Modeling Volcanic Clouds: a Physical, 3D and Efficient Method

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1 Introduction

This paper presents an efficient method based on physical laws to model volcanic clouds. Some physical models have been proposed for simulating volcanic clouds [Woods 1988], but most of the previous models are only two or less dimensional or need huge calculation times. Our approach achieves a physical, 3D and efficient modeling of volcanic clouds. The dynamics of volcanic clouds is modeled using the 2FM (2 fluids model), which can treat two kinds of fluids in a scheme. Furthermore, modeling in the 3D analysis space is efficiently implemented by appropriate and reasonable simplification of the dynamics.

2 Modeling using 2FM

The primary dynamics of the volcanic clouds is the phenomenon called entrainment, which is the mixing of the pyroclasts, volcanic gas and surrounding air. The entrainment assumption can describe the mixing phenomenon and has been justified experimentally [Woods 1988]. However, the assumption can only be applied to a self-similar flow model, where the radius of the flow, for example the volcanic clouds, is exactly proportional to the height. Volcanic clouds, however, are not normally a completely self-similar flow. Therefore, we provide the 2FM to simulate the entrainment. In the 2FM, the volcanic clouds are regarded as two fluids, the magma and the surrounding air. Magma is the a mixture of pyroclasts and volcanic gas; and since the pyroclasts are disintegrated due to the momentum of the eruption, the pyroclasts and the volcanic gas reach thermal equilibrium and the relative velocity between them is negligible. Therefore, the magma can be defined as one fluid, and to simulate the volcanic clouds is then to visualize the magma.

The density distribution of volcanic clouds is formed as $\rho = (\rho_m, T_m, \rho_a, T_a)$, where ρ_m and T_m are the density distribution and the temperature of the magma, respectively, and ρ_a and T_a are those of the surrounding air. The relationship between ρ and the four state variables are nonlinear and complex. Thus, obtaining ρ costs a lot of time. However, the thermal capacity of the magma is very large, this feature implies that the temperature of the magma T_m does not change rapidly, hence it can be assumed as a constant. Then, by verifying the temperature of the surrounding air T_a, the large part of the entrained surrounding air to the volcanic cloud is the atmosphere near the vent. Thus, it can also be regarded as a constant. Therefore, we simplify the model which contains four state variables by setting T_m and T_a to be constants, so that the model becomes $\rho = (\rho_m, \rho_a)$ and the calculation also becomes much simpler. By using this simplified model, simulation time can be reduced approximately 30% when the analysis space is represented by 150^3 voxels; the generated shape of the volcanic clouds is almost the same as using the original model.

3 Result

Figs. 1 (a) and (b) show the images resulting when T_a is 300K and T_m are 900K and 1000K, respectively. Fig. 1 (a) is the mushroom volcanic clouds, since the maximum height of the volcanic clouds is around the ”neutral height”. At this height, the density of the volcanic clouds and the atmosphere are almost balanced, and the volcanic clouds spread horizontally, so that a mushroom is the typical shape of volcanic clouds with an explosive eruption. Fig. 1 (b) shows a phenomenon called ”overshoot”. Overshoot occurs due to high magma temperature, and when the maximum height of the volcanic clouds is beyond the neutral height. Fig. 1 (c) is a real photograph of an overshoot used to compare with Fig. 1 (b). Fig. 2 shows an image sequence of the overshoot generated by our method. Since our method is based on physical laws, it can be used to simulate volcanic clouds from the volcanic eruption to a situation of balance. Further, besides the mushroom and overshoot, it can also be used to generate other kinds of volcanic clouds, such as the conic and round volcanic clouds. We use the method described by [Fedkiw et al. 2001] for numerical calculations. To simulate the mushroom volcanic clouds, it takes 7 sec. per time step on average with 150^3 voxels on a desktop PC with an Intel Pentium 4 2.8GHz CPU. For the overshoot, it takes 3 sec. per time step on average with $100 \times 100 \times 150$ voxels. To render the simulated results, it costs 2 sec. per frame on average using the method proposed by [Dobashi et al. 2000] with some modifications, such as to simulate the single scattering effect using a graphics accelerator.

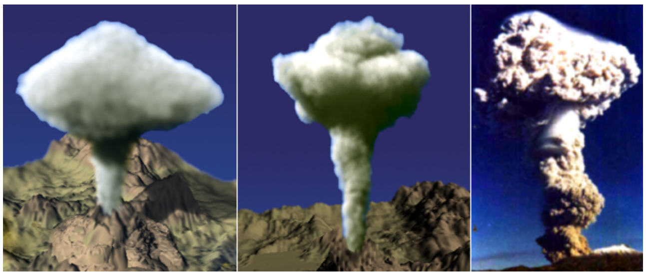
(a) (b) (c)

Figure 1: (a) Mushroom, (b) overshoot and (c) a photograph.

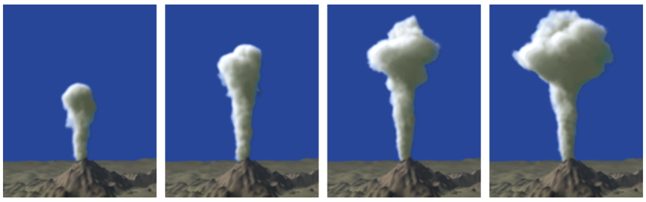
250th frame 375th frame 500th frame 625th frame

Figure 2: An image sequence generated by our method.

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