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Marine heatwaves in a changing climate

Heatwaves in the ocean can rapidly disrupt marine ecosystems and the economies that depend on them. A global analysis of these events casts light on their causes and sets the stage for revealing how they might change in the future.

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Heatwaves that occur over land are well known for having adverse impacts on human health, infrastructure and agriculture. Less attention has been paid to analogous episodes in the ocean, dubbed marine heatwaves (MHWs), but interest in these transient events is growing as their potentially dramatic ecological and economic impacts[1] have become clear. This enhanced awareness of the importance of MHWs has fostered a desire to understand their causes and whether they can be predicted. Writing in *Nature Communications*, Holbrook *et al.*[2] present the first comprehensive analysis of MHWs across the globe. They identify specific drivers of these events, as well as associations between MHWs and known climate oscillations.

On a local scale, MHWs can be induced by anomalous ocean heating at the ocean surface (caused by changes in air temperature, winds or cloud cover, for example), or as a result of horizontal or vertical currents and mixing in the surrounding ocean. These local MHW-driving processes are often tied to large-scale climate oscillations, and Holbrook *et al.* have mapped out such relationships globally for MHWs that occurred between 1982 and 2016. For example, the authors show that some of the most intense MHWs have occurred in the eastern tropical Pacific Ocean during El Niño events — the warm phase of the El Niño–Southern Oscillation (ENSO), which involves episodic warming and cooling of the tropical Pacific's surface waters.

Although the centre of action for ENSO is in the eastern tropical Pacific, Holbrook and colleagues' analyses show that its geographical influence is much broader: not only is ENSO the strongest driver of MHWs in much of the Pacific, but also in large parts of the Indian, Atlantic and Southern oceans (Fig. 1). Such a broad influence is made possible by teleconnections — atmospheric and oceanic pathways through which climate signals can be communicated over thousands of kilometres.

One key motivation for understanding the drivers of MHWs is to determine how they can be used to predict these events. Such efforts can also draw on past research into predicting ocean temperatures more generally. ENSO has previously been identified as a prominent source of predictability, enabling forecasts of atmospheric and oceanic variables such as precipitation and temperature[3,4] up to a year in advance. Holbrook *et al.* suggest that MHWs in many regions could also potentially be predicted on the basis of their connection to ENSO and other climate oscillations. By contrast, intense MHWs associated with ocean currents off the east coasts of Japan, North America and Australia are mainly related to the chaotic nature of the flow in those regions and are less likely to be predictable.

Among the MHW drivers listed by Holbrook *et al.* is long-term climate change, and this raises a key caveat that also applies to other papers published on this topic. To explain, it should first be noted that ocean temperatures during MHWs are much higher than 'normal' temperatures, which themselves will shift as the ocean warms with climate change. In other words, the baseline ocean temperature will shift, and future MHWs should therefore be defined relative to the shifted baseline.

However, several studies (see refs 5 and 6, for example) that describe how MHWs are affected by humans' influence on the climate have defined these events relative to ocean temperatures during a fixed period of time, rather than relative to the shifting baseline. These studies concluded that climate change greatly increases the intensity, frequency and persistence of MHWs. However, their findings mostly reflect a warming trend in the ocean rather than a change in MHWs themselves[6,7]; to put it another way, the mean ocean temperature rises, but the variability around the mean temperature stays relatively steady. Fundamentally, defining MHWs without adjusting for a warming trend conflates regional climate variability with global climate change. Ironically, the same type of argument is used by climate-change deniers when they cite transient temperature extremes (winter storms or cold spells) as 'evidence' against the existence of long-term temperature change (global warming).

This issue of MHW definitions also muddies the relationships described by Holbrook *et al.*, especially when extended into the future. For

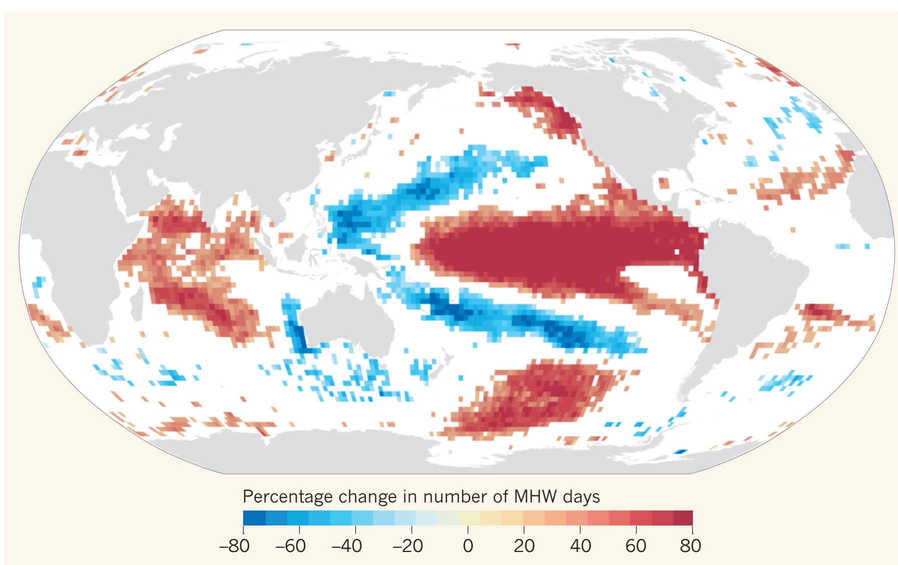

Figure 1 | Climate oscillations are associated with the occurrence of marine heatwaves (MHWs). Holbrook *et al.*[2] report a global analysis of MHWs — extended periods of anomalously warm ocean temperatures. They find that the occurrence of MHWs can be increased or suppressed during climate oscillations such as the El Niño–Southern Oscillation (ENSO), which involves episodic warming and cooling of the tropical Pacific Ocean's surface waters. This map shows the percentage increase or decrease in the number of days of MHWs across the ocean during the warm phase of ENSO, compared with the annual median percentage of MHW days, for the period from 1982 to 2016. (From Figure 3 of ref. 2.)

example, regions that experience MHWs during El Niño events similarly experience cold events during La Niña years (ENSO's cold phase). But if the shifting temperature baseline is not accounted for when defining MHWs, future cold events during La Niña years will eventually be categorized as MHWs, because even these relatively cold future periods might be warm by today's standards.

Nevertheless, there are mechanisms by which long-term climate change might alter or contribute to MHWs. Past studies have found evidence that, under climate change, there might be changes in climate oscillations such as ENSO[8,9], or in the teleconnections that link these oscillations to remote areas of the ocean[10]. Holbrook and colleagues' work enables us to hypothesize about the global imprint of such changes on MHWs. Interestingly, patterns of change in ocean-temperature variability, and consequently in MHW intensity, might be quite different from patterns of ocean warming. Several regions historically associated with intense MHWs are projected to warm strongly until the end of the twenty-first century, but might actually show decreased temperature variability around that warmer baseline[11]. Other regions, particularly those at high latitudes, might see marked increases in temperature variability and MHW intensity, despite a weaker long-term warming trend[11].

Understanding MHWs is key to assessing their impact on marine species, which react to environmental change in different ways. For example, mobile species, including many fishes, can respond to temperature changes by relocating to find favourable conditions[12]. These species might return after being temporarily displaced by an MHW, but long-term warming will probably shift their distributions permanently. Similarly, immobile species such as corals might recover from acute exposure to warmer temperatures (MHWs), but not from chronic exposure (long-term warming)[13].

The science of MHWs, including their drivers, impacts and future evolution, is still in its infancy. Holbrook *et al.* provide a valuable framework for identifying causes of MHWs, one that can be built on to improve the prediction of these events and our understanding of how they will evolve with long-term climate change. ■

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