Severe weather events in the late 19th century and their potential impact on insurance today

Winter storms in Europe: messages from forgotten catastrophes
When it comes to assessing insurance losses from future severe windstorms in Europe, an analysis of the three major events in the late 19th century can prove just as useful as artificial scenarios created by a weather or climate model. Such an approach also helps the insurance industry gain a longer-term perspective on the sequence of strong storms that affected Europe at the end of the 20th century.
Introduction

This publication describes three major winter storms that swept across Europe more than 120 years ago. In an age of live storm chaser reports from inside hurricanes, rainfall radar streamed to your smartphone and numerical weather models delivering seven-day forecasts, you might ask why we even bothered to invest time studying such long-past events.

Pinning down historical storms is no easy task

Our interest in these events was triggered by the development of Swiss Re’s new model for the assessment of European winter storm risks. Irrespective of the peril, we have always been convinced that to devise a sound natural catastrophe model, you need a thorough understanding of historic activity. For European winter storms this is no easy task. While for hurricanes there are publicly available and commonly accepted “best track” lists of past events going back to the 19th century, there is no such database for European winter storms. Furthermore, even if the track of a European winter storm – i.e. its location and pressure at a given time – is known, this does not help a great deal. For a hurricane, its central pressure already gives a rough indication of surface winds. On the other hand, the complex dynamics and strongly asymmetrical wind field of a European winter storm provide no such clues.

The three events described in this publication are considered the most severe to have hit Europe in the late 19th century. Although they appear prominently in the 20th Century Reanalysis¹ data we used for developing our winter storm model, they may be unknown to almost everyone save a few historians and meteorologists. It is consequently reasonable to describe them as “forgotten catastrophes”. That said, it would be inaccurate to assert that nothing at all is known about them. At the time of their occurrence, they triggered both public and scientific curiosity, leaving written traces in newspapers, scientific journals, village chronicles and forestry reports. And at irregular intervals in the years since, some aspects of these events have been highlighted in publications (e.g. Lamb 1991). So where are we adding value to the information that’s already there?

¹ The 20th Century Reanalysis (20CRv2) dataset contains global weather conditions in six hour intervals from the year 1871 to 2012. Further information at http://www.esrl.noaa.gov/psd/data/20thC_Rean/
Investigating historical wind speeds to fashion a model for assessing winter storm risks

While developing the new Swiss Re model we began looking for clues of exactly how strong these forgotten windstorms had been across Europe. We then realised that no one had ever attempted to reconstruct a map of the wind speeds they generated. Starting from this simple observation, we decided to

- Develop “best guess” 3-second peak gust footprints based on all publicly available information on these events, and
- Present modelled losses to the European insurance markets, if these events were to happen today (“as-if” losses)

Lately, the demands on insurers to substantiate their view of risk to meet capital and risk management requirements (e.g. Solvency II in Europe) have been increasing. Cat modelling based on thousands of theoretically possible scenarios will remain at the core of such efforts. Additionally assessing the impact of individual key events is nothing new, but has clearly regained traction recently (e.g. AIR 2013; RMS 2003; Swiss Re 2014, 2015). This publication presents three of the most significant European winter storms of the 19th century, which we hope will contribute to the debate surrounding extreme events and their potential impacts. Poring over all information we had access to, we came up with a best estimate of which areas these events affected exactly and how intense they were. By plugging the resulting wind footprints into our European winter storm model, we are then able to calculate potential insurance market losses, if these events were to happen today (see section: Wind footprints in CatNet®).
In mid-February 1876, the weather across Europe was already beginning to get unusually wet and windy with successive depressions sweeping in from the Atlantic. During the early hours of Sunday March 12, a small but very intense storm approached land from the southwest and barometers started to fall rapidly in southern Ireland and England. Lothar’s Big Brother was embarking on its path across Europe.
Lothar’s Big Brother: the storm of March 1876

Figure 1 shows the track, i.e. the position of minimum surface pressure, of the March 12, 1876 storm. Crossing almost precisely over London, Amsterdam and Hamburg, the centre of the depression travelled eastwards at 70 kilometres per hour. The lowest pressure measured was 963 hPa\(^2\) (Quetelet 1876; Scott 1877). Given the scarcity of observations at the time, the true minimum may have been even slightly lower. Atmospheric pressure could already be measured with modern accuracy in those days, but the art of measuring wind speed was still in its infancy. So to map the most severe wind gusts – which with European winter storms are always to the south of the storm centre – we had to tap into other sources of information.

Figure 1
The minimum surface pressure track and the reconstructed peak gust footprint of the March 1876 storm. The table on the right shows estimated insured property losses for the most affected countries, if this event were to occur in 2014.

**Fallen timber tells the story**

Outside a French royal hunting lodge in a forest north of Paris\(^3\), a large commemorative plaque reads: "On the March 12, 1876, a cyclone travelling from west to east crossed [this] forest and toppled 100 000 trees in just a few hours...". There cannot be very many European winter storms that have ever been immortalised in such a fashion. This is consequently a distinct sign of the havoc that must have been wrought on forests in Europe on that day. Given the economic importance of timber as a production material and energy source in the late 19th century, it is no surprise that highly detailed forestry damage reports have been published in the years after the event. Indeed, such reports are a prime source of information about this storm.

In present-day Germany and Poland in particular, thrown timber volumes and percentages of annual harvest lost have been recorded down to the level of small

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2 hPa = hectopascals, the unit for mean sea level pressure measurements. One hectopascal equals one millibar, a unit formerly used in meteorology.

3 The Pavillon de chasse Eugénie, at Étangs de Saint-Pierre in the Compiègne forest.
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forest districts (Bernhardt 1877, 1880; Kienitz 1877). A forestry report from neighbouring Luxemburg – written 40 years after the 1876 event – indicates that there had been no similar damage from a winter storm in 100 years (Faber 1916). French forest damage figures from Normandy and Picardy regions to the north of Paris imply similar levels of tree throws as those observed in the worst affected areas of Germany (e.g. Lesage 1959, Corvol 2005).

Wealth of evidence

In summary, these reports outline an area of downed trees in excess of annual harvest levels from the north of France, through eastern Belgium and Luxemburg and into the province of Saxony south of Berlin. But even beyond forestry damage, the amount of information available about this event is quite remarkable given it happened 140 years ago. Mapping out locations of reported property damage found on the internet – specifically the mentioning of chimney falls, broken windows or damaged roofs – corresponds well with forest damage areas (e.g. Gras & Garnier 2013). Many of these sources identified the 1876 storm as the worst to hit the area in the 19th century and beyond. And while an accurate measurement of absolute wind speeds was not possible at the time, a report from the observatory of Brussels in Belgium states that the 1876 storm was the most severe event during the 1850 –1894 period (Lancaster 1894).

Reminiscent of Lothar

In our view, combining individual sources of indirect wind speed such as those mentioned above allows a pretty accurate reconstruction of the wind footprint on March 12, 1876. Despite many caveats in interpreting forest damage figures from the 19th century (see section: Forest damage by wind), the scope of loss is clearly reminiscent of that inflicted by storm Lothar in 1999. A variety of reports credibly substantiate that for the main regions affected, this was the worst event in the 19th and early 20th century. And the similarities to storm Lothar are striking, for instance in respect to the meteorological evolution, the minimum pressure reached and its tightly packed size. While storm Lothar was probably slightly more intense due to its more condensed structure and faster forward motion across Europe, the March 1876 storm affected a larger area thanks to its broader wind field. Figure 1 shows our best estimate of a 3-second peak gust footprint for the March 1876 storm.

If the 1876 storm happened today ...

Our prime motivation for conducting this study was, of course, the calculation of insured losses, if these events were to happen today. Based on a European PERILS4 2014 market portfolio, insured property losses alone would reach EUR 10 billion according to our estimates. The table shown in Figure 1 breaks down the estimated losses by country. All figures shown are without impact from post-event loss amplifications, which would actually drive up the losses.

Relative to the assets on the ground, Luxemburg and Belgium would be hit worst if there were a recurrence of the March 1876 storm today. France and Germany show more moderate relative loss levels, but remain the biggest contributors in absolute loss amounts. These resemble those inflicted by storms Lothar (1999) and Kyrill (2007) respectively. The European market loss level of slightly above EUR 10 billion may appear surprisingly small in light of the storm severity described. However, this very intense storm spared major cities and passed through relatively thinly populated areas in France and Germany. Had the same storm tracked only 75 km further north, losses in Germany and Belgium would have multiplied with severe damage inflicted on Antwerp, Brussels and the Ruhr region. Also, insured lines of business other than property (e.g. motor, engineering, agriculture/forestry, inland marine) would add to the overall loss burden.

4 PERILS AG is a company offering insurance exposure and event loss data and associated industry loss index services. Swiss Re is founding member and on the Board of PERILS AG.
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Lothar’s Big Brother: the storm of March 1876

Forest damage by wind
In the absence of trustworthy wind measurements, we used reported forestry damage as a key proxy for estimating peak gust footprints of the events presented in this publication. Obviously, wind speed is only one of many parameters that influences the probability of trees falling or snapping in a storm. Other factors are:

- **Tree type:** In winter time, coniferous trees are generally more vulnerable compared to deciduous trees. In Europe, spruce is considered the most vulnerable species due to its shallow, flat root system, followed by varieties of fir. Pine, beech and oak trees are considerably more stable.

- **Forest structure:** Apart from the tree species composition, characteristics such as stand density, age composition, slenderness – a ratio of tree height to diameter – and the existence of forest openings play an important role in tree stability.

- **Soil conditions:** High ground water tables lead to flatter root growth, thus increasing the risk of tree fall. The same applies to strong water saturation due to extensive prior precipitation periods. Frozen ground has the opposite effect, strengthening tree stability.

- **Tree crown weight:** Freezing snowfall may lead to a strong increase of the weight of the tree top, increasing the risk of toppling. This effect is irrespective of tree type, but broad-leaved trees are more vulnerable in autumn, before shedding their leaves.

There are a number of caveats in comparing the scale of forest damage of the late 19th century with the damage caused by more recent events such as winter storm Lothar. In Denmark for instance, the forested area has about doubled since 1900 (Danish Forest and Nature Agency 2002). In France, Germany or Switzerland, the forested area has increased in the range of 25–50% in the same period (e.g. Ginzler et al. 2001). Even more important is the increase in the size and age of trees, and thus the amount of timber stored in forests. In Switzerland, growing stock per area has roughly tripled since 1900 (Usbeck 2015), with similar developments indicated in Germany or France. Furthermore, forestry damage in mountainous regions may not have been fully accounted for in the 19th century, given difficulties of access in those days.

In western and central Europe, 3-second peak gusts exceeding 125 km/h are often associated with the beginning of forest damage. Judging from events in the past 30 years, extreme wind throws across dozens of acres of forest seem associated with gusts exceeding 140 km/h. Despite all the influencing factors mentioned above, we believe that in addition to other evidence the description of forestry damage in historic reports is a solid basis for reconstructing the peak gust footprints presented in this report.
Daria’s Big Sister: the January 1884 storm

The storm of January 26, 1884 is generally far better known than the 1876 event, mainly because it produced the lowest pressure reading ever recorded over the British Isles and continental Europe. In Ochtentre, close to the town of Crieff in Scotland, the barometer dropped to 925.6 hPa (Marriott 1884).
Gustave Eiffel learns a lesson
On January 19, 1884, a strong depression moving across northern Scotland marked the start of a string of storms coming in from the Atlantic. The strongest event in this series began to unfold on January 26, 1884. During the morning, barometers in northwestern Ireland started to plunge. Figure 2 shows the track and pressure development of this event as it moved across the northern United Kingdom at a fairly moderate speed. However, due to its extremely low central pressure and associated steep pressure gradients, damaging wind speeds extended over a north-south distance of more than 1,000 kilometres. As far away as Evaux-les-Bains in central France for instance, a 50 metre steel truss from a railway bridge under construction was blown from its abutments into a ravine. The bridge’s engineer, Gustave Eiffel, no doubt bore this event in mind when constructing the Eiffel Tower in Paris five years later.

Reconstruction of this event’s wind footprint difficult
For the British Isles, the strongest winds were observed over the north of Ireland, southern Scotland and northern England. According to reports, it rivalled the severe storms of 1839 and 1856 in Ireland and Scotland respectively. Severe forestry damage is described for several locations; however, without precise quantification of thrown timber volumes (e.g. Burt 2007, Symon 1885). In southern England, the winds still caused damage to individual buildings and trees across a wide area, but were clearly lower than in the north. So far, this is as expected – the further south, the lower the wind speeds. However, damage reports and meteorological observations suggest that along the coasts of northern France, peak gusts were actually higher again than in southern England.
Why the storm blew harder in France than England
Back in 1884, it was thought that a secondary depression had perhaps passed over France (Marriott 1884). Given the scarcity of observation data – often only three readings per day and none during the night in few locations across France – the existence of a shallow secondary low cannot be completely ruled out, but is considered unlikely. By the time the southwest-northeast oriented cold front of this storm passed over northern France, it was strongly elongated and can well have produced higher gusts in Paris at 11 pm than it did when passing over London four hours earlier. While gradually weakening in the early morning hours of January 27, stormy conditions reached far into France’s interior, with the Massif Central, Alps, Jura and Vosges mountains affecting the speed and direction of the wind. Reports do not indicate damage on a massive scale, but accounts of fallen chimneys, damaged roofs and broken windows extend far beyond Paris. Similarly, forestry damage seems to have occurred locally, e.g. in the Vosges mountains, but was apparently not significant in France as a whole. Wind speed measurements in Paris, Brussels and Dunkirk indicate that this event was likely the strongest in the 1880s, but not as strong as the severest storms in the decade before and after (Annales Bureau Centrale Meteorol. France 1879–1898; Lancaster 1894).

Damaging wind speeds stretching over one thousand kilometres from north to south
The descriptions above make clear that the January 26, 1884 event was not particularly severe in terms of its maximum intensity. What made the event spectacular was the tremendous reach of damaging wind speeds, which were undoubtedly driven by the exceptionally low central pressure of the storm. Figure 2 shows our best estimate of a 3-second peak gusts footprint of the January 1884 event. We estimate that the area with gusts in excess of 120 km/h spanned some 1 250 km from northern Scotland down to central France. In comparison, the January 1990 storm known as Daria or “Burn’s Day storm” – considered a storm of very large proportions – unleashed comparable wind speeds across an area of only 750 km at the most. So the January 1884 event can undoubtedly be termed Daria’s “big sister”.

1884 storm happening now would generate record insured losses
Based on a European PERILS market portfolio, insured property losses alone would reach close to EUR 14 billion according to our estimates – far beyond the insured losses caused by any European winter storm in history. The table shown in Figure 2 breaks down the estimated losses per country. Again, the figures do not include losses from other lines of business nor from any loss amplification. In line with the footprint is the remarkable fact that the Benelux countries and Germany have not been strongly affected, as the depression veered off sharply to the north after reaching its maximum intensity over Scotland. Had it held a more north-easterly course, the estimated losses would no doubt rise massively for these countries.

Before concluding our account, we should highlight that the storm described in detail above was both preceded and followed by another. Although smaller in size, a preceding storm on January 23/24 was almost equally strong over parts of Britain, and extended its wind footprint across Belgium and Netherlands and into Germany. And during the night of January 27 to January 28, only 24 hours after the big storm had abated, a small secondary depression passed over the southern-most portion of France, where it exceeded the wind speeds of the night before. Neither of these events is accounted for in the peak gust footprint we have presented. Given the partial overlap of areas affected, the short time between the storms and a recent trend to expand event definition clauses in reinsurance contracts, claims adjustment would no doubt be challenging if such a cluster of events took place today.
The North Germany Express: the storm of February 1894

Although southern Denmark and the coastal regions of northern Germany were well acquainted with strong and frequent winds, the storm of February 12, 1894 was such that neither trees nor buildings would escape unscathed.
A series of stiff gales
The storm that crossed Europe on February 11 and 12, 1894 was no single blow. Rather, it marked the culmination of a series of depressions, one closely following the other. At around noon on February 12, 1894, the strongest storm by far of the series roared across the coast of northern Germany. However, the storm was not only felt in Germany, but had already gathered sufficient strength to cause damage when passing over the British Isles the night before.

Figure 3 shows the track of the February 1894 storm. Coming from the northern Atlantic, the intensifying low pressure centre moved across the northernmost portions of the United Kingdom. It continued to deepen further as it made its way eastwards across the North Sea, travelling at some 85 kilometres per hour. It passed south of Oslo at 8 am on the morning of February 12. A remarkably low pressure for this region of 945 hPa was measured, before the depression slowly filled up on its way towards present-day Estonia and Finland (Köppen 1894).

A trail of damage to buildings
As the storm was raging in the old city of Hamburg, rumours spread that the 130 metre-tall tower of the St. Petri church was about to collapse. Onlookers claimed to have seen the tower swaying dangerously. The structure fortunately stayed in place, despite suffering damage to its roof covering (Norddeutsche Allgemeine Zeitung 1894). It is clear, however, that the fear was well-founded: reports of fully or partially collapsed church spires were coming in from Germany’s Hamburg-Altona in the west all the way over to Szczecin in present-day Poland, in the east. Hundreds of private chimneys as well as some large factory chimneys were toppled in the storm. Countless roofs were damaged and not a few buildings collapsed entirely. Along its path, the storm took dozens of lives both at sea and on land. Falling and flying debris left many more injured.
The North Germany Express: the storm of February 1894

Getting a grip on wind speed
Not only do we have vivid descriptions of the impact on property, but there are also comprehensive accounts of the extensive forest damage in both Germany and Denmark (Danckelmann 1897; Oppermann 1894). Many forest districts reported damage exceeding five times the annual timber harvest, and again these reports proved invaluable in reconstructing the peak gust footprints. By the time of the 1894 event, the availability and quality of wind speed measurements – or at least the understanding of respective limitations – had improved (see section: Wind has been a tricky thing to measure). For the Hamburg station, the maximum mean hourly wind speed was measured between 12 noon and 1 pm at 36 m/s (Köppen 1894). However, this was based on an outdated ratio for transferring the speed of the whirling anemometer cups into wind speeds, and it is suggested that the true value should rather be 30 m/s. An estimate of 36–40 m/s is given for “gusts”. However, taking into account the limitations of ancient cup anemometers to record peak gusts, and using hourly mean wind speed conversion factors commonly applied today, we infer that modern devices would have recorded 3-second peak gusts in excess of 45 m/s. For decades, northern Germany had not experienced a storm of such severity.

Packing a punch across 2000 km from east to west
Figure 3 shows our best estimate of the footprint of the 3-second peak gusts during the February 1894 event. While the January 1884 storm impresses with the width of its footprint, this storm is also outstanding in terms of the geographical breadth across which it produced winds of exceptional force. The length of the region experiencing 3-second peak gusts of 135 km/h or more reaches almost 2000 km, from Ireland in the west to the northeastern reaches of Poland.

1894 saw several nasty storms
Not surprisingly, insured losses would be substantial, if this event happened today. Based on a European PERILS 2014 market portfolio, the insured property losses alone would exceed EUR 8 billion. The table in Figure 3 breaks down the estimated losses per country. We must add that while the February 1894 event was the most severe one in terms of potential impact on insurers, it was far from being the only one in the year 1894. In particular, further substantial losses would have been triggered by the strong gales of November 12/13 in France and Belgium, as well as the storm of December 22/23 that caused high winds over the United Kingdom and triggered one of the most severe storm surges of the 19th century along the coasts of Germany and the Netherlands. While back then damage caused by wind had to be borne privately, today it would be reimbursed to a large extent by insurers and reinsurers.
Wind has been a tricky thing to measure

Since today meteorological agencies report wind speeds on a daily basis from dense networks, most people would probably say that measuring wind speed should be easy. However, the reality is quite the opposite – measuring wind speed in a consistent manner has turned out to be one of the more difficult tasks in meteorology.

In the 19th century, the intensity of wind was generally described based on the observed impact on water or on land. Although the “Beaufort scale” is probably the best known, many different scales were used with no reliable comparison between them (e.g. Wallbrink & Koek 2009).

Scientists, of course, wanted a more objective and automated measurement of wind. An early version of such a device, the Robinson cup anemometer, was introduced in 1845 at the Armagh Observatory in Northern Ireland. It became quite widely used at land-based meteorological observatories of the 19th century. However, it took decades to properly understand how the speed of the whirling cups related to average wind speeds. And it was apparent that the design rendered it unsuitable to reliably measure peak gusts.

In France, the company “Richard Frères” produced highly sensitive anemometers in the form of propellers. While theoretically better suited to capture individual gusts, it proved difficult to continuously orient them towards the highest winds during a storm. A major step forward was not made until 1892, when the Dines pressure tube anemometer was introduced. This device was capable of reliably capturing short term variations in wind gusts and was in operational use globally far into the 20th century.

Differences in measured wind speeds by different devices were investigated, but for a long time little was done to understand and resolve these (Mattice 1938). Far into the 20th century, the focus was to keep a single station record consistent through time, rather than achieving consistent measurement standards across many stations (Shaw 1926). This not only had to do with variations between measuring devices, but equally with the absence of common guidelines for the placement (e.g. height above ground) of these devices.

For the events presented in this report, a number of wind speed measurements exist from some of the early European observatories (e.g. Paris, Brussels, London, Hamburg). Given the shortcomings of measurement methods at the time, there are major uncertainties in relating such values to wind speeds as they would be measured today. And this applies particularly to peak gusts. But if not in absolute terms, then such early records nevertheless provide a relative sense of how strong an event was.
People tend to have short memories. If a survey were conducted on the street, some people might recall storm Lothar in 1999 and maybe Daria, Vivian and Wiebke in 1990. And others might even remember the 1987 storm in southern England. But beyond that, storms are not things that stick in people’s minds. In this publication, we have presented three particularly severe examples of such forgotten events. Others that would equally deserve a more detailed investigation – for example the 1902 storm in Denmark and Sweden – were beyond the scope of this publication. Similarly, we have not been able to investigate the insurance impact of event clustering, which was a prominent feature surrounding the 1884 and 1894 events.

**Informed judgment calls**

Our reconstruction of the 1876, 1884 and 1894 wind footprints requires a fair amount of expert judgment due to the limited data available. We deemed it useful to add some historical context from the 19th century, in the hope this would give readers a sense of the uncertainties involved in this process. That being said, having considered all the evidence available to us, we are confident that our peak gust estimates are based on a solid foundation. Clearly, the recent 1980–2000 period of strong winter storm activity was not unique in the last 140 years. In fact, the period of 1875–1895 seems to have witnessed even more damaging storm events.

Running the three event footprints in Swiss Re’s European winter storm model results in insured property losses of between EUR 8 and 14 billion across Europe. However, this does not represent a complete picture. Additional contributors like motor, engineering and forestry insurance would certainly increase the indemnities paid out by insurers. The same holds true for the loss amplification effects of demand surge (costs of labour and material) and insurance claims inflation (settlement time pressure and resource constraints). Assuming that these factors account for 20% of the loss – in our view certainly justified given the severity of the events – drives the total insurance industry burden from the three events up to between EUR 10 and 17 billion.
What actually happened versus what could have happened

The goal of this publication is to contribute to the discussion of the risk of European winter storms. Rather than projecting theoretically possible scenarios through the run of climate and weather models, we focused on reconstructing the characteristics of three storms that actually happened. The January 26/27, 1884 event would likely create the largest European insurance market loss of any historic storm of the past 140 years, if it happened today. However, the notion that this would thus represent a 140-year return period loss for the European insurance industry is wrong. While the three events presented in this publication were exceptional in various aspects, their centre of intensity generally skirted the more densely populated areas of Europe. For example, modelling the 1876 storm, a slight shift northwards over strongly urbanised areas multiplies property losses to EUR 24 billion – with the insurance industry likely to face a total bill in the region of EUR 30 billion once other lines of business and loss amplifications are accounted for. At this level, not only local but even multinational insurance companies could exhaust their reinsurance protection. Ignoring this fact would be turning a blind eye on the tail risk that European winter storms present for the insurance industry.

Obviously, the impact the storms of 1876, 1884 and 1894 would have on an individual insurance company depends strongly on the corresponding distribution of insured risks. We are happy to discuss with our clients the option of tailor-made investigations around these events and their potential impact on balance sheets under current reinsurance protection. Based on our continued ambition to deepen and broaden insights into European winter storm risk, we look forward to share and discuss our findings with a broader stakeholder community.
Methodology

This section provides further details on our approach to estimate the 3-second peak gust footprints and corresponding insurance losses presented in this publication.

Step 1
Information gathering

We searched four primary data sources for information:
- Meteorological literature and data
- Forestry loss reports
- Newspapers
- Internet in general (e.g. village chronicles)

Finding meteorological literature is straightforward, as the number of important publications in the late 19th century was limited. We believe we captured all key papers across Europe. Additionally, we consulted some meteorological observation data accessible on the internet.

Comprehensive forestry loss reports were available from Germany and Denmark, and partially France. From the British Isles, only anecdotal references were found – presumably due to largely private ownership of forests.

For newspaper consultations, we relied on digitised archives on the internet. Together with further internet sources they helped map out places with chimney falls, roof damage, broken windows or tree falls.

In general, we searched internet sources in English, French, German, Danish and Dutch. Typical search terms included “storm”, “hurricane”, “tempest”, “gale” (in the 19th century, these terms were used quite interchangeably), “damage”, “loss”, “tree fall” etc., combined with e.g. day, year and month of the event.

In all data sources, we checked for references with respect to when an event of such intensity had happened the last time.

Loss of timber in percentage of annual harvest as well as northern and southern boundary of “the worst impact” on forests due to the March 1876 storm as described in Bernhardt, 1877.

Map of all locations with mentioning of either chimney, roof, window or tree damage as reported in village chronicle, newspapers etc. in the public domain.
The minimum surface pressure track is generally indicated in the scientific literature we cite. Our peak gust footprints are estimated on the basis of the qualitative damage information gathered, the few measured wind speed indications and any references as to when such storm intensities had been experienced the last time. Footprints of known recent events were consulted for comparison.

The peak gust footprints we show refer to low level terrain and exclude the impact of higher elevations. Given the patchy and qualitative base information, we kept these generalised footprints smoothed compared to the high peak gust variability of real events. As a rule of thumb, we would expect 50% of modern day meteorological stations within a wind speed zone of our generalised footprints to reach or exceed the peak gusts indicated, if this event were to happen today.

For the calculation of insured market losses, we created footprints with a higher geographical resolution, and uploaded them to Swiss Re’s CatNet®.

The basis for these high-resolution footprints were the generalised peak gust footprints. Regional climate model output was employed to introduce a realistic pattern of peak gust variability using a method known as “statistical downscaling”. It would thus be wrong to claim that the three 19th century gust footprints looked exactly like those uploaded to CatNet®. Rather, these footprints represent one statistical possibility of what high-resolution wind patterns could have looked like in these events. Correspondingly, the insurance losses calculated on the basis of these footprints are an average indication of possible loss levels.
To compile this publication, we relied on a large amount of information recorded by devoted meteorologists, who were eager to understand the nature and mechanics behind storms, and by forest wardens and journalists who meticulously compiled information on the damage wrought. Insurance loss data was not an option: Although Swiss Re already existed in the late 19th century, and we may even have paid some claims via marine reinsurance, property damage caused by wind was still deemed uninsurable. Today, we would speak of a “protection gap”. Listed below is the most important literature that helped us write this publication.

1876

  [Note: Based on this report, the thrown timber volume for the 1876 event is often cited in literature as 4.4 million cubic metres. However, this figure only covers damage in government forests. The total thrown volume including private and municipality forests is estimated at around 8 million cubic metres (Bernardt 1877). Nevertheless, even this figure would still not include thrown timber outside Germany and Poland]

1884

- Annales Bureau Centrale Meteorol. France (1886), Bull. obs. françaises et revue climatologique 1884, Tome 2
  [Note: additionally consulted prior and subsequent years of the same publication from 1879–1898]
- Annales Bureau Centrale Meteorol. France (1887), Etudes des Orages en France Année 1885, Tome 1, p. 23–24
- Paulet M. A. (1884): La tempête des 26 et 27 janvier 1884, Meteorologie – Annuaire Soc. Met.. France, 32ème Année
- Symon G.J. (1885): British Rainfall, 1884
1894
- Oppermann A. (1894): Stormen den 12te Februar 1894 og dens virkning i de danske skove. Tidsskrift for Skovvaesen

Measuring wind speed

Forestry
- Danish Forest and Nature Agency (2002): The Danish national forest programme in perspective

General
- H. Thompson (2005): This thing of Darkness. [An account of Captain Fitzroy’s life and the start of the British Meteorological Office]
- RMS (2003): December 1703 Windstorm, a 300-year retrospective
- Swiss Re (2014): The big one: The East Coast’s USD 100 billion event
- Swiss Re (2015): Four earthquakes in 54 days: The New Madrid earthquake series in 1811–1812