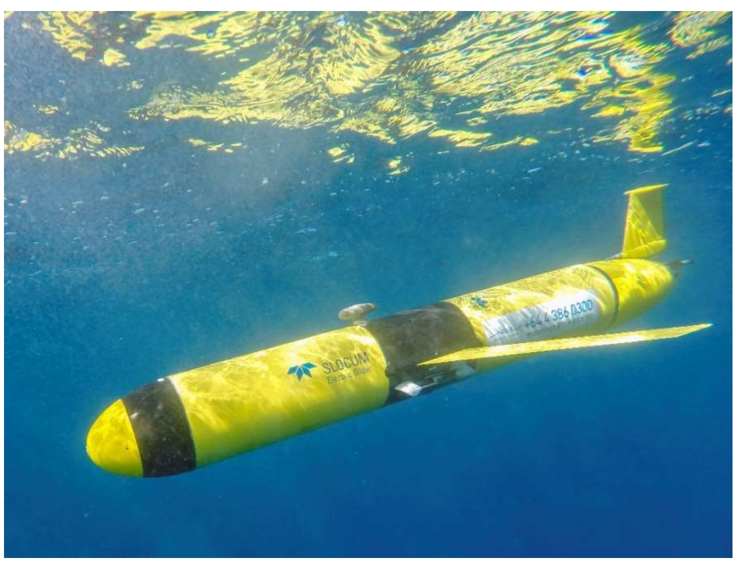
Spatial mapping of subsurface oxygen depletion in Hawke Bay.

Prepared for Hawkes Bay Regional Council

11 October 2019



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Executive summary

Spatial and vertical distributions of dissolved oxygen were obtained in Hawke Bay during Autumn 2019. The 4-week ocean glider mission recorded 8506 profiles over 31 days dramatically increasing the available data in the Hawke Bay system. The timing of the glider mission coincided with coastal Sea Surface Temperature (SST) being between 1-2 degrees above the climatological average for Hawke Bay.

A spatial decrease in surface and subsurface dissolved oxygen occurred from north-east to south-west through Hawke. Lowest dissolved oxygen concentrations were observed closest to Napier. Two regions had surface dissolved oxygen at 60-75%, they were: 1) off from the Mohaka River and 2) adjacent to Cape Kidnappers headland. The subsurface spatial gradient was a decrease from 105% to 65% saturation moving from north-east to south-west.

Vertical variability in dissolved oxygen was due to a mixture of tidal oscillations, wind stirring and in oceanic influences. Depleted oxygen in inner Hawke Bay can be generated by both land and oceanic processes. For example, shallow profiles of lower dissolved oxygen around March 23 were collocated with lowest salinities from a riverine influence. Upslope transport of cold, deoxygenated water from offshore in late March (27-28) was likely due to an upwelling event.

1 Introduction

1.1 Motivation

As a coastal embayment with a large number of river systems, Hawke Bay is the depositional end-point for six broad catchments –Wairoa-Northern Coastal, Mohaka, Waikari-Esk- Aropaoanui, TANK, Tukituki and Porangahau-Southern Coastal (unpublished data HBRC, 2016).

Hawke's Bay Regional Council (HBRC) is seeking advice on the potential scale and magnitude of areas of dissolved oxygen depletion in Hawke Bay. HBRC has invested significantly in equipment that provides near real-time data on dissolved oxygen levels. This equipment provides excellent temporal coverage, but cannot identify the spatial extent of areas potentially at risk of low or depleted dissolved oxygen concentrations.

It was not clear how widespread the dissolved oxygen issue is for Hawke Bay. HBRC were after advice about the spatial extent of dissolved oxygen levels, as well as advice on the scale and magnitude of the results to assist HBRC in its role in managing land and freshwater to meet coastal water quality objectives.

1.2 Historic observations in Hawke Bay

In Hawke Bay, variations in surface and subsurface stratification are described as a balance between wind mixing, tides, river inflows from the seven main rivers, the Wairarapa Coastal Current and East Cape Eddy (ECE). However, few bay-wide observations exist in Hawke Bay. This is not uncommon in New Zealand shelf seas (Stevens et al. 2019). The most recent from Francis (1985) which alternated between a full-depth and surface hydrographic surveys. The latter data were obtained from bucket samples. Surface circulation was described as consisting of two cells defined by an inflow along the midline of the bay and outflows at either end.

The role of upwelling in coastal systems is regularly cited as an important process for ecosystem productivity. Chiswell (2002) used eight years of coastal sea surface temperature (SST) observations from Napier to evaluate the role of the Wairarapa Coastal Current on Hawke Bay. Variations in the Wairarapa Coastal Current are wind stress driven and that alongshore advection of the Wairarapa Coastal Current principally controls temperature at Napier wharf. The Wairarapa Coastal Current is more important in short-term temperature variability than upwelling.

1.3 Dissolved oxygen in coastal systems

Dissolved oxygen observations from other coastal systems around New Zealand are sparse. A 20-year mooring in the outer Firth of Thames is the longest duration observations of dissolved oxygen in any coastal system of New Zealand (Zeldis et al., 2015). Briefly, in the Firth, lowest dissolved oxygen occurs during summer and autumn with dissolved oxygen typically reduced to about 60–70% saturation (4.9 and 5.7 mg L-1, respectively) at the water depths greater than 20 m below the surface. Periods of lower dissolved oxygen in the Firth of Thames nearly always occurred when the water column was stratified.

HBRC has maintained a water quality buoy (HAWQi) in coastal Hawke Bay since 2012. Dissolved oxygen can become depleted to dissolved oxygen levels less than 60% saturation (6.03mg/l) Spring 2016. The dissolved oxygen concentrations in Hawke Bay are comparable to depleted dissolved oxygen observed in the inner Firth of Thames.

2 Methods

An ocean glider was deployed in Hawkes Bay on March 4, 2019. The vehicle followed a gridded pattern across the Bay for 31 days travelling a total of 619 km and performing 8506 profiles. The glider was deployed from Hawkes Bay Coastguard vessel Celia Knowles II at 39° 28.03' S, 177° 11.55' E and water depth of approximately 50 m. Recovery was from the same vessel at 39° 24.17' S, 176° 55.29' E on April 4, 2019. Figure 2-1 shows the surface locations of the glider over the 31 days. The glider mission began in the north-east of Hawke Bay with land-sea transects progressing southwards over the 4 weeks.

A Slocum 200 m electric glider was used for the mission. Slocum gliders are buoyancy-driven autonomous underwater vehicles (AUVs) that provide high-resolution surveys of the physical and bio-optical properties of the water column. The 200 m glider `Betty', was equipped with a Seabird conductivity-temperature-depth (CTD) sensor and carried a WET Labs Environmental Characterization Optics (ECO) puck, that measured chlorophyll-a fluorescence, backscatter at 660 nm —and coloured dissolved organic matter (CDOM). Temperature, conductivity, and pressure data were collected at 0.5 Hz, and subsequently processed to remove spikes. Quality control (QC) procedures from the Balearic Islands Coastal Observing and Forecasting System (SOCIB) data processing toolbox were used for data (Troupin et al., 2016) and include salinity corrections for the thermal lag error for the un-pumped CTD data (Garau et al., 2011). Final profiles have an average horizontal along-track resolution of 0.5 km and vertical bins of 1 m.

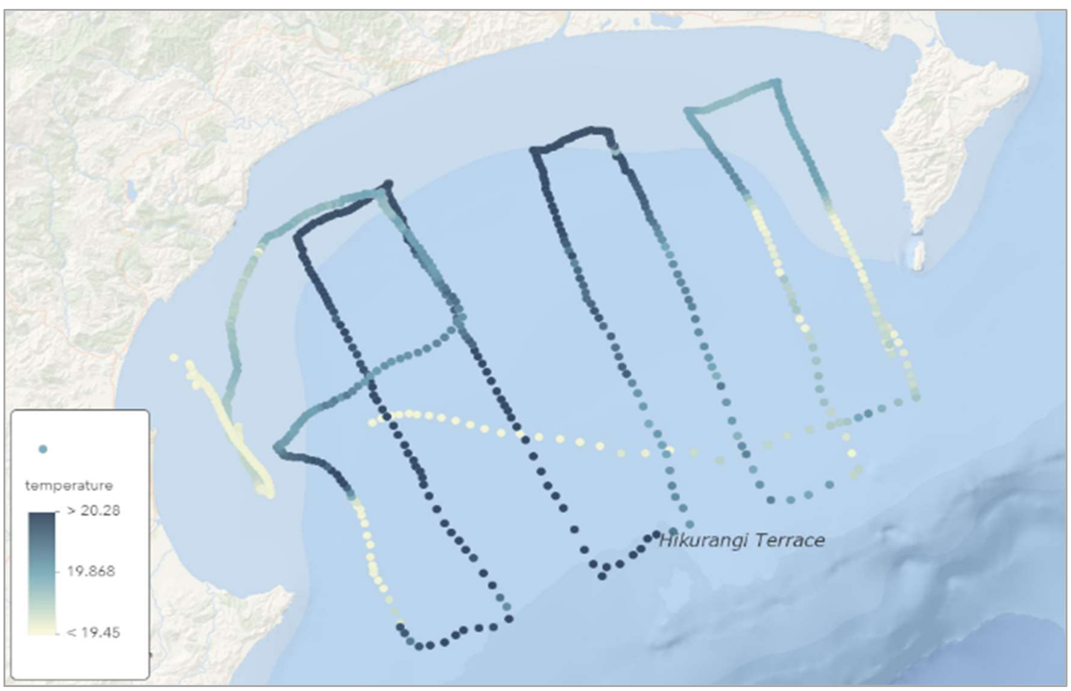

Figure 2-1: Glider track from Hawkes Bay mission with temperature at 10 m displayed for the 31 days.

3 Main results

3.1 Background oceanographic conditions

The ocean glider track traversed from north-east to south-west over the 4-week mission, thus the majority of glider observations will have sampled the ocean conditions for SSTA around 1 °C warmer than average.

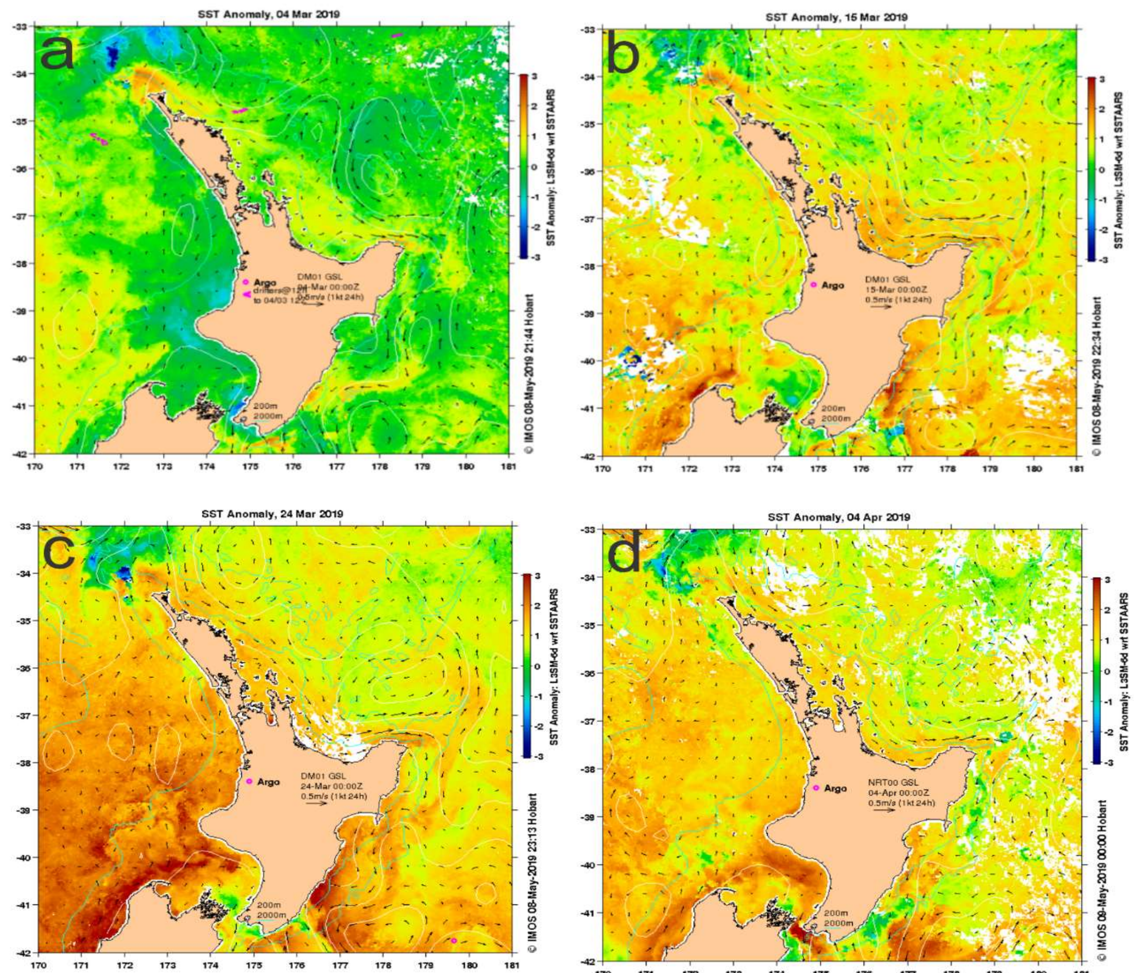

Figure 3-1: Sea surface temperature anomaly (SSTA) for (a) March 4, (b) March 16, (c) March 24 and (d) April 4 2019. Anomalies were neutral at the beginning of the glider mission and increased by 1.5 °C over the 31 days. The SSTA maps were obtained from http://oceancurrent.imos.org.au/product.php

3.2 Near-surface temperature and salinity

The ocean glider collected 8506 profiles over the 4-week mission. These data provide an important link between the more-available surface SSTA and the temperatures in the water column. Near-surface temperatures (5 m) ranged from 18.5 to 21 °C (Figure 3-2) throughout Hawke Bay. At the beginning of the mission, near-surface temperatures were around 18.5 °C. Further to the east (and around 1 week later), surface temperatures were 1 °C warmer. Colder surface water (18.5 °C) was observed at inner Hawke Bay in coastal waters. Warm near-surface temperatures up to 21 °C occurred at the oceanic boundary.

Near-surface salinity variations had a clearer gradient in near-surface salinity and inner Hawke Bay had lower salinity – down to 34.4 psu offshore from the Mohaka River. Higher salinities up to 35.5 psu were evident in offshore transects located in the central part of Hawke Bay. (Figure 3-3).

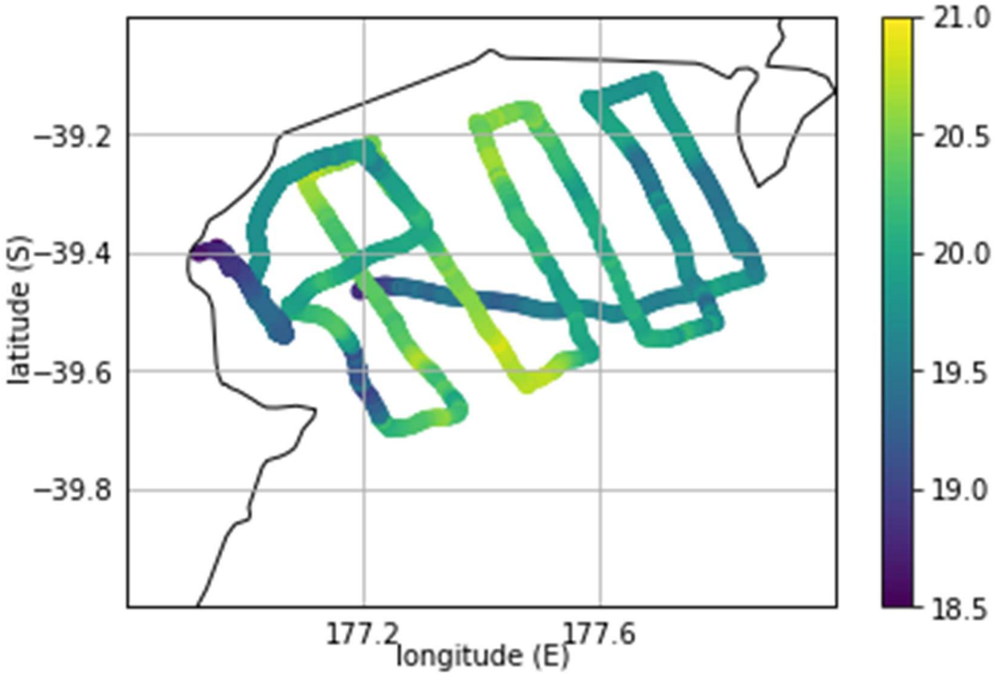

Figure 3-2: Surface temperatures (5m) over the 4-week glider mission in Hawke Bay.

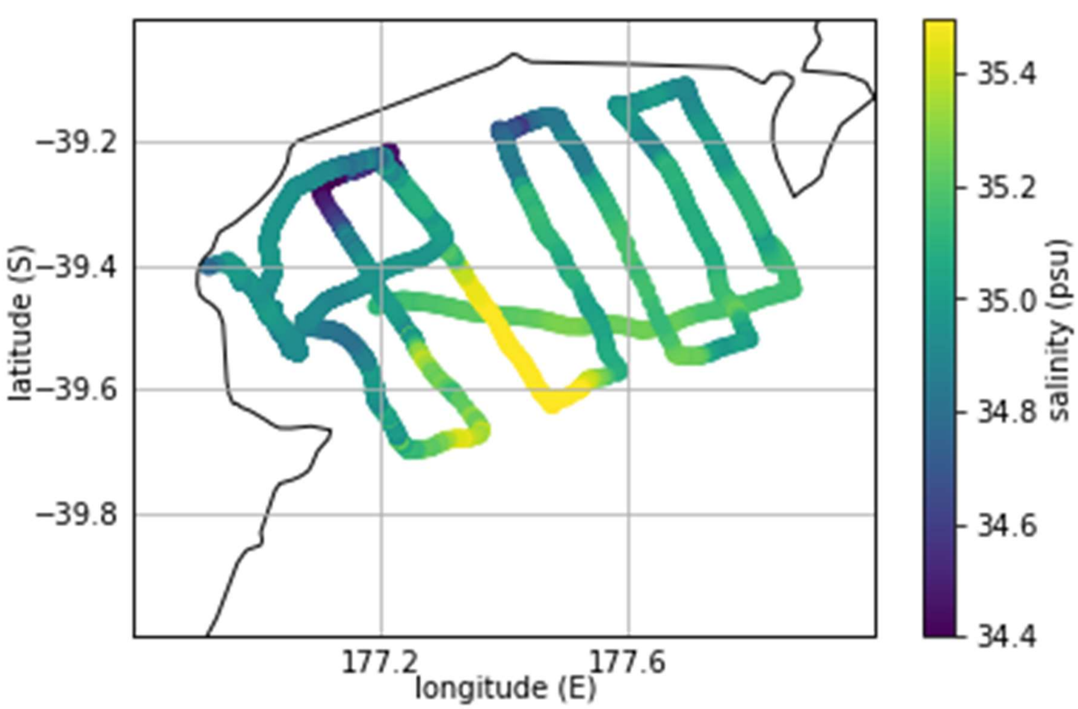

Figure 3-3: Surface salinities (5m) over the 4-week glider mission in Hawke Bay.

3.3 Spatio-temporal glider observations

Subsurface glider observations over the 4-week times series are shown in Figure 3-4. Water temperatures ranged from near-surface values of 21 ^{o}C down to 13.8 ^{o}C at the seabed. Warmest temperatures were observed from March 18 to 20 and a subsequent transect to the southwest also had warm temperatures (21 ^{o}C) in the outer part of Hawke Bay. Tidal oscillations can be seen at the base of the thermocline which was between 30 -50m below the surface. All inshore temperature profiles (less than 40m) were stratified during March 2019. Of note for later comparison to dissolved oxygen observations were the cooler waters observed at the surface on March 28.

Lowest salinities (34.3 psu) over the glider mission were observed at the surface and, as expected, at locations closest to rivers (Figure 3-4). Riverine responses are provided in more detail in section 3.5. High salinity was observed at the outer part of several transects located midway through Hawke Bay. High salinity around March 19 extended to the surface, however by March 26 higher salinities were subsurface features.

Dissolved oxygen concentrations decreased with depth (100 to 85%) in the north-eastern part of Hawke Bay. Towards the southwest, dissolved oxygen decreased down in 65-70% below 50m. The upper 50 m had dissolved oxygen between 90 and 95%. The lowest dissolved oxygen (70%) was observed along the transect closest to Cape Kidnappers. On 28 March, dissolved oxygen was no longer stratified and low dissolved oxygen extended to the surface. Colder temperatures and high chlorophyll were also evident closer to the surface and indicative of upwelling or an intrusion of Wairarapa Coastal Current into Hawke Bay. Dissolved oxygen between 29 and 31 March should be treated with some caution due to an absence of oxygen layering while density stratification persisted. These observations were close to the headland which may result in different dynamics in this part of Hawke Bay. Strong depth averaged currents (0.35 m s^{-1}) – the fastest of the mission - were calculated by the glider off from Cape Kidnappers headland.

CDOM ranged from 0.5 to 2.0 ppb and increased from surface to sea bed, respectively. High surface CDOM was only observed on March 27-28. Otherwise high CDOM was typically located near the sea bed. Chlorophyll maxima (between 2 and 2.5 mgm^{-3}) were typically located 30 to 50 m below the surface for most transects. High surface chlorophyll was only observed on March 27-28, and collocated with colder temperatures, lower dissolved oxygen and high CDOM. The shallow glider transect (~30m) in the inner Hawke Bay from March 30 onwards had high chlorophyll at the sea bed.

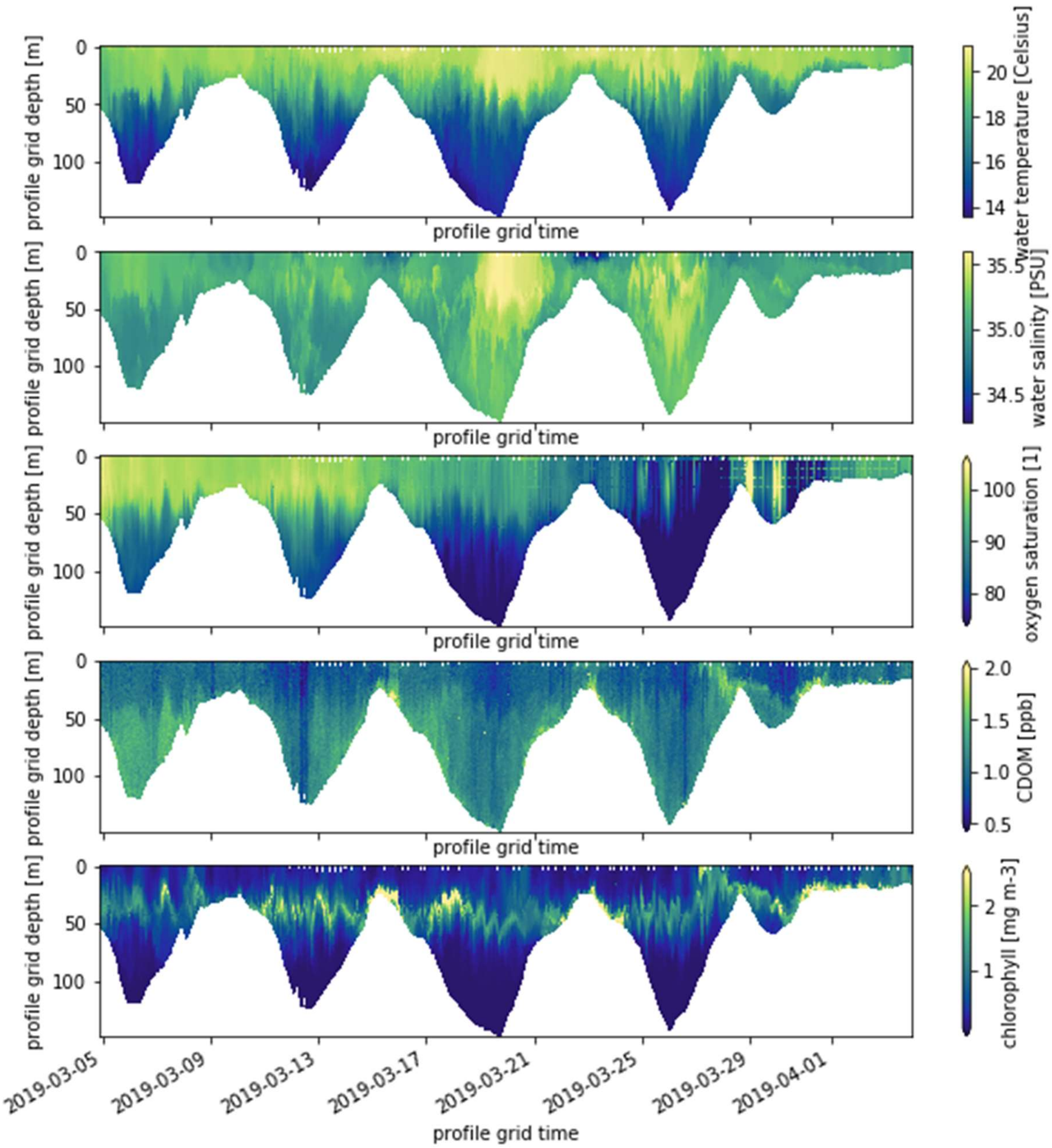

Figure 3-4: High resolution map of ocean properties from March 3 to April 4, 2019 in Hawke Bay.

3.4 Vertical structure of biophysics in Hawke Bay

Averaged-vertical profiles of all observations collected by the ocean glider are shown in Figure 3-5. Although averaging more than 8,500 profiles eliminates the substantial variability observed by the glider, it useful to get a broad description of ocean properties for Hawke Bay.

Lowest salinity was observed at the surface, increasing to a subsurface maxima at 35m. Between 35 and 120 m average salinity was approximately constant., however, the standard deviation was relatively high +/- 0.25 psu. In the lower 20 m, salinity converged to 35.2 psu and although the standard deviation was low this was due to fewer glider profiles in water depths greater than 120m.

Between 18 and 20 m, a slight deviation can be seen in all averaged profiles of ocean properties. As the deviation was retained in the average profiles, it indicates a persistent subsurface feature through Hawke Bay. Temperature decreased linearly from warm to cool over 140 m, with a near-surface average of 20 °C to 14 °C at the seabed. Dissolved oxygen also decreased from surface to seabed from 90 to 70%, respectively. Vertical structure of CDOM was lower at the surface than the seabed (1 to 1.2 ppb). Of note, was the uniform near-surface CDOM layer down to 16 m, with a localised CDOM maxima at 18m.

Chlorophyll-a fluorescence had two subsurface maxima at 18m (~ 1 mg m^{-3}) and deeper in the water column between 30 and 50m (1.2 mg m^{-3}). The latter subsurface maxima will be associated with water depths exceeding 50m and the former with shallower (< 50 m) Hawke Bay. From 50 to 140 m, concentrations decreased from 1.2 to 0.2 mg m^{-3}.

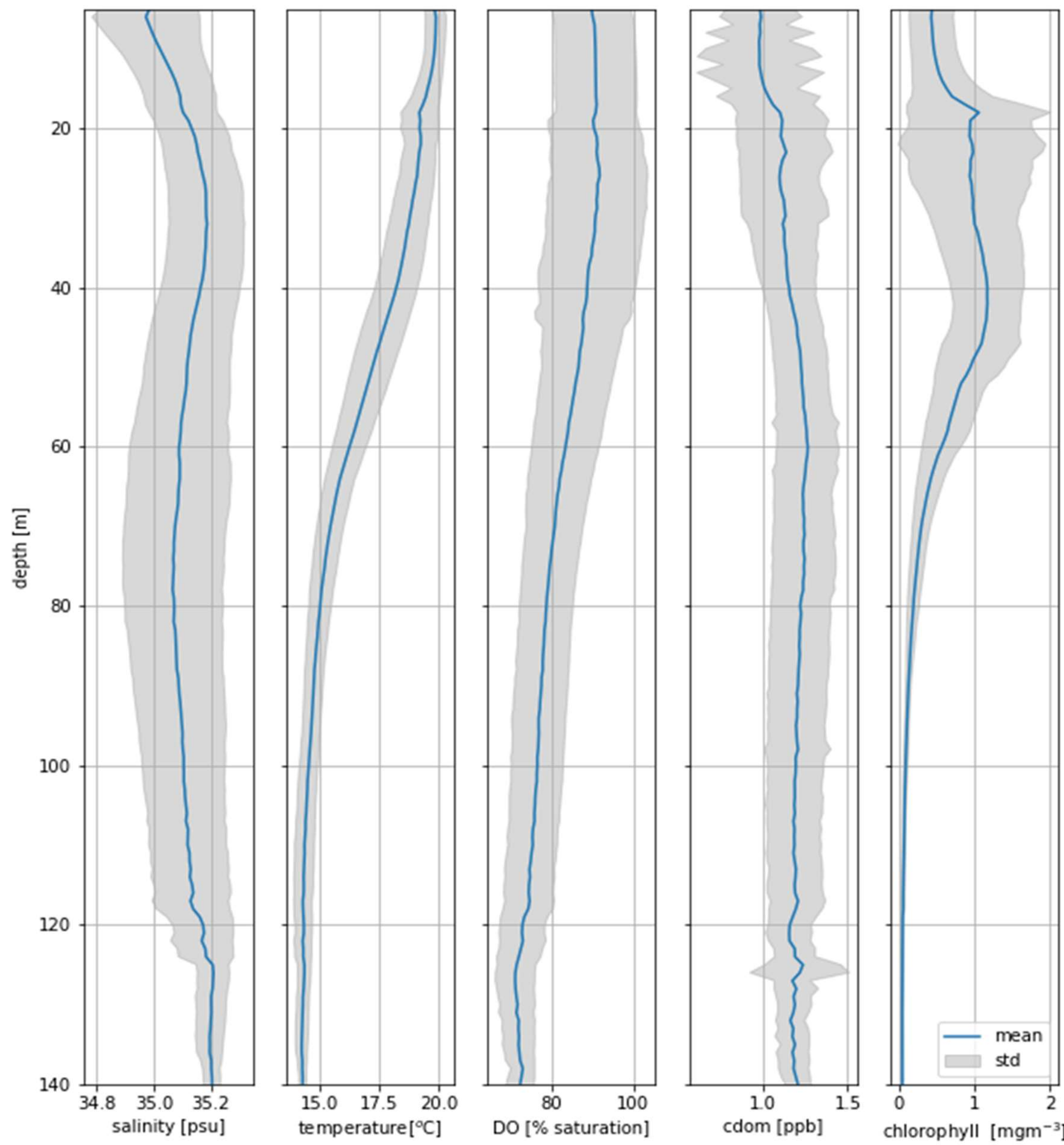

Figure 3-5: Mission-averaged profiles of salinity, temperature, dissolved oxygen, CDOM and Chlorophyll-a. Shaded regions are standard deviations.

3.5 Riverine signals on Hawke Bay stratification

Near-surface salinities decreased to a minimum of 34.38 psu at the inner Hawke Bay (Figure 3-6). The vertical extent of the low salinity water was between 8 to 10 m below the surface and characteristics of a river plume or region of freshwater influence (ROFI) in the coastal ocean. With distance from the freshwater source, observed salinity became closer to oceanic values (35 psu). Vertical stirring by wind will mix and dilute ROFI water with the surrounding ocean. Mixing is in both the vertical and horizontal directions with daily excursions of water from tides. Transect 7 began at 39°17.6’ S, 177° 9' E and went to 39°30.6’ S, 177° 2.3' E.

Beyond water depths of 50 m, salinity increases again to over 35.4 psu as a subsurface salinity maxima. The presence of a subsurface maxima may be due to surface capping by ROFI water advected offshore. In the outer Hawke Bay region, there are some interleaving features in salinity that are evident in frontal regions of the ocean. Most likely at the region where the warm salty East Cape Eddy and the cold salty Wairarapa Coastal Current intersect and subducts in the outer Hawke Bay. Although the analysis was beyond the scope here, understanding the separate roles that salinity and temperature have on water column stability is important for characterising the vertical mixing of nutrients, sediments and plankton of coastal ecosystems.

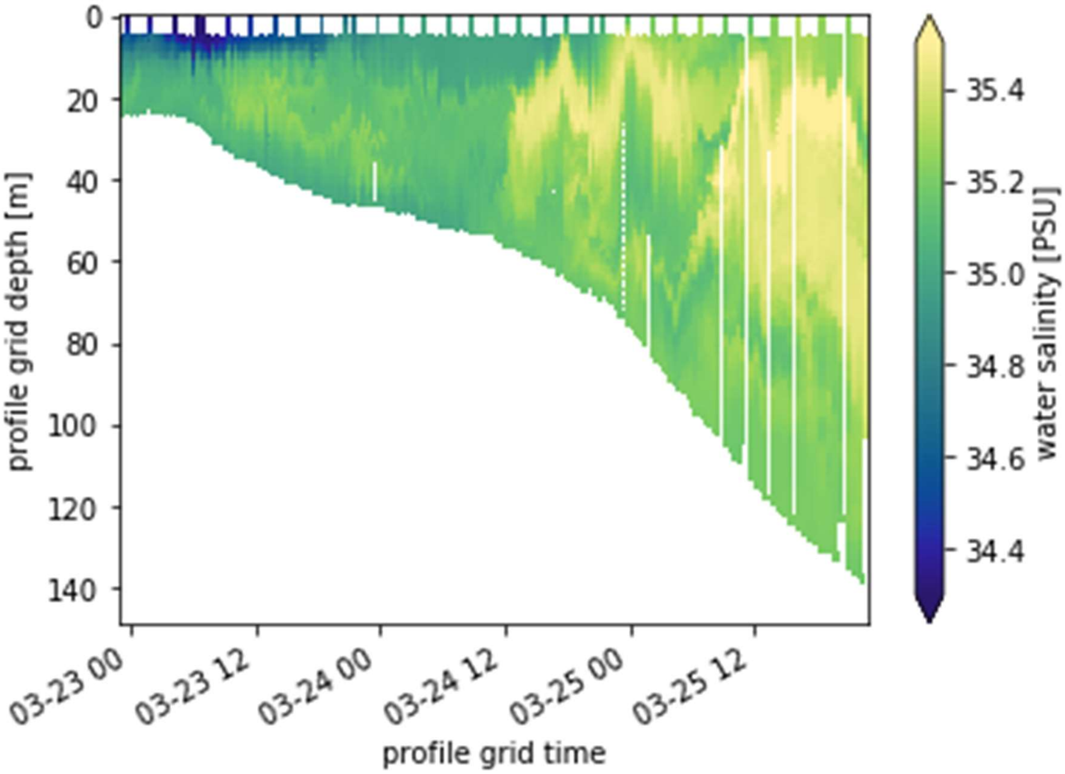

Figure 3-6: Glider transect of salinity from Mohaka River to outer Hawke Bay in the middle part of the Bay.

3.6 Dissolved oxygen from the glider and HBRC data

A 6-day subset of dissolved oxygen observations from the glider mission are shown in Figure 3-7. Oxygen stratification was evident for the first 3 days, with upper ocean oxygen close to 100% saturated and lower water column dissolved oxygen down to 65%. By March 27, dissolved oxygen had decreased to the lowest observed (60%) for the mission at water depths between 40 and 70 m. dissolved oxygen was between 65 and 70% from the surface to 40 m.

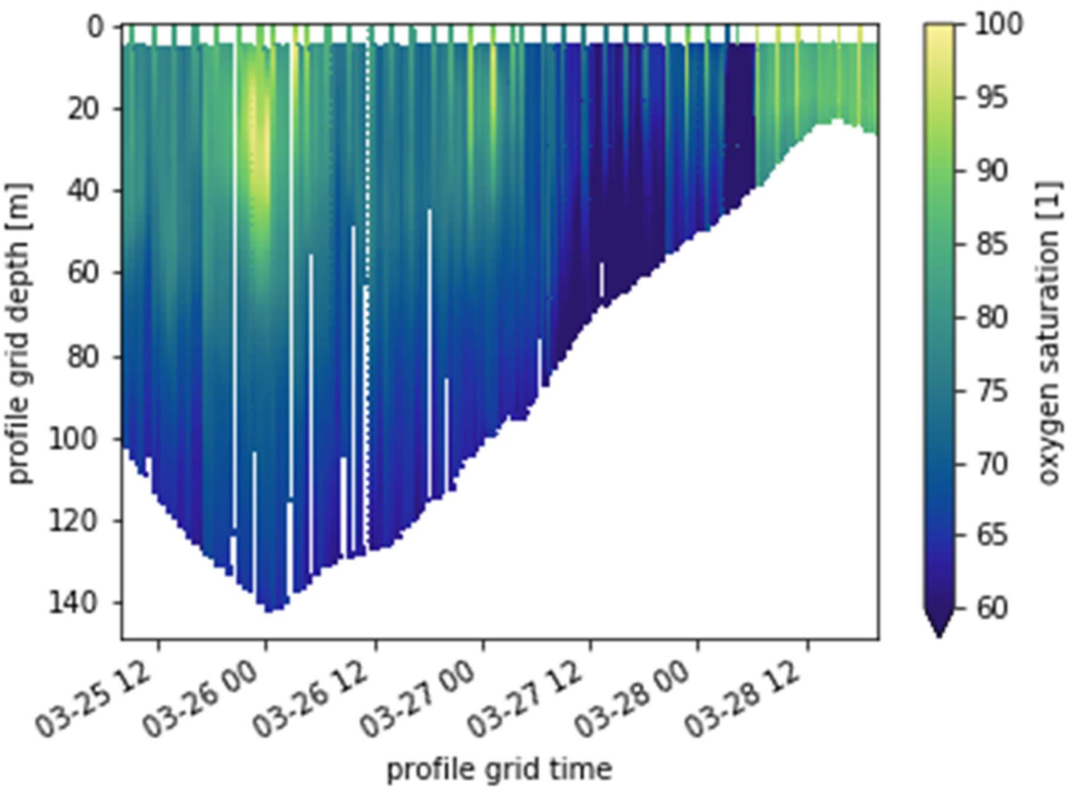

Figure 3-7: Dissolved oxygen profiles from March 25 to 28, 2019.

The spatial distribution of dissolved oxygen from a HBRC vessel survey and glider mission are shown in Figure 3-8 and Figure 3-9, respectively. Broadly, a similar trend was observed for subsurface and near-bed dissolved oxygen data – a decrease in subsurface oxygen towards the southwest of Hawke Bay. Surface dissolved oxygen was, however, much lower, from glider observations during Autumn 2019. A horizontal gradient in surface dissolved oxygen occurred from north-east to south-west with lowest dissolved oxygen in the latter part of the Bay. Two regions had dissolved oxygen at 60-80%, 1) off from the Mohaka River and 2) at Cape Kidnappers headland.

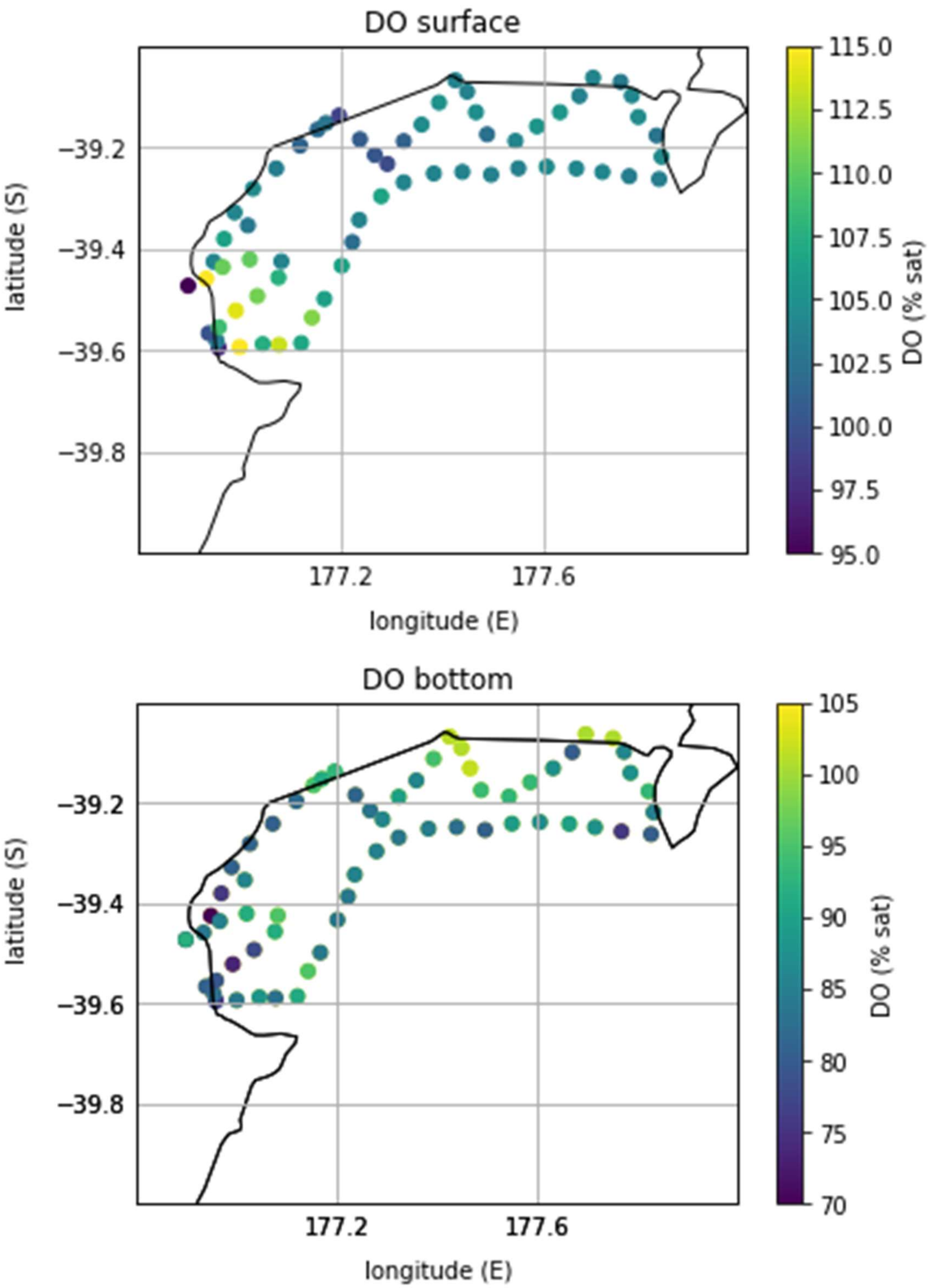

Figure 3-8: Spatial distribution of dissolved oxygen from a HBRC vessel survey during October 2016. Dissolved oxygen at surface (top) and bottom (bottom). N.B. the scale bar is different between plots and data points that appear on land were from estuarine locations.

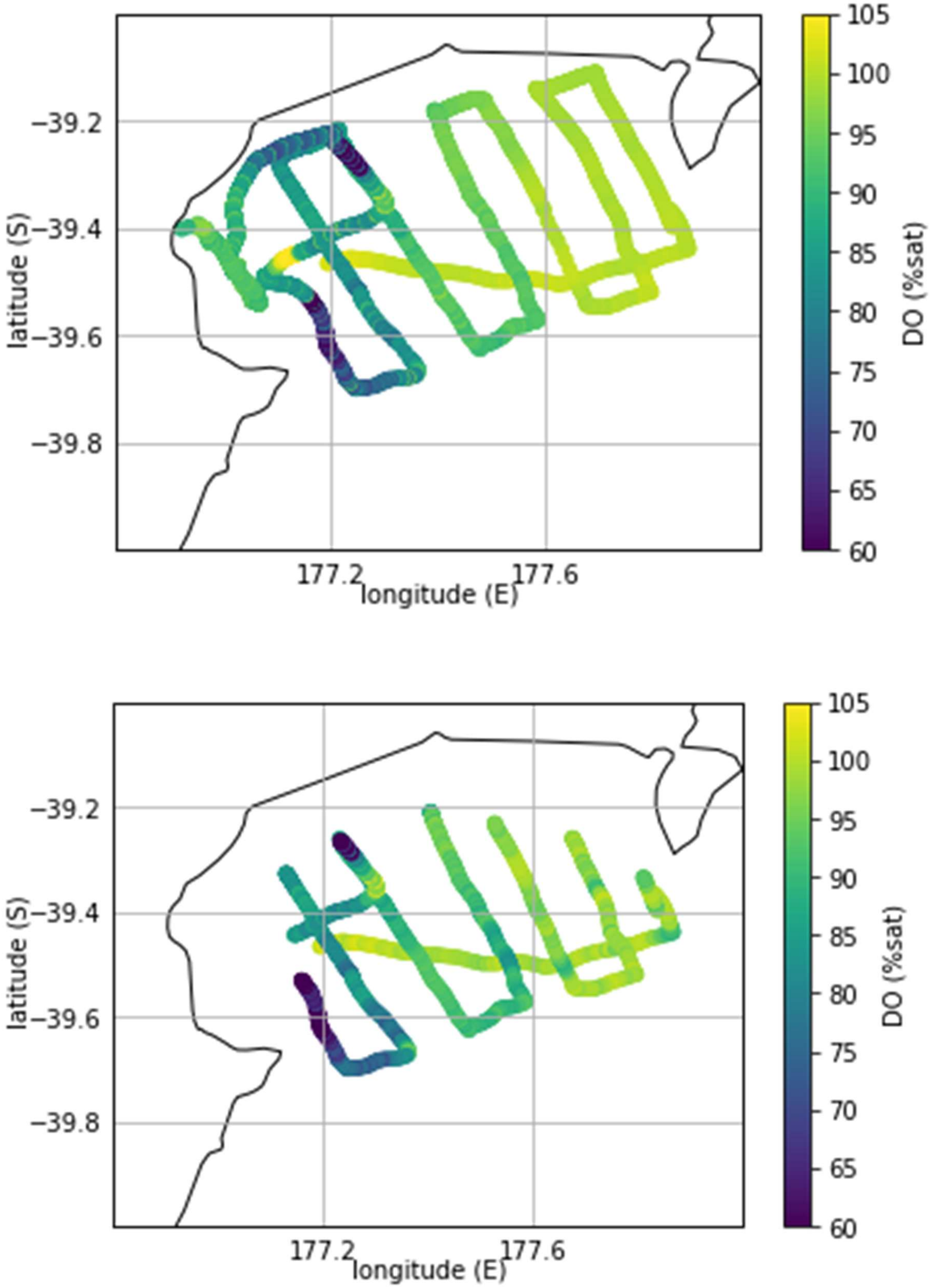

Figure 3-9: Spatial distribution of dissolved oxygen from glider survey during March 2019. Dissolved oxygen at near-surface (top) and 40 m (bottom).

4 Summary

This glider mission, supported by HBRC via an MBIE Envirolink grant, recorded 8506 profiles over 31 days dramatically increasing the available ocean data in the Hawke Bay system. Spatial distributions of dissolved oxygen from glider observations were observed during Autumn 2019. The timing of the glider mission coincided with coastal SST being between 1-2 degrees above a climatological average for Hawke Bay.

A spatial decrease in surface and subsurface dissolved oxygen occurred from north-east to south-west through Hawke. Lowest dissolved oxygen concentrations were observed closest to Napier. Two regions had surface dissolved oxygen at 60-75%, they were: 1) off from the Mohaka River and 2) adjacent to Cape Kidnappers headland. Other parts of Hawke Bay, to the north-east, showed no depleted dissolved signals from glider observations.

A decrease in subsurface dissolved oxygen also occurred across the north-east to south-west spatial gradient with values from 105% to 65% saturation, respectively. Variability in subsurface dissolved oxygen was most apparent in the vertical direction from time series observations. This variability is due to a mixture of tidal oscillations, wind stirring and in oceanic influences.

Depleted oxygen in inner Hawke Bay can be generated by both land and oceanic processes. For example, shallow profiles of lower dissolved oxygen around March 23 were collocated with lowest salinities from a riverine influence. Upslope transport of cold, deoxygenated water from offshore in late March (27-28) was likely due to an upwelling event.

5 Acknowledgements

Many thanks to the Hawkes Bay Coastguard support for the deployment and recovery of the ocean glider, in particular Henry van Tuel (skipper) and the vessel Celia Knowles II. Thank you to Fiona Elliott for all things glider related – planning, preparation, piloting and processing - and Geoff Holland (NIWA Napier) for shoreside support of the operations. The ocean glider Betty is operated as part of the NIWA Ocean Glider Facility and supported by NIWA SSIF and Capex.

6 References

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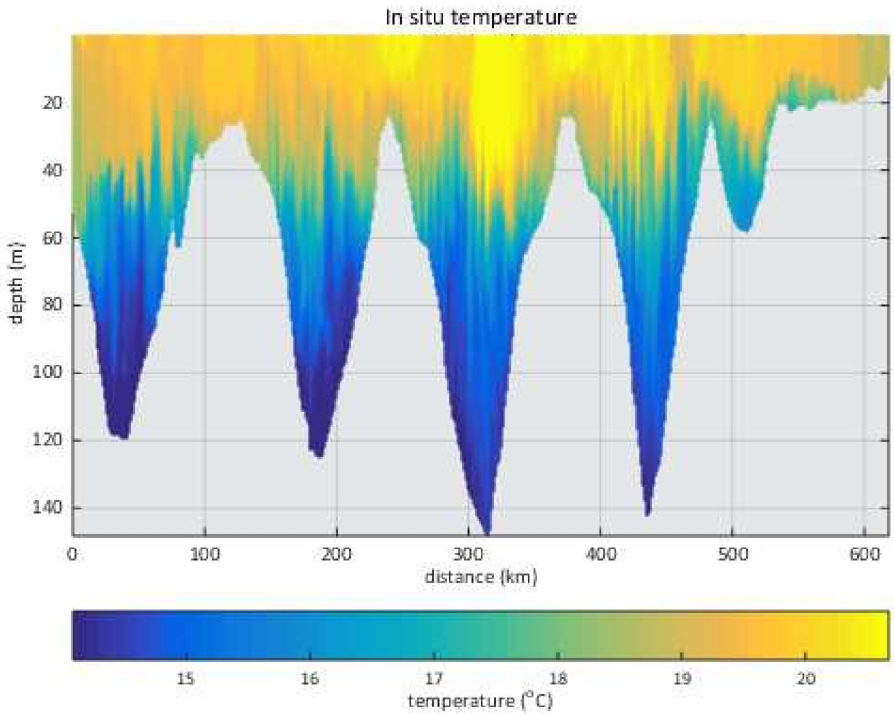
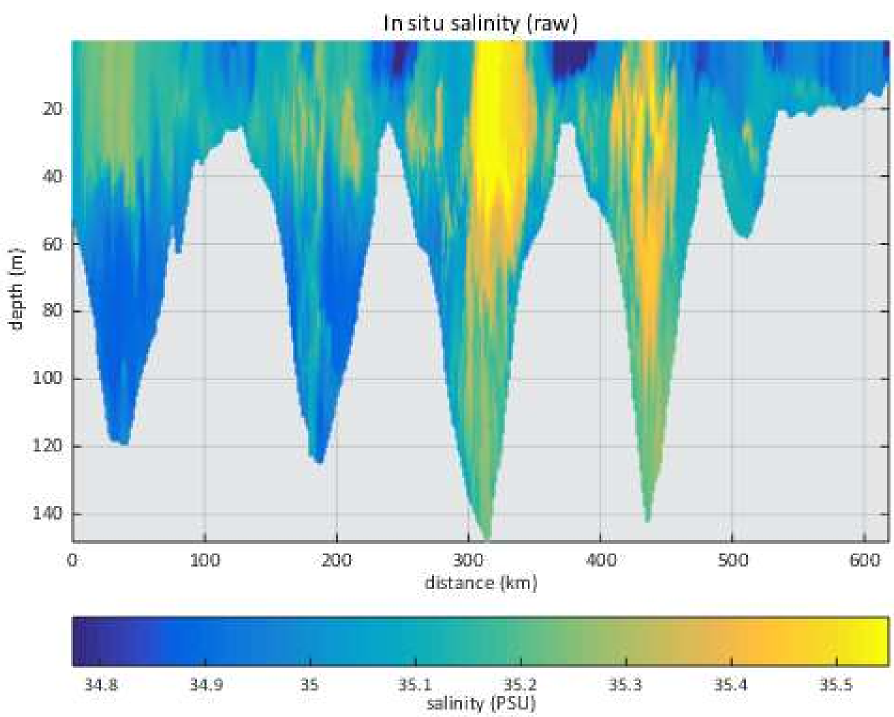
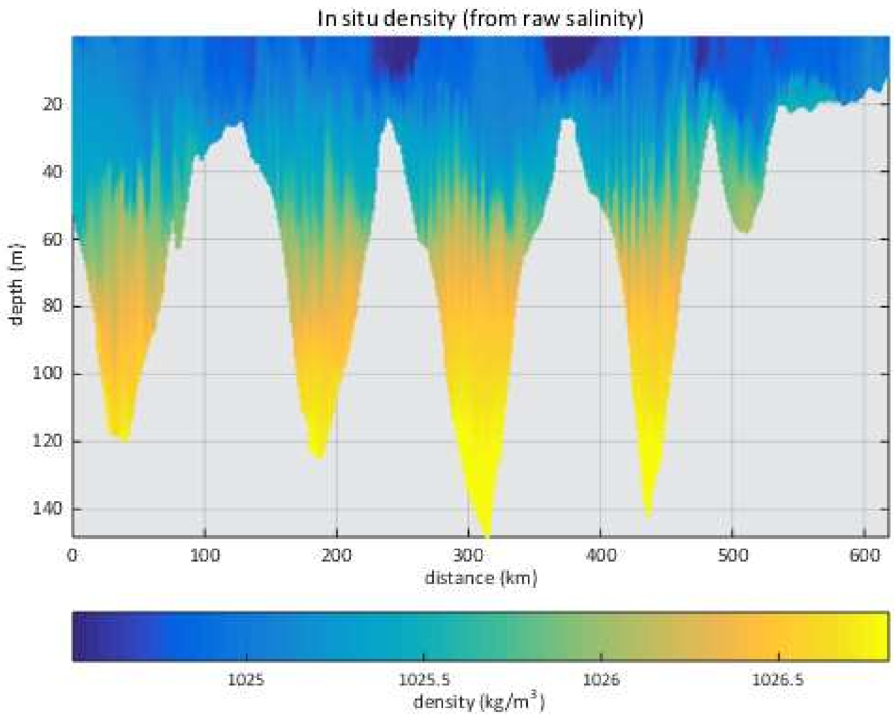
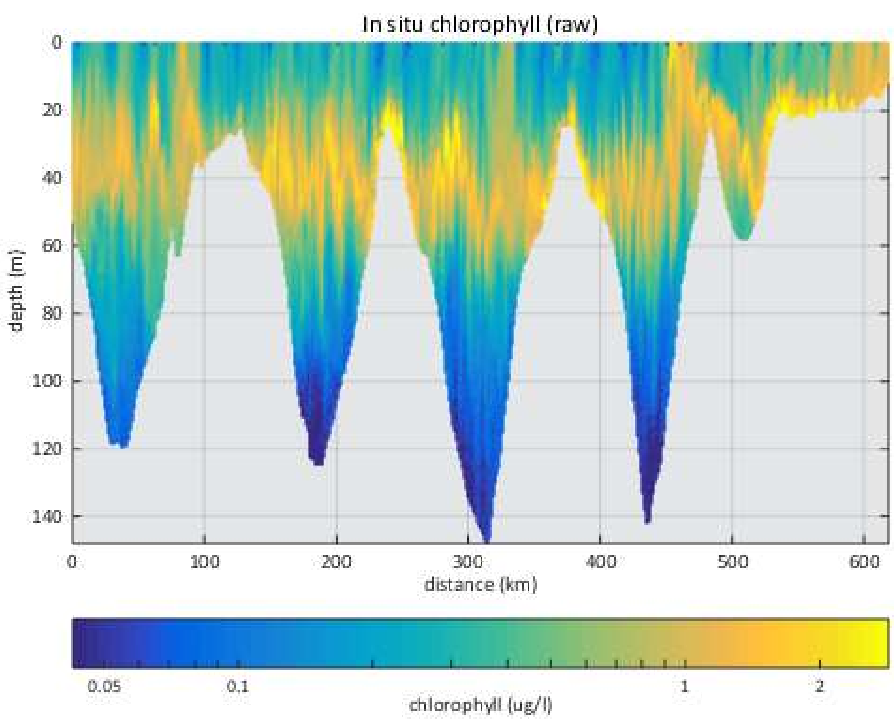
Appendix A Data plots from delayed mode processing



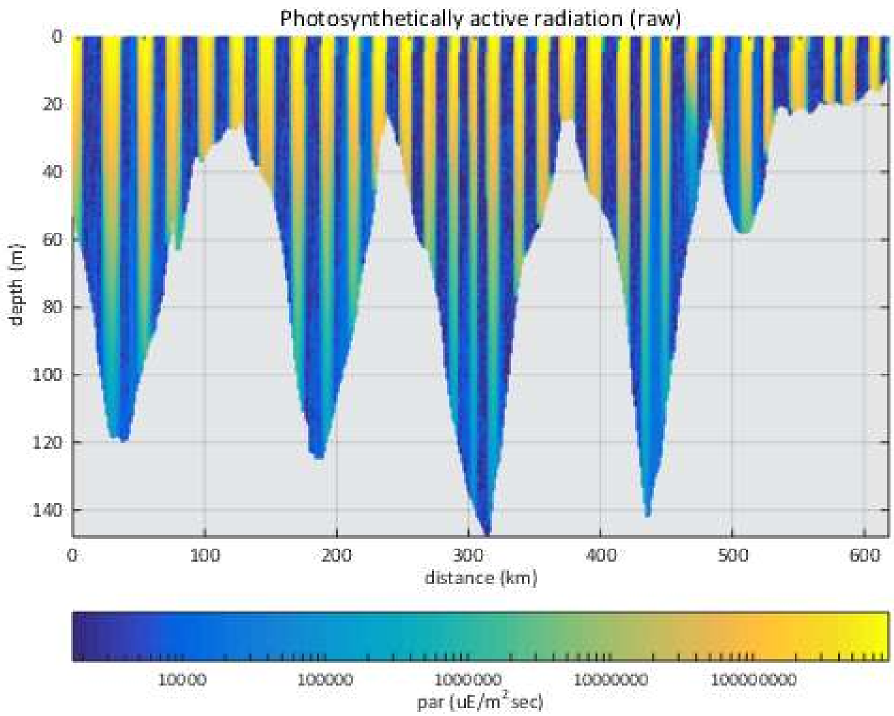


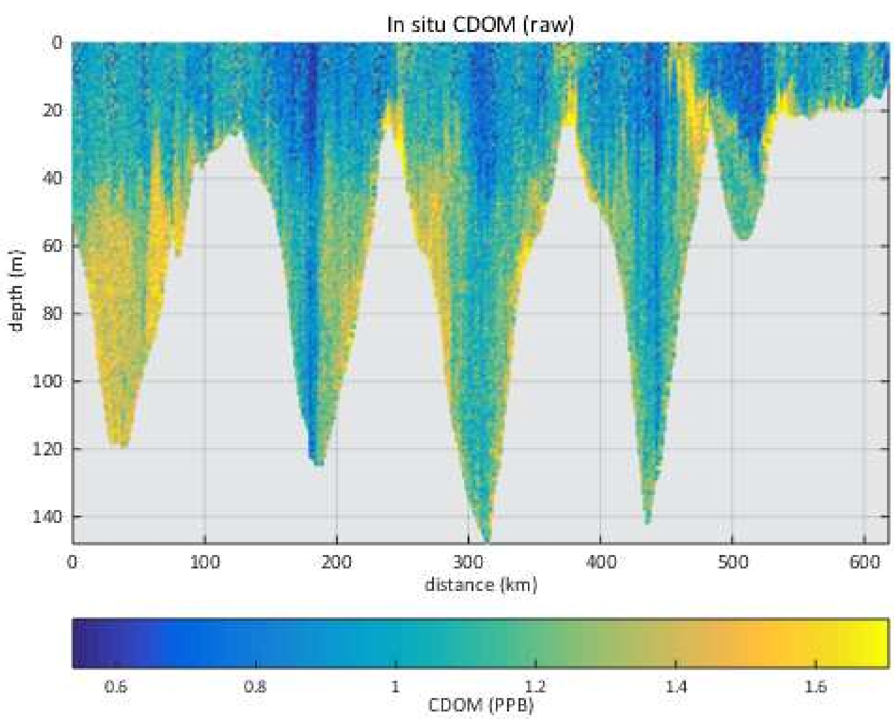


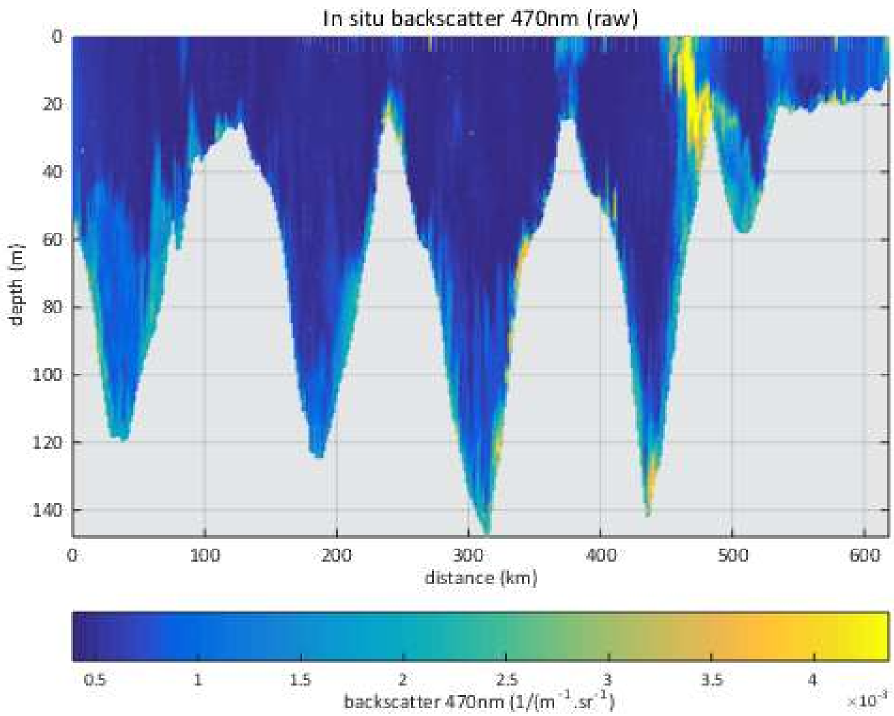
In situ density (from raw salinity)
depth (m)
20
40
60
80
100
120
140
0
100
200
300
400
500
600
distance (km)
1025
1025.5
1026
1026.5
density (kg/m³)

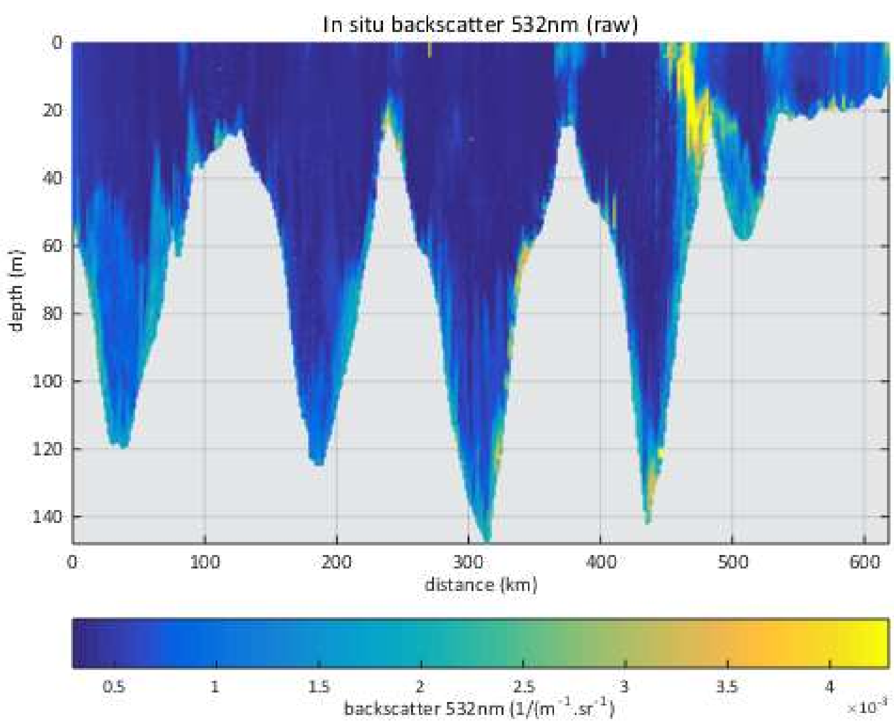


In situ chlorophyll (raw)
depth (m)
0
20
40
60
80
100
120
140
0
100
200
300
400
500
600
distance (km)
0.05
0.1
1
2
chlorophyll (ug/l)


Photosynthetically active radiation (raw)
depth (m)
distance (km)
par (uE/m^2 sec)


In situ CDOM (raw)
depth (m)
distance (km)
CDOM (PPB)


In situ backscatter 470nm (raw)
depth (m)
distance (km)
backscatter 470nm (1/(m^{-1}.sr^{-1})
$\times 10^{-3}$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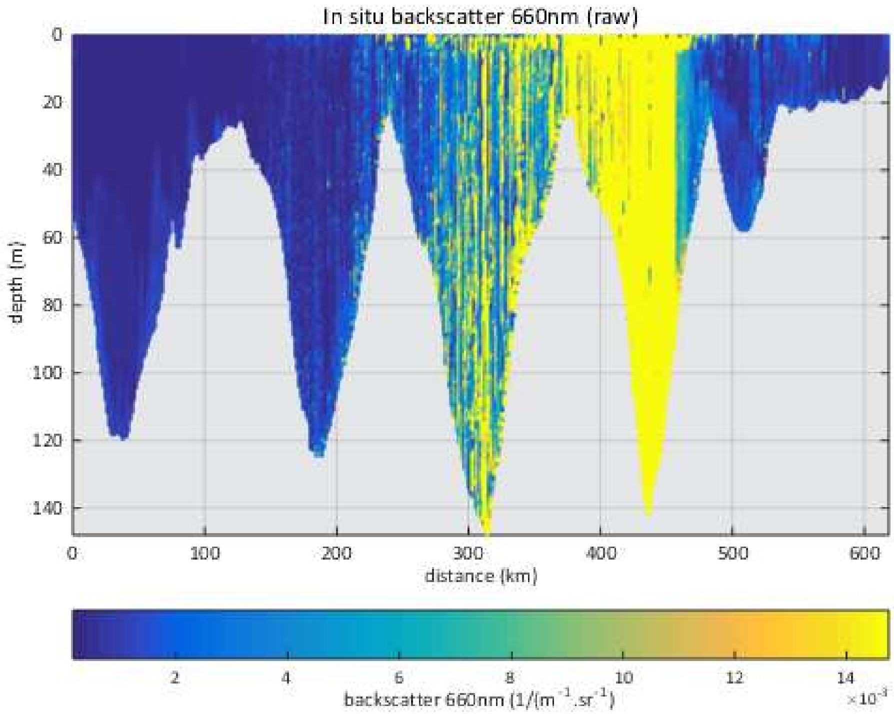
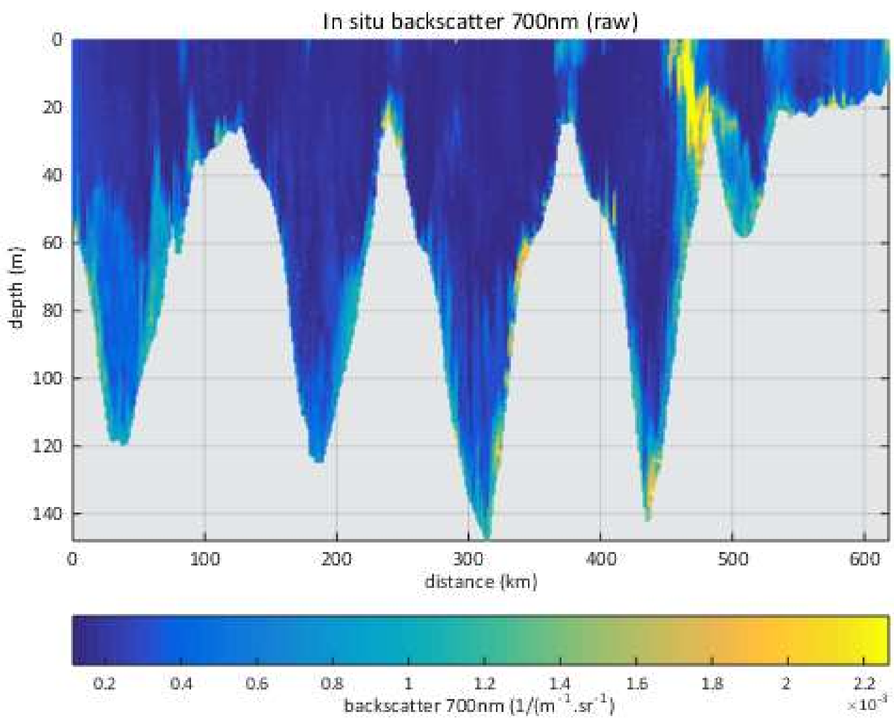

In situ backscatter 660nm (raw)
depth (m)
distance (km)
backscatter 660nm (1/(m⁻¹.sr⁻¹)
×10⁻³


In situ backscatter 700nm (raw)
depth (m)
distance (km)
backscatter 700nm (1/(m⁻¹.sr⁻¹)
×10⁻³