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¹ From 1st April 2014, HPA became part of Public Health England.

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Summary

What is the Laki eruption scenario?

The Laki eruption scenario is based on a large fissure eruption that occurred in 1783-4 for which there is published evidence of significant distal impacts across Europe (see below)³. The impact on Iceland was devastating: more than 60% of the grazing livestock was killed by fluorosis and ultimately ~20% of the island's population died in the aftermath as a result of induced illness, environmental stress and famine⁴.

As well as lava flows, the atmospheric volcanic emissions from such an eruption include mainly water vapour, gases including carbon dioxide, sulphur dioxide, hydrogen chloride and hydrogen fluoride, aerosols (e.g. particles such as sulphates) and trace metals such as mercury, arsenic and iridium. At times, there may also be volcanic ash depending on how explosive the eruption is and the presence of water. Sulphur dioxide (SO₂) is chemically converted during atmospheric transport to sulphate aerosol. The rates of this chemical conversion vary depending on factors such as temperature, humidity and availability of oxidants. The main potential hazards of concern to the UK include volcanic gases and aerosol (air pollution), acid rain and deposition of acids and other aerosols.

There have been four large fissure eruptions in Iceland in historical time (the last c.1130 years), the 1783-4 Laki eruption being the second largest in terms of the volume of volcanic material erupted. This type of eruption is characterised by huge outpourings of mainly lava, gases and aerosols (atmospheric particles) which can cause regional to hemispheric-scale impacts but most risks can be mitigated with effective planning.

Observations in UK and Europe in 1783

In the UK and Europe, from 12 June 1783 there were reports of an atmospheric 'haze' and 'dry sulphurous fogs' at different times which were almost certainly associated with volcanic aerosols³ and possibly gases.

Contemporary records from England and other European countries document some environmental and health impacts of the haze (e.g. workers in fields suffering respiratory difficulty; crop and vegetation damage⁵) but the haze and its effects were variable spatially and temporally at a local scale. This significant variability is controlled by the eruption dynamics and by the influences of regional-to-local scale meteorology.

Meteorological records show that there was extreme heat in the summer of 1783 followed by an exceptionally cold winter in the northern hemisphere. There were unusual thunderstorms, ball lightning and large hailstones. It is not possible to prove that this extreme weather was linked to the

³ Thordarson and Self, 1993

⁴ Thordarson and Self, 2003

⁵ Grattan et al., 2003

eruption though the unusual meteorological phenomena caused commentators to make the suggestion at the time⁶.

A published study⁷ based on 404 parish records in England, provides evidence for two periods of crisis mortality during the Laki eruption period: one peak in August-September 1783 and a second peak in January-February 1784 with above normal mortality rates for the subsequent two months. It is not possible to directly ascribe these excess deaths to the Laki eruption but the unusual monthly mortality pattern indicates a forcing on mortality unrelated to normal seasonal trends and potentially unique in a fifty year series of such data. The significance of these findings and those of some other publications using death records at the time warrant further assessment for their value and possible implications for the UK and Europe today.

Modelling the scenario

In order to be hazardous at ground level in the UK, the air pollutants need to be a) transported to the UK by the wind, b) present at ground levels in the UK, and c) at harmful concentrations.

Different models need to be combined to understand key processes in this scenario – weather models, atmospheric transport (dispersion) models and chemistry models. To produce detailed modelling results including multiple physical and chemical processes requires considerable resources (time) and computing power. Solving the first order problem of whether or not volcanic emissions can physically reach the UK under particular eruption and meteorological conditions has been seen to be possible and can be probabilistically assessed using long range dispersion models but neglecting chemical conversion processes.

Atmospheric dispersion models require knowledge of the source characteristics of an eruption – for example the height of the column of emissions (ash, gas and aerosol) above the vent, the rate of emission and, for ash, the distribution of particle sizes between the vent and the top of the eruption column. In order to facilitate modelling of future eruption scenarios, this report presents a range of eruption characteristics (source parameters) for a Laki-type eruption and their uncertainties based on an expert elicitation. This reflects current knowledge. The report also presents information on the possible dynamic evolution of a future large-volume fissure eruption for modelling purposes.

Models and the results of modelling, and their hazard implications, need to be thoroughly understood by practitioners, in particular the effects of assumptions and uncertainties. Running several models with the same starting parameters helps understanding of these uncertainties and if validated against observational data may inform on model capabilities and limitations.

To inform risk assessments fully, given inevitable scientific uncertainties, a probabilistic modelling approach is needed. Eruption scenarios would be modelled using multiple years of meteorological data. Outputs suitable for health and environmental modelling, including deposition and air concentration data and distribution maps for different scenarios e.g. summer and winter events, could be produced. Outputs can also be produced for different flight levels.

⁶ Franklin, 1784

⁷ Witham and Oppenheimer, 2004

The better our understanding of eruptive and atmospheric processes, the more effective models can be when applied as part of the response to future events. Improved understanding is needed of the composition and transformation of gases and aerosols in the atmosphere and this is best achieved through focused collection of data between and during eruptions, laboratory studies and modelling. For example, more detailed studies are needed to establish wet and dry deposition rates and scavenging coefficients for different species.

A future eruption

The Icelandic Meteorological Office (IMO) is mandated to monitor volcanoes in Iceland and would expect some geophysical and/or geochemical evidence of unrest before a Laki-type fissure eruption. In 1783 there were felt earthquakes three to four weeks before the eruption. Currently, such an increase in activity would be communicated by IMO increasing the 'aviation colour code' (<http://www.wovo.org/aviation-colour-codes.html>) and distributing a notification called a 'Volcano Observatory Notice for Aviation' (<http://www.icao.int/safety/meteorology/ivatf/Meeting%20MetaData/IP.10.pdf>) thus informing the aviation sector, UK Met Office, BGS and others. When an eruption has begun, where possible, the IMO provides real-time eruption source parameters to the UK Met Office for operational forecasting purposes. It is not certain that the potential scale of a Laki-type eruption would be clear at the onset of the eruption.

Once an eruption is underway, the gases, aerosols and ash will be transported away from the volcano by the winds acting at the time. Assuming the worst expected meteorological conditions for the UK (strong wind flow from the northwest) we could have a minimum lead time of approximately six hours.

All large historical fissure eruptions in Iceland appear to have had very similar eruption dynamics with more intense and vigorous activity in the early stages of the eruption. In the case of Laki, about 96% of gases were released in the first 5 months and 60% in the first six weeks of the eruption³.

Monitoring

The IMO make much monitoring data available online (e.g. <http://en.vedur.is/earthquakes-and-volcanism/earthquakes/>). The UK Government, BGS and others in the UK and across Europe are contributing to the IMO-led monitoring effort in Iceland partly in order to secure the maximum possible lead time and effective information flow during an emergency.

Ground-based, airborne and satellite monitoring techniques are of value both near the volcano and in the far-field (e.g. the UK). Nevertheless, none of the existing techniques in isolation would give a high resolution time-series of source parameters/data. There is significant potential to develop new, purpose-specific monitoring techniques and some novel techniques have been developed, or are being developed, but the technology is not yet available commercially. The ideal future situation would involve improved capacity and the sustained coordination of resources and collaboration across institutes and nations in order to effectively respond to eruptions.

This report summarises existing monitoring capability in the UK. We recommend extending existing ground-based air quality networks to increase spatial and temporal resolution of data (e.g. more sites instrumented and more species monitored, especially gases and trace metals). There is currently no capability to monitor hydrogen sulphide, hydrogen fluoride or hydrogen bromide, for example, and also limited air quality monitoring in most rural areas (e.g. the Highlands and Islands of Scotland). Knowledge of the location and vertical characterisation of volcanic clouds can be improved using LiDAR (Light Detection And Ranging), aircraft, balloon sondes, UAVs (unmanned aerial vehicles); new methods could be developed. If there is fine ash, gas or aerosol deposited over the UK, sample collection and analyses should be coordinated (e.g. in a similar manner to the DEFRA Volcanic Ash Network). The UK could engage appropriate and available remote sensing resources, further exploit current sensors, develop new satellite payloads and plan for enhanced observation capabilities to facilitate crisis management.

For the present hazard scenario concerns, detailed analysis of observations from any eruption can lead to significant improvements in understanding processes, development of methods and planning for future eruptions. In this context, future eruptions around the world will offer opportunities to conduct observations, experiments, test new techniques and improve near real-time collection, integration and analysis of multi-parametric data. Observations and monitoring must be combined with improved numerical models of different eruption processes and laboratory experiments of eruption column processes in order to facilitate our future ability to harness data, observations and modelling to better assess eruption parameters in real-time and therefore forecast hazards effectively.

Health impacts

Unfortunately, historical records relating to 1783-4 cannot be critically analysed using the standard epidemiological methods used in modern air pollution research. It is not possible to reliably infer the short-term exposure levels of people to individual air pollutants from the reports of odour, haze or vegetation damage. The available historical data are also inadequate for calculating age-specific death rates, or doing time-series analyses from the parish numbers of deaths, which are also known to be highly unstable in many parishes due to the high prevalence of endemic infectious diseases no longer seen in Britain today, and the much lower life expectancy in 1783.

For a future Laki-type eruption scenario, modelling ambient air concentrations of specific air pollutants is required to provide first order estimates of all-cause and disease specific mortality and morbidity, based on exposure-response data for SO₂ and particulate matter (PM_{2.5} and PM₁₀) from clinical and epidemiological studies. In one published paper⁸ the modelling forecasts that the concentration of volcanic PM_{2.5} particulate matter (particles with diameters <2.5 micrometer) could double across central, western and northern Europe during the first three months of a future Laki eruption scenario. The model dataset was used to estimate the number of days (out of 266 days considered) that could exceed the current World Health Organisation (WHO) 24-h mean PM_{2.5} air quality guideline of 25 µg/m³. Over land areas of Europe (excluding Iceland), the mean number of exceedances could increase by 36 days (range 14-63 days) compared to a 'normal' non-volcanic

⁸ Schmidt et al. 2011

mean of 38 days. The authors estimate 142,000 additional cardiopulmonary fatalities could occur in Europe (with a 95% confidence interval 52,000-228,000) and the UK may experience an increase in mortality of about 3.5% (i.e. about 21,000 additional cardiopulmonary fatalities due to eruption on top of 595,800 all-cause deaths).

Global air quality guidelines are well-established for SO₂ (UK and EU guidelines are similar) which would be a major constituent gas in the erupted plume from Iceland. However, modelling studies are needed to establish the volcanic and meteorological conditions required for SO₂ to reach UK ground level before the gas is chemically converted to sulphate aerosol. At high enough concentrations SO₂ could trigger acute respiratory symptoms in asthma sufferers and aggravate the condition of patients with chronic lung problems. To assess health effects on such individuals, peak concentrations measured and averaged over periods of 15 minutes using air quality networks would need to be compared with existing guideline values.

Models, in theory, predict 15 minute mean SO₂ concentrations needed for health impacts (e.g. 15 minute WHO thresholds for SO₂) but crucially these outputs are considered much more uncertain (due to model limitations) when compared to, for example, 24-h mean concentration outputs. New statistical methods may need to be investigated in order to develop capacity to address health impact requirements given model output constraints.

Particulate matter and SO₂

Further research and modelling will be required to constrain UK-wide mortality and morbidity estimates in worst-case air concentration scenarios based on a future Laki-type eruption, including investigation of the interaction of volcanic with anthropogenic air pollution, evaluation of the role of volcanic sulphate aerosol and its possible neutralisation by ammonia (NH₃) in the atmosphere. Advice may be sought from an expert advisory group (e.g. COMEAP : Committee on the Medical Effects of Air Pollutants) on the potential health implications of likely air pollution scenarios. Contemporary records of mortality and ill-health associated with the Laki eruption in 1783 should be re-evaluated in the light of recent advances in our knowledge of air pollution and its health effects.

Environmental impacts

Any volcanic acid gases and aerosols that reach the UK are likely to be deposited (by settling or sticking) on any surface, including soils, vegetation, crops, buildings and critical infrastructure, vehicles and so on, and – importantly – into surface water such as lakes, reservoirs and streams. This will occur through wet deposition (in rain and snow) or dry deposition. The impacts will depend on pre-existing conditions, the concentrations of the acidic compounds and whether or not they can be quickly removed (e.g. by uncontaminated rainwater or hosing off).

Soil acidification and the potential to impact groundwater (via meteoric water) needs further investigation as well as possible ammonia neutralisation. In some parts of the UK the addition of sulphur may benefit the soils, elsewhere soils are already acidified and sensitive ecosystems are at risk. Localised rainfall carrying a volcanic burden may produce deposition hotspots.

Effective environmental management will rely heavily on good monitoring networks and knowledge of the sensitivity of different crops, vegetation, ecosystems to the pollutants. The impacts of acid gases and aerosols on different vegetation types under different atmospheric conditions was studied to some extent in the late 20th century, however there is limited literature available so further research is needed to carry out sensitivity tests and experiments on a range of plants and crops to establish thresholds and likely impacts, particularly on crops. The development of new products to facilitate emergency management, such as hourly concentration maps based on deposition monitoring, would be of value.

Volcanic particulates and gases can also penetrate into infrastructure systems and buildings, and potential effects on modern electronics, for instance, are not clearly understood. Monitoring of dried grass would be necessary to identify risk of fluorosis. Livestock could be kept indoors to reduce exposure. A volcanic haze or 'vog' is likely to lead to reduced visibility and could impact different sectors including transport. Experience elsewhere suggests that such a haze and its impacts will be spatially and temporally variable.

Aviation and transport impacts

SO₂ and sulphate (in the form of sulphuric acid) could cause damage to airframes and sulphate deposits can accumulate in turbines blocking cooling holes and leading to overheating during flight⁹. Sulphate aerosols also accelerate corrosion thus leading to a need for increased maintenance and decreasing engine lifetime. There is the possibility of crew and passengers being exposed to toxic gases on a plane/helicopter if SO₂ for example has not fully oxidised in the atmosphere. In order to quantify what the effects may be, more research and modelling work is needed. The potential for reduced visibility would also need to be taken into account by others in the transport sector (e.g. shipping).

Official advice in an emergency

In the event of a Laki-type eruption, guidance will be needed for the public and all sectors including transport workers, schools, farmers, veterinarians, water managers and critical infrastructure on living with and managing the consequences of volcanic air pollution. Modelling is needed to establish the likelihood of SO₂ or other gases and aerosols reaching the UK and planning should be in place in the event of a future eruption for warning and advising the population on the possibility of peaks in gas and aerosol concentrations (which cannot currently be modelled at appropriate resolution with sufficient accuracy to characterise human exposure). Modelling and further investigation is also needed to establish whether SO₂ or other gases and aerosols could be a hazard to crew and passengers at flight levels.

⁹ Miller and Casadevall, 2000

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