OCEAN DATA TO SUPPORT ADAPTATION

How much do we know about physical change in our oceans?

What data are available?

Which data are most appropriate for us to consider?

What are the limits of these data?

What types of analysis are available for my work?

What are the latest findings around marine heatwaves?

This data infosheet is for anyone interested in biophysical climate projections of the future ocean around Aotearoa. If, for example, you are interested or involved in marine spatial planning, marine primary industries, or research into the impacts of climate change on the takutai moana, marine species and distributions, this infosheet will help you navigate data produced by the Deep South Challenge.

These data could also be used by Pacific Island Nations within the model domain. However, for analysis of marine heatwaves under climate change we point, in the first instance, to recently-published research by Neil Holbrook et al., 2022, based on multiple global models. This research includes case studies on impacts for Fiji, Palau and Samoa.

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OCEAN DATA FOR CLIMATE ADAPTATION

DEEP SOUTH CHALLENGE RESEARCH DISCUSSED: Erik Behrens (NIWA), "Simulating New Zealand's Changing Climate" and "Marine Heatwaves and the Link with Climate Extremes": https://deepsouthchallenge.co.nz/research-project/marine-heatwaves-oceanic-change/

THE NZ EARTH SYSTEM MODEL AND OCEAN PROJECTIONS

The New Zealand Earth System Model (NZESM) is a global climate model that is being developed to better represent climate processes that are of particular significance to New Zealand and the Southern Hemisphere. Being an island nation, New Zealand's climate is strongly influenced by our surrounding oceans, but coarse global models generally struggle to simulate small-scale ocean processes critical to our climate. Because of this, the NZESM has a finer grid mesh for the oceans around New Zealand (~17 km compared to ~100 km), meaning that ocean processes that act on smaller scales, such as eddies and boundary currents, can be more accurately simulated. This has led to a novel dataset for New Zealand and the south-west Pacific that can contribute to our understanding of projected oceanic changes over the coming decades to century, due to a changing climate.

HOW COULD I APPLY THESE DATA?

These data could be used:

- to assess the impact of climate change on the viability of potential aquaculture sites, and marine spatial planning
- to compare relative stressors on particular marine species
- to analyse climate-related risks to fisheries and aquaculture businesses
- for research purposes: e.g. Predicting the effects of climate change on deep-water coral distribution around New Zealand (see reference at end)

> *"We've found these data useful for predicting the water temperature at our existing aquaculture sites and for providing guidance into siting new farms... Being able to predict water temperatures over the lifetime of a resource consent ensures that the site will not become too warm to farm as the climate changes."*

AQUACULTURE PLANNER

WHAT RESEARCH HAS BEEN DONE SO FAR?

The NZESM projects future ocean climate on a fine ocean model mesh (at high resolution) around New Zealand and the south-west Pacific. To date, these simulations have been analysed to understand future changes to marine heatwaves (MHW), defined as five days or more with sustained sea-surface temperature above the 90th percentile of the climatological mean.

Research is currently ongoing into how these higher resolution projections may give insights into the behaviour of the critical boundary currents around New Zealand and the Sub-Tropical Front. These changes, in turn, also have implications for our ecosystems and fisheries.

WHAT DATA ARE AVAILABLE?

RAW MODEL DATA FOR RESEARCH PURPOSES

Scenarios:

Projections have been run for the historical period (1950–2014), and then continued for three Shared Socio-Economic Pathways (SSPs) (2015–2100):

- SSP1 2.6 (aggressive reduction of greenhouse gas emissions – "Sustainability" pathway)
- SSP2 4.5 ("Middle of the road" pathway)
- SSP3 7.0 (continued increases in greenhouse gas emissions – "Regional rivalry" pathway)

There are three ensemble members (model runs) for the historical period, as well as each SSP, to differentiate climate variability from climate trends.

Spatial resolution and extent:

The nested ocean grid has a horizontal spatial resolution of 1/5 ° (approx. 17 km around NZ), and a variable vertical resolution through the water column, with grid cell size increasing with depth, from 1 m to 200 m at depth.

Temporal resolution:

Raw data is simulated as 5-daily averages.

Variables simulated by the NZESM:

- Horizontal velocities
- Temperature
- Salinity
- Sea surface height / free surface height

CONTINUED...

MARINE HEATWAVE METRICS

Marine heatwaves are defined against the climatology (generated over 1983 – 2012) as when the five-daily averaged SST exceeds the 90th percentile.

Marine heatwave metrics evaluated:

- MHW intensity
- annual MHW days
- the length of MHWs and
- the timing of MHWs.

Time periods of analysis:

MHW metrics were analysed for three time periods:

- Present day conditions: 1995 – 2014
- Middle of the century: 2040 – 2059
- End of the century: 2080 – 2099

With three ensemble members per scenario, there are 60 years of 5-daily MHW statistics used to determine these MHW metrics.

Spatial extent and analysis:

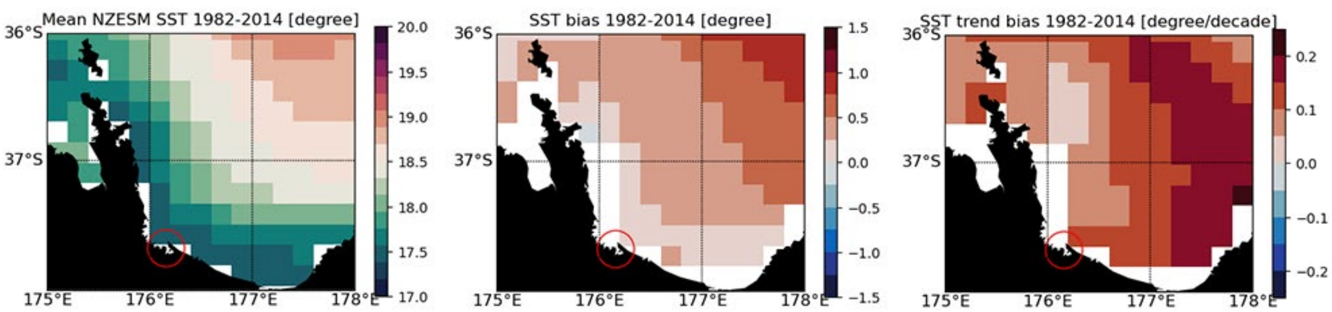
MHW metrics have been completed for the entire domain of the nested grid (see Figs. 1 & 2, Behrens et al., 2022), and detailed analysis has been completed for the Tasman Sea (147-173°E; 43-31°S), as well as three coastal regions: Tasmania, and the North and South Islands of New Zealand. The coastal region is defined as the grid boxes within 50 km of the coastline, and with water depths less than 100 m.

KEY FINDINGS

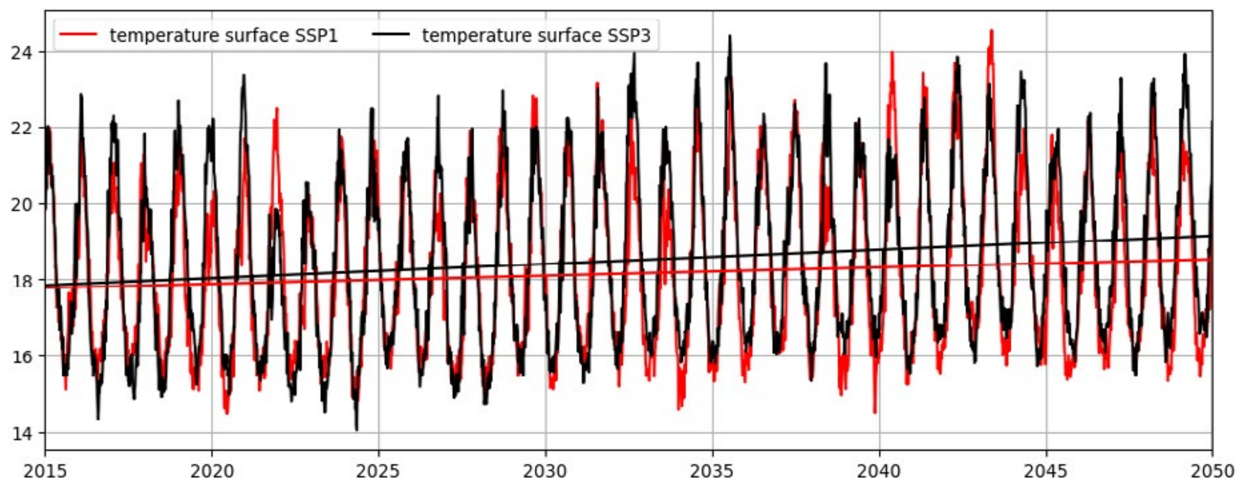
- Marine heatwaves will become more frequent and intense with climate change. This will vary regionally, with more warming in subtropical waters than in subantarctic waters. This pattern reflects present-day observed temperature trends.
- For coastal waters, average marine heatwave intensities will increase by 20% (best case) to 100% (double, worst case) by the end of the century. For the North Island, this means an average marine heatwave could be between 0.5°C to 2°C more intense than they are today.
- By 2100, the 40-odd marine heatwave days we currently see in a normal year will increase to between 80 days (low emissions, best-case scenario) and 170 days (high emissions, worst-case scenario).
- Results show that the marine heatwave season which is centred around summer will disproportionately extend into the autumn season. For some regions, such as southern tip of the South Island, there is a high chance that marine heatwaves start to last more than a year.
- The largest projected changes in annual MHW days are observed south of Australia and of the Tasman Sea around the Sub-Tropical Front. This indicates a southward shift, due to expansion of the sub-tropical gyres and changes to the western boundary currents in the region. This is a topic of the current research.

HOW COULD I EXPLORE THESE DATA?

SPATIAL MAPPING OF NZESM SURFACE TEMPERATURE TRENDS AND BIASES:



EXAMINATION OF TEMPERATURE FOR DIFFERENT SSPS:



MANAGING UNCERTAINTY

These uncertainties are not noted to discourage the use of these data but to inform your decision-making. This will support a nuanced understanding of the robustness of the data and the scope of their use, as well as describe some of the ways that uncertainty is mitigated through experiment design.

- **Using a single model:** The NZESM, notwithstanding its improved ability to simulate ocean heat transport around New Zealand, is only one model. Where possible, because of differences in how they represent our earth system, it is best practice to use the outputs of multiple models to understand the range and variability of possible climate futures.

- **Biases:** The NZESM has been purpose-built to represent the Southern Ocean and the waters around New Zealand, and some previously-identified model biases have been reduced. Some, however, still remain. For example, we know that the model overestimates MHW intensities and underestimates annual MHW days, in comparison to present-day conditions. Though the time-independent aspect of this can be mitigated looking at changes to variables over time, we are not yet aware of how the underlying bias in the model evolves with time. This is true of all models.

- **A "warm" model:** NZESM, like its parent model the UKESM, has a higher climate sensitivity to greenhouse gases, with an Equilibrium Climate Sensitivity of 5.3°C (considered likely range: 1.5-4.5°C) and a Transient Climate Response of 2.8°C (considered likely range: 1-2.5°C). This means that the global mean surface temperature will increase more rapidly for a given level of greenhouse gases than is considered realistic. For marine heatwave metrics, this is mitigated by taking into account the sea surface temperature trend bias (calculated by comparing the NZESM and satellite-derived temperature products over the historical period).

- **Projections for coastal regions:** With the fine-scale ocean grid around New Zealand, the model can resolve boundary currents and their associated variability, and so allows a closer look at coastal regions. There are still, however, other key processes that cannot be resolved by the model – e.g. sub-mesoscale processes (<100 km size) and tides – and so care must be taken with these coastal results.

- **Sampling extreme events:** Due to the computational cost of running global models, they can only be run several times. And like real-life (that we only experience one "run" of) these few runs cannot offer a true distribution of what is expected for extreme, or statistically less-likely events. This is mitigated by using as many runs a possible (in this case, three).

1. Equilibrium Climate Sensitivity and Transient Climate Response are model-derived parameters that help us understand the earth system's response to increased CO_2 concentrations. The Equilibrium Climate Sensitivity of a model is an estimate of how much the globe warms after a doubling of CO_2, once warming stops and a steady-state is achieved. This metric helps us understand the long-term impacts of CO_2 on global climate change.

2. The Transient Climate Response of a model is a measure of the amount of global warming at the time of reaching a doubling of CO_2 concentration, if CO_2 is steadily increased at 1% per year. This metric is the most relevant for warming the next few decades.

WHO DO I CONTACT TO ACCESS THESE DATA OR ANALYSES?

- Ocean Modeller Erik Behrens (NIWA): erik.behrens@niwa.co.nz
- Deep South Challenge Climate Change Knowledge Broker, Kate Turner: kate.turner@niwa.co.nz

REFERENCES:

Behrens, E., Rickard, G., Rosier, S., Williams, J., & Morgenstern, O. (2022). Projections of Future Marine Heatwaves for the Oceans Around New Zealand Using New Zealand's Earth System Model. Frontiers in Climate, 4, 1–13. https://doi.org/10.3389/fclim.2022.798287 (open access)

- This paper details the MHW analysis and results from the previous project, including figures showing the spatial variation of MHW behaviour, and how the NZESM compares to satellite observation products (as a measurement of model bias).

Behrens, E., Williams, J., Morgenstern, O., Sutton, P., Rickard, G., & Williams, M. J. M. (2020). Local Grid Refinement in New Zealand's Earth System Model: Tasman Sea Ocean Circulation Improvements and Super-Gyre Circulation Implications. Journal of Advances in Modeling Earth Systems, 12(7), 1–18. https://doi.org/10.1029/2019MS001996 (open access)

- This paper describes the New Zealand Earth System model and its high-resolution nested region around New Zealand, and compares the performance of the NZESM to its parent model, the UKESM.

Holbrook, N. J., Hernaman, V., Koshiba, S., Lako, J., Kajtar, J. B., Amosa, P., & Singh, A. (2022). Impacts of marine heatwaves on tropical western and central Pacific Island nations and their communities. Global and Planetary Change, 208, 103680. https://doi.org/10.1016/j.gloplacha.2021.103680 (open access)

- This paper uses global model simulations to project future marine heatwave behaviour for the tropical central-western Pacific region, and explores the impacts of marine heatwaves on several Pacific Island Nations: Fiji, Samoa and Palau.

Anderson, O. F., Stephenson, F., Behrens, E., Rowden, A. A. (2022). Predicting the effects of climate change on deep-water coral distribution around New Zealand—Will there be suitable refuges for protection at the end of the 21st century? Global Change Biology, 00, 1-21. https://doi.org/10.1111/gcb.16389 (open access)

- This study developed habitat suitability models for 12 taxa of deep-water corals using both sample and NZESM data predicting present and future seafloor environmental conditions, and showing how habitats may shift and decrease in size by the end of the 21st century.

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