Supplementary table 1. Name, modelling institute and data sources of the 19 (18 for SSP5-8.5) WCRP CMIP6 models used to calculate SST change increments between present and future projections as a baseline for the delta SST downscaling approach

All data available under <https://esgf-node.llnl.gov/projects/cmip6/> .

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  | **Experiment ID** | | |  |
| **Model name** | **Modelling institute** | **Historical** | **SSP2-4.5** | **SSP5-8.5** | **Data source** |
| ACCESS-CM2 | CSIRO Commonwealth Scientific and Industrial Research Organisation | x | x | x | [1]–[3] |
| ACCESS-ESM1-5 | CSIRO Commonwealth Scientific and Industrial Research Organisation | x | x | x | [4]–[6] |
| CAMS-CSM1-0 | CAMS Chinese Academy of Meteorological Sciences | x | x | x | [7]–[9] |
| CanESM5 | CCCma Canadian Centre for Climate Modelling and Analysis | x | x | x | [10]–[12] |
| CAS-ESM2-0 | CAS Chinese Academy of Sciences | x | x | x | [13], [14] |
| CESM2-WACCM | NCAR National Center for Atmospheric Research | x | x | x | [15]–[17] |
| CIESM | THU Tsinghua University | x | x | x | [18]–[20] |
| CMCC-CM2-SR5 | CMCC Euro-Mediterranean Center on Climate Change | x | x | x | [21]–[23] |
| CMCC-ESM2 | CMCC Euro-Mediterranean Center on Climate Change | x | x | x | [24]–[26] |
| FGOALS-f3-L | CAS Chinese Academy of Sciences | x | x | x | [27]–[29] |
| FGOALS-g3 | CAS Chinese Academy of Sciences | x | x |  | [30], [31] |
| FIO-ESM-2-0 | FIO First Institute of Oceanography | x | x | x | [32]–[34] |
| GFDL-CM4 | NOAA National Oceanic and Atmospheric Administration | x | x | x | [35]–[37] |
| GFDL-ESM4 | NOAA National Oceanic and Atmospheric Administration | x | x | x | [38]–[40] |
| MIROC6 | MIROC Japan Agency for Marine-Earth Science and Technology | x | x | x | [41]–[43] |
| MRI-ESM2-0 | MRI Meteorological Research Institute | x | x | x | [44]–[46] |
| NESM3 | NUIST Nanjing University of Information Science and Technology | x | x | x | [47]–[49] |
| NorESM2-LM | NCC NorESM Climate modeling Consortium | x | x | x | [50]–[52] |
| NorESM2-MM | NCC NorESM Climate modeling Consortium | x | x | x | [53]–[55] |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Total** |  | 19 | 19 | 18 |

Supplementary table 2. Northern Hemisphere humpback whale DPS names, numerical population codes (corresponding to Figure 2) and conservation status. Current SSTs and projected SSTs under greenhouse gas emission scenarios SSP2-RCP4.5 and SSP5-RCP8.5 are displayed, and the values are compared between downscaled data and data from the CMIP6 ensemble model median. Light grey cells indicate SSTs within 1 °C of the 28 °C threshold, dark grey cells indicate those SSTs where the threshold is surpassed.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **DPS** | **Numerical population code** (Fig. 2) | **Status** (as DPS) | **Current** mean February SST | **SSP2-RCP4.5:** mean February end-of-century SST | **SSP2-RCP4.5:** mean February end-of-century SST | **SSP5-RCP8.5:** mean February end-of-century SST | **SSP5-RCP8.5:** mean February end-of-century SST |
|  |  |  |  | ***Downscaled data*** | ***CMIP6 ensemble model median*** | ***Downscaled data*** | ***CMIP6 ensemble model median*** |
| West Indies | 1 | Not at risk | 26.67 | **28.02** | **27.73** | **29.32** | **29.02** |
| NW Africa | 2 | Endangered | 22.48 | 24.03 | 24.53 | 25.52 | 26.05 |
| Japan: Ryukyu Islands | 3a | Endangered | 22.17 | 23.33 | 22.14 | 24.54 | 23.35 |
| Japan: Bonin Islands | 3b | Endangered | 22.21 | 23.58 | 22.55 | 25.34 | 24.31 |
| Mariana Islands | 3c | Endangered | **27.41** | **28.70** | **28.02** | **30.33** | **29.64** |
| Hawai’i | 4 | Not at risk | 24.81 | 26.25 | 25.75 | **28.00** | **27.50** |
| Mexico: Baja California | 5a | Threatened | 21.45 | 22.60 | 25.23 | 24.17 | 26.80 |
| Mexico: Revillagigedos | 5b | Threatened | 24.60 | 25.72 | 25.78 | **27.38** | **27.4295328** |
| Mexico: Mainland | 5c | Threatened | 24.96 | 26.12 | 27.97 | **27.71** | **29.57** |
| Central America | 6 | Endangered | **28.94** | **30.40** | **29.14** | **31.91** | **30.70** |
| Arabian Sea | 14 | Endangered | 25.16 | **26.47** | 25.07 | **28.57** | **27.20** |

Summary statistics: Northern hemisphere DPS *within 1 degree or surpassing* 28°C isotherm by 2100:

**SSP2-RCP4.5** - CMIP6 ensemble model median: **3 DPS (27%);** Downscaled: **4 DPS (36%)**

**SSP5-RCP8.5** - CMIP6 ensemble model median: **7 DPS (64%);** Downscaled: **7 DPS (64%)**

Supplementary table 3. Southern Hemisphere humpback whale DPS names, numerical population codes (corresponding to Figure 2) and conservation status. Current SSTs and projected SSTs under greenhouse gas emission scenarios SSP2-RCP4.5 and SSP5-RCP8.5 are displayed, and the values are compared between downscaled data and data from the CMIP6 ensemble model median. Light grey cells indicate SSTs within 1 °C of the 28 °C threshold, dark grey cells indicate those SSTs where the threshold is surpassed.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **DPS** | **Numerical population code** (Fig. 2) | **Status** (as DPS) | **Current** mean August SST | **SSP2-RCP4.5:** mean August end-of-century SST | **SSP2-RCP4.5:** mean August end-of-century SST | **SSP5-RCP8.5:** mean August end-of-century SST | **SSP5-RCP8.5:** mean August end-of-century SST |
|  |  |  |  | ***Downscaled data*** | ***CMIP6 ensemble model median*** | ***Downscaled data*** | ***CMIP6 ensemble model median*** |
| Brazil | 7 | Not at risk | 25.17 | 26.42 | 25.40 | **27.59** | 26.66 |
| SW Africa | 8 | Not at risk | 25.30 | **27.37** | **29.23** | **28.68** | **31.06** |
| East Africa | 9a | Not at risk | 23.87 | 25.25 | 26.08 | 26.71 | **27.60** |
| NE Madagascar | 9b | Not at risk | 24.57 | 25.90 | 25.94 | **27.30** | **27.36** |
| S Madagascar | 9c | Not at risk | 23.32 | 24.42 | 24.39 | 25.98 | 25.82 |
| West Australia | 10 | Not at risk | 25.83 | **27.31** | **27.54** | **29.02** | **29.30** |
| East Australia | 11 | Not at risk | 23.49 | 24.27 | 24.18 | 26.10 | 25.73 |
| Vanuatu | 12a | Not at risk | 26.43 | **27.87** | **27.03** | **29.12** | **28.52** |
| New Caledonia | 12b | Not at risk | 23.48 | 24.61 | 24.16 | 26.16 | 25.65 |
| Tonga | 12c | Not at risk | 24.71 | 25.49 | 25.11 | **27.01** | 26.47 |
| Cook Islands | 12d | Not at risk | 25.17 | 26.02 | 25.41 | **27.26** | 26.58 |
| French Polynesia | 12e | Not at risk | 26.45 | **27.06** | 26.74 | **28.56** | **27.95** |
| SE Pacific | 13 | Not at risk | **27.10** | **28.18** | **29.30** | **30.24** | **31.08** |

Summary statistics: Southern hemisphere DPS *within 1 degree or surpassing* 28°C isotherm by 2100:

**SSP2-RCP4.5** - CMIP6 ensemble model median: **4 DPS (31%);** Downscaled: **5 DPS (38%)**

**SSP5-RCP8.5** - CMIP6 ensemble model median: **7 DPS (54%);** Downscaled: **9 DPS (69%)**

Data sources:

[1] M. Dix *et al.*, “CSIRO-ARCCSS ACCESS-CM2 model output prepared for CMIP6 ScenarioMIP ssp245.” Earth System Grid Federation, 2019.

[2] M. Dix *et al.*, “CSIRO-ARCCSS ACCESS-CM2 model output prepared for CMIP6 ScenarioMIP ssp585.” Earth System Grid Federation, 2019.

[3] M. Dix *et al.*, “CSIRO-ARCCSS ACCESS-CM2 model output prepared for CMIP6 CMIP historical.” Earth System Grid Federation, 2019.

[4] T. Ziehn *et al.*, “CSIRO ACCESS-ESM1.5 model output prepared for CMIP6 ScenarioMIP ssp585.” Earth System Grid Federation, 2019.

[5] T. Ziehn *et al.*, “CSIRO ACCESS-ESM1.5 model output prepared for CMIP6 ScenarioMIP ssp245.” Earth System Grid Federation, 2019.

[6] T. Ziehn *et al.*, “CSIRO ACCESS-ESM1.5 model output prepared for CMIP6 CMIP historical.” Earth System Grid Federation, 2019.

[7] X. Rong, “CAMS CAMS-CSM1.0 model output prepared for CMIP6 ScenarioMIP ssp585.” Earth System Grid Federation, 2019.

[8] X. Rong, “CAMS CAMS-CSM1.0 model output prepared for CMIP6 ScenarioMIP ssp245.” Earth System Grid Federation, 2019.

[9] X. Rong, “CAMS CAMS\_CSM1.0 model output prepared for CMIP6 CMIP historical.” Earth System Grid Federation, 2019.

[10] N. C. Swart *et al.*, “CCCma CanESM5 model output prepared for CMIP6 ScenarioMIP ssp585.” Earth System Grid Federation, 2019.

[11] N. C. Swart *et al.*, “CCCma CanESM5 model output prepared for CMIP6 CMIP historical.” Earth System Grid Federation, 2019.

[12] N. C. Swart *et al.*, “CCCma CanESM5 model output prepared for CMIP6 ScenarioMIP ssp245.” Earth System Grid Federation, 2019.

[13] Z. Chai, “CAS CAS-ESM2.0 model output prepared for CMIP6 CMIP.” Earth System Grid Federation, 2020.

[14] Z. Chai, “CAS CAS-ESM1.0 model output prepared for CMIP6 CMIP historical.” Earth System Grid Federation, 2020.

[15] G. Danabasoglu, “NCAR CESM2-WACCM model output prepared for CMIP6 ScenarioMIP ssp585.” Earth System Grid Federation, 2019.

[16] G. Danabasoglu, “NCAR CESM2-WACCM model output prepared for CMIP6 ScenarioMIP ssp245.” Earth System Grid Federation, 2019.

[17] G. Danabasoglu, “NCAR CESM2-WACCM model output prepared for CMIP6 CMIP historical.” Earth System Grid Federation, 2019.

[18] W. Huang, “THU CIESM model output prepared for CMIP6 ScenarioMIP ssp585.” Earth System Grid Federation, 2020.

[19] W. Huang, “THU CIESM model output prepared for CMIP6 ScenarioMIP ssp245.” Earth System Grid Federation, 2020.

[20] W. Huang, “THU CIESM model output prepared for CMIP6 CMIP historical.” Earth System Grid Federation, 2019.

[21] T. Lovato and D. Peano, “CMCC CMCC-CM2-SR5 model output prepared for CMIP6 ScenarioMIP ssp585.” Earth System Grid Federation, 2020.

[22] T. Lovato and D. Peano, “CMCC CMCC-CM2-SR5 model output prepared for CMIP6 ScenarioMIP ssp245.” Earth System Grid Federation, 2020.

[23] T. Lovato and D. Peano, “CMCC CMCC-CM2-SR5 model output prepared for CMIP6 CMIP historical.” Earth System Grid Federation, 2020.

[24] T. Lovato, D. Peano, and M. Butenschön, “CMCC CMCC-ESM2 model output prepared for CMIP6 ScenarioMIP ssp585.” Earth System Grid Federation, 2021.

[25] T. Lovato, D. Peano, and M. Butenschön, “CMCC CMCC-ESM2 model output prepared for CMIP6 ScenarioMIP ssp245.” Earth System Grid Federation, 2021.

[26] T. Lovato, D. Peano, and M. Butenschön, “CMCC CMCC-ESM2 model output prepared for CMIP6 CMIP historical.” Earth System Grid Federation, 2021.

[27] Y. YU, “CAS FGOALS-f3-L model output prepared for CMIP6 ScenarioMIP ssp585.” Earth System Grid Federation, 2019.

[28] Y. YU, “CAS FGOALS-f3-L model output prepared for CMIP6 ScenarioMIP ssp245.” Earth System Grid Federation, 2019.

[29] Y. YU, “CAS FGOALS-f3-L model output prepared for CMIP6 CMIP historical.” Earth System Grid Federation, 2019.

[30] L. Li, “CAS FGOALS-g3 model output prepared for CMIP6 CMIP historical.” Earth System Grid Federation, 2019.

[31] L. Li, “CAS FGOALS-g3 model output prepared for CMIP6 ScenarioMIP ssp245.” Earth System Grid Federation, 2019.

[32] Z. Song, F. Qiao, Y. Bao, Q. Shu, Y. Song, and X. Yang, “FIO-QLNM FIO-ESM2.0 model output prepared for CMIP6 ScenarioMIP ssp585.” Earth System Grid Federation, 2019.

[33] Z. Song, F. Qiao, Y. Bao, Q. Shu, Y. Song, and X. Yang, “FIO-QLNM FIO-ESM2.0 model output prepared for CMIP6 ScenarioMIP ssp245.” Earth System Grid Federation, 2019.

[34] Z. Song, F. Qiao, Y. Bao, Q. Shu, Y. Song, and X. Yang, “FIO-QLNM FIO-ESM2.0 model output prepared for CMIP6 CMIP historical.” Earth System Grid Federation, 2019.

[35] H. Guo *et al.*, “NOAA-GFDL GFDL-CM4 model output prepared for CMIP6 ScenarioMIP ssp585.” Earth System Grid Federation, 2018.

[36] H. Guo *et al.*, “NOAA-GFDL GFDL-CM4 model output prepared for CMIP6 ScenarioMIP ssp245.” Earth System Grid Federation, 2018.

[37] H. Guo *et al.*, “NOAA-GFDL GFDL-CM4 model output historical.” Earth System Grid Federation, 2018.

[38] J. P. Krasting *et al.*, “NOAA-GFDL GFDL-ESM4 model output prepared for CMIP6 CMIP historical.” Earth System Grid Federation, 2018.

[39] J. G. John *et al.*, “NOAA-GFDL GFDL-ESM4 model output prepared for CMIP6 ScenarioMIP ssp585.” Earth System Grid Federation, 2018.

[40] J. G. John *et al.*, “NOAA-GFDL GFDL-ESM4 model output prepared for CMIP6 ScenarioMIP ssp245.” Earth System Grid Federation, 2018.

[41] H. Tatebe and M. Watanabe, “MIROC MIROC6 model output prepared for CMIP6 CMIP historical.” Earth System Grid Federation, 2018.

[42] H. Shiogama, M. Abe, and H. Tatebe, “MIROC MIROC6 model output prepared for CMIP6 ScenarioMIP ssp245.” Earth System Grid Federation, 2019.

[43] H. Shiogama, M. Abe, and H. Tatebe, “MIROC MIROC6 model output prepared for CMIP6 ScenarioMIP ssp585.” Earth System Grid Federation, 2019.

[44] S. Yukimoto *et al.*, “MRI MRI-ESM2.0 model output prepared for CMIP6 CMIP historical.” Earth System Grid Federation, 2019.

[45] S. Yukimoto *et al.*, “MRI MRI-ESM2.0 model output prepared for CMIP6 ScenarioMIP ssp245.” Earth System Grid Federation, 2019.

[46] S. Yukimoto *et al.*, “MRI MRI-ESM2.0 model output prepared for CMIP6 ScenarioMIP ssp585.” Earth System Grid Federation, 2019.

[47] J. Cao, “NUIST NESMv3 model output prepared for CMIP6 ScenarioMIP ssp585.” Earth System Grid Federation, 2019.

[48] J. Cao, “NUIST NESMv3 model output prepared for CMIP6 ScenarioMIP ssp245.” Earth System Grid Federation, 2019.

[49] J. Cao and B. Wang, “NUIST NESMv3 model output prepared for CMIP6 CMIP historical.” Earth System Grid Federation, 2019.

[50] Ø. Seland *et al.*, “NCC NorESM2-LM model output prepared for CMIP6 CMIP historical.” Earth System Grid Federation, 2019.

[51] Ø. Seland *et al.*, “NCC NorESM2-LM model output prepared for CMIP6 ScenarioMIP ssp245.” Earth System Grid Federation, 2019.

[52] Ø. Seland *et al.*, “NCC NorESM2-LM model output prepared for CMIP6 ScenarioMIP ssp585.” Earth System Grid Federation, 2019.

[53] M. Bentsen *et al.*, “NCC NorESM2-MM model output prepared for CMIP6 CMIP historical.” Earth System Grid Federation, 2019.

[54] M. Bentsen *et al.*, “NCC NorESM2-MM model output prepared for CMIP6 ScenarioMIP ssp245.” Earth System Grid Federation, 2019.

[55] M. Bentsen *et al.*, “NCC NorESM2-MM model output prepared for CMIP6 ScenarioMIP ssp585.” Earth System Grid Federation, 2019.