QUANTIFYING UNCERTAINTY IN CONTINUOUS FRAGMENTAION AIRBURST MODELS

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Introduction: Near-Earth Objects (NEOs) with diameters 1-100 m are abundant [1], difficult to observe, and can strike the Earth with little to no warning. Their potential threat was brought to light on the morning of 15 February 2013, when a ~20 m diameter asteroid entered the Earth's atmosphere above Chelyabinsk, Russia [2], depositing ~550 kT TNT equivalent (1 kT TNT = 4.184 10^{12} J) into the atmosphere and causing $33 million damage [3]. Being able to model a meteoroid's potential damage quickly and accurately is imperative. Several semi-analytical models have been developed to study the atmospheric energy deposition during catastrophic fragmentation of stony meteoroids [4-6]. Here we investigate three of the commonly used semi-analytical models, and quantify the uncertainty in model predictions that originates from the choice of model; numerical model parameters and the physical properties of the meteoroid.

Continuous Fragmentation Airburst Models: Three continuous fragmentation models are described in the literature: the Pancake Model, by Chyba et al., 1993 [4], the Debris Cloud Model, by Hills and Goda, 1993 [5], and the Chain Reaction Model, by Avramenko et al., 2014 [6]. Each model makes different assumptions and use different defining equations to describe spreading after fragmentation. All three models were implemented using a common numerical framework to calculate the change in velocity v, mass m, trajectory θ, and altitude z. They were calibrated to Chelyabinsk, using the same initial conditions and model parameters, except for initial strength and one independent model parameter, which are required for a good fit to the light curve data. The inter-model uncertainty has been quantified by scaling these calibrated models to other events, such as Tunguska.

Parameter Uncertaity: When an asteroid on collision course with Earth is first detected, many of its physical properties are not likely to be known. This results in a wide range of possible impact conditions which can have a large effect on the potential hazard [3]. Probability distribution functions have been described for impact angle, velocity, bulk density, strength, ablation parameter, and other model parameters [3-9]. The first constraint on asteroid size is the H-magnitude of the object. This value, within error bounds, can be combined with the abledo values from NEOWISE observed distribution [10] to provide a potential diameter probability distribution [3].

What are the potential impact effects of an observed H-mag 27 object? Using the Dakota software, developed by Sandia National Laboritiories [11], a 30,000 latin-hypercube sampled uncertainty quantification has been run over all potential impact scenarios of an object with H-magnitude 27±0.5. Figure 1 shows point density plots of burst points (altitude of peak energy deposition per km and the energy deposited) for each of the three models. Also shown are the cumulative probabilities (for each model) of total energy deposited; peak energy deposited; and burst altitude. The observed values for Chelyabinsk are shown for comparison.

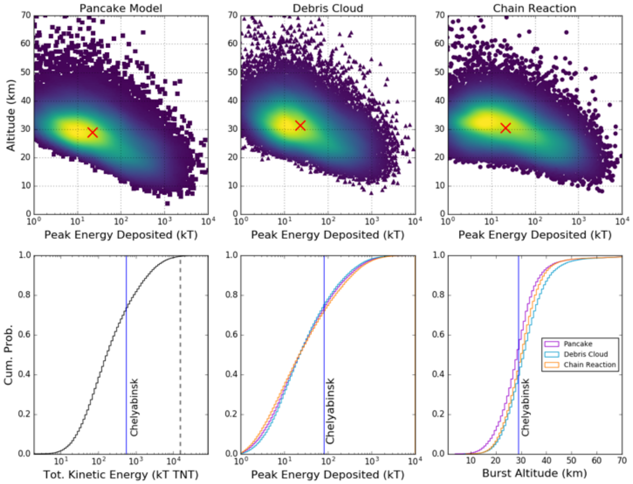

Figure 1: (Top) Point density plots burst points with highest density of points plotting in yellow to purple, where points are lowest in density. Red cross is the median burst altitude and burst energy. (Bottom row): (left) Cumulative probability of specific total kinetic energy, (centre) cum. prob. of peak energy deposition, and (right) burst altitude, compared to Chelyabinsk (blue line).

Results and Discussion: The parameter uncertainty is larger than the inter-model uncertainty, however, there are systematic discrepancies between models. Each model predicts a similar peak energy deposition per km, but the pancake model consistently predicts lower burst altitudes, and the chain reaction model predicts a narrower range of potential burst altitudes. To reduce uncertainty in probabilistic hazard assessment, it is important to reduce the uncertainty in impact conditions.

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