CLIMATIC AND DEMOGRAPHIC CONSEQUENCES OF THE MASSIVE VOLCANIC ERUPTION OF 1258

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Abstract. Somewhere in the tropics, a volcano exploded violently during the year 1258, producing a massive stratospheric aerosol veil that eventually blanketed the globe. Arctic and Antarctic ice cores suggest that this was the world's largest volcanic eruption of the past millennium. According to contemporary chronicles, the stratospheric dry fog possibly manifested itself in Europe as a persistently cloudy aspect of the sky and also through an apparently total darkening of the eclipsed Moon. Based on a sudden temperature drop for several months in England, the eruption's initiation date can be inferred to have been probably January 1258. The frequent cold and rain that year led to severe crop damage and famine throughout much of Europe. Pestilence repeatedly broke out in 1258 and 1259; it occurred also in the Middle East, reportedly there as plague. Another very cold winter followed in 1260–1261. The troubled period's wars, famines, pestilences, and earthquakes appear to have contributed in part to the rise of the European flagellant movement of 1260, one of the most bizarre social phenomena of the Middle Ages. Analogies can be drawn with the climatic aftereffects and European social unrest following another great tropical eruption, Tambora in 1815. Some generalizations about the climatic impacts of tropical eruptions are made from these and other data.

1. Introduction

In the year 1259, a rain of sulfuric acid aerosols and tiny glass shards originating from one of the greatest volcanic eruptions of the past two millennia fell out of the stratosphere onto the North and South polar ice caps. Samples of the debris have been retrieved in modern times from dated ice cores in Greenland (Hammer et al., 1980; Langway et al. 1988; Johnsen et al., 1992; Palais et al., 1992; Zielinski et al., 1994; Zielinski, 1995), the Canadian Arctic (Fisher and Koerner, 1988; Zheng et al., 1998), and Antarctica (Zanolini et al., 1985; Langway et al., 1988; Palais et al., 1990; Delmas et al., 1992; Hammer et al., 1997). On the plausible assumption that this event had to have been a tropical eruption, the total production of sulfuric acid has been estimated as $\sim$300 megatons (Hammer et al., 1980; Langway et al., 1988; Zielinski, 1995; Hammer et al., 1997) and possibly as much as $\sim$600 megatons (Delmas et al., 1992). Thus, this eruption exceeded in magnitude all of the greatest known historic eruptions of post-medieval times, such as Tambora, Indonesia, in 1815 and Laki, Iceland, in 1783.

To the present day, though, the source volcano for the 13th century aerial fallout remains unknown. A Madinah, Saudi Arabia, eruption in 1256 (Camp et al.,

Climatic Change **45:** 361–374, 2000.

1987) seems to have been too early in date and much too small in magnitude to be relevant. A huge eruption of El Chichón, Mexico, occurred at roughly this time (Tilling et al., 1984) and the composition of glass shards from field samples appears to match what is found in Greenland and Antarctic ice cores (Palais et al., 1990, 1992). Yet the match is not perfect in detail and, in any case, glass chemistry is not a highly discriminatory diagnostic for volcanic eruptions.

The year of the volcanic eruption, however, is accurately known. Although the peak fallout of aerosols over the poles occurred in 1259, the rise to maximum started in 1258 (Hammer et al., 1980). Therefore, if modern tropical eruptions provide an applicable analogy, stratospheric injection must have occurred in 1258.

Such a large eruption would probably have had easily observable meteorological consequences. Tropical eruptions in modern times generate globe-girdling stratospheric aerosol veils (dry fogs) that persist for several years, slowly settling out. The aerosols block some of the incoming sunlight and alter atmospheric circulation patterns, and by these means cool much of the Earth's surface. This temporary disturbance of the world's climate, often involving increased precipitation, can adversely affect agriculture. Consequences may be a greater human susceptibility to famine and disease, leading ultimately to social and political unrest. In earlier times, with their more primitive technological conditions, these consequences often occurred in exaggerated form. On the other hand, human beings are flexible as well as vulnerable in the face of adverse climatic events, large or small. There is obvious risk, therefore, in linking natural and social phenomena unless cause and effect are clearly discerned. In the present instance, the largest known volcanic eruption of the past millenium is the subject of inquiry. With such an unambiguous premise, the climatic and social consequences can be readily sought, although the scales that are manifested will need some interpretation in the light of other contingencies.

The present paper traces the aftermath of the eruption of 1258 in Europe and the Middle East, as determined mostly from contemporary historical sources. Although there were no instrumental measurements made at that early time, the anecdotal remarks by careful observers reporting on their own times and localities can serve as limited proxies for such information. Even if these human recorders (usually monks) were not scientifically trained or widely informed, they had at least a formal education. It is always necessary, however, to beware of methodological pitfalls when compiling climatic and related information from the medieval chronicles (Bell and Ogilvie, 1978; Ingram et al., 1978; Alexandre, 1987; Pfister et al., 1996). It is less well understood that this information needs also to be placed in the contemporary historical context, in order to interpret the climatic events correctly.

2. Dry Fog in 1258

Two pieces of evidence suggest the presence of a widespread dry fog in 1258. First, there is the continued cloudy appearance of the sky in the summer of that year across France. Was this appearance due at all times to the abundant rain clouds? According to the reliable, but loquacious Richer (1267) of Sens:

> What, then, shall I say about the fruits of the earth that year, when the weather was so remarkably unseasonable that the warmth of the Sun was hardly able, even a little, to reach the earth, and the fruits of that year could barely attain maturity, if at all? For so great a thickness of clouds covered the sky throughout that whole summer that hardly anyone could tell whether it was summer or autumn. The hay, drenched incessantly by strong rains that year, was unable to dry out, because it could not collect the warmth of the Sun on account of the thickness of the clouds.

In other parts of France, western Germany, and northern Italy, the summer and autumn of 1258 were also very rainy and chilly (*Notae Constantienses*, c. 1260; *Chronicon Savigniacensis*, c. 1300; *Annales Spirenses*, c. 1259; Girard de Fracheto, 1271; Alexandre, 1987). Although in England a brief hot summer did ripen the crops, these were undone by heavy autumn rains, beginning in August (Matthew Paris, 1259; John de Taxter, 1265; Titow, 1960).

Although we are not explicitly informed about the sky conditions that summer in England, the cloudiness in France seems to have persisted between rainstorms. This suggests, but does not prove, that a constant dry fog was present in the atmosphere. Certainly, the known volcanic eruption would be expected to have produced a global stratospheric dry fog. Polar ice cores indicate that the volcanic output of sulfur in 1258 was twice the output from Tambora, implying a worldwide peak aerosol optical depth of $\sim$2, which is comparable to the aerosol optical depth over Europe during the visibly thick dry fog created by the Laki fissure eruption (Stothers, 1996a). Though very large, the drop in direct solar radiation by itself would not have interfered much with surface heating of the earth and with crop growth, as we know from the reported course of the Laki dry fog over England during the summer months of 1783 (Grattan and Charman, 1994).

More conclusive evidence of a large aerosol veil in 1258 comes from the contrasting accounts of two lunar eclipses during this year and a later year. The English chronicler John de Taxter (1265) states that 'the Moon underwent a complete (*totalis*) eclipse' on 18 May 1258, and that 'there was a typical (*generalis*) eclipse of the Moon, of a bloody color' on 24 December 1265. The Englishman Matthew Paris (1259) also uses the term *generalis* for a typical lunar eclipse.

The normal color of the eclipsed Moon is in fact red. When, however, the Earth's stratosphere contains an abundance of volcanic aerosols, the incident sunlight cannot be refracted and scattered into the shadow cone, and therefore the Moon appears completely dark (Link, 1963). For the Moon to effectively vanish, an aerosol optical depth of 0.1 or more is needed. This appears to have been the case on 18 May 1258, confirming that both hemispheres of the Earth were obscured by aerosols. But by 31 August 1262 the stratosphere seems to have cleared, because the eclipsed Moon on that date showed ‘a bloody color’ (*Chronica Minor Auctore Minorita Erphordiensi*, 1265).

A last point to be noted about the weather in 1258, whose relevance will be explained below, is that a long cold spell occurred in England between February and June that year (Matthew Paris, 1259). The same winter is also reported to have been a severe one at Prague in Bohemia (Continuator of Cosmas, 1283) and the springtime was noted as harsh in northern Iceland (Ogilvie, 1990).

3. Weather Patterns after 1258

After the very rainy autumn of 1258, the following winter in England was unexceptional. Matthew Paris (1259), who regularly reports in detail on the weather near London, indicates nothing unusual for that winter. The *Chronicle of Novgorod* (1471) mentions an odd frosty day in Russia during April 1259. The summertime afterward was hot and dry in Austria and Germany (*Continuatio Lambacensis*, 1283; *Annales Wormatienses*, c. 1300) and hot and stormy in France (*Notae Constantienses*, c. 1260), while it rained a lot in England (*Flores Historiarum*, 1265).

Less is known about the weather in the following year, 1260. After a very mild winter, central France experienced severe cold and snow during April (*Chronicon Savigniacensis*, c. 1300). But the summer weather was alternately dry and stormy, with a lot of hail, near Prague (Continuator of Cosmas, 1283) and likewise near London (*Flores Historiarum*, 1265).

It was not until later that year that Europe suffered another very cold winter. The winter of 1260–1261 struck Iceland so severely that people were forced to slaughter many of their livestock (Thórdarson, 1284) and ice formed in the sea all around the island (Storm, 1888). Very harsh winter conditions are also reported for England (*Flores Historiarum*, 1265; Continuator of William of Newburgh, 1298) and for northwestern Italy (Ventura, c. 1325). In Alsace, the Ill River froze (*Annales Colmarienses Minores*, c. 1300), but it is not clear whether this happened in the winter of 1260–1261 or of 1261–1262, or in both winters.

It is apparent that very cold European winters occurred in 1257–1258 and 1260–1261. Does this pattern of cold winters match the behavior of weather anomalies after modern large explosive eruptions in the tropics? Within a month of such a modern tropical eruption, northern land masses experience sudden and prolonged declines of surface air temperature, which last 3–6 months (Kelly and Sear, 1984; Sear et al., 1987; Bradley, 1988; Kelly et al., 1996). If the eruption of 1258 occurred in January, the suddenly cold weather in England between February and June might thus be explained. At least we suspect from that year’s dark lunar eclipse on 18 May that the eruption must have taken place before mid-May. After a modern eruption, a second period of cooling ensues anywhere from 1 to 5 years after the eruption, the most typical elapsed time being 2 or 3 years (Rampino et al., 1988; Angell, 1988; Bradley, 1988; Mass and Portman, 1989; Groisman, 1992; Robock and Mao, 1995; Hansen et al., 1996; Kelly et al., 1996; Parker et al., 1996). After the 1258 eruption, the peak cooling in England did in fact occur 3 years later. Finally, in Europe a relatively normal, or even warm, first winter tends to follow modern large tropical eruptions (Bradley, 1988; Groisman, 1992; Robock and Mao, 1995; Kirchner and Graf, 1995; Kelly et al., 1996). After the eruption of 1258, just such a mild first winter (1258–1259) occurred.

The warm, or at least unexceptional, summers of 1259 and 1260 would be expected to have produced normal growth rings in north temperate trees. In this respect, the summer warmth apparently extended over much of the northern region of the world that dendrochronologists have studied: Fennoscandia (Sirén, 1961; Briffa et al., 1990), Québec (Yamaguchi et al., 1993), and the western United States (LaMarche and Hirschboeck, 1984; Scuderi, 1990). In 1257, however, the Sierra Nevadan foxtail pines (*Pinus balfouriana*) produced very little ring growth (Scuderi, 1990). Since rainfalls over France and England were unusually heavy and frequent during the summer and autumn of 1257 (*Quintum Supplementum Majoris Chronici Lemovicensis*, 1274; Matthew Paris, 1259; John de Taxter, 1265), severe storminess may have been common throughout a wide latitudinal band, including the Sierra Nevada.

4. Famine

Famine was frequent in pre-industrial societies and was often highly localized. What we are looking for, however, is something bigger: evidence of a general European agricultural failure that might have been climatically related. During the four-year period 1258–1261, only the year 1258 fits this criterion of universality. The heavy summer and autumn rains in 1257 and 1258 ruined crops throughout England, western Germany, France, and northern Italy. Severe famine is explicitly attested in many localities, and can also be inferred elsewhere from the high prices of staple agricultural commodities.

England was especially hard hit. Famine in the countryside drove thousands of villagers into London, where many of them perished from hunger (*Flores Historiarum*, 1265; Arnald Fitz-Thedmar, 1274). Richard of Cornwall, the king of Germany, was able to ship some grain from Germany and Holland into London to alleviate the distress of the poor who could afford to buy (Matthew Paris, 1259). The price of food throughout England rose, nonetheless (John de Taxter, 1265; *Annales de Dunstaplia*, 1297; Titow, 1960), and eventually specie itself became in short supply, having been already depleted by heavy tax exactions at the hands of both the church and state (Matthew Paris, 1259).

The situation in France was almost as grim. A severe grain shortage across the country led to widespread famine and sudden inflation of food prices in 1258 (*Quintum Supplementum Majoris Chronici Lemovicensis*, 1274; Alexandre, 1987). In northern Italy, food prices were also very high – for example, in Bologna and Parma (Albertus Miliolus, c. 1265; *Annales Parmenses Maiores*, 1335). Yet this inflation may well have been due more to the decades-long Italian wars between the papal (Guelph) faction and imperial (Ghibelline) faction, which peaked in the years just before 1260.

Finally, in the Middle East the historian Bar-Hebraeus (1286) reports a famine during 1258 in the general region of Iraq, Syria, and southeastern Turkey. Nevertheless, this disaster may have been just one of the side effects of the Mongol conquest of Baghdad in that year, which brought about the end of the Abbasid caliphate.

5. Pestilence

Pestilences of various kinds often break out in times of prolonged wet weather and famine. Unless an accurate description of the symptoms is reported, however, it becomes next to impossible to diagnose the particular disease with certainty. Unfortunately, most medieval descriptions of disease outbreaks in the general population are much too brief and vague for us today to identify the specific ailments referred to.

In England, the cold winter and spring of 1258 produced outbreaks of murrain in sheep, as well as various famine diseases within the human population, especially among the numerous urban paupers (Matthew Paris, 1259). French and Bohemian livestock, too, were afflicted with heavy mortality (Richer, 1267; Continuator of Cosmas, 1283).

The main scourge of human beings in the period, however, was the great pestilence of April 1259. This epidemic is known to have struck London (Matthew Paris, 1259), Paris (*Notae Constantienses*, c. 1260), other parts of France (*Annales Sancti Benigni Divionensis*, 1285), Italy (Salimbene, 1287), and, probably, Austria (*Annales Sancti Rudberti Salisburgenses*, 1286). Riccobaldo of Ferrara (1313) also mentions the pestilence, but under the year 1258. The chief symptoms were chilliness and listlessness (*frigor*) that could linger for several months or else kill rather suddenly. Although an influenza epidemic is a possible explanation, the diagnostic data are too few for us to go beyond this mere speculation.

In the Middle East, there was also reported a great pestilence in 1258, affecting Iraq, Syria, and southeastern Turkey (Bar-Hebraeus, 1286). It was called 'plague' by the 14th century Syrian chronicler Abū l-Fidā' (Dols, 1977), and was said to have been especially severe in Damascus; it is also mentioned by the 15th century Egyptian historian al-Maqrīzī (von Kremer, 1880). This pestilence continued until 1260, or perhaps it merely reappeared then, at least in southeastern Turkey (al-

Makīn, 1260; Bar-Hebraeus, 1286). Because the Middle East has been historically prone to epidemics of bubonic plague, possibly that is what it was.

6. The Flagellants

Flagellation, or scourging, had long been practiced as an occasional form of discipline or penance within Christian monastic communities. In the spring of 1260, however, a popular penitential movement of self-flagellation arose in Perugia, central Italy, and spread south, in the autumn, to Rome and north toward central Europe. Wholly orthodox at first, it attracted not only members of the clergy but all ranks and ages of pious lay people. Early in the following year, though, it degenerated into a heterodox movement of peasants and malcontents, which was put down finally by the ecclesiastical and civil authorities. In its typical manifestation, bands of unshirted male flagellants marched through the streets in double file, uttering hymns and religious slogans and flogging their backs with whips until blood began to flow. Troops of flagellants traveled from town to town. It was one of the oddest mass social phenomena of the Middle Ages.

The origin and spread of the flagellant movement of 1260 have been much analyzed (Dickson, 1989, and references therein). Although the episode arose in the general context of 13th century religious revivals and the Crusades, there was abundant social distress in Italy from local wars at the time, with a serious threat of a Mongol invasion of eastern Europe looming. For the latter reason especially, Austria, Germany, Bohemia, Poland, and Hungary were very fertile ground for such a penitential revival, whereas England and France (though not Provence and Alsace) seem to have been spared (Förstemann, 1828; Goll, 1913; Dickson, 1989). It may be significant that a small flagellant band of ‘Western Franks’ even arrived at Acre in the Levant (al-Makīn, 1260).

Since the geographical distribution of the various flagellant pilgrimages does not closely correspond to the areas hit hardest by the famines and pestilences of 1258 and 1259, some reasonable doubt seems to exist as to a possible connection between those natural disasters and the flagellant movement. Frugoni (1963) and Dickson (1989) have in fact denied such a connection even in the case of Italy, where a potentially best case might be made. Dickson emphasizes the flagellants’ cry for ‘mercy and peace’, not for better harvests or relief from pestilence, which were, at other times, a cause for initiating such solemn processions. Indeed, the organized English processions of 1258 and 1260 are known to have been occasioned by harvest failures (Matthew Paris, 1259; *Flores Historiarum*, 1265), while those in France during 1260 or 1261 were authorized by King Louis IX to avert the Mongol menace in the East (William of Nangis, 1300).

But is it correct to deny any socioreligious impact whatsoever in Italy from the natural disasters of the time? Such a denial would defy common sense, and, indeed, Gregorovius (1906) includes these disasters in the litany of the various forces that provoked a religious revival in 1260. The deliberate Christian symbolism of the flagellants' suffering and blood could relate equally well to the deadly ravages of famine and pestilence as to the bloodshed of the Guelph and Ghibelline wars. Considering also the human deaths and material damage to many Sicilian towns caused by the severe earthquakes in 1259 (Menco, c. 1275), the much-feared New Testament prophecies of the four signs preceding Christ's Second Coming – namely, strife among nations, famines, pestilences, and earthquakes (Matthew 24: 7; Luke 21: 10–11) – might seem to have been fulfilled, to the religious mind of 1260.

Nevertheless, it was not until the Black Death in 1348 that a pestilence would inspire, directly and unambiguously, a revival of mass self-flagellation across Europe.

7. Discussion

Contrary to what might be naively expected, some of the climatic aftereffects of the 1258 eruption seem not to have been very extraordinary. Prompt cooling in Europe occurred, but the following years, except for 1261, were not particularly cold for an eruption of twice Laki's size. The most probable explanation is the eruption's tropical location.

Another large tropical eruption for which such mixed climatic effects might potentially be detected easily in the historical record is the great explosion of Tambora in early April of 1815. This eruption produced roughly as much aerosol as Laki did (Stothers, 1984). To obtain a meaningful comparison with the climatic effects of the 1258 eruption, we shall examine a time series of central England surface air temperatures compiled by Manley (1974). Monthly mean temperatures during the 30-year period 1801–1830 reveal that February and March of 1815 were 2 °C warmer than usual, while April through October had approximately normal temperatures. Now according to Hamilton and Garcia (1986) and Quinn et al. (1987), a major El Niño/Southern Oscillation event (a tropical Pacific ocean and atmosphere warming) occurred in 1814. Although this event has been questioned by Ortlieb and Macharé (1993), it would, if real, have surely warmed much of the global troposphere for approximately a year, counteracting any possible volcanic cooling (Angell, 1988; Robock and Mao, 1995; Kirchner and Graf, 1995; Parker et al., 1996). Thus, the abnormal warmth in England during February and March of 1815, followed by apparently normal temperatures from April through October, suggests that a prompt, but disguised, volcanic cooling did begin in April. Although most of the recent El Niño events have not led to particularly noticeable warmings in the British Isles (Fraedrich and Müller, 1992; Halpert and Ropelewski, 1992; Benner, 1999), the tropical-extratropical teleconnection may be stronger under certain circumstances, such as an origination of the El Niño in the far western Pacific (Hamilton, 1988).

A second observation for central England during this period is that the first winter after the Tambora eruption was nearly normal. However, the remainder of the year 1816 became exceptionally cold and rainy, with only a partial recovery of normal warmth in 1817 (Post, 1977). We may conclude that, when a proper allowance is made for the El Niño warming effect, the weather patterns over England after Tambora did conform more or less to what followed after the great eruption of 1258.

Since other well-dated tropical eruptions generated less than half of Tambora's aerosols, the natural variability of the climate (including El Niño warming) could possibly have hidden any potential climatic effects of these lesser eruptions. Although the method of superposed epoch analysis is sometimes used to try to bring out the volcanic signal, it will prove more useful here to consider the largest of these eruptions on an individual basis.

The Pinatubo, Philippines (June 1991) eruption caused a slight immediate global cooling, followed by a winter warming and then an abnormally cool remainder of the year 1992 (Hansen et al., 1996; Kelly et al., 1996). Surprisingly, Santa Maria, Guatemala (October 1902) seems not to have had as large a climatic impact as Pinatubo, from the evidence of both instrumental (Angell and Korshover, 1985; Mass and Portman, 1989; Robock and Mao, 1995; Kelly et al., 1996) and dendrochronologically inferred (Briffa et al., 1998) surface air temperatures. Yet this was a major aerosol-producing eruption comparable in size to Pinatubo (Stothers, 1996b). On the other hand, the consequences of the larger Krakatau, Indonesia (August 1883) eruption did follow the standard Pinatubo pattern. Nothing is yet known of any prompt climatic impact from the eruption of Huaynaputina, Peru (February 1600), but northern tree rings suggest that the summer of 1600 was relatively mild (Briffa et al., 1998; de Silva and Zielinski, 1998), perhaps because a strong El Niño occurred that year (Quinn, cited by Ortlieb and Macharé, 1993); the following summer, however, was exceptionally cold.

The only other large eruption known not to have been followed by a prompt apparent cooling is the massive Icelandic Laki eruption (June–August 1783). Its extratropical location is probably irrelevant, because the much smaller Katmai, Alaska (June 1912) eruption was immediately followed by noticeable cooling (Mass and Portman, 1989; Robock and Mao, 1995; Briffa et al., 1998). Although the summer of 1783 in Iceland was remarkably cold under the thick volcanic ash clouds (Stothers, 1996a) and low temperatures possibly occurred as well in some far northerly parts of North America (Briffa et al., 1994), an unusual warmth prevailed otherwise at northern mid-latitudes (Wood, 1992). The unknown moderating factor may have been the strong El Niño of 1782–1783 (Quinn, cited by Ortlieb and Macharé, 1993). This illustrates, again, the potentially important effect of an El Niño event and the need to treat each volcanic eruption on an individual basis.

In summary, the present climatological study of the great 1258 eruption, taken in conjunction with published studies of other large tropical eruptions, confirms the tentative findings that have been previously deduced statistically for mostly smaller, modern tropical eruptions. Although natural climate variability (especially El Niño warming) tends to dilute the volcanic signal, a large enough eruption is able to poke through the background noise, producing discernible effects in a climatically sensitive region like Europe. The particular season in which the eruption occurred seems now not to be as important as has been sometimes suspected. If left undisturbed, the normal sequence of events consists of a prompt global surface cooling, a mild following winter on the continents, and a cold remainder of the year. One or more additional cold years may ensue. There can also be adverse agricultural and epidemiological consequences due to the climatic disruption (Stothers, 1999). Events after the 1258 eruption were therefore typical for large tropical eruptions.

The NASA Climate Research Program provided general support for this project. Libraries supplying the older research materials were the Butler Library of Columbia University and the New York Public Library.

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(Received 7 July 1998; accepted 28 April 1999)