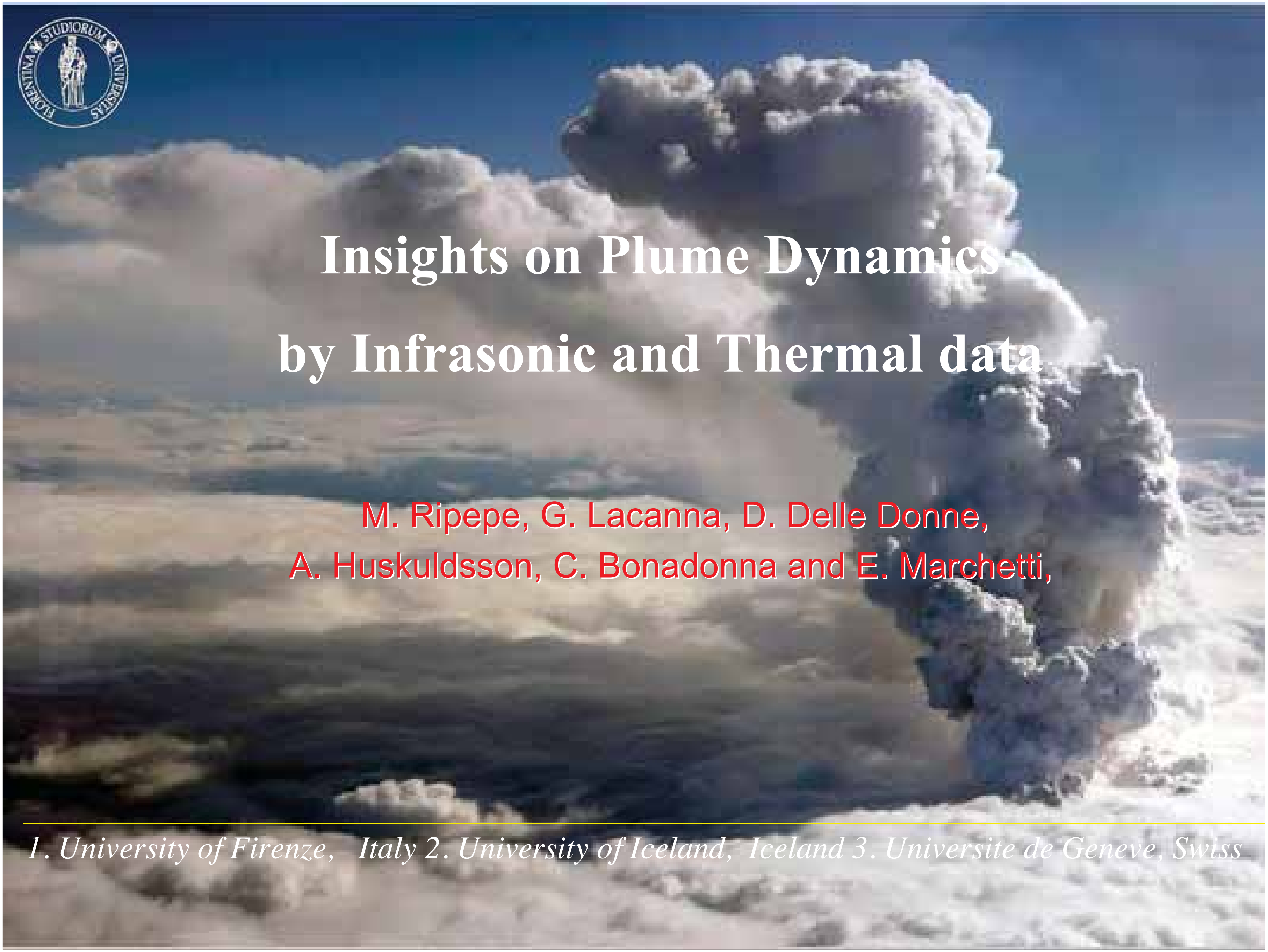


Insights on Plume Dynamics by Infrasonic and Thermal data

M. Ripepe, G. Lacanna, D. Delle Donne,
A. Huskuldsson, C. Bonadonna and E. Marchetti,

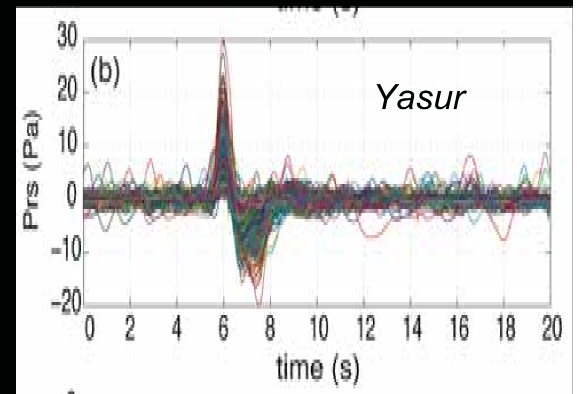
1. University of Firenze, Italy 2. University of Iceland, Iceland 3. Universite de Geneve, Swiss

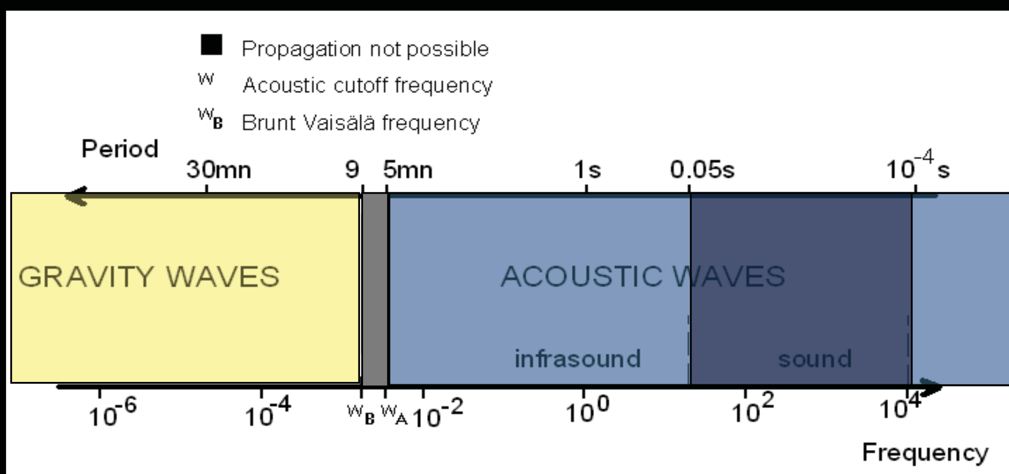
What is Infrasound ?

Yasur (Vanuatu) from 350 m

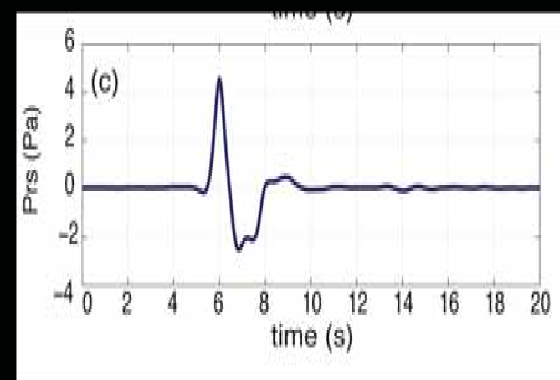
……. at 3000 m from vent

1280 infrasonic waveforms





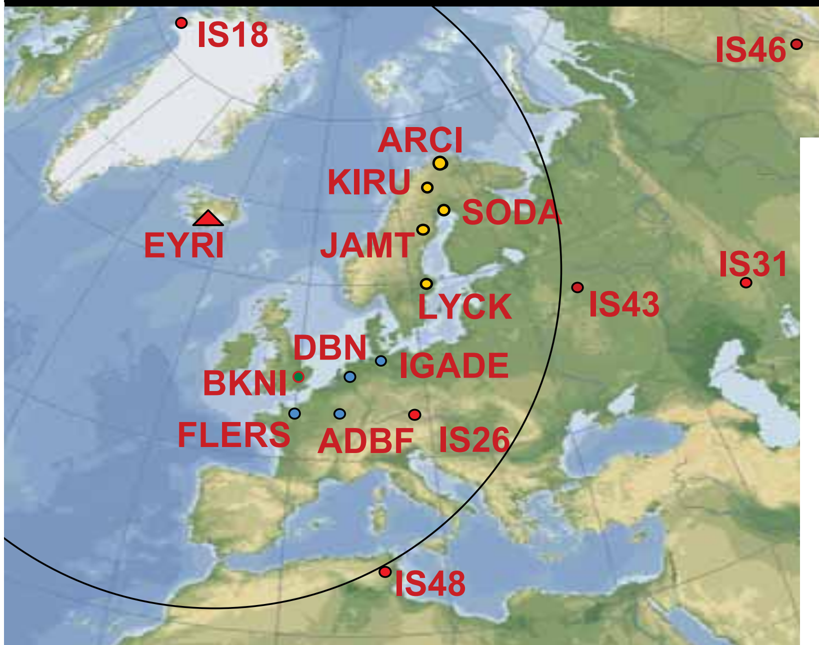
very stable source process !



Infrasound is a pressure perturbation which propagates in the atmosphere
with the speed of sound (~340 m/s) but at frequencies lower that audible (<20 Hz)

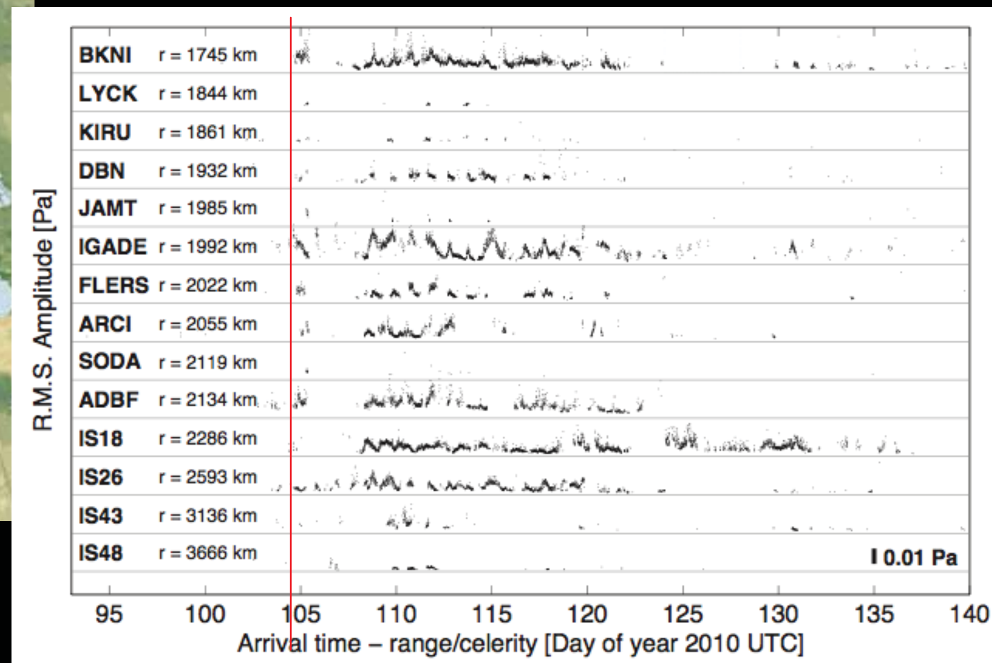
Infrasound Efficiecy as Remote Monitoring

Position of Infrasonic IMS & Nat. Arrays



Travel time ~3 Hours

RMS Amplitude Variation of the Detections



14 April Eruption onset

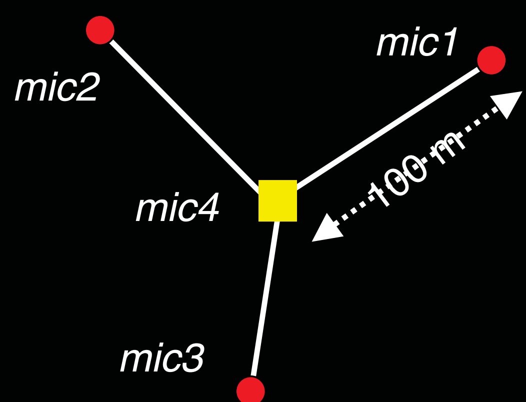
Matoza et al., 2010

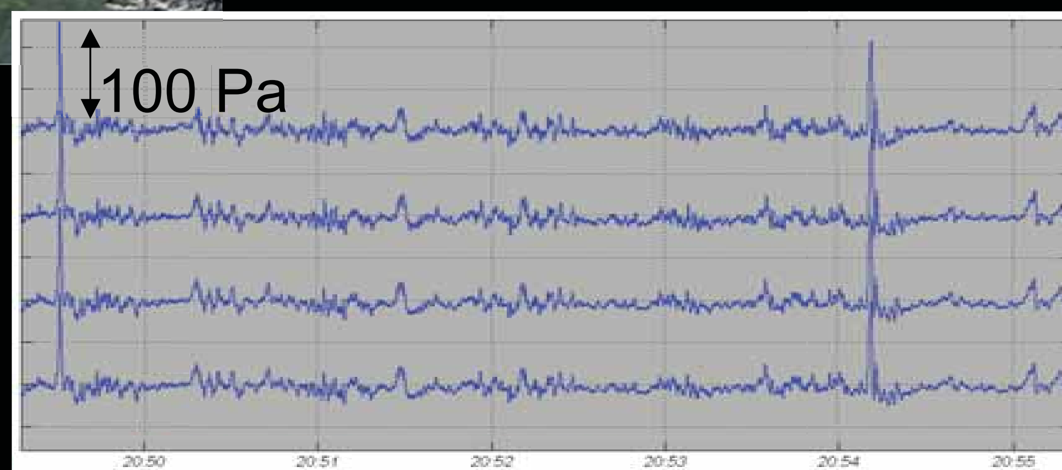
The eruption was detected as far as 3600 Km in Tunisia and Russia

How much acoustic amplitude reflects source or atmospheric propagation ?

How do we Measure Infrasound

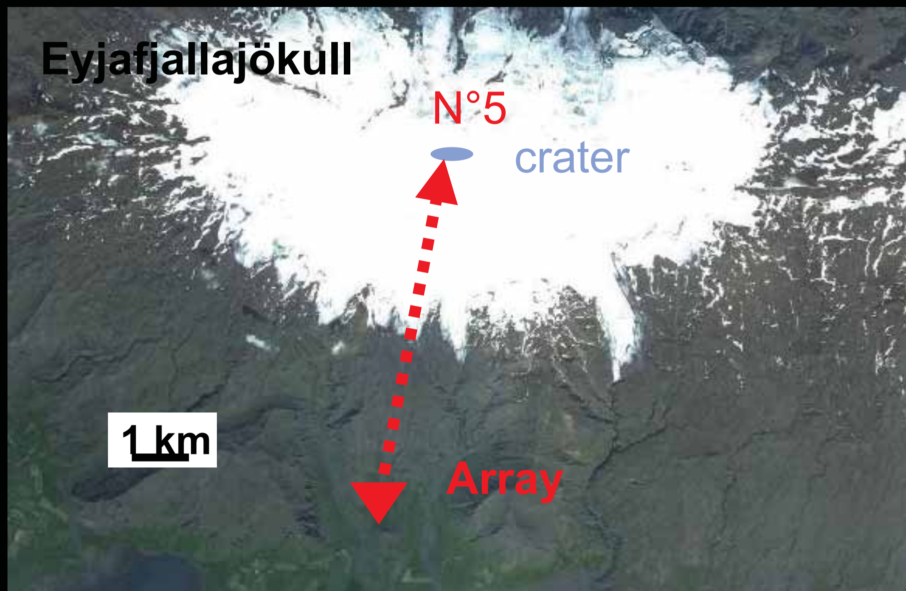
- Guralp DMG24 24 bits
- Sampling rate 100 Hz
- 4 differential pressure sensor
- Wireless Modem 2.4 Ghz
- Baud Rate 19200
- Power cons. 250 mA
- Power supply 3 batt. 12 V 85 Ah
- Time of Deployment <2 hours
- Total Weight ~20 Kg. (no batteries)

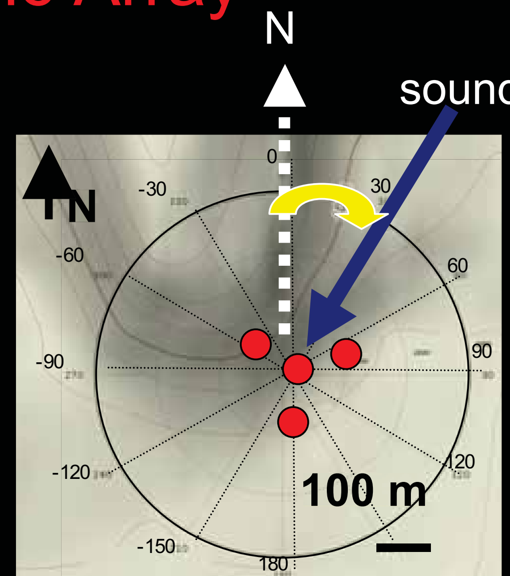




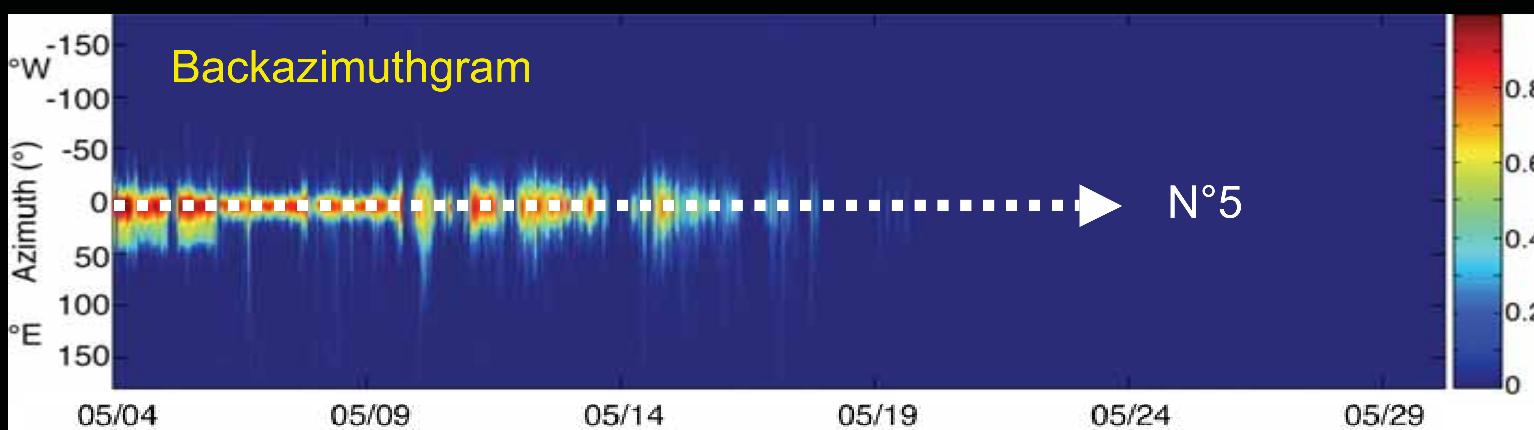
Plume is “sustained” by violent explosions ~ 8 KPa of reduced excess pressuree

Source Location by Infrasonic Array



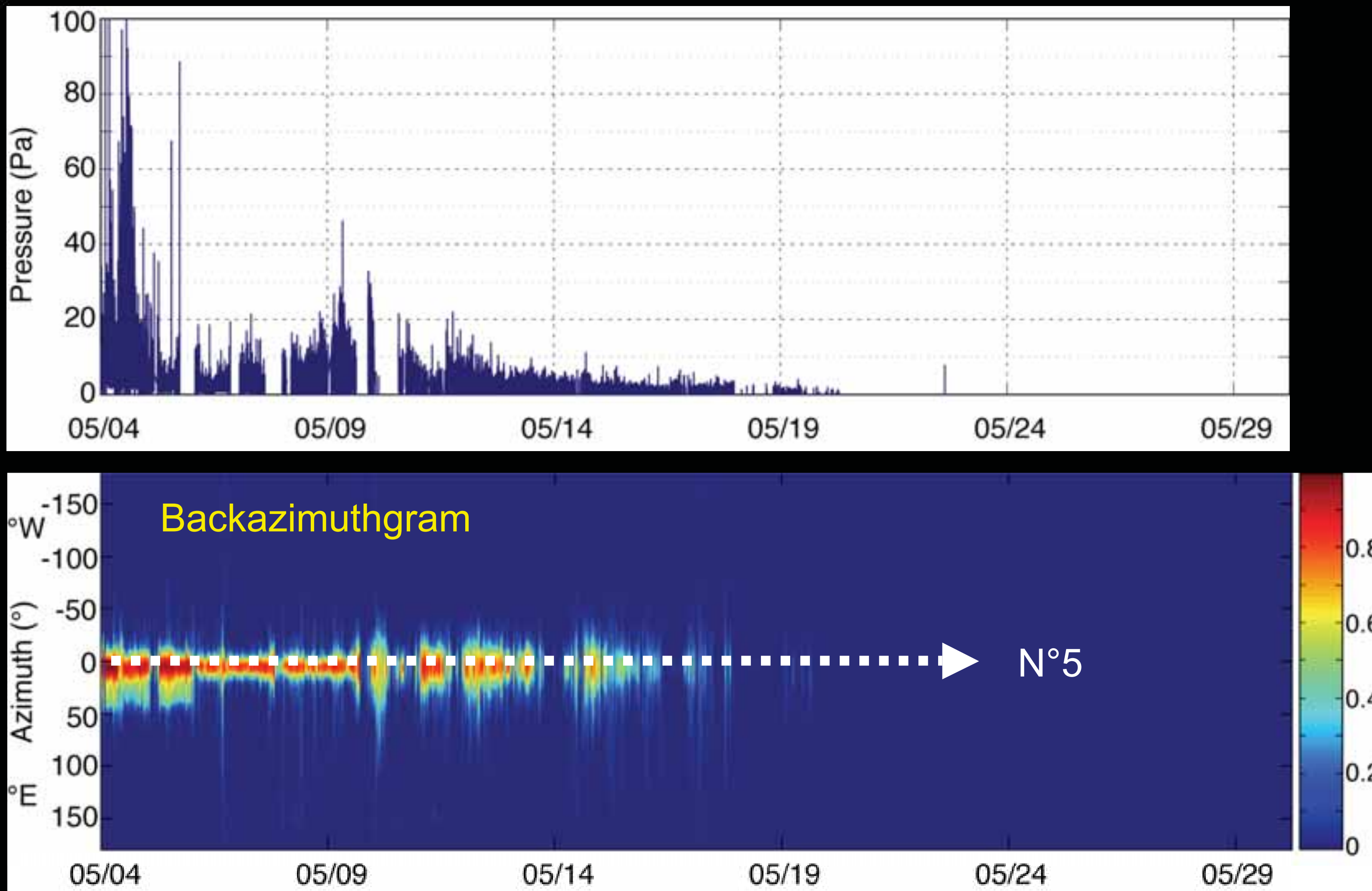


Sound backazimuth



Infrasonic Array provides in real-time Eruptive Onset and Duration

Pressure Variation of Infrasonic Detections



Infrasonic Pressure reflects Eruption Intensity

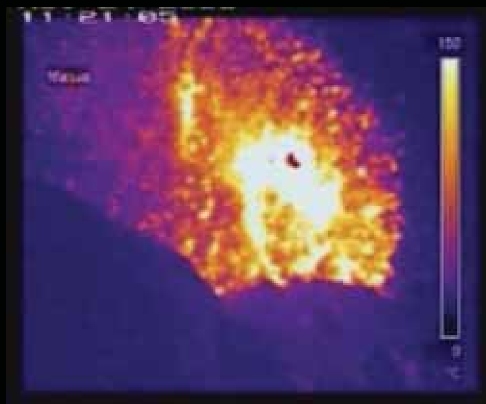
Modeling the Sound Source

Monopole

$$\Delta p = \frac{\dot{q}(t - r/c)}{2\pi r}$$

(Lighthill, 1978)

where:
r - distance from source
c – Speed of sound

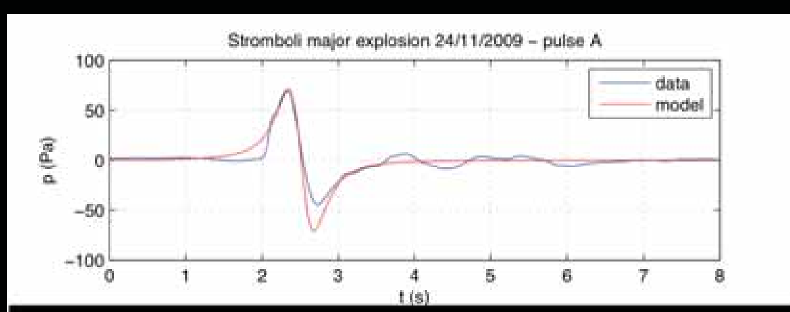


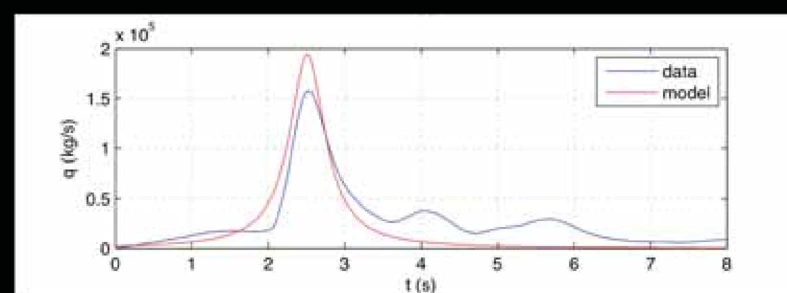
Δp acoustic Pressure

q(t-r/c) is the mass outflow from the source [kg/s]

$$q(t) = 2\pi r \int_0^t \Delta p(t' + r/c)dt'$$

$$q(0) = 0$$





Infrasonic Pressure (*Δp*) can be converted in mass flux *q, but …….*

Modeling the Sound Source

…… the source could be a Dipole !

$$\Delta p = cos\theta \left[\frac{l\ddot{q}(t - r/c)}{2\pi r c} \right]$$

far-field conditions r>>λ *(Lighthill, 1978)*

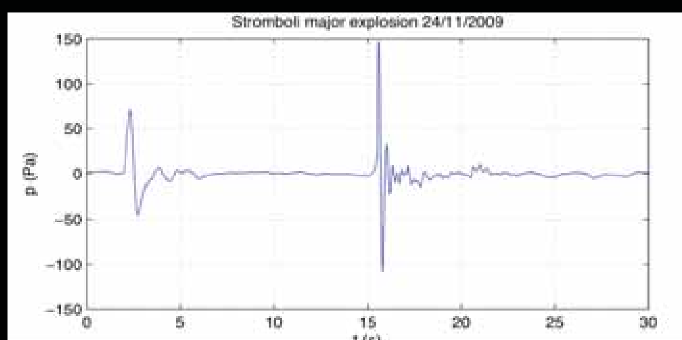
$$\Pi = \frac{\pi r^2}{\rho_{air} c \tau} \int_0^{\tau} |p - p_{air}|^2 dt$$

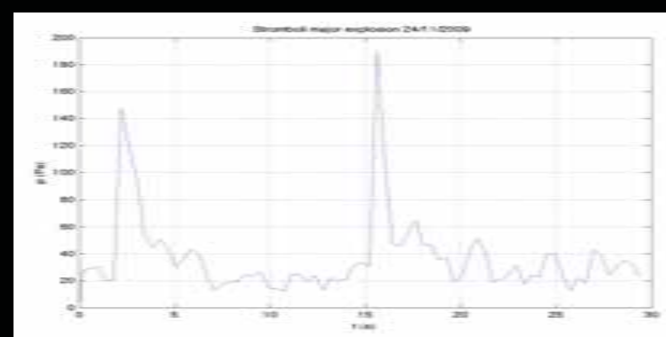
$$\Pi_d = K_d \frac{\pi R^2 \rho_{air} u^6}{c^3}$$

Acoustic Power

where:
r - distance from source
l - leght of dipole
c – Speed of sound
Kd - 0.01
(Woulff & McGetchin, 1976)

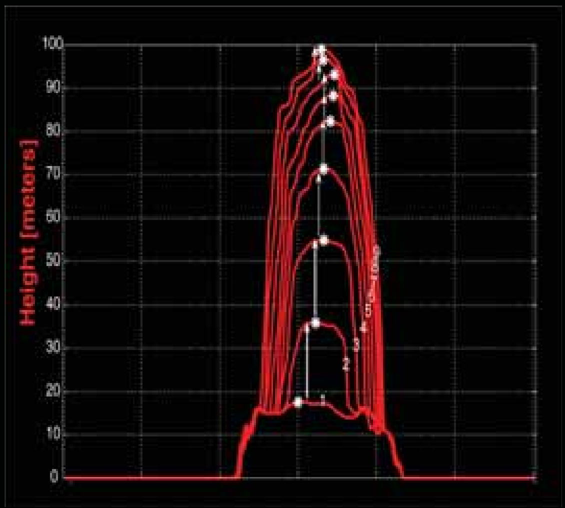
Dipole Source

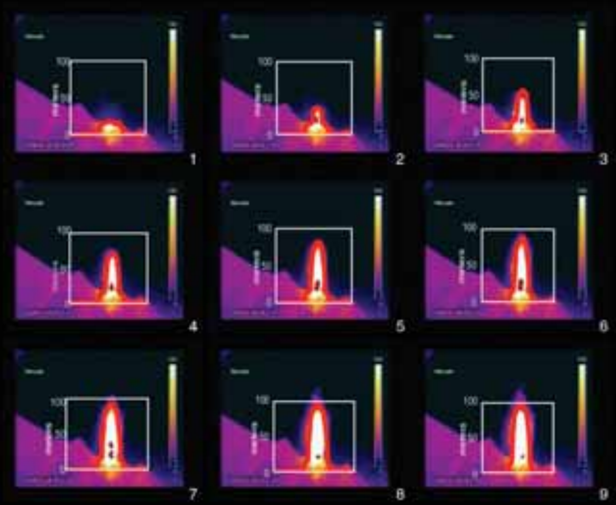


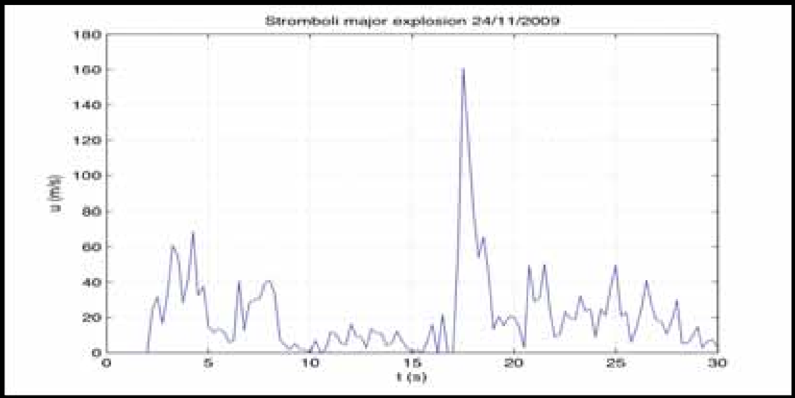


Acoustic Power (Πd) can be converted in plume velocity *u*

Thermal Image Processing

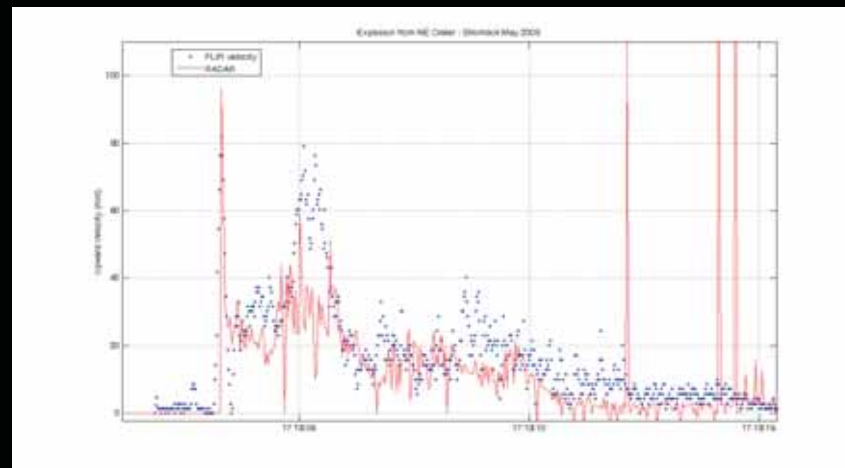


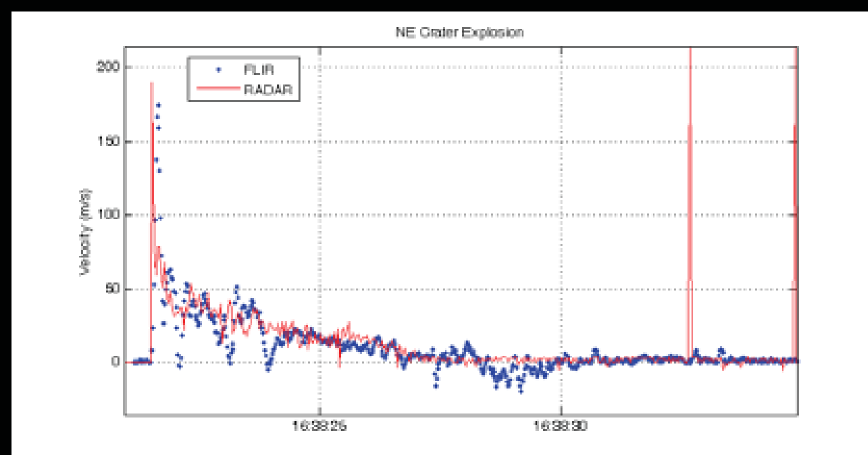




Tracing the Contour line of the 50°C temperature threshold @50 fps

Doppler Radar and Thermal Image Processing

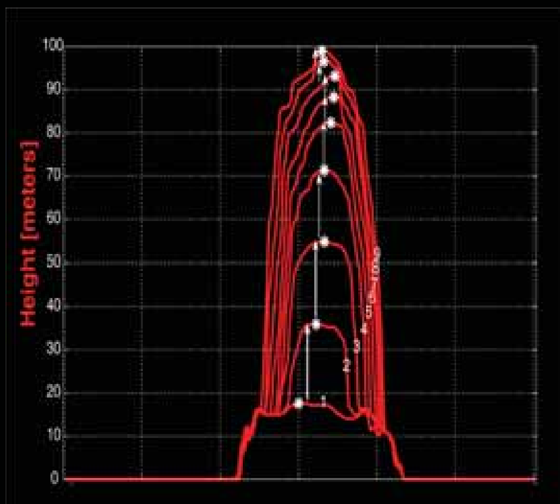


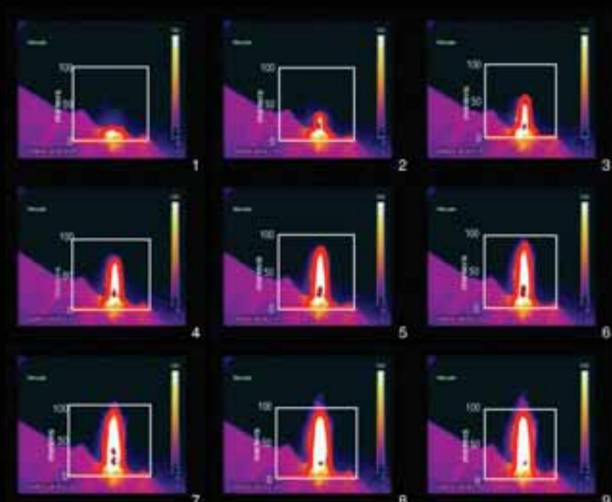


(M. Hort, Hamburg Univ., 2008)

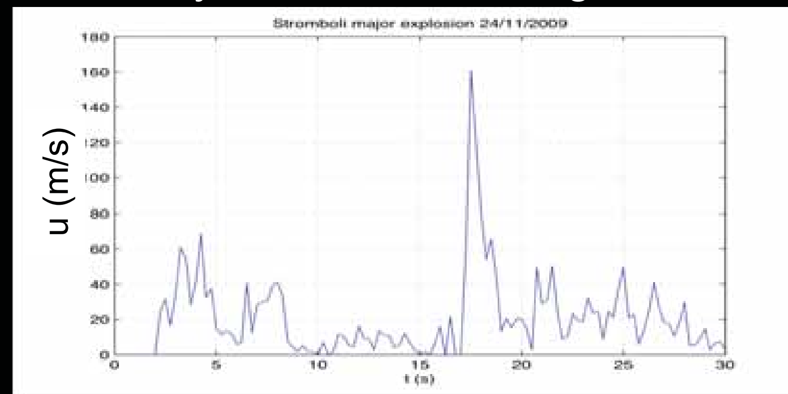
exit velocity derived by thermal image are comparable to doppler radar

Sound Source and Thermal Image Processing

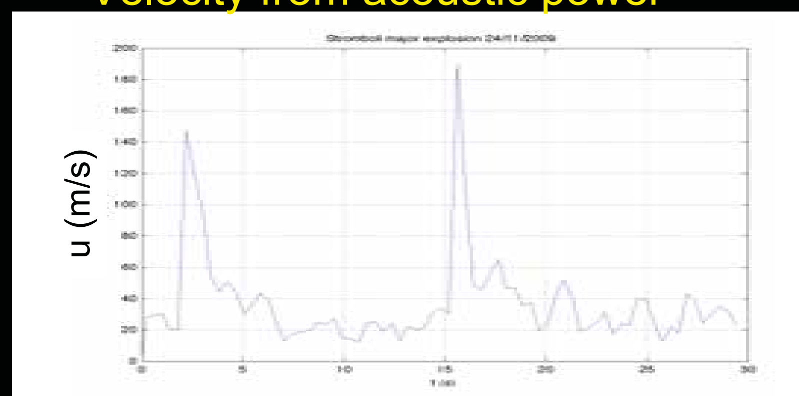




Velocity from thermal images

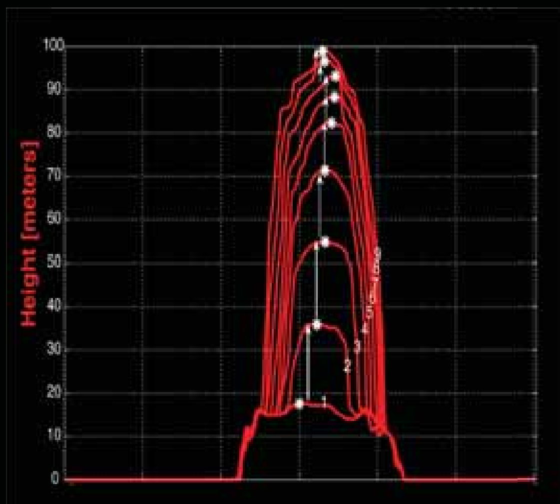


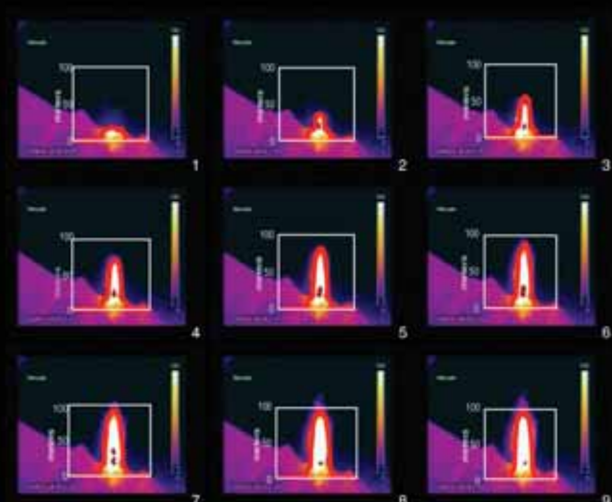
Velocity from acoustic power

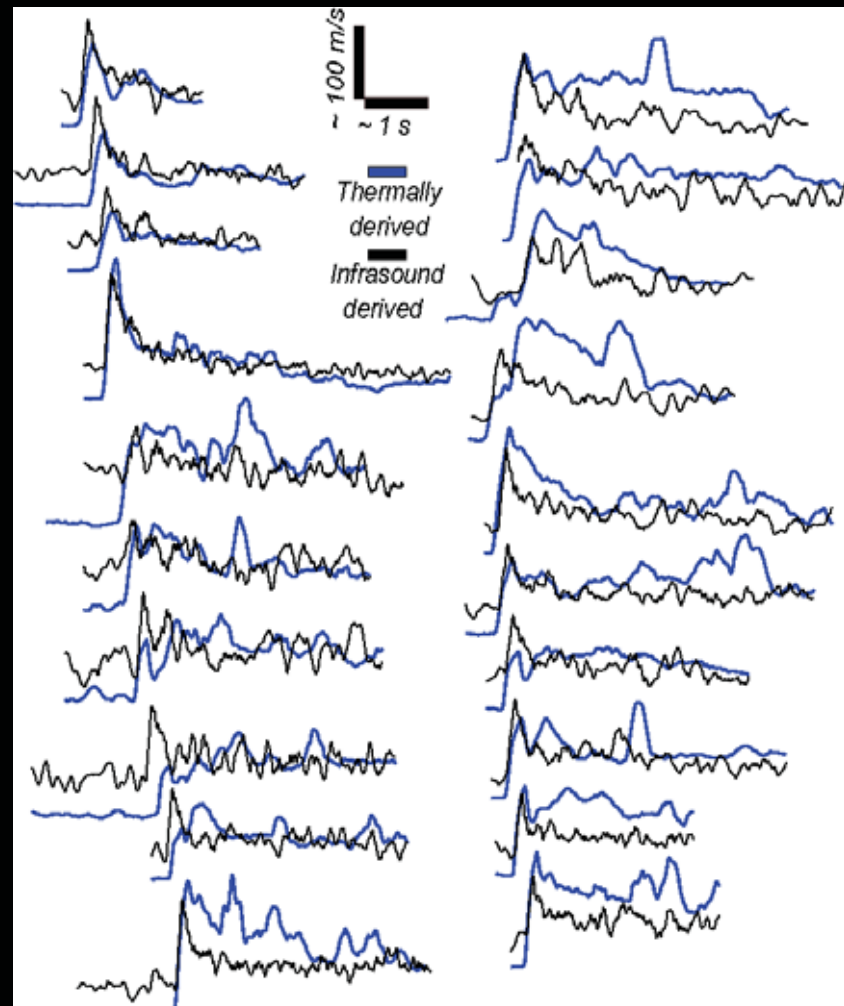


Plume velocity thermally derived is consistent with Infrasonic Dipole

Sound Source and Thermal Image Processing



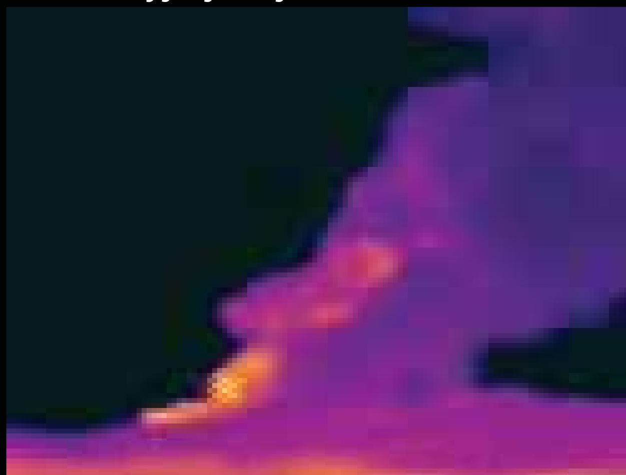


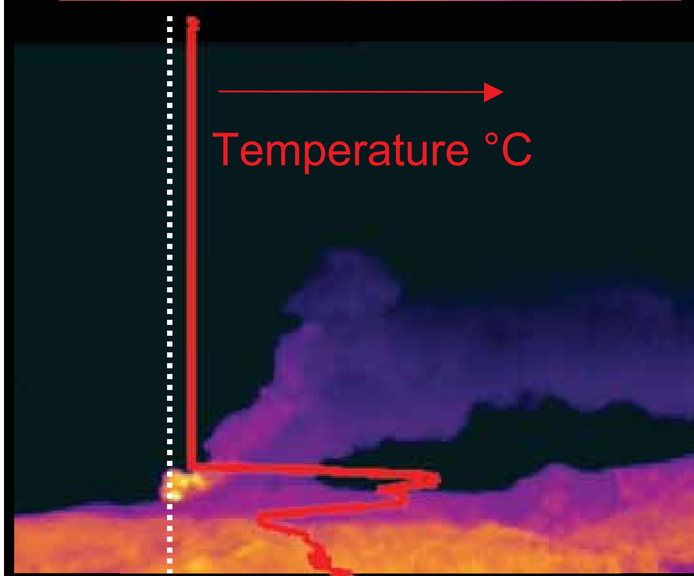


Plume velocity thermally derived is consistent with Infrasonic Dipole

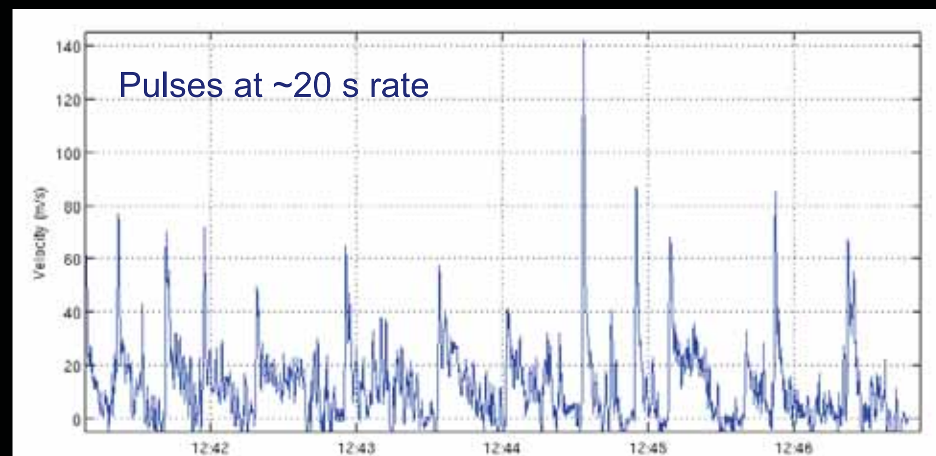
Thermally-derived Plume velocity

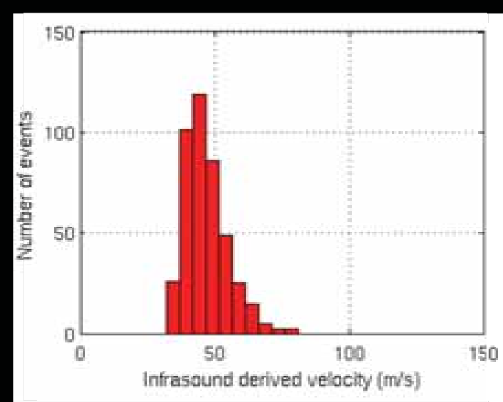
Eyjafjallajokull

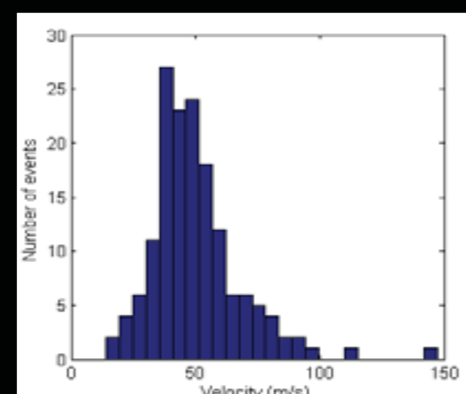




- FLIR A-20 Uncooled Thermocamera
- 50 frames per second at 16 bits
- Distance from the vent ~ 8.2 km





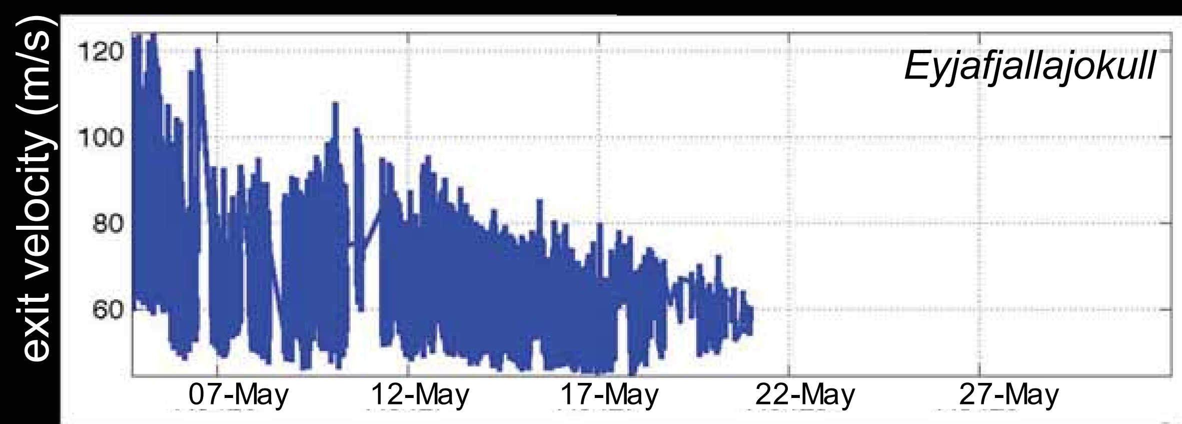


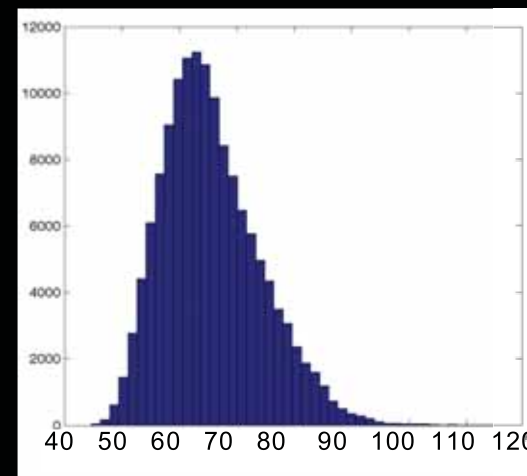
Plume velocities from FLIR are comparable with infrasonic dipole source.

Exit Velocity from Acoustic Power

Dipole Source

$$\Pi_d = K_d \frac{\pi R^2 \rho_{air} u^6}{c^3}$$





45 < U < 124 m/s

U_{mean}=67 m/s

.. to mass flux

$$q(t) = \pi \rho_{plume} R^2 u$$

with:

ρ_{plume} = 6 kg/m^3

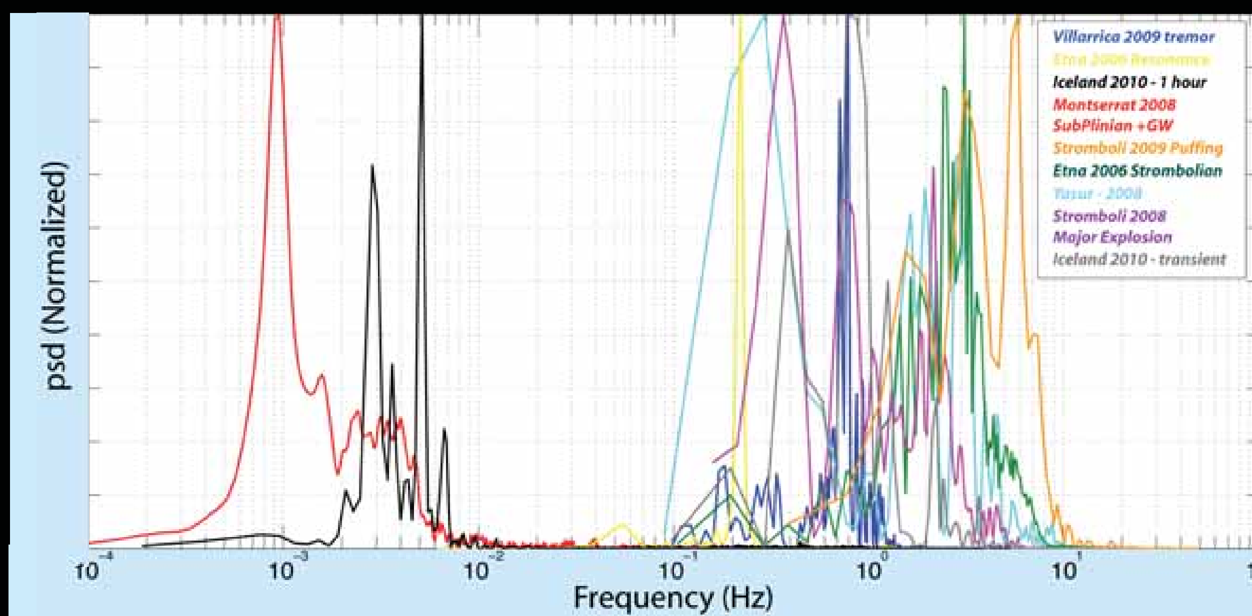
R = 25 m

Frequency Sensivity of Infrasonic Array

Atmospheric Gravity

Volcanic Infrasound

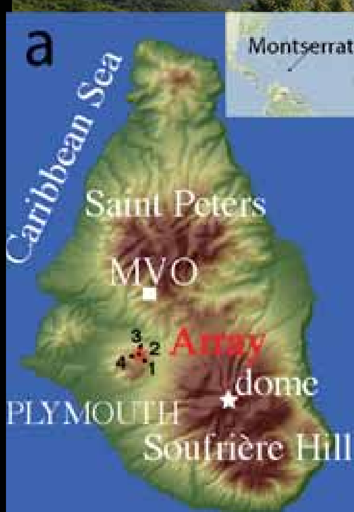
GW AGW VLP LP HF

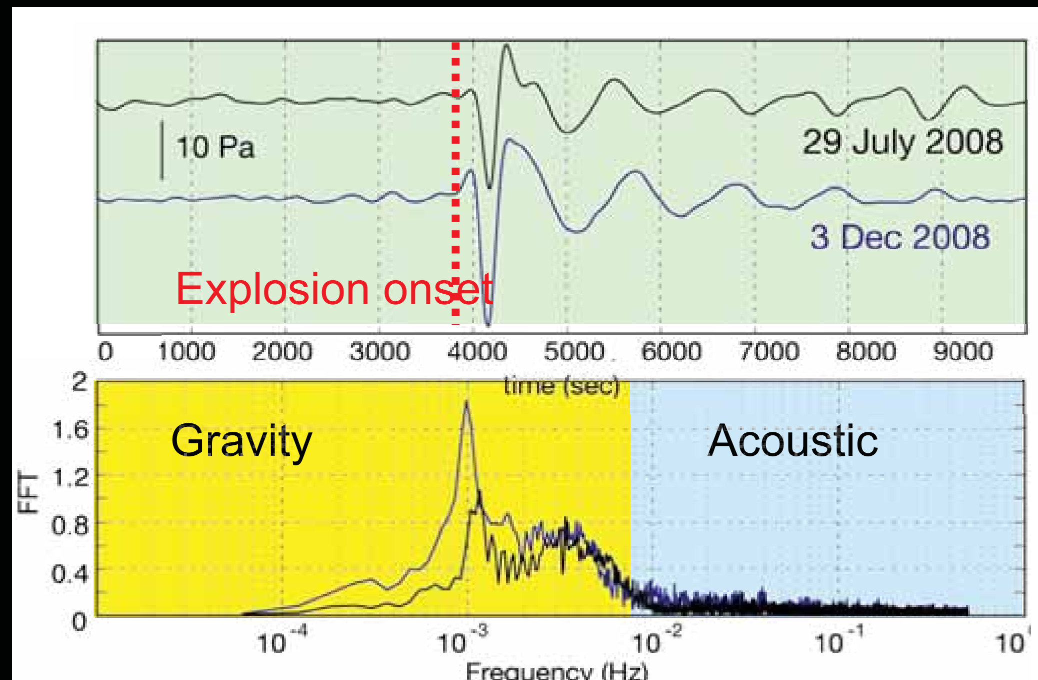


4 orders of magnitude

infrasonic frequency content can span 4 orders of magnitude (10^{-3}-10^{1} Hz)

Gravity Waves Induced by Vulcanian Explosions





Large Vulcanian explosions induce thermal atmospheric oscillations with buoyancy frequency ~1mHz (*N*) propagating at 7 m/s (*c*)

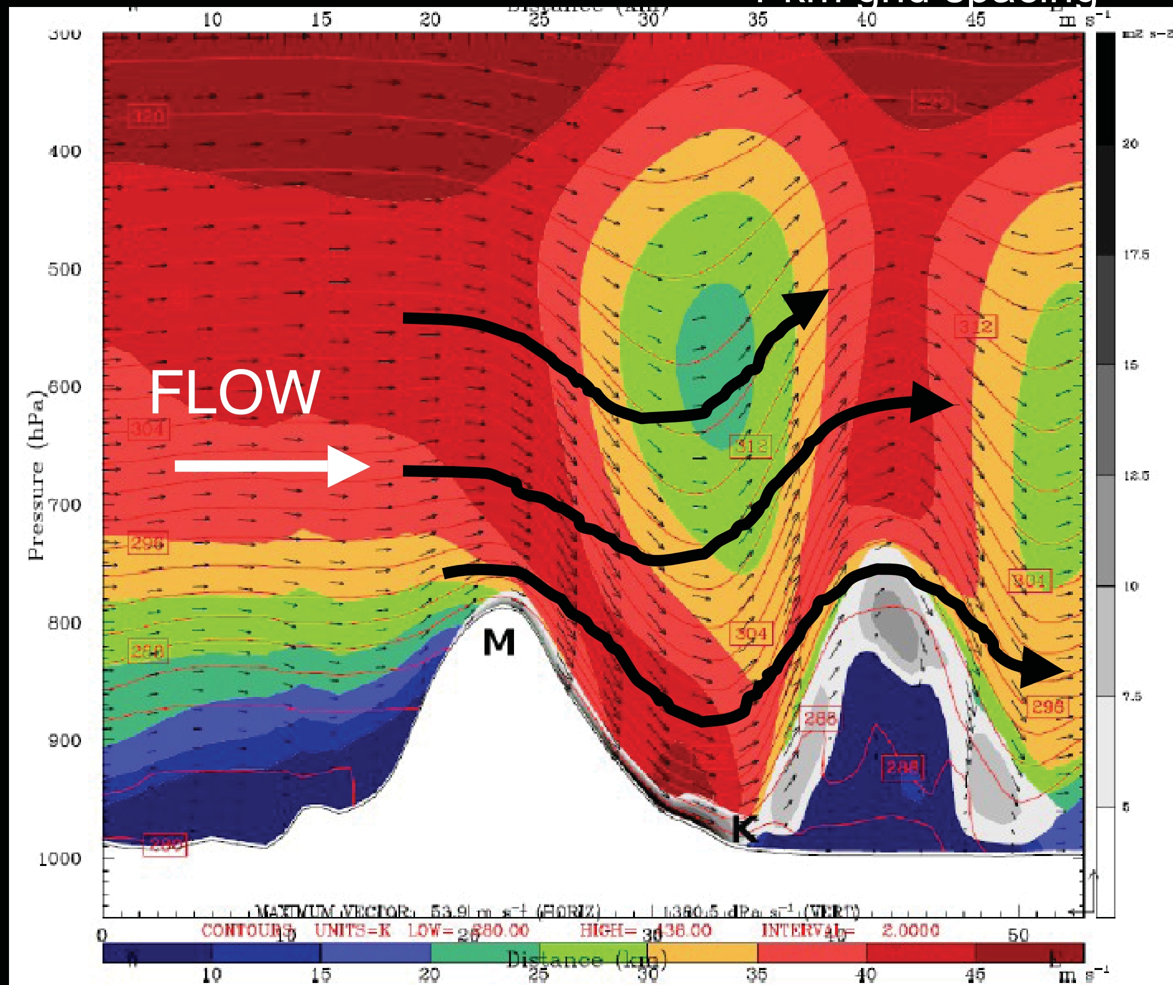
$$c = \frac{NH}{n\pi}$$

n is the gravity wave mode (1)

The heigth *H* of the displaced atmosphere is 22 Km

Mountain-induced Gravity Waves at Eyjafjalla

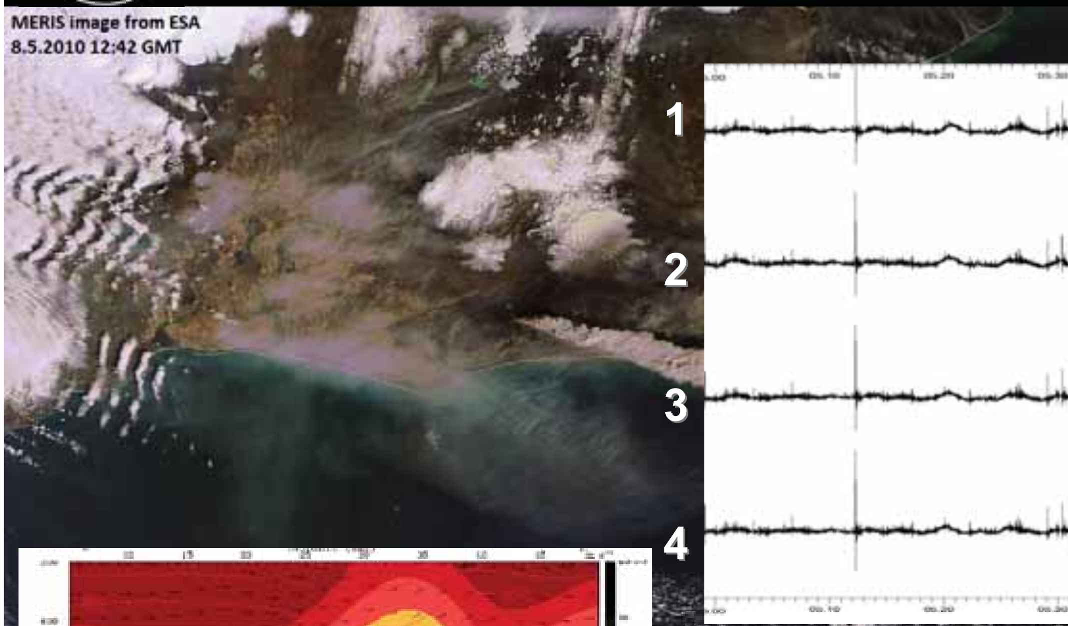
1 km grid spacing



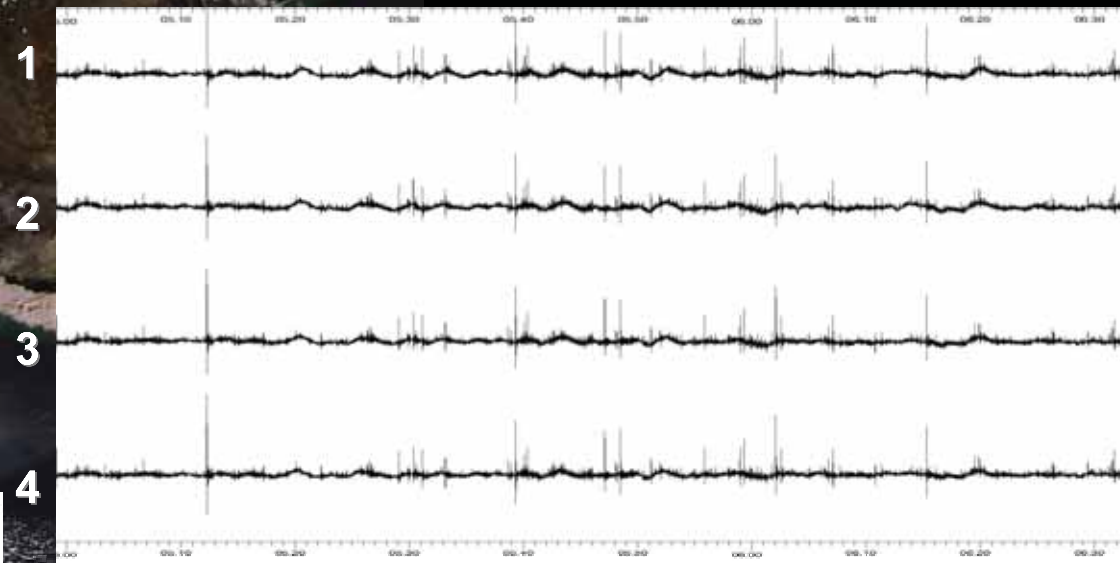
Mountain waves induce vertical mixing in the atmospheric layers

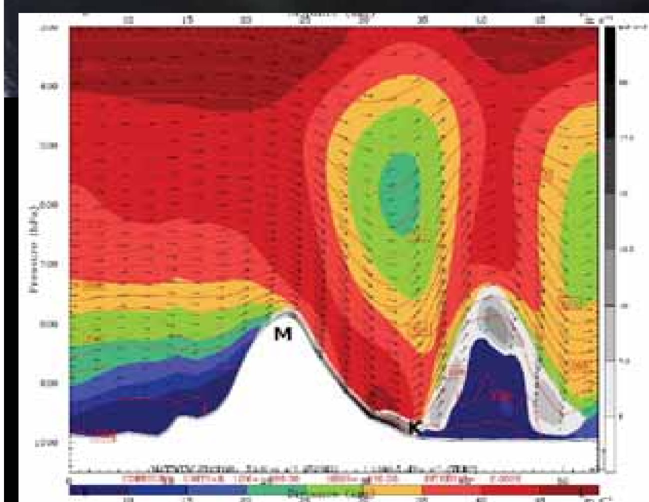
H.Ágústsson and H.Ólafsson, (IMO) 2010.

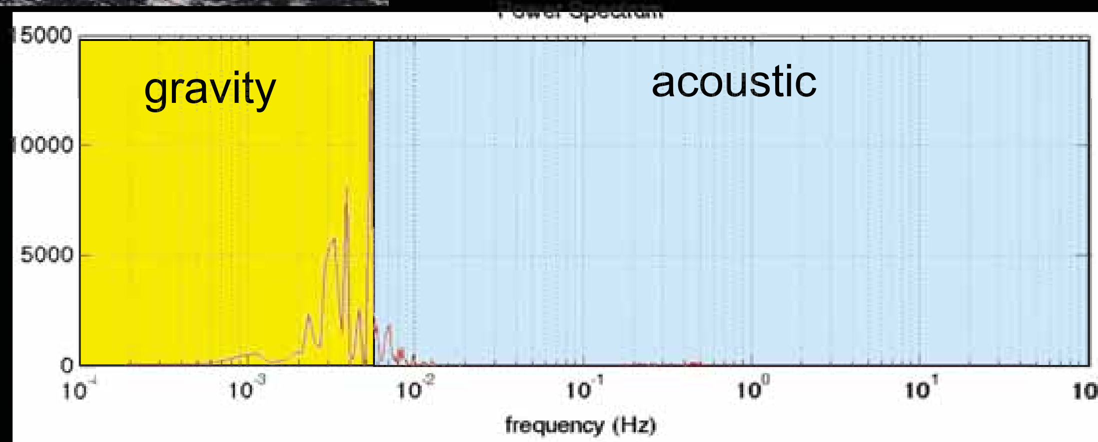
Gravity Waves at Eyjafjalla Eruption



1 hour of infrasonic record

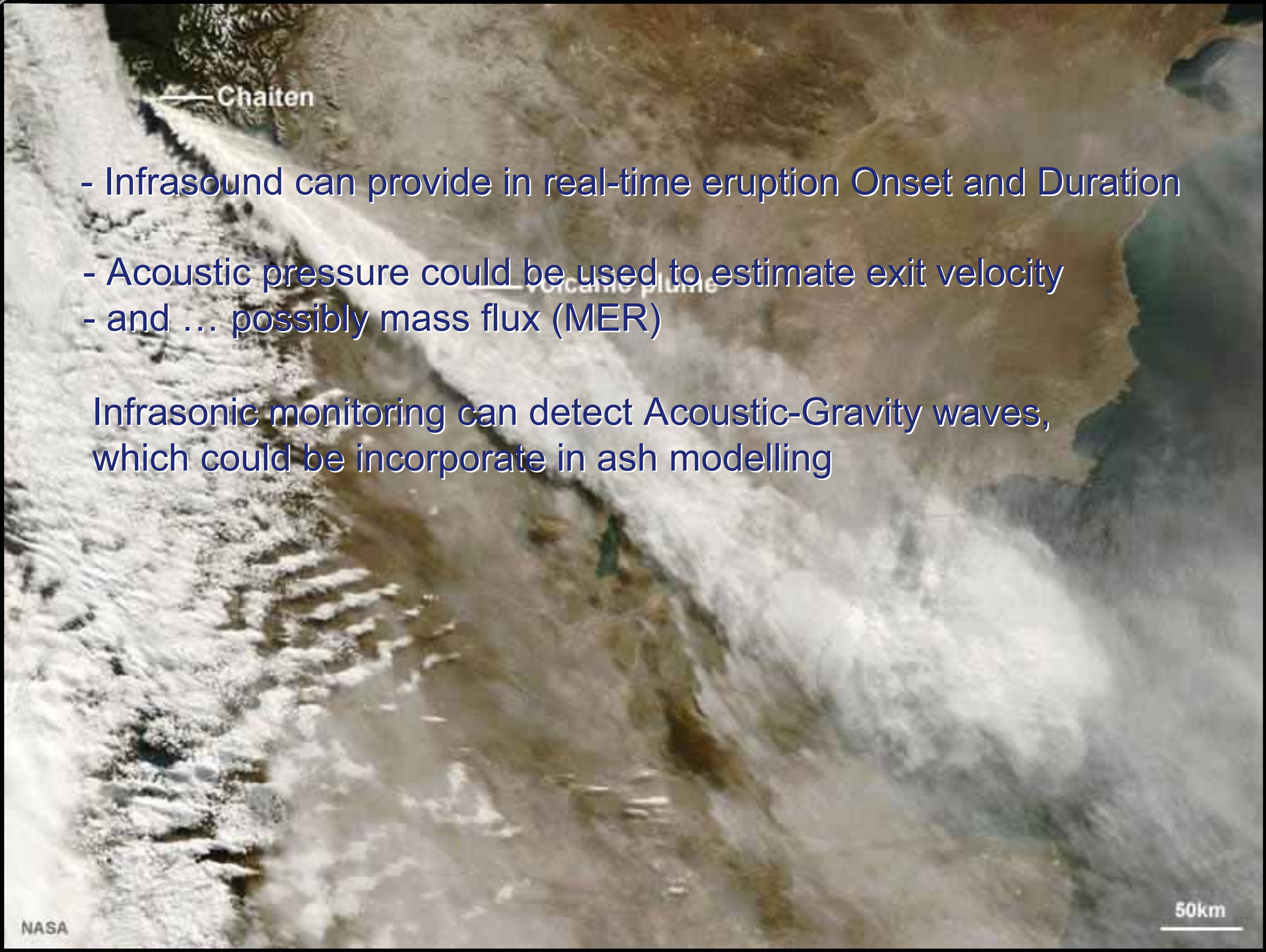






Gravity waves of 200-500 s reveal atmospheric mixing & instabilities.

Summary



- Infrasound can provide in real-time eruption Onset and Duration

- Acoustic pressure could be used to estimate exit velocity
- and … possibly mass flux (MER)

Infrasonic monitoring can detect Acoustic-Gravity waves, which could be incorporate in ash modelling