

Hydrophone deployment in underwater volcanic settings; new data for the community

Corentin Caudron *,^{1,2} Ben Roche ¹, Jean Vandemeulebrouck ³, Julien Barrière ⁴, Leonardo Van der Laat ^{5,6}

¹Laboratoire G-Time, Department of Geosciences, Environment and Society, Université libre de Bruxelles, Brussels, Belgium, ²Wel Research Institute, Wavre, Belgium, ³ISterre, Université Grenoble Alpes, Université Savoie Mont Blanc, CNRS, IRD, IFSTTAR, 38000, Grenoble, France,

⁴European Center for Geodynamics and Seismology, Walferdange, Grand Duchy of Luxembourg, ⁵Observatorio Vulcanológico y Sismológico de Costa Rica, Universidad Nacional, Heredia, Costa Rica, ⁶Programa de Doctorado en Ciencias, Sistema de Estudios de Posgrado, Universidad de Costa Rica, San José, Costa Rica

Author contributions: *Conceptualization:* C.C., J.V.. *Methodology:* C.C.. *Software:* C.C.. *Formal Analysis:* C.C., B.R.. *Resources:* C.C., J.V.. *Writing - Original draft:* C.C.. *Writing - Review & Editing:* C.C., B.R., J.B., L.VdL.. *Visualization:* C.C.. *Supervision:* C.C.. *Project administration:* C.C.. *Funding acquisition:* C.C., J.V..

Abstract Hydroacoustics is an often overlooked tool for volcanic monitoring, capable of recording everything from the release of millimetre sized bubbles to small scale phreatic eruptions and gas blowouts. Over the last 4 years we have deployed hydrophones in a range of subaqueous volcanic environments, from oceans to crater lakes, at depths from 1 to 350 m. Here we report on these experiments, describe our observations and present the recordings for use by the wider scientific community.

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1 Scientific background and motivation

Over the past 4 years, we have deployed hydrophones in a variety of underwater volcanic environments to observe the marine soundscape, with the primary goal of recording and quantifying subaqueous volcanic degassing. Our long-term objective is to develop passive seismo-acoustic monitoring of underwater volcanic gas emissions.

Volcanic gases are a main trigger of explosive eruptions, yet they are emitted in the largest amounts via passive degassing during quiescence (Caudron et al., 2012). Of the dominant volcanic gas species, CO₂ is particularly challenging to detect due to the high CO₂ content already present in the atmosphere (Aiuppa et al., 2019). Global estimates of volcanic CO₂ emissions vary greatly from 66 to 540 MT/yr and are sometimes obtained through questionable statistical approaches still open to debate (Fischer et al., 2019). Moreover, these estimates include mainly subaerial volcanoes (Fischer et al., 2019), while more than 75% of Earth's volcanism occurs underwater (Dziak et al., 2015), including significant output through volcanic lakes. The dynamics of the ideal subaerial volcanic tracer, SO₂, also remain difficult to relate to the source processes due to turbulent interactions in the atmosphere (Woitischek et al., 2021).

But the presence of a large body of water near/on a volcano also provides an under-exploited opportunity to investigate volcanic degassing through non-conventional means. Unlike subaerial settings, the acoustic detection of CO₂ in particular is straightforward in aquatic environments (Caudron et al., 2012), and degassing rates can be tracked at high temporal resolution (kHz) before mixing and dilution in the hydrosphere. Furthermore, the release of gas into the water column in the form of a bubble, is known to produce a distinct and quantifiable acoustic signal from which one can infer its volume (Roche et al., 2024). Note that we are mainly sensitive to gases in the gaseous phase i.e. not dissolved into the ground water / water column.

In this paper, we present the hydroacoustic data we have collected in a variety of volcanic environments and summarise the degassing features observed. These recordings are notably different from those traditionally recorded in the field of volcanology as they were acquired at far higher frequencies, i.e. 4-44 kHz here vs 0.1 kHz typically recorded by ocean bottom seismometers, allowing individual bubble releases/oscillations to be characterised. Our motivation is to highlight the potential for hydroacoustic degassing observations as an eruption and environmental monitoring tool, and encourage the use of this novel dataset by the wider scientific community to encourage further development.

*Corresponding author: corentin.caudron@ulb.be

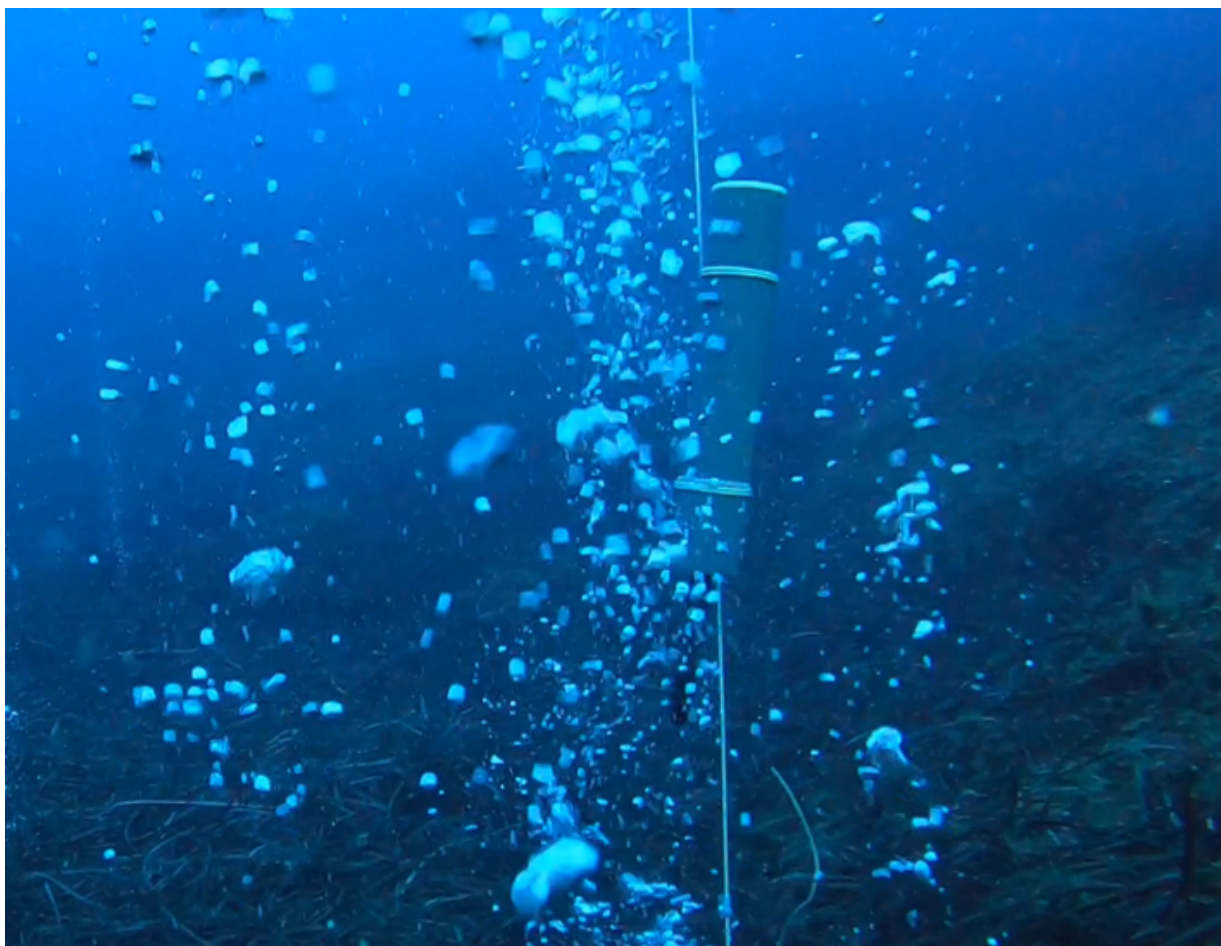


Figure 1 Typical hydrophone setup in Panarea (Italy)

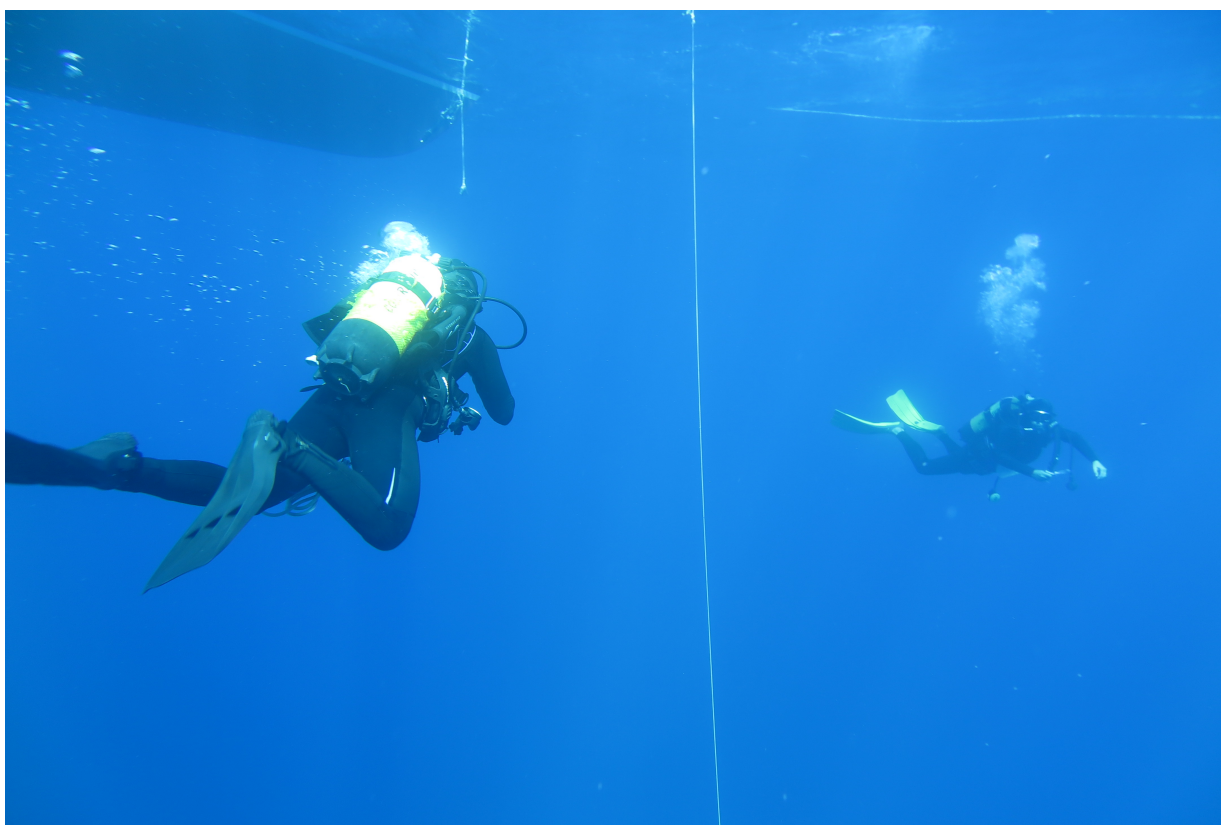


Figure 2 Divers installing a hydrophone at Panarea (Italy)

Location	Description	Depth (m)	Date	Duration	Sampling Frequency (kHz)	Sensitivity (dBV re:1 µPa)	Gain (dB)	Observation
Laacher See (Germany)	Crater Lake	3	30/06/2021 and 02/07/2021	3 days	44.1	-180	18.4	Continuous degassing and pulsed
Panarea (Italy)	Shallow Marine Shelf	23	03/10/2022 to 05/10/2022	3 days	44.1	-180	18.4	Continuous degassing
Vulcano (Italy)	Shallow Marine Shelf	2	03/10/2022 to 06/10/2022	4 days	44.1	-180	18.4	Continuous degassing
Poás (Costa Rica)	Active Crater Lake	1-3	01/03/2023 to 15/03/2023 and 01/06/2023 to 30/06/2023	15 days and 1 month	8	-180	18.4	Continuous degassing and large bubble events
Lake Kivu (Rwanda)	Great Lake	350	31/5/2021	12 hr	44.1	-180	18.4	Pulsed degassing, explosive blowouts, earthquakes

Table 1 Table summarising the main parameters used during our experiments.

2 Instrument and data

All data were recorded using Loggerhead SNAP acoustic recorders via HTI96-min hydrophones (sensitivity -170 to 180 dBV re:1 µPa). The instrument response correction is provided on github. Data are provided in Zenodo repositories.

3 Typical installation

The hydrophones were typically installed near the sea/lakebeds and as close to the seep sites as possible, without being in direct contact with the bubble streams (Fig. 1). This provided the best opportunity to record the acoustic emissions of bubbles oscillating as they were released into the water column. Ideally, divers positioned sensors (Fig. 2) although when this was not possible, sensors were simply lowered into place from the side of a boat. The hydrophones were secured in place via an anchor weight and surface buoy. Data were recorded as .wav files for ease of use. For short monitoring periods, we sampled the data at 44.1 kHz as sound files (.wav). This allows to easily check their quality with standard audio softwares. A list of the available data and main characteristics can be found in Tab. 1.

4 Sites

4.1 Laacher See volcano (Germany)

We recorded a moderate seep field at Laacher See, a volcanic crater lake located in western Germany. The volcano had a major Plinian eruption ~13,000 years ago and still emits significant CO₂ emissions within the volcanic lake and its surroundings (Caudron et al., 2024). We recorded both discrete events, typical of individual bubble releases (Fig. 3), and continuous features (Fig. 4)

that are also characteristic of continuous degassing (between ~ 700 and 1100 Hz, Figure 4).

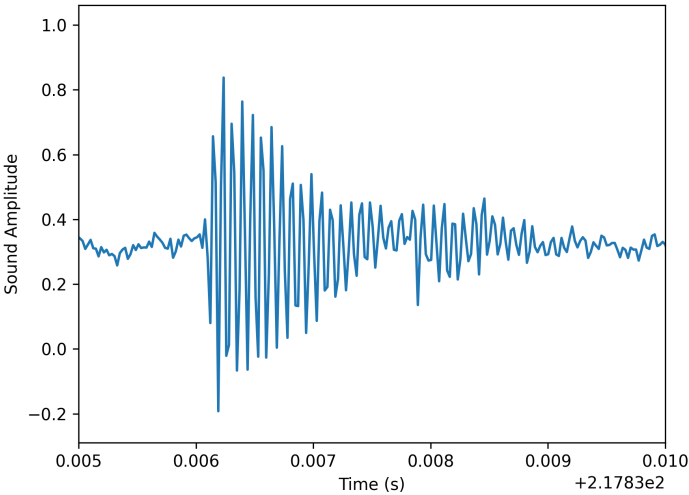


Figure 3 Typical bubble (mm) recorded at Laacher See during an experiment in 2021 with the SNAP instrument. The pressure amplitude is normalized.

This field experiment was led by Corentin Caudron (ULB). This fieldwork was carried out with Alexander Yates (ISterre) and Bernd Schmidt (LGB). Data were recorded continuously between 30 June and 2 July 2021 with a sampling rate of 44.1kHz. The hydrophone was placed next to one of the main degassing areas described in Caudron et al. (2024) for a few days. The sensor was installed within 50 m in the SW part (Figure 1 in Caudron et al., 2024) at a depth of ~3 m.

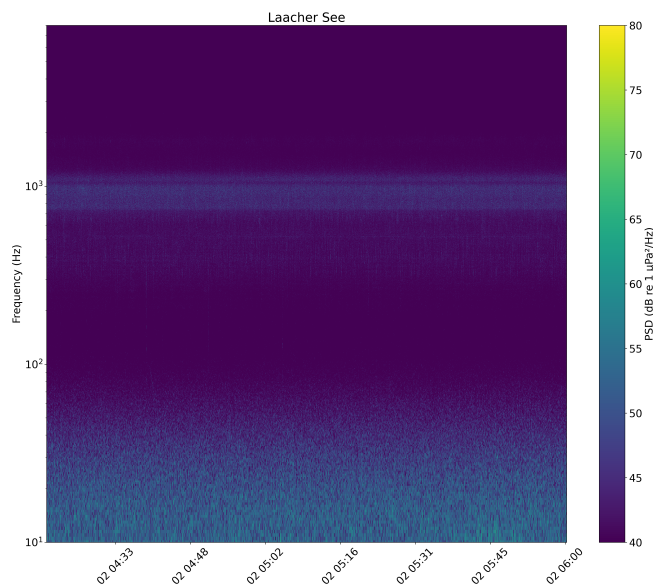


Figure 4 Spectrogram showing continuous degassing at Laacher See volcano with the SNAP instrument. The colour scale corresponds to the power (in dB).

4.2 Panarea (Italy)

We recorded a vigorous degassing plume on offshore Panarea (Italy, Aeolian island) over a 48 hour period. We show a spectrogram of the data (Fig. 5). The shallow waters surrounding the island represent the deeply eroded remnant of an ancient stratovolcano that was active during the Middle to Late Pleistocene (approximately 200–150 ka). While volcanic eruptions ceased tens of thousands of years ago, the surrounding area remains geothermally active due to the shallow magmatic–hydrothermal system resulting in wide spreading degassing in the clear shallow waters. Further information on volcano degassing features can be found in [Roche et al. \(2019\)](#); [Longo et al. \(2024\)](#).

This fieldwork was carried out with Manfredi Longo, Gianluca Lazzaro and Agostino Semprebello (INGV), Olivier Fontaine and Lorenzo Cappelli (ULB), Jean Vandemeulebrouck (ISTerre), Franco Tassi and Orlando Vasselli (U Firenze), and Dmitri Rouwet (INGV). Data were recorded continuously between 3 October and 5 October 2022 with a sampling frequency of 44.1 kHz. The hydrophone next to Bottaro crater at a depth of ~23 m.

4.3 Vulcano (Italy), June 2023

Vulcano volcano (Italy) was experiencing a vigorous unrest ([Neri et al., 2025](#)) when we installed our hydrophone. From 2021–2023, it even prompted an evacuation, among other things due to increased CO₂ emissions. We recorded a vigorous degassing plume, akin to a geyser offshore Vulcano (Italy, Aeolian island) (Fig. 6) over a 48 hour period. We show an example where continuous degassing slightly fluctuate in time between 100 and 400 Hz (Fig. 7).

This fieldwork was carried out with Manfredi Longo, Gianluca Lazzaro and Agostino Semprebello (INGV), Olivier Fontaine and Lorenzo Cappelli (ULB), Jean Van-

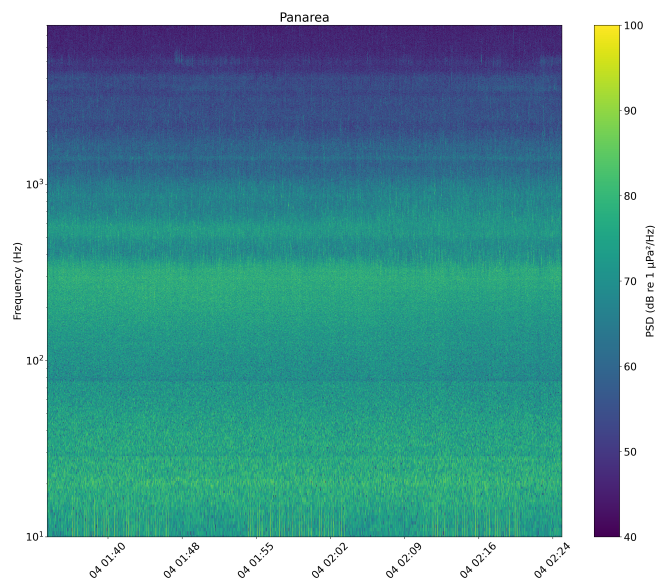


Figure 5 Spectrogram showing continuous degassing at Panarea with the SNAP instrument. The colour scale corresponds to the power (in dB).

demeulebrouck (ISTerre), Franco Tassi and Orlando Vasselli (U Firenze), and Dmitri Rouwet (INGV). Data were recorded continuously between 3 October and 6 October 2022 with a sampling frequency of 44.1 kHz. The hydrophone was deployed at 38.416 degrees N, 14.944 degrees W at a depth of ~3 m.

4.4 Poás (Costa Rica) - Active Crater Lake

We recorded multiple seep fields in the acidic waters of Poás volcanic lake over the course of two weeks in March, then one month in June. This was a few months prior to a vigorous sequence of phreatic eruptions. Some of the results from this short-term experiment are published in [Roche et al. \(2025\)](#) where we estimate the gas flux based on hydroacoustic data and observe 2 large degassing / ebullition events. We show the spectrogram of data (Fig. 8) acquired in March 2023.

This fieldwork was carried out by Alain Bernard (ULB), Geoffrey Avard, Javier Pacheco, Maarten de Moor, Alejandro Rodriguez and Henriette Bakkar (OVSICORI-UNA). Data were recorded continuously between 3 and 15 March, and 1 and 28 June 2023 with a sampling frequency of 4 kHz. Originally, the hydrophone was deployed at a depth of 3 m. As the water level decreased, its depth was reduced to approximately 1 m. Complementary datasets include air gas concentrations and seismic data via the OVSICORI seismic network.

4.5 Lake Kivu (Rwanda) - Great Lake

We recorded the marine soundscape at the bottom of Lake Kivu (360 m depth) during the 2021 eruption of Mount Nyiragongo when a large dyke intrusion was tracked migrating beneath the area. Analysis of the recorded data has revealed evidence of numerous earthquakes, pulsed degassing from small scale seep(s) and previously unreported explosions. These explosions



Figure 6 Aerial view of the Vulcano Baia Di Levante area where a hydrophone was installed. The image was acquired with a drone

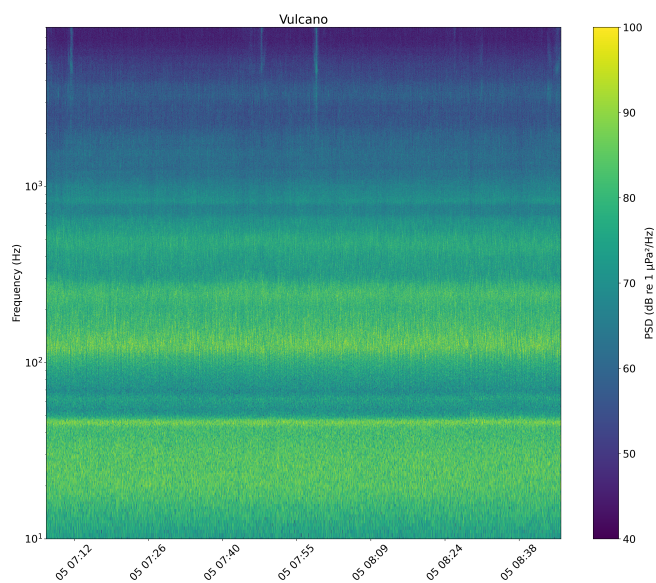


Figure 7 Spectrogram showing continuous degassing at Vulcano with the SNAP instrument. The colour scale corresponds to the power (in dB).

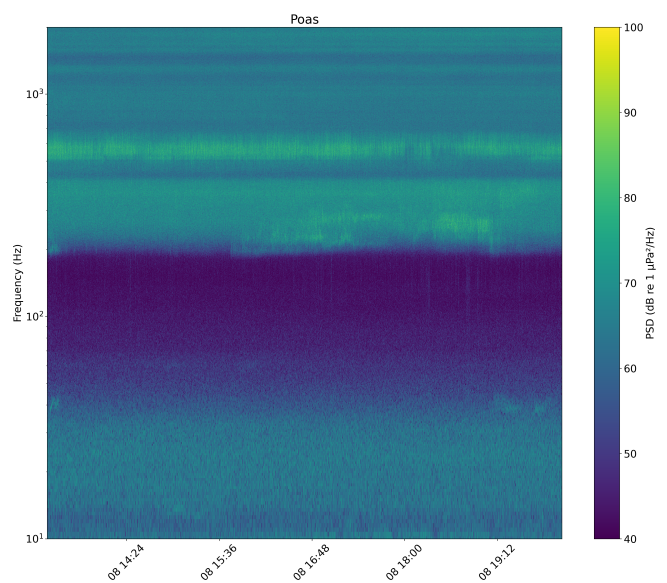


Figure 8 Spectrogram showing continuous degassing at Poas with the SNAP instrument. The colour scale corresponds to the power (in dB).

were most likely caused by blowouts from lakebed gas pockets. Notably, these events occurred without detection by the local seismic network, underscoring the limitations of current monitoring systems and the need for increased hydroacoustic monitoring in the area. The results of this work are in review (Roche et al., 2026).

This fieldwork was carried out by Francois Darchambeau (ULiège, KivuWatt). Data were recorded continuously between 07:15 and 19:15 on May 31st, 2021, (Fig. 9) with an effective frequency range up to 22 kHz.

The hydrophone was deployed at a depth of 350 m (10 m above the lakebed). Complementary seismic data is available via the KivuSNet seismic network.

5 Future perspectives

Hydroacoustics is an underutilized method for monitoring volcanic activity, particularly at higher frequencies (> 0.5 kHz). We have demonstrated their ability to characterize magmatic degassing from rates as low as a cou-

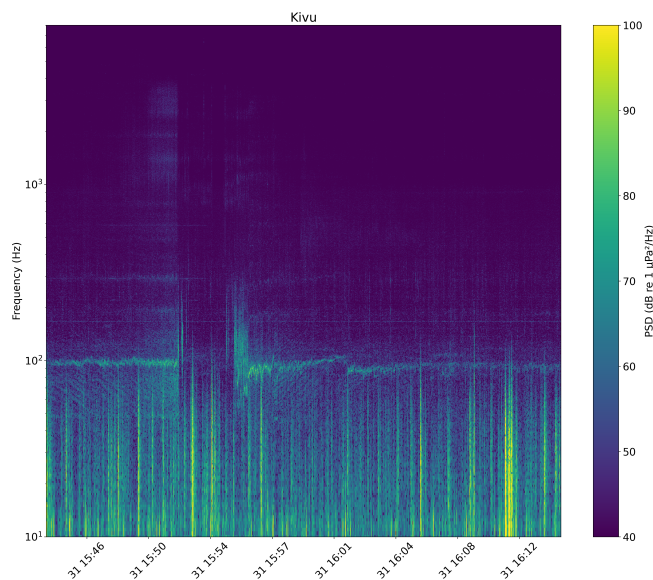


Figure 9 Spectrogram at Lake Kivu with the SNAP instrument. The colour scale corresponds to the power (in dB).

ple bubbles a second to tens of litters a second, to record gas blowouts and act as an additional earthquake observation stations. Each hydrophone deployment detailed in this paper has granted fresh insight into the underlying volcano hydrothermal system. We hope that researchers will process them and possibly find new features.

Based on our experience, future studies would benefit from deploying multiple recorders at a time at moderate distances (10–50 m) apart. This would allow for a greater degree of quantitative signal analysis and source localization. The price for this being a need to synchronize recorders or use more expensive multi-source data loggers. To this end, the use of distributed acoustic sensors / fibre optic sensing is becoming increasingly promising as it allows a linear array of sensors to be deployed at a fraction of the cost of traditional hydrophone arrays and has been proven to be sensitive to various degassing and seismic processes (Caudron et al., 2024).

Ongoing observations by this group that we hope to make available in the future include; Dziani Dzaha crater lake (Mayotte, Indian Ocean), Viti crater lake (Iceland), El Tatio geyser field (Chile), as well as continuing work at Poás (Costa Rica), Lake Kivu (Rwanda) and Laacher See (Germany). With several of these projects incorporating the use of fiber optic cables. We welcome any inquiries about this dataset, our work, or the possibility of future collaboration.

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jandro Rodriguez, Henriette Bakkar, Leonardo Van der Laat (OVSICORI-UNA), Bernd Schmidt (LGB-Germany) that all contributed to this work.

Data and code availability

Data are shared through various Zenodo repositories. We provide miniseed format through these repositories, but we can also share .wav formats upon request. Due to the large volume of data, we only uploaded ~100 files for each site, but the rest is available upon request to the author.

- For Laacher See: Caudron (2025a)
- For Panarea: Caudron (2025b)
- For Kivu: Caudron (2025c)
- For Poas: Caudron (2025d)
- For Vulcano: Caudron (2025e)

The code to correct the instrument response can be found in this repository: <https://github.com/Corentin3/Hydroacoustic-Hydrophone>.

The Kivu Seismological Network data have been used (Oth et al., 2013).

Competing interests

We do not have any competing interests to declare.

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