Provision of multi-decadal ocean boundary conditions and field measurements

Theme: Hydrodynamic Modelling

WAMSI Westport Marine Science Program

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WAMSI WESTPORT MARINE SCIENCE PROGRAM

ABOUT THE MARINE SCIENCE PROGRAM

The WAMSI Westport Marine Science Program (WWMSP) is a $13.5 million body of marine research funded by the WA Government. The aims of the WWMSP are to increase knowledge of Cockburn Sound in areas that will inform the environmental impact assessment of the proposed Westport development and help to manage this important and heavily used marine area into the future. Westport is the State Government's program to move container trade from Fremantle to Kwinana, and includes a new container port and associated freight, road and rail, and logistics. The WWMSP comprises more than 30 research projects in the biological, physical and social sciences that are focused on the Cockburn Sound area. They are being delivered by more than 100 scientists from the WAMSI partnership and other organisations.

FUNDING SOURCES
The $13.5 million WAMSI Westport Marine Science Program was funded by the Western Australian Government, Department of Transport. WAMSI partners provided significant in-kind funding to the program to increase the value to >$22 million.

DATA
Finalised datasets will be released as open data, and data and/or metadata will be discoverable through Data WA and the Shared Land Information Platform (SLIP).

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Contents

1 PROVISION OF MULTI-DECADAL OCEAN BOUNDARY CONDITIONS AND FIELD MEASUREMENTS............. I

2 INTRODUCTION 1

2.1 NEED 1
2.2 OBJECTIVES 1
2.3 OUTCOMES 1

3 NUMERICAL SIMULATIONS (HINDCAST SIMULATIONS).. 2

3.1 MODEL SET-UP AND EXAMPLE OUTPUT 2
3.2 MODEL OUTPUT AND STORAGE 7

4 RESULTS: NUMERICAL SIMULATIONS (CLIMATE FORECASTS).. 8

4.1 ACCESSING AND USING CMIP6 CLIMATE MODEL DATA...9
4.2 CMPI6 SSP245 AND SSP585 FUTURE SCENARIOS ALONG THE WA COAST...12
4.2.1 Sea surface temperature. 12
4.2.2 Mean sea level.. 20
4.2.3 Notes on mean sea Level projections. 24

5 RESULTS: FIELD MEASUREMENTS 25

5.1 EXAMPLE TIME SERIES DATA..27
5.1.1 ADCP data (vertical current profiles)... 27
5.1.2 Directional wave data... 28
5.1.3 Dissolved Oxygen data 31
5.1.4 Underwater PAR data... 31
5.1.5 Time series water depth data.. 32
5.1.6 Meteorological data 33

6 CONCLUSIONS/RECOMMENDATIONS 34

6.1 RECOMMENDATIONS..34

7 APPENDICES... 35

7.1 APPENDIX 1 – MODEL DATA OUTPUT INFORMATION 35
7.2 APPENDIX 2 – DETAILS OF DATA AVAILABILITY FROM EACH FIELD DEPLOYMENT 37

The WAMSI Westport Marine Science Program is a $13.5 million body of research that is designed to fill knowledge gaps relating to the Cockburn Sound region. It was developed with the objectives of improving the capacity to avoid, mitigate and offset environmental impacts of the proposed Westport container port development and increase the WA Government's ability to manage other pressures acting on Cockburn Sound into the future. Funding for the program has been provided by Westport (through the Department of Transport) and the science projects are being delivered by the Western Australian Marine Science Institution.

1 Provision of multi-decadal ocean boundary conditions and field measurements

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Project

Theme 5.1 Hydrodynamics Provision of multi-decadal ocean boundary conditions and field measurements

Executive Summary

Open ocean boundary conditions and field measurements for model validation are essential for the operation of high resolution local numerical models. Therefore, the main objectives of this theme were to: (1) provide open ocean boundary conditions for the period 2000-2022 and future climate scenarios (to 2100) under different emission scenarios; and (2) collect oceanographic data within Cockburn Sound and Owen Anchorage in 2021-2022. This report provides results against these two aims and is structured into 2 sections (Sections 4 and 5 of this report):

Section 4 – Boundary conditions for local models

(1) The Regional Ocean Modelling System (ROMS) numerical model runs were completed for the period 2000-2022. This output has been uploaded to the WAMSI/WESTPORT data portal (https://catalogue.data.wa.gov.au/org/western-australian-marine-science-institution).

To simulate realistic ocean currents, mixing, temperature and salinity fields in the whole water column to be used as boundary conditions for a higher resolution model of Cockburn Sound, we used the Regional Ocean Modelling System (ROMS). The modelling system set by the UWA coastal oceanography group consisted of a model domain for wider western region of Australia at ~ 1.5 – 2.5 km horizontal resolution nested inside global Mercator Nucleus for European Modelling of the Ocean (NEMO) Ocean model with additional tidal boundary forcing. Complete hourly bulk flux ERA-5 (fifth generation European Centre for Medium-range Weather Forecast reanalysis for the global climate and weather) atmospheric forcing fields (winds, air temp, humidity, mean sea level pressure, precipitation, total short-wave and outgoing long-wave heat fluxes) were used to provide realistic atmospheric forcing for the ocean model. This model configuration was run in hindcast mode for the period 2000-2022 (i.e. a total of 23 years). The model output is available from the whole grid to provide realistic and consistent boundary conditions to a higher resolution local model. The data includes: (a) one-hourly intervals in two dimensions for water level, sea surface temperature, sea surface salinity, and ocean vertical averaged currents; and, (b) three-hourly intervals in three dimensions for temperature, salinity and ocean currents.

(2) Future scenarios under climate change for two different Shared Socioeconomic Pathways (SSP) scenarios: SSP245 and SSP585

Climate models are one of the primary means for scientists to understand how the climate has changed in the past and may change in the future. These models simulate the physics, chemistry and biology of the atmosphere, land and oceans in detail. Climate models are constantly being updated and these

updates coordinated with the Intergovernmental Panel on Climate Change (IPCC) assessments. These models are part of the Coupled Model Intercomparison Project (CMIP). The latest IPCC sixth assessment report (AR6) featured new state-of-the-art CMIP6 models. In this project we used the most recent global CMIP6 product with the highest temporal and spatial resolutions for ocean variables for the south-east Indian Ocean. We used two separate Shared Socioeconomic Pathways (SSP) scenarios assumed to continue throughout the 21st century: (i) SSP245 represented a “middle of the road” scenario that assumed historical patterns of development; and, (ii) SSP585 assumes an energy-intensive, fossil fuel-based economy (‘high’ emission). CMIP6 model outputs are daily means at 25 km resolution for Sea Surface Temperature (SST), surface winds, sea level and precipitation. For this study, we focused on the SST and steric sea level (sea level due to density changes). We initially computed monthly mean anomalies for the two scenarios (SSP245 and SSP585) and then applied the anomaly as a future scenario “offset” for the UWA model. In other words, we created synthetic high-resolution sea surface temperature fields for any year to the future, under the SSP245/585 scenarios using pre-computed local offsets based on the climate models (long term variability) and superimposed them on the local model keeping high frequency energetic content.

The SST predictions to 2100 indicated that the annual mean rate of SST increase was 0.015 and 0.03^{o}C per annum, under SSP245 and SSP585, respectively. This is predicted to increase the mean SST by 1.27^{o} and 3.31^{o}Celsius by 2100 under SSP2 and SSP5, respectively.

Section 5 - Field measurements collected over the period 2021-2022

Collection of field measurement form an integral part of any oceanographic investigation. Analysis of the data allows for the documentation of the dominant processes that are active in the study region as well as for validating numerical models. As part of Theme 5 of the WAMSI Westport Marine Science Program field measurements were collected at up to seven locations over five deployment periods within Cockburn Sound and Owen Anchorage over the period 2021-2022. The deployments covered winter, spring, summer and autumn conditions. The project also included the installation of meteorological station for the provision of weather data including PAR in Cockburn Sound which was installed on the Cockburn Cement landing jetty. In this report a summary of the deployments is provided with example time series of data collected. Data analysis did not form part of this project.

During the field campaign up to 25 different sensors were deployed. All the data collected have been quality assured and controlled and are available through the WAMSI data portal. The complete data set, in compressed netCDF data format, amounts to 45.7Gb.

2 Introduction

Open ocean boundary conditions are essential for the operation of high resolution local numerical models. Therefore, the main objectives of this theme are to: (1) provide open ocean boundary conditions using the existing UWA Regional Ocean Modelling System (ROMS) for the period 2000-2022 and future climate scenarios; and (2) collect oceanographic data, in particular on ocean currents at seven locations within Cockburn Sound and Owen Anchorage in 2021-2022 that will cover spring, summer and autumn conditions. Field measurements also included the installation of an ongoing weather station (wind speed/direction; dry/wet bulb temperature; atmospheric pressure; precipitation, solar radiation and PAR) along the eastern shoreline.

Cockburn Sound is situated on the coast of Western Australia, 35km south of Perth. Its total surface area is 80 km^2 and volume is approximately 1.2 x109m^3. The Sound is bounded to the west by Garden Island and to the south and east by the Australian mainland. It is oval shaped consisting of a central deep basin approximately 14 km long, 5 km wide with a maximum depth of 22m. Along the eastern side, between Woodman Point and James Point, lies a shelf region (Kwinana Shelf) with a maximum width of four km and a depth less than ten metres. The northern entrance (Garden Island - Carnac Island - Woodman Point) has a cross-sectional area of approximately 28000 m^2 and depth of five metres or less. There are two shallow submerged sills, the Parmelia Bank and Success Bank, which cover the full entrance with depths between two to five metres. There is also a narrow shipping channel that cuts through the Sound's northern opening with a depth of 15m. To the south of the Sound is Mangles Bay, which forms a protected pocket along with the Southern Flats are approximately one to three metres deep. Due to the presence of these sills Cockburn Sound can be considered to act as a 'Mediterranean Sea' with restricted outflow of deep basin water at the southern entrance.

2.1 Need

Open ocean boundary conditions for a realistic local high-resolution model and field measurements for model validation are essential for any coastal development project. This theme provided open ocean boundary conditions for the local hydrodynamic modelling to be used for Environmental Impact Assessment (EIA) and collect field data for model calibration and validation.

2.2 Objectives

The main objectives of the project were to provide ocean boundary conditions required for the development and application of local numerical models within Cockburn Sound:

(1) in hindcast mode for the period 2000-2022.
(2) for future climate scenarios (to 2100) under two Shared Socioeconomic Pathways (SSP) scenarios: (i) SSP2 representing a "middle of the road" scenario that assumed historical patterns of development (business as usual scenario); and (ii) SSP5 assumes an energy-intensive, fossil fuel-based economy ('high' emission scenario).
(3) acquire hydrodynamic data on ocean currents (for the purpose of validating a local hydrodynamic model), at up to seven locations over five deployment periods within Cockburn Sound and Owen Anchorage over the period 2021-2022. The deployments covered winter, spring, summer and autumn conditions.

2.3 Outcomes

All the objectives were successfully completed, and all of the data lodged with the WAMSI-WESTPORT data repository as S3 buckets in Pawsey Supercomputing Centre.

3 Numerical simulations (hindcast simulations)

The University of Western Australia (UWA) was contracted by WAMSI to provide ocean current circulation dataset for a 23-year period covering western region of WA. Model output derived from this dataset will used to provide initial and boundary conditions for the higher resolution local model to be developed for the specific region of the scope, i.e. Cockburn Sound.

To appropriately define ocean dynamics, a three-dimensional numerical model capable of simulating the circulation effects arising from atmospheric-driven systems (i.e. fluxes between ocean and atmosphere) as well as their interaction with the sub-mesoscale features (e.g. eddies), at sufficient horizontal and vertical resolution across the whole range along the West coast was required.

The three-dimensional Regional Ocean Modelling System (ROMS) numerical model (http://www.myroms.org/) was selected for the circulation modelling. It is a modern, globally recognized, 3-D hydrostatic, non-linear, free surface, s-coordinate, time splitting finite difference primitive equation numerical ocean model. The ROMS model includes high order, state-of-the-art numerical algorithms that use full atmospheric-ocean boundary layer exchange (i.e. wind, short/longwave heat fluxes, moisture flux, rainfall and pressure) forcing together with tidal forcing to reproduce three-dimensional density and current fields in time. ROMS is a split-explicit time stepping, free-surface oceanic model which numerically solves the set of equations used to describe the physics of the ocean (e.g., mass and momentum budgets, the equation of state for seawater, and conservation equations for tracers such as temperature). These equations are discretised on an orthogonal, curvilinear coordinate system in the horizontal direction and a stretched, terrain-following coordinate system in the vertical direction. The ROMS model is a widely accepted and validated within the global oceanographic community and successfully used by UWA for many applications in Australia.

The existing modelling system set by the UWA coastal oceanography group consists of a model domain for the wider western region of Australia at ~ 1.5 – 2.5 km horizontal resolution. The boundaries of the model are shown on Figure 3.1. This model grid was nested inside global Mercator NEMO Ocean model (https://www.nemo-ocean.eu/) with additional tidal boundary forcing. Simulations were undertaken at Pawsey Supercomputing Centre. Complete hourly bulk flux ERA-5 atmospheric forcing fields (winds, air temp, humidity, mean sea level pressure, precipitation, total short-wave and outgoing long-wave heat fluxes) were used to provide realistic atmospheric forcing for the ocean model. This model configuration was run in hindcast mode for the period 2000-2022 (23 years) and then for a future scenario to encompass climate change effects (see section 4). The model bathymetry and resolution are presented in Figure 3.2.

3.1 Model set-up and example output

To configure a numerical model some parameters (e.g. bottom friction) are well established with known characteristics, whilst other aspects (e.g., model domain, appropriate bathymetry, initial state and boundary conditions) are determined on a case-by-case basis on the balance of data availability, computational running time versus project schedule, minimum resolution needed to resolve relevant processes, and model simulation extent. UWA has been using and further developing the ROMS model configuration for the near real-time and hindcast applications for more than ten years.

The complete surface bulk flux from the ERA5 - ECMWF European Centre for Medium-range Weather Forecast (https://www.ecmwf.int/en/forecasts/dataset/ecmwf-reanalysis-v5) at the native spatial ~ 25 km and 1-hour temporal resolution was downloaded for the 23 years (2000 - 2022) to provide realistic model forcing in our re-analysis simulations. In the ocean, NEMO – Mercator global ocean model 3D daily ocean fields without tides and at the native horizontal resolution ~10 km was downloaded for the model region (Figures 2.1 and 2.2) and the time period to provide realistic initial and boundary conditions for the ROMS model. In addition, tidal forcing included using 15 tidal constituents (Pugh, 1987): M_2, S_2, N_2, K_2, K_1, O_1, P_1, Q_1, M_M, M_F, M_4, MN_4, MS_4, $2N_2$, S_1. The tidal forcing was synthesised for each year (to account for nodal correction), and then added at the NEMO boundary conditions to provide additionally forcing for realistic ocean dynamics at the wider range of higher-tidal frequency band. The final model domain and key model parameters are shown in Figures 3.1 and Table 1, respectively.

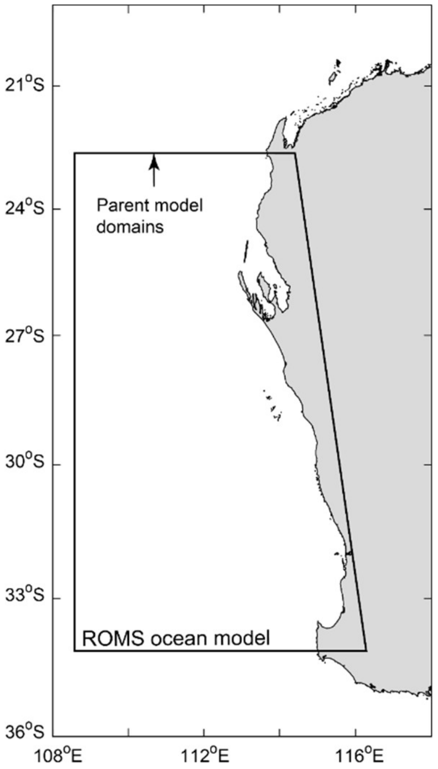


Figure 3.1. The extent of the UWA ROMS ocean model domain

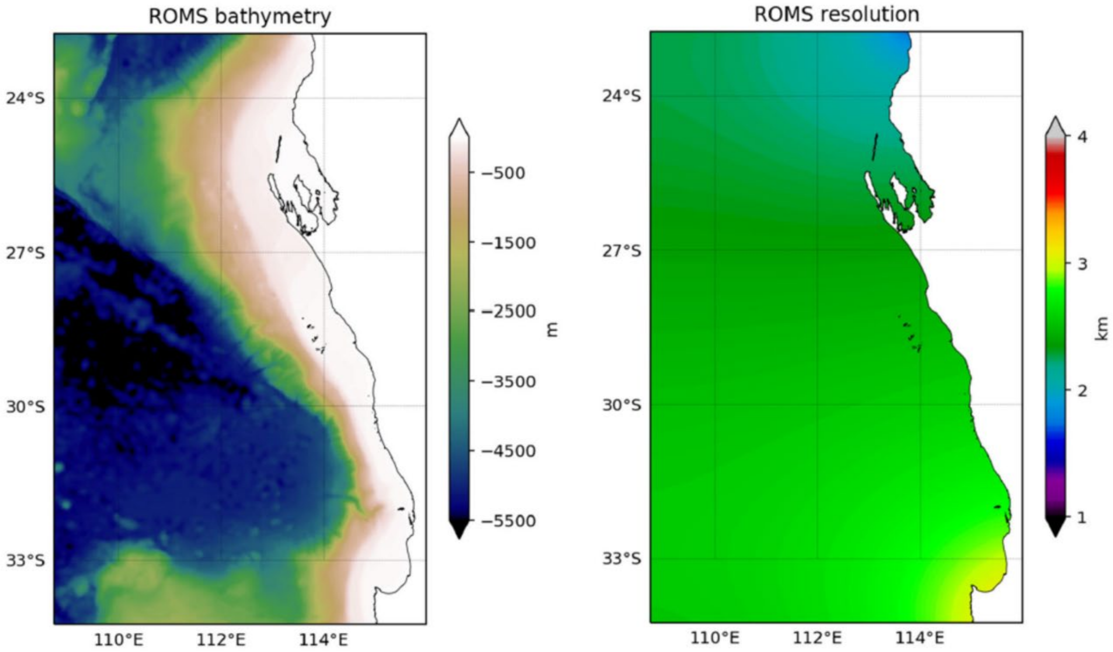


Figure 3.2. Bathymetry (left) and model resolution (right) used in the UWA ROMS model simulations. (colours shows bathymetry in metres and resolution in km)

Table 1. Model parameters used in the ROMS simulations.

Parameter	Comment
Horizontal resolution Model	Minimum 1.0 km Maximum 3.0 km
Time step	Baroclinic/Barotropic: 60s/2s
Number of vertical layers, terrain following)	25
Number of horizontal grid points	480 x 640
Initial and boundary conditions	From NEMO
Vertical mixing scheme Horizontal	K-Epsilon
Advection scheme	3rd order HSIMT-TVD

Using this approach, we were able to downscale global ocean model to five times finer horizontal resolution, better capturing regional features (such as bathymetry, islands important for spectral signature of the model) and provide frequent (hourly) boundary conditions for future high resolution nested modelling activity inside the Cockburn Sound.

The initial model run for year 2000 required approximately 10Gb of input data from the NEMO global ocean model and 10Gb of ERA-5 atmospheric forcing to hold all required variables at hourly intervals, whilst the ROMS model created ~1.6Tb of model outputs. Post-processing the ROMS output files and using efficient compression in netCDF compressed files reduced the size to a more manageable 200Gb of model data/year (a compression rate of ~10 times). In total, about 4Tb of model outputs for the 23-year simulation were archived instead of an initial volume of about 40Tb of model output.

We have completed the simulation for the whole period (see section 3.3). An example time series of temperature and salinity for Cockburn Sound over the simulation period (2000-2022) indicated the severe heatwave in 2011 with the maximum temperature of 27.0^{o}Celsius with the higher temperatures continuing to 2014 (Figure 3.3). There was also a salinity minimum (34.8) associated with this event. The minimum temperature occurred in 2016 (15.0^{o}Celsius). Another feature is the almost constant maximum and minimum values of both temperature and salinity over the period 2001-2009, reflecting the ‘hiatus’ of the Leeuwin Current system (Figure 3.3). Note that these values reflect the ocean conditions and do not include local forcing such as freshwater input from the Swan River.

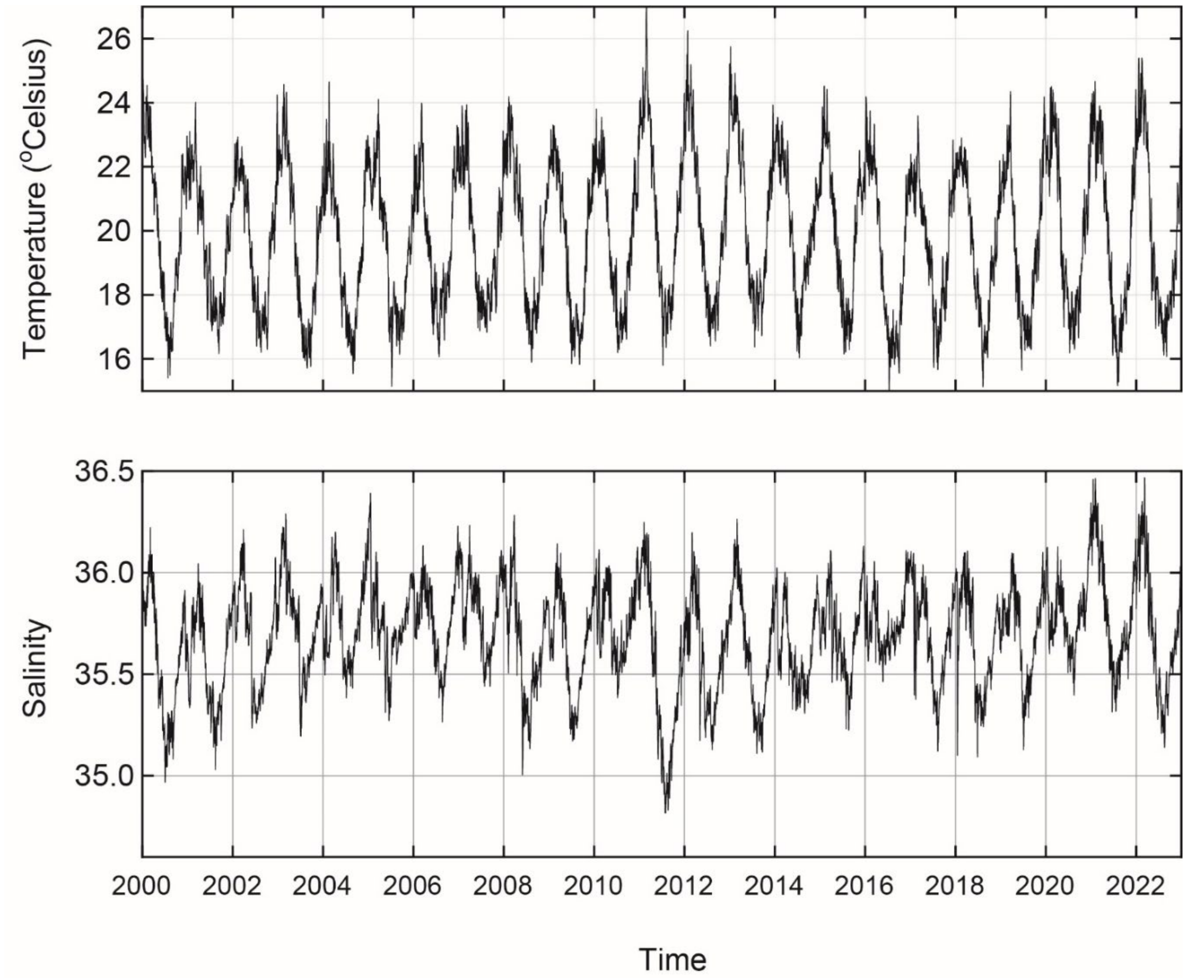


Figure 3.3. Time series of temperature and salinity for the period 2000-2022 from Cockburn Sound.

An example time series for 2001 is shown for a location to the north-west of Rottnest Island (31.6174°S 115.2524°E) in approximately100 m water depth (Figures 3.5 and 3.6). This location is at the boundary of the Leeuwin and Capes Currents, and this is reflected in the time series data. The water level data (Figure 3.4) reflect the tidal variability over the annual cycle with increased tidal range close to solstice (December and June) and lower range close to the equinox (March and September). The annual cycle of the mean sea level is also reproduced with higher (lower) mean sea level in May/June (September/October) co-incident with the stronger (weaker) Leeuwin Current. Note that individual storm surges are not reproduced due to the lower time and space resolution of the atmospheric forcing. These include water level, current speed (Figure 3.5), north-south currents (Figure 3.6) temperature (Figure 3.7) and salinity (Figure 2.8). The currents reflect the seasonal cycle of the winds with stronger currents speed and north-south component) being stronger during the warmer months reflecting the synoptic southerly wind forcing (Figures 3.5 and 3.6). In general (Figure 3.6), there were northward currents during the warmer months (October-April) and southward currents during the cooler months (May to September). There were also strong northward currents in July 2011, most likely due to eddies associated with the Leeuwin Current (Figure 3.6). The temperature and salinity time series reflected the seasonal cycle. During January there was vertical stratification, most likely due to coastal upwelling (Figures 3.7 and 3.8). The maximum temperature was over the period April to June coinciding with late autumn and winter associated with the lower wind speeds and strengthening of the Leeuwin Current. There was progressive cooling over the period August to November (Figure 3.7). The salinity was a maximum during April/May and lowest during June to August (Figure 3.8). Although these figures relate to 2001, all the other years had similar seasonal features.

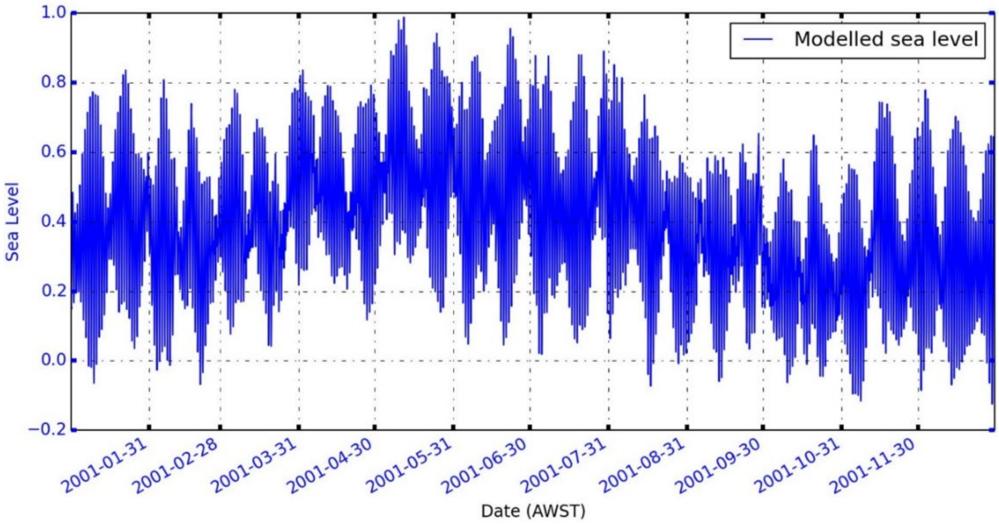


Figure 3.4. Time series of predicted water level in m for 2001 (AWST: Australian Western Standard Time)

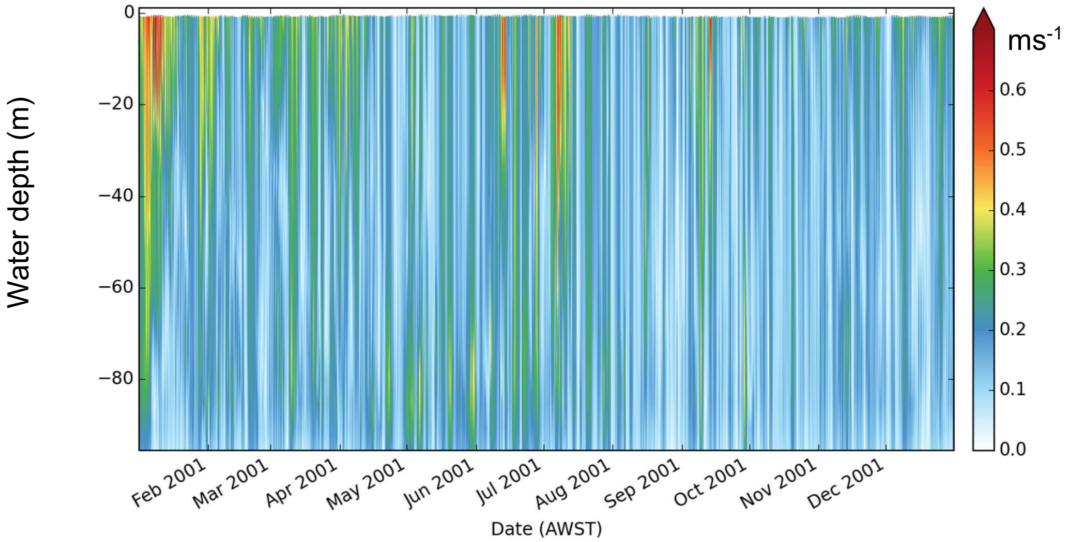


Figure 3.5. Time series of current speed for 2001 (AWST: Australian Western Standard Time)

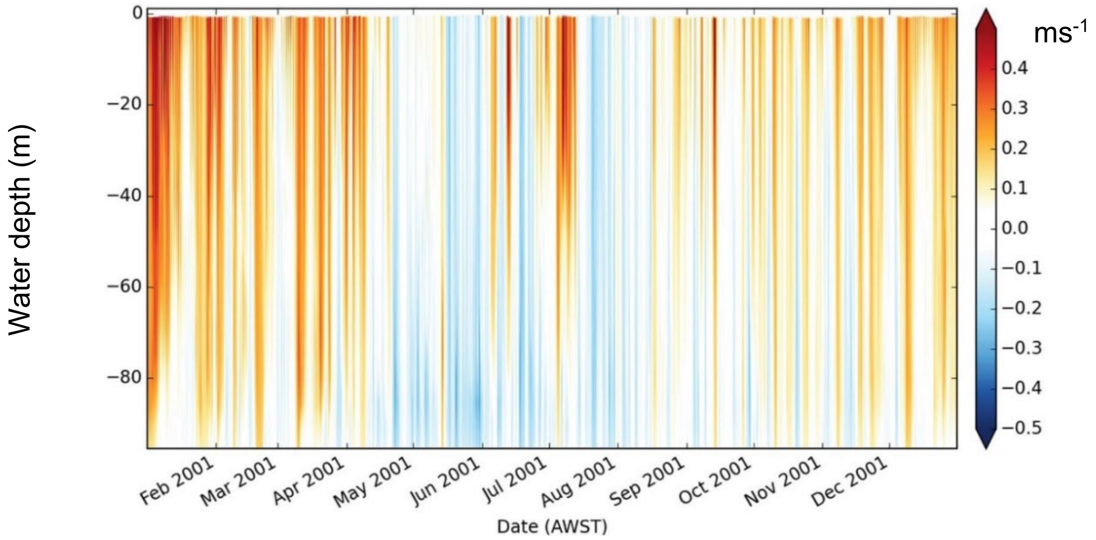


Figure 3.6. Time series of north-south component of currents for 2001 (AWST: Australian Western Standard Time)

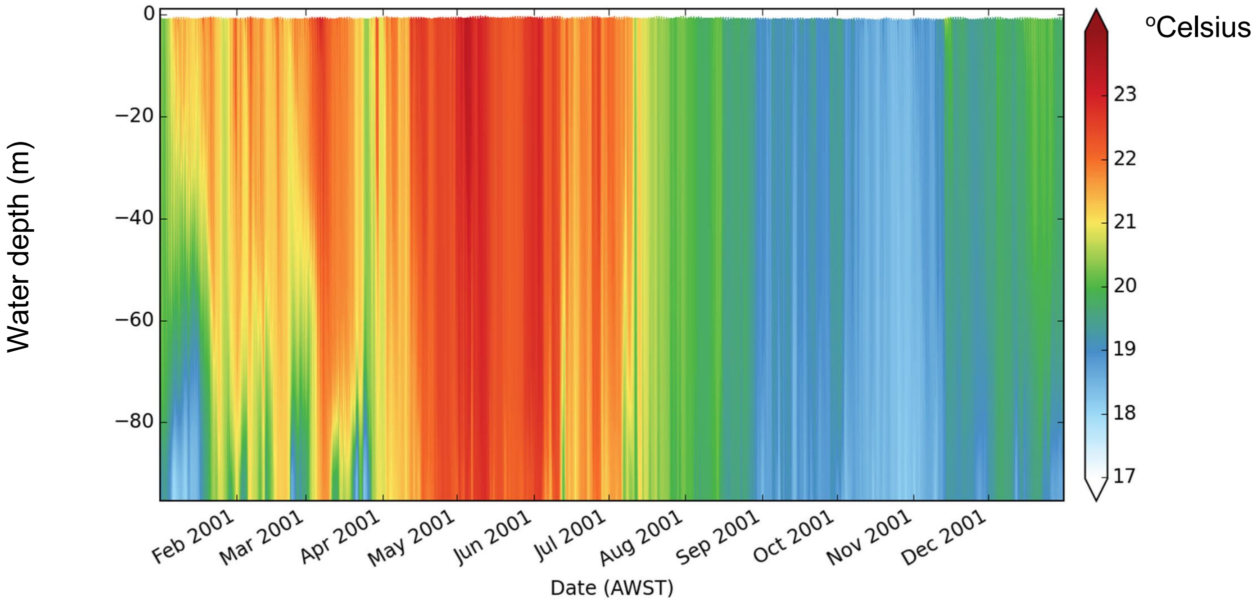


Figure 3.7. Time series of temperature for 2001. (AWST: Australian Western Standard Time)

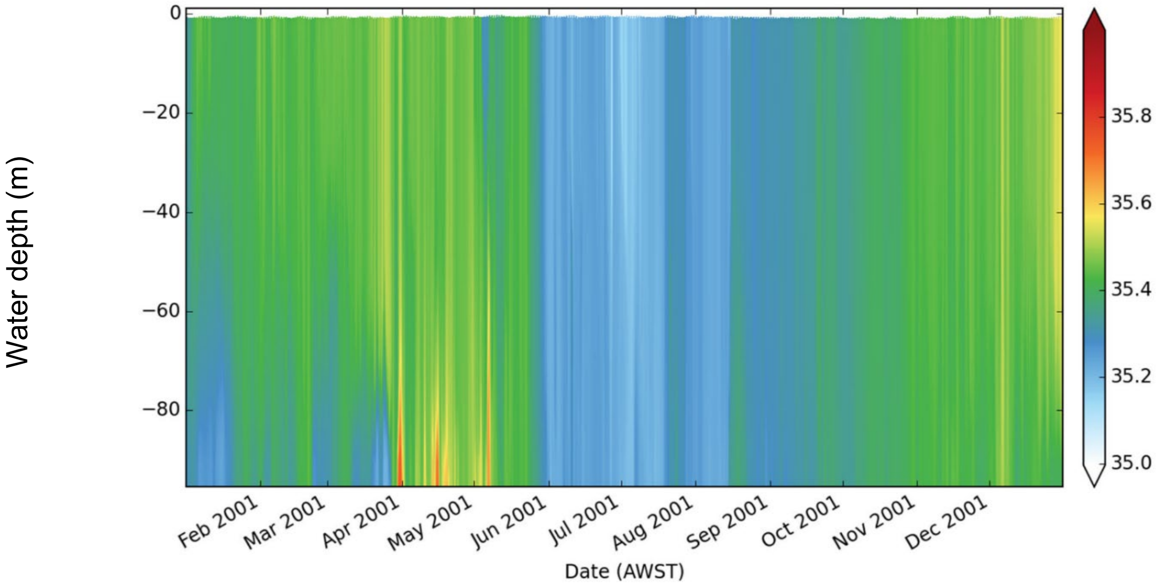


Figure 3.8. Time series of salinity for 2001 (AWST: Australian Western Standard Time).

3.2 Model output and storage

The archived model output is available for the whole grid (Figure 3.1) to provide realistic and consistent boundary conditions to any higher resolution local model and includes:

- water level, sea surface temperature, sea surface salinity, and ocean vertical averaged currents at hourly intervals (these are 2D parameters that change with time)
- temperature, salinity and ocean currents at three-hourly intervals in three dimensions (i.e. through the whole model domain in Figure 3.1) at three hourly intervals.

The model output has been uploaded to the WAMSI/Westport data portal (https://catalogue.data.wa.gov.au/org/western-australian-marine-science-institution) housed at the Pawsey Supercomputing Centre and details of file structure is listed in Appendix A. In total, there are 23607 objects in the archive with 3.5Tb of compressed data.

4 Results: Numerical simulations (climate forecasts)

Climate models are one of the primary means for scientists to understand how the climate has changed in the past and may change in the future. These models simulate the physics, chemistry and biology of the atmosphere, land and oceans in detail. Climate models are constantly being updated and these updates are coordinated with the Intergovernmental Panel on Climate Change (IPCC) assessments. Global climate modelling groups are actively producing large model outputs although they are not easily accessible for regional studies. These models are part of the Coupled Model Intercomparison Project (CMIP). The latest IPCC sixth assessment report (AR6) featured new state-of-the-art CMIP6 models. In this project we used the most recent global CMIP6 product with the highest temporal and spatial resolutions for ocean variables for the south-east Indian Ocean. We used two separate Shared Socioeconomic Pathways (SSP) scenarios assumed to continue throughout the 21st century: (i) SSP2 represented a “middle of the road” scenario that assumed historical patterns of development. We used the SSP245 scenario reflecting a 2100 atmospheric forcing of 4.5 Wm^{-2}; and, (ii) SSP5, which assumes an energy-intensive, fossil fuel-based economy (‘high’ emission). We used the SSP585 scenario reflecting a 2100 atmospheric forcing of 8.5 Wm^{-2}. CMIP6 model outputs are daily means at 25 km resolution for SST, surface winds, sea level and precipitation. For this study, we focused on SST and steric sea level (sea level due to density changes). We initially computed monthly mean anomalies for the two scenarios (SSP245 and SSP585) and then applied the anomaly as a future scenario “offset” for the UWA ROMS model. In other words, we created synthetic high-resolution SST fields for any year to the future, under the SSP245 and SSP585 scenarios using pre-computed local offsets based on the climate models (long term variability) and superimposed them on the local model keeping high frequency energetic content.

We focused on the latest available CMIP6 product and the highest temporal and spatial resolutions for ocean variables using “historical” and “medium emissions” scenarios (CMIP6 scenario SSP245 is equivalent to RCP45 in CMIP5). Historical values are needed to validate climate global models for a certain area, as well as to assess their capabilities to resolve temporal (daily) variations and spatial complex features, as well to compare those values with true observations (i.e. satellite data) or against high resolution data assimilative operational global and local models.

CMIP6 data were available for the period 2015 to 2100 and for the two different scenarios, SSP245 and SSP585. The CMIP6 model outputs are daily means at 25 km resolution for SST, surface winds, sea level and precipitation.

The aim of this modelling exercise was to provide boundary conditions to a higher resolution model of the Cockburn Sound region. A comparison between data available to run hindcast and climate scenarios are summarised in Table 2.

Table 2 – Comparison between the availability of boundary conditions to undertake hindcast and climate scenarios models.

Parameter	Hindcast model boundary conditions	Climate model boundary conditions (CMIP6)
Wind speed and direction	hourly	daily
Surface heat fluxes	hourly	none
3D currents	hourly	monthly
3D temperature and salinity	hourly	monthly
Sea surface temperature	hourly*	daily
Sea surface elevation	hourly	daily

* included in 3D files

4.1 Accessing and using CMIP6 climate model data.

Global climate modelling groups are actively producing large datasets not easily ingested by standard users and wider scientific community. The problem is that we have many products from multiple organizations focusing on a different future scenario, with differing model setups on native model resolutions.

It is important to note that global climate model results cannot be used directly for our local studies simply because they do not reproduce high enough (daily to weekly) variability. In case of the ocean 3D variables within CMIP6 archived datasets they are available at monthly mean values, posing limits to using them for local studies. To make them usable an option was to apply CPU/data expensive dynamical down-scaling (both for ocean and atmosphere as we need 2-way coupled consistent system). However, a more feasible method of computing daily/monthly anomalies using corresponding offsets for a specific year and global climate model historical outputs with our local high resolution validated ocean model (taking care of averaging for the same model spatial grid cells) requires that we first adjust for differences between our local ROMS and global model trends. For future scenario we computed anomalies with respect to the same historical years (the future emissions scenario effect inside the global model) and used them in the high-resolution local model (previously adjusted) for that specific year.

In our case we focused on the SST (“tos” variable in CIMP6) along the west coast of WA based on two climate models/institutions (“BCC” on native model resolution and “NOAA GFDL”). For example, BCC model for SSP245 experiment and years 2015-2034 is holding 7300 daily values on the 232x360 (1 degree resolution), while NOAA-GFDL model for years 2015-2100 is holding 31390 daily values on 1080x1440 spatial grid.

To check the ability to reproduce standard ocean features along the WA coast we extracted the CMIP6 NOAA-GFDL model (1/25^{o} spatial resolution) output and 3D monthly mean ocean temperatures (Figure 4.1a, at the 2.5m depth) and compared with the equivalent from global assimilative operational models such as HYCOM (Figure 4.1b) or Mercator NEMO (Figure 4.1c). Note that this compares results between models whilst comparison against satellite observed daily mean product (in our case we used L3S daily scenes from IMOS-AODN and computed monthly mean value) (Figure 4.1d) can further evaluate model(s) deviations from the true ocean state.

Focusing further on the Perth waters and extracting the data from both the BCC and NOAA-GFDL models, we can compare their capability in capturing seasonal and monthly variability (Figure 4.2). The NOAA-GFDL model reproduced the WA summer 2011 marine heat wave (MHW) more clearly than the BCC model. However, both models still underestimated MHW maximum temperature by 3^{o}C (Figure 4.2). In contrast, the BCC model showed a warmer 2013 summer (Figure 4.2).

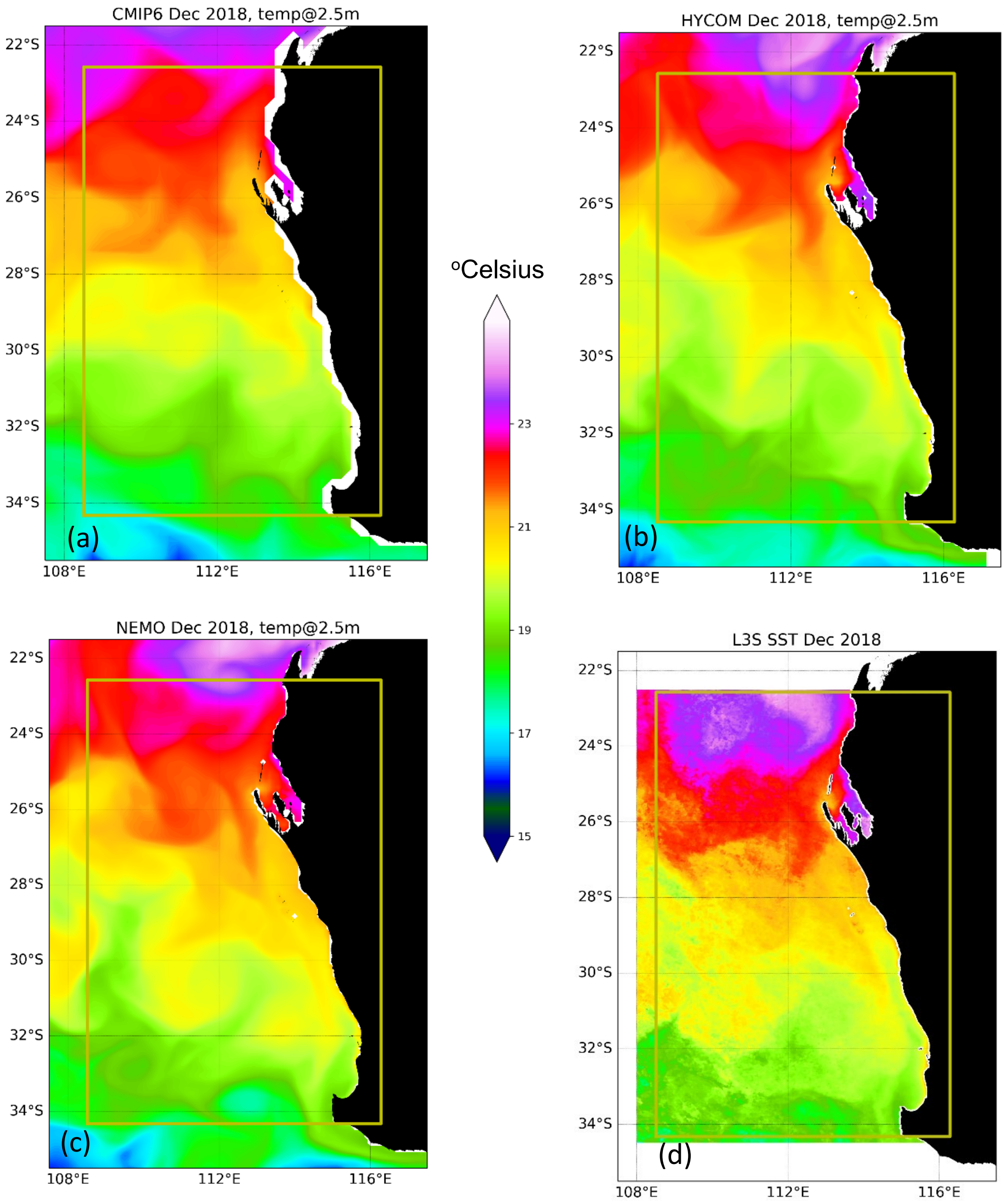


Figure 4.1. Monthly mean surface (2.5m depth) temperature for CMIP6 (a) NOAA-GFDL; (b) HYCOM model; (c) Mercator NEMO model; and (d) satellite L3S SST during Dec 2018.

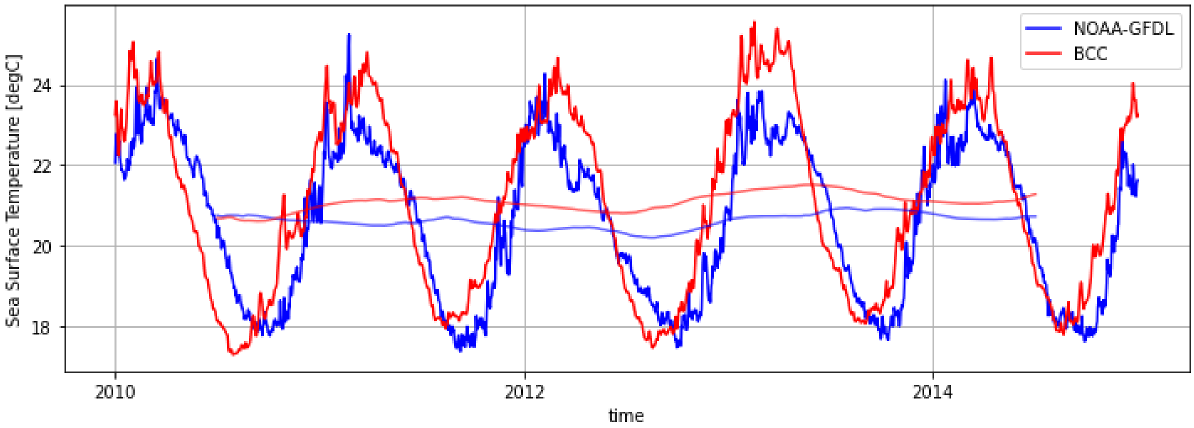


Figure 4.2. Daily SST for Perth waters based on 2 different global climate models.

Computing daily anomalies for the same period showed higher temperatures in 2011 associated with the severe heat wave offshore, as in the case of NOAA-GFDL solution based on the historical global model data (Figure 4.3).

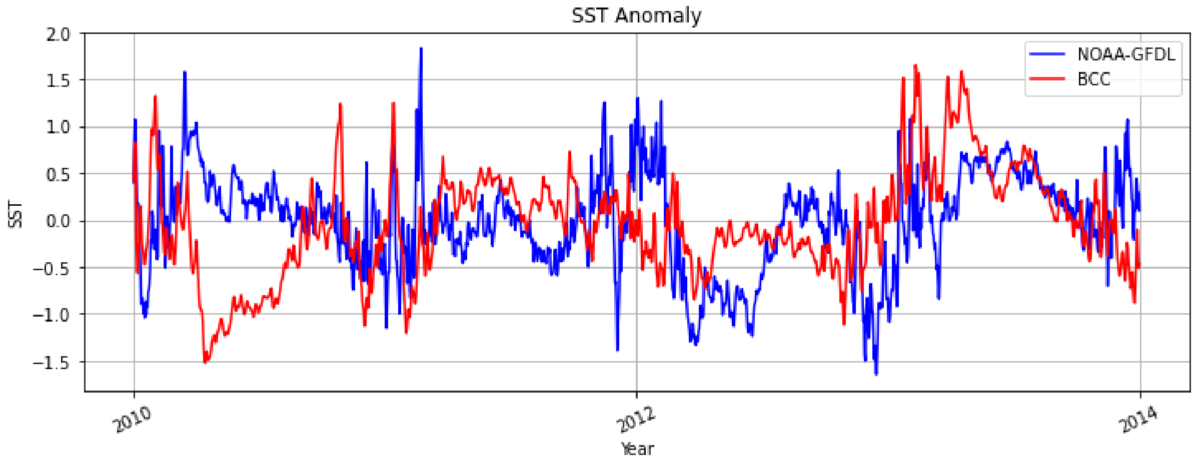


Figure 4.3. Daily sea surface temperature anomalies for both global climate models and Perth region.

However, comparison with daily L3S satellite data (representing the truth) indicate that climate models are still missing those high intensity peaks during the WA 2011 heat wave period (Figure 3.4). In contrast they are better resolved within the Mercator NEMO model (Figure 4.4. black curve).

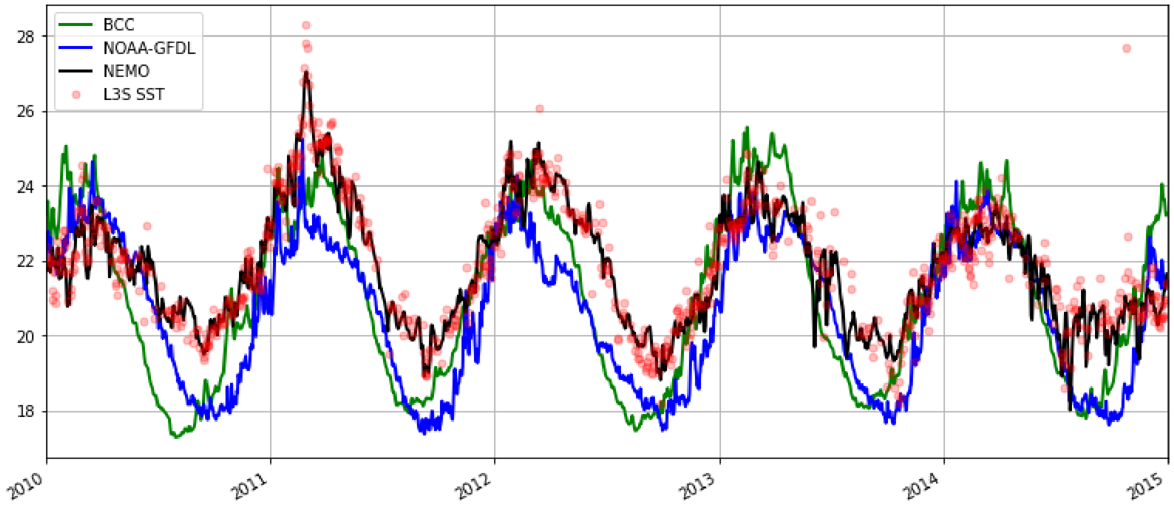


Figure 4.4. Comparison between different global climate (BCC and GFDL), operational (NEMO) models with the observed L3S remote sensing surface temperature and Perth waters.

We computed monthly mean anomalies for the targeted scenarios and chosen years (all based on the global climate models) and then applied them as anomaly-induced future scenario “offsets” for our small-scale (i.e. local Perth) high resolution models. In other words, we created synthetic high-resolution SST fields for any year in the future (and for the SSP245 and SPP/585 scenarios) using precomputed local offsets based on the climate models (long term variability) and superimposed them on the local model preserving the high frequency energetic content.

4.2 CMPI6 SSP245 and SSP585 future scenarios along the WA coast

4.2.1 Sea surface temperature.

In this section, we focussed on the CMIP6 global experiments and two scenarios (SSP245 and SSP585). For ocean variables we used surface ocean temperature (TOS) at the best available spatial and temporal (daily) and spatial (0.25o) resolutions. To that end we used GFDL-CM4 model outputs (https://www.gfdl.noaa.gov/coupled-physical-model-cm4/), validated and described in referenced publication https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2019MS001726. For this analysis we downloaded historical multiyear subset for WA coastal waters and then computed anomalies for each individual scenario (i.e. SSP245 and 2035 with historic 2014 SST). Therefore, the historic run for 2014 was used as a reference year to compute the change between SSP245 (during any year 2015-2100) with respect to the 2014 baseline solution (Figure 4.5a). The resulting anomalies were used as a correction for the ROMS model run and for the same 2014 year.

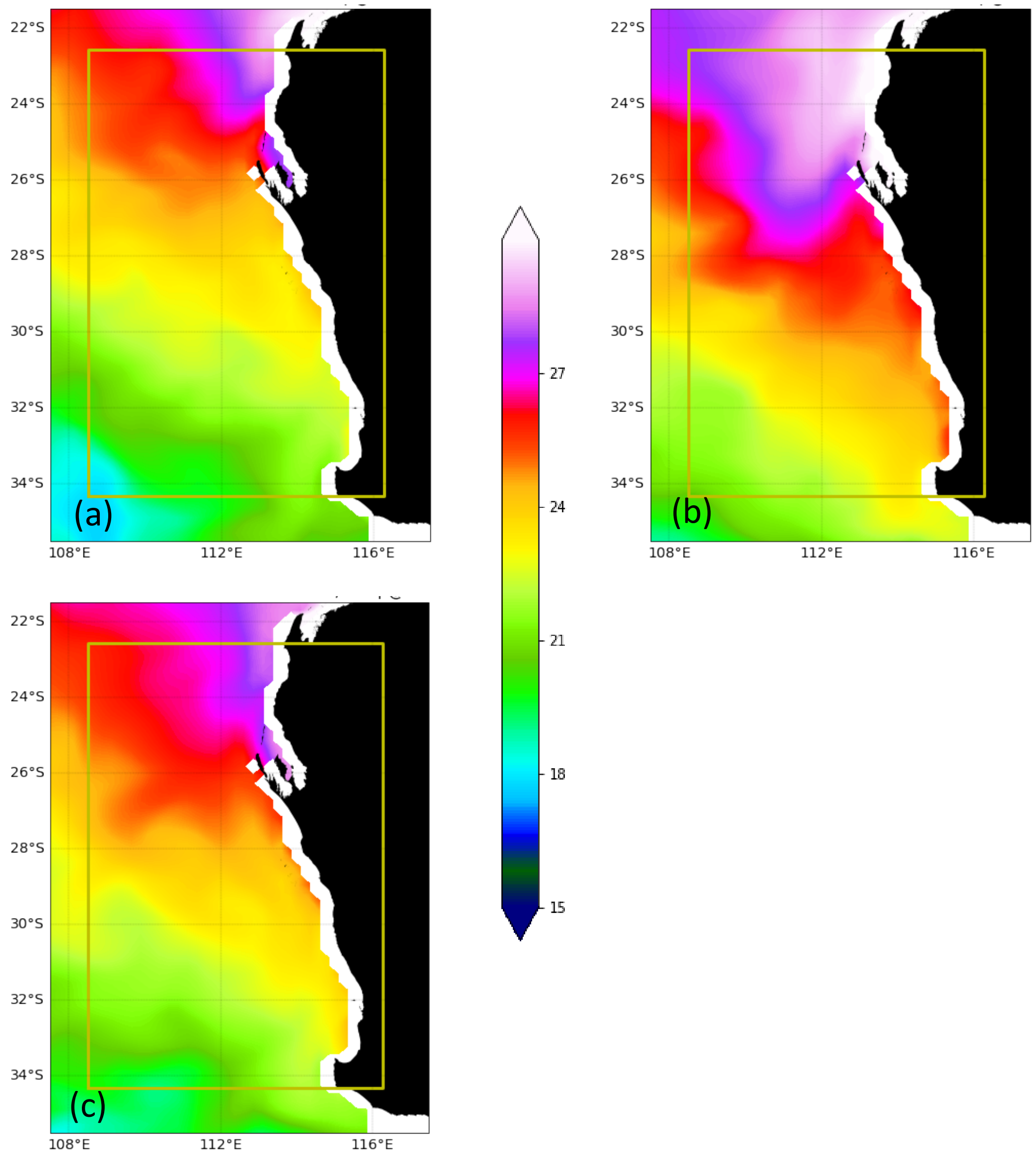


Figure 4.5. Sea surface temperature in February for the SSP 245 scenario. (a) 2014 (existing state); (b) 2025; and, (c) 2035.

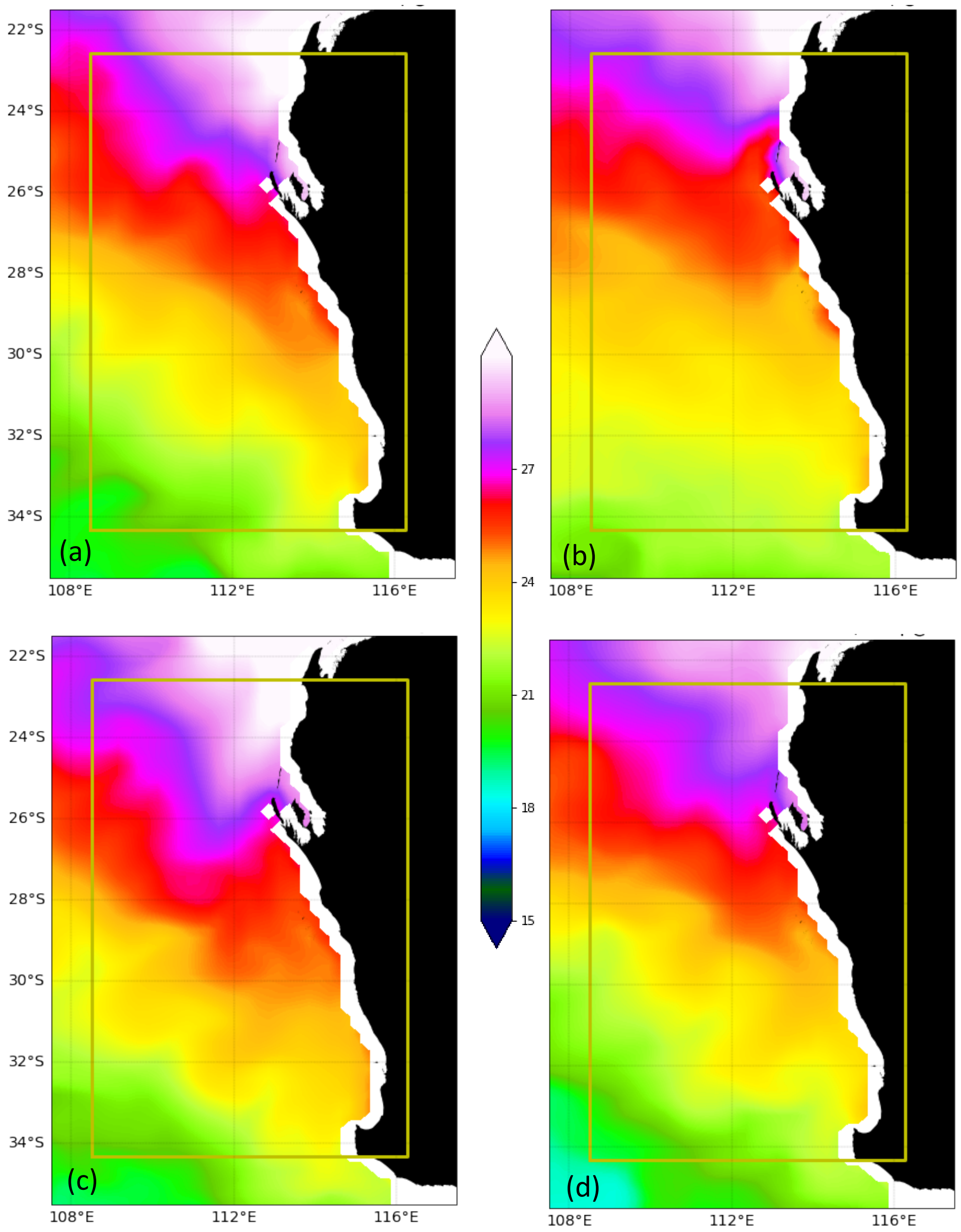


Figure 4.6. Sea surface temperature in February for the SSP 245 scenario. (a) 2090; (b) 2095; (c) 2099; and, (d) 2100.

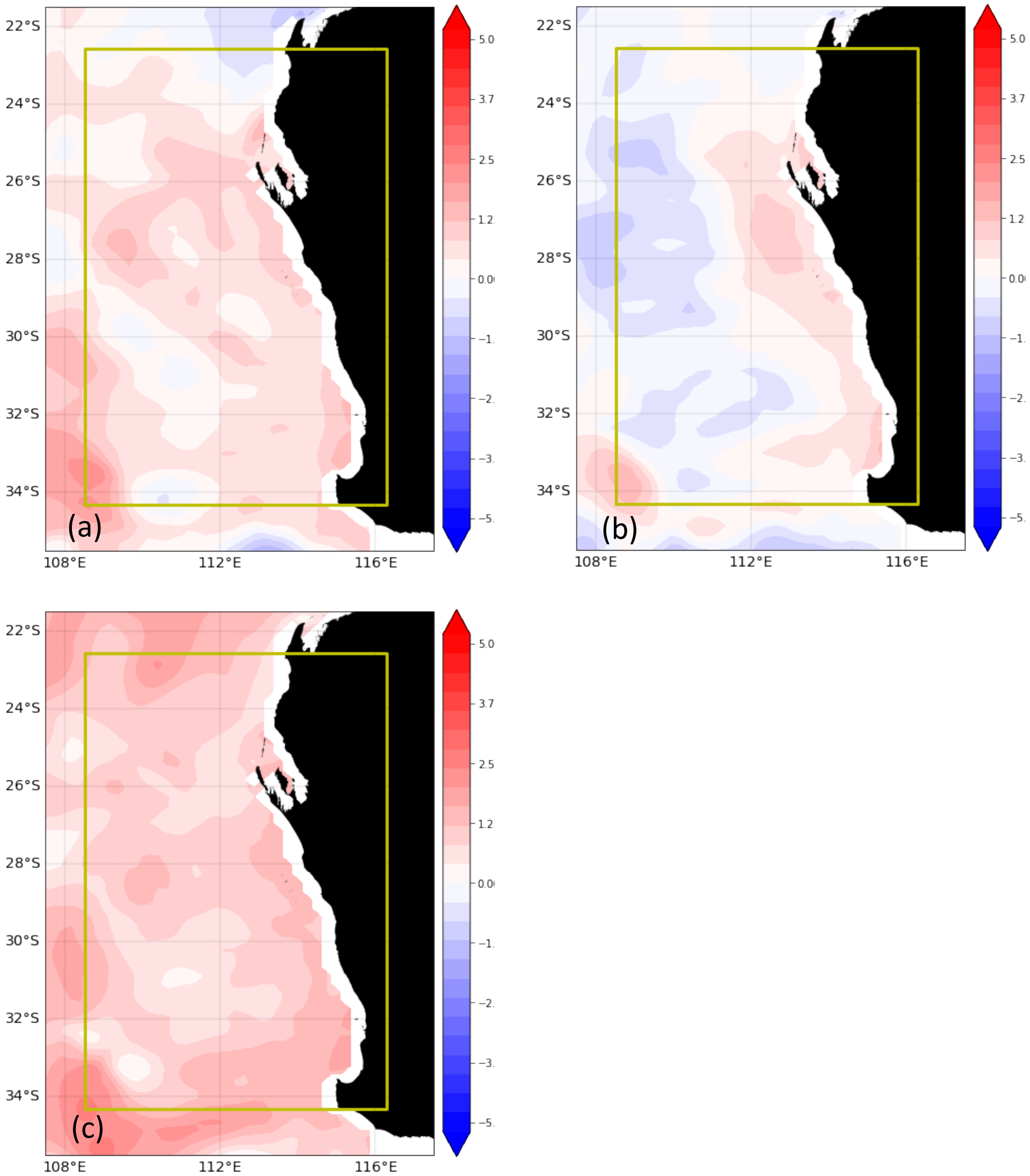


Figure 4.7. Sea surface temperature differences in February for the SSP 245 scenario. (a) 2035-2014; (b) 2037-2014; and (c) 2039-2014.

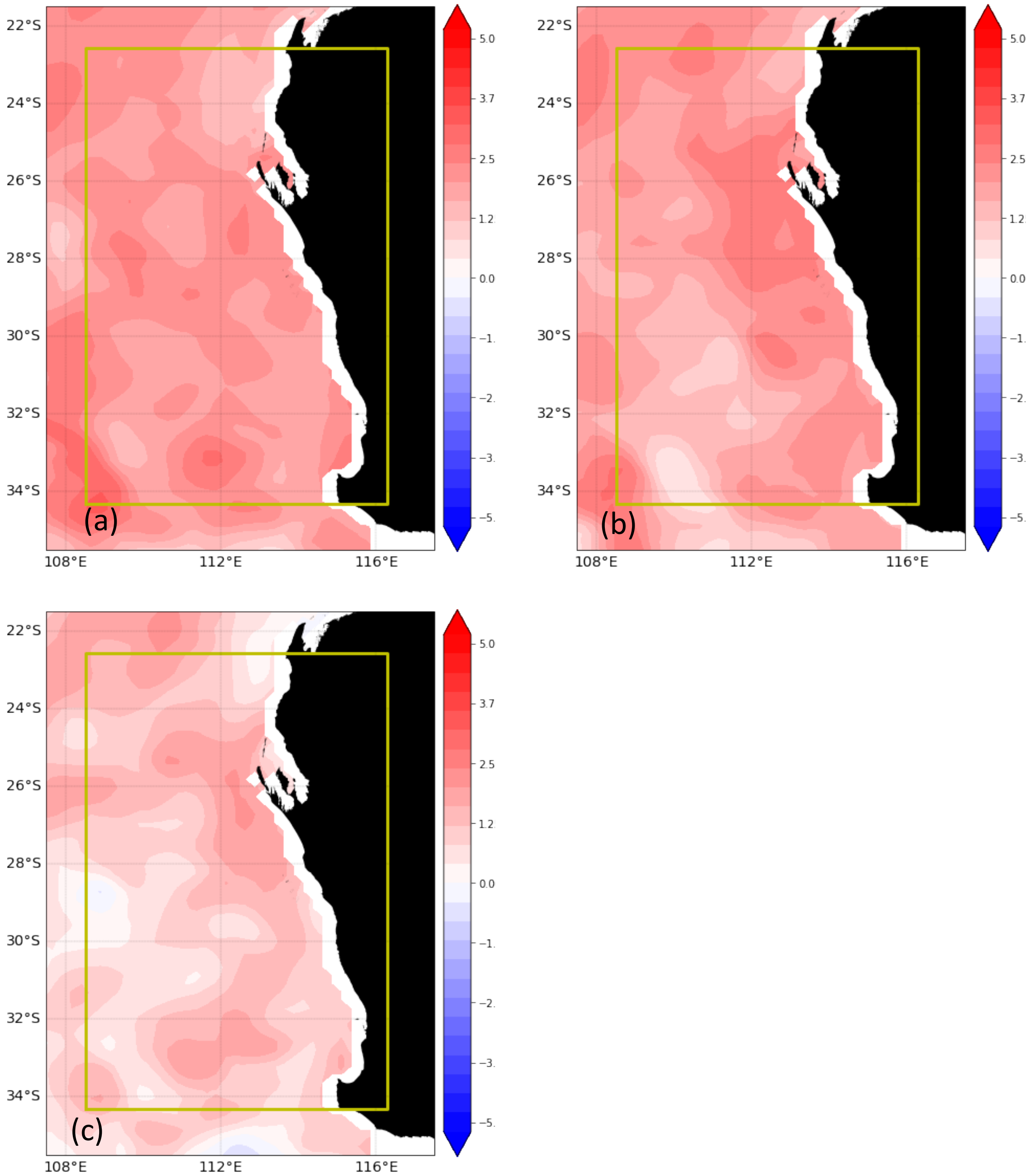


Figure 4.8. Sea surface temperature differences in February for the SSP 245 scenario. (a) 2096-2014; (b) 2098-2014; and (c) 2100-2014.

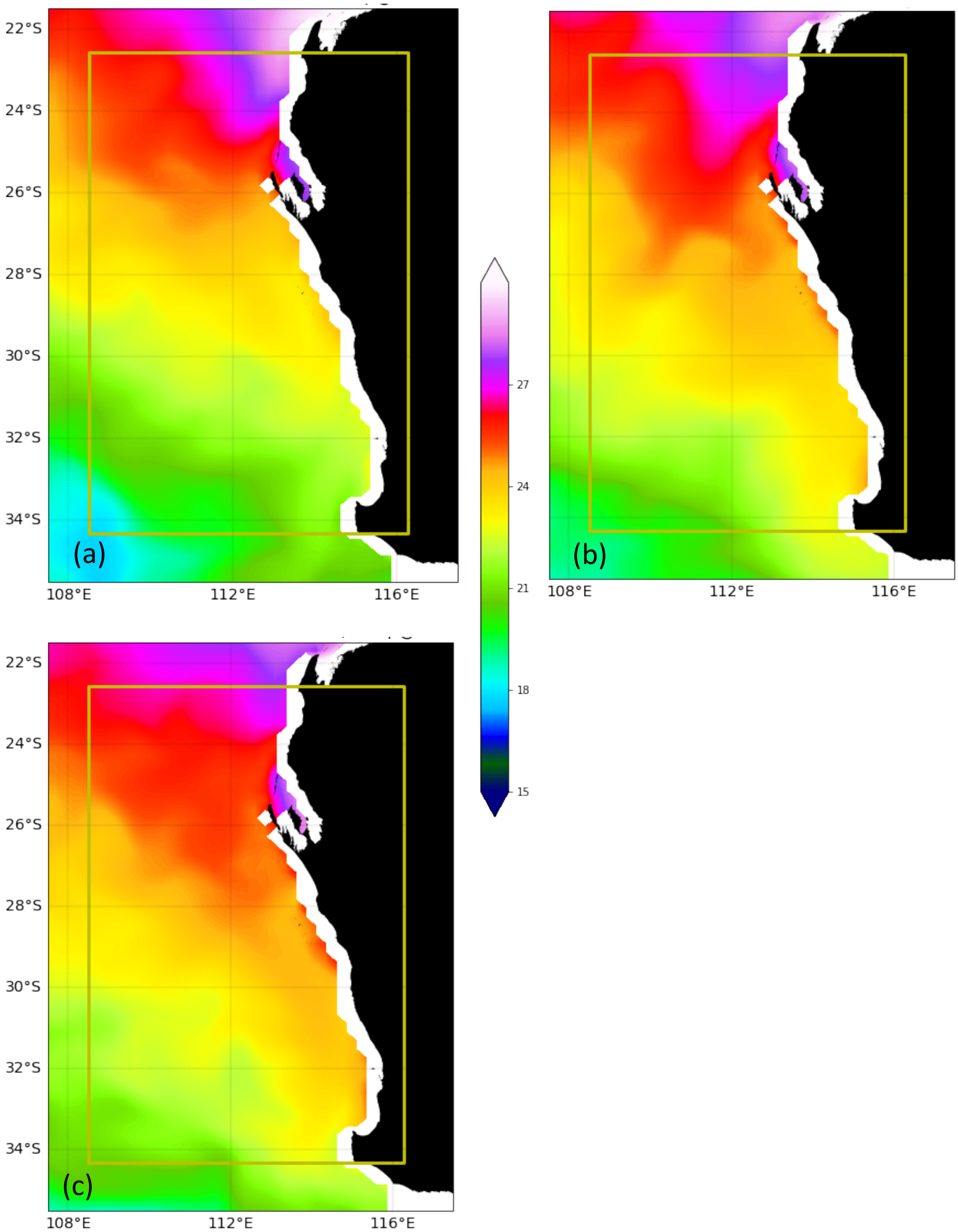


Figure 4.9. Sea surface temperature in February for the SSP 245 scenario. (a) 2014; (b) 2025; and (c) 2035.

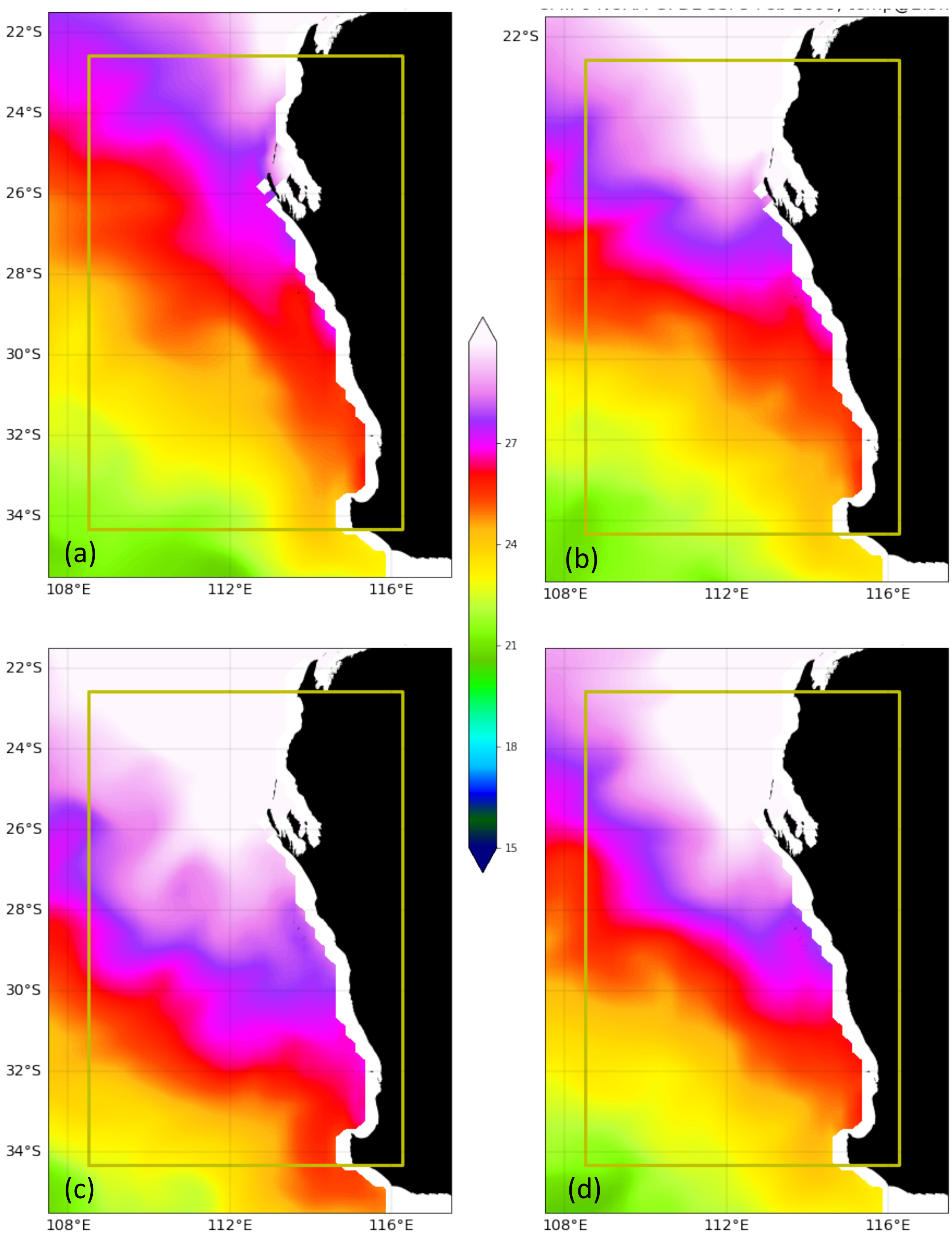


Figure 4.10. Sea surface temperature in February for the SSP 585 scenario. (a) 2090; (b) 2095; (c) 2099; and, (d) 2100.

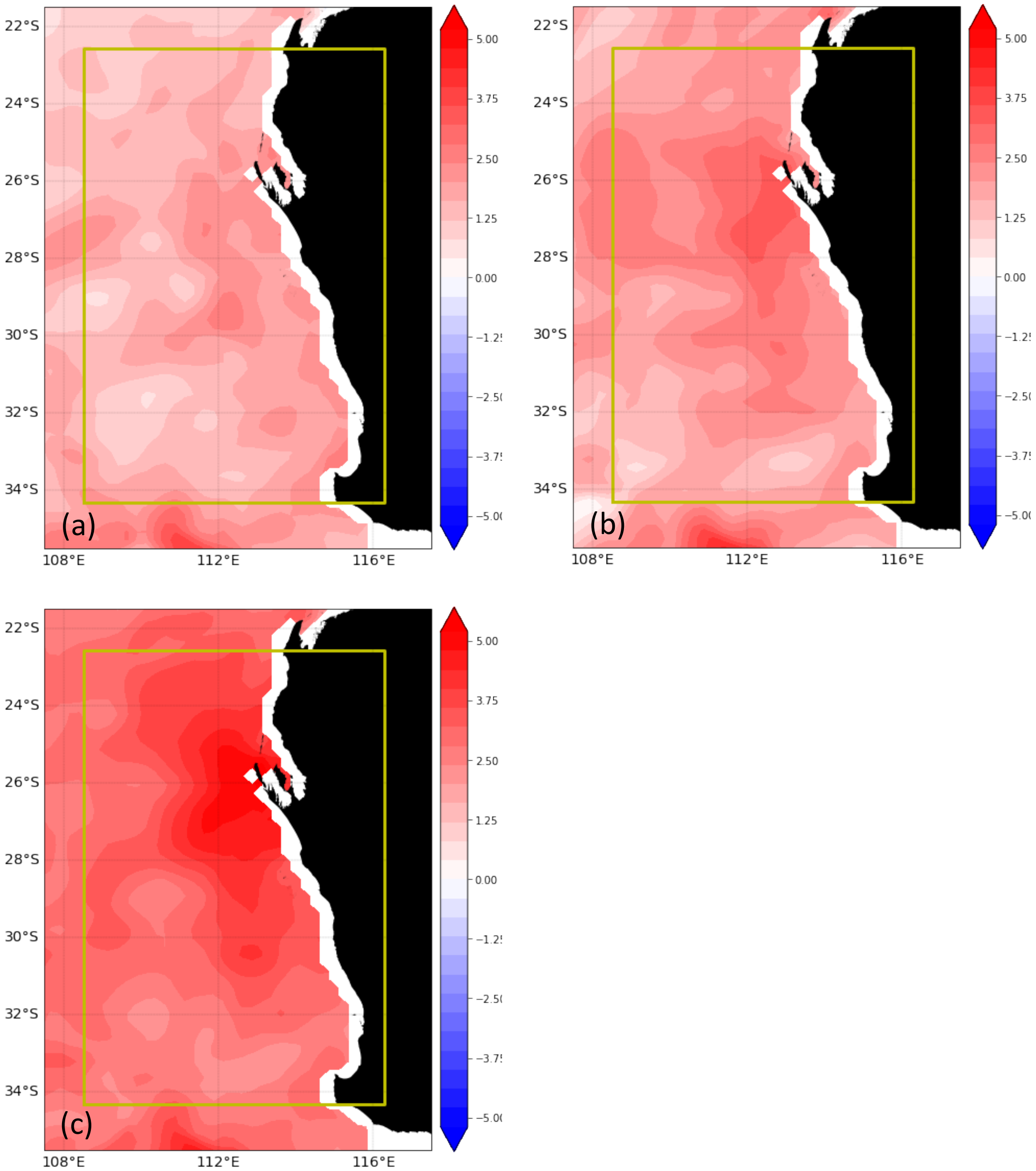


Figure 4.11. Sea surface temperature differences in February for the SSP 585 scenario. (a) 2050-2012; (b) 2070-2012; and (c) 2100-2012.

Time series of projected SST off the Perth region for the SSP245 scenario indicated a progressive increase in SST (Figure 4.12). We used the annual mean SST to fit a linear trend that indicated that the mean increase in SST was 0.0146°Celsius/year with a correlation coefficient of r= 0.74. This predicted an increase in the mean annual SST of 1.27°Celsius by 2100.

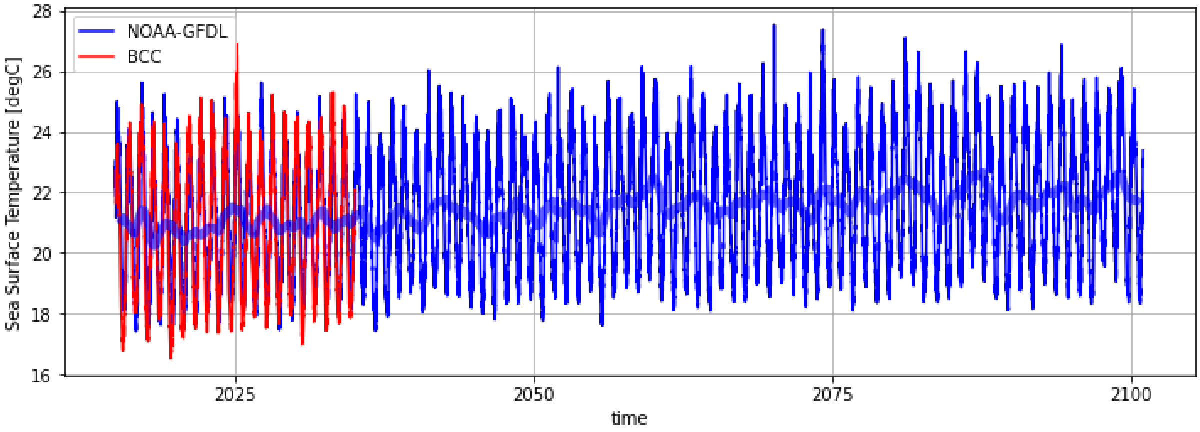


Figure 4.12. SSP245 scenario sea surface temperature for Perth waters.

Time series of projected SST off the Perth region for the SSP585 scenario indicated an increase higher than for SSP245 (Figure 4.13). The annual maximum, mean and minimum SST are predicted to increase at 0.0267, 0.0301 and 0.0381°Celsius/year, respectively. These values are about twice as high as those for SSP245. The trend in annual minimum temperature increase is lower than that for the annual mean and maximum SST (Figure 4.13). This predicted an increase in the mean annual SST of 2.62°Celsius by 2100. These values reflect a temperature increase of 3.31°Celsius by 2100 for the maximum annual SST.

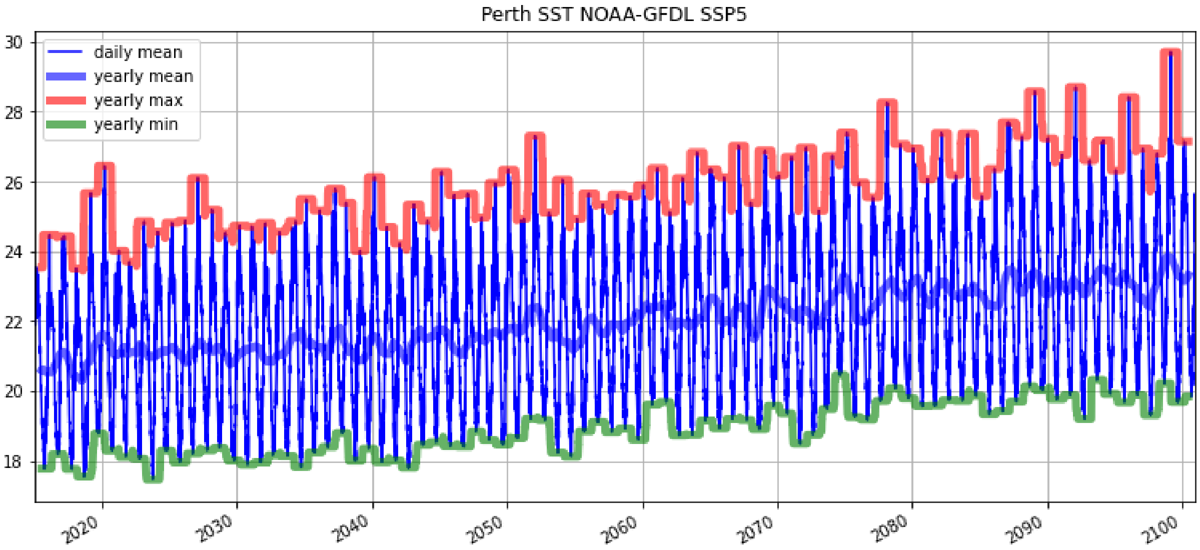


Figure 4.13. SSP585 scenario sea surface temperature for Perth waters.

4.2.2 Mean sea level.

To compute sea level rise effects for specific climate scenarios (SSP245/SSP585) we used two parameters: ocean surface height with and without steric height change. To further validate the model results and computed trends we used observed sea level hourly data for 35 years (1985-2022) recorded at the Department of Transport's Fremantle tide gauge (Figure 4.14). Note that this period included three very strong La Nina events (1999-2000, 2011-2013, 2020-2021) that elevated the mean sea levels as well as the modulation at the 18.6 year lunar nodal tidal cycle.

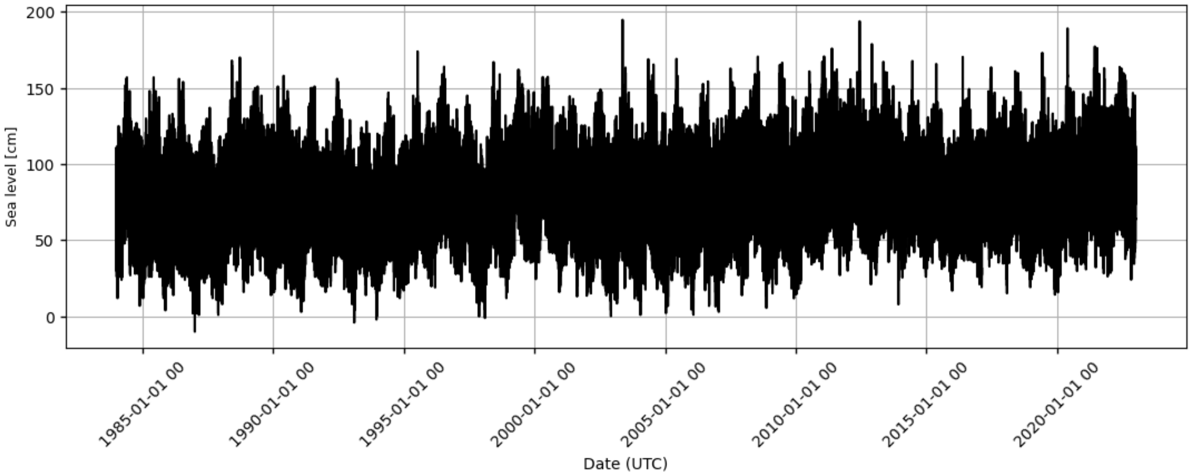


Figure 4.14. Fremantle hourly sea level data 1984-2022.

From the time series sea level data, we computed annual mean values and corresponding sea level trend (Figure 4.15). Based on the Fremantle data record 1984-2022, the linear mean sea level rise trend rate is 4.4 mmyear^{-1} (correlation coefficient = 0.67). This is comparable to the same rate of global mean sea level rise estimated from satellite altimeter data (https://sealevel.nasa.gov/understanding-sea-level/key-indicators/global-mean-sea-level). Locally this could also be an overestimate as this period includes elevated mean sea levels during La Niña events as reflected in the high sea levels during 1999-2000, 2011-2013, 2020-2021 (Figure 4.15).

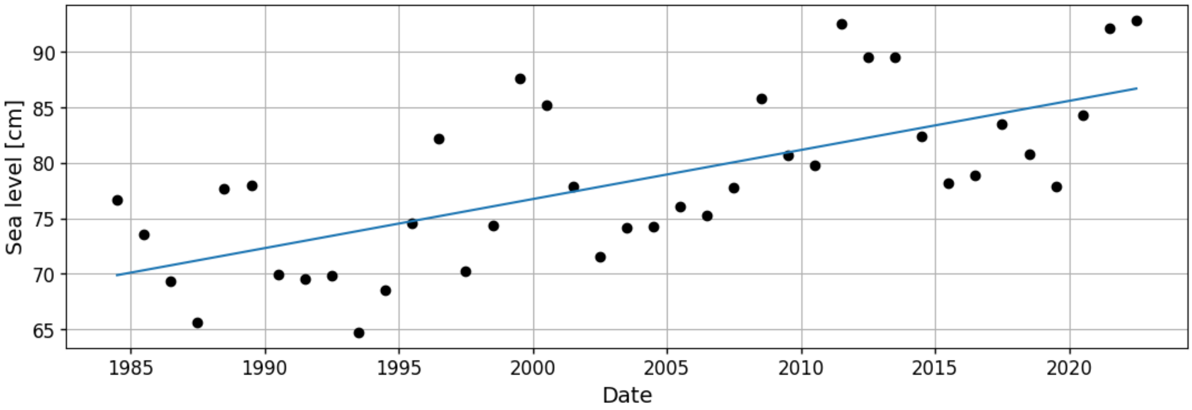


Figure 4.15. Annual mean sea level at Fremantle, 1984-2022, with the linear trend.

In case of the SSP245 simulation using the closest model output to the Perth location (115°E, 32°S), we predicted month to month and annual changes in sea level variation (Figures 4.16 and 4.17). These data only include increases in mean sea level due to steric height changes due to density and is mainly due to ocean warming. It does not include mean sea level changes due to El Niño Southern Oscillation (ENSO) events and the 18.6-year lunar nodal tidal cycle. Model output estimating sea level rise due to steric change is only given as a single point for the whole globe time series (Figure 4.18). Adding that steric contribution to the monthly mean SSP245 values projects sea level (Figure 4.19). Important to note is that this effect does not include other processes (glacial melting, Antarctica contribution, land contribution etc.). Linear fit of the time series gives a rise in mean sea level due only to ocean warming for next 20 years of 0.03 m with a trend estimated as 1.55 ± 0.06 mm/year. This is only for density change induced sea level rise.

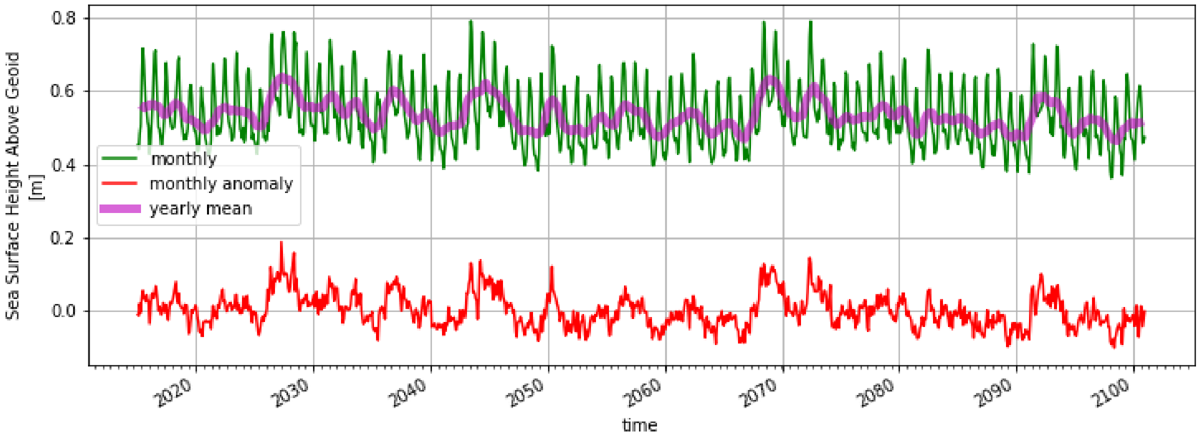


Figure 4.16. Sea level variations for the Perth area using SSP245 scenario model output.

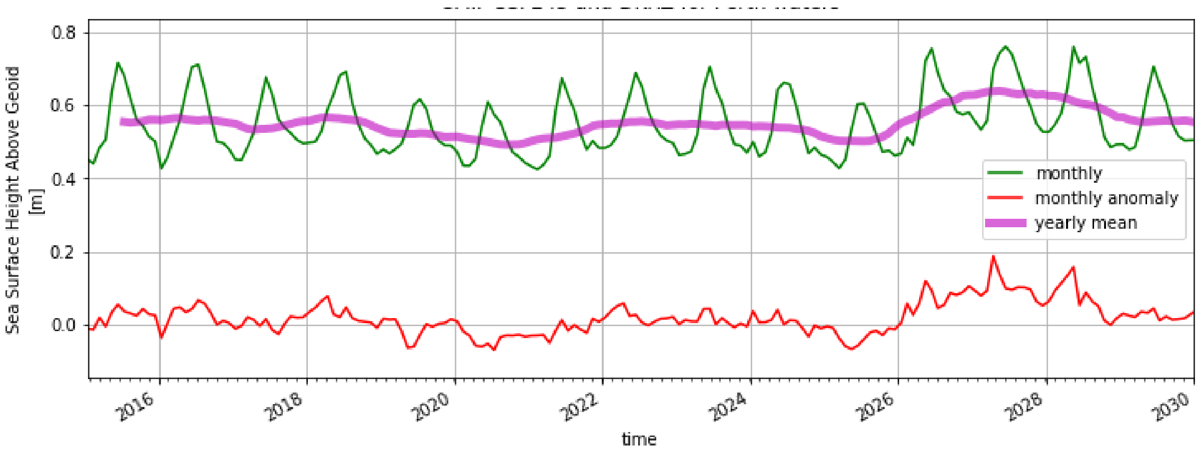


Figure 4.17. as Figure 4.16 (SSP245 scenario) but zoomed at the 2015–2030-time span.

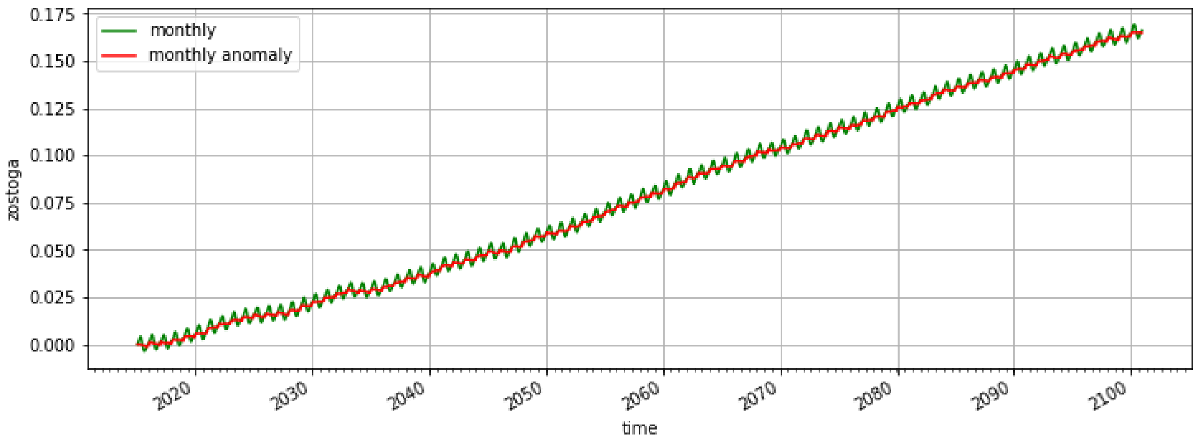


Figure 4.18. Steric effect for the SSP245 scenario.

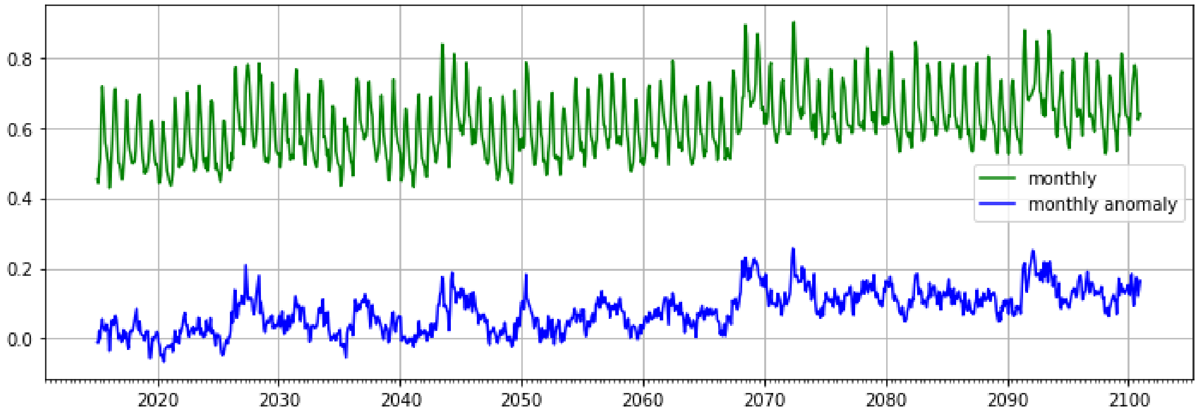


Figure 4.19. Combined steric height effect with the global climate model estimate (SSP245 scenario).

Using the same methods as above, we evaluated the SSP585 scenario, the impact of stronger greenhouse effect scenario on estimated sea level rise. In doing so, we found monthly and yearly variability (Figure 4.20) is similar as before, whilst the steric contribution was higher (Figure 3.21).

In the case of SSP585 sea level rise for next 20 years would be 0.04 m with trend 2.11 ± 0.05 mm/year.

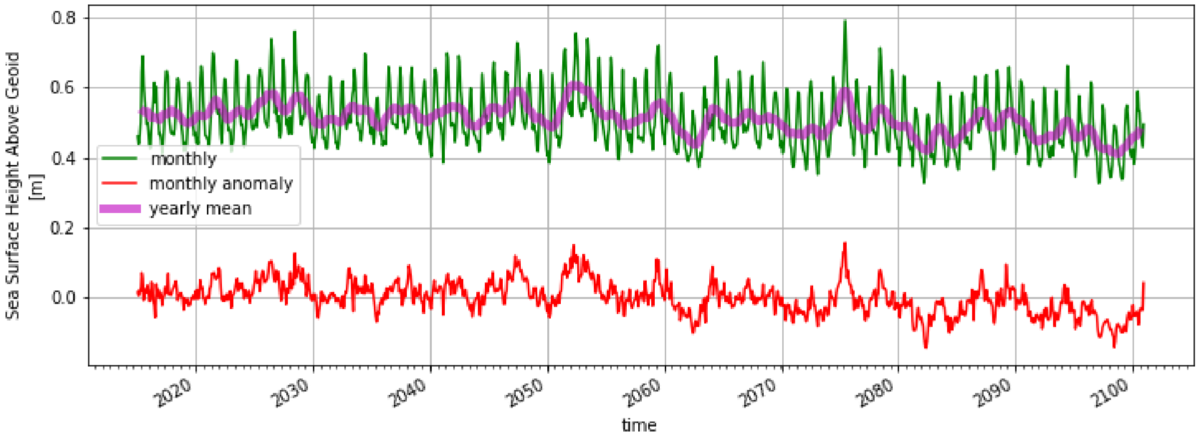


Figure 4.20. as Figure 4.16 but for SSP585 scenario.

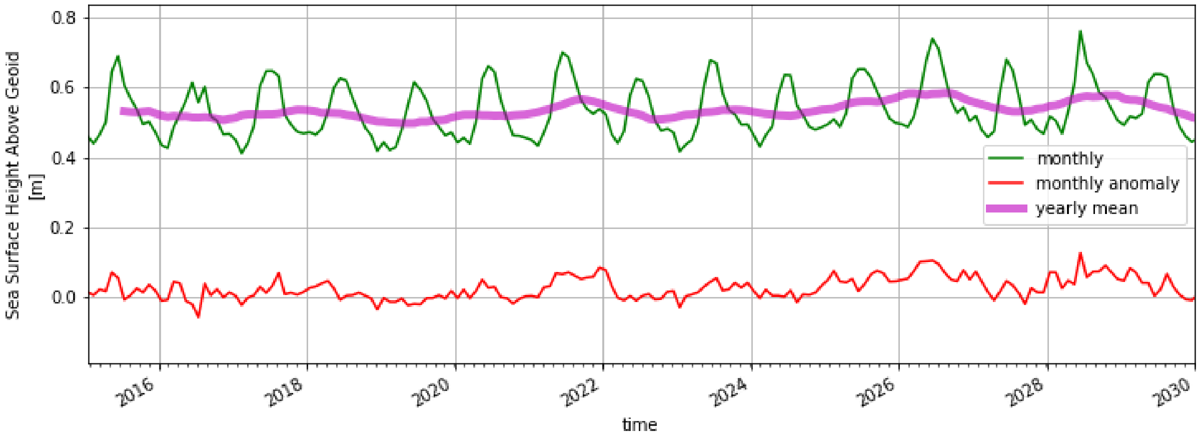


Figure 4.21. as Figure 4.17 but SSP585 scenario.

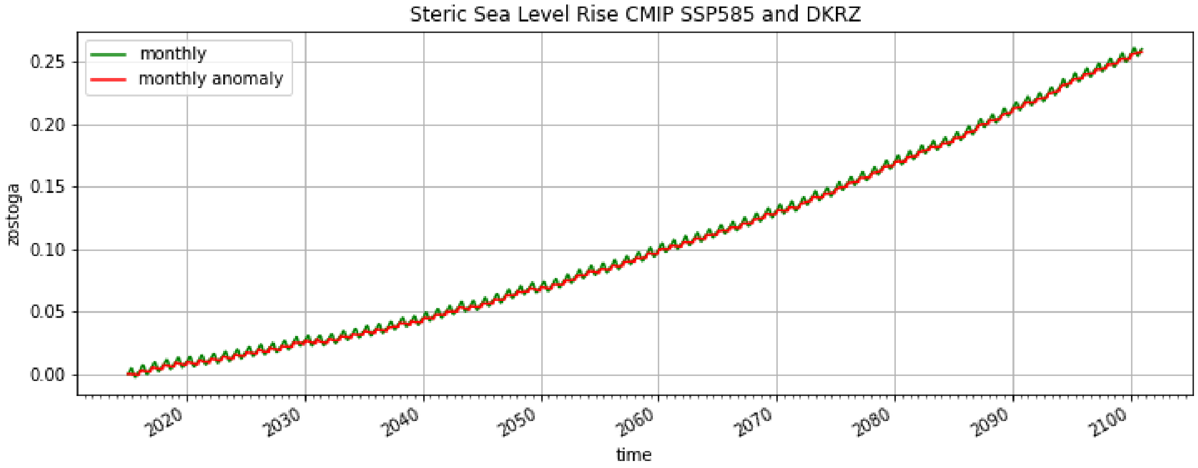


Figure 4.22. as Figure 4.18 but SSP585 scenario.

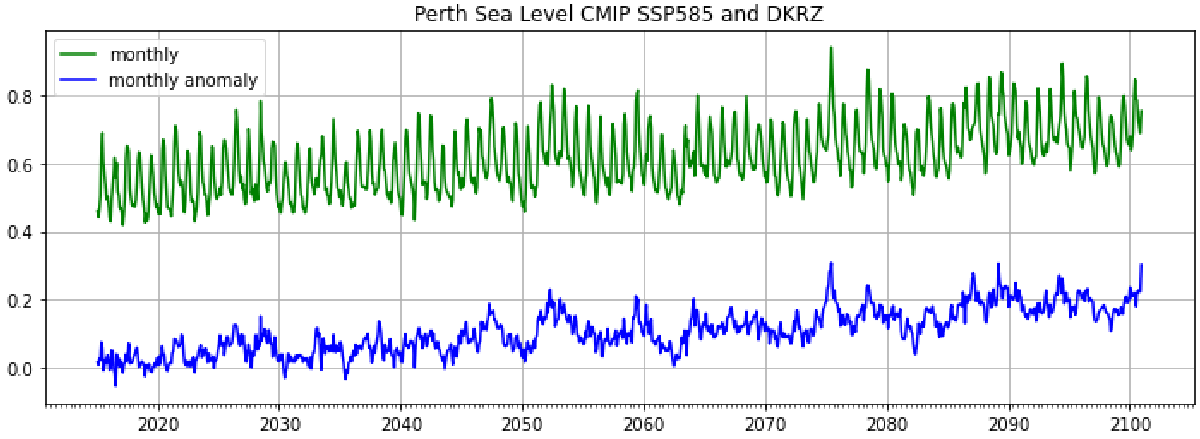


Figure 4.23. Figure 4.20 but SSP585 scenario.

4.2.3 Notes on mean sea Level projections.

The observed mean sea level rise in Fremantle over the period 1984-2022 is 4.4 mmyear^{-1} (Section 4.2.2). This is the observed trend and includes a combination of a range of processes including storm surge, ocean warming (thermal expansion), ENSO effects and long-term tidal effects. Climate scenarios presented here includes only ocean warming and predict mean sea level rise rates of 1.55 mmyear^{-1} and 2.11 mmyear^{-1} for SSP245 and SSP585, respectively. This indicates there are other important mechanisms that should be considered but is out-of-scope for this project. The total sea level rise is a combination of:

1. Thermal (steric) effect with global estimates of 0.25–0.39 m for 2100 year.
2. Glaciers effect adding 0.10 – 0.26 m (reported model extreme 0.35 m)
3. Greenland melting 0.4–0.22 m
4. Antarctica static -0.9–0.2 m
5. Antarctica dynamic 0.2–0.19 m (reported model extreme 0.41 m)
6. Land sources 0.1–0.11 m

Literature available (probabilistic median) value is estimated as 0.80 m, with the 95th percentile at 1.80 m sea level rise for 2100 year under the strong emission scenario (SSP585).

5 Results: Field measurements

The aim of the field measurements was to acquire hydrodynamic data, in particular on ocean currents, at up to seven locations over five deployment periods within Cockburn Sound and Owen Anchorage over the period 2021-2022. The deployments covered winter, spring, summer and autumn conditions. Autumn and winter conditions were captured in 2021 and 2022 noting a quite strong storm (with significant wave heights close to a 1:100 ARI) was experienced on 1-2 August 2022. Summary of the deployment periods and station locations are provided in Table 1 and Figure 4.1, respectively. The project also included the installation of a meteorological station for the provision of weather data including PAR in Cockburn Sound (Cockburn Cement landing jetty; Figure 4.1). The field measurement program was designed to be used primarily for hydrodynamic model validation including locations (Figure 4.1):

- Close to the boundaries of Cockburn Sound: north of Garden Island (CS1); within the Causeway (CS7);
- Middle and southern ends of the Sound (CS2, CS3);
- Kwinana Shelf (CS4 and CS5); and, Owen Anchorage (CS6)

A summary of instruments and the parameters measured at each station is provided on Table 3. Note that due to availability of instruments and some malfunction of the sensors all parameters are not available for every deployment. The April 2021 deployment only included the three deeper stations. Details of data recovered are provided in the Appendix for each of the stations.

All the data collected have been quality assured and controlled QA/QC'd and are available through the WAMSI/WESTPORT data portal (https://catalogue.data.wa.gov.au/org/western-australian-marine-science-institution) whilst collection of meteorological is ongoing.

Table 3. Timing of field campaigns.

Field campaign	Start	End
1. April 2021	16 April 2021	17 May 2021
2. November 2021	17 November 2021	21 December 2021
3. January 2022	28 January 2022	11 March 2022
4. March 2022	17 March 2022	20 May 2022
5. June 2022	11 June 2022	16 August 2022

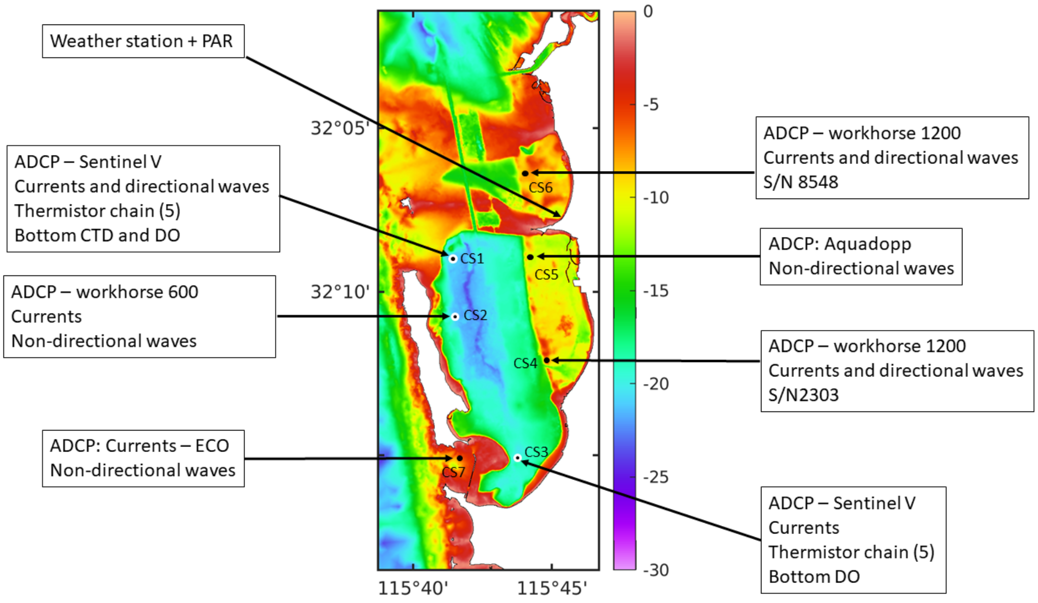


Figure 5.1. Location of field measurements and measured parameters (see Appendix for details). Colour scale represent water depths.

Table 4. Summary of parameters and instruments deployed (details are in the Appendix)

Parameter	Instrument	Stations
Vertical current profiles	RDI workhorse 1200 kHz RDI workhorse 600 kHz RDI Sentinel V 1000 kHz RDI Sentinel V 1000 kHz Nortek 1200 kHz Aquadopp Nortek ECO	CS4, CS6 CS1 CS2 CS3 CS5 CS7
Directional waves	RDI workhorse 1200 kHz RDI workhorse 600 kHz RDI Sentinel V 1000 kHz Nortek 1200 kHz Aquadopp	CS4, CS6 CS1 CS2 CS5
Non-directional waves	RBR Solo	CS4 CS5 CS6 CS7
Vertical temperature profiles	RBR Duet Seabird SB39	CS1 CS3
Bottom temperature, salinity	RBR Brevio	CS1 CS6
Bottom dissolved oxygen	PME MiniDOT2T	CS1 CS3
Bottom PAR	PME PAR	CS4 CS5 CS6
Wind speed and direction, atmospheric pressure, air temperature, humidity, solar radiation, PAR	Campbell Scientific meteorology station	Cockburn Cement landing jetty

5.1 Example time series data.

During the field campaign up to 25 different sensors were deployed across the seven sampling stations (see Appendix for details). In this section only time series examples of data collected are presented as data analysis and interpretation was not included in the project. All the data collected have been quality assured and controlled (QA/QC'd) and are available through the WAMSI data portal whilst collection of meteorological is ongoing.

All the data, including the metadata imbedded in the netCDF files, are available from the WAMSI/WESTPORT data portal. The data, in compressed netCDF data format amounts to 45.7Gb.

5.1.1 ADCP data (vertical current profiles)

CS1 (Figure 5.2): Cockburn Sound is mainly wind driven and currents through the water column respond to wind events. At the beginning of the record (28/1-4/2) there were strong sea breezes that forced currents through the whole water column. There were periods of low currents (e.g., 22-23 February). There were also strong sea breeze periods at the end of the record. Many of the profiles indicated stronger currents at the surface and near the seabed moving in opposite directions reflecting two-layer flow.

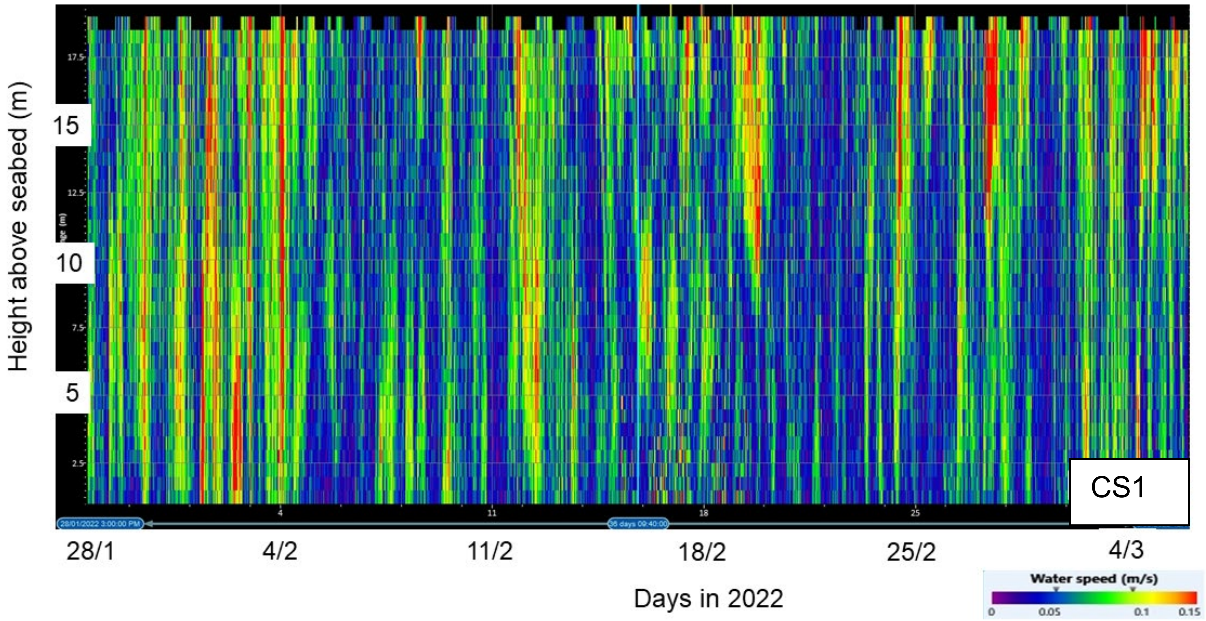


Figure 5.2. Time series of vertical current profiles at Station CS1 from 28 January-8 March 2022.

CS3 (Figure 5.3)**.** Wind driven currents are more evident in comparison to CS1, particularly in the top 10 m. Stronger currents in the bottom layer move in the opposite direction to that at the surface.

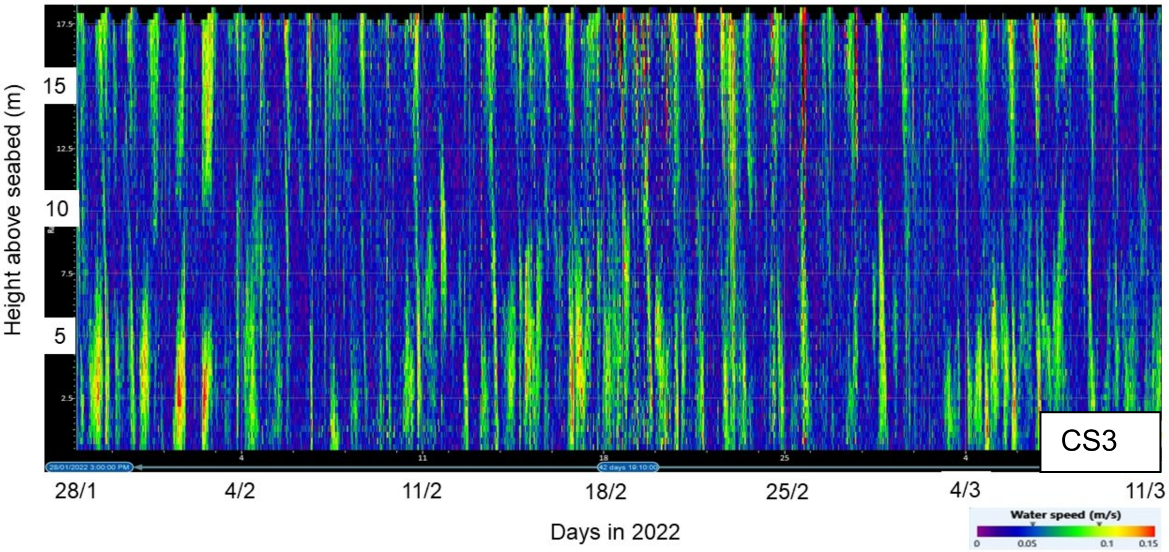


Figure 5.3. Time series of vertical current profiles at Station CS3 from 28 January-8 March 2022.

CS4 (Figure 5.4). This is on the Kwinana shelf in shallower water, < 10 m water depth. The wind forcing is apparent in particular from 8-15 February. However, when the winds are weaker (3-7 February) there are current reversals through the water column.

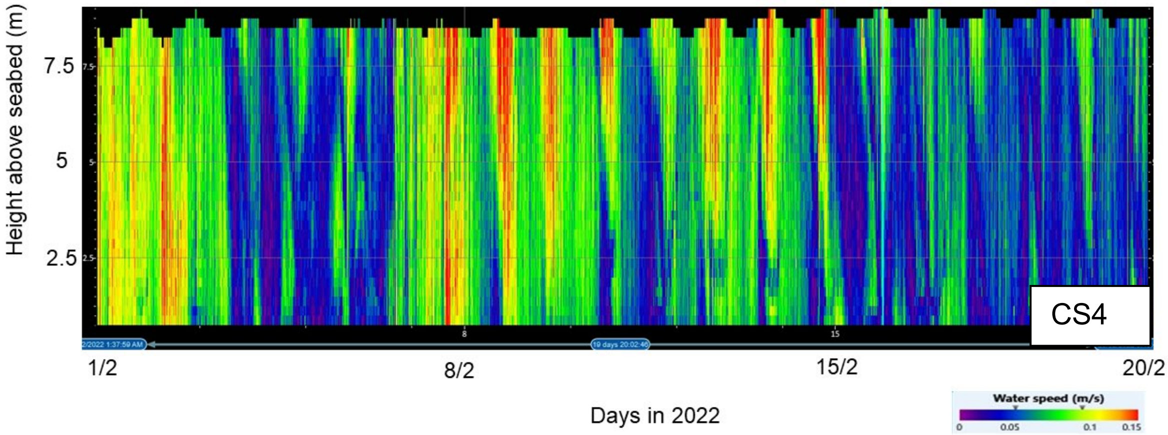


Figure 5.4. Time series of vertical current profiles at Station CS4 from 1-20 February 2022.

5.1.2 Directional wave data

Directional wave data were collected at Stations CS1, CS4, CS5 and CS6 with the latter three stations located in shallower water along the Kwinana Shelf (Figure 4.1). Example time series from the winter deployment (June 2022) are presented. A major storm was recorded on 1-3 August with maximum wave heights at CS1 and CS6 being 1.35 m and 1.45 m, respectively (Figures 5.5 and 5.6). This storm is close to a 1:100 ARI for wave height in Cockburn Sound. At CS1, the waves were dominated by swell waves (periods 13-15 s) incident from the north-west (Figures 5.5 and 5.7). After the storm on 1-3 August the wave incident angle was from the west-north-west. At CS6, the waves were dominated by sea waves (periods 4-5 s) incident from the west (Figures 5.6 and 5.8).

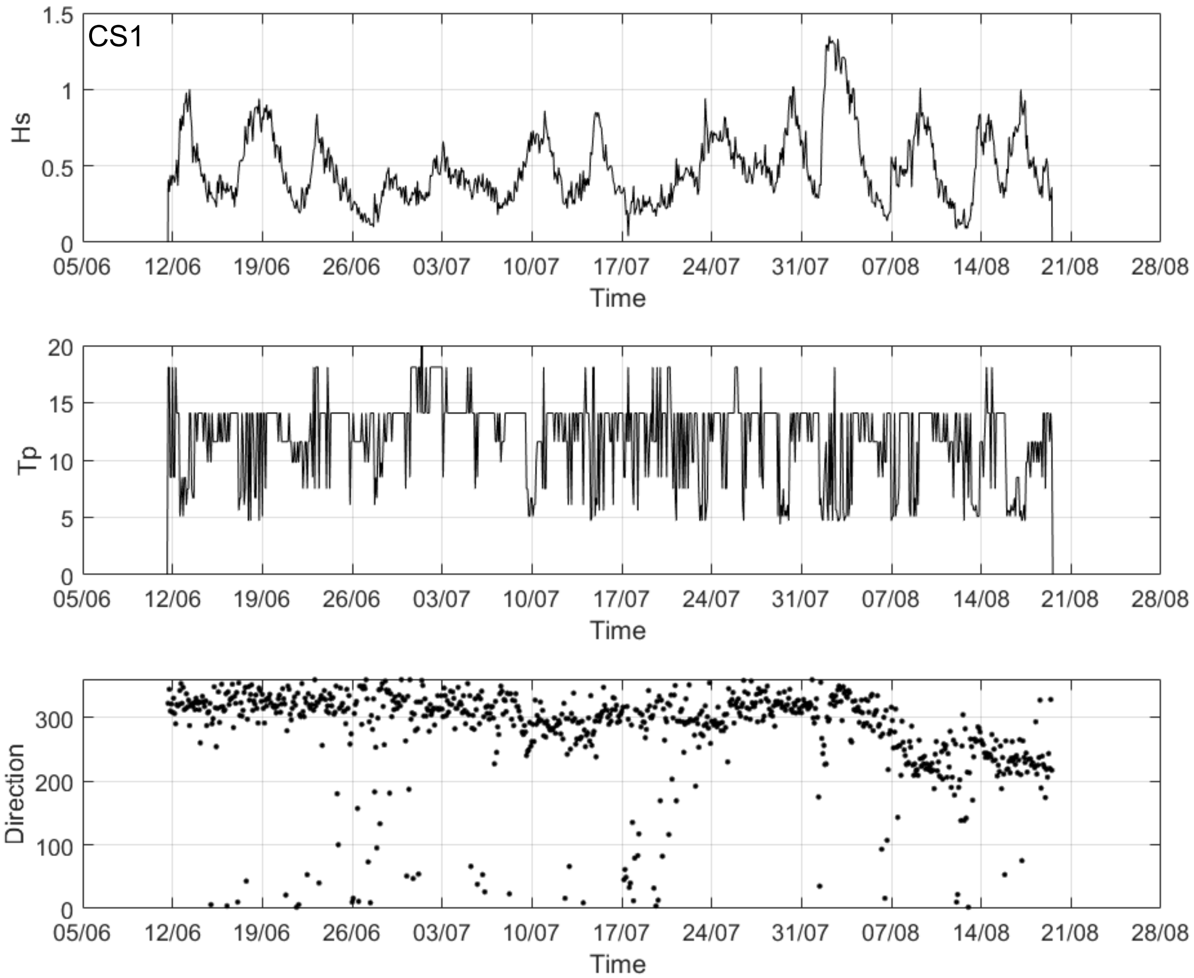


Figure 5.5. Time series of significant wave height (Hs in m), peak wave period (Tp in s) and wave direction (^{o}) at CS1 from 12 June – 21 August 2022.

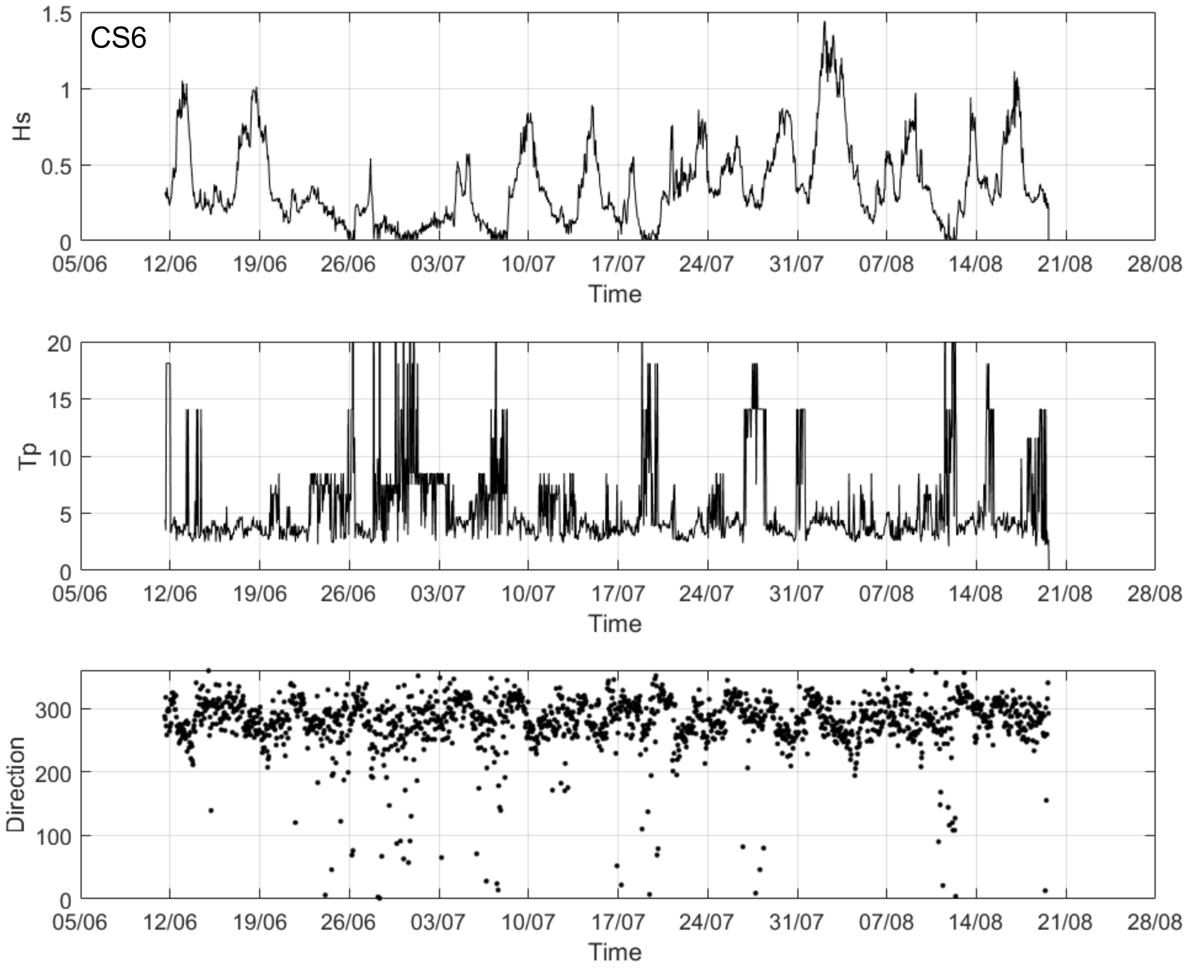


Figure 5.6. Time series of significant wave height (Hs in m), peak wave period (Tp in s) and wave direction (^{o}) at CS6 from 12 June – 21 August 2022

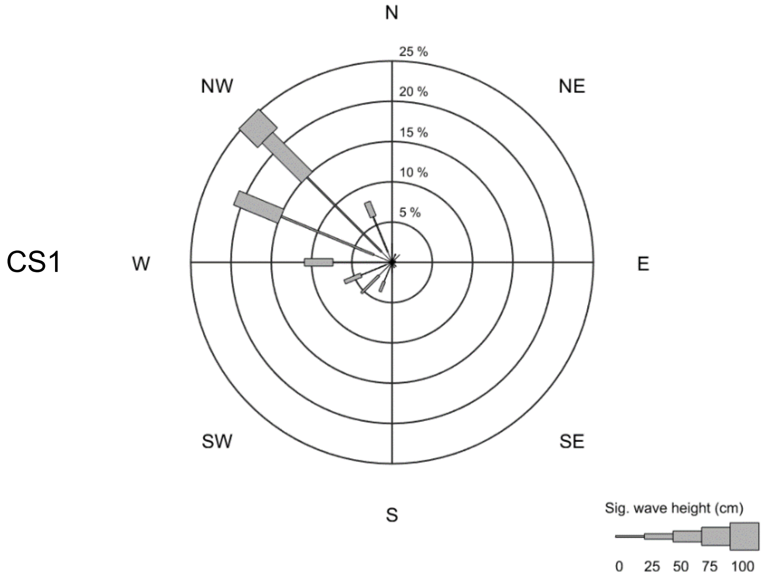


Figure 5.7. Wave rose at CS1 for the period 12 June – 21 August 2022

5.1.3 Dissolved Oxygen data

Time series of dissolved oxygen (DO) concentration, close to the seabed (~20 m water depth) at CS1 and CS3 on early 2022 indicated large fluctuations ranging from > 8.5 to 5.6 mg/l (Figure 5.9). The lower DO levels are short lived (1-2 days) and could be related to weather events.

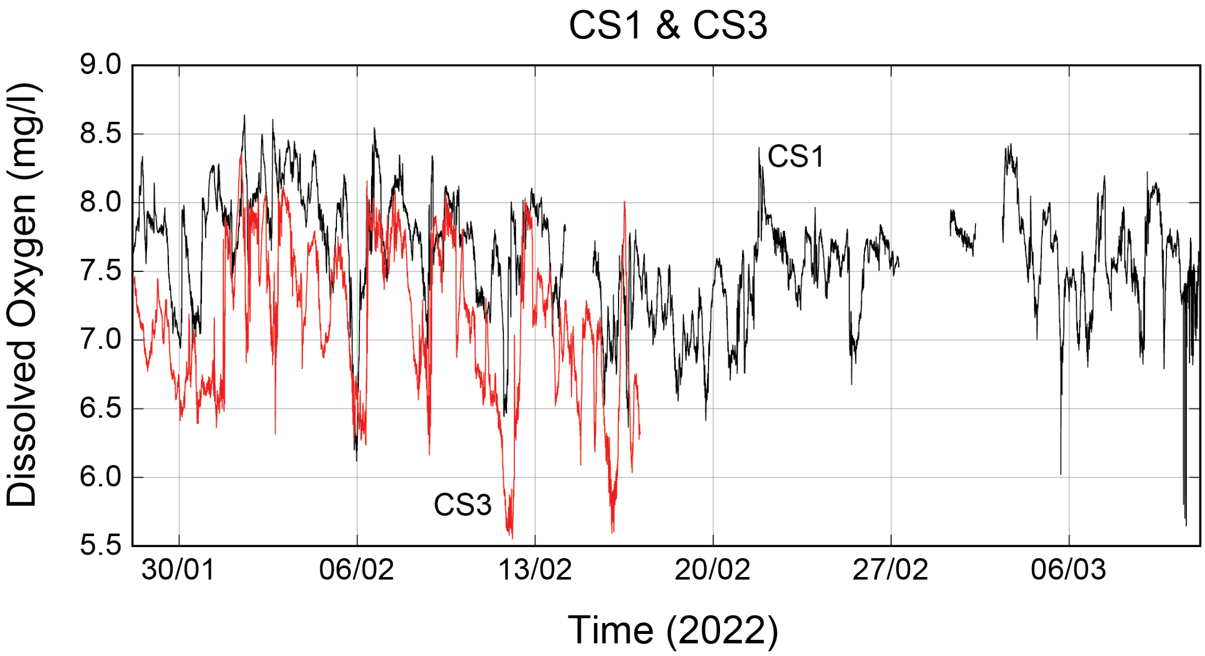


Figure 5.9. Time series of dissolved oxygen at Stations CS1 and CS3 from 28 January-8 March 2022.

5.1.4 Underwater PAR data

Time series of photosynthetically active radiation (PAR) data, close to the seabed (~10 m water depth) at stations CS4 and CS 6 on the Kwinana shelf indicate values exceeding 400 mmol m -2 with high values recorded at CS4 (Figure 5.10).

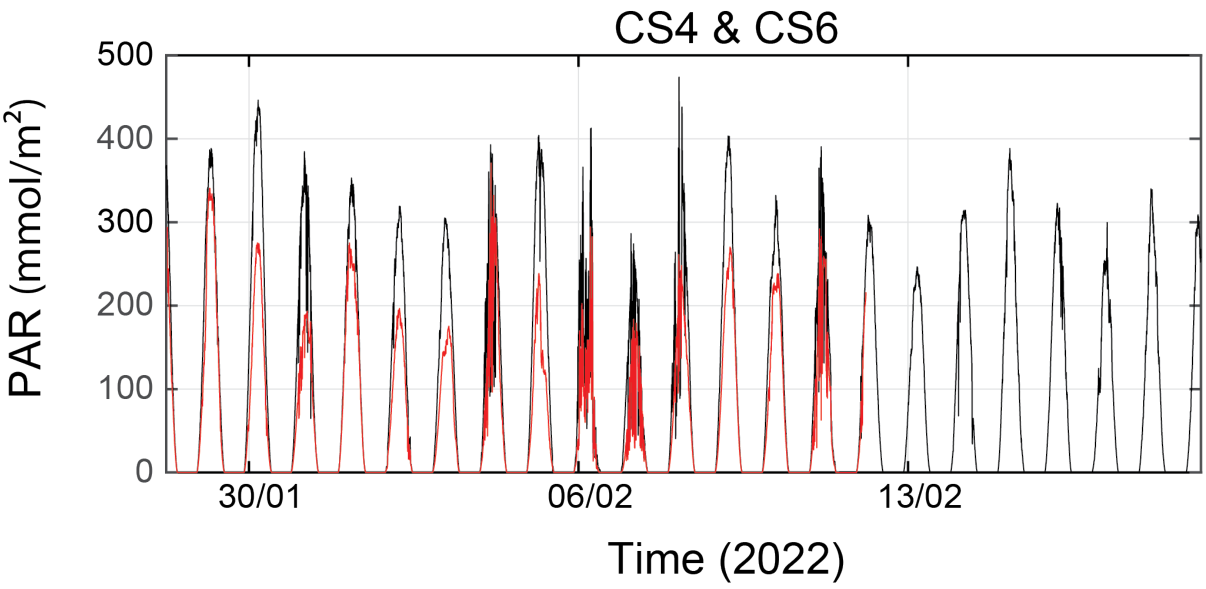


Figure 5.10. Time series of PAR at Stations CS4 (black) and CS6 (CS6) from 28 January-8 March 2022.

5.1.5 *Time series water depth data*

Time series of sea level data, collected at 2Hz, includes non-directional wave data as well as tidal and non-tidal variations. CS6 is located along the Kwinana shelf whilst CS7 was located along the cause way. The more 'noisy' data at CS7 indicated more exposure to incoming surface gravity waves (Figure 5.11).

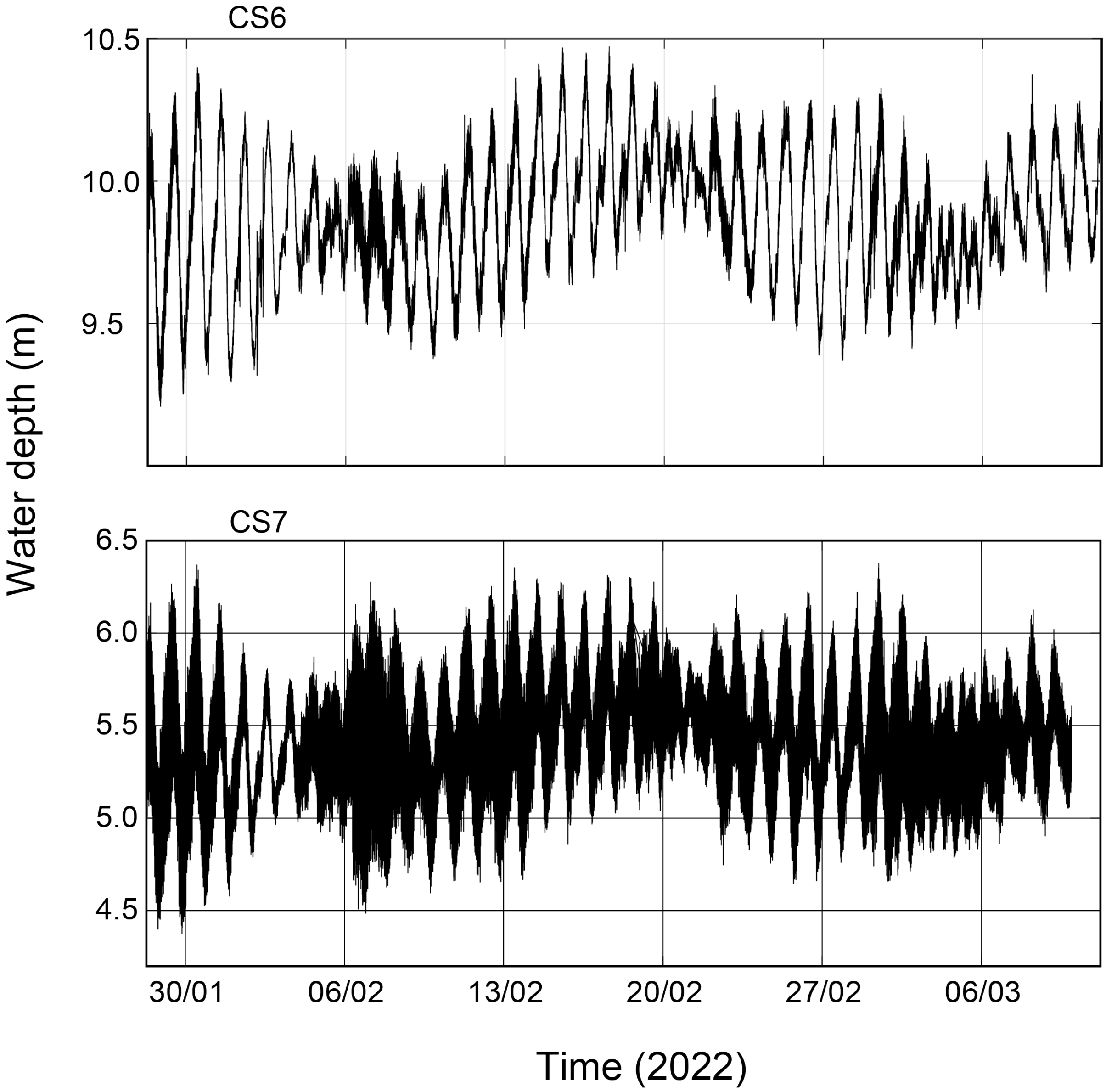


Figure 5.11 – Time series of water levels at Stations CS6 and CS7 from 28 January-8 March 2022.

5.1.6 Meteorological data

Time series of wind speed (including gust), wind direction, atmospheric pressure, incoming total solar radiation, and PAR data are being collected continuously from Cockburn Cement Landing jetty, north of Woodman Point (Figure 5.1) since 13 July 2022. Additional data on wet/dry bulb temperature are also recorded. The data is available at different sampling intervals: 30 seconds, five minutes and as daily averages. Data collected at five minute intervals since 13 July to 10 March 2023 are shown on Figure 5.12. The data collection is real-time (transferred to UWA via the cellular network and is ongoing.

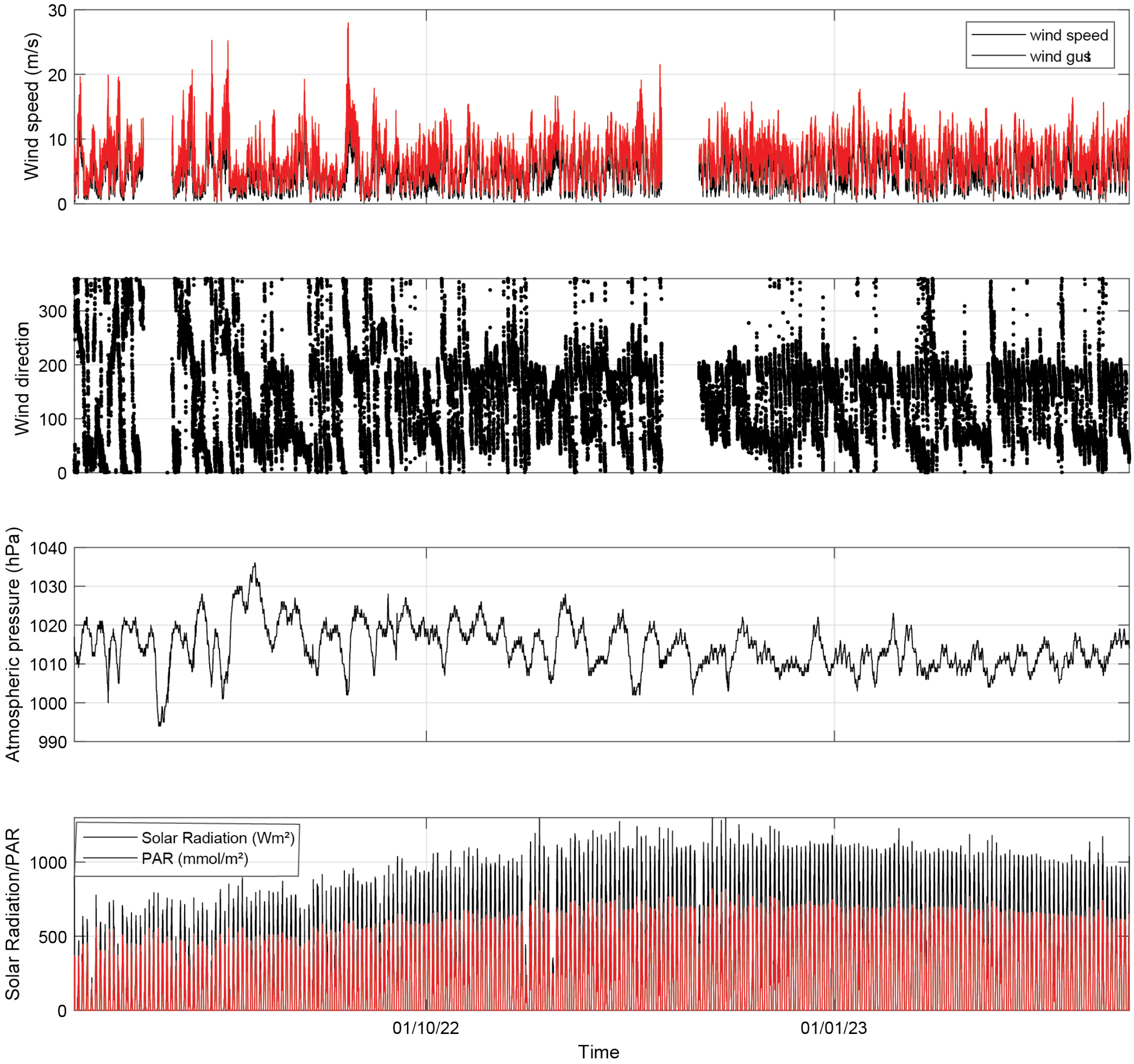


Figure 5.12. Time series of Meteorological data from Cockburn Cement landing jetty (Figure 5.1).

6 Conclusions/recommendations

The main objectives of this theme were to: (1) use large modelling to provide open ocean boundary conditions and future climate scenarios under different emission scenarios; and, (2) collect oceanographic data within Cockburn Sound and Owen Anchorage in 2021-2022. Both of the tasks were completed successfully and all the output are available from the WAMSI/WESTPORT data repository.

Model output in hindcast mode is available for the period 2000-2022 (23 years) and includes: (a) one-hour intervals in two dimensions for water level, sea surface temperature, sea surface salinity, and ocean vertical averaged currents; and, (b) three-hourly intervals in three dimensions for temperature, salinity and ocean currents.

We predicted future ocean conditions under climate change scenarios for two different Shared Socioeconomic Pathways (SSP) scenarios: SSP245 and SSP585. The SST predictions to 2100 indicated that the annual mean rate of SST increase was 0.015 and 0.03^{o}C per annum, under SSP245 and SSP585, respectively. This is predicted to increase the mean SST by 1.27^{o} and 3.31^{o}Celsius by 2100 under SSP2 and SSP5, respectively.

An extensive set of oceanographic field measurements were collected over the period 2021-2022. The field measurement program collected measurements at up to seven locations over five deployment periods within Cockburn Sound and Owen Anchorage. The deployments covered winter, spring, summer and autumn conditions. The project also included the installation of meteorological station for the provision of weather data including PAR in Cockburn Sound which was installed on the Cockburn Cement landing jetty. During the field campaign up to 25 different sensors were deployed for each field campaign. All the data collected have been quality assured and controlled and are available through the WAMSI data portal.

6.1 Recommendations

This project has created a very large database of model output and field measurements relevant to Cockburn Sound and the surrounding region. The model output includes 23-year hindcast of three-dimensional oceanographic parameters (temperature, salinity, water levels and velocities) and future climate scenarios. The field measurements are the extensive collected from the Perth coastal water for more 30 years and include state-of-art instrumentation. It is recommended that the model output and field data are carefully analysed to allow for the basic understanding of the different physical processes that are critical for understanding the behaviour of Cockburn Sound.

7 Appendices

7.1 Appendix 1 – Model data output information

The model output has been uploaded to the WAMSI/WESTPORT data portal housed at the Pawsey Supercomputing Centre as the Acacia object store. In the WAMSI data portal there is a bucket named "wamsi-westport-project-5" and within this bucket there are two folders: "virtual folder" structure "model".

Inside the "model" there are 3 additional subfolders: ERA5, NEMO, and ROMS.

Inside ROMS data output are stored yearly in "year" subfolder structure: https://acacia.pawsey.org.au s3 ls wamsi-westport-project-5/model/ROMS/
(Access to datasets held within Pawsey Acacia storage can be requested by contacting Westport and/or WAMSI)

```
PRE 2000/
PRE 2001/
PRE 2002/
PRE 2003/
PRE 2004/
PRE 2005/
PRE 2006/
PRE 2007/
PRE 2008/
PRE 2009/
PRE 2010/
PRE 2011/
PRE 2012/
PRE 2013/
PRE 2014/
PRE 2015/
PRE 2016/
PRE 2017/
PRE 2018/
PRE 2019/
PRE 2020/
```

And then inside each specific year we have "3 types" of ROMS model outputs:

1. Quick (qck) files - holding hourly 3D variables (time, lat, lon) such as: zeta, ubar_eastward, v_bar_northward, u_sur_eastward, v_sur_northward, shflux, ssflux, sustr, svstr
2. History (his) files - holding 3-hourly 4D variables (time, depth, lat, lon) such as: temp, salt, u_eastward, v_northward, zeta, u, v
3. Daily average (avg) files - holding 2D and 3D variables (from points 1 and 2)

For example, in 2000 year we have (>1000 files in total):

```
2022-04-04 16:31:24   73741906 cwa_20000102_00__avg.nc
2022-04-04 16:31:24   79951889 cwa_20000102_13__qck.nc
2022-04-04 16:31:39   244963075 cwa_20000102_15__his.nc
2022-04-04 16:31:29   73302819 cwa_20000103_00__avg.nc
2022-04-04 16:31:30   78431903 cwa_20000103_13__qck.nc
```

```
2022-04-04 16:31:44   236687298 cwa_20000103_15__his.nc
2022-04-04 16:31:35   72835583 cwa_20000104_00__avg.nc
```

Inside ERA5 folder there are 20 years of hourly atmospheric forcing data were used to force ROMS model (with extra for 2021 if needed):

```
aws --endpoint-url=https://acacia.pawsey.org.au s3 ls wamsi-westport-project-5/model/ERA5/
```

(Access to datasets held within Pawsey Acacia storage can be requested by contacting Westport and/or WAMSI)

```
2022-04-05 10:55:14 1080351602 era5_roms_forcing_20000101.nc
2022-04-05 10:55:14 1077414159 era5_roms_forcing_20010101.nc
2022-04-05 10:55:13 1077414142 era5_roms_forcing_20020101.nc
2022-04-05 10:55:14 1077413994 era5_roms_forcing_20030101.nc
2022-04-05 10:55:14 1080351768 era5_roms_forcing_20040101.nc
2022-04-05 10:56:19 1077414287 era5_roms_forcing_20050101.nc
2022-04-05 10:56:20 1077414056 era5_roms_forcing_20060101.nc
2022-04-05 10:56:20 1077414339 era5_roms_forcing_20070101.nc
2022-04-05 10:56:20 1080351382 era5_roms_forcing_20080101.nc
2022-04-05 10:56:20 1077413804 era5_roms_forcing_20090101.nc
2022-04-05 10:57:28 1077414245 era5_roms_forcing_20100101.nc
2022-04-05 10:57:29 1077414253 era5_roms_forcing_20110101.nc
2022-04-05 10:57:30 1080351379 era5_roms_forcing_20120101.nc
2022-04-05 10:57:30 1077413779 era5_roms_forcing_20130101.nc
2022-04-05 10:57:30 1077413779 era5_roms_forcing_20140101.nc
2022-04-05 10:58:35 1077414216 era5_roms_forcing_20150101.nc
2022-04-05 10:58:36 1080351379 era5_roms_forcing_20160101.nc
2022-04-05 10:58:36 1077413779 era5_roms_forcing_20170101.nc
2022-04-05 10:58:37 1077413779 era5_roms_forcing_20180101.nc
2022-04-05 10:58:36 1077413779 era5_roms_forcing_20190101.nc
2022-04-05 10:58:58 1080351378 era5_roms_forcing_20200101.nc
2022-04-05 10:58:54 1700484274 era5_roms_forcing_20210101.nc
```

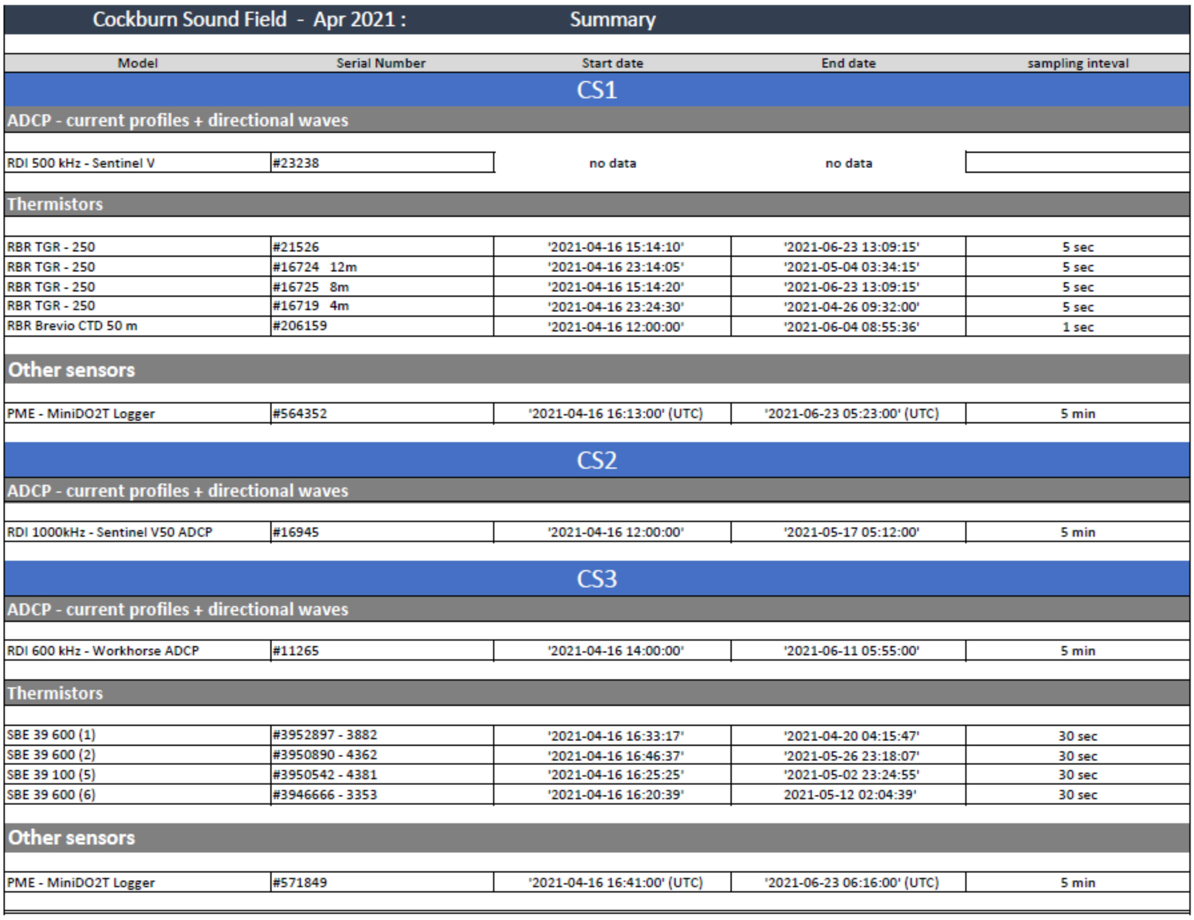
Inside NEMO folder there are 20 years of NEMO model data:

1. Boundary (bry) files holding interpolated NEMO data onto our ROMS open ocean boundary, they are saved as monthly files, and in total we have 253 files
2. Climatology (clim) files holding interpolated NEMO data onto our ROMS grid (3D), in total 253 files which were used for model nudging of our ROMS model `aws --endpoint-url= https://acacia.pawsey.org.au s3 ls wamsi-westport-project-5/model/NEMO/`
   (Access to datasets held within Pawsey Acacia storage can be requested by contacting Westport and/or WAMSI)

```
2022-04-05 09:29:49   37722568 nemo_bry_2000_01.nc
2022-04-05 09:29:51   36404792 nemo_bry_2000_02.nc
2022-04-05 09:29:51   37722568 nemo_bry_2000_03.nc
2022-04-05 09:29:52   37063680 nemo_bry_2000_04.nc
2022-04-05 09:29:52   37722568 nemo_bry_2000_05.nc
2022-04-05 09:32:57   851619815 nemo_clim_2000_01.nc
2022-04-05 09:32:56   788750991 nemo_clim_2000_02.nc
```

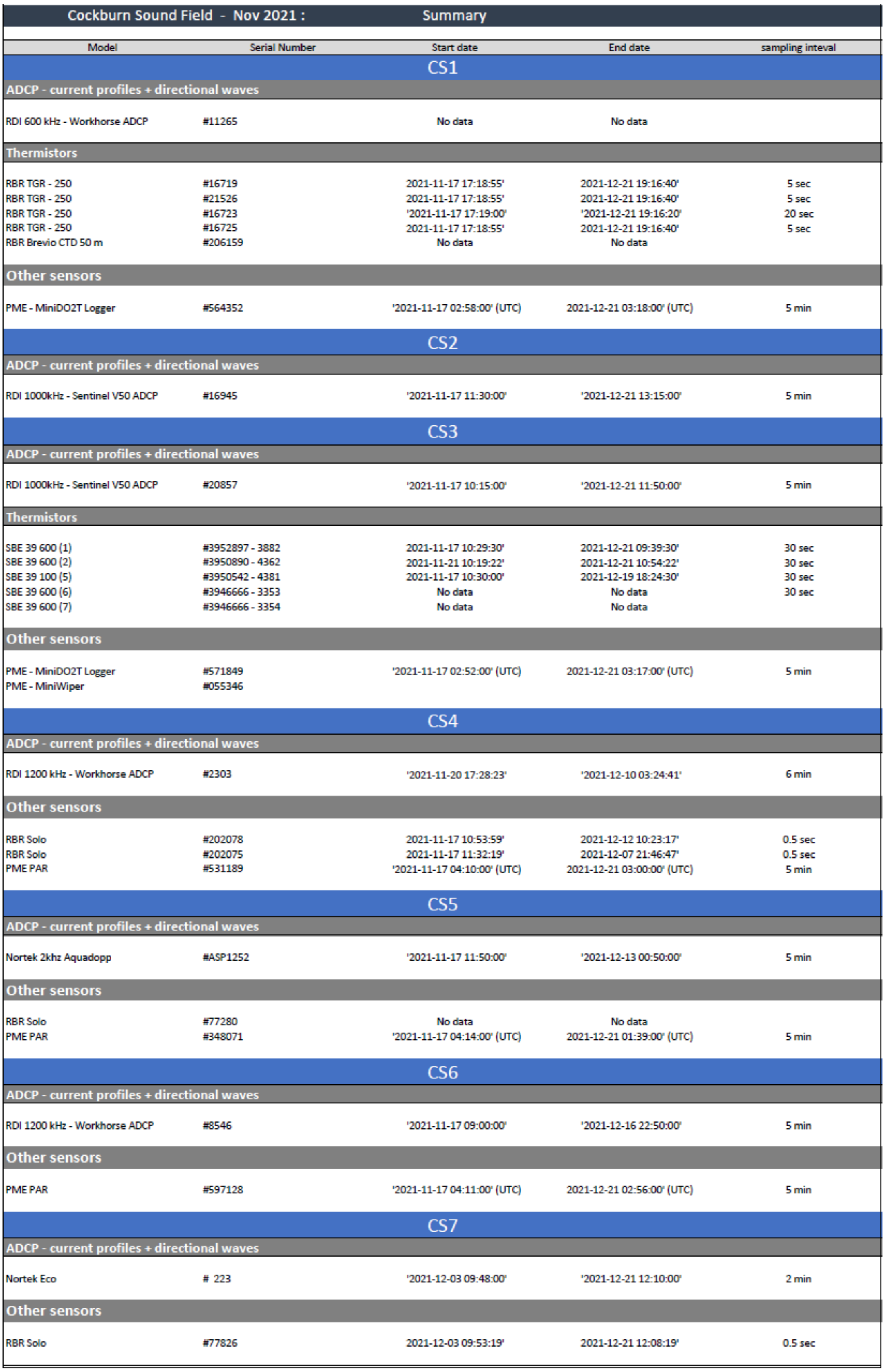
In total there are 23607 objects in the archive with 3.5Tb of compressed data.

7.2 Appendix 2 – Details of data availability from each field deployment



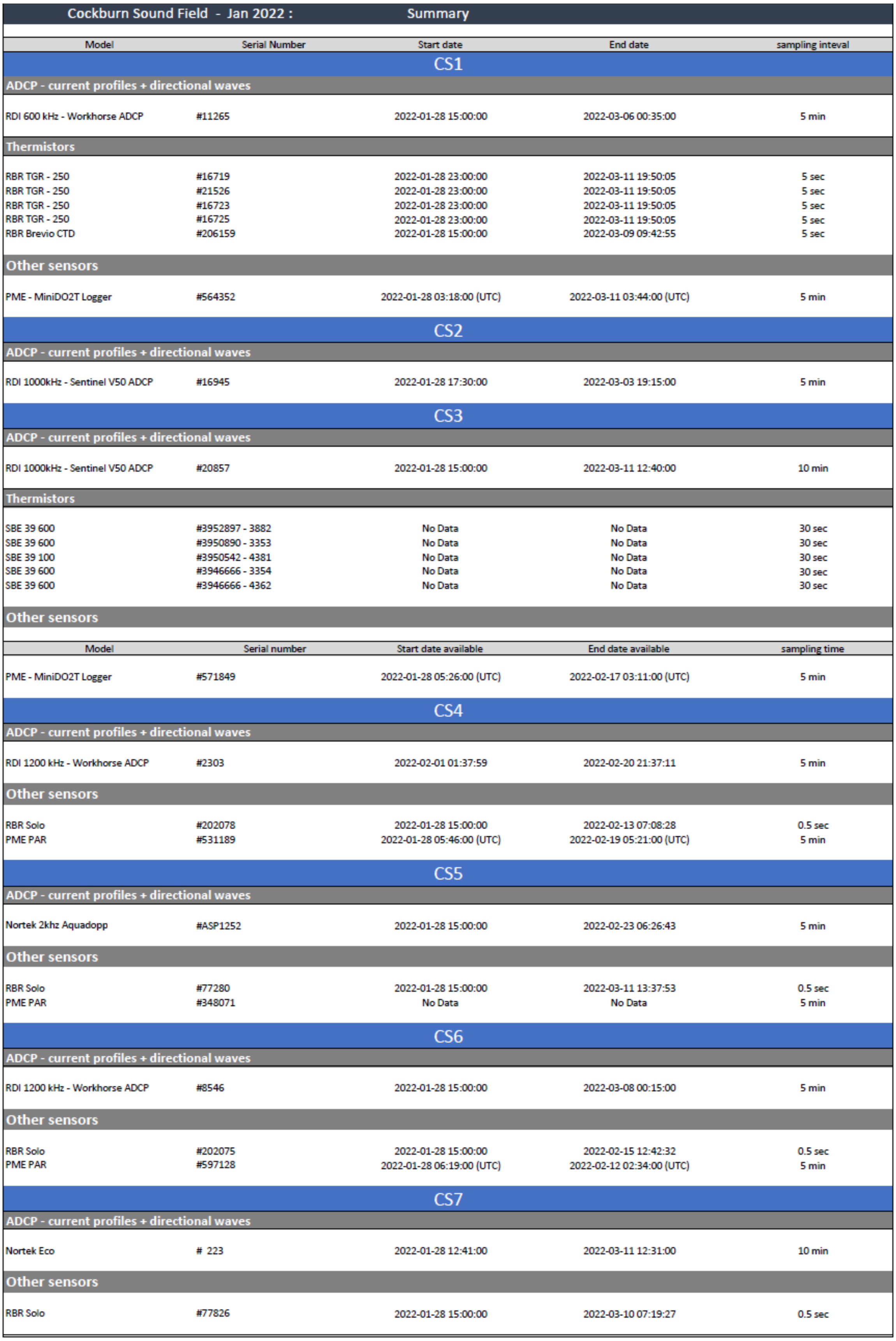
Cockburn Sound Field - Apr 2021 : Summary

Model	Serial Number	Start date	End date	sampling inteval
CS1				
ADCP - current profiles + directional waves				
RDI 500 kHz - Sentinel V	#23238	no data	no data	
Thermistors				
RBR TGR - 250	#21526	'2021-04-16 15:14:10'	'2021-06-23 13:09:15'	5 sec
RBR TGR - 250	#16724 12m	'2021-04-16 23:14:05'	'2021-05-04 03:34:15'	5 sec
RBR TGR - 250	#16725 8m	'2021-04-16 15:14:20'	'2021-06-23 13:09:15'	5 sec
RBR TGR - 250	#16719 4m	'2021-04-16 23:24:30'	'2021-04-26 09:32:00'	5 sec
RBR Brevio CTD 50 m	#206159	'2021-04-16 12:00:00'	'2021-06-04 08:55:36'	1 sec
Other sensors				
PME - MiniDO2T Logger	#564352	'2021-04-16 16:13:00' (UTC)	'2021-06-23 05:23:00' (UTC)	5 min
CS2				
ADCP - current profiles + directional waves				
RDI 1000kHz - Sentinel V50 ADCP	#16945	'2021-04-16 12:00:00'	'2021-05-17 05:12:00'	5 min
CS3				
ADCP - current profiles + directional waves				
RDI 600 kHz - Workhorse ADCP	#11265	'2021-04-16 14:00:00'	'2021-06-11 05:55:00'	5 min
Thermistors				
SBE 39 600 (1)	#3952897 - 3882	'2021-04-16 16:33:17'	'2021-04-20 04:15:47'	30 sec
SBE 39 600 (2)	#3950890 - 4362	'2021-04-16 16:46:37'	'2021-05-26 23:18:07'	30 sec
SBE 39 100 (5)	#3950542 - 4381	'2021-04-16 16:25:25'	'2021-05-02 23:24:55'	30 sec
SBE 39 600 (6)	#3946666 - 3353	'2021-04-16 16:20:39'	2021-05-12 02:04:39'	30 sec
Other sensors				
PME - MiniDO2T Logger	#571849	'2021-04-16 16:41:00' (UTC)	'2021-06-23 06:16:00' (UTC)	5 min

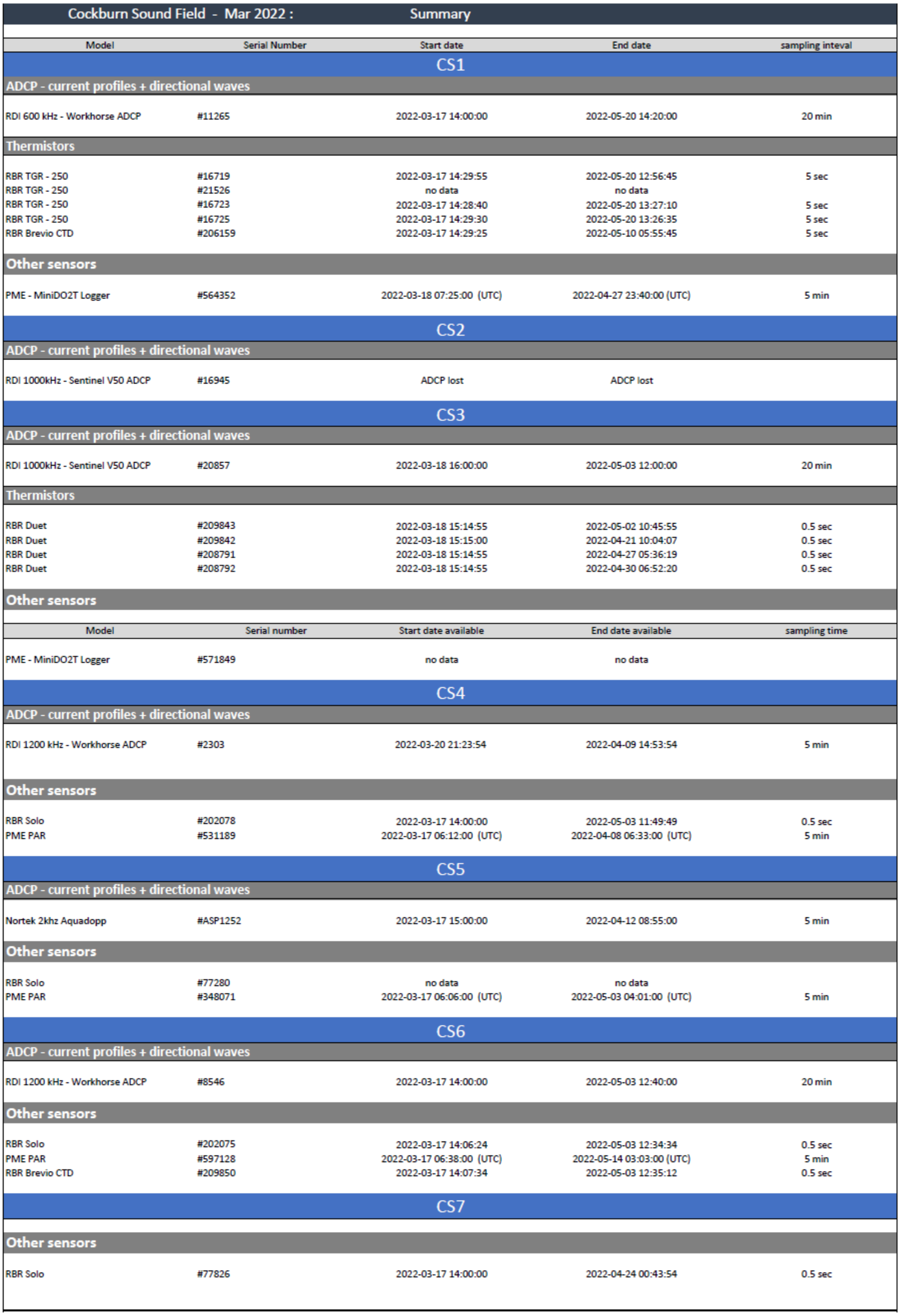


Cockburn Sound Field - Nov 2021 : Summary

Model	Serial Number	Start date	End date	sampling inteval
CS1				
ADCP - current profiles + directional waves				
RDI 600 kHz - Workhorse ADCP	#11265	No data	No data	
Thermistors				
RBR TGR - 250	#16719	2021-11-17 17:18:55'	2021-12-21 19:16:40'	5 sec
RBR TGR - 250	#21526	2021-11-17 17:18:55'	2021-12-21 19:16:40'	5 sec
RBR TGR - 250	#16723	'2021-11-17 17:19:00'	'2021-12-21 19:16:20'	20 sec
RBR TGR - 250	#16725	2021-11-17 17:18:55'	2021-12-21 19:16:40'	5 sec
RBR Brevio CTD 50 m	#206159	No data	No data	
Other sensors				
PME - MiniDO2T Logger	#564352	'2021-11-17 02:58:00' (UTC)	2021-12-21 03:18:00' (UTC)	5 min
CS2				
ADCP - current profiles + directional waves				
RDI 1000kHz - Sentinel V50 ADCP	#16945	'2021-11-17 11:30:00'	'2021-12-21 13:15:00'	5 min
CS3				
ADCP - current profiles + directional waves				
RDI 1000kHz - Sentinel V50 ADCP	#20857	'2021-11-17 10:15:00'	'2021-12-21 11:50:00'	5 min
Thermistors				
SBE 39 600 (1)	#3952897 - 3882	2021-11-17 10:29:30'	2021-12-21 09:39:30'	30 sec
SBE 39 600 (2)	#3950890 - 4362	2021-11-21 10:19:22'	2021-12-21 10:54:22'	30 sec
SBE 39 100 (5)	#3950542 - 4381	2021-11-17 10:30:00'	2021-12-19 18:24:30'	30 sec
SBE 39 600 (6)	#3946666 - 3353	No data	No data	30 sec
SBE 39 600 (7)	#3946666 - 3354	No data	No data	
Other sensors				
PME - MiniDO2T Logger	#571849	'2021-11-17 02:52:00' (UTC)	2021-12-21 03:17:00' (UTC)	5 min
PME - MiniWiper	#055346			
CS4				
ADCP - current profiles + directional waves				
RDI 1200 kHz - Workhorse ADCP	#2303	'2021-11-20 17:28:23'	'2021-12-10 03:24:41'	6 min
Other sensors				
RBR Solo	#202078	2021-11-17 10:53:59'	2021-12-12 10:23:17'	0.5 sec
RBR Solo	#202075	2021-11-17 11:32:19'	2021-12-07 21:46:47'	0.5 sec
PME PAR	#531189	'2021-11-17 04:10:00' (UTC)	2021-12-21 03:00:00' (UTC)	5 min
CS5				
ADCP - current profiles + directional waves				
Nortek 2khz Aquadopp	#ASP1252	'2021-11-17 11:50:00'	'2021-12-13 00:50:00'	5 min
Other sensors				
RBR Solo	#77280	No data	No data	
PME PAR	#348071	'2021-11-17 04:14:00' (UTC)	2021-12-21 01:39:00' (UTC)	5 min
CS6				
ADCP - current profiles + directional waves				
RDI 1200 kHz - Workhorse ADCP	#8546	'2021-11-17 09:00:00'	'2021-12-16 22:50:00'	5 min
Other sensors				
PME PAR	#597128	'2021-11-17 04:11:00' (UTC)	2021-12-21 02:56:00' (UTC)	5 min
CS7				
ADCP - current profiles + directional waves				
Nortek Eco	# 223	'2021-12-03 09:48:00'	'2021-12-21 12:10:00'	2 min
Other sensors				
RBR Solo	#77826	2021-12-03 09:53:19'	2021-12-21 12:08:19'	0.5 sec



Cockburn Sound Field - Jan 2022 :		Summary		
Model	Serial Number	Start date	End date	sampling inteval
		CS1		
ADCP - current profiles + directional waves				
RDI 600 kHz - Workhorse ADCP	#11265	2022-01-28 15:00:00	2022-03-06 00:35:00	5 min
Thermistors				
RBR TGR - 250	#16719	2022-01-28 23:00:00	2022-03-11 19:50:05	5 sec
RBR TGR - 250	#21526	2022-01-28 23:00:00	2022-03-11 19:50:05	5 sec
RBR TGR - 250	#16723	2022-01-28 23:00:00	2022-03-11 19:50:05	5 sec
RBR TGR - 250	#16725	2022-01-28 23:00:00	2022-03-11 19:50:05	5 sec
RBR Brevio CTD	#206159	2022-01-28 15:00:00	2022-03-09 09:42:55	5 sec
Other sensors				
PME - MiniDO2T Logger	#564352	2022-01-28 03:18:00 (UTC)	2022-03-11 03:44:00 (UTC)	5 min
		CS2		
ADCP - current profiles + directional waves				
RDI 1000kHz - Sentinel V50 ADCP	#16945	2022-01-28 17:30:00	2022-03-03 19:15:00	5 min
		CS3		
ADCP - current profiles + directional waves				
RDI 1000kHz - Sentinel V50 ADCP	#20857	2022-01-28 15:00:00	2022-03-11 12:40:00	10 min
Thermistors				
SBE 39 600	#3952897 - 3882	No Data	No Data	30 sec
SBE 39 600	#3950890 - 3353	No Data	No Data	30 sec
SBE 39 100	#3950542 - 4381	No Data	No Data	30 sec
SBE 39 600	#3946666 - 3354	No Data	No Data	30 sec
SBE 39 600	#3946666 - 4362	No Data	No Data	30 sec
Other sensors				
Model	Serial number	Start date available	End date available	sampling time
PME - MiniDO2T Logger	#571849	2022-01-28 05:26:00 (UTC)	2022-02-17 03:11:00 (UTC)	5 min
		CS4		
ADCP - current profiles + directional waves				
RDI 1200 kHz - Workhorse ADCP	#2303	2022-02-01 01:37:59	2022-02-20 21:37:11	5 min
Other sensors				
RBR Solo	#202078	2022-01-28 15:00:00	2022-02-13 07:08:28	0.5 sec
PME PAR	#531189	2022-01-28 05:46:00 (UTC)	2022-02-19 05:21:00 (UTC)	5 min
		CS5		
ADCP - current profiles + directional waves				
Nortek 2khz Aquadopp	#ASP1252	2022-01-28 15:00:00	2022-02-23 06:26:43	5 min
Other sensors				
RBR Solo	#77280	2022-01-28 15:00:00	2022-03-11 13:37:53	0.5 sec
PME PAR	#348071	No Data	No Data	5 min
		CS6		
ADCP - current profiles + directional waves				
RDI 1200 kHz - Workhorse ADCP	#8546	2022-01-28 15:00:00	2022-03-08 00:15:00	5 min
Other sensors				
RBR Solo	#202075	2022-01-28 15:00:00	2022-02-15 12:42:32	0.5 sec
PME PAR	#597128	2022-01-28 06:19:00 (UTC)	2022-02-12 02:34:00 (UTC)	5 min
		CS7		
ADCP - current profiles + directional waves				
Nortek Eco	# 223	2022-01-28 12:41:00	2022-03-11 12:31:00	10 min
Other sensors				
RBR Solo	#77826	2022-01-28 15:00:00	2022-03-10 07:19:27	0.5 sec



Cockburn Sound Field - Mar 2022 :		Summary		
Model	Serial Number	Start date	End date	sampling inteval
CS1				
ADCP - current profiles + directional waves				
RDI 600 kHz - Workhorse ADCP	#11265	2022-03-17 14:00:00	2022-05-20 14:20:00	20 min
Thermistors				
RBR TGR - 250	#16719	2022-03-17 14:29:55	2022-05-20 12:56:45	5 sec
RBR TGR - 250	#21526	no data	no data	
RBR TGR - 250	#16723	2022-03-17 14:28:40	2022-05-20 13:27:10	5 sec
RBR TGR - 250	#16725	2022-03-17 14:29:30	2022-05-20 13:26:35	5 sec
RBR Brevio CTD	#206159	2022-03-17 14:29:25	2022-05-10 05:55:45	5 sec
Other sensors				
PME - MiniDO2T Logger	#564352	2022-03-18 07:25:00 (UTC)	2022-04-27 23:40:00 (UTC)	5 min
CS2				
ADCP - current profiles + directional waves				
RDI 1000kHz - Sentinel V50 ADCP	#16945	ADCP lost	ADCP lost	
CS3				
ADCP - current profiles + directional waves				
RDI 1000kHz - Sentinel V50 ADCP	#20857	2022-03-18 16:00:00	2022-05-03 12:00:00	20 min
Thermistors				
RBR Duet	#209843	2022-03-18 15:14:55	2022-05-02 10:45:55	0.5 sec
RBR Duet	#209842	2022-03-18 15:15:00	2022-04-21 10:04:07	0.5 sec
RBR Duet	#208791	2022-03-18 15:14:55	2022-04-27 05:36:19	0.5 sec
RBR Duet	#208792	2022-03-18 15:14:55	2022-04-30 06:52:20	0.5 sec
Other sensors				
Model	Serial number	Start date available	End date available	sampling time
PME - MiniDO2T Logger	#571849	no data	no data	
CS4				
ADCP - current profiles + directional waves				
RDI 1200 kHz - Workhorse ADCP	#2303	2022-03-20 21:23:54	2022-04-09 14:53:54	5 min
Other sensors				
RBR Solo	#202078	2022-03-17 14:00:00	2022-05-03 11:49:49	0.5 sec
PME PAR	#531189	2022-03-17 06:12:00 (UTC)	2022-04-08 06:33:00 (UTC)	5 min
CS5				
ADCP - current profiles + directional waves				
Nortek 2khz Aquadopp	#ASP1252	2022-03-17 15:00:00	2022-04-12 08:55:00	5 min
Other sensors				
RBR Solo	#77280	no data	no data	
PME PAR	#348071	2022-03-17 06:06:00 (UTC)	2022-05-03 04:01:00 (UTC)	5 min
CS6				
ADCP - current profiles + directional waves				
RDI 1200 kHz - Workhorse ADCP	#8546	2022-03-17 14:00:00	2022-05-03 12:40:00	20 min
Other sensors				
RBR Solo	#202075	2022-03-17 14:06:24	2022-05-03 12:34:34	0.5 sec
PME PAR	#597128	2022-03-17 06:38:00 (UTC)	2022-05-14 03:03:00 (UTC)	5 min
RBR Brevio CTD	#209850	2022-03-17 14:07:34	2022-05-03 12:35:12	0.5 sec
CS7				
Other sensors				
RBR Solo	#77826	2022-03-17 14:00:00	2022-04-24 00:43:54	0.5 sec

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