Use of Infrasound Data in support of IAVW

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Item: 4.2. Remote sensing monitoring of volcanoes

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Using infrasound to monitor volcanic eruptions

- Many research studies demonstrated the feasibility of detecting volcanic eruptions with infrasound*
  
  Ex: large-scale eruptions of Sarychev Peak, Kuril Islands, June 2009

- 6 detecting IMS stations downwind (640-6400 km range)

- At 640 km (I44RU), eruption sequence detailed in high resolution

- Infrasound can complement satellite monitoring, especially in case of dense cloud coverage

* McCornack et al, 2006
  Garcés et al, 2008
  Dabrowa et al, 2011
  Olivieri et al, 2013
  Fee et al, 2013
Using the IMS* infrasound network

Distribution of IMS infrasound arrays and volcanoes (triangles) that had activity during the last 10,000 years. For each volcano, the distance to the nearest IMS infrasound station is colour-coded.

- Multi-year continuous quality recordings
- Global coverage: as of December 2016, median distance from any volcano to the nearest IMS infrasound array was ~980 km
  ➔ mean travel time of ~55 min assuming an isotropic propagation with a celerity of 0.3 km/s

*International Monitoring System operated by CTBTO (Comprehensive Nuclear-Test-Ban Treaty-Organization)
From science to operations

Development of a Volcanic Information System (VIS)

The synergy CTBTO / ARISE (Atmospheric dynamics Research InfraStructure in Europe, H2020 project funded by EU 2015-2018; arise-project.eu) offers a unique opportunity for the VIS establishment using infrasound data from a global station network.

- ARISE advanced products provide valuable parametric inputs on the atmosphere dynamics that drives the infrasound wave propagation.
- CTBTO brings its operational infrastructure to support dissemination of information to VAACs through the VIS.
- The proposed approached is tested with VAAC Toulouse, mandated by the ICAO, to demonstrate the usefulness of infrasonic data to International Airways Volcano Watch.

Prototype system has been developed within ARISE-2 project (2018)
Overview of VIS processing

Search for infrasound detections matching with a known volcano

Select and filter data, search criteria: distance (<3000 km), azimuth (+/- 10°), frequency [Brachet et al, 2010]

Search for grouped detections: the origin time of the eruption corresponds to the period overlap T0 +/- DT for the detecting stations

Infer source amplitude from far field observations using semi-empirical frequency and wind-dependent attenuation relation [Le Pichon et al., 2012]; discard strongly attenuated signals (>110 dB)

Build eruption events from detections

Eruptive sequences triggered evaluating Infrasound Parameter (IP)

Sequencing: notification sent every 3 hours when an eruption is detected; 1 notification with state "Ended" when no detection have been recorded for 6 h
Adapting near-field results to improve far-field analysis

Infrasound Parameter (IP) used to characterize the eruption persistency and magnitude. It used to reduce false alarms:

\[ IP = N_{\text{det}} \times A_m \]

\( N_{\text{det}} \): ratio of detections duration over time interval

\( A_m \): average RMS pressure @1 km of the source

2 infrasound arrays
- ETN @ 5 km
- MVT @ 6 km
processed in real time to provide a single parameter describing activity (IP)
Well monitored volcano by experimental nearfield infrasound arrays operated by Univ. of Firenze (UNIFI) since 2007. Good candidate to assess the detection capability of the European infrasound network.

Downwind, there are clear detections from Etna eruptive episodes at I48TN (550 km), I26DE (1240 km) and other ARISE experimental arrays (e.g. OHP, France – 1040 km).
Etna, Italy – Eruptions of May 2016

Comparison between infrasound detections from regional arrays and VAAC advisories

I48TN – 549 km

OHP – 1041 km

I26DE – 1239 km
Etna, Italy – Eruptions of May 2016

Comparison between IP calculated for regional arrays and VAAC advisories

- IP every 15 min
- Threshold: IP ≥ 10
- Attenuation <110 dB
Etna, Italy – Eruptions of May 2016

- The 3 major eruptive sequences are well observed by stations and match the issued VAAs
- The IP indicator timely accounts for the dynamic of the eruption
- VIS notifications are often raised before VAAC alerts

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**VOLCANO NOTIFICATION TO VAAC**

Volcanic Information System v2018.2

**Notification**

- **ID**: ETNA2016014
- **ISSUED**: 2016/05/15 12:55:00 UTC
- **REVISION**: 17
- **ISSUED BY**: CEA (ARISE)
- **RECIPIENT**: VAAC TOULOUSE (METEO FRANCE)

**Volcano**

- **NAME**: ETNA
- **ID**: 211060
- **LATITUDE**: 37.73
- **LONGITUDE**: 15.0
- **ELEVATION**: 3350 m

**Summary**

- **START TIME**: 2016/05/23 20:35:06 UTC
- **END TIME**: 2016/05/25 20:29:58 UTC
- **STATUS**: ENDED

<table>
<thead>
<tr>
<th>STATION</th>
<th>DISTANCE (km)</th>
<th>NB DETECTIONS</th>
<th>MAX AMPLITUDE (Pa)</th>
<th>EST. AMPLITUDE (Pa)</th>
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<tbody>
<tr>
<td>I48IN</td>
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<td>I26SE</td>
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<td>510</td>
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</tbody>
</table>

**SOURCE AMPLITUDE**: 510 Pa
Extension of VIS evaluation to historical data

- VIS was able to detect all the major eruptions (VEI > 3) associated with the VAAs we tested
- Systematic comparison with UNIFI Early Warning results (2008-2016)
  -> The most significant episodes of lava fountaining and ash eruptions are well identified
  -> For smaller events, system performances highly depend on favorable propagation conditions
On July 3 and August 28, 2019, two paroxysms occurred at Stromboli volcano with significant volcanic ash emission. Despite the event was observed in real-time by volcano observatory, no VONA was issued.

Infrasound was recorded at great source-to-receiver distances (>500 km) within 1 hour from event occurrence.
Thanks to easterly winds the July 3, 2019 event was recorded at distances >590 km

Remote arrays would have allowed the automatic notification ~ 45 minutes after the eruption.
VIS evaluation Stromboli, July 3rd

- On July 3rd 2019 at 14.46 UTC, volcanic eruption occurred at Stromboli leading to a significant ash emission into the atmosphere.

- This eruption has been detected at 4 IMS infrasound stations: I48TN (620 km), I26DE (1125km), I37NO (3380km) and I42PT (3530km).
VIS triggers a notification of volcanic eruption and keeps sending updates of the volcanic activity.

- With standard parameters, only the high amplitude signals recorded (red arrow) could trigger VIS notification.

- If implemented in real-time VIS would have been able to send the notification from 15.30 (~45min after the main signal).
Summary and Perspectives

- Scientific collaboration on VIS is an asset for ARISE (research), CTBTO (operations) and ICAO/WMO (civil application, safety) communities

- VIS prototype developed and tested in ARISE-2 Design Study with the operational support of CTBTO

- First results are promising, especially in the case of major eruptions

**Future work:**

- Improve the reliability of the notification results, reduce the false alarms rate. Further evaluation required: extension to other VAACs?

- Calculate the source amplitude from long range infrasound measurements to estimate the acoustic energy (in relation with the flux of ash injection in the atmosphere)

- Integrate data from regional infrasound array to lower response time and improve reliability

- Evolve from data reanalysis tool to near real-time alert system