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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, tsunamis, 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

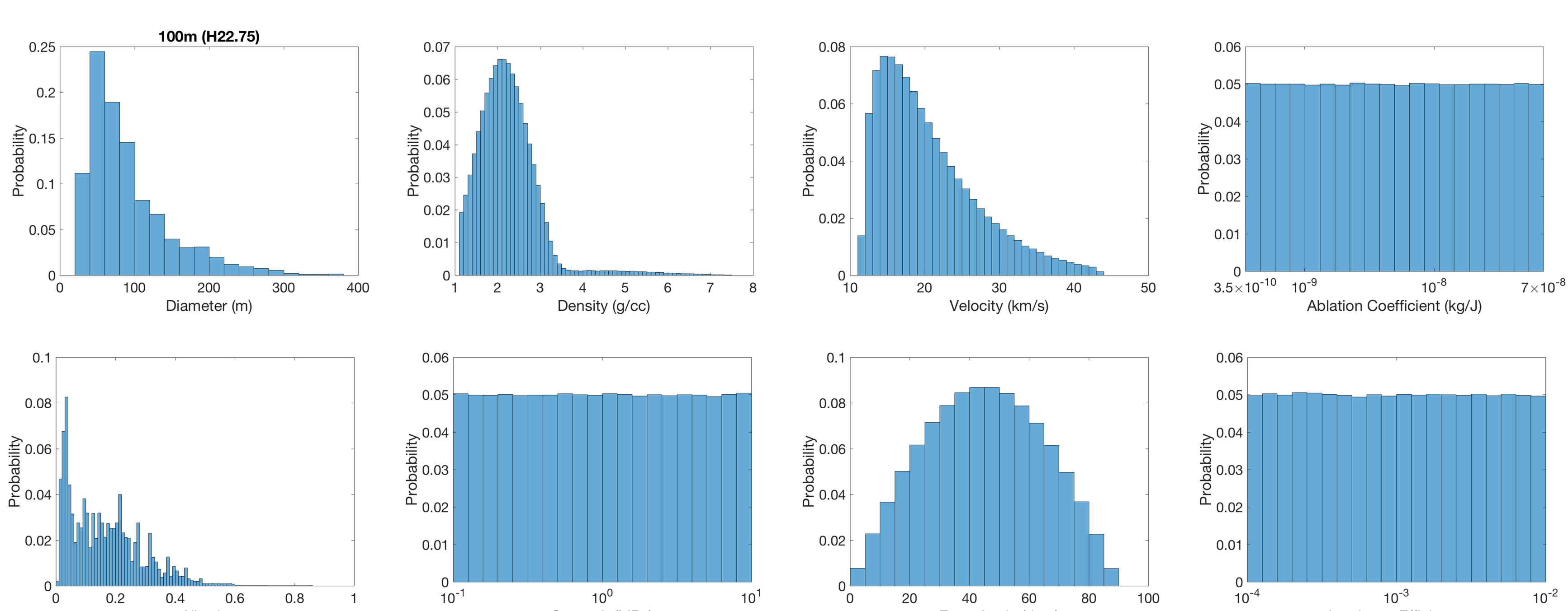
Four damage severity levels are considered for both blast overpressure and thermal radiation. For each severity, the corresponding blast and thermal damage radii are compared and the larger is used to define the damage area. Different fractions of the local populations within each damage zone are counted as affected according to the severity.

Damage Level	Population fraction	Blast Overpressure Threshold (psi)	Thermal Exposure Threshold (MJ/m^2) [3] [4]
Serious	0.1	1 (window breakage, minor structural damage)	0.25 (2nd degree burns)
Severe	0.3	2 (widespread structural damage)	0.42 (3rd degree burns)
Critical	0.6	4 (most residential structures collapse)	0.84 (ignition of plywood, light clothing)
Unsurvivable	1.0	10 (total devastation)	1.2 (ignition of roll roofing)

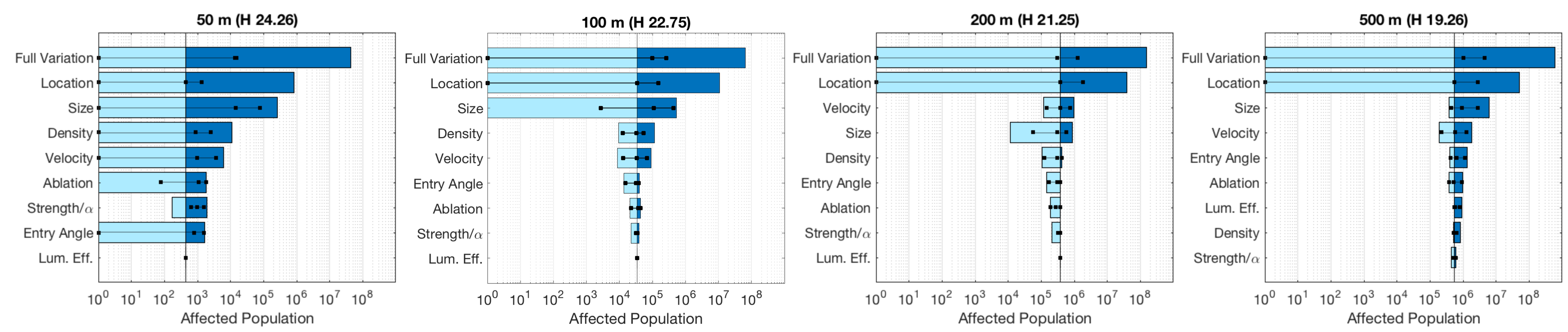
Input Parameter Uncertainty Distributions

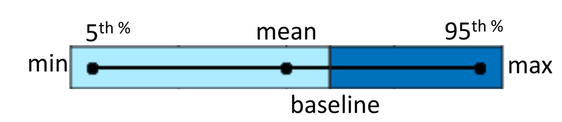
The asteroid, entry, and modeling parameter distributions used in this study are based on those presented in Mathias et al. (2017) [1]. Here we consider four different nominal size cases from 50-500m in diameter. The nominal size represents the assumed diameter of an object with a given H-magnitude, 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.

Parameter	Distribution	Baseline	Range
Diameter	$D = (1.326\times10^6)\times10^{-H/5}/p_v$ with NEOWISE albedo (p_v) distribution [5]	50 m (H 24.26 , p_v 0.14)	20-187 m (mean 62 m)
		100 m (H 22.75, p_v 0.14)	80-750 m (mean 249 m)
		200 m (H 21.25, p_v 0.14)	40-375 m (mean 124 m)
		500 m (H 19.26, p_v 0.14)	201-187 6m (mean 622 m)
Density	Gaussian meteorite densities and macro-porosities, weighted by type abundance.	2.26 g/cm^3	1.1 – 7.5 g/cm^3
Strength	Logarithmic	2.15 MPa	0.1 – 10 MPa [7]
Strength Scaling α	Uniform	0.2	0.1 – 0.3 [7]
Entry Velocity	Greenstreet et al. [6]	20.5	11.5 – 43.5 km/s
Entry Angle	Cosine	45°	0 – 90°
Ablation Coefficient	Logarithmic	1.3e-8	3.5e-10 – 7e-8 kg/J
Luminous Efficiency	Logarithmic	2e-3	1e-4 – 1e-2 [3]
Local Population	Gridded population data [2]	11.8738 $people/km^2$	0 – 123k $people/km^2$



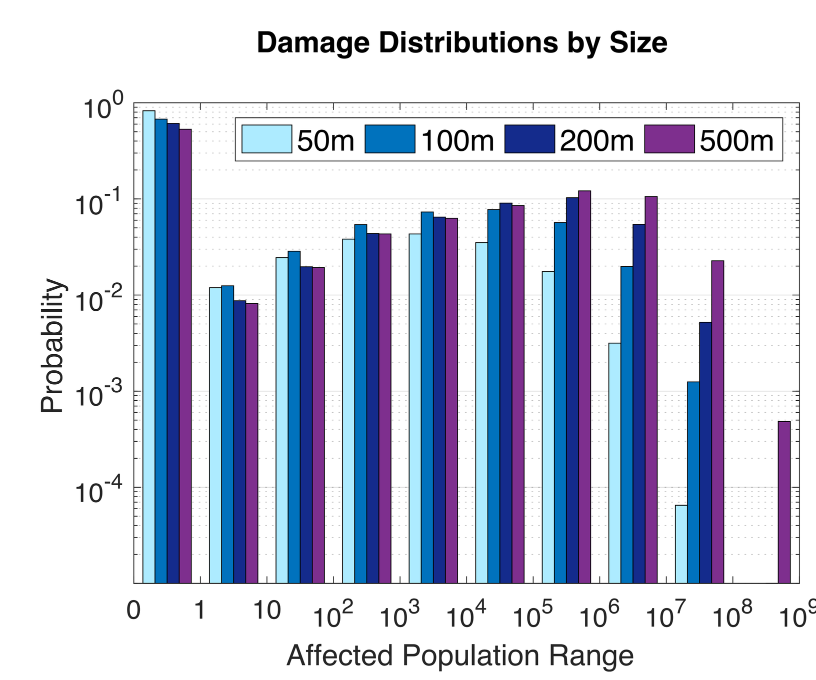
Ranking of Risk Uncertainty Ranges





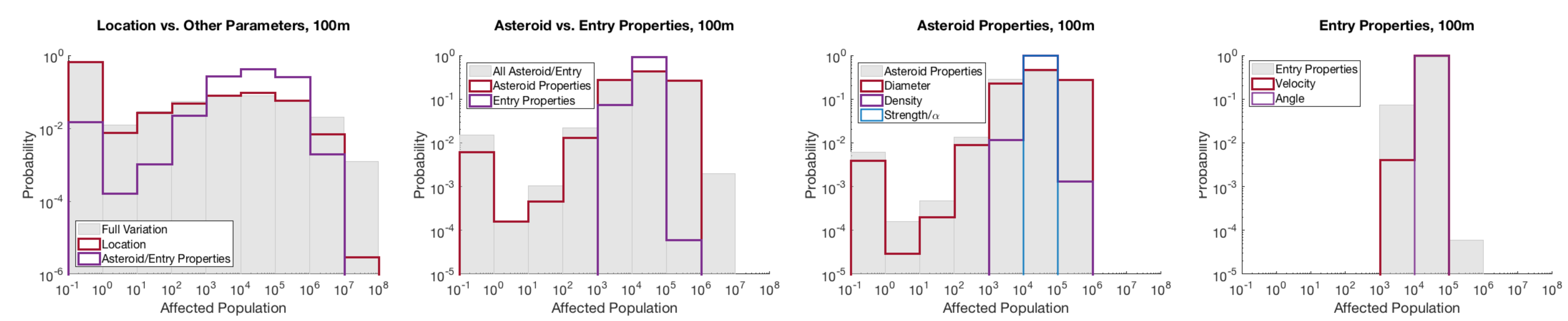
These "tornado" plots show the relative risk uncertainty ranges resulting from the uncertainty distribution of each asteroid and entry input parameter for four nominal asteroid sizes. The central tornado axis is the affected population within the damage area resulting from an asteroid impact with all parameters at the baseline values, using the average population density. Each row shows the damage ranges resulting from the variation of each parameter over its uncertainty distribution, while holding the other parameters at their baseline values. The blue bars show the min/max spread, and the black squares show the mean, 5th percentile, and 95th percentile values. Note that the mean parameter value does not generally align with the mean resulting damage. The bars are stacked in order of the min/max population ranges.

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 tornados 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 contributions 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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