The 'Winter' Analogy Fallacy:

From superbombs to supervolcanoes

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In the late 1980s, a few volcanologists created an ill-founded analogy. Drawing upon the then-fashionable 'nuclear winter' theory, they claimed that certain explosive eruptions in historic times might have led to 'volcanic winters.' The nuclear winter debate of the 1980s was about the possibly disastrous effects of a nuclear war on the Earth's atmosphere and climate, thus on agriculture, and human beings; the term implied that the dust and soot released into the atmosphere by nuclear bombs and the resulting fires would drop world-wide temperatures enough to turn summer into winter. Major effects, it was inferred then, would last for weeks or at most a few months. The exact consequences of nuclear war remained subject to a lively debate lasting throughout the 1980s. Modeling was still in its infancy, and uncertainty was high. This was also true of research into the topic of volcanism and climate. The global influence of explosive volcanic eruptions on the Earth's climate was still contested by volcanologists, who in the early 1980s had grudgingly conceded to atmospheric scientists' argument that it was not volcanic dust, but sulphate aerosols in the stratosphere that affected global atmospheric temperatures (and this, as increasingly became clear, for periods of more than three years). Given the uncertainties in both models and the significant differences concerning the causes (dust and soot, versus sulphates) and length (three months to several years), the analogy between 'nuclear winter' and ' volcanic winter' was unsubstantiated, having only a vague commonality in a short-term diminution of global temperatures. In fact, as I will show, the analogy never underwent scrutiny, debate or substantiation, as some volcanologists succeeded in turning a passing speculation into a matter of fact.

Over the following years, the analogy took on a life of its own and spawned further analogies: large-scale volcanic eruptions turned into 'supereruptions,' and 'supervolcanoes' became natural equivalents for the human-made 'superbomb,' the hydrogen bomb. Some volcanologists played up this hype and tendency to self-aggrandizement, not only in their scientific articles, but also in popular TV features. For example, BBC and Discovery Channel programs on supervolcanoes played out the horrific scenario of a possible repetition of the eruption of the Yellowstone volcano in the state of Wyoming, which last erupted 600,000 years ago. Prominent volcanologists painted a somber picture of future eruptions —while ill concealing their excitement at how they had figured out that doom is inevitable. These programs obfuscated the fact that the more dangerous and also more imminent threats came, and still come from humans themselves—and volcanologists tended to play along.

The shortcomings of the analogy appear most decisively when considering the larger societal framework to which these concepts pertained: Nuclear war results from human decisions; a volcanic eruption doesn't, and there is nothing that we can do to prevent one. The thesis of nuclear winter, therefore, was (and still is) a political appeal to reconsider choices that might affect our lives directly, and about which we could actually do something, today, in this world. Volcanic winter, in contrast, might affect future generations in ways that could well dwarf the effects of nuclear bombs, but we don't know when, or to what extent—and, given the historical frequency of large-scale explosive eruptions (1 in every 120.000 to 200.000 years), we cannot even be sure that human beings will still be around when the next one strikes.[1]

This article examines how this analogy infiltrated scientific publications that then served as the scientific foundation for apocalyptic TV entertainment and education. It studies how scientists actually speak about prehistoric large-scale volcanic eruptions in a professional context, and how they address their larger social, political and economic considerations within the constraints of scientific publication. Some scientists abstain completely from any discussion of the larger societal impact of their research on large-scale eruptions; others prefer to engage with this issue, sometimes framing their findings in terms of worst-case scenarios for humanity. In the following I will argue that those scientists who created and fostered an unsubstantiated analogy during the late 1980s, also subscribed to a long-term vision of a gloomy future for humanity, creating a fallacy that over the next decades guided and misled them and some of their colleagues in the description and interpretation of the larger societal impact of their scientific results.

In pursuing this argument, I narrow my inquiry to scientific studies of the Quaternary eruption of Toba in Sumatra, approximately 74,000 years ago, the most widely studied case of a large-scale historic explosive eruption. In this context, it will be helpful to say a few words about the nineteenth-century eruptions of Krakatau (1883) and Tambora (1815) and their impact, as these two explosive eruptions have formed the lens through which volcanologists have viewed eruptions in earlier historic and geological eras. I will then explore how the label of 'volcanic winter' was attached to Toba during the 1980s, and show how much the 'winter' analogy, which has never undergone scrutiny by scientists, guided some volcanologists' argumentation during the following decades.

Explosive Volcanic Eruptions in Historic Time

The first geologists exploring the island of Sumatra came across a huge caldera lake.[2] However, they were not able to give a precise date for the eruption that created it, or to evaluate its local and global environmental effects. Up to the 1960s, only past eruptions for which written historic records were available could be dated with some accuracy, and volcanological studies aiming at a complete record remained limited to the period after 1500.[3] A series of new techniques developed during the 1960s, including radiocarbon dating, pollen counts, ice and sea core drillings, and tree ring analysis, provided important new clues to the Earth's deep volcanic and climatic past, ranging back from one hundred thousand to millions of years. These techniques allowed rough first approximations of the dates of major past events, and revealed formerly unknown eruptions of catastrophic scale. But the new techniques not only allowed chronologies of past events to be established, they also provided data that made it possible to speculate about their size and climatic and environmental impact, although this depended heavily on guesswork and extrapolation from reliable data from more recent volcanic events. In short, the distant volcanic past was a matter of interpretation, and tended to be framed by some volcanologists in terms of catastrophic and worst-case scenarios.

The so-called super-eruption of Toba, which erupted after the evolutionary appearance of human beings, became a symbol of volcanoes' catastrophic effects on humanity and on the Earth's climate, and must be seen against the background of vigorous environmental debates about limited resources and climate change that started during the late 1960s and flourished in the 1970s.[4] While Toba provided an occasion to evaluate the fragility or robustness of the climatic system and the possible consequences of a super-eruption for vegetation and human civilization, climatologists nevertheless urged caution, as data were sparse and indirect, available only through proxy indicators whose interpretation requires experience and skill.

Given this uncertainty, scientists returned to studies of recent historic volcanic eruptions, such as Krakatau in 1883 and Tambora in 1815, from which in a second step they extrapolated the likely consequences of eruptions on a much larger scale, such as Toba's. Krakatau, located between the islands of Sumatra and Java, in what was then the Netherlands East Indies, erupted spectacularly in 1883. Preliminary eruptions led up to a violent explosion on August 27, which plunged the island's immediate surroundings into utter darkness, interrupted only by fierce flashes of lightning. Altogether, some 30 gigatons of material erupted (corresponding roughly to 11 cubic kilometers of dense rock). Of two thirds of the island, there remained only an undersea caldera. The explosive eruption caused tsunami in the oceans that moved towards the coastlines of Java and Sumatra. These waves, with a period of 100 km, moving with a speed proportional to the square of the depth of the ocean, slowed down near the shorelines, and built up to heights of fourteen to thirty meters. They killed about 36,000 people in some 160 villages along the coastlines. The news of the disaster spread rapidly around the world, and Krakatau became a benchmark event in scientific and popular imagination. A flood of pictures and articles filled popular and scientific journals, providing images of the destruction due to the tsunami.

Krakatau's eruption had world-wide effects, for the first time traceable by means of recently established worldwide scientific networks. For example, the dust (as it was called then) projected in the higher atmosphere started spreading around the whole world, causing spectacular red sunsets, observed in Europe, North America and elsewhere. The link between these colorful sunsets and Krakatau, several thousand miles away, was not evident at all, but scientists finally reassured a wary public, which had interpreted these as signs of doom.[5] Their work culminated in a report of the Royal Society published in 1888, which showed that the so-called smoke stream (then defined by scientists as fine dust projected into the high atmosphere) was the cause of red skies seen throughout the world. The commission in fact determined the expansion of the smoke-stream by tracing observations of the red skies.[6]

The Krakatau disaster triggered research into earlier explosive volcanic eruptions. While an article in *Nature* in 1883 took Krakatau to be the “greatest phenomenon in physical geography which has occurred during at least the historical period,” it became evident that there had been a number of previous eruptions with equal or greater global impact.[7] The Royal Society report included a list of all known volcanic eruptions after 1500 and correlated these with unusual atmospheric phenomena. It was in this context that the 1815 eruption of Tambora in Sumbawa, also in today's Indonesia, became interesting. Tambora blew up in an eruption that was yet an order of magnitude bigger than Krakatau in terms of material erupted. Altogether some 140gt (corresponding to 50 cubic kilometers of dense rock) erupted within 3-24 hours.[8]

The immediate effects of the eruption, including pyroclastic flows at distances of over 20 kilometers from the volcano, killed more than 10,000 people in the vicinity of Tambora, and the subsequent famine and diseases due to crop failures (the wet-rice crop was still in the fields at the time of the eruption) and contaminated water caused another 38,000 deaths on the island of Sumbawa alone, and further tens of thousands in the neighboring islands of Lombok and Bali.[9] Its long-lasting effects were likewise severe; agriculture in the islands recovered only after several years.

The eruption of Tambora also affected Europe. The report of the Royal Society listed in detail previous glow phenomena analogous to those caused by Krakatau, and came to the conclusion that 1815 was the "most remarkable [year] as regards sunset lights recorded up to this date."[10] Spectacular red and orange sunsets and twilights were observed in Europe three to five months after the eruption. From the northeastern part of the United States came reports of persistent 'dry fog' located high in the atmosphere and unaffected by wind or rain. The possibility that Tambora had had an influence on the global climate was discussed from the beginning of the 20th century, when the unusual weather of 1816 was connected for the first time to the 1815 eruption. 1816 became famous for its unusually cold weather; it was often called "the year without a summer," the "poverty year," or "eighteen hundred and froze to death."[11] Meteorological observations from Europe and the northeastern part of the United States and Canada showed that there was abundant rain in the particularly chilly summer months of June, July, and August. Subsequent crop failures and high food prices led to famine and death in America, Switzerland, and Ireland. Recent estimates of the effect of Tambora on climate speak of a drop of the mean summer temperature in the northern hemisphere of about 0.5° Celsius in 1816.[12]

Deep Time: Toba

In 1976, Dragoslav Ninkovich and William L. Donn of the Lamont-Doherty Geological Observatory in Palisades, New York came across the Toba eruption when they studied the climatic impact of explosive volcanic eruptions during the last 65 million years, the Cenozoic era, with the help of sea cores.[13] A comparative study of various sea cores (piston cores of limited depth, and deep sea drilling cores that ranged back some 60 million years) allowed them to look into geologic time. They pointed to Toba's caldera dimensions of 30 km to 100 km, and estimated the eruption volume at 2000 km^3 (current estimates give 2800 km^3 of dense rock equivalent, thus 3500 times the size of Tambora).[14] Toba, they speculated, might have influenced climate by way of feedback on the already existing cooling trend during the Cenozoic period. Nevertheless, they were careful to stress that to prove this point would require more knowledge of the frequency of such large-scale volcanic eruptions:

> Only an unusually high frequency of eruptions could have a long-term climatic effect. During historic times this has not occurred, and the deep-sea core record has not been adequately correlated on a global scale, nor adequately resolved on the vertical time scale, to determine whether such a high frequency of explosive volcanism occurred during the Cenozoic. ... Such events, when occurring at

> critical times of climate evolution, might have strongly modulated the intensity of climate change.[15]

Ninkovich's work took place at a time when the century-old debate over the causes of ice ages took an interesting and ultimately decisive turn with the orbital explanation by Hays et al. in 1976.[16] Volcanoes no longer figured as primary suspects in long-term cooling periods, but were reduced to an "important second-order" effect.[17] Two years later, thanks to further analysis of drillings in South Asia and South-East Asia, Ninkovich and his co-authors, among them Nicholas Shackleton, provided more precise data for the Toba ash layer and its distribution over Asia. They were now able to date Toba's explosive eruption to some 75,000 years ago, and to confirm it as "an order of magnitude larger than any other documented for the Quaternary," the last 1.8 million years.[18]

Another important clue was provided by ice cores, which contained information about sulphur and acid, deposited by major explosive eruptions. In the 1970s, some scientists began to argue that it was the sulphur dioxide released during an eruption and transformed into sulphuric acid droplets that was responsible for the warming of the stratosphere and the cooling of the Earth surface temperatures, and therefore for a global effect on climate. Many volcanologists considered volcanic dust rather than sulphate aerosols the prime suspect and were reluctant to accept this idea, but data obtained after the eruptions of Mt. St. Helens (1980) and El Chichón (1982), and the globally averaged surface warming after the Pinatubo eruption of 1991 ultimately convinced the last skeptics. Analysis of the ice cores could lead to estimates of the amount of sulphuric acid released during major volcanic eruptions, and therefore play a role as an indicator of climate modification.

Given these uncertainties, many research lines were pursued in parallel. More ice cores from various places narrowed down previous dates, and more data from recent volcanic eruptions shed new light on past eruptions. Another way of conceiving past events was by way of modeling. Modeling of the atmosphere and climate had picked up during the 1970s, and climate modification due to volcanic eruptions had become *the* test case for modelers. The models were in their infancy, and modelers attributed little certainty to the outcome of their calculations. Still, they rapidly increased in sophistication, with scientists eager to feed their computers with available data to test their validity. This allowed—though still with a high degree of uncertainty—a better understanding of climate modification due to aerosols released by volcanoes. Given the scarcity of major explosive volcanic eruptions, modelers and volcanologists thus had an interest in careful examinations of the effects of past volcanic eruptions in order to adjust and improve their models.

Volcanic Winter

In this context, during the mid-1980s, Toba became a test case in supporting or discrediting the theory of so-called 'nuclear winter' that fuelled public scientific debate throughout the 1980s. The term 'nuclear winter' was coined by the atmospheric scientist Richard Turco.[19] Based on relatively simple computer models, Turco and a few collaborators studied the possible consequences of a nuclear war, did a few simulations, and came to the conclusion that due to the dust and smoke, particularly soot, caused by large-scale fires after a nuclear war, temperatures in the northern hemisphere could drop by 15 to 25°C for up to several weeks or months, causing "a harsh 'nuclear winter' in any season."[20] These scenarios were heavily debated in the following years.

The nuclear winter idea followed an earlier influential study of "doom," the 1997 book by Walter Alvarez, *T. Rex and the Crater of Doom*. In 1980 the geologist Walter Alvarez and others had explained the extinction of the dinosaurs by the impact of an asteroid on the Earth, evidenced by anomalous levels of iridium deposited 65 million years ago they traced in deep sea limestones in several places around the globe. They argued that an asteroid impact would entail such an accumulation of dust in the stratosphere that, for a few years, photosynthesis and food chains would be severely disrupted. The authors used the term "biological crises" and spoke of "dramatic extinctions."[21] Their article caught the attention of the atmospheric scientists P.J. Crutzen and J.W. Birks, who were invited by the Swedish Academy to give a talk on the possible impact of nuclear war on the atmosphere.[22] Their general discussion of the possible climatic effects of asteroids or massive fires caused by nuclear explosions was picked up by Turco and other atmospheric scientists, who spoke of a "serious threat to human survivors and to other species," but were also prudent enough to admit that their conclusions were based on numerous speculations:

> Our estimates of the physical and chemical impacts of nuclear war are necessarily uncertain because we have used one-dimensional models, because the data base is incomplete, and because the problem is not amenable to experimental investigation. We are also unable to forecast the detailed nature of the changes in atmospheric dynamics and meteorology implied by our nuclear war scenarios, or the effect of such changes on the maintenance or dispersal of the initiating dust and smoke clouds. Nevertheless, the magnitudes of the first-order effects are so large, and the implications so serious, that we hope the scientific issues raised here will be vigorously and critically examined.[23]

For the authors the issue was one of such imminent political importance that they deemed scientific involvement necessary, despite many remaining uncertainties. Subsequent research by numerous research groups during the 1980s confirmed in principle the 'nuclear winter' theory, but lowered the climatic impact to average coolings between 10° to 20°C in the mid-latitudes, lasting for several weeks, still nevertheless with detrimental environmental effects.[24]

In this highly politically charged context, three volcanologists, Michael R. Rampino, Stephen Self, and Richard B. Stothers, suggested in a letter to *Nature* in 1985 that a look at Toba might be useful as a test case, "as a basis for estimating the climatic effects of nuclear war." For them, the relatively small historic volcanic eruptions could not serve as comparisons, but only "the largest-scale eruptions."[25] Three years later, they published a general article entitled "*Volcanic winters,*" in which they gave a historical review of the climatic effects of all known major explosive eruptions, historic and geologic. The term 'volcanic winter' figured in the title, but was in fact suggested only in passing with no further discussion: "... much larger eruptions may possibly have caused severe 'volcanic winters,' perhaps similar to the recently proposed 'nuclear winter.'"[26] Further extending the analogy to nuclear weapons, the authors spoke of 'supereruptions,' in an inexplicit analogy to the 'superbomb,' the hydrogen bomb. Though the authors pointed to "many uncertainties in the nuclear winter analyses," and also stressed the significant differences of the "optical properties between volcanic aerosols and black, sooty smoke from urban fires" caused by a nuclear war, they nevertheless pressed the winter analogy. Most of their claims relied on extrapolation: Assuming that the climatic effects of historic eruptions would be similar to those of geologic eruptions, they extrapolated from well-studied volcanic eruption values for climate-affecting sulphate aerosols to the 'supereruption' of Toba. However, their figures for the sulphate aerosols were only guesses, as no reliable data existed. They concluded that "The atmospheric after-effects of a Toba-sized explosive eruption might be comparable to some scenarios of nuclear winter, although the aerosols are expected to have a longer atmospheric residence time than would the nuclear winter smoke."[27] The quotation both affirms the analogy, and then slightly retracts it. Indeed, the difference between the optical effects of volcanic fine-ash dust clouds, soot, and sulphate aerosols *is* crucial, since it was assumed at the time that volcanic dust and soot remained in the atmosphere for only a few weeks, while sulphate aerosols could remain in the stratosphere for years, potentially affecting the climate.

While pointing to the limits of their study and admitting their ignorance of possible feedback mechanisms emerging with higher concentrations of sulphate aerosols in the atmosphere, Rampino, Self, and Stothers pushed the catastrophic scenario: "It is important to stress ... that these are 'worst-case' situations, made simply by extrapolating a linear increase in mass of aerosols ..."[28] They argued that "severe short-term coolings or 'volcanic winters'" could have "drastic effects on crop yields" and engender "food supply crises in many areas," and concluded in somber terms: "There is no question that such large eruptions will recur, the only uncertainty lies in where and when."[29] This article from 1988 came closest to something like doomsday science within the constraints of a scholarly journal, being highly speculative about worst-case scenarios, transferring the doomsday picture of a nuclear war to the geologic past without discussion of the validity and limits of this analogy. It also contrasts with the geological work in the 1980s by William I. Rose and Craig A. Chesner of the Michigan Technical University in Houghton, who refrained from any catastrophic discourse in their studies of Toba's ash dispersal, magma volume and eruption column height.[30] In the following years, this dubious 'winter' analogy took on a life of its own. In a 1992 article on Toba, the term 'volcanic winter' had become a matter of accepted fact, requiring no further discussion from Rampino and Self. The authors simply referred to their earlier article—which, as I have discussed, had never subjected the analogy to any in-depth discussion.

In a 1993 general article on Pleistocene population explosions, a staff writer for *Science*, Ann Gibbons, identified Toba as the cause of a significant global temperature drop, leading to a population bottleneck thought to have occurred in human evolution. The two-page article was accompanied by a picture of the Toba caldera lake with the catching caption: "Big bang? The same volcano that made this lake—Mt. Toba in Sumatra—may have triggered a climate change that made life tough for early humans about 70,000 years ago."[31] The article triggered a letter from Rampino and Self, summarizing their evidence for a volcanic bottleneck thesis in a tone of assurance about their results:

> ...we calculated that climate cooling for 1 or 2 years after the eruption could have been quite severe, representing 'volcanic winter' conditions similar to those proposed in scenarios of nuclear winter following a major nuclear exchange.[32]

They had now prolonged the volcanic winter to one or two years, though a nuclear winter in Turco's sense was projected at the time to last for weeks or months at best, a conflation parallel to their attributing the cooling from the Toba eruption summarily to the "dust and aerosols," without making a clear distinction between the two.[33]

In the mid 1990s, the anthropologist Stanley Ambrose of the University of Illinois, Urbana, who worked in contact with Michael Rampino, picked up the thesis of volcanic winter to explain the decimation of modern human populations outside a few tropical regions, particularly equatorial Africa:

> Volcanic winter may have reduced populations to levels low enough for founder effects, genetic drift and local adaptations to produce rapid population differentiation. If Toba caused the bottlenecks, then modern human races may have differentiated abruptly, only 70 thousand years ago.[34]

Ambrose further weakened the winter analogy's meaning, by further prolonging the 'volcanic winter' to "several years."[35] Further details and catastrophic scenarios were provided in a subsequent article written jointly by Rampino and Ambrose.[36]

Given this potential to wipe out human civilization, super-eruptions caught the public eye and were dramatized on TV under the spectacular title of 'Supervolcanoes.' This hugely successful program, first shown on a BBC Horizon program on February 3, 2000, featured the supervolcanoes of Yellowstone and Toba, which had pushed "mankind ... to the edge of extinction ... and … could happen again."[37] The program figured prominent scientists, among them Ambrose (University of Illinois, Urbana), and volcanologists including Rampino (New York University), Stephen J. Sparks (Bristol University), and Bill McGuire (University College London).[38] In the familiar pattern of these TV features, uncertainties in the interpretation of the scientific data were lost to sight, and doom was exaggerated: for example, the Toba caldera lake had doubled in size, attaining the "colossal" dimensions of 100 km by 60 km (though 100 km by 30 km is closer to the mark). Michael Rampino painted a dark future for humankind:

> If Yellowstone goes off again, and it will, it'll be disastrous for the United States and eventually for the whole world. ... We can't really overstate the effect of these huge eruptions. Civilisation will start to creak at the seams in a sense. ... It 's really not a question of if it'll go off, it's a question of when because sooner or later one of these large super eruptions will happen.[39]

It is not clear what inspired Michael Rampino's optimism that the United States will still exist when Yellowstone erupts again.

In Rampino's research, his 2002 article on "Supervolcanoes as a threat to civilizations on Earth-like planets," exemplifies the tendency to stick with the 'winter' metaphor, even in the light of new scientific evidence that large-scale volcanic eruptions showed temperature effects lasting much longer than previously thought. For Rampino a volcanic winter now implied a "global cooling of 3 to 5°C for several years." This was a considerable inflation of what he and Self had defined as volcanic winter ten years before in the 1992 *Nature* article as a "brief, pronounced regional and perhaps hemispheric cooling caused by the volcanic dust," or, in 1993, as a "brief, dramatic cooling."[40]

The article painted a dire picture of the consequences of super-eruptions, limiting : "the longevity of technological civilizations, " or, at least, causing a human bottleneck, like Toba.[41] In the face of possible total destruction of human civilization, Rampino suggested a technological fix, the "development of an interplanetary repository for terrestrial civilization":

> The repository would be a means of providing a backup system for the planet, fostering recovery of terrestrial civilization in the wake of global disasters such as

> asteroid collisions or volcanic catastrophes. This might sound like science fiction, but such a strategy will soon be technologically feasible.[42]

Rampino took the long view.

American Geophysical Union Conference in Santorini (2002)

In June 2002 many of the leading volcanologists and climatologists convened at a Chapman Conference on "Volcanism and the Earth's Atmosphere," organized by the American Geophysical Union. The conference, which I attended, took place in Santorini, site of a famous Bronze Age eruption, and took up the theme of super-eruptions. Volcanic eruptions as threats to civilization figured prominently in the five-day program, attended by most of the leading scientists in the field. All four keynote lectures addressed the issue: David Pyle of Cambridge University proposed a talk on the scale and impact of the Santorini eruption; John Gratton of the University of Wales, Aberystwyth, discussed "The role of volcanic eruptions in human history and civilization;" Stephen J. Sparks of the University of Bristol considered "Global and environmental effects of supervolcano eruptions: a threat to civilization?", finally, Stephen Self of the Open University looked at the effects on global climate of flood basalt eruptions. In addition, in a session on explosive and flood basalts supervolcanoes, Michael R. Rampino discussed "Environmental effects of the largest volcanic eruptions: From mass extinctions to threats to civilization," and Gareth S. Jones of the Hadley Centre for Climate Prediction and Research, Meteorological Office, London**)** presented a simulation of climatic response to a super-eruption, followed by a series of oral poster introductions dealing with mega-eruptions, among them Toba. Historic eruptions and supervolcanoes were given considerable time on the last day of the conference, which also addressed the issue of future research priorities. However, the scientists did not speak in unison, as becomes evident on reading their abstracts.

I pick out here only the 'catastrophic' talks. Given the success of the BBC feature, it seems unsurprising that most of the contributions came from Great Britain; the feature had clearly left a mark. Stephen J. Sparks, himself on the program committee for the Santorini conference, used the term 'supervolcanoes' without brackets. He also set up a contest: supervolcanoes versus killer asteroids or comets, arguing that the former would likely occur more frequently that the latter, and, for that reason, deserved more attention, as "an area the size of North America can be devastated." Mass starvation would ensue, and the effects might be "sufficiently severe to threaten the fabric of civilization." Sparks suggested confronting the issue within a framework of other problems of global dimensions:

> Problems like global warming, impacts by asteroids and comets, rapid use of natural resources, and nuclear waste disposal are requiring world leaders and governments to address issues which have very long-term consequences for the global community. Sooner or later a supervolcanic eruption will happen on the Earth and this is an issue which demands serious attention.[43]

Sparks succumbed to the winter analogy fallacy, confounding human-induced with nature-induced changes. While we can actually do something about our rapid use of natural resources and nuclear weapons, and most likely about global warming, and possibly even about asteroids (if we believe in Hollywood movies), there will be little we can do when volcanoes erupt in the future.

In his contribution, Michael Rampino repeated the somber assessment of his 2002 article: “Prediction, prevention, and mitigation of global volcanic climatic disasters may be potentially more difficult than planetary protection from the threat of large impacts, so that explosive volcanism might limit the longevity of technological civilizations.”[44] A poster on “Impacts on society from future unrest and/or eruptions from caldera volcanoes in New Zealand” gave perhaps the most ominous warnings, of the consequences of a major eruption of Taupo or Okataina, which have happened at 30,000-year intervals. Apart from the destruction of the North Island, which would “leave it uninhabitable for a significant period,” the authors (G.S. Leonard (lead author), I.A. Nairn, D. Johnston, C.J.N. Wilson, J.W. Cole, S. Self) also drew a curiously precise picture of the social consequences of warnings given in advance of a possible eruption. They prognosticated “a significant risk of over-reaction amongst New Zealand media,” the cancellation of property insurance, population and capital flight, “a general decline in tourism,” and “negative mental and physical health effects on the New Zealand population,” and concluded that “the potential physical damage from any indicated future eruption at these volcanoes may be far outweighed by social consequences, driven by perceptions of the largest, worst-case eruption scenarios.”[45] However, in a brief report in the Transactions of the American Geophysical Union (EOS) on the 2002 meeting, Alan Robock of the Department of Environmental Sciences at Rutgers University, the conference convener, did not mention super-eruptions in his outline of promising future research.[46]

Clive Oppenheimer, from the Department of Geography at Cambridge University, was the first to give the existing Toba literature a critical review. Oppenheimer revived the tradition of British pragmatism and understatement in the title of his 2002 article “Limited global change due to ... Toba.” He did not engage in catastrophic discourse, and took care to lay emphasis on the uncertainties concerning the Toba eruption:

> there remain major gaps in our understanding of the ... Toba eruption that hinder attempts to model its global atmospheric and climatic, and hence human consequences. ... The volcanological uncertainties need to be appreciated before accepting arguments for catastrophic consequences of the Toba super-eruption.[47]

Oppenheimer pointed out that figures for the eruption's basic parameters like intensity, height, and magnitude were more or less the result of guesswork. He furthermore made it clear that Toba's climatic impact should be judged by the sulphate aerosols, whose amount differed by several magnitudes in various studies. For Oppenheimer, globally averaged surface temperatures were more likely to have dropped only 1°C than the 3-5°C proposed by Rampino and Self. In addition, Oppenheimer saw no “firm evidence ... linking ... [Toba] to a human demographic crash,” particularly, because there was “no clear picture even of the relative timing of events,” which made it impossible to “establish a causal chain.”[48] He pointed out that the year of the eruption was not uniquely cold, and that human beings have survived perhaps several of these super-eruptions. In short, “... a number of conclusions have been based on unreliable assumptions and inferences,” and more research was necessary.[49]

Supervolcanoes and the British Government

Oppenheimer's attempt to cool things down was cut short by British prime minister Tony Blair. When the December 2004 tsunami struck Asia, much discussion focused on the lack of an early warning system, and Blair asked for the creation of a group of experts “to advise on the mechanisms that could and should be established for the detection and early warning of global physical natural hazards." The body, the Natural Hazards Working Group (NHWG), looked primarily at global risks of rare occurrence but high impact. It analyzed current international scientific and political networks that might optimize research and put effective early warning systems in place.[50] The group met early in 2005 and submitted its final report in June 2005. It looks at natural hazards ranging from earthquakes, volcanoes, hydrometeorological hazards (tsunami, tropical cyclones, storm surges, floods, mudslides and mudflows) to Near Earth Objects (NEOs) and space weather. Supervolcanoes figure in the final report, although the report stresses the manifold uncertainties in detecting upcoming super-eruptions.

Governmental interest opened the way for volcanologists to make a point and subsequently to cash in. A working group was formed within the Geological Society, with Stephen Sparks, who was a member of the NHWG group, and Stephen Self as lead authors. They submitted a report to the NHWG in 2005 with the title: *Super-eruptions: global effects and future threats*. In this report, meant for a larger public, the tone is alarmist, sounding a dire warning at very beginning: "It's not a question of 'if'—it's a question of 'when...'"[51] Just as Sparks had argued at the conference in Santorini, the report tries to convince the reader that supervolcanoes deserve the same public and political attention that Near Earth Objects (asteroids or comets) had received "through Hollywood movies."[52] The report concluded that medium-scale supereruptions would be similar to the impact of asteroids of one kilometer diameter, but were "five to ten times more likely to occur within the next few thousand years than an impact."[53] It also stressed that there was "no technical fix for averting super-eruptions," and that "even science fiction cannot produce a credible mechanism," but suggested preparedness through "improved monitoring, awareness-raising, and research-based planning."[54] Effects in the immediate vicinity of a super-eruption were judged "completely catastrophic" and long-term effects "could result in the ruin of world agriculture, severe disruption of food supplies, and mass starvation;" and thus "threaten the fabric of civilisation."[55] Nevertheless, the report admitted also that detailed predictions of the effects of such an eruption were still impossible and that research was still in a "hypothesis stage."[56] Other passages of the report, however, paint a direr picture:

> What might happen if several billion people needed evacuation from most of Asia, and, simultaneously, three or four years of severe volcanic winter threatened agriculture throughout North America and Europe? This is not fanciful, but the kind of acute problem and inevitable consequence of the next super-eruption.[57]

Given the recent difficulties of the wealthy American government in dealing with an in comparison, minor environmental crisis in New Orleans, the prospect of successfully evacuating three billion people certainly does appear fanciful.

The report equally falls victim to the 'winter' analogy fallacy, equating issues of man-made global warming and nuclear waste with natural super-eruptions. While the former are "addressed with utmost seriousness by individual governments and the international community," super-eruptions also "present a severe threat to the global human civilisation of the time and could, in the extreme case, endanger our species." The authors conclude: "We are certain that humanity will, at some stage, need to deal with this unavoidable issue."[58] In its summary, the report (unsurprisingly) suggested improved funding of interdisciplinary research, the necessity for a better public understanding of the nature of volcanic hazards (why? one might ask), and better international cooperation to deal with the consequences of a super-eruption (as it "could happen tomorrow"—or, alternatively, in "ten thousand years.")[59]

Conclusion

Public and scientific fascination with volcanic eruptions is nothing new. An advertisement in *Film Daily* in 1928 promised exciting footage of an eruption of Mt. Etna, "the most graphic, awesome and sensational pictures of this cataclysm recorded": "'As Doom Came Creeping Down'. A river of hell bringing inexorable doom! An irresistible flood of disaster engulfing an entire city! Crowds fleeing from certain death! Buildings crumbling like egg-shells! Death and destruction at the hand of wrathful nature!"[60] Recent TV features build upon this public fascination and fear. For example, an all-capitals advertisement filling a whole page in the *New York Times* of October 4, 2004 read: "MT. ST. HELENS ISN'T THE ONLY VOLCANO YOU SHOULD WORRY ABOUT - POMPEII: THE LAST DAY IS COMING · JANUARY 2005 - DISCOVERY CHANNEL - entertain your brain." There is no reason why scientists should not appear in these programs, but they should be aware of the inherent tendency of these programs to frame the issue as apocalyptic, and try to correct it, if possible. Instead, some volcanologists have eagerly played exactly this card. The lurid-sounding 'supervolcano' or 'super-eruption' have now acquired official sanction even within the scientific community (though some still put them in quotation marks), but they also invite scientists to confound—voluntarily or involuntarily—pressing human-produced political issues, like nuclear war and global warming, with questions of the 'longue durée' and natural apocalypse that are in the hand of nature, and which will in all likelihood continue to escape human power in the future.

During the late 1980s and, especially after the downfall of the Berlin wall and the end of the Soviet Union, some volcanologists saw a chance to substitute nuclear fears with volcanic fears, proposing apocalyptic scenarios of nature's destructive forces. During the 1980s volcanoes had suffered comparatively from the publicity blitz enjoyed by NEOs (asteroids), and the extinction of the dinosaurs, which then dominated TV and movie screens. Volcanologists increasingly feared to lose out to other scientific fields, especially atmospheric and climate science, which grew considerably in these years. In the end, volcanologists and atmospheric scientists handled their engagement and openness for societal issues quite differently in their scientific work. Atmospheric scientists focused on human-made catastrophes, making use of the volcanologists' studies of large-scale volcanic explosions to provide a better understanding of the disastrous consequences of nuclear war; their scientific work included a political appeal to take actions to *prevent* further proliferation of nuclear weapons (as later also the case of global warming), and thus apocalypse. Volcanologists could only show that future apocalypse is inevitable, but have nothing to offer to stop nature's wrath.[61]

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Notes

[1] Large-scale explosive eruptions are defined here as the release of more than 450 cubic kilometers of magma. Self, “Effects and consequences”(2006), 2074-5.

[2] Bemmelen, “Origin of Lake Toba” (1939).

[3] Lamb, “Volcanic dust” (1970).

[4] Weart, *Global warming* (2003).

[5] “Two sunsets on the same evening,” *New York Times*, 8 Dec 1883

[6] Symons, *Krakatoa* (1888).

[7] N.N., “The Java Upheaval,” *Nature*, 6 Sep 1883, 443.

[8] Oppenheimer, “Climatic, environmental and human consequences” (2003), 234.

[9] Ibid., 248-253.

[10] Symons, *Krakatoa* (1888), 394.

[11] Milham, “The year 1816” (1924), 563. Stommel and Stommel, *Volcano weather* (1983). Stothers, “The Great Tambora eruption” (1984). Harrington, *Year without summer* (1992).

[12] Oppenheimer, “Climatic, environmental and human consequences” (2003), 255.

[13] Ninkovich and Donn, “Explosive Cenozoic Volcanism “ (1976).

[14] Oppenheimer, “Limited global change” (2002), 1593.

[15] Ninkovich and Donn, “Explosive Cenozoic Volcanism” (1976), 905-906

[16] Hays et al., “Variations in the Earth's orbit” (1976).

[17] Ninkovich and Donn, Explosive Cenozoic Volcanism (1976), 905.

[18] Ninkovich et al., “K-Ar age” (1978), 574.

[19] Turco et al., “Nuclear winter” (1983). Robock, “Nuclear winter” (1996). Badash, “Nuclear Winter” (2001), 87.

[20] Turco et al., “Nuclear winter” (1983), 1290.

[21] Alvarez et al., “Extraterrestrial cause” (1980), 1095.

[22] Crutzen and Birks, “Nuclear war” (1982), 114-125. Badash, “Nuclear Winter” (2001), 80.

[23] Turco et al., “Nuclear winter” (1983), 1283, 1290.

[24] Turco et al., “Climate and smoke” (1990), 166.

[25] Rampino, Self and Stothers, “Climatic effects” (1985), 272.

[26] Rampino, Self and Stothers, “Volcanic winters” (1988), 74.

[27] Ibid., 89-90.

[28] Ibid., 91.

[29] Ibid., 94.

[30] Rose and Chesner (1987).

[31] Gibbons, “Population Explosions” (1993), 27.

[32] Rampino and Self, “Bottleneck in Human Evolution” (1993), 1955.

[33] Ibid.

[34] Ambrose, “Late Pleistocene human Population bottlenecks” (1998), 623.

[35] Ibid., 632.

[36] Rampino and Ambrose, “Volcanic winter in the Garden of Eden” (2000).

[37] BBC, *Supervolcanoes*, http://www.bbc.co.uk/science/horizon/1999/supervolcanoes.shtml

[38] The tone and level was set by McGuire, himself director of the Benfield Hazard Research Centre at UCL, and chief scientific consultant on 'Supervolcanoes':”When you actually

sit down and think about these things [supervolcanoes] they are absolutely apocalyptic in scale. ... You're getting a, an eruption [Yellowstone] which we can barely imagine. We've never seen this sort of thing." BBC, *Supervolcanoes*, Transcript, http://www.bbc.co.uk/science/horizon/1999/supervolcanoes_script.shtml

[39] BBC, *Supervolcanoes*, Transcript, http://www.bbc.co.uk/science/horizon/1999/supervolcanoes_script.shtml

[40] Rampino, "Supereruptions" (2002), 563. Rampino and Self, "Volcanic winter and accelerated glaciation" (1992), 50. Rampino and Self, "Climate-Volcanism feedback" (1993), 269. The analogy is also not saved by recent modelling of nuclear winter scenarios with an atmospheric-oceanic general circulation model, the first studies since the 1980s, which supersedes considerably previous estimations and indicates that the length of the effects of nuclear war has to be extended to at least a decade, as the smoke is lofted far into the stratosphere and lasts much longer than volcanic aerosols, a circumstance that could not be captured by the simple models of the 1980s. Robock et al. "Climatic consequences" (2007) and Robock et al. " Nuclear winter revisited" (2007).

[41] Rampino, "Supereruptions" (2002), 562.

[42] Ibid., 566.

[43] *Volcanism and the Earth's Atmosphere, Abstracts* (2002), 37.

[44] Ibid., 45.

[45] Ibid., 47-48.

[46] Robock, "Blowin' in the wind" (2002). See also the publication that came out of the meeting : Robock and Oppenheimer, *Volcanism and the Earth's Atmosphere* (2003).

[47] Oppenheimer, "Limited global change" (2002), 1593. For critical views of the bottleneck theory, see Gathorne-Hardy "Super-eruption of Toba" (2003), and, on the effects on mammals, Louys, "Limited effect" (2007).

[48] Ibid., 1605.

[49] Ibid., 1606.

[50] See: National Hazards Working Group, *The Role of Science* (2005))

[51] Sparks and Self, *Super-eruptions* (2005), 1.

[52] Ibid., 4.

[53] Ibid., 1.

[54] Ibid., 1-2.

[55] Ibid., 2 and 12.

[56] Ibid., 14-15.

[57] Ibid., 20.

[58] Ibid.

[59] Ibid.

[60] *Film Daily* (1928), 5. I am grateful to Emily Thompson for drawing my attention to this advertisement.

[61] For a more recent study on the climatic effects of super-eruptions, see, for example, Jones, "AOGCM simulation" (2005).