Towards a Volcanic Information System (VIS) using IMS infrasound data

in support of the VAACs
in the framework of ARISE Project

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1500 active volcanoes worldwide in the past 10,000 years

Serious hazards to aircraft in flight near to the ash plume

Many of the world’s volcanoes lack dedicated monitoring instruments (e.g., bad weather, limited infrastructure, satellite coverage)

Infrasound may supplement other monitoring techniques in remote areas poorly instrumented

Siebert and Simkin, 2002
Global Volcanism Program, 2013
Motivation

Large-scale eruptions of Sarychev Peak, Kuril Islands, June 2009

Ash encounters represent a serious threat to aircraft safety (>100 unscheduled fuel stops, re-routed flights)

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

At 640 km, eruption sequence detailed in high resolution

Matoza et al., 2011
Volcanic Ash Advisory Centres (VAACs) in close cooperation with WMO mandated by the International Civil Aviation Organization (ICAO) to coordinate and disseminate information on volcanic ash clouds (Annex 3 of the Convention on International Civil Aviation).

- Global and continuous infrasound recordings supplement other techniques to remotely monitor volcano activity, which has already been expressed in a letter from ICAO to CTBTO in 2005; therefore IDC is in discussions with VAAC Toulouse since 2007.

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Using the IMS Infrasound network

- Multi-year continuous quality recordings
- Median distance from any volcano to the nearest IMS infrasound array ~890 km
  - Mean travel time of ~50 min assuming an isotropic propagation with a celerity of 0.3 km/s
Establishment 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.

- Best use of the infrasound component of the IMS together with the operational capabilities of the IDC for Civil Aviation.
- ARISE advanced products provide valuable parametric inputs on the atmosphere dynamics that drives the infrasound wave propagation.
- These results may serve as quality indicators increasing the VAACs confidence when receiving notification messages.
- CTBTO brings its operational infrastructure to support dissemination of information to VAACs through the VIS.
- The proposed approach is tested with VAAC Toulouse, mandated by the ICAO, to demonstrate the usefulness of infrasonic data to International Airways Volcano Watch.
Basic steps for the VIS

Search for infrasound detections matching with a known volcano

Query databases, search criteria: distance (<4000 km), azimuth, frequency, favorable ducting conditions for propagation

Notification sequencing

Group 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 by Infrasound Parameter (IP) - NEW

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

Filter out smallest events (optional)
Basic steps for the VIS

Triggering VIS for automatic notification of ongoing eruptions: tuning IP using near field observations

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

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

- \( N_{det} \): number of detections per minute
- \( A_m \): 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)

Marchetti et al., 2018
VIS prototype architecture

Prototype system has been developed within ARISE-2 project

**VIS implemented on Virtual Data Exploitation Center (vDEC) environment with the operational support of CTBTO (ongoing)**

**Latest updates about VIS development**

- Software has been made compatible with vDEC technical requirements
- Retrieve data from vDEC IDC database
- Integration of the infrasound parameter (IP) initially developed by UNIFI
- Identify upwind propagation conditions to discriminate detections
- Create a local database for storing results and interacting with ARISE portal
- Sending email to VAAC from vDEC server ➔ *Not yet tested*
**Objectives:**

Detect a volcanic eruption as soon and as certainly as possible

Disseminate the information: provide updates to VAAC in near-real time and regular updates of the ARISE portal supplemented with quality criteria

Estimate volcanic source term, critical parameter to model ash dispersion

Get a low false alerts rate through adequate parameterization
Application
Etna, Italy – Eruptions of May 2016

- Well monitored volcano by experimental nearfield infrasound arrays operated by Univ. of Firenze (UNIFI). 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)
Comparison between infrasound detections from local and regional arrays
VAAC advisories

Application
Etna, Italy – Eruptions of May 2016

Aviation color code
△ Orange: volcanic eruption is underway with no or minor ash emission
△ Red: eruption is underway with significant emission of ash into the atmosphere
Source: Météo France, VAAC Toulouse
Comparison between infrasound detections from local and regional arrays and VAAC advisories

- IP every 15 min
- Threshold: IP ≥ 10
- Attenuation <110 dB

Application
Etna, Italy – Eruptions of May 2016

IP every 15 min
Threshold: IP ≥ 10
Attenuation <110 dB

Source: Météo France, VAAC Toulouse
The 3 major eruptive sequences well identified corresponding to VAAs observed by 2 IMS stations (distance > 550 km).

VIS notifications are often raised before VAAC alerts.

Tested on whole 2016, 16 events are detected for Etna, generating 62 notifications.

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**Application**

**Etna, Italy – Eruptions of May 2016**

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Volcanic Explosivity Index (VEI) 3; total emitted SO$_2$ mass 382,000 t; maximum altitude: 9 km
1,000 people have been evacuated from the area

Volcanic activity continued in January 2015 with lava flow, small explosions, gases and ashes

Sources: Global Volcanism Program (GVP)
Smithsonian Institution
VIS evaluation

- Further analysis using archived IMS detections and comparison with Volcanic Ash Advisories (VAAs) emitted by VAAC Toulouse
- Evaluate the system with a list of active volcanoes (maximum distance of 3000 km)

List of eruptions sent by VAAC Toulouse

Further testing and systematic comparison to be done on catalog of eruptions from other VAACs and Global Volcanism Program (GVP) catalog

<table>
<thead>
<tr>
<th>Volcano name</th>
<th>Country</th>
<th>Year</th>
<th>Start Date</th>
<th>End Date</th>
<th>Associated VAA</th>
<th>Detected by VIS</th>
<th>Stations Detecting</th>
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<tr>
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Summary / Perspectives

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

- VIS has been developed in ARISE-2 Design Study and is being implemented in vDEC with the operational support of CTBTO

- Ongoing work: improve the reliability of the notification results, reduce the false alarms rate
  - Improved accuracy and uncertainty using full wave atmospheric modeling
  - 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)
  - Systematic evaluation of VIS using archived IMS detections and VAAs

- Once the prototype validated, the experiment will be extended to other VAACs

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

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

- CTBTO and ARISE welcome participation from volcano-infrasound research community to enhance VIS