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Natural Hazards and Earth System Sciences Discussions

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2, C2265–C2282, 2014

Interactive Comment

Interactive comment on "Identification of storm surge events over the German Bight from atmospheric reanalysis and climate model data" *by* D. J. Befort et al.

D. J. Befort et al.

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Anonymous Referee 1

Major Comments

1) The simplicity of this approach is, however, the main weakness of the paper. There are 82 surge events in the observational (= ERA-40) period, but these only constitute 5.5% of all weather situations that potentially (high wind + large-scale wind field) lead to a surge. In other words, the rate of false positives is larger than 94%! So the big *question is: What does an increase of potentially surge-generating events say about the actual number of surges, if the false-positive rate is so large?*

As the main critics of referee 1 and 2 is the high ratio of false positives events identified by our algorithm, we would like to better explain the methodology applied to identify relevant storm surge events in reanalysis and climate model data. This will include the argumentation why this pretended high ratio has no harm to the basic conclusion of the paper.

As pointed out in the manuscript, for storm surge identification in real world we used available wind surge data, which is only provided for extreme surge events, exceeding a minimum total water level at Cuxhaven. Thus, the majority of (potential) weather situations relevant (high effective wind component + large-scale wind field = potential storm surge events) will not be included in this storm surge catalog, as the potential events were not transformed by non-atmospheric factors (tide) into an absolute storm surge events. Thus, many events with reasonable high wind surges (due to wind speed and direction) are not included in this dataset because it did not exceed the minimum criterion for a storm surge (e.g. because they happened during low tide). Nevertheless, wind surge produced by these potential events would have been sufficient to realize a storm surge if it would have happened during high tide and these events are thus "potential storm surge events". We do not anticipate that non-climatic factors are influenced by anthropogenic climate change scenarios. The revised manuscript tries to emphasize this reason for the high ratio between number of ***potential*** storm surge events and observed storm surge events. Most important to note is that with increasing effective wind component values the percentage of wind storm events, which can be assigned to an observed storm surge event increases (Fig. 2a and Fig. 2b). Thus, the influence of non-climatic factors (tide) is reduced with increasing intensity of the potential event.

To analyze this effect and to discuss the related consequences for impact of storm surges we added an additional part to section 4.2 of the revised manuscript. By splitting

all potential storm surge events into four different categories according to their effective wind component intensity, we investigate if an increase of potential storm surge events in A1B compared to 20C is found for these different categories. In general, we find an increase of ***potential storm surge events*** in three out of four categories (weak, moderate, strong, very strong), with significant changes for the moderate potential event category (+ ca.17%) in the climate change signal. As given in the revised text, this class has a probability of about 13% to lead to a storm surge event in reality. The increase of the number of very strong potential storm surge events (with a probability of 100% to be an observed storm surge) is about 45%, which is (due to the small sample size) not statistically significant.
Please find attached an updated version of Figure 5 giving the boundaries of the four potential storm surge categories (1:weak, 2:moderate, 3:strong, 4: very strong). Additionally, we attached an updated version of Figure 3 showing the annual number or all potential storm surge events and for the four categories (class1: weak, class2: moderate, class3: strong, class4: very strong).

2) Sterl et al. (2009) (referenced in the present paper) use winds from the same model (ECHAM5/MPI-OM) as used here to drive a surge model. They find no change of storm surges in Cuxhaven (their Fig. 7). So what is the value of the present paper?

Thank you very much for picking this up. The value of this paper is to present a new and simple technique to identify the storm surge risk, which can be easily (and without much computational effort) applied to a large number of model simulations. This advantage is now better emphasized in the text.
Further on, our study does not contradict the findings from Sterl et al., but presents additional inside into potential climate change signals of storm surges, especially with respect to the changes in four different intensity classes of potential storm surges.
Besides, there are more technical differences between our work and the work published by Sterl et al.: Sterl et al. have used a larger number of runs than we do, and

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Interactive Discussion
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they interpolated the coarse climate model grid and temporal resolution of the climate model data for driving the WAQUA model. From the information given in Sterl et al. it is clear that they used an ensemble of AOGCM runs made out of 17 ensemble members. It is not clear whether the IPCC CMIP3 ECHAM5-OM1 configuration was used in their study, as the ensemble was independently derived from the IPCC set-up of ECHAM5-OM1 simulations. Thus, one has to assume that both studies do not use the same model ensemble member simulations. Studies of the authors have proven a large member-to-member variability, even for a single-model ensemble (Grieger et al., 2014) with respect to wind storm.
Sterl et al., 2009 showed realistic results for water levels if interpolating ERA-40 data to the WAQUA model grid and adding 10% to the original (ERA-40) wind speed. Using ERA data, however, the observational data are assigned to a real point in time, allowing the assignment of a real tidal phase. Such an assignment is not possible for climate model runs. Thus, our study does not use any arbitrary climate model-tide phase relationship. We, thus, identify a relationship between wind speeds and storm surge from observational data in such a way that the climate model time-tidal phase relationship is mapped to a probability for a storm surge (Please confer reply to reviewer comment 1).

Grieger, J. et al., 2014: Southern Hemisphere winter cyclone activity under recent and future climate conditions in multi-model AOGCM simulations, Int. J. Climatol., DOI: 10.1002/joc.3917

3) 3938, 16-20 De Winter et al. (2012) also find no increase in more extreme wave heights (up to return period of 1000 years, see their Figs. 8 and 11). However, they do not consider the German Bight. Note that they drove their wave model with winds from the same model as used in this paper (ECHMA5/MPI-OM).

In contrast to the work by deWinter et al. (2012), our study focuses only on storm

NHESSD
2, C2265–C2282, 2014

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surge water levels, thus the atmospheric component of the storm surge (wind speed and wind direction), and not on wave heights. It does thus not include any additional atmosphere-ocean interactions than already accounted for in the AOGCM simulation itself. Furthermore, results presented in this manuscript are derived for the location of Cuxhaven and the methodology would have to be changed to be valid for other regions, as the most effective wind component is different for each site.
Furthermore, our analyses of return levels of effective wind components for Cuxhaven do also indicate only small, non-significant changes (see Sect. 4.2.3), and are thus not contradicting findings from de Winter et al.

4) sect. 3.1 This definition of U_eff suggests that you look at winds coming from WNW, which is reasonable. However, later (Fig. 2) it appears that there are also events with a negative Ueff, which are probably winds from ESE (and thus do not project on 295°, but on 115°). First, this is a contradictio in terminis, as by definition a speed cannot be negative, and secondly it does not make sense to consider these events, as winds from ESE can never cause a surge at Cuxhaven.

We are thankful for this comment, but this is obviously a misunderstanding. For clarity, we changed the terminus of "effective wind speed" to "effective wind component" to not confuse the readers, and give further explanation:
Section 4.1 and Figure 2a/b show the results of the methodology using ERA-40 reanalysis data and the storm surge atlas at Cuxhaven. As we hypothesize that storm surges are related to large-scale wind storm events, we used a wind storm tracking algorithm to identify these large scale wind storm events in reanalysis and climate model data. Earlier studies show that wind speed and direction are crucial for the development of storm surge events. Thus, we calculated the effective wind components for all large-scale wind storm events, which affect the North Sea region. Obviously, not all of these large-scale wind storm events are related to high effective

NHESSD
2, C2265–C2282, 2014

wind components. Figure 2 shows the maximum effective wind component of each wind storm track over the North Sea (grey bars). In a next step we assigned observed storm surge events to these large scale wind storm events, which are shown as “red” bars. As it can be seen, all large-scale wind storm events with maximum effective wind components below +9m/s never led to an observed storm surge. Thus, we chose the threshold of potential storm surge events to be the lowest effective wind component value of all large-scale wind storm events, which could be assigned to an observed storm surge at Cuxhaven. As mentioned in the text, all large-scale wind storm events with effective wind components below this threshold (thus also all events with negative effective wind components) are no potential storm surge events.
We revised the manuscript to better explain the methodology used to identify potential storm surge events (please see Section 3.3).

5) sect. 3.2 In which region do you look for large-scale wind fields? There are a lot of severe storms in the north-east Atlantic that affect Cuxhaven not at all. In the next section you suggest that storms should at least have one point in the North Sea. Seems reasonable, but even then a storm that has only one point within the North Sea, while its centre moves hundreds of kilometres further north, might not be relevant at all. Perhaps better to discuss the choice of area here in greater depth and sharpen the criteria to improve the false positive rate.

As pointed out in the manuscript, a necessary condition for a potential storm surge event is a large-scale wind storm event affecting the North Sea region. We carried out sensitivity studies using different regions for the identification and it was found that the one used in this study is the most suitable. Additionally, we would like to clarify that the algorithm we use is specifically targeted at the identification of the severe wind field of cyclones and does not use the position of the minimum core pressure, which indeed could be relatively far away. Thus, our identification algorithm is already taking strong winds in the North Sea region into account. In fact, this is why we are using this technique here. We hope that our answer to comment 1 demonstrates that the high ratio of potential storm surge events to observed storm surge events is mainly due to the intended neglect of the astronomical tide. It should be further noticed that the algorithm used to identify large-scale wind events is based on absolute wind speeds only (after passing a certain threshold; details to be found in Leckebusch et al., 2008), and does not include any information about the wind direction. This is included in the 2nd condition regarding the effective wind component in the German Bight.

6) A linear trend is plotted. However, GHG concentrations as the driver of climate change grow exponentially, and temperature increase is much larger during the 21st century (3 K or so) than over the 20th century (< 1 K). So if climate change were to impact surge frequency, one would expect a larger increase in the later 21st century than during the 20th century. Taking this into account, is the small increase still significant?

Firstly, this assumption would neglect any influence of e.g. multi-decadal natural variability to be present in the recent climate. As this is obviously not the case, changes of extremes may not be linear related to changes in GHG concentrations alone. Secondly, the observed increase of GHG concentration in the atmosphere is not exponentially, and for the future strongly dependent on the scenario assumed. Nevertheless, we analyzed an exponential trend as well and found no evidence that the changes in the number of storm surge events can be reflected more accurate than using a linear trend. The relationship between the GHG concentrations and the number of storm events (relevant for storm surges) is not necessarily linear proportional.

7) A comparison with ERA-40 is missing! Are the average numbers of relevant situations equal in ERA-40 and ECHAM5?

Thank you very much for this comment. We added the number of relevant events calculated from ERA40 reanalysis data to Table 1. The number of potential storm surge events in ERA-40 is only slightly higher (11 per year) compared to 20C (run1: 9.6, run2: 10.1, run3:10.7).

8) sect. 4.2.3 Stationarity is required for the EVS/GPD approach to be valid. If you apply the method for the whole 21st century you thus implicitly assume that there is no long-term trend over that century. If there is no trend, although the forcing (GHG concentration) has one, why would you expect a difference with the 20th century, when the forcing was even lower?

For the GPD approach we only take potential storm surge events into account with a minimum effective wind component of 18 m/s. Our new analyses (using four different intensity classes for potential storm surge events) show that there are no significant changes in the number of these (strong and very strong) potential storm surge events. Furthermore, we cannot identify a trend of the yearly number of strong and very strong potential storm surge events for both categories together. Thus, we can use the stationary GPD approach to calculate the occurrence rate for these two classes.

Minor Comments

1) 3936, 22 over → at
Done

2) 14) 3937/38, 28/1,2, raise → rise – all these effects contribute, mean sea level *changes do not contribute to the rise of the water level during a surge (it is far too slow), but it contributes to the water level reached during a storm. Please reformulate this sentence.*

We changed the sentence to: ‘The future changes of extreme water levels during storm surges are both determined by changes of mean sea level and wind storm intensities.’

3) 3938,25 Reference for CMIP5 needed
Added in the revised manuscript.

4) 3938,27/28 GCM IPCC-AR4 ECHAM5/MPI-OM – what’s this?
We changed this to
‘CMIP3 ECHAM5/MPI-OM simulations’

5) 3940,9 comprising → taking into account
Done

6) 3941, 1 and 3 subcluster → sub-clusters
Done

7) 3941, 7/8 Please reformulate. Hard to understand.

There are two aspects taken into account when restricting the choice of the nearest neighbour: In general, the spatial distance between the identified clusters at subsequent time steps must not be too large to avoid connecting unrelated storm fields.

As the locations of the storm cluster centres (computed from intensity weighted grid points of the cluster) are evaluated for this purpose, sensitivity tests showed that 600 km / 6 hours is a reasonable threshold at first order. However, a problem occurred for large storm clusters, as due to variations in the intensity distribution within the cluster the apparent movement of the centre was larger for some events. This was accounted for by augmenting the threshold by a cluster-size dependent addition, chosen as half of the maximum storm extension. While we hope this clarifies the procedure for the reviewer, we are convinced it is not adequate to describe this somewhat complex procedure in the paper in this detail. Our suggestion of re-writing the phrase is thus as follows:

'These identified clusters are tracked in time using a nearest-neighbour algorithm, obeying a maximum permitted movement of the cluster centre of 600 km /6 hour time step, plus an additional allowance for movements of the centre within the cluster (half of the cluster extension).'

8) 3941, 8 Eventually → Finally
We reformulated this part (see Minor Comment 7)

9) 3941, 22 their → its
Done

10) 3942, 24 deviated → derived
Done

11) 3943, 4-7 Sentence too long. Please reformulate

We reworded this part to:

‘In general no wind data from reanalysis (six hourly) is available at the exact date of wind surge maximum (every five minutes). Thus, we take effective wind component data for the time step before and after wind surge maximum into account.’

12) 3943, 10/11 What does the ratio of 3.7% mean? No interpretation is given. To me it suggests that the method is useless (see major remark).

We reformulated the sentence in the revised manuscript and explained the ratio of this method in more detail. As discussed in Comment No.1, it should be kept in mind that no information about the astronomical tide is included. Furthermore, (as shown in Fig. 2a/b) the ratio of potential storm surge events and observed storm surge events increases with higher effective wind components. We changed the paragraph to:

‘To estimate the usability of this method we calculate the total number of the 6 hourly time steps in ERA-40 data, for which this threshold of the effective wind component is exceeded. Afterwards, we calculate the ratio between all observed storm surge events at Cuxhaven and the total number of time steps exceeding this threshold. We calculate a value of about 3.7 %, indicating that only 3.7 % of all time steps in ERA-40 reanalysis data, which exceed the minimal value of the effective wind component (observed for the storm surges at Cuxhaven), lead to a storm surge.’

13) 3943, 2nd para Here you come with the North Sea argument (see also major remark). That all those storms that do not enter the North Sea are irrelevant for Cuxhaven could have been anticipated.

We hope the new structure of this section helps in understanding the methodology (applied to the model data) to identify storm surge relevant events.

‘In a first step, potential storm surge are identified based on effective wind components over the German Bight only. In a second approach information about large-scale wind fields is used additionally. Thus, an event with storm surge potential is characterized by its mean effective wind component over the German Bight region (see Sect. 3.1) and a large-scale wind storm event, detected by the algorithm explained (see Sect. 3.2) in the vicinity of the German North Sea coast. Events are only considered if the large-scale wind storm is located over parts of the North Sea region. This region is illustrated in Fig. 1a and Fig. 1b for ERA-40 reanalysis and ECHAM5 model grids, respectively. In total, the region consists of 99 grid boxes in ERA-40 and 35 grid boxes in ECHAM5.’

14) 3944,19 comparable → comparably
Done

15) 3944, 20 comma needed after surge
Done

16) 3944/45 27-2 Please reformulate. Clumsy sentence

We reformulated this part:

‘Similar to the first approach based on the effective wind component only, we try to assess the usability of the new method. Therefore, we calculate the ratio of all potential storm surge events in ERA-40 reanalysis data and all storm surge events, which could be assigned to a large-scale wind storm.'

17) 3946, 2 9.84 > 9.45, but you employed the percentile-correction because you expected that winds in ECHAM5 would be lower than those in ERA-40. Explanation? Comment? Do your results depend on the correction? Do you need it at all?

The percentile remapping approach is widely used for different analyses. As also pointed out by Sterl et al., 2009 differences in wind speeds derived from ERA-40 reanalysis and global climate model simulations are possible, which led to a correction of the ERA-40 wind speeds by adding 10% (in the study by Sterl et al., 2009).
Thus, to avoid complications due to different wind speed distributions in ECHAM5 and ERA-40, we used percentile values rather than absolute wind speeds as threshold to identify storm surge relevant events in ECHAM5. The difference for this threshold is only about 0.4m/s, but for our new analysis (see revised paper) the percentile mapping shows up to be more important for higher effective wind components, e.g. an effective wind of 16.73 m/s (99.76th percentile) refers to an effective wind of 17.84 m/s in ECHAM5. Percentile values for higher effective wind components are used in Section 4.21 (for the new analysis, see above) to calculate the probability of four different categories of potential storm surges to lead to a storm surge at Cuxhaven.

18) 3946,7 significant → significantly
Done

19) 3946,22+23 statistical → statistically
Done

20) 3946, 27 what do you mean by 'and for whose mean values'
We reformulated this sentence:

'In Fig. 5 the 30 year moving mean of the total number of potential storm surge events per year is shown for the considered runs and for the ensemble mean.'

21) 3947,1 As well – > Furthermore
Done

22) 3947, 4 of → over

We reworded this sentence in the revised manuscript.

'We calculate the number of all potential storm surge events (effective wind component above 9.84 m/s) in ECHAM5 20C and A1B data for all ensemble members according to their effective wind components (Fig. 3).'

23) 3947, 5/6 from its → of their
Please see Comment 22

24) 3947, 4-17 In this para you use absolute wind speeds and exceedence wind speed at the same time. This is extremely confusing! Please reformulate, using only one measure of speed, and stick to it. This also applies to Fig. 5.

We reformulated this paragraph:

NHESSD
2, C2265–C2282, 2014

‘We find a high increase of at least 10 % occurs for events with effective wind components of 11.84–16.84 m/s . Particularly, extreme events with effective wind components of 20.84– 21.84 become frequent. However, the storms with effective wind components of 17.84–20.84 and 21.84–22.84 m/s become infrequent for the A1B runs (see Fig. 3).’

25) 3847, 15-17 Is this statement true for Uexceed > 14 m/s, or for the whole distribution?
This statement is true for the whole distribution. We reformulated this sentence in the revised manuscript.

‘A Kolmogorow-Smirnow-test with a error probability of α = 0.05 reveals that the whole distributions arise from the same population.’

26) 3948,12 comma needed after as
Done

27) 3948,27 amount $\rightarrow$ number
Done

28) 3949,7 bigger $\rightarrow$ larger
Done

29) 3950, 7-10 Not to follow. Please reformulate.
We reformulated this sentence.
‘The analysis presented in this paper shows that the proposed method using large-

NHESSD
2, C2265–C2282, 2014

scale wind field information as well as effective wind components over the German Bight enhances the detection of potential storm surge events compared to using effective wind component values solely.'

30) 3953, 15 KÅllberg → Kållberg
Done

31) 3961 caption says numbers, y-axis label says percentage. Presumably, numbers is correct.
We updated the caption in the revised manuscript.

32) 3962, 4 of the exceeding what?

The exceeding refers the two thresholds (historical and derived from EVS) mentioned in the sentence before. We updated the caption:

'Figure 7. Mean residual life plot for the effective wind component of all three 20C runs. The mean excess (continuous line) and the 95 % confidence intervals (dashed lines) are shown. Thresholds derived from historical storm surge events (red) and derived from the extreme value statistics (blue) are indicated as vertical lines. In addition the percentage of these exceedings are specified.'

Interactive comment on Nat. Hazards Earth Syst. Sci. Discuss., 2, 3935, 2014.

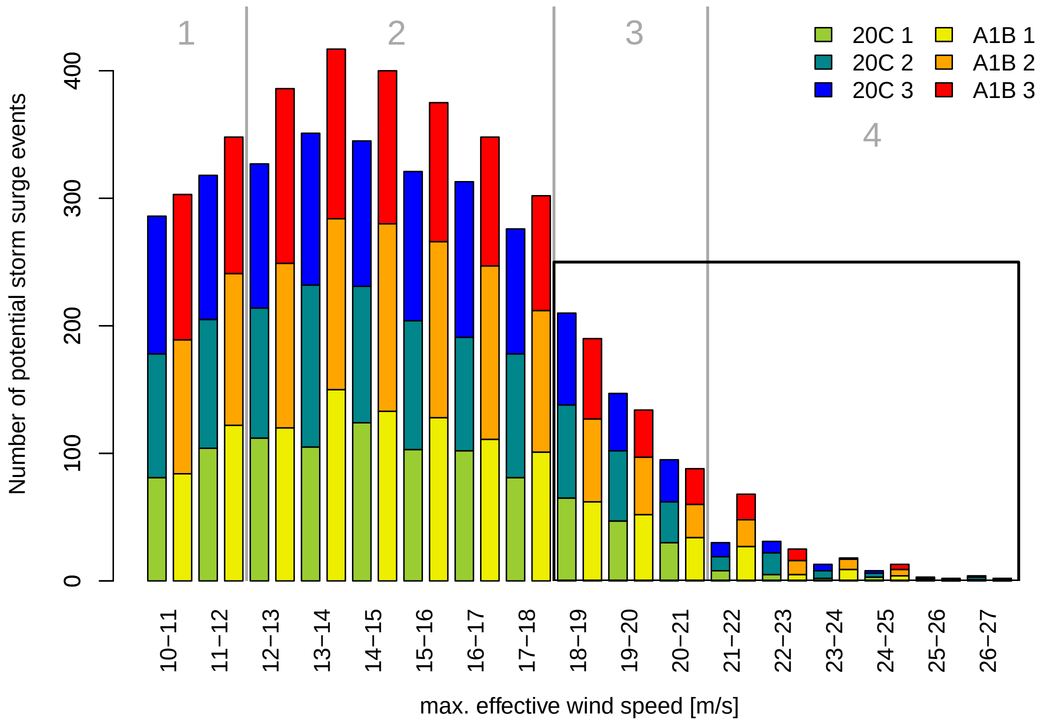

Fig. 1. Fig 5 (revised): Number of potential storm surge events with respect to their maximum eff. wind comp. over the German Bight in 20C and A1B + Boundaries of the 4 pot. storm surge classes (grey bars)

NHESSD

2, C2265–C2282, 2014

Interactive Comment

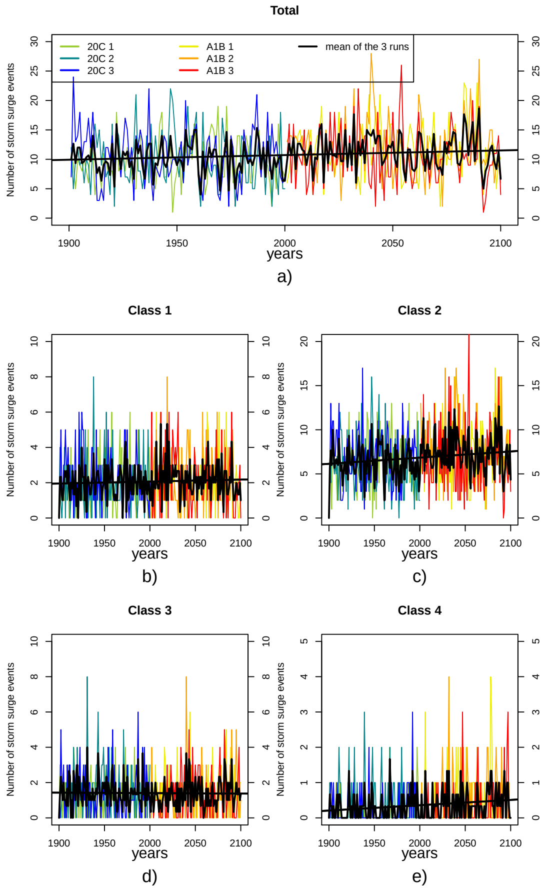

Fig. 2. Fig 3 (revised): Annual number of all pot. storm surge events + four different pot. storm surge classes (1: weak, 2:moderate, 3:strong, 4:very strong)

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