

AUTHORS' REPLY TO REVIEWER 2

We thank the Editor and the Reviewers for their careful assessment and constructive comments. We have addressed all the points raised and revised the manuscript accordingly. The comments (in italics) have helped us clarify the scope, limitations, and operational relevance of the proposed framework. Detailed responses are provided below.

My major remark occurred to me during reading of the discussion. The authors mention that CFI is difficult to compare to observations because of i) lack of them and ii) lack of knowledge of uncertainties in bathymetry and topographs and coastal structure characteristics. I completely understand this remark. However, it also exposes a serious objection to the usage of CFI index: let's imagine an ideal modeling scenario where the authors can generate CFI index daily operationally for the entire basin. If CFI index is so difficult to compare to observations, what will this number then mean to local authorities? I suspect local Civil Rescue can either rely on CFI index or it cannot. I think it is imperative for the authors to give some thought into what CFI operational predictions, of which this paper is a "proof-of-concept", will mean to responders and local public on the ground. If CFI cannot be made to correspond to local observations, then I see this as a big problem for this metric.

We thank the Reviewer for raising this important point, which gives us the opportunity to clarify the role, current limitations, and validation requirements of the CFI.

We agree that an index intended to support operational decisions must ultimately be related to observed coastal flooding and impacts. The lack of a sufficiently extensive and consistent observational dataset prevents such an operational validation in this study. This limitation does not imply that the CFI cannot be validated, but rather that validation requires a dedicated framework covering a larger number of events and combining multiple sources of data, such as coastal video imagery, surveyed flooding limits, water-level and wave measurements, post-event surveys, and impact reports collected by local authorities.

We have therefore clarified that the CFI is not proposed here as a number to be communicated directly to the public. The CFI is a site-specific, hazard-oriented early warning index that translates total water level forecast into physically interpretable coastal flooding categories by comparing them with local berm and defence-crest elevations. In a future operational setting, CFI forecasts could support forecasters and civil-protection authorities by identifying potentially affected coastal sectors, distinguishing beach flooding, wave overtopping, and sustained overflow, and providing information on their timing, duration, and forecast uncertainty. However, the conversion of CFI classes and probabilities into official warning levels or predefined protective actions would require site-specific validation and the co-development of decision thresholds and procedures with the responsible authorities.

Operational coastal early warning systems already provide examples of this general approach. For instance, the Emilia-Romagna coastal early warning system uses physically interpretable indicators such as the Safe Corridor Width and Building-Waterline Distance to translate model predictions into information relevant to user safety and the potential flooding of buildings. This example illustrates how model-derived coastal indicators can contribute to decision support once they are locally implemented, monitored, and linked to end-user requirements.

We also agree that uncertainty in bathymetry, topography, and coastal-defence geometry must be considered. In the present proof-of-concept, the ensemble represents uncertainty arising from the atmospheric initial conditions and their nonlinear evolution through the modelling chain, whereas uncertainties in the coastal geometry are not propagated.

This limitation does not invalidate the physical definition of the CFI, but it may affect the assigned CFI class when forecast total water levels are close to the berm or defence-crest elevations. Quantifying this sensitivity through perturbation experiments and improved local surveys is therefore a necessary step toward operational implementation.

Accordingly, the present study demonstrates the computational and methodological feasibility of producing ensemble-based CFI forecasts and, specifically, assesses whether ensemble reduction preserves the information provided by the full ensemble up to the coastal hazard-classification stage. It does not establish the CFI as an independently validated operational warning product. We have revised the Introduction, the CFI definition, the Discussion, and the Final remarks to make this scope explicit and to describe the intended role of the CFI within the wider early warning process.

- *p5 L130: how is still-water shoreline position defined? As the line where $msl = 0$?*

We thank the reviewer for pointing out this ambiguity. In our formulation, the still-water shoreline is not defined as the fixed contour where $MSL = 0$. It is the instantaneous intersection between the coastal profile and the hourly still-water level h , which includes the astronomical and meteorological contributions but excludes wave-induced set-up and swash. We have rephrased in the manuscript to make it more clear.

- *p5 L131: can you include an equation or explanation of how is $R_{up,2\%}$ defined?*

Yes, we have included a short explanation in Section 3.1 and another in 3.2.3.

- *p6 L141: you write that high water and wave setup increase the "mean sea level". What is meant by this? Is this correct? If it is - over what temporal period is "mean" sea level computed here or elsewhere in the paper?*

Thanks again for pointing out an ambiguous sentence. We mean that the sea level near the coast is increased during storms because of the combination of tides (high water) and wave set-up. The effect of waves breaking in the nearshore is to cause an average increase of the sea level (the set-up), which varies with temporal scale of minutes (related to the speed of wave groups reaching the coastline, called surf beat). We have changed "mean sea level" to "sea level" to avoid confusion with msl .

- *I generally quite dislike the usage of parameters α , β and τ in the manuscript. I couldn't really follow the manuscript until i translated those symbols into height-references. I strongly suggest the authors to rethink whether current α, β, τ notation is truly instrumental to the paper. If i understand correctly, we have this correspondence which is much clearer to me:*

CFI	α, β, τ notation	h_1, h_2, h_B, h_C notation	Interpretation
0	$\beta < 0$	$h_1 < h_B$	run-up lower than berm, no flood
1	$0 \leq \beta < \tau$	$h_C > h_1 > h_B$	run-up floods the beach but not inland
2	$\beta \geq \tau$ and $\beta - \alpha < \tau$	$h_1 > h_c$ and $h_2 < h_C$	overtopping of coastal defense but no overflow
3	$\beta \geq \tau$ and $\beta - \alpha \geq \tau$	$h_1 > h_c$ and $h_2 > h_C$	overtopping and overflow of coastal defense

Table 1: An alternative naming of the cases. Also: in the manuscript you refer to these cases (1,2,3a,3b) but they are never clearly defined. Please define them explicitly.

Your interpretation is correct. We really appreciated the Table you prepared and we decided to include it in the manuscript (with some developments) in order to better convey the CFI explanation. We decided to keep the α , β and τ notation as it allows us to distinguish among the cases more clearly, for instance, between no flooding ($\beta < 0$) and flooding ($\beta \geq 0$). We are grateful for your suggestion. The Table we have included in the manuscript is the following:

Flooding conditions	CFI	Flooding parameters	Levels	Interpretation	Example protective action
NON-CRITICAL ($\beta < 0$)	0	$\beta < 0$	$h_1 < h_B$	<i>Run-up lower than berm. Possible partial flooding of the emerged beach</i>	<i>Routine monitoring; no specific coastal action</i>
FLOODING ($\beta \geq 0$)	1	$0 \leq \beta < \tau$	$h_B \leq h_1 < h_C$	<i>Run-up <u>floods the beach</u> but not inland</i>	<i>Restrict access to exposed beach areas</i>
	2	$\beta \geq \tau$ $\beta - \alpha < \tau$	$h_1 \geq h_C$ $h_2 < h_C$	<i><u>Overtopping</u> of coastal defence but no overflow</i>	<i>Close exposed promenades and secure movable assets</i>
	3	$\beta \geq \tau$ $\beta - \alpha \geq \tau$	$h_1 \geq h_C$ $h_2 \geq h_C$	<i>Overtopping and <u>overflow</u> of coastal defence</i>	<i>Restrict access to exposed inland areas and prepare local emergency measures</i>

Table 1 - CFI classes, physical interpretation, and examples of possible protective actions. The primary distinction is between non-critical conditions ($CFI = 0, \beta < 0$) and flooding ($CFI > 0, \beta \geq 0$). For flooding conditions, CFI distinguishes beach flooding, wave overtopping, and overflow. Actions are illustrative and do not represent operational alert thresholds. $\beta = h_1 - h_B$ is the flooding parameter; $\tau = h_C - h_B$ is the relative coastal-defence height; $\alpha = h_1 - h_2$ is the swash-uprush contribution. h_1 and h_2 are the total water levels for overtopping and overflow, respectively; h_B and h_C are the berm and defence-crest elevations.

- *Formulas 6a and 6b seem unclear. What is n ? Doesn't $n_i=1$ simply give us N ? Where does CFI come into this probability estimation p_{CFI} ? What is n_{CFI} . Please define all terms clearly.*

We have checked and we confirm that formulas are correct. n is the number of REMs (the members of the reduced ensembles, while N is the total number of ensemble members), while w are the weights assigned to the REMS, whose sum is 1 by construction. p_{CFI} is the probability that a CFI class is forecasted; n_{CFI} is the number of REMs that forecast a CFI class. Hence, if we are interested for instance in $CFI=2$, $\hat{p}_{CFI=2}$ is computed as $n_{CFI=2}/n$, that is, as the ratio between the REM that issued a $CFI=2$ forecast and the total number of REM. We have completely rephrased the section, also making notation more straightforward, adding a definition for all the terms involved.

- *Why do you only show temporal evolution of $\beta > 0$, namely $CFI=1$? Why not also other CFI cases? Once again - define cases, please. Does "case 1" correspond to $CFI=1$?*

We have chosen to only show the temporal evolution of $\beta > 0$ because it summarizes critical conditions. Showing all the probabilities would make the figure hard to read or requires to add more figure. As this is just an example of the information that can be extracted we decided to focus on the most interesting cases, i.e., those associated to flooding. About "case 1": it is correct, it corresponds to $CFI=1$ and as it might be confusing referring to an outdated notation, we have made notations uniform across the paper, using only CFI and talking about a CFI classes rather than cases.

- *p19 L190-1: the authors write they did not focus on forecast accuracy. I agree that forecast accuracy of the modeling chain is beyond scope, but i have to reiterate my major objection. I really miss some sort of comparison of computed CFI and actual situation of the ground. I suggest that the authors check if there are any testimonies that could help them qualitatively reconstruct the actual situation in Jesolo, perhaps through webcams or local population or civil rescue experience. Was the beach flooded and where? Was inland flooded and where? Is there any footage that could help the authors comment on the value of CFI during those storms? If this cannot be done even qualitatively for the special situation and two events in the manuscript, then i worry about the relevance of this index.*

We thank the Reviewer for the suggestion. *Vaia* and *Detlef* storms were selected because both caused documented coastal flooding along the Jesolo coastline. In particular, Figure 2 shows inundations during the storms at some structures. There, ENS and RENS assign a non-zero probability of flooding, whereas DET predicts only $CFI = 0$. The ensemble prediction is therefore qualitatively consistent with the documented situation and we have added a paragraph providing a qualitative comparison of CFI probabilities and flooding documented in Figure 2 pictures.

A complete correspondence between predicted *CFI* classes and observed impacts is, however, neither expected nor assessed here, as it would require validation of forecast accuracy throughout the atmosphere-ocean-wave-nearshore modelling chain, which is beyond the scope of this study. Our objective is to introduce *CFI* and determine whether RENS preserves the coastal hazard information and probabilities produced by ENS. Furthermore, both storm peaks occurred at night and under active weather warnings, hence available observations are limited, sparse and do not allow a time-resolved assessment at all seven structures. We have however added a paragraph in the manuscript, presenting this comparison as a qualitative check to support the physical relevance of the *CFI*, rather than as a formal validation.