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Institut de physique du globe de Paris
Observatoire volcanologique du Piton de la Fournaise

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August, 2023

PITON DE LA FOURNAISE *(VNUM #233020)*
Latitude: *21.244°S*
Longitude: *55.708°E*
Summit elevation: *2632 m*

Piton de la Fournaise is a basaltic hot spot volcano located in the southeastern part of La Réunion Island (Indian Ocean).
The volcano first erupted about 500,000 years ago. Its volcanic activity is characterized by frequent effusive eruptions (with emissions of lava fountains and lava flows) that occur on average twice a year since 1998. More rarely, larger explosive eruptions (with blocks covering the summit area and ash emissions that can disperse over long distances) have happened in the past with a centennial recurrence rate.
Most of the current eruptive activity (97% during the last 300 years) occurs from vents inside the Enclos Fouqué caldera. A few eruptions, however, have occurred from vents outside the caldera (most recently in 1977, 1986, and 1998). Such eruptions can potentially threaten communities that live in the surrounding areas.
Since late 1979, the activity of Piton de la Fournaise is monitored by the Piton de la Fournaise Volcanological Observatory (Observatoire Volcanologique du Piton de la Fournaise - OVPF), which belongs to the Institut de Physique du Globe de Paris (IPGP).

Alert level: Vigilance **(Since August 31, 2023)**	
April 24, 2023 (14h00) to July 2, 2023 (8h00): Vigilance ***July 2, 2023 (8h00) to August 31, 2023 (8h00): Sauvegarde***	***(cf. table in the appendix)***

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A. Piton de la Fournaise activity

Seismicity

In August 2023, the OVPF-IPGP recorded at Piton de La Fournaise:

- 60 shallow volcano-tectonic earthquakes (0 to 2.5 km above sea level) below the summit craters;
- no deep earthquake (below sea level);
- no long-period earthquake;
- 330 rockfalls.

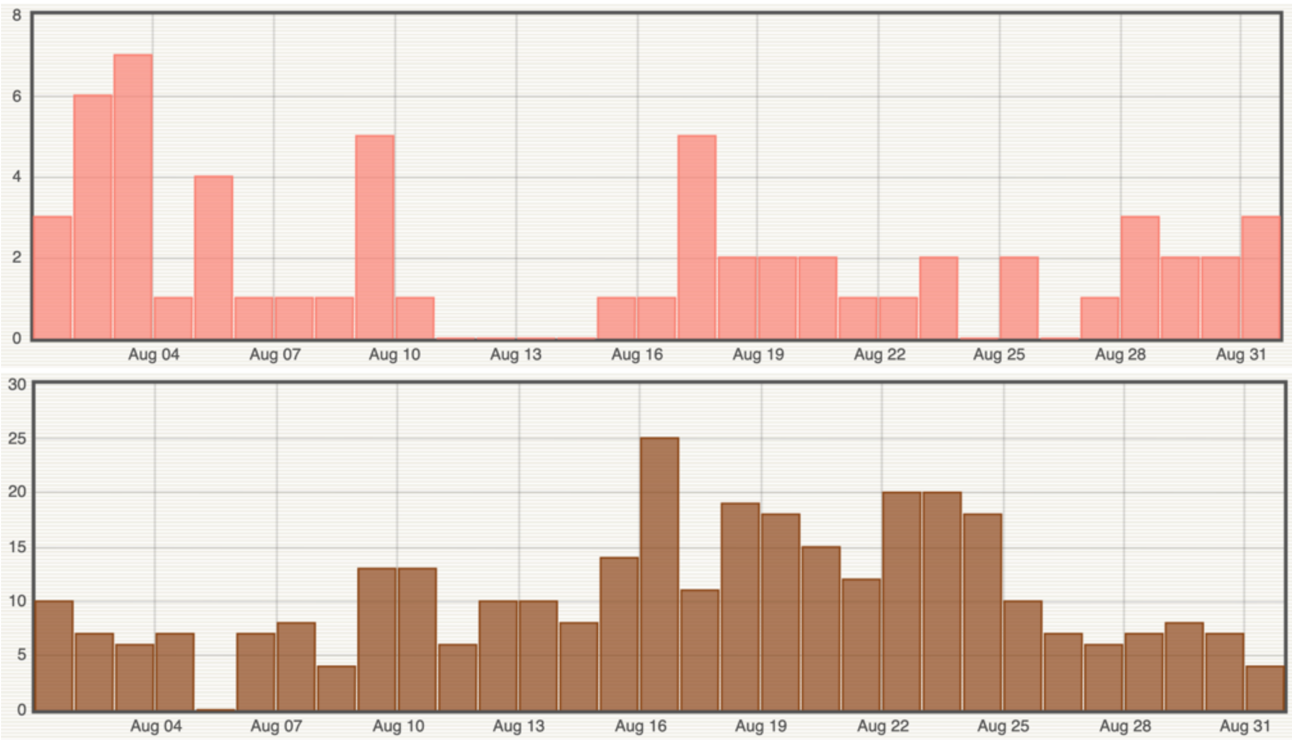

Figure 1: Number of (top) shallow volcano-tectonic earthquakes and (bottom) rockfalls per day recorded in August 2023 (© OVPF-IPGP).

The eruption that began on July 2, 2023, ended on August 10, 2023 (see section B for more details).
The seismic activity beneath Piton de la Fournaise in August 2023 was low. Although seismicity persisted until the end of the eruption, the number of shallow volcano-tectonic earthquakes recorded beneath the summit zone was low, with an average of 3 events per day.

Following the end of the eruption, the number of daily shallow volcano-tectonic earthquakes remained low, with an average of 2 events per day. These events were mainly located beneath the eastern rim of the Dolomieu crater (Figure 2).

Numerous rockfalls also occurred inside the *Dolomieu* crater, along the cliffs of the *Rivière de l'Est* and on the recent lava flows (Figure 1).

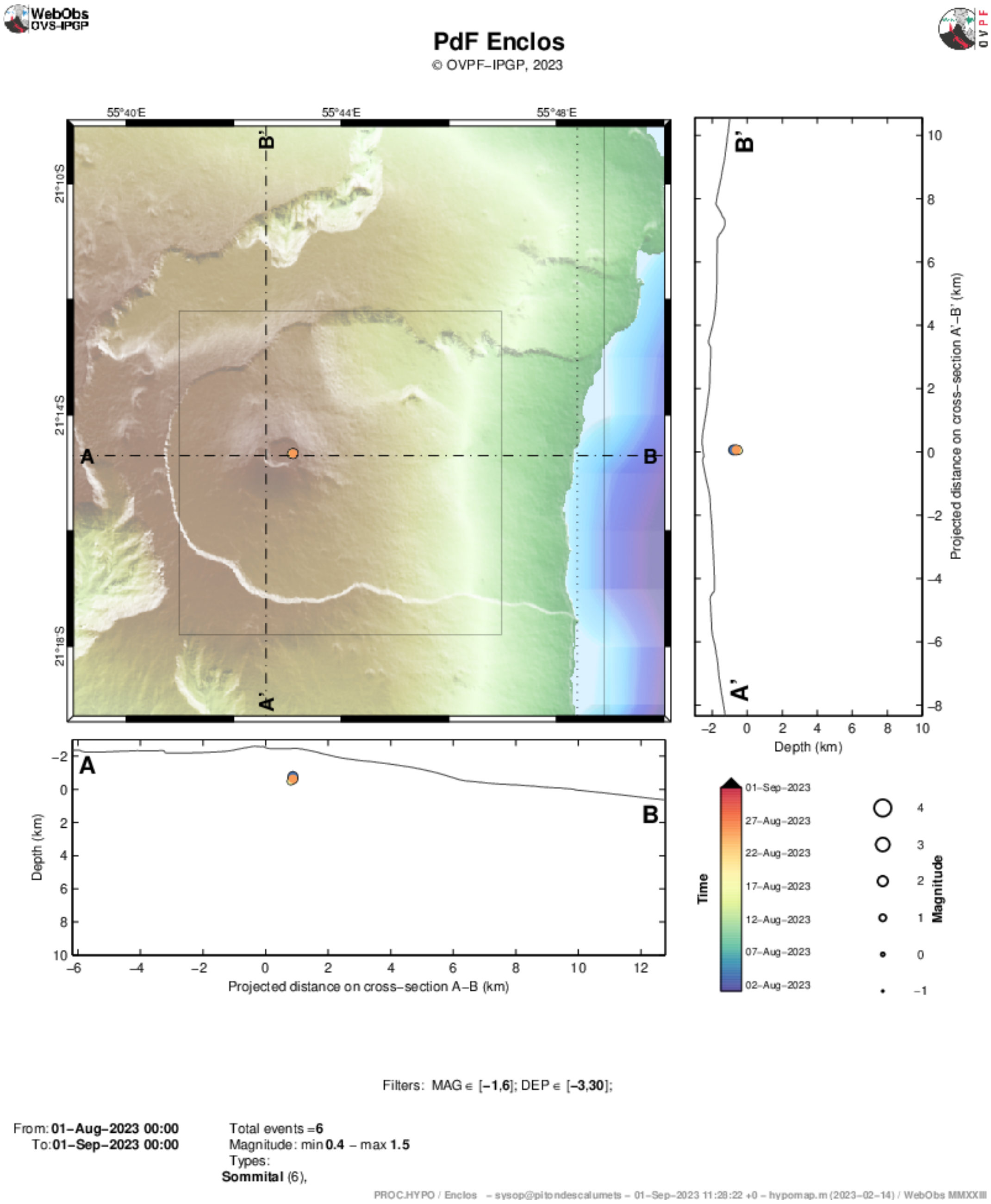

Figure 2: Seismicity below Piton de la Fournaise in August 2023. Location map (epicenters) and north-south and east-west cross-sections (hypocenters) of earthquakes as recorded by OVPF-IPGP. Only manually located earthquakes are shown on the map (© OVPF-IPGP).

Deformation

From mid-July, a slight inflation of the summit zone was recorded (Figures 3 and 4), indicating pressurization of the shallow magma reservoir located at about 2 km below the summit. The persistence of this inflation throughout the eruption ensured continuous feeding of the eruption during 39 days (see section B for more details).

Inflation continued after the end of the eruption, before to stop in mid-August. Since then, a slight deflation of the edifice is recorded (Figures 3 and 4).

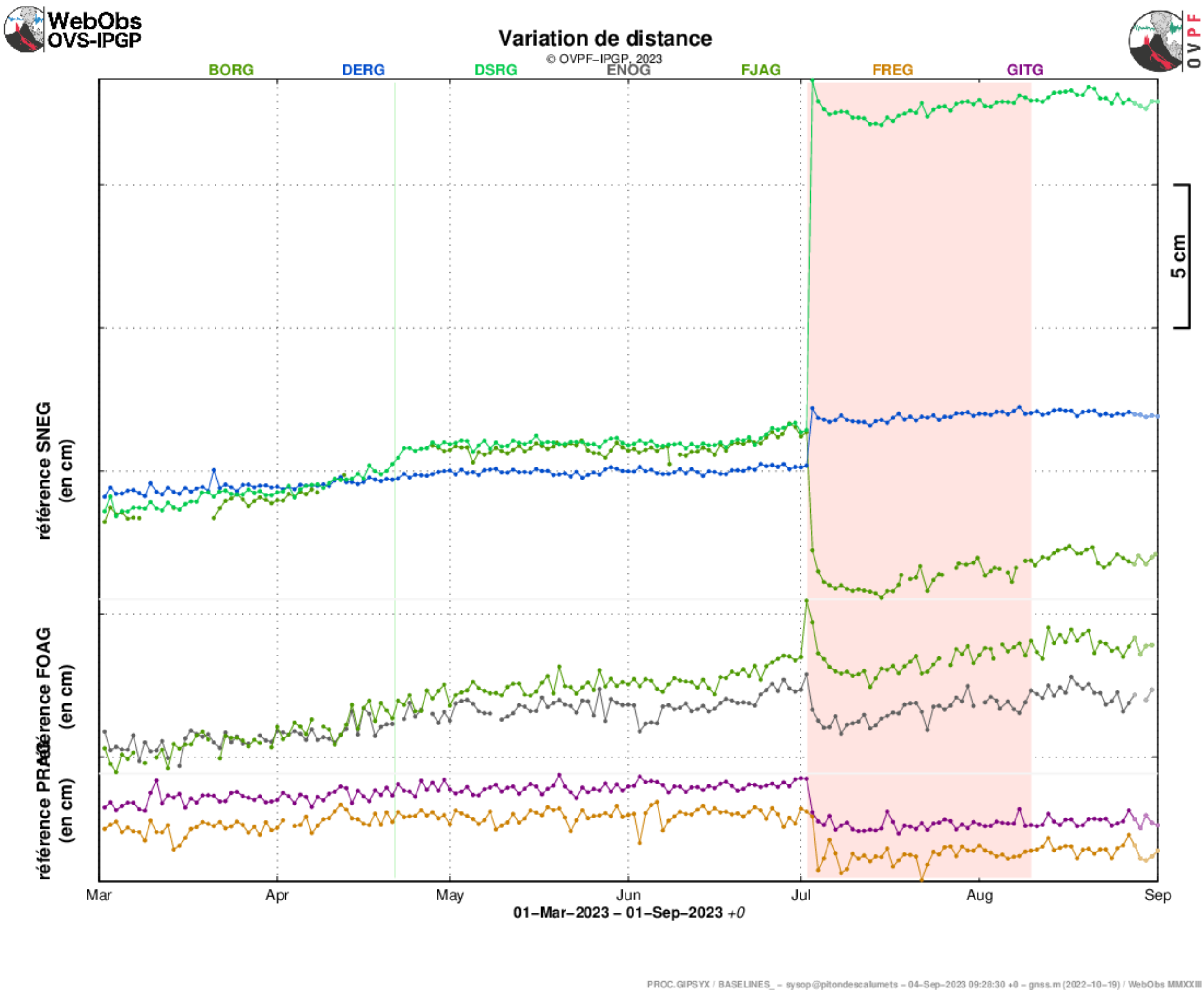

Figure 3: Ground deformation records over the past six months (in case of eruptive or intrusive periods, red and green bars represent eruptions and intrusions, respectively). The time series plots show the changes in distance between pairs of GPS stations located around the Dolomieu summit crater (reference: SNEG; top graph), the terminal cone (reference: FOAG; middle graph) and the Enclos Fouqué caldera (reference: PRAG; bottom graph), from north to south (see location in Figure 5). Increasing distances (or baseline elongation) indicate volcano inflation, while decreasing distances (or baseline contraction) reflect edifice deflation (© OVPF-IPGP).

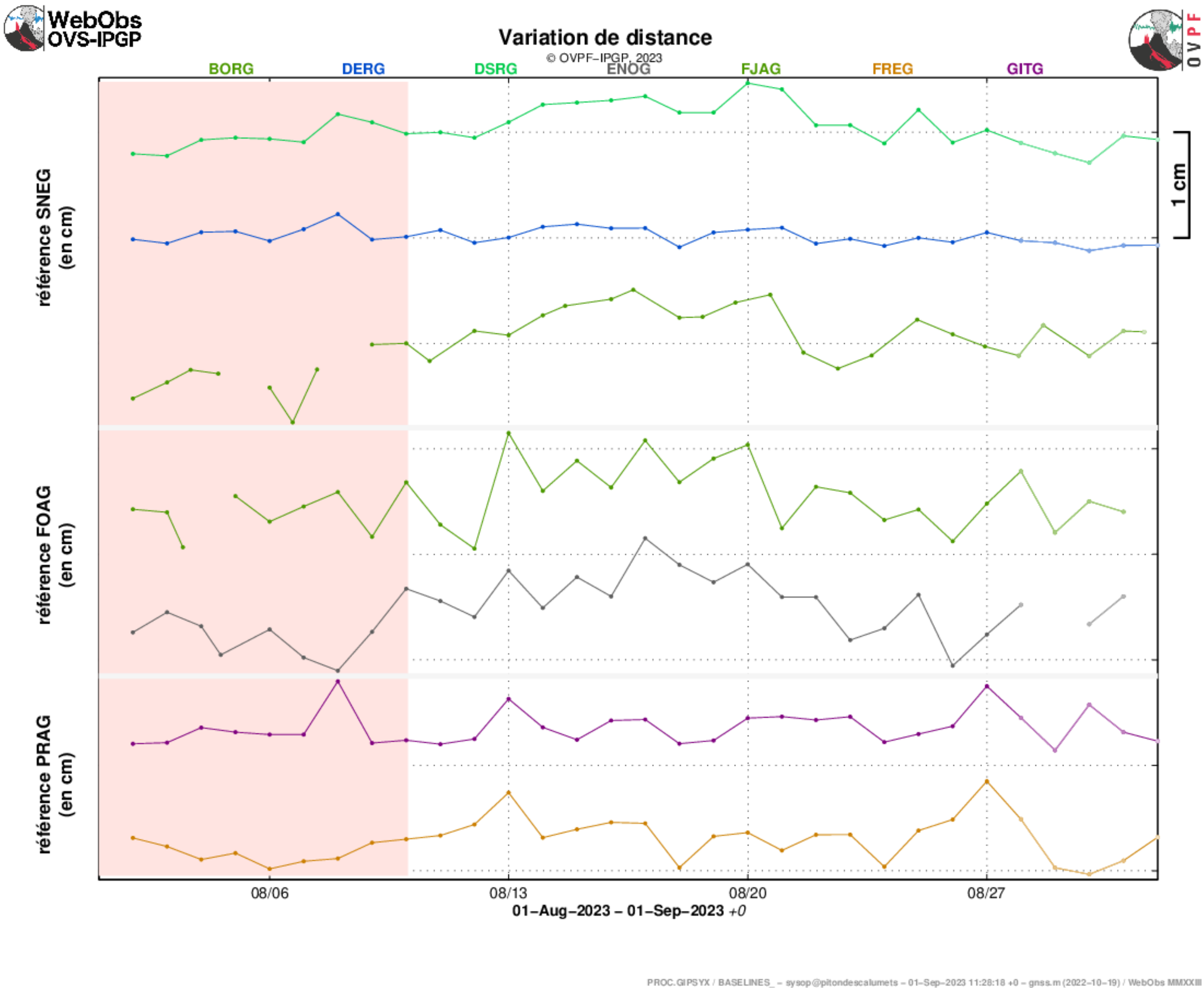

Figure 4: Ground deformation records over the course of August 2023 (in case of eruptive or intrusive periods, red and green bars represent eruptions and intrusions, respectively). The time series plots show the changes in distance between pairs of GPS stations located around the Dolomieu summit crater (reference: SNEG; top graph), the terminal cone (reference: FOAG; middle graph) and the Enclos Fouqué caldera (reference: PRAG; bottom graph), from north to south (see location in Figure 5). Increasing distances (or baseline elongation) indicate volcano inflation, while decreasing distances (or baseline contraction) reflect edifice deflation (© OVPF-IPGP).

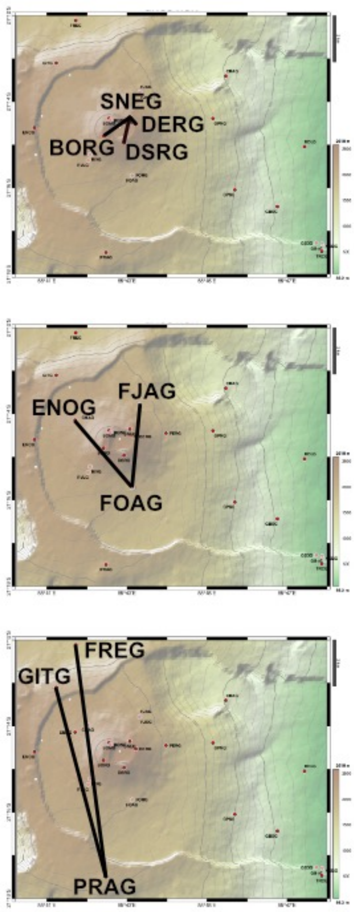

Figure 5: Location map of GPS stations and baselines as discussed in the text and shown in Figures 3 and 4 (© OVPF-IPGP).

** Glossary: The summit GPS signals indicate the influence of a shallow pressure source below the volcano, while distant GPS signals indicate the influence of a deep pressure source below the volcano. Inflation usually means pressurization; and conversely deflation usually means depressurization.*

Gas geochemistry

CO_2 concentration in the soil

In the proximal *Gîte du volcan* site, a sudden drop to very low CO_2 fluxes was detected after January 3, 2022. Since the end of the December 22 - January 17 eruption a new phase of increase was recorded, but with a lower rate.
The significant fluctuations observed during February 2022 are likely related to the environmental influence of two cyclonic events (Figure 6).

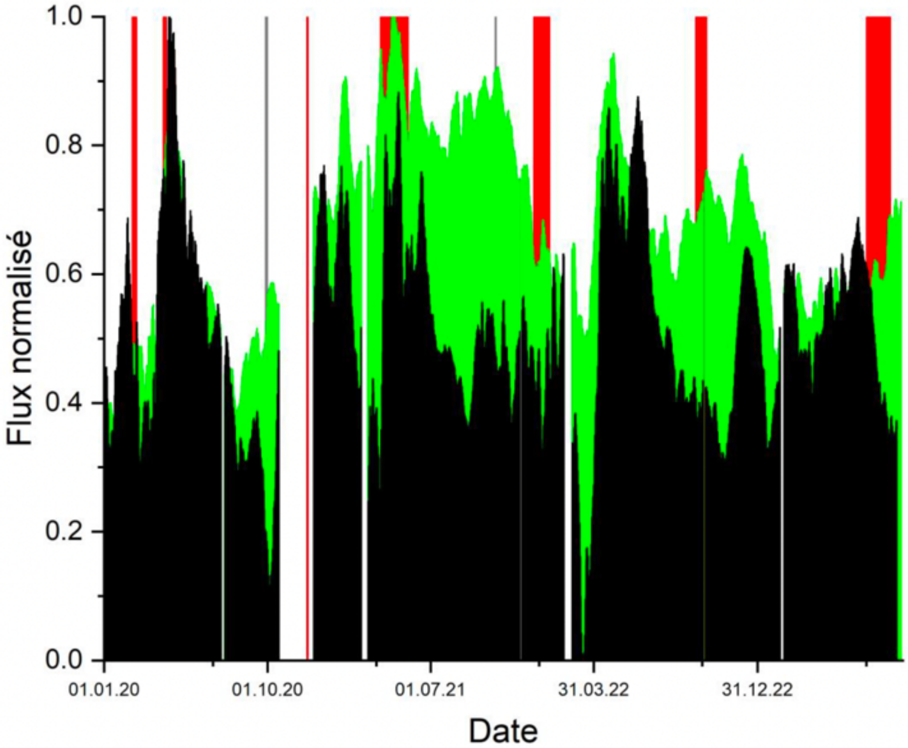

Figure 6: Comparison between the normalized average of corrected for short (OVPF-model; 15 days moving average; in green) and long-term influence of environmental parameters (INGV MALFIT model; in black) soil CO_2 flux from all distal stations since October 2016 (last station set). Red bars: eruptions; Gray bars: intrusions (© OVPF-IPGP).

A new increase in soil CO_2 emissions was recorded in both distal (*Plaine des Cafres, Plaine des Palmistes*) and proximal (*Gîte du volcan*) stations at the end of February 2022 (Figure 6), with a strong acceleration from March 15. The new phase of increase in CO_2 soil emissions has lasted till May 05 in the distal area and till May 19, 2022 in the proximal area.

Since mid-May 2022, a trend of decrease in CO_2 gas fluxes is recorded in both proximal and distal sites. The September 19, 2022 eruption occurred after a significant decrease in CO_2 fluxes, likely recording the progressive transfer of magma to shallow crustal levels. Since the end of the September 19 – October 5 eruption CO_2 fluxes have remained on a stable level.

Interestingly, isotopic analysis of gas sampled at both distal (PNRN, BLEN, PCNR) and proximal (P0; GITN) sites shows a marked increase in the magmatic contribution in the March-April 2022 period (Figure 7). The magmatic contribution has then decreased in the second half of 2022.

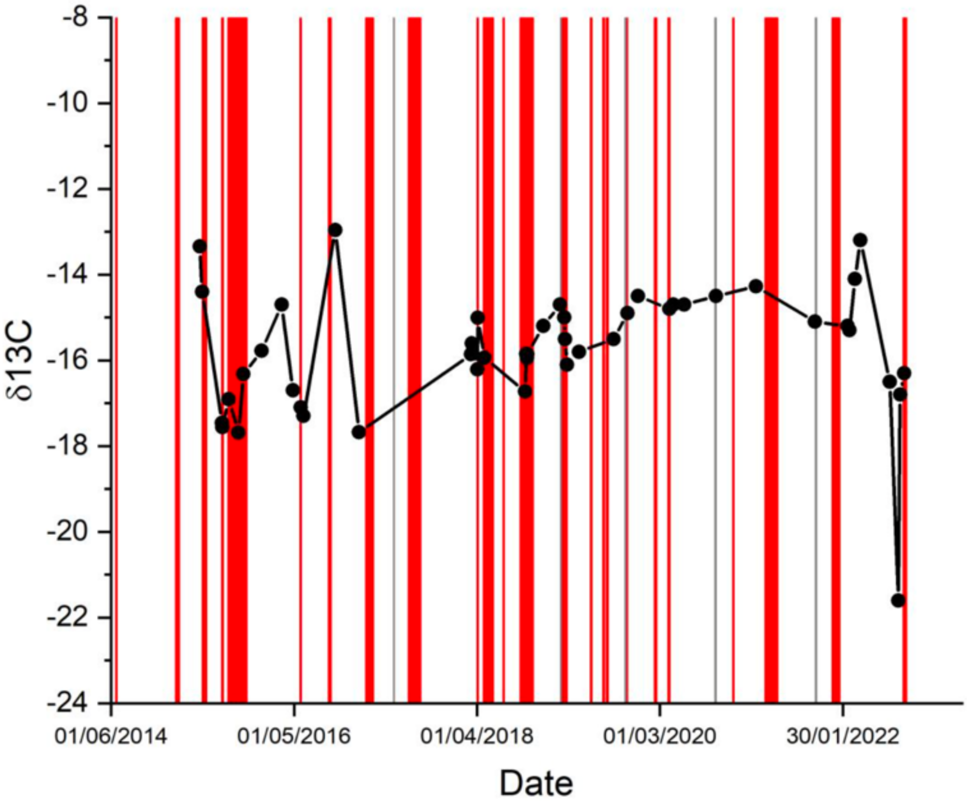

Figure 7: Carbon isotope (δ13C) variations in CO_2 from soil gas emitted from the control point with the highest flux in the proximal area (control point: GIT0).

A new trend of increase in soil CO_2 emissions has started since the beginning of December 2022 in both distal and proximal sites. The increase has occurred with a high rate till mid-march 2023 and then it has slowed down.
A continuous decrease in the CO_2 emission rate in both the distal and the proximal stations is measured since mid-June, possibly heralding a progressive transfer of magma to shallow depth.
CO_2 fluxes have remained stable since the end of the July-August 2023 eruption.

** Glossary: CO_2 is the first gas to be released from deep magma (rising from the mantle), so its detection in the far field often means a deep rise of magma. Its near-field evolution may be related to magmatic transfer in the shallowest part of the feeding system (< 2-4 km below the surface).*

Summit fumaroles composition obtained by the MultiGas method
- Awaiting replacement of the current station by a new one.

** Glossary: The MultiGaS method allows measuring the concentrations of H_2O, H_2S, SO_2 and CO_2 in the atmosphere at the summit of the Piton de la Fournaise volcano. Magmatic transfer in the Piton de la Fournaise feeding system can result in an increase in SO_2 concentrations and in the C/S ratio (carbon/sulfur).*

SO_2 flux in the air obtained by DOAS method

The NOVAC stations located on the edge of the Enclos Fouqué caldera (“Enclos0” to the west, “Piton de Bert” to the south, “Piton Partage” to the north) detected the gas plume linked to the July 2 – August 10 eruption (Figure 8).
The flux at the beginning of the eruption were of around 10-20000 t/day (recorded on the “Enclos0” station) on the first day of the eruption, and then <1000 t/day the following days.

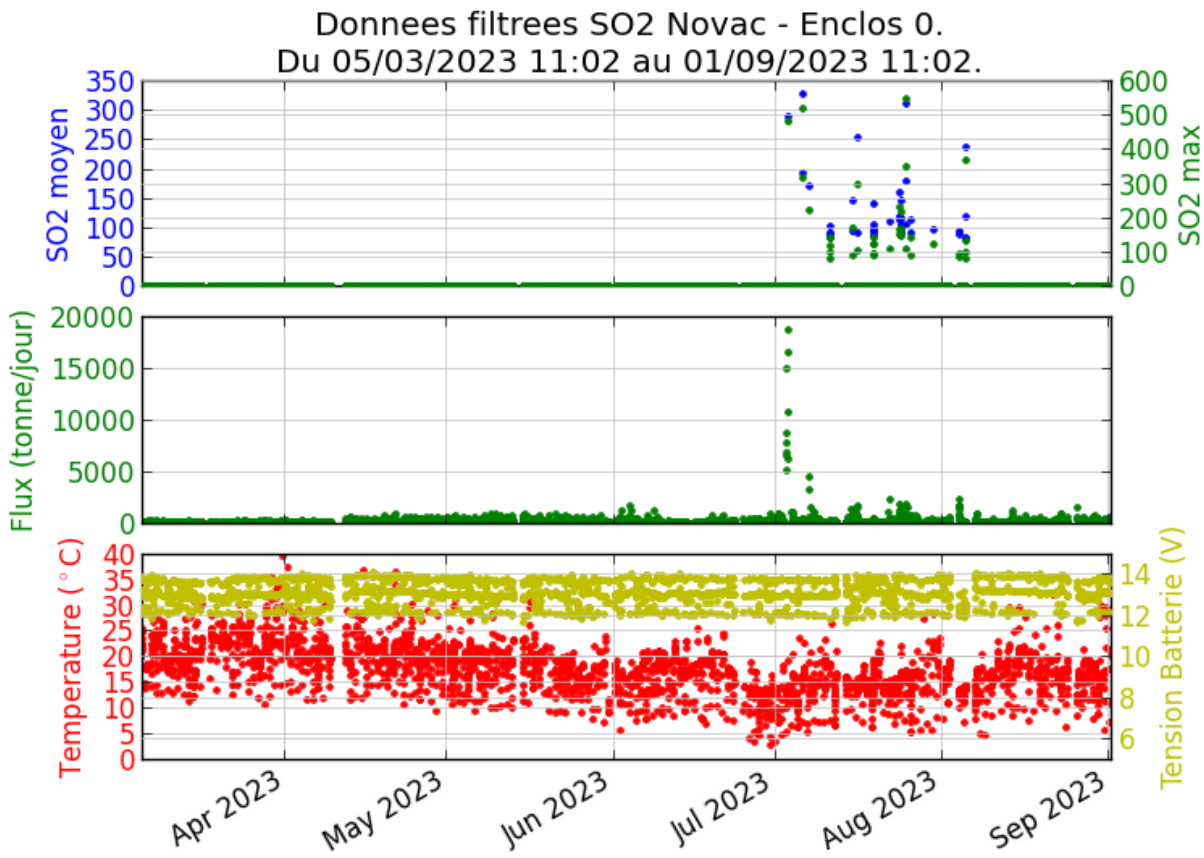

Figure 8a: SO_2 flux in the air detected by the DOAS method on the « Enclos0 » station during the last 180 days (© OVPF-IPGP).

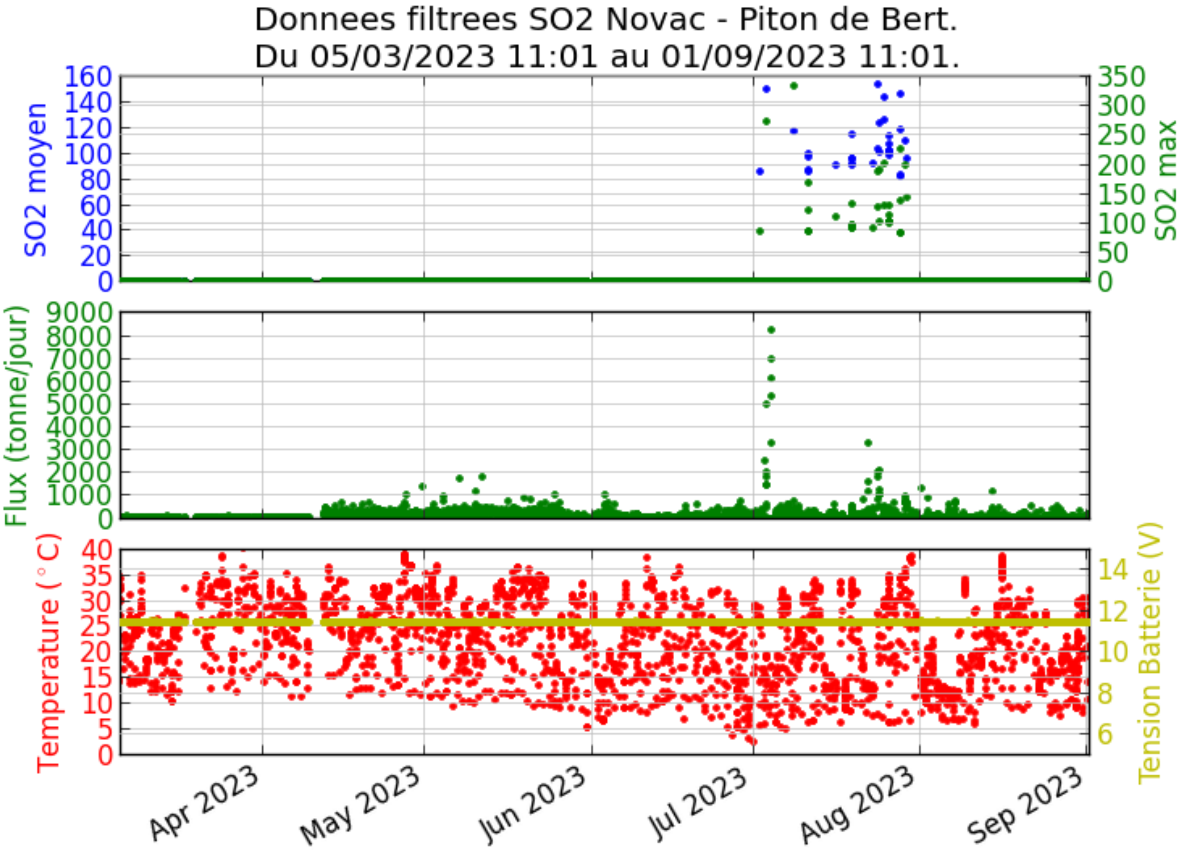

Figure 8b: SO_2 flux in the air detected by the DOAS method on the « Piton de Bert » station during the last 180 days (© OVPF-IPGP).

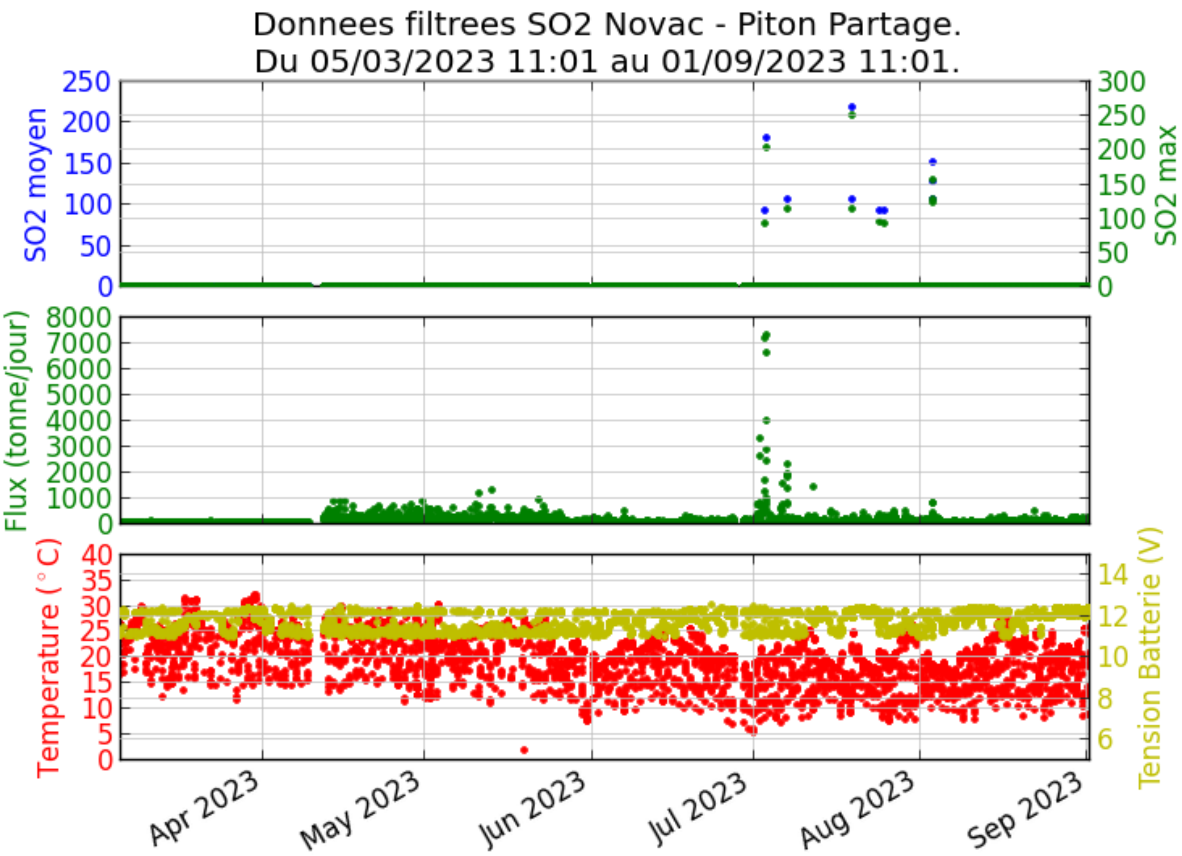

Figure 8C: SO_2 flux in the air detected by the DOAS method on the « Piton Partage » station during the last 180 days (© OVPF-IPGP).

** Glossary: During rest periods, SO_2 flux at Piton de la Fournaise is below the detection threshold. The SO_2 flux may increase during magma transfer in the shallowest part of the feeding system. During eruptions, it is directly proportional to the amount of lava emitted at the surface.*

Phenomenology

The month of August 2023 was marked by the continuation of the eruption – started on July 2, 2023 – until August 10, 2023, date of the end of surface eruptive activity (see section B for more detail).

Summary

Following the end of the eruption on August 10, 2023, seismic activity remained relatively low beneath Piton de La Fournaise, with a mean of two shallow volcano-tectonic earthquakes per day. From mid-August, edifice inflation stopped, indicating the end of pressurization of the shallow magma reservoir.

B. The July 2 – August 10, 2023 eruption

** Information on the start of this eruption and its precursors can be found in the July 2023 monthly bulletin.*

Deformation

Following the dike propagation of July 2, which generated multi-decimetric displacements on the eastern south-eastern flank of the volcano - and reaching up to an uplift of 75 cm on the eastern flank of the terminal cone (see OVPF-IPGP monthly bulletin of July 2023) -, a slight edifice deflation has been recorded linked to the magma transfer from the magma storage area below the summit to the eruptive site (Figures 4, 5).
From mid-July, a slight inflation of the summit zone was recorded, indicating a re-pressurization of the volcano feeding system located beneath the summit zone (Figure 10), with the possible transfer of deep magma to the shallow reservoir, and feeding then the eruption - explaining thus its duration (39 days, compared with the average duration of eruptions at Piton de la Fournaise of 20 days).

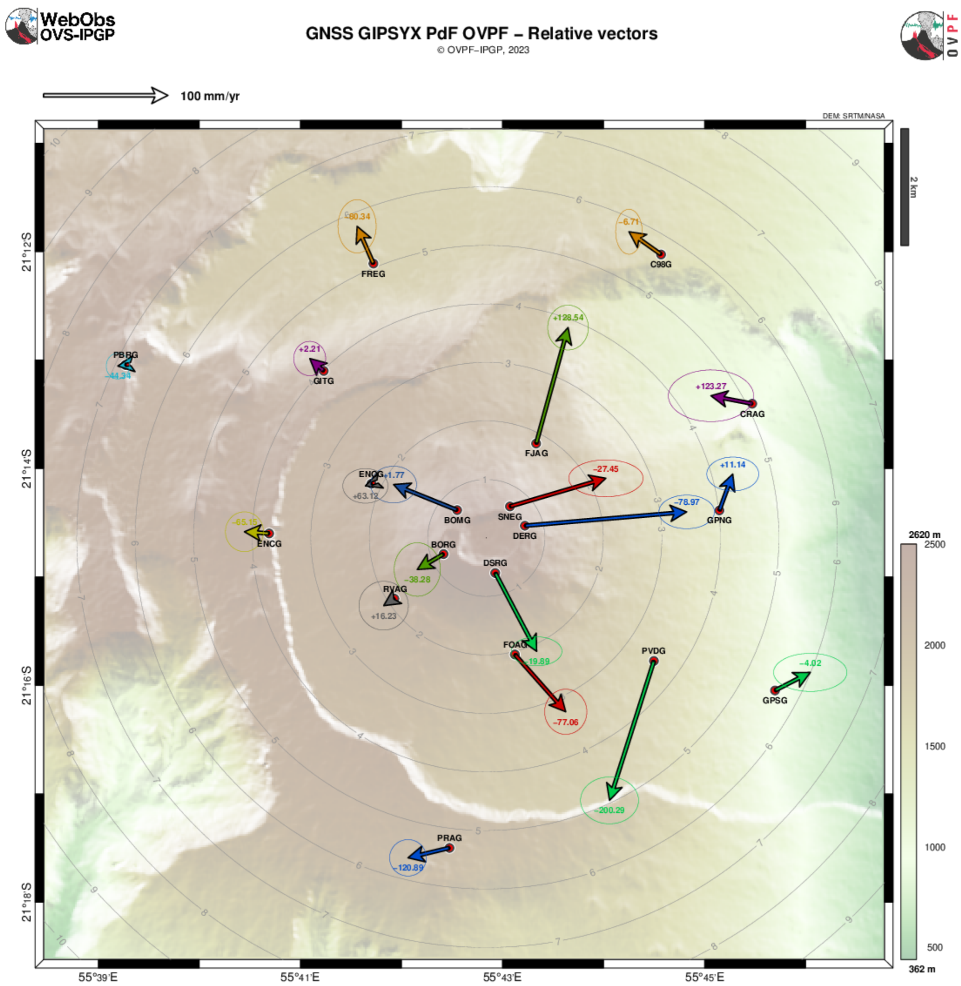

Figure 10: Map of ground displacements (expressed in velocity) recorded between July 15 and August 10, 2023 by the OVPF-IPGP permanent GPS network. Horizontal displacements are represented in vector form and vertical displacements are indicated by numerical values in color (© OVPF-IPGP)

Tremor and seismicity

The amplitude of the tremor (an indicator of lava and gas emission in surface) increased sharply at the onset of the eruption, before to drop as usually observed during the first hours of eruptions at Piton de la Fournaise. Two new increases in tremor amplitude were recorded on July 2, corresponding to the opening of new eruptive fissures (see the OVPF-IPGP monthly bulletin of July 2023).

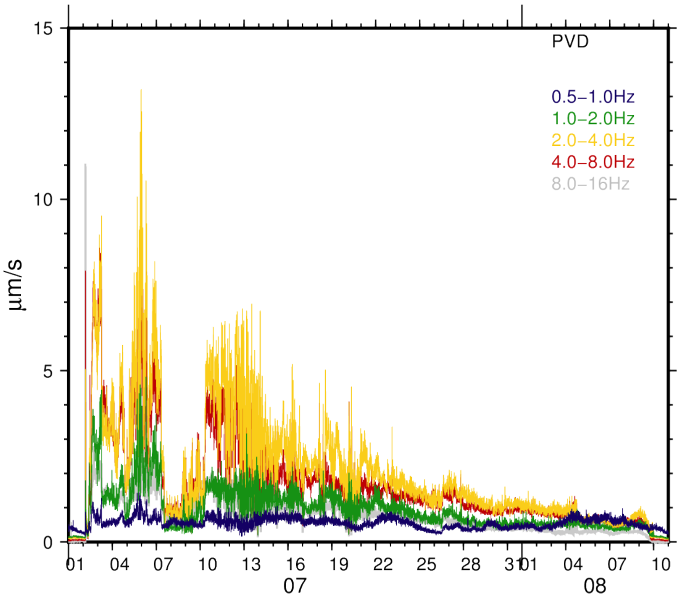

Figure 11: Evolution of the amplitude of the tremor at the seismological station PVD (Piton Parvedi) between 01/07/2023 and 10/08/2023. The RSAM curves (Real-time Seismic-Amplitude Measurement) represent the average amplitude of the seismic signal over a period of 1 minute in different frequency bands (see caption at top right) (© OVPF/IPGP).

The amplitude of the tremor increased again between July 9 and 11 - due to the formation and the lateral closure of the eruptive cone in formation - before to decrease relatively continuously (Figure 11).
From July 9, the amplitude of the volcanic tremor began to fluctuate over time on the scale of a few tens of minutes, with phases of continuous tremor and phases of intermittent tremor. Fluctuations in the tremor correspond at the eruption site to variations in the intensity of activity, with lava fountains projected from the eruption cone of varying degrees of intensity.

The tremor, and the surface eruptive activity, stopped abruptly on August 10 around 5h00 (local time, 1h00 UTC; Figure 11).

Degassing

In addition to the data from the OVPF-IPGP NOVAC permanent ground stations installed around the Enclos Fouqué caldera (Figure 8), gas emissions were monitored using satellite data (OMI, OMPS, TROPOMI; Figure 12).
As observed in the field (Figure 13) and on the NOVAC stations of OVPF-IPGP, satellite data recorded the highest emissions of sulfur dioxide during the two first days of eruption (Figure 12). A significant drop in sulfur dioxide emissions was then recorded as early as July 4 (Figure 12).

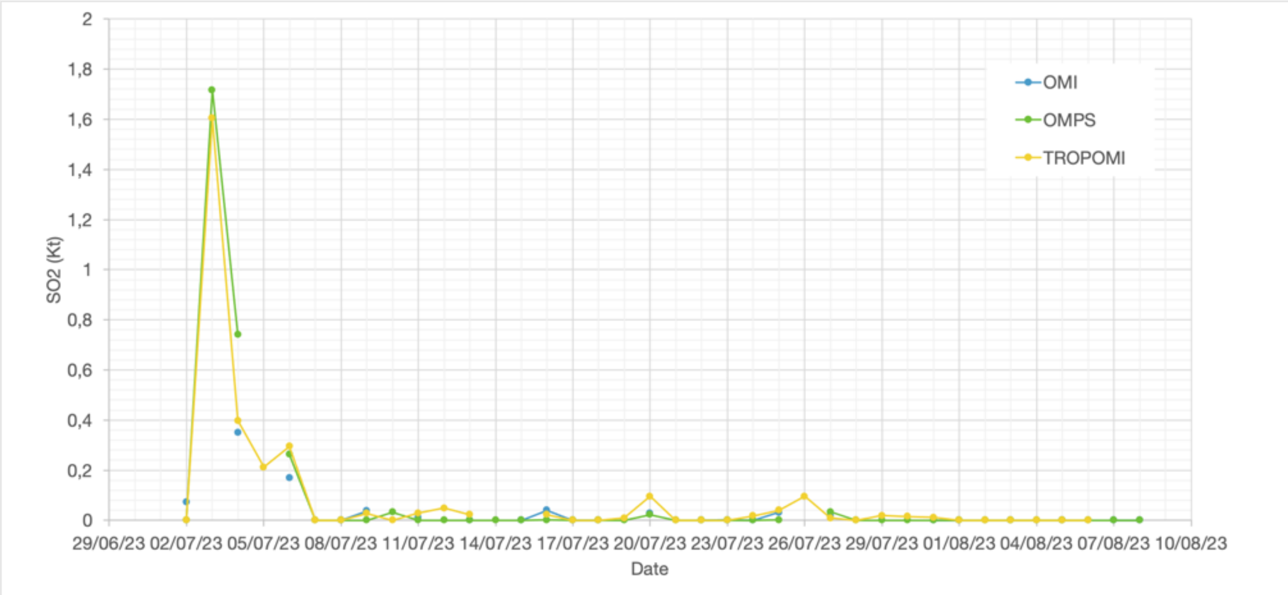

Figure 12: Evolution of the SO_2 mass recorded by satellite methods (in kton, ©OMI-OMPS-TROPOMI, NASA AURA project, Suomi-NPP/OMPS project et BIRA-IASB/DLR/ESA/EU Copernicus Program).

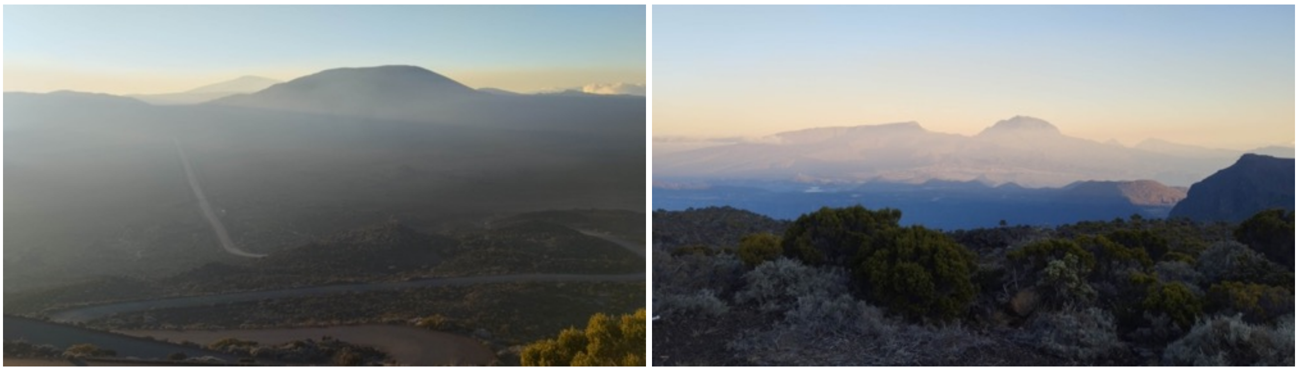

Figure 13: Photographs of the gas plume on July 3 at around 7h15 (local time) on the volcano road (©OVPF-IPGP).

Surface activity

Discharge rates estimated from satellite data, via the HOTVOLC (OPGC – Université Clermont Auvergne) and MIROVA (University of Turin) platforms showed mean values of 20 m^3/sec at the beginning of the eruption, then a stabilization around 2-4 m^3/sec before to decrease from the beginning of August (Figure 14). Variations are explained by the method, which is based on the infrared radiation of the lave flows, whose detection by the satellites is largely influenced by the meteorological conditions and by the surface conditions of the lava flows (in surface or in lave tubes). These estimates are therefore minimum values.

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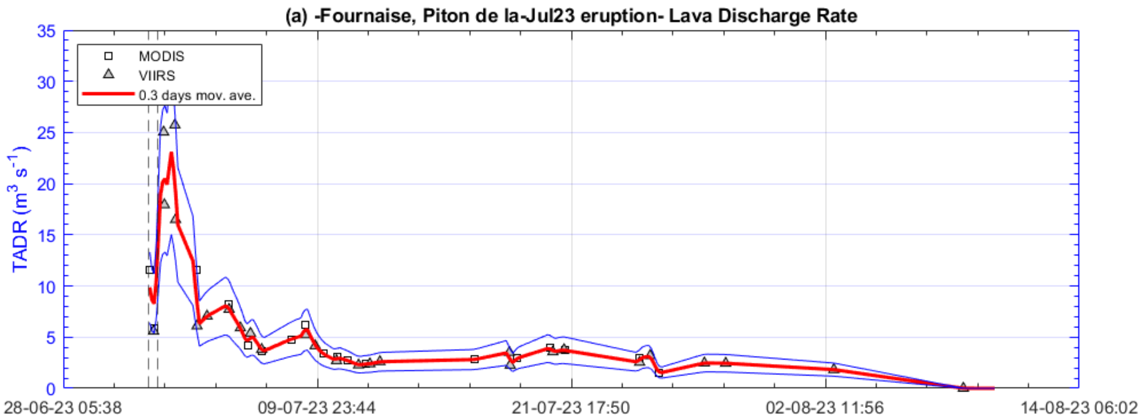

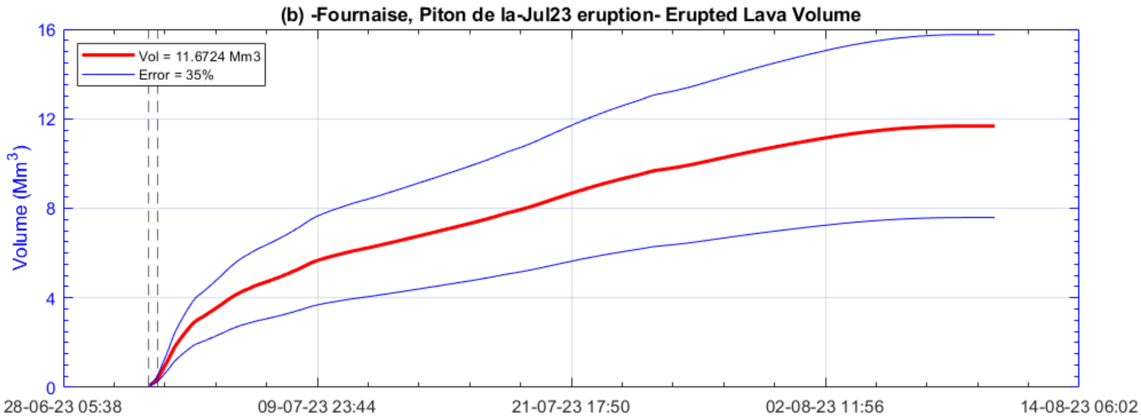

Figure 14: Evolution of discharge rates (top) and cumulative volume (bottom) between July 2 and August 10, 2023 estimated from satellite images (©MIROVA, University of Turin).

From these rates, it is possible to estimate that 11.7 (± 4) million m^3 of lava were emitted at the surface during the eruption (Figure 14).

The surface activity was characterized by the formation of an eruptive cone, built by the accumulation of fallout from lava fountains (Figure 15), as well as by a lava tube activity set up quickly downstream of the eruptive cone. Numerous resurgences of lava flows were observed at the roof of the lava tube field throughout the eruption.

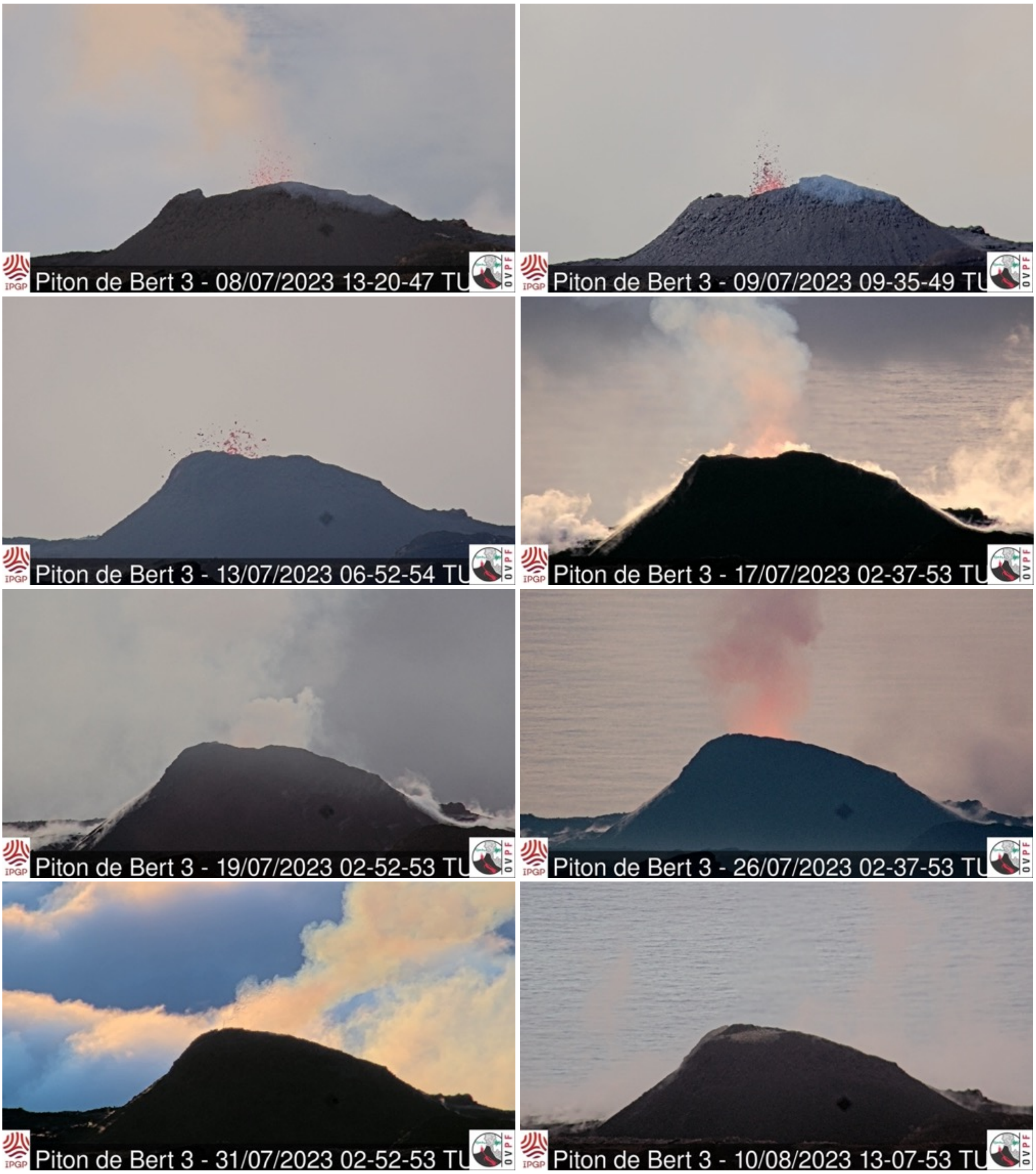

Figure 15: Views of the active vent located southeast of the Enclos Fouqué caldera. Images zoomed from the IRT-OVPF-IPGP webcam at Piton de Bert. Dates and times are indicated on the images in UTC time (©IRT and OVPF-IPGP).

From the beginning of the eruption, the lava flow path was modelled using DOWNFLOWGO (LMV-Clermont Auvergne University, (Figure 16), which was communicated to the «*Etat-Major de Zone et de Protection Civile de l'Océan Indien*» (EMZPCOI) for assisting with crisis response operations.

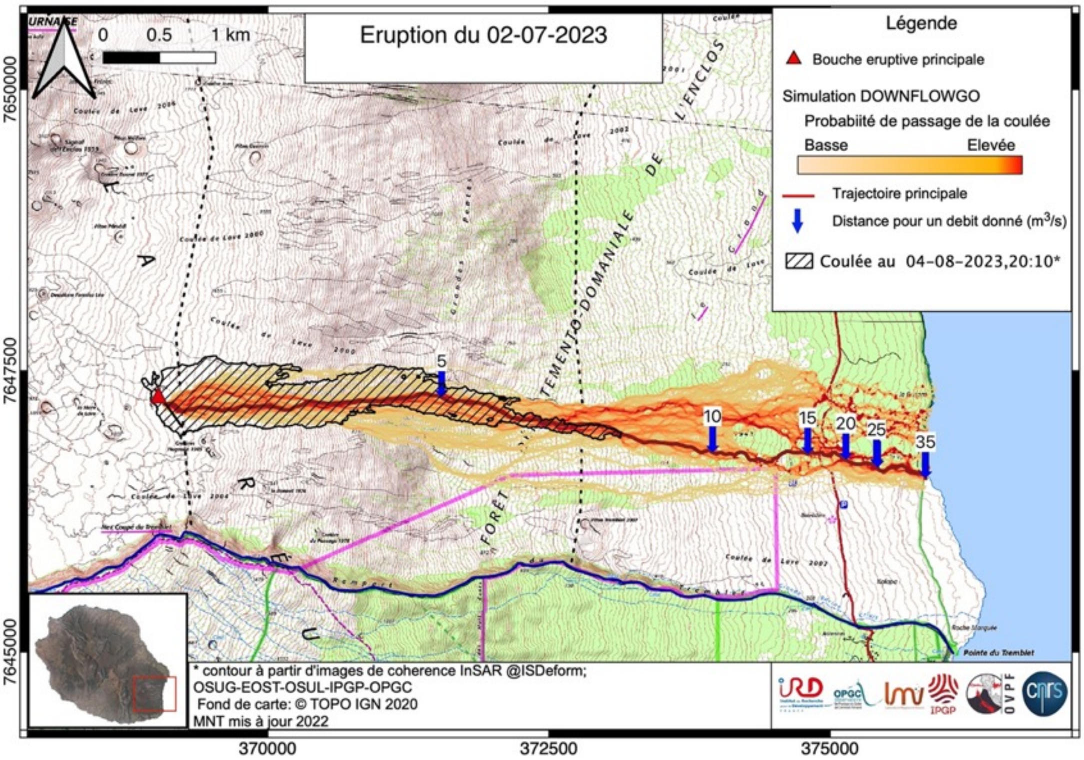

Figure 16: Numerical simulations of probable lava flow inundation paths for the July 2, 2023 eruption (following the protocol described in Harris et al. 2019). The inundation area is computed for 10000 iterations from the initial vent location with vertical elevation noise of 2 m via the DOWNFLOW model (Favalli et al. 2005). Yellow to red lines represent the frequency of lava paths from low (yellow) to high (red). The line of steepest descent (LoSD) is shown in red. Blue arrows represent the location at which the lava could extend along the LoSD for given effusion rates (numbers are in m^3/s) as computed using the FLOWGO model (Harris and Rowland 2001; Chevrel et al. 2018). The black outline shows the final contour of the lava flow (Figure 17) (©OPGC-LMV-OVPF-IPGP).

References:
. Chevrel MO, Labroquere J, Harris AJL, Rowland SK (2018) PyFLOWGO: An Open-Source Platform for Simulation of Channelized Lava Thermo-Rheological Properties. Comput. Geosci. 111: 167–80. https://doi.org/10.1016/j.cageo.2017.11.009
. Favalli M, Pareschi MT, Neri A, Isola I (2005) Forecasting Lava Flow Paths by a Stochastic Approach. Geophys. Res. Lett. 32(3): 1–4. https://doi.org/10.1029/2004GL021718
. Harris AJL, Chevrel MO, Coppola D, Ramsey MS, Hrysiewicz A, Thivet S, Villeneuve N et al. (2019) Validation of an Integrated Satellite-data-driven Response to an Effusive Crisis: The April–May 2018 Eruption of Piton de La Fournaise. Ann. Geophys. 61. https://doi.org/10.4401/ag-7972
. Harris AJL, Rowland SK (2001) FLOWGO: A Kinematic Thermo-Rheological Model for Lava Flowing in a Channel. Bull. Volcanol. 63: 20–44. https://doi.org/10.1007/s004450000120

Thanks to satellite data (InSAR coherence images and space imagery), a precise follow up of the evolution of the lava field during the eruption was able to be carried out (Figure 17). The map shows that the numerical simulations (Figure 16) allowed good anticipation of the trajectory and the area covered by the lava flows (Figure 17).
It should be noted that from July 24 the lava field did not significantly change (Figure 17).

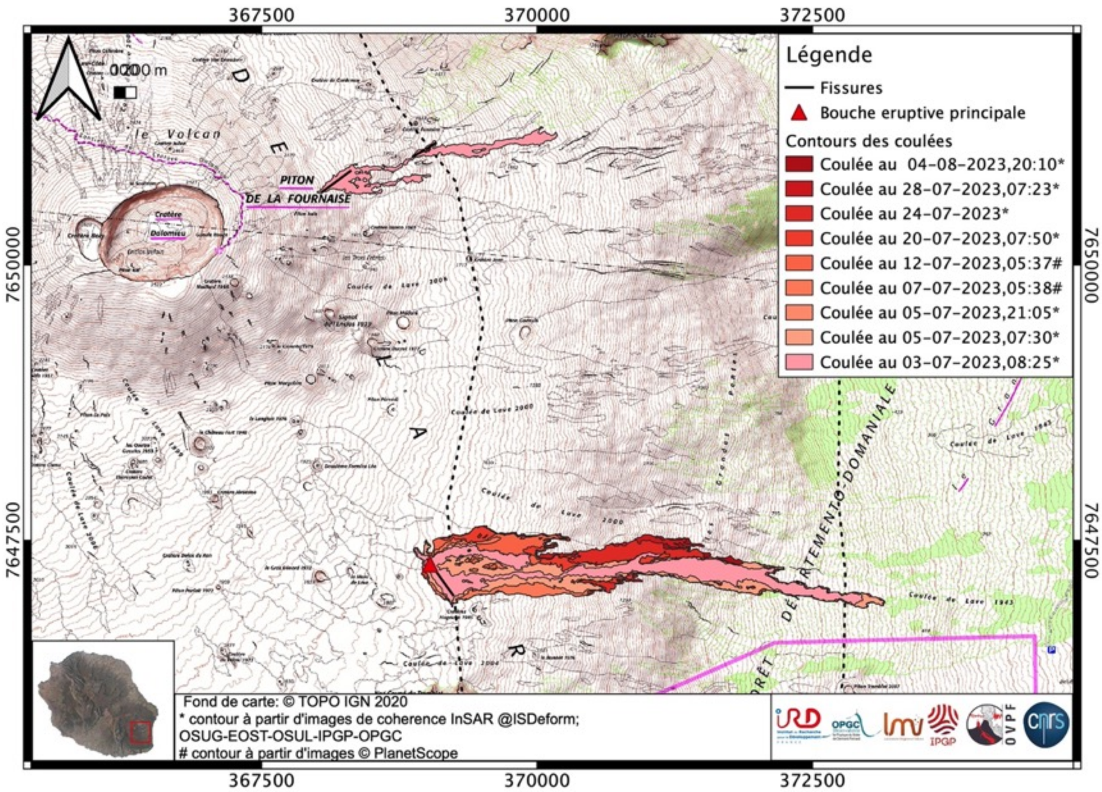

Figure 17: Evolution of the lava flow mapped from satellite data between 03/07/2023 and 10/08/2023 (© ISDeform, OSUG-EOST-OSUL-IPGP-OPGC).

C. Seismic activity on La Réunion and in the Indian Ocean basin

Local and regional seismicity

In August 2023, the OVPF-IPGP recorded:

- 70 local earthquakes (below the island, within a radius of 200 km around the island, Figures 18 and 19);
- 1 regional earthquake (in the Indian Ocean basin).

In August, the OVPF-IPGP recorded 70 local earthquakes below the La Réunion island, and mainly near *Roche Ecrite* and *Cirque de Salazie* (Figure 19).

These earthquakes were located between 10 km and 25 km depth in oceanic lithosphere on which was built the volcanic edifice at the origin of La Réunion.

The earthquake of August 11, 2023, 20h31 (local time), - M1.8 - located 17.9 km below sea level - north of *Grand Etang*, was felt by some of the island's inhabitants, mainly in the *Cirque de Salazie* area.

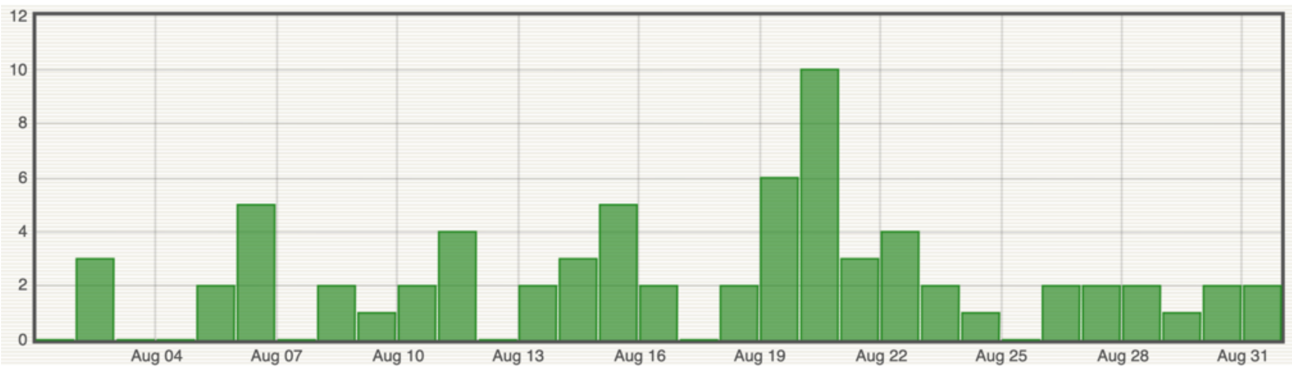

Figure 18: Number of local earthquakes (La Réunion island) per day recorded in August 2023 (© OVPF-IPGP).

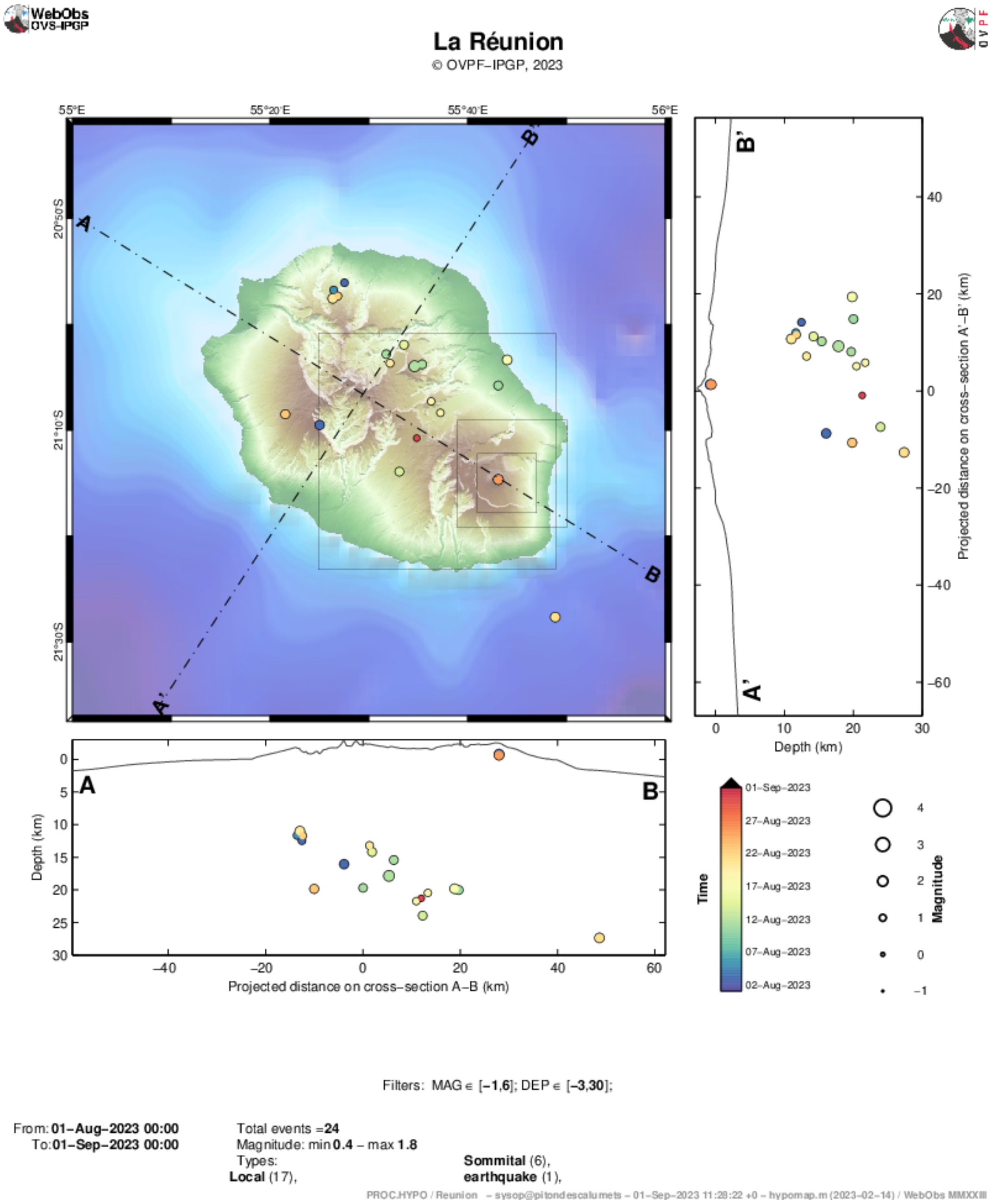

Figure 19: Seismicity below La Réunion in August 2023. Location map (epicenters) and north-west – south-east and south-west – north-east cross-sections (hypocenters) of earthquakes as recorded by OVPF-IPGP. Only localizable earthquakes are shown on the map (© OVPF-IPGP).

Seismic-volcano activity in Mayotte

The « REseau de surveillance VOlcanologique et SIsmologique de MAyotte (REVOSIMA) » is the structure in charge of the volcano and seismic monitoring of Mayotte. IPGP operates this network through the Piton de la Fournaise Volcanological Observatory in La Réunion with the support of the BRGM regional office in Mayotte. REVOSIMA is supported by a scientific and technical partnership. The REVOSIMA consortium: IPGP and Université Paris Cité, BRGM, IFREMER, CNRS, BCSF-RéNaSS, ITES and Université de Strasbourg, IGN, ENS, SHOM, TAAF, Météo France, CNES, Université Grenoble Alpes and ISTerre, Université Clermont Auvergne, LMV and OPGC, Université de La Réunion, Université Paul Sabatier, Toulouse and GET-OMP, Université de la Rochelle, Université de Bretagne Occidentale, IRD and collaborators.

All information on the REVOSIMA and the activity in Mayotte can be found on the dedicated webpages:
- https://www.ipgp.fr/observation/infrastructures-nationales-hebergees/revosima/
- https://www.ipgp.fr/actualites-du-revosima/
- https://www.facebook.com/ReseauVolcanoSismoMayotte/

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D. Appendix

Definition of Volcanic Alert Levels for Piton de la Fournaise

from *disposition spécifique « Volcan Piton de la Fournaise » - arrêté n°2242*- Emergency plan set up by the department responsible for the protection of the population in the event of unrest or activity of the Piton de la Fournaise

•**"Vigilance"**: possible eruption in medium term (a few days or weeks) **or** presence of risks on the sector (rockfalls, increase of gas emissions, still hot lava flows…).

Access to the Enclos Fouqué caldera and to the summit volcano are allowed with restrictions.

• **"Alert 1"**: probable or imminent.

Access to the Enclos Fouqué caldera and to the summit are closed and prohibited.

• **"Alert 2"**: ongoing eruption.
Alert 2-1: ongoing eruption inside the Enclos Fouqué caldera without threat to the safety of people, property or the environment

Alert 2-2: ongoing eruption inside the Enclos Fouqué caldera with direct or indirectthreat to the safety of people, property or the environment.

Access to the Enclos Fouqué caldera and to the summit are closed and prohibited. For Alert 2-2, evacuation of the people and vehicles depending on the issues.

• **"Alert 2-3"**: ongoing eruption outside the Enclos Fouqué caldera with threat to the safety of people, property or the environment.

Access to the Enclos Fouqué caldera and to the summit are closed and prohibited. Evacuation of the people and vehicles depending on the issues.

• **"Sauvegarde"**: end of eruption.

Evaluation of a partial reopening of the Enclos Fouqué caldera access.

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Acknowledgments

Thank you to organizations, communities and associations for publicly posting this report for the widest dissemination

Information

All information on the Piton de la Fournaise activity can be found on the OVPF-IPGP media:
- Internet website : ipgp.fr/fr/ovpf/actualites-ovpf
- Twitter : twitter.com/obsfournaise
- Facebook : facebook.com/ObsVolcanoPitonFournaise

A preliminary automatic daily bulletin of the OVPF-IPGP, relating to the activities of the day before, validated by an analyst, is published daily. It can be accessed directly at this link:
http://volcano.ipgp.fr/reunion/Bulletin_quotidien/bulletin.html

The seismicity validated in continuous by OVPF-IPGP can also be followed on the RENASS portal: https://renass.unistra.fr/fr/zones/la-reunion

The information in this document may not be used without explicit reference.

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