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

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Abstract.

Plume-SPH provides the the first particle based simulation of volcanic plumes. SPH (smoothed particle hydrodynamics) has several advantages over currently used mesh based methods in modeling of multiphase free boundary flows like volcanic plumes. This tool will provide more accurate eruption source terms to users of VATDs (Volcanic ash transport and dispersion models) greatly improving volcanic ash forecasts. The accuracy of these terms is crucial for forecasts from VATDs and the 3D SPH model presented here will provide better numerical accuracy. As an initial effort to exploit the feasibility and advantages of SPH in volcanic plume modeling, we adopt a relatively simple physics model (3D dusty-gas dynamic model assuming well mixed eruption materiel and dynamic and thermodynamic equilibrium between air and erupted material and minimal effect of winds) targeted at capturing the salient features of a volcanic plume. The documented open source code is easily obtained and extended to incorporate other models of physics of interest to the large community of researchers investigating multiphase free boundary flows of volcanic or other origins.

The Plume-SPH code also incorporates several newly developed techniques in SPH needed to address numerical challenges in simulating multiphase compressible turbulent flow. The code should thus be also of general interest to the much larger community of researchers using and developing SPH based tools. In particular, the $SPH-\varepsilon$ turbulence model is to capture mixing at unresolved scales, heat exchange due to turbulence is calculated by a Reynolds analogy and a corrected SPH is used to handle tensile instability and deficiency of particle distribution near the boundaries. We also developed methodology 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 using novel techniques for data management using a SFCs (space-filling curves) and object creation time based indexing and hash table based storage scheme. These techniques are of interest to researchers engaged in developing particle in cell type methods. 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) and the top height of the Pinatubo eruption of 15 June 1991. Our results are 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 physics of plume development.