Response to reviewer

Manuscript title: Marine heatwave amplifies extreme multi-hazards of extratropical cyclone Babet

Journal: Natural Hazards and Earth System Sciences (NHESS)

Reviewer 1:

Marine heatwave amplifies extreme multi-hazards of extratropical cyclone Babet Review for NHESS Goswami et al present their case study of the interaction between the autumn 2023 marine heatwave (MHW) and extratropical cyclone Babet, demonstrating through the use of a counterfactual scenario that the strong MHW influenced the development and hazards of the storm. While certain elements could use slightly more explanation as to the reasoning behind choosing that method, it is based securely in peer-reviewed methods which are combined and applied to a novel case; this is a well-structured, clearly written paper that after some minor revisions would be an excellent candidate for publishing. Please see my comments below for the specifics.

Response: *We thank the Reviewer for the positive and constructive comments. We appreciate the encouraging assessment of the manuscript and the helpful suggestions for improvement. We address the comments below and will revise the manuscript accordingly.*

Several points require a little more explanation:

Line 153-154: Why is the atmosphere ensemble based and the wave components deterministic?

Response: *The starting conditions and the boundary conditions are deterministic because of the set-up of the current operational system for waves and ocean. Nevertheless, the waves and ocean will inherit some spread from the atmospheric model. We will edit the sentence to explain this in the manuscript: "While the atmospheric component is ensemble-based, the ocean and wave components* ***use deterministic initial and boundary conditions****, with coupling handled consistently across all members.* ***The ensemble spread in ocean and waves therefore only grows through coupling."***

Line 300-301: Can you add a justification for why you choose the two times you did for the lagrangian parcel tracking?

Response: *Thank you for this suggestion. We will clarify in the text that the two release times, 04 UTC and 22 UTC on 19 October, were chosen to represent two different stages of the precipitation event, allowing us to examine whether the pathways and thermodynamic*

evolution of the air parcels varied over the course of Storm Babet. These release times were the most representative of the two different stages of the storm: the first stage bringing warm and near-saturated air, the second stage bringing cold and dry air.

3.3 Air mass trajectories and moisture origin

To explain the origins of the multi-hazard in ~~storm~~ Storm Babet, we performed air mass Lagrangian trajectories (Section 2.2) using the Met Office global deterministic forecasts to provide insight into the pathways and moisture history of air parcels feeding precipitation during Storm Babet. Backward trajectory analyses were conducted for two trajectory release times on 19 October at ~~04UTC~~ 04 UTC (Figure 6) and at ~~22UTC~~ 22 UTC (Figure 7), ~~to trace the origin and~~ chosen to represent two different stages of the precipitation event and to examine whether the pathways and thermodynamic evolution of ~~air masses reaching Eastern Scotland~~the air parcels varied through time. Air parcels were released from near-surface levels (950-970 hPa) over the target region (56.0-57.0°N, 1.0°W-0.0°E), with a spatial resolution of 0.2° in both latitude and longitude. Each parcel was tracked 16 hours backward and 2 hours forward in time, providing a continuous reconstruction of their pathways and thermodynamic history.

Page 12 paragraph 2: You mention that the peak wind (and thus the surge amplitude) is underestimated by the models, but barely reference this in the discussion. Do you have an idea as to why this is underestimated?

Response: *We will add the following sentence at the end of this paragraph: "the most extreme winds and waves (and to a lesser extent surge) are underestimated by the model. Sensitivity studies conducted by Berthou et al. (2026) showed the wave amplitude could be increased to some extent by changing the coupling strength between wind and waves. However, this deteriorated the winds. Therefore, the origin of the problem is thought to be a lack of free-tropospheric momentum entrainment into the unstable boundary layer. Further work is needed to improve this in the next atmosphere and land configuration of this model.*

Other:

Line 74: I think there's a word missing "the use of the global model enables **us** to…"

Response: *Thank you for spotting this. We will correct the sentence to read: 'The global model allows us to use…'.*

L162-164: Mentioning that the 2020 run is started 3 years and 2 days before the forecast model could lead to confusion – I understood this initially as the no_MHW ocean being allowed to run for 3 years before the simulation starts, which would introduce great amounts of uncertainty. Rephrasing for clarity is suggested.

Response: *Thank you for pointing this out. We agree that this wording could be misleading and will rephrase the text to make the experimental setup clearer:*

Two ensemble 5-day forecast simulations were triggered for storm Babet, both starting on 17 October 2023. ~~The ocean model is either initialised~~ In the MHW experiment, the ocean initial conditions were taken from 17 October 2023, ~~2~~ two days before the storm~~starts in the~~. In the no_MHW experiment, ~~or~~ the ocean initial conditions were instead taken from 17 October 2020, ~~3 years and 2 days before the storm in the no_MHW experiment.~~ chosen as a non-MHW reference state for the same calendar date, while the atmospheric initial conditions and simulation start date remained 17 October 2023. 2020 is chosen

L194: Consider specifying that this is the specific heat capacity of sea water and not just water in general.

Response: *We will specify that this is the specific heat capacity of seawater.*

Section 3.1, paragraph 2: The description of weather regimes/how to read Fig 2a comes after conclusion drawn from 2a, and thus the 1/3/6/12/16 mentioned have little significance for the reader not familiar with these weather regimes. I would move the lines "Weather regimes between 1-10…autumn and spring." to after the first sentence in the paragraph.

Response: *We agree and will move the explanation of the weather-regime numbering earlier in the paragraph so that the specific regimes shown in Fig. 2a are easier to interpret.*

The primary catalyst for the MHW was a sequence of persistent atmospheric anticyclonic weather regimes in September 2023. Weather regimes between 1 and 10 correspond to weak circulation, more typical of summer, while regimes between 20 and 30 represent strong circulation, more typical in winter, and regimes 10-20 are intermediate, most frequent in autumn and spring (Neal et al., 2016). As shown in Figure 2a, the period leading up to and during the MHW's peak (20th August - 20th September) was dominated by regimes 1, 3, 6, 12, 16 which are all characterised by weak winds~~(Neal et al., 2016)~~, and most with ~~anticycleonic~~ anticyclonic conditions over the North Sea. High-pressure systems (anticyclonic conditions) suppress cloud formation and reduce wind speeds, favouring ~~marine heatwaves~~ MHWs (Berthou et al., 2024). The prolonged presence of these regimes created an extended window of clear skies and calm seas, maximizing the amount of solar radiation reaching the ocean surface. ~~Weather regimes between 1 and 10 correspond to weak circulation, more typical of summer, while regimes between~~

Line 209: typo – *anticyclonic*

Response: *Thanks, we will correct this typo.*

Section 3.2 paragraph 1: I think an extra reference here would be useful, as the only reference is Kendon et al at the beginning of the paragraph.

Response: *We will add the published Kendon et al. (2024) alongside the existing event-specific reference.*

Line 291: typo – observations show~~s~~

Response: *Thanks, we will correct this typo.*

Line 296: extraneous semicolon

Response: *We will remove the extraneous semicolon.*

Line 330: maybe specify Northwestern European shelf **sea**? I wondered why the shelf itself was warm

Response: *We agree and will specify 'Northwest European shelf seas' for clarity*.

Figure 7 – MHW is yellow but the caption says red, also the solid MHW line is really difficult to see. I suggest trying to find a better way of indicating significance than the red asterisks (shading of the background perhaps?)

Response: *This is a very helpful suggestion. We will remove the stars, change the colour from yellow to red and make the MHW line thicker when significant, here is an example of the new figures:*

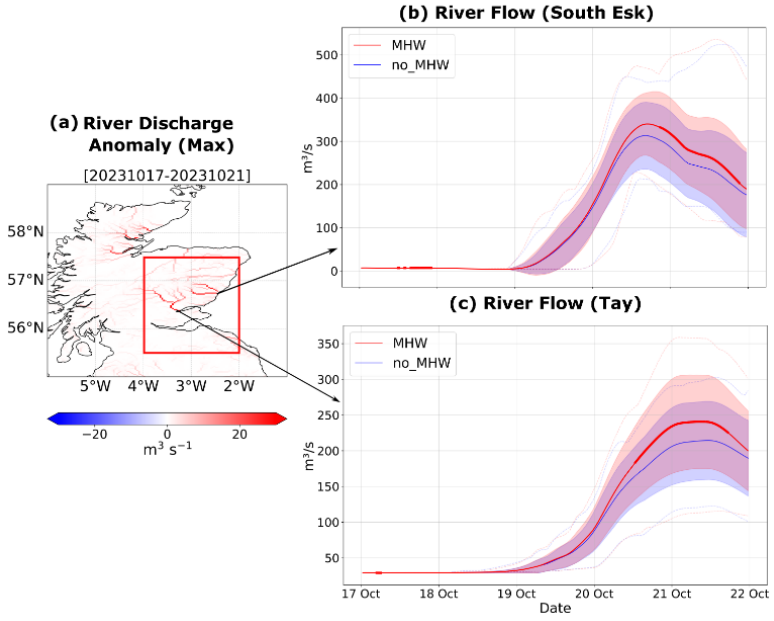

Figure 8 – It may be useful to add the red box of the domain to this map as well, as you refer to it twice in the caption alone

Response: *We agree and will revise Figure 8 to show a smaller northern UK region and to include the domain box for improved clarity (see above)*

One last suggestion I have is to add a figure to help understand the evolution/life/path of Babet. I had trouble picturing the path of the storm or how East Scotland was the area hardest hit with rain despite it coming from the south. I understand it is difficult what with Babet being composed of the multiple different lows combining, but if possible (and useful) I think this could add clarity. Perhaps through the use of (radar) images as in Kendon et al(2023)?

Response: *We agree that an additional figure illustrating the evolution of Storm Babet would improve the clarity of the event description. In the revised manuscript, we will add a synoptic figure illustrating the storm evolution and the associated wind and pressure patterns, in order to provide clearer large-scale context for the rainfall distribution.*