

AUTHORS' REPLY TO REVIEWER 1

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.

1. Clarify the scope of the contribution within the early warning process

The title, abstract, and introduction frame the study as an early warning application and discuss the role of early warning systems in supporting preparedness and emergency action. The manuscript itself concentrates on the generation of a probabilistic coastal flooding indicator through numerical modelling.

A brief clarification of the intended scope would help readers understand how the proposed framework fits within the wider early warning process. This could include a short discussion of the intended role of the Coastal Flooding Index and how it is expected to support decision-making in practice. Such clarification would strengthen the positioning of the manuscript without requiring additional modelling or analysis.

We thank the Reviewer for giving us the opportunity to clarify the scope of our paper. The proposed CFI is intended as a candidate Early-Warning Index (EWI) that can be adopted to support coastal flood forecasting, warning and decision-making. At this stage, we are providing elements that allow to consider CFI a tool to forecast the coastal flooding hazard rather than to directly deliver coastal flooding alerts and to take actions. To that latter end, it would require, at least, (i) the definition of alert thresholds that might be translated into warnings (and, eventually, decisions) and (ii) a systematic validation of the EW system skills, in terms of correspondence between the forecasted CFI levels and observed impact (as true alarms, false alarms, missed events, etc). In practice, when those requirements would be fulfilled, local civil protection authorities could benefit of an EW system that provides site-specific probabilities of flooding and inundation of the beach and inland. This might allow coastal communities to be prepared and take mitigating and protecting actions in advance.

We have clarified this in the manuscript, including specific text in the “Introduction”, “Coastal Flooding Index” and “Discussion” sections. In the “Discussion” section, we have devoted a sub-section on the scope, contributions and limitations of our study.

2. Discuss the practical significance of the 48-hour forecast horizon

The manuscript identifies short-range 48-hour ensemble forecasts as a key component of the proposed framework and highlights the importance of meeting operational time constraints. It would be helpful to include a short discussion of the practical significance of this forecast horizon and the types of preparedness or decision-making activities that it is intended to support. This would provide useful operational context and further motivate the choice of forecasting window.

We thank the Reviewer for this suggestion. In this proof-of-concept, the 48-hour horizon was selected as a practical compromise between useful lead time for short-term preparedness, forecast predictability, and the computational cost of the ensemble modelling chain. It could support enhanced monitoring, coordination among responsible authorities, inspection of exposed coastal sectors, access restrictions, and preparation of local protective measures. Successive forecast cycles would progressively refine the expected flooding location, timing, severity, and probability. This timescale is consistent with the 48-hour water-level forecasts

provided by the NOAA Coastal Inundation Dashboard for near-term coastal flood preparedness. Moreover, the European Coastal Flood Awareness System evaluation found limited lead-time effects on extreme sea-level forecast performance up to four days, although peak levels were systematically underestimated. We clarify, however, that our study neither compares alternative forecast horizons nor assesses CFI performance as a function of lead time. Therefore, 48 hours should be regarded as a practical choice rather than an optimal horizon. This has been made explicit in the “Discussion” section.

3. Clarify the interpretation of the Coastal Flooding Index

The Coastal Flooding Index is defined through physical conditions associated with beach inundation, overtopping, and overflow relative to coastal defences. The manuscript also refers to different alert levels and discusses the broader context of impact-oriented forecasting. A clearer explanation of how the different CFI levels should be interpreted would strengthen the manuscript. In particular, further discussion of how these physically defined categories relate to their intended use within early warning and decision support would improve clarity and make the framework more accessible to practitioners.

To answer this comment that is common among both the Reviewers, we have introduced a Table (Table 1 in the manuscript) that we believe will make the understanding and interpretation of the CFI clearer to the Reviewers and the readers:

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.

In Table 1, we have directly related the flooding parameters to the water and defence levels, to the interpretation of each class and we have provided examples of protective actions. We are grateful to Reviewer 2 who have proposed a Table that we appreciated, adopted and further developed.

4. Strengthen the discussion of the existing early warning literature

The introduction cites recent work describing challenges and fragmentation within coastal early warning systems and identifies the need for improved forecasting products. Revisiting these themes in the discussion would strengthen the positioning of the study.

A brief explanation of how the proposed framework contributes to this existing body of literature would help readers place the manuscript within the broader context of coastal flood early warning research.

We thank the Reviewer for this suggestion. Our proposed framework contributes to addressing these limitations by: (i) translating ensemble forecasts of total water level into site-specific and physically interpretable coastal flooding categories through the CFI; (ii) propagating meteorological uncertainty through the atmosphere-ocean-wave-nearshore modelling chain; and (iii) reducing the computational burden through the selection of representative ensemble members. Therefore it combines localized hazard information with a representation of forecast uncertainty while remaining compatible with short-range forecasting constraints. We have expanded the “Discussion” section including a sub-section purposely devoted to clarify how the proposed framework contributes to current coastal flooding early warning research.

Minor comments

- The manuscript compares “warnings” produced by the ensemble, reduced ensemble, and deterministic approaches. In several places, terminology such as “forecast outputs”, “flood indicators”, or “CFI results” may more precisely describe what is being evaluated.

Thanks, we do agree, especially in the light of the modifications that have been done to better define the scope of the paper and the CFI role. We have adjusted the manuscript accordingly.

- The statement that CFI levels “can be associated” with different alert levels would benefit from further clarification regarding the intended interpretation.

Thanks, we have restructured the whole explanation of CFI following the requests and suggestions of Reviewer 2. Hence, this sentence has been rephrased and we believe the present version is more clear.

- One of the most interesting findings is that the deterministic approach frequently produces lower-severity outcomes and would not have triggered an alert at five of the seven coastal defence structures considered during the Vaia event. This result has clear practical significance and deserves greater prominence in the Discussion and Final Remarks.

Thanks, we do agree and, following your suggestion, we have added a discussion on this point in the “Discussion” section.

- There are several minor language and typographical issues throughout the manuscript that should be corrected during revision.

Thanks for pointing this out, we have therefore revised the manuscript with great attention to fix those issues.