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Modelling volcanic plumes: from eruption column to umbrella cloud

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Two distinct models of volcanic plumes are presented.

The first is a co-flowing integral plume model for the transition from an eruption column to an umbrella cloud. This occurs above the level of neutral buoyancy where the rising plume is surrounded by a descending annulus. We model this transition by extending the co-flowing plume model of Bloomfield & Kerr (JFM 2000), which was originally developed for Boussinesq turbulent fountains, to volcanic plumes. In addition to the transition region, the new model includes the part of the eruption column below the level of neutral buoyancy and reduces to the model of Devenish (JVGR 2013) in the absence of a descending annulus. The interaction between the upward and downward plumes is accounted for by two entrainment relations: from the upward to the downward plume or vice-versa; entrainment from the environment into the downward plume (or the upward plume below the level of neutral buoyancy) is also accounted for. The model is applied to the two eruptions considered by Costa et al. (JVGR 2016) for the volcanic-plume intercomparison study. Profiles of the mass and momentum fluxes are compared with those from an equivalent large-eddy simulation (LES). The new model captures the order of magnitude of the fluxes, the relative magnitudes of the upward and downward fluxes and aspects of the profiles' shape. In particular, the upward plume reaches a maximum before decreasing towards the top of the plume consistent with the LES plume. A practical benefit of the model is that the maximum downward mass flux may provide a more accurate estimate of the outflow of material from the eruption column into an intrusion.

The second model is a Lagrangian stochastic model (LSM) of a volcanic plume in which the mean flow is provided by an integral plume model of the eruption column and vertical velocity fluctuations are modelled by a suitably constructed stochastic differential equation. The practical purpose of the model is twofold: to provide more realistic profiles of the vertical spread of ash in the eruption column, especially above the level of neutral buoyancy, and as a potential dynamic source model in a long-range atmospheric dispersion model. Vertical profiles of the mass concentration for the two eruptions considered above are computed from the LSM and are compared with equivalent results from LES for the case of no ambient wind. The LSM captures the order of magnitude of the LES mass concentrations and some aspects of their profiles. In contrast with a standard integral plume model, i.e. without fluctuations, the LSM decays (to zero) towards the top of the plume which is consistent with the LES plumes. In the lower part of the plume, we show that the presence of ash leads to a peak in the mass concentration at the level at which there is a transition from a negatively buoyant jet to a positively buoyant plume. The effects of the ambient wind and moisture are also investigated.