# Remote Sensing Surface Explosions with an Ionospheric Doppler Radar

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We present recent observations of ionospheric responses to small (1-ton TNT equivalent) surface explosions. These observations were made using a low-power mid-frequency (MF; 0.3 - 3 MHz) and high frequency (HF; 3-30 MHz) Doppler soundings of the lower E region. As the explosion-generated infrasound propagates upward it eventually couples to the ionospheric plasma and perturbs the reflective ionospheric layer. This perturbation manifests as a "pulse" in the MF/HF Doppler signal. The Doppler signal is calculated simply using the time derivative of the phase ($d\phi/dt$), providing Doppler samples at the pulse repetition rate (50 Hz in our case). We find that running the the raw Doppler samples through a continuous wavelet transform (CWT) allows for easy identification of the "N" shaped waves at 5.35 and 8.35 minutes after the first shot . Figure 1 shows both the CWT and the raw phase samples from two 1-ton shots, separated by 3 minutes, each shot had a measured peak frequency near 0.5 Hz.

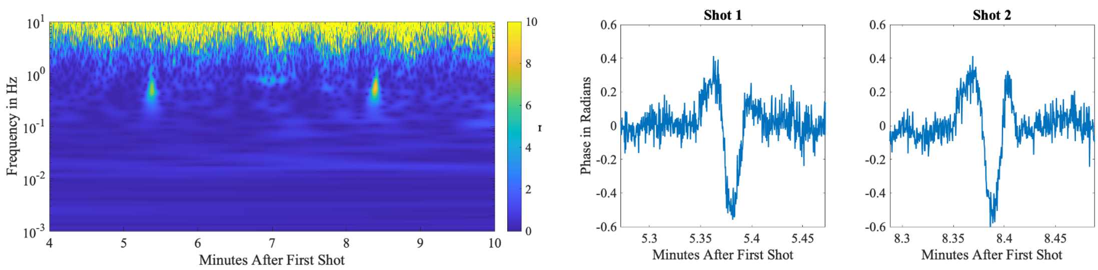


**Figure 1.** (Left) Continuous wavelet transform of Doppler signals showing detections near 0.5 Hz at 5.35 and 8.35 minutes after the shot. (Right) Zoomed views of the measured phase for each detection. The phase ($\phi$) is shown rather than the Doppler ($d\phi/dt$) as it is easier for visual identification.

We can use the InfraGA infrasound [1] ray tracing and waveform propagation model to predict what both the arrival times and primary frequency should be. Using input parameters from the Horizontal Wind Model (HWM) [2] and the Mass Spectrometer and Incoherent Scatter Radar Exosphere (MSISE) model [3], we find the waves should peak near 0.5 Hz and have arrival times of 5.5 and 8.5 minutes, respectively, after the first shot. Comparing these to the measured results we find very good agreement where the small error can be explained by the input model atmosphere from HWM and MSISE being different from reality.

These observations prove that the ionosphere can be used for remote sensing of even small explosives. Moreover, this method could be used to remote sense small yet potentially disruptive eruptions from remote volcanoes or other natural sources of infrasound.

## References

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