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Multi-hazard and multi-risk assessment: The example of Iceland

7-9 July 2025 – EW4All workshop
Geneva

Grindavík, southwest Iceland
14 January 2024

Icelandic Met Office

ALMANNAVARNIR
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Sara Barsotti and Matthew J. Roberts, Icelandic Meteorological Office
Björn Oddsson, Department of Civil Protection and Emergency Management National Commissioner of the Icelandic Police (NCIP)

7-9 July 2025 – EW4All workshop
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The role of the Icelandic Meteorological Office

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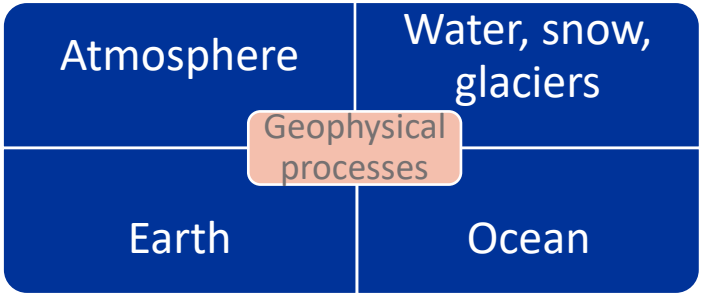
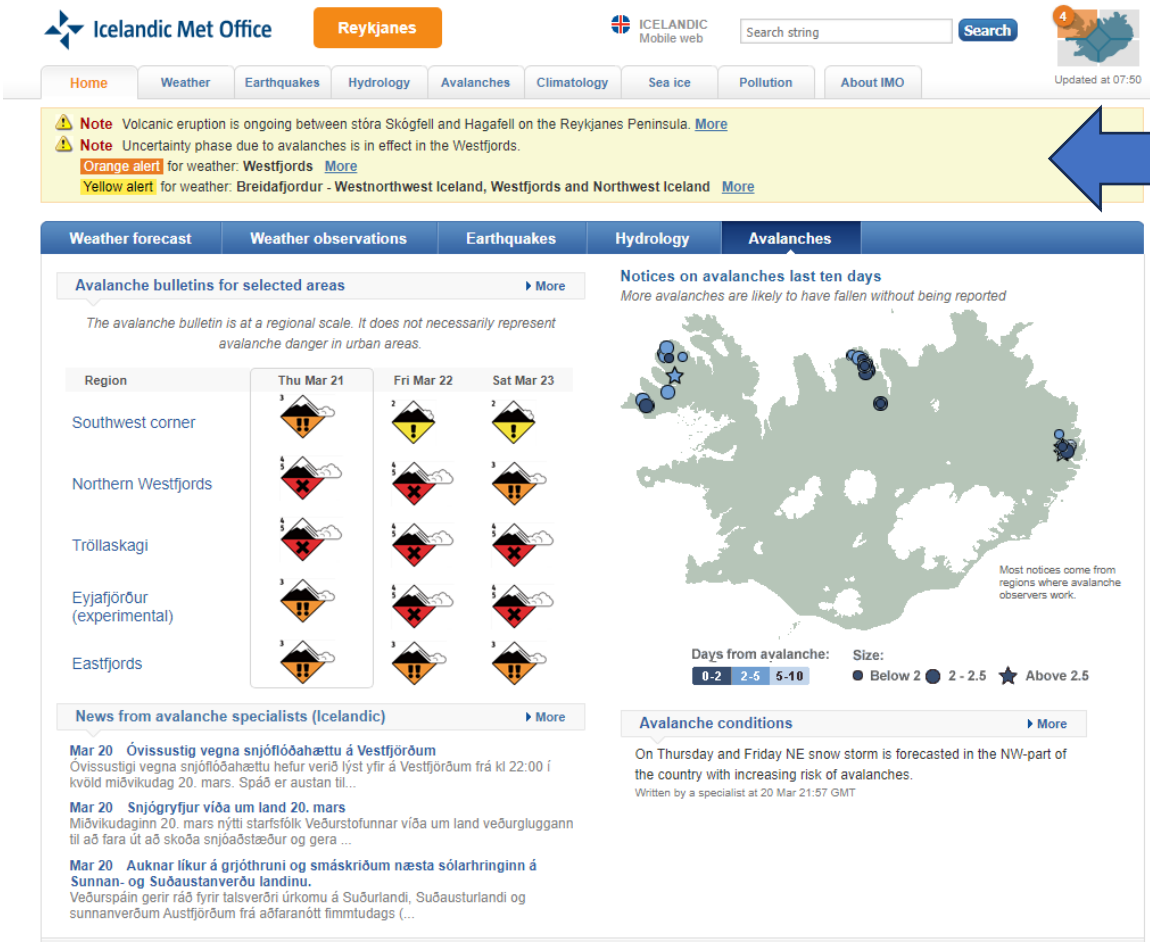
The main purpose of IMO is to contribute towards increased security and efficiency in society by:

- Monitoring, analysing, interpreting, informing, giving advice and counsel, providing warnings and forecasts and where possible, predicting natural processes and natural hazards.
- Issuing public and aviation alerts about impending natural hazards, such as volcanic ash, extreme weather and flooding



Natural Hazard Monitoring at IMO



In a normal (winter) day, Iceland can experience multiple hazards at the same time:

- **Severe weather warning**
- **Volcanic hazards associated with ongoing eruption**
- **Increased risk for avalanches**

The emergency response chain in Iceland

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IMO does not work alone!

During crisis time:

- **IMO** monitor, interprets, informs the general public and provides advice to NCIP
- **NCIP** alerts and activates evacuations/temporary exclusion zones plans*; manages information to/from stakeholders and the general public
- **Local police** manages the accesses on site and control areas (with the support of Environmental Agency)
- Other governmental agencies like, Directorate of Health Department (DHD), Environmental Agency of Iceland (EAI), take part to meetings and advice for health safety mainly regarding air quality issues

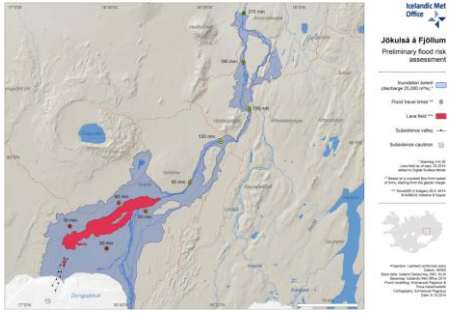
During quiet time:

- **IMO** monitor, interprets, maintains regular exchanges with NCIP (via bulletins, meetings, reports), practices contigency plans, reviews monitoring needs and capabilities
- **NCIP** plans for evacuation and response, maintains contacts and enganging key stakeholders (e.g. road authorities, electricity companies) and population

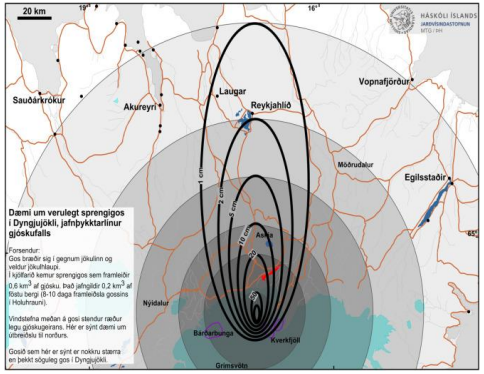
Eruptions are multi-hazard events

The case of Bárðarbunga eruption in 2014-2015 *

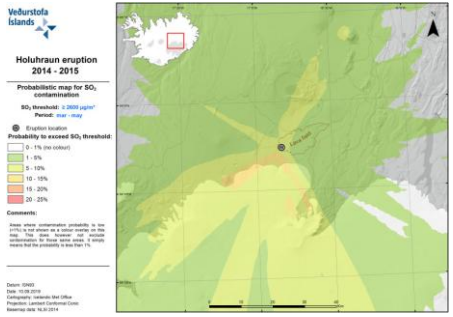
Flood inundation map from IMO



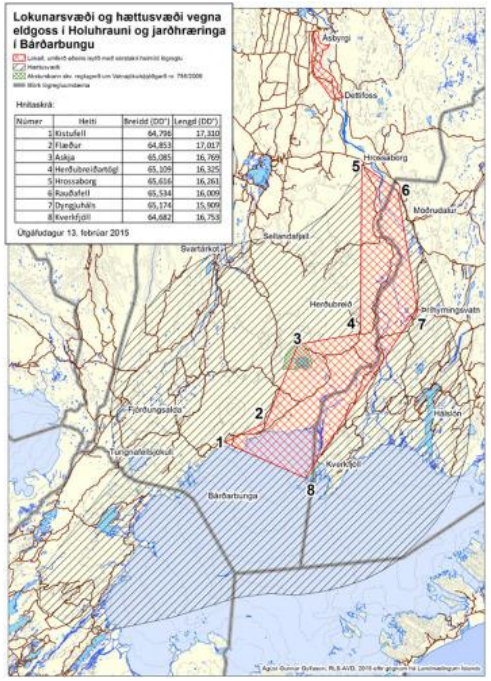
Tephra distribution map from Grímsvötn eruption from UI



Probabilistic **gas pollution** map from IMO



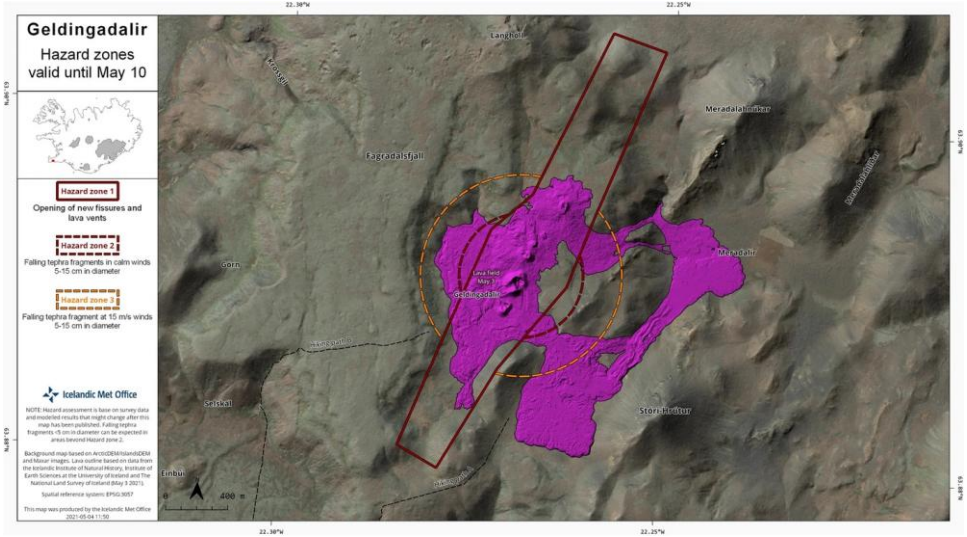
Exclusion zones and restricted areas defined by NCIP



(*) Barsotti et al. 2020, JVGR

Eruptions are multi-hazard events

The case of Fagradalsfjall eruption in 2021*

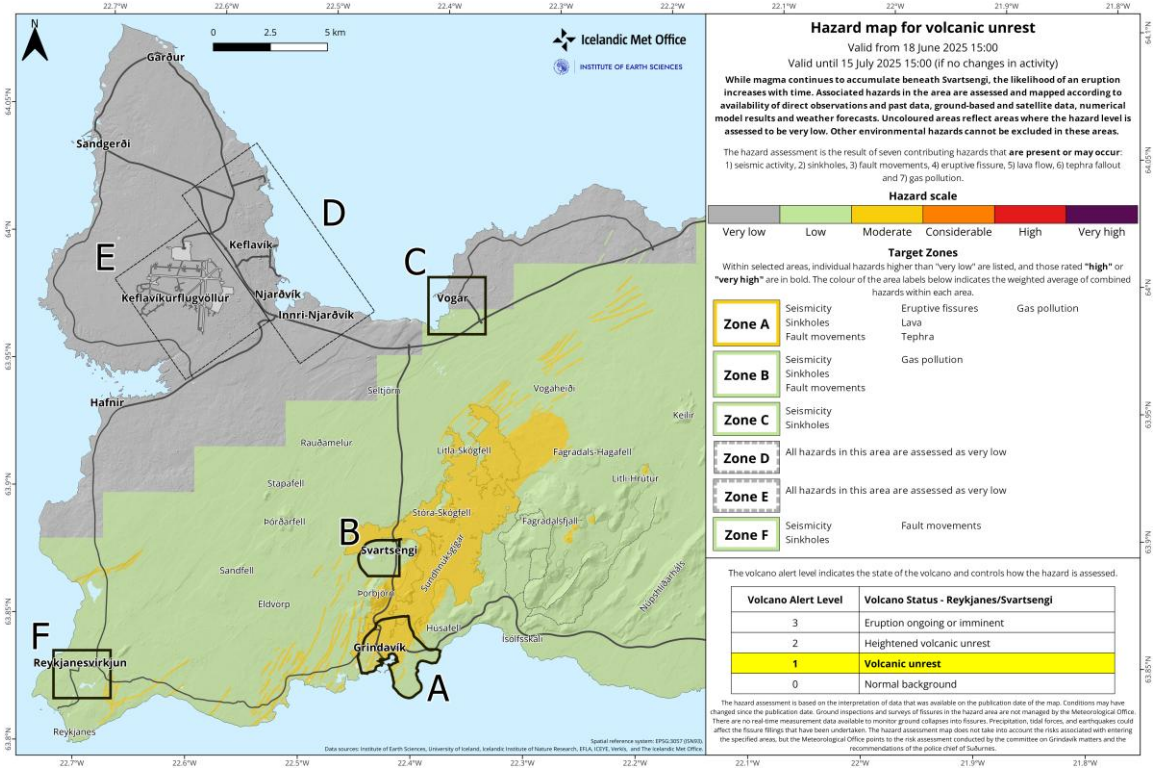


To allow safe access for tourists, hiking paths and view points were designed and built outside the hazard zone.

(*) Barsotti et al. 2023, NH

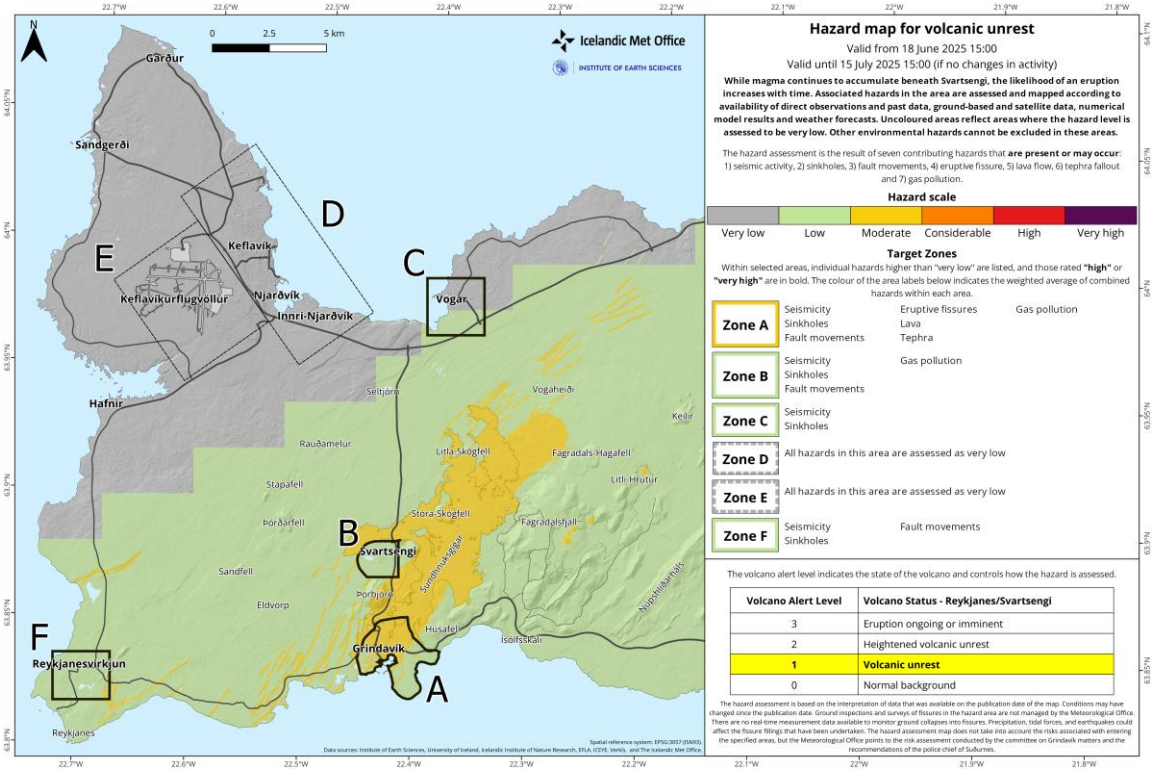
Eruptions are multi-hazard events

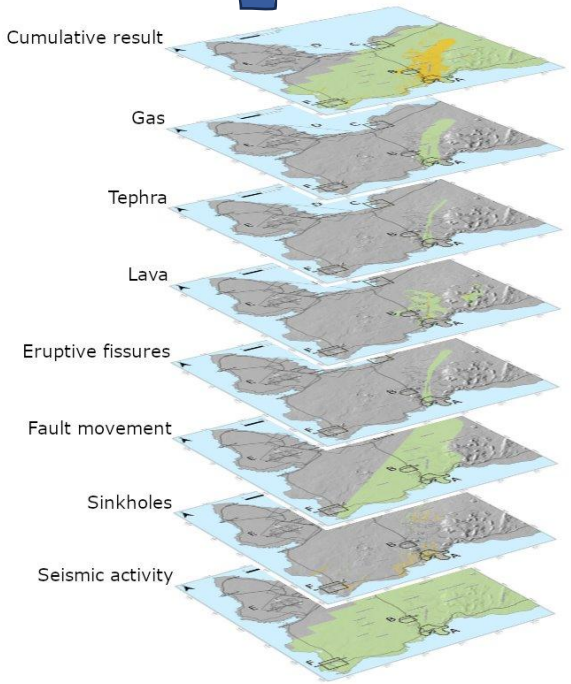
The case of Reykjanes fires (2023-ongoing).



Eruptions are multi-hazard events

The case of Reykjanes fires (2023-ongoing)*.





* See Parks et al. poster

Cascading events

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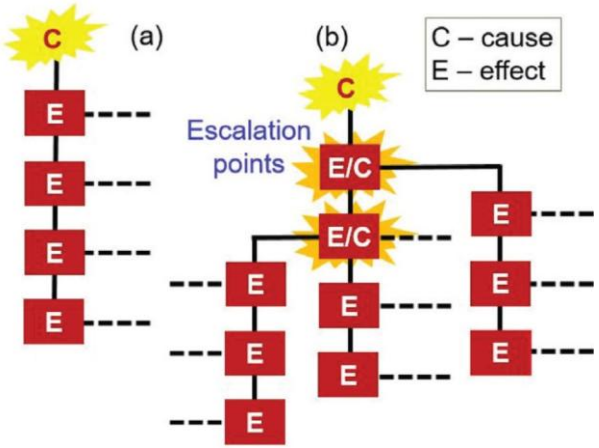
Linear and non-linear escalation of cascading natural hazards

- **Sub-glacial eruptions**
  - Formation of crevasses on glacier surface
  - Phreato-magmatic eruptions (ash and tephra)
  - Floods (jökulhlaup)
    - Tsunamis when a flood enters into the sea
- **Explosive eruptions**
  - Tephra fallout in the vicinity of the volcano
  - Potential for ash cloud transport over long distance
- **Landslides**
  - Causing tsunamis
  - Triggering eruption (if volcano edifice collapses)
- **Heavy precipitation, increasing temperature**
  - Changes in geothermal activity at ice-covered volcanoes
- **Lava flows**
  - In dry conditions may trigger wildfires



Cascading events

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Promoting synergy in the monitoring: some examples

- **Hydrological stations**
  - Inform about potential floods
  - Inform about increased conductivity which may indicate geothermal water leakages
- **Meteorological observations**
  - Radar is used for confirming the onset of an eruption, its location and the plume height
  - Satellite data can track position and extension of volcanic plume
  - Ceilometers/LiDARs can identify presence of ash layers in the atmosphere
- **Infrasound**
  - Can detect landslides/avalanches
  - Can detect the onset of an eruption and its position
- **GNSS stations**
  - Can identify ice-surface movement associated with the drainage of glacial water from cauldrons
  - Can identify deformation due to magma accumulation/drainage

Compounding hazards

When weather intensifies volcanic risk

- **Monitoring network sensitivity can be affected by severe weather conditions**
- **In some circumstances, the capability of detecting key volcanic processes (e.g. magma movements) is reduced**
- **Increasing the risk in the area (delayed warning, more complex evacuation procedures, additional hazards)**

IMO‘s news on 30 January 2025

New hazard assessment reflects increased eruption likelihood

The Icelandic Meteorological Office has updated the hazard assessment, which is now valid until February 11, barring any changes. It has been decided to raise the hazard level in zones 4 and 6 from “moderate” (yellow) to “considerable” (orange). This change is based on modeling calculations indicating that the volume of magma accumulating beneath Svartsengi is nearing the volume drop that occurred during the last event.

According to the weather forecast, severe weather is expected to occur in the coming days, beginning January 30 throughout the week. A southern storm accompanied by significant warming, rain, and drizzle is forecasted for southern and western parts of the country later this week and into the weekend. Adverse weather could reduce the sensitivity of the monitoring network, potentially delaying response times to an eruption.

Hiking paths closed today

The hiking paths are closed due to smoke and bad weather conditions

15.07.2023

Image: HÖrður

The Reykjanes Police authorities have decided to keep the hiking paths closed today.

Effects of climate change induced Ice-retreat on Seismic and VOLCanic activity

Icelandic Met Office

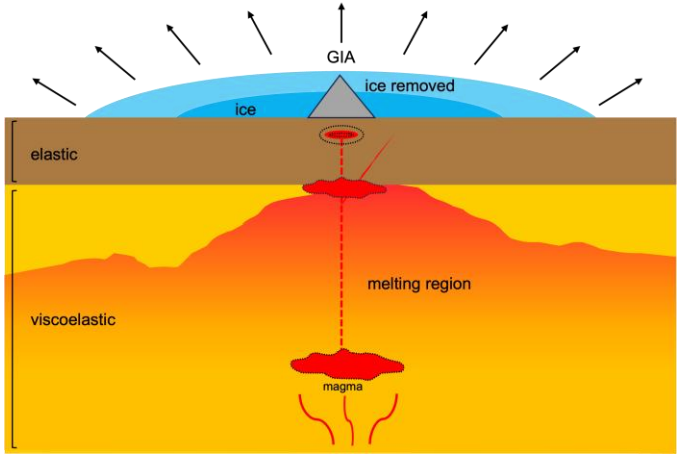
ISVOLC research project funded by the Icelandic Research Fund.
Project Leader: Michelle Parks (IMO)

- Glaciers have been retreating since 1890
- Climate change predictions indicate this will continue
- Volcanic activity increased during and shortly after the late Pleistocene deglaciation
- It is expected to be only a matter of time when deglaciation once again affects eruptive activity here – with the potential for more frequent or larger eruptions

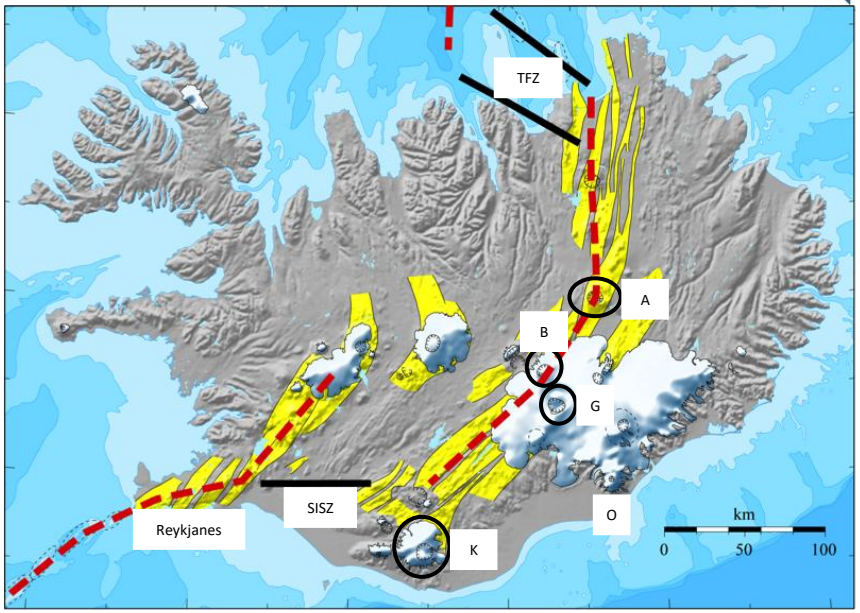
Skálafellsjökull 1989-2019. Photo: Kieran Baxter.

The ISVOLC hypothesis:

- That glacier mass loss is already producing excessive melt, affecting magma migration beneath Iceland, and stress changes are affecting the stability of existing magma bodies *
- The project focuses on key volcanoes and seismic zones in Iceland that serve as a natural laboratory for studying the effects of deglaciation on volcanism and seismicity to investigate potential volcanic hazards and eruptive scenarios**



Effects of deglaciation on volcanic systems.



ISVOLC study areas: Map of Iceland with glaciers (white) and fissure swarms (yellow), showing target areas: Katla (K), Askja (A), Grímsvötn (G), Bárðarbunga (B), Öræfajökull (O), South Iceland Seismic Zone (SISZ), Tjörnes Fracture Zone (TFZ) and Reykjanes.

** See Parks et al. poster

(*) Pagli and Sigmundsson, 2008, GRL

Good practices at IMO

In quiet times

- **Regular daily meetings with key stakeholders**
  - At 14.00 each day IMO personnel on duty held an information meeting for key stakeholders
  - All different monitoring groups (weather, avalanches/landslides, water, solid earth) present the current state and possible evolution
  - Questions are taken and summary of the meeting is distributed afterwards
- **Weekly reports on volcanic activity is sent to a large group of national and international people/institutions**
  - A review of the past activity in terms of seismic events, deformation, geochemical observations is provided
  - Once a month, a more detailed report is distributed containing the outcomes of the monthly long term meeting hold at IMO
- **Monthly exercise are practised**
  - Mainly in collaboration with the aviation community (ANSP, VAAC), occasionally participated by NCIP

Good practices at IMO

Icelandic Met Office

In crisis times

- **IMO organizes daily meetings with key emergency responders**
  - At 09.00 each day IMO personnel on duty held an information meeting with emergency responders reporting on the state of the eruption, evolution and potential hazards
  - Emergency responders report on accessibility in the area, mitigation actions, …
- **IMO participates to meetings with stakeholders organized by NCIP**
  - During the meeting IMO specialists present the current state, implications for the hazards, and the current hazard assessment
- **IMO participates to regular meetings with key stakeholder with business in the area**
  - IMO explains in details the monitoring data and the implication for the hazard assessment.
- **IMO participates to meetings with the population organized by NCIP**
  - IMO contributes by showing the monitoring data and the interpretation, hazard assessment is illustrated. Questions are answered by IMO‘s specialists.

In summary

Improvements and challenges

In Iceland natural events are always multi-hazard events

Cascading and compounding hazards are frequent in Iceland

Quantifying, mapping and communicating volcanic hazards remains a challenging topic which needs constant improvements, collaborations, and developments

In small countries dealing with multiple hazards at the same time is a big toll in terms of human resources and monitoring effort

Multi-hazards events can and need to be approached with an integrated and synergic monitoring system

Good practices in information distribution are first steps to build common knowledge, shared language and informed decision process.

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Thank you!

Photo: M. Di Marco

Managing prolonged volcanic unrest in the Reykjanes-Svartsengi system:

Challenges in monitoring, hazard assessment and risk communication

Photograph: M. Di Marco

Icelandic Met Office

IAVCEI conference, 30 June – 4 July 2025

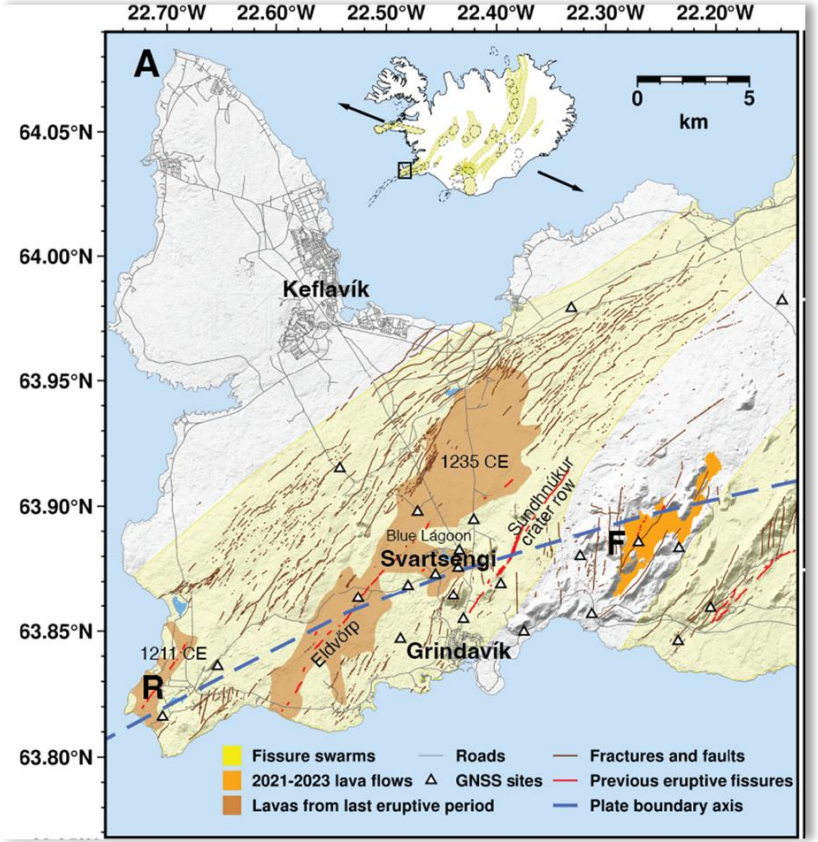
Sara Barsotti, Matthew J. Roberts, Bergrún A. Óladóttir, Haukur Hauksson, Kristín Jónsdóttir, Benedikt G. Ófeigsson, Einar B. Gestsson, Melissa A. Pfeffer, Michelle M. Parks, Gro Pedersen, Ásta R. Hjartadóttir, William M. Moreland, Ragnar H. Þrastarsson, Kristín Vogfjörð, Benedikt Halldórsson, Vincent Drouin, Chiara Lanzi

The Reykjanes fires (2021 – ongoing)*

The beginning of long-term volcanic unrest

- Multiple volcanic systems
- Volcanic activity migrating between systems
- The preceding period of eruptive activity lasted for ~500 years, with the last eruption taking place in 1240 CE

The activity on the peninsula heralds a new period of volcanic unrest for Iceland which could last for centuries



* Júlíusdóttir et al. 2024: Nýtt gosskeið hafið á Reykjanesskaga DOI: 10.33112/nfr.94.3.1

Locations of the eight eruptions in Sundhnúks crater row

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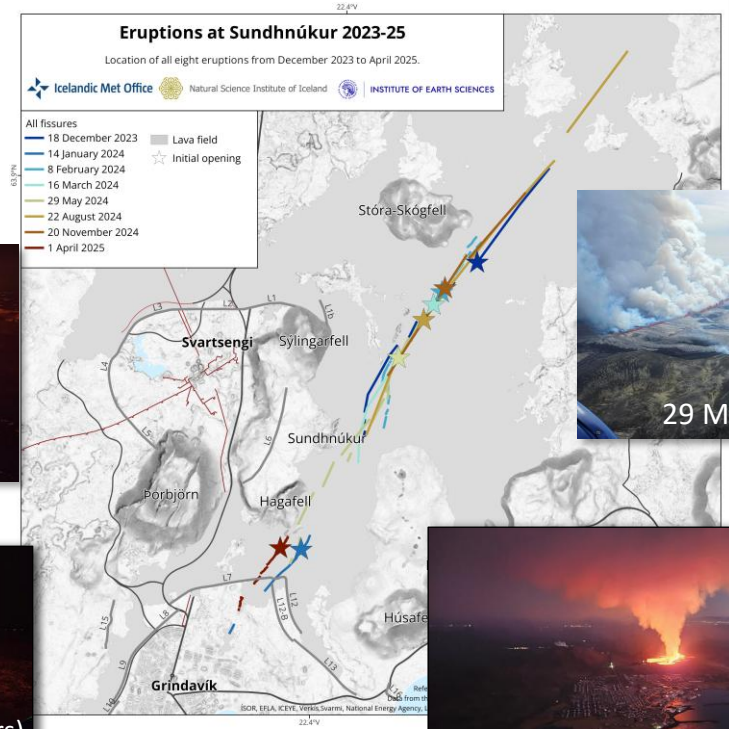
Svartsengi – Sundhnúks crater row



Volcanic eruption, 14 January 2024

Photograph: Björn Oddsson

Impact and consequences

At national scale

- Grindavík evacuated (3,800 inhabitants) - November 2023
- Major damage to buildings and infrastructure – November 2023
- One fatality (while performing engineering work to fill up the fractures/openings formed in town) – January 2024
- Eruptive fissure opening on the northern edge of Grindavík – January 2024
- Lava-flow within the town – three houses destroyed – January 2024

- **Unprecedented engineering efforts to protect critical infrastructure**

ICELANDIC MET OFFICE
1920-2020

Impact and consequences

At national scale

- The main road for accessing Grindavík from the north inundated by lava – February, May and November 2024
- District hot-water pipe inundated by lava, ~30,000 residents on the peninsula without hot and cold water for over three days – February 2024
- SO_2 concentration at ground level in Grindavík > 15,000 µg/m^3 - March 2024
- SO_2 concentration at ground level at Blue Lagoon > 8,000 µg/m^3 - March and May 2024
- High-voltage power lines affected – May and November 2024

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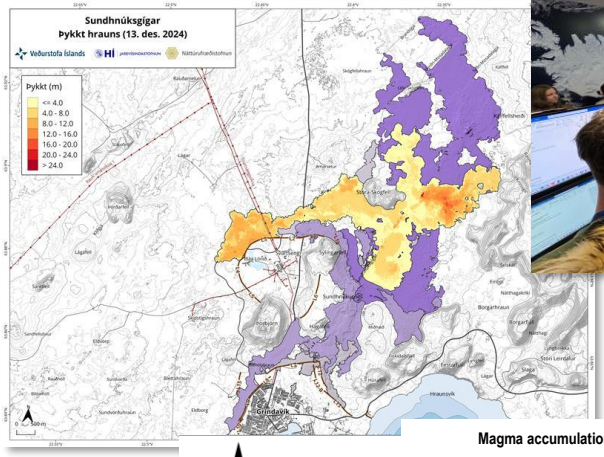
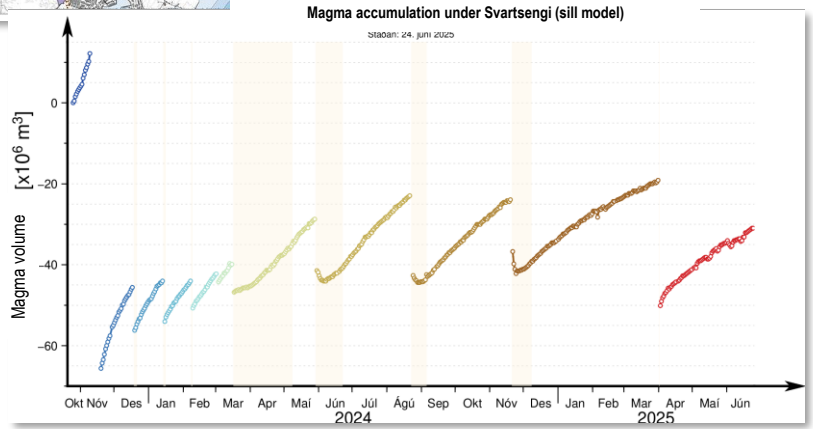
1920-2020

IMO and its role as SVO

- During volcanic crises, IMO is responsible to provide advice to Civil Protection authorities and to the aviation community
- Since the crisis onset in October 2023, IMO calls for regular scientific meetings involving scientists and experts from national and international institutions
- Participation to meetings with the affected population
- Regular updates on the media (interviews, news, social posts)

Need for a sustainable, long-term response and prevention strategies to manage the crisis

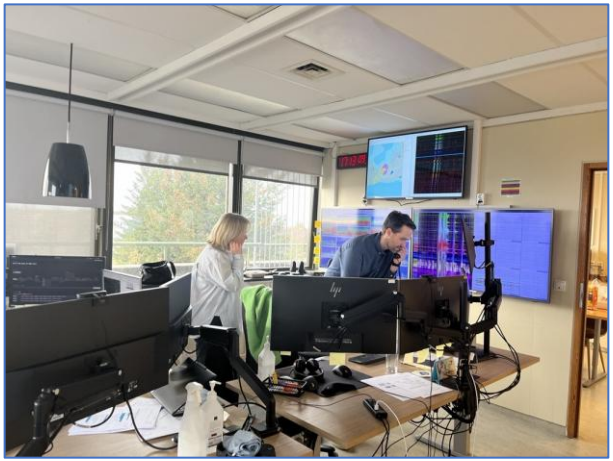


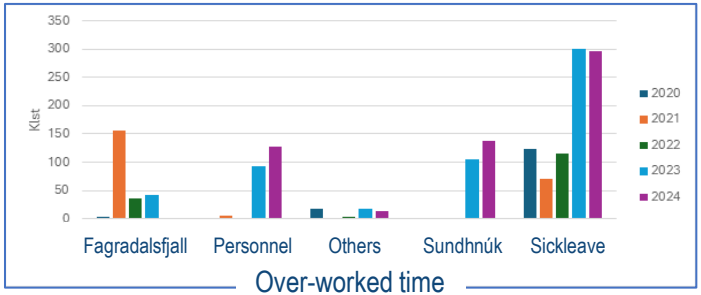


Challenges in monitoring

Repeated events do not allow for recovery phases

- A group of 12 people takes shifts in the monitoring room (NVS)
- Since the beginning of the crises, two persons quit the job due to overload
- Three have been recruited, but had few months of training before getting into full and autonomous shifts
- The reported sickness (and the need for replacing on shift) doubled from 2020
- The extra hours worked in shifts in 2024 reaches half-a-full-job-position





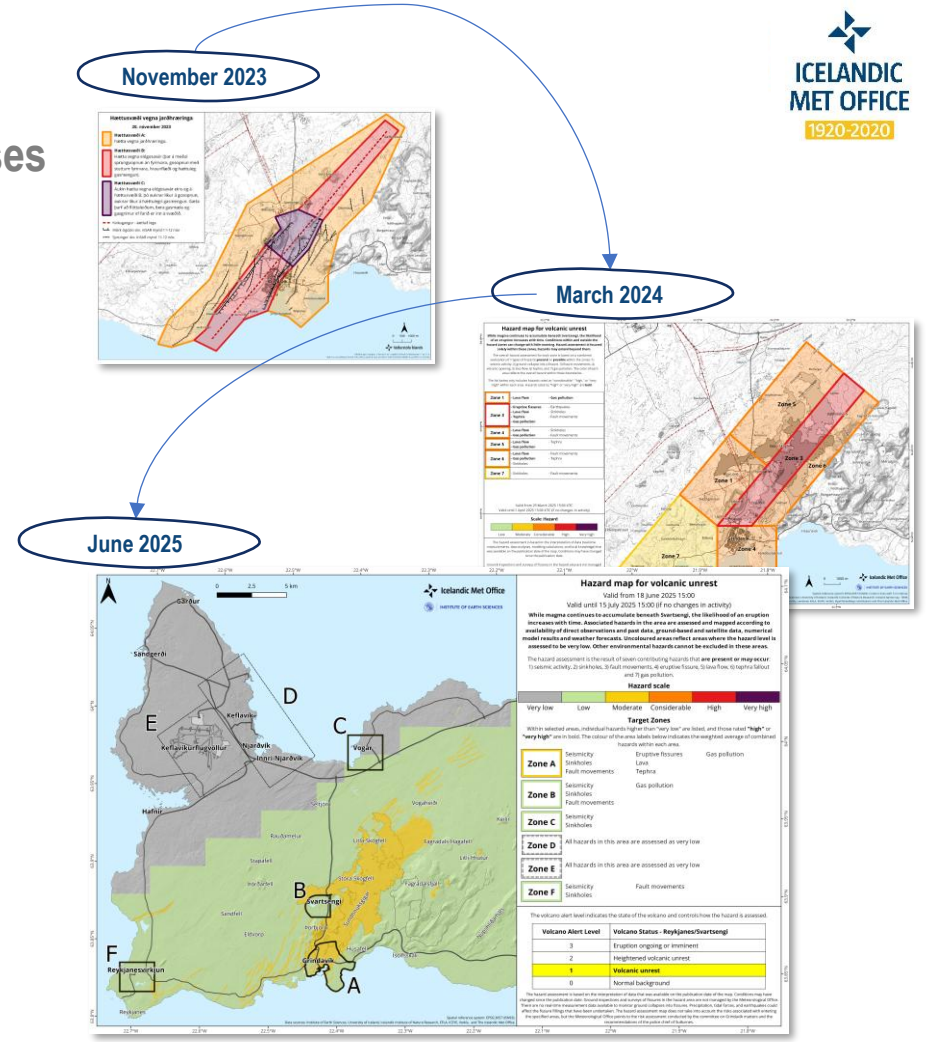
- **The warning time ranged between 21 minutes and 4 hours and 37 minutes**

Challenges in hazard assessment

Multi-hazards and prolonged uncertainty phases

- >100 published maps since November 2023
- Seven hazards assessed (and mapped)
- The map layout, design and concept needed evolving with time to reflect the evolution of the events
- Monitoring data, model results, forecasts, expert opinions

- **General public, operators and workers in the area, the Civil Protection authorities used it as a tool for planning and decision making**



Challenges in hazard assessment and communication

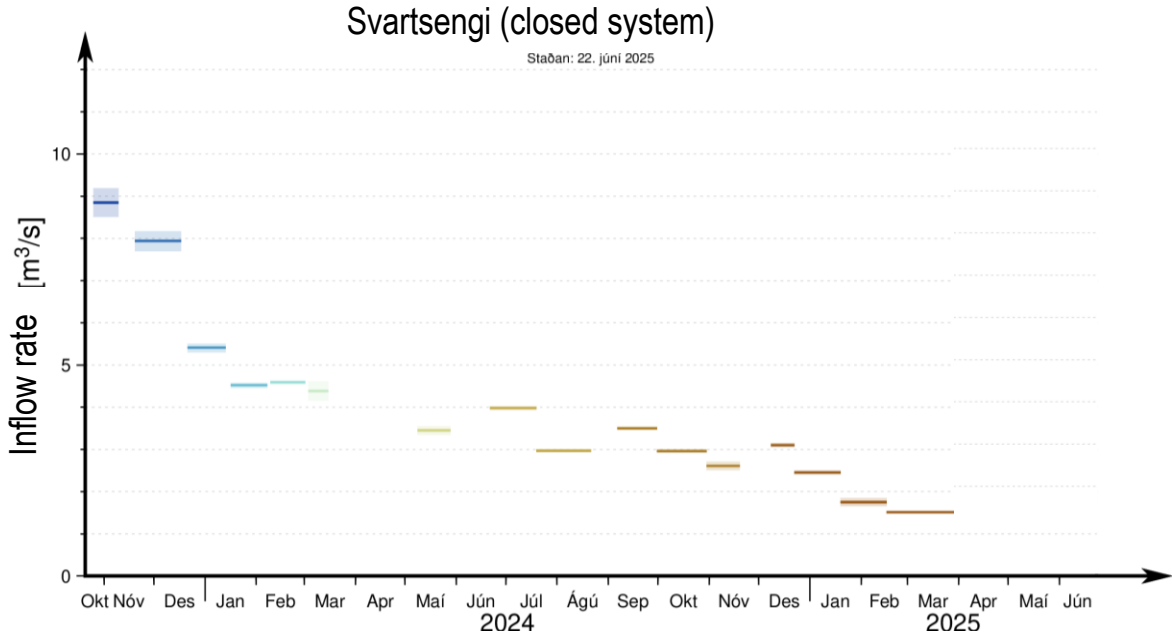
Regular meetings with private companies have been maintained throughout the crisis

The communication becomes very difficult when everyone becomes expert of the matter!

In March 2025 geodetic modelling results indicated the inflow rate into the magma body was declining, but at the same time the magma volume within the chamber reached the previous failure level.

The comment was

„…we do not need to be experts to understand this is going to end soon“

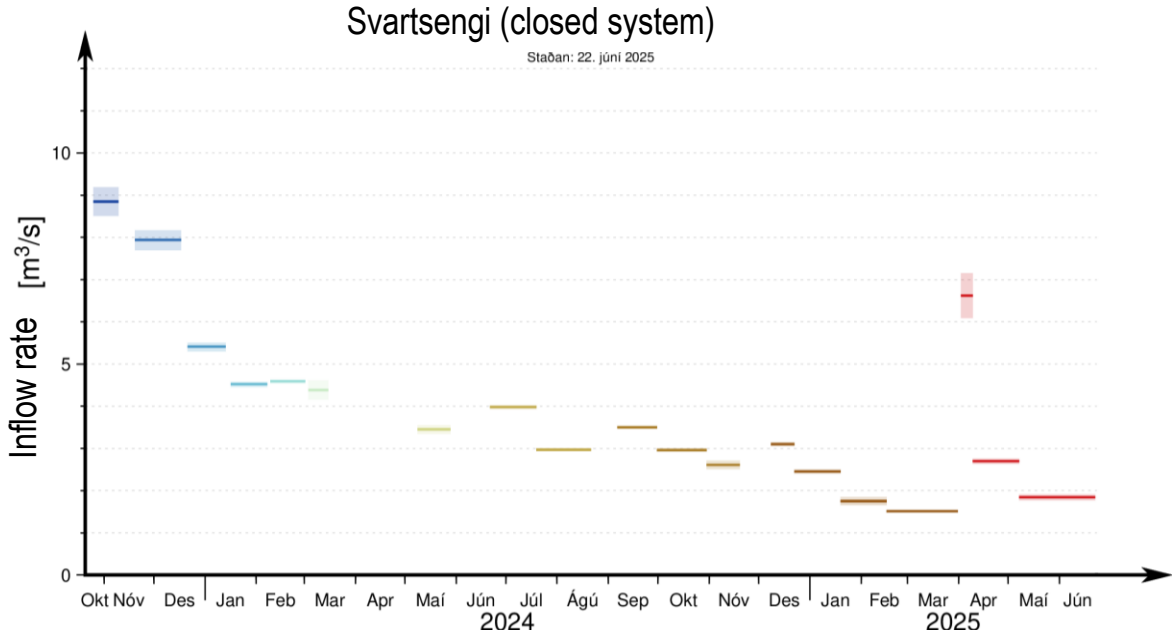


Challenges in hazard assessment and communication

Regular meetings with private companies have been maintained throughout the crisis

However,

on 1 April 2025, a 20 km long magmatic dike formed, intruding about 90 millions m^3 of magma up to a depth of 2 km - a small eruption took place north of Grindavík crossing the protective barriers.



Challenges in risk communication when dealing with uncertainty

Lack of an official risk assessment, fully dynamic and publicly open

- On 21 October 2024, the Governmental committee in charge of making Grindavík *flourishing again* decided to open the town without any further restrictions
- This was done without an actionable preparedness plan, which required IMO to develop ad-hoc contingency plans for enhanced monitoring and assessment
- On 19 November, IMO stated an eruption considered unlikely in November

- **An eruption started on 20 November (preterm!) with 43 minutes of warning time (since the first call to the Civil Protection until the eruption onset)**

"Everyone is responsible for their own actions or inactions. The Chief of Police has also reiterated that Grindavík is not a place for children, a stance fully supported by the Grindavík committee" @mbl.is

In summary

Reykjanes fires (2021-ongoing)

- Prolonged, ongoing crisis with cascading socio-economic impacts
- Repeated eruptive events do not allow for recovery phases – impacting severely human resources at emergency responder institutions and, potentially, reducing the quality of services
- Multi-hazards and prolonged uncertainty phases create a complex condition for maintaining an effective level of alertness, possibly mining the trust of the general public towards the monitoring institutions
- Decisions taken regardless scientist recommendations increase the risks by underplaying the level of uncertainty and adding responsibilities to those in charge of the monitoring

If you want to hear more about hazards associated with the ongoing volcanic unrest in the Reykjanes (Iceland)…

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- **Hjartardóttir et al. Monday 16:30 - 18:30, session 7.2 -** Hazard and risk assessment for fault movements on the Reykjanes peninsula, Iceland
- **Hrafnsdóttir and Guðgeirsdóttir Tuesday 09:30 - 09:45, session 6.5 -** The layout and elevation design of the lava barriers on the Reykjanes Peninsula, Iceland
- **Drouin et al. Monday 14:15 - 14:30, session 2.4 -** Lessons learned from near real-time monitoring of volcanic unrest and dike propagation/eruption forecasting in Iceland
- **Óladóttir et al. Monday 16:30 - 18:30, session 7.2 -** A long-term volcanic hazard and risk assessment for the Reykjanes peninsula, Iceland. Overview and communication with stakeholders
- **Pedersen et al. Tuesday 09:15 - 09:30, session 6.5 -** Lava flow monitoring and modelling during the 2021-2024 Reykjanes peninsula unrest, SW Iceland
- **Pfeffer et al. Friday 16:30 - 18:00, session 6.7 -**Mapped geologic features used to forecast long-term likelihood of future eruption locations: applications during an ongoing series of frequent, differing-impact eruptions on the Reykjanes Peninsula, Iceland
- **Lanzi et al. Friday 16:30 - 18:00, session 1.5 -** 2023-2025 inflation episodes within the Svartsengi Volcanic System, SW Iceland: Implications for improved forecasting and hazard assessment
- **Wainman et al. Friday 16:30 - 18:00, session 3.17 -** Gas and Trace Element Emissions at the Lava-Moss interface during the Litli-Hrutur eruption, Iceland 2023