Leveraging infrasound detected by stations of the IMS network for estimating the characteristics of shock waves generated by large bolides

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1. Introduction

Natural and artificial impulsive sources in the atmosphere can generate infrasound, or very low frequency (f<20 Hz) acoustic waves. Infrasound can travel over long distances with minimal attenuation.

Traditionally confined to ground-based sensors, the domain of infrasound sensing has expanded in recent years to include airborne platforms (e.g., balloons).

Unlike other sensing modalities that might have geographic (e.g., inaccessible regions), time-of-day (e.g., optical) or other limitations, infrasound can be utilized continuously (day and night) on a global scale.

Volcanoes, lightning, chemical explosions, re-entry vehicles, space debris, and bolides are among the diverse sources producing infrasound phenomena. Among these, bolides (Fig. 1) present a particularly intriguing scientific challenge due to their varying velocities, entry angles, and physical properties.

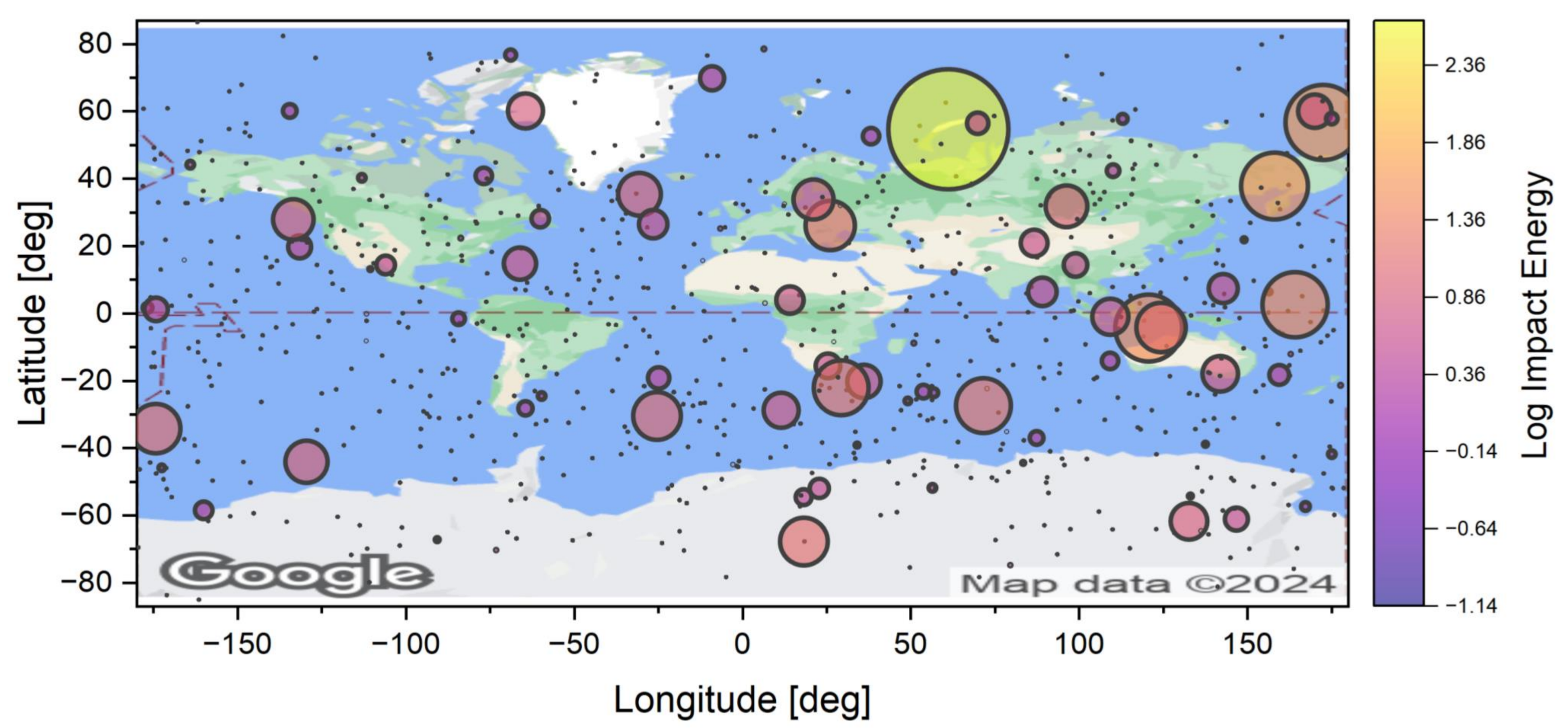

Figure 1: Bolides detected by the USG sensors from 1998 until February of 2024. CNEOS database provides important ground truth (GT) that can be used for searching for infrasound signals. Data source: https://cneos.jpl.nasa.gov/fireballs

2. Bolide infrasound

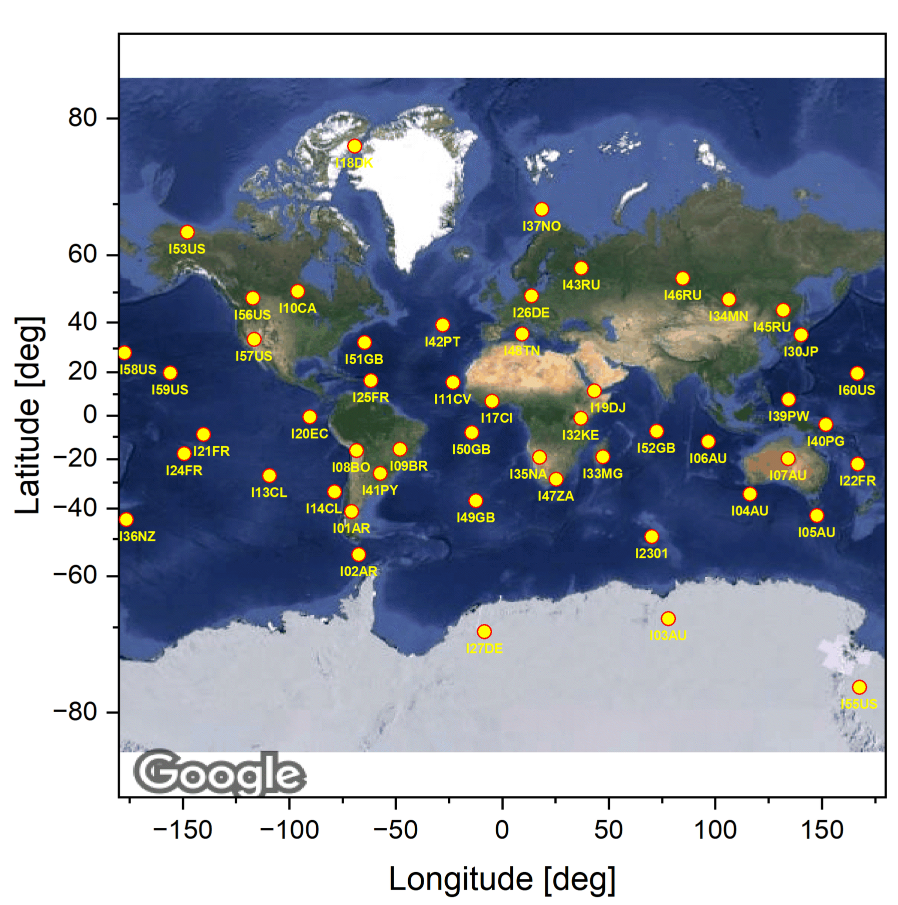

Figure 2: Global (Mercator projected) map showing infrasound stations of the IMS.

Depending on initial conditions, atmospheric propagation paths, and the mode of shock production, infrasound emanating from a bolide can be detected by instruments hundreds and even thousands of kilometers from the source [1-3].

Infrasound data collected by the International Monitoring System (IMS) of the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO PrepCom) can be leveraged in detection and characterization of bolides on a global scale (Fig.3).

Theoretically, bolide infrasound signatures should carry information about the source (Fig. 2) but the dynamic changes in the atmosphere that occur on temporal scales of minutes to hours might lead to loss of that information.

To fully utilize infrasound in characterization of bolides and sources alike, it is useful to have both the event ground truth and accurate atmospheric specifications [4].

3. A case study

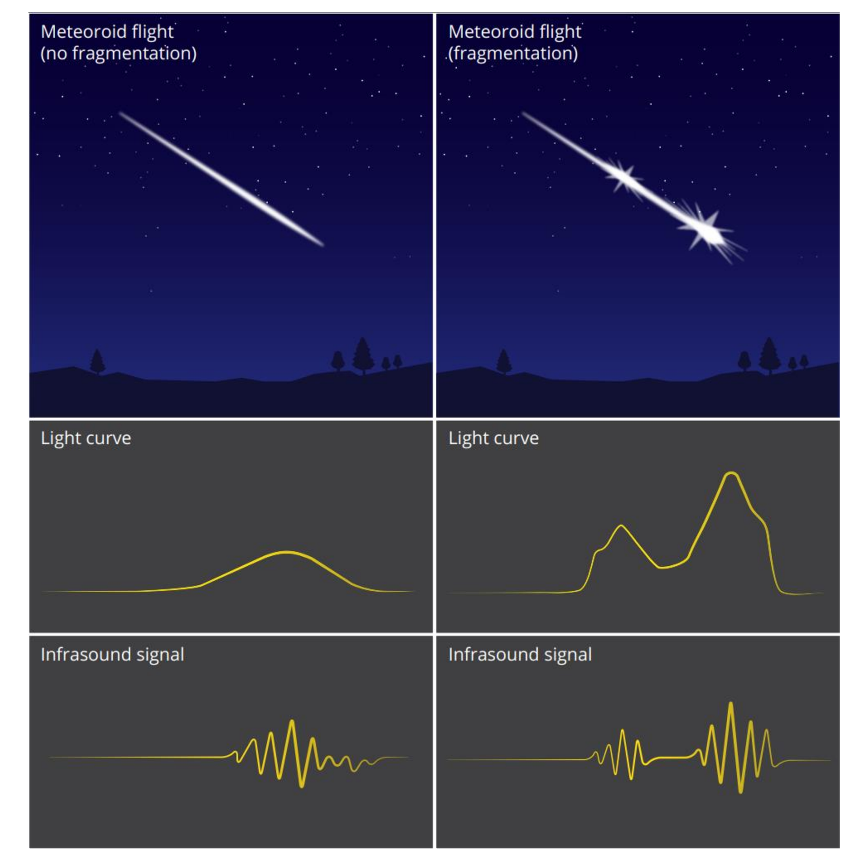

Figure 3: Diagram showing how features seen in infrasound signal might be diagnostic of meteoroid flight parameters. Figure source [4].

On 23 July 2008 at 14:45:25 UTC a bolide entered the atmosphere over Tajikistan (Fig. 4), producing a series of audible sounds, as reported by casual witnesses [5].

The signal was detected at two IMS stations, I31KZ (16:04:28 UTC) and I46RU (16:42:35 UTC), 1,530 and 2,130 km, respectively, away from the source [4].

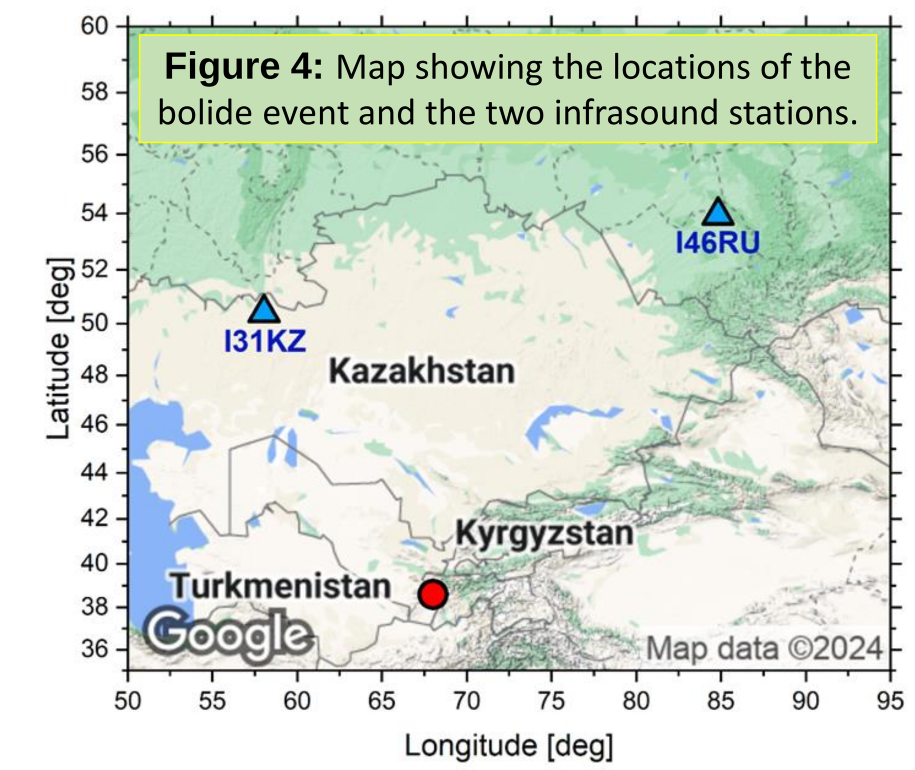

Figure 4: Map showing the locations of the bolide event and the two infrasound stations.

There was a well-developed stratospheric duct between the source and I31KZ, and a weak and narrow stratospheric duct consistent with the AtmoSOFAR channel between the source and I46RU (Fig. 5).

As per infrasound analysis, the shock originated at the point of the main breakup at an altitude of 35 km.

The primary mode of shock production of the signal detected at the two stations was a spherical blast resulting from the main gross fragmentation episode. Additional details are available in open access publication (doi: 10.3847/1538-3881/ad47c3).

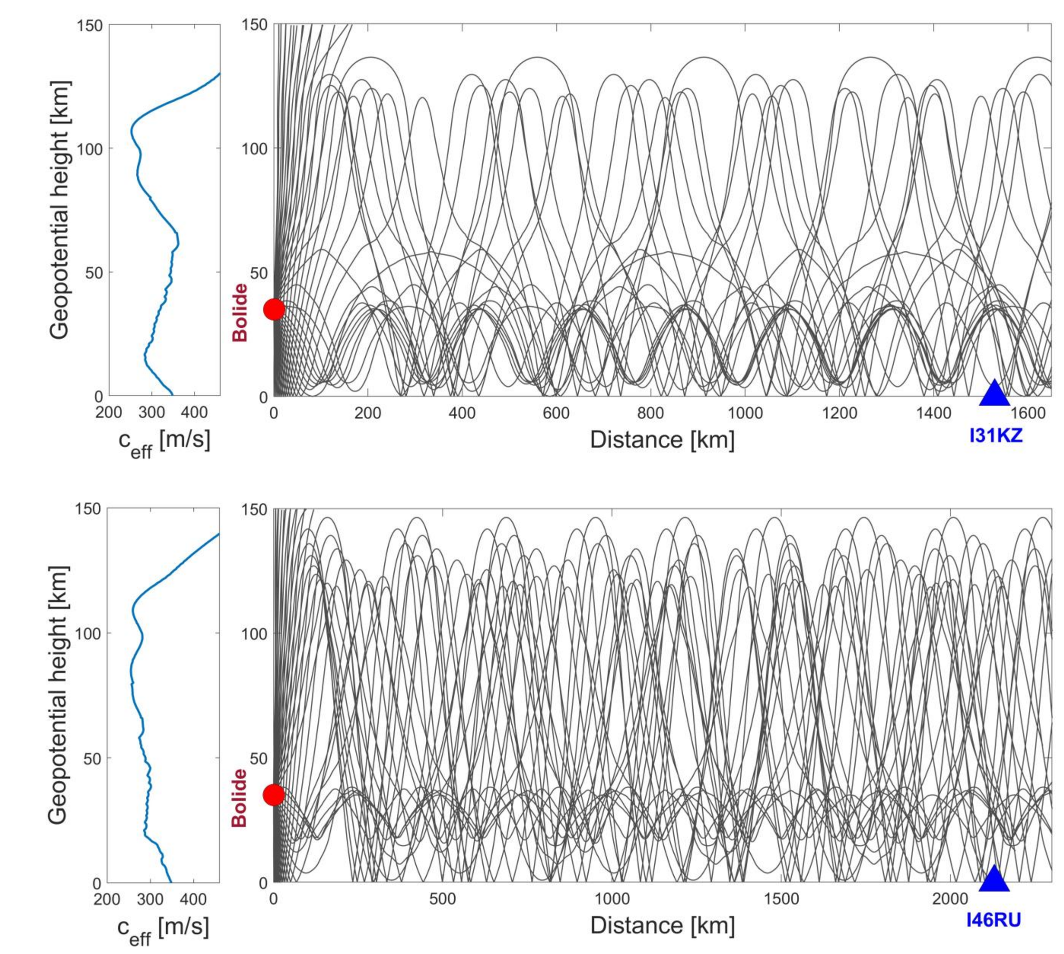

Figure 5: Raytracing results. The effective sound speed is plotted on the left.

4. Conclusions

Due to its intrinsic properties, infrasound can serve as a valuable tool for bolstering planetary defense capabilities. The fusion of infrasound data with other sensing modalities can help improve model refinement and validation. The overarching goal is to utilize infrasound alone to infer source characteristics, driving the need for advancements in data fusion methodologies.

References

[1] Silber et al. (2018). Physics of meteor generated shock waves in the Earth's atmosphere–A review. Advances in Space Research, 62(3), 489-532.. [2] https://cneos.jpl.nasa.gov/fireballs/ [3] Silber & Brown (2019). Infrasound monitoring as a tool to characterize impacting near-earth objects (NEOs). Infrasound Monitoring for Atmospheric Studies, 939-986. [4] Silber (2024) The utility of infrasound in global monitoring of extraterrestrial impacts: A case study of the 23 July 2008 Tajikistan bolide, The Astronomical Journal [5] Konovalova et al. (2013) Meteoritics & Planetary Science, 48, 2469.

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