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Historical hail cases in Finland: 1776–1910

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Historical hail events were found by searching the archives of the Historical Newspaper Library of Finland. Altogether, 461 hail events came from 119 different newspapers from 1776 to 1910. Without any proper observation network during that era, historical newspapers are the only source of severe-weather events. The motivation for reporting such details was fear of survival over a long harsh winter and the hope of getting regional aid after crop damage. Areal, diurnal, seasonal, and size distributions were constructed from this historical hail dataset and compared to a dataset of severe hail from 1930 to 2006. These two datasets were similar, albeit with small differences. Combining both hail datasets (1776–1910 and 1930–2006) yields nearly 250 years of data, only missing the years 1911–1929. Seventy-six percent of all known hail sizes were severe (≥ 2 cm in diameter). Most hail occurred in the afternoon during June and July over western Finland. Two events are studied in more detail using reanalysis data: the most active hail season of 1896 and an extreme hailstorm of 19 July 1882.

Introduction

Weather events had a large effect on people living in the 18th and 19th centuries. Living could be especially challenging at high latitudes in Finland where winters could be long and harsh. The amount of food produced during the short summer had to be sufficient for the following six or seven months, enabling survival. During an average winter, inland lakes and the Gulf of Bothnia were fully ice-covered for several months. Ice would typically start forming in the last week of November or early December and would melt later in April, with the largest lakes and the northern Gulf of Bothnia remaining ice-covered until late May (Klingbjer and Moberg 2003, Korhonen 2005).

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During the worst years, crops could be badly damaged by hailstorms or completely lost due to cold spells that would shorten a growing season. A storm with a hail cell just a few kilometres wide could easily destroy the total annual income or food source of a whole village, which became a matter of life or death. Also, short and rainy summers or an early frost during July and August could reduce the yield of the harvest. Poor lodgers were especially vulnerable. Starvation and even famine occurred in some locations before the Industrial Revolution strengthened societal resilience during the late 19th century.

Newspapers from the past centuries can reveal amazing stories of severe storms with striking detail. Hailstorms with reported damage provided particularly dramatic stories for the readership. This type of reporting was a common practise in newspapers. If a hailstorm struck and devastated a community, villagers or local spokesmen were often left to appeal for some food or financial relief from the governor, partly explaining why newspapers reported on hail incidents so frequently. Even reports of strong hailstorms around the world were often seen in Finnish newspapers.

Strong storms and storm damage were tightly related to the religion, as wicked weather was often seen as some sort of punishment from the greater force above. Religious terms or expressions like *the coming of Last Judgement Day*, *God's weather*, and *God opened the windows of Heaven* were used among the storyline to emphasize the strength and impact of an individual storm event. Clearly, the fury of Nature was greatly respected, even something to be afraid of. Since those days, there has been a change in attitude of how Finns, especially farmers, understand Nature (Silvasti 2003). The reason for this change is twofold. First, most Finns probably have a better understanding of weather being explained by science rather than by a greater force. Second, the church's pivotal role in the society has decreased during the 20th century.

In the past five years, we gathered more knowledge about hail occurrence in Finland. Tuovinen *et al.* (2009) constructed a climatology of severe hail mostly from newspaper articles (65% of all cases) and other historical archives from 1930 to 2006. We have since continued to grow our climatology annually by collecting reports from the public and social media with the help of a radar-based hail-detection algorithm (Tuovinen *et al.* 2009, Tuovinen and Schultz 2010). These climatologies indicate that, despite Finland's high latitude, hail occurs an average of 43 days a year (based on the 2008–2012 average; Tuovinen *et al.* 2015). Even damaging severe hail (2 cm or larger) occurs an average of 17 days a year, with at least one report of significant hail (5 cm or larger) occurring about once a year (Tuovinen *et al.* 2015). A hail dataset for Finland has not been constructed before the 20th century.

There are some studies describing other historical weather events, hailstorms affecting people's well-being, and climatologies in Finland in the pre-instrument era. Neumann and Lindgrén (1979) studied the Great Famine of 1695–1697 in Finland and emphasized the importance of severe-hail events to the society of that time. They were able to find the first known hail event from 1694, but we decided not to use this event in our dataset because it would have been an isolated case. Jantunen and Ruosteenoja (2000) studied the synoptic-weather situation related to the famine of 1867, estimated to have taken the lives of 8% of the population in Finland during 1868. The famine was caused by a cold spring and an extremely harsh May, followed by a cool and wet summer, which led to widespread crop failure and starvation. Jantunen and Ruosteenoja (2000) also estimated that such a similar May coldness would be quite rare, occurring about once every 500 years. Solantie (2012) focused on a historical overview of population migration ruled by climate conditions between the 17th and 20th centuries. Solantie (2012) pointed out that during the early 1800s the growing population in southern Finland forced people to move northward and eastward to the areas with less productive farmland that was more often affected by crop failures.

Jokinen (2010) studied an extreme summer windstorm of 1890 by reanalysing surface observations. Widespread damage near the south coast of Finland occurred, caused by a deep summertime low-pressure system that has not been observed in Finland since. Rauhala *et al.* (2012) constructed a tornado climatology of Finland from 1796 to 2007, in part by looking through newspaper archives. The historical dataset of tornado reports in Finland (before the 1930s) covered only nine newspapers, which may have contributed to the small number of tornado reports that were found (fewer than 20).

Some historical studies have been performed in other European countries. A few were written in Great Britain (e.g. Webb *et al.* 2001) and Austria (e.g. Pfeifer and Pfeifer 2011, 2013), both having the old newspapers as the main source of hail information. A study of Britain's worst hailstorm in August 1843 by Webb and Elsom (1994) demonstrated two interesting points. First, the London-area newspapers reported very little about central Britain's devastating hailstorm because London was not affected. Second, the amount of insurance claims grew so high, helped by numerous tornadoes, that a whole new insurance company was founded (The General Hail Insurance Company) to cope with the claims. Old economic records are also a great source of old weather data. Brázdil *et al.* (2014) studied old taxation records between the 1650s and 1940s in Moravia in the eastern Czech Republic. Farmers were able to apply for tax alleviation or even rebate when crop damage occurred. Other kinds of scientific approaches have also been used to construct historical hail records. For example, Hohl *et al.* (2002) reconstructed past severe-hail storms in central Switzerland by investigating damage on tree rings.

The purpose of this paper is to describe the construction of a dataset of damaging-hail reports over a 136-year period during 1776–1910 and to compare the results to the more recent dataset during 1930–2006 from Tuovinen *et al.* (2009). Also, two interesting case studies (the dataset's most active hail season and the most damaging hail case) are presented to reveal special characteristics of the synoptic weather patterns around these hail incidents at the northern latitudes. Observations of extreme-weather events from the past provide a basis for further studies. Long time series of severe-weather events allow a study of the effect of climate change on severe-weather events and allow projection of how the behaviour of severe weather changes in the future. Observations like these can also help determine how often certain hail sizes may occur and if some location is more frequently affected. Furthermore, studying these extreme events reveals the synoptic-weather patterns and conditions that cause the most damaging weather events.

The structure of this article is the following. We start with a short description of the study period's historical background, especially how the changing geopolitical landscape affected data collection for this study. After describing the methods leading to the dataset construction and some common characteristics and descriptions of hail events by historical newspapers, we will present hail statistics with a comparison to the previous statistics by Tuovinen *et al.* (2009). Hail damage is also briefly discussed. Finally, we will describe two interesting hail events: the hail season of 1896 and extreme hailstorm in Oulu on 19 July 1882. For these two events, we introduce an eyewitness account, meteorological observations and analyses leading to the cause of occurrence of these events.

Historical background

Before describing the method of obtaining reports, a bit of Finland's history is warranted. Finland was part of Sweden during 1300–1809 and part of the Russian Empire during 1809–1917 before declaring independence in 1917. Under Russian rule, Finland was given the special autonomous status of Grand Principality of Finland, which allowed the use of both Finnish and Swedish languages in the press and among the population. This resolution guaranteed the continuity of an over hundred-year tradition of printing media in Finland where the first newspaper was published in 1771. In the 1860s and 1870s, Finland started to experience industrialization, growing cities, and reduced dependence upon farming. This period also ended the famine era that continued up to 1868.

Finland's national frontier and provinces, as well as religious bishoprics (local administration regions of the Evangelical Lutheran Church), changed many times during the period of our study, and the biggest areal changes occurred over eastern and northern Finland (Fig. 1a–g). In the 17th and 18th centuries, Sweden lost some of eastern Finland to the Russian Empire (Fig. 1a, b and c), before losing the whole territory. After independence 1917, Finland briefly conquered additional areas between World War I and II (Fig. 1e and f), but these areas were returned, leading to the current national frontier after the peace treaty (Fig. 1g). To construct a homogeneous dataset and to make comparison to the Tuovinen *et al.* (2009) dataset easier, only hail incidents from the current national borders are considered. The greatest impact of this choice was upon the southeastern-most province of Viipuri (or Wiipuri) on the Karelian Isthmus (Table 1 and highlighted area A in Fig. 1d), which became Russian territory after World War II. Although this region will not be included in our climatology, damaging-hail events occurred

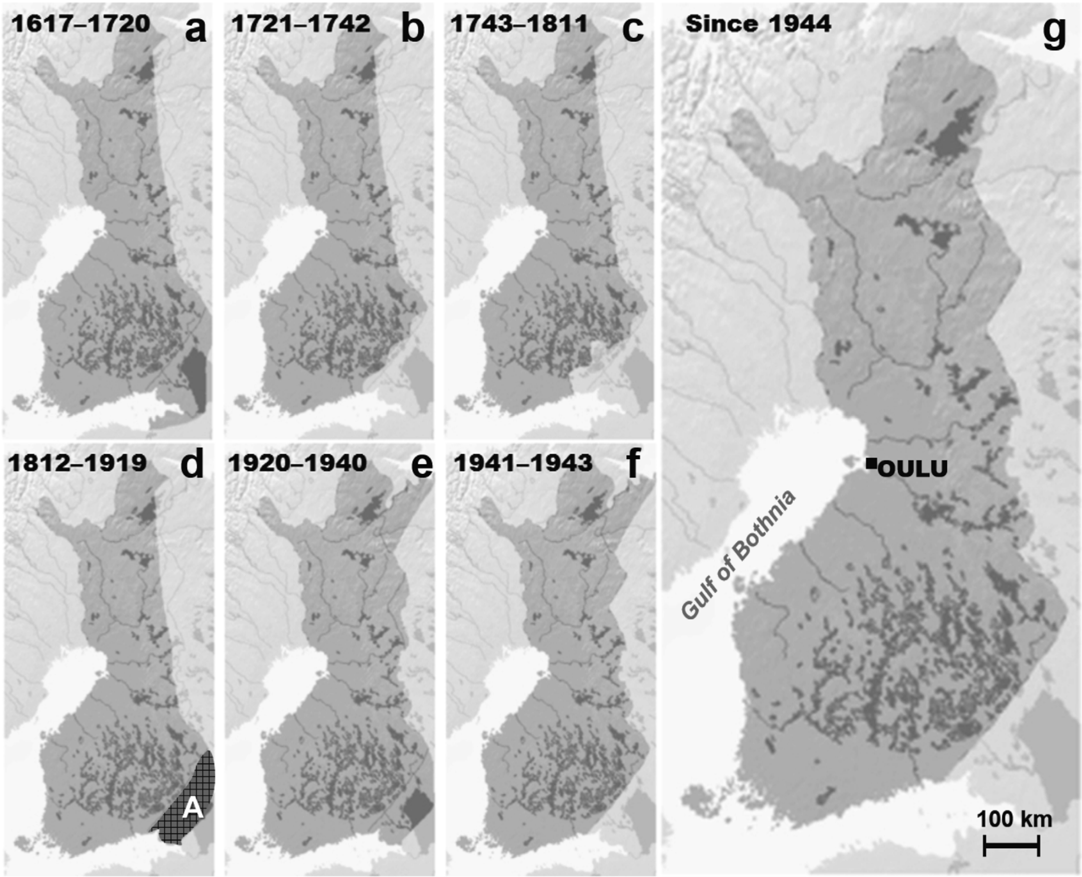

Fig. 1. Map of Finland during different era since 1617. Finland was part of Sweden until 1809 and part of Russian Empire between 1809 and 1917. Finland declared independence in 1917. The national frontier has not changed since 1944.

frequently in this area according to multiple local historical newspapers.

Table 1. Finland's population density (inhabitants km^{-2}) by provinces between the years 1840 and 1900. Location of each province is shown in Fig. 2. Less than 10% of people lived in cities and the vast majority in the countryside.

	1840	1870	1880	1890	1900
Uusimaa province	13.5	15.1	18.2	21.5	26.8
Turku/Pori province	11.2	12.7	14.9	17.1	19.3
Häme province	7.7	10.4	12.3	14.4	16.8
Wiipuri province	7.9	8.9	9.6	11.2	13.4
Mikkeli province	7.8	9.0	9.6	10.5	11.0
Kuopio province	4.7	6.1	7.2	8.1	8.8
Waasa province	5.6	7.8	9.4	10.9	12.0
Oulu province	0.8	1.1	1.3	1.6	1.8
Whole country	4.3	5.3	6.2	7.2	8.2

The density of human observers has a strong influence on the availability of reports of severe weather in the historical record (e.g. Tuovinen *et al.* 2009). The population density of the provinces between 1840 and 1900 was the highest near the south and west coast regions where most of the cities were situated (Table 1 and Fig. 2). In the other regions of vast forests and thousands of lakes (forests and lakes cover almost 85% of the ground area), population density is lower. In particular, the Oulu province, the northernmost region in Finland until 1938 (today, the northernmost province is Lapland), was an almost unpopulated territory (Table 1). In such situations, possible hailstorms would simply be missed or unreported, unless these storms directly struck a city (*see* section "Oulu hail of 19 July 1882"). Since 1900, population has increased by approximately 1 inhabitant km^{-2} in each decade. In 2016, Finland's average population density was 18 inhabitants km^{-2} (http://www.stat.fi/).

Construction of the hail dataset

We used the user-friendly, web-based interface of the National Library's Internet database (http://digi.lib.helsinki.fi) called the Historical Newspaper Library. This dataset holds all newspapers published in Finland since 1771. This public utility is free of charge and available to everybody. Over 300 different newspapers are stored in the Internet database, covering both Finnish- and Swedish-language newspapers. The web-based interface operates with a keyword search, and the completed search highlights parts of each newspaper article where the keyword(s) occurred. This convenience means that there is no need to look for the article containing the keyword amidst the whole newspaper (typically 4–8 pages with small font size). The text is old typeface and differs a lot from the present. The text is read with an optical character recognition (OCR) program, which minimizes misspelling errors in scanned images of printed text. This same technique also recognizes the search words. In the beginning of our study, progress in reading the text was slow as we had to understand the text around our keywords. By the end, our growing experience enabled faster processing of the text.

We made searches using multiple hail-related keywords in Finnish (e.g. *raekuuro*, *raesade*, *rakeita*) and Swedish (e.g. *hagel*, *hagelfall*, *hagelskur*). The search was restricted to months between May and September because damaging hail tends not to occur outside these months (Tuovinen *et al.* 2009). Moreover, we focused our search upon the period between 1 May and 15 October, because there was up to a two-week lag between the hail event and its published news article. Sometimes pinpointing the actual day of occurrence was not straightforward. Hail-event days were mostly mentioned as days of the week, not as the date. Old calendars listing religious holidays helped to determine the date of occurrence from the article.

During our search in autumn 2010 and spring 2011, the earliest available newspaper was from the 1830s. During summers 2011–2014, the online newspaper archive was expanded to include older newspapers, allowing our study to start in 1771. As of the completion of the search part of this research project (15 October 2016), the dataset ended in 1910 because copyright law restricts the online use of newer material. Our goal in the future is to update the dataset as new material comes available and make cases public for additional research opportunities. In February 2017, as a part of Finland's hundred-year independence celebration, the National Library made the majority of 1911–1920 newspapers available to be searched. We decided not to add any new material at this point.

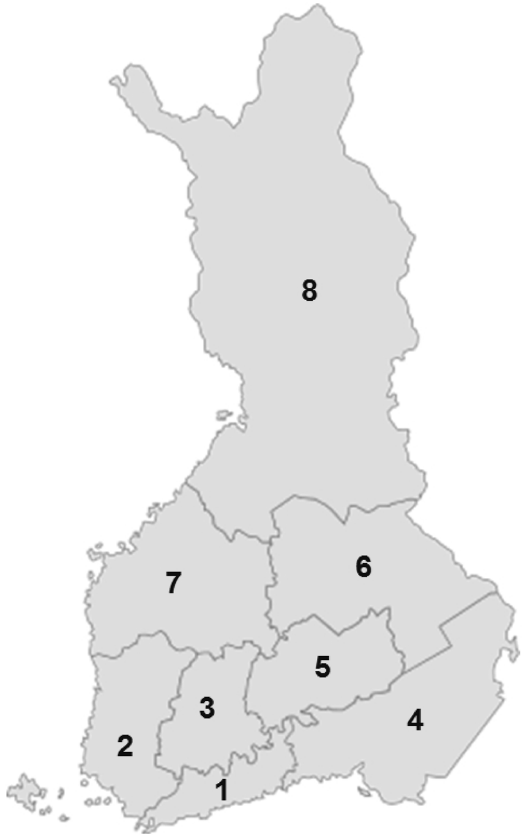

Fig. 2. Finland's eight provinces in the 19th century: (1) Uusimaa, (2) Turku and Pori, (3) Häme, (4) Wiipuri, (5) Mikkeli, (6) Kuopio, (7) Waasa, and (8) Oulu.

The period from 1911 to 1929 was particularly harsh from Finland's perspective, because of the First World War (1914–1918) and the Finnish Civil War (1918). We suspect that this period would not add many new reports to the dataset as newspapers focused on reporting about more important issues. Such declines in reporting of weather events during periods of societal unrest have been documented by other studies of historical weather archives (e.g. Antonescu *et al.* 2016). In total, 119 different newspapers (including four digitized Swedish newspapers that were used to collect severe-weather reports for the case study in the section "Oulu hailstorm of 19 July 1882"; http://magasin.kb.se/searchinterface/browse_title.jsp) with 461 news articles contained reports of hail. For newspapers with dates, issue numbers, and the number of cases *see* Appendix.

The oldest reference to a damaging hail fall that we found — and the first case of the dataset — occurred in summer 1776 in the Eura, Vesilahti, and Pori areas. This report comes from a *Borgå Tidning* article from June 1838 discussing remarkable historical natural phenomena in Finland during 1770–1820. Although the newspaper archive starts in 1771, no articles about hail were found in the early years of our searches. Occasionally, the newspaper articles would include stories about devastating hailstorms across Europe, Asia and North America, as well. This fact highlighted the high standards of information flow among Finnish newspapers, as well as Finland's interest in the surrounding world. These cases from abroad were not used in this study.

Articles about hailstorms typically possessed certain characteristics. First, the intensity of the hailstorm was described by comparing the hailstone size to some known object (most commonly different bird eggs, berries, nuts, potatoes, peas, rocks, thumbs, or fingertips). When quantitative size information was provided, measurements were given in inches (1 inch = 2.54 cm). Second, the weight of hailstones was quite often mentioned (9% of cases), measured in grams or bullets (1 bullet = 13.3 g). As a lot of trading depended on weighing of goods, the scale was a common tool of households and businesses. The most typical hail weight was 26–40 g, but three cases reached 100–145 g. Weight, however, is not a good indicator of hail size alone because the amount of liquid water or air bubbles trapped inside varies substantially, affecting the hailstone's weight. Third, a common characteristic mentioned in the article was how long the hail stayed on the ground before melting (e.g. "... *hail was still found in the shade on the following morning*"; "... *five hours after the hail fall, the hail was still covering the ground*"). Fourth, the fear and respect for Nature's power is emphasized in many articles and eyewitness stories, as the case study in section "Oulu hail of 19 July 1882" of this article demonstrates.

All hail reports that were found in the archives and any additional information were transferred to a Microsoft Excel spreadsheet. Reports were constructed in chronological order with the date, time of occurrence, size, location, newspaper source, and any additional information (e.g. damage). Each reported location was searched via multiple map tools, and the coordinates of the locations were placed on the map. As many small villages and towns no longer exist, finding a specific location by name ended up being a difficult task and took a great deal of time. If the exact location or part of village where the hail report occurred was unknown, we placed the case near the local church. Churches are usually the oldest and most central buildings in the community. This procedure was used throughout the dataset, minimizing the location bias.

We likely missed a number of potential hail articles during the searches through the archive, just because of the vast number of newspapers to search. All newspapers did not have 100% availability each year due to some small data gaps. Also, hailstorms without any damage (regardless of the size) were likely unreported because there was no need for economic relief. Newspapers themselves were likely location-oriented and were keen to report weather events near their own area. Areas without such newspapers (easternmost Finland and Lapland until the early 1900s), along with areas of low population density, definitely suffered from reporting biases. In the late 1700s and early 1800s, newspapers were printed three or four times a week. In the late 1800s and early 1900s, many newspapers started appearing five or six times a week, and some even appeared daily. The number of newspapers gradually increased throughout the study period and covered a larger area of the country (Fig. 3). That the latter part of study period had many times more newspapers available likely explains the increasing trend of reported hail cases since the 1880s (Fig. 3).

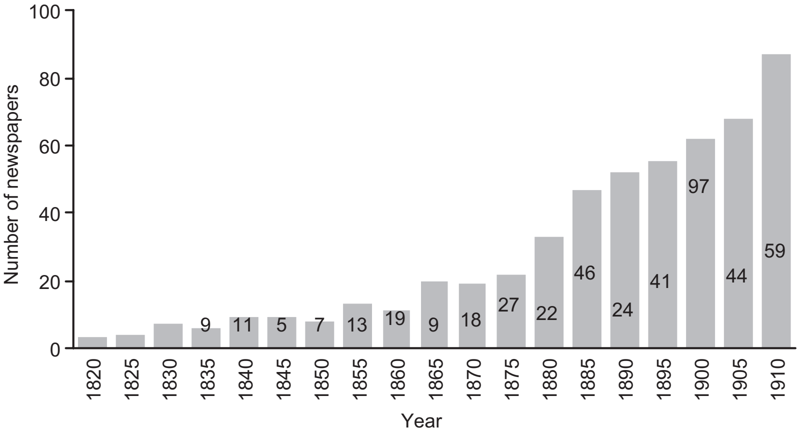

Fig. 3. Number of available newspapers in period of every five years (grey bars). Number on bars indicates the five year cumulative amount of hail cases (e.g. value of 27 indicates cases between 1871 and 1875). Hail cases before the first cumulative period of 1831–1835 were too sporadic to overlay.

Hail statistics

We found 461 different hail cases, and 80% of them caused some sort of damage. The hail size varied from 1 cm to 7.5 cm in diameter. The cases were spread from the south coast to southern Lapland, generally in the agriculturally intensive areas and closer to population centres. If hail size was compared to an object rather than reported numerically, we assign an approximate size to construct the statistics (e.g. the thrush egg was placed in the 2–3 cm category throughout the dataset). News about hail occurrence was usually published within ten days from the event, but, during the early part of the dataset, newspaper publishing took much longer (partly because some newspapers were not issued daily, Fig. 3). Occasionally there were also nomadic reporters that visited remote villages a few times during each warm season (between May and September) asking about the crop or health situation and collecting possible weather-related phenomena for the newspaper. Not all cases have the time of occurrence or size information. Results are compared to the more recent dataset (1930–2006) of Tuovinen *et al.* (2009). Table 2 summarizes both statistics.

As expected, the year-to-year variation was considerable. Most years had between two and five reported cases of hail, and only one year after 1833 (i.e. 1845) was without a single event (Fig. 4). The number of hail days started increasing in the 1870s and 1880s. The summers of the late 1890s had a large number of hail reports, with summer 1896 having the most: 40 hail cases during 18 days.

Table 2. Summary of results from two hail datasets (1776–1910 and 1930–2006) compared.

	1776–1910	1930–2006
Annual	• increase through dataset due to growing number of available newspapers	• increase due to multiple sources at the end of dataset
	• peak year 1896	• peak year 1957
Monthly	• June (32%) and July (39%) more evenly distributed months for severe hail	• July clearly most active (66%) severe-hail month
	• 93.5% of severe hail in June–August	• 94% of severe hail in June–August
Diurnal	• afternoon and early evening (14:00–20:00 LST) of 71% severe hail	• afternoon and early evening (14:00–20:00 LST) of 74% severe hail
Size	• 76% severe hail, 24% non-severe	• all cases severe
	• 13% of significant size	• 20% of significant size
	• 2% of 7 cm or larger	• 6% of 7 cm or larger
Areas	• majority of cases in agriculture intensive western and southwestern Finland area	• mostly in west central Finland, increase of cases in eastern and northern parts

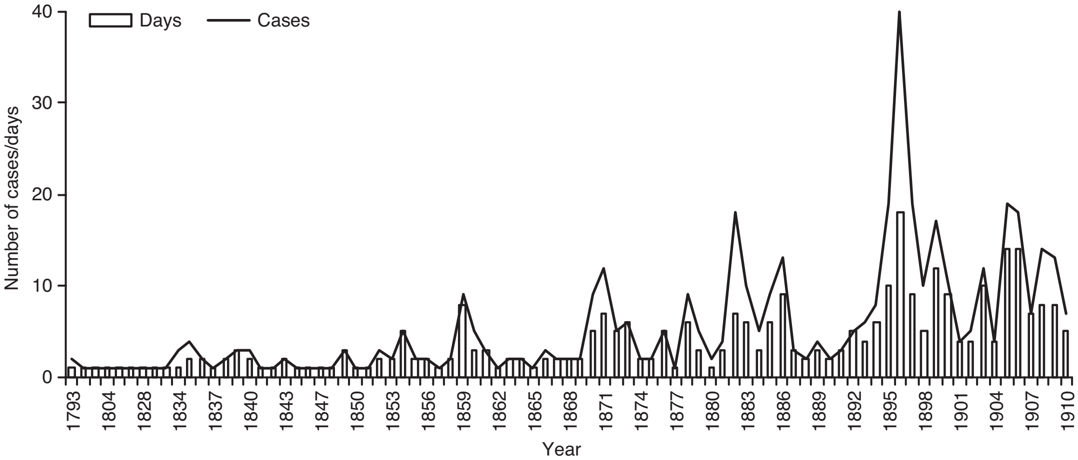

Fig. 4. Number of cases (solid line) and hail days (bars) per each year between 1776 and 1910.

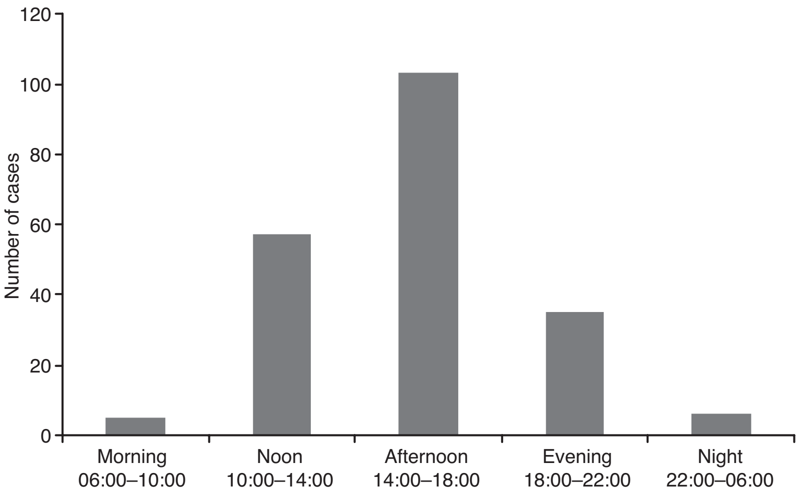

Fig. 5. Diurnal distribution with 206 cases (*y*-axis) divided into five time bins (*x*-axis; 06:00–10:00 or morning, 10:00–14:00 or noon, 14:00–18:00 or afternoon, 18:00–22:00 or evening, and 22:00–06:00 or night, all LST).

The time of hail occurrence was usually of secondary importance in the news article or it was expressed generally (e.g. morning, afternoon) in 44.7% or 206 cases. We tried to avoid applying too strict a timing criterion in order to keep as many cases in the dataset as possible. Thus, we chose five time bins (06:00–10:00 local summer time (LST) or morning, 10:00–14:00 LST or noon, 14:00–18:00 LST or afternoon, 18:00–22:00 LST or evening, and 22:00–06:00 LST or night). The time of occurrence was not stated in 55.3% or 255 cases. All in all 77.7% of cases occurred during noon (27.7%) or afternoon (50%) whereas evening had 17% of cases, and the night and morning had 5.3% (Fig. 5). Cases with reported times of occurrences were mostly the size of severe hail with diameters of 2 cm or greater (85%). In particular, 71% of severe-hail cases occurred during 14:00–20:00 LST. By comparison, Tuovinen *et al.* (2009) found that 74% of 1930–2006 severe-hail cases occurred during 14:00–20:00 LST (Table 2).

The monthly distribution includes all 461 cases and showed that over 92% of the cases occurred during summer (June–August), with July having almost 40% of cases (Fig. 6). About 34% cases occurred during June and 19% in August. The peak two-week periods occurred during 16–30 June and 16–31 July (99 and 102 cases), which might be because of the societal importance of Midsummer (the summer solstice holiday) and the peak of the crop's growth

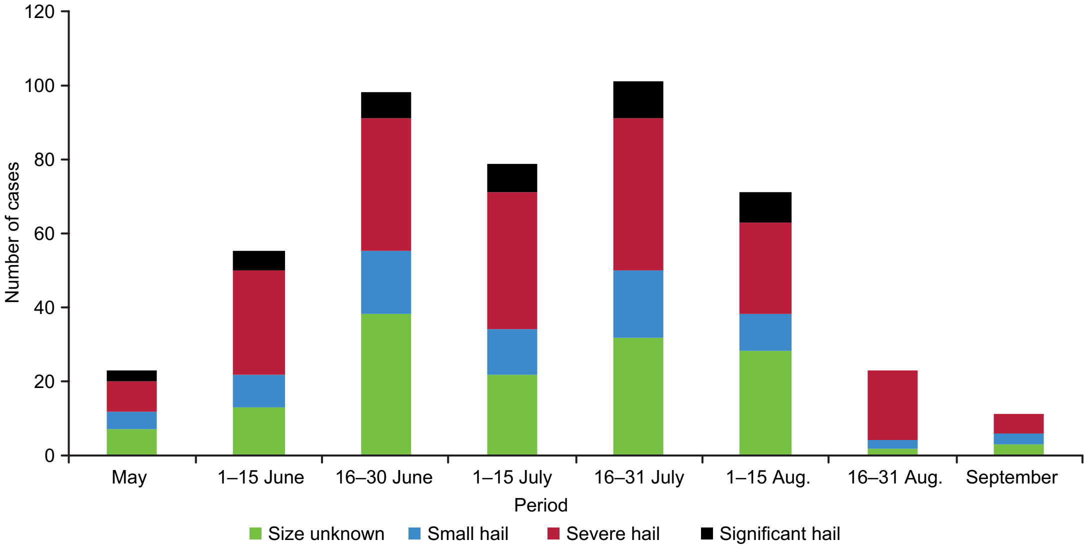

Fig. 6. Monthly distribution of hail. In total there were 145 cases of unknown hail size, 76 cases of small hail, 199 cases of severe-hail size, and 41 cases of significant-hail size.

period. Late July was also the most active among the severe- and significant-hail cases.

The collected dataset includes 316 cases with known hail-size information, of which 240 cases or 75.9% are severe hail (2 cm and larger) and 76 cases or 24.1% are small hail (less than 2 cm). Overall, 41 cases or 13.0% are of significant-hail size (5 cm and larger), and five cases reached at least 7 cm. The hail size was indeterminate or too vague in 31.4% of the cases (Fig. 6). Interestingly, the dataset of Tuovinen *et al.* (2009) had exactly 240 severe-hail cases from 1930–2006.

For severe hail, 93.5% occurred during summer (4% in May, 32.3% in June, 39% in July, 22.2% in August, and 2.5% in September) whereas the major part of significant-hail cases took place 16 June to 15 August (33 cases or 80.5%). The dataset of Tuovinen *et al.* (2009) had exactly the same percentage of cases occurring between June and August (94%), suggesting that the historical dataset contains reliable and useful information. One clear difference between the monthly distributions was July's smaller portion compared to the Tuovinen *et al.* (2009) 1930–2006 dataset (39% versus 66%). Similarly, almost all significant-hail cases occurred between late June and early August with 43 cases or 93.5%.

Areal distribution

We also compared areal differences of severe and significant hail of these two datasets. Most of the 1930–2006 severe-hail reports were located in western Finland, which is also the case with the historical dataset. As western Finland was more suitable for farming from the early days compared to eastern and northern Finland, the majority of people and newspapers settled there (Solantie 2012). As agriculture was the most important livelihood for so many, the number of fields vulnerable for hailstorm damage was also at its highest. Even small hail (< 2 cm in diameter) got reported as usually the duration of hail fall is more critical for crop damage than the size (Tuovinen and Rauhala 2010). In fact, easternmost Finland and Lapland were nearly unpopulated back in the 18th and 19th centuries, and cities like Joensuu and Lieksa in eastern Finland (area number 6 in Fig. 2) were founded later, in 1848 and 1936, respectively. The geographical centre point of severe-hail cases has moved somewhat northeast in the more recent dataset as a result of newer cities and towns being founded (Fig. 7). In the historical dataset, there was indeed a huge under-reporting towards eastern and northern Finland simply because only a few towns and cities existed at that time.

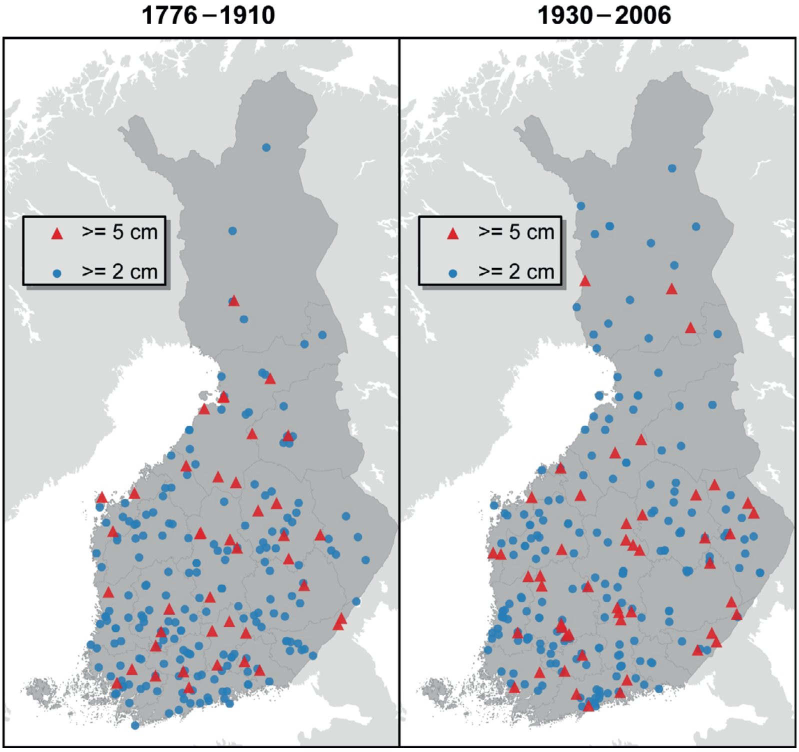

Fig. 7. All known hail cases 1776–1910 (map on the left) and severe-hail cases 1930–2006 (map on the right) placed on the map. Blue dots indicate severe-hail cases and red triangles significant-severe hail cases.

Even though the population in the middle 19th century was much smaller than in the middle 20th century (1840 with 1.5 million inhabitants versus 1940 with 3.7 million inhabitants), the vast majority of people (94.1%) lived in small rural communities (Suomenmaan virallinen tilasto 1896–1900). This changed drastically during the 20th century as people started moving into growing cities (in 1900 12.6%, in 1950 27.5% and in 1970 63% of the people were living in cities). This population bias should have had a big effect on the more recent dataset, but that effect is not clear in Fig. 7. One explanation for this statistical oddity is because rural areas are not sparsely populated year around. Even recently, many urban residents spend their summer holidays (usually starting just before Midsummer and lasting five to six weeks) at summer cottages in the countryside. In 2015, there were 501 600 summer cottages in Finland spread all across the country (http://www.stat.fi/), explaining why the population bias gets smaller from late June to early August (Tuovinen *et al.* 2009).

The monthly distribution of severe hail varied more clearly between datasets (Table 2). As previously mentioned, under-reporting of severe-hail cases before Midsummer may be one explanation for the difference. Clearly, the number of cases has increased over eastern and northern Finland during the time period of the Tuovinen *et al.* (2009) dataset compared to the historical dataset. The northernmost province of Finland has quadruple the number of cases compared to the historical dataset, a reminder that, even sparsely populated area under suitable atmospheric conditions can sometimes be a source of numerous hail reports. In 2016, southern Lapland was the hotspot for severe hail, with more cases than anywhere else in Finland (http://ilmatieteenlaitos.fi/tiedote/249959142).

Hail damage

In 80% of all cases in the dataset, some sort of damage occurred. The most typical damage was broken windows (224 cases or 49%) and crops being destroyed (188 cases or 41%), and both damage types occurred simultaneously in many cases. There were 48 cases where several hun-

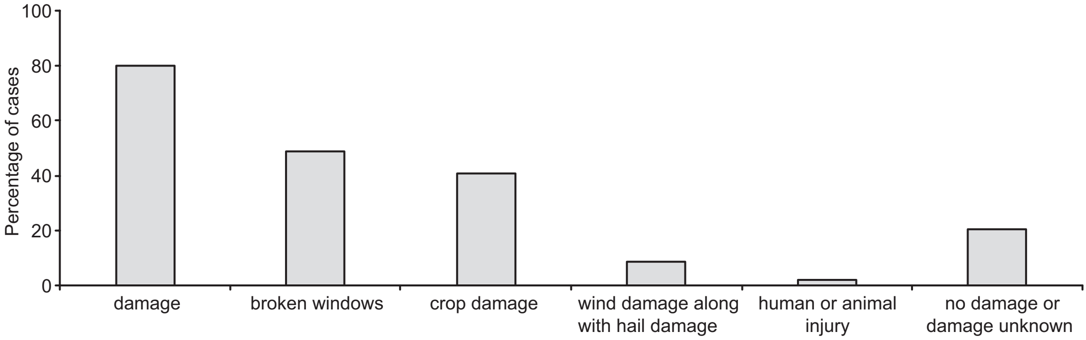

Fig. 8. All hail cases with damage data: 369 cases with damage (224 cases of broken windows, 188 cases of crop damage, and nine cases with human or animal injuries). Additionally 41 cases had wind damage along with hail and in 92 cases there was no damage or damage was unknown.

dred broken windows were reported. Injuries for humans or domestic animals were described in only nine cases (2%), being mostly bruises and bleeding cuts (Fig. 8). Damage was not reported, was unknown, or was not caused in 20% of the cases. Additionally, 41 cases (11%) mentioned wind damage to trees, houses and roofs, indicating the possibility of microbursts or tornadoes.

There has been a change in the types of hail damage over the past centuries. According to Tuovinen and Rauhala (2010), damage to the sheet metal of automobiles and other property is currently much more typical than damage to crops or windows in buildings. Also, fewer severe-hail cases are causing damage these days compared to the historical period. This change can be easily explained by three main reasons. First, even though Finland is still the northernmost agriculture country in the world, the importance of crops being the main source of livelihood has decreased drastically since the Industrial Revolution. Second, older houses that had thatched roofs and thin single-layered glass windows were more likely to be damaged than modern houses with harder shingles and thicker multi-layered glass. Our statistics indicate that in 36% of cases a hail size of less than 3 cm was enough to break windows. Thicker glass today can withstand an impact from hailstones up to 4–5 cm in diameter (Tuovinen and Rauhala 2010). Finally, with fewer people working outside during the day and with a greater number of sturdy buildings for people to shelter during storms now, human injuries from hail have become more rare. Animals, however, are still vulnerable to hailstorms.

Hail season 1896

The hail season of 1896 was the most active season of our dataset: 40 hail reports during 18 days. These numbers stand out from rest of the dataset with more than twice the number of cases and 50% more hail days than the second busiest hail year. The significance of 1896's hail statistics is most impressive when it is realized that 1896 was the most active hail season before the 21st century in the statistics. In terms of the number of severe-hail days, 1896 beats 2015 (http://ilmatieteenlaitos.fi/tiedote/106721524), despite 2015 having the advantage of radar-based hail-algorithms, e-mail surveys, hail-reporting forms, social media, mobile phones, cameras, etc. (Table 3). Additionally, the 1896 season had 16 severe-hail cases and eight severe-hail days. In this section, we focus on June 1896 or, more specifically, the time period between 5 June and 3 July. During this period, 75% of these 40 hail reports and 78% of these 18 hail days occurred.

Summer 1896 was warm throughout Finland, with the highest measured mean monthly temperatures reaching nearly 20 °C. For exam-

Table 3. Statistics of hail seasons 1896, 1957 and 2015.

	Severe-hail cases	Severe-hail days	Hail cases
1896	16	8	40
1957	23	8	no data
2015	12	5	305

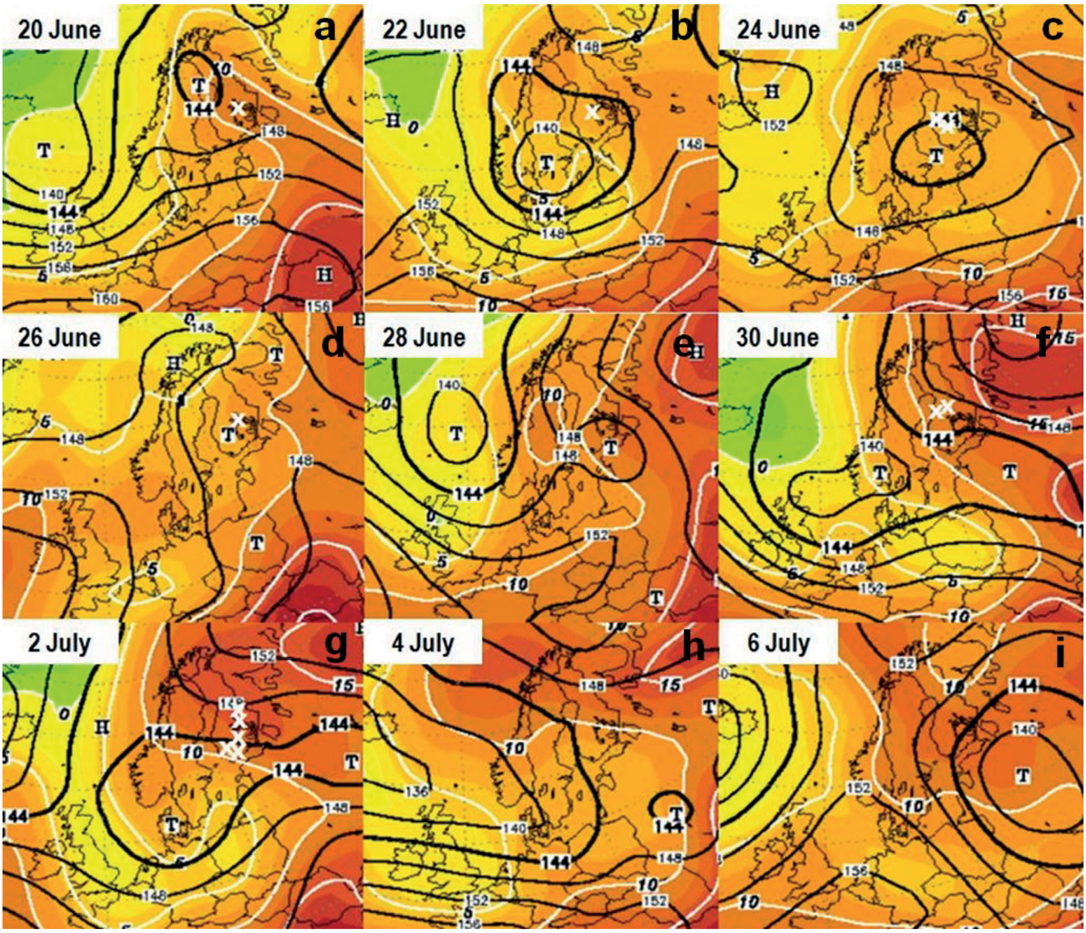

Fig. 9. The 850-hPa geopotential height (black lines, contour difference 40 gpdm) and temperature (colour shaded) between 20 June and 6 July 1896 over north central Europe (each map at 12:00 UTC). Time runs from left to right and top to bottom. Hail cases have been indicated with white 'x' on each day of occurrence. Data from the 20th Century Reanalysis, obtained from the archive of wetter3 (www.wetter3.de).

ple, Oulu reported the warmest month during this period of 19.6 °C (Suomenmaan virallinen tilasto 1896–1900). This monthly mean temperature was 2–3 °C above long-time average, even if compared to latest (1981–2010) climatological statistics (Pirinen *et al.* 2012). The majority of hail cases (21 out of 40 cases) occurred close to Midsummer in June (20 June to 3 July) when a vast and slow-moving low-pressure system arrived from the Norwegian Sea (Fig. 9a–d). This low-pressure system affected the synoptic weather pattern over Finland roughly between 20 June and 3 July and led to numerous hail events (white 'x' symbols in Fig. 9). During the initial presence of the low-pressure system, the hail size was not particularly large, ranging mostly from 1.0 to 2.5 cm. During late June, however, substantially warmer air flowed from the southeast to Finland, resulting more severe-hail events on 2 and 3 July, with an observed hail size of 5–7 cm (Fig. 9e–g). After the low-pressure system exited Finland on 5–6 July, hail events became more infrequent (Fig. 9h–i).

Interestingly, the more recent dataset of 1930–2006 also included one summer (1957) that clearly exceeded other years (Tuovinen *et al.* 2009: fig. 1) and therefore was similar to summer 1896. July 1957 had a large number of events with larger hail sizes, resulting in seven significant-hail reports, a value that was not exceeded until 2010. We next examine whether June 1896 and July 1957 had similar synoptic weather patterns. Tuovinen *et al.* (2009) stated that July 1957's synoptic-weather pattern was favourable for hailstorms as a low-pressure center was situated over southern Norway for a long period of time (roughly between 15 and 30 July), allowing persistent warm and moist southerly airflow (July 1957 was 1.0–2.5 °C warmer than the long-time average; *Meteorological Yearbook of Finland 1955–1958*).

Oulu hailstorm of 19 July 1882

The Oulu hailstorm of 19 July 1882 is considered to be the most impressive and damaging hailstorm in Finland. Compared to both the historical and the Tuovinen *et al.* (2009) datasets, no similar event could be found occurring in Oulu. In 1882, meteorological observations within the Finnish Meteorological Institute's historical observations archive were made in 20 different stations that were mostly located in the southern and central Finland. We also used the available meteorological observations (e.g. temperature, wind, pressure) from Hailuoto Marjaniemi, Oulu city center and Kokkola to highlight conditions prior to and around the hailstorm. Weather parameters were typically measured three times a day (07:00, 14:00 and 21:00 LST) and precipitation once a day.

To explore the large-scale meteorological conditions of the Oulu hailstorm, we use the 20th Century Reanalysis (Compo *et al.* 2011). This reanalysis dataset is the only source that goes back as far as the 18th century and has been previously used by researchers studying meteorological history and severe-weather events from the past. Data are available every 6-h and at 2° horizontal grid spacing from 24 pressure levels. Compo *et al*. (2011) emphasizes that the best-quality reanalysis comes from the areas where sea-level pressure observations were made frequently (North America and Europe), especially in the late 19th century.

The hailstorm occurred in the city of Oulu on early Wednesday afternoon 19 July 1882. At that time, Oulu was a rather small city with fewer than 10,000 inhabitants (there were about 2.2 million people living in Finland; Suomenmaan virallinen tilasto 1881–1885). The following eyewitness description below was published on 31 July 1882 in *Sanomia Turusta*, but the event was widely discussed in many national and local newspapers throughout July and August 1882:

"Last Wednesday started out with beautiful and warm weather. In the early mid-day, a tiny dark cloud appeared to the northern sky, and grew bigger. Around noon, it turned into a thunderstorm, with black clouds sending heavy rain from high above. After a while, it cleared but the heat did not go away, and the air didn't feel fresh either, as is typical after rain. An hour and a half after that heavy rain, around 13:30 LST, the sky started to darken, twice as dark as it was earlier. The ground and the sky turned dark and thunder started to rumble with such force that many feared that doomsday would arrive. The storm pounded rain and hail, turning city streets into streams. That kind of hail fall has never been felt here before. All the windows on the windward side were broken into thousands of pieces because of the wind and the egg-sized hail. The largest hailstones were 3 inches wide. Inside the old Pharmacy Store, a few hailstones weighed as much as a bullet (13.3 g), but some hailstones were as heavy as seven bullets (93 g). The barometer decreased 20 mm within a matter of minutes, a rare event of nature in a scientific light. The scene on the streets was unreal; hail and glass was everywhere. On the subsequent days, citizens of Oulu cleaned up after the damage and filled the broken windows with anything suitable, if glass was not available. No less than 41 000 windows were broken, hundreds of felt-covered roofs were filled with holes, and the interiors of many rooms were destroyed by heavy rain."

Synoptic weather setup and pre-storm environment

The coast of the Gulf of Bothnia (Fig. 1) became mostly free from snow and ice several weeks earlier than average (around 20–25 April, compared to long-time average of 5–10 May; Jouni Vainio 2017, personal conversation) as spring started early and was followed by a warm summer (Suomenmaan virallinen tilasto 1881–1885). These higher-than-average temperatures,

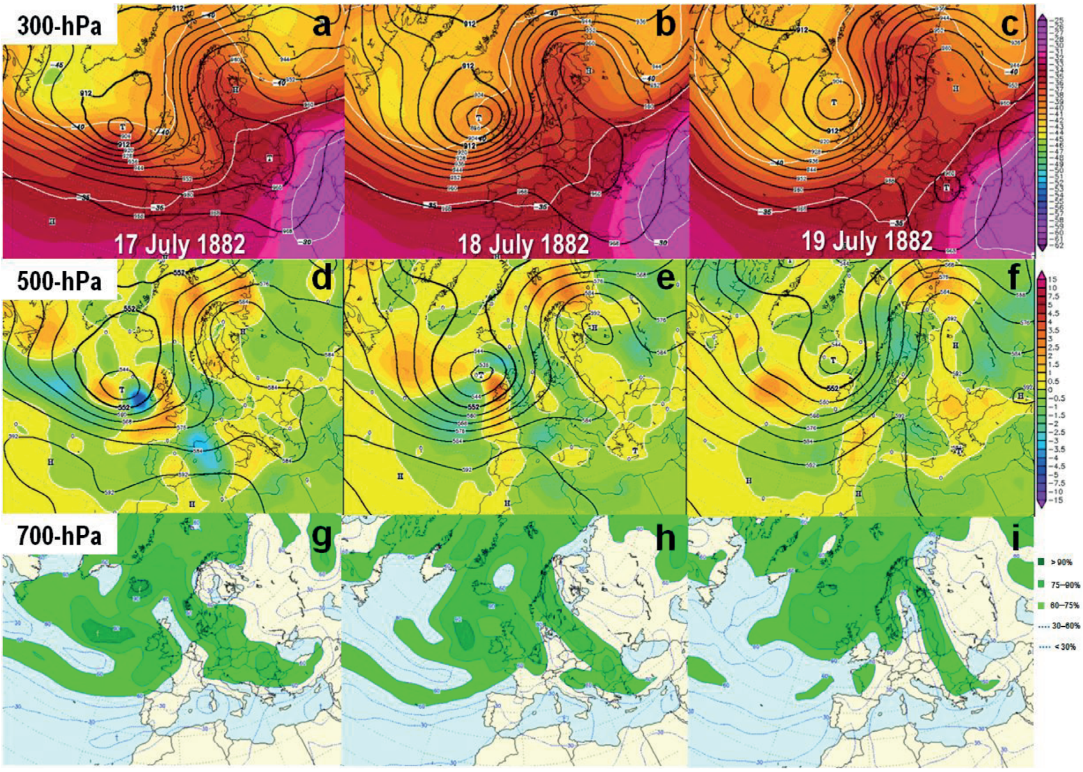

Fig. 10. The middle- and upper-level fields of 12:00 UTC 17 July, 18 July, and 19 July 1882. Time runs from left to right and data includes. (**a**–**c**) 300-hPa geopotential height (black lines, contour difference 80 gpdm) and temperature (colour shaded); (**d**–**f**) 500-hPa geopotential height (black lines, contour difference 80 gpdm) and thickness advection between 500-hPa and 1000-hPa layers (colour shaded); and (**g**–**i**) 700-hPa relative humidity (values < 30%, and 30%–60% blue thin line; whereas values of 60%–75%, 75%–90%, and 90% colour shaded in green). Data from the 20th Century Reanalysis, obtained from the archive of wetter3 (www.wetter3.de).

combined with pulses of moist southerly flow, are suitable for strong hailstorms. Two rounds of severe weather with significant hail were experienced in Oulu on 19 July and 1 August 1882. The latter case caused some damage mainly south of Oulu, in the Siikajoki area, with a maximum observed hail size of 6 cm. However, we focus on the 19 July case that was in every way more significant.

The synoptic weather pattern leading to the event day is presented in Figs. 10 and 11. On 17 July, a strong high pressure settled in to the east of Finland, bringing hot and dry air mass from the southeast (850-hPa temperature in the Baltic States reached 20 °C; Fig. 10g–h, and Fig. 11a–b). This high pressure also reached middle and upper levels of the atmosphere yielding rather weak winds and positive thickness advection or thermal advection (thickness height increase) over Finland. The air column's increased thickness (Fig. 10d–e) is a sign of warm-air advection, also evident from Fig. 11. On 18 July, the strong high pressure moved slightly eastward giving way to a westward approaching upper-level trough that was under increasing upper-level flow regime (geopotential gradient becoming tighter over southern Scandinavia with increasing wind speeds; Fig. 10a and c). Eventually on 19 July, the 300-hPa flow over Finland has increased significantly, as well as the 700-hPa relative humidity (Fig. 10c and i). Noteworthy is also the negative thickness advection (thermal advection) between 500-hPa and 1000-hPa layers over Scandinavia (thickness height decrease), a factor that is related to cold-air advection and amplification

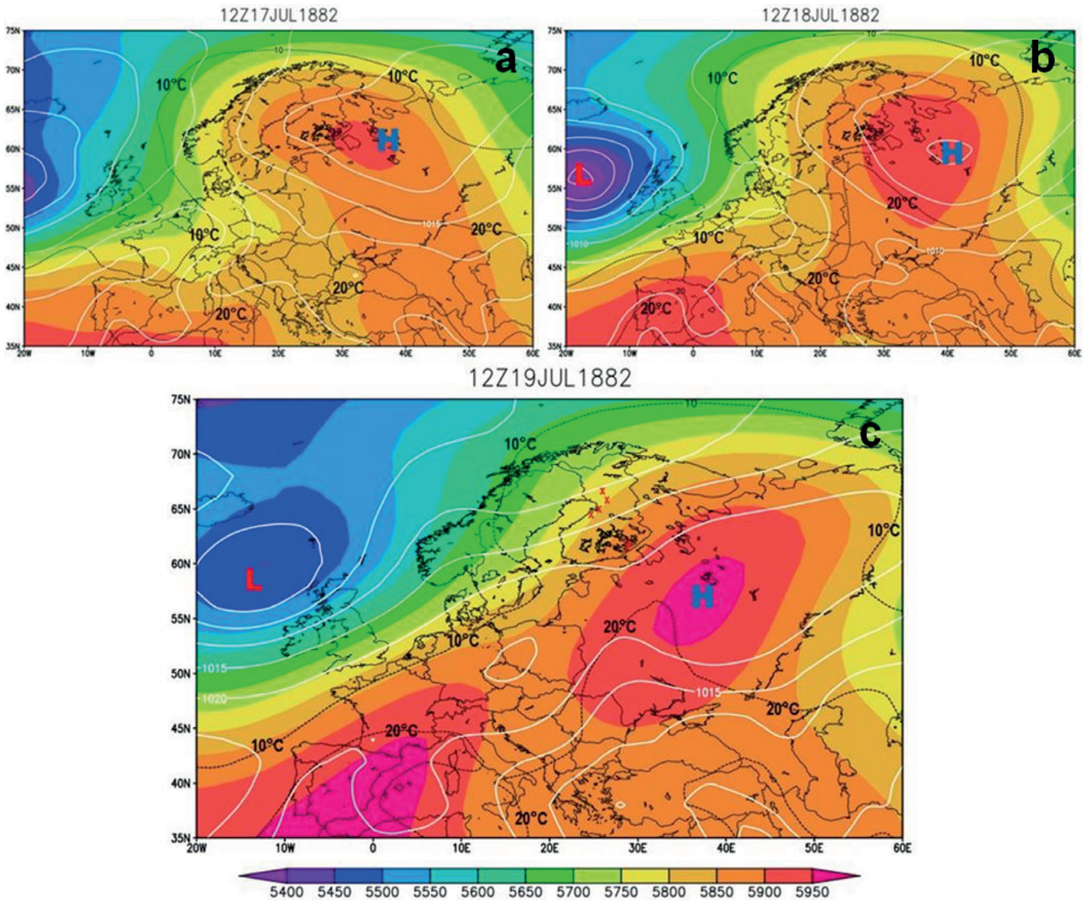

Fig. 11. The synoptic situation between 12:00 UTC 17 July 1882 and 12:00 UTC 19 July 1882 in northern Europe. The 500-hPa geopotential height is presented with different colors and surface pressure with isobars (white contours, contour interval 5 hPa). Thin black line indicates the 850-hPa temperature (°C). Hail observations of 19 July 1882 are also present in the last image (red x's). Data from the 20th Century Reanalysis.

of a trough (Fig. 10f). Cold-air advection situated downwind from a region of maximum vorticity (around the North Sea on 19 July) where typically positive-vorticity advection (PVA) and warm-air advection is encountered, strongly suggest a possibility of shortwave trough. Warm-air advection ahead of the approaching trough, increasing upper-level winds and the presence of positive-vorticity advection (PVA) are tightly linked to large-scale forcing for ascent, as the omega equation demonstrates (Holton 1992).

The presence of the trough was most prominently evident at the 850-hPa geopotential height field (*see* Fig. 12) but also higher in the atmosphere at the 500-hPa and 300-hPa levels (Fig. 10a–b and d–e). All the evidence gathered from severe-weather observations and reanalysis data suggests that a broad upper-level trough played a major part on severe-weather situation over parts of Europe between 17 and 19 July 1882. The severe-weather observations from western and northern Europe reveals the slow progress of 500-hPa trough axis towards north-east (Fig. 13 and Table 4). At first, the severe-weather type in central Europe was mostly related to heavy rain or wind storm events under a broad upper-level trough. As time progressed, more severe convective storms associated with severe hail occurred in Sweden and Finland on the leading edge of 500-hPa trough axis (cases 10–15 in Fig. 13 and Table 4). This change in observed severe-weather type was probably

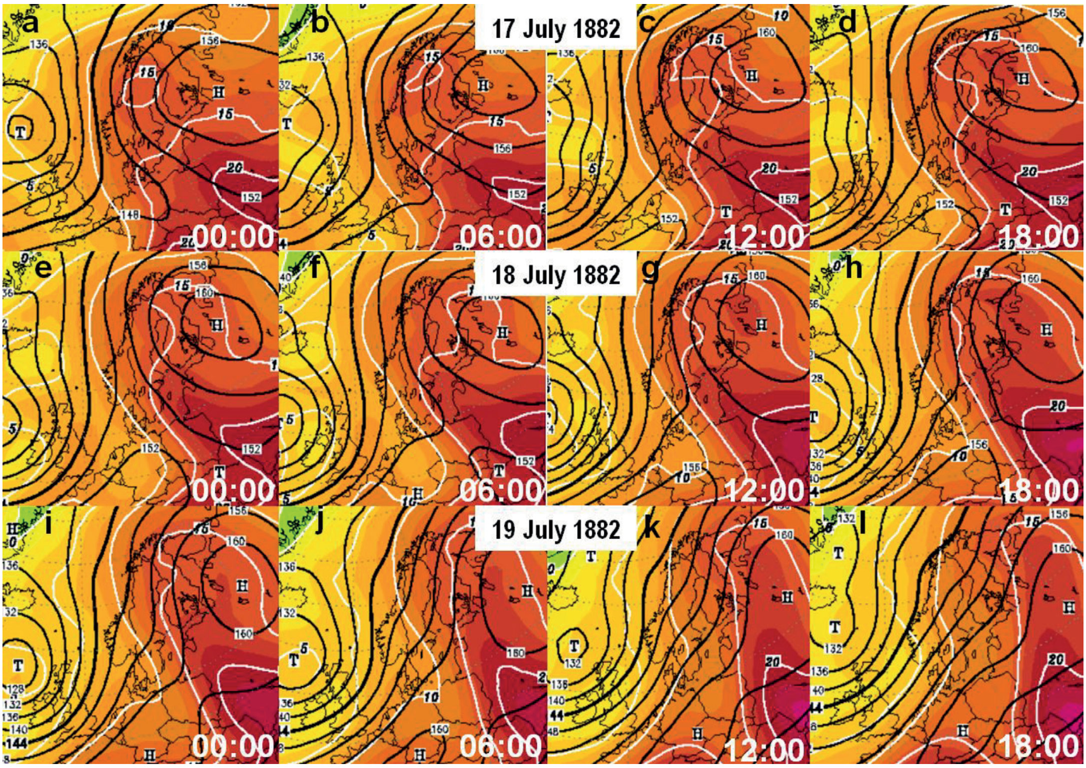

Fig. 12. The 850-hPa geopotential height (black lines, contour difference 40 gpdm) and temperature (colour shaded) showing the progress of trough between 17 and 19 July 1882. All panels show time in UTC in white. Data from the 20th Century Reanalysis, obtained from the archive of wetter3 (www.wetter3.de).

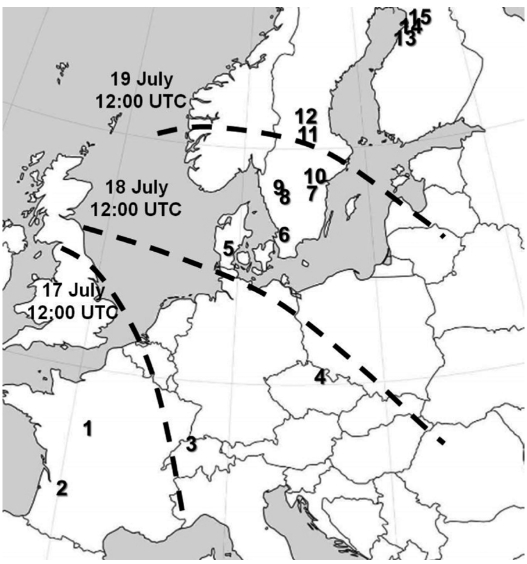

Fig. 13. Severe-weather observations across Europe between 17 and 19 July 1882. Each numbered case has location, date, possible time of occurrence, and type of severe weather indicated. Dashed line shows the location of 500-hPa trough axis on each day at 12:00 UTC.

due to development of the embedded shortwave trough that enhanced deep-moist convection.

The analysis suggests that the 500-hPa trough axis extended from the British Isles towards the Alps at 12:00 UTC 17 July, leading to reports of flash flooding and wind damage from France, Switzerland and Czech Republic (cases 1–4 in Fig. 13 and Table 4). At 850 hPa, however, the trough axis was situated farther north, over the North Sea and Denmark between 00:00 UTC and 12:00 UTC 17 July (Fig. 12a–c). The first sign of convective initiation and evidence of the shortwave trough's presence over Scandinavia came on 17 July, as strong thunderstorms with 3-cm hail caused damage in Jutland, Denmark (*Tapio,* 5 August 1882). On 18 July, the 500-hPa trough became even more well-defined over the central Europe (Fig. 10e). Meanwhile, the shortwave trough crossed over Sweden and moved closer to Finland, advecting moist air from the south (Figs. 10h–i, 11b and 12f–h). Again, multiple strong thunderstorms occurred in Sweden on 18 July, with a mix of long-lasting heavy-rain episodes and severe-hail events. Interestingly, reports of flash flooding occurred in south central Sweden in the early morning hours whereas severe-hail cases were reported in the afternoon farther north (e.g. *Helsingfors Tidning,* 24 July 1882 and *Dalpilen,* 21 July 1882; Fig. 13). These observations further strengthen the idea that the probable embedded shortwave trough influenced severe-hail events within the upper-level trough, especially on 18 and 19 July. The large-scale forcing with rich low-level moisture, adequate amount of deep-layer wind shear, lift (ascent) and instability provided even better atmospheric conditions for severe thunderstorms on 19 July, resulting in strong hailstorms in Finland (Figs. 11c, 12j–k and 13). The trough at the 850-hPa and 500-hPa levels was not so evident anymore in the analysis on 19 July (Fig. 10c and f). This might be because of the modification of large-scale forcing over the trough (e.g. strengthening of upper-level flow). The same synoptic-scale changes might even explain the trough becoming visible at sea-level pressure at the same time (Figs. 11c and 12).

Strong hailstorms need persistent and vigorous updrafts to transport lower-level ambient moisture upward and keep hailstones growing as long as possible in the middle parts of the cloud (e.g. Johnson and Mapes 2001). One crucial element is a modest or strong capping inversion that is usually found atop a moist low-level air mass and is an important precursor among severe-weather events (e.g. Carlson *et al.* 1983). This process can lead to larger convective instability by inhibiting weaker updrafts that would push through the inversion and release instability prematurely. The eyewitness description presented earlier does hint at a possibility of a strong capping inversion in place during 19 July 1882 near Oulu. With humid and warm conditions prevailing, the daytime heating must have been destabilizing the boundary layer by the late morning. Being a coastal location, the start of a sea breeze may have been enough to locally strengthen low-level convergence onshore and allow a brief thunderstorm to develop just north of the city before noon. According to observations (Fig. 14), there was a modest 6 m s^{-1} southeasterly flow at Oulu in the morning of 19 July. Sea breezes tend stay close to the coast or completely over the ocean if the offshore wind is too strong (Gahmberg *et al.* 2010). The occurrence of a sea-breeze circulation along the Finnish coast was studied by Rossi (1957). The average number (1920–1934) of sea breeze occurrences in Oulu was 15 days. Some hours later, the arrival of the trough could have provided a favou rable environment to further destabilize the column and by increasing deep-layer wind shear, ultimately releasing the instability and producing the severe thunderstorms and hail.

Table 4. Severe-weather observations in Europe between 17 and 19 July 1882. Each observation location (numbered) is presented in Fig. 13.

Location (number)	Date	Time (LT)	Type of severe weather
Loir-et-Cher (1)	17 July	–	Wind storm
Agen (2)	17 July	–	Wind storm
Aarau (3)	17 July	–	Flooding rain
Trautenau (4)	17 July	–	Flooding rain
Jutland (5)	17 July	–	Severe hail (3cm), heavy rain
Malmö (6)	17 July	22:00–00:00	Flooding rain
Linköping (7)	18 July	04:00–08:00	Flooding rain
Lidköping (8)	18 July	04:00–08:00	Flooding rain
Erikstad/Gestad (9)	18 July	08:00–18:00	Flooding rain
Norrköping (10)	18 July	13:00–14:00	Severe hail (6cm), wind storm
Falun (11)	18 July	16:00–17:00	Severe hail, heavy rain
Enviken (12)	18 July	17:00–18:00	Severe hail (4.5 cm), wind storm
Lumijoki (13)	19 July	13:30–14:00	Severe hail (5.5 cm)
Oulu (14)	19 July	13:30–14:00	Severe hail (7.5 cm), wind storm
Ala-Kiiminki (15)	19 July	14:00–14:30	Severe hail (7.5 cm)

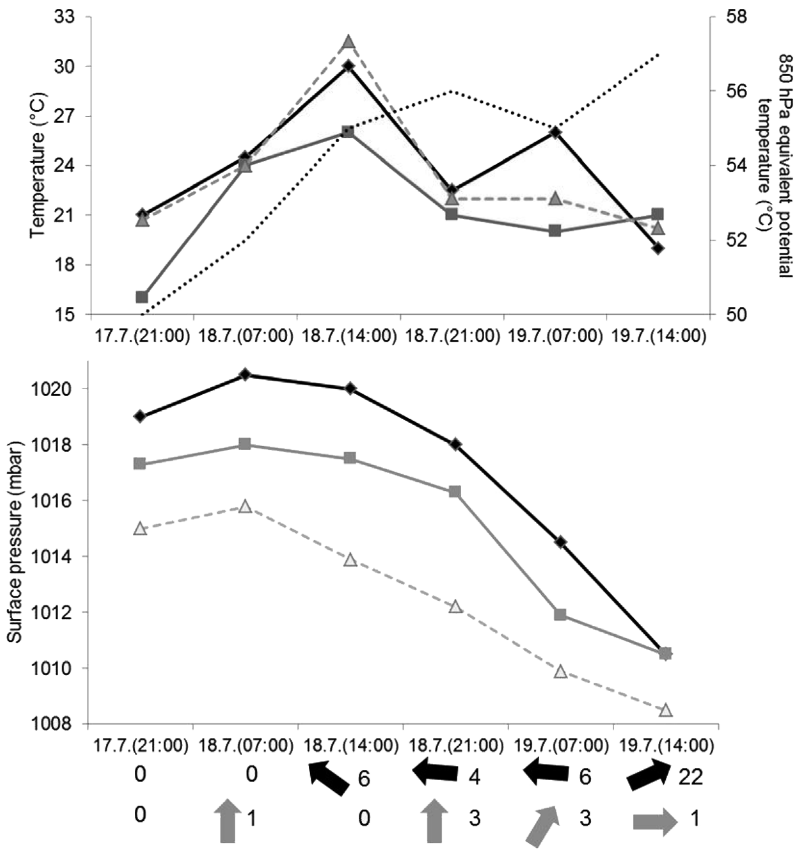

Fig. 14. Meteorological observations (temperature, sea-surface pressure, wind speed and direction) from Oulu (black solid line), Hailuoto (grey solid line) and Kokkola (grey dashed line) stations between 21:00 LST 17 July 1882 and 14:00 LST 19 July 1882. Additionally, 850-hPa equivalent potential temperature around Oulu area is presented in the upper chart (dotted black line, data from 20th Century Reanalysis, obtained from www.wetter3.de). Similarly, surface pressure observations from the same locations are presented in lower chart. Surface wind speed (m s^{-1}) and direction (°) below the lower chart are from Oulu (black arrows) and Hailuoto (grey arrows) stations.

Meteorological observations

The Finnish Meteorological Institute's historical observations archive holds old yearbooks with all meteorological stations and observations. According to this archive, 18 July, the day before the hail event, was already very warm. Observations at 14:00 LST reached of 26 °C at Hailuoto (43 km west of Oulu) and 30 °C in the city of Oulu. Temperatures remained high even during the evening and the following morning (Fig. 14). High observed evening and morning temperatures, along with high values of 850-hPa equivalent potential temperature from the 20th Century Reanalysis, suggest the presence of rich low-level moisture that is confirmed by looking the 700 hPa relatively humidity on 19 July (Fig. 10i). The temperature reached 30.4 °C at 11:00 LST 19 July in Oulu, just around the time when the weak thunderstorm occurred north of the city. At 14:00 LST, the hailstorm moved through Oulu with a southwest wind that measured 9 on the Beaufort scale (22 m s^{-1}). The sea-level pressures from three stations were all decreasing, but nothing too extreme (Fig. 14). Overall, both temporal and spatial sea-level pressure measurements were too sparse for detailed analysis (stations were separated some 40–70 km from each other and measurements were made only three times a day). All eyewitness reports described that the storm passage lasted only a few minutes and started with wind gusts from the southwest. During the storm passage, winds turned clockwise, ultimately blowing from the northwest. No tornado was mentioned in any newspapers.

The *Helsingfors Tidning* newspaper had a practice of providing the previous morning's meteorological observations from around Finland, but they were missing in the 20 July edition because the hailstorm cut all the telegraphic transmissions. This same reporting issue was noticed by Jokinen (2010) during the powerful windstorm of summer 1890.

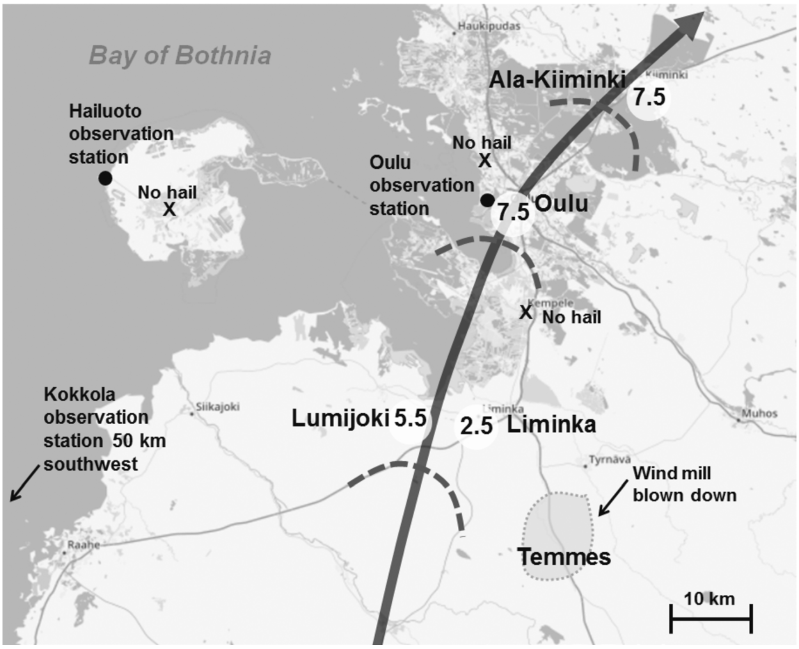

Fig. 15. The estimated south to north track of 19 July 1882 Oulu hailstorm with maximum observed hail sizes and other observations. Three observation stations are marked with dark dots.

Societal impact

As a result of this devastating storm, the governor of the Oulu district sent a telegraph to the Senate's Cash Equivalents Committee pleading for emergency funding to the area. This type of request has only happened on rare occasions when local economic destruction was too great for the local authorities to overcome. The city constabulary counted 41 000 shattered windows in the city area alone with 3000 more in nearby villages (*Sanomia Turusta,* 31 July 1882). Hundreds of roofs were perforated by the sizable hailstones. A few people suffered small bruises or cuts. One young man was described as being hit in the forehead with the wound bleeding down to his toes. Hail damage also occurred south of Oulu in the Lumijoki and Liminka areas (Fig. 15; hail observations of 5.5 and 2.5 cm) and north of the city in Ala-Kiiminki village (Fig. 15; 7.5 cm hail observation, today known as Kiiminki) (*Helsingfors Tidning,* 3 August 1882; *Uleåborgs Tidning,* 27 July 1882; *Finlands Allmänna Tidning,* 12 August 1882). According to the newspaper reports, hail was not observed in Kempele (just south of Oulu), Pateniemi (just north of Oulu), nor in at the Hailuoto observation station, which gives us some idea of the dimension of the storm cell or cells. The distance between Kempele and Pateniemi is 19 km, indicating that the hailstorm was likely 10–15 km wide in size. Uprooted trees and roofless buildings were reported farther east of Oulu (e.g. a windmill was destroyed in Temmes; *Suomalainen Wirallinen Lehti,* 2 August 1882). It was surprising that no wind damage was mentioned in newspaper articles from the Oulu city area, even though the observed wind speed peaked at least 22 m s^{-1}. Thus, the locations of the reported wind damages were separated from the locations of the reported hail.

Conclusions

Historical hail events in Finland during 1776–1910 are compiled from the archives of the National Library's Historical Newspaper Internet database by keyword search. Overall, 119 different Finnish- and Swedish-language newspapers contained news reports of hail observations during the warm season. Many of the 461 hail cases that were found contained amazingly detailed eyewitness stories and characteristics of hail that also highlighted people's respect for unknown greater force.

Over 76% of cases were severe-hail size, and 13% reached significant-hail size. The hailstone's size was most commonly compared to the egg size of different birds or some other known object, and the weight was mentioned in 9% of cases. Most cases occurred in the area of highest population and farming density (western Finland) where most of the newspapers also were published. Cities and towns over eastern and northern Finland were founded much later and remained almost unpopulated during study period. Population and reporting bias likely affected areas over eastern and northern Finland. The more recent dataset of severe hail (1930–2006) contained much more cases from these areas. Even though more people have moved into cities and the rural areas have become less populated over time, rural regions are often better populated during summer vacations, improving the situation during the peak of hail season. The number of newspapers increased steadily towards the 1900s, in conjunction with an increase in the number of reports. Overall, 55% of cases had no exact time of occurrence. For those cases which had timing reported, 85% were severe in size and 71% severe-hail cases occurred between 14:00 and 20:00 LST. July was the month with the most cases (overall, 40% and severe-hail 39%), whereas 80.5% of significant hail occurred between late June and early August. Some sort of damage occurred in 80% of cases and was most often broken windows or crop damage. Crop damage had a much greater impact to society in the past than nowadays and in some cases aid to prevent starvation or even famine was needed.

We also compared this dataset to the Tuovinen *et al.* (2009) dataset of 1930–2006, which was constructed in part from newspaper sources. Distributions of different hail statistics compared favourably between the two studies, despite their different provenances and different time periods.

Two different events from the statistics from the 1776–1910 dataset were examined. The first case covered the dataset's most active hail season (1896), and the second case was the most damaging hail event (biggest reported hail size 7.5 cm). The synoptic setup for the busiest hail season of statistics (in number of hail days and cases) was dominated by two main factors: (1) the nearby presence of surface low west of Finland that allowed suitable low-level moisture and broad area of updrafts over Finland, and (2) strong and stationary high pressure east of Finland allowed flow of warm air near surface. Both factors were simultaneously in place for about two weeks, leading to a number of consecutive hail days around Midsummer. A similar active period (July 1957) was found from more recent dataset of Tuovinen *et al.* (2009) and showed similar synoptic-scale patterns.

The hail event in Oulu city on 19 July 1882 is arguably the strongest recorded hailstorm in Finland. Up to 7.5-cm hailstones broke about 44 000 windows and hundreds of roofs. The maximum observed hail size was one of the largest of the whole dataset and produced possibly the worst damage ever in Finland. The synoptic analysis leading to the event showed a favorable setup for severe storms in Finland (Tuovinen 2007; Tuovinen *et al.* 2009): (1) continental high east of Finland and low-pressure area southwest of Finland, allowing initially warm and dry southeasterly airflow, followed by moist southerly airflow into Finland; (2) large-scale warm-air advection and thickness increase ahead of the trough, yielding observations of high temperatures (> 30 °C); (3) the approach of a broad upper-level trough from central Europe, increasing instability (advecting rich low-level moisture and increasing deep-layer wind shear); (4) severe-weather reports in central Europe and Scandinavia from previous days indicating high-amplitude convection along the trough while progressing northeast; 5) hailstorms in Scandinavia possibly enhanced by embedded shortwave trough; and (6) eyewitness reports describing weaker pre-convective cell(s), possibly enhanced by the sea-breeze circulation and giving a hint of convective inhibition with further destabilizing boundary layer.

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Appendix. All newspapers with dates (dd.mm.yyyy), issue numbers, and the number of hail reports.

Newspaper	Date	Issue	Number of hail reports
Tidningar Utgivne av et Sällskap i Åbo	30.4.1777	8	2
Inrikes Tidningar	6.9.1799	30	1
Åbo Tidning/(ar)	22.7.1793	30	2
	15.9.1802	73	1
	12.9.1804	74	1
	31.7.1805	62	1
	28.7.1828	69	1
	28.7.1838	59	1
Åbo Allmänna Tidning	10.9.1812	107	1
Helsingfors Tidning/(ar)	10.9.1831	72	1
	27.9.1834	77	1
	11.10.1834	81	3
	12.8.1835	62	1
	17.9.1836	74	1
	20.9.1837	73	1
	29.8.1838	68	1
	18.8.1858	64	1
	24.7.1882	168	1
Oulun Viikko-Sanomia	31.8.1833	35	1
	3.7.1841	27	1
	3.6.1856	41	1
Sanan Saattajat	15.9.1834	36	1
	18.6.1836	25	1
Wasa Tidning	15.6.1839	24	1
	17.8.1839	33	1
	27.6.1840	26	1
	5.8.1843	31	1
	23.9.1892	149	1
	4.6.1897	127	1
	20.7.1898	164	1
Borgå Tidning	3.8.1839	61	1
	18.9.1841	74	1
	27.8.1842	67	1
	22.7.1843	56	1
Finlands Allmänna Tidning	4.8.1840	178	1
	21.6.1855	141	1
	9.6.1857	130	1
	18.9.1861	217	1
	7.9.1870	206	1
	10.8.1870	182	2
	1.8.1876	175	1
Wasabladet	1.6.1844	22	1
	1.8.1863	31	1
	6.8.1870	31	1
	27.8.1870	34	1

continued

Appendix. Continued.

Newspaper	Date	Issue	Number of hail reports
Åbo Underrättelser	6.8.1846	61	1
	12.8.1851	61	1
	11.9.1855	72	1
	8.9.1866	105	1
	3.7.1873	99	1
Morgonbladet	1.7.1847	47	1
	27.6.1878	146	1
	2.8.1878	177	1
	9.8.1881	180	1
Ilmarinen	13.9.1848	71	1
	15.8.1849	64	1
	18.8.1849	65	1
	28.9.1850	77	1
	8.7.1854	23	1
	24.8.1882	98	1
	28.6.1883	74	1
(Uusi) Suometar	17.8.1849	33	1
	10.8.1852	32	1
	14.7.1854	28	2
	22.8.1856	34	1
	16.8.1869	65	1
	7.8.1882	180	1
	24.8.1882	195	1
	25.8.1882	196	1
	29.8.1882	199	2
	30.8.1882	200	1
	8.7.1896	155	1
	9.6.1897	149	1
	16.6.1897	155	1
	1.7.1897	167	2
	25.7.1899	187	1
	27.9.1899	242	1
	7.8.1900	199	1
	11.8.1901	185	1
	10.6.1903	131	1
	26.6.1906	144	1
Sanomia Turusta	6.7.1852	14	1
	17.8.1852	17	1
	2.8.1861	31	1
	13.7.1866	28	1
	16.8.1867	33	1
	12.7.1872	28	1
	16.6.1877	46	1
	24.8.1878	68	2
	31.7.1882	116	1
	16.6.1883	90	1
	23.7.1884	169	2
	6.8.1886	179	1
	8.7.1899	155	1
Maamiehen Ystävä	2.7.1853	26	2
	23.6.1854	25	1
	1.7.1854	26	1
Sanan-Lennätin	30.7.1858	30	1
Hämäläinen	10.6.1859	23	1
	22.7.1859	29	4

continued

Appendix. Continued.

Newspaper	Date	Issue	Number of hail reports
Hämäläinen	5.8.1859	31	1
	19.7.1859	33	2
	27.7.1860	30	3
	12.6.1861	28	1
	28.6.1865	30	1
	11.8.1870	32	2
	17.8.1871	33	2
	26.6.1873	26	3
	29.6.1876	26	1
	12.6.1886	47	1
	23.6.1886	50	1
	26.6.1886	51	1
	28.7.1888	60	1
	23.8.1893	67	2
	22.7.1896	58	1
Ilmoitus-Lehti	25.6.1859	25	1
	28.7.1860	3	1
Porin Kaupungin Sanomia	21.7.1860	3	1
Folkvännen	10.9.1862	37	1
	10.8.1864	31	1
	10.7.1878	28	1
	23.8.1883	195	1
	24.7.1885	168	1
	4.7.1892	151	1
Helsingfors Dagbladet	6.7.1863	152	1
	30.7.1879	204	1
	8.8.1881	212	1
	23.7.1885	196	1
	12.8.1888	130	1
Borgåbladet	6.8.1864	31	1
	28.7.1866	28	1
	25.7.1885	57	1
Suomalainen Wirallinen Lehti	2.7.1867	53	1
	11.8.1868	96	2
	17.6.1869	72	1
	20.8.1870	98	1
	22.7.1871	86	1
	5.8.1871	92	2
	10.8.1871	94	3
	12.8.1871	95	1
	26.8.1871	101	2
	27.7.1872	89	2
	10.7.1873	81	1
	24.7.1873	87	1
	28.7.1874	91	1
	1.9.1874	104	1
	27.6.1876	74	1
	27.7.1876	87	1
	3.8.1876	90	1
	11.9.1879	108	1
	12.8.1882	185	1
	8.6.1883	130	1
	5.7.1883	153	1
Tampereen Sanomat	12.7.1870	28	1
	5.7.1886	79	1

continued

Appendix. Continued.

Newspaper	Date	Issue	Number of hail reports
Tampereen Sanomat	19.6.1903	115	1
	24.7.1906	165	1
	26.7.1906	167	1
	1.8.1906	172	1
	26.6.1907	141	1
	6.8.1907	176	1
	28.7.1908	171	1
Tapio	5.8.1871	31	1
	16.8.1882	63	2
Suomenlehti	4.6.1872	23	1
Hufvudstadsbladet	16.8.1872	189	1
	18.8.1875	189	1
	30.6.1878	149A	1
	14.9.1881	211A	1
	23.8.1891	227	1
	5.7.1900	177	1
	5.8.1900	12	1
	17.9.1902	252	1
Työmiehen Ystävä	10.9.1875	36	1
Östra Finland	4.7.1879	75	1
	24.5.1890	118	1
	8.7.1890	154	1
Vaasan Sanomat	7.7.1879	23	1
	8.7.1879	27	1
Savo	29.6.1880	50	1
	11.6.1883	66	1
Päijänne	14.7.1880	28	1
Tidning för Wenersborgs Stad och Län	20.7.1882	58	2
	27.7.1882	60	4
Kalmar	20.7.1882	110	1
	22.7.1882	111	2
Dalpilen	21.7.1882	29	1
Faluposten	22.7.1882	29	1
Pellervo	29.7.1882	30	1
Satakunta	29.7.1882	58	1
	5.8.1882	60	2
	13.6.1883	46	1
	27.6.1896	73	1
	7.7.1896	77	1
	4.8.1896	89	2
Oulun Lehti	9.8.1882	32	3
Turun Lehti	14.7.1883	55	1
	8.7.1884	78	2
	18.7.1885	83	1
	12.7.1887	80	1
	6.6.1899	66	1
	18.7.1899	84	1
	1.8.1899	90	1
	2.6.1891	62	1
	23.7.1896	87	1
Helsingin-Viikko Sanomia	27.7.1883	30	1
Nya Pressen	30.8.1883	235	1
Sawo	14.7.1884	81	1
	21.7.1884	84	1
Finland	12.6.1885	133	1
	18.6.1885	138	1

continued

Appendix. Continued.

Newspaper	Date	Issue	Number of hail reports
Finland	21.6.1885	141	1
	2.7.1892	150	1
Tammerfors Aftonblad	21.7.1885	58	1
	8.5.1891	37	1
Österbottniska Postern	13.8.1885	33	1
Aamulehti	23.6.1886	75	2
	21.7.1886	86	3
	24.7.1886	88	1
	27.6.1895	145	1
	11.6.1896	133	1
	3.7.1896	151	1
	4.8.1896	178	1
Waasan Lehti	30.6.1886	52	1
	4.8.1886	62	1
	20.7.1887	58	2
	7.8.1889	63	1
	6.7.1892	54	1
Västra Nyland	10.8.1892	63	1
Savo-Karjala	30.6.1893	71	1
	31.7.1893	84	1
	27.6.1894	72	1
	27.7.1894	85	2
	28.8.1895	96	1
	5.8.1896	86	1
Rauman Lehti	5.8.1893	62	3
	6.6.1894	45	2
	23.6.1894	50	1
	4.7.1896	54	1
	23.7.1898	81	1
	23.7.1910	81	1
Pohjalainen	23.8.1894	98	1
	26.6.1895	74	1
	29.6.1895	76	1
	2.7.1895	77	1
	3.9.1895	104	1
	27.6.1896	75	1
	17.6.1897	71	1
	19.6.1897	72	1
	22.6.1897	73	1
Tampereen Uutiset	24.8.1894	129	1
	3.7.1900	126	1
	4.7.1905	150	1
	7.7.1905	153	1
Itä-Suomen Sanomat	1.6.1895	63	1
	3.7.1896	52	1
	14.6.1898	45	1
	16.6.1906	66	1
	22.8.1908	96	1
	22.7.1909	80	1
Karjalatar	20.6.1895	69	1
	2.7.1896	72	1
Päivälehti	27.6.1895	145	1
	26.7.1899	188	1
	4.8.1899	196	1
	11.8.1900	186	1
	24.6.1903	143	1
Saimaa	28.6.1895	51	1

continued

Appendix. Continued.

Newspaper	Date	Issue	Number of hail reports
Hämeen Sanomat	29.6.1895	71	1
	15.7.1897	77	1
	12.8.1897	89	1
	14.8.1905	91	1
Keski-Suomi	6.7.1895	77	1
	11.6.1896	68	1
	13.6.1896	69	3
	6.8.1896	91	1
	15.8.1896	95	1
	14.6.1898	67	1
Oulun Ilmoituslehti	10.7.1895	78	1
	12.7.1896	80	1
Porilainen	10.7.1895	310	1
Kaiku	30.8.1895	99	1
	1.7.1896	73	2
	12.7.1896	76	1
	4.8.1897	86	1
	9.8.1897	88	2
	20.7.1898	80	1
	11.8.1899	90	1
	11.7.1900	82	2
	22.8.1902	97	1
Louhi	30.8.1895	102	1
	1.9.1895	103	1
	3.7.1896	79	2
	23.9.1896	114	3
	9.7.1899	78	1
	14.7.1899	80	1
	30.7.1899	87	1
	9.7.1900	79	1
	3.8.1901	91	1
	14.9.1905	110	1
Uusimaa	9.6.1896	44	1
	12.6.1896	45	1
	18.6.1897	47	3
	9.8.1898	60	1
	7.7.1899	78	1
Sanomia Porista	10.6.1896	65	1
Suomalainen	15.6.1896	66	1
	1.7.1896	72	2
	7.8.1896	88	1
	26.7.1899	85	1
Uusi Savo	27.6.1896	72	1
	18.7.1896	81	1
	15.6.1898	135	2
	7.7.1899	152	1
Savonlinna	14.5.1897	37	1
	16.8.1900	93	1
	30.6.1896	65	1
Aftonposten	14.7.1897	159	1
Wiipuri	18.6.1898	49	1
	10.6.1903	46	1
	10.6.1910	65	1
Kotkan Sanomat	8.7.1899	77	1
	22.7.1899	83	1
	10.7.1902	53	1

continued

Appendix. Continued.

Newspaper	Date	Issue	Number of hail reports
Tornio	19.7.1899	54	1
Mikkelin Sanomat	25.7.1899	83	1
	4.7.1903	73A	1
	14.7.1903	77	1
	12.7.1904	76	1
Kaleva	26.5.1900	121	1
	8.8.1901	182	1
	29.6.1906	148	1
Uudenkaupungin Sanomat	21.6.1900	68	1
	31.7.1906	41	1
Koitar	24.8.1901	95	1
Suurpohjan Kaiku	26.7.1902	82	1
Wiborgs Nyheter	17.9.1902	215	1
Kotkan Uutiset	4.6.1903	45	1
	19.7.1903	57	1
Hämetär	4.6.1903	44	1
	29.6.1905	71	1
	22.5.1906	58	1
Kajaanin Lehti	26.8.1903	68	1
	23.5.1906	41	1
Kokkola	13.7.1904	55	1
	5.7.1905	53	1
	19.7.1905	57	1
	7.8.1907	63	1
	20.7.1909	78	1
Uusi Aura	21.7.1904	166	1
	14.8.1904	187	1
	19.6.1906	71	1
	26.6.1906	142	1
Salmetar	3.6.1905	43	1
Karjala	20.6.1905	140	1
	28.7.1908	170	1
	23.6.1910	142	1
Helsingin Sanomat	28.6.1905	146	1
	30.7.1905	174	1
	3.7.1906	150	1
	25.7.1908	168	1
Pohjan Poika	7.7.1905	43	1
Kaskisten Lehti	18.7.1905	54	1
Turun Sanomat	30.7.1905	174	1
	19.8.1905	191	1
	5.8.1908	173	1
Vaasa	3.8.1905	54	1
	8.8.1905	90	1
	21.9.1905	109	1
	29.6.1909	145	1
Lahden Lehti	5.8.1905	87	1
	17.6.1906	88	1
Raahen Sanomat	16.5.1906	29	1
Perä-Pohjalainen	21.7.1906	84	1
Ilkka	28.7.1906	12	1
	23.6.1908	69	1
Etelä-Suomi	31.7.1906	86	1
Talonpojan Lehti	13.9.1906	43	1
Vapaa Sana	12.7.1907	78	1

continued

Appendix. Continued.

Newspaper	Date	Issue	Number of hail reports
Pohjois-Savo	29.7.1907	83	1
Karjalan Sanomat	3.9.1907	99	1
Työmies	3.9.1907	202	1
	5.6.1908	128	1
Vapaus	2.6.1908	87	1
Lounais-Häme	17.7.1908	79	1
Savon Työmies	23.7.1908	78	1
	12.8.1909	88	1
Savolainen	1.8.1908	87	1
Työkansa	7.8.1908	87	1
Otava	11.8.1908	87	1
Lappeenranta	11.8.1908	89	1
Haminan Lehti	22.6.1909	67	1
Työ	25.6.1909	142	1
	29.6.1909	145	1
Savotar	26.6.1909	68	1
Suur-Savo	28.6.1909	71	1
Uusmaalainen	18.8.1909	93	1
Tornion Lehti	21.8.1909	63	1
Sorretun Voima	13.6.1910	64	1
Savon Sanomat	20.6.1910	67	1
Vakka-Suomi	28.6.1910	70	1
Hämeen Voima	26.7.1910	82	1