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SIMULATION-BASED HEIGHT OF BURST MAP FOR ASTEROID AIRBURST DAMAGE PREDICTION

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ABSTRACT

Entry and breakup models predict that airburst in the Earth’s atmosphere is likely for asteroids up to over 200 meters in diameter. Objects of this size can deposit over 250 megatons of energy into the atmosphere. Fast-running ground damage prediction codes for such events rely heavily upon methods developed from nuclear weapons research to estimate the damage potential for an airburst at altitude. (Collins, 2005; Mathias, 2016; Hills and Goda, 1993). In particular, these tools rely on the powerful yield-scaling laws developed for point-source blasts which are used in conjunction with a height-of-burst map to predict ground damage for a detonation of a specific energy at a given altitude. While this approach works extremely well for yields as large as tens of megatons, they are less accurate as yields increase to the hundreds of megatons potentially released in larger airburst events. The proposed paper revisits the assumptions underlying this approach and shows how atmospheric buoyancy becomes important as yield increases beyond a few megatons. We then use large-scale three-dimensional simulations to construct updated height-of-burst maps that are appropriate at the higher energy levels associated with the entry of asteroids with diameters of hundreds of meters. These updated maps can then be

incorporated into engineering methods for damage prediction, significantly improving their accuracy for asteroids with diameters greater than 80-100 m.

Classical blast theory is based upon the observation that, in the absence of external length scales all blasts triggered by a point source are self-similar. “Yield scaling” makes use of this similarity to relate distances, d_1, in one blast to an equivalent distance, d_2 in another where the local state (density, pressure, etc.) is identical.

$$\frac{d_1}{d_2} = \left(\frac{E_1}{E_2}\right)^{1/3} \tag{1}$$

Knowing the ground overpressure for a blast of a given yield E_1, and altitude, yield scaling allows us to determine the altitude for which a blast of another yield, E_2, will produce the same ground overpressure. Self similarity also allows us to relate the time scales in blasts of different energies.

$$\left(\frac{t_2}{t_1}\right)^2 = \frac{\rho_{\circ 2}}{\rho_{\circ 1}}\frac{E_1}{E_2}\left(\frac{d_2}{d_1}\right)^5 \tag{2}$$

As a concrete example, Eqs. (1) and (2) say that a blast with an energy of 5 MT at a burst height of 5 km will produce the same ground overpressures as a 100 MT blast at 13.58 km (= 5km x $(100/5)^{1/3}$). This is the basis for the canonical height-of-burst maps found in Glasstone and Dolan (1977) and other sources.

At yields smaller than about 10 megatons, these relationships provide excellent engineering estimates of ground overpressure footprints. Since it contracts the length scales in the larger blasts, yield scaling effectively steepens the vertical gradients in density and pressure due to body forces in the governing equations. This may be viewed as a contraction of the atmospheric scale height in the larger simulation, making the effects of buoyancy more pronounced. For blasts smaller than a few megatons, this effect is small, and the standard height-of-burst map remains reasonably accurate. However, at large yields these effects become significant. Figure 1 shows a comparison of point source blasts of 5 and 100 megatons at equivalent yield-scaled altitudes (Eq.1) and yield-scaled times (Eq.2). The distance scales in the image at the right have been contracted by 2.71 = $(100/5)^{1/3}$ to account for the yield scaling so the size of the blasts should appear identical. While this is true for the horizontal extent, the larger blast shows significant deformation due to buoyancy.

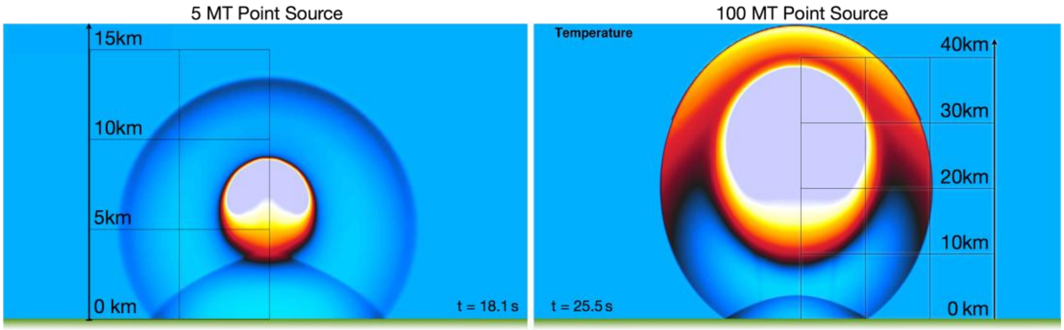

Figure 1. Comparison of 5MT and 100MT blasts at equivalent yield scaled altitudes and times showing deformation of the larger blast due to buoyancy.

Figure 2 shows a comparison of the standard 1 kiloton height-of-burst map from Glasstone and Dolan (1977) with a similar map for a series of 250 megaton bursts that have been yield scaled to 1 kt for the purpose of comparison. This larger energy roughly corresponds to the entry of a 200 m asteroid with density of 1.5 g/cc at a speed of 17 km/sec. The 250 megaton map was developed through 3D simulation of blasts at 12 different altitudes and recording peak blast overpressures at ground level in the theater. The differences are significant and the physics behind them will be discussed in detail in our final work.

Our final poster will show how we combine numerically generated height-of-burst maps developed at several large yields to significantly improve damage estimates in fast-running engineering tools and probabilistic damage assessment codes and show the impact of this fidelity on key metrics such as casualty rate, affected population, and property damage.

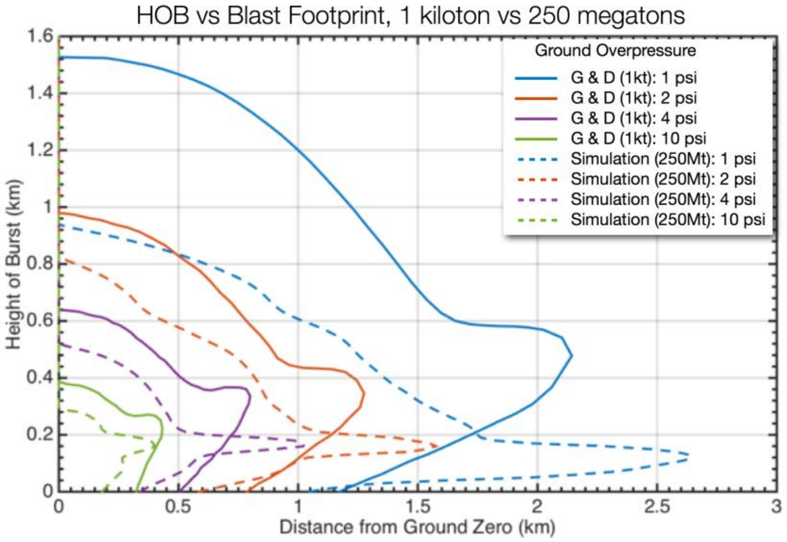

Figure 2. Comparison of 1kt height-of-burst map from Glasstone & Dolan (1977) with simulation-based map developed at 250 MT showing effects of atmospheric buoyancy. All distances-scaled to a 1 kt yield.

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