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article in press

Risk perception, trust and culture: the 2014-15 Holuhraun eruption, Iceland

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Abstract

This paper presents data and analysis from a survey of residents and tourists in Iceland undertaken following the eruption of Barðarbunga volcano in 2014-15. This eruption produced significant localised gas hazard, leading to a widespread closure of national parks and tourist attractions in Iceland. It also lasted for several months, throughout the winter time, and at times gas was detected in settlements across the country. The survey was carried out online in 2016-17, asking Icelanders and international tourists about their experiences during this eruption and also about volcanoes and volcanic eruptions in Iceland more generally. We find that both residents and tourists used a wide range of sources of information about the eruption, both official and unofficial, but that they differ in their trust and reliance on particular groups. We further demonstrate the complex interplay between the eruption-as-spectacle and eruption-as-risk, relating this to the significance of eruptions in Icelandic culture and history, and discuss the implications for eruption management.

Keywords: volcanoes and culture; risk communication; volcano tourism; Holuhraun; volcanic gas hazard; trust

Introduction and background

The 2014-15 eruption of Barðarbunga volcano in Iceland was the largest basaltic eruption since Laki (1783-4) (Schmidt et al., 2015; Sigmundsson et al., 2015). It occurred in the volcanic rift zone to the north of Vatnajökull ice cap, on the flood plains of the Jökulsá á Fjöllum (Figure 1), and has widely been referred to as the Holuhraun eruption, after another lava unit in the area (Hartley and Thordarson, 2013). The eruption started just after the peak of the tourist season, in late August, but the earthquakes had clearly delineated a dyke intrusion for 3 weeks prior to the eruption, and a number of key tourist attractions in the region had been closed, including parts of Jökulsárgljúfur National Park, due to the risk of jökulhlaups across the north of Iceland. This was controversial among the tour companies, which lost significant income as a result of the closures.

In 2010, a fissure eruption at Fimmvörðuháls had been a very successful tourist attraction (Donovan, 2018), and there was considerable pressure in the early days of the Holuhraun eruption to allow tourists into the area. However, unlike Fimmvörðuháls, the Holuhraun eruption was very gas-rich and hazardous levels of SO₂, H₂S and CO₂ were detected at the site (Carlsen et al., 2019). The decision was taken to restrict access due to the remoteness, the potential jökulhlaup hazard and the high gas levels. Furthermore, while the eruption itself was very remote, its impacts did at times

extend to inhabited areas, with residents being exposed to volcanic gas at times due to the high gas emission and dependent on wind direction (Carlsen et al., 2021a, 2021b; Donovan et al., 2023a; Ilyinskaya et al., 2017; Simmons et al., 2017). More recently, the eruptions at Fagradalsfjall and Sundhnúkur have involved both restrictions and free access, navigating between the expectation of freedom of access and the challenges of managing safety (Langridge and Michaud, 2023). However, the gas emissions from these eruptions have been much lower than those at Holuhraun (Barsotti et al., 2023; Pfeffer et al., 2024).

The Icelandic Meteorological Office (IMO) is the responsible agency for volcano monitoring in Iceland, and its website contains substantial resources for volcano watchers (Bird et al., 2008), including gas forecasts (Barsotti, 2020). Iceland has a long history of allowing a “right to roam”, about which people feel strongly (Langridge and Michaud, 2023), yet there are tensions between this and the relative inexperience of many tourists in the challenging terrain of the Icelandic highlands, which requires effective risk communication to be in place (Bird and Gísladóttir, 2020a; Matti et al., 2022).

Volcano tourism has grown globally in recent years, with tourists seeking out geoparks and volcanoes for skiing, hiking and sight-seeing (Erfurt-Cooper, 2014, 2011; Heimisdóttir et al., 2019). Volcano tourism during eruptions is a subset of this, but one that is also growing – perhaps particularly in Iceland (Donovan, 2018; Langridge and Michaud, 2023). There is a tension between the exhilaration of experiencing an eruption as an impressive natural spectacle, and viewing it as primarily something hazardous and risky. The style of volcanism is clearly a major factor in this, but there are other concerns regarding the accessibility of the eruption site (e.g. road access versus long hikes), the prevalence and variation of hazards (including volcanic gas), the climatic conditions and their interaction with volcanic hazards (e.g. acid rain, contaminated groundwater) and people’s individual characteristics and emotions (Ilyinskaya et al., 2024).

Volcano tourism in Iceland is very well documented, both in the volcanic risk reduction literature and within tourism studies (Bird et al., 2010; Bird and Gísladóttir, 2018, 2014; Heimisdóttir et al., 2019; Helgadóttir et al., 2019; Ólafsdóttir et al., 2018; Sæþórsdóttir et al., 2020). The tourism literature focusses on the sustainability of increasing levels of tourism in the vulnerable environment of Iceland (Ólafsdóttir et al., 2018). It has also started to explore the ways in which tourism may be managed to facilitate sustainability and safety (Bird and Gísladóttir, 2020b; Ólafsdóttir et al., 2018). More broadly, there have been discussions within volcanology concerning the use of social media during eruptions (Giordano et al., 2016; Sennert et al., 2015; Todesco et al., 2022). Social media presents both an opportunity and a challenge in terms of communication: it enables direct contact between scientific agencies and the public, but it is also open to misinformation and to sensationalism (Goldman et al., 2024; Mani et al., 2024; Stovall et al., 2023; Williams and Krippner, 2018). As volcanic eruptions increasingly attract photojournalism, drones and influencers – particularly where they occur in accessible areas – and observatories and civil protection organisations have had to adapt their practices accordingly, even as volcanologists have also found such resources useful (Wadsworth et al., 2022).

Iceland’s history of volcanism has been widely represented not only in twenty-first century tourist brochures but also in manuscripts and images dating back to the Sagas (Barracough, 2012; Nordvig, 2021, 2019; Oslund, 2011; Pyle, 2017). It is also well documented in the scientific literature (Thordarson and Larsen, 2007; Thordarson and Self, 1993), and there have been claims that volcanism has had an impact on cultural shifts (Oppenheimer et al., 2018). In literary and social theory, the notion of “the sublime” has been used to encapsulate – often imperfectly – the contradictions that are experienced in extreme situations, such as eruptions. It has also been

theorised widely, including in relation to landscape and geological processes (Bell and Lyall, 2002; Brady, 2010; Burke, 1990; Dixon et al., 2013; Donovan, 2018; Shaw, 2006). It refers to a combination of beauty and terror that results in enhanced emotional experience that is characterised in part by the conflict between different responses. It is also characterised by a sense of being overwhelmed and of being small (self-negation). Indeed, it draws together a wide range of responses, bodily, emotional and imaginative (Ashfield and De Bolla, 1996; Cochrane, 2012; Duffy, 2013). This seeking of the sublime is closely associated with the experience of eruptions that is sought by those attracted to volcanic areas as tourists (Dixon and Beech, 2017; Donovan, 2018).

This study sought to combine these bodies of research and examine the perceptions of both residents and tourists concerning Icelandic volcanism – its significance both to the history and culture of Iceland and to modern-day tourism – and its management by scientists and decision-makers. It also sought to investigate the sources of information that people depend upon during eruptions. It takes a mixed-methods approach, using qualitative and quantitative survey data from over five hundred respondents, collected during 2017 (prior to the Reykjanes eruptions). As such, it also presents a baseline from which new research may be designed to track changes over time and through different types, locations and durations of eruptive activity.

Methodology

This paper documents a study that was designed to examine the intersections between risk perception, warnings and culture in Iceland, focussing on the Holuhraun eruption but also exploring some more general themes. It involved an online survey that was advertised via the IMO website during early 2017, two years or so after the end of the Holuhraun eruption.

Survey design

This work is based on a survey that was advertised via the IMO website from February to May 2017. This was deliberately aimed at respondents with an interest in Icelandic culture and nature, both Icelanders and internationals. The survey was available in two languages (Icelandic and English), and had slightly different questions depending on whether the respondent lived in Iceland or was a tourist. This resulted in four sets of respondents: Icelandic residents (279), Icelandic tourists (mainly Icelanders living overseas) (5), International residents (13) and International tourists (235). There were also three respondents who were Icelanders who had moved back to Iceland after living overseas – they are counted as residents (total therefore 282). Those who took the survey in Icelandic were not all Icelanders – some were Icelandic-speaking internationals, so language did not provide a useful separator. In general, residents were treated separately from non-residents (denoted as tourists here), whether or not they were Icelandic nationals. However, tests were also done between those identifying as Icelandic nationality and those not; this is specified below in the results (“Icelander” versus “International”, or “Resident” versus “Tourist”). In the qualitative results, it was possible to separate out the four possible categories (Icelandic Residents, Icelandic Tourists, International Residents and International Tourists). The small numbers in two categories (see above) did not permit statistical tests between the four.

Questions in the survey covered demographic variables (age, gender, education level, profession, years lived in Iceland – for residents; number of times visited in last decade – for tourists; location in Iceland – for residents; time spent in Iceland – for tourists). It then covered five topics:

- Further relevant information about the participant
- The Holuhraun eruption
- Eruptions in Icelandic culture and society

- 130 • Keeping people safe
- 131 • Reactions to volcanoes and eruptions

132 The scales were varied in direction throughout the survey.

133 Further information about the participants

134 In this section, we collected data about some key interests relevant to later questions (asking how
135 important the following were to the respondent: outdoor activities, travel in Iceland, travel
136 elsewhere, surfing the web, business activities, retail/shopping) and whether or not they have
137 witnessed an eruption. For this last question, they were asked to give qualitative accounts. Finally,
138 they were asked if they were aware of the 2014-15 eruption of Holuhraun. Those that were aware of
139 it were taken to the section about the eruption.

140 The Holuhraun eruption: information and impacts

141 This section asked respondents how closely they had followed the eruption; where they obtained
142 their information from; specifically which IMO products they used, how informative IMO's website
143 was and how well they understood it; and finally whether they were affected by gas during the
144 eruption – this question asked for a qualitative account, which was subsequently coded into four
145 categories (type of gas impact) and again into two (impact or no impact).

146 Eruptions in Icelandic culture and society

147 This part of the survey asked about expected frequencies of eruption in Iceland, the importance of
148 eruptions to different elements of Icelandic life, and the importance of different kinds of impacts of
149 eruptions. It also asked about emotions and fears in relation to volcanic eruptions.

150 Trust in institutions and other groups

151 This section asked questions about respondents' perceptions of different groups, looking at how
152 much different groups are relied upon, whether they are perceived to **respond** wisely, whether they
153 are perceived to be **knowledgeable**, whether they are perceived to be **accurate**, whether they are
154 perceived to be **altruistic**, and whether they **gain or lose** in eruptions. The groups were:

- 155 • Scientists
- 156 • The civil protection
- 157 • The IMO
- 158 • ICE-SAR
- 159 • The local government
- 160 • The national government
- 161 • The news media
- 162 • Social networks
- 163 • Your own friends and family
- 164 • Tourist agencies
- 165 • Foreign tourists

166 Anticipatory actions and warnings

167 This section asked about the different actions that people take when they are travelling around
168 active volcanoes in Iceland. It also asked about the importance of issuing warnings in relation to
169 business interests, safety and the risk of false alarms.

170 The survey questions in full are provided in A1.

Data analysis

The complex dataset was analysed both quantitatively and qualitatively. The quantitative analysis was done in SPSS and used a wide range of statistical tests to look for statistically significant relationships between the variables. The research questions in particular looked at:

- Links between people's views about tourism, business and risk
- Links between people's views about nature and risk

Data were recoded in order to clarify the dataset. Residents and tourists were recoded by both language and nationality, to distinguish between Icelanders who live in Iceland, those who live overseas, and non-Icelanders in both categories (rather than as the survey initially did – Icelandic speakers, which included a number of non-Icelanders). Rating scales were coded 1-10, according to the scale. Variables with yes/no answers and textboxes were coded into (i) a binary dummy variable (yes/no as 1/0) and (ii) qualitative text for analysis. Other dummy variables (ie binary variables that denote whether a respondent belongs to a particular category or not) were created for other categorical variables. This enables the software to compare groups (e.g. for comparison of means or medians). Variables with more than two categories were also numerically coded.

The tests used to analyse the data are standard statistical tests appropriate for the variables in question. Initially, frequencies and key descriptive statistics were used to assess the data. Where data are normally distributed, parametric tests (t tests, ANOVA) are used to look for relationships. Many variables were not normally distributed, and these are investigated using non-parametric tests (Mann Whitney U, Kruskal Wallis H). Appropriate measures of effect size are calculated for each statistic, as is the statistical significance. While effect size shows the magnitude of the effect (small to high), statistical significance reflects how likely the result would be to occur randomly. While $p < 0.05$ is normally regarded as significant, $p < 0.01$ more readily avoids type 2 errors.

For the Kruskal-Wallis test, effect size was measured using eta squared:

$$\eta^2 = \frac{(H - k + 1)}{(n - k)}$$

Where H is the test statistic, k is the number of groups and n is the number of responses. An effect size of 0.01 to 0.06 is a small effect; 0.06 to 0.14 is a medium effect. For the Mann Whitney test, effect size is calculated from the normalised z-statistic:

$$r = \frac{|z|}{\sqrt{n}}$$

An r value of 0.1 to 0.3 records a small effect; 0.3 to 0.5 a medium effect and > 0.5 a large effect. For χ^2 , Cramer's V is used – an effect size of < 0.2 is small; 0.2 to 0.6 is moderate and > 0.6 is large. For t tests, Cohen's d is used – an effect size of < 0.2 is small; 0.2 to 0.5 is medium and > 0.5 is large.

Qualitative sections of the survey were coded in NVivo software using a grounded theory approach (in which the data are allowed to generate the themes). Two passes of coding were made to refine the codes. Nine coding groups were identified (actions, emotions, encounters, impacts, hazards, gas effects, information sources, science and volcano names). Each of these had multiple subcodes – there were a total of 127 codes (33 were volcano names).

Results

Demographics

Recoding of variables by nationality resulted in 535 total respondents. Of these, 284 were Icelandic (5 living overseas); 16 were internationals living in Iceland and the remaining 235 were international tourists or prospective tourists. In total, 208 non-Icelanders were European and 43 were from other parts of the world (from New Zealand to Georgia to Latin America: see supplementary spreadsheet for the full list).

The mean age of respondents was 49.6. For residents, the mean time they had lived in Iceland was 47.7 years. Tourists had made on average 4 trips in the last 10 years – suggesting a number of repeat travellers. This was further coded for “regular visitors or long trips” – defined as someone who had either visited more than 5 times in the last 10 years, or had spent 3 months or more in Iceland at a single time. The rationale for this was that these people had a more involved relationship with Iceland than someone who visited once or twice for 2 weeks. Most of the people in this category were either involved in education, in tourism or journalism.

Of residents, most lived in the Capital area of Iceland (183 of 290), with 211 living in the south east region more broadly. There were also 18 from South Iceland, 19 from the north west, 19 from the eastern region and 23 from the north.

The modal education level was bachelor’s degree (217 of 535), with slightly more people at postgraduate level (156) than at school level (144), reflecting a relatively highly educated dataset. The majority of respondents were employed, in a wide range of jobs. The dataset included 16 homemakers, 38 retired people and 28 students.

Looking for differences between the groups, the tourists tended to have slightly higher levels of education than the residents ($\chi^2 = 29.8$, $V = 0.24$, $p < 0.001$). This was dominated by the PhD group – 29 in the tourist group to 11 in the residents, perhaps reflecting different reasons for visiting the IMO website. There were also some differences in the kinds of jobs that people did between the groups ($\chi^2 = 22.6$, $V = 0.21$, $p < 0.001$), with residents more likely to work in outdoor roles, and tourists more likely to be in teaching or technical roles. Gender distribution was not significantly different between the groups.

Participants regarded outdoor activities and travel in Iceland as very important to them ($\bar{x}=2.1$, $sd = 1.4$ for both, with lower numbers implying greater importance on the scale). Icelandic residents were slightly more likely to find it important than tourists ($U=40593$, $r=0.16$, $p < 0.001$; $U=41766$, $r=0.19$, $p < 0.001$). Travel elsewhere in the world was also important, suggesting a group that is generally interested in travel ($\bar{x}=3.0$, $sd = 1.8$). Surfing the internet was viewed as important but less so ($\bar{x}=3.3$, $sd=2.0$), with Icelandic residents finding it a little more important ($U=43767$, $r=0.24$, $p < 0.001$), business was rated moderately important ($\bar{x}=4.1$, $sd=2.6$) but more so (considerably) by Icelandic residents ($U=54227$, $r=0.53$, $p < 0.001$); and shopping was less important ($\bar{x} = 5.3$, $sd=2.6$) but again considerably more so by residents ($U=53361$, $r=0.51$, $p < 0.001$). Note that this set was as rated on a scale of 1-10, with 10 as least important. Among these variables, there were strong cross-correlations between the outdoors and travel variables, and between the shopping, business and web-surfing variables (Table 1). A factor analysis produced two factors that explain 62% of the total variance – one representing outdoors/travel and the other business and retail. These factors are discussed later, in relation to other variables.

Categories	Outdoors	Travel in Iceland	Travel Elsewhere	Surfing the web	Business	Shopping
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Outdoors	0.52*	0.20*	0.10	0.13*	n.s.
Travel in Iceland		0.38*	0.18*	0.20*	0.22*
Travel elsewhere			0.19*	0.16*	0.12*
Surfing the web				0.43*	0.41*
Business					0.65*
Shopping					

Table 1. Cross correlations between activities people felt were important to them. All values are significant at 5% level. Asterisk indicates significance at 1% level. Bold and asterisk is significance at 0.1% level.

A majority (58%) of the respondents had witnessed a volcanic eruption (although not all of them in Iceland), and almost all (95%) had been aware of the Holuhraun eruption. Looking between the groups, internationals were much less likely than residents to have witnessed an eruption ($\chi^2 = 108$, $p < 0.001$, $V = 0.455$), and internationals were also less likely than residents to have been aware of the Holuhraun eruption ($\chi^2 = 17.3$, $p < 0.001$, $V = 0.185$).

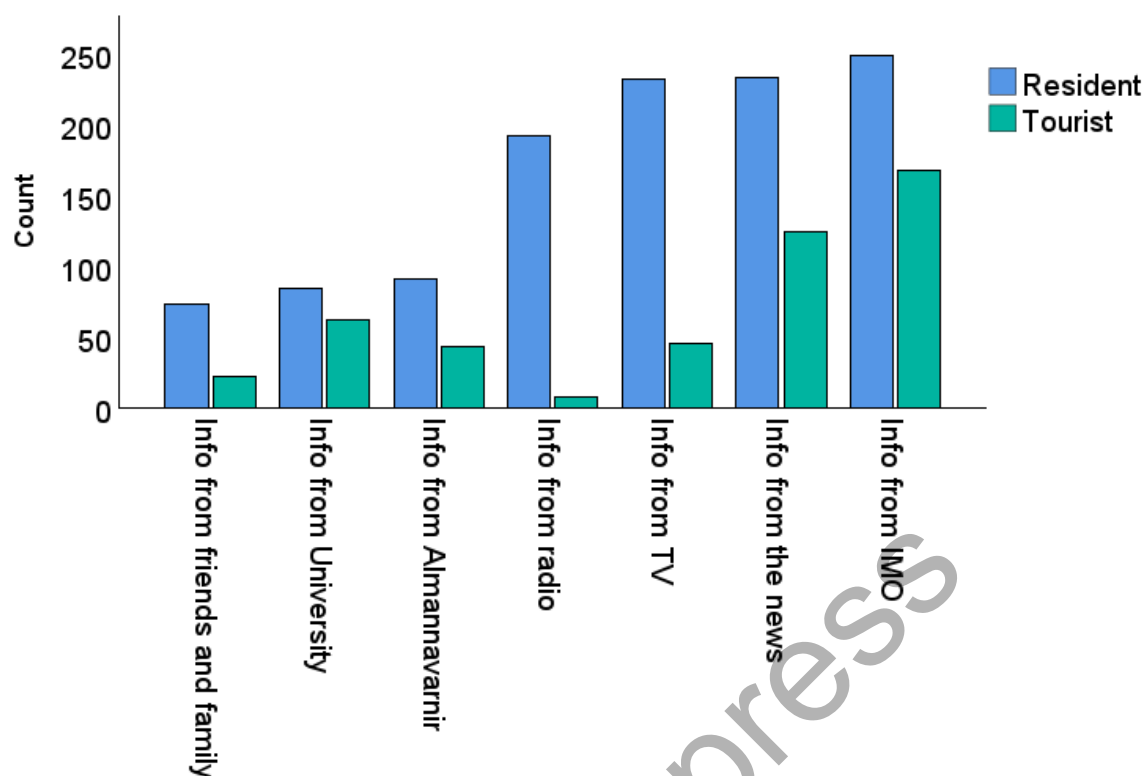
In summary, the demographic data showed that the respondents to the survey were generally highly educated, with postgraduate qualifications slightly more likely in the international respondents (who may have been checking the IMO website for technical reasons) than the residents. Key predictor variables that are used below include age, gender, education level, residents/tourists, Icelanders/internationals, travel/shopping interests and employment status.

The Holuhraun eruption

Information sources

These questions appeared to any respondent who had been aware of the eruption in 2014-2015, which was 95% of the survey respondents. They were asked about where they got information in the eruption, which IMO products they used, how useful they were and whether or not they felt they understood them. They were also asked about any impacts they might have experienced from volcanic gas.

Sources of information across the whole dataset are shown in Figure 1.



272

273 **Figure 1. Simple bar chart of the sources of information given by respondents, separated by**
274 **tourists and residents.**

275 Internationals were less likely to get information from IMO ($\chi^2= 18.0$, $V=0.2$, $p<0.001$) or
276 Almannavarnir ($\chi^2=11.4$, $V=0.1$, $p<0.001$). They were also less likely to get information from the news
277 (perhaps due to lack of reporting outside Iceland) – $\chi^2=47.9$, $V=0.3$, $p<0.001$ or from the radio
278 ($\chi^2=234.4$, $V=0.7$, $p<0.001$) or TV ($\chi^2=208.0$, $V=0.6$, $p<0.001$) – note large effect size here. More
279 Icelandic residents also got information from friends and family ($\chi^2=27.5$, $V=0.2$, $p<0.001$). A similar
280 pattern was found coding by nationality alone (Icelandic v non Icelandic) and also by resident v
281 tourist. There was no difference between groups in getting information from the University.

282 Looking at other predictor variables, older people were slightly more likely to get their information
283 from IMO ($t=3.1$, $d=0.3$, $p<0.01$). Older people resident in Iceland were also more much likely to get
284 information from the radio ($t=7.2$, $d=0.9$, $p<0.001$) or TV ($t=4.3$, $d=0.6$, $p<0.001$). Residents of Iceland
285 who were younger were more likely to get their information from friends and family ($t=-3.1$, $d=-0.4$,
286 $p<0.01$). People resident in Iceland and with higher degrees were more likely to get information
287 from the university ($t=3.7$, $d=0.5$, $p<0.001$) or the news ($t=2.3$, $d=0.4$, $p<0.05$). There were no
288 significant results for internationals in these groups.

289 Qualitative results showed that internationals were obtaining their information from other online
290 sources, such as volcano and disaster blogs, Facebook pages and Twitter, and were also viewing the
291 eruption webcams. Some had obtained their information from tour guides and hotels. However, the
292 prevalence of references to blogs and other informal social media sources was striking – particularly
293 given the results for trust (see below).

Focussing on products produced by IMO, the news and updates and earthquake plots were the most used products (Figure 2)¹. There were no differences by education level or gender. Icelandic residents were much more likely than international tourists to use the wind plot ($\chi^2=20.8$, $V=0.2$, $p<0.001$) or the news and updates ($\chi^2=27.6$, $V=0.2$, $p<0.001$). Older people were slightly more likely to use the wind plot ($t=2.6$, $d=0.2$, $p<0.05$) and the earthquake plot ($t=2.5$, $d=0.2$, $p<0.05$), and to look at news and updates ($t=2.3$, $d=0.2$, $p<0.05$) – i.e. there was a positive effect for the continuous age variable here. Icelanders living in the north and east were slightly more likely to use the gas forecast ($\chi^2=14.3$, $V=0.2$, $p<0.05$). Those living in the south and east were slightly more likely to use the wind plot ($\chi^2=12.9$, $V=0.2$, $p<0.05$). People who had witnessed an eruption were more likely to use the gas forecast ($\chi^2=19.7$, $V=0.2$, $p<0.001$), earthquake plot ($\chi^2=22.0$, $V=0.2$, $p<0.001$), wind plot ($\chi^2=28.8$, $V=0.2$, $p<0.001$) and news and updates ($\chi^2=15.4$, $V=0.2$, $p<0.001$). This was also the case for those aware of the Holuhraun eruption, but there is cross correlation here, suggesting considerable overlap between these groups – those that knew about Holuhraun and also have witnessed an eruption. Only 27 people in the whole dataset were not aware of Holuhraun.

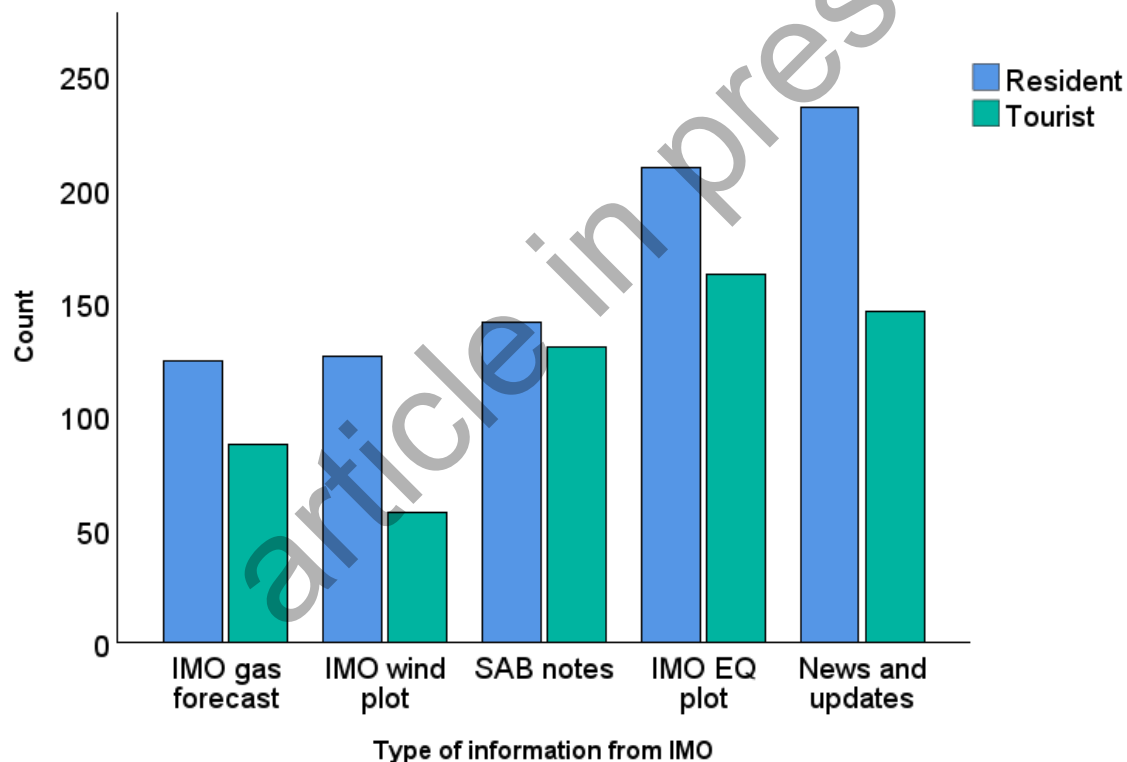


Figure 2. Simple bar chart of the use of IMO products, separated for tourists and residents. SAB=Scientific Advisory Board; EQ = earthquake. Examples of the gas forecast plots can be found in Barsotti, 2020; Barsotti et al., 2020. Examples of the other plots can be found on the IMO website.

In general, respondents felt that they understood the information provided by IMO very well, with 70% rating their understanding as 8 out of 10 or higher. People who had witnessed an eruption were more likely to have followed the news closely ($U=31534$, $r=0.15$, $p<0.01$), and more likely to think

¹ The full web content that IMO produced during the eruption may be found here: <https://en.vedur.is/earthquakes-and-volcanism/articles/nr/2947>. Accessed 16.7.26.

they understood it ($U=28864$, $r=0.22$, $p<0.001$). There were strong cross-correlations between how closely people followed the news, how interesting the IMO information was and how well people understood it. Some of these variables also correlated with the interest demographic variables (Table 2).

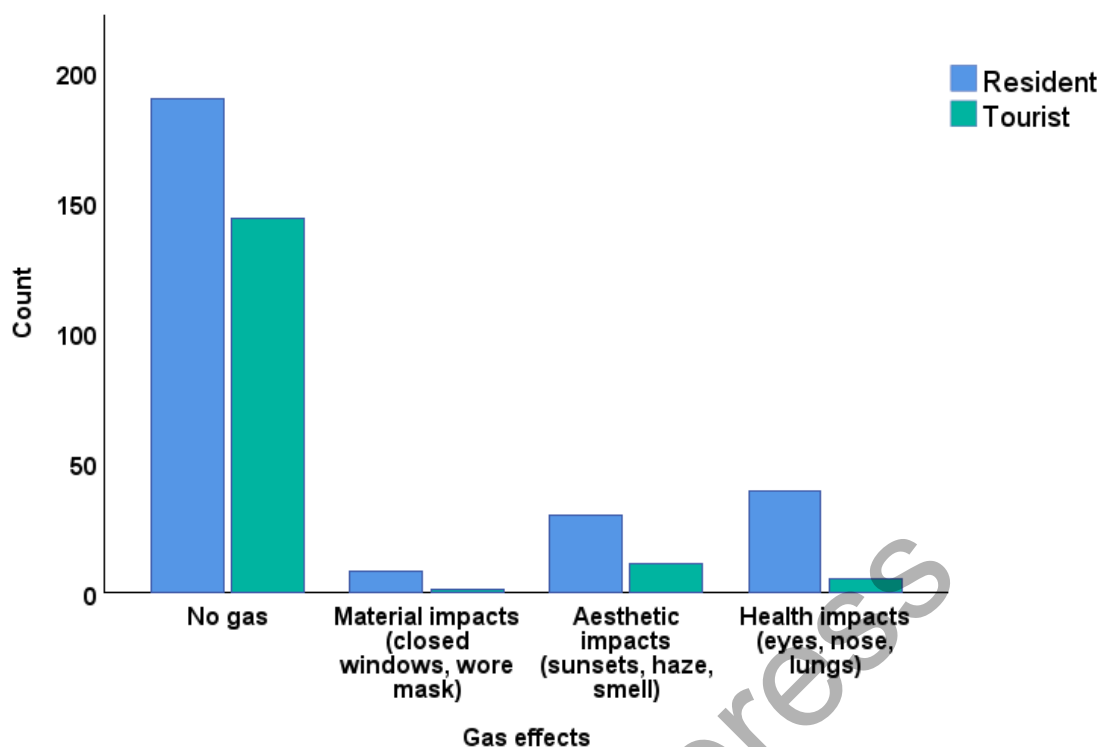
	Following the news about the eruption	Interested in IMO	Understood IMO information
Outdoors	n.s.	-0.18*	-0.18*
Travel in Iceland	-0.20*	-0.26*	-0.25*
Surfing the web	-0.10	-0.11	n.s.
Shopping	n.s.	-0.11	n.s.
Business	n.s.	-0.10	-0.13*
Following news			
Interested in IMO	0.27*		
Understood IMO	0.31*	0.53*	

Table 2. Correlations between interest variables and information variables. Asterisks show significance at the 1% level.

Overall, this shows that there are different groups – the majority of respondents were very keen, had seen eruptions and liked to travel, especially in Iceland; another group found shopping, business and the internet important, and were less likely to have seen an eruption. Using the factors, people interested in travel and the outdoors were more likely to be interested in the information from IMO ($p = -0.2$, $p<0.001$). Both groups had confidence in their ability to interpret the IMO information.

Volcanic gas impacts

The impacts of volcanic gas from Holuhraun on respondents were very variable. The qualitative responses were coded into a variable with four categories: no impact, material impact (e.g. they closed a window or wore a mask), aesthetic impact (e.g. red sunsets, haze, smell) and health impact (recorded effects on eyes, nose, lungs). The results are shown in Figure 3.



334

335 **Figure 3. Impacts of volcanic gas on respondents, split by tourists and residents.**

336 As Figure 3 shows, the majority of respondents did not record any impact from the gas. Residents
337 outside the Capital region were more likely to have experienced some form of gas impact ($\chi^2=15.8$,
338 $V=0.25$, $p<0.001$). Those with outdoor occupations and those retired or homemaking were also
339 slightly more likely to experience an impact ($LR=12.2$, $V=0.21$, $p<0.05$). Investigating the geography
340 in more detail, impacts from gas were considerably more likely in Northern ($LR=19.7$, $V=0.3$,
341 $p<0.001$), Eastern ($LR= 8.0$, $V=0.2$, $p<0.05$) and Southern Iceland (excluding the Capital and Reykjanes
342 regions; $LR=12.8$, $V=0.2$, $p<0.01$). Northern Iceland had the largest effect size, and many of these
343 were health-related impacts. That gas was experienced more often in the south, east and north of
344 the country is also consistent with the result above that these areas were more likely to consult the
345 wind plots and/or gas forecasts.

346 The qualitative data on gas impacts was further analysed to extract specific anecdotes and
347 experiences. Some residents had taken action on the basis of the information they received from
348 IMO and the Environment Agency. For example, one resident commented:

349 *Looked almost daily at the site. Also watched air pollution on the Environment Agency's website. If I*
350 *saw that the pollution figures were rising in the vicinity of us, we slept with a closed window.*

351 The health impacts can be further broken down:

- 352
- Eleven respondents described eye irritation
 - 353 • Three had headaches
 - 354 • Forty-four people referred to smells and odours.
 - 355 • Thirty-five people felt that they had experienced some sort of respiratory symptom – either
 - 356 an exacerbation of asthma/other condition, or shortness of breath (or some combination of
 - 357 these).

- Eleven people mentioned irritation of the throat.

Six people mentioned that they had bought gas masks or SO₂ handheld devices to mitigate exposure to the gas. Twenty-five others mentioned changes to the atmosphere – either red sunsets or haze/mist that they interpreted as volcanic in origin. Some mists were perceived as bluish, while others commented on the link to historical events:

Except that it changed the colors of the sunset, making it more beautiful. Even though there was haze, it was nothing like the "haze famines" of the past. (Resident)

Other comments mentioned impacts on livestock. One respondent said that herdsmen had been impacted, and that reindeer and birds came further south than usual, and five mentioned livestock issues, particularly in the north and east.

Summary

In summary, residents were more likely to get information from IMO and other official sources, whereas internationals tended to use a wide range of online sources. Of IMO resources, the earthquake plot and news/updates were most commonly used, but a significant number of residents did use the gas forecast and wind plot. In spite of the location of the eruption in the highlands, a number of residents did experience gas pollution in some way, including as health impacts, and they did take mitigation actions in some of these cases. This is consistent with the results of studies that have focussed on the gas impacts (Carlsen et al., 2021b), which found that the primary impacts were on those who had prior respiratory morbidities.

Eruptions in Icelandic culture and society

Frequency of eruptions

On frequency of eruptions, there were no significant differences between residents and tourists or between Icelanders and internationals, although the range of values given for frequency was greater among people from countries outside of Europe. The mean value was one eruption every 5.8 years (sd=7.0), and the full range was one every month to one every hundred years. One Icelander suggested that volcanoes erupted "too often", and several commented that there seems to be something going on "almost all the time". Older people were slightly more likely to give higher numbers ($p=0.14$, $p<0.01$).

Respondents had witnessed eruptions in Iceland and elsewhere in the world:

- 62 had visited Fimmvorduhals (2010);
- Five mentioned the 1961 eruption of Askja;
- 105 residents and 16 tourists had witnessed Eyjafjallajökull 2010. Many more tourists had been impacted in some way.
- 18 mentioned Gjalp in 1996;
- 47 had witnessed Grimsvotn in 2011;
- 37 had observed Heimaey in 1973;
- 129 had seen one or more of the eruptions of Hekla (1970, 1980, 1981, 1991, 2000);
- 55 had seen Holuhraun (many from the air, either in a tourist flight or from a commercial aircraft);
- 26 mentioned the Krafla eruptions (1975-1984);
- 21 had visited Surtsey (1963-1967).

Comments mentioned that the sound of the volcano that they witnessed erupting was ‘like a jet engine’. Others focussed on the ash impacts from Grimsvotn and Eyjafjallajokull in particular.

Outside of Iceland, individuals had visited Anak Krakatau (1), Arenal (2), Augustine (1), Erta Ale (1), Etna (15), Fuego (1), Kilauea (14), Mount St Helens (3), Okmok (1), Pavlof (1), Piton de la Fournaise (2), Quizapu (1), Sakurajima (1), Soufriere Hills (1), Stromboli (11), Tungurahua (1), Villarica (2), Yasur (1). Non-specified eruptions in New Zealand (1) and Tanzania (1) were also mentioned. Note that many of these are duplicates and likely represent people working either in research or in photography/science journalism.

Most of the responses listed the eruptions, but some also provided commentary:

“I was fascinated by the feeling of tranquility experienced on the spot despite the magnitude of the phenomenon and the great quantity of lapilli fallout.” (Etna)

Another respondent had hiked up Etna and had to dodge falling rocks and sulfurous gases in 1965.

In Iceland, a non-Icelandic tourist had visited Krafla 24 hours after an eruption ended in 1980: *“The area covered by fresh lava was astonishing, as were the evidence of earth movements and other landforms associated with the eruption. Had the eruption been continuing when we arrived at the site, we would not have been able to climb the vent or walk on the lava, so it was advantageous to arrive when we did. This whole experience contributed to my life-long love affair with Iceland and its people.”*

Another tourist had arrived in August 2014:

“Some tour guides in Reykjavik and Akureyri were telling stories about deadly gases and the mist hardships, trying to scare tourists! At no point did I feel any danger though. Locals told me about Laki and I did my own research into the Skafta fires because I became interested in the history - so I was also interested to follow the news on Holuhraun, especially as it was being reported in other countries.”

These two anecdotes demonstrate the power of eruptions to trigger learning experiences and inspire people to find out more about volcanology.

Eruptions in Icelandic culture

Both residents and tourists generally thought that volcanoes are important in Icelandic culture ($\bar{x}=8.73$, $sd=2.05$), that eruptions are important in Icelandic history ($\bar{x}=9.35$, $sd=1.61$), and that they are exciting ($\bar{x}=8.60$, $sd=2.23$) – with very slightly more ambivalence from Icelanders on the last. The distributions for “volcanic eruptions are frightening” are slightly different ($\bar{x}=6.31$, $sd=2.75$), with tourists giving slightly higher scores here (see also supplementary data). Icelanders are also marginally more ambivalent about whether eruptions are not interesting ($\bar{x}=1.81$, $sd=1.99$). Residents who had witnessed an eruption were more likely to think volcanoes important to culture ($U=8245$, $r=0.18$, $p<0.01$). Both residents ($U=8739$, $r=0.23$, $p<0.001$) and tourists ($U=7129$, $r=0.15$, $p<0.05$) were slightly more likely to think eruptions exciting if they had witnessed one. Residents who had witnessed an eruption were a little less likely to find them frightening ($U=5344$, $r=0.15$, $p<0.05$) and less likely to find them uninteresting ($U=5754$, $r=0.14$, $p<0.05$). Female tourists were more likely to find eruptions frightening ($U=8160$, $r=0.20$, $p<0.001$). Residents in Iceland who were originally from Europe were slightly more likely to think that eruptions are less important in Icelandic history ($H=10.0$, $\eta^2=0.03$, $p<0.01$). Across the entire dataset, retired people were slightly more likely to find eruptions frightening ($H=10.1$, $\eta^2=0.01$, $p<0.05$).

Women were more likely to experience fear ($H=25.44$, $\eta^2=0.04$, $p<0.001$), awe ($H=8.40$, $\eta^2=0.01$, $p<0.01$) and anxiety during eruptions ($H=18.05$, $\eta^2=0.03$, $p<0.001$). Tourists were also more likely to experience fear ($U=44414$, $r=0.37$, $p<0.001$), awe ($U=39100$, $r=0.23$, $p<0.001$), excitement ($U=39942$, $r=0.24$, $p<0.001$) and anxiety during eruptions ($U=43369$, $r=0.33$, $p<0.001$). Those who had witnessed eruptions were generally less likely to experience fear ($U=19889$, $r=0.29$, $p<0.001$) and anxiety ($U=22515$, $r=0.21$, $p<0.001$). People who had lived in Iceland a long time were less likely to experience excitement ($\rho=0.25$, $p<0.001$),

In general, witnessing an eruption does seem to be linked to regarding eruptions as important and significant for culture and history, again suggesting that experience of an eruption affects how people think.

People who did not find the IMO information about Holuhraun very interesting also tended to find volcanoes uninteresting ($\rho=-0.17$, $p<0.001$). Conversely, finding IMO information interesting correlated with thinking volcanoes are important in culture ($\rho=0.26$, $p<0.001$) and history ($\rho=0.31$, $p<0.001$) and that eruptions are exciting ($\rho=0.25$, $p<0.001$). People who felt that they understood the IMO information also tended to have these views, and there was strong cross-correlation between them too (as well as negative correlations with the “not interesting” variable). These results are not surprising, but do show consistency between responses. Students were a bit less likely to find eruptions frightening ($H=7.9$, $\eta^2=0.01$, $p<0.05$), and this was not associated with an effect for age.

These results suggest that people who seek out eruptions think they are important and exciting. Lack of significance for tourists on the last two might mean that they just have not been able to witness but would like to – there were a number of comments to this effect.

There was rich qualitative data on the relationship between volcanism, history and culture in Iceland, and we have space only for a brief discussion here.

The volcanic activity is part of our national language. (Icelander)

Volcanic eruptions have shaped the land and greatly influenced human life. (Icelander)

Have shaped our country, not just geographically but socially as well. Are an important part of our past and future. Volcanic eruption is part of living in Iceland, it is Iceland's specialty, living with ice and fire, and has a cultural impact. (Icelander)

Exciting living in a living country. (Icelander)

These responses show the ease with which Icelanders are able to talk about volcanism as a part of the human world. It is not merely external, but it is something that has impacted and continues to impact upon the creation of the social, through encounters with an active landscape. Tourists also reflected on this.

I think that Icelanders have a culture of ephemera, they know that things can disappear and it is useless to fight against. (Tourist)

Natural disasters breed a deep resilience and sense of community within a population along with a deep connection with the land. (Tourist)

There were also numerous references to the need for Icelanders to co-exist with the volcanoes.

They spice up existence and unite the people. (Icelander)

486 *This teaches us to respect and appreciate the forces of nature. Nature is stronger than we,*
 487 *fortunately. (Icelander)*

488 *Teaches us to respect nature and stop self-pity. Volcanic eruptions have perhaps taught us to respect*
 489 *the forces of nature. It must always be a part of life with advantages and disadvantages just like the*
 490 *ocean. (Icelander)*

491 *Nature shows us... what matters in life. (Icelander)*

492 *Iceland and its people are very close knit society, always helping each other out, they have to be to*
 493 *keep one step ahead, if an eruption happens and it say damages a family home or they can't farm*
 494 *because of ash, gas emissions etc, the whole community then makes sure that family or families are*
 495 *taken care of and helped out until they can either go back to their home and farm, or job. (Tourist)*

496 Tourists in particular mentioned the economic benefits of volcanism too.

497 *The ash is extremely important for agriculture. Icelandic people tend to respect physical nature and*
 498 *geography more than most others, because volcanoes are such a normal part of their lives. They also*
 499 *know how to avoid taking risks and being safe around volcanoes. They are more attuned to the*
 500 *geologic forces around them, day by day. (Tourist)*

501 *Having touched lava, having seen how devastating it can be - and at the same time how fertile a soil*
 502 *can become afterwards I think the eruptions are an important part of Iceland - good and bad! People*
 503 *and animals dying, making life difficult - and at the same time making Iceland unique, having*
 504 *thermal spots....it is a very eerie mixture of good and evil. (Tourist)*

505 The creation of culture through the earth comes through strongly in these responses.

506 [Eruption impacts](#)

507 For the variables about the impacts of eruptions, there were numerous significant differences
 508 between tourists and residents (Figure 4). Tourists tended to think income from tourism was more
 509 important ($U=52722$, $r=0.50$, $p<0.001$). Residents felt that giving access to the site was a bit less
 510 important ($U=39412$, $r=0.14$, $p<0.001$). They also regarded protecting livelihoods (other than
 511 tourism) as less important ($U=41395$, $r=0.24$, $p<0.001$) but protecting the aviation industry as more
 512 important ($U=29307$, $r=0.13$, $p<0.01$). Students tended to think this was not important, while retired
 513 people and homemakers thought it was ($H=12.6$, $\eta^2=0.02$, $p<0.01$).

514 Women tended to view keeping people safe as more important ($H=24.9$, $\eta^2=0.04$, $p<0.001$) and
 515 protecting their health ($H=23.3$, $\eta^2=0.04$, $p<0.001$). They also had a slightly higher rating for
 516 protecting property ($H=4.0$, $\eta^2=0.01$, $p<0.05$) and livelihoods ($H=5.0$, $\eta^2=0.01$, $p<0.05$). Men rated the
 517 importance of good photos more highly ($H=5.78$, $\eta^2=0.01$, $p<0.05$) and also thought it more
 518 important for people to be able to see the site ($H=20.1$, $\eta^2=0.04$, $p<0.001$).

519 In general, women are more interested in safety, while men are interested in viewing the eruption
 520 and capturing it on camera. Precaution has been observed to be gendered in previous studies too.

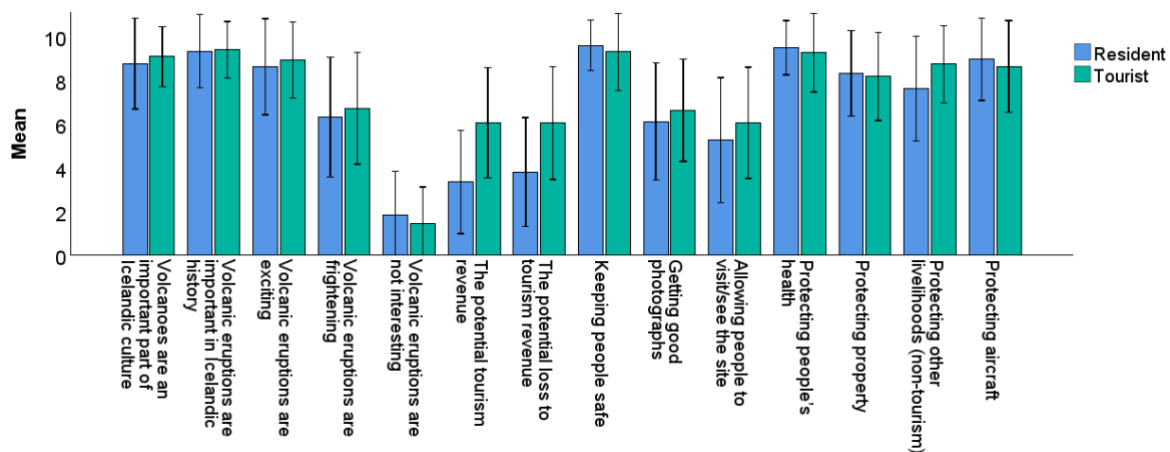


Figure 4 Comparison of tourist and resident responses to the culture and impact variables. Error bars show the standard deviation.

People who had seen an eruption were less likely to worry about the potential tourism income ($U=24384$, $r=0.20$, $p<0.001$). Older people tended to worry about aviation ($p=0.15$, $p<0.001$). People who had visited Iceland a lot were keen that sites be open to the public ($p=0.22$, $p<0.001$). They were also less worried about keeping people safe ($p=-0.21$, $p<0.001$) and protecting health ($p=-0.22$, $p<0.001$). People who find eruptions exciting tended to value photographs ($p=0.26$, $p<0.001$) and visiting the site ($p=0.21$, $p<0.001$), while those who find eruptions frightening tended to value keeping people safe ($p=0.17$, $p<0.001$) and protecting health ($p=0.22$, $p<0.001$) and property ($p=0.12$, $p<0.01$), and other livelihoods ($p=0.16$, $p<0.001$). Concern about tourism income potential ($p=0.217$, $p<0.001$) and loss of income ($p=0.17$, $p<0.001$) was felt by those who were interested in business in general. There was considerable ambiguity around allowing visits – this is shown in supplementary data.

Given the cross-correlations in the datasets mentioned in this section, factor analyses were carried out separately for the impact variables and identified three factors that explained 72% of the variance ("safetyfirst", "tourism" and "sightseeing"). Factor analysis used a direct oblimin rotation because it was likely that the factors were correlated. The factors were saved for further analysis with other variables.

	SAFETY FIRST (36% VAR)	TOURISM ECONOMICS (22% VAR)	ACCESS (14% VAR)
TOURISM REVENUE		0.88	
TOURISM LOSSES		0.90	
KEEPING PEOPLE SAFE	0.85		
GOOD PHOTOGRAPHS			0.85
ALLOWING ACCESS			0.84
PROTECTING HEALTH	0.87		
PROTECTING PROPERTY	0.80		
PROTECTING OTHER LIVELIHOODS	0.71		

Table 3. Factor analysis results, showing the factor loadings for different variables and their separation into the three underlying factors.

In general, people who had lived in Iceland a long time tended to put safety first ($p = 0.18$, $p < 0.01$). People who thought access important tended to have visited Iceland a lot in the last 10 years ($p = 0.23$, $p < 0.001$).

Tourists gave higher ratings for all four of the emotion variables, fear ($U=44414$, $r=0.37$, $p < 0.001$), anxiety ($U=44369$, $r=0.33$, $p < 0.001$), excitement ($U=39942$, $r=0.24$, $p < 0.001$) and awe ($U=39100$, $r=0.23$, $p < 0.001$). Women were also more likely to experience fear ($H=25.44$, $\eta^2=0.05$, $p < 0.002$) and anxiety ($H=18.05$, $\eta^2=0.03$, $p < 0.001$). It is noteworthy that having a high rating for “fear” and “anxiety” did not preclude having high ratings for “excitement” and “awe” – this reflects the complexity of the experience. It is not simply the case that some people were frightened and others were excited – plenty of people were both at the same time. This is consistent with the experience that the concept of the “sublime” encapsulates.

The non-health impacts of the volcanoes themselves were further described in qualitative responses. Five people mentioned the importance of geothermal energy in Iceland and internationals commented on it as “inspirational”. There were 49 specific comments about managing tourism, particularly during eruptions but also more generally in the Icelandic environment. Comments from tourists tended to state that they “felt safe” in Iceland relative to other countries that they had visited with active volcanoes. There were also a number of comments from internationals and a few from Icelanders who felt that the eruption site at Holuhraun should have been more open for visits by tourists.

I think volcanic eruptions are currently viewed by the Icelanders as more of a hazard to be taken seriously by tourists than as an opportunity for tourism. A balance between both would be better. (Tourist)

Others commented on the need for tourists to behave more responsibly. This came from both Internationals and Icelanders. Some Icelanders put the growth in tourism since 2010 as down to the volcanic eruptions, and recognised that this was both beneficial and problematic:

We must always let the impending danger be weighed more than any profit aspect discussed in evacuation, but we must also give the public the opportunity to view volcanoes as was done at Fimmvörðuháls but not block traffic as was done in Holuhraun, but of course it is important to record personnel in and out of adjacent areas to respond if something changes... Volcanic eruptions I've seen up close are some of the most amazing experiences I've experienced in nature, and we also need to allow travellers to experience volcanic eruptions.

This quote sums up the tension that is inherent within and between many responses.

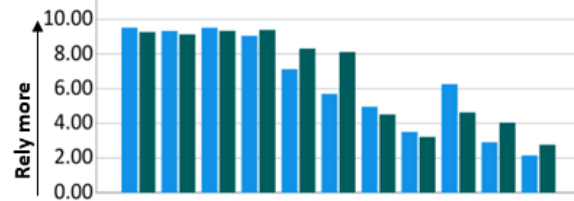
Trust in institutions and other groups

The next set of variables asked about the participants’ belief about the capabilities and motives of different groups (Figure 5). Overall, scientists, civil protection, ICE-SAR and IMO were generally regarded in a positive light. Tourists were generally more likely to rely on scientists, the Icelandic government and tourist companies to keep people safe, while Icelandic residents tended to be more trusting of friends and family and social networks. The results for tests between tourists and residents that were significant are given in the supplementary data.

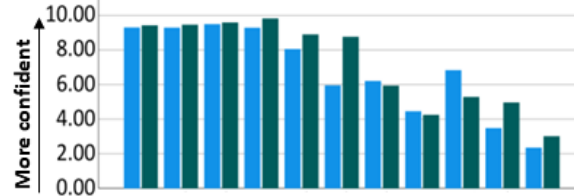
583 There are persistent differences here, with residents having a more positive view of friends and
584 family than tourists – and a more negative view of the national government, tourist agencies and
585 foreign tourists.

article in press

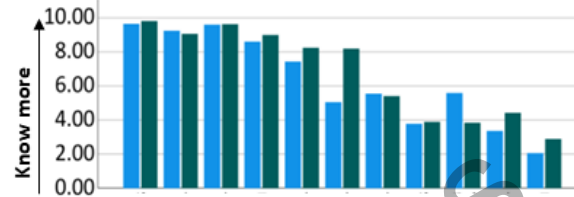
If there is an eruption, how much do you rely on the following groups to keep people safe?



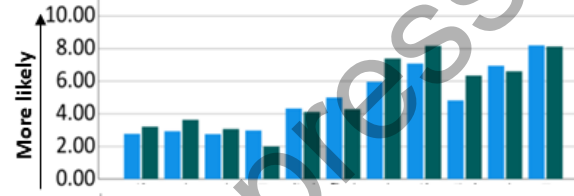
If there is an eruption, how confident are you that the following groups will respond wisely?



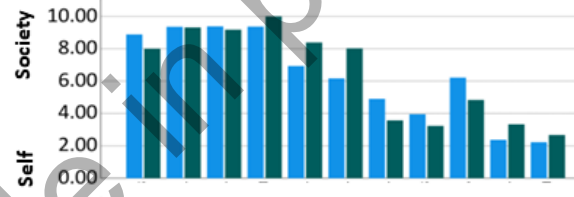
How much do each of the following groups know about volcanic eruptions?



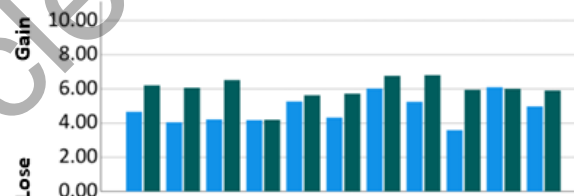
During an eruption, to what extent are the following groups likely to under/overestimate the danger?



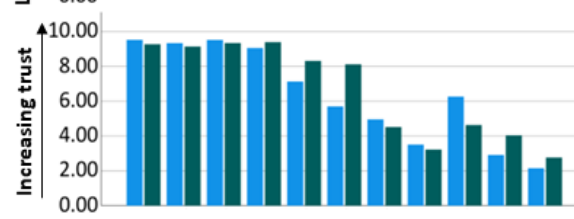
During an eruption, to what extent do the following groups serve their own interests rather than those of society as a whole?



How much do each of the following groups lose or gain as a result of volcanic eruptions?



How much do you trust each of the following groups to make good decisions about volcanic activity?



Residents
Tourists

Scientists
The civil protection
The IMO
ICE-SAR
The local government
The national government
The news media
Social networks
Your own friends and family
Tourist agencies
Foreign tourists

Figure 5. Comparison of mean scores for perceptions of different groups by residents and tourists. Standard deviations are not shown for clarity of the figure, but may be found in the supplementary data.

The dataset was split and further predictors were examined. There were differences between the genders, with women more likely to rely on the civil protection and IMO among both tourists and residents, while female residents were also more likely to rely on ICESAR.

The variable sets here – reliance, wisdom, knowledge, accuracy, altruism, profit and trust – were combined in a regression analysis to predict trust in the two groups (tourists and residents).

With the exception of the loss/gain variable, all of the others had Cronbach's alpha > 0.8 for the official sources, so new variables were calculated, taking the mean of scientists, civil protection, IMO, ICE-SAR and governments.

The other groups were considered separately because of the significant differences between them.

Official sources	Residents				Tourists			
	β	t	sig	R ²	β	t	sig	R ²
Knowledge	0.52	10.94	<0.001	0.42	0.48	9.14	<0.001	0.42
Altruism	0.29	6.10	<0.001	0.07	0.37	6.99	<0.001	0.11

Table 4. Regression results for trust in the decisions of official sources

For trust in the decisions made by official sources, the two variables that were useful predictors were perceived knowledge and perceived altruism (ie that these groups are serving society's interests). There were no measurable effects of people's views about whether or not tourists should be allowed access to the site or any of the other variables.

Trust in social networks (Table 5) was also slightly different between the two groups, though knowledge was again the dominant factor. However, tourists linked their own reliance on social networks to trust, while residents tended to trust the networks if they thought they had responded wisely.

News media	Residents				Tourists			
	β	t	sig	R ²	β	t	sig	R ²
Knowledge	0.49	10.22	<0.001	0.42	0.31	4.15	<0.001	0.04
Response					0.32	4.24	<0.001	0.45
Altruism	0.36	7.53	<0.001	0.11	0.30	5.84	<0.001	0.09

Social networks	Residents				Tourists			
	β	t	sig	R ²	β	t	sig	R ²
Knowledge	0.48	7.62	<0.001	0.50	0.38	5.64	<0.001	0.40
Response	0.21	3.21	0.002	0.03				
Altruism	0.15	2.88	0.004	0.02	0.29	5.26	<0.001	0.07
Dependence					0.23	3.61	<0.001	0.03

Friends and family	Residents				Tourists			
	β	t	sig	R ²	β	t	sig	R ²
Knowledge	0.36	5.82	<0.001	0.35	0.26	3.58	<0.001	0.04
Response	0.30	4.80	<0.001	0.08	0.46	6.25	<0.001	0.40
Altruism	0.20	3.85	<0.001	0.04				

610

Tourist agencies	Residents				Tourists			
	β	t	sig	R ²	β	t	sig	R ²
Knowledge	0.25	3.80	<0.001	0.03	0.35	5.02	<0.001	0.40
Response	0.34	5.23	<0.001	0.36	0.31	4.33	<0.001	0.08
Altruism	0.23	4.08	<0.001	0.06	0.20	3.56	<0.001	0.03

611

Foreign tourists	Residents				Tourists			
	β	t	sig	R ²	β	t	sig	R ²
Knowledge	0.23	3.83	<0.001	0.03	0.40	6.44	<0.001	0.44
Response	0.32	5.28	<0.001	0.31	0.28	4.45	<0.001	0.04
Altruism	0.26	5.14	<0.001	0.09	0.24	4.84	<0.001	0.07

612

Table 5 Regression results for non-official information sources

613

In general, people tend to trust groups based on their perceived knowledge, although perceived

614

altruism is also clearly important. They also depend upon the groups that they trust and consider

615

would respond wisely. Regression analysis of the dependence of people on official sources gave the

616

results shown in Table 6.

Official sources	Residents				Tourists			
	β	t	sig	R ²	β	t	sig	R ²
Response	0.64	12.91	<0.001	0.60	0.53	8.60	<0.001	0.53
Trust	0.20	4.01	<0.001	0.03	0.30	4.84	<0.001	0.05

617

Table 6. Regression results for reliance on official sources.

618

Anticipatory actions and warnings

619

The survey contained a number of statements about warnings and precaution.

620

Residents were more likely to think it is important to warn people ($U=21845$, $r=0.31$, $p<0.001$) and to

621

disagree that 'warnings that turn out to be unnecessary do more harm than good' ($U=39634$, $r=0.19$,

622

$p<0.001$). They tended to feel more strongly that in the event of any risk, the public should be

623

warned ($U=22912$, $r=0.27$, $p<0.001$), whereas tourists were more likely to agree that 'if too many

624

warnings are given, people stop taking them seriously' ($U=41197$, $r=0.24$, $p<0.001$). Tourists were

625

also more likely to think businesses should be protected from the effects of warnings ($U=39817$,

626

$r=0.20$, $p<0.001$). Together, these results suggest that residents were generally in favour of warnings

627

being issued, and less concerned about false alarms. Men were more likely to think that 'warnings

628

that turn out to be unnecessary do more harm than good' ($H=7.93$, $\eta^2=0.01$, $p<0.01$).

629

In terms of anticipatory actions that people might take, people who had witnessed an eruption were

630

a little more likely to think they could escape from one ($U=33974$, $r=0.11$, $p<0.05$) and to think

631

forecasting is relatively easy for scientists ($U=26707$, $r=0.13$, $p<0.01$). People with postgraduate

632

degrees were slightly less likely to check the IMO website before a hike ($H=10.26$, $\eta^2=0.01$, $p<0.01$).

633

Men were more likely to think they could escape ($H=10.39$, $\eta^2=0.01$, $p<0.001$). Tourists were more

634

likely to think about chances of eruption during a hike ($U=36700$, $r=0.12$, $p<0.01$), more likely to

635

check the IMO website ($U=36391$, $r=0.13$, $p<0.01$) and less likely to listen to television or radio for

636

alerts ($U=24772$, $r=0.17$, $p<0.001$). Residents were more likely to say that they didn't think about

637

whether they were hiking on a volcano or not ($U=24249$, $r=0.18$, $p<0.001$) and think that forecasting

638

an eruption is challenging ($U=40280$, $r=0.20$, $p<0.001$). People who had lived in Iceland a long time

639

were more likely to think an eruption wouldn't happen ($\rho=0.25$, $p<0.001$). Older people were

640 more likely to use TV or radio to listen for alerts ($\rho=0.13$, $p<0.01$). People who had visited Iceland
641 many times were more likely to think they could escape ($\rho=0.21$, $p<0.01$) and to view forecasting
642 as relatively easy ($\rho=0.18$, $p<0.01$).

643 There were also comments about eruption management:

644 *I found it great to be able to post questions on Facebook, and our scientists answered us, and at the*
645 *same time we experienced strong fires, and I found it amazing what the scientists wanted to answer*
646 *and put pictures of the scene when they were at the fire. thank you for that.*

647 *I want access to volcanic eruptions not to be restricted as the development of recent years has been.*
648 *Prohibiting people from experiencing these disasters is not a good development and a sign of modern*
649 *day care. But that said, some volcanic eruptions are naturally not for tourists and tourists even*
650 *though we have been able to escape incredibly well over the last few decades, when larger volcanoes*
651 *arrive at a point and then they can close and pray.*

652 *Do not prevent people from experiencing volcanic eruptions, rather informing them where to go and*
653 *seeing them as safe and secure.*

654 *Would like to see plans for escape routes where the greatest risk is. This is an island and cannot*
655 *escape far.*

656 *(Icelanders)*

657 These comments from Icelanders show awareness of the risk, but also a desire to have access to the
658 eruption when that is possible.

659 *We had the privilege to be able to have a long conversation with an active SARTech and I was able to*
660 *compare my own emergency response approach and training with his. It is a very impressive system*
661 *that needing to respond to many situations, only one of which is volcanism.*

662 *The population need to understand and know when to react to eruption warnings.*

663 *The people of Iceland live with this every day and need to know what the risks are. I hope your*
664 *country will be still colourful after every eruption. That no people get hurt! And that you keep the*
665 *laws as previous, only photographer and scientist are able to go further to a volcano.*

666 *I think volcanic eruptions are currently viewed by the Icelanders as more of a hazard to be taken*
667 *seriously by tourists than as an opportunity for tourism. A balance between both would be better.*

668 *Icelanders respect volcanos, they have experience - how to monitor, what to do etc. So, as a tourist i*
669 *know, that they will do all the best to warn and protect people. More money should go to research.*

670 *I think the Icelandic people have a very good attitude towards the possibility of eruption; calm and*
671 *careful and watchful. I would feel fairly safe from sudden eruption travelling anywhere in Iceland*
672 *because the Icelandic people would make sure we were OK and well-informed.*

673 *(Internationals)*

674 These comments from tourists share their perception not only of Icelandic relationships with
675 volcanoes, but also the respondents' confidence in the ability of Iceland to manage its hazards. As all
676 the comments demonstrate, there is a range of opinions about access and the challenges of
677 protecting the population from volcanic hazards.

Discussion

Information sources

The survey results demonstrate that people visiting the IMO website during 2017 had used a wide range of sources to get information about the Holuhraun eruption. These ranged from official sources such as IMO and Almannavarnir (Civil Protection) to the blogs and Twitter (now known as X) accounts of both Icelandic and foreign scientists – some of whom were working as volcanologists but others were not. There were also references to the Twitter accounts of photographers and science writers.

In general, the most valued sources of information were those provided by scientists, but people following the eruption from overseas used a broader range of sources, including blogs by prominent geoscientists. People in Iceland were more likely to use news media sources such as RUV. This partly reflects a lack of reporting outside of Iceland much of the time, but it also reflects the proliferation of popular science blogs in the geosciences. Volcano Café was one example. Others were blogs by faculty in the US. This reflects a growing tendency for people to gain their information from unofficial sources of scientific information, and this seems to be based on perceived knowledge. What is not clear from these data is how people assess whether or not a particular source is knowledgeable, beyond reading the websites. This also raises ethical questions around the potential for differences between official and unofficial sources of information, where that information pertains to risk management.

Official information sources, such as the civil protection and volcano observatories, may have restrictions on what and how they communicate and when. However, they also arguably have the most holistic view of the situation, and the most available data for assessment of it – as well as experience in detailing with volcanic eruptions. They may also have legal responsibilities. Their purpose in providing information also differs from that of unofficial sources. Unofficial sources may have a range of motivations for their work, and it is often more accessible – particularly through the algorithms that generate social media feeds and because it may be written in a more informal and journalistic style. This presents several challenges – some to observatories and those who provide them resources, underscoring the importance of proactive outreach – but also to the wider community in terms of the ethics of risk communication and how to do it in a way that enhances rather than contradicts official messaging (Stovall et al., 2023). Tourism and volcanic eruptions

The primary goal in the quantitative analysis was to investigate the differences in perception between residents of Iceland and international tourists. There were substantial differences between these two groups, reflecting the more directed interest of the tourist groups in visiting a geologically active country. Tourists consistently tended to be more interested in volcanic eruptions and experience stronger emotions in relation to them. They also tended to be more concerned about the tourism sector in general. Icelanders were more ambivalent about this – some felt strongly that the sector needed protection, but others felt that it received too much attention and led to a lack of safety. This is consistent with research on the sustainability of tourism in Iceland (Helgadóttir et al., 2019; Sæþórsdóttir et al., 2020)

Tourists themselves typically felt safe in Iceland, even when visiting eruption sites. There was frustration about the eruption of Holuhraun not being accessible – although other respondents did

understand the rationale for this. Almost everyone who responded had been aware of the eruption at Holuhraun, and some had visited it. There were also some who had been concerned about the eruption impacts in terms of gas pollution and agriculture, consistent with work on these topics (Carlsen et al., 2021a; Ilyinskaya et al., 2017).

Culture and experiencing the active earth

Respondents – both Icelanders and tourists – related the geological activity to Icelandic culture in many cases. They described feelings of elation in experiencing eruptions, consistent with descriptions of “the sublime” in nature (Ashfield and De Bolla, 1996; Bell and Lyall, 2002; Donovan, 2018) as holding together feelings of fear and excitement. These experiences were also associated with the motivation to learn – to gain knowledge through this experience, or encounter, with active nature.

Respondents were also very interested in the long-term interaction between the active earth and Icelandic culture. Icelanders expressed a clear recognition that their own culture has evolved in close dialogue with the volcanic activity of the island – and in many ways depends upon it. While tourists sometimes put this in economic terms, Icelanders were much more likely to express it in terms of what “nature teaches us” and the formation of national identity, or as one person put it, “the national soul”. They also recognised that the volcanoes literally built the island, and so they are dependent on them.

Both Icelanders and tourists linked Icelandic volcano culture to the resilience of Icelanders. Several tourists emphasised how safe they felt in Iceland because they knew and trusted the Icelandic authorities to protect them. Icelanders used language of dealing with volcanoes and having to learn to manage an extreme environment more generally.

The data show that there is a second tension between volcanic eruptions as spectacle – accessible for tourist industries (economic importance), and for residents to experience something that they may feel is a right linked to their identity – or for tourists to experience something that they feel is formative for them – and volcanic eruptions as inherently risky. The tension has to be navigated by civil authorities in relation to the hazard levels, which may include invisible hazards such as gas emissions (as has been the case in the Reykjanes Fires, for example; (Barsotti et al., 2023), and require careful attention to the safety of emergency service personnel.

As well as the visual and auditory spectacle of eruptions in general, respondents (especially residents) did also refer to volcanic gas hazards as presenting physical or visual impacts even in distal areas. This included having to take actions to mitigate the hazard (such as wearing masks or closing windows) or experiencing human or animal health impacts (Carlsen et al., 2021b). While 44 of these referred to “minor” impacts from the gas, a few respondents did refer to more substantive health problems. These tended to be people who also noted that they suffered from asthma. The general level of awareness of the gas was relatively high, as demonstrated by the widespread use of the gas forecast provided by IMO. Furthermore, the gas was related by several respondents to various visual disturbances during the eruption, including hazes and reduced visibility, which itself could be hazardous, as well as the more aesthetically pleasing perceived effect of the gas on sunsets. Again, the sensory experience of the eruption is both positive and negative. Figure 6 sums up the two key tensions discussed here – that between experiences of an eruption and that between sources of information.

Trust and precautionary decision-making

The regressions demonstrated clearly that trust in official sources was related to their perceived knowledge and their perceived service to society, rather than on respondents' views about access to the eruption site or eruption impacts. This is an important result, because it suggests that while there is politics around access and tourism – and many respondents felt very strongly about it – their trust was not dependent on whether they got their own way about accessing the site or not.

The differences between Icelanders and tourists in trust – particularly that Icelanders tended to trust friends and family more and national government (ie politicians) less – are consistent with earlier studies (Eiser et al., 2015). Given the higher level of popular knowledge of volcanism in Iceland and the potential for people to have friends and family living in the areas around volcanoes, this is not particularly surprising. This does contrast with work elsewhere, which shows that people often do not trust friends and family in relation to volcanic risk (e.g. Donovan et al., 2023b).

Residents were more likely to regard warnings as important in spite of the possibility of false alarms: again, this is consistent with previous work. There were a number of comments backing this up, and emphasising the importance of repeating warnings and informing people not only of the volcanic activity but about exactly what they should do in the event of an eruption. The long-term experience of Icelandic residents is critical here: it demonstrates that populations with a lot of knowledge and experience may be more likely to understand and accept that so-called false alarms may be a justified side-effect of managing uncertain hazards (Eiser et al., 2012; Hincks et al., 2014). This in turn suggests that proactive outreach with communities even in periods of low volcanic activity will enhance relationships and trust even if there are “false” alarms in the future – and, indeed, may mitigate the effect of misinformation. This is also consistent with work in other locations (Goldman et al., 2024; Mani et al., 2024).

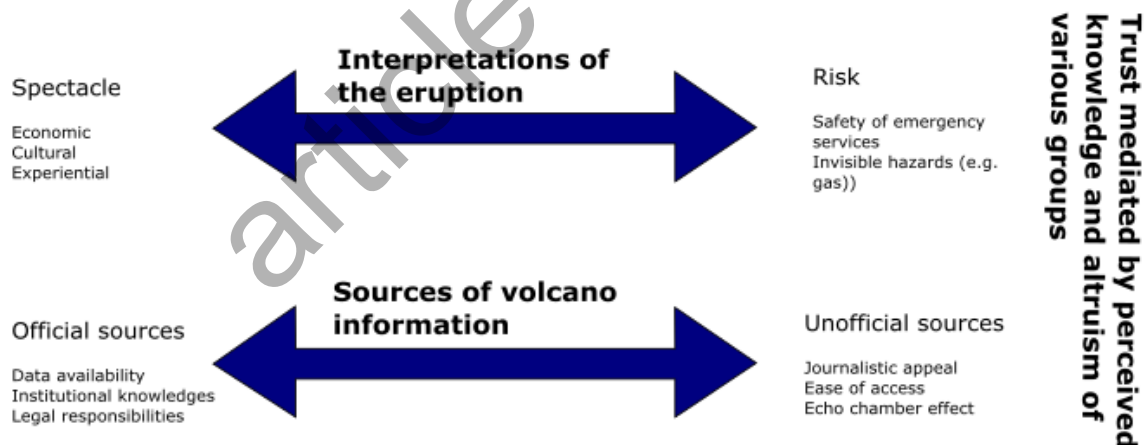


Figure 6. Summary of the findings in this paper: there are tensions inherent between interpreting the eruption primarily as a risk and interpreting it primarily as a spectacle. There are also tensions between the use of official sources of information and those that may be easier to read and access, but that are not carrying official messages.

Overall, the data show that community relationships with volcanism are complex in ways that are specific to volcanoes as a hazard: the spectacle and cultural significance of eruptions can be significant. While this may add to the complexity of risk management (Langridge and Michaud,

2023), it also highlights that there are multiple visions of what volcanoes are and mean to the people that live on them: they are not purely “risks”, but also contribute to communities in a wide range of ways, including as resources (Erfurt-Cooper and Cooper, 2010; Kelman and Mather, 2008) but also as sources of social identity and powerful emotive experiences that enhance people’s lives and inspire them.

Conclusions and limitations

Since the Holuhraun eruption, Iceland has experienced the Reykjanes Fires (2021-), and another scenario in which tourists have been given access at some times and not at others. The need for careful management of this has been raised in several papers about those eruptions, too (S. Barsotti et al., 2023; Langridge and Michaud, 2023). Iceland’s growing and successful tourist industry remains in a state of dialogue with eruption management. In this paper, we show that even prior to the present eruptions, there was awareness in both resident and tourist populations of the trade-offs and challenges facing the authorities in Iceland. We also show the range of sources of information that have become the mainstay of both groups – and this points to a wider need within volcanology for discussion of communications around eruptions, particularly by those who are not part of nodal agencies.

The data here also demonstrate, however, that the experience of volcanic eruptions can be transformative and motivate people to find out more and educate themselves about volcanology and volcanic risk. Respondents clearly related the volcanism to Icelandic culture and resilience, and appreciated opportunities to ask questions of scientists during the eruptions.

This study took the form of an online survey, and was advertised via the IMO website. It is not representative of any particular population other than visitors to that website, but nevertheless captures a wide range of opinions and perceptions within that population. Future work could combine a repeat of this survey with interviews with stakeholders to investigate the findings further and evaluate changes since 2017.

Data availability

Due to the ethical approval procedures for this work (which predated the availability of repositories for this kind of data), the full dataset may be obtained with some redacted elements from the first author directly.

Author contributions

All authors contributed to the design and implementation of the survey; AD analysed the data and wrote the MS with assistance from SB.

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