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NSF EAPSI: Analysis of Fumarole Acoustics at Aso Volcano, Japan

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Research Questions

- What are the characteristics of acoustic signals produced by fumarolic degassing?
- Do fumaroles produce jet noise?
- Does jet noise from fumaroles scale to larger, sustained volcanic eruptions?

Motivation

- Subplinian to plinain eruptions produce an acoustic signal similar to the sound of a jet, but at lower frequencies (Matoza et al., 2009; Fee et al., 2013)
- Hazard mitigation efforts would benefit greatly from real-time eruption data
- Human-made jet noise community has empirical equations relating radiated sound to jet source parameters, but these may not hold for volcanoes due to their complexity
- If fumarolic jet noise scales, then fumaroles could be valuable, natural laboratories for further research into volcanic jet noise

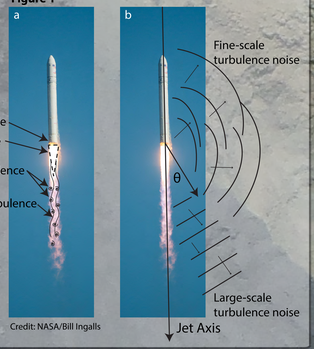
What is Jet Noise?

- The sound produced by momentum-driven fluid flow through a nozzle
- Generated by lab-scale jets, aircraft jet engines, rockets, and volcanoes!

- Two main sources of jet noise
  - Fine-scale turbulence (FST)
  - Large-scale turbulence (LST)
- Jet noise is highly directional
  - LST noise is dominant at small angles of θ
  - FST noise is dominant at larger angles

- Jet noise features show self-similarity, meaning they scale according to the scale of the jet
- The spectral shape from a small diameter jet will have similar shape and characteristics as noise produced by a larger diameter jet, just over a different frequency range and amplitude.

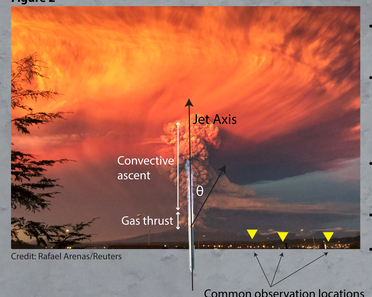
Figure 1



Credit: NASA/Bill Ingalls

What is Volcanic Jet Noise?

Figure 2



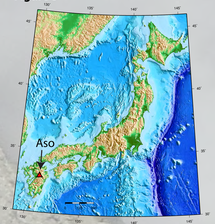
Credit: Rafael Arenas/Reuters

- The sound produced by gas and lithics being thrust (momentum-driven) through the vent
- Volcanoes generate jet noise at a variety of scales, from low-level gas jetting to violent subplinian-plinian volcanic jets
- Research on jet engines and volcanoes, alike, has shown there is a relationship between jet noise and source parameters that continues to evolve with increased understanding.

- Volcano Acoustics Community Goal: quantitatively link volcanic jet flow with its radiated sound
- A quantitative link would allow us to infer volcanic jet parameters such as jet velocity
- Determining jet velocity will help us to calculate the mass eruption rate which has implications in hazard mitigation.

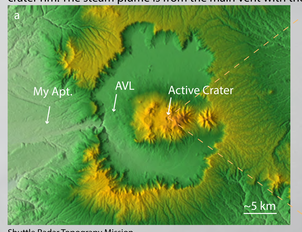
Aso Volcano, Japan

Figure 3



- Located in central Kyushu, Japan
- Popular tourist destination that is accessible by road and cable car
- Large caldera (18 X 25 km)
- Recent activity:
  - Fumarolic degassing
  - Strombolian to vulcanian ash poor to rich explosions
  - Gas jetting
  - Jet noise

Figure 4 a) DEM of Aso caldera with the current active crater highlighted; b) view into the active crater from southwest crater rim. The steam plume is from the main vent with the partially collapsed pyroclastic cone.



Shuttle Radar Topograpy Mission

Field Deployment

- July 2015 deployed a 6-element array of infrasound sensors along the western rim of the active crater (sample rate 250 Hz)
- Rain and wind dominated first 4 weeks of data
- A new vent opened up at approximately 17:00 UTC July 13, 2015
- Audible jet noise when standing where the vent was visible, but this audible nose was not evident on the west rim of the crater where the array was located
- Moved the array to the southwestern rim to better capture the sound produced by the new vent

Figure 5

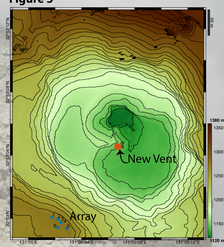
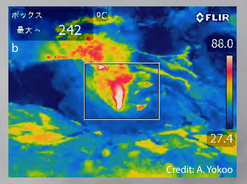


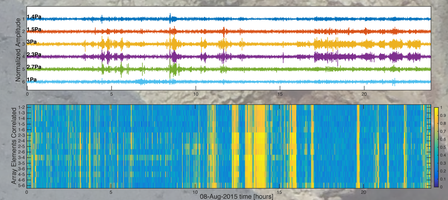
Figure 6



a) View from center of array looking northeast across the active crater; b) Infrared image of new vent taken from point of view of array elements 3 & 4; c) Image of new vent taken from same vantage point as b.

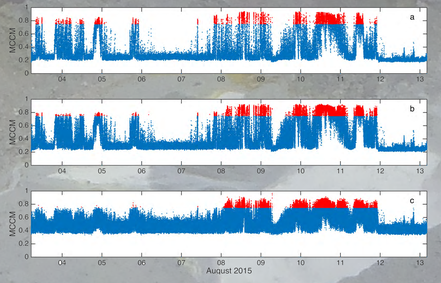
Data set: Signal from New Vent

Figure 8 24 hours of array data from August 8, 2015. (Top) Normalized waveforms filtered from 0.5 to 3 Hz with the peak pressures listed. (Bottom) Maximum cross-correlation values of unique element pairs using a window length of 5 seconds.



- We cross-correlated all data from the unique array element pairs
- No correlated data was found for the first array location
- We observed times in the dataset where the waveforms are visually similar and of higher amplitude, but do not correlate (Figure 8); this is likely wind noise.
- In Figure 8: we note the low pressures and the decrease in maximum cross-correlation values between elements 1 and 6 and the others
- Array elements 1 and 6 did not have clear views of the new vent.
- The decrease in correlation and reduction in power (Figure 10) suggest directionality at the source and the influence of topography along the propagation path.

Figure 9 Mean Cross-Correlation Maximum of array data at a) 0.5 – 5 Hz, b) 5 – 15 Hz, and c) 15 – 25 Hz. MCCM values greater then 0.75 are plotted in red.



- We determined times of signal by calculating the mean cross-correlation maximum (MCCM)
- During the ~10 days the array was in the second location hours to days of correlated signal were recorded

Characteristics of the Acoustic Signal

- Infra- to audible sound (5 - 25+ Hz)
- Sustained long-duration signal
- Low- amplitude (especially compared to wind noise)
- Spectral peak around 8 to 10 Hz
- Array elements 1 and 6 have lower power, likely due to topography and directionality

Figure 10 a) sustained gas-jetting signal; b) spectrogram of signal; c) PSD curve of signal

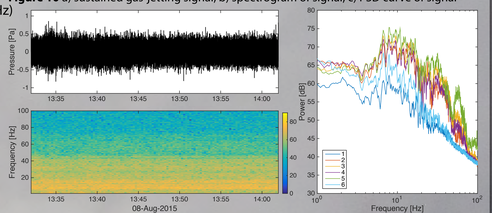
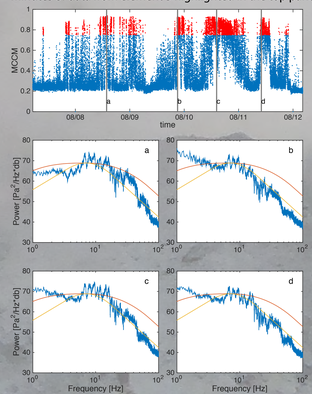


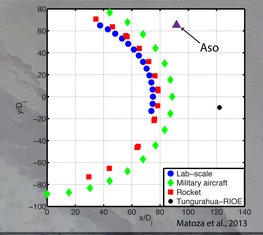
Figure 11 (top) MCCM from Figure 9a; a-d) PSD curves with FST (red) and LST (yellow) similarity spectra for 30 minutes of data from element 3 highlighted in the top panel



- Second array 230 meters from the vent
- Positioned 54 degrees from the vertical jet axis
- A recording angle usually not feasible in volcanic environments

- PSD curves seem to match the LST spectra better than the FST spectra
- PSD curves are similar over the data collection period

Figure 12 compares measurement locations for jets of different scales originally from Matoza et al., 2013. The purple triangle is an approximation for the measurement location at Aso volcano.



Preliminary results

- Aso fumarolic jet noise has sustained, low-amplitude signal with spectral peak around 8-10 Hz
- Signal is easily buried in wind noise
- Acoustic signal is infrasonic and audible

- Observed influence of directionality and topography in lower power and cross-correlation values for array elements 1 and 6
- Fumarolic jet noise PSD curves better match the large-scale versus the fine-scale turbulence similarity spectra

Next Steps

- Compare seismic and acoustic data
- Use FLIR imagery to better approximate dimensions and velocity of fumarolic jet
- Compare to other volcano and human-made jet noise
- Evaluate fumarolic jet noise scaling
- Write a paper!

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Acknowledgements

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