Community Network for Volcanic Eruption Response (CONVERSE) - Infrasound Workshop Report

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Workshop website and agenda:
https://sites.google.com/alaska.edu/davidfee/home/converse-infrasound-workshop

Introduction

The purpose of the NSF-funded Community Network for Volcanic Eruption Response (CONVERSE) Research Coordination Network (RCN) is to enable, organize, and focus the collaboration of US academic and government researchers, along with foreign entities, involved in volcano science. The goal of the enhanced collaboration is to advance our ability to adequately monitor the unrest and run-up to volcanic eruptions and once an eruption occurs, to adequately collect critical data and samples to develop nextgeneration physical/chemical models of volcanoes and through these understand processes of magma generation, transfer and eruption.

As part of CONVERSE we are holding discipline-focused workshops where researchers can gather and work towards achieving CONVERSE's goals. A volcano infrasound workshop was hosted at the University of Alaska Fairbanks in November 2019. Twenty-eight people participated, including 11 students and a variety of academics and government/observatory employees. Most participants were from the U.S. The major workshop goals were to:

1) Explore key science questions that can be answered with infrasound during eruptions
2) Develop a "best practices" document for deployment of infrasound sensors, acquisition systems, and documenting metadata
3) Work towards software routines and recommendations for data analysis, particularly those suited for monitoring institutions during eruption response
4) Establish a set of shared codes for scientific analysis and modeling of infrasound data
5) Train early career scientists and establish mentoring networks
6) Identify and explore new technologies and strategies that will further volcano infrasound science

The workshop was held over two days and consisted of a mixture of short "lightning talks" from each participant on their research; longer, more-detailed presentations on select topics; and a full day devoted to "breakout" groups of small (~10) people. The aim was to have a mix of background presentations and discussions, and encourage as much participation as possible. Workshop presentations are available at: https://drive.google.com/drive/u/1/folders/1_ESemvLmcS1lqg4_mBdIj4wrlRZmoIeA.

Major Workshop Outcomes and Recommendations:
The workshop's primary goal was to explore how volcano infrasound could facilitate eruption response and maximize scientific benefit obtained during volcanic eruptions. Key scientific and monitoring topics discussed during the workshop were:

1) Infrasound provides a means to quantify eruption source parameters at a variety of ranges and eruption styles. At a basic level it can easily detect and locate explosions. More advanced studies allow, for example, detailed, quantitative estimates of mass flow rates from eruptions and changes in eruption intensity. These have become key monitoring tools at many volcano observatories.
2) Detection, tracking, and characterization of surficial mass flows is becoming increasingly feasible and possible using infrasound. Source models are limited but are an area of active research.
3) Integrated seismo-acoustic studies provide key monitoring information on both the eruption source and wave propagation.
4) Combining infrasound with other technologies, such as remote sensing and lightning, provides greater insight into eruption processes and can be effective for monitoring.
5) Eruption forecasting using infrasound can be possible for open-vent volcanoes and should be explored more. Infrasound can often provide information on changes in crater morphology and lava surface level that precede eruptions.
6) Many open questions still remain in volcano infrasound. In particular, nonlinear wave propagation, characterization of the heterogeneous atmosphere, more complex sources were highlighted as major growth areas. Uncertainty is generally not addressed but should be.

The following key outcomes were developed during the workshop.

1) **Infrasound sensors and recording units are at a level of maturity that allows high-resolution measurements that allow key science questions to be answered.**

A wide variety of high-quality sensors and recording devices are now available. Observatory-grade, high-end sensors allow recording a broad spectrum of signals, from low-level background degassing to very large explosions. These sensors are broadband and have high dynamic range and are best suited for long-term deployment. Lower-resolution, cheaper, but still high quality sensors allow for dense deployments, getting closer to “Large-N” infrasound data collection. Multiple sensors and recording devices are now low power (<150 mW). Lower frequencies (i.e. <0.1 Hz) studies are rare but may provide unique information. This frequency range should be explored more. We also discussed the target frequency content of signals of interest for volcano-acoustics. The existing literature has largely focused on the band from 0.01–20 Hz. However, audible acoustic signals are generated at higher frequencies, and acoustic-gravity and gravity wave signals are generated at lower frequencies, depending on the source size and dynamics. We noted that the modern instrumental infrasound record is limited to VEI 4 eruptions and smaller, while VEI 5, 6, 7, or 8 would produce much more energetic, longer period acoustic-gravity and gravity modes. For example, the 1883 VEI 6 eruption of Krakatoa produce acoustic-gravity modes with periods of 100 to 200 minutes. To be prepared to capitalize on a future large eruption, we should build sensors capable of as wide a bandwidth as possible.

2) **Effort should be made to balance and implement sparse, long-term and dense, short-term infrasound networks. Long-term recordings are key for understanding background activity and capturing unexpected eruptions, while dense campaign networks are needed for detailed quantitative studies and modeling. The combination of these will reduce observational bias. Real-time data are needed for some but not all stations. Sensors should be deployed in both array and network configurations, and co-located with seismic stations when possible. Tools should be made available or developed to help model where stations should be deployed.**

There was broad agreement to have more infrasound sensors permanently deployed at volcanoes around the world to establish baseline and detect unexpected activity. Once unrest begins, then denser networks will allow high-resolution, quantitative source studies. Arrays are helpful in identifying low-amplitude and sustained signals within background noise (incoherent wind noise and coherent background infrasound) They can also be effective at regional distances and when there is sparse instrumentation. In the case of higher signal-to-noise ratios, e.g., high-amplitude signals recorded at local distances (<15 km) from the source, single infrasound sensors can be adequate. A network configuration allows unique source constraints that a single array cannot. Ideally, a network of arrays would be deployed, but to balance cost and logistics, a network of single sensors can be adequate in cases of high signal to noise. The deployment type should be suited toward the specific monitoring and research goals and weighed against logistical constraints. Co-located seismo-acoustic studies are an area of active research and allow unique insight into wave propagation and source processes. Further research on identifying and estimating wavefront parameters of coherent infrasound signals on collocated single infrasound and seismic stations will help in utilizing this common sensor deployment configuration. Some tools currently exist to model array response and propagation conditions, and these should be made available to the community. Further work in this area would also be helpful.

3) **Provision of open source codes and data are key using established data repositories.**

Universal agreement exists that modeling and analysis codes should be open source in easily accessible locations (i.e. github). Open-source languages, such as Python, also facilitate rapid response and do not limit the user base. Open-access data and publications are also strongly encouraged and should be strived for, although a data embargo period is understood for some NSF-style research projects. IRIS is the unequivocal data repository choice.

4) **Additional training on infrasound theory, code usage, modeling, data analysis, deployment strategies, etc is needed. More early career development and training is also needed, including expanding diversity in the field.**

Volcano infrasound is a small but growing community and is now a staple in volcano monitoring and research. Both observatory scientists and academics request additional training and documentation on nearly all aspects of infrasound science, so when an eruption occurs no training is required. A high number of the participants were early career and/or new to the field of infrasound. Toward this goal, we recommend increasing the number of training and internship opportunities in seismo-acoustic and volcano infrasound topics and increasing efforts to expand diversity.

5) **A single community-run "volcano infrasound" website is needed to host best practices documents and link to codes and other resources.**

A volcano infrasound-specific website is long overdue to provide a variety of resources for the community. Many were unaware of what codes and data are available and how to use them. UAF graduate student Alex Iezzi offered to start and help maintain this website, with forum and best practices assistance from Boise State Postdoc Jake Anderson and Jefferson Chang from the USGS. However, this website should be community-focused and not run by a single person or group. CONVERSE infrasound lead David Fee will also assist. Work is needed to develop the best practices documents, while linking to publicly available codes and data can occur immediately. A forum to discuss issues or ask questions would also be helpful. This website is now online at https://sites.google.com/view/volcano-infrasound.

6) **Infrasound metadata are often an afterthought and incorrect. More effort should be put into establishing accurate metadata and easing metadata dissemination.**

Metadata formats and standards are typically derived from seismology and infrasound does not always conform well. Much of the infrasound metadata at IRIS is incorrect or incomplete, although recent improvements have been made. All are encouraged to work towards accurate metadata from the beginning, which will give our community more credibility and repeatability. IRIS is aware of this issue and is working towards expanding compatibility.

7) **Community resources are needed for improved waveform modeling. Modeling codes and software tools are often only available to certain groups, and significant advances could be made with more open-source, standardized tools. High-resolution Digital Elevation Models (DEM) are needed by these codes, and availability of such models should be improved.**

Accurate characterization of acoustic wave propagation is key to accurate, quantitative source modeling. Some high-quality codes exist but are not open source and/or easy to use. Many would benefit from more open-source, well-documented, benchmarked, easy-to-use wave propagation codes. There was broad support for publicly available tools for generating synthetic infrasound signals using finite-difference, finite element, or spectral element methods based on an input DEM and meteorological specifications, perhaps generated through a web interface so that high-performance computers are not required on the user side. Some expressed the need for open-source array processing tools as well, which will likely be available to the community in the near future and documented on the volcano infrasound website. Tools such as ObsPy were also touted as effective.

8) **A community pool of infrasound instruments would be invaluable to advance infrasound science and be of great value during eruption response.**

Although more infrasound data are being collected by observatories and researchers, scientific advances could be made if a community pool of infrasound equipment was available, such as the PASSCAL instrument pool for seismology. IRIS is aware of this and working toward this goal. This pool could be used in “rapid response” mode during eruptions. The Alaska Volcano Observatory now has a rapid response instrument pool for Alaska eruptions. A major barrier to entry for new infrasound researchers is the availability of the infrasound sensors. Making infrasound sensors available through an instrument pool has the potential to greatly expand the seismo-acoustics research community and open new research areas and frontiers.

9) Community volcano infrasound experiments and further practical workshops, focused on developing best practices and education/outreach, are recommended.

Hands-on training during data collection and analysis would broaden the use and effectiveness of infrasound and facilitate eruption response.

This report was prepared by the organizers with input from the participants.