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FIRENZE

DE LA RECHERCHE À L'INDUSTRIE  
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LGS  
Laboratorio Geofisica Sperimentale

# Infrasound monitoring of active volcanoes at local and regional scale.

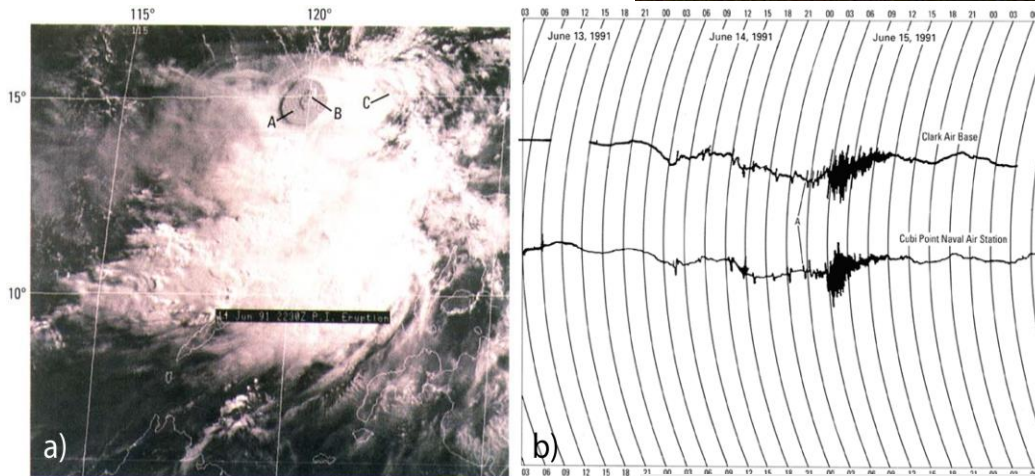
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1. Dept. Earth Sciences, University of Firenze, Italy
2. CEA/DAM, France
3. CTBTO, Austria
4. Toulouse VAAC

**ARISE**

**Atmospheric Dynamic Research Infrastructure in Europe**

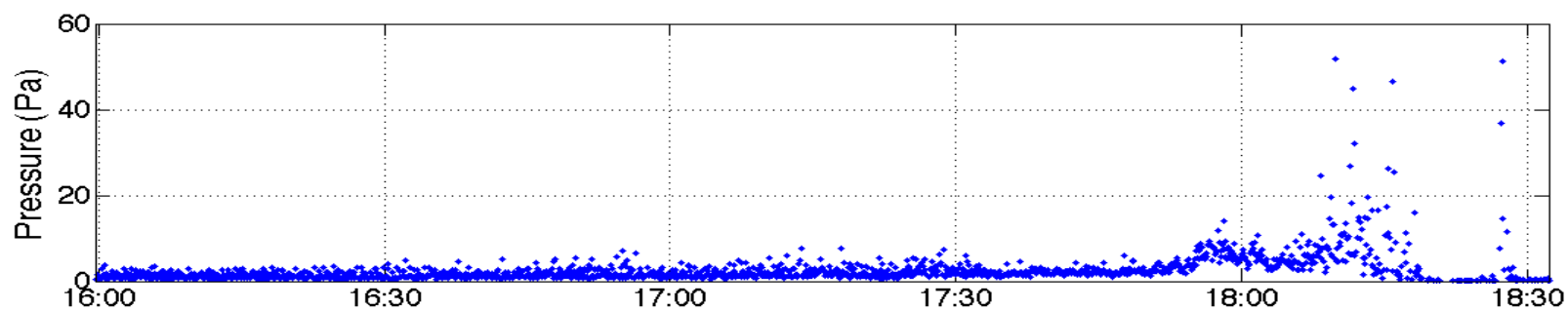
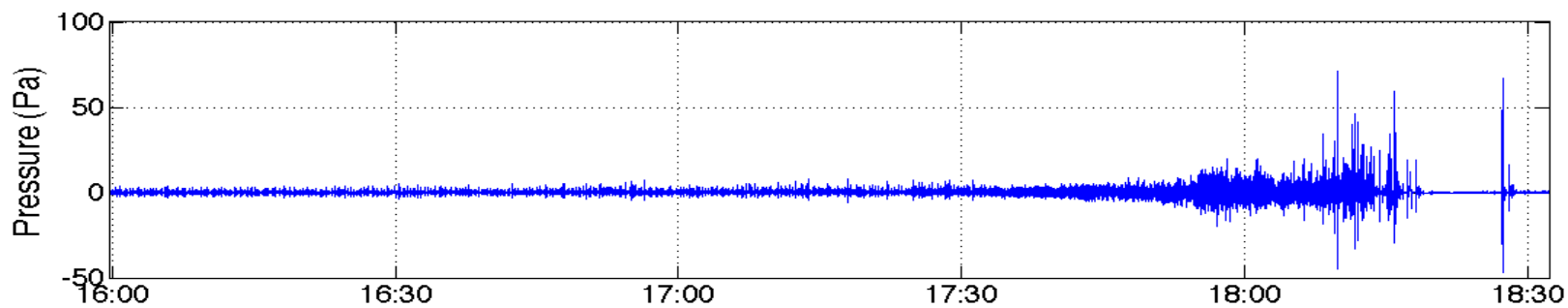


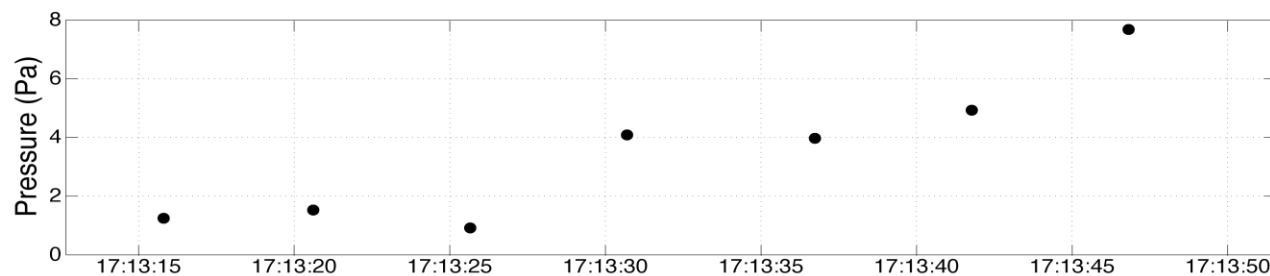
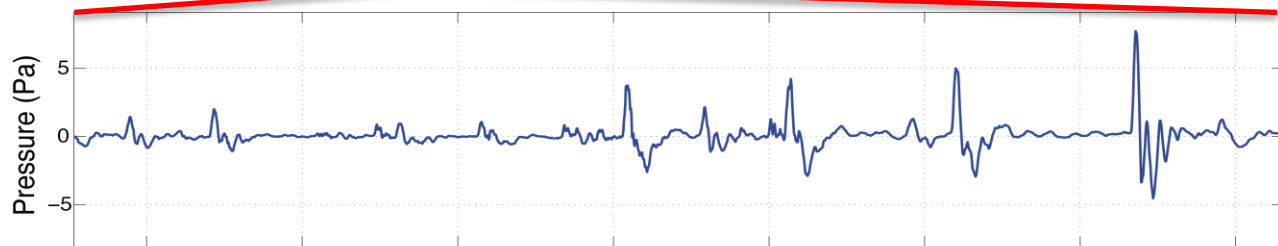
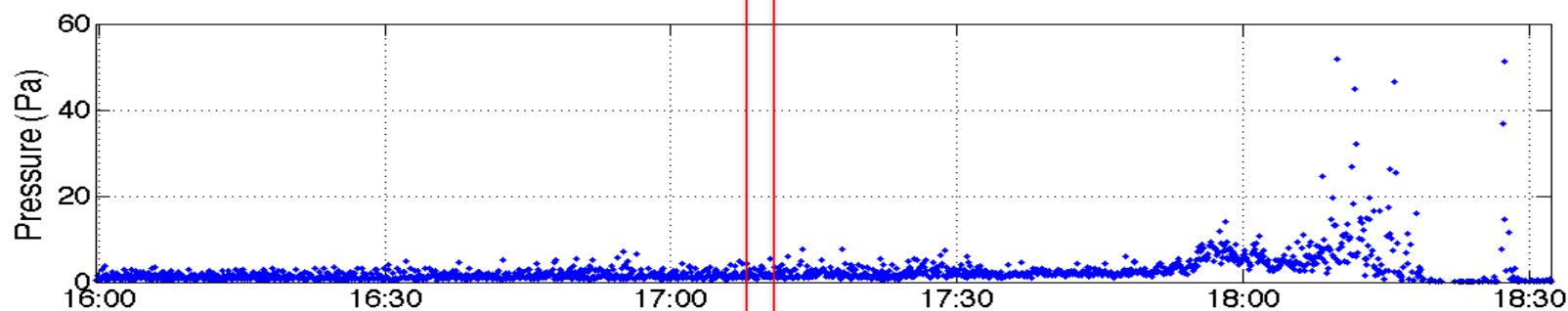
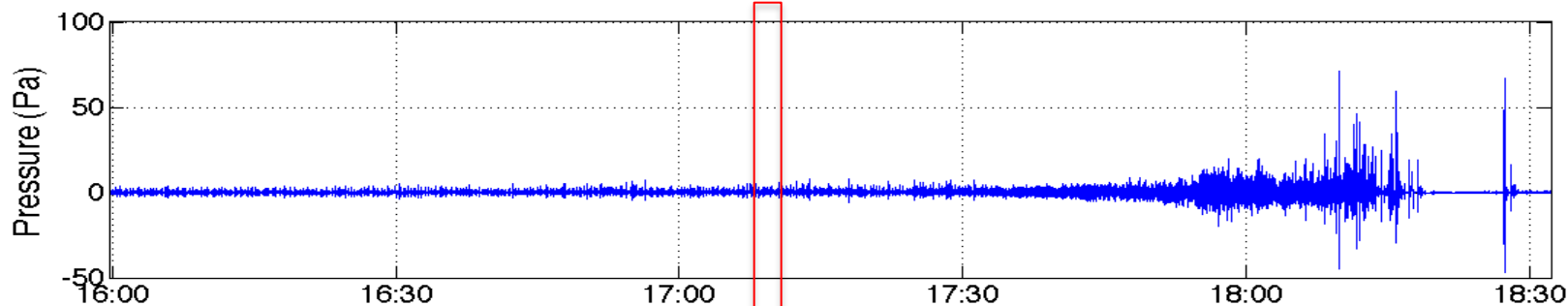


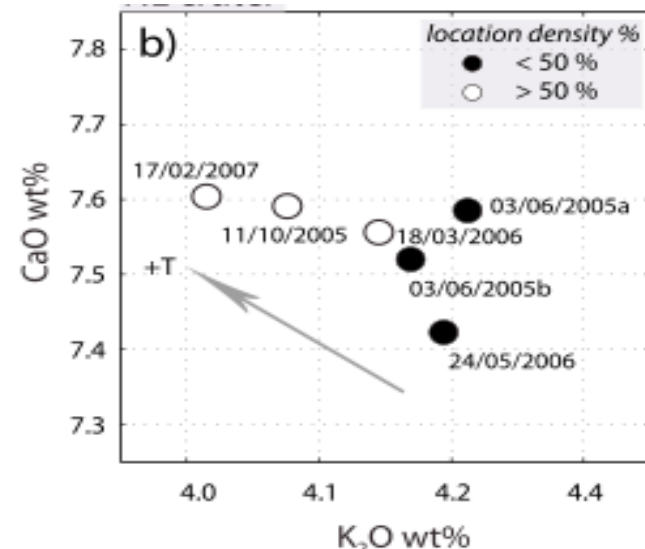
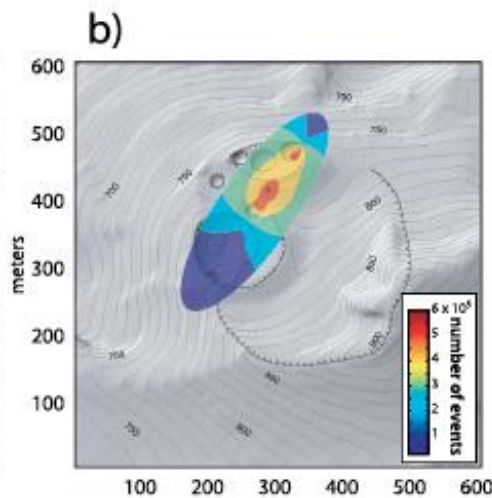
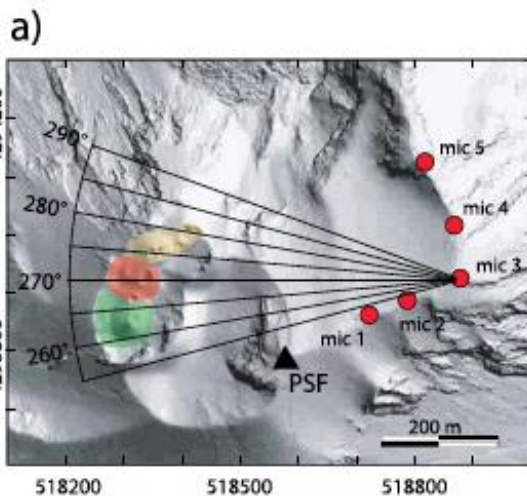
Until late '80 acoustic observations of volcanic activity was mostly limited to far-field barometric record of Major eruptions [Osvald et al., 1996; Makoto et al., 1996]

In early '90 infrasound moved to short range observations on active volcanoes. Now several volcanoes worldwide have permanent infrasound monitoring systems.

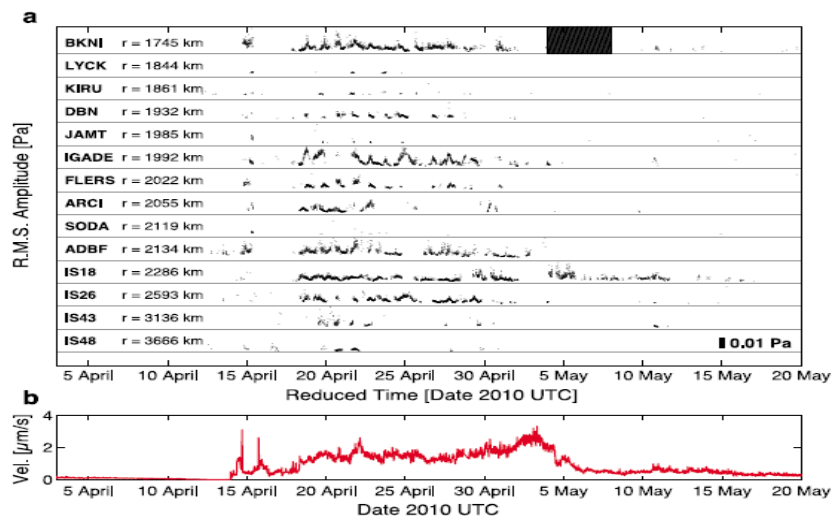
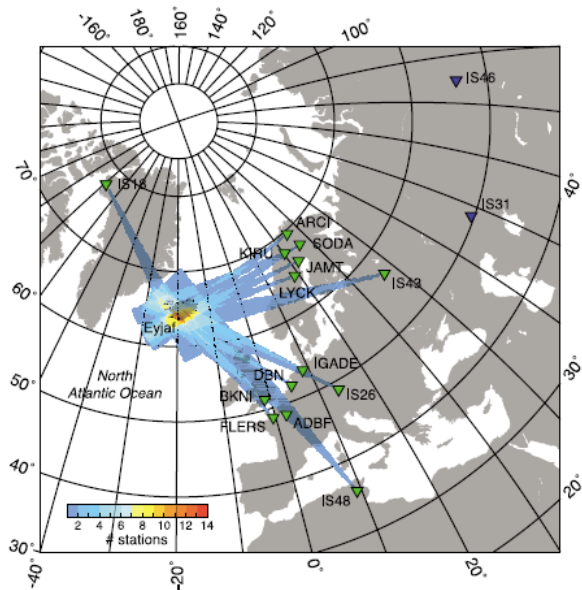








Landi et al., GRL, 2011



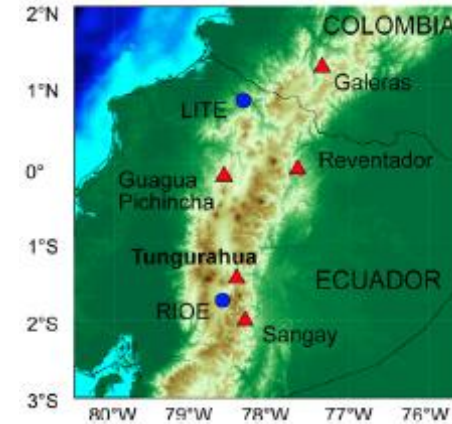
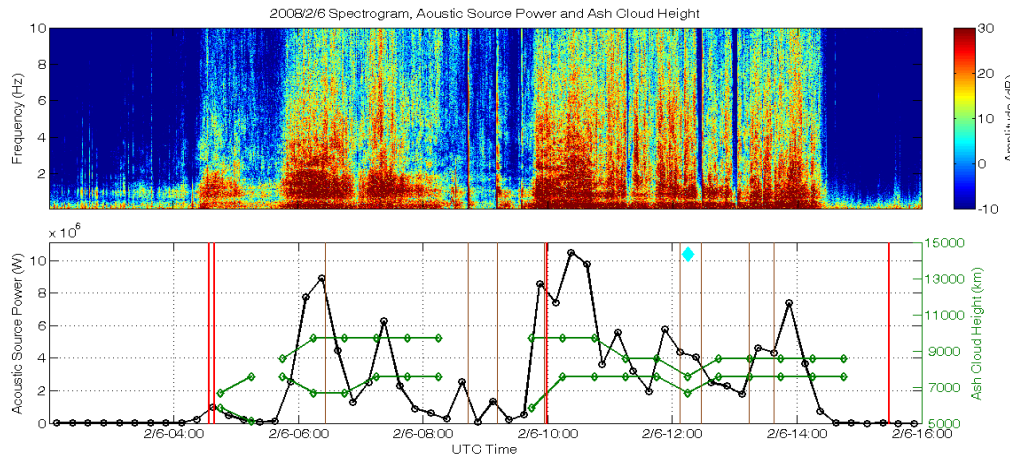
Matoza et al., GRL, 2011



# Operational infrasound monitoring of volcanoes

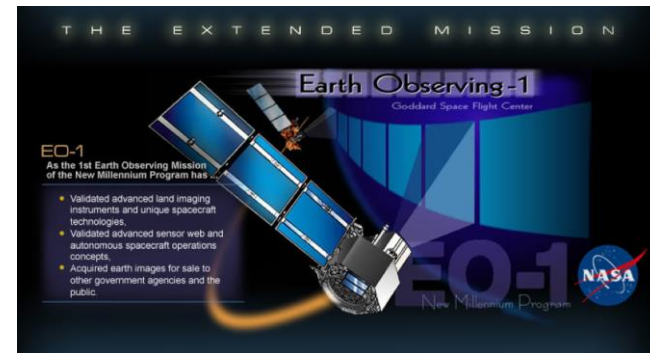
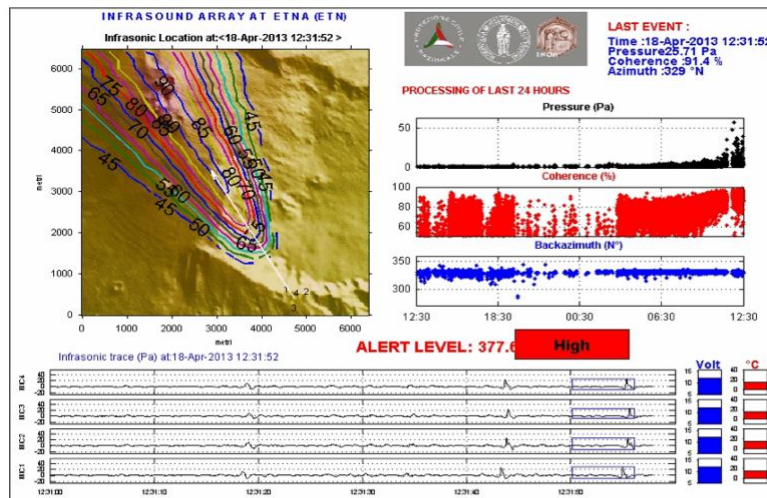
2004-2012: Ecuador

ASHE, M. Garces, ISLA, UH



2007-now: Italy

Volcano System Web (VSW) at NASA  
(<http://lgs.geo.unifi.it/Etna/VSW.txt>)



(Davies et al., 2013)



# Volcano Infrasound Early Warning at Etna

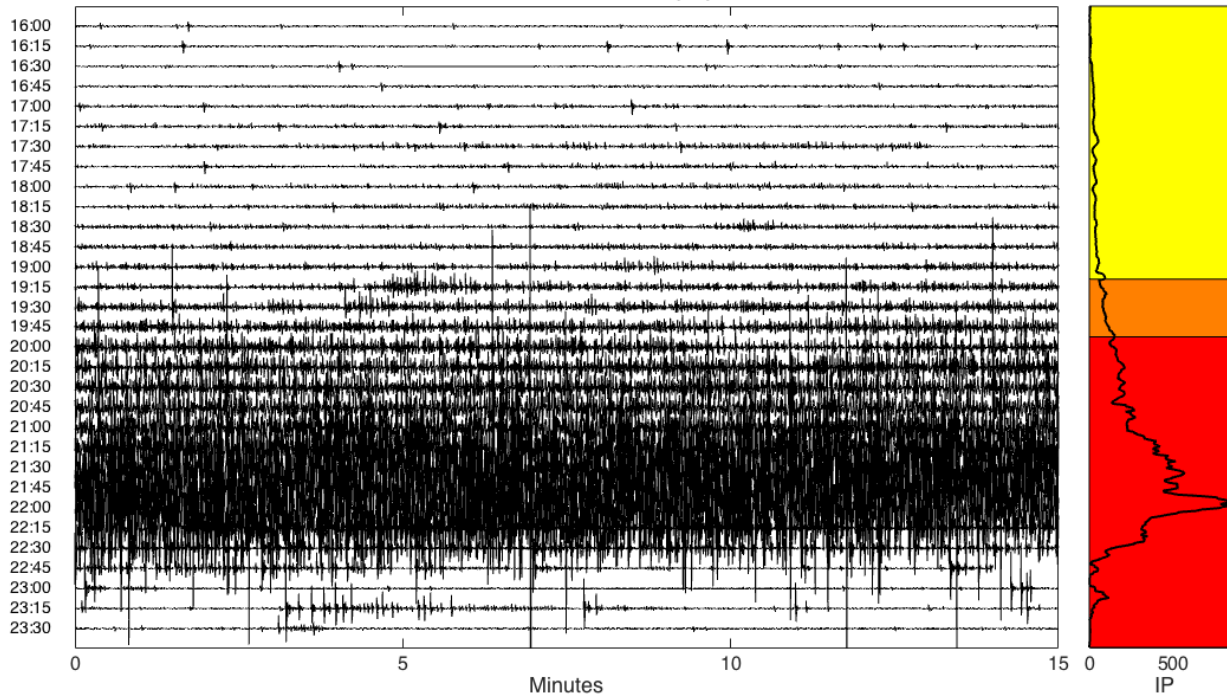
$$IP = N_{det} \times P_m$$

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

$P_m$  = infrasound pressure corrected for attenuation



Etna:02-Dec-2013,shift=5(Pa)

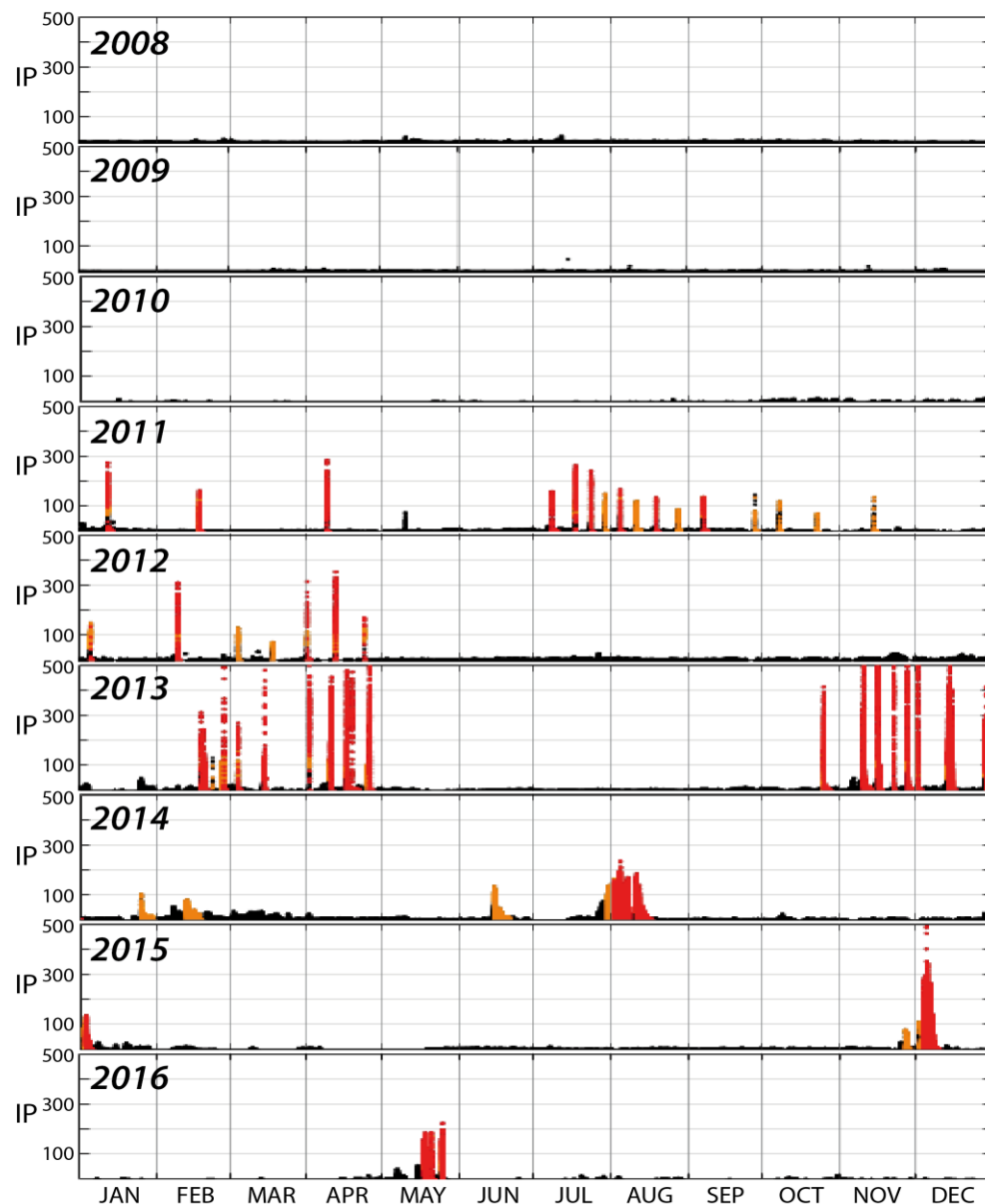
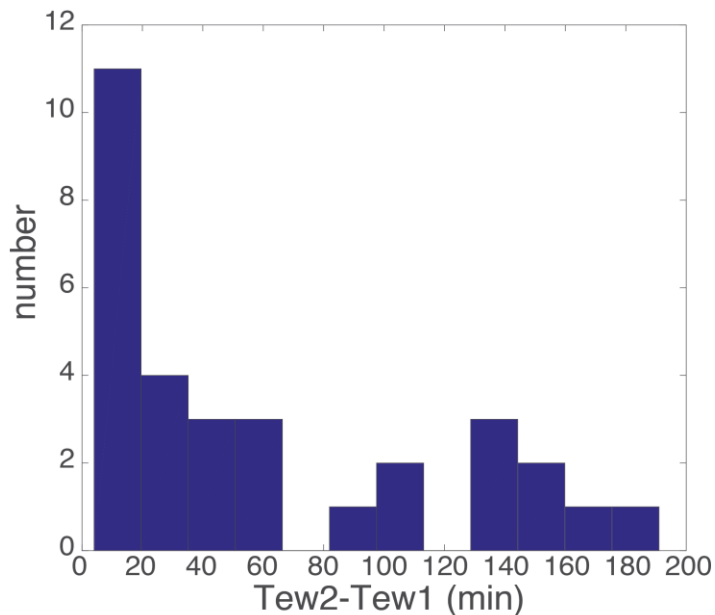


IP > 60 EW1;  
IP > 120 EW2;  
IP < 8 EW0;



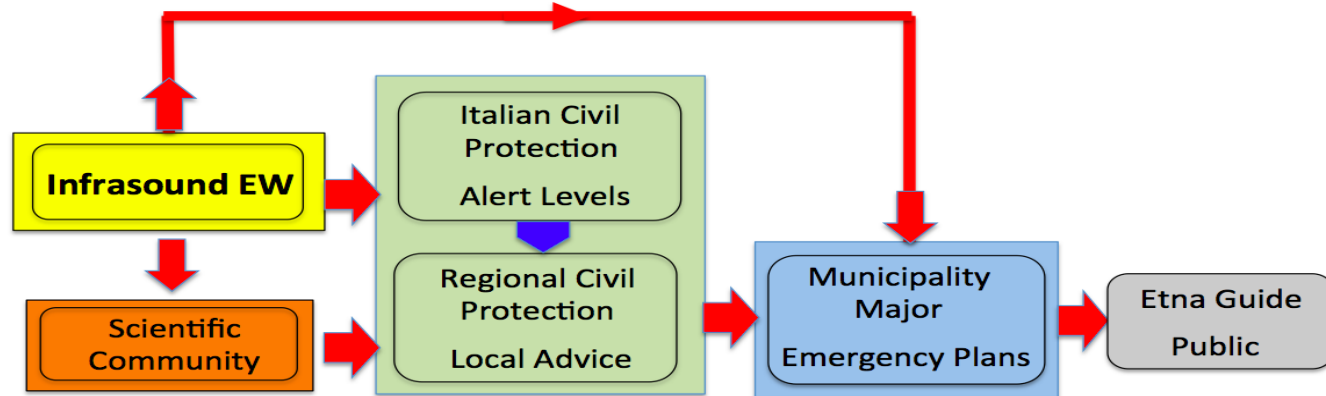


At Etna, infrasound provides a fully automatic early-warning system. In the last 8 years, might have issued pre-alert notifications (EW1) preceding in average of 74 minutes the occurrence of the eruption (EW2) with a reliability rate of 96.5% and no negative false alerts.





# Communication workflow



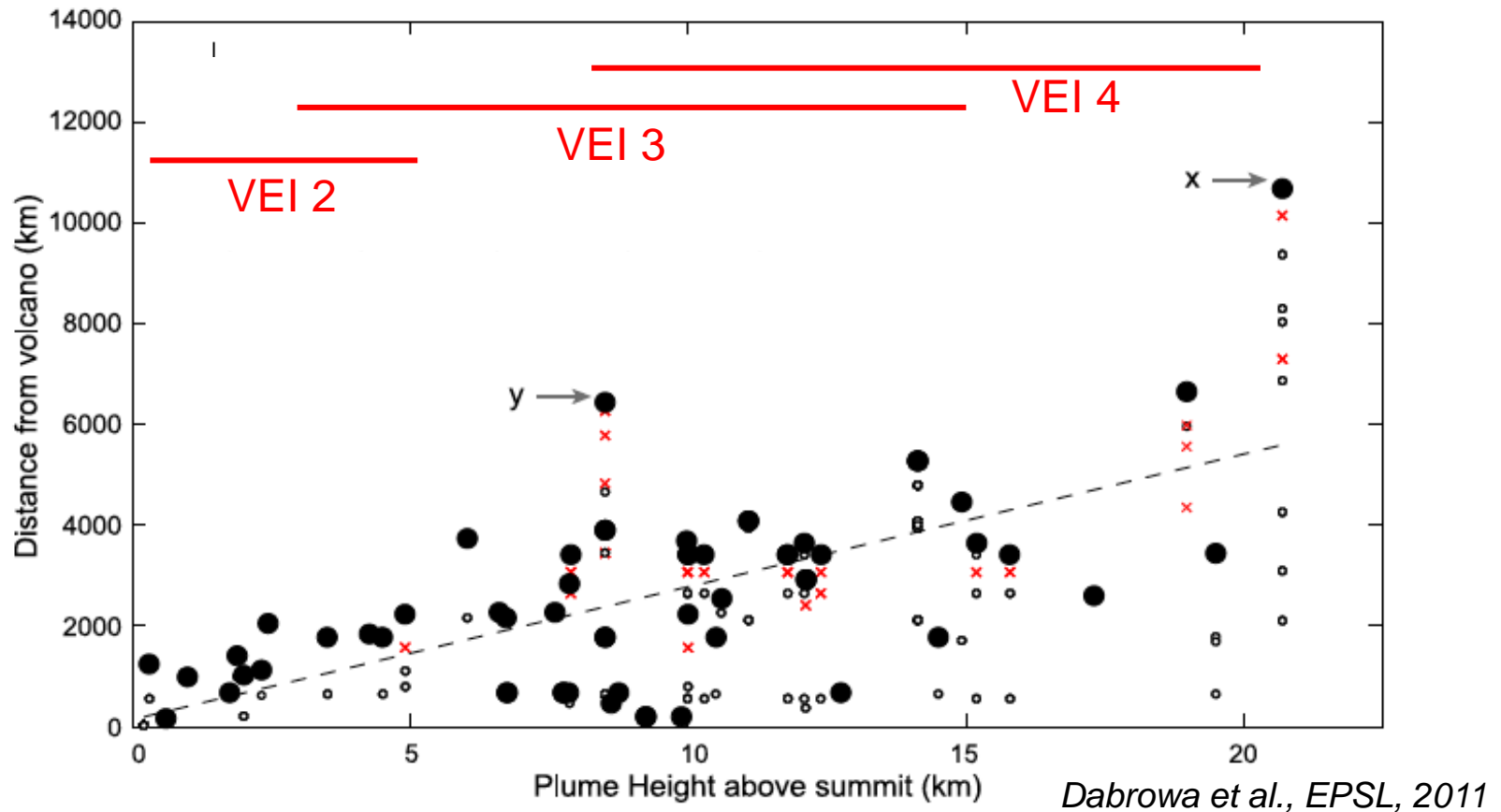
Since 2015 is Operational at Etna volcano providing in automatic and real-time direct notification to local Authorities and allowing the deliver of alerts before the eruption occurs

**Key Points:**

- We present the first example of operational early warning for volcanic eruptions based on automatic and unsupervised algorithms



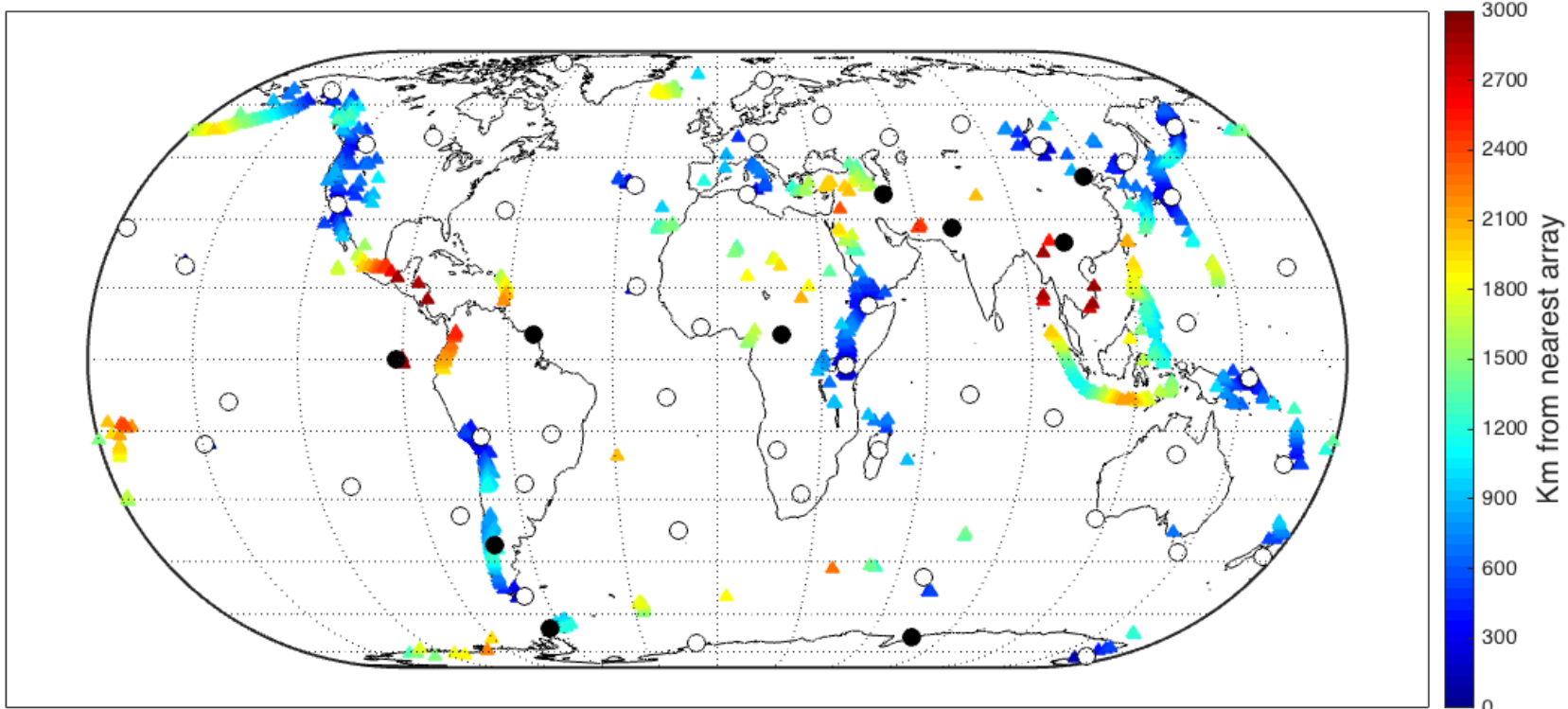
# Infrasound Detections and Plume Height



maximum distance of detection generally increases with the plume height, but eruptions can be undetected



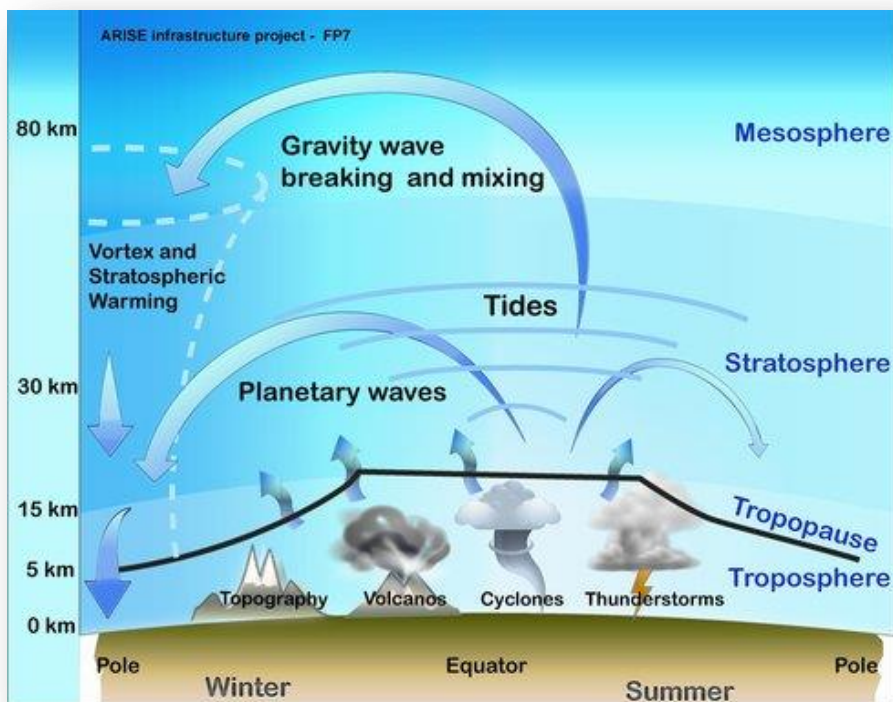
Global distribution of IMS infrasound arrays (white dots certified, black dots planned) and of volcanoes (triangles) that had activity during the last 10000 years.



median distance from any volcano and the nearest IMS infrasound array of 890 km (std 600 km), which results into a mean travel time of  $\sim 50$  minutes.

## arise-project.eu

- Atmospheric dynamics Research Infrastructure in Europe, project funded by EU FP7 (2012-2015) and H2020 (2015-2018) -> integrating activities for starting communities.



1) Combining multiple techniques (infrasound/lidar/airglow/radars) for the study of small scale atmospheric disturbances

2) Monitoring extreme events (affecting the atmosphere)

3) Strong connection with:

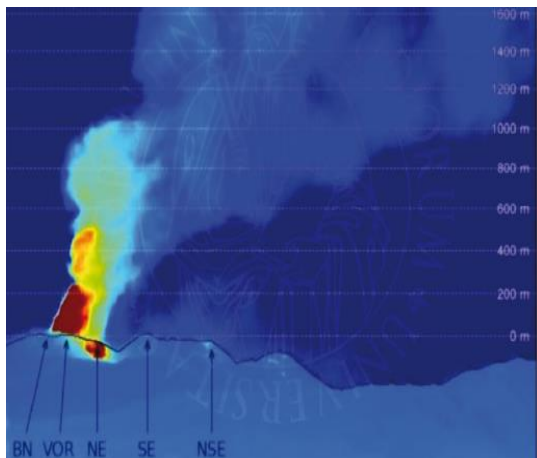


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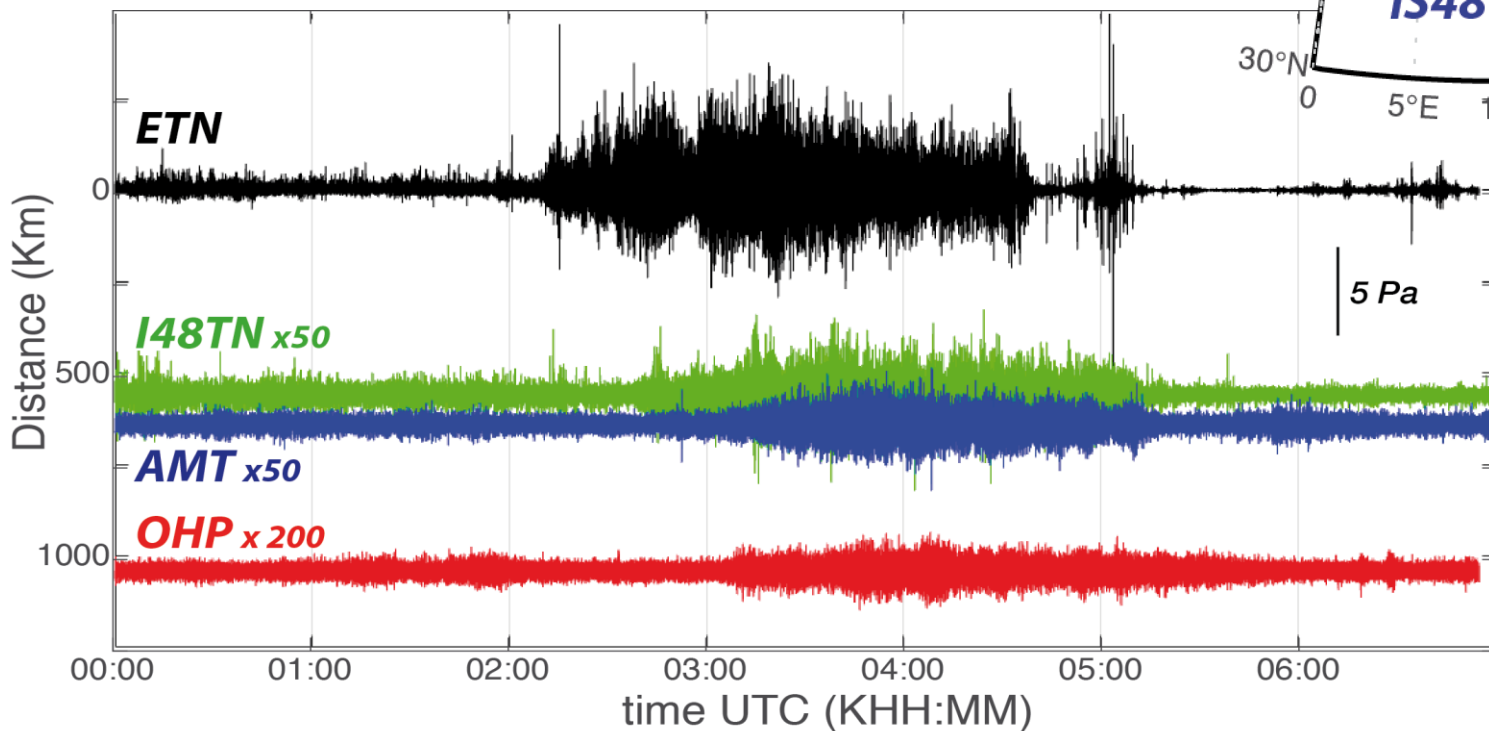
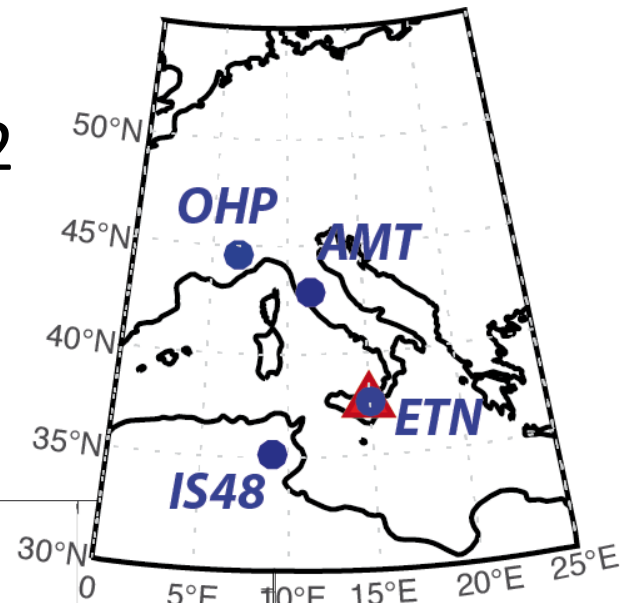




# Etna LF

## May 21<sup>th</sup>, 2016, VEI 2

400-600 m lava column and  
ash plume > several kms



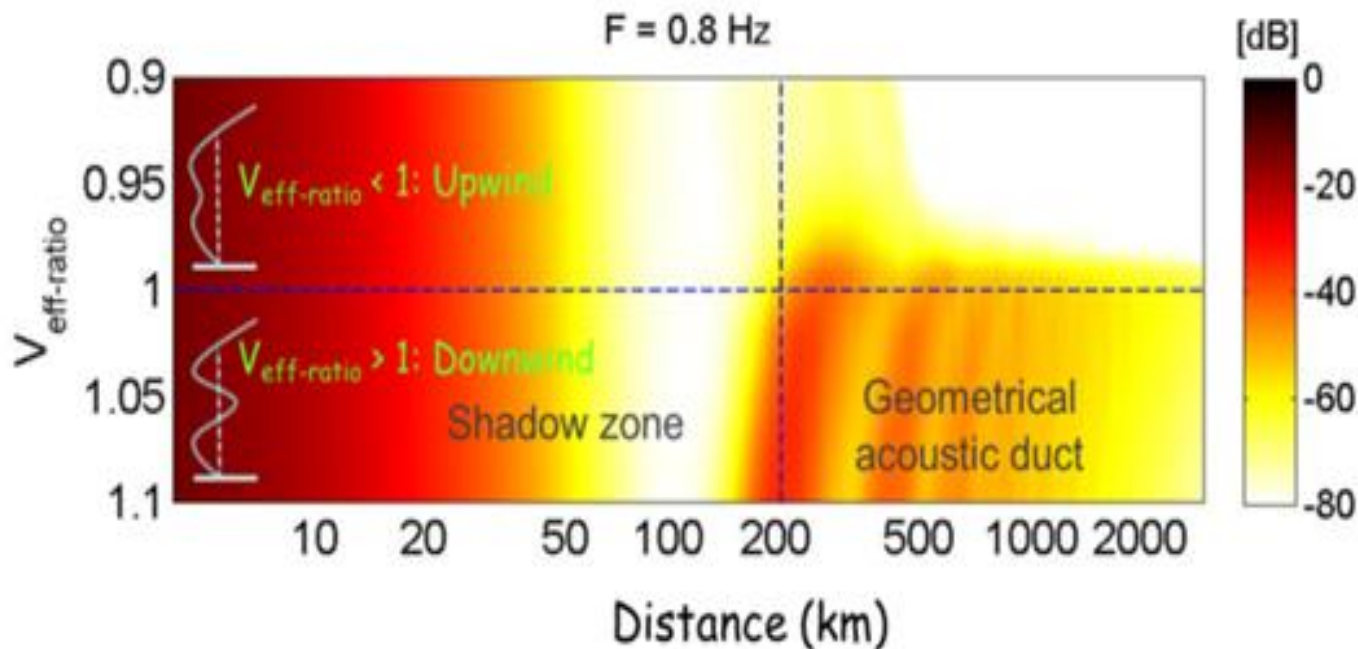


## Accounting for propagation effects

$$Ap(f, V_{eff-ratio}) = \frac{1}{R} 10^{\frac{\alpha(f)R}{20}} + \frac{R^{\beta(f, V_{eff-ratio})}}{1 + 10^{\frac{\delta - R}{\sigma(f)}}}$$

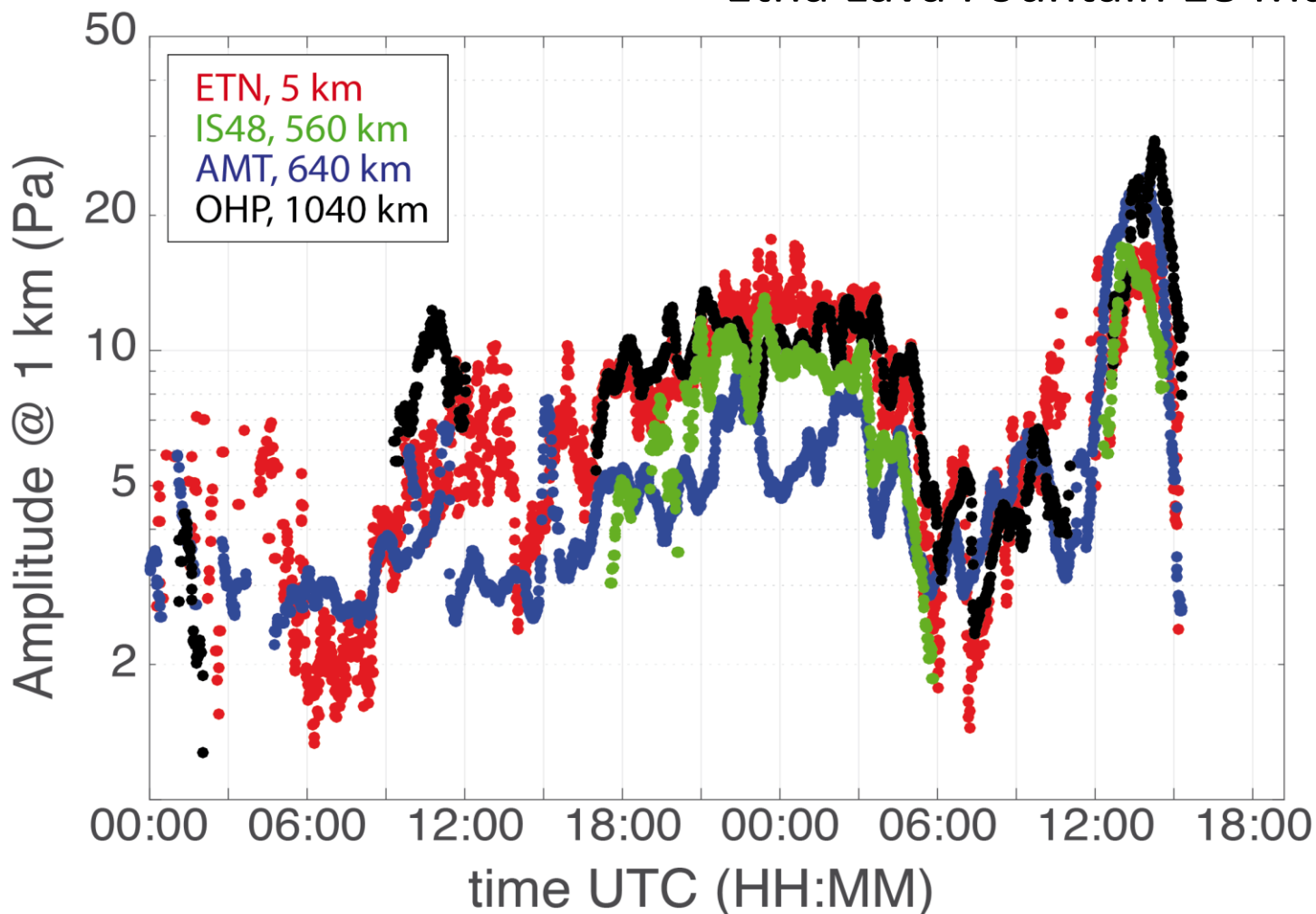
Near-field: geometrical spreading and attenuation decay

Far-field: attenuation in the acoustic duct



We correct for attenuation considering both the frequency of the signal and atmospheric conditions along the path [Le Pichon et al., 2012].

## Etna Lava Fountain 18 May 2016



Once corrected for attenuation the pressure time history can be reconstructed even from stations located hundreds of km far from the source.



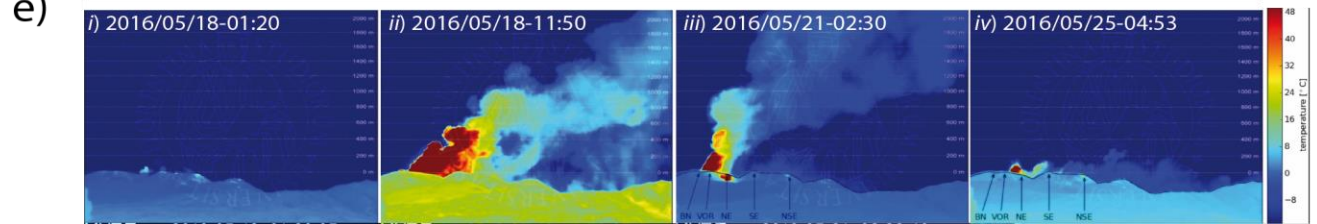
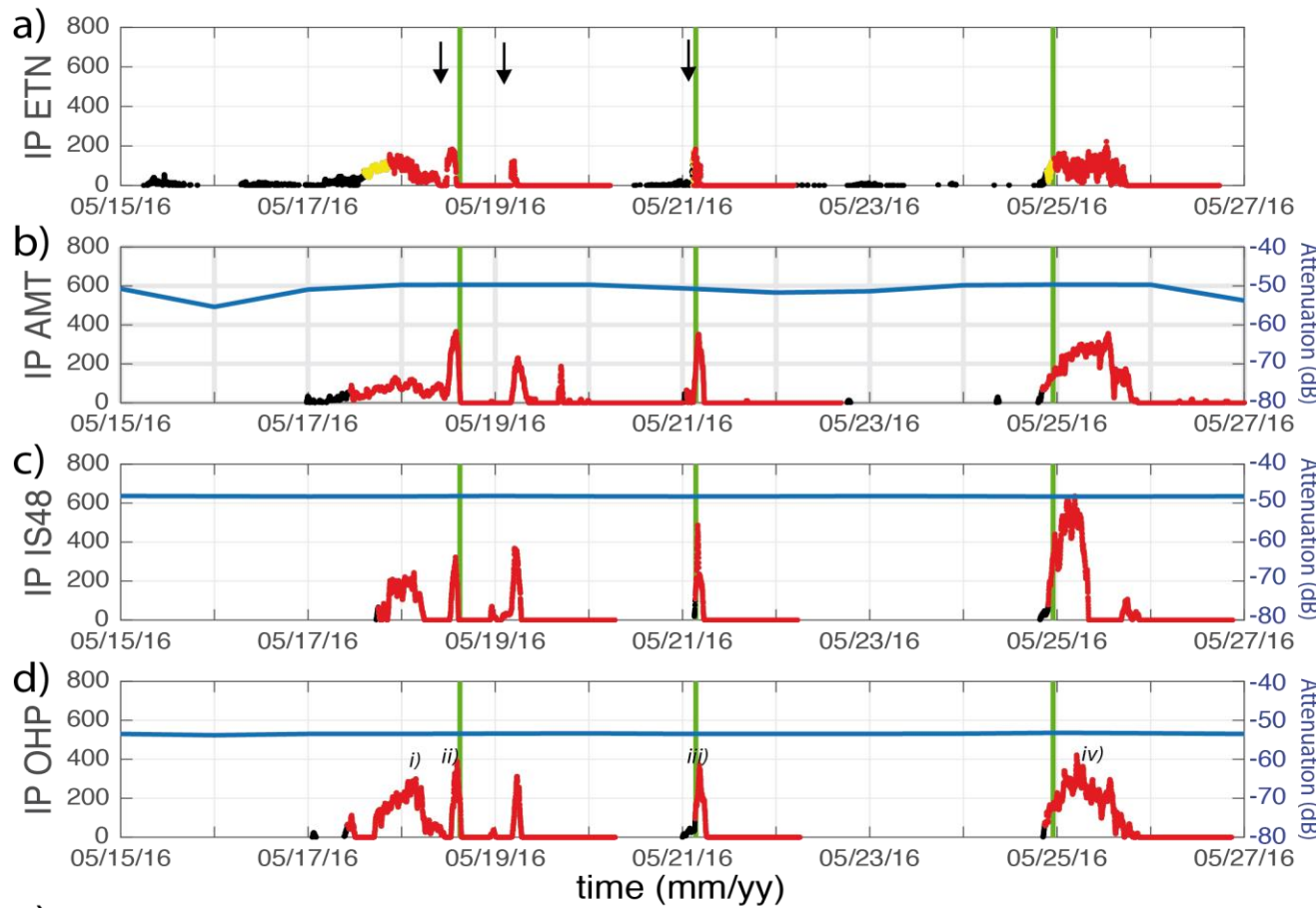
# Early warning from regional observations (VIEW)

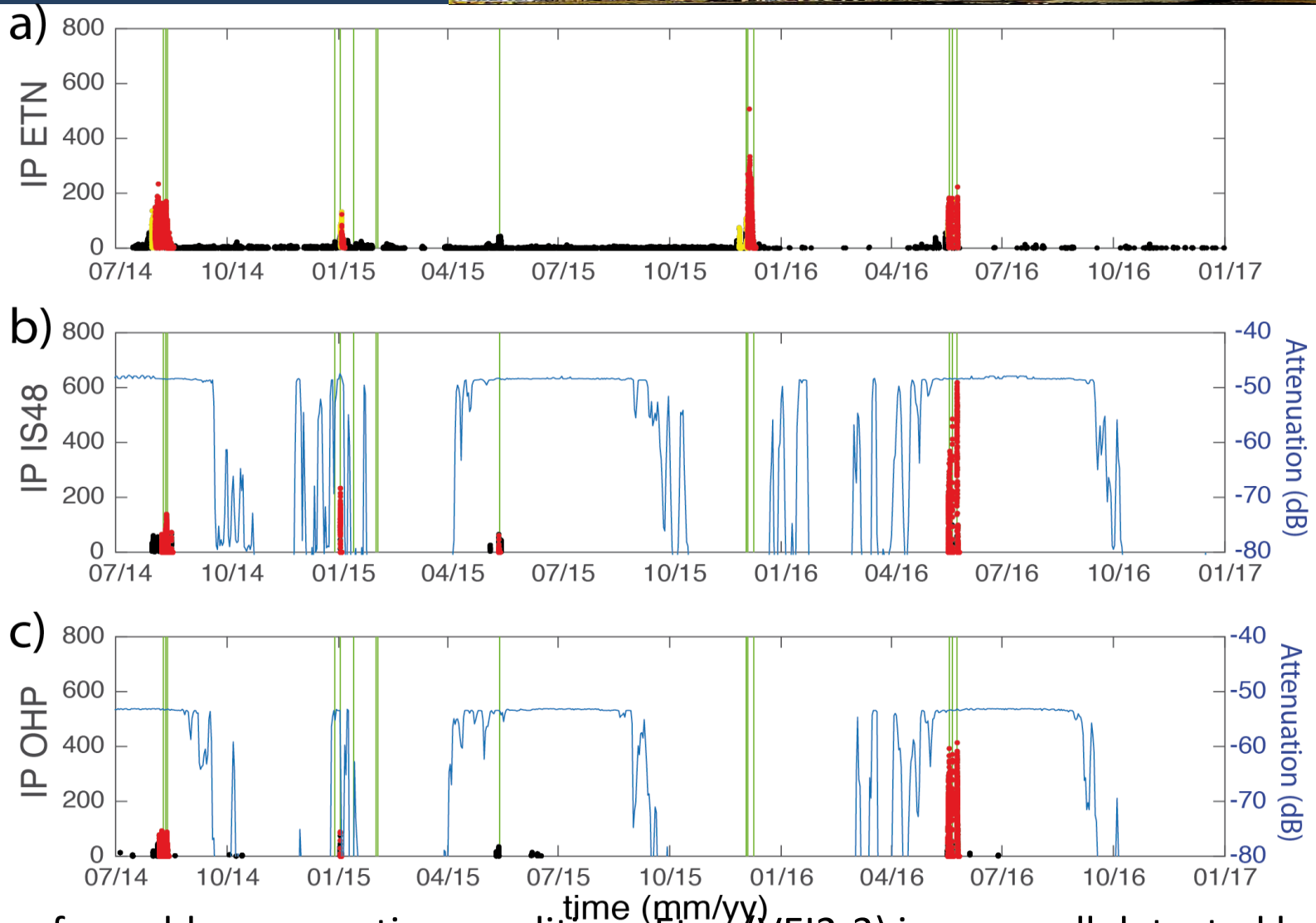
$$IP = N_{det} \times Pm$$

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

$Pm$  = infrasound retrieved @ 5 km

$IP > 60$  EW;  
 $IP < 8$  EW0;





During favorable propagation conditions Etna (VEI2-3) is very well detected by regional infrasound arrays and based the IP an automatic alarm could be delivered.



## Conclusions

1. Local ( $< 10\text{-}20$  km) infrasound arrays can be used operationally for volcano monitoring and provide notification.
2. During favorable propagation conditions Etna ( $\text{VEI} \leq 2$ ) eruptions are very well detected by regional infrasound arrays.
3. Regional infrasound observation still valuable in terms of timing for VAACs.
4. VIEW (single array) can be adapted to various source-to-receiver distances