State of the Science FACT SHEET

Marine Heatwaves

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION • UNITED STATES DEPARTMENT OF COMMERCE

Scientists and communication experts from the National Oceanic and Atmospheric Administration (NOAA) developed this assessment of marine heatwaves.

What are Marine Heatwaves?

Marine heatwaves (MHWs) occur when ocean temperatures are exceptionally high for prolonged periods. They can be thought of as the marine equivalent of heatwaves over land, which are known to impact ecosystems, human health, infrastructure, and agriculture. While a number of MHW definitions have been proposed, they generally state that temperatures must remain above a specified threshold for a prolonged period of time. For example, one common definition states that ocean temperatures must exceed the 90th percentile of temperatures for a given location and time of year (based on a 30-year historical baseline), and must remain elevated for at least five days[1]. While most MHW research has focused on ocean surface temperature, which is easily observed by satellites, MHWs also extend beneath the ocean surface where observations are sparser. In fact, MHWs occurring below the sea surface can be even stronger and longer lasting than those at the surface[2,3].

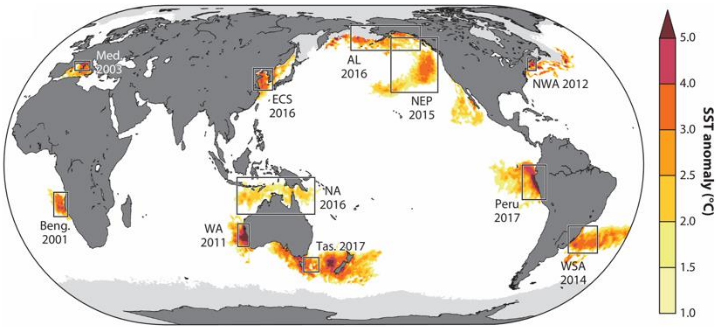


Figure 1. Selected MHWs since 2000. Sea surface temperature (SST) anomalies are departures from average temperatures for each location. Beng: Benguela Current, Med: Mediterranean Sea, WA: Western Australia, ECS: East China Sea, NA: Northern Australia, Tas: Tasmanian Sea, AL: Alaska, NEP: Northeast Pacific, NWA: Northwest Atlantic, WSA: Western South Atlantic. From Oliver et al. (2021)[4].

Causes and Characteristics of Marine Heatwaves

While the term "marine heatwave" is relatively new, unusually warm ocean temperature events are not. For example, some of the most prominent MHWs have been associated with naturally-occurring El Niño events, which can cause severe ecological impacts and have long been a topic of scientific and public interest. However, MHWs can occur in wide ranging forms, and those associated with El Niño are just one flavor. MHWs can affect small local areas or cover millions of square kilometers, and may last just a few days or persist for many months or even years – much longer than atmospheric heatwaves. In general, MHWs occur as a result of other changes in the ocean or atmosphere[5]. Some result from changes in how heat is transported through the ocean, such as shifts in major currents like the Gulf Stream. Others are driven by large-scale atmospheric systems, such as the persistent high pressure system that gave rise to the 2013-16 North Pacific "Blob".

Impacts of Marine Heatwaves

Recorded impacts of MHWs include changes to species' metabolism, growth, health, survival, and distributions, as well as complex and cascading disruptions to ecosystem structure. Research has shown that MHWs can increase mortality of species that have limited ability to relocate, including corals, seagrasses, and kelp, which provide critical habitat and valuable services for marine life and coastal communities. Highly mobile species may respond to MHWs by temporarily shifting their ranges (sometimes by thousands of kilometers) to find more favorable conditions. These changes in distribution can have significant ecological and socioeconomic impacts, including the establishment of invasive species, increased overlap between fisheries and protected species, and reduced viability of commercial, recreational, and subsistence fisheries.

Some recent MHWs illustrate their ability to impact marine ecosystems and human communities:

Coral bleaching in the Caribbean Sea and Gulf of Mexico

Coral reefs are among the most valuable ecosystems globally. These ecosystems, in addition to forming the cultural heritage for many indigenous island and coastal communities, support 25% of all marine biodiversity and provide \$3.4B/year in economic value for the U.S. (including ~\$200M from fisheries and \$1.8B in coastal protection benefits)[6]. MHWs can break down an essential relationship between corals and their symbiotic algae, leading to coral bleaching that can result in mass coral mortality. In 2023, record high ocean temperatures associated with long-lasting MHWs pervaded the Gulf of Mexico and Caribbean Sea[7,8]. In the Florida Keys, the cumulative stress of these persistent extreme temperatures caused widespread coral bleaching and rapid, extensive mortality of both wild and out-planted corals, including species listed as threatened under the Endangered Species Act. Complete coral losses occurred within several coral nurseries, while there was near-total mortality of branching corals in the middle and lower keys, and widespread mortality of branching gorgonians and sea fans (Figures 2, 3).

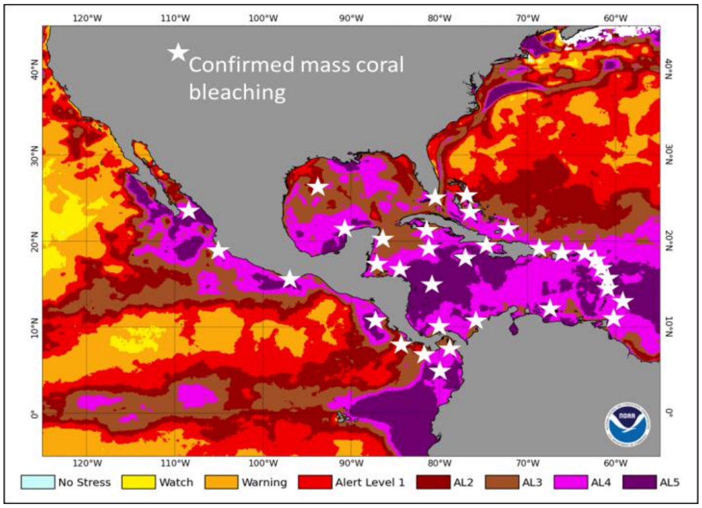
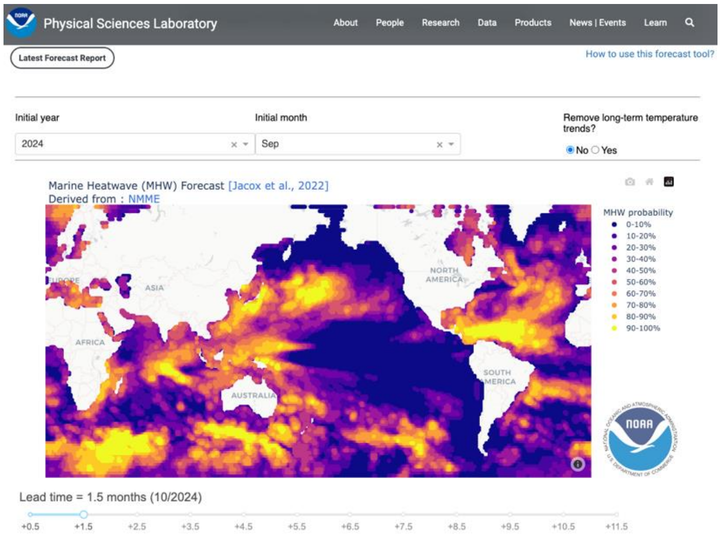


Figure 2. NOAA's Coral Reef Watch's maximum bleaching alert area product for the Caribbean from 2023. New alert levels (3-5) were added in response to the 2023 MHWs. Colors indicate the maximum alert level for 2023 and stars indicate locations of confirmed mass coral bleaching.

Figure 3. Summer 2023 coral bleaching and mortality at Cheeca Rocks, Florida Keys National Marine Sanctuary. *NOAA Briefing 8/17/23*

Snow crab collapse in the eastern Bering Sea

Between 2018 and 2021, the eastern Bering Sea (off western Alaska) lost over 90% of its snow crab population – approximately 47 billion crabs[9]. This population decline closed a fishery historically valued up to~$227M/year, and the Secretary of Commerce determined that federal fishery disasters occurred for fishing years 2021-2024. NOAA scientists determined that the most likely cause of the collapse was starvation linked to widespread MHW conditions in 2018-2019, along with a human-caused longer-term climate transition from Arctic ecosystem conditions to more boreal (subarctic) conditions[9,10]. Bottom temperatures on the eastern Bering Sea shelf had been above average since 2014, peaking in 2018-2019 with temperatures almost 4°C above normal. This warm water event followed a spike in the snow crab population and also increased the animals' metabolism, producing excessive demand for food. At the same time, food availability in normal forage areas was reduced. The mismatch of food supply and demand caused crabs to starve (also see NOAA web story). Based on climate projections, the trend from Arctic to boreal conditions is expected to continue in coming decades, threatening long-term snow crab recovery in the traditional fishing grounds[9].



Initial year: 2024

Initial month: Sep

Remove long-term temperature trends? ● No ○ Yes

Lead time = 1.5 months (10/2024)

Figure 4. NOAA's MHW forecasts are issued monthly, giving outlooks of the coming 12 months. In this example, forecasts issued in September 2024 show the likelihood of MHWs around the globe in October 2024. Warmer colors indicate a higher chance of MHWs. *NOAA website*

Forecasting Marine Heatwaves

Research and development of MHW forecasts has accelerated in recent years. Like weather or hurricane forecasts, MHW forecasts enable proactive decision-making to help mitigate negative environmental and economic outcomes. In many cases, MHWs can be predicted months in advance, especially when they are associated with large-scale climate events such as El Niño[11]. Since 2022, NOAA has provided monthly outlooks of MHW likelihoods around the globe (Figure 4). Predictability research is ongoing, supporting the development of other forecasts using climate models, machine learning, and artificial intelligence. The quality of these forecasts depends on ocean observations, and their development and evaluation will be aided by enhanced subsurface ocean observation systems.

The Future of Marine Heatwaves

MHWs are occurring against a backdrop of ocean temperatures that have warmed over the past century and are expected to continue warming into the future. This warming trend implies that even if MHWs do not become more intense, temperatures that we now consider extreme will occur more often[12,13]. Some interpret this shift as an increase in MHWs, while others separate MHWs from long-term warming trends[14]. Studies suggest that in some regions, climate change will alter the dynamics of the climate system such that ocean temperature variability will change. Such changes could increase or decrease the intensity of MHWs; for example, reduced ice cover in the Arctic would expose the sea surface directly to the atmosphere, increasing ocean temperature variability and MHW intensity.

As MHWs and long-term warming push ocean temperatures to unprecedented levels[15], marine ecosystems will likely undergo widespread change. To reduce impacts and risks, marine resource-dependent communities and economies must adapt to both lost and emerging opportunities while promoting sustainable use of ecosystems. NOAA continues to track and forecast MHWs (Northeast Pacific MHW tracker, Coral Reef Watch, MHW Forecasts, Ocean Heat Content), and conduct research to improve understanding of MHWs and their impacts. NOAA is also working to disseminate information and advice to the general public and decision makers through initiatives such as the Climate, Ecosystems, and Fisheries Initiative. Their work provides critical information to understand and help mitigate potential impacts from MHW events.

Additional Resources

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5. Capotondi, A. *et al.* (2024) *Commun Earth Env*, in press.
6. https://coast.noaa.gov/states/fast-facts/coral-reefs.html
7. Johnson, G.C. *et al.* (2024) *Bull Am Met Soc*, 105(8), S156-S213.
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15. Huang et al. (2024) Geophys Res Lett, 2024GL108369