Brought back my joy in seeing just as soon
as I had left behind the air of death
that had afflicted both my sight and breast.

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Spotlight

The marine heatwave west of Ireland in June 2023

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The summer of 2023 had been notable for a number of climate extremes: sea ice in the Antarctic dropped to its lowest for the time of year since satellite records began in the 1970s (NASA Earth Observatory, 2023), terrestrial heatwaves engulfed southern Europe and southern United States/Mexico that would have been 'virtually impossible' without climate change (WorldWeatherAttribution, 2023), and sea-surface temperatures (SSTs) in the North Atlantic reached their highest since satellite records began in 1982 (NOAA, 2023). In concert with these terrestrial heatwaves and high Atlantic SSTs, a severe marine heatwave (MHW) developed in the eastern North Atlantic, west of Ireland (Figure 1a). Except for a narrow band close to the coast from Greenland to Canada, SSTs everywhere in the North Atlantic were above the 41-year average (1982–2023), with many regions experiencing temperatures 2 degC higher than average. In the study region west of Ireland (highlighted in Figure 1b), the SST reached an impressive 4 degC above average.

A MHW is a discrete, prolonged (5 days or longer), intensely warm water (>90th percentile temperature for a given time of year) event (Hobday *et al.*, 2016). MHWs have a direct impact on ocean ecosystems. Famously, extreme heat can lead to widespread coral bleaching in shallow water corals, mass mortalities of marine species and marine deforestation. In Irish waters, there is a recognition of the growing influence of warm water Lusitanian species over the cold water boreal species, such as exemplified by the growing numbers of anchovies in Irish waters (Vaughan *et al.*, 2023). However, while studies of the North Sea and the English Channel exist, the study of MHWs on ecosystems in Irish waters is limited.

The metric of MHW activity (Simon *et al.*, 2022) allows us to quantitatively characterise MHW events for a certain period and study area. It is computed for each grid cell as the sum, over every event detected, of the product of their duration (days), intensity (degC) and area affected (km^2). Therefore, the higher the occurrence, duration, intensity and area are, the higher will be the activity value. For satellite products, the area is the grid cell area of the detected event and for *in situ*, the area is taken to be 1 km^2. The MHW activity between June 2023 and mid-July is shown in Figure 1(b). It shows a broad warming over the domain with maximum activity near the west coast of Ireland. The activity reached for the domain as a whole approached 60 degC day $10^3 km^2$, which is approximately equivalent to temperatures of 2 degC above average lasting for the full month of June.

With such elevated temperatures, it is not surprising to find that the June 2023 MHW was confined to a shallow layer, near the sea-surface. Argo floats, which provide profiles of the top 2000m of the deep ocean, show the depth profile of ocean temperature offshore of Ireland during June 2023 (Figure 1c). In June, the North Atlantic has

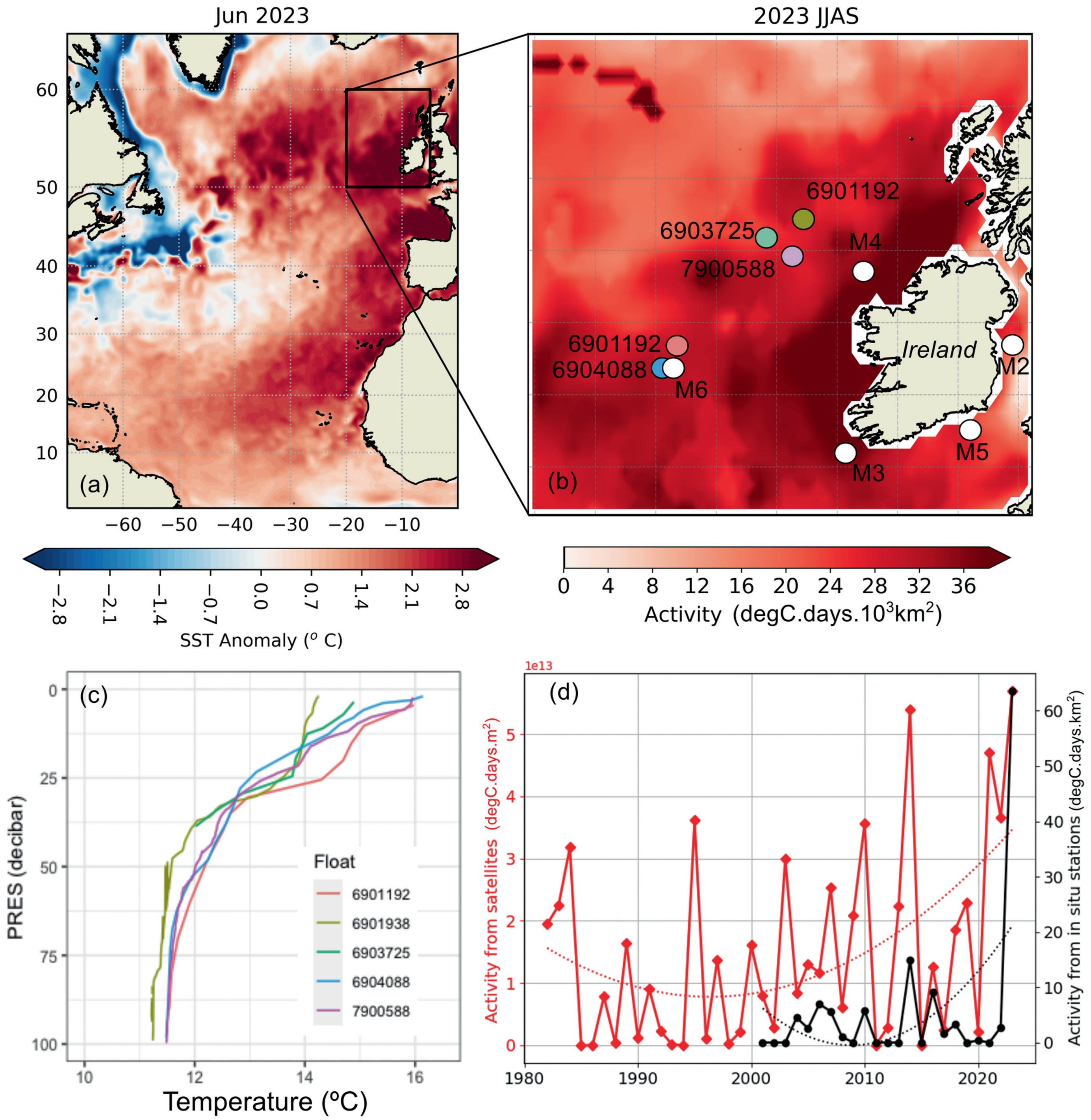

Figure 1. (a) Sea-surface temperature anomaly observed in June 2023 (degC) relative to 1982–2023. The black rectangle defines the study area (50–60°N, 20–5°W). (b) Activity of 2023 summer (June-July-August-September; JJAS) marine heatwave (MHW) (degC days 10³ km²) in study area. In situ observations from Irish meteorological buoys are shown in white open circles. Locations of Argo floats are shown with coloured open circles. (c) Depth profiles of the MHW based on Argo profiling float profiles from 11 to 15 June. Colours correspond to the locations in (b). (d) Times series of (red) satellite-derived summer (JJAS) and (black) buoy-derived June marine heatwaves mean activity. Dashed line represents the regression of a third-order polynomial. Daily sea-surface temperature (SST) data are from the NOAA Optimum Interpolation SST product (OISSTV2; Huang et al., 2020).

cold, deep mixed layers of the winter keeping temperatures between 11 and 12°C for much of the upper ocean. On top of this cold layer, the MHW developed in the top 25m of water. While the action of wind and waves would typically mix colder deeper water with this warm upper layer, June 2023 was characterised by settled conditions that meant this did not occur (Met Éireann, 2023).

Observations of SSTs from satellites and *in situ* buoys allow us to contextualise this MHW in terms of historical events. Figure 1(d) shows that the MHW activity in summer 2023 was the highest of any MHW in the waters west of Ireland since satellite records began in 1982. *In situ* meteorological buoy data (locations shown in Figure 1b) provide observations closer to the Irish coast. These data show the exceptional nature of this MHW where, looking at all June data, across all five met buoys (M2–M6), the activity in 2023 topped 60 degC days km², when the previous highest value recorded was in 2014 peaked at approximately 15 degC days km². The increased frequency of warm events in Irish water in recent years is evident in the years 2021–2023 occupying 3 of the top 4 years, in terms of maximum MHW activity. Since 2000, there has been a linear positive trend in MHW in June (or June–July) to the west of Ireland.

Globally, MHWs have been increasing in frequency and duration largely in response to rising mean ocean temperatures (Frölicher and Laufkötter, 2018; Oliver *et al*., 2018). However, since 2007, temperatures in Irish waters have been cooling (McCarthy *et al*., 2023), linked by some authors to a decline in the Atlantic Meridional Overturning Circulation, sometimes referred to as the Gulf Stream System (Caesar *et al*., 2018). The observed increase in MHWs in Irish waters presented here suggests that these waters are not immune from the effects of extreme ocean warming.

It is unlikely that Irish waters will escape the forecast increased frequency of MHWs for the world's oceans (IPCC, 2021). In this context, the MHW of June 2023 could well be a warning for the future.

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Author contributions

Gerard McCarthy: Conceptualisation; writing – original draft; writing – review and editing. **Sandra Plecha:** Formal analysis; writing – review and editing. **Guillaume Charria:** Formal analysis; writing – review and editing. **Amélie Simon:** Formal analysis; writing – review and editing. **Coline Poppeschi:** Formal analysis; writing – review and editing. **Ana Russo:** Formal analysis; writing – review and editing.

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