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The ‘Meteorological Imaginations and Conjectures’ of Benjamin Franklin

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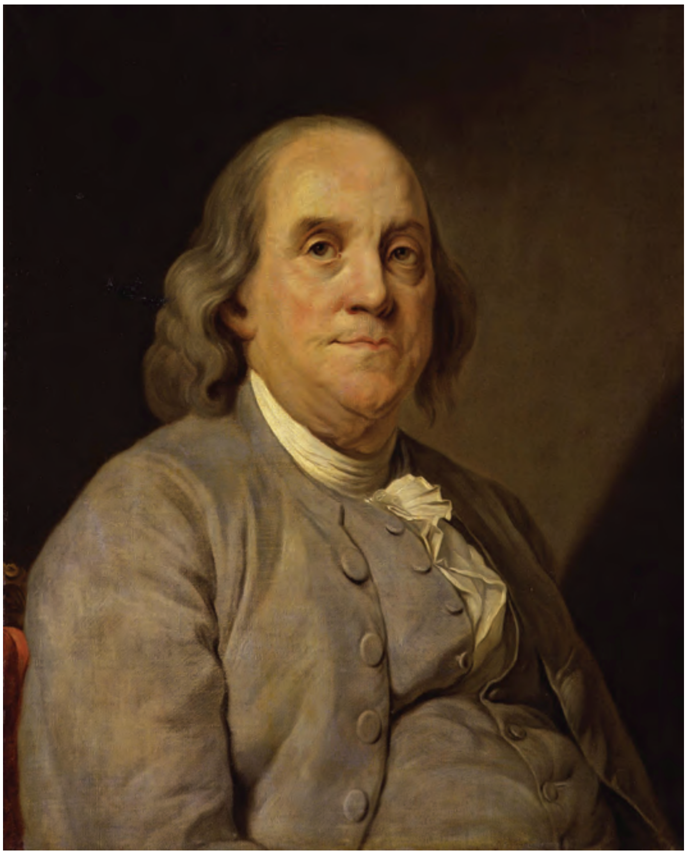
Abstract

On the 22nd December 1784 an essay by the American polymath Benjamin Franklin was presented to a meeting of the Manchester Literary and Philosophical Society. This extraordinary essay entitled ‘Meteorological Imaginations and Conjectures’ contains a variety of remarkable ideas which have since been supported by modern geographical research. In particular Franklin’s speculation that the cold year of 1783-4 might be related to a massive volcanic eruption in Iceland or the impact of extra-terrestrial bodies was the first time that volcanoes and meteors had been suggested as a cause of climate change. Franklin’s essay forms a milestone in geographical thought but is little known among most geographers. Here Franklin’s essay is reprinted in full and placed into its context, both historically and in the light of current scientific knowledge.

Keywords

Benjamin Franklin; Laki; volcanoes; meteors; dry fog



Benjamin Franklin. Painted by Joseph-Siffred Duplessis, ca. 1785.

“There seems to be a region higher in the air over all countries, where it is always winter, where frost exists continually, since, in the midst of summer on the surface of the earth, ice falls often from above in the form of hail. Hailstones, of the great weight we sometimes find them, did not probably acquire their magnitude before they began to descend. The air, being eight hundred times rarer than water, is unable to support it but in the shape of vapour, a state in which its particles are separated. As soon as they are condensed by the cold of the upper region, so as to form a drop, that drop begins to fall. It freezes into a grain of ice, that ice descends. In descending, both the drop of water and the grain of ice are augmented by particles of the vapour they pass through in falling, and which they condense by their cold-ness, and attach to themselves. It is possible that, in summer, much of what is rain, when it arrives at the surface of the earth, might have been snow when it began its descent; but being thawed in passing through the warm air near the surface, it is changed from snow into rain. How immensely cold must be the original particle of hail, which forms the centre of the future hailstone, since it is capable of communicating sufficient cold, if I may so speak, to freeze all the mass of vapour condensed round it, and form a lump of perhaps six or eight ounces in weight.

When in summer time, the sun is high and continues long every day above the horizon, his rays strike the earth more directly, and with longer continuance, than in the winter; hence the surface is more heated, and to a greater depth, *by the effect of those rays. When rain falls on the heated earth, and soaks down into it, it carries down with it a greater part of the heat, which by that means descends still deeper. The mass of the earth, to the depth of perhaps 30 feet, being thus heated to a certain degree, continues to retain its heat for some time. Thus the first snows that fall in the beginning of winter seldom lie long on the surface, but are soon melted and soon absorbed. After which the winds that blow over the country on which the snows had fallen, are not rendered so cold as they would have been by those snows if they had remained. And thus the approach of the severity of winter is retarded and the extreme degree of its cold is not always at the time we might expect it, viz. when the sun is at its greatest distance, and the day shortest, but some time after that period, according to the English proverb, which says, 'as the day lengthens, the cold strengthens'; the causes of refrigeration continuing to operate, while the sun returns too slowly, and his force continues to weak to counteract them.*

During several of the summer months of the year 1783, when the effect of the sun's rays to heat the earth in these northern regions should have been greatest, there existed a constant fog over all Europe and great part of North America. This fog was of a permanent nature; it was dry, and the rays of the sun seemed to have little effect towards dissipating it, as they easily do a moist fog, arising from water. They were indeed rendered so faint in passing through it, that when collected in the focus of a burning glass, they would scarce kindle brown paper. Of course, their summer effect in heating the earth was exceedingly diminished. Hence the surface was early frozen. Hence the first snows remained on it unmelted, and received continual additions. Hence the air was more chilled, and the winds more severely cold. Hence perhaps the winter of 1783-4 was more severe than any that had happened for many years.

The cause of this universal fog is not yet ascertained. Whether it was adventitious to this earth and merely a smoke proceeding from the consumption by fire of some of those great burning balls or globes which we happen to meet with in our rapid course round the sun, and which are sometimes seen to kindle and be destroyed in passing our atmosphere, and whose smoke might be attracted and retained by our earth: or whether it was the vast quantity of smoke, long continuing to issue during the summer from Hecla in Iceland, and that other volcano which arose out of the sea near that island, which smoke might be spread by various winds over the northern part of the world, is yet uncertain. It seems however worth the inquiry, whether other hard winters, recorded in history, were preceded by similar permanent and widely extended summer fogs, because if found to be so, men might from such fogs conjecture the probability of a succeeding hard winter, and of the damage to be expected by the breaking up of frozen rivers in spring, and take such measures as are possible and practicable, to secure themselves and effects from the mischiefs that attended the last." (Franklin 1784a)

Introduction

The above remarks were presented in 1784 by the American author, statesman and scientist Benjamin Franklin. They display a remarkable geographical insight on several key themes including seasonal temperature variability and the climatic impact of volcanoes and extra-terrestrial impacts. This commentary explores these ideas from a contemporary geographical viewpoint. Franklin's essay was written during a period of rapid and dramatic environmental change and reflects the widespread attempts of Enlightenment science to link disparate phenomena. Franklin's ideas are of interest from a point of view of both the history of geography and of conceptions of environmental change in late 18th century Europe and North America.

Franklin's essay was originally communicated in a May 1784 letter to the eminent Manchester physician Thomas Percival, Franklin's principal correspondent on matters of meteorology. Percival subsequently read this letter to the Manchester Literary and Philosophical Society on 22nd December 1784 (Franklin *et al*. 1834). The essay was printed in the second volume of the Society's *Memoirs* (the second oldest continuously published British scientific periodical) and it is through this publication that Franklin's thoughts have been disseminated. At the time of writing Franklin, then 78, was resident in Passy near Paris as United States Minister to France, a position he held until his return to the US in 1785. The essay forms part of a sequence of meteorological ideas and experiments throughout Franklin's life (Abbe 1906). Franklin's experiments on lightning are particularly well known but his interests extended to other geographical subjects including aurorae, magnetism, earthquakes and stratigraphy (Dean 2009). Franklin discussed his ideas with many of the most eminent scientists of the day; his correspondents on the topics spanned by *Meteorological Imaginations and Conjectures* included Nevil Maskelyne, William Herschel, Joseph Priestley and Erasmus Darwin.

The period 1783-4 included an extraordinary number of natural disasters. The most remarkable of these was the Lakagígar (Laki) eruption in Iceland. This vast flood basalt eruption produced a cloud of volcanogenic gases which spread across all of Europe and much of the northern Hemisphere. Impacts within Iceland were devastating with a large proportion of livestock, and much of the human population, perishing. Across Europe there were peaks in human mortality (Witham and Oppenheimer 2005; Grattan *et al*. 2005) and widespread damage to crops and other plants (Grattan and Gilbertson 1994; Grattan and Charman 1994). Over-lapping with the Laki eruption there were also volcanic eruptions in Japan and Italy, which both caused severe local impacts (Camuffo and Enzi 1995; Zielinski *et al*. 1994). There were large earthquakes in southern Italy leading to more than 40,000 deaths (Hamilton 1783) and major floods in Central Europe (Brazdil *et al*. 2010). Franklin was writing Meteorological Imaginations and Conjectures during a period when there were frequent and varying reports of natural disasters from around the world and his essay clearly reflects this context.

Hail and seasonal temperature variability

The first half of Franklin's essay might be considered the least interesting, and has certainly received the least modern attention, however the ideas here are worth discussion. Franklin begins by hypothesising a mechanism for the formation of hail whereby condensation in the cold upper atmosphere forms a drop of rain which instantly freezes and in falling causes other water vapour to condense onto the surface, freezing and augmenting the size of the hail stone. Franklin's idea of a drop of water freezing and falling, attracting more water to itself as it falls appears to be relatively consistent with much established knowledge of the time (the first edition of the *Encyclopaedia Britannica* (1770) discusses hail in very similar terms). The discussion of hail in *Meteorological Imaginations and Conjectures* also closely parallels that contained within a previous letter to Percival almost 13 years previously: *'It seems then, that each beginning drop, and particle of hail, receives continual addition in its progress downwards'* (Franklin 1784b). The missing piece of knowledge in Franklin's mechanism is that hail can be moved upwards within a thunder cloud – something both *Meteorological Imaginations and Conjectures* and Franklin's earlier letter reject – allowing a much longer residence time than Franklin envisages.

It is interesting to speculate why Franklin's thoughts might have turned to the formation of hailstones when writing his essay in the spring of 1784. Could it be that he had recently heard about, or experienced severe hail? His reference to hail stones *'perhaps six or eight ounces in weight'* (160-270g) certainly could be taken to imply that he had particularly severe hail storms in mind when writing. The historical record contains reference to numerous severe storms in the summer of 1783, including many producing heavy hail (Grattan and Brayshay 1995; Camuffo and Enzi 1995). For instance a letter to the Gazeteer and New Daily Advertiser (22/8/1783) describes *'one of the heaviest falls of hail and rain that perhaps has been ever known in this Kingdom'*. It seems quite likely that Franklin may have had such events in mind while writing.

In the subsequent section of the essay Franklin discusses seasonal variability of temperature, seeking an explanation for the off-set between the winter equinox and the timing of greatest cold. Franklin proposes that in summer the percolation of rainwater into the earth carries heat to depth which is then retained into winter. Franklin's idea of water percolation as a mechanism of storing heat seems reasonable but current understanding is that the seasonal lag is due to the moderating influence of the oceans. In an earlier essay Franklin (1818) actually gets very close to this, suggesting: *'Seas, lakes, and great bodies of water agitated by the winds, continually change surfaces; the cold surface in winter is turned under by the rolling of the waves (and the air over it), and a warmer turned up: in summer the warm turned under, and cooler turned up. Hence the more equal temper of sea-water, and the air over it'*.

Climate and the great dry fog of 1783

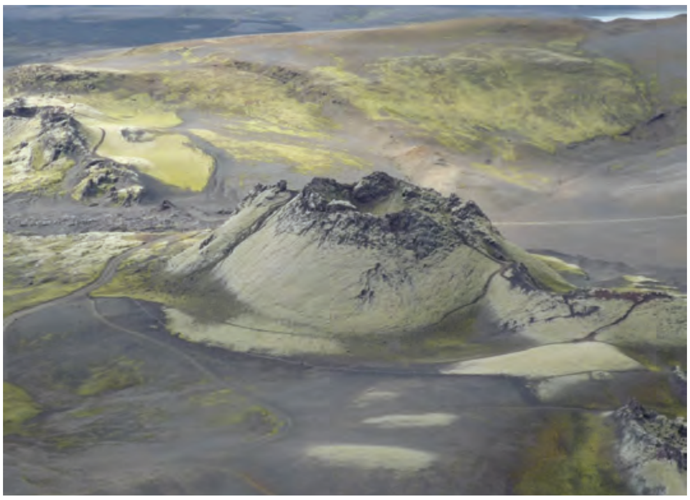
In the second half of the essay Franklin discusses the 'dry fog' and cold winter of 1783-4. Franklin speaks of the winter of 1783-4 being *'more severe than any that had happened for many years'* with early frosts, heavy snows, and cold temperatures. This cold winter is unambiguously shown by climate records for the period. The Central England Temperature series suggests January 1784 temperatures were over 3°C below the longer-term mean (Witham and Oppenheimer's 2005). A compilation of meteorological records suggests this cooling was widespread (Thordarson and Self 2003) with proxy-records suggesting an overall Northern Hemisphere cooling of 0.27°C (Briffa 1998). Clearly Franklin's personal observations were representative of a wider event.

Franklin's essay directly links this cold weather in 1783-4 to a widely extended 'dry fog'. *'This fog was of a permanent nature; it was dry, and the rays of the sun seemed to have little effect towards dissipating it'*. Franklin's comment that the suns rays *'were indeed rendered so faint in passing through it, that when collected in the focus of a burning glass, they would scarce kindle brown paper'* suggests that he may have personally carried out such experiments. The dry fog of 1783-4 is a well-known event and has been attributed to the gases produced by the Laki eruption (Stothers 1996). Franklin's observations parallel those of many others identifying the characteristic dryness of the vapours and their insensitivity to sunlight, other authors also mention a sulphurous smell (Thordarson and Self 2003). The dry fog was noted in as distant places as North Africa, Turkey, the Altai Mountains of central Asia, and perhaps even Brazil (Thorarinsson 1981; Demaree *et al*. 1998; Thordarson and Self 2003; Trigo *et al*. 2009). There has been debate over the validity of Franklin's assertion of dry fog over a *'great part of North America'* (Stothers 1996) but there is documentary evidence for its occurrence in at least some locations (Demaree *et al*. 1998). Franklin proposes two possible causes of the dry fog: volcanic eruptions and meteors.

Volcanoes and climate

Franklin names two volcanoes in his consideration of volcanic impacts on climate: Hecla (now generally spelt Hekla) and *'that other volcano which arose out of the sea near that island'* by which he means the island of Nyey, formed by a submarine volcanic eruption off the Reykjanes Peninsula of SE Iceland in 1783. There are no eruptions of Hekla recorded between 1766 and 1845 and we can be confident that Franklin is actually referring to the immense eruption of Laki (which was sometimes misreported as Hekla in the European press), part of the Grímsvötn volcanic system. That Franklin gives equal weight to both the vast Laki eruption and the much smaller eruption forming Nyey represents the attention paid to the two events in the European press where the Nyey eruption received at least as much reporting. Franklin suggests that the 'smoke' emitted from one of these volcanoes was spread round the *'northern part of the world'* blocking sunlight and leading to the cold winter.

Franklin's essay makes two distinct links, suggesting that the dry fog may have been caused by the volcanic eruption in Iceland and that the dry fog was the cause of the cold winter. Franklin was not the only person to suggest such links. Thorarinsson (1981) suggests the Danish scientist Christian Gottlieb Kratzenstein was the first to link the dry fog to Iceland. In France Mourgue de Montredon noted the coincidence of volcanic eruptions and extreme weather only a few months after the start of the eruption (Montredon 1784; Courtillot 2005). While Franklin was not the first to explore this issue he probably was the first to complete the chain of reasoning connecting the eruption in Iceland to the cold winter and his essay certainly had a role in popularizing this idea (Dean 2009). The idea that a volcanic eruption could affect climate was remarkably prescient, fore-shadowing a considerable amount of modern research. It was not until the era of satellite monitoring and direct observation of atmospheric chemistry changes in the late 20th Century (particularly following the 1991 Pinatubo eruption) that the power of volcanic eruptions to modify climate was firmly established (McCormick 1995). Franklin's ideas are remarkably close to modern understanding of how volcanoes impact climate. The crucial missing piece in Franklin's ideas concerns the height to which gases are ejected. Franklin assumes that volcanogenic gases in the lower atmosphere (the troposphere) are capable of changing climate. Today we understand that while gases in the troposphere may cause devastating impacts at ground level (as was the case in 1783) it is gases in the stratosphere which are largely responsible for climate-forcing (Grattan and Pyatt 1999).



Laki volcano, Iceland. Photo © Juhász Péter, Wikipedia.

Meteors and climate

Franklin's other hypothesis for the origin of the great dry fog and the cold winter of 1783-4 is that it could be due to *'some of those great burning balls or globes which we happen to meet with in our rapid course round the sun'* i.e. the atmospheric input of cometary or asteroidal material. This element of the essay has been over-looked compared to the suggestion of volcanic impacts however this idea is at least as remarkable. To my knowledge this is the first instance in which the impact of an extra-terrestrial body was cited as a possible cause of climatic change.

So, why did Franklin suggest this possibility? The historical record suggests that as well as the volcanic phenomena discussed above, 1783 was also notable for the number of meteors observed from northern Europe. A letter from the Astronomer Royal, Nevil Maskelyne, dated 6th November 1783 (Whitehall Evening Post 27/12/1783) comments on the recent frequency of meteor sightings and lists five dated August 18th, September 26th, October 4th, October 19th and October 29th 1783.

'An accurate representation of the meteor seen at Winthorpe on 18th August 1783'. By Henry Robinson © Trustees of the British Museum.

The meteor of 18th August 1783 was particular notable: a dramatic ball of fire which passed the length of the British Isles from Shetland to Dover and on over continental Europe with sightings in the Netherlands, Belgium, France and Germany to perhaps as far away as Rome (Blagden 1784; Beech 1989). A letter from Whitby to the London Chronicle (26/8/1783) speaks of *'an extraordinary meteor … whose lustre almost equalled the sun'*. In a speech before the Royal Society Cavallo (1784) notes that *'every object appeared very distinct; the whole face of the country … being instantly illuminated'*. The meteor of 4th October was almost as spectacular, described by Aubert (1784) thus: *'I saw, towards the N.N.E. a train of fire, resembling in its motion a common meteor, vulgarly called a falling star, but the colour of it was red … almost as large as the moon; it illuminated the street and houses much more than any lightening I have seen'*. Both of these meteors were seen from northern continental Europe, the 18th August meteor passing not far from Paris. It is extremely probable that Franklin either saw one of these meteors personally, or was at least aware of their observation through his correspondence or personal contacts. It is likely that in suggesting meteors as a possible cause of the dry fog Franklin was not simply speculating but was well aware that a large number of bright meteors had been recently observed.

It is interesting to note that Franklin considers meteors to be due to extra-terrestrial bodies *'destroyed in passing our atmosphere'*. Franklin refers to *'great burning balls or globes'* and clearly identifies them as celestial bodies, not merely a feature of the earth's upper atmosphere. This was not a generally accepted view at the time. Meteors had traditionally been seen as balls of burning 'dry vapours' in the upper atmosphere, a suggestion originally made by Aristotle but still apparent in much of the popular literature from 1783. By the late 18th Century two further theories had been proposed: that meteors were an electrical phenomenon (e.g. Blagden 1784), or that that they represented extra-terrestrial objects (Beech 1989). Given Franklin's well known interests in electricity (including lightning and aurorae) it is perhaps surprising that he opts for the extra-terrestrial theory. Franklin was certainly aware of the electrical hypothesis (e.g. Perkins 1838), his rejection of this idea might reflect his acquaintance with the American astronomer David Rittenhouse who both advocated the extra-terrestrial view and corresponded extensively with Franklin in this period (Rittenhouse 1783).

Franklin's ideas on meteors in *Meteorological Imaginations and Conjectures* echo his previous comments on the subject. In a letter of 1782 Franklin interprets meteors in terms of the *'Universal Fluid'*, a *'subtle fluid, whose motion, or vibration, is called light'*. Franklin hypothesises a 'sphere of fire' of this fluid surrounding the earth. He suggests: *'Is it not this sphere of fire which kindles the wandering globes that sometimes pass through it in our course round the sun, have their surface kindled by it, and burst when their included air is greatly rarified by the heat of their burning surfaces?'* (Franklin 1824). This comment suggests that as well as accepting a celestial origin of meteors Franklin believes them to include both solid and gaseous components.

In the suggestion of a climatic role for impacts of extra-terrestrial bodies we have another example of Franklin's ideas foreshadowing modern scientific knowledge. Today we have good evidence for the power of the impacts of extra-terrestrial bodies (albeit on a larger scale than the meteors of 1783) to affect climate. The putative link between the Chicxulub impact and the K-T extinction event has been one of the hottest topics of scientific debate over the last decade (e.g. Kring *et al*. 2007; Keller *et al*. 2009) and much recent research has been focused on the 1908 'Tunguska event' (Turco *et al*. 1982; Bronshtehn and Zotkin 1995) and a possible Younger-Dryas comet impact (Firestone *et al*. 2007).

The historical context to Franklin's hypotheses

Franklin was just one of many contemporary scientists who had an interest in environmental change in 1783-4 (Demaree and Ogilvie 2001). Given the large number and diverse range of natural disasters in the period it is perhaps unsurprising that scientists and the public speculated many links between these phenomena, the majority of which have not been supported by subsequent research. For instance, a correspondent to the *London Chronicle* (26/8/1783) suggests the 18th August meteor may have *'been occasioned by some of the vapours issuing from the volcanoes upon the New Island* *lately sprung up in the ocean, about nine leagues to the S.W. of Iceland'*. A letter to the *General Evening Post* (13/9/1784) notes that: *'When we combine the time and circumstances of this phenomena* [in Iceland] *with the late earthquakes in Calabria, in Germany, in Sweden, in Siberia, we readily have recourse to the same common cause, namely that subterraneous fire which has lately spread terror over so great a part of the globe'*. The existence of a link between the earthquakes in Italy and the dry fog was a popular notion at the time. The hypotheses set out in Franklin's essay therefore sit in a context of the response of Enlightenment science to the large number of natural disasters in 1783. Many links were speculated between these disparate environmental phenomena, what distinguishes Franklin's ideas is the clarity of the mechanism proposed. Linking the dry fog to the cold winter was an entirely reasonable deduction and may have been backed up by the personal experimentation alluded to in the essay. Franklin's two hypotheses for the cause of this dry fog reflect his awareness of the concurrent volcanic eruptions in Iceland and the meteors reported in late 1783.

The climatic impact of stochastic geophysical processes continues to be an active area of geographical research, particularly stimulated by the imperative to understand natural mechanisms of climatic variability and thereby isolate the anthropogenic signal. *Meterological Imaginations and Conjectures* contains the first suggestion of the power of volcanoes and extra-terrestrial impacts to modify climate. Franklin's essay forms an important milestone in geographical thought and should be of wide interest to contemporary geographers. That these ideas were first communicated in Manchester should add to their interest for those of us in northwest England.

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