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9 Climatic conditions and mobility from 1000 to 1500. Hermeneutic and statistical approaches

9.1 Introduction

The present paper is based on two well-researched areas, namely medieval climate developments from 1000 to 1500 and patterns of historical mobility. However, the connection between climatic influences and mobility has been taken up only fragmentarily in both fields. For example, there are general references from the content-rich, historical research area on trade and transport,[1] which refer to weather and road conditions, including the risk posed to sea routes from storms, water depths and water levels, the cessation of navigation in the event of ice, and other effects of natural events on navigation.[2]

Elsewhere, historical climatology has produced reconstructions of climate developments that are rich in content and regionally differentiated. These mainly refer to general temperature trends,[3] temperature patterns[4] and precipitation patterns,[5] but also include extremes such as storms,[6] floods[7] and droughts.[8] Even in these, however, impacts on mobility are only marginally addressed, for example the ice conditions in the Öresund[9] and the impact on customs revenues.[10] The connection between climate, weather and mobility is also mentioned in works on environmental history,[11] but not analysed systematically there. This article shows to what extent this connection can be quantified and divided into temporal phases on the basis of the available sources

1 *Schwinges*, Straßenwesen (2007).
2 *Oberste*, Handel (2017), 147–156; *Vavra*, Verkehr (2017), 156–164.
3 *Glaser/Riemann*, Temperature (2009), 435–449.
4 *Riemann*, Klimarekonstruktion (2012).
5 *Van Engelen/Buisman/Ijnsen*, Weather (2001).
6 *Lamb*, Storm (1991), 204.
7 *Himmelsbach* et al., Flood (2015), 4149–4164; *Glaser/Stangl*, Floods (2003), 93–98.
8 *Glaser/Kahle*, Droughts (2020), 1207–1222.
9 *Speerschneider*, Isforholdene (1915 and 1927).
10 *Koslowski/Glaser*, Ice winter severity (1999), 175–191.
11 *Hoffmann*, Environmental History (2014), 428.

Acknowledgements: This paper benefited from the participation in the Climate Reconstruction and Impacts from the Archives of Societies (CRIAS) working group of the Past Global Changes (PAGES) project.

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https://doi.org/10.1515/9783111166698-009

with the help of new statistical methods. Due to the current availability of sources, the temporal focus of the material discussed is the period between 1000 and 1500.

9.2 The general climate development of Central Europe 1000–1500

The climate regime of Central Europe from 1000 to 1500 was characterised by the so-called "Medieval Warm Period" and the gradual transition into the "Little Ice Age".[12] Between 1000 and 1500, however, the temperature level was 0.5 to 1 degree Celsius below the modern "warm period", dated from 1900 onwards. It also differed significantly from the modern warm phase beginning in 1900, and especially from the strong exponential warming taking place since the 1980s. Compared to the modern warming from 1980 onwards, temperatures in 1000 to 1500 were 1.5 degrees lower. This also puts the concept of the "heat optimum" into perspective. At best, it is justified from the perspective of the "Little Ice Age" that became particularly apparent after 1500.

The medium-term temperature development from 1000 to 1500 was mainly determined by higher summer temperatures, while winter temperatures remained significantly lower than in the modern warming period from 1900. The transitional seasons were also cooler than in the modern era from 1900 onwards. In addition to this fundamental seasonal pattern, the climate trend exhibits further medium-term fluctuations and structures. These become visible, when temperature or precipitation data is averaged over some decades, which is typically done for 30 years. During the "Medieval Warm Period", warming and cooling phases occurred alternately several times.

The temperature developments presented here are confirmed by further studies.[13] Deviations arise from other regional focuses and different methodological approaches, for example, when not only written sources but also natural proxies were used for the reconstructions. In addition to reconstructions of long-term developments, there are also elaborations on particularly striking phases, such as the "Spörer Minimum", which covers the years from 1430 to 1445.[14]

Since the precipitation situation is basically structured on a smaller scale, the research results of the present study show significantly greater spatial and temporal variability than temperature trends.[15] Basically, precipitation increased after 1000,

12 *Glaser/Riemann*, Temperature (2009); *Glaser*, Klimageschichte (2013).
13 *Ladurie*, Histoire du climat (1983) I, 287 and II, 254; *Alexandre*, Climat (1987), 708–785; *van Engelen/Buisman/Ijnsen*, Millennium (2001); *Büntgen* et al., Climate Variability (2011), 578–582; *Wanner*, Klima, (2016), 276.
14 *Camenisch* et al., Spörer Minimum (2016), 2107–2126.
15 *Glaser*, Klimageschichte (2013), 264; *Cook* et al., Megadroughts, 2015, 1–9; *Büntgen* et al., Drought (2021), 190–196.

and there was a tendency towards drier conditions between 1200 and 1300. This period was followed by a wet phase, developing between 1300 and 1350, after which point precipitation decreased again – especially in summer and spring – until 1500, while heavier precipitation was recorded in the winter months. The fluctuations in this season remained at a higher level, and autumn precipitation also increased in the long term.

The force of solar activity is the main energy source for the terrestrial climate system. The variations of solar radiation – which are documented in sunspots, among other phenomena – are, besides the variations of the orbital parameters, an essential cause for so-called 'natural forcing', a major cause for changes of the terrestrial climate system. All known phases of reduced solar activity in historical times are accompanied by global phases of cooling. These known phases of significantly reduced solar forcing are the so-called "Oort Minimum" from 1040 to 1080, the "Wolf Minimum" between 1280 and 1350, the "Spörer Minimum" 1460 to 1550, and the later "Maunder" 1645 to 1715, "Dalton" 1790 to 1830, and "Glassberg Minimum" 1880 to 1914. In particular, the "Spörer Minimum" is seen as one possible trigger for the transition from the "Medieval Warm Optimum" to the "Little Ice Age".

In addition to solar forcing, other natural forms of forcing exist, one noted example being volcanic activity that interacts with solar forcing.[16] Explosive volcanic events also had a cooling effect, such as the Lombok eruption of 1257,[17] the eruption of Tambora in 1815 and the following "year without summer", 1816, or the Krakatau eruption of 1883 and Pinatubo in 1991. Other natural forcings are the interactions between ocean and atmosphere, as can be seen in variations of the El Niño/La Niña occurrences and oscillations in the Northern Atlantic (NAO).

Of particular relevance to the questions of mobility pursued here are weather extremes, which could have very different effects. These include extremely cold and snowy winters, hot summers and droughts, high and low water levels, storms, and especially storm surges. Numerous works have already dealt with individual extremes – such as storm surges,[18] flood events,[19] and the occurrence of droughts.[20] Small-scale heavy rain, which sometimes led to landslides, and severe weather, also had impacts. Some relevant publications here include compilations, such as those by Weikinn[21] on weather history or Pfaff[22] on severe winters. These somewhat uncritical

16 *Lamb*, Volcanic Dust (1970), 425–533; *Guillet* et al., Lunar Eclipses (2023), 90–95.

17 *Lavigne* et al., Eruption (2013), 16742–16747.

18 *Jakubowski-Thiessen*, Mandräken (2000), 122–133; *Schenk*, Meeresmacht (2009), 52–66.

19 *Glaser/Stangl*, Floods (2003), 93–98; *Glaser/Stangl/Lang*, Floods (2004), 63; *Himmelsbach* et al., Flood (2015), 4149–4164; *Blöschl*, Flood (2020), 560–566; *Tuset*, Floods (2022), 1–17.

20 *Cook* et al., Drought Atlas (2020), 2317–2335; *Büntgen* et al., Drought (2021), 190–196; *Ionita* et al., Megadroughts (2021), 1–9; *Stahl* et al., Drought (2016), 801–819.

21 *Weikinn*, Witterungsgeschichte (1958–1963).

22 *Pfaff*, Winter (1809).

text compilations are repeatedly criticised, for example by Alexandre.[23] In such compilations, passages of text were sometimes recompiled uncritically without indication of the original authors. On the one hand, then, it is unclear whether this is authentic information from contemporary witnesses. Moreover, the same sources were used again and again in different compilations without citing them, so that a density of content and spatial coverage is given that *de facto* did not exist. On the other hand, they help to compensate for source losses due to wars and fires. Overall, the climate history of Central Europe can be considered relatively well-researched.

9.3 Data and methods

In the framework of the present study, the impacts of climate change and extreme weather events on mobility were analysed by assessing data from the virtual research environment tambora.org. Tambora.org stores medieval evidence along with the coding of relevant locations and times as well as the content of the individual weather-climatic events. In particular, the weather and climate content has been transcribed into indices that are also available for further calibration, through which we can derive estimated values.[24] All information is critically reviewed in the sense of the hermeneutic principles.

In a first step, relevant sources from the period 1000 to 1500 were screened via keywords and codings including low water, floods, cold winters, frozen-over waters, extreme snowfall and storms. From this an impact on mobility could potentially be expected, and this information was subsequently compiled into a separate text corpus (Figure 9.1). Additionally, the texts were analysed for mobility-related keywords pertaining to transportation routes and infrastructure, modes of transportation, and means of travel. Search terms here included, for example, roads, bridges, driving, travelling, riding, horse, carriage, sled, and ships.

The selection is based not only on these key terms, but also on the damage, consequences, restrictions, and impacts caused by the events. Direct references to the effects and consequences of travel, such as walkability, navigability, passability and transport options, were identified. Descriptions of extreme weather events and statements about their effects on mobility are often placed next to each other, allowing for the determination of causal pathways. A total of 1628 quotations from relevant references in the written evidence were available and coded according to place, time and content.[25] The following quotations in sections 2.1 (and those that succeed it) provide

23 *Alexandre*, Climat (1987), 9–19.
24 *Riemann*, Klimarekonstruktion (2012), 178; *Riemann* et al., tambora.org (2016), 63–67.
25 *Kahle/Glaser*, Mobility (2022).

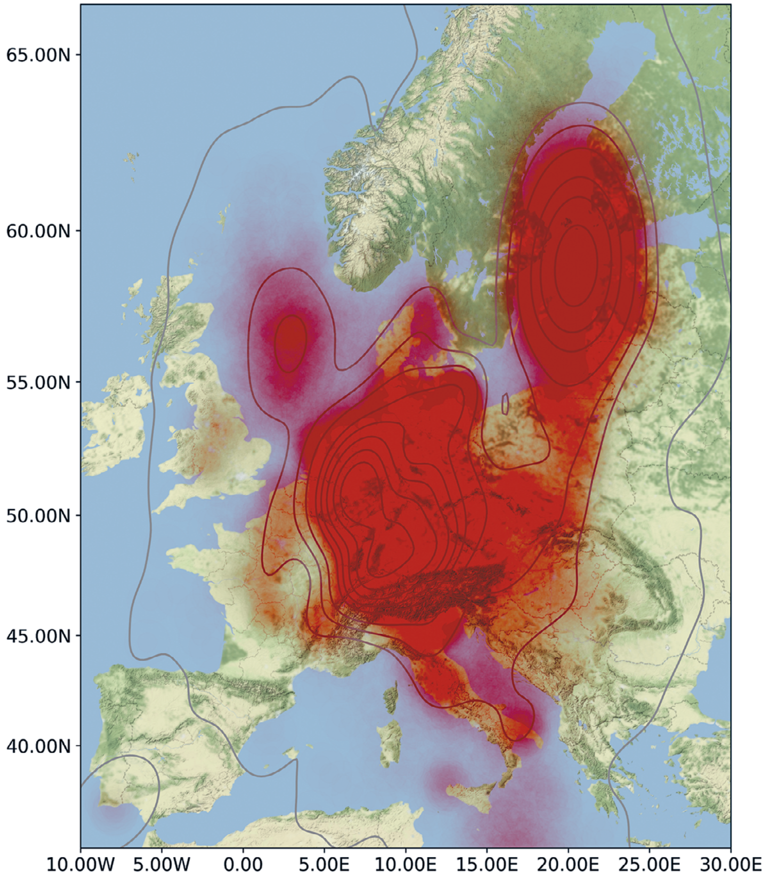


Figure 9.1: Density map of locations and events considered by the study.

insight into the structure of the sources by exemplifying the consequences of the particularly exposed extremes and their effects on mobility.

The written evidence discussed below illustrates the interrelations, impacts, and pathways from a contemporary perspective. An English translation is provided below the Latin original, while Early New High German originals are transcribed in their original wording, together with an English translation. The supplemented bibliographic references are complemented by a link to tambora.org, offering access to the original texts and further codings. The selection of quotes here is intended to represent the range of climatic stressors and impacts to be addressed in each case.

9.3.1 The impacts of extreme cold on mobility

The written sources are dominated by references to extreme cold, in particular the freezing-over of large bodies of water, and the resulting possibility of crossing coastlines, straits, and inland waters. The following discusses the effects of freezing – in a landscape made otherwise impassable by swamps and water bodies – in the context of war campaigns:

> [. . .] rex [. . .] moxque expeditionem contra Liutizos in ipso hiemis tempore paravi iussit. [. . .] Terra etenim illa paganorum aquis et paludibus est plena, sed tunc, hiemis scilicet tempore, nimium erat congelata, et ideo exercitui facta est facilis ingrediendi et egrediendi via.
>
> The king [. . .] soon ordered the preparation of an expedition against the Liutizians during the very time of winter. [. . .] For that, land of the pagans is full of waters and marshes, but at that time, during winter, it was excessively frozen, and therefore, it became an easy way for the army to enter and exit. Source: AAM:3045.

The following reference was made in relation to the possibility of travelling on frozen rivers, an important alternative to the usual "land routes":

> Nimio quippe frigoris congelamento Renus pariter et Eridanus, ut de fluviis caeteris taceatur, in tantum consolidati sunt, ut per longum tempus quasi per terram viam in se glacialem exhiberent cunctis itinerantibus.
>
> Indeed, due to the excessive cold, both the Rhine and the Po (Eridanus), not to mention other rivers, froze to such an extent that they remained solid for a long time, providing a frozen path to all travellers, as if walking on land. Source: BA3101.

The texts below discuss the freezing of isthmuses and sea bays, which obviously had an impact on shipping, and make reference to the use of sledges:

> 1496. Item diesen winter wars so lange kaldt und war so sehr gefroren, das man den 6 tag im Martio fur mit 4 pferden mit einem slitten mit dorsche geladen recht zu von Heel bisz hier in die elbe (Weissel). Auch furen sie aus Pomern in Denmarken mit hantslitten zu Gesso (Gester auf Falster) und zu Mone (Insel Möen). Es war so ausz dermossen kald, das das voryor vil eisz in die sehe treib; auf Philippi und Jacobi [1. Mai] kwemen erst schiffe ken Dantzke und hatten grosse not von eisz gehat.
>
> In 1496, during this winter, it was so bitter cold and frozen that on the 6th day of March, they travelled here to the Elbe (Weissel) from Heel with a sled loaded with codfish, pulled by four horses. They also travelled from Pomerania to Denmark with hand sleds to Gesso (Gester on Falster) and to Mone (Island of Möen). It was so intensely cold that a lot of ice drifted into the sea. Even on the feast days of Philippus and Jacobus [1st May], no ships arrived in Danzig (Gdansk), and they suffered greatly from the ice. Source: NWP10531.

> Das Meer war so stark gefroren, daß man auf dem Eise von Oslo (in Norwegen) nach Jütland (also übers Kattegatt) reiten konnte.

> The sea was so much frozen that one could ride on the ice from Oslo (in Norway) to Jutland (across the Kattegat). Source: NSH6078.

Frozen rivers were crossed with wagons and with horses, as emerges from the following:

> 1292 giengen beladene Wagen über das Eiß bei Breisach.
>
> In 1292, loaded wagons travelled over the ice near Breisach. Source: VCK6095.

> Hiems temperata usque ad purificationem, postea invaluit frigus, quod Renus in Brisaco ex utraque parte pontis fuit congelatus, quod equis et bigis communiter transiverunt. Cives dederunt 10 libras, quo glacies scinderetur, ut naves possent transire.
>
> The winter remained mild until the Feast of the Purification (February 2nd), but afterward, the cold intensified. The Rhine River at Breisach froze on both sides of the bridge, allowing horses and carts to pass over it. The citizens paid 10 pounds to break the ice so that boats could pass through. Source: ACM6092.

Frozen bays also allowed raids while, on the other hand, enabling merchants to communicate between their frozen ships:

> Item ipso anno a festo beati Andreae ad medium quadragesimae sequentis gelu fuit inauditum. Fuit enim inter Daciam et Slaviam et Imbriam totum mare Balticum congelatum, ita quod latrones, de Slavia intrantes, quasdam partes Daciae depraedarunt, et tabernae in medio maris in glacie pro transeuntibus factae fuerunt. Inter Norwegiam etiam, Angliam et Flandriam multae naves in medio maris congelatae fuerunt in glacie, ita quod mercatores ex navibus se mutuo visitabant, eundo per glaciem, pro solatiis habendis. Cum autem resolveretur glacies, fere omnes naves, quae declinaverunt ad partes australes, salvatae fuerunt; sed quae versus aquilonem venerunt, paucae sunt salvatae.
>
> In the same year, from the feast of Saint Andrew [30.11.1322] until the middle of Lent [6.3.1323], an unprecedented cold spell occurred. The entire Baltic Sea was frozen between Dacia, Slavia, and Imbria. Thieves from Slavia entered certain parts of Dacia and looted them, and there were makeshift shops on the ice in the middle of the sea for passers-by. Many ships were also frozen in the ice between Norway, England, and Flanders, and merchants from these ships visited each other by walking on the ice for comfort and support. As the ice began to melt, almost all ships that headed towards the south were saved, but few were saved for those that went towards the north. Source: AL6447.

Frozen bays were also crossed by horse and on foot:

> Anno 1338 was so grodt Wynter und Frost dat men redt und gyngk over de Ostsee van Lubek yn Dennemerken und Prutzen.
>
> In the year 1338, there was such a great winter and frost that people rode and walked over the Baltic Sea from Lübeck to Denmark and Prussia. Source: HR6684.

9.3.2 The impacts of heavy snowfall on mobility

Extreme snowfall made travelling difficult. Indeed, floods after snowmelt often led to the collapse of bridges:

> Hoc anno ex habundantia nivium facta est inundatio, que subruit villas et pontes.
>
> This year, due to the abundance of snow, a flood occurred, which destroyed villages and bridges. Source: ARC3984.

> 1275 Es gab viel Schnee: bei Basel war er erträglich, bei Ruffach konnte man kaum zu Pferde durchkommen, bei Bern und Münster lag er vier Fuß hoch.
>
> In 1275, there was much snow: it was bearable in Basel, in Ruffach, one could barely pass through on horseback, and in Bern and Münster, it was four feet deep. Source: JB5773.

> [between 01.02. and 14.04.] [. . .] Am Mittwoch nach Seragefima [20.02.] war ein gewaltiger Sturm, starker Schneefall und strenge Kälte. [. . .] Am Feste Peter und Paul [29.06.] zerstörte der Rhein die Brücke zu Basel, wobei an hundert Menschen ertranken.
>
> [between 01.02. and 14.04.] [. . .] On Wednesday after Seragefima [20.02.], there was a tremendous storm, heavy snowfall, and severe cold. [. . .] On the Feast of Peter and Paul [29.06.], the Rhine destroyed the bridge in Basel, and around a hundred people drowned. Source: JB5773.

> 1442 war d. kälteste Winter, fielen 36 Schnee aufeinander, alle Wege gesperret, weil der Schnee rührig war.
>
> In 1442, the coldest winter occurred, with thirty-six snowfalls stacking on top of each other, blocking all roads because the snow was cumbersome. Source: KLÖ8400.

> 1442 in diesem Jahr da war ein großer kalter Winter, daß sein kein Man nie gedacht und war gar viel Schnee. Es kamen bey 36 Schnee übereinander zusammen. Es konnt niemand wandern weder zu Roß noch zu Fuß noch mit Wagen, wan der Schnee war wenig und macht kein Bahn werden und man kund zu Augsburg nicht mahlen, man also das Korn in die Dörfer senden, daß man Mühlen, und gab armen Leuten ein Mezen Mehl und 4 Groschen, daß thet ein Rath zu Augsburg.
>
> In 1442, there was a great cold winter, unlike any that anyone had ever experienced, and snow was abundant. Around thirty-six snowfalls accumulated on top of each other. No one could travel, whether on horseback, on foot, or by wagon, as the snow was deep and made it impossible to create paths. People could not even grind grain in Augsburg, so they had to send the grain to the villages where there were mills. The city council of Augsburg provided poor people with a small amount of flour and 4 *Groschen*, which was a charitable act. Source: GCH8399.

> Desselben winters da lag ein grosser schnei, als kain man nye gedacht, das man nit wol wanndlen mocht auff dem lannd vnnd lag 9 wochen bis fassnacht, da gieng er hin weg vnd was fast darvnnder gefroren vnnd mochts wasser nitt wol wol ein vnd warden gross gissen vnd gewesser das dem volck grosser schad geschache vnnd was vast theur.

The same winter there was a lot of snow like no man had ever imagined, so that you couldn't walk across the land. It stayed for nine weeks until carnival, then it went away and was frozen solid underneath. The water could not get away easily and there was a big outpouring leading to a flood that caused great damage to the people and incurred vast expense. Source: CCP10343.

9.3.3 The impact of low water levels on mobility

During periods of low water levels, rivers could be crossed on foot or with horses and wagons. This also had implications for navigation and towpath operations, as mentioned in one case. Low water levels on the Danube at Regensburg allowed the construction of bridges:

1117 [. . .] et fulmina, terra de glutiente, exsiccata sunt, ut qui vellent pedibus transire possent. [. . .]

In 1117 [. . .] and the lightnings, the earth from the sinking, were dried up, so that those who wished could cross on foot. Source: ASD3197.

1130 Auf der Annwend war so ein heisser Sommer, daß es gleich schiene, als gingen wir in die Erde durch die Risse in der Erde und ward lang sondern Wein und das Erdreich war so dürr, daß alle Bäume, Weihere und fliessende Wasser beinahe vertrugten. Der Rhein war so klein, daß man ober Rhein weit an allen Enden und mochte darüber wandeln und die Früchte in dem Felde verdorrte und verdarb ganz über all und daselbe brachte grosse Dürre iezt bey, daß viele Leute Hungers starben.

1130 On the Annwend, there was such a hot summer that it seemed as if we were walking into the earth through the cracks in the ground. The season was long, but the vineyards flourished, and the soil was so dry that almost all the trees, ponds, and flowing waters suffered. The river Rhine was so shallow that one could walk across it in many places. The crops in the fields dried up and perished everywhere. This brought about a severe drought, leading to many people dying of hunger. Source: KLÖ3766.

Anno domini MCCCLXXXIII zoe sent Remeyss missen was der Rijn so kleyne dat men dar ouer reit tuschen Collen Bunne ind Nuyssen.

In the year of our Lord 1383, the water level of the river Rhine was so low that one could ride across it between Cologne, Bonn, and Neuss. Source: MC7315.

1135 So trockner Sommer mit Winden, daß viele kleine Bäche austrokneten. Die Regensburger Brücke konnte damals gebaut werden.

In 1135, there was such a dry summer with winds that many small streams dried up. It was during this time that the Regensburg bridge was constructed. Source: KLÖ3889.

> 1304 war die Hize im Sommer so groß, daß man alle Furten in der Donau sehen konnte und zu manchen Orten bey trockenen Fuß darüber gehen konnte. Bey diesem Umstand bauten die Regensburger die Beschlachte.
>
> In 1304, the heat during the summer was so intense that all the fords in the Danube River became visible, and in some places, people could cross over them with dry feet. Taking advantage of this situation, the people of Regensburg constructed the "Beschlachte". Source: GBH6237.

9.3.4 The impacts of heavy rainfall and severe weather events

Severe weather conditions affected paths and roads, strong winds and storms destroyed infrastructure, and heavy rainfall led to the collapse of bridges:

> [1017] In der nächstfolgenden Nacht, nämlich Sonntag, den 7. Juli brach ein furchtbares Unwetter herein, welches Menschen und Vieh, Gebäude und Fruchtfelder weithin verzehrt. Und erschütterte ein ungeheures Donnern und Krachen die Wälder, und alle Wege und Straßen wurden auf eine gewaltige Weise mit umgestürzten Bäumen und Aesten bedeckt.
>
> [1017] In the following night, that is Sunday, July 7th, a terrible storm broke out, which consumed people and livestock, buildings, and fields far and wide. An enormous thundering and cracking shook the forests, and all roads and streets were covered with uprooted trees and branches. Source: CTM2709.

> Ventus validus partem pontis Brisacensis 10. Kalendas Octobris destruxit.
>
> A strong wind damaged parts of the bridge of Brisacenis at the [22nd September]. Source: ACM6088.

> [. . .] im Monat August ergoß sich der Main von vielem Platzregen so, daß mehrere steinerne Brücken ruiniert wurden.
>
> [. . .] In the month of August, the Main River overflowed due to heavy and localised rain, causing several stone bridges to be ruined. Source: CM5808.

9.3.5 The impacts of flooding on mobility

Floods regularly had a strong impact on mobility. During floods, navigation, as well as timber rafting and towage, were impossible. Long-term effects regularly resulted from the destruction of important bridges. These were temporarily repaired and – as far as stone bridges were concerned – often replaced by wooden constructions and pontoons:

In Vigilia Mariae Magdalenae 1342 et in die usque ad aliam diem tanta fuit inundatio aquarum ut Moganus intraret in ecclesiam sancti Bartholomaei. pons etiam prope Sachsenhausen cecidit.

On the Eve of the Feast of Saint Mary Magdalene in 1342, and on the following day, there was such a great flooding of the waters that the Main River entered the church of Saint Bartholomew [in Mainz]. Additionally, a bridge near Sachsenhausen collapsed. Source: AF6751.

Fuit tanta inundacio aquarum in Erphordia in die Braxedis virginis, ut nemo in runcino equitqre posset, et destruxit longas temetes Erphordie, pontem ante valvam Sancti Augustini, Sancti Iohannis ante Kramphfentore, pontem in Herbipoli cum magna turri, pontem in Ratispona, in Dreseden, in Frankenfordia, in Wezindorf, in Babinberg et multa alia dampna peregit.

There was such a great flood in Erfurt on the day of Saint Braxeda the Virgin that no one could ride on horse-drawn carts. It destroyed the long fields in Erfurt, the bridge before the gate of Saint Augustine, the bridge before the Kramphfentor of Saint John, the bridge in Würzburg with a large tower, the bridge in Regensburg, Dresden, Frankfurt, Wezindorf, Babinberg, and caused many other [forms of] damage. Source: CSP6753.

Um Magdalena fiel Regenwetter ein, drey Tag an einander, dadurch alle Wasser, und der Rhein, mit solchem Brausen anlieffen, daß er am 15 Tag Heumonats über der mindern Stadt Basel Zwingelmauer einlieffe, und zwey gewaltige Joch von der Bruck hinführete. Nach Ablauffung des ungestümen Wassers, bande man drey Schiff in die Lucke, überschloß die zur Noht mit Dielen, stellte zu jeder Seiten fünf Leitern an, damit die Leut auf und absteigend hinüber kommen möchten, das bliebe vierzehn Tag also. Nachmalen ward besserer Kommlichkeit halben, auf ein jedes Schiff ein Joch, den übrigen gleich hoch, gesetzt, und gleicherweis bedecket, daß auch die Müller mit den Eseln hinüber fahren mochten. mit Karren und Wägen war es unmöglich. Uber einen Monat ohngefehr, bauete man eine andere Rüstung, welche auch Wägen truge, dieselbige brache hernach, daß fünfzehn Personen in das Wasser fielen, wurden wieder ausgebracht, item ein Wagen mit fünf Pferden, welche ohne das Stellroß alle ertruncken. Solches gab Ursach neuer Rüstung, daß man andere Schiff und Joch darauf also zurichtete, daß die Bruck an grossen Trottspinnlen dem Wasser nach, hoch und nieder konnte geschraubet werden, bis auf bequeme Zeit neue Joch zu schlagen. Dieser Uberschwall thät an Feldern und Wiesen überschwenglichen Schaden.

During Magdalena, rainy weather persisted for three consecutive days, causing all waters and the river Rhine to surge with such force that on the 15th day of the month of Heumonat (June), it overflowed the lower part of Basel's city walls and carried away two massive bridge spans. After the turbulent water subsided, three ships were moored in the gap, the opening was closed with planks, and five ladders were placed on each side so that people could cross over. This arrangement remained for fourteen days. Later, for improved convenience, one bridge span was added to each ship, equal in height to the others, and covered in the same way, allowing millers to cross over with their donkeys. It was impossible for carts and wagons to pass. Approximately a month later, another contraption was built, capable of carrying wagons, but it collapsed, causing fifteen people to fall into the water. They were rescued along with a wagon pulled by five horses, all of which drowned except for the leading horse. This incident led to the construction of a new device, where other ships and spans were prepared in such a way that the bridge, supported by large wooden spindles, could be raised and lowered as needed until new bridge spans could be put in place during more favourable conditions. This inundation caused excessive damage to fields and meadows. Source: BC138400.

9.3.6 The impacts of storm surges on mobility

Storm surges led to the destruction of houses and infrastructure in coastal regions. Ports and protective structures, such as dams, were also affected. Obviously, ships were likewise affected, which sunk after they were destroyed. Losses were high, many victims were mourned, and cargo was lost:

> Anno 1449 do sande koning Carsten vth 5 schepe tho rouen; de scholden nehmen vp Godtlandt, vnd allen den städten wehren; de ehn thofören wolden, de scholden se nehmen. Ein deel vorfroren se in der see, vnd vordruncken; men se voren so duel in dat lateste, vnd quehmen mit schanden weddervmme tho huß.
>
> In the year 1449, King Carsten sent five ships to Rouen. They were supposed to take over Gotland and prevent all the cities from resisting. Those who resisted were to be captured. Some of them froze to death at sea, and others drowned. However, they were deeply sorrowful in their final moments and returned home in shame. Source: SC8596.

> Dessuluigen jahres van dem dingestage an beth vp den middewecken vor St. Gallen dage, do was thom Sunde so groth ein wather, vnd weiede so sehr van dem norden vnd nord-osten, dath alle de brügcken, de husecken alle mit einander enttwey brecken. Alle schepe, seuten, boete, zesekahn, de thoschlogen althomale, wente se dreuen an den dammen, vnd vele degelicken lude vordruncken an allen enden; wente idt waß ein schwar vnbegriplick storm, dath vele ehrlicke lude hadden des stormes gelicken nicht gedacht by erem leuende.
>
> In the same year, from the day of St. Gallen before midweek to the day of St. Gallen, there was an enormous water surge on Sunday, driven intensely from the north and northeast, causing all the bridges and gables to break apart together. All ships, boats, and barges were smashed to pieces as they crashed into the dams, and many decent people drowned in various locations. It was an unprecedented and indescribable storm, something many honourable people had never experienced in their lives. Source: SC8596.

> Anno 1449 vp St Gallen nacht was hier en so grot storm van dem norden vnd nordosten, desgliken ken minsch gedacht hedde; denn he makede hir grot water, dat idt ouer den steendamm in de döhre floth beth in de straten, ock in etlicke keller. Kene brüggen bleuen vor der stadt hele; vele schepe, schuten vnd bote, item zesekahne zerstötten, dat se hernamals thor seewerts edder tho water nemande nutte wurden; ock vordruncken vele lüde. Und geschach solk schaden nicht allene hir, sondern ock an andern orten mehr; als tho Lübeck schlog idt in de soltkeller vnd in de boden by der Trauen; der dede idt groten vnd grulicken schaden. Vor der Weichsel bleuen wol by de 60 schöne schepe, vnd wurden thor Dliue int kloster in de druddehalf hundert mann vp enem dag begrauen, vnd was der andern kene tall, de noch van dagen tho dagen gefunden vnd thor erden bestediget wurden. Disse storm warde twe dage.
>
> In the night after St. Gallen's day in 1449, there was an immense storm from the north and northeast, the likes of which no one could have imagined. It caused such high water that it flowed over the stone dam into the streets and flooded several cellars. No bridges remained intact in the city. Many ships, boats, and barges were destroyed, rendering them useless for seafaring or any other purpose, and many people drowned. This damage did not only occur here but also in other places. In Lübeck, it flooded the salt cellars and the floors near the town hall, causing significant and dreadful damage.

On the Vistula River, around 60 beautiful ships were lost, and about 150 people were buried in one day at the monastery in Dliue, while others could not be counted as they continued to be found and buried day after day. This storm lasted for two days. Source: SC8596.

Na gades bort 1449 jar in sunte Gallen (16.10.) nacht do was altomechtich eyn grot storm, also dat desgheliik un gehort ys edder ghedacht, unde warde bette an den anderen dach beth an den avent. De storm was so swar, also dat vor deme sunde nicht ene hele brugghe bleff of te Schythuseken, unde alle schepe tofloghen, also dat dar nouwe fos hele lude vorzopeden unde vordrunken tusschen deme sunde unde de veren der jamer, de dar so schach, dat kan nement na segghen. Unde dat water was so hoch unde grot, dat yd ghynck in de dore der stat unde lep in de kelre der lude, de vor deme dore waneden, also dat se nouwe ere lyf konden redden. Unde ok lep dysse fulve vlot to Lubeke in de solt kelre unde ok in de boden by de Traven, unde allent, dat dar inner was, dat vordorf, unde des gheliken vor de Wytzelen 6 leven wol 40 schone holke wol gheladen unde vele andere schepe [. . .].

After God’s birth in the year 1449, on the night of St. Gallen (October 16), there was an exceedingly great storm, the likes of which had never been heard or imagined. It continued until the next day and into the evening. The storm was so severe that not a single intact bridge remained near the Schythuseken, and all ships were tossed around so violently that very few people could escape from drowning and perishing between the sea and the waves of misery. The terrible events that occurred were beyond description. The water was so high and immense that it entered the city’s doors and flooded people’s cellars, leaving them with little chance to save their lives. This same violent flood also reached Lubeck, entering the salt cellars and the floors near the Trave River, devastating everything inside. Similarly, on the Vistula River, around 40 beautiful cargo ships and many other vessels were destroyed [. . .]. Source: SC8610.

9.3.7 Methodological approach – classification and merging

The present corpus was exported from tambora.org and processed using Python[26] and the pandas library.[27] Python is a well-established programming language, widely used for statistics, machine learning and data visualisation. Pandas is a library in python used for efficient handling of data structured in tables. The coded quotes were then grouped according to the criteria of “same time” and “same place”. From these codings, the four criteria or subgroups “Hazard”, “Zone” for transportation routes, “Means” for means of transportation, and “Impact” for the effects and type of impairment or strengthening were extracted. In summary, the key terms and the impact relationships were used for further analysis via the quadruples “Hazard, Transport Route, Transport Means and Impact”. In this way, a total of around 600 events containing direct and indirect references to mobility were identified. To document the connections and depict the corresponding causality, the stressors (Hazards) were vi-

26 *Van Rossum/Drake*, Python (2009).
27 *Reback* et al., Pandas (2021).

sualised with the transportation routes (Zones), means of transportation (Means), and impacts as connecting lines using the parallel categories diagram type (Parcats).[28]

9.4 Results

The relationship between hazards, zones, means and impacts is shown in Figure 9.2. The colours in the top part reflect the different impacts, while the lower part highlights the different hazards. This provides an illustration of the respective proportions. The analyses primarily allow conclusions to be drawn about the individual proportions in the various groups. Accordingly, hazards related to cold weather dominate in the "Hazards" category. Secondarily, there are indications of floods, followed by storms, droughts, and snowfall.

The second group, "Zones" mainly refers to rivers, flowing to the sea, in most cases to the North Sea and the Baltic Sea. The next two groups refer to bridges and streets in nearly equal numbers. Minor evidence is related to plains and lakes or unknown features.

In the third category, "Means", walking or "foot" is the most frequently mentioned mode of transportation for the time between 1000 and 1500, followed by "ships". The next two features are "wagons" and "horses", which make up approximately equal shares. In terms of "Impacts", surprisingly, both positive, indicated by "enabled" or "possible" and negative proportions, indicated by "restricted" or "impossible" are equal.

The graphical representations also allow conclusions to be drawn about the cause-effect relationships. When comparing the proportions of impacts in the other categories, cold and drought events are found to be mostly positively connoted, while floods, storms, and snow are mostly described with negative effects. This is also reflected in the "Transportation Zone" category. Here, waters are mostly positively connoted, while infrastructure such as "bridges and roads" is predominantly negative. Regarding the means of transport, the distribution is generally balanced, except for ships, which are almost exclusively negatively connoted, because they perished and were lost.

The lower part of the figure, with the color-coded hazards, shows the distribution of the hazards among the other categories. Relating to transport, water-related mobility is dominated by cold hazards, while bridges are mainly affected by floods, and roads and plains are mainly affected by snow. Regarding the means of transportation, the proportions are roughly equally distributed, except for ships, which are unilaterally affected negatively by storms. Negative impacts are distributed approximately equally among the hazards. In terms of positive impacts, cold and drought dominate, while the others play no role.

The following overall relationships can be observed: The most frequently mentioned climatically relevant stressors are cold and frost, ice formation and, in particu-

28 *Plotly*, Plotly Technologies (2015).

lar, the freezing over of water bodies. While negative consequences are emphasised, positive opportunities, such as using sleds and traversing frozen bodies of water, are also described. This accounts for approximately 25% of the references. Harsh winters were long-lasting and widespread phenomena.

Floods had a major impact on mobility, particularly when corresponding infrastructure was affected. They represent the second largest climatic stressor that had negative effects and hindered transportation. In terms of time, they tend to be short-term events of a few days or a few weeks at most – unlike severe cold spells. However, destroyed bridges, roads or paths had long-lasting impacts. If bridges were destroyed, makeshift constructions were used; in one case, ships were tied together to form pontoons.

The particularly destructive ice floes and ice rafting were causally related to harsh winters and were therefore attributed to this type. Although floods occurred only for a few days or weeks, at most, the destruction persisted for a long time. Besides the removal of soil by erosion, sedimentation of paths with mud, debris and rubble was also relevant.

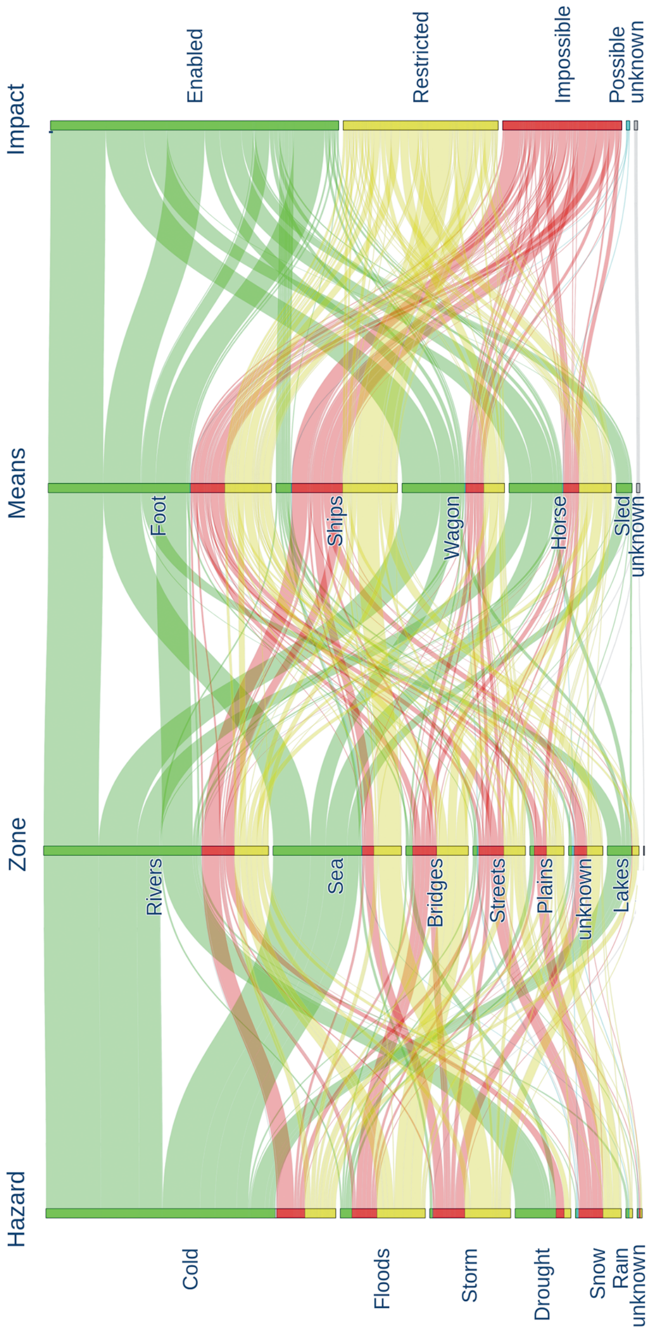
Storms mainly affect or destroy shipping or ships on the coasts and on lakes, as well as on rivers, although these are rarely mentioned. In addition to the often-tragic accidents with high human losses, mobility and transport capacity were also impaired during longer periods of time when ships were destroyed.

Droughts affect the water levels of rivers, with particular emphasis on the ability to cross them. Most frequently, wading and riding through during low water were mentioned. There are fewer references to impairments of shipping, particularly in terms of “towing”. Furthermore, a low water level facilitates the laying of the foundation of bridges and thus leads to better mobility in the medium term. Similar to winters, droughts are also a large-scale phenomenon.

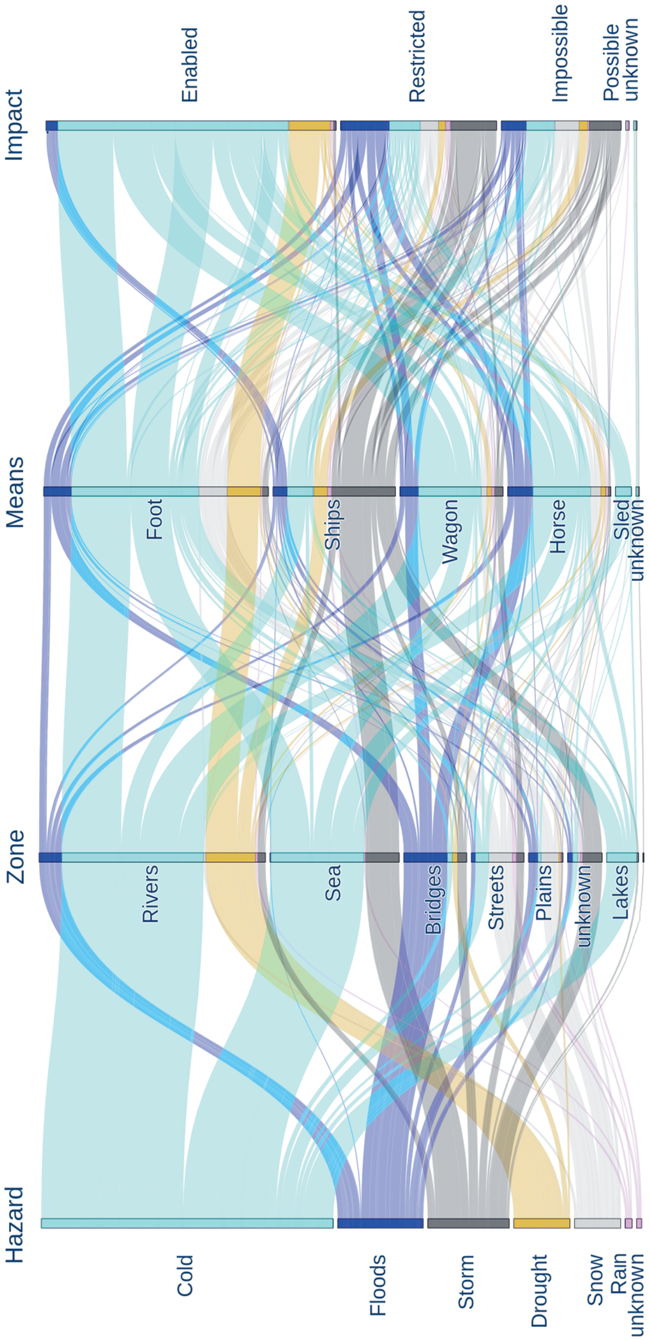
Intense snowfall primarily hindered walking, travelling, and riding on trails and thus trade, even on the plains. Small-scale events such as heavy rain and storms had more local and regional impacts. Landslides occurred as a result of heavy rain.

The temporal distribution and development of hazards, zones, means and impacts is shown in Figure 9.3. The data is averaged over 61 years to better represent the overall climatic trend, with the data being triangularly weighted. The summer and winter situations are also presented to assess seasonality.

The source density, given by the “number of events”, shows an increase between 1000 and 1500, resulting from the data availability and source density. As shown in the second plot of Figure 9.3, the information regarding winters dominates. This is remarkable because the overarching climatic imprint generally assumes a medieval warm optimum. Information related to summer is only more frequent between 1100 and 1200, as well as between 1250 and 1330. From the individual categories, the following patterns and findings emerge. In the first period, it is mainly droughts, while in the second, flood events characterise this imprint. Pronounced cold stressors shape the periods between 1050 and 1100, as well as 1200 to 1250, and also after 1330. The



Figures 9.2 and 9.3: Quadruples consisting of different hazards, zones of transportation, means of transportation, and consequences. The colours reflect the different consequences in the upper part of the figure, and the different hazards in the lower part. This makes the respective proportions visible.



Figures 9.2 and 9.3 (continued)

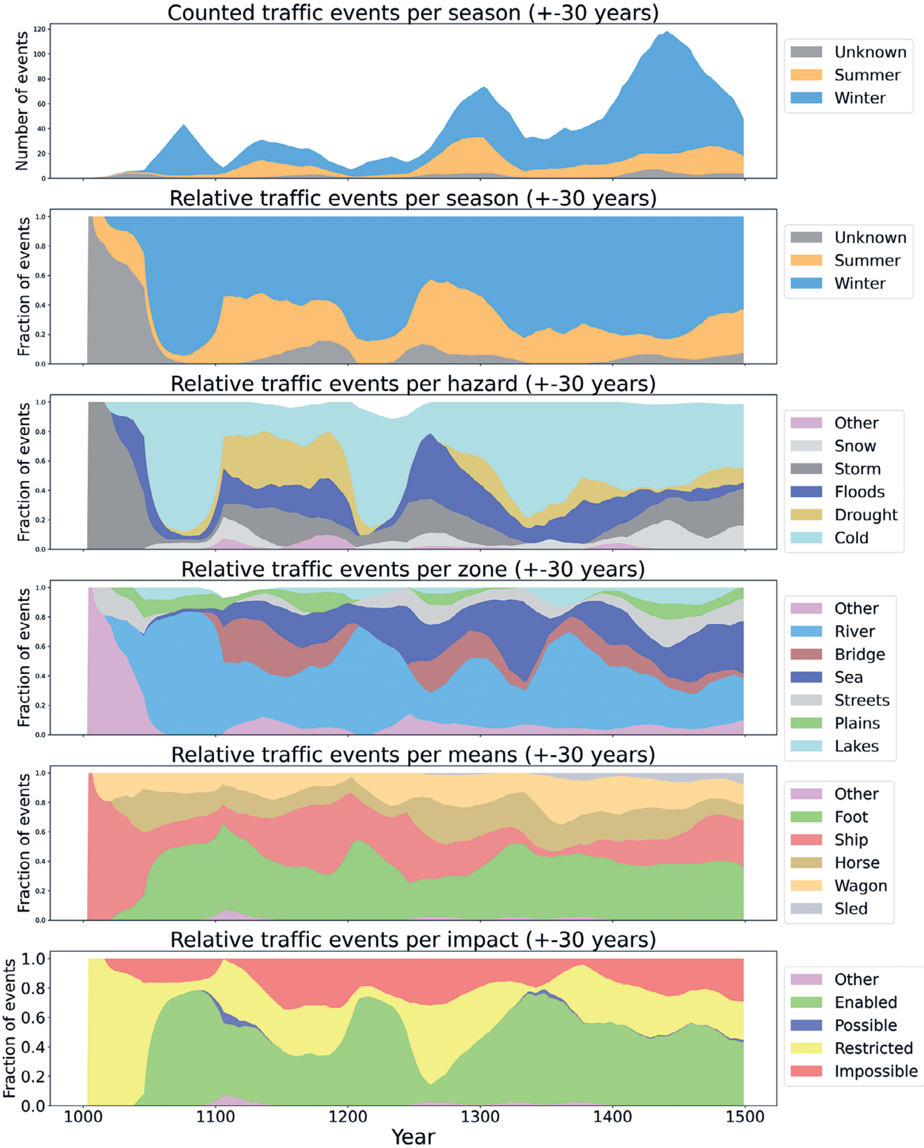


Figure 9.4: Temporal development of information and the respective proportions of hazard, zones of transport, means of transport, and impacts.

cold phases correspond to the class "enable", while the other two, floods and droughts, fall into the classes "restricted" and "impossible". Severe flood phases correspond with damage to bridges. Only few structural changes are discernible regarding the means of transportation: at the beginning, references to ships dominate, while references to sledges slightly increase at a low level after 1300.

9.5 Summary and discussion

The available sources allow conclusions on mobility and climate. They refer to the weather-climatic causes, the transport routes and means of transport, and the effects. The methodological approach presented here has proven to be viable. Stringent impact paths can be mapped using written references: The complex illustrations of the content-related and temporal structures via the parallel categories diagram type and time series provide insights into the causal relationships, the frequencies and temporal progressions.

Basically, certain types or groupings and interrelationships can be identified: First, the general structures and classification in "Hazards", "Zones", "Means" and "Impacts" can be grouped and assigned. Their synopsis shows the combinations and causal relationships that occurred in real life. Interestingly, indications and consequences of cold and, secondarily, floods and storms dominate. This is remarkable given that this phase is usually called the "Medieval Warm Optimum" Obviously, the reports primarily focussed on the exceptions and had a stronger impact than the "ordinary", average events.

Further interesting patterns and structures emerge from the synopsis of the temporal trajectories: Source density and data availability map out as a time trend, meaning that information increases over time. Within this overarching trend, however, there are also pronounced peaks. In the synopsis with the content aspects, these can be explained as follows: The first peak, around 1080, corresponds to an accumulation of cold-related information. The second, from 1100 to 1200, is not as pronounced, but shows correlations with summer droughts. Floods dominate a third peak around 1250 to 1300. The last dominant phase, with a peak around 1450, has a more complex structure and is determined by weather situations, storms and also, obviously, cold events.

There are numerous works on mobility in the Middle Ages,[29] as well as on climate and climatic extremes.[30] Some are not based on written sources, but on natural proxies such as tree-rings, sediments and speleothems.[31] These multi-proxy approaches arguably provide valid climate reconstructions, but they do not allow for conclusions on consequences and effects. In summary, well-known phenomena such as the "Medieval Warm Optimum" can be derived from these research results, as well as numerous extremes such as floods, droughts and heat waves, and cold snaps.

Another aspect that is dealt with in historical climatology is the analysis and presentation of consequences and effects. These mostly refer to individual phases[32] or outstanding extremes, such as droughts.[33] Even though these mostly address socio-economic consequences such as water shortages, crop losses and hunger, as well as

29 *Schwinges*, Straßenwesen (2007), 9–18.

30 *Glaser/Riemann*, Temperature (2009), 435–449.

31 *Cook* et al., Megadroughts (2015), 1–9; *Wilhelm* et al., Future Floods (2018), 1–22; *Büntgen* et al., Climate Variability (2011), 578–582; *Büntgen* et al., Drought (2021), 190–196.

32 *Camenisch* et al., Spörer Minimum (2016), 2107–2126.

33 *Glaser/Kahle*, Droughts (2020), 1207–1222; *Ionita*, Megadroughts (2021), 1–9.

price increases, the impact pathways can be used methodologically and conceptually to map the issues of impacts on mobility.

Nevertheless, research works of the relationship between mobility and climatic conditions are rare. Works on the context of travel and climate are largely limited to travel literature. These include accounts of long-distance travel to exotic countries and regions such as the Near East, to particular travels such as pilgrimages, or to specific trade routes. As these accounts sometimes contain references to weather, weathering, and climate in the context of travel, they have been used in the past to reconstruct climate,[34] but without connecting this topic to mobility. Exceptions are elaborations referring to the perceptions and impressions of weather and climate on travellers and their reliability regarding reconstruction.[35]

Another approach is represented by research on the reception of weather and climate in medieval literature, in which manifold references exist and weather phenomena were seen, among other things, as challenges for chivalric heroism and also other forms of life and expression, "In particular love affairs could be severely impacted by bad weather" due to difficulties of travelling, as presented by Clasen.[36]

Elaborations on mobility in the Middle Ages refer to numerous facets and aspects, such as the background, purpose of travel, social issues and trade opportunities as well as strategic and socio-political content.[37] The collection, edited by O'Doherty and Schmieder[38] focuses on "key medieval modes of travel and mobility" and their connections to religion, diplomacy, migration, governance and other topics and thus underlines the importance of smoothly functioning mobility and the societal consequences of disrupted mobility due to weather extremes.

In the few studies exploring the direct relationship between mobility and climate, such as by Hindle on the seasonality of weather conditions and travel opportunities in England,[39] the findings made here may be confirmed with the examples described. This applies to the impairments in winter as well as to the poor road conditions in rainy periods, which are described as "rainy seasons".

From this point of view, the approach presented here represents a new approach to this important topic, both in terms of the subject matter and the findings and, above all, the methods used. It must be understood as a first step, which can be extended and refined by further analyses in terms of space, content, time and method. It can be assumed that the means of transport and routes available and used (riding, wagons, sledges) have not changed significantly compared to the Early Middle Ages. The impact chains from weather extremes to the effects on mobility also remain unchanged, even

34 *Bell/Ogilvie*, Weather compilations (1978), 331–348; *Matuschek*, Data Mining (2014).

35 *Metzler*, Hot Climate (1997), 69–105.

36 *Classen*, Bad Weather (2010), 3–20.

37 *O'Doherty/Schmieder*, Travels (2015); *Gascoigne/Hicks/O'Doherty*, Journeying (2016), 296.

38 *O'Doherty/Schmieder*, Travels (2015).

39 *Hindle*, Variations in Travel (1978), 170–178.

until modern times. However, the frequency and relative number with which the various extremes (cold, snow, drought, storms, etc.) occur can change, particularly in cold periods such as the "Late Antique Little Ice Age" in the sixth and seventh centuries,[40] which were more similar, climatically, to the Little Ice Age from 1500.

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