CLIMATE, CONFLICTS AND CRISES
Temperature variations in relation to violent conflict, subsistence crisis, and social struggle in Novgorod and Ladoga region AD 1100–1500

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UNIVERSITY OF EASTERN FINLAND RESEARCH STATEMENT

This paper investigated the relations between temperature variations and social struggle (hunger, disease, and conflicts) in the Novgorod and Ladoga regions in 1100–1500. The temperature data was drawn from regional paleoclimatological reconstructions and the social data was collected from medieval Russian chronicles. Two analysis methods were applied to investigate the data, logistic regression analysis and descriptive approach. The findings of this paper implied that one method alone may not be sufficient to examine the possible relations between climatic conditions and human actions, as these connections have been considerably complex and variable through history. In addition, different theoretical frameworks and bodies of knowledge were drawn into the examination throughout research process, which was discovered to be more adequate than limit the examination into one specific field of study alone.

The social data responded rather weakly to the temperature data. However, the spatial distance between the studied area and the regional temperature reconstructions may explain this weak connection partly. The strongest connection between temperature variations and social phenomena was found in warm summer temperatures and attacks from the studied area to the surrounding regions. With food security incidents, the relative change from a previous year's temperature was found to be a considerably greater factor than the absolute temperature figures. The results implied that food security was vulnerable to any sudden temperature changes, to unexpected conditions rather than specific temperature conditions. Thus, the significance of cold summer temperatures may have been overestimated in previous research. The biggest challenge this paper confronted was the methodological difficulties to examine qualitatively and quantitatively differing data. In order to conduct the examination, the social and climatic data needed to be analyzed on temporarily and spatially comparable and combinable scales. A geographical approach proved to be flexible enough to draw and examine different materials together, and to reach and borrow theoretical understanding from different disciplines.

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1 Introduction

1.1 The challenge

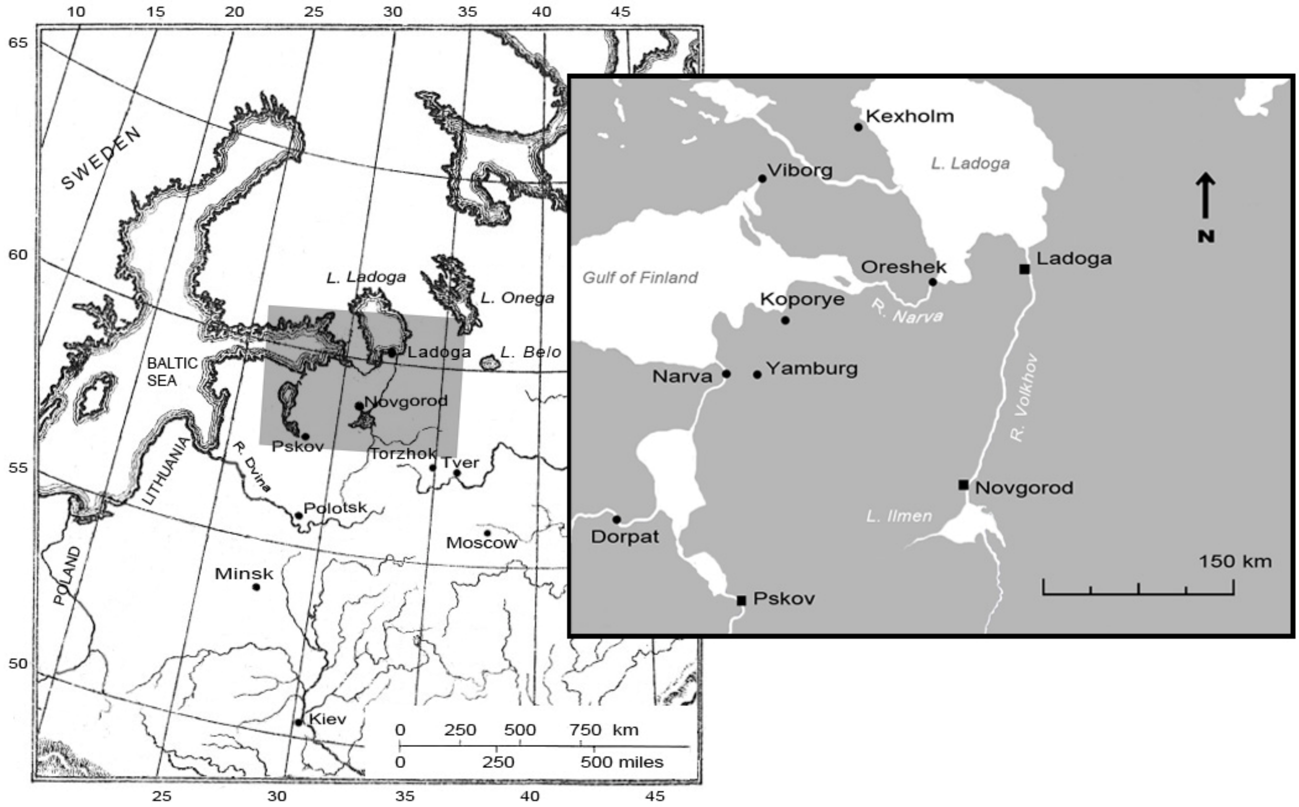
Over the last few years future changes in climate and their possible impacts on human well-being have gained ever-increasing interest, in science, politics and everyday life alike. The knowledge of social responses to climatic change is usually drawn from the past experience (Pfister 2010, 29). In order to understand the present and to be able for prepare to the future we need to know our past, although universally applicable picture of the climate-human relationship may be impossible to draw. Yet, the studies that examine the past climatic changes and their impacts on human life may illustrate the plurality of human responses to climate variability (Pfister 2010, 29). Climate has generally been considered as a trigger for societies to change. However, climate is a chaotic system and most situations allow the societies to make some choices. Thus it is difficult to connect certain climatic conditions to certain human behavior indisputably. Nevertheless, through history, climate has brought disaster and struggle to the societies, for example by crop failures, flood or drought. Climatic phenomena have disturbed societies. People have managed to adjust to certain climatic changes, but other anomalies have caused disasters. By studying the impact of climatic variations upon the past social systems, we may improve our understanding of the current issues concerning climate change and social struggle. (Lamb 1995, 1–6.)

For a long time now, geographers have avoided emphasizing the climatic factors when studying the societal changes of the past. This may emerge from the shame of past determinism (Hulme 2008, 10). However, while the geographers have left the climatic aspects alone, other disciplines have taken the challenge, and have begun to study climatic variations of the past and their relationship with social struggle. Especially natural scientists have recently become interested in examining the historical responses of the climatic changes. The research has found temporal correlation between past climatic variations and societal crises and violent conflict in pre-modern Europe (see, e.g. Zhang et al. 2011a & Zhang et al. 2011b). Especially cold temperatures have been found to cause social struggle in northern Europe (Zhang et al. 2007, 21619). Medieval agricultural societies have been considered to be especially vulnerable to climatic changes (Fraser 2011), and the shorter the growing season, the more vulnerable the society is considered to be (Zhang et al. 2011, Appendix II). Thus, it may be fertile to focus the investigation of climate's impact on social struggle on medieval society somewhere in the northernmost Europe.

In addition, focusing the research on the Middle Ages is interesting from the climatic perspective, because the change to cooling climate from the 14th century onwards has been interpreted to have caused suffering to the societies of the time (Lamb 1995, 1–6). It has been estimated that approximately in A.D. 1000–1300 the weather was more optimal in Northern Hemisphere than in the previous or following centuries. This period has been called the Medieval Warm Period (MWP). From the fourteenth century onwards the climate started to cool, culminating in a period called the Little Ice Age (LIA, c. A.D. 1550–1800). However, especially the interpretation of the medieval warmth has received harsh criticism. (Ogilvie 2010, 39–43; Bradley et al. 2003, 404–405.) Therefore, this paper will examine if temporal connection between temperature variations and social struggle can be found in medieval Novgorod and Ladoga regions AD 1100–1500. In this paper, violent conflicts, distress, hunger and disease are considered as social struggle.

Geography, as a discipline, has a heritage of creating synthesis (Thornes & McGregor 2003, 3–4). It is evident that we cannot comprehensively understand climate's impact and its importance on the past social struggle by drawing traditions from one field of study alone (Fraser 2011, 12777). The research must be open to different theories, experimental and, above all, interdisciplinary. Geography has flexible scientific foundations and is capable to explore climate-human relationship in a holistic manner. Therefore, the discipline has a huge potential to contribute to the research of the field.

In this paper, I will first draw an overview of the study area and its geographical, climatical and socio-economical conditions. In chapter two, I will shortly introduce previous research that has examined the climatic effects on social struggle and discuss the possible theoretical and methodological frameworks for this paper. In chapter three, I will introduce the objective, the research questions and the materials used. Chapters four and five contain the results and discussion. The analysis process consists of two stages. First, the data will be analyzed with logistic regression analysis, and then the phenomena of hunger, disease and conflict and their possible connections to climatic variations will be examined in more detail with a descriptive approach. Finally, this paper discusses briefly the methodological challenges the study raised, and possible approaches and conceptual frameworks for further research.



Map 1: *The study area and place names (original source for the map on the left is "The Tale of the Armament of Igor (1915)", drawing by H. Huhtamaa).*

1.2 Area of the study

The research area is located in North-East Europe, between the easternmost Baltic Sea and Lake Onega, in an area roughly between 58°N and 63°N, and between 28°E and 35°E. Historically the area covers the north-western parts of the medieval Novgorod, from the southern shores of Lake Ilmen to the northern shores of Lake Ladoga (see, Map 1). The climate of the area is continental, divided to the hemiboreal south and to the boreal north in the Karelian Isthmus. The climate is mostly influenced by the Westerlies, which bring warmth and precipitation in winter and cooler and wetter climate in summer. The precipitation in summer is caused by the circulation at the Arctic and temperate fronts, and only approximately 10 % of the precipitation is associated with inner air mass processes. The growing season of the area is approximately four to five months. (Klimenko & Solomina 2010, 71–72; Korpela 2008, 38.)

The area was rather sparsely populated in AD 1100–1500, especially when compared to Western Europe of the time. The area held two bigger towns, Ladoga and Novgorod, whose population varied regionally and temporally between 2 000 and 30 000 inhabitants. Due to little historical and archaeological evidence, an accurate estimation of population density is difficult to make. Rapid changes in the vital rate of the population were normal, and population growth varied regionally. The death rate was more important for the population growth than the birth rate, albeit economical growth most likely affected the birth rates positively. The population growth was restricted by the capacity of food production and disease epidemics. The population most likely grew during the Middle Ages, even though there is rather limited evidence of this growth. The study area can be divided to low population density region of the north, and higher population density of the south (following roughly the geographical division of the boreal north and the hemiboreal south). When the regional population levels are taken into account, the population growth was more rapid in the southern parts of the studied area during the 12th and 13th centuries, and more moderate and stable in the northern parts during the whole studied period. (Martin 2007, 65–69; Korpela 2008, 202–203.)

Environmental conditions set limits to the population of the area. Permanent agriculture was introduced in the area late by European standards, generally during the first millennium or in the first half of the second millennium AD. Climatic conditions, such as short growing season, determined the possible agricultural methods and cultivable crops in the area. Soil, geographical landscape and other environmental factors also affected to the agricultural system. Arable cultivation was the dominant farming method, although in the northern and less densely populated areas slash-and-burn cultivation was practiced widely. Livestock was kept all around the studied area, although in the sparsely populated north extensive forests provided good resources of game. Fish was an important supplement to people’s diet all around the studied area. (Korpela 2008, 42–46, 129–135; Jordan 1996, 192; Alsleben 2001, 111.)

It is characteristic for north-eastern Europe that the cultivation methods and the source of livelihood were connected to the extent of state administration among environmental conditions. As grain cultivation was uncertain due to changing climatic conditions, and the northern forests were rich in game and fish, farming was not the first choice for food acquisition, and it became stabilized only after states established their power in the region.

When population density increased[1], or when the state administration took aim to bind people more tightly to certain locations and obliged people to pay taxes, the societies most likely switched over to arable cultivation in order to produce a surplus in grain yields. (Solantie 1997, 11–14; Korpela 2008, 199–202; Taavitsainen et al. 1998, 236–240.)

Conflicts were rather regular, albeit considerably small scale, in the studied area. These conflicts were acts of violence, which were either state-sponsored or private operations. An all-out war was an extremely rare (if not non-existing) phenomenon in the studied area at the time. At a very general level, struggles arose when the living conditions changed or external pressure from the surrounding regions strengthened. These conflicts were often linked with the establishing and extending processes of authority and control, and of course, with maintaining or enhancing economic dominance. Control over resources was the key factor in the medieval conflicts of the area. In the studied area, two trends of the regionality of the violent conflicts can be identified: 1) intradynastic violence, which created pressure to the studied area mainly from the east and south, and 2) commercial and territorial pressure, which challenged the studied area from the west[2]. (Martin 2007, 139, 200–205.)

The town of Novgorod was unquestionably the biggest and strongest power and commercial centre of the studied area. Another important town was Ladoga. Both centers were located by the River Volchov, a key waterway linking the Baltic Sea with the interior of eastern Europe. Trade was important for both Novgorod and Ladoga, and the ability to exploit the natural resources of a vast wilderness region up in the north was crucial for the growth of both centers. Due to Ladoga's geographical location, the town did not have an agricultural hinterland. In Novgorod region, arable land was limited due to seasonal flooding, but its hinterlands provided excellent conditions for agriculture and the keeping of livestock. Thus, both centers were dependent on the ability to exploit the surrounding regions' resources, which sustained the centers' subsistence demands, and both centers gained their economic importance by controlling these resources. (Alsleben 2001, 107; Nosov 2001, 5–9; Martin 2007, 200.)

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[1] This classical interpretation has been, however, criticized in some of the most recent studies. The switching to arable cultivation in the northern parts of the Baltic Sea might have resulted from the changes in cultural, technological, political or economic circumstances, not because of the population growth. See, e.g. Korpela 2008, 44–45; Pihlman 2004; Orrman 1999.

[2] From the areas of modern day Baltic states, Germany, Poland, and Sweden

2 Climatic effects on social struggle: previous research

2.1 The shame of determinism

Despite the ever-increasing number of scientific research on climate change and studies on our contemporary interaction with climate, climatic aspects remain marginal when the past is studied, especially from the human sciences' perspective. Studies on past climate are mainly focused on reconstructing climatic conditions from a variety of sources (see Chapter 3.3.3). However, climatic effects have been *acknowledged* in human sciences for a long time now, although whether the approaches have been appropriate or not can be questioned.

When climate's impact on social struggle is discussed in a geographical context, Ellsworth Huntington's name usually turns up at some stage or another. He saw climate as a dominant factor for societies to evolve and succeed. Huntigton combined climatic aspects to economic geography, and argued in *"Climate and Civilization"* (1924) that cultural achievements are linked with certain climatic conditions. Huntington's work spread widely in the academia and influenced many geographers, although his accomplishments are highly controversial. In 1973 he was cited as the most widely reviewed and read American geographer ever (Martin 1973, 238), but in the 1970's his work also confronted harsh criticism of being deterministic and unscientific. Indeed, his work can be seen to emphasize eugenics. When the impacts of climatic variations on society were studied, strong deterministic view and an anthropocentric approach continued to be prevalent among geographers in the first half of the twentieth century. Climatic explanation was commonly agreed when analyzing the events and changes in human history. The academic response, which followed this deterministic approach in the second half of the century, defined the dichotomist approach that became dominant in the field up to the twenty-first century. As it became acknowledged that climatic explanation is biased and scientifically inadequate, researchers began to write the history of climate and the history of societal struggle separately. (Brown 1999, 24–29; Hulme 2007, 5–6; Pfister 2010, 26–27.)

The uniqueness of events and the variety of human responses to environmental conditions soon became the dominant approach when studying human actions of the past, and it was widely agreed that a single climatic explanation on the course of human history is dangerous.

Admittedly, the role of climatic variations in social struggle is difficult to demonstrate. Emmanuel Le Roy Ladurie, whose notions of climate-human interactions have influenced a vast number of modern day historians and geographers, argued in the *"Times of Feast, Times of Famine"* (1972) that:

> *"In the short or relatively short term (on an intradecannary, decannary, and in certain cases interdecannary scale), agricultural history is vulnerable to the caprices of meteorology which produce bad harvests and used to produce food crises. But in the long term the human consequences of climate seem to be slight, perhaps negligible, and certainly difficult to detect."* (Le Roy Ladurie 1972, 199.)

Le Roy Ladurie was not the only one to support this view, as the majority of historians, geographers and other human scientists agree that the significance of climatic effects to human actions is too uncertain and complex to define. The only exception appears when studying the climate's impact on food systems, where climate is commonly agreed to be the main determinant for agricultural production, like Le Roy Ladurie also proposed. Temporary weather extremes and climatic anomalies are the common explanation for harvest failures, which are seen as the main factor for malnutrition, hunger, famine and to other subsistence crises, especially in the medieval European and other pre-modern agricultural societies. (Hybel & Poulsen 2007, 64–78; Pfister 2010, 27; Ó Gradá 2009, 31–33.)

Thus, it can be argued that the link between subsistence crises and unfavorable weather conditions has become a paradigm in the field, especially when medieval European and other pre-modern societies are studied (although opposed arguments do exist, see, e.g. Fogel 1992). Ironically, this particular view can be seen to have deterministic tendencies, as there is not an undisputable theoretical framework to prove this connection. The causal pathway from climatic change to subsistence crisis remains to be undefined. This may result from the temporal and spatial variations of pre-modern societies, as agricultural methods, societal systems, availability of resources and other regional factors affected the society's response to climatic changes. In addition, climate is a complex and chaotic system, thus it is hardly surprising that human scientists are reluctant to bring climatic aspects under a closer examination.

Although the question of climatic effects on social struggle in the past has been evaded, the importance of new research on the topic is recognized. Human sciences acknowledge the connection between climate and society (despite their unwillingness to explore it themselves), and understand that this connection has been dynamic throughout human history. Unfortunately, the shame of past determinism may have directed the research until very recently, and therefore the relationship between climatic cause and societal effects has not drawn the attention it clearly deserves. (Pfister 2010, 26–28.)

2.2 Modern science and pre-modern history

While human scientists gradually receded from the research, natural scientists became involved in the study of climate's impacts on past societies. Hubert H. Lamb introduced modern scientific knowledge of climate and a climatological approach into the research. His studies (e.g. *"Climate: Present, Past and Future"* (1977); *"Weather, Climate and Human Affairs"* (1988); *"Climate, History and the Modern World"* (1995)) defined the course of the research for the next decades. Lamb studied the effects of both long term and short term climatic variations, and especially the cooling that started around AD 1300's in Europe (the shift from the so called Medieval Warm Period to the Little Ice Age, see pp. 41). Although Lamb argued that cooling climate affected agricultural production and demography in the Middle Ages negatively, therefore causing social struggle in certain regions, he was rather cautious to propose a universal model linking certain climatic variations to certain social events. (Lamb 1995, 200–207, 316–318.)

Some of the most interesting findings in the field have been made only very recently. The advances in mathematical modeling have enabled scientists to explore climate and social data simultaneously. In addition to the previous understanding of the connection between climate and agricultural production, studies like Zhang et al. (2007) *"Global climate change, war, and population decline in recent human history"*, Tol & Wagner (2010) *"Climate change and violent conflict over the last millennium"*, and Zhang et al. (2011a) *"Climate change and large-scale population collapses in the pre-industrial era"* now linked pre-modern societies' increased number of wars, conflicts and other social disturbances, population decline and epidemic outbreaks to cooling climate in pre-modern Europe. All of these studies agree that climate is more a contributing factor to the outbreak of conflict and crisis in an already tense situation, rather than a root cause. However, statistical correlation between climatic change and conflicts and population decline has been found. These studies cover a large geographical scale and temporal span, and focus mainly on relatively long term climatic changes.

However, although these studies introduce a groundbreaking approach, some of them are unfortunately insufficient from a historical and geographical perspective. These studies lack crucial sensitivity to temporal and spatial social variations. In addition, these studies tend to derive their climate estimates from the most well known climate reconstructions, which represent climatic fluctuations on a continental, hemispheric or even on a global scale. This, in part, makes these studies even more indefinite. This scope of global and long-term scale variations may arise rather often from the needs of contemporary (climate change) politics. The most well known scientific studies on past climates, conducted by such bodies as The Intergovernmental Panel of Climate Change, examine climatic variations almost invariably on global or hemispheric scales because political decision makers require information on these particular scales.

However, these spatial and temporal scopes are not usually adaptable to a study that examines pre-modern societies. For example, Tol and Wagner (2010) examined the relationship between European conflicts and climatic conditions over the past thousand years, and argued that conflicts have been more intense during cold periods. The central defect in Tol and Wagner's study is the inadequate acquisition and interpretation of historical data. Their data of violent conflict has been collected from a questionable secondary source (internet site) and it represents a spatially and temporally biased account of past conflicts. Moreover, they have not done any rescaling of the data, which would have been necessary. For example, the regional battles of the mid 15th century are seen as intense and severe as the World War II (Tol & Wagner 2010, 68). In addition, they have not noted that if a certain region in a certain era lacks the conflict data (especially northern and eastern Europe during the Middle Ages), this does not necessary imply that the region did not have any conflicts at the time. Our knowledge of the past is temporally and spatially biased, as historical research has laid emphasis only on specific cultures, eras and locations. Thus, Tol and Wagner's historical data do not represent adequately the intensity or the frequency of the European violent conflicts of the past.

This example represents the fundamental danger in multidisciplinary research when the social and natural scientific aspects are combined. The most recent historical research, as well as regional climate estimates, has not reached a wider audience. Thus, the latest improvements in these fields are not known to the public. Instead, the researchers who study the climate-human interactions might only be familiar with an outdated and biased image of the past, and prefer to use only the most well known (and the easiest to access) climate data, which, without an exception, represents the most wide scale climatic variations.

2.3 Geographical prospects

As reviewed above, the study on climatic effects on social struggle in the past is divided into two approaches: human and natural scientific. The nature-human interaction itself is one of Geography's key research foci, and Geography as a discipline has a heritage of creating synthesis. Geographers have tools to analyze how all types of climatic and social processes and events articulate in space and time, which is a noteworthy advantage when compared to the other disciplines which are engaged in the climate-human studies. Still, for one reason or another, traditions of geographical thought have not been established in the field. (Thornes & McGregor 2003, 3–4; Skaggs 2004.)

In part, this may result from the fact that geographical research on climate and society remains theoretically and empirically diverse. On the one side, physical geographers study the atmosphere through climatology using their own subdisciplinary language. On the other side, human geographers try to understand the socially constructed interaction between climate and society with the language from the social sciences. Thus, the same dichotomy that troubles the whole matter of climate-human research also intrudes within the discipline of Geography. The gap between physical and human geography can be traced to the middle of the twentieth century, thus the two halves of the discipline have been drifting apart theoretically from each other for more than half of a century now. As a result, physical and human geography deal with different subject matter and draw their ideas from different bodies of knowledge. (Herbert & Matthews 2004, 10–16; Castree 2004.) However, the most recent geographical discussion holds signs of looking for the means of convergence, and has recognized *"that the single-stranded theories of the past, whether derived from natural science, physical science, social science or the humanities, are no longer appropriate"* (Herbert & Matthews 2004, 13).

This conceptually common approach within the dualistic geography, just proposed, is however difficult to define. In addition, the shame of past determinism troubles also geographers. However, a step forward in this challenging task has been taken, and especially research focusing on climatic change and its human interactions has been proposed to provide a path that would bring physical and human geography back together. Yet, this is only possible if the researchers *"identify their work as geography, […] and clearly explain how their geographic approaches uniquely led to solutions to the key questions"* (Balling 2000, 121). As far as the research *respects* the traditions of both physical and human geography, the geographer does *not have to follow* strictly neither of the traditions, but can rather freely experiment new approaches to combine physical and social matters. As a result, geography may offer a unifying tool to understand climatic effects on human actions, also for other disciplines. (Herbert & Matthews 2004, 14; Hulme 2007, 6–7.)

Although studies on climate's impact on pre-industrial societies may be rather marginal in contemporary geographical research, geography has long roots in bringing historical events and the study of past societies into geographical research. Historical geography is a broad interdisciplinary field of enquiry, not just a subdiscipline of geography. It has established its place through intense and dynamic exchange of ideas and projects between historians and geographers, thus the field acknowledges the importance of both spatial and temporal aspects in research. (Winder 2009, 152.)

As discussed above, climate's significance for the past societies has been read either through physical (natural sciences) or through cultural (human sciences) entities. The cultural approach lacks accuracy in proving solid linkages between climate and society, and the physical approach is not sensitive[3] to temporal and regional variations. Geographer Mike Hulme's (2008, 7) argument, *"climates do not travel well between scales"*, may lead us closer to an answer for the problems introduced above. Climate means different things for different people and places, and the relationship between people and places varies over time. Thus, if climatic effects on human actions are viewed only from the scientific perspective, regional and temporal information may be lost or intentionally ignored. On the other hand, climatic effects on human actions can not be studied only from the cultural perspective either if we

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[3] Although there are a good number of researches that examine regional variations of the past climate, these studies have not been included in the above mentioned scientific studies on climate's impact on human actions, which as a rule use continental or hemispheric climate data.

want to explore the causal pathways adequately. Certain climatological aspects, such as temperature reconstructions and statistical tools have to be adopted to explore these connections. Therefore, when studying the impacts of climatic variations on human actions, we need to be able to examine both, climatic variations and human actions, in comparative and compatible scales.

3 Materials and methods

3.1 Approach and scope

This paper's research question rises from the previous research. An answer for the challenges discussed above is explored through a geographical approach. Here, a geographical approach means that it is acknowledged that climate means different things in different places, to different people, and at different times. In other words, a special emphasis is laid on temporality and spatiality, in both social and climatic contexts. A universalized image of climate and its impacts on human life, which is practiced especially in natural scientific research, is intentionally avoided.

There is evidence of temporal correlation between past climatic changes and societal crises and conflicts in pre-modern Europe (e.g. Lamb 1995, Zhang et al. 2011a & 2011b). However, the pathways and causality between climate, crises and conflicts have been left without closer examination, or too wide scale macro theories have been created, which may not be adaptable to regional examination of a certain era. Natural sciences seek correlation between long-term climatic changes and global history, and regional effects of short-term climatic variations and weather extremes are ignored as a rule, regardless of how interesting answers this scope may provide (Le Roy Ladurie, 1972, 119; Ingram et al. 1981, 28). Ingram et al. pointed out in 1981 that *"it is striking that comparatively little research has been devoted to investigating in precise detail just how important such [short-term] fluctuations were"* (Ingram et al. 1981, 28), and the situation has not changed almost at all in twenty years. Nevertheless, if the events are examined solely at a micro level, the results may be too fragmented to comprehensively understand the significance of the past climate and its variations on human actions. (Pfister 2010, 27.)

Therefore, this paper a lays special emphasis on regionality. A sufficiently extensive study period and area is selected, however, so that the examination can be connected to scientific knowledge of the past climate. The prerequisite is that the climatic variations and human events studied in this paper must be compatible with each other. Thus, the information of the climatic conditions of the past (i.e. climate reconstructions, see Chapter 3.3.3) is used as regionally and temporally as possible. The regional approach also requires focusing on a certain time period, when relatively compatible social and economical conditions were dominant.

The examination is scoped to cover Novgorod and Ladoga regions between AD 1100 and 1500. Medieval agricultural societies have been considered as especially vulnerable to climatic changes (see: e.g. Fraser 2006 & 2011; Jutikkala 1981, 115). In addition, the shorter the growing season was, the more vulnerable the society is considered to be (Zhang et al. 2011, Appendix II). Thus, it may be fertile to focus the investigation of climate's impact on human events on medieval society somewhere in the northernmost Europe. However, at the beginning of the second millennium, the majority of the population in the northernmost Europe was not solely dependent on agricultural production, as people gained their livelihood in various ways: by hunting and gathering, fishing, and from slash-and-burn agriculture (Korpela 2008, 199–202). Some societies, however, were dependent on agricultural production, and very importantly, there is historical evidence from these societies. Thus, in northern Europe, the medieval centers of Novgorod and Ladoga qualify for this examination. The scope of the investigation is adequate also from the historical and geographical perspectives, as the events that took place in the study area in AD 1100–1500 are comparable with each other (although the societies were not stable) and as the socio-economic conditions and the environment of the study area are compatible enough (for discussion about the geographical area and socio economic conditions, see Chapter 1.2; for further discussion about the events, see Chapter 3.3.2).

3.2 Objective, questions and method

As scientific and historical research proposes that violent conflicts, hunger and other forms of social struggle were connected to cold temperature conditions in medieval North Europe, this paper examines if temporal connection between temperature variations and social struggle on an annual scale can be found in medieval Novgorod and Ladoga regions AD 1100–1500. In this paper, conflicts, distress, hunger and disease are considered as social struggle.

In addition, this paper aims to explore how a geographical approach can contribute to the field of climate-human research. Can the geographical approach bring natural and human sciences closer together, and is it possible to consider both climatic and human aspects in one study? Would this geographical approach create dialogue between human and natural sciences, and can it propose new perspectives? Furthermore, can regional human action in a specific time period be connected to natural scientific (universal) understanding of the climate? Can two different scales, regional human action and a wide climatic scale, be reached in one study? Can the geographical approach help us to better understand the temporal and spatial meanings of climatic variations?

The possible climatic impact on social struggle may be difficult to examine in detail, as in medieval Novgorod and Ladoga a wide range of possible economic and social variables existed. Thus, a special method, the so called *"semi-descriptive case study"*, is applied. In this method, the links between climatic variations and social events are as far as possible examined quantitatively. At the point where rigorous modeling becomes unfeasible, a more qualitative approach is adapted. However, with quantitative interpretations, the researcher must be careful not to overestimate the importance of climatic impact. (Ingram et al. 1981, 26.)

In this paper, possible temporal connections between temperature variations and social struggle on an annual scale will be first examined quantitatively. With a logistic regression analysis the probability of the dependency between certain social events (conflicts, distress, hunger and disease) and temperature variations is investigated. The method of logistic regression analysis is introduced in more detail in Chapter 4.2. If the connection is found, the relationship between temperature variables and a social event will be examined in more detail, through a descriptive approach. Signals and connections which cannot be detected in a statistical analysis, are aimed to be found with the descriptive approach. In addition, in the descriptive analysis, the understanding of the connections found in the logistic regression analysis will be deepened.

3.3 Materials

3.3.1 The chronicles

Medieval chronicles record mainly political and religious events, but also weather phenomena and different indicators of societal distress. The sources' information is more often regional rather than 'national'. From climatic data, the documents usually record the so called 'parameteorological' events, such as floods, storms, heavy rain, drought, autumn frosts and hot summers. These records are always relative, as meteorological parameters were not standardized or measurement instruments (e.g. thermometer) did not yet exist in the Middle Ages, and thus the records are dependent on the observer. The medieval documents do not usually report favorable or reasonable weather conditions. Instead, they emphasize extreme and extraordinary weather conditions and weather-related phenomena, like floods and famines. Misinterpretations, especially on medieval documents, are common in climatic research, and without a proper source analysis, the documents' climatic information might provide a false impression of the seasonal or annual fluctuations. In addition, the texts usually describe the main characteristics of the weather or phenomenon in just a few words. Moreover, climatic data differs quantitatively and qualitatively in medieval sources. The lack of climatic data from one year or decade might not mean favorable climatic conditions, as records might have been lost, destroyed or the climatic conditions might have been considered not to be important events and thus might have never been written down. (Lamb 1995, 82; Jones & Mann 2004, 149; Pfister et al. 1996, 93)

Social struggle is recorded in medieval documents in quite extensive numbers, especially in the chronicles. Mentions of famines, hunger, lack of bread and crop failures are the basic elements of chronicles' narratives. Also descriptions of warfare, violent conflicts and internal uprisings and tumults are central components of the medieval chronicle tradition. As with climatic records, the extent and the severity of these social phenomena may be difficult to estimate. Unwanted events may not have been written down, and the scale of the pleasant events may have been overestimated. In addition, years of good harvest or peaceful periods were not documented as easily as the times of trouble. (Korpela 2009, 341–344.)

For this study, I will collect all records of climatic conditions, weather-related phenomena, and events dependent on weather from sources mentioned below. I will also collect all records of famines, crop failures, scarcity of bread or grain, and mentions of expensive food. In addition, I will pay attention to documentation of plagues and other diseases, as my aim is to examine climate's impact on human well-being on a wider scale. Last, I will collect all records of social distress, warfare, tumults, and other mentions of social struggle. When studying the impact of climatic variations on historical events, it is crucially important to collect the historical data from primary sources. If the data is taken from earlier historical research, the list of past events is most likely inadequate or biased, as in the case of Tol & Wagner's study (2010). Historians make choices, by the standards of their own discipline, and thus all possible social events are not covered in historical research.

The Novgorod First Chronicle[4] (N1) consists of two groups of manuscripts, the older (1016–1333) and the younger (854–1447) edition. The older edition has been written in the thirteenth and fourteenth centuries and the oldest manuscripts of the younger edition are from the mid-fifteenth century (Korpela 2009, 343). Matthias Akiander has collected mentions about Finland from Russian chronicles[5] in his 1849 published compilation called the *Utdrag ur Ryska annaler*[6]. Yet, this compilation does not only focus on Finland, as there are records covering the whole eastern Baltic region and western Russia. The compilation can be criticized to be fragmentary, however, as many records that are documented in the original chronicles, for example in the Novgorod First Chronicle, cannot be found in Akiander's text. Akiander collected his information from qualitatively varying manuscripts, as the edited chronicles, like the Novgorod First Chronicle, had not been published at the time. (Akiander 1849, 5.)

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[4] The 1914 edition: *The Chronicle of Novgorod 1016-1471*. Intr. C. Raymond Beazley, A. A. Shakhmatov, London

[5] Including *the Chronicle of Bygone Years; the Laurentian Chronicle; the Nestor's Chronicle; the First Sophia Chronicle; the Nikon Chronicle; the Suzdal' Chronicle; the First Novgorod Annals (not the same as 1914 edition used in this study); the Second Novgorod Annals; the Third Novgorod Annals; the Pskov Annals; the Arkhangelsk transcript; the Annals of Solovetsky; the Annals of Dvina.*

[6] Akiander 1849. In *Suomi, Tidskrift i fosterländska ämnen 1848*.

Chronicles have been written backdated, have been compiled by multiple writers, and they have gone through multiple editorial proceedings. The texts have been copied in various occasions within times, and the editors might have dropped some records that have been considered as unwanted or unimportant at the time. The chronicles served as a political manifesto at the time, rather than an accurate description of the events bygone. (Korpela 2009, 342; Reko 2003, 21–23) However, climatic data and records of societal events can be collected from medieval chronicles with adequate source criticism. Chronicles record a relatively good number of climatic events, such as droughts, floods, severe winters, hot summers, frosty nights and other events dependent on weather, including famines and crop failures. Social struggle is documented in the chronicles in quite extensively, including famine, warfare, conflicts, uprisings and tumults. (Brázdil et al. 2005, 373–375; Pfister et al. 1996, 96)

It is essential to keep in mind that all of the events mentioned in the chronicles are characterized by Christian principles of universality, of providential guidance, of prophetic revelation, and of periodization. Weather phenomena and social events were interpreted as omens of God's will or as punishments of sins. Thus some of the records may be extremely symbolic by their nature. (Hanak 1970, xliv, lvii–lix.) The chronicles reported outcomes of God's wrath or mercy, not natural phenomena or objective analysis of social conflicts and conditions. Famine and hunger were interpreted to be God's punishment for sins, and warefare and conflicts were rather often connected to Christian missions. In addition, with social data, political manifesto is obvious. Thus, even though the chronicles hold a good amount of climatic and social data, this data must first be 'filtered out' from the traditional medieval Christian 'noise' that might distort the information. For example, a phenomenon that has happened on a certain religious feast day should be considered with adequate prudence, as the event might have been recorded only to emphasize the significance of the feast day.[7] When data is collected from the medieval chronicles, the most common errors are usually related to incorrect dating. (Korpela 2009, 342; Brázdil et al. 2005, 373–375.)

The historical sources I am using are all translations, edited versions, and compilations. The Novgorod First Chronicle is translated into English and the compilation *Utdrag ur Ryska*

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[7] Surprisingly, the documents did not have any records of unusual climatic phenomena, famine, hunger, or diseases on A.D. 1492, the year of the new millennium (A.M. 7000) in the 'Anno Mundi' calendar system, which was used in the medieval Russia.

annaler is written in Swedish. I had to use these editions, as it is impossible to get access to the original manuscripts. However, the edited copies and compilations are adequate for this study, as my aim is to collect all possible information of weather- or climate-related phenomena and the most accurate records of social conditions of the area at the time. The possible contextual deficiency, resulting from the editing and translation processes of the chronicles, is not a significant problem in this case, considering the focus of this paper.

3.3.2 The medieval data

As mentioned above, the most common errors with medieval records are related to incorrect dating, especially when different calendar systems are combined. In medieval Novgorod and the surrounding areas 'Anno Mundi' calendar system was used, according to which the new year could start either on 1st of September or on 1st of March. In addition, it is possible that in some of the later editions of the compilations the editor has updated the new year to start on 1st of January. This has been noted, and in cases when it is obvious that the chronicle's record should be placed in the following year according to the 'Anno Domini' calendar system (which climate reconstructions use), the event is dated to correspond this dating system.[8] In addition, incorrect dating may occur with seasonal events, as those may give just one year for identification. For example, the Novgorod First Chronicle records that in the year 1303 *"there was no snow all through the winter"*[9], when it is almost impossible to conclude whether the 'old' or the 'new' year is meant. Thus, the dating of a phenomenon that has happened in 'winter' may vary over eleven months.

As the *Utdrag ur Ryska Annaler* (URA) and the Novgorod First Chronicle (N1) are compiled partly from the same sources, in some cases the same climatic or social event is mentioned in both. If the records are similar, the 'primary' source is used, which is the N1. In cases the phenomenon is mentioned in both but the record in the URA is in more detail, the URA is used. The fact that the records from the URA and the N1 differ from each other, even though both of them have been compiled from the preceding manuscripts of the Novgorod's chronicle, proves that some information has been lost during the editing processes of the

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[8] One such case occurs, for example, in the year 1133, when the N1 records an attack to Estonia, which actually took place early in the year 1134.

[9] N1: 1914 ed.,115.

chronicles and compilations. Thus the medieval sources do not provide a comprehensive record of all significant events of the time.

From the medieval records, such climatic and weather-related events are collected which possibly could be identified from paleoclimatological reconstructions (see Table 2, 26). These include, for example, mentions of warm summers, cold winters and autumn frosts. Extremely temporary phenomena, like storms lasting a few days, are not collected. Forest or bog fires are commonly related in the documents to hot and dry summers, as in the N1: *"[t]he same autumn [A.D. 1430] the water was exceeding low; the soil and the forests burned"*[10]*,* or as in the URA in the year 1365: *"summer warmth and heat was intense, forests, bogs, and soil burned, rivers dried out and other watery places became utterly dry"*[11] Thus, as the forest fires are connected to hot and dry summer conditions in the texts, and require relatively dry conditions to spread, the four mentions of extensive summer forest fires (without any records of weather conditions) in the years 1298, 1324, 1330, and 1364 can be interpreted as indirect indicators of hot and/or dry summer weather.

All mentions of famine and lack of food are collected from the chronicles. In addition, mentions of malnutrition, food's expensive pricing, usage of substitute foods, and other possible characteristics of food shortage are collected. Grain and food prices are determined by both demand and supply, and thus the mentions of prices are considered as good indicators of agrarian economy and hunger (Zhang et al. 2011b, 2; Ó Gradá 2009, 144; Le Roy Ladurie 1972, 92). The term *famine* refers to a catastrophic subsistence crisis, albeit the definition of famine has differed through time. Especially the medieval chroniclers may have been loose in their use of the term, recording temporary local food shortages as famines, even though famine is understood as widespread catastrophic scarcity of food with high mortality. (Jordan 1996, 11; Ó Gráda 2009, 6–7.) Thus, in this paper, records of famine and food shortage are considered as indications of a phenomenon called *hunger*. Mentions of summer or autumn frosts, crop failures and bad harvests are commonly connected to hunger in the chronicles, but not always[12]. Therefore, mentions of frost and harvest failures are collected, but analyzed

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[10] N1: 1914 ed., 193.

[11] URA, 108–109 (Nik IV, 8. Kar. V not 137. Arch 83): *"sommarvärmen och hettan voro starka, skogar, kärr och marken uppbrunno, floder torkade ut och andra vattenrika ställen blefvo alldeles torra"* Translation from Swedish to English by H. Huhtamaa.

[12] For example, the N1 records a severe crop failure and autumn frost in the year 1251, but the same record notes that these adversities did not result in famine or hunger.

separately from the hunger records, and hence the data of food security is divided into three main groups: frost, crop failure and hunger (see Table 3, 27).

With the medieval conflict, distress and war data, strictly regional focus is exercised. Only those events are collected, which can be located spatially in the Novgorod and/or Ladoga regions (see Map 1). The event must have either happened in the studied area (e.g. battles or riots), originated from the studied area (e.g. violent attacks from the studied area to the surrounding regions), or been targeted to the studied area (e.g. attacks from the surrounding regions to the area). This paper does not speculate if surrounding external wars and conflicts which Novgorod or Ladoga were not involved in may have affected the distress level in the studied area.

All of these collected records of social struggle, distress and conflicts are rather small-scale events, even in medieval context. All of the records are collected from one source group, Russian medieval chronicles, and thus are comparable with each other. It is impossible, however, to scale accurately the extent or magnitude of these events, and thus the conflict data has been categorized by the spatial extent and location and/or the nature of the event (see Table 4, pp. 28). The conflict data has been divided into three main groups: wars, tumults and attacks. The group ‘wars’ includes all mentions of battles in the studied area and any external attacks to the area. The group ‘tumults’ includes all mentions of internal distress, riots and uprisings, and the group ‘attacks’ includes all attacks, campaigns and plundering expeditions from the area to the surrounding regions. Personal fights for the throne or other small-scale events have not been considered as conflicts, and the context of the documentation has to imply that it was a matter of a larger social phenomenon. The end result of the battles is not important in this paper. Instead, special attention is given to the accurate interpretation of the chronicles’ information from a historical perspective.

3.3.3 Paleoclimatological reconstructions

A paleoclimatological reconstruction is an estimate of past records of temperatures, humidity and other climatic conditions. Reconstructions are made by transforming climate-sensitive data (natural and/or documental records) into paleoclimate estimates. This climatically sensitive data is called proxy data, and it can be derived, for example, from tree rings, sediment varves and from historical sources. To create as accurate climate reconstruction as possible, the proxy data must be collected from various sources and locations, and the researcher must be able to combine quantitatively and qualitatively differing data. (Ogilvie 2010, 33; Bradley & Jones 1995, 3–4.) The principles, methodology and prospects of paleoclimatological reconstructions and the different kinds of proxy records are demonstrated and discussed elsewhere (see e.g. Bradley 1999), and thus are not introduced in this paper in more detail. The reliability and validity of the paleoclimate estimates are not questioned in this paper, as that has already been done in the reconstruction process of each study. Thus, the climate data is drawn directly from the studies introduced below.

The climatic data for this paper was derived from four individual paleoclimatological studies (see Table 1). From these studies, five different temperature reconstructions were included. The temperature data was downloaded from the NOAA (2012) paleoclimate web-page or received directly from the corresponding author (Helama et al. 2009; Helama et al. 2010). Most of the reconstructions emphasize summer temperatures, as tree ring data was the mostly used proxy source. Sensitivity to annual and high-frequency temperature variations was the main prerequisite when selecting the temperature reconstructions. Geographically the reconstructions cover northern Lapland, North West Russia and Continental Europe.

Table 1. *Temperature reconstructions*

Temperature reconstruction	No. of recons.	Reconstructed season	Proxy	Region
Hantemirov & Shiyatov 2002	1	Summer (June-July)	Tree ring	Yamal Peninsula 67°–70°N, 71–68°E
Helama et al. 2009	1	Summer (July)	Tree ring	Finnish Lapland, 70°–68°N, 30°–20°E
Helama et al. 2010	2	Summer (July)	Tree ring, pollen stratigraphy	Lapland, NW Russia, 70°–66°N, 35°–15°E
Lindholm et al. 2010	1	Summer (June-August)	Tree ring	Finnish Lapland, 68°N, 25°E

In their study Hantemirov & Shiyatov (2002) reconstructed southern Yamal mean June-July temperature (°C) anomalies, which are relative to the mean of the full reconstructed series (from BC 2000 to AD 2000). A study by Helama et al. (2009) holds a reconstruction that represents absolute annual July temperatures (°C). Helama et al. (2010) holds two high-resolution reconstructions, which are both in yearly resolution and represent the mean July anomalies (°C). In both of these studies (Helama et al. 2009; Helama et al. 2010), meteorological records from AD 1876–1998 have been used as predictands for the reconstructions. Lindholm et al. (2010) reconstructed mean June-August temperatures in absolute temperature (°C) anomalies, where instrumental records from AD 1908–2007 are used as predictand.

4 Results

4.1 Descriptive statistics

First the historical climate, conflict and hunger data was reviewed and its validity for statistical analysis was examined. The chronicles' climate data is presented in Table 2 (see next page). The majority of the chronicles' climatic information was related to hydroclimatic phenomena, and only less than 30 per cent of the records reported temperature related events.

The majority of the paleoclimatological temperature reconstructions were made from tree ring data, and therefore these represent best the summer temperature variations (Helama et al. 2009, 451). The chronicles' 14 records of hot or dry summers and 7 records of cold or rainy summers were compared to 20 warmest and coldest years between AD 1100–1500 of each temperature reconstruction. None of the documented years of warm or dry summers matched with the 20 warmest years from each reconstruction. In one reconstruction[13] only, 20 coldest years had two years in common (AD 1201, 1445) with the documented cold or rainy summers. Thus, the chronicles' and the reconstructions' climatic information does not correspond when the annual minimum and maximum temperature records are examined.

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[13] Helama et al. 2009.

Climatic information from the medieval documents seems to be very relative in nature, and the records of warm or cold temperature may have rather little in common with absolute temperature conditions. Unfortunately, the number of different climatic phenomena was too small to make valid further statistical analysis with the paleoclimatological temperature estimates.

Table 2: *Climatic information from the chronicles (source: N1 and URA).*

Climatic event	**Year**
Hot / dry summer	1145, 1161, 1223, 1298, 1324, 1330, 1364, 1365, 1366, 1371, 1374, 1403, 1430, 1485
Cold / rainy summer	1201, 1230, 1251, 1404, 1421, 1454, 1468
Cold / snowy winter	1165–1166, 1378, 1389, 1393, 1496
Mild / rainy winter	1145, 1161–1162, 1303, 1404, 1420, 1453, 1484–1485
Rainy autumn	1143, 1145, 1228, 1356, 1370, 1389
Late summer	1127
Floods	1109, 1127, 1128, 1143, 1145, 1176, 1291, 1293, 1314, 1338, 1352, 1373, 1376, 1394, 1404, 1415, 1421, 1436, 1437, 1496
Total number of climatic events:	**60**

The collected data of food security is presented in Table 3 (see next page). In the chronicles, hunger or crop failure was related to non-climatic factors in five years, AD 1123 (warfare), AD 1308 and 1309 (mice eating the grain), and AD 1312 and 1316 (warfare). These five years were excluded from the statistical analysis. Hunger was directly related to extreme temperature variations in seven cases: AD 1128 (severe winter in 1127), AD 1161 (summer heat), AD 1303 (warm winter), AD 1366 (summer heat), AD 1371 (summer heat), AD 1389 (severe winter), and AD 1421 (mild winter 1420–1421). Summer or autumn frost was most likely the primary, or one of the main factors, for hunger in AD 1127, 1251, 1230, 1314, and 1447. Surprisingly, in most hunger cases, the temperature factor was not evident in the chronicles' records. Cold summer conditions were never named in the chronicles as a pivotal reason for hunger. Summer frost or cold summer weather was connected to crop failures twice (AD 1466 & 1479) but the chronicles did not report that these incidents would have led to hunger. This suggests that cold temperatures might not have been the major factor to cause hunger (through crop failures) in medieval northern Europe, unlike it has been argued (see, e.g. Hybel & Poulsen 2007, 64–78; Le Roy Ladurie 1972, 118–119).

Table 3: *Data of food security from the chronicles (source: N1 and URA).*

Phenomenon		Years:	Total number of years
Frost	Autumn frost:	1127, 1161, 1215, 1230, 1251, 1291, 1314, 1436	**12**
	Summer frost:	1259, 1466, 1467, 1479	
Crop failure (reason)	Frost	1127, 1230, 1291, 1436, 1466, 1479	**13**
	Flood or rain	1447	
	Not mentioned/ other	1145, 1161, 1228, 1251, 1293, 1303	
Hunger	Famine	1127, 1128, 1213, 1215, 1230, 1231, 1366, 1371, 1420, 1421, 1422, 1423	**36**
	Need	1170, 1181, 1272, 1298, 1303, 1314, 1333, 1389	
	Expensive grain / bread	1127, 1128, 1137, 1161, 1170, 1188, 1215, 1228, 1230, 1273, 1303, 1308, 1366, 1371, 1423, 1437, 1445, 1446, 1447, 1448, 1449, 1450, 1451, 1452, 1453, 1454	

When hunger and crop failure data was compared to chronicles' records of cold and rainy summers, the years 1230, 1421 and 1454 matched. AD 1230 holds a record of a crop failure and a famine, AD 1421 a famine, and the *Utdrag ur Ryska annaler* records expensive bread in AD 1454. Unfortunately, valid conclusions could not be drawn even though the three years of hunger records matched with the recorded cold or rainy summers. Tree matching years in the studied 401 years are not statistically or qualitatively significant. Therefore, in this case the possible connection between climatic variations and hunger could not be detected simply from the medieval documents. However, it can be proposed that unfavorable weather conditions and other climatic phenomena were probably recorded more frequently at the same time with other events that were interpreted as divine interventions, such as crop failure, hunger or famine.

The records of conflicts, wars, uprisings and other forms of social distress composed the majority of the chronicles' collected data. The data is presented in Table 4. In order conduct further spatial analysis with the data, the conflict data was divided into spatial sub-categories. The spatial division is presented in Map 2 (see next page). Many of the different conflicts took place during the same years, and therefore the numbers in the column 'number of recorded years' and in the column 'spatially specified events' do not mach.

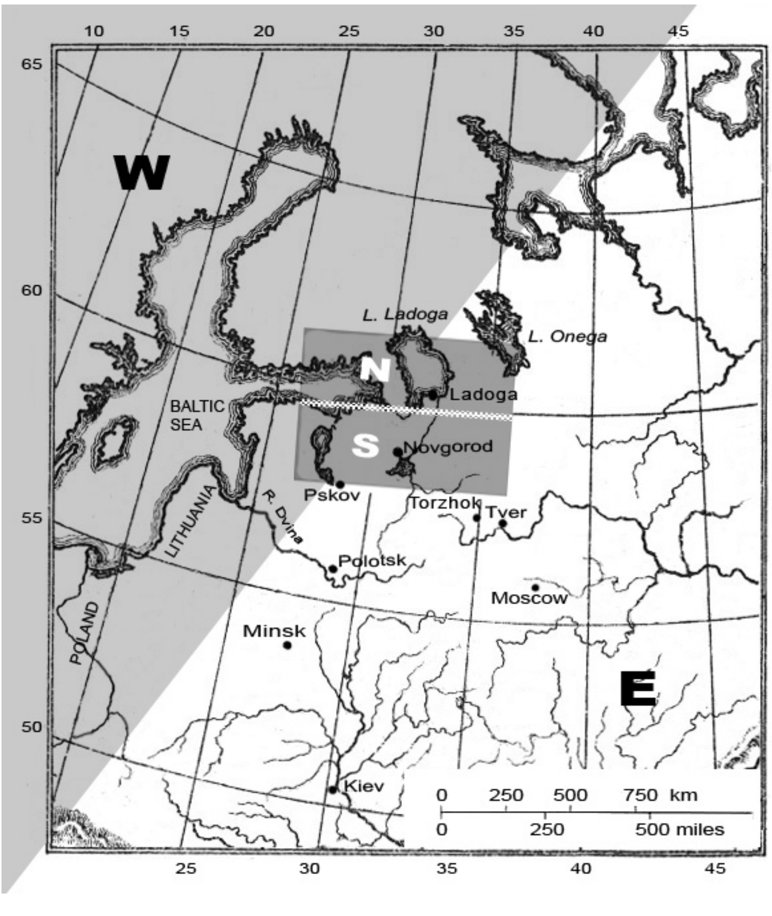
Table 4: *Conflict data from the chronicles (source: N1 and URA).*

Total number of **years** with records of…	No. of years	From which… (spatially specified events)
wars / battles in the studied area	**55**	32 were records of attacks from West to the area 12 were records of attacks from East to the area 30 were records of battles in the southern areas 29 were records of battles in the northern areas
internal distress / tumults in the studied area	**43**	38 were records of distress in the southern areas 8 were records of distress in the northern areas
attacks from the studied area to surrounding regions	**64**	37 were records of attacks to west 29 were records of attacks to east

Many researchers have argued that the changes in food security may increase the risk of violent conflicts (e.g. Barnett and Adger 2007, 644–646; Zhang et al. 2011b, 6; Brown 2001, 17–19). Therefore, the chronicles' hunger and conflict data was compared with each other. The wars and battles that occurred in the studied area did not correspond well with food security data. War and frost occurred once in the same year (AD 1314), war and crop failure twice (AD 1228 & 1293), and war and hunger four times in the same year (AD 1181, 1188, 1314, 1445). Data of internal distress and tumults corresponded better with the food security data. Some kind of tumult occurred four times in the same year with frost (AD 1161, 1230, 1259 & 1291), five times in the same year with crop failure (AD 1161, 1228, 1230, 1291 & 1312), and six times in the same year with hunger (AD 1137, 116, 1228, 1230, 1445, 1446). This may suggest that internal distress and negative change in food security may have a connection. However, because of the limited amount of the data, the relationship could not be validly proved.

Data of attacks from the studied area corresponded very poorly with the food security data. During the years when the chronicles record an attack to surrounding regions, no frosts or crop failures were recorded. An attack from the studied area and hunger occurred only twice in the same year (AD 1231 & 1448). This may suggest that the studied societies chose not to attack to surrounding regions at the times of poor food security. However, the data is not comprehensive enough, in this case either, to draw solid conclusions. This question will be examined in more detail in Chapter 5.1.

For further analysis, the study area and the surrounding regions were divided spatially. The study area was divided approximately on 60°N latitude into northern and southern spatial areas. The division into regions of ‘west’ and ‘east’ has been done broadly following the power regimes of the time. West includes the areas in modern day Finland, Sweden, Poland, Latvia, Lithuania, Estonia, and the Livonian, Chud (Estonia) and Pskov domains of the time. East includes the Kievan and Muscovite polities, and other northern and eastern domains of medieval Rus.



Map 2: *Spatial division into northern (N) and southern (S) study areas, and into ‘west’ (W) and ‘east’ (E). The division into west and east has been done broadly following the power regimes of the time.*
(Map’s original source: “The Tale of the Armament of Igor (1915)”).

4.2 Regression models

Previous research implies that temperature variations and social crises and conflicts may have a connection, also in pre-modern times (see, e.g. Zhang 2011b). In order to investigate this connection adequately in this case study, statistical analysis is required. Because the magnitude or the extent of the medieval events would have been extremely difficult (or even impossible) to estimate, the choice of the analysis method needed to be considered carefully. Even with the most delicate examination of the medieval chronicles, the most precise interpretation of the past events simply indicated if a certain event happened or not in a certain year. Thus the dependent variable of the statistical analysis ended up to be dichotomous. Therefore, logistic regression analysis was chosen as a method to compare paleoclimatic temperature estimates and social data.

Logistic regression analysis (also known as logistic or logit model) estimates the probability of a certain event to occur in certain circumstances. With the method it is possible to specify the functional relationship between response and explanatory variables. (Clark & Hosking 1986, 448) Here, the annual temperature variations from the selected reconstructions are the explanatory variables and the different social and food security data are the response variables. The explanatory variables (annual temperature variations) are continuous, and the response variables (social events) are dichotomous, that is, can have only two exclusive values (here: 1 = certain social event occurred / 0 = did not occur). Hence, with logistic regression analysis, the probability of specific social events to occur under certain temperature conditions is estimated.

Temperature variations can impact directly in the same year or at a few years' delay. Zhang et al. (2011b) discovered that agricultural production responses to temperature change immediately, but social disturbance, conflicts, crises and famine responses to temperature changes at a delay of even up to 15 to 30 years. However, as this paper focuses on temporal variations, the direct impacts are under primary examination. Thus, the impacts of temperature variations are examined with the maximum of five year' time lag. The paleoclimate estimates from selected studies (see Table 1, pp. 24) are analyzed with four different time series: the absolute calendar year, with a one year lag, with a two years' lag, and with a five years lag. Hence, from the five different paleoclimatological reconstructions, 20 different variable series are examined as the explanatory variables in logistic regression analysis. Social events are examined as response variables. First, only the main groups of social conflict data (sum of wars, tumults, and attacks from the area, see Table 3, pp. 27) and food security data (frost, crop failure, hunger) was analyzed. The more detailed spatial examination was conducted if a connection between temperature variations and (the main group of) social event was found.

From the 20 continuous temperature series and six dichotomous series of social events 120 different models were formulated. The models estimated the probability of a certain social event to occur under certain temperature conditions. The logistic regression equation links social events mentioned above to temperature time series as follows:

$$\mathbf{Pr\ (SOC = 1) = F\ (} \boldsymbol{\beta_0} + \boldsymbol{\beta}\ \mathbf{TEMP\ )}$$

where SOC represents a social event and TEMP represents temperature. The fit of the models were tested with chi-square analysis. Statistically significant ($p < .05$) connection between the variables was found in 19 models. The results of the chi-square tests of these 19 models are found in Appendix B. With the models where significant connections between the variables were found, logistic regression analysis was carried out.

The results show that only few social events were connected to certain temperature estimates. In addition, these models' coefficient of determination was rather low, from 1 to 6 % (see Appendix B, "Model Summary"). However, with logistic regression models, low values of the coefficient of determination are common (Hosmer & Lemenshow 2000, 167). None of the social events were significantly connected with all of the same time series' paleoclimate estimates. The coefficients of temperature estimates on social events are presented in Table 5.

Table 5*. Regression coefficients from selected models. The significance level of the coefficient is represented in parentheses (only the models where P < .05 were selected). For the abbreviations, see: Appendix A.*

	HAN02	HEL09	HEL09 1_LAG	HEL09 2_LAG	HEL09 5_LAG	HEL10_R1	HEL10_R1 1_LAG
Variable	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
SUM_WAR	0.342 (.014)			-0.299 (.044)			
SUM_TUM			0.418 (.010)				0.509 (.003)
SUM_ATT		0.328 (.017)				0.414 (.004)	
FROST							
CROP_F	-0.626 (.013)				0.584 (.029)		
HUNG							
DISE			-0.464 (.028)				-0.645 (.004)

	HEL10_R1 5_LAG	HEL10_R2	HEL10_R2 1_LAG	HEL10_R2 5_LAG	LIN10	LIN10 5_LAG
Variable	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
SUM_WAR						-0.560 (.005)
SUM_TUM	0.353 (.035)		0.468 (.005)			
SUM_ATT		0.374 (.009)			0.636 (.000)	
FROST					-0.845 (.044)	
CROP_F	0.632 (.022)			0.615 (.025)		
HUNG						
DISE			-0.556 (.011)			

4.3 Conflicts

Surprisingly, the paleoclimatological temperature estimates connected better with the social conflict variables than with the food security data. The most strongly related social event was the attack incidences from the studied area to the surrounding regions. However, only temperature estimates which were done from a data collected from Lapland and represented summer variations connected with the recorded attacks. The probability of attacks increased when the temperatures were higher. The connection between temperature variables and attacks was direct, that is, a 1 °C increase in temperature led to a significant increase in attacks in the same year. Because each of the reconstructions represented temperature variations in slightly different scales, the probabilities in each model varied. The increase of attacks with different temperature estimates is illustrated in Figure 1.

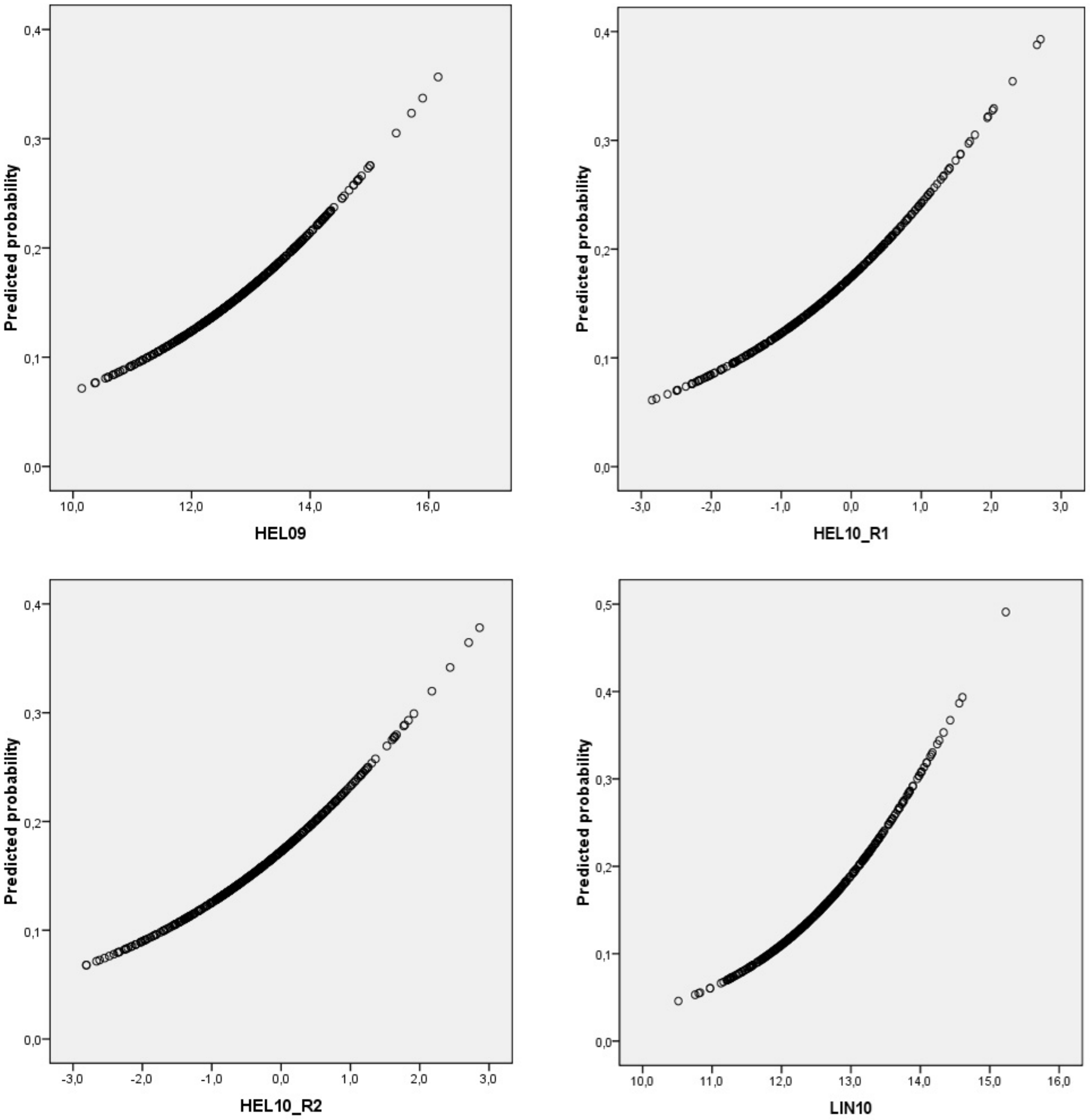


Figure 1. Predicted probabilities of attack from the studied area. *The Y-axis represents the increase of the probability in decimals (0,1 = 10 % etc.) and the X-axis represents the temperature variations (in absolute summer °C temperatures: HEL09 & LIN10, and in mean July °C anomalies: HEL10_R1 & HEL10_R2).*

Usually, the relationship between predicted probability and the explanatory variable makes an s-curve -shaped scatter plot graphic in logistic regression analysis (Hosmer & Lemenshow 2000, 97–98). Here, the relationships make quadratic curves. Thus, the analysis did not find cases where certain temperature values would predict with 100% probability these attacks to happen. However, the results are still rather noteworthy, as they imply that when it was approximately 2 °C degrees warmer than the average temperature, there was a 30 % probability that an attack from the studied area would happen.

The temperature variables and war incidents did not have an apparent relationship. The coefficients of the models were both negative and positive and the variables did not relate to certain temporal time series, as did the attack incidents. When examining the tumult data, the results imply that after a warm summer the probability of internal distress increased in the next year. However, the predicted probabilities were not as strong as with the attack data.

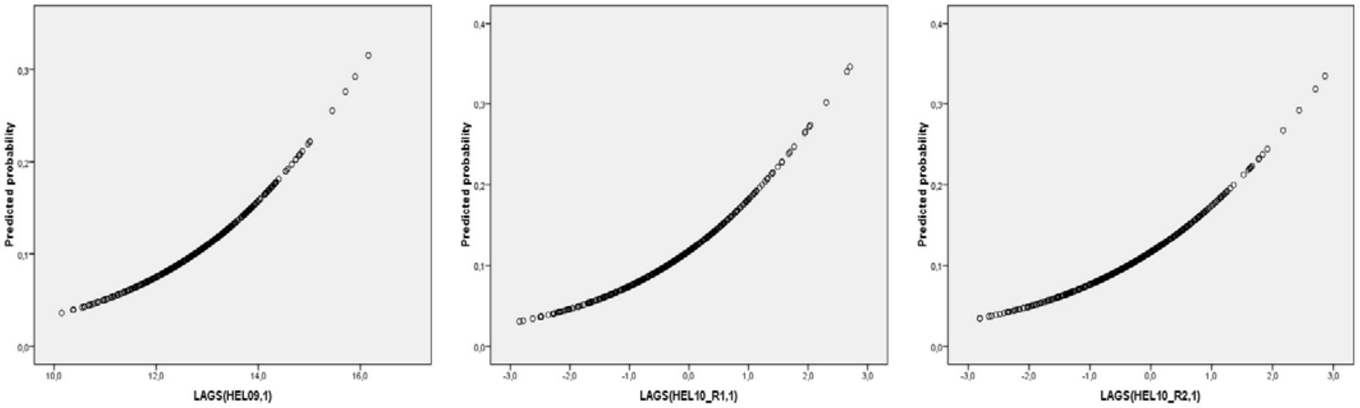


Figure 2. Predicted probabilities of internal distress (tumult). *The Y-axis represents the increase of the probability in decimals (0,1 = 10 % etc.) and the X-axis represents the temperature variations (in absolute summer °C temperatures: HEL09, and in mean July °C anomalies: HEL10_R1 & HEL10_R2).*

4.4 Food security and diseases

It has been argued that temperature was a parameter that directly dictated fluctuations in harvest in pre-modern North Europe. Colder climate meant more frost and crop failures in the same year. (Le Roy Ladurie 1972, 118; Zhang et al. 2011, Appendix II.) Therefore, the frost and crop failure variables should response to the temperature variables without a lag, and the coefficients should be negative. The results of this study were not consistent with this hypothesis, however. Only with two models[14] the predicted probability of frost or crop failures increased as the temperatures got colder. However, the probabilities of frost or crop failure to occur were rather low, even with the coldest temperature variables (from 10 to 20 %). The predicted probabilities of these two models are presented in Figure 3.

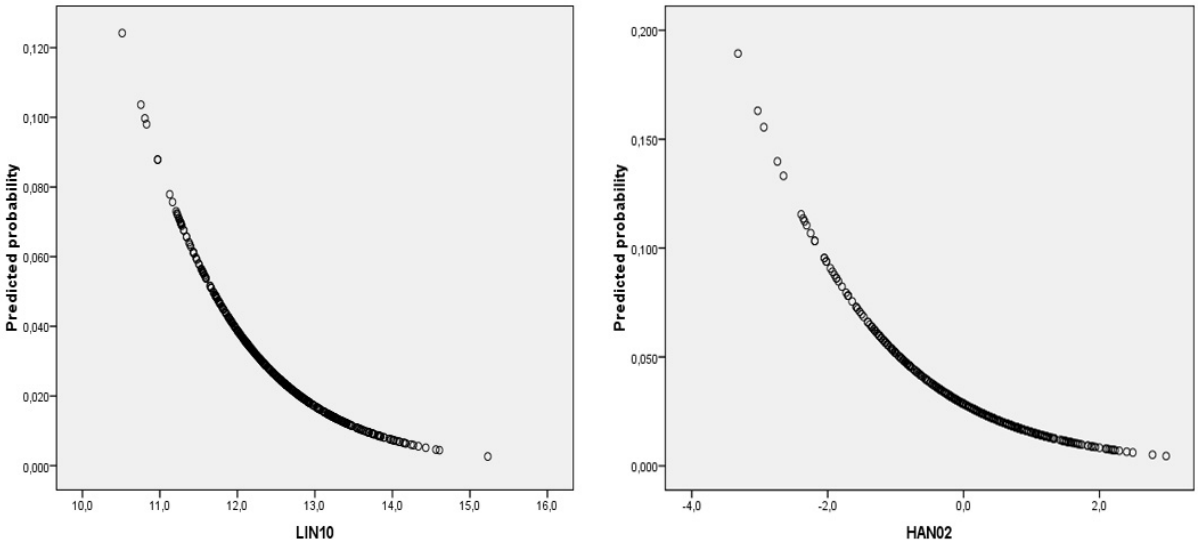


Figure 3. Predicted probabilities of frost (LIN10) or crop failure (HAN20) to happen. *The Y-axis represents the increase of the probability in decimals (0,100 = 10 % etc.) and the X-axis represents the temperature variations (in absolute summer °C temperatures: LIN10, and in mean summer °C anomalies: HAN02).*

In addition, crop failure incidents responded with three paleoclimate estimates (HEL09, HEL10_R1 and HEL10_R2) with a 5 years' time lag. The coefficients were positive, so the

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[14] (Pr (FROST = 1) = F (β_0 + β LIN10) and Pr (CROP_F = 1) = F (β_0 + β HAN02)

probability of crop failure increased the warmer it was five years ago. However, the predicted probabilities were rather low, and it seems that the response may have been just a statistical coincidence. The hunger incidents did not respond to any of the temperature variable series. Yet, we will examine the possible links between temperature conditions and food security further in Chapter 5.1. Diseases (mostly plague) responded to the cooling of the climate with a one year time lag in three models (paleoclimate estimates from HEL09, HEL10_R1 and HEL10_R2). The increase of the predicted probabilities of disease to occur with the three different temperature estimates are illustrated in Figure 4.

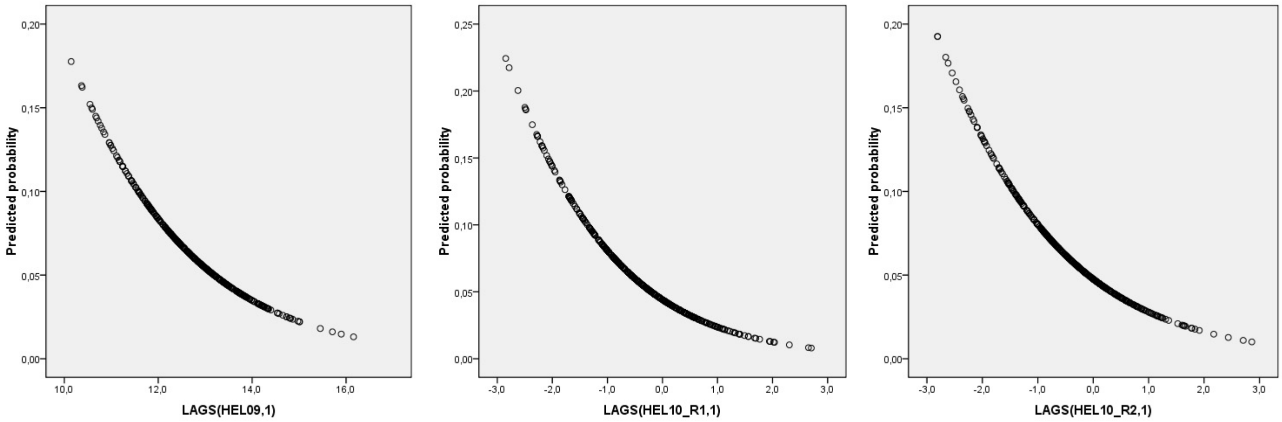

Figure 4. Predicted probabilities of disease to occur. *The Y-axis represents the increase of the probability in decimals (0,1 = 10 % etc.) and the X-axis represents the temperature variations (in absolute summer °C temperatures: HEL09, and in mean July °C anomalies: HEL10_R1 & HEL10_R2).*

4.5 Spatial scope

Because attack incidents responded to warming temperatures immediately, the attack data was analyzed in more detail with a spatial focus. The possible tendency of whether the attacks were more likely to orient to the west or to the east, was examined. In addition, because attacks *from* the studied area responded to temperature variations, it was explored if attacks *to* the studied area also responded to temperatures. Therefore, 20 more models were tested with logistic regression analysis. The tested response variables were 1) attacks from the west to the studied area, 2) attacks from the east to the studied area, 3) attacks to the west from the studied area, and 4) attacks to the east from the studied area (see Table 4, pp. 28).

Only one temperature variable series (HAN02) responded to the attacks to the studied area. An interesting notion is that it was the only reconstruction in which proxy data was collected exclusively from northern Russia (Yamal Peninsula). The coefficients of these two models were 0,366 (.036)[15] and 0,750 (.012)[16], the significance level is presented in parentheses. The "attacks from the east" incidents responded stronger with the warming temperatures than the "attacks from the west" incidents. The coefficient was positive, so the predicted probability of an attack to happen increased when the temperatures rose, just like in the case of attacks from the studied area. However, the predicted probabilities of "attacks to the area" were not as strong as those of the "attacks from the area". The weaker response may result, however, from a smaller number of reported events (see Table 4, pp. 28). The predicted probabilities are presented in Figure 5.

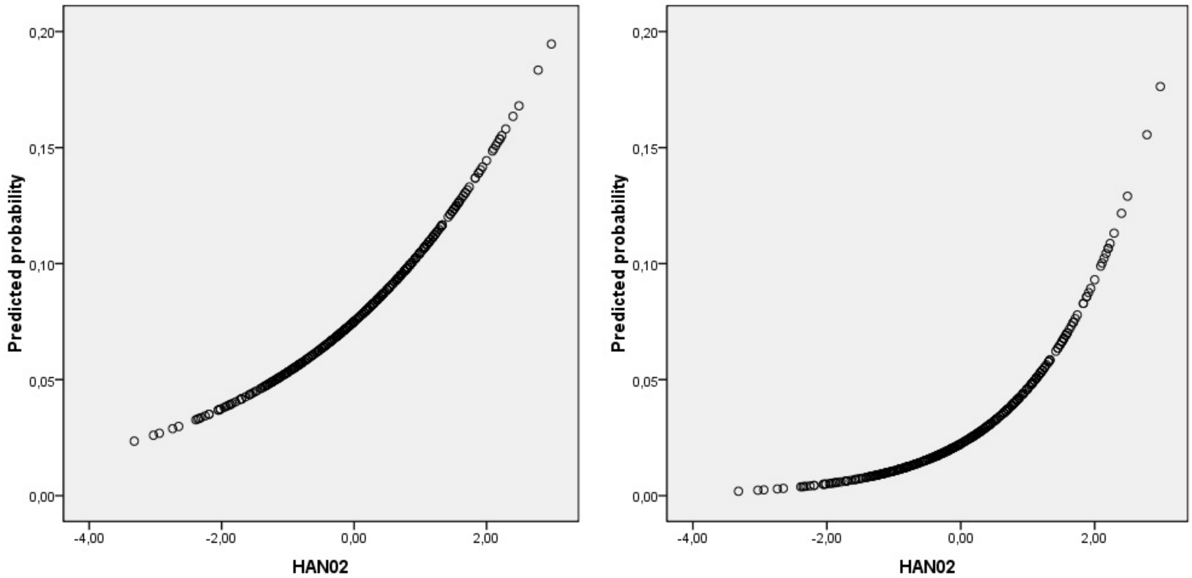

Figure 5. Predicted probabilities of attack to the studied area *("attack from the West to the studied area" on the left, "attack from the East" on the right). The Y-axis represents the increase of the probability in decimals (0,10 = 10 % etc.) and the X-axis represents the temperature variations (in mean July °C anomalies).*

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[15] Pr (R_ATT_FRM_W = 1) = F (β0 + β HAN02)

[16] Pr (R_ATT_FRM_E = 1) = F (β0 + β HAN02)

From the spatial attack data (attacks to the West/East from the studied area), “attacks to the east” responded better to the temperature data. Only one temperature variable series (LIN10) found a significant connection between warming temperature and increased “attack to the west” incidents. The coefficient was 0,603 (.006). A response between attack to the east and warming temperatures was found in four models (temperature estimates from HEL09, HEL10_R1, HEL10_R2, and LIN10). The coefficients were 0,460 (.017)[17], 0,481 (.017)[18], 0,476 (.016)[19], and 0,529 (.030)[20] (the significance level of the coefficient is presented in parentheses). In conclusion, the results of the logistic regression analyses imply that attack incidents, overall, orienting to or originating from the east, responded better with the increased temperatures than attacks to/from the west.

5 Discussion

5.1 Hunger and temperature variations

In history and natural science alike, the belief that medieval hunger was primarily caused by unfavorable climate conditions (and especially in northern Europe because of the cool summer temperatures) has been established as a paradigm. Hence, I wanted examine this issue in more detail, even though the logistic regression analysis did not find a connection between temperature and food security variables. Therefore, a more descriptive approach was adopted. The paleoclimatological temperature reconstructions were compared visually to the food security data, and illustrated in the same graph. This is represented in Figures 6 and 7 (next page). In order for this approach to function, it was important that the climate reconstructions represented annual variations, with as regional accuracy as possible. The reconstructions selected for this study met these requirements. Hemispheric reconstructions, which represent long-term climatic change, would have been useless for this kind of an approach, as it is essential to be able to compare the annual variability.

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[17] $\Pr(\text{R\_ATT\_TO\_E} = 1) = F(\beta_0 + \beta\ \text{HEL09})$

[18] $\Pr(\text{R\_ATT\_TO\_E} = 1) = F(\beta_0 + \beta\ \text{HEL10\_R1})$

[19] $\Pr(\text{R\_ATT\_TO\_E} = 1) = F(\beta_0 + \beta\ \text{HEL10\_R2})$

[20] $\Pr(\text{R\_ATT\_TO\_E} = 1) = F(\beta_0 + \beta\ \text{LIN10})$

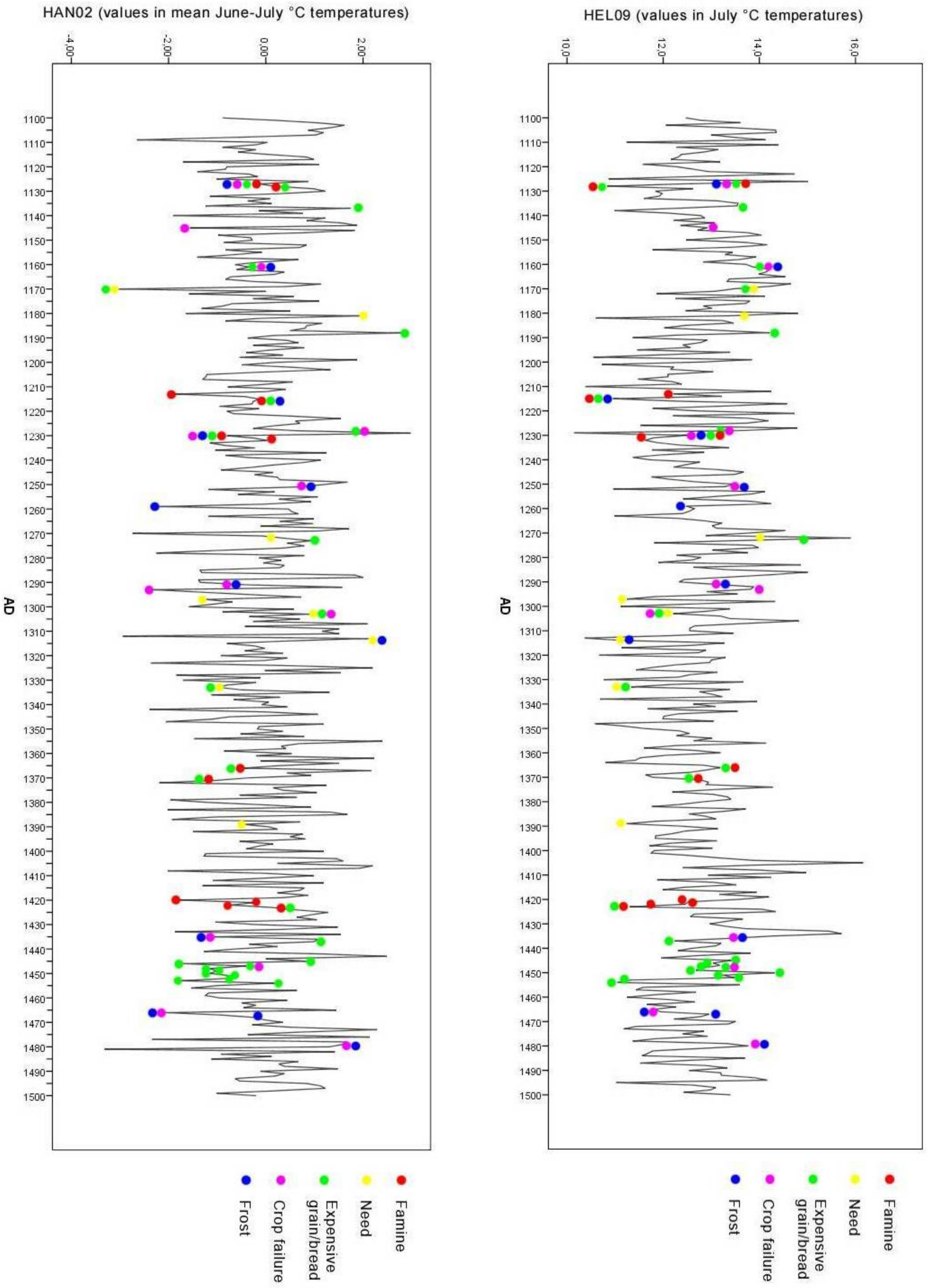

Figure 6. Temperature variations and food security (HAN02 & HEL09).

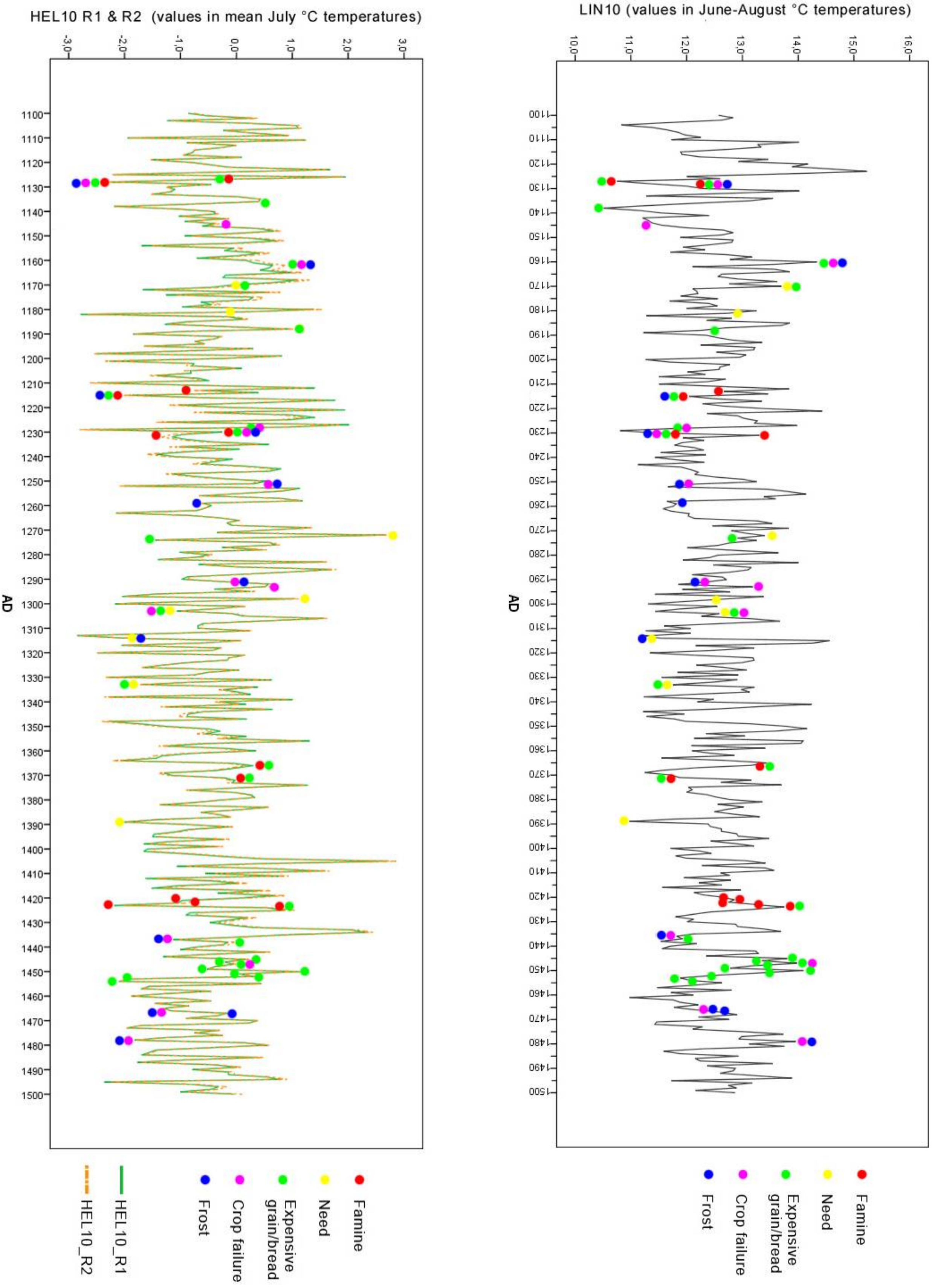

Figure 7. Temperature variations and food security (HEL10 & LIN10).

All of the reconstructions indicate highly variable summer temperatures during the studied period, and no dramatic drop from the Medieval Warm Period (MWP) to the Little Ice Age can be detected. The term Medieval Warm Period was first used by the British climatologist Hubert Howard Lamb in 1965. He discovered a period of generally warmer temperatures in Western Europe between A.D. 1000 and 1300. The term quickly became established in the academic world, and it spread widely into different fields of research, from anthropology to geology (Lamb 1977, Jansen et al. 2007, 468). Yet, from the late 1990's, the unwarranted use of the term Medieval Warm Period has confronted harsh criticism from several scientists. For example, climatologists Bradley, Hughes and Diaz even dispute the whole existence of the MWP and point out that the term has lost its original meaning (Jones & Mann 2004, 163; Brázdil et al. 2005, 391; Bradley et al. 2003, 405).

The term Little Ice Age (LIA) was first introduced by François E. Matthes in 1939, and the term LIA is used to demonstrate the colder climate that occurred in Europe from the mid-16th century to the end of the 19th century. However, it has been difficult to define the beginning or the termination of the LIA, because the characteristics of the LIA varied considerably regionally (like the characteristics of the MWP). For example, in northern Europe the temperatures started to drop already in the 14th century, but transient warmth occurred in the first half of the 15th century (Nesje & Dahl 2003, 139–140; Bradley 1999, 462–463). This view corresponds to the climate reconstructions used in this thesis, which note a trend of cooler temperatures lasting a few decades in the 14th century. In history, some of the most well-known catastrophes and events of the Middle Ages have been linked to the beginning of the LIA, such as the Great Famine (A.D. 1315–1322), decline of European population, desertion of settlements (especially in the north), and even the Black Death. Especially the problems in food security have been seen to result from the cooling climate (Lamb 1995, 195–206; Jordan 1996, 7–8, 15; Brázdil et al. 2005, 390).

Interestingly, during the 14th century, when the paleoclimate reconstructions indicate evenly cooler average temperatures, the chronicles hold very few records of poor food security (see Figures 6 & 7). Thus, it seems like the long term climatic changes, with a decadal or centennial temporal mean variations, did not affect food security. However, when the graphs are examined, it is discovered that the records of poor food security, in most cases, fall on temperature drops or peaks. The temperature drops do not hold a significantly greater number of poor food security records than the temperature peaks. Thus, cold climate does not indicate poor harvest and hunger, or vice versa, as the previous research proposes (Le Roy Ladurie 1972, 118; Hybel & Poulsen 2007, 64–78; Ó Gradá 2009, 31–33). Instead, it seems like the food security was vulnerable to sudden temperature changes, to conditions that were not expected. As the records of poor food security fall evenly on temperature peaks and drops, no certain temperature conditions can be detected, which would cause crop failure or hunger in the studied period and area. The relative change from a previous year's temperature seems to be a considerably greater factor than the absolute temperature figures.

All of the reconstructions indicate cooling temperatures from the AD 1190's onwards, culminating in the 1210's, in a decade when the chronicles also hold records of famine. Moreover, the reconstructions indicate that the temperatures started to get warmer in the 1220's, but suddenly got cooler in the end of the decade. Again, the chronicles hold records of hunger and crop failures in the beginning of the 1230's. Another cool period, which most of the reconstructions[21] indicate, occurred in the 1420's when the chronicles recorded the worst famine period of the studied time. In addition, from the mid 1440's onward reconstructions indicate highly variable temperature conditions and a sudden drop, on a congruent with a time period during which the chronicles hold a record of expensive price of bread for ten years[22]. Therefore, it seems like hunger and crop failures were, to some degree, connected to cool climatic conditions. However, not all sudden or longer-term temperature drops were congruent with the food security data, and crop failures and hunger occurred during the temperature peaks as well. Especially interesting is that summer and autumn frosts occurred during those summers, when the average temperature was high. In the chronicles' records, if a climatic phenomenon was named as the reason for hunger, the summer heat and drought were given the most mentions (see pp. 26). These results suggest that although cold temperatures may have caused hunger and crop failures in the medieval Novgorod and Ladoga regions, the significance of cold summer temperatures may have been overestimated in previous research.

Instead, it seems that any temperature change which was unexpected and relatively dramatic threatened the food security of the time. If the temperature was steadily and moderately cooling or warming, people had time to adapt to the changing circumstances. This notion corresponds with the theory of *vulnerability*, exercised especially in the fields of environment politics, development studies and human geography, although in a contemporary context. By

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[21] All the other reconstructions, except LIN10.

[22] URA, AD 1445–1454.

acknowledging societies' vulnerability, the climate's direct impact on food security has been questioned. It has been argued that rather than just climatic factors, the interaction between social and environmental forces creates situations where society is vulnerable to sudden climatic changes. Societies' food systems have always evolved, as farmers have constantly seeked new strategies to cope with changing climatic circumstances. (Fraser 2006, 329–331.) Geographers Watts and Bohle (1993) have created a frequently cited conceptual model that links climatic changes (among other environmental factors) to the possibility of famine and hunger. According to them, the probability of famines is dependent on three factors: the exposure to a climatic hazard, the capacity to adapt to this risk, and the potential of the problem to have severe consequences (Watts & Bohle 1993, 118). Yet, this theory has rarely been applied to research that studies pre-modern societies (see, e.g. Jordan 1996, 15).

Although the theory of vulnerability has been mainly used to study the contemporary societies' relationship to climatic conditions, the theory helps us to understand the temperature variations' impact on food security in the medieval Novgorod and Ladoga regions. According to Evan D. G. Fraser (2011, 1274–1276), population, agricultural methods, diseases, and socio-cultural factors all had an effect on the vulnerability of food system to climatic changes. Most of the studied area was sparsely populated in the medieval times, thus overpopulation was not an actual challenge. However, the relative size of the population mattered, and the societies that lived close to the margin of subsistence, or were dependent on imported food, like Novgorod and Ladoga, were the most vulnerable. Fraser sees that the shift from the subsistence agrarian economy to a specialized agricultural system, which was controlled by strong institutions, was one of the key factors in why medieval society became more vulnerable to climatic changes (Fraser 2011, 1276). A society whose vulnerability level was high could not cope efficiently with hazards and disturbances, climatic and man-made alike. Thus, a climatic hazard or anomaly rarely caused severe hunger or famine by itself in the studied area. A climatic anomaly, such as unusually early autumn frost or summer heat, was usually the trigger for hunger, as it affected the harvest ratio, but the society's level of vulnerability determined whether the shortage of food developed into famine. Cultural, political, and institutional factors shaped the landscape and the society, which either increased or decreased the vulnerability to the climatic anomalies.

Novgorod and Ladoga practiced sophisticated economy, and were dependent on agricultural trade (Nosov 2001, 7–9). Thus, these economies seem to be vulnerable to climatic changes.

However, because of the nature of the economics practiced, the links between temperature anomalies and harvests and between harvests and economic life is difficult to detect (Ingram et al. 1981, 27–29). Thus, based on the observations discussed above, the relationship between temperature anomalies and food security was determined by the society's level of vulnerability in the medieval Novgorod and Ladoga regions. However, it is beyond the scope of this paper to investigate this question in more detail, but hopefully these notions provide ideas for prospective research.

Thus, it can be said that the food security (crop failures and hunger) was related to temperature variations to a certain extent in the Novgorod and Ladoga regions in AD 1100–1500. The relative change from a previous year's temperature seems to be a considerably greater factor than the absolute temperature figures. Because the incidents of poor food security were dependent on the relative change from the previous year's temperature conditions, this relationship could not have been detected from the statistical analysis. The connection became evident only after descriptive analysis. Therefore, these results propose, that a statistical approach alone may not be sufficient when examining the impacts of climatic variations on human actions in pre-modern times. In addition, as the results did not hold evidence of long term climatic shifts (like the MWP or the LIA) having an effect on food security, the need for further research that would lay emphasis on regional and short-term (seasonal and annual) temperature variations is proven. Furthermore, the results imply that the level of vulnerability may have had a notable impact on how severe the consequences of the climatic anomalies were on the food security.

5.2 Disease

The Black Death, which broke out in Europe in the end of the 1340's, was the most severe pandemic in the Middle Ages. Both of the medieval chronicles note the plague. The Novgorod First Chronicle and the *Utdrag ur Ryska Annaler* have a considerably greater number of plague records from the 1390's onwards, even though the sources also hold mentions of plague prior to the 1340's. The sources hold seven mentions of plague or diseases prior to AD 1340, and after AD 1340 these records were found in 19 single years. Thus, all of the mentions of *plague* can not refer to the Black Death, which was caused by the bacterium *Yersinia pestis*. However, identifying the actual cause of the disease or the precise epidemic is irrelevant for this study. It is more important to identify when the disease broke out in the studied area. The chronicles imply that the plague reached Novgorod in AD 1352, and the historical research supports this notion (Crummey 1987, 42–43). The sources mention plague relatively regularly between AD 1352 and 1550, with a substantially greater number of plague records in AD 1417–1427. During this period, almost every year had a record of plague. In general, each decade between AD 1370 and 1500 had one or two plague mentions.

The connection between climatic change and diseases has been discussed in a rather large extent. While it is evident that some of the diseases occurred more likely in certain climatic conditions, the question of whether the Black Death was connected to climatic conditions is still open, even though Hubert H. Lamb, among others (see, e.g. Jutikkala[23] 1987, 67), proposes this possibility. Also, the connection between hunger and diseases from a historical perspective has been in special focus. The *Yersinia pestis* that caused the plague was such a strong bacterium that the victim's nutritional condition was most likely irrelevant. Some other diseases, however, may have transmitted more easily to a body that was weakened by malnutrition. Demographically, diseases killed more people in the medieval North-East Europe than hunger, even though it is sometimes extremely difficult to specify whether the cause of death was a disease or hunger. (Lamb 1995, 198–200; Kallioinen 2009, 126–130; Brown 1999, 9–10; Ó Gráda 2009.)

The chronicles hold 27 mentions of disease, of which 21 are mentions of plague[24] and 5 are mentions of other undefined illness[25]. The logistic regression analysis found that diseases responded to the drop in temperatures with a one year lag in three models[26]. However, the predicted probabilities were rather low: even with the coldest temperature variables the probability for disease was less than 20 % (see, Figure 4, pp. 36). Yet, the results imply that there is a weak connection between cool temperatures and diseases. Perhaps, the vulnerability theory can be used to explain this connection as well: unstable and unusual temperature variations exposed the food security and other essential mechanisms of the society, and a

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[23] Jutikkala proposed that as the grain supplies were decreased due to unfavourable climatic conditions of the LIA, rats died of hunger, and the plague carrier fleas transmitted more easily from them to the human population.

[24] AD 1308, 1309, 1321, 1352, 1374, 1389, 1390, 1391, 1408, 1417, 1419, 1421, 1422, 1424, 1425, 1427, 1448, 1466, 1467, 1474 & 1478.

[25] AD 1158, 1187, 1230, 1278 & 1414.

[26] $\Pr(\mathrm{DISE} = 1) = F(\beta_0 + \beta\,\mathrm{HEL09\_1LAG})$; $\Pr(\mathrm{DISE} = 1) = F(\beta_0 + \beta\,\mathrm{HEL10\_R1\_1LAG})$;
$\Pr(\mathrm{DISE} = 1) = F(\beta_0 + \beta\,\mathrm{HEL10\_R2\_1LAG})$.

disease epidemic was more likely to outburst the next year, due to the society's increased vulnerability.

In the classical Malthusian *theory of population* (Malthus 1807) plague and other diseases, like famine, are seen as a natural way to control the population growth, as the diseases rebalanced the levels of population and food production. According to this view, a severe plague pandemic would hence decrease the possibility of famines in the long run, as the disease would dramatically reduce the population and there would be fewer mouths to feed (Malthus 1807, 19–20, 480). Nevertheless, the medieval sources do not support this interpretation: the famine mentions did not decline after the 1350's. Quite the opposite, when the sources hold the biggest cluster of plague mentions AD 1417–1427, the sources also hold a record of the severest famine period of the studied time. If the disease reached Novgorod already in the 1350's, why did the worst plague outbreak happen only in the 1410's and 1420's?

These observations imply that cool temperature variations increased societies' vulnerability to disease, diseases increased societies' vulnerability to hunger, and malnutrition probably made people more vulnerable to disease. As the diseases weakened and reduced the population, the food production most likely also decreased, as there was not enough labour on the fields. In addition, the disease epidemics were rapid to spread and cause death in a short time, thus the societies most likely had to struggle to cope with these sudden changes in population (Ó Gráda 2009, 121; Jordan 1996, 182). Although the climate was most likely not the trigger for the plague to outbreak in the studied area, it may have been a contributing factor. Especially, if we combine this paper's findings of the climate's impact on food security and on disease, we can conclude that temperature variations could have led to hunger and illness in the studied area. Thus, the linkages between temperature conditions, hunger and disease are complex, but the connection can be detected.

5.3 Attacks and violent conflicts

Medieval conflicts are commonly linked with the struggle for resources. According to previous research, unfavorable climatic conditions endangered the food security, which increased the risk of violent conflicts and attacks to neighboring regions to gain more resources (Barnett & Adger 2007, 644, 649–651). Especially the cooling temperatures in northern Europe have been seen as a trigger for distress, and there is evidence that war incidents respond to temperature drops with a few years' lag (Zhang et al. 2007, Zhang et al. 2011b). Moreover, the chronicles used in this study imply that most of the warfare happened during winters, due to poor roads. Only when the ground was frozen, it was possible to mobilize heavy armed troops.[27] The logistic regression analysis found the strongest connection between temperature variables and social events in warm summer temperatures and attacks from the studied area. Why did warm summer temperatures increase the risk of an attack if the battles happened during winters? Moreover, the results of the analysis challenge the previous research, by implying that violent conflict in the medieval northern Europe was not connected to cooling temperatures. Therefore, the question of temperature variations and violent conflict will be examined in more detail.

By studying the residuals of the logistic regression models, we can examine which cases (years) deviated the most from the estimated probability of an attack to happen under warmer temperature conditions. Certain years[28] stood out[29] noticeably from the models. Most of these were attacks to the west, and only in four cases the attack was targeted to the south or to the east. The majority of these attacks originated from Novgorod and was directed to the areas of modern day Estonia and Latvia. These areas were well connected to Novgorod via waterways (see Map 1). Thus, the attacks to these areas were probably not crucially dependent on climatic conditions (that is, on cold climatic conditions during the winter) as the army troops could be transported through waterways, and frozen ground was not a prerequisite to mobilize the troops in these attacks. In addition, as these routes were crucial for trade and Novgorod placed priority on its commerce (Martin 2007, 139), the primary reason for these attacks was probably not to gain more natural resources, but to get the dominance on foreign trade. These

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[27] See, e.g. N1 AD 1147, 1168, 1169.

[28] AD 1105, 1115, 1116, 1130, 1131, 1143, 1179, 1186, 1195, 1222, 1226, 1231, 1262, 1311, 1324, 1349, 1370, 1398 & 1460.

[29] Cases which either occurred in three or more models or when the standardized residual temporary variable was ≥ 3,0.

observations are congruent with the regional logistic regression analysis (see: Chapter 4.5), which found that conflicts in the East were more strongly connected to temperature variations. Thus, the geographical landscape may explain why in certain areas attacks were not as dependent on climatic conditions.

How about the temperature variations then? Why did warm summer temperatures increase the risk of an attack if the battles happened during winters? In the studied area, warm summer temperatures do not necessarily imply warmer annual mean or winter temperatures (Klimenko & Solomina 2010, 79–80). In addition, if warm summer temperatures advanced harvest success (although this view has been questioned in this paper), the state / individuals may have been prosperous enough to arm the military troops. Alternatively, if warm summer temperatures also imply drought, and if the summer drought was one of the major reasons for poor harvest (as proposed above), this may have caused raids to the neighboring regions in the following autumn or early winter. Moreover, if warm summer temperatures imply drought, floods or wet roads did not hinder the troops' transportation.

The connections between poor harvest, heavy tax burden and uprisings, tumults or other forms of internal distress have been discussed widely in historical research (see, e.g. Korpela 2008, 232–240; Katajala 2002, 105–109). The tax burden is impossible to estimate from the chronicle sources used in this study, but there is evidence of years of poor harvest and hunger. As discussed in Chapter 4.1, internal distress and poor food security may have a connection. Therefore, the records of internal distress and food security will be compared in descriptive analysis.

In the 1130's the chronicles hold four mentions of distress, all happening in Novgorod. The chronicles hold records of famine in AD 1127 and 1128, and all of the climate reconstructions indicate highly variable temperatures during those years. Thus, the time of internal distress may have a connection to the 1120's famines and unfavorable climatic conditions. The next period of great distress happened in AD 1228–1230, in a period when all of the reconstructions indicate a sudden drop in temperatures. In addition, the chronicles also record a famine in 1230. However, unlike the case of 1130's uprisings, famine was not one of the possible causes in this case, as the famine occurred two years after the first distress incident. In the 1280's the chronicles hold four records of distress, happening in Koporye, Ladoga and Novgorod. During this period, no hunger was recorded and the reconstructions did not indicate dramatic climatic anomalies. The next cluster of records of internal distress can be found in AD 1335–1344 when five incidents occurred in Novgorod, Narva and Ladoga. During this period all of the reconstructions indicate a period of cooler climate, but no dramatic temperature anomalies. Also, during this period, the chronicles do not hold records of poor food security. In the mid-1380's the chronicles hold three mentions of distress in Novgorod, but no mentions of hunger, although the temperature reconstructions indicate moderately variable temperatures. The last great tumults in the studied period occurred in AD 1445 and 1446 in Novgorod, during years when all of the reconstructions indicate warming temperature. The time of distress was followed by a record of expensive pricing of bread that lasted the next ten years.

Thus, hunger and poor harvest may have been the cause or the consequence of internal distress. The results suggest that there may be a link between food security and internal distress, but there is not enough evidence to prove any causal linkages. Moreover, no certain temperature trends can be connected to the distress incidents, even though logistic regression analysis found a weak link between warming temperatures and internal distress with a one year time lag. These results suggest that the reasons and causes behind riots, tumults and other forms of internal distress were complex, and did not arise simply from the need of gaining more resources.

However, based on all the evidence discussed above, it can be argued that favorable climatic conditions increased human actions, including violent conflicts. This view corresponds with Christian Pfister's argument that *"beneficial climatic effects tend to enlarge the scope of human action, whereas climatic shocks tend to restrict it"* (Pfister 2010, 28). In addition, the results of the descriptive analysis concerning the connection between temperature variations, hunger and disease support this notion. Therefore, the dominant approach can be validly challenged when examining climate's impacts on human actions. As a rule, the research focuses on to examine how *unfavorable* climatic conditions bring hunger, disease, warfare, and death upon humankind. If favorable climate conditions tend to enlarge the scope of human actions, why have beneficial climatic conditions been under so little examination?

5.4 Vulnerability and the diversity of scales

The subsistence and the success of medieval centers of Novgorod and Ladoga were based on the possibility to exploit natural and cultural resources that sustained the centers’ demands (Monk & Johnston 2001, 116). Some of these natural and cultural resources were most likely determined by temperature conditions (e.g. what resources the wilderness would provide, which variety of grain was cultivated, and which cultivation methods were practiced). In addition, some of the exploitation processes were most likely linked to certain climatic conditions (e.g. this study implies that attacks to the East were connected to warm summer temperatures). However, even thought the temperature variations may have had an impact on these resources and processes, the temperature variations did not cause social struggle if the society was able to cope with the changing conditions. Because these centers were able to exploit the periphery’s resources and because the centers practiced extensive trade, the unfavorable temperature conditions did not directly cause social struggle. These centers were not dependent on a single economical system, but had various coping mechanisms to respond to the changing conditions (Korpela 2008, 313–315; Monk & Johnston 2001, 116).

This may explain why the logistic regression analysis did not find a significant response between cool temperature variables and the records of social struggle. The medieval societies may not have been as vulnerable to unfavorable climatic conditions as it has been supposed. Yet, favorable climatic conditions may have enlarged the scope of actions and strengthened the society’s resilience to climatic anomalies (Pfister 2010, 28). However, the medieval society that created a system of exploited periphery which supported the wealthy core economy increased its vulnerability in the long run (Fraser 2011, 1276). This notion corresponds with the explored connection between food security and temperature anomalies. Not every year, during which summer temperatures were extreme, has a record of poor food security. But in some cases the society’s resilience to temperature extremes was weakened, and an incident of social struggle occurred. Most likely the socially-produced vulnerability weakened the resilience. As none of the events of social struggle (warfare, attacks, internal distress, crop failures, hunger, or disease) was inevitably connected to certain temperature conditions, it can be concluded that the level of vulnerability was the dominant factor to determine if some temperature linked incidents led to crises or conflicts.

The focus on the vulnerability of medieval societies to climatic variations may provide a fruitful approach for prospective research. This has been noted (e.g. Pfister 2010), but only very few attempts have been made (see, e.g. Fraser 2011). Moreover, not just the vulnerability needs to be recognized in future research, but the different mechanisms of vulnerability and the different spatial and temporal factors of vulnerability need to be examined as well. Some of the findings of this paper suggest that the societal response to temperature variations was diversified in the studied area, sometimes the response was immediate and direct (as in the case of food security) and sometimes it was more complex and followed the climatic events with a few years' lag (as in the case of disease and internal distress). As noted many times above, the connection between climatic events and human action is difficult to demonstrate, but perhaps by studying the mechanisms between these two phenomena a more comprehensive understanding can be achieved.

The vulnerability is a function of multiple processes, in the same way as human actions and climatic events. These functions operate across space, over time, and at multiple scales. In addition, these functions are open to external and internal influences, and can be connected with each other (Barnet & Adger 2007, 642). Therefore, the different scales of these functions need to be acknowledged and considered with sensitivity in research.

For example, in this study, it is important to acknowledge that when paleoclimatological estimates indicate certain temperature conditions, these were not necessarily similar in Novgorod or in Ladoga. Climate has always varied regionally, and the Middle Ages is not an exception (Bradley et al. 2003, 405). The paleoclimatological temperature estimates alone differ from each other, even though all of the proxy records have been collected roughly from the same latitudes. Novgorod and Ladoga are located hundreds of kilometers south from the collected proxy records. Thus, it is evident that the paleoclimatological temperature estimates do not indicate temperature conditions in the studied area comprehensively. However, these can indicate relative temperature variation in the studied area. The spatial synchrony in annual temperature is considerable and detectable over large geographic distances (Koenig 2002, 286). Moreover, because the centers were dependent on the ability of exploiting the resources of the north (Nosov 2001, 5–9), it was reasonable to use these reconstructions.

In addition, the geographical distance between the existing and accessible paleoclimatological temperature estimates and the studied area is as short as possible. Tree rings, which are the main proxy source for the paleoclimatological temperature estimates used in this study, respond most sensitively to temperature variations in the uppermost tree-line limit, in locations such as Lapland, Kola Peninsula and Yamal (Lamb 1995, 98). However, these locations do not hold any historical evidence of human action of the time, and in these regions agriculture cannot be practiced. Although the temperature synchrony declines with distance, the distance between the temperature reconstructions' collected proxy records and the studied area is not too long to make comparisons to a certain degree (Koenig 2002, 286–288). The distance between the sites of the proxy records and the studied area, for part, can explain why the connections found by logistic regression analysis were rather weak.

Regional environmental factors (e.g. ecological and geographical landscape) affect regional temperature factors. In addition, temperature variations impact on human actions. Further, human actions (e.g. land use) affect regional environmental factors (Koenig 2002, 286–288). Thus, the systems of human actions, climatic conditions and environmental factors are all connected and open, and it is important to recognize the regional environmental conditions. For example, in this study, the geographical landscape (waterways) decreased the climate's significance on human actions in the west of the studied area. Climate functions on a large scale, high up in the atmosphere. Humans (in the studied time and area) functioned on a relatively regional scale, and the processes of vulnerability functioned somewhere between and across these scales. However, it can be argued that the climatic stress is always local, to some degree. The social response does not occur somewhere in the undefined atmosphere, but always in some spatial location. Moreover, human societies are never stable or uniform, not even the medieval ones. Thus, a regional approach is appropriate when studying the effects of temperature variations on social struggle. Yet, the regional approach must reach these different scales. This can be achieved with a holistic approach.

5.5 Unifying geography?

Evan D. G. Frasier argues that *"no single theoretical body of literature is able to provide a full account of medieval history because different socio-economic dynamics were more or less important at different points of time"* and continues that *"it is possible to create a collage of bodies of literature that together create more compelling and complete explanation than any one theory could on its own"* (Fraser 2011, 1269). The findings of this paper support this notion. The information from medieval chronicles is too fragmented and limited to detect the climatic effects on social struggle. However, the historical approach and understanding needs to be brought into research, or otherwise the diversity of socio-economic dynamics cannot be taken into consideration, and the understanding of climatic effects will be too indefinite. Thus, research needs to emerge from historical and climatological understanding of society and climate, but the research process needs to be flexible enough to be able to bring interdisciplinary theories into the interpretation phase of the results.

In addition, according to new scientific knowledge of the past climate, old theories of human-climate relationship are inadequate. The results cannot be interpreted through a deterministic framework, although the human sciences can no longer avoid taking climatic factors into consideration when studying the causes of social struggle in the Middle Ages. It is evident that a more holistic approach is needed when the climate's impacts are studied. In this paper, geography provided a flexible ground for mixing different theoretical frameworks, scientific traditions and interdisciplinary theories. It seems that the research focusing on climatic effects on social struggle can explore the natural and human worlds simultaneously. Perhaps the natural and human sciences can be brought closer together in future research. Mike Hulme's argument *"climates do not travel well between scales"* (Hulme 2008, 7) can be challenged with this holistic approach, which is able to understand and examine these different scales simultaneously.

However, as noted earlier in this paper, research can claim to be Geography only if the researchers *"identify their work as geography, [...] and clearly explain how their geographic approaches uniquely led to solutions to the key questions"* (Balling 2000, 121). This paper examined the interface between the physical world and the human world at the Earth's surface, the core of Geography (Matthews & Herbert 2004, 371). Thus, the research topic itself is identified as geography. In addition, the examination found certain themes that existed in and affected the climate-human relationship in every aspect. These were time, process, openness (connectivity) and scale. These are also central dimensions in Geography (Matthews & Herbert 2004, 381). This paper evaluated and examined the results through these geographical dimensions. Through a geographical approach, climate's relationship to human actions (and vice versa) can be examined in a holistic manner. Geography as a discipline provides a framework that is flexible enough to draw and examine different materials and sources together, and to reach and borrow theoretical understanding from other disciplines. This paper succeeded in understanding human actions through climatic perspective, and so was able to examine the climatic impact on social struggle. Therefore, it can be argued that a holistic geographical approach may provide a bridge to connect the different sides of human-climate research, and to create a fruitful dialogue between human and natural sciences.

6 Conclusions

The objective of this thesis has been to investigate the relations between temperature variations and social struggle in Novgorod and Ladoga regions AD 1100–1500. All forms of violent conflict, disease and hunger were considered as social struggle. The logistic regression analysis and the descriptive approach were selected as methods to investigate the possible relations. Logistic regression analysis was chosen as the paleoclimatological temperature estimates and the data of social struggle both represented annual variations, and because the events of social struggle were quantified as dichotomous variables. The analysis method proved to be suitable for the investigation, although it was demonstrated that quantitative analysis alone is not sufficient to examine the relations between temperature variations and social struggle in pre-modern context. In addition, it was proved that the relations cannot be detected only from historical sources, as those are too fragmented and qualitatively variable. Climatic information from medieval documents was found to be very relative in nature, as the records might have rather little in common with absolute temperature conditions.

The paleoclimatological temperature estimates connected better with the social conflict variables than with the food security data. In fact, the temperature variables responded surprisingly poorly to the food security data in the logistic regression analysis. However, with the descriptive approach the connection between temperature variations and food security was found. The records of poor food security, in most cases, fall on temperature drops or peaks. The relative change from a previous year’s temperature was found to be a considerably greater factor than the absolute temperature figures. The temperature drops did not hold a significantly greater number of poor food security records than the temperature peaks. Thus, cold climate does not indicate poor harvest and hunger, or vice versa, as previous research proposes. Instead, it seems that the food security was vulnerable to sudden temperature changes, to conditions that were not expected. It was discovered that the significance of cold summer temperatures may have been overestimated in previous research. Disease incidents responded to cold temperature records with a one year lag in logistic regression analysis, although this connection was rather weak. In a descriptive analysis a connection between famine and plague incidents was found, especially in the 15th century. The observations imply that cool temperature variations increased societies' vulnerability to disease, diseases increased societies' vulnerability to hunger, and malnutrition probably made people more vulnerable to disease.

The strongest connection between temperature variations and social phenomena was found in warm summer temperatures and attacks from the studied area to the surrounding regions. This connection was found in the logistic regression analysis, and the descriptive approach strengthened this interpretation. Especially the attacks targeting to the east seemed to be strongly related to warm summer conditions. The geographical landscape was found to explain why certain areas (the west) were not as dependent on climatic conditions. The results indicate a possible link between food security and internal distress, but there was not enough evidence to prove any causal linkages. In addition, no certain temperature trends could be connected to the distress incidents. The results suggest that the reasons and causes behind riots, tumults and other forms of internal distress were complex, and did not arise simply from the need of gaining more resources.

Two reasons were discovered which may explain the relatively weak connections found in logistic regression analysis. First, the spatial distance between the studied area and the sites from where the proxy records were collected was rather considerable. Second, this paper discovered that the connection between temperature variations and social struggle is rarely a direct one. None of the events of social struggle (warfare, attacks, internal distress, crop failures, hunger, or disease) was inevitably connected to certain temperature conditions. The level of vulnerability was discovered as the dominant factor to determine if some temperature-linked incidents led to crisis and conflicts or not. Thus, exploring the medieval societies' climate vulnerability may provide a fruitful approach for future research.

In addition, it was found that short term temperature variations probably caused more social struggle than long-term climatic changes. The short term connection is at least easier to detect. Thus, prospective research should lay emphasis on annual and seasonal climatic fluctuations. Another important perspective for prospective research, is the process of comparing and combining climatic and social information, data and knowledge of different scales. Finally, this paper proved that only one analysis method might not be comprehensive enough to understand the climatic effects on social struggle in pre-modern times. Different approaches and bodies of knowledge need to be applied in a single study. The biggest challenge this paper confronted was the methodological difficulties to examine qualitatively and quantitatively differing materials (paleoclimatological temperature estimates and records from medieval chronicles) and to understand the linkages between different scales of climatic and human actions. Therefore, special attention will be given to the theoretical aspects in further research.

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List of Abbreviations (for abbreviations used in logit models, see Appendix A)

AD	=	Anno Domini (Common Era)
MWP	=	Medieval Warm Period
N1	=	Novgorod First Chronicle
LIA	=	Little Ice Age
URA	=	Utdrag ur ryska annaler (The Extract From Russian Annals)

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APPENDIX

Appendix A: ABBREVIATIONS II (For the spatial divisions, see: Map 2, pp. 29)

TEMP = Temperature (different paleoclimate estimates and time series)

HAN02 = Hantemirov & Shiuatov 2002
  HAN02_1LAG = Hantemirov & Shiyatov 2002 with a 1 year lag
  HAN02_2LAG = Hantemirov & Shiyatov 2002 with 2 year lag
  HAN02_5LAG = Hantemirov & Shiyatov 2002 with 5 year lag
HEL09 = Helama et al. 2009
  HEL09_1LAG = Helama et al. 2009 with a 1 year lag
  HEL09_2LAG = Helama et al. 2009 with 2 year lag
  HEL09_5LAG = Helama et al. 2009 with 5 year lag
HEL10_R1 = Helama et al. 2010, reconstruction 1.
  HEL10_R1_1LAG = Helama et al. 2010, reconstruction 1 with a 1 year lag
  HEL10_R1_2LAG = Helama et al. 2010, reconstruction 1 with 2 year lag
  HEL10_R1_5LAG = Helama et al. 2010, reconstruction 1 with 5 year lag
HEL10_R2 = Helama et al. 2010, reconstruction 2.
  HEL10_R1_1LAG = Helama et al. 2010, reconstruction 2 with a 1 year lag
  HEL10_R1_2LAG = Helama et al. 2010, reconstruction 2 with 2 year lag
  HEL10_R1_5LAG = Helama et al. 2010, reconstruction 2 with 5 year lag
LIN10 = Lindholm et al. 2010
  LIN10_1LAG = Lindholm et al. 2010 with a 1 year lag
  LIN10_2LAG = Lindholm et al. 2010 with 2 year lag
  LIN10_2LAG = Lindholm et al. 2010 with 2 year lag

SOC = Social events

SUM_WAR = All wars and battles in the studied area (including attacks from outside into the studied area)
SUM_TUM = All tumults, riots and other forms of internal distress in the studied area
SUM_ATT = All attacks from the studied area to external regions
FROST = All recorded frosts in the studied area
CROP_F = All recorded crop failures in the studied area
HUNG = All records of famine, hunger, and need for / expensive bread.
DISE = All records of disease

R_ATT_FRM_W = Attack to the studied area from the west
R_ATT_FRM_E = Attack to the studied area from the east
R_WAR_S = War or battles in the southern parts of the studied area
R_WAR_N = War or battles in the northern parts of the studied area
R_TUM_S = Internal tumults and riots in the southern parts of the studied area
R_TUM_N = Internal tumults and riots in the northern parts of the studied area
R_ATT_TO_W = Attack to the west from the studied area
R_ATT_TO_E = Attack to the east from the studied area

Appendix B: CHI-SQUARE TESTS FOR THE SELECTED MODELS (where $p < .05$)

(For abbreviations, see Appendix A)

Hantemirov & Shiyatov 2002

Pr (SUM_WAR = 1) = F ($\beta_0 + \beta$ HAN02)

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	6,204	1	,013
	Block	6,204	1	,013
	Model	6,204	1	,013

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	314,411[a]	,015	,028

a. Estimation terminated at iteration number 5 because parameter estimates changed by less than ,001.

Pr (CROP_F = 1) = F ($\beta_0 + \beta$ HAN02)

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	6,328	1	,012
	Block	6,328	1	,012
	Model	6,328	1	,012

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	115,115[a]	,016	,060

a. Estimation terminated at iteration number 7 because parameter estimates changed by less than ,001.

Helama et al. 2009

Pr (SUM_ATT = 1) = F ($\beta_0 + \beta$ HEL09)

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	5,754	1	,016
	Block	5,754	1	,016
	Model	5,754	1	,016

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	346,330[a]	,014	,024

a. Estimation terminated at iteration number 5 because parameter estimates changed by less than ,001.

$\Pr(\text{SUM\_TUM} = 1) = F(\beta_0 + \beta\ \text{HEL09\_1LAG})$

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	6,692	1	,010
	Block	6,692	1	,010
	Model	6,692	1	,010

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	266,313[a]	,017	,034

a. Estimation terminated at iteration number 5 because parameter estimates changed by less than ,001.

$\Pr(\text{SUM\_WAR} = 1) = F(\beta_0 + \beta\ \text{HEL09\_2LAG})$

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	4,131	1	,042
	Block	4,131	1	,042
	Model	4,131	1	,042

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	315,892[a]	,010	,019

a. Estimation terminated at iteration number 5 because parameter estimates changed by less than ,001.

$\Pr(\text{DISE} = 1) = F(\beta_0 + \beta\ \text{HEL09\_1LAG})$

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	5,008	1	,025
	Block	5,008	1	,025
	Model	5,008	1	,025

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	187,399[a]	,012	,033

a. Estimation terminated at iteration number 6 because parameter estimates changed by less than ,001.

$\Pr(\text{CROP\_F} = 1) = F(\beta_0 + \beta\ \text{HEL09\_5LAG})$

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	4,774	1	,029
	Block	4,774	1	,029
	Model	4,774	1	,029

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	116,312[a]	,012	,045

a. Estimation terminated at iteration number 7 because parameter estimates changed by less than ,001.

Helama et al. 2010, Reconstruction 1

Pr (SUM_ATT = 1) = F ($\beta_0 + \beta$ HEL10_R1)

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	8,383	1	,004
	Block	8,383	1	,004
	Model	8,383	1	,004

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	343,701[a]	,021	,035

a. Estimation terminated at iteration number 5 because parameter estimates changed by less than ,001.

Pr (SUM_TUM = 1) = F ($\beta_0 + \beta$ HEL10_R1_1LAG)

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	9,148	1	,002
	Block	9,148	1	,002
	Model	9,148	1	,002

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	263,857[a]	,023	,046

a. Estimation terminated at iteration number 5 because parameter estimates changed by less than ,001.

Pr (DISE = 1) = F ($\beta_0 + \beta$ HEL10_R1_1LAG)

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	8,645	1	,003
	Block	8,645	1	,003
	Model	8,645	1	,003

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	183,763[a]	,021	,056

a. Estimation terminated at iteration number 6 because parameter estimates changed by less than ,001.

Pr (SUM_TUM = 1) = F (β_0 + β HEL10_R1_5LAG)

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	4,459	1	,035
	Block	4,459	1	,035
	Model	4,459	1	,035

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	267,632[a]	,011	,023

a. Estimation terminated at iteration number 5 because parameter estimates changed by less than ,001.

Pr (CROP_F = 1) = F (β_0 + β HEL10_R1_5LAG)

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	5,191	1	,023
	Block	5,191	1	,023
	Model	5,191	1	,023

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	115,894[a]	,013	,049

a. Estimation terminated at iteration number 6 because parameter estimates changed by less than ,001.

Helama et al. 2010, Reconstruction 2

Pr (SUM_ATT = 1) = F (β_0 + β HEL10_R2)

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	7,065	1	,008
	Block	7,065	1	,008
	Model	7,065	1	,008

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	345,019[a]	,017	,030

a. Estimation terminated at iteration number 4 because parameter estimates changed by less than ,001.

Pr (SUM_TUM = 1) = F (β_0 + β HEL10_R2_1LAG)

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	7,944	1	,005
	Block	7,944	1	,005
	Model	7,944	1	,005

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	265,061[a]	,020	,040

a. Estimation terminated at iteration number 5 because parameter estimates changed by less than ,001.

Pr (DISE = 1) = F (β_0 + β HEL10_R2_1LAG)

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	6,736	1	,009
	Block	6,736	1	,009
	Model	6,736	1	,009

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	185,671[a]	,017	,044

a. Estimation terminated at iteration number 6 because parameter estimates changed by less than ,001.

Pr (CROP_F = 1) = F (β_0 + β HEL10_R2_5LAG)

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	5,037	1	,025
	Block	5,037	1	,025
	Model	5,037	1	,025

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	116,049[a]	,013	,048

a. Estimation terminated at iteration number 6 because parameter estimates changed by less than ,001.

Lindholm et al. 2010

Pr (SUM_ATT = 1) = F ($\beta_0 + \beta$ LIN10)

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	13,174	1	,000
	Block	13,174	1	,000
	Model	13,174	1	,000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	338,910[a]	,032	,055

a. Estimation terminated at iteration number 5 because parameter estimates changed by less than ,001.

Pr (FROST = 1) = F ($\beta_0 + \beta$ LIN10)

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	4,413	1	,036
	Block	4,413	1	,036
	Model	4,413	1	,036

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	103,442[a]	,011	,046

a. Estimation terminated at iteration number 7 because parameter estimates changed by less than ,001.

Pr (SUM_WAR = 1) = F ($\beta_0 + \beta$ LIN10_5LAG)

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	8,340	1	,004
	Block	8,340	1	,004
	Model	8,340	1	,004

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	310,790[a]	,021	,038

a. Estimation terminated at iteration number 5 because parameter estimates changed by less than ,001.

Appendix C: VARIABLES IN THE EQUATIONS IN THE LOGIT MODELS

Hantemirov & Shiyatov 2002

Pr (SUM_WAR = 1) = F ($\beta_0 + \beta$ HAN02)

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	HAN02	,342	,140	5,981	1	,014	1,407
	Constant	-1,890	,152	155,258	1	,000	,151

a. Variable(s) entered on step 1: HAN10.

Pr (CROP_F = 1) = F ($\beta_0 + \beta$ HAN02)

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	HAN02	-,626	,251	6,222	1	,013	,535
	Constant	-3,531	,323	119,590	1	,000	,029

a. Variable(s) entered on step 1: HAN02.

Helama et al. 2009

Pr (SUM_ATT = 1) = F ($\beta_0 + \beta$ HEL09)

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	HEL09	,328	,138	5,663	1	,017	1,389
	Constant	-5,897	1,800	10,733	1	,001	,003

a. Variable(s) entered on step 1: HEL09.

Pr (SUM_TUM = 1) = F ($\beta_0 + \beta$ HEL09_1LAG)

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	HEL09_1LAG	,418	,163	6,582	1	,010	1,519
	Constant	-7,528	2,141	12,362	1	,000	,001

a. Variable(s) entered on step 1: HEL09_1LAG.

Pr (SUM_WAR = 1) = F (β_0 + β HEL09_2LAG)

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	HEL09_2LAGS	-,299	,149	4,041	1	,044	,741
	Constant	1,961	1,878	1,091	1	,296	7,106

a. Variable(s) entered on step 1: HEL09_2LAG.

Pr (DISE = 1) = F (β_0 + β HEL09_1LAG)

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	HEL09_1LAG	-,464	,211	4,848	1	,028	,629
	Constant	3,179	2,623	1,470	1	,225	24,031

a. Variable(s) entered on step 1: HEL09_1LAG.

Pr (CROP_F = 1) = F (β_0 + β HEL09_5LAG)

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	HEL09_5LAGS	,584	,267	4,783	1	,029	1,793
	Constant	-10,935	3,572	9,374	1	,002	,000

a. Variable(s) entered on step 1: HEL09_5LAG.

Helama et al. 2010, Reconstruction 1

Pr (SUM_ATT = 1) = F (β_0 + β HEL10_R1)

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	HEL10_R1	,414	,145	8,187	1	,004	1,512
	Constant	-1,554	,139	124,471	1	,000	,211

a. Variable(s) entered on step 1: HEL10_R1.

Pr (SUM_TUM = 1) = F (β_0 + β HEL10_R1_1LAG)

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	HEL10_R1_1LAG	,509	,170	8,946	1	,003	1,664
	Constant	-2,012	,164	151,323	1	,000	,134

a. Variable(s) entered on step 1: HEL10_R1_1LAG.

Pr (DISE = 1) = F (β_0 + β HEL10_R1_1LAG)

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	HEL10_R1_1LAG	-,645	,225	8,195	1	,004	,525
	Constant	-3,076	,284	117,526	1	,000	,046

a. Variable(s) entered on step 1: HEL10_R1_1LAG.

Pr (SUM_TUM = 1) = F (β_0 + β HEL10_R1_5LAG)

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	HEL10_R1_5LAG	,353	,168	4,429	1	,035	1,423
	Constant	-2,015	,164	150,972	1	,000	,133

a. Variable(s) entered on step 1: HEL10_R1_5LAG.

Pr (CROP_F = 1) = F (β_0 + β HEL10_R1_5LAG)

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	HEL10_R1_5LAG	,632	,277	5,222	1	,022	1,881
	Constant	-3,237	,278	135,558	1	,000	,039

a. Variable(s) entered on step 1: HEL10_R1_5LAG.

Helama et al. 2010, Reconstruction 2

Pr (SUM_ATT = 1) = F (β_0 + β HEL10_R2)

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	HEL10_R2	,374	,142	6,925	1	,009	1,454
	Constant	-1,568	,139	127,347	1	,000	,208

a. Variable(s) entered on step 1: HEL10_R2.

Pr (SUM_TUM = 1) = F (β_0 + β HEL10_R2_1LAG)

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	HEL10_R2_1LAG	,468	,168	7,787	1	,005	1,596
	Constant	-2,024	,163	153,751	1	,000	,132

a. Variable(s) entered on step 1: HEL10_R2_1LAG.

Pr (DISE = 1) = F (β_0 + β HEL10_R2_1LAG)

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	HEL10_R2_1LAG	-,556	,219	6,459	1	,011	,573
	Constant	-2,996	,270	123,041	1	,000	,050

a. Variable(s) entered on step 1: HEL10_R2_1LAG.

Pr (CROP_F = 1) = F (β_0 + β HEL10_R2_5LAG)

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	HEL10_R2_5LAG	,615	,273	5,054	1	,025	1,849
	Constant	-3,250	,279	135,998	1	,000	,039

a. Variable(s) entered on step 1: HEL10_R2_5LAG.

Lindholm et al. 2010

Pr (SUM_ATT = 1) = F ($\beta_0 + \beta$ LIN10)

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	LIN10	,636	,178	12,736	1	,000	1,888
	Constant	-9,718	2,284	18,108	1	,000	,000

a. Variable(s) entered on step 1: LIN10.

Pr (FROST = 1) = F ($\beta_0 + \beta$ LIN10)

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	LIN10	-,845	,420	4,048	1	,044	,429
	Constant	6,933	5,095	1,851	1	,174	1025,251

a. Variable(s) entered on step 1: LIN10.

Pr (SUM_WAR = 1) = F ($\beta_0 + \beta$ LIN10_5LAG)

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	LIN10_5LAG	-,560	,200	7,845	1	,005	,571
	Constant	5,129	2,464	4,332	1	,037	168,813

a. Variable(s) entered on step 1: LIN10_5LAG.