Estimating bolide energy deposition with a simple Monte-Carlo meteoroid ablation model

E. Stokan, P. Brown
The University of Western Ontario (estokan@uwo.ca)

Meteoroids with radii larger than 10 m can potentially penetrate deep enough into the atmosphere to cause damage to structures as well as casualties. Rapid deceleration and ablation of the meteoroid results in significant deposition of energy into the atmosphere, which is subsequently propagated to the ground as a shockwave. A recent example of this is the Chelyabinsk airburst, with an estimated blast yield of nearly 500 kT TNT equivalent, which resulted from a meteoroid with an estimated initial radius of 10 m [1,2,3]. There is a need to rapidly estimate the potential ground damage, computed from the atmospheric energy deposition, for large meteoroids that are observed before impact.

The ReVelle model for bolide ablation, referred to as the triggered progressive fragmentation model (TPFM), is a fast, semi-empirical model that computes mass loss, light production, atmospheric energy deposition, and other effects associated with the atmospheric entry of bodies with radii between 0.1 and 100 m [4,5]. This model was able to provide information on the initial radius, density, and strength of the Chelyabinsk meteoroid through simultaneous reproduction of the observed light curve and energy deposition [2]. The match to the energy deposition rate is shown in Fig. 1.

We estimate atmospheric energy deposition for meteoroids of a given radius and speed by examining an ensemble of Monte Carlo runs of the ReVelle model, drawing from empirical distributions for object strength and porosity, which have an acute influence on the meteor behaviour. The object strength distribution is based on a compilation of light curve observations of meteoroids larger than 1 m in size [6]. As output, the energy deposition per unit height is computed, with associated bounds for uncertainty based on the initial parameter distributions. Ultimately, the goal of coupling the ReVelle model with Monte Carlo parameter selection is to assist civil defense authorities in estimating damage on the ground resulting from Chelyabinsk-sized meteoroid airbursts.

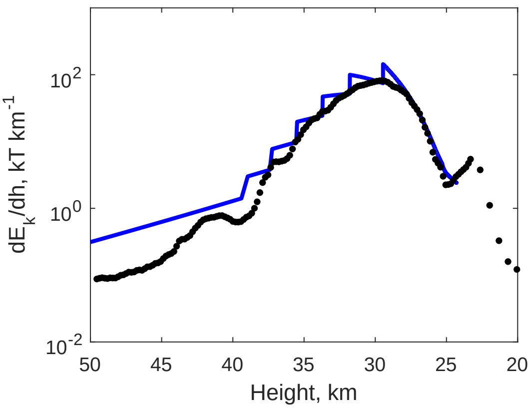

Figure 1: Modelled energy deposition per unit height for the Chelyabinsk meteoroid (blue curve) as well as observations (black dots). Matching the general shape of the atmospheric energy deposition allowed for estimates of the Chelyabinsk meteoroid initial radius, strength, and density, as discussed in [2].

References

[1] Borovička, J., Spurný, P., Brown, P., Kalenda, P., Clark, D., Shrbený, L., (2013). Nature, 503, 235.

[2] Brown, P. G. et al., (2013). Nature, 503, 238.

[3] Popova O. P. et al., (2013). Science, 342, 1069.

[4] ReVelle, D. O., (2005). Earth, Moon, and Planets, 95, 441.

[5] ReVelle, D. O., (2007). Proceedings IAU Symposium 236, eds. A. Milani, G. B. Valsecchi, D. Vokrouhlický. 95.

[6] Brown, P., Wiegert, P., Clark, D., Tagliaferri, E., (2016). Icarus, 266, 96.