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Interactive comment on "A semi-implicit, second order accurate numerical model for multiphase underexpanded volcanic jets" *by* S. Carcano et al.

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We welcome comments by Prof. Sesterhenn, which give us the opportunity to clarify some points and discuss some future development of our work, aimed at continuous PDAC model evaluation and improvement.

1) Numerical scheme benchmark. Following Oreskes et al. (1994), we distinguish between model benchmark and validation. As reported in the paper, the numerical schemes on which we have based our numerical improvement of the PDAC code are well established and have been widely benchmarked. Nevertheless, we have tested the new spatial discretization and time-advancement schemes on the one-dimensional single-phase shock tube problem (as also discussed by Esposti Ongaro et al.,

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2007). The results (see auxiliary Figure 1) demonstrate that, for the 1D problem, the improvement is not significant (since the scheme is still second-order accurate). However, as clearly demonstrated in the paper, for multidimensional problems the new numerical scheme is far more accurate than the old one. In its general formulation, the multiphase flow model is not strictly hyperbolic in all regimes (see e.g., the discussion on Model A by Hudson and Harris, 2006). Only in some particular cases, a numerical solution based on approximated Riemann solvers can be found (see, e.g. Pelanti and LeVeque, 2006). A complete discussion on the best numerical scheme to solve the flow equations was therefore beyond the scope of this paper.

2) Model validation. As a *model evaluation* paper the main aim of this work is to assess the capability of our model to reproduce some of the main features of volcanic eruptions. The supersonic, underexpanded volcanic jet was our first choice, due to its relevance in controlling the initial stages of explosive eruptions. We agree, however, that turbulence is a key process in the subsequent development of volcanic plumes and that the numerical code accuracy should also be assessed on turbulent flows. We are currently working on that and will explore such phenomenology in a future paper.

3) Turbulence. The interaction between turbulence and shock waves is a challenging topic, even for single-phase gas dynamics. In multiphase flow, the situation is complicated by the presence of the dispersed phase, whose influence on fluid turbulence depends on the degree of coupling between gas and particles but is also strongly affected by total particle concentration (Balachandar and Eaton, 2009). A detailed study on multiphase turbulence-shock interaction in volcanic jets is certainly beyond the aims of the presented work (but we would be very happy to discuss how to proceed in this direction). To partially answer the question, however, we have tested the influence of the subgrid model and viscous terms on our results, in a few test cases. When focusing on the near-vent explosive behaviour of volcanic eruptions, turbulent entrainment likely

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plays a minor role in the jet development, which is the reason why the sub-grid terms have not been considered. In its general formulation, we model the effect of sub-grid turbulence by adopting a viscous model with LES-Smagorinsky closure (see Esposti Ongaro et al., 2007). Comparison of the results of the same test case (auxiliary Figures 2 and 3), with or without the viscous and subgrid terms demonstrates that, in the development of the supersonic jet above the vent, the dynamics is controlled by inertial, pressure, and drag terms, so that it is possible to neglect any diffusion term in the equations. The 2D plots of temperature and vertical velocity (Figures 8 and 10 in the paper) do not show significant differences when viscous and turbulent terms are on.

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Table 1. Left and right initial conditions for the one-dimensional single phase shock tube problem. The initial discontinuity in the flow is located at x = 0.5 m.

P_{left}	[Pa]	1.0
ρ_{left}	[kg·m^{-3}]	1.0
u_{left}	[m·s^{-1}]	0.0
P_{right}	[Pa]	0.1
ρ_{right}	[kg·m^{-3}]	0.125
u_{right}	[m·s^{-1}]	0.0

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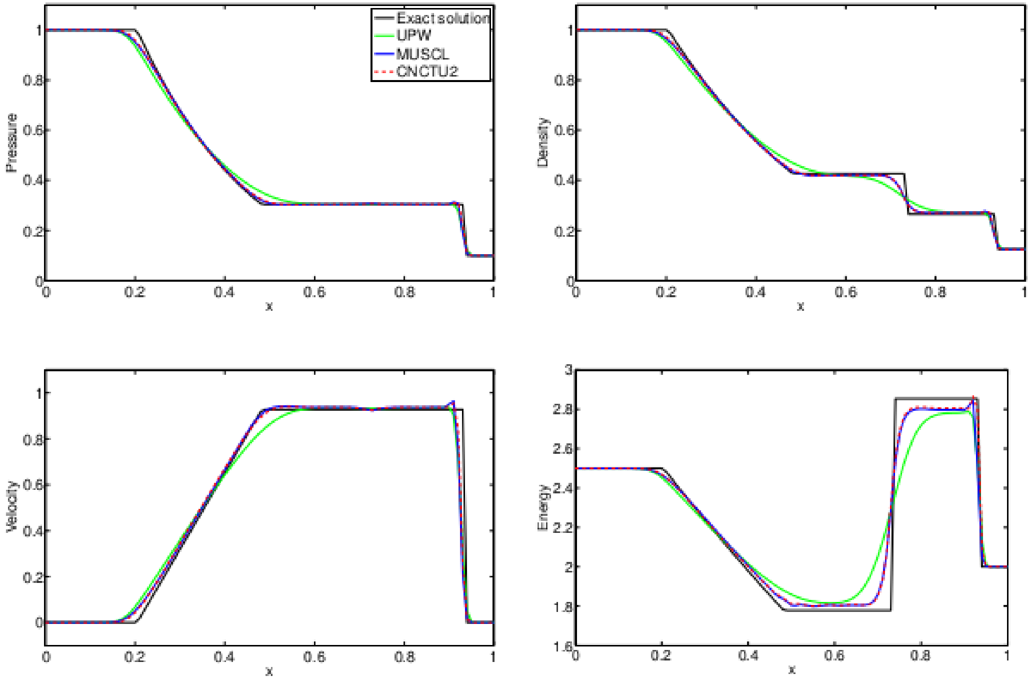

Fig. 1. One-dimensional single phase shock tube problem. Numerical solution at time t = 0.25 s.

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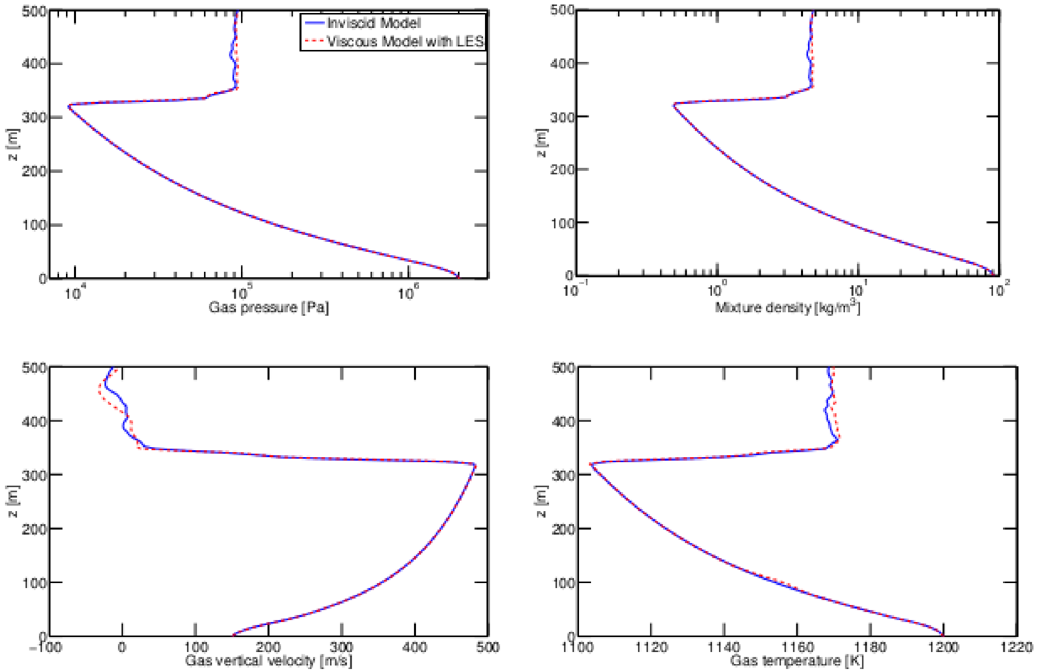

Fig. 2. Case A. Axial profiles of gas pressure, mixture density, gas vertical velocity and temperature. Comparison between results obtained with inviscid model and a viscous model with LES-Smagorinsky closure

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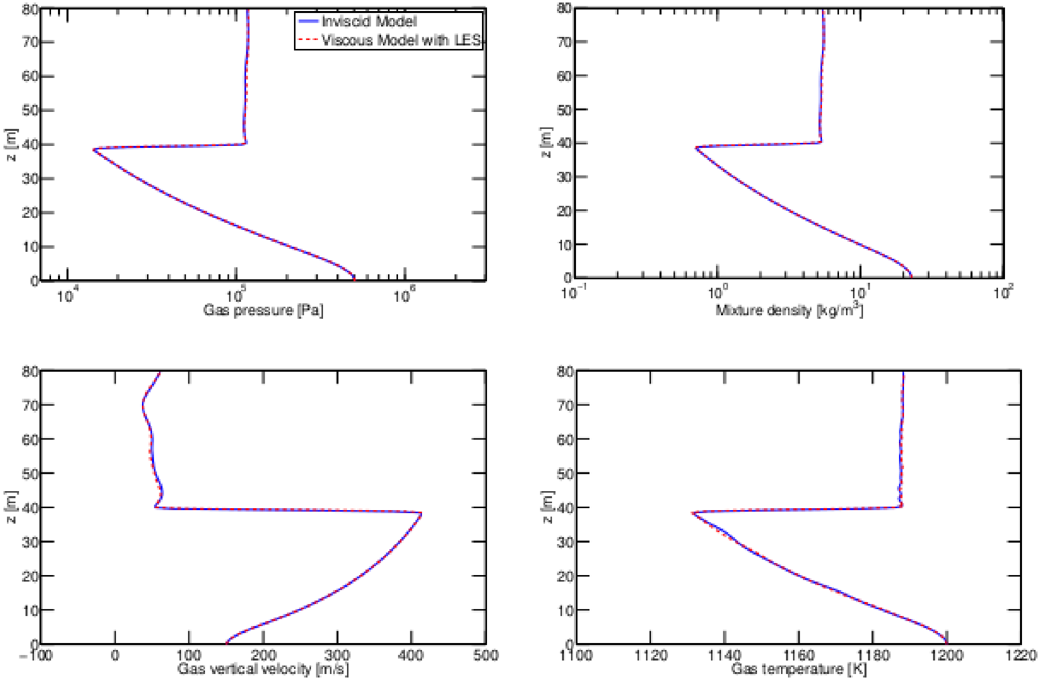

Fig. 3. Case B. Axial profiles of gas pressure, mixture density, gas vertical velocity and temperature. Comparison between results obtained with inviscid model and a viscous model with LES-Smagorinsky closure

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