**Natural Hazards
and Earth System
Sciences**

A catalog of high-impact windstorms in Switzerland since 1859

P. Stucki[1], S. Brönnimann[1], O. Martius[1,2], C. Welker[1], M. Imhof[3], N. von Wattenwyl[1], and N. Philipp[1]

[1]Oeschger Centre for Climate Change Research and Institute of Geography, University of Bern, Bern, Switzerland
[2]Mobiliar Lab for Natural Risks, Bern, Switzerland
[3]Interkantonaler Rückversicherungsverband, Bern, Switzerland

Correspondence to: P. Stucki (peter.stucki@giub.unibe.ch)

Abstract. In recent decades, extremely hazardous windstorms have caused enormous losses to buildings, infrastructure and forests in Switzerland. This has increased societal and scientific interest in the intensity and frequency of historical high-impact storms. However, high-resolution wind data and damage statistics mostly span recent decades only.

For this study, we collected quantitative (e.g., volumes of windfall timber, losses relating to buildings) and descriptive (e.g., forestry or insurance reports) information on the impact of historical windstorms. To define windstorm severity, normalized and declustered quantitative data were processed by extreme value statistics. Descriptive information was classified using a conceptual guideline. Validation with independent damage information, as well as comparison with wind measurements and a reanalysis, indicates that the most hazardous winter storms are captured, while too few moderate windstorms are detected. Strong storms in the wind measurements and reanalysis are thus added to the catalog.

The final catalog encompasses approximately 240 high-impact windstorms in Switzerland since 1859. It features three robust severity classes and contains eight extreme windstorms. Evidence of high winter storm activity in the early and late 20th century compared to the mid-20th century in both damage and wind data indicates a co-variability of hazard and related damage on decadal timescales.

1 Introduction

Windstorms have accounted for approximately 1/3 of the total losses relating to buildings from natural hazards in Switzerland since 1950 (Imhof, 2011). Storms are also the main damage factor to Swiss forests (Usbeck et al., 2010b).

The damage to buildings and forests from recent, extreme windstorms, such as Vivian (February 1990) and Lothar (December 1999), have been perceived as unprecedented and unanticipated (Bründl and Rickli, 2002; Holenstein, 1994; Schüepp et al., 1994; Brändli, 1996; WSL, 2001).

Public perception of a potentially increasing windstorm hazard (Schmith et al., 1998) motivated several studies on the intensity and occurrence frequency of high-impact storms (e.g., Pfister, 1999). Such knowledge is required for adequate risk analyses and preventive measures, e.g., in the field of forest management or assessment of wind loss potential (Munich Re, 1973, 2002; Bresch et al., 2000; WSL, 2001; Swiss Re, 2006; Kron et al., 2012).

As a consequence, several compilations of high-impact windstorms in Switzerland have been produced (Grünenfelder, 1990; Brändli, 1996; Schiesser et al., 1997b; Pfister, 1999; Bründl and Rickli, 2002). However, these compilations have limitations due to the sparse information available for earlier times, the small number of described events, or restrictions in seasonality and dating (Brändli, 1996; Pfister, 1999). In turn, insurance companies have increasingly set up electronic databases to assess and monitor losses from windstorms (Kron et al., 2012).

Such data show that economic losses from windstorms significantly increased in Switzerland between 1950 and 2010 (Imhof, 2011). Furthermore, a considerable year-to-year variability in windstorm losses becomes apparent, and the losses from Vivian and Lothar in the 1990s clearly dominate the statistics. On a centennial timescale, Usbeck et al. (2010a) found evidence of increasing damage to Swiss forests from winter storms between 1858 and 2007.

Variations and trends in reported windstorm losses can arise from (i) changes in the frequency and intensity of the

hazard itself as well as from (ii) socioeconomic developments, such as changes in population, values at risk and damage susceptibility, and not least from (iii) enhanced awareness and reporting of loss events (Crichton, 1999; Bengtsson and Nilsson, 2007; Usbeck et al., 2010a; Bouwer, 2011; Imhof, 2011; Kron et al., 2012). Hence, attributing windstorm losses to changes in the actual hazard is difficult and must correct for a number of dynamic socioeconomic factors in the first place.

Alternatively, storminess and the potential losses from windstorms are often assessed via proxies (overview in Cusack, 2013). Matulla et al. (2008) assessed storminess for a region north of the eastern Alps from the 99th percentile of pressure-derived geostrophic winds. They found a gradual increase in annual storminess between the 1920s and the 1990s. Wang et al. (2011) used sub-daily surface pressure observations to investigate the occurrence frequency of strong geostrophic winds over western Europe. For winter, they detected a notable increase over an area from the central Alps to Paris from the mid to the late 20th century. In contrast, Schiesser et al. (1997a) found negative trends in winter storm days (≥ Beaufort 7–9) between 1864 and 1995, using historical wind speed observations from Zurich. However, they did not address multi-decadal variability. Welker and Martius (2013) detected pronounced decadal-scale variations of hazardous winds over northern Switzerland for the winter half year and since around 1900. They analyzed the ensemble members of the Twentieth Century Reanalysis (20CR; Compo et al., 2011) and independent wind measurements from the Zurich climate station (Usbeck et al., 2010b).

For summer, Wang et al. (2011) found a decrease in geostrophic wind maxima over the Alpine region from 1878 to 2007 (cf. Cornes and Jones, 2011, for a northeast Atlantic region). To our knowledge, there are no other climatological studies on central European windstorms and their impacts in the summer half year. In fact, it is difficult to capture maximum winds in summer accurately and to assess resulting economic losses. Wind damage in summer is primarily due to high wind gust speeds associated with severe thunderstorms on smaller spatial scales (Imhof, 2011) and is often enhanced by concurrent hail, torrential rain or lightning (Kron et al., 2012).

A direct assessment of potential losses using historical wind measurements is difficult because adequate wind records in Switzerland are very sparse before 1980. In addition, they suffer from possible inhomogeneities such as relocation and change of instruments and changes in observed variables and times (Schiesser et al., 1997a; Matulla et al., 2008; Brönnimann et al., 2012). As an alternative, the global 20CR data set reaches back to 1871 and provides instantaneous wind speed information which is physically consistent in space and time. However, the 2-degree spatial resolution of 20CR is relatively coarse. Thus, the complex orography of Switzerland is not represented realistically, which has considerable ramifications for the representation of local wind

systems such as foehn winds (Stucki et al., 2012; Welker and Martius, 2013).

All these approaches to assess hazard from past windstorms (i.e., based on damage, wind or proxy information) are recognized methods with specific advantages and deficiencies. In this study, we focus on documentary impact data in a first step before using wind observations and reanalysis data for comparison and validation. We primarily use damage information from the insurance industry, forestry reports and other documentary sources. The aim of the study is to establish an extended catalog of high-impact windstorms in Switzerland since 1859. This is the time span for which sufficient information is available (Bütikofer, 1987).

It has to be taken into account that loss data are not perfectly accurate: e.g., dating tends to spread around extreme events, may be missing for small events and damage may have uncertain meteorological reasons (Bouwer, 2011; Imhof, 2011; Kron et al., 2012). It is therefore important to use multiple types of data for comparisons and validation, i.e., damage data as well as wind data.

The article is structured as follows. Section 2 specifies the sources used to compile long-term quantitative and descriptive information about historical windstorm damages and losses. In Sect. 3, we describe the techniques applied to classify serial data, i.e., loss normalization, declustering and subsequent extreme value analyses. In the same section, we introduce a conceptual guideline for indexing descriptive information. Section 4 focuses on the final compilation of the damage-based set of windstorms (denoted CAT-DAM). In Sect. 5, CAT-DAM is compared to independent serial and sporadic impact information as well as to wind data retrieved from 20CR and independent measurements taken at Zurich climate station. Furthermore, we describe the generation of a wind-based set of high-wind days (denoted CAT-WIND) occurring in the winter half year. A summary, recommendations for use of the catalog and basic conclusions are given in Sect. 6.

2   Data

The damage data used in this study have been provided by the insurance industry or have been gathered from documentary sources. Data from the insurance industry are mostly continuous, electronic data sets containing quantitative information and, in part, some descriptive metadata. Data from documentary sources are compiled in our own electronic storm collection database (STC, hereafter). These records are both quantitative and descriptive and mostly sporadic. Wind data are based on 20CR and independent historic wind speed measurements from Zurich. Refer also to Table 1 for a summary of the specific properties of each source.

Table 1. Properties and considered time periods of sources used.

	Origin of data		Spatial extent		Time intervals		Series length		Usage		Impact measure			
	Wind	Damage	Point	Area	Continuous	Sporadic	Centennial	Decadal	Compilation	Validation	Number	Losses	Volume	Indices
Intercantonal Reinsurance (IRV, 1991–2012)		✓		✓	✓			✓	✓		✓	✓		
Munich Re NatCatSERVICE (MRE, 1980–2011)		✓		✓		✓		✓	✓			✓		
Swiss Mobiliar Movable Property Losses (MOB, 1984–2011)		✓		✓	✓	✓		✓	✓			✓		
Vereinigung Kantonaler Feuerversicherungen (VKF, 1941–1984)		✓		✓	✓			✓	✓			✓		
Storm collection database (STC, 1859–2011)		✓		✓		✓	✓		✓		✓	✓	✓	✓
Elementarschädenfonds (ESF, 1982–2013)		✓		✓		✓		✓		✓		✓		
Swiss Mobiliar Building Losses (1984–2011)		✓		✓	✓	✓		✓		✓		✓		
Perils AG (1999–2012)		✓		✓		✓		✓		✓		✓		
AON Benfield (1999–2012)		✓		✓		✓		✓		✓		✓		
European Forest Institute (1962–2010)		✓		✓		✓		✓		✓			✓	
OBS Zurich (Usbeck, et al., 2010b, 1891–2011)	✓		✓			✓		✓		✓				
20CR Zurich (1871–2010)	✓		✓			✓		✓		✓				
20CR CH (1871–2010)	✓													

2.1 Data sets from the insurance industry

2.1.1 Intercantonal Reinsurance (IRV)

The Intercantonal Reinsurance (IRV) is the association of the 19 state-owned cantonal insurances for natural loss and damage to buildings. For these cantons, it has provided statistics of daily storm damage data (number of affected buildings, total financial losses) since 1991.

2.1.2 Association of Public Insurance Companies for Buildings (VKF)

The Association of Public Insurance Companies for Buildings (*Vereinigung Kantonaler Feuerversicherungen* – VKF) is the competencey center of the cantonal fire insurers. Damage statistics are available from 1941 to 1984. They contain monthly sums of storm and total damage for most cantons of Switzerland. From 1968, monthly and annual numbers of affected buildings are also available. The data were digitized and analyzed to find a suitable selection of months with high storm activity in that period, and the most probable storm days were assigned by literature review (see Sect. 2.2.6).

2.1.3 Swiss Mobiliar (MOB)

Swiss Mobiliar (MOB) is the largest private insurer against property loss and the largest provider of insurance for natural loss and damage to buildings in the seven non-state-regulated Swiss cantons. The windstorm-related data reach back to 1984. Movable property and building losses are distinguished. Some of the temporal information is lost in the early periods as large proportions of the losses were assigned to the first day of month. Therefore, the data are split into one monthly and one daily resolved series; the daily series starts in January 1994. The movable property series are used for the setup of the damage-based set of windstorms; the building losses for validation only.

2.1.4 Munich Re's NatCatSERVICE database (MRE)

Data provided by Munich Re cover 148 windstorm events in the period from 1980 to 2011. In their NatCatSERVICE database, "winter storms" (October to March) are distinguished from "tempest storms" and "local windstorms". Overall and insured losses are given per event in million US dollars (original values). We excluded the minor, i.e., non-monetized, loss events. For further analyses, US dollars were converted to Swiss francs by using historical exchange rates which are based on data from the European Central Bank and

several European state banks for rates before the year 2000 (FXTOP, 2014).

2.1.5 Further insurance-related sources

The Swiss fund for non-insurable losses from natural hazards (*Elementarschädenfonds*; ESF) is a private foundation, which has existed since 1901. It makes subsidiary contributions to repair costs from damage that is caused by non-insurable natural events. An event-based electronic data set was provided, spanning 1982 to 2013. Further insurance-related lists of high-impact windstorms in central Europe were available from Perils AG and AON Benfield, two companies involved in international catastrophe loss estimations. These three sources are used for the validation of the obtained results (see Sect. 5).

2.2 Data from documentary sources

2.2.1 Bütikofer (1987)

Bütikofer (1987) collected data on historical forest damages in Switzerland from 1800 to 1960 caused by windstorms and other hazardous weather events such as drought, frost or snow pressure. It is primarily based on administrative and forestry reports and claims to completely cover the major damages in the main forested areas of Switzerland after 1860. The digital version was unavailable, so we redigitized the windstorm information such as date and place, storm type, spatial extent, and damage descriptions.

2.2.2 Lanz-Stauffer and Rommel (1936)

Lanz-Stauffer and Rommel (1936) is a comprehensive study of historical losses from natural perils in Switzerland since around 1860; it had the objective of promoting a nationwide compulsory insurance against natural hazards. The categories of data gathered are similar to Bütikofer (1987).

2.2.3 Brändli (1996)

Brändli (1996) provides a chronicle of severe winter storms in Switzerland since 1515. It uses Bütikofer (1987) and Lanz-Stauffer and Rommel (1936), among other sources. The condensed information was published in Pfister (1999). We also consider their concept for storm severity assessment.

2.2.4 Burger (1932)

Burger (1932) compiled a list of 29 historical storms between 1879 and 1930. The list indicates storm type, wind direction, location and amount of windfall timber. Although the storms only have monthly time stamps, they could all be attributed to specific events except for an unknown storm affecting Graubünden in 1922. In eight cases, Burger (1932) is in agreement with Bütikofer (1987) and Lanz-Stauffer and

Rommel (1936); six windfall estimates are lower, and five have not been used so far.

2.2.5 Swiss Forestry Journal

The Swiss Forestry Journal is the current official publication of the Swiss forestry society. Its archive reaches back to 1850 (details in Bütikofer, 1987) and has been used by the aforementioned authors. Comparisons revealed good documentation, and additional information could be found in a range of articles, among them a list of forest damages related to a windstorm in 1962.

2.2.6 Further documentary sources

The archives of several Swiss newspapers were examined in order to detect exact dates, meteorological features and loss descriptions of the storms from the monthly VKF loss data. The Neue Zürcher Zeitung (NZZ) newspaper offered a range of quantitative windfall information on a windstorm series in 1967 in particular, but also on a number of other events since 1902.

After the windstorm Vivian in 1990, damage publications by the Swiss Agency for the Environment, Forests and Landscape (today mostly integrated into the Federal Office for the Environment) featured lists of historical storm activity. Grünenfelder (1990) contains a figure featuring 14 individual years with the largest forest damages since 1900. Holenstein (1994) listed the years of occurrence of 17 storm events since 1879 with large damage to forests. Schiesser et al. (1997b) adopted these annual damage values and related them to all dates within that year when substantial windstorms occurred.

2.3 Wind information

2.3.1 Historic wind speed measurements from Zurich (OBS Zurich)

We analyze homogenized daily maxima of hourly wind speed measurements from Zurich climate station (operated by the Federal Office of Meteorology and Climatology MeteoSwiss), which are available for the winter half year (October to March) from 1891 to the present (Usbeck et al., 2010b; the data are called OBS Zurich hereafter). OBS Zurich is the only long-term time series of maximum wind data in Switzerland. We use it for comparisons with the damage-based set of windstorms.

2.3.2 Twentieth Century Reanalysis (20CR)

We use version 2 of the 20CR ensemble data set, a global atmospheric reanalysis with 2-degree spatial and 6-hourly temporal resolution spanning 1871 to 2010 (see Compo et al., 2011, for details). For all 56 ensemble members, we computed instantaneous wind speeds averaged over all 20CR
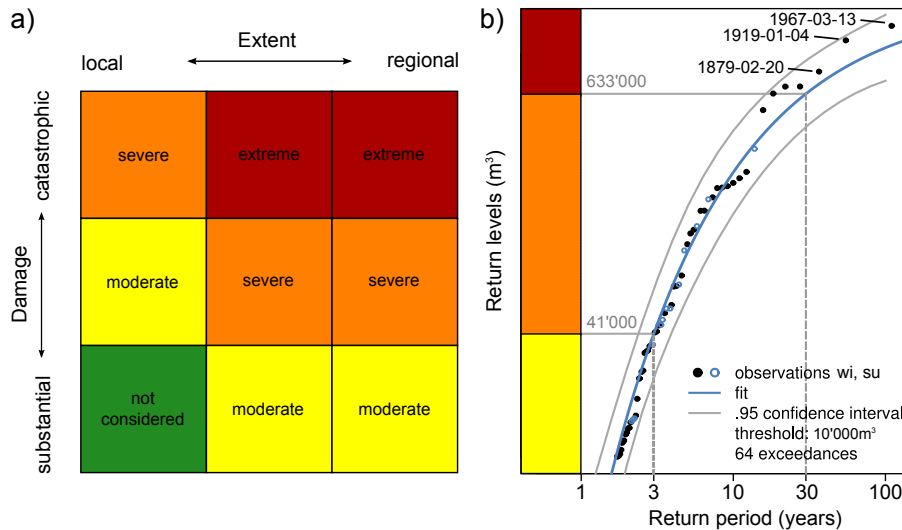
Figure 1. (a) Conceptual guideline for the three-step classification of windstorm severity, based on two-dimension intensity and spatial extent. Minor storms are not considered (green box) for the windstorm catalog. Classes are called moderate (yellow boxes), severe (orange) and extreme (red). See also Table 2. **(b)** Return level plot of the normalized, declustered windfall timber volumes (m^3; black dots for winter, blue circles for summer storms) from the storm collection database (STC) between 1959 and 1967. Return periods (years, *x* axis) of 1, 3 and 30 years set the threshold return levels (m^3, *y* axis) for moderate (here, all 64 exceedances $\geq 10\,000$ m^3), severe (41 000 m^3) and extreme (633 000 m^3) events. The color bar visualizes the analogy with **(a)**. Dates of the three most extreme windstorm events are indicated.

Switzerland grid cells (i.e., the domain 6–10° E, 46–48° N; see Welker and Martius, 2013) for the winter half year. We extracted the ensemble median of these 56 field means. Then, we produced a daily resolved time series (denoted 20CR CH) with the largest value per day. Analogously, a time series for the 20CR grid point closest to Zurich (8° E, 48° N; see Brönnimann et al., 2012) was compiled, hereinafter referred to as 20CR Zurich.

3 Methods

Defining severe and extreme windstorms and finding appropriate criteria to distinguish them is difficult, due to the heterogeneity of the information gathered. A statistical approach was used for quantitative time series (e.g., in currency or timber volumes) from the continuous insurance data sets. Furthermore, sporadic quantitative information found in the forestry or insurance reports were also assembled to quantitative series. Indices were applied to the descriptive information contained in such historical reports. Here, descriptive information is mostly qualitative (e.g., use of superlatives for extreme events) but can also contain valuable, isolated quantitative information.

3.1 Descriptive information

Generally, information on the severity of windstorms becomes more descriptive going back in time. Sporadic quantitative values in the windstorm database (e.g., from Lanz-Stauffer and Rommel, 1936; Bütikofer, 1987; or newspaper

articles) are accompanied with further descriptions of an event. For instance, qualitative attributes such as "devastating effect", "numerous chimneys destroyed" or "very well-known storm" are added.

Such information can be transformed into indices, which describe the deviation from a normal state. Indexing is a state-of-the-art method in historical climatology (Brázdil et al., 2005). Often, a three-level classification is used (Pfister, 1999; Brázdil et al., 2005) based on one to several dimensions. For instance, the storm severity indices by Lamb and Frydendahl (1991) include maximum wind speeds, affected area and duration of damaging winds.

For this study, we opted for a three-level classification based on two dimensions. More than three classes were not feasible because storm severities are hard to discriminate from descriptions, and fewer classes would neglect the discrimination potential of quantitative data. We use two dimensions, which are storm intensity and spatial extent. For this, we refine a classification scheme by Brändli (1996; cf. Pfister, 1999; for historical winter storms in Switzerland) with information from BAFU (2008), Usbeck et al. (2010a) and the Beaufort Scale (Table 2).

The conceptual guideline given in Fig. 1a is the visual translation of Table 2. Minor windstorms with isolated damage or extent are not considered. *Moderate* windstorms can be of larger spatial damage extent or larger local intensity. Damage from moderate windstorms comprises numerous windfall timber events and substantial damage to roofs, windows, cultivated land and structures. Typical key words of this class are "numerous", "considerable", "significant",

Table 2. Conceptual guideline for indexing of windstorm damage*.

Index	Not considered	Moderate	Severe	Extreme
Summary	Isolated damage to light structures or trees	Numerous instances of smaller damage to light structures or trees; some greater damage to solid structures	Numerous instances of greater damage to solid structures over larger areas	Enormous amount of damage to solid structures over very large areas/nationwide
Spatial extent	Isolated	Local	(Sub-) Regional	Regional to national
# Cantons		3–5 ($\sim$ surface area)	4–9 ($\sim$ surface area)	> 9
Beaufort Scale	< 9	> 9	> 10	> 11–12
Linguistic terms	Isolated damage	Substantial damage, significant, serious	Devastating damage, very significant, very large	Catastrophic damage, superlatives, in living memory
Tiles, windows, chimneys		Numerous instances	Vast area of numerous instances of damage, hundreds or thousands	
Stables, solid buildings		A number of stables, a small number of houses	Numerous houses, capsized boats	> 1 ‰ of total actuarial values
Quays, massive walls		Some damage	Heavy damage to quays	Collapses
Trees, forests		Numerous trees	Strong trees, thousands of trees, entire forest plots devastated, widespread uprooting and splintering	Entire forests devastated in numerous places
Windfall timber m^3 (equivalent to 2010)		Several thousand m^3 10 000–41 000	Many thousands m^3 41 000–633 000 (Usbeck et al., 2010b: 70 000)	> Annual harvest > 633 000 (Usbeck et al., 2010b: 500 000)

* Adapted from Brändli (1996), Pfister (1999), Usbeck et al. (2010a), Lamb and Fyrendahl (1991), BAFU, (2008) and the Beaufort Scale. See the Supplement for three examples showing how indexing is conducted.

"extraordinary" and similar. *Severe* windstorms can either be locally very intense (e.g., tornadoes) or have a large footprint from hurricane force winds which destroy buildings and numerous, entire forest plots. Key words comprise "devastating", "terrible", "massive", "enormous" and "huge", among others. *Extreme* storms have regional to (supra-) national extent and, hence, leave a very large documentary footprint of the windstorm "catastrophe". Insured losses are typically > 1 ‰ of the total actuarial values, and nationwide windfall typically exceeds an annual timber harvest.

As an example of such intersubjective assignment, windstorms with descriptions in Lanz-Stauffer and Rommel (1936) as "well-known storms" in 3 to 5 cantons were assigned index 1 (moderate); 6 to 9 cantonal entries were given index 2 (severe); and ≥ 10 cantonal entries were given index 3 (extreme). This list was used for the validation of the other documentary information. In addition, the classification by Brändli (1996) of 20 storms or storm series between 1875 and 1995 was reviewed and used to validate and refine the documentary classification. The classified descriptive information for three examples is given in the Supplement.

3.2 Quantitative data

After adjustments for socioeconomic changes over time, sufficiently large quantitative time series (i.e., containing ≥ 25 to 30 extreme values) of damage and wind data allow the use of extreme value statistics in order to assess return periods

of high-impact windstorms (Bengtsson and Nilsson, 2007; Della-Marta et al., 2009) or probable maximum losses (e.g., Brodin and Rootzén, 2009).

3.2.1 Normalization of economic loss

Our catalog will reach back to the 19th century. Since then, there have been large changes in the value distribution in urbanized, agricultural and forested areas. The changes are most obvious in inflation but also in population density and wealth. Changes are furthermore manifest in the growing number, size and construction quality of buildings, increasing actuarial values and changing forest management systems. Such dynamics must be accounted for by normalization, i.e., the adjustment of past losses to near-present levels of exposed wealth (Pielke and Landsea, 1998; Brodin and Rootzén, 2009; Barredo, 2010; Usbeck et al., 2010a; Bouwer, 2011; Imhof, 2011; Kron et al., 2012).

However, there is also considerable potential for introducing additional bias. Normalization attempts mostly assume a spatially homogeneous development of the values at risk, which is normally not the case, and they cannot account for changes in vulnerability in most cases, such as increasing demands on the facilities and quality of buildings (Imhof, 2011). On the other hand, statistical bias can easily be introduced by improper or overadjustments, which can in turn hamper the correct interpretation of the resulting values.

In this study, the original loss data were multiplied by the ratio between a defined exposure value at a particular time and a year-of-2010 exposure value. This yields loss data which are normalized to year-of-2010 levels of exposure. We restricted the adjustments to well-recognized modifications and to no more than two serial data manipulations (e.g., currency followed by construction cost adjustments for original values in USD).

3.2.2 Construction costs vs. actuarial values

There are several approaches for inflation-related normalization. We tested two methods, namely total actuarial values versus construction costs.

The first method involves dividing current windstorm losses by the total current actuarial value, which gives loss ratios. These can be multiplied by year-of-2010 total actuarial values. The results are probable amounts of loss under present-day portfolio conditions.

The second method is a combination of two historical construction cost indices for inflation correction (Imhof, 2011). For the period prior to 1919, we used the wholesale index (for construction material) provided by the Research Center for Social and Economic History of the University of Zurich (HISTAT, 2014). Starting from 1920, we use the construction price index (*Baukostenindex*, BKI) provided by the Zurich statistics office (2014). The two indices are almost identical

in the overlapping period from 1920 to the 1960s, and then the BKI gradually becomes $\leq 10\%$ larger.

We compared the original with adjusted annual storm and total losses between 1941 and 1984. The BKI method has less effect on the distribution of the most hazardous years than the actuarial values method. The BKI method adjusts losses from buildings destroyed then to present-day reconstruction costs. Hence, it most probably underestimates the damage potential of past storms to the present, larger building stock. The actuarial method increased normalized losses by up to several orders of magnitude because it is sensitive to increases in building stock. It simulates present-day damage to a building stock that was much smaller in reality and differently susceptible to storms. Therefore, it may largely misestimate the damage potential of past storms.

In order to avoid systematic, very large overcorrection, only the conservative BKI adjustment was applied in the present study. Moreover, the total actuarial value is not available for all series. As a result, we have to accept systematic underestimations of losses. In fact, the corrected losses in years with low to average storminess remain approximately constant until around 1960, while, in the more recent decades, the costs gradually increase despite the adjustment. This indicates good correction by the applied model until 1960 and also indicates that additional cost-driving dynamics in recent periods are not captured.

3.2.3 Total forest area and growing stock

An analogue procedure was applied to the collected amounts of windfall timber in cubic meters. In fact, the total forested area in Switzerland increased by 22 % between 1880 and 2000 (Ginzler et al., 2011), but large local differences are found, ranging from a reduction of $> 35\%$ in some areas of the Jura mountains to an increase of $> 250\%$ in parts of southern Switzerland.

In a first step, windfall timber was therefore attributed to a forestry region and then specifically normalized following Ginzler et al. (2011). In a second step, the overall volume estimates per event were corrected for stock density using the adjustment curve provided in Usbeck et al. (2010a). Indeed, mean forest density in Switzerland since the mid-19th century increased from about 120 to 369 $m^3 ha^{-1}$ in 2011 (Kurz et al., 1998; Usbeck et al., 2010a; BAFU, 2012). Again, regional differences are probably large, but no information on historical stock densities per forestry region was available.

3.2.4 Uncertainties of estimation

There are further causes of uncertainty in the estimates of accrued losses. For instance, uncertainty comes from the conversion of old units such as *Klafter* (a solid measure for piled wood) or of the number of trees into cubic meters of wood. We converted numbers of trees to windfall timber volumes assuming mean Swiss midland and prealpine tree sizes of

27 m and a form factor of 0.47 (following Prodan, 1965). Calculation with the approximate formula following Denzin (see Kleinn, 2013) yielded a mean diameter of 45 cm at 1.3 m above ground and $2 \, \text{m}^3$ of windfall timber per stem. Another effect is known as loss history (Kron et al., 2012), which can stem from misestimation, new observation of dispersed damage or from the integration of secondary storm effects such as bark-beetle attacks a couple of years later. For instance, Grünenfelder (1990) estimated 3.5 million m^3 of windfall timber immediately after storm Vivian in February 1990, while, a few years later, Holenstein (1994) published an estimate of 4.9 million m^3 on behalf of the same federal authority.

3.2.5 GPD/POT

Time series of normalized losses from windstorms show statistical particularities. For instance, the claims from the most extreme storms may account for a very large proportion of all claims (e.g., $> 50\%$ in a 12-year period; Rootzén and Tajvidi, 1997). Such extreme values form the heavy tail in the statistical distribution. It has been shown that the general Pareto distribution (GPD) is a suitable model for a wide range of extreme windstorm-related variables such as wind speeds (Ceppi et al., 2008; Della-Marta et al., 2009), windstorm losses (Rootzén and Tajvidi, 1997; Brodin and Rootzén, 2009) or windfall timber (Bengtsson and Nilsson, 2007), besides many other applications (e.g., Coles, 2001; Sanders, 2005).

Here, we use the peak over threshold (POT) method, where GPD is applied to threshold exceedances. This has several advantages for this study. First of all, the POT method uses the information of all available exceeding samples, i.e., more than one data point per time window as with the block maxima method. Secondly, POT is suitable for event-based data. For instance, MRE can be thought of as a set of serial, but pre-filtered losses. Thirdly, we can assume independence of samples as the vast majority of the events occurred several days apart. In fact, shorter time intervals are mostly neglected in event-based data sets. Assuming temporal independence in most instances, no declustering was applied to the monthly sums of losses and number of affected buildings by VKF and MOB. However, we applied a minimum separation filter of 2 days for the declustering of daily resolved data (IRV, MOB). Within a sequence of storm days, only the largest daily damage is chosen as an indicator of storm severity. This attenuated overrepresentation of very persistent storms and the related spreading of claims around a peak day (Imhof, 2011).

At this stage of the study, the magnitude of economic impacts from windstorms was assessed without discrimination of meteorological processes. Nevertheless, all quantitative series contain a sufficient number of independent episodes from the season with the largest damage values (winter half year in this case; shown in Fig. 1b); this assures identical distribution (i.e., their probability distributions should be approximately identical; see Coles, 2001).

3.2.6 Threshold selection

Thresholds used with extreme value statistics are required to be sufficiently large to ensure meaningful behavior of the exceedance values, but leaving statistically reasonable sample sizes. The selected threshold should approximately reflect several underlying asymptotic assumptions (e.g., independent and identically distributed (i.i.d.) values; Coles, 2001). Particular considerations are that (i) the scale and modified shape of the fitting curve should be independent of the chosen threshold, i.e., stable above the chosen threshold; (ii) the behavior of the mean excess of values with increasing thresholds should be approximately linear. To meet these requirements, threshold selection with POT was conducted by the use of diagnostic plots according to Coles (2001), and to applications in Ceppi et al. (2008). Similar thresholds for comparable variables in other series were selected where reasonable.

3.2.7 Return periods

Three classes of windstorm severity were defined according to the return periods of accrued losses, number of affected buildings and volume of windfall timber (Fig. 1b). Values with a return period of less than 1 year represent minor windstorms, which were not considered for the catalog. Values related to return periods between 1 and 3 years represent *moderate* windstorms. The class associated with return periods between 3 and 30 years is called *severe*. Events with a return period of 30 years and more are called *extreme*. A time period of 3 decades may approximately reflect the "societal memory" of extreme natural events (Pfister, 2009).

3.2.8 Subjective classification

A deviation from this procedure was necessary for a small sample of 20 normalized losses to forested areas over the period 1860 to 1927 (collected from Brändli, 1996, and Lanz-Stauffer and Rommel, 1936) and an additional loss estimation for a windstorm in 1967 (from the NZZ newspaper archive). The windstorms of February 1879, January 1919 and February 1967 were subjectively classified as extreme, and the average loss from these three events was chosen as a reference. The classes of the remaining 18 non-extreme windstorms were then discriminated by two thresholds, which were defined as being one (two) order(s) of magnitude lower than the reference.
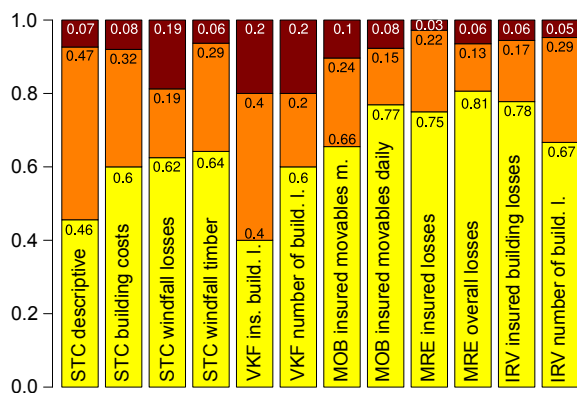
Figure 2. Proportion of moderate (yellow), severe (orange), and extreme (red) windstorm severity classes per partial series (refer Sect. 2 or Fig. 3 for abbreviations). In the labeling of the diagram, "ins.", "build.", "l." and "m." stand for "insured", "building", "losses" and "monthly", respectively.

4 The damage-based windstorm data set

4.1 Partial series

The applied procedures yielded 12 partial time series of classified windstorms. Figure 2 depicts the proportion of classes for each series. It is salient that the emphasis of descriptive information is on severe windstorms at the expense of moderate windstorms. This systematic bias is reflected in all sporadic series from the storm collection database (STC series, see Sect. 2) and can be explained by the concept of the historical perception threshold, i.e., an underrepresentation of smaller and moderate windstorms in the documentary sources. The quantitative series deliver quite similar proportions and within-series variations are small. There are two exceptions, though. In one case, the overrepresentation of extreme windstorms in the relatively short windfall loss series is a result of the subjective classification (see Sect. 3.2.8). In the other case (the two VKF series), the classified monthly data were only considered if they could be linked to a windstorm event by literature research. Only 15 (5) mostly severe and extreme windstorms in 44 (17) years were selected, which explains the classification offset.

4.2 Composite series

The composite series generated from the partial series is called the damage-based windstorm data set (CAT-DAM). The final class indices are set by the rounded mean of eight weights. These weights are the indices of the four sporadic STC series and the index averages within the four continuous sources (IRV, MRE, MOB and VKF).

CAT-DAM is displayed in the Supplement and summarized in Fig. 3. It comprises 202 windstorms; 8 of these are extreme, 59 severe and 135 moderate. In winter (summer), there are 6 (2) extreme, 43 (16) severe and 70 (65) moderate

windstorms. Based on CAT-DAM, extreme winter storms (of a total of 119 winter storms) occurred on 20 February 1879, 4 January 1919, 23 February 1935, 23 February 1967, 26 February 1990 and 26 December 1999. All storms except for 1919 (foehn) were storms with westerly winds, which is also the prevailing weather type during all classified winter storms (not shown). Extreme summer windstorms occurred on 8 June 1861 and 1 July 1987. The classification of the former storm is based on one series only, which is the construction-cost adjusted series of building losses. Literature research (primarily Lanz-Stauffer and Rommel, 1936) revealed that the losses probably included an unknown share from hail and flooding. Also, the latter storm was a thunderstorm with concurrent hail, intense precipitation and flash floods (e.g., Muriset, 2003).

Periods of high windstorm frequencies and intensities are found both in the early and late decades of the 20th century. Decades with low windstorm severity were the 1930s to 1950s and the 1970s; severity was also less distinct around 1870. CAT-DAM features actual gaps in high-impact windstorm activity during these periods. Such peculiarities require a thorough validation with independent data sets, which is provided in the next section.

5 Validation

A range of sources has been unused so far because of large spatial or temporal data inhomogeneities (Table 1). For instance, the building loss data provided by MOB are limited to the seven Swiss cantons with free-market building insurance. The available wind data sets are continuous over a centennial timescale but are limited in their spatial representation. However, such sources are valuable when validating the windstorm catalog.

Specifically, we perform intra-composite verifications and comparisons to modern-period data to assess (i) the accuracy of the three-level classification and (ii) the completeness and accuracy of the windstorm catalog. Comparisons to long-term wind information (for the winter half year) address (iii) the concurrence of the damage- and wind-based windstorm selections and (iv) the variability of windstorm occurrence. We also infer a wind-based data set of winter storms (CAT-WIND).

5.1 CAT-DAM compared to damage information

5.1.1 Intra-composite verification

The accuracy of the proposed windstorm severity classes is verified by applying extreme value analysis to the weighted means of the composite series (see Sect. 4.2). Considering the rather ordinal nature of the weighted means, the grouping of the classes is excellent (Fig. 4). All extreme winter storms are correctly classified; and only winter storm Vivian is on the threshold of index 2 (severe). The threshold
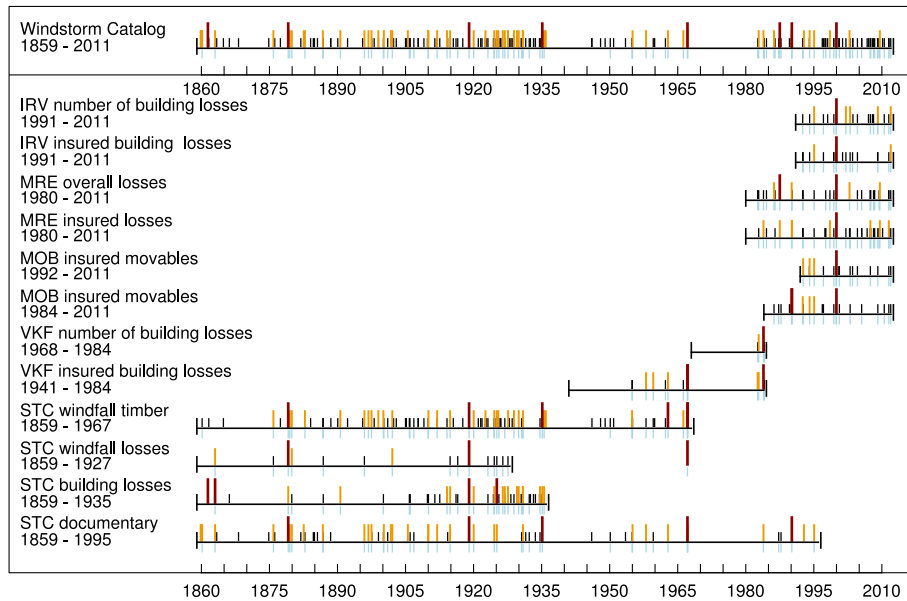
Figure 3. Compilation of the damage-based data set of windstorms (CAT-DAM): temporal distribution and severity classes of windstorm damage in the composite series (upper panel) and in the 12 contributing partial series (lower panel). Moderate windstorm events are symbolized by black vertical bars (yellow in Figs. 1 and 2), severe events are marked in orange and extreme events are red. Blue negative tips indicate concurrences in the partial series. Black horizontal distance bars indicate the analyzed period per series. Abbreviations of the sources are as follows: IRV – Intercantonal Reinsurance; MRE – Munich Re NatCatSERVICE; MOB – Swiss Mobiliar; VKF – Vereinigung Kantonaler Feuerversicherungen; STC – storm collection database from literature review. See text for details.
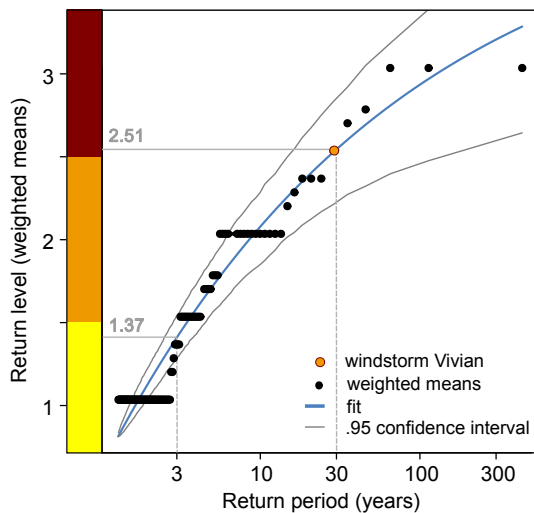
Figure 4. Return level plot using the weighted means of the CAT-DAM classification (dots), e.g., the weighted mean for windstorm Vivian (orange dot) is 2.5. Grey horizontal lines indicate recalculated return levels as a function of return periods of 3 and 30 years (grey dotted vertical lines). Filled boxes are as in Fig. 1.

return levels are well reproduced (at 1.4 for severe and 2.5 for extreme windstorms). Obviously, the approach of expressing severity levels depending on return periods (e.g., severe windstorms having a return period between 3 and 30 years)

ensures overall consistency in the classification, even if applied to partial series over differing periods of time and differing parameters.

Moreover, the conceptual guideline is very compatible with the return period approach. For instance, the tornado in August 1890 is considered a local, but catastrophic event following the conceptual guideline and, in fact, lies in the upper range of severe windfall losses with $> 300\,000\,\mathrm{m}^3$ of timber. Even assuming large uncertainty in the windfall estimate, it was clearly a severe summer storm. We infer that the three-level classification is a robust method that provides a meaningful discrimination of windstorm severities.

5.1.2 Comparison to independent windfall timber data

The accuracy of the classification back to 1962 is furthermore validated with indications of damage to Swiss forests for 11 destructive storms since 1962, provided by the European Forest Institute (details in Gardiner et al., 2010; windstorm lists are available at www.efiatlantic.efi.int/portal/databases/forestorms/). We compared these values to the weighted means in CAT-DAM (see Sect. 4.2). The data sets agree on the classification in 9 out of 11 windstorms (Fig. 5a). Calvann (January 2003) and a windstorm in November 1962 have a lower class in CAT-DAM than in Gardiner et al. (2010). It seems that Calvann was more destructive to forests than to buildings, as it was classified as moderate in four out of five partial series. Similarly, the
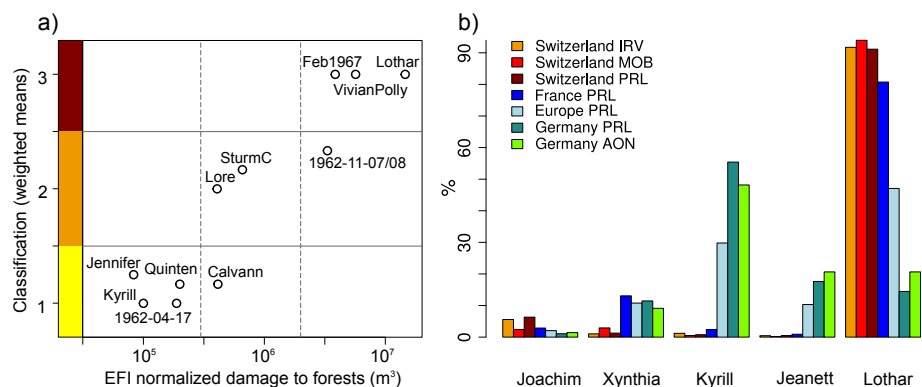
Figure 5. (a) Weighted means of the CAT-DAM classification with regard to normalized (year-of-2010 levels) damage to Swiss forests for 11 windstorms since 1962 (circles; see Sect. 5.1.2 for details) from the European Forest Institute EFI (Gardiner et al., 2010). Filled boxes as in Fig. 1. Grey dotted lines visualize an ideal grouping. **(b)** Relative losses (%) from five hazardous windstorms (see Sect. 5.1.4) since 1999 in different countries of Central Europe and over the continent with regard to the total losses from the five windstorms. The bars of each color add up to 100 %. Abbreviations of sources are as in Fig. 3; in addition, the following two abbreviations are used: PRL – Perils AG; AON – Benfield (see text for details).

windstorm in November 1962 was classified as extreme in the STC windfall timber series but not in two other series. In any case, a higher rating for windfall timber would not have led to a higher overall rating. This and the fact that no overrating is evident strongly confirm the robustness of the classification for winter storms since the 1960s.

5.1.3 Comparison to ESF/MOB data sets

The completeness of CAT-DAM back to the early 1980s is checked by comparisons with two independent data sets: damage data from ESF and the building loss data from MOB. Both were treated in the same way as all other quantitative series (Sect. 3.2). When a windstorm is listed in both validation data sets with at least one severe classification, it is also recorded in CAT-DAM (not shown) in 11 out of 12 instances. The exception is a summer storm on 29 July 2005, which resulted in substantial damage from hail and heavy rain with an unknown contribution from wind gusts (IRV, MRE, STC). In summary, important severe and extreme winter storms since around 1980 are listed in CAT-DAM, while a few high-impact summer storms may be missed.

5.1.4 Comparison to international catalogs

The comparability of CAT-DAM to international windstorm classifications is evaluated with loss data from five recent winter storms: Joachim (December 2012), Xynthia (February 2010), Kyrill (January 2007), Jeanett (October 2002) and Lothar (December 1999). Loss data by IRV and MOB are compared to independent data from Perils and AON Benfield (see Sect. 2 and Table 1).

The relative fraction of losses from each storm with regard to the total losses from all five storms is shown in Fig. 5b. On the one hand, the estimated country-specific fractions

of losses are within 7 % in all data sets and even lower for Switzerland. This indicates that MOB and IRV data, used for constructing CAT-DAM, represent windstorm losses in Switzerland well.

On the other hand, supranational windstorms are only partially captured, as the impacts from the same winter storm can differ strongly even between neighboring countries. For instance, losses from Kyrill were highest (> 50 %) in Germany but small in Switzerland and France. This is due to topographical and meteorological particularities (e.g., orographic deflection of air flow, evolution of the storm tracks), and also due to differing methodologies and variables analyzed to produce the windstorm sets. For instance, the wind-field-based storm catalog by Heneka et al. (2006) for Baden-Wuerttemberg, a similar-sized area adjacent to northern Switzerland, and CAT-DAM only co-list 5 out of the strongest 20 windstorms.

5.1.5 Comparison to further impact information

Most existing compilations consider windstorms during the winter half year only, as the detection, classification and validation of summer storms involves considerable uncertainties. Typically, summer storms are convective storms with regional to local impact. This means that some of the smaller-scale summer storms were presumably not detected in literature on storm impacts or the coarse measurement network. Besides wind gusts, concurrent heavy precipitation or hail may contribute to the overall damages. A comparison of major hail days in Switzerland between 2003 and 2010 to the summer storms in CAT-DAM revealed that 13 out of 15 summer windstorms during this period co-occurred with a major hail event (L. Nisi, personal communication, 2014). Thus, losses attributed to summer windstorms by literature reviews or insurance databases presumably contain large losses from
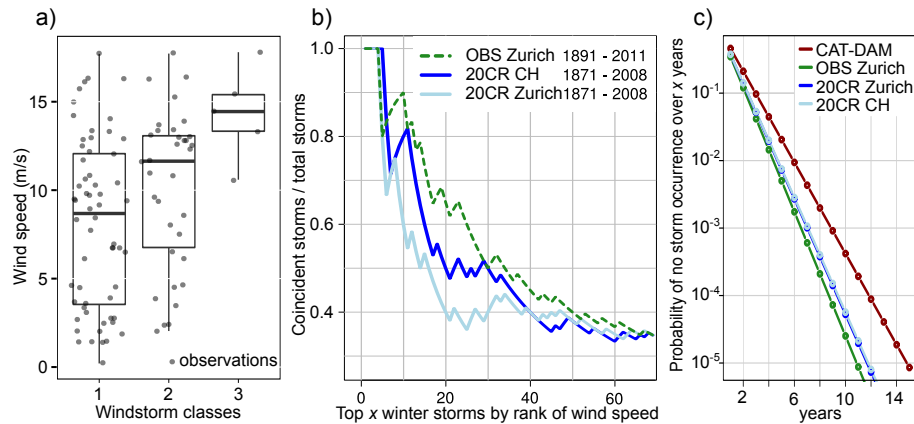
Figure 6. (a) Boxplots (box gives median and interquartile range, whiskers $\pm 1.5 \times$ interquartile range) of the largest mean hourly wind speed at OBS Zurich (1891–2011, October to March; observations are represented as grey dots) as a function of windstorm class in CAT-DAM. **(b)** Ratio of coincidental windstorms to total windstorms (y axis) as a function of the days with the highest wind speeds at OBS Zurich and in 20CR from October to March (x axis). **(c)** Probability that no windstorms occurs during x years in the four considered windstorm series, assuming a Poisson point process.

hail and other coincident hazards. At times, the terminology describing the hazard is rather vague, and the meteorological causes of storm damage in summer remain open. It follows that the convective summer storms in CAT-DAM may incorporate damage from multiple weather phenomena. The uncertain contribution of wind gusts must be considered when analyzing the summer samples of the catalog.

5.2 CAT-DAM compared to wind information

Historical windstorms occurring during the winter half year are compared to three continuous, long-term wind data sets. These are OBS Zurich, 20CR CH and 20CR Zurich (see Sect. 2.3 for details).

5.2.1 Windstorm classes in CAT-DAM compared to OBS Zurich

To assess concurrence, the windstorm classes of CAT-DAM are compared to OBS Zurich. In general, a high index concurs with high-wind-speed observations (Fig. 6a). However, the range of mean wind speeds at OBS Zurich within a class (e.g., approximately 11 to 18 m s^{-1} for extreme windstorms) is considerable. Obviously, not all severe winter storms in Switzerland result in extreme wind speeds at Zurich and vice versa. This is particularly true for foehn storms: none of the 11 documented foehn storms in CAT-DAM since 1900 resulted in extreme values at OBS Zurich (see also Brönnimann et al., 2012 for the 1919 case).

5.2.2 Concurrence of CAT-DAM with ranked wind speeds

The concurrence of high-wind days in OBS Zurich, 20CR CH and 20CR Zurich with regard to CAT-DAM is examined

next. The storm days in the three wind series are ranked by wind speed, and the ratio of co-occurrences in CAT-DAM for the top x windstorm days is calculated (Fig. 6b). From this perspective, concurrence is largest between OBS Zurich and CAT-DAM. The four windiest days in each of the three wind series are all in CAT-DAM. Nine (15) out of the top 10 (30) high-wind days in OBS Zurich and in 20CR CH still coincide with windstorms in CAT-DAM, and then the ratio drops to approximately 1/3 of the storm days. We infer from this that, except for foehn storms, the most hazardous (i.e., the extreme and highest-ranked severe events) large-scale windstorms in (northern) Switzerland are reflected in OBS Zurich and in 20CR CH.

5.2.3 CAT-DAM compared to classified wind speeds in OBS Zurich and 20CR

For the following comparisons, we apply the GPD/POT methodology to the wind speed data, classify the data according to their return periods (see Sect. 3) and present them in the same way as the damage data for the composite series.

Figure 7 shows the concurrence of winter storms in the wind series (OBS Zurich, 20CR Zurich and 20CR CH) with regard to the damage-based data set of windstorms (CAT-DAM). The 119 winter storms since 1859 in CAT-DAM are the smallest sample relative to the series length. In addition, CAT-DAM features fewer moderate windstorms and more severe to extreme windstorms than the wind series.

Distributions of high-wind days within the two 20CR time series are closely related. Moreover, they are similar to the distributions of high-wind days in OBS Zurich, except for two short periods around 1900 and 1980 (see also Brönnimann et al., 2012). This indicates good quality of all three
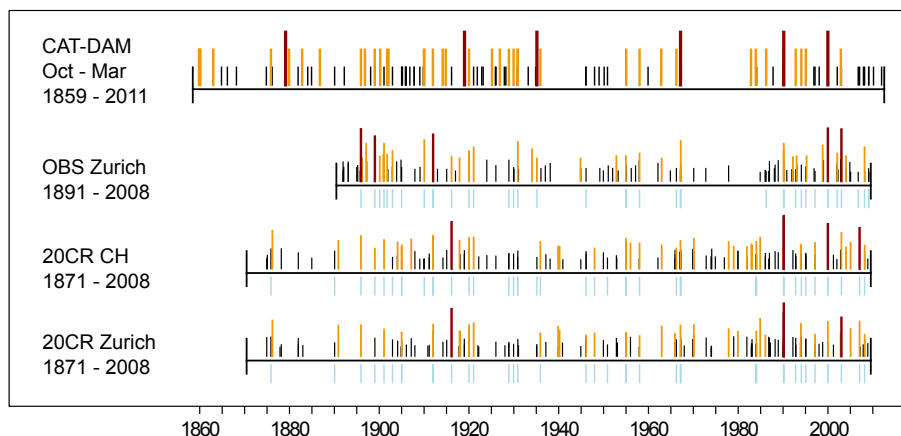
Figure 7. Top to bottom: classified winter (October to March) storms from the damage-based data set (CAT-DAM); classified windstorm days from wind observations at Zurich station (OBS Zurich), from 20CR CH (six grid points over Switzerland) and from 20CR Zurich (grid point near Zurich). Horizontal and vertical bars are as in Fig. 3; in addition, the bar lengths of the wind series indicate scaled wind speeds.

wind series and confirms their usefulness for comparisons to CAT-DAM.

However, there are some prominent omissions in 20CR, such as the well-documented westerly storm in February 1879 or the extreme foehn storm in January 1919 (Brönnimann et al., 2012). This may be due to the coarse horizontal resolution of 20CR and increasing uncertainties going back in time.

On the other hand, OBS Zurich and 20CR overestimate a number of winter storms with rather isolated impacts around and north of Zurich. For instance, windstorm Kirsten, on 12 March 2008, was a minor storm according to our damage information. However, it is considered severe in 20CR (moderate in OBS Zurich) due to high winds over the northernmost parts of Switzerland. This explains why 5 of 24 high-wind days (defined in this case as concurrent severe or extreme windstorms in OBS Zurich and 20CR) are not found in CAT-DAM.

We infer from these comparisons (refer also to Sect. 5.1) that CAT-DAM most likely contains all hazardous (i.e., all extreme and practically all severe) winter storms since 1859, while some moderate storms may not be captured.

On decadal timescales, the concurrence of the wind series with CAT-DAM is good back to 1935. The lack of severe windstorms in CAT-DAM during the 1970s and around 1940 is reflected in OBS Zurich and 20CR, although the wind series feature some moderate to severe winter storms. This indicates the omission of moderate winter storms and, conceivably, a severe winter storm in CAT-DAM during these periods, which could be due to conservative normalization and the inclusion of the VKF loss data. Nevertheless, we see low storminess over Switzerland during these decades in both the wind and damage data sets.

Differences become larger going further back in time. For instance, the frequency and intensity of winter storms in the

1920s to 1930s might be overestimated in CAT-DAM due to the overrepresentation of these decades in Lanz-Stauffer and Rommel (1936). Lower concurrence among the time series prior to around 1895 probably reflects increasing overall uncertainties.

5.3 The wind-based data set of winter storms

It might be important to minimize the possible omission of the strongest storms for specific uses of the windstorm catalog. For such purposes, we produced a wind-based data set of winter storms from OBS Zurich and 20CR called CAT-WIND (see Supplement). It features the 30 days with the largest mean hourly wind speeds in OBS Zurich ($\geq 14.7\,\mathrm{m\,s^{-1}}$) and the 30 days with the largest wind speeds in 20CR (based on averaged ranks of wind speeds in the 20CR series). The same declustering as for CAT-DAM was applied. CAT-WIND contains 54 windstorms, and 31 of these are additional to CAT-DAM. Windstorms occurring during the summer half year are not included due to low representativity of the available long-term wind data for summer storms over Switzerland. Considering the top 30 high-wind days is a tradeoff between a meaningful extension (i.e., avoiding redundancy with CAT-DAM; see Fig. 6b) and a representative selection of the largest high-wind days only.

5.4 Decadal-scale variability in storminess

A major purpose of the windstorm catalog is to provide an extended number of consolidated windstorms for climatological and meteorological studies, e.g., knowledge about temporal variations of windstorm occurrences could be used for extrapolations of future storminess. For a first assessment of historical variations, we considered the windstorm occurrences as a Poisson point process (Mailier et al., 2006; Della-Marta et al., 2009). We calculated the probabilities

of no windstorm occurring during x subsequent winter half years (Fig. 6c). In theory, storm-free periods of more than 5 years are very unlikely ($< 1\%$) for each of the four windstorm series and storm-free periods of a decadal scale are extremely unlikely ($\ll 1\%$). However, the longest period without windstorms in CAT-DAM (OBS Zurich) lasts 15 (6) winter half years around 1940 and 9 (6) winter half years between 1967 and 1984. In 20CR CH (20CR Zurich), the longest period without a high-wind day between October and March lasts 6 (4) years. Long periods with low storminess in both wind- and damage-based data sets can hardly be explained by randomness, and, as shown above, undersampling cannot fully explain the low storminess in CAT-DAM either. Hence, there is a strong indication that a climate-driven variation in windstorms over Switzerland manifests itself in a decadal-scale variability of windstorm losses.

Moreover, the decadal-scale windstorm variability largely exceeds trends. This is established by counting the number of storms per winter half year in each series or by weighting the storm counts with their severities (e.g., double weight for index 2 storms, triple for index 3). Subsequent logit regression for count data reveals only small and nonsignificant trends (not shown).

The emphasis on decadal-scale variations of windstorms over Switzerland is in line with earlier studies that found pronounced decadal variations in central European storminess (e.g., Matulla et al., 2008; Welker and Martius, 2013, 2014).

From a historical perspective, Pfister (2009) defined the disaster gap as a period of rare loss-intense natural hazards in Switzerland from the late 18th century to the 1970s, and he inferred a societal loss of disaster memory. In this context, our gaps in the occurrence of high-impact windstorms fit the disaster gap. More importantly, however, they may reflect a decreased societal interest in the decades prior to 1990 (windstorm Vivian) in documenting the rather moderate impacts from windstorms.

6 Summary and conclusions

We present a catalog of approximately 240 high-impact windstorms (120 winter storms) in Switzerland since 1859, featuring three robust severity classes.

The catalog provides a basis for a range of practical and scientific applications, such as analyses of potential wind hazard. A methodological benefit may be found in the novel combination of extreme value statistics (e.g., applied to normalized windfall timber volumes) with traditional historical indexing procedures (e.g., applied to descriptive damage information) for impact assessment. Particularly, return periods from GPD/POT can be used as a semi-objective proxy for windstorm severity over a range of physical and economic parameters and over differing time periods. Uncertainties may arise from data availability and quality and

normalization and fitting procedures, among others, and require error-tolerant classifications.

The catalog most likely contains all hazardous (i.e., all extreme and practically all severe) winter storms since 1859, while some moderate storms may not be captured, particularly during the 1940s and 1970s. There is possible oversampling from around 1920 to 1935, and the completeness of the catalog becomes more uncertain for the 19th century. To compensate, a wind-based set of windstorms (CAT-WIND) additionally provides the windiest winter storm days derived from observations at Zurich and 20CR.

The set of summer storms includes convective storms with concurrent, superimposed and not necessarily wind-induced damage. Moreover, a number of moderate summer storms are probably missed. Therefore, the windstorm catalog cannot be considered as comprehensive for the summer season.

We find concurrent periods with enhanced or reduced winter storm activity in all damage as well as wind data sets considered here, although there are some incoherencies prior to 1890. Storminess in Switzerland during the 20th century was high until around 1920, then low to medium until around 1970. The latest 40 years were characterized by a gradual increase from the calm 1970s to the extreme storms in the 1990s and a quieter situation since. We presume that particularly the early 20th century could have been as stormy as the last few decades. The decadal variability is present in both the wind data (i.e., the hazard) as well as the loss and damage information.

The present article sets the historical context for recent natural hazard events, and it extends traditional compilations. Hence, it may contribute to the understanding of socioeconomic factors (e.g., monetized material values, societal perceptions of losses and impacts) versus processes in nature (e.g., climate variability) that add up to a moderate or an extreme windstorm event.

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References

BAFU (Bundesamt für Umwelt): Sturmschaden-Handbuch. Vollzugshilfe für die Bewältigung von Sturmschadenereignissen von nationaler Bedeutung im Wald., Umwelt-Vollzug, Bundesamt für Umwelt, Bern, 0801, 241, 2008 (in German).

BAFU (Bundesamt für Umwelt): Jahrbuch Wald und Holz – Annuaire La forêt et le bois, Umwelt-Zustand, 1224, 174, 2012 (in German and French).

Barredo, J. I.: No upward trend in normalised windstorm losses in Europe: 1970–2008, Nat. Hazards Earth Syst. Sci., 10, 97–104, doi:10.5194/nhess-10-97-2010, 2010.

Bengtsson, A. and Nilsson, C.: Extreme value modelling of storm damage in Swedish forests, Nat. Hazards Earth Syst. Sci., 7, 515–521, doi:10.5194/nhess-7-515-2007, 2007.

Bouwer, L. M.: Have Disaster Losses Increased Due to Anthropogenic Climate Change?, B. Am. Meteorol. Soc., 92, 39–46, 2011.

Brändli, D.: Schwere Winterstürme über der Schweiz 1500–1995, 40 pp., Universität Bern, 1996 (in German).

Brázdil, R., Pfister, C., Wanner, H., Von Storch, H., and Luterbacher, J.: Historical climatology in Europe – The state of the art, Clim. Change, 70, 363–430, 2005.

Bresch, D., Bisping, M., and Lemcke, G.: Storm over Europe, an underestimated risk, Swiss Reinsurance Company, Zurich, 2000.

Brodin, E. and Rootzén, H.: Univariate and bivariate GPD methods for predicting extreme wind storm losses, Insur. Math. Econ., 44, 345–356, 2009.

Brönnimann, S., Martius, O., von Waldow, H., Welker, C., Luterbacher, J., Compo, G. P., Sardeshmukh, P. D., and Usbeck, T.: Extreme winds at northern mid-latitudes since 1871, Meteorol. Z., 21, 13–27, 2012.

Bründl, M. and Rickli, C.: The storm Lothar 1999 in Switzerland: An incident analysis, Forest Snow Landsc. Res., 77, 207–216, 2002.

Burger, H.: Sturmschaden, Mitteilungen der Schweizerischen Anstalt für das Forstl. Versuchswesen, (Eidgenössische Forschungsanstalt für Wald, Schnee und Landschaft WSL), 17, 341–376, 1932 (in German).

Bütikofer, N.: Historische Waldschäden in der Schweiz (1800–1960). Unveröffentlichte Lizentiatsarbeit im Fach Schweizergeschichte, Univ. Bern, 1987 (in German).

Ceppi, P., Della-Marta, P. M., and Appenzeller, C.: Extreme Value Analysis of Wind Speed Observations over Switzerland, Arbeitsberichte der MeteoSchweiz, 219, 43 pp., 2008.

Coles, S.: An Introduction to Statistical Modeling of Extreme Values, Springer, London, 2001.

Compo, G. P., Whitaker, J. S., Sardeshmukh, P. D., Matsui, N., Allan, R. J., Yin, X., Gleason, B. E., Vose, R. S., Rutledge, G., Bessemoulin, P., Brönnimann, S., Brunet, M., Crouthamel, R. I., Grant, A. N., Groisman, P. Y., Jones, P. D., Kruk, M. C., Kruger, A. C., Marshall, G. J., Maugeri, M., Mok, H. Y., Nordli, O., Ross, T. F., Trigo, R. M., Wang, X. L., Woodruff, S. D., and Worley, S. J.: The Twentieth Century Reanalysis Project, Q. J. Roy. Meteorol. Soc., 137, 1–28, 2011.

Cornes, R. C. and Jones, P. D.: An examination of storm activity in the northeast Atlantic region over the 1851–2003 period using the EMULATE gridded MSLP data series, J. Geophys. Res.-Atmos., 116, D16110, doi:10.1029/2011JD016007, 2011.

Crichton, D.: The risk triangle, in: Natural disaster management, edited by: Ingleton, J., p. 320, Tudor Rose, London, 1999.

Cusack, S.: A 101 year record of windstorms in the Netherlands, Clim. Change, 116, 693–704, 2013.

Della-Marta, P. M., Mathis, H., Frei, C., Liniger, M. A., and Kleinn, J.: The return period of wind storms over Europe, Int. J. Climatol., 459, 437–459, 2009.

HISTAT: Historical statistics of switzerland online, available at: www.fsw.uzh.ch/histstat/main.php, last access: 16 May 2014.

FXTOP sarl: available at: http://fxtop.com/, last access: 16 May 2014.

Gardiner, B., Blennow, K., Carnus, J., Fleischer, P., Ingemarson, F., Landmann, G., Lindner, M., Marzano, M., Nicoll, B., Orazio, C., Peyron, J., Schelhaas, M., Schuck, A., Spielmann, M., and Usbeck, T.: Destructive Storms in European Forests: Past and Forthcoming Impacts, European Forest Institute Atlantic European Regional Office – EFIATLANTIC, Bordeaux, 2010.

Ginzler, C., Brändli, U.-B., and Hägeli, M.: Waldflächenentwicklung der letzten 120 Jahre in der Schweiz, Schweizerische Zeitschrift für Forstwesen, 162, 337–343, 2011 (in German).

Grünenfelder, T.: Sturmschäden im Wald 1990, edited by: Swiss Agency for the Environment, Forests and Landscape, Umweltschutz der Schweiz, Bull. des Bundesamtes für Umwelt, Wald und Landschaft, 2, 1990 (in German).

Heneka, P., Hofherr, T., Ruck, B., and Kottmeier, C.: Winter storm risk of residential structures – model development and application to the German state of Baden-Württemberg, Nat. Hazards Earth Syst. Sci., 6, 721–733, doi:10.5194/nhess-6-721-2006, 2006.

Holenstein, B.: Sturmschäden 1990 im Schweizer Wald, Schriftenr. Umwelt, Swiss Agency for the Environment, Forests Landsc., 218, 41 pp., 1994 (in German).

Imhof, M.: Analyse langfristiger Gebäudeschadendaten, Interkantonaler Rückversicherungsverband IRV, 2011 (in German and French).

Kleinn, C.: Skript Waldmesslehre, Waldinventur I, Course Notes 2013, available at: www.iww.forst.uni-goettingen.de (last access: 16 May 2014), 2013.

Kron, W., Steuer, M., Löw, P., and Wirtz, A.: How to deal properly with a natural catastrophe database – analysis of flood losses, Nat. Hazards Earth Syst. Sci., 12, 535–550, doi:10.5194/nhess-12-535-2012, 2012.

Kurz, D., Alveteg, M., and Sverdrup, H.: Acidification of Swiss forest soils: development of a regional dynamic assessment, Bundesamt für Umwelt, Wald und Landschaft, Bern, 1998.

Lamb, H. and Frydendahl, K.: Historic storms of the North Sea, British Isles, and Northwest Europe, Cambridge, edited by: Frydendahl, K., Cambridge University Press, Cambridge, 1991.

Lanz-Stauffer, H. and Rommel, C.: Elementarschäden und Versicherung: Studie des Rückversicherungsverbandes kantonal-schweizerischer Feuerversicherungsanstalten zur Förderung der Elementarschadenversicherung, Im Selbstverlag des Rückversicherungsverbandes, Bern, 1936 (in German).

Mailier, P., Stephenson, D. B., Ferro, C. A. T., and Hodges, K. I.: Serial Clustering of Extratropical Cyclones, Mon. Weather Rev., 134, 2224–2240, 2006.

Matulla, C., Schöner, W., Alexandersson, H., Storch, H., and Wang, X. L.: European storminess: late nineteenth century to present, Clim. Dynam., 31, 125–130, 2008.

Munich Re: Sturmschäden in Europa Erkenntnisse und Schlussfolgerungen aus den Sturmereignissen der letzten zehn Jahre, Münchener Rückversicherungs-Gesellschaft, 1973 (in German).

Munich Re: Winter storms in Europe (II), Analysis of 1999 Losses and Loss Potentials, Münchener Rückversicherungs-Gesellschaft, Munich, 2002.

Muriset, F.: Schwergewitter auf der Alpennordseite der Schweiz, Berner Maturitätsschule für Erwachsene BME, Bern, 92, 2003 (in German).

Pfister, C.: Wetternachhersage: 500 Jahre Klimavariationen und Naturkatastrophen (1496–1995), Verlag Paul Haupt, Bern, 1999 (in German).

Pfister, C.: The "Disaster Gap" of the 20(th) Century and the Loss of Traditional Disaster Memory, Gaia – Ecological Perspect. Sci. Soc., 18, 239–246, 2009.

Pielke, R. and Landsea, C.: Normalized hurricane damages in the United States: 1925-95, Weather Forecast., 13, 621–631, 1998.

Prodan, M.: Holzmesslehre, Verlag Sauerländer, Frankfurt a.M., 1965 (in German).

Rootzén, H. and Tajvidi, N.: Extreme value statistics and wind storm losses: a case study, Scand. Actuar. J., 1, 70–94, 1997.

Sanders, D. E. A: The modelling of extreme events, Br. Actuar. J., 11, 519–572, 2005.

Schiesser, H. H., Pfister, C., and Bader, J.: Winter Storms in Switzerland North of the Alps 1864 / 1865-1993 / 1994, Theor. Appl. Clim., 19, 1–19, 1997a.

Schiesser, H. H., Waldvogel, A., Schmid, W., and Willemse, S.: Klimatologie der Stürme und Sturmsysteme anhand von Radar- und Schadendaten, Schlussber., vdf Hochschulverlag AG an der ETH Zürich, Zürich, 1997b (in German).

Schmith, T., Kaas, E., and Li, T. S.: Northeast Atlantic winter storminess 1875-1995 re-analysed, Clim. Dynam., 14, 529–536, 1998.

Schüepp, M., Schiesser, H. H., Huntrieser, H., Scherrer, H. U., and Schmidtke, H.: The winter storm Vivian of 27 February 1990: About the meteorological development, wind forces and damage situation in the forests of Switzerland, Theor. Appl. Climatol., 49, 183–200, 1994.

Stucki, P., Rickli, R., Brönnimann, S., Martius, O., Wanner, H., Grebner, D., and Luterbacher, J.: Weather patterns and hydro-climatological precursors of extreme floods in Switzerland since 1868, Meteorol. Z., 21, 531–550, 2012.

Swiss Re: Folgen der Klimaveränderung: Mehr Sturmschäden in Europa, 2006.

Usbeck, T., Wohlgemuth, T., Dobbertin, M., Pfister, C., Bürgi, A., Rebetez, M., and Buergi, A.: Increasing storm damage to forests in Switzerland from 1858 to 2007, Agr. Forest Meteorol., 150, 47–55, 2010a.

Usbeck, T., Wohlgemuth, T., Pfister, C., Volz, R., Beniston, M., and Dobbertin, M.: Wind speed measurements and forest damage in Canton Zurich (Central Europe) from 1891 to winter 2007, Int. J. Climatol., 30, 347–358, 2010b.

Wang, X. L., Wan, H., Zwiers, F. W., Swail, V. R., Compo, G. P., Allan, R. J., Vose, R. S., Jourdain, S., and Yin, X.: Trends and low-frequency variability of storminess over western Europe, 1878-2007, Clim. Dynam., 37, 2355–2371, 2011.

Welker, C. and Martius, O.: Decadal-scale variability in hazardous winds in northern Switzerland since end of the 19th century, Atmos. Sci. Lett., 15, 86–91, 2013.

Welker, C. and Martius, O.: Large-scale atmospheric flow conditions and sea surface temperatures associated with hazardous winds in Switzerland, Clim. Dyn., in revision, 2014.

WSL: Lothar Der Orkan 1999 Ereignisanalyse, Eidg. Forschungsanstalt für Wald, Schnee und Landschaft, 2001 (in German).

Zurich Statistics Office (Stadt Zürich Statistik), available at: https://www.stadt-zuerich.ch/statistik.html, last access: 16 May 2014 (in German).