Plume-SPH 1.0: A three-dimensional, dusty-gas volcanic plume model based on smoothed particle hydrodynamics

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VATDs (Volcanic ash transport and dispersion models) used for volcanic ash forecasts often take outputs of eruption plume models as source terms. The accuracy of these terms is crucial for forecasts from VATDs. All existing 3D (three dimensional) plume models described in the literature use mesh based methods. SPH (smoothed particle hydrodynamics), as a mesh free method, has several advantages over mesh based methods in modeling of multiphase free boundary flows. As an initial effort to exploit the feasibility and advantages of SPH in volcanic plume modeling, we adopt a relatively simple model, a 3D dusty-gas dynamic model, targeted at capturing the salient features of a volcanic plume. In this model, erupted material is assumed to be well-mixed, and represented by one phase while air is another phase. We also assume dynamic and thermodynamic equilibrium between air and erupted material and that the effect of wind is not significant.
Several newly developed techniques in SPH are adapted and extended to address numerical challenges in simulating multiphase compressible turbulent flow with classical SPH method. The $SPH-\varepsilon$ turbulence model is to capture mixing at unresolved scales. Heat exchange due to turbulence is then calculated by Reynolds analogy. A corrected SPH is used to handle tensile instability and deficiency of particle distribution near the boundaries. We also propose to impose velocity inlet and pressure outlet boundary conditions, both of which are scarce in traditional implementations of SPH. The core solver of our model is parallelized with MPI (message passing interface) obtaining good weak and strong scalability. The model is verified by comparing velocity and concentration distribution along the central axis and on the transverse cross with experimental results of JPUE (jet or plume that is ejected from a nozzle into a uniform environment). Next, the top height of the Pinatubo eruption of 15 June 1991, as simulated by our model, is consistent with both observations and existing 3D plume models. Profiles of several integrated variables are compared with those calculated in existing 3D plume models, and further verify our model. Analysis of the plume evolution process illustrates that this model is able to reproduce the basic physics of plume development. The comparison also implies that the turbulence model plays a significant role in 3D volcanic plume modeling.