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Atmospheric
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Interactive comment on “Numerical simulation of tropospheric injection of biomass burning products by pyro-thermal plumes” *by* C. Rio et al.

C. Rio et al.

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Answer to Reviewer 1 comments on the manuscript ’Numerical simulation of tropospheric injection of biomass burning products by pyro-thermal plumes’ by C. Rio, F. Hourdin and A. Chédin.

The authors thank Reviewer 1 for his/her relevant comments we took into account to clarify the submitted manuscript.

General comments: The manuscript describes an adaptation of a mass flux scheme designed to represent convection within the boundary layer to simulate convective plumes induced by vegetation fires. In general, the text is well written and the adapted

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mass flux scheme for pyro-convection and its implementation within a 3d large scale transport model, in spite of the discussed discrepancies with previous studies and observations, seems to be promising. I would recommend the publication after the points below are properly addressed.

We addressed all specific comments below.

P18660-L7: mixing of what?

We mean the mixing between the convective plume and its environment, which refers to lateral entrainment of air from the environment inside the plume and to lateral detrainment of air from the plume to the environment. We thus modify the sentence in the abstract:
'The parameterization, which takes into account the excess of near surface temperature induced by fires and the mixing between convective plumes and environmental air, is first evaluated on two well-documented fires.'
We also clarify this point P18663-L21:
'The thermal plume model is a mass-flux scheme, which computes vertical profiles of water, temperature and velocity inside a plume generated by a buoyancy excess near the surface, given some assumptions about the geometry of the plume and the mixing of air between the plume and its environment, referred to as lateral entrainment and detrainment.'

P18661-L7: add a sentence explaining why the observed excess of CO2 should not be associated to convective transport of boundary layer CO2 by natural cumulus convection.

We add at the beginning of the sentence line 5: 'As there are no meteorological convective systems over those regions at that time of the year which could transport fire emissions to the upper troposphere at a daily scale, the question we try to answer...'

P18661-L1: Change 'condensation' to 'condensation of water vapor'.

This has been done.

P18661-L14: This statement does not apply to the Tropics in general. On deforestation areas of South America and Africa, for example, the atmospheric condition is not permanently too dry and stable and the predominant burnt biome is dense forests.

We modified the paragraph the following way:
'During the dry season, conditions can be less favourable in some regions of the Tropics, where atmospheric conditions can be dry and stable with a strong inversion at the top of the boundary layer, and predominant vegetation is woodlands and grasslands. Even if there are large deforestation areas in South Africa as in South America, high pyro-clouds are rarely referenced in Southern Africa, where pyro-plumes are mostly reported to stay confined within the boundary layer. However...'

P18661-L18: The ECMWF model does not include pyro-convection to estimate the injection height of emissions either GFEDv2 inventory has this information. So, I think this statement is out of context of the discussion.

We deleted this part of the sentence.

P18661-L19: Explain what do you meant with 'off-line'.

We meant that the model is not implemented in the 3D transport model. The 3D model provides synoptic conditions from which the model for pyro-convection deduces a minimal and a maximal injection heights which are then provided to the 3D transport model. However, this point is not really important here, and we simplified the sentence: 'In the latter study, the model for pyro-convection is used to deduce from fire characteristics and synoptic conditions a minimal and a maximal injection height, between which gases are then uniformely emitted and transported by the 3-D model.'

P18663-L9: Combustion heat needs definition and reference.

We modified the sentence the following way:
'The heat released by combustion (E in J m^{-2}) after the passing of the active fire is the product of the density of biomass burned ω (in kg m^{-2}) by the fuel low heat of combustion C (Byram, 1959): $E = C\omega$, with $C \approx 17\,781$ kJ kg^{-1} (Stockes and D., 1987).' and added here the definition of I we removed from page 18669-L2-5.

P18663-L10: Check units of the heat flux (F).

Reviewer 1 is right. Units of the heat flux are J s^{-1} m^{-2} and not J kg^{-1} m^{-2}. This has been corrected.

P18664-L10: Change 'environmental values' to 'environmental mean values'

This has been done.

P18664-Eq. 5: The 2nd term of right side must me wrong, check it.

Reviewer 1 is right. We wrote g instead of ρ in Eq. 5. The right equation is:

$$\frac{\partial f w_u}{\partial z} = -d w_u + \alpha \rho \gamma \tag{1}$$

where

$$\gamma = g \frac{\theta_{vu} - \theta_{ve}}{\theta_{ve}} \tag{2}$$

is the plume buoyancy, θ_v being the virtual potential temperature and g the gravity acceleration.

P18664-Eq 5 and 6: Define in the text the gravity acceleration 'g' and delete it from Eq. 5

This has been done (see previous comment).

P18665-L09: Explain how you specify the diffusion coefficient (K) and the height 'h' within that you assume the diffusion process dominates.

In fact, this part explains the theoritical view behind the pyro-thermal model presented. It aims to explain that there are two scales of turbulence involved. However, as we explain further and remark on page 18666 lines 10-13, the initialization of the plume (excess of temperature and vertical velocity in the first model layer) finally does not depend neither on K nor on h. So, we do not need to define them in the present study. The purpose of Eq. 7 is to show that it may be possible to deduce $\theta_s - \theta_h$ by

making further assumptions on h (for example by defining it as a roughness length) and K (following for example Louis (1979) or Yamada (1983)). But this question is not addressed here and not fundamental for the present study.
We slightly modified the text the following way:
'Note that this initialization does not depend on the K coefficient or h, which thus not need to be specified in the framework of this study. Those coefficients are related to the surface temperature excess $\theta_s - \theta_h$, which thus could be deduced from θ'_0 making further assumptions on K and h.'

P18664- Section 2.2: How do you treat the cloud microphysics in this model? There is not any information, e. g., about the how autoconversion is parameterized in this pyro-convection model.

This depends on what you are referring to by 'microphysics'. Condensation of water can occur within the plume during the ascent, and the condensed water is transported by the plume. However this pyro-convection model does not take into account particle size and growth. At this stage, the aim of the model is to represent the dynamics of pyro-convective plumes. On the one hand, the model does not interact with the radiation scheme of the 3D model, and on the other hand we assume that the microphysics is here of second order on the plume dynamics. Even if it could have some impacts, we are not at the stage of including it in a large-scale model. We added at the end of section 2.2: 'Note that there is no sophisticated representation of cloud microphysics in this model, which aims to represent the dynamics of pyro-convection at a first order. The water is instantaneously condensed when supersaturation occurs, and the condensed water in transported within the plume.'

P18665- L 16: Change 'air specific heat' to 'specific heat of air'.

This has been done.

P 18668-L21: Trentmann et al. (2002) discusses ATHAM simulations for the Quinault fire not Chisholm.

We removed the citation.

P18669-L5: C is combustion heat not combusting heating rate.

We changed it.

P18670-L16: Since the top of boundary layer in S. Africa case is at 1500 m and the plume reaches 2700 m, seems inappropriate to use the expression ˘2018plume being trapped in the boundary layer˘2019. Perhaps ˘2018in the low troposphere˘2019 would be more accurate.

We replaced ’boundary layer’ by ’lower troposphere’.

P18671-L17and18: This finding was reported by several previous works and needs appropriated references to them.

We added the following references:
’The injection height is thus sensitive to both environmental conditions and fire characteristics, as already reported by Kahn et al. (2007), Trentmann et al. (2002) or Freitas et al. (2007). ’

P18673-18674-Section 4.1: An active burning area of 2 km$_2$ *represents an extremely large fire and seems not be a realistic hypothesis. From the presented discussion and Fig 7, one can deduce that the authors treat an ensemble of thousand fires inside a coarse grid box (5 x 5 degrees?) as a only one 'gigantic' fire. Obviously, each fire has your own plume rise which is determined by the local environment condition and the actual fire characteristics. Additionally, the net vertical smoke distribution in the environment of ensemble of fires is not the same as that one produced by the 'gigantic' fire. This hypothesis must be better justified or explained.*

We correct and precise the resolution of the GCM at the beginning of section 4.2: 72 points in latitude and 96 points in longitude corresponding to grid cells of 2.5×3.75 degrees.
The pyro-thermal plume model aims to represent the vertical transport associated with an ensemble of fires (contained in a grid cell) by a single mean plume, which is not meant to be a giantic fire but a typical plume corresponding to a mean fire which will carry out the transport of CO_2 emissions from all fires (emissions given by Fig. 7). The model is not able to really take into account the variability of fire characteristics within a grid cell. This is why we choose fire characteristics which may correspond to the largest fires. As mentionned in the text (page 18673-L15) they are not the most frequent but are responsible for the major part of the emissions. 'Korontzi et al. (2003) estimate that in semi-arid regions, 60% of the total area burned is related to 3% of the fires, those burning more than 100 km^2, while 43% of fires burn less than 1 km^2, devastating only 2% of the total area burned in those regions.' $S = 2$ km^2 may be quite extreme. However, in the model, S is not meant to correspond exactly to the active burning area of a fire, but to the area warmed enough by the fire to initiate convection. This may include the fire area and the just burnt surrounding area.
We thus include in the text:
P18673-L16:'However, the pyro-thermal plume model is not able to take into account the variability of fire characteristics within a grid cell. As an alternative, we choose to

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specify mean values of fire characteristics which may contribute the most to the total emissions.'

P18674-L4:'For simplicity, the active burning area of a fire is kept constant during the day, and we take $S = 2\,\mathrm{km}^2$. This value is quite large, but does not intend to take into account the restrictive active burning area, but an area warmed enough by the fire to initiate convection, which may include the flaming part of the fire and the just burnt surrounding area.'

P18674-L 8-9: Discusses which observations were used to derive the map of emissions and its temporal and spatial resolution

We recognize this point deserves more information. CO_2 emissions used are derived by Liousse et al. (2009). Liousse et al. (2009) derive daily global biomass burning emissions for gases and particles for the period 2000-2007, covering the AMMA field campaign, at a resolution of 1km×1km over Africa. CO_2 emissions are the product of the biomass burnt and an emission factor. The biomass burnt is computed using burnt area given by the L3JRC product using Spot-Vegetation satellite (Tansey et al., 2008), vegetation map is from the Global Land Cover product developed at JRC-Ispra (http://ies.jrc.ec.europa.eu/our-activities/global-support/global-land-cover-2000.html), biomass densities and burning efficiencies used are from specific studies using AMMA observations (Mieville et al., 2009). Emissions factors are taken from the previous literature (Liousse et al., 2004). We thus modified the sentence:

'For $\overline{F_{CO2}}$, we use monthly mean emissions for July 2006 as derived by Liousse et al. (2009) in the framework of the AMMA field campaign at a daily scale with a resolution of 1 km×1 km. Emissions estimates are computed from burnt areas given by the L3JRC product using Spot-Vegetation satellite (Tansey et al., 2008), the Global Land Cover vegetation map developed at JRC-Ispra, biomass densities and burning efficiencies from AMMA observations (Mieville et al., 2009). Fig. 7 displays the mean emissions over July extrapolated to the GCM grid.’

P18674- Section 4.2: How does your model deal with the smoldering phase emission?

The model does not really deal with the smoldering phase emission. The model is not a fire model but a pyro-convection model and thus uses a quite simple representation of fires. The model is activated in each grid cell where CO_2 emissions from biomass burning occur. The model is then initialized with an active burning area and a heat flux. There are no dictinctions between the flaming and the smoldering phases of fires to define those two quantities. We consider that the heat flux follows a gaussian centered around 15:45LT with a standard deviation of 1 hour, so that the heat flux varies during the life cycle of a typical fire, while the active burning area is kept constant for simplicity.

P18675-Section 4.3: It’ll be important if the authors explained better how they actually derive the source emission on vertical. Even better if a figure with the vertical distribution of CO2 emission field is provided.

In fact, the vertical distribution of CO_2 obtained with the three simulations is given in Fig. 9. In the simulations CO_2 is emitted in the first model layer (H=70 m), uniformely in REF, and in the area covered by the pyro-plume in TH. Then, the parameterizations of the model transport the emissions (boundary layer turbulence, deep convection scheme where deep convection occurs). The difference between REF and TH is that CO_2 is also transported by the pyro-thermal plume in TH, and the vertical distribution is then deduced from Eq. 4 applied to CO_2 concentration. This question is discussed in section 4.4. We add page 18675-L21:
’In both simulations, CO_2 is emitted in the first model layer, uniformely in simulation REF, only in the grid area covered by the pyro-plume in simulation TH. It is then

transported by the different parameterizations of LMDz (boundary layer turbulence, deep convection and pyro-convection for TH)'.

Technical corrections:

We made the following technical corrections.

At several places, change 'cloudy liquid water' to 'cloud liquid water'.

P18672-L6: Change 'left' to 'right'.

Caption of figure 6: delete the letter 'n' of the word 'ration'.

Caption of figures 9, 10: change 'concentration' to 'mixing ratio'.

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