National Environmental Science Program

Understanding the marine heatwave hazard in the nearshore and inner shelf zone of southeast Tasmania

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Executive summary

As our climate warms, marine heatwaves (MHWs) are becoming more frequent and longer lasting (e.g. Oliver et al. 2018a). Detrimental consequences for marine ecosystems, fishing, aquaculture and the tourism industry include:

- Large-scale dieoffs of habitat forming species, as seen in the diebacks or collapses of kelp forests in Tasmania (e.g. Kajtar et al. 2021), Western Australia (e.g. Wernberg et al. 2021) and California (e.g. McPherson et al. 2021), or extensive bleaching seen on many coral reefs (e.g. Leggat et al. 2019).
- Range shifts bringing new species into a region, potentially driving increased competition or displacement of endemic species, for example, the establishment of tropical fish species in waters off southern Western Australia during the 2010-11 marine heatwave (Lenanton et al. 2017).
- Increased occurrence of harmful algal blooms which can cause large-scale die-off of fish and shellfish, as seen in South Australia in 2013 (Roberts et al. 2017)
- Precautionary interventions such as moving insurance populations into captivity such as the intervention to protect Red Handfish during the 2023–24 Tasman Sea MHW (e.g. Hobday et al. 2024), or closures of fisheries such as the Californian Dungeness crab fishery during the 2014–16 'the Blob' marine heatwave (Jardine et al. 2020).
- Increased bacterial or viral disease outbreaks, such as the Pacific Oyster Mortality Syndrome outbreak in Tasmania during the 2015–16 MHW (Ugalde et al. 2018; Shi et al. 2024) or the case of humans suffering *Vibrio* infection during a 2018–19 MHW in the Baltic Sea (Brehm et al. 2021).
- Increased stress on organisms resulting in reduced condition, as seen in a laboratory study simulating MHW impacts on Green Lipped Mussels (Venter et al. 2023), or decreased reproductive success as seen in multiple invertebrate species off Oregon during the 2014–16 'the Blob' marine heatwave (Shanks et al. 2019).

While the science around marine heatwaves is relatively mature for open ocean regions where large-scale climate drivers can play an important role, our understanding of marine heatwaves in the nearshore and estuaries is still developing. These coastal and estuarine systems are typically bathymetrically, hydrodynamically and ecologically complex, with socio-ecological co-dependencies.

For example, they are often important habitats for species and are where fisheries and aquaculture operations are concentrated. The risk of significant impacts highlights the need to improve our understanding of marine heatwaves in these coastal and estuarine regions.

Hub researchers are using observations and ultra-high-resolution models to explore marine heatwave impacts and hazards in the Derwent-Huon-Storm Bay system located in southeast Tasmania. The area supports diverse environments from kelp forests and rocky reefs home to several critically endangered species. It also hosts the state's major oyster and salmon aquaculture operations and abalone and rock lobster fisheries. The region also plays host to on-water tourism including whale and seal watching cruises, seafood experiences and diving, and is popular for boating, yachting and recreational fishing.

Hub researchers are developing marine heatwave hazard maps to quantify marine heatwave intensities and exposure, co-designed with a range of decision makers. Informed by this engagement, this report presents a deep dive into three recent major MHWs that represent significantly different offshore dynamics and forcing, raising awareness and providing new insights at finer spatial scales than previously available.

What are marine heatwaves?

Marine heatwaves are discrete and prolonged warm ocean temperature extremes, often quantified when temperatures exceed the 90th percentile threshold relative to an estimated seasonally varying baseline climatology, for at least five consecutive days (Hobday et al. 2016). A schematic of a marine heatwave is shown in Figure 1.

A marine heatwave is characterised by:

- its duration (from onset to end, that is the period when temperatures exceed the 90th percentile)
- its intensity – the difference between the temperature and the climatology at a particular time

- its category – intensity measured as a multiple of the difference between the threshold and climatology, typically ranging between moderate (1–2 times the difference), strong (2–3 times the difference), severe (3–4 times the difference) and extreme (over 4 times the difference).
- cumulative intensity – the incremental sum of intensity over the duration of the event.

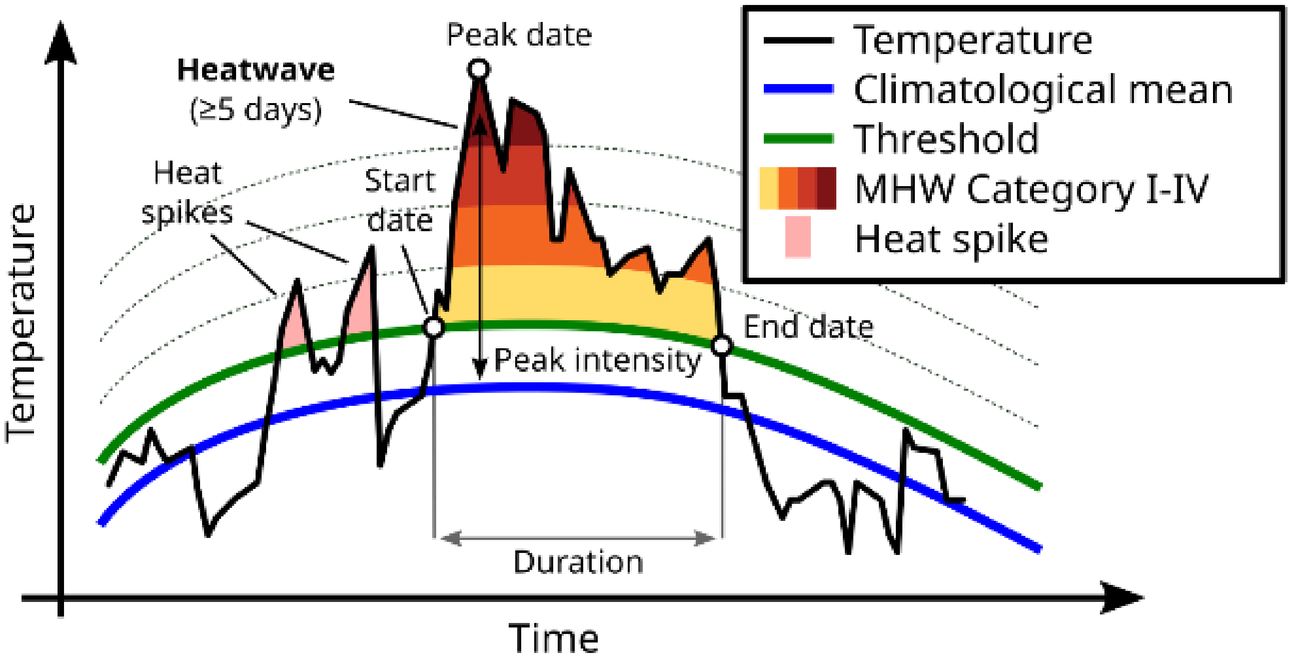


Figure 1: Schematic of a marine heatwave sourced from www.marineheatwaves.org. The blue line indicates the seasonally varying climatology (mean temperature on a given day of year), and the green line indicates the 90th percentile threshold. Colours indicate MHW categories, moderate (category 1, yellow), strong (category 2, orange), severe (category 3, red) and extreme (category 4, dark red). The definition and categorisation scheme were developed by Hobday et al. (2016, 2018)

What are the impacts of marine heatwaves?

Marine heatwaves can have significant impacts on marine habitats and species. Smith et al. (2023) identified major impacts, including causing large-scale species mortality, stress leading to decreased reproductive success or increased vulnerability to disease, range shifts of warmer water species into cooler regions, and increased occurrences of algal blooms.

These impacts can combine to cause changes to entire ecosystems, particularly when marine heatwaves cause the loss of key habitat forming species, as seen in the Western Australian 2011 MHW (e.g., Wernberg et al. 2013, 2016, 2021) which caused a permanent loss of many kelp forests. Ecosystem changes can, in turn, cause socioeconomic impacts (Smith et al. 2021), such as disruptions to fisheries and tourism. While marine heatwaves in the open ocean and outer margins of the continental shelves have been extensively studied, we have less understanding of how MHWs extend into the coastal domain.

Temperate reefs and kelp forests in southeast Tasmania form part of the Great Southern Reef system (Bennett et al. 2015) and play host to endangered species including the Bruny Island Sea Star; and the critically endangered Live-Bearing Sea Star, Red Handfish and Spotted Handfish. The region is also a major centre of aquaculture and wild fisheries, accounting for the majority (around 75%) of Tasmania's salmon production –which equates to around 68% of Australia's total salmon production) and 65% of Tasmania's oyster production (Oysters Tasmania, 2026). It also accounts for one third of the state's total abalone harvest and most of the commercial abalone catch on Tasmania's east coast (McAllister and Mundy 2025). Prior to management changes in 2013, the region accounted for 15–20% of the state's Southern Rock Lobster commercial catch (Hartmann et al. 2019). Southeast Tasmania is also a very popular region for recreational fishing, with 40% of the state's recreational catch of both Southern Rock Lobster and abalone in 2023–24 (Twiname et al. 2024) and 50% of the Sand Flathead recreational catch in 2017–18 occurring in the region (Lyle et al. 2019).

The Tasmanian marine environment

The continental shelf and offshore waters around Tasmania are influenced by two major ocean current systems and extensions (Figure 2):

- The East Australian Current (EAC) Extension, a system of eddies splitting off from the separating East Australian Current around 32 ºS, that transport warm waters southward down the east coast of Australia.
- The Zeehan Current (ZC), flowing anticlockwise around the western and southern coasts of Tasmania, which transports cooler water to meet the warm EAC Extension waters.

The strength of these two systems varies in time. Typically, the EAC Extension is strongest during summer (December–March) and the Zeehan Current is at peak strength during winter (June–July) (Cresswell 2010; Ridgway 2007). As a result, the confluence zone of the two currents typically shifts between South Cape in summer and Freycinet Peninsula in winter (Figure 2). Anomalously strong transport of warm water by the EAC Extension has been identified as a major driver of MHWs off Tasmania's east coast (e.g., Oliver et al. 2018b).

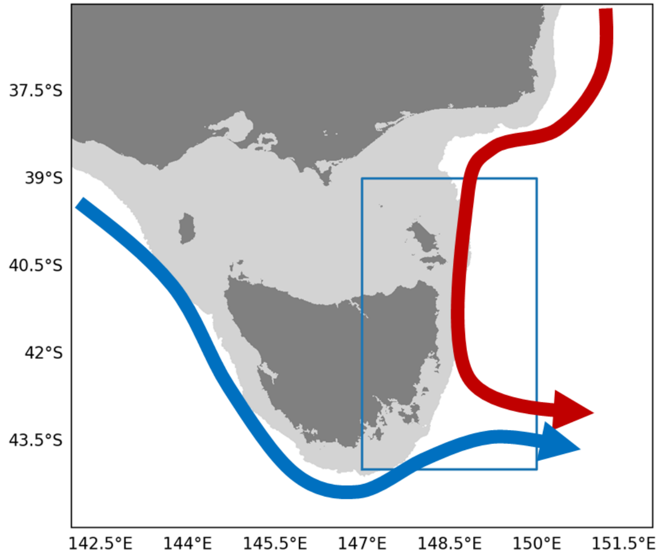


Figure 2: Tasmania is influenced by two ocean current systems, the Zeehan current (blue) and the East Australian Current Extension (red). Land is shown in dark grey and the continental shelf (here out to the 200 m isobath) in light grey. The blue box indicates the area for which MHWs are shown in Figure 5

The coastal waters of southeast Tasmania consist of a system of bays, channels and estuaries including Storm Bay, the D'Entrecasteaux Channel, the Derwent Estuary and Huon Estuary (Figure 3). The seafloor of the region is dominated by sand with areas of silt and soft substrate in both estuaries; Norfolk Bay and the northern end of the D'Entrecasteaux Channel, with rocky reefs occurring in proximity to the coast. Fresh water enters the system as runoff and principally arrives via the Derwent and Huon Rivers with secondary contributions provided by the Coal River and North-West Bay River.

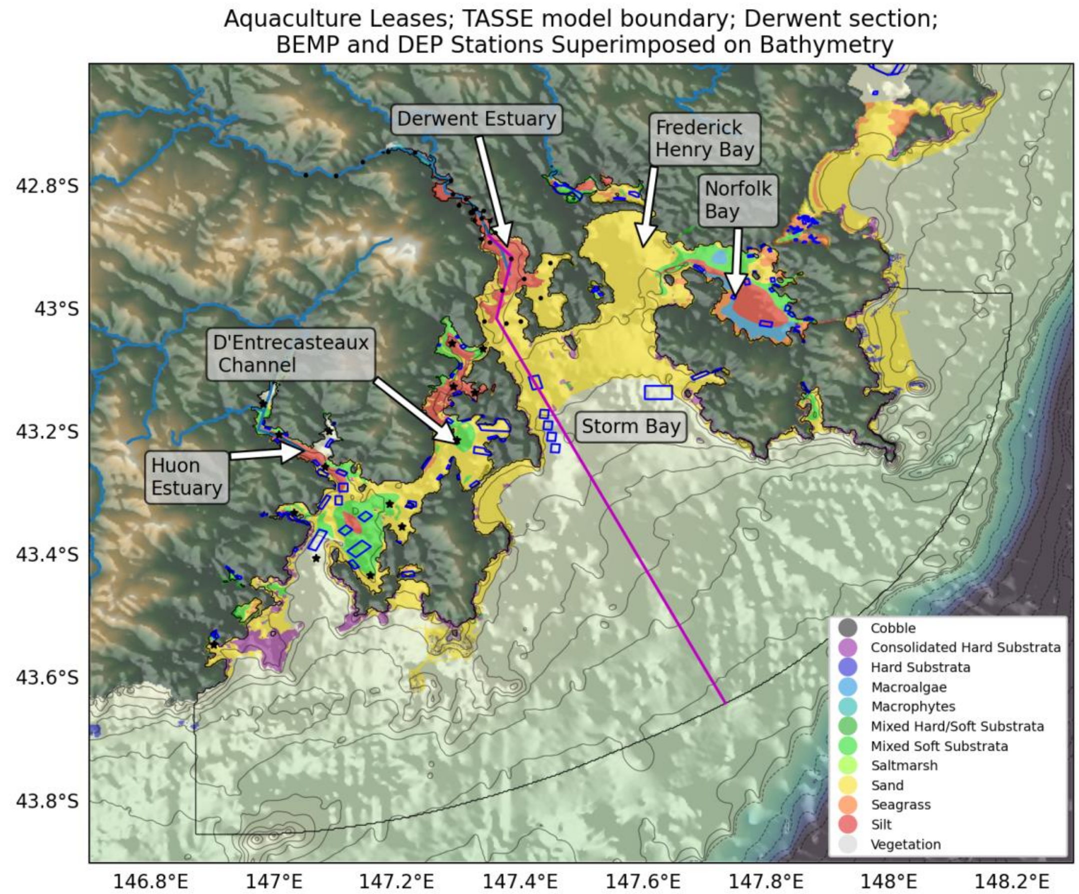


Figure 3: Map of southeast Tasmanian bathymetry from AusBathy Topo 2024 (Beaman 2024) and inshore benthic environment from the SeaMap National Benthic Habitat Layer (Lucieer et al. 2026). Solid contours indicate isobaths at 20m intervals between the surface and 200m depth, dashed contours indicate isobaths at 200m intervals between 200m and 3000m. Aquaculture leases are indicated in blue (Land Tasmania 2025) while stations with long-term observations are indicated in black (stars denote Broad Scale Ecological Monitoring Program (BEMP) stations, dots denote Derwent Estuary Program (DEP) stations). Major bays, estuaries and channels are labelled. The boundary of CSIRO's Storm Bay model (TASSE) is marked by the thin black line while the pink line indicates the section, from the Derwent Estuary out through Storm Bay, shown in Figure 9.

What causes marine heatwaves?

Marine heatwaves are caused by several different mechanisms (Figure 4), such as when anomalously warm water is transported into a region (known as warm advection) by ocean currents or eddies, or by the atmosphere, where anomalous heating of the ocean surface occurs, often under clear sky conditions and low wind conditions (Holbrook et al. 2019, 2020). Near the coast, MHWs may be caused by downwelling of warm surface waters (e.g., Schaeffer et al. 2023) or the local surface heating of waters trapped in bays, channels and estuaries.

About half of the MHWs in the southwestern Tasman Sea are caused by anomalous ocean advection, and the other half are due to anomalous surface heating or other processes (Li et al 2020; Elzahaby et al 2021; Gregory et al. 2023). The interplay between offshore MHWs and shelf and estuarine environments is complex. For example, shelf break currents can act as barriers to water moving onshore while some configurations of offshore mesoscale (50–300 km diameter) eddies can inject warm offshore extreme conditions onto the shelf.

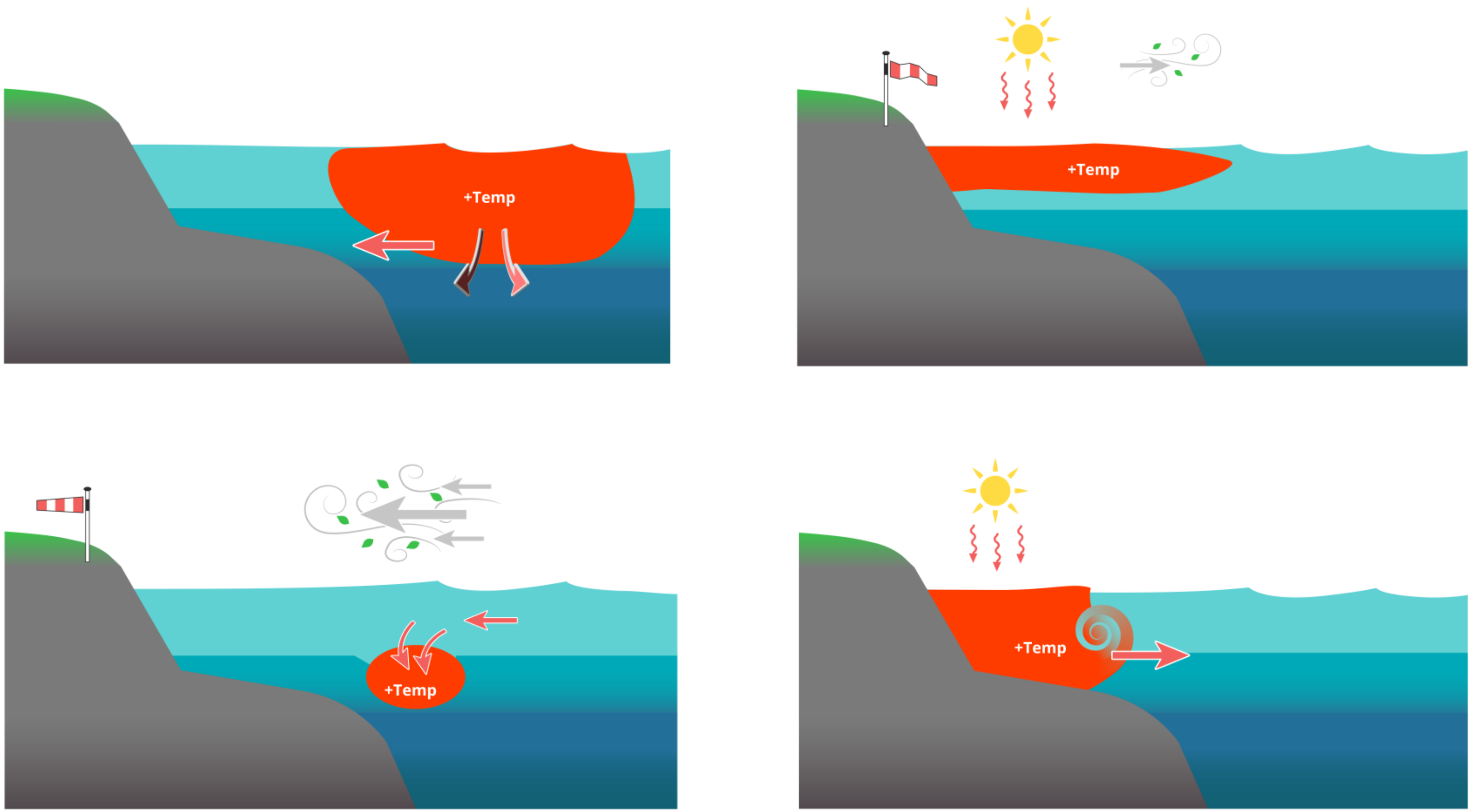


Figure 4: Common types of marine heatwaves. Currents or eddies can move warm water (indicated in red) into cooler regions (top left). Periods of sunny and low wind conditions can cause widespread heating at the surface while also limiting mixing with deeper waters, resulting in a shallow layer of warm water (top right). Movement of water towards the coast driven by larger scale alongshore wind or local scale onshore wind can force warm surface water down to depth where the surrounding water is colder (bottom left). Water trapped in shallow coastal features such as bays or estuaries can be heated before 'escaping' offshore (bottom right).

Marine heatwave impacts along Tasmania's east coast

Marine heatwaves offshore of Tasmania have been observed in the NOAA Optimum Interpolation Sea Surface Temperature (OISST) v2.1 satellite data (Huang et al. 2020) going back to the 1980s (Figure 5, detection relative to the 1993–2014 climatological baseline). Prior to the year 2000, these western Tasman Sea MHWs were typically of shorter duration, lower intensity and affected a relatively small part of the southwestern Tasman Sea. The notable exception was the 1988 MHW which lasted from April to August, possibly associated with the transition between the 1986–1987 El Niño into the 1988–89 La Niña.

Marine heatwaves have become more frequent, longer-lasting, and influence a larger area of ocean both globally (e.g. Oliver et al. 2018a) and in the Tasman Sea region (Oliver et al. 2018b) as shown in Figure 5.

The Tasman Sea, off the east coast of Tasmania, has seen three recent large-scale marine heatwave events in 2015–16; 2017–18 and 2023–24. Impacts of these events reached onto the continental shelf and into the Derwent and Huon Estuary systems. Impacts included:

- 2015–16: Outbreaks of Pacific Oyster Mortality Syndrome (POMS, Ugalde et al. 2018; Shi et al. 2024); reduced productivity of salmon farms and die-off of Black Lipped Abalone (Oliver et al. 2017); shifts in phytoplankton diversity (Evans et al. 2020, Brown et al. 2024)
- 2017–18: Further POMS outbreaks (Shi et al. 2024); shifts in phytoplankton diversity (Evans et al. 2020; Brown et al. 2024)
- 2023–24: Emergency intervention to move Red Handfish into captivity (Hobday et al. 2024); oyster die-off in Pipeclay Lagoon (Breen and Smith 2024).

These MHWs are discussed in further detail below, and key results are presented in the Appendix.

Smaller scale MHWs or MHW-like events have also been reported on the Tasmanian east coast with impacts including:

- 1988: Die-off of *Macrocystis* kelp species (Sanderson 1990).
- 2001: Die-back of *Macrocystis* kelp species (Kajtar et al. 2021); reduced abalone catch rates (Kajtar et al. 2021) and die-back of native macroalgae allowing expansion of an invasive kelp species (Valentine and Johnson, 2004).
- 2010: Reduced abalone catch rates with reports of increased mortality (Tarbath and Gardner 2011).
- 2012: Salmon mortality due to an outbreak of orthomyxovirus (Mohr et al. 2020: Godwin et al. 2020).
- 2024–25: Salmon mortality due to an outbreak of Salmon Rickettsial Septicaemia (Department of Natural Resources and Environment Tasmania, 2025).

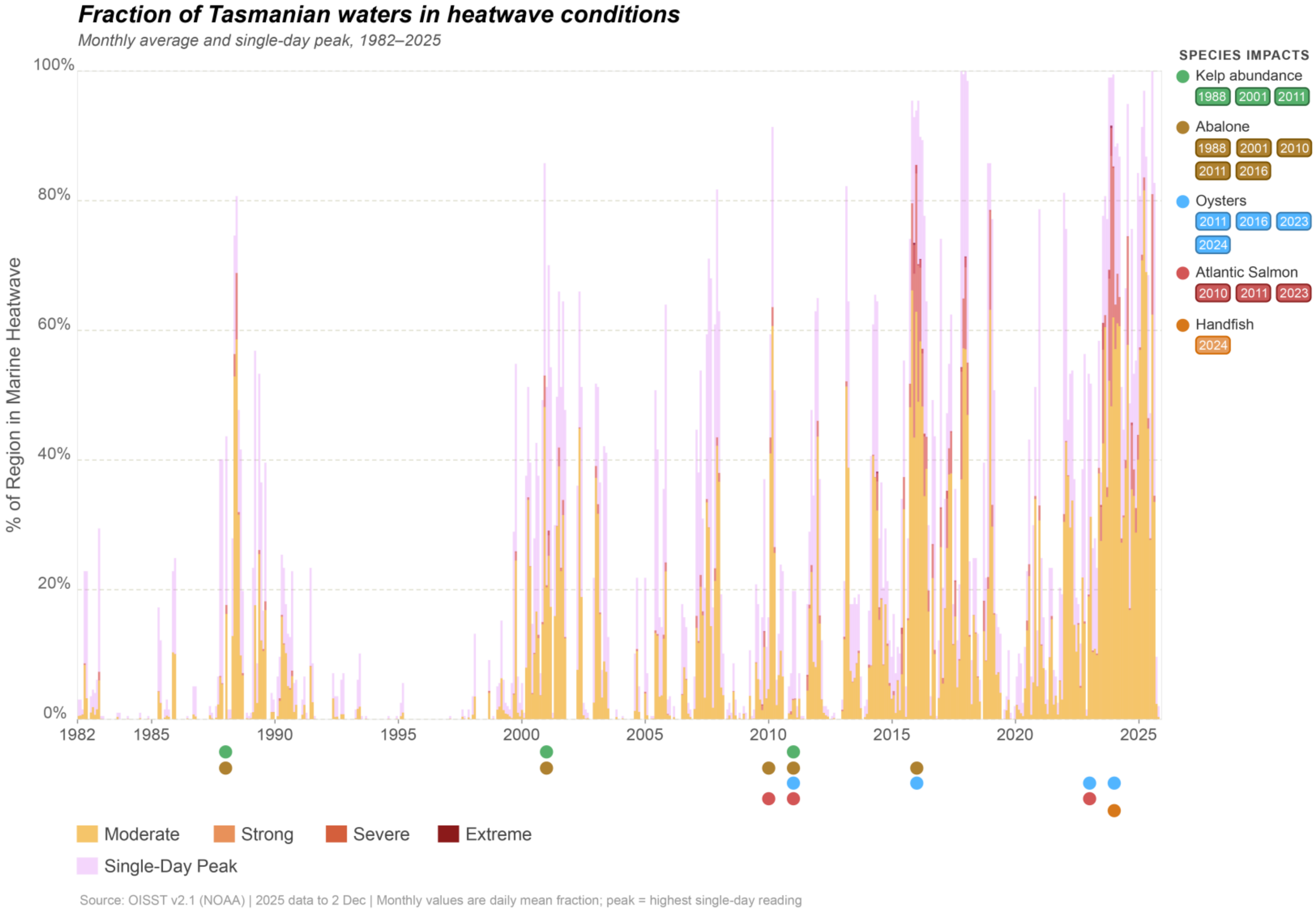


Figure 5: Historical MHW occurrences as a fraction of the region 39–44 °S 147–150 °E (see Figure 2), covering the eastern coast of Tasmania and the western Tasman Sea, calculated from the OISST v2.1 daily satellite SST dataset (Huang et al. 2020) using a 1993–2014 baseline. Species impacted by major events are indicated in boxes.

Characteristics of important marine heatwaves in the Derwent-Huon system of southeast Tasmania

The three marine heatwaves featured in the following section provide important insights into the complexities of these events. Through this research and with the use of new measurements and ultra-high-resolution modelling we now have a clearer picture of how Tasmania's marine coastal and estuarine regions have been affected. Further information about the offshore and inshore characteristics and the hazard maps for each marine heatwave can be found in Table A1 in the Appendix.

Exploring offshore impacts of recent marine heatwaves

The 2015–16 MHW was deep reaching, with warm waters extending to at least 200 m depth. It was also long-lived, lasting eight months between September 2015 and May 2016 (Oliver et al. 2017). An initially mild (+1.5 ºC sea surface temperature (SST) anomaly) MHW formed off the Tasmanian coast in September–October before strengthening (to a +2.5 to +3 ºC SST anomaly) during November and December as warm waters were transported south. The MHW was initially prevalent off the Tasmanian east coast north of the Tasman Peninsula and only intruded on the southeast coast from January 2016. Peak summertime SST anomalies exceeded +3 °C. The 2015–16 MHW was limited to the western Tasman Sea (Figure 6). Evidence suggests that the 2015–16 MHW was almost exclusively driven by unusually strong southward advection of warm Eastern Australian Current waters (Oliver et al. 2017).

2017–18 marine heatwave

The 2017–18 MHW was moderately shorter than the event in 2015–16, lasting five to six months (Perkins-Kirkpatrick et al. 2019; Salinger et al. 2019) in total, but had moved away from Tasmania within three months (Kajtar et al. 2022). Unlike the 2015–16 MHW, the 2017–18 event was shallow, only reaching to around 30m depth (Perkins-Kirkpatrick et al. 2019; Salinger et al. 2019), and extended across the full longitudinal extent of the Tasman Sea (Figure 6) from Australia to New Zealand. The rapid onset of the 2017-18 MHW appears to have been caused by strong surface driven heating (Holmes and Malan 2026). Its extreme strength and long duration for a surface-forced MHW were caused by a blocking high-pressure system (Perkins-Kirkpatrick et al. 2019; Salinger et al. 2019).

This high-pressure system caused clear, hot and low-wind conditions which allowed solar heating of the upper ocean. At the same time these conditions suppressed heat loss to the atmosphere and wind-driven mixing which usually would cause a deepening of mixed-layer, mixing with colder water below (Elzahaby et al. 2025).

2023–24 marine heatwave

The 2023–24 MHW extended from December 2023 and mostly ended by May 2024, although small areas of MHW persisted until July 2024 further south. All areas of the state's coastline (Figure 6) experienced moderate category marine heatwave conditions and the north and northeast of the state experienced severe and extreme MHW category conditions (Department of Natural Resources and Environment Tasmania, 2025). As noted above, emergency intervention was mobilised to move up to 25 Red Handfish (about ¼ of the estimated wild stock) into temporary captivity, resulting in a successful captive breeding program and subsequent successful releases of both captured and captive-bred individuals. At the time of writing, the causes and impacts of the 2023–24 MHW are still under investigation, although it does appear to have been primarily due to warm advection.

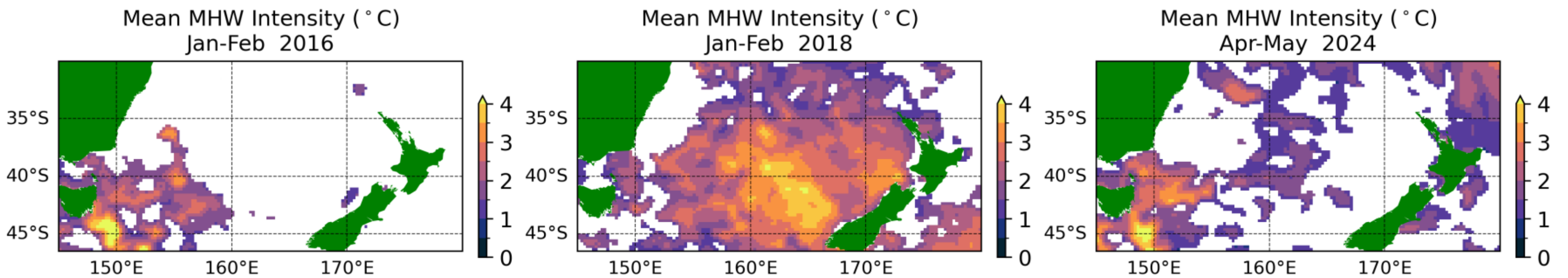


Figure 6: Mean marine heatwave intensities in the two months around the peak of three separate Tasman Sea MHWs (°C above climatological values) from the OISST v2.1 satellite SST dataset (Huang et al. 2020): respectively the 2015–16 (left), 2017–18 (centre) and 2023–24 (right) MHWs. Areas of white are locations which did not experience MHW conditions during the averaging periods.

Future marine heatwaves

Studies suggest MHWs are expected to become stronger and more frequent (e.g. Frölicher et al. 2018) driven by both the 'background' increase in ocean temperature (e.g. Bindoff et al. 2019) and local changes in oceanic and atmospheric forcing. Events in the Tasman Sea comparable to the 2015–16 MHW are likely to become commonplace by mid-century (Kajtar et al. 2024). This is due to both an increase in the strength of the EAC Extension (e.g. Oliver and Holbrook 2014), and potentially an increase in the occurrence of blocking high pressure systems (Grose et al. 2010) which could drive more atmosphere-driven events similar to the 2017–18 MHW.

Exploring inshore impacts of recent marine heatwaves

To explore how the 2015–16, 2017–18 and 2023–24 offshore MHWs have impacted the inshore regions of southeast Tasmania in more detail and at depth, we use the output of two ultra-high resolution coastal ocean models developed by CSIRO: (1) ETAS (Oliver et al. 2016), a ~2km resolution model, covering Tasmania's eastern shelf and offshore, that was run from 1993 to 2016, and (2) TASSE (Wild-Allen et al. 2023), a ~200m resolution model, encompassing Tasmania's southeast including the Huon and Derwent estuaries and D'Entrecasteaux Channel, that was run from 2015 to the present. These ultra-high-resolution models allow us to explore the coastal impacts of MHWs at spatial scales too small for regional to global ocean model to resolve; to describe the vertical structure of MHWs which is not possible with high resolution satellite sea surface temperature products, and to resolve time scales not practical to observe with the existing fortnightly to monthly sampling undertaken by the Derwent Estuary Program (DEP) and Broadscale Ecological Monitoring Program (BEMP).

We have mapped both model outputs onto a common 250m grid and then adjusted the models so that the overlapping period best represents observations taken by the DEP and the Tasmanian Environmental Protection Authority (EPA)-Salmon Tasmania BEMP. This step, termed bias correction, allows a smooth transition in time of the output from the two models and provides an uninterrupted time series from 1993 to the end of 2024. We then define the MHW baseline using the 1993–2015 data and use the XMHW python package (Petrelli, 2021, https://github.com/coecms/xmhw) to perform MHW detection over the full time-period (1993–2024).

Sea surface temperatures (SSTs) and MHW Categories near the peaks of the 2015–16, 2017–18 and 2023–24 MHWs are shown in Figure 7. The peak of the MHW is considered here to be when the largest area experiences MHW conditions. This occurred in February for the 2015–16 and 2017–18 MHWs, and in April for the 2023–24 MHW. In 2015–16 and 2017–18, February SSTs ranged from about 17 °C offshore and in the lower Huon River to about 20 °C in the Derwent Estuary, Frederick-Henry Bay, and Norfolk Bay. During the 2023–24 MHW, April temperatures varied from 15 °C in the southwest of the domain, the Channel, Fredrick-Henry Bay, and Norfolk Bay to 18 °C offshore in the west of the model domain. In all three cases, while most of the domain experienced Moderate category MHWs, the surface MHW category did not exceed strong anywhere.

Interestingly, the distribution of MHW category at peak varied between the three events. In 2015–16 we saw Strong MHWs in the Derwent and Huon Estuaries and in a narrow band in the outer region of Storm Bay. By contrast, the year 2017–18 saw Strong MHWs in the Derwent and in a continuous band along the southern and western edges of the model domain and up into the Huon Estuary and D'Entrecasteaux Channel. The year 2023–24 was instead characterised by Strong MHWs in the southeast of the domain extending into Storm Bay and the Derwent Estuary. In all three cases Norfolk Bay and Fredrick Henry Bay saw little MHW exposure at the peak.

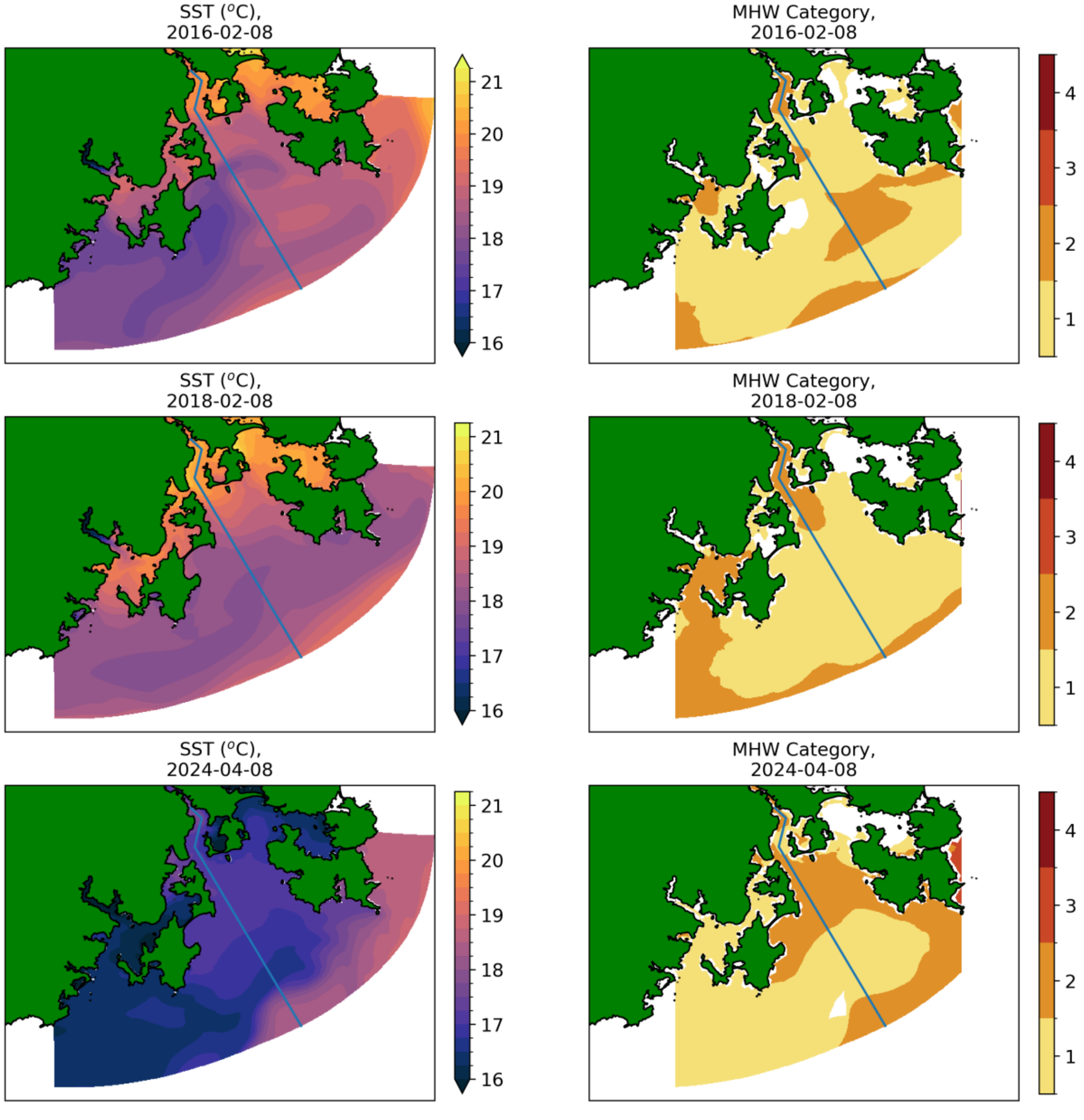


Figure 7: Sea surface temperature (left) and MHW category (right) in the Derwent-Huon system at the peaks of the 2015–16 (top), 2017–18 (middle) and 2023–24 (bottom) MHWs. The blue line indicates the cross-section shown in Figure 8.

We can also consider the maximum inshore MHW properties on a grid-point by grid-point basis over the course of the three offshore MHWs (Figure 8). Notably the inshore response to the offshore MHWs consists of a mosaic of local MHWs overlapping in time and space (top row of Figure 8).

During the 2015–16 event, inshore MHWs in the surface layer of the Derwent-Huon system were short, lasting less than 40 days, while MHWs in the more offshore regions of the model domain were longer, reaching 60–80 days. The highest MHW intensities were seen in the south and southeast of the model domain (~+4 ºC), in Norfolk Bay (~+4.5 ºC) and in Ralph’s Bay (~+5 ºC) in the south of the Derwent Estuary. A tongue of low intensities (<+2 ºC) extended from the southwest of the domain, along the east coast of Bruny Island and across to the Tasman Peninsula. This resulted in the strongest cumulative intensity, exceeding 100 °C days, occurring in a large patch in the southeast of the domain (south of the Tasman Peninsula), and in small pockets within the Derwent Estuary and southern D'Entrecasteaux Channel. Meanwhile more moderate cumulative intensities (40–60 °C days) were seen in in Storm Bay, Norfolk Bay and Fredrick Henry Bay.

During the 2017–18 event inshore MHWs were very short (< 20 days) in the southeast of our study domain and in Norfolk Bay and Fredrick-Henry Bay while MHWs in the Derwent Estuary and in the southwest of the domain tended to last longer (40–70 days). The southern D'Entrecasteaux Channel experienced extremely long MHWs (>100 days). The highest intensities (>4 ºC) were seen in the D'Entrecasteaux Channel and Ralphs Bay while the lowest intensities (<2 ºC) were seen between the southeast of Bruny Island and the Tasman Peninsular. Cumulative impacts are strongest (exceeding 100 °C days) in the southern D'Entrecasteaux Channel; the Derwent Estuary and along the northeast coast of Bruny Island, and high cumulative intensities (> 60 °C days) were also observed in the southwest of the domain. The area between the east coast of South Bruny Island and south of the Tasman Peninsular experienced moderate (20–60 °C Day) exposure.

During the 2023–24 event inshore surface MHWs tended to be extremely long (>100 days) in the Derwent Estuary and south of the Tasman Peninsular while the D'Entrecasteaux Channel and a narrow band off the southeast of Bruny Island also experienced long MHWs (60–90 days). The highest intensities (>3.5 ºC) were seen south of the Tasman Peninsula, while the lowest intensities (<2 ºC) were seen southwest of Bruny Island and in Norfolk Bay.

Cumulative impacts are strongest (exceeding 100 °C days) along the southern boundary of the domain (starting a large patch south of the Tasman Peninsula and narrowing further southwest); in the southern D'Entrecasteaux Channel, and in the Derwent Estuary reaching out into Storm Bay along the northeast coast of Bruny Island. Moderate cumulative intensities are seen in the southwest of the domain (40–60 °C days) while weak cumulative intensities (<40 °C days) were seen between the east of Bruny Island and the Tasman Peninsula.

All three MHWs show relatively limited impacts (short durations combined with low intensities in 2015–16 and 2017–18, no MHW exposure in 2023–24) in the Norfolk Bay-Fredrick Henry Bay region However, this conclusion must be treated with some caution due to: 1) a lack of long-term observational data which means the bias correction may not be adequate in this area, and 2) subsurface MHWs which do not show up in sea surface temperature are common in other parts of our study domain (e.g. Figure 9).

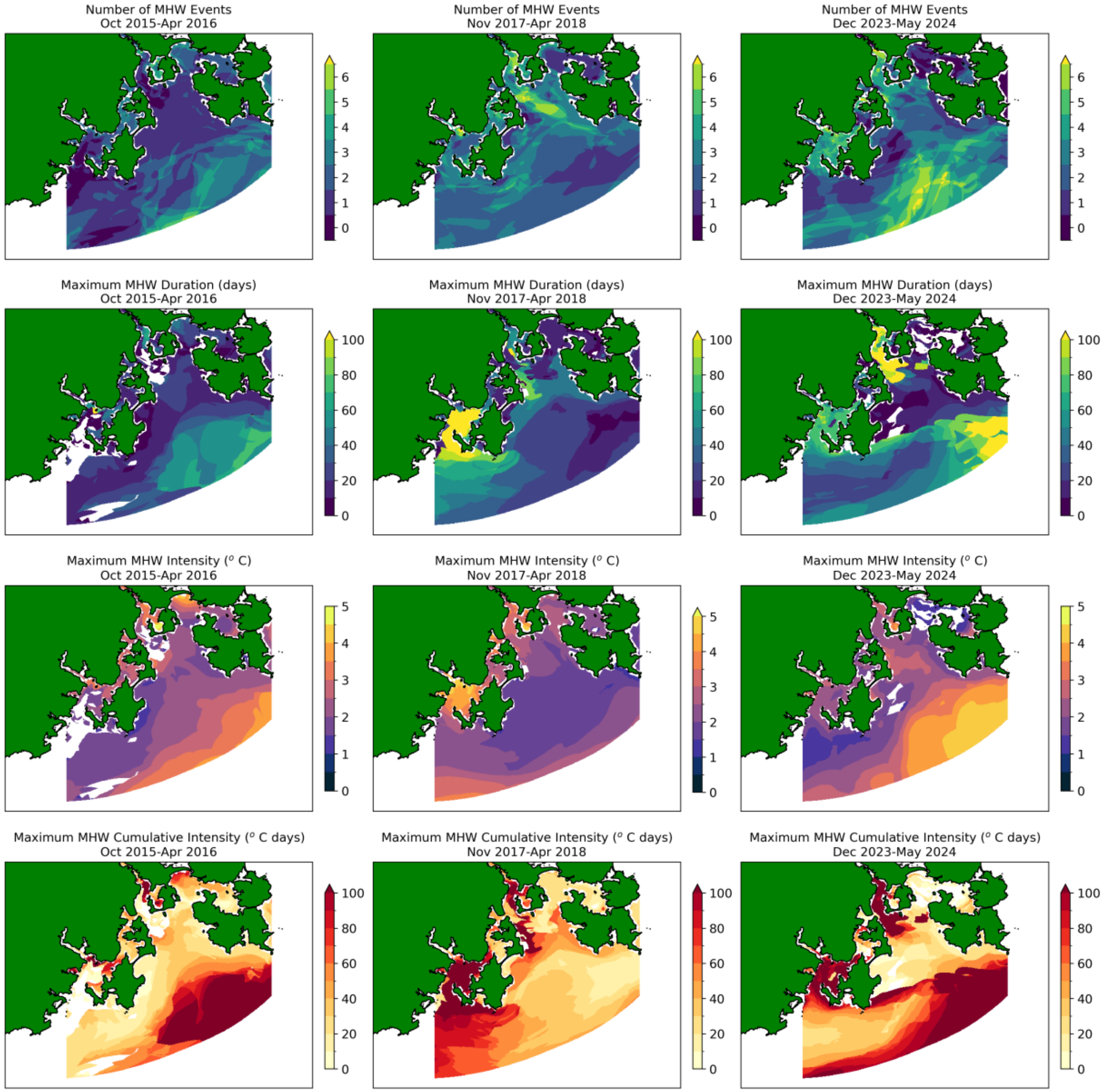


Figure 8: Number of inshore MHW events (top row) Maximum MHW duration (upper middle row), intensity (lower middle row), and cumulative intensity (bottom row) for the 2015–16 (left column), 2017–18 (centre column) and 2023–24 (right column) offshore MHWs. White space indicates areas where no MHWs were recorded.

To examine how the vertical structure of MHWs evolved in time, we sampled our 4D fields along a transect through the Derwent River Estuary and out into Storm Bay (indicated in Figure 3) The resulting plot (Figure 9) shows the evolution of MHW category for each of the three major MHWs (top row 2015–16, middle row 2017–18 and bottom row 2023–24) along the transect over the course of the four months leading up to peak MHW conditions (columns, time increasing from the left to right). We see that all three events are characterised by subsurface warm extremes across the shelf in October–November before the arrival of the offshore MHW in December–January. The locally forced MHWs typically evolve in the subsurface – with the 2015–16 MHW taking six weeks to reach the surface while the 2017–18 MHW outcropped to the surface within two weeks. The heatwaves are subsurface intensified within the river, with the highest categories at depth, often Severe or Extreme despite the surface MHW category not exceeding Strong. Despite the offshore MHW in 2015–16 reaching depths of at least 200m, the onshore expression in December–February was found not to exceed 80m depth. The 2017–18 MHW shows evidence of downwelling of warm waters driving an extension of the MHW to depth at the edge of the model domain.

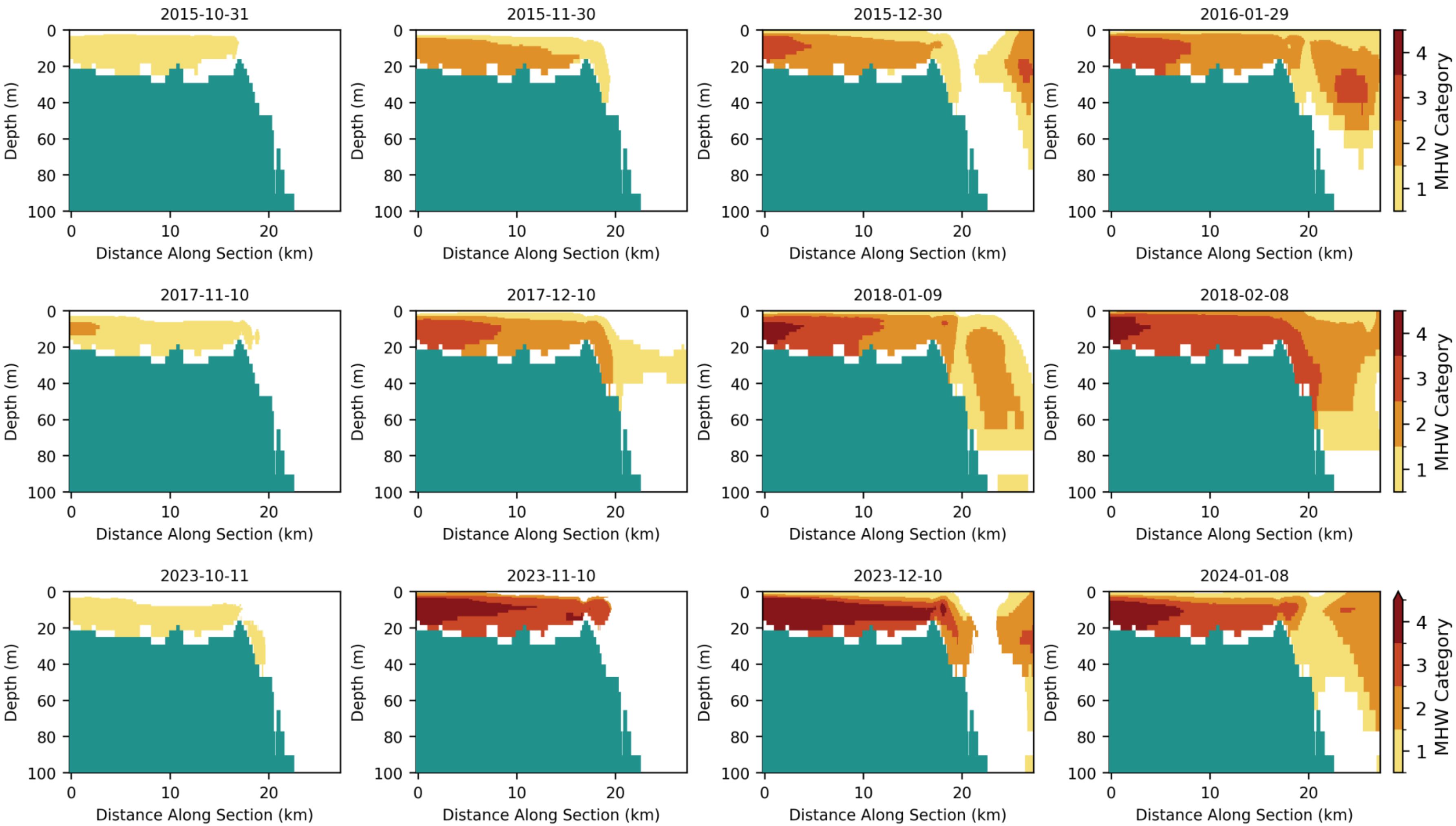


Figure 9: Marine heatwave category by depth and distance along a transect running down the Derwent River and out into Storm Bay (shown as a pink line in Figure 3) for the 2015–16 (top row, October to January), 2017–18 (middle row, November to February), and 2023–24 (bottom row, October to January) marine heatwave.

Benthic species, such as oysters, abalone and kelp, are much less mobile than pelagic species, and so are unable to move from waters impacted by MHWs to cooler areas. Thus, we mapped marine heatwave exposure at the sea floor (Appendix) for the 2015–16, 2017–18 and 2023–24 MHWs. We found that across all three MHWs, the Derwent Estuary and the southern D'Entrecasteaux Channel experienced the longest exposure to MHW conditions while Norfolk Bay and Fredrick Henry Bay experienced the least exposure. Under the 2015–16 MHW, maximum exposure was less than 80 days, while in the 2017–18 MHW maximum exposure was around 160 days and during 2023–24 maximum exposure reached 200 days.

Ongoing research

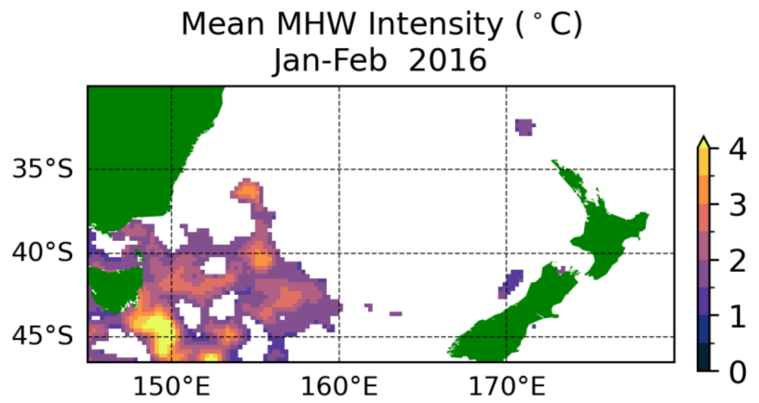
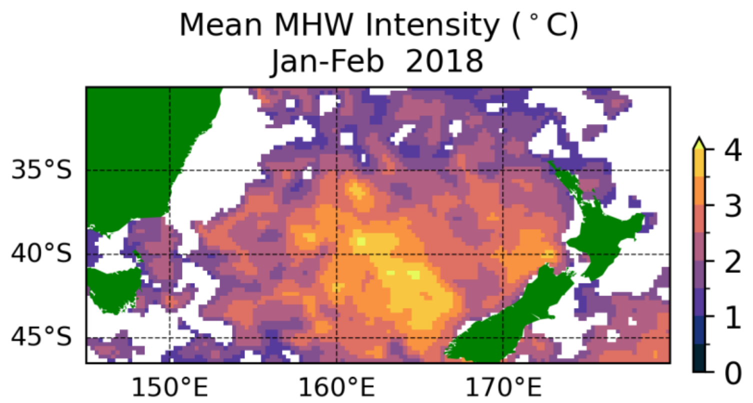
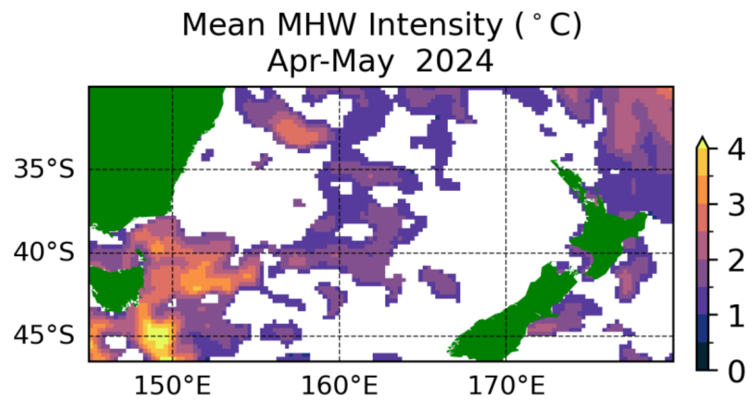
During this project we intend to extend our analysis to cover the full 1993–2024 period, allowing a detailed examination of the long-term MHW baseline; how MHW occurrence in the coastal zone has changed over time; the occurrence of cold spells (the opposite of MHWs, when temperature is in the lowest 10% of the climatological range), and heat spikes (extreme warm events of shorter duration than MHWs). We also intend to conduct a deeper dive into the Broad Scale Ecological Monitoring Program and Derwent Estuary Program observational data and the Storm Bay/TASSE model to examine how MHWs correspond with salinity, productivity (measured by chlorophyll concentration), oxygen concentration and nutrient concentrations. This will allow us to explore MHW impacts in a more complete manner and potentially examine the occurrence of compound events where ecosystems and fisheries experience multiple stressors at the same time. Combining these findings, we will develop maps of metrics quantifying MHW hazard for use by stakeholders. We would also like this project to drive efforts to:

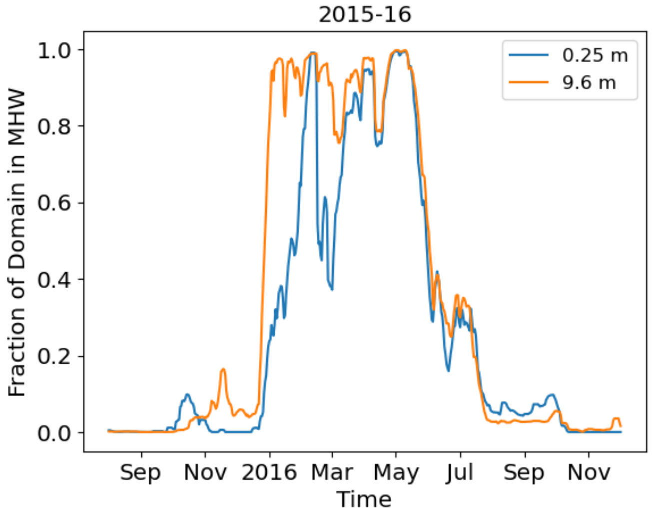
- explore the value of very high-resolution coastal modelling for Tasmania more broadly
- supplement the present weekly to fortnightly resolution Derwent Estuary Program and Broadscale Ecological Monitoring Program observations with deployment of coastal moorings (such as the SOFAR Spotter platform) and an expansion of the FishSOOP program (https://www.unsw.edu.au/research/oceanography/fishsoop) onto local fishing vessels and other vessels of opportunity to provide real-time monitoring of sub-surface MHWs.

The development of such real time monitoring could allow the detection of 'early-warning' indicator for MHWs and so provide a critical decision-making tool for marine managers.

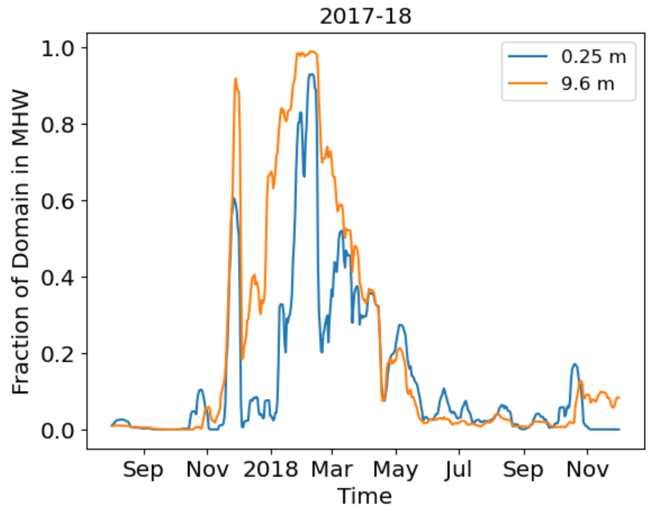
Appendix

Table A1: Characteristics of marine heatwaves in the Derwent-Huon system of southeast Tasmania

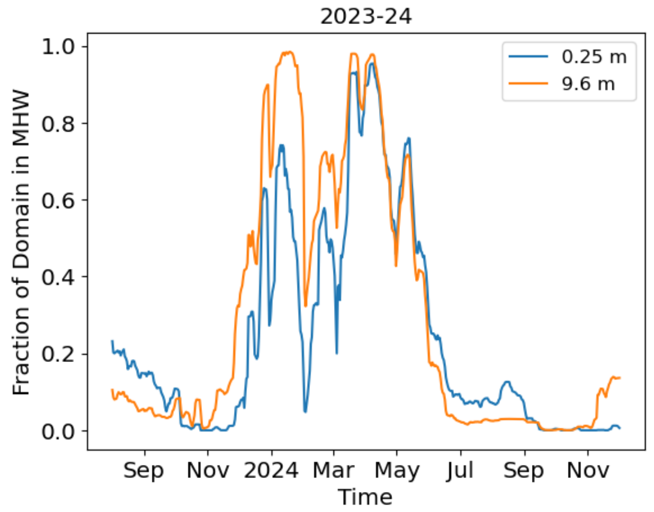
	Marine heatwave year		
Characteristic	**2015–16**	**2017–18**	**2023–24**
	Tasman Sea		
Extent	 The 2015–16 open-ocean marine heatwave (MHW) was confined to the western Tasman Sea with peak intensity in the East Australian Current (EAC) Extension. It was generally deep, reaching 200 m depth.	 The 2017–18 marine heatwave (MHW) spread over the entire width of the Tasman Sea with peak intensity off the South Island of New Zealand. It was relatively shallow with the MHW not exceeding 20–40 m depth.	 The 2023–24 marine heatwave (MHW) that impacted Tasmania was confined to the western Tasman Sea with peak intensity in the EAC Extension. Other independent MHW events occurred elsewhere in the Tasman Sea during this time.
Timing and duration	Eight months between September 2015 and April 2016 with peak strength in February 2016.	Five to six months from November 2017 to April 2018. The MHW had moved away from Tasmania after three months.	Six months along the Tasmanian East coast December 2023 to April 2024. Eight months in the broader Tasman Sea, from December 2023 to July 2024
Causes	Ocean driven. Driven by unusually strong southward movement of warm EAC waters (Oliver et al. 2017).	Surface driven. Onset driven by strong surface driven heating (Holmes and Malan 2026. Long duration due to shallow mixed layer and calm, clear conditions due to a blocking high pressure system (Perkins-Kirkpatrick et al. 2019; Salinger et al. 2019).	Causes under investigation. The most likely driver is the southward movement of EAC waters similar to 2015–16.

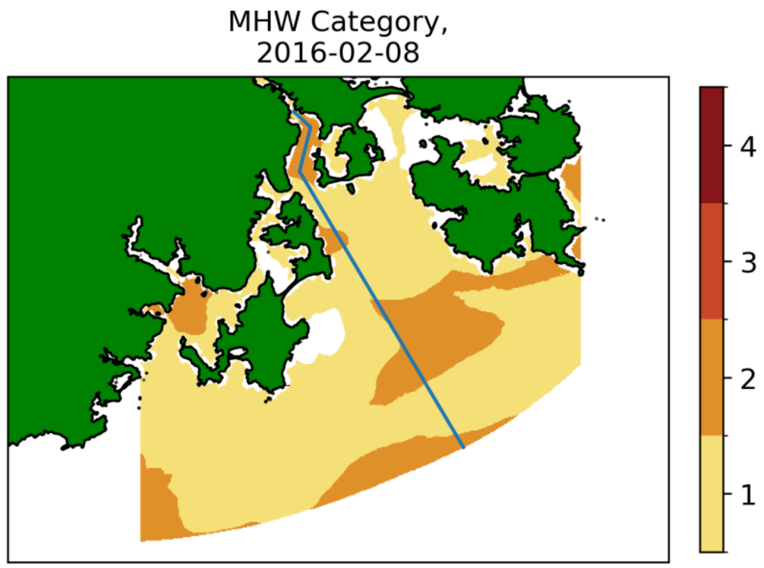
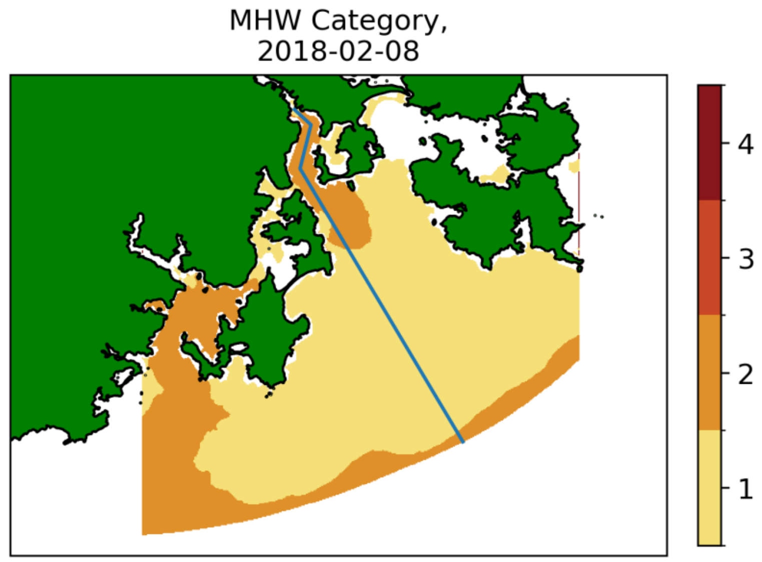
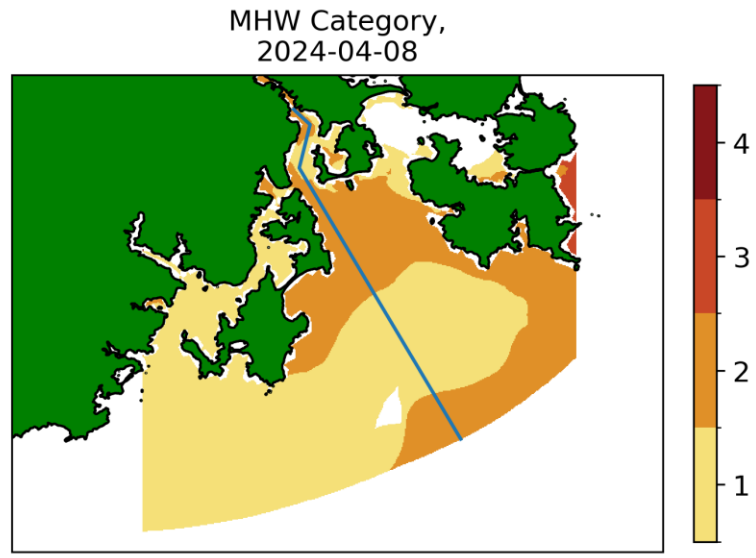
<table>
<tr><th colspan="4">Southeast Tasmania</th></tr>
<tr>
<td><u>How the MHW evolved</u></td>
<td>

Inshore MHW initiates later (late October) than the offshore MHW (September). Near the surface (blue line) the MHW expands to fill the model domain during late December and January, before retreating during mid-late February, expanding again in March before weakening in May and June.

At 9.6m depth MHW rapidly expands to fill over 70% of the domain in late December and early January and remained widespread until retreating in May and June.</td>
<td>

Inshore MHW initiated at the same time as offshore MHW (Nov) with an initial sharp spike in late Nov/early Dec. At the surface MHW remains limited through December into early January before MHW area expands reaching a peak in February before rapidly shrinking. The MHW then expands to cover 50% of the domain in March before slowly shrinking over April and May.

At 9.6m the MHW expands faster, reaching its peak earlier in February before showing a steady decline between March and June.</td>
<td>

Inshore MHW at the surface started in December like the offshore MHW, but at 9.6m depth the MHW started earlier (November). MHW expands both at the surface and at 9.6m depth to a peak in January before receding in February. MHW expands again to a second peak in April before decaying slowly, with the MHW at 9.6m essentially ceasing in July while persisting at the surface until the start of September.</td>
</tr>
<tr>
<td><u>Strongest impacts</u></td>
<td>Offshore, Derwent</td>
<td>Southern Channel, Storm Bay, Derwent</td>
<td>Offshore, Storm Bay</td>
</tr>
<tr>
<td><u>Weakest impacts</u></td>
<td>South and southwest of Bruny Island</td>
<td>Norfolk Bay and Fredrick Henry Bay</td>
<td>Norfolk Bay and Fredrick Henry Bay</td>
</tr>
<tr>
<td><u>Surface MHW category at the maximum MHW extent</u></td>
<td>
</td>
<td>
</td>
<td>
</td>
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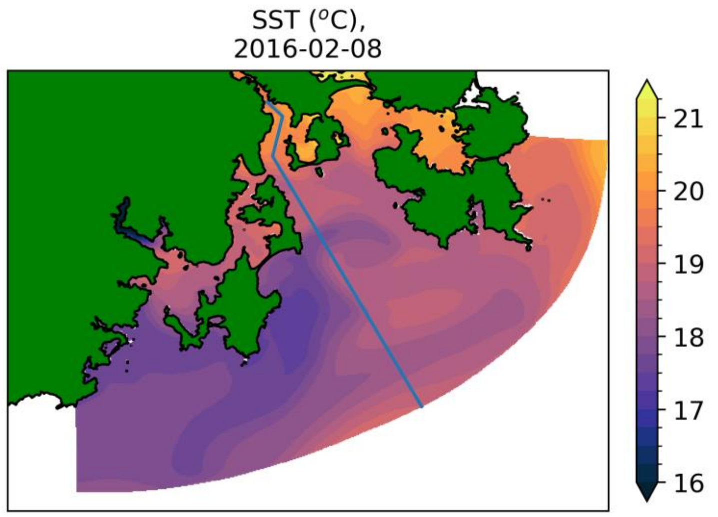
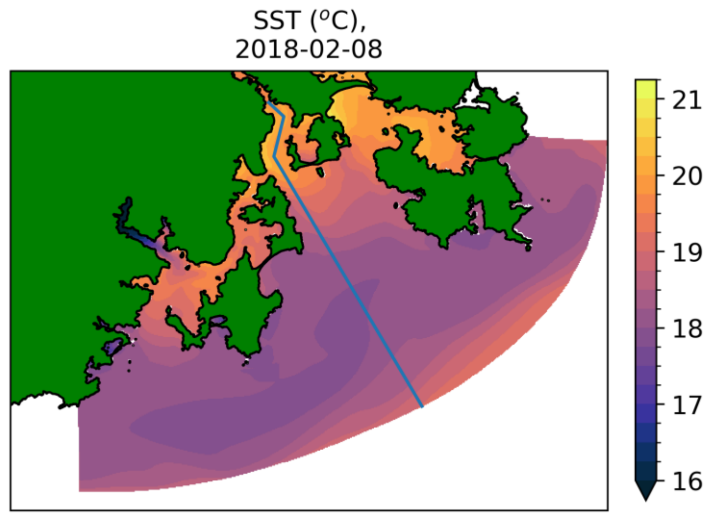
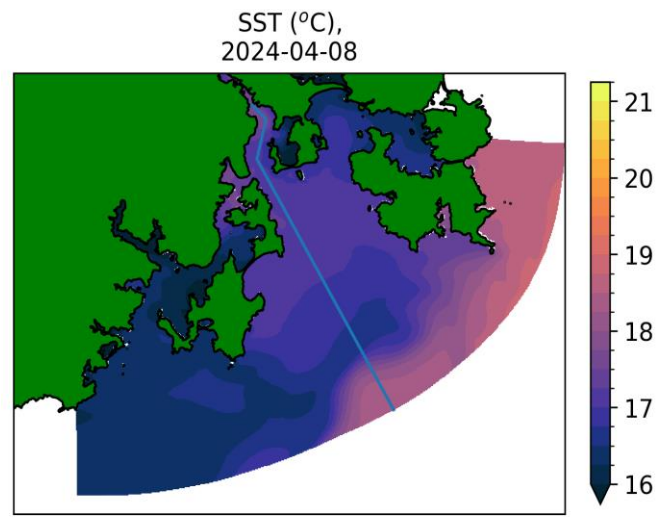
<table>
<tr>
<td></td>
<td>Near peak MHW coverage, most of the coastal domain experienced MHWs except for small areas in the central D’Entrecasteaux Channel, Norfolk Bay, Fredrick Henry Bay and offshore off the east coast of Bruny Island. Most of the domain experiences moderate (category 1) MHWs with areas of strong (category 2) MHWs in the Derwent Estuary, southern D’Entrecasteaux Channel, along the southern boundary of the model domain and southwest of the Tasman Peninsula.</td>
<td>Norfolk Bay and Fredrick Henry Bay saw little MHW exposure. Most of the model domain experienced moderate MHWs. We identified two ‘tongues’ of strong MHWs, one running down the Derwent Estuary into the inner margins of Storm Bay (off the northeast coast of Bruny Island) and the other running from the southwestern boundary of the model domain into the southern D’Entrecasteaux Channel.</td>
<td>Norfolk Bay and Fredrick Henry Bay saw little MHW exposure. The southwest of the model domain and the D’Entrecasteaux Channel experienced moderate MHWs while a tonguee of strong MHWs extended from the southeast of the model domain, along the coast of the Tasman Peninsula, into Storm Bay and the Derwent Estuary, and down the east coast of Bruny Island.</td>
</tr>
<tr>
<td><u>Sea surface temp (SST) at maximum MHW extent</u></td>
<td>

Near peak MHW coverage, SSTs reached around 20.5 °C in Norfolk Bay, Storm Bay and Ralph’s Bay (in the Derwent Estuary). The SST was lower in the southwest of the model domain, reaching a minimum of around 16.5 °C off the southeastern coast of Bruny Island.</td>
<td>

Maximum SST reached around 20 °C in Norfolk Bay, Storm Bay and the Derwent Estuary. Temperatures in the D’Entrecasteaux Channel were around 19 °C. Temperatures were cooler offshore, with a band of 17–18.5 °C water running from the Tasman Peninsula to the southwest of the domain.</td>
<td>

Maximum SSTs of 18.5–19 °C were seen offshore along the east and southeast boundaries of the domain. Lowest SSTs of 16–16.5 °C were seen in the southwest of the model domain, southern D’Entrecasteaux Channel and Norfolk Bay.</td>
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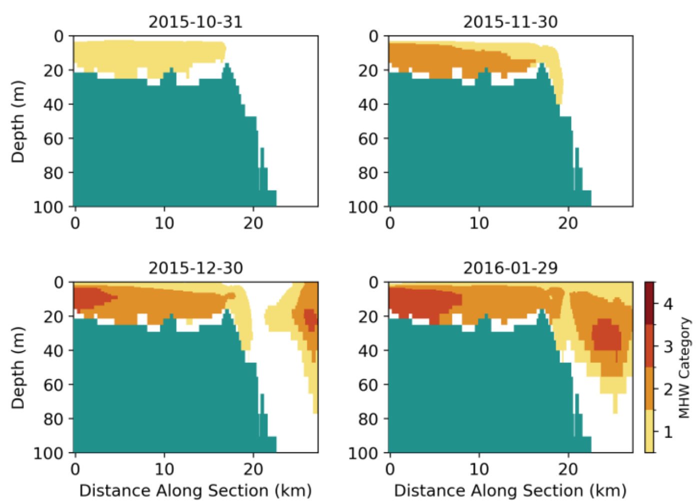
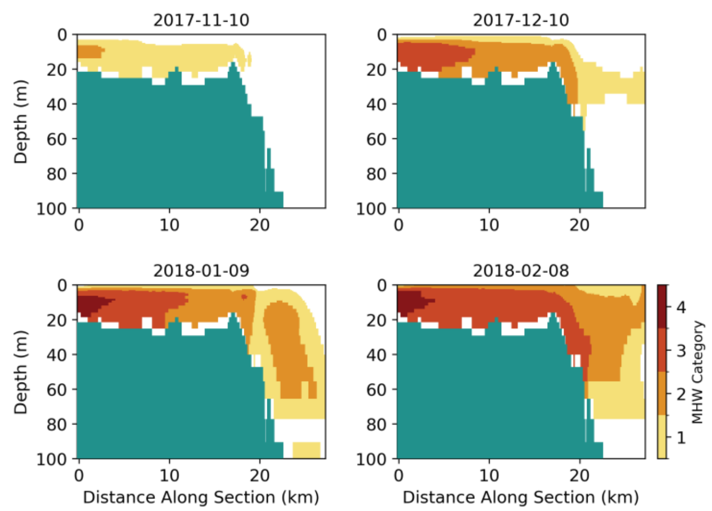
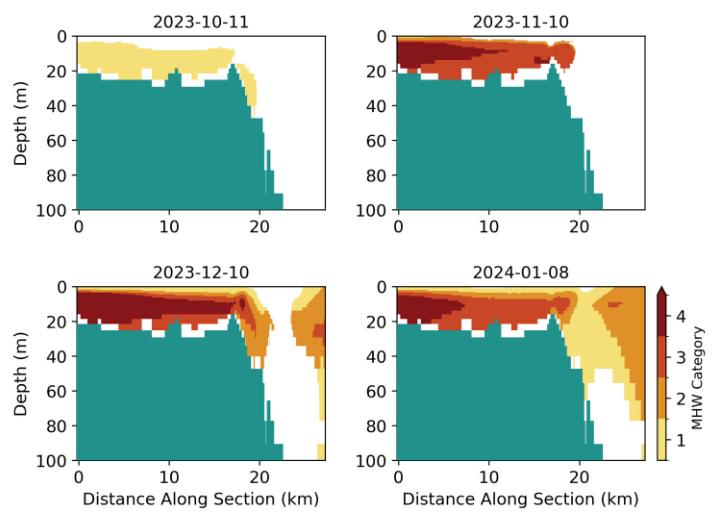
<tr>
<td><u>Evolution of the vertical structure</u></td>
<td>

Started with a locally forced moderate-strong sub-surface MHW (top left) on the shelf in October–November, growing to severe in December, before the arrival of the offshore MHW in December–January (bottom).

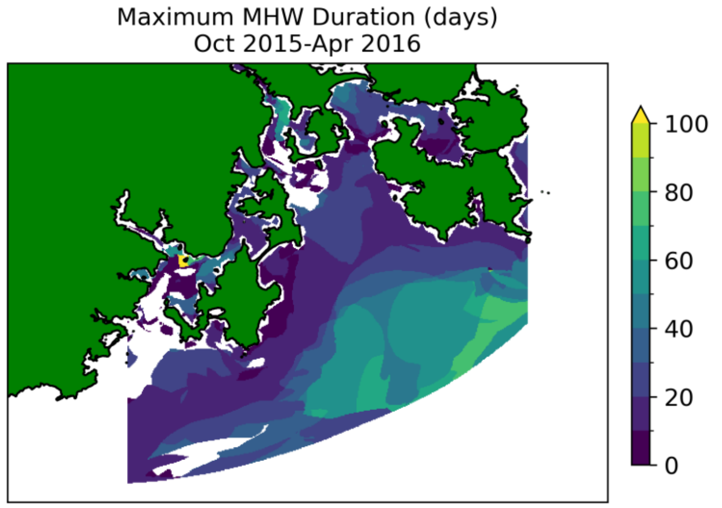
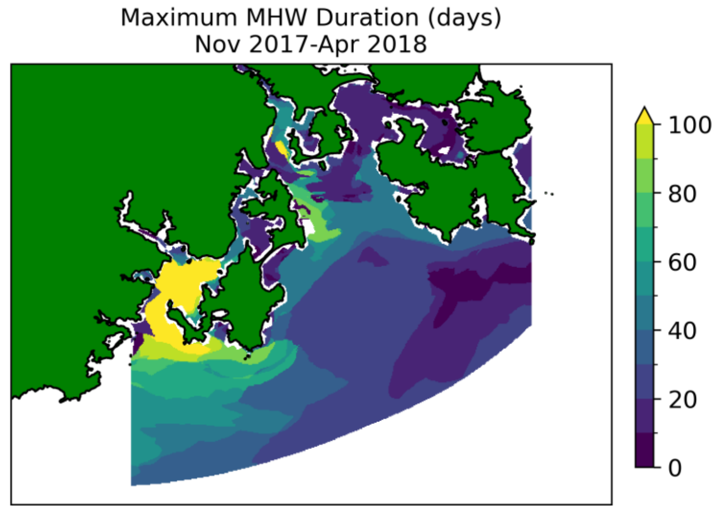
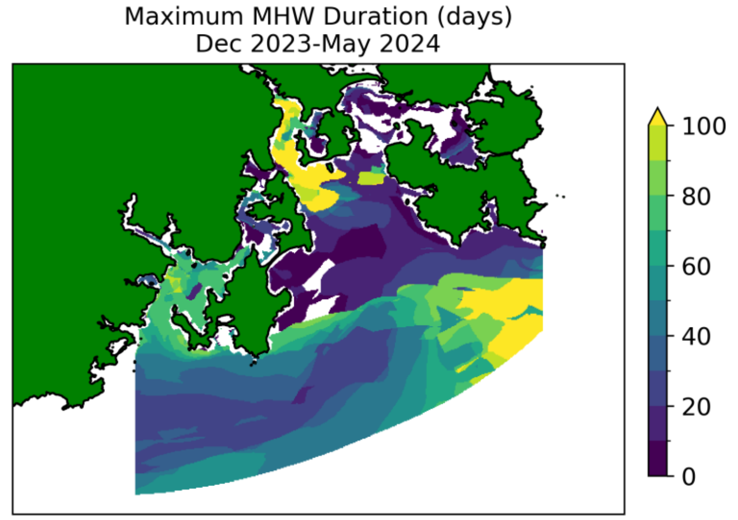
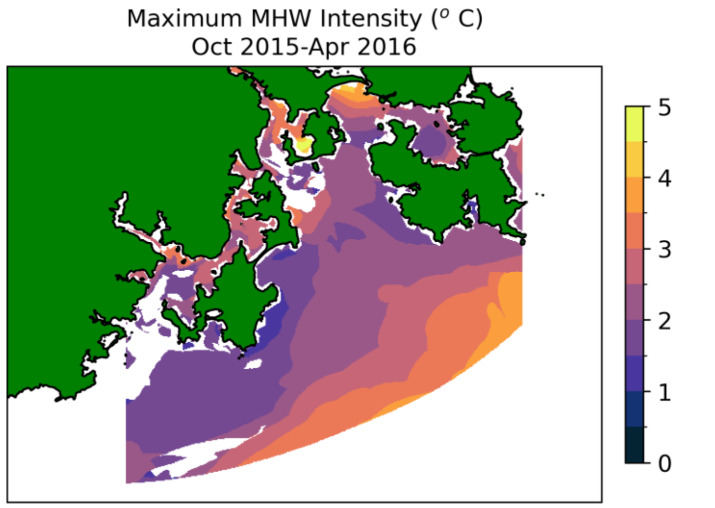
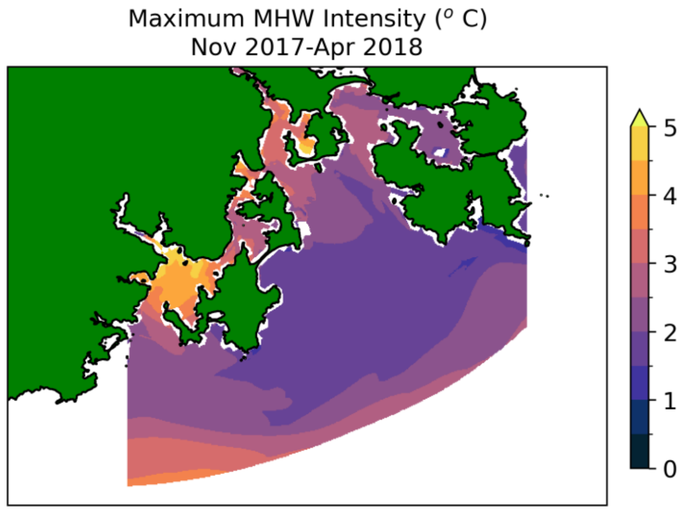
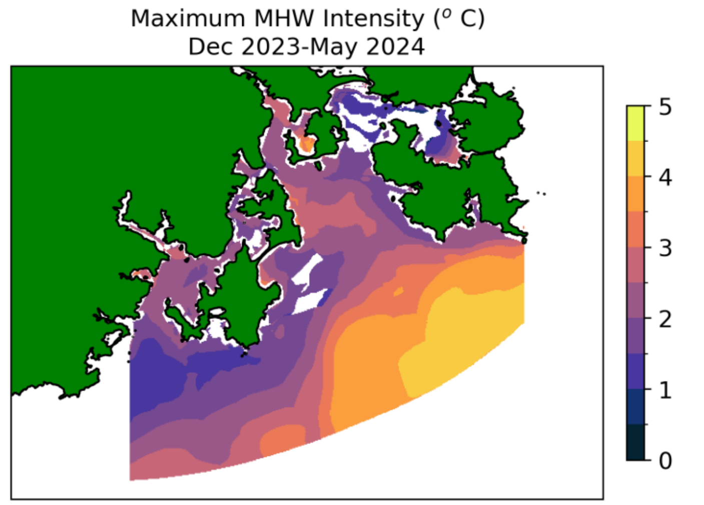
The locally forced MHWs typically evolve in the subsurface – taking 6 weeks to come to the surface.</td>
<td>

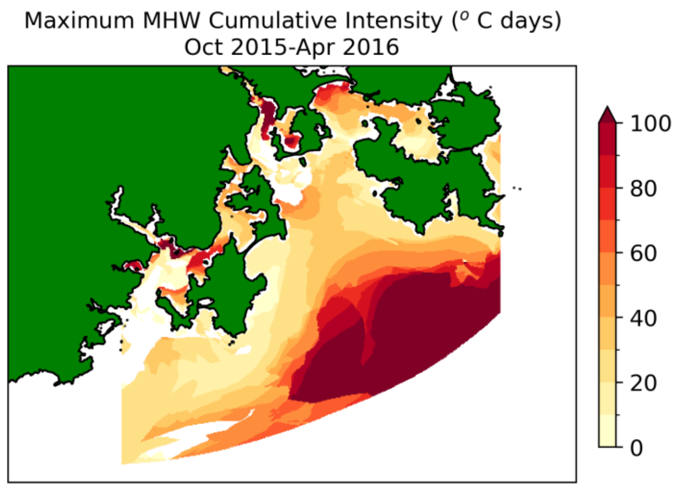
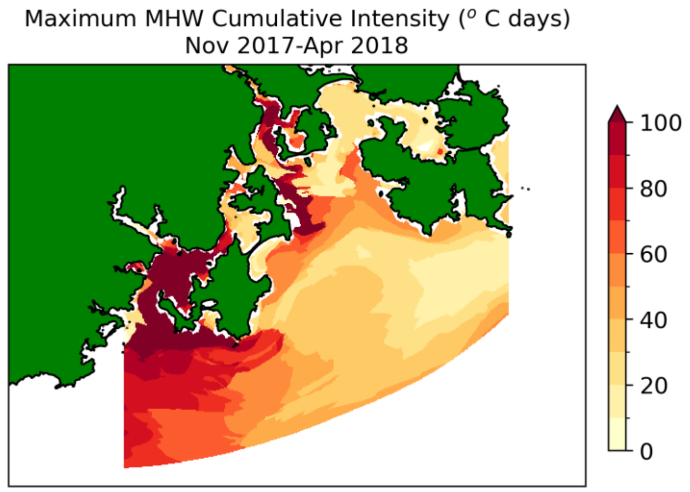
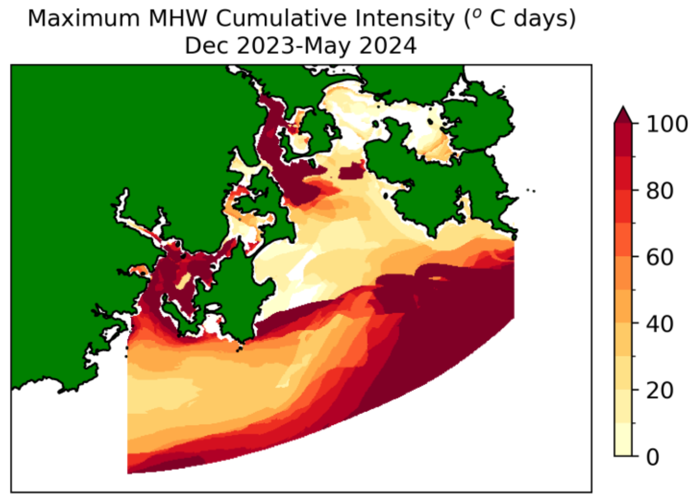
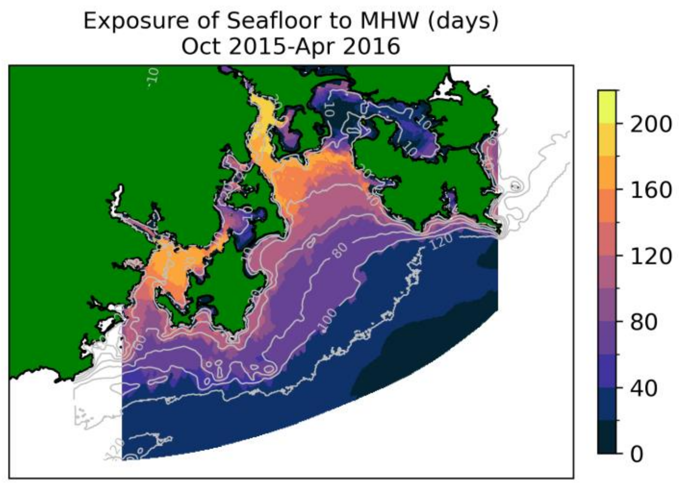
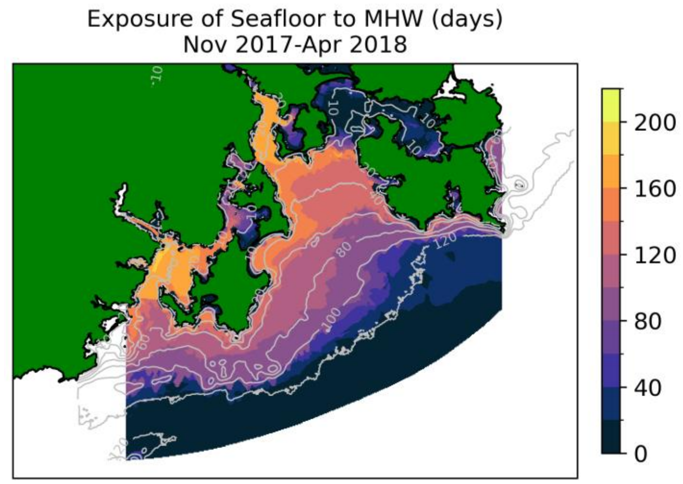
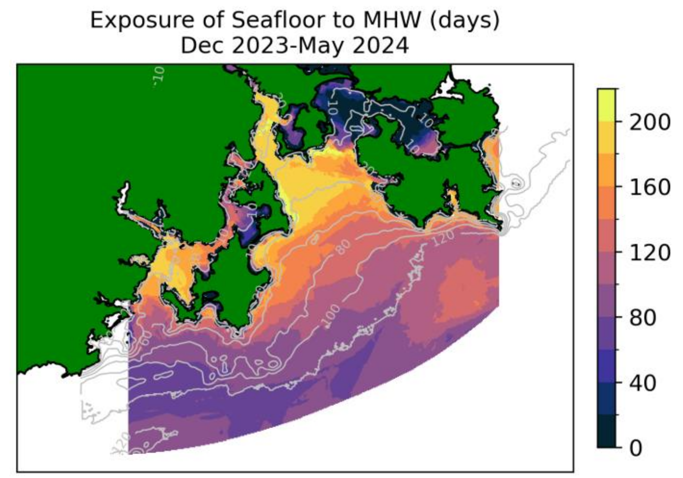
Started with a locally forced MHW on the shelf in November (top left), becoming severe in December and extreme in January, before the arrival of the offshore MHW in
January–February (bottom right).

The locally forced MHWs typically evolve in the subsurface – taking 2 weeks to come to the surface.</td>
<td>

Started with a locally forced sub-surface MHW on the shelf in October–November (top left), becoming extreme in November (top right), before the arrival of the offshore MHW in December–January (bottom right).

The locally forced MHWs typically evolve in the subsurface – taking 3 weeks to come to the surface</td>
</tr>
</table>

Duration of local MHWs	 Despite the long MHW offshore in the Tasman Sea, MHWs in the surface layer of the Derwent-Huon system were short, lasting less than 40 days. Offshore MHWs were longer, reaching 60–80 days.	 Surface MHWs tended to be very short (< 20 days) offshore and in Norfolk Bay and Fredrick-Henry Bay. MHWs in the Derwent Estuary and in the southwest of the model domain tended to last longer (40–70 days) with the southern D'Entrecasteaux Channel experiencing extremely long MHWs (> 100 days).	 Surface MHWs tended to be extremely long (> 100 days) in the Derwent Estuary and offshore south of the Tasman Peninsula. The D'Entrecasteaux Channel and a narrow band off the southeast of Bruny Island experienced long MHWs (60–90 days). The outer margins of Storm Bay and a tongue extending in from the southwest of the domain experienced relatively short MHWs (< 40 days).
Surface peak intensity	 Highest intensities were seen offshore in the south and southeast of the model domain (~+4 °C), in Norfolk Bay (~+4.5 °C) and Ralph's Bay (~+5 °C). A tongue of low intensities (<+2 °C) extended from the southwest of the domain, along the east coast of Bruny Island and across to the Tasman Peninsula.	 Highest intensities (>+4 °C) were seen in the D'Entrecasteaux Channel and Ralphs Bay. Lowest intensities (<+2 °C) were seen between the southeast of Bruny Island and the Tasman Peninsula.	 Highest intensities (>+3.5 °C) were seen offshore, south of the Tasman Peninsula. Lowest intensities (<+2 °C) were seen southwest of Bruny Island and in Norfolk Bay.

Maximum surface cumulative intensity	 Cumulative intensity is strongest, exceeding 100 °C days, offshore in the southeast of the domain (south of the Tasman Peninsula). Other small areas of very high cumulative intensity also occur in the Derwent Estuary and parts of the southern D'Entrecasteaux Channel. Cumulative intensity was moderate (40–60 °C days) in Storm Bay, Norfolk Bay and Fredrick Henry Bay, Cumulative intensity was low along the southeast and south of Bruny Island.	 Cumulative impacts are strongest, exceeding 100 °C days, in the Huon Estuary/southern Channel, the Derwent Estuary and along the northeast coast of Bruny Island. Impacts remain high (> 60 °C days) in the southwest of the model domain. The area east of South Bruny Island, south of the Tasman Peninsula, and the northern Channel experienced moderate exposure (20–60 °C days).	 Cumulative impacts are strongest (exceeding 100 °C days) offshore along the southern boundary of the domain; in the southern D'Entrecasteaux Channel, and in the Derwent Estuary reaching out into Storm Bay along the northeast coast of Bruny Island. Moderate cumulative intensities are seen in the southwest of the domain (40–60 °C days) while weak cumulative intensities (< 40 °C days) were seen between the east of Bruny Island and the Tasman Peninsula.
Exposure of benthos to marine heatwave conditions	 Seafloor in the Derwent Estuary, southern Channel and the inner margin of Storm Bay experience over 160 days of MHW exposure. MHW exposure generally decreased with increasing depth, with seafloor deeper than 80m experiencing 20–60 days of MHW exposure. Norfolk Bay and Fredrick Henry show little MHW exposure (< 20 days).	 Seafloor in the Derwent Estuary, southern Channel and the inner margin of Storm Bay experience 120–160 days of MHW exposure. MHW exposure generally decreases with depth, though showing longer MHW exposure in the 60–100m depth range than during the 2015–16 MHW. Norfolk Bay and Fredrick Henry show little MHW exposure (< 20 days).	 Benthic environment is exposed to >180 days of MHWs in Storm Bay, Derwent Estuary and southern Channel. Exposure remains elevated even at depth, with seafloor offshore of the100m isobath experiencing up to 80 days of MHWs. Norfolk Bay and Fredrick Henry show little MHW exposure (< 20 days).

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