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Perspective

New evidence for massive pollution and mortality in Europe in 1783–1784 may have bearing on global change and mass extinctions

Vincent Courtillot

Institut de physique du Globe, 4, place Jussieu, 75252 Paris cedex 05, France

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The year 1783 has been referred to in Europe as the 'Annus Mirabilis' or 'Year of Awe' given the large number of extreme climatic, volcanic and tectonic events that took place. An unusually hot summer of 1783 in western Europe, followed by one of the most severe winters (1783–1784) in the northern hemisphere, an unusual 'deadly' haze that covered it down to rather low latitudes, poor crops in various places... On the same year, volcanoes erupted around the world (Etna, Stromboli, Vesuvius, Asama) and earthquakes shook Calabria. Last and probably foremost was the second largest historical basaltic fissure eruption at Laki (Iceland) from June 1783 to February 1784. Only two months after the onset of the eruption, Mourgue de Montredon [4], in a lecture to the Royal Academy of Montpellier (France), noted the coincidence of extreme weather conditions and earthquakes and volcanic eruptions. This was followed by the better-publicized contribution of Benjamin Franklin [6]. The paper by Montredon, which was published in the Memoirs of the French Academy of Sciences a few years later [4], is a remarkable piece of careful observation in real time, with daily measurements of temperature, humidity, wind characteristics and state of the sky: Montredon correctly concluded that the exceptional haze was both dry and sulphur-rich, all precious indications for reconstructing the detailed conditions of the meteorological consequences of the eruption. In a very thorough reassessment of all data pertaining to the Laki, Thordarson and Self [12] were able to reconstruct the detailed history of the eruption, a sequence of 10 explosive events, most of them reaching the stratosphere and followed by a quieter phase of basaltic lava effusion.

Mortality induced by the eruption locally in Iceland, mostly due to fluorine poisoning, has been well studied (e.g., [10]). For almost a decade, John Grattan from the University of Wales at Aberystwyth and his colleagues have studied the distal environmental impact of this eruption, and in particular the social and health effects in Britain. In 2003, they gave evidence for elevated degrees of illness and mortality in England [7]. Grattan et al. have just extended the range of their observations to France in a paper published in this issue of *Comptes rendus Geoscience* [8]. The eruption started on 9 June 1783, and injected some 100 Tg of SO_2 up to lower stratospheric altitudes. The resulting sulphuric aerosol was injected well into the westerly jet stream over at least the first three months of the eruption. Grattan et al. [8] point out that this explains well the relative dates of arrival of the dense dry

E-mail address: courtil@ipgp.jussieu.fr (V. Courtillot).

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fog on the ground as early as 14 June in France and by 21 June in England. Grattan et al. had already shown that this resulted in at least 10 000 extra deaths, 10% above the 50-year mean, in England (see references in [8]). They now report that the mortality crisis was actually even worse in France and in the Low Countries: they table original reports of the first occurrence of the haze and conclude that all observations are similar to those in severe modern air pollution crises, implying sulphur concentrations in excess of thresholds for human illness. R. Rabartin, the second author of the paper, and students of the 'Université du temps libre' have visited local archives in a number of French departmental archives and provided striking time series of mortality in the three years surrounding the onset of eruption. The data demonstrate a completely anomalous peak of deaths in all areas, centred on September and October 1783. Mortality was almost 40% above monthly average between August and October. Grattan et al. [8] conclude that if these results can be extended to most of France (it seems to be the case in eastern France, E. Le Roy Ladurie, pers. commun., 2005), as is likely, then the death toll must have been very much in excess of the 16 000 people who died because of the 2003 heat wave and resulting pollution. The new study further demonstrates that the Laki fissure eruption did generate a continental-scale pollution crisis (also reported in northern Holland and probably extending over much of western and northern Europe), leading to acid concentrations above critical thresholds for humans. Summer heat and winter cold also linked to the eruption amplified the lethal effects, and the death rate of people with respiratory or cardiovascular diseases, or under some form of severe stress increased very significantly.

Very recently, Chenet [1] and Chenet et al. [2] have attempted to model the massive sulphate aerosol pollution due to the Laki using an atmospheric general circulation model (AGCM) and the aerosol input sequence reconstructed by Thordarson and Self [12]. The results, which are yet to be fully published, are very encouraging. They allow in particular to reconstruct the global distribution of the sulphuric haze and to determine the characteristic time in which the pollution peaks reach England and France, for instance. One can also evaluate the SO_2 threshold that is critical for haze formation. Simulations also confirm that the eruptive column must have reached well into the lower stratosphere over an extended period of several months and that the entire northern hemisphere was invaded by products injected by the eruption.

The recent paper by Grattan et al. [8], and in general the renewed interest in exploiting as well as possible a wealth of previously ill-known or unsuspected historical information concerning what was one of the most severe volcanic events in the past millennium, may have far-reaching and diverse implications. First, they confirm the views that large basaltic fissure eruptions can affect the weather, mostly through SO_2 injection up into the stratosphere, as much or more than explosive eruptions, which have long been recognized as significant agents of climate change [5,9]. Second, they should be a warning of the consequences that future similar eruptions could trigger. The 'repeat time' of Laki-type eruptions in Iceland is not known accurately but is likely on the order of a few centuries to a millennium. There is no (geological) doubt that there will be a new such eruption at some time in the future (on those timescales). This kind of event would halt all air traffic over the north Atlantic for months [9], in addition to causing severe health damage. That health damage would be compounded by the current pollution and allergy levels in Western Europe. Note that meteorological and climate models could allow forecasting pollution propagation with a few days warning.

Given the consequences of a major historical Laki-type eruption on populations in Iceland, Britain, France and Holland, and likely much of Western Europe, one can wonder what could be the consequences of a rapid succession of several such eruptions, as has been the case in flood basalt eruptions. It is being increasingly recognised that episodes of massive flood basalts correlate with mass extinction events (for a recent review, see [3]). These flood basalts comprise hundreds of flows, many of which are up to a hundred times the volume of the Laki flow (15 km^3). The eruptive duration of such flows has been estimated to be on the order of years to decades [11]. This implies that individual flows from such flood basalt events may have injected ten times more SO_2 in the atmosphere than the Laki and for ten times longer durations. And there were tens to hundreds of flows in sequence. Modelling of the climatic consequences of flood basalts is in progress [7,8]. But it already appears that such models, born from the collaboration of geologists, geophysicists and climate modellers, may actually be a benchmark much needed by those who attempt to model ongoing climate change. Indeed, an individual flood basalt flow may have been the building block of a mass extinction, with injection rates on the same order of time and duration than the changes generated by mankind in the past two centuries.

Grattan et al.'s work [8] shows us that collaborative work on Laki-type eruptions should also include the social and human sciences, with efforts to research rich archives. It would be particularly interesting if the French institute for demographic studies (INED) could extend this work in detail to the entire country.

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