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Tini a Tangaroa

Environmental variability and change in the LIN 3&4 stock region

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PLAIN LANGUAGE SUMMARY

- Ling is a commercially important fish species. An important ling fishery takes place on Chatham Rise.
- Fish and fisheries are affected by environmental conditions. Environmental conditions in Aotearoa New Zealand are affected by climate variability and change.
- We used information from drifting buoys, satellites and computer modelling to describe the oceanographic conditions experienced by ling on Chatham Rise over the last 40 years.
- Chatham Rise is an underwater feature that extends eastwards for about 800 km off the east coast of the South Island, with the Chatham Islands at the far end. The ocean is particularly productive here because it is where ocean currents meet, leading to good conditions for phytoplankton; the tiny plants living in the upper ocean. This in turn supports a rich food web, including ling and other deepwater fish.
- Environmental observations show that the oceans around New Zealand are getting warmer, and the pace of warming has accelerated over the last 20 years. Chatham Rise is warming particularly quickly, and the warming extends from the sea-surface to the seabed though warming at the seabed is slower than at the surface.
- Part of the mixing zone (front) that forms on Chatham Rise has also moved.
- Warming has been accompanied by variations in ocean productivity in the Chatham Rise region, but with no substantial long-term trend.
- The changes in environmental conditions on the Chatham Rise do not explain the change in ling catch rates or recruitment since 1990.
- In parallel with the environmental change, from about 2018 the ling bottom longline fishery partially moved and contracted into areas that have slightly cooler surface temperatures but warmer bottom temperatures.

EXECUTIVE SUMMARY

Pinkerton, M.H.; Holmes, S.J.; Sutton, P.J.H.; Behrens, E.; Dunn, M.R. (2026). Environmental variability and change in the LIN 3&4 stock region.

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Ling (*Genypterus blacodes*) is a commercially important middle depth species taken by bottom trawl, bottom longline, and pot fisheries in the Chatham Rise (stock LIN 3&4) region. Environmental conditions in Aotearoa New Zealand are affected by climate variability and change, and the Chatham Rise region is an area of particularly rapid change. In this report we characterised environmental variability and change across the LIN 3&4 region from 1991–2025. This environmental characterisation can be read alongside the ling fishery characterisation (Holmes et al. 2025) and ling stock assessment (Holmes & Dunn 2025).

By combining data from autonomous instrumentation (Argo floats), remote sensing and numerical models (global- and local-scale Earth-System Models, ESM) we obtained a reasonably accurate and complete broad-scale picture of oceanographic variability and change across the New Zealand region. Consistent with previous studies, we found that New Zealand oceans are warming (especially in winter) and the rate of warming has accelerated in the last 10 years. Over the last 40 years, surface waters in the Chatham Rise region warmed 51% faster than the global average. Water near the seabed has also warmed, though more slowly than at the surface. Warming has led to an increasing occurrence, intensity and duration of marine heatwaves (MHW), with substantial increases in cumulative intensity since 2010. More recently, from 2015, changes to the local flows of subantarctic water to the south of New Zealand have caused an area of persistent warmth to be established south of Chatham Islands. Temperature, salinity and altimetry changes indicate that the southern margin of the Subtropical Front south of the Chatham Rise has moved west approximately 120 km, creating an area where the surface warming rate is more than three times greater than the mean global rate over the last 20 years. This warming has placed the LIN 3&4 region in almost perpetual marine heatwave conditions. *In situ* observations show that warming extends through the whole water column to the seabed, though warming at the seabed is slower than at the surface.

From other MPI research, ling Catch Per Unit Effort (CPUE) from the bottom longline fishery declined between 1991 and 1997, and again between 2021 and 2024. The reasons for these CPUE declines are not well known, and the patterns of change over time contrast to the steady abundance index of ling since 1992 from the Chatham Rise trawl survey. The changes in environmental conditions on the Chatham Rise do not explain the change in ling CPUE or ling recruitment (year class strength) since 1990 from the most recent stock assessment. In parallel with the environmental change and concurrently with the development of a potting fishery for ling in LIN 3&4 since 2018, the location of bottom longline effort moved and contracted. The more recent areas of bottom longline effort coincided with slightly elevated particulate organic matter fluxes to the seabed, slightly cooler surface temperatures and warmer bottom temperatures (by $\sim 2^{\circ}\text{C}$).

Recent oceanographic changes in the Chatham Rise region are reproduced in global-scale ESMs but the biological response is less well modelled and understood. Although changes to phytoplankton primary production in Subtropical and Subantarctic waters over the last few decades have generally followed our established understanding of phytoplankton ecology, the Chatham Rise region is particularly complex biologically because of the confluence of the Subtropical Front and the shallow bathymetry. Although primary production in the Chatham Rise region is the highest in the New Zealand ocean and has been slightly increasing since the start of satellite observation in 1997, there was a synchronous reduction in phytoplankton biomass between 2020–2024 across much of the New Zealand ocean. Although this reduction in primary production has since reversed and values have reverted to near-normal levels, it is concerning that the causes for this change are not understood and could re-occur in the future.

1. INTRODUCTION

There is substantial research around the world on the potential effects of anthropogenically-induced environmental change on the seafood sector (Valdes et al. 2009; Rice & Garcia 2011; Lam et al. 2016; Savo et al. 2017), particularly the impacts of climate change on fisheries (shifts in distributions and abundance) and the communities they support (Morrison et al. 2015; Hare et al. 2016; Blanchet et al. 2019; Bindoff et al. 2022). In Aotearoa New Zealand, there is increasing recognition of the current and potential future impacts of environmental variability and change on New Zealand fisheries (Fisheries New Zealand 2020; Cummings et al. 2021; Lundquist et al. 2023; Cook et al. 2024, 2025). The physical and biological oceanographic conditions in New Zealand marine waters exhibit substantial variation in response to local climate and weather, spanning a wide range of spatial and temporal scales (Pinkerton et al. 2024; Sutton & Bowen 2019). In addition to long-term warming, climate change can lead to more marine heatwaves (MHW) (Cheung & Frölicher 2020; Smith et al. 2023), increased ocean acidification (Law et al. 2018), increased climate variability (Collins 2000), deoxygenation (Kim et al. 2023), synergistic effects between fishing and climate change (Morrongiello et al. 2021) and changes to ocean primary production (Pinkerton et al. 2024).

Ling (*Genypterus blacodes*) is a commercially important middle depth species with substantial catches taken in the Chatham Rise region (LIN 3&4), off the west coast of the South Island (LIN 7), and on the Campbell Plateau (LIN 5&6), at depths between about 100 and 800 m (Hurst et al. 2000; Fisheries New Zealand 2024; Holmes & Dunn 2025; Holmes et al. 2025). Ling forage close to the seabed and are not strong swimmers, making them vulnerable to bottom trawl (BT) fishing gear, and they are predators and scavengers so are also targeted with baited hooks on bottom longlines (BLL, Dunn et al. 2010). On the Chatham Rise, a potting fishery has also developed since 2018 (Mormede et al. 2022; Holmes et al. 2025). Adult ling can grow to about 140–165 cm (Mormede et al. 2023; Holmes & Dunn 2025).

Stock assessments for the Chatham Rise and east coast South Island ling stock (LIN 3&4), Sub-Antarctic stock (LIN 5&6), and West Coast South Island stock (LIN 7) have been updated regularly. In 2014, trawl and longline ling fisheries for LIN 3&4, LIN 5&6, and LIN 7 were certified by the Marine Stewardship Council. Regular credible stock assessments are essential to retaining the certification of these fisheries, and the vulnerability of the fishery to the effects of climate should therefore be considered. The LIN 3&4 stock was last assessed in 2025, funded by Fisheries New Zealand project LIN2024-03 (Holmes et al. 2025; Holmes & Dunn 2025).

An addition to the LIN2024-03 project was to conduct an “environmental characterisation” of the stock region. The purpose was to collate and summarise environmental information relevant to the LIN 3&4 stock (and potentially other similarly-distributed fish stocks). The project scope did not include any statistical analyses of the influence of environmental covariates on the ling fishery or biology. The ling environmental characterisation reported here can therefore be read alongside the LIN 3&4 fishery characterisation (Holmes et al. 2025) and LIN 3&4 stock assessment (Holmes & Dunn 2025).

The Subtropical Front (STF) mixing zone creates a unique habitat that supports some of the most productive deep-sea fisheries in the world. The STF forms over Chatham Rise, making primary productivity there the highest in the New Zealand Exclusive Economic Zone (EEZ; Murphy et al. 2001; Pinkerton et al. 2024). The ocean is particularly productive on Chatham Rise because mixing between warm subtropical waters to the north of the Rise and cold subantarctic waters to the south leads to ideal conditions for phytoplankton growth. Phytoplankton are tiny plants living in the upper ocean that ultimately form the energy on which the whole marine food web depends.

The area just south of Chatham Rise has recently been identified as the location of an unprecedented shift in ocean currents (Sutton et al. 2024), where there is a warming hotspot (Pinkerton et al. 2024). In addition, rapid drops in indices of primary productivity on Chatham Rise between 2019–2023 (-

9.2% per year) were noted (Pinkerton et al. 2024), and this decline in productivity has the potential to work through the food web and influence ling productivity.

In this report, we describe variability and change in oceanographic conditions in the Chatham Rise region using a combination of *in situ* monitoring (including samples and instrumentation collected from research vessels and autonomous equipment such as drifting instrumented buoys), satellite remote sensing (Hooker et al. 1992; Murphy et al. 2001) and coupled model-observation analyses (Behrens et al. 2020). We link changes to ocean conditions with the location of the ling fisheries (BT and BLL) using Catch Per Unit Effort (CPUE) indices between 1991–2025 to produce indices of environmental change specific to ling.

This Fisheries Assessment Report (FAR) is the “environmental characterisation” part of Milestone #8 (reporting requirement #3) of Objective 1, project “LIN2024-03: Stock assessment of ling in LIN 3&4”, contract 407301. The fishery characterisation part of Objective 1 is given by Holmes et al. (2025).

Objective One: *To carry out a descriptive analysis of the commercial catch and effort data for ling (LIN 3-4) on the Chatham Rise, including analyses of standardised catch per unit effort up to the most recent fishing year available.*

2. METHODS

2.1 *In situ* observations

Argo observations were used as these are the most reliable, long-term and spatially-extensive source of *in situ* information on temperature and salinity for the Chatham Rise (Sutton et al. 2024). Argo is a programme with more than 3500 profiling floats deployed across the world's oceans (Riser et al. 2016; Sutton et al. 2024). Each Core Argo float typically measures and transmits profiles of temperature and salinity between the surface and 2000 m every 10 days. The analyses here are based on the “RG-Argo climatology”, an objectively-mapped Argo product which uses the nearest 100 Argo profiles to estimate monthly temperature and salinity between the surface and 2000 m at each degree of latitude and longitude from 2004 to the present (Roemmich & Gilson 2009; Roemmich & Gilson n.d.). Following Sutton et al. (2024), we used Argo data in the core period 2006–2024 and divided the time series into two equal 5-year periods: early (2006–2010) and late (2019–2023).

We note that *in situ* observations of temperature and, in some case salinity, are also available from CTD (conductivity-temperature-depth) instruments deployed from the research vessel RV *Tangaroa* and, more recently, from sensors deployed in collaboration with the fishing industry as part of the MBIE-funded *Moana* project (Souza et al. 2023; Van Vranken et al. 2023). However, the relatively sparse and inconsistent sampling on the Chatham Rise, and relatively short time-series (*Moana* was funded between 2018–2023) meant that within the resources of this project we focussed exclusively on Argo data. Further investigation and comparison with other *in situ* data sources could be useful in the future.

2.2 Satellite remote sensing and model hindcasts

We primarily used satellite information following the methods of the New Zealand Environment Monitoring series (e.g., Pinkerton et al. 2018, 2024), augmented for other environmental variables as described in Dunn et al. (2023) and Kaiser et al. (2023). Data from assimilating models were used for bottom-temperature and mixed layer depth. Key variables are shown in Table 1.

Data were reprojected to a nominal 9 km grid and composited at monthly resolution. For trend analyses, these data were deseasonalised using monthly anomalies (Murphy et al. 2001; Pinkerton et

al. 2024) which removes the effect of seasonal cycles and highlights long-term change (“trends”). Temporal trend magnitudes were determined by using the Sen slope (Sen, 1968), which is insensitive to outliers or distribution (Hipel & McLeod 1994). Statistical significance was assessed using Mann-Kendall Z statistic and p-values (Mann 1945; Kendall 1975), corrected for autocorrelation using the method of Yue & Wang (2004), and converted to categories representing the confidence that the assessment of the slope is in the correct direction (i.e., positive or negative) following previous work (McBride et al. 2014; Makowski et al. 2019; Pinkerton et al. 2024).

Table 1: Satellite- and model-derived observations used in this report. The period of data availability are also shown.

Variable	Label	Description
Chlorophyll-a concentration indicative of ocean primary production (1997–2024)	Chl-a	Open-ocean chlorophyll-a concentration produced by blending SeaWiFS (NASA, 2018a) and MODIS-Aqua (NASA, 2018b) observations using the overlap period (Pinkerton et al. 2024). Monthly, 9 km ² resolution. Open-ocean chlorophyll-a (mg m ⁻³). Nearshore estimates will be dubious (within ~5 km), so values within the New Zealand territorial seas are excluded from analysis.
Sea surface temperature (°C) (1981–2024)	SST	Optimal-interpolation ocean product (OI-SST v2.1; Reynolds et al. 2007; Huang et al. 2021). Monthly composites, at 0.25° latitude × 0.25° longitude from daily analyses.
Rate of net primary production (NPP) using a satellite-based model (1997–2024)	NPP	NPP (mgC m ⁻² d ⁻¹) from the Carbon, Absorption, and Fluorescence Euphotic-resolving model (CAFE, Silsbe et al. 2016). based on MODIS-Aqua and SeaWiFS (sourced from Oregon State University Ocean Productivity project (n.d.) at 9 km, monthly resolution and blended as Pinkerton et al. (2018, 2024). “Net” means after allowing for phytoplankton respiration.
Frontal activity (spatial gradient of SST) (1981–2024)	SSTgrad	Spatial gradient in SST (°C km ⁻¹) as indicative of fronts. Based on the smoothed OI-SST v2.1 dataset (Reynolds et al. 2007; Huang et al. 2021). Monthly, 0.25° latitude × 0.25° longitude resolution.
Particulate organic matter (POM) flux to the seabed. (1997–2024)	POCflux	POC flux (mgC m ⁻² d ⁻¹) - sometimes called “marine snow” - from the Lutz et al. (2007) POC flux model, based on the CAFE NPP model, sea-surface temperature (OISSTv2.1), mixed-layer depth (MLD, 0.030 kg m ⁻³ potential density difference) as described by Fernández-Urruzola et al. (2021) and Kaiser et al. (2023).
Marine heatwaves (MHW) (1981–2024)	MHW	Five MHW metrics (Schlegel & Smit 2018) based on daily OISSTv2.1 data, following the approach of Montie et al. (2023) and Thorat et al. (2022). Cumulative MHW index has units of “°C days”.
Seabed temperature (1979–2025)	btemp	Seabed temperatures were taken from European Centre for Medium-Range Weather Forecasts (ECMWF) Ocean Reanalysis System 5 (ORAS5), which provides global ocean fields from 1979–present at ~0.25° resolution using the NEMO model with NEMOVAR data assimilation (Zuo et al. 2019).
Mixed layer depth (1997–2024)	MLD	Estimates of the depth of the seasonal thermocline was obtained from the GLBu0.08 hindcast results (Chassignet et al. 2007) sourced from Oregon State University, “Ocean Productivity” project. We used a 0.030 kg m ⁻³ potential density difference from the surface. Comparisons with MLD based on a 0.125 kg m ⁻³ density difference showed negligible differences.

2.3 Fishery footprint analyses

Catch and effort data for his report were extracted by Fisheries New Zealand for the period from 1 October 1989 to 31 December 2024, including all available data at the date of the extract (30 January 2025) (REPLOG 16396A). The data extract included all data from trips where hoki (*Macruronus novaezelandiae*), hake (*Merluccius australis*), or ling were reported as being either caught, processed, or landed, for all fishing recorded on trawl catch, effort and processing returns

(TCEPRs); trawl catch and effort returns (TCERs); catch, effort and landing returns (CELRs); lining catch and effort returns (LCERs); lining trip catch and effort returns (LTCERs); netting catch, effort and landing returns (NCELRs); electronic reporting system returns for all methods (ERS); and any high seas reports. We extracted data from the LIN 3 and LIN 4 areas (Figure 1a) and divided these data into “bottom trawl” (BT) and “bottom longline” (BLL) components. The footprints of the ling BT and BLL fisheries from Holmes et al. (2025) up to the end of 2024 are shown in Figure 1b,c (respectively). We note that the spatial accuracy of the BLL records will likely have improved since the introduction of mandatory electronic catch reporting for smaller vessels in 2019.

On Chatham Rise, a potting fishery has also developed since 2018 (Mormede et al. 2022; Holmes et al. 2025), but the time-series of information is too short to provide useful indications of environmental change across its footprint. Although the ling potting fishery was not considered in the present environmental characterisation, our results on environmental changes in LIN 3&4 will be relevant to it.

Two different CPUE-weighted averages of the environmental data (y at a given time, t) were calculated (Equation 1a,b), where $x(i,t)$ is the environmental satellite or model-hindcast anomaly at the location of a fishing event (i) and time (t), where the time resolution is monthly. Here, $cpue$ is the CPUE for fishing event (i), and “ $i \in t$ ” means that we only consider fishing events in the monthly interval, t . This means that for the “monthly” index (Equation 1a) we sum only over all the fishing events in a given month whereas for the “footprint” index we sum over all fishing events for which ling were caught over the whole history of the fishery for which we have data (1991–2024). The area over which we average the environmental information is hence always the same for “footprint” but follows the location of the fishing effort for the “month” index. Comparing these two indices allows us to investigate to what extent any change in the spatial distribution of the fishing effort exacerbates or offsets the underlying environmental variability and change. This could happen for example if the fish move to maintain consistent environmental conditions and the fishery follows them.

For time series comparisons, we used standardised CPUE where covariates were vessel, number of hooks and day of the year (Dunn et al. 2025).

$$y_{month}(t) = \frac{\sum_{i \in t} x(i, t) \cdot cpue(i \in t)}{\sum_{i \in t} cpue(i \in t)} \quad \text{Equation 1a}$$

$$y_{footprint}(t) = \frac{\sum_{all\ i} x(i, t) \cdot cpue(i)}{\sum_{all\ i} cpue(i)} \quad \text{Equation 1b}$$

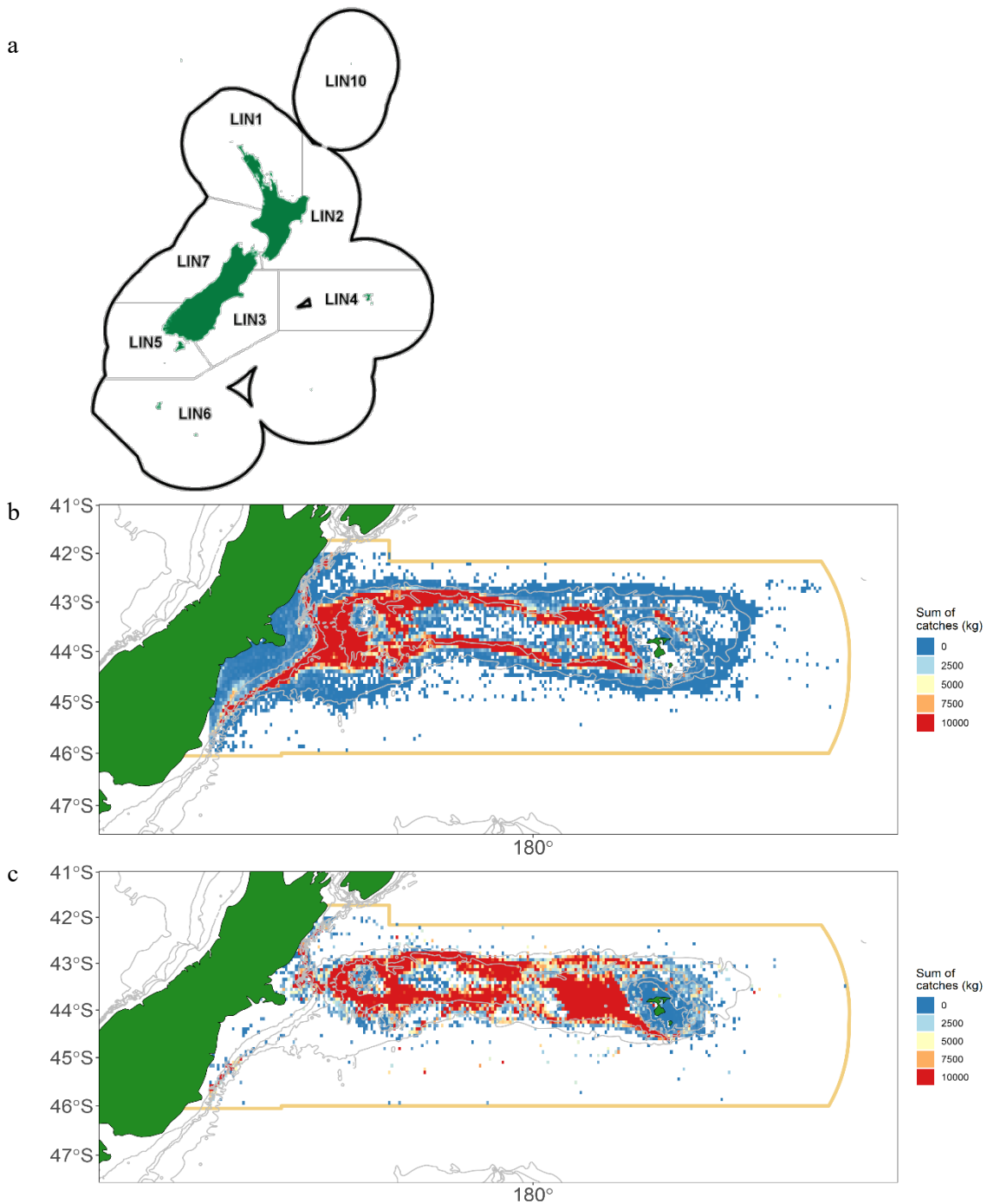


Figure 1: Ling fishery footprint on the Chatham Rise region from Holmes et al. (2025). a: Ling management areas, showing LIN 3&4 in the Chatham Rise region; b: Footprint for the ling bottom trawl (BT) fishery, 1991–2024; c: Footprint for the ling bottom longline (BLL) fishery, 1991–2024. The Orange outline is the boundary of the LIN 3&4 stock assessment area. Depth contours (in grey) are at 100, 200, 500, 1000 metres.

3. RESULTS

3.1 In situ observations

The objectively-mapped Argo product for the Chatham Rise shows that over the 2006–2022 period, the local sea surface temperature (SST) rate of change in the Chatham Rise region of 1.20 °C/decade is almost five times the mean global surface warming rate of 0.26 °C/decade over the same period (Sutton et al. 2024). The local position of the STF on the Chatham Rise is commonly associated with the 11°C isotherm (Garner 1959; Heath 1985). Comparisons between surface height (from satellite altimetry) and the Argo 0–100 m mean temperature and salinity in the early (2006–2010) and late periods (2019–2023) show that the position of the STF zone moved approximately 120 km south and westwards over this period (Figure 2). Argo data also show a positive change in SST and salinity between these periods to the south of the Chatham Rise (Figure 3). The change extends below the surface to full depth (500 m depth shown in Figure 4). Further figures at other depths (250 m, 1000 m, 1975 m, bottom depth) are given in Appendix 1.

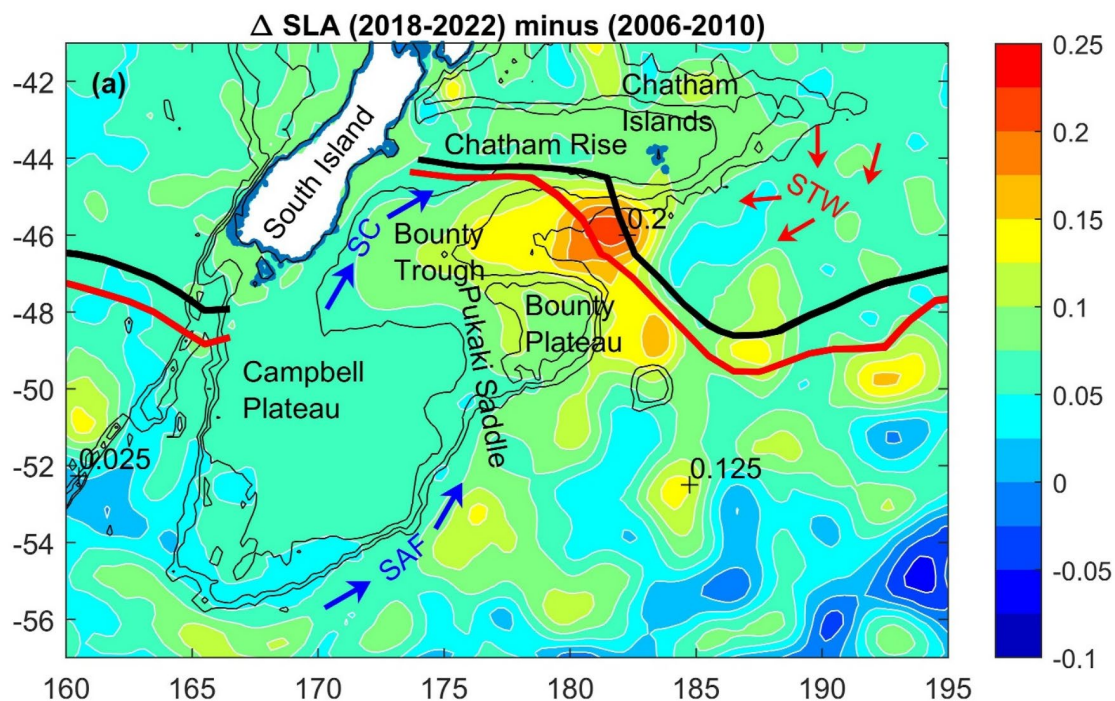


Figure 2: Sea-level altimetry (SLA) showing surface height difference (m): late period (2018–2022) minus early period (2006–2010). The figure also shows bathymetric depth contours at 1000, 2000 and 3000 m, geographic features and oceanographic currents: Southland Current (SC), Subantarctic Front (SAF) and Subtropical Water (STW). The average early and late period, upper-ocean integrated (0–100 m) 11°C temperature contours are shown black and red respectively, indicating movement of the Subtropical Frontal zone to the south and west. SLA data were sourced from “Global Ocean Gridded L4 Sea Surface Heights and Derived Variables Reprocessed Copernicus Climate Service (n.d.)”. [From Sutton et al. 2024]

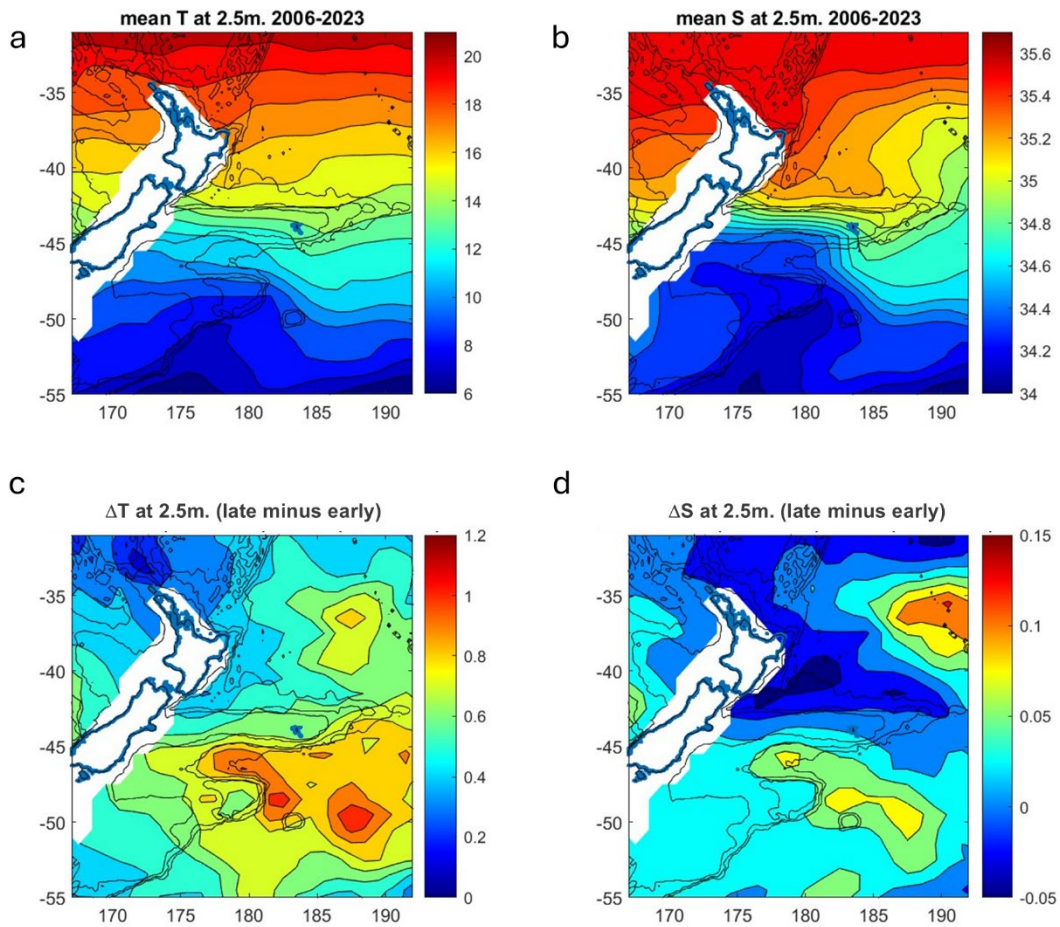


Figure 3: Surface (2.5 m depth) temperature and salinity over the Chatham Rise based on objectively-mapped Argo (autonomous profiling float) data. a: Mean temperature (°C), 2006–2023; b: Mean salinity (PSU), 2006–2023; c: Temperature change (difference between late and early Argo periods, °C); d: Salinity change (difference between late and early Argo periods, PSU).

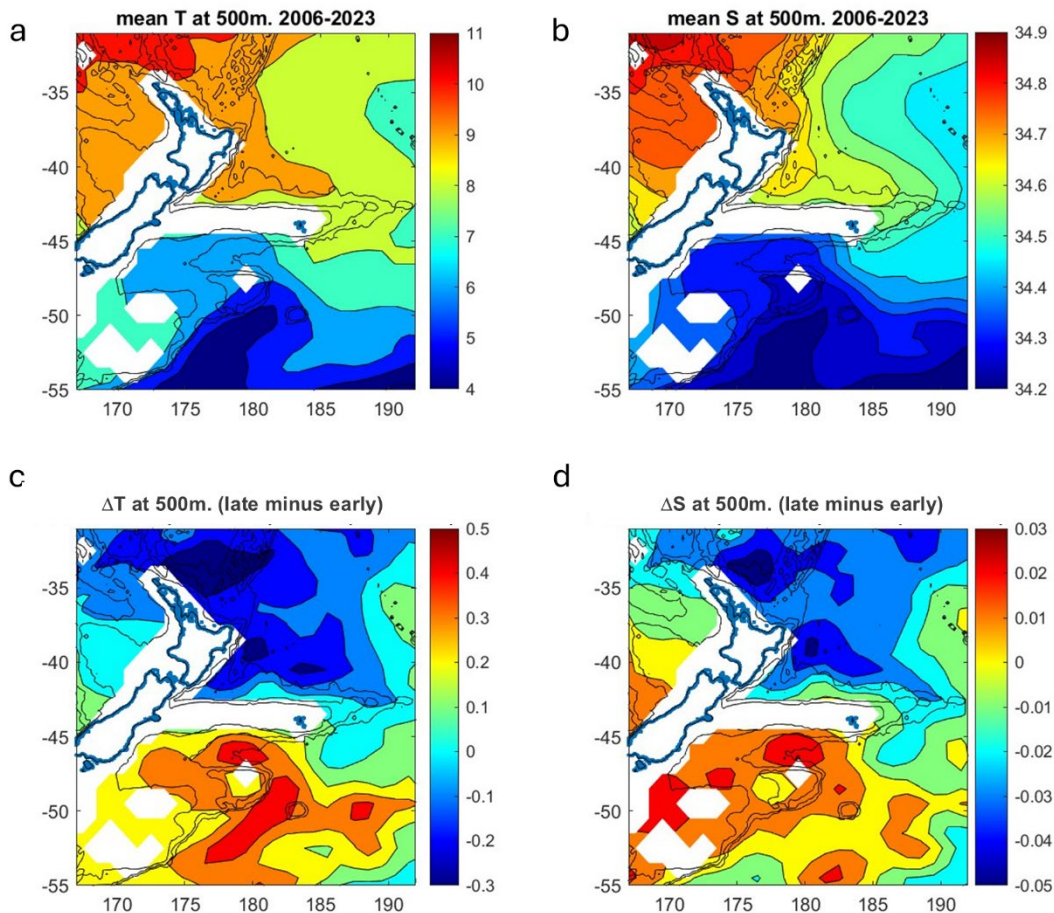


Figure 4: Mid-depth (500 m depth) temperature and salinity over the Chatham Rise based on objectively-mapped Argo (autonomous profiling float) data. a: Mean temperature (°C); b: Mean salinity (PSU); c: Temperature change (°C); d: Salinity change (PSU). See caption Figure 3 for more details.

3.2 Physical oceanographic changes

The changes to surface temperature in the Chatham Rise region seen in Argo data correspond very closely with observations of surface warming from satellites (Pinkerton et al. 2024), and with previous studies (e.g., Sutton & Bowen 2019). For context, almost all of the oceans around New Zealand warmed significantly between 1981 and 2024, as illustrated in their long-term positive trends (Figure 5). Pinkerton et al. (2024) showed that sea warming rates were highest in subtropical areas and the Tasman Sea region, and lowest in subantarctic regions. For the New Zealand EEZ as a whole, the 40-year warming rate was 0.21°C/decade, up from 0.15 °C/decade between 1981 and 2018, and the warming rate for the Chatham Rise was 0.21 °C/decade and “virtually certain” (Pinkerton et al. 2024). Seasonal (3-month average) warming rates of the Chatham Rise region were highest in winter and in autumn, and slightly lower in spring and summer, although significant warming occurred in all seasons (Figure 6).

Bottom temperatures across most of the Chatham Rise region are between about 4 and 7 °C, with higher temperatures at shallower depths (Figure 7a). Within the ling fishing footprint, the average bottom temperature is about 5°C. Trend analysis of seabed temperature data from the Earth-System Model (ESM) indicates that waters close to the seabed are warming more slowly than the surface

ocean, and that only less than about 1000 m depth have warming rates of more than ~ 0.10 °C/decade between 1981–2024 (matched to the period of satellite observation; Figure 7b).

An area-average SST timeseries based on satellite-observations indicate that warming in the LIN 3 and LIN 4 areas was relatively slow between 1981 (start of the satellite record) and about 2010, and then accelerated (Figure 8). Note that the black 5-year smoother lines in Figure 8a and b are relatively flat to 2010 and then slope upwards more steeply. The LIN 3 and LIN 4 regions have significant warming rates of 0.17 and 0.25 °C/decade respectively over the last 40 years. The warming rates in LIN 3 and LIN 4 over the last 20 years (2002–2024) were much higher, at 0.61 and 0.60 °C/decade respectively, which is an increase of 3.6 and 2.4-fold respectively from the 40 year warming rates. SST extracted on the ling fishery BT and BLL footprint (Figure 8c and d) shows warming specific to this region. The red lines are CPUE-weighted SST data averaged across the whole historical footprint of the ling fishery (from 1991–2025) and changes in this mirror those within the spatial areas LIN 3 and LIN 4. The blue and black lines in Figure 8c,d track where the fishery may have operated in different months and years. Where the blue/black lines deviate from the red lines (e.g., from about 2018 for both BT and BLL), this could be because the fishing has moved. After 2018, the blue/black lines are below the red lines indicating that both the BT and BLL fisheries have moved to areas with cooler (by ~ 0.4 °C) surface waters than across their respective historical fishery footprints.

A similar result is shown in the LIN 3 and LIN 4 area trends for seabed temperature (*btemp*) from the hindcast model (Figure 9a,b). Close to the seabed, water temperatures were fairly stable for the period 1960–2010 (noting that the model hindcast time-series starts about 20 years before the advent of SST satellite observation). Between 2010 and present however, bottom temperatures increased by about 0.2°C. Based on satellite data, the rise in SST over the same period in these regions was nearer 1°C (Figure 8), so while warming extends over the full water depth, warming at the surface is much stronger than at depth. There is evidence that the BT and BLL fishery moved in location between about 1998 and 2007 to areas where the bottom waters were cooler than across the historical footprint (Figure 9c,d). The BT fishery seems to have moved to cooler water again between 2013 and 2025, whereas the BLL fishery has actually moved to warmer bottom water than in the fishery footprint since about 2018. We note that the spatial accuracy of the BLL records is likely to have improved since the introduction of mandatory electronic catch reporting for smaller vessels in 2019. The modification in reporting seems unlikely to be related to the change of realised bottom temperature which occurred just before 2018 and does not explain the larger change from 2022 (Figure 9d) when the monthly bottom temperature becomes more than 1°C higher than in the historical footprint.

Surface warming significantly affects mixed layer depth (Figure 10); note the strong reduction (~ 20 m) in the depth of the thermocline from about 2016 in LIN 4 and across the footprint of the ling fishery. Interestingly, there is little recent change in mixed layer depth in LIN 3 despite the surface warming, but the anomaly in MLD increases indicating increasing interannual variability in water column structure. There is some indication that frontal activity in LIN 3, LIN 4 and over the footprint of the fishery has increased slightly since satellite observations began in 1981 (Figure 11) but the trends are small compared to the large variability between years.

Extreme temperatures such as marine heatwaves can become much more common as a result of fairly small increases in mean temperature, and this is observed in the MHW metrics for the Chatham Rise since 1980 (Figure 12). The number of MHW days and the number of separate MHW events increased substantially since about 2010, while the mean intensity and maximum intensity show smaller changes. Combined across MHW metrics, there is a strong increase (~ 4 -fold) in cumulative MHW intensity for the Chatham Rise (and LIN 3 and LIN 4) in the last 15 years.

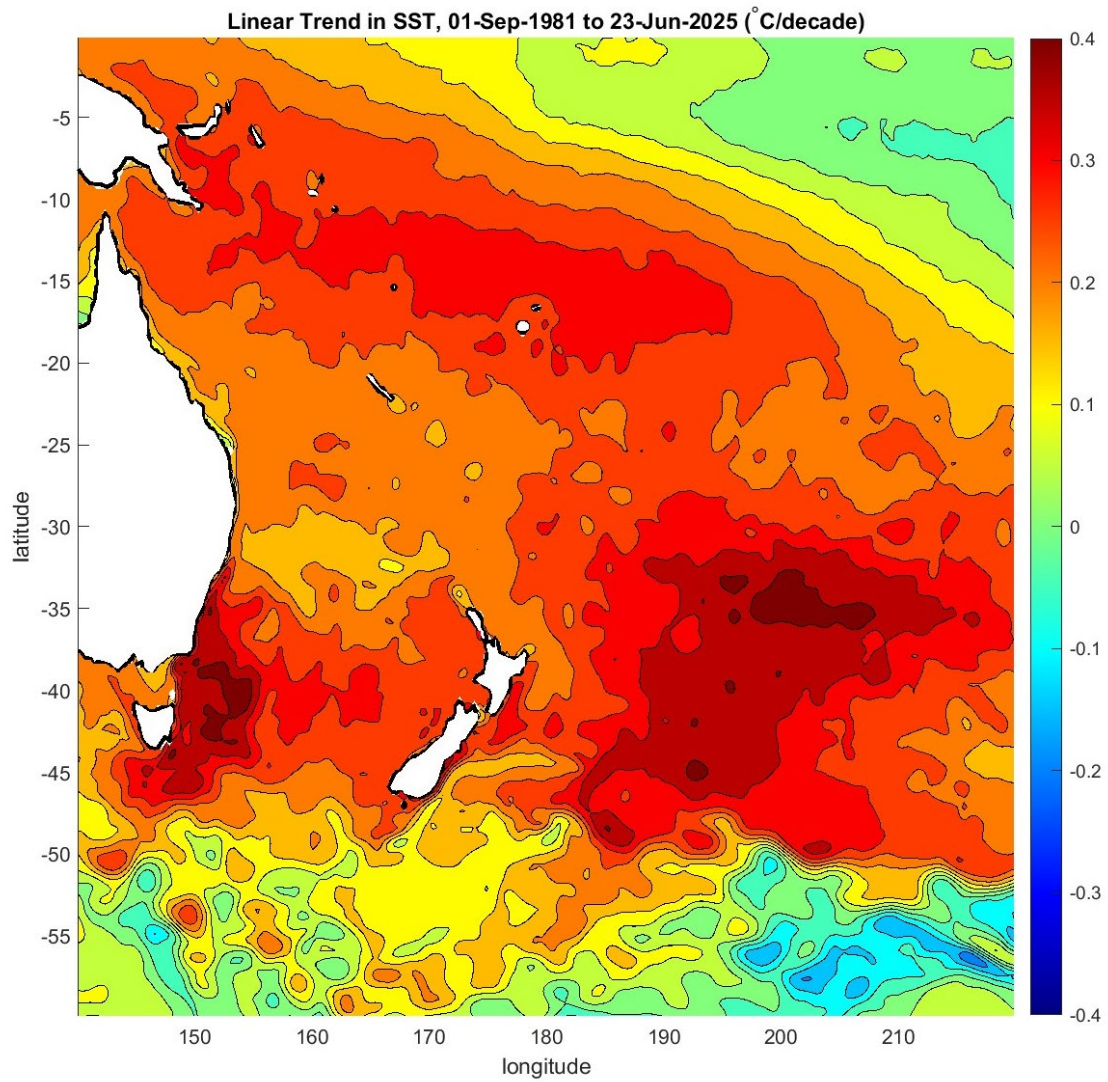


Figure 5: Linear trend (Sen slope) in surface temperature based on OISSTv2.1 satellite observations between 1981–2024, expressed as °C per decade. Warm colours indicate warming (positive temperature) trends.

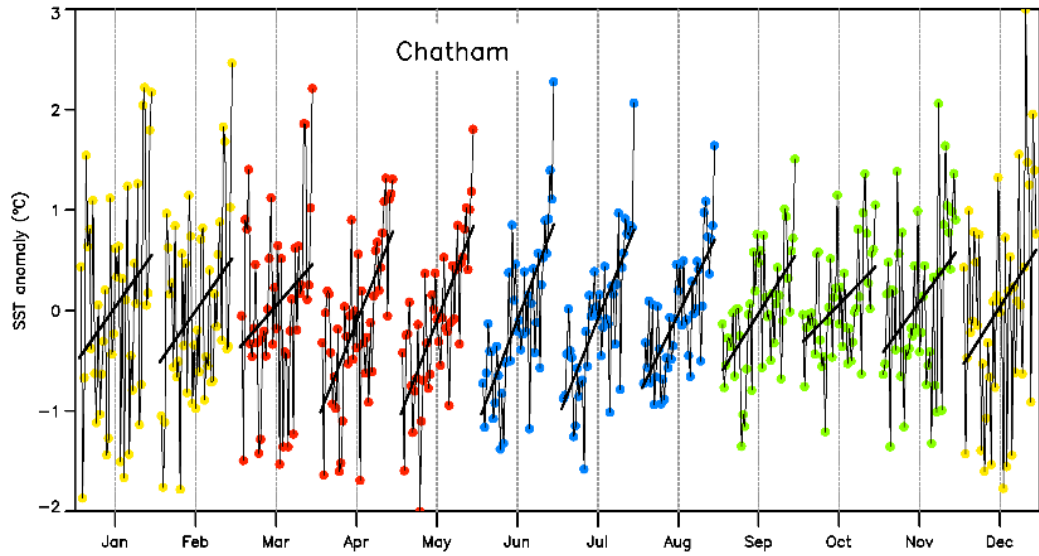


Figure 6: Monthly (seasonal) change in surface temperature over Chatham Rise based on OISSTv2.1 satellite observations between 1981–2024. The dots show the SST anomalies for each year of data, grouped by month and with seasons coloured differently (spring=green; summer=yellow; autumn=red; winter=blue).

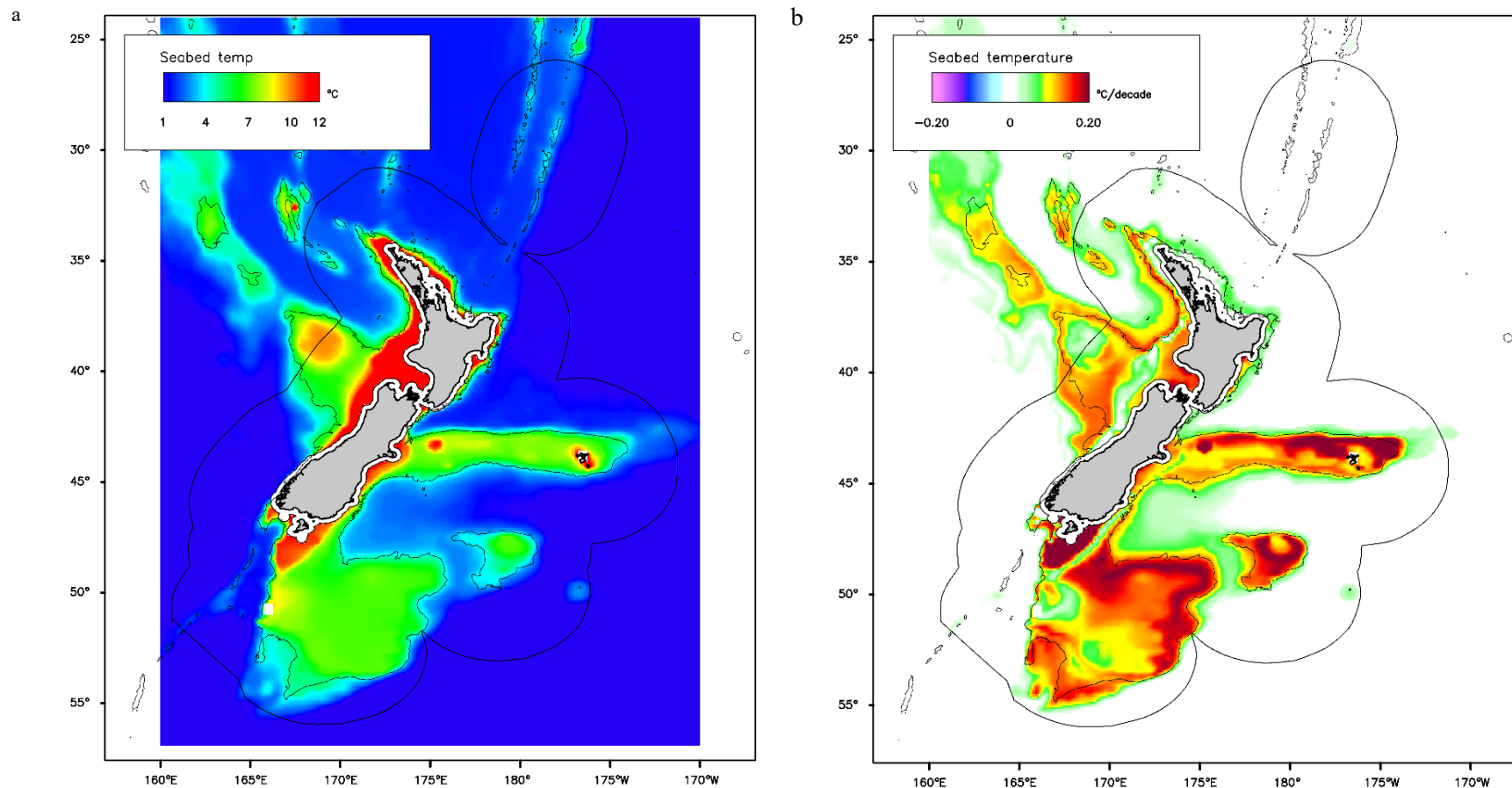


Figure 7: Bottom temperature based on model hindcasts between 1981–2024 (to match the satellite OISST v2.1 time-period). a: Mean bottom temperature (°C); b: Trend in bottom temperature (expressed as °C/decade) where red/orange indicates warming (positive temperature) trends. The 1000 m bathymetric contour and the New Zealand Exclusive Economic Zone (EEZ) boundary are shown.

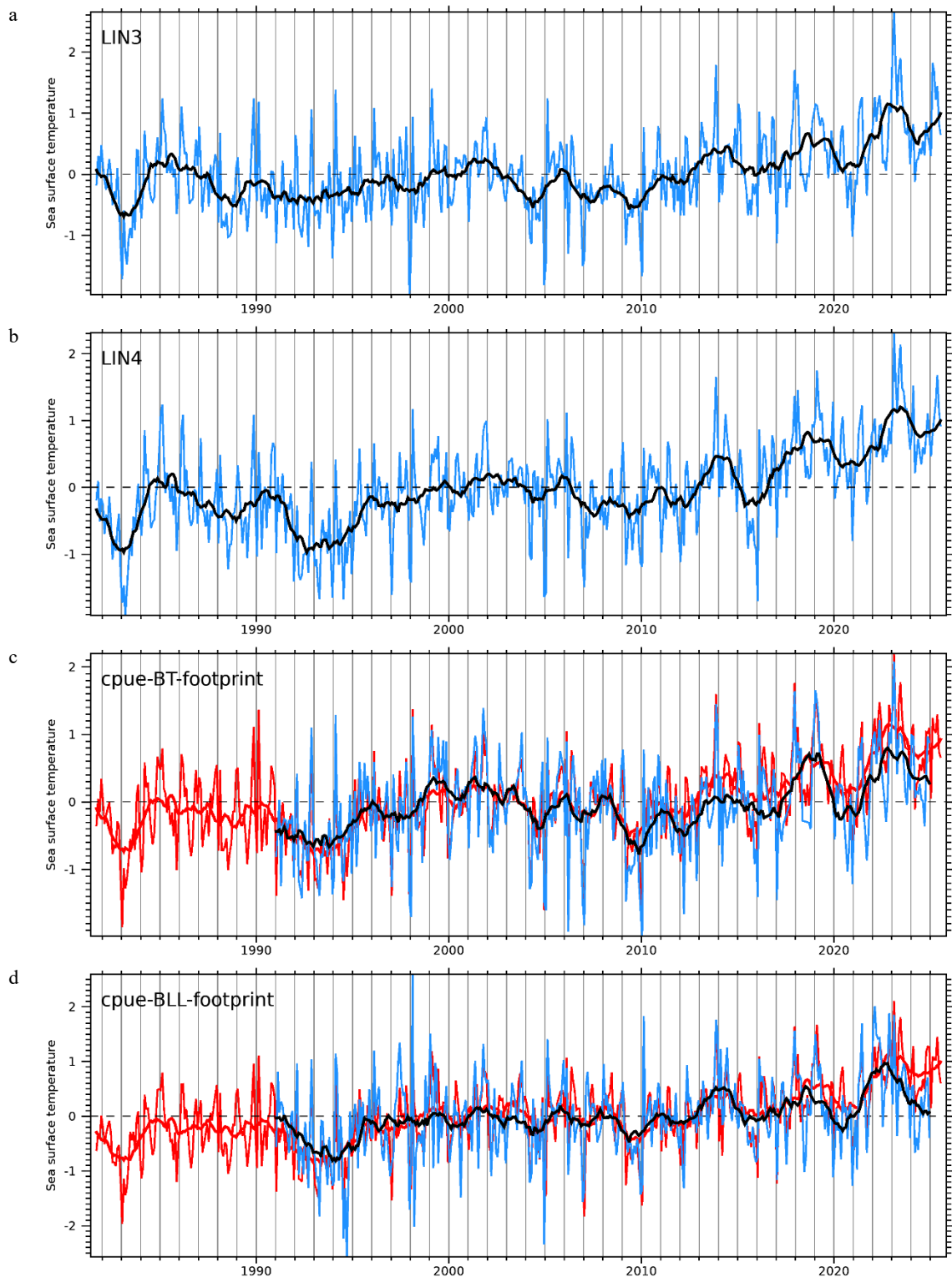


Figure 8: Sea surface temperature (SST) anomalies ($^{\circ}\text{C}$) based on satellite OISSTv2.1 data. a: LIN 3 fishery area; b: LIN 4 fishery area; c: Catch per unit effort (CPUE)-weighted SST for the bottom-trawl ling fishery (BT); d: CPUE-weighted SST for the bottom longline ling fishery (BLL). Blue lines are the monthly data and the black line is the 5-year smoother for these. In c and d, the red lines are the CPUE-weighted SST over the whole historical footprint of the fishery (1991–2025) showing monthly and 5-year smoother.

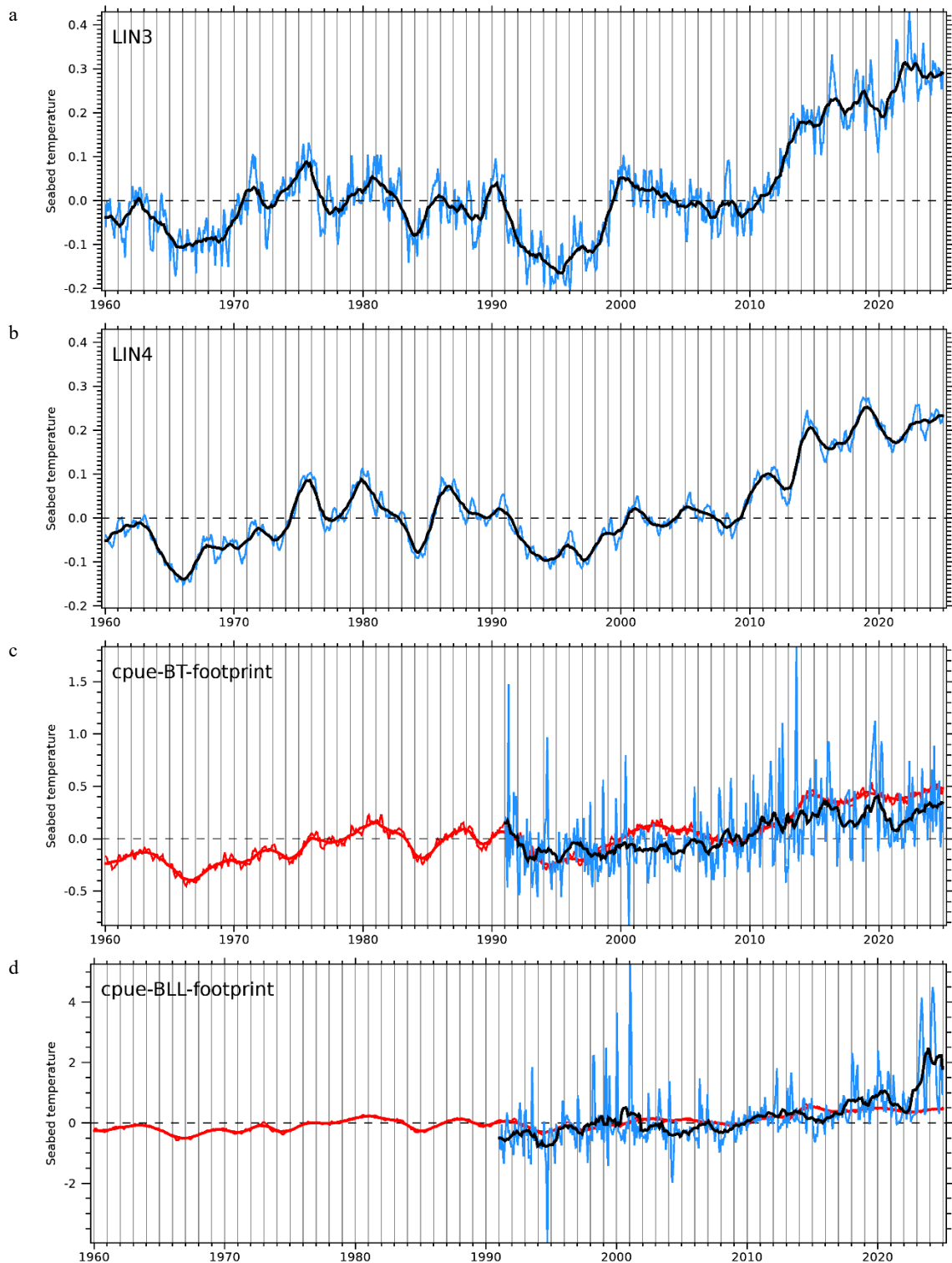


Figure 9: Bottom temperature anomalies, based on the New Zealand Earth System Model hindcast. **a:** LIN 3 fishery area; **b:** LIN 4 fishery area; **c:** Catch per unit effort (CPUE)-weighted bottom temperature for the bottom-trawl ling fishery (BT); **d:** CPUE-weighted bottom temperature for the bottom longline ling fishery (BLL). Blue lines are the monthly data and the black line is the 5-year smoother for these. In c and d, the red lines are the CPUE-weighted bottom temperatures over the whole historical footprint of the fishery (1991–2025) showing monthly and 5-year smoother.

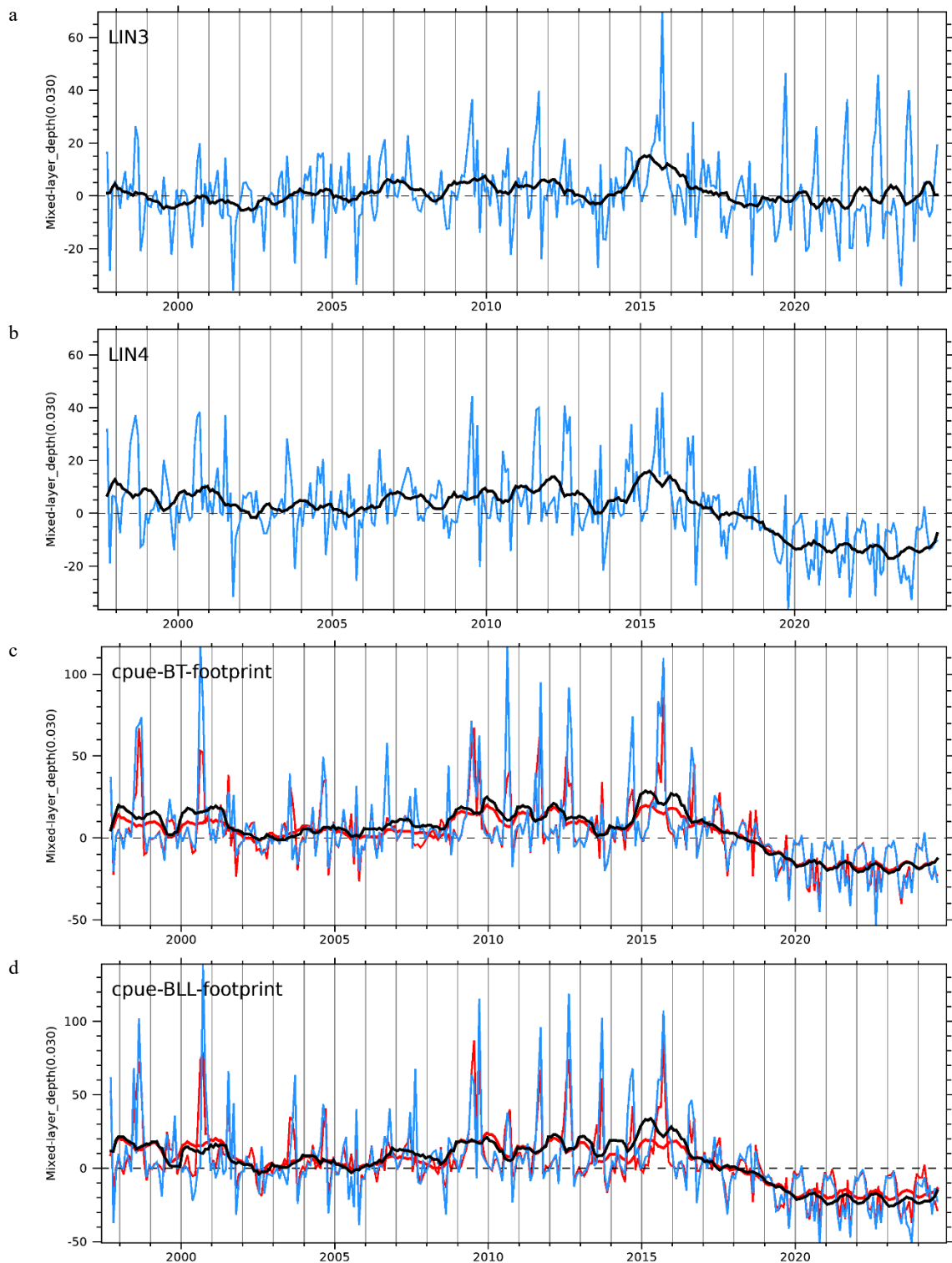


Figure 10. Mixed-layer depth (MLD) anomalies, based on model re-analyses, using a 0.030 kg m^{-3} density difference. a: LIN 3 fishery area; b: LIN 4 fishery area; c: Catch per unit effort (CPUE)-weighted MLD for the bottom-trawl ling fishery (BT); d: CPUE-weighted MLD for the bottom longline ling fishery (BLL). Blue lines are the monthly data and the black line is the 5-year smoother for these. In c and d, the red lines are the CPUE-weighted MLD over the whole historical footprint of the fishery (1991-2025) showing monthly and 5-year smoother. The MLD data for a higher density difference was very similar.

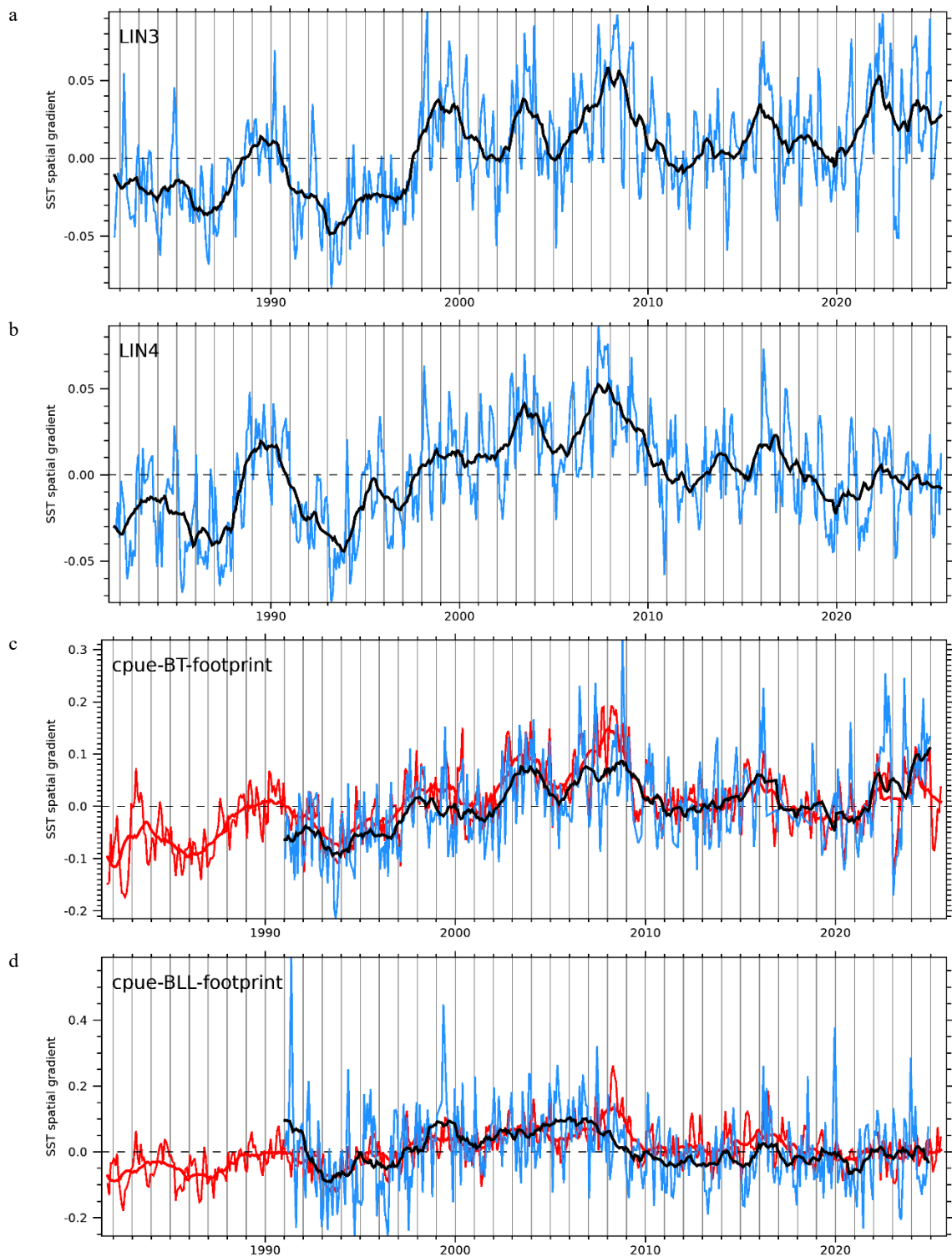


Figure 11: Frontal activity anomalies, based on the spatial gradient of sea surface temperature (SSTgrad). a: LIN 3 fishery area; b: LIN 4 fishery area; c: Catch per unit effort (CPUE)-weighted SSTgrad for the bottom-trawl ling fishery (BT); d: CPUE-weighted SSTgrad for the bottom longline ling fishery (BLL). Blue lines are the monthly data and the black line is the 5-year smoother for these. In c and d, the red lines are the CPUE-weighted SSTgrad over the whole historical footprint of the fishery (1991-2025) showing monthly and 5-year smoother.

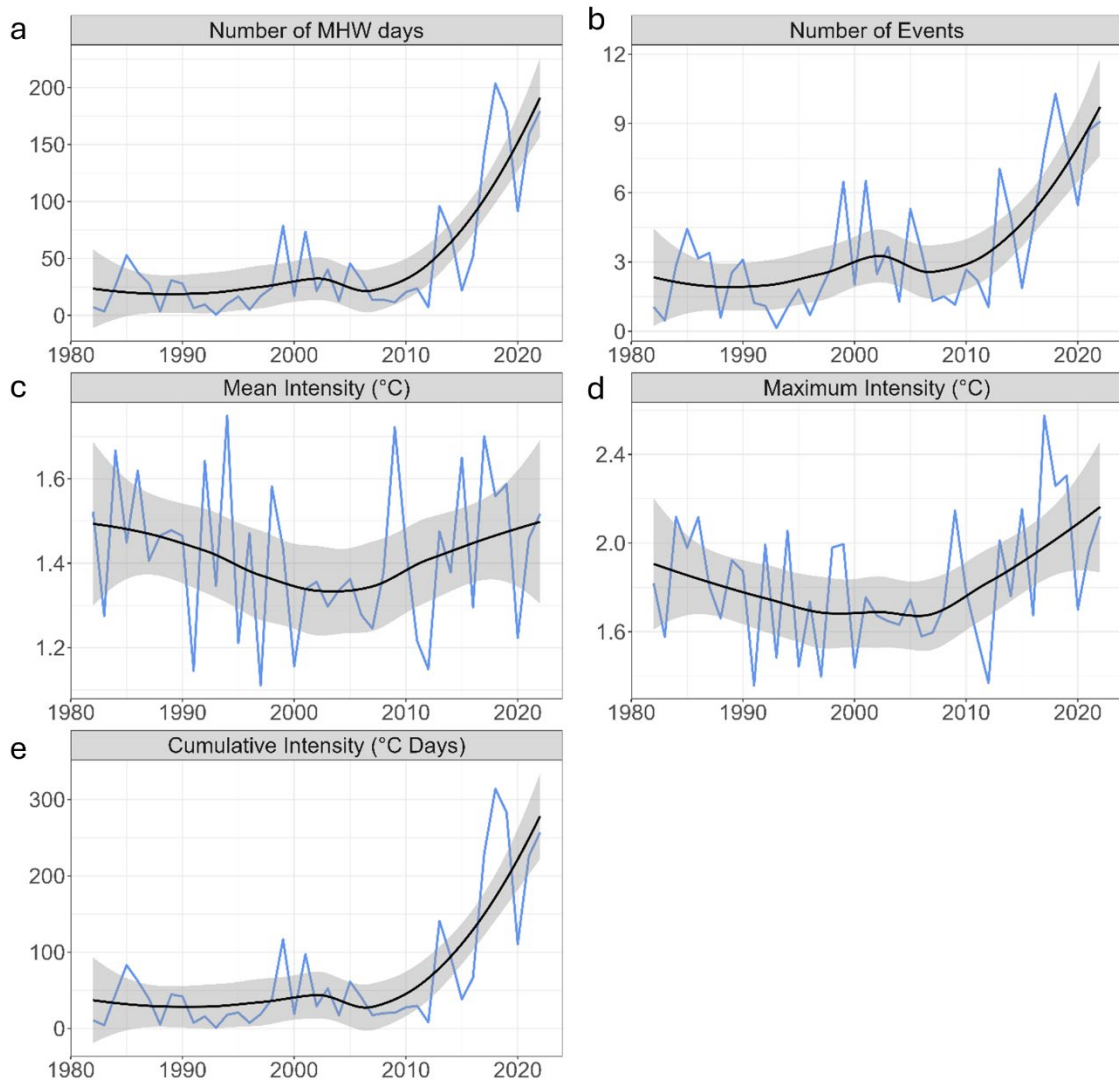


Figure 12. Marine heatwave (MHW) metrics for the Chatham Rise region. a: Number of MHW days; b: Number of MHW events; c: Mean MHW intensity (°C); d: Maximum MHW intensity (°C); e: Cumulative MHW intensity (°C days).

3.3 Biological response

Surface chlorophyll-a concentration (chl-a) is often used as a remote sensing proxy for ocean primary productivity (Pinkerton et al. 2024). Most of the New Zealand ocean domain is considered oligotrophic (chl-a between 0.1 and 1 mg m⁻³), with microtrophic conditions (chl-a 0.05 - 0.1 mg m⁻³) in the extreme subtropical part of the EEZ (Figure 13a). Higher oceanic chl-a is associated with the STF at about 45°S, especially over Chatham Rise, which would be classified as mesotrophic (chl-a 1-3 mg m⁻³). Based on satellite observations 1997–2024, significant positive trends in chl-a concentrations were observed in certain oceanic regions, notably in the STF regions to the east of New Zealand over the Chatham Rise) and west of New Zealand (Figure 13b). Additionally, notable positive trends in chl-a were identified in subantarctic waters located to the south. Conversely, substantial negative trends in chl-a concentrations are evident in the subtropical waters located east and north of New Zealand, specifically northeast of the Chatham Islands and in the regions encompassing Northland across the eastern coastline over the continental shelf and to the west. Trends in chl-a over much of these areas was assessed as “virtually certain” (Figure 13c). Correlations

between monthly anomalies of chl-a and SST for each pixel between 1997 and 2023 (Figure 13d) were found to be generally negative in subtropical waters and the Tasman Sea, and positive in subantarctic waters, consistent with previous analyses (e.g., Pinkerton et al. 2024) and with our understanding of the likely impacts of climate variability and change on phytoplankton in these regions (Murphy et al. 2001). In contrast, the low correlation between SST and chl-a anomalies over the Chatham Rise region implies a more complex and less predictable relationship between temperature and productivity in this region.

This complexity in the response of primary production over the Chatham Rise to climate change is also shown by the seasonal pattern of change in chl-a (Figure 14). Increasing trends in chl-a occurred in the Chatham region in late-autumn/winter (May-August) and late spring (October-November) but we found decreasing chl-a trends over the summer to spring (December–April) and in September. This suggests that the spring bloom is tending to start later in the Chatham region (which might have implications for species that spawn in the spring), and that the autumn and winter productivity is benefiting from the warmer water.

There is evidence of slightly increasing chl-a over time in LIN 3 (at least to 2020), but little evidence of increases in LIN 4 (Figure 15a,b). Between 2020–2024, chl-a decreased substantially ($\sim 0.2 \text{ mg m}^{-3}$) relative to normal conditions, but productivity (as shown by chl-a) seems to have recovered to near normal levels since. There is evidence that the BLL effort has moved to areas with higher chl-a compared to the historical fishing footprint from about 2020 (Figure 15d) but not for the BT fishery (Figure 15c). These conclusions based on chl-a are supported by the CAFÉ model of NPP (Figure 16) and POC flux to the seabed (Figure 17) with very similar results to chl-a. However, we note the particularly low NPP and POC flux in January 2023 that is not evident in chl-a alone and is potentially related to effects of warming on phytoplankton physiology.

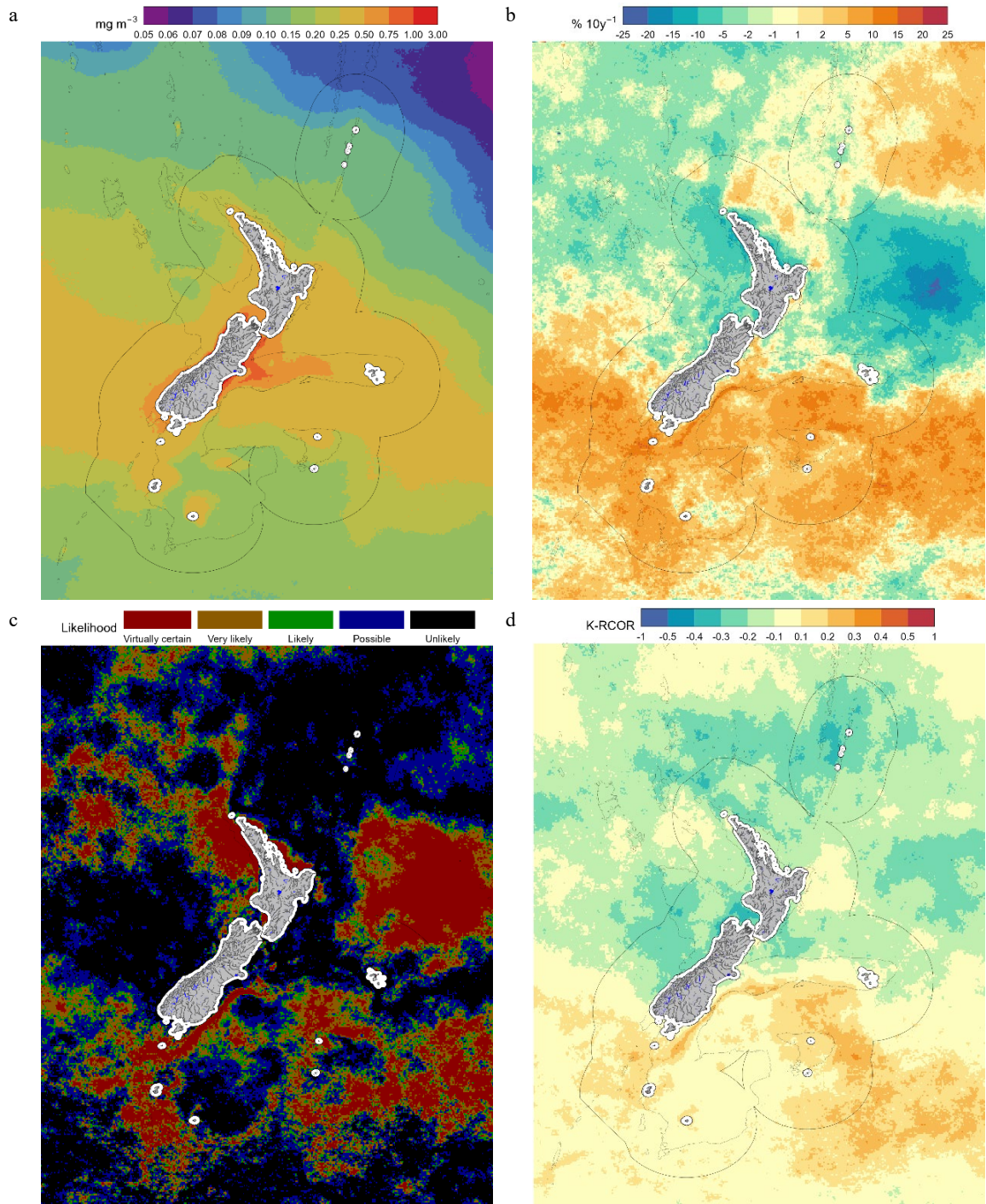


Figure 13: Near-surface chlorophyll-a concentration (chl-a, mg m^{-3} , indicative of primary production) from ocean colour satellite data. a: Long-term mean conditions (1997–2023); b: Linear trend (Sen slope) over the same period, expressed as expressed as proportional change in chl-a per decade; c: Likelihood of non-zero trend based on Mann-Kendall analysis corrected for auto-correlation; d: Linear Kendall correlation coefficient between anomalies of sea surface temperature and chlorophyll-a (1997–2023).

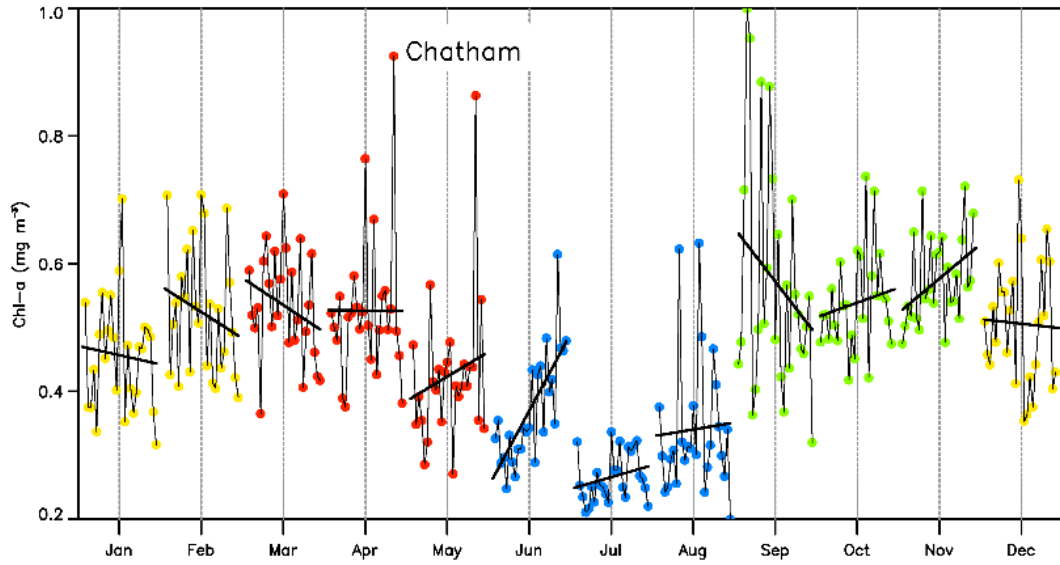


Figure 14: Monthly (seasonal) change in surface chlorophyll-a concentration (chl-a, mg m^{-3} , indicative of primary production) over the Chatham Rise based on ocean-colour satellite observations between 1997–2023. The dots show the chl-a anomalies for each year of data, grouped by month and with seasons coloured differently (spring=green; summer=yellow; autumn=red; winter=blue).

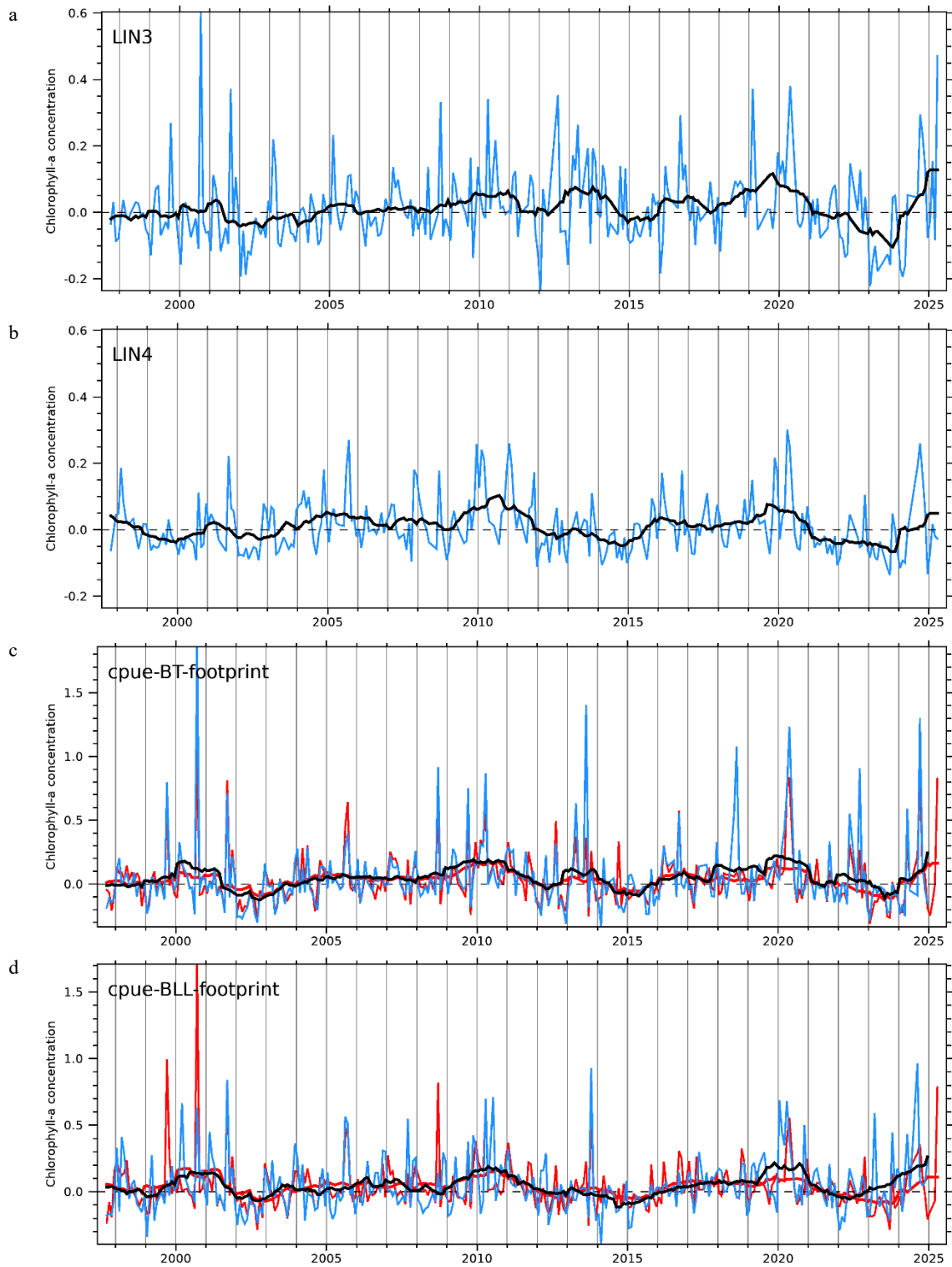


Figure 15: Surface chlorophyll-a anomalies (chl-a), based on merged satellite ocean colour data. a: LIN 3 fishery area; b: LIN 4 fishery area; c: CPUE-weighted chl-a for the bottom-trawl ling fishery (BT); d: CPUE-weighted chl-a for the bottom longline ling fishery (BLL). Blue lines are the monthly data and the black line is the 5-year smoother for these. In c and d, the red lines are the CPUE-weighted chl-a data over the whole historical footprint of the fishery (1991–2025) showing monthly and 5-year smoother.

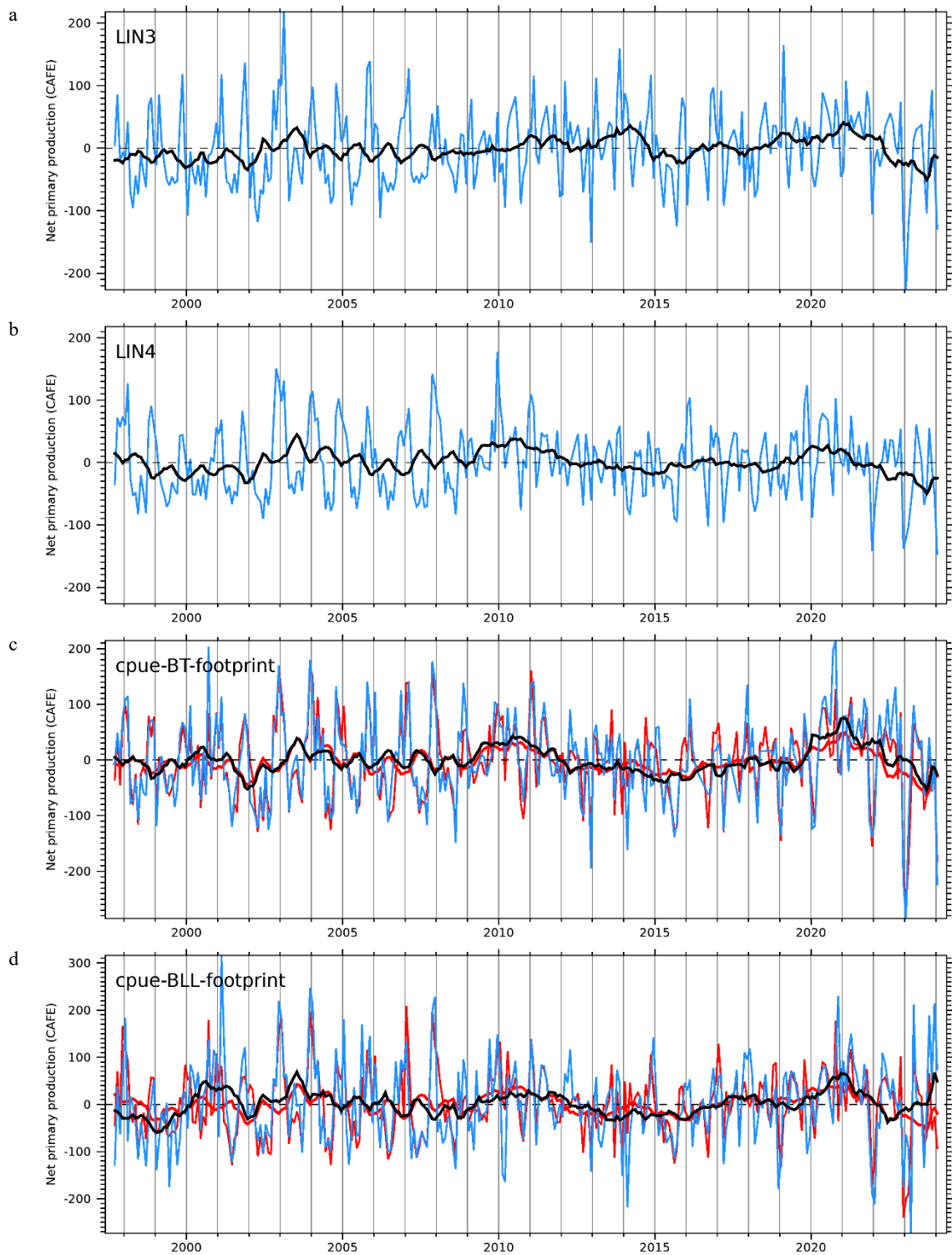


Figure 16: Net (of respiration) phytoplankton primary production (NPP) anomalies ($\text{mgC m}^{-2} \text{d}^{-1}$) based on the CAFÉ (Carbon, Absorption, and Fluorescence Euphotic-resolving model). a: LIN 3 fishery area; b: LIN 4 fishery area; c: Catch per unit effort (CPUE)-weighted NPP for the bottom-trawl ling fishery (BT); d: CPUE-weighted NPP for the bottom longline ling fishery (BLL). Blue lines are the monthly data and the black line is the 5-year smoother for these. In c and d, the red lines are the CPUE-weighted NPP over the whole historical footprint of the fishery (1991–2025) showing monthly and 5-year smoother.

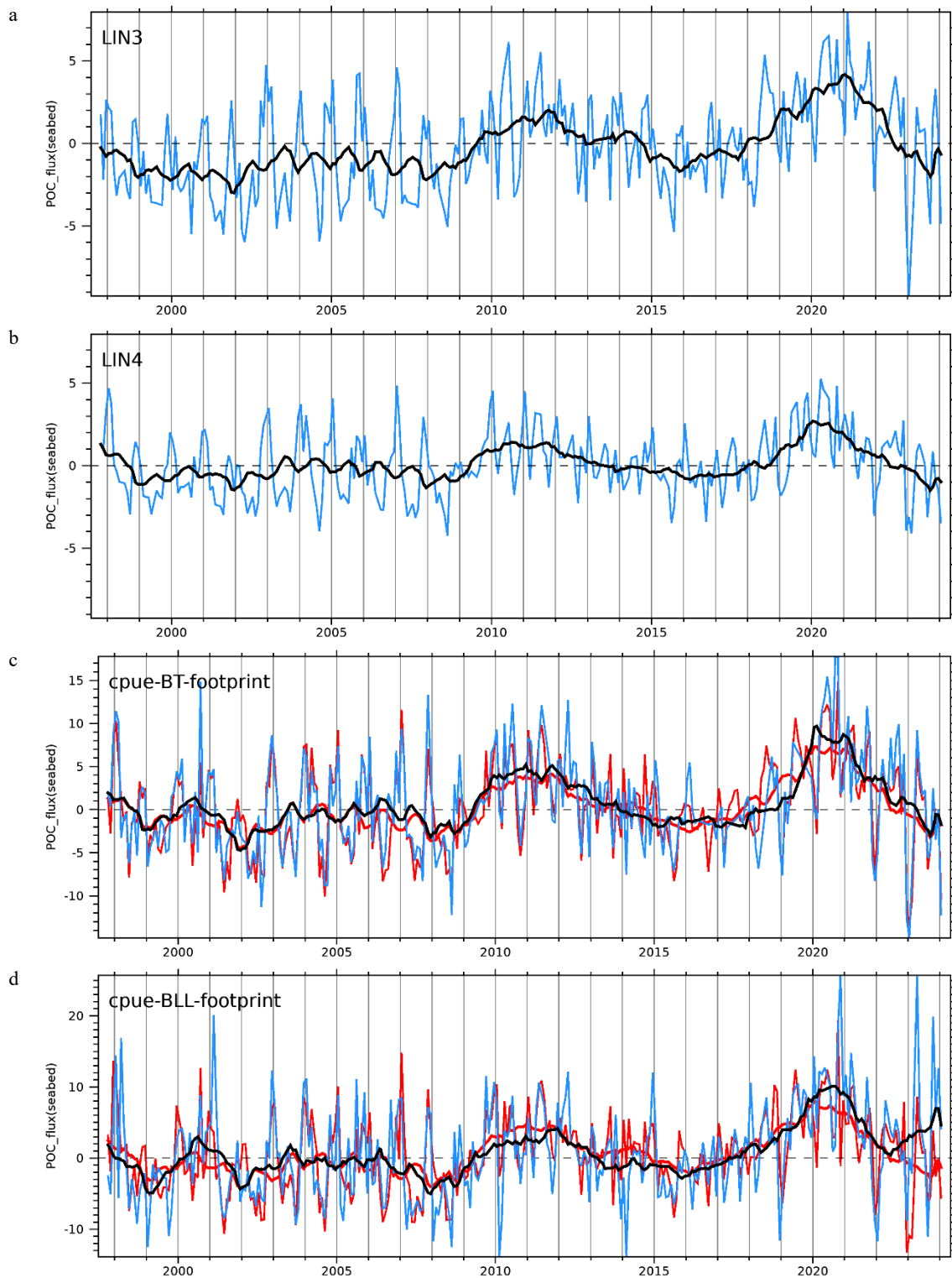


Figure 17: Particulate organic matter (POM) flux anomalies ($\text{mgC m}^{-2} \text{d}^{-1}$) based on satellite observations and the Lutz et al. (2007) export model. a: LIN 3 fishery area; b: LIN 4 fishery area; c: Catch per unit effort (CPUE)-weighted POM for the bottom-trawl ling fishery (BT); d: CPUE-weighted POM for the bottom longline ling fishery (BLL). Blue lines are the monthly data and the black line is the 5-year smoother for these. In c and d, the red lines are the CPUE-weighted POM flux over the whole historical footprint of the fishery (1991–2025) showing monthly and 5-year smoother.

3.4 Changes in fishing activity

As part of the ling characterisation (Holmes et al. 2025) and relevant to the most recent ling assessment (Dunn & Holmes 2025), a ridge plot of catch of ling by bottom depth was produced (Figure 18). For BT it was noted the primary mode of catch had gradually shifted deeper over time but there were secondary modes appearing at shallower depths. Fishing effort in both the shallow and deeper areas is substantial (Figure 19) showing ling are less abundant in the shallower areas (Holmes et al. 2025) and much less abundant in shallower areas than was seen from about 2006–2012. Given that water temperature tends to reduce with depth, the increasing depth of the BT fishery catches over time will lead to the cooler waters being encountered compared to averages over the historical BT footprint as observed (Figure 9c). In contrast, there was little recent change in the depth of the BLL fishery, so this does not explain bottom temperature anomalies being higher than over the historical BLL footprint as observed from 2022 (Figure 9d).

Holmes et al. (2025, Figures 15 and 16) shows evidence of declines in the area fished by BLL since about 2020, with effort being concentrated in more recent years to the eastern end of the Chatham Rise, and away from BLL effort on the northern slope and to the west of the rise. This contraction and refocussing of BLL effort is likely to be responsible for the change in CPUE-weighted bottom temperature shown by the divergence between the red and blue/black lines in Figure 9d. The recent change in the spatial pattern of BLL effort coincides with the advent of the ling potting fishery from 2018 and may be associated with it (i.e., transfer of effort to the west of the Chatham Rise from BLL to pot).

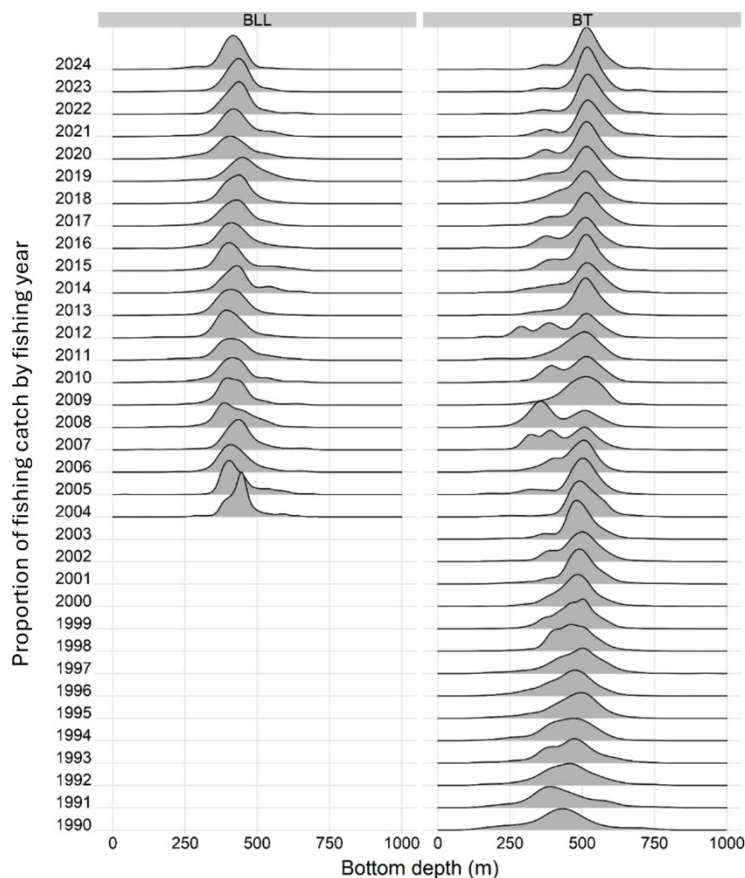


Figure 18. Ling catch by bottom depth for bottom longline (BLL, left) and bottom-trawl (BT, right) fisheries showing the change in the depth of the fishing effort over time (Holmes et al. 2025, Figure 11). Depth information is mostly missing from the catch reporting data for BLL before 2004.

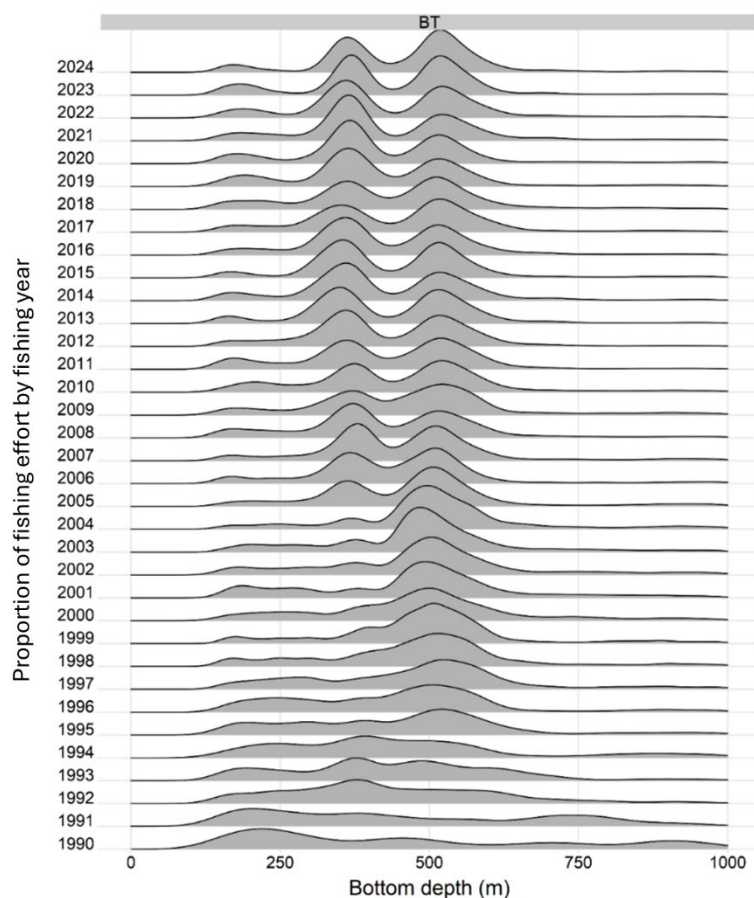


Figure 19. Fishing effort by bottom-trawl (BT) fisheries showing the depth of the fishing effort over time (Holmes et al. 2025), showing the emergence of a second (shallower) mode of effort in the BT fishery since about 2004.

In considering changes over time in standardised CPUE for ling we focus only on the BLL fishery because this targets ling, whereas the BT fishery takes ling whilst mainly targeting other species. Ling CPUE from BLL showed a sharp decline between 1991 and 1997, and more recently between 2021 and 2024 (Figure 20a). The reasons for these declines in CPUE are not well known, and the patterns of change over time contrast to the steady abundance index of ling from 1992 from the Chatham Rise trawl survey. Ling recruitment was elevated in 1995 and declined subsequently to 2015 as shown in Figure 20b (taken from Holmes & Dunn 2025) and does not seem to explain the temporal pattern of CPUE from BLL.

The CPUE-based indices of ling abundance are compared with time-series of three key environmental indices developed here (SST, bottom temperature and particulate organic matter (POM) at the seabed; Figure 20 b,c,d). What we are looking for here is an unprecedented change in the red and/or blue/black lines at around 2021 that might indicate an environmental change which effects ling. A change in the red lines would indicate a change in environmental conditions in the areas where ling are found on average within the whole historical footprint of the fishery: effectively an environmental change index. A change in the blue/black line would indicate a change in environmental conditions across ling-biomass within the month-specific (present) footprint of the fishery. Differences between the red and blue/black lines arise from a combination of the change in where the fishery is operating and/or a change in the spatial distribution of ling biomass within the BLL fishing footprint.

The fall in the fishery CPUE index since 2021 is not consistent with a threshold ecological effect of SST. If SST anomalies above about +0.5 °C are considered “unprecedented” with a potentially detrimental effect on the availability of ling, this effect would be first triggered in about 2023 not 2021 as observed. If environmental changes have a lagged effect on ling through recruitment, then such a threshold temperature effect will not be seen yet (as recruitment to the fishery typically occurs at around age 10; Holmes & Dunn 2025). There is also no major change in the red versus blue/black lines in 2021 in Figure 20c. There is also no indication of any major change in seabed temperature in 2021 (Figure 20d), but this figure does indicate a substantial change in within the fishery footprint from ~2022 that approximately fits the observed change in BLL CPUE, and furthermore, the difference persists between 2022 and 2025. For POC flux, there is no major change in in the historical fishery footprint (Figure 20e, red line), or in the POC flux in the actual fishing areas (Figure 20e, blue/black lines). However, the POC flux anomaly difference between the red and blue/black lines in BLL increases substantially from about 2020.

Overall, these patterns are generally consistent with the BLL effort moving in location from after 2022, to areas that have slightly cooler surface temperatures, warmer bottom temperatures (by ~2°C) and slightly higher POC flux. It is possible that these environmental differences correspond to lower local densities of ling and hence lead to lower BLL ling CPUE.

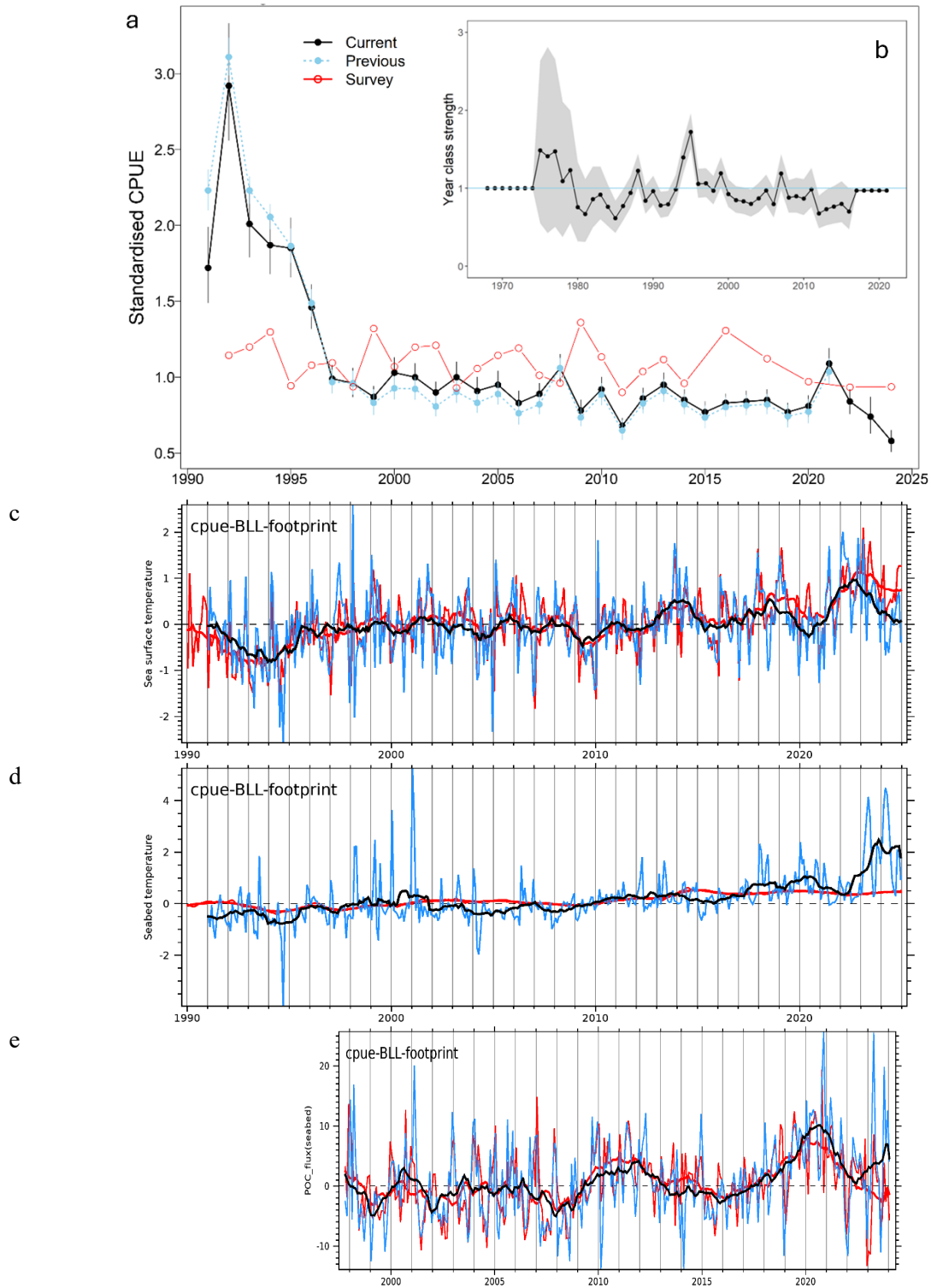


Figure 20. Ling biomass indices estimated from the stock assessment and Chatham Rise trawl survey against environmental series. **a:** Standardised catch per unit effort (CPUE) for the bottom longline (BLL) fleet for current (black, Holmes et al. 2025) and previous (blue, Mormede et al. 2023) LING 3&4 analyses. The red line is the abundance index from the Chatham Rise trawl survey. **b (inset):** Estimated posterior distributions of true year class strength (spawning years; Holmes & Dunn 2025, with median (line and individual points) and 95% credible interval (grey band)). The horizontal line indicates a year class strength of one. **c:** SST time-series (see caption Figure 8). **d:** Seabed temperature (see caption Figure 9). **e:** Particulate organic matter at the seabed (see caption Figure 17).

4. DISCUSSION

This work has added to our understanding of how the oceanographic conditions in the New Zealand marine region are changing because of climate change. Consistent with previous work (e.g., Pinkerton et al. 2024; Sutton & Bowen 2019; Sutton et al. 2024) we used autonomous *in situ* instrumentation (Argo), satellite remote sensing and computer modelling to observe and understand environmental change in the LIN 3 and LIN 4 areas of the Chatham Rise. Remotely-sensed observations which use sensors on Earth-orbiting satellites serve as a crucial component to tracking marine variability and change by providing frequent, long-term, wide-area, and spatially-resolved monitoring. Satellite methods are cost-effective because products are freely accessible, courtesy of long-term research programmes, especially in USA and Europe. One key drawback to satellite observation is that only near-surface conditions are observed, so that changes to deeper parts of the water column must be inferred or obtained by other means. Here, we have combined surface satellite data with information on bottom temperature from models and *in situ* instrumentation to provide information on the whole water column.

In general, physical oceanographic changes are well observed. Together, complementary observation methods give us a reasonably good and complete picture of oceanographic variability and change, at least at broad ocean scales. Using actual observations of oceanographic conditions is more powerful than using simple climate indices (such as Southern Oscillation Index (SOI) or El Niño-Southern Oscillation (ENSO)), because large-scale climate cycles affect the local marine environment in inconsistent ways over time. Analysis of these data show that the seas around New Zealand are warming (especially in winter) and the rate of warming has accelerated in the last 20 years. The New Zealand EEZ has warmed 34% faster than the global average warming rate (all marine areas worldwide) over the last 40 years and 2.3 times faster than the global average over the last 20 years. Over the last 40 years, this warming has led to an increasing number of prolonged, anomalously warm-water events or MHWs around New Zealand. We report on substantial increases in the cumulative intensity of marine heat waves in the Chatham Rise region since 2010, consistent with Montie et al. (2023) and Thorat et al. (2022). Changes around New Zealand echo similar observations across the globe, where MHWs have substantially increased in number, duration and intensity over recent years (Frölicher et al. 2018; Holbrook et al. 2019; Oliver et al. 2019; Smale et al. 2019; Smith et al. 2021).

Climate change has also led to hemispheric changes in ocean heat content and winds that are embedded into the Earth's climate system (Sutton et al. 2024). The oceans in mid-latitudes have warmed more than the oceans further south, resulting in a stronger gradient across the Southern Ocean. Additionally, westerly winds over the Southern Ocean have strengthened. These mechanisms have accelerated the west-to-east surface flows in the Southern Ocean and led to particularly pronounced oceanographic change in the LIN 3 and LIN 4 areas. Sutton et al. (2024) reports that an area of ocean centred on 179°E, 46°S has warmed to full depth since 2006, with surface warming around five times the global rate. This part of the STF is associated with a confluence of warm, salty, subtropical water from the north carried in a western boundary current and cold, fresh, subantarctic water from the south carried in the northernmost branch of the Antarctic Circumpolar Current. Temperature and salinity changes observed from Argo floats indicate that the STF zone has moved west about 120 km, creating this area of strong warming analogous to changes in extension regions of other western boundary currents. The warming has placed the LIN 3 and LIN 4 regions in almost perpetual marine heatwave conditions.

Computer modelling of oceanographic change using global (international) ESMs and the local New Zealand ESM (Behrens et al. 2020) are rapidly improving in accuracy and resolution. It is notable that the recent change in the circulation and conditions in the Chatham Rise were reproduced even in a relatively coarse-resolution global ESM. In general, this result provides increasing confidence that ESMs are capable of projecting future changes in physical oceanographic conditions with reasonable confidence, and in the New Zealand region specifically, a set of global ensemble projections of future changes to oceanographic conditions that are generally consistent can be identified (Rickard et al.

2023, 2026. Under future scenarios, these climate models project that the change to the Chatham Rise oceanography will strengthen and persist until at least the end of this century.

In contrast, biological responses to oceanographic change are more poorly observed, less well understood, and future biological and ecological responses to climate variability and change remain highly uncertain (Rickard et al. 2023). There are substantial variations between different biogeochemical ESMs in how the base of the food web will change in the future. Both the response of phytoplankton primary production itself, and the response of phytoplankton loss terms (grazing by zooplankton, and detrital sinking to the seabed) to ongoing climate change are poorly known. As a local example, responses of phytoplankton primary production to warming in subtropical and subantarctic waters are generally following established understanding of phytoplankton ecology (Murphy et al. 2001). Essentially, surface warming of subtropical water stabilises the surface mixed layer (reductions in MLD), reduces water-column mixing and nutrient supply to the photic zone which inhibits phytoplankton growth (Pinkerton et al. 2024). In contrast, warming of subantarctic waters hold phytoplankton closer to the surface for longer, and the increased irradiance boosts primary production. However, the Chatham Rise region, the area of highest primary production in the New Zealand ocean, is more complex oceanographically and biologically because of the confluence of subtropical and subantarctic waters along the STF. Primary production has been slightly increasing in the Chatham Rise region since the start of satellite observation of chl-a and the reasons for this are not well understood. Furthermore, there was a rapid, unexpected and unexplained synchronous reduction in chl-a between 2020–2024 across much of the New Zealand ocean, encompassing the subtropical, subantarctic, STF regions and including LIN 3 and LIN 4. Though changes in chl-a have since reversed back to near-normal levels by mid-2025, causes for this change are not understood, and the change highlights our inability to anticipate the long-term biological response of the New Zealand ocean to ongoing climate change.

Climate-driven changes to primary production and oceanographic conditions (including warming, extreme warming events, salinity changes, acidification, de-oxygenation) will have broader impacts on New Zealand marine ecosystems, extending to ling and other deepwater commercial species through physiological, distributional and trophic (food web) processes (Bradford-Grieve et al. 2003; Pinkerton & MacDiarmid 2013; Pinkerton 2014; Cummings et al. 2021; Cook et al. 2024, 2025) but are hard to predict and manage for.

Research elsewhere has found that a species related to ling (*Genypterus chilensis*) is negatively influenced by thermal stress (Dettleff et al. 2020; Dettleff et al. 2022) both from gradual warming and extreme events (marine heatwaves). *G. chilensis* is found in the Southeast Pacific from southern Peru to Chile, inhabiting rocky continental shelf bottoms between 20–150 m, and growing to 100–250 cm in length, so is larger and shallower-living than ling round New Zealand. In experimental work by Dettleff et al. 2020, physiological stress in *G. chilensis* increased as individuals were warmed from a mean control temperature (14°C) to 19°C over 24 hours. Seabed temperatures on the Chatham Rise are much colder, closer to approximately 5 °C in the ling footprint area, and we would not anticipate such high temperature changes to seabed temperatures on the Chatham Rise, even in MHW conditions and even 100 years hence, so these results should be seen as more extreme than ling in New Zealand are likely to ever encounter.

In this report we characterised environmental variability and change across the LIN 3&4 region encompassing the footprint of the ling BT and BLL fisheries from 1991–2025. This environmental characterisation should be read alongside the ling fishery characterisation (Holmes et al. 2025) and ling stock assessment (Holmes & Dunn 2025). We found that oceanographic conditions and primary productivity are changing across the Chatham Rise region. In parallel to this climate-driven environmental change, and concurrent with the development of a potting fishery for ling, the location of BLL effort has moved and contracted since 2018. The more recent areas of BLL effort coincide with slightly elevated particulate organic matter fluxes to the seabed, cooler surface water and warmer bottom water temperatures (even though they are not shallower). To take this into account, future ling assessments would need to consider both changes in oceanographic conditions (including bottom temperature) and primary productivity, and how the spatial distribution of fishing is changing.

5. POTENTIAL RESEARCH

- Improved understanding of ling life-history (especially spawning) and trophic connections (diet of ling, and changes in diet over time) will likely help to understand and anticipate effects of climate change on this species.
- It could be instructive to repeat the analysis of environmental conditions on the Chatham Rise region within a CPUE-weighted footprint for other species or fisheries, potentially starting with hoki.
- An environmental characterisation could be carried out for ling in other stock areas.

6. FULFILMENT OF BROADER OUTCOMES

On the basis of the Biodiversity Research Advisory Group presentation associated with this project, information on environmental change was provided to representatives from the fishing industry contributing to Priority Outcome 1: “Increasing access for New Zealand businesses”. The advance is in terms of providing the fishing industry with information that potentially opens up new opportunities e.g. for green certification of fisheries. Cross-disciplinary research between oceanographic and fisheries areas of expertise delivers progress on Priority Outcome 2: “Increasing the size and skills of New Zealand’s workforce”. In terms of leading to further cross-disciplinary outcomes that potentially lead to new developments in the “green fishery” space, a presentation was made based on this project to the Ministry for Primary Industries Science and Information Directorate Monthly standup meeting.

Pinkerton, M.H.; P. Sutton (2025). Environmental changes and effects on ling, LIN2024-03. Presentation to FNZ/MPI working group, 16 May 2025.

Pinkerton, M.H. (2025). Satellite remote sensing of New Zealand’s coasts and oceans: mapping environmental change to understand ecological consequences. MPI Science and Information Directorate Monthly standup meeting, Friday 13 June 2025 (online).

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(OB.DAAC). We also acknowledge the National Oceanic and Atmospheric Administration (NOAA, USA) for providing access to AVHRR data.

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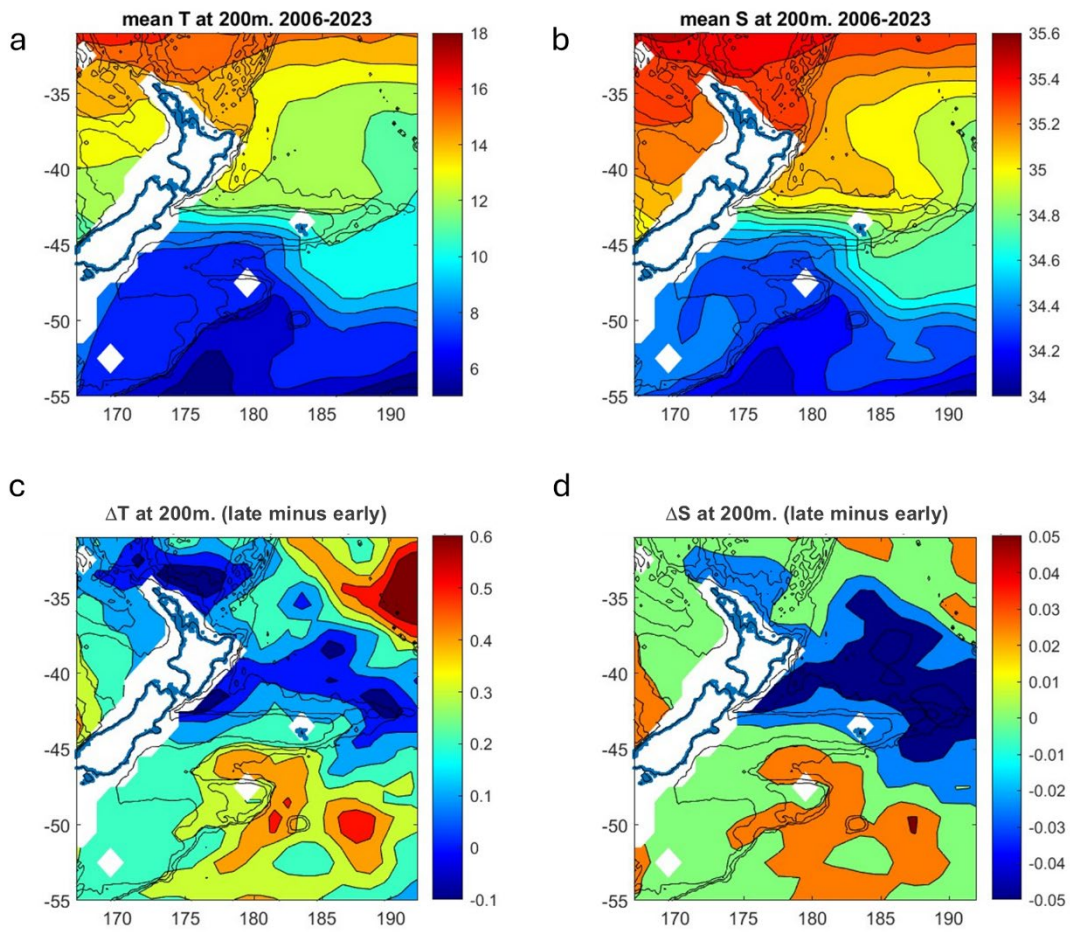
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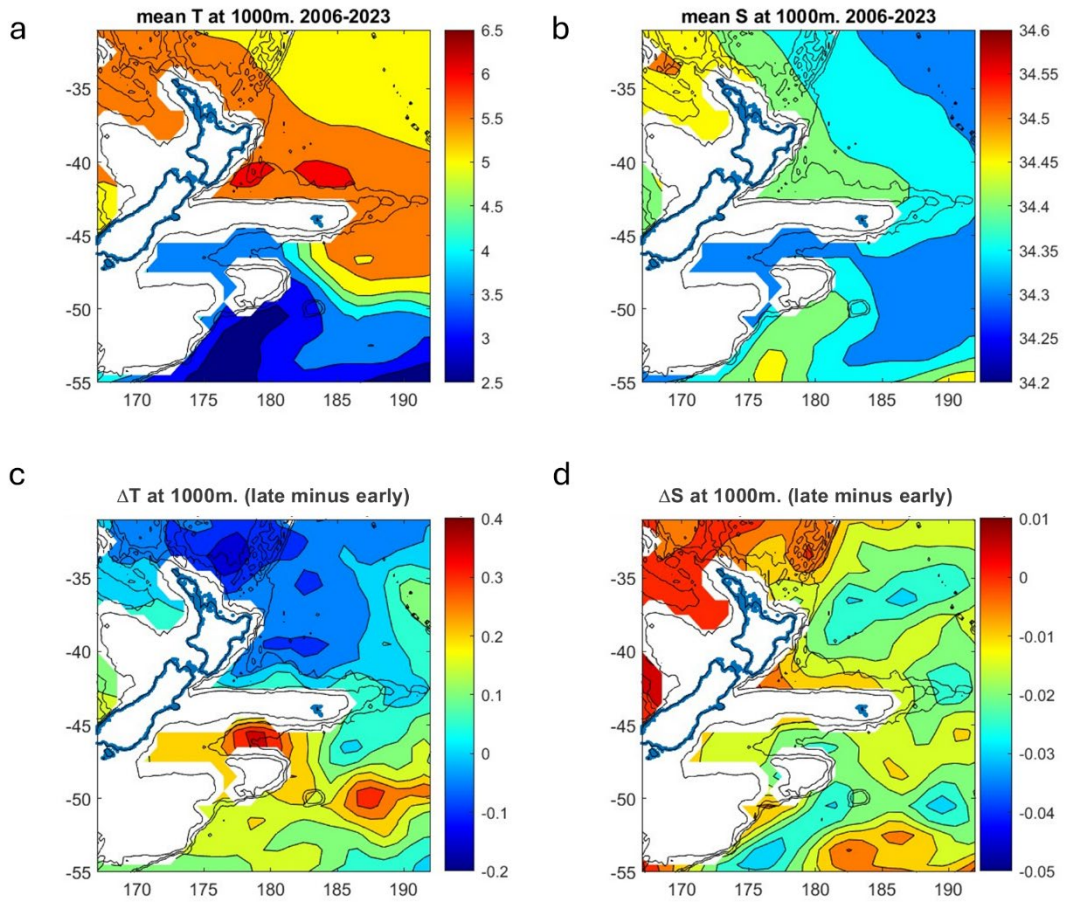
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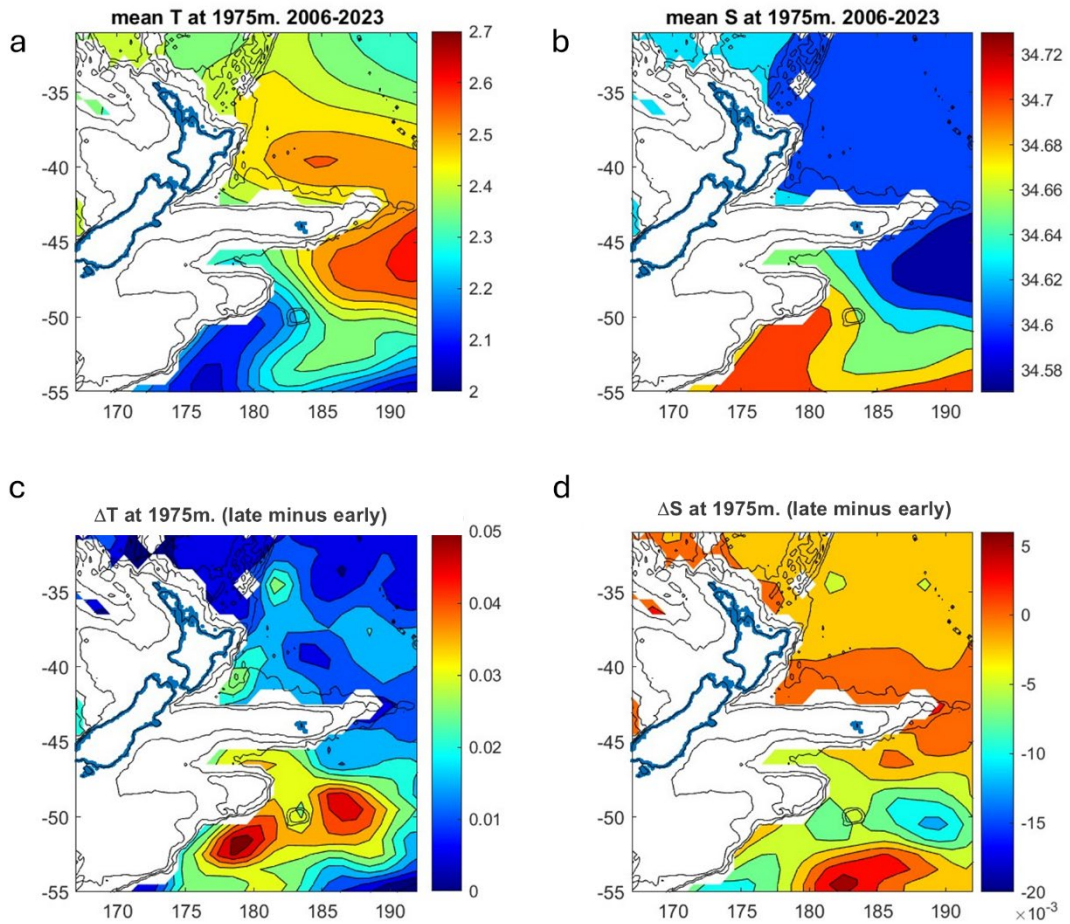
APPENDIX 1: Variations with depth from Argo



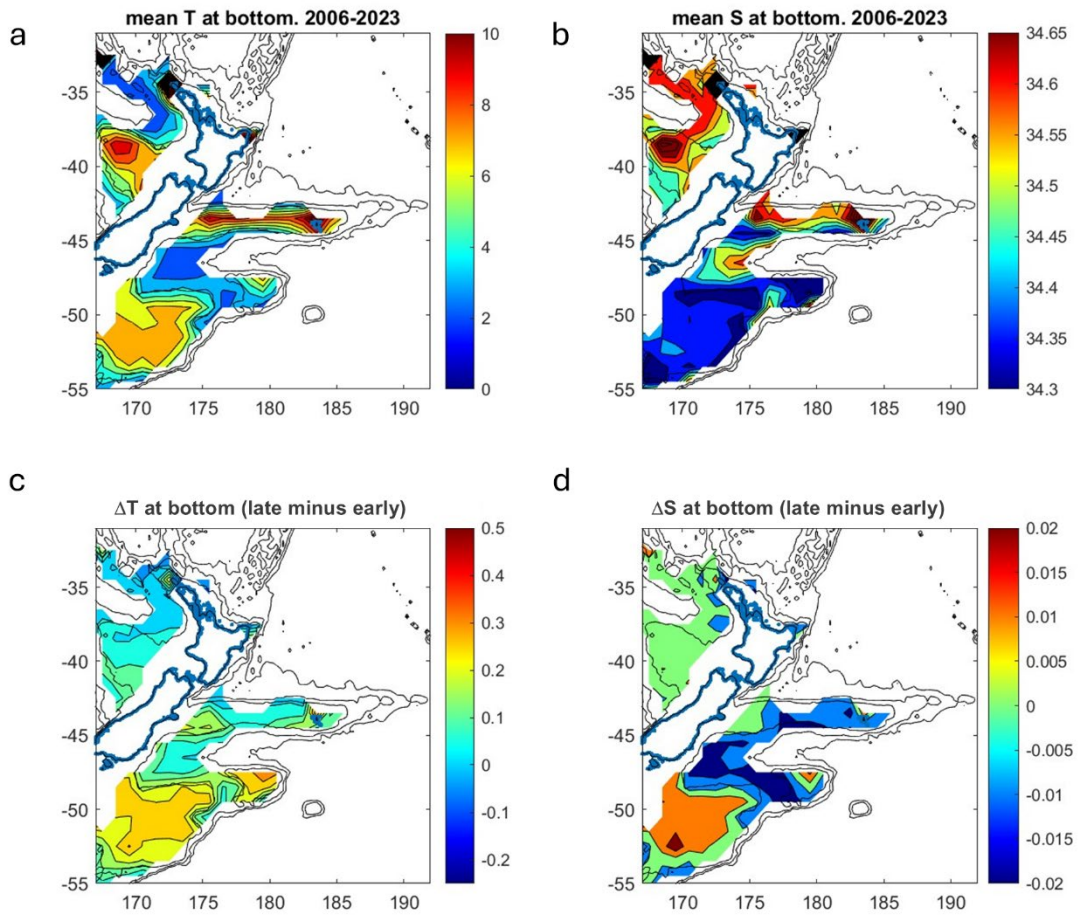
Appendix 1 Figure A.1. Shallow (250 m depth) temperature and salinity over the Chatham Rise based on objectively-mapped Argo (autonomous profiling float) data. a: Mean temperature (°C); b: Mean salinity (PSU); c: Temperature change (°C); d: Salinity change (PSU). See caption Figure 3 for more details.



Appendix 1 Figure A.2. Deep (1000 m depth) temperature and salinity over the Chatham Rise based on objectively-mapped Argo (autonomous profiling float) data. a: Mean temperature (°C); b: Mean salinity (PSU); c: Temperature change (°C); d: Salinity change (PSU). See caption Figure 3 for more details.



Appendix 1 Figure A.3. Abyssal (1975 m depth) temperature and salinity over the Chatham Rise based on objectively-mapped Argo (autonomous profiling float) data. a: Mean temperature (°C); b: Mean salinity (PSU); c: Temperature change (°C); d: Salinity change (PSU). See caption Figure 3 for more details.



Appendix 1 Figure A.4. Seabed (“bottom”) temperature and salinity over the Chatham Rise based on objectively-mapped Argo (autonomous profiling float) data. a: Mean temperature (°C); b: Mean salinity (PSU); c: Temperature change (°C); d: Salinity change (PSU). See caption Figure 3 for more details.