GLOBAL DETECTION OF AIRBURSTS: A COMBINED SATELLITE - INFRASOUND STUDY

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Introduction: The impact of meter-sized NEOs with Earth occurs several times per month [1]. Such impacts deposit the bulk of their kinetic energy in the atmosphere, producing airbursts [2,3]. In some cases meteoritic material may also be recovered, providing an opportunity to link the associated fireball with a particular class of asteroid or even with pre-impact telescopic detection [4] and thereby further refine asteroid-meteorite connections. Characterizing airbursts also helps to define the physical nature of the original meter-sized NEO and provides ground-truth for entry models which may then be scaled to larger events. Discrimination of these energetic natural events from atmospheric nuclear detonations is also a major study focus of the Comprehensive Test-Ban Treaty Organization (CTBTO) [5].

The majority of airbursts occur in remote regions without ground observation. Two technologies which have been used to record a large fraction of all airbursts globally have been satellites [6] and infrasound networks [5]. The former rely on the light production associated with large airbursts which can be detcted from orbiting platforms with suitably large coverage areas, while the latter use ground-based microbarometers to record the passage of airburst derived shocks at long distances. Satellite data has not been released for several years [7], leaving infrasound the only currently public source of information for global airbursts.

Infrasound (20 Hz < f < 0.001 Hz) is a desirable means to monitor atmospheric airbursts as sound attenuation at low frequencies is small. Using detections at two or more infrasound stations the location of an airburst in the atmosphere can be localized and rough source timing may also be determined assuming an atmospheric propagation model [8]. Airburst energy estimates using infrasound data alone has been attempted in the past, but rarely are such infrasound energy values verified by other techniques [1]. Infrasound data is usually unable to determine airburst height, bolide trajectory or speed. As all of these influence the characteristics of the waveform detected at an infrasound array, in the absence of supplementary information from other sources, each event needs to be interpreted within a statistical framework of previous detections. The goal of our work is to develop empirical relations between airbursts detected by satellites (where energy, timing and range to a station is known) and the corresponding infrasound signal properites, such as period and amplitude. We also wish to develop frequency vs. range and energy discrimnators as a first step to isolating airbursts from other possible infrasound sources.

Observations: We have selected 71 airbursts detected by satellite systems (see [1,6,9] for details) and found the corresponding infrasound airburst signals at one or more infrasound arrays operated by the CTBTO [5]. These airbursts have satellite determined total yields between 0.04 kilotons (kT) TNT equivalent (1 kT = 4.185×10^{12} J) and 20 kT. Each airburst associated infrasound arrival had a series of measurements extracted following the procedure described in [9], including signal period, maximum amplitude, duration, lower and upper signal frequency.

Results: We find that the most robust means of estimating airburst source energy is through the observed period at maximum amplitude (Fig. 1). This relation follows closely that given by the Air Force Technical Applications Centre (AFTAC) between nuclear airburst yield and dominant infrasound period [10]. We find that an inverse square-root yield scaling exponent together with a distance scaling exponent of -1.06 best represents the amplitude fall-off for our airburst dataset provided the effects of atmospheric winds are included, in agreement with earlier shorter-range ground-based explosion results [11].

One result of this study is an estimate of the average range as a function of source energy an airburst can be expected to be detected using current infrasound technology (Fig. 2). Airbursts in excess of ~20 kT are detectable globally. As the current average interstation spacing is roughly ~2000 km [12], from Fig 2, we expect that most small airbursts will be detectable at a minimum of one station in the current network, provided propagation conditions are favourable. However, positive identification and geolocation usually require at least two and more often three stations such that the practical coverage limit is closer to ~0.5 - 1 kT. More than 50% of all >1 kT satellite detected airbursts during our study period were detected infrasonically. This is a lower limit relative to the current infrasound network operated by the CTBTO as many of these events occurred when the network had only a fraction its current number of stations. Finally, we empirically determined the upper and lower frequency envelope for airbursts as a function of scaled range (ie. scaled to a standard yield of 1 kT TNT) to provide a means of discriminating airbursts from local infrasound sources based on frequency content alone if range is known. All these relations are summarized in Table 1.

Conclusions: We have analysed 71 airbursts which were simultaneously detected by satellite systems and infrasound arrays. Using satellite data as ground truth for location and total energy we have generated a series of empirical relations between airburst energy and infrasound period, amplitude and frequency roll-off with range. Infrasound measurements can be used to robustly characterize airburst energy and in some cases timing and location [8]. It is not an effective technology to define airburst height or trajectory/speed for most events.

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Table 1, Summary of relations between infrasound period P [secs], maximum amplitude A [Pa], upper, f_U, and lower, f_L, signal frequency content [Hz] and range R [km] to source as a function of satellite derived energy E [kT TNT] and average stratospheric wind speed from source to receiver V [m/s].

Relation	**Description**
log R=3.8+0.33logE	Max distance (R) airburst of energy (E) is detectable
log E=3.28logP-2.29	Energy (E) and period (P)
log A = 4.4 - 1.06 logR -0.47 log E - 0.0068V	Max. signal amplitude (A) as a function of range (R), airburst energy (E) and stratospheric wind speed (V).
f_U=1.09+13.4exp(-Rs/3950)	Upper frequency content (Hz) of airburst signal at scaled-range R_s (km/kT$^{1/2}$)
f_L=0.31+4.25exp(-Rs/1901)	Lower frequency content (Hz) of airburst signal at scaled-range R_s (km/kT$^{1/2}$)

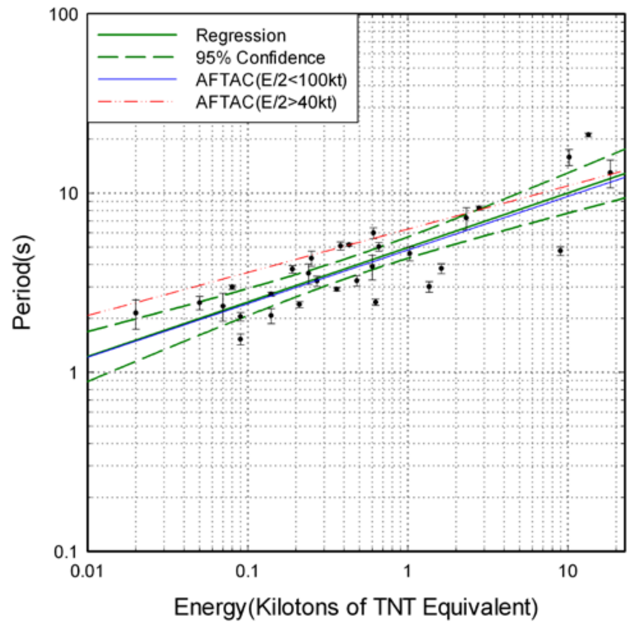

Figure 1. The station-averaged infrasonic period at maximum amplitude for airbursts detected at more than one station. The error in period represents the standard deviation across all stations. The energy, E, is determined from optical satellite sensors. Also shown are the AFTAC period-yield relations [10].

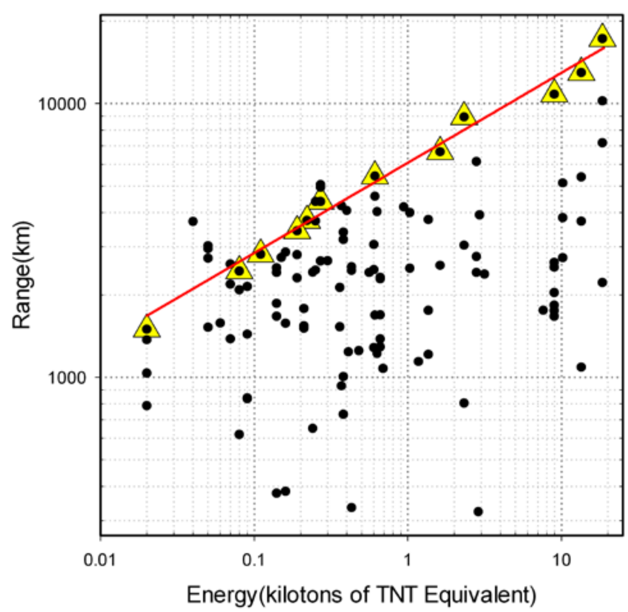

Figure 2. Range of infrasound detection as a function of satellite determined airburst energy. Note that all station detections are listed and hence individual airburst events may be represented multiple times (as a vertical collections of points) The red line corresponds to the first relation given in Table 1 as a fit to the yellow trianglar symbols.