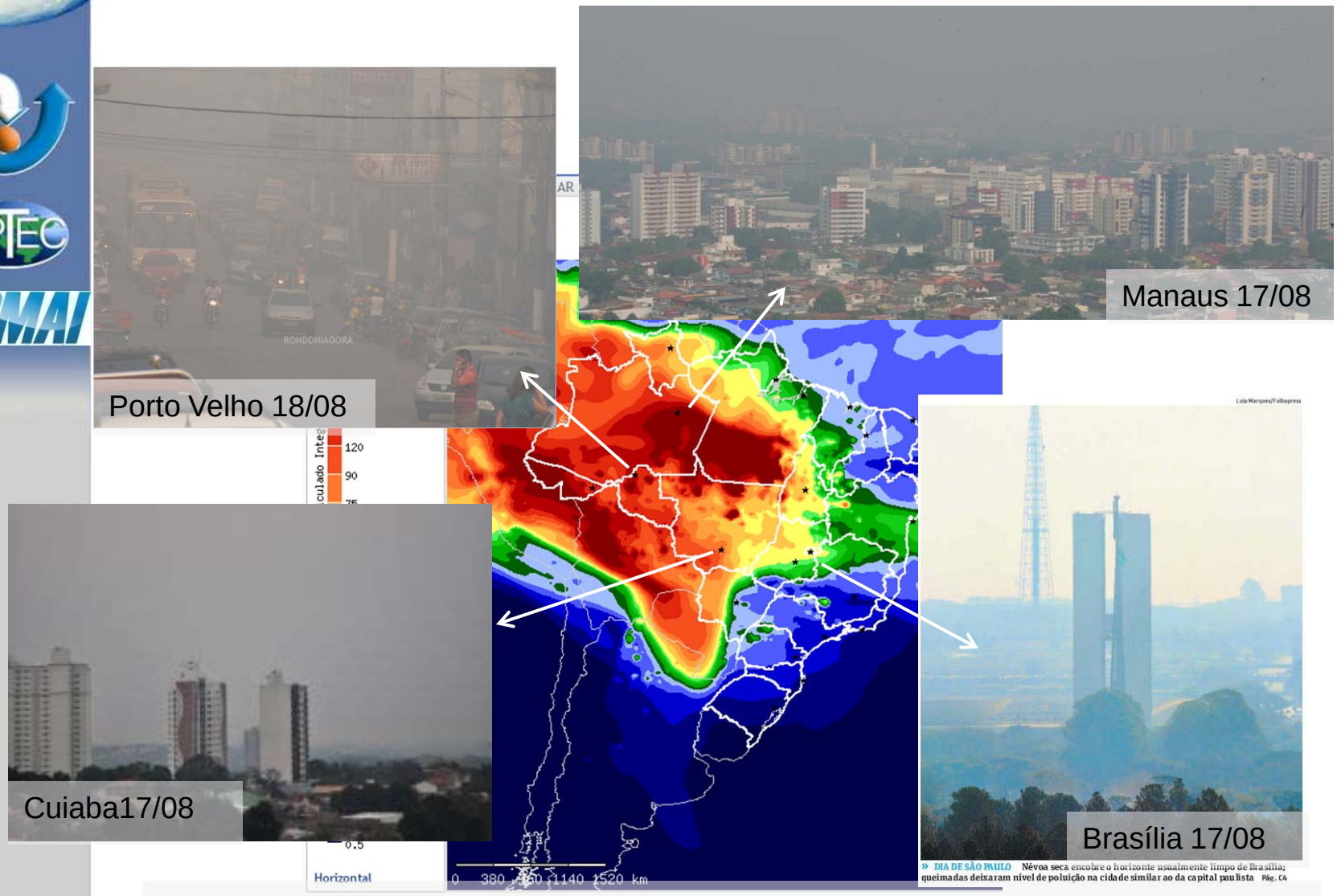
new fresh plumes injected by pyrocumulus

Past Cases

Smoke over Buenos Aires and the CATT-BRAMS forecast (16/04/2008)

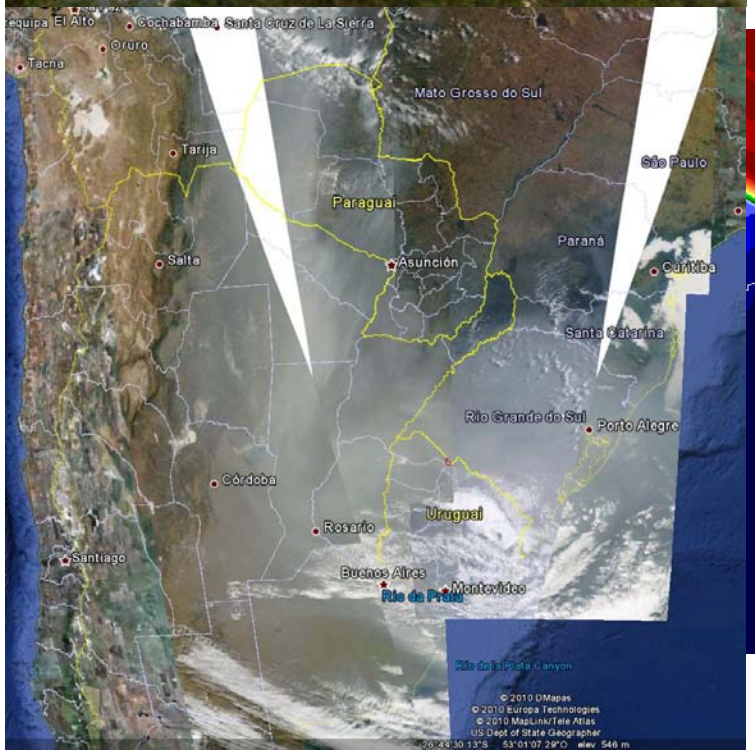


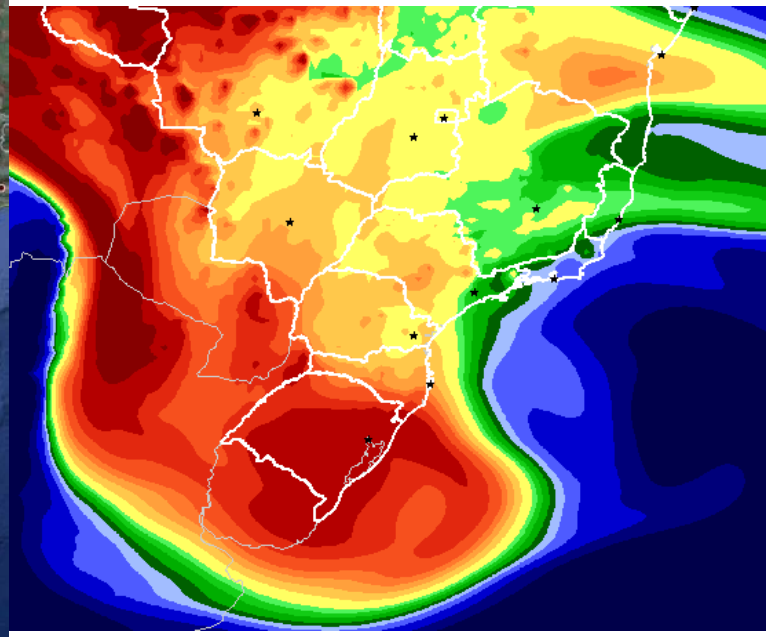
Biomass Burning Smoke and the main urban areas of Amazonia and Central part of Brazil 17-18/08/2010



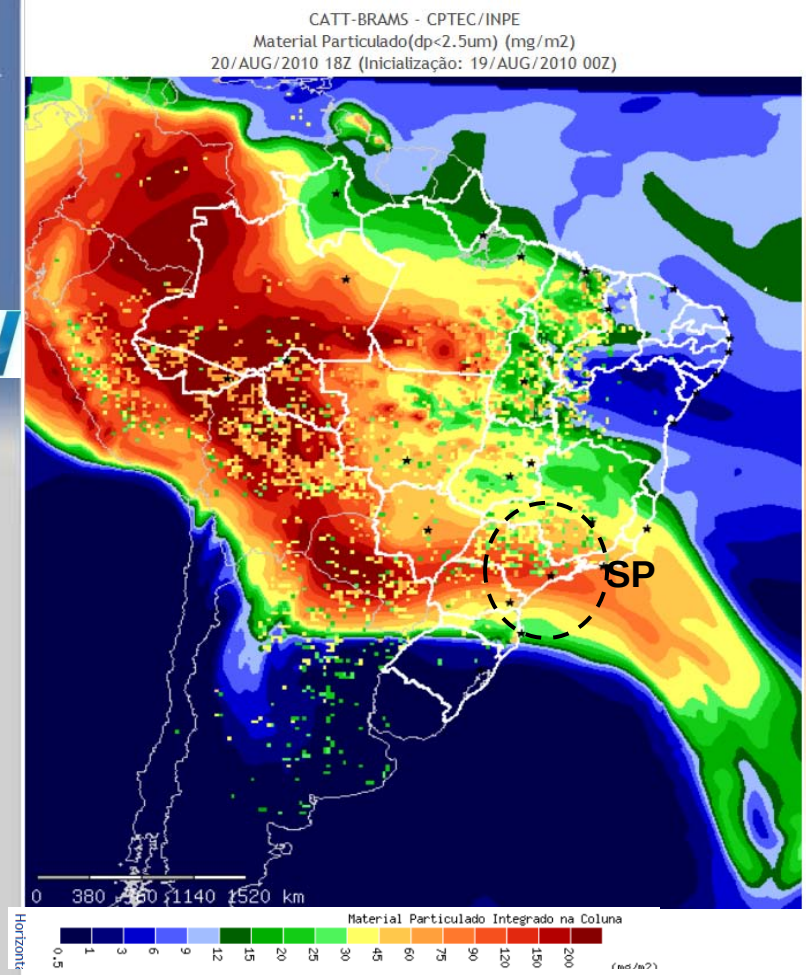
CATT-BRAMS PM2.5 surface concentration
Forecast for 18UTC 17/08/2010 – Initialized on 00UTC 16/08/2010

Smoke - Porto Alegre – RS 22/08/2010



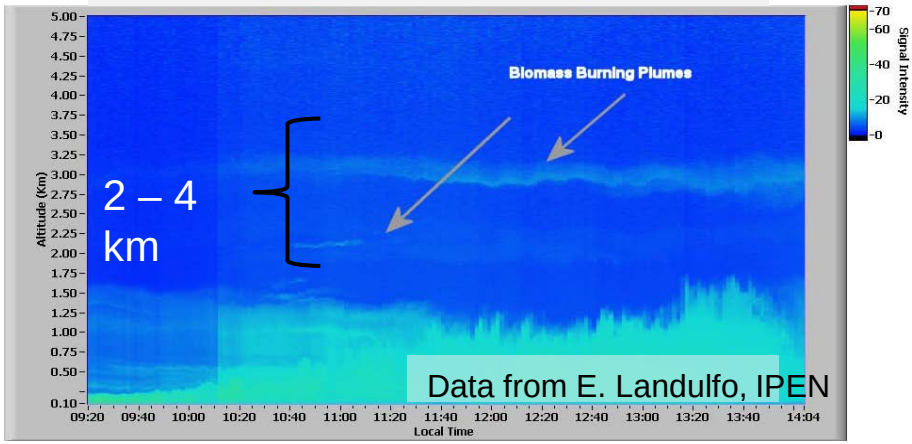


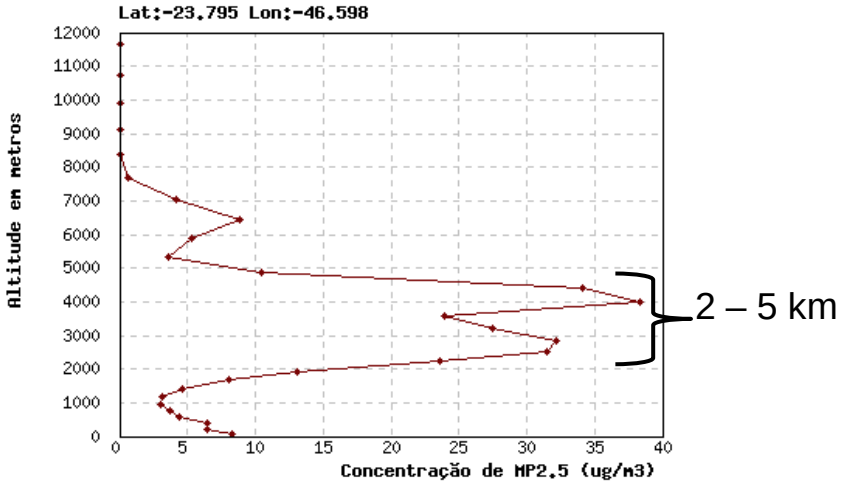
Long range transport of biomass burning smoke: the smoke river over São Paulo (SP) - Brazil - 20 August 2010



CATT-BRAMS : Material Particulado fino integrado na coluna (mg/m^2)
Previsão para 18UTC 20082010

Range corrected backscatter profile



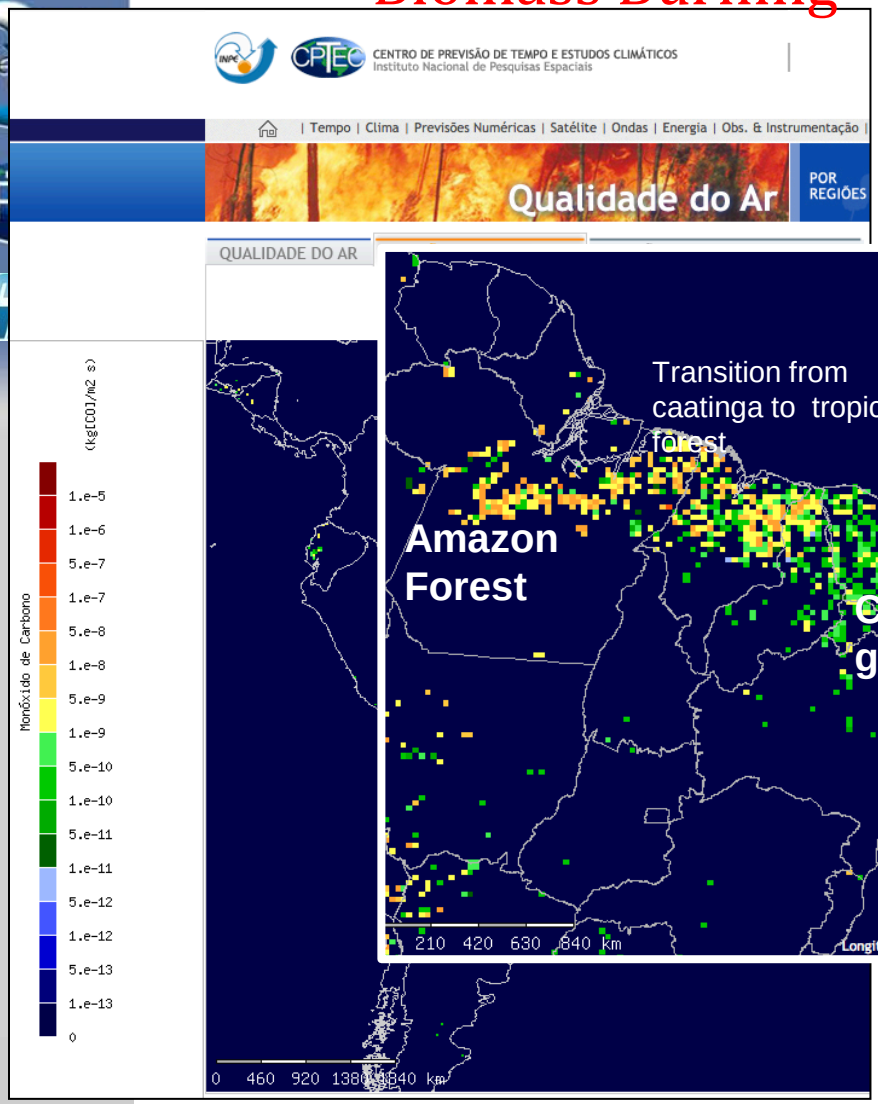


CATT-BRAMS : Perfil vertical de PM 2.5 (ug/m^3)
20/AUG/2010 18Z (Inic: 19/AUG/2010 00Z)

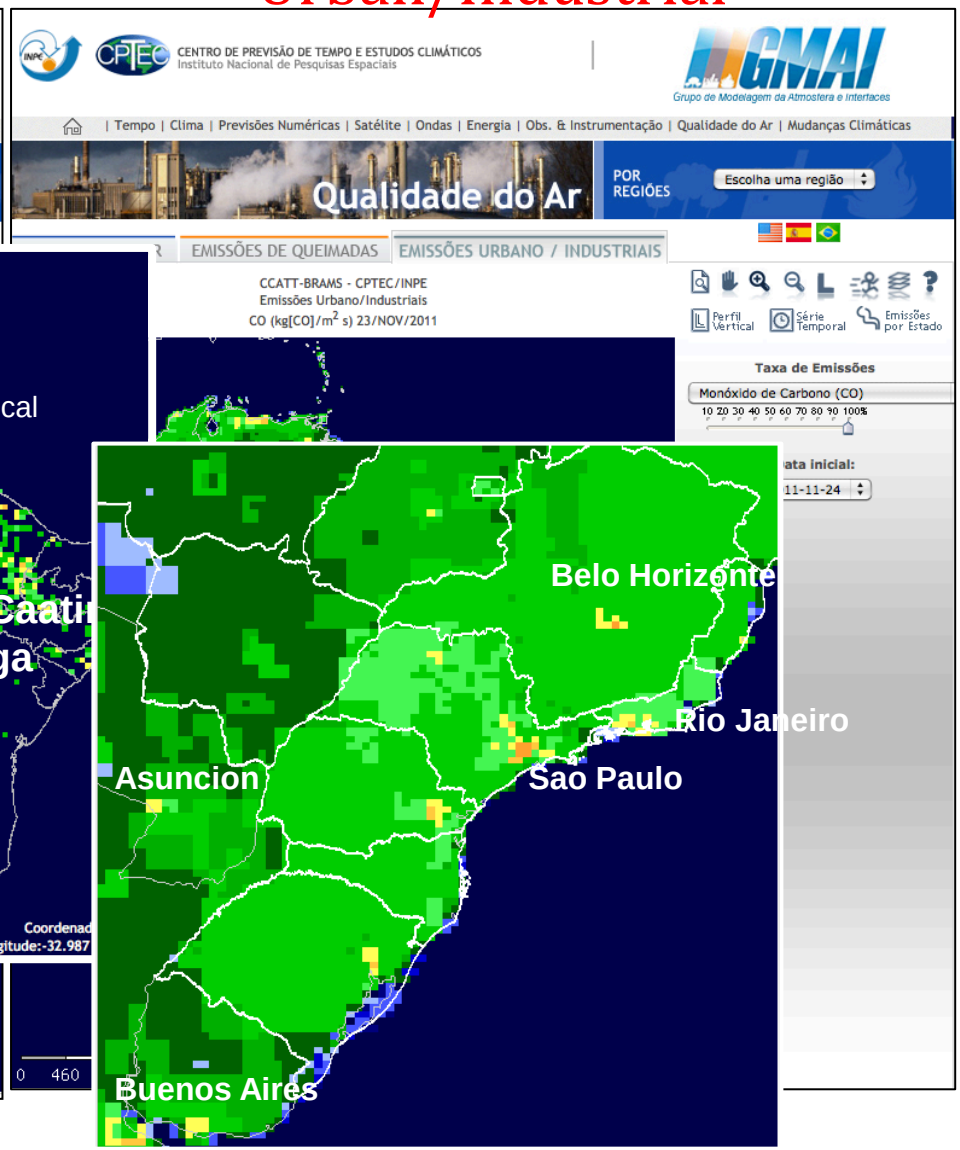
Recent cases

Air Quality Forecast
Emission Sources of Carbon Monoxide

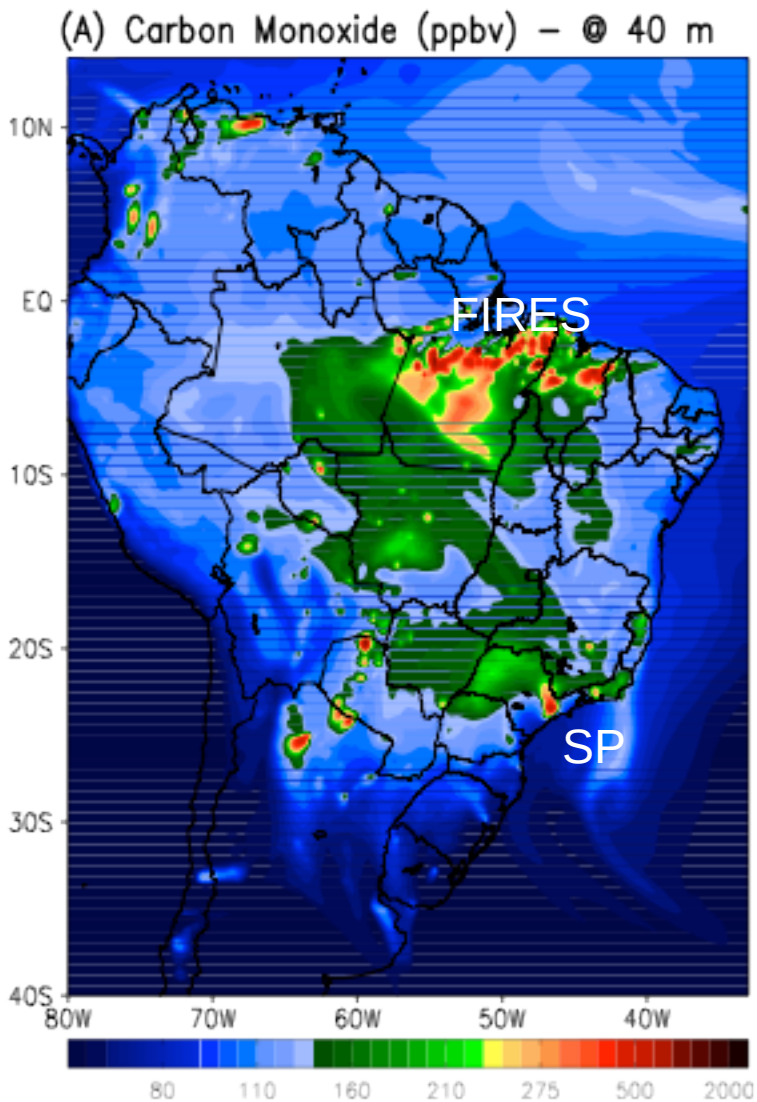
Biomass Burning

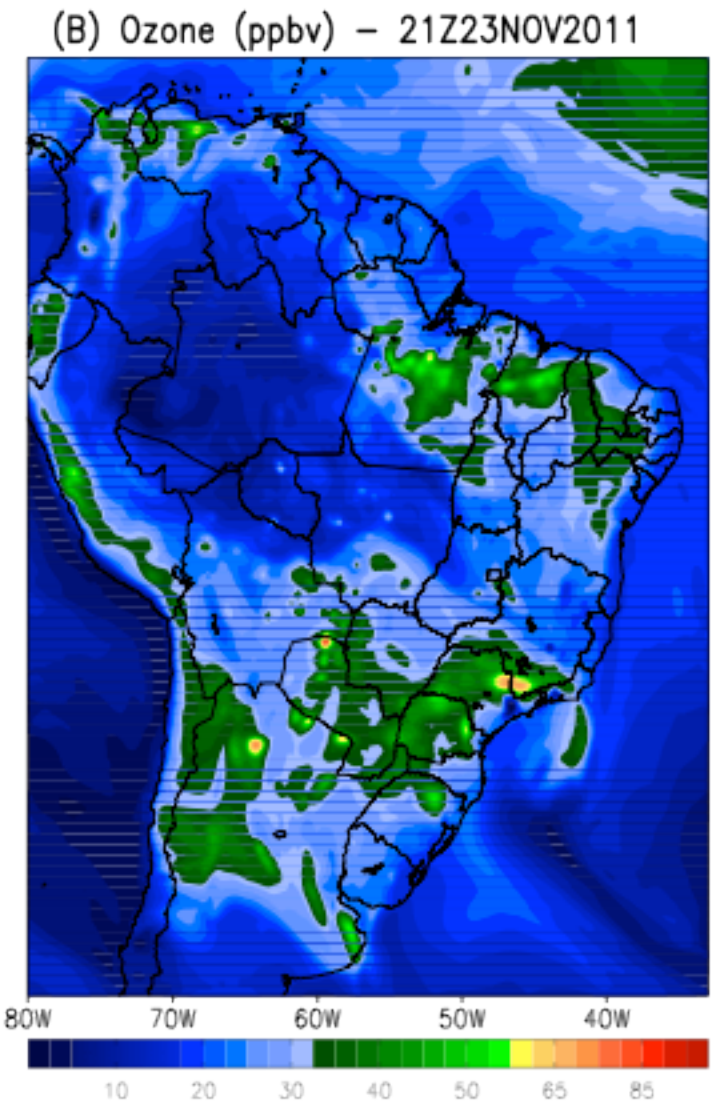


Urban/Industrial



Carbon Monoxide and Ozone : Forecast for 6 PM 23 NOV 2011

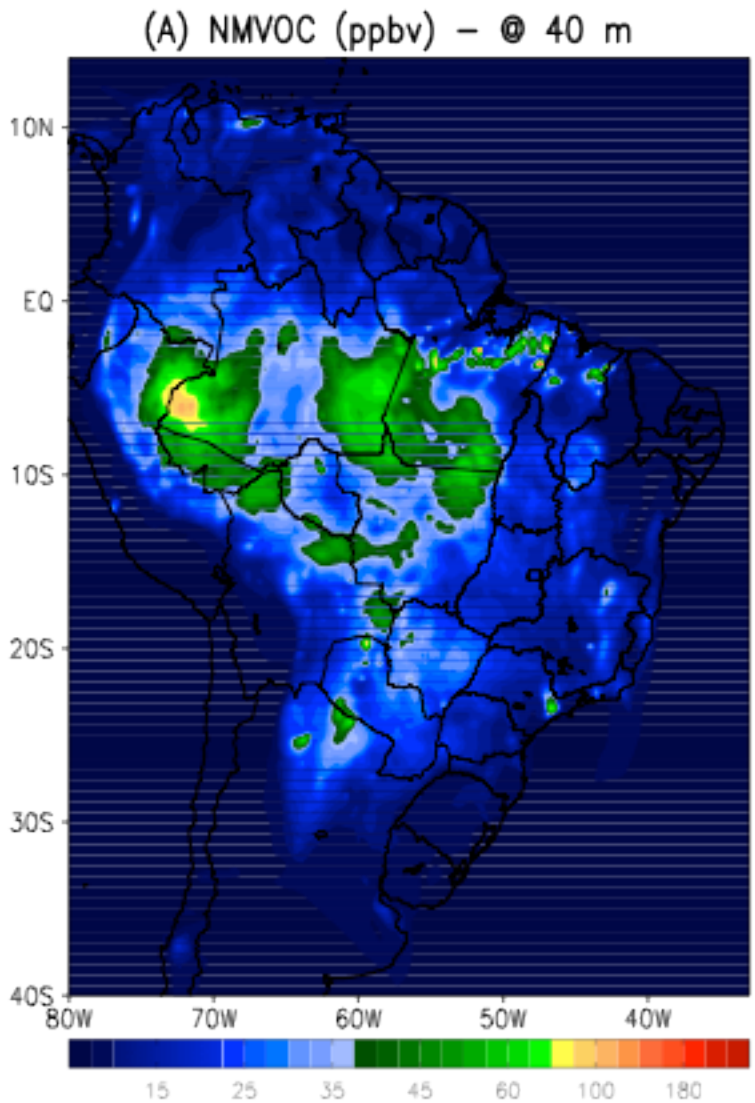




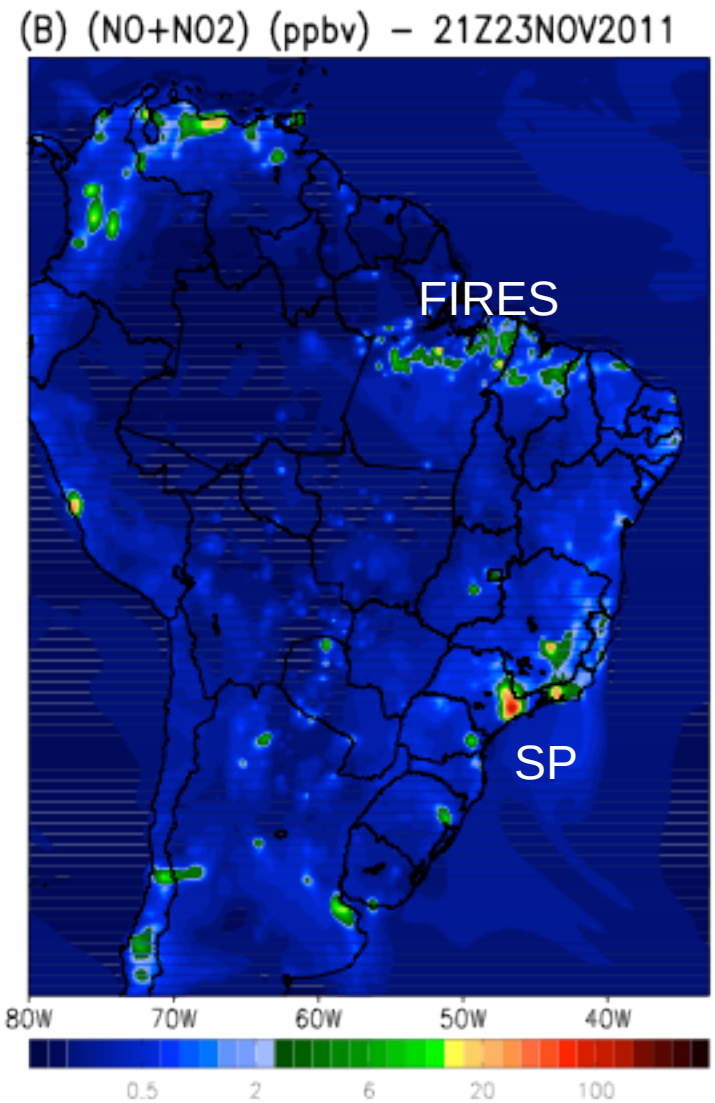
CO (ppbv) 80 110 160 210 275 500 2000

O3(ppbv) 20 30 40 50 65 85

NMVOC and (NO+NO2): Forecast for 6 PM 23 NOV 2011



NMVOC



NO + NO2

- Thanks for your attention!
- http://meioambiente.cptec.inpe.br

- Backup slides

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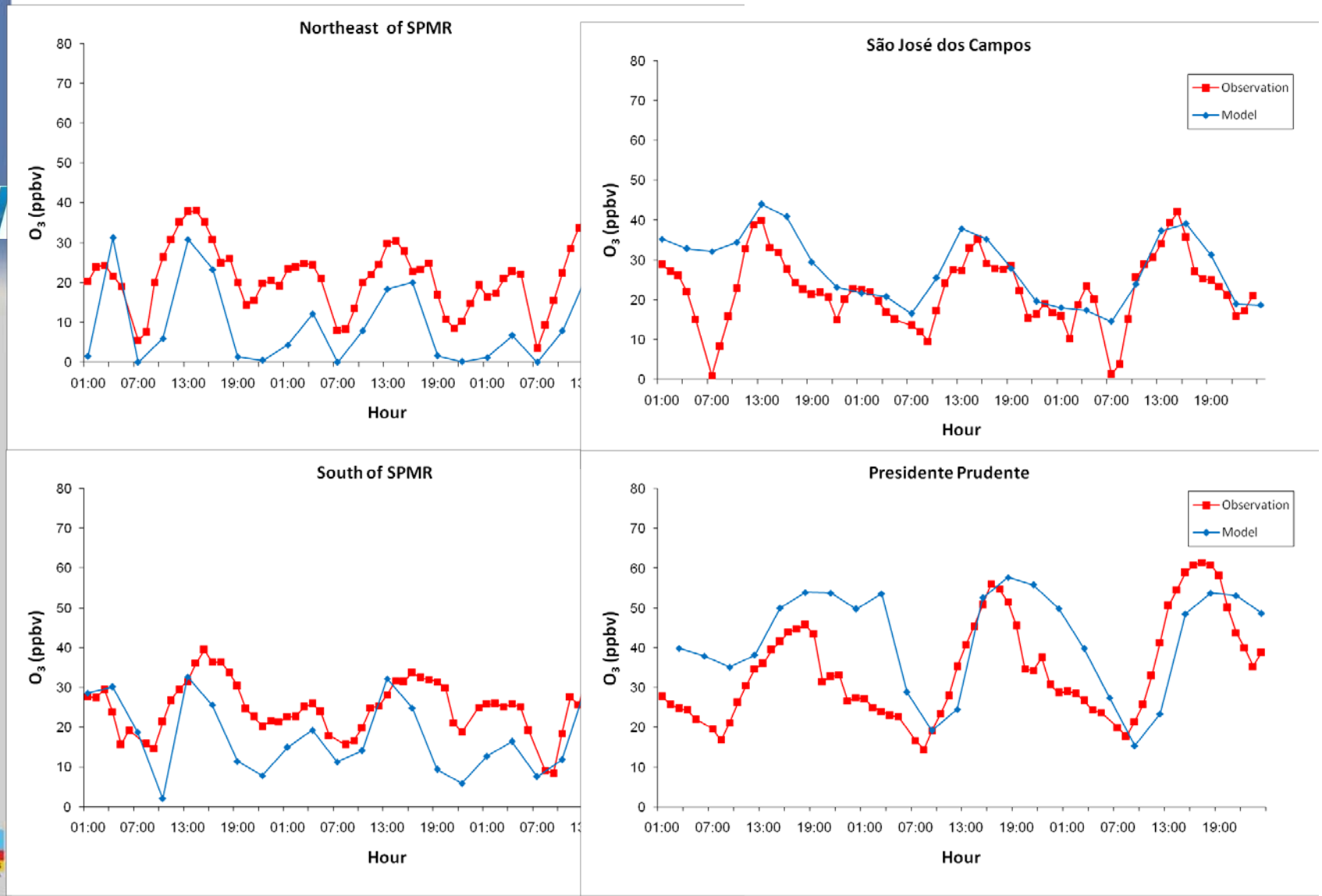
NO_X vs VOC and O_3

São Paulo Metropolitan Region (RMSP) (september 21, 2011)



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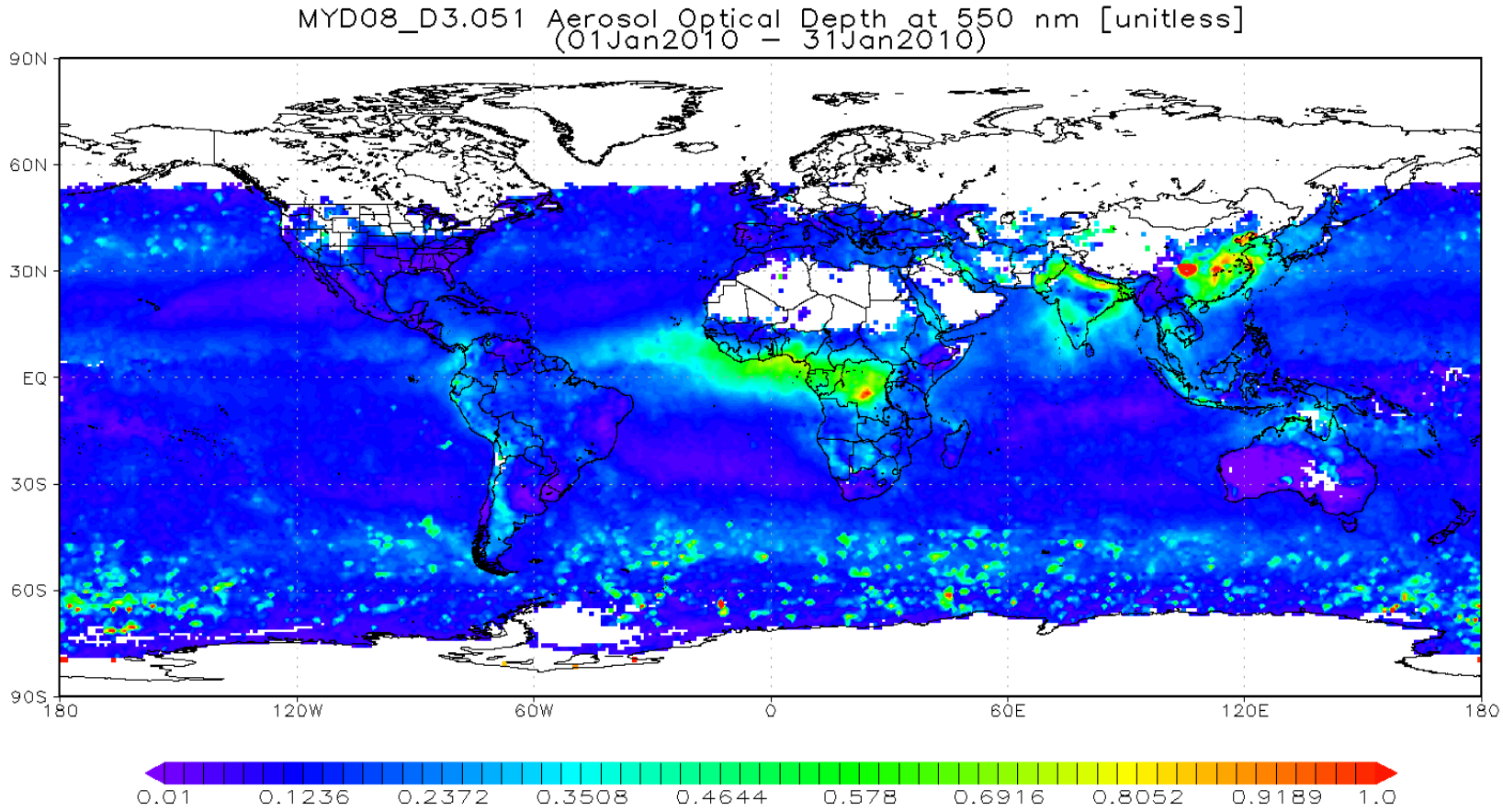
Espessura óptica de aerossol (550 nm)
Produto mensal do sensor MODIS/AQUA



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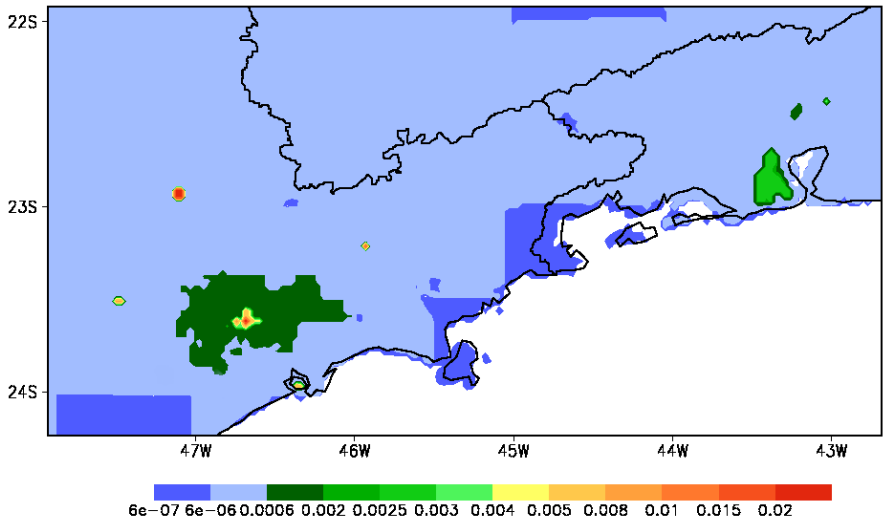
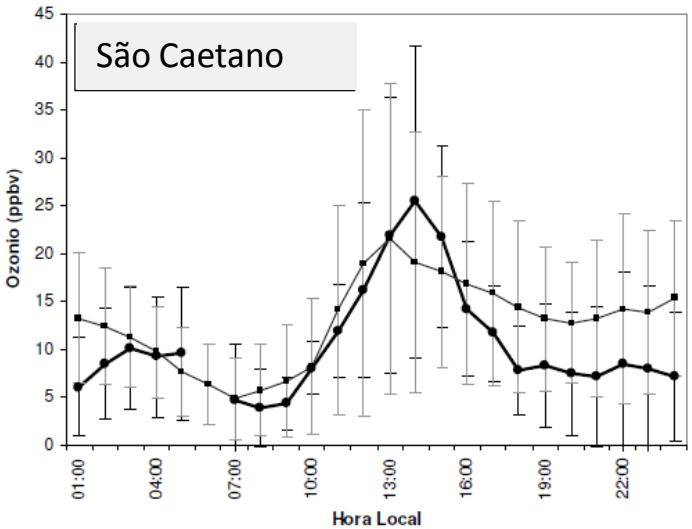
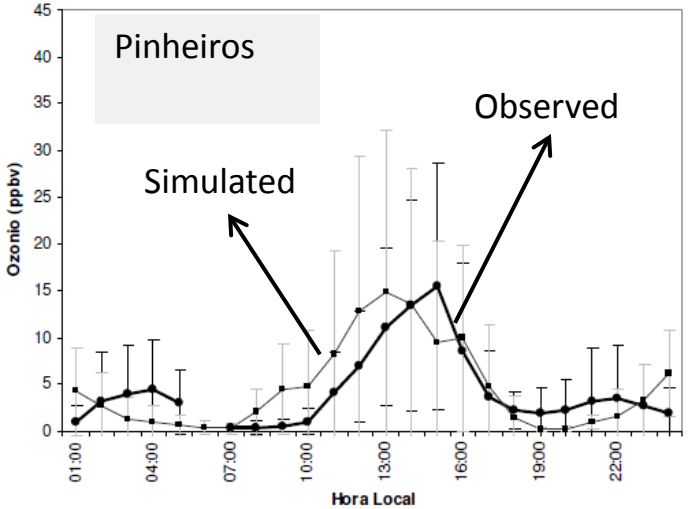
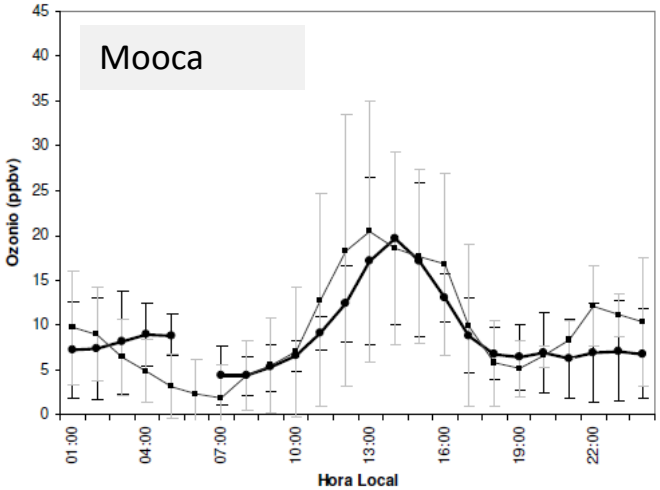
Simulation of ozone on RM São Paulo – In collaboration with CETESB









Marcelo Alonso, Ph.D. Thesis

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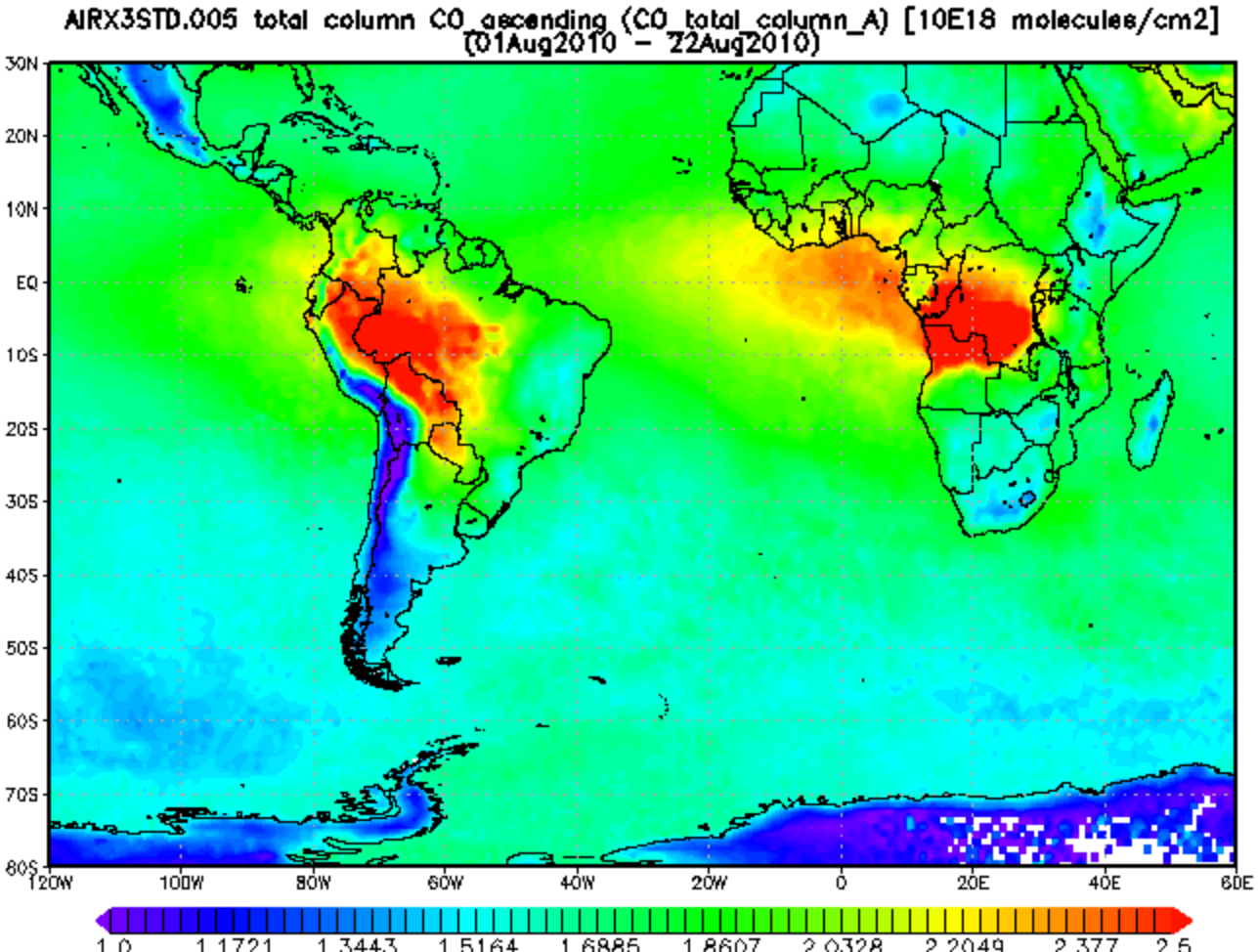
Strong increase from July to August 2010



Biomass Burning Emissions

- Fundamental reaction and primary emissions:

$$[CH_2O]+O_2 \rightarrow CO_2+H_2O+heat$$

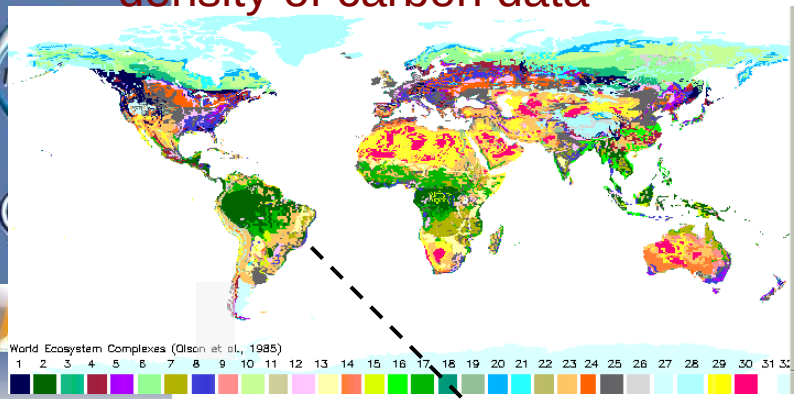
- Secondary emissions: CO, NO_x, hydrocarbons (CH_4, e.g.), particulate material, etc.

- Greenhouse gases: CO_2, N_2O, CH_4

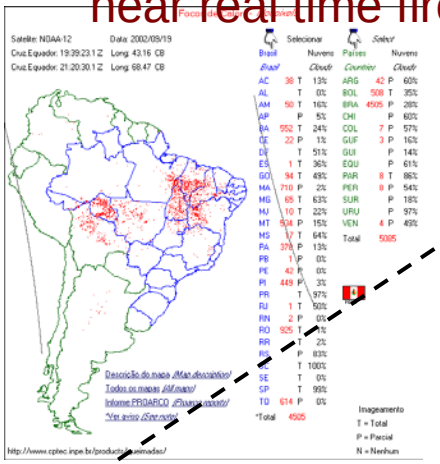
- Particulate material has also radiative and microphysics effects with potential impact on the hydrological cycle.

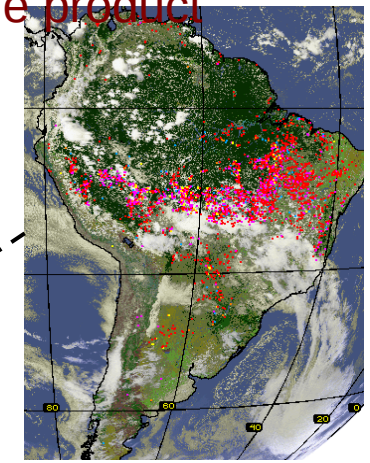
Biomass burning emissions inventory: regional scale – daily basis

density of carbon data

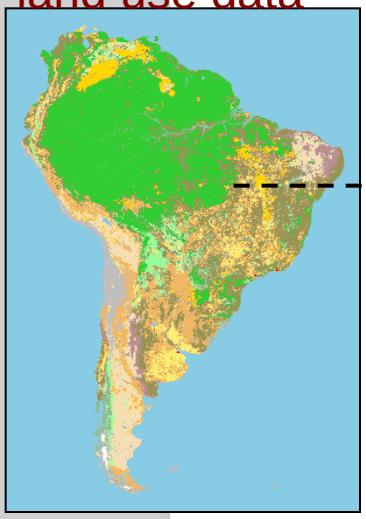


near real time fire product

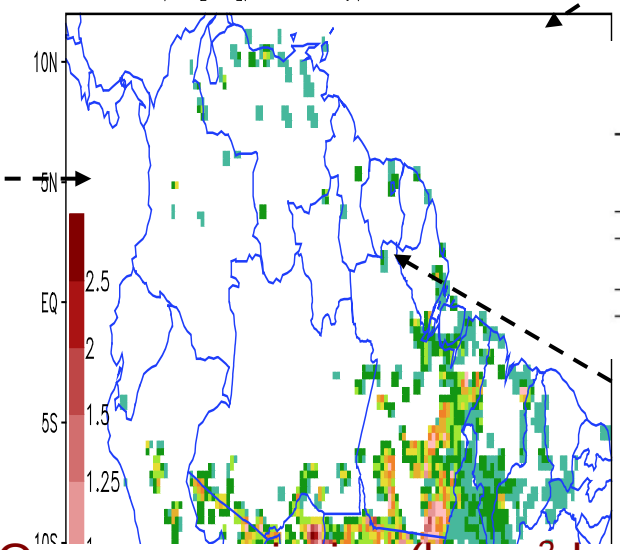




land use data



CO Source Emission
(ton[CO]/km^2 day) – 07SEP2002



CO source emission (kg m^{-2}day^{-1})

emission & combustion factors

Biome category	Emission Factor for CO (g/kg)	Emission Factor for PM2.5 (g/kg)	Aboveground biomass density (α, kg/m^2)	Combustion factor (β, fraction)
Tropical forest[1]	110.	8.3	20.7	0.48
South America savanna[2]	63.	4.4	0.9	0.78
Pasture[3]	49.	2.1	0.7	1.00

[1] Average values for primary and second-growth tropical forests, [2] Average values for campo cerrado (C3) and cerrado sensu stricto (C4), [3] value for campo limpo (C1). All numbers are from Ward et al.,

mass estimation

$$M_{[\eta]} = \alpha_{veg} . \beta_{veg} . \mathrm{E}f_{veg}^{[\eta]} . a_{fire},$$

fire emissions

Biomass burning and wildfires

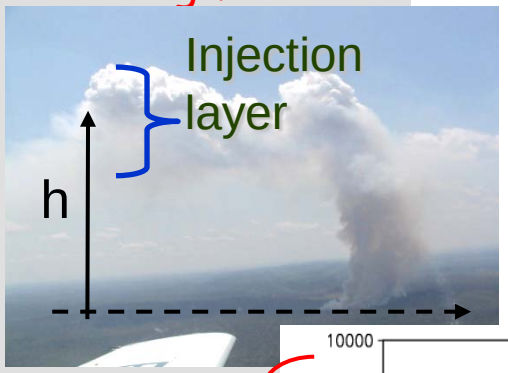
- Smoldering : mostly surface emission.
- Flaming: mostly direct injection in the PBL, free troposphere or stratosphere.

Plume rise model

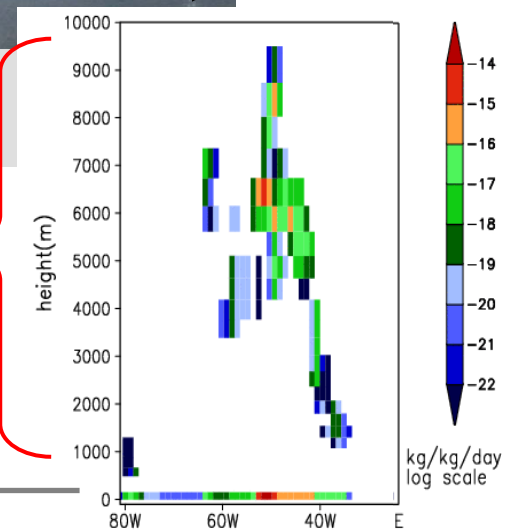
total emission flux: F_η being λ the smoldering fraction

smoldering term : $$E_\eta = \frac{\lambda F_\eta}{\rho_{air} \Delta z_{\text{first phys. model layer}}}$$

flaming term : $$E_\eta = \frac{(1-\lambda) F_\eta}{\rho_{air} \Delta z_{\text{injection layer}}}$$



flaming emission

Example in the model:

smoldering emission