The Interdisciplinary Nature-Induced Disaster Index: Eldgjá, Laki, and How to Evaluate Historical Sources in an Interdisciplinary Framework

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Abstract

The integration of archives of society with archives of nature has helped scholars to date extreme events precisely. This approach has led to collaboration between the natural sciences and the humanities. While it has helped to highlight the dimensions of nature-induced disasters and their societal consequences, it has often led to rather monocausal explanations, promoting nature as the prime agent in history. The field is currently experiencing a shift away from monocausal explanations. Cultural factors need to be examined as well in order to analyze their contribution to disasters properly. To aid in this endeavor, we introduce the "Interdisciplinary Nature-Induced Disaster index" (INID-index), a tool to successfully integrate historical material into research on natural extreme events and their impacts on past societies. Eldgjá (ca. 934–940 CE) and Laki (1783–1784 CE)—the two major Icelandic eruptions of the Common Era—will be used as case studies to demonstrate the benefits of the index. A third contrasting study on a volcanic event in around 913 CE highlights the desiderata that the index can indicate, and its limitations. We consider this paper an offer to make transparent the questions that historians ask themselves and an example of a way to increase understanding across disciplinary cultures.

1. Introduction

In July 1893, geologist Thorvaldur Thoroddsen traveled through southern Iceland on horseback. During this trip, he came across traces of the largest volcanic eruptions in Iceland—he discovered Eldgjá (ca. 934–940 CE) and visited Laki (1783–1784 CE) (Thoroddsen 1925). Both are volcanic fissures located above the Iceland mantle plume in the Eastern Volcanic Zone (Thordarson and Larsen 2007; Brugnatelli and Tibaldi 2020). The two eruptions are comparable in both their eruption style and their consequences. Large amounts of lava, tephra, and SO_2 were emitted, which had serious effects on climate and society. These included winter cooling, famine, and a rise in mortality. Due to the volcanic aerosols in the atmosphere, remarkable celestial phenomena were observed in both cases (McCarthy and Breen 1997; Stothers 1998; McCormick et al. 2007; Oppenheimer et al. 2018; Brugnatelli and Tibaldi 2020). The relationship between cause and effect can in these examples be described as teleconnections—a meteorological term that is often used in the context of atmospheric oscillations that have global effects. Recently, historians have adopted the concept of societal teleconnections to study "direct and indirect causal links between historical phenomena of climatic and societal change" (Bauch and Schenk 2020). This allows for the study of effects of natural events far away from the original source (Moser and Finzi Hart 2015; Kleemann 2022).

As natural stressors, Eldgjá and Laki had the potential to endanger historical societies and produce a disaster. To this day, the approach is to identify a volcanic event by looking into paleoclimatological data (i.e., ice cores) using historiographical evidence in the next step to date the past eruption more accurately. This has led to new insights on "nature" as an agent in history (Wozniak 2020). It has also created an interdisciplinary discourse going beyond traditional boundaries in the academic world. Frameworks have been developed, for example, to study the local impacts of past volcanic eruptions on human societies (Riede 2018). Using findings from the archives of nature and looking for their possible impacts on society, however, promotes deterministic explanations because social distress is then primarily linked to natural factors. Societal aspects play a secondary role, and anthropogenic (human-made) factors aggravating or mitigating natural factors are less considered when natural scientists and historians come together. Our approach is therefore integrative.

Our index allows for the application of historical findings in interdisciplinary studies in order to obtain new insights regarding the interrelation of natural events and their influence upon societies—not only in the past but also in the present and future. This may contribute to the "investigation of the response of societies to sudden climate shocks resulting from volcanic eruptions" (Volcanic Impacts on Climate and Society (VICS) working group).

2. The Volcanic Eruptions – State Of Research

2.1. Eldgjá

Eldgjá is a 75 km long fissure associated with the Katla volcanic system (Oppenheimer et al. 2018). Its eruption was the largest volcanic event of the Katla system in the Common Era. It produced 19.7 km³ of lava flow, 1.3 km³ of tephra, and 232 megatons of SO_2 (Brugnatelli and Tibaldi 2020). Studies from the natural sciences have dated the event to 934, 938 or 939 (with a tolerance of ± 2–4 years), and have argued for multiple eruptions between 934 and 939 or continuing volcanic activity from spring 939 to autumn 940 (Oppenheimer et al. 2018).

The climatic response to the eruption has been examined via tree-ring-based reconstructions of northern hemisphere summer land temperatures covering the months of June, July, and August (JJA). The reconstructions indicate a possible cooling of ~1.1 °C (with respect to 1961–1990 CE) after the Eldgjá eruption, similar to the cooling effects after the Laki eruption (~1.2 °C) (Oppenheimer et al. 2018). Regions affected by the temperature decline include central Europe, Scandinavia, the Canadian Rockies, Alaska, and central Asia (Fei and Zhou 2006; Oppenheimer et al. 2018). Multi-annual cooling effects, however, have not been identified in tree-ring reconstructions. According to dendrochronological data, it was the summer of 940 that was most affected by the volcanic event (Luterbacher et al. 2016; Oppenheimer et al. 2018).

Pre-modern agrarian societies were highly sensitive to meteorological variations. In central Europe, the growing season for crops lasts from early spring to June and August (BMEL 2019). Environmental conditions during this period affect the quality and quantity of a given harvest. Pre-modern societies lived on a subsistence economy having limited access to grain imports. Therefore, cooling effects in the aftermath of the Eldgjá eruptions could have easily led to harvest shortfalls and famine. Because of their relevance to societies, such hazards were documented. As were celestial phenomena. According to medieval understanding, observations in the atmosphere could be interpreted as portents of calamitous events to come, such as the death of a king, a change of rulership, epidemics, wars, winds, or heat (Isidore 1862; Bede 1862). The sky was therefore watched with great interest. High-latitude volcanoes such as

Eldgjá and Laki generated stratospheric aerosol veils that dimmed and reddened the sun (Stothers 1998). In medieval writings, such phenomena were described as a dry fogs, reddish skies, or sometimes as an unusual brightness. Medieval manuscripts have been scoured by multiple scholars for possible responses to the Eldgjá eruptions (McCarthy and Breen 1997; Stothers 1998; McCormick et al. 2007; Newfield 2010; Kostick and Ludlow 2015; Sigl et al. 2015; Oppenheimer et al. 2018; Brugnatelli and Tibaldi 2020, see also the recent critique on this paper by Newfield and Oppenheimer 2021). In fact, hard winters, solar eclipses, observations of a blood-red sun, comets, floods, and famines are documented in the medieval writings of 934–940 and the subsequent years. Concerning western and central Europe, 29 sources are available (Ebert 2021). This is a remarkable number for a time known to medievalists as "the dark tenth century" due to the relative scarcity of sources for this period (Lubich 2010). The societal impact of Eldgjá must have been considerable. These events might have helped to stimulate the Christianization of Iceland, as Oppenheimer et al. (2018) suggested. McCarthy and Breen (1997) argued a chronicler in Ireland must have seen Eldgjá's plume with his own eyes because "the sun was of the colour of blood from the beginning of day to midday on the following day" (Chronicum Scotorum, a. 939).

2.2. Laki

Between 8 June 1783 and 7 February 1784 CE, another fissure eruption took place in Iceland. The Grímsvötn volcanic system located underneath Vatnajökull produced the Laki eruption. Modern natural scientists regard the Laki eruption as part of a larger eruptive episode at Grímsvötn, lasting from May 1783 to May 1785 (Thordarson and Self 1993; Thordarson 2003; Thordarson and Self 2003). Throughout its eight-month-long eruption, the fissure reached a length of 27 kilometers. It produced 14.7 km^3 of lava, covering an area of 599 km^2 (Thordarson and Self 1993).

The eruption had devastating effects on Iceland, particularly the southeast. Lava flows affected this area, which damaged and destroyed farmsteads and churches, changed the landscape, and rerouted rivers. Tephra fall and volcanic gases, such as sulfur dioxide and fluorine, poisoned the fields, meadows, ponds, and subsequently the animals living off them, which in turn affected the human population (Pétursson, Pálsson, Georgsson 1984; Larsen, Thordarson 1984; Steingrímsson 1998). The consequence was fluorosis in many animals, malnutrition, diseases, and ultimately starvation in the human population. By 1785, approximately one-fifth of the Icelandic population had perished. The Icelanders remember the aftermath of the Laki eruption as *móðuharðindin* ("the famine of the mist") and the worst disaster in Icelandic history (Gunnarsson 1984; Kristinsdóttir 1984; Vasey 1991; Riede 2018).

The eruption produced 122 megatons of sulfur dioxide and other gases. Roughly 60 percent of these were released within the first month of the eruption, between 8 June and 8 July 1783 (Grattan and Brayshay 1995). These gases reached far beyond Iceland and formed a dry fog visible in large parts of the northern hemisphere (from Labrador in today's Canada to the Altai mountains in central Asia) for much of the summer of 1783. In western and central Europe, the dry fog—in varying intensities—lasted until autumn of 1783. In addition to the dry fog, which at times had a sulfurous odor, the "blood-red" color of the sun was a cause of concern for contemporaries. This unusual weather inspired much debate among the naturalists of the day across Europe, mainly because the origins of these phenomena were unknown (Grattan and Brayshay 1995; Stothers 1996; Demarée and Ogilvie 2017; Kleemann 2019a, 2022).

In 1783, Iceland was a Danish dependency. Due to a trade monopoly, only certain Danish merchants were allowed to trade. Usually, the merchants traveled to Iceland in the spring and returned to Denmark in the late summer (Karlsson 2000; Oslund 2011). This is why the news of an Icelandic eruption only reached Copenhagen—and subsequently the rest of Europe—in early September of 1783. However, by that point, the dry fog had largely vanished. Although naturalists discussed an Icelandic volcanic eruption as a potential source of the fog, this remained just one theory among many (Demarée and Ogilvie 2001; Kleemann 2019a, 2019b).

The Icelandic naturalist Sveinn Pálsson discovered the Laki fissure in 1794 (Pálsson 1945; Pálsson 2004). However, his findings—detailed in his manuscript—remained unpublished until the 1880s, when the Norwegian geologist Amund Helland rediscovered the manuscript in Copenhagen and published parts of it (Helland 1881, 1886). Upon the suggestion of Thorvaldur Thoroddsen, Helland visited the Laki fissure in 1881 (Thoroddsen 1925). When Krakatau erupted in the Dutch East Indies in 1883, news of the event spread around the world within days due to the recent invention of telegraphy. Scientists realized that volcanic eruptions in other parts of the globe could have far-reaching effects. Due to this realization and the almost simultaneous rediscovery of the Laki eruption by Helland and Thoroddsen, the connection between the Laki eruption and the dry fog of 1783 was finally established (Kleemann 2020, 2022).

While the summer of 1783 was very warm in western Europe, it was colder than average in eastern and southern Europe. Recently, Zambri et al. (2019a, 2019b) have modeled this hot summer and found that it was a consequence of natural climatic variability due to the presence of an anticyclone in western Europe and that without the eruption, it would likely have been even warmer. The winter of 1783/1784 was very cold in Europe as well as North America (Ludlum 1966; Ogilvie 1986; Wood 1992; Thordarson 2005; Glaser 2008; Brázdil et al. 2010).

2.3. Summary

Both Eldgjá and Laki were fissure eruptions in southern Iceland that released exceptionally large volumes of lava and volcanic gases. In their respective millennia, both produced the largest volumes of lava on planet Earth. In both cases, the eruptions' effects in Iceland were substantial, be it through lava flows that changed the landscape (Eldgjá and Laki) or poisoning gases and debris that affected agriculture (Laki). The two eruptions' effects were not limited to Iceland, larger parts of the northern hemisphere were also affected. In this paper, we focus on the eruptions' consequences for western and central Europe.

3. The Inid-index

As Degroot et al. (2021) demonstrated recently, a lot of scholarship in the field of the "history of climate and society" (HCS) is being produced by scholars from different disciplines. The same applies to an ever increasing amount of scholarship dedicated to volcanic eruptions, as becomes apparent with interdisciplinary collaborations such as the VICS-group, which is part of the PAGES (Past Global Changes) network.

Often in interdisciplinary collaborations between natural scientists and historians, difficulties arise when dealing with the specifics of the sources of both disciplines. We define sources as original material from the past. Regarding the archives of nature, this can include volcanic material captured in ice cores (e.g., ash, tephra), pollen found in lake sediments, or evidence gleaned from tree rings to name a few. The archives of society can be documents written during the time in question such as chronicles, newspaper articles, administrative literature, poetry, ego-documents, weather records, etc., but also inscriptions referring to a certain event (e.g., flood marks on bridges, dikes, buildings, etc.), and epitaphs. Every type of source has its particular strengths and weaknesses. With the "Interdisciplinary Nature-Induced Disaster Index" (INID-index), we want to offer scientists a tool to assess the quality of historical sources when analyzing nature-induced disasters, such as historical volcanic eruptions, from an interdisciplinary perspective.

The starting point of the index is a "signal" in the archives of nature (e.g., ice cores). This indication is verified by further analyses following the single steps on the index. Each step of the analysis is evaluated in terms of its significance. If the analysis is clearly in favor of the natural event, the value of the index increases by 1. If additional effects contributing to the event can be identified, the value is increased by 1 as well. If no evidence for a naturally caused effect can be identified, the value decreases by 1. In any case of uncertainty, the value remains neutral at 0.

Once a signal or peak has been identified in the archives of nature, the next step is to date the event. Statistical uncertainties must be addressed clearly in this case and need to be discussed and evaluated in terms of +1/0/−1. Additional paleoclimatological evidence (e.g., tree-ring data) should be used to determine whether more data is available that may support the initial information. Evidence from the archives of society (e.g., chronicles) is often used to calibrate studies and finetune the dating of specific events. Historical evidence, however, is challenging. A series of research steps need to be taken in order to verify its validity.

It should be considered that historical documents are available in different forms. There are plain translations of manuscripts, publications offering the original language and a translation, and critical editions informing readers about the status of the manuscripts (some parts might have been inserted years after the initial text had been written), varying handwritings in the manuscripts (which would indicate different authors), etc. Finally, there are the original documents themselves. For example, only a critical edition will indicate whether a report of extreme weather is authentic or simply a copy taken from a different source from a different region. Also, inserts from authors having worked on the given document years after it was initially written will only be described in critical editions or become obvious when looking at the original archival material. In some cases, critical editions or the original documents are not available. Some manuscripts did not stand the test of time and are lost forever. Some documents are still waiting to be critically edited, and some might have been transcribed in the past but destroyed during military conflicts or fires for example. In the case of the latter, a critical edition will therefore never be realized. This needs to be evaluated when looking for historical evidence. Only when original material or critical editions are available and analyzed by a specialist can a positive value be applied to the index (+1). Because of the uncertainty that lies in non-critical transcriptions, their value is neutral (0). This is also the case when using translations of critical editions without consulting the editions themselves. Translations without any information concerning critical editions should be excluded from interdisciplinary research (–1). In order to avoid negative values, an expert should be consulted here.

After a source has been identified, more historical material is needed that meets the aforementioned quality standards. This may help to identify the regional scope of a natural impact. Besides the availability of historical sources and their critical editions, however, it is necessary to evaluate their authors and their credibility. What is known about the author(s)? What was their intellectual background (what knowledge was available to them), at which location were the authors writing the text, and/or what was the quality of the information they could possibly rely on? An educated abbot writing a letter to his king informing him about poor provisions in his monastery due to a bad harvest related to unfavorable weather conditions is a considerably more trustworthy informant than an anonymous monk writing about some misery in a distant region he heard about. These questions can contribute to a deeper understanding of the environmental circumstances possibly related to an event spotted in the archives of nature (INID-index 0–5).

In order to distinguish between reliable and less reliable sources, historians look for “contemporary” evidence. “Contemporary” means that the author and/or the historical document, as well as the events described, belong to the same time period in the past (at best, the text was written by an eyewitness the same year, month, and day). Historical writings often depend on one another and so do the pieces of information they provide. Through clerical connections, for example, information written in one monastery could well be transferred to another, and accounts written in one region could be copied in another so that the same information can be found in two historical sources from different regions. This information is not independent—it is simply a copy. By evaluating and considering these factors in an interdisciplinary context, the findings in the archives of nature can be combined with dense, corroborative historical evidence. These evaluations can lead to an increase in the likelihood of a nature-induced disaster for a given incident (INID-index 5–7).

Historical documents—especially chronicles and similar literature—are rarely “fact-reports”. Information in these texts was often adjusted to the purpose of the author(s). Culture and religious belief play an important role here. There is evidence that in some instances writers fabricated natural events, or spun real events in a certain way simply for dramatic purposes (Wozniak 2020). Topoi and narrative motifs are frequently used when describing extreme events or social distress (Nünning 2013; Schellbach 2021). Often motifs from the Bible like hordes of locusts or cannibalism indicate cultural patterns of processing certain events rather than historical facts (Stathakopoulos 2016). It is necessary to rule out such aspects when looking for nature-induced disasters.

Vulnerability and resilience studies indicate that a key element in understanding the dimensions of an extreme event is the social structures it collides with. In order to overcome monocausal explanations, researchers need to distinguish between a nature-induced disaster and a disaster caused by multiple factors. It is therefore crucial to look for other/social stressors that could have contributed to the situation. This could be social and/or political conflicts during the time in question, failing infrastructure, insufficient aid programs, and so on. These factors need to be excluded when arguing for a nature-induced disaster (+1). In order to ascertain how past societies were impacted by and responded to climatic shocks, understanding historic coping strategies is important; this may help identify particular measures related to a certain natural impact (e.g., drought, heavy precipitation, volcanic cooling) or shed light on how people interact(ed) with their environment more generally. By following the index, uncertainties regarding a nature-induced disaster can therefore be limited to a low level (INID-index 7–9).

In the context of measures taken, it should be considered that the way people react to certain events highly depends on how they interpret them (Schenk 2010). An analysis of the connection between the interpretation of a natural event and measures taken may provide a deeper understanding of how past societies responded to climatic shocks. By looking for multiple causes for cascading effects (Pescaroli and Alexander 2015) and by analyzing them precisely, it is possible to evaluate the natural dimensions of a disaster. This not only reduces the uncertainty; it also helps to improve our understanding of extreme natural events and under which circumstances they likely cause the most damage (INID-index 9–11). Since a precise distinction cannot be achieved in every case, the index is designed to ensure a certain flexibility by overlapping values (INID-index 5/7/9).

Eldgjá and Laki will be used as two examples of how to implement the index during research. In addition, an event in ca. 913 is discussed to clarify the contours of the method presented and to highlight desiderata proposed by the index.

3.1. Eldgjá

Following the INID-index, several aspects can be attributed to the Eldgjá event. The natural event has been identified and dated accurately by paleoclimatology using ice-core data, tree rings, and also historical records from various regions (+5). A substantial number of records are copies from later centuries and they depend on each other. Contemporary and independent manuscripts from Europe, however, remain (Ebert 2021) (+2). They were written in the historical regions of *Lotharingia*, *Saxony*, *Swabia*, and the eastern borders of *West Francia* as well as northern Italy and the monastery of Montecassino (Italy). While these manuscripts mostly describe hard winters, famines, cattle mortality, comets, or a solar eclipse, four medieval texts, in particular, have been used to date and explain volcanic impacts on climate and society in the tenth century: The *Chronicum Scotorum* (a compilation of Irish annals from the 1700s based on earlier manuscripts), the *Res gestae Saxonicae* ("Deeds of the Saxons") by the Saxon chronicler Widukind of Corvey (written ca. 967–973), the Icelandic *Landnámabók* ("Book of Settlements," written in the 1200s), and the *Codex Regius* that contains the Poetic Edda (written ca. 1270). The *Landnámabók* and the *Codex Regius* need to be excluded because of their significant temporal distance. They may refer to a volcanic event, but the information given is too vague to be clearly assigned to Eldgjá. Writing more than 250 years after the eruption, the scribes might have included experiences and reports of other volcanic eruptions in their descriptions (Ebert 2021). Current assumptions based on the *Codex Regius* about the Christianization of Iceland stimulated by Eldgjá are therefore questionable because the source is not contemporary (see above). The value of the *Chronicum Scotorum* is ambiguous. Due to its substantial temporal distance, the source can be excluded from the analysis. Studies on the *Chronicum Scotorum*, however, have at least put its distorted chronology in order so that a dating of phenomena described in the text is possible (McCarthy 1998, 2005). Yet, the account in the *Chronicum Scotorum* regarding a blood-red sun (see above) cannot be attributed to Eldgjá because the duration of one and a half days is too short and—more important—the subsequent line in the chronicle refers to the siege of the fortification Ailech by “the heathens” (Chronicum Scotorum, a. 939). The blood-red sun could therefore be a topos—a prodigy—indicating that blood will be spilled in the future. The same must be applied to the writing of Widukind of Corvey († after 973). In the second book of the “Deeds of the Saxons,” he writes: “Many people were terrified at the sight of the comets, fearing that there would be a great pestilence or at least a change in ruler since great prodigies were seen before the death of King Henry. For example, the light of the sun could hardly be seen outdoors because of the dark sky, but inside sunlight poured red as blood in through the windows of houses” (eds. Hirsch and Lohmann 1935; trans. Bachrach and Bachrach 2014). King Henry I died in 936. Hence, Widukind refers to an event that occurred not later than this year. According to recent paleoclimatological research, an eruption date for Eldgjá of around 939/940 is likely, which allows for the conclusion that the phenomena that Widukind describes were not connected to the Icelandic eruption. There may have been communication networks from Iceland via England to Saxony, but there is no evidence that supports historical observations connected to the Eldgjá eruption (Wozniak 2020; Ebert 2021). Since there is no evidence for or against the natural signal, the INID-index value is 0.

Social stressors are considerable during the time in question—especially in *East Francia* ruled by Otto I (912–973). In the subsequent years after his coronation in 936 warlike conflicts set in as Otto pursued a new policy that some magnates in his kingdom did not support (Ebert 2021). War, plunder, and looting increased severely. In particular, *Saxony*, *Swabia*, and *Lotharingia* fell victim to these conflicts. Most of the tenth-century sources are located in these very regions (Ebert 2019, 2021; see also the GIS map available at https://arcg.is/rbn5i). This means that the Eldgjá eruption coincided with a period of military conflicts, and political and social instability that severely threatened people’s livelihoods. The disastrous situation was not entirely nature-induced (–1). Rather, the volcanic event contributed to worsening the situation, and was one factor amongst many (+1).

In most climate reconstruction papers reaching back to the first millennium CE, historiography is the primary genre consulted, whereas administrative documents play a secondary role. These sources can cover coping strategies and measures taken in reaction to extreme events. In the case of Eldgjá only two administrative documents offer insights into how people might have reacted to environmental stressors. In the first half of the tenth century, a capitulary (royal decree) dealing with famine in 779 was included in a codex compiled in the regions between *Lotharingia* and *West Francia* (Mordek 1995). The capitulary aimed to overcome hunger with spiritual guidance and food aid (i.e., prayers, almsgiving/pecuniary fees, feeding of paupers, and fasting). In the event of social turmoil during the time in question and natural stressors setting in, monastic communities could have found orientation in such a decree and acted accordingly (Ebert 2021). These measures only make sense when interpreting changes in the natural and social environment as divine punishment (+1). In 940, abbess Markswid of the Saxon monastery Schildesche (Germany) ordered her sisters to participate in an annual rogation to pray for a good harvest and an end to adverse weather (Holder-Egger 1888). In a social environment in which Christian belief was not yet totally engrained, instructions of this kind helped to actively involve the population in Christian rituals. Measures such as this, show that extreme events could conceivably lead to the ubiquitous influence of Christianity in everyday life. The historical evidence, however, is very poor. While at least in the case of the capitulary, the dating in the relevant period is certain (+1), the vita of Markswid mentioning the rogation was not written until the thirteenth century and is therefore uncertain—even if it clearly refers to 940 (0).

If the values obtained from the index are added together, the result is an INID-index value of 9. A nature-induced event is likely. This can be confirmed with methods from the natural sciences and historical records. In addition, social stressors and multi-causal effects can be observed, which offer a new perspective on the diverse relation of nature-induced and anthropogenic factors during and after the Eldgjá event. Contemporary coping strategies related to specific societal interpretations of historical events can be observed. Due to the limited quantity and quality of the relevant sources in this case, however, some uncertainty remains for the Eldgjá event as a whole. This might be unsatisfying, but the benefit obtained from the index compensates for this shortcoming: Although the Eldgjá eruption had a high intensity, its impact on western and central European societies was only significant due to an interaction with human-made factors.

3.2. Laki

Paleoclimatological reconstructions using ice-core data, tree rings, and several historical sources from Europe, North America, North Africa, and Asia are in good agreement about this event (+5) (Hantemirov et al. 2004; D’Arrigo et al. 2011; Sigl et al. 2015; Edwards 2021). The eruption and its effects upon Iceland are well documented by Icelandic eyewitnesses: One example is the Lutheran priest Jón Steingrímsson who kept detailed notes. He lived in Kirkjubæjarklaustur, 32 km from the Laki fissure. These reports give us the eruption’s exact start and end dates as well as its local consequences (Steingrímsson 1998; Steingrímsson 2002; other contemporary Icelandic reports are mentioned in Thordarson 2003; Thordarson et al. 2003). In 1788, Steingrímsson authored a fire treatise (*eldrit*) about the Laki eruption, which was intended for publication so that all Icelanders “born and yet unborn” would remember the event (Steingrímsson 1998). He also wrote a memoir of his life, most likely in 1788. However, he did not intend for this to be published; it was written exclusively for his descendants, which allows for the assumption that he wrote openly about his struggles. The autobiography was published posthumously in 1916 (Steingrímsson 2002). Both manuscripts survived and are housed at the National and University Library of Iceland. They are also available in English translations.

As the Laki eruption occurred in the late eighteenth century, many historical sources were produced by contemporaries and have survived up to the present. Some of the numerous sources that make mention of the unusual weather in Europe include newspapers, weather diaries, private correspondence, and scientific publications.

Many articles in dozens of newspapers from different parts of central and western Europe mention unusual weather phenomena. At times, however, different newspapers used the same correspondent or copied from one another, which becomes apparent from the phrasing of individual articles. While newspaper articles can be dated exactly, as most newspapers were printed one to six times per week, the identities of the correspondents responsible for penning the articles are rarely known. Nevertheless, the large number of articles regarding the unusual weather in different regions during the summer of 1783 published by dozens of newspapers over the course of several months make the sources independent. In weather diaries, amateur weather observers and naturalists made observations regularly, often daily. This is the case, for instance, with the weather diary of British naturalist Gilbert White at Selbourne (England), whose “Naturalist’s Journal” manuscript for 1783 and the following years are available at the British Library (White 1783). Several other contemporary naturalists also kept weather diaries, where they wrote about their meteorological observations (Woodforde 1782–1784; Barker 1783; Beroldingen 1783; Christ 1783; and many others). These sources are also contemporary and independent (+2) (Kleemann 2022).

At the time, the *Societas Meteorologica Palatina*, a meteorological society with its headquarters in Mannheim (Germany), operated a network of more than thirty weather stations across Europe and beyond. The society’s weather observers received standardized instruments and forms with instructions to take note of the instruments’ readings at three specific times per day. After the year’s end, the forms were sent to Mannheim, where they were compiled into annual compilations called *Ephemerides*. The Ephemerides for 1783 include instrumental data on temperature and pressure and sometimes remarks on *meteora*, unusual observations that include descriptions of the sun setting in a blood-red color or the Laki haze (Societas Meteorologica Palatina 1783 (1785)). The application of careful scientific methods by many various documentations from different weather stations in different parts of Europe and the collection of large quantities of data rule out topoi (+1).

Throughout the summer of 1783 and the following year(s), several naturalists published their speculations about the source of this unusual weather, particularly the dry fog. Many different theories were in circulation at the time. Some blamed the earthquakes in Calabria in February of that year, which allegedly had caused cracks in the Earth that released the noxious gas, Others suggested that the large-scale introduction of lightning rods deprived the air of its “fertilizing electricity,” which in turn led to the formation of the fog. A few naturalists, as early as the summer of 1783, postulated that an Icelandic volcano, such as Hekla, or the emergence of a new “burning island” off the coast of Iceland was to blame. These scientific explanations were published by contemporary newspapers with an emphasis on calming the readership, which can be seen as a coping strategy. Additionally, newspapers undertook interviews with the elderly who reassuringly stated that similar events in the past were usually followed by good harvests. The newspapers also searched chronicles, which corroborated what the elderly interviewees had said, further comforting their readership (+1) (Kleemann 2019a; 2019b).

While the hot temperatures and Laki haze did affect vegetation in some parts of western Europe, it largely recovered and did not cause a bad harvest or famine that year (Grattan and Pyatt 1994; Stothers 1996). In the same areas, those with pre-existing respiratory diseases did suffer because of the Laki haze. Others complained about sore throats and eyes (Brugmans 1783; Santel 1997; van Swinden 2001). Some regions in England and France experienced increased mortality in the summer and autumn months of 1783. It is, however, inconclusive as to whether these bouts of diseases occurred independently from the Laki haze or were aggravated by it (Durand and Grattan 2001; Grattan, Durand, Taylor 2003; Witham and Oppenheimer 2004; Garnier 2011). Further research is needed to establish which regions in Europe were affected by this increased mortality in the second half of 1783. This may lead to insights about the possible causes of death. Currently, the Laki eruption cannot yet be ruled out as the culprit (0).

The Laki haze—then known as "the dry fog," "haze," or "mist"—was blamed for several of the observed unusual phenomena in nature, such as a seeming increase in the number of thunderstorms (with frequent lightning strikes that injured and killed people) and the unusually hot summer. Some contemporaries suggested there was a connection between the eruption and the severe winter(s) that followed. Modern natural scientists confirm some of these assumptions, at least for a connection between the eruption and the subsequent cold winter(s) (+1) (Franklin 1785; Hochadel 2009; Zambri 2019a; 2019b). During the summer of 1783, contemporaries in Europe were unaware of the eruption in Iceland, instead the Calabrian earthquakes were discussed as a potential cause of the dry fog. Many coping strategies were developed: A newspaper report in the *Königlich-Privilegirte Zeitung*, a Berlin-based newspaper, from 24 July 1783 suggested that vegetables affected by the fog should be washed properly before consumption. The diligent smoking of tobacco was also recommended, as was keeping livestock inside. These recommendations were written by an anonymous correspondent from Hanau (Germany) in a newspaper. From the records there is no indication that suggestions like those mentioned above were widely adopted. (Kleemann 2022).

When calculating the values from the index, the result is an INID-index value of 10. Therefore, a nature-induced event is likely from both the perspective of interpreting paleoclimatological data and historical records. While it is not yet clear beyond a reasonable doubt whether the Laki eruption was responsible for the peak in mortality in 1783, the dry fog and other unusual phenomena definitely captivated onlookers and naturalists alike. They collectively processed the various observable events that included a sulfuric-smelling dry fog, which triggered respiratory problems, sore throats and eyes in some regions, the withering of vegetation, "blood-red" sunsets, many thunderstorms, and a colder-than-usual period following an unusually warm summer. Contemporaries developed many different interpretations of the unusual weather and numerous coping strategies.

3.3. Volcanic Induced Harsh Winter Around 913 CE?

In this chapter we aim to contrast the previous analyses by comparing the INID-index results with a case notably different toEldgjá and Laki. A peak in SO_4 sediment in the GISP2 ice core dated to ca. 913 has been assumed to be connected to an Icelandic eruption—probably Katla (Zielinski et al. 1995) (+1). A precise dating or localization of the eruption, however, has yet to be published (0). Dendrochronological reconstructions of the summer months (JJA) do not indicate a significant temperature decrease (Luterbacher et al. 2016) and a wet summer can only be identified in Ireland in 912 where dry summers followed in the years after—beginning in 914 (Cook et al. 2015). Regarding the INID-index, additional studies from the natural sciences are available, however, their results do not support a definite nature-induced disaster (0). Harsh winters were documented in Ireland and along the river Rhine in 912–914 (McCormick et al. 2007; Wozniak 2020) by various, contemporary, and independent writers (+3). The Irish *Annals of Ulster* even mention "a dark and rainy year" in 912 and 913. It is not clear whether this report refers to both years or one report is simply a duplicate of the other. The observations could well be influenced by volcanic aerosols in the atmosphere, but there is no similar report from another region that supports this assumption. The annals document many deaths of various individuals in 913, and so, the "dark and rainy year" could also be interpreted as metaphorically dark and rainy, given the events mentioned (0). From a dendrochronological perspective, however, this account matches the wet summer reconstructions in Ireland in 912 (see above) (+1). The only reference that may explain the darkness in the Irish annals is a solar eclipse documented in Córdoba (Spain) on 17 June 912 (Wozniak 2020), but according to the NASA Catalog of Solar Eclipses it is unlikely that this event was visible in Ireland (−1). Adémar of Chabannes (989–1034), a chronicler from Aquitaine (southwest France), describes a severe famine in ca. 913, but he attributes the widespread hunger and punishment to the rule of Alduinus, a French count who had unlawfully acquired a relic (Wozniak 2020). Hence, a link between the famine and environmental circumstances is uncertain in this case (0). Hunger is not reported elsewhere and social stressors during the time in question are mainly documented in *Lotharingia*, *Saxony*, *Bavaria*, and *Alemannia*—regions not affected by famine. A connection between a harsh winter, limited food provisions, and social conflicts contributing to the limited food supply is not possible in the case of 913 (−1).

In short: There are indications of a volcanic induced winter, but there is a high uncertainty regarding a nature-induced disaster so the index value is 3. Due to the poor evidence in the archives of nature and society it is difficult to evaluate how much the event spotted in the GISP2 ice core contributed to the winters of 912/913 and 913/914. The impact on society, it seems, was not substantial as there are no reports of vast mortality in multiple regions in Europe. The chronicle of Adémar of Chabannes, however, could be a case for further investigation. Micro studies on the historical region of Aquitaine and its environmental conditions could prove whether Adémar really uses the famine as a topos or if there is more evidence for a natural impact and its cultural consequences—a desideratum highlighted by following the steps of the INID-index and contributing to the understanding of past interrelations of humans and nature.

4. Discussion

The INID-index is a tool to aid and support the interdisciplinary cooperation and communication between historians and natural scientists from various different disciplinary backgrounds. This index provides a checklist to assure historical sources are suitable to use as corroborative evidence in conjunction with paleoclimatological data.

The INID-index enables natural scientists to select reliable, solid sources to support their paleoclimatological studies with data from archives of society by following the different steps illustrated in the index, discussing the given uncertainty, and comparing the resulting number with figure 2. The INID-index also reminds historians to look beyond the realm of history and to include findings and data from the natural sciences by considering the first few steps of the index. This is crucial in order to confirm whether an event that is described in historical sources can be cross-referenced by other means, such as paleoclimatological data. The INID-index, therefore, is a powerful and easy-to-use tool in interdisciplinary approaches to historical climatology, historical disaster studies, and more broadly environmental history. The proposed integration of findings based on studies from both paleoclimatological and historical sciences will increase the validity and significance of all disciplines involved. This is strengthened by the consilience approach (Haldon et al. 2018) as the methods of the natural sciences and the humanities are epistemically completely different and independent.

As we have shown, not every historical source is equally suited to serve as proof of a distant volcanic eruption or another extreme event. A given source is only safe to use if it meets certain criteria. Ideally, the source should have been written by an eyewitness of the event or its teleconnections close to the time. In order to be able to adequately evaluate the source, we need to know its provenance and, in the best-case scenario, have access to the original in its language. Furthermore, we need to establish why the authors wrote about the event and what their motives might have been. Was the writing motivated by religious motifs, political interests, or curiosity? Evaluating a single source becomes easier when we compare it to other sources from the time if they are available.

Both Eldgjá and Laki are examples of Icelandic flood basalt volcanic eruptions. Eldgjá and Laki combined produced more than half of all the lava ejected from Icelandic volcanoes in historical times (Thordarson and Höskuldsson 2014). These are low-probability but high-impact events (Schmidt et al. 2011; Ágústsdóttir 2015). Applying the INID-index to these two volcanic eruptions and their effects on Europe shows that the index can be utilized for nature-induced disasters that occurred during periods for which few written sources are available (tenth century) and periods for which we have a rich source base (eighteenth century). Although both eruptions are very similar in geographic origin, eruption style, and volumes of lava and gases released, the consequences were different: While descriptions of the dry fog and the subsequent “blood-red” sunsets feature prominently in sources from the summer of 1783, similar descriptions are few and far between for 939–940. It is, of course, possible that differing conditions at the time of year (jetstream, wind patterns, high and low-pressure systems) led to less obvious phenomena. It is also possible that the contemporary perceptions of the environmental consequences of the volcanic eruptions were different. Hence, the index pushes research forward as it creates new desiderata (e.g., differentiated view on large scale historical eruptions and conditions contributing to their wide range effects, natural influences not previously considered in the context of social conflicts, analyses of local coping strategies on a wider geographical scope, interdisciplinary research on historical atmospheric conditions during the time in question). Limitations of the INID-index are to be found when data is poor. The ca. 913 case demonstrates that the index cannot compensate for missing sources. Rather, it helps scrutinize the data available from different disciplines critically, and it can also highlight new questions. By applying an INID-index value to a specific case the certainty of the nature-induced impact becomes measurable and increases the validity of the given study. While we have applied the INID-index to volcanic eruptions, the index is also suitable for studying other nature-induced disasters throughout history, such as flooding events, droughts, earthquakes or even epidemics.

5. Conclusion

The INID-index is an analytical tool for interdisciplinary studies. It can be used to examine the impact of nature-induced extreme events and to measure their contribution to historical disasters. The step-by-step evaluation of the single finding not only provides a methodological guide for research but also reveals the uncertainties contained in this finding in a comprehensible way. By classifying the single steps, the index simultaneously stimulates a reflection on the interpretation of individual research data. Overall, the index allows for new paths of investigation, which—in the end—provides a more precise result on a specific natural event from the perspective of the disciplines concerned. In this way, a large number of factors that may have been involved in the emergence of a disaster are examined. Monocausal explanations can thus be avoided. If, however, the investigation proves that only one specific factor was decisive, the result is all the more convincing. The use of our index on the examples of Eldgjá and Laki demonstrates that the effects of two comparable volcanic eruptions were different due to natural but especially human-made factors. In this respect, the index gives differentiated insights into how past societies were affected by natural impacts and how they dealt with them.

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Figures

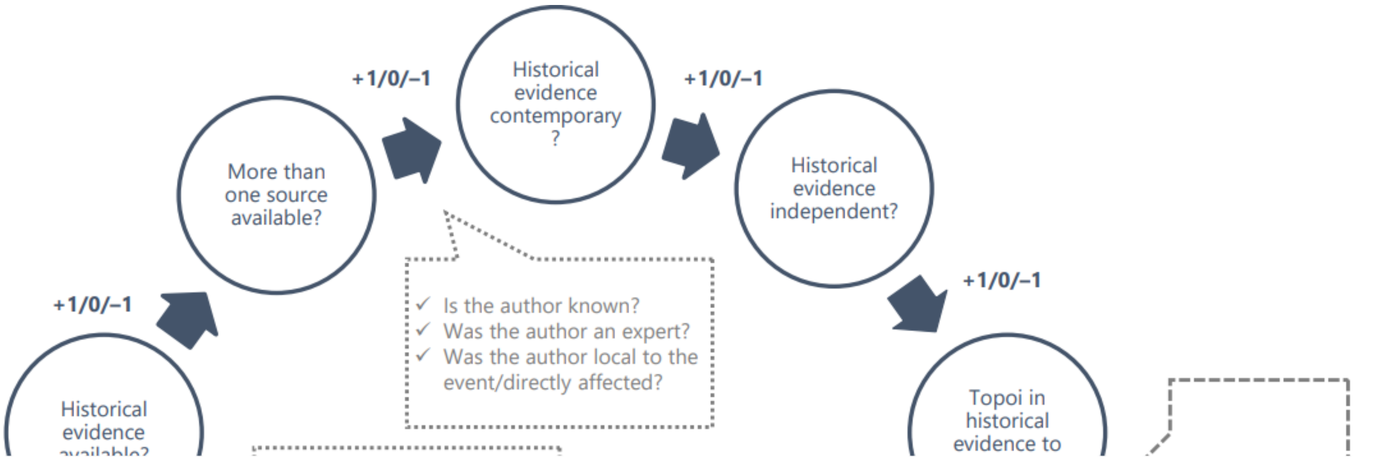

Figure 1

Interdisciplinary Nature-Induced Disaster-index (INID-index)

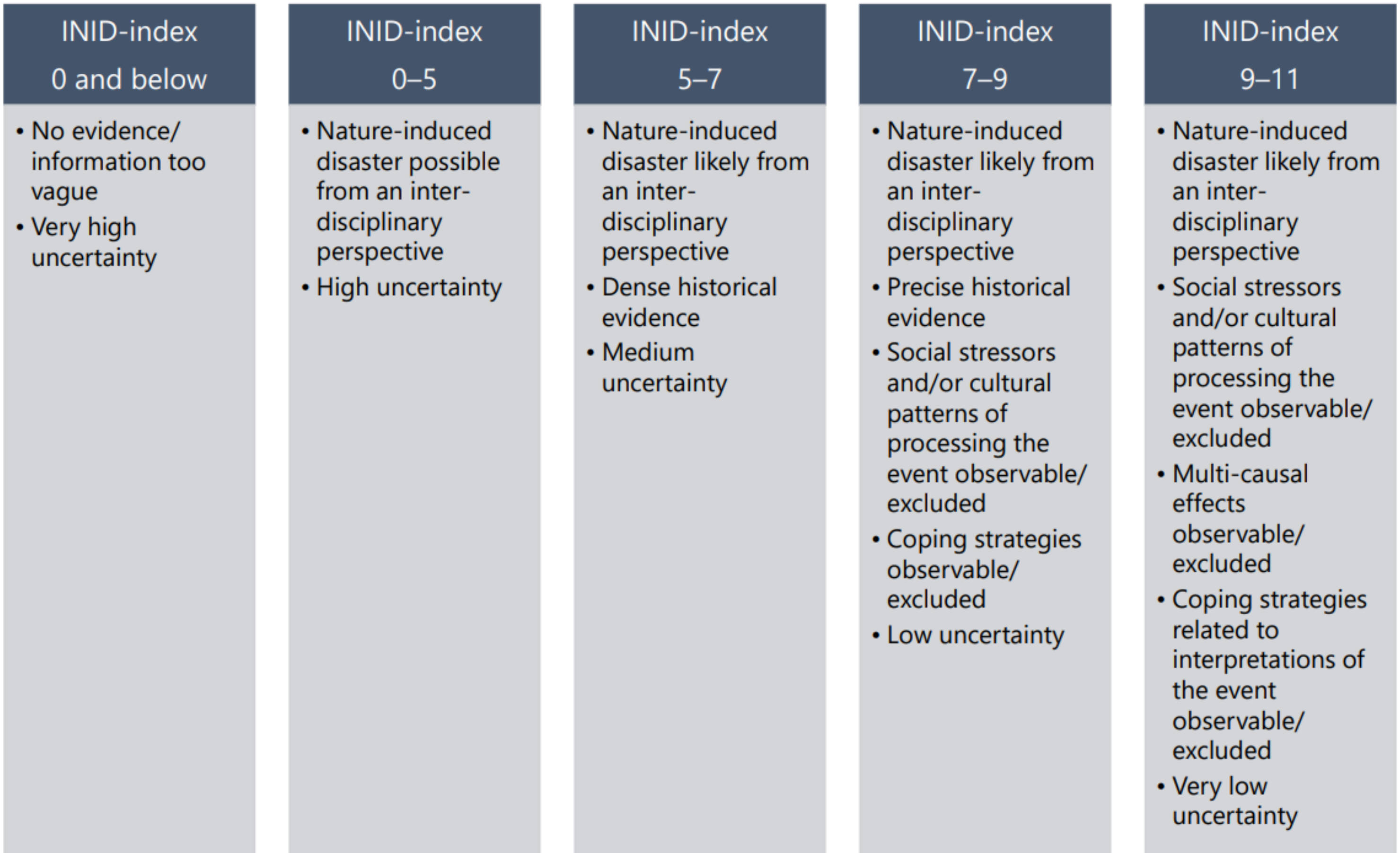

Figure 2

Overview of values of the INID-index