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THE NEXT GENERATION OF MARINE HEATWAVES SCIENCE

Takeaways from A Two Week Training Workshop

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Marine heatwaves (MHWs), periods of anomalously warm ocean temperatures lasting days to months (Hobday et al., 2016), have been linked to negative ecological impacts (Smale et al. 2019) and have been increasing in frequency and duration (Oliver et al. 2019). Considerable research is being conducted to identify the drivers of these extreme events and to assess their physical, ecological, and biogeochemical impacts (Oliver et al. 2021; Smith et al. 2023). As is the case for many questions in marine biological, ecological, and oceanographic sciences, there is an evident need in this area for interdisciplinary collaboration, where members of

distinct research fields can benefit from sharing their expertise and data with a broader scientific community (Brodie et al. 2022). Interdisciplinary research is of high interest to early career researchers; however, they face particular barriers in developing and sustaining these research networks (Pannell et al. 2019; Brasier et al. 2020). This is in part because their progress is often evaluated in respect to a singular discipline and their career advancement relies upon fast publication rates that are not always compatible with large collaborations (Goring et al. 2014).

From August 18–31, 2024, the Marine Heatwaves Training Workshop was held at the University of Washington Friday Harbor Laboratories to support early career researchers pursuing interdisciplinary research. In this piece, we, the 15 in-person workshop participants with the support of our workshop organizer (Fig. 1), discuss the importance of this instructional, project-focused workshop for developing interdisciplinary questions in marine science. Our career stages range from postbaccalaureate to postdoctoral researchers, with the majority being doctoral students or candidates. We, along with our remote participant counterparts, come from countries around the globe, including Australia, Brazil, Canada, Chile, China, Germany, India, Israel, Korea, Mexico, Portugal, and the United States. Our expertise covers a broad range of marine

and climate science: we are physical and biological oceanographers, marine scientists, ocean-atmosphere scientists, marine ecologists and biologists, quantitative ecologists, climate scientists, and Earth systems scientists, with many of us identifying with more than one subdiscipline.

We joined this workshop with different goals, but all arrived with a common desire to establish interdisciplinary research connections. Many of us were drawn to the opportunity to learn about emerging tools for detecting MHWs and assessing their impacts in our specific disciplines. Others primarily sought to establish collaborations with experts in the field and early career researchers from other institutions and disciplines. As early career researchers, we were primarily seeking to gain technical knowledge, broader research context, and collaborative opportunities to strengthen our current and future MHW research.

Dr. Charles Greene organized the Marine Heatwaves Training Workshop, and the CO₂ Foundation (<https://co2foundation.org/>) supported our student participation costs. Fifteen in-person participants were selected based on a review of their resume, statement of interest, and a letter of recommendation. Students were selected to diversify the career stages, number of countries, and the number of institutions/organizations represented. The original intention was to hold an in-person only workshop. However, because the applicant pool was so outstanding, the decision was made to hold a hybrid workshop with both in-person and remote student participants. During the first week of the workshop, recognized experts in the field delivered hybrid lectures designed to: (1) investigate the local and remote drivers of surface and subsurface MHWs, (2) quantify the links between MHWs and other physical or biogeochemical processes, and (3) explore the impacts of MHWs on ecosystem function and species interactions. In the second week, we worked collaboratively in small groups (2–5 people) to analyze MHW datasets that participants or instructors supplied for analysis.

During the first week of the workshop, 14 MHW experts delivered 18 lectures and one hands-on training session. All expenses, including travel and honoraria, were covered for the instructors and guest speakers. The lectures are detailed in Supporting Information Table S1 and the recordings are available on the University of Washington Friday Harbor Laboratories YouTube channel (<https://www.youtube.com/playlist?list=PLQLS9LFNUOSKLMgqLy9or3MqQOrHCqYA->), which supported the participation of remote participants from widely different time



Fig. 1. The workshop participants on the dock at Friday Harbor Laboratories.

zones. The lecture topics included defining and characterizing MHWs, available analytical tools, case studies highlighting MHW dynamics and impacts, and more. We also compiled an annotated bibliography of key readings that can be found in Supporting Information Table S2.

During the second week of the workshop, we worked on small group projects with themes such as surface and subsurface MHW detection and tracking tool development, methods for characterizing MHWs, assessment of oceanic-atmospheric interactions during MHWs, analysis of the ecological impacts of MHWs that compound with other environmental stressors, climate change attribution, and this article. These short projects provided us with opportunities to establish interdisciplinary collaborations, and at least five groups have continued to develop their research with the hope of eventually publishing their workshop projects.

The Marine Heatwaves Training Workshop provided us with a collaborative and intellectually diverse learning environment and helped us forge interdisciplinary connections with other early career researchers and established experts in the field. Common takeaways from the workshop included the importance of establishing a shared vocabulary across disciplines, fluency in multiple coding languages (notably Python, R, and MATLAB), and inclusive open access resources (e.g., data, toolboxes, and Python packages) for MHW analysis. As the workshop participants, we emphasize the importance of interdisciplinary collaboration and the need for open data and open science across disciplines. We encourage other early career researchers to access the recorded workshop material and reach out to authors with shared interests.

We are overwhelmingly excited to continue the research established during the workshop but recognize that maintaining the momentum to do so will be challenging. We suggest that, when possible, future workshops seeking to build interdisciplinary collaboration among early career researchers should consider allocating a portion of funding towards providing computational resources, and supporting open-access post-workshop publications, perhaps by having portions of the first week be delivered to all participants via zoom. We recommend the use of pre-workshop surveys to gauge what resources students have regarding computing time and publication cost and the use of pre-workshop video conferencing to establish preliminary research connections. During the formation of workshop projects, we recommend identifying a

project lead, connecting them with an established researcher project mentor, and developing a project goal and timeline. This workshop was instrumental in fostering cross-disciplinary research collaborations, and we thus strongly advocate for the development of similar training opportunities for other early career researchers.

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AUTHOR CONTRIBUTIONS

R.F., E.M.F., O.J.G., and C.E.K. developed the framework for this piece. R.F. led the writing, and all authors contributed to writing and revision.

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