Towards a Volcanic Notification System With Infrasound Data

Use of infrasound data in support of the VAACs in the Framework of ARISE Project

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Presented by Nicolas Brachet (CEA)
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Large scale volcanic eruptions may eject ash and hazardous gas high into the atmosphere.

Ash encounters represent a serious threat to the safety of aircraft.

Volcanic Ash Advisory Centers (VAACs) are mandated by the International Civil Aviation Organization (ICAO) to coordinate and disseminate information on volcanic ash clouds.

Timely availability of reliable information is crucial to mitigate the risk of aircraft encountering volcanic ash.

- Volcanic and seismological observatories
- Remote sensing
- Pilot report

Infrasound (<20Hz) may supplement other techniques for monitoring volcanic activity, especially in remote areas that are poorly instrumented.
CTBTO Operational system

The Organization ensures the build-up of a global verification regime capable of detecting nuclear explosions underground, underwater and in the atmosphere.

CTBTO-WMO/ICAO collaboration

ARISE: Applied science

Atmospheric dynamics Research Infrastructure in Europe, H2020 project funded by EU (2015-2018)

24 international partners working with CTBTO on the characterization of the atmosphere and monitoring of extreme events.
Establishment of a Volcanic Notification System (VNS)

The synergy CTBTO / ARISE offers a unique opportunity for the establishment of a VNS using infrasound data from a global station network.

- The VNS makes best use of the infrasound component of the IMS together with the operational capabilities of the IDC.
- 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.
- The proposed approached is tested with VAAC Toulouse, mandated by the ICAO, to demonstrate the usefulness of infrasonic data to International Airways Volcano Watch.
- Formalization through a future CTBTO-ICAO/WMO agreement.
Search for infrasound detections matching with a known volcano

Query the IDC/ARISE databases, search criteria

- **Distance** source-stations < MAX_DISTANCE (4000 km)
- **Azimuth** +/- ΔAZIM (10 deg)
- **Central frequency** (attenuation with distance)
  - $c_{freq} < 4 - 0.055 \Delta$ for $\Delta < 60$ deg
  - $c_{freq} < 0.5$ Hz for $\Delta > 60$ deg (Brachet et al. 2010)

- **Effective sound speed ratio** (favorable ducting conditions for propagation)
  - $C_{eff}$-ratio = MEAN (MAX$_i$ [C$_{eff}$-ratio 30-60 km]) > MIN_CEFF_RATIO (0.95)

A “binary”-like pattern

- $C_{eff}$-ratio < 1: signals strongly absorbed for $f > 1$Hz
- $C_{eff}$-ratio > 1: stratospheric duct efficiently propagates acoustic energy
Build eruption events from detections

- **Group detections**: the origin time of the eruption corresponds to the period overlap $T_0 +/- \Delta T$ for the detecting stations

  $$T_0 = \Delta / \text{REF\_SPEED} \quad (\text{REF\_SPEED}=300\text{m/s})$$

  $$\Delta T = \Delta * [1/\text{MIN\_SPEED} - 1/\text{MAX\_SPEED}] \quad (\text{RANGE\_SPEED}=270-330\text{m/s})$$

- **Eruptive sequences**: Origins belong to a same event if they are separated by less than $\Delta T_{CLOSE}$ (6 hours)

- **Filter out smallest events** (optional) based on MIN_NBSTATIONS, MIN_MAX_DURATION

![Diagram showing Basic Steps for the VNS](image)

- 2 eruptive events
  - $T_01 \pm \Delta T_1$
  - $T_03 \pm \Delta T_3$
Attenuation is function of the frequency and wind conditions.

- **Low frequency:** Attenuation weakly depends on $C_{\text{eff-ratio}}$.
- **High frequency:** Higher attenuation in upwind conditions (low $C_{\text{eff-ratio}}$).

![Graph showing the relationship between attenuation and frequency with distance and $C_{\text{eff-ratio}}$.](image-url)
Probabilistic predictions (Etna detected at IS48) using empirical attenuation relation and atmospheric uncertainty estimates (from OHP campaign)

Minimum detectable source amplitude vs. detections @ IS48

Probabilistic predictions without (top) / with (bottom) wind perturbations (2006-2014)
### APPLICATION: ERUPTION OF CALBUCO, CHILE, 22-23 APRIL 2015

Table 1: Event associated with the first eruption on 22 April 2015 at 21:50 UT.

<table>
<thead>
<tr>
<th>Stations</th>
<th>Distance (km)</th>
<th>Theor. Az (°)</th>
<th>Arriving Time (TU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IS02 Argentina</td>
<td>1525</td>
<td>343</td>
<td>22:50:59</td>
</tr>
<tr>
<td>IS08 Bolivia</td>
<td>2810</td>
<td>187</td>
<td>00:09:19</td>
</tr>
<tr>
<td>IS13 Eastern Island Chili</td>
<td>3695</td>
<td>125</td>
<td>02:19:00</td>
</tr>
<tr>
<td>IS09 Brazil</td>
<td>3700</td>
<td>215</td>
<td>00:35:09</td>
</tr>
<tr>
<td>IS49 Tristan de Cunha United Kingdom</td>
<td>5120</td>
<td>245</td>
<td>02:10:30</td>
</tr>
<tr>
<td>IS50 Ascension United Kingdom</td>
<td>6795</td>
<td>230</td>
<td>04:18:00</td>
</tr>
<tr>
<td>IS35 Namibia</td>
<td>8640</td>
<td>230</td>
<td>04:51:30</td>
</tr>
<tr>
<td>IS17 Ivory Coast</td>
<td>8675</td>
<td>225</td>
<td>05:13:00</td>
</tr>
<tr>
<td>IS32 Kenya</td>
<td>11625</td>
<td>227</td>
<td>08:20:10</td>
</tr>
</tbody>
</table>

Table 2: Event associated with the second eruption 23 April 2015 at 04:22 UT.

<table>
<thead>
<tr>
<th>Stations</th>
<th>Distance (km)</th>
<th>Theor. Az (°)</th>
<th>Arriving Time (TU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IS14 Robinson Crusoe Chili</td>
<td>1010</td>
<td>149</td>
<td>06:39:14</td>
</tr>
<tr>
<td>IS02 Argentina</td>
<td>1525</td>
<td>343</td>
<td>05:32:19</td>
</tr>
<tr>
<td>IS08 Bolivia</td>
<td>2810</td>
<td>187</td>
<td>06:43:55</td>
</tr>
<tr>
<td>IS09 Brazil</td>
<td>3700</td>
<td>215</td>
<td>07:23:05</td>
</tr>
<tr>
<td>IS27 Neumayer Antarctic</td>
<td>4800</td>
<td>277</td>
<td>08:22:55</td>
</tr>
<tr>
<td>IS13 Eastern Island Chili</td>
<td>3695</td>
<td>125</td>
<td>10:26:24</td>
</tr>
<tr>
<td>IS49 Tristan de Cunha United Kingdom</td>
<td>5120</td>
<td>245</td>
<td>08:39:19</td>
</tr>
<tr>
<td>IS47 South Africa</td>
<td>8570</td>
<td>230</td>
<td>11:52:04</td>
</tr>
<tr>
<td>IS35 Namibia</td>
<td>8640</td>
<td>230</td>
<td>12:01:04</td>
</tr>
<tr>
<td>IS17 Ivory Coast</td>
<td>8675</td>
<td>225</td>
<td>12:26:00</td>
</tr>
<tr>
<td>IS32 Kenya</td>
<td>11625</td>
<td>227</td>
<td>15:10:00</td>
</tr>
</tbody>
</table>

Source: Marcelo Utreras ©DR
## Application: Eruption of Calbuco, Chile, 22-23 April 2015

<table>
<thead>
<tr>
<th>Station</th>
<th>Sensor</th>
<th>Time (absolute)</th>
<th>Dist (km)</th>
<th>Vel (km/s)</th>
<th>Amplitude (Pa)</th>
<th>Freq (Hz)</th>
<th>Amplitude Factor</th>
<th>Az (deg)</th>
<th>Pmax (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S0KE</td>
<td>1152km - 1950km</td>
<td>0.34 km/s</td>
<td>1.6 Hz</td>
<td>0.34 km/s</td>
<td>300 Hz</td>
<td>0.25 km/s</td>
<td>1.6 Hz</td>
<td>0.34 km/s</td>
<td>300 Hz</td>
</tr>
<tr>
<td>S070K</td>
<td>865km - 700km</td>
<td>0.30 km/s</td>
<td>0.6 Hz</td>
<td>0.25 km/s</td>
<td>300 Hz</td>
<td>0.20 km/s</td>
<td>1.6 Hz</td>
<td>0.34 km/s</td>
<td>300 Hz</td>
</tr>
<tr>
<td>S034K</td>
<td>860km - 1050km</td>
<td>0.25 km/s</td>
<td>1.6 Hz</td>
<td>0.34 km/s</td>
<td>300 Hz</td>
<td>0.25 km/s</td>
<td>1.6 Hz</td>
<td>0.34 km/s</td>
<td>300 Hz</td>
</tr>
<tr>
<td>S02A</td>
<td>1170km - 1170km</td>
<td>0.30 km/s</td>
<td>0.6 Hz</td>
<td>0.25 km/s</td>
<td>300 Hz</td>
<td>0.20 km/s</td>
<td>1.6 Hz</td>
<td>0.34 km/s</td>
<td>300 Hz</td>
</tr>
<tr>
<td>S02N</td>
<td>860km - 1050km</td>
<td>0.25 km/s</td>
<td>1.6 Hz</td>
<td>0.34 km/s</td>
<td>300 Hz</td>
<td>0.25 km/s</td>
<td>1.6 Hz</td>
<td>0.34 km/s</td>
<td>300 Hz</td>
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<tr>
<td>S070K</td>
<td>865km - 700km</td>
<td>0.30 km/s</td>
<td>0.6 Hz</td>
<td>0.25 km/s</td>
<td>300 Hz</td>
<td>0.20 km/s</td>
<td>1.6 Hz</td>
<td>0.34 km/s</td>
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<tr>
<td>S02A</td>
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<td>0.30 km/s</td>
<td>0.6 Hz</td>
<td>0.25 km/s</td>
<td>300 Hz</td>
<td>0.20 km/s</td>
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<td>0.34 km/s</td>
<td>300 Hz</td>
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<tr>
<td>S02N</td>
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<td>1.6 Hz</td>
<td>0.34 km/s</td>
<td>300 Hz</td>
<td>0.25 km/s</td>
<td>1.6 Hz</td>
<td>0.34 km/s</td>
<td>300 Hz</td>
</tr>
</tbody>
</table>

**IS08 Bolivia – 2810 km**

**Reduced Time after 0.3 km/s [HH:MM:SS]**
APPLICATION: ERUPTION OF CALBUCO
CHILE, 22-23 APRIL 2015

VOLCANO NOTIFICATION TO VAAC
Prototype volcano notification system

Message

NOTIVAAC : 20120401.1
ISSUED : 2015/06/11 17:02:50
ISSUED BY : CEA (ARISE-PROTO)
RECIPIENT : TOULCUSE VAAC (METEOFRANCE)
NO.PAGES : 1

Summary

START TIME : 2015/04/23 03:50:00 UTC
END TIME : 2015/04/23 09:34:00 UTC
DETECTIONS :

<table>
<thead>
<tr>
<th>STATION</th>
<th>DIST. (km)</th>
<th>AMP. (Pa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>114CL</td>
<td>1012</td>
<td>0.37</td>
</tr>
<tr>
<td>102AR</td>
<td>1526</td>
<td>0.27</td>
</tr>
<tr>
<td>108BO</td>
<td>2811</td>
<td>0.22</td>
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<tr>
<td>109BR</td>
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<td>127DE</td>
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<td>149GB</td>
<td>5124</td>
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<td>147ZA</td>
<td>8574</td>
<td>0.10</td>
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<tr>
<td>135NA</td>
<td>8642</td>
<td>0.08</td>
</tr>
<tr>
<td>117CI</td>
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<td>0.02</td>
</tr>
<tr>
<td>132KE</td>
<td>11528</td>
<td>0.39</td>
</tr>
</tbody>
</table>

Detectability

DAY = 20150423,
F = 0.15 Hz, NSTA = 1

Att [dB]

SCIENCE AND TECHNOLOGY CONFERENCE, VIENNA, AUSTRIA | 22-26 JUNE 2015 | PAGE 11
In the framework of ARISE project, the infrasound community develops a Volcanic Notification System (VNS) for Civil Aviation.

As ARISE partner, CTBTO brings its operational infrastructure to support dissemination of information to VAACs through the VNS.

CTBTO and ARISE welcome participation from volcano-infrasound research community to enhance the VNS.

Ongoing work: Improve VNS reliability to reduce false alarms rate
- Enhancement of atmospheric specifications (ECMWF) for modeling infrasound wave propagation
- Improved accuracy and uncertainty of infrasound wave parameters using atm. modeling
- Calculate source amplitude from long range infrasound measurements to estimate the acoustic energy (in relation with the flux of ash injection in the atmosphere → link to the volcano community)

Once the VNS is functional with Toulouse VAAC, this pilot project will be extended to other VAACs.
More on ARISE

- Dynamics of the middle atmosphere as observed by the ARISE project
  E.Blanc  S&T2015 T1.1-P7

More on infrasound & volcanoes

- Global Cataloging of Explosive Volcanism Using the IMS Infrasound Network
  R. Matoza, D. Green, A. Le Pichon, D. Fee:  S&T2015 T1.1-P10


