Are measurements of infrasonic signal duration useful in the context of nuclear explosion monitoring?

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1. The Research Problem

- Developing robust signal association algorithms for the sparse IMS infrasound network is difficult.
- One challenge is to identify how far a signal has propagated to the station.
- Current measured signal characteristics do not provide an estimate of signal propagation distance.
- Infrasound propagation within atmospheric waveguides causes temporal dispersion of the waveform, therefore:

Does signal duration contain information about how far the signal has propagated?

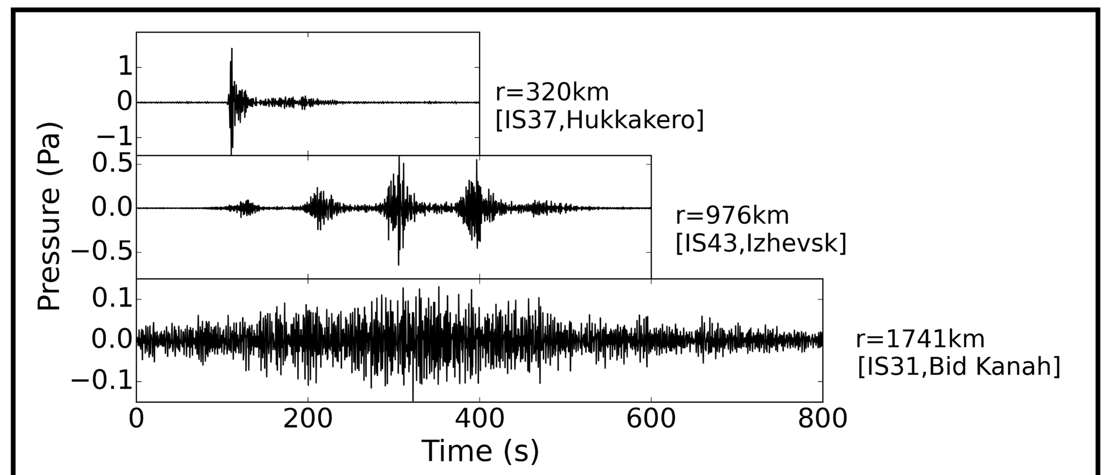

Figure 1: Examples of signals recorded from three different ground-truth events at different propagation ranges. The signals appear to temporally extend with range. Can this information be used to assist signal association procedures?

2. Measuring Signal Duration

Input: array data

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Over beamset identify maximum semblance for each time window

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Construct semblance weighted signal envelope

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Identify signal points (cluster analysis)

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Calculate duration (extent of signal points)

Cluster Analysis

- Highest five semblance points seed the cluster.
- Signal properties:
  - Within ±5° of median seed backazimuth value
  - $0.31 < V_{app} < 0.40$
  - Semblance > 95% level of all noise points outside signal backazimuth swath.

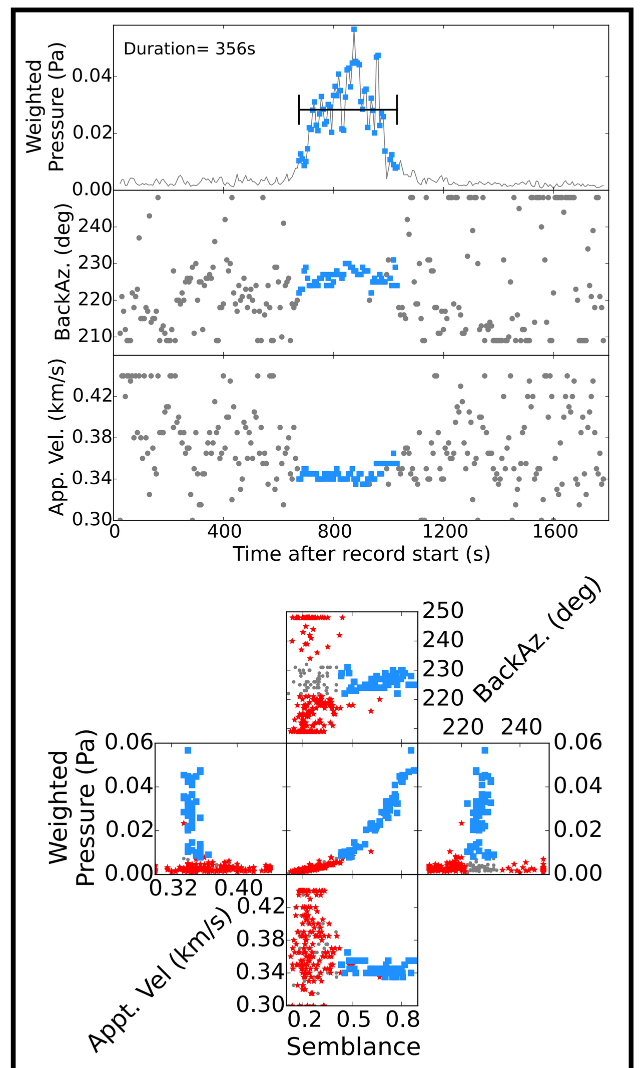


Figure 2. The calculated duration (bar, top panel) for 2011 Sayarim explosion recorded at IS31. The lower plot shows the parameters used in the cluster analysis to separate signal from noise.

3. Signal Durations: Results

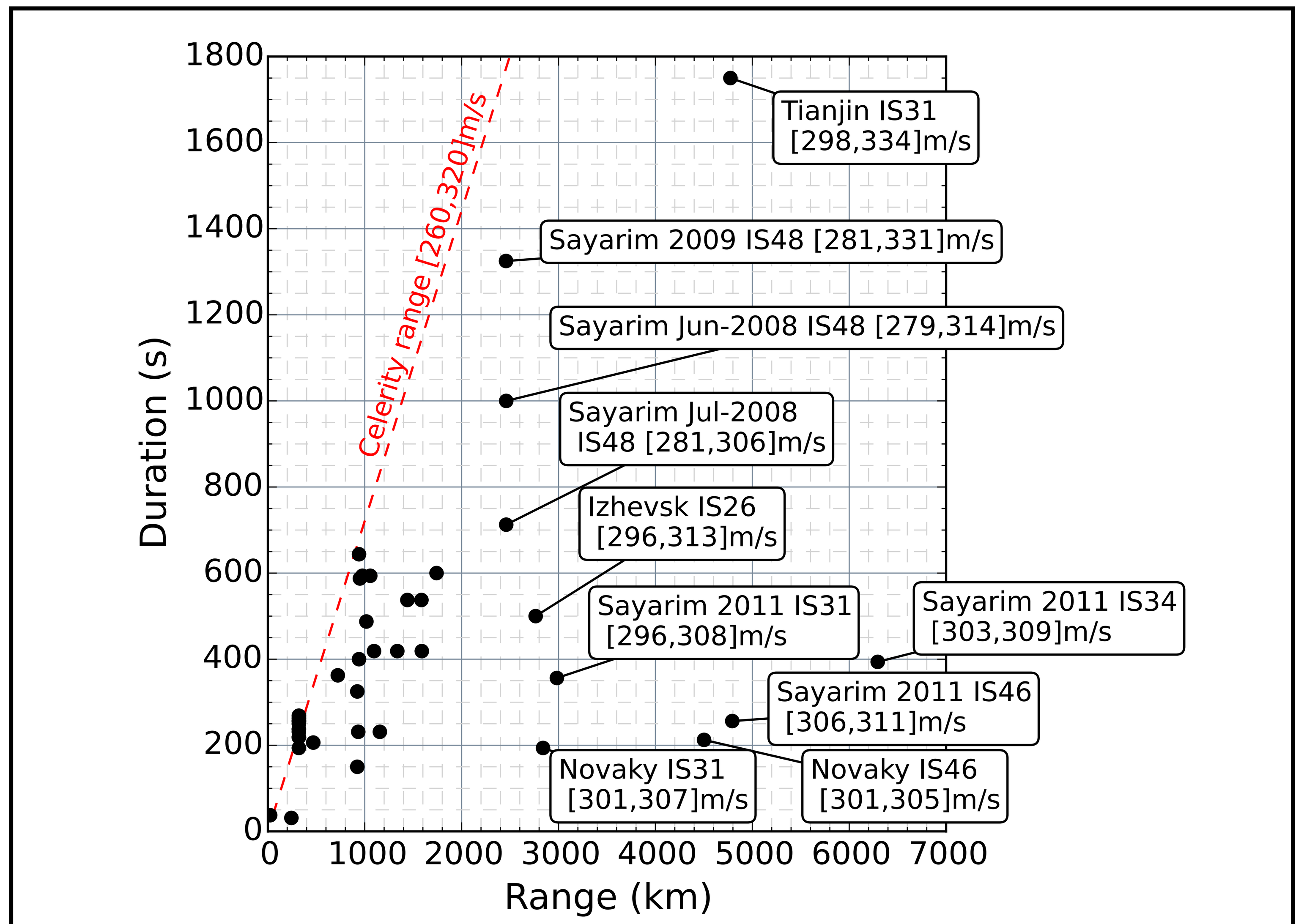
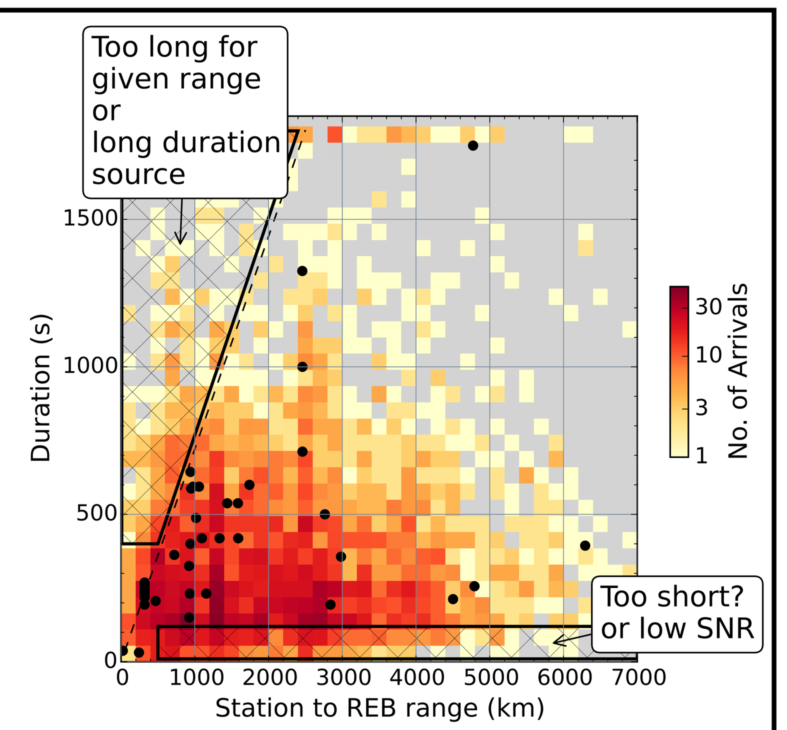


Figure 3: The durations of 42 signals from single impulsive events with known locations and origin times. The signals associated with longer ranges (>2000km) are annotated with the name of the event, the recording station code and the celerity of the [end, start] of the signal. The red dashed line represents the maximum expected signal duration for a physically reasonable maximum celerity range of [260,320] m/s.

- Durations calculated from ground-truth events exhibit significant scatter as a function of range (Figure 3).
- Shorter signals at long propagation distances (>2000km) do not contain fast arriving (high celerity) energy compared to longer signals.
- Reviewed Event Bulletin (REB) entries suggest some bulletin arrivals have unphysical durations if sources are assumed to be impulsive: the signals are too long at short ranges (Figure 4).

Figure 4: A comparison of the durations calculated for this study (black dots) and those calculated during International Data Centre processing for signals that were included in the Apr-2010 to May-2015 Reviewed Event Bulletin (background coloured 2D histogram). The cross-hatched regions indicate areas where no ground truth signals were observed, indicating possible misassociations within the REB catalogue.



Further Information

All infrasound data analysed for this project was recorded on International Monitoring System infrasound arrays.
MERRA-2 atmospheric specification profiles are available from https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2
For further information about datasets used and methods, please contact David Green at dgreen@blacknest.gov.uk

4. Is There a Relationship with Stratospheric Meteorology?

- Multiple studies have shown that long-range infrasound propagation is controlled by the structure of an acoustic waveguide formed between the ground and the upper stratosphere (altitudes ~ 40km).
- Some signal duration variability appears to be due to which acoustic propagation modes can be supported by the waveguide; seen as propagation speed (celerity) variations in Figure 3.
- A comparison of signal durations with the stratospheric meteorology supports this (Figure 5). Weaker ducts appear to support propagation of higher celerity arrivals with observable amplitudes (i.e., observable arrivals with fewer ground-to-stratosphere bounces).

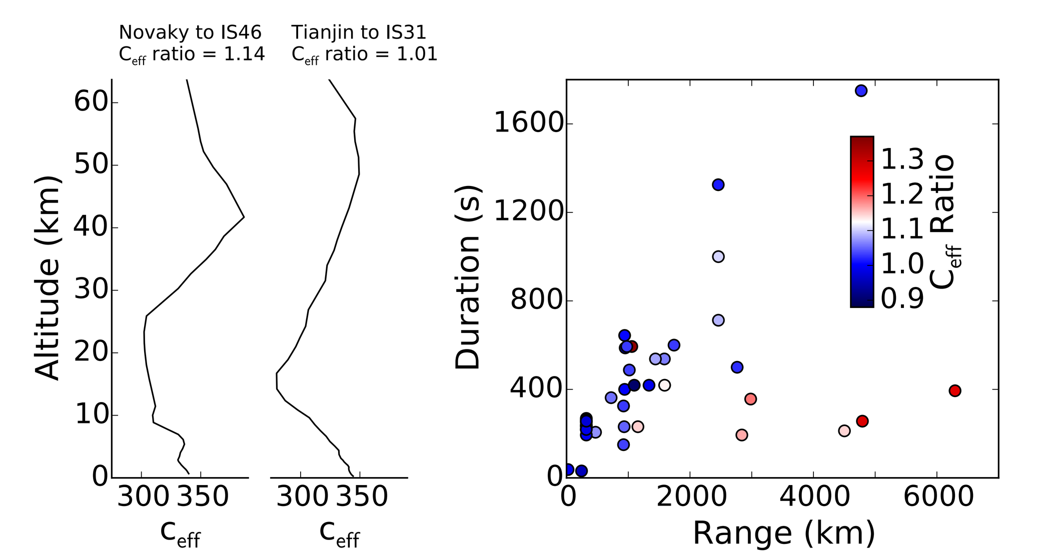


Figure 5: A simple parameterization of the stratospheric duct is the ratio of effective sound speeds (C_{eff}) at the stratospheric maximum and the ground surface. Effective sound speed is the sum of the adiabatic sound speed and the along-path windspeed. The two example MERRA-2 atmospheric specification profiles to the left of the plot show a strong stratospheric waveguide (Novaky to IS46) and a weak stratospheric waveguide (Tianjin to IS31). The right-hand panel shows the propagation range against signal duration relationship (Figure 3) as a function of C_{eff} ratio.

5. Signal-to-Noise Ratio Effects

- For the ground-truth dataset of high amplitude arrivals the signal-to-noise ratio (SNR) is not a major control on measured signal duration (Figure 6).
- However, preliminary simulations suggest SNR will have a significant effect on weaker signals impacting upon the usefulness of duration measures within routine monitoring operations (Figure 7).

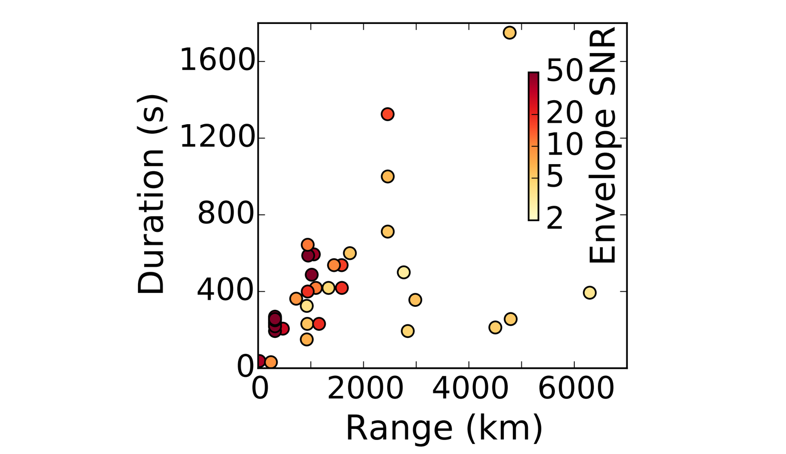


Figure 6: The propagation range against signal duration as a function of signal-to-noise ratio (SNR), calculated as the ratio of the maximum envelope pressure in the signal window to the median envelope pressure in a 300s window preceding the signal.

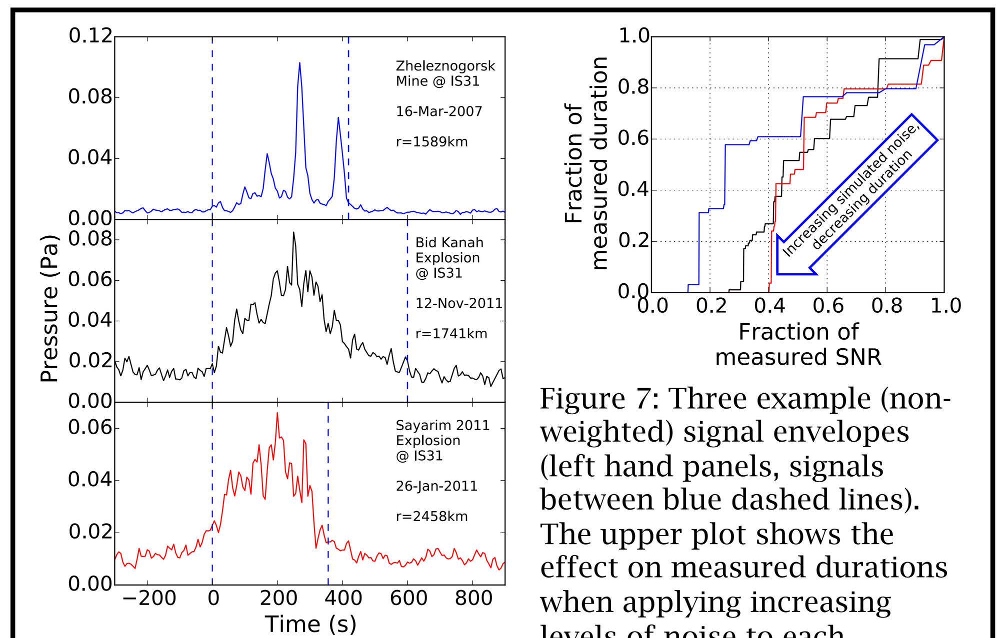


Figure 7: Three example (non-weighted) signal envelopes (left hand panels, signals between blue dashed lines). The upper plot shows the effect on measured durations when applying increasing levels of noise to each envelope.

6. Summary

- Infrasonic signal durations exhibit a weak relationship with propagation range, although some of the variability may be attributable to differences in atmospheric acoustic ducting.
- Some REB bulletin events have unphysical durations if the sources are assumed to be impulsive events.
- Variations in signal-to-noise ratios are likely to complicate the integration of signal duration parameters into any future signal association procedures.

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