Development of a storm damage risk map of Germany – A review of storm damage functions

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Abstract

This paper reviews activities on storm damage investigation and discusses the results with regard to an application for storm risk assessment in Germany. The major focus is on damage to buildings, especially residential buildings, which suffer most in storm events. So-called storm damage functions of various authors are presented and compared for countries exposed to tropical and extra-tropical storms. On the basis of the existing knowledge, requirements for a storm damage model for Germany are discussed.

Keywords: Storm damage, storm risk assessment, vulnerability, buildings, hurricane, winter storm.

1 Introduction

For storm risk assessment both information, the storm hazard and the vulnerability of affected structures, have to be considered. An illustration of the generalized approach to wind risk assessment is presented in Figure 1. The storm hazard describes the probability of the occurrence of a certain wind speed at a specific location. Generally, the records of wind speed at meteorological weather stations serve as database for the hazard assessment. As extreme storm events are rare and associated time series very short, extreme value statistics is used to calculate local occurrence probabilities of wind speeds.

Similar to other natural events, storm events are of interest only, if they cause significant damage to population or structures. Therefore, the vulnerability of the affected structures has to be taken into account. The main questions are: When does wind damage start and which loss has to be expected at a certain level of wind speed? The investigation of the vulnerability of structures leads to the development of storm damage functions, where a predicted storm damage is assigned to a certain wind speed.

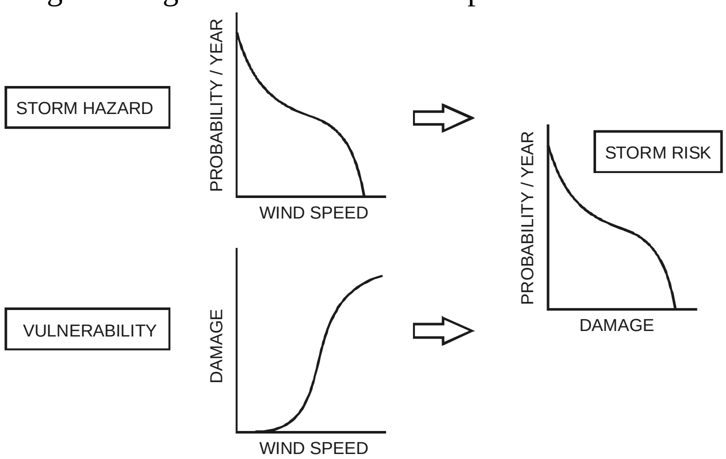

Figure 1: Illustration of the generalized approach to storm risk assessment.

Currently, within the starting project of CEDIM (Center for Disaster Management and Risk Reduction Technology), a storm damage risk map is developed for Germany. For the development of storm damage functions, a literature survey was conducted. Research on this field began in the 1970s and was strongly motivated by catastrophic storm events like cyclone “Tracey” in 1974 in Australia, followed by US-Hurricanes “Andrew” and “Hugo” in 1989 and 1992, respectively, and the winter storms series of 1990 and 1999 in Europe.

2 Comparability of literature results

Wind speed is the most important parameter for damage estimation. Unfortunately, wind speeds are given in many different averaging time intervals reaching from seconds up to 10 min. In order to be able to compare the different results, all wind speeds are converted to a maximum gust wind speed at 10m height over ground assuming the following conversion factors: For severe winds of extra-tropical cyclones the gust factors $G_{10min} = 1.43$ and $G_{1min} = 1.22$ in urban areas are used (Schroers *et al*, 1990). For hurricanes, 1.45 in urban areas and 1.33 at coastal sides are used (Sparks, 2003). Sparks also concludes in his study that the boundary layer and turbulence characteristics in tropical cyclones appear similar to those in extra-tropical cyclones. Thus, from the point of view of wind characteristics, a comparison of damage models seems to be valid.

Also, ‘damage’ to buildings is expressed in various ways according to the area of interest. The mechanical damage is used to describe tendencies of vulnerability of structural parts of buildings (e.g. Buller, 1978; Sacré, 2002). As an equivalent expression for the monetary damage, the damage repair index DI (or: damage degree) is used with DI defined as percentage of repair costs to initial building costs (e.g. Leicester, 1979; Unanwa, 2000). For insurance business, the insured loss is of main interest. Some authors work with absolute values (e.g. Klawa, 2003; Dorland, 1999) while insurers prefer the usage of damage expressed as loss ratio LR (percentage of insured losses to total insured sum within a region).

The conversion between damage index and loss ratio turns out to be difficult. The latter is due to the fact that not all affected buildings are insured against wind damage and, as a consequence, are not considered in loss statistics (although they are damaged). Further on, the level of retention strongly influences the number of claims and the loss ratios of insurers (Swiss Re, 1993). Loss ratios from different insurance companies should be campared carfully when additional actuarial information is lacking (Chapter 4.1).

Another important value is the claim ratio denoting the percentage of affected insurance policies to the total number of insurance policies within a region.

3 Damage to structures due to extreme winds

While this review is concerned with the vulnerability of structures in case of hazardous wind events, i.e. events with high wind speed over large areas (as it is the case in extra tropical and tropical storms), it is worthwhile mentioning that only vulnerability investigations of large numbers of structures are considered here. The vulnerability of individual buildings with specific properties is not considered (e.g. Natasha-A, 1996). Also, tornado damage is not included in this review, because tornados cause damages different to tropical and extra-tropical storms due to their extremely high wind speeds.

The physical storm damage is the consequence of wind loads that are stronger than the resistance of the structure and affects parts of buildings, like roofs, envelopes, and openings. Sacré (2002) described storm damage in France caused by winter storm "Lothar" in 1999 and gave tendencies of the reported damage with respect to the surface roughness type of the environment. More severe and structural damage were observed on buildings located near the sea and in open country as well as in front of open fields. Buildings in urban areas suffered more damage to openings.

A survey of storm damage to buildings in the United Kingdom was conducted by Buller (1978) based on newspaper reports for the period 1970-1976. It is shown that 40% of all incidents suffered damage to roofing, although the removal of complete roofs was rarer and confined to older buildings. Further notable damage occurred to chimneystacks, to gable and sides walls, and breakage of windows. Concerning the financial side, an annual damage of at least 13 million British Pounds (in 1970 values) was observed which led to an average domestic building damage of some 20 pounds. This low average was justified with the very large numbers of small incidents.

Sparks (1994) gives a detailed study of the insured damage caused by the Hurricanes “Hugo”, in 1989, and “Andrew”, in 1992. Most of the loss (60%) took place to housing in urban non-coastal areas. Ocean-front communities had losses due to storm surge and wind forces of only 20% of the total loss, although they provided the most spectacular failures. The envelope of buildings, especially the roof, wall envelopes and openings, suffered most wind damage. Very few buildings collapsed completely, serious damage was mainly caused by rain entering the building. The average insured loss to residential buildings from Hurricane Hugo in South Carolina was 5,550$ and 44,350$ from Hurricane Andrew in Florida (Sparks, 2003). According to the author, the average loss has strongly been influenced by a few poorly constructed buildings experiencing extensive loss.

Investigations of Munich Re (1993, 2001) of the 1990 and 1999 storm series showed that the main damage was also to roofs, facades, scaffolds, forests and power lines. Millions of properties were affected with an average insured damage to residential buildings of some 400€ (1990) and 1300€ (1999).

Reference	**Observed area + year**	**Damage due to**	**Average loss per building**
Buller (1978)	UK 1970-1976	Winter storms	20 BP (1970)
Sparks (1994)	US 1989 and 1992	Hurricanes	5,550$ (1989) 44,350$ (1992)
Munich Re	Europe 1990, 1999	Winter storms	400€ (1990) 1300€ (1999)

Table 1: Summary of storm damage investigations in different countries.

The results show similarities in the observed damage to buildings. Roofs and building envelopes (facades, openings) are most endangered by severe winds in the investigated countries. Large differences can be seen with regard to the average insured damage per building for hurricanes and winter storms. Although the sample size of the investigated events is surely not sufficient to be representative, the trend indicates a higher vulnerability to storm damage in the US. As we will see later, Figure 2 points up this assumption: The upper curves of loss ratio are assigned to hurricane loss in the United States, the lower curve to winter storm loss in Europe.

4 Storm damage functions

The motivation of modeling storm damage is the need to assess expected damage in the future. On the one hand, this holds for insurance companies, but on the other hand also for the society as the knowledge of risk provides helpful information for loss mitigation and management strategies. As mentioned before, the published models give an assessment of storm damage behaviour of large units, from postal-code areas to districts. All models, except the theoretical approach of Unanwa (2000), are empiric functions and adjusted to loss data provided by insurers.

Huang (2001) studied insurance loss data of the Hurricanes "Hugo" and "Andrew" in South Carolina and Florida. The expected loss ratio *LR(v)* in percent corresponding to a surface 10-min mean wind speed v in 10m heights is given as

$$\begin{aligned} LR(v) &= \exp(0.252v - 5.823), \quad && v \leq 41.1 \\ LR(v) &= 100, && v > 41.1 \end{aligned} \tag{1}$$

The loss ratio curve adjusted to the gust wind speed is shown in Figure 2. Also a claim ratio function is given in Figure 3, however, the underlying equation was not published.

Dorland (1999) investigated the vulnerability to storm damage in the Netherlands by analysing insurance data of 5 storm events between 1987 and 1992. An exponential storm damage function applicable for 2-digit postal code areas including three parameters is suggested:

$$\ln TDO = \alpha \ln A + \beta \ln O + \chi \ln v_{\max} + C \tag{2}$$

where *TDO* is the total loss for objects (houses or business), *O* the number of objects, *A* the postal code area, and v_{max} the maximum gust speed. α, β, χ, and C are regression coefficients. Although the model works with absolute figures instead of ratios, which raises problems for a reasonable comparison, the behaviour of storm damage seems to be quite similar to the study of Huang (2001).

Munich Re (1993, 2001) suggests a power law model to describe storm losses related to wind speed. Analyses of insurance data of the winter storm series in 1990 (Gales "Daria", "Vivian", "Wiebke") and 1999 (Gales "Anatol", "Lothar", "Martin") show that the loss ratio increases with maximum wind speed to the power of α=2.7, for the 1990 data, and of α =4 to 5, for the 1999 data. The equation writes simply as

$$LR(v) = LR(160)\left(\frac{v}{160}\right)^{\alpha} \tag{3}$$

where $LR(v)$ is the loss ratio at maximum wind speed v, $LR(160)$ is the calculated loss ratio at 160 km/h based on "Lothar"-Data and α the power coefficient.

Further investigations of storm damage in Germany were conducted by Klawa and Ulbrich (2003) in order to quantify a model for the estimation of annual insured storm losses. Input wind data are the daily maximum wind speeds exceeding the local 98% percentile at meteorological stations. Assuming a cubic relationship between loss and maximum wind speed, the model is adjusted to fit the annual insurance loss data published by the Germany Insurance Union (GDV). The equation writes as

$$loss = c \sum_i pop(i) \left(\frac{v_{max}(i)}{v_{98}(i)} - 1 \right)^3 \qquad \text{for} \quad v_{max} > v_{98} \qquad (4)$$

where c is a regression coefficient, *pop* the population number, v_{max} the maximum wind speed and v_{98} the 98%-percentile of the wind speed for every district i. It has to be noted that this model considers the local wind climate because the maximum wind speed is related to the local 98% percentile.

Unanwa (2000) proposed a new approach to hurricane damage prediction using the concept of wind damage bands. The damage band methodology considers component cost factors, component fragility, and location parameters to assess upper and lower bounds to building damage thresholds. The lower bound of the residential band is show in Figure 2.

Swiss Re (1993) found a strong relationship between loss and storm duration as well as precipitation. In Figure 3 two claim ratio curves for storm durations of 6h and 24h, respectively, are given.

Reference	**Damage definition**	**Wind speed**	**Wind damage relationship**	**Further model Parameters**
Huang 2001	Loss ratio	10-min mean speed	Exponential	
Dorland 1999	Total absolute loss	Max. gust speed	Exponential	Number of objects, size of area
Munich Re 1993, 2001	Loss ratio, claim frequency	Max. wind speed	Power law v^{α}, $\alpha = 2.7$ (1990), $\alpha = 4\text{-}5$ (1999)	
Swiss Re 1993	Claim ratio	Max. wind speed		Storm duration, insurance conditions
Klawa 2001	Absolute loss	Max. wind speed	Power law v^{α}, $\alpha = 3$	
Unanwa 2000	Damage degree	1-min mean speed	Wind damage bands	

Table 3: Summary of the characteristics of published storm damage models.

4.1 Further parameters influencing insured wind damage

As insurance companies provide the most complete information about storm events and damage, it is necessary to highlight further actuarial parameters influencing the insured storm damage. Additionally to meteorological and structural parameters of the storm damage functions, the storm loss of insurers is highly variable with the extent of cover and with the level of the retention (Swiss Re, 1993). The former determines, whether storm damage is insured and consequently registered in databases and the latter affects strongly the amount of loss and claims. A ratio of 0.2 of level of retention to average damage leads already to a reduction of losses of about 20%.

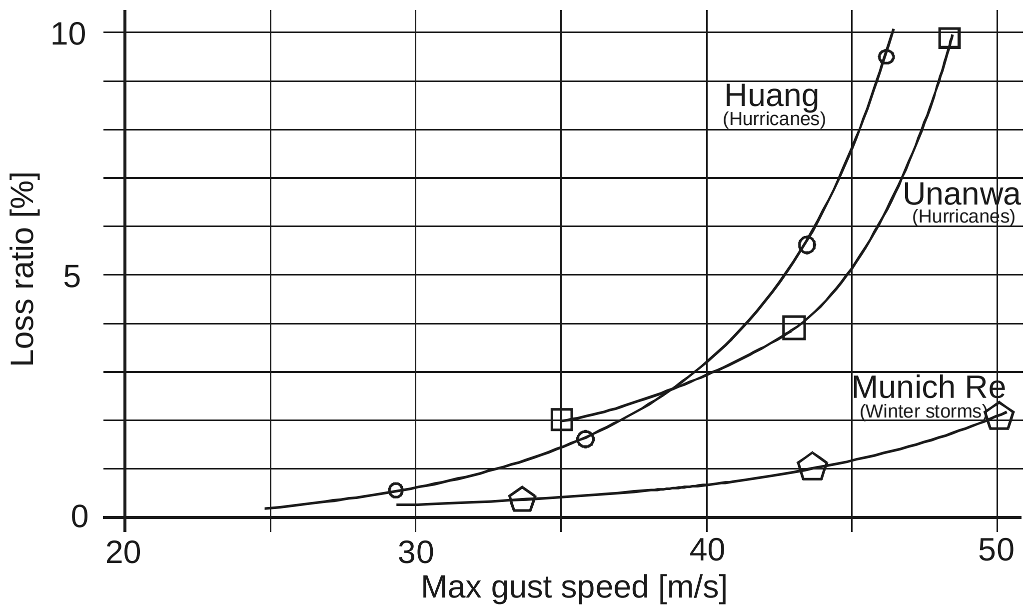

Figure 2: Loss ratio functions of Huang (2001), Munich Re (2001) and Unanwa (2000). Note that no adjustment of the functions could be executed concerning different insurance conditions of the models.

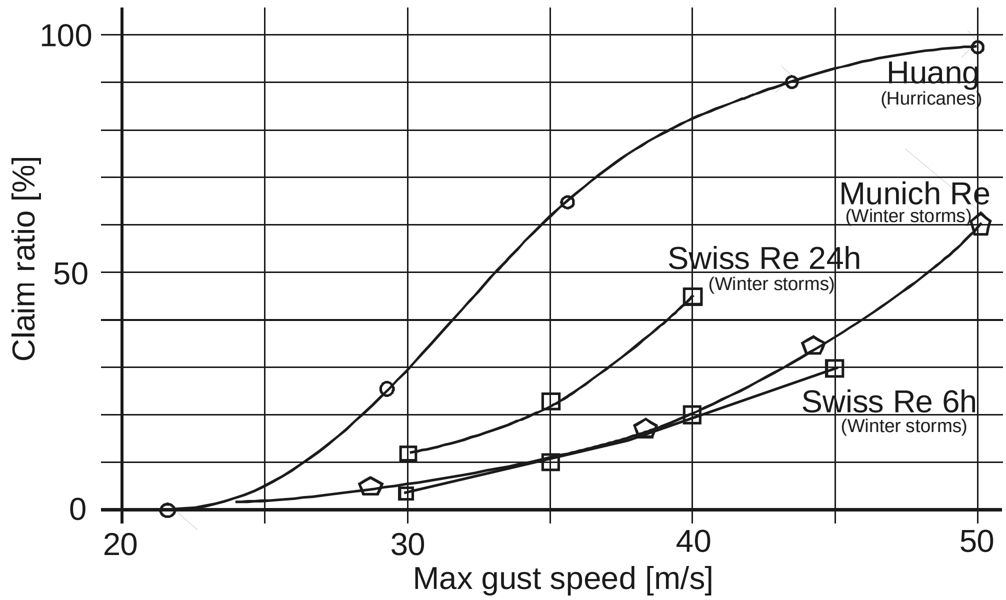

Figure 3: Claim ratio functions of Huang (2001), Munich Re (2001) and Swiss Re (1993). Note that no adjustment of the functions could be executed concerning different insurance conditions of the models.

5 Discussion

In the previous chapter all published storm damage functions were presented. However, only few models are described in detail, especially publications of insurance companies often do not contain detailed information about the models' applicability. This discussion shall point out the requirements of a storm damage model for Germany and whether existing models can be used to be implemented into the model or for the validation of the model.

Which damage definition is reasonable? Since the total damage to structures should be calculated, i.e. not only the insured loss, the damage repair index DI should be used preferably. In Germany, however, only loss data of insurers are available, no information of damage repair costs has been registered so far. Thus, in order to calibrate a DI model with loss ratio data of insurers, a conversion technique has to be developed including actuarial information (Chapter 4.1).

Does vulnerability to wind loading of structures vary over the country? In Germany, the north is more exposed to higher wind speeds than the south. Also, from the point of view of construction requirements, building resistance of existing structures cannot be considered as homogeneous over the country. Klawa (2003) uses wind speeds relative to the local wind climate with the result that the same wind speed would produce more damage in Southern than in Northern Germany. So, it is likely to assume that building resistance is somehow adapted to wind climate. This assumption is also reflected in the Munich Re (2001) model as it is calibrated with real local damage data.

Which relationship between wind speed and damage shall be used? Huang (2001) and Dorland (1999) proposed exponential functions, whereas Munich Re (1993, 2001) suggested potential functions later on also applied by Klawa (2003). Both types where derived to fit statistical damage data, thus, both may be valid for the observed regions and wind speeds. However, Munich Re revised their 1990-prediction of the power coefficient from α=2.7 to α=4-5 for the 1999 storm events. It was noted that storm loss increases much faster with higher wind speeds. Thus, as this characteristic is already the nature of the exponential functions, one might favorite an exponential function as relationship between wind speed and damage.

Finally, it should be marked that the proposed functions given by the authors in their publications represent the “best-fit” curves while the data themselves are highly variant. As a consequence, storm damage is not described accurately by simple models with wind speed as the only parameter. Therefore, existing storm damage functions can reflect tendencies only for wind speed ranges based on a great number of data, however, this implies that it might be difficult to apply these functions to extreme wind speeds with a low probability of occurrence.

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