# Reply to referee comment 2

**Windstorm damage relations - Assessment of storm damage functions in complex terrain**

We thank the reviewer for reading our manuscript and giving thoughtful comments and suggestions. A detailed response to all comments is found below in blue.

This paper compares the performance of four different damage functions in estimating windstorm losses over Norway. The damage functions are assessed at municipality and national spatial scales, and daily and annual time scales. All damage functions can reproduce the spatial loss patterns of the most extreme storms, and when aggregated nationally have high temporal correlations with observations on daily timescales. Time series of national aggregate losses on annual timescales correlate well with the deterministic damage models, but the probabilistic models produce very large errors for some years. Using the probability of damage function from the probabilistic models, a damage classifier is developed to distinguish between damaging and non-damaging wind speeds at the municipality level. The classifier has a low hit rate when considering all events, but does predict the most extreme events.

I think this is a worthwhile study and the paper has some interesting results. However, I have a few major concerns that need addressing before I can recommend publication. Detailed comments are listed below.

## Major comments

### Comment 1

I think it needs to be emphasised that the damage functions were developed to work on different spatial and temporal scales. For example, the Klawa and Ulbrich (2003) cubic model was originally used for annually and nationally aggregated data, whereas the Prahl et al (2012) model was applied to smaller scale daily data (hence the need to be stochastic). It is surprising that the cubic model works so well on the municipality scale.

We agree with the reviewers' observation on the need to emphasise the characteristics of the damage functions. As you pointed out, initially, the Klawa and Ulbrich (2003) cubic model was applied to the annual and national aggregated data. Donat et al. (2011) and Pinto et al. (2012) refined the cubic model and applied it to the district level insurance loss data. Later, Prahl et al. (2015) applied several models, including the cubic model to daily insurance losses for the districts in Germany and found that the application of the cubic model should be restricted to model extreme loss events. We have added the following in section 2.4.2: *The Klawa model was originally developed as a loss index for German districts and to estimate annual national losses using the German Insurance data. Later, Pinto et al. (2012) calibrated the damage function for the affected areas of individual storm events using the German insurance data. In the present study, we follow a similar methodology, except that we chose to calibrate the Klawa* *damage damage function with insurance loss at municipality level. Prahl et al. (2015) applied the damage function at district level on daily German insurance losses.*

## Comment 2

As you mention there are zeros in the daily municipality data, so for the linear regression step for the exponential and cubic models ($L(v) = \beta 0 + \beta 1d(v)$) the residuals will not be Gaussian. It's not clear to me how you dealt with the zeros – were they included in the fit? Was the data binned for the cubic model as well as the exponential one?

While fitting the damage functions, we focused on the extreme observations and tried to minimise the impact of zero and low losses. For the exponential model, the losses are split into bins and at least five loss days (i.e non-zero losses) should belong to each bin. The zero losses in the bins that satisfy the described conditions are also used to obtain the bin average loss. The bin average losses are then log-transformed to fit the exponential damage function. For the Klawa model, we use all the loss data above the 98th percentile wind speed (including zeroes) and do not apply binning. We do not perform binning for the Klawa damage function as the model is only suitable for high loss events and inherently removes the low losses with the use of a high wind speed threshold.

## Comment 3

For the cubic model, in this paper each municipality is fitted separately, whereas in the Klawa & Ulbrich (2003) they aggregate the data nationally (and annually) then apply the linear regression fit. How much does the regression fit vary between municipalities? i.e. did you prove it's necessary to fit each region separately?

Klawa and Ulbrich (2003) used annual insurance data at national level and therefore could not fit storm-damage functions at a smaller level, such as region or municipality level. However, we have insurance data at higher spatial resolution and took advantage of it by fitting the storm-damage functions at the municipality level. Moreover, using municipality level is more relevant to forecasters who will have information on potential damage at such spatial level that they can issue a warning for a local region (and not nationally). We have added this justification of our method in the manuscript.

## Comment 4

Klawa & Ulbrich (2003) only fitted above the 98th percentile assuming that no damage occurred below this. How good an approximation is this for the Norwegian data? From fig 1 there is clearly damage below the 98th percentile but hard to tell how significant this is because I assume there is a very high proportion of days with zero loss at lower wind speeds.

The 98th percentile wind speed threshold in the Klawa model is not particularly well justified in the literature. Klawa and Ulbrich (2003) used the 98th percentile wind speed as the threshold for two reasons: 1) the assumption by Palutikof and Skellern (1991) that storm damages occur in 2% of all days and 2) the German insurance threshold for storm damage claim settlement is 20 m/s which roughly coincides with the 98th percentile. For Norway, 72% of the insurance losses are caused by wind speed above the 98th percentile. Given that the Klawa model only is suitable for high loss cases, the 98th percentile seems like a reasonable choice. We agree that rather than a fixed deterministic threshold, statistically-determined estimates for wind speed thresholds are desired, but it is not clear how this could be best done. Thus, for simplicity we have chosen not to do this. One alternative would be to make the threshold municipality dependent. Another alternative would be to have a fixed value as the threshold. Karremann et al. (2014b) assumed a minimum threshold of 9 m/s for wind speeds causing damage in Norway. From our analysis, 75% of the municipalities exhibit a 98th percentile population-weighted wind speed above 9 m/s. Thus, our threshold is higher than previous assumed thresholds. We have added the following paragraph in section 2.4.2 for the justification of choice of wind speed threshold:

*Several studies across Europe use the 98th percentile wind speed as a threshold for the Klawa damage function (Pinto et al., 2012; Karremann et al., 2014a, b). Ideally, the threshold for damaging wind should be locally chosen using statistically-determined estimates, but, for simplicity, we have kept the often used 98th percentile. In Norway, 72% of the insurance losses are caused by wind speeds above the 98th percentile. As the Klawa model is not designed for low loss cases, this is a fairly reasonable simplification. Note that if grid point wind speeds are chosen, this choice of percentile can be problematic for places with weak winds, such as southeastern Norway (see Fig. 7a). Therefore, for example, Karremann et al. (2014b) and Little et al. (2023) suggested a fixed 9 m/s as threshold for wind speeds causing damage in Norway. The present study uses the mean population weighted winds speeds reducing the relative importance of grid cells with very low wind speeds and therefore avoiding the problem of very low 98th percentile wind speeds.*

**Comment 5**

L214: It's confusing to define the evaluation of damage classifier here, before you've defined the damage classifier. Maybe put section 2.6 before 2.5?

Thanks for the suggestion. Since defining a damage classifier involves metrics such as precision and recall, we will also define them along with the methodology of the damage classifier.

## Comment 6

L256 and L326: “The choice of wind data has the potential to influence the performance of the damage functions…” and “The predictive performances of the damage function and the damage classifier confirms the importance of weighting wind speed with population for better performance of the damage functions.” In the paper you show that the population weighting gives different maximum wind speeds for the municipalities (Fig 7b), but you don’t actually show that it makes the damage models perform better. Does it?

Thank you for your comment. To address it, we have fitted the damage functions using the raw wind speeds instead of the population-weighted wind speeds. Figure R1 here below shows that the population weighted wind speed has lower coefficient of variance (CV) in 67% of the municipalities (including almost all of the high population municipalities) than the raw wind speeds, hence highlighting the usefulness of the population-weighting step in the majority of the municipalities. We have added the following paragraph in section 3.2*:*

*To demonstrate the advantage of weighting wind speed with population, damage functions were also fitted with the original wind speed as the predictor variable. The prediction error on the test data shows that the population weighted wind speed has lower CV in 67% of municipalities (see also Fig. R1 for the spatial distribution of where each wind speed input data performs better). From these results, we conclude that weighting wind speeds with population improves the predictive performance of the damage functions. Therefore, from now on, we only use the population weighted wind speeds when fitting the damage functions.*

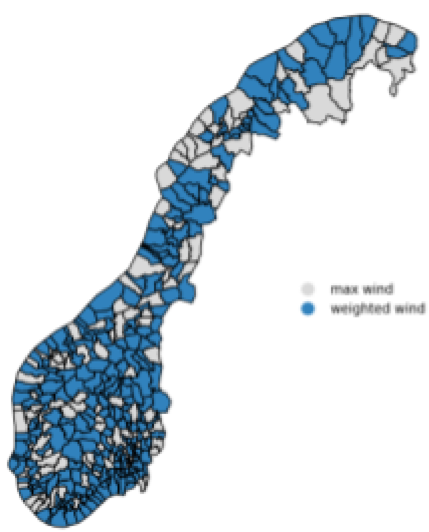


Figure R1: Municipalities with smallest CV among the five models with weighted and maximum wind speeds on test data. Municipalities in grey are where maximum wind speed shows lower and blues are weighted wind speed shows lower CV.

### Comment 7

In the abstract and conclusions (L324) it's stated that all models perform well on national scales, but from Fig S4 it looks like the probabilistic models perform very poorly on this scale.

The reviewer is correct, the probabilistic models significantly overestimate the losses in certain municipalities, as reflected in Fig. S4. However, if the 15-20% municipalities that have poor fit are removed from the estimation, the probabilistic models are also able to reproduce the annual national losses. We have tried to make it clearer in the abstract and conclusion.

We removed 'annual national losses' in line 324 and rephrased to: *The models' ability to reproduce spatial loss patterns of extreme loss events with a high degree of accuracy confirms the utility of both deterministic and probabilistic damage functions in estimating extreme loss events.*

In the abstract, the sentence *The good agreement between the observed and estimated losses at municipality and national levels suggests that the damage functions used in this study are well suited for estimating severe wind storm-induced damages.* has been rephrased to *There is no single damage function that outperforms others. However, a good agreement between the observed and estimated losses at municipality and national levels for a combination of damage functions suggests their usability in estimating severe wind storm-induced damages.*

## Minor comments:

### Comment 1

L103 "Figure 1 highlights a record high number of claims in years 1992, 2011 and 2015. This can be attributed to the New Year Storm in 1992, storm Dagmar in 2011 and storms Nina and Ole in 2015 (Table 1)." In the figure it looks like there's high loss in 1994, not 1992.

Thank you for your careful reading, we have changed the text to: *Figure 1 highlights a record high number of claims in years 1994, 2011 and 2015. This can be attributed to the Storm of 1994, storm Dagmar in 2011 and storms Nina and Ole in 2015 (Table S1)*.

### Comment 2

Fig 2: How do you have zero on a log scale (y-axis)? It looks like zero losses are not actually plotted so this should be stated.

The reviewer is correct. The following line is added to the caption of Fig 2: *Note that the y-axis is on a logarithmic scale and the zero loss on the y-axis is only for reference but the zero losses are not plotted/displayed.*

## Comment 3

Section 2.5, L204 “For robust storm-damage relations, extreme care should be taken in the parameters estimation of damage functions. To ensure robustness of the damage functions, we bin the loss data with respect to wind speeds to eliminate the sensitivity of damage functions to extreme events.” I’m not sure what you mean by this. Are you talking about the binning done when fitting the parameters, or do you bin the data when evaluating the errors as well?

We understand the lack of clarity here. We only bin the losses when fitting parameters. The above mentioned lines are deleted and the following is added in section 2.4:

*For robust storm-damage relations, extreme care should be taken when calibrating the damage functions. To ensure robustness of the damage functions, we bin the loss data with respect to wind speeds to reduce the weight of low loss events. Note that we do not perform binning for the Klawa damage function as the model is only suitable for high loss events and inherently removes the low losses with the use of a high wind speed threshold. More about binning in individual models is explained in the following sections.*

## Comment 4

Section 3.3: Since storms last more than one day, how did you estimate the losses for a single storm? e.g. did you sum the losses over a few days? Choose the maximum loss day?

For the major recorded historical storms, we sum the loss days given in Table 1. We have added the following lines in the first paragraph of section 3.3: *To compare the estimated and observed losses caused by major storm events, we sum the losses within the date range given by the Norwegian Natural Perils Pool and written in Table 1.*

To make it clear we have made the following changes.

We add the following to the title of Table 1: *The event periods are as defined by the Norwegian Natural Perils Pool.*

And in the caption of Fig. 10 and Fig. S2: *For each storm, we sum all the loss days as given in Table 1.*

## Comment 5

Fig 12 caption – what does it mean ‘Annual time series of observed and estimated national losses using the extreme loss class'? Are these not just annually aggregated losses (i.e. the sum of all days?)

Fig. 12 is the annual aggregate loss in the extreme loss class. We have modified the caption accordingly: *Annually aggregated national losses using only the loss days in the extreme loss class from the insurance data (red line) along with the annual national loss estimates (blue line),* *which are the sum of each municipality's best-performing-model estimate (see also Table 2). Note that the y-axis is logarithmic and the shaded region represents the testing period.*

### Comment 6

Fig 11 – panels aren't labelled.

Thanks for bringing this to our attention. We will label the panels in the revised manuscript.

## References


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