RC2: 'Comment on egusphere-2026-2363', Anonymous Referee #2, 06 Jul 2026

This paper presents an assessment of compound wind–snow extremes, defined as hourly occurrences during which both wind speed and snowfall exceed specified thresholds (the 95th and 98th percentiles). Consecutive hourly occurrence are then used to define events from which they can extract characteristics such as duration. The authors examine these events across Finland, characterising their spatial variability and historical occurrence. The topic is both scientifically relevant and societally important, particularly given the potential impacts associated with concurrent weather hazards.

While the study has merit, I believe several aspects require refinement before the manuscript can be recommended for publication. In particular, the motivation for certain methodological choices could be explained more clearly, and the interpretation of some results would benefit from greater precision. I also think that a small number of additional analyses and refinements to the metrics used would strengthen the paper and provide a more complete characterisation of wind–snow compound events.

Overall, the manuscript is generally well written and presents a valuable contribution to the literature. With some revisions to improve the motivation, interpretation, and presentation of the results, I believe it would be suitable for publication. I have outlined a number of suggestions below that I hope the authors will find constructive and helpful.

Reply: We thank the reviewer for the constructive feedback, which has helped us to improve the manuscript. The general comments of the reviewer, given above, are addressed by detailed responses to the Specific Comments.

Specific Comments:

1. Definition of Extremes and comparison of SWG95 to SWG98

The definition of an "extreme" is inevitably somewhat subjective, but I am not convinced that the 95th percentile of hourly values is sufficiently rare to constitute an extreme event. For example, if 95th percentile exceedances were uniformly distributed in time, one would expect around 216 exceedance hours per winter season (24 hours × 180 days × 0.05), which suggests that such conditions occur relatively frequently. This is not to imply that these exceedances are unimportant from an impact perspective; however, I think the authors could provide a stronger justification for adopting a threshold that is exceeded so often.

I also think the rationale for using both the 95th and 98th percentile thresholds could be explained more clearly. From my reading, the comparison does not appear to yield any substantive scientific conclusions beyond the expected differences in event frequency and duration that arise from using a more stringent threshold. If this is the case, I would suggest focusing on a single threshold, which would considerably simplify the presentation and improve readability. At present, the frequent switching between SWG95 and SWG98 events makes parts of the manuscript difficult to follow.

If there are scientific reasons for analysing both thresholds, beyond simply demonstrating sensitivity to threshold choice, I encourage the authors to state these motivations explicitly and to more clearly articulate the specific insights that emerge from the comparison. This would help the reader understand the value of maintaining both event definitions throughout the paper.

Reply: We thank the reviewer for this valuable comment. We agree that the choice of percentile threshold requires clear justification. Our intention was not to define the 95th percentile of snowfall or wind gust as an extreme event in isolation. Rather, our focus is on compound events, which require the simultaneous exceedance of thresholds in both variables. Although each individual variable exceeds its 95th percentile relatively frequently, the simultaneous occurrence of both exceedances is considerably rarer and therefore represents a distinct class of hazardous events. The 95th percentile threshold also provides a sufficient number of events for statistical analysis, whereas substantially higher thresholds would result in a much smaller sample size.

We also agree that the motivation for analysing both the 95th and 98th percentile thresholds should be stated more clearly. The purpose is not merely to demonstrate sensitivity to threshold selection, but to investigate compound events across two severity levels. The 95th percentile captures high-impact events that occur frequently enough to allow characterization of their climatology, while the 98th percentile isolates the most severe and rare compound events. Comparing these thresholds enables us to assess how the spatial patterns or temporal variability of compound snowfall–wind events changes across different severity levels, and thereby might increase confidence that the conclusions are not dependent on a single, arbitrary threshold definition.

To address the reviewer's suggestion and to clarify the rationale for the compound-event definition applied here and the use of two percentile thresholds, we have expanded the 2.4 Methods -Section (lines 142 and 148, lines in corrected manuscript 147-151 and 157-159) as well as to Discussion section (lines 396, lines in corrected manuscript 501-517). For detailed additions/expansions, see below:

line 142, (lines in corrected manuscript 147-151):

"The individual thresholds are not intended to identify isolated extremes; they are used to identify rare joint occurrences. The definition of a compound event is inherently impact-dependent. Different temporal definitions may be appropriate for different sectors, whereas the simultaneous occurrence of extreme wind and snowfall is particularly relevant for assessing risks associated with snow drifting, reduced visibility, infrastructure operation, and transportation."

line 148, (lines in revised manuscript 157-159):

“SWG95 represents high-impact but relatively more frequent compound events that are likely relevant for operational preparedness and infrastructure management. SWG98 isolates the most severe compound events from the SWG95 group and allows assessment of whether conclusions remain valid when attention is restricted to the upper tail.”

line 396, (lines in revised manuscript 501-517): *“A key challenge in identifying extreme events involving snowfall and wind gusts lies in the choice of threshold values. The use of percentile-based thresholds provides a data-driven approach that accounts for the underlying distributions of the meteorological variables. By defining extreme wind gusts and snowfall relative to their respective distributions, the thresholds identify conditions that are unusual for each variable while maintaining a consistent statistical basis for compound-event detection. In contrast, fixed thresholds, such as 17 m s* $^{-1}$ *for wind gusts and 10 mm day* $^{-1}$ *for snowfall, are typically selected based on predefined levels of severity or potential societal impacts (Vajda et al., 2014, Rauhala and Juga, 2010). Although such thresholds are relevant for impact-oriented assessments, they do not necessarily represent equally unusual conditions across locations or variables. Percentile-based thresholds therefore provide a more distribution-informed basis for identifying concurrent meteorological extremes and facilitate comparisons of meteorological rarity across locations.*

While the 95th and 98th percentiles provide a useful framework for identifying extremes, the two threshold definitions should not be interpreted as identifying independent populations of compound events. Instead, the 98th percentile definition represents a more restrictive characterization of the same underlying events as identified using the 95th percentile threshold, but now only those periods are retained during which both snowfall and wind gust simultaneously reach the highest intensities (Figure 7). Comparing the two thresholds therefore provides insight into how estimates of event duration, accumulated snowfall during threshold exceedance, and event frequency depend on the severity level used to define the compound event.”

2. Interpretation of SWG95 and SWG98 comparison

The comparison between the SWG95 and SWG98 events would benefit from a more careful interpretation. Throughout the manuscript, these are often presented as two distinct sets of events, whereas the SWG98 events are simply a subset of the SWG95 events. As a result, some of the conclusions are misleading. For example, on P23, L400, the authors state that “events detected with the higher threshold (e.g. 98th percentile) are typically more intense but shorter in duration and may result in total accumulation”. While the higher threshold does isolate the most intense portions of the events and therefore reduces their duration, it does not fundamentally identify different events or imply different total accumulations. Rather, the SWG98 definition focuses on the most extreme segments of the same underlying events captured by the SWG95 threshold.

Similar interpretations appear elsewhere in the manuscript and should be revised to more clearly distinguish between differences arising from the threshold definition and differences in the underlying event characteristics. Doing so would make the results and their interpretation more precise and avoid implying that the two thresholds identify independent event populations.

Reply: We thank the reviewer for this helpful observation and agree that our previous wording could be interpreted as implying that the SWG95 and SWG98 definitions would identify distinct populations of compound events. This was not our intention. We have revised the manuscript throughout to clarify that events identified using the 98th percentile threshold are a subset of those identified using the 95th percentile threshold and therefore represent the most intense portions of the same underlying meteorological events rather than separate event types.

Accordingly, we have revised the interpretation of the results. In particular, we now explain that the shorter durations associated with the 98th percentile definition are an expected consequence of applying a more stringent threshold, which retains only the periods during which both snowfall and wind gust simultaneously exceed the higher percentile. Similarly, references to snowfall accumulation have been clarified to indicate that the reported values refer to the accumulation during the threshold exceedance period, rather than to differences in the total accumulation of the underlying meteorological event.

We hope these revisions improve the precision of the terminology and better reflect the relationship between the two threshold definitions. Here are examples of the modifications we made throughout the manuscript:

line 142, (lines 157-159 in revised manuscript): *SWG95 represents high-impact but relatively more frequent compound events that are likely relevant for operational preparedness and infrastructure management. SWG98 isolates the most severe compound events from the SWG95 group and allows assessment of whether conclusions remain valid when attention is restricted to the upper tail.*

lines 233-235, (lines in revised manuscript 260-266): The choice of threshold had a modest effect on the mean duration of the classified compound events, with SWG95 events lasting 4.0–4.5 h on average, compared with 3.4–3.9 h for SWG98 events. The shorter duration of SWG98 events is a consequence of the stricter thresholds, which capture only the most extreme portions of the underlying meteorological events. In contrast, the lower SWG95 thresholds encompass a longer period of the same events, resulting in longer classified durations.

lines 241-242, (lines in revised manuscript 272-274): *As expected, SWG95 events generally lasted longer than their SWG98 counterparts, reflecting the shorter persistence of simultaneous exceedance at the higher threshold.*

lines 267-268, (lines in revised manuscript 300-301): *On average, the hourly mean snowfall as well as wind gusts are higher with events fulfilling the stricter SWG98 conditions than with loser SWG95 conditions as detailed below.*

3. Compound nature of wind-snow events

I believe the paper would benefit from additional analyses and metrics that explicitly quantify the dependence between wind and snow extremes. Figure 3 presents the proportion of winter hours characterised by concurrent wind-snow extremes, which is useful for assessing spatial variability; however, it provides limited insight into the strength of the relationship between the two hazard types. For example, an analysis of extremal dependence using conditional probabilities would provide a more direct assessment of their co-occurrence behaviour. Owen et al. (2021), particularly Figure 2, offers a useful example of this approach.

I also feel that the definition of compound events adopted in this study is somewhat narrow. The authors define compound events only as hours during which both wind and snow exceed their respective thresholds simultaneously. However, these extremes are often embedded within larger-scale weather systems (e.g. cyclones or frontal systems), in which wind and snow extremes may occur at different times while still being associated with the same event. Similarly, the extremes may occur in different locations but arise from the same underlying system, as illustrated by the Storm Lyly case study in Figure 8. This distinction is important because impacts can compound and accumulate over both time and space, potentially leading to greater overall consequences than those associated with a single extreme. Such compounding does not necessarily require the hazards to be perfectly co-located in time or space. The current definition is entirely valid for the purposes of this study, but it would be helpful for the authors to acknowledge the broader range of compound event definitions and clarify that their analysis focuses on one specific definition of compound risk.

Overall, I think the authors and the paper's discussion would benefit more broadly from engaging with the wider literature around compound events, particularly studies of wind and rainfall extremes, which may be directly relevant for this study.

Reply: Thank you for the constructive comment. We agree that mentioning other ways of defining compound events would be a good addition to the discussion. In our study, we intentionally considered only those compound events in which extreme wind gust and snowfall occur in the same location at the same time, without a lag, because such events are associated with specific impacts that may differ from those of non-simultaneous occurrences. For example, when intense snowfall and strong wind gusts occur at the same time, snow is more easily transported and redistributed by the wind, resulting in potential blockage of air ventilation inlets and other infrastructure. Due to our focus on simultaneous occurrence of snow and wind, we decided not to make additional analysis on showing the influence of time lag between the two hazard types. However, we have now revised the whole Discussion-section and added discussion on this topic and relevant citations.

lines 396-441, (lines in revised manuscript 485-578):

Previous studies have adopted various definitions for temporally compounding wind–precipitation events, including simultaneous exceedances, events linked by specified sub-daily time lags or temporal windows, and daily co-occurrence approaches allowing exceedances to occur on the same day or with a separation of several days (e.g. Xoplaki et al., 2025, Hénin et al., 2021, Owen et al., 2021, Zhang et al., 2021, Martius et al., 2016). Each approach addresses different research questions and impact pathways. Thus, the choice of definition should ultimately be guided by the intended application and the underlying impact mechanisms rather than by a single universal definition of compound events.

In the present study, compound events were defined as the simultaneous occurrence of extreme wind gusts and extreme snowfall at hourly resolution. This definition was chosen because many of the most severe wintertime impacts on infrastructure, transportation, and industrial facilities arise from the interaction of these hazards when they occur concurrently. Strong winds acting on falling snow enhance snow drifting and deposition, potentially leading to substantial snow accumulation on structures and formation of large snow drifts that can block roads, railways, and access routes, reduce visibility, and obstruct ventilation systems and air intakes in critical infrastructure. Concurrent heavy snowfall and strong winds also increase the likelihood of trees falling onto power lines and transport networks due to the combined effects of snow loading and wind forcing. Although heavy snowfall and strong winds occurring with a time lag may also cause substantial societal impacts, the potential for snow drifting, redistribution, and decreased visibility is likely reduced in such cases compared with exactly concurrent events.

A key challenge in identifying extreme events involving snowfall and wind gusts lies in the choice of threshold values. The use of percentile-based thresholds provides a data-driven approach that accounts for the underlying distributions of the meteorological variables. By defining extreme wind gusts and snowfall relative to their respective distributions, the thresholds identify conditions that are unusual for each variable while maintaining a consistent statistical basis for compound-event detection. In contrast, fixed thresholds, such as 17 m s $^{-1}$ *for wind gusts and 10 mm day* $^{-1}$ *for snowfall, are typically selected based on predefined levels of severity or potential societal impacts (Vajda et al., 2014, Rauhala and Juga, 2010). Although such thresholds are relevant for impact-oriented assessments, they do not necessarily represent equally unusual conditions across locations or variables. Percentile-based thresholds therefore provide a more distribution-informed basis for* *identifying concurrent meteorological extremes and facilitate comparisons of meteorological rarity across locations.*

While the 95th and 98th percentiles provide a useful framework for identifying extremes, the two threshold definitions should not be interpreted as identifying independent populations of compound events. Instead, the 98th percentile definition represents a more restrictive characterization of the same underlying events as identified using the 95th percentile threshold, but now only those periods are retained during which both snowfall and wind gust simultaneously reach the highest intensities (Figure 7). Comparing the two thresholds therefore provides insight into how estimates of event duration, accumulated snowfall during threshold exceedance, and event frequency depend on the severity level used to define the compound event.

While the intensity of individual hourly snowfall and wind gust values is an important characteristic of compound events, event duration is also relevant from an impact perspective. Persistent compound events may lead to prolonged loading of structures, reduced accessibility, and extended operational challenges for critical infrastructure. In the case of nuclear power plants, adverse weather conditions that persist for many hours can have greater operational significance than isolated short-lived exceedances (Helander, 2017). Consequently, evaluating both the intensity and persistence of compound snowfall–wind events provide a more complete characterization of their potential impacts. This is particularly important for snowfall, where long-lasting events identified using a lower percentile threshold (e.g. the 95th percentile) may lead to substantial snow accumulation, even if hourly snowfall rates are moderate. When a higher threshold (e.g. the 98th percentile) is applied, only the most intense part of the compound event satisfies the event definition, resulting in shorter identified durations. Therefore, absolute accumulation metrics were tested alongside percentile-based thresholds to compare the wind gust and snowfall values during the most extreme events (Table 4).

The relevance of short-duration extremes should also be emphasized. One to a few hours of coincident high snowfall rates and strong wind gusts may not disrupt industrial operations or power generation but can still trigger severe traffic accidents, hinder emergency services, and overwhelm snow removal capacity. Thus, even relatively short-lived compound extremes can have significant societal consequences.

Recent storms in Finland further highlight the importance of compound-event analysis. For example, storm Jari qualified as an extreme compound event under our framework, while storm Lyly—occurring only two weeks earlier—did not satisfy the simultaneous compound-event definition adopted in this study (see Section 3.5). Although Lyly produced very high wind speeds and widespread warnings for heavy snowfall, the maxima of these two hazards did not exactly coincide spatially or temporally. As a result, it did not meet the compound-event definition, despite causing significant impacts across south-western Finland. In contrast, during Jari, extreme snowfall and wind gust thresholds were exceeded simultaneously for prolonged periods and across a relatively large area. Thus, although the wind gusts during Jari were lower than those observed during Lyly, Jari was classified as severe compound event because the two hazards occurred concurrently, persistently, and over a wider area (Figure 9, Table C1). This contrast illustrates that compound-event severity is not necessarily determined by the magnitude of the individual hazards alone, but also by their temporal and spatial co-occurrence.

The identification of extremes is also influenced by how meteorological condition are represented in the underlying dataset. Care should be taken when comparing ERA5 variables with observations, because observations are local to a particular point in space and time, rather than representing averages over a model grid box and model time step (Hersbach et al., 2020). Furthermore, observational practices (e.g., precipitation recorded at 0.1 mm resolution) differ from the continuous output of reanalysis, where values <0.1 mm h^{-1} are retained. Such differences are also evident in histogram comparisons of snowfall frequency distributions (Figure 2). Nevertheless, winter precipitation is commonly produced by extratropical cyclones, and ERA5 resolves these large-scale atmospheric processes better than convective processes (Lavers et al., 2022). Accordingly, the smallest differences between ERA5 and observed precipitation have been found to occur during winter in the Extratropics including many stations in northern Europe (Lavers et al., 2022). Because of the ERA5 tendency to underestimate the snowfall and wind gust values (Laurila et al., 2025a), we wanted to avoid using fixed absolute thresholds. The percentile-based approach defines extremes relative to the local climatology, allowing meaningful comparisons of compound-event characteristics across regions with markedly different snowfall and wind climates. In addition, using percentile thresholds provides a sufficiently large sample of compound events for robust statistical analysis while still focusing on the upper tail of the climatological distributions.

Finally, the geographical location of observation stations used in comparison between station observations and ERA5 (Section 3.1) strongly influences both snowfall and wind gust values. As *shown in Figure 6, large differences arise over short spatial scales, particularly in coastal regions where exposure to open sea versus inland modifies event intensity.*

Technical Correction

P3 L64-65: I think it would be helpful if you could mention the dataset that the wind speeds are measured from. Absolute values can mean different things depending on if the wind exceeds 17ms-1 according to ERA5 or according to in-situ station observations.

Reply: It is mentioned in the previous sentence that these two articles are based on weather station observations. However, we now added one additional sentence to give more details on the used observations

line 63, (lines in revised manuscript 64-66): *Gregow et al. (2008) used wind speed observations from 19 weather stations that were standardized to 10-m height, and Niinimäki (2008) used wind speed and precipitation observations from 49 weather stations.*

P8 L174: Correct EAR5 to ERA5.

Reply: Corrected (lines in revised manuscript 191).

P8 182-186: If observations only include snowfall amounts above 0.01, then should you not remove such measurements from ERA5 also? Please outline why this is justified.

Reply: Our focus in this study is to examine the compound events using ERA5, and we do not aim to define the thresholds only to have the best possible similarity to the observed values. As mentioned in the manuscript, because the snowfall measurements do not have smaller observed values than 0.1 mm/h, the observations potentially underrepresent lighter snowfall events. Since ERA5 can have smaller than 0.1 mm/h values, ERA5 possibly have light snowfall occurrences better captured, and we do not want to remove likely real snowfall occurrences.

P8 L187-190: I think it would be beneficial to additionally discuss the differences between in-situ observations and a grid-based product such as ERA5. This will automatically introduce differences between the datasets and so a one-to-one comparison is unlikely to yield exact like for like comparison. Additionally, I'm surprised to see higher wind speeds in ERA5 compared to the in-situ wind speeds given that ERA5 provides a grid cell average. I wonder if this arises due to the location along the coast. For instance, does the nearest grid cell overlap land and sea? And if so, which roughness coefficient does ERA5 use at this grid cell? If its using a roughness coefficient from the sea, then this could explain why the wind speeds are higher. If that's the case, it might useful to have an additional comparison with a grid cell that is entirely over land.

Reply: Thank you for your good comments. We have now added a short paragraph to line 187 (lines in revised manuscript 206-211) to discuss the different nature of in-situ observations and gridded reanalysis datasets.

We were also surprised that ERA5 shows higher extreme wind gusts than the observations at these two stations, as reanalysis datasets often underestimate local extremes. We therefore investigated this issue further by checking the land-sea mask in ERA5 in these locations. We found that the land-sea mask values of the ERA5 grid cells closest to the stations are 0.91 in Turku Artukainen and 0.44 in Tornio Torppi (0 = sea, 1 = land). Especially for Tornio, the ERA5 grid cell therefore represents a substantial fraction of sea area. Because surface roughness is lower over the sea than over land, ERA5 may produce stronger wind gusts than those observed at a land-based station.

To further examine this hypothesis, we identified the closest ERA5 grid cells with the land-sea mask values of at least 0.9999 i.e. effectively inland grid cells. The differences between ERA5 and observed wind gust percentiles are shown in Table 1.

Table 1. The difference between ERA5 and observed wind gust (ERA5 minus observed) with 98th and 95th percentiles with the closest ERA5 grid cell (used in the manuscript) and the closest ERA5 grid cell with land-sea mask (lsm) at least 0.9999.

	Closest ERA5 grid cell	Closest ERA5 grid cell with lsm >=0.9999	Distance of grid cell with lsm >=0.9999 and the observation station
Turku Artukainen			
98th percentile	2.5 m/s	1.1 m/s	55 km
95th percentile	2.1 m/s	1.4 m/s	55 km
Tornio Torppi			
98th percentile	3.1 m/s	1.1 m/s	155 km
955th percentile	2.9 m/s	1.3 m/s	155 km

From Table 1 we can see that the differences for the 98th and 95th percentile wind gusts decrease from 2.1–3.1 m/s to 1.1–1.4 m/s when inland ERA5 grid cells are used instead. This supports the hypothesis that the land–sea contrast contributes to the observed differences. However, these inland grid cells are located 55 km and 155 km from the stations and are therefore not directly comparable to the station locations.

We also examined the station environment in more detail. Wind measurements are performed at a 23-m height in Turku Artukainen and at a 13-m height in Tornio Torppi, and this information has now been added to line 132 (lines in revised manuscript 136-137). Both locations also have nearby trees and buildings that may affect the observed wind conditions. We calculated the potential wind speed, which takes into account the measurement height and local surface roughness and is intended to be comparable to WMO standards i.e. wind measured at 10-m height at an open and smooth surface, and which is also what ERA5 winds represent. The potential wind speeds are higher than the measured wind speeds at both stations, indicating that local roughness reduces the observed wind speeds. However, this correction is available only for mean wind speed, and its applicability to wind gust is uncertain.

Overall, we conclude that there is unlikely to be a single explanation for the higher extreme wind gusts in ERA5. The additional analyses suggest that the coastal location and the representation of land-sea contrasts within ERA5 are probably the main contributing factors. Local effects related to station exposure, such as nearby trees and buildings, may also play a role. We have included a brief discussion of these factors in the revised manuscript in line 177 (lines in revised manuscript 193-195).

As the primary objective of this study is to investigate the climatology of compound events based on ERA5, while the comparison with observations is included mainly as supporting analysis, we hope that the additional analyses and discussion adequately address this issue.

line 132, (lines in revised manuscript 136-137): *The wind measurements are taken at a 13-m height in Tornio Torppi and at a 23-m height in Turku Artukainen.*

line 187, (lines in revised manuscript 206-211): *There are inherent differences between in-situ weather observations and grid-based reanalysis datasets. Weather stations observations are point measurements that represent conditions at a specific location and are influenced by local factors such as vegetation, topography and nearby buildings. In contrast ERA5 represents average conditions over a grid cell of 30-km and therefore the small-scale and local extremes are smoothed. In addition, ERA5 winds are given at a 10-m height, while the wind measurements in weather stations are made at various heights. Therefore, one can expect to see differences between weather station observations and ERA5, instead of direct one-to-one agreement.*

line 177, (lines in revised manuscript 193-195): *The reasons for the higher wind gust percentiles in ERA5 are not entirely clear, however, a likely contributing factor is the coastal location of the stations and the associated land-sea contrasts within ERA5. Local effects related to station exposure may also contribute to the differences, as both stations have nearby trees and buildings affecting the surrounding roughness.*

P15 L270-271: The result does not indicate anything about impacts. It shows that the hazards are more likely, but without knowledge of exposure or vulnerability, we have no indication if impacts are greater here.

Reply: Yes, that is true. We have now removed the statement of impacts from the sentence.

Lines 270-271, (lines in corrected manuscript 303-305): *This indicates that the western coast of Finland could be more affected by strong wind gusts and the southern coast by heavy snowfall during the SWG compound events.*

P17 Table: Please reduce the text in the first column to give only the conditions. Text such as 'Number of SWG event with…' is redundant and makes it quite difficult to read the table. I would also suggest using a figure instead of a table to show these results. In that way, you could also assess frequencies across a range of thresholds. Furthermore, an additional improvement would be the replace frequency metrics with return periods which is easier to interpret. Otherwise, one has to continuously refer to the total number of years assessed when trying to see how often these events are likely to occur.

Reply: We thank the reviewer for these helpful suggestions. Following the reviewer's recommendation, we have simplified the text in the first column of Table 4 by retaining only the threshold conditions, which improves the readability of the table.

We considered replacing the table with a figure. However, the table includes many different threshold definitions, and we did not find a way to put the results to a figure format in a clear representative way. We appreciate the suggestion to express the results as return periods. We agree that return periods can be an intuitive way to describe the rarity of events, but we think that the mean decadal number of events is even easier to comprehend by stakeholders. Accordingly, to consider how often the events are likely to occur, we have replaced the total number of events with mean decadal number of events (Table 4) and changed the numbers in text in section 3.4 accordingly (lines in corrected manuscript 326-366 and 401-409).

Table 4. The mean decadal ~~number~~frequency of SWG compound events with the 95th (and the 98th in parentheses) threshold(s) in four study locations along the coastline from northwest to southeast; Tornio, Eurajoki, Turku and Loviisa, during October-March in 1960-2024 based on ERA5. The table includes ~~percentage~~the mean decadal frequency of compound events with maximum hourly snowfall exceeding 1 mm h $^{-1}$ (1st row), ~~total number of~~ compound events exceeding snowfall of 2.5 mm h $^{-1}$ (2nd row) as well as 20 mm per event (3rd row), ~~total number of~~ compound events with maximum wind gusts exceeding 20 m s $^{-1}$ (4th row) and 25 m s $^{-1}$ (5th row), ~~total number of SWG~~compund events exceeding maximum wind gust ≥ 20 m s $^{-1}$ and maximum snowfall 2,5 mm h $^{-1}$ (6th row), ~~the total number of~~ compound events with blizzard conditions (maximum wind gust ≥ 17 m s $^{-1}$, snow accumulation ≥ 10 mm per event, 7th row) as well as with stricter conditions (maximum wind gust ≥ 20 m s $^{-1}$, snow accumulation ≥ 20 mm per event, 8th row) are presented.

Location	Tornio Torppi	Eurajoki Olkiluoto	Turku Artukainen	Loviisa Hästholmen
~~Percentage (%) of SWG events with~~ max snowfall ≥ 1 mm h $^{-1}$	~~38~~34.2 (~~60~~21.7)	~~30~~18.8 (~~53~~12.6)	~~43~~32.5 (~~68~~20.2)	~~30~~24.0 (~~51~~16.0)
~~Number of SWG events with~~ max snowfall ≥ 2.5 mm h $^{-1}$	~~7~~1.1 (~~2~~0.31)	~~9~~1.4 (~~7~~1.1)	~~17~~2.6 (~~14~~2.2)	~~4~~0.6 (~~4~~0.6)
~~Number of SWG events with~~ snowfall accumulation ≥ 20 mm per event	~~4~~0.6 (~~2~~0.31)	~~4~~0.62 (~~2~~0.31)	~~3~~0.46 (~~3~~0.46)	~~2~~0.31 (0.15)
~~Number of SWG events~~ max wind gust ≥ 20 m s $^{-1}$	~~51~~7.9 (~~44~~6.8)	~~129~~19.9 (~~95~~14.6)	~~57~~8.9 (~~47~~7.2)	~~119~~18.3 (~~84~~12.9)
~~Number of SWG events with~~ max wind gust ≥ 25 m s $^{-1}$	~~2~~0.31 (0.00)	1.9~~2~~ (1.5~~0~~)	~~4~~0.6 (~~4~~0.6)	1.9~~2~~ (1.5~~0~~)
~~Number of SWG events with~~ max wind gust ≥ 20 m s $^{-1}$ and max snowfall ≥ 2.5 mm h $^{-1}$	0.15 (0.15)	1.1~~7~~ (~~7~~1.1)	1.5~~0~~ (1.5~~0~~)	~~4~~0.6 (0.6~~4~~)
~~Number of SWG events with~~ blizzard conditions (max wind gust ≥ 17 m s $^{-1}$ and accumulated snowfall ≥ 10 mm per event)	~~37~~5.7 (~~18~~2.8)	~~21~~3.2 (1.7~~1~~)	~~32~~4.9 (~~20~~3.1)	~~25~~3.9 (1.7~~1~~)
~~Number of SWG events with~~ extreme blizzard conditions (max wind gust ≥ 20 m s $^{-1}$ and accumulated snowfall ≥ 20 mm per event)	0.15 (0.15)	~~4~~0.62 (~~2~~0.31)	0.15 (0.15)	~~2~~0.31 (0.15)

P19 Figure 7: It is not clear why Figure 7 is used, nor why events with durations longer than 12 hours are highlighted in red. The authors mention Figure 7 on P18 L328-334 but we are not given any insight as why we need to look at this figure. Please discuss this more and highlight exactly what you are concluding from Figure 7. There is likely a lot more information in this Figure than the Authors discuss including information on the dependence of snowfall and wind gust during events.

Reply: We thank the reviewer for this helpful comment. We agree that the purpose of Figure 7 and the conclusions that can be drawn from it were not sufficiently explained in the original manuscript. In the revised manuscript, we have expanded the Methods section 2.4 and Results section 3.4 to clarify the motivation for including this figure.

Figure 7 is intended to illustrate the joint distribution of hourly snowfall and wind gust values during compound-event hours and to examine the characteristics of persistent compound events. The hours belonging to compound events lasting at least 12 consecutive hours are highlighted because event persistence is an important impact-related characteristic in addition to event intensity. In particular, prolonged periods of simultaneously elevated snowfall and wind gust may pose greater operational challenges for critical infrastructure, such as nuclear power plants, than short-lived exceedances do.

line 155, (lines in revised manuscript 166-169): *In addition to the intensity of compound events, their persistence is of practical importance. For critical infrastructure such as nuclear power plants, prolonged periods of simultaneously strong winds and snowfall may present greater operational challenges than short-lived exceedances because in the adverse conditions are sustained over many hours. Therefore, compound events lasting at least 12 consecutive hours are assessed to illustrate the characteristics of persistent events.*

lines 325-334, (lines in revised manuscript 377-393): *Figure 7 illustrates the joint distribution of hourly snowfall and wind gust values during compound-event hours. Most observations are concentrated close to the percentile thresholds, while combinations of very high snowfall rates and very strong wind gusts are relatively rare. The scatterplots exhibit a triangular-shaped distribution, indicating that moderate wind gusts (snowfall) are associated with a wide range of snowfall (wind gust) intensities. This suggests that the simultaneous magnitudes of hourly snowfall and wind gust vary considerably within compound events and that the highest values of the two variables do not necessarily occur at the same time.*

The points highlighted with red correspond to hours belonging to compound events that persist for at least 12 consecutive hours. Their distribution indicates that long-duration compound events do not necessarily coincide with the highest hourly snowfall or wind gust intensities. Instead, these events are characterized by the persistence of simultaneously elevated snowfall and wind gust conditions over many consecutive hours. The figure therefore demonstrates that both event intensity and duration contribute to the overall severity of compound snowfall–wind events. Applying the higher (98th percentile) threshold isolates only the most intense portions of the compound events identified using the 95th percentile threshold. Consequently, the durations become shorter because fewer consecutive hours exceed the more stringent threshold, while the identified periods represent *the peak intensity within the same underlying meteorological events. In Figure 7, lines for wind gust of 20 m s^{-1} and snowfall of 2.5 mm h^{-1} are added to showcase the event hours when snowfall and wind gust exceeds their warning levels discussed in Introduction -section. Only in Eurajoki Olkiluoto and Turku Artukainen the most extreme events with maximum snowfall > 2.5 mm h^{-1} and wind gust > 20 m s^{-1} exceeded 12 h duration.*

P20 Section 3.5: What is the motivation for these case studies. It is not clear what they are adding to the paper and how they relate to previous results. I believe would be useful to expand this section, in particular to link it in with previous results as well as highlight why it is necessary.

Reply: We agree that the additional value of the case studies was not sufficiently explained in the original manuscript. Our intention was not simply to distinguish between different storm types, but to demonstrate how a simultaneous compound-event framework provides information that is not obtained by analysing individual hazards separately. To clarify this, we have revised the case study section 3.5 and added text to Discussion.

lines 359, (lines in revised manuscript 432-436): *To illustrate the practical application of the compound-event framework, we examine two recent high-impact winter storms that affected Finland in November 2024. Although both storms produced severe weather and widespread societal impacts, they differed markedly in the temporal and spatial co-occurrence of extreme snowfall and wind gusts. These case studies demonstrate how the compound-event approach complements hazard assessments by distinguishing storms that produce simultaneous hazards from those in which the individual hazards occur separately.*

line 387, (lines in revised manuscript 469-476): *These two storms illustrate that the severity of individual hazards alone does not determine whether a storm constitutes an extreme compound event. While Lyly was characterized by record-breaking wind speeds, the limited temporal and spatial overlap with heavy snowfall meant that it did not satisfy the simultaneous compound-event definition. In contrast, Jari produced lower peak wind speeds but a much greater overlap between extreme snowfall and wind gust, resulting in widespread compound conditions. These case studies demonstrate that the simultaneous occurrence of extreme snowfall and wind gust provides impact-relevant information beyond the magnitude of the individual hazards. While both storms caused widespread disruption, only Jari produced extensive concurrent exceedances of both hazards, a* *situation that may lead to enhanced snow drifting, reduced visibility, and greater operational challenges than when the hazards occur separately.*

Line 423-428, (lines in revised manuscript 549-561): *Recent storms in Finland further highlight the importance of compound-event analysis. For example, storm Jari qualified as an extreme compound event under our framework, while storm Lyly—occurring only two weeks earlier—did not satisfy the simultaneous compound-event definition adopted in this study (see Section 3.5). Although Lyly produced very high wind speeds and widespread warnings for heavy snowfall, the maxima of these two hazards did not coincide spatially or temporally. As a result, it did not meet the compound-event definition, despite causing significant impacts across south-western Finland. In contrast, during Jari, extreme snowfall and wind gust thresholds were exceeded simultaneously for prolonged periods and across a relatively large area. Thus, although the wind gusts during Jari were lower than those observed during Lyly, Jari was classified as severe compound event because the two hazards occurred concurrently, persistently, and over a wider area (Figure 9, Table C1). This contrast illustrates that compound-event severity is not necessarily determined by the magnitude of the individual hazards alone, but also by their temporal and spatial co-occurrence*

P24 L427: The distinction demonstrates different types of compound events but I do not agree that it demonstrates an additional value. However, please further explain this value if there is another reason beyond identifying different types of events.

Reply: We have revised the text to emphasize that our compound-event definition was chosen to address specific impact-oriented research question, while acknowledging that alternative definitions allowing temporal lags are appropriate for different applications. The original sentence was removed when we rewrote the Discussion section.

lines 427-428, (lines in revised manuscript 485-500): *Previous studies have adopted various definitions for temporally compounding wind–precipitation events, including simultaneous exceedances, events linked by specified sub-daily time lags or temporal windows, and daily co-occurrence approaches allowing exceedances to occur on the same day or with a separation of several days (e.g. Xoplaki et al., 2025, Hénin et al., 2021, Owen et al., 2021, Zhang et al., 2021, Martius et al., 2016). Each approach addresses different research questions and impact pathways. Thus, the choice of definition should ultimately be guided by the intended application and the underlying impact mechanisms rather than by a single universal definition of compound events.*

In the present study, compound events were defined as the simultaneous occurrence of extreme wind gusts and extreme snowfall at hourly resolution. This definition was chosen because many of *the most severe wintertime impacts on infrastructure, transportation, and industrial facilities arise from the interaction of these hazards when they occur concurrently. Strong winds acting on falling snow enhance snow drifting and deposition, potentially leading to substantial snow accumulation on structures and formation of large snow drifts that can block roads, railways, and access routes, reduce visibility, and obstruct ventilation systems and air intakes in critical infrastructure. Concurrent heavy snowfall and strong winds also increase the likelihood of trees falling onto power lines and transport networks due to the combined effects of snow loading and wind forcing. Although heavy snowfall and strong winds occurring with a time lag may also cause substantial societal impacts, the potential for snow drifting, redistribution, and decreased visibility is reduced in such cases compared with exactly concurrent events.*

P24 L436-437: In what sense does the percentile based approach make the analysis in ERA5 more robust?

Reply: Thank you for noting the unclear sentence; it has now been rewritten.

lines 436-438, (lines in corrected manuscript 569-575): *Because of the ERA5 tendency to underestimate the snowfall and wind gust values (Laurila et al., 2025a), we wanted to avoid using fixed absolute thresholds. The percentile-based approach defines extremes relative to the local climatology, allowing meaningful comparisons of compound-event characteristics across regions with markedly different snowfall and wind climates. In addition, using percentile thresholds provides a sufficiently large sample of compound events for robust statistical analysis while still focusing on the upper tail of the climatological distributions.*

Citation: https://doi.org/10.5194/egusphere-2026-2363-RC2