Answers to Referee 1

We thank the referee for the positive and constructive feedback that led to a considerable improvement of our manuscript. In the following, we answer point by point to the comments raised. Regarding the implemented changes, **we refer to the lines in the submitted version of the manuscript**, i.e., the preprint available at `https://egusphere.copernicus.org/preprints/2026/egusphere-2026-1344/`.

- *Line 10-14: In the abstract, when you mention the "linear coastal response" to the winds of storm Hans, it is unclear what this linear response specifically refers to. Furthermore, you report outcomes from linear regression models, but a brief sentence specifying the type of model implemented (e.g., which predictor variables were used) or which aspect of hazard forecasting it supports should be added in the abstract.*

  We agree that this was unclear. We will change this part of the abstract accordingly:

  "~~The linear coastal response to southwesterly winds of storm Hans was found to be the primary driver, either directly or indirectly, of the coastal hazards impacts~~The coastal circulation response to southwesterly winds of storm Hans was found to be the primary driver of the coastal hazards impacts. Motivated by the previous work showing relevance of the linear wind-driven coastal circulation theory in the Baltic Sea, we applied linear regression models for the zonal current (proxy for the extreme transport and clogging) and the sea bottom temperature (proxy for the cold sea temperature spells) using the alongshore wind stress and the alongshore wind impulse, respectively. ~~The linear regression models building upon this finding~~The results show a potential for future development of forecast framework to inform the water management on Gotland, if continued reporting and observational efforts can be secured."

- *Line 38-40: The aspects related to low water resources are only briefly mentioned here. I suggest adding some details about the hydrogeological features of Gotland (e.g., thin soil layers, impermeable bedrock, efficient drainage) to better explain the high surface runoff and the consequent limited groundwater recharge that characterize this area and lead to water stress.*

  We will add the details about the hydrogeological features of Gotland at **line 38**:

  "~~Gotland's hydrological conditions, thin soil layers, impermeable rock, and drainage from agriculture, make much of the precipitation running off into the surrounding Baltic Sea resulting in limited ground water reservoirs.~~Thin soil layers and impermeable rocks characterize Gotland's hydrological conditions, which results in a limited groundwater reservoir and high surface runoff from agriculture. The bedrock on Gotland consists mainly of Silurian limestone and marlstone, which represents the upper part of a 250-800-m-thick sequence with Palaeozoic sedimentary rocks overlying the crystalline basement. The thin (less than 2 m) Quaternary cover consisting of till and postglacial sand deposits and the karstification processes render many areas vulnerable to surface pollution. Moreover, saline groundwater is a problem because relict saltwater occurs under the entire island at a depth of 20-100 m b.s.l. (Erlström et al., 2009; Dahlqvist et al., 2019)."

- *Line 55-60: The description of the desalination process is clear, but it would be helpful to specify at which stage(s) the clogging problems typically occur (e.g., intake pipes, drum filters, membrane nanofilters). This would strengthen the link between the hazard (material transport) and the reported operational impact.*

  This information is already provided to the reader in the later part **line 75** and more in detail at **lines 106-112** of the submitted manuscript (preprint). We are not allowed to provide more details about the disturbances than this, because the desalination plants in Gotland are a strategic national infrastructure.

	Hazard	Hazard impact	Occurrence
1	**Strong water velocity** (volume transport) events, called hereafter ***coastal storms***, tearing off, stirring and whipping up organic material in the vicinity of the desalination plant	Organic matter cause **clogging of the intake pipes**, and sometimes even of filter membranes on land, reducing the water intake and requiring costly manual maintenance.	Year round and are associated with meteorological (wind) forcing (i.e., atmospheric storms)
2	Sudden (hourly-time scale) sea temperature drops below 12°C at the intake pipe during summer (***cold spells***)	Require a change in water treatment operating mode from summer to winter.	Summer (June-September). Does not cause a severe disruption by itself, only if it occurs as compound hazard with coastal storms [1] adding to overall burden.
3	High turbidity	A general decrease in water quality and higher costs of filtering.	Often associated with coastal storms [1] due to wind-driven mixing, and during phytoplankton blooms, frequently dominated by cyanobacteria during summer (Hajdu et al., 2007).

Table 1: A summary of the coastal hazards, their impacts on the operation of the desalination plants, and occurrence. See text for details.

- *Lines 73-85: It could be useful for readers to summarize the three coastal hazards and their impacts in a small table, which would facilitate comparison and provide a quick reference for the hazard-impact pairs described in the text.*

  As suggested, instead of using a bullet list, we will summarize the hazards, their impacts and occurrences in a table (Table 1 in the revised manuscript) that will be referred to in line 80:

  "These coastal hazards and their negative impacts are summarized ~~as follows:~~in Table 1."

  Note that in the Table, we have also appended the text with the word "summer" that was missing after the word "during" (second raw, first column: "during summer").

- *Lines 97-100: You mention that storm Poly caused no reports of significant disturbance at the desalination plants, despite comparable wind speeds to Hans. This is a key observation. I suggest adding a brief hypothesis here (e.g., differences in storm duration, wind direction steadiness, or antecedent conditions) to guide the reader before the detailed analysis in Section 3.*

  Thank you for your comment, which made us to analyze this fact in more detail and consult the references, and we found out the following: The wind speed reached values higher than the 98th-percentile for Hans, but not for Poly (this information is already given in the submitted manuscript in **lines 113-115**). The 98th-percentile is a common threshold used to identify the extreme winds causing impacts, including the applications like wind severity index (Klawa and Ulbrich, 2003; Pinto et al., 2012; Martius et al., 2016; Stanković et al., 2024; Klimavičius et al., 2025).

  We will add this comment in the Discussion **line 514**:

  "No disturbances have been reported for Poly. Notably, the 98th percentile is a common threshold used to identify the extreme winds causing impacts, including the applications like wind severity index (Klawa and Ulbrich, 2003; Pinto et al., 2012; Martius et al., 2016; Stanković et al., 2024; Klimavičius et al., 2025). This suggests that the 98th percentile could be used to identify storms associated with southwesterly winds potentially leading to disturbances at the desalination plants, but more reports of impacts from the desalination plants are needed to confirm this."

  Since we have only impact reports about two storms (i.e., none for Poly, one for Hans), we do not think we have enough information to quantify the relation between parameters like storm duration, wind direction steadiness, antecedent conditions and the hazard impacts on the desalination plants.

- *Line 120: The flowchart summarizing your approach (Reported impact → Analysis → Identify drivers → Develop forecast) could be presented as a figure with a proper caption. Alternatively, if you prefer to keep it as text, I suggest integrating it into a continuous sentence rather than leaving it as a bullet list, to improve readability.*

  As suggested, in the new version of the manuscript we will summarize our approach as a figure with a proper caption. This will become Figure 3 in the revised manuscript and will be referred to in the text in **line 119**:

  "~~Our approach can be summarized as follows: ■ ⟹ ■ ⟹ ■ ⟹ ■~~ Our approach is summarized in figure 3"

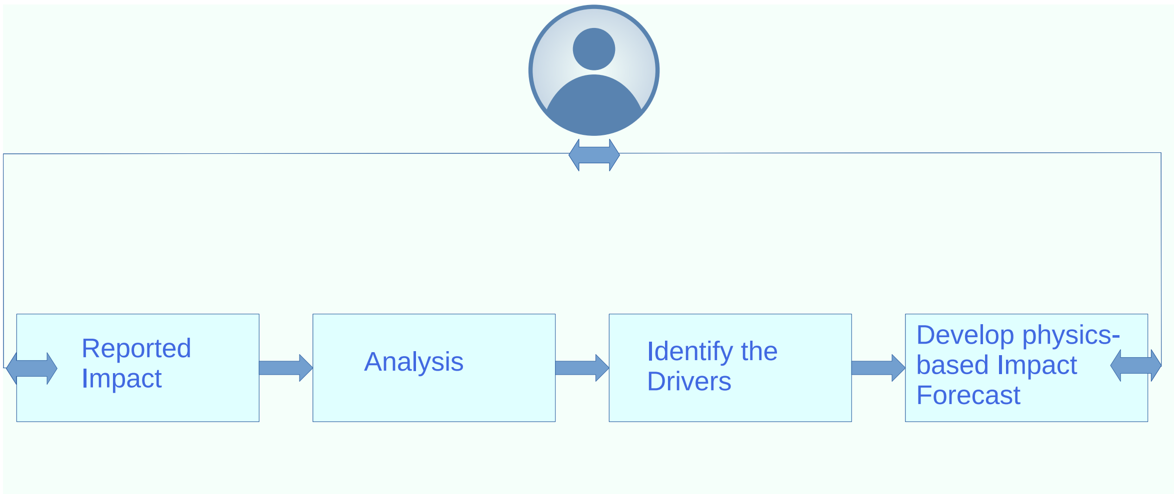

Figure R1: (Figure 3 in the revised version of the manuscript) A schematic illustrating the approach of the study. See the text for the details about the different elements of the approach. The reported impact from the stakeholders, as well as the dissemination of the forecasts to the stakeholders (to be implemented in the future) requires a two-way dialogue (marked with double arrow) with the stakeholders (represented by the person icon).

- *Line 130: A more accurate approach to represent the material transport proxy would be to consider the magnitude of the horizontal velocity vector (i.e., the composition of u and v components) rather than using the zonal (u) component alone, especially given the complex coastal circulation patterns around Gotland.*

  We motivate using the two velocity components separately for the analysis in the submitted manuscript in **lines 277-284 and 394-396**: According to the linear theory we would expect different responses of the cross-shore and alongshore velocity to the wind forcing: for the coastal upwelling and downwelling, the cross-shore Ekman transport sets in within an inertial period and is independent of time thereafter, while the along-shore coastal jet velocity increases with time; and the along-shore velocity could also be carry the signature of the CTWs. We tried different projections, and based on the results presented in Sect. 3.1.2, we selected the zonal component as proxy for the transport cross-shore.

  However, you are right that the complex bathymetry complicates the view presented above, so we implemented your suggestion and used the current speed ($\sqrt{U^2+V^2}$) as the predicted variable and the wind stress as the predictor for the training period 2023. The linear regression results are shown in Figure R2 and are to be compared with the results for the zonal component shown in **figure 8** in the submitted manuscript (top and middle rows). It is evident that the number of predicted events for the current speed ($20-40\%$) is much smaller than for the zonal component ($\geq 80\%$), and the R^2 score is also lower for the current speed.
  We also tested the wind impulse as the predictor for the current speed, as well as regression models for the meridional component with either wind impulse or wind stress as the predictor, yet the best model skill in terms of predicted events, as well as R^2 score, is obtained for the alongshore wind stress as the predictor and the zonal velocity component as the predicted variable, as presented in the submitted manuscript.

  We think that it was very useful to verify that, so we will add the figure R2 in the Appendix (it will become figure A5) and will mention the above result in the text in **line 490**:

  "Different projections of wind stress or ocean velocity and introducing a delay of about the inertial period for transport does not change significantly the linear regression results (sensitivity to the projections are

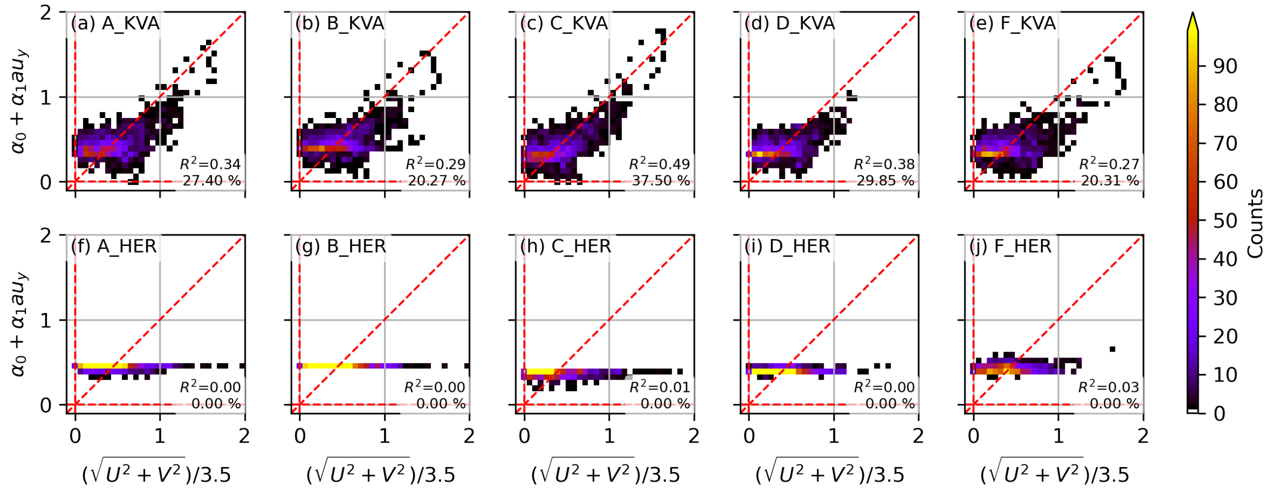

Figure R2: Actual-Predicted histograms for the linear regression of the vertically-integrated current speed ($\sqrt{U^2 + V^2}$) and extreme transport events ($\sqrt{U^2 + V^2}) > 3.5\sigma$) at KVA (top row, a-e) and HER (bottom row, f-j). See Figure 6 for the location of the model grid points.

presented in figure A4. When the current speed is used as the predicted variable, with either the alongshore wind stress or wind impulse as the predictor, there is a much smaller number of predicted events ($20 - 40\%$ for the alongshore wind stress, see figure A5).

- *Line 347: You state that "surface chlorophyll decreases in areas of upwelled cold water". Does this refer to a decrease in chlorophyll concentration (i.e., lower biomass) or a decrease in the spatial extent of the bloom? Clarifying this would help readers understand whether the effect is due to physiological inhibition of cyanobacteria growth or physical redistribution of the bloom.*

The upwelling can cause both, decrease in chlorophyll concentration due to lower temperature of the upwelled water (because the growth of the summer-dominant cyanobacteria depends strongly on the temperature), and due to the horizontal advection of bloom from the coast and its dispersion in open waters. To quantify which of the two factors dominate would require using Lagrangian models, which is beyond the scope of this paper and we therefore prefer to keep the statement as it is.

- *Line 575-580 (Sec. 4.2, future outlook): You mention that continued reporting from desalination plants is needed for future forecast development. I suggest adding a short recommendation on what specific parameters should be routinely logged by plant operators (e.g., filter pressure drop, cleaning frequency, water temperature at intake) to best support model validation. This would provide actionable guidance for stakeholders.*

That was a very good suggestion. We have discussed it among the co-authors what would be needed to further develop the hazard impact models for extreme currents and cold spells in the future, but also for the high turbidity and its drivers (see Table 1 above). We came up with a recommendation that will be added in **line 604**:

"~~However, any further tuning and development of the hazard impacts models as well as the validation of the operational ocean model are dependent on the collaboration and continuous validation (through the impact reports) from the desalination plants. It is also necessary to collect hydrographic and current observations in the vicinity of the desalination plants to further validate the operational ocean model and the statistical models.~~However, any further tuning and development of the hazard impacts models as well as the validation of the operational model are dependent on the collaboration and continuous validation through impact reports from the desalination plants about the events of fouling, filter pressure drop and manual cleaning to best support model validation. Moreover, focused monitoring efforts should aim on collecting observations at the intake station as well as in the sea outside the desalination plants, of the following hydrographic and biogeochemical variables: salinity, temperature, turbidity, chlorophyll-a fluorescence, phycocyanin fluorescence, proxy total phytoplankton biomass and proxy cyanobacteria biomass. Further validation of the operational ocean model and the statistical models would also benefit of collection of fixed point current measurements (a mooring near the intake pipe equipped with a bottom-mounted acoustic current meter)."

- *Table 1 (Page 23): The table shows that validation R^2 values for KVA in F2024 are lower than in-sample, but the number of extreme events is zero. It would be helpful to add a note in the caption or footer explaining that the validation metrics for KVA in 2024 are based on a period with no extreme events, which affects the interpretation of predictive skill.*

  Thank you for your comment. First of all, we revised these results and realized that we used a wrong threshold for 2024. This did not change the results much because there were no extreme transport events in summer 2024. So in order to have more storm events to validate our regression models, we use now two validation periods, one for autumn (September-November) 2023 (”F2023 autumn”) and the second for summer-autumn (July-November) 2024 (”F2024 summer-autumn”). The validation have been extended to the autumn seasons only for the extreme zonal current, not for the sea temperature spells which are cause hazard impacts only during the summer months (see Table 1). The results from these two validation periods are shown in Table 2 (a new version of Table 1 in the manuscript, which will become Table 2; please note that the table includes also regression parameters requested by Reviewer 2; note that the Table refers to Figure 3 which will become Figure 4 in the revised version of the manuscript). In order to interpret these results, we show also wind roses and wind vectors in figures R3 and R4.

  Regarding the validation period F2023 autumn, the linear regression model for zonal transport U predicted 100% of the extreme transport events at all the near-by model points for KVA except one (the furthermost point N where the local recirculation weakens off, see Figure 4 and sect. 3.2.1 in the submitted version of the manuscript). At HER, up to about 40% events were predicted at two near-by model points (I and P, south off the desalination plant where the coastal jet associated with SW storms is pronounced, see Figure 4 in the old version of the manuscript), which is similar to the training period F2023 summer, but for point B only 20% events were predicted compared to 100% for the training period. The R^2 scores for the validation F2023 autumn are comparable to the training period F2023 summer at both, KVA and HER.

  However, for the validation period of F2024 summer-autumn, the percentage of predicted events was reduced to maximum 40% at two near-by model points for KVA, and none was predicted for HER.

  We attribute these results about the regression model performance to the different wind directions characterizing the storms during the two validation periods that in turn determined the coastal circulation. In the validation period F2023 autumn, there are two storms with extreme southwesterly winds similar to Poly and Hans in the training period F2023 summer, hence the similar performance of the regression model (see Sect. 3.1.2). In summer 2024 there are no storms, and in autumn 2024 there are four storms with extreme winds from varying directions and the coastal current response to these was not well captured by our linear regression model with the alongshore wind stress as predictor. We have no impact reports from the desalination plant for 2024 however to test alternative versions of the model for the winds from other directions than southwesterly.

Table 2: Performance metrics for linear regression models of the zonal (proxy cross-shore) transport ($U/(3.5\sigma)$) evaluated at ocean model grid points around KVA and HER. ~~in summer 2023.~~Position of the points are marked in ~~Fig. 3~~figure 4. The linear regression model is trained for the ocean model output in summer 2023 (In-sample F2023) using the wind stress at HOB as a predictor (Eq.4). The validation of the regression model is done using ocean model output in the ~~subsequent summer~~autumn 2023 (F2023 autumn) and in the summer-autumn 2024 (F2024 summer-autumn). The metrics include the number of identified extreme transport events ($|U| > 3.5\sigma$, see below) in a given model point, percentage of correctly predicted events (relative to the total number of events), the coefficient of determination (R^2), the non-dimensional root-mean-square error (RMSE) and the standard deviation σ [m s^{-1}]. The regression results are statistically significant at 95% confidence level ($p < 0.05$). The number of predicted events can be found by multiplying the values in the row of "Predicted" with the corresponding values of the "Events".

KVA – In-sample (F2023 summer)							
Station	A	B	C	D	F	H	N
Events (count)	12	11	11	12	11	12	11
Predicted (%)	91.7	90.9	100.0	100.0	81.8	83.3	72.7
R^2	0.544	0.565	0.622	0.616	0.483	0.543	0.419
RMSE	0.193	0.188	0.176	0.177	0.205	0.193	0.218
σ [m s^{-1}]	0.036	0.037	0.063	0.046	0.041	0.038	0.039
Intercept A_0	-0.054	-0.039	-0.068	-0.055	-0.030	-0.018	-0.005
Slope A_1 [Pa^{-1}]	-4.064	-4.143	-4.348	-4.325	-3.831	-4.060	-3.568
KVA – Validation (F2023 autumn)							
Events (count)	8	7	7	8	5	6	4
Predicted (%)	100.0	100.0	100.0	100.0	100.0	100.0	75.0
R^2	0.586	0.669	0.653	0.647	0.560	0.589	0.491
RMSE	0.184	0.164	0.168	0.170	0.190	0.183	0.204
σ [m s^{-1}]	0.046	0.052	0.081	0.059	0.054	0.050	0.054
KVA – Validation (F2024 summer-autumn)							
Events (count)	5	18	3	5	2	6	4
Predicted (%)	40.0	33.3	33.3	40.0	0.0	33.3	25.0
R^2	0.507	0.590	0.633	0.604	0.445	0.478	0.323
RMSE	0.207	0.215	0.184	0.182	0.230	0.217	0.265
σ [m s^{-1}]	0.037	0.044	0.067	0.047	0.044	0.040	0.044

HER – In-sample (F2023 summer)							
Station	A	B	C	D	F	I	P
Events (count)	5	2	10	11	13	14	9
Predicted (%)	0.0	100.0	0.0	0.0	7.7	50.0	44.4
R^2	0.034	0.301	0.158	0.168	0.277	0.463	0.370
RMSE	0.281	0.239	0.262	0.261	0.243	0.209	0.227
σ [m s^{-1}]	0.013	0.019	0.031	0.015	0.024	0.042	0.035
Intercept A_0	-0.041	-0.075	0.172	0.150	-0.121	-0.113	-0.139
Slope A_1 [Pa^{-1}]	1.009	3.026	-2.189	-2.259	2.901	3.750	3.353
HER – Validation (F2023 autumn)							
Events (count)	6	5	4	13	3	9	8
Predicted (%)	0.0	20.0	0.0	0.0	0.0	44.4	37.5
R^2	-0.152	0.130	0.265	0.289	0.183	0.446	0.341
RMSE	0.307	0.267	0.245	0.241	0.258	0.213	0.232
σ [m s^{-1}]	0.018	0.019	0.044	0.022	0.029	0.054	0.044
HER – Validation (F2024 summer-autumn)							
Events (count)	42	19	50	62	31	39	25
Predicted (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
R^2	-0.080	0.196	0.203	0.217	0.189	0.409	0.288
RMSE	0.349	0.256	0.313	0.310	0.289	0.263	0.294
σ [m s^{-1}]	0.015	0.019	0.038	0.019	0.027	0.050	0.043

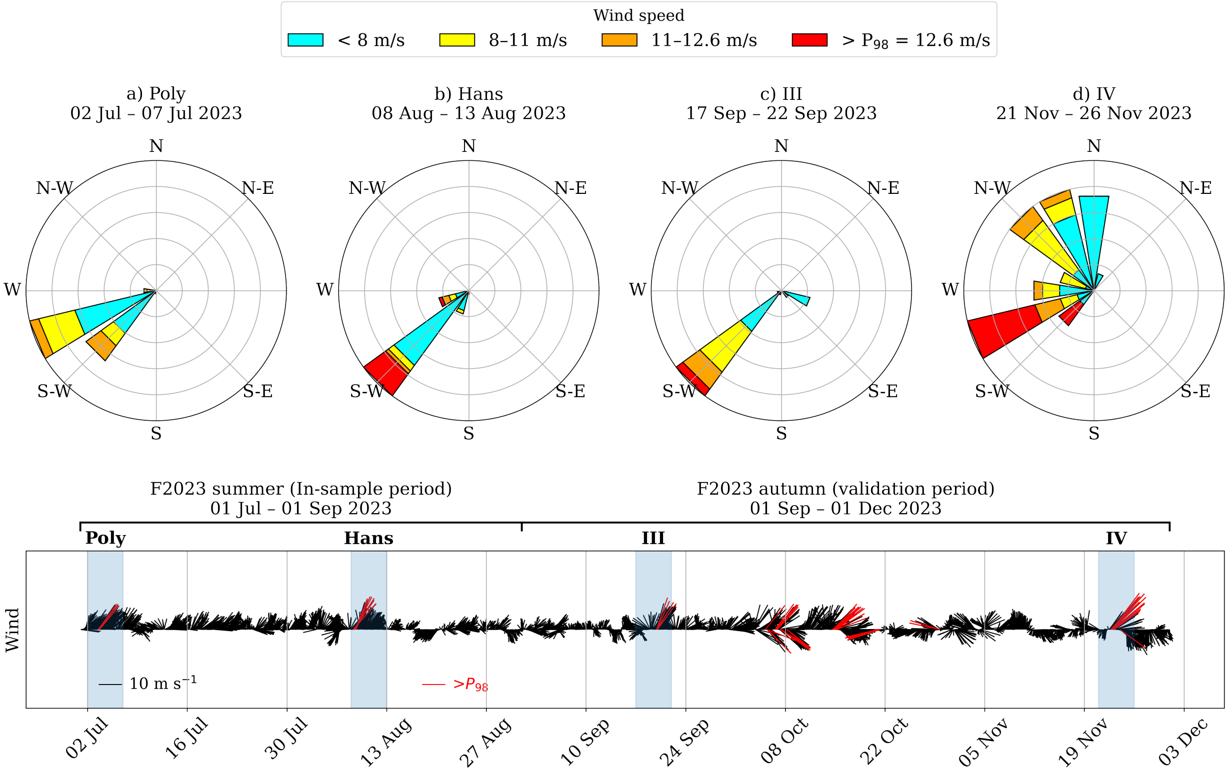

Figure R3: Wind roses (upper row) showing distribution of wind direction and speeds. The range of speeds is *calm* wind conditions$<$ 8 m/s, *breeze* $8 - 11$ and *strong breeze* 11-12.6 m/s. The exceedances of the 98th-percentile ($P_{98} = 13.6$ m/s) are shown in red. The bottom panel shows the stick plot for the wind. The period shown is from 1 July till 1 December 2023.

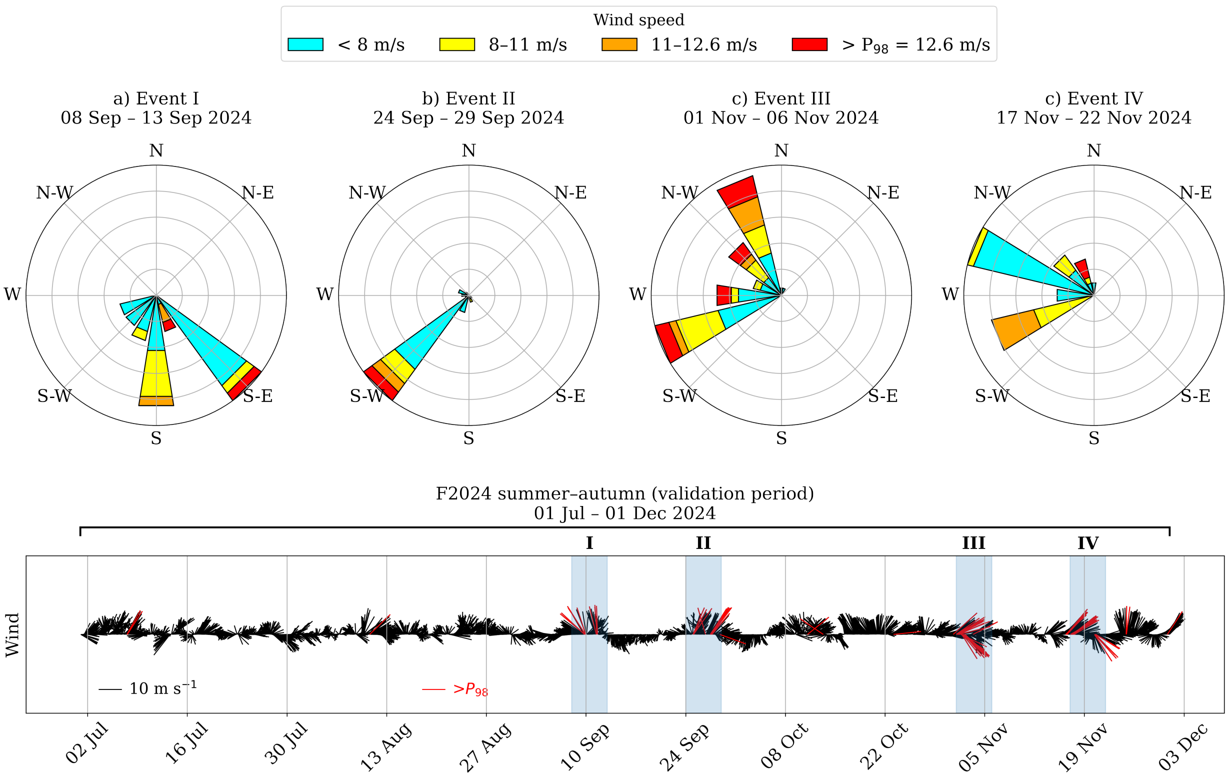

Figure R4: Same as figure above for the period 1 July till 1 December 2024.

We will incorporate the updated validation results in the following way:

First of all, we will add define the various ocean model data sets for 2023 and 2024 in section 2.2, **line 235**:

"This data set is called F2023 summer. To validate the linear regression model (see sect. 3.2), we also use data for ~~the following~~autumn (September-November) (F2023 autumn) as well as data for summer-autumn (July-November) ~~of the following year~~2024 (F2024 summer-autumn) in order to validate the linear regression model".

and at **line 323**, we will add:

"We validate the regression model using ocean model data for ~~the following summer 2024~~autumm (F2023 autumn) as well as summer and autumn 2024 (F2024 summer-autumn)."

In the Results section 3.2.1, **at line 485**, we will present the results from the validation as in the answer above, but for the updated references to the Table (this will be Table 2 in the new version of the manuscript) as well as figures (Figure 4 will become Figure 5 in the new version, and Figures R3 and R4 will become Figures A6 and A7 in the Appendix):

~~The validation of the linear regression model in the following summer (F2024) is shown in Table 1. We got no impact reports from desalination plants for summer 2024 due to unremarkable summer conditions. There were no extreme transport events at KVA and only a couple of events at HER which were not predicted~~The validation of the linear regression model is shown in Table 2. Regarding the validation period F2023 autumn, the linear regression model for zonal transport U predicted 100% of the extreme transport events at all the near-by model points for KVA except one (the furthermost point N where the local recirculation weakens off, see Figure 5 and section 3.2.1). At HER, about 40% events were predicted at two near-by model points (I and P, south off the desalination plant where the coastal jet associated with SW storms is pronounced, see Figure 5 and section 3.2.1), which is similar to the training period F2023 summer, but for point B only 20% events were predicted compared to 100% for the training period. The R^2 scores for the validation F2023 autumn are comparable to the training period F2023 summer at both, KVA and HER.

However, for the validation period of F2024 summer-autumn, the percentage of predicted events was reduced to maximum 40% at two near-by model points for KVA and none was predicted for HER. We attribute these results to the different wind directions characterizing the storms during the two validation periods (see Appendix Figures A6-A7). In the validation period F2023 autumn, there were two storms associated with SW winds and wind speeds exceeding 98th percentile, similar to Hans, hence the similar performance of the regression model. In summer 2024 there were no extreme storms, and in autumn 2024 there were four storms with extreme winds from different directions and the coastal current response to these was not well captured by our linear regression model with the alongshore wind stress as predictor.

The following text will be inserted into the Discussion (**line 571**):

"The linear regression models captured 100% of the extreme transport events at least at one near-by model point for KVA and HER for the training period in summer 2023. For the validation period in autumn 2024 (when two other storms with SW winds exceeding 98th-percentile wind speeds occurred), the linear regression model predicted 100% of the extreme transport events at all but one near-by model points for KVA and about 40% events were predicted at two near-by model points at HER. However, for the validation period of summer-autumn F2024, only about 40% events were predicted near KVA, and none was predicted at HER. This was due to the different wind directions characterizing the storms during this period and the coastal current response to these was not well captured by our linear regression model with the alongshore wind stress as predictor. We have no impact reports from the desalination plant for 2024 however to test alternative versions of the model. .

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