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Simulation of ejecta–atmosphere interaction

R. Luther (1), N. Artemieva (2,3) and K. Wünnemann (1)
(1) Museum für Naturkunde Berlin, Leibniz Institute for Evolution and Biodiversity Science, (2) Planetary Science Institute, Tucson, USA, (3) Institute for Dynamics of Geospheres, RAS, Russia (robert.luther@mfn-berlin.de)

Abstract

We study the interaction of ejected material from impact craters with an atmosphere or an impact induced vapour phase. This interaction depends on the size distribution of ejected particles.

1. Introduction

The ejection of material during impact cratering is an important process that is relevant for various aspects. In our study, we focus on the deposition of ejecta and the formation of an ejecta blanket. The initial characteristics of ejecta (launch velocity and ejection angle) have been shown to depend on target properties (e.g. strength and porosity; see e.g., [1-3]). Based on these characteristics, ejecta trajectories can be calculated in vacuum as parabolas. However, in the presence of an atmosphere, ejection trajectories deviate from pure ballistic trajectories and the final deposition will be different from vacuum conditions [e.g. 4]. In this study, we present numerical results of ejecta interaction with an atmosphere.

2. Method

We use the iSALE shock physics code [5-7] to simulate the behaviour of ejected material in contact with gas from an atmosphere. The strengths of iSALE are the availability of: (1) different material models (brittle/ductile rheology), (2) a damage model, (3) various equations of state, and (4) a porosity compaction model. Having been used mostly for the simulation of crater formation in dense materials, iSALE has been applied recently to the simulation of shock events in an atmosphere [8]. In order to simulate the interaction of ejected particles with an atmosphere, we added a dusty flow model [9-11]. Therefore, we transform material from a cell (continuum behaviour in a grid) into representative particles once ejection (transformation) criteria are fulfilled [10-11]. Representative particles are characterized by a velocity, shape and size. Two main forces act on the ejected particles: gravity, and drag by the surrounding gaseous medium:

$$m\frac{d\boldsymbol{v}}{dt} = m\boldsymbol{g} + C_D\pi r^2\rho_g|\boldsymbol{v}_g-\boldsymbol{v}|(\boldsymbol{v}_g-\boldsymbol{v}) + 6\pi r\mu(\boldsymbol{v}_g-\boldsymbol{v}), \quad (1)$$

where C_D is the drag coefficient, g the gravitational acceleration, m and r the particle mass and radius, ρ_g and μ are gas density and viscosity, and $\boldsymbol{v}$ and $\boldsymbol{v}_g$ are the particle and gas velocity. Representative particles also exchange energy and momentum with the surrounding gas/vapour. We use an ideal gas as equation of state with a surface density of ~1kg/m³.

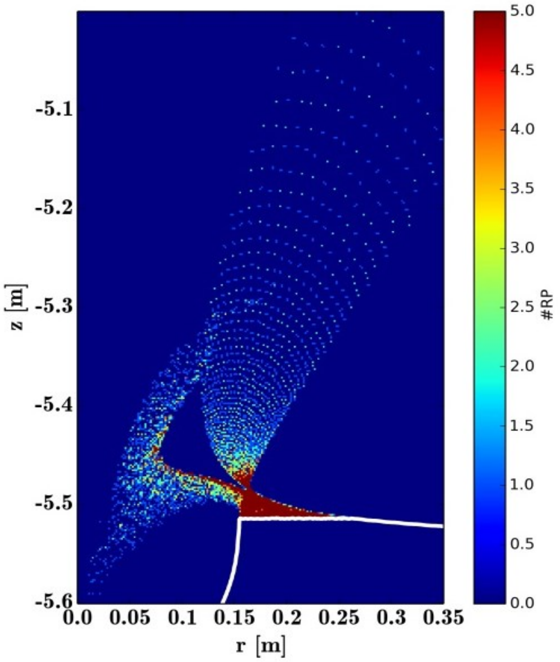

Figure 1: Representative particles (10 µm and 1 cm in size) are ejected from a forming crater cavity. Both size classes separate from each other by atmospheric interaction. Small particles are affected by a gas flow into the cavity. Note, that due to the different sizes of particles, the colour scale is not equivalent to the mass of each representative particle. The impact velocity is 4.5 km/s.

3. Preliminary Results

In a first series, we simulate the movement of representative particles in a static atmosphere and analyse the trajectory of representative particles of different sizes. Particle-gas-interaction is size dependent (eq. 1) and small particles experience more gaseous drag and are decelerated faster than larger fragments. However, when particles of two size classes move along a trajectory at the same time, the larger particle will influence the atmosphere in such a way that smaller particles can travel further relative to a scenario where larger particles are absent; i.e. large particles increase the velocity of the gaseous medium, reducing relative velocities for the smaller particles and the gas (eq. 1), leading to a reduced deceleration of the smaller particles.

In a second series, we simulate an impact into a target, where representative particles are created by transforming material from the grid as described above. We use different particle sizes in different runs, ranging from 10 µm to 1 cm. We also run a simulation with both 10 µm and 1 cm sized particles (Figure 1). We see a separation of particles according to their size. Small particles are engaged in a gas flow into the expanding cavity.

4. Discussion

Our results show that the interaction of ejecta and an atmosphere cannot be neglected. It causes ejection trajectories that differ significantly from pure ballistics trajectories. Thus, ejecta deposition will be different and a layering according to particle size is possible. Furthermore, depending on the size distribution of particles and wind fields, small dust particles can be moved to various positions including the crater cavity. Especially trajectories of dust particles are crucial for estimating the climatic effects of large impact event [e.g., 12].

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