The year without a summer

J. Luterbacher and C. Pfister

The 1815 eruption of Tambora caused an unusually cold summer in much of Europe in 1816. The extreme weather led to poor harvests and malnutrition, but also demonstrated the capability of humans to adapt and help others in worse conditions.

Large volcanic eruptions in the tropics can temporarily alter climate around the world, causing global cooling[1] and shifting precipitation patterns. One particularly well-described example is the 1815 eruption of Tambora, which caused the 1816 "year without a summer" in Europe[2–5]. The unusual cooling and anomalous rainfall led to a host of problems for many residents of western and central Europe, and may have helped to spur emigration to the Americas. But as we argue here, the effects of the Tambora eruption were not uniform across Europe. And people who were not the hardest hit showed a surprising willingness to help those who were suffering.

Summer 1816 after Tambora

Large tropical volcanic eruptions impose short but substantial energy imbalances in the climate system. The effects of the eruptions mainly arise from the release of large amounts of SO_2, which is transformed into sulphate aerosols. In the lower atmosphere, the particles are removed within a few weeks, and have no long-term climatic effects[1]. However, particles that are formed in the stratosphere — above about 15 km in altitude — can persist for up a couple of years. The aerosols warm the stratosphere but cool the surface[1]. The April 1815 eruption of the Tambora volcano, located about 300 km east of Bali, resulted in a massive release of sulphur to the stratosphere.

However, the effects were not uniform. In June, July and August of 1816, temperatures were persistently cold — 2 to 4°C below the 1951–1980 reference period — over western and central Europe and the western Mediterranean (Fig. 1). But in eastern Europe, western Russia and parts of eastern Scandinavia, summer temperatures were normal or slightly warmer than average. Temperature fluctuations in the central and eastern Mediterranean are less certain, owing to a lack of temperature station data for these areas[6,7].

The limited rainfall records suggest that precipitation over parts of Europe was anomalous throughout the summer of 1816. The British Isles, France, Benelux countries, Germany and Switzerland experienced approximately twice the amount of rainfall in June than the 1951 to 1980 baseline. For these regions, July was generally less wet, with wet conditions returning again in August for areas north of 40°N and east of 5°E. Recently recovered rainfall data from Iberia (not included in Fig. 1) suggests that for much of the summer 1816, eastern Spain was drier than average (M. Barriendos, personal communication). In Portugal, however, July and August were wetter than usual[8].

Atmospheric circulation over the summer of 1816 was also anomalous (Fig. 1). Storm tracks were shifted to the south, and recurrent low pressure systems brought cold air and heavy and long-lasting rainfall to western and central Europe. The cold and wet conditions have been attributed to a weakening of the Asian and African summer monsoons[9]: according to this hypothesis, the monsoon weakening altered atmospheric circulation over the North Atlantic and Europe, leading to more frequent low pressure systems and generally a stronger westerly and north-westerly air flow. Cool weather and heavy precipitation in the year following the eruption could have been the consequence of this pattern of atmospheric circulation.

Climate, harvests, and charity

The consequences of the unsettled cold and wet conditions during summer 1816 in parts of Europe were devastating both economically and socially[3,10–12]. Modelling of climate and society interactions[13] — albeit simplified — suggests that extreme weather events can have a range of consequences, including immediate first-order effects on biomass production and water availability as well as fourth-order impacts such as an increase in charitable giving (Fig. 2).

The extremely cold of summer 1816 manifested in record-breaking delays in the start of plant growth[11,13]. When finally picked in early November, the few grapes that had survived on their vines in France and Switzerland were still hard and green. Likewise, most crops in the hilly areas of western and central Europe and the Balkans did not reach maturity. In the lowlands of central and western Europe, grain and potatoes suffered under unending rain. And of the potatoes and grains that were eventually harvested, substantial amounts went on to rot in barns and grain silos[14]. The cold summer in Iberia had similarly strong impacts on agriculture: fruit was of poor quality and the ripening of grapes and cereals was delayed, which lowered yields[8]. Cool temperatures and heavy rains resulted in harvest failure and famine in Ireland, Wales and parts of Britain. The agricultural disaster following the Tambora eruption was described as "the last great subsistence crisis in the Western world"[14].

However, in Scandinavia and the northern Baltic region harvests were almost normal, and in eastern Europe and western Russia the impacts were so minor that the Russian Emperor Alexander I was able to provide grains to western Europe along with monetary donations.

The crisis in the western Mediterranean, western and central Europe persisted beyond 1816. In 1817, grain prices rose throughout Europe. There were also regional differences in the magnitude of the spike in prices, depending not only on the local harvest, but also the ease with which imported grains could be transported. Price increases were the smallest in cities such as Cracow (Poland), where the harvest was average. Port cities such as London and Hamburg had only modest price rises thanks to lower transport costs, whereas prices soared in inland areas that relied on the expensive transport of food upstream along towpaths[14].

Grain shortages and price hikes may have led to undernourishment, which in turn could have caused the unusually small size of birth cohorts in 1817 and 1818[13]. The level of vulnerability to undernourishment seems to be a function of market integration as well as local conditions. Only mild food deprivation occurred in the grain-growing districts in western Switzerland[13]. In contrast, famine was pronounced in regions

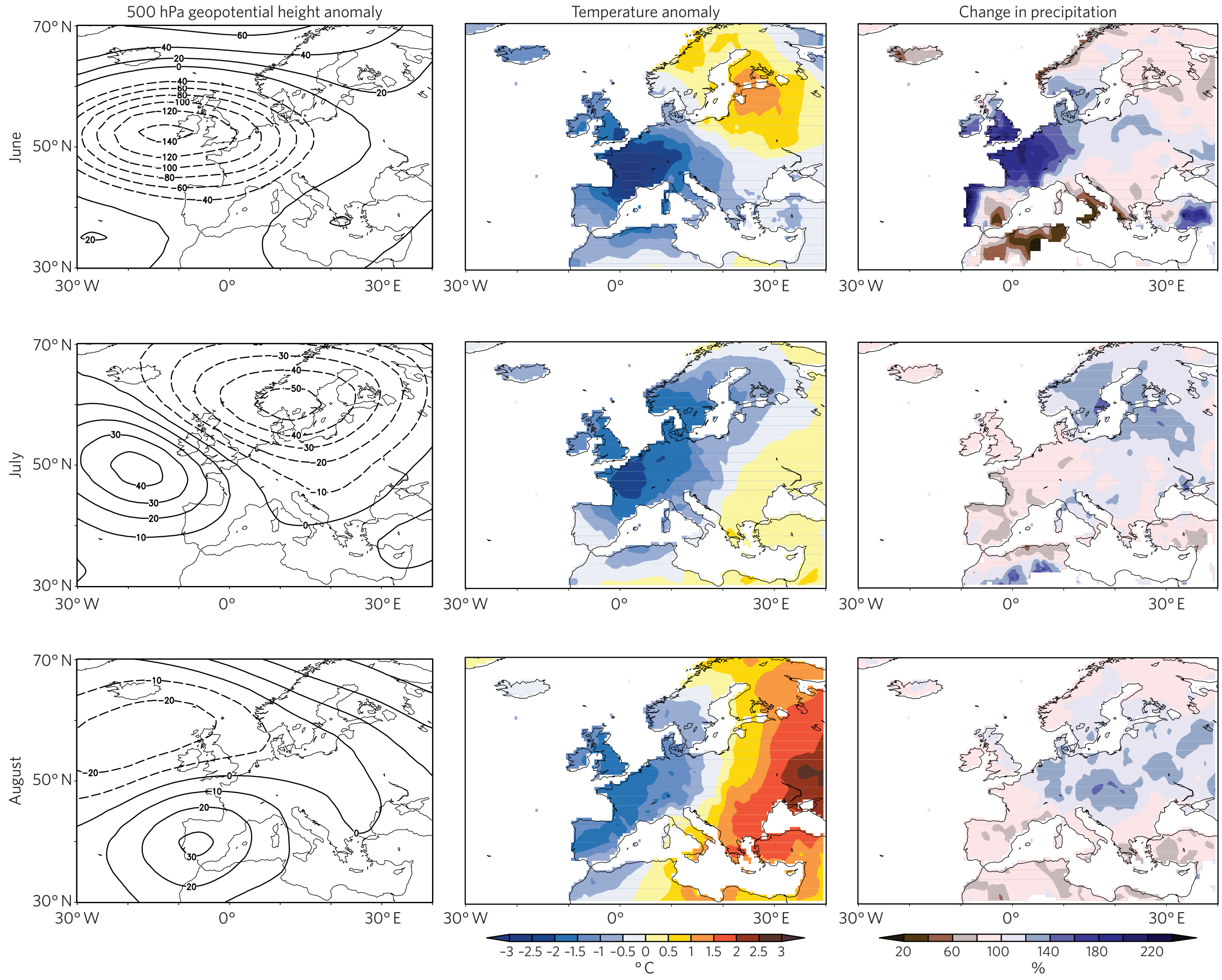

Figure 1 | Climate anomalies with respect to the 1951–1980 period in 1816. During June (top row), July (middle) and August (bottom) of 1816, low and high pressure anomalies persisted over much of Europe (left column). These anomalies resulted in cooling over much of western and central Europe, but warming to the east (middle column). Rainfall was also anomalously high over parts of Europe, particularly in June and August (right column). Data from independently reconstructed climate variables from long instrumental station records[7]. Pressure is presented as 500 hPa geopotential height in geopotential decametres.

of eastern Switzerland that were in the early stages of industrialization, and hence were dependent on grain exports from the bread baskets of southern Germany. To prevent rioting in southern Germany, however, local rulers embargoed grain exports, and thereby cut off the textile workers to the south.

A pastor in the town of St Gallen, eastern Switzerland, described the suffering experienced in the most vulnerable households in this region, which moved a girl to deliver a pouch containing 25 gulden (today about 4,400 Swiss francs) along with a note stating, “My cash for the poor. Jesus may bless this small gift.” (ref. 15). Her act, mentioned in the pastor’s next sermon, sparked a wave of charitable giving that resulted in so many donations that the pastor had to hire a man with a donkey to distribute the gifts to the poor.

For others, emigration was a way to escape from the misery, but relatively few emigrants — fewer than 60,000 — managed to cross the Atlantic. Most of them came from Great Britain and Ireland, because they could get to the harbours from which the ships departed for relatively small fares. For most people in the hotspots of the crisis, in Germany and Switzerland, the boat trip down the Rhine required to reach continental harbours was too expensive. Even this moderate number of emigrants was enough to end one popular scheme of getting to the USA on a low budget. Previously, emigrants travelling to the port of Philadelphia could sail without paying, provided they worked for a contracted amount of time for a local employer; their employer directly reimbursed the ship captain for the passenger’s fare. However, when the Philadelphia regional job market was flooded by jobseekers in 1817 and 1818, captains could not find employers for their passengers, and thus lost interest[16].

The violent eruption of a volcano that few Europeans of the nineteenth century would ever see influenced climate, agriculture, and societies in Europe and America. The summer of 1816 (and the following couple of years) therefore provides a remarkable case study for the exploration of various direct and indirect interactions between climate variability and human history. The level of human suffering and

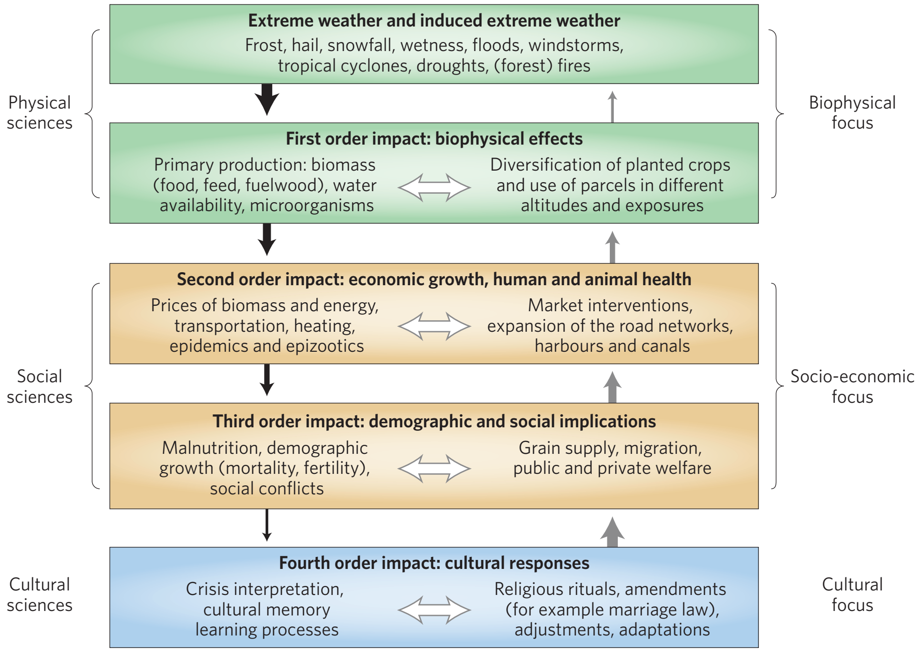

Figure 2 | Climate and societal interactions. This model[1] captures the way extreme climate events can cascade through society (black arrows), and the adjustment and/or adaptation strategies societies can respond with (grey arrows). Figure adapted with permission from ref. 13, © 2015 Schwabe.

human agency identified in this example show the level of detail that will need to be achieved in our efforts to understand any potential future impacts of regional climate change on humans, and their responses to these challenges. ❐

J. Luterbacher is in the Department of Geography, Climatology, Climate Dynamics and Climate Change, Justus Liebig University of Giessen, Senckenbergstrasse 1, D-35390 Giessen, Germany. C. Pfister is at the Oeschger Centre for Climatic Change Research (OCCR), Falkenplatz 16, CH-3012 Bern, Switzerland.
e-mail: juerg.luterbacher@geogr.uni-giessen.de

References

1. Robock, A. *Rev. Geophys.* **38,** 191–219 (2000).
2. Fischer, E. M. *et al. Geophys. Res. Lett.* **34,** L05707 (2007).
3. Stothers, R. *Science* **224,** 1191–1198 (1984).
4. Harington, C. R. (ed.) *The Year Without a Summer? World Climate in 1816* (Canadian Museum of Nature, 1992).
5. Robock, A. *Climatic Change* **26,** 105–108 (1994).
6. Luterbacher, J., Dietrich, D., Xoplaki, E., Grosjean, M. & Wanner, H. *Science* **303,** 1499–1503 (2004).
7. Casty, C., Raible, C. C., Stocker, T. F.,Wanner, H. & Luterbacher, J. *Clim. Dynam.* **29,** 791–805 (2007).
8. Trigo, R. M. *Int. J. Climatol.* **29,** 99–115 (2009).
9. Wegmann, M. *et al. J. Clim.* **27,** 3683–3691 (2014).
10. Hoyt, J. *Ann. Assoc. Am. Geogr.* **48,** 118–131 (1958).
11. Pfister, C. in *The Year Without a Summer? World Climate in 1816* (ed. Harington, C. R.) 416–417 (Canadian Museum of Nature, 1992).
12. Oppenheimer, C. *Prog. Phys. Geog.* **27,** 230–259 (2003).
13. Krämer, D. *Menschen Grasten nun mit dem Vieh. Die Letzte Grosse Hungerkrise der Schweiz 1816/17* (Schwabe, 2015).
14. Post, J. D. *The Last Great Subsistence Crisis in the Western World* (Johns Hopkins Univ. Press, 1977).
15. Scheitlin, P. *Meine Armenreisen in den Kanton Glarus und in die Umgebung der Stadt St. Gallen in den Jahren 1816 und 1817, Nebst Einer Darstellung, Wie es den Armen in des Gesammten Vaterlandes im Jahr 1817 Erging. St. Gallen* (Huber, 1820).
16. Grabbe, H-J. *Die Grosse Flut. Die Europäische Migration in die Vereinigten Staaten von Amerika, 1783–1820* (Franz Steiner, 2001).

Tying down eruption risk

Stephen Self and Ralf Gertisser

200 years after the eruption of Mount Tambora, the eruption volume remains poorly known, as is true for other volcanic eruptions over past millennia. We need better records of size and occurrence if we are to predict future large eruptions more accurately.

On 10 April 1815, the volcano Mount Tambora, on Sumbawa Island in Indonesia, erupted violently. The event was the most disastrous volcanic eruption in recent history. More than 60,000 deaths on Sumbawa and neighbouring islands alone are attributed to the eruption[1]. But the worldwide suffering and deaths (caused indirectly) continued into the following year as a result of volcanic-induced cooling. This fatality approximation must therefore be an underestimate.

The Tambora eruption has been assigned a magnitude[2] of 6–7, yet the precise size of the eruption is still under scrutiny. In a giant eruption, like this one 200 years ago, the land surface can collapse into the empty magma chamber once its contents have been ejected. The resulting caldera provides an indirect estimate of the eruption size (Fig. 1). Tambora is probably the largest caldera-forming eruption of the last few centuries, at least since 1257 when the Samalas eruption on neighbouring Lombok Island occurred[3]. But the volume of the Samalas eruption is poorly constrained, too. Going back 3,600 years, the Minoan eruption of Santorini[4] in Greece may have formed a bigger caldera than Tambora's and was probably larger in magma volume. And the Kikai eruption that occurred offshore from Japan 7,300 years ago was almost certainly larger[5].

We argue that constraining the size and recurrence times of these giant eruptions is more than scientific curiosity; we need these answers to more accurately predict when the next one might happen.

Restricted assessment of recurrence

Determining the recurrence time of the largest, most catastrophic eruptions is particularly difficult because they are so rare. Traces of these eruptions can sometimes be found in ice cores, but the volcanic source is not always obvious. Without an identified source volcano or clear ice-core