Annual Report 2024

EUROPEAN CENTER FOR GEODYNAMICS AND SEISMOLOGY (ECGS)

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- **Dr. Nicolas d'Oreye**, geophysicist, National Museum of Natural History
- **Gilles Celli,** technical engineer, National Museum of Natural History

- **Josué Subira,** PhD student, Liège University & Royal Museum for Central Africa (Belgium) / Goma Volcano Observatory (DR Congo), visit at ECGS from 19 August to 9 September 2024
- **Prof. emeritus Antoine Kies**, physicist

INTRODUCTION

ECGS collaborates intimately with the Geophysics/Astrophysics section of the National Museum of Natural History (Mnhn). The Earth Science research group of ECGS and the Mnhn is composed of four permanent scientists (Dr. Adrien Oth, Dr. Julien Barrière, Dr. Delphine Smittarello and Dr. Nicolas d'Oreye), two technical engineers (Gilles Celli and Maxime Jaspard) and one administrative assistant (Yannick Breh).

In 2024, ECGS went through the final stages of the implementation of the 2019 – 2024 strategic 5-year plan, with all aspects covered in the 5-year plan now being operational for the future. Note that some of our activities could only be pursued at slightly reduced pace due to parental leave of two of our staff members (continued from 2023). We continue to work on the maintenance, development and optimisation of the Luxembourg Seismological Network (LuxSNet), which is currently composed of 12 real-time broadband seismic stations. While we unfortunately had to close one station for operational reasons, we are actively exploring sites for additional stations, two among which are foreseen to most probably lead to operational installations during the year 2025. Besides our seismological monitoring and research activities on a national level, we are also aiming at expanding our activities as CTBTO National Data Center (NDC).

Together with French partners from the University of Lorraine and ISTerre, ECGS wrote a bilateral proposal for an AFR-FNR INTER[1] project under the acronym SLIDE (Assessing the contribution of slow-moving landslides to erosion in the Himalayas). This proposal was granted funding and the project started officially on 1 December 2024. We also keep in constant development our tools for the automatic monitoring of ground deformation by satellite radar interferometry (AMSTer software). This allows for the systematic monitoring of several targets for studying deformation of natural (e.g., volcanoes, tectonic activity, landslides) and anthropogenic (e.g., mining activities) origins in various regions of the World (Luxembourg national territory, Nepal, Chile-Argentina, Guadeloupe, Comoros, La Réunion, DR Congo).

Notwithstanding the closure of collaboration with the Goma Volcano Observatory (GVO) in eastern DR Congo in 2022 (see previous annual reports for more information on this issue), the scientific research in this region still plays a role in ECGS's activity portfolio and will do so also in the years to come. Over more than a decade, ECGS/Mnhn researchers have collected vast databases of ground-based and space-born data in the Kivu Rift region. Obviously, the 2021 Nyiragongo eruption plays a key role in this research. In 2024, the PhD candidate Josué Subira from DR Congo, co-supervised by ECGS scientist Dr. Julien Barrière, successfully defended his PhD thesis at the University of Liège. Furthermore, we have selected a post-doctoral candidate to carry out further cutting-edge research work on these data during the coming two years (2025-2026).

As usual, ECGS/Mnhn was involved in a range of strong international collaborations, which are the living proof of the wide recognition of its expertise. In 2024, ECGS/Mnhn researchers published 3 articles in international peer-reviewed scientific journals and (co-)authored 20 contributions at international conferences. In his function as European Seismological Commission Secretary General, the ECGS Scientific Director played a major role in the organisation of ESC's 39th General Assembly in Corfu in September 2024[2,3]. ECGS/Mnhn also successfully organised the 102nd edition of the Journées Luxembourgeoises de Géodynamique (JLG)[4], which was held in conjunction with the 2024 Scientific Session of the European Facilities for Earthquake Hazard and Risk (EFEHR) in November 2024. This meeting brought together 60 participants from 18 countries to discuss challenges faced in multi-hazard and risk assessment.

[1] https://www.fnr.lu/funding-instruments/inter/
[2] https://www.erasmus.gr/microsites/1277
[3] http://www.esc-web.org
[4] https://www.ecgs.lu/102nd-jlg/

Seismological Research & Monitoring Activities

❖ Seismological monitoring infrastructure operated by ECGS

In 2024, ECGS continued the development and maintenance of the **Luxembourg National Seismic Network (LuxSNet)**. LuxSNet is designed to provide adequate coverage with high-quality broadband seismic stations throughout the entire country for monitoring the seismic activity within and around Luxembourg's territory. The current status of LuxSNet is shown in Figure 1, including the temporary stations deployed in 2022-2023 in the framework of the Large-N project in the Eifel[5] coordinated by the GFZ German Research Centre for Geosciences in Potsdam, as well as two station sites currently under planning.

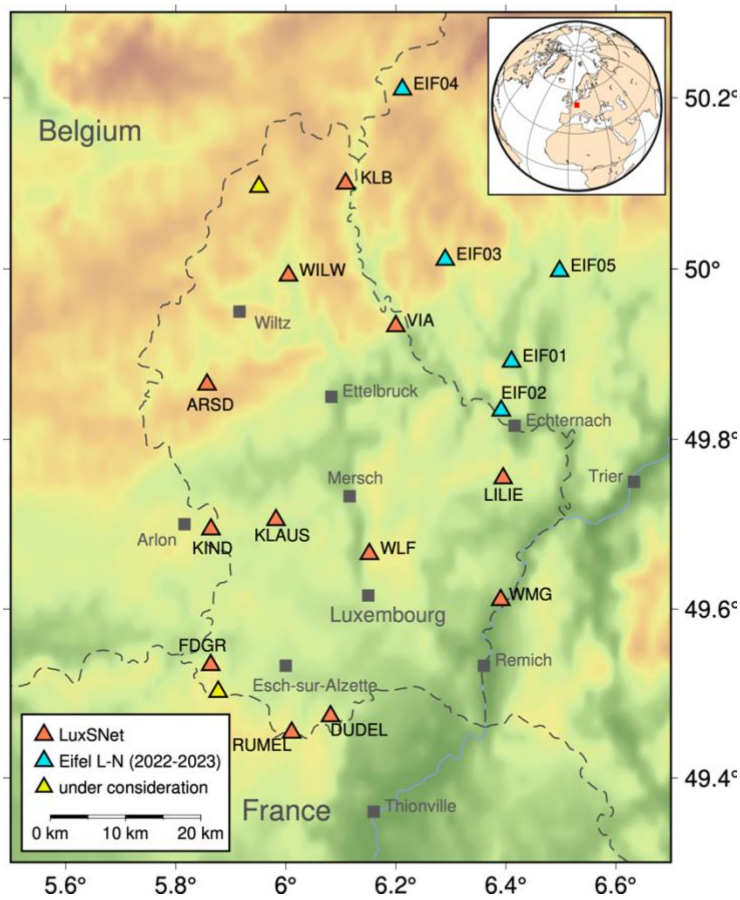

Figure 1: Current status of LuxSNet. The temporary stations EIF01 – EIF05 have been dismantled at the end of August 2023 after one year of operation.

Luxembourg is a region of overall low seismic activity and hazard, as it is located well within the Eurasian Plate, far away from its boundaries. However, even though the Luxembourgish territory does not show significant present-day or historical seismicity, this is not the case for regions as close as 100 – 150 km from the Grand Duchy. For instance, the Roermond earthquake in 1992, which took place close to the border of the Netherlands and Germany and had a magnitude of 5.4, was also widely felt in Luxembourg. We will discuss the new scientific results of our monitoring activities in Luxembourg here below.

ECGS is involved as a partner institution in a large-scale seismological experiment covering the **Eifel region** in western Germany, a project coordinated by the GFZ German Research Centre for Geosciences. The Eifel, located at the doorstep of Luxembourg, represents an intracontinental volcanic field, yet the magmatic system underlying this field is still not very well understood. Since 2013, episodic swarms of deep low-frequency earthquakes, typically related to fluid movements in the Earth's crust and upper mantle, have been recurrently observed in the East Eifel. To obtain new insights into this system, more than 350 seismic measurement stations have been installed in late 2022 and were operated for one year (dismantlement took place in August 2023), recording earthquakes as well as continuous ambient background noise. ECGS participates in this so-called Large-N seismic experiment by (1) providing five broadband stations for temporary deployment (Figure 1) as well as the data from the LuxSNet network and (2) through scientific contributions in the data analysis, e.g. as cooperation partner in the SURVIVE project lead by GFZ[6].

[5] https://www.gfz.de/en/section/physics-of-earthquakes-and-volcanoes/projects/eifel-a-large-n-volcano-seismology-experiment

[6] https://www.gfz.de/en/section/physics-of-earthquakes-and-volcanoes/projects/survive-follow-the-co2-icdp-eifel-pre-site-survey-by-large-n-passive-seismology

The permanent LuxSNet network currently counts 12 active broadband seismic stations (Figure 1), covering the entirety of the Grand-Duchy. Station ETLBK in the vicinity of Ettelbruck unfortunately had to be closed for operational reasons, and we are currently looking for an appropriate replacement site in that area. The temporary broadband stations that were installed in the Eifel for the Large-N experiment were integrated into the LuxSNet archives and will also be archived alongside with the entirety of the Large-N data (network code 6E) at the GFZ Helmholtz Centre for Geosciences EIDA node[7] in a virtual network.

LuxSNet is under continuous development for 15 years now (Figure 2), which allows for a better understanding, year by year, of the natural seismicity in Luxembourg. We are always on the look-out for good monitoring sites in the different regions of Luxembourg. At present, a new seismic station is planned to be set up in the former slate mine in Wincrange (required authorisations received), and the option to install a shallow borehole station (10 m depth) is currently explored for a site near Differdange, which is already occupied by a weather station from the meteorological service of the Administration des services techniques de l'agriculture (ASTA) (see Figure 1 for locations).

All LuxSNet data are transmitted in real time to the ECGS office in Walferdange and evaluated with the real-time, automatic SeisComP software package developed by scientists at the GFZ Helmholtz Centre for Geosciences and the company Gempa. Since early 2024, ECGS also operates a SeisComPro system with a set of a few additional commercial modules by Gempa, improving LuxSNet's real-time detection and location capabilities.

ECGS shares seismic data of its broadband network with the Royal Observatory of Belgium (a decades-long collaboration exists already for the seismic stations in Kalborn and Vianden), the Erdbebendienst Südwest (Rheinland-Pfalz & Baden-Württemberg) and the Bensberg Observatory of the University of Cologne in Germany.

On the German side, we have real-time access to station RIVT close to Trier as well as several stations from the Bensberg observatory towards the north of Luxembourg and towards Koblenz, while we provide data from our station WMG, KLB, VIA and WILW to the German colleagues. All data from the Belgian National Seismic Network are now available in real-time via the ORFEUS Data Center (ODC)[8] (since 2024), and we use in particular stations DOU, HOU, RCHB and MEM to improve our azimuthal coverage on the Belgian side. In turn, we provide our colleagues in Brussels with access to real-time data from our stations KIND and WILW. These collaborations show that the Luxembourg seismic data are also of interest to the monitoring agencies in our neighbouring countries and that the expertise of ECGS as Luxembourgish partner institution is recognized. Furthermore, we also make use of the openly available seismic data of the French ReNaSS network that are located in the vicinity of our borders.

We are currently also in discussion with our colleagues from ODC and the GFZ EIDA node in order to make all LuxSNet data freely available without restrictions, and we expect that this open data access will be finalised in the first few months of 2025.

Since 2020, ECGS assumes the role of National Data Centre in the framework of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) on a best-efforts basis, for which we were

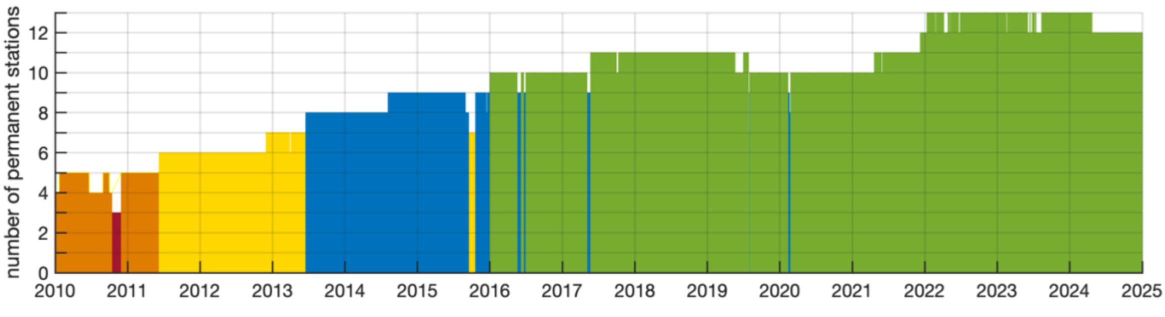

Figure 2: Timeline of data availability (number of operational permanent stations per day) for the Luxembourgish seismic network since 2010.

[7] https://geofon.gfz.de/waveform/archive/network.php?ncode=6E&year=2022
[8] https://www.orfeus-eu.org/data/odc/

approached by the Ministry of Foreign Affairs in 2019 as potential scientific partner in the framework of a Benelux Memorandum of Understanding. In this context, ECGS's scientific director regularly participates in the WG-B meetings of CTBTO in Vienna (or remotely) and we maintain close contacts and collaboration in particular with our colleagues from the Dutch NDC at KNMI. Since mid-2024, ECGS also has a functioning GCI connection with the CTBTO International Data Center (IDC).

Until mid-2022, ECGS/Mnhn also operated a large network of seismic, geodetic and infrasound instruments in the Kivu Rift region in Central Africa (see previous reports for more detailed information). However, the collaboration of ECGS/Mnhn with GVO and hence also the acquisition and/or transmission of any new data via ECGS/Mnhn infrastructure ended on 1 July 2022.

❖ Natural (Tectonic) Seismicity in Luxembourg

As already stated in previous reports, the Luxembourgish seismic picture (either discrete events or continuous noise) is dominated by anthropogenic activity (quarry blasts, road traffic, industrial activities, etc.), like for any other populated areas worldwide (Lecocq et al., 2020). However, it becomes clear that some small-scale tectonic activity has repeatedly occurred in some faulted areas (Figure 3). We provide in the present report the manual revision of the 2010-2024 seismic catalog, leading to the detection and location of 16 natural earthquakes occurring on Luxembourg's territory or nearby (within 10 km from the boundary). This review is based on results from the automatic XCloc event location software developed at ECGS. For local to regional earthquakes, errors in location can be large depending on the earthquake specificities (source mechanisms, magnitude, depth), the Earth's structure, the network's spatial configuration and the signal-to-noise ratio at the available stations (controlling the quality and number of seismic phase observations). Thanks to its grid-search approach based on travel times extracted from waveform cross-correlation between station pairs, XCloc provides a better evaluation of the location error compared to standard iterative inversion techniques commonly used in observatories, at the expense of a longer computational time (e.g., Barrière et al., 2022; Subira, 2024). For the investigated area discretized as a 3D grid, the result is on the form of 3D gridded location coefficients for each detected event. In its last version (2024), XCloc provides two estimates of the final hypocentre solution, the maximum of the location coefficients (i.e., comparable to the most probable location) and the centre of the 68.3% confidence ellipsoid (i.e., the hypocentre has a 68.3 % chance to be located inside the ellipsoid). The confidence ellipsoid is constructed from the gridded location data following the approach of the NonLinLoc software[9] for estimating the 3D covariance matrix.

The final hypocentres plotted in Figures 3 and 4 correspond to the maximum of the location coefficients. If the solution is well constrained, the centre of the confidence ellipsoid would be close and the projected ellipsoid in the longitude/latitude plane would be small (i.e., a few kms). The error along the depth is always much larger compared to the epicentre uncertainty because of a poorly known Earth's structure. For routine applications, a 1D velocity model (i.e., velocity only varies with depth for the whole area) is often assumed and used for earthquake locations, as it is the case in Luxembourg. Figure 3 depicts the epicentres and the records at WLF station (Walferdange mine). Figure 4 represents the 3D view with the confidence ellipsoids, of which the extents at depth are significant for all events (> 10 km). Most events are located at shallow to mid-crustal depths with most probable focal depths around 10 km b.s.l. (below sea level). One can note that events n°1 and 4 at the North have a very large horizontal (longitude/latitude) uncertainty because they occurred outside the network and their confidence ellipsoids cannot be well constrained with all available recordings south of the epicentres. Hence, the spotted locations in Figures 3 and 4 for these two events are given in/near Luxembourg but other potential solutions somewhat further to the north (and at larger depths) cannot be fully excluded.

We give below some final remarks regarding the located events:

- To our knowledge, none of the above-mentioned events were felt by humans;
- The two most energetic events occurred around Mondorf/Schengen (event n°5, local magnitude M_L 2) and Hesperange/Alzingen (event n°8, M_L 1.9), both in 2019. A smaller replica of the event n°5 occurred in April 2022.

[9] http://www.alomax.net/nlloc

- The smallest magnitude event (M_L 0.6) occurred around Mertert/Wasserbillig.
- Highly similar events n° 3 (M_L 1) and 14 (M_L 1.1) belong to the Grünewald multiplet (i.e., similar waveforms = similar source processes). This family of repetitive events has occurred over 10 years at the same location. In total, 15 such events have been detected between 2013 and 2023 (see 2023 report), albeit only these two could be detected on national network scale, while the remainder was detected using a template matching approach.

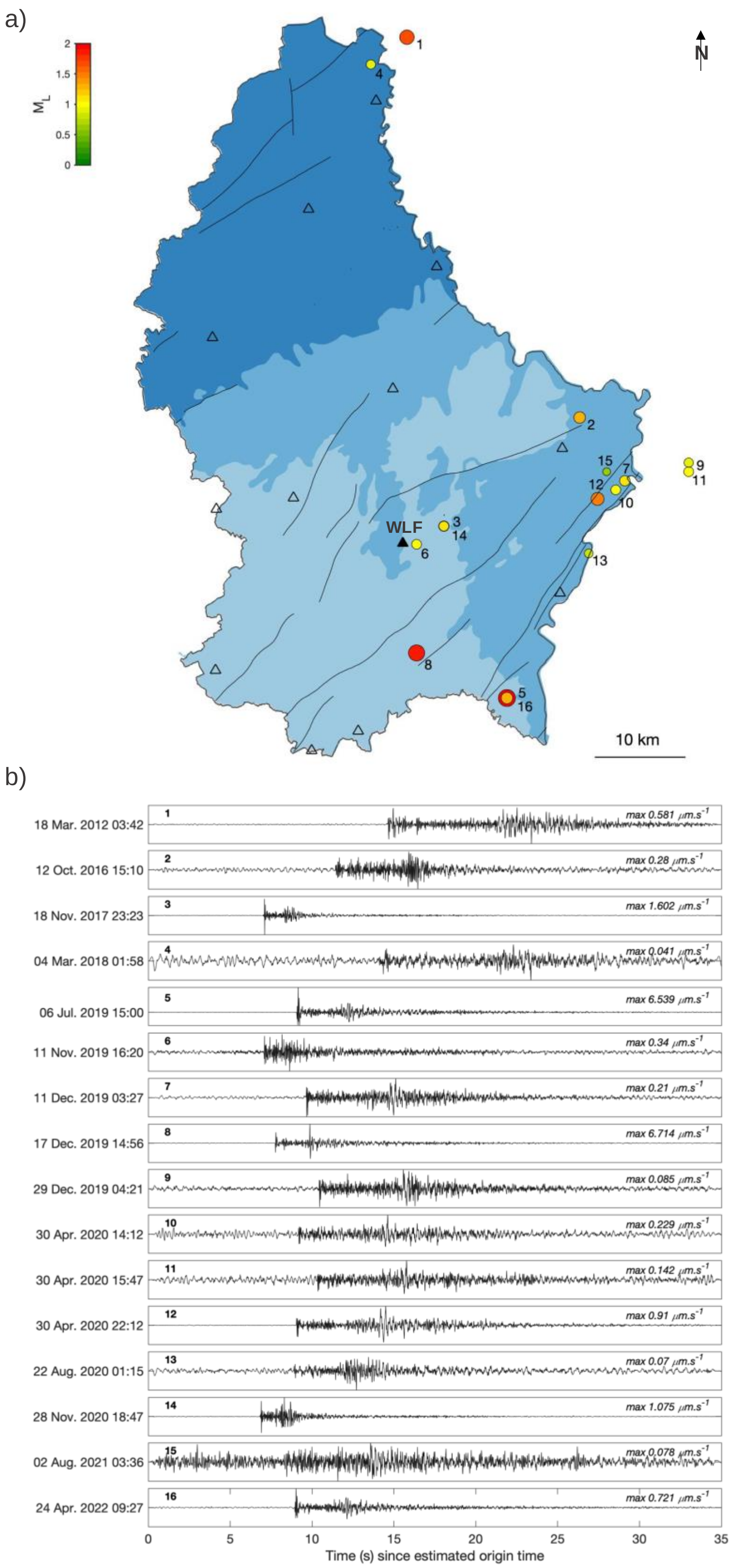

Figure 3: Natural (tectonic) earthquakes located in Luxembourg. **a)** Map of epicenters (size and color of the round markers are proportional to the magnitude M_L (computed using records from horizontal components). The three main bedrock geological units of Luxembourg (Devonian-Trias-Jurassic) are colored from dark to light blue, respectively, and the main geological faults are depicted in solid black lines (source: geoportail.lu). Lux-SNet stations (network code LU) are depicted with unfilled triangles. The Walferdange station (WLF, network code GE) is represented by the filled black triangle. **b)** The vertical component records at station WLF for each earthquake (filtered above 2 Hz). Note that amplitude of the seismic traces is normalized for each record.

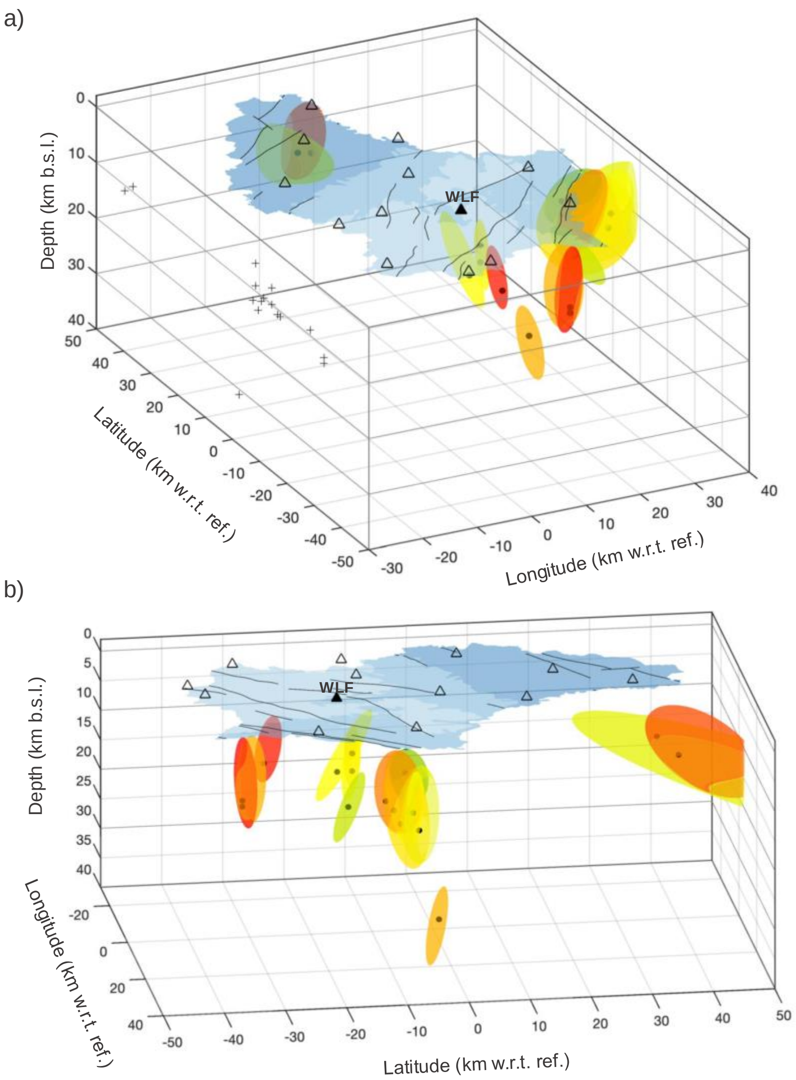

Figure 4: 3D view of hypocentres located in Luxembourg. **a)** Black dots at depth represent the maximum of the location coefficients (i.e., the most probable hypocentres) and the crosses are their projections onto the Latitude-Depth plane. For each event, the corresponding confidence ellipsoid is coloured according to the magnitude (see colour scale in Figure 3. **b)** Same as in a) with a different viewing angle. Note that too large ellipsoids at the limits of the selected domain can be clipped.

❖ Environmental Seismology in Luxembourg: Preliminary results & perspectives

Modern seismology encompasses several research fields, from the “traditional” seismology consisting in analyzing tectonic earthquakes to recent innovative uses of seismometers for studying and monitoring various natural phenomena, e.g., flood events, landslides, glaciers, avalanches, debris flows, etc. The term “Environmental Seismology” is generally used for describing such approaches (Larose et al., 2015). The above-mentioned surface processes occur at the interaction of the solid Earth and the atmosphere and can also generate acoustic waves (pressure disturbance in the atmosphere) in the infrasound band (inaudible, <20 Hz). Coupling of acoustic waves to the ground (i.e., detected by seismometers) or ground-to-air coupling (generated by a seismic wave passing through the infrasound station) can occur as well. In a world affected by increasing effects of global climate change, studying the complex seismo-acoustic signature of such natural hazards has diverse implications, from the understanding of the physical processes (e.g., Tsai et al., 2012; Sovilla et al., 2025) to detection and early warning (e.g., Mayer et al., 2019; Cook et al., 2021).

Storms and flood events

Ten years ago, ECGS performed the first field study in Luxembourg on this topic in collaboration with LIST by analyzing the seismic noise generated by a summer flood event in a low-gradient rural gravel-bed stream (Barrière et al., 2015). While the method is well adapted for tracking flood events in powerful rivers in mountain environment, this study pointed out the relevance of using seismometers for monitoring fluvial processes in small stream (discharge < 2.3 m^3/s) even if the dominant seismic noise was of human origin (road traffic in this case). Near-field measurements (a few meters from the riverbank) and dedicated signal processing allowed to retrieve the signature of the river flow and the sediment bedload transport in the seismic records. Such approaches are case-study specific and can be applied to any other catchments of any sizes.

In Luxembourg, as for many places worldwide, catastrophic floods in densely populated areas generated by extreme hydro-meteorological events are of major concern. Because hydrological/meteorological data acquired on the ground may lack the necessary spatial and/or temporal resolution, recent studies have highlighted the added value of using seismometers for monitoring in real-time the spatio-temporal evolution of severe storms and their consequences (e.g., Dietze et al., 2022; Coviello et al., 2024). Even without dedicated local deployment in critical areas, the Luxembourg national seismic network in its current configuration could be already useful in complement to hydrological/meteorological observations to track severe storms impacting the country, generating floods, landslides, tree falls, etc.

For testing this hypothesis, we looked at major events occurring in the past few years in Luxembourg, causing significant physical and material damages and financial losses. This first preliminary comparison between hydrological/meteorological data with seismic records was performed using reports from MeteoLux and is described in Figures 5 and 6. Here below, the source **MeteoLux** refers to the following documents:

- MeteoLux Webpage[10], last consulted on 27 January 2025;
- Mathias, L. (2019). Major flood event in the Mullerthal region on 1 June 2018: event analysis and predictability, MeteoLux report, 17 pages[11], last consulted on 27 January 2025.

It is well-known that wind is a dominant source of seismic noise during storms, both at high frequency (> 1 Hz) due to unsteady shearing and turbulence near the ground and from atmospheric-induced pressure variations that push down on the ground at very-low frequency (<0.05 Hz) (Smith and Tape, 2019). Strong rainfall can be at the origin of seismic signals at much higher frequency, e.g. > 30 Hz (Coviello et al., 2024). Frequency content of river-induced signals (fluid flow and bedload transport) overlap the frequency bands of wind and rainfall noise at high frequency (> 1 Hz). This contribution is not considered in the two examples described below because the sensors are not close enough to large rivers (e.g., <100 m for a river with discharge > 500 m^3/s, Smith and Tape, 2019).

Figure 5 shows the propagation of severe thunderstorms impacting Luxembourg on 29 June 2024 as viewed by a weather radar located in Germany (Figure 5a) as well as three LuxSNet seismic station recordings (DUDEL, KLAUS, WILW) and one infrasound recording (WALFER) (Figure 5b). The infrasound station was installed for a 1-month period in June 2024 in ECGS's facilities during F. Waligora's internship for testing purposes. The seismic and acoustic recordings clearly reveal the signature of the storm and its propagation from the south to the north as seen on the radar images. Seismic signals exhibit different frequency content between Dudelange and Klaushaff/Wilwerwitz, which could indicate site effects and/or a change in the nature of the storm (rainfall, wind). The infrasound signal is less noisy as compared with the seismic traces and the atmospheric perturbations due to the wind gusts are well detected above 0.1 Hz (corner frequency of the instrument).

Figure 6 shows weather data (rainfall and wind speed) obtained in Waldbillig at the heart of a major flood event impacting the Mullerthal region on 1 June 2018. We obtain a clear signal from a seismic station located less than 10 km away in the south-east direction (LILIEN, Lilien/Rosport-Mompach). There is a time shift between wind and rainfall peaks that could be seen in the seismic record but because both stations (weather and seismic) are not collocated, it is difficult to infer whether the rainfall or the wind is the dominant source of seismic noise. The seismic data was originally sampled at 100 Hz so only frequencies below 50 Hz can be resolved. The noise is broadband above 5 Hz and no clear frequency shift with time is observed so the two most likely sources of noise cannot be distinguished. Considering the 3-hour long storm-related seismic signal (approx. 23:30 to 02:30), both wind and rainfall likely contributed to the recorded ground motion.

As raised by Coviello et al. (2024), many more multi-parametric studies are needed to understand the multiple contributions of different sources (rainfall, wind, water flow, bedload transport) to the recorded signal before it will be possible to routinely integrate seismic data into risk management

[10] https://www.meteolux.lu/fr/actualites/the-severe-thunderstorms-of-june-29-2024-a-brief-analysis
[11] https://www.meteolux.lu/fr/filedownload/595/floodmullerthal_fullreport_en_final-1.pdf/type/pdf

procedures as a real-time product for detecting and characterizing floods. Following these promising preliminary results obtained in Luxembourg using the LuxSNet and a starting collaboration on this topic in 2025 with University of Catania (V. Gangemi's PhD thesis about the seismic noise recorded at the Tagliamento river), ECGS will continue to contribute to this research field.

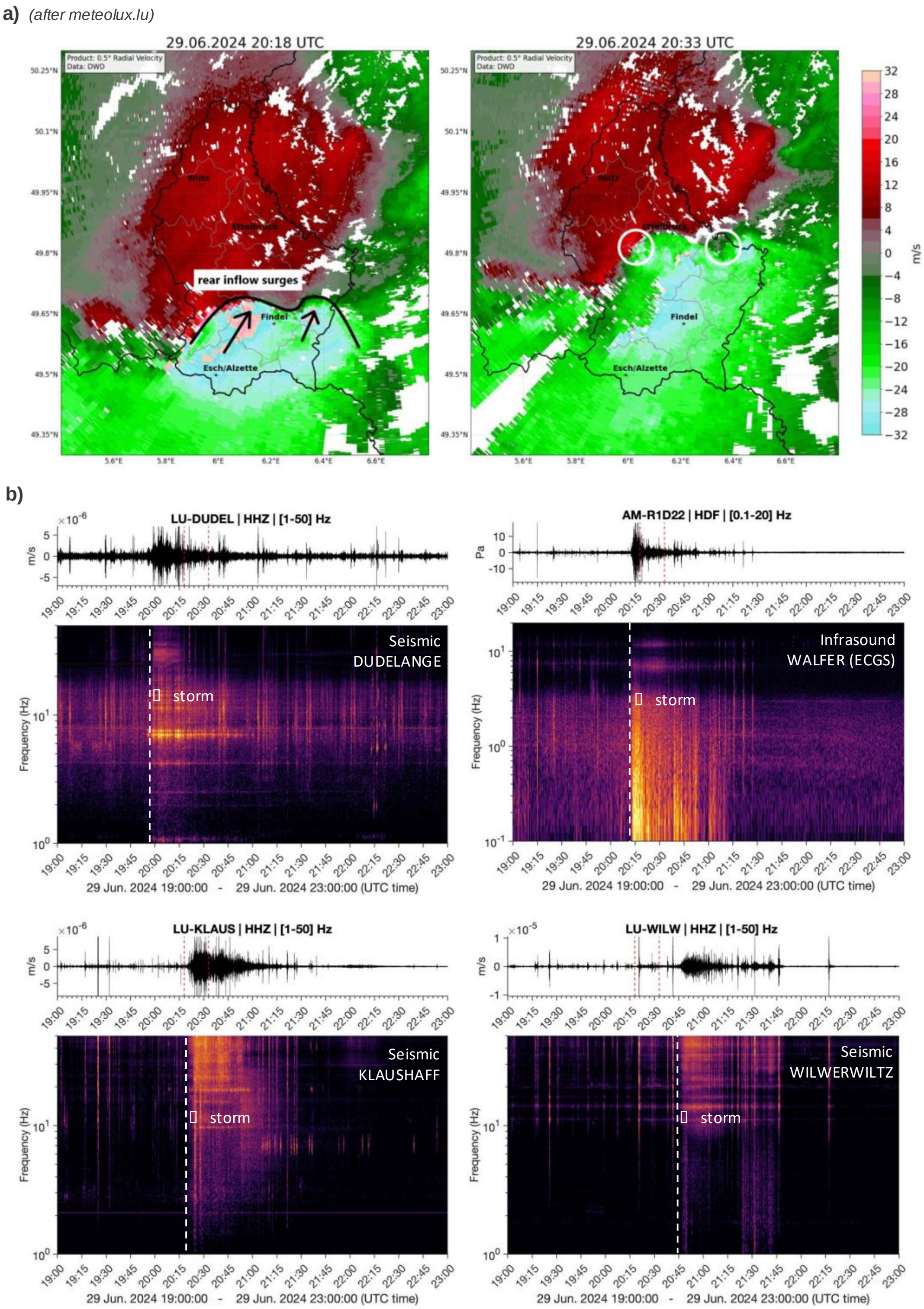

Figure 5: a) After meteolux.lu**: "**Radial velocity (m/s) measured on 29 June 2024 at 20:18 UTC (22:18 CEST) and at 20:33 UTC (22:33 CEST) by a weather radar located in Neuheilenbach (Germany) with an elevation angle of 0.5°. The mesovortices are denoted by white circles. Data source: Deutscher Wetterdienst." **b)** Vertical-component seismic (DUDEL, KLAUS, WILW) and infrasound (WALFER/R1D22) records and their corresponding spectrograms (Short-Time Fourier Transform). The vertical red dashed lines indicate the timing of the two radar images depicted above (20:18 and 20:33). The vertical white dashed lines indicate the start of storm-related signals at each station. Records are clipped below the 99.99th percentile. The spectrogram's amplitude scale (dB, black-to-yellow colorscale) is ranging between the 50th and 99.99th percentile.

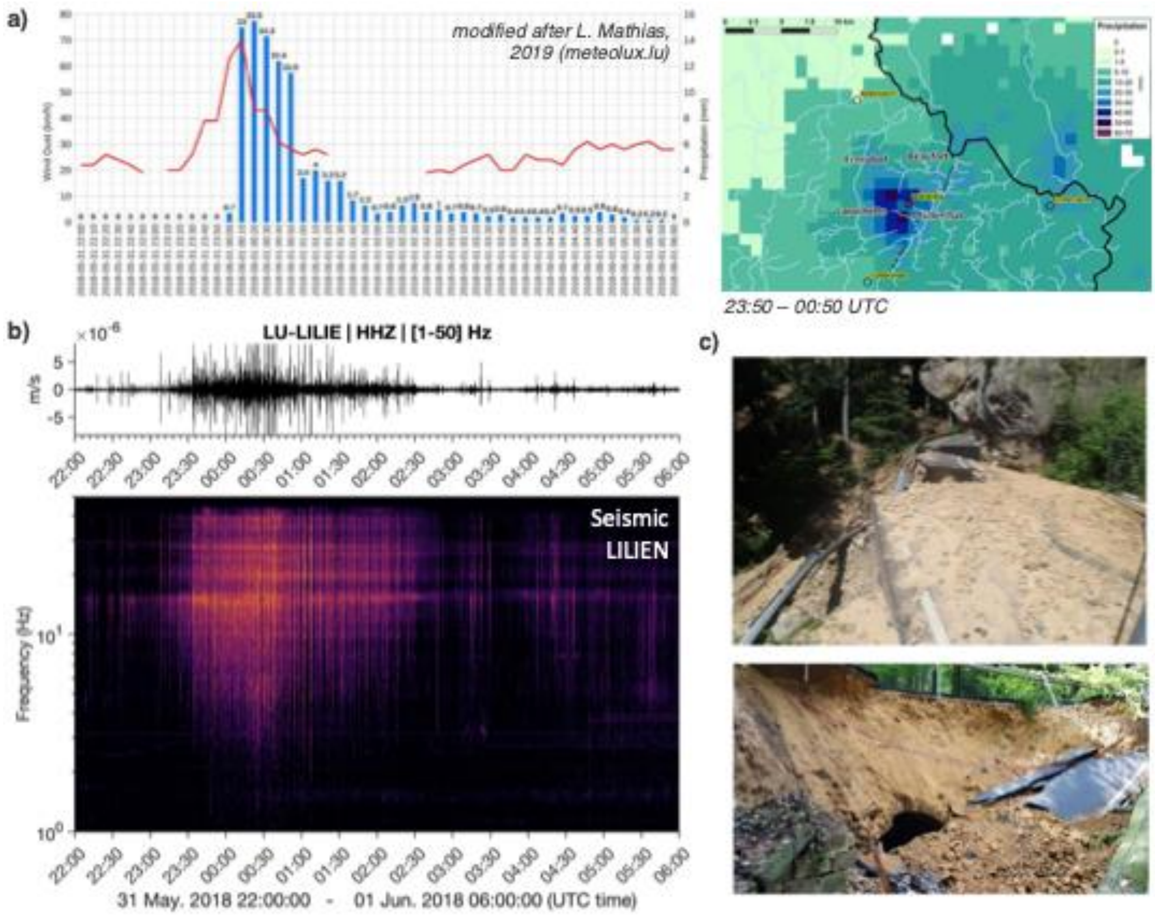

Figure 6: a) After meteolux.lu: Left, "Accumulated precipitation (blue bars; mm) and maximum wind gusts (red line; km h-1) during the preceding 10 minutes measured by the ASTA surface weather station in Waldbillig between 2200 UTC on 31 May 2018 and 0600 UTC on 1 June 2018.". Right, "Accumulated precipitation between 2350 UTC on 31 May 2018 and 0050 UTC on 01 June 2018 in the study area, derived by RADOLAN (shaded; mm) and measured by ASTA surface weather stations (towns with yellow text buffer; Waldbillig: 69.4 mm, Echternach: 25.5 mm, Godbrange: 7.8 mm, Bettendorf: 2.2 mm)." **b)** Vertical-component seismic record at LILIEN station and it corresponding spectrogram (Short-Time Fourier Transform). The record is clipped below the 99.99th percentile. The spectrogram's amplitude scale (dB, black-to-yellow colorscale) is ranging between the 50th and 99.99th percentile. **c)** Photos of damages in the impacted area (Berdorf, Haller) (source: Luxembourg Institute of Science and Technology).

Tornados

A surprising, yet very interesting, outcome of this first attempt at comparing severe meteorological phenomena and seismic records in Luxembourg, is the detection of the impressive tornado (with secondary vortexes) that hit the south of Luxembourg in 2019, classified IF2+ on the International Fujita Scale after MeteoLux (i.e., maximum wind speed around 240 km/h). Here below, the source **MeteoLux** refers to the following documents:

- MeteoLux Webpage[12], last consulted on 27 January 2025;
- Mathias, L. (2020). Tornado in south-western Luxembourg on 9 August 2019: Meteorological context and damage assessment, MeteoLux report, 30 pages[13], last consulted on 27 January 2025.

Tornados are highly localized phenomena. While the storm cell at the origin of the tornado can be well identified in radar reflectivity data, meteorological radar images cannot image the tornado's path

[12] https://www.meteolux.lu/fr/actualites/retour-sur-la-tornade-du-9-aout-2019
[13] https://www.meteolux.lu/fr/filedownload/675/tornado20190809_report_final.pdf/type/pdf

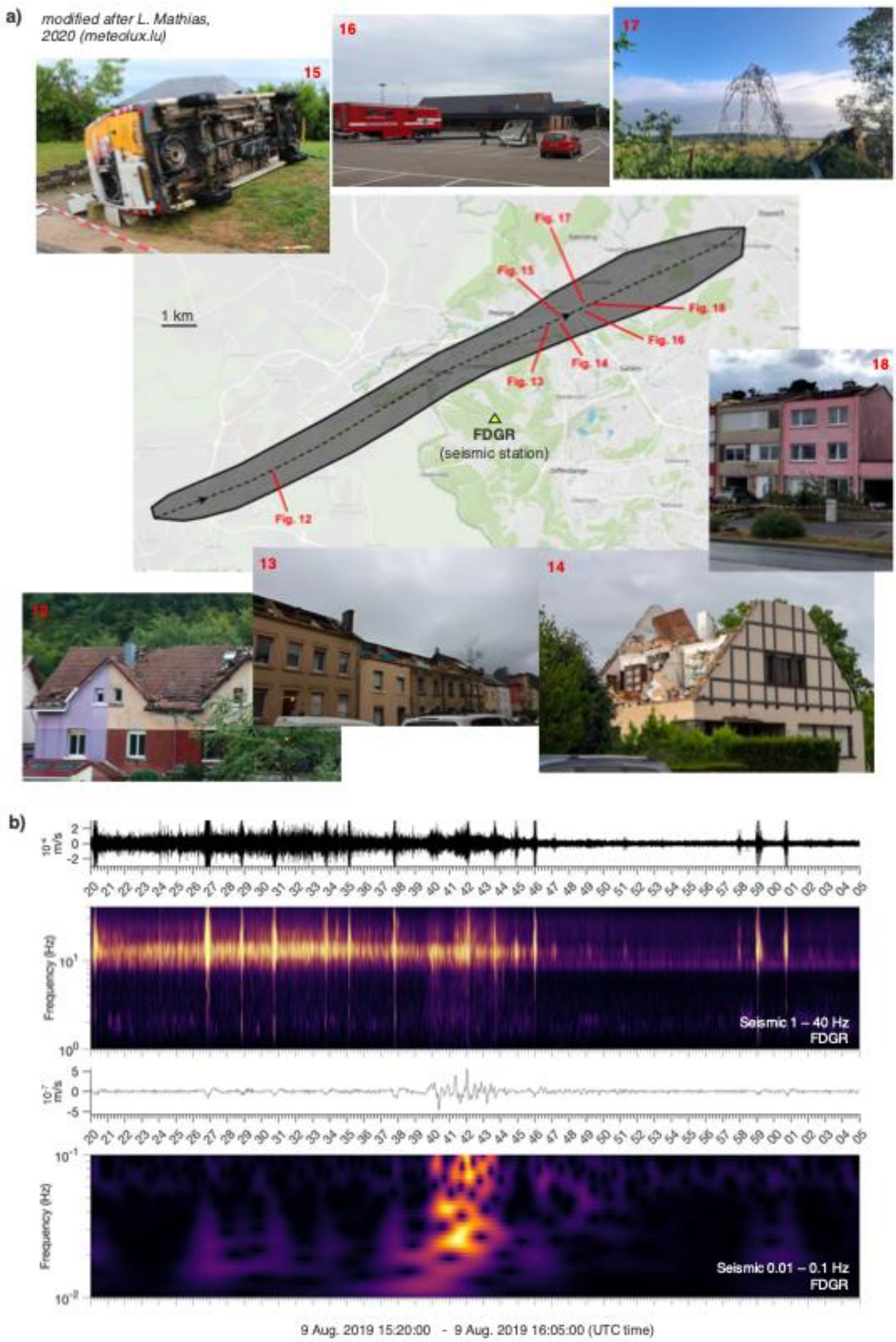

Figure 7: a) After MeteoLux: "Analysed track of the tornado with references of damage pictures shown in this study. Note that the width of the black polygon does not represent the true width of the tornado, but the estimated maximum damage radius." For description of photos, see original figures 12-18 in MeteoLux report[13]. **b)** Vertical-component seismic record at FDGR station between 15:20 and 16:05 UTC on 9 August 2019, filtered into two frequency bands: high frequency (1-40 Hz) and very low frequency (0.01-0.1 Hz). The time-frequency representation is obtained using a continuous wavelet transform.

on the ground (**MeteoLux**). The tornado's track (Figure 7) produced by **MeteoLux** was based on media reports, witness reports, storm chaser reports and documentation by the city of Bascharage technical department. The presence of the seismic station FDGR (Fond-de-Gras) a few km south of the tornado's path offers the chance to investigate a potential signature of the tornado touchdown in seismic measurements (Figure 7). As observed for the storm events, wind is most likely the primary source of seismic noise in this case. We detect a clear signal above 1Hz (i.e., high-frequency signal) on the form of a continuous tremor, with a sharp decrease around 15:45-15:46 UTC. This time is in excellent agreement with the estimation by **MeteoLux** of the complete dissipation of the tornado while exiting Bascharage with last minor damages to vegetation**.** One seismic sensor is insufficient to locate the source of noise but an increase of the signal amplitude conveys either a closer and/or a stronger source. The tornado could have lasted a bit more than 10 minutes, between Longwy and Bascharage. According to its transit time in Longwy and Herserange around 15:35 UTC before it gained more intensity in Luxembourg up to 15:45 UTC, there is no clear seismic signature of the tornado's touchdown in the high-frequency signal. The strong background level around 10 Hz that shuts down after 15:45 UTC is most likely related to the supercell storm that produced the tornado at the end of its life cycle (**MeteoLux**).

However, filtering into a very long-period frequency band (0.01-0.1 Hz) highlights a distinct signal between 15:39 and 15:44. This timing correspond to the strongest phase of the tornado over the towns of Pétange and Bascharage (Photos 13 to 18 in Figure 7). This signal should contain contributions from the tornado-generated vertical seismic signal and from air waves coupling to the ground. To remove the contribution from air waves, co-located barometer measurements are required (Valovcin and Tanimoto, 2017).

It is also interesting to observe that the number of impulsive (broadband) signals decreased significantly after the tornado disappeared. While human activity was plausible at that moment (road traffic for instance), this observation suggests that some of these transients could be due to lightning strikes (Hinzen, 2012) and/or thunder-induced ground motions (Lin and Langston, 2007) because a significant decrease of the lightning density was also observed at that moment (**MeteoLux**). More research is needed to better understand the complex seismic signature of this unique meteorological phenomena in Luxembourg by combing seismic with available weather data (wind, rainfall, lightning).

Landslides

As many other places worldwide, Luxembourg is also impacted by landslides, either natural- or human-caused (e.g., crassier de Mondercange). Landslides are the most widespread Earth's surface phenomena, which can cause dramatic geomorphologic changes.

In the framework of the recently funded ANR/FNR 4-year project SLIDE (see also page 21), ECGS will deploy a dense seismic monitoring network at the landslide scale (~1 km) in Nepal for studying the time-varying properties changes of subsurface materials and the forcing mechanisms (earthquake, rainfall) of slow-moving landslides. Infrasound will be also monitored as landslide rupture and debris flows that can occur nearby during monsoon periods would generate acoustic waves. The envisaged monitoring network consists of 12 short-period (Smartsolo 5 Hz 3-component sensors), 4-5 broadband stations (Nanometrics Trillium Compact stations from ECGS' instrument pool), up to 4 infrasound sensors and 12 GNSS stations.

In Luxembourg, landslides are smaller and typically triggered by heavy rainfall, which can be highly time-limited and localized, or long-term accumulated precipitation. Note that the occurrence of earthquake-induced landslides in Luxembourg cannot be fully excluded due to the moderate seismic activity in the neighbouring regions. The national network cannot be used to monitor such small-scale objects but it can be useful to provide constraint to the triggering mechanisms, as evidenced by the Mullerthal storm (Figure 6). The instrumentation acquired through the SLIDE project (short-period seismic nodes) could be also of interest in the future for studying targeted landslides in Luxembourg.

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❖ Seismo-acoustic research in the Kivu Rift region

Imaging lava drainage into Nyiragongo's edifice and eruption on its flank with infrasound

Eruptions at continental basaltic volcanoes, the dominant mode of volcanism on Earth, can take and combine various forms, including lava lake, lava flows and fountaining, explosions or structural collapses. Aside from a few well-instrumented cases, accurately reconstructing their precise processes and chronology is hampered by the lack of detailed visual observations in space and time. However, because they emit low-pitched inaudible sounds, called infrasounds, any changing and potentially hazardous eruptive activity can be inferred with specialised microphones. At Nyiragongo volcano (D.R. Congo), its flank eruption in 2021 was accompanied by the drainage of the world's largest lava lake modifying the acoustic resonance of the summit pit crater. The excitation of resonance frequencies (fundamental f_0 and first overtone f_1) were recorded from local distance (0-20 km) up to Kenya (~800 km) and are interpreted in terms of the time-varying pit-crater geometry using acoustic numerical modelling (Figure 8). We also tracked lava fountaining and flows on Nyiragongo's flank by means of the emitted infrasound to get a consistent scenario of lava movements between crater and flank. Since eruptive mechanisms are encoded into every volcano's acoustic signature, our results highlight the potential of infrasound approaches for real-time volcano monitoring and multi-hazard early warning systems. This work is carried out in collaboration with KNMI and has been presented at several conferences in 2024. The related manuscript will be submitted in early 2025.

Seismological aspects of Nyiragongo and the Kivu rift (J. Subira's PhD thesis)

In 2019-2020, the local capacity-building project HARISSA[14] was launched by the RMCA for training a PhD student at the Department of Seismology of Goma Volcano Observatory (GVO). As a young seismic analyst, Mr. Josué Subira rapidly emerged as the best individual for this position. His work took place in an exceptional geological context, the Kivu Rift region, which is marked by sustained seismicity and intense volcanic activity from Nyiragongo and Nyamulagira volcanoes in the Virunga province. He was able to carry out his PhD research project between DRC and Europe despite many challenges and the socio-political instability in the region. His determination to pursue research alongside his work duties at GVO in such a difficult context is a remarkable example of scientific dedication. Besides the research aspects, Josué played a key role in the past years in the development of sustainable monitoring capabilities at GVO in collaboration with ECGS and RMCA.

Josué successfully earned his PhD in seismology in September 2024 from University of Liège (Belgium) under the co-supervision of Dr. Aurélia Hubert-Ferrari (Univ. Liège, promotor), Dr. Julien Barrière (ECGS, co-promotor), Dr. François Kervyn (RMCA) and Dr. Corentin Caudron (ULB). He is now the only PhD researcher at the GVO Department of Seismology.

[14] https://georiska.africamuseum.be

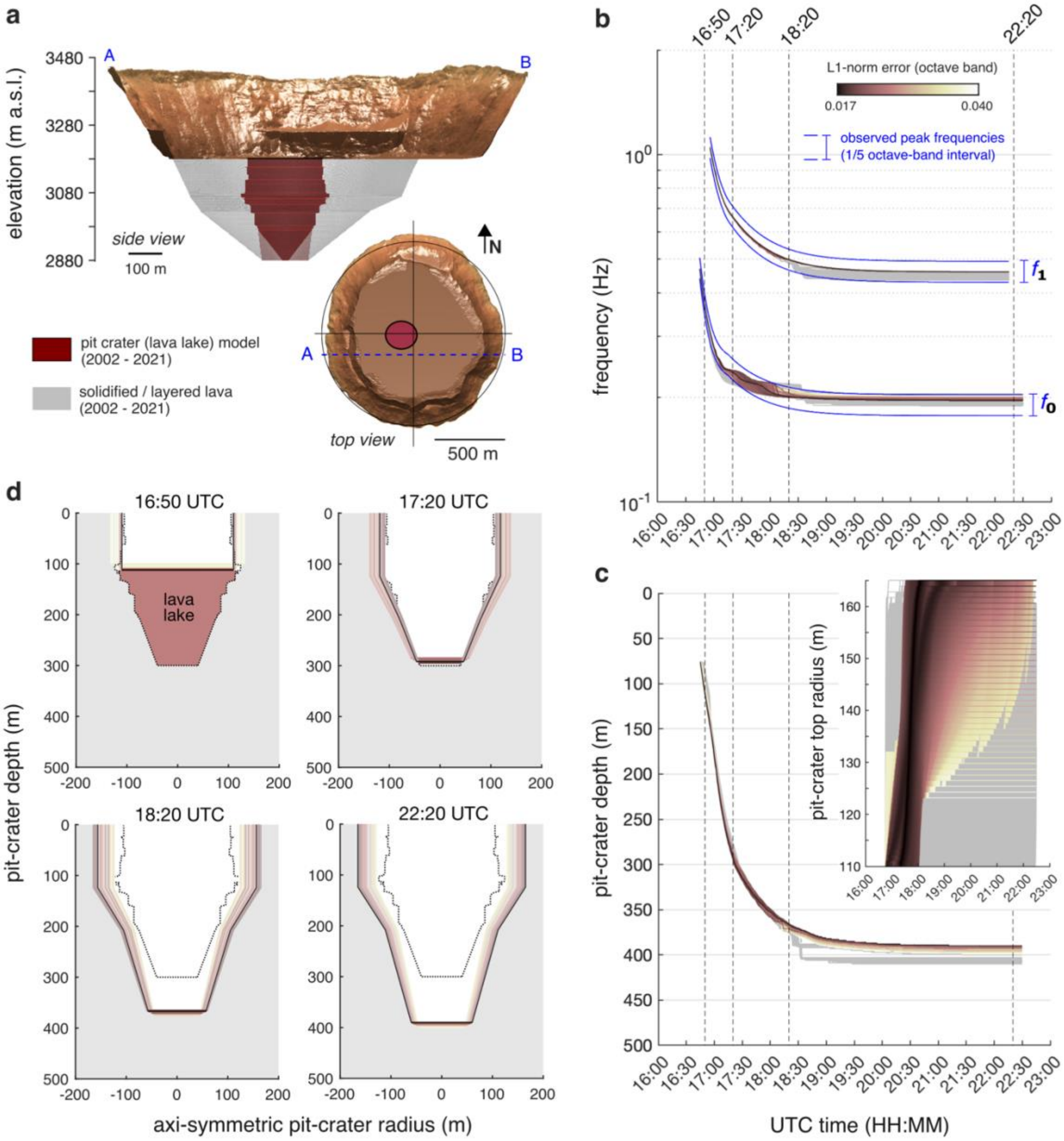

Figure 8: Time-varying acoustic resonance model of Nyiragongo's pit crater. **a)** Nyiragongo's cross-section model on 22 May 2021 before the eruption obtained from UAV-based photogrammetry model (DEM as brown surface) and from SAR-based amplitude images (Barrière et al., 2022). Note that the diameter of the pit crater hosting the lava lake is poorly constrained below ~3.000 m a.s.l., that is along the last ~100 m of depth (bottom radii of 70 or 10 m are both represented). **b)** Top, best-fit models of dominant (f0) and secondary (f1) peak frequencies. Observations are given as 1/5 octave-band intervals (blue lines) encompassing the range of observed peak frequencies. Models are coloured according to misfit (L1-norm) expressed in octave band. Models in grey are the ones going over the 1/5 octave band interval (blue lines). **c)** Inverted pit-crater depth and top radius (inset) models corresponding to f_0 and f_1 models plotted above. **d)** Pit-crater cross-sections corresponding to model estimates (i.e., crater part not filled by lava) at 16:50, 17:20, 18:20 and 22:20 (vertical black dashed lines in **b** and **c** plotted on the lava-lake extent (i.e., fully filled) estimated before the eruption (dotted lines). The inverted pit-crater models are coloured according to the colour code used in **b** and **c**.

His main research has aimed at developing and improving dedicated seismic monitoring methods to the Virunga volcanoes to be implemented at GVO as well as defining new local seismological models for the Kivu. He already published one article in Bulletin of Volcanology as first author in 2023 and two more articles are in preparation about his PhD's work, which provides new fundamental knowledge about the region. Based on the recent instrumental improvement between 2013 and 2022 (i.e., the KivuSNet network; Oth et al., 2017), this work presents the lessons learned from about 7 years (July 2015 – June 2022) of continuous seismic monitoring in the Kivu rift, which can be summarized as follows:

- In the first part of the thesis, we have investigated the relevance of using the recorded seismic amplitude at each available station to assess the seismic activity in the Virunga volcanic Province (VVP). Under certain conditions, the spatio-temporal variability of volcanic seismicity can be monitored from the analysis of the seismic amplitude recorded across the network. The chosen approach is based on the amplitude at each station as well as the amplitude ratios between pairs of stations, which has proved to be efficient to track high-frequency volcano-tectonic seismicity (> 2Hz) at other volcanoes. In our case, we took advantage of the existence of shallow tremor sources (i.e., continuous seismic pertubations) of volcanic origin at low frequency (< 2 Hz) to successfully apply this technique for the first time in this context. Coupled with other geophysical datasets, the same approach was also well suited over the period 2018-2022 for interpreting the variations of seismic amplitudes in terms of volcano-related processes before, during and after the 2021 flank eruption at Nyiragongo. These results have direct implications in the monitoring of the Virunga volcanoes since they can provide guidance to GVO on the use of similar amplitude-based tools, which are easy-to-implement and relevant to use in case of seismic data scarcity using only a few stations.
- In the second part, our aim was to fill the knowledge gap of the seismic velocity structure and seismicity patterns in the region. We used the seismological information derived from KivuSNet to obtain robust 1D seismic (P- and S-wave) velocity models for the Kivu Rift region. A first local magnitude scale was also proposed using the same data set. We recommend the use of these models as new routine models at GVO and as starting point for further works in the region. Both the methodology and the results were extensively detailed, which allowed a comprehensive comparison between this new model and existing ones. Then, a seismic catalogue of nearly 50,000 detected events (volcanic and tectonic) over 7 years (2015-2022) was assembled. The main characteristics (spatial distribution, count, magnitude, spectral frequency) were discussed with a special emphasis on Nyiragongo and Nyamulagira and how this new knowledge can help GVO in improving its monitoring tasks. This analysis must be seen as a first promising outcome, which should encourage further research in the region on this large topic.

As an example, a map and time-depth distributions of moderate-magnitude earthquakes ($M_L \geq 3.5$) are provided in Figure 9. Two significant events have marked the seismic activity in the Kivu Rift during the period 2015-2022 :

- The 2015 Katana earthquake sequence: the Katana earthquake (M_L 6.1) occurred on 7 August 2015, followed by several major aftershocks (zoom in Figure 9c);
- The 2021 dyke intrusion: the second major event is the 1-week dyke intrusion following the flank eruption of Nyiragongo on 22 May 2021, which was accompanied by sustained seismicity in northern Lake Kivu (zoom in Figure 9c). This recent crisis was marked by numerous felt earthquakes in Goma, Gisenyi and surrounding area.

Apart from these two major events, significant felt seismicity is noticeable in the northern part of VVP and in Lake Kivu. These observations from the moderate seismicity between 2015 and 2022 are also consistent with the seismotectonic delimitation zones in the Kivu rift proposed by Delvaux et al. (2017). These delimitations are based on various instrumental and historical catalogs ranging from 1888 to 2015 (1031 events with $M_W = [1.4 - 6.3]$ + 37 macroseismic events after assessing reports of felt seismicity). It is important to note that no moderate-size earthquake was detected in the VVP, thus confirming that the volcanic seismicity was dominated by low-magnitude events and tremors.

Part of this work was presented as poster presentation at the 2024 SSA (Seismological Society of America) Annual Meeting under the title "Seismological models and seismicity patterns in the Kivu rift and Virunga volcanic Province (D.R. Congo)" by J. Subira, J. Barrière, C. Caudron, A. Oth, N. d'Oreye, A. Hubert-Ferrari and F. Kervyn.

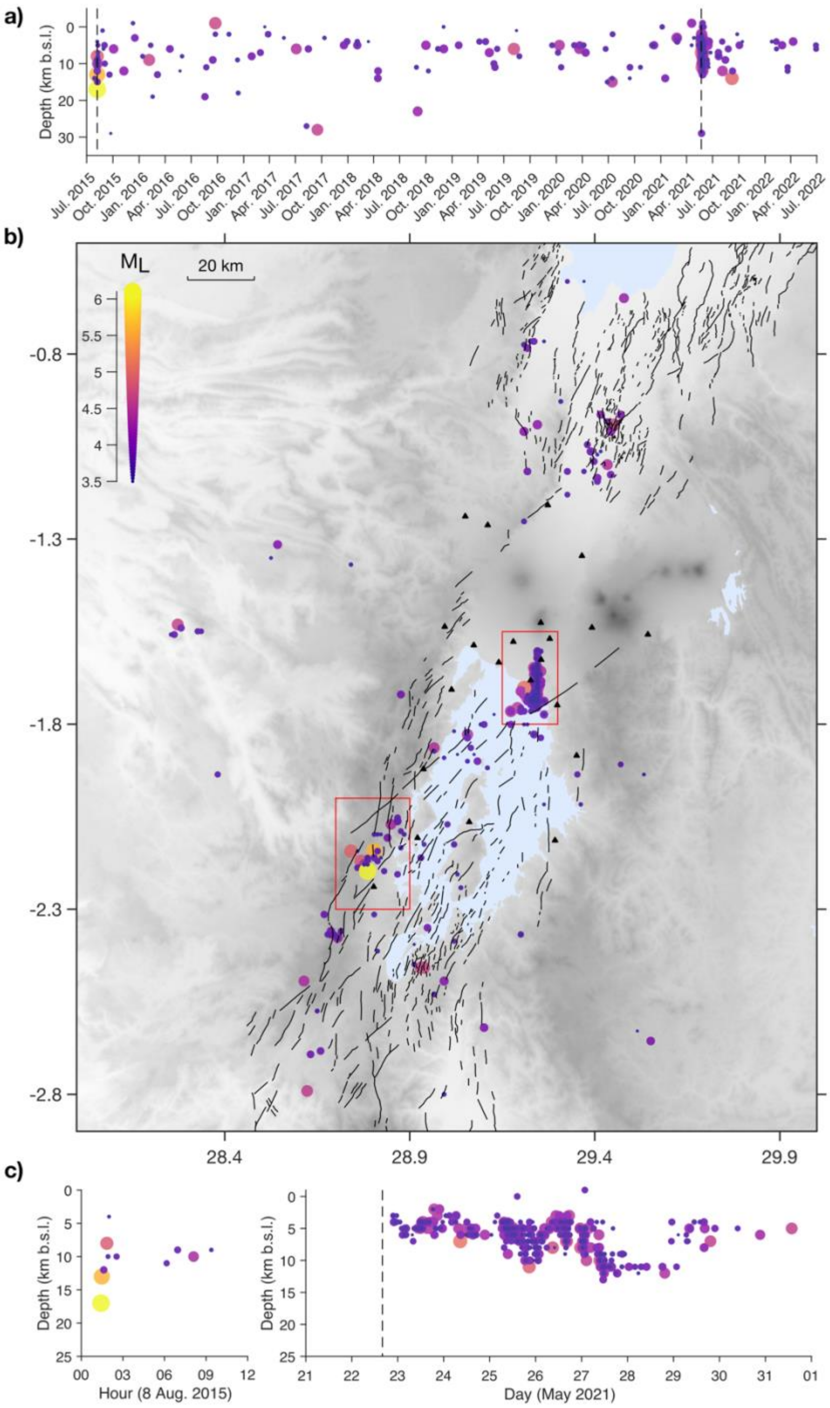

Figure 9: a) Time-depth distribution of events from the catalogue of seismicity with magnitude larger than $M_L \geq 3.5$. The two dashed black lines represent the 8/8/2015 Katana earthquake sequence and the 22 May 2021 dyke intrusion seismicity. **b)** Events with magnitude larger than $M_L \geq 3.5$ plotted on the regional topographic map with fault indicated by black lines (Smets et al., 2016). The two red rectangles delineate the area affected by the 22 May 2021 dyke intrusion seismicity and the 8/08/2015 Katana earthquake sequence **c)** Time-depth distribution of the 8/8/2015 Katana earthquake sequence and the May 2021 dyke intrusion.

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❖ Various international seismological collaborations

▪ Earthquake source parameter studies

Back in 2021, a Technical Activity Group (TAG) has been set up in the framework of the *Statewide California Earthquake Center (SCEC)*, addressing the need to better understand the large variability in earthquake source parameters observed across many studies, and to better gauge their physical and methodological origins in order to improve the usefulness of these parameters for ground motion prediction.

This TAG is based on the dataset of the 2019 Ridgecrest earthquake, on which A. Oth has already co-authored studies led by D. Bindi form the GFZ German Research Centre for Geosciences in Potsdam, Germany (published in 2021 & 2023). In 2024, A. Oth co-authored one more study, carrying out numerical tests in order to evaluate the effect of constraining the spectral shape of reference events when deriving earthquake source parameters (see Publications list, page 34). This study is available online already in *Bulletin of the Seismological Society of America* and will be part of the special issue of this journal, for which A. Oth also serves as one of four guest editors.

▪ A proposal for a high-frequency earthquake magnitude (m_{3Hz}) for seismic hazard and rapid damage assessment

Obtaining a reliable size estimate of an earthquake that well represents its potential impact is a matter of prime importance in seismology and earthquake engineering. The magnitude scales typically used in earthquake catalogues, primarily the moment magnitude Mw, are not designed to represent the variability in high-frequency radiation of the earthquake source.

In order to address this issue, a study led by Prof. S. Parolai, we propose a new high-frequency magnitude scale, m_{3Hz}, which is an extension of the basic concept of high-frequency magnitude introduced in 1995 by Aktinson and Hanks. This magnitude is estimated from the spectral amplitude at 3 Hz considering necessary corrections for site effects and seismic wave propagation. We apply this new magnitude scale to two test datasets from Japan and Italy and confirm it is capable of adequately representing high-frequency radiation effects. Finally, we also show how this magnitude scale can be applied to pre-instrumental earthquakes.

The study has been accepted for publication in 2024 in *Seismological Research Letters* and is available online.

▪ Source parameters and scaling relationships of stress drop for shallow crustal earthquakes in Western Europe

This study is a collaboration between GFZ German Research Centre for Geosciences scientists, ECGS and the University of Liverpool. The study investigates the source characteristics of natural and induced earthquakes on a large scale throughout Western Europe, during the time period from January 1990 to May 2020. We show in this study that stress drops are generally higher in Southern Europe as compared to Northern Europe and discuss the scaling relationship of stress drop and magnitude.

A paper on this study was published in Journal of Seismology in 2024.

▪ A seismological large-N multisensor experiment to study the magma transfer of intracontinental volcanic fields: The example of the Eifel, Germany

This is a collaborative manuscript submitted to Seismica and serving as an overview paper of the Large-N array experiment in the Eifel region, carried out under the lead of the GFZ Helmholtz Centre for Geosciences in the years 2022-2023 and to which ECGS contributed with five broadband seismic stations (see *Seismological monitoring infrastructure operated by ECGS* above).

Remote Sensing, Volcanology and Ground Deformation Modelling

❖ Development of software: "AMSTer: SAR & InSAR Automated Mass processing Software for Multidimensional Time series"

AMSTer is a software for SAR and InSAR processing and computation of ground deformation time series (see details below), written by Nicolas d'Oreye, Dominique Derauw, Sergey Samsonov, Delphine Smittarello, Maxime Jaspard and Gilles Celli (d'Oreye et al. 2021; Derauw et al. 2020; Smittarello et al. 2022; Smittarello et al. 2023). It licensed under CC BY-NC-SA 4.0[15] (Attribution-NonCommercial-ShareAlike 4.0 International).

In 2024, we continued the development of AMSTer. The most recent version (December 2024) was updated on the public GitHub repository, which can be found under the following link:

https://github.com/AMSTerUsers/AMSTer_Distribution

The principal improvements realised in 2024 are:

- Adaptation of new AMSTer Engine functionalities:
  - New Sentinel-1 images and orbits download and management procedure;
  - New functionalities to create DEM and water bodies mask;
  - New multi-level masking procedure and strategy, including a specific procedure to mask deforming regions (date dependant) when computing the residual phase ramp;
  - Ability to read compressed Sentinel-1 data and restrict the reading to only the bursts overlapping a given area of interest.
- MSBAS full 3D inversion (only valid when enough LOS diversity is available, e.g. when right and left looking Ascending and Descending acquisitions are available);
- AMSTer Toolbox scripts:
  - Scripts for performing 3D inversion (either when displacement is expected along the steepest slopes like for landslides, or when enough diversity of looking geometries is available);
  - Updated and improved installer;
  - Several new tools e.g. to test and compare baseline plots, compute Earth to satellite unit vectors, compute semi-variograms;
  - Several minor improvements and small corrections in scripts.
- AMSTer Documentation:
  - Update of manuals according to points above;
  - Include slides of last training course.

In 2024, the AMSTer software and its developments **fuelled the following international collaborations or opportunities**:

a. With the Space Agency of Argentina (CONAE): we continued the systematic processing of SAOCOM images acquired over the **Laguna Fea region (Argentina)**. Results from the monitoring, and comparison with the systematic processing of Sentinel-1 images, are shared thanks to dedicated web page.

b. With the Laboratoire Magmas et Volcans, Université Clermont Auvergne (France): we continued the systematic processing of Sentinel-1 images acquired over the **Karthala volcano on Comores Island**. The ground deformation associated with the 2021 seismic crisis recorded on the volcano is still under study with the additional results obtained with CosmoSkyMed images. In 2024, we participated to 12 remote meetings for these studies. A paper is in preparation with Valerie Cayol and her former Master student Alexis Hautecoeur (among others). Preliminary results were also presented at 19-22 November 2024 MDIS meeting in Orléans (France).

[15] http://creativecommons.org/licenses/by-nc-sa/4.0/

c. With the Ecole et Observatoire des Sciences de la Terre (EOST) de Strasbourg (France): AMSTer was containerised by David Michea (EOST) for *Docker* and *Singularity* and is now used on a HPC computer infrastructure as a component of an **image correlation web services.** Results were presented at 19-22 November 2024 MDIS meeting in Orléans (France).

d. With the Africa Museum (Belgium), the Université Officielle de Bukavu (Democratic Republic of Congo) and the Centre de Recherche et d'Information sur les Risques Naturels, i.e. CIRRINA (Democratic Republic of Congo): AMSTer is used to routinely provide authorised users with 2D and 3D ground deformation **time series of the Funu landslide in Bukavu** (South Kivu, Democratic Republic of Congo) computed using Sentinel-1 images and shared through the dedicated web pages.

e. With the Institut de Physique du Globe de Paris (France): AMSTer is used to compute **2D and 3D ground deformation time series of landslides** in vegetated areas in La Réunion Island in the frame of a PhD thesis (Colline Hopquin).

f. With Laboratoire de Géologie de Lyon - Université Jean Monnet, Saint Etienne (France), Magmas & Volcanoes Laboratory, Clermont Auvergne University (France), IPGP (France), and several other teams, we submitted a 3 years project entitled "*High-Resolution, High-Frequency InSAR Monitoring of Volcanic Activity at Piton de la Fournaise Using ALOS-2/-4 Spotlight Data*" to JAXA. The project aims at assessing the improvements provided by the enhanced capabilities of ALOS-4 (e.g., the enlarged footprint in Spotlight mode) and the potential of jointly using ALOS-2 and ALOS-4 data. The project was approved in early January 2025.

In parallel, we carry on with our systematic processing of InSAR ground deformation time series over several targets for

- volcano monitoring (e.g., on Comoros Island, Guadeloupe Island, La Réunion Island, Domuyo, Laguna del Maule and Laguna Fea regions in Argentina and Chile…),
- landslides (e.g., in the Democratic Republic of Congo, La Réunion Island, Central Nepal…)
- other deformations of anthropogenic and natural origins (e.g., in Luxembourg).

The results from all these automatic incremental processing procedures are available on dedicated web pages (https://terra4.ecgs.lu/).

We also carried on our systematic SAR amplitude time series processing for geomorphological changes monitoring (e.g. at Nyiragongo and Nyamulagira volcanoes in the Virunga Volcanic Province in Democratic Republic of Congo).

The recent developments of AMSTer motivated the following education and training activities and remote assistance in 2024:

- The organization in Walferdange of a **one-week training session (June 10-14, 2024)** for 3 students from the University of California, Berkley, USA (Françiszek Waligora), the Ecole Normale Supérieur de Paris (Nelly-Wangue Moussissa), and the Ecole Normale Supérieur de Lyon (Lisa Mollinier);
- The remote assistance for several colleagues and users from Belgium, France, Austria, Chile, Pakistan…

As a brief reminder, AMSTer is aiming at:

- Processing automatically and incrementally a large number of interferometric pairs and feeding and running the MSBAS processor [Samsonov and d'Oreye, 2012, 2017; Samsonov et al., 2017, 2020] in order to obtain the desired 2D or 3D deformation maps and time series;
- Performing individual differential interferograms (for deformation measurement or DEM creation purposes);
- Creating time series of coherence or amplitude maps coregistered on a Global Primary (both in radar geometry or in geographic coordinates), e.g. for land use or geomorphological changes tracking.

AMSTer can process any type of SAR data (ERS1 & 2, EnviSAT, ALOS, ALOS2, RadarSAT, CosmoSkyMed, TerraSAR-X, TanDEM-X (incl. bistatic mode), Sentinel-1 A & B (incl. SM mode), Kompsat5, PAZ, SAOCOM, ICEYE...). AMSTer Engine (a command line InSAR processor derived from the Centre Spatial de Liege (CSL) InSAR Suite (CIS) (Derauw, 1999; Derauw et al, 2019) is optimized to fit the needs of the AMSTer Toolbox, which benefitted from some of its unique specificities.

AMSTer comes with a ~270 pages detailed manual in constant evolution to follow the developments of the software.

❖ MUVE: Suivi SAR multi-capteurs des processus de versant" (2024-2025)

MUVE is a 2 years project with the Centre de Recherches Pétrographiques et Géochimiques (CRPG) from the University of Lorraine in Nancy, the ISTerre (Grenoble) and ECGS. The project is funded by the French "Programme National de Télédétection Spatiale" (PNTS). It is aiming at studying displacements along steep slopes in Nepal using Sentinel-1, PAZ, TerraSAR-X SAR images and Pleiades, SPOT, Landsat-8, Sentinel-2 optical images. High spatial and temporal resolution optical and radar data are used to characterize the dynamics of a slow-moving landslide in the Marsyandi and Khudi valleys, and to understand how it responds to monsoon rainfall. Multi-temporal SAR and optical pixel-tracking displacement time series are projected and combined in the line of steepest slope to derive average velocities in several identified periods. The study reveals coherent cumulative displacement of mobile panels of several meters (up to 15 m) during monsoons as well as non-linear responses to the monsoon. These non-linear responses differ from one site to another.

Preliminary results (Figure 10) were presented at the SNO (Service National d'Observation) ISDeform meeting in Paris (January 31 – February 2, 2024), MDIS meeting in Orléans (19-22 November 2024) and EGU in Vienna (14–19 April 2024).

❖ SLIDE: Assessing the contribution of slow-moving landslides to erosion in the Himalayas" (2024-2028)

SLIDE is a 4-years project with the Centre de Recherches Pétrographiques et Géochimiques (CRPG) from the University of Lorraine in Nancy, the ISTerre (Grenoble), the Centre Spatial de Liège (Belgium) and ECGS. It is co-funded by the ANR (France) and the FNR (Luxembourg).

The project aims at studying the **contribution of slow-moving, deep-seated landslides in the denudation and evolution of mountain landscapes in Central Himalayas** using InSAR time series, optical imagery, GNSS, seismic and infrasound methods.

The project officially commenced on 1 December 2024. The initial tasks involved selecting and testing GNSS, seismic, and infrasound equipment for deployment at a landslide site to be identified in Central Nepal. Several potential landslide monitoring sites are currently under evaluation.

To support this, preliminary 2D and 3D ground deformation time series were generated with AMSTer using Sentinel-1 data collected in three different geometries over a 140 km^2 area (Figure 11). More than 1400 Time Series of ground deformation were generated over the 17 main landslides that were identified manually.
The mass processing of Sentinel-1 images over the whole Central Nepal was prepared and started (146.350 km^2; 5 modes of acquisition).

❖ ALOS2: studying inter-eruptive ground deformation at Piton de la Fournaise using ALOS2 data (2024-2025)

ALOS2 is a 1-year project with the Laboratoire de Géologie de Lyon - Université Jean Monnet, Saint Etienne (France), the Centre Spatial de Liège (Belgium) and ECGS, funded by the Direction de la Recherche et de la Valorisation de l'Universté J. Monnet. The project aims at studying inter-eruptive deformations at Piton de la Fournaise (Reunion Island) using InSAR time series combining ALOS-2 and Sentinel-1 SAR images.

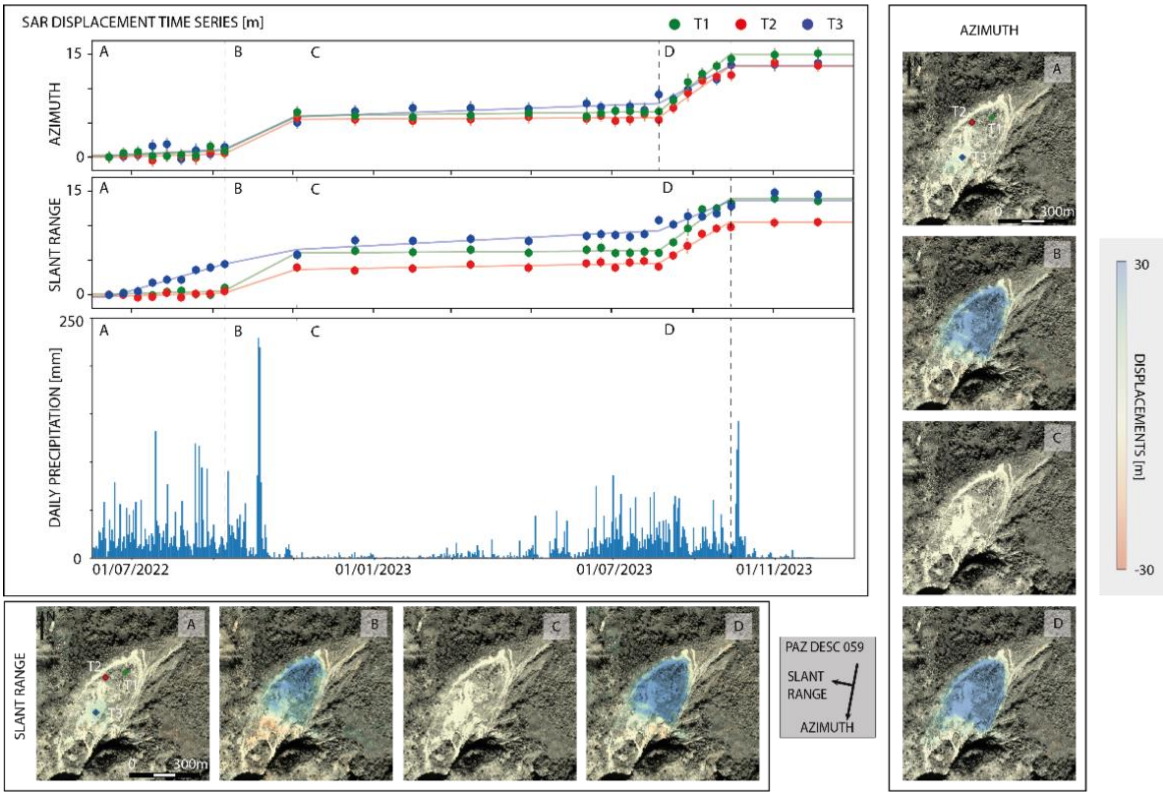

Figure 10: Top-left: SAR amplitude pixel tracking cumulative time series in slant range and azimuth for three selected pixels on the Mathilo landslide (Marsyandi valley, Central Nepal) using PAZ descending track 059. Displacement time series are modelled by linear trends in the four periods A-D. Bottom and right: Maps showing slant range and azimuth velocities for the four periods, superimposed on a panchromatic Pléiades image. (Courtesy: Florian Leder).

Thanks to 1,626 ALOS-2 SpotLight images acquired using 27 different incidence angles from both right- and left-looking modes between April 2021 and April 2024, we computed more than 7.000 interferograms that were inverted to produce 3D deformation time series (Figures 12 and 13). Thanks to the exceptional diversity of looking geometry, we could recover the North-South component of the displacement, which is generally impossible because the sub-polar orbits of SAR satellites with only left-side viewing do not provide enough sensitivity in this direction. Double-difference ground deformation time series between pixels collocated with GNSS receivers are compared to GNSS time series for validation. InSAR-derived deformation maps, corrected from co-eruptive signals can then be analysied for tracking the inter-eruptive signals.

We participated to 6 remote meetings for these studies. Preliminary results were presented at the MDIS meeting in Orléans (19-22 November 2024) and ALOS2-ALOS4 JFY2024 meeting at the Japanese Space Agency, JAXA (19-21 November 2024).

❖ Dike Propagation Modelling

As part of the master's thesis of Nelly-Wangue Moussisa (5 months), we performed inversion modelling of the Nyiragongo 2021 dike intrusion (Figure 14). We used six interferograms spanning progressively longer periods during the intrusion's advance. We are also testing the DEFVOLC software developed by V. Cayol and comparing the results with an experimental GETFEM solution, which uses fictitious domains to reduce the computational load.

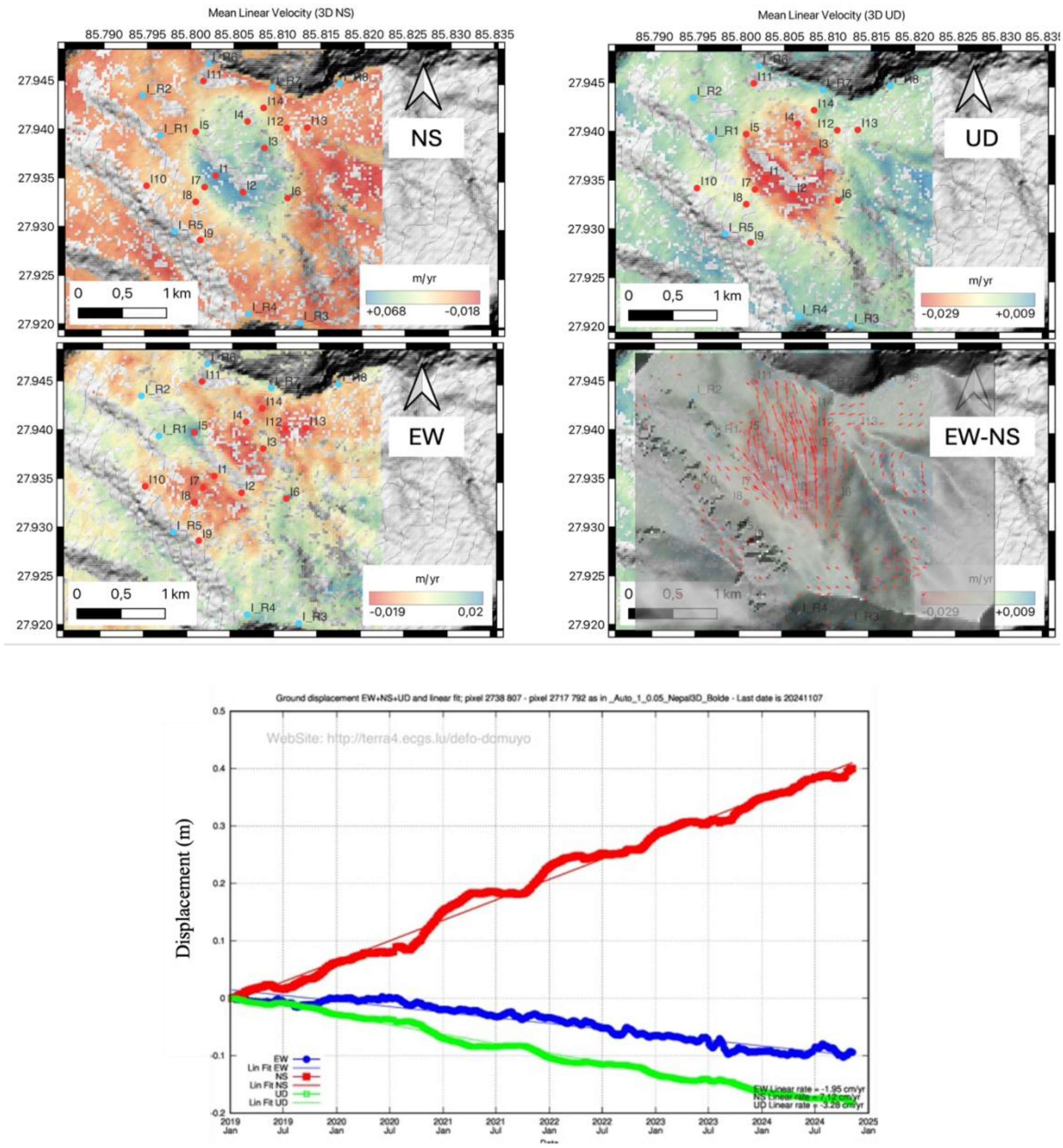

Figure 11: Maps above: Vertical (UD), EW, NS mean linear velocity and horizontal vector (EW-NS) ground deformation maps near Bolde village, Central Nepal. Graph below: Vertical (green), EW (blue) and NS (red) time series of differential ground deformation observed at pixel I1 with respect to pixel I_R1 from 2019 to 2024 (see pixels' location on maps).

❖ Nyamulagira Crater Collapse

In 2024, in the framework of Lisa Mollinier Licence Internship (6 weeks), we continued the development of PickCraterSAR, a Python toolbox that allows users to pick features in SAR images of volcano craters in order to determine their depth and other geometrical characteristics. We developed an original method to estimate the volume of lava accumulating in the SW depression by measuring changes in the floor length of the depression along an azimuth axis over time (Figure 15).

This project is still on-going as we plan to go further into a statistical comparison of both volcanoes' activities.

We quantitatively analyzed the collapses and replenishment of the pit crater in the Nyamulagira caldera since 2011 using COSMO SkyMed SAR images and compared the resulting crater elevation time series with that of Nyiragongo (Figure 16).

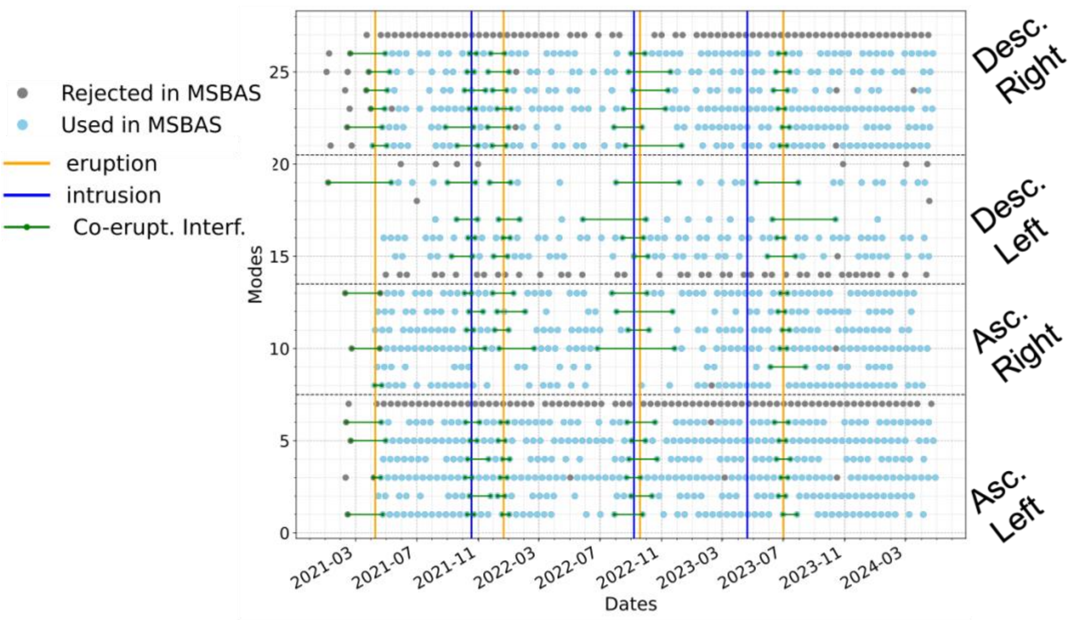

Figure 12: ALOS-2 SpotLight dataset used. Each dot represents a SAR image acquisition. There are 27 modes in total, with those in gray discarded. Pairs of green dots represent co-eruptive interferograms. Orange and blue vertical bars indicate eruption and intrusion times, respectively.

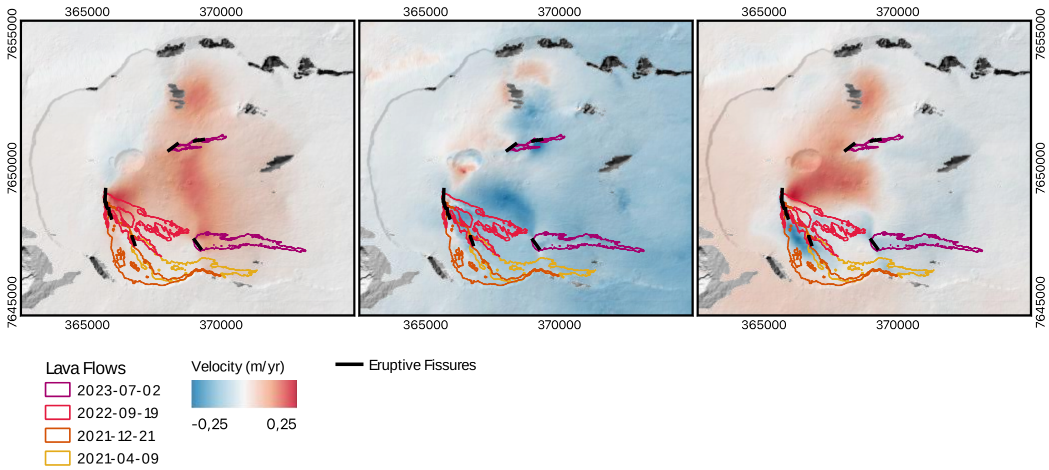

Figure 13: East-West, North-South and Vertical linear rates estimated with an MSBAS inversion. Lava flows contours and eruptive fissures of all 4 eruptions are indicated with plain lines.

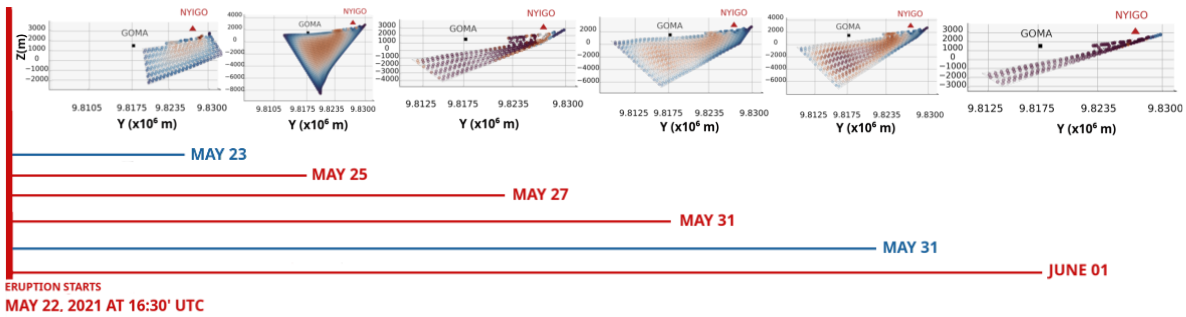

Figure 14: Nyiragongo 2021 dike sources inverted with DEFVOLC software for six time spans during the intrusion's advance. Dates in blue and red are for interferograms from COSMO Sky Med and Sentinel-1 respectively. Colors of the source represent the opening.

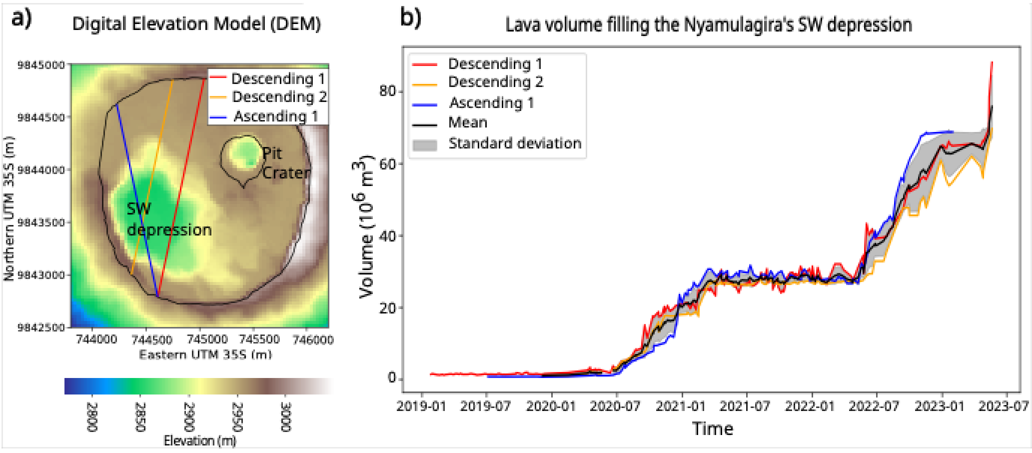

Figure 15: (a) Digital elevation model of the Nyamulagira caldera. (b) Time series of lava volume accumulation in the SW depression of Nyamulagira. Blue, orange and red lines are measurements from corresponding profiles in (a).

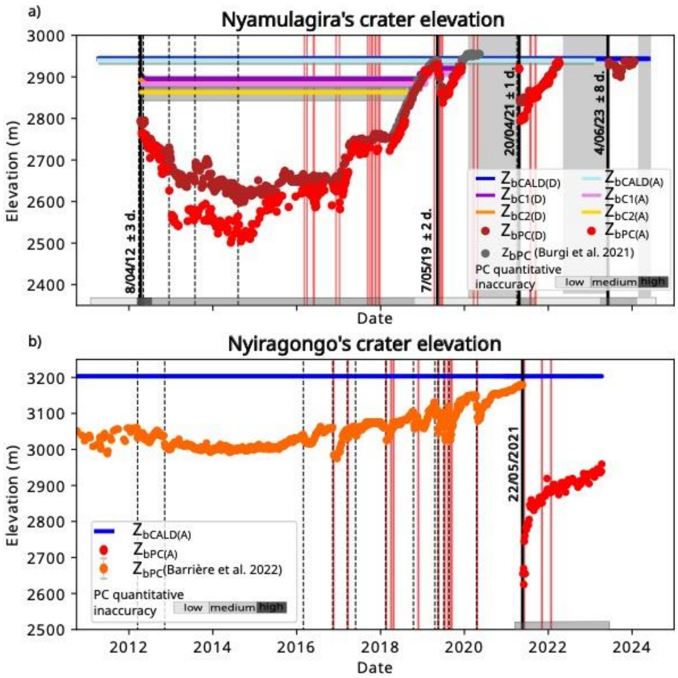

Figure 16: Time series of Nyamulagira (a) and Nyiragongo (b) crater elevation since 2011. (a) Measurements were done using ascending (red) and descending (dark red) Lines Of Sight and compared to the measurements made by Burgi et al (2021) (grey) over a shorter period. (b) Orange dots mark elevation data from Barriere et al (2022) and red dots are new measurements from Sentinel-1 data.

❖ Displacements from high-resolution SAR images in low-coherence areas

In collaboration with R. Grandin (IPGP) and the French SNO ISDEFORM, we began evaluating the potential of a TerraSAR-X archive of SpotLight images from 2021 to 2024 over Guadeloupe and Martinique Islands to detect the deformation of the Soufrière de Guadeloupe and Montagne Pelée volcanoes. The objective is to assess the ability of X-band, high-resolution SAR images to detect displacements in low-coherence tropical areas.

❖ Side projects

- Study of the 2021-2022 unrest phase at Karthala volcano using InSAR time series, SVD decomposition and DEFVOLC invert modeling in the framework of the Master Internship of Alexis Hautecoeur. The deformation detected from InSAR Time Series on the Grande Comore Island was caused by a magmatic intrusion below the volcanic edifice of Karthala that did not reach the surface.
- Following previous work on Grand Eboulis sliding, we pursue the collaboration with C. Hopquin in the framework of her PhD (Figure 17). We studied the climate forcings that influence this sliding. We also performed a 3D computation of displacement time series over the northern part of La Reunion Island. A manuscript is in preparation for publication next year.

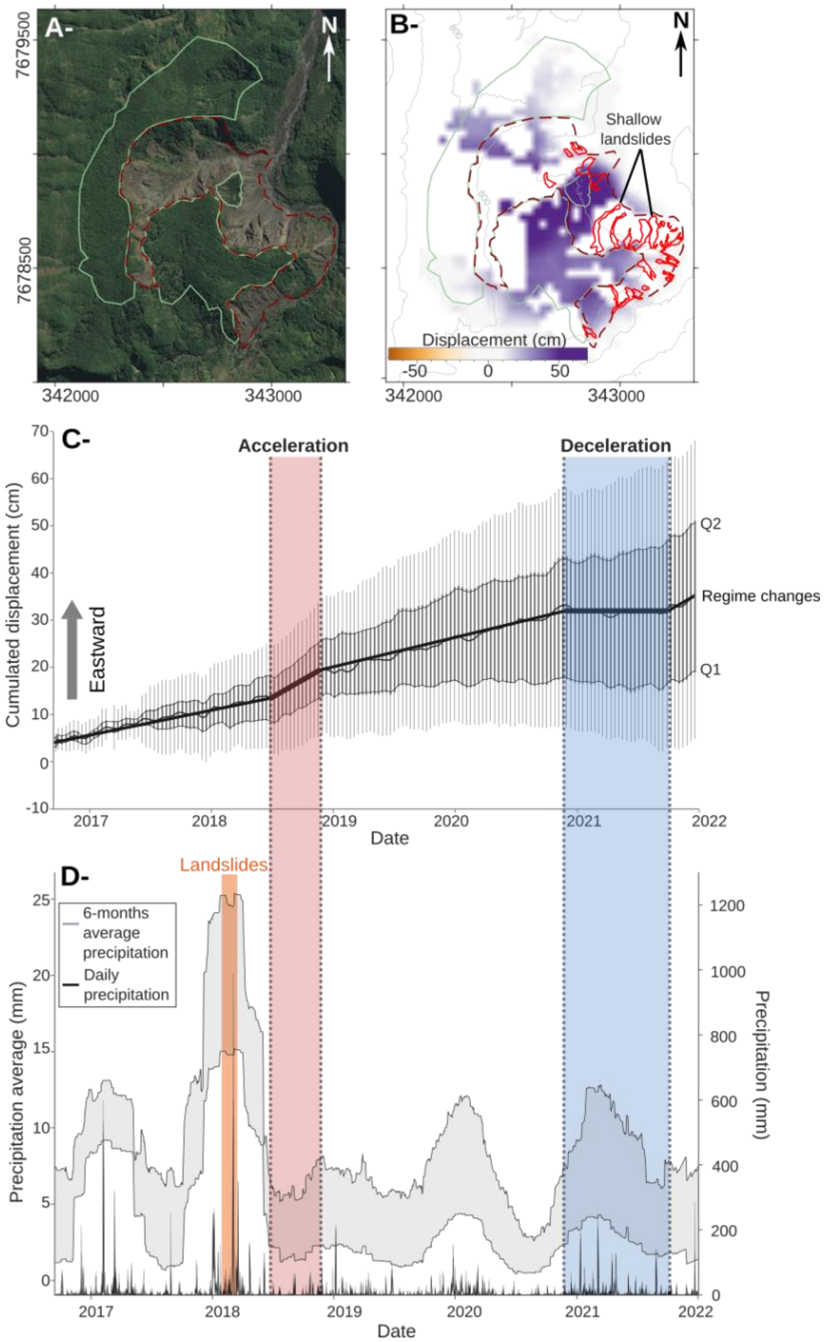

Figure 17: Grand Eboulis dynamics and controls. A- orthophotograph of Grand Eboulis (IGN) with the main structures (polygons) B- East-West displacement maps and location of mapped shallow landslides (red). C- Box plot of east-west cumulated displacement time series with regime changes highlighted in red and blue. D- Daily precipitation and 6 month moving average of the precipitation recorded at 5 weather stations near Grand Eboulis over the studied period (Météo France). The occurrence of shallow landslides is highlighted in orange.

Walferdange Underground Laboratory for Geodynamics (WULG)

The Underground Laboratory for Geodynamics in Walferdange, hosted in the former gypsum mine at 100m depth, remains an exceptional station for high quality seismic and geophysical measurements and tests.

Following the first seismic measurements obtained with three Sprengnether from 1973, the WULG was equipped with a Lennartz 3D short period seismometer in 1987 and a broad-band STS-2 GEOFON in 1994, providing us with more than 40 years of uninterrupted high-quality seismic observations. The data from the STS-2 very broadband seismometer are an important component of the national seismic network operated by ECGS as well as the global GEOFON seismic network operated by the GFZ Helmholtz Centre for Geosciences.

The University of Luxembourg carries out the maintenance of the superconducting gravimeter installed in the WULG since the beginning of the twenty-first century. Between 2010 and 2018, Prof. Dr. Manfred Bonatz established and operated the Walferdange Geodynamical Laboratory (*GeoDynLab*) in a dedicated section of the WULG, operating various measurement devices for measuring gravity, rock dynamics (tilt), atmospheric pressure and chamber temperature for metrological investigations.

Given its outstanding quality, the WULG remains an exceptional measurement and test site for geophysical instrumentation in a highly stable environment since 1968. The interest in using the WULG as a high-quality test site for instrumentation is unbroken. Following a request in 2020, Mr. Bruno Pagliccia from the private company SeisBEE established in Luxembourg carried out instrumental performance studies for MEMS-based accelerometers in the WULG in collaboration with ECGS staff. In July 2022, the Luxembourg-based company FIRIS tested a new autonomous drone for carrying out 3D scans of underground structures in the WULG. In 2023, a request was addressed to ECGS/Mnhn by the University of Luxembourg PhD student Gabriel Garcia, SnT) for carrying out experiments in the WULG in order to test autonomous navigation algorithms for roboters in underground settings. These experiments were carried out in early 2024.

Continuous radon (Rn) measurements in the Laboratory and the entrance gallery have also performed during the past decade. These data, along with the very long data base already acquired over the previous decades, allow for an assessment of the long-term evolution and the seasonal variations of Rn. It also allows monitoring transient signals or assessing gas transport into the underground environment and link them with external causes (e.g., changes in air circulation conditions). The two Alphaguard radon detectors operated by ECGS collaborator A. Kies failed during the year 2023, but measurements could be resumed in 2024 (see short report below).

For several years now, issues regarding the stability of the entrance have been noticed and discussed among the administrations and ministries involved (see previous reports). Following a number of meetings and analyses by the *Inspection du Travail et des Mines (ITM)* and their collaborators over the past years, including among others a 3D scan of the mine carried out in early 2023 in order to get a better overview of its situation, the ITM presented their report on the security situation of the mine entrance to the Minister of Culture in 2024. In addition, in a letter from 1 July 2024, the rector of the University of Luxembourg (Uni.lu) confirmed the university's keen interest in the continuation of their activities within the WULG, in particular in the context of the Interdisciplinary Centre for Socio-Environmental Systems that is being established at Uni.lu.

No final conclusions on how to proceed have yet been reached. For this reason, access is currently still restricted to ECGS/Mnhn and Uni.lu staff for instruments operation and maintenance purposes only, following strict security regulations.

❖ Radon measurements in the WULG during 2024

Prof. em. Antoine Kies

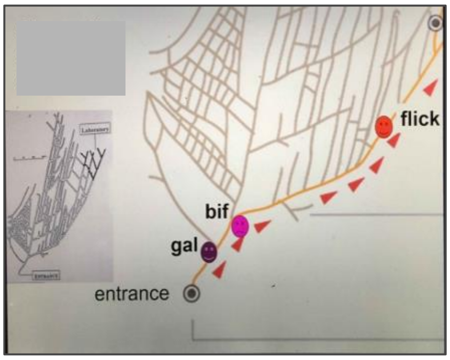

Figure 18: Radon observation sites in WULG.

We report from radon data recorded continuously in the mine at two locations (Figure 18):

- **'flick'** in the main gallery, representing the mine interior (except the geophysical laboratory separated by doors and the less ventilated gallery endpoints);
- **'gal'** endpoint of a collapsed lateral gallery joining the entrance gallery between the entrance and the first bifurcation.

Furthermore, we rely on the meteorological data from MeteoLux.

One of the Alphaguard detectors could be repaired and measurements restarted in early June. Radon concentrations in the mine in 2024 (Figure 19) were unusually low and the yearly high radon summer period was extremely short. May was very cold and punctual radon measurements showed values lower than 4 kBq/m^3.

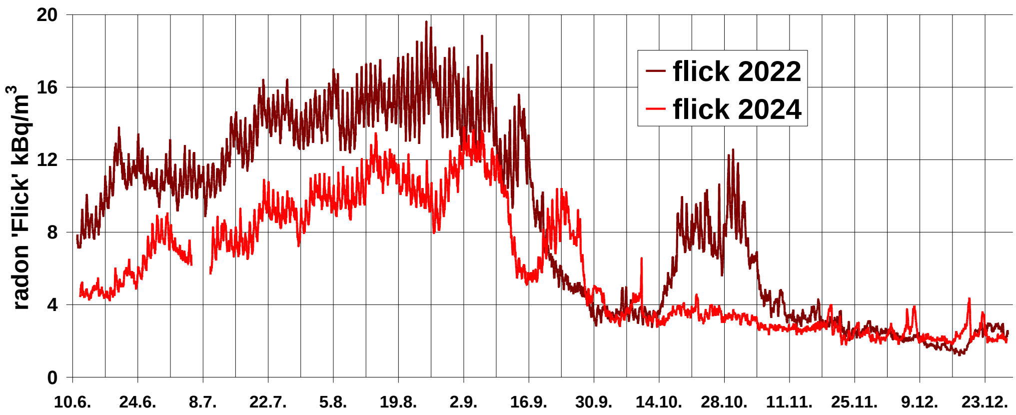

Figure 19: Radon concentration at 'flick' from 11 June to 28 December 2022 (dark red) as compared with 2024 (red).

As compared with the radon levels measured in 2022 as a reference, radon concentrations in the warm season 2024 were low and of shorter duration. This happened rarely since continuous radon monitoring started in the mine. Even the October Indian summer high, clearly visible on the radon measurements in 2022, was missing in 2024.

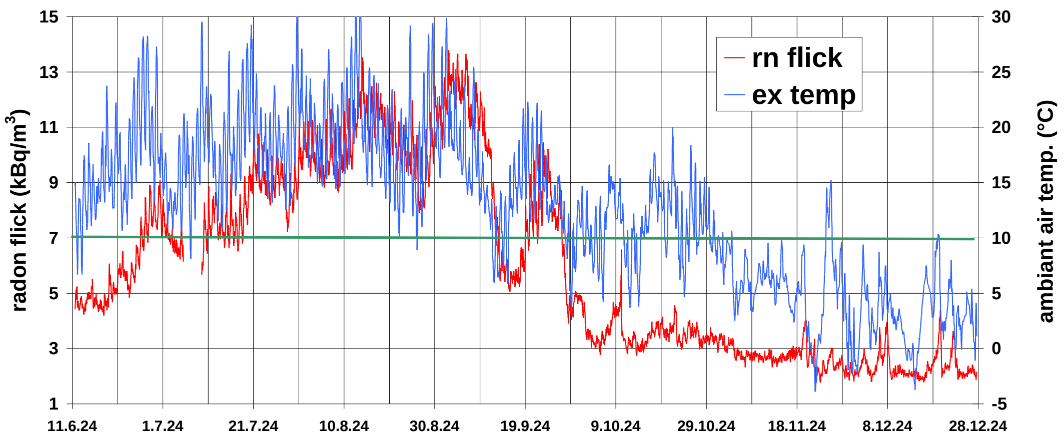

Figure 20: Radon concentration at 'flick' from 11 June 2024 to 28 December 2024 (red curve), plotted together with external temperature (blue curve).

Figure 20 shows the record of mine radon and ambient (external) temperature. Only three times did the daily maximum temperature reach 30 °C. For mine radon dynamics, ambient temperature lows approaching or dropping below the mine temperature of 10 °C (solid line) induce a reversal of air flow in the inaccessible lateral gallery ending at 'gal' and no additional radon is delivered to the mine. Whenever daily temperatures stay below 10 °C, as it is the case in Figure 3, all mine radon is produced by mine ore.

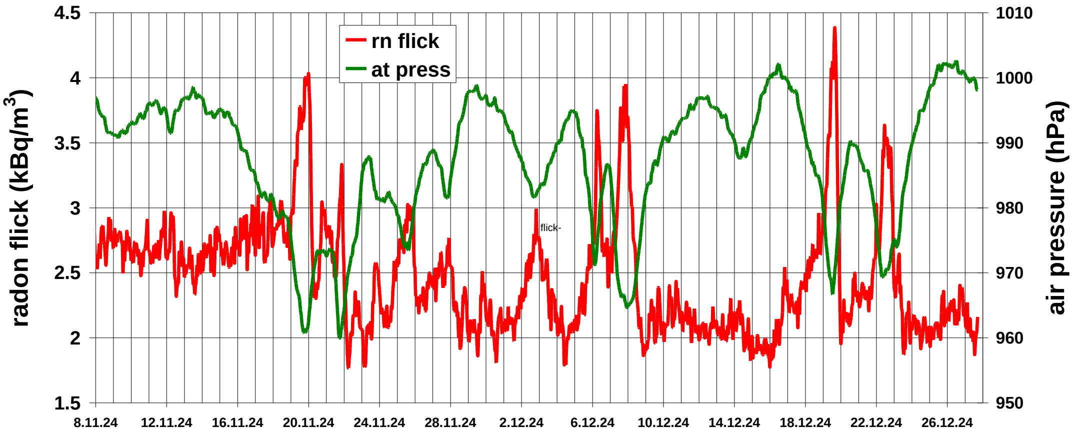

Figure 21: Radon concentration at 'flick' from 8 November 2024 to 28 December 2024 (red curve), plotted together with atmospheric pressure (green curve).

In Figure 21, the observed peaks are due to changing air pressure; especially abrupt air pressure drops induce radon peaks: radon atoms trapped close to walls, grains and fissures are sucked into the mine air. In the cold season radon peaks are due to changing air pressure, whereas in summer the radon peaks of higher magnitude are induced by ambient temperature changes, masking mainly the atmospheric influence; also in summer rapid pressure changes don't happen not so often. Figure 21 is a perfect illustration of atmospheric pumping.

The radon levels of 2 kBq/m^3 or lower, instead of the expected 2.3 kBq/m^3, is due to the plastic shielding that has not been removed so far. Before the plastic shielding installation in 2015, no radon-depleted fresh air from outside reached the 'flick' location, and radon levels in the mine never went below 2.3 kBq/m^3 (constant level measured at the sheltered endpoint of the geophysical laboratory).

In 2025 we will continue our measurements; one has to keep in mind that an important aim of our study is to detect any major changes in the structures of the mine, especially close to the hill side. Radon is a very sensible tracer for slides, soil and rock movements. Our study so far shows no important changes and also proves that there is no communication between the mine body and galleries from neighbouring mines or the exterior, except the main entrance.

The results on radon concentrations in the Walferdange gypsum mine were presented at the International Conference on Gas and Geochemistry, Tenerife, June 2024.

102nd JOURNEES LUXEMBOURGEOISES DE GEODYNAMIQUE / EFEHR SCIENTIFIC SESSION 2024

From 27 to 29 November 2024, ECGS organised, in collaboration with the European Facilities for Earthquake Hazard and Risk (EFEHR), the 102nd edition of the Journées Luxembourgeoises de Géodynamique (JLG), which were co-hosted by EFEHR as the 2024 EFEHR Scientific Session. The meeting was supported by the European Seismological Commission (ESC) and the Horizon Europe project Geo-INQUIRE.

This 102nd edition of the JLG was dedicated to the subject of **Multi-hazard and multi-risk assessment for geohazards**. Risk assessment bridges the geohazards to their societal consequences. As such, it constitutes the most outward-facing component in the chain, starting from gathering the data and modeling the phenomenon towards understanding its consequences. This is where models meet reality; and the reality is invariably complex and multi-risk. In the past decades, the scientific community has established an understanding of single hazards and their direct consequences. However, there is still a lot to explore regarding the complex interactions between hazards and their consequences on society, those situations in which the union is larger than the simple mathematical sum, and where a direct cause and effect pattern can be sometimes difficult to establish.

At the 102nd JLG, an outlook through some of the challenges faced in multi-hazard and multi-risk analysis of geohazards was provided, discussing questions such as:

- What are the challenges, needs and gaps as seen from the "real world"? What is the point of view of stakeholders and the private sector?
- How can we make the most of multidisciplinary datasets?
- Towards multi-hazard or hazard-agnostic exposure models? Can multi-hazard vulnerabilities be possibly harmonised?
- What is the future of earthquake ground motion models?
- Which are the challenges for time-dependent seismic hazard assessment? Can short-term forecasting become operational?
- How to capture the interactions between slow-onset (e.g., sea-level rise, ageing, heat waves) and fast-onset events (e.g., tsunami, earthquakes, landslides)?
- Cross-cutting: how can Machine learning and AI help us with the above challenges?
- How to communicate our research with a broader audience?

Conveners

- Dr. Laurentiu Danciu, ETH Zurich
- Dr. Adrien Oth, ECGS
- Prof. Dr. Fatemeh Jalayer, UC London

Local Organizing Committee

- Dr. Adrien Oth
- Yannick Breh
- Maxime Jaspard
- Gilles Celli

The 102nd JLG gathered **60 participants from 18 countrie**s at the Alvisse Parc Hotel in Luxembourg to discuss these questions and the ways forward in the multi-hazard and multi-risk assessment.

The programme was designed to be as interactive as possible, including mentimeter sessions and a dedicated session on best practices communicating seismic hazard and risk communication to different target audiences, including the greater public. The workshop included 21 oral and 15 poster presentations, with an emphasis on discussion and networking time among participants.

More information and the full scientific programme, including PDFs of most presentations, can be found on the website[16] of the meeting.

102nd JLG programme

Tuesday 26/11/2024

18:30 - 21:00 Icebreaker upon arrival of participants

Wednesday 27/11/2024

09:00 - 09:15 **Opening** of JLG / EFEHR Scientific Session
Adrien Oth (ECGS) & Laurentiu Danciu (ETH)

09:15 - 10:45 **Block Ia Multirisk: Exposure and vulnerability to geohazards**
Moderators: Fatemeh Jalayer (UCL), Vitor Silva (University of Aveiro) & **Radmila Salic (Ss. Cyril and Methodius University in Skopje)**

- Warm-up (10-15 min): An interactive session with Mentimeter. The style is semi-structured and the aim is to hear from the community about the largest challenges, gaps.

16 https://www.ecgs.lu/102nd-jlg/

- Intro and Narrative of the Multirisk Session (5 minutes)
- Short 15-min talks:
  1. Vitor Silva (University of Aveiro): *Multi-hazard Exposure Model of GEM*
  2. Gerard O'Reilly (EUCENTRE FOUNDATION): *Built environment data for multi-hazard vulnerability models within EPOS*
  3. Fatemeh Jalayer (UCL): *Multi-hazard vulnerability models within EPOS*
- *Q/A Discussions (20-25 minutes)*

10:45 - 11:15 Coffee + Posters

11:15 - 12:30 **Block Ib Multirisk: Exposure and multirisks**
Moderators: **Fatemeh Jalayer (UCL)**, Vitor Silva (University of Aveiro) & Radmila Salic (Ss. Cyril and Methodius University in Skopje)

- Short 15-min talks:
  1. Danijel Schorlemmer (GFZ/ETH): *Every building on Earth!*
  2. Subash Ghimire (ISTerre): *Evaluation of Machine Learning Models for Average Annual Losses Assessment and Comparison with ESRM20 Results in France*
  3. Salvatore Iacoletti (AXA XL)*: Modelling earthquake risk and its secondary effects – The (Re)Insurance Industry Perspective and Needs*
- *Q/A Discussions (25 minutes)*

12:30 - 13:30 Lunch

13:30 - 15:00 **Block Ic Multirisk: Managing Georisks**
Moderators: Fatemeh Jalayer (UCL), **Vitor Silva (University of Aveiro)** & Radmila Salic (Ss. Cyril and Methodius University in Skopje)

- Warm-up (20 min): Second interactive session with Mentimeter. The style is semi-structured and the aim is to hear from the community about the largest challenges, gaps.
- Short 15-min talks:
  1. Radmila Salic Makreska (Ss. Cyril and Methodius University in Skopje, Institute of Earthquake Engineering and Engineering Seismology): *UCPM efforts in addressing multi-risk cross-border and multi-country challenges in the Western Balkans through several recent initiatives*
  2. Zuzana Stanton-Geddes (World Bank)*: From data to decisions – using data and information for scaling up disaster and climate resilience*
  3. *Alexandra Tsioulou (Gallagher RE): Multi-risk perils: The view, needs and gap from the re(insurance) industry*
- *Q/A and Closing Discussions (25 minutes)* An interactive session summing up the discussions in the three multirisk sessions

15:00 - 15:30 Coffee

15:30 - 17:30 **Block II Communication Session**
Michèle Marti (ETH) and Sarah Dryhurst (UCL)

1. Design your own communication plan (45 minutes + 30 minutes break)
2. Best practices in launching seismic hazard and risk models (45 minutes)

Thursday 28/11/2024

09:00 - 10:30 **Block III: Multidisciplinary Datasets (Interactive & Discussion)**
Moderators: Olga Ktenidou (NOA), Roberto Basili (INGV), Laurentiu Danciu (ETH)

Keynotes:

1. Susana Custodio (University of Lisbon): *Earthquake processes in Low-Strain Regions, Challenges and Opportunities: An example from West Iberia*
2. Panagiotis Elias (NOA / University of Patras)*: Space geodesy for geohazards assessment and monitoring: Well established applications, new insights and potential*

10:30 - 11:00 Coffee + Posters

11:00 - 12:00 **Block III: Seismic Hazard (QA only)**

Keynote:

Leila Mizrahi (ETH): *Towards European Operational Earthquake Forecasting and Time-Dependent Hazard and risk Assessment*

12:00 - 12:30 **Block IV: Seismic Hazard (QA only)**

Keynote:

Francesco Visini (INGV)*: Testing Seismic Hazard Models: lessons learned from Italy*

12:30 - 13:30 Lunch

13:30 - 15:30 **Block V: Ground Shaking (Interactive & Discussion)**
Moderators: Aybige Akinci (INGV), Carmine Galasso (UCL) & Adrien Oth (ECGS)

Keynotes:

1. Dino Bindi (GFZ): *From magnitude-distance scaling to the non-ergodic paradigm: the long journey of ground motion models*
2. Chiara Smerzini (Politecnico di Milano): *Physics-based numerical simulations: recent advances and challenges of a new frontier for earthquake ground motion prediction*
3. Filippo Gatti (CentraleSupélec): *Generative strategies to empower physics-based wave propagation with deep learning*
4. Carlos Molina Hutt (Univ. British Columbia): *Utilization of earthquake-induced ground motions in engineering practice and risk analysis*

Each speaker will conclude with 3-4 questions for the audience. Following the talks, there will be 4 breakout groups corresponding to talk topics. Breakout groups will then feed back into a general discussion at the end of the session.

15:30 - 16:00 Coffee

16:00 - 18:00 **Networking time for discussion, get-together**

18:30 - 19:30 **Social event** (Jeu de Quilles) + Apéritif
19:30 - **Meeting dinner**

Friday 29/11/2024

09:30 - 10:30 **Block VI: National Contributions** (QA only)

- Carlo Meletti (INGV): *The legacy of MPS19, the useless Italian hazard model*
- António A. Correira (LNEC): *Increasing earthquake resilience in Almada, Portugal. Seismic risk assessment and communication*

10:30 - 11:00 Coffee

11:00 - 12:30 **Block VII: GEO-inquire Multi-hazard, multi-risk Services**
(*Hands-on*)

Hands-on: Andrea Rovida (INGV), Roberto Basili (INGV) & Laurentiu Danciu (ETH)

12:30 - 13:30 Lunch
13:30 - 14:00 End of Meeting, Departure of Participants

OUTREACH & MEDIA COVERAGE

- RTL Radio: *Äerdbiewen a Vulkanausbrech: Och zu Lëtzebuerg?*, featuring A.Oth (23 January 2024), https://www.rtl.lu/radio/reportage/s/4680181.html
- EAIFR (East African Institute for Fundamental Research under the auspices of UNESCO): An unpredictable eruption? The mechanism behind the Nyiragongo 2021 eruption, featuring D. Smittarello (20 March 2024), https://eaifr.ictp.it/events/geo-eaifr-webinar-series-2024
- RTL: *Méiglecht Megabiewen a Japan: Expert schwätzt vu „ganz klenger Probabilitéit*, featuring A. Oth (16 August 2024), https://www.rtl.lu/news/international/a/2222980.html

PUBLICATIONS & PRESENTATIONS

❖ Peer-reviewed Journal Publications

Bindi, D., K. Mayeda, D. Spallarossa, M. Picozzi, **A. Oth**, P. Morasca and W. R. Walter (2024). Numerical tests to evaluate the effect of constraining the spectral shape of reference events on source parameter scaling. *Bull. Seismol. Soc. Am., Special Section: Improving Measurements of Earthquake Source Parameters*, Early Publication, doi: 10.1785/0120240132.

Parolai, S., D. Spallarossa, **A. Oth**, and M. Picozzi (2024). A Proposal for a High-Frequency Earthquake Magnitude (m3Hz) for Seismic Hazard and Rapid Damage Assessment, *Seismol. Res. Lett.*, Early Publication, doi: 10.1785/0220240226.

Yen, M.-H., D. Bindi, **A. Oth**, B. Edwards, R. Zaccarelli and F. Cotton (2024). Source parameters and scaling relationships of stress drop for shallow crustal earthquakes in Western Europe. *J. Seismol.*, 28, 63-79, doi: 10.1007/s10950-023-10188-y.

❖ Conference Presentations and Abstracts

Assink, J., C. Gueibe, P. de Meutter, P. Brandhoff, J. Camps, A. Delcloo, L. Evers, **A. Oth** and H. Schreurs (2024). Joint Benelux NDC analysis of the NDC Preparedness Exercise 2024. *2024 NDC Workshop, 21-25 October 2024, Beijing, China.*

Barrière J., **A. Oth**, **N. d'Oreye**, J. Subira, **D. Smittarello**, H. Brenot, N. Theys and B. Smets (2024). Local infrasound monitoring of lava eruptions at Nyiragongo volcano (D.R. Congo) using urban and near-source stations. *SSA Annual Meeting, 29 April – 3 May 2024, Anchorage, Alaska, USA.*

Barrière, J., **A. Oth**, J. Assink and L. Evers (2024). The infrasound signature of the 6-hour long flank eruption of Nyiragongo volcano (D.R. Congo) on 22 May 2021. *ESC General Assembly, 22-27 September 2924, Corfu, Greece.*

d'Oreye, N., D. Derauw, **D. Smittarello**, S. Samsonov, **M. Jaspard** and **G. Celli** (2024). AMSTer goes 3D, but not only: What is new with this InSAR Time Series Software. *MDIS 2024, 19-22 November 2024, Orléans, France.*

Dahm, T., M.P. Isken, C. Milkereit, S. Mikulla, X.i Yuan, C. Sens-Schönfelder, T. Meier, F. Eckel, M. Reiss, G. Rümpker, M. Zeckra, S. Carrasco, M. Hensch, B. Schmidt, **A. Oth**, S. Busch and G. Petersen (2024). The Eifel large-N multisensor seismological experiment sheds light on magmatic processes from the upper mantle to diffuse degassing points at the surface of the Eifel volcanic fields, Germany. *ESC General Assembly, 22-27 September 2024, Corfu, Greece.*

Deijns, A., W. Thiery, F. Kervyn, J.-P. Malet, **N. d'Oreye**, A. Dille, J. Zscheischler and O. Dewitte (2024). Regional landslide and flash flood compound event analysis in the African tropics. *3rd Int. Conf. "Natural Hazards and Risks in a Changing World: Addressing Compound and Multi-Hazard Risk", 2-13 June 2024, Amsterdam, Netherlands.*

Froger, J.-L., **D. Smittarello**, **N. d'Oreye**, D. Derauw, Q. Dumont, M.O. Chevrel, N. Villeneuve, A. Peltier, F. Albino, A. Hrysiewicz, R. Grandin and J. Kubanek (2024). High-Resolution, High-Frequency InSAR Monitoring of Volcanic Activity at Piton de la Fournaise Using ALOS-2 Spotlight Data. *Joint PI Meeting of JAXA Earth Observation Missions FY2024, Tokyo, Japan, 18-22 November 2024.*

Hautecoeur, A., V. Cayol, **D. Smittarello**, **N. d'Oreye**, J.-L. Froger and B. Smets (2024). InSAR Time Series and SVD Decomposition Unravel a Dyke Intrusion at a Tropical Volcano, Karthala 2021-2022. *MDIS 2024, 19-22 November 2024, Orléans, France.*

Hopquin, C., **D. Smittarello**, N. Villeneuve, A. Lucas, E. Gayer and L. Michon (2024). Revealing Landslide Bi-Monthly and Annual Dynamics Using a Combination of RADAR Interferometry and Structure-from-motion: the study case of Grand Eboulis. *MDIS 2024, 19-22 November 2024, Orléans, France.*

Hopquin, C., E. Gayer, L. Michon, **D. Smittarello** and A. Lucas (2024). Dynamics and controls of a tropical slow-moving landslide measured by remote sensing: the study case of Grand Éboulis, Réunion Island. *EGU General Assembly 2024, 14-19 April 2024, Vienna, Austria.*

Leder, F., S. Daout, J. Lavé, **N. d'Oreye** and P. Lacroix (2024). Recent satellite-based radar and optical monitoring of the activity slow-moving landslides in Nepal during monsoon. *MDIS 2024, 19-22 November 2024, Orléans, France.*

Leder, F., S. Daout, J. Lavé, **N. d'Oreye** and P. Lacroix (2024). Recent satellite-based radar and optical monitoring of the activity of a slow-moving landslide in Nepal during monsoon. *EGU General Assembly 2024, 14-19 April 2024, Vienna, Austria.*

Leder F., S. Daout, J. Lavé, **N. d'Oreye** and P. Lacroix (2024). Suivi de glissements de terrain à érosion rétrograde au Népal Central par corrélation d'images SAR. *General Assembly of the "ISDeform" Service National d'Observation (SNO), 31 January – 2 February 2024, Institut de Physique du Globe de Paris, France.*

Morasca, P., M. D'Amico, D. Spallarossa, D. Bindi, M. Picozzi, **A. Oth**, F. Pacor and L. Vitrano (2024). GITpy: a Python implementation of the Generalized Inversion Technique. *ESC General Assembly, 22-27 September 2924, Corfu, Greece.*

Parolai, S., D. Spallarossa, **A. Oth** and M. Picozzi (2024). A high frequency earthquake magnitude (m3Hz) for seismic hazard and rapid damage assessment. *ESC General Assembly, 22-27 September 2924, Corfu, Greece.*

Provost, F., D. Michéa, J.-P. Malet, E. Pointal, A. Lamielle, **N. d'Oreye** and D. Derauw (2024). New image correlation web services in the FormaTerre GDM portfolio. *MDIS 2024, 19-22 November 2024, Orléans, France.*

Segou, M., A. Kiratzi, C. Cauzz, S. Custódio, R. Bossu, F. Haslinger, L. Danciu, F. Jalayer, R Basili, I. Molinari and **A. Oth** (2024). EPOS Seismology: Connecting Communities, Advancing Research, and Paving the Way Forward, *EGU General Assembly 2024, 14-19 April 2024, Vienna, Austria, EGU24-12844.*

Smittarello D., J.-L. Froger, **N. d'Oreye**, D. Derauw, A. Peltier, F. Albino and J. Kubanek (2024). 3D Ground Deformation Time Series at Piton de la Fournaise Using ALOS-2 Data. *MDIS 2024, 19-22 November 2024, Orléans, France.*

Subira, J., **J. Barrière**, C. Caudron, **A. Oth**, **N. d'Oreye**, A. Hubert-Ferrari and F. Kervyn (2024). Seismological Models and Seismicity Patterns in the Kivu Rift and Virunga Volcanic Province (D.R. Congo), *SSA Annual Meeting, 29 April – 3 May 2024, Anchorage, Alaska, USA.*

Subira, J., **J. Barrière**, C. Caudron, **A. Oth**, **N. d'Oreye**, A. Hubert-Ferrari and F. Kervyn (2024). Seismological Models and Seismicity Patterns in the Kivu Rift and Virunga Volcanic Province (D.R. Congo), *ESC General Assembly, 22-27 September 2924, Corfu, Greece.*

MEETING ATTENDANCE & WORK VISITS

Adrien Oth

- Annual Meeting of Seismological Society of America, Anchorage, USA (29 April – 3 May)
- KNMI Supervisory Board Meeting, De Bilt, The Netherlands (4-5 April)
- CBTBO WG-B Meeting, Vienna International Centre, Vienna, Austria (1-4 September)
- Thesis defence of Josue Subira (Univ. Liège, MRAC & GVO), Tervuren, Belgium (10 September)
- 39th ESC General Assembly, Corfu, Greece (22-27 September), **duties as Secretary General**
- EMSC Executive Council & General Assembly, Corfu, Greece (24 & 25 September)

- ORFEUS Board of Directors Meeting, Corfu, Greece (24 September)
- Conseil de l'Europe, EUR-OPA Major Hazards Agreement: Meeting of Permanent Correspondents & Directors of Centres, Paris, France (21-22 November)
- 102nd Journées Luxembourgeoises de Géodynamique (JLG) & EFEHR Scientific Session 2024, Luxembourg (27-29 November) **as organiser**
- Work visits & visitors at ECGS, virtual meetings:
    - Virtual Associate Editor meetings of Seismological Society of America (12 January, 14 February, 16 February)
    - Eifel Large-N Array Virtual Meeting (19 January)
    - Virtual SCEC Stress Drop Validation Study Meeting (22 January, 4 June)
    - Visit of Mnhn Stagiaires at ECGS (25 January, 18 December)
    - Virtual ORFEUS Board of Directors Meeting (8 February)
    - Visit of ITM for Report/Discussion on WULG Safety (13 February, 14 April)
    - Virtual JLG / EFEHR Preparation Meetings with L. Danciu & F. Jalayer (7 March, 25 March, 13 May, 18 June, 6 September, 13 September, 10 October, 18 October)
    - Virtual meetings for SLIDE project preparation with Université of Lorraine and ISTerre Grenoble (15, 20, 25 and 26 March 2024)
    - Virtual EPOS TCS Seismology Meetings (8 March, 3 December)
    - Virtual ESC General Assembly Preparation Meeting (10 April)
    - Virtual participation in CAIAG Scientific Advisory Board (24 May)
    - Virtual participation in KNMI Supervisory Board Meeting (5 June)
    - Kick-off virtual meeting for SLIDE project with Université of Lorraine and ISTerre Grenoble (6 November 2024)
    - Virtual EFEHR Consortium Meetings (5 December)

Nicolas d'Oreye

- General Assembly of the "ISDeform" Service National d'Observation (SNO), Institut de Physique du Globe de Paris (France), 31 January – 2 February 2024.
- Training session AMSTer software. June 10 - 14, 2024, ECGS, Walferdange, Luxembourg
- 6th edition of the MDIS - FormaTerre Symposium, Orléans, France (19-22 November 2024)
- 102nd Journées Luxembourgeoises de Géodynamique (JLG) & EFEHR Scientific Session 2024, Luxembourg (27-29 November)
- Work visits & visitors at ECGS, virtual meetings:
    - Visit of ITM for Report/Discussion on WULG Safety (13 February, 14 April)
    - Virtual meetings for the ongoing research on Karthala volcano (Comoros Island) (16 February, 29 April, 7 June, 15 July, 18 September, 13 November 2024).
    - Virtual meeting with Haldor Geirsson about research on dyke intrusion in the Virunga Volcanic Province (26 April 2024)
    - Virtual meeting of Bastien Wirtz's PhD thesis committee (19 June 2024)
    - Virtual meeting of Florian Leder Master thesis committee (19 June 2024)
    - Virtual meetings for SLIDE project preparation with Université of Lorraine and ISTerre Grenoble (6, 15, 20, 25 and 26 March 2024)
    - Kick-off virtual meeting for SLIDE project with Université of Lorraine and ISTerre Grenoble (6 November 2024)
    - Virtual meeting with Université of Lorraine and ISTerre Grenoble for the interview of Léo Letellier as a candidate for a PhD to be performed at the Université of Lorraine in the frame of the SLIDE project (2 December 2024)
    - Virtual participation to the PhD defence of Axel Deijns at the Africa Museum (3 December 2024)

Julien Barrière

- Thesis defence of Josue Subira (Univ. Liège, MRAC & GVO), Tervuren, Belgium (10 September) **as co-supervisor**
- **Jury member** for private and public defense of S. Nowé's PhD thesis at ULB (8 July & 2 September 2024)

- 39th ESC General Assembly, Corfu, Greece (22-27 September)
- 102nd Journées Luxembourgeoises de Géodynamique (JLG) & EFEHR Scientific Session 2024, Luxembourg (27-29 November)
- Work visits & visitors at ECGS, virtual meetings:
  - Virtual meetings with Josué Subira (some with co-supervisors) about his thesis and post-thesis work (9-19 January, 8-14 February, 11-19-29 March, 8-10-15 April, 3 May, 10-19 June, 17-19-22-25-26 July, 8 October, 5-18 November)
  - Eifel Large-N Array Virtual Meeting (19 January)
  - Virtual meetings for SLIDE project preparation with Université of Lorraine and ISTerre Grenoble (6, 15, 20, 25 and 26 March 2024)
  - Virtual meetings of J. Subira's PhD thesis committee (17 May, 6 September)
  - Kick-off virtual meeting for SLIDE project with Université of Lorraine and ISTerre Grenoble (6 November 2024)

Delphine Smittarello

- 6th edition of the MDIS - FormaTerre Symposium, Orléans, France (19-22 November 2024)
- 102nd Journées Luxembourgeoises de Géodynamique (JLG) & EFEHR Scientific Session 2024, Luxembourg (27-29 November)
- Work visits & visitors at ECGS, virtual meetings:
  - Virtual meetings for the ongoing research on Karthala volcano (Comoros Island) (16 February, 29 April, 7 June, 15 July, 18 September, 13 November 2024).
  - Virtual meetings for SLIDE project preparation with Université of Lorraine and ISTerre Grenoble (6, 15, 20, 25 and 26 March 2024)
  - Virtual meeting with Haldor Geirsson about research on dyke intrusion in the Virunga Volcanic Province (26 April 2024)
  - Kick-off virtual meeting for SLIDE project with Université of Lorraine and ISTerre Grenoble (6 November 2024)

SCIENTIFIC COMMUNITY SERVICE

Adrien Oth

- European Seismological Commission (ESC) **Secretary General** (2022 – present)
- European Seismological Commission (ESC) **Titular Member** for Luxembourg
- **ESC Representative** in EPOS TCS Seismology, ORFEURS Board of Directors, EMSC Executive Council, EFEHR
- **ECGS Representative in EFEHR consortium**
- International Association of Seismology and Physics of the Earth's Interior (IASPEI) **National Correspondent** for Luxembourg
- **Associate Editor** of *Bulletin of the Seismological Society of America* (November 2017 – present)
- Member of the **Supervisory Board** of the **Koninklijk Nederlands Meteorologisch Institutt (KNMI)**, Netherlands
- Member of **Science Advisory Board** of the **Central Asian Institute for Applied Geosciences** (CAIAG), Kyrgyz Republic
- **Session Convener** of two sessions ("General Seismology" and "Seismic Interferometry, ambient noise and seismo-acoustics: From theory to monitoring") at 39th ESC General Assembly in Corfu, Greece
- **Reviewer** for *Seismological Research Letters, J. Volc. Geotherm. Res.*
- **Member** of Seismological Society of America, Deutsche Geophysikalische Gesellschaft
- **Mentorships & Supervision**
  - Support to PhD thesis performed by Josué Subira (Univ. Liège, MRAC & GVO)
  - Co-supervison of Françiszek Waligora's (student at UC Berkeley, USA) internship (20 May – 28 June 2024)

  - Internship of Sally Bausch from Utrecht University, six months from 15 December 2024 to 15 June 2025

Nicolas d'Oreye

- International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI) **National Correspondent** for Luxembourg
- IAVCEI Board member of the Volcano Geodesy Commission
- **Scientific Committee Member** for *ESA Fringe workshop*
- **Scientific Committee Member** for French "Service National d'Observation (SNO) ISDeform"
- **Member** of American Geophysical Union, European Geosciences Union, IAVCEI & Academy of Sciences Luxembourg
- **Mentorships & Supervision**
  - Support to PhD thesis performed by Axel Deijns (RMCA), Jos Subira (RMCA, OVG), Colline Hopquin (IPGP).
  - Committee member for Bastien Wirtz's PhD thesis (Univ. Strasbourg)
  - Committee member for Leo Letellier's PhD thesis (Univ. Nancy)
  - Jury member for Leo Marconato's PhD thesis (Univ. Grenoble)
  - Support to Master thesis at the Laboratoire Magmas et Volcans (univ. Clermont Auvergne): Alexis Hautecoeur
  - Support to Master thesis at the Université de Lorraine (Nancy): Florian Leder
  - Co-supervison of Françiszek Waligora's (student at UC Berkeley, USA) internship (20 May – 28 June 2024)

Julien Barrière

- **Associate Member Representative** for ECGS at EarthScope Consortium
- **Session Convener** ("Seismic Interferometry, ambient noise and seismo-acoustics: From theory to monitoring") at 39th ESC General Assembly in Corfu, Greece
- **Reviewer** for *Earth Space Sci., Annals Geophys., Volcanica, Bull. Soc. Geograph. Liège*
- **Member** of American Geophysical Union & IAVCEI
- **Mentorships & Supervision**
  - Co-supervision & jury member of the PhD thesis "*Seismicity analysis and seismological models in the Virunga Volcanic Province and Kivu rift region, DR Congo*" of Josué Subira (Univ. Liège, MRAC & GVO, project HARISSA/Belspo)
  - Reviewer & jury member of the PhD thesis jury "*Characterization of cryo-, hydro- and volcano-seismic sources in the Vatnajökull icecap region (Iceland), from the analysis ff ambient seismic noise correlograms*" by Sylvain Nowé (ULB)
  - Co-supervison of Françiszek Waligora's (student at UC Berkeley, USA) internship (20 May – 28 June 2024)

Delphine Smittarello

- **Reviewer** for *J. Volc. Geotherm. Res., Bulletin of Volcanology, Physics of the Earth and Planetary Interiors. ECOS-SUD projects*
- **Member** of IAVCEI
- **Mentorships & Supervision**
  - Supervision of the Master Thesis of Nelly-Wangue Moussisa (Student at ENS, Paris) defended in June 2024
  - Supervision of the Licence Internship of Lisa Mollinier (Student at ENS Lyon) defended in September 2024
  - Co-supervison of Françiszek Waligora's (student at UC Berkeley, USA) internship (20 May – 28 June 2024)