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Physical Oceanographic Conditions on the Scotian Shelf and in the Gulf of Maine during 2019

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

In 2019, the North Atlantic Oscillation index was above normal (+0.6, +1.1 SD [standard deviation]) but much smaller than in 2015, which had the largest value in the 70-year record. Mean annual-air-temperature anomalies ranged from -0.4°C (-0.6 SD) below climatology to near normal for most stations except for Boston, which was above normal (+1.2°C [+1.7 SD]). Satellite-based Sea Surface Temperature (SST) annual anomalies ranged from -0.8°C (-1.5 SD) in Northwest Atlantic Fisheries Organization (NAFO) Division 4Vn to +0.1°C (+0.2 SD) in the eastern Gulf of Maine/Bay of Fundy. Long-term coastal-monitoring sites at St. Andrews (New Brunswick) and Halifax (Nova Scotia) recorded annual SST anomalies of +0.4°C (+0.6 SD) and +0.1°C (+0.2 SD), respectively. At other selected sites across the region, annual water-temperature anomalies were positive: +1.6°C (+4.8 SD) for Cabot Strait at 200–300 m depth range (the warmest anomaly; four of the last five years were the warmest on record); -0.2°C (-0.3 SD) for Misaine Bank at 100 m; +1.8°C (+2.2 SD) for Emerald Basin at 250 m (the warmest anomaly; the last six years were the warmest on record); +1.7°C (+3.2 SD) for Georges Basin at 200 m (the second warmest); near-normal conditions for Eastern Georges Bank at 50 m; and +0.3°C (+0.4 SD) for Lurcher Shoals at 50 m. The average bottom-temperature anomaly in NAFO Division 4Vn was +1.0°C (+2.4 SD), the second warmest on record. Divisions 4Vs, 4W, and 4X were +0.8°C (+1.2 SD), +0.9°C (+1.2 SD), and +1.2°C (+1.6 SD), respectively. Stratification in 2019 was significantly greater than in 2018 due to the surface freshening that had a greater effect than the surface cooling. Since 1948, the stratification has slowly been increasing on the Scotian Shelf due mainly to half freshening and half warming of the surface waters. A composite index, consisting of 22 ocean-temperature time series from surface to bottom across the region, indicated that 2019 was the 14th warmest of 50 years of observations (2012 was the warmest), with an averaged normalized anomaly of +0.9 SD relative to the 1981–2010 period.

INTRODUCTION

This document discusses air-temperature trends, ice cover, Sea Surface Temperatures (SST), and physical oceanographic variability during 2019 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. 2020, Galbraith et al. 2019), which together serve as a basis for a zonal Science Advisory Report (DFO 2019). Environmental conditions are compared with 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 standardized 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 1981–2010. The use of standardized anomalies and the same base period allow direct comparison of anomalies among sites and 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 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 counterclockwise 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°C–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).

METEOROLOGICAL OBSERVATIONS

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 it 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. Starting this year, the NAO index is based on a Rotated Principal Component Analysis (Barnston and Livezey 1987) applied to the monthly-standardized 500 mb height anomalies (Hurrel et al. 2003), averaged over winter months of December through March. The anomalies are based on the 1950–2000 climatology mean and standard deviation. Monthly data were obtained from the National Oceanic and Atmospheric Administration.

A high NAO index corresponds to an intensification of the 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 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 2019, the winter NAO index was near normal, +0.7(+1.1 SD) above the 1981–2010 mean but much smaller than in 2015, which had the largest positive value in the 70-year record (Figure 2, upper panel). The lower panels of Figure 2 show the sea-level atmospheric-pressure conditions during the winter of 2019 compared to the 1981–2010 mean. The Icelandic low and Azores high were close to the long-term average.

AIR TEMPERATURES

Surface-air-temperature-anomalies maps relative to the 1981–2010 means for the North Atlantic region are available from the U.S. National Oceanic and Atmospheric Administration's (NOAA 2019) interactive website. In 2019, the annual anomalies were normal over the Scotian Shelf and the Gulf of Maine (Figure 3). The seasonal anomaly of these regions was normal during the summer and fall, and below normal during winter and spring (Figure 4).

Monthly air-temperature anomalies for 2018 and 2019 relative to their 1981–2010 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 Canada's Adjusted Homogenized Canadian Climate Data (AHCCD) where available (Vincent et al. 2012). In cases where no data were available, observed monthly mean values from the Canadian Climate Summaries (CCS) at the Environment Canada website were used, and anomalies are relative to the CCS long-term means. This is the case for 2009–2011 and 2014–2016 at Sable Island. Monthly means from the Monthly Climatic Data for the World (NOAA 2020) were used for Boston. In general, all sites except Boston show that 2019 had slightly-below or normal temperatures throughout the year except the summer. Air temperatures during summer were either normal or slightly-above normal (Figure 5). Boston air temperatures were above normal for the year except for November 2019. The observed and normalized annual anomalies for these stations are listed in Table 1.

In 2019, the mean annual-air-temperature anomalies were negative or normal at all sites, with anomalies ranging from -0.6 to 0.0 SD, except for Boston, which was 1.7 SD above the climatology. 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 +0.6°C (0.4°C, +0.9°C), +1.3°C (+1.0°C, +1.6°C), +1.1°C (+0.8°C, +1.3°C), +1.0°C (+0.8°C, +1.2°C), +1.0°C (+0.8°C, +1.3°C), and +2.5°C (+2.2°C, +2.7°C), respectively (Figure 6).

The air-temperature anomalies for the six Scotian Shelf/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, when all sites were operating, 96 of the 120 years had five or more stations with the annual anomalies having the same signs; for 67 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 scale of 1800 km (Petrie et al. 2009). Secondly, the time scale of the dominant variability has been changing from longer periods for the first half of the record to shorter periods for the second half.

REMOTELY-SENSED SEA SURFACE TEMPERATURE (SST)

The remotely-sensed SST data used consist of a composite of three products: the 4 km resolution Pathfinder 5.3 dataset that runs from August 1981 to 2014 (Casey et al. 2010); data from the 1.5 km resolution Advanced Very High Resolution Radiometer (AVHRR), SST data downloaded from the NOAA and European Organization for the Exploration of Meteorological Satellites (EUMETSAT) satellites by the operational remote sensing group at the Bedford Institute of Oceanography (BIO); and a version of similar product developed by Maurice Lamontagne Institute (MLI) for the period of 1985–2013 (details in Galbraith and Larouche 2011, and Galbraith et al. 2012). Galbraith et al. (2020) provides details on how these data products are merged to provide the time series presented here.

Starting this year, the regions presented have changed from previous years of reporting on the Scotian Shelf. Weekly, monthly, and annual temperature anomalies are shown for five subareas in the Scotian Shelf/Gulf of Maine region based on the NAFO Divisions on the Scotian Shelf and eastern Gulf of Maine/Bay of Fundy (Figure 8). Sea-surface temperatures were slightly below normal at the start of 2019, followed by a period of near-normal temperatures until August when temperatures were above normal, then below normal in September, except in the Bay of Fundy (Figure 9). A record-low temperature in March was observed for 4Vn and 4Vs. A record-low temperature in September was also observed for 4W, 4Vn, and 4Vs. These low temperatures in September are likely due to Tropical storm Dorian mixing cold water from depth, as recorded by the Viking buoy AZMP-ESG in the Gulf of St. Lawrence (Galbraith et al. 2020). Annual anomalies were calculated from monthly-averaged temperatures for the five subareas (Table 2 and Figure 10). The annual anomalies during 2019 ranged from -0.8°C (-1.5 SD) in 4Vn to +0.1°C (+0.2 SD) in eastern Gulf of Maine/Bay of Fundy. Over the lengths of the records, all areas show increasing temperature trends (Figure 10), based on a linear-least-squares fit, ranging from the lowest value +0.2°C/decade (4Vn and 4Vs) to a highest value of +0.4°C/decade (eastern Gulf of Maine/Bay of Fundy). A similar trend in SST from AVHRR measurements was found in the Gulf of St. Lawrence (Galbraith et al. 2012).

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 2019, the SST anomalies were +0.1°C (+0.2 SD) for Halifax (a decrease of 0.3°C from 2018) and +0.4°C (+0.6 SD) for St. Andrews (a decrease of 0.7°C from 2018).

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. The depth-averaged (0–90 m) temperature, salinity, and density time series are shown in Figure 11. In 2019, the annual temperature anomaly was +0.4°C (+0.8 SD) and the salinity anomaly was -0.1 (-0.7 SD). These represent changes of -0.7°C and -0.3 from the 2018 values. The below-normal density anomaly is accounted for by both positive temperature anomaly and negative salinity anomaly.

The 2019 annual cycle at Prince 5 shows normal temperatures throughout the year except for a slightly above-normal temperature (+1°C) in October/November with not much depth dependence in the anomaly (Figure 12). Likewise, salinity was near normal except during May, due to the timing of the freshet arrival from the Saint John River (a nearby source).

The 2019 annual temperature, salinity, and density cycles at Halifax 2 are shown in Figure 13. The structure of the anomalies in temperature and salinity is complicated. The source of the positive temperature anomaly in November is clear given there was no associated salinity anomaly and cannot just be the result of an intrusion of slope water.

STANDARD SECTIONS

The sections across the Louisbourg, Halifax, and Browns Bank Lines (Figure 1) were sampled during the spring of 2019 (Figure 14). There was no sampling during the fall of 2019 due to lack of a suitable vessel. The Cabot Strait section showed above-normal April temperatures between 100 and 350 m. Lower-than-normal temperatures below the surface in the center of the strait, and at the surface on the eastern half of the strait, were observed (Figure 15). Interestingly, there was not a salinity anomaly associated with the deep temperature anomaly, except on the western side of the strait at 150 m. These waters correspond to the outflow of the Gulf of St. Lawrence.

In the spring of 2019, there was anomalously warm, salty water on the offshore portion of the Louisbourg section—evidence of slope water on the continental slope (Figure 16). On the shelf, conditions were near normal.

The Halifax section shows anomalously warm waters near the bottom of the outer shelf and slope at the same depth and deeper in the spring (Figure 17). Similarly, warm waters are also present in Emerald Basin.

During the spring of 2019, the Browns Bank section showed anomalous warm, salty water over the middle shelf and farther off the slope (Figure 18). There is anomalously cold, fresh water at the shelf break. The temperature and salinity of this water are much lower than that of Labrador Sea Water, and this is probably water that exited the Gulf of St. Lawrence. It is not clear why this water was not observed in the other sections to the east.

The Appendix contains sections in the region conducted by the Maurice-Lamontagne Institute for Cabot Strait in Winter (Figure A1), Summer (Figure A2) and Fall (Figure A3), St. Anns Bank Marine Protected Area (Figure A4), and across the Northeast Channel (Figure A5) and the Gulf of Maine (Figure A6). If there exist 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 this document, the data are used in the analysis presented here.

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 provide higher temporal and spatial coverage than the vessel-based sampling (Figure 19). For ease of analysis, the glider data are averaged into hourly, 1m bins. 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 20). Thus, only glider data collected within 15 nm of the Halifax Line are considered, which explains some of the gaps in Figure 19. Station 2 (HL2) is sampled throughout the year from a small vessel and provides the highest temporal resolution of our stations (Figure 21). Glider data do not significantly add information at Station 2 except when vessel sampling is not available (see August/September in Figure 21).

For this document, the variability in temperature, salinity, and chlorophyll fluorescence are shown for a few of the Halifax Line stations over the 2018–2019 period (Figure 22). This is only a small fraction of the data available for analysis. As this period was the initial operation period, the sampling rate and stations that were occupied varied, as experience with glider operations increased. At HL3 and HL4, the glider sampling was sufficient to resolve the seasonal cycle of temperature and the spring and fall phytoplankton blooms. For HL5 and HL6, the sampling was less frequent, but there were more in 2019 than 2018 due to increased experience in glider operations, and missions extending further offshore. Due to battery limits, the glider cannot reach HL7 consistently, especially in winter (Figure 19). Upgrade to the glider battery is underway and should allow more regular sampling in the future and inclusion of HL7.

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. An updated time series of annual mean and filtered (five-year-running means) temperature anomalies at selected depths for six areas (Figure 23) is presented (Figure 24). 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 Figure 24C, 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, Georges Basin, Eastern Georges Bank, and Lurcher Shoals, the 2019 annual anomalies are based on observations from five, two, five, eight, seven, and two months, respectively.

In 2019, the annual anomaly was +1.6°C (+4.8 SD) for Cabot Strait at 200–300 m (the largest anomaly of the time series; four of the last five years were the warmest). For the shallow Misaine Bank on the eastern Scotian Shelf, the annual anomaly was -0.2°C (-0.3 SD) at 100 m. For the deep basins on the central Scotian Shelf and Gulf of Maine, the 2019 anomalies were +1.8°C (+2.2 SD) for Emerald Basin at 250 m (a record high; the last six years were the warmest on record) and +1.7°C (+3.2 SD) for Georges Basin at 200 m (second warmest with 2018 the warmest; the last seven years were the warmest on record). For the shallow banks in western Nova Scotia, the anomalies were -0.0°C (-0.1 SD) for Eastern Georges Bank at 50 m and +0.3°C (+0.4 SD) for Lurcher Shoals at 50 m (2018 was the second highest with 2012 having the record). These values correspond to changes of +0.7°C, -0.7°C, +0.2°C,-0.2°C, -0.5°C and -2.9°C, respectively, from the 2018 values. The 2010 and 2011 NAO anomalies were well-below normal and based on similar atmospheric forcing in the past, notably in the mid-1960s, cooler deep-water temperatures might have been expected on the Scotian Shelf in 2012 (Petrie 2007). Anomalies were highly positive for that year and started to return to normal in 2013, but they increased to record or near-record values in 2014 and continued to remain high in 2019. Deep-water temperature anomalies continued to increase due to intrusions from offshore slope water. The correlation between the NAO and deep-water temperatures appears to have changed.

TEMPERATURES DURING THE ECOSYSTEM TRAWL SURVEYS

In the Maritimes Region, Fisheries and Oceans Canada (DFO), conducts two Research Vessel (RV) 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 isobaths. 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 optimal estimation (Petrie et al. 1996). The interpolation method uses the 15 "nearest neighbours" with a horizontal length scale of 30 km and a vertical length scale of 15 m in the upper 40 m and 25 m at deeper depths. Data near the interpolation grid point are weighted proportionately more than those farther away. 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.

WINTER SURVEY

The 2019 winter survey took place between February 12th and March 22nd. A total of 115 Conductivity-Temperature-Depth (CTD) stations were sampled (Figure 25). Sampling was on Georges Bank (NAFO Division 5Ze) and Western Scotian Shelf (NAFO Division 4X). For most of Georges Bank, the bottom temperatures were near normal (Figure 26). At the southeast and east side of the bank, the bottom temperatures were above normal. This is indicative of the Warm Slope Water moving adjacent to bank and in the Northeast Channel. The bottom temperature anomalies on the Scotian Shelf were more variable with regions of above and below normal.

SUMMER SURVEY

The 2019 summer survey took place between July 3rd and August 10th. A total of 236 CTD stations were sampled (Figure 27). The survey covered the Bay of Fundy, Eastern George Bank and east on the Scotian Shelf to Cabot Strait. The near-bottom-temperature anomalies for 2019 were positive for most of the region (Figure 28). Browns Bank and part of the eastern Scotian Shelf had negative anomalies. The anomaly was positive for all of NAFO Divisions on the Scotian Shelf in 2019: +1.0°C (+2.4 SD) for 4Vn (the 2nd warmest in the record; 2014 was the warmest); +0.8°C (+1.2 SD) for 4Vs; +0.9°C (+1.2 SD) for 4W; and +1.2°C (+1.6 SD) for 4X (Figure 29). While no value in 2019 is a record, all values were well above normal. Except for Division 4X, the bottom temperature in the other divisions show above-normal temperatures from the mid-1970s to mid-1980s, followed by a period of below-normal temperatures until around 2000 (Figure 29). All regions, including 4X, show a steadily increasing temperature from approximately 2010.

The volume of the Cold Intermediate Layer (CIL), defined as waters with temperatures less than 4°C, was estimated from the full depth CTD profiles for the region, from Cabot Strait to Cape Sable (Figure 30). For the period 1970 to 1989, the number of CTD profiles per year was limited; therefore, five-year blocks of data, for example 1970–1974 (centre date 1972) were used as input for the procedure to map the irregularly spaced data onto a regular grid. The data were then incremented by one year and a new set of estimates made (i.e., 1970–1974, 1971–1975, etc.). This procedure is similar to filtering (five-year running mean) the data for the 1970–1989 period, effectively reducing the variance. Thus, the long-term mean and particularly the SD (based on the 1981–2010 data in Figure 30) could be affected. It is expected that the true SD is higher than the one derived here. There is considerable variation in the volume of the CIL from 1998 until 2009 (Figure 30). In 2019, the CIL volume was slightly below normal. In the last five years, the CIL volume has been trending toward normal. The low-frequency variability of the area-weighted average minimum temperature mirrors the CIL volume.

DENSITY STRATIFICATION

Stratification of the near-surface layer influences physical 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 available for the deeper layers. The variability in stratification was examined by calculating the density (sigma-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 33) as defined by Petrie et al. (1996). The long-term, monthly mean-density gradients for 1981–2010 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 (kg m^{-3})/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 31). 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 0.34 kg m^{-3} over 50 years. This change in mean stratification is due mainly to a decrease in the surface density, composed equally of warming and freshening (Figure 32). Stratification in 2019 was significantly greater than in 2018 due to the surface freshening that had a greater effect than the surface cooling. Examining the 2019 stratification anomaly for areas 4–23 on the Scotian Shelf shows that the near-normal anomaly for the Scotian Shelf (Figure 31) is due to an area-average of positive and negative on the Scotian Shelf with no obvious pattern (Figure 33).

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 true changes of sea level and a second caused by sinking or rising of the land. In Atlantic Canada, Post-Glacial Rebound (PGR) is causing the area roughly south (north) of the north shore of the Gulf of St. Lawrence to sink (rise) in response to glacial retreat; this results in an apparent rise (fall) of sea level. The PGR rates for Yarmouth, Halifax, and North Sydney have been obtained from Natural Resource Canada's gridded GPS-based vertical velocities (Phillip MacAulay, DFO, pers. comm. 2012; Craymer et al. 2011).

Relative sea level at Yarmouth (1967–2019), Halifax[1] (1920–2019) and North Sydney (1970–2019) are plotted as monthly means and as a filtered series using a 5-year-running-mean filter (Figure 34). The linear trend of the monthly mean data has a positive slope of 37.3 cm/century (Yarmouth), 33.2 cm/century (Halifax), and 39.2 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 as discussed below. With the removal of the PGR for Yarmouth (-10.3 cm/century), Halifax (-14.7 cm/century), and North Sydney (-16.8 cm/ century), sea-level rise is +27.0 cm/century, +18.5 cm/century, and +22.4 cm/century, respectively. An interesting feature of the data is the long-term variation that has occurred since the 1920s (Figure 35). It is apparent that from the 1920s to the early 1970s, the sea-level-rise trend at Halifax was greater than the 1981–2010 trends. The residual sea-level data for the common period 1970–2019 show that the variability has a large spatial structure given the coherence between the three sites. Several potential causes of this decadal scale variability have been examined; however, the cause of these changes is still not understood. Further south, near Delaware, USA, variations in the wind stress in the subtropical gyre appears to be responsible for the low frequency variation in sea level (Hong et al. 2000); yet, 20 years of observed Gulf Stream transport does not show a significant decrease (Rossby et al. 2014).

RESULTS FROM A NUMERICAL SIMULATION MODEL

Currents and transports are derived from the BNAM (Bedford Institute of Oceanography North Atlantic Model) ocean circulation model (Wang et al. 2018). The model has a spatial resolution of 1/12° with 50 z-levels in the vertical (22 in the top 100m), 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 model is run in various configurations. 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 (Wang et al. 2016; Brickman et al. 2015, 2018). 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 36.

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.

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 37). 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

[1] The 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.

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 1999–2019 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 37). From these data, standardized anomaly plots (based on a 1999–2010 averaging period) were constructed to illustrate transport variability. The results for the nearshore regions at CS, HFX, and CSI (where nearshore is taken as the subsection between the 100 m isobath and the coastline), the shelf break at HFX, and the inflow at NEC are displayed in Figure 38. 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 (nearshore and shelf break), and CSI (Figure 39). On a monthly basis, on average, the nearshore series (CS, HFX nearshore, 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 38, 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). Three upward looking ADCPs had been deployed for six-month periods from July 2008 to April 2015 on the 100 m (T1), 170 m (T2), and 180 m (T3) isobaths to monitor the velocity field associated with the Nova Scotia Current along the Halifax Line. Located 12 km east of station 2 (Figure 1) is T2. T1 and T3 are approximately 15 km to the northwest and southeast of T2, respectively. The observations start from 5 m above the bottom to approximately 10 m below the surface, with a 4 m vertical resolution. The horizontal spacing between ADCPs is about 16 km, with T2 located close to the current maximum. The velocity components are rotated by 58° relative to True North to obtain the velocity field with the maximum variance along the major axis. Daily averages of the alongshore velocity were gridded using linear interpolation and multiplied by the cross-sectional area between T1 and T3 to provide monthly estimates of the Nova Scotia Current transport in 10^6 m^3 s^{-1}. When data are available from all three stations, these periods are used to establish a linear relationship between the transport estimated using all stations and the transport estimated using only one or two ADCP stations. These relationships have been used to extrapolate the transport estimations to periods where one of the ADCP has failed during the deployment. As of May 2015, only the mooring at T2 has been deployed. Work by Dever (2017) showed a high correlation (r^2=0.87) between the depth-integrated current at T2 and the total transport. Transport anomalies are based on the mean for each month using all data available for that month. A negative transport means a southwestward transport toward the Gulf of Maine. Anomalies that are less than 0.5 standard deviations are coloured red and those greater than 0.5 standard deviations are coloured blue.[2] The data indicate a period of negative anomalies (stronger southwestward flow) starting in mid-2010 and extending to mid-2011, followed by average or weaker flow that persists until summer 2016 (Figure 40). For the fall of 2016 and winter of 2017, the flow was above normal, followed by mostly near-normal transport until September 2018 where above-

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

normal transport was observed until the end of the year. Transport was near normal for the first half of 2019. These trends are overall well simulated by the model although differences exist (see HFX nearshore panel of Figure 38).

The fraction of transport into the Gulf of Maine through the Cable Sable Island section (GoM inflow ratio - Figure 41) 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. Interannually (Figure 39), the GoM inflow ratio was near neutral from 1999–2007 (with only 2001 and 2004 above normal) and mostly negative from 2008–2019, although neutral values predominated during the last 5 years. 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 42) by summing the standardized anomalies (Figures 38 and 39) 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 strong negative anomalies in 1999–2000, generally weak positive anomalies from 2001–2007, alternating stronger negative and positive anomalies until 2015, followed by positive anomalies until the present year.

SUMMARY

In 2019, the North Atlantic Oscillation index was slightly above normal (+0.6, +1.1 SD) but much smaller than in 2015, which had the largest value in the 70-year record. The analysis of satellite data indicates that sea-surface temperatures were slightly below normal at the start of 2019, followed by a period of near-normal temperatures until August where temperatures were above normal and below normal in September except in the Bay of Fundy.

A graphical summary of selected time series already shown indicates that the periods 1987–1993 and 2003–2004 were predominantly colder than normal, and 1999–2000 and 2010–2019 were warmer than normal (Figure 43). The period 1979–1986 also tended to be warmer than normal. It is apparent that 2012 was an exceptional year based on these series, with 17 values above 2 SD. In 2019, 17 of the 22 series shown had positive anomalies; 10 variables were more than 1 SD above their normal values. Of these, 4 were more than 2 SD above normal and two were more than 3 SD (deep Emerald Basin and Cabot Strait were record values). In 2019, the average (median) normalized anomaly was +0.9 (+0.6) SD, the 14th highest in the 50-year series.

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TABLES

Table 1. The 2019 annual mean air temperature anomaly in degrees and normalized anomaly (relative to the 1981–2010 climatology) and SD of the monthly anomalies for Scotian Shelf and Gulf of Maine.

	Annual Anomaly		1981–2010 Climatology	
Site	**Observed (°C)**	**Normalized (SD)**	**Mean (°C)**	**SD (°C)**
Sydney	-0.3	-0.4	5.87	0.81
Sable Island	-0.4	-0.6	7.88	0.68
Shearwater (Halifax)	-0.2	-0.3	6.99	0.74
Yarmouth	0.0	0.0	7.16	0.62
Saint John	0.0	0.0	5.19	0.74
Boston	+1.2	+1.7	10.91	0.60

Table 2. 2019 SST anomalies and long-term SST statistics including 1982–2019 temperature change based on the linear trend.

Site	**2019 SST Anomaly (°C)**	**2019 SST Anomaly Normalized**	**1981–2010 Mean Annual SST (ºC)**	**1982–2019 Temperature Trend (ºC/decade)**
4Vn	-0.8	-1.5	6.4	0.2
4Vs	-0.0	-0.1	7.4	0.2
4W	-0.6	-1.0	8.4	0.3
4X SS	-0.2	-0.4	8.0	0.3
4X eGoM+BoF	+0.1	+0.2	7.8	0.4

FIGURES

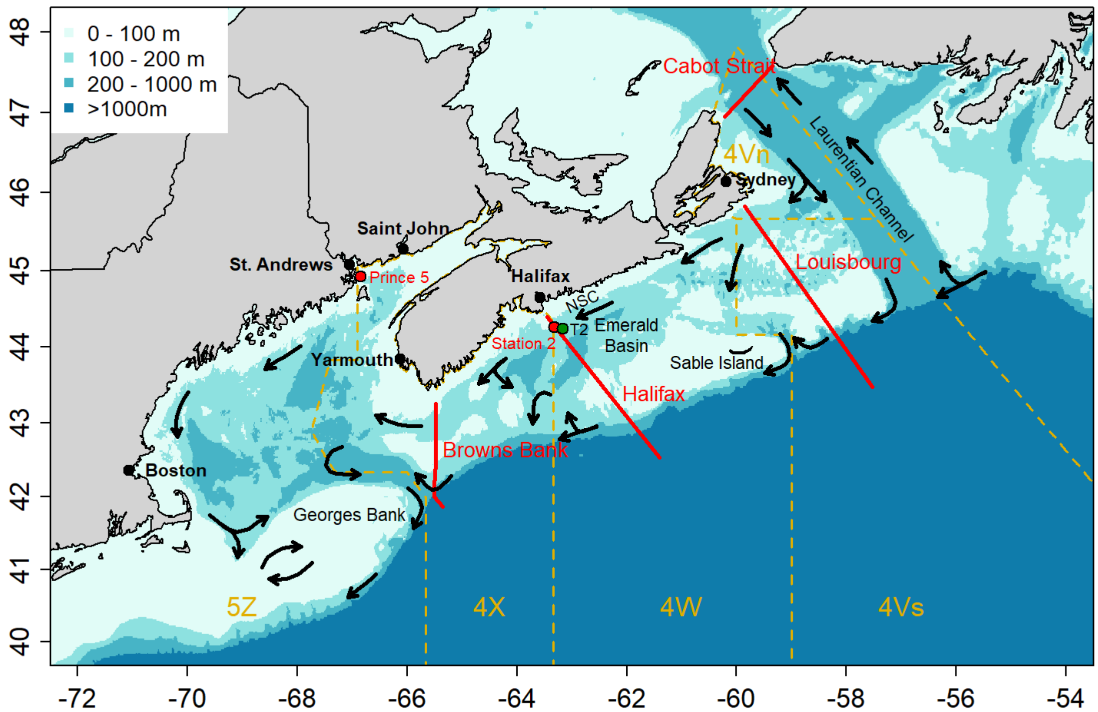

Figure 1. Map of the Scotian Shelf and the Gulf of Maine showing hydrographic stations (red circles), standard sections (red lines), current meter mooring (green) and topographic features. The Nova Scotia Current (NSC) is shown. The dotted lines indicate the boundaries of the Northwest Atlantic Fisheries Organization Divisions.

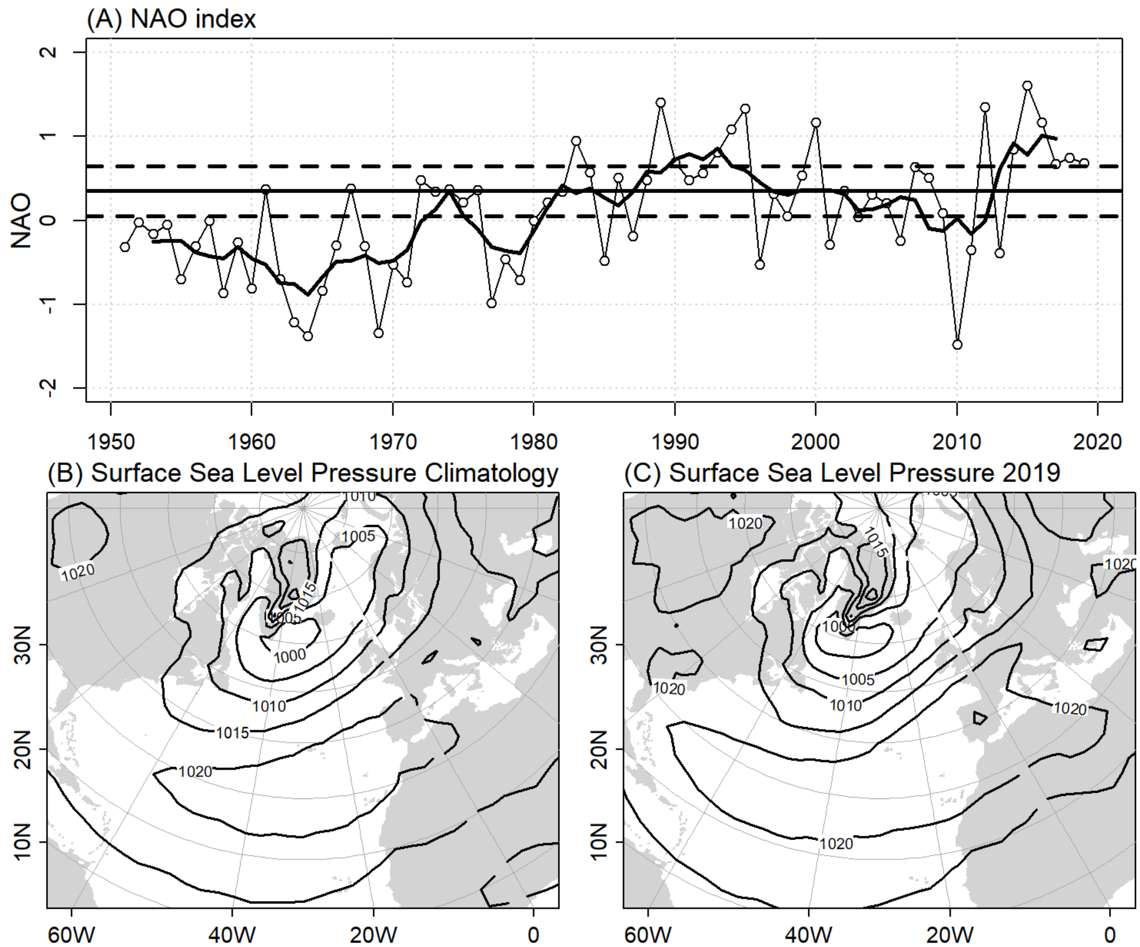

Figure 2. The North Atlantic Oscillation (NAO) index, defined as the winter (December, January, February, March) 500 mb pressure Principal Component Analysis which is representative of the difference between the Icelandic low and Azores high. Thick line is a 5-year moving average. Climatological mean is shown as the solid line. Dashed lines (upper panel) are ±0.5 standard deviation (SD). The lower panels show the 1981–2010 December–March mean (bottom left panel) and December 2018–March 2019 mean (bottom right panel) sea level atmospheric pressure over the North Atlantic. (Images provided by the NOAA/ESRL Physical Sciences Division, Boulder, Colorado.)

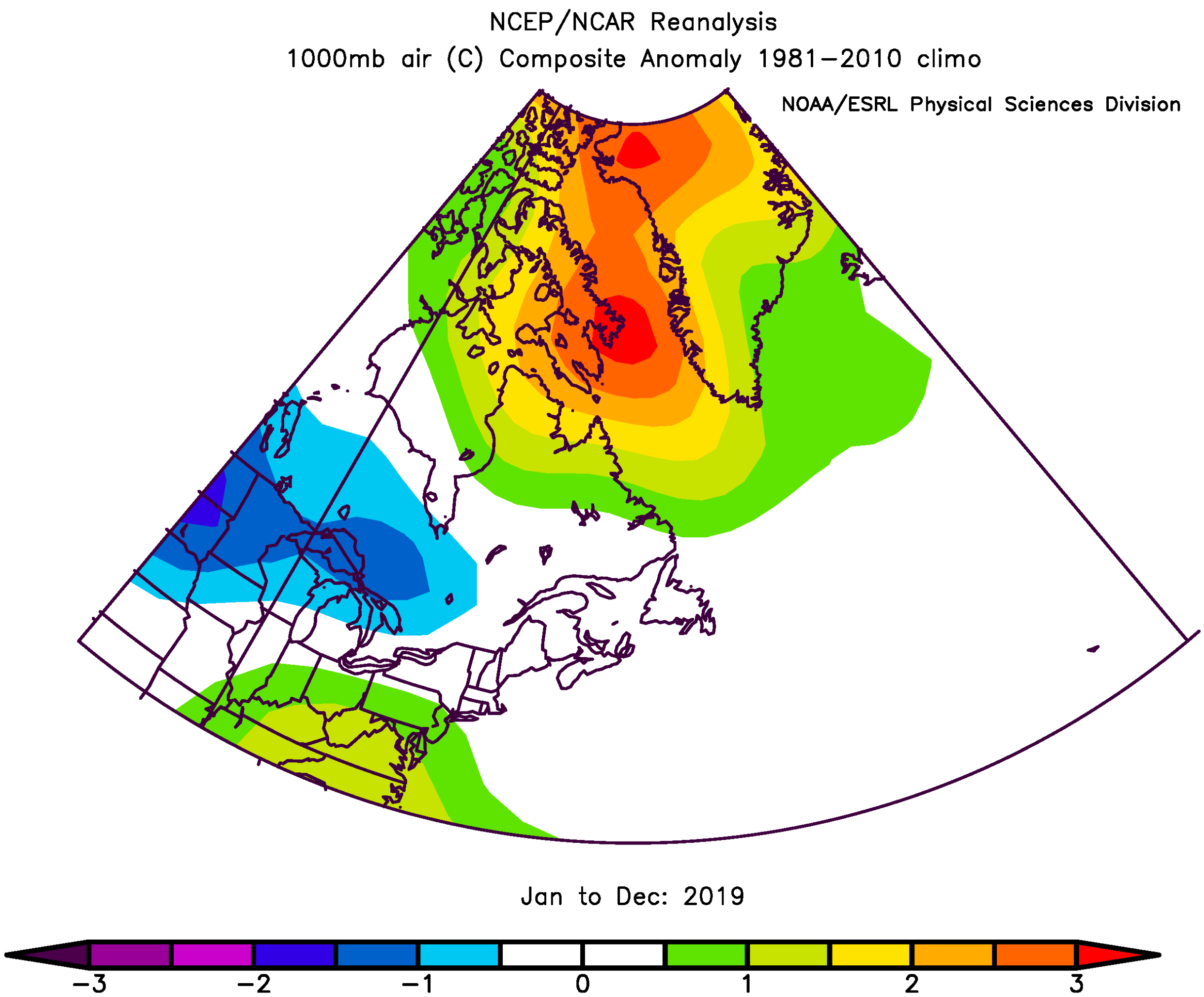

Figure 3. Annual air temperature anomalies (ºC) over the Northwest Atlantic relative to the 1981–2010 means; data were obtained from NOAA Internet site (accessed 13 February 2020). (Images provided by the NOAA/ESRL Physical Sciences Division, Boulder, Colorado.)

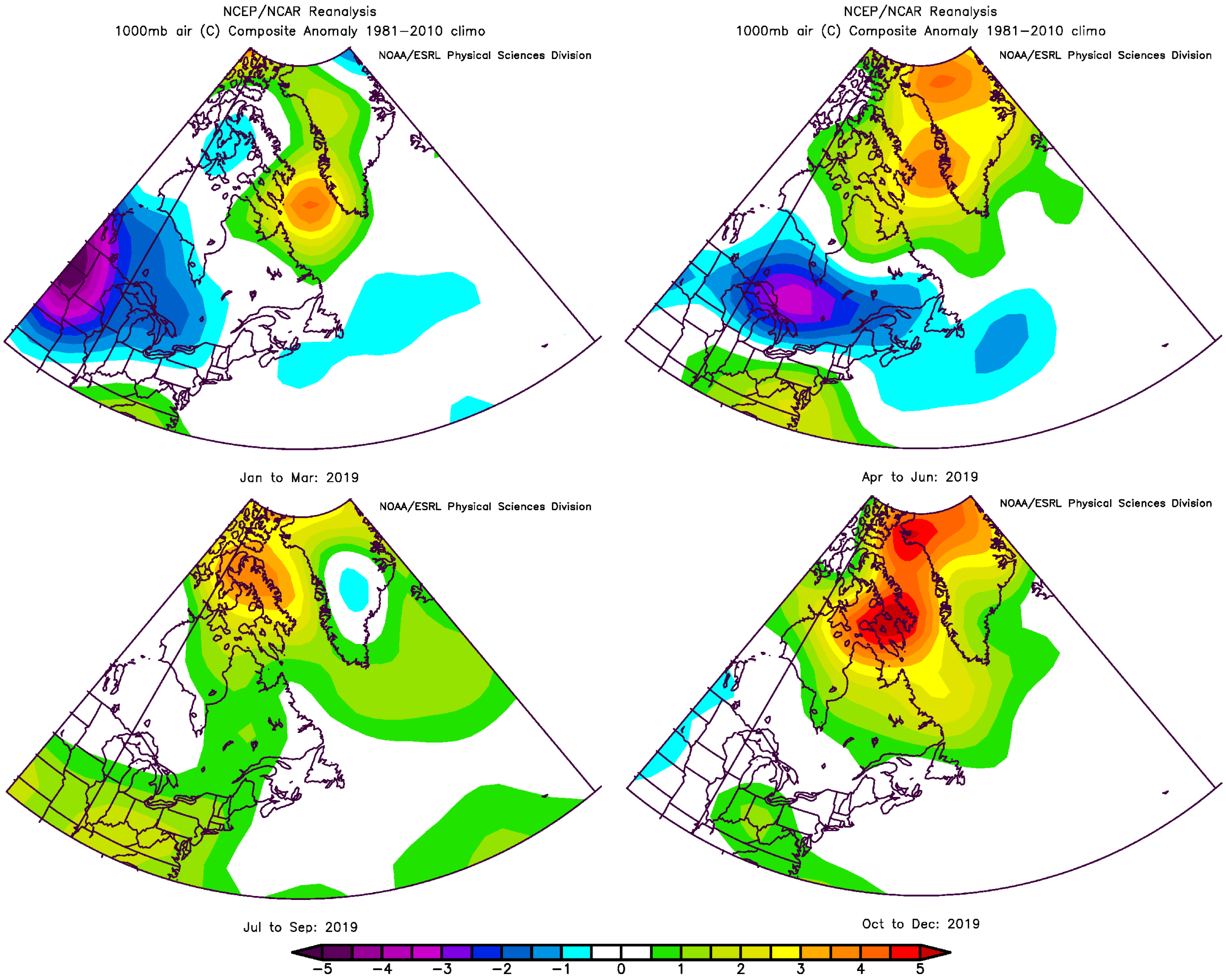

Figure 4. Seasonal air temperature anomalies (ºC) over the Northwest Atlantic relative to the 1981–2010 means; data were obtained from NOAA Internet site (accessed 13 February 2020). (Images provided by the NOAA/ESRL Physical Sciences Division, Boulder, Colorado.)

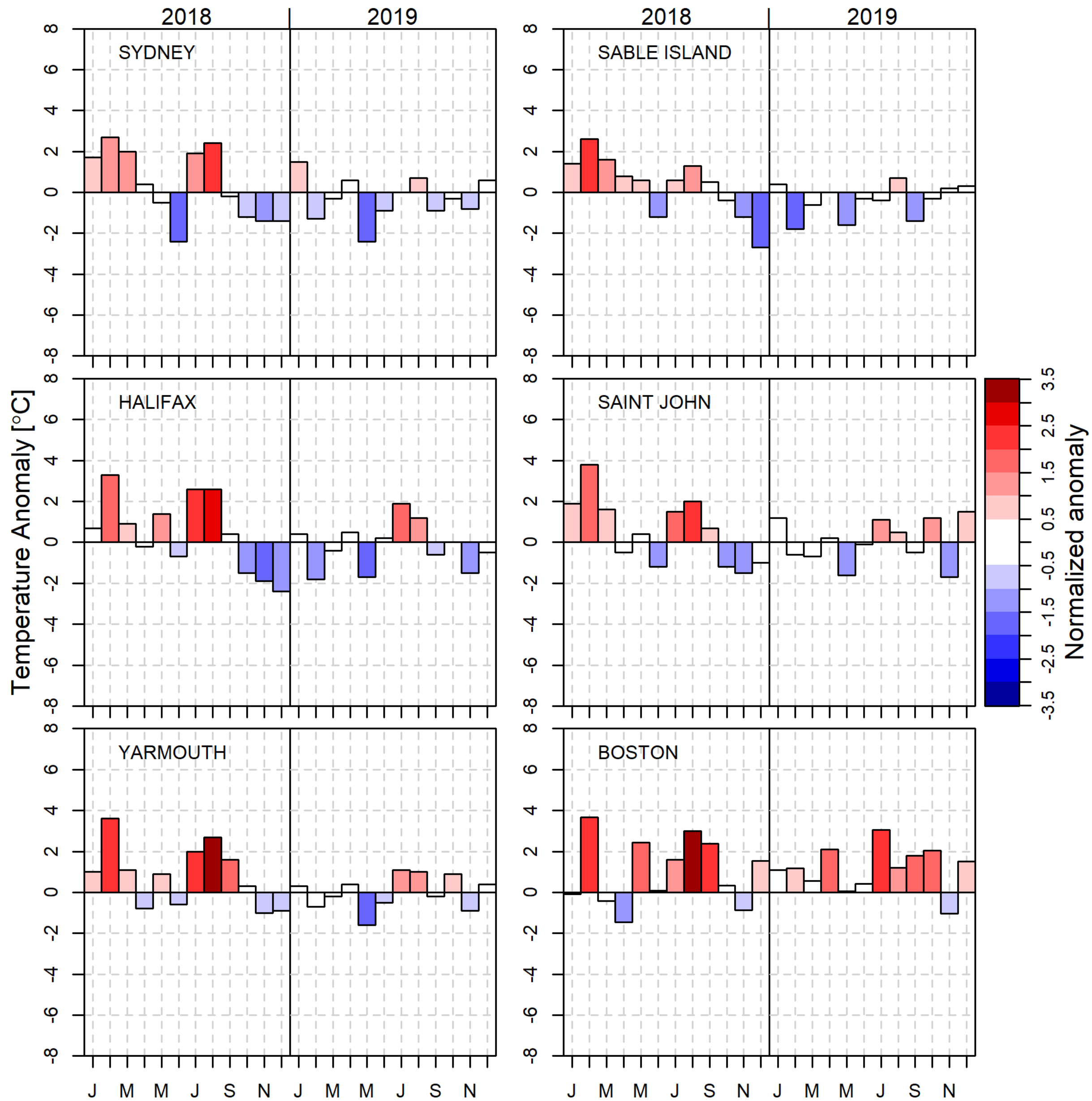

Figure 5. Monthly air temperature anomalies (°C) at several sites in Scotian Shelf/Gulf of Maine region for 2018 and 2019. See Figure 1 for locations. JMMJSN on x-axis represent January, March, May, June, September, and November. Anomalies are colour coded in terms of the numbers of SD above or below normal relative to monthly statistics.

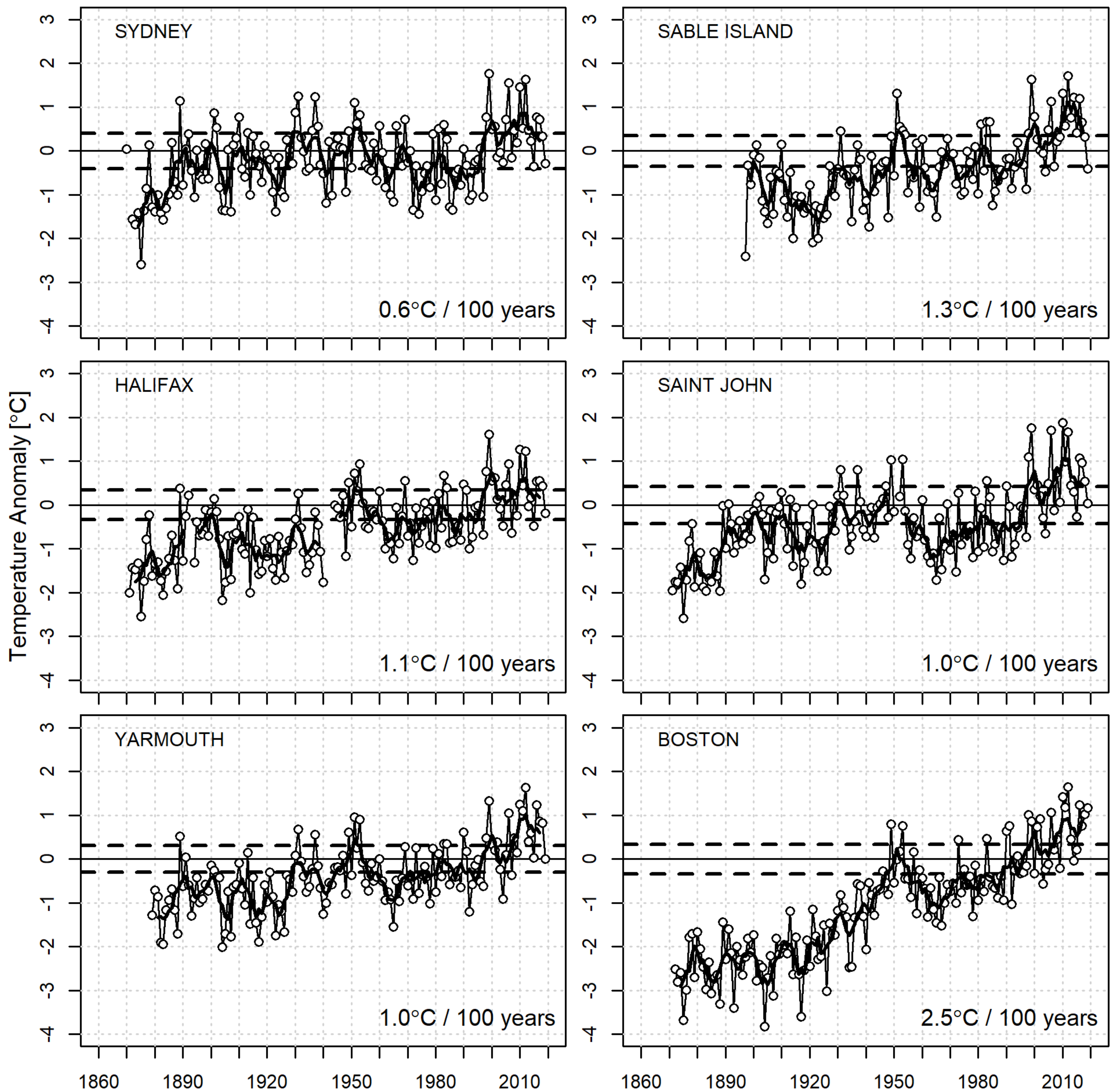

Figure 6. Annual air temperature anomalies in °C (dashed line) and five year running means (solid line) at selected sites (Sydney, Sable Island, Halifax (Shearwater), Yarmouth, Saint John, and Boston) in Scotian Shelf/Gulf of Maine region (years 1860 to 2019). Horizontal dashed lines represent plus or minus 0.5 SD for the 1981–2010 period. Linear trend for the period 1900–present are shown.

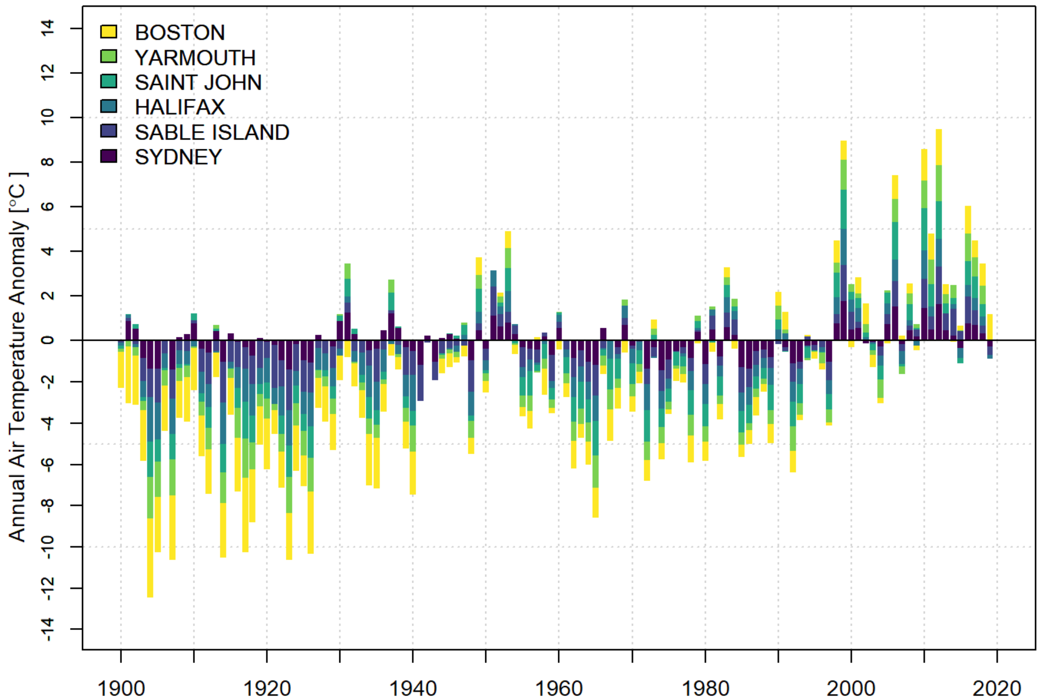

Figure 7. The contributions of each of the annual air temperature anomalies for six Scotian Shelf/Gulf of Maine sites (Boston, Saint John, Yarmouth, Halifax (Shearwater), Sable Island, and Sydney) are shown as a stacked bar chart. Anomalies referenced to 1981–2010.

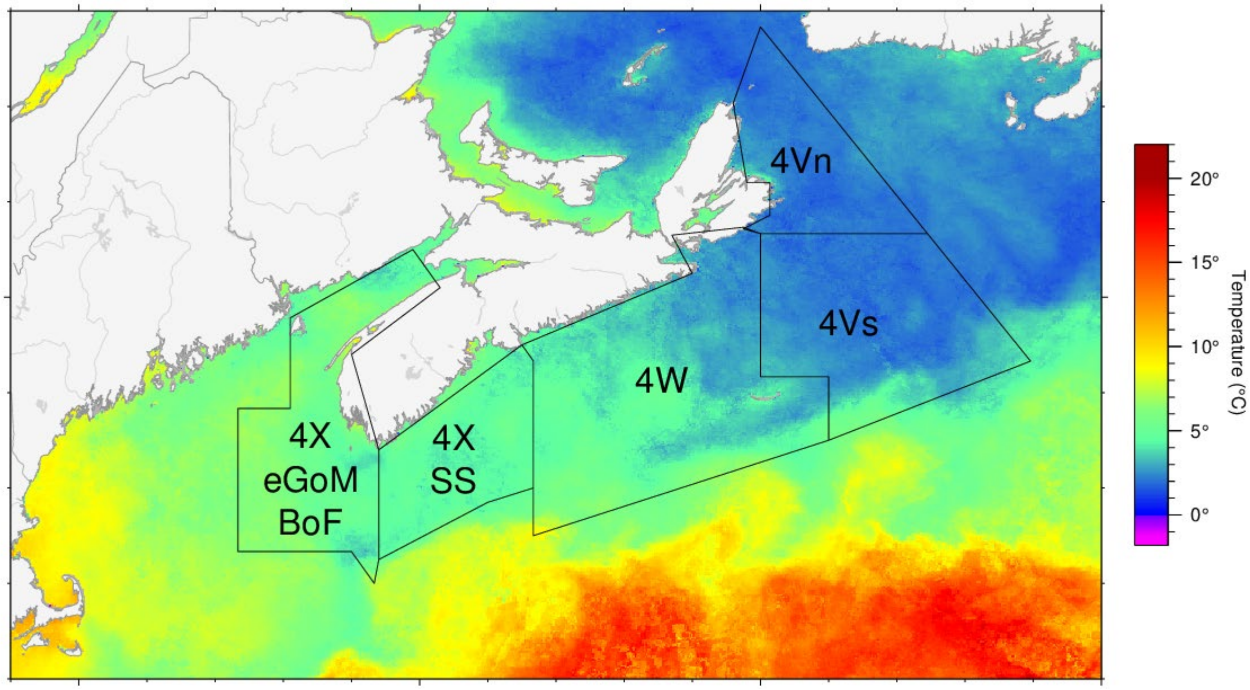

Figure 8. Scotian Shelf/Gulf of Maine areas (4Vn, 4Vs, 4W, 4X SS and 4X eGoM-BoF) used for extraction of sea surface temperature.

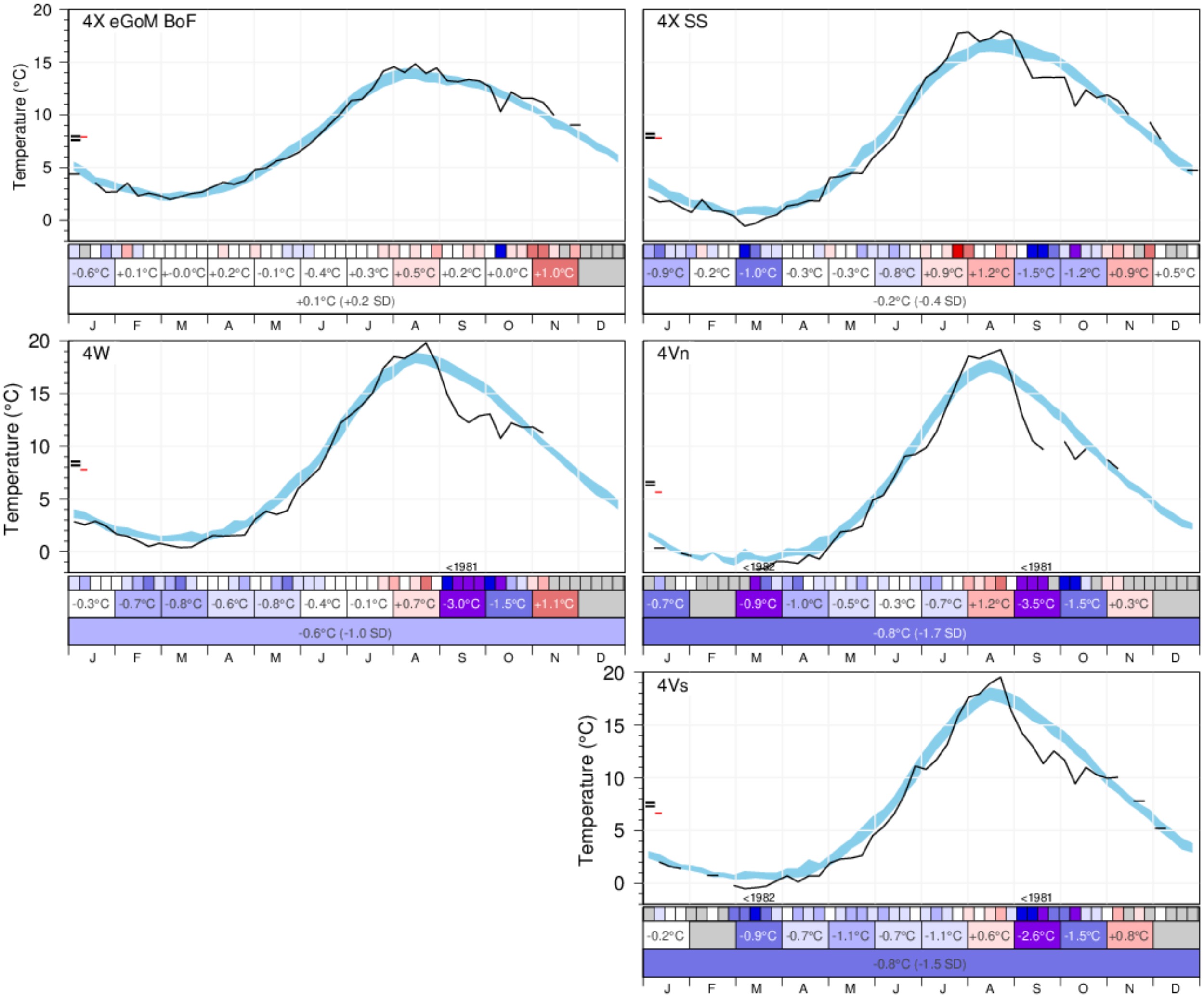

Figure 9. AVHRR SST weekly, monthly, and annual averages over the five regions of the Scotian Shelf and Gulf of Maine. The blue area represents the 1981–2010 climatological weekly mean ± 0.5 SD. The scorecards are colour-coded according to the normalized anomalies based on the 1981–2010 climatologies for each week (top row), month (middle row), or for the year (bottom row).

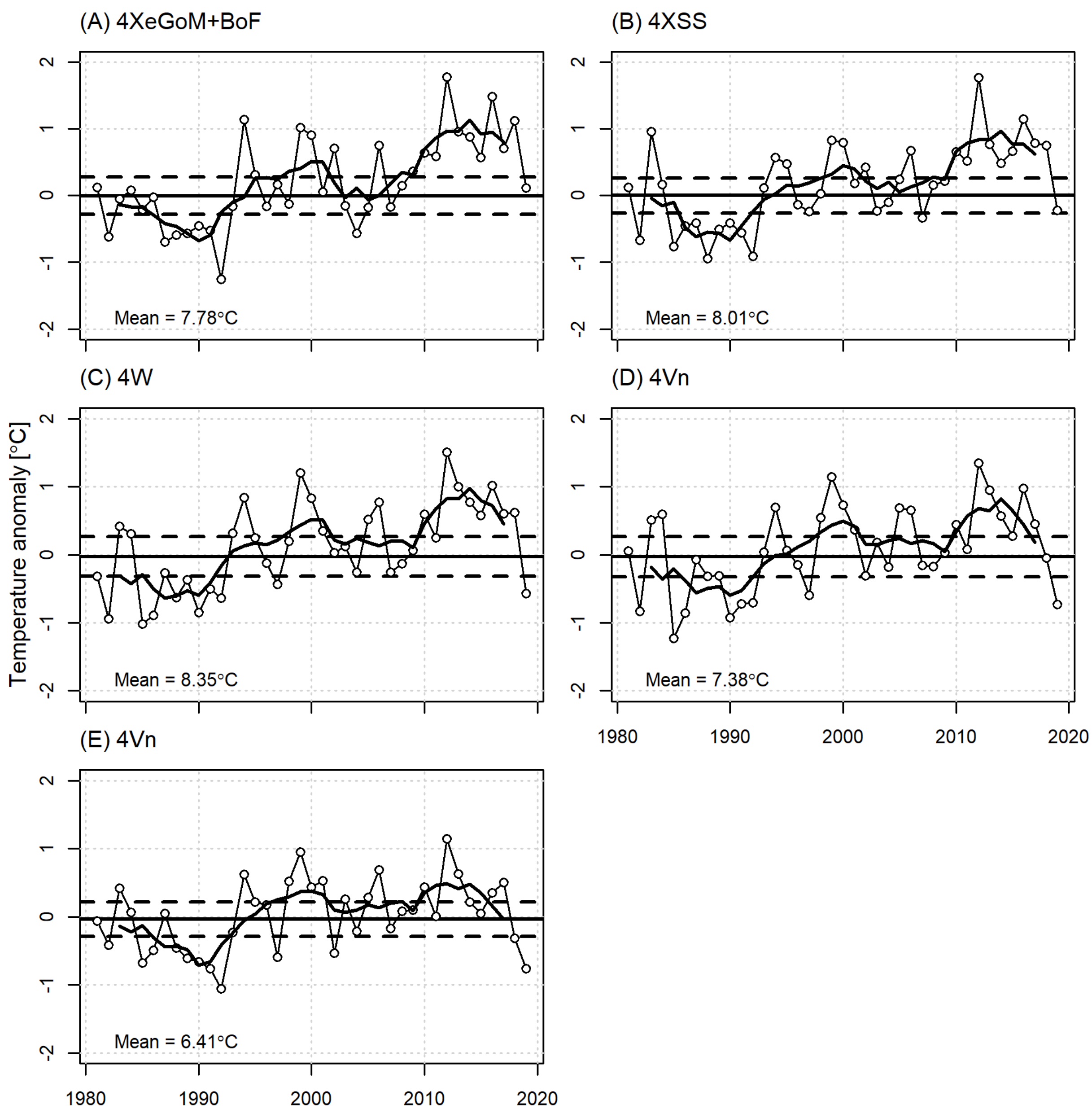

Figure 10. The annual sea-surface- temperature normalized anomalies derived from satellite imagery compared to their long-term monthly means (five Scotian Shelf and Gulf of Maine regions–4Vn, 4Vs, 4W, 4X Scotian Shelf, and 4X eastern Gulf of Maine/Bay of Fundy–Figure 8).

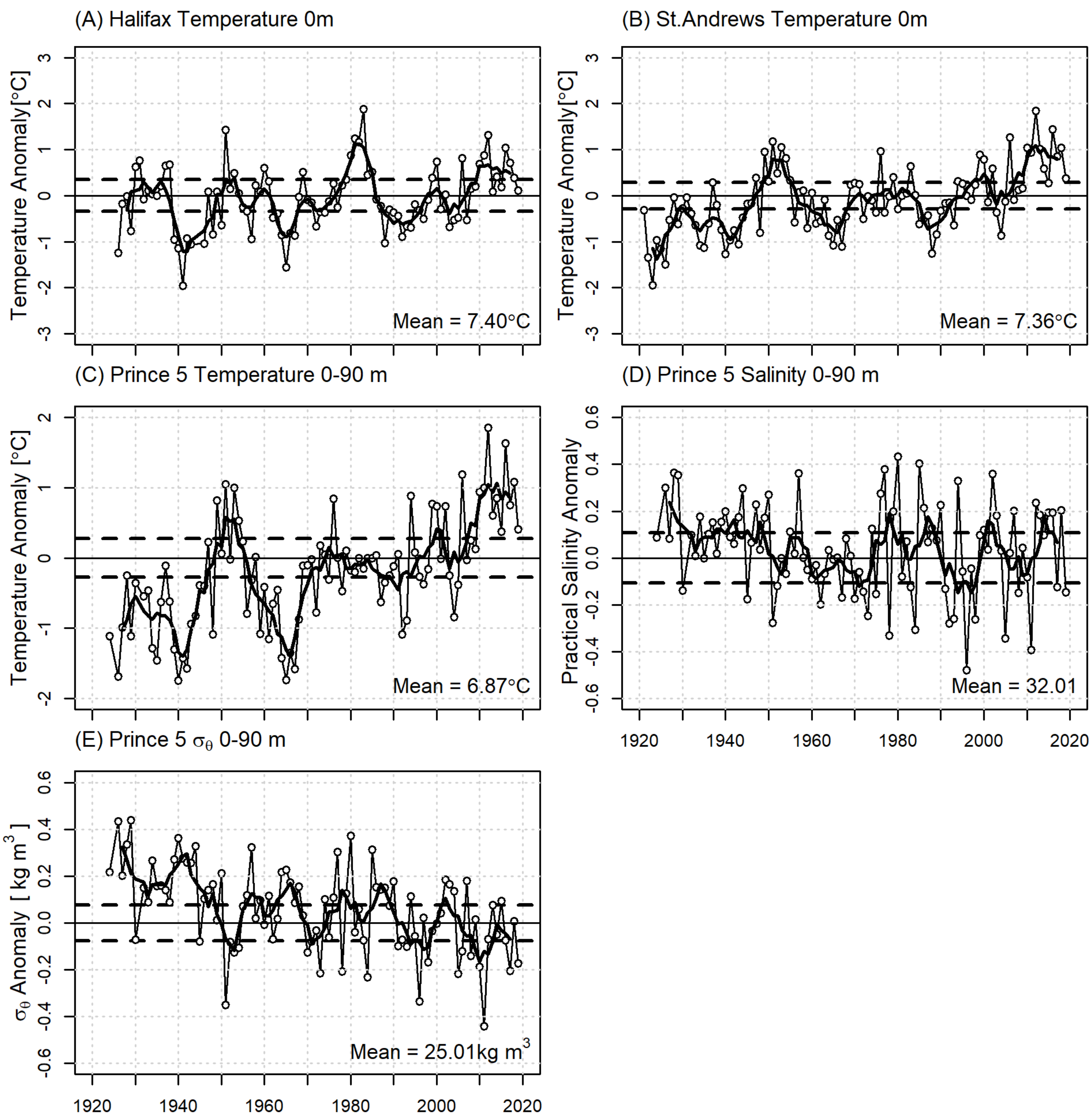

Figure 11. The annual surface-temperature anomalies (dotted line with circles) and their five-year running means (heavy black line) for: (A) Halifax Harbour and (B) St. Andrews and annual depth-averaged (0–90 m) temperature (C), salinity (D), and density (E) anomalies for the Prince 5 monitoring station at the mouth of the Bay of Fundy. Horizontal dashed lines are mean plus and minus 0.5 SD.

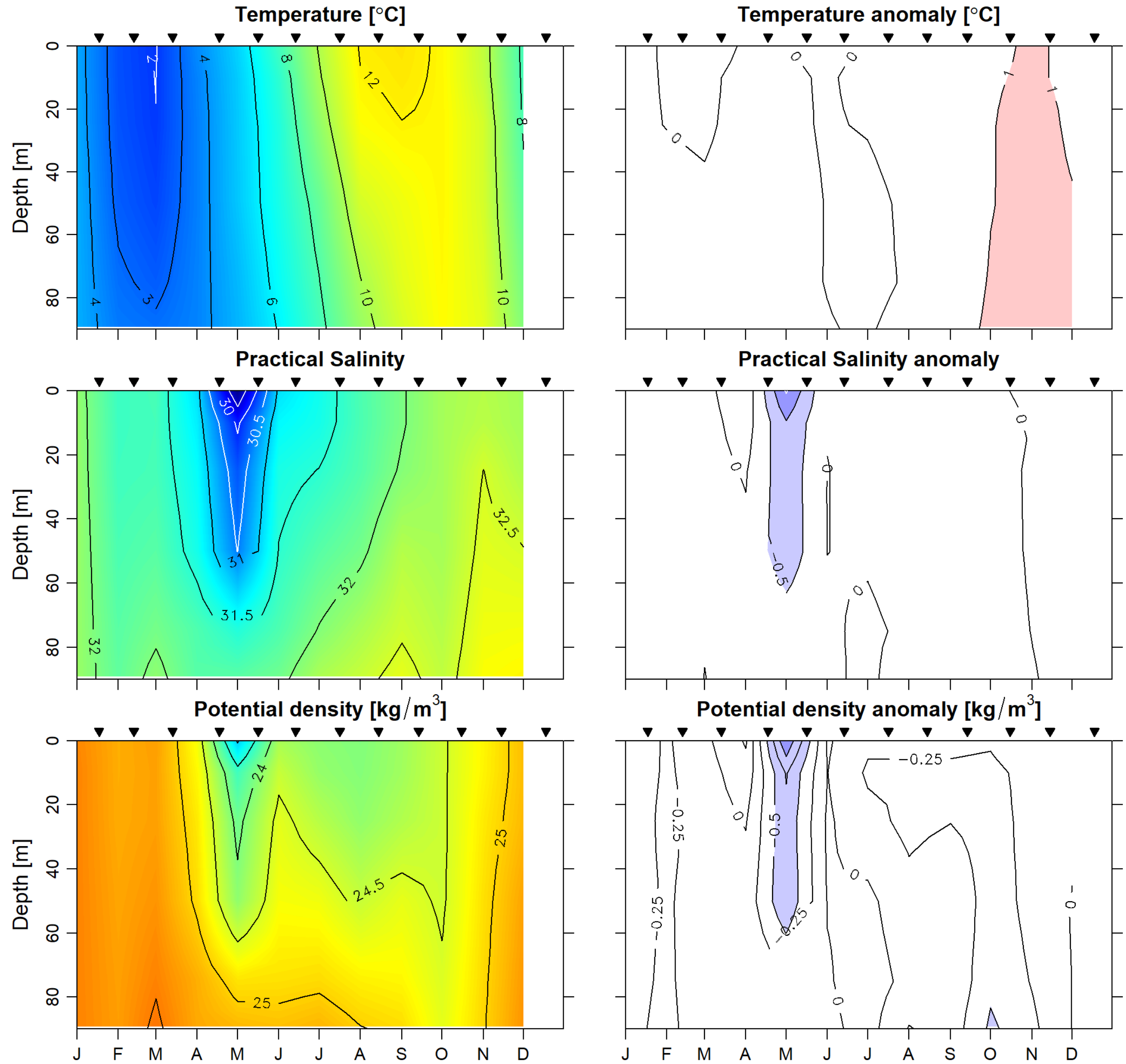

Figure 12. The 2019 annual cycle of temperature (top panel), salinity (middle panel), and density (lower panel) and their anomalies with respect to 1981–2010 monthly means (right panels) for the Prince 5 monitoring station at the mouth of the Bay of Fundy. Bullets indicate periods of sampling.

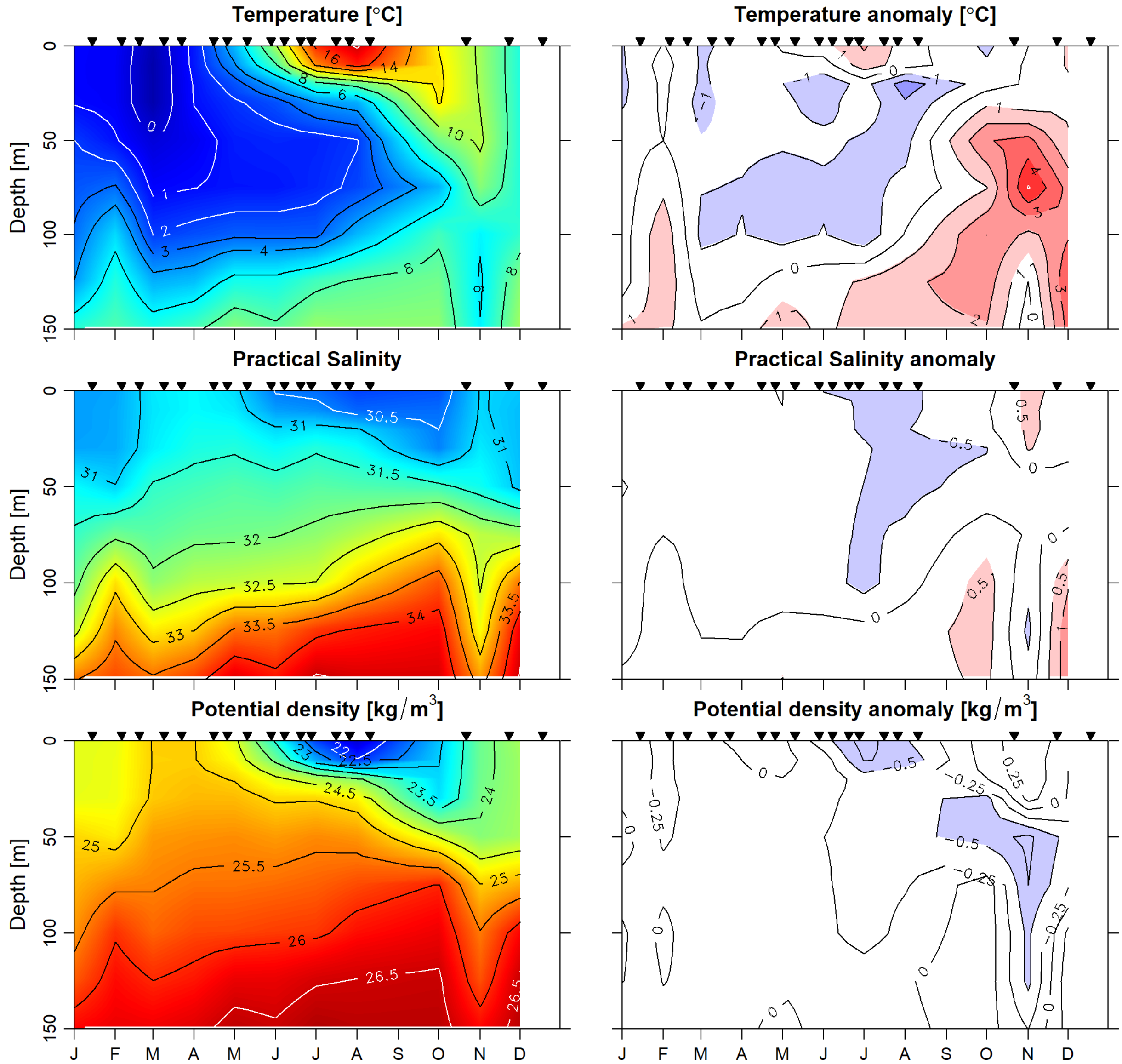

Figure 13. The 2019 annual cycle of temperature (top panel), salinity (middle panel), and density (lower panel) and their anomalies with respect to 1981–2010 monthly means (right panels) for Halifax station 2. Bullets indicate periods of sampling.

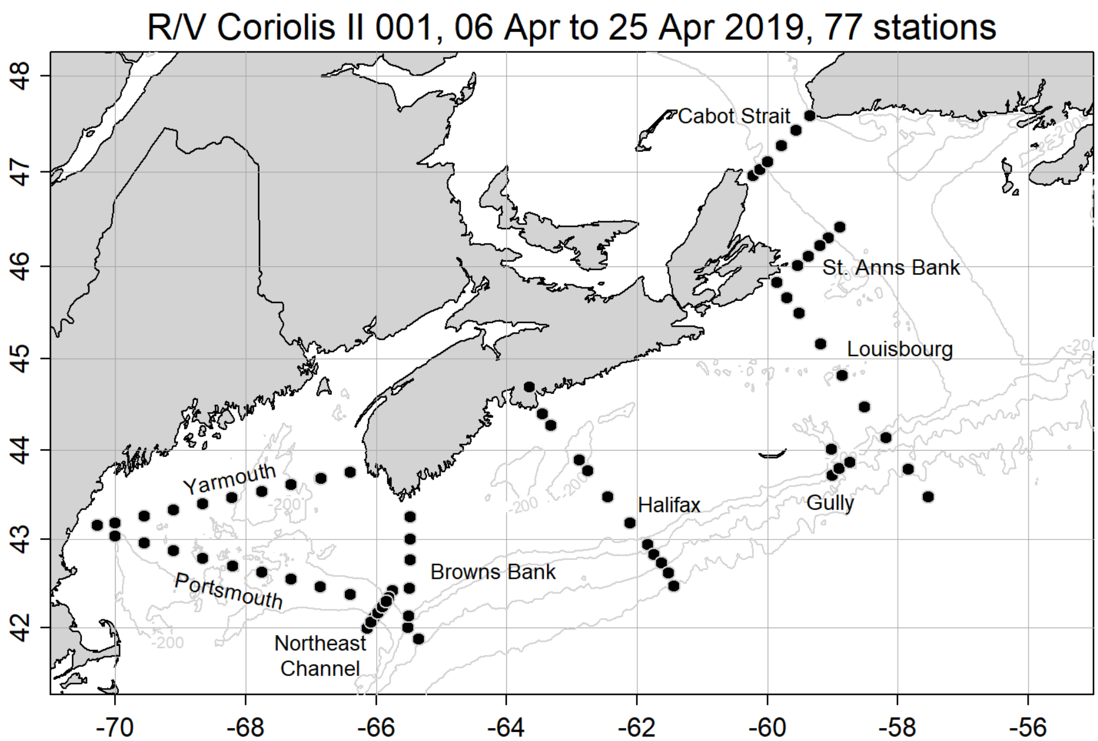

Figure 14. The 2019 sampling of the Scotian Shelf/Gulf of Maine for the Spring survey. There was no Fall survey.

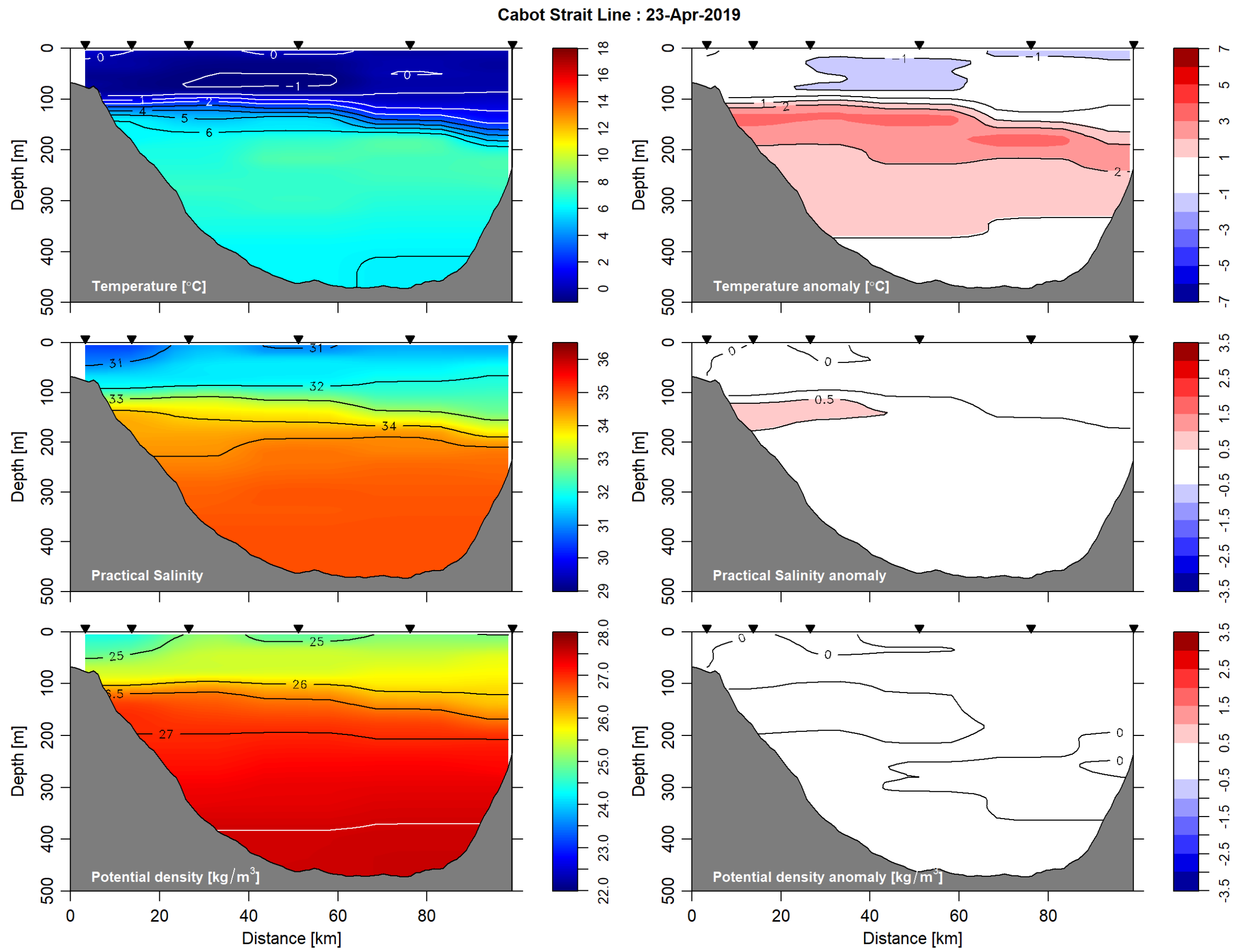

Figure 15. The 2019 sampling of the Cabot Strait Section for Spring. Temperature (top panel), salinity (middle panel), and density (lower panel) and their anomalies with respect to 1981–2010 monthly means (right panels). Bullets indicate locations of sampling.

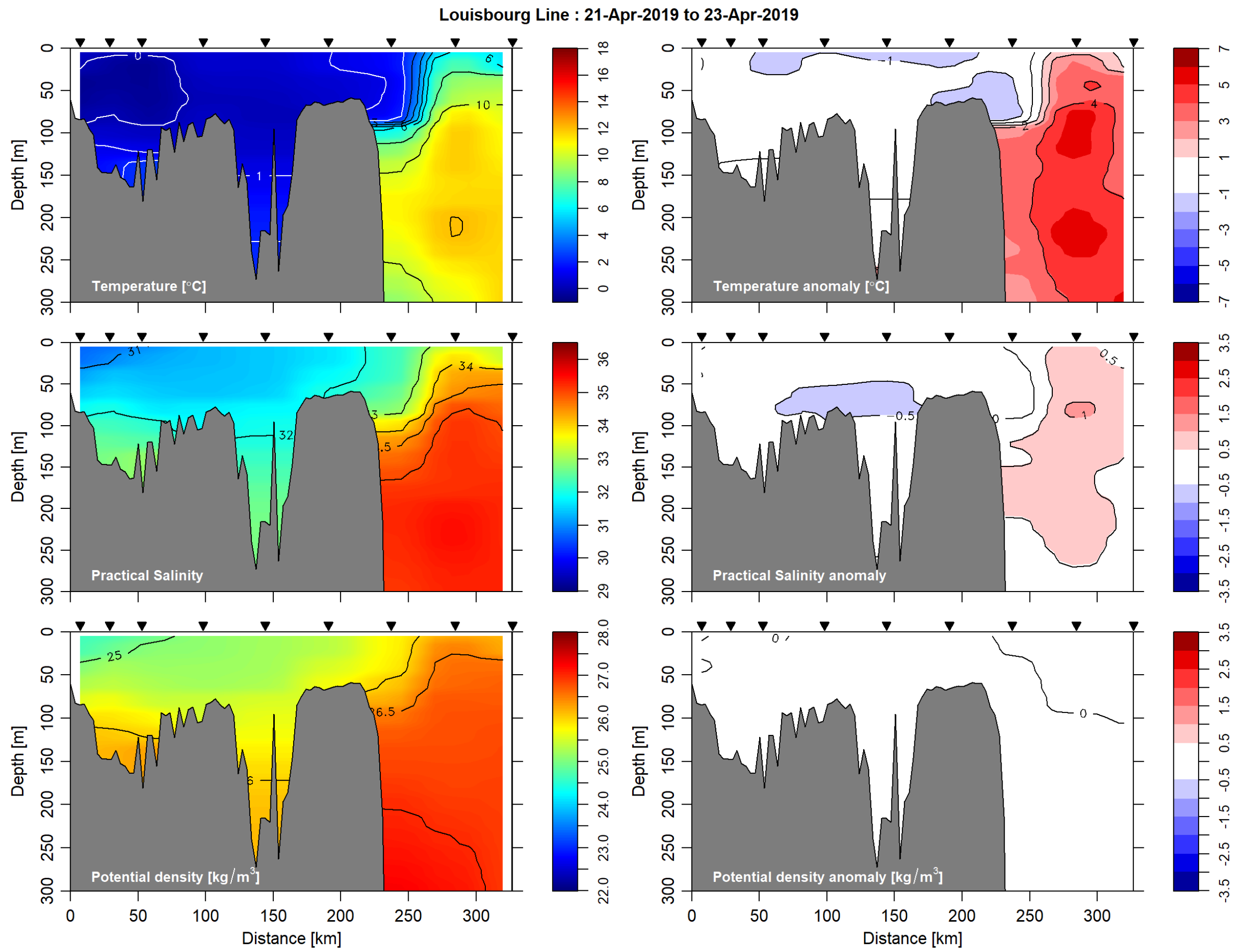

Figure 16. The 2019 sampling of the Louisbourg Section for Spring. Temperature (top panel), salinity (middle panel), and density (lower panel) and their anomalies with respect to 1981–2010 monthly means (right panels). Bullets indicate locations of sampling.

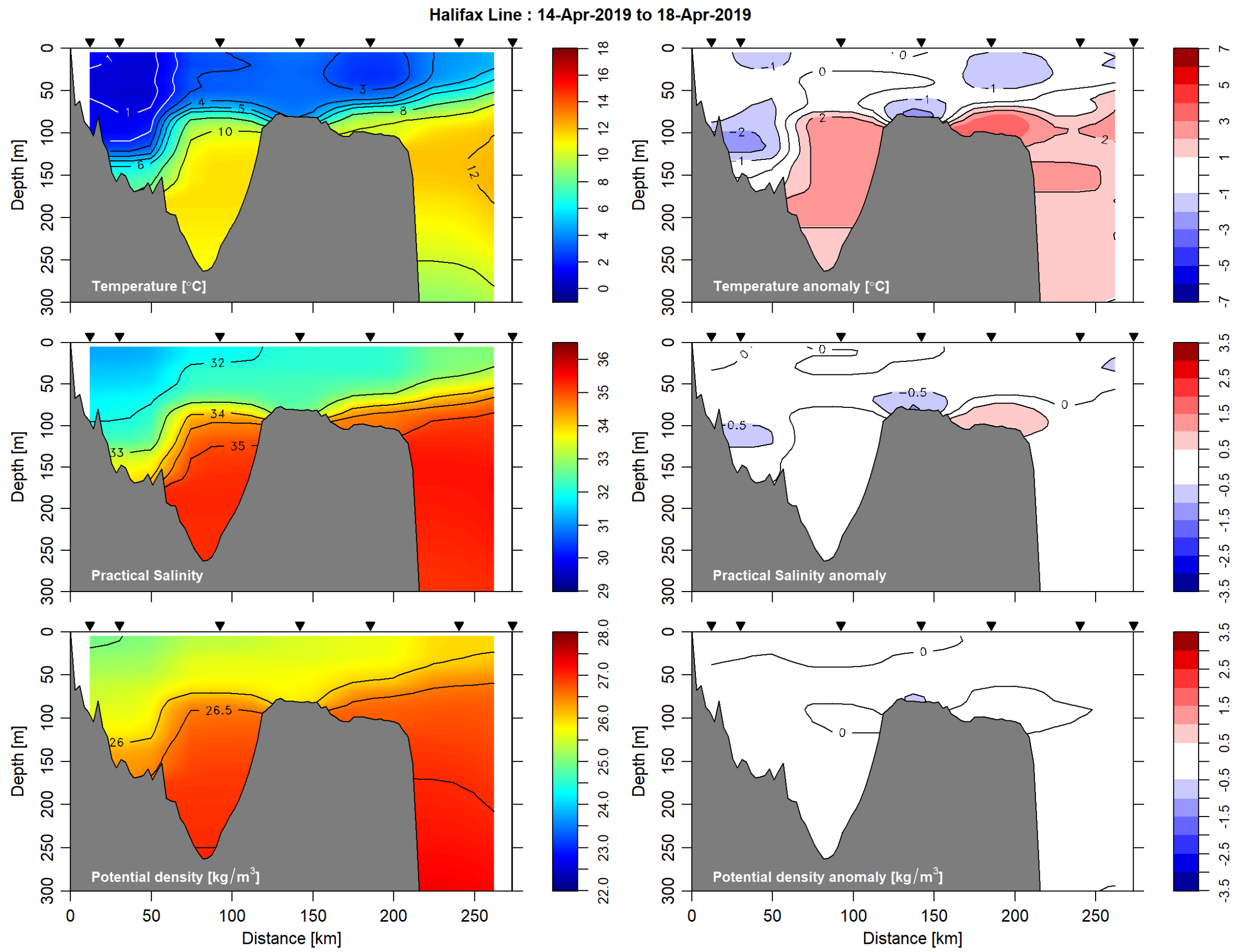

Figure 17. The 2019 sampling of the Halifax Section for Spring. Temperature (top panel), salinity (middle panel), and density (lower panel) and their anomalies with respect to 1981–2010 monthly means (right panels). Bullets indicate locations of sampling.

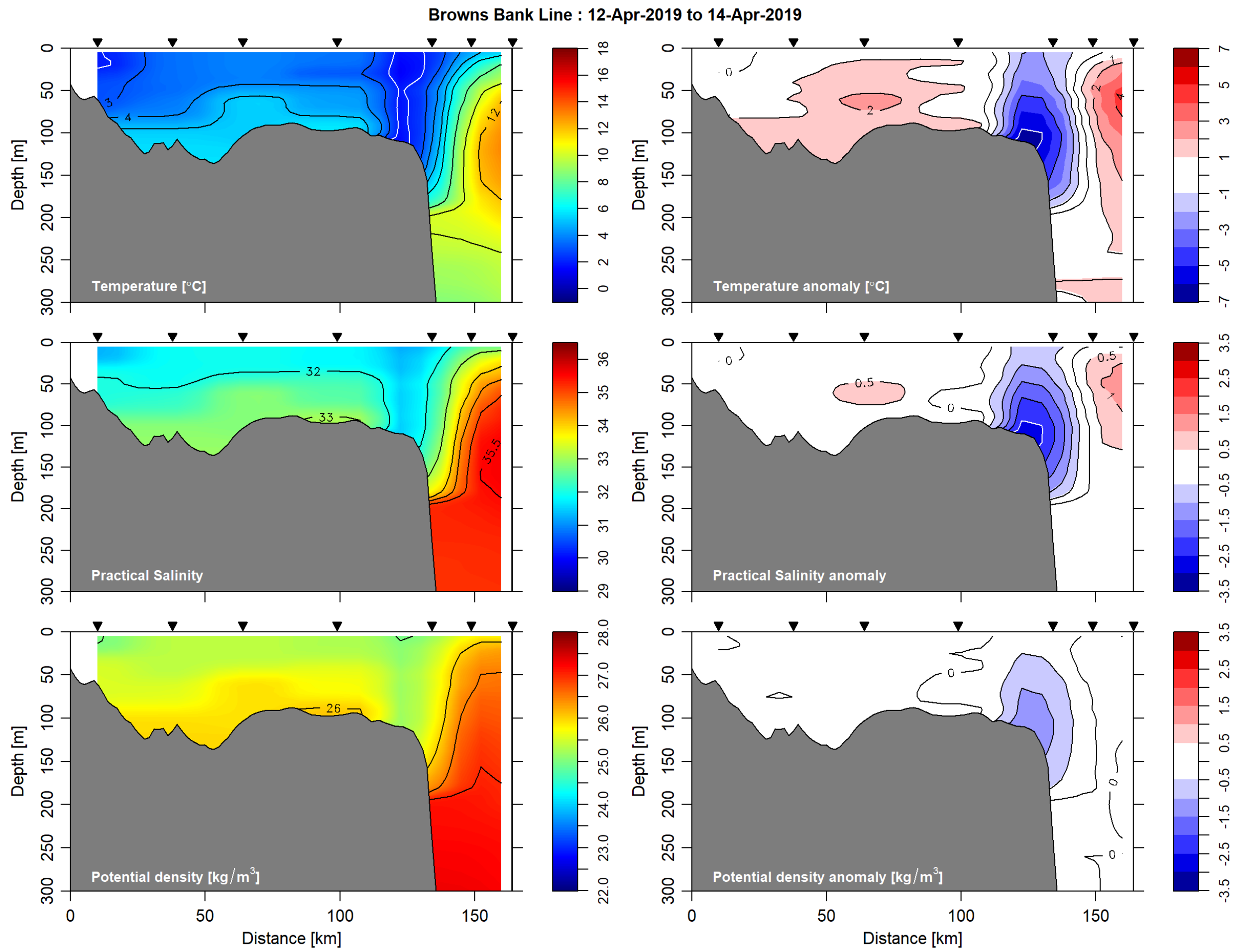

Figure 18. The 2019 sampling of the Browns Bank Section for Spring. Temperature (top panel), salinity (middle panel), and density (lower panel) and their anomalies with respect to 1981–2010 monthly means (right panels). Bullets indicate locations of sampling.

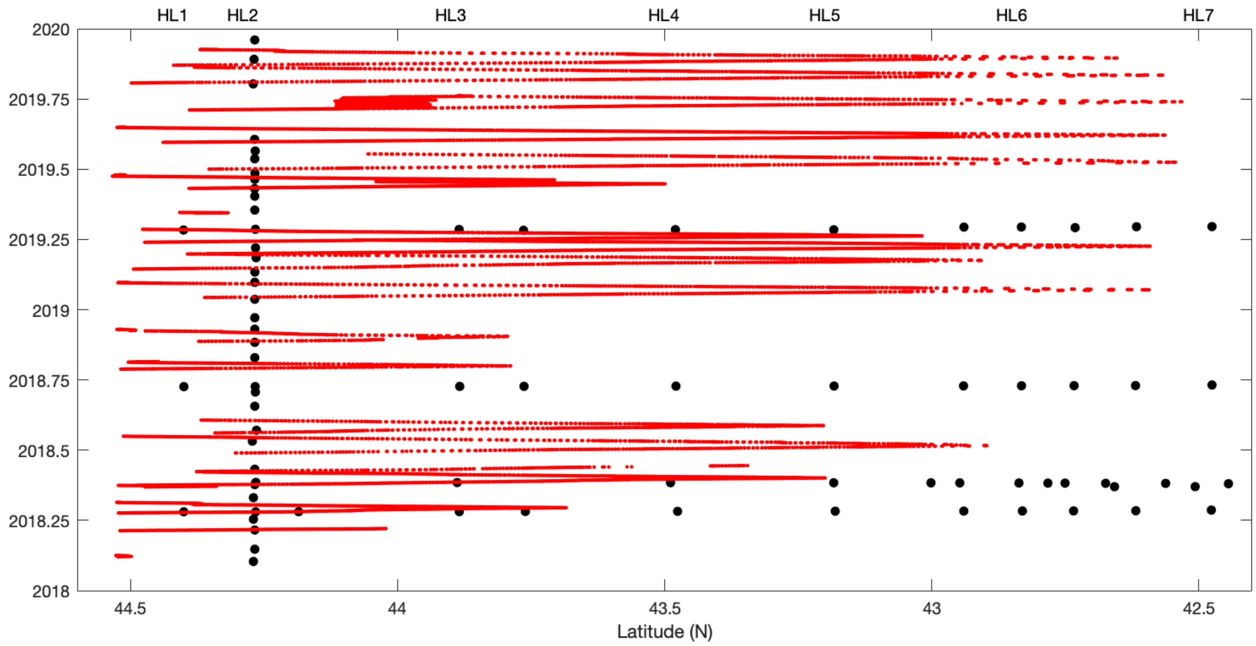

Figure 19. Hodograph of sampling on the Halifax Line for 2018 and 2019. Black dots represent the sampling by a vessel. Red dots represent sampling by the gliders.

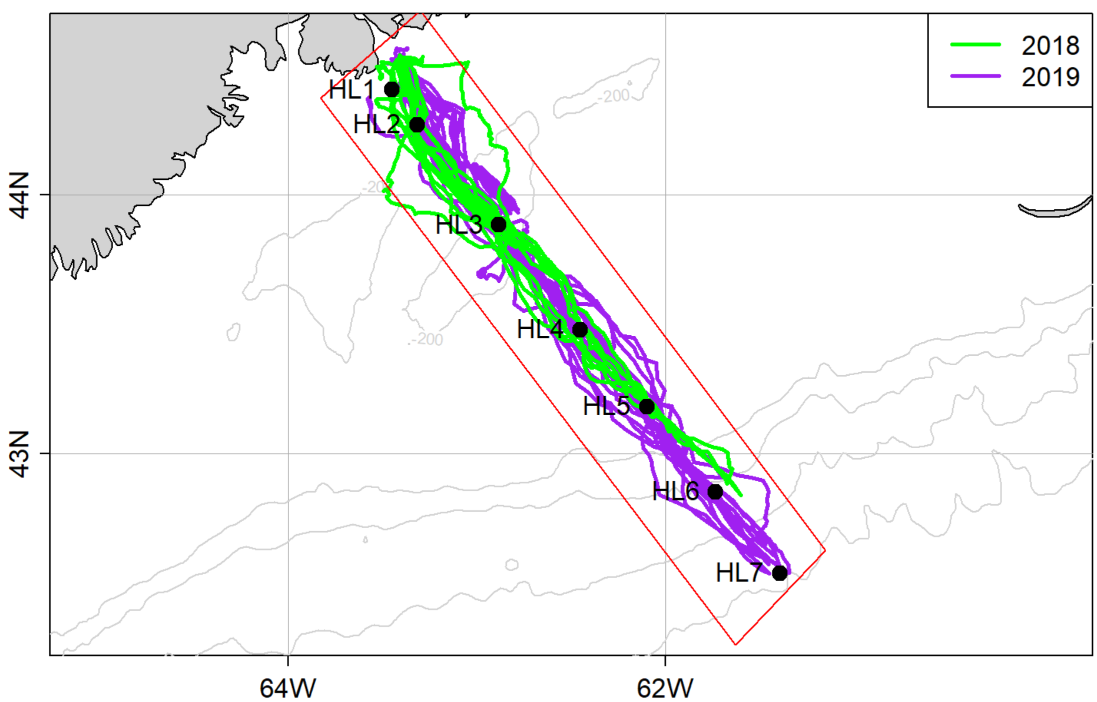

Figure 20. Glider trajectories on the Halifax Line for 2018 and 2019. Locations of the Halifax Line stations are shown by the black dots.

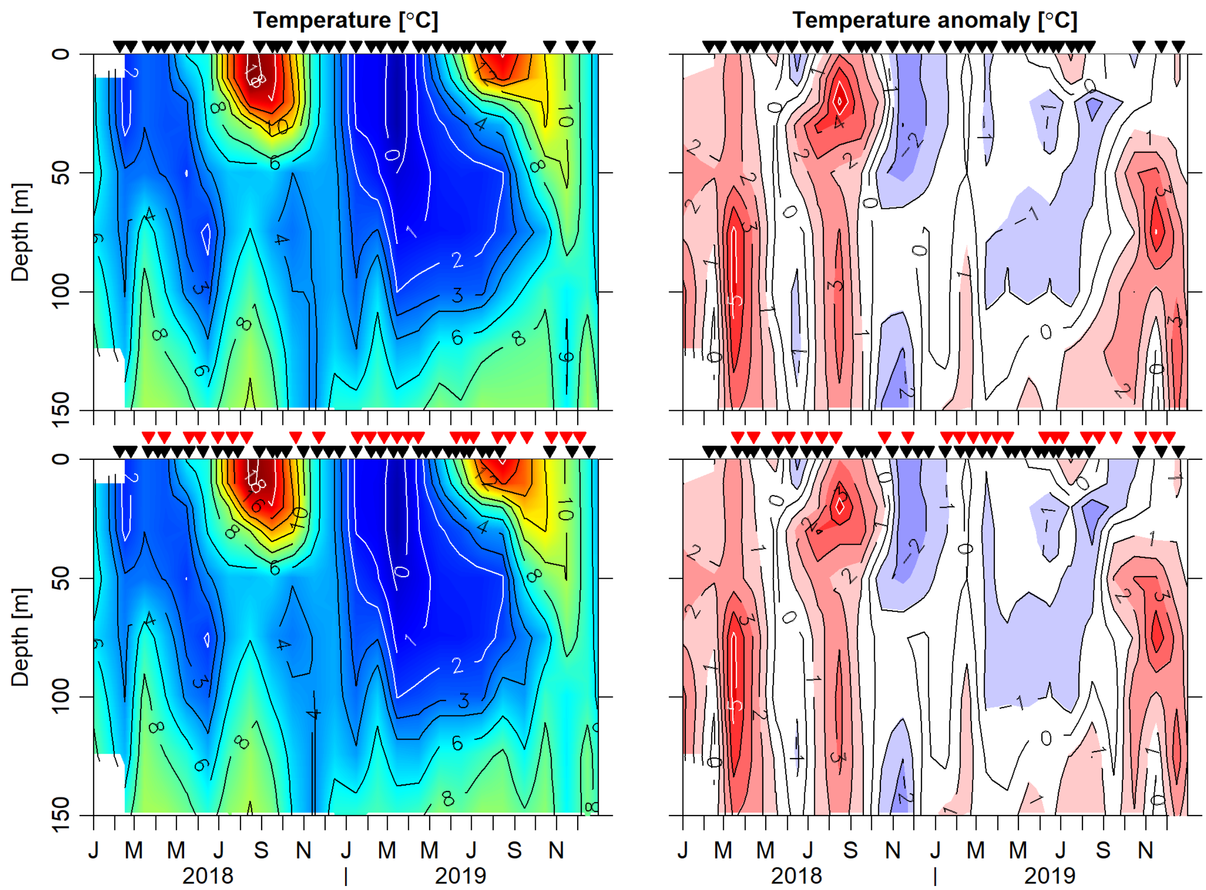

Figure 21. Top panels for temperature (left) and temperature anomaly (right) with standard vessel sampling at Station 2. Bottom panels includes the additional glider data with has been averaged hourly. Times of vessel sampling (black triangles) and glider sampling (red triangles) are shown for each panel.

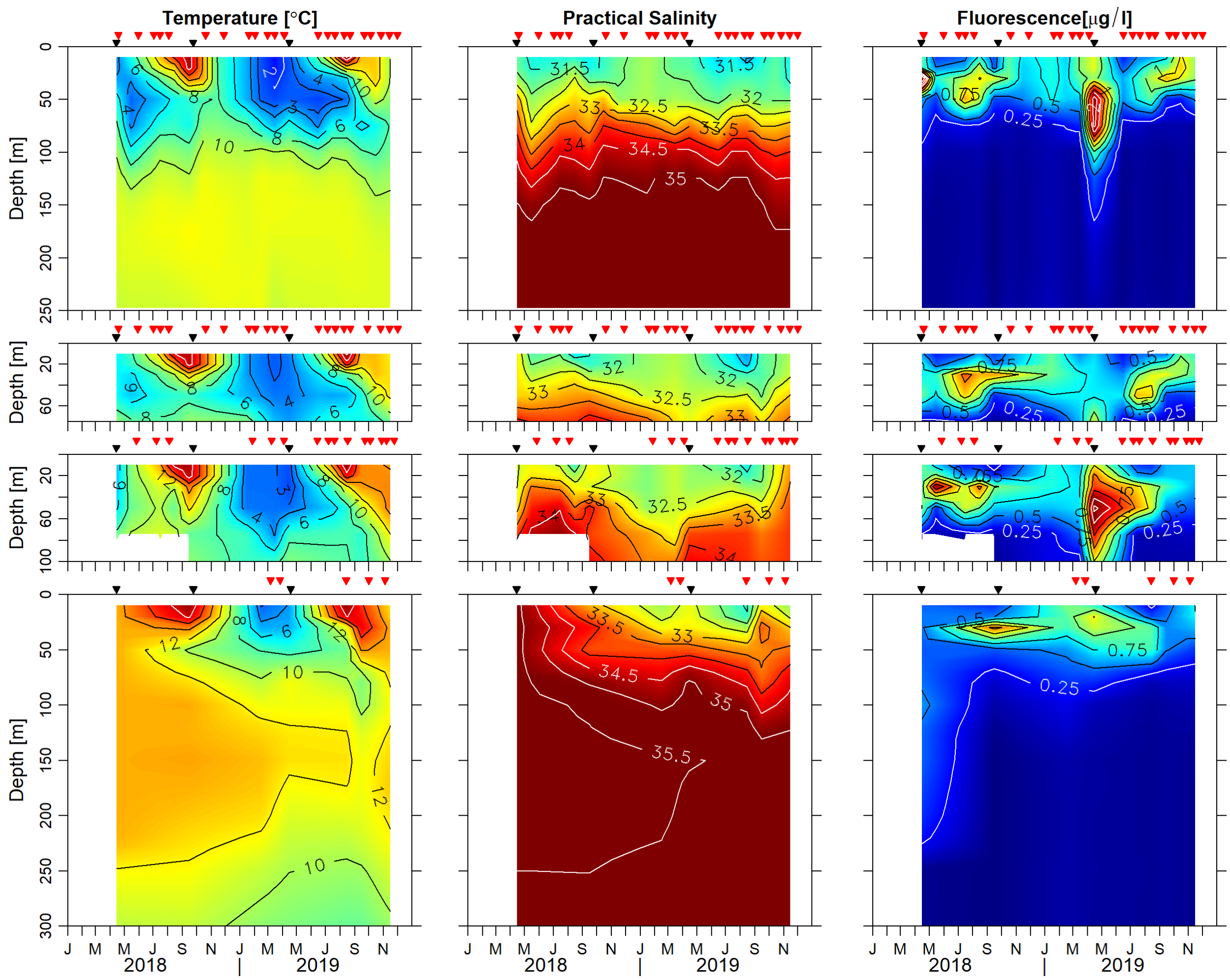

Figure 22. Temperature (left), salinity (middle) and chlorophyll fluorescence (right) for the standard hydrographic stations on the Halifax Line: HL3 (top panel), HL4 (second panel from the top), HL5 (third panel from the top), and HL6 (bottom panel). Only the top 300 m of HL data is shown. Times of vessel sampling (black triangles) and glider sampling (red triangles) are shown for each panel.

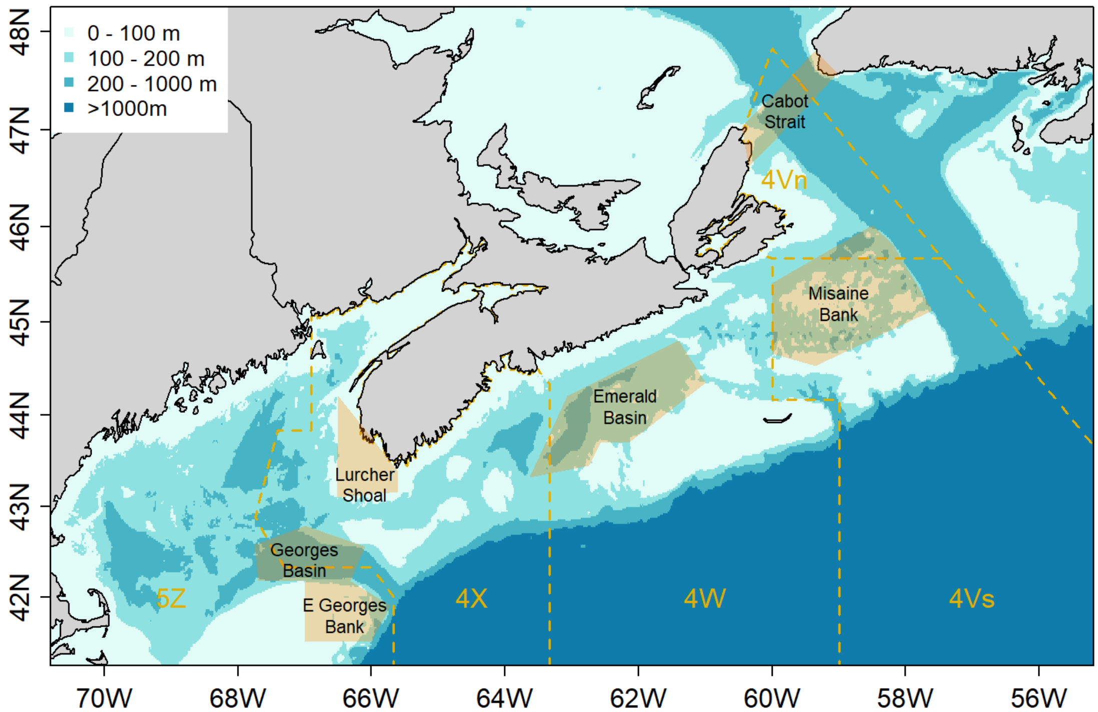

Figure 23. Areas on the Scotian Shelf and eastern Gulf of Maine depicting the different water masses: Cabot Strait; Misaine Bank; Emerald Basin; Lurcher Shoals; Georges Basin; and Eastern Georges Bank.

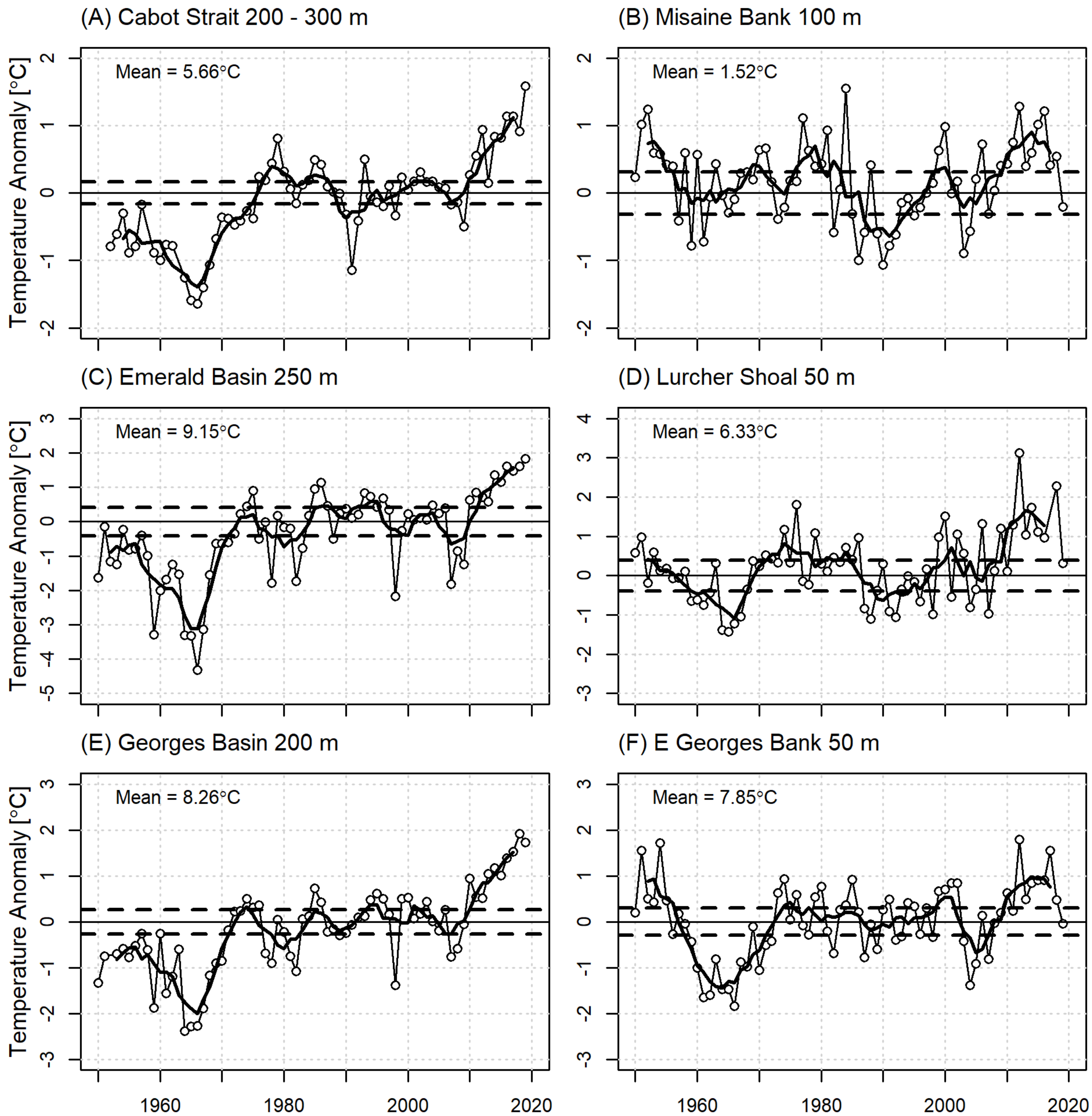

Figure 24. The annual mean temperature anomaly time series (line with circles) and the five-year-running-mean filtered anomalies (heavy solid line) on the Scotian Shelf and in the Gulf of Maine at: (A) Cabot Strait at 200–300 m, (B) Misaine Bank at 100 m, (C) Emerald Basin at 250 m, (D) Lurcher Shoals at 50 m, (E) Georges Basin at 200 m, and (F) Eastern Georges Bank at 50 m (see Figure 24 for locations of regions). Horizontal dashed lines are mean plus and minus 0.5 SD.

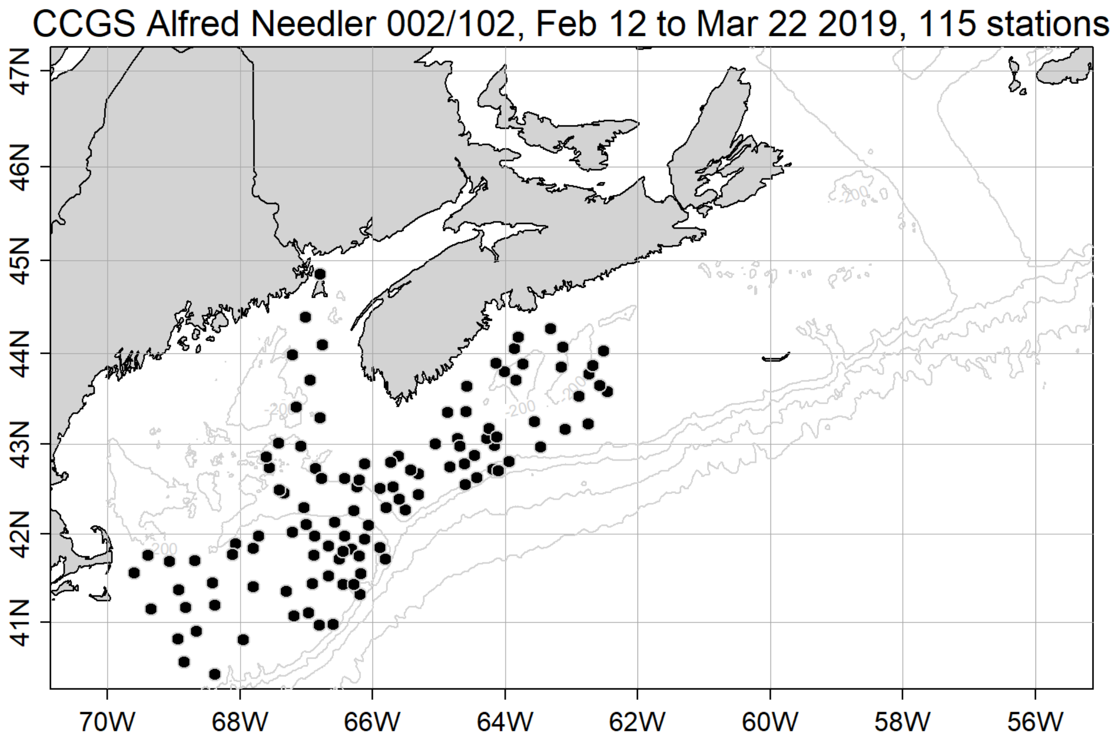

Figure 25. Locations of CTD sampling during the 2019 winter survey.

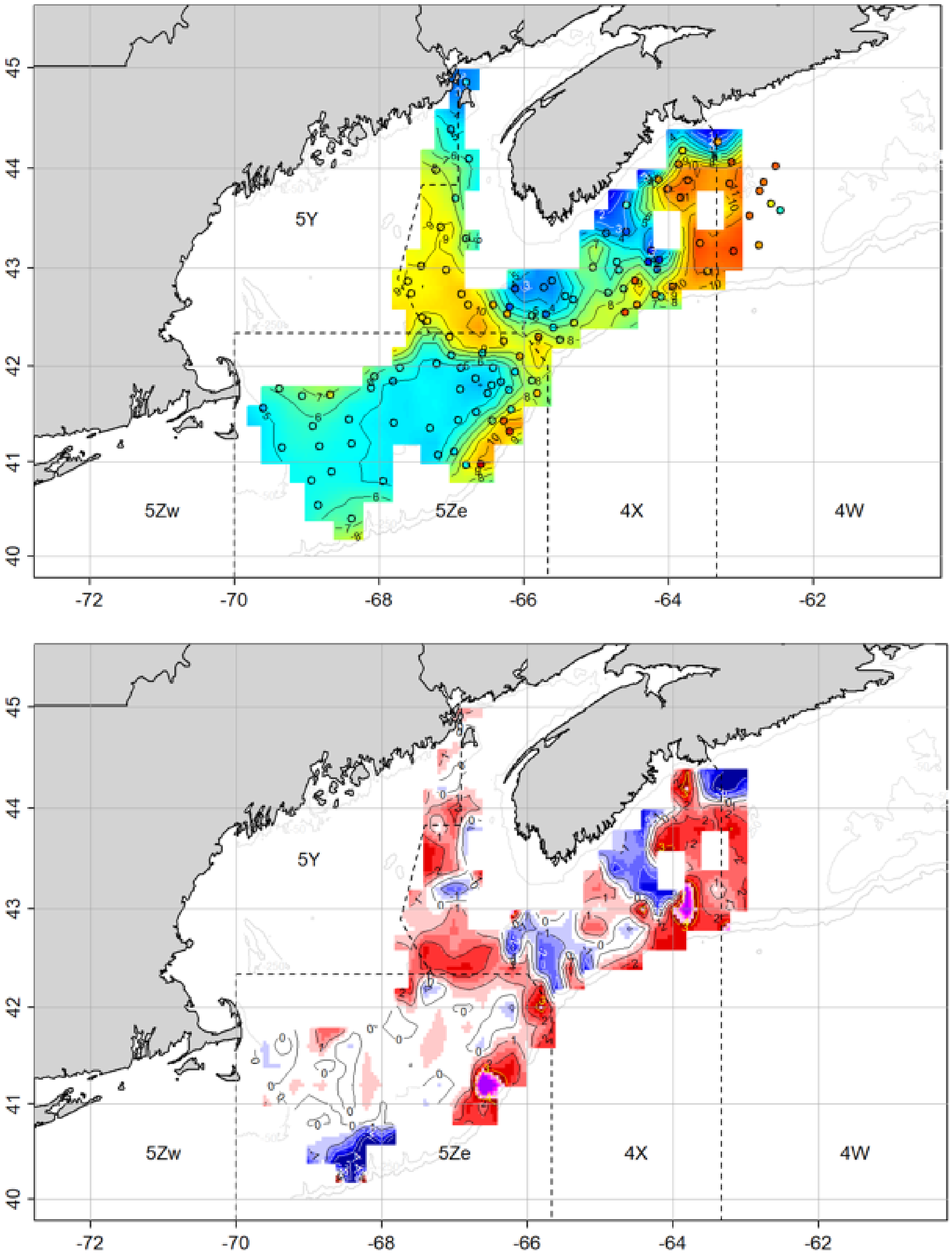

Figure 26. Winter bottom-temperature (upper panel) and anomaly (lower panel; relative to 1981–2010) maps for 2019. NAFO Divisions 4X, 4W, 5Ze, 5Y, and 5Zw are shown.

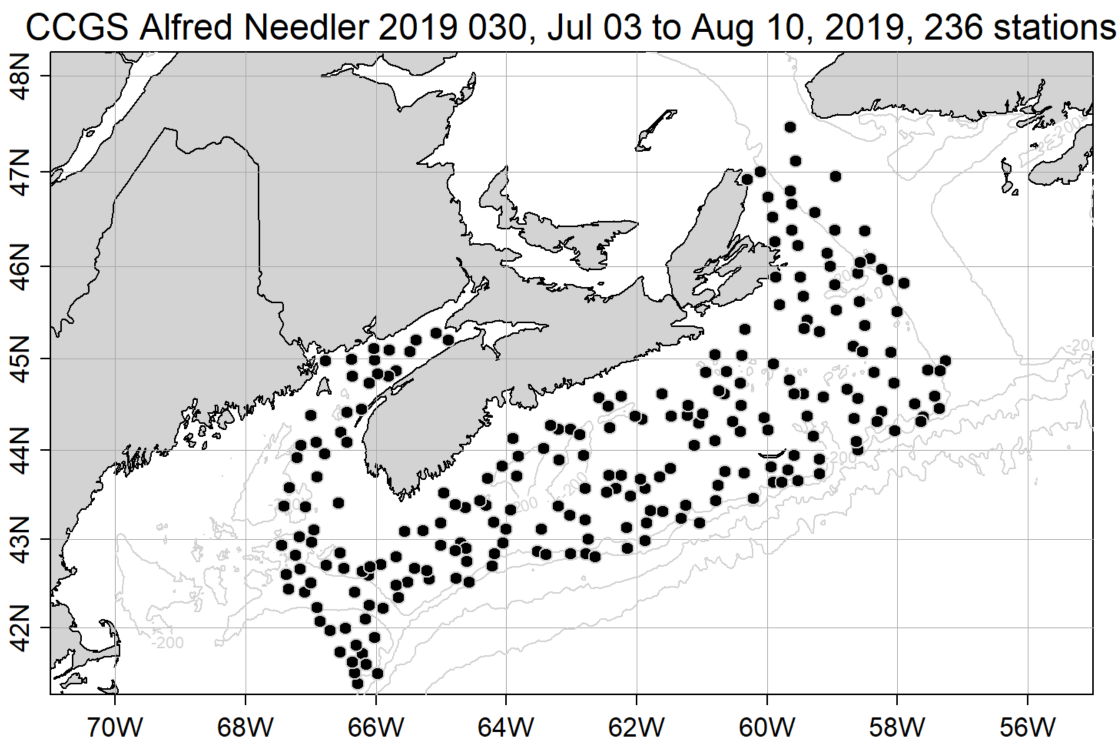

Figure 27. Locations of CTD sampling during the 2019 summer survey.

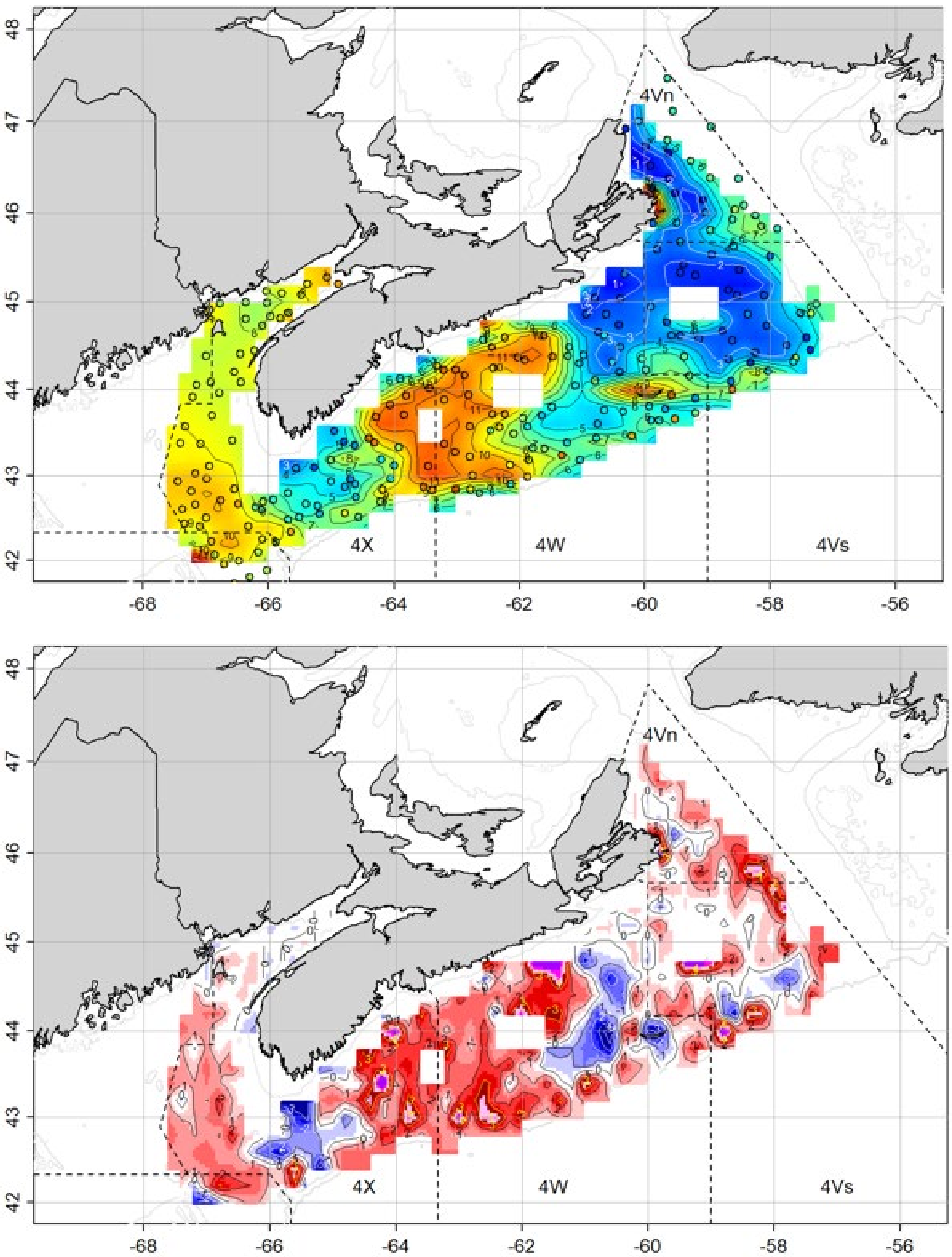

Figure 28. Summer bottom-temperature (upper panel) and anomaly (lower panel; relative to 1981–2010) maps for 2019. NAFO Divisions 4Vn, 4Vs, 4X, and 4W are shown.

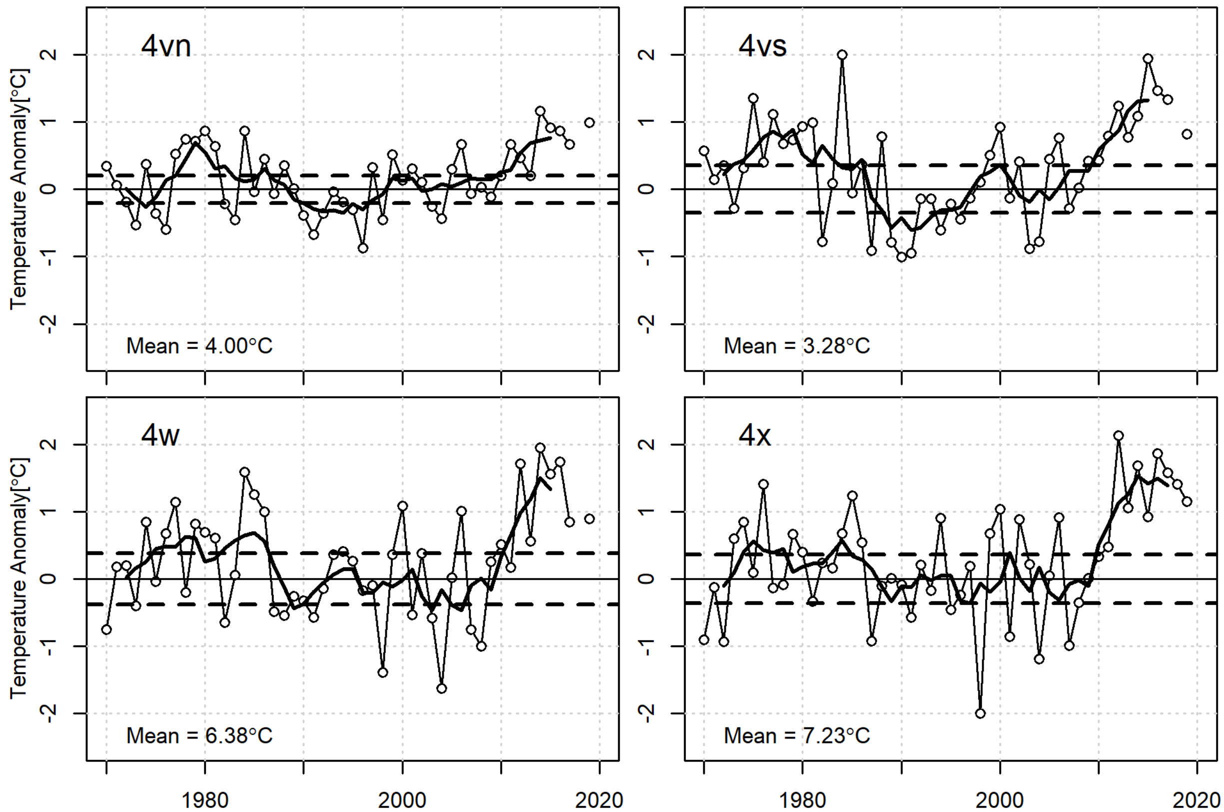

Figure 29. Time series of July bottom-temperature anomalies (thin lines with circles) and five-year-running-mean filtered series (heavy line) for NAFO Divisions: 4Vn, 4Vs, 4W, and 4X. In 2018, only 4X was sampled sufficiently to calculate bottom temperatures. The solid horizontal line is the 1981–2010 mean and dashed lines represent ±0.5 SD.

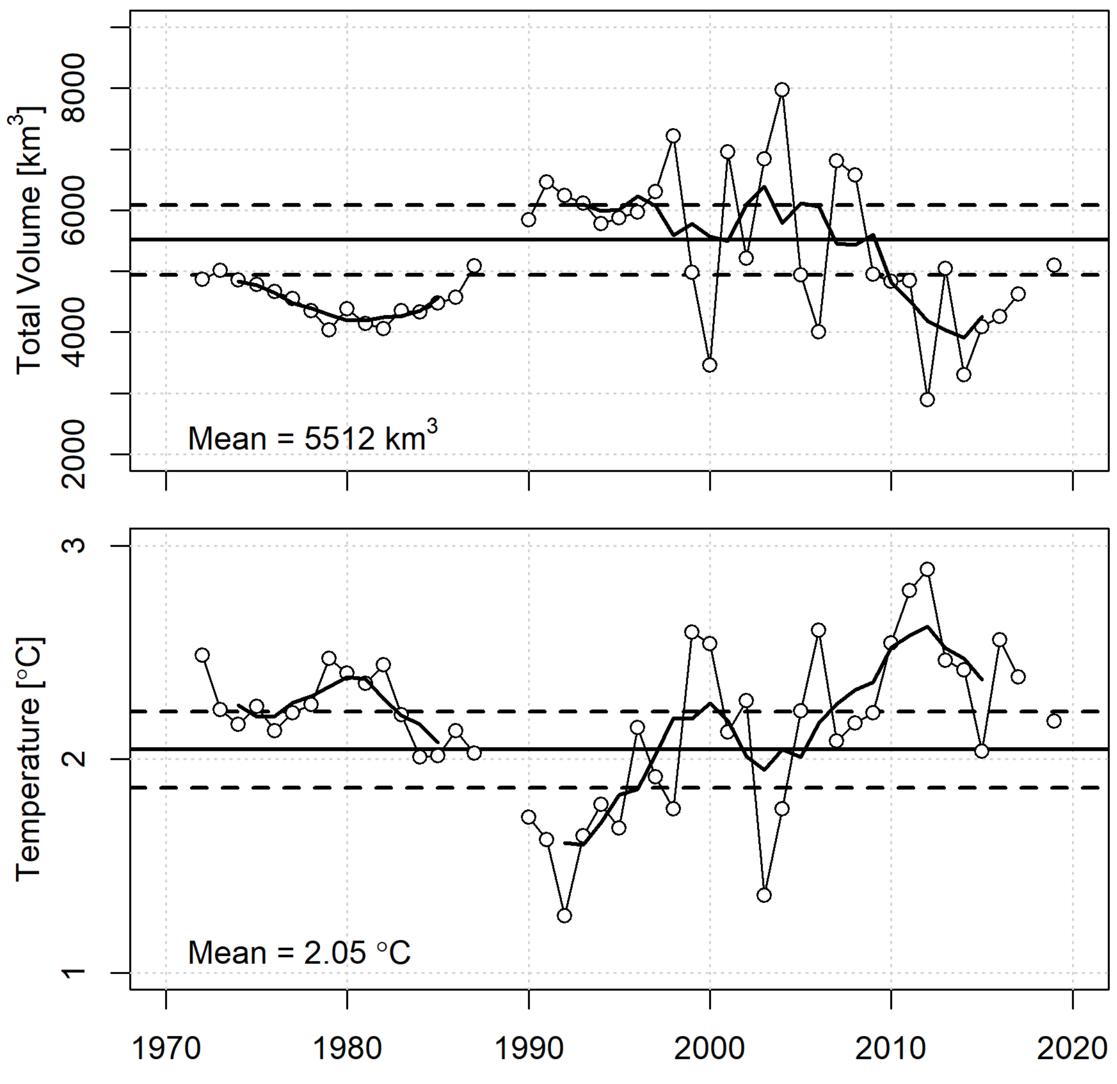

Figure 30. Time series of the Cold Intermediate Layer (CIL; defined as waters with temperature < 4°C) volume on the Scotian Shelf based on the DFO RV summer trawl survey (top pane). The area-weighted average minimum temperature in the CIL (bottom panel). The solid horizontal lines are the 1981–2010 means and dashed lines represent ±0.5 SD.

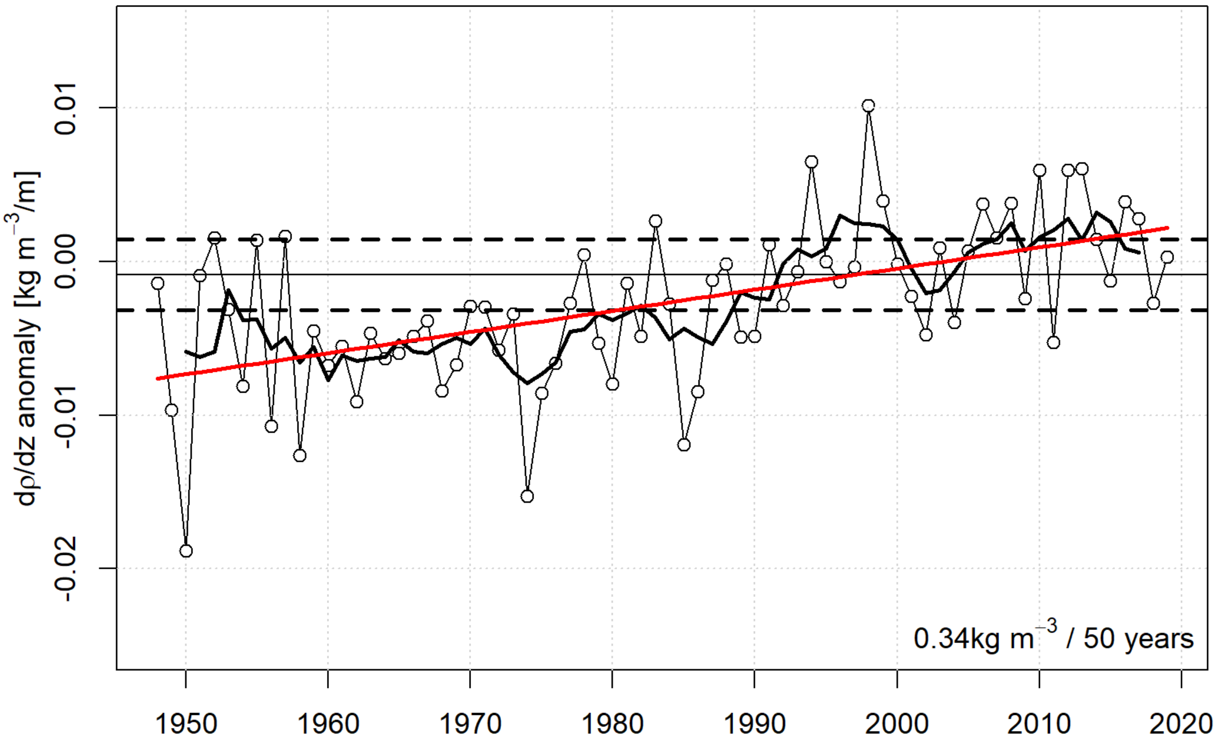

Figure 31. Stratification index (0–50 m density gradient) mean annual anomaly (black line with circles) and five-year running mean (black heavy solid line) averaged over the Scotian Shelf. The linear trend (red line) shows a change in the 0–50 m density difference of 0.34 kg m^{-3} over 50 years.

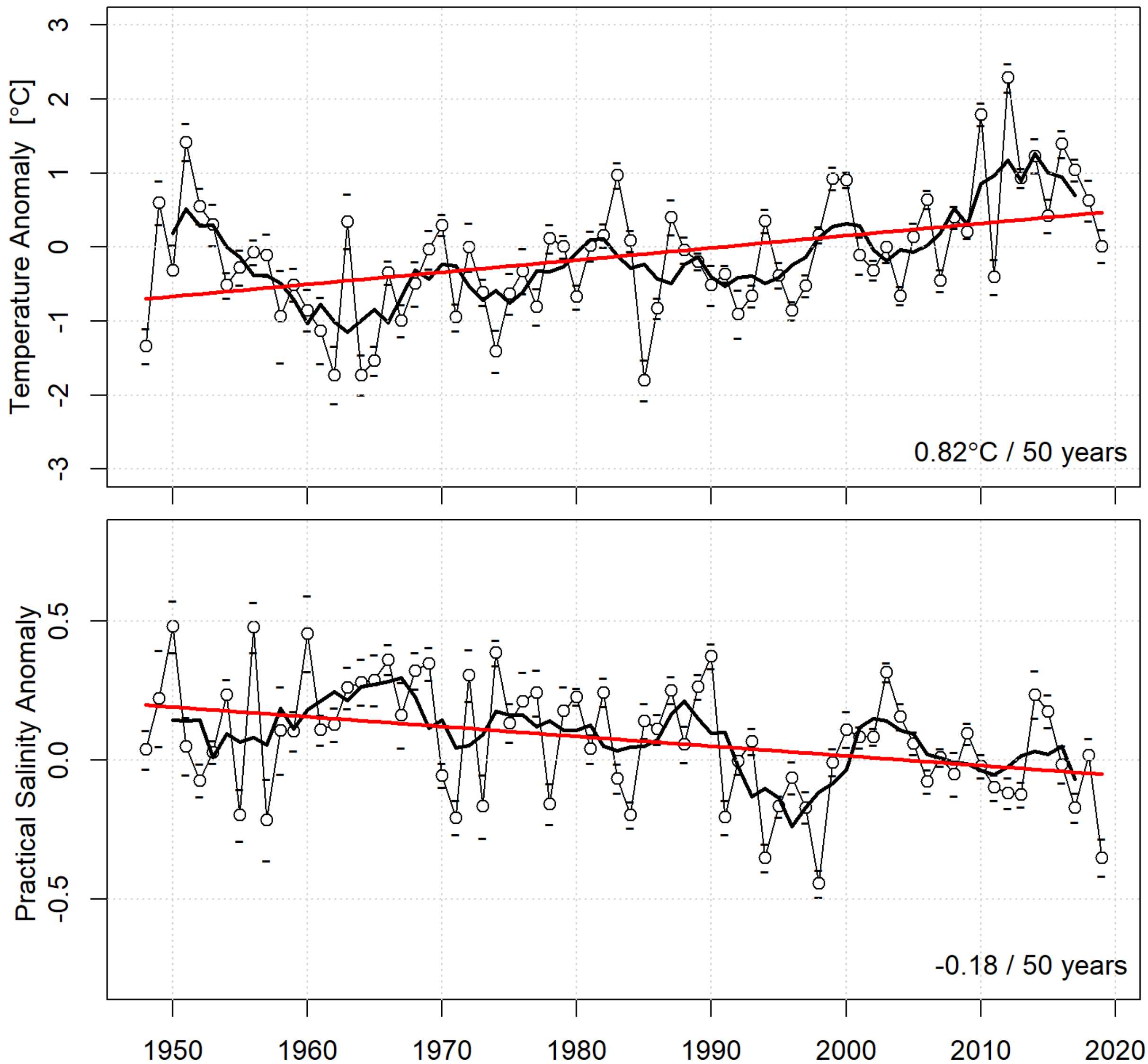

Figure 32. The mean-annual-surface-temperature (top panel) and salinity (lower panel) anomalies (black line with circles) and five-year running mean (black heavy solid line) averaged over the Scotian Shelf. Standard error estimates for each annual anomaly value are also shown. The linear trend (red line) shows a warming of 0.82°C and a freshening of 0.18 over a 50 year period.

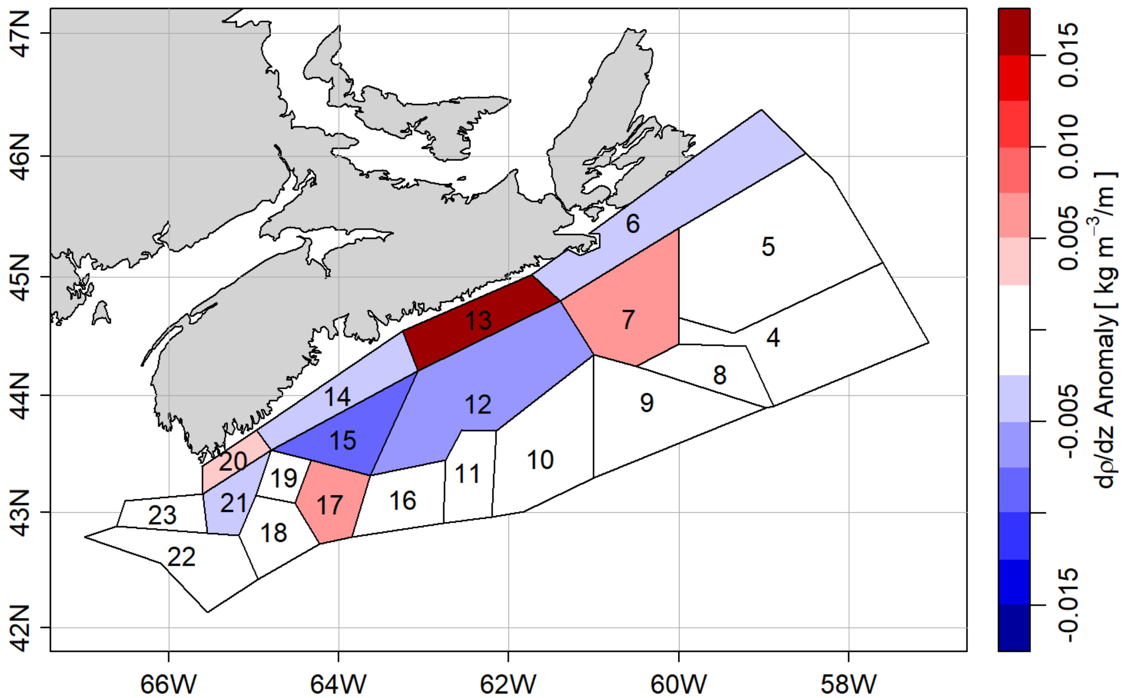

Figure 33. Stratification index (0–50 m density gradient) mean 2019 annual anomaly over the Scotian Shelf. The different areas were defined by Petrie et al. (1996).

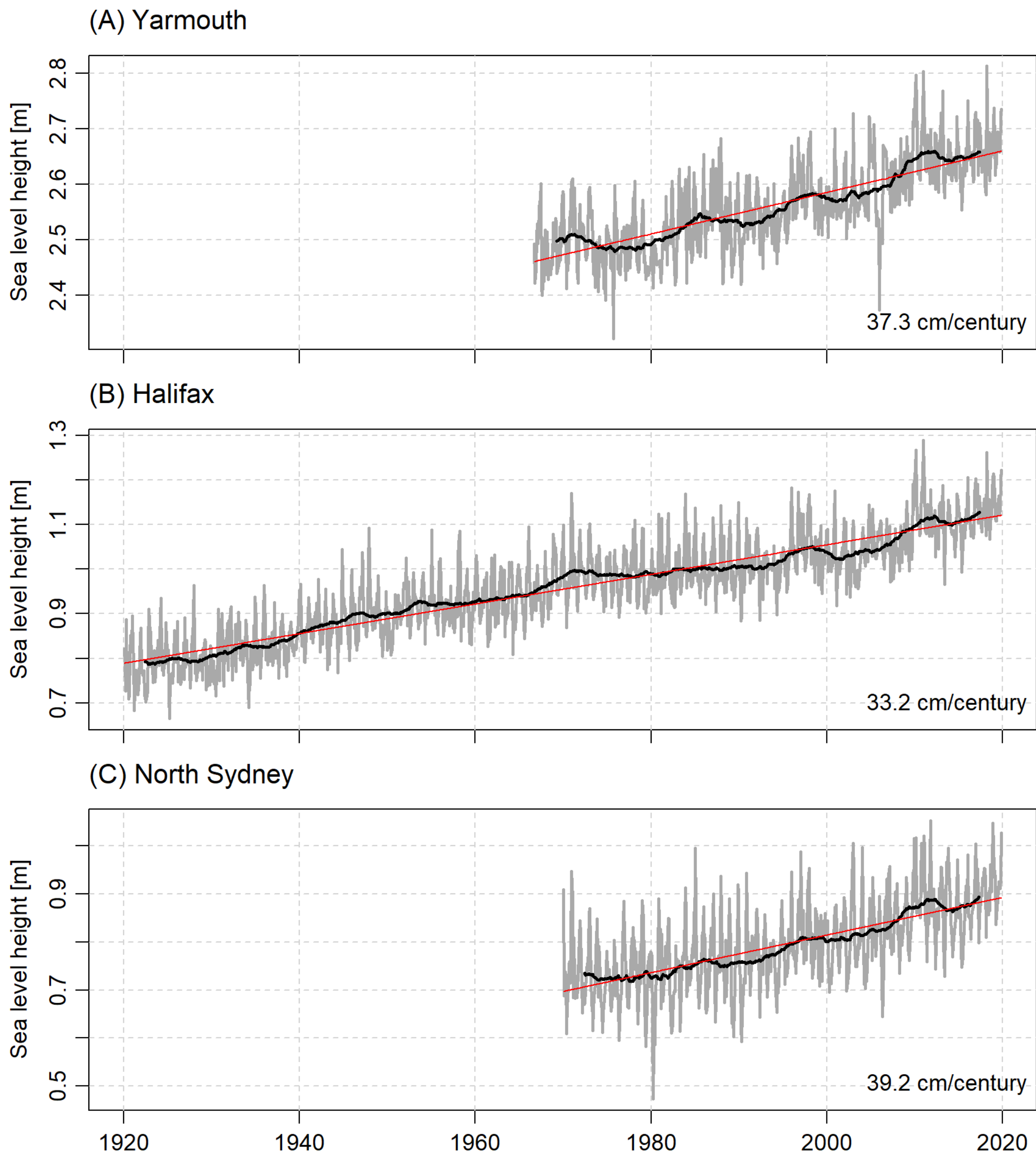

Figure 34. The time series of the monthly means (grey line) and a five-year running mean (black line) of the relative sea-level elevations at Yarmouth (top panel), Halifax (middle panel), and North Sydney (bottom panel), along with the linear trend (red line) over the observation period.

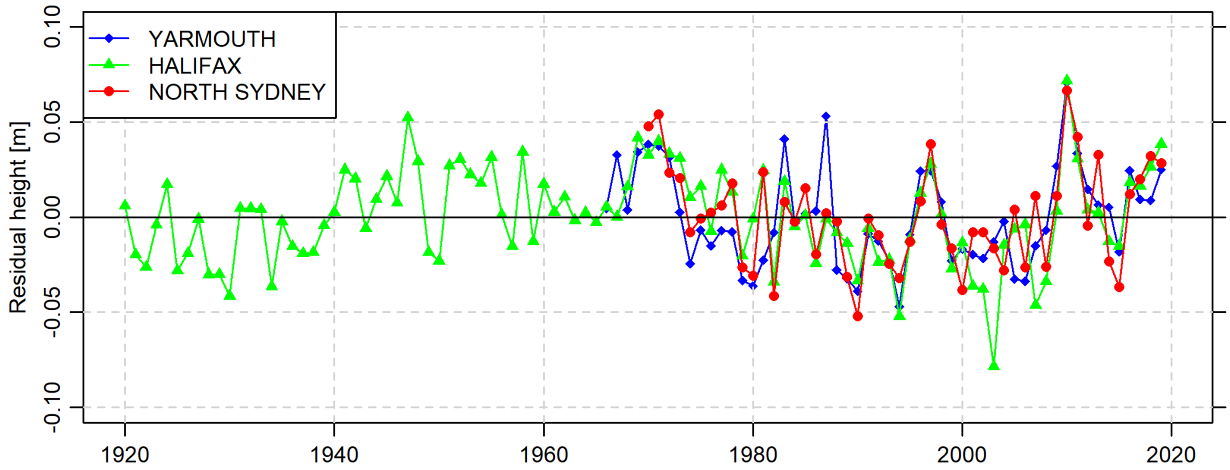

Figure 35. Residual relative sea level (annual observed values – linear trend based on annual values) for Yarmouth (blue line with diamonds), Halifax (green line with triangles), and North Sydney (red line with circles).

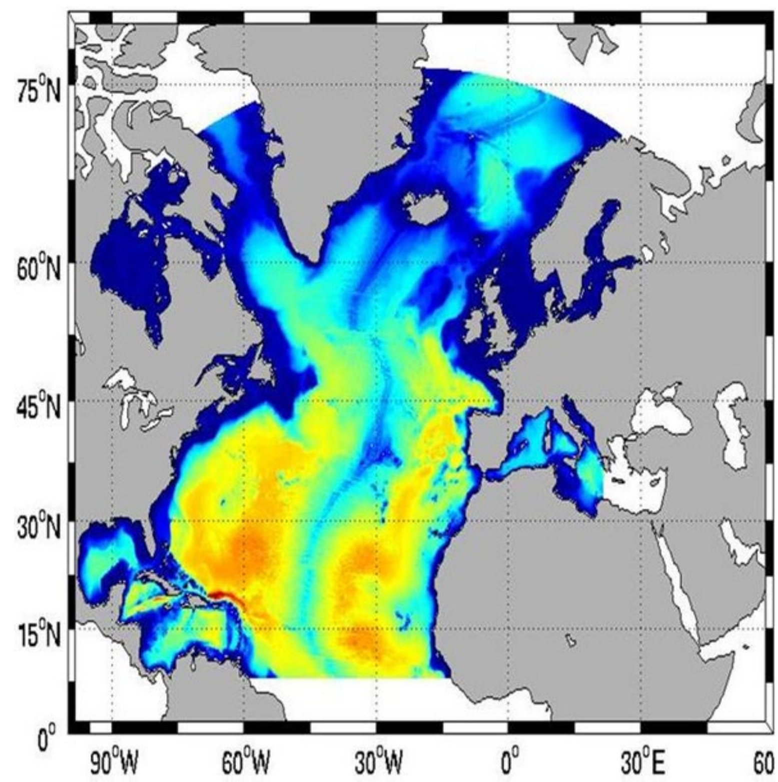

Figure 36. The BIO North Atlantic Model (BNAM) domain Bathymetry coloured from red (deep) to blue (shallow).

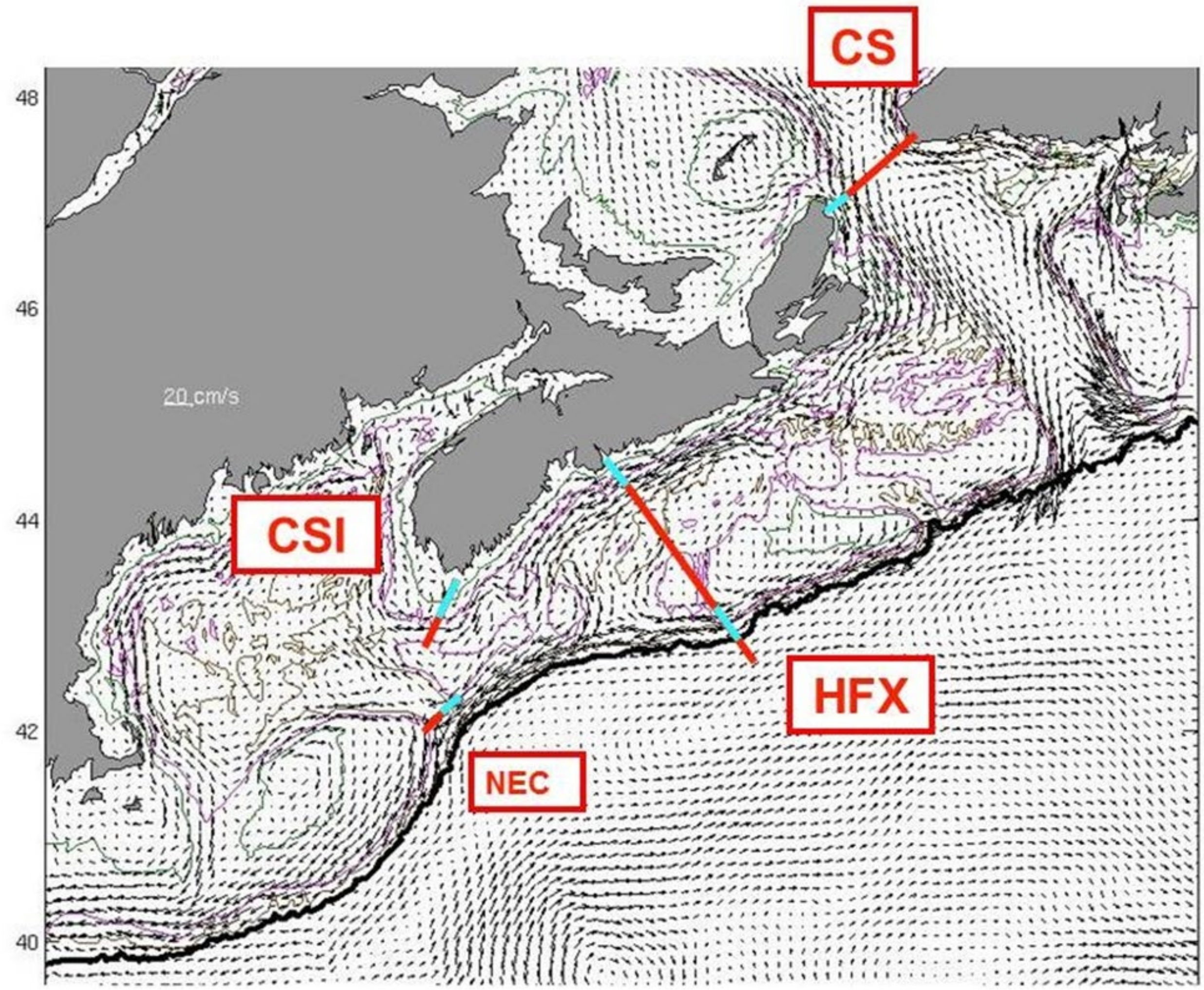

Figure 37. Climatological-annual and depth-averaged circulation illustrating the principal flow pathways from the southern Gulf of St. Lawrence to the Gulf of Maine and the subsections where transport calculations were made (cyan). CS = Cabot Strait; HFX = Halifax; CSI = Cape Sable Island/Browns Bank; NEC = Northeast Channel.

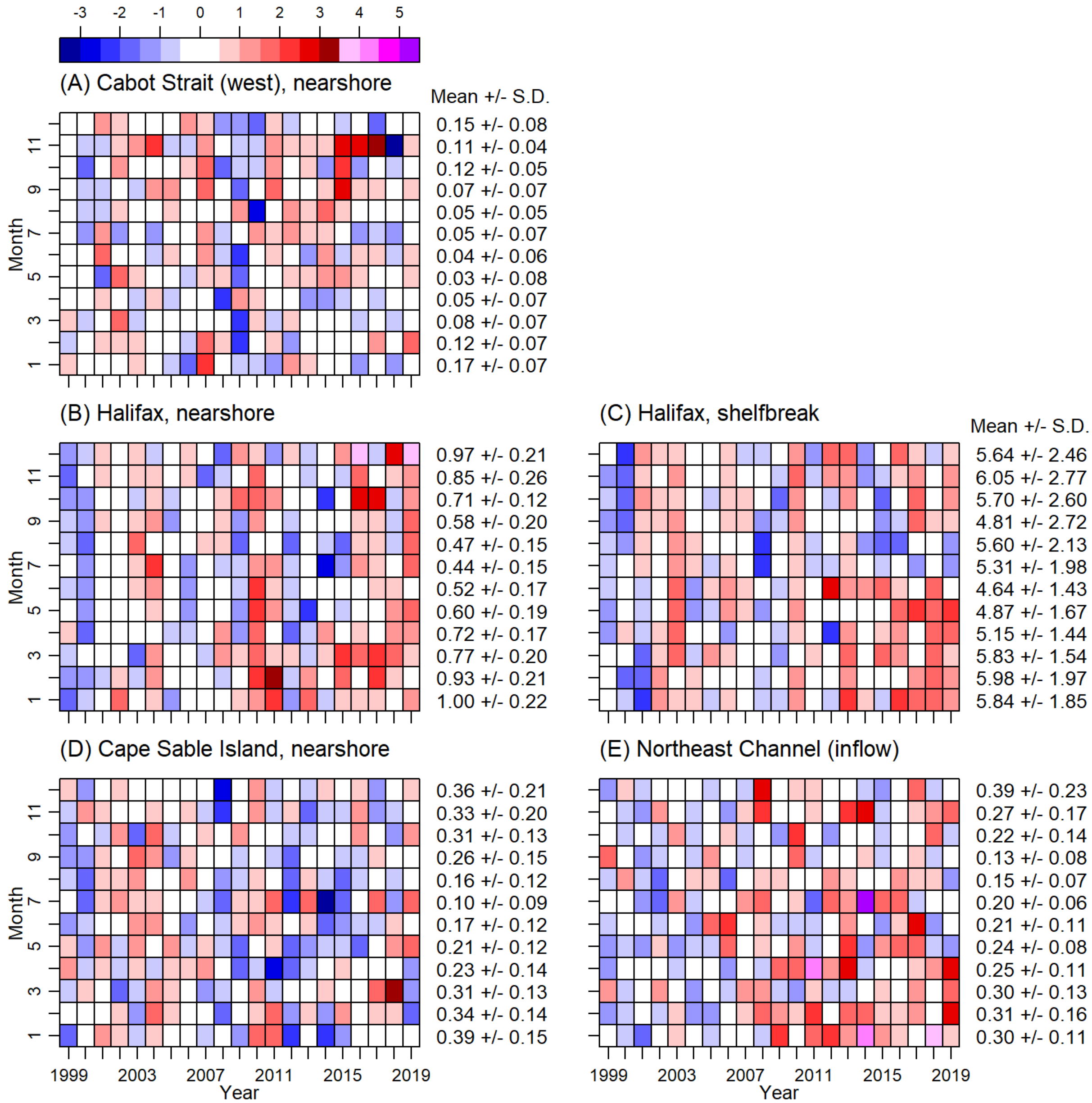

Figure 38. Standardized anomalies of the monthly transport for years 1999–2019 for four Maritime sections: (A) Cabot Strait (CS) west nearshore; Halifax (HFX) (B) nearshore and (C) shelf break; (D) Cape Sable Island (CSI) nearshore; and (E) the Northeast Channel (NEC). Numbers to the right are monthly means and standard deviations.

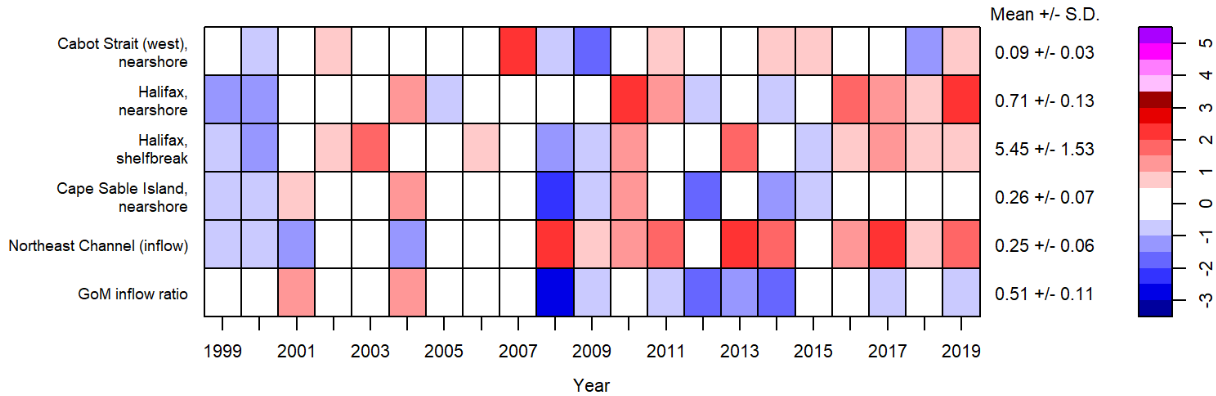

Figure 39. Annual transport anomalies scaled by the standard deviation for the monthly values shown in Figures 38 and 41 for years 1999–2019. Numbers to the right are annual means and standard deviations.

Transport (SV)													
Month / Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Grand Total
12	-0.46	-0.59	-0.58	-0.33	-0.50	-0.83	-0.42	-0.53	-0.82	-0.40	-0.89		-0.58
11	-0.22	-0.34	-0.52	-0.49	-0.43	-0.30	-0.50	-0.38	-0.57	-0.21	-0.85		-0.44
10	-0.22	-0.51	-0.36	-0.30	-0.32	-0.22	-0.21	-0.17	-0.40	-0.33	-0.36		-0.31
9	-0.43	-0.21	-0.30	-0.12	-0.14	-0.03	-0.17	-0.13	-0.20	-0.28	-0.28		-0.21
8	-0.40	-0.26	-0.32	-0.23	-0.13	-0.08	-0.12	-0.18	-0.27	-0.05	-0.22		-0.21
7	-0.04	-0.29	-0.39	-0.37	-0.11	-0.15	-0.07	-0.22	-0.31	-0.23	-0.34	-0.35	-0.24
6		-0.31	-0.54	-0.40	-0.09	-0.16	-0.28	-0.35	0.05	-0.28	-0.23	-0.16	-0.25
5		-0.33	-0.52	-0.43	-0.22	-0.12	-0.26	0.04	-0.23	-0.35	-0.32	-0.34	-0.28
4		-0.34	-0.33	-0.48	-0.23	-0.37	-0.39	-0.32	-0.31	-0.33	-0.35	-0.39	-0.35
3		-0.48	-0.47	-0.55	-0.64		-0.53	-0.63	-0.40	-0.79	-0.31	-0.47	-0.53
2		-0.66	-0.68	-0.85	-0.59	-0.64	-0.44	-0.62	-0.46	-0.88	-0.66	-0.70	-0.65
1		-0.80	-0.65	-0.67	-0.38	-0.60	-0.45	-0.74	-0.60	-0.71	-0.78	-0.64	-0.64
Grand Total	-0.30	-0.43	-0.47	-0.43	-0.32	-0.32	-0.32	-0.35	-0.38	-0.40	-0.46	-0.44	-0.39

Figure 40. Monthly transport (1 Sv = 10^6 m^3 s^{-1}) for years 2008–2019 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.

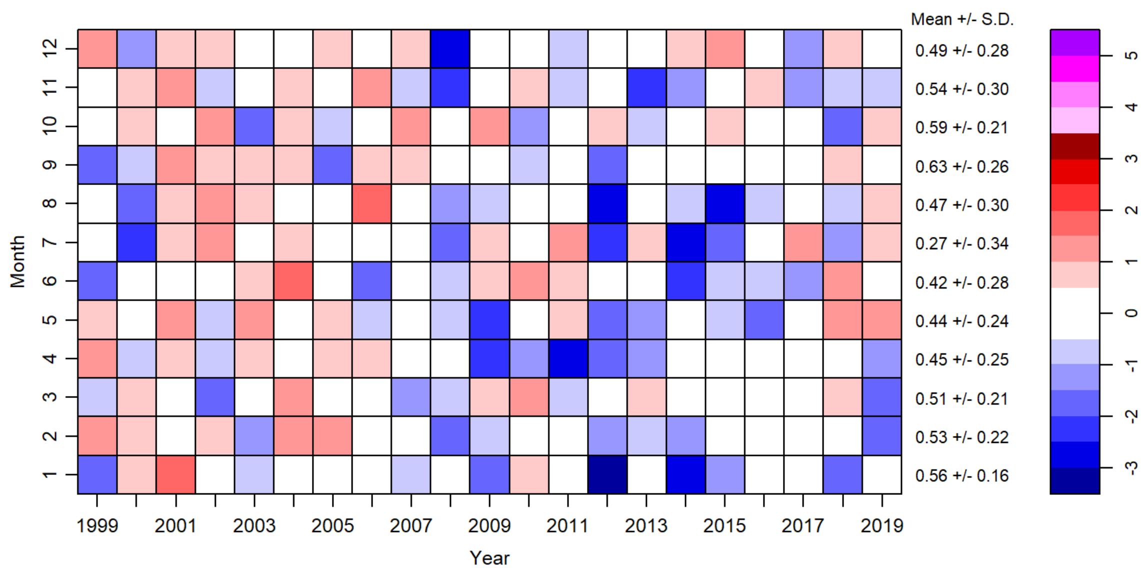

Figure 41. Standardized anomalies of the Gulf of Maine inflow ratio for years 1999–2019. Numbers to the right are monthly means and standard deviations.

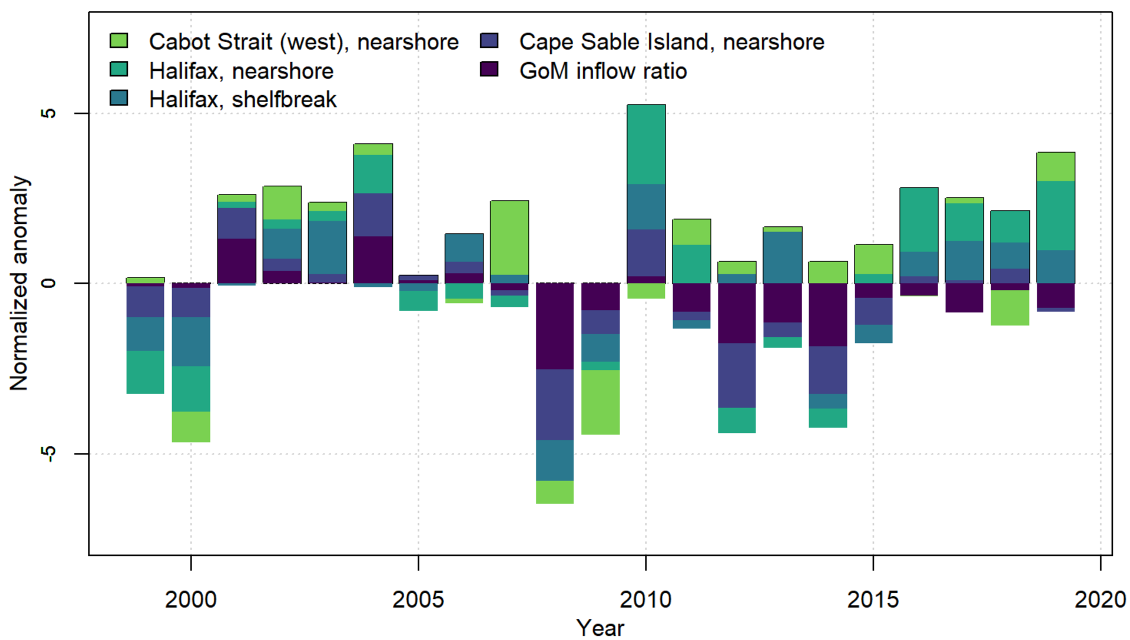

Figure 42. Sum of standardized anomalies for 1999–2019, for the variables in Figure 39.

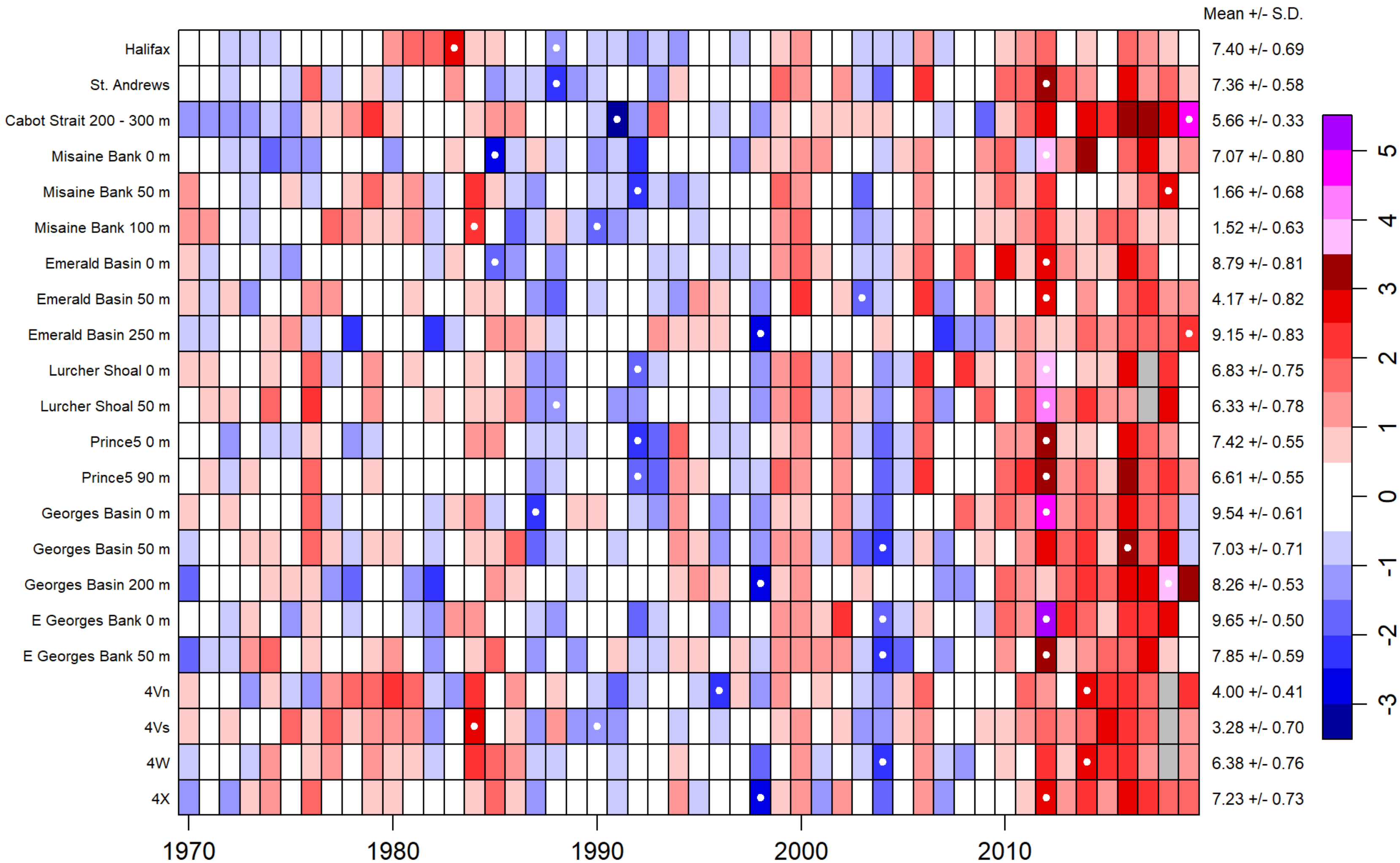

Figure 43. Normalized annual anomalies of temperatures at the bottom and discrete depths for the Scotian Shelf/Gulf of Maine region. These anomalies are based on the 1981–2010 means divided by the standard deviation. Blue colours indicate below-normal anomalies.Rred and purple (for 2012, the colour scale had to be increased above +3.5°SD and is shaded in purple) colours indicate above-normal anomalies. White dots represent record minimum and maximum years for each parameter. Gray represents lack of data.

APPENDIX

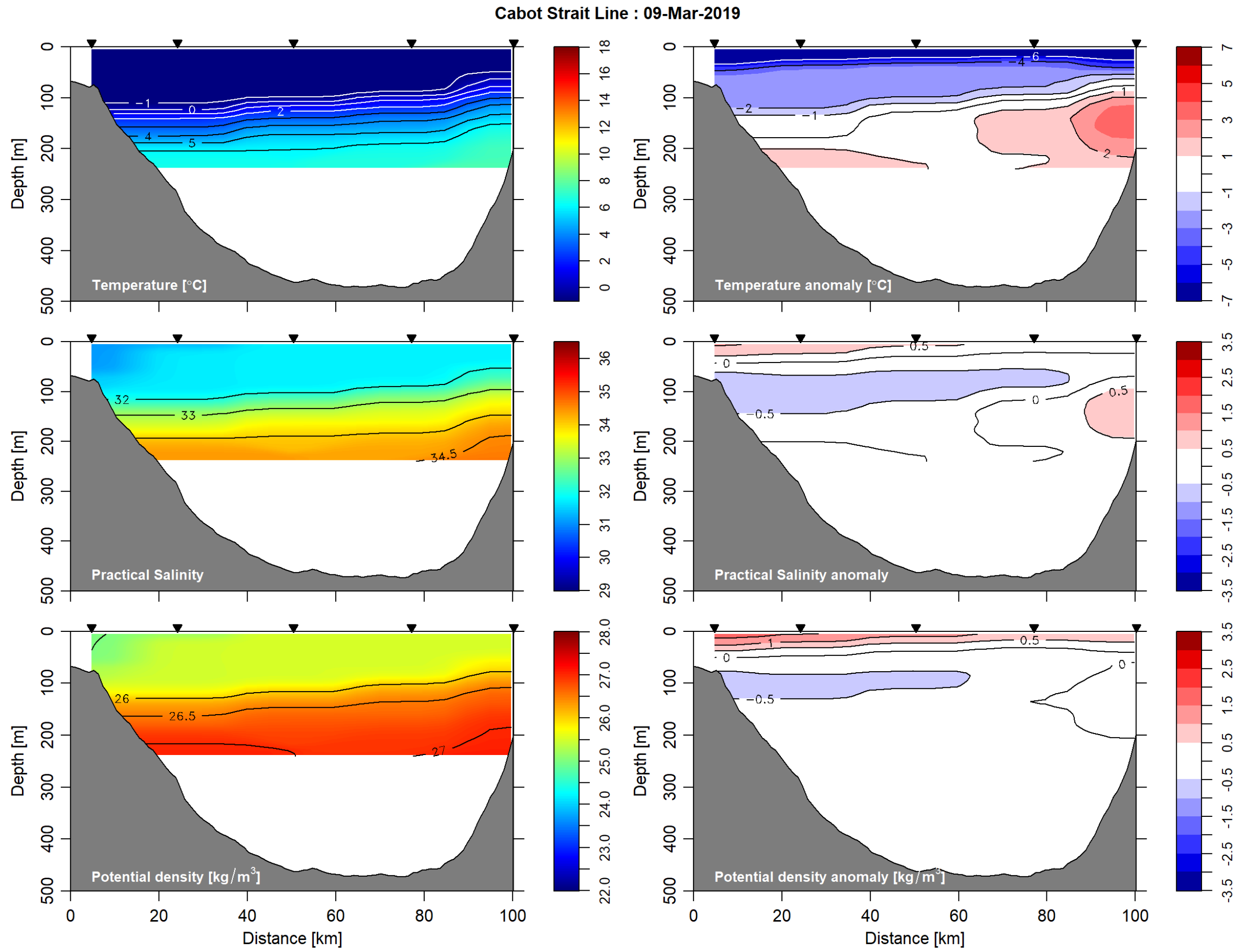

Figure A1. The 2019 sampling of the Cabot Strait Section for Winter collected by the Quebec Region AZMP. Temperature (top panel), salinity (middle panel), and density (lower panel) and their anomalies with respect to 1981–2010 monthly means (right panels). Bullets indicate locations of sampling.

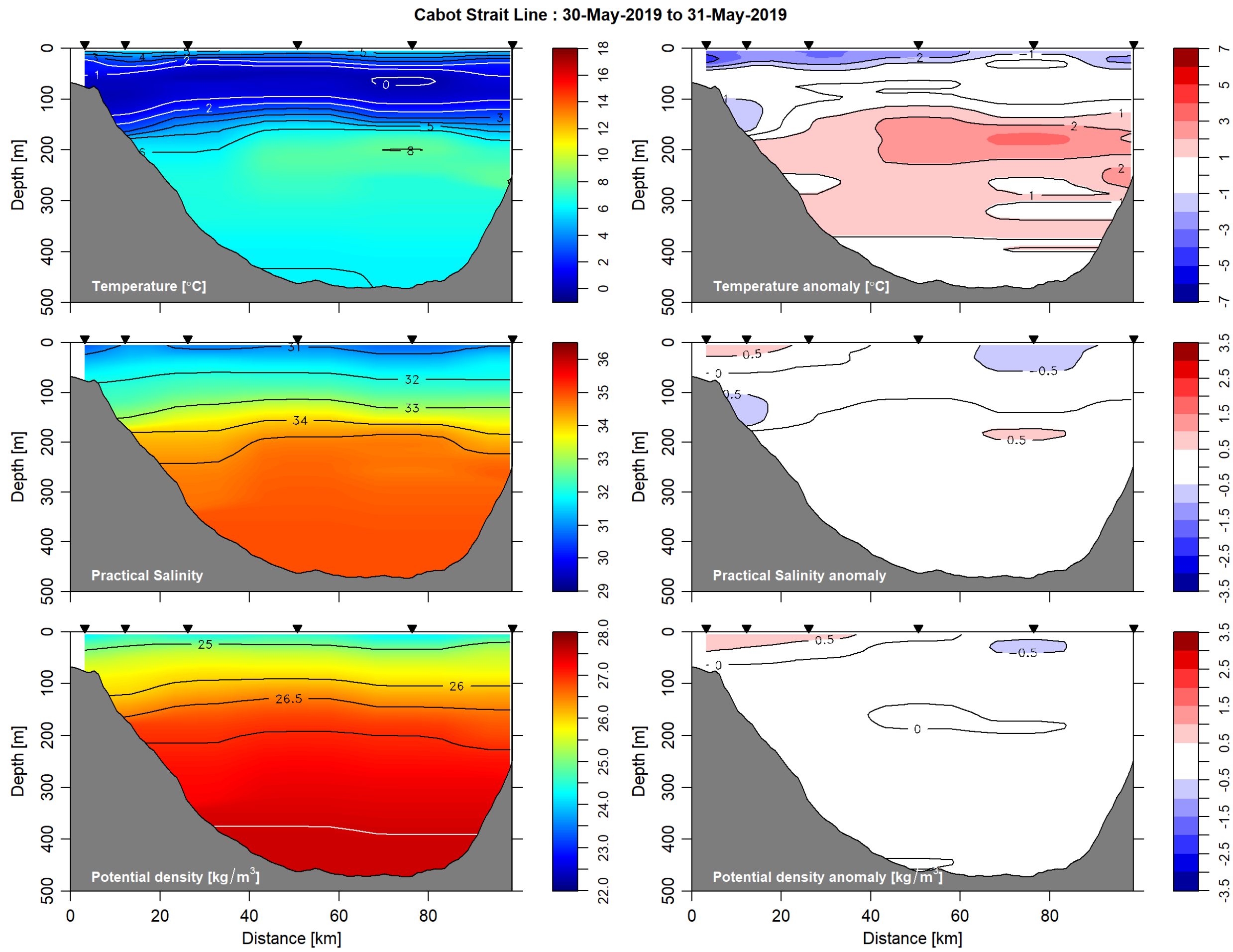

Figure A2. The 2019 sampling of the Cabot Strait Section for Summer collected by the Quebec Region AZMP. Temperature (top panel), salinity (middle panel), and density (lower panel) and their anomalies with respect to 1981–2010 monthly means (right panels). Bullets indicate locations of sampling.

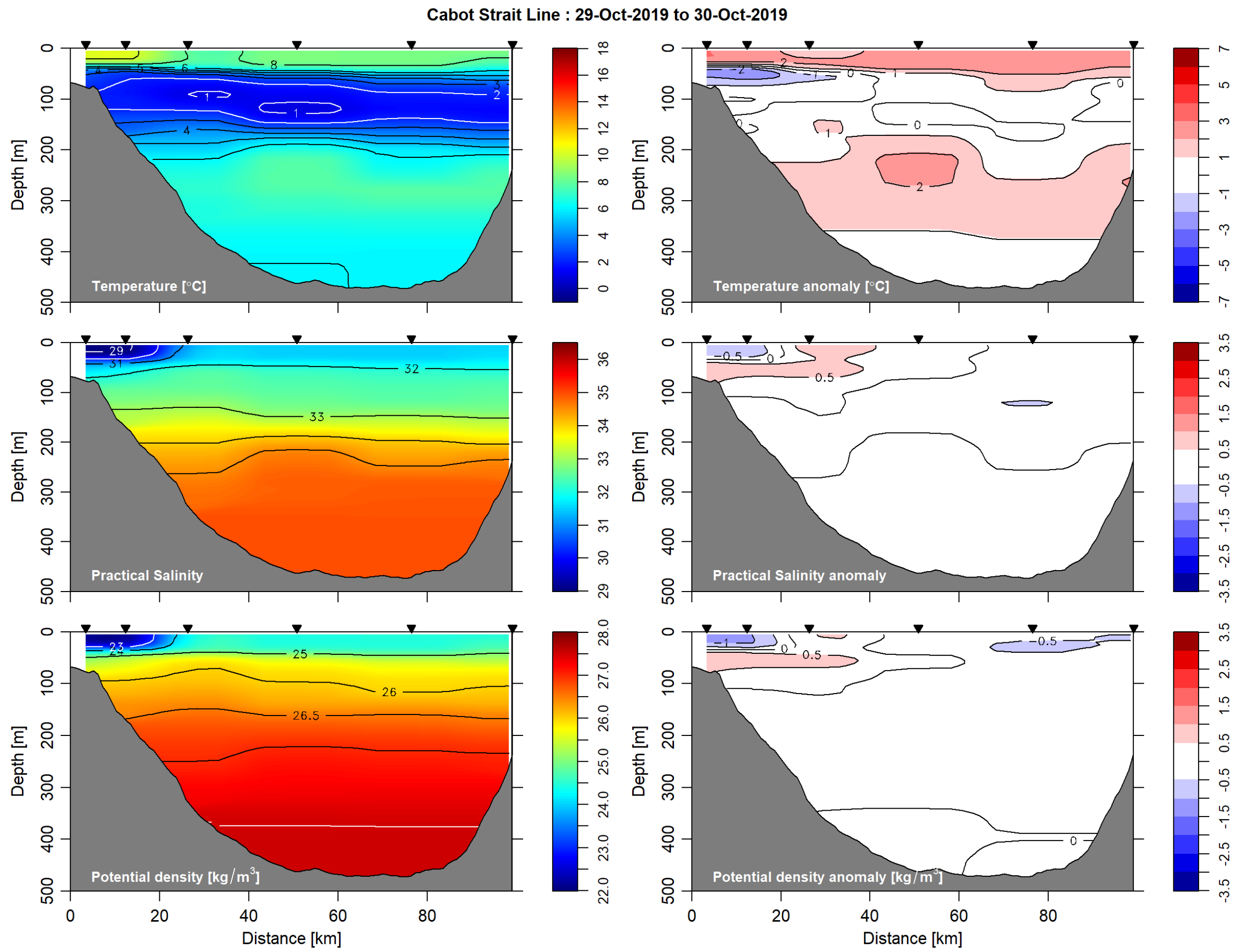

Figure A3. The 2019 sampling of the Cabot Strait Section for Fall collected by the Quebec Region AZMP. Temperature (top panel), salinity (middle panel), and density (lower panel) and their anomalies with respect to 1981–2010 monthly means (right panels). Bullets indicate locations of sampling.

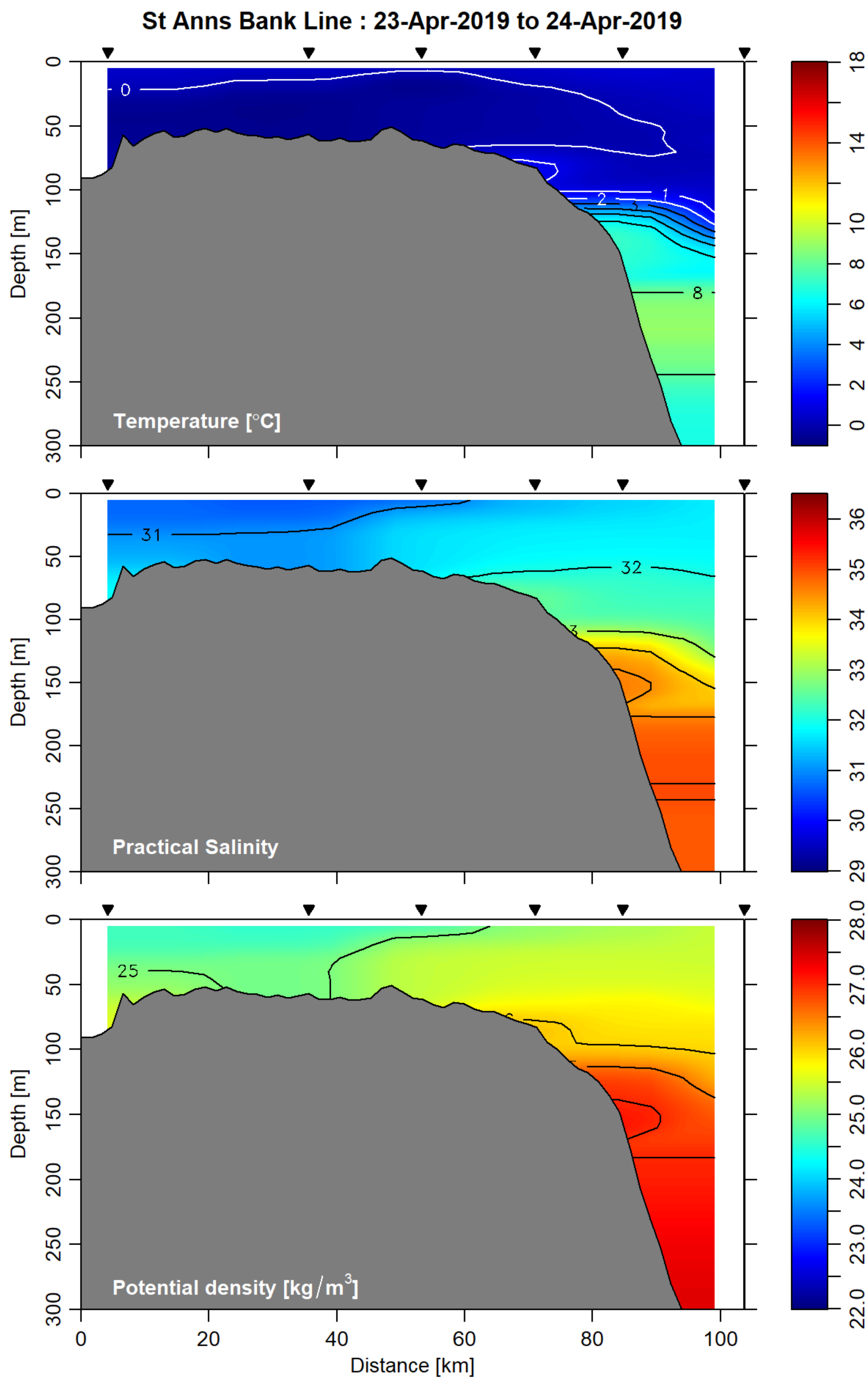

Figure A4. The 2019 sampling of the St Anns Bank Section for Spring collected by the Maritimes AZMP. Temperature (top panel), salinity (middle panel), and density (lower panel). Bullets indicate locations of sampling.

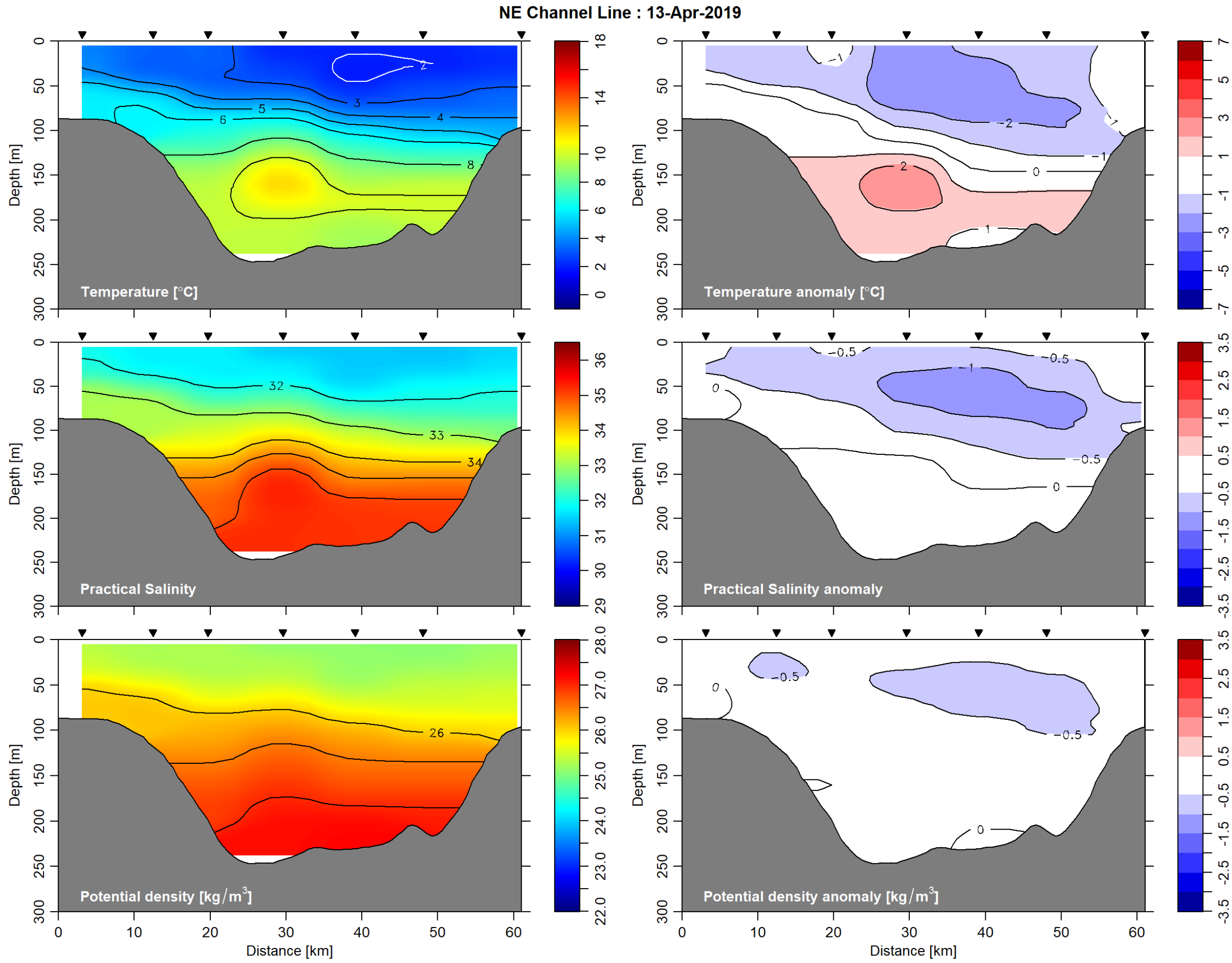

Figure A5. The 2019 sampling of the Northeast Channel Section for Spring collected by the Maritimes AZMP. Temperature (top panel), salinity (middle panel), and density (lower panel) and their anomalies with respect to 1981–2010 monthly means (right panels). Bullets indicate locations of sampling.

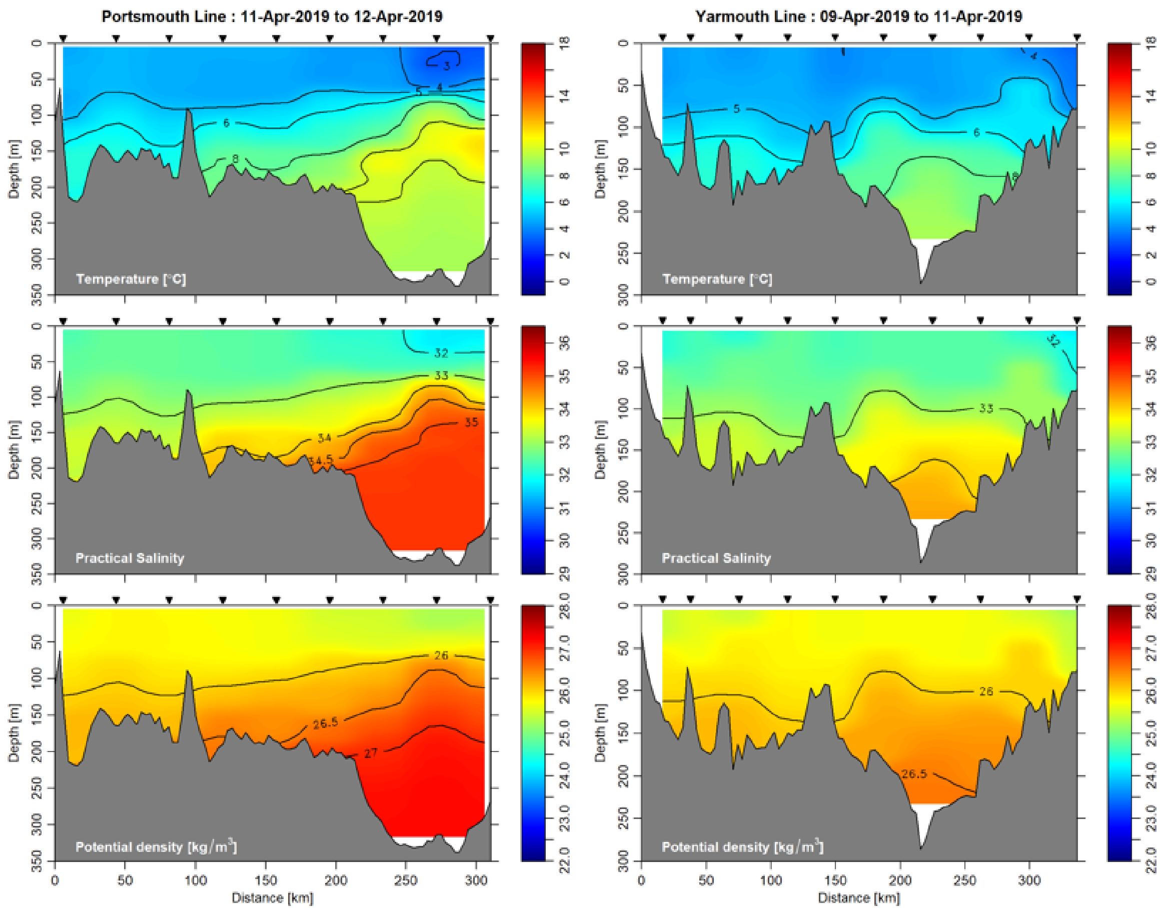

Figure A6. The 2019 sampling of the Portsmouth Section (left panels) and Yarmouth Section (right panels) for Spring collected by the Maritimes AZMP: temperature (top panel in each group), salinity (middle panel in each group), and density (lower panel in each group). Bullets indicate locations of sampling.