

# 30<sup>th</sup> Report of the Scientific Advisory Committee on Montserrat Volcanic Activity<sup>1</sup>

Based on a meeting held between 24<sup>th</sup> and 27<sup>th</sup> November 2025,  
at the Montserrat Volcano Observatory, Montserrat

## Full Report

Issued on 13 February 2026



Collage of images from the MVO social media relating to the Soufriere Hills Volcano 30 Years on conference in July 2025 organised by the MVO.

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<sup>1</sup> The information provided in all parts of this Report is advisory. It is offered, without prejudice, for the purpose of informing the party commissioning the study of the risks that might arise in the near future from volcanic activity in Montserrat, and has been prepared subject to constraints imposed on the performance of the work. While Committee members believe that they have acted honestly and in good faith, they accept no responsibility or liability, jointly or severally, for any decisions or actions taken by HMG or GoM or others, directly or indirectly resulting from, arising out of, or influenced by the information provided in this report, nor can they accept any liability to any third party in any way whatsoever.

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## Summary

1. **SAC report:** This report results from the 30<sup>th</sup> meeting of the Scientific Advisory Committee (SAC) on Montserrat Volcanic Activity that took place at the Montserrat Volcano Observatory (MVO) from 24<sup>th</sup> to 27<sup>th</sup> November, 2025. The meeting agenda is provided in Appendix II. This report provides the findings of that meeting, and gives the underlying technical data and analysis, including several appendices, that led to those findings.
2. **SAC meeting attendees:** The SAC meeting took place one year after we last met in November 2024, and involved seven SAC members, along with all MVO scientists and technicians. It was the sixth meeting under MVO director, Dr Graham Ryan. We also welcomed Dr Erouscilla (Pat) Joseph, Director and Prof Richie Robertson Ex-Director of Seismic Research Centre, University of the West Indies, as participants. A list of all participants and their affiliations is given in Appendix III. Prof. Eliza Calder from the University of Edinburgh chaired the meeting.
3. **MVO activity reports:** The MVO produced two six-month volcanic activity reports<sup>23</sup>, which were distributed to all SAC members prior to the meeting. These reports covered the period from 1<sup>st</sup> October 2024 to 31<sup>st</sup> March 2025, and 1<sup>st</sup> April 2025 to 30<sup>th</sup> September 2025, respectively. MVO staff delivered oral presentations on the monitoring data and observations covering the same period.
4. **Stakeholder involvement:** Continuing the practice from the 2023 and 2024 SAC meetings, we held an open meeting on Tuesday 25<sup>th</sup> November with key stakeholders from Montserrat attending in person. Attendees at this meeting were Mr Sam Paice, the Head of the Governor's Office and chair of the Operations Board, Mr Clement Meade, Chief Physical Planner at the Physical Planning Unit and Mr Astrid Wade, Senior Disaster Management Coordinator at the Disaster Management Coordination Agency (DMCA). The purpose of this meeting was to ensure that SAC discussions around hazard and risk are orientated on specific issues of current interest to the Government of Montserrat. On Thursday 27<sup>th</sup> November we also held a briefing meeting with the Deputy Governor Hon. Lindorna Lambert-Sweeney and Honourable Deputy Premier and Minister of BUILTE, Mrs. Veronica Dorsette-Hector and presented a summary of the SAC discussions. We consider stakeholders in Montserrat to be the primary audience for our annual SAC report.
5. **Activity summary:** A summary of the monitoring data gathered by MVO over the past year shows the following: The activity at the Soufrière Hills Volcano has remained low and is broadly consistent with levels of unrest observed since 2019, with some changes in seismicity. The volcano has produced higher rates of volcano-tectonic earthquakes since around 2019, and this has been sustained over the last 12 months. A small number of these are more widely distributed around the volcano than has been observed in recent years. In addition, an increase in low frequency seismicity has been

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<sup>2</sup> Ryan et al., 2025, MVO Scientific Report for Volcanic Activity between 1 October 2024 and 31 March 2025, Open File Report OFR 25-01

<sup>3</sup> Ryan et al., 2025, MVO Scientific Report for Volcanic Activity between 1 April 2025 and 30 September 2025, Open File Report OFR 25-02

observed since June 2024 to levels not seen since 2012<sup>4</sup>. Ground deformation during the reporting period shows a continuation of the pattern of inflation observed over the last 14 years. The rate of inflation continues to gradually decrease, i.e. the inflation pattern is slowly flattening out. Measured SO<sub>2</sub> fluxes have averaged ~289 tonnes per day over the last year, a decrease from the previous year and slightly below the long-term average. Thermal camera images of fumaroles on the dome show a temperature range between 200 and 580 °C. Some fumaroles show a slight decline in temperature.

- 6. Understanding of the system:** The presentations on the monitoring data by the MVO staff were followed by presentations by the SAC members, who provided wider context on specific aspects of the plumbing system and surface activity by describing relevant activity from other volcanic systems worldwide. In the scientific discussion that ensued, we covered the observed changes in style and location of the seismicity, as well as conceptual models that could explain the continuing seismicity, shifting seismic parameters and deformation patterns, and outgassing. **The emerging interpretation is that the same general shift in behaviour of the SHV volcanic system that occurred between 2018 and 2024 has been responsible for the observations in monitoring data during this reporting period.** Given that the level of unrest at Soufrière Hills Volcano over the last 12 months has been low and broadly similar to last year, the best overall explanation for this unrest is the continuing pressurisation of the magmatic reservoir at depth, possibly driven by a continued deep supply of magma and gas. Slowing inflation since 2010 suggests a modest but progressive reduction in these deeper processes. SO<sub>2</sub> flux has shown a decreasing trend in the last 2-3 years and there are indications of cooling in some fumarole temperatures. However, the long-term pattern of variation in SO<sub>2</sub> flux over the last four years is similar to that prior to 2010. There are several, non-mutually exclusive hypotheses which can explain the unrest signals: 1. magma and/or gas supply into the deep magmatic system; 2. migration of hydrothermal fluids associated with the hydrothermal system; 3. increased embrittlement of the system caused by gradual cooling leading to higher seismicity rates for the same deformation and stress changes; and/or 4. regional tectonic stress changes facilitating seismicity on local faults.

It is important to note that although these hypotheses reinforce the understanding that the magmatic system of the SHV is still active and evolving at depth, **they do not imply any impending restart of eruptive activity.**

In other volcanic systems cooling and sealing of shallow degassing pathways has sometimes led to non-magmatic, steam-driven, explosions. Such steam-driven explosions are possible at SHV in the future. These usually occur with only subtle precursory signals, which are difficult to detect, but steam-driven explosions are usually limited to areas within 1 or 2 km from the active vents. We would expect increases in unrest prior to the resumption of any significant eruptive activity.

- 7. Elicitation results:** Following discussions on the state of the volcanic system as well as hazard and risk aspects, we elicited the probabilities of a number of volcanic scenarios for the next 12 months. The elicitation results were, overall, similar to last year's, indicating the likely continuation of the current situation for the next year and

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<sup>4</sup> Ryan et al., 2025, MVO Scientific Report for Volcanic Activity between 1 April 2025 and 30 September 2025, Open File Report OFR 25-02

therefore **no change to the risk levels foreseen for the population of Montserrat in Zones A, B, C for the next year.** Hazard levels in Zone V are spatially variable but overall consistent with last year. Risk levels in Zone V will depend on how exposure for different groups working or visiting Zone V varies with the specific location, time spent in Zone V, and access routes.

8. **Out-of-the-blue eruption scenarios:** We consider it most likely that any restart in volcanic activity, such as magmatic explosion or lava extrusion, would present precursory signals that would be identified as such by the MVO and which would as a consequence result in the closing of Zone V (an effective risk mitigation action). However, low probability out-of-the-blue eruption scenarios such as unheralded explosive eruptions or lava dome collapses could catch people, working in or visiting Zone V, unprepared. As such it was important to revisit the likelihood of these low probability, but potentially high consequence hazard events, in order to take that information into account during discussions around access as well as for framing risk mitigation activities. We revisited Out-of-the-blue eruption scenarios, including discussions about relevant eruption processes known from elsewhere. In other volcanic systems, cooling and sealing of shallow degassing pathways has sometimes led to non-magmatic explosions, so-called phreatic explosions. A key outcome of the meeting was discussion around the very low likelihood of an Out-of-the-blue event that could pose a threat to anybody working or visiting zone V. The annual risk of death by volcanic activity to a worker in zone V based on the current levels of access is estimated to be less than 1-in-a-million (i.e., negligible risk) and on a par with risk posed by other natural hazards such as death from hurricanes, regional earthquakes over the next year.
9. **A Preliminary Statement** (Appendix IV): was issued to the Governor, HE Harriet Cross, and presented on ZJB radio on Thursday, 27<sup>th</sup> November 2025. The interview was recorded at the ZJB studios with seven SAC members, including Dr Ryan, MVO Director, attending the radio interview.

### **SHV Activity and Observations**

We summarise key points from the MVO Open File Reports:

10. **Phase 5 pause:** There has been no lava extrusion since the end of Phase 5 on 11<sup>th</sup> February 2010. **This 16-year pause now represents just over half of the time since the beginning of the eruption in 1995.** During this pause period, surface activity has been low with residual degradation of the dome, but sustained ground deformation indicates that SHV is inflating, and together with the still substantial SO<sub>2</sub> fluxes, this indicates that the magmatic system at depth remains active and in a state of unrest. A summary of the key MVO monitoring data over the entire eruption is shown in Figure 1.

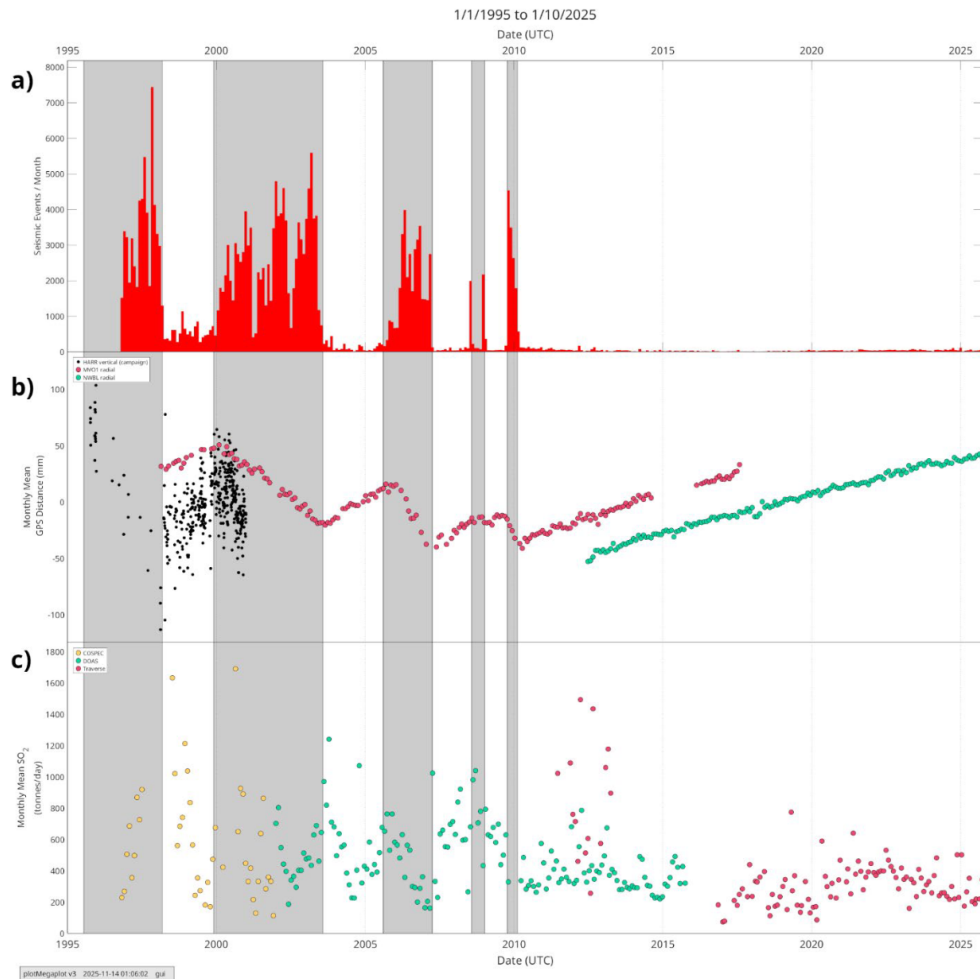


Fig. 1. Summary of the Seismic, GPS and SO<sub>2</sub> monitoring data for the entire eruption of the Soufrière Hills volcano between 1995 and November 2025. Extrusive phases are shown in grey. Top: Number of seismic events detected and identified by the seismic system. Middle: Radial displacement of cGPS stations MVO1 (red) and NWBL (green). Bottom: Measured daily SO<sub>2</sub> flux, filtered with 7-day running median filter. Yellow: COSPEC, Green: old DOAS, Red: Traverse data. (Image courtesy of MVO.)

11. **Rockfall activity** has been very low, in keeping with the trend over the last few years as the dome has stabilised. The occasional rockfalls (e.g. 6 June 2025) that do occur are often associated with rainfall. Observations made during routine helicopter flights in the reporting period revealed no significant changes to the overall morphology of the lava dome, nor to any of the main fumaroles and steam/gas vents.
12. **Fumaroles** on and around the lava dome are an important focus of continued degassing of the system. Fumarole location, activity and temperatures remain broadly consistent with that of the previous years, although the data suggest a potential slow decline in measured temperatures.
13. **Seismic activity** during this reporting period has remained low, although continuing the slightly higher trend that started early in 2018 and increased again in 2021. VT activity is characterised by individual events as well as brief swarms of events (referred to as VT strings). A total of 55 strings, of varying length and intensity, occurred during the reporting period. None of the strings were associated with any observable changes in SO<sub>2</sub> flux, fumarole activity, surface deformation or the occurrence of ash venting. The mean daily rate of VTs for the last six months is 1.07, a reduction from the levels

seen since mid-2021 but still higher than the average of 0.8 across the whole of the current pause. The cumulative seismic moment (Figure 2), can be considered a proxy for energy release during these earthquakes. The distinct changes in slope seen in late-2019 and in mid-2022 indicates an increase in the rate of seismic stress release in the crust above the magmatic system<sup>5</sup>.

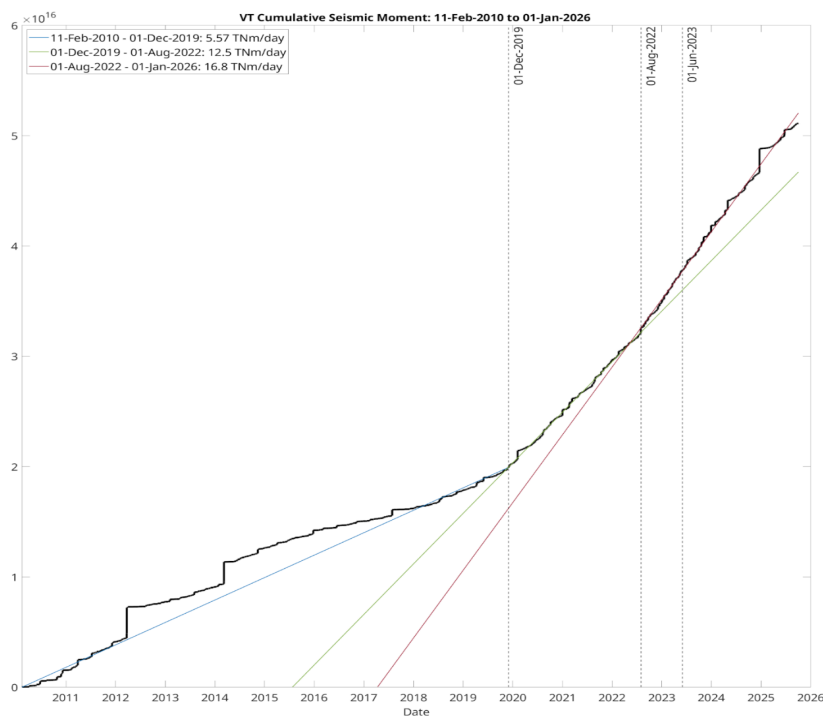


Figure 2. Cumulative seismic moment for all VT earthquakes for Pause 5 from 12 February 2010 to 30 September 2025 from MVO OFR25-02. The coloured lines are the best-fit straight lines for the data for three time periods (see legend).

Large VT strings tend to be followed by a reduction in the seismic moment release (i.e. the slope of the cumulative seismic moment curve in Figure 2 flattens out after every sudden rapid increase, until the long-term slope is recovered). The slightly lower level of VT activity in 2025 might therefore be an effect of the large VT string recorded on 19 December 2024. VT hypocenters are located around 1 km below sea level. A minor distal VT string was recorded for the first time under Gages Mountain. In addition, Low Frequency (LF) earthquakes (LPs and hybrids) which have been absent since 2014, have been detected at rates of 0.05/day for the last 6 months. The number of events remains low however. Their locations are unknown as these events are difficult to locate due to non-sharp wave arrivals. In summary, although more variation occurred during this time period than during the rest of Pause 5, the overall pattern remains typical of a pause in lava extrusion at SHV.

#### 14. **Ground deformation** during this reporting period continues to show the long-term inflation trend, centred on the SHV, that has been present since the beginning of Pause

<sup>5</sup> Ryan et al., 2025, MVO Scientific Report for Volcanic Activity between 1 April 2025 and 30 September 2025, Open File Report OFR 25-02

5 (February 2010). The rate of this inflation has continued to decrease. The most plausible explanation, so far, for this long-term inflation pattern remains ongoing - yet slowing - pressurisation of the deep magmatic system (Neuberg et al., 2022<sup>6</sup>, Hickey et al., 2022<sup>7</sup>).

15. **SO<sub>2</sub> fluxes** for the reporting period derived from measurements undertaken mainly via helicopter traverses under the plume have varied between a high 1317 t/d on 8<sup>th</sup> Jan 2025 to a low of 79 t/d on 29<sup>th</sup> May 2025 with a daily mean for this last year of 288 t/d which is slightly lower than the daily mean of 342 t/d established since 2017. The flux values obtained during the reporting period fit into the long term (18-24 month) cycle that has been re-established in the SO<sub>2</sub> flux data since 2017. There is some evidence of two long-term cycles in the SO<sub>2</sub> flux peaking in 2018 and 2022.
16. **Ground level SO<sub>2</sub> concentrations** are measured by MVO using a network of diffusion tubes which allow for the measurement of average SO<sub>2</sub> concentration over an approximate four-week window. The concentration at all stations remains low but the more proximal sites, including Chance's Peak, Plymouth, Broderick's and Richmond Hill, continue a clear decreasing trend since around 2018. All stations, apart from Chance's Peak station show SO<sub>2</sub> concentrations well below that of the United States National Ambient Air Quality Standards.
17. **Lahars and flash floods** generated by periods of heavy rain occurred on 14 occasions during the reporting period. The lahar in the lower Belham valley on 17 May 2025 was the largest event in the last four years; it washed out all three crossings and reached the coast.

### **Long-term internal processes**

18. The increased seismicity rates that have been detected since 2019 and again in 2021 could reflect enhanced stresses in the system caused by fluid intrusion and/or the gradual cooling of the system, leading to embrittlement. Cooling would change the local stress conditions by leading to contraction of the rocks and sealing of some pathways thereby triggering VT and LP activity as gases force their way through these sealed pathways to escape. This would also lead to an overall increase in seismic energy released. The recent VT swarms could reflect the exploration of new paths by fluids as a result of gradual cooling reducing permeability of the conduit. Some details were provided on the network capability to detect more exotic seismicity such as 'swarmettes'. Isolated VT events and VT strings also seem to share the same source according to MVO seismologist Rod Stewart. RSAM, a measure of the 'seismic noise' created by tiny seismic events below the volcano and in the conduit system is available and could provide additional information in future analysis. Some infrasound sensors are also available and would be useful for tracking lahars.

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<sup>6</sup> Neuberg, J.W., Taisne, B., Burton, M., Ryan, G.A., Calder, E., Fournier, N., Collinson, A.S.D. (2022) A review of tectonic, elastic and visco-elastic models exploring the deformation patterns throughout the eruption of Soufrière Hills volcano on Montserrat, West Indies, *Journal of Volcanology and Geothermal Research*, Volume 425. <https://doi.org/10.1016/j.jvolgeores.2022.107518>.

<sup>7</sup> Hickey, J., Pascal, K., Head, M., Gottsmann J., Fournier, N., Hreinsdottir, S. and Syers, R. 2022, Magma pressurization sustains ongoing eruptive episode at dome-building Soufrière Hills volcano, Montserrat: *Geology*, <https://doi.org/10.1130/G50239.1>

19. Time series of **ground deformation at Soufrière Hills Volcano (SHV)** suggest that deformation rates, which had been observed to begin to decelerate since 2018-2020, are now showing a clear, although subtle, deceleration. GNSS (GPS) processing work carried out by the MVO and their partners over the past few years has dramatically increased the level of confidence in the interpretation of observed continued deformation signal that is being driven by pressurisation of the magmatic system at depth. Using our understanding of the system as published by Neuberg et al., 2022 and Hickey et al., 2022, and further discussed during the SAC meeting, we reiterate that **the simplest explanation for the island-wide deformation is a continuing, but slowing, magma influx in a magma reservoir at about 6 km depth. Such a magma input flux may also explain sustained SO<sub>2</sub> flux observations, which are also showing a gentle decrease.**

***Recommendation:** Continue the analysis, in particular of the geodetic data time series, specifically to explore models of different complexity, in collaboration with partners.*

20. **Conceptual model(s) for plumbing and hydrothermal system:** An up-to-date conceptual model based on various integrated components of existing knowledge can provide a robust framework upon which new monitoring data can be interpreted (e.g., are the observed earthquakes close to the inferred location of magma or, hydrothermal system, or instead, located near known faults). The intent of such conceptual models is to provide, (1) a multidisciplinary, common understanding of the inner structure of the volcano, and the location of the key processes driving its activity and producing monitoring observables; (2) a framework (i.e., Common Operating Picture) that can be used operationally by volcano observatories to interpret monitoring data and forecast future volcanic activity; and (3) a basis for further simplified versions that can be used for engagement with key stakeholders and public outreach.

***Recommendation:** MVO to continue the program of science meetings to discuss, develop and refine together the conceptual model of SHV by integrating the seismic, deformation, gas and fumarole information obtained by the different team members. This should lead to increased collaboration and the development of an in-depth integrated analysis and reflection based on the monitoring data gathered.*

21. **Overall, MVO has observed an increasing rate in some categories of seismic events since 2019. This is consistent with a changed dynamism of the magmatic and/or hydrothermal system which could be related to the observed inflation and degassing at SHV.** There are several, non-mutually exclusive main hypotheses which can explain these signals, but it is not currently possible to determine unequivocally which of these is/are dominant:
1. stress change due to change in magma supply into the deep system has been most favoured in the past.
  2. stress change in the system caused by the migration of hydrothermal fluids.
  3. Progressive gas flow permeability reduction of the system, caused by gradual cooling, leading to higher seismicity rates in spite of decreasing deformation and stress changes.
  4. regional tectonic stress changes facilitating seismicity on local faults.

**Continued close vigilance of the signals produced by SHV remains essential in order to swiftly detect any significant change in the system.**

## Volcanic Hazard and Risk

### *Hazard Maps*

22. **SRC-MVO Volcanic Hazard Map Series:** MVO has not had a Hazard and Risk officer during this past year, and as such during SAC 30 we did not explicitly discuss the MVO hazard maps. We consider that the information in SAC 28 Report<sup>8</sup> (section 28-30) and SAC 29 Report<sup>9</sup> (section 23-24), along with the associated recommendation to prioritise completion of the ballistics, pyroclastic flow and lahar hazard layers, are still valid for consideration when the new Hazard and Risk officer arrives in February 2026.

### *Decision support for the Government of Montserrat*

23. **Decision-making regarding access to Zone V:** Scientific information about both the long term and short term state of the volcano, and the potential for future hazards around SHV, is one of the strands of information that plays into the decision-making process around access to Zone V. As such, the following statements are provided with the intention of being useful information for decision makers to consider:
24. **Variable hazard levels in Zone V:** There has been no lava extrusion for 16 years. During this pause period, surface activity has been low with only residual degradation of the dome evidenced through a small number of rockfalls. Our understanding of the SHV system indicates that volcanic activity could reactivate at some point, but that there is no sign that this will happen soon (see Section 6 and 30-36). **Thus, there is the possibility of considering the current use of, and access to, some areas in Zone V where the hazard level is considered very low.** It is clear, in part through hazard process modelling, that some areas within Zone V are exposed to very low levels of hazard, and those areas can be identified through hazard assessments already undertaken by, or available to, MVO.
25. Under the assumption that risk to life (and the risk tolerance associated with that) is the cornerstone of decision making for the GoM, a pragmatic approach for MVO to support such decisions could be:
  1. Identify broad areas in Zone V that have a general level of volcanic risk of the same order of magnitude as that associated with other natural hazards in the region (e.g., risk of fatality associated with hurricanes) over both the short period (5 years) and a longer period (30 years). Activity in those areas could then be considered based on other factors and needs (e.g., economic, etc).
  2. Identify areas in zone V which clearly should not be considered for development/activities (e.g., Tar River, the area immediately around/below the dome in either the short or long term. This could become, for instance, a long-term "high risk" zone.
  3. Only conduct site-specific risk assessments for areas not fitting in 1 (low risk) or 2 (high risk) as above but for which there is some basis for interest to access.

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<sup>8</sup> 28th Report of the Scientific Advisory Committee on Montserrat Volcanic Activity (2024).

<sup>9</sup> 29th Report of the Scientific Advisory Committee on Montserrat Volcanic Activity (2025).

26. **Hazard assessments for pyroclastic flows and ballistics** have already been undertaken by the MVO and collaborators in previous years. These have been used as the basis for site-specific risk assessments, as has been done previously for Upper Belham River Valley<sup>10</sup>, Fort Ghaut/Plymouth<sup>11</sup> and St Georges Hill<sup>12</sup>. Finalising the hazard maps associated with these hazard assessments for operational use, or generating an integrated hazard map that indicates the zones of highest or least hazard would allow for the high and low risk areas (suggested in Section 25), and subsequent planning based on broad areas, rather than on a request-by-request basis.
27. **Out-of-the-blue eruption scenarios:** The likelihood of eruptive activity, for example, lava dome collapse and pyroclastic flows or significant explosions with no precursory activity (so-called ‘Out of the blue events’), is considered very low indeed. We consider these events as *highly* unlikely, but they do remain plausible. Occurring without any precursors or warning means that they could have important consequences threatening the safety of people working in or visiting Zone V. As such, out-of-the-blue eruptions should be considered amongst the volcanic hazard scenarios that are discussed and planned for on Montserrat. **Any decision making about access to Zone V hinges on the capacity to respond to and the mitigation measures in place that relate to ‘Out-of-the-blue’ volcanic events and their potential areas of impact. We identify two main potential scenarios for generating Out-of-the-blue eruption scenarios: (1) Lava dome collapse** that can occur years, decades, or millennia after volcanic activity is over, due to intense rainfall, shaking by regional earthquakes, and/or weakening by hydrothermal activity and structural instabilities. These are rare events and, as such, for any given volcano there are few data to constrain the frequency of occurrence for such events. However, this is a hazard type that is prudent to consider in hazard scenarios for Montserrat and so is considered in Question 7 of the elicitation (see Section 33; Table 1 in Appendix VI). **(2) Phreatic explosions** that result from rapid heating and vaporization of fluids (mainly water) situated at shallow levels beneath a volcano and, by definition, do not contain juvenile material (new magma). They can form from upward migration of volcanic fluids, including gases, and melts, into a hydrothermal system or shallow aquifer and they commonly occur with few, if any, precursors. In SAC28, SAC29 and now SAC30, we have tried different approaches to try to constrain the very low likelihoods of such Out-of-the-blue events (Section 34).
28. **Workplace/occupational safety and health risk assessments:** There is a recognised need to develop a structured, yet flexible, system to allow exceptions for certain activities with a controlled degree of access to Zone V and avoid, for example, requirements for access to Zone V being dealt with on an *ad hoc* basis. In the SAC28 Report (section 38-39) and the SAC29 Report (section 30) we provided suggestions for the Government of Montserrat with respect to the need for development of a system

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<sup>10</sup> Miller, V., and Calder, E.S. (2020) Site Specific Risk Assessment for the Upper Belham Valley of the Soufrière Hills Volcano, Montserrat July 2020. Open File Report OFR 20-03.

<sup>11</sup> Miller, V., and Calder, E.S. (2020) Site Specific Risk Assessment for Fort Ghaut, Plymouth area of the Soufrière Hills Volcano, Montserrat July 2020. Open File Report OFR 20-04

<sup>12</sup> Miller, V., James, D., Calder, E.S., Ryan, G. (2022) Site-Specific Risk Assessment for the St. George’s Hill area of the Soufrière Hills Volcano, Montserrat, October 2022. Open File Report OFR 22-01

on which to make those assessments that would support evidence-based defensible decisions that may cover those involved against legal risks. At the core of this is the suggestion to implement the use of **workplace risk assessments for the volcanic environment in Zone V. Workplace/occupational safety and health risk assessments are commonly carried out for occupational safety and health (OSH) risk and management purposes in many work environments. These generally comprise explanatory text in a table format where the diverse sources of hazard and risk in that working environment are identified, along with proposed associated mitigation strategies.** Typically, such risk assessments provide a framework for systematic considerations of the potential hazards and their impacts to aid in developing a conceptual understanding of how, and to what extent, the risk of these hazards can be controlled or mitigated in order to reduce the risk. In the Montserrat context, companies/workers working in Zone V might undertake workplace risk assessments which take into consideration non-volcanic hazards present in their work environment (such as the use of heavy machinery), but also risk related to the volcanic environment or landscape (including exposure to gas or particulates), as well as volcanic activity itself (volcanic unrest and eruptive activity). The feasibility of implementing mitigation measures (e.g., dust masks, the construction of reinforced roof shelters or an effective evacuation route), then presents the key to reducing the *initial* risk (before the measures are in place) to the (lower) *residual* risk (after the mitigation measures have been implemented (see SAC 28 Appendix IV). Scientific volcanic hazard and risk assessments, produced by the MVO, and where available, can be used to **support** workplace/OSH risk assessments, with the former providing the critically important scientific hazard identification and risk evaluation information to be used within, and as part of, the latter.

***Recommendation:*** *A strong recommendation is that the Government of Montserrat should implement Workplace/occupational safety and health risk assessments for all those working within Zone V. A system, as used in the OSH risk assessment in SAC28 Appendix IV, could be adapted and tailored for use on Montserrat to support decision-making related to access to Zone V. The advantages that such a system offers is that it provides a means to systematise the evaluation procedure by the Government of Montserrat for any exceptions to work in Zone V, it gives structure to the thinking around the hazards and effective mitigation or control measures, and it could help the Government of Montserrat carry out due diligence in overseeing access permissions.*

#### ***Future activity – hazard scenarios and elicitation results***

29. We now summarise the results of the formal elicitation of the views of the SAC members and MVO and SRC staff on the probabilities of occurrence over the next year of various hazardous events. In order to assign quantitative estimates to these probabilities, we use our knowledge of the factors that influence specific hazard scenarios, results of any available modelling analyses, and the expert elicitation method. In SAC29 we initiated the use of new software (ELICIPY<sup>13</sup>), for the elicitation. The rationale for moving to a different calibration method is provided in Appendix V, it was, in error, omitted from the Appendices of SAC29 report. The

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<sup>13</sup> Vitturi, M., Bevilacqua, A., Tadini, A., and Neri, A. (2024) 'ELICIPY 1.0: A Python online tool for expert elicitation', SoftwareX, vol. 25, p. 101641, doi: 10.1016/j.softx.2024.101641.

questions, explanations of their context and the ranges of uncertainties derived from the group’s responses are presented in detail in table 1 and 2 in Appendix VI and VII respectively. ELICIPY produces plots for the outcome of each target question (see Figure 3) for each anonymised expert and computes the consensus values using an equal weights model (green line), or the Expected Relative Frequency (ERF) model (lilac line), along with their associated uncertainty. We use the Expected Relative Frequency (ERF) model for calibration of the experts (see Appendix V for explanation) and report below the elicited median value for each question (ERF Md). The results are also listed in table 1 (Appendix VI).

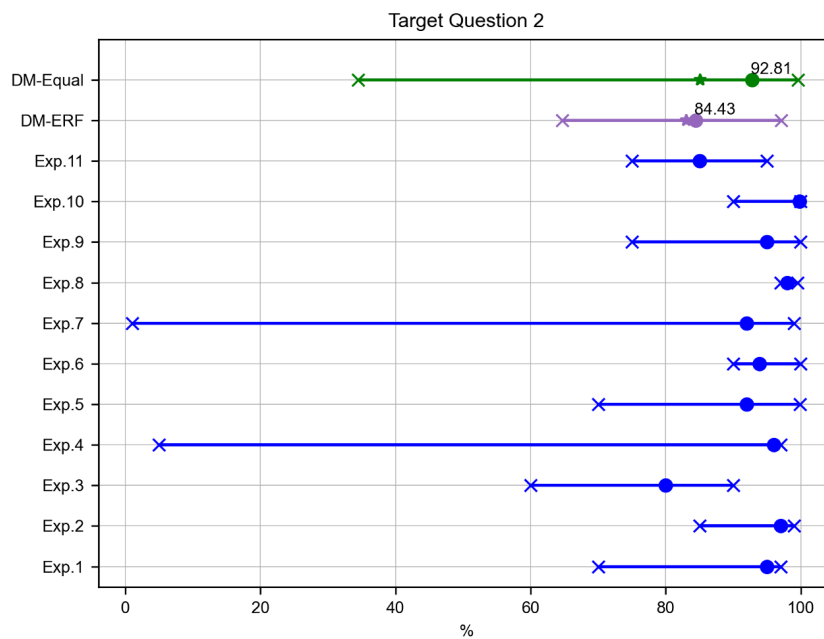


Figure. 3. The plot above shows an example of the expert elicitation results using the results from Question 2 “GIVEN what has happened up to the present and GIVEN current conditions, what is the probability that nothing significant will happen (i.e. no collapse, no restart of dome growth, no explosion) in the next 12 months?” Each anonymised expert provides their estimate of the probability as well as their uncertainty, and ELICIPY computes the consensus values using an equal weights model for each expert (green line), or the Expected Relative Frequency (ERF) model (lilac line), each with their associated uncertainty. It is the mean value from the ERF that we report in the sections below.

30. The first elicitation question asks what is the probability that the volcanic system (including its internal plumbing system) will remain active over the next 12 months. **The result of 75.7% reflects the confidence that the group has that the volcanic system will continue in a state of unrest** over the next year.
31. The series of questions 2a-2d ask what the probability is that one of four scenarios will happen in the next 12 months: nothing significant occurs, resumption of lava extrusion, lava dome collapse, and explosive eruption.
  - The likelihood of nothing significant occurring in the next twelve months (Scenario 2a), is **84.4%**

- The likelihood of a quiet resumption of lava extrusion taking place as the first significant event in the next twelve months (Scenario 2b), is **2.5%**
- The likelihood of a lava dome collapse taking place as the first significant event in the next twelve months (Scenario 2c), is **2.9%**
- The likelihood of an explosion taking place as the first significant event in the next twelve months (Scenario 2d), is **4.6%**

**The scenario that ‘nothing significant happens’ has increased by 11% in comparison to last year's results, returning to similar values as pre-2024.**

32. We also elicited a conditional probability for magma extrusion or an explosive eruption to follow within one month of a major dome collapse (Question 3) as 44.7%. **This indicates that it’s collectively considered to be a slightly less than 50:50 chance that new magma would reach the surface after an initial dome collapse or explosion.** It is possible that discussion surrounding conditions for phreatic explosions (steam-driven not magma-driven explosions), have re-framed the responses to this question as steam-driven explosions are not commonly followed by magma ascent.
33. We discussed the stability of the lava dome in the context of intense bouts of rainfall and regional seismic activity and, in line with previous year’s elicited for ‘the probability over the next 12 months that there will be a significant, externally-triggered dome collapse’. The likelihood of this to occur was deemed to be 0.05%, or a 1 in two thousand chance, which is on par with previous years (apart from the anomalous results of 2024). It should be noted that the uncertainties on this low probability scenario are high, spanning approximately two orders of magnitude (Question 7 – see table 1 in Appendix VI).
34. **Out-of-the-blue probability through elicitation:** We elicited the probability of an ‘**Out-of-the -blue**’ event, such as one which would affect the safety of workers in Zone V (by implication an event of considerable size). This was a new question (Question 8) added in SAC28 **to estimate the probability that an eruption threatening people’s safety in Zone V would occur without producing recognised precursors at least 3 hours prior to the eruption.** Implicit in this question is that any individuals in Zone V would only be in the lower or mid reaches of the Belham valley, Plymouth or St Georges Hill area and that the impact of the events under consideration would have to reach those areas. **The initial results of this elicited question unfortunately indicated it was interpreted too variably across the expert pool to provide a usable result.** Very small probabilities are notoriously difficult for people to estimate<sup>14 15</sup> and uncertainties will inherently be high (several orders of magnitude). We therefore designed an additional set of joint probability elicitation questions (Appendix VII) in order to unpack the broader question into its component parts. Based on the elicitation

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<sup>14</sup> Sundh, J. Human behavior in the context of low-probability high-impact events. *Humanit Soc Sci Commun* 11, 902 (2024). <https://doi.org/10.1057/s41599-024-03403-9>

<sup>15</sup> O'Hagan, Anthony, Caitlin E. Buck, Alireza Daneshkhah, J. Richard Eiser, Paul H. Garthwaite, David J. Jenkinson, Jeremy E. Oakley, and Tim Rakow. "Uncertain judgements: eliciting experts' probabilities." (2006).

results of this new set of nine question we can make the following probability statements:

- The probability that there is a phreatic eruption in the next 12 months that could impact people in Zone V that would occur with no recognisable precursory activity in the 3 hours before is 0.000014% (approximately 1-in-10,000,000).
- The probability that there is a magmatic explosive eruption in the next 12 months that could impact people in Zone V that would occur with no recognisable precursory activity in the 3 hours before is 0.000027% (approximately 3-in-10,000,000).
- The probability that there is a lava dome collapse in the next 12 months that could impact people in Zone V that would occur with no recognisable precursory activity in the 3 hours before is 0.000053% (approximately 5-in-10,000,000 or 1-in-2,000,000).
- The joint probability that there is an event (phreatic **or** magmatic explosion **or** dome collapse) in the next 12 months that could impact people in Zone V and that would occur with no recognisable precursory activity in the 3 hours before is 0.000095% (approximately 9.5-in-10,000,000 or 1-in-1,000,000).

**In other words, a conservative estimate is that there is a 1-in-a-million chance that in a given 24h period in the next 12 months such a scenario could occur.** If this is divided by 3 to take into consideration an approximate 8h work day, the probability reduces to 0.0000316% or 1-in-three-million chance. **A 1-in-a-million to 1-in-three-million chance of an event is deemed to be “negligible risk” based on CMO risk scale** (see probability notations, and conversions and annual risk scales in Appendix VIII). An analysis of the propagation of uncertainty through these joint probabilities determines that uncertainty is however several orders of magnitude on these values<sup>16</sup>. These values are on a par with last year and certainly within the uncertainty.

35. **Long term evolution of risk results:** It is useful to see how the elicitation results have evolved over time during the Phase 5 pause. The relative likelihood of the scenarios (nothing significant happens, resumption of lava extrusion, dome collapse, and explosive eruption) for the next year have now been asked during the elicitation for 15 consecutive years (see Figure 4). We point out that changes in the results last year across all the questions results in part from using a different calibration method, but also that all changes are well within the uncertainty ranges for both the 2023 and 2024/2025 results. What we see, in general over the 15 consecutive years of these results, is an increasing perceived likelihood that the pause will extend through the following year, with an accompanying slight decrease in the associated uncertainty. There is a potential levelling off of this trend from around 2018 (just for the scenario - nothing significant happens). **In other words, as the pause in the eruption has extended, there has been increased confidence in the volcano remaining quiet** (albeit in a state of unrest). The other scenarios, the resumption of lava extrusion, dome

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<sup>16</sup> Eliciting very low likelihood events is known to be problematic (O'Hagan et al., 2006). When trying to constrain low probabilities through elicitation using joint probability these become, in addition, highly sensitive to subjective processing decisions (e.g. choice of central tendency – Arithmetic vs Geometric mean vs median as well as calibration method). Uncertainties in our joint probabilities associated with these choices span up to four orders of magnitude. This is a source of epistemic uncertainty arising from the elicitation technique – which is a recognised issue when trying to elicit very low probabilities.

collapse and an explosive eruption, have been perceived to become less likely through time, again with an overall decrease in associated uncertainty. This is a unique data set because, a) the methods are quite specialised, and b) this type of assessment has not been carried out at any other volcano worldwide over such long timescales.

*What is the probability that **nothing significant** will happen (i.e. no collapse, no restart of dome growth, no explosion) in the next 12 months.*

*What is the probability that within the next year the first significant development will be a **resumption** of lava extrusion.*

*What is the probability that in the next year the first significant activity will be **collapse of the dome**.*

*What is the probability that in the next year the first significant event will be an **explosion**.*

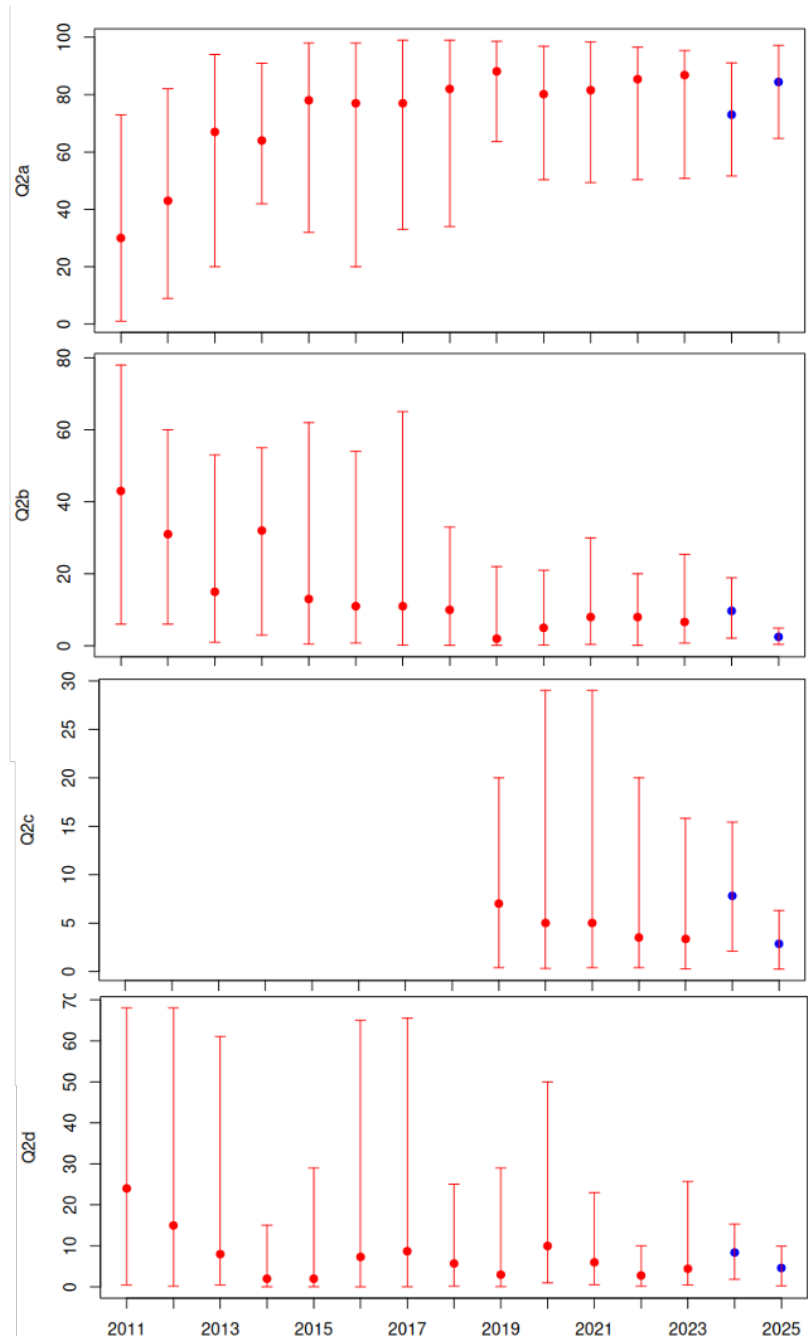
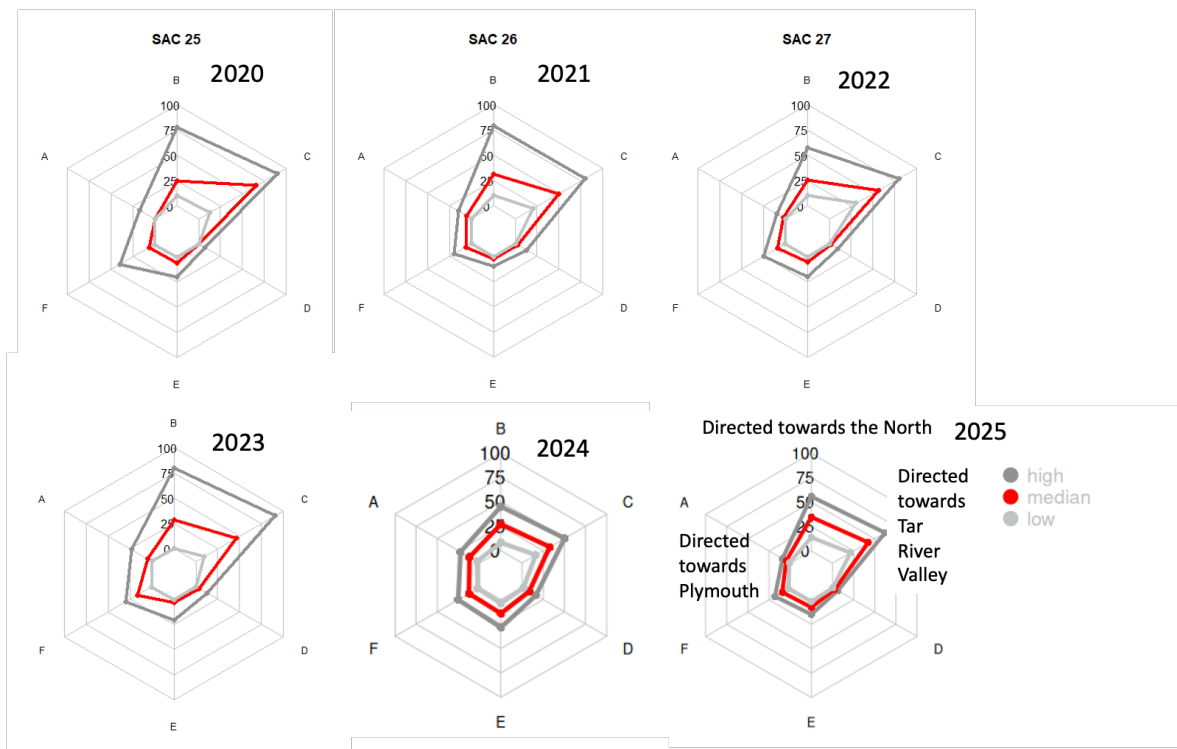


Fig 4. The relative likelihood of the different scenarios in the next year as determined by SAC elicitation results from 2011 to 2025. The points represent the central median probability while the vertical bars represent the uncertainty. The 2024 and 2025 values (shown in blue points) are those given by the ERF calibration median values for 16 experts using the new ELICIPY software. There is general consensus that changes observed between the 2023 and 2024/2025 results are more likely due to the change in the procedure than a change in how we collectively believe the volcano will behave. All changes are also well within the uncertainty ranges from both the 2023 and 2024/2025 results.

**36. Lava dome collapse direction:** The lava dome configuration has been very stable over the last six years however dome collapses are still possible. The elicitation results (see plots in Figure 5) provide the relative likelihoods for collapses in different directions around the dome. Consistently, over the last six years, it is considered that the most likely collapse direction would be towards the NE, i.e., towards the Tar River valley (42% in 2025), followed by the North (35% in 2025), followed by the SW towards Plymouth (9% in 2025).



*Fig. 5. Shows the elicitation results for the most likely directions of potential future dome collapse from 2020 (SAC24) to 2025 (SAC30). The numbers on the vertical axis are probability expressed as a percentage. The directions of the 'spokes' relate to the different sectors around the dome as indicated on the elicitation questionnaire. A – centres on NW, B on N, C on NE, D on SE, E on S, F on SW. Towards the NE (Tar River Valley), and towards the North remain the most likely direction for collapse. The new elicitation procedure brought in in 2024 means that the results are a little more evenly spread around the dome than in previous years.*

### The operation of MVO

**37. Hire of new Seismologist and Hazard and Risk Officer:** The new MVO seismologist and hazard and risk officer will be in place in February 2026. The delays of several years to these hires caused by lack of MVO contract and the subsequent slow UWI recruiting process, is a serious issue. In particular, the MVO contract structure works against continuity of high-level professionals working at the MVO, which undermines MVO's capacity to respond in a crisis, and must be avoided in the future (see section 50).

38. **Seismic network:** Seismic monitoring is the backbone of real-time monitoring capabilities. The system is considered fit for purpose with 9-10 stations used for routine processing. Stations close to the dome allow to detect more subtle seismicity. Some infrasound sensors would allow for tracking lahar activity. Seismologist Rod Stewart presented a rich phenomenology of signals that, due to their small size, had not previously been investigated in detail. Given the current low level of activity, and with a newly hired seismologist at MVO, there is an opportunity for investigating these signals more deeply. This could provide constraints on the physical processes occurring as fluids rise through the conduit.
39. **Ground deformation:** Geodetic monitoring is mature and effective and provides essential insights into the long-term, deep volcanic processes (e.g., deep pressurisation of the system). The continuous GNSS (GPS) network has been stable over the last few years and there are no need or current plans for extension of the network. The continuous GNSS network is complemented by campaigns every few months, occupying 9 additional benchmarks. These episodic measurements provide additional spatial coverage between continuous GNSS sites. Finally, the MVO routinely measures 6 EDM baselines (e.g., weekly at most). MVO staff have long-standing collaborations with international partners related to work on processing and modelling the ground deformation data.

***Recommendation:*** *MVO to report on the modelling and interpretation of the ground deformation from internal and/collaborative research in subsequent MVO reports and lead a discussion on this topic at the next SAC meeting.*

40. **Degassing:** The SO<sub>2</sub> flux monitoring system via scanners which was being worked on last year, is still not completed (OpenSO<sub>2</sub> and NOVAC). Scanners need stronger persistent technical support to get them fully operational. A new FTIR (which measures SO<sub>2</sub>/HCl ratios in the magmatic gas) has been delivered and is producing initial measurements and a permanent MultiGas (which measures CO<sub>2</sub>/SO<sub>2</sub> ratios in the magmatic gas) is planned to be acquired / installed in the next 12 months. These parameters will be very useful for tracking changes in the system, particularly any magma movement or changes in thermal conditions, both of which will be extremely useful indicators. These work items require dedicated time of the electronics technician, and helicopter time. When operational, this network will greatly support and add to the capacities of the MVO including that data continues to be collected when the MVO Gas Officer is away. Continued traverse-based SO<sub>2</sub> flux monitoring will remain a priority, because this provides the highest quality measurement of SO<sub>2</sub> flux. SAC member Prof Mike Burton is available to provide expertise as and when required by MVO.

***Recommendation:*** *MVO director to prioritise scanner-based SO<sub>2</sub> flux monitoring as the key monitoring capability to have operational within the next year.*

41. **Dome morphology and fumarole temperatures:** Photogrammetry and thermal imaging work carried out either from the helicopter and/or via a network of remote cameras are key tools for mapping any changes in the lava dome, including assessments of dome stability and/or new lava extrusion. The remote cameras run continuously with nearly 360-degree coverage including several that work at night providing live video and still images to the MVO. Measurements and detection of

changes in the fumarole activity on the lava dome is another key component of the monitoring system that could detect changes ahead of an eruption restart. The MVO has two FLIR thermal cameras for obtaining measurements from the high temperature fumaroles on the lava dome. Together these monitoring capabilities provide a uniquely comprehensive system for monitoring the state of the lava dome so that, visibility-allowing, even minor changes are likely to be detected.

42. **Detection of precursors ahead on an eruption restart:** There is significant confidence, as determined by our elicitation results, in the MVO’s ability to detect, and recognise precursory activity ahead of any restart in eruptive activity. Two of our elicitation questions ask whether it is considered likely that there will be precursory activity in the 6 months before a restart as well as the likelihood that it will be recognised as such at the time. The results from the SAC30 elicitation (ERF Md in table Appendix VI) are that there is an **81% likelihood that there will be precursory signals** during this time, and a **75% likelihood that it will be recognised as such** at the time. The elicitation results for these questions over the last ten years indicate a gradual overall increase in confidence for both questions (Figure 6), along with overall decreasing uncertainty (illustrated by shorter vertical bars on the data points representing the mean) for both questions. The results of this year and last year being slightly lower is likely due to the change in elicitation procedure, but again the changes are within the uncertainty ranges for previous years. Overall, this indicates that across SAC, SRC and MVO, there is a collective high degree of confidence in MVO monitoring.

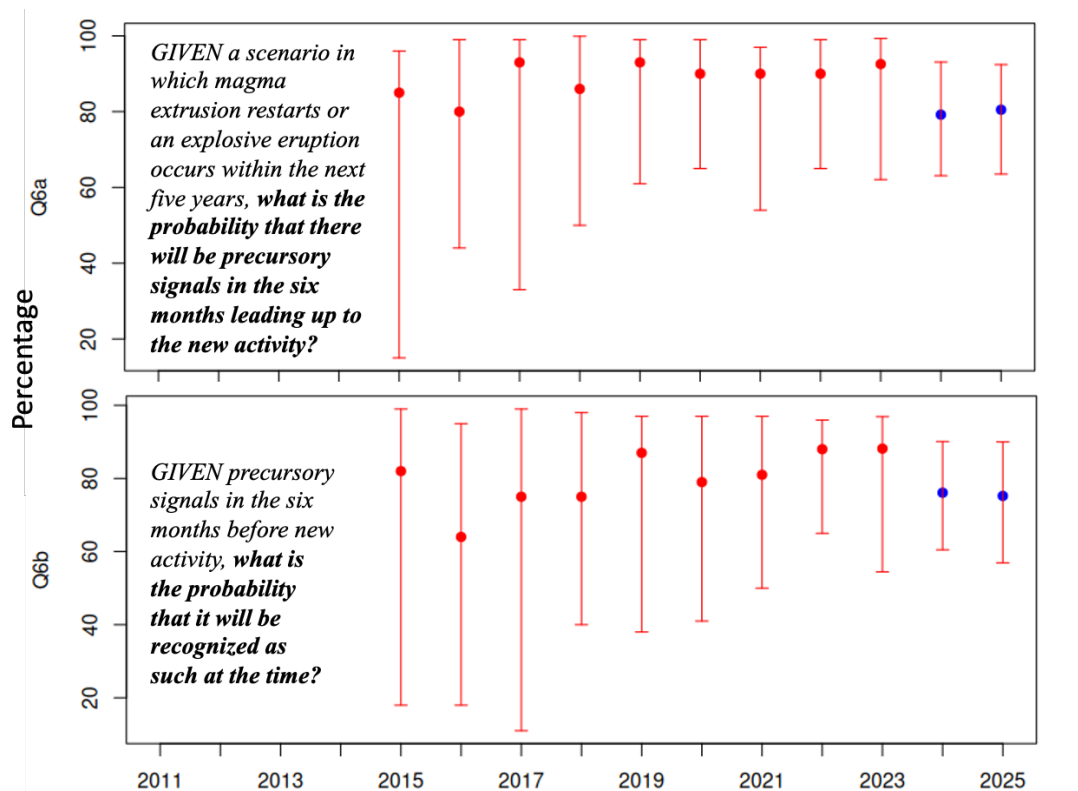


Fig 6. The likelihood that there will be precursory signals ahead of any restart in eruption, and that they will be recognised as such at the time as determined by SAC elicitation results from 2011 to 2025. The points represent the central median probability while the vertical bars represent the uncertainty. The 2024 and 2025 values (shown in blue points) are those given by the ERF calibration

*median values for 16 experts using the new ELICIPY software.*

43. **Education and Outreach:** MVO is undertaking excellent work in education and outreach and exceeding ‘fit for purpose’ expectations, even while the principal Outreach officer Thiffanie Williams has been on leave for part of this time. During this reporting period there is an impressive list of activities accomplished, including activities with schools and high and increasing social media engagement. We note that the GoM’s expectation of the extent to which the MVO should undertake outreach and, in particular, support tourism, is very high. **These expectations of the MVO far exceed that of many volcano observatories worldwide. The extent of these activities is commendable. MVO and GoM need to continue to ensure that they are resourced appropriately in terms of staffing and time, and not at the cost of monitoring.**
44. **SHV 30 years on Conference:** The MVO team, led by conference chair Dr Karen Pascal, and conference coordinator, Ms Thandie Williams, organised and hosted the 30 Years on conference between 14<sup>th</sup>-18<sup>th</sup> July 2025. This was a major undertaking that attracted around 100 delegates including international scientists and key stakeholders from the region. The conference represented a chance to bring together volcanology from across the region, but importantly also reflect on the historical, social and cultural aspects of the eruption as well as air important forward-looking discussions about the future of Zone V. The recorded materials from this event, when they are made available, will be an extremely important archive for both Montserratians and the international community. MVO can be commended on the organising of such an important and impactful conference and celebration of Montserrat which now represents another key achievement in the history of MVO.
45. **MVO overall operations and response readiness:** Looking at the overall operations of the MVO, we state that due to the proficiency, competence, experience, and motivation of the scientific and technical staff, the monitoring capacity of MVO regarding the measurements of ground deformation, gas emissions, seismicity and dome stability can be considered to be up to standard. One issue that does arise in discussions about the SHV system, is that staff at MVO often compartmentalise the work that they do. This undermines the possibility for a fully integrated understanding of the system which could impact overall readiness to a resumption of eruptive activity.

***Recommendation:*** *MVO staff would improve the quality and rigor of the analysis and understanding of the data they collect by working more closely as a team to better integrate the analysis of their results. We suggest this could be done through dedicated workshops every few months to present recent observations and reach consensus on the conceptual models and state of the system. This will also provide the integrative understanding and interpretation of the system needed for completing the six-monthly reports.*

46. **Enabling and supporting access exceptions to Zone V:** The MVO provides support for access to Zone V by provision of a professional operation in order to provide safety advice, to the extent possible, to workers and visitors in Zone V. The vast majority of current Zone V visits are for sand mining operations in the Upper Belham, as well as facilitating export of these volcanic materials via the jetty in Plymouth, and guided tours of Plymouth with tourists. Sand mining operations occur during normal MVO

working hours during the week, on most Saturdays and Sundays. New in 2025, are the GoM plans to re-open St. Georges Hill for tourism, which represents a significant change in terms of access and potentially oversight support needed from the MVO. Outside of normal working hours, Operations Room staff work overtime to provide cover. Guided tours of Plymouth are also frequent with much increased numbers during the high season. **MVO's operations enable these economic activities through supporting access to Zone V.** The MVO also actively engages with the Government of Montserrat regarding the overall volcanic hazards and risks in zone V to support as well as **provide expert advice into government planning decision-making forums.** If the additional MVO support which is needed for the St. Georges Hill development is to be effective, it's clear that the GoM needs to engage with MVO during all stages of planning and executing of this development.

47. **Precautionary response to increased unrest:** There have been no recommended precautionary closures to Zone V during the past year. However, MVO have been reviewing their operational practice, collective decision-making process and documentation in this regard. MVO procedures determine that for changes in activity which are perceived as non-imminent threats, an MVO emergency meeting is convened to discuss the observations and determine whether a response is necessary. If it is, the Director initiates the call down to the DMCA, Governor, Premier and Police Commissioner.
48. **MVO response/collaboration in the region:** The collaboration and response activities of MVO staff in the region are important, as the MVO is a key source of volcanology expertise in the area. The collaborations built with professionals across the Caribbean (St Vincent, St Lucia, Martinique, Trinidad, etc.), strengthen the broader regional volcanic crisis response 'system', which in turn reduces systemic and institutional risk both in Montserrat and across the region. During this reporting period MVO staff member Dr T. Christopher participated in monitoring-related fieldwork in St Vincent and St Lucia and Mr Pyiko Williams travelled to upgrade the SRC seismic installation at the Donkey Sanctuary in Antigua.
49. **Engagement/collaboration with the broader international volcanology community:** The MVO has a long list of ongoing collaborative research projects with researchers in the UK and USA especially. Of particular relevance this year is the newly funded NERC large grant; Ex-X: Expecting the Unexpected led by Prof. Barclay at the University of Bristol which kicked off in early 2026. There is also another upcoming major international volcanology conference in the region; "SOUFRIÈRE 50" to be held in Guadeloupe in July 2026. This conference commemorates the 50th anniversary of the 1976-1977 eruption of La Soufrière of Guadeloupe and focuses on advances in volcano science, risk mitigation, and societal resilience. As a key neighbour and resource in the region, MVO might engage in the organising as well as attending the event itself.
50. **The MVO contract:** The current MVO contract runs from 2024-2029 and is extendable for two further years. We do reiterate again in this report our concern about the absence of a long-term funding structure for MVO that would avoid the problems experienced in recent years which impacted staff contracts. We understand the political and structural systems currently in place require a tender process to occur on Montserrat in order to establish contracts for the MVO in open competition. However,

the reality is that the tender process has real and tangible negative impacts on the operation of the MVO, an entity made up of an experienced team of highly specialised staff, and whose functionality is dependent on continuity. We previously documented the negative impacts of the tender process<sup>17, 18</sup>. The uncertainty that renewal and short contracts have on the specialized staff is a major issue. For four years, it was not possible for SRC to recruit permanent staff on long-term contracts having a knock-on effect that impacted the Seismologist and Hazard and Risk Officer positions, two key roles for the operation of the MVO. The current UK Government approach to the management of MVO creates institutional vulnerability that increases systemic risk. **The UK Government needs to consider the liability and risks associated with making MVO staffing and processes precarious through regular tender procedures, even with the current 5-year +2 year model.**

***Recommendation: MVO requires long-term stability in funding, staffing, administration and renewal. Given the fundamental and long-term need to assess and minimise volcanic risks on Montserrat there should be a legal requirement that the UK properly supports a long-term, effective volcano observatory. We reiterate our offer to work with the FCDO in London to look at alternative models and to prepare an evidence-based case for changing the current management model going forward. We are concerned that FCDO has not engaged with this concern, in spite of it having been raised in the SAC reports of the last two consecutive years.***

## SAC Matters

51. SAC members charge fixed professional fees for the typically four official days of the meeting. This fixed maximum amount for all SAC members facilitates easier budgeting and forward planning. In this context, we would like to point out that SAC members provide significant input by preparing scientific documents, running numerical simulations and reviewing the latest, relevant, scientific literature, an effort far beyond the official days of the meeting. Without these in-kind contributions, the work of the SAC would not be possible.
52. The SAC committee discussed future rotations. SAC Chair Eliza Calder is stepping down and it was collectively agreed that SAC member Nico Fournier would take over as Chair of the next meeting. SAC member Eleonora Rivalta is also stepping down. Calder and Rivalta have both served on SAC since 2014, and both MVO and SAC thanked them for their service over these years. Going forward, and with approval from FCDO, the SAC committee anticipates advertising for two new positions in 2026. Fournier will liaise with FCDO around the hiring of these new positions.
53. We propose that the next meeting of the SAC will take place the week **beginning 23<sup>th</sup> November 2026**, to be confirmed after consultation with GoM, and unless a significant event on the volcano brings this forward.

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<sup>17</sup> 28<sup>th</sup> Report of the Scientific Advisory Committee on Montserrat Volcanic Activity (2024).

<sup>18</sup> 29<sup>th</sup> Report of the Scientific Advisory Committee on Montserrat Volcanic Activity (2025).

## **Appendix I:**

### **Terms of Reference of the Scientific Advisory Committee (Amended in 2023)**

#### **Constitution of the Scientific Advisory Committee on Montserrat Volcanic Activity**

This document outlines the main responsibilities of the Scientific Advisory Committee (SAC) on the Soufrière Hills Volcano, Montserrat. The document includes the terms of reference for the SAC and a membership template. The SAC is commissioned by the Overseas Territories Directorate (OTD) of the Foreign, Commonwealth and Development Office (FCDO). The SAC will work according to the Office of Science and Technology (OST) Code of Practice for Scientific Advisory Committees. The SAC will not incur expenditure without prior FCDO (OTD) authority.

#### *Terms of Reference*

The main responsibilities of the SAC are:

1. to carry out an annual hazard and risk assessment of the volcano in co-operation with the Montserrat Volcano Observatory (MVO) and to report its findings to HMG and the Government of Montserrat, and
2. to provide scientific advice at a strategic level to HMG and the Government of Montserrat outside these regular assessments in co-operation with the MVO.

NB: The “Government of Montserrat” will normally mean, in the first instance, the Governor as s/he has the constitutional responsibility for the safety of the Montserrat population. The Governor will be responsible for ensuring appropriate dissemination of SAC assessments or recommendations to the broader, elected, Government and people of Montserrat.

The SAC is also required to perform these additional functions:

3. to provide advice on the scientific and technical operations of the MVO to ensure that the work matches the level of risk;
4. to provide scientific advice and assistance to the MVO as required by the MVO Director; and
5. to offer advice on new developments that were not foreseen when the TORs were set up, and if appropriate make recommendations for changes to the TORs.

These general terms of reference are supplemented with the following specific points:

- (a) The work of the SAC concerns annual scientific assessment of the volcanic activity and related hazards and risks, with a focus on the long-term risks posed by the volcano. This scientific work is underpinned by the monitoring data and interpretations arising from the work of the MVO.
- (b) The MVO, with support from SAC as required by MVO, inputs to day-to-day decisions made by the HMG and the Government of Montserrat related to the safety of the people

of Montserrat (such as evacuation and extent of Controlled Access Zones), to issues of planning and sustainable development of Montserrat and to the mitigation of external hazards (e.g. to civil aviation).

- (c) The MVO Director (or scientific staff designated by the Director) participate in all SAC activities except for ToRs 3 and 4.
- (d) The SAC has the function of giving advice and assistance to MVO relating to scientific matters as required by the MVO Director.
- (e) With respect to ToR 3 the Chair of the SAC will be a member of the MVO Board of Directors and can provide scientific advice to the Board as required. The Chair will be expected to attend MVO Board meetings (currently twice a year).
- (f) Given the special circumstances of Montserrat as a United Kingdom Overseas Territory, reports of the SAC would be provided for both Governments. Reports would also be given to the MVO Management Board.
- (g) The SAC will be required to present its findings from SAC meetings in a manner suitable for release to the public and play a role, along with the MVO, in its dissemination. It will also be required to assist the Governments and the MVO in explaining the activity of the volcano and the scientific information pertinent to decision-making by the authorities.
- (h) The SAC will liaise with other relevant scientific organisations or committees as required.
- (i) The Chair of the SAC will make an annual report to the MVO Board of Directors.

## **MEMBERSHIP**

Membership of the SAC will be at the invitation of the FCDO (OTD) and will cover the key areas of expertise required to assess the level of activity, hazards and risks of erupting volcanoes. Expertise will include such areas as volcanology, volcano geophysics, and hazard analysis. The SAC will continue the approach of the former Risk Assessment Panel that was endorsed by the UK Chief Government Scientist in December 1997. Thus, the Committee requires a facilitator as a member for applying expert elicitation methods to estimate volcanic risk. These considerations imply a minimum of four members, excluding the Director of the MVO. If a lack of expertise becomes apparent on a particular issue, additional experts will be sought as and when needed through open advertisement of the post and open competition with prior agreement from the FCDO (OTD). As required by the Code the SAC is expected to consider external opinion. The membership will be considered on an annual basis with a view to regular, 3-5 year changes, refreshment of membership and rotation of the chair.

## **MEMBERSHIP TEMPLATE**

Members invited to serve on the SAC for the Montserrat Volcano are expected to attend all hazards and risk assessment meetings and to participate in the formalised elicitation procedure. Members have the responsibility to use their scientific judgement and expertise to meet the Terms of Reference. Opinions of the Members on scientific matters should be expressed through participation in the work of the SAC. Divergences of scientific opinion will normally be reported in terms of scientific uncertainty through the formal expert elicitation procedure. Differences that cannot be incorporated through the elicitation methodology should be included in the reports of the SAC as required by the OST Code. The Chair of the SAC, or his or her delegate from the Committee, will be responsible for presenting the findings of the SAC's work to the Governments of Montserrat and the United Kingdom and to the public in co-operation with the Director of the MVO. Any disagreement or divergence of opinion with the Director of the MVO that cannot be reconciled or incorporated through the elicitation method should be reported through the MVO Board of Directors.

## **SECRETARIAT**

The FCDO (OTD) will provide a Secretariat for the SAC, as set out in the Code of Practice. FCDO (OTD) will reimburse premium economy travel costs, reasonable hotel accommodation, meals and professional fees (once agreed) in full. The SAC will not incur additional expenditure without prior FCDO (OTD) authority. The Secretariat's main point of contact is Shelby Millen, Montserrat Desk Officer – Caribbean and Bermuda Section, OTD. His contact details are as follows:

Email: [shelby.millen@fcdo.gov.uk](mailto:shelby.millen@fcdo.gov.uk)

Tel: +44 7554 338221

## Appendix II:

### SAC30 Meeting Agenda 2025

#### Monday, 24<sup>th</sup> Nov 2025 Volcanic System Activity

9:00am-5:00pm Meeting (SAC & MVO staff & Pat Joseph/Richie Robertson)

- 9:00am Welcome and meeting agenda (Eliza – 10 mins)
- Presentations related to SHV activity and monitoring networks (state, issues, plans):
  - Dome Volume Geology monitoring (state, issues, plans); Observations - Adam
  - Gas monitoring (state, issues, plans); Observations - TC
  - Volcano-deformation monitoring (state, issues, plans); Observations - Graham
  - Seismic monitoring (state, issues, plans); Observations - Rod
  - Synthesis: Graham
- General discussion of monitoring observations
- MVO developments
  - Drone program - Adam
  - Tool development: low-cost GPS; low-cost Rpi cameras; MVO monitoring health tool development and database - Arvid
  - Outreach - Thiffanie
  - Summary of SHV30 years on conference and any outcomes - Thiffanie
  - Geothermal update

#### Tuesday, 25<sup>th</sup> Nov 2025 Volcanic, Magmatic, & Hydrothermal System Understanding

9:00-12:30 am (SAC & MVO staff & Pat Joseph/Richie Robertson)

- 9:30-11:00 – Alteration by Corentin and Fidel + SHV degassing Mike
- 11:00-12:00; Discussion following Monday's presentations
- Ongoing/upcoming research - Adam -

1:30-5:00pm (SAC, MVO, SRC and invitees) **Volcanic Hazards and Risk**

Invited: Sam Paice - Head of the Governor's Office

Astrid Wade/Alvin Ryan – Disaster Management Coordination Agency

Jerome Meade/Clement Meade – Chief Physical Planner

Presentations about specific hazard and risk related items

- Invited contributions (such as Plans for the new Physical Development Plan and what might be needed from MVO, or an overview of new plans for SGH tours)
- Hazard and risk analysis by MVO, update on recruiting (Graham)
- Update on requests for **site-specific risk assessments** -agriculture, sand mining, solar panels? Molyneux, Lees, Gages, St Georges Hill, Barton Bay (Graham).
- Eliza to present 10-year SAC overview from the SHV30 conference.
- Revisit Out of the Blue elicitation questions

#### Wed, 26<sup>th</sup> Nov 2025

09:00am-5:00pm meeting (SAC & MVO staff)

- Elicitation

- Consideration of elicitation questions based on GoM needs. Including refined out of the blue question
- Prep discussion for elicitation (Monitoring data & dome morphology recap (Adam).
- Elicitation (30 mins-1h answers submitted online).

## 2-5pm Other discussions

5. MVO matters
  - a. Reactivation scenarios – and what changes needed in monitoring strategy and how these can be implemented.
  - b. Discuss/review operational plan (process/documents) for key actions that would be taken by MVO and SRC in case of, for example;
    - i. 1. A rapid increase in VT activity
    - ii. 2. Onset of lava effusion or explosions (including SAC contributions/roles)
  - c. MVO funding and management model pathway to a more stable system.
  - d. Development and outreach including with other VO's
  
6. Final discussions

SAC-MVO-SRC dinner Olveston House

**Thurs, 27<sup>th</sup> Nov 2025**

09:00am-5:00pm meeting (SAC & MVO staff)

- Elicitation results and discussion (All)
- Prepare preliminary statement (SAC)
- SAC matters
  1. SAC Membership
  2. Next meeting

2:30 pm Briefing meeting with the Deputy Governor Hon. Dorsette-Hector and Deputy Premier

- Re-elicitation of Out-of-the-Blue Question (in parts)
- Discussion of relevant ongoing/published work **and ideas for future work**
- Mike to introduce Ex-X NERC Large Grant project aims and objectives
- Feedback to MVO – SAC's comments & suggestions
- 'Volcano Vibes' with Kafu ZJB (6pm)
- Elicitation results and discussion
- Discussion of relevant ongoing/published work **and ideas for future**
- 2:30 (tbc) pm Briefing meeting with the Governor and Premier
- SAC matters
  - SAC Membership
  - Next meeting
- Feedback to MVO – SAC's comments & suggestions
- 'Volcano Vibes' with Kafu ZJB (6pm)

## **Appendix III:**

### **List of Participants**

#### **SAC Members**

Prof Eliza Calder	University of Edinburgh, UK (Chair)
Prof Mike Burton	University of Manchester, UK
Dr Nico Fournier	GNS, New Zealand
Prof Fidel Costa	IPGP, Paris
Prof Eleonora Rivalta	University of Bologna, Italy
Dr Corentin Caudron	Université Libre de Bruxelles, Belgium
Dr Graham A Ryan	Director, MVO; University of the West Indies

#### **MVO Participants**

Mr Rod Stewart  
Dr Thomas Christopher  
Dr Adam Stinton  
Ms Venus Bass  
Mr Racquel 'Tappy' Syers  
Mr Barry 'Pyiko' Williams

#### **SRC Participants**

Dr Erouscilla Joseph, Seismic Research Centre, University of the West Indies (Director)  
Prof Richard Robertson, Seismic Research Centre, University of the West Indies

## Appendix IV: Preliminary Statement SAC 30

**27<sup>th</sup> November 2025**

The Montserrat Volcano Observatory reports that activity at the Soufrière Hills Volcano has remained low and is broadly consistent with levels of unrest observed since 2019, with some changes in seismicity.

The volcano has produced higher rates of volcano-tectonic earthquakes since around 2019, and this has been sustained over the last 12 months. A small number of these are more widely distributed around the volcano than has been observed in recent years. In addition, an increase in low frequency seismicity has been observed since June 2024 to levels not seen since 2012. Monitoring of ground deformation shows a continuation of the pattern of inflation observed over the last 14 years. The rate of inflation continues to gradually decrease. Measured SO<sub>2</sub> fluxes have averaged ~250 tonnes per day over the last 6 months, a decrease from the previous year and slightly below the long-term average. Thermal camera images of fumaroles on the dome show a temperature range between 200 and 580 °C. Some fumaroles show a slight decline in temperature.

Overall, the level of unrest at Soufrière Hills Volcano over the last 12 months has been low and broadly similar to last year, with some changes in seismicity. Based on previous restarts, we would expect a further increase in unrest prior to the resumption of any significant eruptive activity. The best overall explanation for this unrest is pressurisation of the magmatic reservoir at depth, possibly driven by a continued deep supply of magma and gas. However, slowing inflation since 2010 suggests a modest reduction in these deeper processes. SO<sub>2</sub> flux has shown a decreasing trend in the last 2-3 years and there are indications of cooling in some fumarole temperatures. In other volcanic systems cooling and sealing of shallow degassing pathways has sometimes led to non-magmatic explosions.

The volcano, with its large lava dome, is still a potential source of hazards within Zone V, including explosions, pyroclastic flows and lahars. Resumption of lava extrusion, or explosions, is still possible, however, the chance that explosions or pyroclastic flows will occur within the next year remains low. Continuous monitoring of the volcano is essential.

## Appendix V: Introduction to a new elicitation procedure for MVO

Ben Clarke and Eliza Calder, prepared 9th September 2024

### Background/reminder on how elicitations work

Structured expert elicitation is a quantitative way of pooling expert knowledge to estimate the value of parameters, as well as reflecting the collective confidence in those estimates [1]. In short, it aims to take a snapshot of the current (approximate) view of a group of experts. It is a statistically robust method of establishing a ‘rational consensus’, that faithfully represents the uncertainty of the group. The most commonly used method of structured elicitation in volcanology (Cooke method [2]) was developed in the 1990s, and has been applied in the aviation industry, nuclear industry, civil engineering, climate science and volcanology to name a few.

There are now many methods by which expert elicitation is conducted, each designed to achieve the most accurate result given the nature of the parameters being estimated, and the dynamics of the group of experts. At MVO, expert elicitations have been conducted by completing the questionnaires; asking for the best estimate, as well as upper and lower reasonable bounds for the requested parameters. This has allowed the elicitation facilitators to obtain the private views of individual experts, capturing their opinion as well as their degree of certainty.

Extensive literature explores the best methods for aggregating questionnaire results to achieve the most accurate pooled answers. Consistently, these studies have found that to obtain the most precise estimate, it is important to weight the opinions of individual experts [1], [3], [4], [5], [6]. This weight reflects an expert’s ability to provide accurate estimates (i.e., close to the true value) as well as their tendency to avoid expressing unrealistic confidence or providing overly broad confidence intervals that render their answers less informative.

To obtain the weighting factor, each expert is asked a set of ‘seed’ or ‘calibration’ questions. These questions should be somewhat relevant to the topic being discussed [7] (for example, volcano monitoring staff should be asked about volcanoes, and preferably volcanoes similar to those being assessed). Each question should have a specific numerical answer, and experts should provide their best estimate along with reasonable upper and lower bounds. These bounds are often mathematically formalised as the 5th and 95th percentiles, but they essentially represent the expert’s subjective opinion of a credible range.

Once the answers are collected, they are compared with the ‘true’ answers to calculate a weight. There are two common weighting methodologies: ‘Classical/Cooke’ [2] and ‘ERF’ [6]. ERF is found to most accurately reflect collective uncertainty, while the Classical method statistically provides the most accurate central estimate [6]. It’s the Classical/Cooke, method that has been used by MVO during the early years of the eruption, as well as the SAC elicitations. Alternatively, equal weights can be applied to each expert, ensuring that no single opinion has more influence over the pooled result than any other. This scheme is useful for identifying where there are ‘splits’ in opinion, or identifying where uncertainties are greatest.

These weights are applied to the elicited questions to provide a pooled answer (often called the ‘decision maker: DM’). This is done on a question-by-question basis using a Monte Carlo

sampling approach. For each elicited question, a distribution is fitted to each expert's answer (the form of this distribution depends on whether the Classical or ERF scheme is being used), that respects the 5<sup>th</sup>, 50<sup>th</sup> and 95<sup>th</sup> percentiles provided by the expert. The answer is sampled many times (typically 10,000), each time sampling from a distribution from a randomly selected expert. Where weights are equal, the probability of sampling each expert is the same. Where one expert is weighted more strongly than others, there is a greater probability of sampling the distribution of the strongly weighted expert. This generates an implicitly weighted list of sampled answers from the set of experts, from which a mean, median, and 5<sup>th</sup>/95<sup>th</sup> percentile is calculated (non-parametrically). This is the 'decision maker' response that represents the central best-estimate and uncertainty of the group for the elicited parameter.

For a more detailed explanation of the statistical process of weighting and data aggregation, please see the section '*Statistical Background of weighting and aggregation*', at the end of this document.

### **New software to streamline elicitations**

There are several software applications designed to streamline the process of expert weighting, and performing expert elicitation. Historically, MVO/SAC has used 'EXCALIBR,' a standalone, closed-source, free-to-use software. While Excalibur effectively calculates elicitation results with a user-friendly interface, it operates as a 'black-box' with limited flexibility for input data, processing methodologies, and results presentation. Consequently, results had to be processed and visualized separately, which was time-consuming.

More recently, an open-source, Python-based application: 'Elicipy'[8], has been developed, which combines data collection, expert weighting, results processing, and results presentation into one package. There is greater flexibility to adjust important parameters, modify functions if necessary, and the process is more automated, and faster. The new software allows answers to be filled out using a secure webform, with data submitted to a secure GitHub repository. The automated submission and formatting of these responses reduces the risk of copying errors, and expedites the process significantly. Responses are downloaded and processed offline, and are automatically collated into a PowerPoint presentation containing the results and comparative plots. The pooled response, as well as its uncertainty, is calculated using three weighting schemes, the Classical, ERF and the Equal weighting scheme, and the results of these are presented side-by-side. Although Elicipy is less user-friendly for the analyst, once the correct structural components are in place, a full expert elicitation (excluding questionnaire response times) can be performed in less than 10 minutes by a trained user. This allows results to be presented and discussed during the same meeting that they were elicited.

Elicipy was developed by volcanologists following the body of work that Prof. W. Aspinall was involved in developing, and has been used operationally for volcanological expert elicitations at INGV (Italy) and the IMO (Iceland). We wish to trial this new software method for expert elicitation at MVO, and hope that it will be a more effective way of undertaking the work that is already done through elicitations at MVO, both for MVO and for the SAC meetings.

### **Why do we need to recalibrate our experts?**

Expert calibrations have been taking place at MVO since 1996, using as far as we can tell, the same set of original seed questions, or with only minor modifications. Since then, experts have been calibrated individually as required, as they have rotated on to MVO staff, or the SAC, and therefore undertaken many years after the initial seed questions were used. Since 1996, knowledge of the SHV and how it operates have changed significantly. Indeed, the original ‘true’ answer to some of the seed questions, against which experts’ estimates are calibrated, would no longer be considered accurate. An expert being calibrated today may be unfairly penalised in their weighting not due to their ability, but because they happen to have a different information available to them compared to nearly 30 years ago. For several reasons, the current weighting scheme is not a level playing field. This does not mean that existing weights are without merit, or that the elicitations based upon these are inaccurate. Instead, 28 years on, a ‘clean slate’ is needed to provide a fair, representative weighting scheme that will ultimately form the most robust basis achievable for future expert elicitations, and to most accurately reflect the collective expert opinions of MVO and SAC.

### **New seed questions: the rationale behind their development**

To ensure fairness amongst experts, a new calibration requires a new set of seed questions. These seed questions have been developed through consultation with academics who have extensive experience with MVO and SHV. There are 15 questions, split into two broad categories: *general* questions, which aim to assess an expert’s general judgement and ‘precision’, and *topical* questions which aim to evaluate an expert’s ability to estimate values more relevant for Soufriere Hills Volcano, and volcano monitoring in general.

We have developed these questions following a set of principles:

1. **Cover a Range of Topics:** Questions should span various relevant topics for experts at MVO or on SAC. Including volcano geophysics/seismology; volcanic gases/petrology, physical volcanology/volcanic hazard and risk. While no expert is likely to excel across all areas, this approach facilitates everyone contributing positively to their weighting.
2. **Relate to Volcano Monitoring and Hazard Assessment:** Whenever possible, questions should relate to monitoring signals, or issues that relate to understanding and knowing hazards, as these are most relevant for predicting future activity.
3. **Relevance to SHV:** Questions should, more or less, pertain to the Soufrière Hills Volcano in terms of eruption style, volcanic processes, or geological setting.
4. **Require Estimation:** Experts should need to estimate their answers. Questions where the exact answers are well known have been avoided, especially where source-papers are authored by the experts being evaluated, to prevent unfair advantages.
5. **Vary in Difficulty:** Questions should cover a range of difficulties.
6. **Diverse Approaches:** Questions should require different approaches to answer, from intuitive guesses to rough mathematical estimations.
7. **Clarity:** Questions should be clear and unambiguous in their intent.
8. **Range of Data Types:** Values should include various data types and units, such as rates, volumes, percentages, and counts.

9. **Transparency and Accountability:** The source of the question and the true answer should be transparent, justifiable, and accountable.

We propose to use the same seed questions for MVO staff now and for SAC members in the November 2024 SAC meeting. The responsibility for guiding the process and establishing the criteria for the questions was undertaken by Eliza Calder but she did not formulate the questions and is not aware of the answers. The responsible for researching and formulating the seed questions, and their answers, was undertaken by Ben Clarke, and an external reviewer familiar with elicitations has reviewed the questions. Ben will facilitate the MVO elicitations, and Eliza and Ben will together will facilitate the SAC elicitations (contingent on agreement with the rest of the SAC committee). This will ensure seamless application of the new method, and the most robust form of continuity as possible.

### Statistical Background of weighting and aggregation

Here we present a summary of the statistical techniques used to weight and aggregate data in structured elicitations. For a fuller description of these methods, including their background, please refer to references [4], [6], [8], [9], [10].

#### *Classical weighting*

The classical weighting method scores each expert ( $e$ ) as the product of their ‘Calibration’ ( $C_{(e)}$ ), which measures the ‘statistical accuracy’ of their responses, and their ‘Informativeness’ ( $I_{(e)}$ ), which measures the spread of their uncertainty. This is normalised amongst the group of experts so that the sum of expert weights equals 1:

$$w_{(e)} = \frac{C_{(e)} \cdot I_{(e)}}{\sum_{j=1}^E C_{(j)} \cdot I_{(j)}}$$

where  $w_{(e)}$  is the weight of an individual expert, and  $E$  is the total number of experts in the group. Of the two characteristics  $C$  is the most mathematically important when determining  $w$ , as it is a comparatively sensitive function compared to  $I$  [4].

$C$  and  $I$  are initially calculated on a per-expert basis, and so are based upon their collective seed question responses. For each seed question, the true value is compared to each percentile reported by the expert, and the true value will fall into one of 4 bins:  $[-\infty$  to 0.05];  $[0.05$  to 0.5],  $[0.5$  to 0.95],  $[0.95$  to  $\infty]$ . Across all questions, an expert will have a discrete distribution ( $S$ ) of outcomes, describing the proportion of times the true value landed between their particular reported percentiles. According to the Classical scheme, a perfectly calibrated expert would have the distribution ( $P$ ):

$$P = [0.05, 0.45, 0.45, 0.05]$$

where 5% of the true values were less than their 5<sup>th</sup> percentiles, 45% of the true values were between their 5<sup>th</sup> and 50<sup>th</sup> percentiles, and so on. Deviation of  $S$  from this ‘perfectly calibrated expert’ distribution ( $P$ ), indicates a lower statistical accuracy, and a lower calibration. This is determined as the relative entropy of ( $S, P$ ) [6], which also relates to a p-value of a chi-squared statistical test (see [10]). Therefore, ‘calibration’ is a measure of how symmetrically balanced their estimates tend to be around the 50<sup>th</sup> percentile, not necessarily how close their answers tend to be to the true value. A significance level threshold ( $\alpha$ ) is often applied based upon the calibration score, were the overall weight of an expert is defined as zero where the calibration (p-value) is less than  $\alpha$  [6], [8].

Informativeness measures how concentrated an expert’s distribution is compared to a ‘background’ distribution for each of the seed questions. This is quantified as the relative Shannon information of the two distributions [11]. The final information score for each

expert is then their mean information score across all seed questions [10]. The background distribution for a given seed question is typically a uniform or log-uniform distribution covering an ‘intrinsic range’ based upon the extrema of collective values reported by every expert, plus a defined fractional ‘overshoot’ at either end [4], [8], [10]. Therefore, an individual’s information score is dependent on the values provided by the rest of the group, and so an expert’s Classical weight cannot be ported between groups.

This process is automatically performed within the Elicipy software, with the ability to modify:

- the **significance level** ( $\alpha$ ) threshold for the calibration chi-squared test, below which weights are set to 0. (default = 0.05; a higher value is less stringent, and fewer experts will be penalised)
- the fractional overshoot for the **intrinsic range** (default = 0.1; a higher value will improve the information score for all experts)
- the **power** of the chi-squared test for calibration. In effect, this acts to modify the group’s calibration scores as desired (default = 1; range 0.1-1; a lower value will reduce the ratio of the highest:lowest expert score – reduce the range of scores) (see [4])

### ERF weighting

The ‘Expected Relative Frequency’ (ERF) model [6] is, at least to our minds, a more intuitive weighting procedure. This determines an expert’s weight by the proximity of their central estimate to the true value of each seed question, and by informativeness, using one simultaneous measure. Here for a given seed question, the expert’s responses are used to define a triangular distribution, where the mode (apex) is assumed to equal the reported 50<sup>th</sup> percentile, spans the 0<sup>th</sup> to 100<sup>th</sup> percentile, and satisfied the experts estimated 5<sup>th</sup> and 95<sup>th</sup> percentiles. An interval is then defined, centred on the true value, with a half-width equalling a defined percentage of the true value. The weight (termed:  $L$ ) is then the integral of the triangular distribution over this interval (Figure 1). The arithmetic mean of  $L$  across all seed questions provides a more robust estimate of the expert’s weight ( $w_{(e)}$ ).

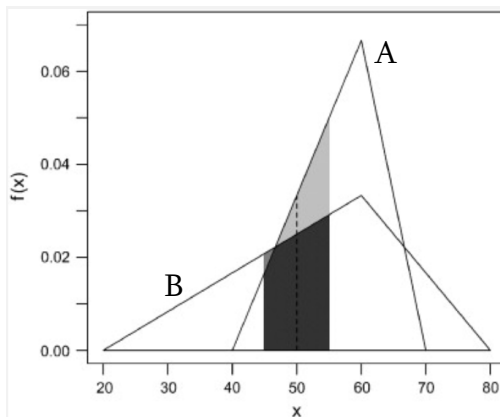


Figure 1. A visual representation of the ERF weighting scheme. The triangles (A and B), defined by two expert’s 5<sup>th</sup>, 50<sup>th</sup> and 95<sup>th</sup> percentile estimates for the same seed question, represents their estimated probability distributions. Their 50<sup>th</sup> % estimates are equal, but A has a narrower uncertainty range than B. The true answer to the seed question, here at an absolute value of ‘50’ with a 10% half-interval, is shown by the shaded region. The area of the shaded region is equal to the expert weight. Expert A is rewarded for providing a narrower range of certainty (and so is more informative) than B. (after [6])

Intuitively, a lower informativeness (wider percentile range) defines a shallow, wide triangle; that for a fixed interval, lowers an expert’s weight. Equally, where the interval (centred on the true value) aligns with the apex of the triangle (ie. where the 50<sup>th</sup> percentile estimate and the true value agree), this maximises the integral; rewarding an accurate estimate. Where experts are overly confident, this increases the likelihood that the triangle misses the interval altogether, lowering the value of  $L$ , potentially to zero.

The selection of an appropriate interval is important. A narrow interval will be more selective, and fewer experts will achieve a positive or high weight for each seed question. For a wider interval, the results become less consequential, and eventually approach an Equal weighting scheme [6]. The Elicipy software assumes a 5% half-interval around the true value for integration [8]. Currently, this interval half-width can be only modified within the code, but is a simple adjustment.

#### *Aggregation of elicited answers to generate a pooled ‘decision-maker’ response*

Once elicitation responses are gathered and expert weights have been calculated. The responses must be aggregated to calculate the ‘decision maker’ (DM) response for each question. This is conducted by a Monte Carlo sampling approach. For each expert, a distribution is fitted to the reported percentiles for a particular question. In the Classical and Equal weights methods, this is a ‘maximum entropy distribution’ [8]. In the ERF method, this is a triangular distribution, where the apex is centred on the 50<sup>th</sup> percentile, and the 0<sup>th</sup> and 100<sup>th</sup> percentiles of the distribution are defined so that the reported 5<sup>th</sup> and 95<sup>th</sup> percentiles are satisfied. The DM response is built by sampling this set of distributions  $N$  times (where  $N$  is a large number; 10000 by default). Each sample is taken from the distribution of one of  $E$  experts, and the probability of expert  $e$  being sampled on each iteration is equal to  $w_{(e)}$ . In an equal weighting scheme,  $w_{(e)} = 1/E$ . In the ERF and Classical weighting schemes,  $w_{(e)}$  is calculated as described previously. This generates a set of  $N$  realisations for the response, which is weighted implicitly by the sampling procedure. The mean, median, 5<sup>th</sup> and 95<sup>th</sup> percentiles are then calculated to generate a summary of the DM response. This process is repeated for all elicited questions. The Equal weights, Classical and ERF decision makers are presented side-by-side in the report generated by Elicipy. The  $N$  Responses are also plotted as histograms, and fitted by 1D Gaussian KDE curve. These are presented in the final report. The  $N$  samples for each question are retained, allowing further processing or analysis to be conducted.

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## Appendix VI: SAC30 elicitation results of probabilities for hazard scenarios I

### *Target questions*

1. GIVEN what has happened up to the present and GIVEN current conditions, what is the probability that, *irrespective of whether there is eruptive activity at the surface, or not*, the volcanic system will remain active over the next 12 months.
- 2a. GIVEN what has happened up to the present and GIVEN current conditions, what is the probability that **nothing significant** will happen (*i.e., no collapse, no restart of dome growth, no explosion*) in the next 12 months.
- 2b. GIVEN current conditions, what is the probability that within the next year the **first** significant development will be a **resumption** of lava extrusion.
- 2c. GIVEN current conditions, what is the probability that in the next year the **first** significant activity will be collapse of the dome.
- 2d. GIVEN current conditions, what is the probability that the **first** significant event will be *an explosion*.
3. If, in the next year the **first** significant activity is a major dome collapse, what is the probability of magma extrusion or explosion within the following month:
4. GIVEN current conditions, what is the probability that within the next year the first significant event will be a dome collapse in the following sectors:
5. GIVEN what has happened up to the present and GIVEN current conditions, what is the probability that nothing significant will happen (*i.e., no collapse, no restart of dome growth, no magmatic explosion*) in the next 30 years?
- 6a. GIVEN a scenario in which magma extrusion restarts or an explosive eruption occurs within the next five years, what is the probability that there will be precursory signals in the six months leading up to the new activity?
- 6b. GIVEN precursory signals in the six months before new activity, what is the probability that it will be recognized as such at the time?
7. GIVEN current conditions, what is the probability that there will be a significant, externally-triggered, dome collapse?
8. What is the probability that an eruption threatening people's safety in Zone V would occur without producing recognised precursors at least 3 hours prior to the eruption?

Table 1. Elicitation results using two calibration methods, equal weighting of experts (EW) and ERF for each question. For comparison, the last column (greyed) shows elicitation results for SAC 2024 using the preferred ERF method.

Question		EW Lower %	EW Upper %	EW M %	EW Md %	ERF Lower %	ERF Upper %	ERF M %	2025 ERF Md %	2024 ERF Md %
Remain active	1	19.98	99.17	76.15	<b>85.78</b>	57.09	89.19	74.69	<b>75.67</b>	<b>83</b>
Nothing	2A	34.46	99.62	85.12	<b>92.81</b>	64.72	97.14	83.09	<b>84.43</b>	<b>73</b>
Lava extrusion	2B	0.01	8.51	2.28	<b>1.13</b>	0.36	4.94	2.58	<b>2.51</b>	<b>9.7</b>
Dome collapse	2C	0.01	14.70	2.83	<b>1.24</b>	0.23	6.31	3.02	<b>2.85</b>	<b>7.8</b>
Explosion	2D	0.13	18.53	4.86	<b>2.90</b>	0.26	9.91	4.82	<b>4.64</b>	<b>8.4</b>
Follow-on activity	3	3.28	94.04	45.32	<b>45.20</b>	23.88	64.95	44.58	<b>44.70</b>	<b>57.4</b>
Collapse NW	4a	0.11	25.09	5.21	<b>1.87</b>	0.89	9.06	4.78	<b>4.64</b>	<b>12</b>
Collapse N	4b	4.81	92.56	35.46	<b>30.36</b>	13.84	55.76	34.77	<b>34.73</b>	<b>27.1</b>
Collapse NE	4c	2.09	87.88	42.85	<b>39.15</b>	21.35	62.18	42.12	<b>42.39</b>	<b>32.7</b>
Collapse SE	4d	0.27	15.59	3.78	<b>1.87</b>	0.42	6.20	3.12	<b>3.01</b>	<b>8.4</b>
Collapse S	4e	0.38	38.40	9.53	<b>3.41</b>	1.81	14.87	7.94	<b>7.65</b>	<b>14.2</b>
Collapse SW	4f	0.39	44.94	10.74	<b>3.97</b>	2.26	18.00	9.74	<b>9.41</b>	<b>12.7</b>
Nothing 30yrs	5	12.74	96.80	58.12	<b>57.99</b>	22.37	76.08	50.97	<b>52.08</b>	<b>33</b>
Precursor	6a	38.75	99.53	80.71	<b>86.46</b>	63.51	92.41	79.47	<b>80.51</b>	<b>79.2</b>
Rec precursor	6b	22.69	98.98	75.52	<b>85.40</b>	56.94	89.98	74.49	<b>75.22</b>	<b>76.1</b>
External trigger	7	2.46E-04	5.19E+00	7.03E-02	7.53E-02	4.63E-03	3.94E-01	4.80E-02	<b>5.14E-02</b>	<b>7.8</b>
Blue	8	4.16E-06	3.90E+01	9.54E-03	1.11E-02	1.20E-03	5.90E-02	8.85E-03	<b>9.17E-03</b>	<b>13.8</b>

**Note:** Question 7 and 8 treat very low likelihood events, which are inherently significantly harder to estimate. The significantly higher values in 2024 for the externally-triggered dome collapse and the Out-of-the-blue elicitation questions were not due to a general sentiment that the probability of such events had substantially increased. Instead, it was due to having new experts in the pool, a new elicitation method with a new calibration method. Because the probabilities in question are very small, results can vary orders of magnitude (versus, some of the other questions). In Appendix VII we investigate an alternative way to assess out of the blue eruption probability by eliciting not one but a series of three nested questions associated with an event tree framework.

## **Appendix VII: Elicitation results of joint probabilities for target questions for an out-of-the-blue event**

### **Target Questions:**

1a. GIVEN what has happened up to the present and GIVEN current conditions, what is the probability that there would be a phreatic eruption over the next 12 months ?

1b. *Conditional on the event in 1a occurring:* What is the probability that such an event would impact people working in, or visiting, zone V (areas with daily activities such as St. Georges Hill, Plymouth, and Upper Belham) ?

1c. *Conditional on the event in 1b occurring:* What is the probability that such an impactful event would occur with no recognisable precursory activity in the 3 hours before ?

2a. GIVEN what has happened up to the present and GIVEN current conditions, what is the probability that there would be a magmatic explosive eruption over the next 12 months ?

2b. *Conditional on the event in 2a occurring:* What is the probability that such an event would impact people working in, or visiting, zone V (areas with daily activities such as St. Georges Hill, Plymouth, Upper Belham) ?

2c. *Conditional on the event in 2b occurring:* What is the probability that such an impactful event would occur with no recognisable precursory activity in the 3 hours before ?

3a. GIVEN what has happened up to the present and GIVEN current conditions, what is the probability that there would be a dome collapse over the next 12 months ?

3b. *Condition on the event in 3a occurring:* What is the probability that such an event would impact people working in, or visiting, zone V (areas with daily activities such as St. Georges Hill, Plymouth, Upper Belham) ?

3c. *Conditional on the event on 3b occurring:* What is the probability that such an impactful event would occur with no recognisable precursory activity in the 3 hours before ?

Table 2. Elicitation results using two calibration methods, Equal weight (EW) and ERF for each question.

	Q05 (EW) %	Q50 (EW) %	Q95 (EW) %	Qmean (EW) %	Q05 (ERF) %	Q50 (ERF) %	Q95 (ERF) %	Qmean (ERF) %	Ans %
TQ 1 1a Phreatic 12Mo	0.003	1.280	7.150	0.568	0.066	0.530	2.910	0.486	
TQ 2 1b Cond on 1a V	0.000	0.043	7.680	0.027	0.003	0.032	0.278	0.030	
TQ 3 1c Cond on 1b No P	0.079	28.200	84.600	11.100	1.970	11.000	37.300	9.900	0.000014
TQ 4 2a Magmatic 12mo	0.001	0.394	69.700	0.247	0.032	0.308	2.250	0.289	
TQ 5 2b Cond on 2a V	0.001	5.390	46.500	1.330	0.265	1.190	4.120	1.130	
TQ 6 2c Cond on 1b No P	0.000	1.840	81.700	0.543	0.226	0.849	2.910	0.831	0.0000271
TQ 7 3a Dome coll 12mo	0.001	0.328	12.100	0.230	0.031	0.231	1.370	0.220	
TQ 8 3b Cond on 3a V	0.054	5.410	80.000	3.800	0.579	3.330	13.100	3.080	
TQ 9 3c Cond on 3b No P	0.000	4.600	55.600	0.738	0.091	0.874	4.750	0.786	0.0000533
									0.0000948

The four resulting probability statements that can be determined by combining these elicitation questions and their results are:

1. The probability that there is a phreatic eruption in the next 12 months that could impact people in Zone V that would occur with no recognisable precursory activity in the 3 hours before is 0.000014% (approximately 1-in-10,000,000).
2. The probability that there is a magmatic explosive eruption in the next 12 months that could impact people in Zone V that would occur with no recognisable precursory activity in the 3 hours before is 0.000027% (approximately 3-in-10,000,000 or 1-in-3,000,000).
3. The probability that there is a lava dome collapse in the next 12 months that could impact people in Zone V that would occur with no recognisable precursory activity in the 3 hours before is 0.000053% (approximately 5-in-10,000,000 or 1-in-2,000,000).
4. The probability that there is an event (phreatic **or** magmatic explosion **or** dome collapse) in the next 12 months that could impact people in Zone V and that would occur with no recognisable precursory activity in the 3 hours before is 0.000095% (approximately 9-in-10,000,000 or 1-in-1,000,000).

## Appendix VIII: Probability notations, conversions and odds scale

### Notations and conversions for low probabilities

Verbal description	Numerical description	Percent	Decimal notation	Scientific notation
1 in ten	1 in 10	10%	0.1	1.00E-01
1 in hundred	1 in 100	1%	0.01	1.00E-02
1 in thousand	1 in 1000	0.1%	0.001	1.00E-03
1 in ten thousand	1 in 10,000	0.01%	0.0001	1.00E-04
1 in hundred thousand	1 in 100,000	0.001%	0.00001	1.00E-05
1 in a million	1 in 1,000,000	0.0001%	0.000001	1.00E-06
1 in ten million	1 in 10,000,000	0.00001%	0.0000001	1.00E-07
1 in hundred million	1 in 100,000,000	0.000001%	0.00000001	1.00E-08

### Example Individual annual risk

	Individual annual risk of death (order of magnitude) for Caribbean <sup>19</sup>	Odds of death over a lifetime (order of magnitude) USA various sources	UK CMO Risk scale
1 in 10		Cancer/Cardiovascular disease	High (A)
1 in 100	Cancer / Cardiovascular disease	Motorcycle/ a fall/ CO <sup>19</sup> /childbirth	Moderate (B)
1 in 1000	Accidents	Influenza/Pneumonia/Drowning/ Vehicle crash/Fire	Low (C)
1 in 10,000	Hurricanes	Electrocution/Vehicle	Very Low (D)
1 in 100,000	Hurricanes & Earthquakes	Flood/Earthquake	Minimal (E)
1 in a 1,000,000		Lightning strike/Commercial airplane crash	Negligible (F)
1 in 10,000,000		Lightning strike/Tornado/ Commercial airplane crash	

<sup>19</sup> Wadge, G., & Aspinall, W. P. (2014). A Review of Volcanic Hazard and Risk Assessments at the Soufrière Hills Volcano, Montserrat from 1997 to 2011. In G. Wadge, B. Voight, & R. E. Robertson (Eds.), *The Eruption of Soufrière Hills Volcano, Montserrat, from 2000 to 2010* (Memoir 39). Geological Society of London.

## Appendix IX: Modified Chief Medical Officer's Risk Scale (CMO\*)

**Negligible (F):** an adverse event occurring at a frequency below one per million. This would be of little concern for ordinary living if the issue was an environmental one, or the consequence of a health care intervention. It should be noted, however, that this does not mean that the event is not important – it almost certainly will be to the individual – nor that it is not possible to reduce the risk even further. Other words which can be used in this context are 'remote' or 'insignificant'. If the word 'safe' is to be used it must be seen to mean negligible, but should not import no, or zero, risk.

**Minimal (E):** a risk of an adverse event occurring in the range of between one in a million and one in 100,000, and that the conduct of normal life is not generally affected as long as reasonable precautions are taken. The possibility of a risk is thus clearly noted and could be described as 'acceptable' or 'very small'. But what is acceptable to one individual may not be to another.

**Very low (D):** a risk of between one in 100,000 and one in 10,000, and thus begins to describe an event, or a consequence of a health care procedure, occurring more frequently.

**Low (C):** a risk of between one in 10,000 and one in 1,000. Once again this would fit into many clinical procedures and environmental hazards. Other words which might be used include 'reasonable', 'tolerable' and 'small'. Many risks fall into this very broad category.

**Moderate (B):** a risk of between one in 1,000 and one in 100. It would cover a wide range of procedures, treatment and environmental events.

**High (A):** fairly regular events that would occur at a rate greater than one in 100. They may also be described as 'frequent', 'significant' or 'serious'. It may be appropriate further to subdivide this category.

**Unknown:** when the level of risk is unknown or unquantifiable. This is not uncommon in the early stages of an environmental concern or the beginning of a newly recognised disease process (such as the beginning of the HIV epidemic).

**Reference:** On the State of Public Health: The Annual Report of the Chief Medical Officer of the Department of Health for the Year 1995. London: HMSO, 1996.

## Appendix X: Glossary of Terms

**Andesite:** The name given to the type of magma erupted in Montserrat.

**Basalt:** The type of magma entering the magma reservoir below Montserrat.

**cGPS:** Continuously-measured Global Positioning System for repeated measurement of ground deformation.

**Conduit:** In a volcano magma flows to the earth's surface along a pathway known as a conduit. The conduit is usually thought to be a cylindrical tube or a long fracture.

**Dyke:** Vertical, tabular body of magma within a fracture below the volcano that can act as the conduit for flow to the surface.

**EDM:** Electronic Distance Measurements made by laser ranging to reflectors gives length changes of a few millimetres accuracy over several kilometres.

**Fumarole:** A vent in the surface of the dome where hot gases exit.

**Hybrid/LP Seismicity:** Varieties of earthquake signal often indicative of magma motion in the upper part of the conduit.

**Lava:** Once magma gets to earth's surface and extrudes it can be called lava. Below ground it is always called magma.

**Lateral Blast:** An energetic sideways-directed explosion from a lava dome that can generate highly fluid pyroclastic flows.

**Low-frequency earthquake** see LP (long period earthquake)

**Magma:** The material that erupts in a volcano is known as magma. It is not simply a liquid, but a mixture of liquid, crystals and volcanic gases. Magma must contain enough liquid to be able to flow.

**Magnitude:** The magnitude of an explosive eruption is the total mass of material erupted.

**Mudflow:** A flow of rock debris, ash and mud that occurs on many volcanoes particularly during eruptions and after very heavy rain (equivalent to "lahar").

**Pyroclastic flow:** These are flows of volcanic fragments similar to avalanches of rock in landslides and snow avalanches. They can be formed both by explosions and by parts of an unstable lava dome avalanching.

**Pyroclastic surge:** These are also flows, but they are dilute clouds rather than dense avalanches. A surge is a rapidly moving mixture of hot particles and hot gas and their behaviour can be compared to a very severe hurricane. Surges can be formed above pyroclastic flows or directly by very violent explosions.

**Simulation:** Use of a computer program to mimic (or model) the behaviour of a physical process.

**Swarm:** A large number of, in this case, earthquakes occurring in rapid succession with characteristics indicating they are generated from a similar region in the earth. Can merge into tremor.

**Talus:** A pile of cool lava blocks and ash that accumulate by rockfall around the core of the hot lava dome.

**Volcanic ash:** Ash particles are defined as less than 4 millimetres in diameter. Respirable ash consists of particles less than 10 microns (a micron is one thousandth of a millimetre) in diameter.

**VT string:** Bursts of seismic energy in form of several volcano-tectonic earthquakes, sometimes accompanied by ash venting.

## Appendix XI: Limitations of Risk Assessment

It should be recognised that there are generic limitations to risk assessments of this kind. The present exercise has been a relatively quick assessment, based on a limited amount of field and observatory information and on a brief review of previous research material. The Foreign & Commonwealth Office, who commissioned the assessment, allocated four days for the formal meeting. Thus the assessment has been undertaken subject to constraints imposed in respect of time and cost allowed for the performance of the work.

While the outcome of the assessment relies heavily on the judgement and experience of the Committee in evaluating conditions at the volcano and its eruptive behaviour, key decisions were made with the use of a structured opinion elicitation methodology<sup>20</sup>, by which means the views of the Committee as a whole were synthesised impartially.

It is important to be mindful of the intrinsic unpredictability of volcanoes, the inherent uncertainties in the scientific knowledge of their behaviour, and the implications of this uncertainty for probabilistic forecasting and decision-making. There are a number of sources of uncertainty, including:

- Fundamental randomness in the processes that drive volcanoes into eruption, and in the nature and intensities of those eruptions.
- Uncertainties in our understanding of the behaviour of complex volcano systems and eruption processes (for example, the relationships between pyroclastic flow length, channel conditions and topography, and the physics of pyroclastic flows and surges).
- Data and observational uncertainties (e.g. incomplete knowledge of the actual channel and interfluvial topography and conditions, material properties inside pyroclastic currents, the uncertain nature of future eruption intensities, dome collapse geometries and volumes etc).
- Simulation uncertainties, arising from limitations or simplifications involved in modelling techniques, and the choices of input parameters.

These are all factors that are present when contemplating future hazards of any kind in the Earth sciences (e.g. earthquakes, hurricanes, floods etc.) and, in such circumstances, it is conventional to consider the chance of occurrence of such events in probabilistic terms. Volcanic activity is no different. There is, however, a further generic condition that must be understood by anyone using this report, which concerns the concept of validation, verification or confirmation of a hazard assessment model (or the converse, attempts to demonstrate agreement or failure between observations and predicted outcomes). The fact is that such validation, verification or confirmation is logically precluded on non-uniqueness grounds for numerical or probabilistic models of natural systems, an exclusion that has been explicitly stated in the particular context of natural hazards models<sup>21</sup>.

This report may contain certain ‘forward-looking statements’ with respect to the contributors’ expectations relating to the future behaviour of the volcano. Statements containing the words ‘believe’, ‘expect’ and ‘anticipate’, and words of similar meaning, are forward-looking and, by their nature, all forward-looking statements involve uncertainty because they relate to future events and circumstances most of which are beyond anyone’s control. Such future

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<sup>20</sup> Cooke R.M., *Experts in Uncertainty*. Oxford University Press, 1991.

<sup>21</sup> Oreskes, N., Schrader-Frechette, K. and Belitz, K., 1994. Verification, validation, and confirmation of numerical models in the Earth Sciences. *Science*, 263: 641-646.

events may result in changes to assumptions used for assessing hazards and risks and, as a consequence, actual future outcomes may differ materially from the expectations set forth in forward-looking statements in this report. The contributors undertake no obligation to update the forward-looking statements contained in this report.

Given all these factors, the Committee members believe that they have acted honestly and in good faith, and that the information provided in the report is offered, without prejudice, for the purpose of informing the party commissioning the study of the risks that might arise in the near future from volcanic activity in Montserrat. However, the state of the art is such that no technical assessment of this kind can eliminate uncertainties such as, but not limited to, those discussed above. Thus, for the avoidance of doubt, nothing contained in this report shall be construed as representing an express or implied warranty or guarantee on the part of the contributors to the report as to its fitness for purpose or suitability for use, and the commissioning party must assume full responsibility for decisions in this regard. The Committee accepts no responsibility or liability, jointly or severally, for any decisions or actions taken by HMG, GoM, or others, directly or indirectly resulting from, arising out of, or influenced by the information provided in this report, nor do they accept any responsibility or liability to any third party in any way whatsoever. The responsibility of the contributors is restricted solely to the rectification of factual errors.

This Appendix must be read as part of the whole Report.