

Physical Oceanographic Conditions on the Scotian Shelf and in the Gulf of Maine during 2024

Chantelle Layton, David Brickman, Blair Greenan, Peter S. Galbraith,
and Jean-Luc Shaw

2025

Canadian Technical Report of
Hydrography and Ocean Sciences 403



Fisheries and Oceans
Canada

Pêches et Océans
Canada

Canada

Canadian Technical Report of Hydrography and Ocean Sciences

Technical reports contain scientific and technical information of a type that represents a contribution to existing knowledge but which is not normally found in the primary literature. The subject matter is generally related to programs and interests of the Oceans and Science sectors of Fisheries and Oceans Canada.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in the data base *Aquatic Sciences and Fisheries Abstracts*.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page.

Regional and headquarters establishments of Ocean Science and Surveys ceased publication of their various report series as of December 1981. A complete listing of these publications and the last number issued under each title are published in the *Canadian Journal of Fisheries and Aquatic Sciences*, Volume 38: Index to Publications 1981. The current series began with Report Number 1 in January 1982.

Rapport technique canadien sur l'hydrographie et les sciences océaniques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles mais que l'on ne trouve pas normalement dans les revues scientifiques. Le sujet est généralement rattaché aux programmes et intérêts des secteurs des Océans et des Sciences de Pêches et Océans Canada.

Les rapports techniques peuvent être cités comme des publications à part entière. Le titre exact figure au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la base de données *Résumés des sciences aquatiques et halieutiques*.

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page de titre.

Les établissements de l'ancien secteur des Sciences et Levés océaniques dans les régions et à l'administration centrale ont cessé de publier leurs diverses séries de rapports en décembre 1981. Vous trouverez dans l'index des publications du volume 38 du *Journal canadien des sciences halieutiques et aquatiques*, la liste de ces publications ainsi que le dernier numéro paru dans chaque catégorie. La nouvelle série a commencé avec la publication du rapport numéro 1 en janvier 1982.

Canadian Technical Report of
Hydrography and Ocean Sciences 403

2025

PHYSICAL OCEANOGRAPHIC CONDITIONS ON THE SCOTIAN SHELF AND IN THE GULF
OF MAINE DURING 2024

by

Chantelle Layton¹, David Brickman¹, Blair Greenan¹, Peter S. Galbraith² and Jean-Luc Shaw²

¹Fisheries and Oceans Canada
Bedford Institute of Oceanography
P.O. Box 1006, 1 Challenger Drive
Dartmouth, Nova Scotia, B2Y 4A2

²Fisheries and Oceans Canada
Maurice Lamontagne Institute
P.O. Box 1000
Mont-Joli, Québec, G5H 3Z4

© His Majesty the King in Right of Canada, as represented by the Minister of the
Department of Fisheries and Oceans, 2025
Cat. No. Fs97-18/403E-PDF ISBN 978-0-660-78249-2 ISSN 1488-5417
<https://doi.org/10.60825/x7wv-tf78>

Correct citation for this publication:

Layton, C., Brickman, D., Greenan, B., Galbraith, P.S., and Shaw, J.-L. 2025. Physical
Oceanographic Conditions on the Scotian Shelf and in the Gulf of Maine during 2024. Can.
Tech. Rep. Hydrogr. Ocean Sci. 403: vi + 82 p. <https://doi.org/10.60825/x7wv-tf78>

CONTENTS

ABSTRACT	v
RÉSUMÉ	vi
1 INTRODUCTION	1
2 METEOROLOGICAL OBSERVATIONS	1
2.1 NORTH ATLANTIC OSCILLATION INDEX	1
2.2 AIR TEMPERATURES	2
3 REMOTELY-SENSED SEA SURFACE TEMPERATURE (SST)	3
4 COASTAL TEMPERATURES AND SALINITIES	3
5 STANDARD SECTIONS	5
6 GLIDER OPERATIONS ON THE HALIFAX LINE	6
7 SCOTIAN SHELF AND GULF OF MAINE TEMPERATURES	7
8 TEMPERATURES DURING THE ECOSYSTEM TRAWL SURVEYS	8
8.1 WINTER SURVEY	8
8.2 SUMMER SURVEY	9
9 DENSITY STRATIFICATION	9
10 SEA LEVEL	10
11 RESULTS FROM A NUMERICAL SIMULATION MODEL	11
11.1 VARIATION IN TRANSPORTS IN THE SCOTIAN SHELF/GULF OF MAINE REGION	11
12 MARINE HEAT WAVES	12

13 SUMMARY	13
14 ACKNOWLEDGEMENTS	14
REFERENCES	16
15 TABLES	18
16 FIGURES	19
APPENDICES	69
A ANCILLARY SECTIONS	70

ABSTRACT

Layton, C., Brickman, D., Greenan, B., Galbraith, P.S., and Shaw, J.-L. 2025. Physical Oceanographic Conditions on the Scotian Shelf and in the Gulf of Maine during 2024. Can. Tech. Rep. Hydrogr. Ocean Sci. 403: vi + 82 p. <https://doi.org/10.60825/x7wv-tf78>

The physical oceanographic conditions on the Scotian Shelf and in the Gulf of Maine observed in 2024 are presented. Mean annual air temperature anomalies relative to 1991–2020 climatology, at six sites were positive. Satellite-based Sea Surface Temperature (SST) annual anomalies were also positive for all seven subregions based on NAFO areas. Long-term coastal monitoring at Halifax (Nova Scotia) recorded the tenth highest value annual SST and at St. Andrews (New Brunswick) the fourth highest value. At selected sites across the region, three of the six annual bottom water temperatures were above normal, two normal, and one below normal. Four of the regions were cooler than the previous year. A composite index, consisting of 22 ocean temperature time series from surface to bottom across the region indicated that 2024 was primarily above normal with 9 of the time series greater than one standard deviation.

RÉSUMÉ

Layton, C., Brickman, D., Greenan, B., Galbraith, P.S., and Shaw, J.-L. 2025. Physical Oceanographic Conditions on the Scotian Shelf and in the Gulf of Maine during 2024. Can. Tech. Rep. Hydrogr. Ocean Sci. 403: vi + 82 p. <https://doi.org/10.60825/x7wv-tf78>

Les conditions océanographiques physiques observées sur le plateau néo-écossais et dans le golfe du Maine en 2024 sont présentées. Par rapport à la climatologie de 1991-2020, les anomalies de la température de l'air annuelle moyenne ont été positives à six sites. Les anomalies annuelles de la température de surface de la mer (TSM) mesurée par satellite étaient également positives dans les sept sous zones de l'OPANO dans la région. La surveillance côtière à long terme a enregistré la dixième TSM annuelle la plus élevée à Halifax (Nouvelle Écosse) et la quatrième TSM annuelle la plus élevée à St. Andrews (Nouveau Brunswick). Dans des sites sélectionnés de la région, trois des six températures annuelles des eaux de fond étaient supérieures à la normale, deux normales et une inférieure à la normale. Quatre des régions ont été plus froides que l'année précédente. Un indice composite, composé de 22 séries chronologiques de températures océaniques de la surface au fond dans la région, montre qu'en 2024 ces températures ont été principalement supérieures à la normale, de plus d'un écart-type dans le cas de neuf des séries chronologiques.

1 INTRODUCTION

This document discusses meteorological and physical oceanographic trends and variability during 2024 on the Scotian Shelf, Bay of Fundy, and the Gulf of Maine (Figure 1), from observations and model results. It complements similar reviews of the conditions in the Gulf of St. Lawrence and the Newfoundland-Labrador regions for the Atlantic Zone Monitoring Program (AZMP) (Cyr et al. 2024; Galbraith et al. 2025), which together serve as a basis for a zonal summary (Galbraith et al. 2024). Environmental conditions are compared using the long-term monthly and annual means. These comparisons are often expressed as anomalies, which are the deviations from the long-term means, or as normalized anomalies; that is, the anomaly divided by the Standard Deviation (SD). If the data permit, the long-term means and SDs are calculated for the 30-year base period of 1991–2020. The use of normalized anomalies and the same base period allow direct comparison among sites variables.

Temperature and salinity conditions on the Scotian Shelf, in the Bay of Fundy and Gulf of Maine regions, are determined by many processes: heat transfer between the ocean and atmosphere; inflow from the Gulf of St. Lawrence supplemented by flow from the Newfoundland Shelf; exchange with offshore slope waters; local mixing; freshwater runoff; direct precipitation; and melting of sea-ice. The Nova Scotia Current (NSC) is the dominant inflow, originating in the Gulf of St. Lawrence and entering the region through Cabot Strait (Figure 1). This current, whose path is strongly affected by topography, has a general southwestward drift over the Scotian Shelf and continues into the Gulf of Maine where it contributes to the counter-clockwise mean circulation. Mixing with offshore waters from the continental slope also modifies the water-mass properties of shelf waters. These offshore waters are generally of two types: Warm Slope Water, with temperatures in the range of 8–12°C and salinities from 34.7–35.5; and Labrador Slope Water, with temperatures from 4–8°C and salinities from 34.3–35 (Gatien 1976). Shelf-water properties have large seasonal cycles, along- and across-shelf gradients, and vary with depth (Petrie et al. 1996).

2 METEOROLOGICAL OBSERVATIONS

2.1 NORTH ATLANTIC OSCILLATION INDEX

The North Atlantic Oscillation (NAO) index was originally defined as the difference in sea-level atmospheric pressures between the Azores and Iceland (Rogers 1984), and is a measure of the strength of the westerly winds over the Northwest Atlantic. It represents the dominant, large-scale meteorological forcing over the North Atlantic Ocean. The NAO index is based on a Rotated Principal Component Analysis (Barnston and Livezey 1987) applied to the monthly-standardized 500 mb height anomalies (Hurrell et al. 2003), averaged over winter months of December through March. The anomalies are based on the 1991–2020 climatology mean and standard deviation. Monthly data was obtained from the [National Oceanic and Atmospheric Administration](#) (NOAA).

A high NAO index corresponds to an increased pressure difference between the Icelandic Low and the Azores High. Strong northwest winds, cold air and sea temperatures, and heavy ice in

the Labrador Sea and on the NL shelf areas, are usually associated with a high positive NAO index (Colbourne et al. 1994; Drinkwater 1996). The opposite response typically occurs during years with a negative NAO index.

The NAO has been shown to strongly affect bottom temperature distributions throughout the region from the Labrador Shelf to the Gulf of Maine (Petrie 2007). The response is bimodal, the product of direct and advective effects, with positive (negative) NAO generally corresponding to colder (warmer) than normal bottom temperatures over the Labrador-Newfoundland Shelf, the Gulf of St. Lawrence, and the Eastern Scotian Shelf, and warmer (colder) than normal conditions on the Central and Western Scotian Shelf and in the Gulf of Maine.

In 2024, the winter (December–March) NAO index was above the 1991 – 2020 mean, +0.76 (+1.13 SD) (Figure 2A). The lower panels of Figure 2 show the sea-level atmospheric pressure conditions during the winter of 2024 compared to the 1991 – 2020 mean. The 2024 Icelandic low pressure cell was located similarly when compared to the seasonal mean. Meanwhile, the 2024 Azores high pressure cell was more east compared to the seasonal mean.

2.2 AIR TEMPERATURES

Surface air temperature anomalies maps relative to the 1991–2020 means for the North Atlantic region are available from the U.S. National Oceanic and Atmospheric Administration’s [interactive website](#). In 2024, the annual anomalies were normal to above normal over the Scotian Shelf and the Gulf of Maine (Figure 3). The seasonal anomaly of these regions was above normal during the winter and ranged from normal to above normal for spring, summer and fall (Figure 4).

Monthly air temperature anomalies for 2023 and 2024 relative to their 1991–2020 means at six sites in the Scotian Shelf/Gulf of Maine region are shown in Figure 5. Monthly mean-temperature data for Canadian sites are from Environment and Climate Change Canada’s [Adjusted Homogenized Canadian Climate Data \(AHCCD\)](#) where available (Vincent et al. 2020). In cases where no data were available, observed monthly mean values from the Canadian Climate Summaries (CCS) at the [Environment and Climate Change Canada website](#) were used. Monthly means from the [Monthly Climatic Data for the World](#) (Menne et al. 2018) were used for Boston. Monthly air temperatures were normal to above normal at all six sites throughout the year, with the exception of one month at Sydney.

In 2024, the mean annual air temperature anomalies relative to 1991–2020 climatology were positive for all sites, with anomalies ranging from +0.6°C (+1.0 SD) for Sable Island to +1.2°C (+1.6 SD) for Boston (Table 1). The time series of annual anomalies indicates that all sites have increasing temperatures over the long-term with decadal-scale variability superimposed (Figure 6). Over decadal and shorter periods, there are times when there is no trend or a decreasing trend in the temperature. Linear trends from 1900 to present for Sydney, Sable Island, Halifax, Yarmouth, Saint John, and Boston correspond to changes (and 95% confidence limits) per century of +1.3°C (+1.0°C, +1.7°C), +1.4°C (+1.1°C, +1.7°C), +2.1°C (+1.7°C, +2.4°C), +1.3°C (+1.0°C, +1.6°C), +1.4°C (+1.0°C, +1.7°C), and +2.7°C (+2.4°C, +3.1°C), respectively (Figure 6).

The air temperature anomalies for the six Scotian Shelf and Gulf of Maine sites are summarized

in Figure 7 as a composite sum that illustrates two points. Firstly, for most years the anomalies have the same sign; that is, the stacked bars coincide. Since 1900, for the 113 years when all sites were operating, 97 had five or more stations with the annual anomalies having the same signs; for 89 years, all six stations had anomalies with the same sign. This indicates that the spatial scale of the air temperature patterns is greater than the largest spacing between sites. Previous analyses yielded an e-folding decorrelation scale of 1800 km (Petrie et al. 2009).

3 REMOTELY-SENSED SEA SURFACE TEMPERATURE (SST)

The satellite-based sea surface temperature product is derived from a blend of Pathfinder version 5.3 (4 km resolution for 1982 to 1985 and sparsely to 2020; Casey et al. (2010)), Maurice Lamontagne Institute (MLI; 1.1 km resolution for 1985 to 2013; Larouche and Galbraith (2016)) with the NOAA STAR CoastWatch Advanced Clear-Sky Processor for Ocean (ACSPO) L3S-LEO-Daily “super-collated” v2.81 product (0.02 degree resolution for 2000 to current; Jonasson et al. (2022)). Details of the regional calibration are found in Galbraith et al. (2025). Because the SST blend is different than in previous reports, certain previously reported records have changed although the geospatial patterns remain similar.

Monthly and annual temperature anomalies relative to the 1991–2020 climatology are calculated for seven subareas based on the NAFO divisions in the Scotian Shelf/Gulf of Maine region (Figure 8). In 2024, monthly sea surface temperatures (SST) were normal to above normal throughout the year, with the exception of December in 4W, 4X Scotian Shelf (SS), 4X eastern Gulf of Maine and Bay of Fundy (eGoM+BoF), and 5Ze. (Figure 9). Annual anomalies were calculated from monthly-averaged temperatures for the seven subareas (Table 2 and Figure 10). The annual anomalies during 2024 ranged from +0.1°C (+0.1 SD) in 5Ze to +1.4°C (+2.7 SD) in 4Vn. SST remained above normal at all NAFO divisions with the exception of 5Ze. The last four years were consistently above normal for both 4Vn and 4Vs. NAFO divisions 4W, 4X Scotian Shelf, 4X eastern Gulf of Maine and Bay of Fundy, and 5Y remained above normal, but were cooler than the previous three years. Division 5Ze continued on a cooling trend and was normal. A regime shift algorithm to detect a step change using mean levels was applied to the annual time-series (Rodionov 2004). Over the length of the record, the temperature has three distinct periods in all regions, a relatively cooler period from 1982 to 1993, near the climatological mean from 1994 to 2011, and a relatively warmer period from 2012 to present. However, since 2021, for regions 4Vn and 4Vs, it suggests that these regions are in an even warmer period.

4 COASTAL TEMPERATURES AND SALINITIES

Coastal near-surface temperatures have been collected at Halifax (Nova Scotia) and St. Andrews (New Brunswick) since the 1920s (Figure 11). In 2024, the SST anomalies relative to the 1991 – 2020 mean for Halifax was +0.8°C (+1.3 SD), a decrease of -0.7°C from 2023. St. Andrews was +1.1°C (+1.6 SD)(2022 was the record high), a decrease of -0.1°C from 2023.

Temperature and salinity measurements through the water column have been sampled monthly for the most part since 1924 at Prince 5, at the entrance to the Bay of Fundy (Figure 1). It is

the longest continuously operating hydrographic monitoring site in eastern Canada. Its waters are generally well-mixed from the surface to the bottom (90 m), except in the spring. Crew and vessel availability issues in January and April, respectively, and inclement weather in November affected the sampling of the station during 2024.

The 2024 annual cycle at Prince 5 shows primarily above normal temperature throughout the year with the exception of December which was normal (Figure 12). Monthly series high records occurred through most of the water column for the month of March. The average upper ocean temperatures, those averaged in the top 50m, were above normal with the exception of December which was normal. Bottom (90m) temperatures varied throughout the year. From February to June, conditions were above normal, July and August were normal, and continued to cool with below normal temperatures for September. Above normal temperatures returned for October and were normal for December. Salinity was below normal during March, and then ranged from slightly below normal to slightly above normal. Near surface salinity ranged from below normal to normal for most of the year with the exception of December which was above normal. Bottom salinity conditions ranged from below normal to normal throughout the year with a series record low in March. Density was primarily below normal to normal, with the exception of December which was normal to slightly above normal throughout the water column. Mean surface density conditions were below normal to normal with the exception of December which was above normal. Bottom density conditions were below normal to normal with the exception of above normal conditions in September. Series record lows occurred in March and June. The freshet in the spring was not observed because there was no vessel available to carry out the sampling.

Annual near surface temperatures at Prince 5 were $+0.70^{\circ}\text{C}$ ($+1.10$ SD) (2021 was the record high) (Figure 13). While it remained above normal, temperatures have continued to decrease from the series record high in 2021. Bottom temperature was $+0.40^{\circ}\text{C}$ ($+0.40$ SD) (2012 was the record high). Similar to near surface temperature, bottom conditions continue to cool from the second warmest year in 2021. Near surface salinity was -0.10 (-0.40 SD) and stratification was $-0.00\text{kg}/\text{m}^3$ (-0.30 SD).

As an indication of the upper ocean conditions, two variables, stratification index and mixed-layer depth, are examined for annual variability. The stratification index (SI) is the density difference between 50 m and 5 m. The mixed-layer depth (MLD) is the depth at which the density at 5m is exceeded by $0.03 \text{ kg}/\text{m}^3$.

In 2024, the SI at Prince 5 was above normal for March, July, and September, below normal for June and October, and normal for the remainder of the year (Figure 14). The MLD was thicker than normal for June, normal for May and October, and shallower than normal for the remainder of the year.

The 2024 annual temperature, salinity, and density cycles at Halifax 2, located at the mouth of Halifax harbour (Figure 1), are shown in Figure 15. Near surface temperatures, in the top 40m, was normal in January, then above normal in February. As the year progressed, above normal conditions increased with depth down to 100m in July, then, in August conditions ranged from below normal to normal. Conditions throughout the remainder of the year ranged from below normal to normal throughout the water column. The mean temperature in the top 50m was above normal from March to July, and then below normal to normal for the remainder of the year, excluding October which was above normal. The bottom temperature was primarily

below normal with monthly series record lows for February and November. Salinity throughout the year was primarily below normal to normal. Series record lows occurred in January from 10 to 50m and in August from 75 to 100m, and near bottom in October. Series record highs occurred near the surface in September. Mean surface salinity conditions ranged from below normal to normal with the exception of July and September (series record high). Bottom salinity ranged from below normal to normal. Density was primarily below normal to normal with series record lows in January from 5 to 45m, similar to salinity, mid-depth in May, and 70 to 120m in August, and one isolated record at 10m in July. There were two isolated record density highs. One at 70m in January and 20m in September. Mean surface density was below normal to normal with the exception of August and September. A record low occurred in January. Bottom density ranged from below normal to normal.

Annual near surface temperatures at Halifax 2 were $+0.70^{\circ}\text{C}$ ($+0.90$ SD) (2012 was the record high) (Figure 16). Bottom temperature was -1.50°C (-1.50 SD). This is the first year since 2011 that temperatures were below normal. Near surface salinity was -0.10 (-0.40 SD) (2000 was the record high) and stratification was $+0.20\text{kg/m}^3$ ($+1.50$ SD) (2023 was the record high). The SI was normal to above normal from January to July, and then below normal to normal for the remainder of the year. The MLD was above normal, or thicker, for June, July, November, and December and was normal to below normal, or shallower, for the remainder of the year (Figure 17).

5 STANDARD SECTIONS

The Maritimes region AZMP core lines, Cabot Strait, Louisbourg, Halifax, and Browns Bank were sampled in the spring of 2024 (Figure 18). In addition, the following ancillary lines were occupied: the Laurentian Channel Mouth to support modelling efforts and monitor water masses entering the Gulf of St. Lawrence, the Gully line to continue monitoring the Marine Protected Area, and in the Gulf of Maine, the Northeast Channel, Yarmouth, and Portsmouth lines as part of the collaborative agreement with Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOOS).

During the spring of 2024, the Cabot Strait had above normal temperatures and more fresh, thus less dense, waters in the top 50 to 75m across the entire strait (Figure 19). Throughout the remainder of the water column, conditions were normal. For the Louisbourg line, temperatures on the shelf in the top 50 to 75m were above normal with salinity and density being normal to below normal (Figure 20). Throughout the remainder of the water column, conditions were near normal. Off the shelf, temperature was primarily below normal throughout the entire water column with salinity being primarily below normal in the top 150m and normal for the remainder of the depicted water column. Density was near normal off the shelf. For the Halifax line, temperatures in the top 50m in the first 50km of the line were above normal (Figure 21). Temperature and salinity between 50 and 100m were below normal between 100 and 150km from the beginning of the line. Remaining conditions on the shelf were near normal. Off the shelf, conditions were normal to below normal throughout the water column. Most notably, temperatures from 50 to 100m were 4 to 6°C below normal, with coinciding salinity being 1 to 1.5 below normal which is likely due to a higher proportion of Labrador Sea water. On Browns Bank, temperatures in the top 25m from the beginning of the line to 100km were above normal (Figure 22). Conditions

throughout the remainder of the water column on the shelf and off the shelf were normal to below normal. A decrease in salinity between 0-50m at the shelf break coincides with an area of below normal density.

The Maritimes region AZMP core lines, Cabot Strait, Louisbourg, Halifax, and Browns Bank were sampled in fall 2024 (Figure 23). In addition, the St. Anns Bank and The Gully lines were occupied to continue Marine Protected Areas monitoring efforts. In the Gulf of Maine, the Northeast Channel, Yarmouth, and Portsmouth lines were occupied as part of the collaborative agreement with NERACOOS.

During the fall of 2024, the Cabot Strait has temperatures above normal and density below normal in the top 75m from the western side to the centre of the strait (Figure 24). Near-surface temperatures on the eastern side of the strait are below normal. On the western side of the strait between 100 and 200m, temperature and salinity are below normal. For the remainder of the water column across the strait, conditions are near normal. For the Louisbourg line, near surface temperatures on the shelf were below normal (Figure 25). Conditions on the remainder of the shelf were near normal. Off the shelf, temperatures were generally normal to below normal. Near surface salinity and density were above normal, and then near normal for the remainder of the depicted water column. For the Halifax line, temperatures in the top 50m across the entire transect were mostly above normal (Figure 26). On the shelf, conditions for the remainder of the water column are normal to below normal. Off the shelf, temperatures between 25 and 100m were up to 6°C above normal, and salinity was 0.5 to 1.0 above normal. Conditions in the remainder of the water column were near normal. Evidence of a coastal upwelling event was observed inshore of HL2 with colder, saltier water from mid-depth shallowing by several tens of metres. For the Browns Bank line, near surface temperatures from the beginning of the line to 100km were above normal, and consequently density was below normal (Figure 27). For the remainder of the water column and across the entire line, temperatures were below normal. In the top 100m across the entire line, salinity was below normal and deeper waters off the shelf were near normal.

The Appendix contains lines in the Maritimes region conducted by Maurice Lamontagne Institute for Cabot Strait in winter (Figure A.1) and summer (Figure A.2). For both spring and fall Maritimes AZMP missions, additional lines were sampled. This includes lines St. Anns Bank during the fall (Figure A.3), Laurentian Channel Mouth in the spring (Figure A.4), The Gully in the spring (Figure A.5) and in the fall (Figure A.6), Northeast Channel in the spring (Figure A.7) and fall (Figure A.8), Yarmouth in the spring (Figure A.9) and fall (Figure A.10), and Portsmouth in the spring (Figure A.11) and fall (Figure A.12). During the Atlantic Zone Off-Shelf Monitoring Program (AZOMP) occupied the extended Halifax line (Figure A.13). If there exists a sufficient number of historical occupations of the sections at the same time of year, anomaly sections are also shown. While these data are not discussed in detail, the data are used in other analyses presented in this document.

6 GLIDER OPERATIONS ON THE HALIFAX LINE

In 2018, glider operations were started along the Halifax Line as an enhancement to the normally tri-annual sections. The glider data provides higher temporal and spatial coverage than the

vessel-based sampling, but only down to a maximum depth of 650m (Figure 28). For ease of analysis, the glider data are temporally averaged to hourly and vertically binned to 1-m. On regular missions, the glider attempts to follow the Halifax Line from approximately HL2 to HL7. Currents can, however, affect the actual trajectory of the glider (Figure 29). Thus, only glider data collected within 15 nm of the Halifax Line are considered, which explains some of the gaps in Figure 28. Battery upgrades were completed for the entire fleet in year 2022. This has allowed for more consistent coverage out to HL7 (Figure 28).

Station 2 (HL2) is sampled throughout the year from a small vessel and provides the highest temporal resolution of the Halifax Line stations (Figure 30). Glider data do not significantly add information at Station 2 except when vessel sampling is not available. In addition, the variability in temperature, salinity, and chlorophyll fluorescence is shown for a few of the Halifax Line stations over the 2023 – 2024 period (Figure 31). This is only a small fraction of the data available for analysis. At HL3, HL4, HL5 and HL6, the glider sampling was sufficient to resolve the seasonal cycle of temperature, salinity, and chlorophyll (Figure 31).

7 SCOTIAN SHELF AND GULF OF MAINE TEMPERATURES

Drinkwater and Trites (1987) tabulated monthly mean temperatures and salinities from available bottle data for 35 areas on the Scotian Shelf and in the eastern Gulf of Maine that generally corresponded to topographic features such as banks and basins. Petrie et al. (1996) updated their report using these same areas and all available hydrographic data. A time series of annual mean and filtered (five-year running means) temperature anomalies at selected depths for six areas (Figure 32) is presented (Figure 33). The Cabot Strait temperatures represent a mix of Labrador Current Water and Warm Slope Water entering the Gulf of St. Lawrence along the Laurentian Channel (e.g. Gilbert et al. 2005); the Misaine Bank series characterizes the colder near-bottom temperatures on the Eastern Scotian Shelf, mainly influenced by either inshore Labrador Current water or cold intermediate layer water from the Gulf of St. Lawrence (Dever et al. 2016); the deep Emerald Basin temperature anomalies represent the warmer slope-water intrusions onto the Shelf that are subsequently trapped in the inner deep basins (note the large anomaly “events” in the Emerald Basin panel of Figure 33C, for example, around 1980, 1998, and 2009, indicative of pulses of Labrador Slope Water); the Lurcher Shoals observations define the ocean climate in the southwest Scotian Shelf and the shallow waters entering the Gulf of Maine via the Nova Scotia Current; lastly, the Georges Basin series represents the slope waters entering the Gulf of Maine through the Northeast Channel. Annual anomalies are based on the averages of monthly anomalies; however, observations may not be available for all months in each area. For Cabot Strait, Misaine Bank, Emerald Basin, Lurcher Shoal, Georges Basin, and E Georges Bank, the 2024 annual anomalies are based on observations from three, four, three, two, five, and five months, respectively.

In 2024, the annual anomaly was $+0.6^{\circ}\text{C}$ ($+1.0$ SD) for Cabot Strait at 200-300 m (2022 was the record high; 2023 anomaly was 1.4°C). For the shallow Misaine Bank on the eastern Scotian Shelf, the annual anomaly was $+0.3^{\circ}\text{C}$ ($+0.5$ SD) at 100 m (2022 was the record high; 2023 anomaly was 0.3°C). For the deep basins on the central Scotian Shelf and Gulf of Maine, the 2024 anomalies were -0.3°C (-0.4 SD) for Emerald Basin at 250 m (2019 was the record high; 2023 anomaly was 1.3°C) and -0.3°C (-0.5 SD) for Georges Basin at 200 m (2018 was the

record high; 2023 anomaly was 0.2°C) . For the shallow banks in western Nova Scotia, the anomalies were +0.0°C (+0.0 SD) for Eastern Georges Bank at 50 m (2023 anomaly was 0.2°C) and +0.9°C (+1.0 SD) for Lurcher Shoals at 50 m (2012 was the record high; 2023 anomaly was 0.7°C). Over the length of the timeseries, temperature patterns at all areas are in general agreement. For the two relatively near-shore and shallow areas, Misaine Bank and Lurcher Shoal, from approximately the mid to late 1960s to the mid 1980s, temperatures were above and near the climatological mean, respectively, from the mid 1980s to 2010 temperatures were below normal, and from 2011 to present have been above normal. For the deeper and off-shore areas, Cabot Strait, Emerald Basin, Georges Basin, and Eastern Georges Bank, temperatures were relatively below normal from 1970 to 2010, and have been above normal since 2011. Until 2023, the transport of the colder shelf break current of Labrador origin has been negative (Galbraith et al. 2024). On the Scotian Shelf, near-bottom temperatures have decreased from the warm anomalies in the previous years.

8 TEMPERATURES DURING THE ECOSYSTEM TRAWL SURVEYS

In the Maritimes Region, Fisheries and Oceans Canada (DFO), conducts two trawl surveys each year. During winter, the survey covers Georges Bank, the Bay of Fundy, and the western Scotian Shelf. The deep-water boundary of the survey is marked roughly by the 200 m isobath. The broadest spatial temperature and salinity coverage of the Scotian Shelf is obtained during the summer trawl survey, which covers the Scotian Shelf from Cabot Strait to the Bay of Fundy. The deep-water boundary of this survey is also marked roughly by the 200 m isobath along the shelf break.

The temperatures from each survey were interpolated onto a 0.2°-by-0.2° latitude-longitude grid using an objective analysis procedure known as Barnes interpolation (Koch et al. 1983). The Barnes method requires four input parameters, the x and y radii of the weighted ellipse, defined as xr and yr , where x and y are relative to east and north respectively, the grid focussing parameter γ , and the number of iterations. For the winter survey, $xr = 0.71$, $yr = 0.52$, $\gamma = 0.47$, and 3 iterations was used. For the summer survey, $xr = 0.81$, $yr = 0.58$, $\gamma = 0.53$, and 3 iterations was used. Temperatures were optimally estimated at the standard depths (e.g., 0 m, 10 m, 20 m, etc.) and for near the bottom. Only the near-bottom temperatures are presented here.

8.1 WINTER SURVEY

The winter survey took place from 02 March to 02 April 2024. A total of 108 Conductivity-Temperature-Depth (CTD) stations were sampled (Figure 34). Sampling was mainly on Georges Bank (NAFO Division 5Ze) and Georges Basin (along the boundary between NAFO Division 5Ze and 4X), with additional sampling in the Bay of Fundy (NAFO Division 4X). Additional data from the NOAA National Marine Fisheries Service (NMFS) Northeast Fisheries Center (NEFSC) was used to increase coverage on the western portion of the grid. A total of 279 CTD stations were used, which were sampled between 01 February to 30 April 2024. Bottom temperatures within the Fundian Channel and along the shelf break were below normal, with the remainder of the

Gulf of Maine and Bay of Fundy being normal to above normal (Figure 35).

8.2 SUMMER SURVEY

The summer survey took place from 25 June to 06 August 2024. A total of 239 Conductivity-Temperature-Depth (CTD) stations were sampled (Figure 36). The survey covered part of Cabot Strait, the entirety of the Scotian Shelf (NAFO Divisions 4Vn, 4Vs, 4W, and 4X) to the mouth of the Bay of Fundy (northwest portion of NAFO Division 4X), and part of Eastern Georges Bank (NAFO Division 5Ze). The near-bottom temperature anomalies for 2024 were variable in NAFO Divisions 4Vn and 4Vs, the entirety of 4W was mostly below normal, and the near coastal portion of the western Scotian Shelf 4X region was normal to above normal with the remainder of the 4X region ranging from normal to below normal (Figure 37). The anomaly varied for the NAFO Divisions sampled on the Scotian Shelf in 2024 : $+0.6^{\circ}\text{C}$ ($+0.7$ SD) for 4Vn (2020 was the record high), $+0.0^{\circ}\text{C}$ ($+0.0$ SD) for 4Vs (2015 was the record high), -1.0°C (-1.0 SD) for 4W (2022 was the record high) and -0.5°C (-0.5 SD) for 4X (2012 was the record high) (Figure 38). All regions show elevated bottom temperatures from approximately year 2010 to 2022. In 2023, with the exception of 4Vn which remained above normal, all regions went from above normal to normal. This trend continued in year 2024, with conditions remaining similar for 4Vn and 4X eastern Gulf of Maine and Bay of Fundy and temperatures continuing to decrease for 4W, 4X, and 4X Scotian Shelf. At 4W, it was below normal for the first time since 2008, and was -3.51°C from the series record in 2022.

The volume of the Cold Intermediate Layer (CIL), defined as waters with temperatures less than 4°C , was estimated from Barnes interpolated data using the full depth CTD profiles for the region, from Cabot Strait to Cape Sable (Figure 39). For years where grid coverage is less than 70%, a blended CIL volume is used. It uses the measured CIL for the region where data was collected. Where data wasn't collected, the CIL is calculated from the climatology that is adjusted using the mean minimum temperature (for additional details see Hebert et al. (2023)). There is considerable variation in the volume of the CIL from 1998 until 2009 (Figure 39). In 2024, the CIL volume was near normal (Figure 39). The low-frequency variability of the area-weighted average minimum temperature mirrors the CIL volume. In 2024, the minimum temperature was above normal, and has been for the previous 3 years.

9 DENSITY STRATIFICATION

Stratification of the near-surface layer influences physical, chemical and biological processes in the ocean such as the extent of vertical mixing, the ocean's response to wind forcing, the timing of the spring bloom, vertical nutrient fluxes, and plankton distribution. Under increased stratification, there is a tendency for more primary production to be recycled within the upper mixed layer and hence less production in the deeper layers. The variability in stratification was examined by calculating the density ($\sigma\text{-t}$) difference between the near-surface and 50 m water depth. The density differences were based on monthly mean density profiles calculated for several hydrographic areas on the Scotian Shelf (see Figure 40) as defined by Petrie et al. (1996). The long-term, monthly mean density gradients for 1991 – 2020 were estimated;

these were subtracted from the individual monthly values to obtain monthly anomalies. Annual anomalies for each area were estimated by averaging all available monthly anomalies within a calendar year. These estimates could be biased if, in a particular year, most data were collected in months when stratification was weak, while in another year sampling was in months when stratification was strong. However, initial results using normalized monthly anomalies obtained by dividing the anomalies by their monthly SDs were qualitatively similar to the plots presented here. The Scotian Shelf-wide average annual anomalies and their five-year running means were then calculated for an area-weighted combination of subareas 4–23 on the Scotian Shelf. A stratification of $0.01 \text{ (kg m}^{-3}\text{)/m}$ represents a difference of 0.5 kg m^{-3} over 50 m.

The dominant feature is the period from about 1950 to 1990 with generally below-average stratification in contrast to the past 25 years that are characterized by above normal values (Figure 41). Since 1948, there has been an increase in the mean stratification on the Scotian Shelf, resulting in a change in the 0–50 m density difference of 0.78 kg m^{-3} over 100 years. It should be noted the change over time is not linear but could consist of two periods of constant stratification with a jump around 1990. This change in mean stratification is due mainly to a decrease in the surface density, composed equally of warming and freshening (Figure 42). Stratification in 2024 was lower than in 2023 due to the surface becoming cooler and fresher. Examining the 2024 stratification anomaly for areas 4-23 on the Scotian Shelf show that the above normal anomaly for the Scotian Shelf (Figure 41) is due to an area-average of normal to above normal values on the eastern Scotian Shelf and along the shelf break (Figure 40).

10 SEA LEVEL

Sea level is a primary variable in the Global Ocean Observing System. Relative sea level is measured with respect to a fixed reference point on land. Consequently, relative sea level consists of two major components: one due to changes in the global mean sea level and a second caused by sinking or rising of the land. In Atlantic Canada, Glacial Isostatic Adjustment (GIA) is causing the area roughly south (north) of the Chaleur Bay to sink (rise) in response to glacial retreat; this results in an apparent rise (fall) of sea level.

Relative sea level at Yarmouth (1966-2024) , Halifax ¹ (1920-2024) , and North Sydney (1970-2024) are plotted as monthly means and as a filtered series using a five-year running mean filter (Figure 43). The linear trend of the monthly mean data has a positive slope of +39.8 cm/century (Yarmouth), +34.6 cm/century (Halifax), and +43.0 cm/century (North Sydney). Barnett (1984) found a slightly higher sea-level rise for Halifax (36.7 cm/century) for the period 1897–1980. This is due to the decrease in sea-level rise after 1980. Relative sea level changes over two periods, 1981–2010 and 1991–2020, shows that sea level rise is increasing with time. An interesting feature of the data is the long-term variation that has occurred since the 1920s (Figure 44). The residual sea-level data for the common period 1970-2024 shows that the variability has a large spatial structure given the coherence between the three sites.

¹The historical station in Halifax failed in early-2014. The nearby tidal station at Bedford Institute of Oceanography in Dartmouth, Nova Scotia, was used for 2014. For the common operating period, there was no significant difference in the two tide gauges.

11 RESULTS FROM A NUMERICAL SIMULATION MODEL

Currents and transports are derived from the Bedford Institute of Oceanography North Atlantic Model (BNAM) ocean circulation model (Wang et al. 2018). The model has a spatial resolution of $1/12^\circ$ with 50 z-levels in the vertical (22 in the top 100 m), and partial cells in the bottom layer to adapt to the bathymetry. The model is prognostic, that is, it allows for evolving temperature and salinity fields. Atmospheric forcing is derived from NCEP/NCAR reanalysis forcing (Kalnay et al. 1996). The analyses in this report come from a version of the model that has been used to study various phenomena in the Atlantic monitoring zone (Brickman et al. 2016, 2018; Wang et al. 2016). This version has a simple representation of the major river systems in the Atlantic region and no tidal forcing. The simulation runs from 1990 to the present, with the latest year updated annually when the surface forcing is available. The model domain is shown in Figure 45.

Some calculations intended to help interpret data collected by the AZMP are presented. Results are presented in terms of standardized anomalies to facilitate comparison to other AZMP analyses. The reader is cautioned that the results outlined below are not measurements, and simulations and improvements in the model may lead to changes in them.

11.1 VARIATION IN TRANSPORTS IN THE SCOTIAN SHELF/GULF OF MAINE REGION

The general circulation on the shelf seas of the Maritimes Region of Canada can be characterized as a general northeast-to-southwest flow from the Strait of Belle Isle, through Cabot Strait, and along the Scotian Shelf toward the Gulf of Maine (Figure 46). Part of the water that flows out of the Gulf of St. Lawrence through the western side of Cabot Strait follows the Nova Scotia coastline as the Nova Scotia Current, which ultimately flows into the Gulf of Maine. Another part follows the shelf break and contributes to the Gulf of Maine inflow at the Northeast Channel. Variations in these currents may influence the distribution of various fish and invertebrate larvae from the southern Gulf of St. Lawrence westward to the Gulf of Maine. As well, the currents that stream past Cape Sable Island and through Northeast Channel bring on-shelf and off-shelf water properties into the Gulf of Maine, and the partitioning of the transports is potentially important to processes occurring in the Gulf of Maine.

Monthly mean transports for the 1990–2024 period were extracted from the model simulation for four Maritime sections: Cabot Strait (CS), Halifax (HFX), Cape Sable Island/Browns Bank (CSI) and Northeast Channel (NEC) (Figure 46). From these data, standardized anomaly plots (based on a 1991–2020 averaging period) were constructed to illustrate transport variability. The results for the near-shore regions at CS, HFX, and CSI, the shelf break at HFX, and the inflow at NEC are displayed in Figure 47. Here, nearshore is taken as the subsection between the coastline and 30 km, 80 km, and the 100 m isobath for CS, HFX, and CSI respectively. From the inflows through the CSI and NEC sections the Gulf of Maine (GoM), the inflow ratio $CSI/(CSI + NEC)$ was computed (see below). Note that for all sections except NEC, positive transport denotes a flow direction through CS towards the GoM. For NEC, positive transport denotes flow into the GoM.

Transport variability on the Scotian Shelf shows a fairly coherent pattern of annual anomalies for CS, HFX (near-shore and shelf-break), and CSI (Figure 48). On a monthly basis, on average, the

near-shore series (CS, HFX near-shore, and CSI) and the transport into the GoM at NEC exhibit a seasonal cycle with mid-to-late-year transport minima, while the shelf-break transport along the Halifax section shows no clear seasonality (Figure 47, although note interannual variability).

For a qualitative comparison with the numerical model transport estimates, the monthly transport of the Nova Scotia Current off Halifax was calculated using bottom-mounted Acoustic Doppler Current Profilers (ADCP). Work by Dever (2017) showed a high correlation ($r^2 = 0.87$) between the depth-integrated current and the total transport at the mooring location T2 located 12 km east of Station 2 (Figure 1 and Figure 46). Transport anomalies are based on the mean for each month using all data available for that month. Red anomalies denote an increase in transport toward the Gulf of Maine, while blue anomalies indicate decreased transport². The data indicate a period of negative anomalies (stronger south-westward flow) starting in mid-2010 and extending to mid-2011, followed by average or weaker flow that persists until summer 2016 (Figure 49). For the fall of 2016 and winter of 2017, the flow was above normal, followed by mostly normal transport until September 2018 where above normal transport was observed until the end of the year. Transport has been mostly normal from 2019 to the end of 2022, with the exception of a strong increase in transport in April 2022. For most of 2023, transport was above normal, and then followed by mostly normal conditions for 2024 with the exception of February and July which were below normal and June and August were above normal. These trends are overall well simulated by the model, although differences exist. Notably, the positive anomaly in April, 2022, is captured by the model (see HFX nearshore panel of Figure 47).

The fraction of transport into the Gulf of Maine through the Cable Sable Island section (GoM inflow ratio of Figure 50) exhibits a seasonal cycle with a minimum during the summer months. On average, the model predicts that about one half of the transport into the Gulf of Maine enters through the CSI section. Inter-annually (Figure 48) the GoM inflow ratio was near neutral from 1990–2007 (with only 2001 and 2004 above normal), mostly negative from 2008–2014, near-neutral from 2015–2019, strongly negative from 2020–2022, and near neutral in 2023 and 2024. From the model simulation, the general warming trend over the last decade, seen in many data series, is evident as increased transport into the GoM at NEC and a reduced GoM inflow ratio.

An overall annual composite transport index was computed (Figure 51) by summing the standardized anomalies (Figures 47 and 48) for five of the six transport variables (the inflow through NEC was omitted as this metric is not independent of the GoM inflow ratio). If one considers this summation as a measure of the on-shelf flow-through in the system from the southern Gulf of St. Lawrence to the Gulf of Maine, it is found that the model hindcasts generally negative anomalies from 1990–2000, with strong negative anomalies in 1990, 1993–94, and 1999–2000; generally weak positive anomalies from 2001–2007; alternating stronger negative and positive anomalies until 2015 followed by weak positive anomalies until 2021 with 2022 exhibiting strong negative anomalies flip-flopping to strong positive anomalies in 2023 and 2024.

12 MARINE HEAT WAVES

Marine heatwaves (MHWs) are prolonged, anomalously warm ocean events or, quantitatively, by temperatures exceeding the 90th percentile of temperatures for that day of year during at least

²These anomalies are based on a different averaging period than used for the model simulations.

5 consecutive days (Hobday et al. 2016; Oliver et al. 2021). The 90th percentile thresholds are calculated using the standard 1991–2020 climatology period of the daily averages over each subarea based on the satellite SST NAFO divisions (Figure 8) in the Scotian Shelf/Gulf of Maine region.

MHWs are commonly discussed in terms of intensity (I), i.e., the difference between temperature and the daily climatology. Single events are then summarized using four standard metrics: duration (D), average intensity (I_{mean}), maximum intensity (I_{max}), and integrated intensity (I_{cum}). These metrics were calculated over daily polygon averages time series using the [Python implementation](#) of Hobday et al. (2016) written by Eric Oliver. Following Hobday et al. (2018), MHWs with I_{max} values greater than 1, 2, 3, and 4 times the difference between the 90th percentile and the climatology are respectively referred to as moderate, strong, severe and extreme events. Sea surface temperature has higher variability in summer and lower variability in winter, which results in a seasonal bias: summer and winter moderate thresholds correspond to different intensity values. To facilitate comparison of events during different seasons, a normalized intensity index, denoted c , calculated for each day (using that day's 90th percentile threshold) and examined over all days of the year that meet MHW criteria. This normalized intensity is a continuous equivalent to the Hobday et al. (2018) category system. Event metrics for individual years are thus aggregated into annual metrics shown in Figure 52 (sum of durations, $\sum D$; annual maximum of the normalized intensity, \hat{c}_{max} ; annually integrated normalized intensity, $\sum c_{cum}$; and the MHW event count).

Although moderate MHW conditions were frequent, only one event reached the strong threshold ($c_{max} = 2.0$) in the 4Vn region from July 9th to September 8th (Figure 9 and Figure 52). The integrated intensity was highest in the 4Vn region, mostly due to a large number days (211) in moderate conditions (Figure 53). Overall, most metrics in most regions were below the values measured in recent years (2021–2023).

13 SUMMARY

In 2024, the North Atlantic Oscillation index was above normal (+0.76 , +1.13 SD). The analysis of satellite data indicates that sea-surface temperatures remained above normal at all NAFO divisions. The last four years were consistently above normal for both 4Vn and 4Vs. Divisions 4W, 4X SS, and 4X eGoM+BoF remained above normal, but were cooler than the previous three years.

In 2024, 9 of 22 temperature variables that were able to be measured were more than 1 SD above their normal values (Figure 54). Of these, 2 were more than 2 SD above normal. One of the series were record highs in 2024. One other series were the third highest. Composite indices of these temperature records, Figure 55, indicate that near surface temperatures remained above normal and was the fourth highest in the series. Mid-depth records were normal. Bottom composite anomalies were normal, the lowest since year 2005.

14 ACKNOWLEDGEMENTS

The authors would like to recognize, and extend their gratitude, to all those who are involved in acquisition of CTD data used in this report:

- Station 2 monitoring: Maddison Proudfoot, Kevin Pauley, multiple support science staff, and the crew of CCGS Sigma-t.
- Prince 5 monitoring: Fred Page, Jack Fife, multiple support science staff, and the officers and crew of CCGS Viola M. Davidson.
- Glider Halifax line monitoring: Clark Richards David Hebert, Melany Belzile (Program Coordinator), Chris Beck, Chantelle Layton, Laura Boehner, Matthew Lawson, and the crew of CCGS Sigma-t.
- Winter ecosystem survey: Ryan Martin and Jamie Emberley for facilitating hydrographic sampling during the survey, Maddison Proudfoot and Kevin Pauley for their technical expertise, multiple support science staff, and the officers and crew of CCGS Capt. Jacques Cartier.
- Spring AZMP survey: Lindsay Beazley (Chief Scientist), Adam Hartling, Shawn Roach, Katie Thistle, Chris Gordon, Chantelle Layton, and the officers and crew of CCGS Teleost.
- AZOMP survey : Marc Ringuette (Chief Scientist), Adam Hartling, Mike Vining, Jeffrey Jackson, Chris Gordon, and the officers and crew of CCGS Capt. Jacques Cartier.
- Summer ecosystem survey: Ryan Martin and Jamie Emberley for facilitating hydrographic sampling during the survey, Maddison Proudfoot for technical expertise, multiple support science staff, and the officers and crew of CCGS Capt. Jacques Cartier.
- Fall AZMP survey: Lindsay Beazley (Chief Scientist), Mike Vining, Katie Warman, Matthew Lawson, Patrick Upson, Benoit Casault, and the officers and crew of RRS Discovery.

The authors are also grateful for the following data, and the agency or people, who make it possible for it to be provided:

- NAO, sea-level atmospheric pressure, global surface air temperature : National Oceanic and Atmospheric Administration.
- Air temperature: Environment and Climate Change Canada, National Oceanic and Atmospheric Administration (Boston).
- Remotely-sensed sea surface temperature: Peter Galbraith.
- Halifax in-situ sea surface temperature: Katie Thistle and Shawn Roach.
- St. Andrews in-situ sea surface temperature: Fred Page and Jack Fife.
- Sea level: Canadian Hydrographic Survey.

- Nova scotia current mooring: Jay Barthelotte, Mike Vining, Christiane Theriault, Matthew Lawson, Katie Warman, Jennifer Field, the officers and crew of CCGS Captain Jacques Cartier, and the officers and crew of RRS Discovery.
- Numerical model transport results: Zeliang Wang

They also thank Joël Chassé (Gulf region) and Jonathan Coyne (Newfoundland and Labrador region) for reviewing and providing insightful comments which improved the document.

REFERENCES

- Barnett, T. 1984. [The estimation of “global” sea level change: A problem of uniqueness](#). Journal of Geophysical Research: Oceans 89(C5): 7980–7988. Wiley Online Library.
- Barnston, A.G., and Livezey, R.E. 1987. [Classification, seasonality and persistence of low-frequency atmospheric circulation patterns](#). Monthly weather review 115(6): 1083–1126. American Meteorological Society.
- Brickman, D., Hebert, D., and Wang, Z. 2018. [Mechanism for the recent ocean warming events on the Scotian shelf of eastern Canada](#). Continental Shelf Research 156: 11–22. Elsevier.
- Brickman, D., Wang, Z., and DeTracey, B. 2016. [Variability of current streams in Atlantic Canadian waters: A model study](#). Atmosphere-Ocean 54(3): 218–229. Taylor & Francis.
- Casey, K.S., Brandon, T.B., Cornillon, P., and Evans, R. 2010. The past, present, and future of the AVHRR Pathfinder SST program. Oceanography from space: Revisited: 273–287.
- Colbourne, E., Narayanan, S., and Prinsenber, S. 1994. [Climatic changes and environmental conditions in the Northwest Atlantic, 1970–1993](#).
- Cyr, F., Snook, S., Bishop, C., Galbraith, P.S., Chen, N., and Han, G. 2024. [Physical Oceanographic conditions on the Newfoundland and Labrador Shelf during 2023](#). Can. Tech. Rep. Hydrogr. Ocean Sci.: iv + 54 p.
- Dever, M. 2017. [Dynamics of the Nova Scotia Current and linkages with Atlantic salmon migration patterns over the Scotian Shelf](#). PhD thesis.
- Dever, M., Hebert, D., Greenan, B., Sheng, J., and Smith, P. 2016. [Hydrography and coastal circulation along the Halifax line and the connections with the Gulf of St. Lawrence](#). Atmosphere-Ocean 54(3): 199–217.
- Drinkwater, K.F. 1996. [Atmospheric and oceanic variability in the Northwest Atlantic during the 1980s and early 1990s](#). Journal of Northwest Atlantic Fishery Science 18.
- Drinkwater, K.F., and Trites, R.W. 1987. [Month means of temperature and salinity in the Scotian Shelf region](#). Can. Tech. Rep. Fish. Aquat. Sci. 1539: iv + 101 p.
- Galbraith, P.S., Blais, M., Lizotte, M., Cyr, F., Bélanger, D., Casault, B., Clay, S., Layton, C., Starr, M., Chassé, J., Azetsu-Scott, K., Coyne, J., Devred, E., Gabriel, J.C.L., C.-E., Maillet, G., Pepin, P., Plourde, S., and Ringuette, J.-L., M. and Shaw. 2024. [Oceanographic conditions in the Atlantic zone in 2023](#). Can. Tech. Rep. Hydrogr. Ocean Sci 379: v + 38 pp.
- Galbraith, P.S., Chassé, J., Shaw, J.-L., Lefavre, D., and Bourassa, M.-N. 2025. Physical Oceanographic Conditions in the Gulf of St. Lawrence during 2024. Can. Tech. Rep. Hydrogr. Ocean Sci. in press.
- Gatien, M.G. 1976. [A study in the slope water region south of Halifax](#). Journal of the Fisheries Board of Canada 33(10): 2213–2217.
- Gilbert, D., Sundby, B., Gobeil, C., Mucci, A., and Tremblay, G.-H. 2005. [A seventy-two-year record of diminishing deep-water oxygen in the St. Lawrence estuary: The northwest Atlantic connection](#). Limnology and oceanography 50(5): 1654–1666.
- Hebert, D., Layton, C., Brickman, D., and Galbraith, P.S. 2023. [Physical Oceanographic Conditions on the Scotian Shelf and in the Gulf of Maine during 2022](#). DFO Can. Sci. Advis. Sec. Res. Doc 349: iv + 81 p.
- Hobday, A.J., Alexander, L.V., Perkins, S.E., Smale, D.A., Straub, S.C., Oliver, E.C., Benthuisen, J.A., Burrows, M.T., Donat, M.G., Feng, M., and others. 2016. [A hierarchical approach to defining marine heatwaves](#). Progress in oceanography 141: 227–238. Elsevier.
- Hobday, A.J., Oliver, E.C., Gupta, A.S., Benthuisen, J.A., Burrows, M.T., Donat, M.G., Holbrook,

- N.J., Moore, P.J., Thomsen, M.S., Wernberg, T., and others. 2018. Categorizing and naming marine heatwaves. *Oceanography* 31(2): 162–173. JSTOR.
- Hurrell, J.W., Kushnir, Y., Ottersen, G., and Visbeck, M. 2003. [An overview of the north atlantic oscillation](#). *Geophysical Monograph-American Geophysical Union* 134: 1–36.
- Jonasson, O., Gladkova, I., and Ignatov, A. 2022. [Towards global daily gridded super-collated SST product from low earth orbiting satellites \(L3S-LEO-daily\) at NOAA](#). In *Ocean sensing and monitoring XIV*. SPIE. pp. 40–51.
- Kalnay, E., Kanamitsu, M., Kistler, R., Collins, W., Deaven, D., Gandin, L., Iredell, M., Saha, S., White, G., Woollen, J., and others. 1996. [The NCEP/NCAR 40-year reanalysis project](#). *Bulletin of the American meteorological Society* 77(3): 437–472.
- Koch, S., DesJardins, M., and Kocin, P. 1983. [An interactive Barnes objective map analysis scheme for use with satellite and conventional data](#). *Journal of Climate and Applied Meteorology* 22: 1487–1503.
- Larouche, P., and Galbraith, P.S. 2016. [Canadian coastal seas and great lakes sea surface temperature climatology and recent trends](#). *Canadian Journal of Remote Sensing* 42(3): 243–258. Taylor & Francis.
- Menne, M.J., Williams, C.N., Gleason, B.E., Rennie, J.J., and Lawrimore, J.H. 2018. [The global historical climatology network monthly temperature dataset, version 4](#). *Journal of Climate* 31(24): 9835–9854.
- Oliver, E.C., Benthuisen, J.A., Darmaraki, S., Donat, M.G., Hobday, A.J., Holbrook, N.J., Schlegel, R.W., and Sen Gupta, A. 2021. [Marine heatwaves](#). *Annual review of marine science* 13: 313–342. *Annual Reviews*.
- Petrie, B. 2007. [Does the North Atlantic Oscillation affect hydrographic properties on the Canadian Atlantic continental shelf?](#) *Atmosphere-ocean* 45(3): 141–151.
- Petrie, B., Drinkwater, K., Gregory, D., Pettipas, R., and A., S. 1996. [Temperature and salinity atlas for the Scotian Shelf and the Gulf of Maine](#). *Can. Tech. Rep. Hydrogr. Ocean Sci.* 171: v + 398 pp.
- Petrie, B., Pettipas, R.G., and Petrie, W.M. 2009. [An Overview of Meteorological, Sea Ice and Sea-Surface Temperature Conditions off Nova Scotia and the Gulf of Maine during 2008](#). *DFO Can. Sci. Advis. Sec. Res. Doc.* 2009/014. vi + 32 p.
- Rodionov, S.N. 2004. [A sequential algorithm for testing climate regime shifts](#). *Geophysical Research Letters* 31(9). Wiley Online Library.
- Rogers, J.C. 1984. [The association between the North Atlantic Oscillation and the Southern Oscillation in the northern hemisphere](#). *Monthly Weather Review* 112(10): 1999–2015. American Meteorological Society.
- Vincent, L.A., Hartwell, M.M., and Wang, X.L. 2020. [A third generation of homogenized temperature for trend analysis and monitoring changes in Canada's climate](#). *Atmosphere-Ocean* 58(3): 173–191. Taylor & Francis.
- Wang, Z., Brickman, D., Greenan, B.J., and Yashayaev, I. 2016. [An abrupt shift in the Labrador Current System in relation to winter NAO events](#). *Journal of Geophysical Research: Oceans* 121(7): 5338–5349.
- Wang, Z., Lu, Y., Brickman, B., and DeTracey, B. 2018. [BNAM: An eddy-resolving North Atlantic Ocean model to support ocean monitoring](#). *Can. Tech. Rep. Hydrogr. Ocean Sci.* 327: vii + 18 pp.

15 TABLES

Table 1. The 2024 annual mean air temperature anomaly in degrees and normalized anomaly (relative to the 1991-2020 climatology) and SD of the monthly anomalies for Scotian Shelf and Gulf of Maine.

Site	Annual Anomaly		1991-2020 Climatology	
	Observed (°C)	Normalized (SD)	Mean (°C)	SD
Sydney	+1.1	+1.5	+6.45	+0.72
Sable Island	+0.6	+1.0	+8.35	+0.67
Halifax	+0.9	+1.4	+7.16	+0.70
Yarmouth	+0.8	+1.1	+7.69	+0.71
Saint John	+1.0	+1.4	+5.71	+0.77
Boston	+1.2	+1.6	+10.90	+0.71

Table 2. The 2024 SST anomalies and long-term statistics.

NAFO Zone	Annual Anomaly		1991-2020 Climatology	
	Observed (°C)	Normalized (SD)	Mean (°C)	SD
4Vn	+1.4	+2.7	+6.88	+0.52
4Vs	+1.2	+1.9	+8.01	+0.61
4W	+0.6	+1.0	+9.06	+0.63
4XSS	+0.6	+1.0	+8.71	+0.63
4XeGoM+BoF	+0.5	+0.7	+8.51	+0.72
5Y	+0.6	+1.0	+9.98	+0.61
5Ze	+0.1	+0.1	+11.56	+0.67

Table 3. The 2024 summer ecosystem trawl survey bottom temperature anomalies and long-term statistics.

NAFO Zone	Annual Anomaly		1991-2020 Climatology	
	Observed (°C)	Normalized (SD)	Mean (°C)	SD
4Vn	+0.6	+0.7	+3.88	+0.83
4Vs	+0.0	+0.0	+3.43	+0.89
4W	-1.0	-1.0	+6.76	+0.99
4X	-0.4	-0.5	+7.84	+0.93
4XSS	-0.4	-0.3	+7.06	+1.06
4XeGoM BoF	-0.0	-0.0	+8.22	+0.92

16 FIGURES

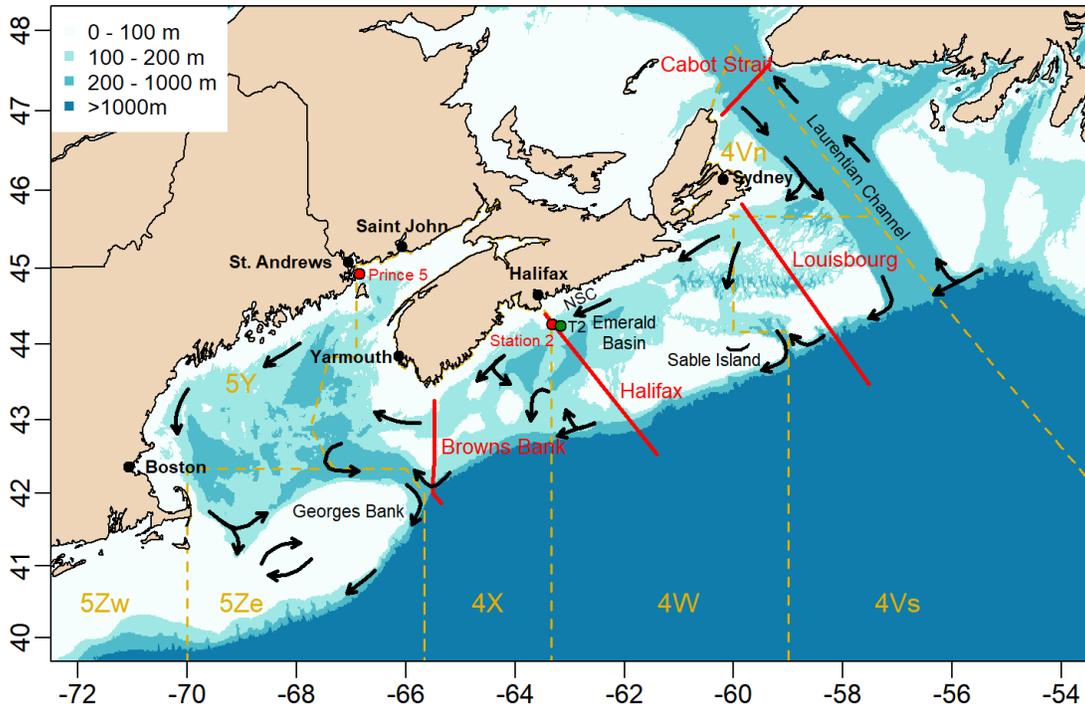


Figure 1. Map of the Scotian Shelf and the Gulf of Maine showing high frequency sampled hydrographic stations (red circles) near Halifax and St. Andrews, core AZMP lines (red lines), Nova Scotia Current mooring, T2, (green dot) near Halifax, weather stations (black dots) and topographic features. The Nova Scotia Current (NSC) is shown. The dashed yellow lines indicate the boundaries of the Northwest Atlantic Fisheries Organization Divisions.

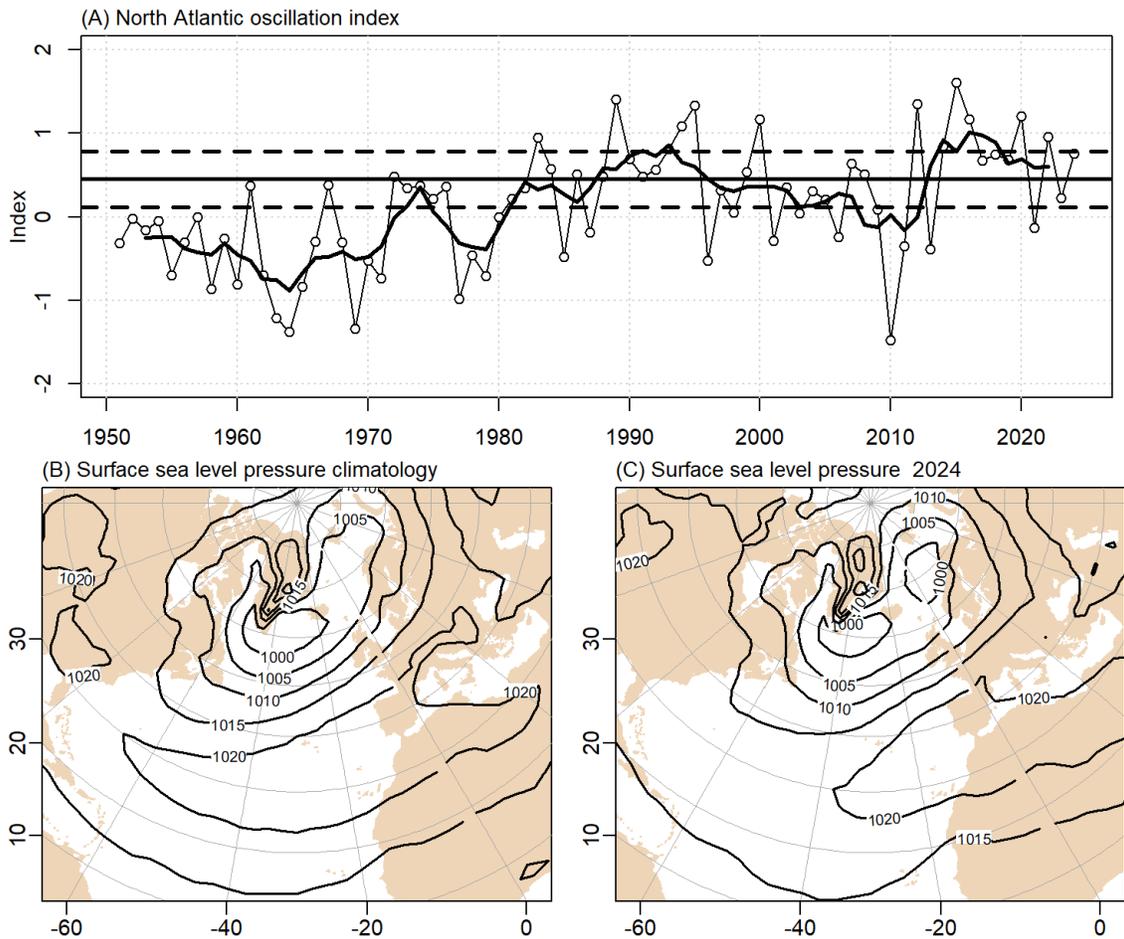


Figure 2. (A) The North Atlantic Oscillation (NAO) index, defined as the winter (December, January, February, March) 500 mb pressure Principal Component Analysis which is representative of the difference between the Icelandic low and Azores high. The thick line is a 5-year moving average. The 1991-2020 climatological mean is shown as a solid horizontal line. Dashed lines are ± 0.5 standard deviation (SD). (B) The 1991-2020 December – March mean and (C) December 2023 – March 2024 mean sea-level atmospheric pressure over the North Atlantic. (Data provided by the [NOAA/ESRL Physical Sciences Division](#), Boulder, Colorado.)

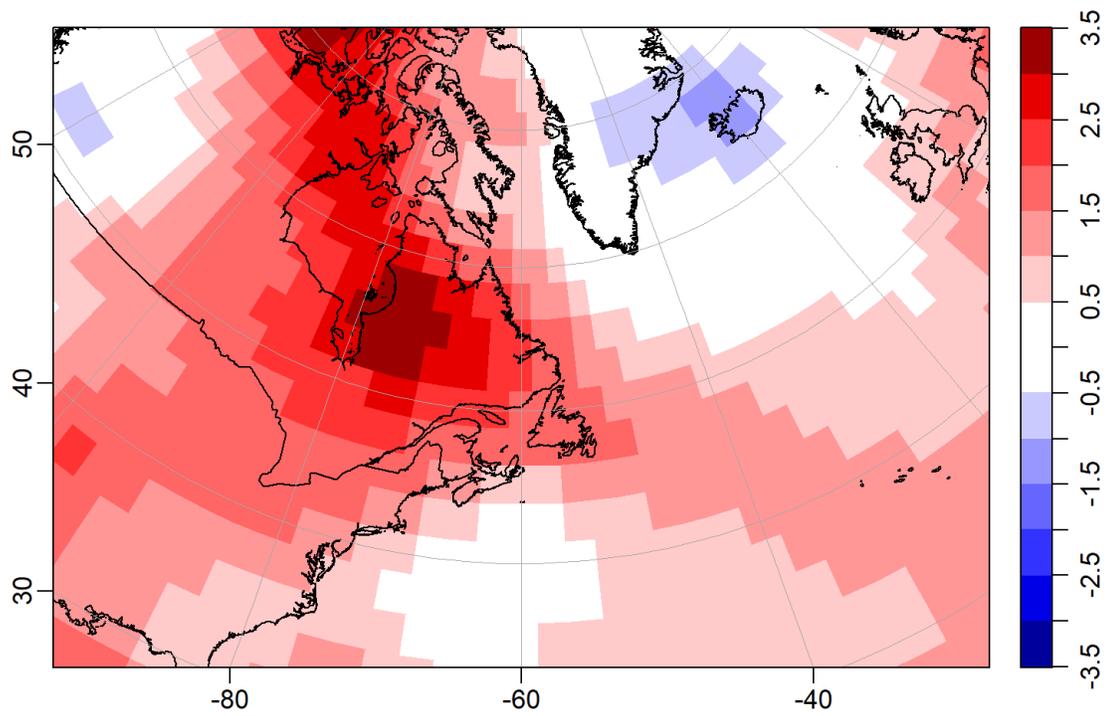


Figure 3. Annual air temperature anomalies ($^{\circ}\text{C}$) over the Northwest Atlantic relative to the 1991-2020 mean; data were obtained from [NOAA Internet site](#) (accessed 13 January 2025).

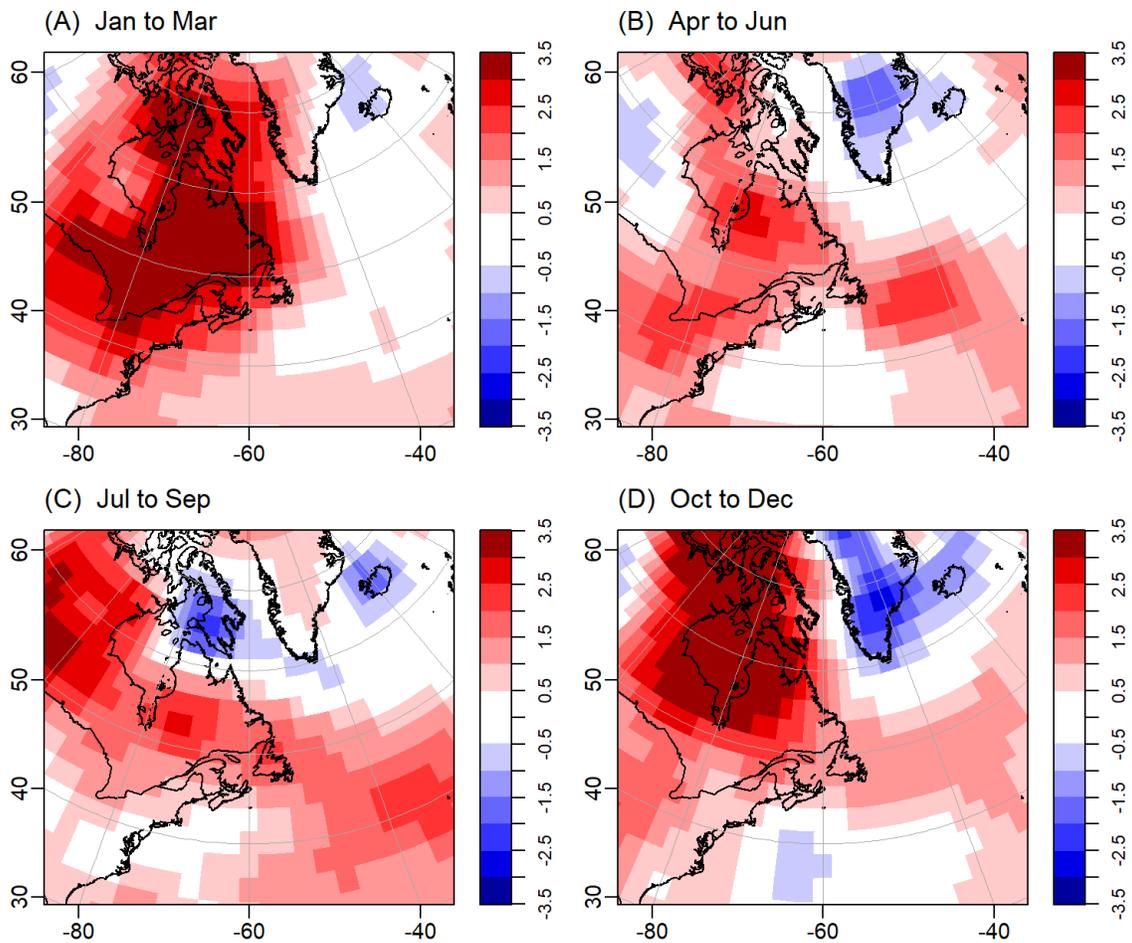


Figure 4. Seasonal air temperature anomalies (°C) over the Northwest Atlantic relative to the 1991-2020 means; data were obtained from [NOAA Internet site](#) (accessed 13 January 2025).

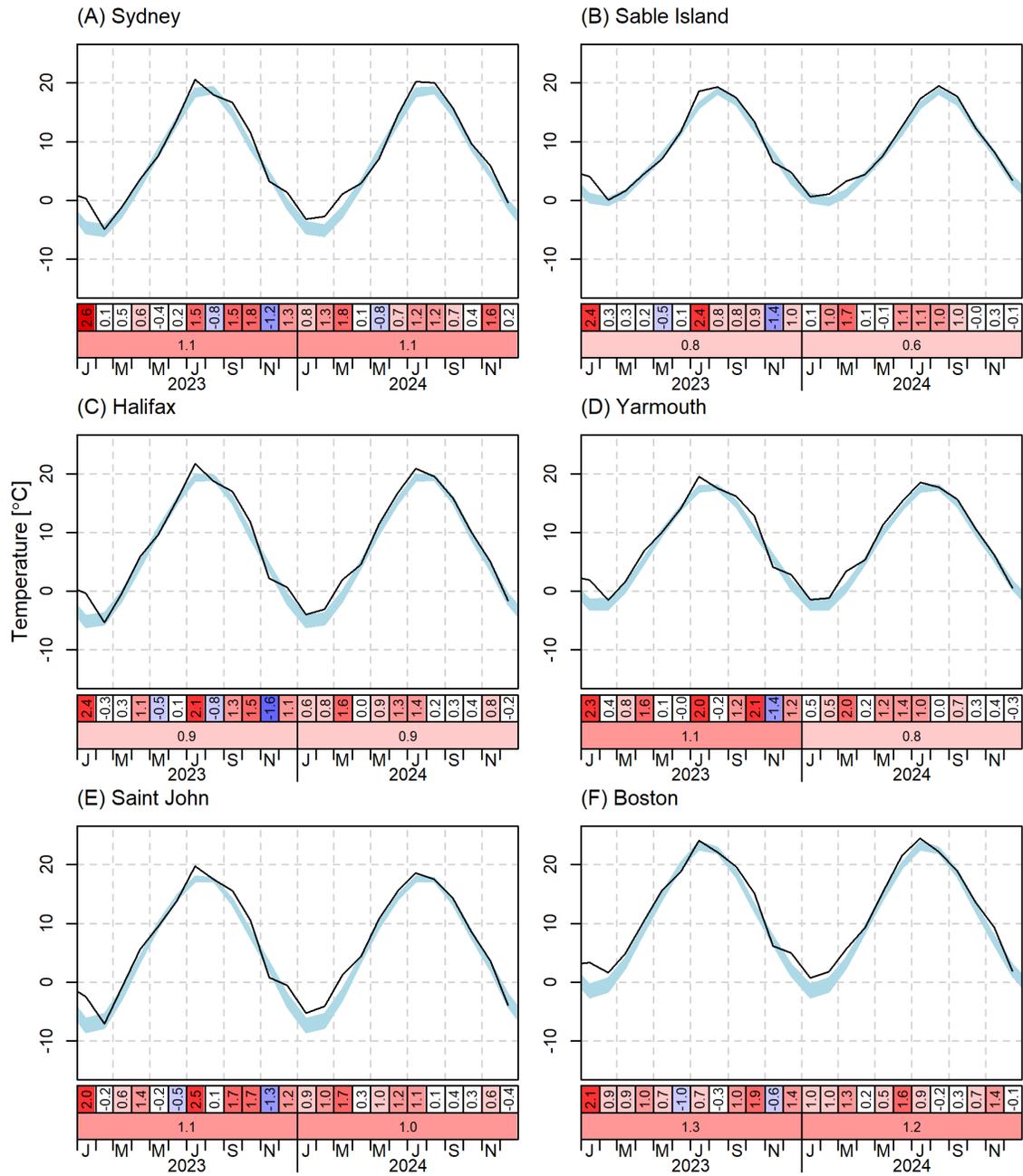


Figure 5. Monthly air temperature ($^{\circ}\text{C}$), denoted by the thin black line, at selected sites in the Scotian Shelf/Gulf of Maine region for 2023 and 2024. See Figure 1 for locations. The blue area represents the 1991-2020 climatological monthly mean ± 0.5 SD. The scorecards are colour-coded according to the normalized anomalies based on the 1991-2020 climatologies for each month (top row) and for the year (bottom row).

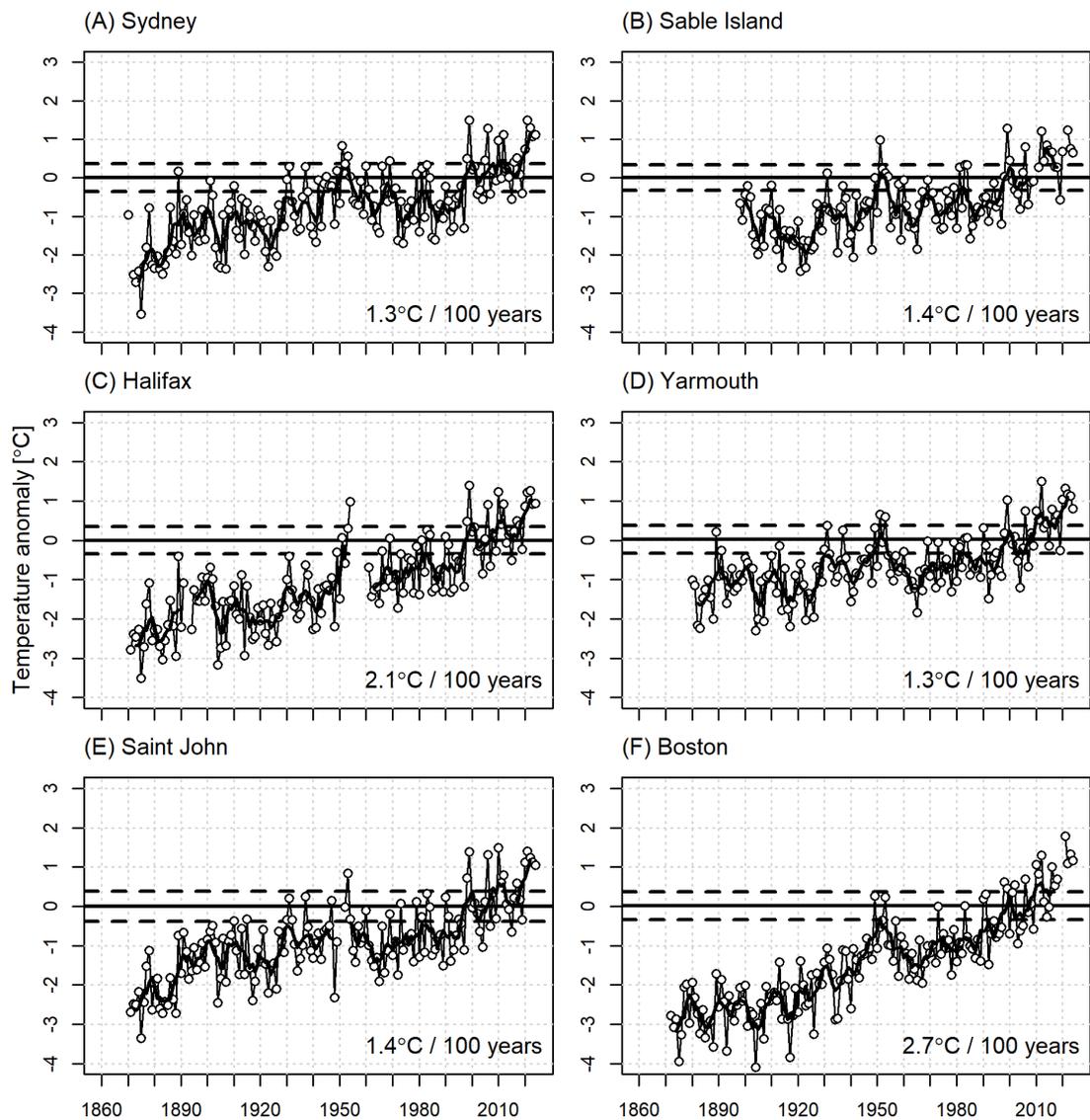


Figure 6. Annual air temperature anomalies in $^{\circ}\text{C}$ (circles connected by thin black line) and five-year running means (thick solid line) at selected sites in Scotian Shelf/Gulf of Maine region (years 1870 to 2024). Horizontal dashed thick lines represent plus or minus 0.5 SD for the 1991-2020 period. Linear trends for 1900–present are shown.

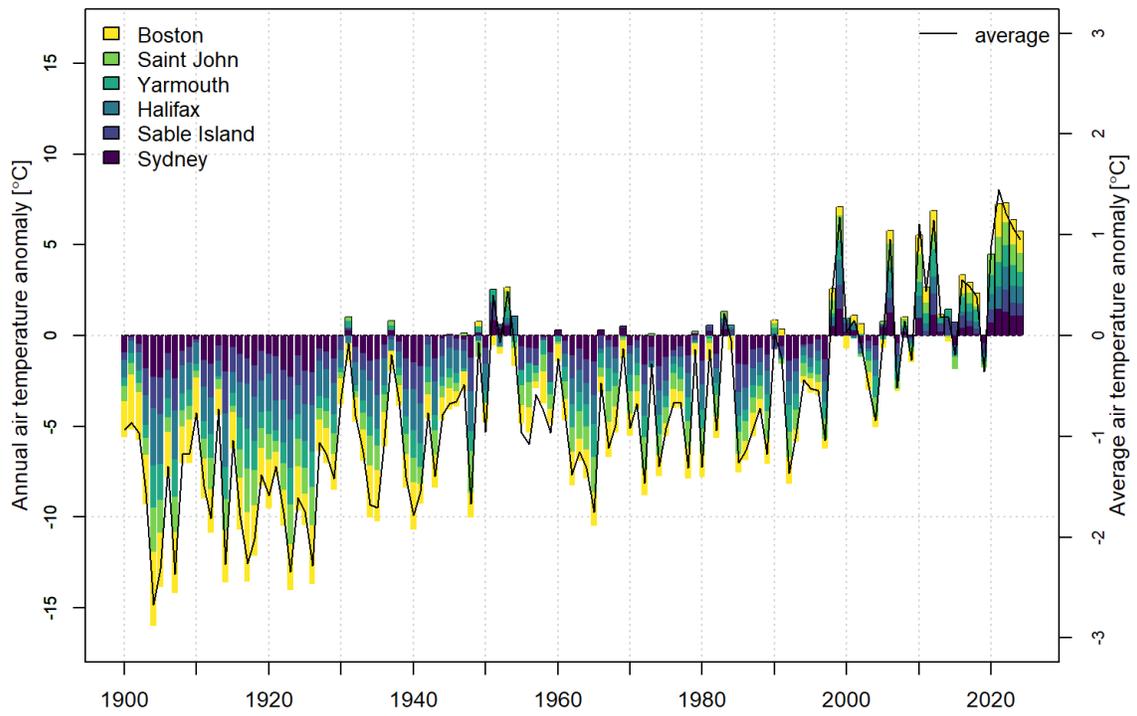


Figure 7. The contributions of the annual air temperature anomaly for selected sites in Scotian Shelf/Gulf of Maine shown as a stacked bar chart. Anomalies referenced to 1991-2020.

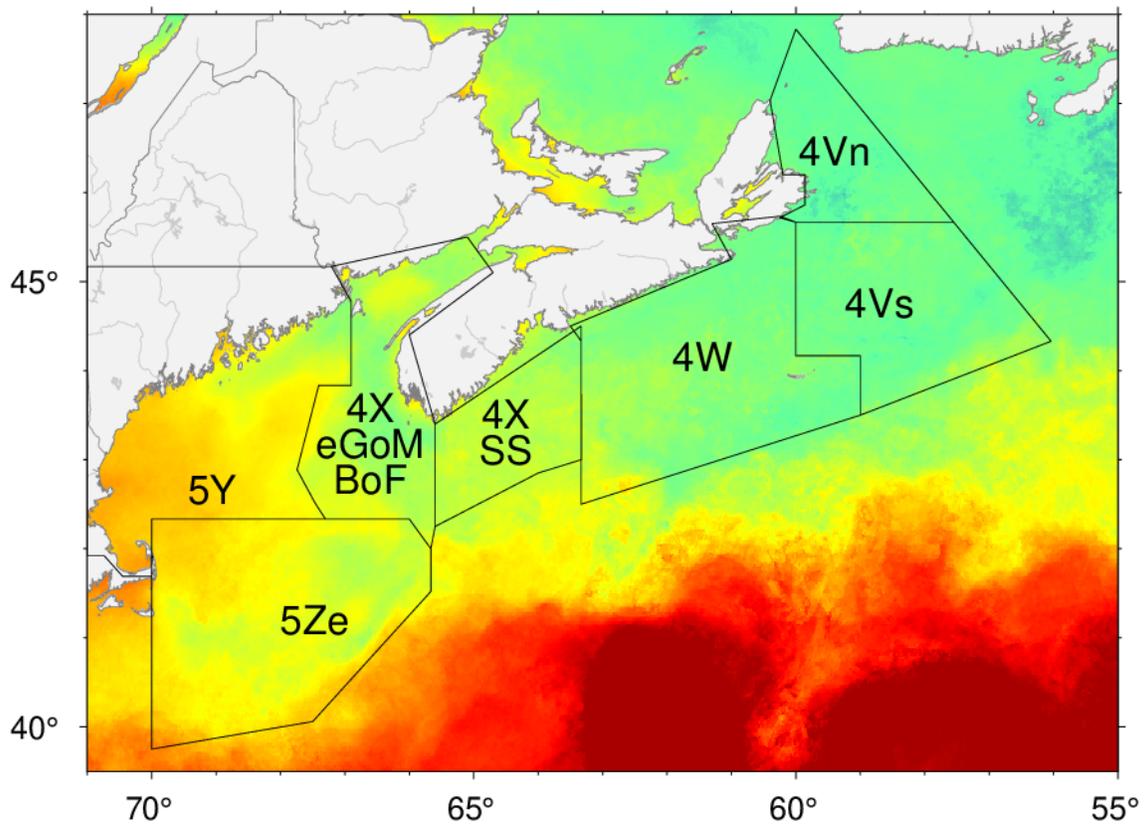


Figure 8. Scotian Shelf/Gulf of Maine NAFO divisions (4Vn, 4Vs, 4W, 4X SS, 4X eGoM-BoF, 5Y and 5Ze) used for extraction of sea surface temperature.

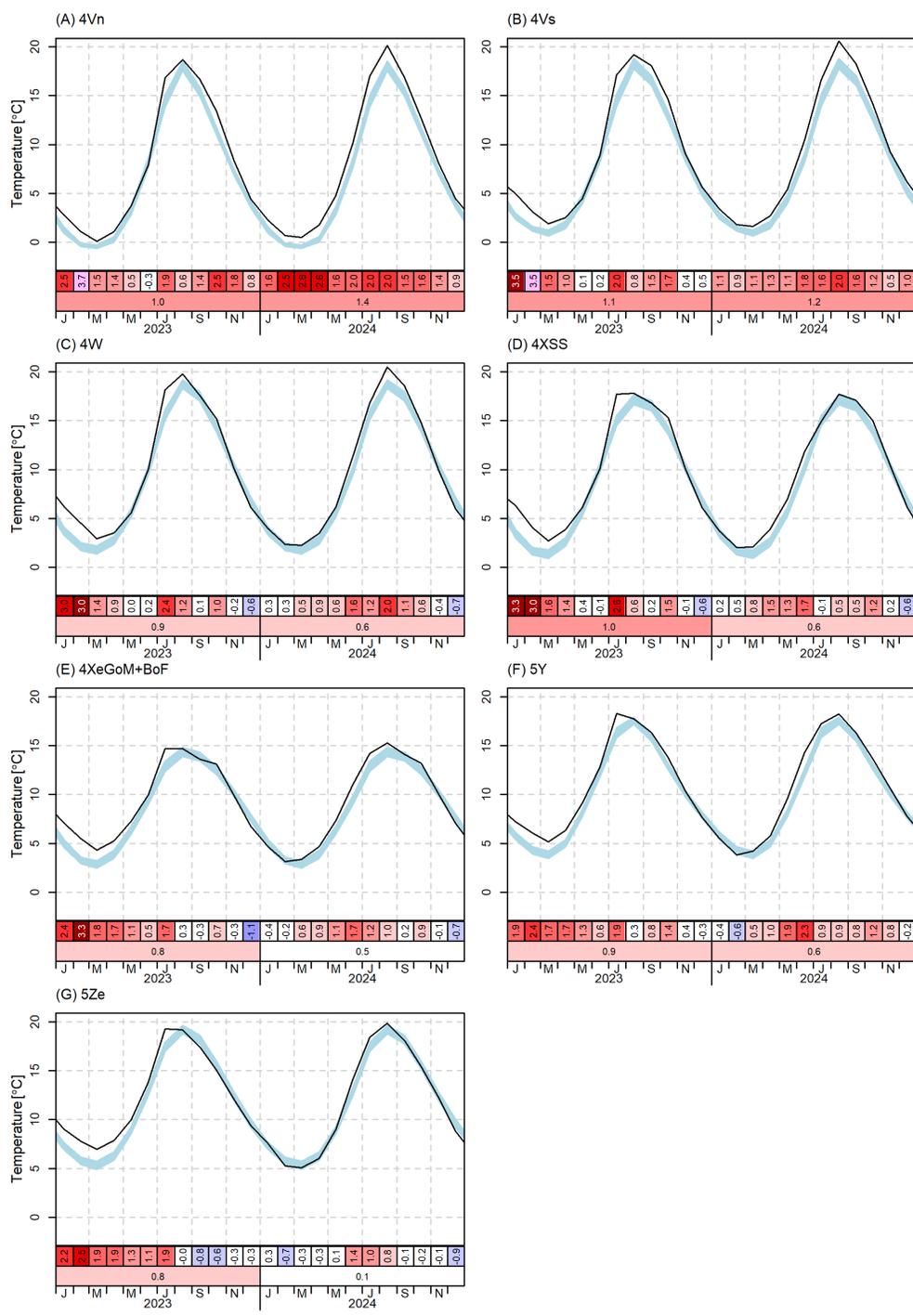


Figure 9. Satellite sea-surface temperature monthly averages (black line) over the seven regions of the Scotian Shelf and Gulf of Maine. The blue area represents the 1991-2020 climatological monthly mean ± 0.5 SD. The scorecards are colour-coded according to the normalized anomalies based on the 1991-2020 climatologies for each month (top row) or for the year (bottom row).

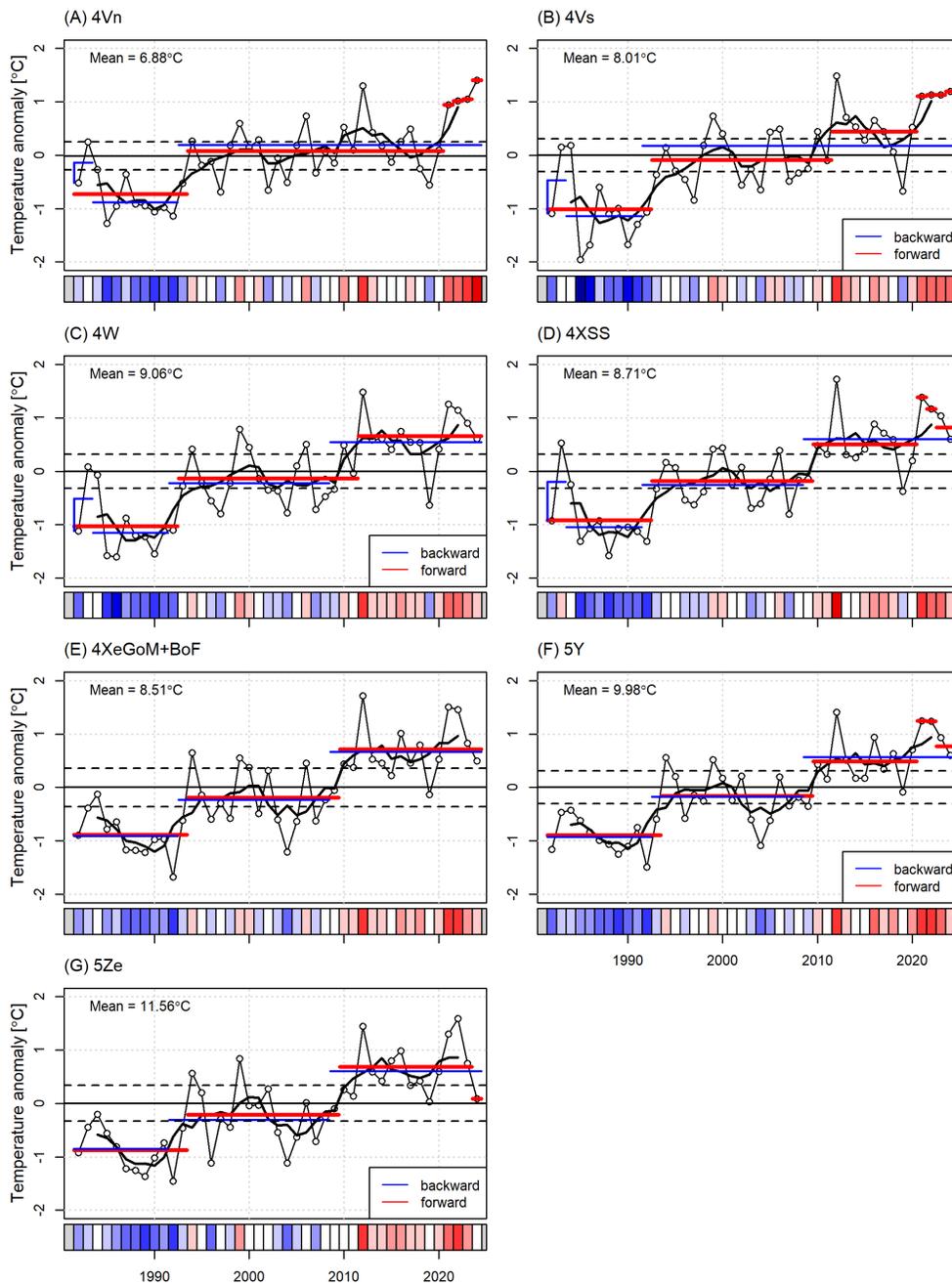


Figure 10. The annual satellite sea-surface temperature normalized anomalies derived from their monthly means over the seven regions of the Scotian Shelf and Gulf of Maine (Figure 8). Horizontal dashed lines represent ± 0.5 SD for the 1991-2020 period. Regime shift analysis results from running the method forwards and backwards on the time series depicted by the red and blue horizontal lines, respectively. Scorecards below each timeseries plot are colour coded based on the normalized anomalies, with blue indicating below normal, white indicating normal, and red above normal.

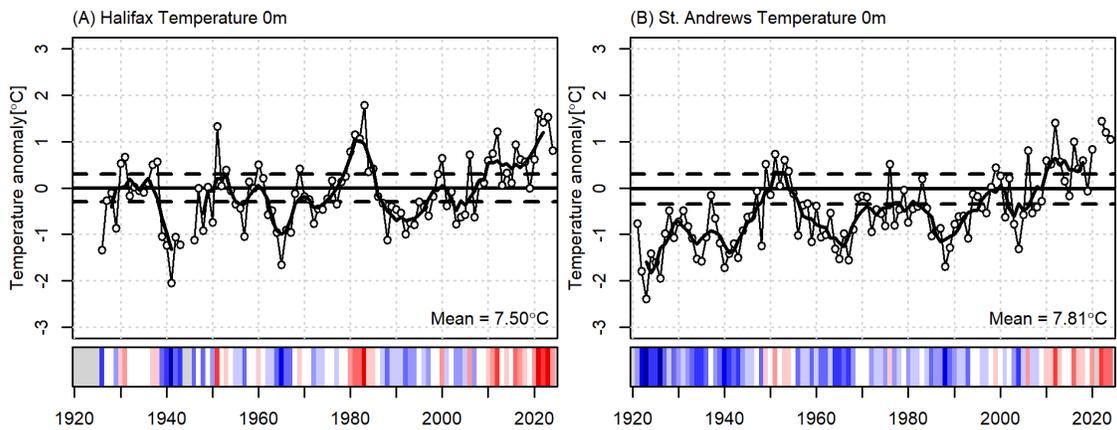


Figure 11. The annual surface-temperature anomalies with respect to the 1991–2020 climatology (thin solid line with circles) and their five-year running means (thick black line) for (A) Halifax Harbour and (B) St. Andrews. Horizontal dashed lines represent the mean ± 0.5 SD. Scorecards below each timeseries plot are colour coded based on the normalized anomalies, with blue indicating below normal, white indicating normal, and red above normal.

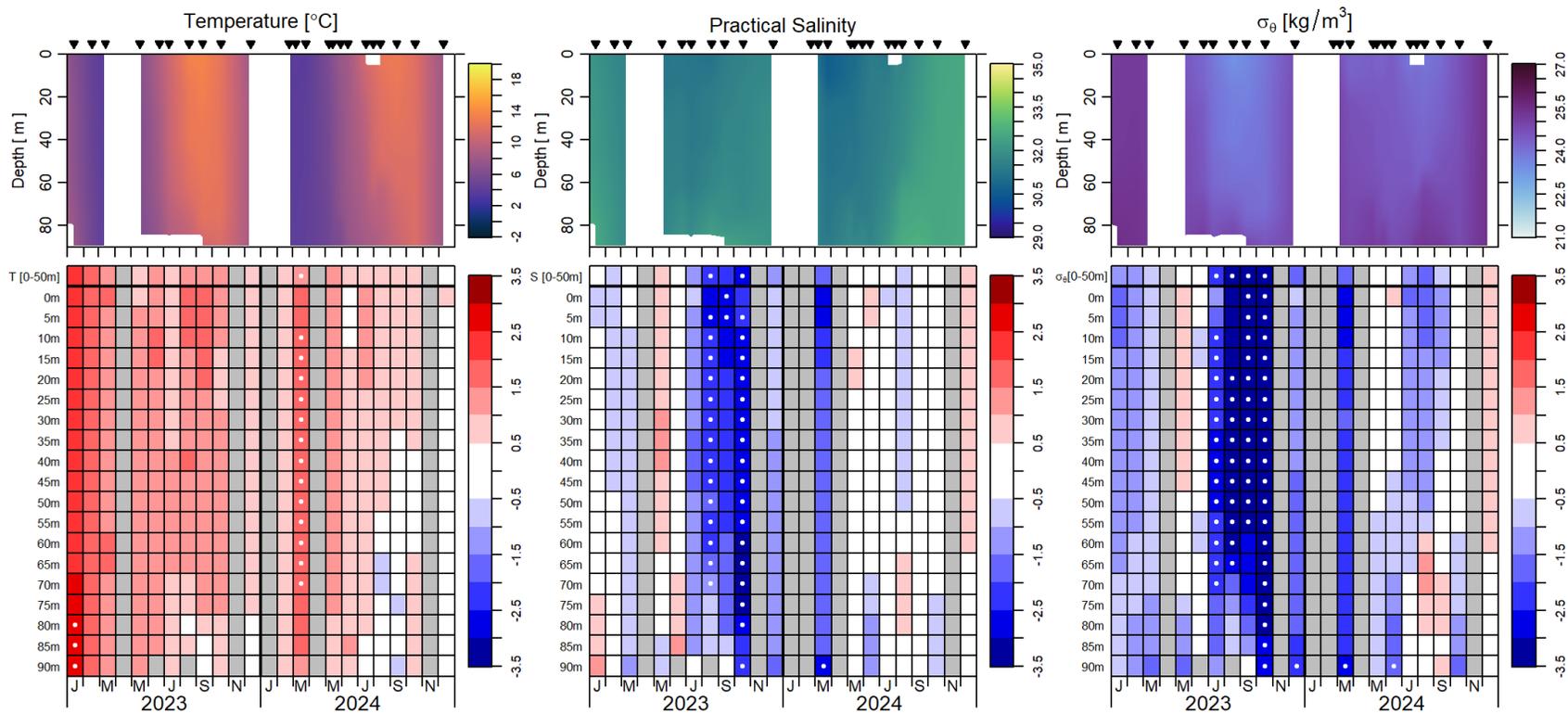


Figure 12. Prince 5 2023-2024 annual cycles of temperature (top left), salinity (top center), and density (top right), triangles indicate periods of sampling. Scorecard tables with 0-50m mean values (T [0-50m], S [0-50m], σ_θ [0-50m]), and depth average monthly normalized anomalies with respect to the 1991–2020 climatology (bottom panels). White dots indicate series records.

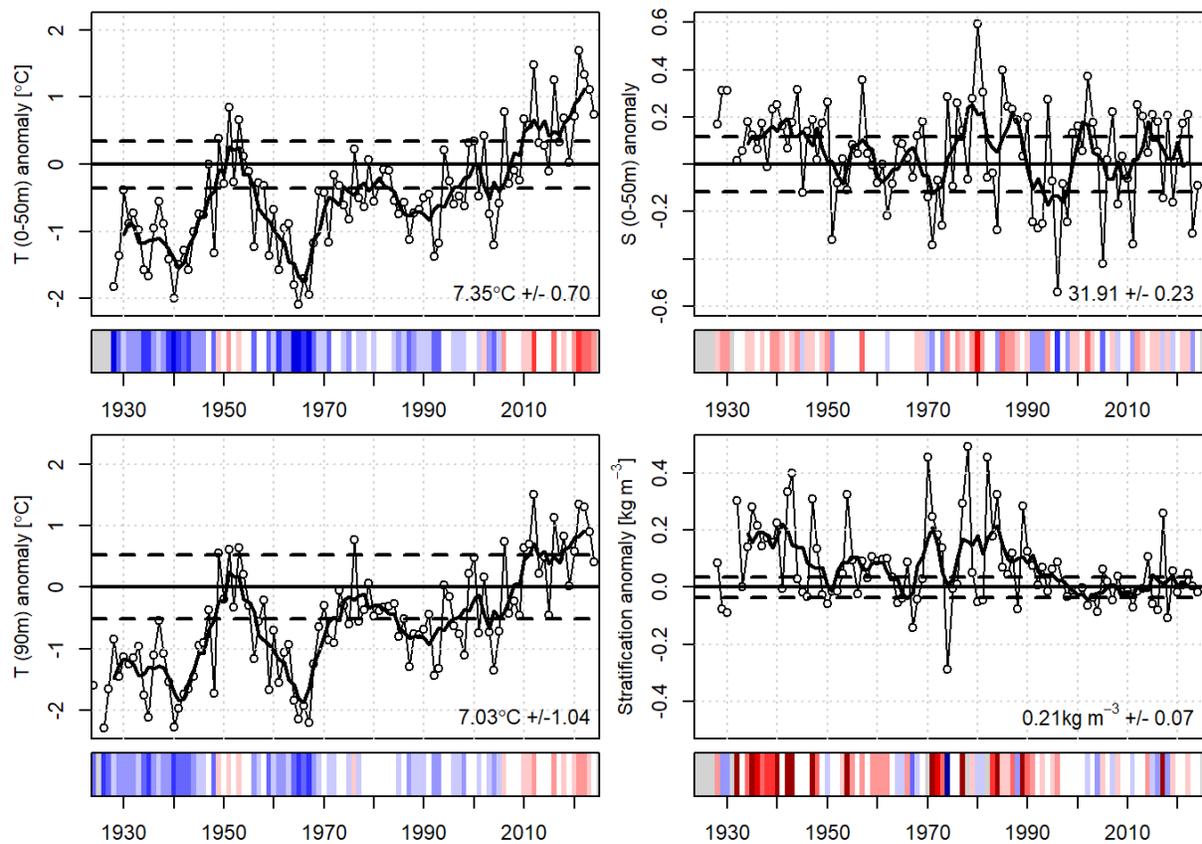


Figure 13. Prince 5 annual anomaly time series (circles connected by a thin black line) of temperature (top left) and salinity (top right) averaged from 0 to 50m, the bottom temperature (bottom left), and the stratification (bottom right) which is the density difference between 0 and 50m with the five-year running mean (thick solid line). Horizontal dashed lines represent the mean ± 0.5 SD for the 1991-2020 period. Scorecards below each timeseries plot are colour coded based on the normalized anomalies, with blue indicating below normal, white indicating normal, and red above normal.

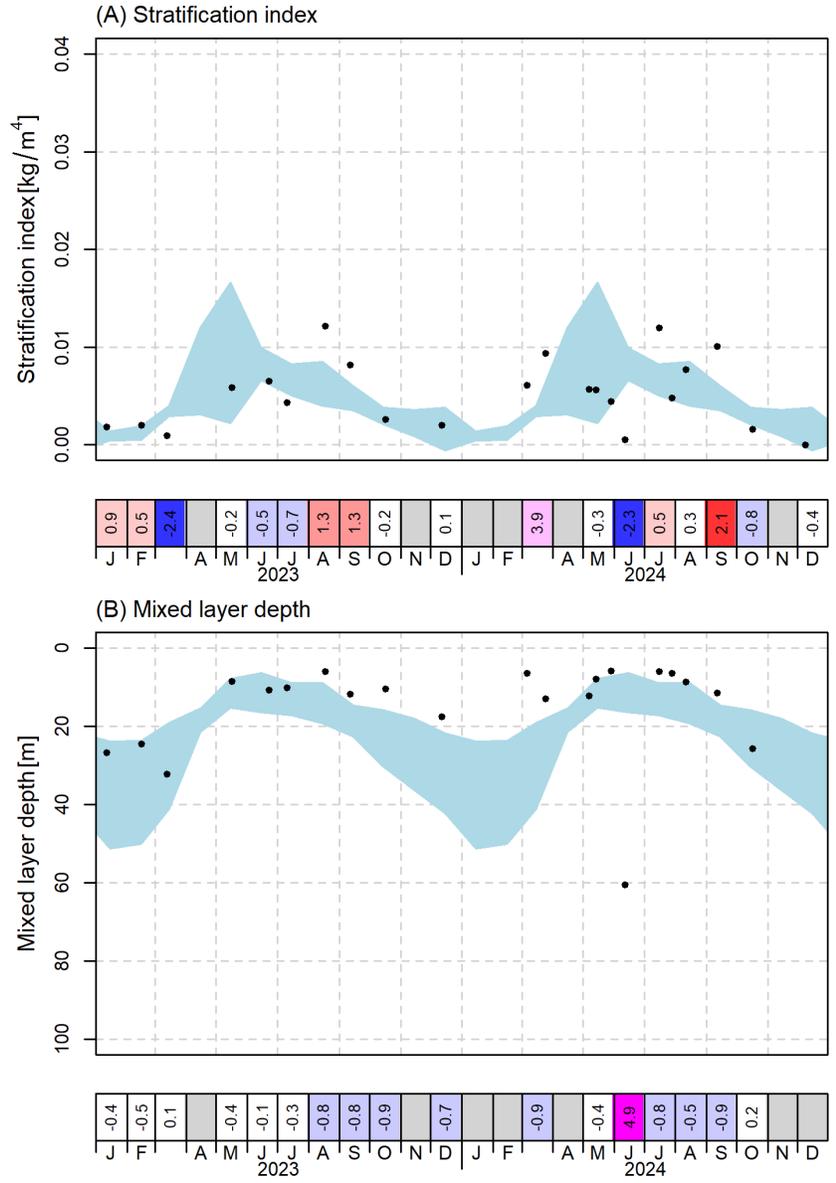


Figure 14. The 2023–2024 annual cycle of stratification index (top panel) and mixed layer depth (lower panel) for Prince 5. The shaded area is the 1991–2020 climatological mean \pm 0.5 standard deviations. The dots represent individual calculations. Their anomalies with respect to 1991–2020 monthly means are shown below each figure.

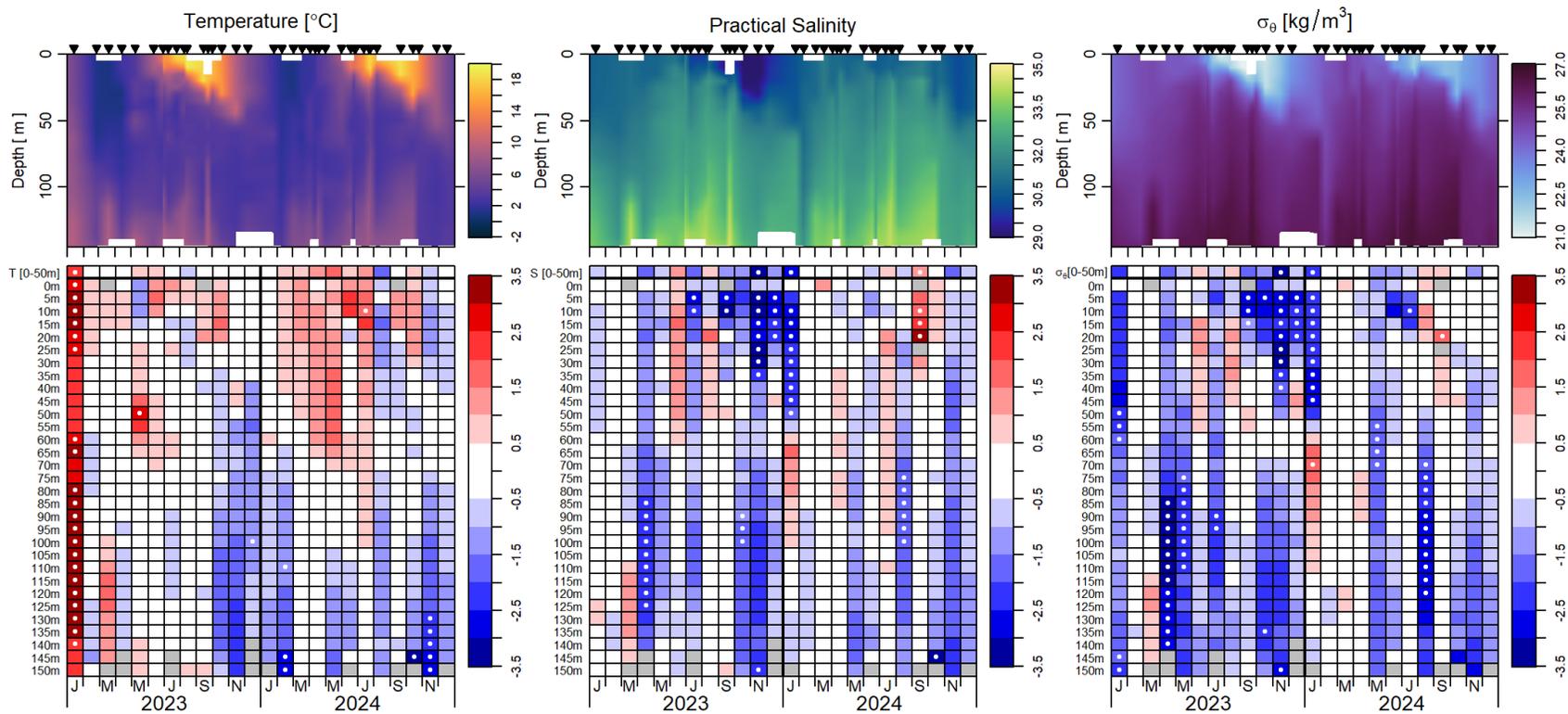


Figure 15. Halifax station 2 2023-2024 annual cycles of temperature (top left), salinity (top center), and density (top right), triangles indicate periods of sampling. Scorecard tables with 0-50m mean values (T [0-50m], S [0-50m], σ_θ [0-50m]), and depth average monthly normalized anomalies with respect to the 1991–2020 climatology (bottom panels). White dots indicate series records.

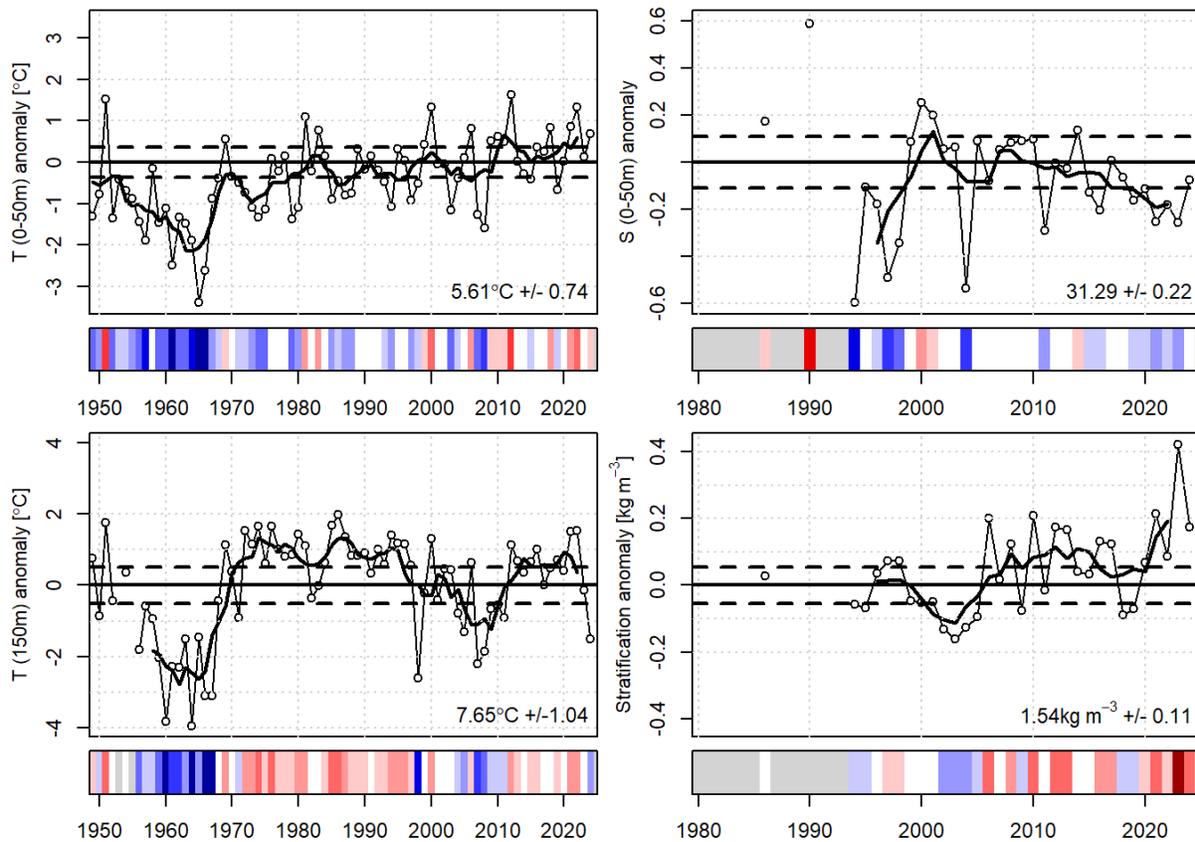


Figure 16. Halifax station 2 annual anomaly time series of temperature (top left) and salinity (top right) averaged from 0 to 50m, the bottom temperature (bottom left), and the stratification (bottom right) which is the density difference between 0 and 50m. Horizontal dashed thick lines represent the mean \pm 0.5 SD for the 1991-2020 period. Note the differing x-axis ranges between variables as salinity data was sparse prior to year 1980. Scorecards below each time series plot are colour coded based on the normalized anomalies, with blue indicating below normal, white indicating normal, and red above normal.

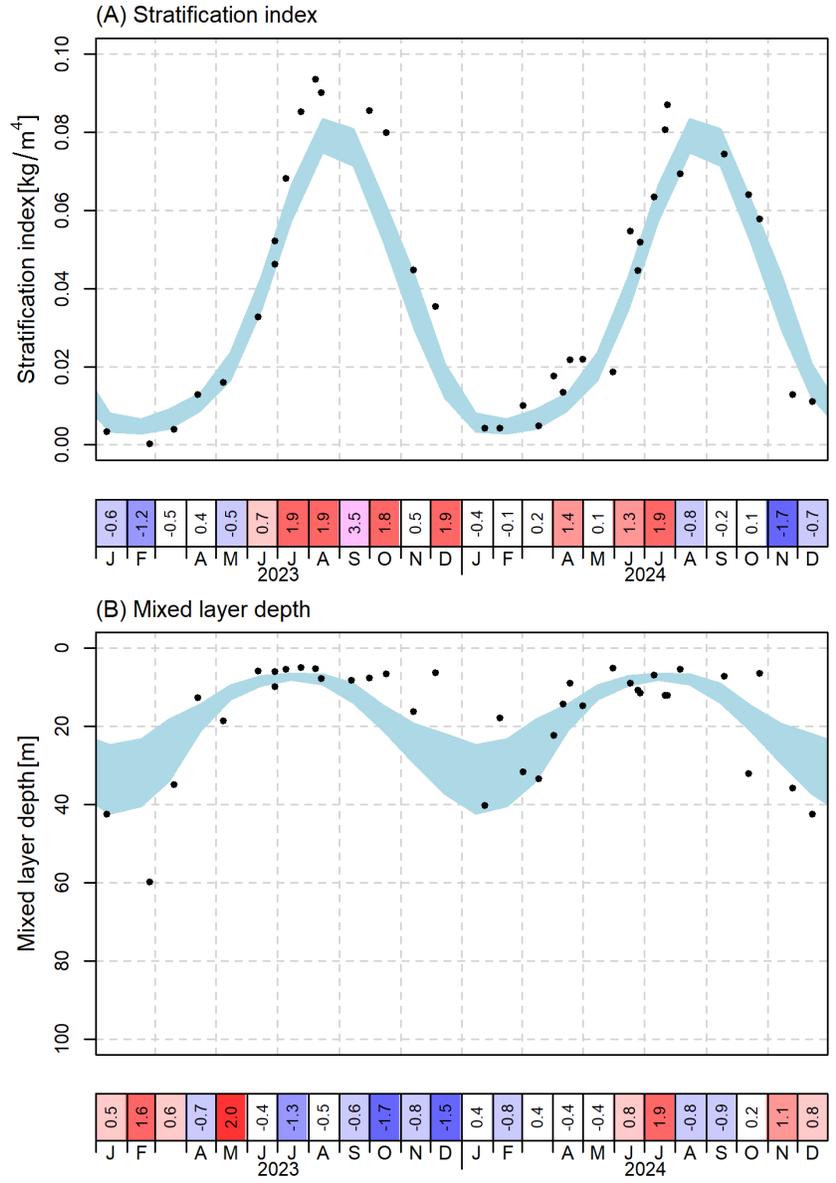


Figure 17. The 2023– 2024 annual cycle of stratification index (top panel) and mixed layer depth (lower panel) for Halifax station 2. The shaded area is the 1991–2020 climatological mean ± 0.5 standard deviations. The dots represent individual calculations. Their anomalies with respect to 1991–2020 monthly means are shown below each figure.

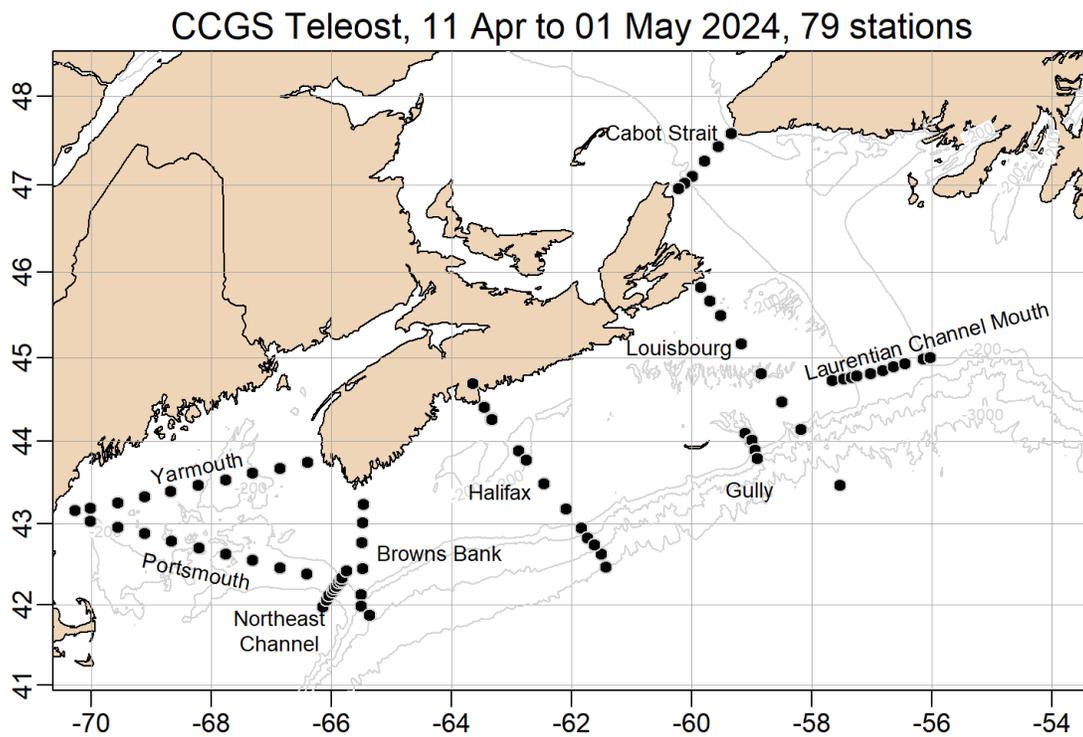


Figure 18. The 2024 sampling of the Scotian Shelf/Gulf of Maine for the spring AZMP survey.

Cabot Strait: 29 Apr to 30 Apr 2024

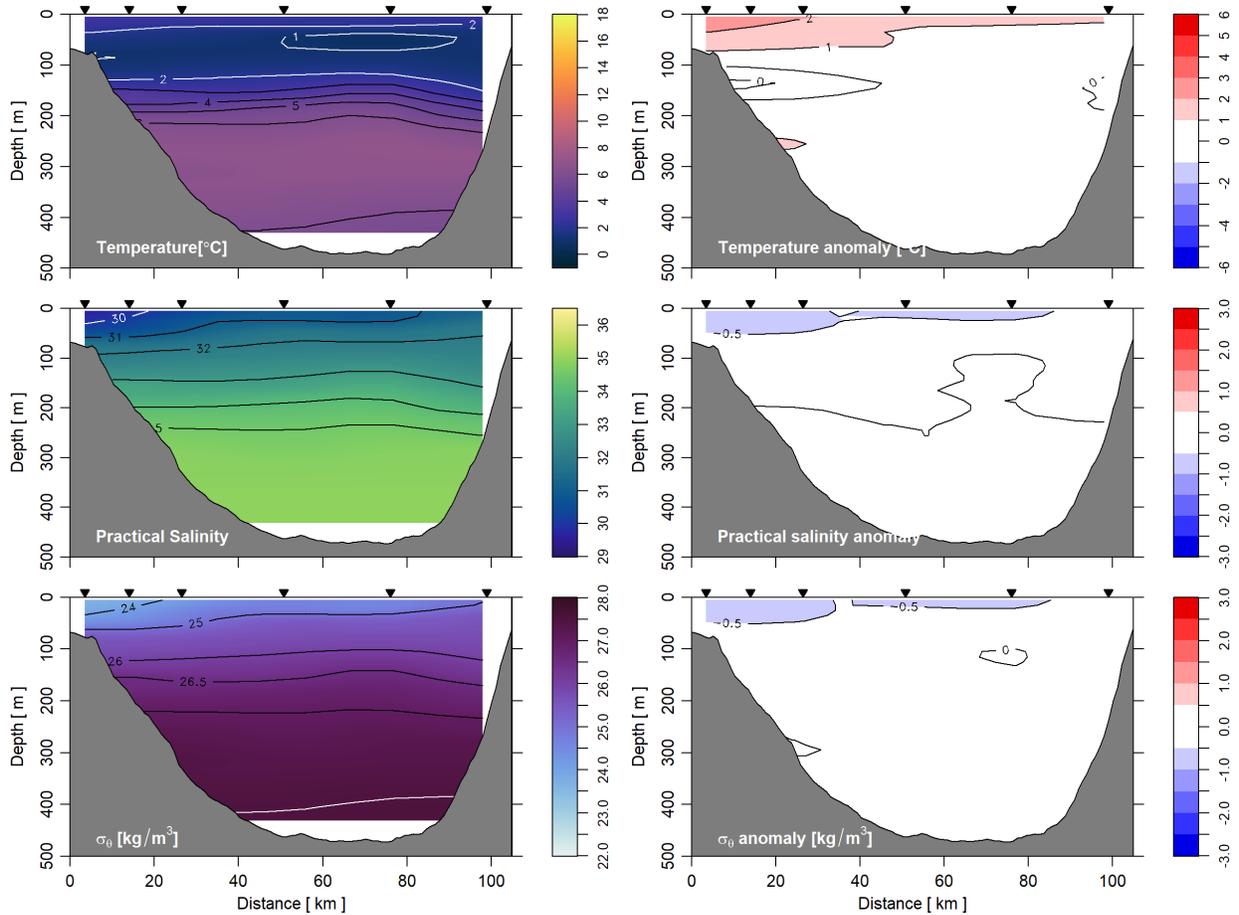


Figure 19. The 2024 sampling of the Cabot Strait line for spring. Temperature (top panel), salinity (middle panel), and density (lower panel) and their anomalies with respect to the 1991–2020 climatology (right panels). Triangles indicate locations of sampling.

Louisbourg: 27 Apr to 28 Apr 2024

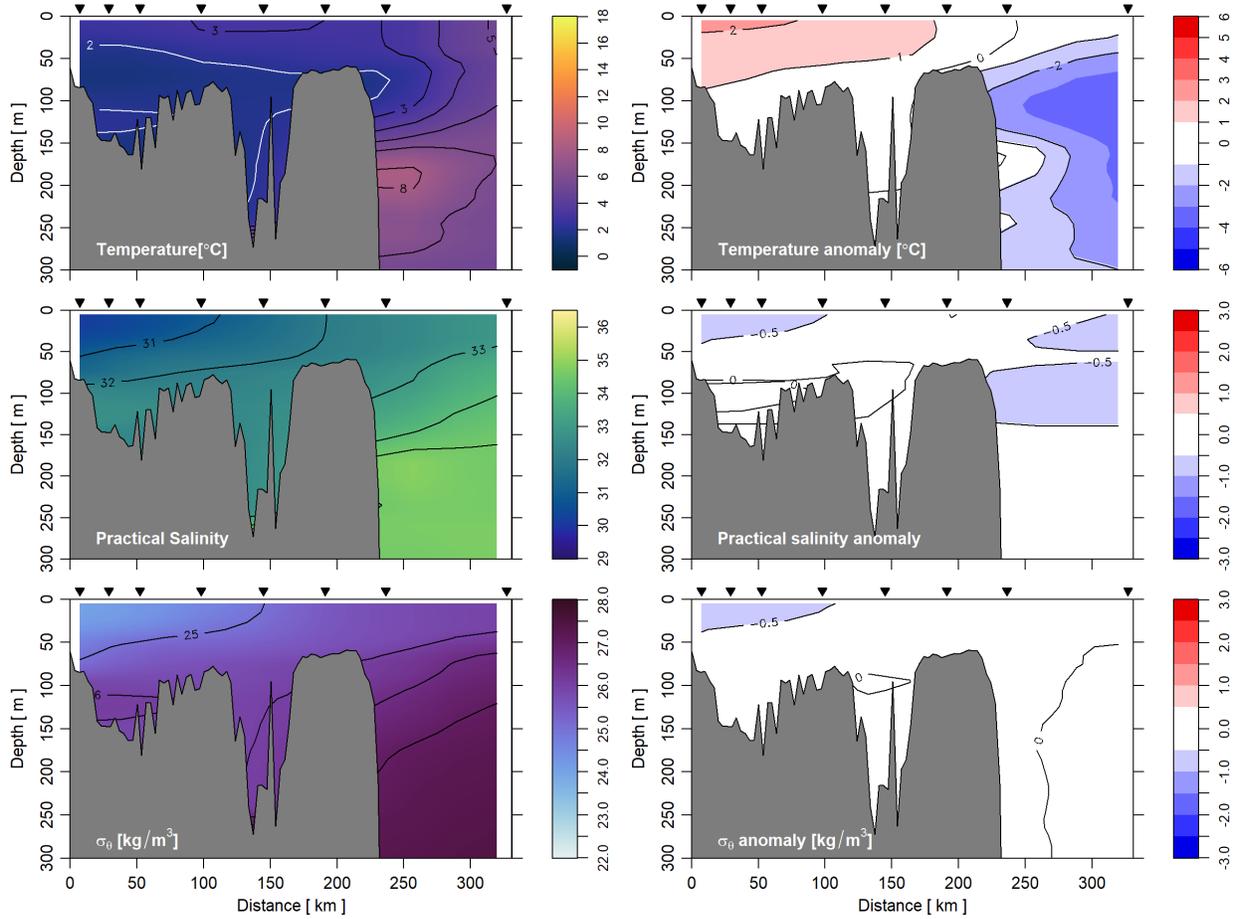


Figure 20. The 2024 sampling of the Louisbourg line for spring. Temperature (top panel), salinity (middle panel), and density (lower panel) and their anomalies with respect to the 1991–2020 climatology (right panels). Triangles indicate locations of sampling.

Halifax: 11 Apr to 01 May 2024

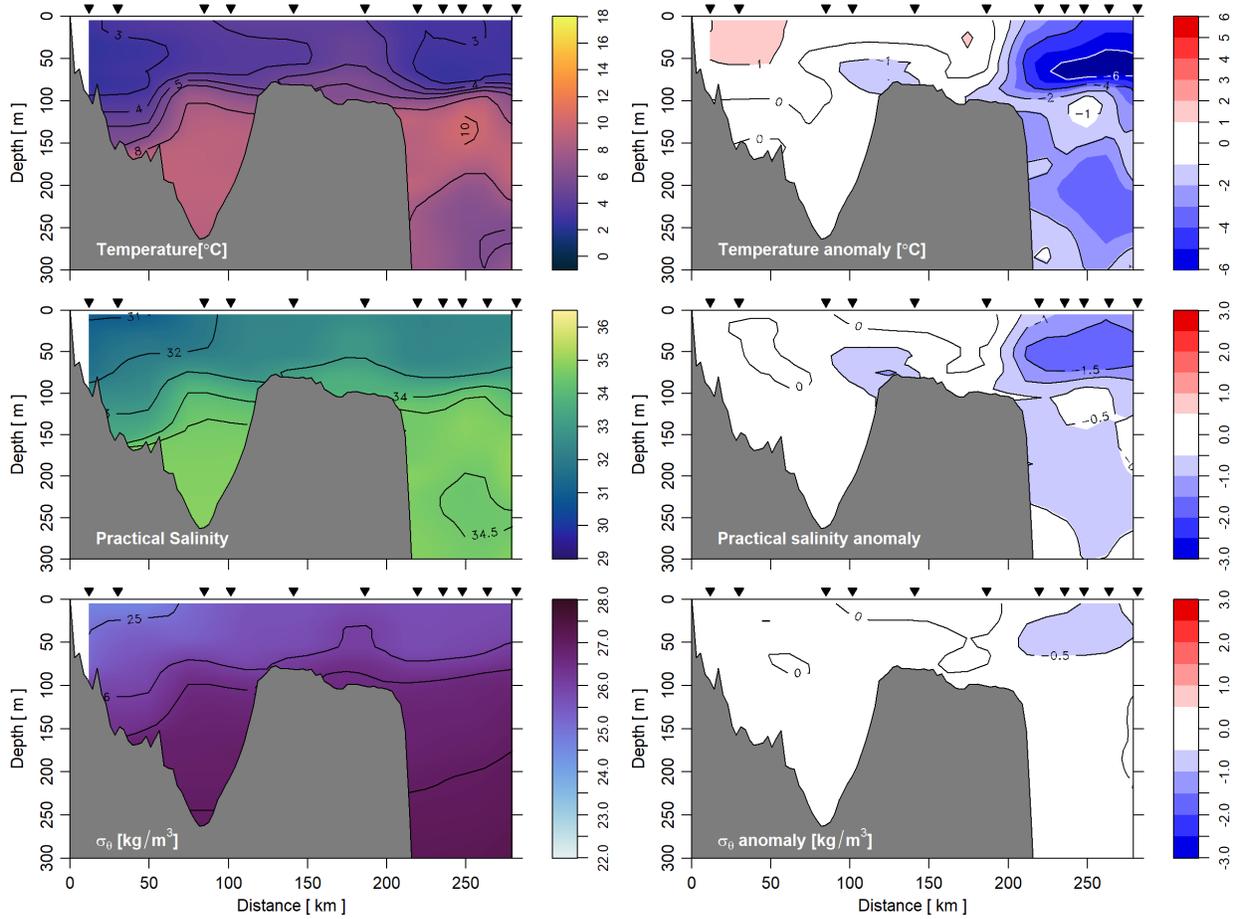


Figure 21. The 2024 sampling of the Halifax line for spring. Temperature (top panel), salinity (middle panel), and density (lower panel) and their anomalies with respect to the 1991–2020 climatology (right panels). Triangles indicate locations of sampling.

Browns Bank: 18 Apr to 19 Apr 2024

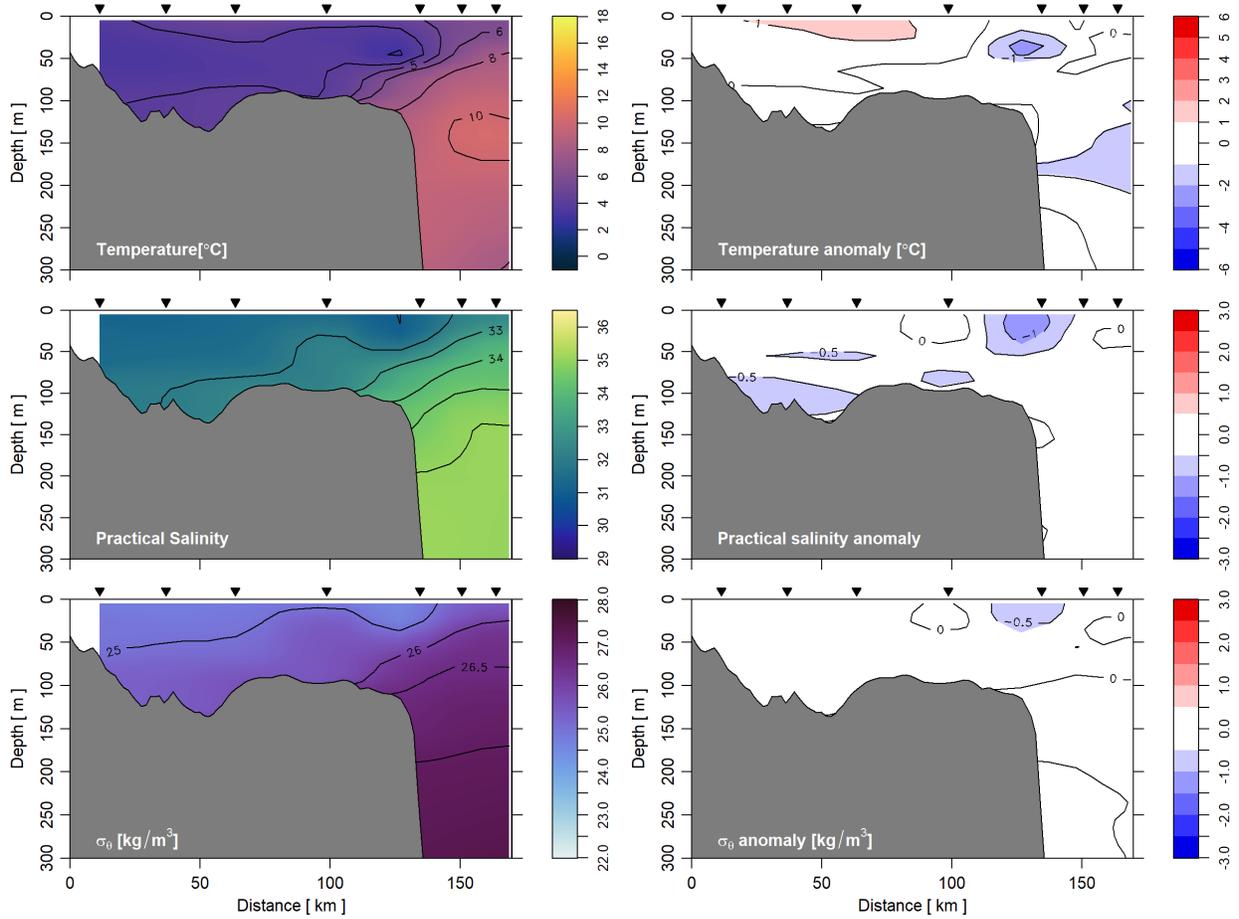


Figure 22. The 2024 sampling of the Browns Bank line for spring. Temperature (top panel), salinity (middle panel), and density (lower panel) and their anomalies with respect to the 1991–2020 climatology(right panels). Triangles indicate locations of sampling.

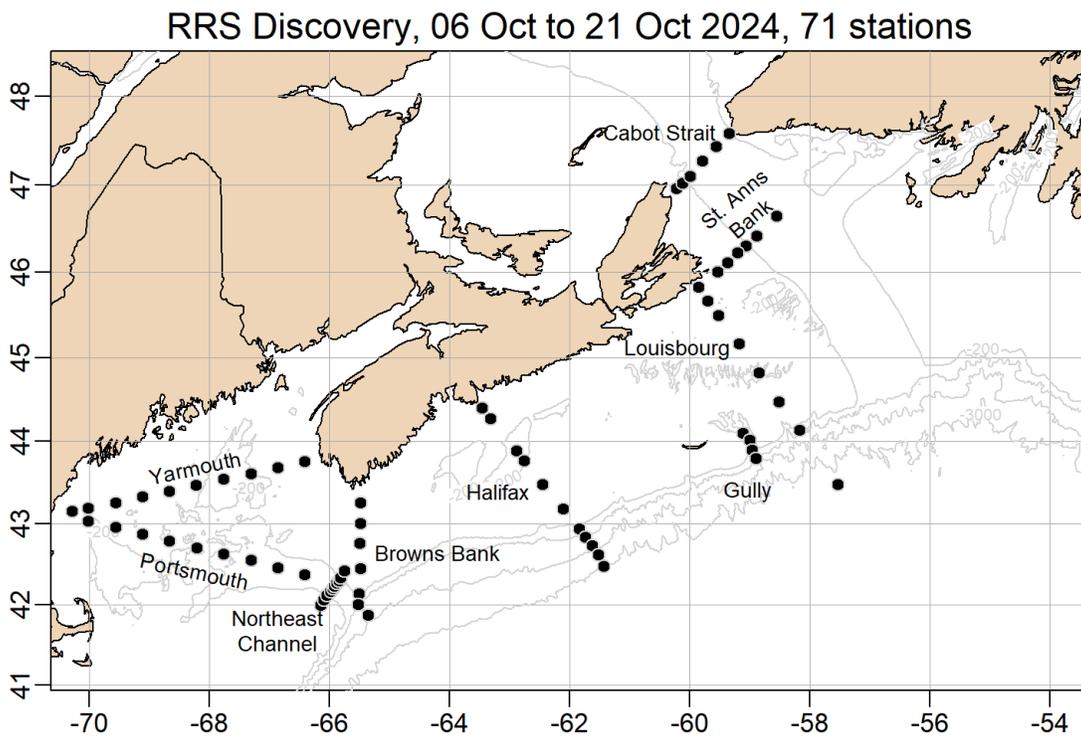


Figure 23. The 2024 sampling of the Scotian Shelf/Gulf of Maine for the fall AZMP survey.

Cabot Strait: 19 Oct to 20 Oct 2024

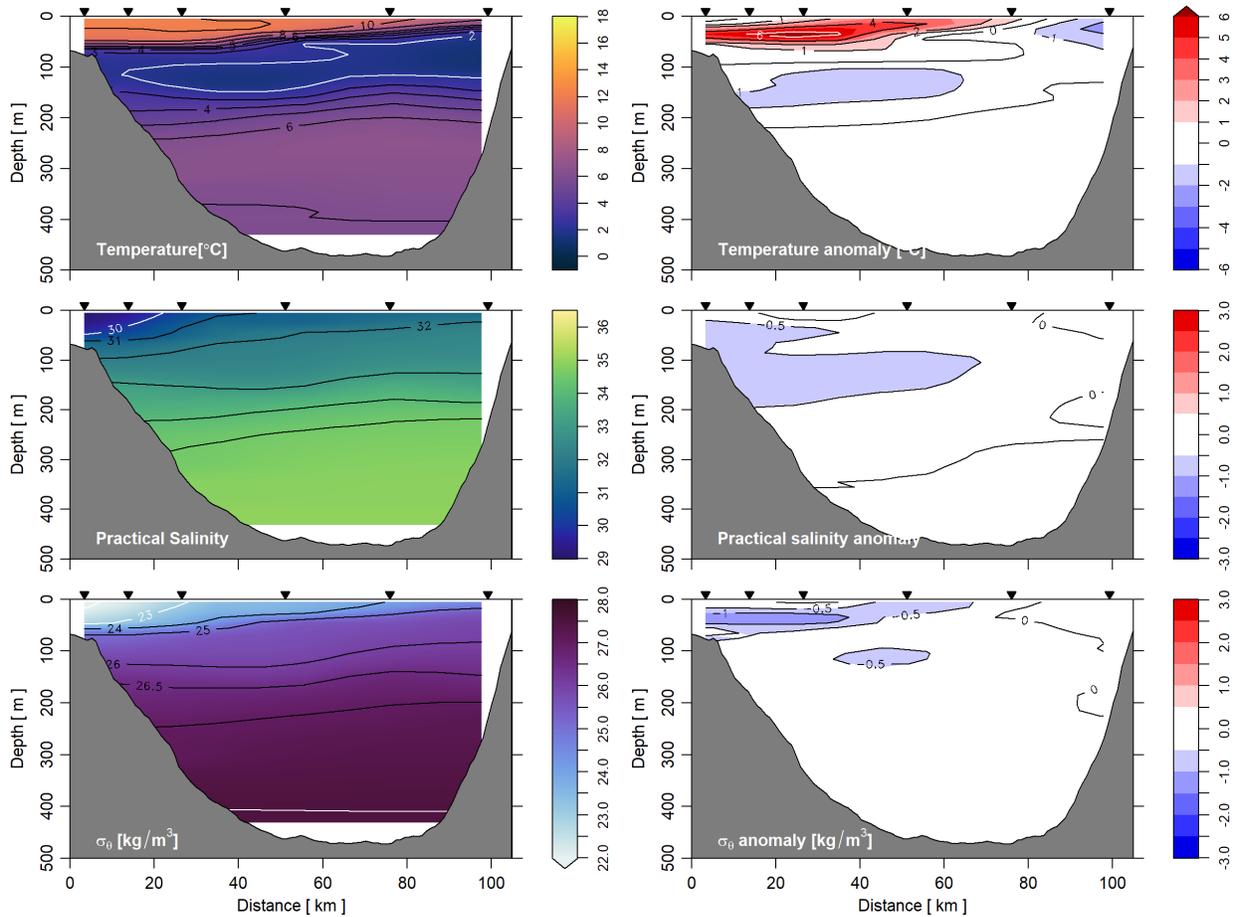


Figure 24. The 2024 sampling of the Cabot Strait line for fall. Temperature (top panel), salinity (middle panel), and density (lower panel) and their anomalies with respect to the 1991–2020 climatology (right panels). Triangles indicate locations of sampling.

Louisbourg: 16 Oct to 18 Oct 2024

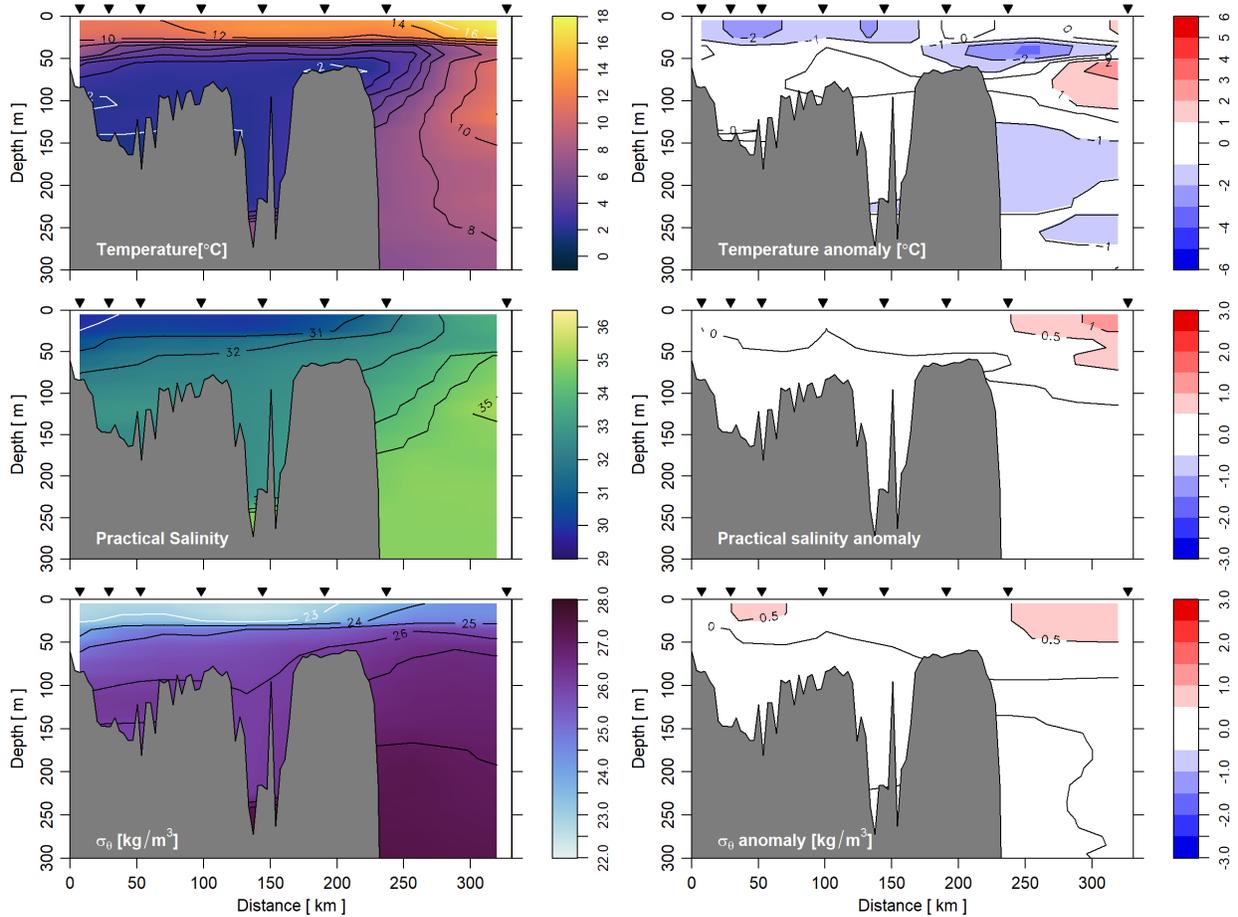


Figure 25. The 2024 sampling of the Louisbourg line for fall. Temperature (top panel), salinity (middle panel), and density (lower panel) and their anomalies with respect to the 1991–2020 climatology (right panels). Triangles indicate locations of sampling.

Halifax: 13 Oct to 14 Oct 2024

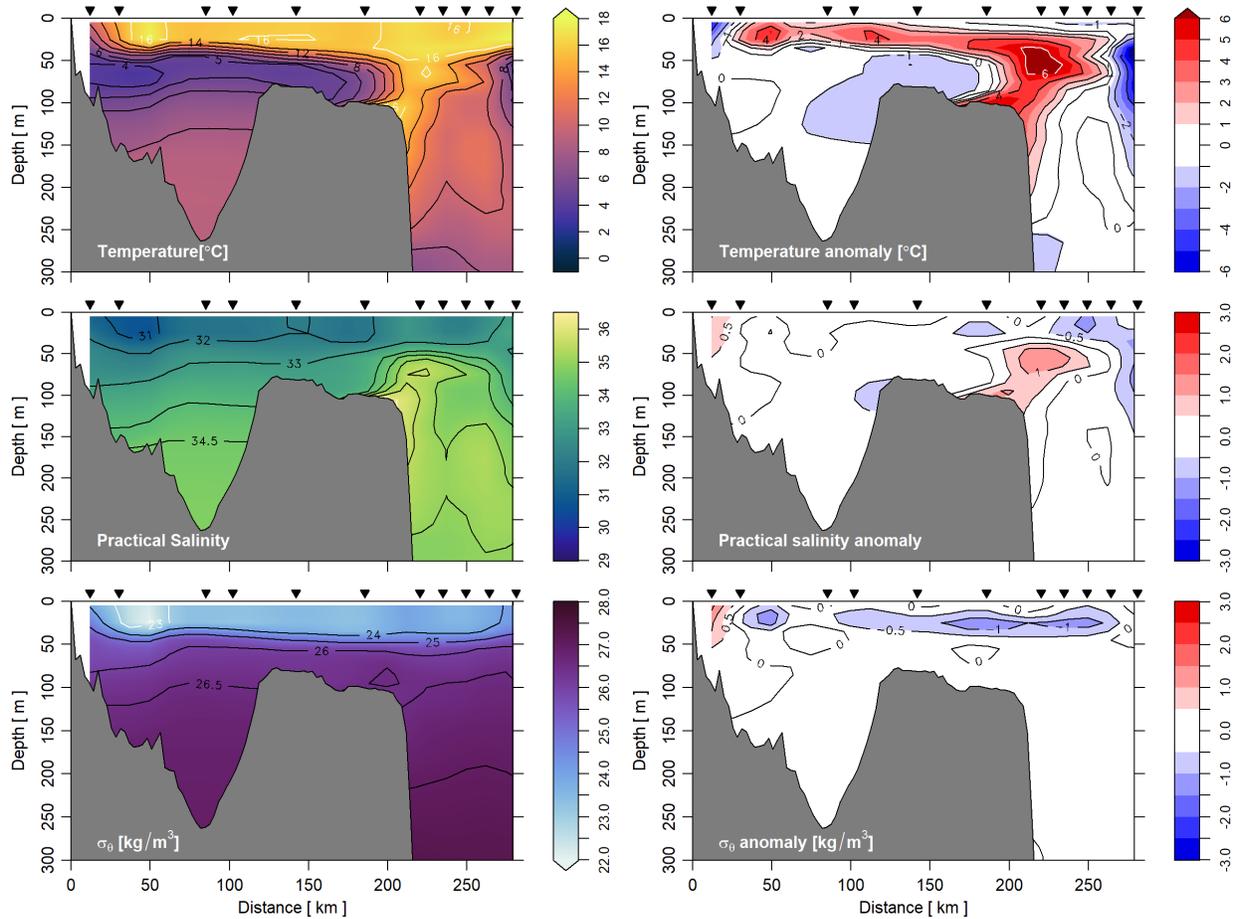


Figure 26. The 2024 sampling of the Halifax line for fall. Temperature (top panel), salinity (middle panel), and density (lower panel) and their anomalies with respect to the 1991–2020 climatology (right panels). Triangles indicate locations of sampling.

Browns Bank: 06 Oct to 07 Oct 2024

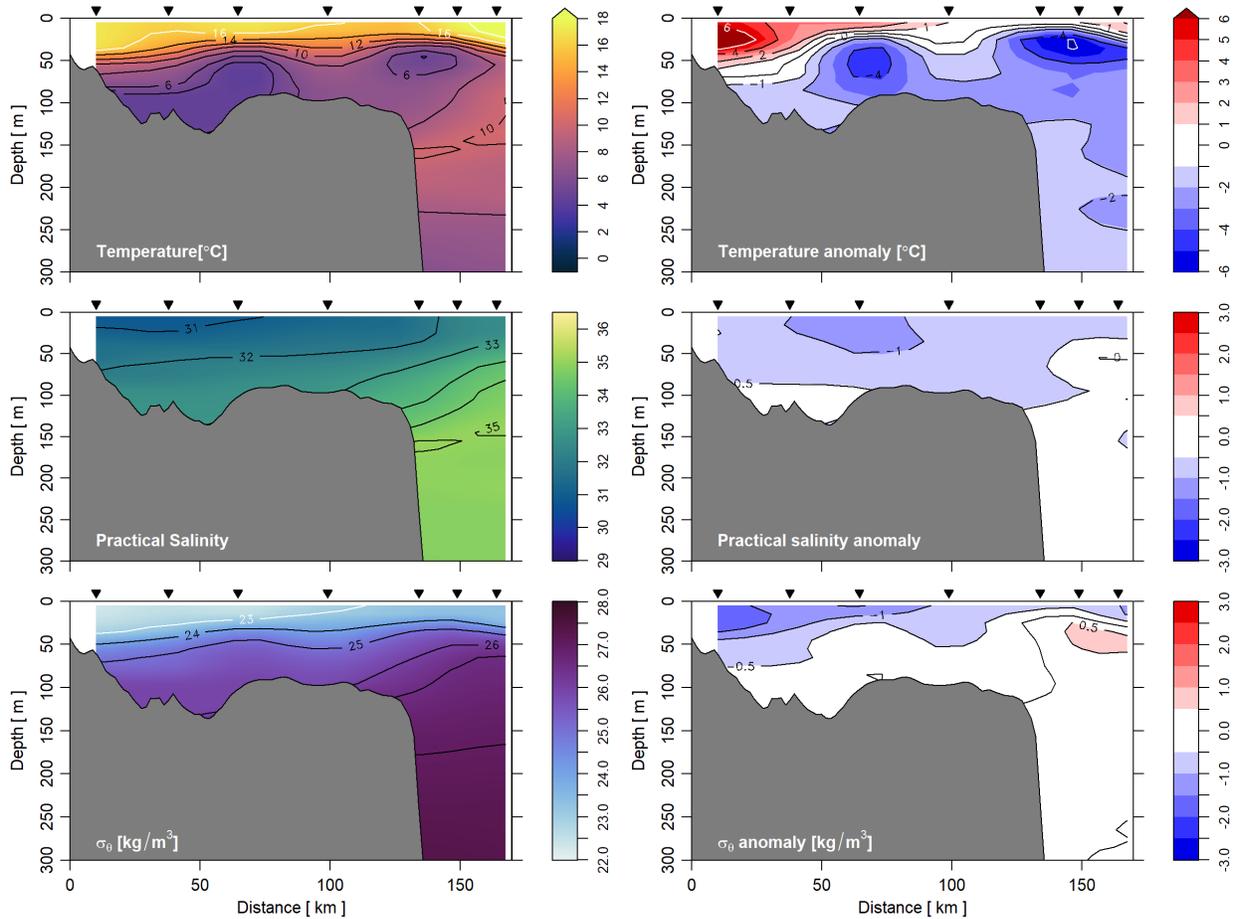


Figure 27. The 2024 sampling of the Browns Bank line for fall. Temperature (top panel), salinity (middle panel), and density (lower panel) and their anomalies with respect to the 1991–2020 climatology (right panels). Triangles indicate locations of sampling.

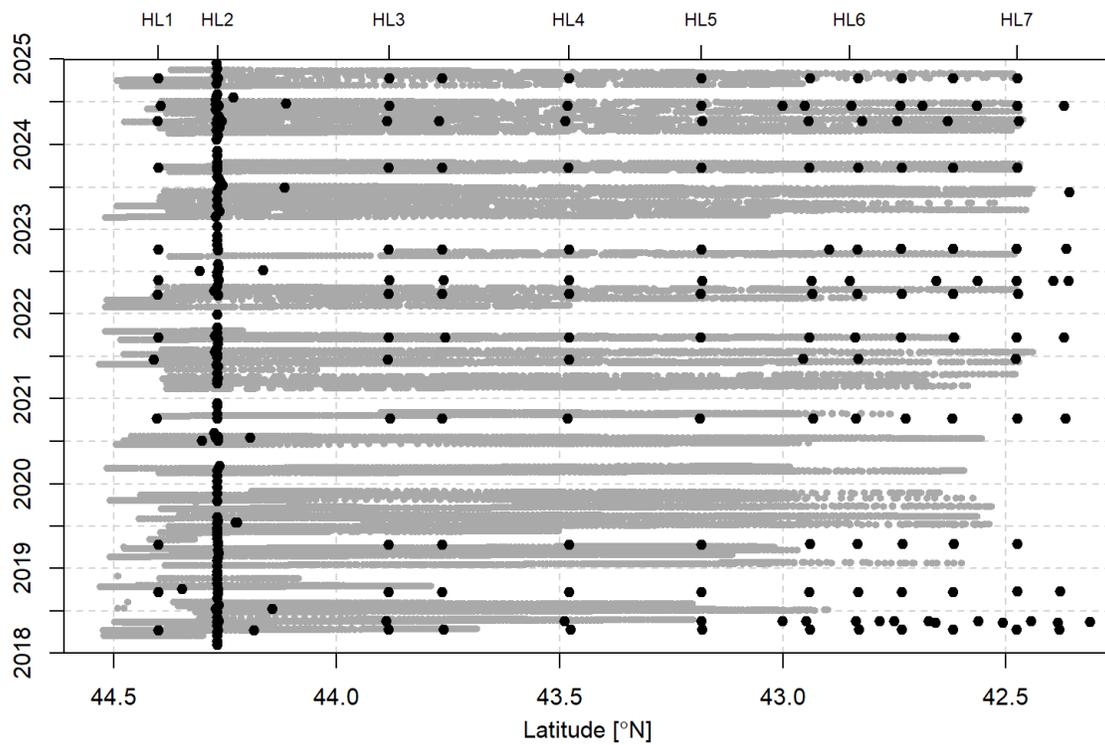


Figure 28. Hodograph of sampling on the Halifax line for 2018-2024. Black dots represent the sampling by a vessel. Grey dots represent sampling by the gliders.

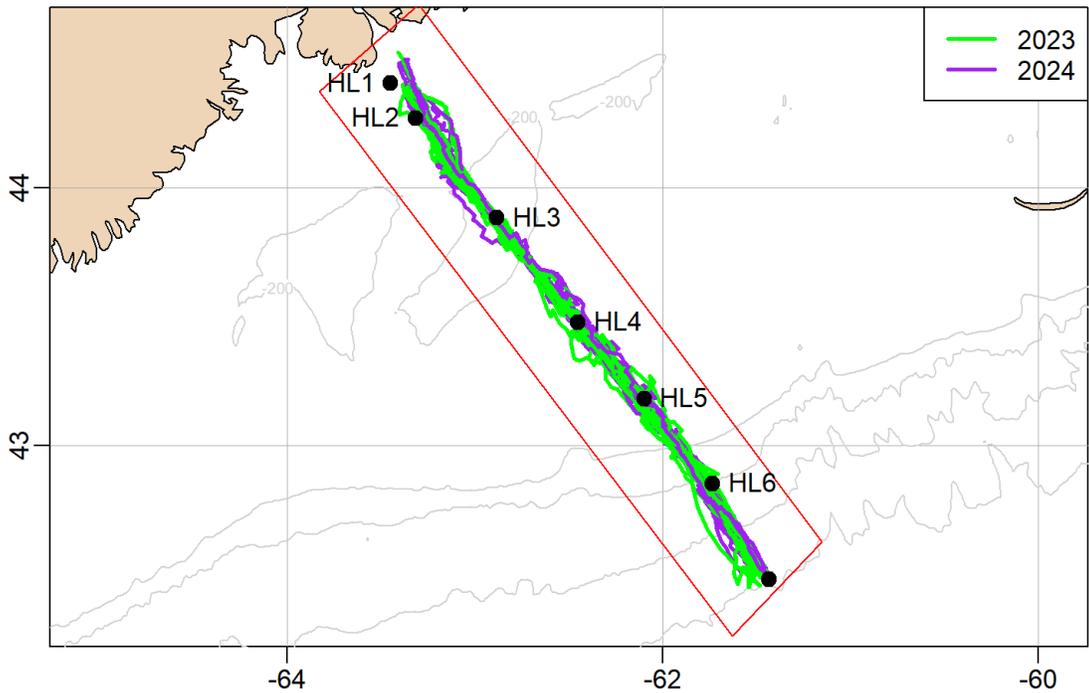


Figure 29. Glider trajectories on the Halifax line (HL) for 2023 and 2024. Locations of the HL stations are shown by the black dots. Red box shows the limitations applied to glider data to be considered on HL.

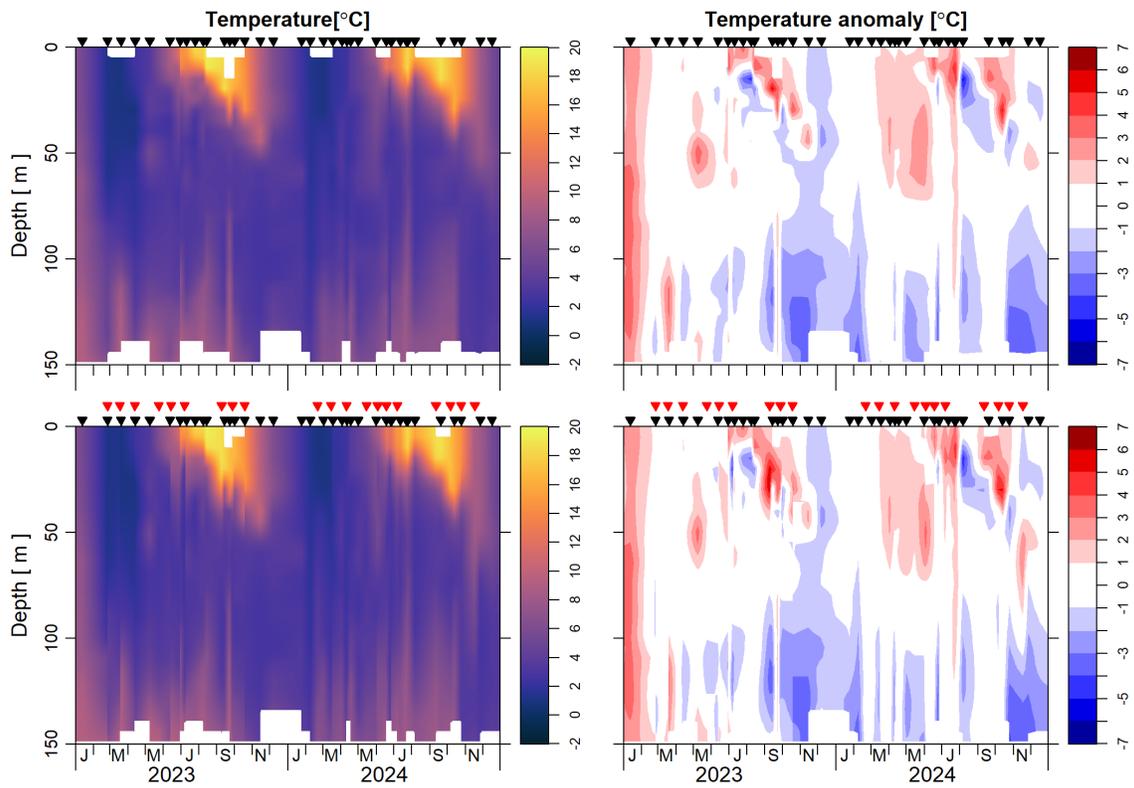


Figure 30. Top panels for temperature (left) and temperature anomaly (right) with standard vessel sampling at Station 2. Bottom panels include the additional glider data that has been averaged hourly. Times of vessel sampling (black triangles) and glider sampling (red triangles) are shown for each panel.

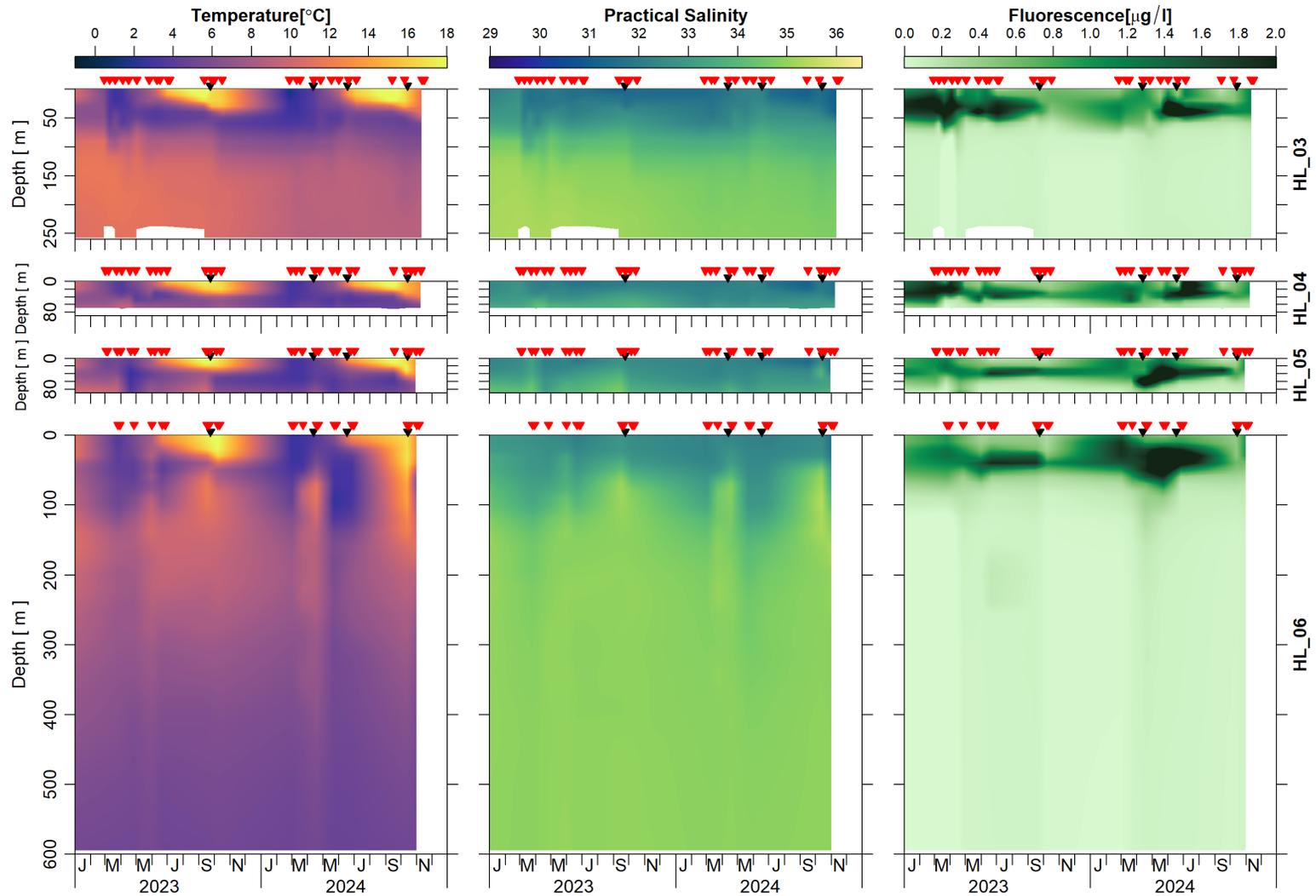


Figure 31. Temperature (left), salinity (middle), and chlorophyll fluorescence (right) for the standard hydrographic stations on the Halifax Line: HL3 (top panel), HL4 (second panel from the top), HL5 (third panel from the top), and HL6 (bottom panel). Only the top 300 m of HL data is shown. Times of vessel sampling (black triangles) and glider sampling (red triangles) are shown for each panel.

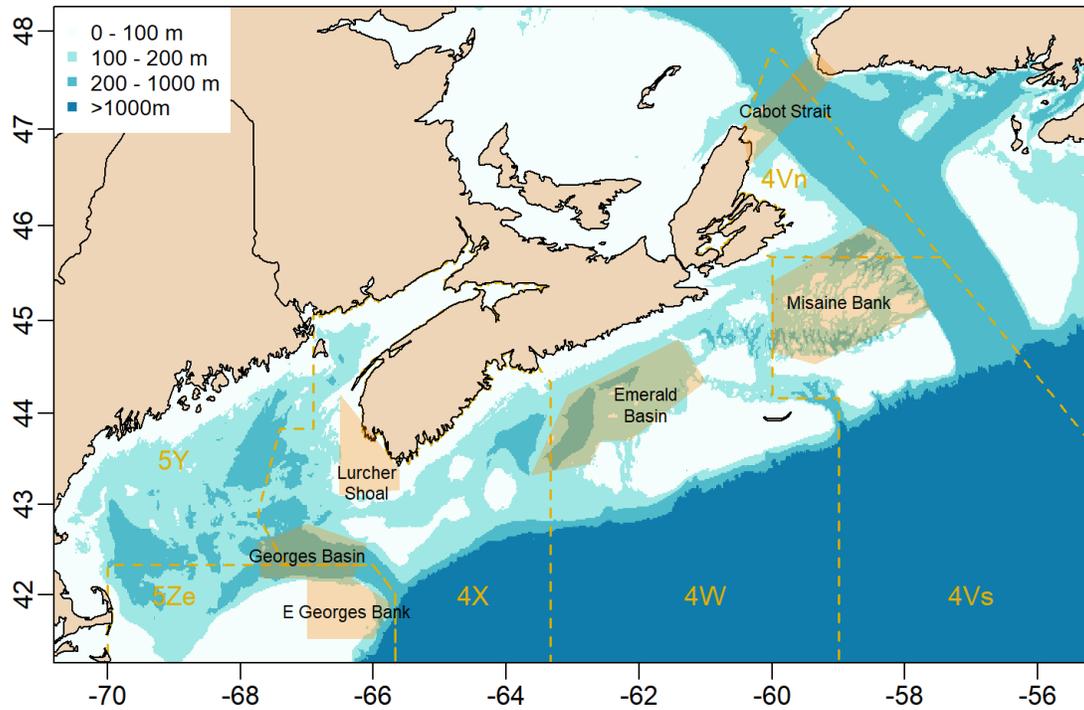


Figure 32. Areas on the Scotian Shelf and eastern Gulf of Maine depicting the different water masses: Cabot Strait; Misaine Bank; Emerald Basin; Lurcher Shoals; Georges Basin; and Eastern Georges Bank.

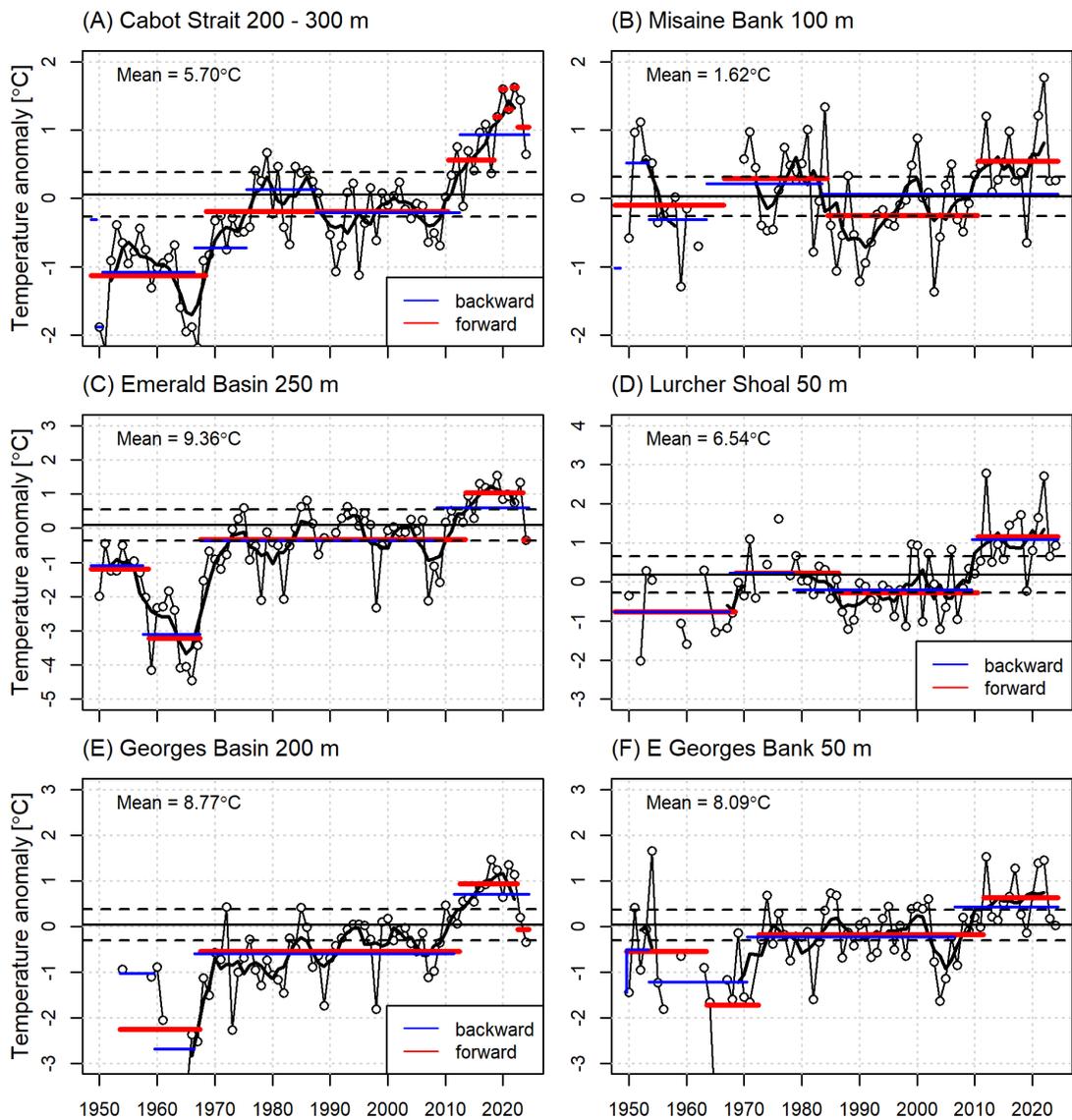


Figure 33. The annual mean temperature anomaly time series (line with circles) and the five-year-running-mean filtered anomalies (thick solid line) on the Scotian Shelf and in the Gulf of Maine at: (A) Cabot Strait at 200–300 m, (B) Misaine Bank at 100 m, (C) Emerald Basin at 250 m, (D) Lurcher Shoals at 50 m, (E) Georges Basin at 200 m, and (F) Eastern Georges Bank at 50 m (see Figure 32 for locations of regions). Horizontal dashed lines represent the mean ± 0.5 SD for the 1991–2020 period. Regime shift analysis results from running the method forwards and backwards on the time series depicted by the red and blue horizontal lines, respectively. Note that the y-axis range is different for each panel.

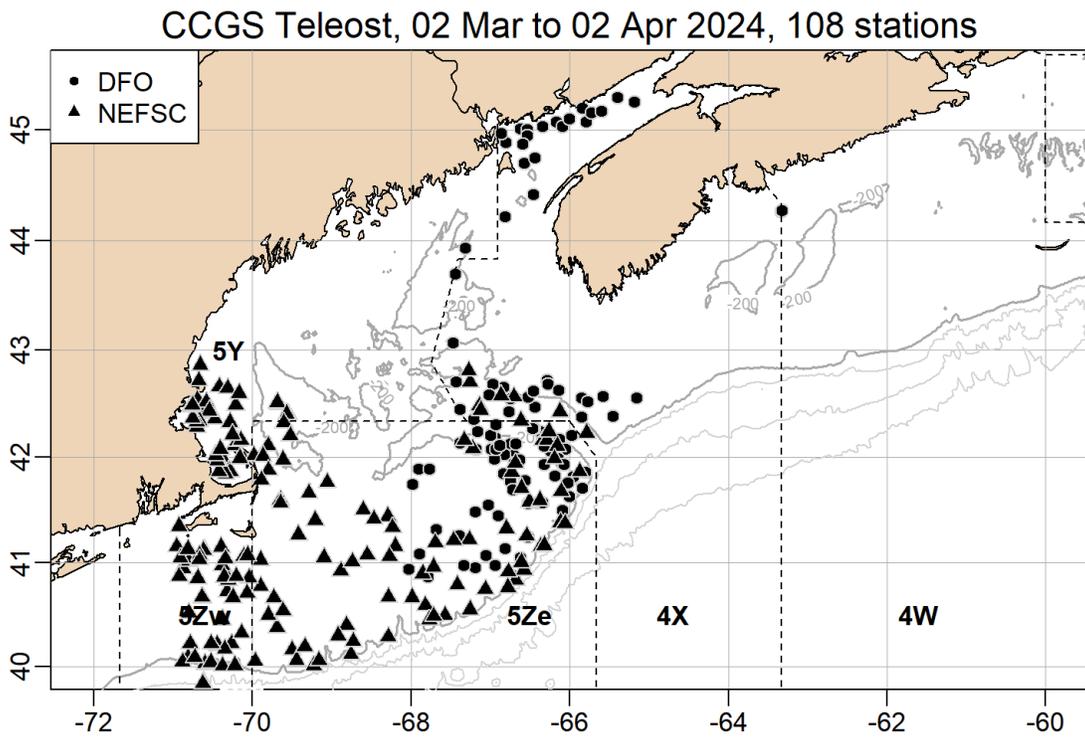


Figure 34. Locations of CTD sampling during the 2024 winter ecosystem trawl survey. The 200 m isobath is shown as a darker line. NAFO Divisions 4W, 4X, 5Ze, 5Y, and 5Zw are shown.

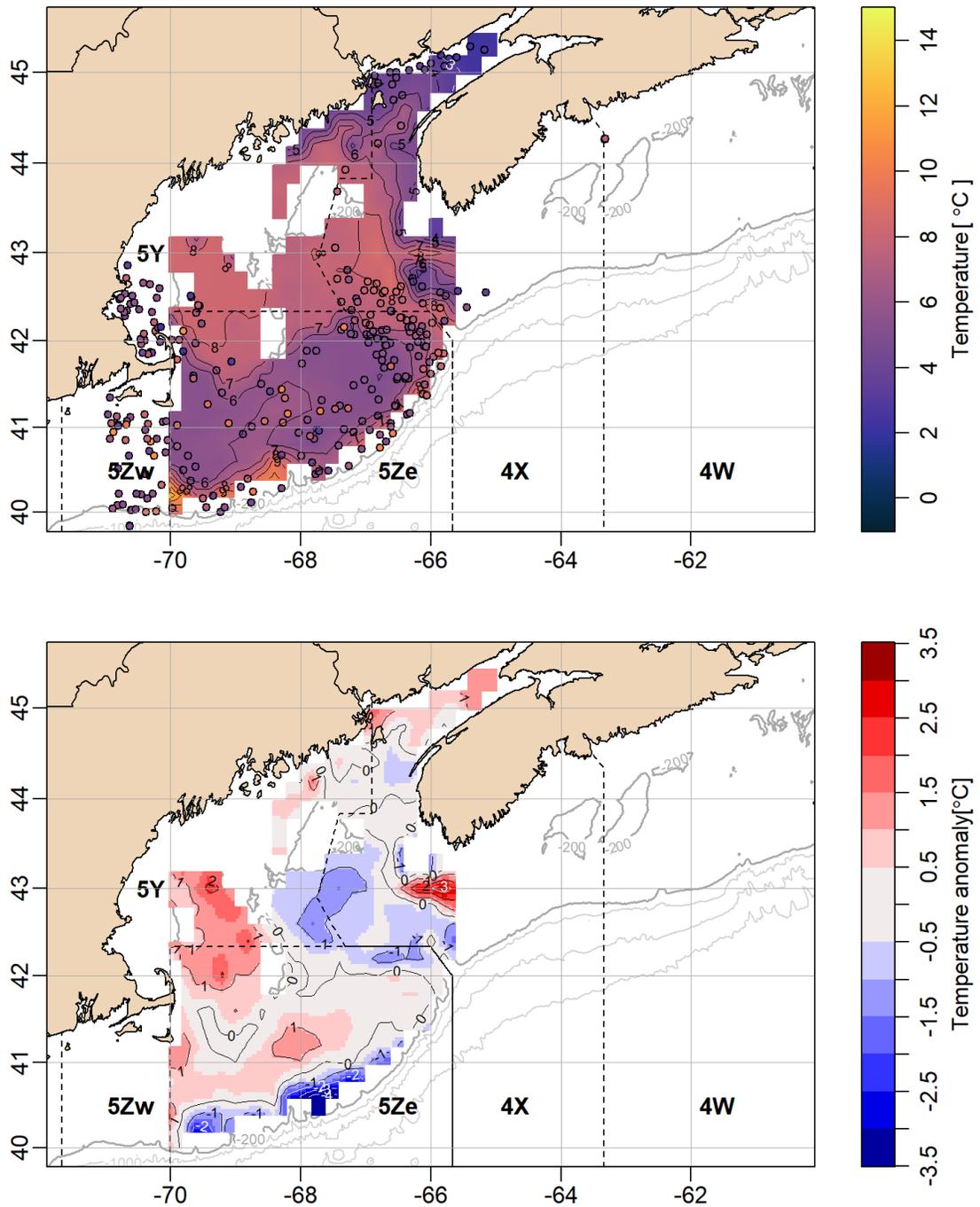


Figure 35. Winter bottom-temperature (upper panel) and anomaly (lower panel; relative to 1991–2020) maps for 2024. NAFO Divisions 4W, 4X, 5Ze, 5Y, and 5Zw are shown.

CCGS Capt. Jacques Cartier, 25 Jun to 06 Aug 2024, 239 stations

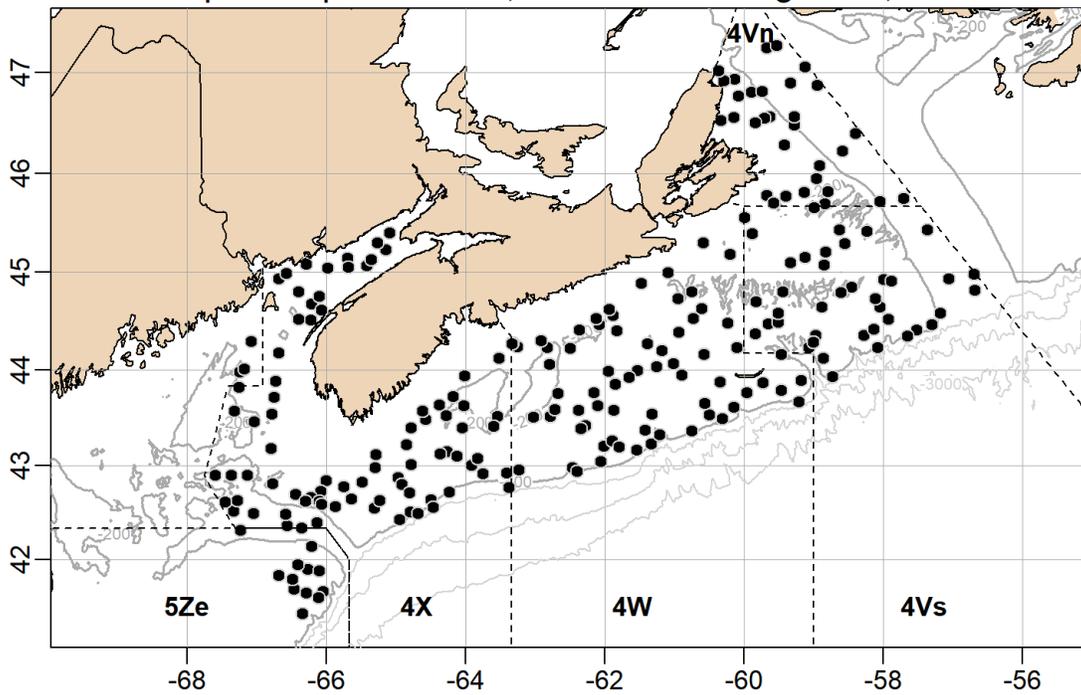


Figure 36. Locations of CTD sampling during the 2024 summer ecosystem trawl survey. The 200 m isobath is shown as a darker line. NAFO Divisions 4Vn, 4Vs, 4W, 4X, 5Ze, and 5Y, are shown.

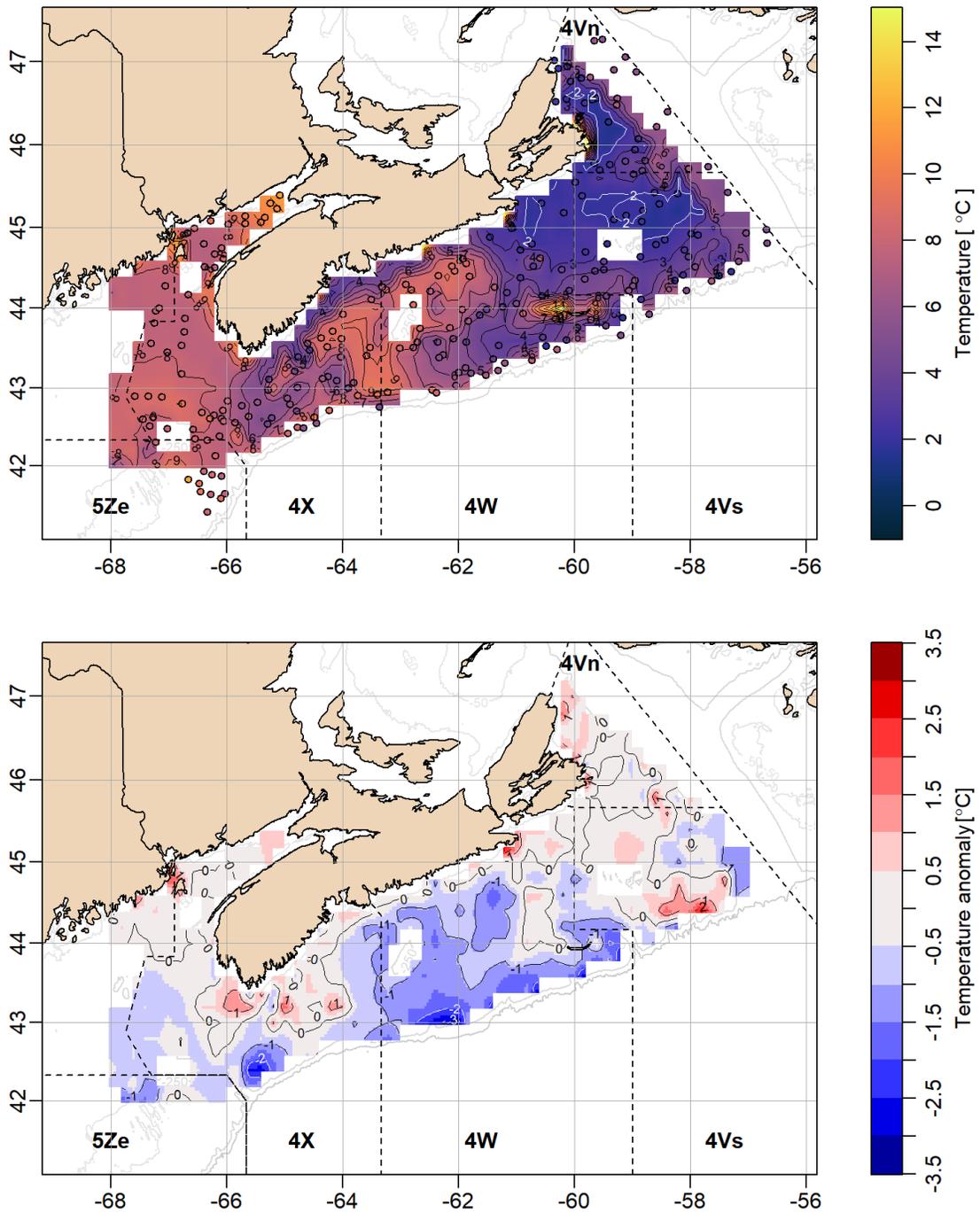


Figure 37. Summer bottom-temperature (upper panel) and anomaly (lower panel; relative to 1991–2020) maps for 2024. NAFO Divisions 4Vn, 4Vs, 4W, 4X, 5Ze, and 5Y are shown.

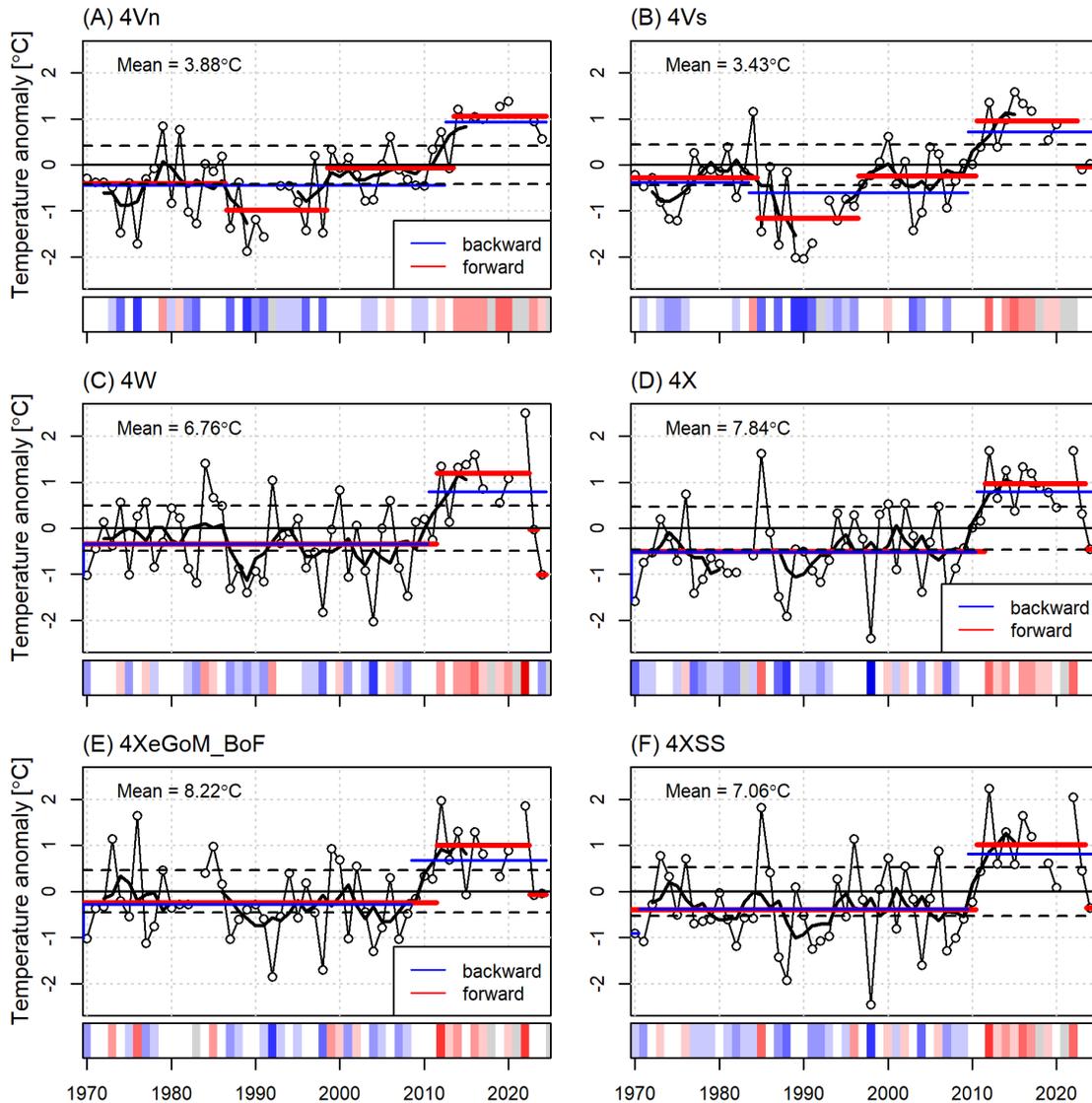


Figure 38. Time series of July bottom temperature anomalies (thin lines with circles) and five year running mean filtered series (thick line) for NAFO Divisions: 4Vn, 4Vs, 4W, 4X, and 4X separated into two regions; the eastern Gulf of Maine/Bay of Fundy(eGoMBoF) and the Scotian Shelf (SS). The solid horizontal line is the 1991-2020 mean and dashed lines represent ± 0.5 SD. Regime shift analysis results from running the method forwards and backwards on the time series depicted by the red and blue horizontal lines, respectively.

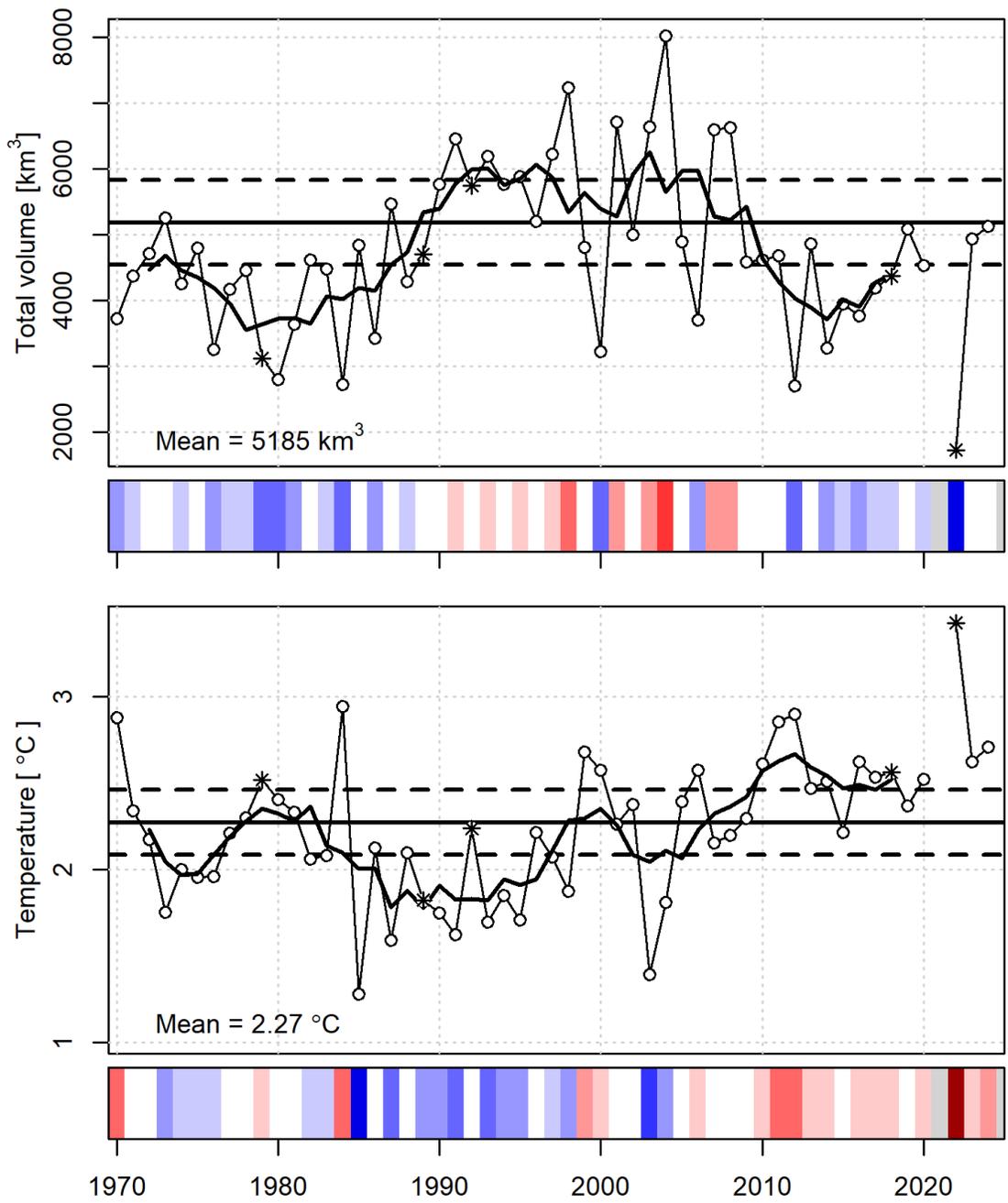


Figure 39. Time series of the Cold Intermediate Layer (CIL; defined as waters with temperature $< 4^{\circ}\text{C}$) volume (circles connected by a thin black line) on the Scotian Shelf based on the DFO ecosystem summer trawl survey (top panel) with the five-year running mean (thick solid line). When grid coverage is less than 70%, a blended CIL calculation is used, indicated by an asterisk. The area-weighted average minimum temperature (circles connected by a thin black line) in the CIL (bottom panel) with the five-year running mean (thick solid line). The solid horizontal lines are the 1991–2020 means and dashed lines represent ± 0.5 SD.

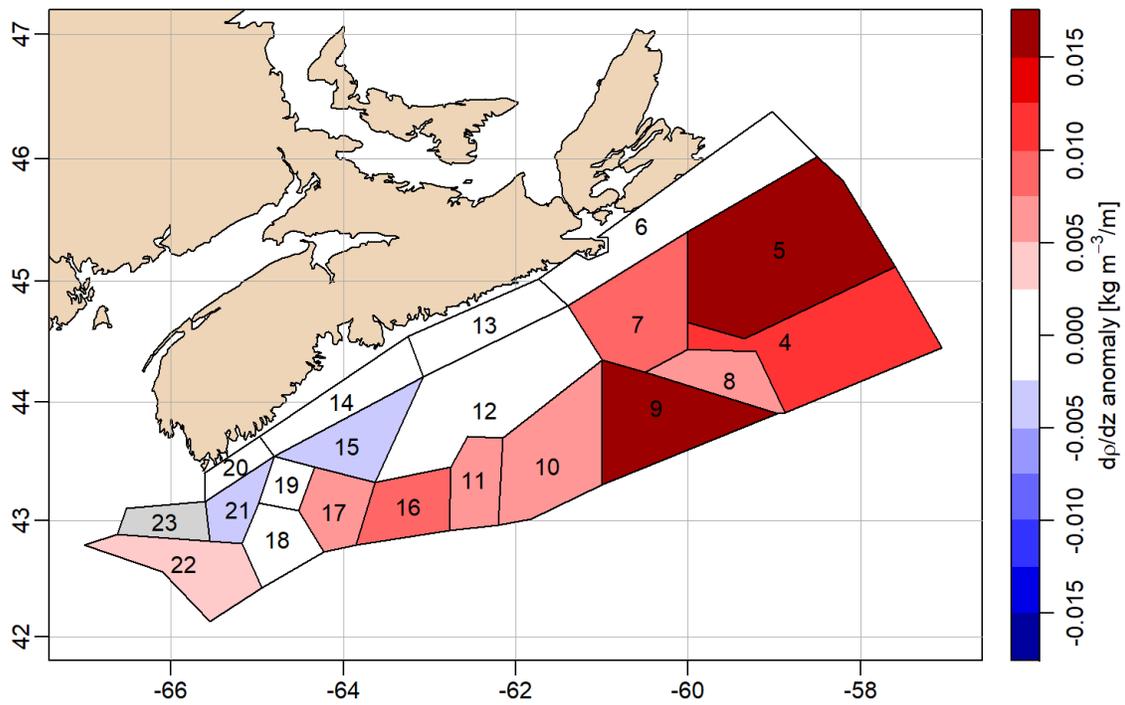


Figure 40. Stratification annual anomaly over the Scotian Shelf for 2024. The different areas were defined by Petrie et al. (1996).

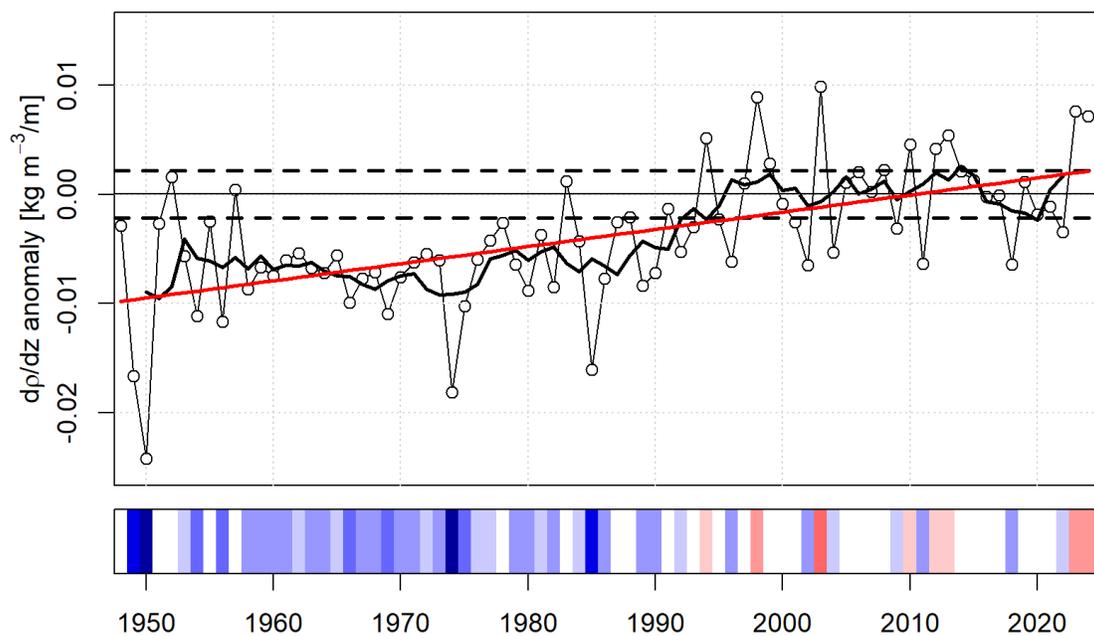


Figure 41. Stratification index (0–50 m density gradient) mean annual anomaly (black line with circles) and five-year running mean (black thick solid line) averaged over the Scotian Shelf. The linear trend (red line) shows a change in the 0–50 m density difference of 0.78 kg m^{-3} over 100 years for the 1991-2020 period.

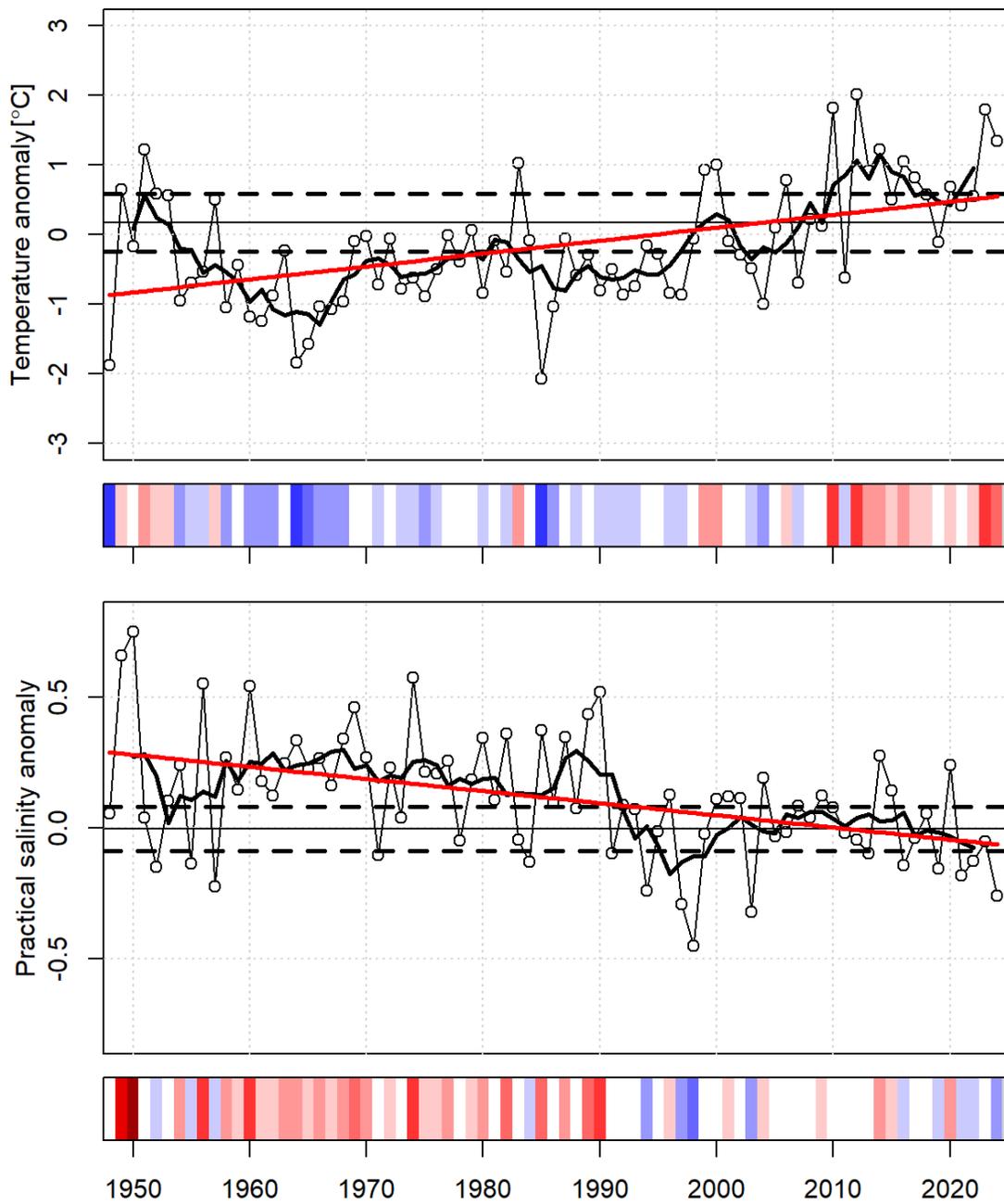


Figure 42. The mean-annual-surface-temperature (top panel) and salinity (lower panel) anomalies (black line with circles) and five-year running mean (black thick solid line) averaged over the Scotian Shelf. The linear trend (red line) shows a warming of 0.93°C and a freshening of 0.46 over a 100-year period.

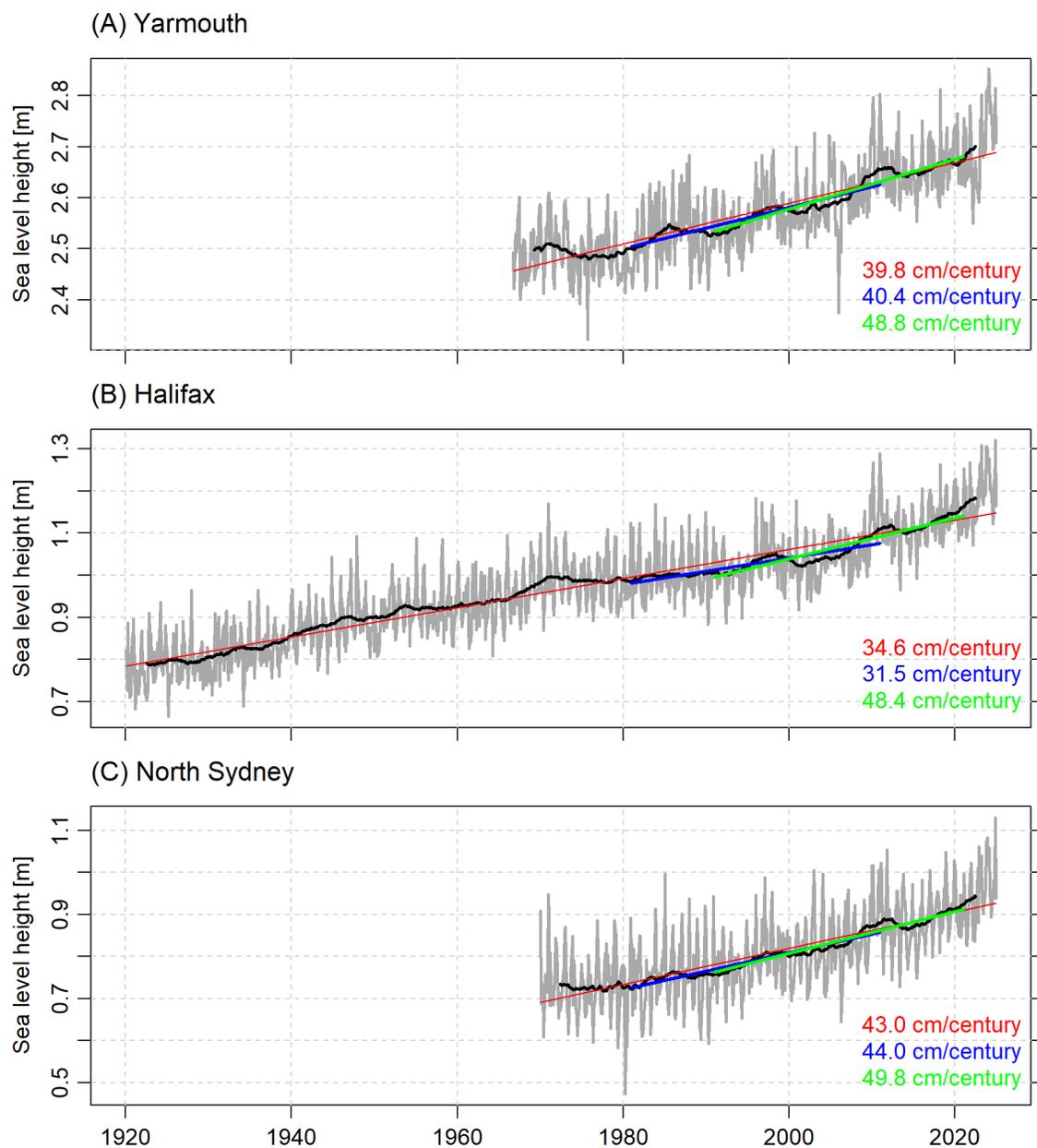


Figure 43. The time series of the monthly means (grey line) and a five-year running mean (black line) of the relative sea-level elevations at Yarmouth (top panel), Halifax (middle panel), and North Sydney (bottom panel), along with the linear trend (red line) over the observation period, over 1981–2010 (blue line) and over 1991–2020 (green line).

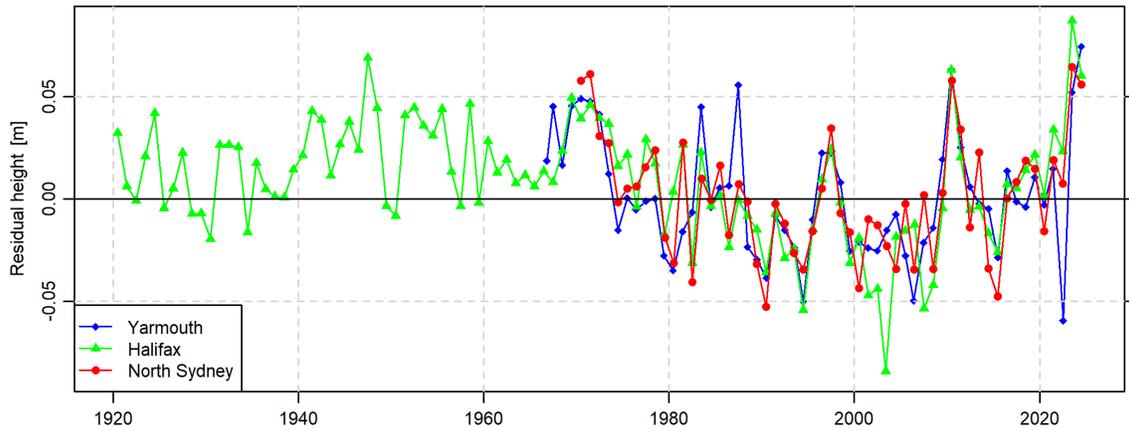


Figure 44. Residual relative sea level (annual observed values minus linear trend based on the 1970— 2024 period) for Yarmouth (blue line with diamonds), Halifax (green line with triangles), and North Sydney (red line with circles).

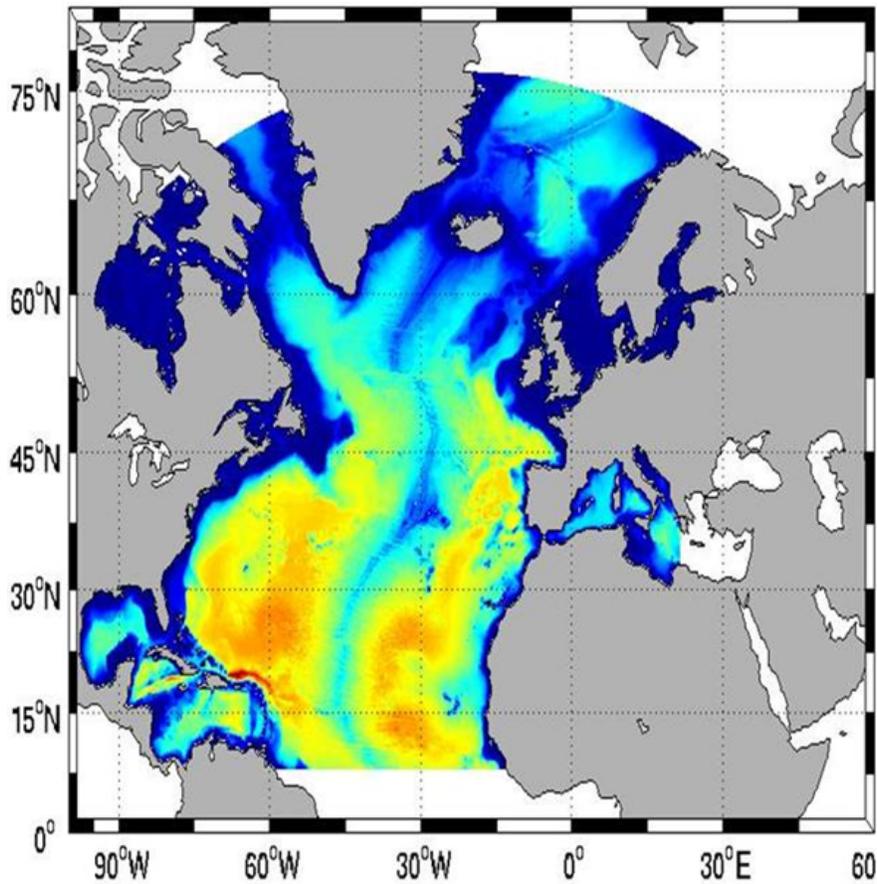


Figure 45. The BIO North Atlantic Model (BNAM) domain Bathymetry coloured from red (deep) to blue (shallow).

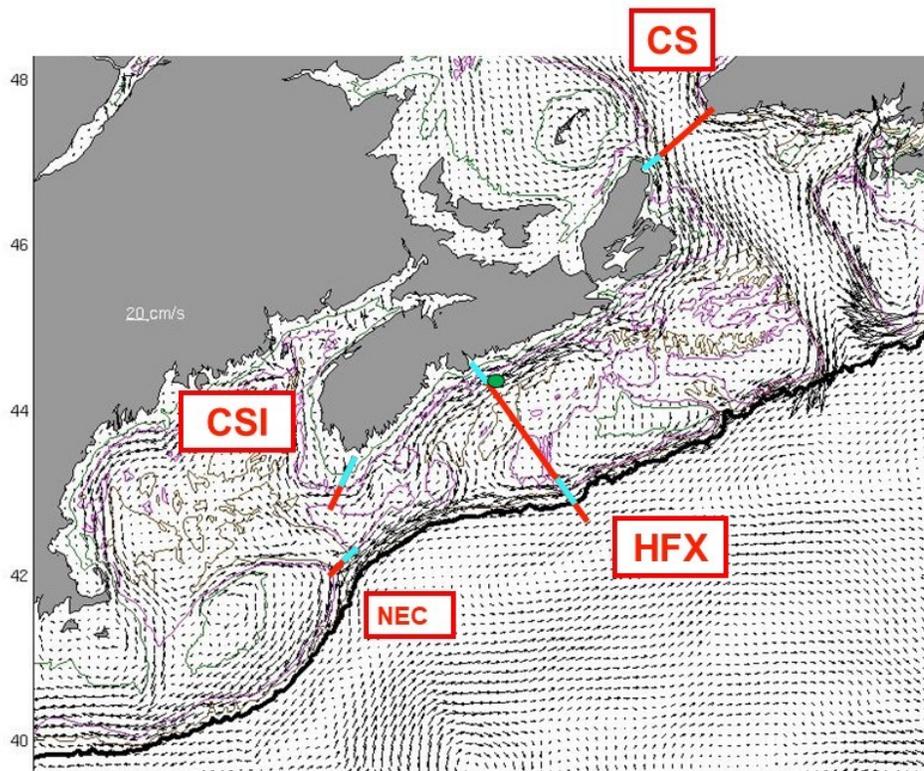


Figure 46. Climatological-annual and depth-averaged circulation illustrating the principal flow pathways from the southern Gulf of St. Lawrence to the Gulf of Maine and the subsections where transport calculations were made (cyan). CS = Cabot Strait; HFX = Halifax; CSI = Cape Sable Island/Browns Bank; NEC = Northeast Channel. Green circle shows the location off T2.

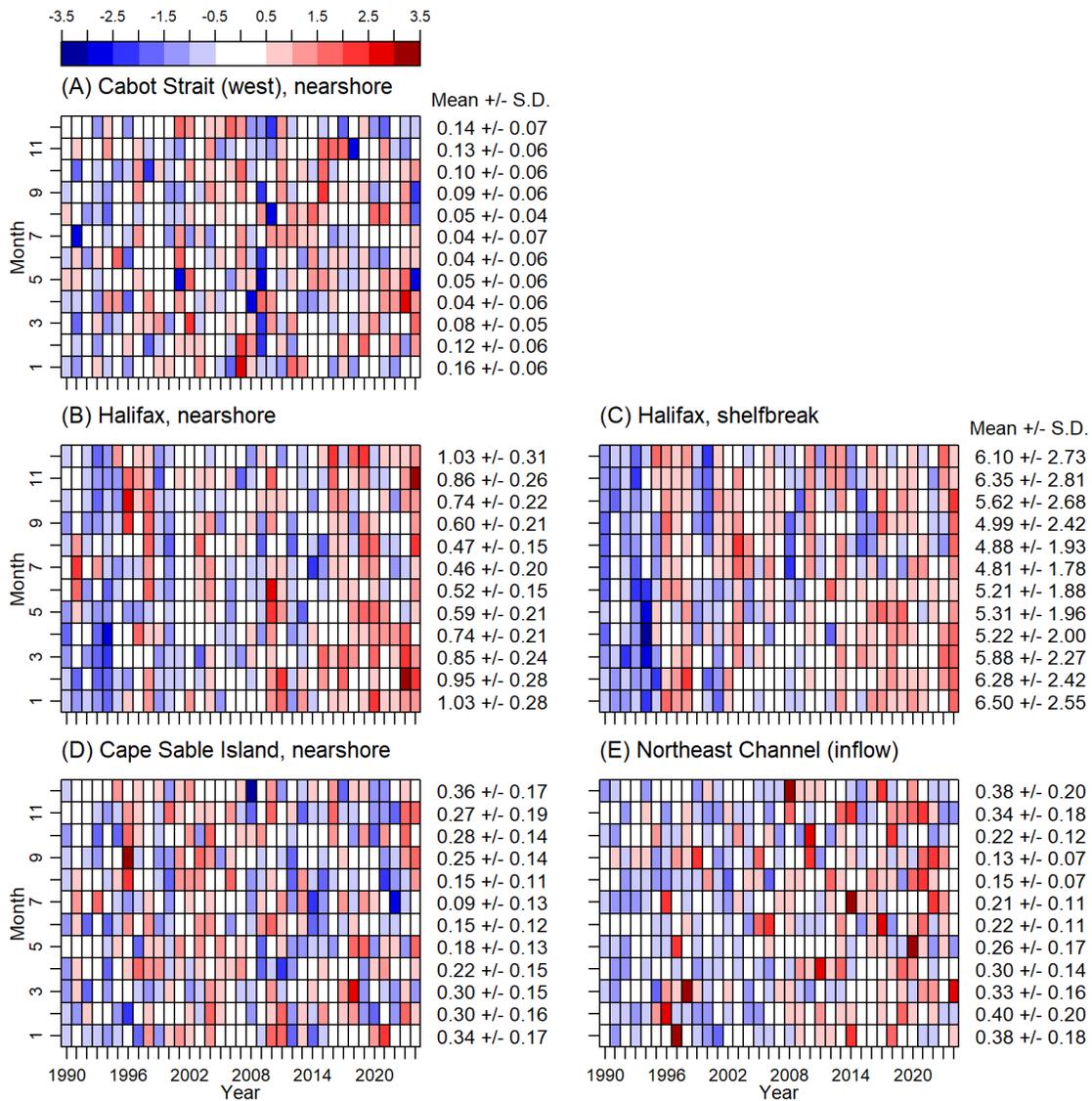


Figure 47. Standardized anomalies of the monthly transport relative to the 1991-2020 climatology for four Maritime sections: (A) Cabot Strait (CS) west nearshore; Halifax (HF) (B) nearshore and (C) shelf break; (D) Cape Sable Island (CSI) nearshore; and (E) the Northeast Channel (NEC). Numbers to the right are climatology monthly means and standard deviations in Sverdrups ($1 \text{ Sv} = 10^6 \text{ m}^3 \text{ s}^{-1}$).

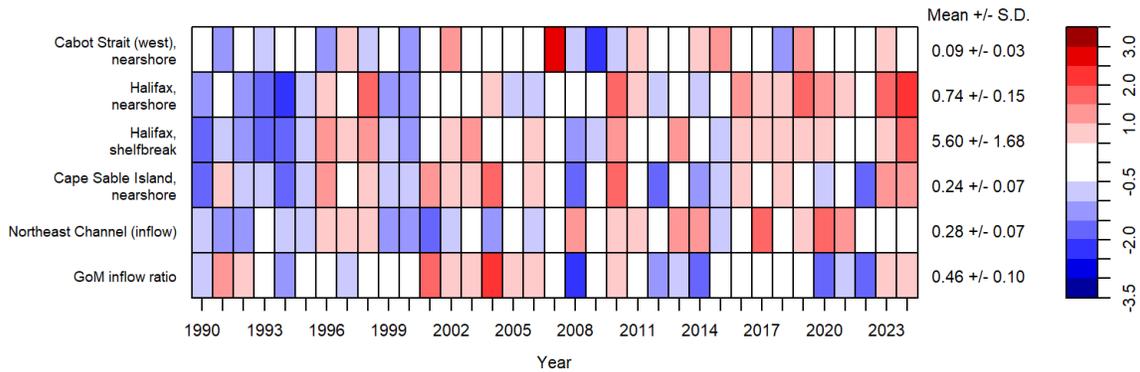


Figure 48. Annual transport anomalies scaled by the standard deviation for the monthly values shown in Figure 47 and Figure 50. Numbers to the right are climatological (1991-2020) annual means and standard deviations (in Sverdrups).

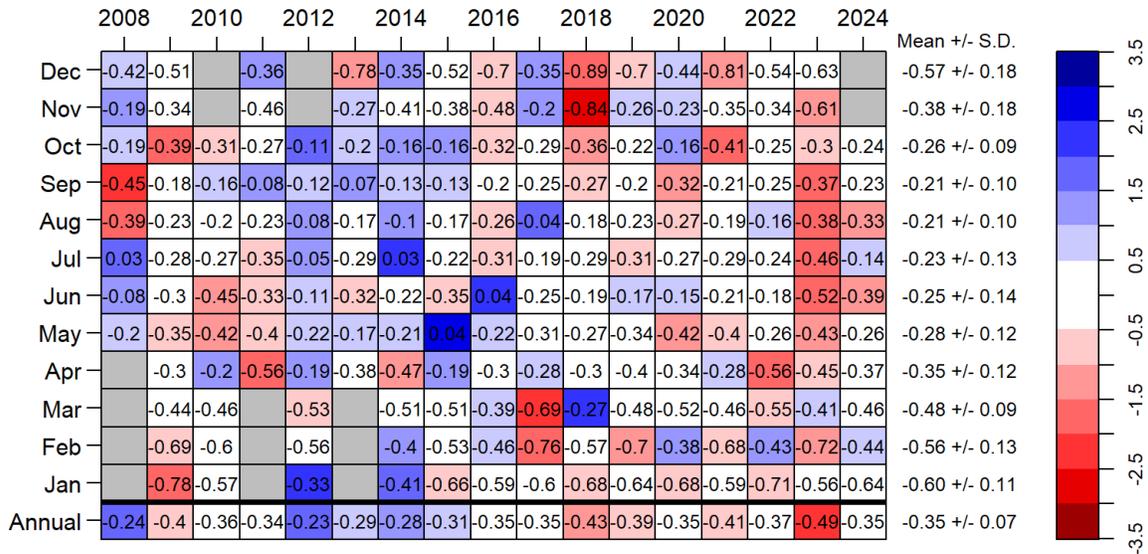


Figure 49. Monthly transport (Sv) for the Nova Scotia Current south of Halifax from ADCP measurements. Negative transports are to the southwest. The monthly transports are colour-coded for whether they are above, less southwestward (blue), or below, stronger southwestward (red), than the monthly average for the observation period (numbers to the right) by more than one-half standard deviation.

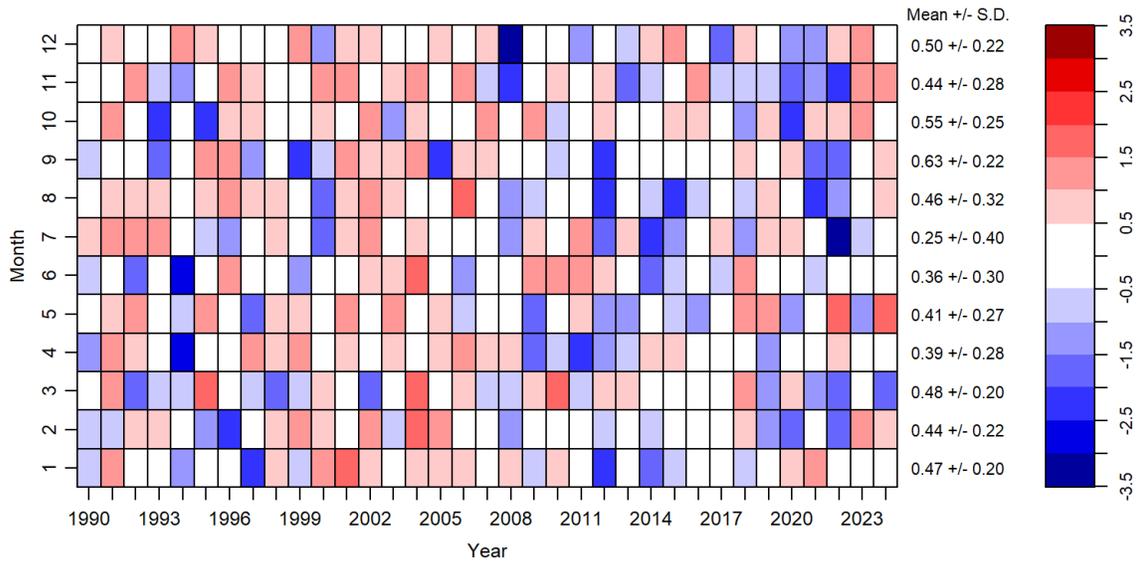


Figure 50. Standardized anomalies of the Gulf of Maine inflow ratio. Numbers to the right are 1991-2020 climatological monthly means and standard deviations.

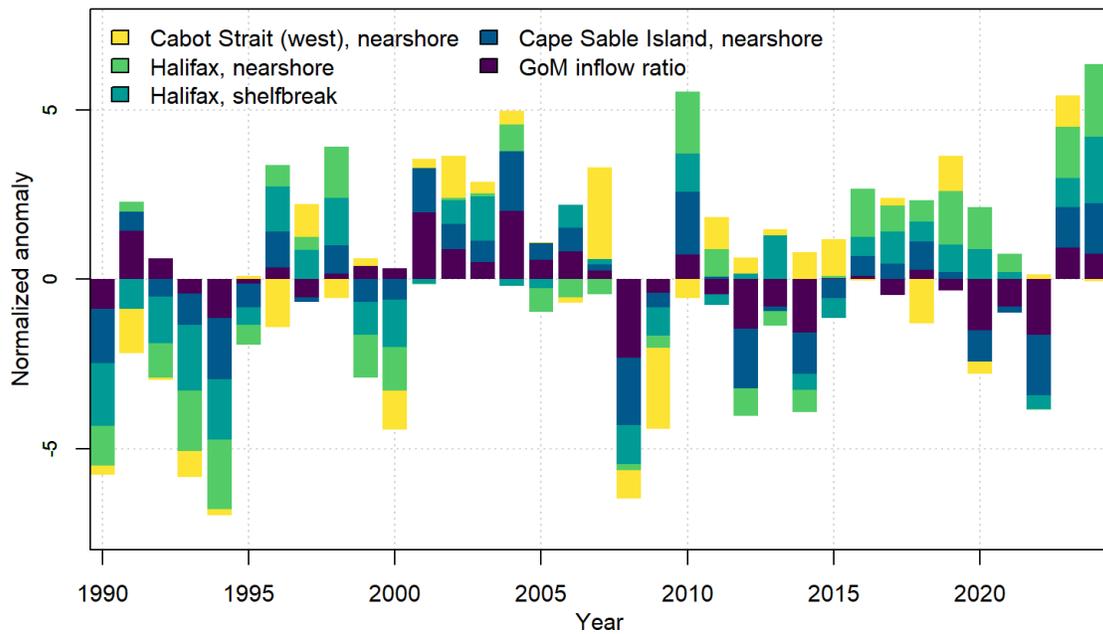


Figure 51. Sum of standardized transport anomalies for the variables in Figure 48.

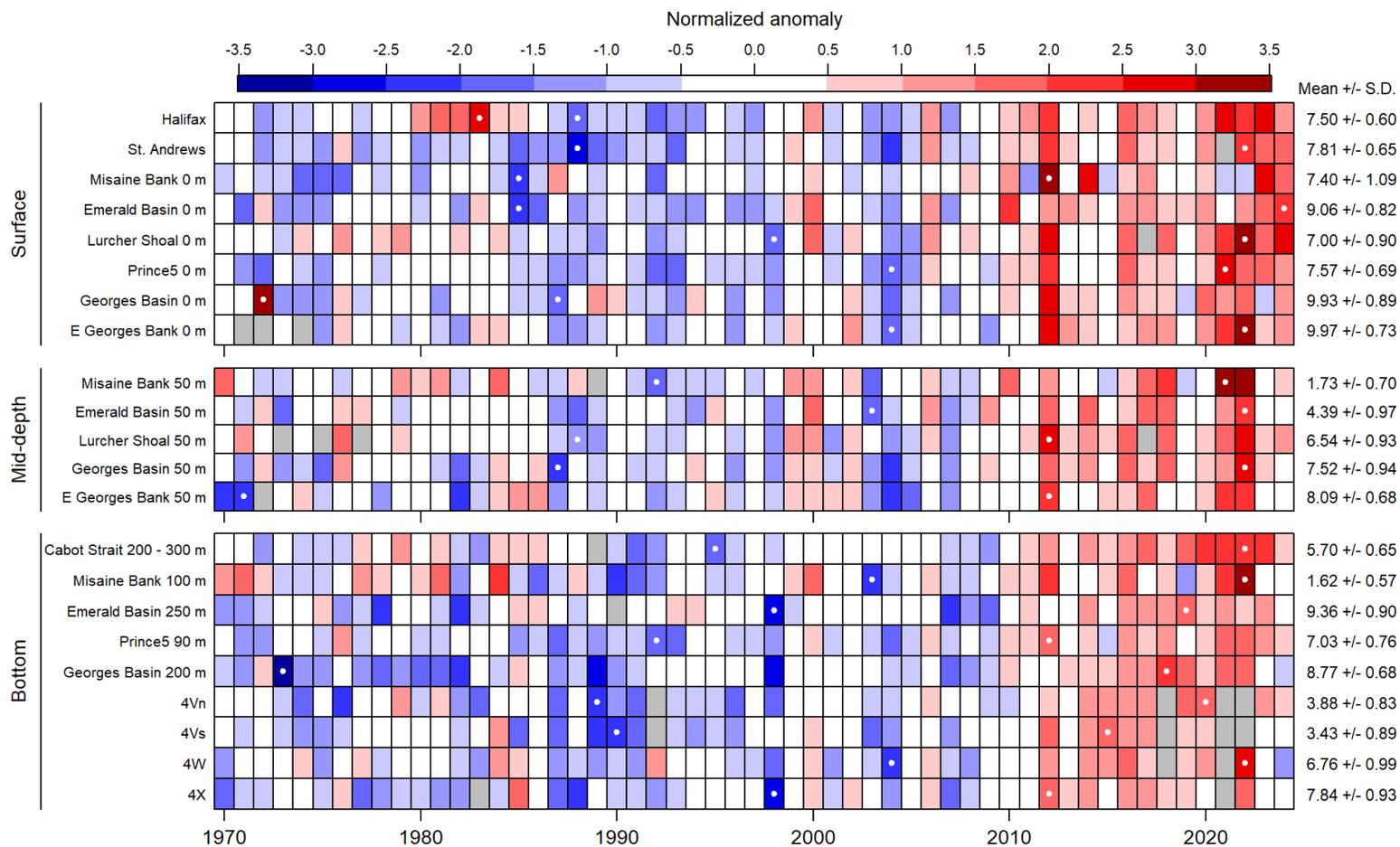


Figure 54. Normalized annual anomalies of temperatures surface, mid-depth, and bottom for the Scotian Shelf/Gulf of Maine region. These anomalies are based on the 1991–2020 means divided by the standard deviation. Blue colours indicate below-normal anomalies. Red colours indicate above-normal anomalies. White dots represent record minimum and maximum years for each parameter. Gray represents lack of data.

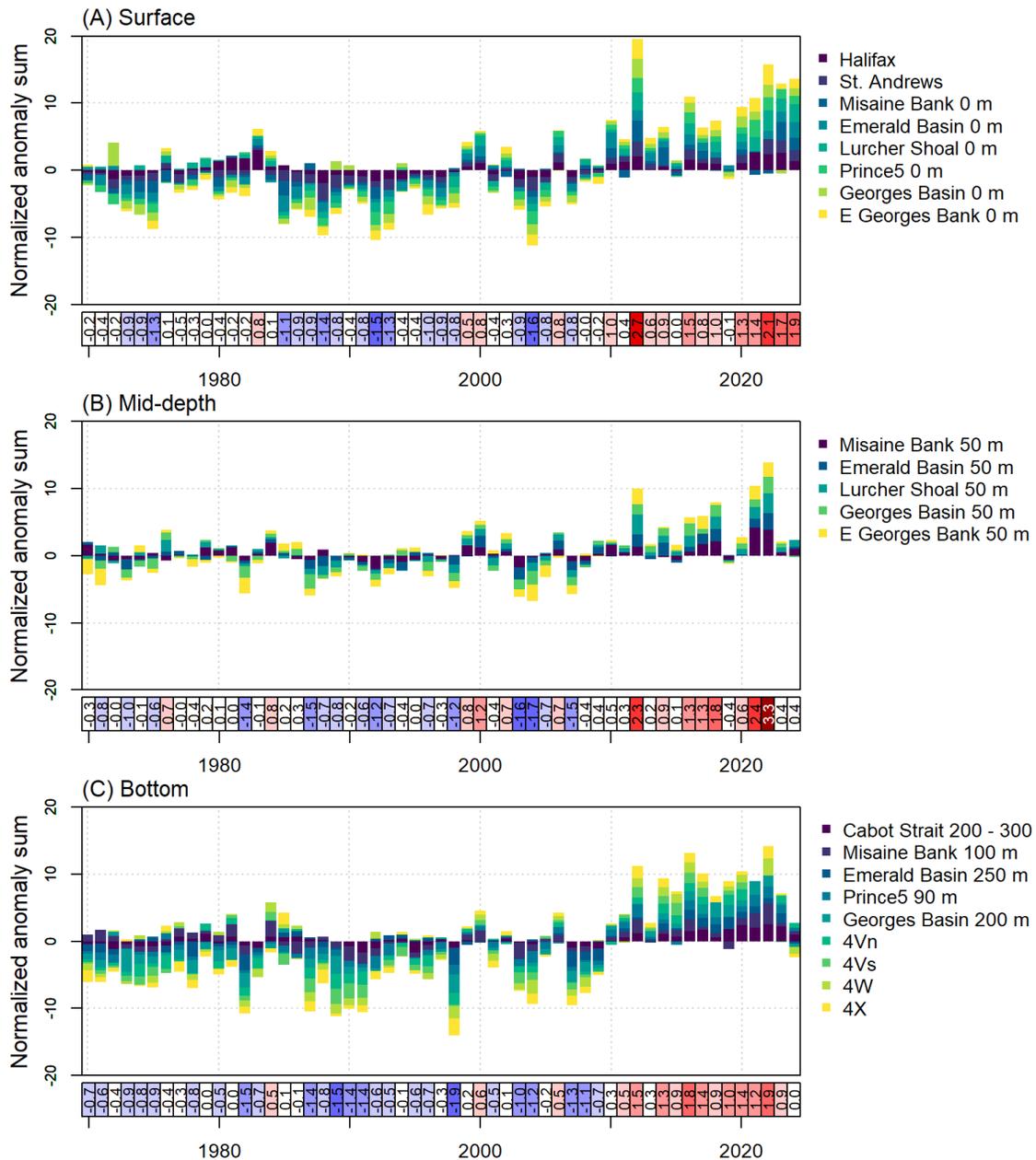


Figure 55. Composite indices from variables represented in Figure 54 by summing the normalized anomaly for temperatures measured at the surface (top), mid-depth (middle), and bottom (bottom). Values above the zero line are positive anomalies and below are negative anomalies. Scorecard values below each panels are re-normalized to the 1991 to 2020 climatology period. Blue colours indicate below-normal anomalies, white colours indicate normal anomalies, and red colours indicate above-normal anomalies.

APPENDIX A ANCILLARY SECTIONS

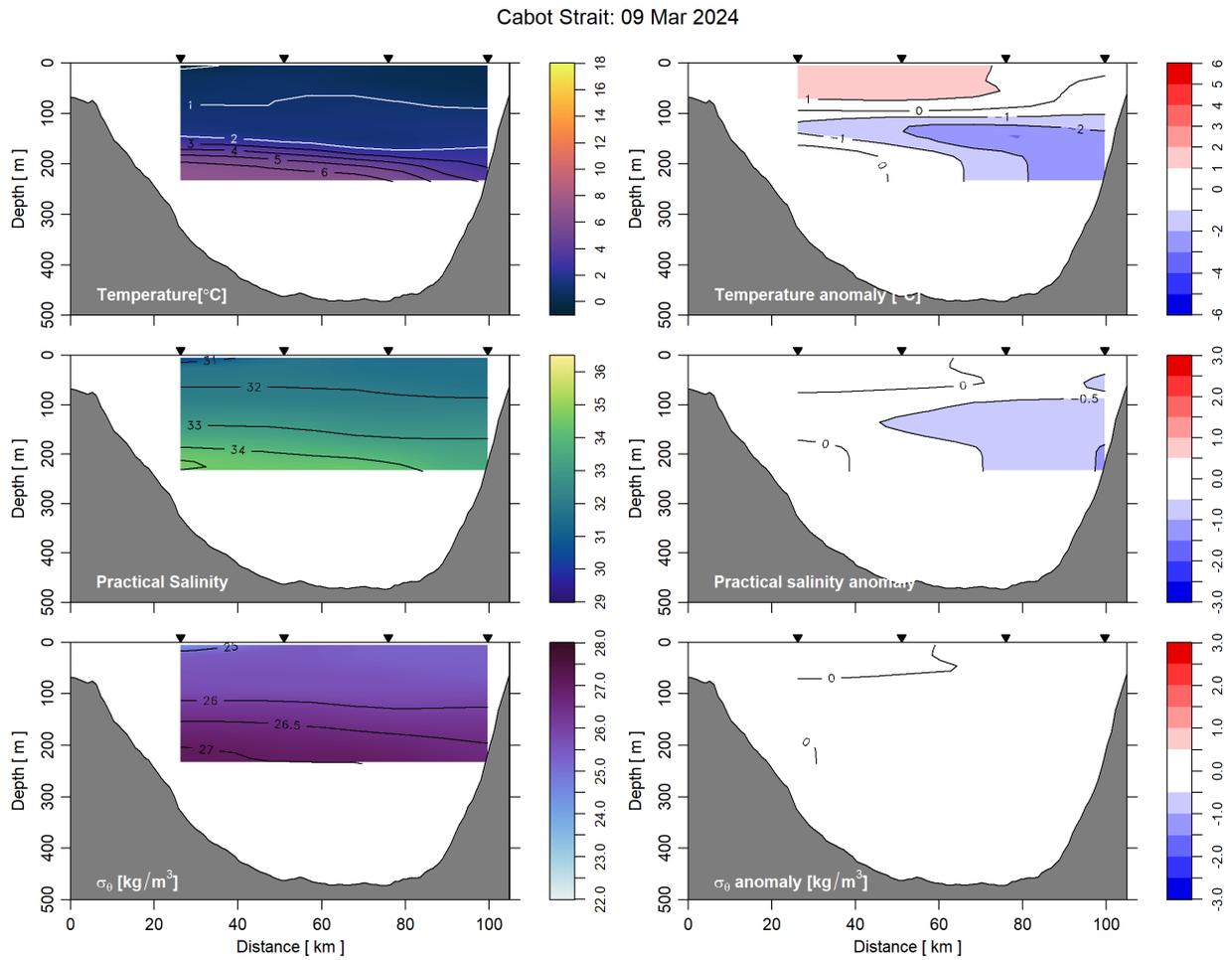


Figure A.1. The spring 2024 sampling of the Cabot Strait line collected by Quebec Region AZMP. Temperature (top panel), salinity (middle panel), and density (lower panel) and their anomalies with respect to 1991–2020 monthly means (right panels). Triangles indicate locations of sampling.

Cabot Strait: 13 Jun 2024

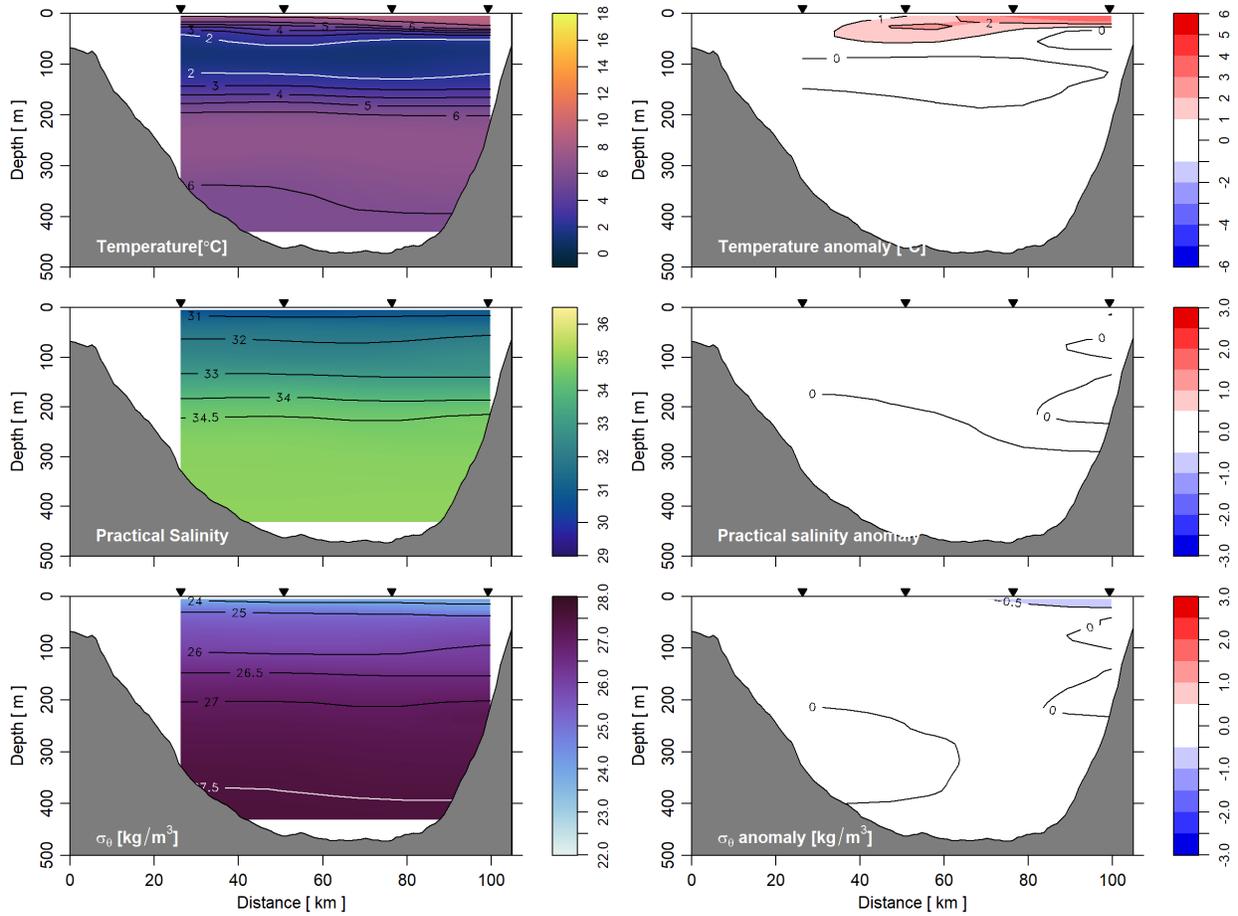


Figure A.2. The summer 2024 sampling of the Cabot Strait line collected by Quebec Region AZMP. Temperature (top panel), salinity (middle panel), and density (lower panel) and their anomalies with respect to 1991–2020 monthly means (right panels). Triangles indicate locations of sampling.

St. Anns Bank: 18 Oct to 21 Oct 2024

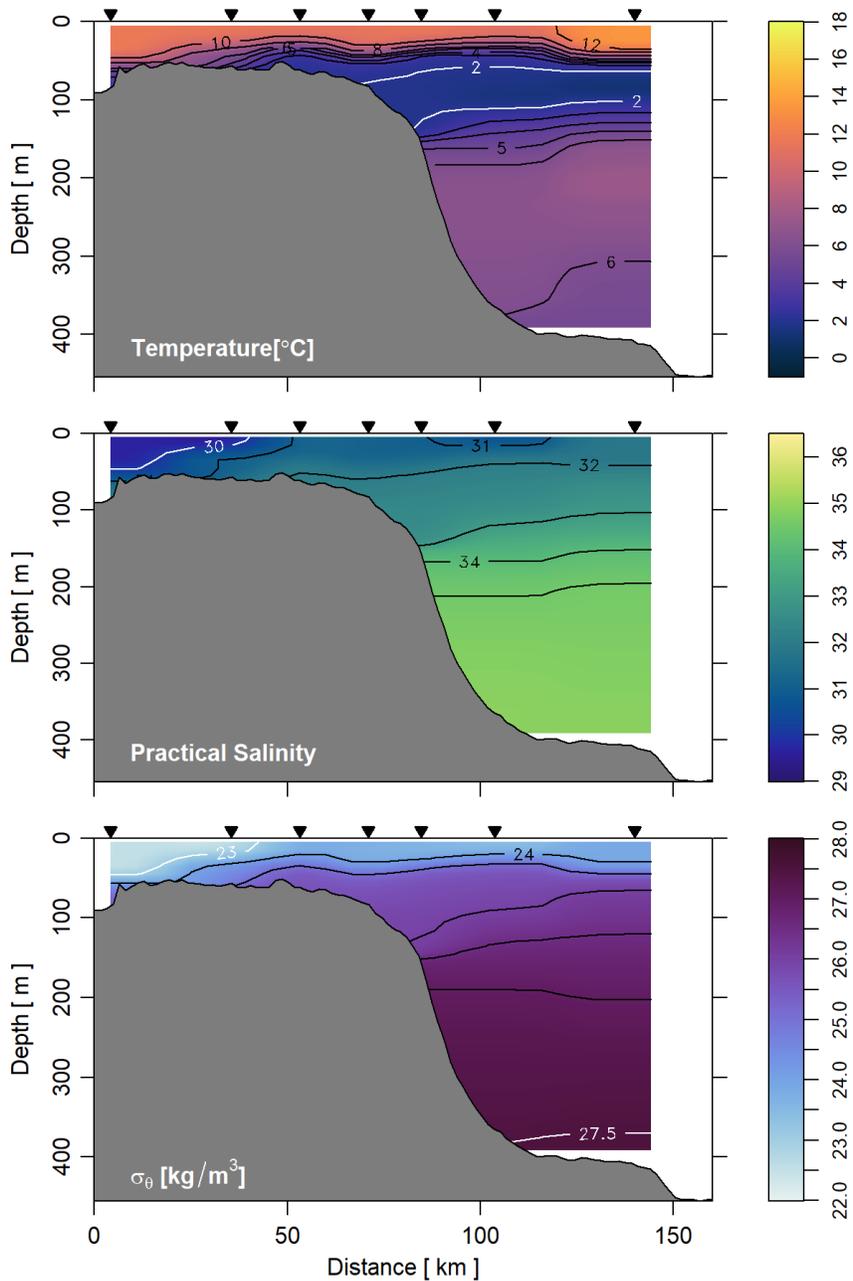


Figure A.3. The fall 2024 sampling of the St. Anns Bank section collected by Maritimes AZMP. Temperature (top panel), salinity (middle panel), and density (lower panel). Triangles indicate locations of sampling.

Laurentian Channel Mouth: 22 Apr to 23 Apr 2024

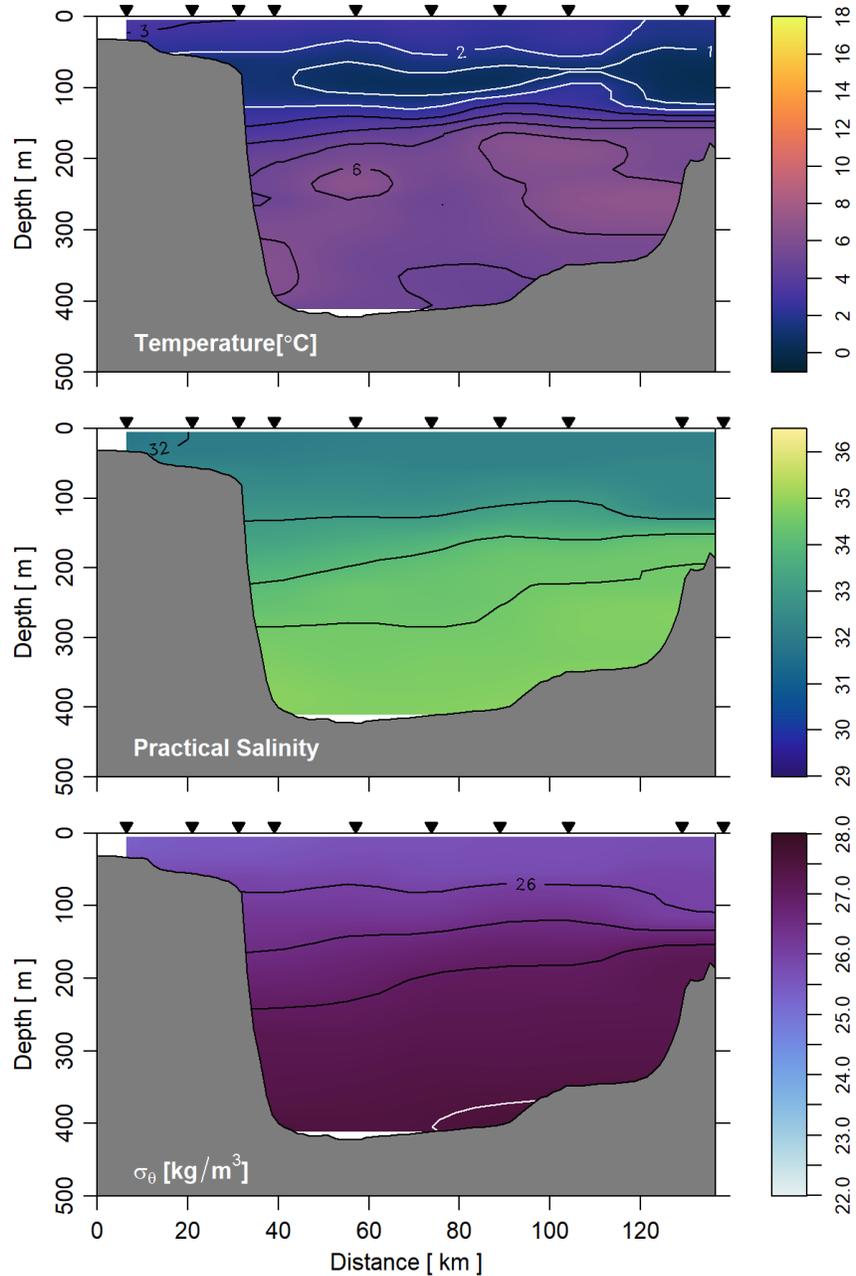


Figure A.4. The spring 2024 sampling of the Laurentian Channel Mouth line collected by Maritimes AZMP. Temperature (top panel), salinity (middle panel), and density (lower panel). Triangles indicate locations of sampling.

The Gully: 21 Apr to 22 Apr 2024

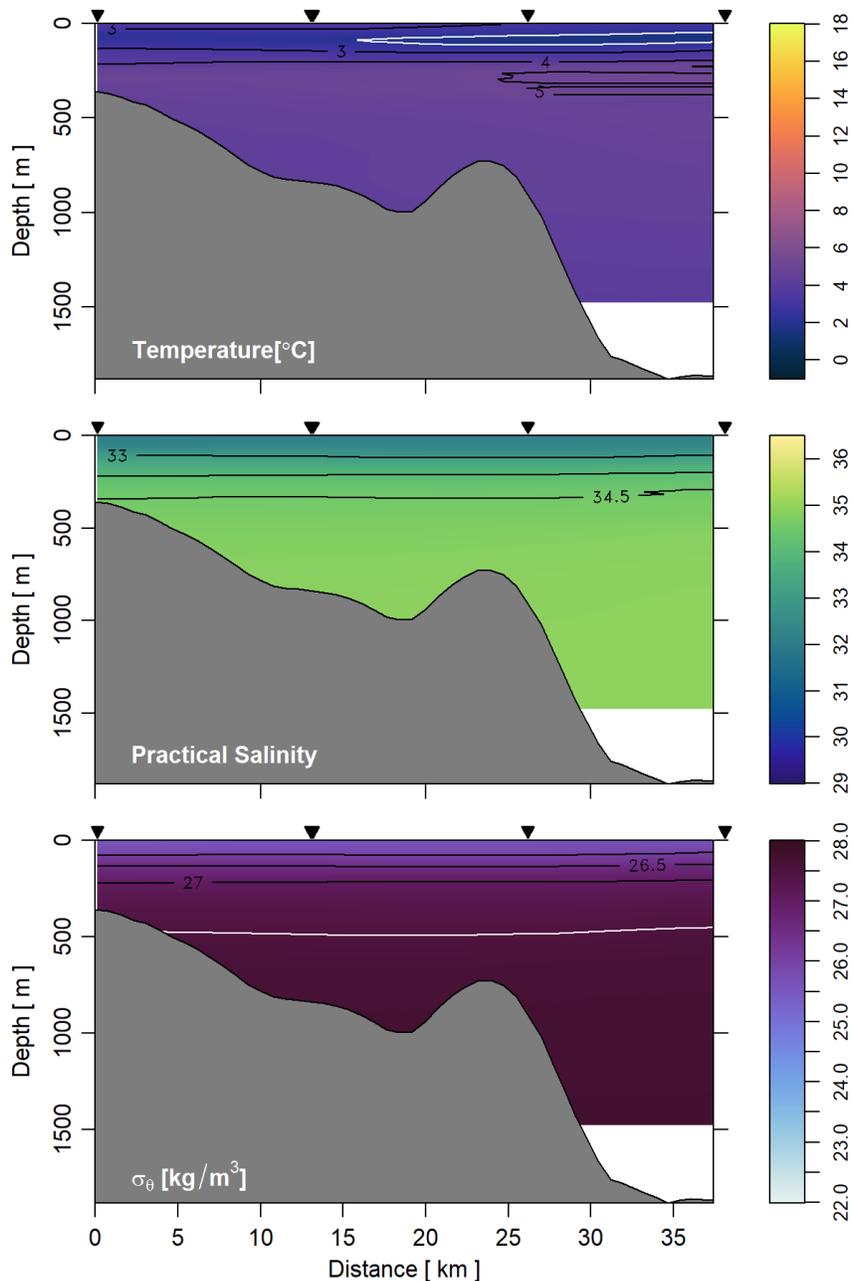


Figure A.5. The spring 2024 sampling of The Gully line collected by Maritimes AZMP. Temperature (top panel), salinity (middle panel), and density (lower panel). Triangles indicate locations of sampling.

The Gully: 15 Oct to 16 Oct 2024

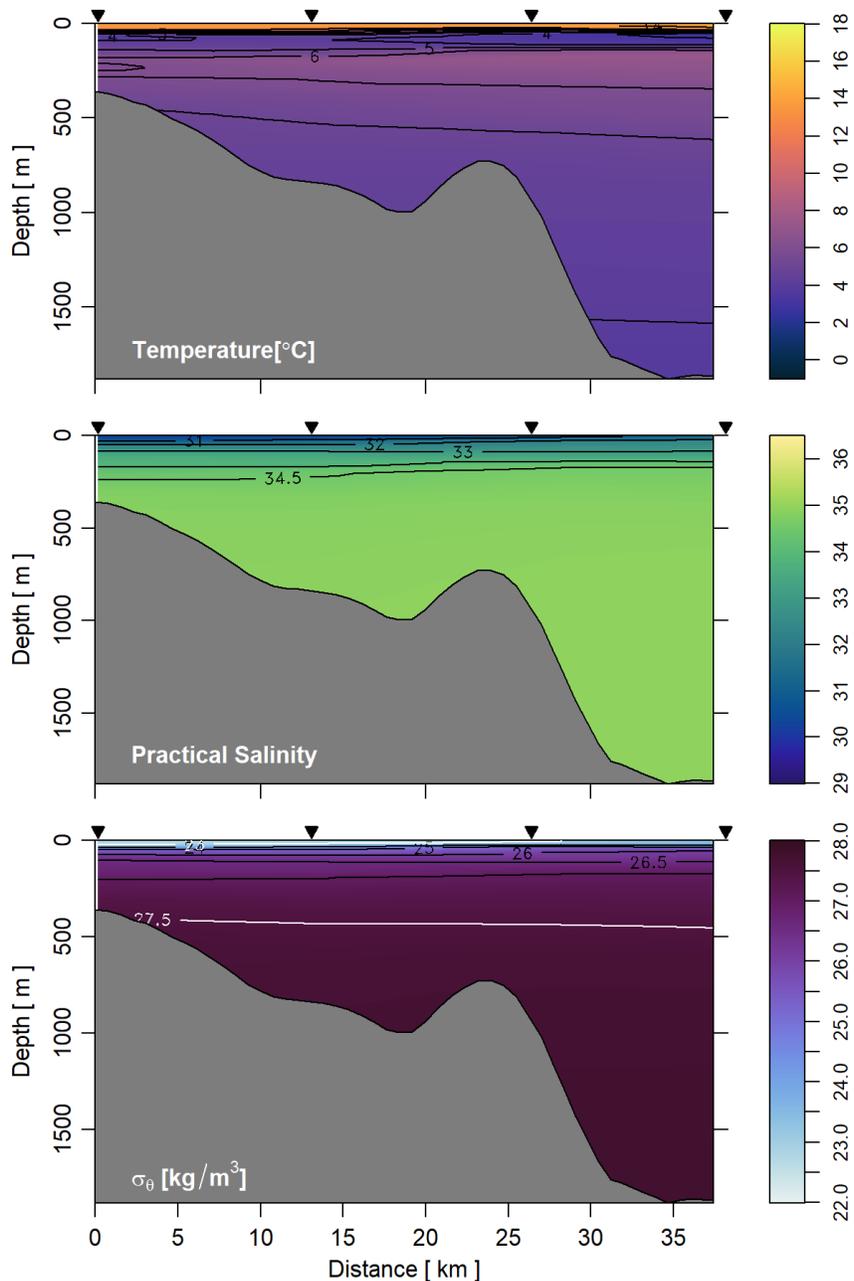


Figure A.6. The fall 2024 sampling of The Gully line collected by Maritimes AZMP. Temperature (top panel), salinity (middle panel), and density (lower panel). Triangles indicate locations of sampling.

Northeast Channel: 19 Apr to 20 Apr 2024

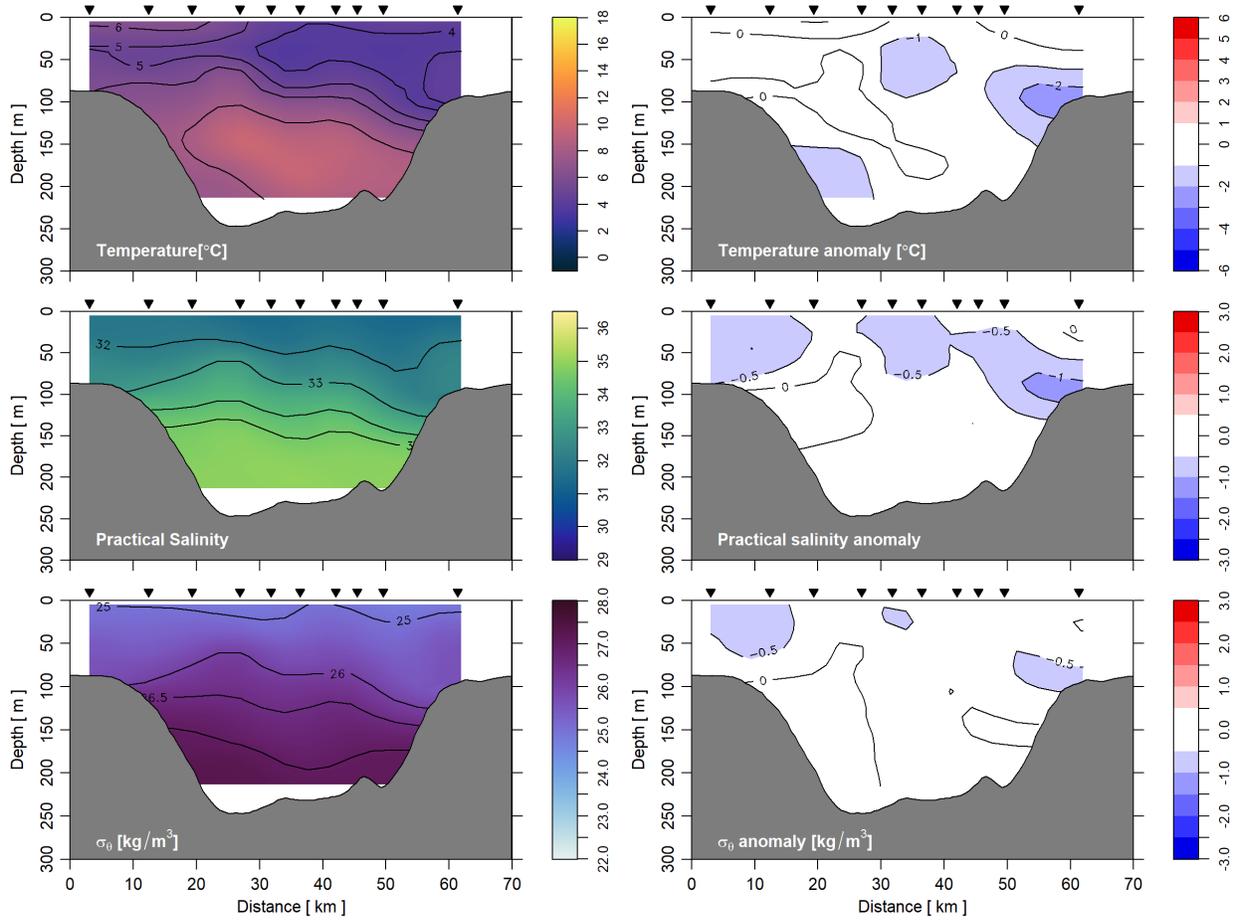


Figure A.7. The spring 2024 sampling of the Northeast Channel line collected by Maritimes AZMP. Temperature (top panel), salinity (middle panel), and density (lower panel) and their anomalies with respect to 1991–2020 monthly means (right panels). Triangles indicate locations of sampling.

Northeast Channel: 11 Oct 2024

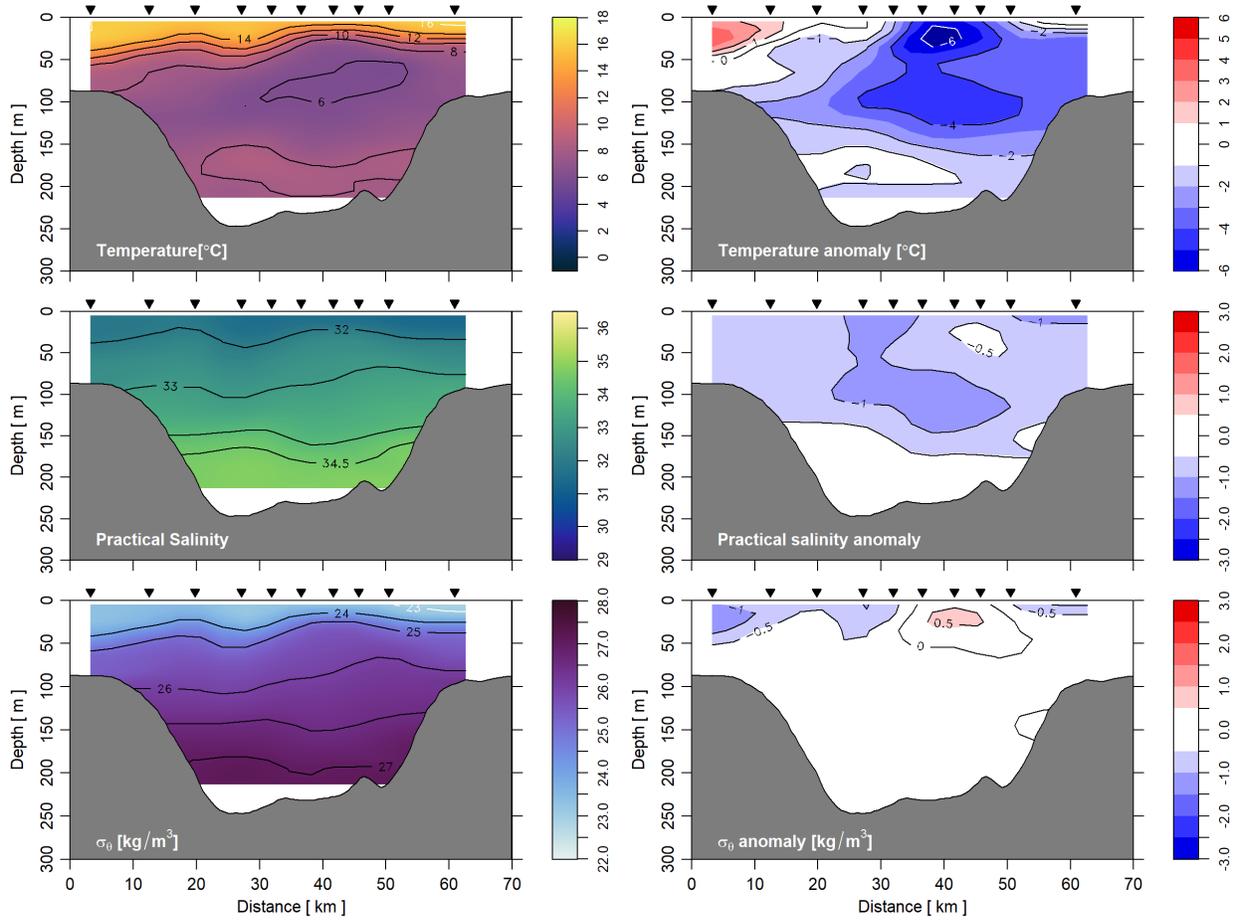


Figure A.8. The fall 2024 sampling of the Northeast Channel line collected by Maritimes AZMP. Temperature (top panel), salinity (middle panel), and density (lower panel) and their anomalies with respect to 1991–2020 monthly means (right panels). Triangles indicate locations of sampling.

Yarmouth: 14 Apr to 15 Apr 2024

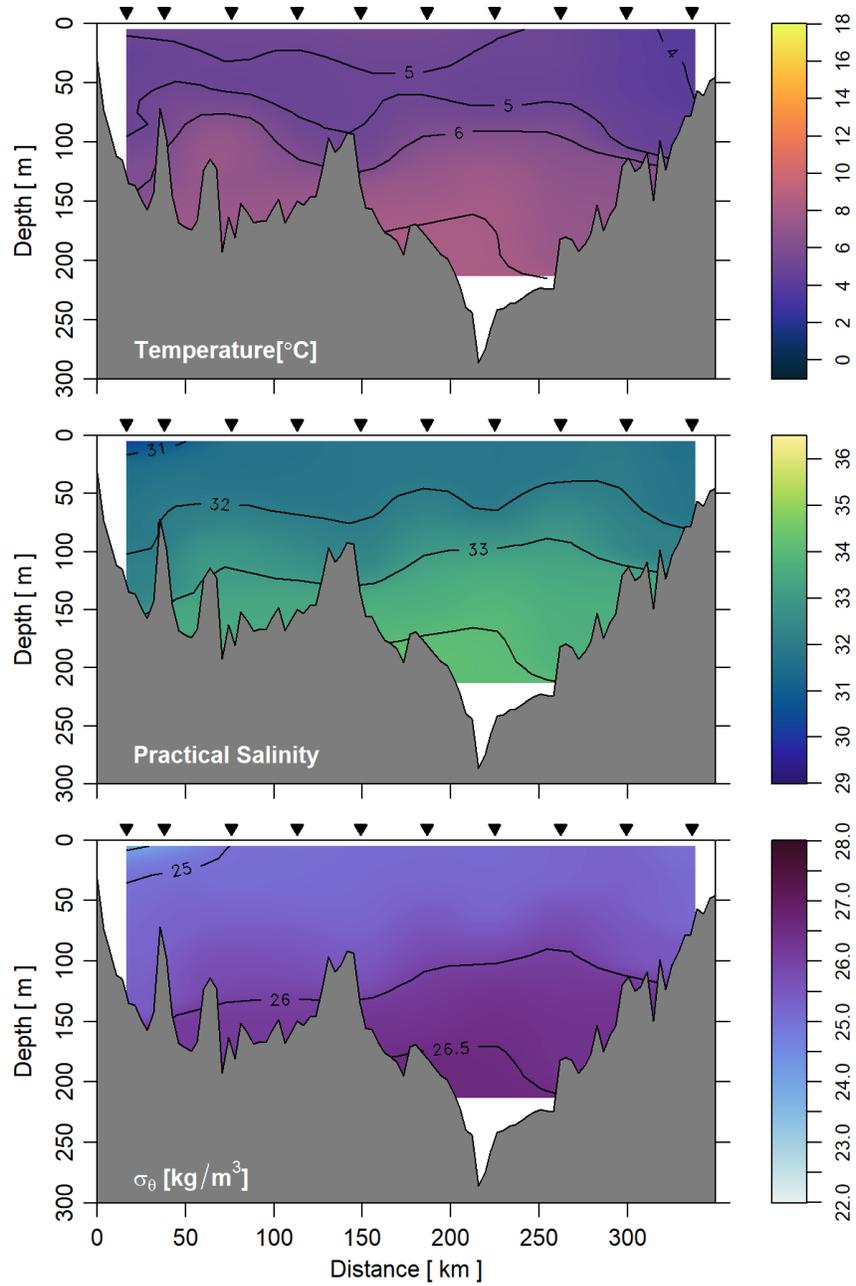


Figure A.9. The spring 2024 sampling of the Yarmouth line collected by Maritimes AZMP. Temperature (top panel), salinity (middle panel), and density (lower panel). Triangles indicate locations of sampling.

Yarmouth: 07 Oct to 09 Oct 2024

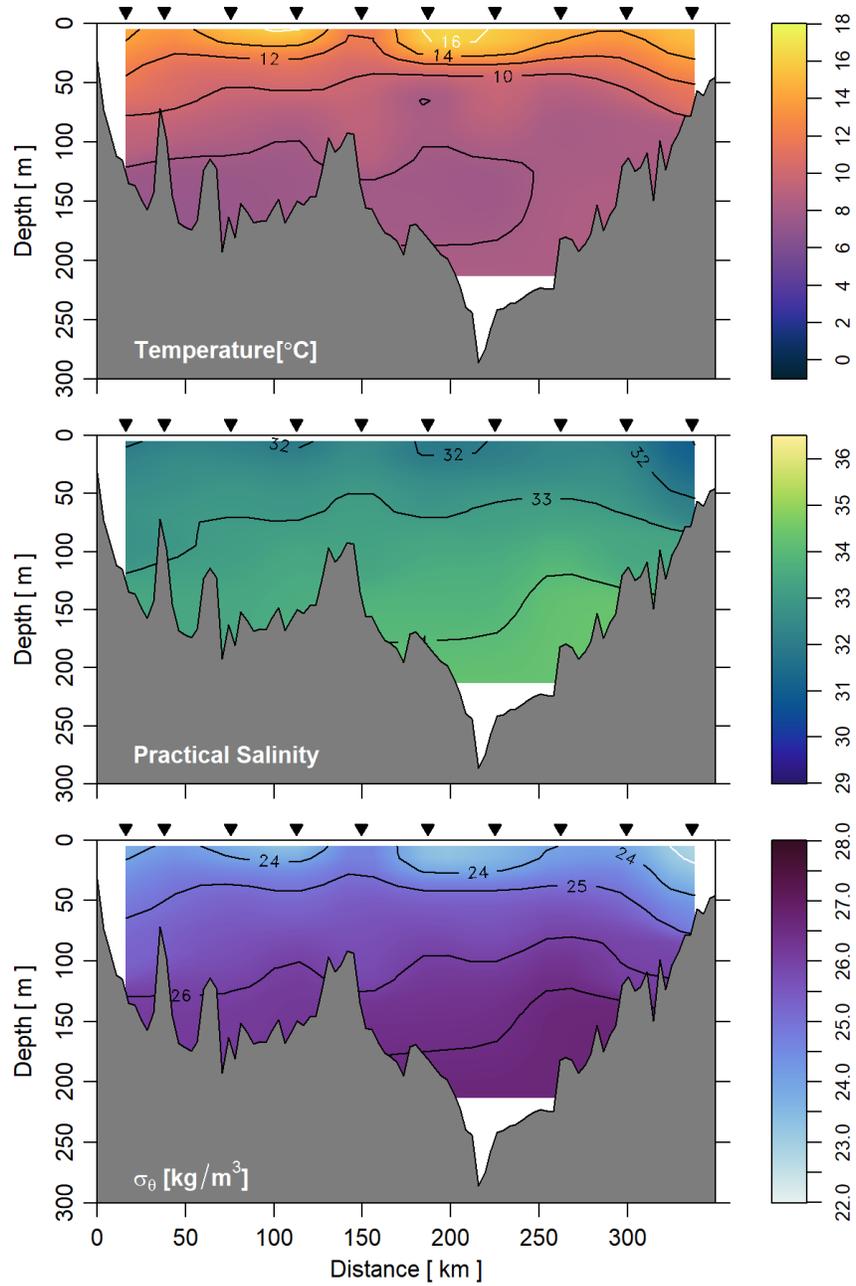


Figure A.10. The fall 2024 sampling of the Yarmouth line collected by Maritimes AZMP. Temperature (top panel), salinity (middle panel), and density (lower panel). Triangles indicate locations of sampling.

Portsmouth: 15 Apr to 16 Apr 2024

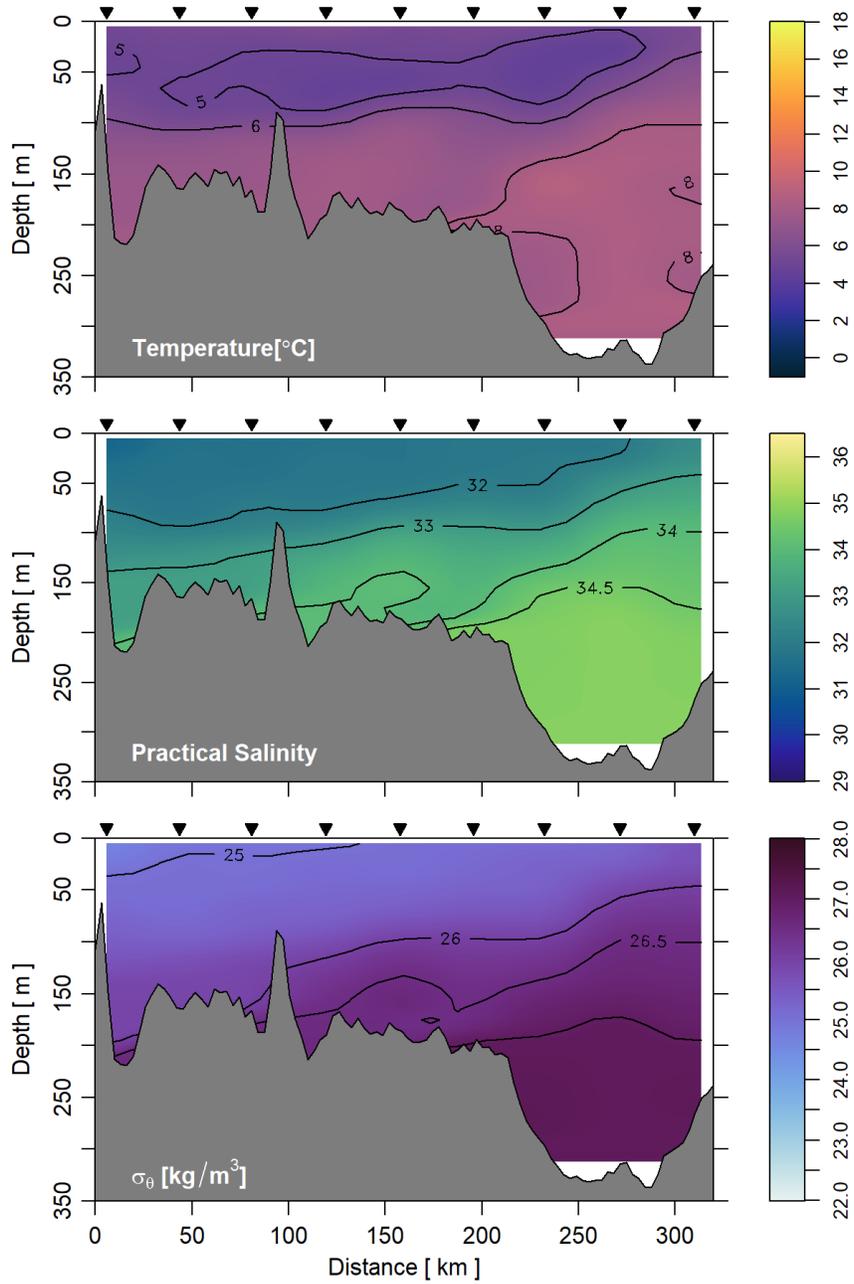


Figure A.11. The spring 2024 sampling of the Portsmouth line collected by Maritimes AZMP. Temperature (top panel), salinity (middle panel), and density (lower panel). Triangles indicate locations of sampling.

Portsmouth: 09 Oct to 10 Oct 2024

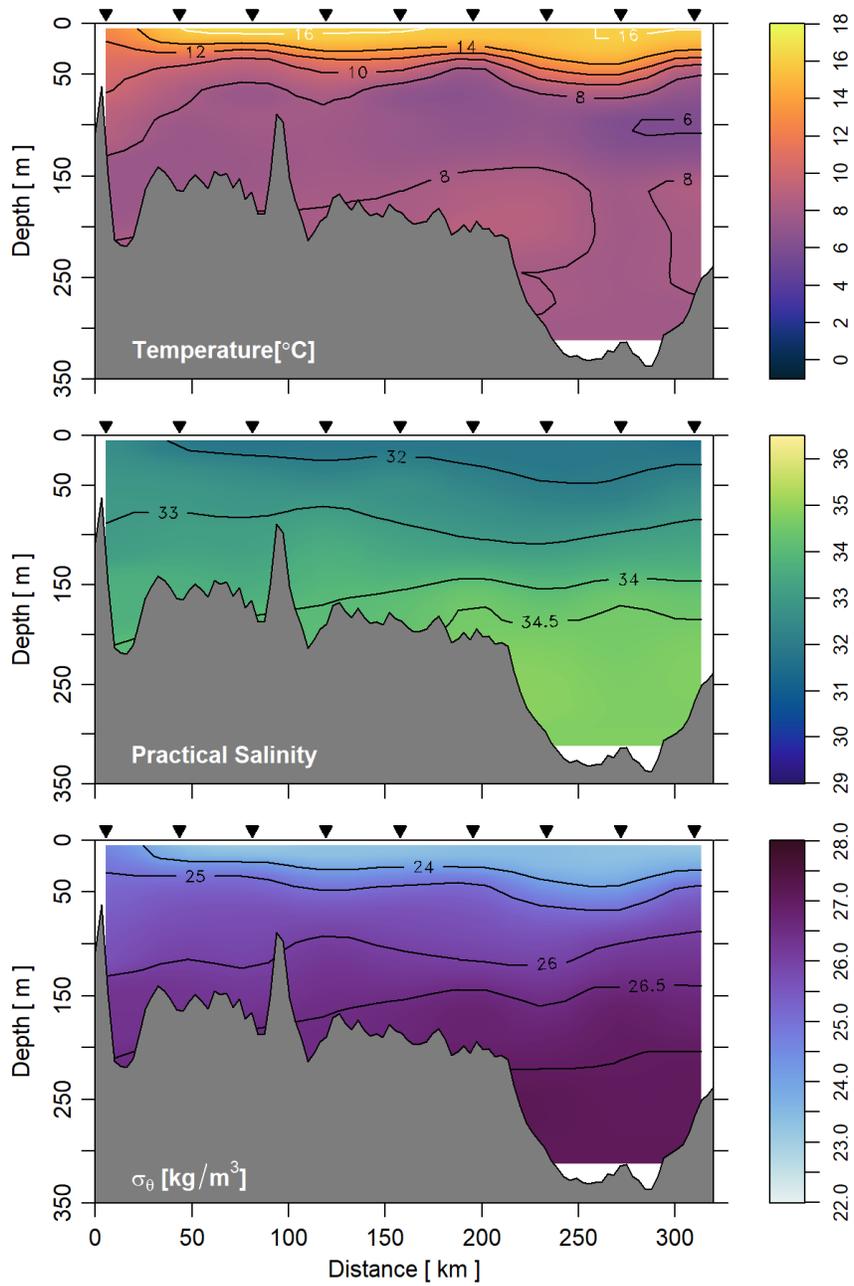


Figure A.12. The fall 2024 sampling of the Portsmouth line collected by Maritimes AZMP. Temperature (top panel), salinity (middle panel), and density (lower panel). Triangles indicate locations of sampling.

Halifax extended: 14 Jun to 18 Jun 2024

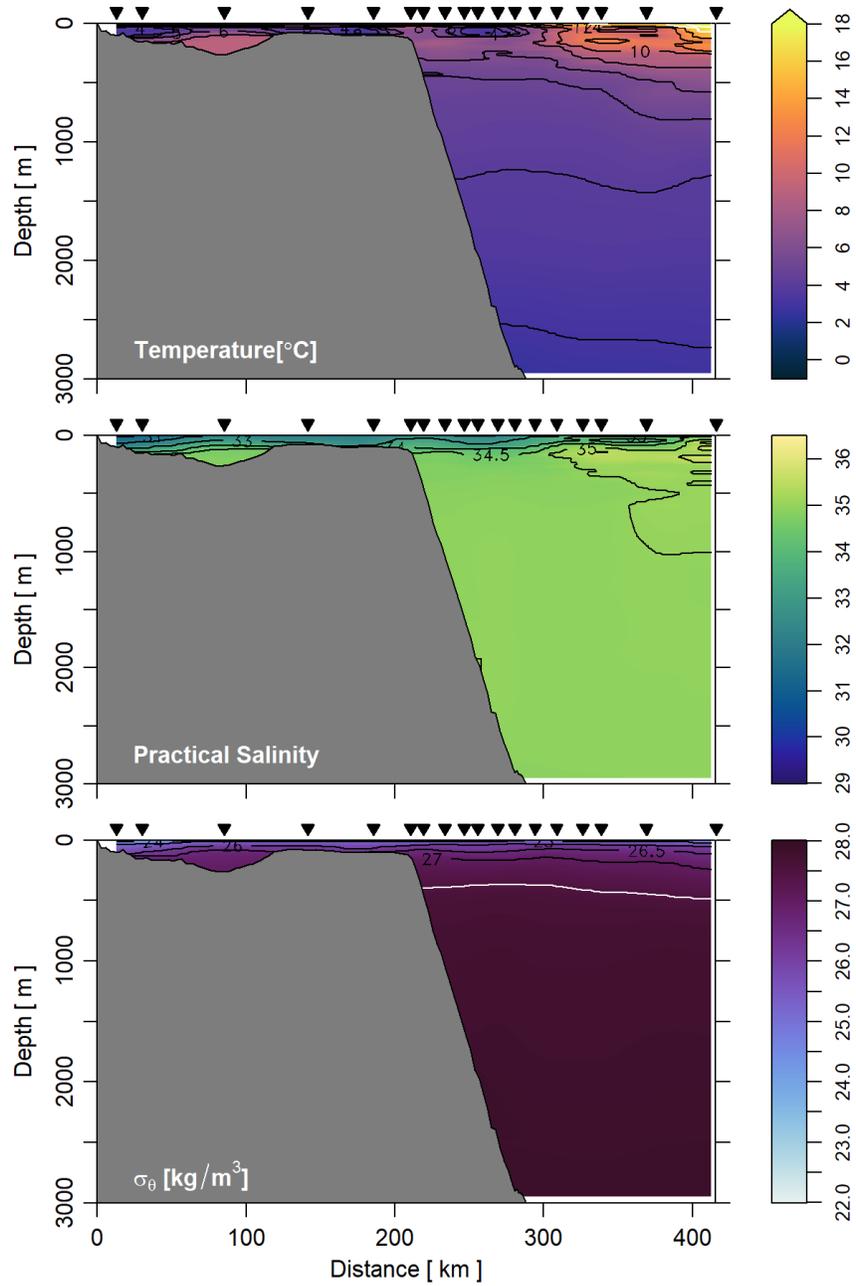


Figure A.13. The spring 2024 sampling of the Halifax extended line collected by Maritimes AZOMP. Temperature (top panel), salinity (middle panel), and density (lower panel). Triangles indicate locations of sampling.