# *Including the sub-grid plume-rise of vegetation fires in low resolution atmospheric-chemistry transport models*

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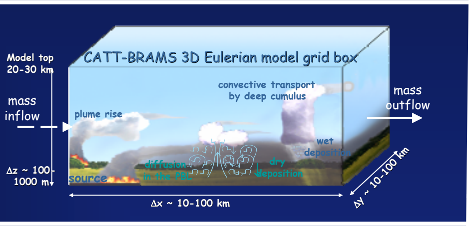
We adopt the super-parameterization concept (Grabowsky 2001) to include the vertical transport of hot gases and particles emitted from biomass burning in low resolution atmospheric-chemistry transport models. This sub-grid transport mechanism is simulated imbibing a 1D cloud resolving model with appropriate lower boundary condition in each column of the 3D host model. Through assimilation of remote sensing fire product, we recognize which columns have 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. We compare model results with 500 mb AIRS carbon monoxide data (McMillan et al, 2005) for September 2002 and show the huge impact that this mechanism has at the model performance.

## Some sub-grid process involved at gases/aerosols transport



## Eulerian Transport Model : CATT-BRAMS Atmospheric Model

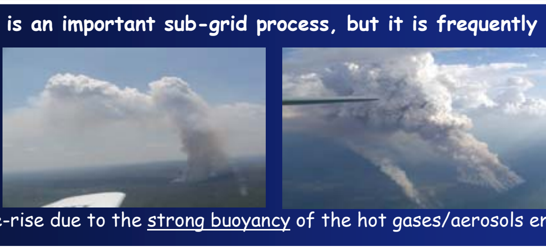
- in-line transport model fully coupled to the atmospheric dynamics,
- suitable for feedbacks studies,
- tracer mixing ratio tendency equation:

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

where:

| | |
|---|---|
| •*adv* | grid-scale advection |
| •*PBL turb* | sub-grid transport in the PBL |
| •*deep conv* | sub-grid transport associated to the deep convection |
| •*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. |

## Plume rise is an important sub-grid process, but it is frequently ignored



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

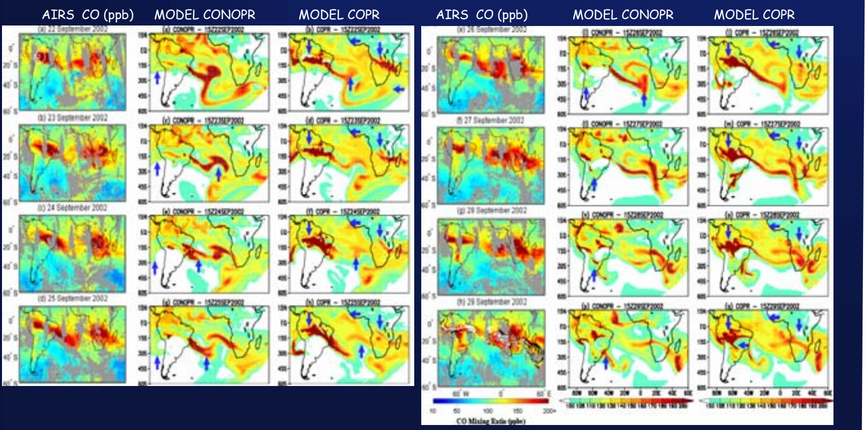
## How to include this sub-grid transport in the model?

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

Use a 1D CRM embedded within 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.

## CATT-BRAMS model results and comparison with AIRS CO satellite estimation

Figure below shows the tropospheric CO mixing ratio (ppb) retrievals from the Atmospheric In-fraRed Sounder (AIRS) onboard NASA's Aqua satellite (McMillan et al., 2005) from 22 to 29 September 2002 at 500 hPa. The figure also shows model results for the tracers CONOPR (at center) and COPR (at right) at 5.9 km height above the surface for the same dates.



## The 1D cloud resolving model - governing equations and numerics

dynamics: $\frac{\partial w}{\partial t}+w\frac{\partial w}{\partial z}=\gamma gB-\frac{2\alpha}{R}w^2$ $\begin{cases}\gamma=\frac{1}{1+0.5} & \text{Simpson\&Wiggert, 1968}\\ \gamma=\frac{1}{1-2\mu} & \text{Siebesma et al, subm. JAS}\end{cases}$

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

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

cloud liquid water cons.: $\frac{\partial r_c}{\partial t}+w\frac{\partial r_c}{\partial z}=-\frac{2\alpha}{R}|w|r_c+\left(\frac{\partial r_c}{\partial t}\right)_{microphysics}$

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

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

- Arakawa-C grid with 100 m resolution, 200 grid points;
- timestep = min (5 s, $\Delta z/w_{max}$);
- upper boundary condition is defined by a Rayleigh friction layer with 60 s timescale;
- 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

Morton, Taylor & Turner (1956):

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

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)

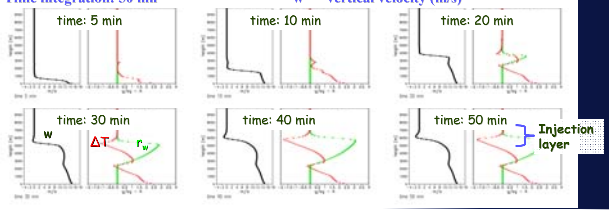
$$\Xi_{flux}(\text{energy flux})=\frac{h\beta c}{\Delta t}\begin{cases}h=1.5 \text{ to } 2.1\;10^7 \text{ joules kg}^{-1}\\ \beta c= \text{fuel load / combustion factor}\\ \Delta t = \text{flaming phase duration}\end{cases}$$

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

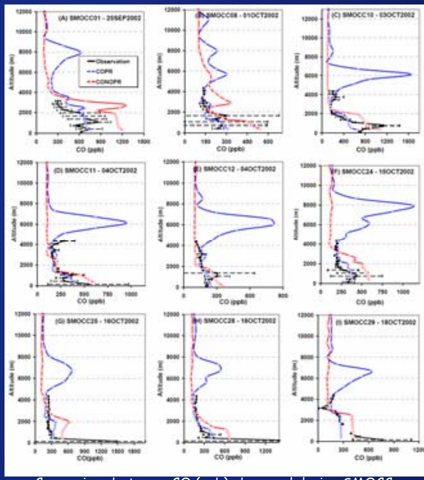
## The 1D cloud resolving model – an example for forest fire

**Heat flux : 80 kW/m²**
**Fire size : 20 ha**
**Time integration: 50 mn**

**$r_w$ = condensate total water (g/kg)**
**$\Delta T$ = T(parcel) – T(environment) (K)**
**w = vertical velocity (m/s)**



## CATT-BRAMS model results and comparison with airborne CO measurements of SMOCC/LBA campaign



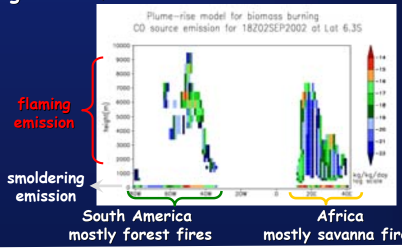
Comparison between CO (ppb) observed during SMOCC flights (black) and model results with plume rise (COPR, blue) and without (CONOPR, red).

Observation
COPR — CO with plume rise (PR)
CONOPR — CO without PR

Comparison of simulated CO profiles in the planetary boundary layer (PBL) and lower troposphere were performed using the SMOCC campaign airborne measurements (Andreae et al., 2004). The airborne part of SMOCC took place in the Amazon Basin during September and October of 2002.

The figure at left shows comparisons for several flights. The mean and standard deviations (STD) of the observed CO profiles are shown; note that STD represents the actual variability of the concentrations, not the measurement error. For flight 11 (figure D, e. g.) the observed CO profile shows the high variability inside the PBL (< 1.5 km) associated with local plumes, which cannot be resolved by the model. Above the PBL and below 3 km there was relatively clean layer, with only a minor haze layer with about 200 ppb CO. However, above 3 km CO starts to increase with height, reaching around 350 ppb at about 4.5 km, the typical maximum altitude reached by the SMOCC aircraft. Haze layers resulting from the detrainment of smoke from convective clouds were visually observed at this height level and also well above the aircraft ceiling altitude during almost all flights in the dry season. Model COPR agrees very well with the observed CO profile, being inside the variability range in the PBL, and following very closely the CO distribution in the lower troposphere. Model CONOPR over-predicts CO in the PBL, and simulates too clean a lower troposphere. For the others flights the results are very similar, confirming the importance of the inclusion of the convective plume rise mechanism.

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



## Conclusions and future works:

- 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 in low resolution atmospheric transport models.
- The super-parameterization technique provides a powerful and feasible approach to include this mechanism.
- Future works will include the effects of environment wind on the dispersion and dilution of the plume at the cloud scale.

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