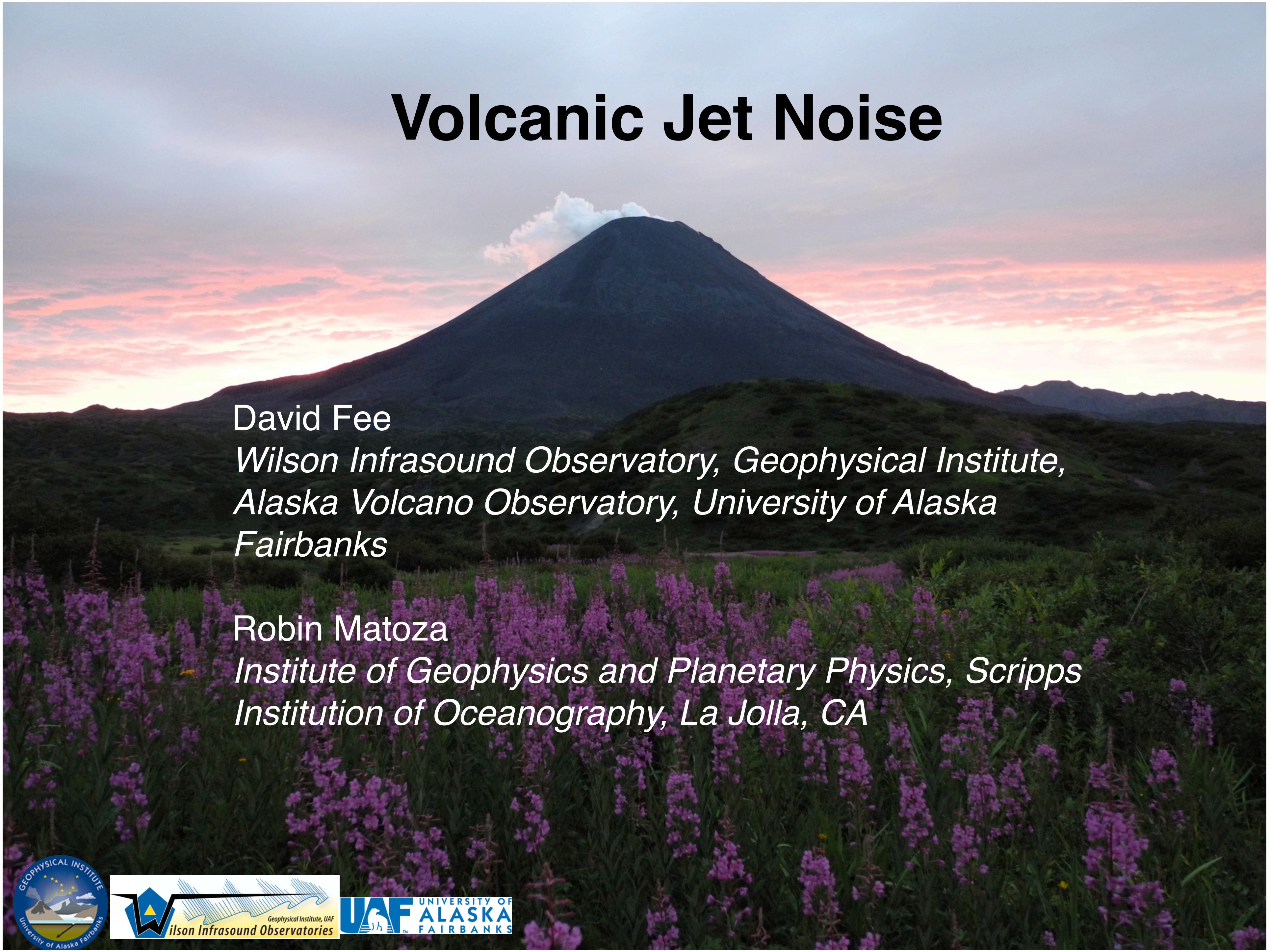

Volcanic Jet Noise

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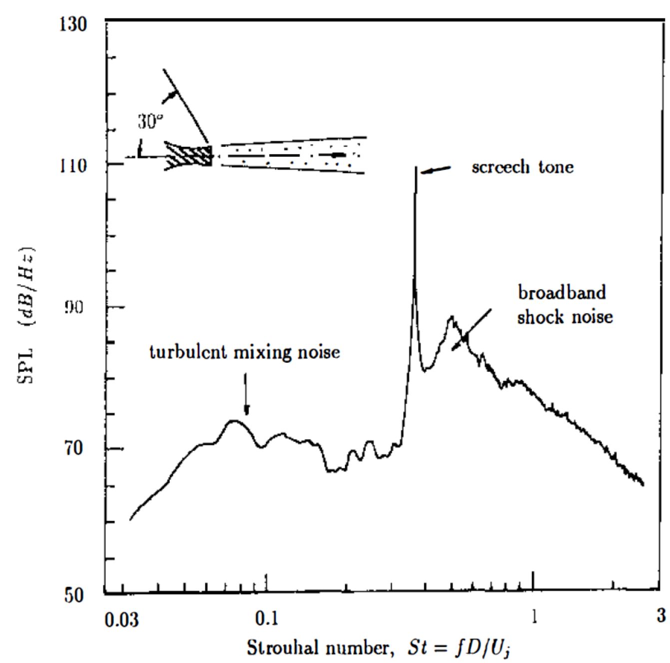
Overview

Sustained, high-energy eruptions produce a low frequency form of jet noise

- Jet noise background
- Volcanic Jet Noise Observations
  - Regional (10-50 km)
    - Mount St. Helens
    - Tungurahua, Ecuador
  - Long-range (>250 km)
    - Kasatochi, Alaska
  - Supersonic Volcanic Noise and Directionality
- Conclusions/Future Work

Jet Noise Background

- Definition: sound produced by interactions between the turbulent exhaust flow and the ambient air
- Studied extensively for man-made jets
- Dominant noise sources related to turbulence structures within the jet
- Lighthill [1952]: primary sound source is small-scale eddies (fine-scale turbulence)
  - Acoustic power ~ v^8
- Shock cell structure: screech tones and broadband shock noise
- 1970's: large scale turbulence also important → dominate dynamics



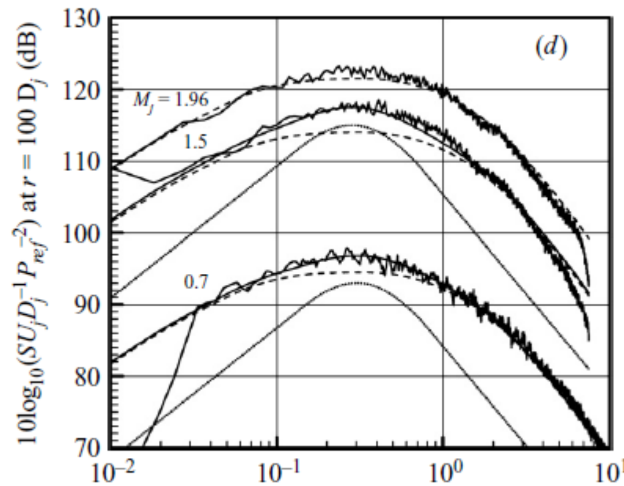
Jet Noise Spectrum

Tam et al. [1996]: Similarity spectra: two universal, empirically derived spectra for each form of turbulence

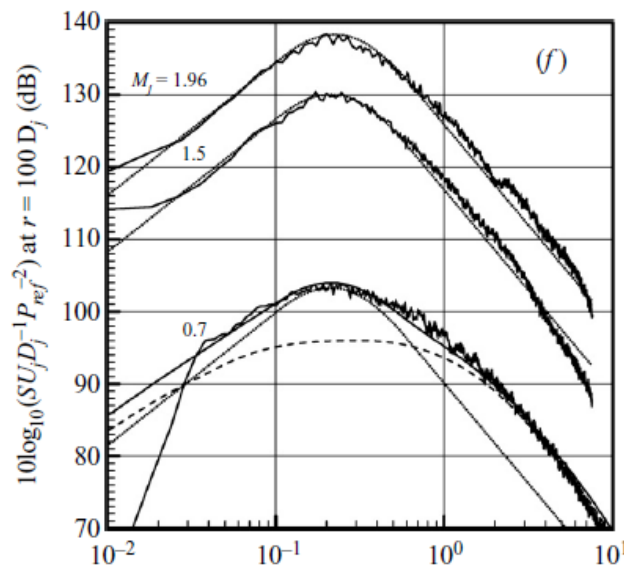
Small Scale Turbulence (SST) – dominant in subsonic jets (broad spectrum)

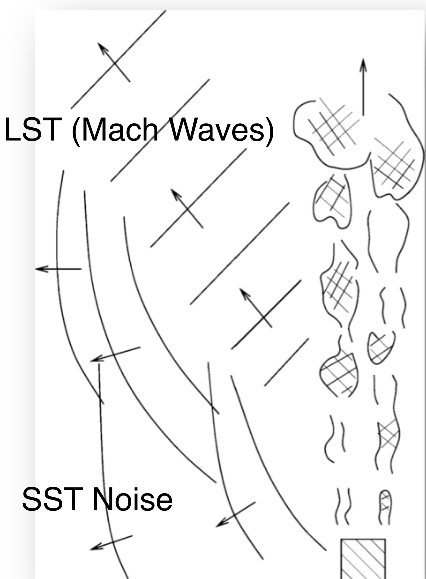
Large Scale Turbulence (LST) – instability waves moving downstream generating mach waves (sharper roll-off), dominant in supersonic jets

SST



LST





[Tam et al. 2009]

Mt. Spurr- 1992

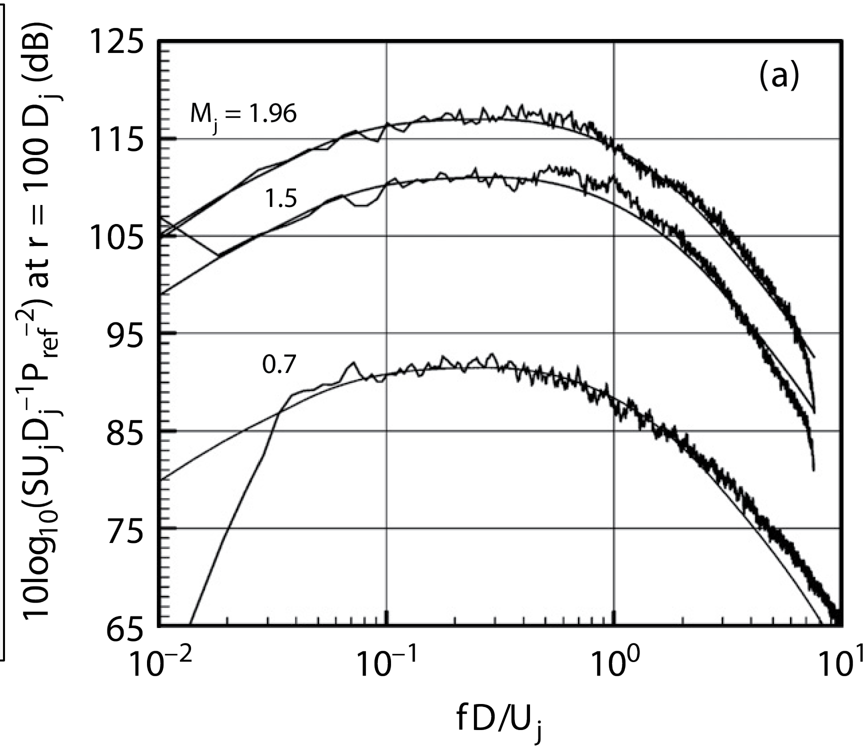
Strouhal Number

- Jet noise scales via the Strouhal Number:

$$St = \frac{fD_j}{U_j}$$

f=the peak jet noise frequency, D_j=expanded jet diameter, U_j=jet velocity

- St for pure-air, experimental jets between 0.1-0.25



[Tam 09]

Volcanic Jet Noise

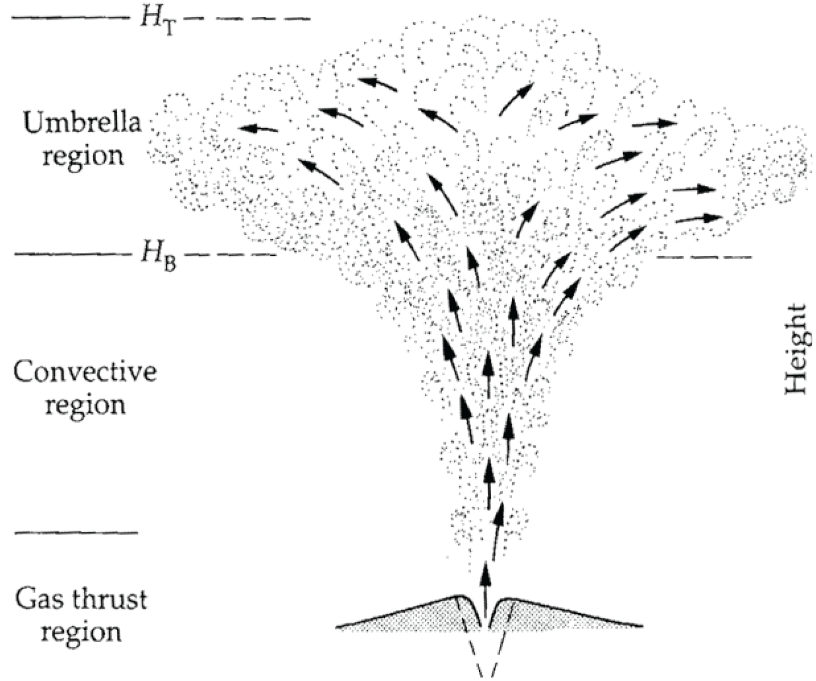
Jet (gas thrust):

- Momentum-driven
- Typically 1-3 km high
- Entrains air and transitions to buoyancy-driven flow
- Poorly constrained

Turbulence-driven volcanic jet noise first proposed by Woulff and McGetchin [1976]

Difficult to record and much more complex than man-made jets

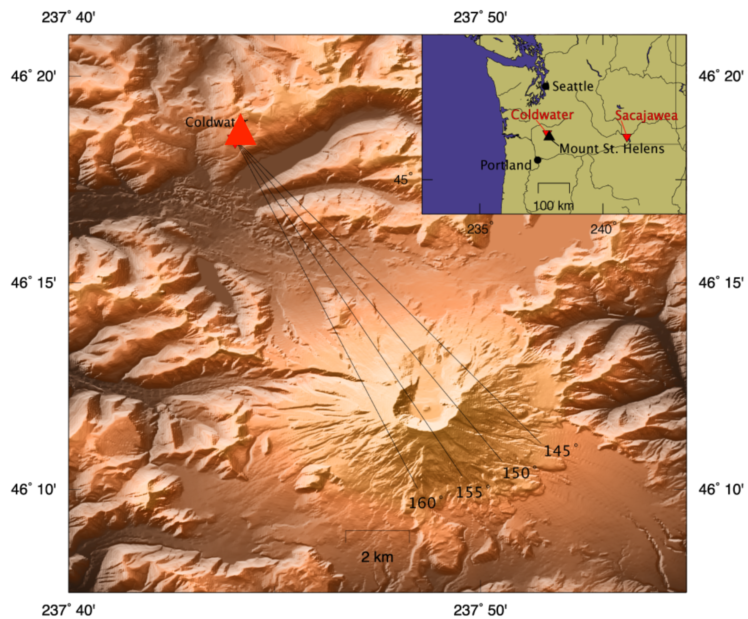
Volcanic Column



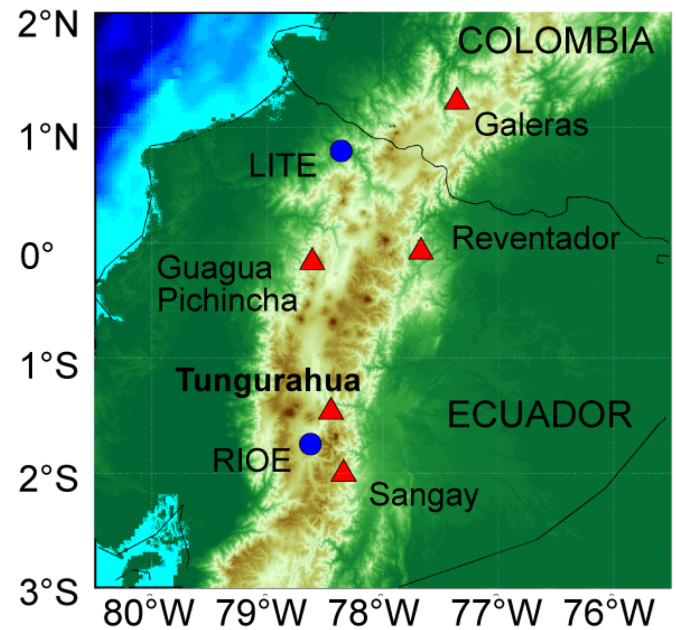
ASHE (Acoustic Surveillance for Hazardous Eruptions)

- Test viability of monitoring remote volcanic regions using infrasound
- Work with Washington DC Volcanic Ash Advisory Center (VAAC) to mitigate aviation hazard
- Mount St. Helens: arrays at 13 and 250 km
- Ecuador: arrays at 37 (RIOE) and 251 km (LITE)

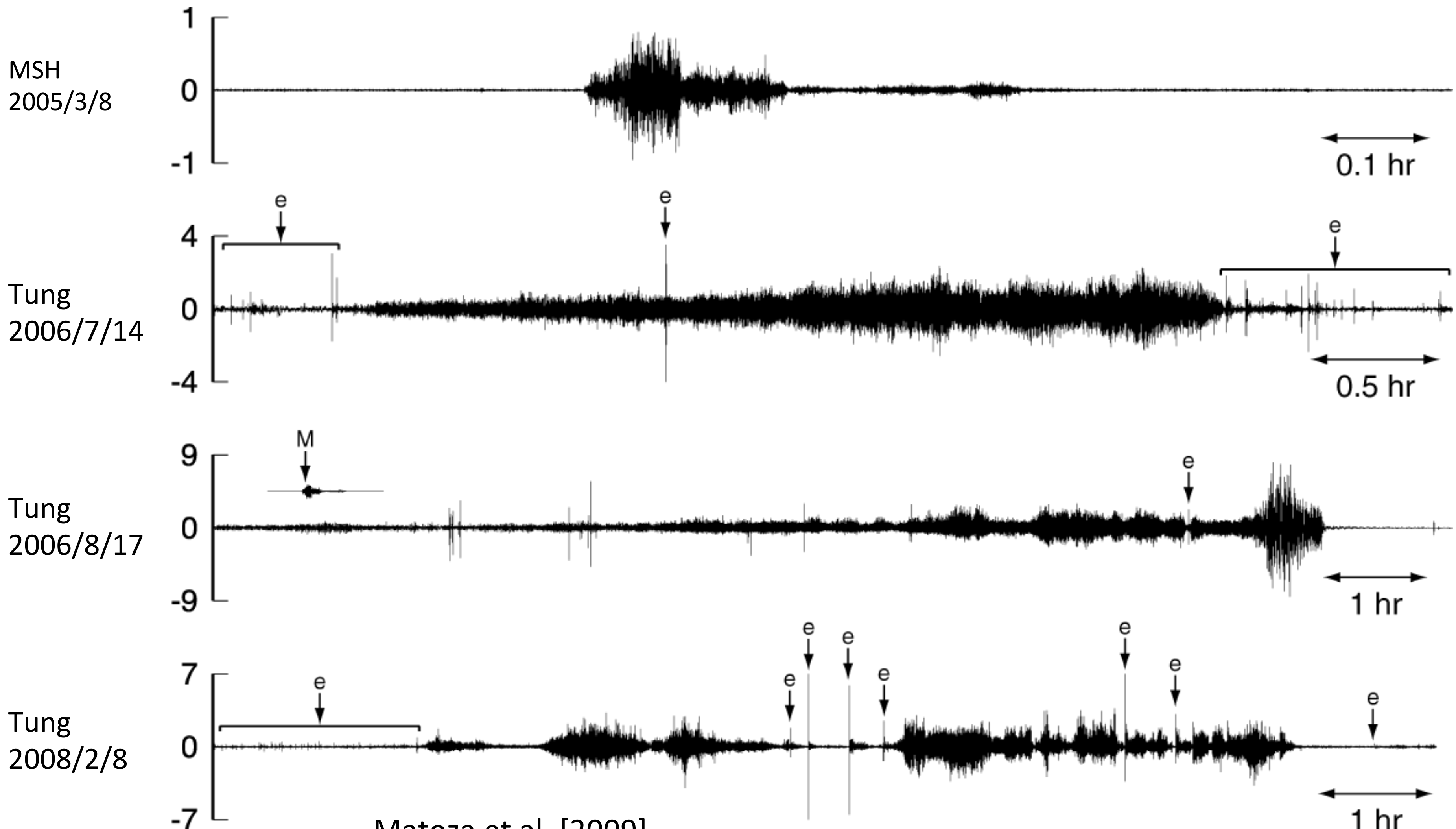
MSH



Tungurahua



Eruption Infrasound

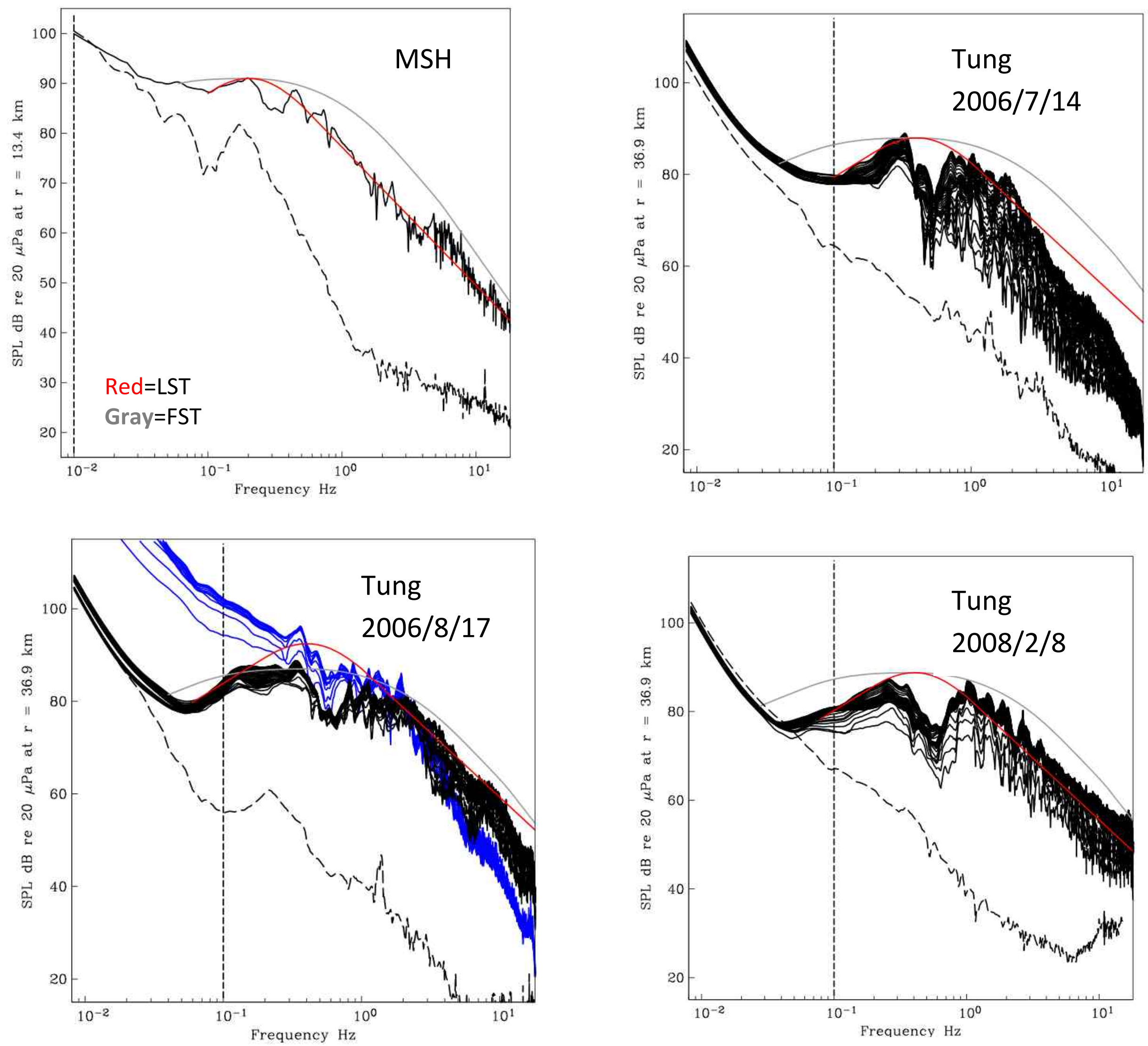


Matoza et al. [2009]

Spectra

- MSH spectra resemble LST spectra
- Tungurahua similar spectra for all 3 eruptions, LST fits best
- "Notch" in Tungurahua spectra
- Roll-off for Tungurahua 7/14 and 8/17 does not match as well
- Complexities
  - Interactions with crater
  - Volcanic jets multiphase, high temp
  - Propagation
  - Anisotropic source

Jetting coincident with high-altitude ash emissions

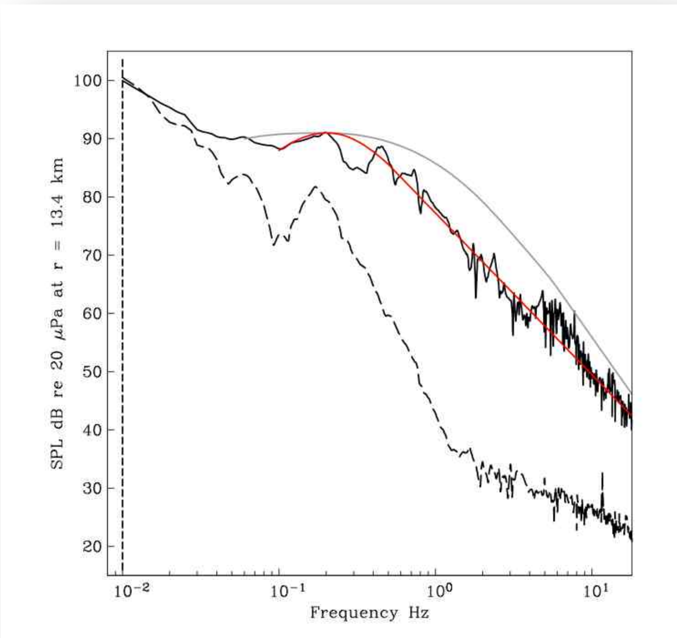


Matoza et al. [2009]

Strouhal Number: Mount St. Helens

$$St = \frac{fD_j}{U_j}$$

f~0.2 Hz
U_j~100 m/s from ballistics
D_j~30 m [Mastin 2007]
→ St~0.06

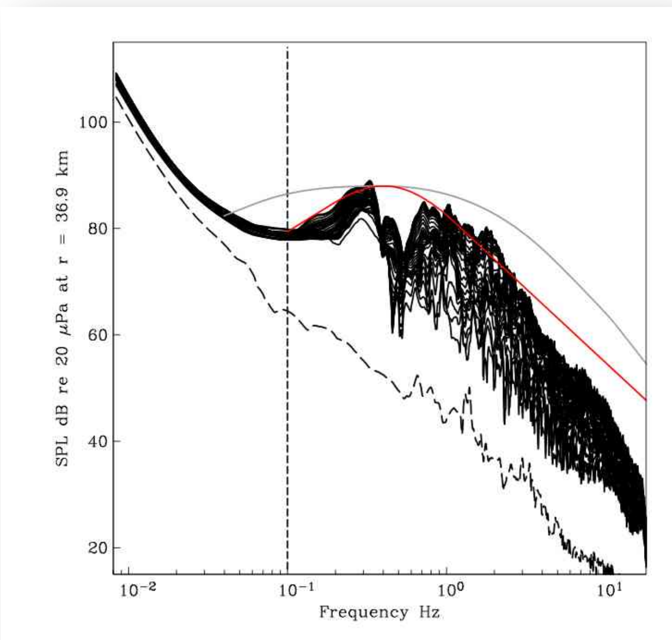


Matoza et al. [2009]

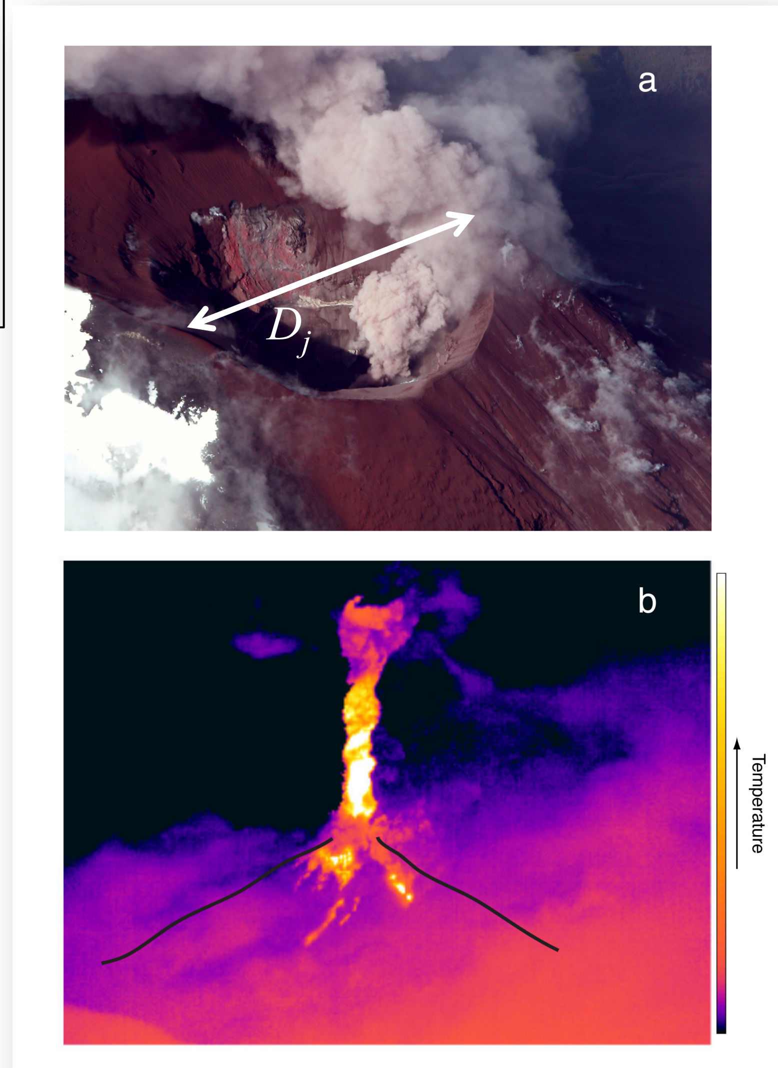
Strouhal Number: Tungurahua

$$St = \frac{fD_j}{U_j}$$

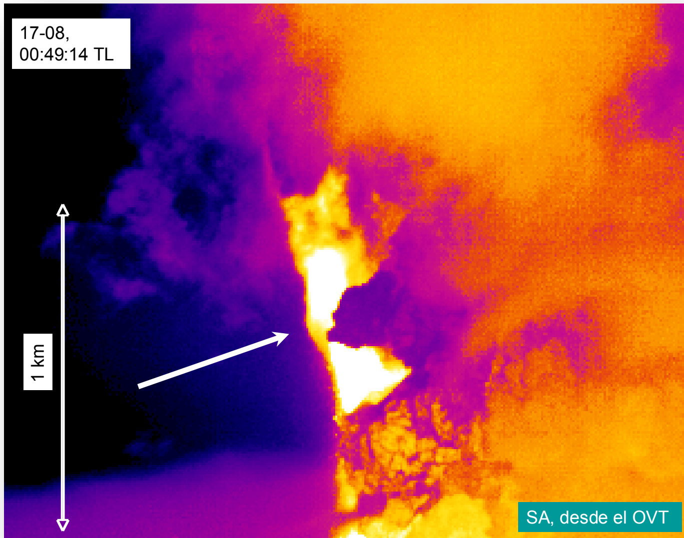
- f~0.4 Hz
- U_j~300 m/s from ballistics
- D_j~300-400 m from video
- → St~0.4

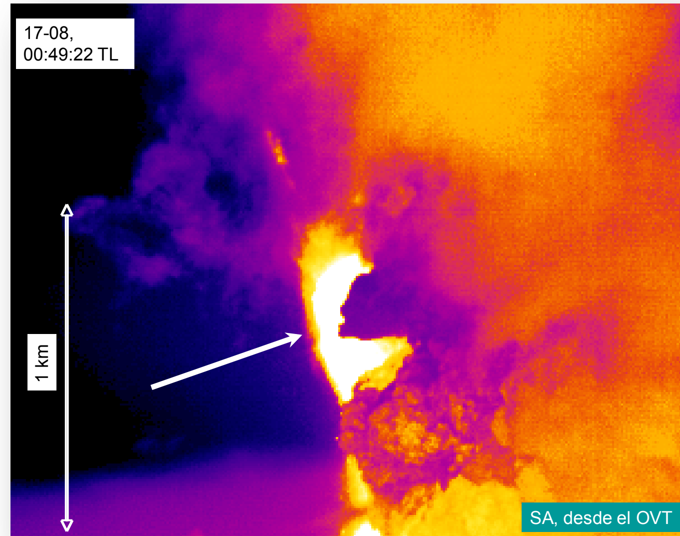


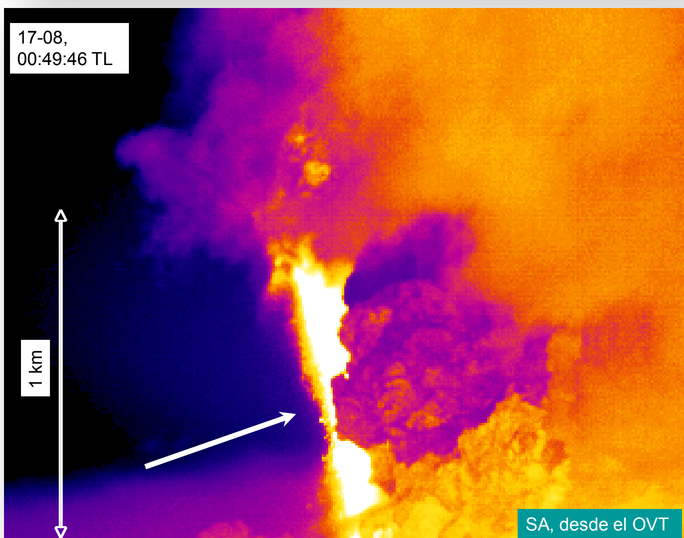
Matoza et al. [2009]

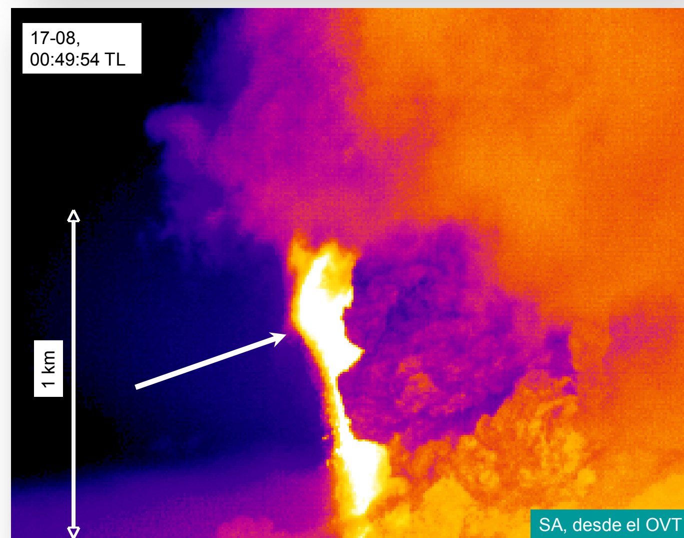


Tungurahua IR Images









15 July Tungurahua Jetting Spectrum

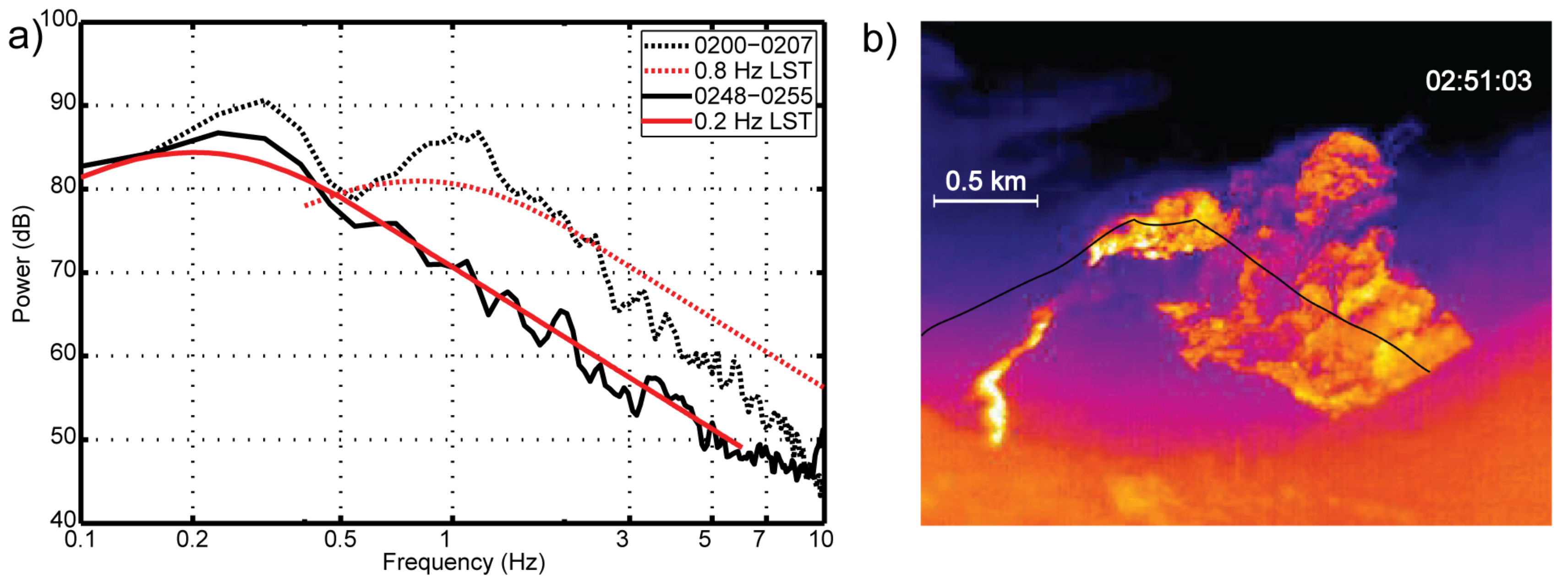
Typical double-peaked spectrum during sustained column above vent and intermittent pyroclastic density currents (PDC) (dashed line in a)

Single-peaked spectrum when large PDC and no sustained vertical column (solid black line in a) and thermal image in b)

→ First peak does not require vertical eruption column

→ Two separate jet noise sources?

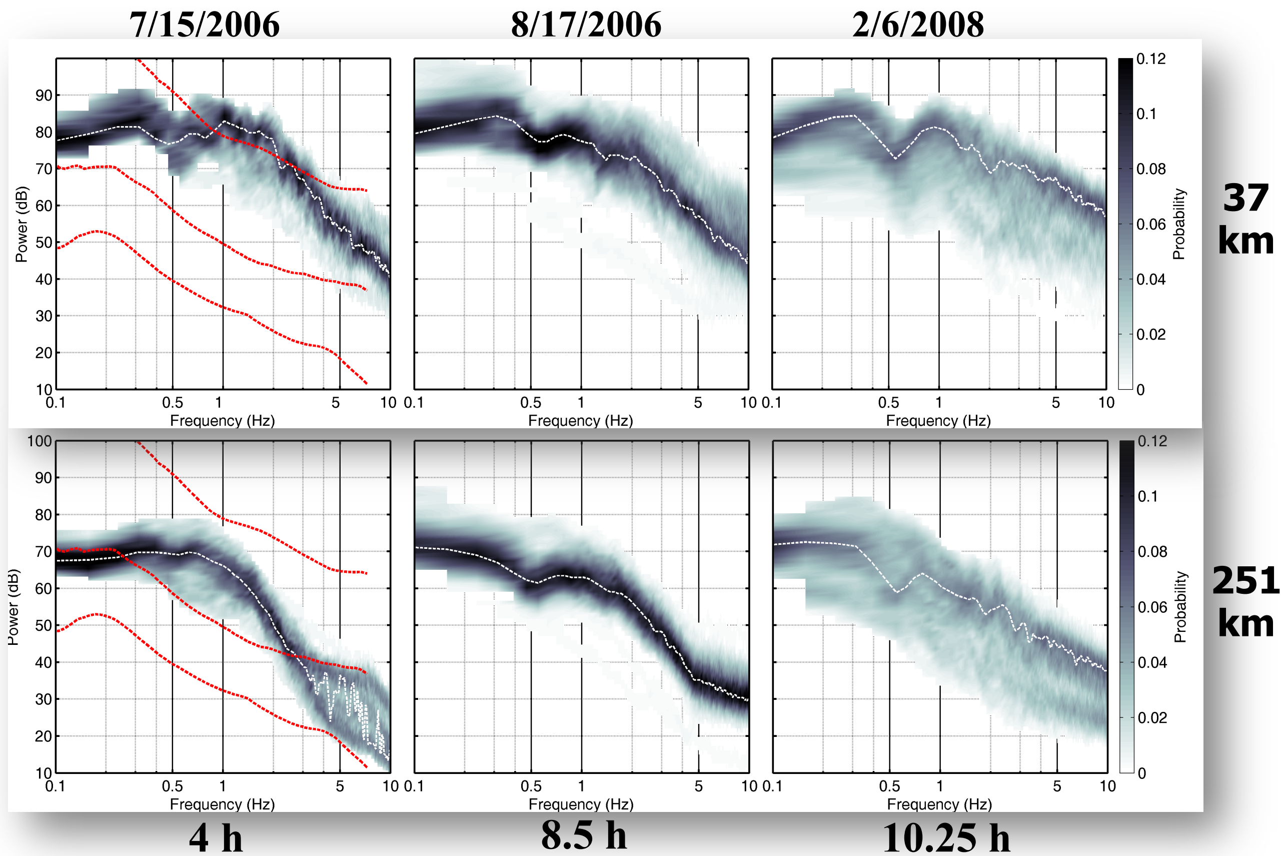
- Interactions with crater may be important



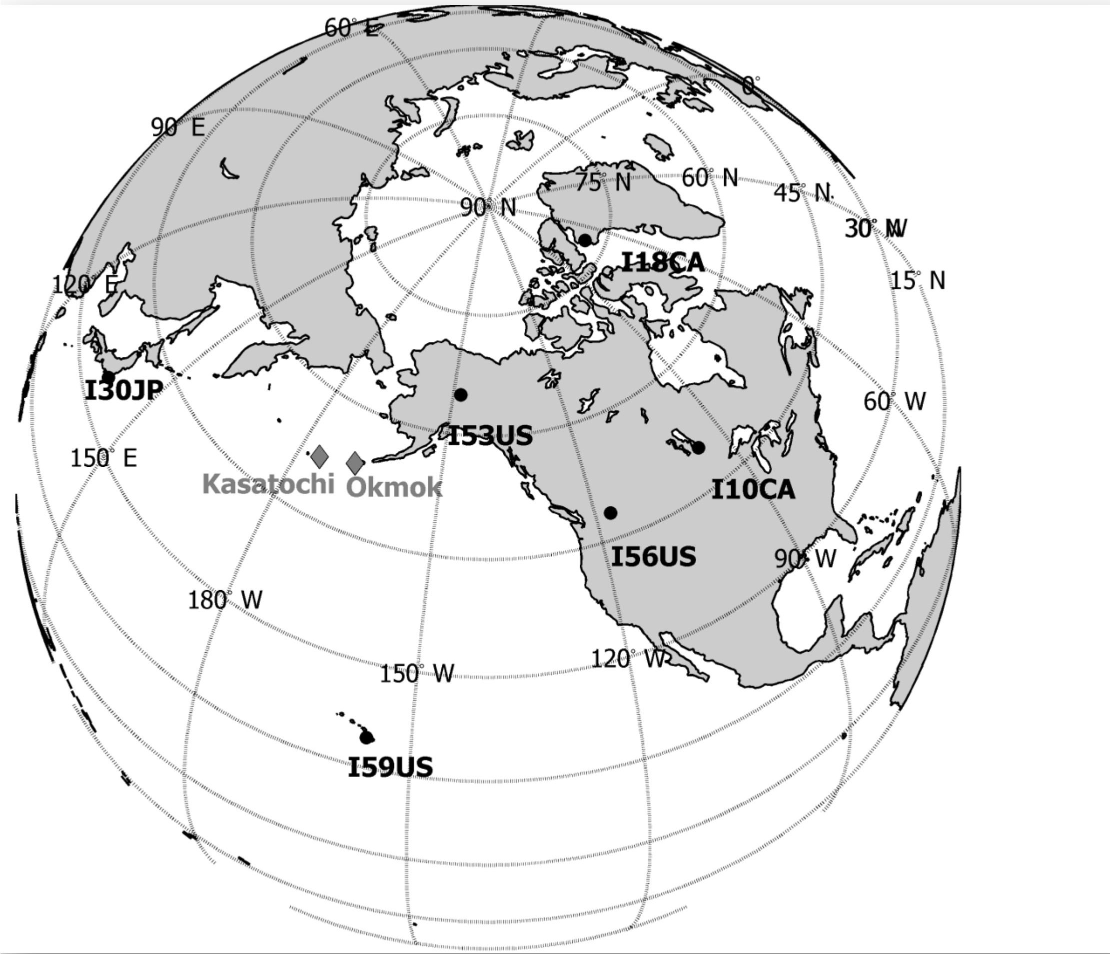
Propagation Effect?

Compare Tungurahua spectra at 37 and 251 km

- PSD Probability Density Functions
- Main spectral features apparent at 251 km



Kasatochi, Alaska



Extend ASHE to greater distances

- Viability of volcano monitoring
- Interest in using global network
- Identification of jet noise at distance?

Kasatochi Volcano

- Erupted August 7^{th}-9^{th}, 2008
- Previously unmonitored
- Ash to ~55,000' (17 km)
- Most SO_2 since 1991
- Disrupted N Pacific air travel

Kasatochi Infrasound

Highly correlated at three stations

Signal focused in VLP (0.01-0.1 Hz) band

High amplitudes considering great distance

Four pulses detected:

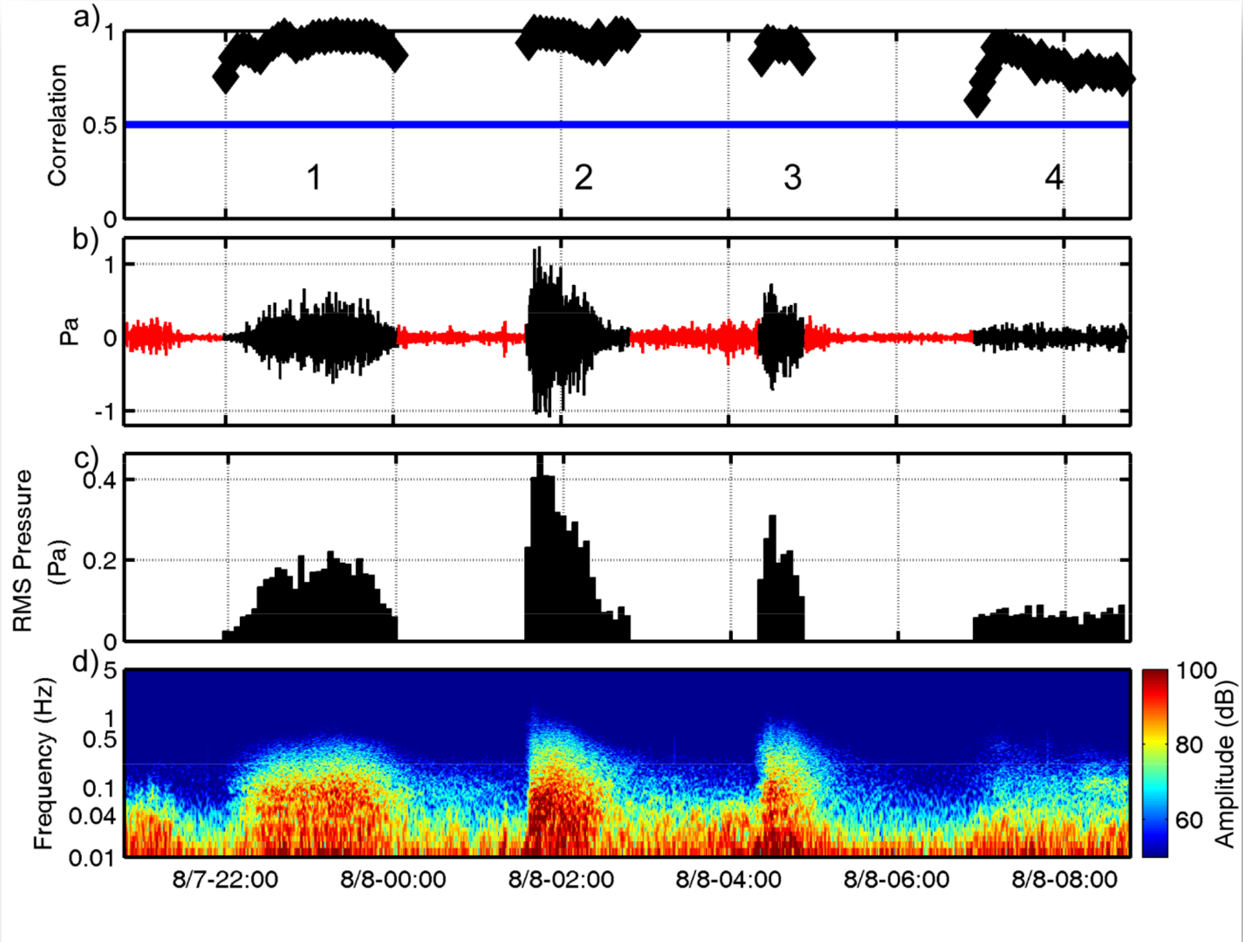
1: 2159 UTC, 123 min

2: 0135 UTC, 59 min

3: 0420 UTC, 33 min

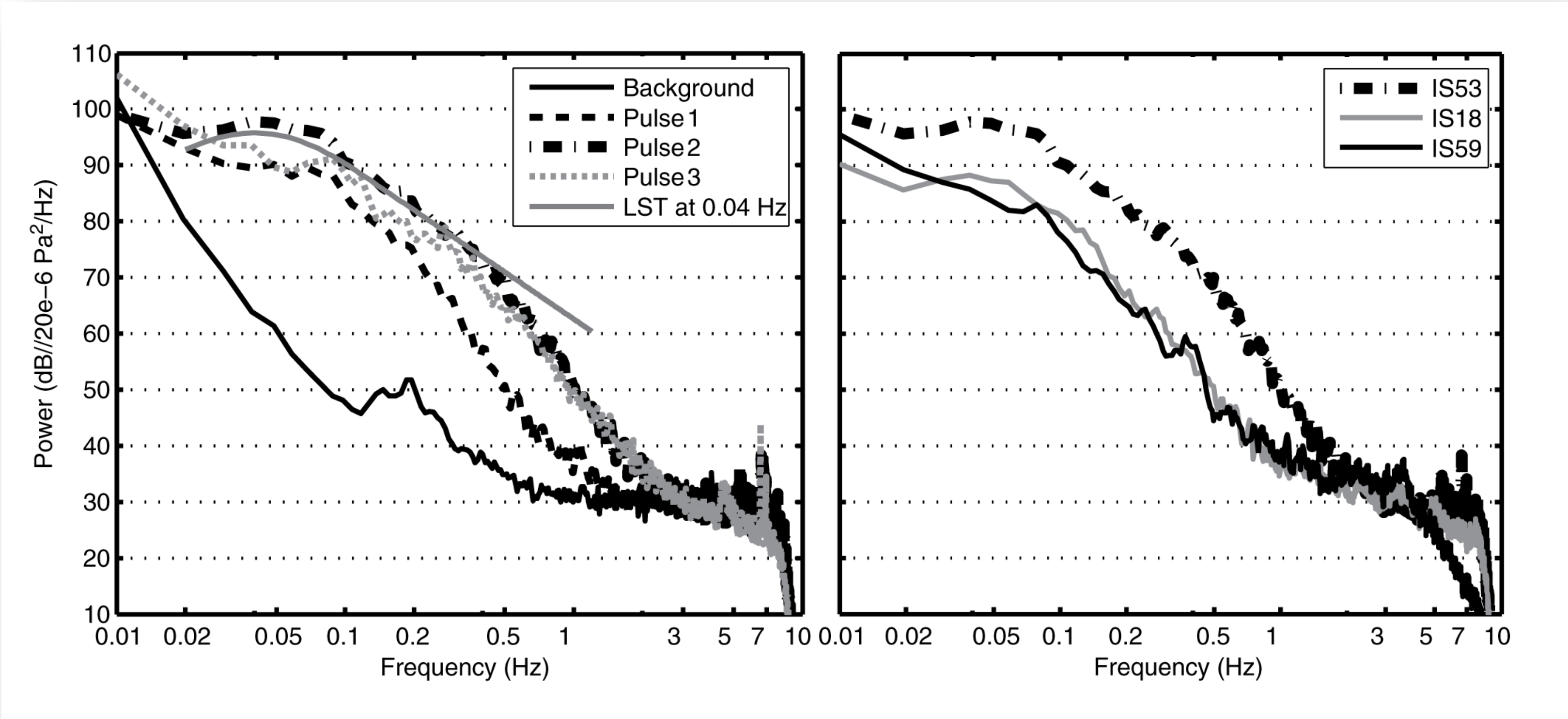
4: 0654 UTC, 112 min

Pulse 4 previously undetected



Black = Correlated Signal from Kasatochi
Red = Uncorrelated Noise

Kasatochi PSD



Spectra of three main pulses resemble that of man-made jets (solid gray)

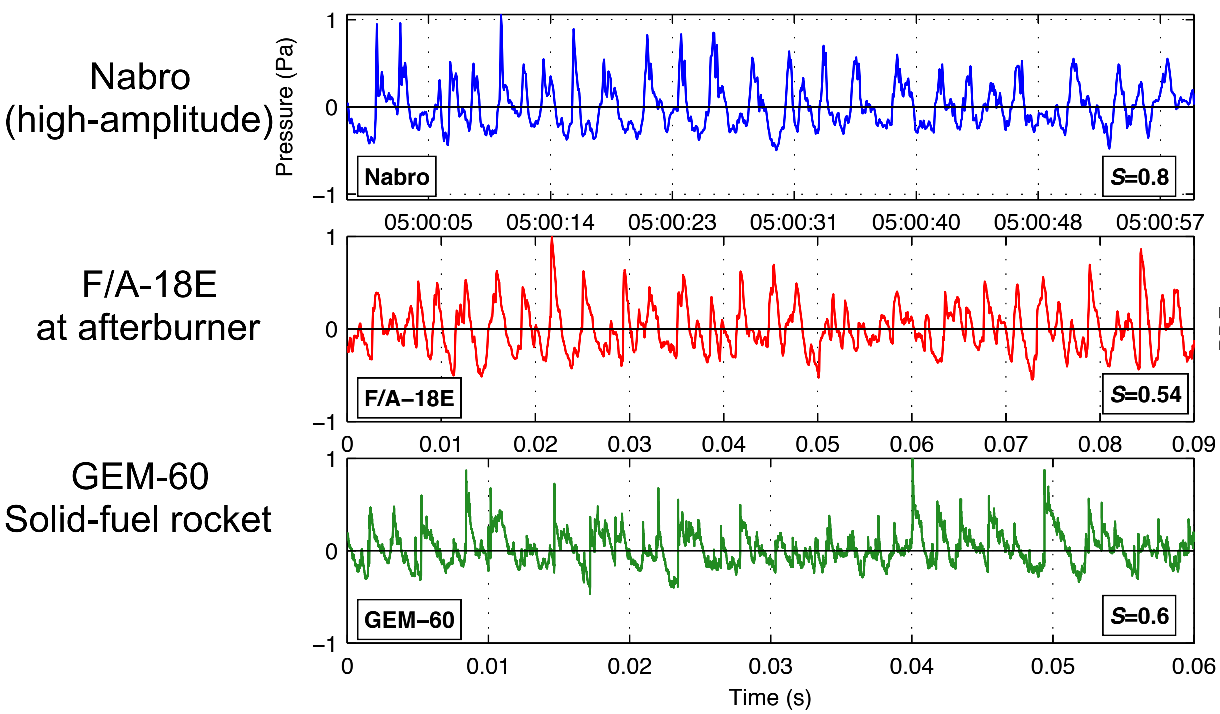
Minor variations in spectra between pulses

-Negligible effect of ash particles in jet

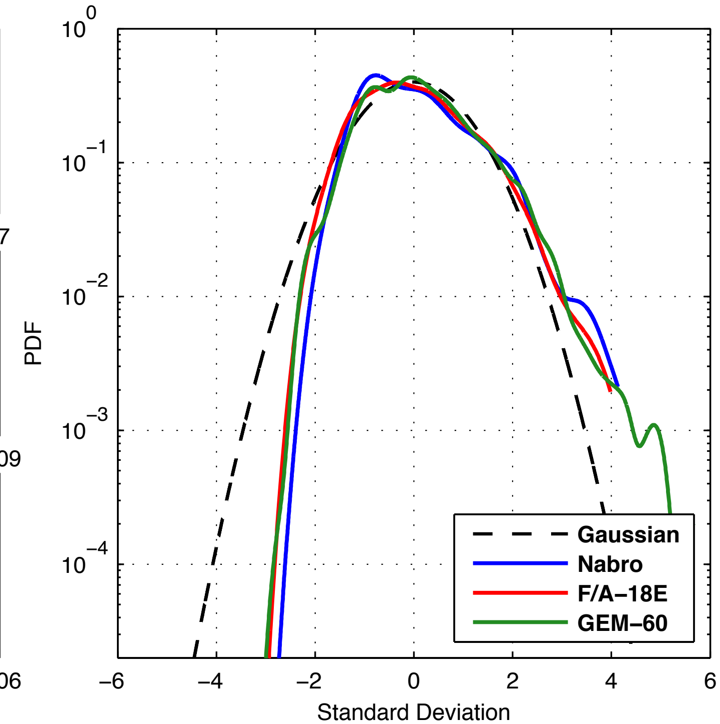
Similar spectra between IS53, IS18, and IS59

Frequency-dependent propagation effects similar between stations

Nabro – Supersonic Jet Noise



PDF of Pressure



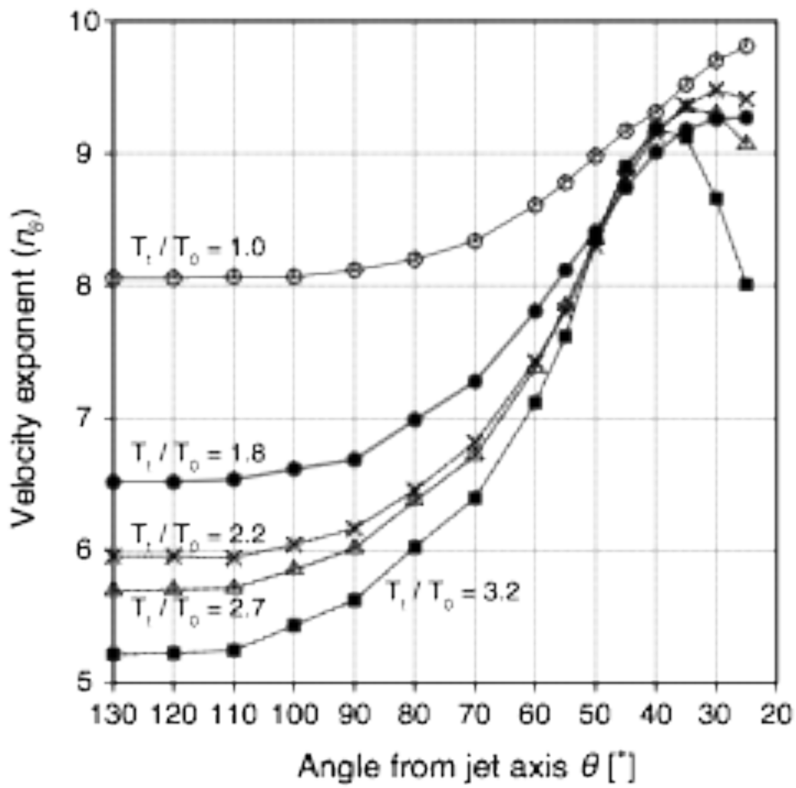
- All three waveforms have high positive skewness values
- PDFs all have long positive tails
- Rocket and Nabro show strongest similarity
- Rocket data from [Gee et al., 2009]

Jet Noise Directionality

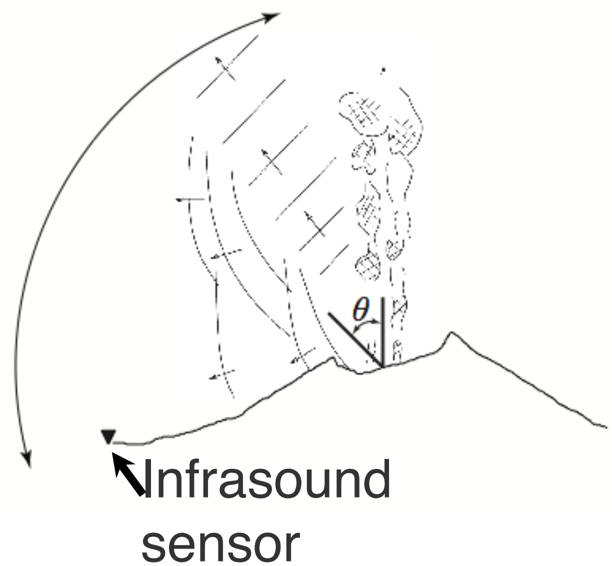
Woulff and McGetchin [1976]: volcanoes generate 3 basic types of sound

Acoustic **monopoles (n=4)**, **dipoles(n=6)**, and **quadrupoles (n=8)**

Results from pure-air jet noise studies:



Acoustic power estimates require sampling of jet directionality



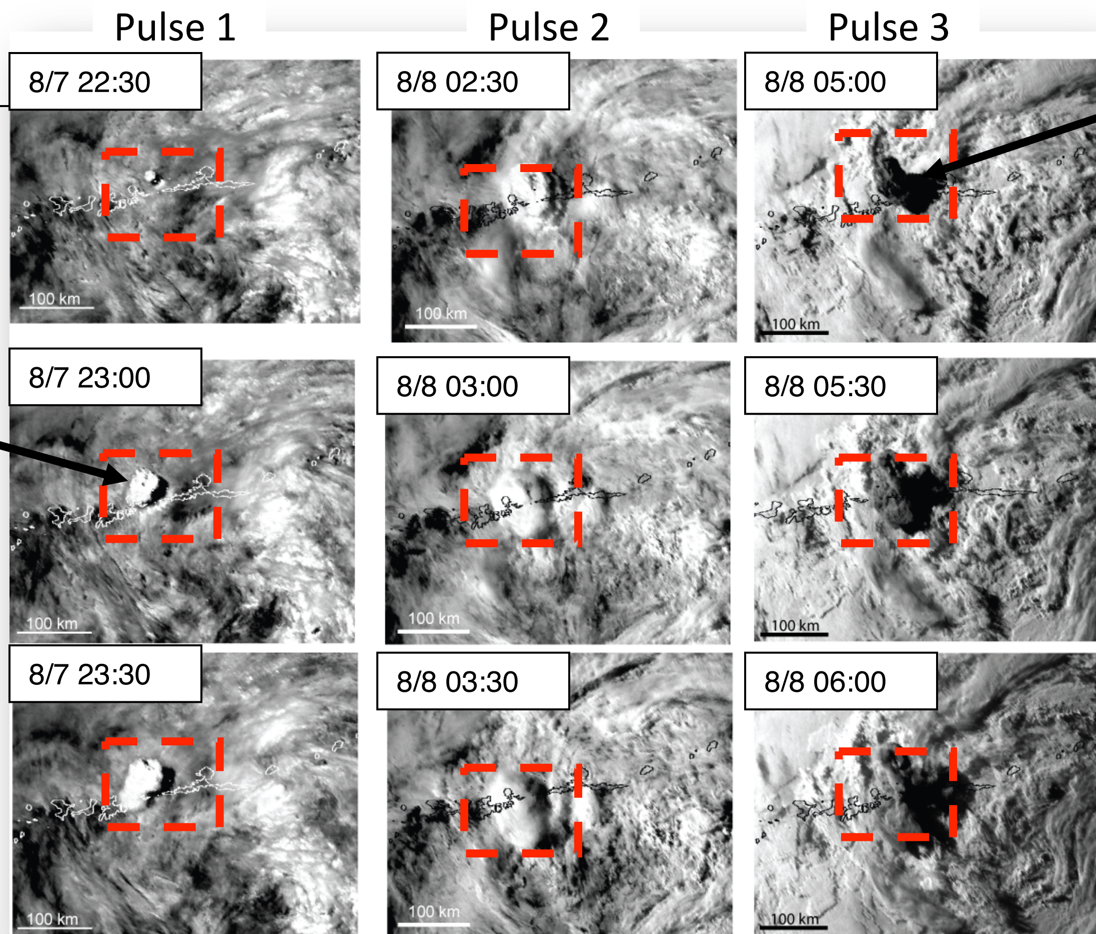
Conclusions

- Sustained, high-energy eruptions produce a low frequency form of jet noise
  - Identifiable based on spectral shape
  - Coincident with high-altitude ash emissions
  - Fit to spectrum is not perfect
  - St between 0.06-0.4
- Jet noise recordings could lend insight into volcanic jets (e.g. velocity, diameter) and assist in hazard mitigation
- Characteristic jet noise spectrum identifiable at long distances
- Supersonic jet noise also observed
- Jet noise directionality is significant

Future Work

- Build up catalog of volcanic jetting
- Compare infrasonic observations with numerical and laboratory modeling
- Better source localization and characterization
- Constrain impact of multi-phase flow, craters, etc.

Kasatochi: Satellite Imagery



Pulse 1-2 steam-rich

Pulse 3 ash-rich

Transition from steam-rich to ash-rich

Plume heights roughly the same for all three pulses:
~16-17 km

All three reached stratosphere

GOES Imagery: high temporal resolution (30 min), low spatial resolution