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Volcanic ash clouds affecting Northern Europe: the long view

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Summary

The volcanic ash or 'tephra' cloud resulting from the relatively small (volume and VEI) eruption of the Icelandic volcano Eyjafjallajökull in 2010 caused major air travel disruption, at substantial global economic cost. On several occasions in the past few centuries, Icelandic eruptions have created ash and/or sulphur dioxide clouds which were detected over Europe (e.g. Hekla in 1947, Askja in 1875, and Laki in 1783). However, these historical observations do not represent a complete record of events serious enough to disrupt aviation in Europe. The only feasible evidence for this is within the geological tephra record. Ash layers are preserved in bogs and lakes where tephra deposited from the atmosphere is incorporated in the peat/mud. In this article we i) introduce the analysis of the Northern European sedimentary tephra record; ii) discuss our findings and modelling results; iii) highlight how these were misinterpreted by the popular media and iv) use this experience to outline several existing problems with current tephra studies and suggest agendas for future research.

The 2010 Eyjafjallajökull ash cloud

The Icelandic volcano Eyjafjallajökull erupted after nearly 190 years of dormancy on the 20th March 2010, creating a large tephra cloud over most of northern Europe (Fig. 1). This eruption was shortly followed by the ash cloud originating from Grímsvötn in May 2011, which deposited basaltic ash over northern Scotland. Together these recent events suggest that volcanic ash clouds regularly affect Northern Europe. However, prior to this, the last major ash cloud to extend into Northern Europe was from the 1947 eruption of Hekla. The volcanic ash cloud resulting from the relatively low volume eruption of Eyjafjallajökull caused major air travel disruption over many parts of Europe, at a substantial cost to the European, and the global economy. Steps are now being taken to prepare for similar events in the future, by revising policies around safe operation of aircraft in and around volcanic ash clouds, using infrared technologies for ash detection, and developing insurance schemes for travellers disrupted by volcanic ash. In order to prepare for future events in a cost-effective manner, it is important to know how frequently such events affect European airspace. Ash from the eruption of Eyjafjallajökull in 2010 was found at a ground level in many northern European countries including the UK, the Faroe Islands, Norway and Hungary.

Ash clouds in the past

One useful approach to determining the frequency of events like Eyjafjallajökull 2010 affecting Northern Europe is to examine deposits of far-travelled ('distal') Icelandic ash across Europe (Figure

1). By compiling records of past ash fallout events we can, in principle, calculate the return interval of such events, making the basic assumption that they are essentially randomly distributed in time. There are, of course, some historical (eye-witness) accounts of previous ash clouds reaching NW Europe, for example, the eruptions of Hekla in 1947, or Askja in 1875. However, these historical records are of limited extent (none before c. 1600), often dubious or difficult to interpret, and lack crucial information that might allow us to estimate whether they would have involved atmospheric ash concentrations sufficient to pose a threat to society and disrupt modern aviation. An alternative source of information is the Holocene geological record. Volcanic ash can be incorporated into natural deposits such as lake sediments and peat (Figure 2). Close to the vent (for example, in Iceland itself), such tephra layers are often visible to the naked eye. More distal tephras are usually very sparse and special techniques are required to isolate them from the surrounding sediment or peat (Figure 3). Despite this difficulty, in recent decades Quaternary scientists working in NW Europe have invested much effort in finding these so-called 'cryptotephras', because they are a valuable tool for dating and correlation: often a tephra layer can be matched to a particular volcanic eruption by the chemistry and optical properties of the tephra shards, among other characteristics.

Tephras can be dated using documentary evidence in the case of recent eruptions such as Hekla 1947, or using techniques such as high-precision radiocarbon dating in the case of prehistoric ashfall events. Once a tephra has been convincingly dated at one site, finds of the same tephra at other sites in the fall-out region provide an extremely precise and reliable chronostratigraphic marker. For the last few centuries, a greater number of tephras have been recorded in sedimentary archives than ash clouds have been historically documented. Swindles et al. (2011) carried out the first comprehensive synthesis of tephra occurrence in NW Europe spanning the last 7000 years and carried out a statistical probability analysis of these comprehensive data compilation. Published tephrochronological data from peat and lake sedimentary archives encompassing Ireland, Great Britain, Germany, Scandinavia and the Faroe Islands were compiled (Table 1, Figure 4). In addition, new unpublished data from Great Britain were included. The chronological span of each sedimentary record was recorded and historical accounts of tephra falls in Great Britain and Scandinavia were also considered. The analysis was curtailed at 7000 years before present (BP) as i) there have been relatively few studies of older Holocene tephras in NW Europe; ii) Icelandic volcanism was potentially more active during the early Holocene than in recent millennia due to glacial unloading of the volcanic source region; iii) early Holocene peat and lake sediments are often difficult to recover, so records are scarcer.

The investigation examined the distribution and frequency of tephra fall events and attempted a calculation of the return interval and probability of such events. Within the investigated 7000 year period, ten tephra layers were identified in the Faroe Islands, 14 in Great Britain, 11 in Germany, 38 in Scandinavia, and 33 in Ireland; in addition, seven ash-fall events were documented since A.D. 1600 (and prior to the Eyjafjallajökull 2010 event) in Scandinavia, Great Britain, and the Faroe Islands. An increased frequency of recorded tephra layers during the last ~1500 years was apparent in the data from Ireland and Scandinavia, which is most likely a product of greater numbers of studies on young deposits. It was found that during the last millennium, Icelandic volcanic ash has demonstrably reached Europe between one and five times per century. It was calculated that in the past 1000 years, volcanic ash clouds reached northern Europe with a mean return interval of 56 year (the range of return intervals is between 6 and 115 years). Probabilistic modelling using the ash records for the last millennium indicated that for any 10 year period there is a 16% probability of a tephra fallout event in northern Europe.

Misunderstandings by the popular media

After publication of the Swindles et al. (2011), several media articles appeared on the internet predicting how long it would be until Europe was hit by the next ash cloud. The first article was published by the BBC with the headline 'The UK is unlikely to see another giant volcanic ash cloud in this lifetime'. This article was followed by several others, including the UK Yorkshire Post who reported 'Scientists predict 50-year relief from volcanic cloud disruption'. These interpretations are both incorrect as they assume tight clustering of ash-fall events about the mean (i.e., a Gaussian distribution). Of course, a mean return interval of 56 years does not mean that ash-fall events are always 56 years apart! In fact, the observed return interval has varied from a maximum of ~115 years to a minimum of ~6 years over the last millennium. The most frequently occurring return interval of the last millennium (modal return interval) is actually in the range of 30-40 years (see Figure 2 in Swindles et al., 2011). On the other hand, the findings of the Swindles et al. (2011) paper were reported correctly within 'Editor's choice' in *Science* and were selected as 'Community choice' contribution in *Nature*. The incorrect headline claims made in the popular media are interesting for a second reason. The eruption of Eyjafjallajökull in March-April 2010 was followed by the eruption of Grímsvötn volcano in May 2011 which led to the deposition of basaltic ash over northern Scotland. In this instance, the observed return interval was 1.2 years. It was clearly stated in the paper that the predicted return interval was a conservative estimate due to preservation issues in the geological record. We also need to tread carefully when using the past to predict the future (or using the so called "reverse-uniformitarian" approach). For example, as climate change causes the melting of ice masses to accelerate, we may see an increase in volcanic activity in Iceland.

Concluding remarks and future work

Analysis of the Northern European tephra record has shown that there is a significant sub-centennial scale risk of volcanic ash clouds affecting Northern Europe. However, there are several outstanding issues and problems in the Northern European Holocene tephra record that are being addressed by on-going research:

1. There are important temporal biases in the dataset: many more sites have been investigated for recent periods, so it is not clear whether the frequency of ash falls has changed over time;
2. There are significant spatial biases in the dataset, with much more research in some regions than others;
3. Basaltic ashes appear to be strongly underrepresented in the distal record, suggesting that they may be poorly preserved in certain conditions;
4. There are differences in the methodological approaches used by researchers: some only focussed on the prominent tephra layers and ignored the sparser ones, whereas others have been more inclusive in their analysis;
5. It remains uncertain whether all types of tephra can be preserved in peat or lake sediments for periods beyond 1000 years, which could account for an apparent increase in tephra deposition in recent centuries;
6. We still do not know how the tephra concentration in sediments is related to ash concentrations in the atmosphere.

Furthermore, as researchers we must contribute science that aims to clarify hazard models for science journalists to avoid future misunderstandings. Our experience reminds us that we need to work closely with science editors and communications experts to avoid misinterpretation and miscommunication.

Suggestions for further reading

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Figure captions

Figure 1. Map of all sites in Northern Europe where Eyjafjallajökull tephra was detected at ground level along with sites where Holocene tephra layers have been found.

Figure 2. Photograph of a peat core from the Shetland Isles. Several tephra layers that are invisible to the naked eye (‘crypto-tephras’) were found in this core. The core is 50 cm long.

Figure 3. Looking for a needle in a haystack! Finding tephra shards amongst quartz grains and plant material. This is the Glen Garry tephra that dates to c. 200 BC. This tephra was found in Malham Tarn Moss in the Yorkshire Dales, UK.

Figure 4. The tephra record from Ireland plotted as a cumulative density function. This indicates an increase in number of tephra layers in the last ~1500 years. This may be due to under-reporting in the older part of the record or an actual change in rate of ash fall events. 95% confidence limits are shown. Ash fall events are stationary with 95% confidence over the last 2000 year, and mostly non-stationary in the earlier part of the record.

Table 1. The tephra layers found in the peat bogs and lakes of Britain and Ireland.