



# Comparative near-field and far-field studies using IMS infrasound data

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The **IMS Infrasound Network**, ensuring compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT), consists of 60 infrasound monitoring stations, of which **49** (i.e. the **90%** of the network) are already **operational**. This network has provided the infrasound community, in the last two decades, with an amount of information about natural and man-made sources without precedent.

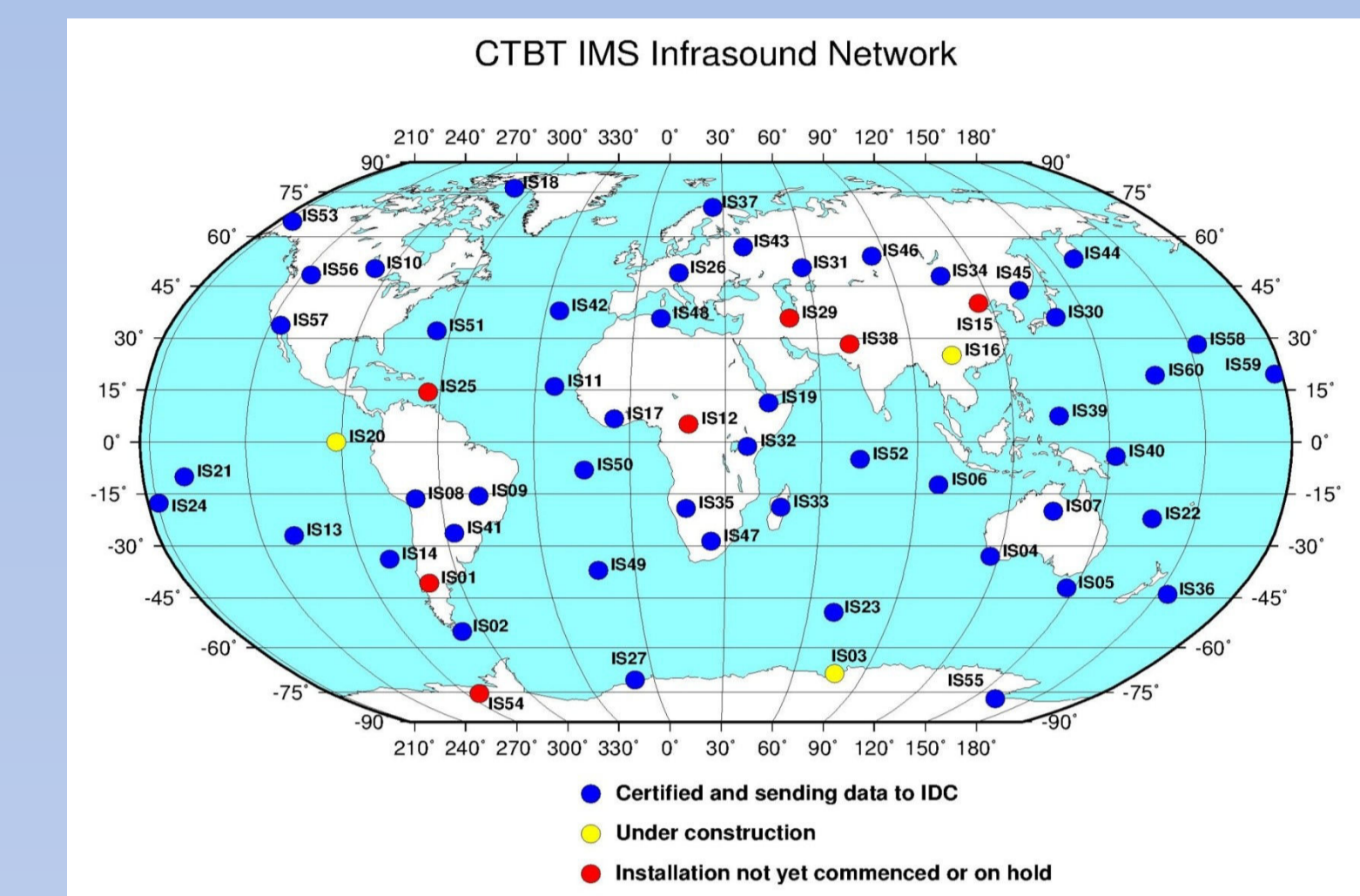
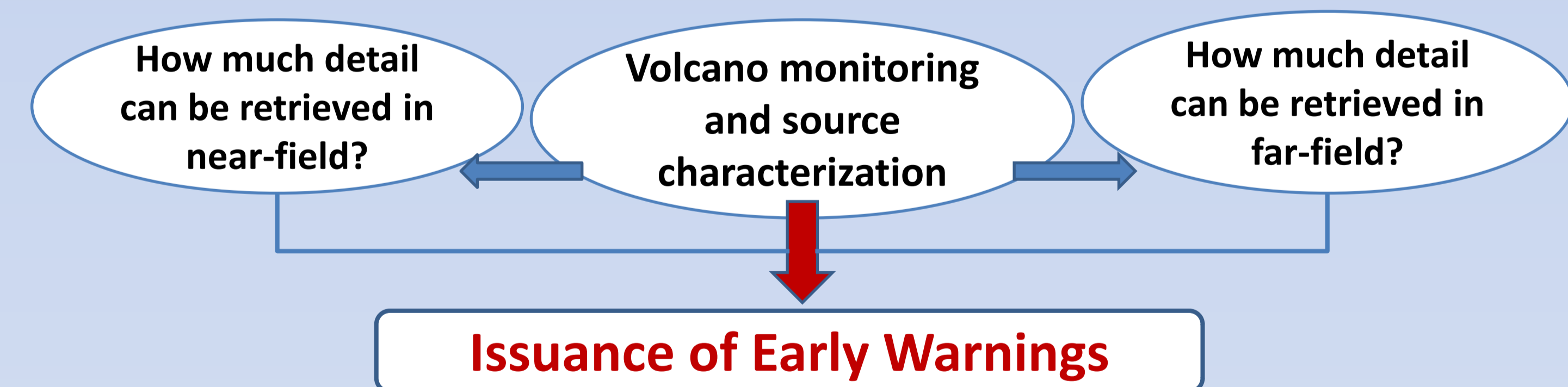


Fig. 1: Current status of the IMS Infrasound Network: of the 60 planned stations, 49 (blue dots) are operational and sending data to the International Data Centre (IDC) in Vienna. Other 3 stations (yellow dots) are under construction. For the remaining stations, along with the station whose location has 'to be determined' (TBD) the construction has not yet started (red dots).

Infrasound technology gained in the course of the last two decades a key role in monitoring several natural and man-made events, highlighting how much information about the source, as well as about the source-to-station path can be embedded in an infrasound signal. A **key question** arises from infrasound observations: **is the source information retrieved in near-field still embedded and retrievable also from signals recorded in far-field?**

To answer this question has not only **important implications** for the assessment of the source characterization in far-field, but also, in specific cases, for the **issuance of early warnings in the framework of Disaster Risk Reduction (DRR)**.

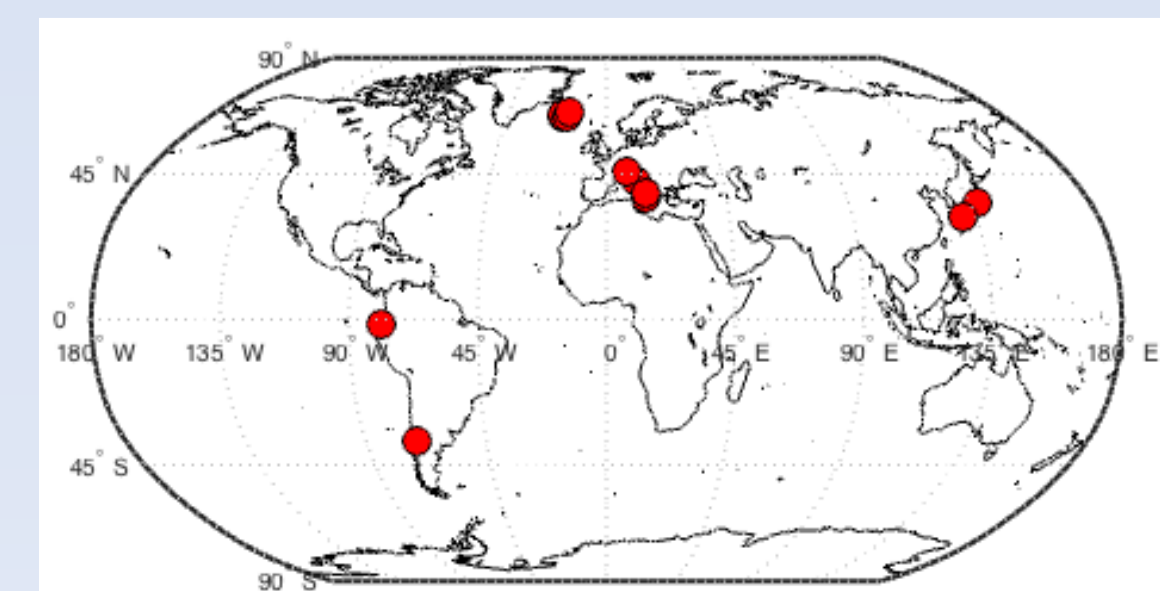
This concept applies in particular, but not exclusively, to **volcano monitoring**: the understanding of all the source phenomena preceding an eruption might play a special role in the **management of early warnings**, and would help **mitigate the impact on population, aviation and goods, increasing resilience**.



In the last decade, in parallel with the development of the IMS Network, several research groups have established local infrasound networks, (permanent and portable arrays). The Department of Earth Sciences of Florence University (**UniFI**), Centre of Competence for Volcano Monitoring and Research of the Department of Civil Protection, **performs since 2003 real-time monitoring of Etna and Stromboli volcanoes (Southern Italy)**. For infrasound technology UniFI operates:

- 2 small-aperture arrays on Etna
- 1 small-aperture array on Stromboli
- 1 large-aperture array at Mount Amiata (Central Italy, ARISE Project)
- 3 small-aperture arrays for avalanches monitoring (North-West Italy)
- 2 small-aperture arrays in Japan (Asama and Sakurajima volcanoes)
- 4 small-aperture arrays in Iceland
- 1 small-aperture array in Ecuador
- 1 small-aperture array in Argentina

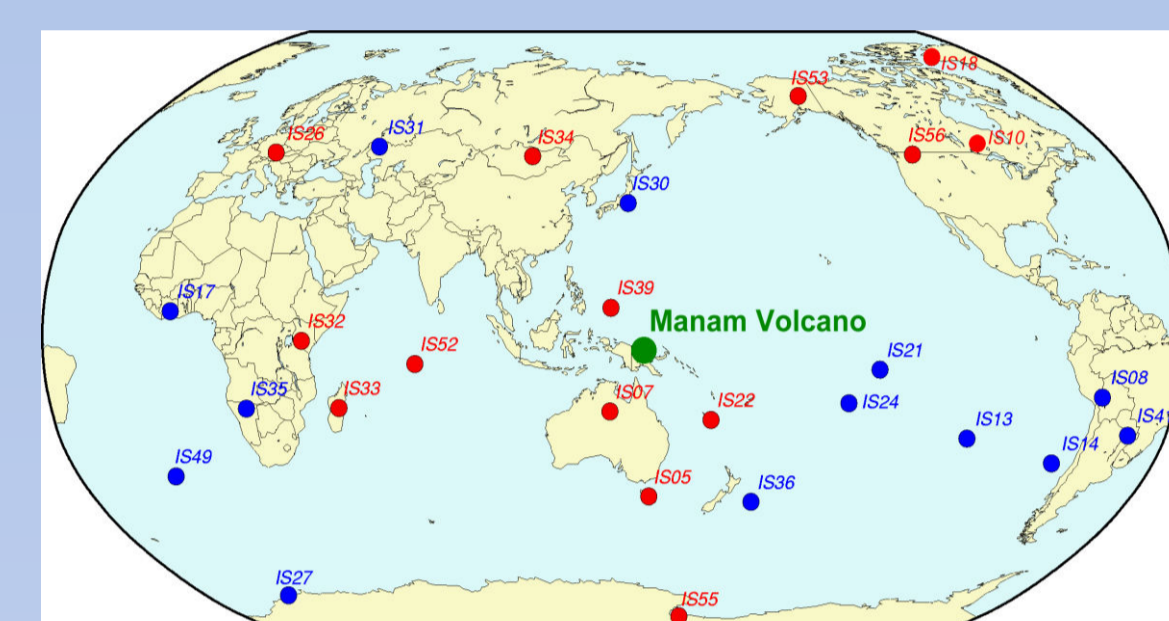
Fig. 2: The infrasound arrays operated by UniFI around the world



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## Detection of volcanic eruptions and the IMS Infrasound Network

The **IMS infrasound network** is designed to **detect, once completed, nuclear explosions with equivalent yield of 1kT or more all around the globe**. The **1kT yield corresponds to small to moderate eruptions** (with a Volcanic Explosivity Index, VEI, value about 2): this highlights the **great potential of the IMS Network for volcano monitoring**. A number of IMS infrasound stations have demonstrated to be instrumental not only for the worldwide detection of volcanic eruptions (e.g. Manam 2005 eruption, Fig.3), but also for the identification, on more local scale, of distinct volcanic eruptions occurring simultaneously and with little backazimuthal variation (Fig.4a, 4b).



Station	Distance	Frequency	Comment
IS39 Palau	1738 km	0.4 - 2.0 Hz	Good high-frequency signal.
IS07 Warramanga	2103 km	0.4 - 2.0 Hz	High signal-to-noise ratios.
IS22 New Caledonia	3086 km	0.05 - 0.1 Hz	Dominated by long-period signals.
IS05 Hobart	4261 km	0.01 - 0.1 Hz	Long-period signals only. High signal-to-noise ratio.
IS14 Mongolia	6914 km	0.05 - 0.1 Hz	Relatively poor detection.
IS52 Diego Garcia	8040 km	0.05 - 0.1 Hz	Signal obscured by noise.
IS55 Windless Bight	8286 km	0.03 - 0.1 Hz	Good long-period signal.
IS51 Fairbanks	9358 km	0.03 - 0.1 Hz	Good long-period signal.
IS33 Madagascar	10653 km	0.008 - 0.1 Hz	Good long-period signal.
IS08 Newport	10927 km	0.05 - 0.1 Hz	Good long-period signal.
IS18 Qaanaaq	11604 km	0.05 - 0.1 Hz	Marginal detection.
IS12 Kenya	12032 km	0.05 - 0.1 Hz	Weak, but clear detection.
IS10 Lac de Bonnet	12383 km	0.05 - 0.1 Hz	Very weak signal - marginal.
IS26 Freyung	13257 km	0.05 - 0.1 Hz	Weak, but clear detection.

Fig. 3: Manam eruption on 2005/01/27: the IMS stations which detected the eruption, their distance from the source and some indication about the quality of the detected infrasound signals (Campus et al., 2005).

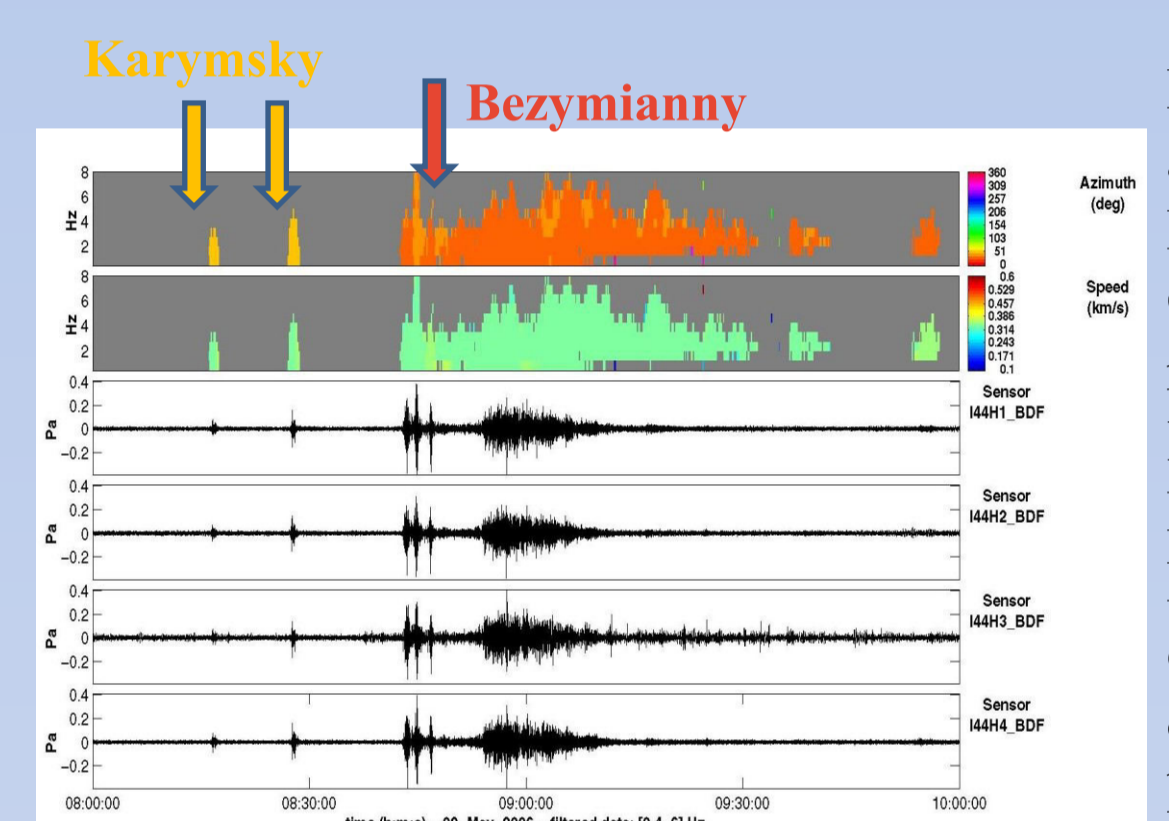


Fig. 4a: Infrasound signals analyzed using the Progressive Multichannel Correlation method and recorded on 2009/05/09 at IS44, Petropavlovsk-Kamchatskiy, Russian Federation: Two distinct eruptions, not visible using other observation systems have been identified (Campus and Christie, 2010)

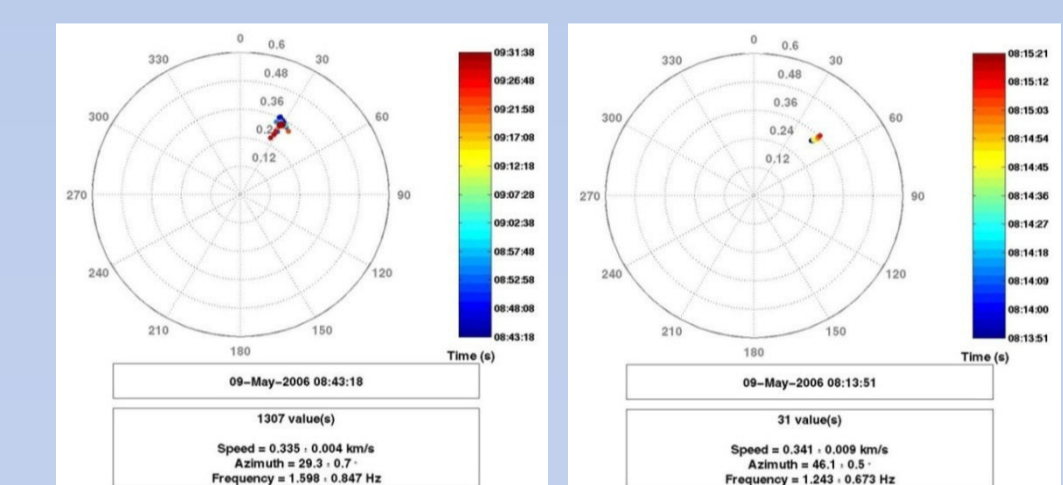


Fig. 4b Polar diagrams associated to the two eruptions of Fig. 4a: Bezymianny's eruption backazimuth is ~29°; Karymsky's eruption backazimuth is ~46°.

## Near-field and far-field observation of volcanic eruptions

The locations of the **UniFI infrasound arrays** along the Italian Peninsula play a **key role in complementing the information retrieved from the IMS infrasound arrays located in the vicinity of the Mediterranean**. The frequent activity of Etna volcano has provided UniFI with the opportunity of performing systematic observations of its eruptive phases and of **comparing the local records with data acquired at regional distances**.

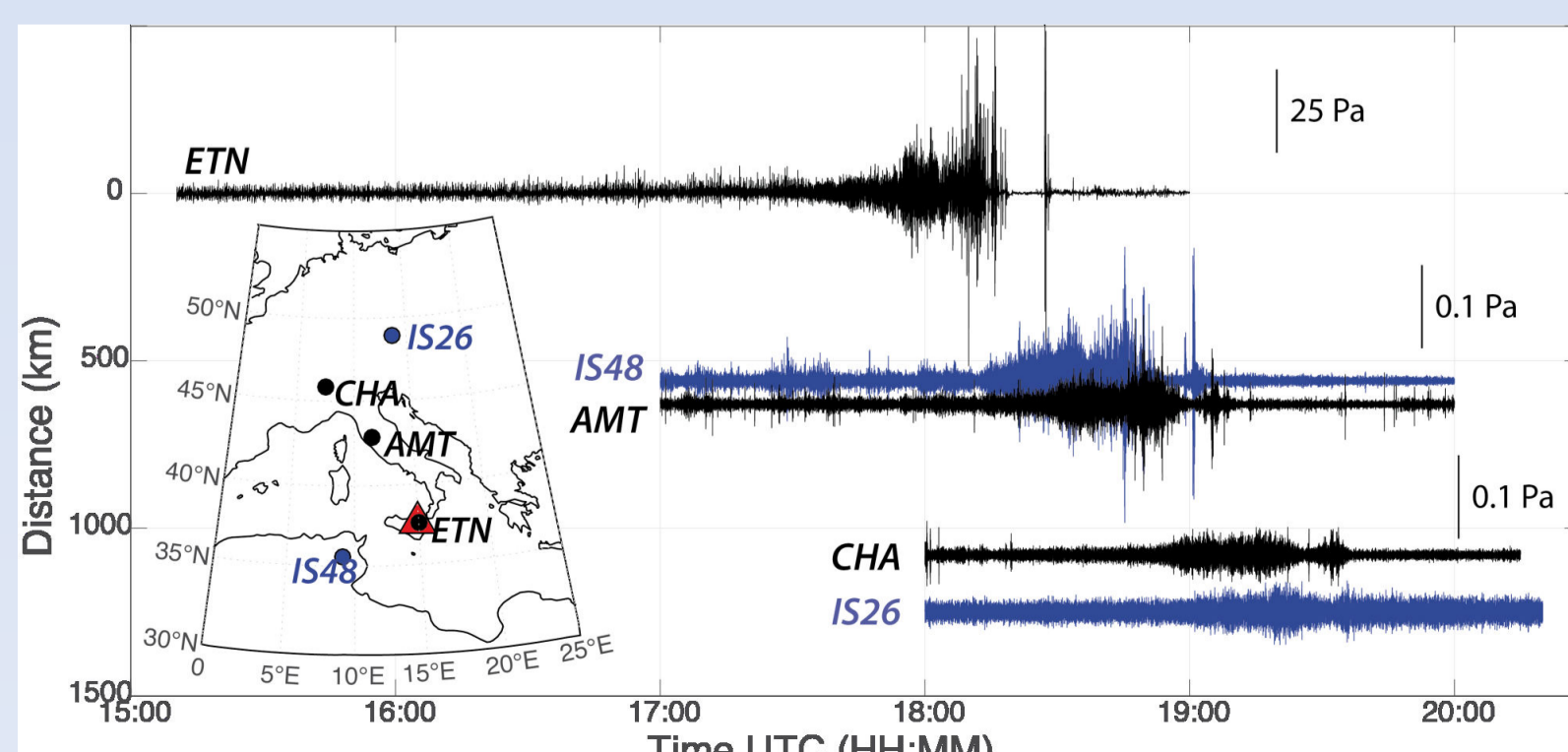


Fig. 5: Left: Etna volcano Right: location of the UniFI infrasound arrays along the Italian peninsula. ETN: Etna STR: Stromboli AMT: Mount Amiata CHA: Champoluc VTN: Valtourmanche GRY: Gressoney



The significant **Etna Lava Fountain (LF) activity in 2013** has been recorded in multiple instances **by the three UniFI arrays ETN, AMT (at 630 km) and CHA (at 1080 km)**, as well as by the IMS infrasound stations **IS26 (at 1240 km) and IS48 (at 560 km)**. **Infrasound waveform characteristics are preserved up to about 500-600 km (arrays ETN, AMT and IS48)**, while the signal-to-noise ratio becomes smaller at larger distances (arrays CHA and IS26).

Fig. 6: Infrasound records of a lava fountain (LF) at Etna volcano recorded on 2013/03/16 at IMS infrasound arrays (IS48 and IS26, blue) and UniFI arrays (ETN, AMT and CHA, black) at source-to-receiver distances spanning between 5 and 1240 km. The near-field source characteristics are visible in far-field up to about 600 km.



## Near-field and far-field monitoring: Volcano Early Warnings

Lava Fountains (LF) from Etna volcano are characterized by a peculiar infrasonic signature: intermittent strombolian-type explosions precede the LFs, with increasing amplitude and rate before the paroxysmal phase, when amplitude and frequency content of the signal show an abrupt change. This amplitude-frequency change has permitted UniFI to define a specific parameter, the **Infrasound Parameter (IP)**, which allows the **issuance of early warnings of strong volcanic activity to Civil Protection (Ripepe and Marchetti, 2017)**.

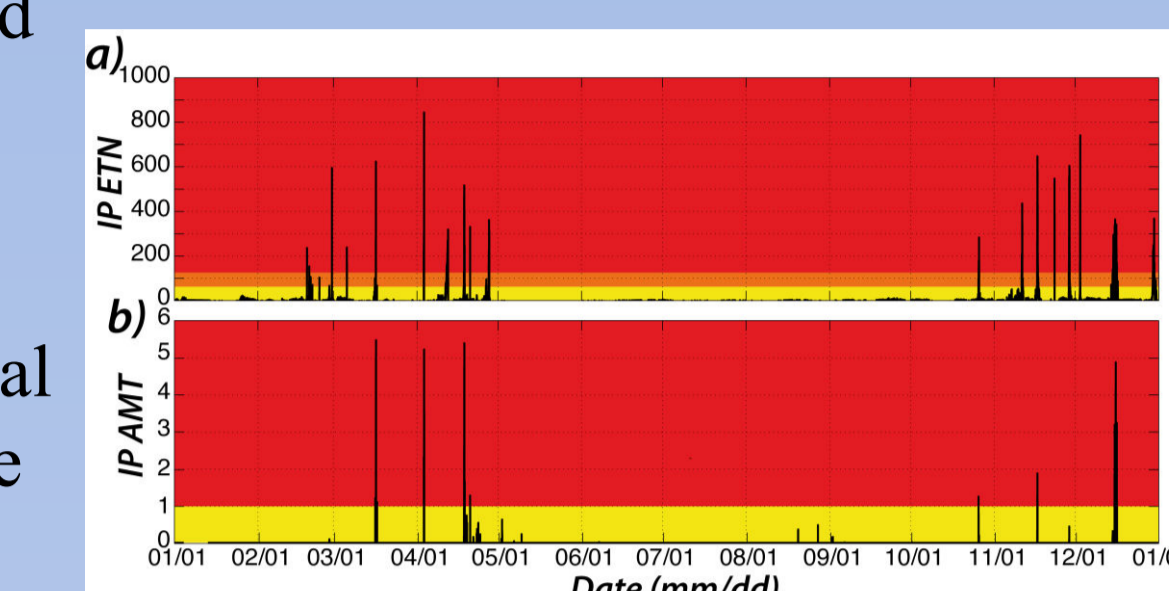


Fig. 7: IP parameter at ETN and AMT arrays in 2013

The observations of Fig. 6 indicate that **the IP criterion can be applied also to regional distances**: a systematic analysis of the 2013 LFs (Fig. 7) shows that at regional distances **43% of the LFs have been detected by the AMT array without false alarms (Marchetti et al., 2017)**.

## The challenge of Volcano Early Warnings for Civil Aviation

If stations at regional distance from a volcano can, in principle, record waveforms showing the fine details of the volcanic source, how much can this concept apply to the IMS Infrasound stations?

**How many IMS infrasound stations could contribute to the issuance of volcano early warnings to the Volcanic Ash Advisory Centers (VAACs)? The strict latency requirements of VAACs put a strong limitation to the number of IMS stations capable of complying with such requirement. A clear example of this constraint has been provided by Calbuco Volcano, which erupted in two sequences on 2015/04/22 and 2015/04/23 with a VEI 4.**



Fig. 8a: Map of IMS arrays (blue dots), UniFI arrays (orange dots) and Calbuco volcano (red triangle)

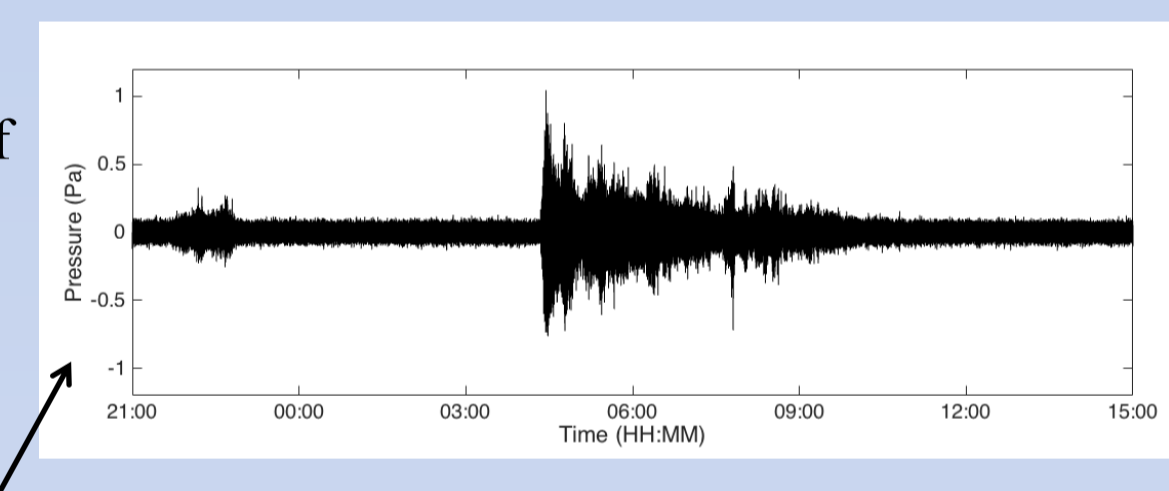


Fig. 8a: Calbuco's eruption VEI 4, on 2015/04/22.

Fig. 8c Infrasound record of the two eruptions of Calbuco on 2015/04/22 and 2015/04/23 as recorded by the small aperture UniFI infrasound array deployed nearby Copahue volcano. The latency at a distance of about 380 km is, approximately, 20 minutes. The fine details of the two eruptive episodes are visible in the UniFI records

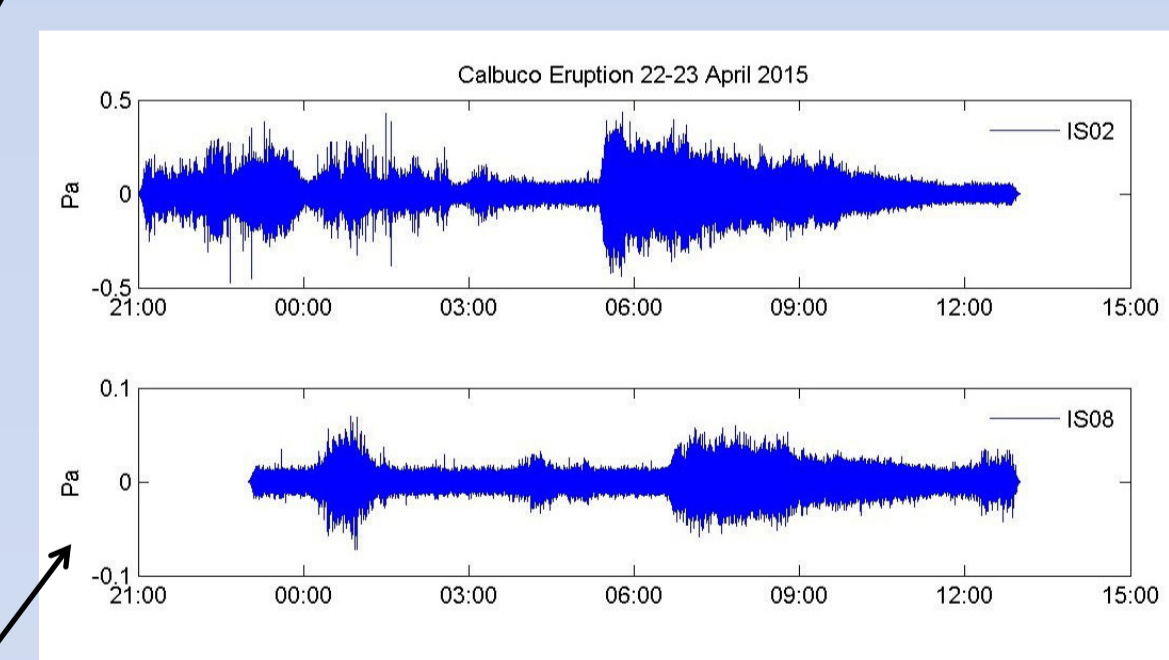


Fig. 8d Signals associated to the two eruptions of Calbuco volcano recorded by the IMS infrasound stations IS02 (distance:~1500 km, backazimuth ~343°), IS08 (distance:~2800 km, backazimuth ~187°) and IS09 (distance:~3700 km, backazimuth ~215°)

## Conclusions

**For most of the IMS infrasound stations, the source-to-station travel time trespasses the latency threshold which would provide the VAACs with valuable information to issue a timely early warning to Civil Aviation: to enhance its performance the IMS Network will benefit from detections of local infrasound arrays.**

**The UniFI arrays, complemented with the UniFI Early Warning algorithm already applied to Etna volcano provide a key support in Early Warning to Volcanic Ash Advisory Centers and to the IMS Network.**

**References:**  
 Campus, P., D. R. Christie, and D. Brown (2005), Detection of infrasound from the eruption of Manam volcano on January 27, 2005. Proceedings of the 2005 Infrasound Technology Workshop, Tahiti, 28 November -2 December 2005 and Proceedings of the First International Workshop on Acoustic Remote Sensing of Volcanoes, Quito, January 22, 2006.  
 Campus, P., and D. R. Christie (2010), The IMS Infrasound Network: Worldwide observations of infrasonic waves, in Infrasound Monitoring for Atmospheric Studies, Springer Geosciences, ISBN: 978-1-4020-9507-8, 745 p.  
 Canis Y. (1995), An automatic seismic event processing for detection and location: The P.M.C.C. Method, Geophys. Res. Lett., 22, 1021-1024, doi:10.1029/95GL00468  
 Marchetti E., M. Ripepe, P. Campus, A. Le Pichon, N. Brachet, Elisabeth Blanc, P. Gaillard, P. Mialle, P. Husson, 2017. Infrasound Monitoring of volcanic eruptions and contribution of ARISE to the Volcanic Ash Advisory Centers, submitted, Springer.  
 Ripepe M. and E. Marchetti, 2017. Infrasound monitoring of volcano-related hazards for civil protection, submitted, Springer