A fast Eulerian multiphase flow model for the three-dimensional numerical simulation of non-equilibrium effects in turbulent volcanic plumes

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We have developed a fast Eulerian model for the Large Eddy Simulation (LES) of turbulent volcanic plumes. The model is based on the equilibrium-Eulerian approximation (Ferry and Balachandar, Int. J. Multiph. Flow 2001; Cantero et al., J. Geophys. Res., 2008) for a polydisperse flow.

This approach gives particular attention to the particle grain size distribution and its interaction with the turbulence. We are indeed particularly interested in the disequilibrium between the ash and the gaseous part of the volcanic mixture, our aim being to properly simulate phenomena like preferential concentration and plume entrainment.

In the limit of fine particles (at Stokes number < 0.2) and dilute regimes (particle volume concentration < 1.e-3), such method allows to overcome the limitations of the pseudogas models (assuming a perfect kinematic and thermal equilibrium between gas and particles - Oberhuber et al, J. Volcanol. Geoth. Res., 1998; Suzuki et al., J. Geophys. Res., 2005) without entailing the complexity and computational cost of the fully coupled multiphase flow Eulerian models (Neri et al., J. Geophys. Res., 2003; Dufek and Bergantz, Theor. Comput. Fluid Dyn., 2007).

To model the non-linear coupling between turbulent scales and the effect of sub-grid turbulence on the large-scale dynamics, we have adopted the LES formalism (which is preferable in transient regimes) for compressible flows.

Our computational work is based on development and exploitation of these models into the numerical solvers of OpenFOAM, which is one of the best known CFD open source parallel software packages.

Preliminary numerical benchmarks demonstrate that the model is able to capture important non-equilibrium phenomena in gas-particle mixtures, such as particle clustering and ejection from large-eddy turbulent structures, as well as compressibility and thermal effects.

A quantitative assessment of the reliability of Direct Numerical Simulation (DNS) and LES results with respect to modeling approximations and numerical errors has been carried out by comparing numerical results to experimental and computational studies of homogeneous, isotropic turbulence.

In such a simplified geometry, the numerical solver is able to accurately reproduce the turbulent spectrum and the Kolmogorov energy cascade.

Preliminary three-dimensional numerical simulation of volcanic plume dynamics demonstrate that gas-particle non-equilibrium phenomena have a significant impact on turbulent structures and can affect the entrainment rate and the atmospheric dispersal of volcanic ash.