The Coupled Aerosol and Tracer Transport model to the Brazilian developments on the Regional Atmospheric Modeling System

(CATT-BRAMS):

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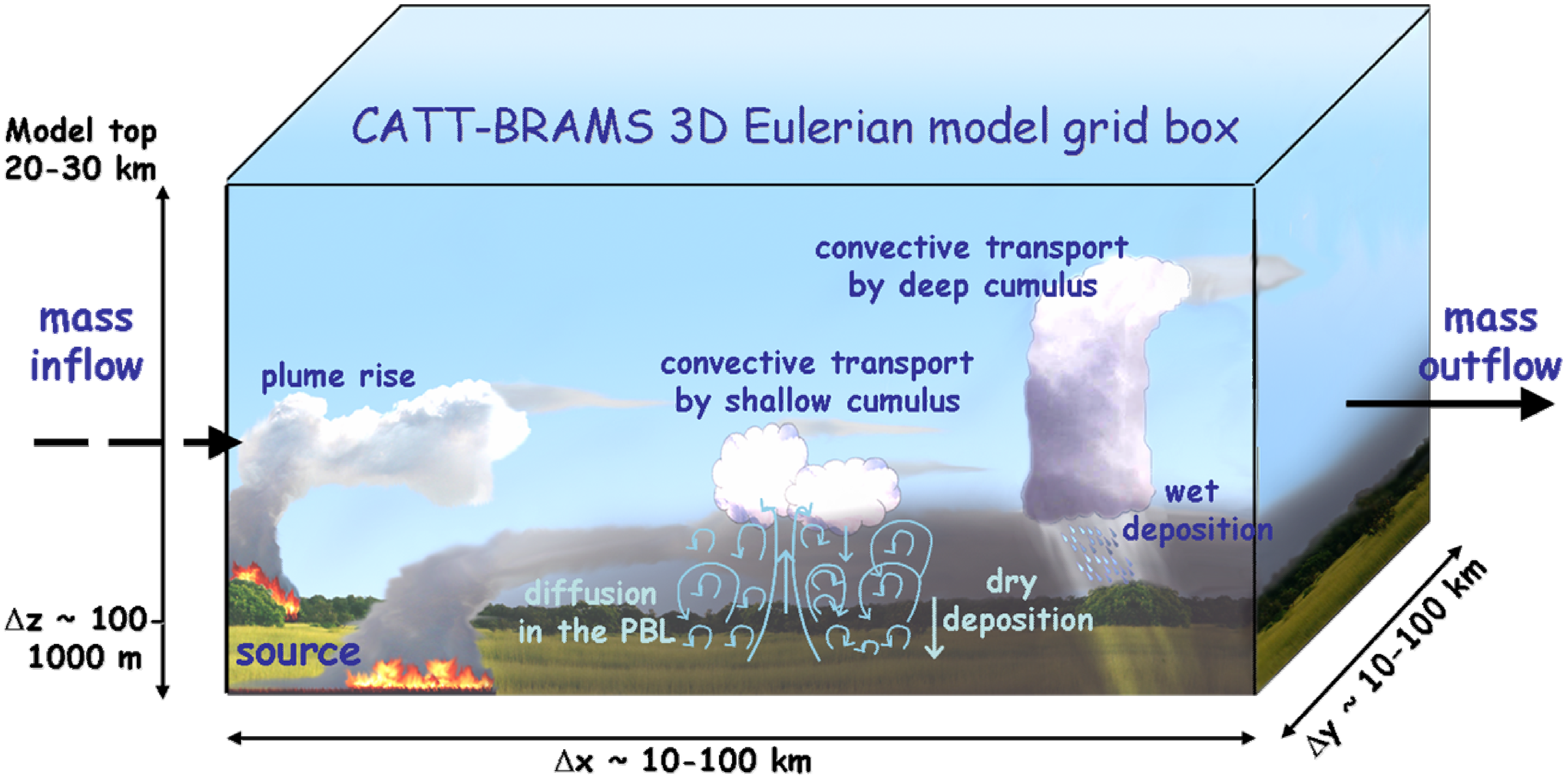
http://www.cptec.inpe.br/meio_ambiente

Center for Weather Forecasting and Climate Studies - INPE – Brazil

Some sub-grid process involved at gases/aerosols transport and simulated by CATT-BRAMS



Eulerian Transport Model : CATT-BRAMS Atmospheric Model

- in-line Eulerian transport model fully coupled to the atmospheric dynamics
- suitable for feedbacks studies
- tracer mixing ratio tendency equation

$$\frac{\partial \bar{s}}{\partial t} = \left(\frac{\partial \bar{s}}{\partial t}\right)_{adv} + \left(\frac{\partial \bar{s}}{\partial t}\right)_{\substack{PBL\\turb}} + \left(\frac{\partial \bar{s}}{\partial t}\right)_{\substack{deep\\conv}} + \left(\frac{\partial \bar{s}}{\partial t}\right)_{\substack{shallow\\conv}} + W_{PM\,2.5} + R + Q_{\substack{plume\\rise}},$$

where:

adv	grid-scale advection
PBL turb	sub-grid transport in the PBL
deep conv	sub-grid transport associated to the deep convection including downdraft at cloud scale
shallow conv	sub-grid transport associated to the shallow convection
W	convective wet removal
R	sink term associated with dry deposition or chemical transformation
Q	source emission with plume rise sub-grid transport.

Freitas et al., 1999, 2005, 2006

Grid Scale Advection Term

Advection term:

$$\left(\frac{\partial \bar{s}}{\partial t}\right)_{adv} = -\sum_i \bar{u}_i \frac{\partial \bar{s}}{\partial x_i}$$

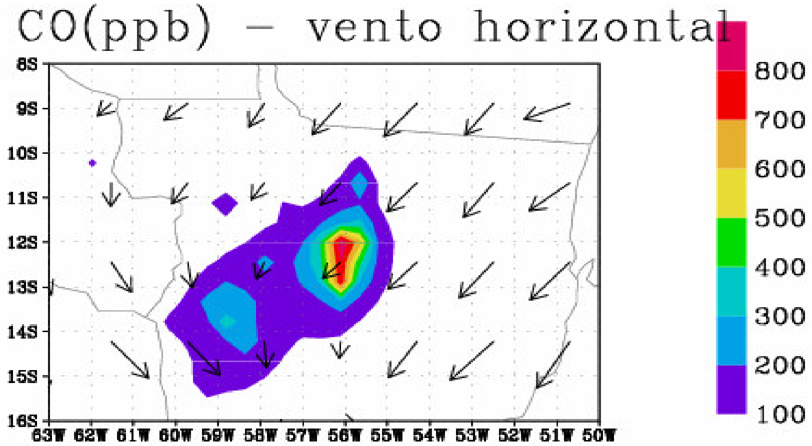
Numerical Solution:

second-order forward upstream (Tremback et al 1987)

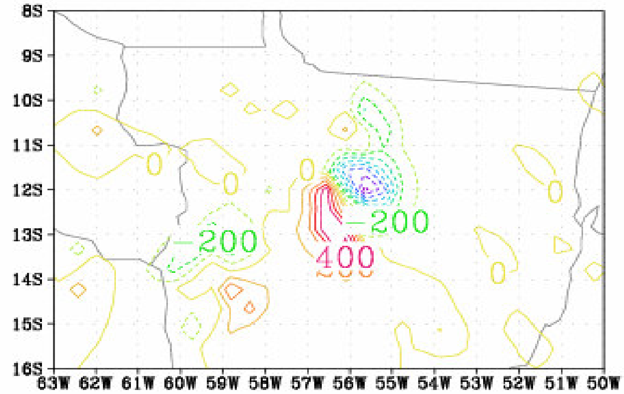
$$\left(-\bar{u}\frac{\partial \bar{s}}{\partial x}\right)_j \approx -\frac{1}{\rho_0 \Delta x}\left\{\left((\rho_0 F)_{j+1/2} - (\rho_0 F)_{j-1/2}\right) - \bar{s}\left((\rho_0 \bar{u})_{j+1/2} - (\rho_0 \bar{u})_{j-1/2}\right)\right\}$$

$$F_{j+1/2} = \frac{\Delta x}{\Delta t}\left[\frac{\alpha}{2}\left(\bar{s}_j + \bar{s}_{j+1}\right) + \frac{\alpha^2}{2}\left(\bar{s}_j - \bar{s}_{j+1}\right)\right]$$

$$and: \alpha = \bar{u}_{j+1/2}\frac{\Delta t}{\Delta x}$$



CO(ppb) – vento horizontal



Termo de adveccao (ppb/day)

$$\left(\frac{\partial \bar{s}}{\partial t}\right)_{adv}$$

Sub-grid Diffusion Transport

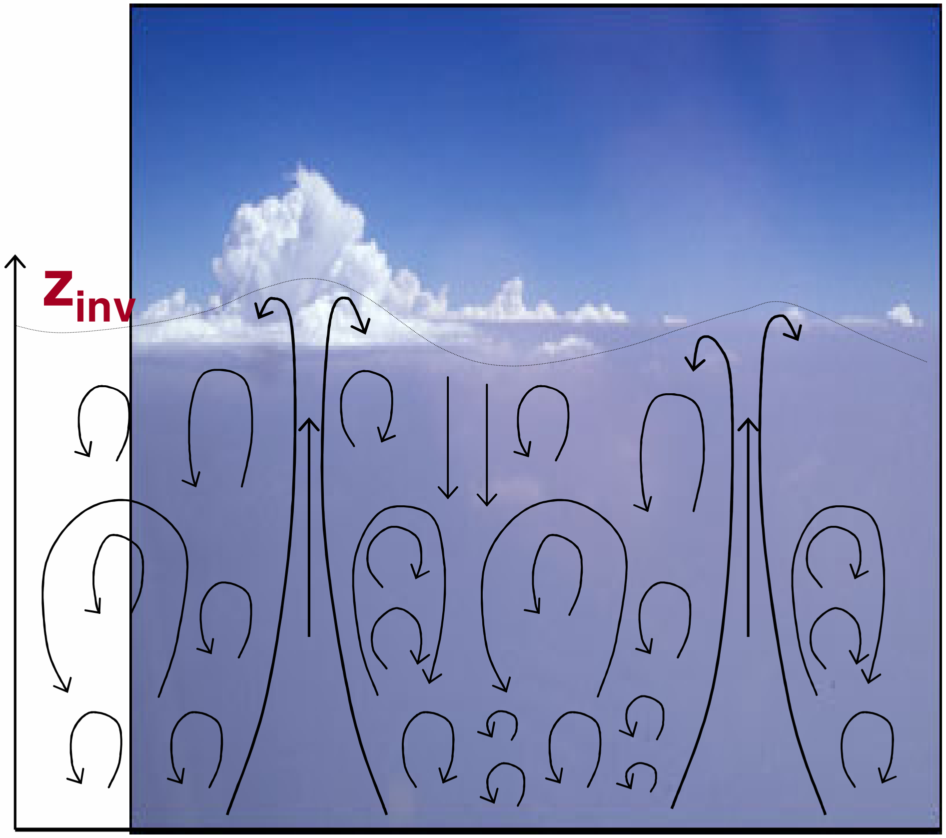
Diffusion term:

$$\left(\frac{\partial \overline{s}}{\partial t}\right)_{\substack{PBL\\turb}} = -\frac{1}{\rho_0}\sum_i \frac{\partial\left(\rho_0 \overline{u_i' s'}\right)}{\partial x_i}$$

Numerical Solution: unresolved transport using K-theory in which the covariances are evaluated as the product of an eddy mixing coefficient and the gradient of the transported mean quantity:

$$\overline{u_i' s'} = -K_{h_i}\frac{\partial \overline{s}}{\partial x_i}$$

Diffusion coefficients need to be specified as a function of flow characteristics (e.g. shear, stability, length scales).

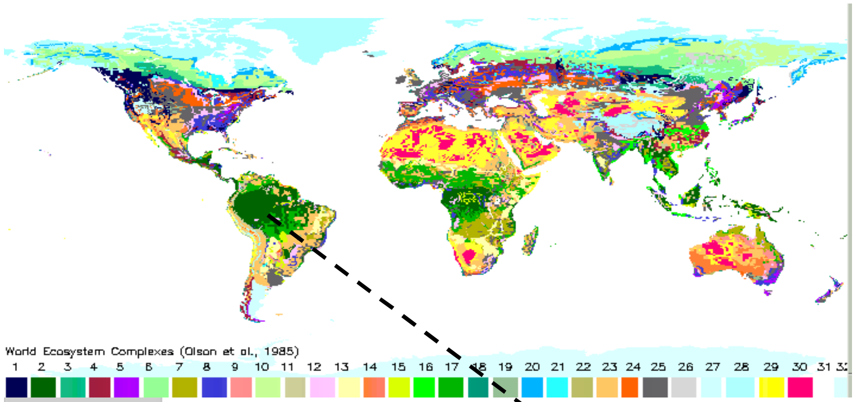


boundary layer eddies

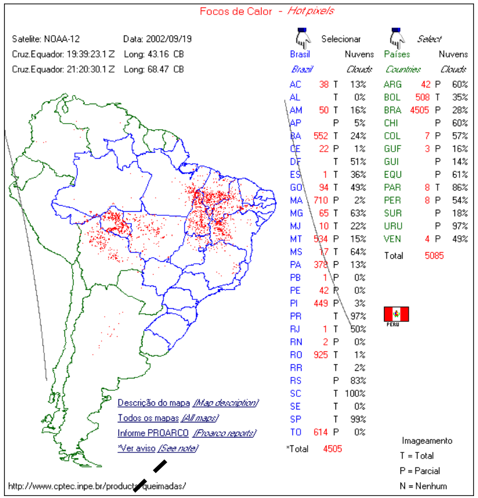
Biomass burning emissions inventory

Brazilian Fire Emission Model: Regional scale - daily basis

density of carbon data



near real time fire product


Focos de Calor - *Hot pixels*

Satelite: NOAA-12 Data: 2002/09/19
Cruz.Equador: 19:39:23.1 Z Long: 43.16 CB
Cruz.Equador: 21:20:30.1 Z Long: 68.47 CB

Selecionar Brasil *Brazil*			Nuvens *Clouds*
AC	38	T	13%
AL		T	0%
AM	50	T	16%
AP		P	5%
BA	552	T	24%
CE	22	P	1%
DF		T	51%
ES	1	T	36%
GO	94	T	49%
MA	710	P	2%
MG	65	T	63%
MJ	10	T	22%
MT	534	P	15%
MS	17	T	64%
PA	378	P	13%
PB	1	P	0%
PE	42	P	0%
PI	449	P	3%
PR		T	97%
RJ	1	T	50%
RN	2	P	0%
RO	925	T	1%
RR		T	2%
RS		P	83%
SC		T	100%
SE		T	0%
SP		T	99%
TO	614	P	0%
*Total	4505		

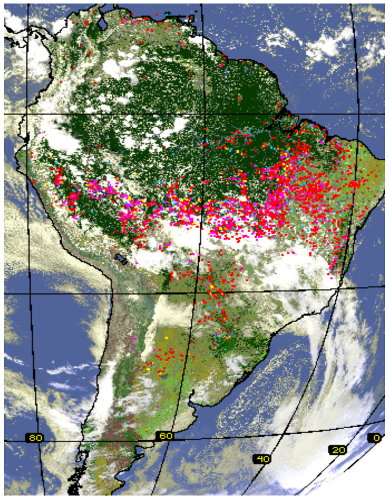
Select Países *Countries*			Nuvens *Clouds*
ARG	42	P	60%
BOL	508	T	35%
BRA	4505	P	28%
CHI		P	60%
COL	7	P	57%
GUF	3	P	16%
GUI		P	14%
EQU		P	61%
PAR	8	T	86%
PER	8	P	54%
SUR		P	18%
URU		P	97%
VEN	4	P	49%
Total	5085		

PERU

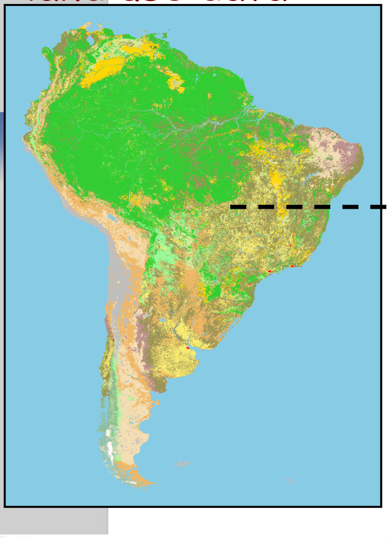
Descrição do mapa *(Map description)*
Todos os mapas *(All maps)*
Informe PROARCO *(Proarco reports)*
*Ver aviso *(See note)*

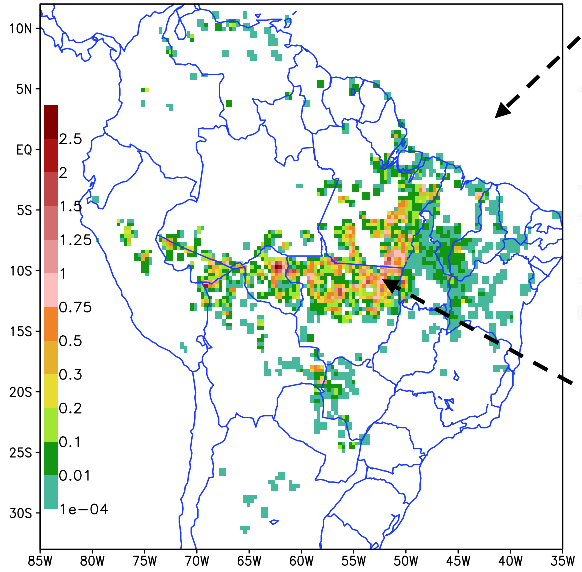
Imageamento
T = Total
P = Parcial
N = Nenhum

http://www.cptec.inpe.br/products/queimadas/



land use data





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

$$M[\eta] = \alpha_{veg} . \beta_{veg} . Ef_{veg}^{[\eta]} . afire,$$

Freitas et al, 1999, 2005

Poluição Atmosférica
MCT - INPE - CPTEC

Sub-grid convective transport term:
(coupled to the cumulus parameterization)

$$\left(\frac{\partial \bar{s}}{\partial t}\right)_{conv} = -\frac{1}{\rho_0}\frac{\partial\left(\rho_0 \overline{w's'}\right)}{\partial z}$$

Mass flux approach

$$\overline{w's'} = \int_{\lambda} [s_u - \tilde{s}]\eta_u(\lambda,z)m_u(\lambda,z_{b,u})d\lambda - \int_{\lambda} [s_d - \tilde{s}]\eta_d(\lambda,z)m_d(\lambda,z_{b,d})d\lambda$$

u,d **: updraft / downdraft flows**

m,η **: mass flux where the flows originate / normalized mass flux profile**

$s_{u/d}$ **: in cloud value of scalar**

$\tilde{s}$ **: enviroment value of scalar**

$\bar{s}$ **: model value**

$\int_{\lambda}$ **: represents integral over all present clouds in the model grid box**

Sub-grid deep convective transport term:

2D spectral model: deep and shallow (non-precipitating) cumulus

case of deep cumulus

$$\overline{w's'}_{\substack{deep\\conv}}(z) = \eta_u\left[s_u - \tilde{s}\right]m_u(z_b) - \eta_d\left[s_d - \tilde{s}\right]m_d(z_d)$$

defining $\varepsilon = \dfrac{m_u(z_b)}{m_d(z_d)}$

using $m_u = m_d + \tilde{M}$

$$\frac{\overline{w's'}_{\substack{deep\\conv}}(z)}{m_u(z_b)} = \eta_u s_u - \varepsilon \eta_d s_d - \tilde{\eta}\tilde{s}$$

Parameterized deep convective transport

$$\frac{1}{m_u(z_b)}\frac{\partial \overline{w's'}_{\substack{deep\\conv}}}{\partial z}=\frac{\partial}{\partial z}\left(\eta_u s_u-\varepsilon\eta_d s_d-\tilde{\eta}\tilde{s}\right)$$

and using the mass conservation equation

$$\left(\frac{\partial\bar{s}}{\partial t}\right)_{\substack{deep\\conv}}=\frac{m_u(z_b)}{\rho_0}\left[\underbrace{\delta_u\eta_u\left(s_u-\tilde{s}\right)}_{\text{updraft detrainment}}+\underbrace{\delta_d\eta_d\left(s_d-\tilde{s}\right)}_{\text{downdraft detrainment}}+\underbrace{\tilde{\eta}\frac{\partial\tilde{s}}{\partial z}}_{\text{environment subsidence}}\right]$$

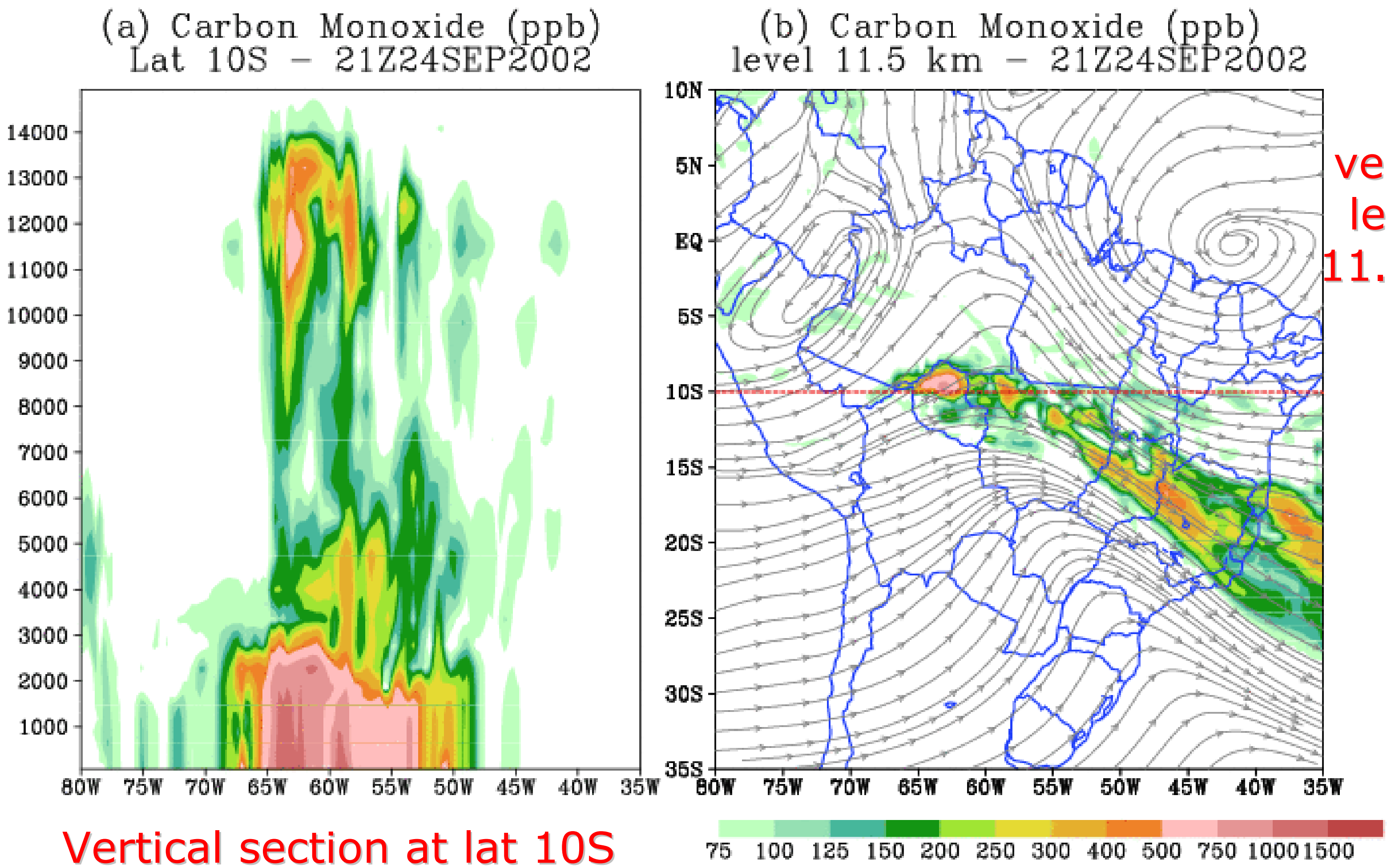
The closure problem

The static control and entrainment /detrainment assumptions determine the vertical structure of the tracer transport, however the determination of the overall magnitude of the transport requires the determination of the mass flux at cloud base : $m_u(z_b)$

We use new Grell´s cumulus scheme that provides this number using an ensemble version of closures (Kuo, Arakawa&Schubert, Grell, Kain&Fritsch, Brown).

Deep convective transport of CO

21Z 24 Sep 2002

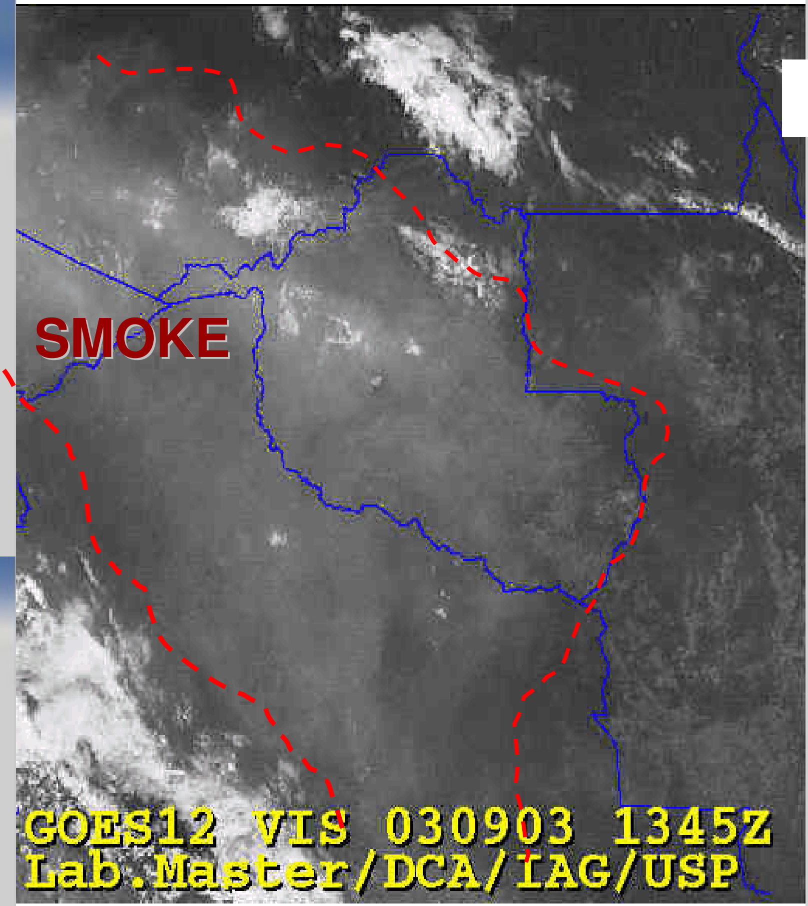


Vertical section at lat 10S

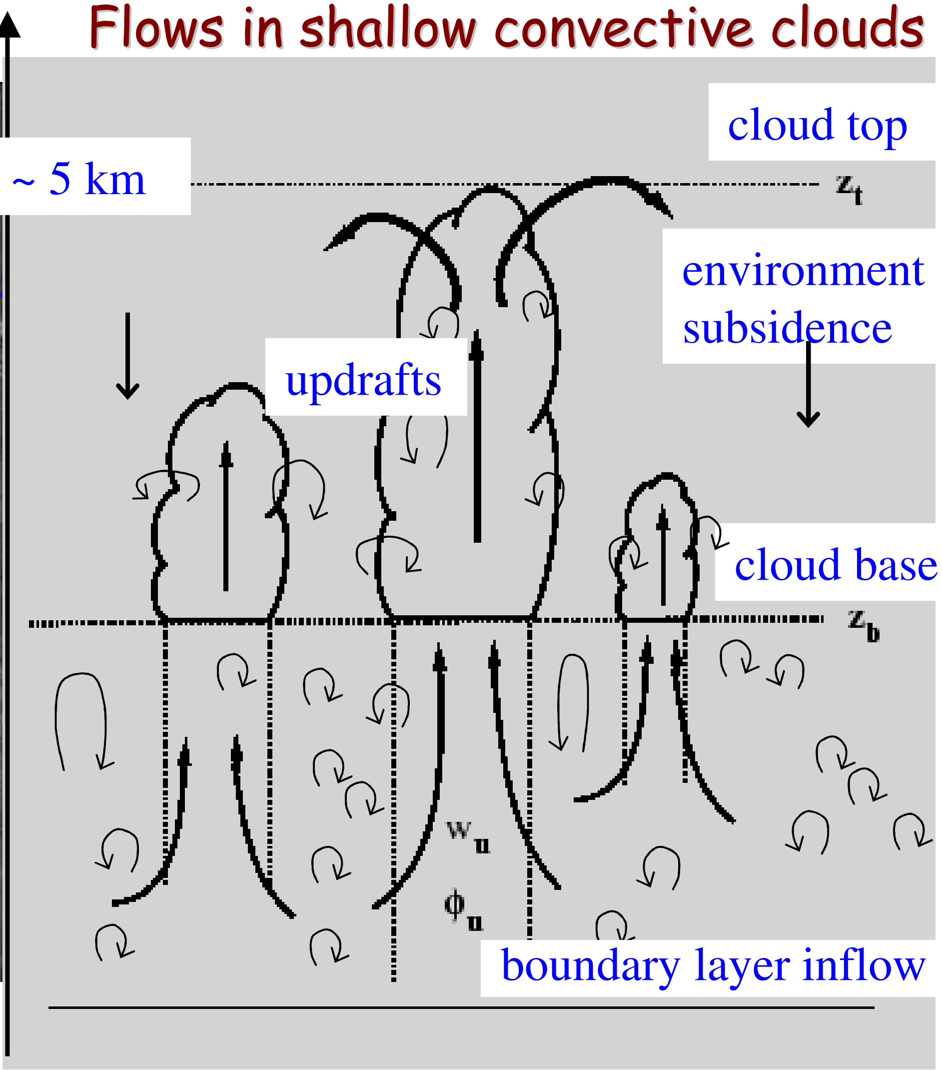
vertical
level
11.5 km

CO (ppb)

Shallow convective transport of smoke/gases from biomass burning



Flows in shallow convective clouds



Parameterized shallow convective transport

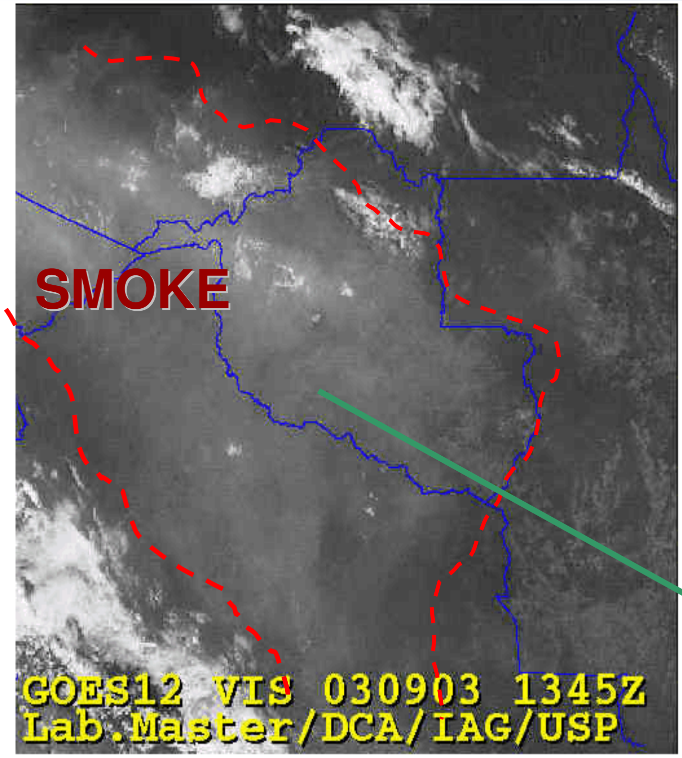
- **Based at the mass flux cumulus scheme** (Grell 1993; Grell and Devenyi 2002).
- **Transport term** (donwdrafts are disregarding)

$$\left(\frac{\partial \overline{s}}{\partial t}\right)_{\substack{shallow\\ conv}} = \frac{m_b}{\rho_0}\left[\underbrace{\delta_u \eta_u \left(s_u - \tilde{s}\right)}_{\text{updraft detrainment}} + \underbrace{\tilde{\eta}\frac{\partial \tilde{s}}{\partial z}}_{\text{environment subsidence}}\right]$$

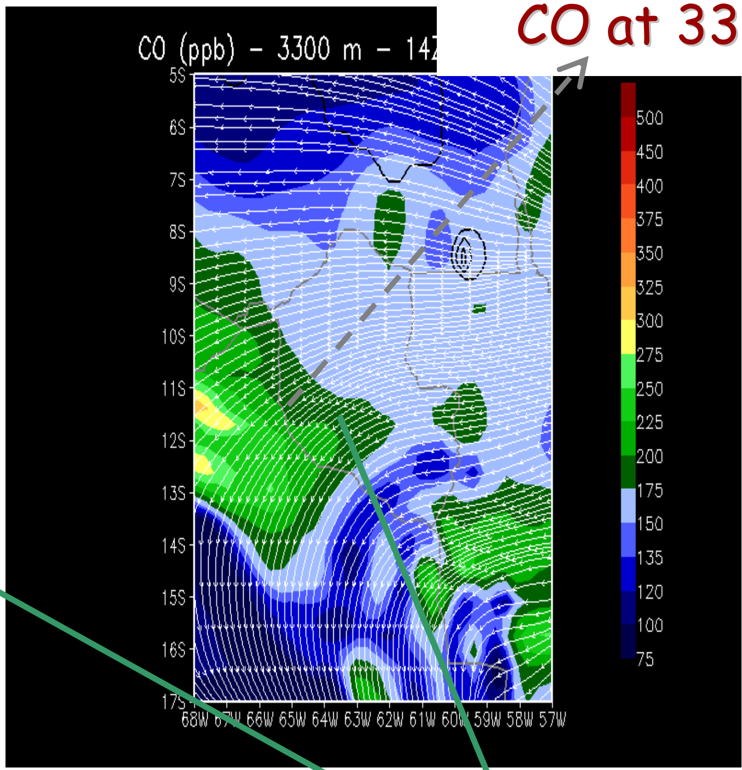
We use a stability closure (like Kain & Fristch) to determine the mass flux at shallow cloud base

Shallow convective transport

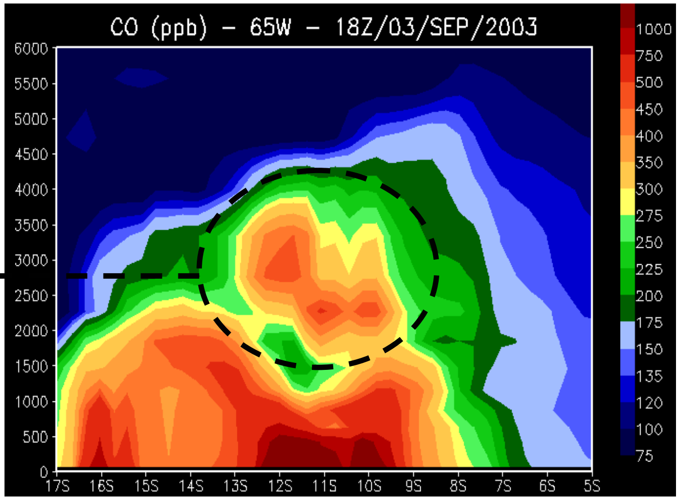
Model simulation for 14-17Z03092003



CO at 3300m



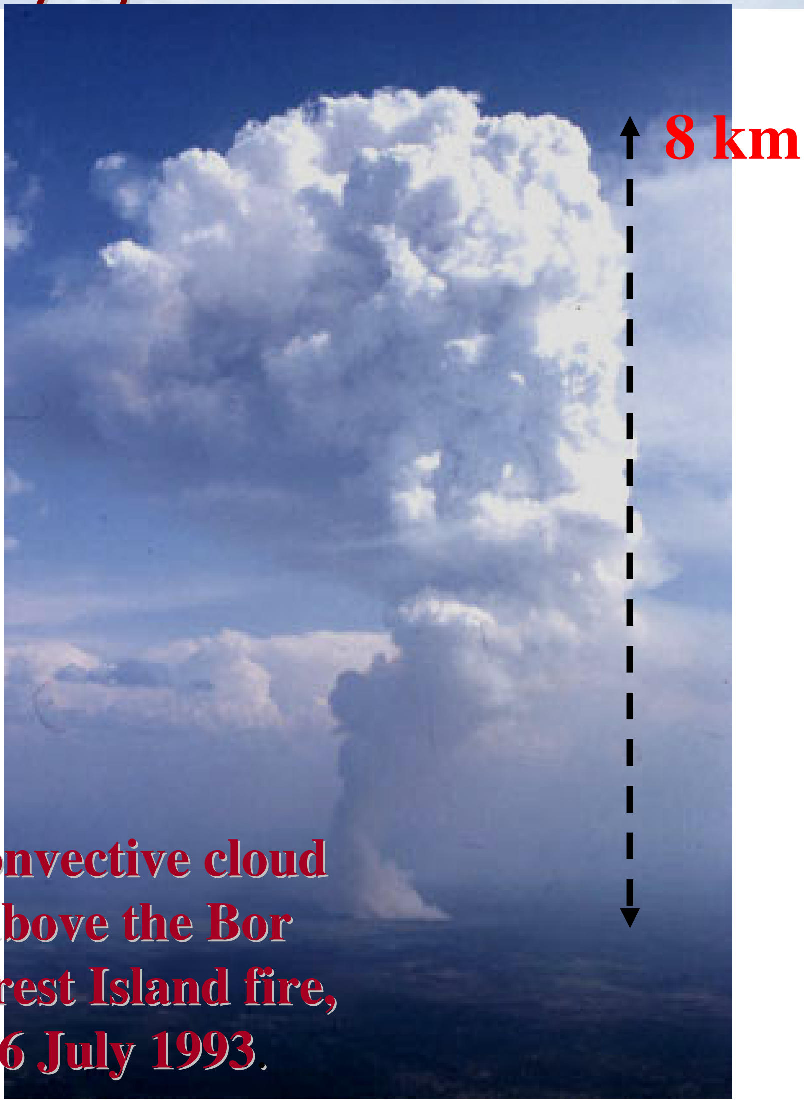
shallow cumulus



Low troposphere CO

PBL

Another important sub-grid process, but frequently ignored



Convective cloud above the Bor Forest Island fire, 6 July 1993.

Plume-rise due to the strong buoyancy of the hot gases/aerosols emitted


01 10 200

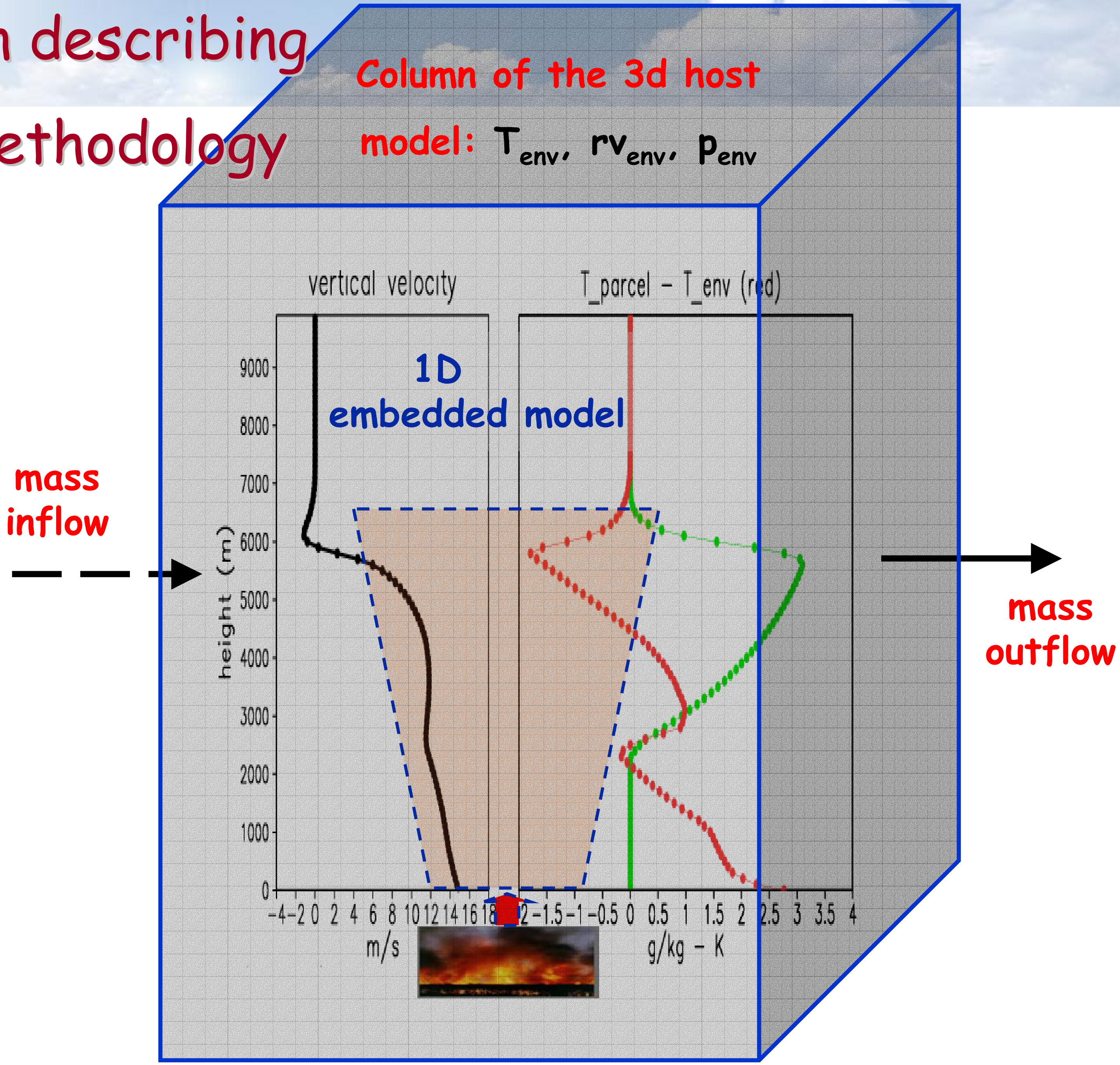

01 10 2002 19:50

How to include this sub-grid transport in the model?

1D cloud resolving model (CRM) using the *super-pameterization* concept:

- 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.

Cartoon describing the methodology



Column of the 3d host model: T_{env}, rv_{env}, p_{env}

1D embedded model

mass inflow

mass outflow

The 1D cloud resolving model: governing equations

dynamics

$$\frac{\partial w}{\partial t}+w\frac{\partial w}{\partial z}=\gamma g B-\frac{2\alpha}{R}w^{2}\quad\begin{cases}\gamma=\dfrac{1}{1+0.5} & \textit{Simpson\&Wiggert, 1968}\\[2ex] \gamma=\dfrac{1}{1-2\mu} & \textit{Siebesma et al, subm. JAS}\end{cases}$$

thermodynamics

$$\frac{\partial T}{\partial t}+w\frac{\partial T}{\partial z}=-w\frac{g}{c_p}-\frac{2\alpha}{R}\left|w\right|(T-T_e)+\left(\frac{\partial T}{\partial t}\right)_{microphysics}$$

water vapor conservation

$$\frac{\partial r_v}{\partial t}+w\frac{\partial r_v}{\partial z}=-\frac{2\alpha}{R}\left|w\right|(r_v-r_{ve})+\left(\frac{\partial r_v}{\partial t}\right)_{microphysics}$$

cloud water conservation

$$\frac{\partial r_c}{\partial t}+w\frac{\partial r_c}{\partial z}=-\frac{2\alpha}{R}\left|w\right|r_c+\left(\frac{\partial r_c}{\partial t}\right)_{microphysics}$$

rain/ice conservation

$$\frac{\partial r_{ice,rain}}{\partial t}+w\frac{\partial r_{ice,rain}}{\partial z}=-\frac{2\alpha}{R}\left|w\right|r_{ice,rain}+\left(\frac{\partial r_{ice,rain}}{\partial t}\right)_{microphysics}+\text{sedim}$$

bulk microphysics

$$\left(\frac{\partial \xi}{\partial t}\right)_{microphysics}\quad(\xi=T,r_v,r_c,r_{rain},r_{ice}),\ \text{sedim}\begin{cases}\textit{bulk microphysics:}\\ \textit{Kessler, 1969}\\ \textit{Ogura \& Takahashi,1971}\\ \textit{Berry,1967}\end{cases}$$

The lower boundary condition

Morton, Taylor & Turner (1956):

"Turbulent grav. convection from maintained and instantaneous sources"

$$\begin{cases} F=\dfrac{g\Re}{\pi c_p}\boxed{\dfrac{E}{\rho_e}A} & \text{buoyancy flux} \\ R=\dfrac{6\alpha}{5}z & \text{plume radius} \\ w(z_v)=\dfrac{5}{6\alpha}\left(\dfrac{0.9\alpha F}{z_v}\right)^{1/3} & \text{boundary condition for } w \\ \dfrac{\Delta\rho}{\rho_e}=\dfrac{5}{6\alpha}\dfrac{F}{g}\dfrac{z_v^{-5/3}}{\left(0.9\alpha F\right)^{1/3}} & \text{density correction} \\ T(z_v)=\dfrac{T_e(z_v)}{1-\dfrac{\Delta\rho}{\rho_e}} & \text{boundary condition for } T \end{cases}$$

where: $\alpha=0.2$ entrainment coefficient,

$z_v=0.9\alpha^{-1}R_{surf}$ virtual boundary height

the closure

$A \equiv$ plume area $\approx$ instantaneous fire size

$E \equiv$ convective energy from fire (Wm^{-2})

$E \cong 0.4-0.8\ \Xi_{flux}$ (McCarter & Broido, 1965)

$$\Xi_{flux}(\text{heat flux}) = \frac{h\beta c}{\Delta t} \begin{cases} h = 1.5 \text{ to } 2.1\ 10^7 \text{ joules kg}^{-1} \\ \beta c = \text{ fuel load / combustion factor} \\ \Delta t = \text{ flaming phase duration} \end{cases}$$

$W_{flux}(\text{water flux}) = 0.5\beta c$

Plume-rise of vegetation fires: typical energy fluxes (kWm^{-2})

Biome type	Lower bound kWm^{-2}	Upper bound kWm^{-2}	Flaming consumption
Tropical forest	30.	80.	45%
Woody savanna - cerrado	4.4	23.	75%
Pasture - grassland cropland	3.3		97%

Refs: Carvalho et al, 1995-2001-2005 (com. pessoal);

Riggan et al, 2004;

Ward et al, 2002;

Ferguson et al, 1998;

Cochrane et al; 200X-com. pessoal;

Miranda et al, 1993.

Including plume rise mechanism trough *super-parameterization* concept

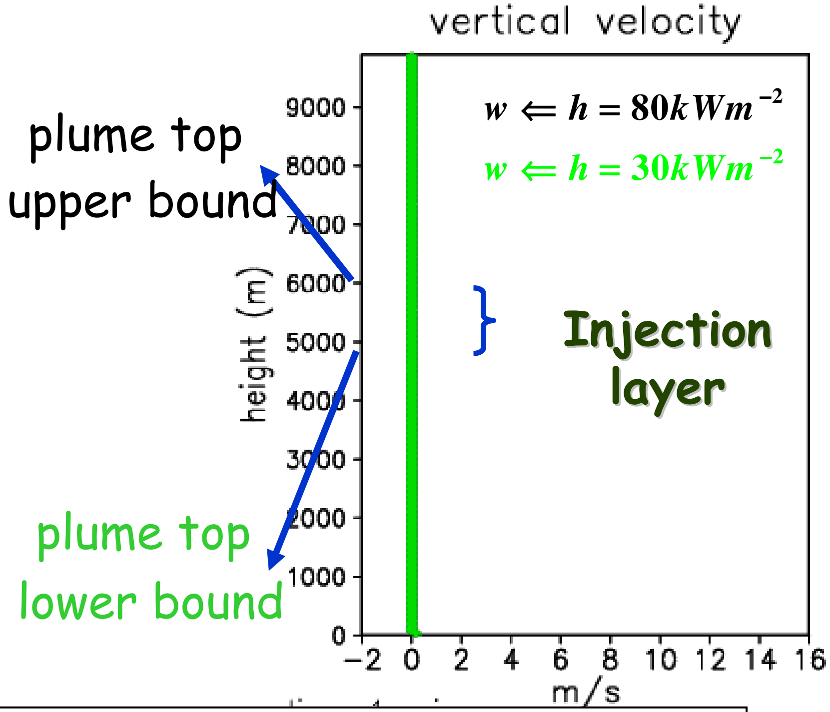
1D plume-rise model for vegetation fires

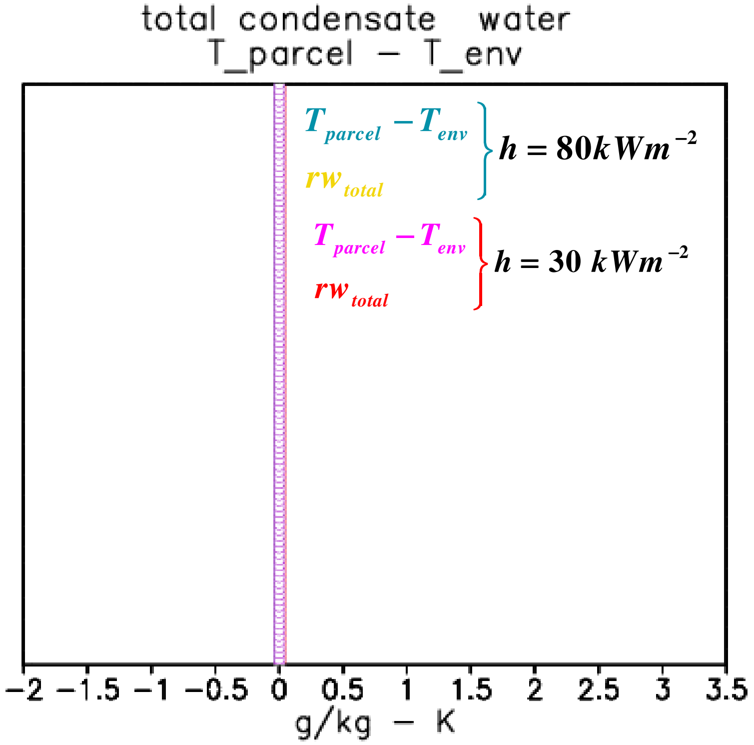
Biome: Forest

Time duration: 50 mn

Fire size: 20 ha

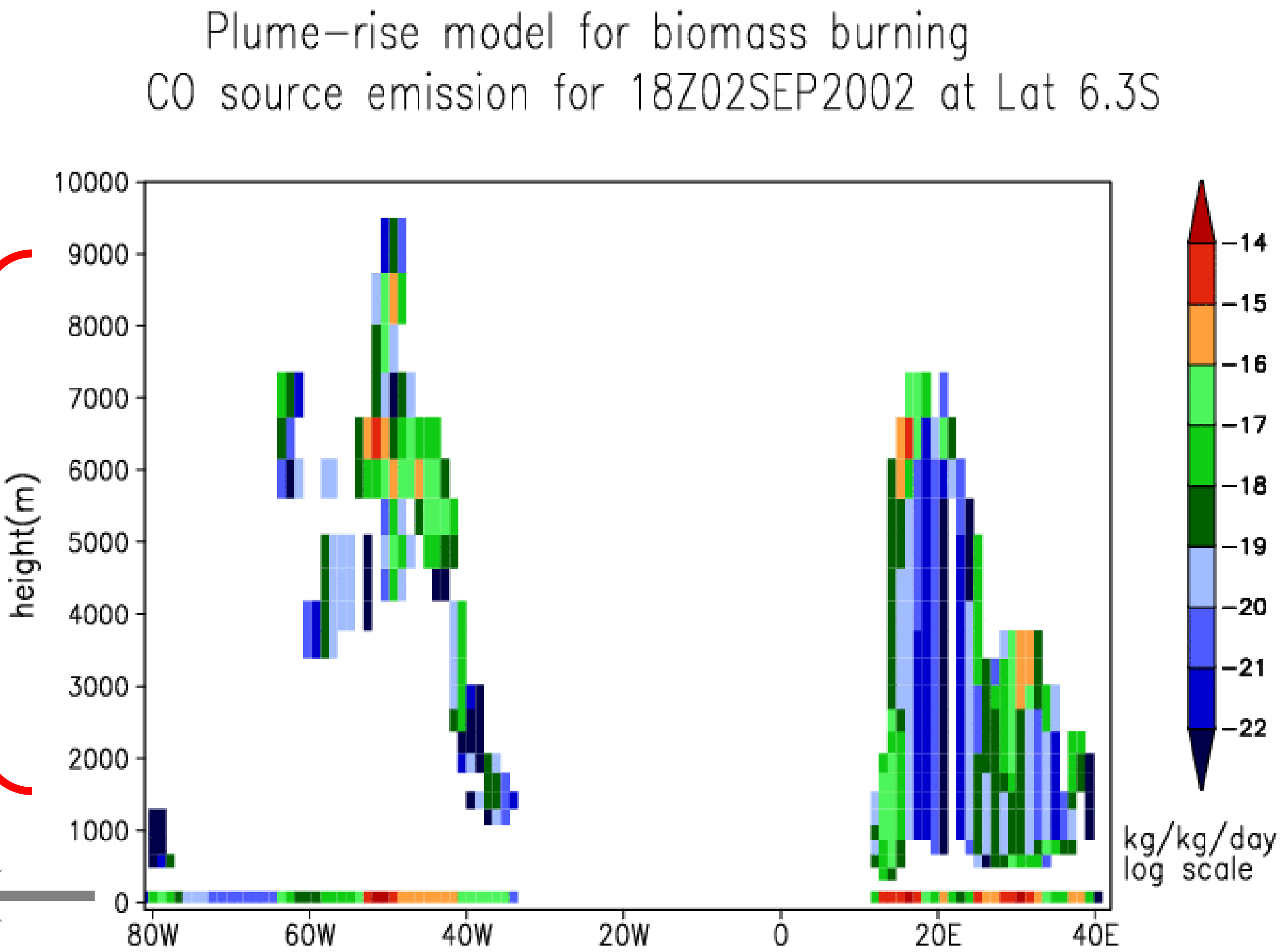
Heat flux: 80 kWm^{-2} / 30 kWm^{-2}





Freitas et al., 2006 GRL under review

Example of CO source emission field with the plume-rise for vegetation fires at the CATT-BRAMS host model



flaming emission

smoldering emission

South America mostly forest fires

Africa mostly savanna fires

Dry deposition and particles sedimentation fully coupled with LEAF-3, including the patches approach

Resistance Formulation

$$F = -v_d S$$

$$v_{d,part,i} = \left(R_a + R_b + R_a R_b V_{f,i}\right)^{-1} + V_{f,i}$$

onde

$$V_{f,i} = \frac{2 r_i^2 (\rho_p - \rho_a) g}{9 \eta_a} G_i$$ é a velocidade de sedimentação

$$R_a = \frac{\int_{z_{0,q}}^{z_r} \phi_h \frac{dz}{z}}{\kappa u_*}$$ é a resistência aerodinâmica

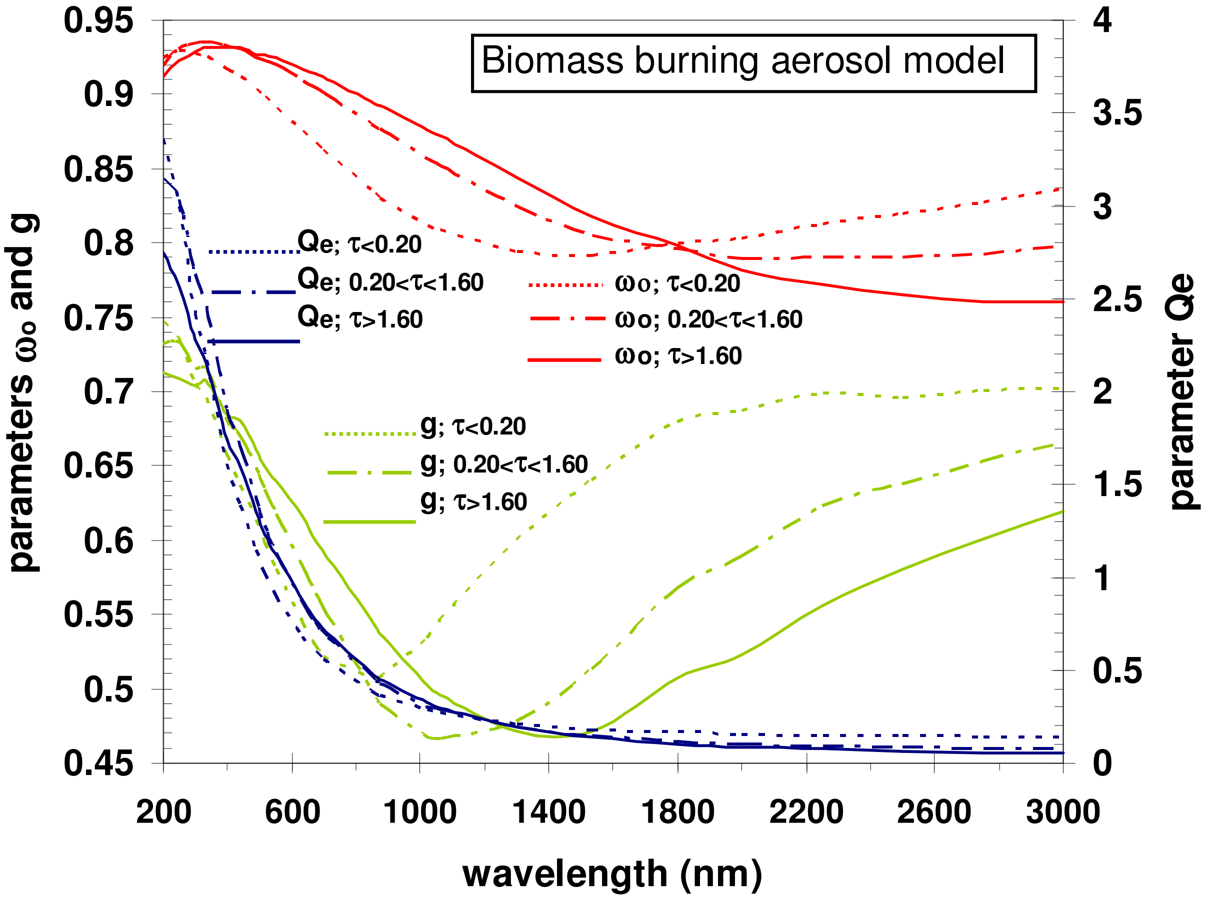
$$R_b = \ln\left(\frac{z_{0,m}}{z_{0,q}}\right) \frac{\left(Sc/\Pr\right)^{2/3}}{k u_*}$$ é a resistência da difusão molecular

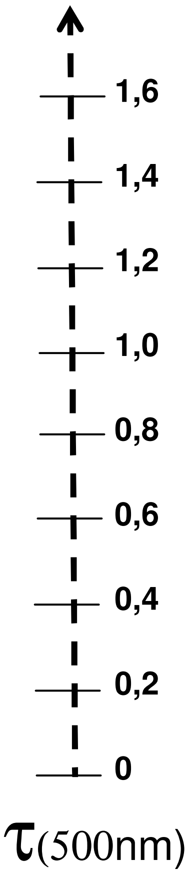
Biomass burning Aerosol model

(Procópio et al., 2003)

Lookup table with $\mathbf{Q_e}$, ω_0 and **g**

as function of τ(500 nm) and λ





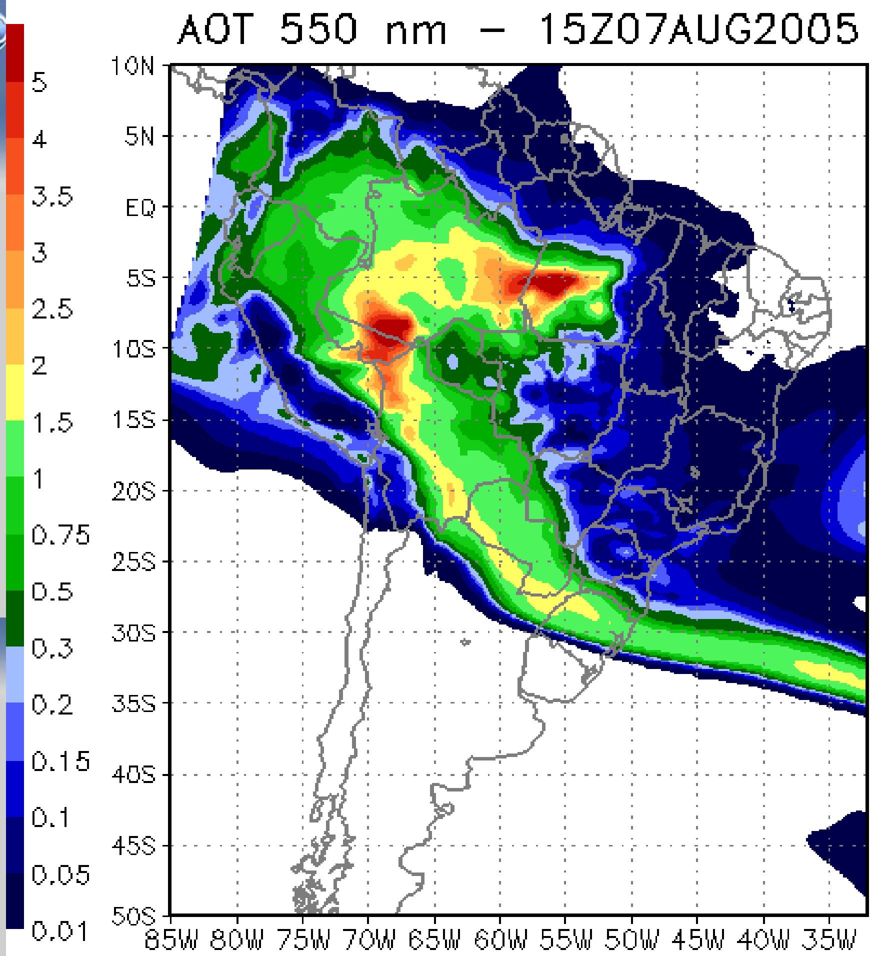
Interação da radiação com a microfísica e convecção

(Sun & Shine, Savijärvi et al.) – ECMWF, Meso-NH

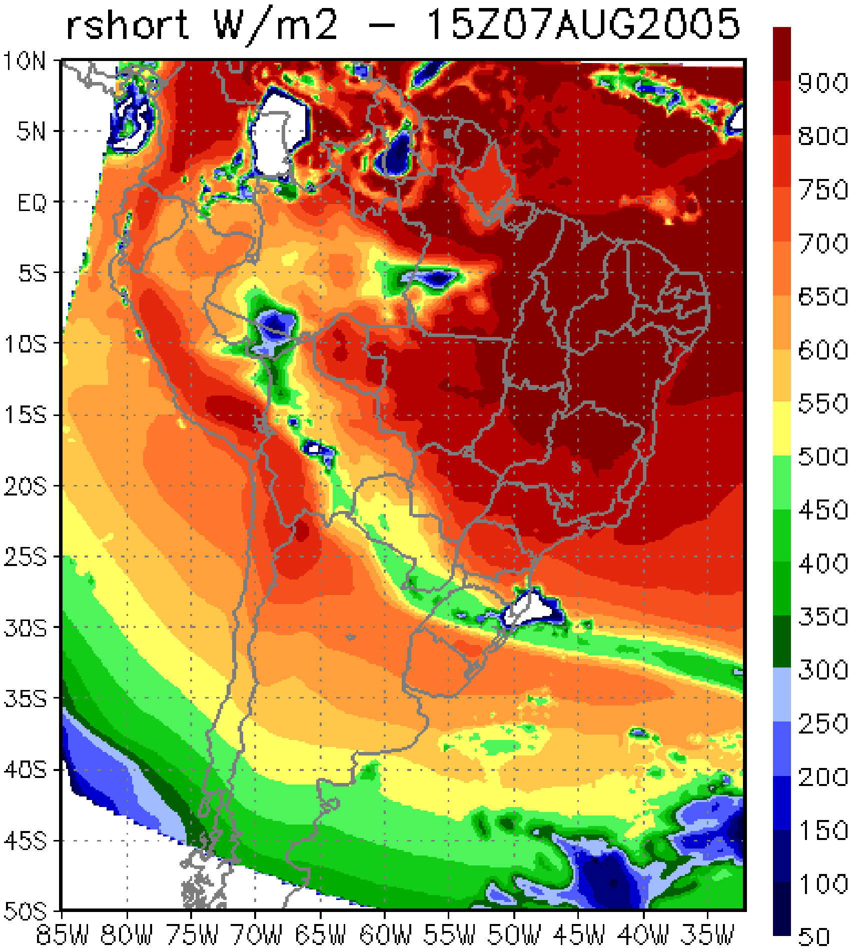
Propriedades ópticas de nuvens e da chuva

$$\left\{\begin{aligned} &\tau = \tau_c + \tau_r = (\tau_L + \tau_I) + \tau_r \\ &\omega_0 = (\omega_{0L}\tau_L + \omega_{0I}\tau_I + \omega_{0r}\tau_r)/\tau \\ &g = (\omega_{0L}\tau_L g_L + \omega_{0I}\tau_I g_I + \omega_{0r}\tau_r g_r)/\omega_0 \end{aligned}\right.$$

AOT 550 nm
(from biomass burning)



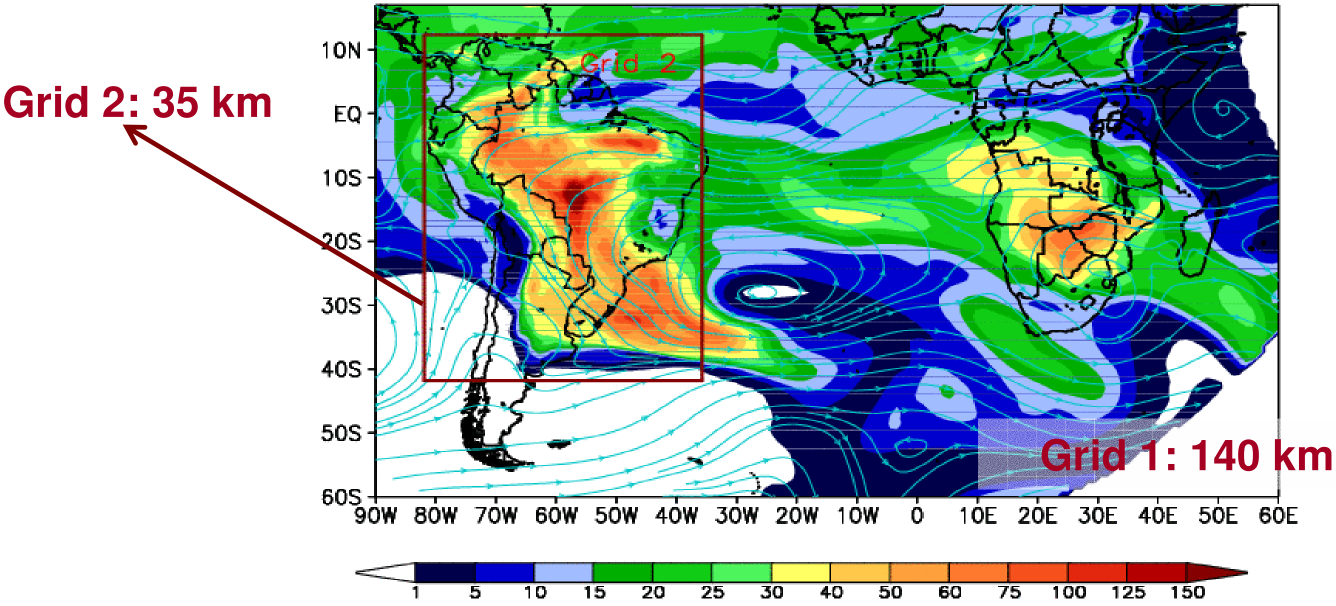
Solar Radiation
at surface (Wm^{-2})



Algumas validações do modelo

Model validation using 2002 data

- Model configuration: 2 grids with 2-way nesting technique.
- Simulation time: 135 days starting 00Z15Jul2002.
- Initial and boundary condition using 4DDA from CPTEC analysis fields.
- Ensemble version of convective parameterization (Grell and Dévényi (2002), deep and shallow)
- Full microphysics, PBL diffusion with TKE closure, etc…
- Soil moisture initialization (Gevaerd & Freitas, 2006).
- Biomass burning emission using a hybrid fire remote sensing database through combination of MODIS/AVHRR/GOES fire products.
- EDGAR 2000FT for anthropogenic emissions.

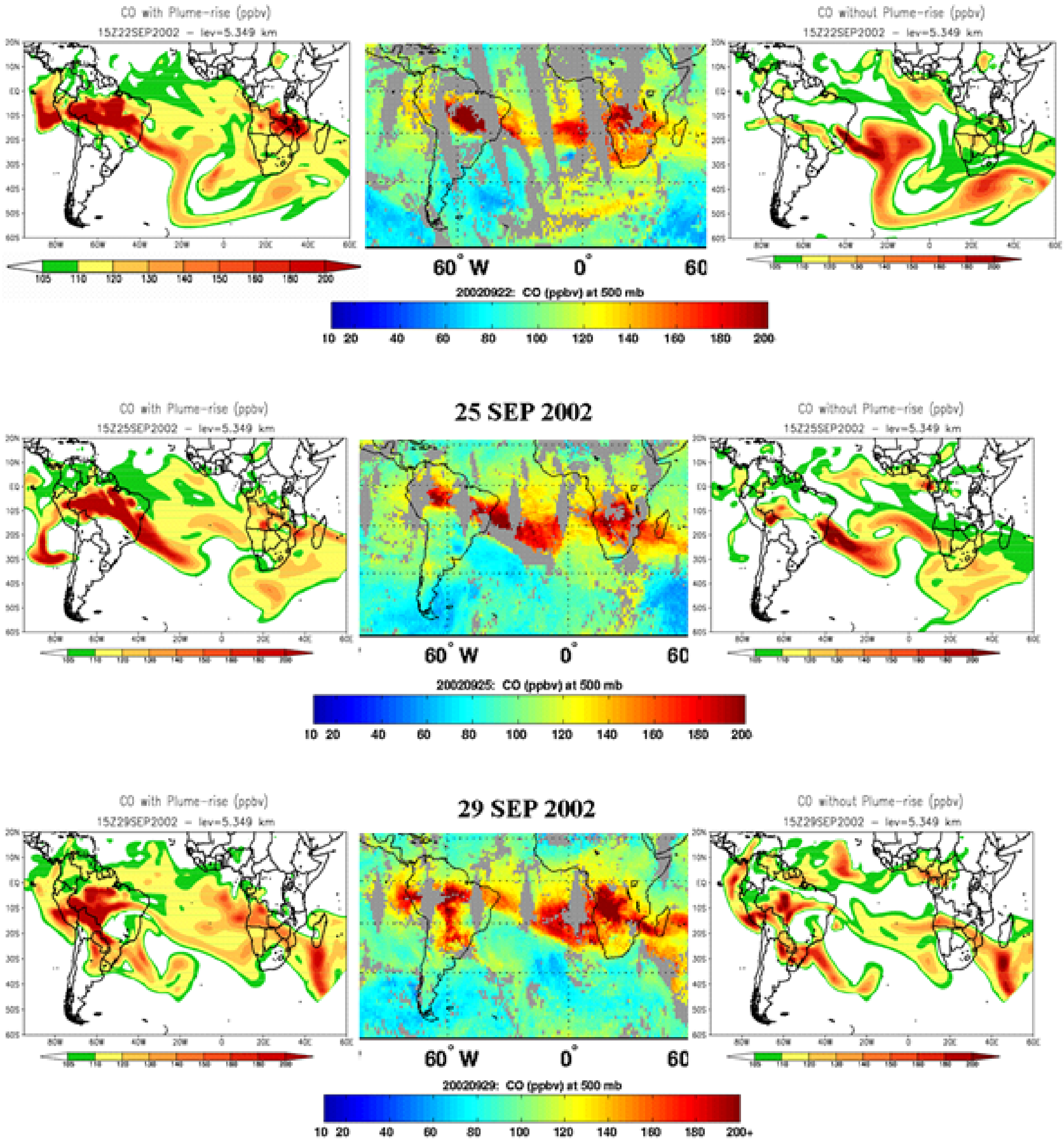


Model Validation with AIRS 500 hPa CO

CO (ppbv) from model at ~5.5 km height with plume-rise

CO (ppbv) from AIRS at 500 mb 22 SEP 2002

CO (ppbv) from model at ~5.5 km height without plume-rise

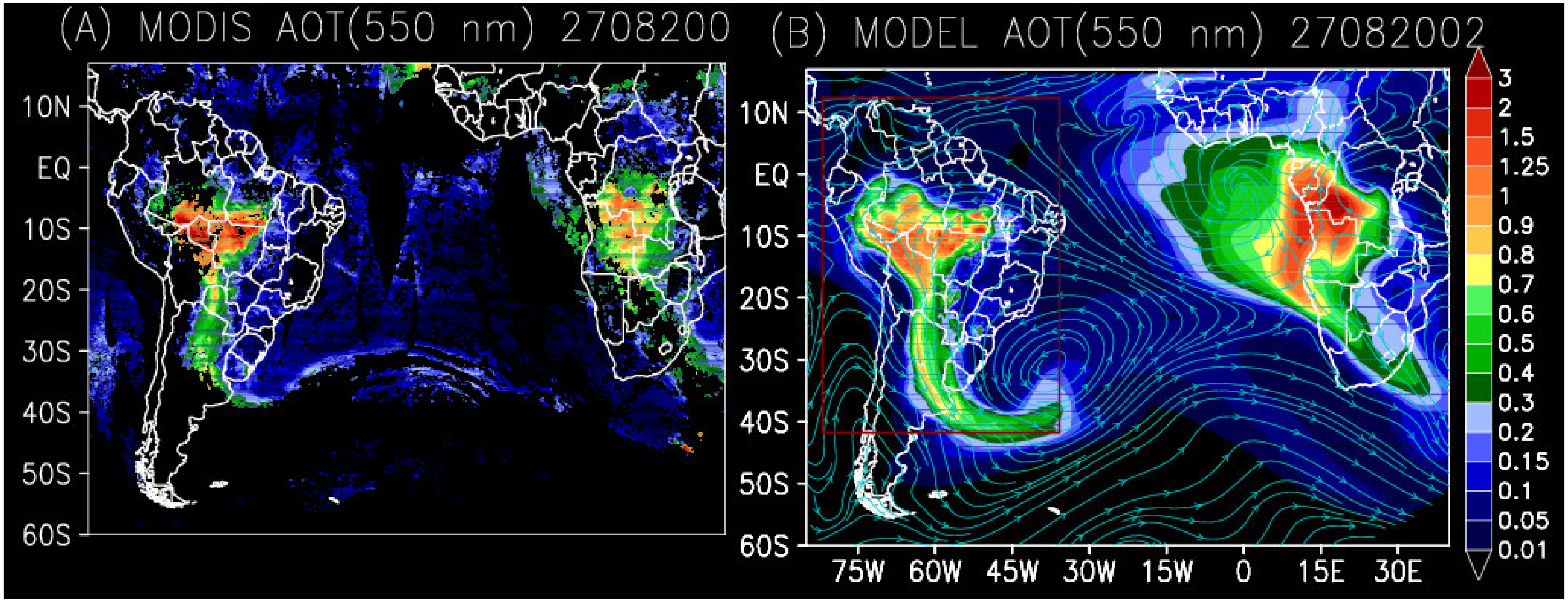


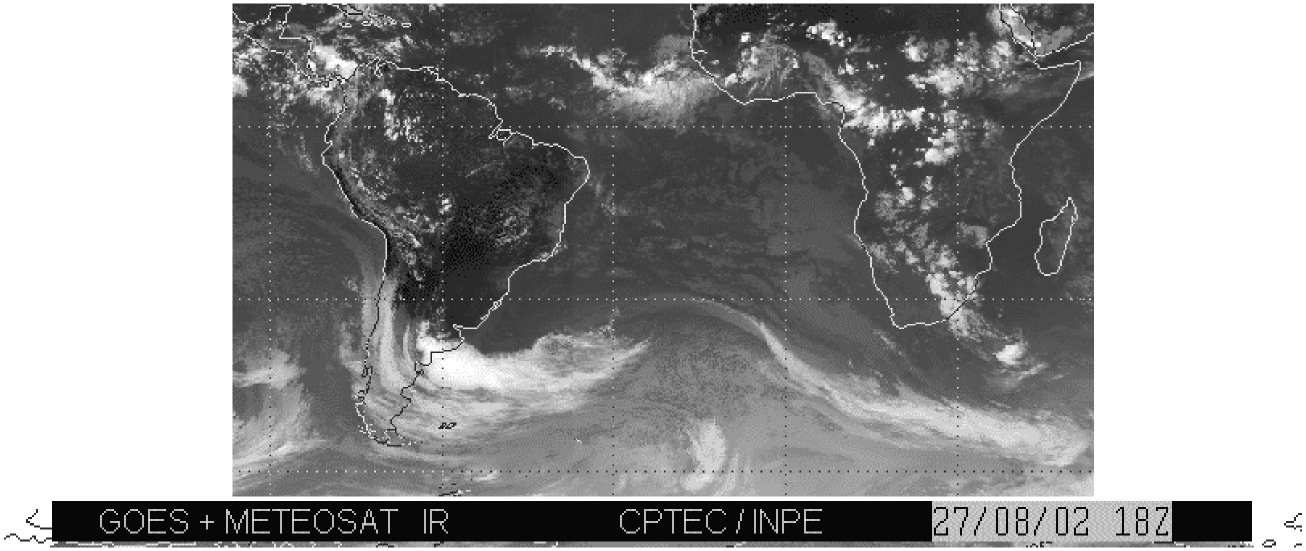
25 SEP 2002

29 SEP 2002

Comparison between AOT (550 nm)

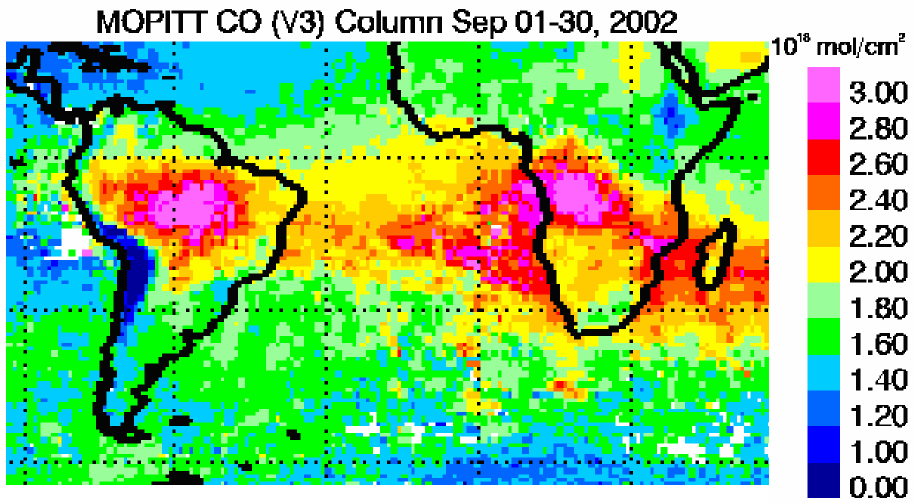
MODIS x MODEL



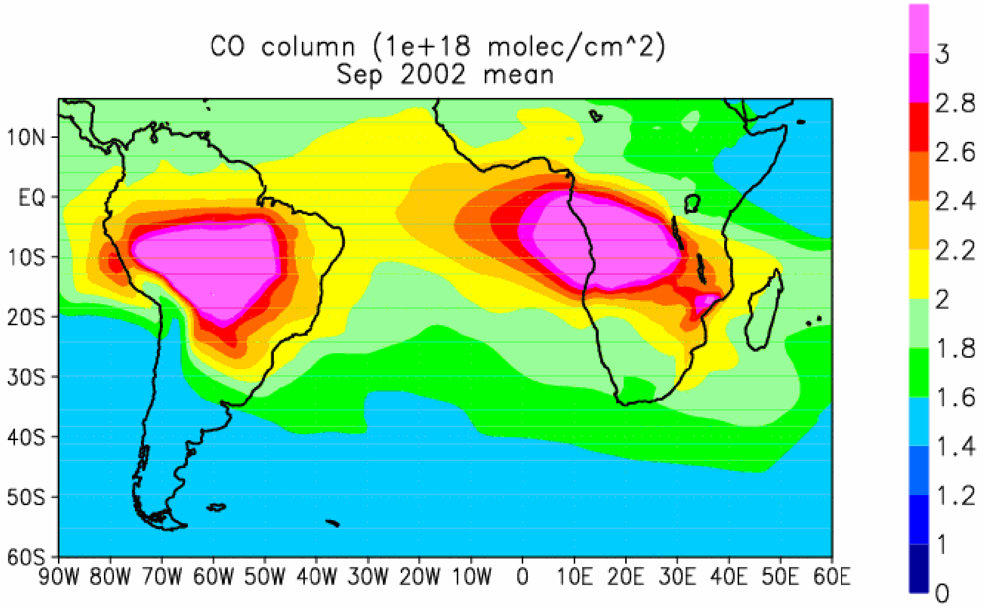


Comparison between CO column (10^{18} molec cm^{-2}) September, 2002 mean

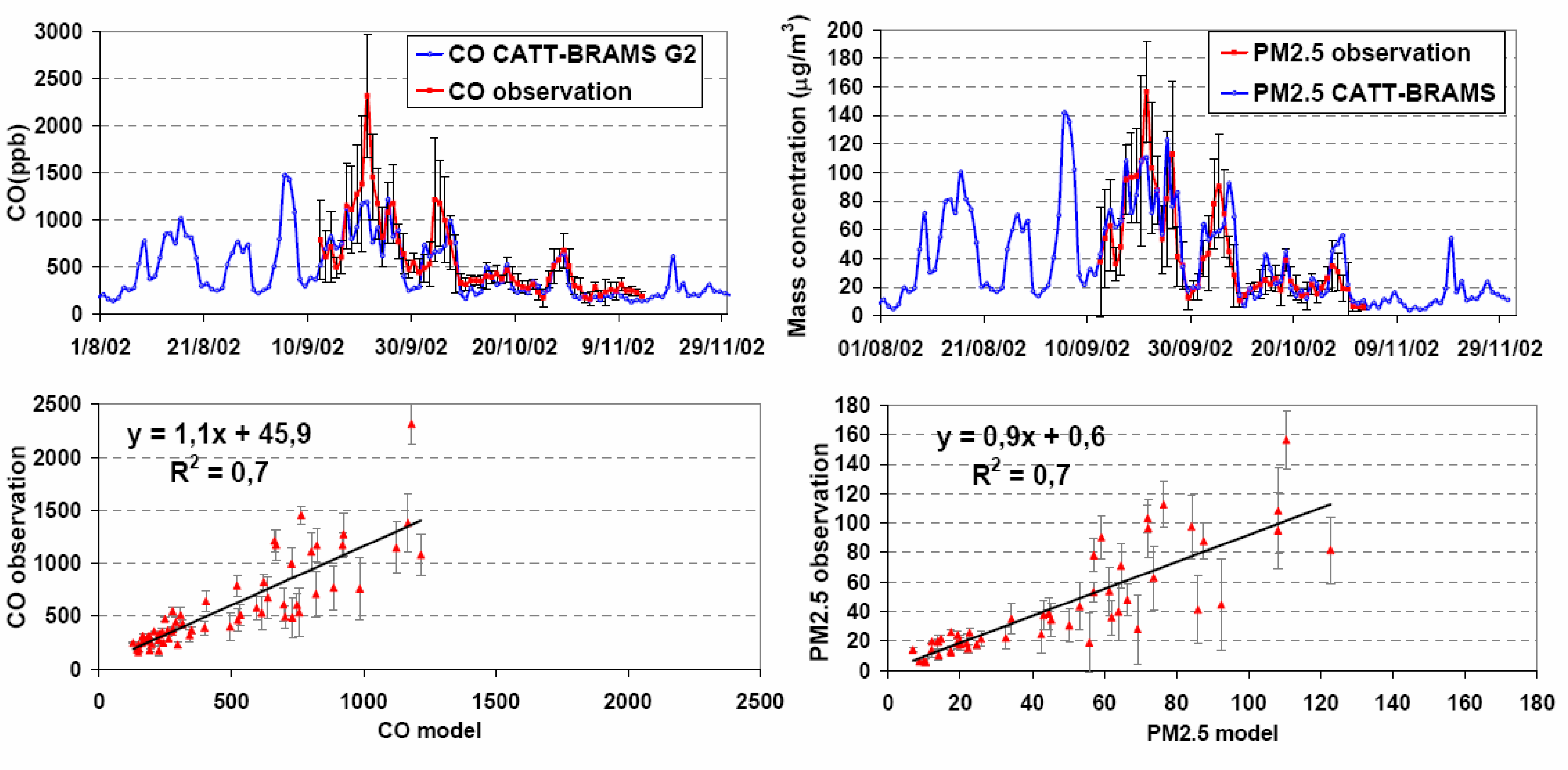
MOPITT (V3)


MOPITT CO (V3) Column Sep 01-30, 2002

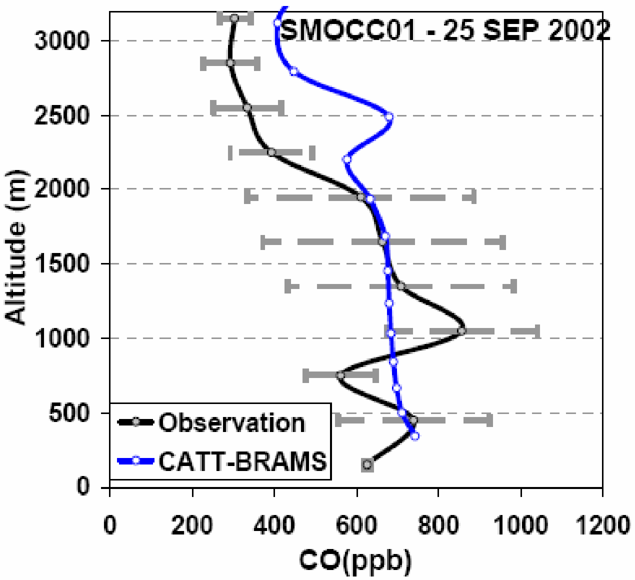
MODEL

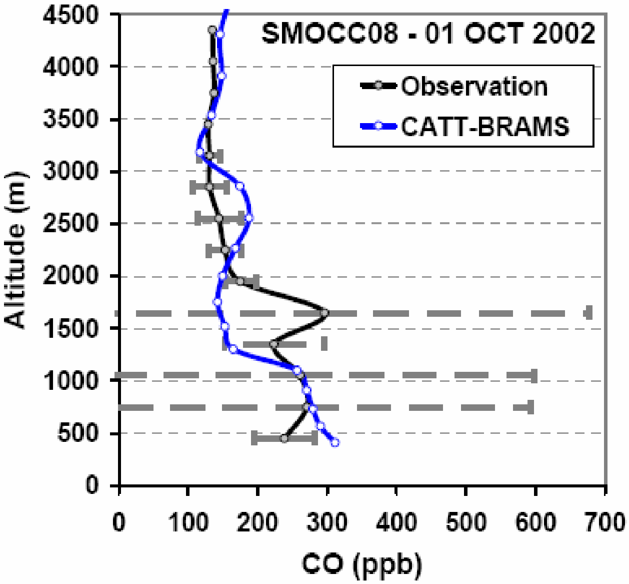

CO column (1e+18 molec/cm^2)
Sep 2002 mean

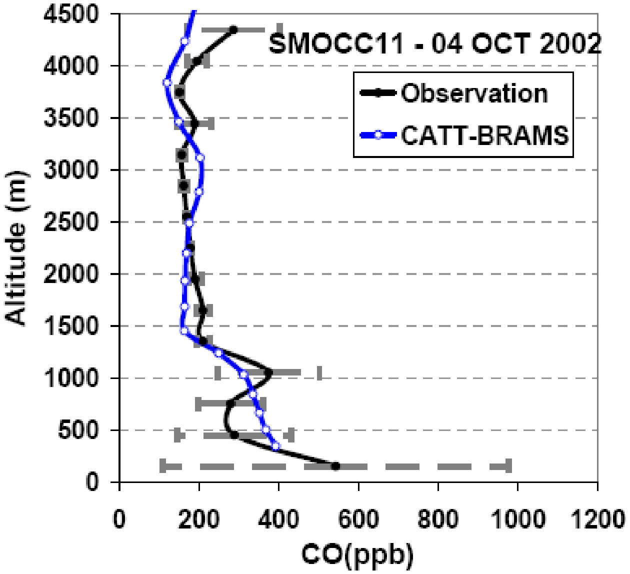
Model comparison with near SMOCC/RACCI surface observations: CO and PM2.5 observations in Rondônia

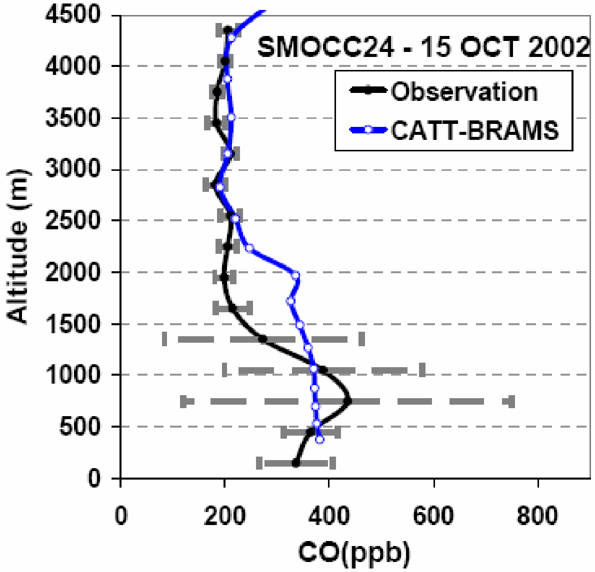


Model comparison with CO airborne observations from SMOCC campaign in Rondônia





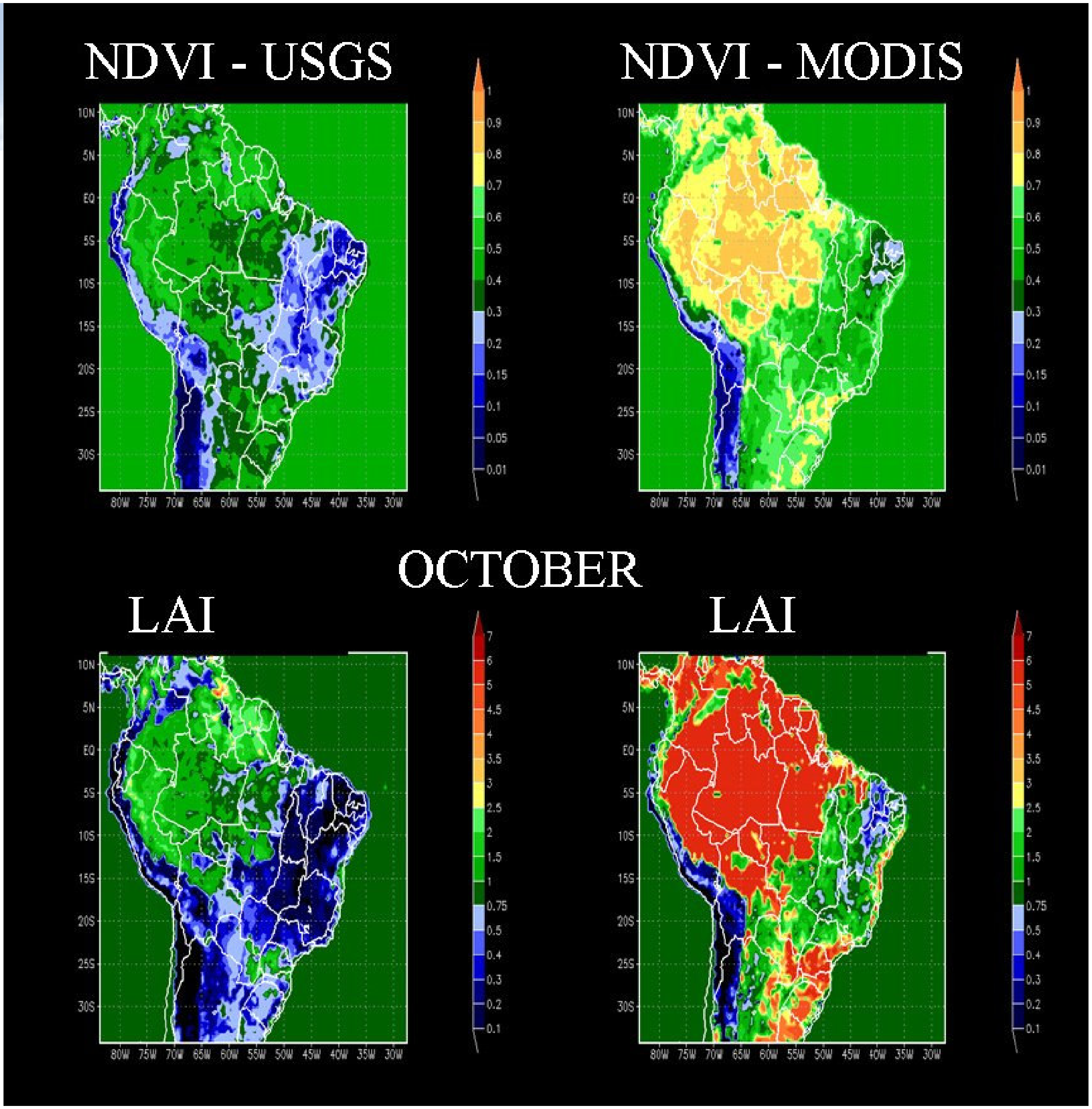




Funcionalidades do CATT que migrarão para o BRAMS 4.0

- Nova versão da parametrização convectiva de Grell (training, acoplamento do CAPMAX com propriedades da PBL, versão bi-espectral)
- Módulo de transporte para espécies gasosas insolúveis e aerossol
- Deposição/sedimentação de aerossóis e parametrização de vida-média para gases
- Radiação CARMA acoplado à microfísica/cumulus e com modelo de aerossol de queimadas
- Leaf -3 com perfil de raízes do Arora&Boer E.I. 200X e com NDVI baseado no MODIS 2000/2001
- Nova umidade do solo utilizando dados mais apropriados para solos tropicais (H&T) seguindo o formalismo de van Genutchen

NDVI e LAI



http://www.cptec.inpe.br/brams/input_data.shtml