Sensitivity of Impact Risk to Uncertainty in Asteroid Properties and Entry Parameters

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Overview
A central challenge in evaluating the threat posed by asteroids striking Earth is the large amount of uncertainty in potential asteroid properties and entry parameters, which can vary the resulting ground damage and affected population by orders of magnitude. We are using our Probabilistic Asteroid Impact Risk (PAIR) model to investigate the sensitivity of asteroid impact damage to these uncertainties. To assess the risk sensitivity, we alternately fix or vary the different input parameters and compare the damage distributions produced. In this study, we consider local ground damage from blast waves or thermal radiation for impactors 50-500m in diameter. The ongoing goal of this work is to help guide future efforts in asteroid characterization and model refinement by determining which properties most significantly affect the potential risk.

Probabilistic Asteroid Impact Risk (PAIR) Model
The PAIR model [1] combines physics-based analytic models of asteroid entry and damage in a probabilistic Monte Carlo framework to assess the risk posed by a wide range of potential impacts. The model samples from uncertainty distributions of asteroid properties and entry parameters to generate millions of hypothetical impact cases, and models the atmospheric entry, breakup, and resulting damage for each case. The model includes damage due to blast overpressure, thermal radiation, tsunami, and global effects, although we only consider local blast/thermal damage in this study. The model determines the number of people within each location-specific damage zone using gridded world population data [2] or an average population density.

Affected Local Population Damage Metric
Four damage severity levels are considered for both blast overpressure and thermal radiation. For each severity, the corresponding blast and thermal damage radii are computed and the larger is used to define the damage area. Damage is compared and the larger is used to define the damage area. For each severity, the corresponding blast and thermal damage radii are computed and the larger is used to define the damage area. The larger damage area is used to define the affected population.

Input Parameter Uncertainty Distributions
The asteroid, entry, and modeling parameter distributions used in this study are based on those presented in Mathias et al. (2017) [1]. Here we consider four different nominal size cases from 50-500m in diameter. The nominal size represents the assumed diameter of an object with a given H-magnitude, assuming a standard albedo value of 0.14. A distribution of actual diameters is obtained by sampling albedos from the NEOWISE distribution [5]. Note that the mean diameter from the albedo distribution differs from the nominal diameter.

Damage Probability Distributions & Breakdowns
The plot to the left shows the full risk probability distributions for each nominal size, with all uncertainty parameters varying (i.e., top bar of the tornado above). Across all sizes, the most likely outcome is that no population is affected, but even the 50m nominal size case can affect up to 43 million people.

The plots below show the distribution of affected population results for the 100m case, and break down the contribution of different groups of parameter variations. The leftmost plot shows the full distribution varying all parameters, overlaid with the distribution from varying just the impact location vs varying all other impact parameters and using average population density. The second plot shows the variation of all parameters except local population, overlaid with the distributions from variation of all the asteroid properties (size, density, strength) vs the entry parameters (velocity, angle). The two right-hand plots then show the breakdown of the asteroid and entry property distributions into their individual parameters.

Result Summary
Impact location is the greatest contributor to local damage risk uncertainty, both in the ranges and the form of the risk distribution. Taken together, asteroid properties drive the risk uncertainty more than the entry parameters. Among the asteroid properties, size uncertainty is the most significant contributor, while the strength parameters have relatively little influence (at least for this distribution). Velocity contributes the majority of the risk uncertainty from the entry parameters. As asteroid size increases, velocity and entry angle contribute an increasing share of the risk uncertainty, while density contributes relatively less for sizes over 100-200m. For modeling parameters, the very large range of the poorly constrained ablation coefficient can yield uncertainty ranges comparable to those from the entry angle. For sizes 300m and smaller, thermal damage is negligible compared to blast damage, but at 500m, thermal damage begins contributing slightly to the risk and luminous efficiency becomes a greater source of uncertainty than density or strength.

Acknowledgements and References

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