

Infrasonic early warning for explosive eruptions

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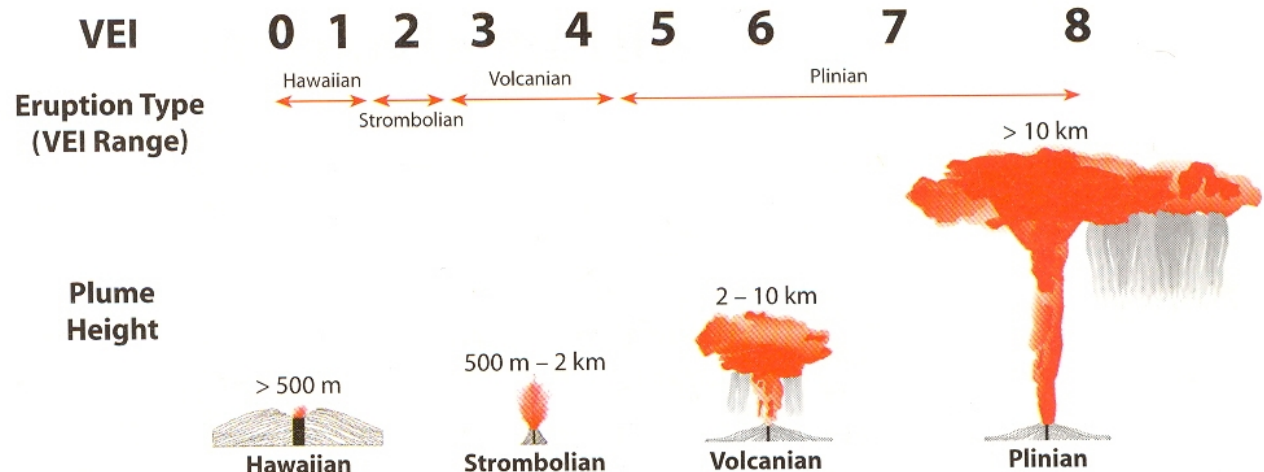
with the support of M. Ripepe, and the ETNA LGS team

D. Delle Donne, R. Genco, L. Innocenti, G. Ulivieri, S. Valade

Energy of Explosive Eruptions



Explosive Volcanic activity spans several order of magnitude in terms of amount of material erupted and affected area.



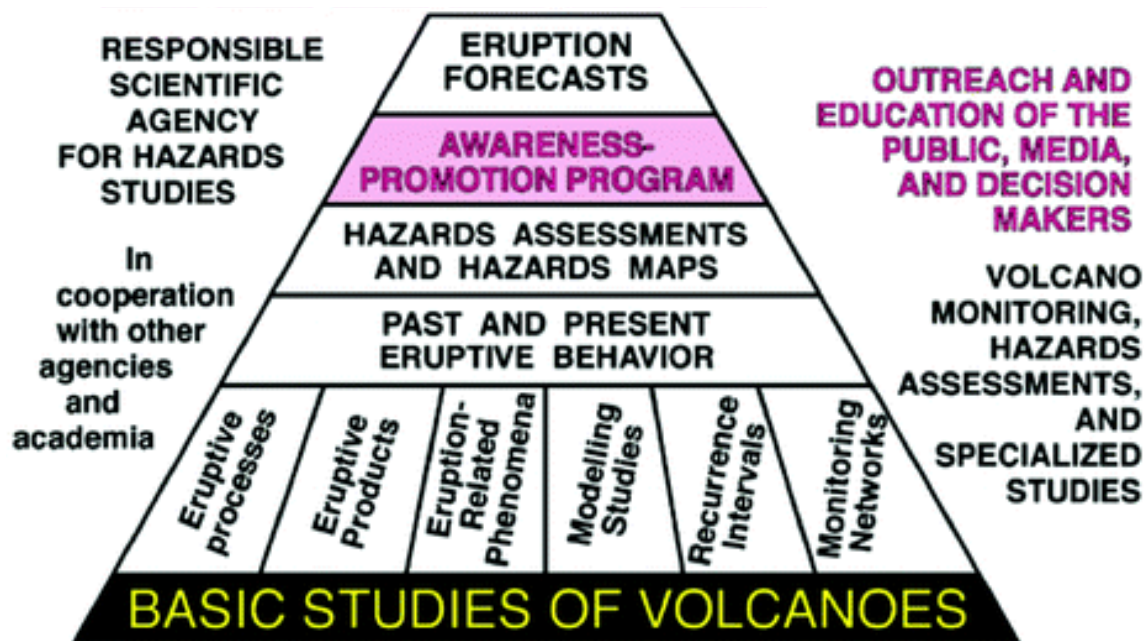
[Newhall and Self, 1982]

Quite periods

Studies are performed:

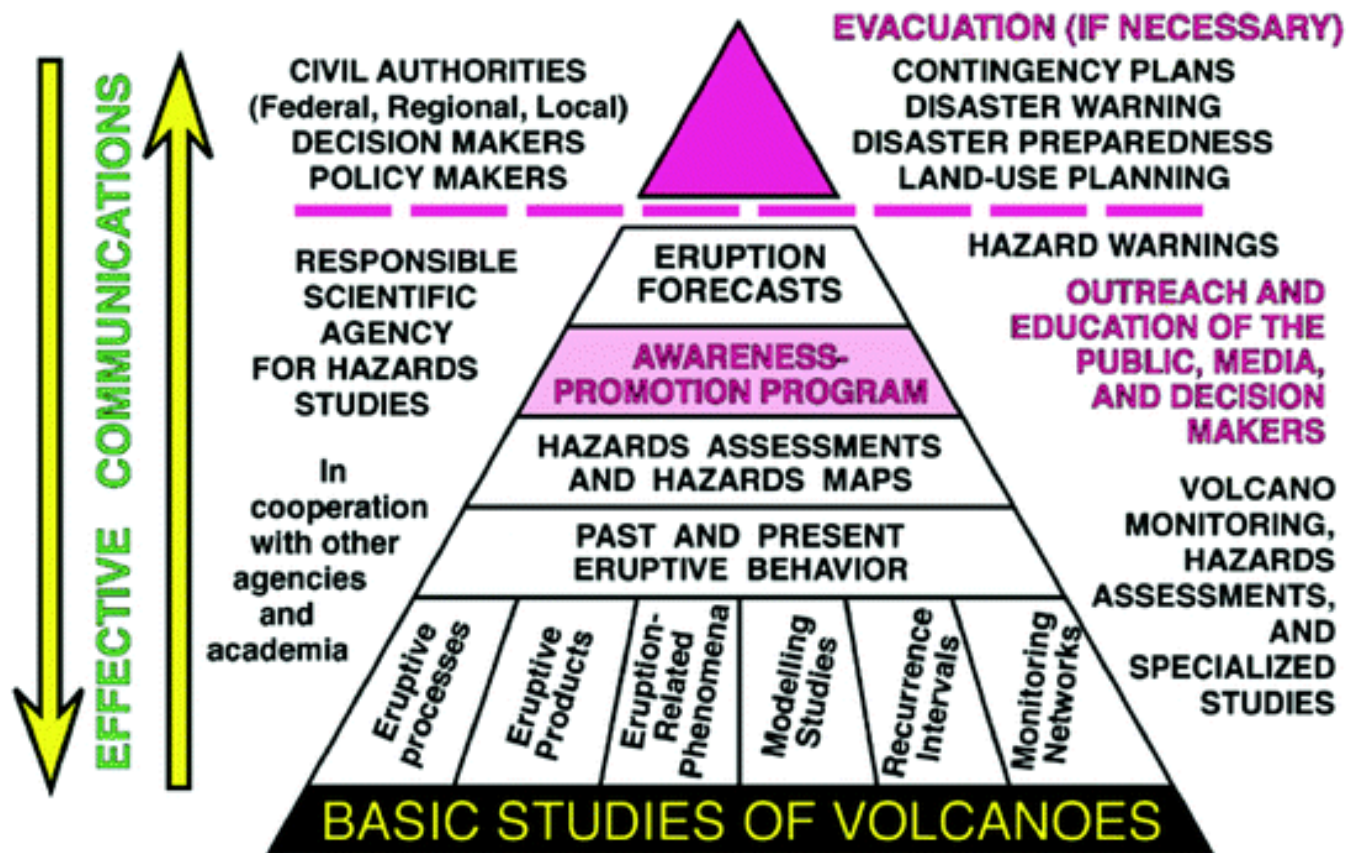
What activity has to be expected? when? How often?

What is the areal extension of the effect?



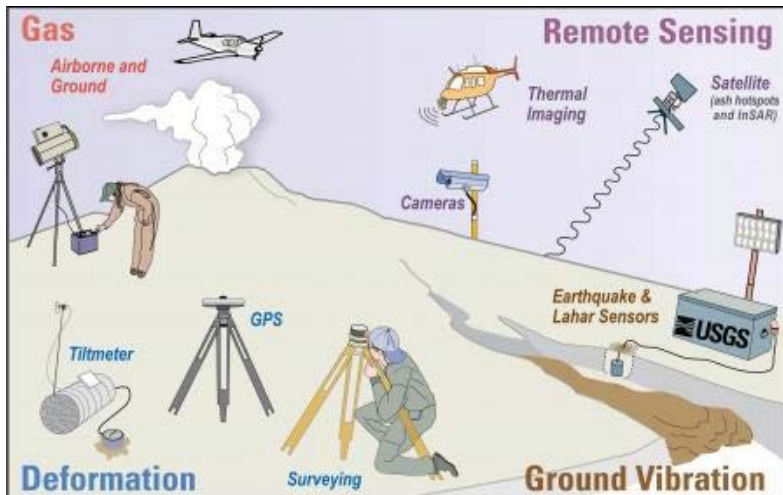
[Tilling 1989, Rev. Geoph.]

Active periods: real time data processing, warnings, action.

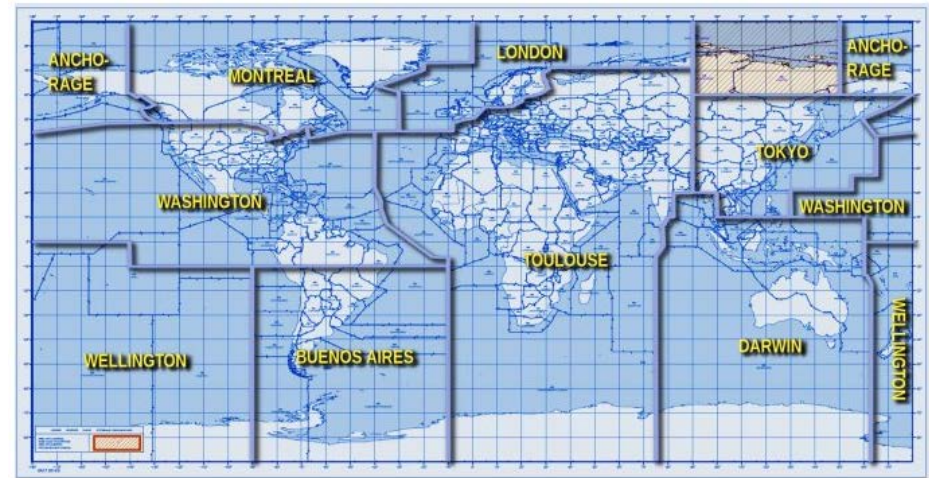


[Tilling 1989, Rev. Geoph.]

Warnings communication workflow

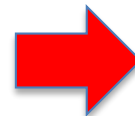


Real-time data 24/7



VONA – VAACs - VAA

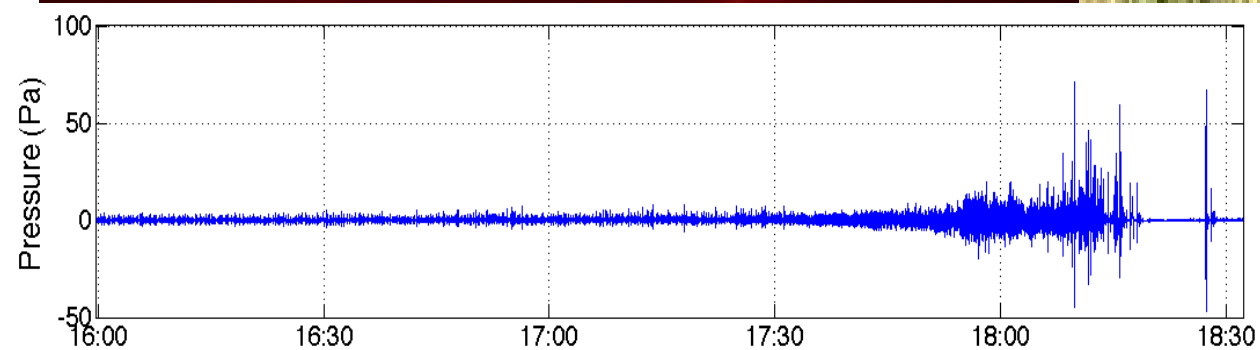
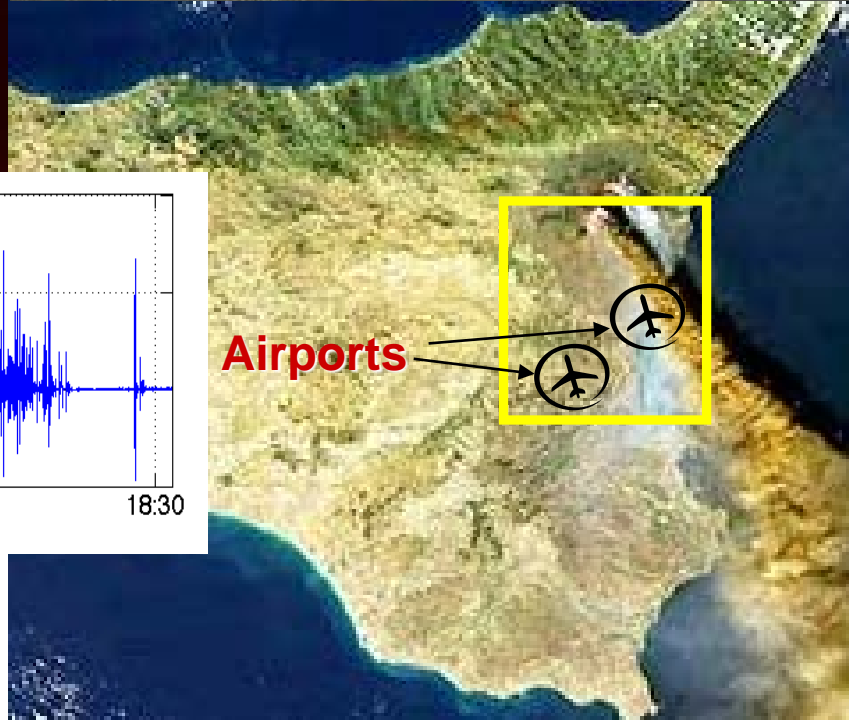
Bulletin



Warning are issued by the Civil Protection

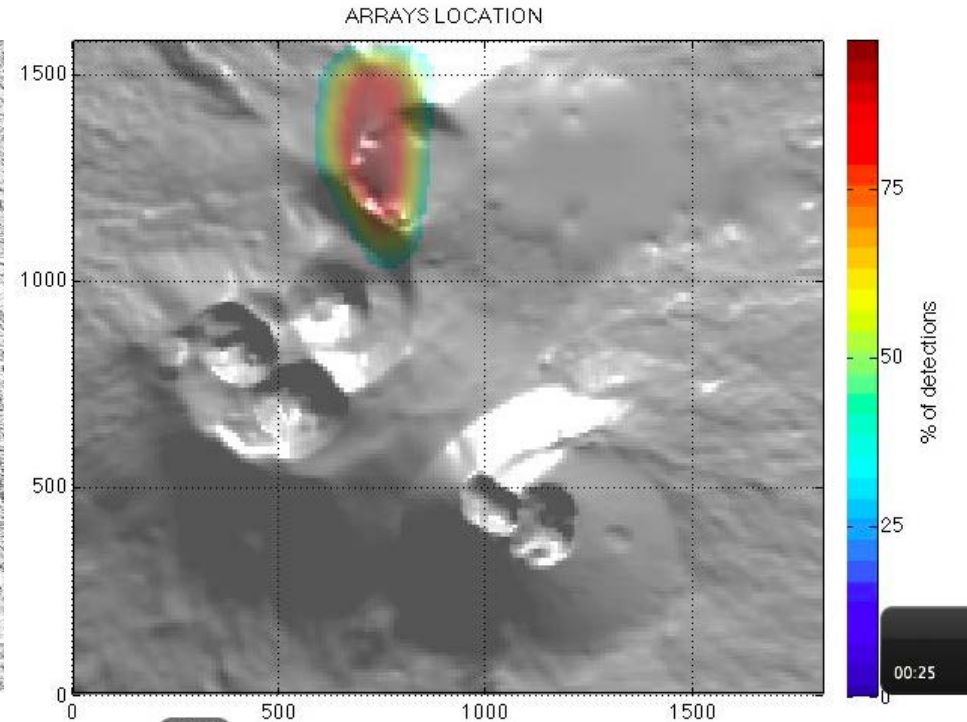
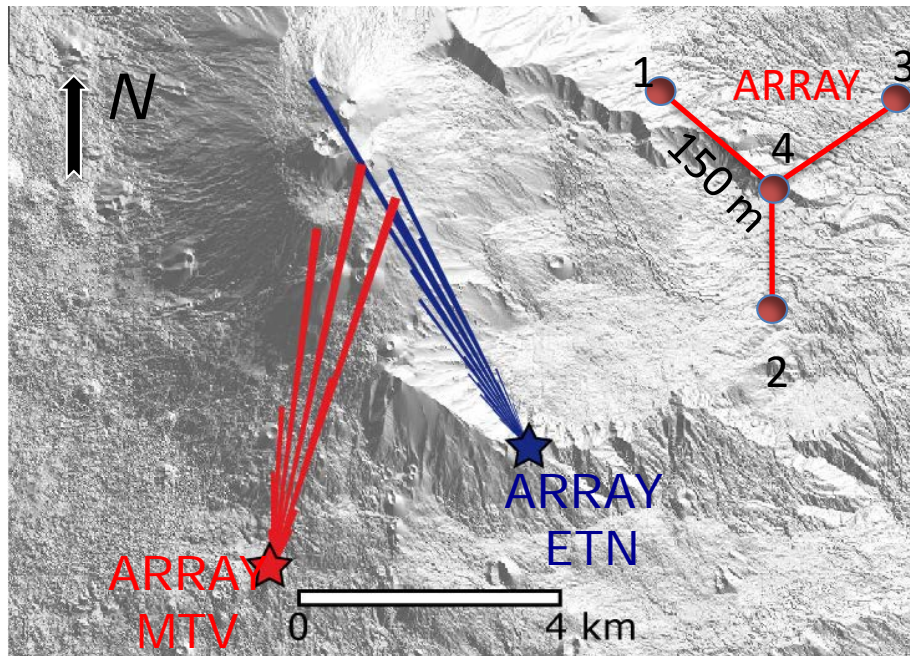
$t_w - t_e > 10-15 \text{ minutes (generally } > 60 \text{ minutes)}$

Lava Fountains from Etna volcano



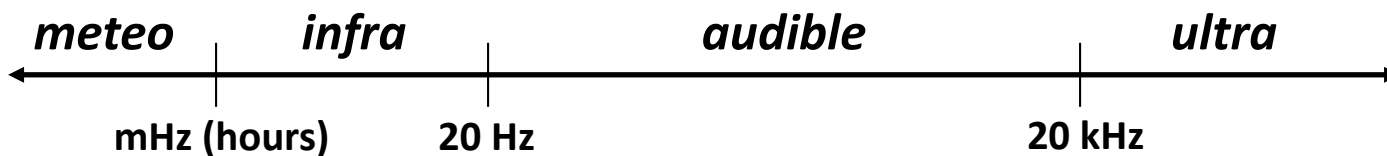
Lava Fountains from Etna can be as short as 20-30 minutes, affecting nearby cities and infrastructures

Infrasonic Monitoring at Etna

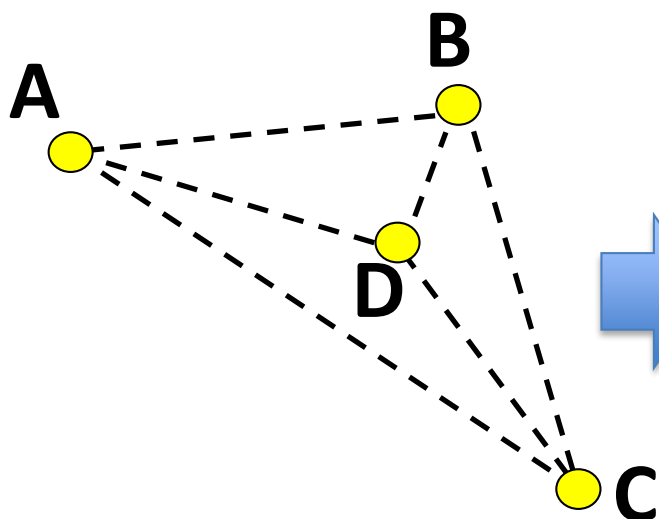


Explosive activity is monitored using two 4-elements small aperture (~120 m) infrasonic arrays which allow precise location of the source

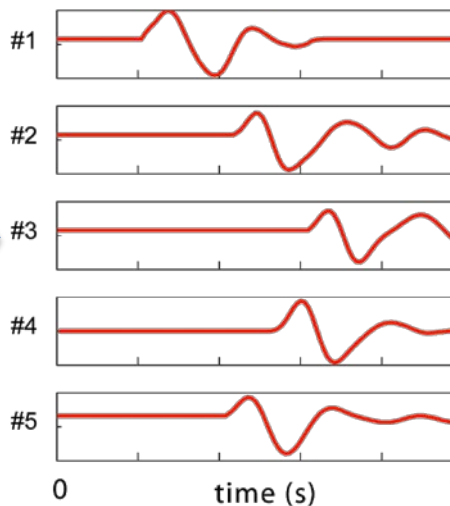
“Infrasound is a wave phenomenon sharing the physical nature of sound but with a range of frequencies below that of human hearing”



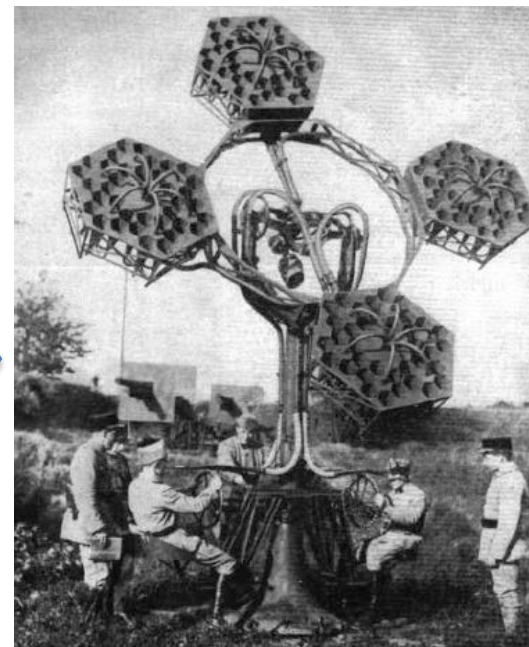
Pressure Perturbations with frequency < 20 Hz



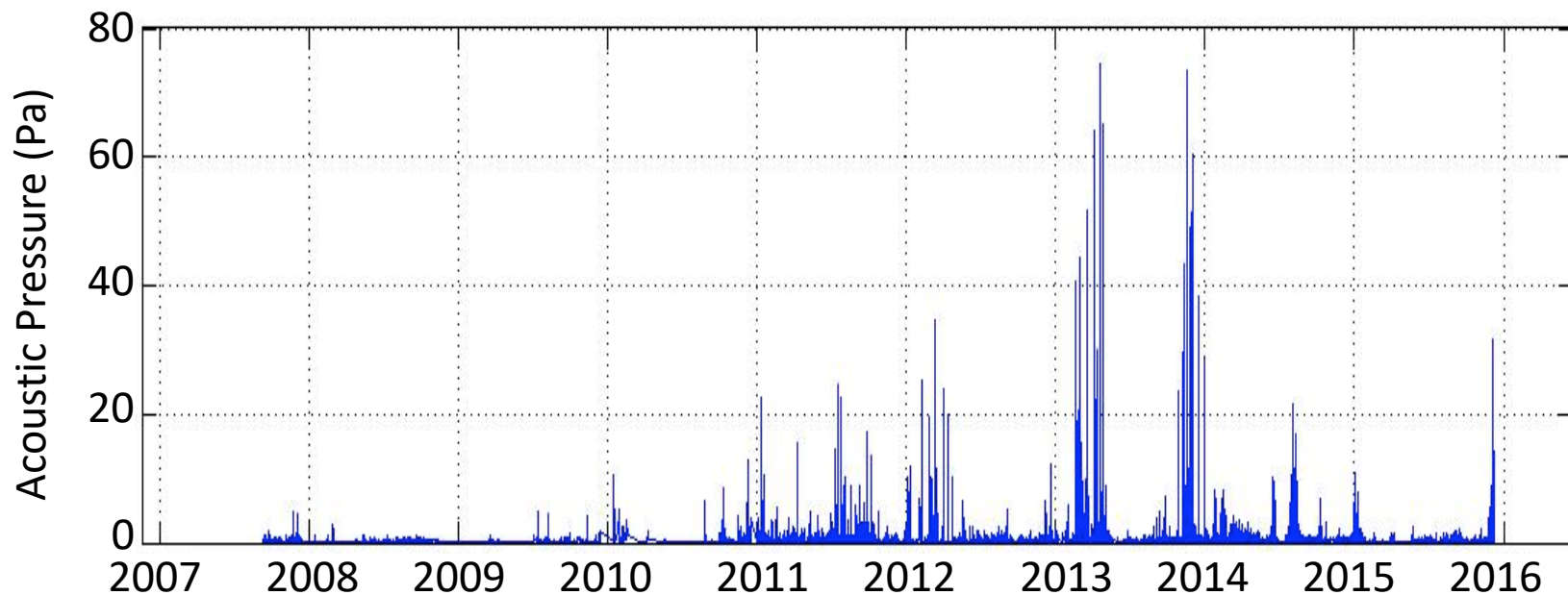
multiple sensors used as an antenna to discriminate signal from noise



arrival time depends on infrasonic ray



signal identified in terms of back-azimuth and apparent velocity

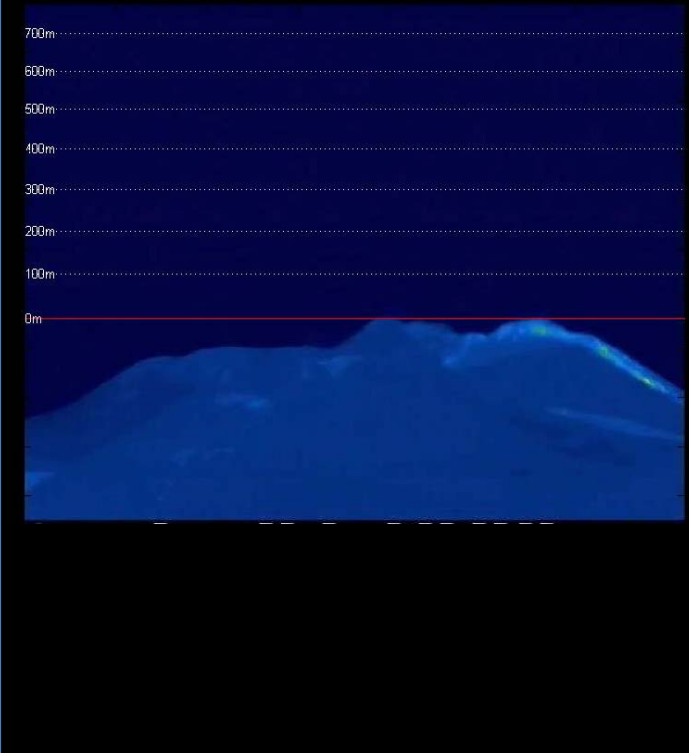


~9 millions of detections localized from 2007 to 2016 in the craters area.
The increase of pressure is always associated with explosive eruptions

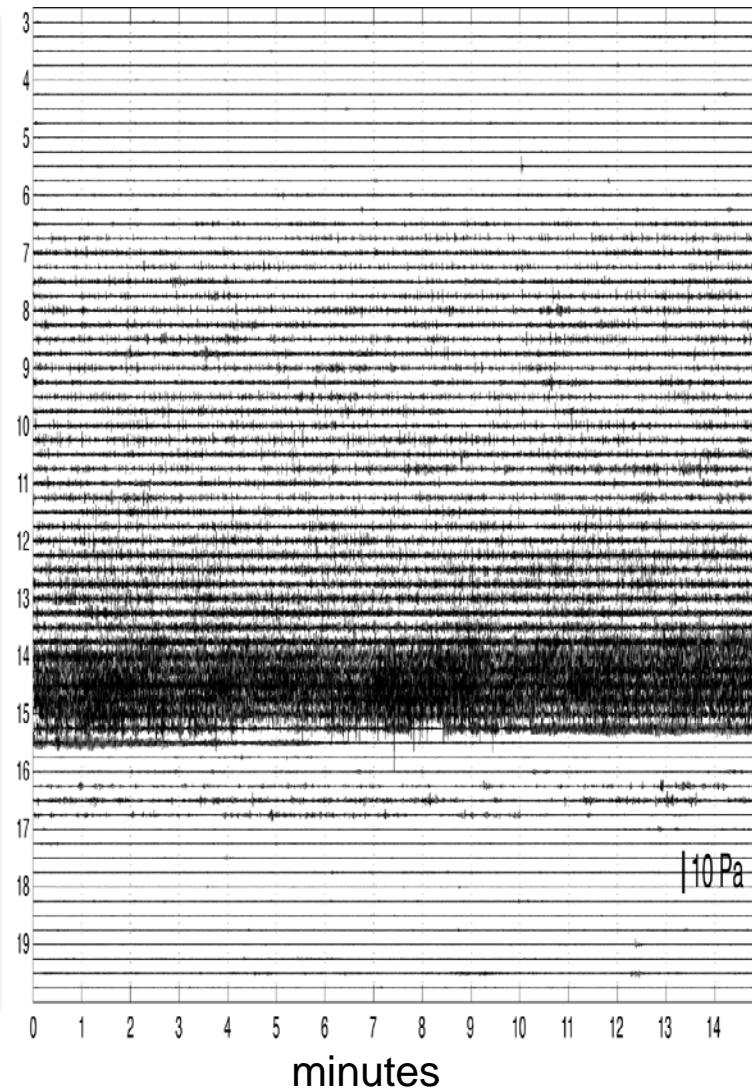
The Infrasonic Parameter IP

Thermal Camera @ 5 km

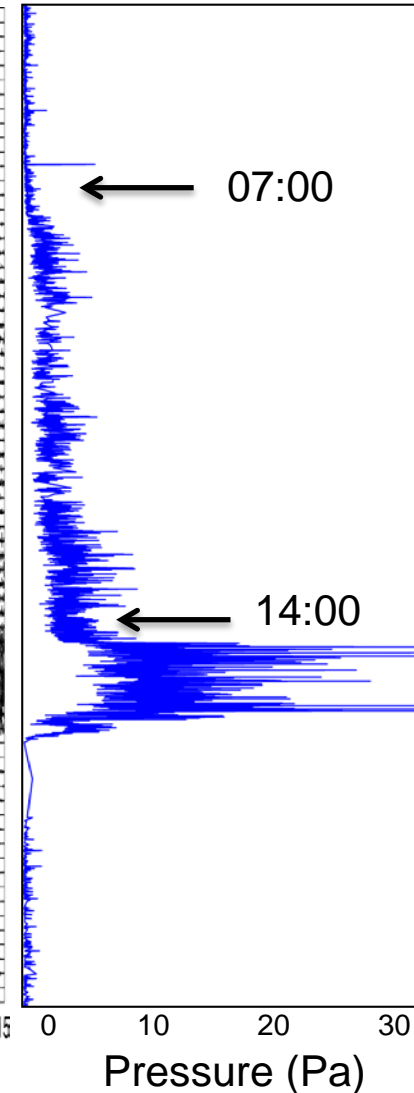
16-Nov-2013 17:00:00



LFN 05 - 9 Jul 2011

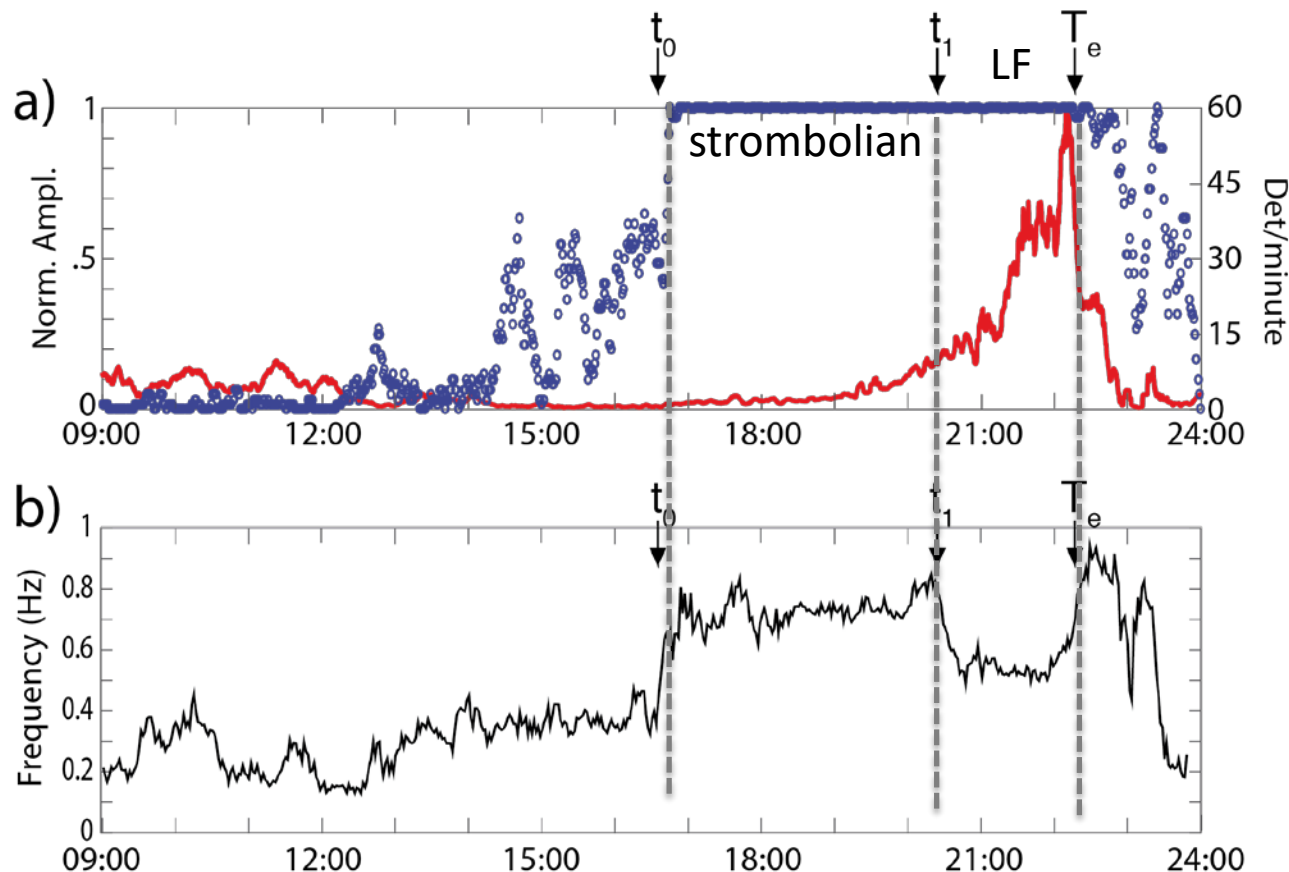


Array detections



Infrasound indicates an increase at volcanic activity ~ 7 hours before eruption

The Infrasonic Parameter IP



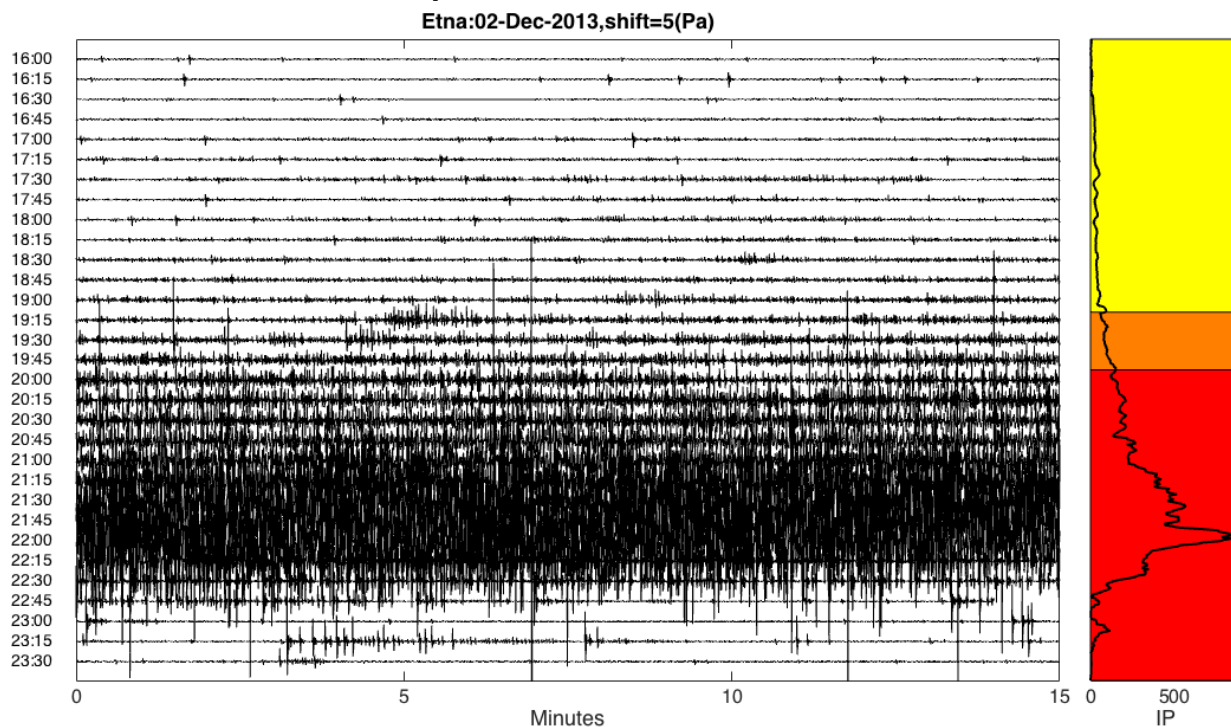
The transition between strombolian and lava fountain is associated to an increase of amplitude (P) and number of detections/minute (Ndet) used to define the Infrasonic Parameter $IP = P \cdot Ndet$.

Volcano Infrasound Early Warning at Etna

$$IP = N_{det} \times Pm$$

N_{det} = number of detections (normalized to 60)

Pm = infrasound pressure corrected for attenuation



IP > 60 EW1;
IP > 120 EW2;
IP < 8 EW0;



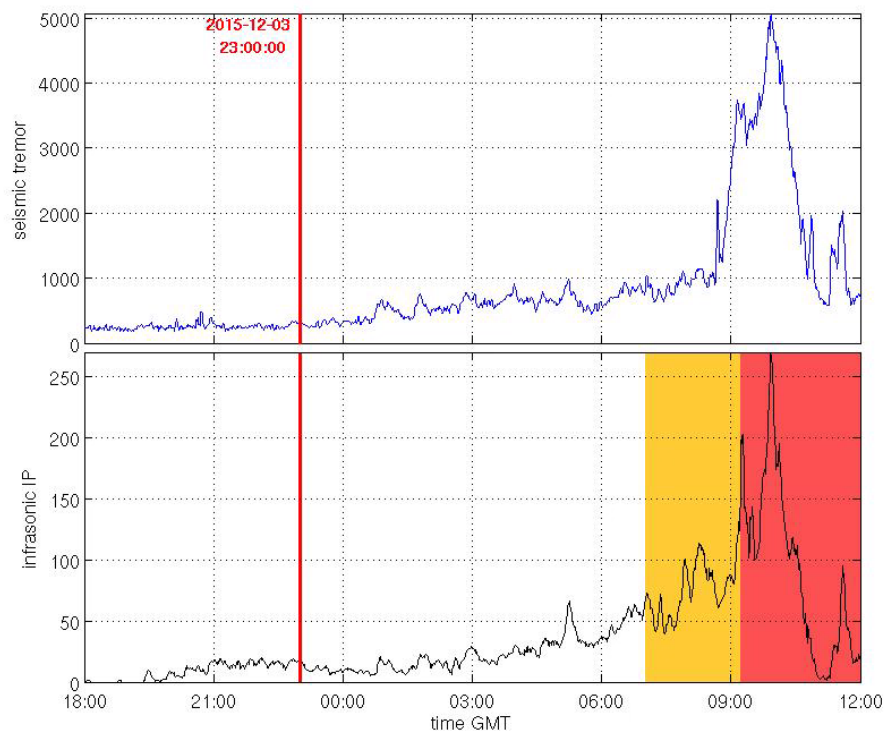
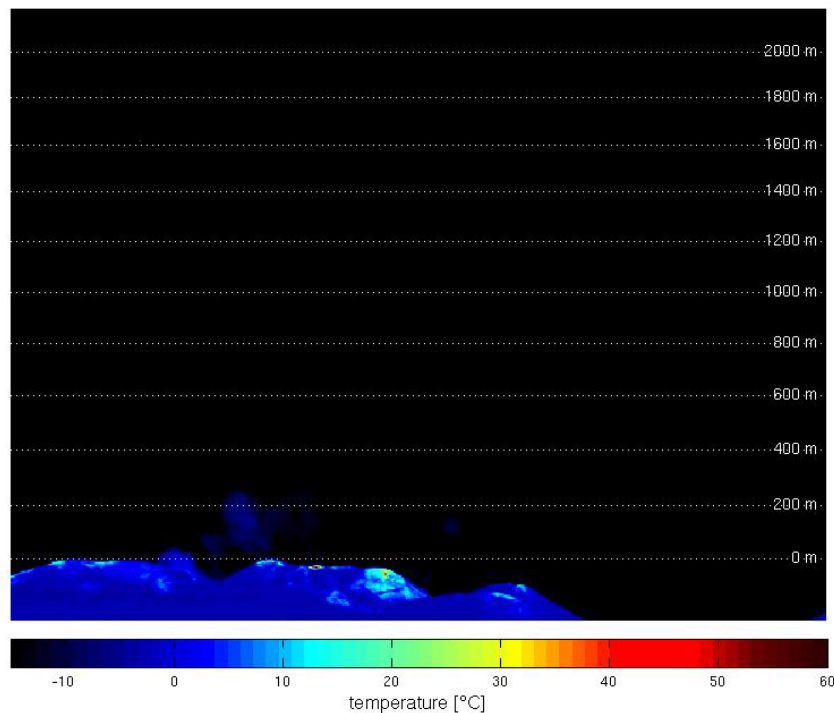


EW1
Violent Explosions



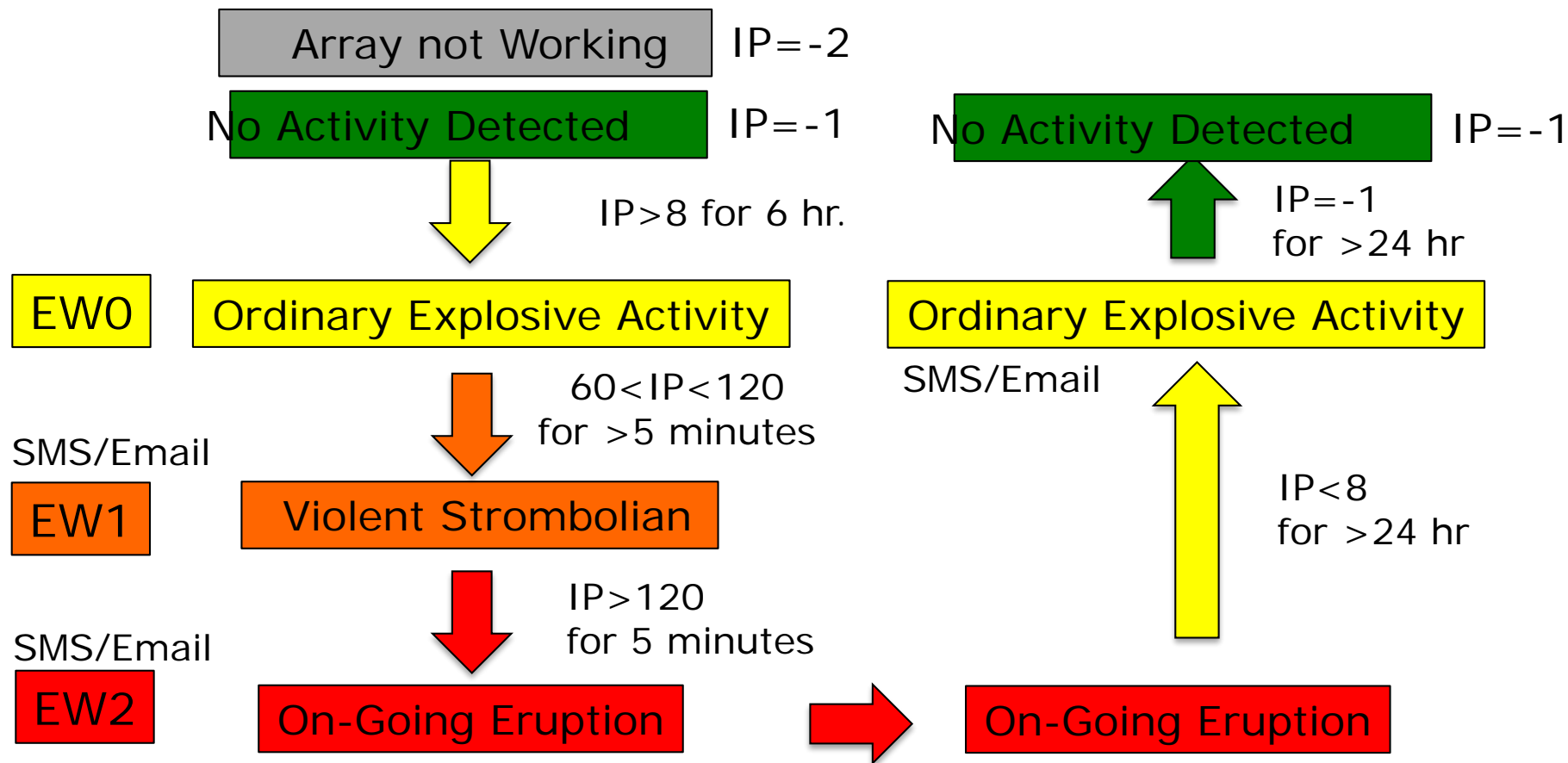
EW2
Eruption

2015-12-03 23:00:00



Alerts automatically delivered by E-MAILS and SMS
before eruption is visible on thermal camera and from seismic tremor

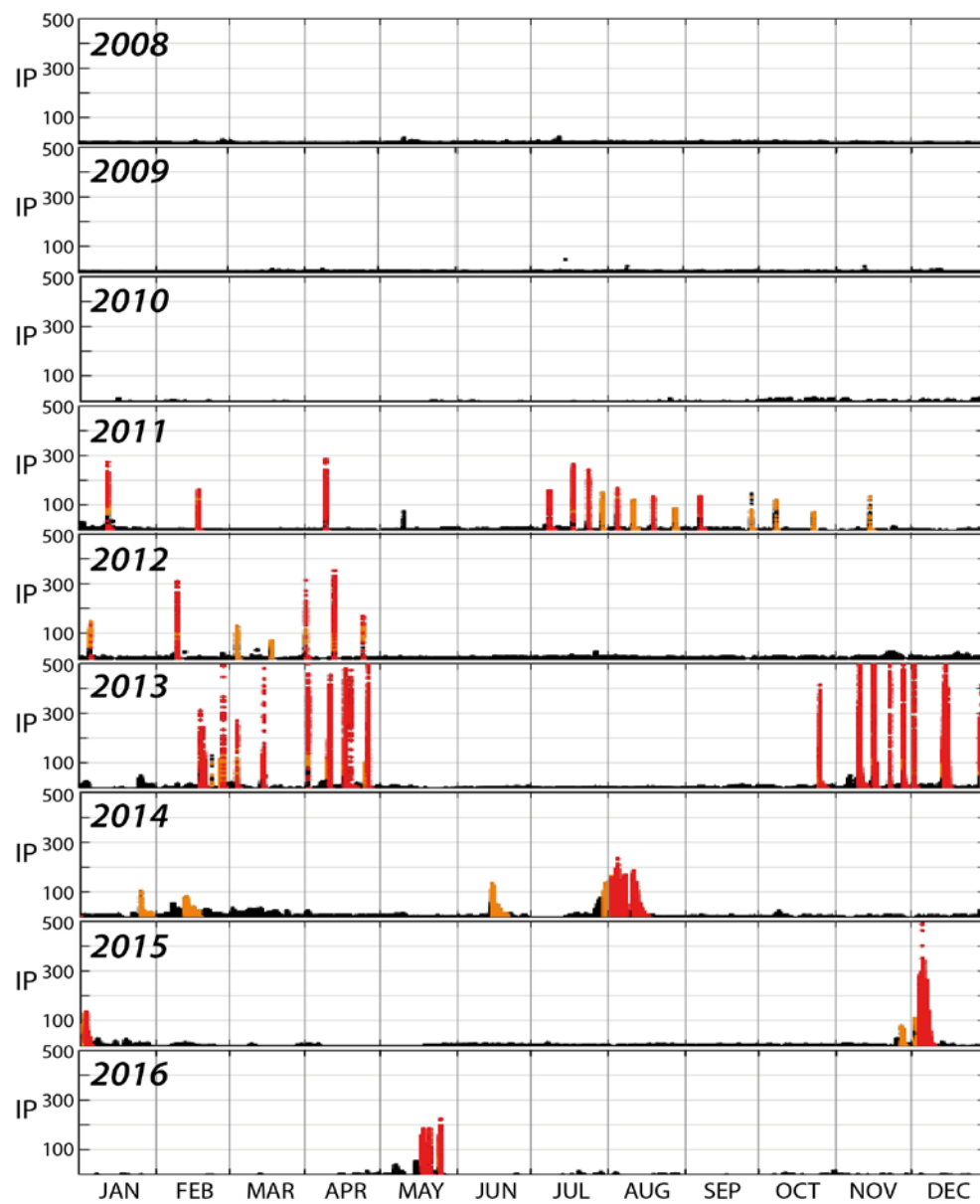
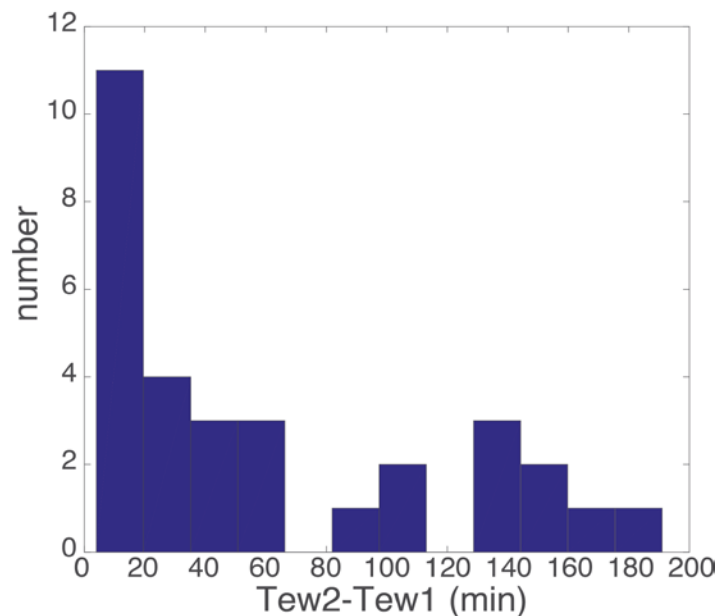
Etna EW – Flow chart



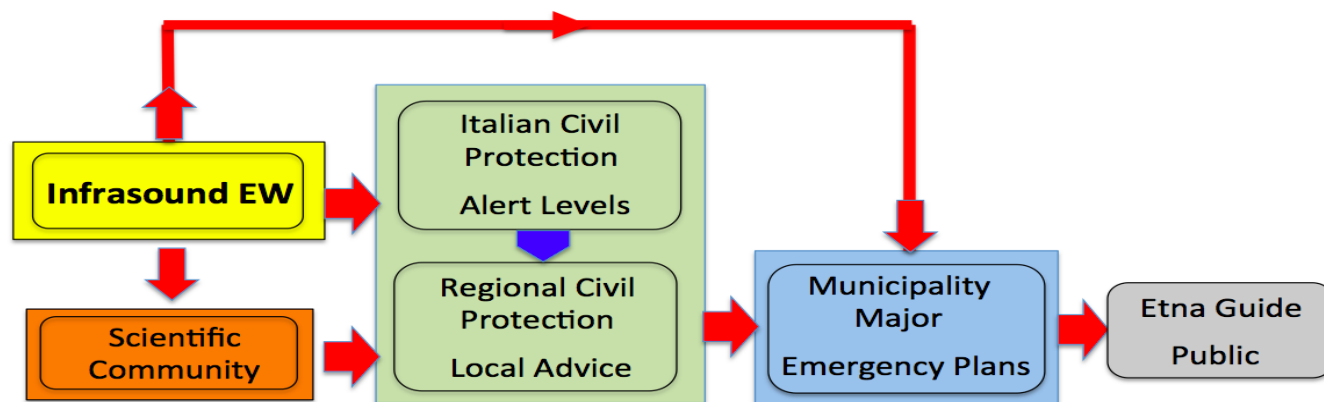
Flow diagram showing the relation between the infrasound parameter (IP) and the corresponding alert level (EW) and notification procedure.

Etna EW – time reliability

At Etna, infrasound provides a fully automatic early-warning system. In the last 8 years, might have issued pre-alert notifications (EW1) preceding in average of 74 minutes the occurrence of the eruption (EW2) with a reliability rate of 96.5% and no negative false alerts.



Communication workflow



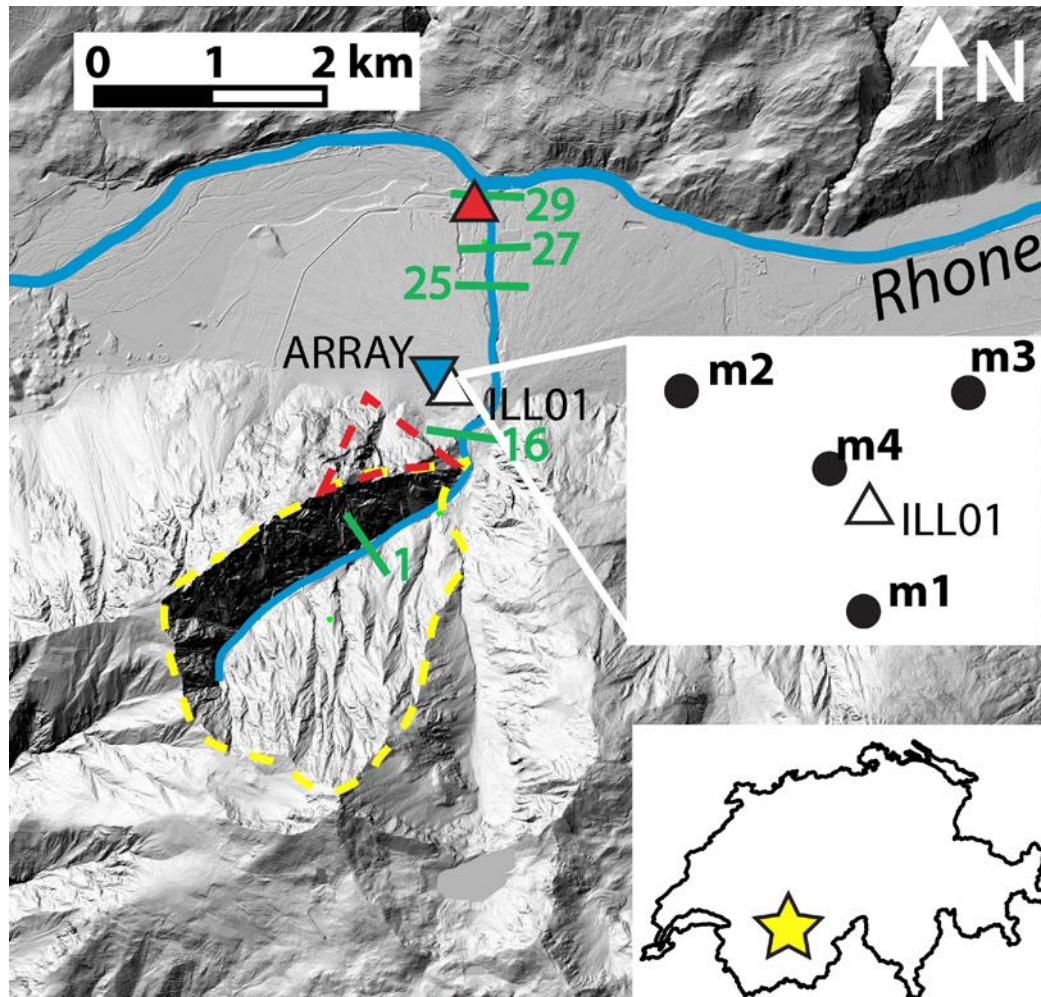
Since 2015 is Operational at Etna volcano providing in automatic and real-time direct notification to local Authorities and allowing the deliver of alerts before the eruption occurs

Conclusions:

- Infrasonic detections are a good tracer of explosive activity
- It can be used as Early-Warning notification for Eruptions
- Efficiency at Etna is 96% and No False Negative Alerts
- The progressive increase of the activity allows 74 minutes of pre-alert
- It can be used as Operative Support to Civil defence Agencies
Civil Aviation, Decision-Makers
- It can be applied with other volcanoes with a similar eruptive style.

....can infrasound be used for other natural hazards?

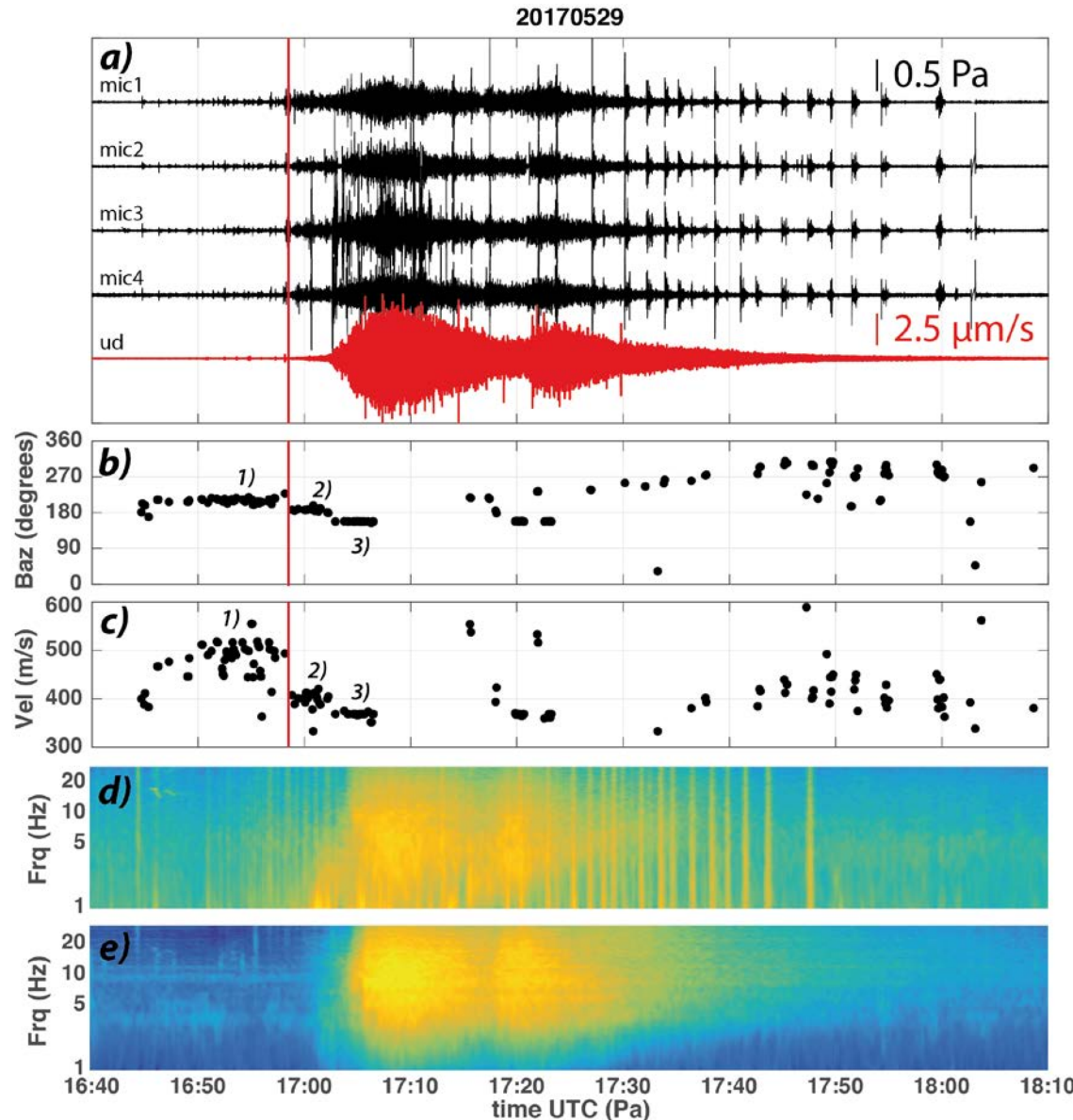
Debris flows - Illgraben



Debris flows - Illgraben

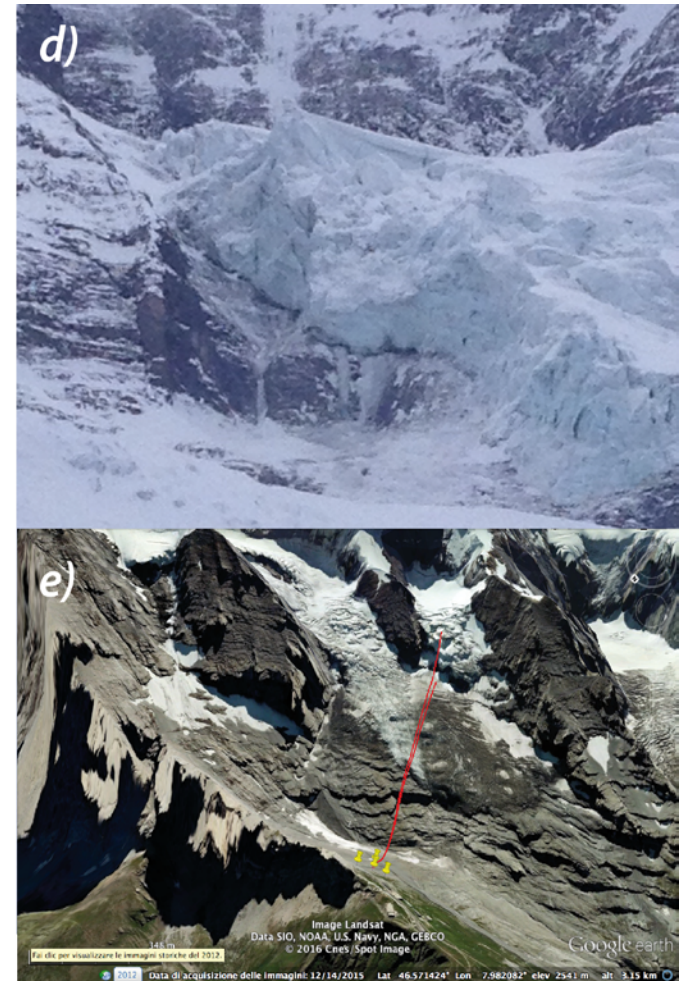
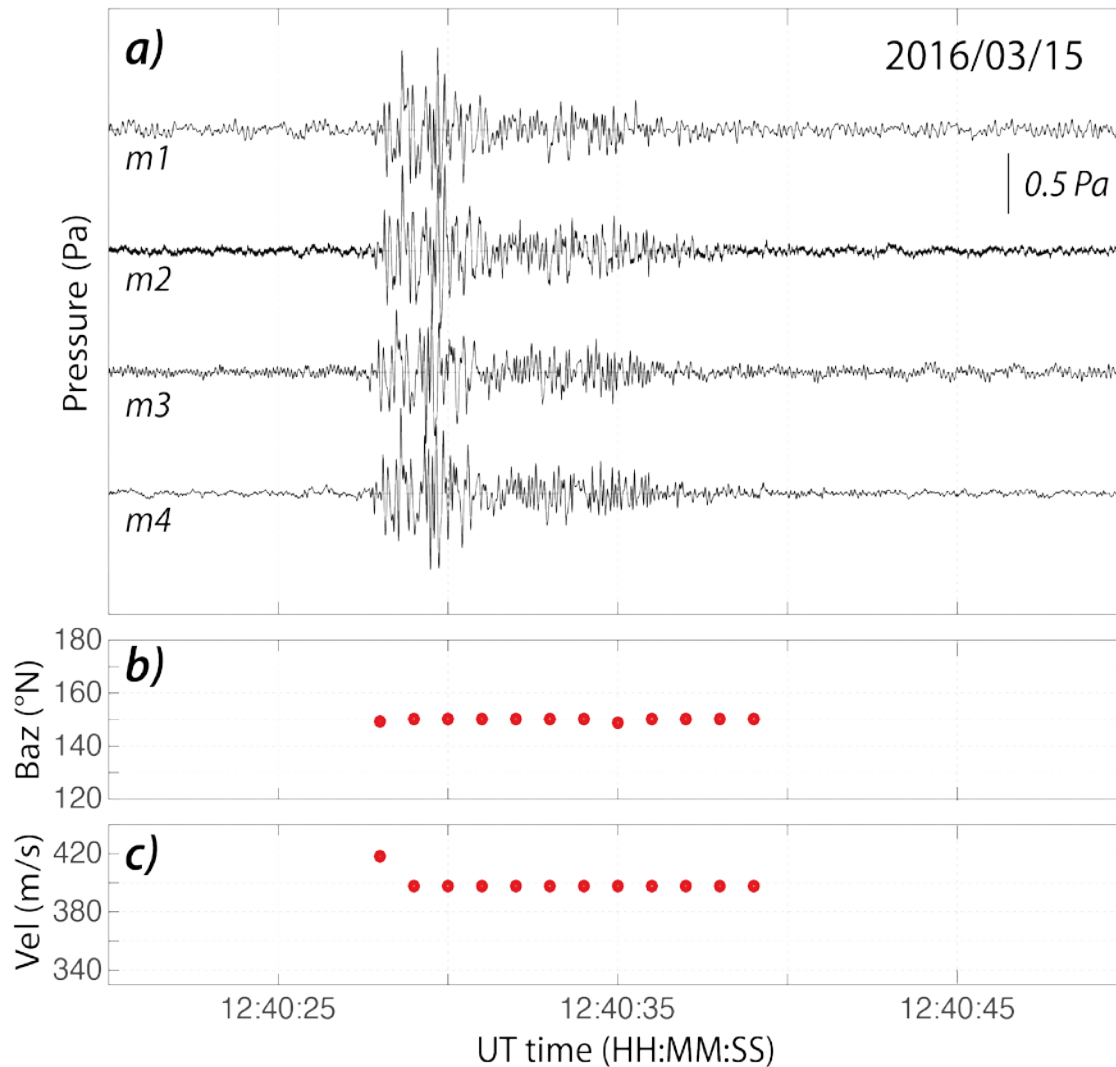


Infrasound radiation by debris flow is highly incoherent, limiting the applicability of xcorr for event detection. Efficiency strongly site dependent.

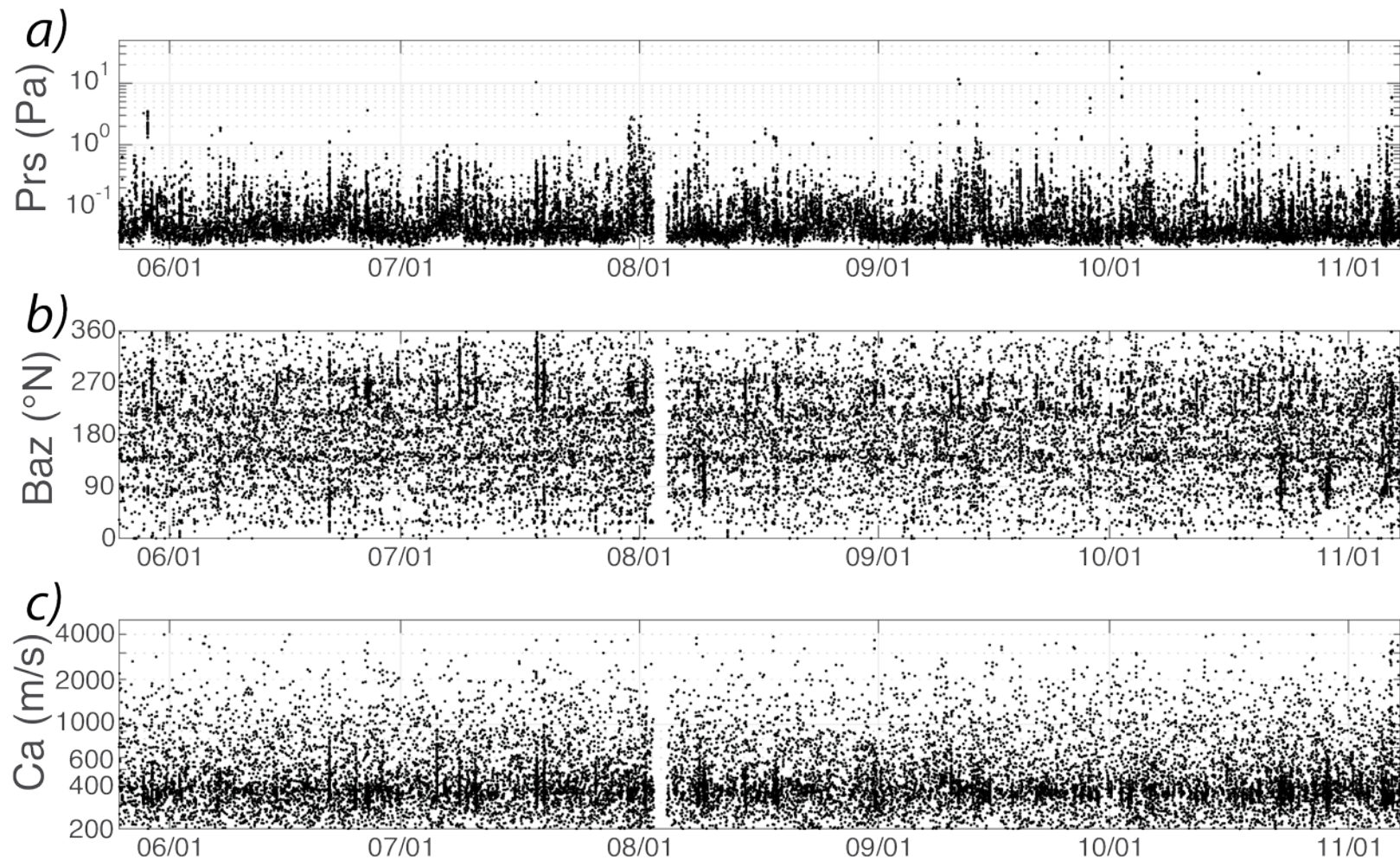


[Marchetti et al., JGR, 2019]

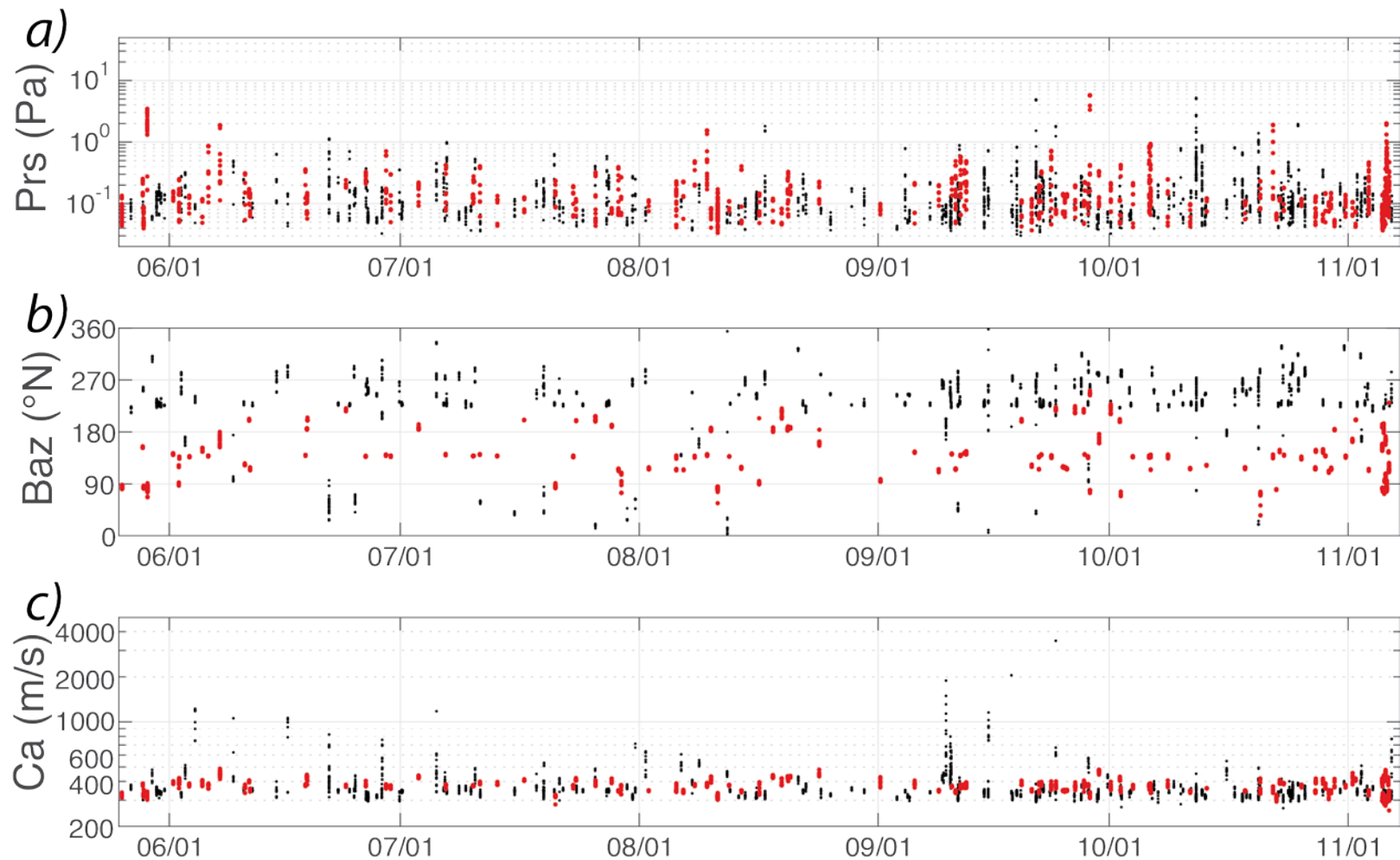
Avalanching Glaciers - Eiger



Collapse detected as sound coming with peculiar wave parameters

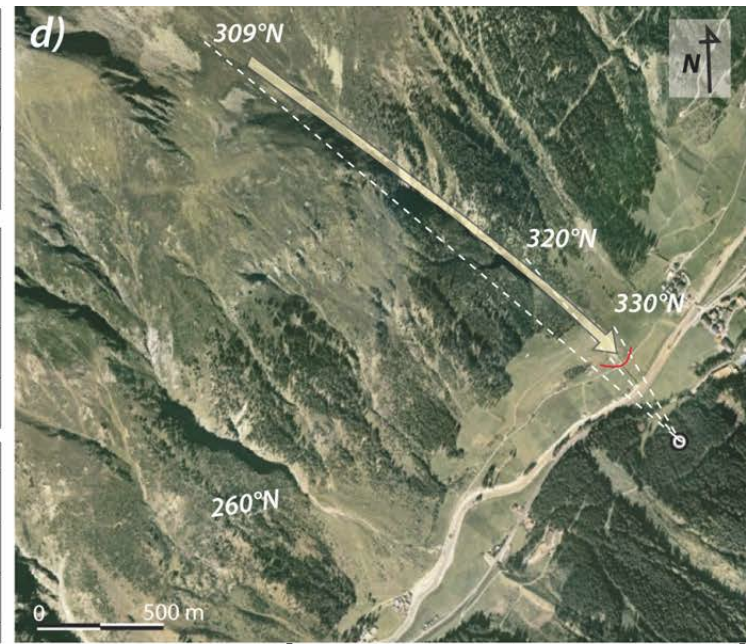
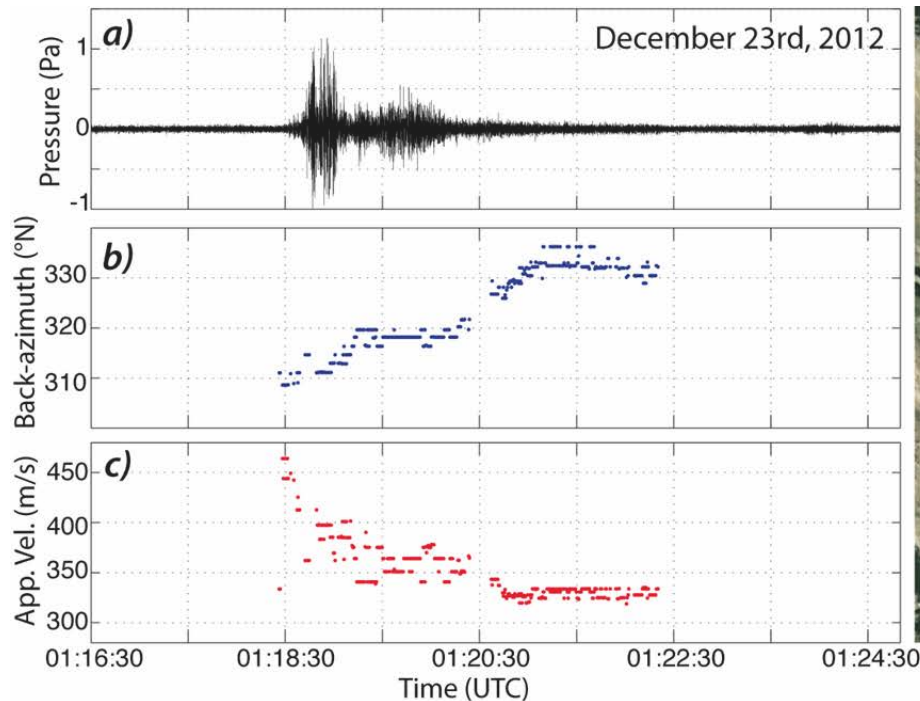


Infrasound signal detected all the time – from multiple sources



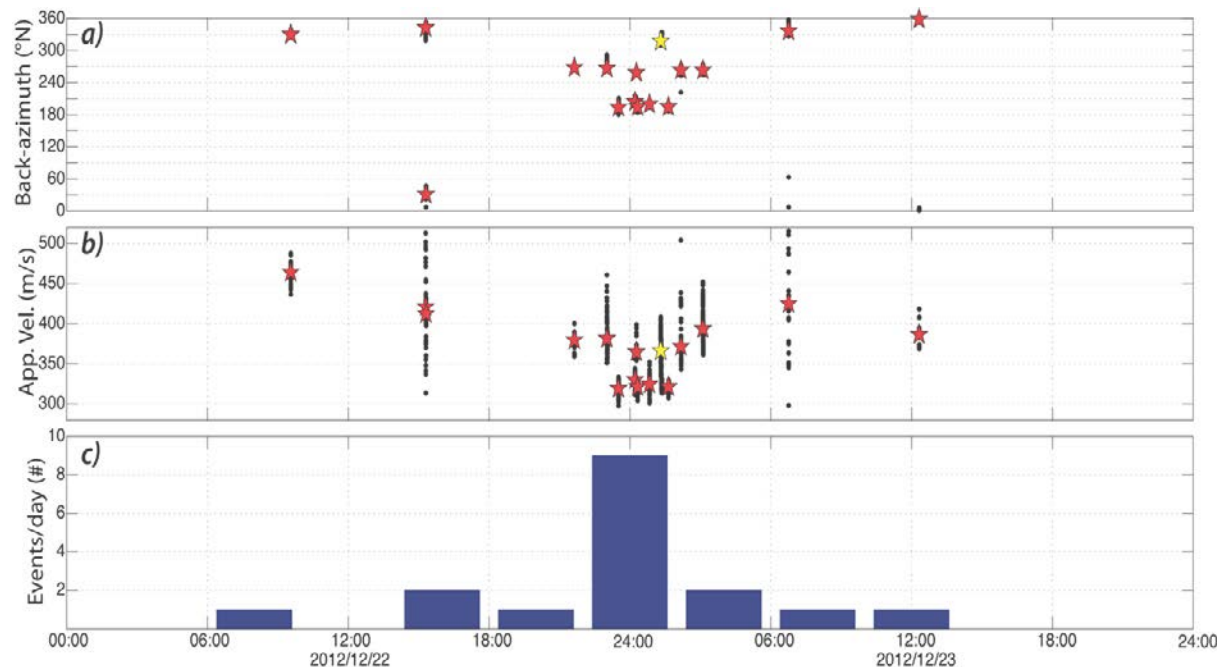
Events compatible with collapsed can be identified and extracted

Snow avalanches are detected as downhill moving sources of infrasound, energy is radiated mostly from the powder cloud.



[Marchetti et al., NHESS, 2015]

Snow avalanches



Infrasound array detection of snow avalanche is very efficient for distances within 2-3 km, much better if inside the valley.

Commercial systems now available sending automatic e-mails and sms.