Response to RC1

This paper uses a wealth of data sources, principally models and re-analyses, to consider the relative influence of atmospheric and oceanic drivers on the generation of marine heatwaves (MHW) in the North Sea, specifically in the German Bight. They report that, save for in winter, weather patterns and climate indices (e.g. the NAO) in a given season cannot alone explain the incidence of MHW: the effects of ocean pre-conditioning must also be taken into account. They also report that ocean-atmosphere heat fluxes tend to dampen the influence of heat transport anomalies, lessening the frequency with which heat transport alone generates MHW, at least in their study region.

This is a nice paper that contains some interesting results that I think will be of interest to the community. I particularly think that the consideration of both vertical (atmospheric) and horizontal (oceanic) heat fluxes is timely. I have only a few fairly minor comments, so I recommend publication after minor revisions. Please accept my apologies for the delay in submitting this review.

Thank you very much for reviewing our manuscript and for your positive feedback. Please find a detailed response to your comments below. Line numbers in our response refer to the revised manuscript.

COMMENTS

Introduction. It would be nice to have a few sentences justifying the choice of study region. Why was the German Bight chosen as the focus of this study? Why is it important? And a bit of background about the region's oceanography would be good too – for instance, annual cycle of stratification, circulation patterns etc.

We have added additional motivation for selecting the German Bight as our main study region and also extended the background on the oceanic conditions with a focus on the German Bight. A main reason for selecting the German Bight is that the German Bight is among the most populated sections of the North Sea coastline, with several important harbors and other critical infrastructure along the coast.

Line 129. Is there likely to be an impact of not including tidal forcing? This is presumably a region with relatively strong tidal currents? Apologies if I've missed something, but a word or two on this would be welcome.

This is a valid question. Tidal mixing is potentially important in the region, however among the datasets the effect of different vertical resolution (BSH versus coastdat1 and VIKING20X) seems to be more important than tides. After this manuscript was submitted, we also analysed other experiments with a coarser horizontal resolution (1/4°) with and without tides in an otherwise identical model set-up. These experiments show a very small impact of including tides on the occurrence and characteristics of MHWs in the German Bight. The reason is probably that in winter the water column is well mixed anyway and in summer stratification (during MHWs) is strong enough to be sustained even with tidal mixing. A short note on the impact of tides was added to the respective line. But a rigid evaluation is outside the scope of this paper.

Line 148. “Dynamically” implies a temporal change, but do you mean a spatial change in this context?

It is indeed a temporal change. The vertical grid used by the BSH model is rather complicated. The grid cell centers are not fixed in depth, but the grid cell thickness is kept constant. This means the first grid cells are all 2m thick, but dependent on the sea surface height, their center can be at different depths at different times (with respect to fixed axis that does not change with SSH). The model output is then provided after interpolation onto such a fixed depth axis. Nevertheless, the uppermost layer is always 2m thick and the corresponding temperature represents a 2m deep layer of uniform temperature at the surface (this is the non-interpolated temperature we use).

We have changed the description of the depth axis to:

“The grid cell thickness is fixed, but their center with respect to a fixed depth axis varies temporally with sea surface height. The temperature is provided after interpolation onto such a fixed depths axis. Additionally, the value of the uppermost model level was used without interpolation as the "surface" temperature.” (line 154)

Also line 148. Taking the sub-surface temperature as the surface temperature: how does this fit with the finding of Berthou et al (2024) that heatwaves peak in a thin surface layer, and anomalies are much smaller below this? Is the depth of your uppermost interpolated value still within this surface layer?

As shown by *Berthou et al.*, during MHWs the surface mixed layer can be as shallow as 10 m. Therefore, we expect the BSH models surface layer (see also our response to the last comment) to be fully within the mixed layer, even when it is very shallow during (summer) MHWs. This is supported by the very good match between the MHW maximum intensity in the BSH model and in the satellite products. The BSH model itself suggests that the mixed layer can be even shallower than 10 m in the German Bight (about 3-4 m). This is the main reason for VIKING20X (6 m surface layer) to underestimate the intensity of summer MHWs.

Impacts of the vertical axis (e.g. a comparison with results obtained by Berthou et al.) are discussed later (line 790) in the text and we didn’t add this discussion in the method section itself.

Line 176. The model might not include the effects of tidal forcing directly, but presumably the observations that are fed into GLORYS12 will include the effects of tidal forcing?

Yes, the model does not include tides, but the observations (e.g. remote sensing SST) will include the effects of tidal mixing. We added this remark to the text (line 184).

Line 283. Apologies if I've missed something here, but will the degree of surface heat lost to deeper model levels be at least partly determined by the degree of turbulent mixing in the model? Which will be influenced by tides – or the lack thereof? That is, will not including tides in products/models such as VIKING20X reduce the amount of vertical heat transport?

Yes this is true. The turbulent mixing is by far the most important contribution to the heat flux from the top to deeper layers. This is simulated by the model, based on the mixed layer parameterization (TKE) scheme. By definition the first model level is fully within the mixed layer. Tides can enhance mixing, but within the mixed layer the contribution of other sources of turbulent mixing (mostly wind) is expected to be much higher.

Apart from this technical/theoretical aspect, the impact of tides in otherwise identical model simulations is small (see our comment above).

Figure 2. I know this is a common way of plotting things, so I don't want to insist – but I do think it makes it harder to interpret these sorts of plots when the bits that *are* significant are stippled out, rather than the bits that *aren't*.

We have changed the stippling according to your suggestion, since we agree this highlights the significant areas.

Line 484. In what direction are the latent heat anomalies? I'd state here for clarity.

The latent heat flux anomalies are directed into the ocean (i.e. anomalous ocean heat gain by latent heat fluxes). For the German Bight, this means reduced heat loss to the atmosphere by evaporation. The corresponding sentence now reads:

"From August to October, the main driver of most events is an anomalous latent heat flux into the ocean." (line 507)

Line 735. This sentence doesn't make a lot of sense to me: there was a warming trend that was followed by a warming trend? I'd re-phrase for clarity.

The main point here is that there was a strong warming in the late 80s. Afterwards the North Sea continued to warm, but at a lower rate. This was not clear and we have changed the sentence to:

“The North Sea experienced a strong warming in the late 1980s and has continued to warm (at a lower rate) afterwards.” (line 765)

Line 805. Temperature is an integrated quantity – do you mean spatially or temporally? (Or both?!) From later context, I assume you mean temporally, but I’d state it here explicitly

Yes, we are referring to a temporally integrated quantity. This means temperature (heat content) is a result of temporally integrated fluxes. It is usually the fluxes, not temperature itself, that are linked to specific weather patterns or climate indices. The text now reads:

“Consistent with the view that temperature is an integrated quantity (i.e. it is set by temporally integrated fluxes) and climate indices being more related to temperature changes than absolute temperature anomalies, we only find a statistically significant dependency of MHWs on the state of the EAP in winter.” (line 841)