Geosci. Model Dev. Discuss.,
https://doi.org/10.5194/gmd-2020-227-RC1, 2020

Geoscientific Model Development Discussions
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Interactive comment on "PLUME-MoM-TSM 1.0.0: A volcanic columns and umbrella cloud spreading model" *by* Mattia de' Michieli Vitturi and Federica Pardini

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Received and published: 2 November 2020

This paper presents a sophisticated one-dimensional plume model with capabilities beyond any that I am aware of in volcanology. One-dimensional volcanic plume models have proven useful for examining properties of real plumes because they run fast, can incorporate real atmospheric conditions, and provide key pieces of information, such as plume height, neutral buoyancy height, and profiles of velocity, radius, and hydrous phases at different elevations.

The main advance in this model is a two-size moment method for calculating particle aggregation, and a new formula for calculating umbrella-cloud growth. The manuscript

is well written and math is appropriate and well-documented. figures for the most part are clear, and for the example application, the conclusions seem to be well supported. Thus I have no hesitancy in recommending this manuscript for publication, following minor changes.

The most important suggested changes are: 1) Some of the constants and input values would be easier to examine if placed in table form. These include for example values of specific heat and reference enthalpy, input data used for the Calbuco simulations, and atmospheric properties, both for the Calbuco simulations and for the Standard Atmosphere illustrated in Figure 9. Details are below. 2) The method used to solve for umbrella-cloud spreading (equations 40) could be described in more detail. In particular, do you set up an x-y grid on a horizontal plane at the neutral buoyancy level and solve these equations at the grid points? If not, how do you do it? 3) It would be beneficial to add a paragraph comparing the aggregate-size distribution shown in Figure 9 with what is known about aggregate size distributions from proximal deposit mapping. I have the impression that most aggregates described in proximal areas occur in a rather narrow size range of millimeters to a few centimeters, and that nearly all fine ash is partitioned into that ash. Figure 9 shows a wider size range for aggregates, and shows a large percentage of the fine ash survives to reach the top of the plume. How must the aggregation parameters, particularly beta, be varied to partition all the fine ash into aggregates having a very narrow size range? 4) Although the English is clear, there are lots of tiny grammatical errors. I have flagged those errors in an accompanying pdf. Below are more specific or technical comments. The attached pdf includes these comments as well as corrections of the grammar. Because all the significant comments are listed here, I think the authors only need to respond to these (not also the ones in the pdf) when returning the revised manuscript.

Overall I think this paper will be a significant contribution to the literature on volcanic plumes.

Larry Mastin

Specific and technical comments Line 108: why is it called the “two-size moment method”? Line 114: “the NDF is reconstructed with a linear function”. Linear with regard to whet? particle mass? Equation 10: there seems to be a subscripted left square bracket in each equation that should not be subscripted. Line 195: It’s interesting that your control volumes are cylindrical sections with a vertical axis, not with an axis parallel to the plume axis. This implies that the axes of stacked cylinders are not co-linear. Yet in the mass flux equation (eq. 12) you calculate the mass flux from one cylinder to another as something like pi*rˆ2*w, where w is the vertical velocity. What sort of approximations are implied in eq. (12) if the stacked cylinders are not co-linear? Line 215: Where does equation 13 come from? Can you provide a reference? Line 220: You need a reference to the Von Smoluchowski equations. Line 264: The equation for entrainment velocity U_e appears to assume a 2D geometry. but you are solving for a 3D system. Are the equations the same for 2D and 3D? Line 282: Where do you list the values of C and h0 that are used in equation 27? Also, I think there should be some discussion in the main body of the paper of the freezing temperature that you use in the model, and whether you consider a temperature range over which liquid and ice coexist. You explain this in Appendix A1 but I think it would be worth mentioning here as well. Line 285: I presume the specific heat capacities C are heat capacities at constant pressure (C_p), not at constant volume (C_v). This would be worth mentioning. Equation 28: the term for enthalpy of dry air on the RHS of this equation is w_atm*(h_wv0-C_wv*T_atm). I thought it would be w_atm*(h_wv0+C_wv*(T_atm-T_0)). Am I missing something? Line 306: Change “A 4-5th order Dormand-Price . . . “. to “a 5th order Dormand-Price . . . “(?) Line 349: change “Appendix A” to “Appendix A1” Lines 353-360: Here you mention that you use the buoyant plume equations to model plume rise up to the neutral buoyancy level, and then use the shallow water equations to model umbrella cloud spreading. Switching to the shallow water equations as soon as you reach the neutral buoyancy elevation would prevent you from modeling plume rise up to the maximum height of the overshooting top. Why not model plume rise up to the maximum height and then descent back to the neutral buoyancy

elevation before switching to the shallow water equations? Line 376: The calculation of N usually requires a numerical calculation of the gradient del(rho_atm)/del(z) over some finite height interval. Over what height interval are you calculating? Figure 4 caption: “Above the neutral buoyancy level, the colored contours represent thickness levels of the steady solution computed by the transient umbrella model.” This is confusing. “the steady solution computed by the transient umbrella model”? What does this mean? equation 40: How do you solve these equations? Do you set up an x-y grid in a horizontal plane at the umbrella-cloud height and solve these equations at each node? equations 41 and 42: I can’t find a definition for chi. equation 42: where is the origin for x and y used in these equations? I think earlier you said it was the vent location, but in this case it would seem more appropriate to be the location of the plume axis at this elevation. Also, chi is written as CHI|(xˆ2+yˆ2>r_nbl). Shouldn’t this be CHI|(sqrt(xˆ2+yˆ2)>r_nbl)? Section 2.3: You need to cite Appendix A1 here for a description of water phase changes. It would help also to cite it near equation 27. line 387: define CFL condition. Section 3.1: April 2015 Calbuco eruption In the first paragraph of this section, you have listed most of the key model inputs, but a few are missing (or were difficult for me to find). In particular, the grain-size distribution, the vent elevation, and an atmospheric sounding. It would be useful to have two tables listing these inputs. Line 409: the information on grain-size distribution in this sentence does not provide the mass fractions of each grain size. It would be better to list it in a table. Figure 5 (and other figures with multiple plots): It would be useful labeling these plots “a”, “b”, “c”, etc. And in the plot of relative density vs. height, it would be useful to have a black vertical dashed line indicating a relative density of zero. Also, it looks like these results are calculated using only the buoyant plume calculations, not the shallow-water equations. The curves of ascent velocity and relative density for example extend above the neutral buoyancy level, apparently all the way to the plume top, where ascent velocity reaches zero. Are the circles plotted at each elevation in the lower right, above the level of neutral buoyancy, also calculated from the buoyant plume model? Or are they calculated using the shallow water equations? Figure 5: it would be useful to have labels in each row: A=”no aggregation”, B=”Costa”, C=”beta=1e-15”, D=”beta=1e-14”, E=”beta=1e-13”. line 469: what are the sizes of the initial particles? Line 471: why did you choose an aggregate density of 1500 kg/m3? This seems dense for an aggregate, but perhaps it’s appropriate for an ice aggregate containing dense particles. Figure 8 caption: I’m a little confused about what is shown in the left column. The caption says it is the GSD at the neutral buoyancy level but then it says that the blue bars represent the particle size distribution released at the vent. Also, it would be useful to indicate the neutral buoyancy level in the plots on the right column. Lines 489-490: “It is important to note that the neutral buoyancy level differs from that obtained without aggregation by less than 0.1%,”. I don’t see the NBL height shown for the runs in Fig. 8. End of Section 3.1: I have the impression that most aggregates that have been mapped in proximal fallout (Self, 1983, Fig. 8; Sisson, 1995, Fig. 9; Wallace and others, 2013) and produced in shaker-pan experiments (Van Eaton and others, 2012) have a narrow size distribution, millimeters to a couple of centimeters in size; and nearly all fine ash (phi>∼4) is incorporated into aggregates. The aggregate size distributions you show in rows B-E show a wider range of aggregate sizes, and, in rows B-D, a large fraction of the finest ash survives as individual particles. How do you think the aggregation parameters would have to differ from those you use in order to produce a similar aggregate size distribution? Non-constant value of beta? Higher value of beta? Line 522: what is orthometric height? line 535: “Moist unsaturated air cools with height at a slightly lower rate than dry air (Dutton, 2002)”. Are you referring to the wet versus dry adiabatic lapse rate? I thought the environmental lapse rate (6.5 C/km for a standard atmosphere) was independent of humidity. line 570: How did you adjust the mass eruption rate? By changing vent diameter? Line 606: change “wincreasing” to “increasing” Section 3.2, paragraph 1. It would be useful to have a table listing the properties of an ISA Standard Atmosphere. equation 43C: should R be R_air? the table of notation in Appendix C1 indicates that R_air is the specific gas constant for air. Figure 9: In the y-axis labels to all the plots, change “Hight” to “Height”. Appendix A1: nice description. A complicated, iterative procedure depending on temperature and saturation conditions

seems like about the only way to solve for T. Line 667: “For T>29.65 K”. Should this be “for T>29.65 C”? Line 688: “where P_wv and e_s are functions of x_wv only”. Do you mean “where P_wv is a function of x_wv only”? I thought e_s was a function of T, as indicated in equation A5. Line 753: I don’t see any explanation of how you calculate Gamma_s, the fluid shear, in equation A20. Appendix B: Figures B2 and B3: in the plot of “liquid water and ice mass fraction”, I don’t see any curves representing ice. Also, it would be useful to label each plot in this figure “a”, “b”, “c”, etc. In the curve of relative density, it would be useful to have a vertical black dashed line at a relative density of 0. Appendix C list of terms is not complete. Missing for example are S terms, OMEGA, the meaning of hats (ˆ) and overbars, N_k and M_k from eq. (11), etc.

References Self, S., 1983, Large scale phreatomagmatic silicic volcanism: a case study from New Zealand: Journal of Volcanology and Geothermal Research, v. 17, p. 433-469. Sisson, T.W., 1995, Blast ashfall deposit of May 18, 1980 at Mount St. Helens, Washington: Journal of Volcanology and Geothermal Research, v. 66, p. 203-216. Van Eaton, A.R., Muirhead, J.D., Wilson, C.J.N., and Cimarelli, C., 2012, Growth of volcanic ash aggregates in the presence of liquid water and ice: an experimental approach: Bulletin of Volcanology, v. 74, no. 9, p. 1963-1984. Wallace, K.L., Schaefer, J.R., and Coombs, M.L., 2013, Character, mass, distribution, and origin of tephra-fall deposits from the 2009 eruption of Redoubt Volcano, AlaskaâĂŤHighlighting the significance of particle aggregation: Journal of Volcanology and Geothermal Research, v. 259, no. 0, p. 145-169.

Please also note the supplement to this comment:
https://gmd.copernicus.org/preprints/gmd-2020-227/gmd-2020-227-RC1-supplement.pdf

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