Asteroid Impact Risk: Ground Hazard versus Impactor Size

Donovan Mathias¹, Lorien Wheeler², Jessie Dotson¹, Michael Aftosmis¹, and Ana Tarano³

¹NASA Ames Research Center, ²CSRA/NASA Ames Research Center, ³STC/NASA Ames Research Center/Stanford University

Overview

We utilized a probabilistic asteroid impact risk (PAIR) model to stochastically assess the impact risk due to an ensemble population of Near-Earth Objects (NEOs). Concretely, we present the variation of risk with impactor size. Results suggest that large impactors dominate the average risk, even when only considering the subset of undiscovered NEOs.

Modeling Approach

The probabilistic asteroid impact risk model [1] uses Monte Carlo sampling to produce stochastic sets of potential impact scenarios based on uncertainty distributions characterizing key asteroid parameters. For each impact case, the entry and fragmentation process is modeled to compute the energy deposited in the atmosphere, determine airburst altitude or surface impact, and estimate the resulting damage areas and affected populations. Local damage due to blast overpressure and thermal radiation is assessed for land impacts, while regional damage due to asteroid-generated tsunami is assessed for impacts over the oceans. Local and regional damage include the latitude and longitude of the impact location and the globally distributed human population [11]. Global effects are considered for impact energies greater than 40 Gt and are independent of specific impact location. The impact outcomes are combined with corresponding impact frequencies [2] to produce an estimate of the ensemble impact risk.

An innovative fragment-cloud model (FCM) [3,4] is used to generate energy deposition curves as the asteroid enters the Earth’s atmosphere. FCM integrates the entry trajectory, accounting for aerodynamic heating and drag, until the stagnation pressure exceeds the “aerodynamic strength” of the object, at which point fragmentation begins. Each fragmentation event breaks the parent object into a set of discrete fragments and a debris cloud. The fragments gain strength according to their reduced size and continue descent until their new strength is exceeded and they break again, or until they ablate completely or impact the surface. The cloud is assumed to have lost its strength and is allowed to rapidly disperse, depositing its energy in the process. An energy deposition curve is produced and used for the subsequent ground hazard assessment.

The local damage models use the height of burst and kinetic energy to establish an equivalent energy source for blast waves and thermal radiation. Empirical damage radii [5] plots, derived from relative small energy events, are combined with computational models to establish a distance at which the resulting blast wave drops to a specified level of overpressure. Thermal radiation is modeled assuming all of the energy is distributed over a hemispherical surface, following Collins [9]. The larger of the blast or thermal damage radii is used for the casualty estimation.

For water impacts, the kinetic energy remaining at the surface is scaled [7] and used to create an initial water impact for the casualty estimation. The larger of the blast/thermal damage radii is used for land impacts, while regional damage due to asteroid-generated tsunami is assessed for objects >900m. Note that this plot shows the fraction of the simulated scenarios driven by each hazard, not the relative rate of casualties.

Risk Assessment

Risk differs from hazard in that it includes the likelihood along with the consequence of an event. This section shows the quantitative risk results using the expected values as well as the output distributions.

Quantifying hazards determines the scope of ground damage for local, regional, and global hazards. The following illustrate how the hazard models are converted to casualty impacts for each scenario [5] [6] [12].

Top: Hazard models are used to compute ground areas associated with overpressure and thermal radiation for four damage levels, shown above. The larger of blast/thermal is used for each damage level, and the affected population is computed. The population fraction in the right column is used to convert population within the damage regions to affected population or casualties.

Bottom: Dominant damage source is shown as a function of object size. Below 300m, the most likely outcome is no casualties. Blast and thermal drive damage for the most cases between 300-800m. Tsunami is the largest fractional damage source for impactors 600-800m, and global effects dominate for objects >900m. Note that this plot shows the fraction of the simulated scenarios driven by each hazard, not the relative rate of casualties.

Conclusions

Average casualties are dominated by large impacts causing global effects. However, when considering only the undiscovered fraction of NEOs, the average cumulative risk decreases by an order of magnitude. At smaller impactor sizes, the annual expected casualty estimates are dominated by blast and thermal damage.