Session 2. Comets, Meteors, and Meteoroids

INFLUX OF SPACE BODIES TO THE EARTH (LA–UR–00–1575)

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Small bodies from within our Solar System enter the atmosphere from space constantly. There is also apparently a small component of this flux ($<\sim 2\%$) entering from Interstellar Space as well. The sources of these objects include both asteroids and comets. Over the full spectrum of masses from $\sim 10^{-20}$ to 10^{15} kg, numerous methods have been employed to observe these materials. These include EM radar, photographic techniques, telescopes, satellite impacts and microphone recordings, infrasound, hydroacoustic and seismic detection techniques, spectral recordings, meteorite falls/finds, *etc.* Very bright and quite large bolides have also been routinely detected globally by US DoD satellites both optically and in the infrared. ReVelle (1997) has analyzed the AFTAC (U.S. Air Force Technical Applications Center, Patrick AFB, Florida) infrasound data and has predicted an influx rate of large bolides as a function of their source energy and compared it with the satellite derived influx estimates. Kruchynenko (1998) also recently presented an independent assessment of the integrated density of the influx of space bodies to the Earth over a much wider range of masses than considered by ReVelle. His results are more similar to the findings of Ceplecha *et al.* (1998), but with a curve fit of each of the various regimes of material and a separate integrated curve fit for the entire range of masses of space bodies impacting the Earth. ReVelle (1999) has also analyzed a more complete set of infrasound bolide detections for a much wider range of energies considered earlier. This set included observations made in Los Alamos, Russia, Sweden, Australia, *etc.* from 1990–1999 (ReVelle and Whitaker, 1996; ReVelle *et al.*, 1997; ReVelle *et al.*, 1998; ReVelle and Whitaker, 1999). This new analysis corroborates the 1997 results with relatively minor slope changes. For Tunguska ($=10$ Mt source energy), we can expect a reoccurrence, on the average, once every 90–220 years on the Earth (nominal value $= 112$ yr). Similar estimates are made for other source energies as well.

I. INTRODUCTION

A. Large Bolides in the Near-Earth Environment: NEO's

There are several type of asteroids that make-up the near-Earth bolide influx. These include the Apollos, the Amors and the Atens (ReVelle and Ceplecha, 1994). All of these types can be seggregated by their orbital parameters. The near-Earth object population is also comprised of meteorite fragments from both asteroidal as well as cometary sources (Ceplecha and McCrosky, 1976; Wetherill and ReVelle, 1981a; 1981b). Since only the strongest objects can penetrate deeply enough to generate a blast wave source, the infrasonic detections are probably a lower limit to the "true" influx rate (ReVelle and Whitaker, 1999).

B. Detection Techniques for Large Bolides

There are three well-known methods for determining the large meteoroid influx, including:

a) Photographic fireball networks: (Panchromatic passband emulsions, requires knowledge of the luminous efficiency to deduce the intial mass of the body).
b) Satellite detection: Visible and infrared light emissions.

c) Infrasound detection: Blast wave generation and detection in the atmospheric waveguide. Arrays of infrasonic sensors provide the elevation and azimuth angle of the plane wave arrivial.

Each of these methods has its optimum size range, detection threshold, *etc.* They each compliment one-another however, in terms of providing a reliable, time-averaged influx rate as is seen in Figures 1 and 2.

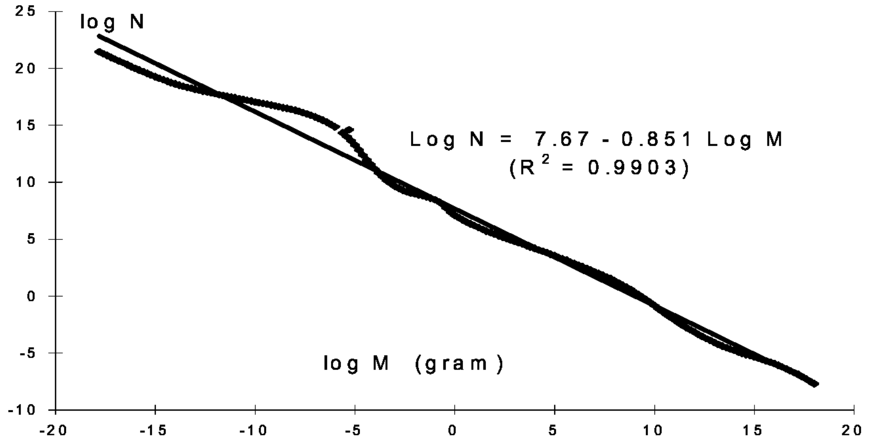

Figure 1: Results from Kruchynenko (on the basis Ceplecha *et al.*, 1998)

II. ANALYSIS

In this section we refer to recent work by Ceplecha *et al.* (1998), by Kruchynneko (1998) and by ReVelle (1997, 1999, *etc.*) on the integral mass influx calculation for the Earth. The work of Ceplecha and Kruchynenko consider nearly the same data sources and seek a curve fit of the data versus mass. The former approach uses a cubic spline interpolation technique, whereas the latter approach uses a single power law, least squares, curve fit over the entire mass range available. In contrast, ReVelle utilized only infrasound data for his source energy influx calculation with his 1997 paper dealing only with historic data sources (from 1960–1974) whereas his 1999 paper also utilized, in addition, the most recent bolides detected infrasonically by Los Alamos National Laboratory and other research groups from 1995–1999. A summary of some of the most recent events used in the analysis of ReVelle (1999) is given below:

1: 11/21/1995, Colorado Springs, Colorado (38.6 N, 104.6 W) – 0918 UTC
ReVelle and Whitaker (1996): US satellite DoD detection, Also, local video/audio on a security camera in Colorado Springs, Colorado, Source energy, $E_s = 5.3e^{-02}$ kt, Max. amp. wave period = 2.0 s (detected at the Los Alamos infrasonic research array in Los Alamos).

2: 10/4/1996, Little Lake, California (36.1 N, 117.6 W) – 0344 UTC
ReVelle *et al.* (1997): US DoD satellite detection, $E_s = 0.538$ kt, Max. amp. wave period = 4.0 s (NTS, Nevada Test Site array opertaed by Los Alamos) and $E_s = 1.136$ kt, Max. amp. wave period = 5.0 s (detected at the Los Alamos array in Pinedale, WY at the PSRF-Pinedale seismic research facility).

3: 10/9/1997, El Paso, Texas (31.8 N, 106.1 W) – 1847:15 UTC
ReVelle *et al.* (1998): US satellite DoD detection, $E_s = 0.293$ kt, Max. amp. wave period = 3.33 s (detected at the CTBT IMS infrasound array in Los Alamos; Also detected infrasonically by the SMU (Southern Methodist University) infrasonic array at Lajitas, Texas, E. Herrin, Geology Department, SMU, Dallas, Texas).

4: 12/9/1997, Southwestern Greenland (62.9 N, 50.9 W) – 0811:55 UTC
Unpublished, L. Liszka, Swedish Isntitute of Space Physics (IRF), Umea, Sweden: US DoD satellite detection, E_s = 0.112 kt, Max. amp. wave period = 2.5 s (detected at the IRF Uppsala infrasound array in Uppsala, Sweden).

5: 8/11/1998, Alice Springs, Australia (19.93 S, 134.3 E) – 1017:36 UTC detection time, not event origin time
Unpublished, D. Christie (CTBTO, Vienna, Austria and K. Muirhead, Australian National University), E_s = 9.3 kt, Lamb wave period = 11.9 s, Max. amp. wave period = 9.4 s (detected at the Waramunga CTBT IMS infrasound array).

III. RESULTS

We first present the graphs of the predicted influx from Kruchynenko (1998), which are based upon essentailly the same data set used in Ceplecha *et al.* (1998). Next we consider the graph of the predictions of ReVelle (1999), since they are quite similar to ReVelle (1997).

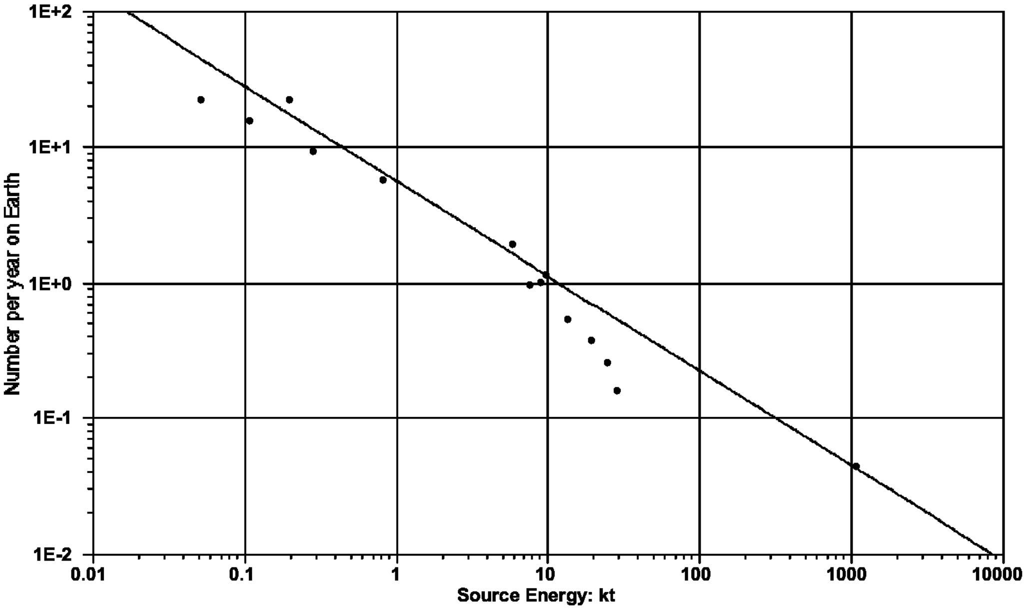

Figure 2: Results from ReVelle (1999)

The various influx relations developed by ReVelle (1999) using this data includes the following:

a) Original relation from ReVelle (1997) for 10 events detected by AFTAC from 1960–1974.
b) New relation using only data recorded since 1995 including five new bolide events.
c) New relation using only data since 1995, but omitting the Alice Springs bolide.
d) All of the infrasound data (15 events) recorded through early 1999 (including Alice Springs).

Using these energy influx relations we can also estimate the influx rate for specific energy sources, with the Tunguska energy clearly an extrapolation beyond the source energies previously detected since the time of event.

a) 1 kt: 7.17/year over Earth
15 kt: 0.99/year over Earth
10 Mt (Tunguska): One every 117.1 years

b) 1 kt: 6.44/year over the Earth
15 kt: 0.765/year over the Earth
10 Mt (Tunguska): One every 217.8 years

c) 1 kt: 7.53/year over the Earth
15 kt: 1.12/year over the Earth
10 Mt (Tunguska): One every 87.7 years

d) 1 kt: 5.61/year over the Earth
15 kt: 0.844/year over the Earth
10 Mt (Tunguska): One every 111.9 years

These estimates are in good agreement with those provided by the US DoD satellite community (Tagliaferri *et al.*, 1994) and also with those of Ceplecha *et al.* (1998) and evaluated independently by Kruchynenko (1998).

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