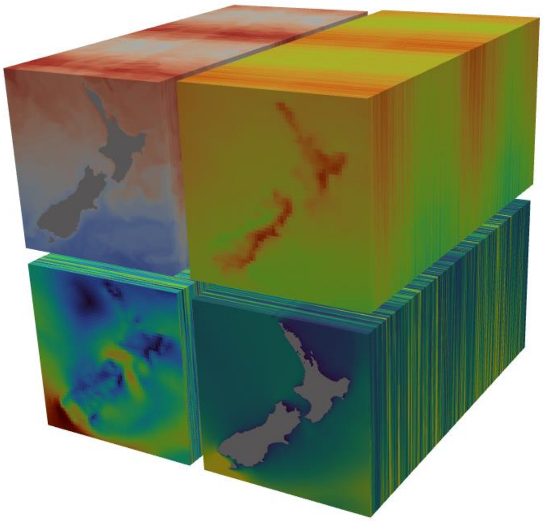
Environmental DataCube for the Ocean Estate of New Zealand



Technical Note prepared for the Ministry of Primary Industries
and the New Zealand Plant and Food Research Institute

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1. INTRODUCTION

The Ministry of Primary Industries (MPI) and the Plant and Food Research Institute (PFR) have jointly commissioned an historical recreation of the wind, wave, current and water properties for the open ocean and continental shelf regions of mainland New Zealand. The purpose of this exercise is to provide an initial decade of physical environmental parameters to allow quantitative evaluations to be made within a range of maritime research and developmental programs.

To achieve this objective, a suite of numerical models has been used to hindcast the atmospheric and oceanographic conditions over a contemporary decade, with the information archived within an online DataCube for subsequent studies and environmental assessments. The hindcast data are made freely available for any use under a Creative Commons CC-BY 4.0 licence, with due attribution of source.

A dynamical downscaling approach has been adopted as the fit-for-purpose methodology to meet the initial core objectives. Accordingly, global reanalysis products have been prescribed as the unmodified boundary conditions to national-scale domains of the waves and ocean currents, while the atmospherics are provided at their native global resolution. We envisage subsequent upgrades to the national hindcast, including downscaled atmospherics and fluvial inputs, which for example will bring coastal-scale improvements to salinity and hydrodynamics. However, until then further regional downscaling can readily be undertaken using the DataCube as a convenient boundary condition for nested domains of interest.

This technical note has been issued to support the release of the DataCube and the document is structured as follows. In Section 2 we describe the hindcast modelling methodology that was used, along with example plots showing validation of selected variables. Example spatial statistics are presented in Section 3, which are a subset of the full package of statistics delivered as GIS layers and raster data. In Section 4, we detail how the cloud-based DataCube can be queried and the data extracted from the Oceanum DataMesh. The references cited are listed in the final Section 5 of this note.

2. METHODOLOGY

2.1. Bathymetry

Bathymetric data for the hindcast modelling and reference maps has been derived from two key sources. These are the NIWA New Zealand bathymetry dataset (Mitchell et al., 2012) and the 2021 GEBCO 400 m global gridded product (GEBCO, 2021).

2.2. Atmospherics

Atmospheric conditions have been prescribed by the ERA5 global reanalysis product (ECMWF, 2019). This is the 5th generation reanalysis produced by the European Centre for Medium-Range Weather Forecasts (ECMWF) and uses the Integrated Forecast System (IFS) CY41R2 (ECMWF 2016), assimilating an unprecedented number of historical observations using 4Dvar assimilation. The system is run with 137 hybrid sigma/pressure model levels in the vertical, with the top-level at 0.01 hPa. The IFS is coupled to a soil model and an ocean wave model. Winds and ice concentration data are available at a 31 km resolution at hourly intervals. ERA5 represents a significant upgrade from the previous ECMWF's reanalysis product, the ERA-Interim.

Previous validation exercises have shown that ERA5 provides a reliable representation of the wind conditions over open ocean and continental shelf regions. We present in Figure 3.1 a one-year comparison against weather station observations from Cape Farewell. Note however that because the model resolution is only 31 km, in some nearshore regions and ocean regions adjacent to strong topographic influences (e.g., Cook Strait), the ERA5 data will not precisely replicate the local wind conditions.

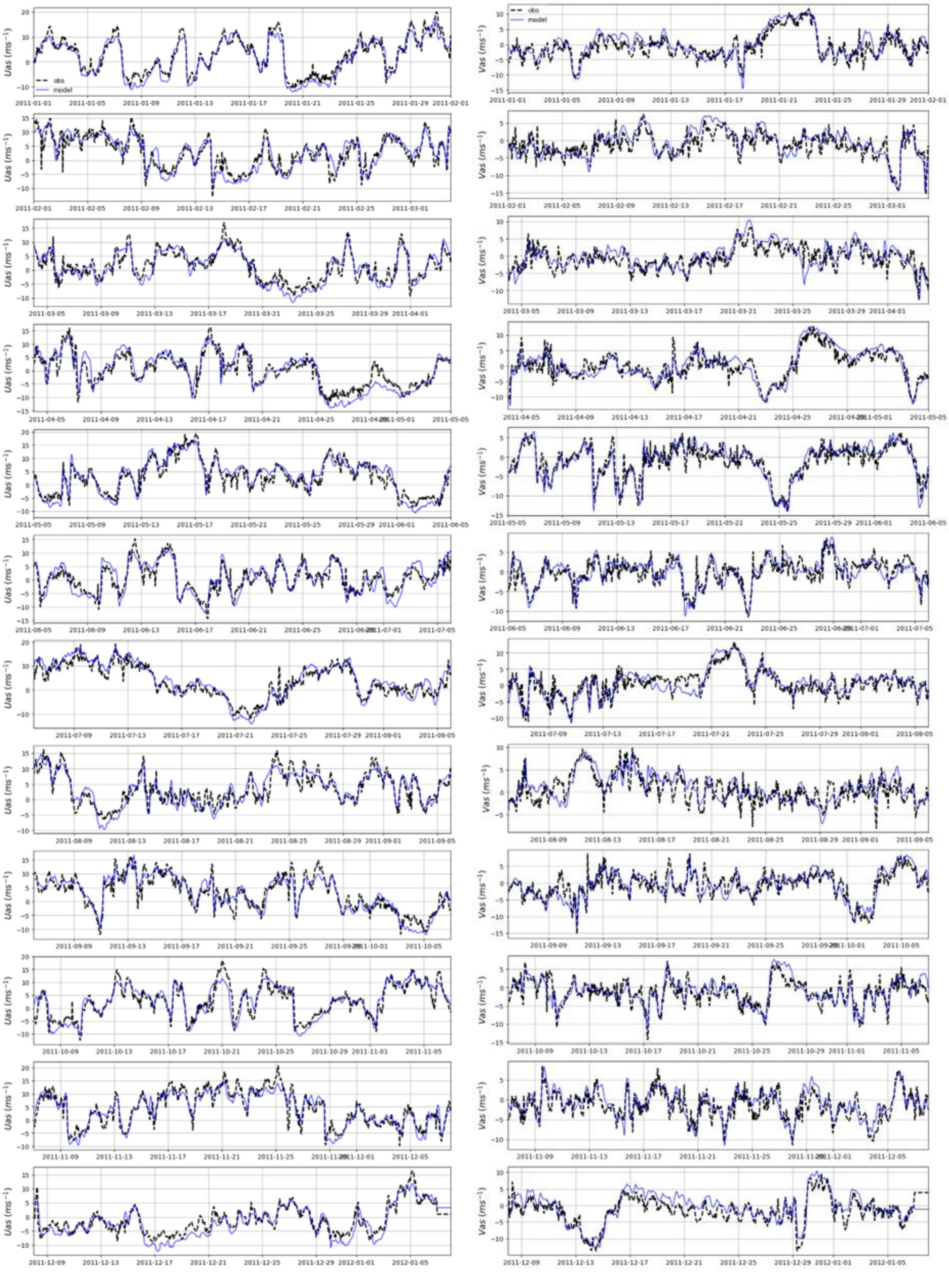

Figure 2.1 Validation of the ERA5 reanalysis against the measured data from Cape Farewell for the year 2011. The model is blue, observations are dashed, and the comparison is provided for the orthogonal vectors (u = velocity east, v = velocity north).

2.3. Waves

The New Zealand wave climate is complex, often featuring local wind seas from one direction and far-field swells from another and further complicated by the local bathymetry that modulates the wave field through intermediate and shallow water processes. To accurately quantify the wave climate, a high-resolution hindcast was produced over a 10-year period (2010-2019) with an unprecedented resolution of 1 km within most of the New Zealand continental shelf and 5 km in deep water (see Figure 2.2).

The SWAN spectral wave model (Simulating WAves Nearshore) was used to generate the wave hindcast. SWAN is a third-generation wave action model designed to provide realistic wave parameters from given wind, bottom, tides and current conditions (Booij et al., 1999). The model includes formulations for wave growth, refraction, shoaling, nonlinear wave interactions and dissipation by whitecapping, bottom friction and depth-induced wave breaking. SWAN is optimised to model coastal regions, lakes and estuaries but can be used on any scale relevant for wind-generated surface gravity waves. A detailed description of the model can be found in Holthuijsen (2007).

The hindcast extends over latitudes 48S and 34S longitudes 165E and 180E and (Figure 2.2). A parent domain was defined with resolution of 5 km and fully spectral boundary sourced from an existing WW3 ERA5 global hindcast. The parent domain was further downscaled near the coast by 20 overlapping child nests with 1 km resolution defined around the entire New Zealand coastline (Figure 2.3). The two resolutions were combined to construct a single 1 km dataset composed by the overlapping nests near the coast and interpolated data from the parent domain offshore (Figure 2.4).

SWAN was forced with hourly wind fields from ECMWF Reanalysis 5th Generation (ERA5) and bathymetry from GEBCO 2021 400 m grid. The model was run in nonstationary mode using the “ST6” source term parameterisations described in Rogers et al. (2012) which provide improvements to wind input and dissipation compared to previous formulations available in SWAN particularly under complex conditions of mixed wind sea and swell. Optimal coefficients for the source terms were defined by calibrating against satellite altimeter data (Fig. 2.5). spectra were discretised with 36 directional bins (10° directional resolution) and over 31 frequencies logarithmically spaced at 10% increments.

The hindcast was validated against satellite altimeters (Queffeulou, 2013) over the area of the 5 km and 1 km SWAN domains. The model agrees well with the altimeters (Table 2.1). Improvements due to the resolution can be assessed by comparing accuracy measures between the 5 km regional model and the 50 km global model over the NZ area (first two rows of Table 2.1) as well as by comparing the 5 and the 1 km domains over the overlapping areas (third and fourth rows in that table). Improvements can be observed for all accuracy statistics despite the limitations with satellite data near the coast due to land effects, where most improvements due to resolution are expected. Good overall agreement can be seen across the wave height ranges (Figure 2.5) with the although the largest waves tend to be somewhat under predicted. Results are consistent over the 10-year period of the hindcast apart from some annual variability due to changes in the wave climate and quality and coverage of different satellite missions (Figure 2.6).

The wave model output includes integrated spectral parameters and frequency-direction wave spectra at hourly intervals. The parameters were stored over the full area of each SWAN domain and merged onto a single 1 km dataset composed by 1 km data within the area of the overlapping grids and interpolated data from the 5 km domain offshore. The model output includes 39 parameters for the full spectrum, wind sea and 3 swell watershed partitions, and sea / swell partitions defined from a simple frequency threshold corresponding to 8 seconds. Two-dimensional wave spectra were stored over the full hindcast area with spacing between sites ranging according to the following criteria: 2.5 km apart under 20 m water depth (starting 2 km from the coast), 5 km between 20 and 50 m water depth, 10 km between 50 and 200 m water depth, 20 km from 200 m water depth up to 1.5 degree away from the shoreline, and 40 km apart in deep water (Figure 2.7). Over 7,000 spectra were archived hourly over the 10-year hindcast period.

Table 2.1 Accuracy statistics calculated from collocations of model and altimeters for the boundary 50 km global WW3 wave model over the SWAN NZ 5 km area, the SWAN 5 km domain, the 5 km domain filtered over the area of the 1 km grids, and the 1 km SWAN grids. SI is the Scatter Index, r is the correlation coefficient.

	Bias (m)	**SI**	**RMSD (m)**	**r**
WW3 50 km	-0.039	0.128	0.370	0.955
NZ 5 km	-0.036	0.121	0.347	0.960
NZ 5 km grids	-0.082	0.156	0.368	0.952
NZ 1 km grids	-0.070	0.151	0.353	0.956

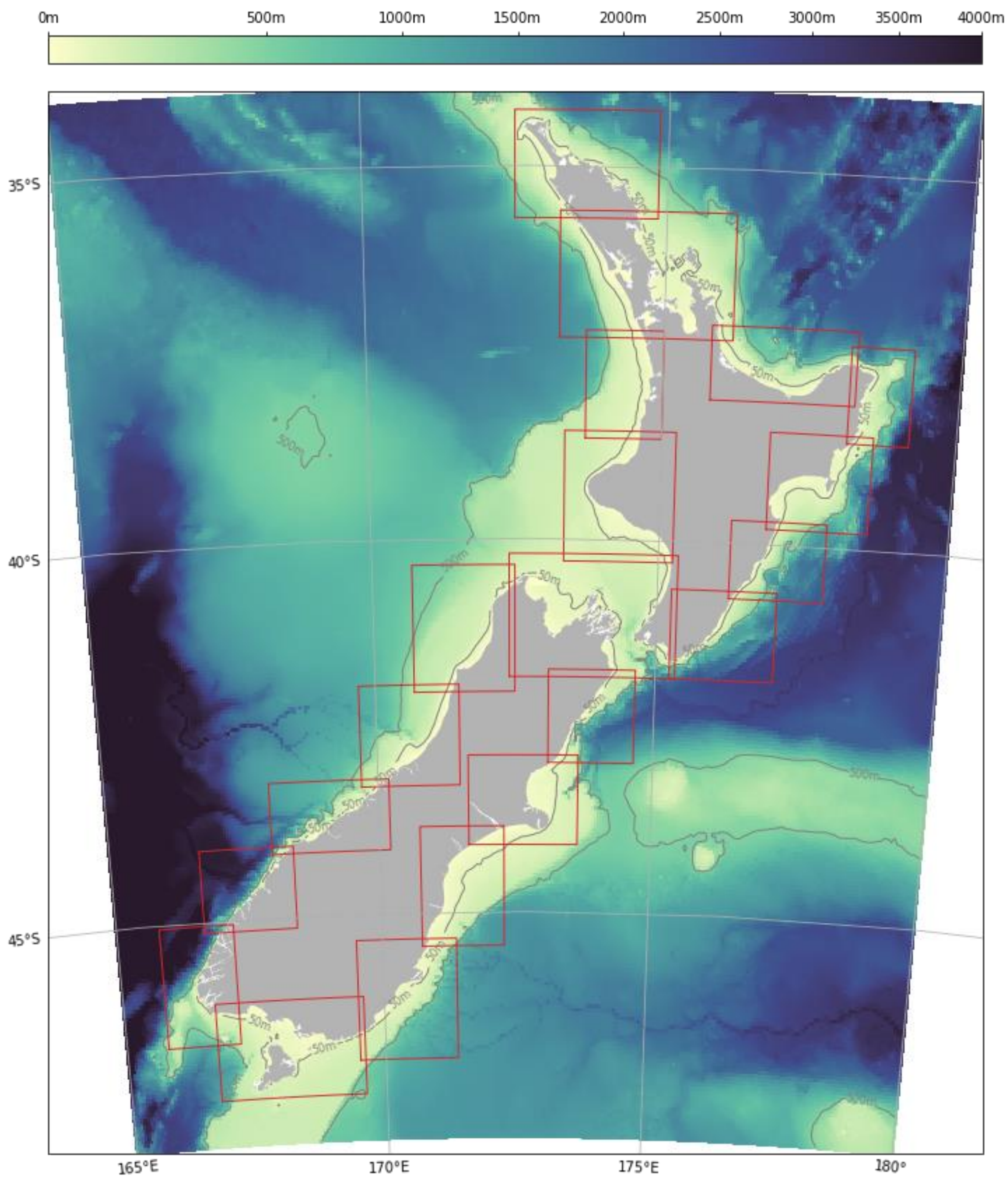

Figure 2.2 Bathymetry map showing the wave model domain of 1 and 5 km resolution (red rectangles and the full area respectively).

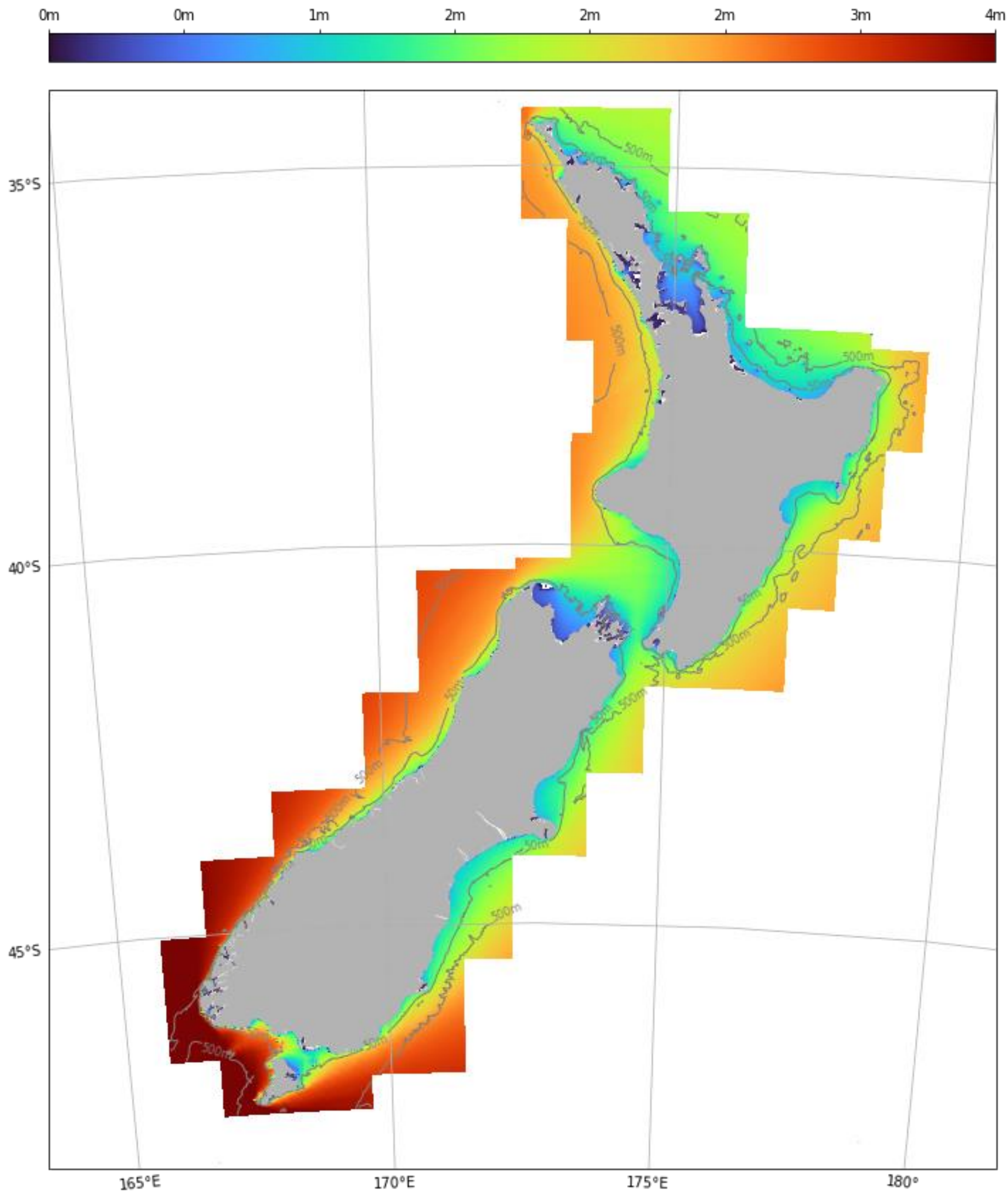

Figure 2.3 Mean significant wave height from the 1 km resolution overlapping domains.

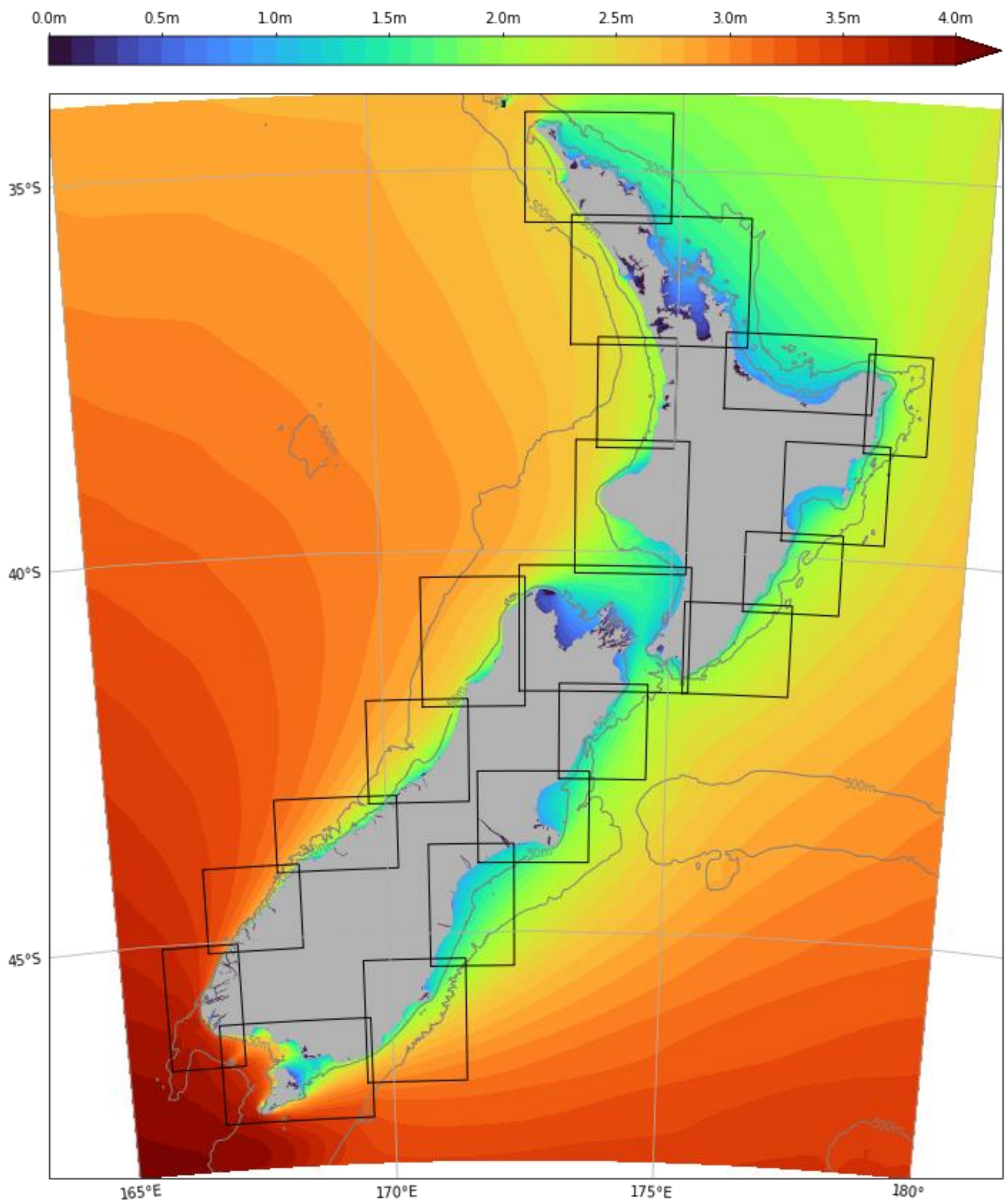

Figure 2.4 Mean significant wave height contours from the combined 1 km resolution dataset.

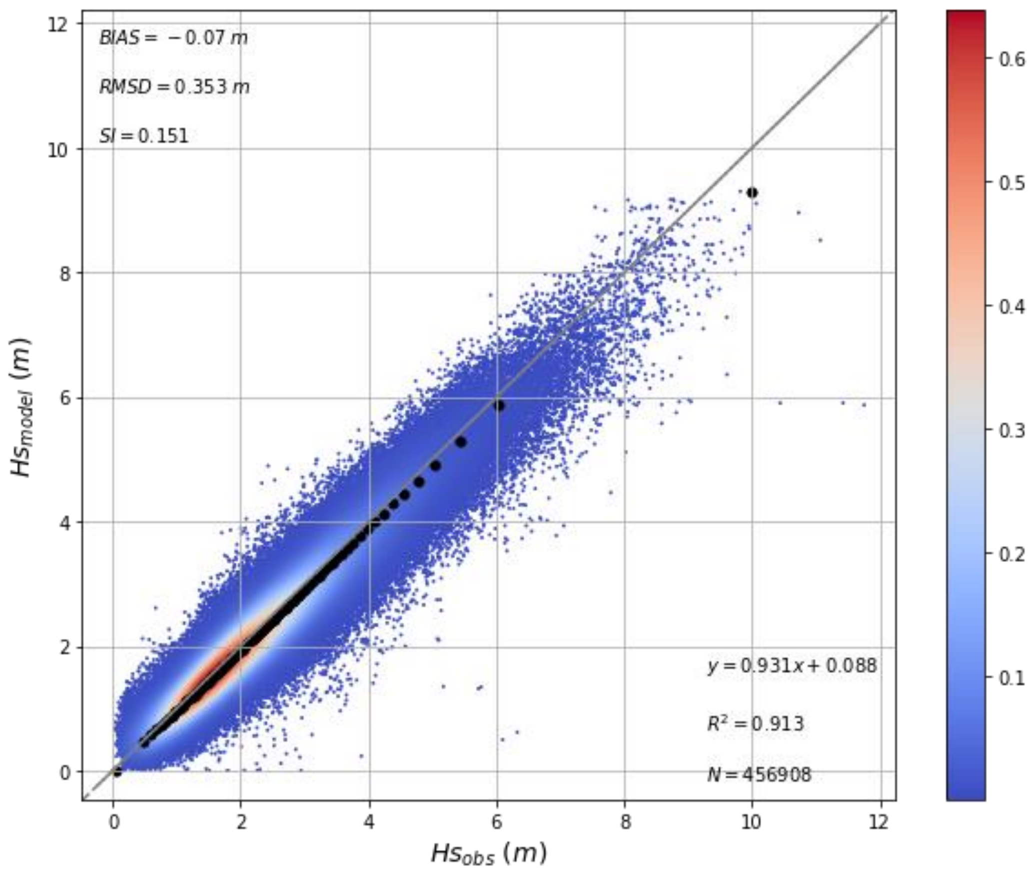

Figure 2.5 Wave model validation against satellite altimetry data within the area of the 1 km grids (see Figure 2.2) for years 2010 and 2019. Colours indicate density of data points; black dots show the quantiles at 0.01 increments.

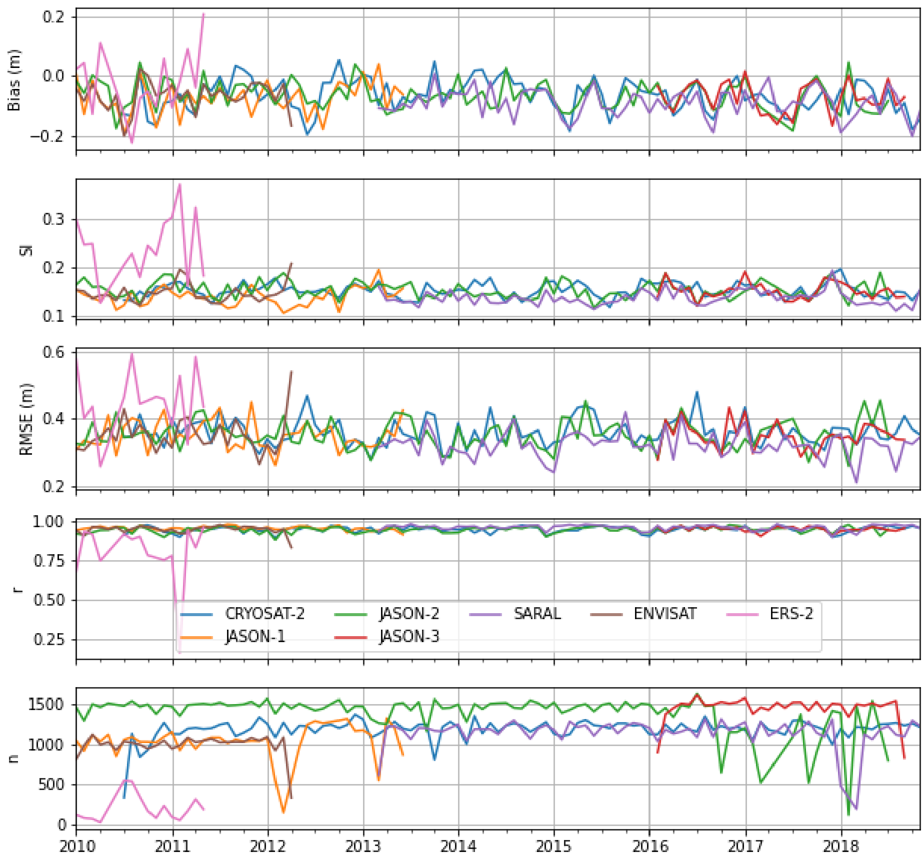

Figure 2.6 Monthly accuracy statistics calculated from collocations of model and altimeters from different satellite missions within the area of the 1 km grids (see Figure 2.2). From top to bottom: Bias, Scatter Index (SI), Root-mean-square deviation (RMSD), correlation coefficient (r) and the number of collocations (n).

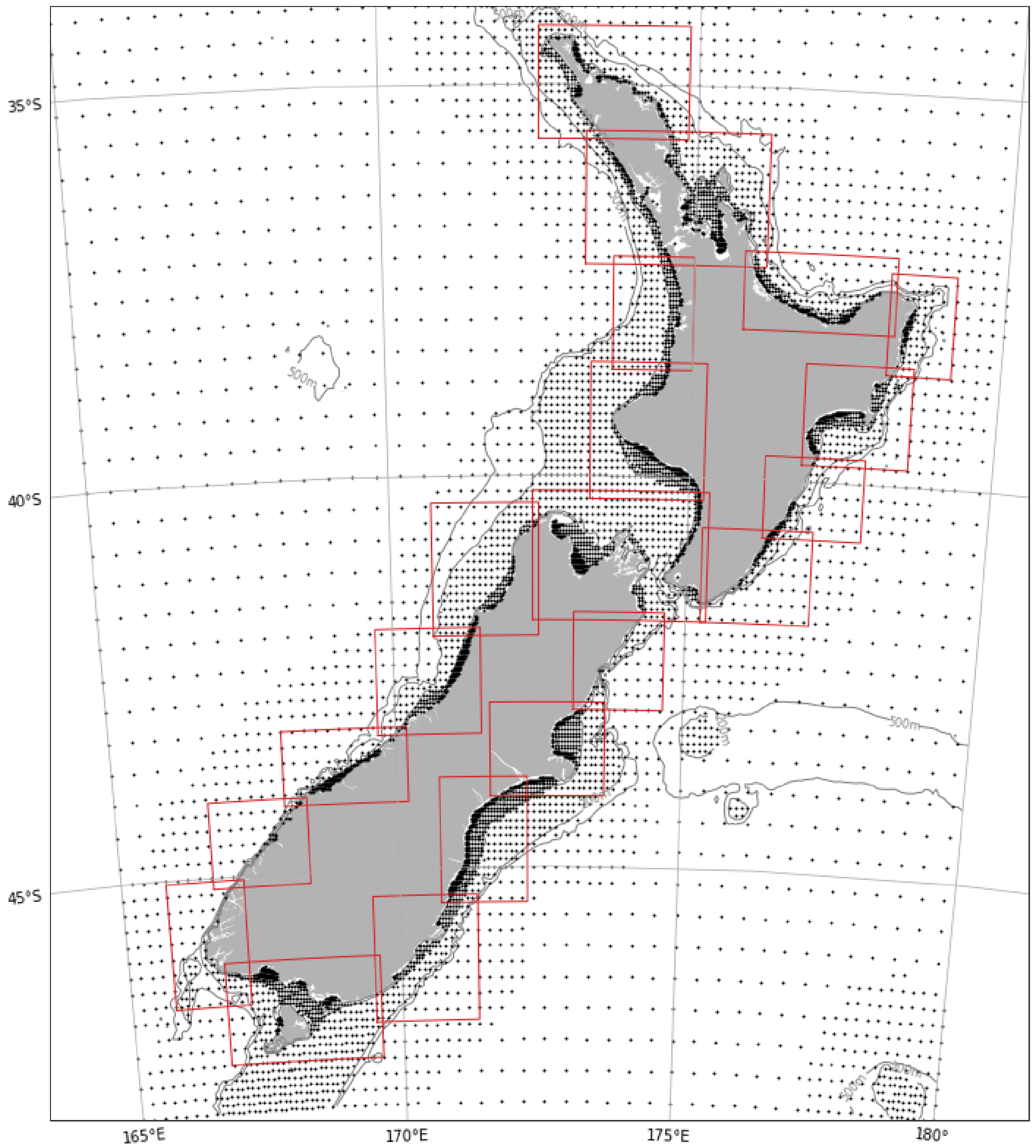

Figure 2.7 Output locations for hourly frequency-direction wave spectra with spacing defined according to the following criteria: sites 2.5 km apart under 20 m water depth (starting 2 km from the coast), 5 km between 20 and 50 m water depth, 10 km between 50 and 200 m water depth, 20 km from 200 m water depth up to 1.5 degree away from the shoreline, and 40 km apart in deep water.

2.4. Currents and water properties

The Semi-implicit Cross-scale Hydroscience Integrated System Model (SCHISM) was used to downscale a global ocean reanalysis product and resolve the hydrodynamics for the continental shelf region of mainland New Zealand. An hour-by-hour replication of the three-dimensional flows plus temperature and salinity was completed for the period 2010 to 2019.

SCHISM is a hydrodynamic model (Zhang et al., 2016) based on an unstructured grid (i.e. a triangular mesh), suitable for 2D or 3D baroclinic/barotropic circulation from ocean to coastal regions. A detailed description of the SCHISM model formulation, governing equations and numerics, can be found in the original publication by Zhang and Baptista (2008).

The model grid (Fig. 2.8) has resolution ranging from 8 km near the open ocean boundary to around 500 m near the coast. SCHISM was run in full 3D baroclinic mode, with 15 vertical sigma layers in 150 m depth and up to 42 layers in deeper water, with a higher concentration of sigma layer near the surface and bottom. Elevation and current amplitudes and phases of the dominant tidal constituents (M2, S2, N2, K2, K1, O1, P1, Q1, MM, MF, M4, MN4, MS4 and 2N2) were sourced from the OTIS (Oregon State University Tidal Inversion Software) assimilated barotropic model. Residual velocities and water column properties were defined from the global 1/12-degree reanalysis products released by the EU-funded Copernicus Project. Atmospheric forcing (10 m wind speed, temperature, humidity, mean sea-level pressure and solar radiation) was sourced from the ERA5 reanalysis. Note that precipitation and fluvial inputs were neglected in this run but will be included in future runs when atmospheric downscaling has also been completed.

For regions outside the SCHISM coverage area, the ocean properties parameters revert to GLORYS at native resolution. For this reason, the vertical discretisation in SCHISM parameters has been aligned with the Copernicus product for the final data delivery.

A qualitative validation of the ocean hindcast was made against the following parameters:

- Sea level - measured elevations from numerous tide gauges around New Zealand were used to verify the model was correctly resolving the phase and amplitude of the tides. Plots showing measured and modelled elevation for 4 representative locations are shown on Figure 2.9.

- Sea surface temperature (SST) - comparisons of the model predictions against satellite observations were made and example plots of the monthly means in January and June 2011 are presented in Figure 2.10. The SST observations were sourced from the Advanced Very High-Resolution Radiometer (AVHRR) infrared satellite and are daily snapshots with a resolution of ¼ of a degree. The estimated temperature errors for these satellite data are 0.12 - 0.86 degC in June and 0.12 - 0.52 degC in January.

- Measured oceanic currents - observations from three instrument deployments on the continental shelf were compared with the model predictions. Because the observation periods predate the hindcast, a statistical comparison was made. Current roses from each deployment period are compared with 5 years of model data from the same months in the year (Figure 2.11).

- Modelled oceanic currents - a statistical comparison was made against an existing low-resolution ocean hindcast from the Moana Project[1] for 7 representative open ocean sites around New Zealand (Figure 2.12). Note the Moana data are 5 km regular grid while the co-located SCHISM data are from an unstructured grid at between 2 and 4 km resolution at these locations.

In summary, validation of the primarily oceanic parameters confirm they are fit for the intended purpose and suitable for characterising the dominant shelf hydrodynamics and water column properties. There are acknowledged limitations stemming from the neglect of fluvial inputs and the use of global-scale atmospherics to represent local-scale conditions. Accordingly, users of this DataCube should be mindful of these limitations when using the data in research applications. This is particularly the case in some nearshore locations where there is strong topographical influence on the wind fields that drive local currents, or where there are significant fluvial inputs that will modify the surface layer salinity.

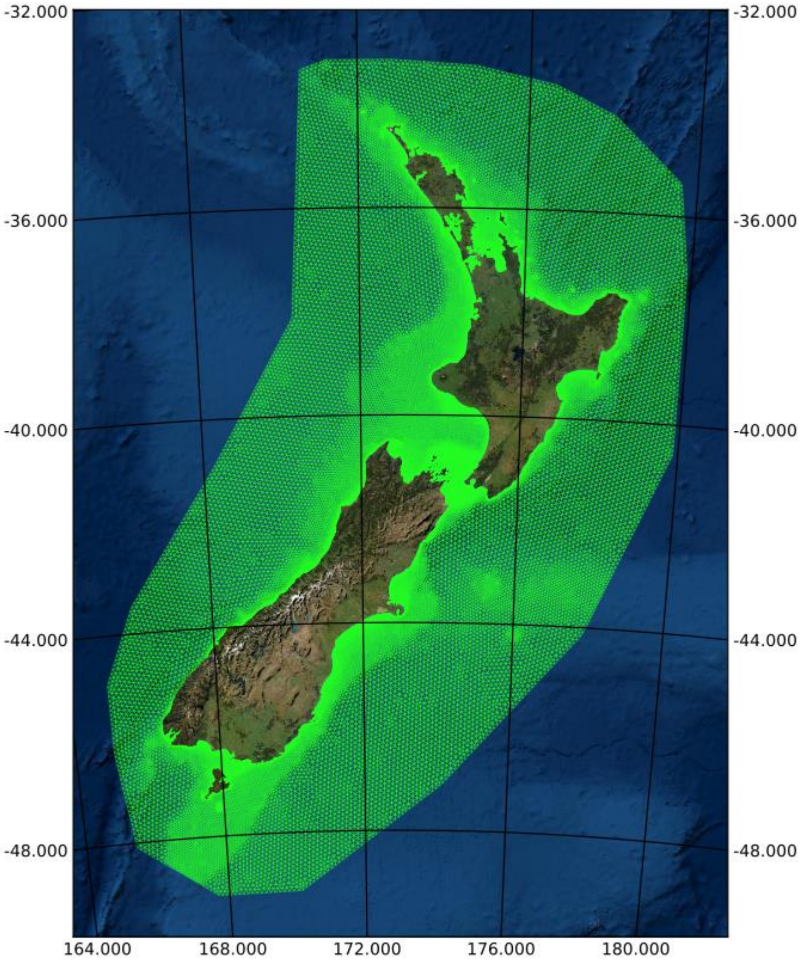

Figure 2.8 Map showing the extent and resolution of the SCHISM hydrodynamical model domain. This model is nested within the 1/12 degree GLORYS hydrodynamical model and is forced with ERA5 atmospherics and OTIS tides.

[1] https://catalogue.data.govt.nz/dataset/moana-hydrodynamic-hindcast-version-1-9

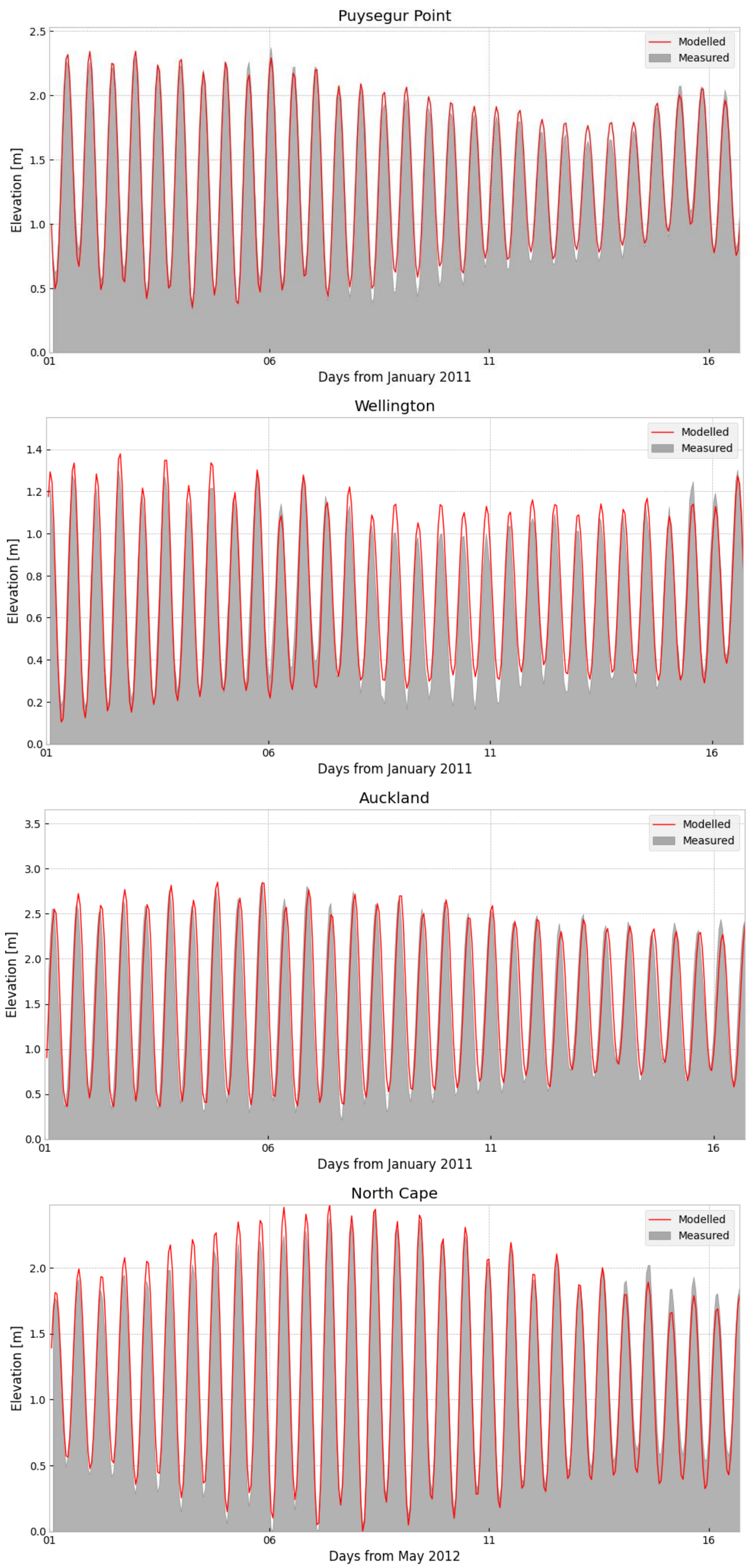

Figure 2.9 Validation plots of tidal elevation from 4 locations around New Zealand.

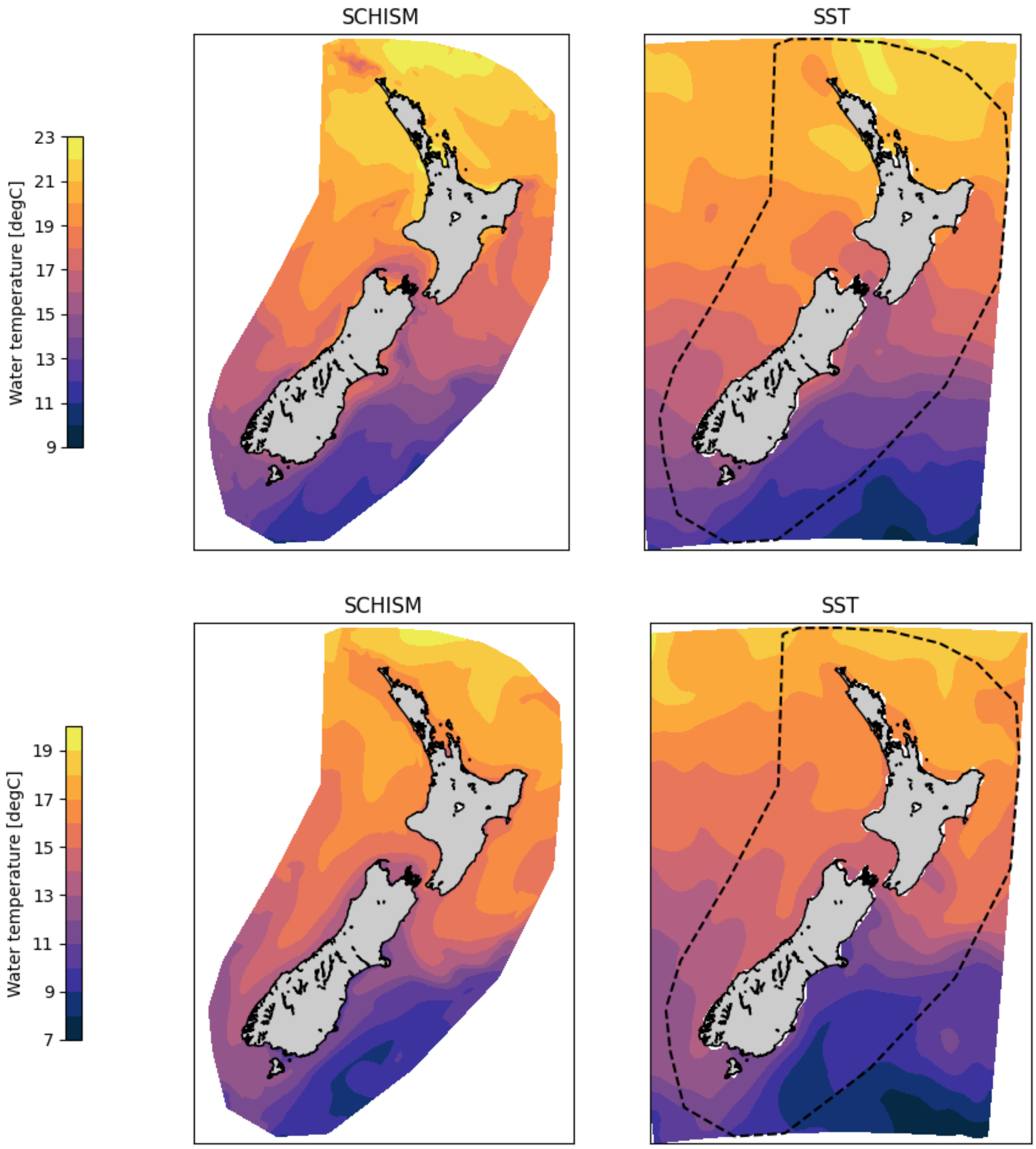

Figure 2.10 Monthly mean sea surface water temperature (SST) from January 2011 (upper plots) and June 2011 (lower plots) extracted from hourly SCHISM (left) and daily AVHRR ¼ degree resolution satellite observations (right).

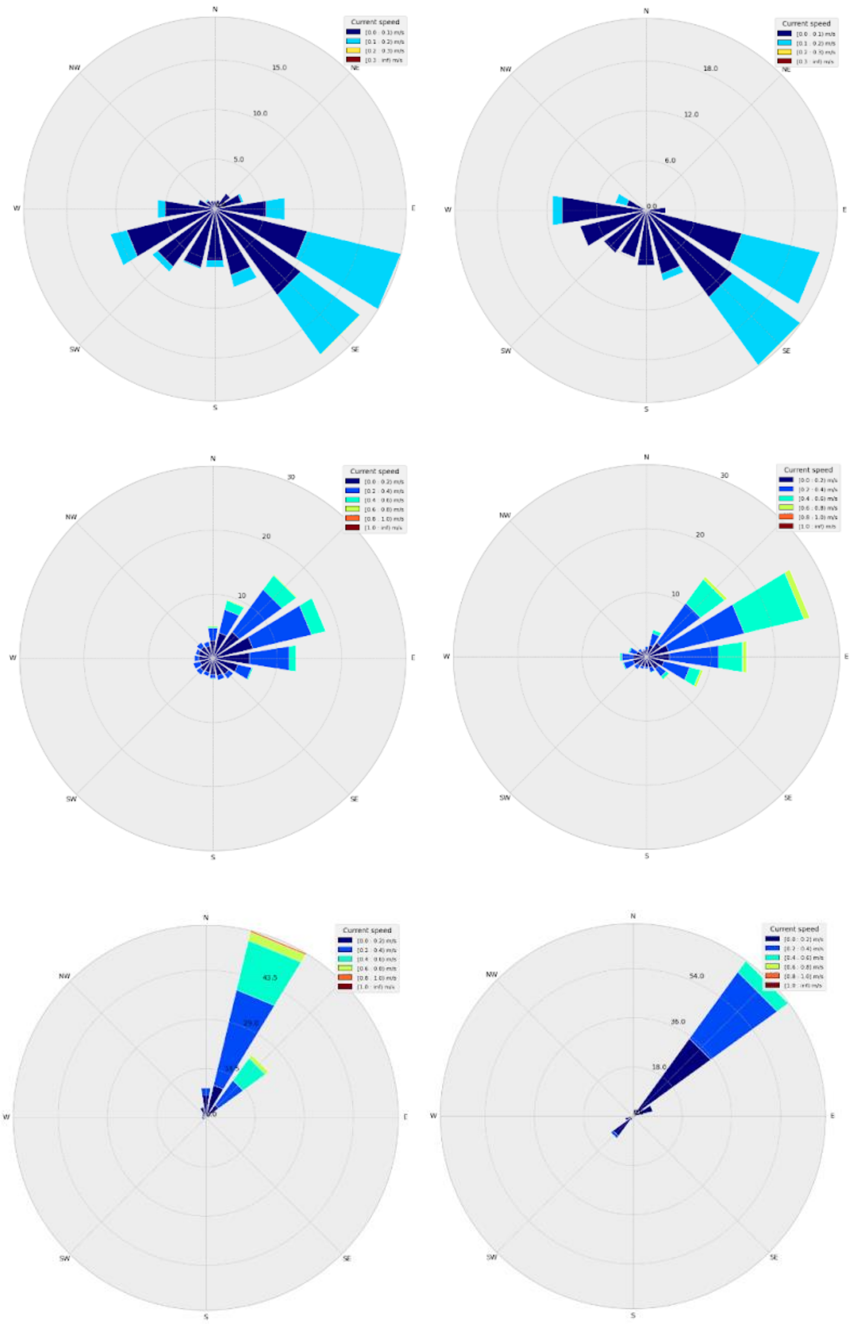

Figure 2.11 Current roses from data recorded by continental shelf moorings (left) and SCHISM predictions (right) over the same months in the year (spanning 2010 - 2014). Upper roses are depth-averaged East Auckland [175.784, -36.219] middle roses are surface Western Central New Zealand [173.309,-39.972] and lower roses are depth-averaged Otago [170.847,-45.998]. Note the measurements from Western Central New Zealand are at 1.5 m below sea surface, while SCHISM data are from the absolute surface. Also, the Otago site is close to the edge of a canyon and has bathymetric features not resolved by the model.

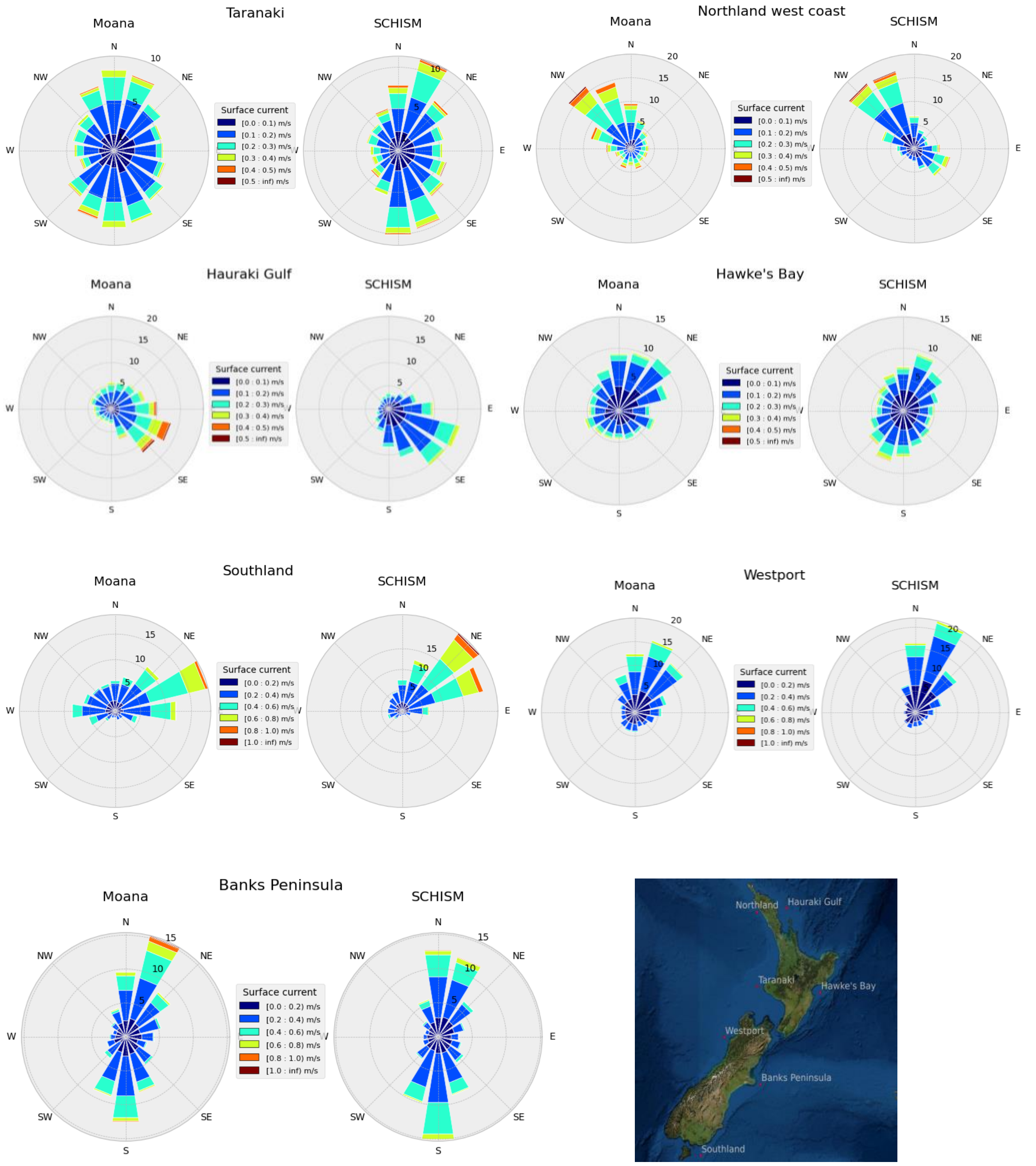

Figure 2.12 Current roses from representative continental shelf locations around New Zealand during 2015. Left plots are from 3-hourly Moana Hydrodynamic Hindcast Version 1.9 and right plots are from 1-hourly SCHISM data. The locations for the comparison are provided on the lower right.

3. SPATIAL STATISTICS

An extensive set of spatial statistics have been prepared from the 10-year DataCube; listed as follows:

- Bathymetry in 10 m isobaths.
- Statistics of wind speed - annual and seasonal wind speeds (mean, P50, P90, P99, maximum).
- Statistics of significant wave height - annual and seasonal values (mean, P50, P90, P99, maximum).
- Statistics of the tidal flow regime (maximum depth-averaged).
- Statistics of the combined tidal and non-tidal flow regime - annual values (mean, P50, P90, P99, maximum) for 0.5 m and 20 m depth.
- Statistics (mean, minimum, maximum, standard deviation) of the annual and seasonal temperature and salinity regime at 0.5 m and 20 m depth.
- Statistics (mean) of the annual and seasonal mixed layer depth.

These statistics have been produced as GIS layers, and a selection of those maps are presented as examples as follows:

- The GEBCO 400 m gridded data is shown in Figure 3.1.
- Example statistics from native ERA5 wind fields are presented in Figures 3.2 and 3.3 for the annual mean and P99 wind speed at 10 m elevation, respectively.
- Example statistics of the annual wave climate are presented in Figures 3.4 - 3.6.
- Example statistics of the regional flow regime are presented in Figures 3.7 - 3.9. Water temperature extremes are provided in Figures 3.10 - 3.13, and the mean surface salinity is presented in Figure 3.14.

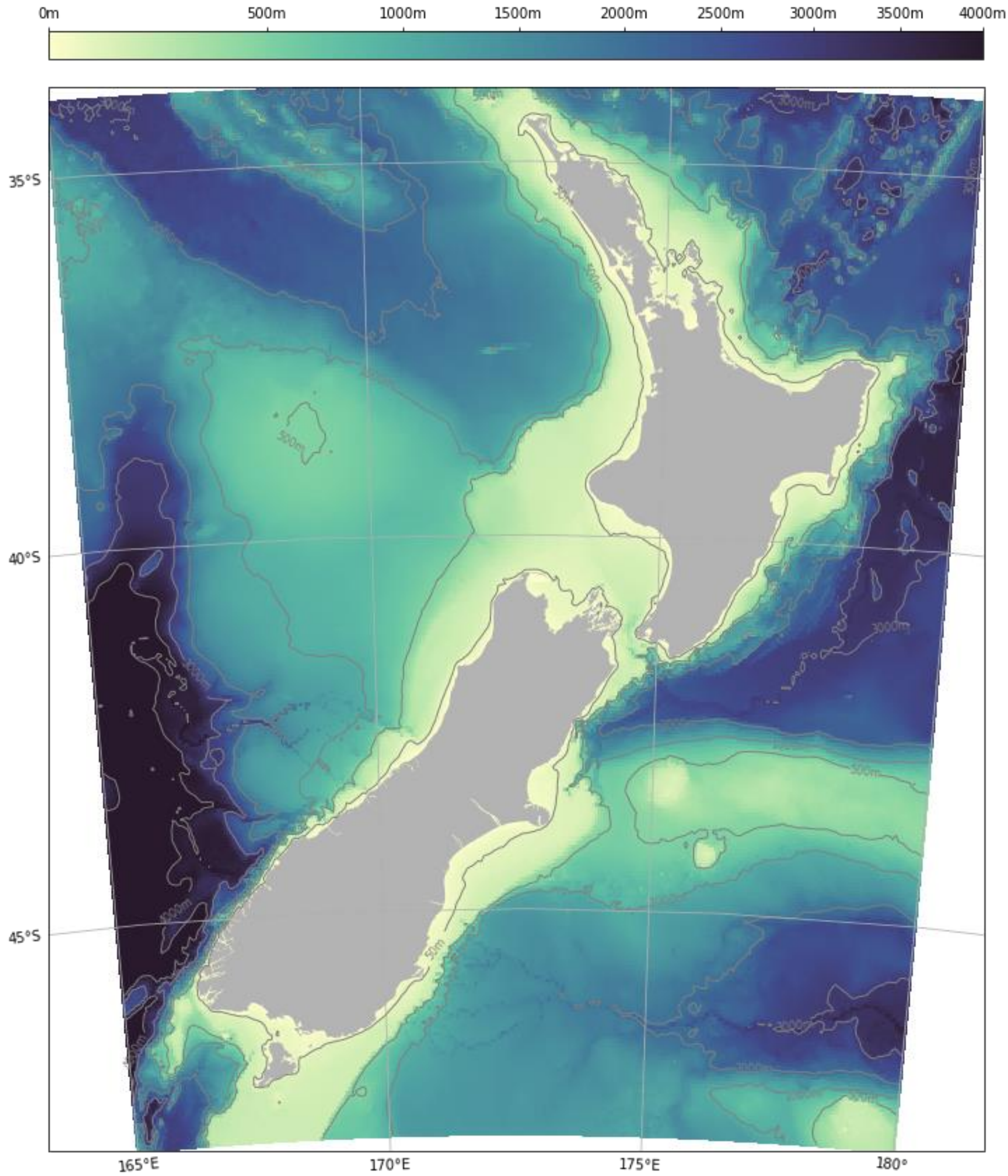

Figure 3.1 Bathymetry from the GEBCO 400 m gridded depths.

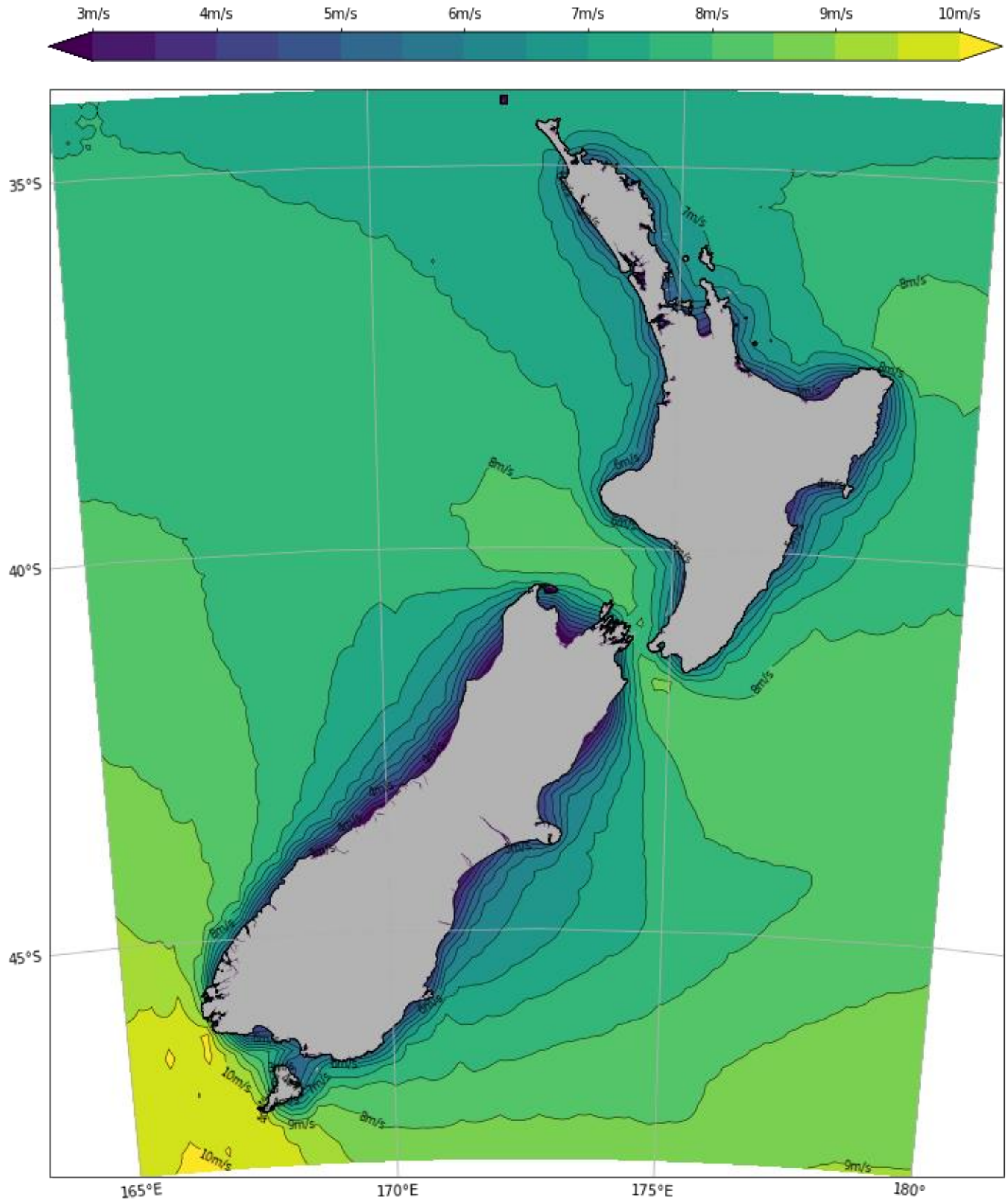

Figure 3.2 Annual mean wind speed at 10 m elevation.

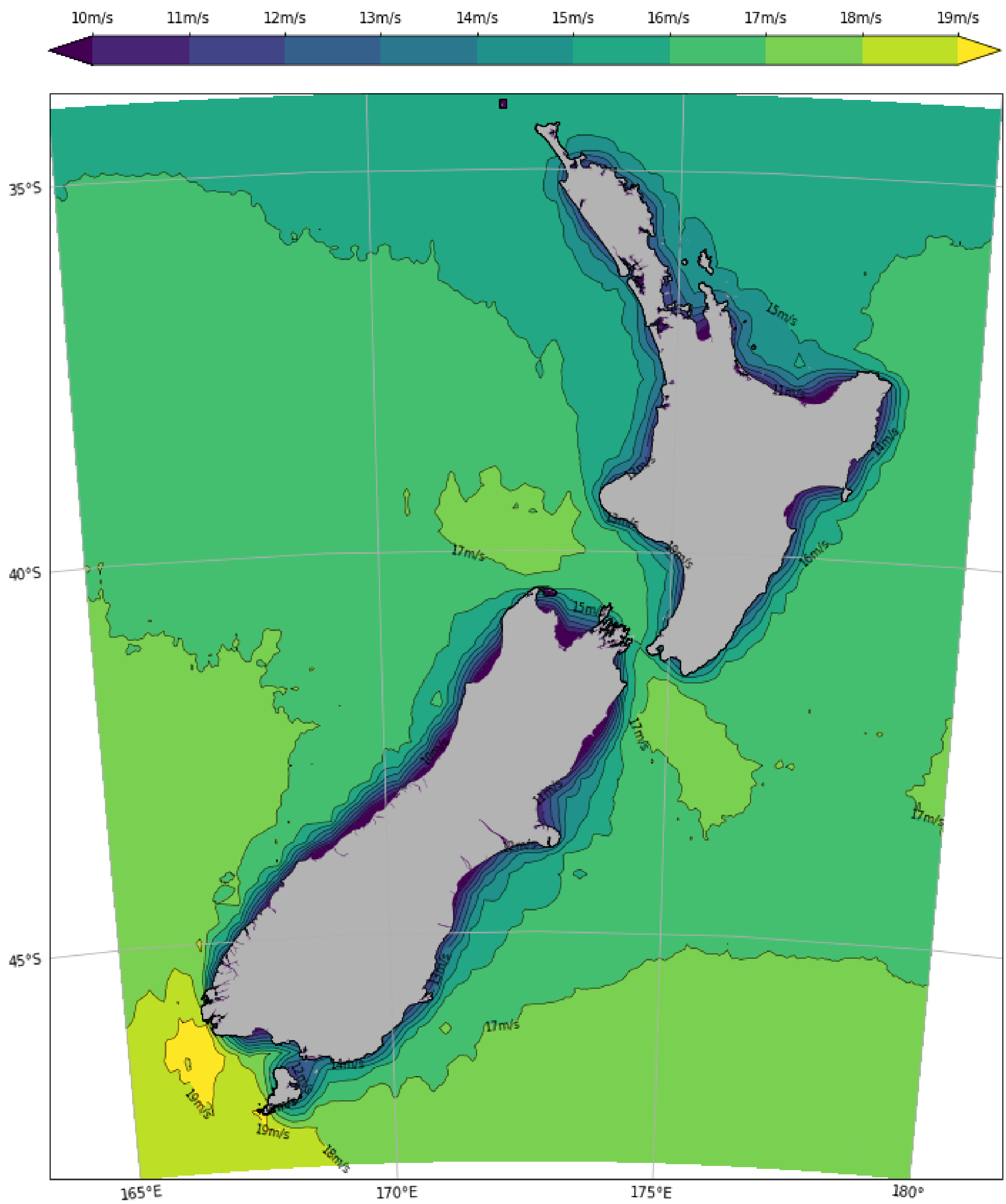

Figure 3.3 Annual P99 wind speed at 10 m elevation.

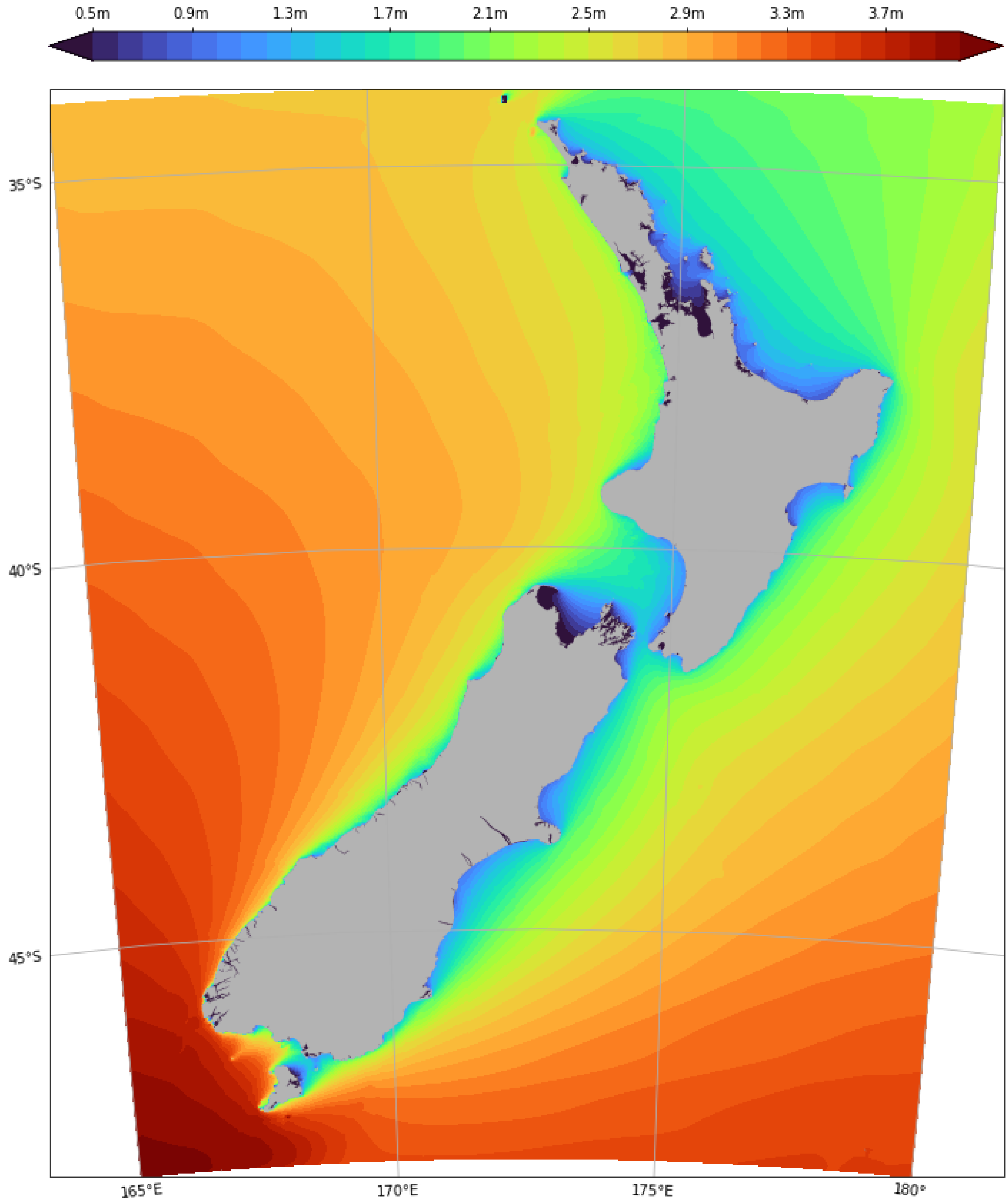

Figure 3.4 Annual mean significant wave height.

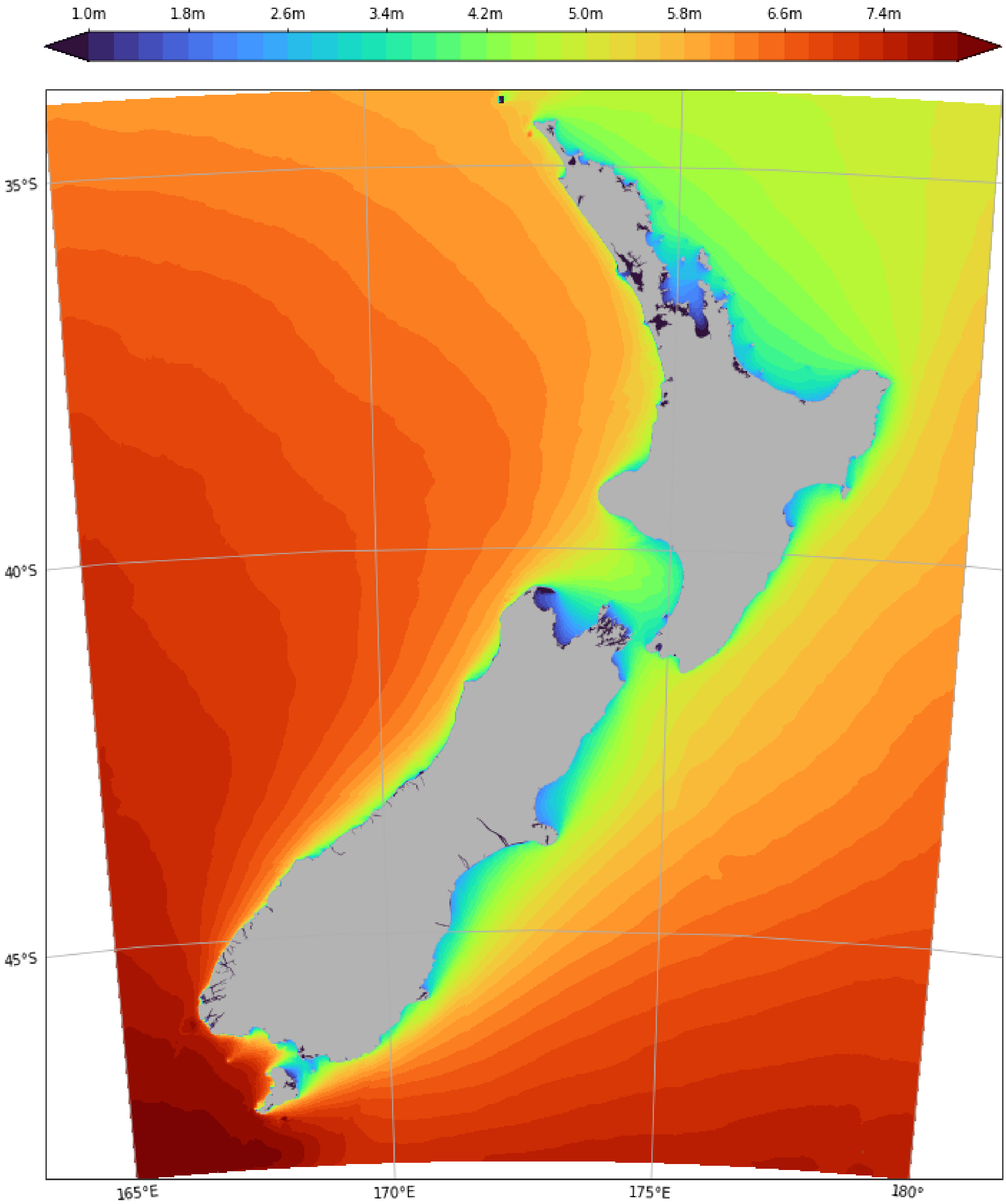

Figure 3.5 Annual P99 significant wave height.

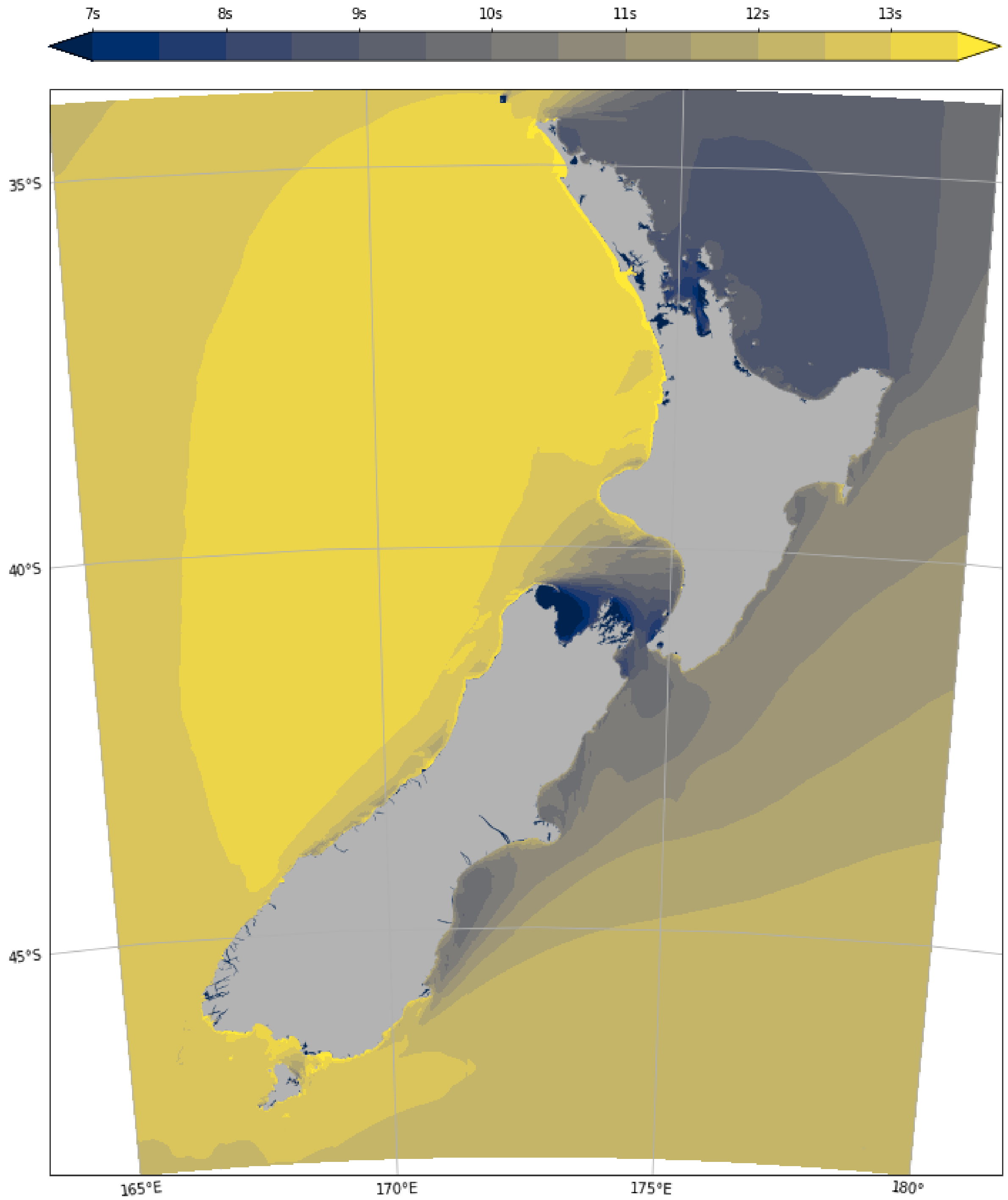

Figure 3.6 Annual mean peak wave period.

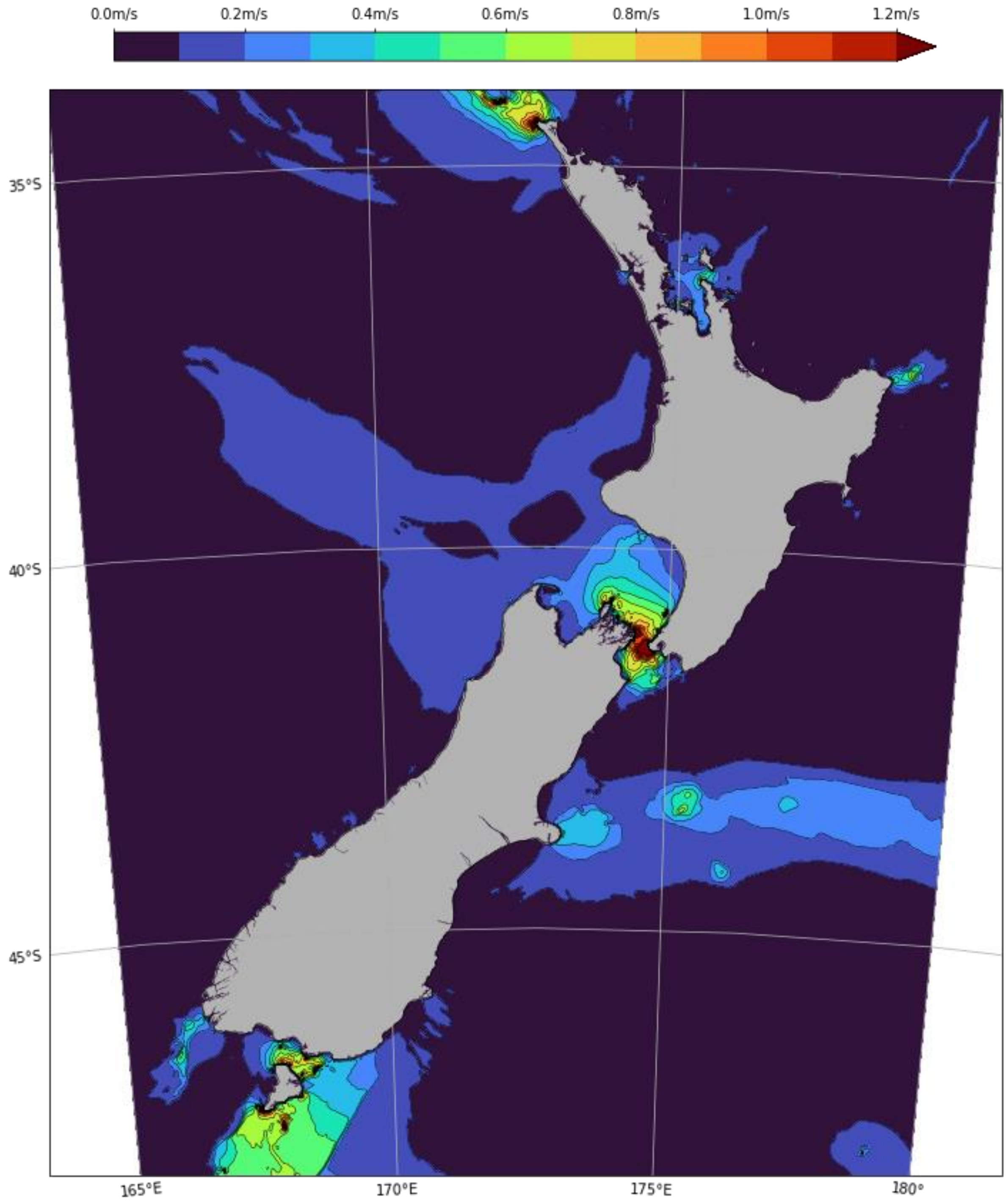

Figure 3.7 Depth averaged tidal currents amplitude (M2+S2).

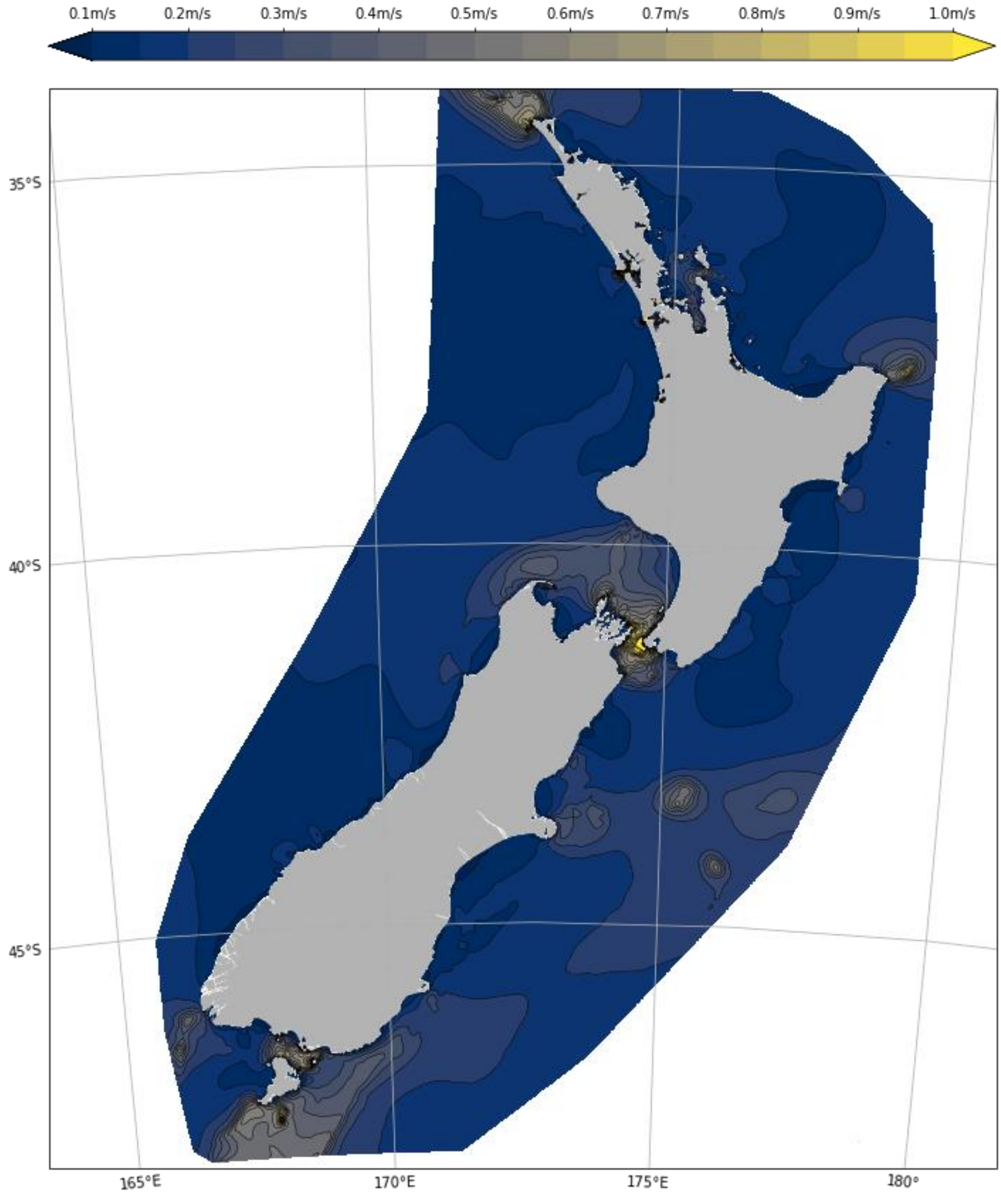

Figure 3.8 Annual mean total current speed (tidal and non-tidal) at 0.5 m depth.

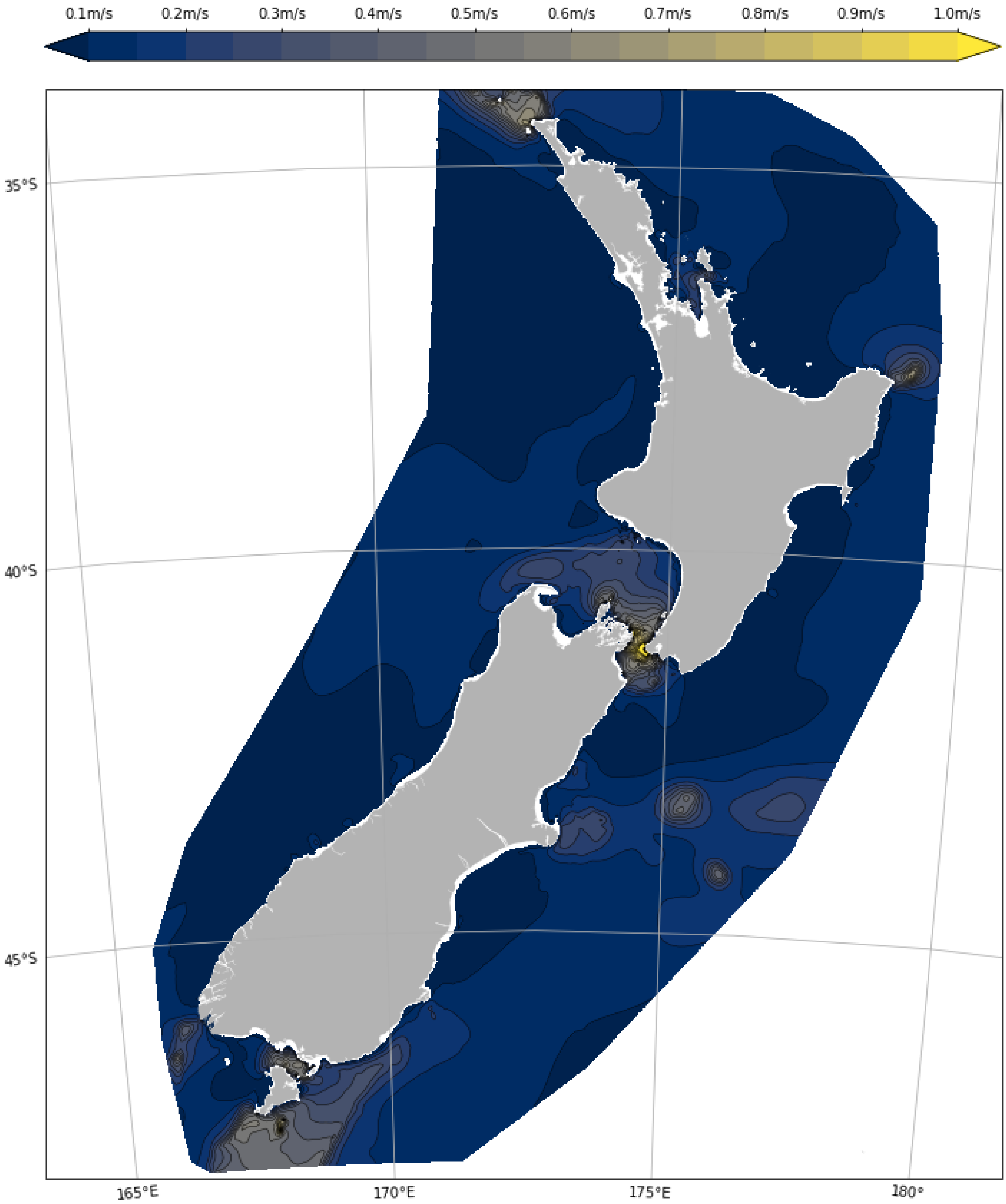

Figure 3.9 Annual mean total current speed (tidal and non-tidal) at 20 m depth.

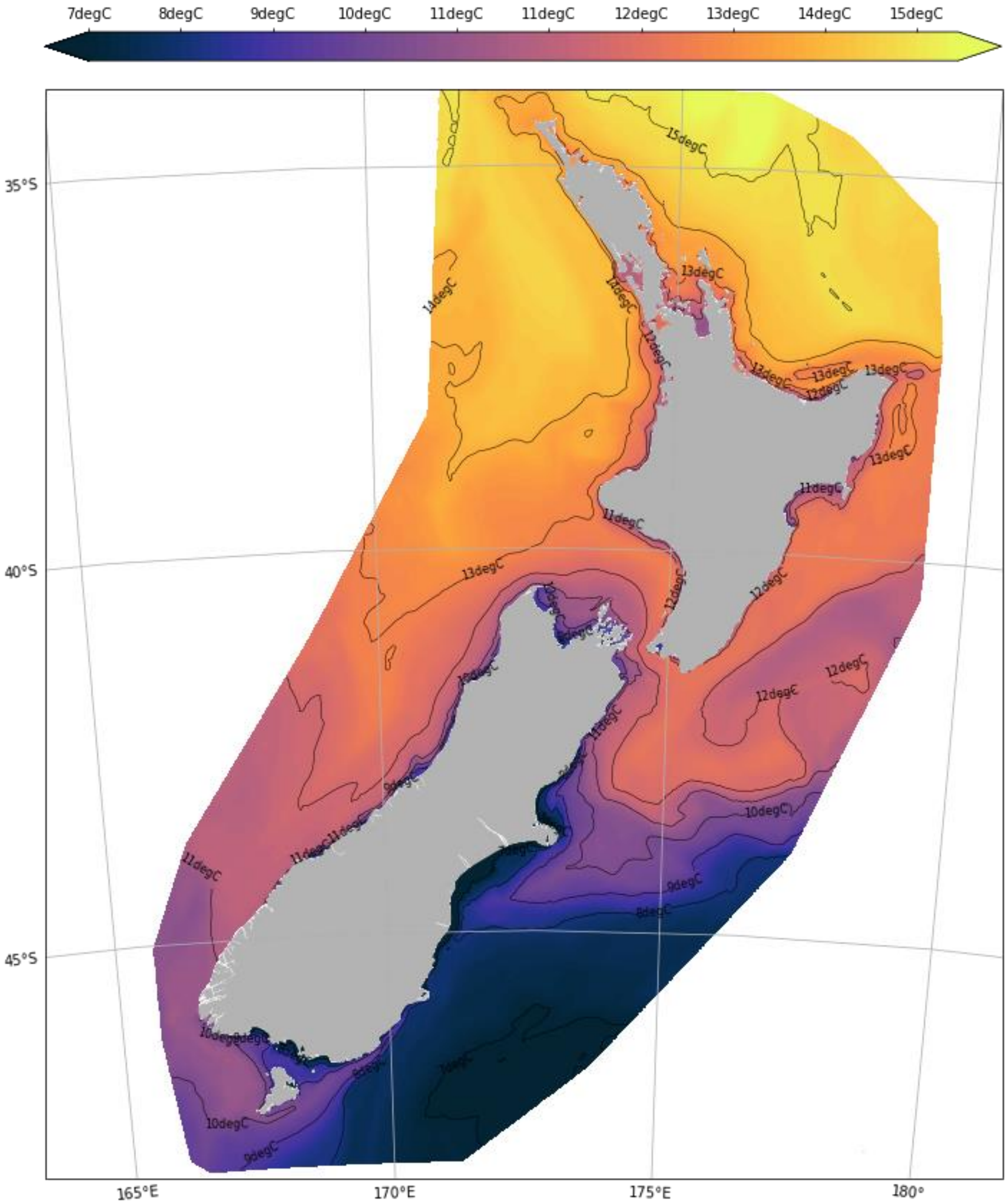

Figure 3.10 Annual minimum water temperature at 0.5 m depth.

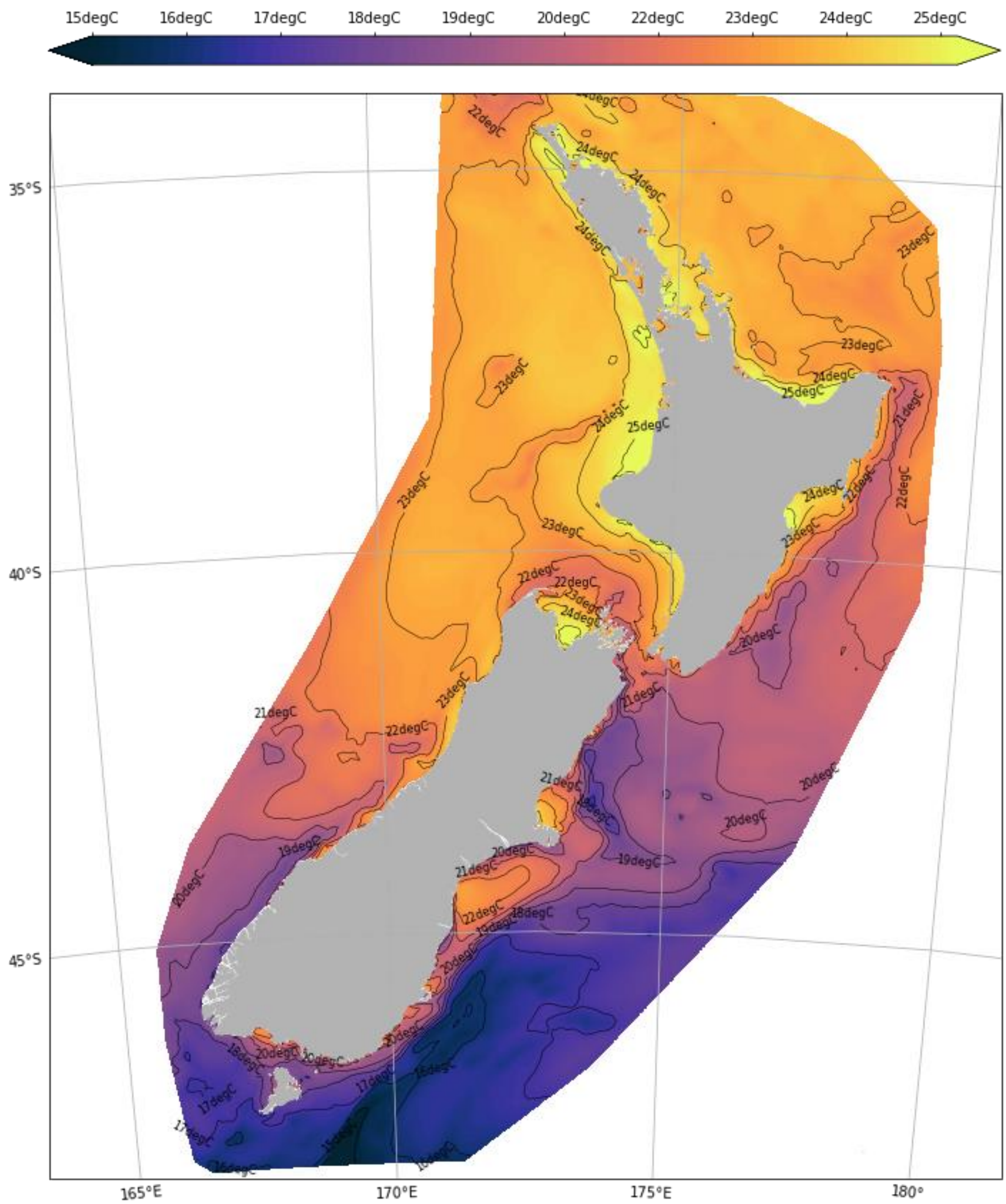

Figure 3.11 Annual maximum water temperature at 0.5 m depth.

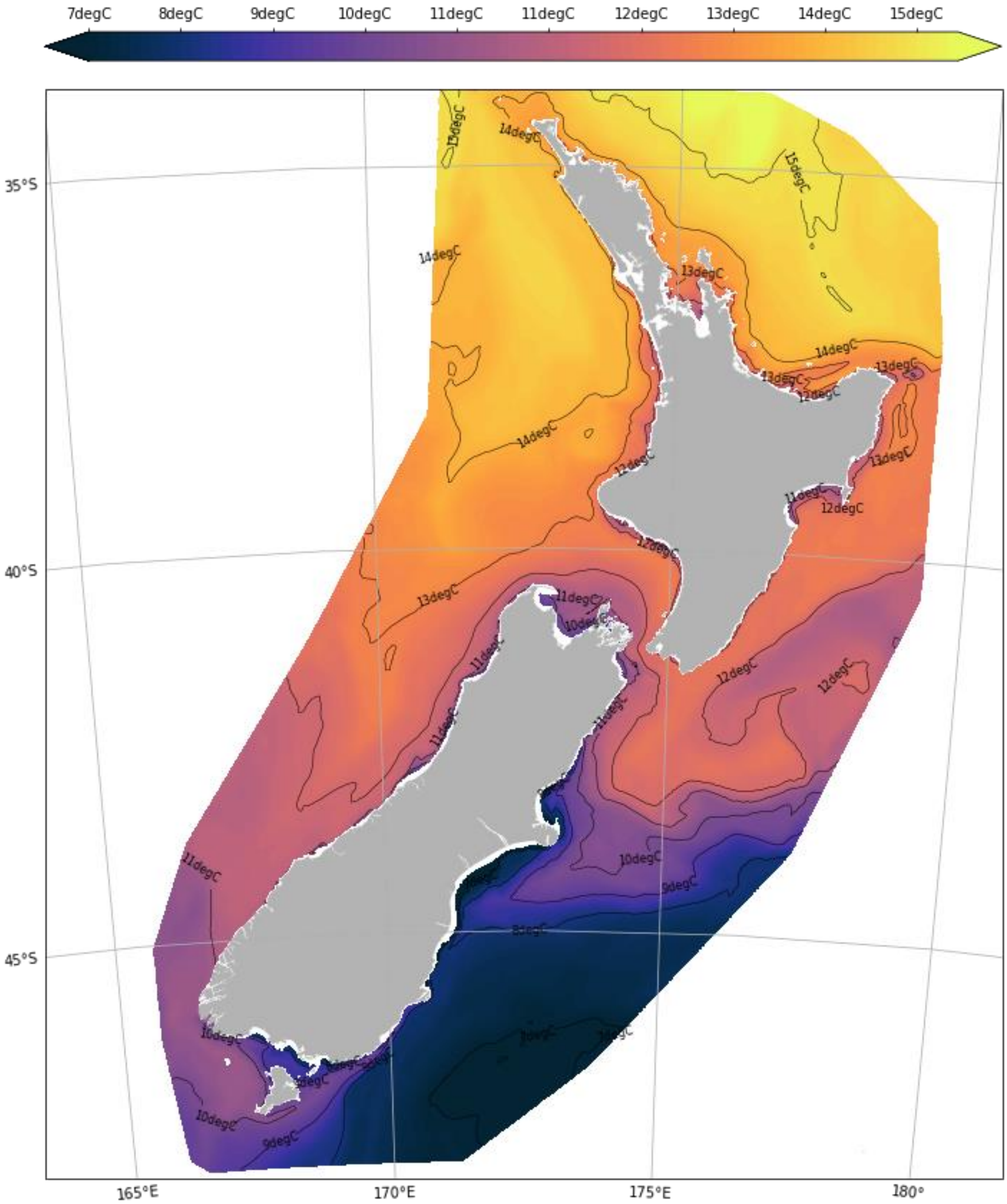

Figure 3.12 Annual minimum water temperature at 20 m depth.

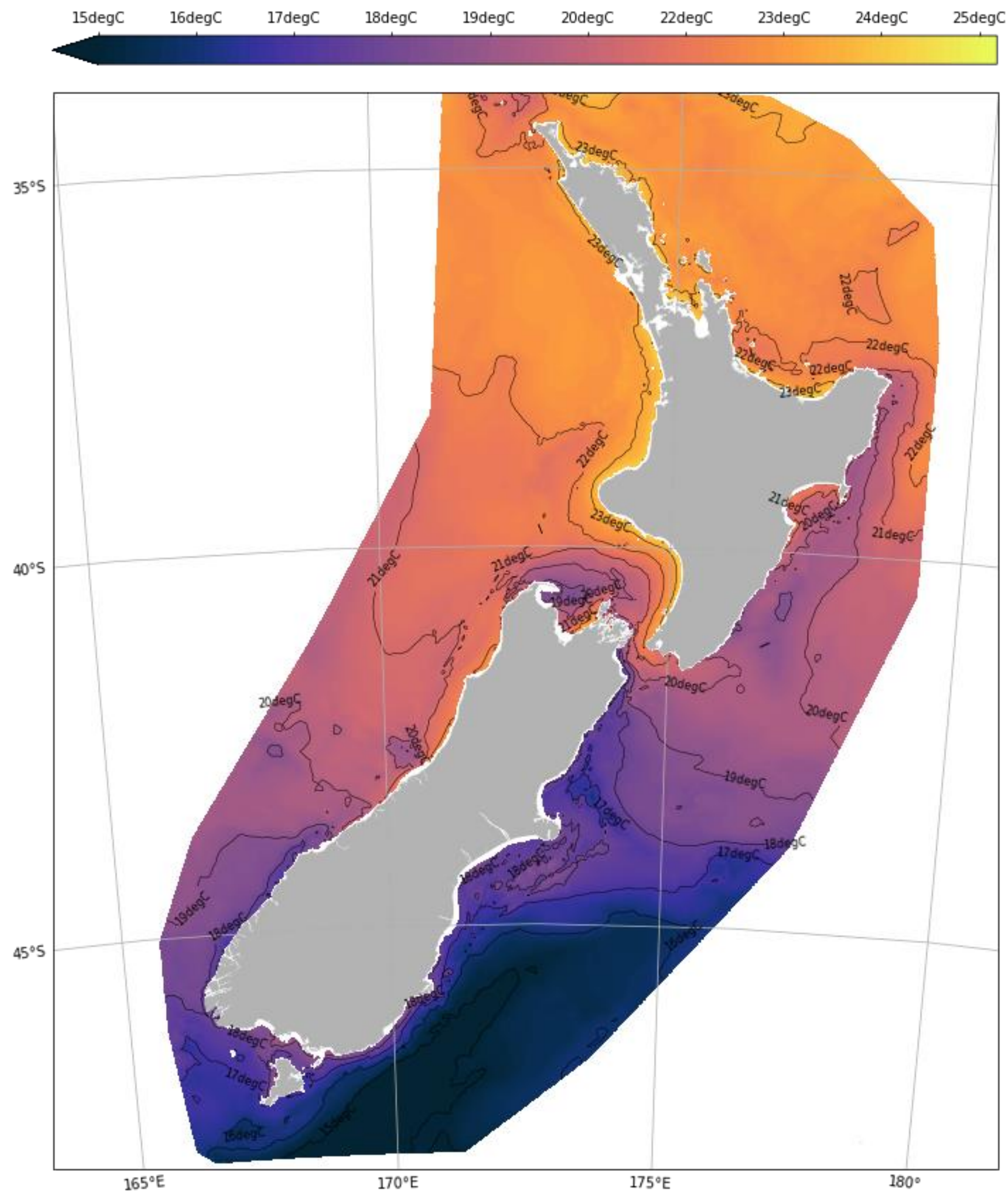

Figure 3.13 Annual maximum water temperature at 20 m depth.

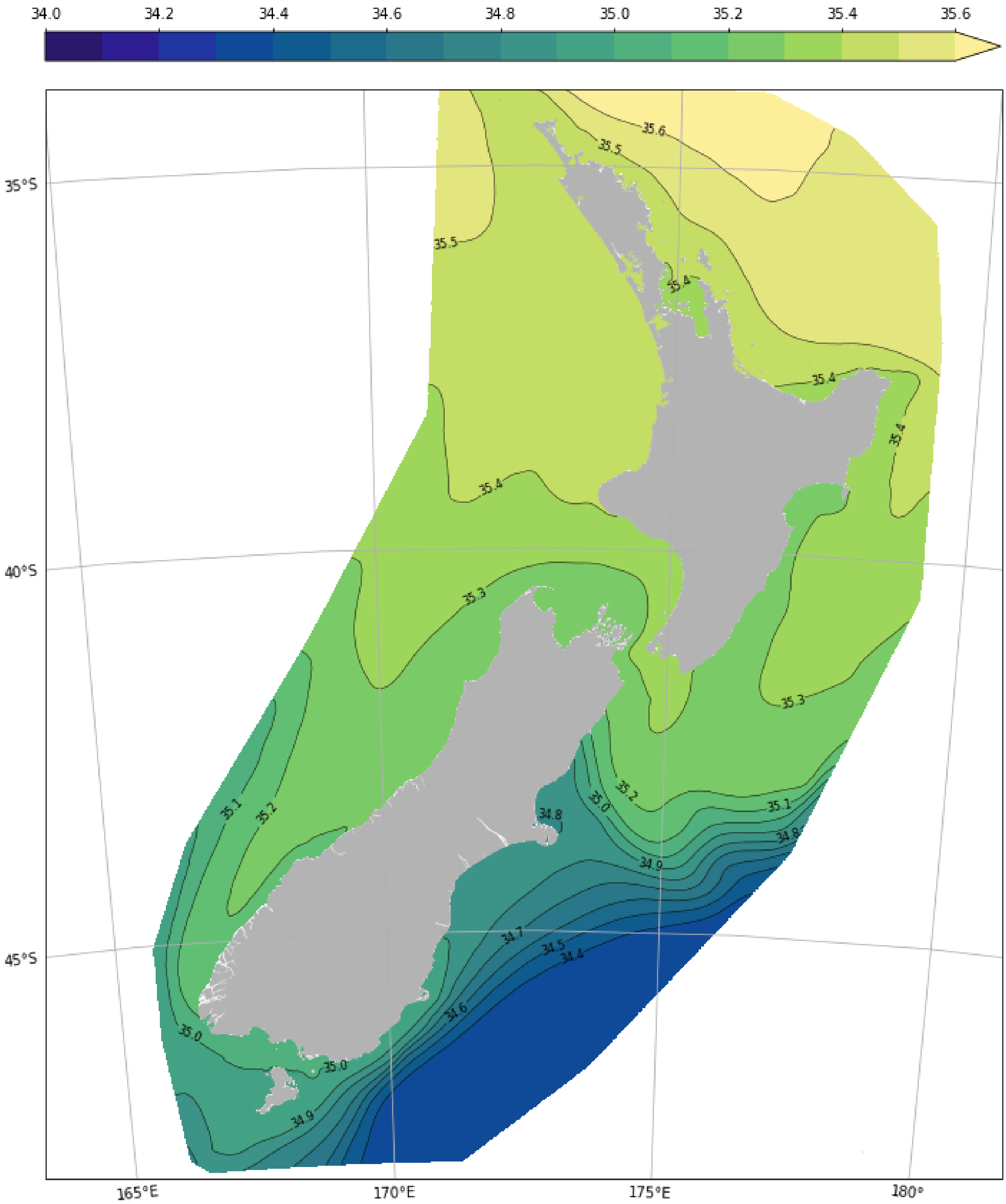

Figure 3.14 Annual mean salinity at 0.5 m depth.

4. DATA ACCESS

The DataCube can be accessed remotely via the Oceanum Data Service, with a request functionality to rapidly download timeseries for any location within the domain, or map layers of the derived statistics. Instructions for the current version of the User Interface (UI) are as follows:

Go to https://oceanum.io/ using a modern browser. When asked to sign in, create a new account or log in to an existing account. For timeseries data extraction:

- Use the data access interface to construct a data request.
- Select a gridded dataset - the geographical extent will appear on the map.
- Select request type (points or a route).
- Select variables (optional).
- Select time range (optional).
- Select file format.
- Choose locations, upload a csv of locations, or draw a route on the map.
- Press the request button to start the request.
- Once the request is complete a download link will appear.

To access the layers of derived statistics from the DataCube, these can be found in the list of gridded datasets or by searching using key words. Metadata and the available variables can be found here. Clicking '*Get Data'* at the bottom of this page will take you directly to the UI described above.

There are several further options available for accessing data, the most up to date documentation can be found at https://docs.oceanum.io.

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