Review of ”Technical Note: Sensitivity of 1-D smoke plume rise models to the inclusion of environmental wind drag” by Freitas et al., for publication in Atmospheric Chemistry and Physics.
MS-NR: acp-2009-333

(The reviewer’s comments are in italic style and blue color)

RC C5305 : Anonymous Referee #2

We thank very much to this reviewer for his/her insightful and helpful comments. The paper is now much improved by his/her comments, corrections and suggestions. In the following we provide individual replies to each question.

The manuscript describes an extension of the parameterization of the 1D fire plume model PRM by including the effects of horizontal wind on the vertical structure of the simulated plume. The results with and without the additional terms are compared to results from the 3D plume model ATHAM. A significant improvement of the vertical structure due to the improved parameterization is shown.

General Comments
- The paper needs major revisions in terms of structure and language.
A full revision of the text was done based on your comments and suggestions.

- The study is presented as a technical note. However, the text in its present form does not sufficiently explain the premises of the parameterization. The description of the equation system, the basic assumptions and the simplifications should be improved so that the reader can understand and judge the parameterization.

This work is an extension of the previously published in Freitas et al. (2007, hereafter F2007). F2007 discusses on details the premises of the plume rise parameterization and describes its equation system and the basic assumptions/simplifications. Along these lines, we assume that all this discussion and information should not be repeated in this manuscript.

- The extension of the existing parameterization is the addition of horizontal entrainment caused by lateral winds. The additional term entrainment coefficient is obtained from first principles of mass flux considerations, the entrainment is proportional to the difference of in-plume and ambient winds. Is this idea new, are there no references to existing work?
To the author’s knowledge no study applied this mass flux budget to include the additional entrainment discussed here.

- The effects of the new parameterization are compared to ATHAM, but how does ATHAM compare to reality? Please discuss.
The following discussion is now included in the text:
“Evaluating the quality of ATHAM simulations with reality is a challenging task. The ATHAM model results substantially depend on the initial and boundary conditions of the atmosphere and the fire. While the atmospheric conditions are usually known within an acceptable accuracy, fire information (e.g., the amount of biomass burned within a known period of time) is rarely available. ATHAM results have been evaluated for two

vegetation fires, for which some information on the fuel was available: the Quinault Fire at the US Pacific Coast and the Chisholm fire in Canada. In both cases, ATHAM was able to realistically simulate the evolution of the plume and its injection height (Trentmann et al., 2002, 2006). "

We agree with the referee that more case studies of such kind would be desirable. Future work with ATHAM will continue to evaluate the model performance for available observations from fire plumes.

- The link of PRM to the Freitas parameterization used in large scale models needs to be explained.

In the introduction section has now the follow paragraph:

"In the methodology proposed by Freitas et al. (2006, 2007), the 1D plume model is embedded in each column of 3D low resolution atmospheric chemistry-transport models (the hosts) to provide interactively the smoke injection height, in which trace gases and aerosols, emitted during the flaming phase of the vegetation fires, are released and then transported and dispersed by the prevailing winds simulated by them."

- Simple parameterizations like the one of PRM are also used in large scale models to obtain the fire injection height that depends on subscale processes that cannot be resolved by the coarse grids of such large scale models. Therefore, the results presented in the manuscript are relevant beyond the scope of the described study, but this should be more highlighted in the paper.

Thanks for the suggestion. In the sections introduction and conclusions this relevance has been discussed, as well as in Freitas et al. 2006, 2007.

Abstract

- Please explain the subject of the paper in an understandable way, i.e. also the purpose of the Freitas parameterization, possibly in the first paragraph. (Short sentences are easier to understand.)

The abstract was rewritten to better explain our subject.

Introduction

- P14714, L 24/25 Due to radiative cooling and the efficient heat transport by convection, there is a rapid decay of temperature above the burning area. Change to: Due to radiative cooling and the efficient dilution due to expansion during convective rise, there is a rapid decay of temperature above the burning area.

The original text:

"Due to radiative cooling and the efficient heat transport by convection, there is a rapid decay of temperature above the burning area. Also, the interaction between the smoke and the environment produces eddies that entrain colder environmental air into the smoke plume, which dilutes the plume and reduces buoyancy."

Was changed to:

"Due to radiative cooling and the work done against the environment due to expansion during convective rise, there is a rapid decay of temperature above the burning area. Also, the interaction between the smoke and the environment produces eddies that entrain colder environmental air into the smoke plume, which cools and dilutes the plume and reduces buoyancy."

- P14715, L8: can lead to a bent-over over and enhance lateral. . .
Done.

- P14715, L 17-20: These references are quite old and only refer to (1D and 2D, discuss this short-coming) simulations of volcanic eruptions. Please add more recent literature, discuss observations of the real world (e.g. the papers of Gerald Ernst et al. in volcanic plumes) and possibly on the dynamics of fires.
We agree that 1D and 2D simulations only have limited value for the determination of the injection height of strong convective events like volcanic eruptions and pyro-convection, which is the reason that we are using 3D model simulations to evaluate the 1D model. However, to the author's knowledge no study using a 3D model is available in the literature that addresses the impact of the horizontal wind on the injection height. In the revised version we comment on the shortcoming of 1D and 2D simulations for the determination of the injection height. In addition, we refer to the work of Ernst at al., 1994 and more recent work on the impact of wind shear on the plume behavior (Cunningham et alk., 2005, Cunningham and Linn, 2007). Reference is also given to observational studies that provide evidence of the dynamical impact of wind shear, e.g., in the plume from Hekla, Iceland, in 2000 (Rose et al., 2003).

Cunningham, P., S. L. Goodrick, M. Y. Hussaini and R. R. Linn, Coherent vortical structures in numerical simulations of buoyant plumes from wildland fires, International Journal of Wildland Fire, 14, 61-75, 2005.

Cunningham, P., R. R. Linn, Numerical simulations of grass fires using a coupled atmosphere-fire model: Dynamics of fire spread, J. Geophys. Res., 112, D05108, 10.1029/2006JD007638, 2007.

Rose, W. I., et al. (2003), The February–March 2000 Eruption of Hekla, Iceland from a Satellite Perspective, in Volcanism and Earth's Atmosphere, Geophys. Monogr. Ser., vol. 139 edited by A. Robock and C. Oppenheimer, pp. 107–132. AGU, Washington, D. C.

Ernst, G G J, J P Davis and R S J Sparks, Bifurcation of volcanic plumes in a crosswind. Bull Volcanol 56: 159-169, 1994.

Methodology

- P14716, L 0: Methodology of what? You are describing the PRM model here. Please change title.
Title changed to "Model formulation".

- P14716, L 1: the rise is not explicitly simulated, but parameterized.
Done

- P14716, L 5: organized flow=advective flow?
This kind of entrainment is normally called 'organized' to differentiate to the diffusive entrainment at the edges of the cloud.

- P14716, L 10: why is the near surface layer accelerated?
The smoke is released into the atmosphere with nearly zero horizontal wind speed which implies on a strong initial entrainment and horizontal acceleration.

- P14716, L 12: delete additional, change size to diameter

We prefer to change to ‘radius’ to keep the consistency with the terminology used.

- P14718: rewrite section:
+ explain all variables (e.g. what are B, g, in eq 1?)
Done.

+ first introduce the concept of horizontal and vertical entrainment by two variables to simplify the equations Ehor= 2/(R pi) (ue − u): horizontal entrainment (why dynamic?) Evert= 2 pi/R |w|: vertical entrainment
Thanks for the suggestions. The equations are simplified now and more readable. However we disagree with the suggested terminology and we’d like to keep the one used in cumulus parameterization: ***lateral*** instead of ***vertical*** entrainment.
We call the new entrainment as ‘dynamic’ because it comes from the organized inflow of ambient air into the plume, resultant from the relative horizontal motion existent between the in-plume air parcels and the ambient.

+ then explain the general meaning of the equations (conservation, motion, thermodyn, . . ., and how do you obtain eq 6?,)
The general meaning of equations are described and for the eq 6 the following text reads now:

”Equation (6) is introduced to represent the gain of horizontal velocity of the plume due to drag by the ambient air flow. It is the horizontal equation of motion and we assume that at the timescale of the plume rise both entrainment terms are main forcings for the horizontal acceleration.”

+ finally explain the new terms and equations and explain their impacts for the inclusion of the effects of horizontal entrainment
Done.

- P14718, L 3: alpha is the entrainment coefficient? why constantly 0.05? please discuss.
Not, entrainment coefficient is the term alpha/Radius. This formulation for the entrainment is normally used at several cumulus parameterization formulations and alpha is a constant normally less than 0.2.

- P14718, L 25: “the horizontal entrainment terms are respon. . .”
Done.

- P14719, L 3: Please give the reader a hint what a Turner style plume might be.
The text reads now:
In ambient at rest, Equation (7) reduces to the traditional formulation described in Turner (1973).

Case Studies, Description
- *Section 3.:*
+ Section 3.2, P14721, L 13-18: Move the complete description of the fire forcing to Section 3.1, as well as the McCarter&Broido factor in L15, and the environment conditions and fire size in the following lines. These have all been the same in the two models and should only be described once.
Done.

+ The model description of both ATHAM and PRM should be moved to Section 3.1, only simulation results should then be described in Section 3.2 and 3.3.
Done.

- P14719, L0: change title, e.g. to Model descriptions and conditions of the simulations, add descriptions of the fire forcing, which is now in Section 3.2., to this paragraph. The description of the simulations should be moved here from section 3.4.
Title changed to "Model descriptions and conditions of the simulations". The descriptions of the fire forcing and simulations were moved to this section.

- P14719, L1: give a short introduction to the following sections, and motivation of the studies. Make a table of all simulations.
Done. A table was included, thanks for the suggestion.

- I would suggest calling the simulations windy and calm, not wet and dry, as you are discussing the effects of wind and not humidity.
Done, thanks for the suggestion.

- P14719, L 26: cloud microphysics is not discussed in this paper!
In section 3, the role of the water vapor condensation and the additional buoyancy gained from latent heat release on the final rise of the plume is discussed for the cases calm (formerly named *dry*) and windy (formerly named *wet*).

3.2 Case Studies, ATHAM
- The description of the simulation results is highly insufficient. Discussion needed: The atmospheric stability is lower in the wet case, so the plume should be higher, but due to lateral wind effects it is bended to the side, at the expense of vertical motion. This also happens in the case of much stronger fire forcing in the 80 ha simulation. ETC. . .
We followed your suggestion including the text:
"At both cases, the atmospheric stability is lower in the windy case, so the plume should be higher, but due to lateral wind effects it is bended to the side, at the expense of vertical motion with stronger mixing with the ambient air properties."

- P14720, L 8: what do you mean with external forcing? are there limitations to the solution of the Navier Stokes equations?
The external forcings mentioned here are the emissions of heat (and momentum) to represent the impact of fire (and volcanic) emissions.

- P14720, L 8/9: what are active tracers? is the aerosol effect on clouds considered?
Active tracers are atmospheric components that are allowed to have such a high concentration that they cannot be neglected in the equation of state for the volume mean density. For the present simulations the hydrometeors and the aerosol particles constitute the active tracers. The concept of active tracers is highly relevant for the simulation of volcanic plume eruptions, but of lesser importance for the simulation of pyro-convection, where the concentration of emitted particles is usually not as high as in the case of volcanic eruptions.

The aerosol effect on clouds in not considered in the present simulations.

- P14720, L 20: Fluxes as in PRM, but how are fluxes in PRM? and what exactly is PRM?

This is now better discussed at the Section 3.1 as recommended by the reviewer. In the PRM model, we did not prescribe fluxes but only the boundary condition for temperature, water vapor, vertical and horizontal velocity of the in-plume air parcels.

- P14720, L 24: Please give a short explanation of the McCarter&Broido factor (and move to Section 3.1.). How can the conversion of heat to convective energy be constant? I guess it would be also depend on ambient conditions?

The following text was included:

"The fraction of the total energy that is effectively available to the plume convection depends on the ambient and fuel conditions and is highly uncertain. Here we use a value in the middle of the commonly accepted range of 0.4–0.8 as described in Trentmann et al. (2002)."

3.2 Case Studies, PRM

- P14721, Section 3.3.: The description of the simulation results is insufficient, should be comparable in detail to the ATHAM results.

The section was entirely rewritten and included 2 sub-sections describing separately the cases of small (10 ha) and big (50 ha) fire size. The simulated injection layer ATHAM is compared with the VMD quantity provided by the 1D PRM.

- P14721, L 19: What do you mean with typically steady state is reached within the simulation time? not always, or are you not sure? In ATHAM, it is 30 min for the small fire (no information given for the large one), how long is it in PRM?

The actual time taken to 1D PRM reach the steady state depends on the heat flux and ambient condition. For the typical conditions on Amazon basin and heat fluxes used (from 20 to 80 kW m^{-2}) this time is between ~ 20 and 50 minutes.

- P14721, L24: It is clear that the fire forcing for the two models are the same, but this should be written in the introduction of Section 1, before 3.1., not in this section.

Here we are referring to smoke plume rise simulations with 1D PRM under two different ambient conditions (calm and windy), but not to the 2 models.

3.3 Case Studies, Comparison

- P14721/22, Section 3.4:

+ Rewrite/Reorder the whole paragraph explaining VMD, separating the description of the simulation (to Section 3.1) the explanation of VMD (We parameterize the vertical mass distribution (VMD) from the vertical wind profile, see Appendix B. The purpose, the limitations... Also provide separate and sufficient descriptions of the simulation results. At the moment everything is mixed, therefore I do not comment on more details.

The section was entirely rewritten and included 2 sub-sections describing separately the cases of small (10 ha) and big (50 ha) fire size.

+ Define and explain all quantities shown in Figure 4, e.g. Ea, Ba, refer to equations. At the moment, the explanations of the figures are obscure.

The formal definitions of Ea and Ba are given in the text now.

+ Ea, Ba: Add definition. How are these simulated by ATHAM? Why are there elevate values above plume top height?
The formal definitions of Ea and Ba are given in the text now. We did not output the equivalent quantities simulated by ATHAM. We did not see any elevate values above plume top height, all acceleration terms converge to zero at the plume top height and above.

+ P14722, L 5: Suddenly you are mentioning regional/global models. How does this relate to PRM? Please explain link to the Freitag parameterization in global models, in the introduction of the paper.
PRM runs embed in regional/global models to provide interactively the injection layer of vegetation fires emissions. The methodology is described in Freitas et al., 2007. This mention was deleted and the link is briefly described in the introduction section as well as in the conclusions.

- P14722, L 20/26: Ea inconsistent: detrainment acceleration or deceleration?
This is fixed now.

- P14721, L 26: Please explain VDM at the beginning of the section.
Done.

4 Conclusions
- How relevant is your work: How are your results linking to fires in the real world (not to the ATHAM world), and to fire simulations in other models on different scales?
As stated at this section, important information obtained from this methodology is the interactive smoke injection height to determine which vertical layers of 3D atmospheric chemistry-transport models will release emissions produced during the flaming phase of vegetation fires. Also, the extended formulation described in this manuscript should improve the simulation of vertical distribution, transport and dispersion of aerosols and trace gases, mainly in areas dominated by small fires, as in savannas, pasture or cropland, and/or in windy environment where the dynamic entrainment processes dominate the plume-environment horizontal mixing. The relevance of this work will be shown by evaluating simulations of the 3-D CATT-BRAMS model embedded with the updated PRM including the horizontal environmental wind drag (as in Freitas et al., 2006). This evaluation is not the goal of the present manuscript, which presents the technical details of the PRM, and will be presented in a forthcoming work.

There are few fires related observational data to be used to evaluate this 1D PRM. So far, we identified two well documented cases: the 1994 Quinault and 2001 Chisholm fires. Since the parameterizations used in the PRM are based on physical principles we expect the PRM results to be robust also compared to fire simulations from other models. Detailed studies comparing the performance of 1D PRM on simulating the plume top and injection heights of these fires will appear on upcoming paper.

- The spatial and temporal resolutions in large scale models are much coarser than in PRM. Please add discussion of the potential effects on your parameterization of this difference.
This issue has been discussed in Freitas et al., 2006, 2007.

Appendix

- P14725, L 17: change in-cloud horizontal mass flux to the turbulent horizontal mass flux within the plume.

We changed to “The horizontal mass flux within the plume”. We prefer do not included the qualification ‘turbulent’ to differentiate this process to that associated to the turbulence occurring at the edge of plume, normally called lateral entrainment.

- P14726, L 9: Add a sentence explaining the purpose of Appendix B: The vertical mass distribution VDM is parameterized from the from the vertical wind profile, in order to compare the results from PRM to those from ATHAM.

The sentence was included, thanks.

- P14726, L 18: why zf > zi ? I would assume the opposite. Is the vertical velocity zero at zf, what is the threshold you use? How does it relate to the final rise of the plume (P14721m L21) which is defined by v<1m/s?

The text was wrong and thanks for point out this error. The text states now that Zf is the level where the vertical velocity is less than 1 m/s. Zf > Zi because Zi is the height below to Zf where the vertical velocity has a local maximum value, looking from above.

- P14726, L 20: VMD is in [%], so this should be multiplied by 100.

Only for visualization purposes we use VMD in [%]. To distribute the total emission from the flaming phase in the vertical layers of 3D transport model VMD must be in the interval [0,1].

***Figures**:*

- Figure 2: in the right hand side figure wet and dry cases cannot be distinguished, use solid and dashed lines. The vertical axes in all 3 figures should cover the same height and the use same axes stretching.

Done.

- Figure 3: Caption: Horizontally averaged vertical aerosol mass distribution (profile?).

Done.

Please use same total height for vertical axis in all plots.

The caption of the figure includes now the text: “Note that the vertical axis uses different ranges for the height Z”.

- Figure 4:

+ What do I see?? I guess it is all from PRM?? Explanations and discussions in the text insufficient.

The caption of the figure 4 was rewritten, see below the new text.

+ The figures are too small. They should be readable in black/which prints (use different line strengths not colors)

The figures look too small because of the format used by ACPD phase. For the final text at ACP, the figure 4 will use an entire A4 page. Not using colors will make the figures harder to be readable because each panel has 4 or 6 curves.

+ Caption: Check grammar, increase understandability and readability.
The caption of the figure 4 was rewritten, it now reads:
"1D PRM model results for the calm and windy cases. For the calm condition, panels A and C show the results for a fire size of 10 ha; while F and H refers to the 50 ha size. The results for the windy case are in panels B and D (10 ha) and G and I (50 ha). The quantities are: vertical velocity (**W**, m s^{-1}), vertical mass distribution (**VMD**, %), entrainment acceleration (**Ea**, 10^{-1} m s^{-2}), buoyancy acceleration (**Ba**, 10^{-1} m s^{-2}), and total condensate water (**CW**, g kg^{-1}). Model results considering the environmental wind drag are in red color. Black color depicts the simulations disregarding this effect. The grey rectangles indicate the main injection height simulated by the ATHAM model."

+ Env. wind ON/OFF should not be written into Panel B, as it applies to all panels.
+ Legend always applys to the two panels in a row, but this should be mentions!
It appears now on each the two panels in a row, thanks.
+ Ea, Ba???
Definitions are in text and caption.

Language and Grammar

- Change throughout the paper 'the ambient' to the ambient atmosphere,
Done.

- Exchange in-cloud with within in the plume: the focus is on fire plumes, which can be without condensed water.
Ok, thanks for the recommendation. We actually exchanged "in-cloud" with "in-plume", to improve the readability of the text.

- P14715, L 7: Remove blank before dot
Done.

- P14716, L 1: we describe the improvement of the 1-D parameterization. . .
Done.

- P14716, L 6: in-cloud = within the plume? if you are discussing the biomass plume, please do not use the term in-cloud, this might lead to confusion, throughout the paper.
Done.

- P14716, L 17: be consistent: either Section or Sect. throughout the paper
Done.

- P14716, L 24-26: check grammar and parentheses. Which quantity appears?
Done.

- P14718, L 1/2: "In the equations above the index e stands for the environmental value, all other variables refer to the center of mass of the plume".
Done.

- P14718, L 3: check expression: in an ambient wind
Done.
.

- P14718, L 6/7: mixing between in-cloud and ambient air inside the plume: cloud=plume? check language throughout the paper
Done.

- P14719: improve language and grammar, which local time is 1800Z (Z time would rather be called UTC)?
Done.

- P14721, L 6 altitude distribution -> vertical extension?
Done.

- P14721, L24: supposed -> assumed?
Done.

- P14722, L 16: broader (horizontal) -> deeper (vertical)?
Done.

- P14722, L 19: condensate water -> condensed water (and ice)?
We refer to condensate water as the sum of liquid and ice contents.

- P14725: change Subscript env to Subscript e to be consistent with the rest of the paper, where subscript e means environment
Done.

- Description of heights are not consistent, definitions unclear:
+ P14720, L 25 outflow height -> height of neutral buoyancy?
It reads now 'injection height".

+ P14721, L 4 emission height (=ground level) -> injection height, height of neutral buoyancy?
It reads now 'injection height".

+ P14721, L 21: The definition of the final rise of the plume -> height of neutral buoyancy should be defined consistently in the 2 models, i.e. in ATHAM horizontally integrated vertical velocity >1m/s, how is this defined in PRM?
The PRM condition uses the threshold value of 1 m/s to determine the top of the injection layer.

+ P14722, L 5: What do you mean with mass detrainment layer, vertical emission source field? Be consistent in language, distinguish top height, injection height, umbrella region, height of neutral buoyancy. VMD gives a height interval, not one layer.
The expression "mass detrainment layer" was replaced by "injection layer", and 'vertical emission source field" by '3-D emission field".

+ P14722, L 10: cloud top-> height of neutral buoyancy? (I repeat this here.)
Done.

+ P14722, L 18: detrainment zone -> height of neutral buoyancy? (repeated again.)
It reads now 'injection height".

+ Appendix B: use other terminology: it is not the upper half part (=50% of total height) of the plume (not cloud), but the umbrella or outflow region.?

The text reads now “ATHAM model results for the vertical velocity profiles (not shown) demonstrated that the main smoke injection layer, defined in terms of the horizontally averaged mass distribution (see Figure 3), is indeed situated in the outflow region close to the plume top. Here we parameterize the outflow region as the upper half part of the plume”.