# NH15C-0461: Frequency Modeling for Bolide Hazard

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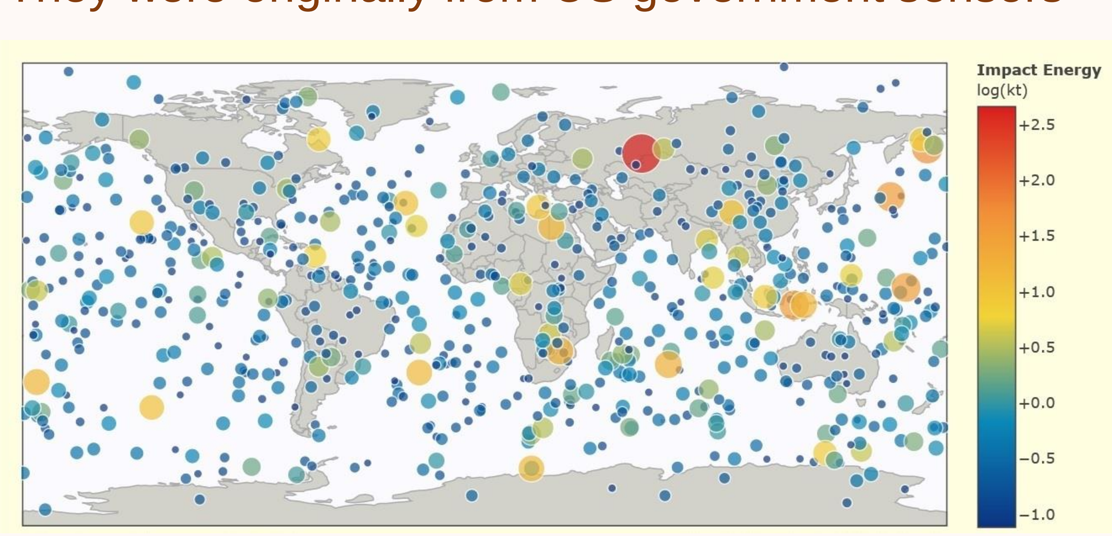
**Abstract:**
Near-Earth asteroids and meteoroids constitute various levels of impact danger to our planet. On the one end, billions of events associated with small-sized meteoroids have resulted in trivial effects. On the other end, the occurrences of large-sized asteroidal collisions that can cause mass extinctions and may wipe out the modern human civilization are extremely rare. In addition, large near-Earth asteroids are being monitored constantly for accurate and precise predictions of potential hazardous visits to our planet. However, small asteroids and large meteoroids can still often go under the radar and cause bolide explosions with potential of significant damage to communities on the ground. To facilitate management of bolide hazard, a number of scholarly works have been dedicated to estimation of frequencies of bolide events from a global perspective for planetary defense and mitigation. Nevertheless, few of the existing bolide frequency models were developed for local hazard management. In this presentation, the author introduces two recently developed frequency models for local management of bolide hazard. The first one, called the Dome model, computes the expected frequency of bolide explosions within a dome-shaped volume around a location. The second one, called the Coffee Cup model, is for a volume above an area. Both models are based on empirical calibrations with historical data on energy, latitude, altitude, and frequency of bolide events. The modeling results indicate a linearly decreasing trend of frequency of bolide events from south to north latitudinally around the globe. The presented models can be applied to any location or area on Earth, including the entire surface of the planet.

*For AGU Fall Meeting 2021, New Orleans, Louisiana, USA, December 13–17, 2021*

## Data

Data for modeling were downloaded from the Center for Near-Earth Object Studies

They were originally from US government sensors

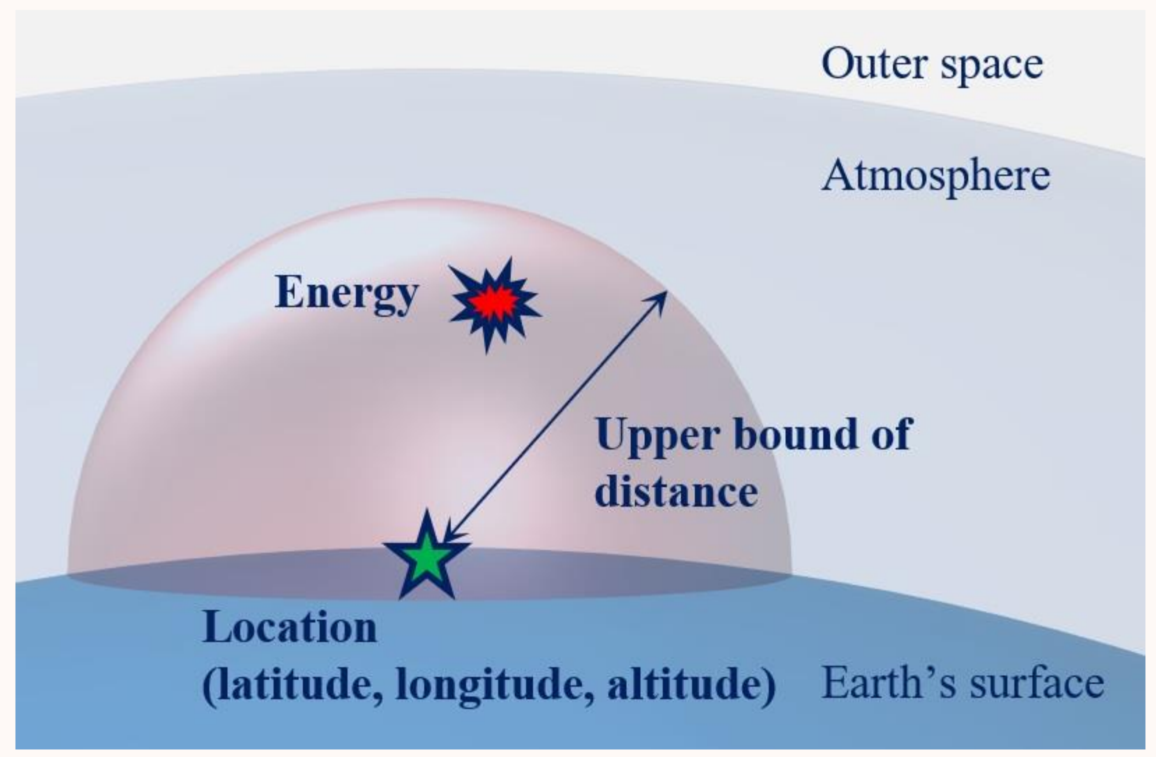



Distribution of bolide explosions recorded by US government sensors (April 15, 1988, to September 6, 2021). Photograph by Alan B. Chamberlin (JPL/Caltech): https://cneos.jpl.nasa.gov/fireballs/

## Models

Models were developed to predict the frequencies, return periods, and/or occurrence probabilities of bolide explosions on a yearly or daily basis

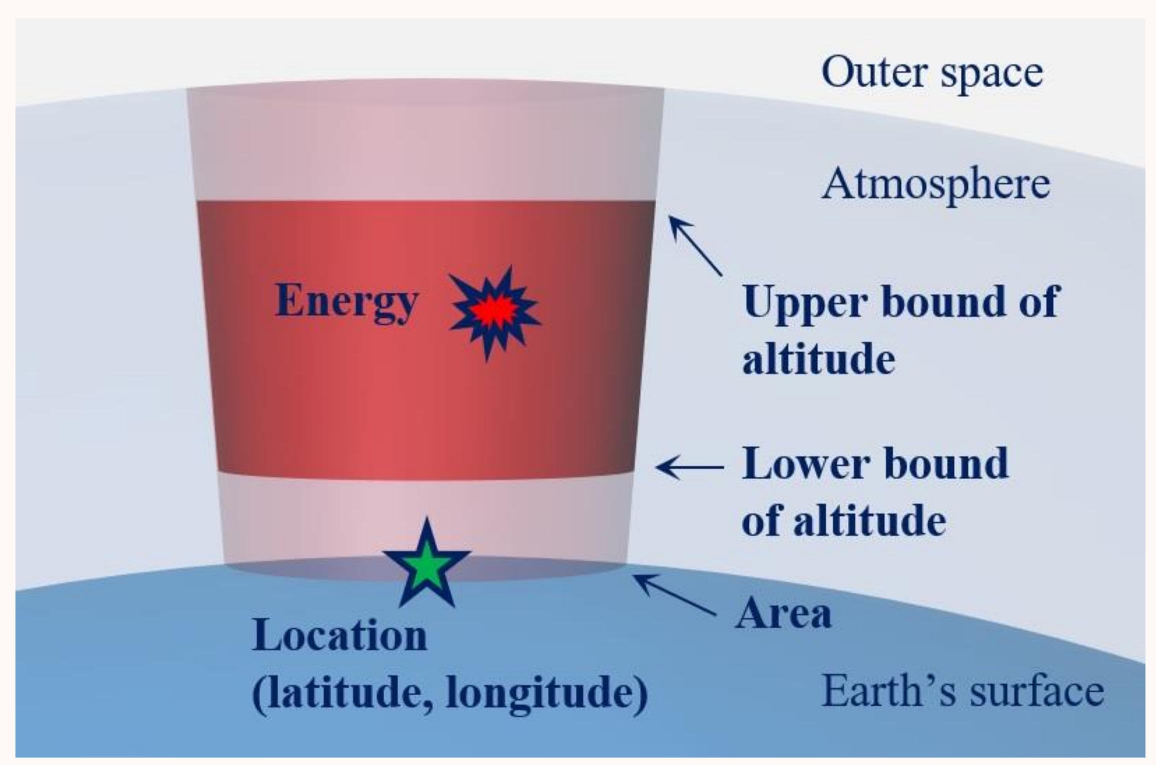
Dome model is for a specific location with a latitude, longitude, and altitude




Dome model. Figure by Y. Victor Wang [1]

Coffee Cup model resembles a disposable coffee cup with a sleeve but without the lid

It is for an area with a geographic center with a latitude and longitude




Coffee Cup model. Figure by Y. Victor Wang [1]

Expected frequencies of bolide explosions with the Dome model can be calculated with the application of a set of Coffee Cup models

Prediction results of the Coffee Cup model can be derived with the assistance of three sets of computational models:

1. ***Energy–exceedance frequency model*** predicts the frequency of events across the world with energy exceeding a certain level

2. ***Latitude–frequency density models*** derive the frequency densities of events within a unit area centered at a location with a latitude

3. ***Energy–altitude model*** presents the probability distribution of log-altitude given the log-energy of an event

## Calibration

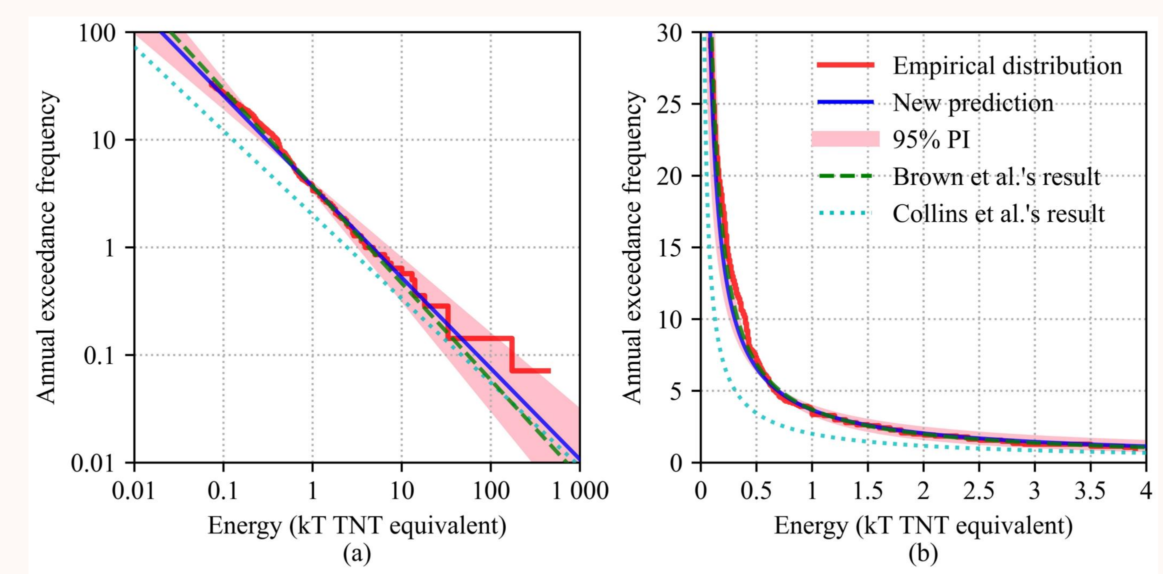
Computational models were calibrated with the maximum likelihood method based on the Newton–Raphson algorithm in Python version 3.6.7

Standard errors of estimates of model parameters were computed based on the negative inverse of observed Fisher information

Monte Carlo approach was adopted to derive the prediction intervals to account for uncertainties

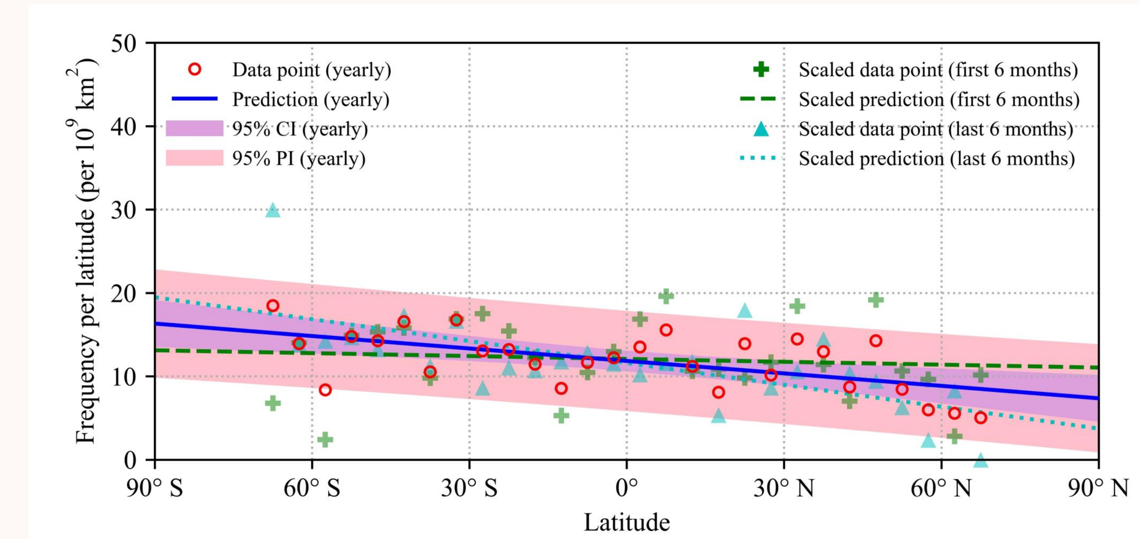
The ***energy–exceedance model*** is a power-law model

The calibration result can be compared with the results of Brown et al. [2] and Collins et al. [3]



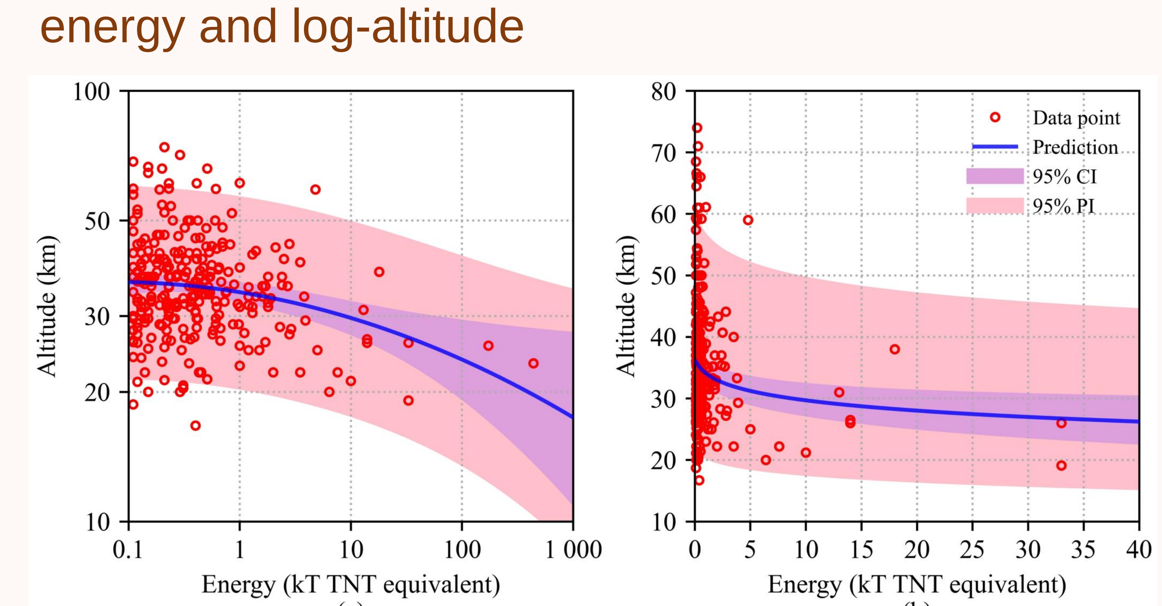

Parametrization of the energy–exceedance frequency model with a logarithmic scale (a) and in the original space (b). Figure by Y. Victor Wang [1]

Results of the ***latitude–frequency density models*** show a linear declining relationship between latitude from south to north and frequency of events per unit area, especially in the second halves of the years




Parametrization of the latitude–frequency density models per unit area of $10^9$ km$^2$. Figure by Y. Victor Wang [1]

Result of the ***energy–altitude model*** indicates a quadratic decreasing relationship between log-energy and log-altitude




Parametrization of the energy–altitude model shown with a logarithmic scale (a) and in the original space (b). Figure by Y. Victor Wang [1]

## Application

Estimate yearly frequencies and return periods of bolides with energy exceeding 0.1 kilotons of TNT equivalent with the yearly Coffee Cup model

| | UAE | UK | USA |
|---|---|---|---|
| Area (km$^2$) | 83,600 | 242,495 | 9,833,520 |
| Centroid latitude | 23.42° N | 55.38° N | 37.09° N |
| Frequency | $3.68\times10^{-3}$ | $9.09\times10^{-3}$ | 0.41 |
| Return period (years) | 272 | 110 | 2.47 |

Table data from Wang 2020 [1]

Evaluate daily occurrence probabilities of bolide explosions with energy between 10 and 100,000 kilotons of TNT equivalent within 50 km from a location on a day in December based on the daily Dome model

| | New York City | Moscow | Christchurch |
|---|---|---|---|
| Altitude (m) | 10 | 153 | 20 |
| Latitude | 40.71° N | 55.75° N | 43.53° S |
| Probability | $1.30\times10^{-8}$ | $1.13\times10^{-8}$ | $2.22\times10^{-8}$ |

Table data from Wang 2020 [1]

## Conclusions

The proposed Dome and Coffee Cup models can be applied to estimate frequencies of bolide explosions for local hazard management at any location and for any area on the surface of planet Earth

Modeling work indicated negative correlation between latitude from south to north and frequency of bolide events

Future work should couple the proposed models with damage propagation models and fragility and vulnerability models for risk analysis

## References

1. Wang, Y. (V.) (2020) Empirical local hazard models for bolide explosions. *Nat. Hazards Rev. 21*(4), 04020037
2. Brown, P., Spalding, R. E., ReVelle, D. O., Tagliaferri, E., Worden, S. P. (2002) The flux of small near-Earth objects colliding with the Earth. *Nature 420*(6913), 294–296
3. Collins, G. S., Melosh, H. J., Marcus, R. A. (2005) Earth Impact Effects Program: A web-based computer program for calculating the regional environmental consequences of a meteoroid impact on Earth. *Meteorit. Planet. Sci. 40*(6), 817–840