CSIRO

Australia's National Science Agency

Ocean warming & marine temperature extremes

Climate Awareness Workshop – Wellington, NZ

Dr Thomas Moore | 20 February 2024
Climate Science Centre | CSIRO Environment

Who we are

Australia’s national science agency

One of the world’s largest multidisciplinary science and technology organisations

6,300+ dedicated people working across 51 sites in Australia and globally

State-of-the-art national research infrastructure

As a statutory agency, legislated to support Australia’s obligations under the Paris Agreement.

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CSIRO Climate Science Centre (CSC)

CSC is part of CSIRO's Environment Business Unit.

World-leading capabilities in ocean, atmosphere and climate science

Australia's national capability in observing and modelling our earth system

Providing our neighbours with climate intelligence to inform a more sustainable and resilient future.

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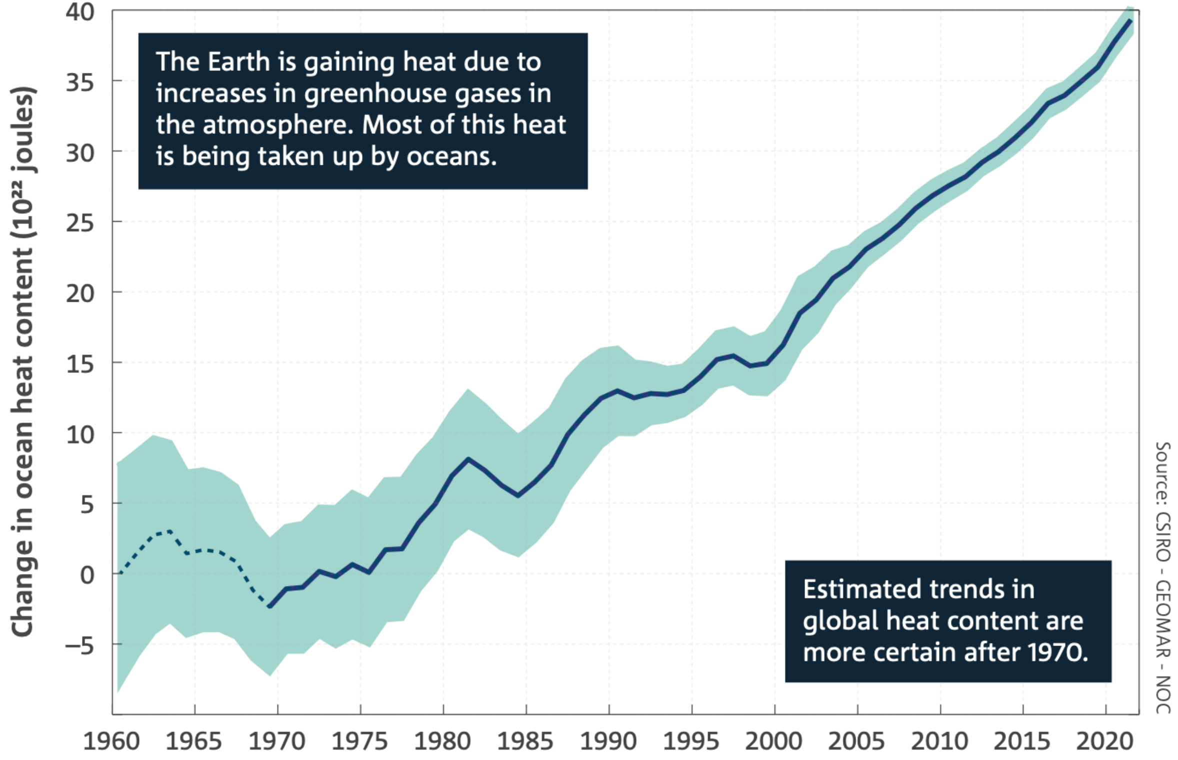
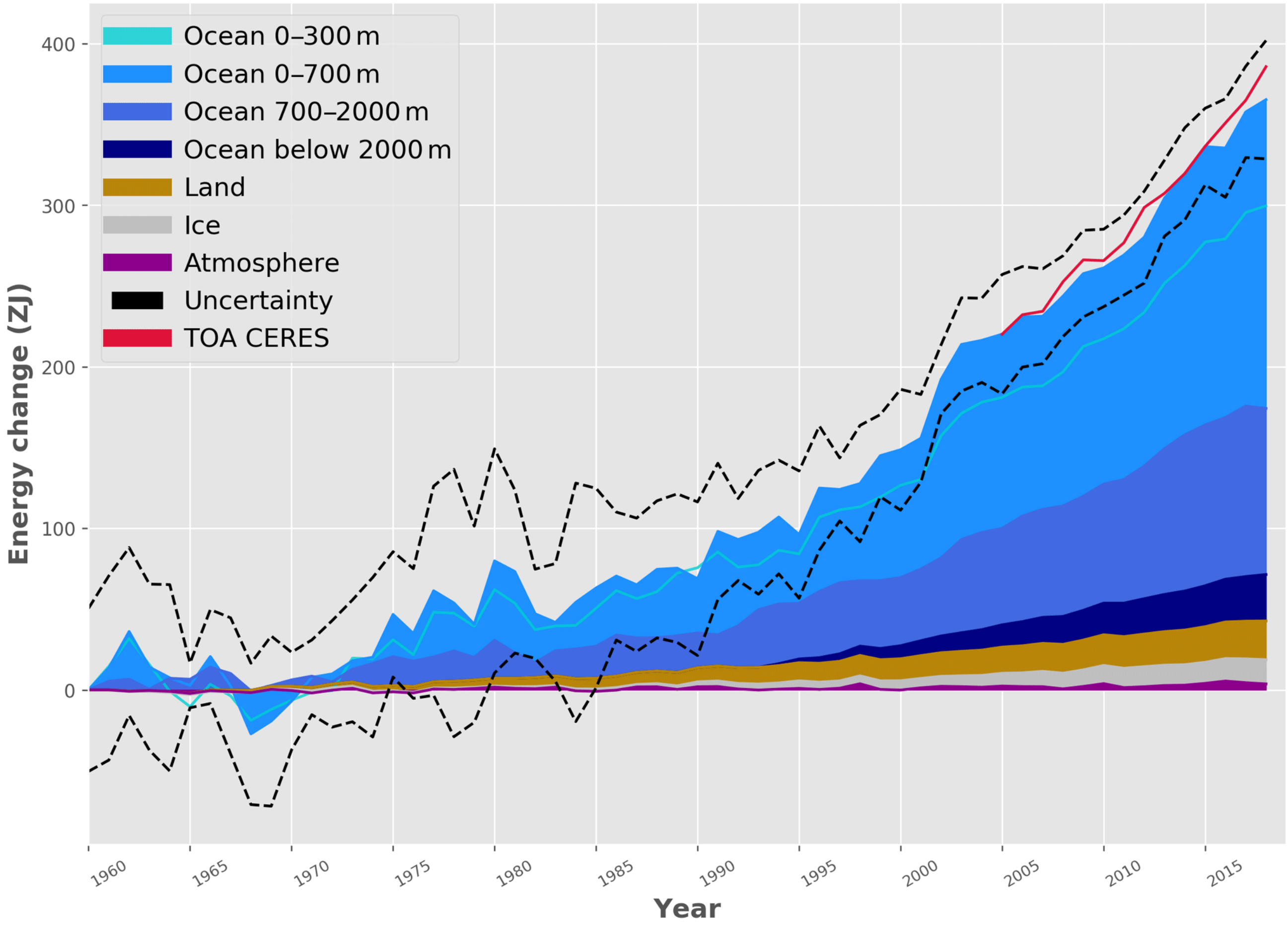
Global warming is primarily stored in the ocean

The world's oceans have taken up 91 per cent of the extra energy stored by the planet as a result of enhanced greenhouse gas concentrations.

- CSIRO/BOM State of the Climate (2022)



Estimated change in ocean heat content globally averaged over the full ocean depth, from 1960–2021. Shading provides an indication of the confidence range of the estimates. The measurements contributing to the early part of the record, before 1970, are sparse and trends estimated over this period are small compared to the confidence range and hence are considered less reliable. Source: CSIRO, GEOMAR (Germany) and National Oceanographic Centre (UK)



von Schuckmann, K., Cheng, L., Palmer, M. D., Hansen, J., Tassone, C., Aich, V., Adusumilli, S., Beltrami, H., Boyer, T., Cuesta-Valero, F. J., Desbruyères, D., Domingues, C., García-García, A., Gentine, P., Gilson, J., Gorfer, M., Haimberger, L., Ishii, M., Johnson, G. C., Killick, R., King, B. A., Kirchengast, G., Kolodziejczyk, N., Lyman, J., Marzeion, B., Mayer, M., Monier, M., Monselesan, D. P., Purkey, S., Roemmich, D., Schweiger, A., Seneviratne, S. I., Shepherd, A., Slater, D. A., Steiner, A. K., Straneo, F., Timmermans, M.-L., and Wijffels, S. E.: **Heat stored in the Earth system: where does the energy go**?, Earth Syst. Sci. Data, 12, 2013–2041, https://doi.org/10.5194/essd-12-2013-2020, 2020.

Table 2.1: Assessment of observed changes in large-scale indicators of mean climate across climate system components, and their attribution to human influence. The colour coding indicates the assessed confidence in / likelihood[76] of the observed change and the human contribution as a driver or main driver (specified in that case) where available (see colour key). Otherwise, explanatory text is provided. {*WGI Table TS.1*}

Change in indicator		Observed change assessment	Human contribution assessment
Atmosphere and water cycle	Warming of global mean surface air temperature since 1850-1900		*likely* range of human contribution ([0.8-1.3°C]) encompasses the very likely range of observed warming ([0.9-1.2°C])
	Warming of the troposphere since 1979		Main driver
	Cooling of the lower stratosphere since the mid-20th century		Main driver 1979 - mid-1990s
	Large-scale precipitation and upper troposphere humidity changes since 1979		
	Expansion of the zonal mean Hadley Circulation since the 1980s		Southern Hemisphere
Ocean	Ocean heat content increase since the 1970s		Main driver
Synthesis	Warming of the global climate system since preindustrial times		

Key: *medium confidence* · *likely / high confidence* · *very likely* · *extremely likely* · *virtually certain* · fact

IPCC, 2023: Sections. In: *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 35-115, doi: 10.59327/IPCC/AR6-9789291691647

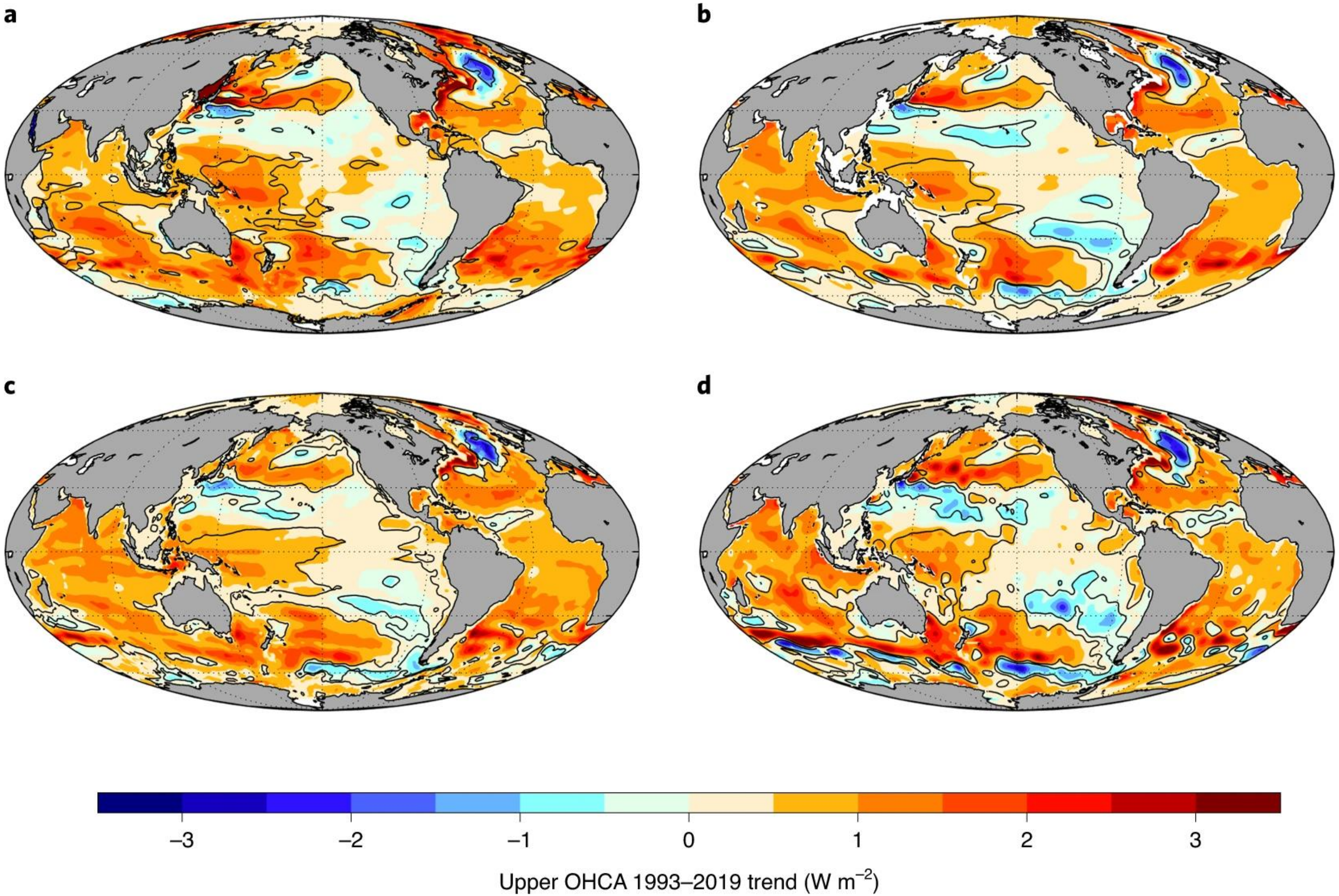
The ocean does not warm evenly. Some regions are warming several times faster than the global mean.

Regionally, ocean warming can vary substantially from year to year due to climate phenomena such as ENSO.

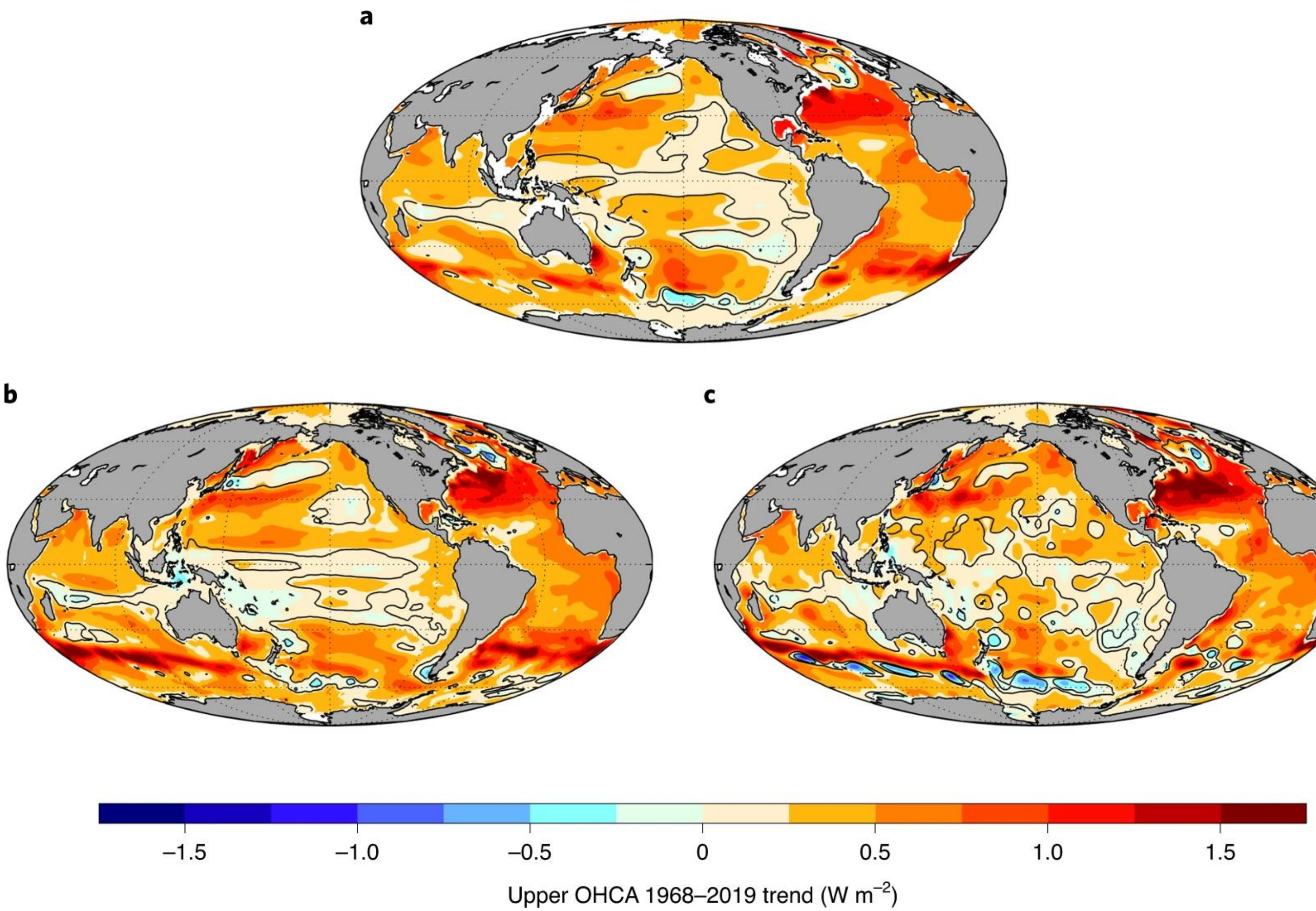
- CSIRO/BOM State of the Climate (2022)

The rate at which the oceans are taking up heat has increased over recent decades.

- CSIRO/BOM State of the Climate (2022)



Warming trends increasingly dominate global ocean – Johnson & Lyman 2020 - Nature CLimate Change | VOL 10 | Aug 2020 | 757–761 |



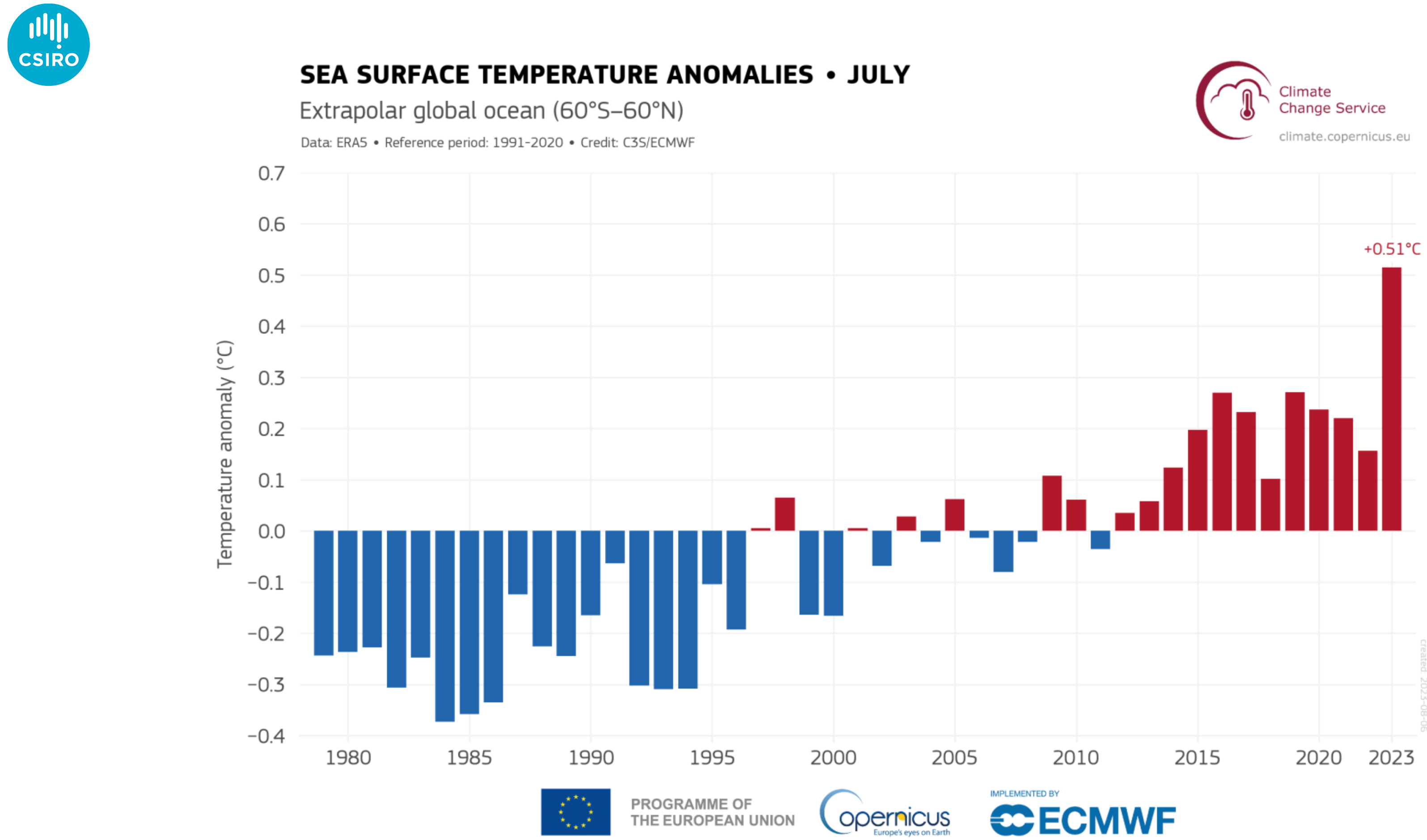
Warming trends increasingly dominate global ocean – Johnson & Lyman 2020 - Nature CLimate Change | VOL 10 | Aug 2020 | 757–761 |

The global ocean heat content, measured from the ocean's surface to a depth of 2,000 meters, continued to increase and reached new record highs in 2022.

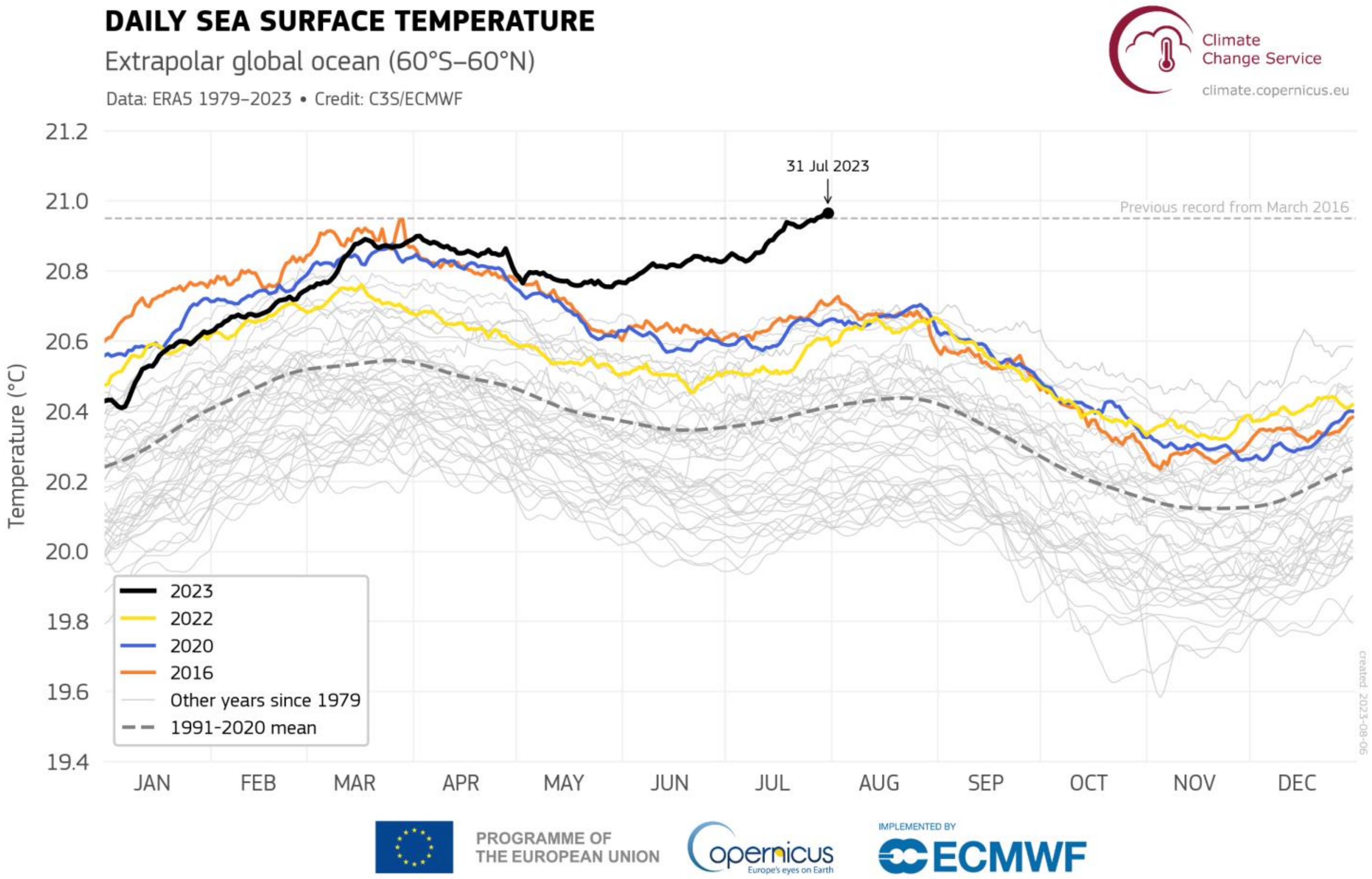
- NOAA State of the Climate in 2022

Average sea surface temperature in the Australian region has warmed by 1.05 °C since 1900, with eight of the 10 warmest years on record occurring since 2010.

- CSIRO / BOM State of the Climate (2022)



Data source: ERA5. Credit: Copernicus Climate Change Service/ECMWF.



Data source: ERA5. Credit: Copernicus Climate Change Service/ECMWF.

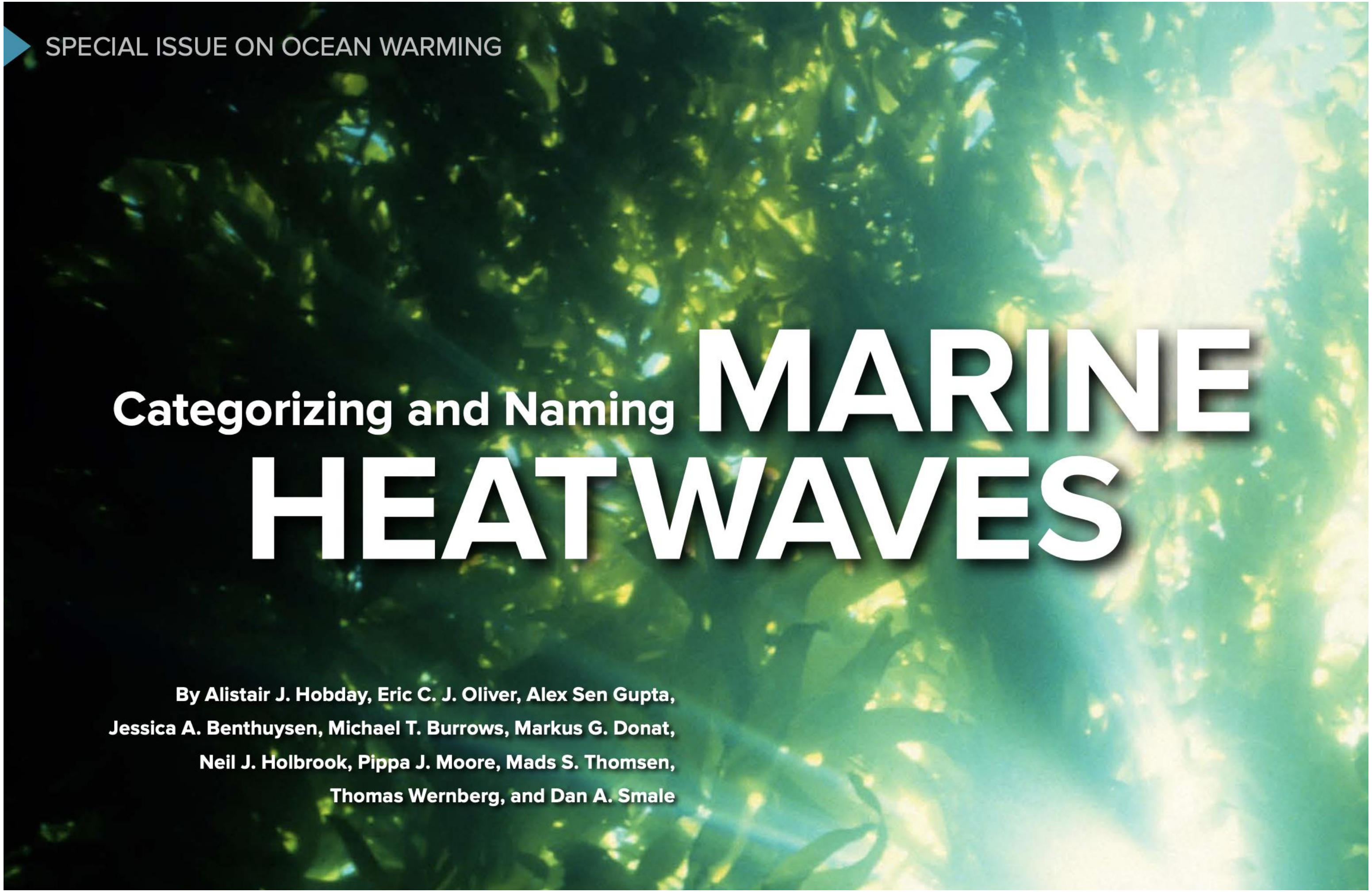
Warming of the ocean has contributed to longer and more frequent marine heatwaves. These have impacts on marine ecosystems, habitats, and species.

- CSIRO/BOM State of the Climate (2022)

Marine Heat Waves (MHW)

Marine heatwaves are periods when ocean temperatures are in the upper range of historical baseline conditions for at least five days.

- CSIRO/BOM State of the Climate (2022)



Hobday, A.J., E.C.J. Oliver, A. Sen Gupta, J.A. Benthuysen, M.T. Burrows, M.G. Donat, N.J. Holbrook, P.J. Moore, M.S. Thomsen, T. Wernberg, and D.A. Smale. 2018. Categorizing and naming marine heatwaves. Oceanography 31(2):162–173, https://doi.org/10.5670/oceanog.2018.205.

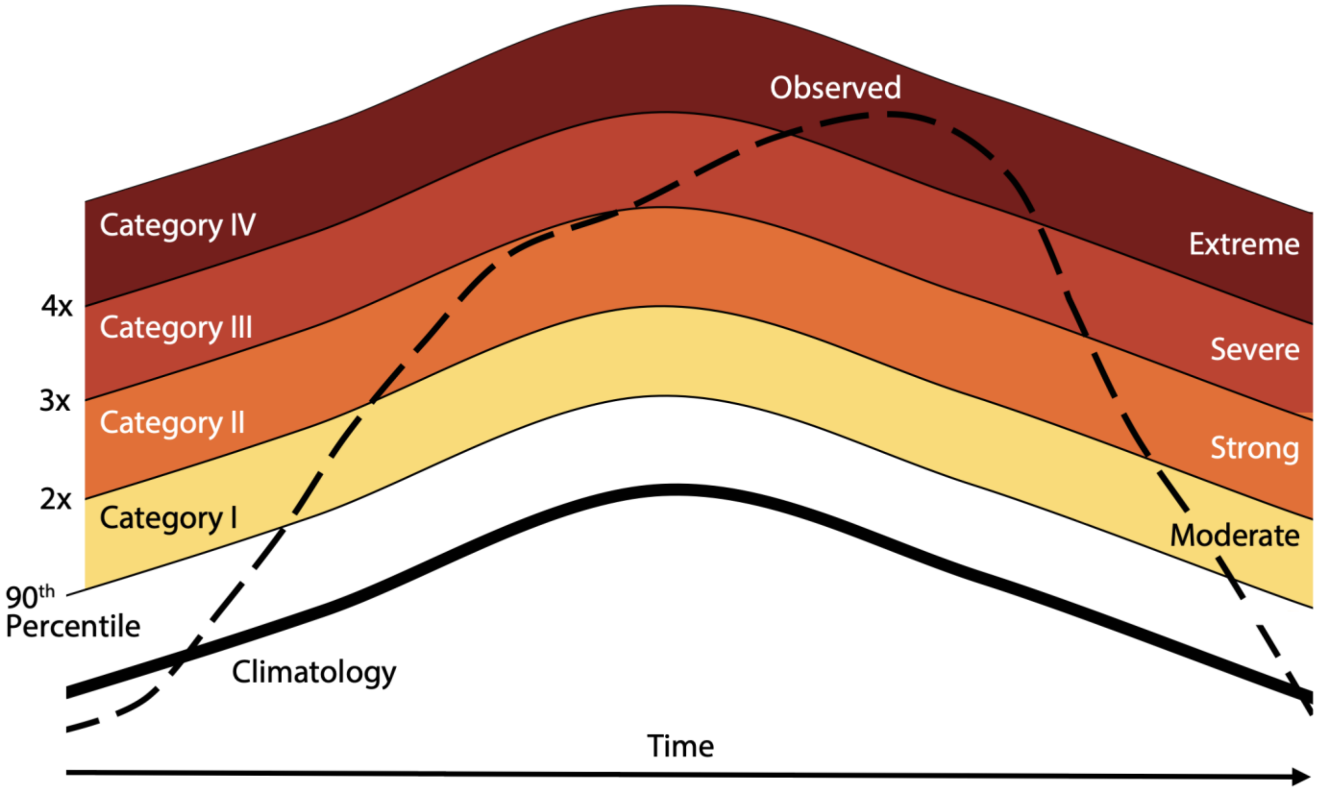
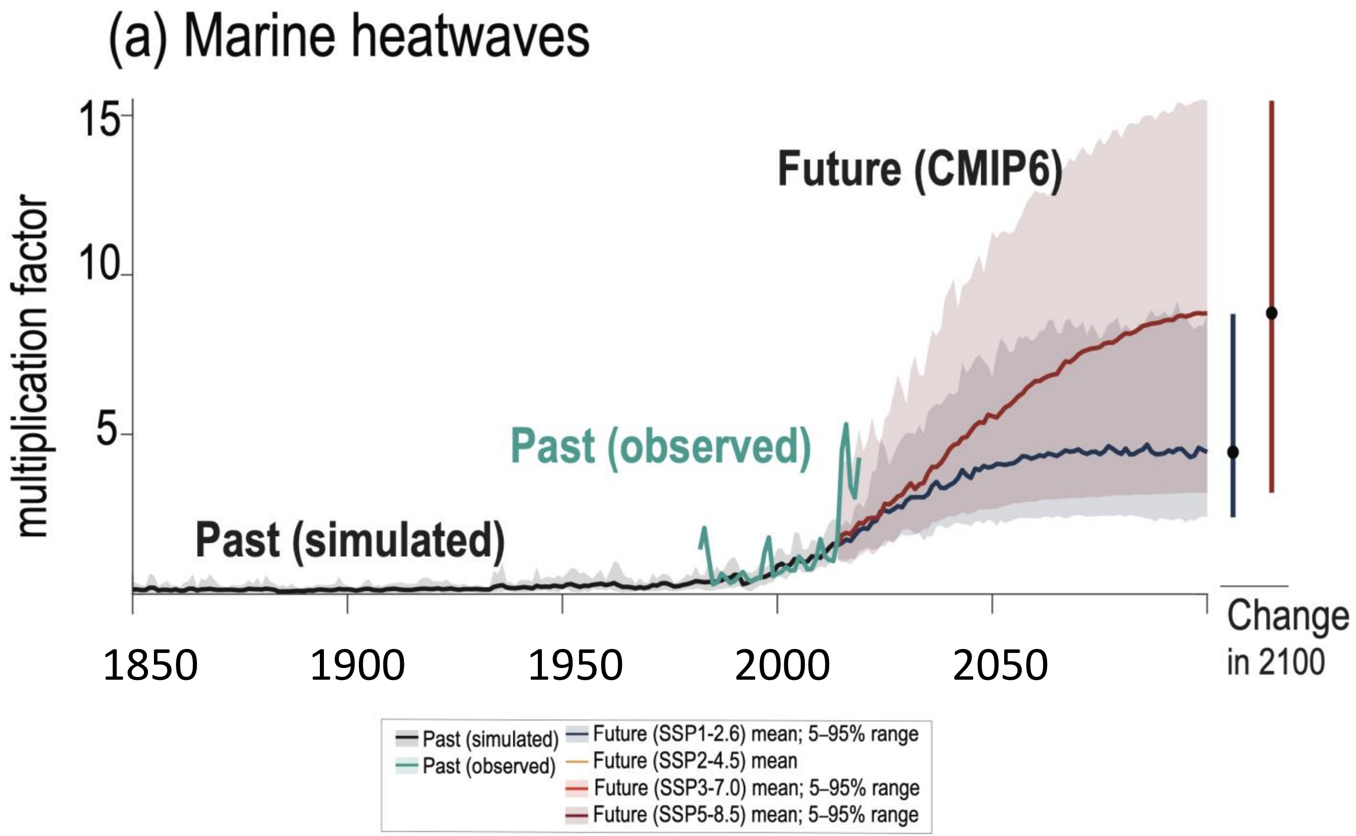


FIGURE 2. Categorization schematic for marine heatwaves (MHWs) showing the observed temperature time series (dashed line), the long-term regional climatology (bold line), and the 90th percentile climatology (thin line). Multiples of the 90th percentile difference (2× twice, 3× three times, etc.) from the mean climatology value define each of the categories I–IV, with corresponding descriptors from moderate to extreme. This example peaked as a Category IV (extreme) MHW.

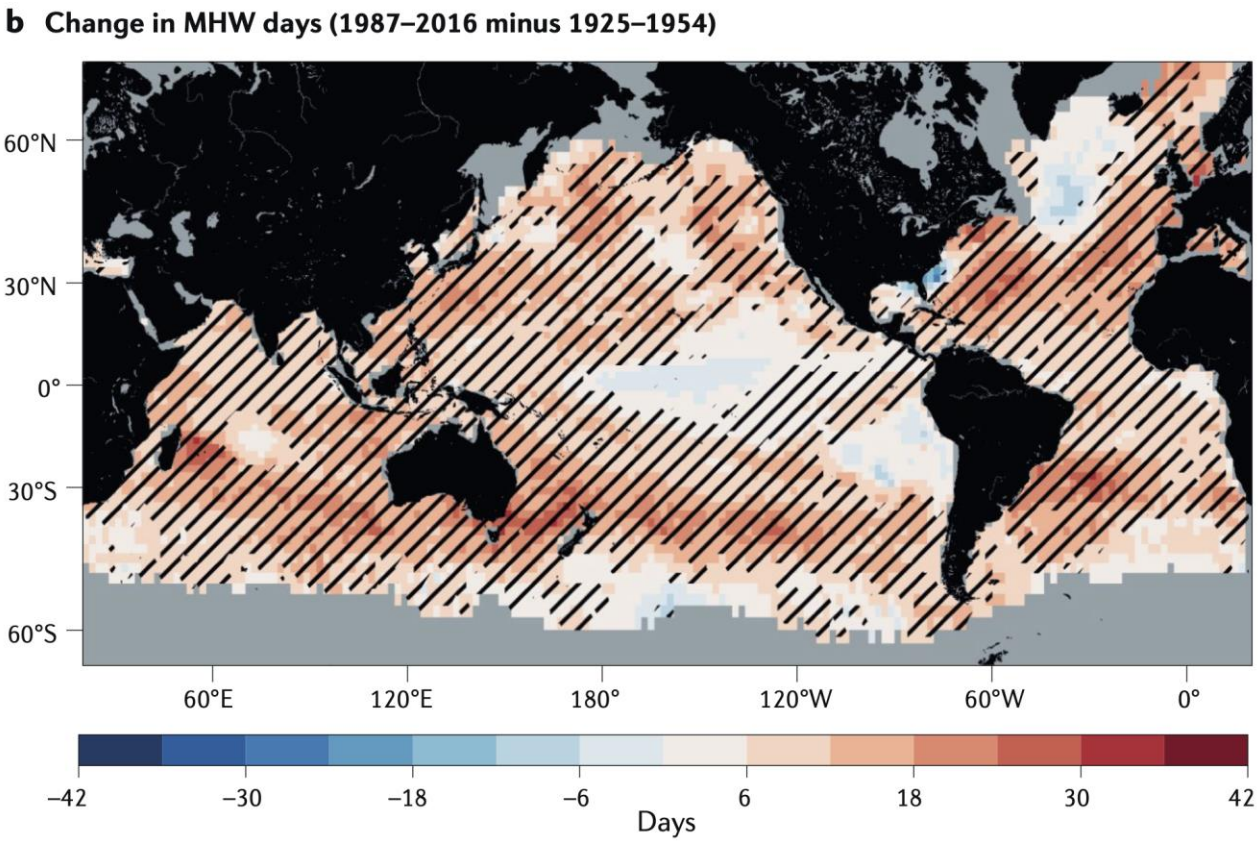
Climate models project more frequent, extensive, intense and longer-lasting marine heatwaves in the future.

The intensification of marine heatwaves is much greater under high greenhouse gas emission scenarios.

- CSIRO / BOM State of the Climate (2022)

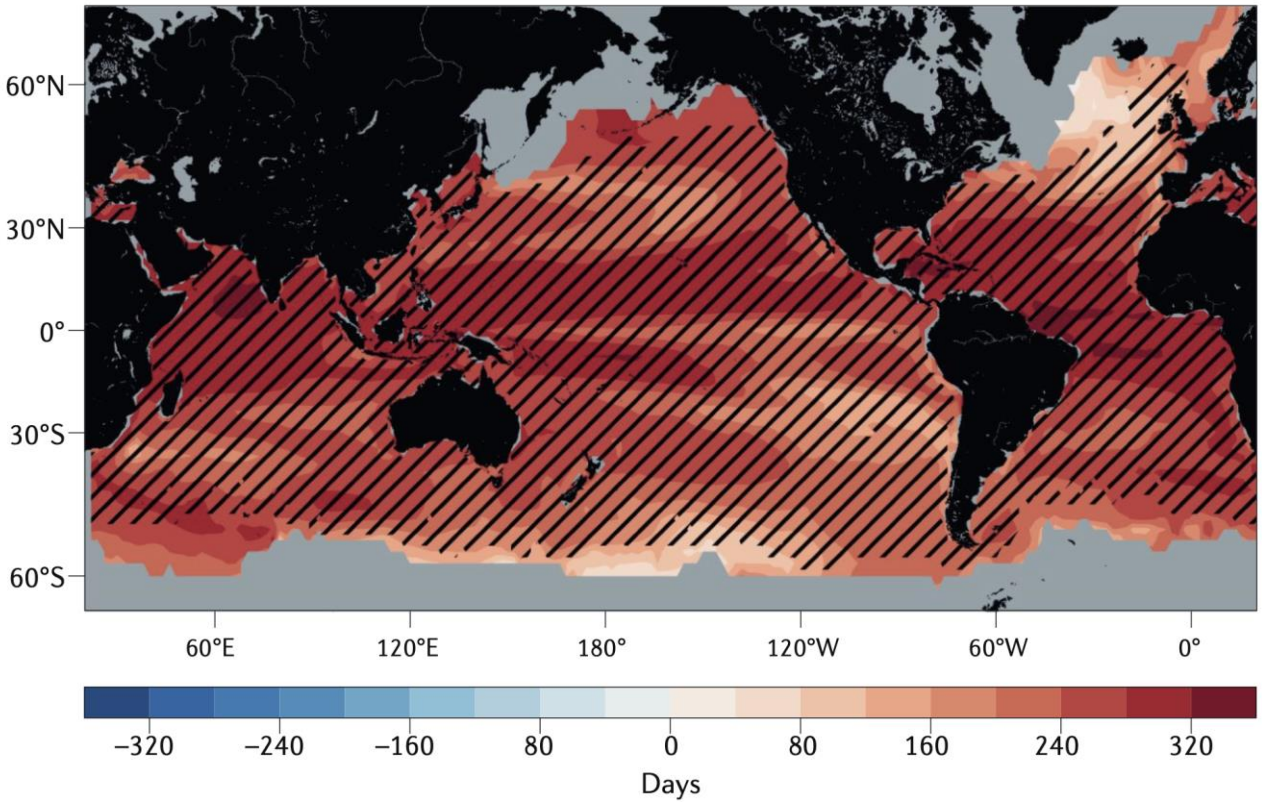


IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391 pp. doi:10.1017/9781009157896.



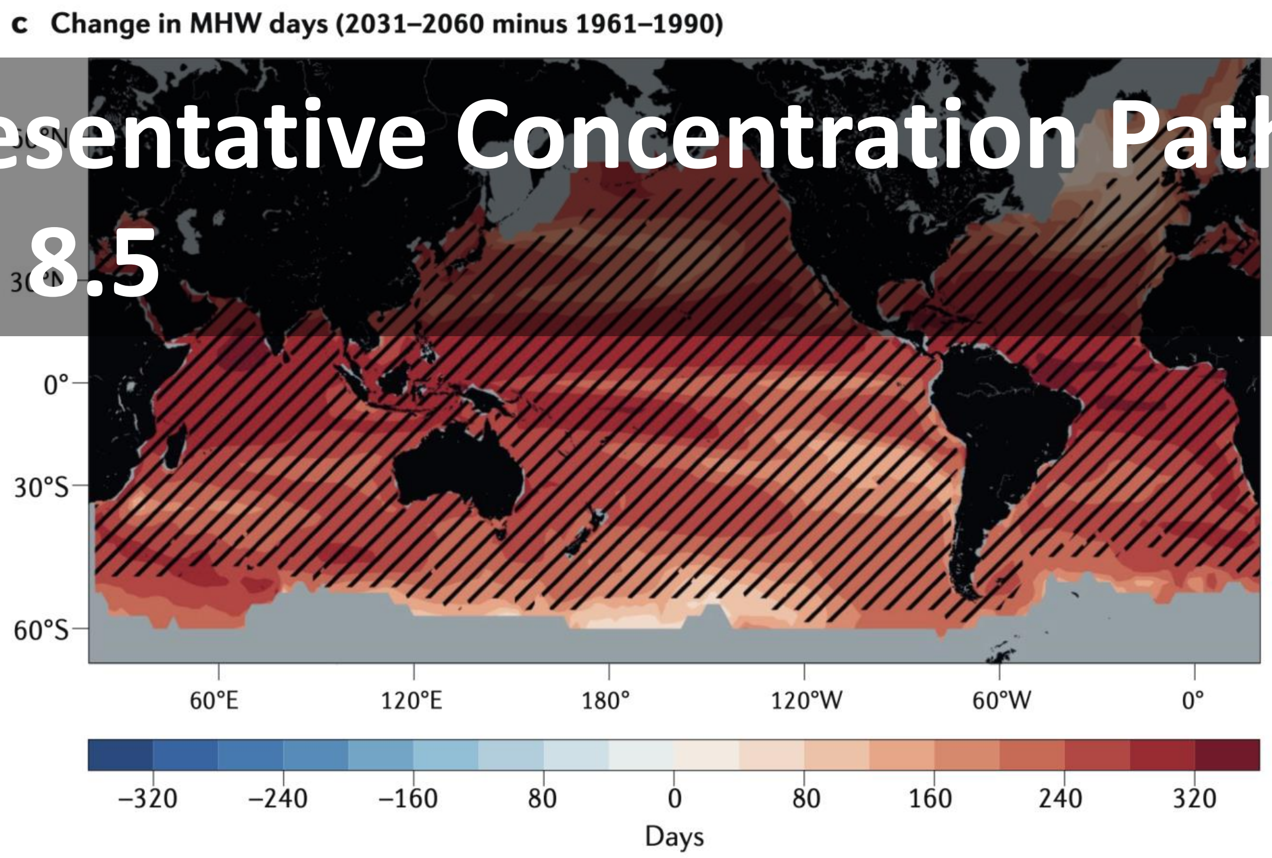
Keeping pace with marine heatwaves – Holbrook et al 2020 - Nature Reviews Earth & Environment

c Change in MHW days (2031–2060 minus 1961–1990)



Keeping pace with marine heatwaves – Holbrook et al 2020 - Nature Reviews Earth & Environment

Representative Concentration Pathway (RCP) 8.5



Keeping pace with marine heatwaves – Holbrook et al 2020 - Nature Reviews Earth & Environment

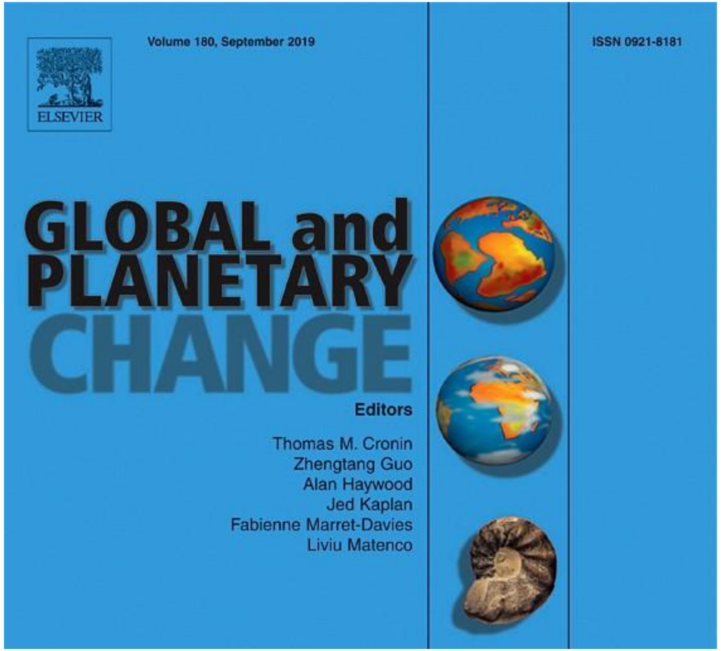
AS OCEANS WARM, MARINE COLD SPELLS ARE DISAPPEARING

- Marine cold spells are cold versions of heat waves: periods of exceptionally cold water, able to hurt or help the ecosystems they hit.
- Recent studies have shown that as the atmosphere and oceans warm, marine cold spells are becoming less intense and less frequent overall.

Understanding the Changing Nature of Marine Cold-Spells (Wang et al 2022) & AGU (2022) - https://news.agu.org/press-release/as-oceans-warm-marine-cold-spells-are-disappearing/

What does this mean for Pacific Community?

“Impacts of marine heatwaves on tropical western and central Pacific Island nations and their communities”



Neil J. Holbrook [a b], Vanessa Hernaman [c], Shirley Koshiba [d], Jimaima Lako [e], Jules B. Kajtar [a b], Patila Amosa [f], Awnesh Singh [g]

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[b] Australian Research Council Centre of Excellence for Climate Extremes, University of Tasmania, Hobart, Tasmania, Australia

[c] Climate Science Centre, CSIRO Oceans and Atmosphere, Aspendale, Victoria, Australia

[d] Palau International Coral Reef Center, Koror, Palau

[e] College of Engineering, Science and Technology, Fiji National University, Suva, Fiji

[f] Faculty of Science, The National University of Samoa, Apia, Samoa

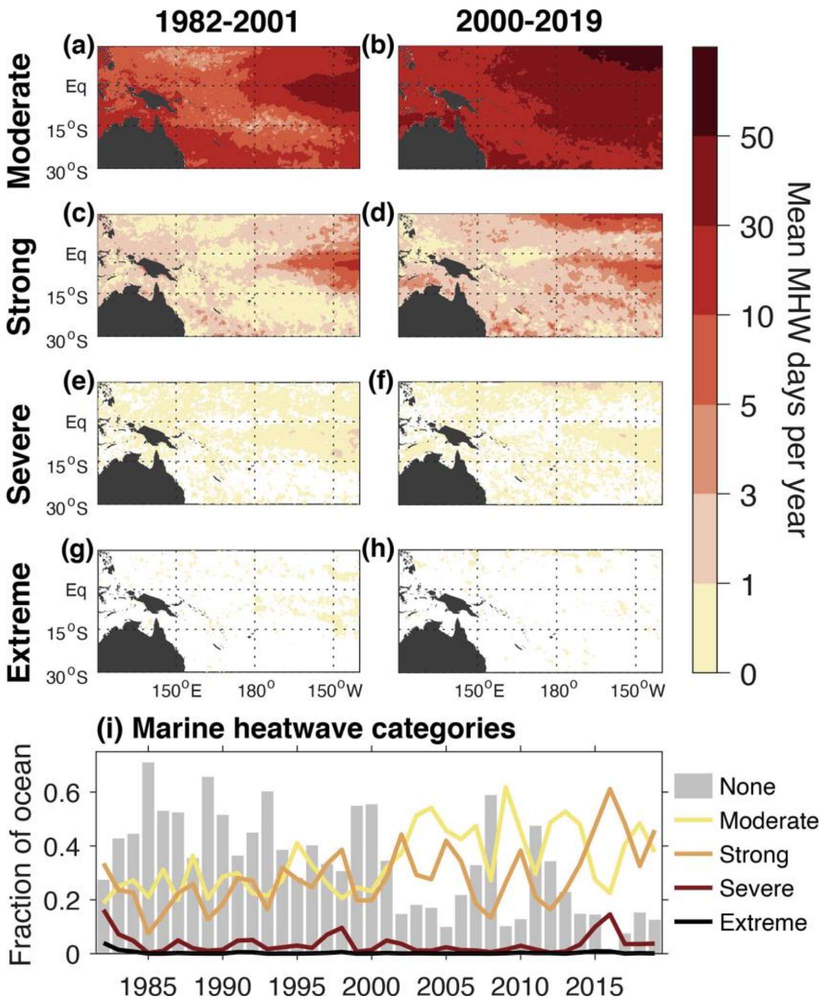
[g] Pacific Centre for Environmental and Sustainable Development, The University of the South Pacific, Suva, Fiji

Received 14 October 2020, Revised 13 July 2021, Accepted 13 October 2021, Available online 22 October 2021, Version of Record 15 November 2021.

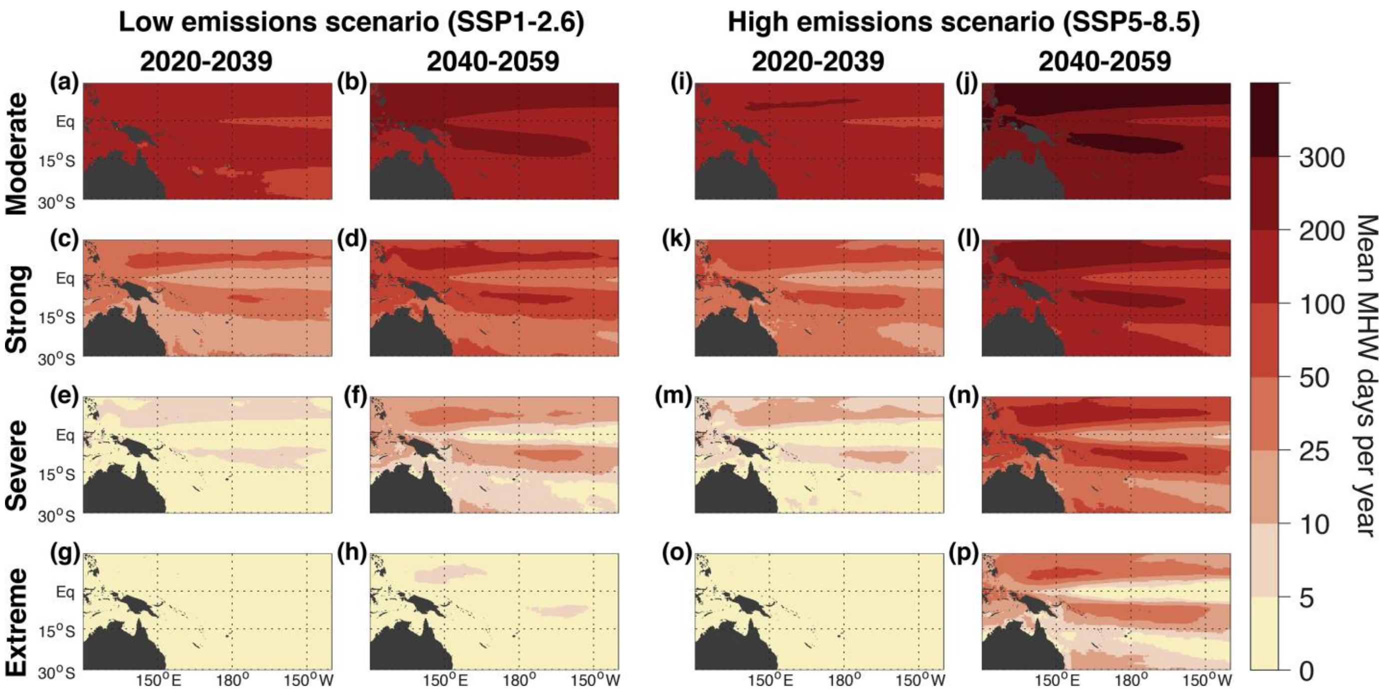
- MHW are already impacting Pacific Island communities.
- Projected increase in MHW metrics in tropical central-western Pacific.
- Poses threats to tropical central-western Pacific Island nation food security.

Observations:

a combination of observations
from different platforms (satellites, ships, buoys, and Argo floats)



Models of possible futures - SSP1-2.6 & SSP5-8.5



Model bias: completeness, correctness, & resolution

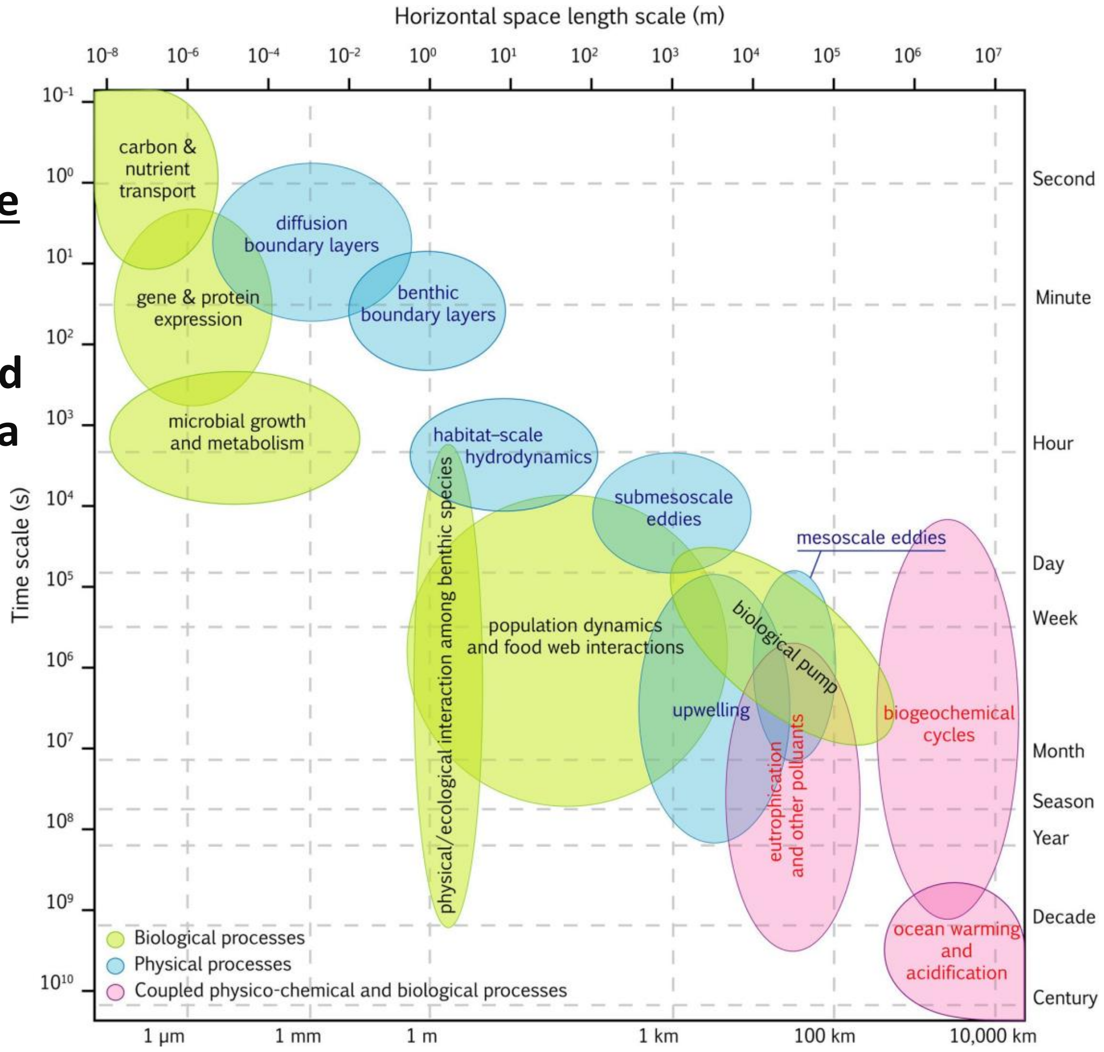
Ocean models simulate current movement and mixing, and biogeochemistry, vital since the ocean is the dominant reservoir of heat and carbon in the climate system. But models can have systematic errors (**bias**) between the simulations and the actual observations of ocean conditions. We can help address model bias through:

- **Completeness:** models may not include all relevant physical, chemical, or biological processes occurring in the ocean. The omission of these processes can lead to biases in the model outputs. For example, the effects of certain biogeochemical cycles, deep ocean currents, and ice sheets might be inadequately represented which can be improved.
- **Correctness:** For example, improving parametrizations such as those being used to represent very small-scale turbulence.
- **Resolution:** The spatial and temporal resolution of models can also lead to biases. Ocean models divide the ocean into a grid, and processes occurring at scales smaller than the grid size cannot be resolved. This can lead to inaccuracies in representing ocean currents, eddies, and other small-scale features.

GFDL – NOAA : https://www.gfdl.noaa.gov/climate-modeling/

Scale - time & space

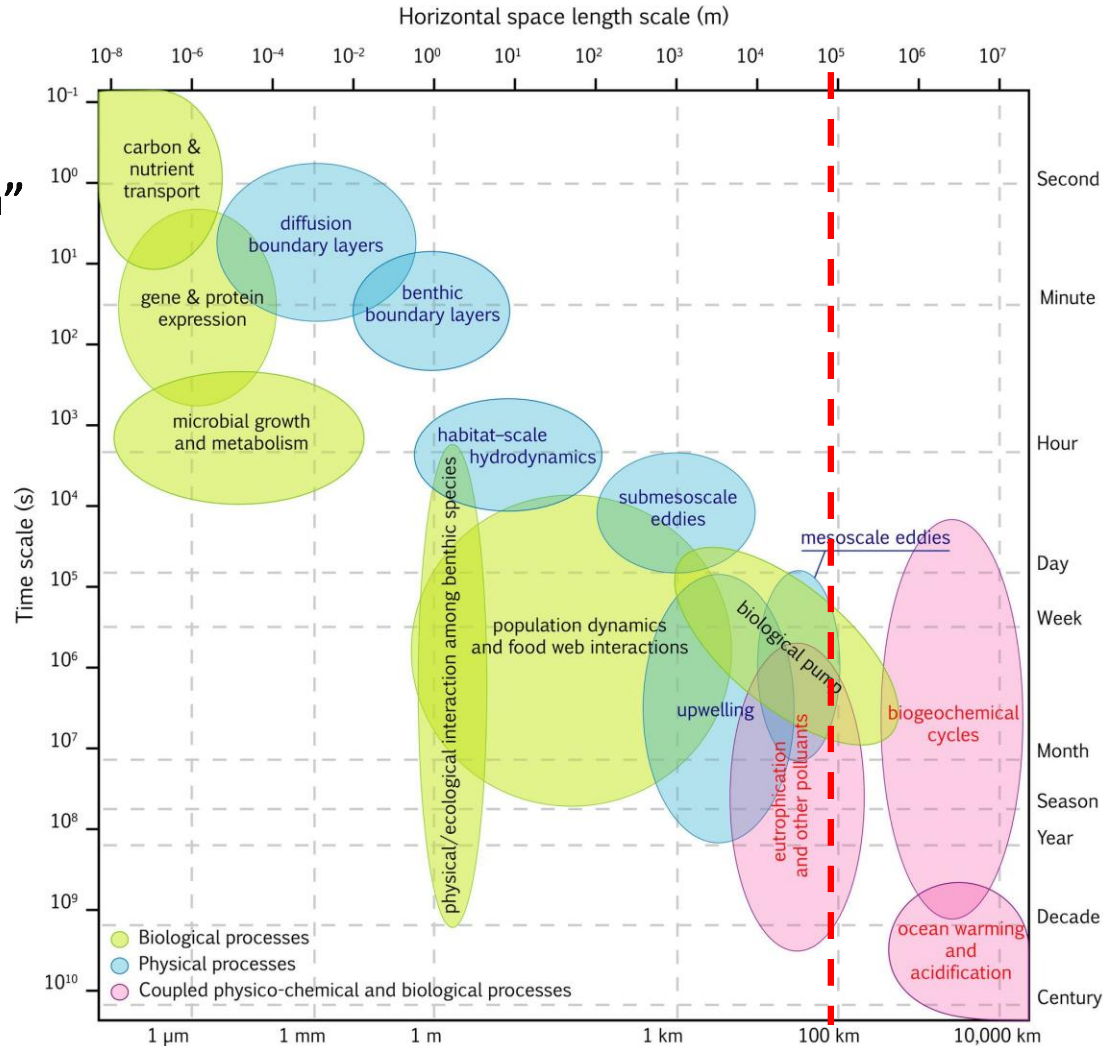
The multi-scale nature of connected ocean processes is a key concept.



"Parameterisation"

Simplified representations of very complex or small-scale processes in climate models.

For example: how heat is transferred in the ocean on small scales.



WHY?

The practical limits of computational resources

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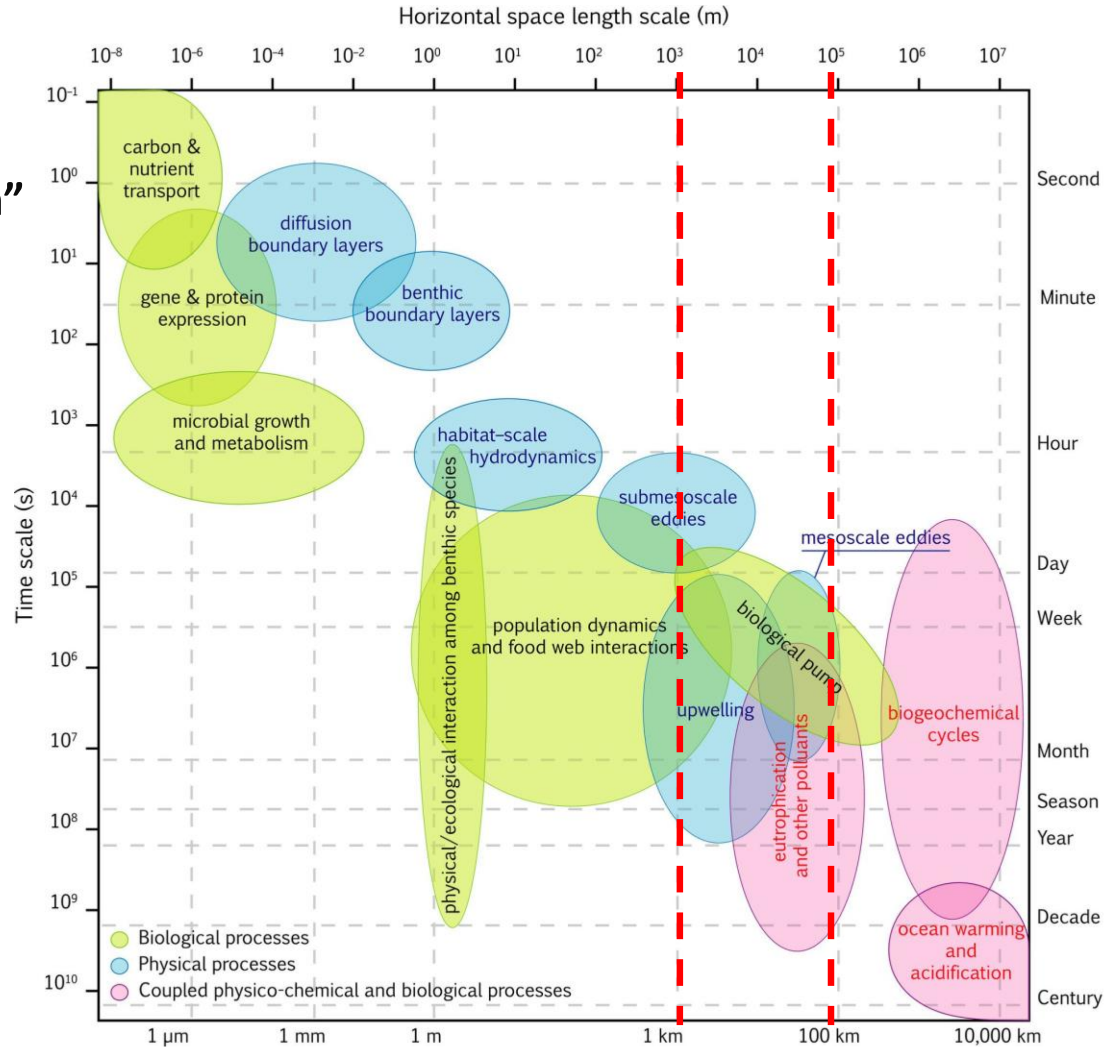

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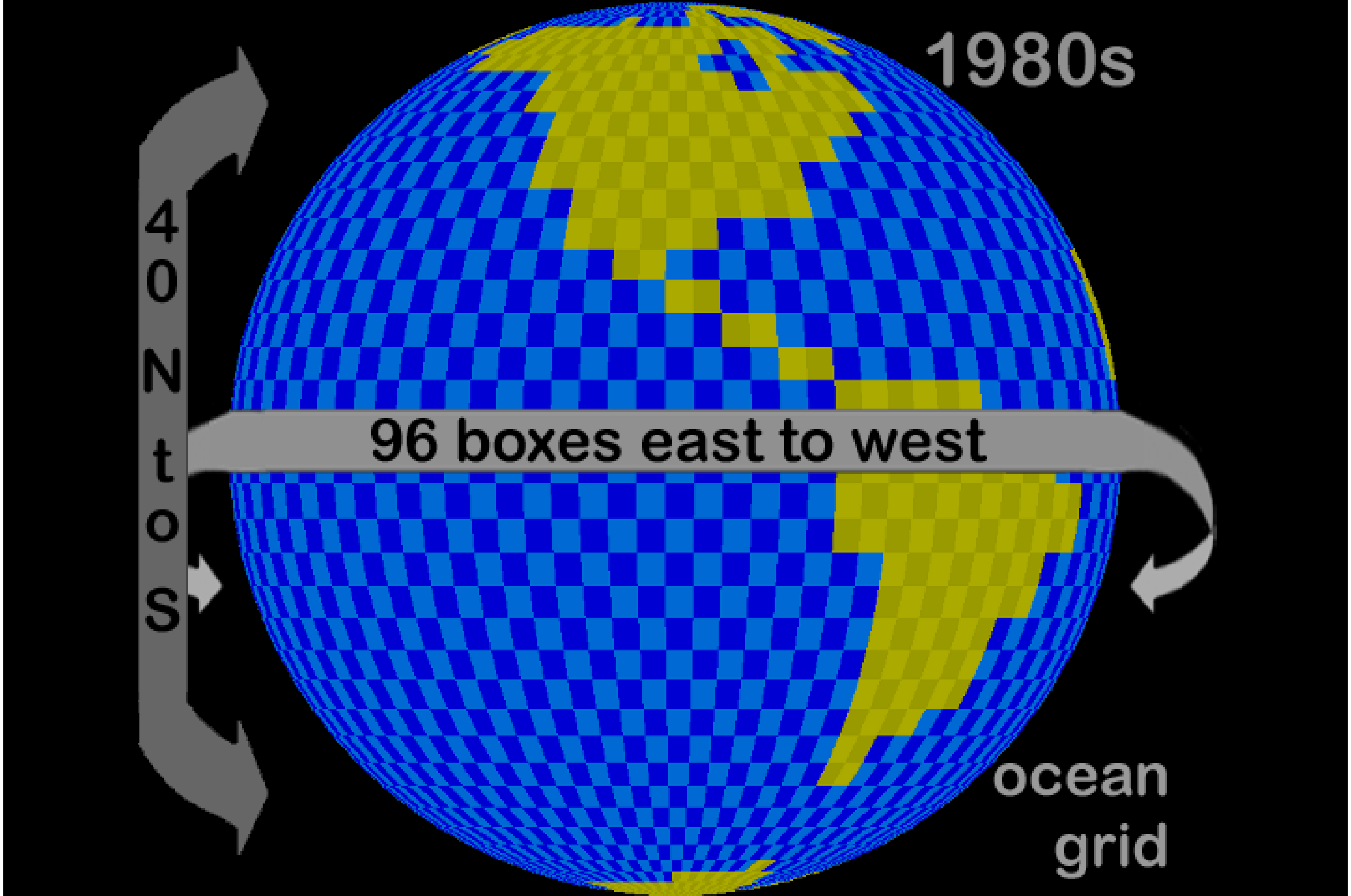
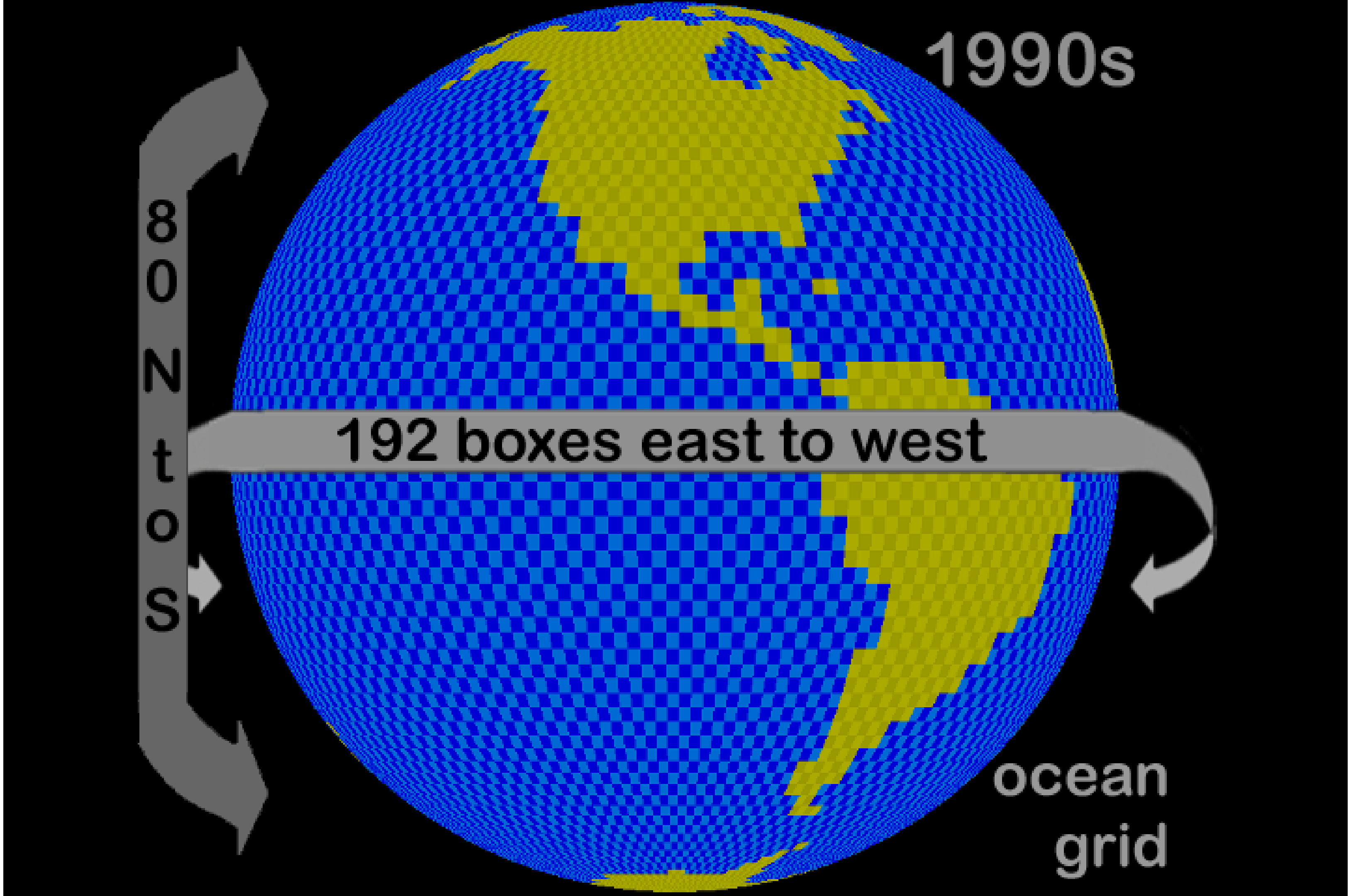
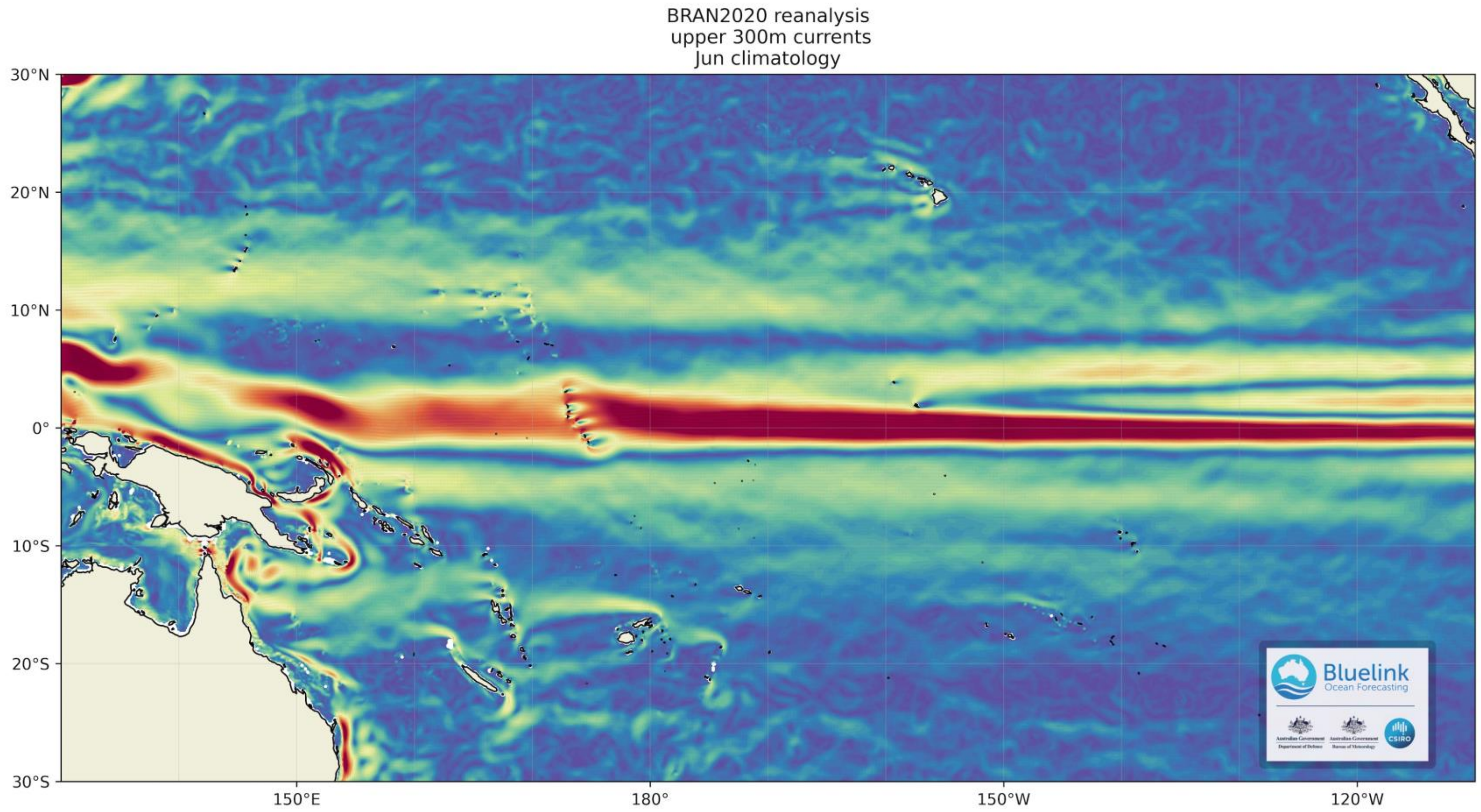
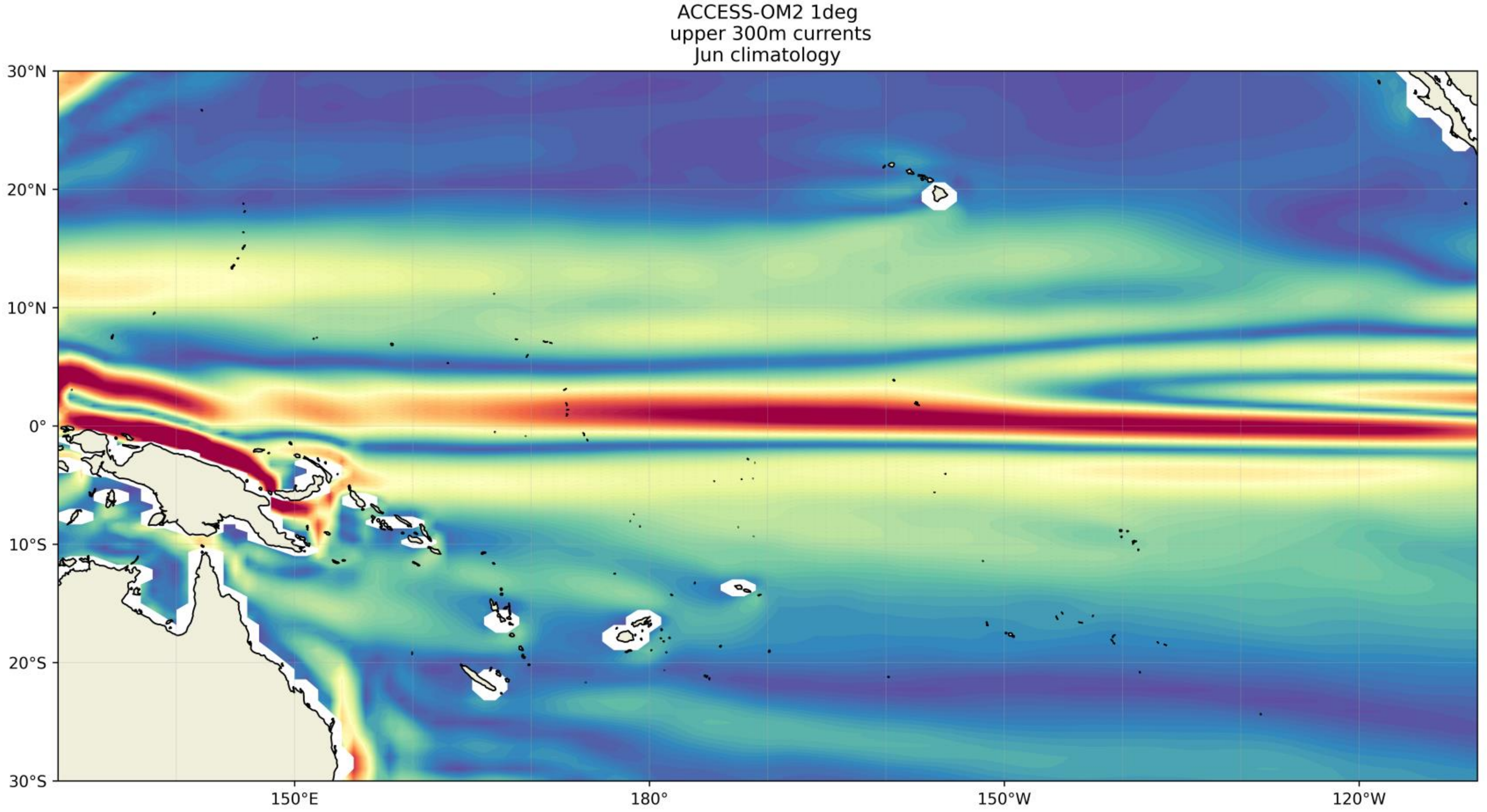

1980s
40 N to S
96 boxes east to west
ocean grid

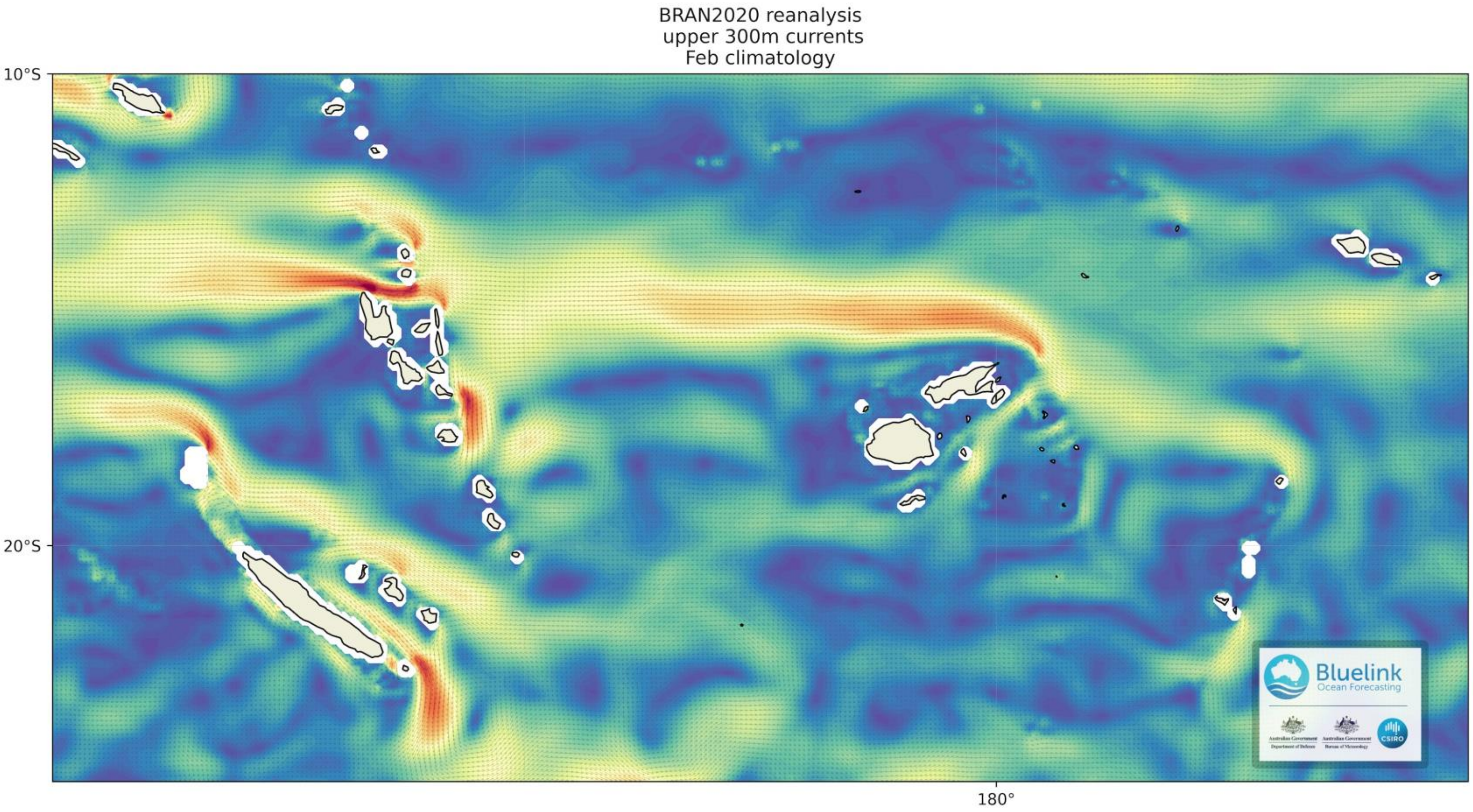

1990s
80 N to S
192 boxes east to west
ocean
grid


2004
200 N to S
360 boxes east to west
ocean grid

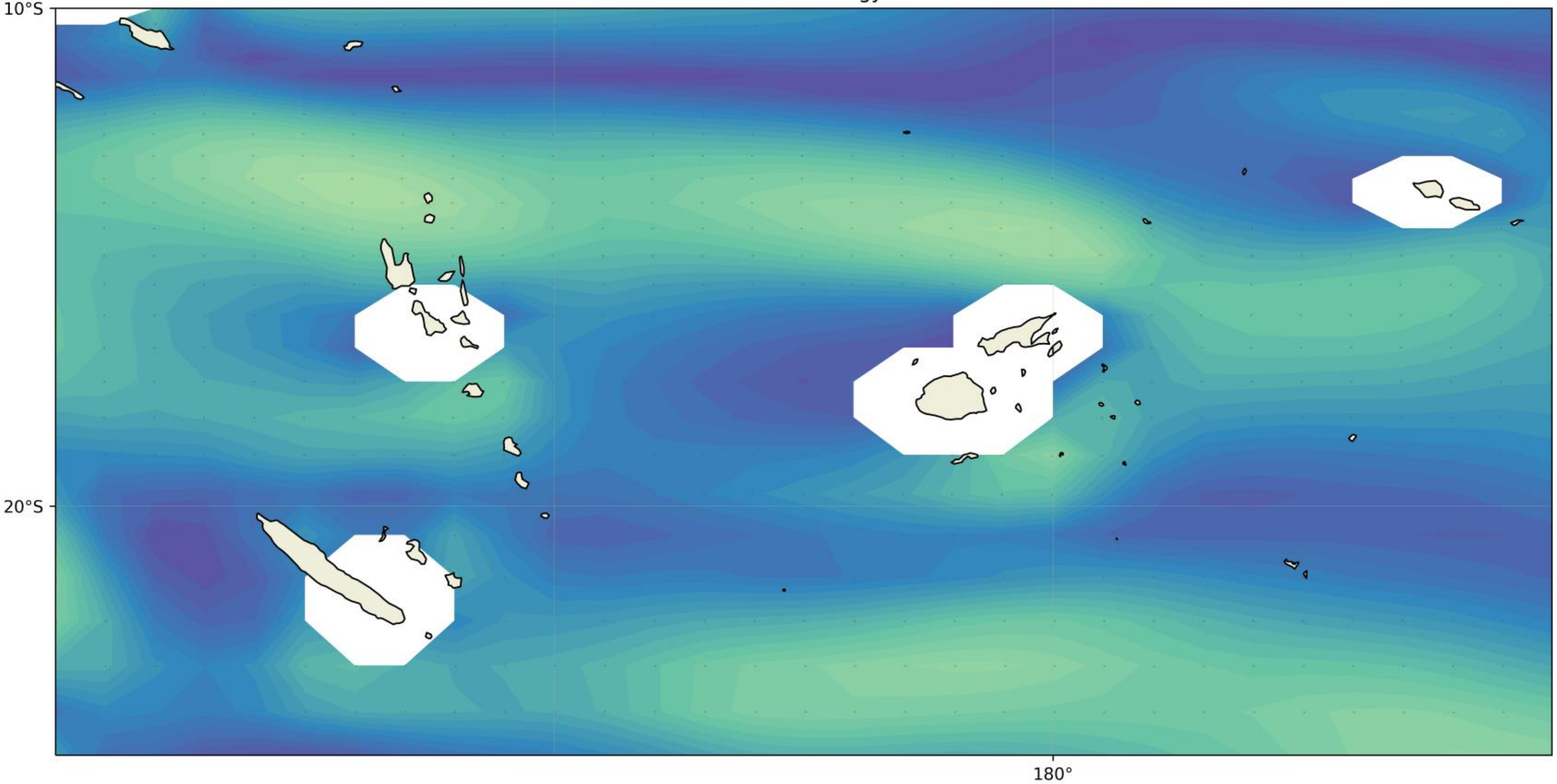

2009
1070 N to S
1440 boxes east to west
ocean
grid


BRAN2020 reanalysis
upper 300m currents
Jun climatology
30°N
20°N
10°N
0°
10°S
20°S
30°S
150°E
180°
150°W
120°W
Bluelink
Ocean Forecasting


ACCESS-OM2 1deg
upper 300m currents
Jun climatology
30°N
20°N
10°N
0°
10°S
20°S
30°S
150°E
180°
150°W
120°W

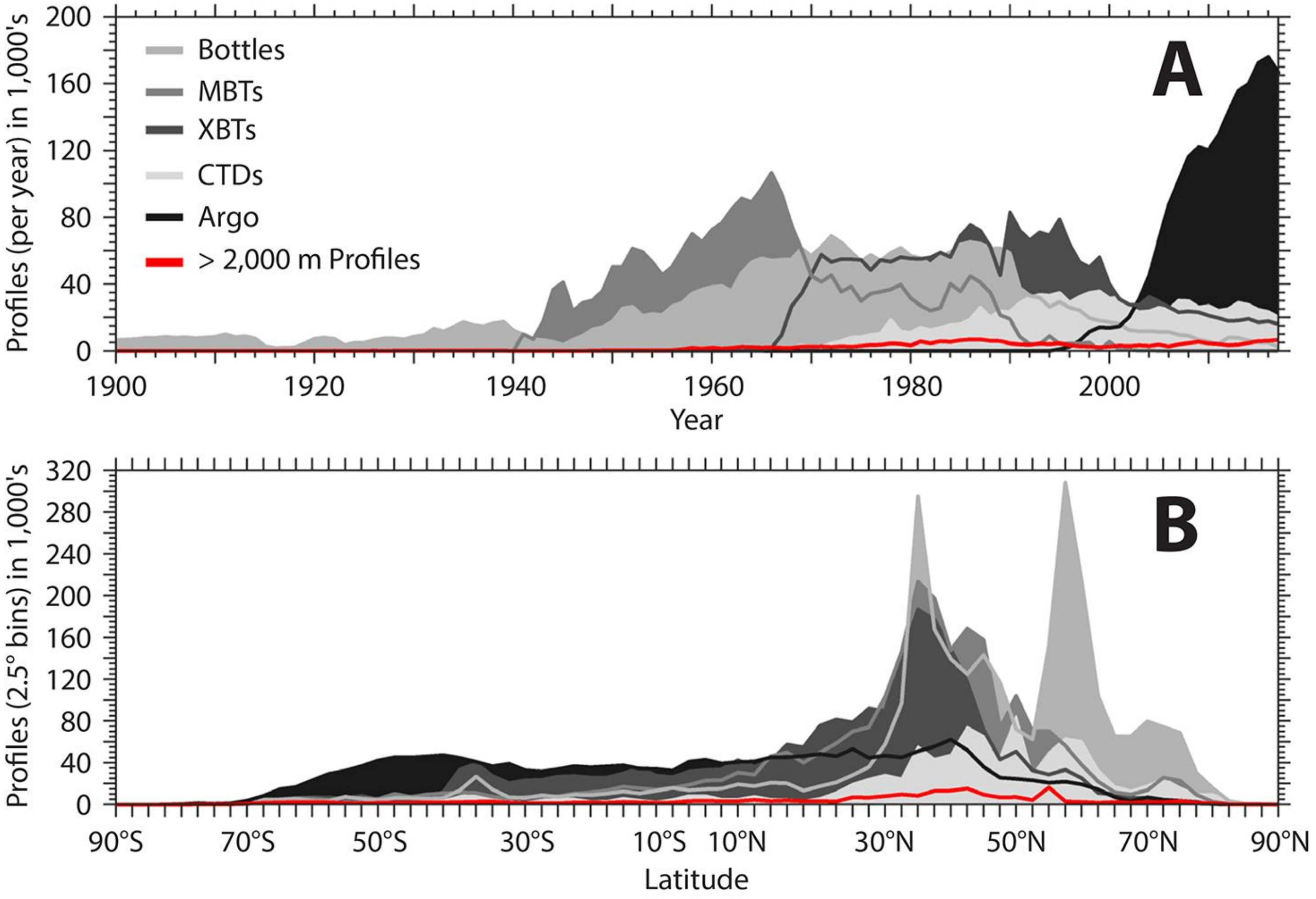

BRAN2020 reanalysis
upper 300m currents
Feb climatology
10°S
20°S
180°
Bluelink
Ocean Forecasting

ACCESS-OM2 1deg
upper 300m currents
Feb climatology

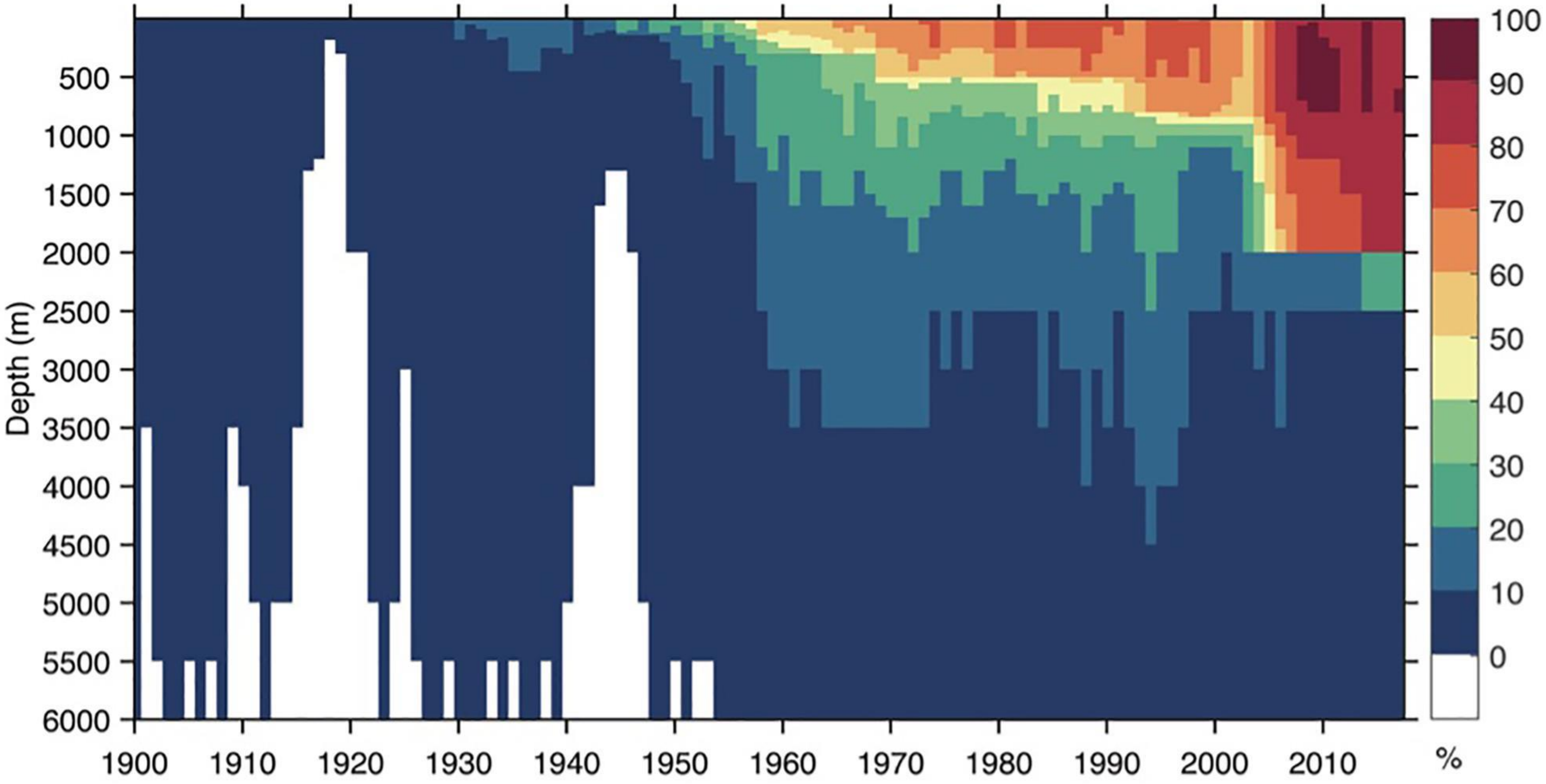


Limitations:

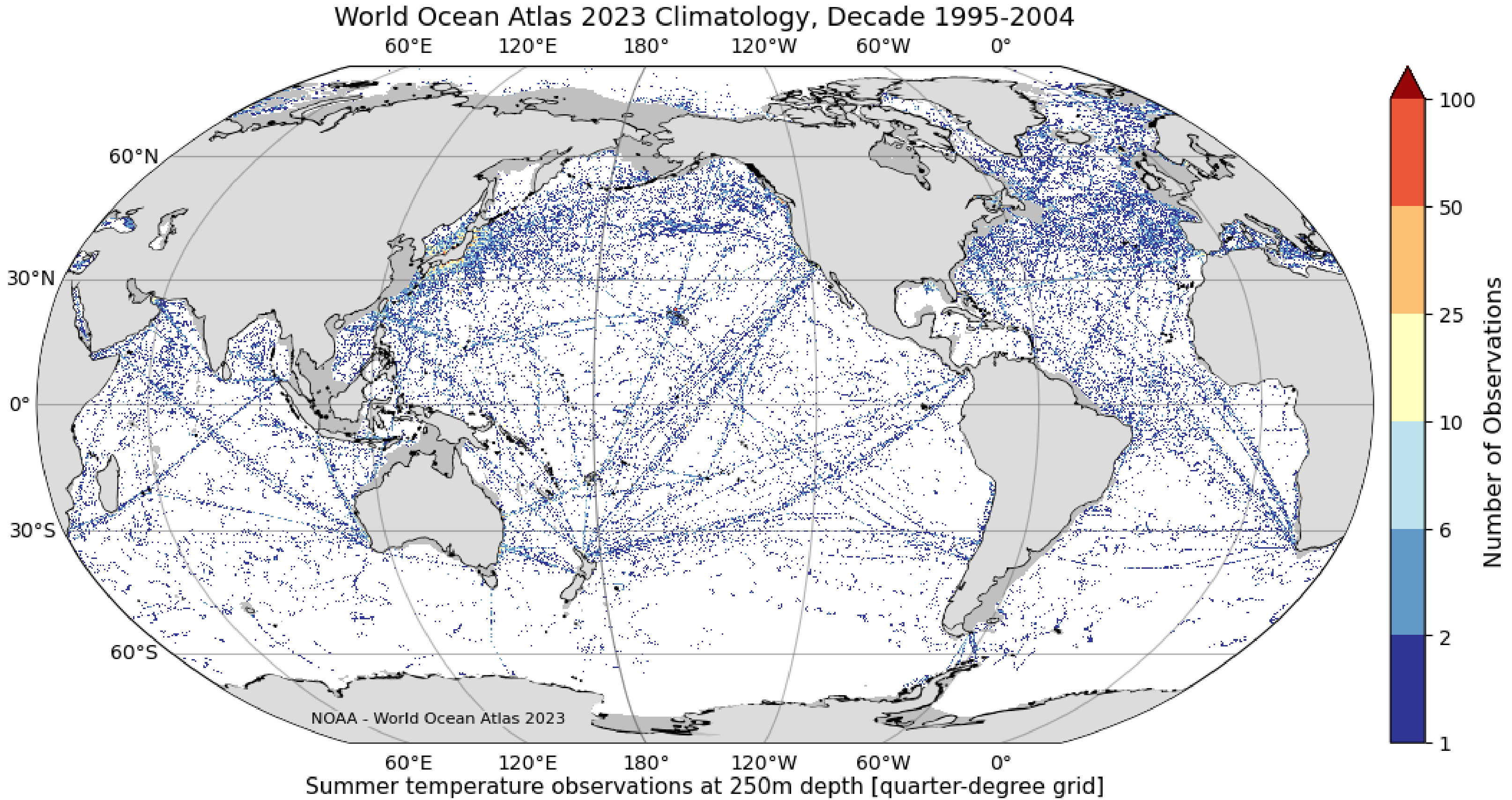
Gaps in observation of ocean "truth"

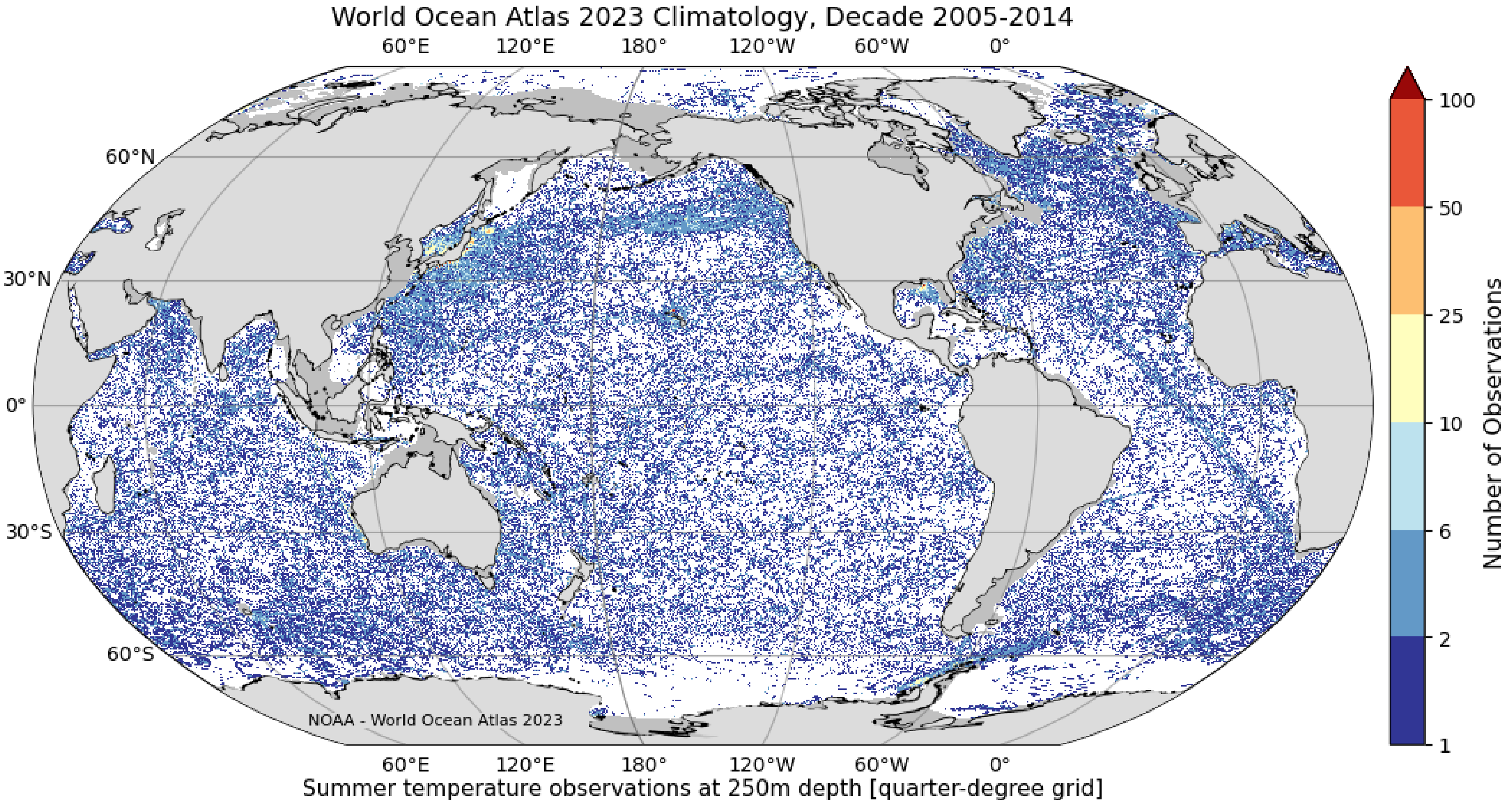


Durack, P.J., P.J. Gleckler, S.G. Purkey, G.C. Johnson, J.M. Lyman, and T.P. Boyer. 2018. Ocean warming: From the surface to the deep in observations and models. *Oceanography* 31(2):41–51, https://doi.org/10.5670/oceanog.2018.227



Meyssignac B, Boyer T, Zhao Z, Hakuba MZ, Landerer FW, Stammer D, Köhl A, Kato S, L'Ecuyer T, Ablain M, Abraham JP, Blazquez A, Cazenave A, Church JA, Cowley R, Cheng L, Domingues CM, Giglio D, Gouretski V, Ishii M, Johnson GC, Killick RE, Legler D, Llovel W, Lyman J, Palmer MD, Piotrowicz S, Purkey SG, Roemmich D, Roca R, Savita A, von Schuckmann K, Speich S, Stephens G, Wang G, Wijffels SE and Zilberman N **(2019) Measuring Global Ocean Heat Content to Estimate the Earth Energy Imbalance**. *Front. Mar. Sci.* 6:432. doi: 10.3389/fmars.2019.00432


World Ocean Atlas 2023 Climatology, Decade 1995-2004
60°E
120°E
180°
120°W
60°W
0°
60°N
30°N
0°
30°S
60°S
NOAA - World Ocean Atlas 2023
100
50
25
10
6
2
1
Number of Observations
Summer temperature observations at 250m depth [quarter-degree grid]



World Ocean Atlas 2023 Climatology, Decade 2005-2014
60°E
120°E
180°
120°W
60°W
0°
60°N
30°N
0°
30°S
60°S
NOAA - World Ocean Atlas 2023
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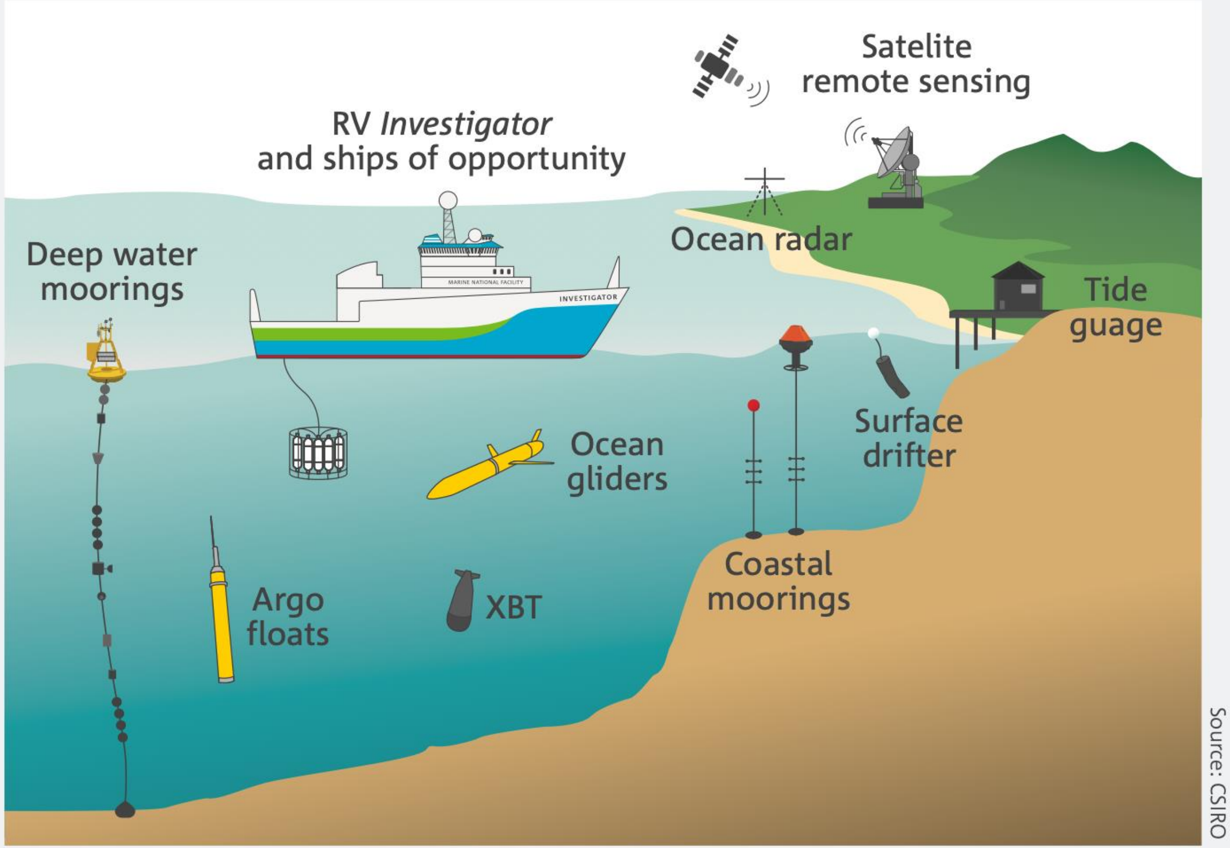
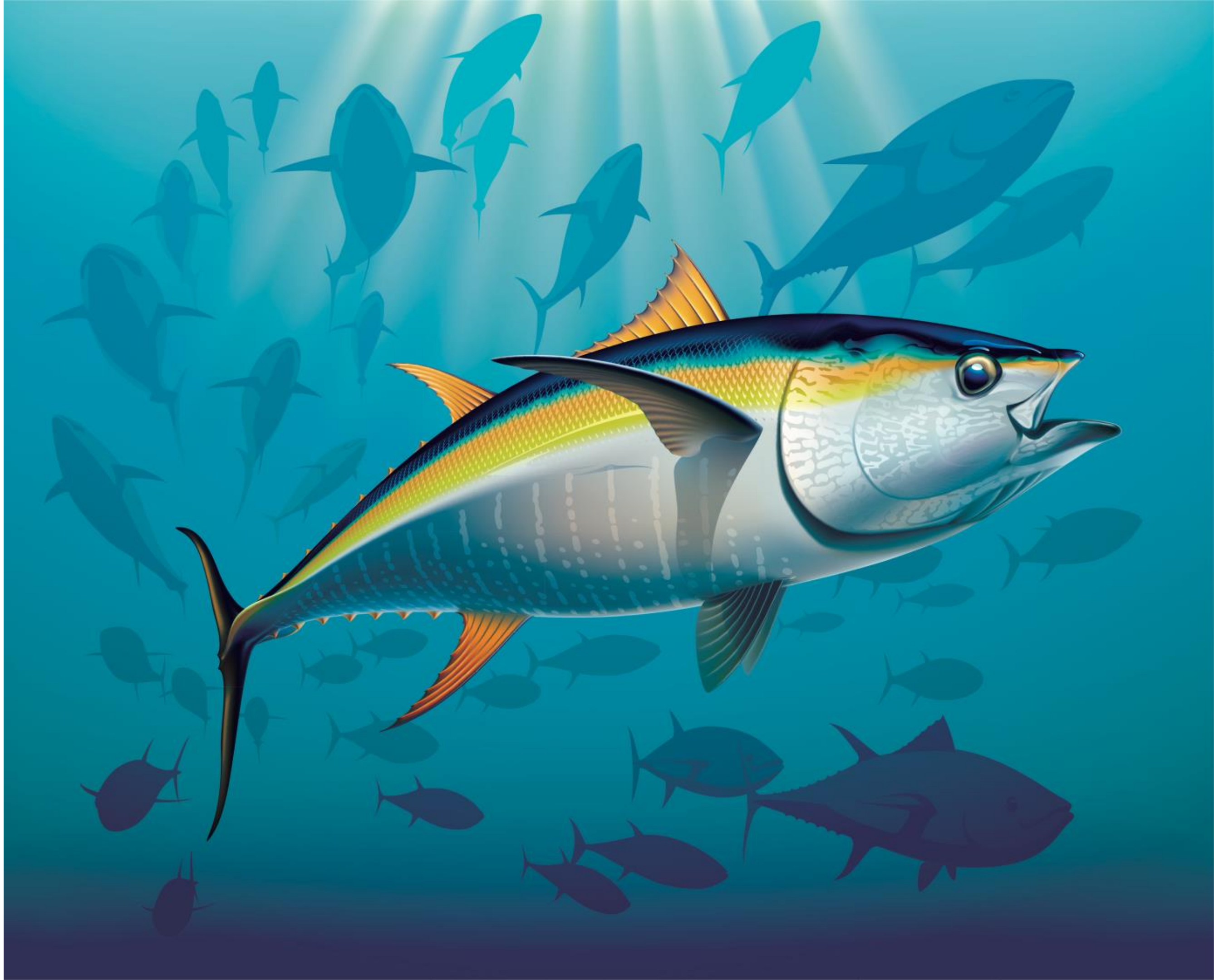


The network of national capabilities observing Australia's interconnected oceans and their influence on our climate. These programs are undertaken by the Bureau of Meteorology, CSIRO, and other partners such as the Integrated Marine Observing System (IMOS), The Australian Institute of Marine Science (AIMS), and universities.

Thank you

CSIRO Climate Science Centre
Dr Thomas Moore
Ocean Data Scientist

thomas.moore@csiro.au



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Comment | Published: 17 April 2023

Event attribution is not ready for a major role in loss and damage

Andrew D. King, Michael R. Grose, Joyce Kimutai, Izidine Pinto & Luke J. Harrington

Nature Climate Change **13**, 415–417 (2023) | Cite this article

Loss and damage funds are intended to support low-income regions experiencing impacts of human-caused climate change. Currently, event attribution should only play a limited role in determining loss and damage spending, but this role could grow as the field advances.

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a limited role in determining loss and damage spending, bu
field advances.**

Comment | Published: 16 November 2023

Event attribution is ready to inform loss and damage negotiations

Ilan Noy, Michael Wehner, Dáithí Stone, Suzanne Rosier, Dave Frame, Kamoru Abiodun Lawal & Rebecca Newman

Nature Climate Change **13**, 1279–1281 (2023) | Cite this article

Extreme weather event attribution techniques quantify anthropogenic contributions to extreme weather disasters, but recently it was argued they are not yet ready to inform decisions on loss and damage funding. Here, we assert that they can substantially help formulate allocations to impacted vulnerable countries for the most damaging extreme events.