



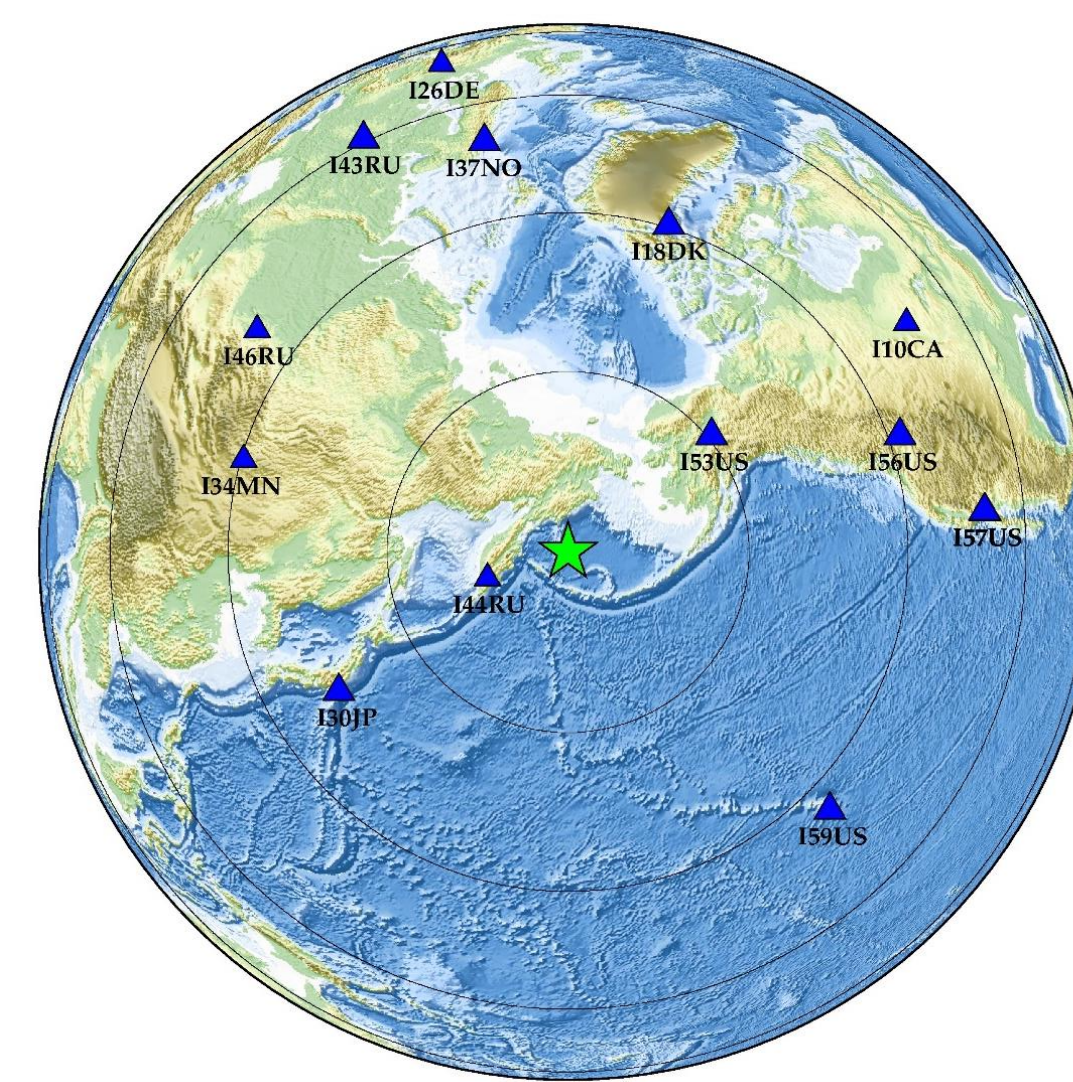
Abstract

In the current work we discuss infrasound data associated with a Near Earth Object impact over the Bering Sea occurring in December 2018 observed on the IMS infrasound network at distances between 1,000 and 8,000 km. Signal detection patterns and celerity observations validate the presence of a stratospheric waveguide north and east of source location, in agreement with the expected state of the atmosphere at the time of the event. The observed frequency range of the signals are variable, dependent on the signal to noise ratio (SNR). Stations with good SNR exhibit a dominant period in the vicinity of 15 seconds, while at arrays with low SNR the local noise conditions dominate and the observed periods are no longer related to the size of the fireball. Applying the period/yield formula on the stations with good SNR (Revelle, 1997) we obtain an approximately equivalent energy release between 4 and 35 kt with a mean of 10 kt. This is much lower than the NASA reported source energy of 173 kt, but such a high energy would require a dominant period of 30 seconds which is not observed in the data. In addition scaling the blast radius with pressure and temperature allows us to approximate the source altitude at 25.8 km, without the need to carry out propagation scenarios.

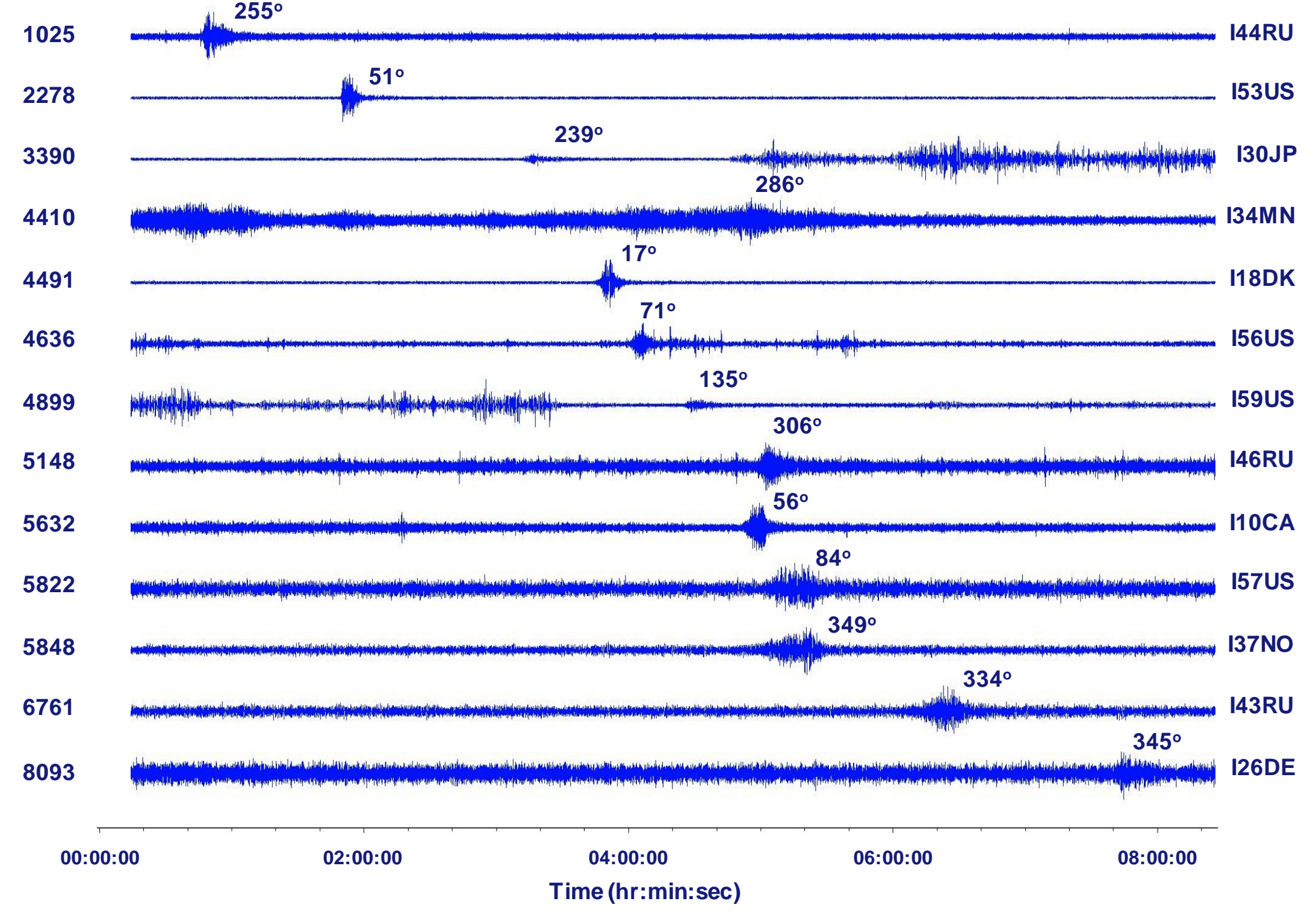
Observations

The bolide was reported on the NASA fireball website (<https://cneos.jpl.nasa.gov/fireballs>) with the origin time of 23:48:20 and the location at 56.9° N and 172.4° E. The reported total radiated energy of the event was 31 kt with the total impact energy at 173 kt making this event the second largest in the NASA database after the Chelyabinsk bolide.

Most of the observations lie east and north of the source location with the largest amplitude observed to the east at I53US in Alaska and I18DK in Greenland, but signals from the event are observed at I26DE at a distance of over 8,000 km. There are a few detections to the west, but in general those have lower signal to noise ratio. Typically signals propagating to the east (favorable wind conditions) show fast celerities above 300 m/s, and allow the observation of a dominant signal period larger than 10 seconds, while to the west they have lower celerities and higher frequency content.



DATA

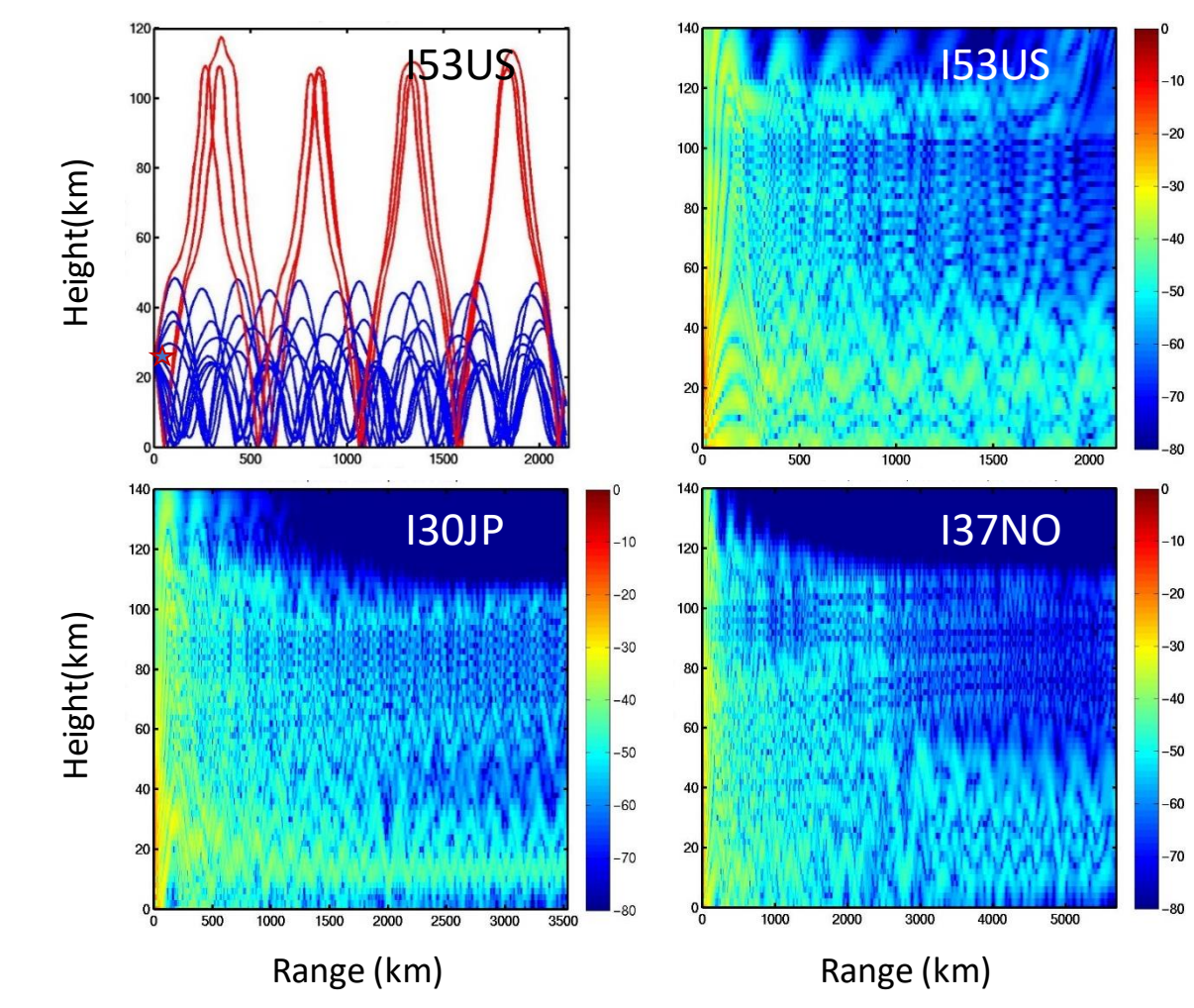


Filtered beams from the bolide sorted against the distance. The numbers on the left show the distance in km, while the numbers above the signals are the source/receiver azimuth.

Station	Distance (km)	Arrival time (hr:min:sec)	Celerity (m/s)	Period (seconds)	Frequency (Hertz)	SR azimuth	Amplitude (Pa)
I44RU	1025	00:47:49	287	2.4	0.3-3	252	0.47
I53US	2278	01:50:14	311	14.4	0.02-1	51	3.35
I30JP	3390	03:13:17	276	10.7	0.02-1	239	0.56
I34MN	4410	04:36:08	255	3.1	0.2-1	286	0.09
I18DK	4491	03:47:04	313	20.1	0.02-1	17	2.14
I56US	4636	04:03:05	303	16.4	0.02-1	71	0.35
I59US	4899	04:26:45	293	12.6	0.02-1	135	0.39
I46RU	5148	04:59:58	275	3.5	0.2-1	306	0.08
I10CA	5632	04:52:33	308	6.2	0.1-1	56	0.06
I57US	5822	05:06:59	305	12.7	0.02-1	84	0.24
I37NO	5848	05:02:17	310	21	0.02-1	349	0.47
I43RU	6761	06:13:53	292	10.7	0.02-1	334	0.23
I26DE	8093	07:42:35	284	6.2	0.1-1	345	0.21

The distance and celerity is relative to the NASA published location and origin time. The frequency column shows the bandwidths used to calculate the beam. The bold rows are the arrays with dominant periods higher than 10 seconds which are used to calculate the energy release.

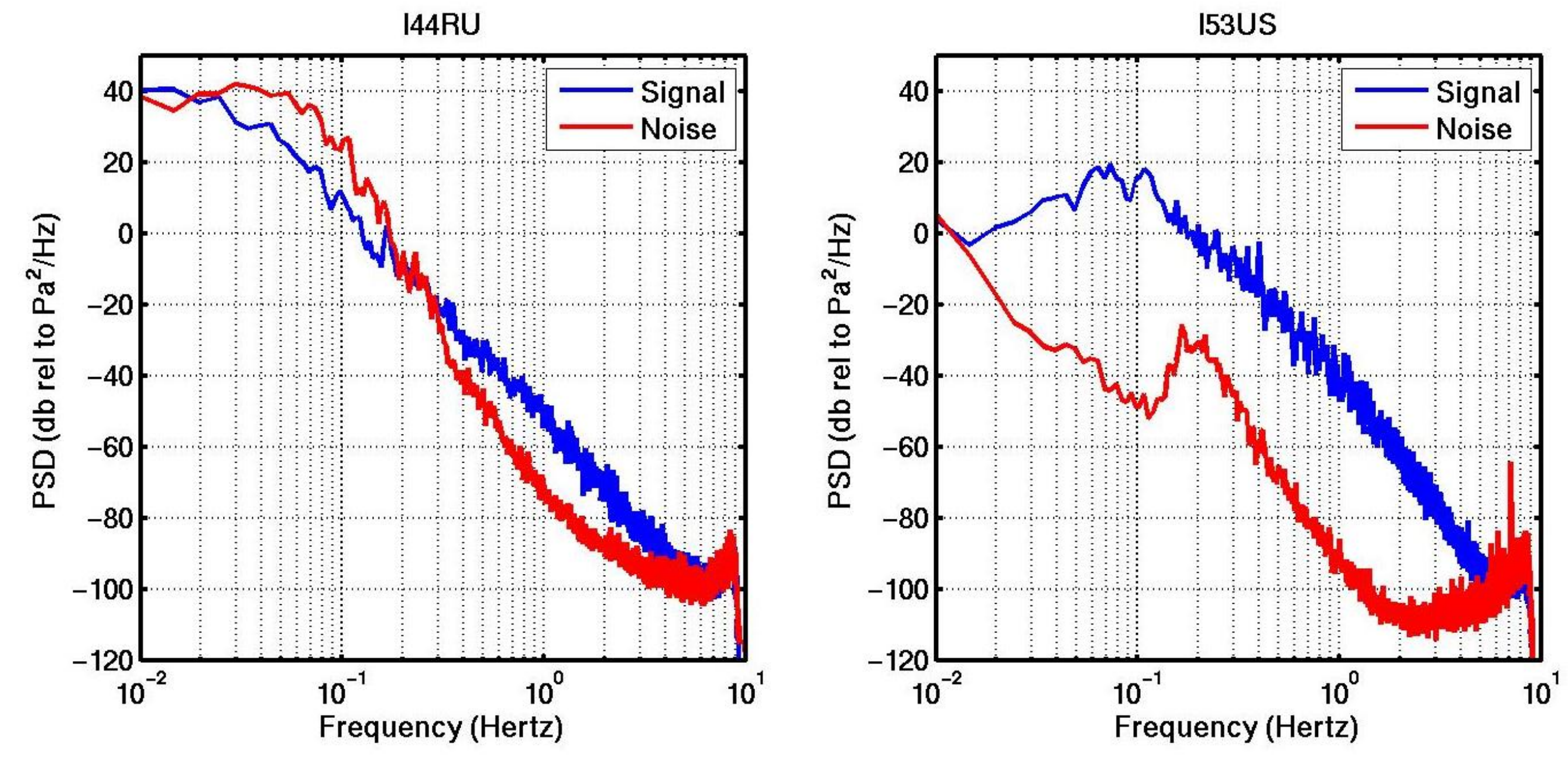
Propagation Results



The celerities shown in the table suggest the observed signals propagated as stratospheric waveguides, which is partly validated by preliminary modeling results. The modelling predicts stratospheric eigenrays at the arrays east of the source (I53US shown in top left), but no stratospheric eigenrays are predicted at the arrays in the other directions. Due to the high temperature gradients in the thermosphere, thermospheric eigenrays are always predicted yet the celerity observations suggest the observed arrivals are stratospheric. Given the long propagation range tropospheric arrivals are not observed from the event.

Due to the higher altitude of the source, PE results show the presence of persistent ducts between the upper troposphere and the thermal stratospheric maximum which can trap the energy for thousands of km. In this case the observed signals at the arrays located in unfavorable stratospheric wind conditions could potentially be explained by leakages from these ducts.

Spectral content



Power spectral density functions for the closest stations (I44RU and I53US) located at distances of 1025 and 2278 km west and east from the source for both the signal and the noise.

I44RU shows no observable signal above the noise for frequencies below 0.3 Hz, and if we were to estimate the dominant period from this spectrum it would be in the vicinity of the lowest frequency at which a signal can be observed above the noise (3.3 seconds). In contrast, I53US even if it is further than I44RU has a high SNR and the signal is above the noise almost in the entire bandwidth, with the peak power around a frequency of 0.07 Hz. The I53US noise spectrum also exhibits a prominent microbarom peak which is usually a good indicator of low background noise conditions while the I44RU does not.

Energy Calculations

We use the period/yield formula (Revelle, 1997) to calculate the equivalent energy release for the bolide:

$$\log(Y) = 3.34 \log(\tau) - 2.58$$

Where Y is the nuclear yield in kt and τ is the dominant period of the signals.

The observed mean period of the eight arrays which show good SNR in the 0.02-1 Hz bandwidth is 14.83 seconds \pm 4.00 seconds. Assuming a log normal distribution of the periods this would give an equivalent nuclear energy of 20 kt, equal to 10 kt TNT equivalent with individual estimate from 4 to 34 kt TNT equivalent. This mean energy estimate is more than one order of magnitude smaller than the reported total impact energy of 173 kt. In order to obtain 173 kt the observed period needs to be in the range of 30-31 seconds which is not observed at any of the arrays.

Event Altitude Estimation

The event altitude can be approximated by scaling the blast radius as a function of temperature and pressure. The size of the fireball depends on the ambient pressure which decays with height. For a spherical explosion the blast radius (R_B) can be written as:

$$R_B = \left(\frac{Y}{4\pi P/3} \right)^{1/3}$$

Where R_B is the blast radius, Y is the yield and the ambient pressure P can be scaled with altitude using:

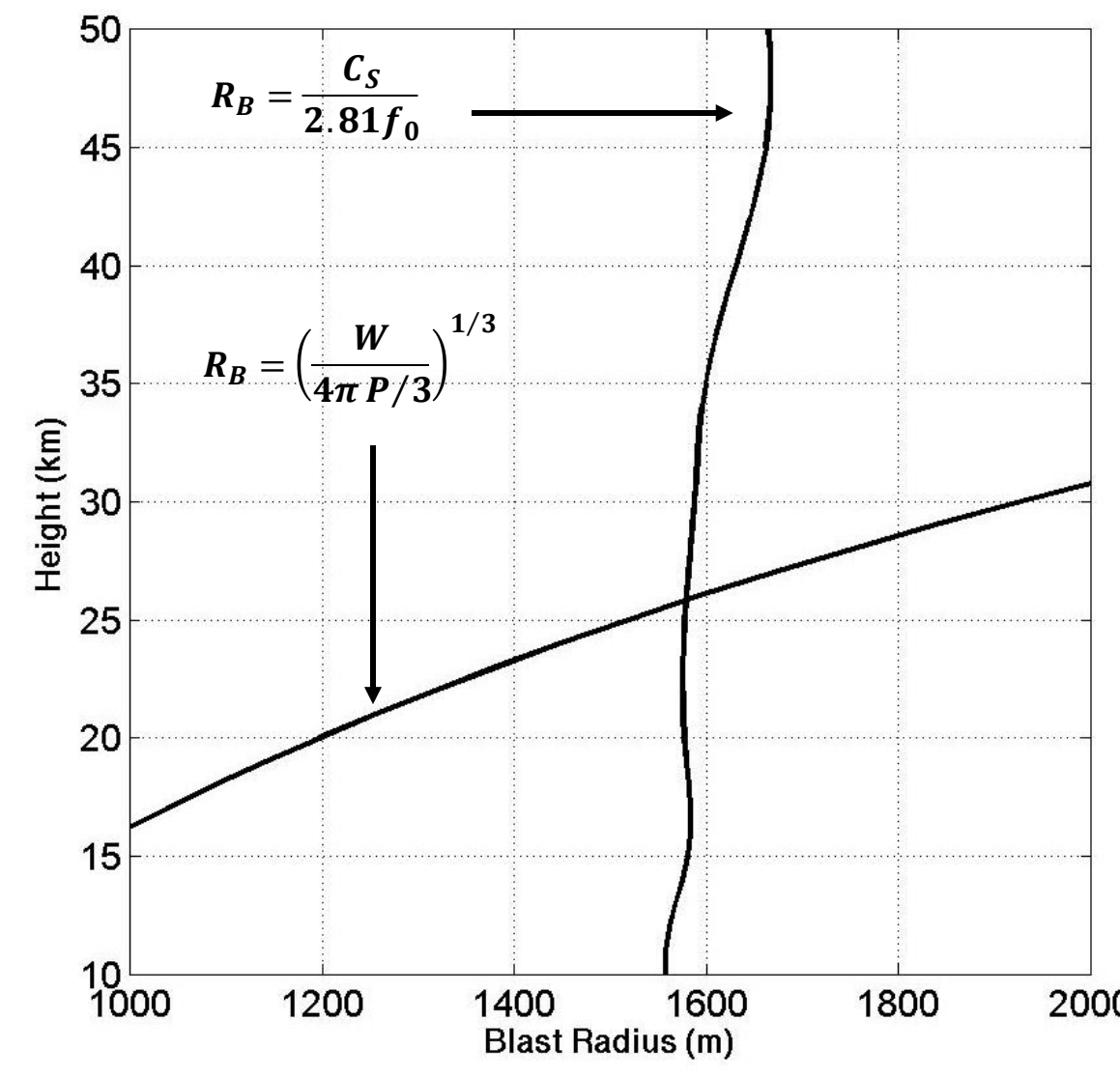
$$P = P_0 e^{-(Z/H)}$$

Where P_0 is the sea level pressure, Z is the altitude, H is scale height of the atmosphere (taken as 7 km).

Similarly the blast radius can be written as a function of the dominant frequency (f_0) and sound speed (C_s) (Edwards 2010, Revelle 1976)

$$R_B = \frac{C_s}{2.81 f_0}$$

Where C_s is the sound speed and is related to the temperature T by $C_s = 20\sqrt{T}$



The altitude of the event is at the intersection of the two R_B estimates and for this bolide it is approximately 25.8 km (NASA published altitude is at 25.6 km) for a blast radius little less than 1,600 m.

Conclusions

The observed frequency range of the signals is variable, dependent on the local noise conditions. Stations with good SNR exhibit a dominant period in the vicinity of 15 seconds while at arrays with low SNR the observed periods are no longer related to the source size of the event.

Using the period/yield formula we obtain an approximately equivalent energy release between 4 and 35 kt with a mean of 10 kt. This is much lower than the NASA reported source energy of 173 kt, but such a high energy would require a dominant period of 30 which is not observed in the data.

Scaling the blast radius with pressure and temperature allows us to approximate the source altitude at 25.8 km, without the need to carry out propagation scenarios.

References

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