Analyzing bolide shock source and propagation variability through a case study

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INTRODUCTION AND MAIN RESULTS

Infrasound detection of the 2008 Tajikistan bolide demonstrates the capability to capture explosive atmospheric events thousands of kilometers away. Analysis of signal propagation revealed unexpected atmospheric channeling, confirming bolide breakup altitude and explosion energy. This event illustrates the value of infrasound for characterization of distant explosive sources.

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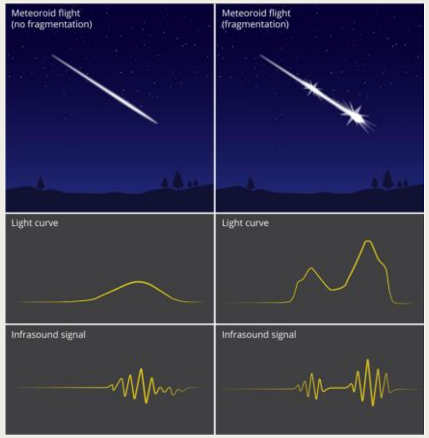
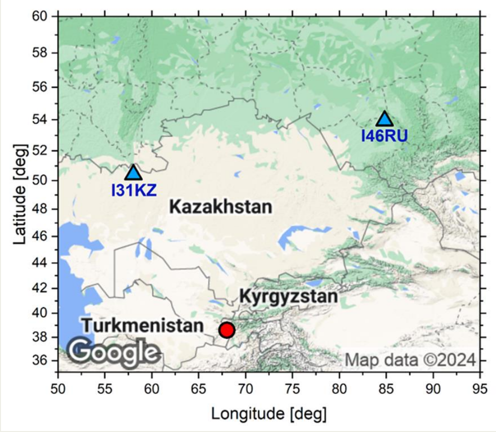
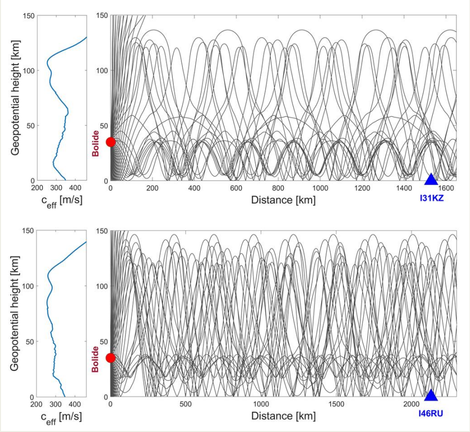
- Infrasound captures explosive bolide events from thousands of kilometers away, supporting global monitoring efforts.
- Atmospheric conditions can channel infrasound signals, allowing unexpected detections.
- The Tajikistan bolide event demonstrated long-distance infrasound propagation through a “leaky” atmospheric duct.
- Infrasound can be leveraged for inferring the type of shock even at large distances.
- If you want to find out more, come and visit my poster!

SCAN ME







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Introduction

Natural and artificial impulsive sources in the atmosphere can generate infrasound. Infrasound can travel over long distances with minimal attenuation.

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

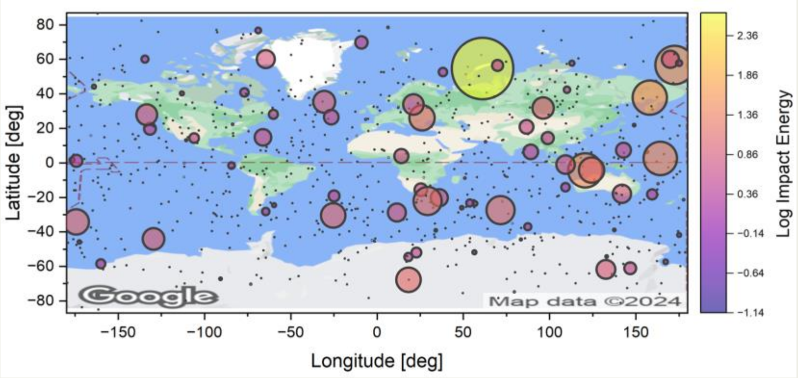
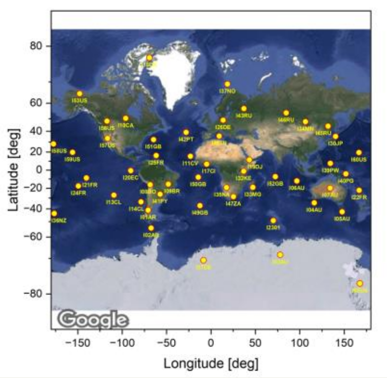
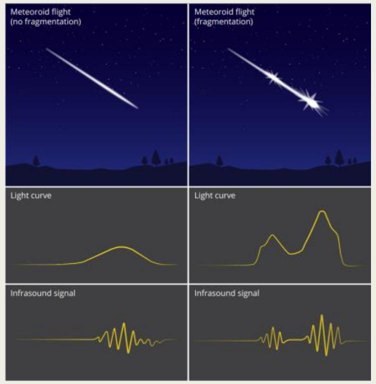


Figure above shows bolides detected by the US governemnt sensors from 1998 until February of 2024. CNEOS database provides important ground truth (GT) that can be used for searching for infrasound signals. Data source: https://cneos.jpl.nasa.gov/fireballs

Bolide Infrasound

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. Map with IMS stations is shown below, left.

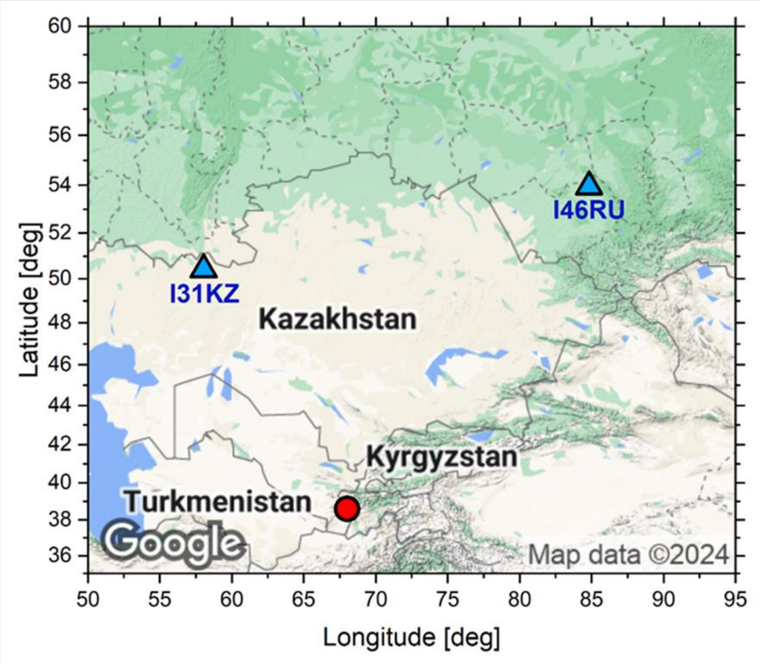




Theoretically, bolide infrasound signatures should carry information about the source, depicted above (right) but the dynamic changes in the atmosphere that occur on temporal scales of minutes to hours might lead to loss of that information.

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].

A Case Study



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

The map with the event location and two IMS stations , I31KZ (16:04:28 UTC) and I46RU (16:42:35 UTC), is shown in the figure above.

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Results

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].

Further analysis revealed that the shock originated at an altitude of ~35 km, coinciding with the main fragmentation event.

Further examination revealed that the primary mode of shock production detectable by these stations was consistent with a spherical blast wave, a direct consequence of the bolide undergoing a significant fragmentation event at high altitude.

This type of explosive fragmentation rapidly deposits energy into the atmosphere, creating powerful acoustic waves capable of traveling thousands of kilometers.

Detection at such significant distances emphasizes the utility of infrasound for characterizing high-altitude explosive processes and in some instances, such as in the case of Tajikistan bolide, infer the type of shock and its altitude.

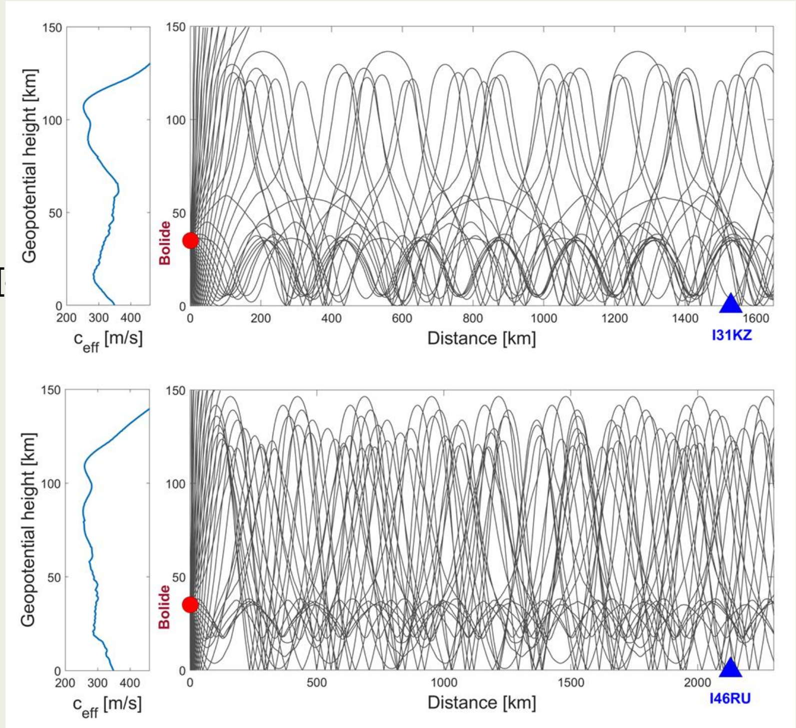
Additional details are available in open access publication (doi: 10.3847/1538-3881/ad47c3).

SCAN ME

Bolide Infrasound

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.

The raytracing results are illustrated in the figure below.



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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