Supplementary Information For

Threat by marine heatwaves to adaptive large marine ecosystems in
an eddy-resolving model

Xiuwen Guo1, Yang Gao1,2,3*, Shaoqing Zhang2,3,4*, Lixin Wu3,4, Ping Chang3,5, Wenju Cai6,7, Jakob Zscheischler8,9,10, L. Ruby Leung11, Justin Small3,12, Gokhan Danabasoglu3,12, Luanne Thompson13 and Huiwang Gao1

1Frontiers Science Center for Deep Ocean Multispheres and Earth System, and Key Laboratory of Marine Environmental Science and Ecology, Ministry of Education, Ocean University of China, Qingdao, 266100, China
2Laboratory for Ocean Dynamics and Climate, Qingdao National Laboratory for Marine Science and Technology, Qingdao, 266237, China
3International Laboratory for High-Resolution Earth System Prediction (iHESP), College Station, TX USA
4Key Laboratory of Physical Oceanography, Institute for Advanced Ocean Study, Frontiers Science Center for Deep Ocean Multispheres and Earth System (FDOMES), College of Oceanic and Atmospheric Sciences, Ocean University of China, Qingdao, 266100, China
5Department of Oceanography, Texas A&M University, College Station, Texas, 77843, USA
6Physical Oceanography Laboratory/CIMST, Ocean University of China and Qingdao National Laboratory for Marine Science and Technology, Qingdao, 266100, China
7CSIRO Marine and Atmospheric Research, Aspendale, Victoria, 3195, Australia
8Department of Computational Hydrosystems, Helmholtz Centre for Environmental Research – UFZ, 04318 Leipzig, Germany
9Climate and Environmental Physics, University of Bern, Bern, 3012, Switzerland
10Oeschger Centre for Climate Change Research, University of Bern, Bern, 3012, Switzerland
11Atmospheric Sciences and Global Change Division, Pacific Northwest National Laboratory, Richland, WA, 99354, USA
12National Center for Atmospheric Research, Boulder, CO, 80305, USA
13University of Washington, School of Oceanography, Seattle, WA, 98195, USA

*Corresponding author: Y. Gao: yanggao@ouc.edu.cn; S. Zhang: szhang@ouc.edu.cn
| Model         | Institution                                                                 |
|--------------|-----------------------------------------------------------------------------|
| ACCESS1.0     | Commonwealth Scientific and Industrial Research Organization                 |
| ACCESS1.3     | (CSIRO), Australia and Bureau of Meteorology (BOM), Australia               |
| CanESM2       | Canadian Centre for Climate Modelling and Analysis, Canada                   |
| CMCC-CM       | Euro-Mediterraneo sui Cambiamenti Climatici, Italy                          |
| CMCC-CESM     | State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics, China |
| FGOALS-s2     | State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics, China |
| GFDL-ESM2G    | NOAA Geophysical Fluid Dynamics Laboratory, USA                              |
| GFDL-CM3      | Institute for Numerical Mathematics, Russia                                 |
| INM-CM4       | Institut Pierre-Simon Laplace, France                                        |
| IPSL-CM5A-LR  | Institut Pierre-Simon Laplace, France                                        |
| IPSL-CM5A-MR  | Institut Pierre-Simon Laplace, France                                        |
| IPSL-CM5B-LR  | Institut Pierre-Simon Laplace, France                                        |
| MIROC-ESM     | Atmosphere and Ocean Research Institute (The University of Tokyo),           |
| MIROC-ESM-CHEM| National Institute for Environmental Studies and Japan Agency for Marine-Earth Science and Technology |
| MIROC5        | Max Planck Institute for Meteorology, Germany                                |
| MPI-ESM-LR    | Meteorological Research Institute, Japan                                     |
Supplementary Table 2 | The SST trends, mean and standard deviation (std) of annual MHW days and mean intensity during historical and future periods.

| Large Marine Ecosystem (LME) | 1975-2004 | 2071-2100 | Historical period (1975-2004) | Future period (2071-2100) |
|-----------------------------|------------|-----------|-------------------------------|--------------------------|
|                             | SST trend  | Annual days | Mean intensity | Mean warming-inclusive threshold | Future threshold |
|                             | (°C decade⁻¹) | (days) | (°C) | (days) | (°C) | (days) | (°C) | (days) | (°C) |
| 1. East Bering Sea           | -0.13      | 33.8       | 1.7 | 1.2 | 0.3 | 361.8 | 5.8 | 3.5 | 0.6 | 41.3 | 2.3 | 1.5 | 0.3 |
| 2. Gulf of Alaska            | -0.10      | 34.3       | 2.2 | 1.4 | 0.2 | 356.7 | 8.6 | 2.6 | 0.4 | 37.7 | 2.8 | 1.5 | 0.2 |
| 3. California Current        | -0.11      | 34.6       | 1.5 | 1.4 | 0.2 | 355.3 | 9.7 | 2.6 | 0.3 | 35.2 | 1.9 | 1.5 | 0.2 |
| 4. Gulf of California        | 0.08       | 36.6       | 1.7 | 1.1 | 0.2 | 360.1 | 5.0 | 2.6 | 0.3 | 37.8 | 2.2 | 1.2 | 0.1 |
| 5. Gulf of Mexico            | 0.13       | 32.7       | 2.3 | 1.0 | 0.2 | 362.3 | 5.4 | 3.3 | 0.3 | 36.2 | 2.2 | 1.1 | 0.2 |
| 6. Southeast U.S. Continental Shelf | 0.11     | 27.4       | 5.0 | 1.2 | 0.4 | 353.3 | 17.7 | 2.9 | 0.2 | 31.9 | 4.3 | 1.2 | 0.3 |
| 7. Northeast U.S. Continental Shelf* | 0.27   | 32.7       | 4.1 | 2.4 | 0.9 | 349.8 | 29.8 | 5.0 | 0.8 | 35.6 | 3.8 | 2.1 | 0.5 |
| 8. Scotian Shelf*            | 0.18       | 33.9       | 3.4 | 2.1 | 0.6 | 362.7 | 6.8 | 5.8 | 0.6 | 38.3 | 3.9 | 2.2 | 0.4 |
| 9. Newfoundland-Labrador Shelf* | 0.02    | 29.3       | 5.3 | 1.8 | 0.4 | 333.3 | 36.1 | 3.5 | 1.5 | 35.2 | 4.1 | 2.6 | 0.8 |
| 10. Insular Pacific-Hawaiian  | 0.14       | 35.6       | 2.1 | 1.0 | 0.2 | 361.3 | 3.5 | 2.7 | 0.2 | 35.9 | 1.6 | 1.1 | 0.1 |
| 11. Pacific Central-American  | 0.07       | 32.4       | 2.6 | 1.1 | 0.3 | 357.8 | 10.8 | 2.6 | 0.4 | 33.6 | 2.9 | 1.2 | 0.3 |
| 12. Caribbean Sea            | 0.08       | 34.0       | 3.1 | 0.6 | 0.1 | 364.8 | 1.3 | 2.6 | 0.3 | 35.8 | 2.0 | 0.8 | 0.1 |
| 13. Humboldt Current*        | -0.09      | 33.8       | 2.6 | 1.2 | 0.3 | 324.1 | 44.2 | 2.0 | 0.8 | 34.9 | 2.5 | 1.4 | 0.3 |
| 14. Patagonian Shelf         | -0.03      | 30.6       | 3.0 | 1.2 | 0.5 | 352.8 | 13.1 | 2.0 | 0.7 | 35.6 | 3.3 | 1.3 | 0.4 |
| 15. South Brazil Shelf       | -0.08      | 29.4       | 2.9 | 1.2 | 0.2 | 333.4 | 26.7 | 2.1 | 0.2 | 30.2 | 3.0 | 1.4 | 0.2 |
| 16. East Brazil Shelf        | 0.02       | 33.6       | 2.6 | 0.6 | 0.1 | 363.7 | 8.6 | 2.4 | 0.2 | 35.0 | 2.8 | 0.6 | 0.2 |
| 17. North Brazil Shelf       | 0.07       | 30.2       | 3.5 | 0.6 | 0.1 | 365.0 | 0.2 | 2.5 | 0.1 | 32.8 | 2.4 | 0.7 | 0.1 |
| 22. North Sea*               | 0.19       | 35.9       | 2.7 | 1.2 | 0.2 | 358.4 | 8.6 | 2.6 | 0.3 | 36.8 | 2.7 | 1.4 | 0.2 |
| Region                      | Latitude | Longitude | Temperature | Salinity | Dissolved O2 | pH | Conductivity | Alkalinity |
|-----------------------------|----------|-----------|-------------|----------|--------------|----|--------------|------------|
| Baltic Sea                  | 0.35     | 0.54      | 39.8        | 2.3      | 1.7          | 0.2| 361.6        | 3.2        |
| Celtic-Biscay Shelf         | 0.17     | 0.49      | 35.8        | 2.1      | 1.1          | 0.2| 351.0        | 9.8        |
| Iberian Coastal*            | 0.05     | 0.43      | 35.9        | 2.1      | 1.0          | 0.2| 331.6        | 38.3       |
| Mediterranean               | 0.28     | 0.57      | 40.3        | 3.8      | 1.1          | 0.2| 364.1        | 3.3        |
| Canary Current*             | 0.07     | 0.39      | 33.6        | 2.1      | 0.9          | 0.2| 355.2        | 16.6       |
| Guinea Current              | 0.08     | 0.40      | 30.3        | 1.9      | 0.7          | 0.2| 364.9        | 0.4        |
| Benguela Current*           | 0.09     | 0.32      | 33.0        | 2.7      | 1.2          | 0.4| 352.4        | 20.7       |
| Agulhas Current             | 0.06     | 0.37      | 28.8        | 4.3      | 1.3          | 0.5| 336.3        | 51.5       |
| Somali Coastal Current      | 0.07     | 0.46      | 31.8        | 1.8      | 1.0          | 0.2| 363.7        | 4.0        |
| Arabian Sea                 | 0.08     | 0.51      | 32.6        | 2.4      | 0.9          | 0.2| 360.8        | 7.1        |
| Red Sea                     | 0.17     | 0.50      | 35.4        | 2.6      | 1.1          | 0.2| 360.5        | 4.6        |
| Bay of Bengal               | 0.10     | 0.39      | 32.2        | 1.8      | 0.7          | 0.1| 364.3        | 1.7        |
| Gulf of Thailand*           | 0.06     | 0.42      | 33.0        | 1.4      | 0.8          | 0.1| 364.7        | 0.5        |
| South China Sea*            | 0.03     | 0.47      | 32.3        | 1.6      | 1.0          | 0.2| 361.5        | 4.1        |
| Sulu-Celebes Sea            | 0.13     | 0.37      | 29.7        | 2.5      | 0.7          | 0.1| 364.8        | 0.3        |
| Indonesian Sea              | 0.12     | 0.37      | 31.4        | 2.5      | 0.7          | 0.1| 364.3        | 3.0        |
| North Australian Shelf      | 0.15     | 0.45      | 35.0        | 1.7      | 0.9          | 0.1| 363.5        | 1.9        |
| Northeast Australian Shelf  | 0.08     | 0.43      | 33.7        | 1.8      | 1.0          | 0.1| 360.6        | 3.2        |
| East-Central Australian Shelf | -0.02  | 0.44     | 31.2       | 3.3      | 1.6          | 0.4| 329.5        | 31.5       |
| Southeast Australian Shelf  | -0.01    | 0.29      | 31.6        | 2.1      | 1.6          | 0.6| 315.0        | 35.6       |
| Southwest Australian Shelf  | 0.10     | 0.26      | 31.7        | 3.1      | 1.4          | 0.6| 302.7        | 49.9       |
| West-Central Australian Shelf | 0.17    | 0.27     | 30.2        | 2.5      | 1.7          | 0.3| 301.2        | 34.0       |
| Northwest Australian Shelf  | 0.15     | 0.38      | 34.9        | 1.7      | 1.0          | 0.1| 361.4        | 5.0        |
| New Zealand Shelf           | -0.01    | 0.27      | 33.1        | 2.8      | 1.1          | 0.2| 343.7        | 36.9       |
| East China Sea*             | 0.06     | 0.49      | 31.4        | 5.6      | 1.6          | 0.2| 340.8        | 15.6       |
| Yellow Sea*                 | 0.13     | 0.60      | 34.8        | 2.9      | 1.7          | 0.2| 360.9        | 7.8        |

4
|        |          |        |        |        |        |        |        |        |        |        |        |        |        |        |
|--------|----------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| 49. Kuroshio Current | 0.17 | 0.58 | 31.2 | 4.0 | 2.1 | 1.0 | 300.3 | 51.9 | 3.2 | 0.9 | 32.8 | 3.8 | 2.2 | 0.8 |
| 50. Sea of Japan/East Sea* | 0.16 | 0.64 | 33.4 | 3.0 | 2.4 | 0.5 | 342.7 | 14.8 | 3.9 | 0.6 | 35.7 | 3.9 | 2.3 | 0.4 |
| 51. Oyashio Current | 0.32 | 0.81 | 33.6 | 2.3 | 2.5 | 1.2 | 342.5 | 41.8 | 4.6 | 0.5 | 35.6 | 2.4 | 2.8 | 0.9 |
| 52. Sea of Okhotsk* | -0.05 | 0.73 | 33.7 | 3.7 | 1.5 | 0.2 | 362.4 | 7.8 | 4.7 | 1.0 | 41.5 | 3.9 | 1.8 | 0.3 |
| 53. West Bering Sea | -0.12 | 0.56 | 33.1 | 2.1 | 1.3 | 0.2 | 363.5 | 4.0 | 3.9 | 0.5 | 40.5 | 2.8 | 1.4 | 0.2 |
| 54. Iceland Shelf and Sea | 0.15 | 0.74 | 33.8 | 5.6 | 1.3 | 0.4 | 352.5 | 22.8 | 3.5 | 1.3 | 38.5 | 3.6 | 1.5 | 0.2 |
| 60. Faroe Plateau* | 0.18 | 0.57 | 33.8 | 3.5 | 1.0 | 0.3 | 362.5 | 2.8 | 2.5 | 0.5 | 35.5 | 2.8 | 1.3 | 0.2 |
| 62. Black Sea | 0.33 | 0.64 | 40.6 | 2.7 | 1.3 | 0.1 | 363.2 | 1.2 | 3.7 | 0.4 | 40.1 | 2.4 | 1.5 | 0.1 |
| 63. Hudson Bay Complex | 0.00 | 1.17 | 29.6 | 3.9 | 1.1 | 0.3 | 342.3 | 28.7 | 2.3 | 0.7 | 41.0 | 2.8 | 2.1 | 0.2 |
| 65. Aleutian Islands | -0.02 | 0.53 | 33.2 | 2.7 | 1.1 | 0.1 | 364.9 | 0.3 | 4.0 | 0.5 | 39.2 | 2.5 | 1.4 | 0.1 |

# The standard deviation is calculated based on the spatial coverage on each LME, and for future period, both the mean warming-inclusive and future thresholds are applied

* The LME with the fishing capacity ranking the top 15 among all the LMEs (Fig. 1A in ref. 1)
Supplementary Reference

1. Stock, C. A. et al. Reconciling fisheries catch and ocean productivity. *Proc. Natl. Acad. Sci. USA.* 114, E1441-E1449 (2017).