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Physical Oceanographic Conditions on the Scotian Shelf and in the Gulf of Maine during 2021

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Canada

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 2021, the North Atlantic Oscillation index was near normal (−0.1, −0.2 SD [standard deviation]). Mean annual air temperature anomalies relative to 1991–2020 climatology were positive for all sites, with anomalies ranging from +1.0 °C (+1.3 SD) for Saint John to +1.2 °C (+1.7 SD) at Sydney. Valid data for Boston are only for the last three months of year. Satellite-based Sea Surface Temperature (SST) annual anomalies were above normal (1991–2020 average temperature) with values ranging from +0.6 °C (+1.3 SD) in 4Vn to +1.3 °C (+1.9 SD) in the eastern Gulf of Maine/Bay of Fundy, the warmest year in the record. It was the 2nd warmest year for 4Vs, 4W and 4X on the Scotian Shelf and 3rd warmest for 4Vn. Long-term coastal monitoring at Halifax (Nova Scotia) recorded annual SST anomalies of +1.7 °C (+2.8 SD), the 2nd warmest temperature in the record. At other selected sites across the region, annual water temperature anomalies were above normal. Cabot Strait at 200–300 m depth range was the second largest anomaly with 2020 being record high, +1.2°C (+1.9 SD); five of the last six years survived the warmest on record. Emerald Basin at 250 m was the sixth warmest anomaly, +1.6 °C (+1.1 SD); the last six years were the warmest on record with 2019 a high record. Georges Basin at 200 m was the third warmest year, +1.1 °C (+1.6 SD) with 2018 as the warmest. Also, the last nine years were the warmest. Stratification in 2021 was higher than in 2020 due to the surface becoming fresher. Since 1948, the stratification has slowly been increasing on the Scotian Shelf due to half-freshening and half-warming of the surface waters. A composite index, consisting of 17 ocean temperature time series from surface to bottom across the region, indicated that 2021 was mainly above normal by at least one standard deviation.

INTRODUCTION

This document discusses air temperature trends, ice cover, Sea Surface Temperatures (SST), and physical oceanographic variability during 2020 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 (NL) regions for the Atlantic Zone Monitoring Program (AZMP) (Cyr et al. 2021, Galbraith et al. 2021a) which together serve as a basis for a zonal Science Advisory Report (DFO 2021). 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 1991–2020. 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 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).

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 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 (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 Newfoundland and Labrador 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 2021, the winter (December–March) NAO index was below the 1991–2020 mean, −0.1 (−0.2 SD) after seven years of above normal values (Figure 2A). The lower panels of Figure 2 show the sea-level atmospheric pressure conditions during the winter of 2021 compared to the 1981–2010 mean. The Icelandic low and Azores high were lower and higher, respectively, to the long-term 1981–2010 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 interactive website. In 2021, the annual anomalies were above normal over the Scotian Shelf and the Gulf of Maine (Figure 3). The seasonal anomaly of these regions was normal during the summer, and above normal during winter, spring, and fall (Figure 4). The winter anomaly was the greatest.

Monthly air temperature anomalies for 2020 and 2021 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 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 and Climate Change Canada website were used. Monthly means from the Monthly Climatic Data for the World (Menne et al. 2017) were used for Boston. In general, all sites show that 2021 has above- or near-normal temperatures for most of the year, with July being below normal for Sydney, Saint John, and Boston.

In 2021, the mean annual air temperature anomalies were above normal at all sites with anomalies ranging from +1.3 to +1.7 SD (Table 1). Valid data for Boston are only for the last three months of 2021. 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 +1.2 °C (0.8 °C, +1.6 °C), +1.4 °C (+1.1 °C, +1.8 °C), +2.0 °C (+1.6 °C, +2.3 °C), +1.2 °C (+0.9 °C, +1.5 °C), +1.2 °C (+0.9 °C, +1.6 °C) and +2.5 °C (+2.2 °C, +2.9 °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, for the 113 years when all sites were operating, 99 had five or more stations with the annual anomalies having the same signs; for 92 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). 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 satellite-based sea surface temperature product used since last year's report blends data from Pathfinder version 5.3 (1982–2020), Maurice Lamontagne Institute (1985–2013) and Bedford Institute of Oceanography (1997–2020). Galbraith et al (2021b) provides details on how these data products are merged to provide the time series presented here.

Weekly, monthly, and annual temperature anomalies relative to the 1991–2020 climatology 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 above normal at the start of 2021 followed by a period of near normal temperatures during the summer, then above normal near the end of the year (Figure 9). Annual anomalies were calculated from monthly-averaged temperatures for the five subareas (Table 2 and Figure 10). The annual anomalies during 2021 ranged from +0.6 °C (+1.3 SD) in 4Vn to +1.3 °C (+1.9 SD) in eastern Gulf of Maine/Bay of Fundy, the warmest year in the record. It was the 2nd warmest year for 4Vs, 4W and 4X on the Scotian Shelf and 3rd warmest for 4Vn. The warmest for these regions was in 2012. 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 of +0.2 °C/decade (4Vn) to a highest value of +0.4 °C/decade (eastern Gulf of Maine/Bay of Fundy). A similar trend in SST from Advanced Very High Resolution Radiometer (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). Unfortunately, due to work on the St. Andrews pier, no data was collected in 2021. In 2021, the SST anomaly relative to the 1991–2020 climatology was +1.7 °C (+2.8 SD) for Halifax (an increase of 1.1 °C from 2020) and the 2nd warmest temperature in the record. In 2020, St. Andrews had anomaly of +0.9 °C (+1.3 SD) and the 3rd warmest temperature in the record.

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. COVID-19 protocol affected the sampling of the station during spring 2021. The depth-averaged (0–90 m) temperature, salinity, and density time series are shown in Figure 11. In 2021, the annual temperature anomaly was +1.6 °C (+2.2 SD), which was the 2nd warmest in the record (2012 was the warmest), and the salinity anomaly was +0.2 (+1.0 SD). These represent changes of +0.9 °C and +0.2 from the 2020 values. The below-normal density anomaly is accounted for by the positive temperature anomaly.

The 2021 annual cycle at Prince 5 shows above-normal temperatures throughout the year with not much depth dependence in the anomaly (Figure 12) when sampling was undertaken. The freshet in the spring was missed since there was no sampling due to COVID-19. The new 1991–2020 climatology was used. The structure of the seasonal cycle for the 1991–2020 climatology was similar to the 1981–2010 climatology with a small temperature change (approximately +0.5°C) throughout the year (Figure 13).

The 2021 annual temperature, salinity, and density cycles at Halifax 2, located at the mouth of Halifax Harbour (Figure 1), are shown in Figure 14. COVID-19 limited the ability to collect data at the start of the year. The temperature anomaly is variable through the year with a positive anomaly throughout the water column at the start of the summer heating period and in the mixed layer during the heating period. This summer warm anomaly shows up a below normal anomaly in density. The new 1991–2020 climatology was used. The structure of the seasonal cycle for this climatology was similar to the 1981–2010 climatology with temperature difference at depth throughout the year and at the beginning and end of the year at all depths (Figure 15).

STANDARD SECTIONS

The sections across the Cabot Strait, part of the Louisbourg Line and the Halifax, and Browns Bank Lines (Figure 1) were sampled during the late spring of 2021 using two missions (Figure 16). Since the sampling of these sections were later than the normal AZMP spring sampling, anomalies of temperature, salinity and density are not shown.

During the late spring of 2021, the Cabot Strait section showed near-normal March temperatures with slightly above normal around 300 m (Figure 17). Sampling on the Louisbourg section was cut short due to an issue with the vessel that required it to return to Halifax (Figure18). The Halifax section shows anomalously warm waters in Emerald Basin (Figure 19). The waters at the slope is not as warm and salty as found in the past.

During the late spring, the Browns Bank section showed anomalous warm, salty water over the outer shelf in the lower half of the water column (Figure 20).

During the fall of 2021, a more successful mission was completed which included the sampling in the Gulf of Maine, Gully and across the mouth of Laurentian Channel (Figure 21). Starting this year, anomalies were based on the 1991–2020 climatology compared to previous years that used the 1981–2010 climatology.

The occupation of the Cabot Strait section was in collaboration with the Maurice Lamontagne Institute (IML) as they normally sample it shortly after this time. The Cabot Strait section showed above-normal temperatures between 200 and 400 m although not as large in recent years. Above-normal temperatures at the surface for most of the strait were observed (Figure 22).

In the fall of 2021, there was anomalously cold, fresh water on the offshore portion of the Louisbourg section—evidence of Labrador Slope water on the continental slope (Figure 23). On the shelf, conditions were above normal at the mid-shelf and below normal next to the coast.

The Halifax section shows anomalously warm waters near the bottom over most of shelf, including Emerald Basin, and slope (Figure 24). Associated with this water is above-normal salinity. During the fall of 2021, the Browns Bank section showed anomalous warm, salty water over most of the shelf near the bottom (Figure 25).

The Appendix contains sections in the region conducted by IML for Cabot Strait in winter (Figure A1), summer (Figure A2) and fall (Figure A3). For the fall AZMP mission, additional regions were sampled: St. Anns Bank Marine Protected Area (Figure A4), the Laurentian Channel Mouth (Figure A5), St. Pierre Bank (Figure A6), the Gully Marine Protected Area (Figure A7), across the Northeast Channel in the late spring (Figure A8) and fall (Figure A9). Two sections across the Gulf of Maine, Yarmouth Line (Figure A10) and Portsmouth Line (Figure A11) were completed during the fall. 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 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 26). For ease of analysis, the glider data are averaged into hourly, 1-m 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 27). Thus, only glider data collected within 15 nautical miles (nm) of the Halifax Line are considered, which explains some of the gaps in Figure 26. Station 2 (HL2) is sampled throughout the year from a small vessel and provides the highest temporal resolution of the stations (Figure 28). Glider data do not significantly add information at Station 2 except when vessel sampling is not available. COVID-19 affected all field operations in the spring of 2020 and the start of 2021.

For this document, the variability in temperature, salinity, and chlorophyll fluorescence is shown for a few of the Halifax Line stations over the 2020–2021 period (Figure 29). This is only a small fraction of the data available for analysis. At HL3, HL4 and HL5, the glider sampling was sufficient to resolve the seasonal cycle of temperature and the spring and fall phytoplankton blooms. For HL6, the sampling was less frequent at the start of 2020. An improved battery allowed better coverage in 2021. Due to battery limits and weather, the glider cannot reach HL7 consistently, especially in winter (Figure 26).

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 30) is presented (Figure 31). 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 31, 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 2021 annual anomalies are based on observations from five, two, five, six, five, and one month, respectively.

In 2021, the annual anomaly was +1.2 °C (+1.9 SD) for Cabot Strait at 200–300 m (the second largest anomaly of the time series with 2020, the largest; five of the last six years were the warmest). For the shallow Misaine Bank on the eastern Scotian Shelf, the annual anomaly was +1.3 °C (+2.2 SD) at 100 m, the second warmest in the record. For the deep basins on the central Scotian Shelf and Gulf of Maine, the 2021 anomalies were +1.1 °C (+1.2 SD) for Emerald Basin at 250 m (6th highest value; 2019 was a record high; the last six years were the warmest on record) and +1.1 °C (+1.6 SD) for Georges Basin at 200 m (third warmest; 2019 was the 2nd warmest with 2018 the warmest; the last nine years were the warmest on record). For the shallow banks in western Nova Scotia, the anomalies were +1.0 °C (+1.5 SD) for Eastern Georges Bank at 50 m and +1.6 °C (+1.8 SD) for Lurcher Shoals at 50 m (2021 was the third warmest, 2018 was the 2nd highest with 2012 having the record). These values correspond to changes of −0.4 °C, +0.9 °C, −0.2 °C, +0.4 °C, +0.4 °C, and +0.9 °C, respectively, from the 2020 values. The 2010 and 2011 winter NAO index were strongly negative 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 increased to record or near-record values in 2014 and continued to remain high in 2020. The transport of colder shelf break current of Labrador origin has been negatived since 2014 (Cyr et al., 2022). 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

WINTER SURVEY

There was no 2021 winter survey due to lack of vessel availability.

SUMMER SURVEY

There was no 2021 summer survey due to lack of vessel availability. This resulted in no bottom temperature values for the different NAFO Divisions on the Scotian Shelf. As well, the volume of the Cold Intermediate Layer (CIL), defined as waters with temperatures less than 4°C, could not be estimated for 2021. However, past bottom temperature anomalies for the NAFO Divisions on the Scotian Shelf were determined using the 1991–2020 climatology (Figure 32).

The volume of the Cold Intermediate Layer (CIL) is defined as waters with temperatures less than 4 °C. For completeness, the volume and the average minimum temperature in the CIL are shown in Figure 33.

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 36) 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 (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 34). 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 0.38 kg m^{-3} over 50 years. It should be noted the change that occurred in 1990 so the change over time is not gradual. This change in mean stratification is due mainly to a decrease in the surface density, composed equally of warming and freshening (Figure 35). Stratification in 2021 was higher than in 2020 due to the surface becoming fresher. Examining the 2021 stratification anomaly for areas 4–23 on the Scotian Shelf shows that the near-normal anomaly for the Scotian Shelf (Figure 34) is due to an area-average of positive and negative on the Scotian Shelf (Figure 36).

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 Chaleur Bay 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 (1967–2021), Halifax[1] (1920–2021) and North Sydney (1970–2021) are plotted as monthly means and as a filtered series using a five-year-running-mean filter (Figure 37). The linear trend of the monthly mean data over the length of the time series has a positive slope of 38.0 cm/century (Yarmouth), 33.5 cm/century (Halifax), and 39.8 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. Relative sea level changes over two periods, 1981–2010 and 1991–2020, shows higher relative sea level changes and increasing with time. With the removal of the PGR for Yarmouth (−10.3 cm/century), Halifax (−14.7 cm/century), and North Sydney (−16.8 cm/ century), the absolute sea-level rise over the total length of the time series is +27.2 cm/century, +18.6 cm/century, and +22.3 cm/century, respectively. An interesting feature of the data is the long-term variation that has occurred since the 1920s (Figure 38). The residual sea-level data for the common period 1970–2021 shows 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).

[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.

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° 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 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. 2016, 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 39.

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 that 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 40). 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 1990–2021 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 1991–2020 averaging period) were constructed to illustrate transport variability. The results for the nearshore regions at CS, HFX, and CSI, the shelf break at HFX, and the inflow at NEC are displayed in Figure 41. (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 (nearshore and shelf-break), and CSI (Figure 42). 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 41, 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 and Figure 40) 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}(Sv). 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. Red anomalies denote an increase in transport toward the Gulf of Maine, while blue anomalies indicate decreased transport[2]. 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 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-normal transport was observed until the end of the year. Transport has been mostly near normal from 2019 to the end of the timeseries. These trends are overall well simulated by the model, although differences exist, particularly during the last few years (see HFX nearshore panel of Figure 41).

The fraction of transport into the Gulf of Maine through the Cable Sable Island section (GoM inflow ratio of Figure 44) 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 42) the GoM inflow ratio was near neutral from 1990–2007 (with only 2001 and 2004 significantly above normal), mostly negative from 2008–2014, and near-neutral from 2015–2021 (with the exception of a strongly negative value in 2020). 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 45) by summing the standardized anomalies (Figures 41 and 42) 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 positive anomalies until the end of the time series.

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

SUMMARY

In 2021, the North Atlantic Oscillation index was close to normal (−0.1, −0.2 SD). The analysis of satellite data indicates that sea-surface temperatures were above normal at regions with all having a record or near record value.

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 2010–2020 were warmer than normal (Figure 46). 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 2021, 16 of the 17 series shown had positive anomalies; 16 variables were more than 1 SD above their normal values. Of these, 8 were more than 2 SD above normal and one was more than 3 SD (Emerald Basin at 0 m). Emerald Basin at 0 m and 50 m and Prince 5 at 0 m were record values and Eastern Georges Bank, the 2nd highest value.

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TABLES

Table 1. The 2021 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. The 1991–2020 climatology and 1981-2020 climatology for comparison. No data is available for Boston in 2021.

	Annual Anomaly		1991–2020 Climatology		1981–2010 Climatology	
Site	**Observed (°C)**	**Normalized (SD)**	**Mean (°C)**	**SD (°C)**	**Mean (°C)**	**SD (°C)**
Sydney	+1.2	+1.7	6.45	0.72	5.87	0.81
Sable Island	+1.0	+1.4	8.35	0.69	7.88	0.68
Shearwater (Halifax)	+1.0	+1.4	7.16	0.70	6.99	0.74
Yarmouth	+1.1	+1.6	7.69	0.71	7.16	0.62
Saint John	+1.0	+1.3	5.71	0.77	5.19	0.74
Boston	-	-	10.83	0.69	10.91	0.60

Table 2. 2021 SST anomalies and long-term SST statistics including 1982–2021 temperature change based on the linear trend.

Site	2021 SST Anomaly (°C)	2021 SST Anomaly Normalized	1991–2020 Mean Annual SST (°C)	1982–2021 Temperature Trend (°C/decade)
4Vn	+0.6	+1.3	6.5	0.2
4Vs	+0.9	+1.6	7.6	0.3
4W	+1.0	+1.8	8.7	0.3
4X SS	+1.1	+2.0	8.3	0.3
4X eGoM+BoF	+1.3	+1.9	8.2	0.4

FIGURES

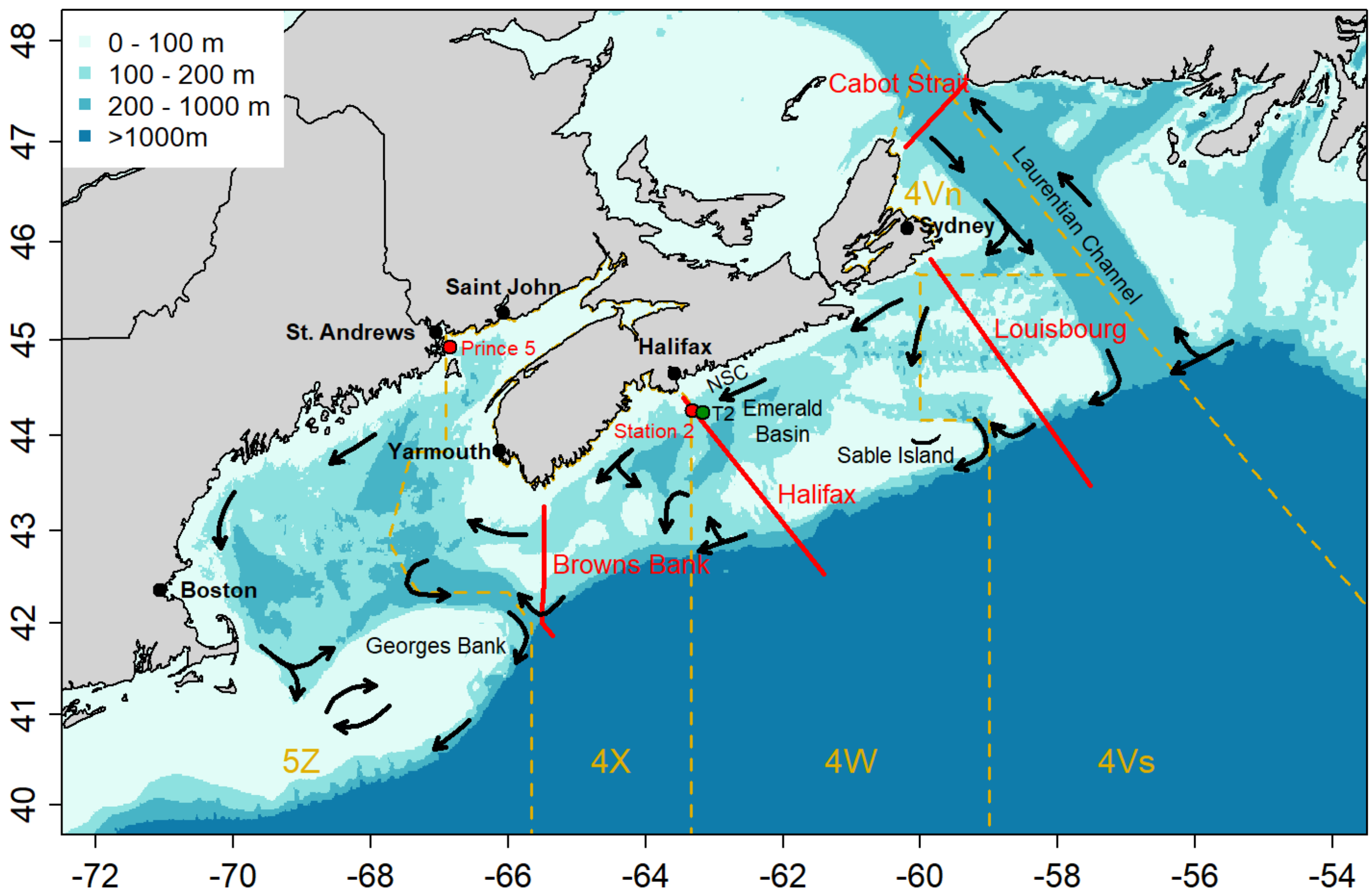

Figure 1. Map of the Scotian Shelf and the Gulf of Maine showing hydrographic stations (red circles), standard sections (red lines), current meter mooring (green), and topographic features. The Nova Scotia Current (NSC) is shown. The dotted lines indicate the boundaries of the Northwest Atlantic Fisheries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

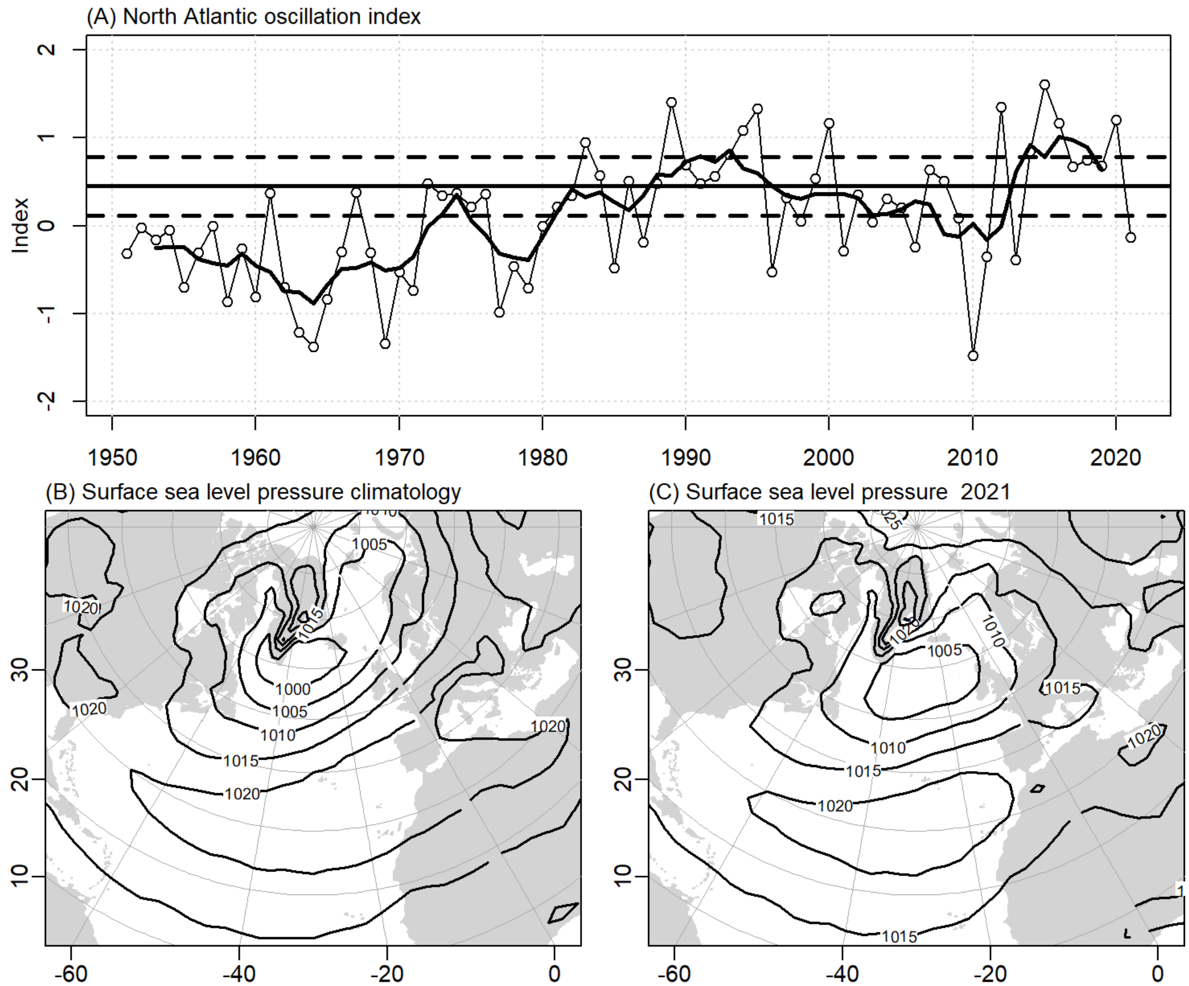

Figure 2. (A) The North Atlantic Oscillation (NAO) index, defined as the winter (December, January, February, March) 500 mb pressure Principal Component Analysis which is representative of the difference between the Icelandic low and Azores high. Thick line is a 5-year moving average. Climatological mean is shown as the solid line. Dashed lines are ±0.5 standard deviation (SD). (B) The 1981–2010 December–March mean and (C) December 2019–March 2020 mean sea-level atmospheric pressure over the North Atlantic. (Data provided by the [NOAA/ESRL Physical Sciences Division](), Boulder, Colorado.)

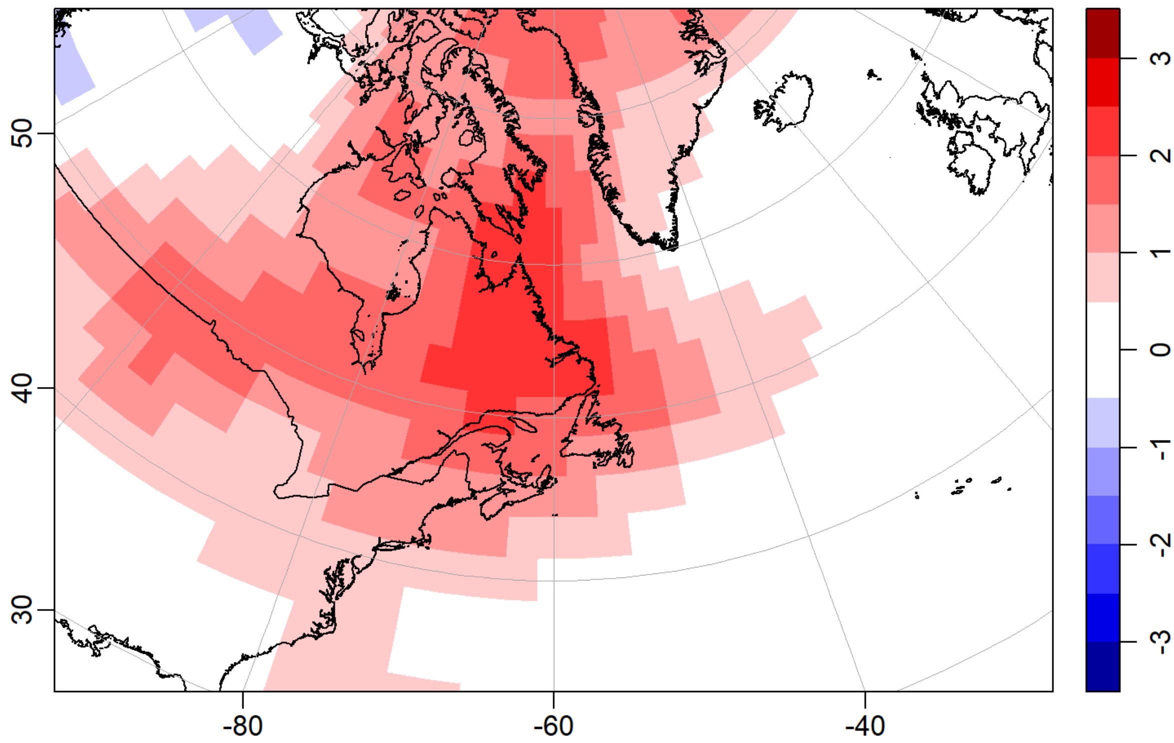

Figure 3. Annual air temperature anomalies (ºC) over the Northwest Atlantic relative to the 1981–2010 means; data were obtained from NOAA Internet site (accessed 7 January 2022).

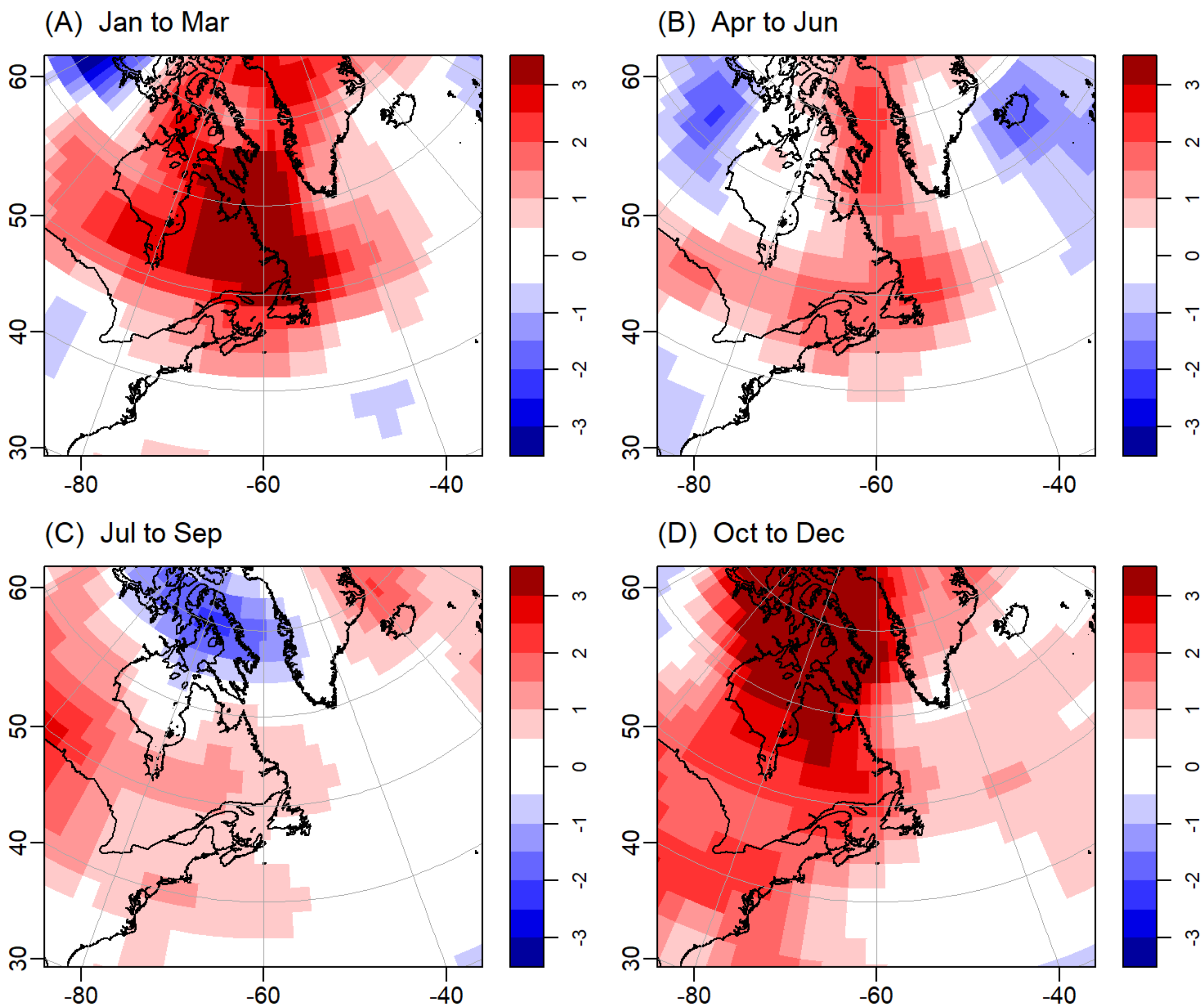

Figure 4. Seasonal air temperature anomalies (ºC) over the Northwest Atlantic relative to the 1981–2010 means; data were obtained from [NOAA Internet site]() (accessed 7 January 2022).

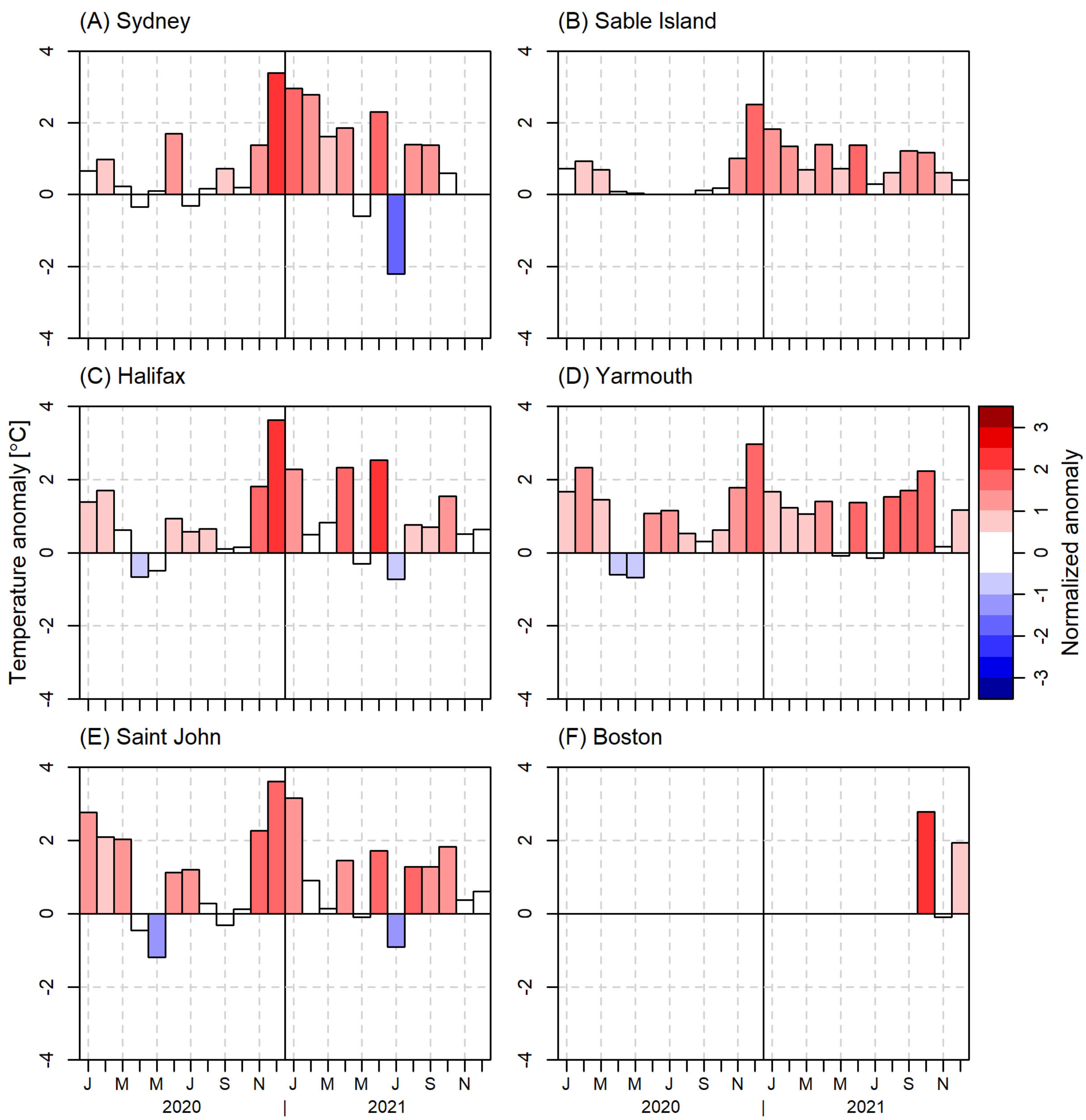

Figure 5. Monthly air temperature anomalies (°C) at several sites in Scotian Shelf/Gulf of Maine region for 2020 and 2021. See Figure 1 for locations. JMMJSN on x-axis represent January, March, May, June, September, and November. Anomalies are colour coded in terms of the numbers of SD above or below normal relative to monthly statistics.

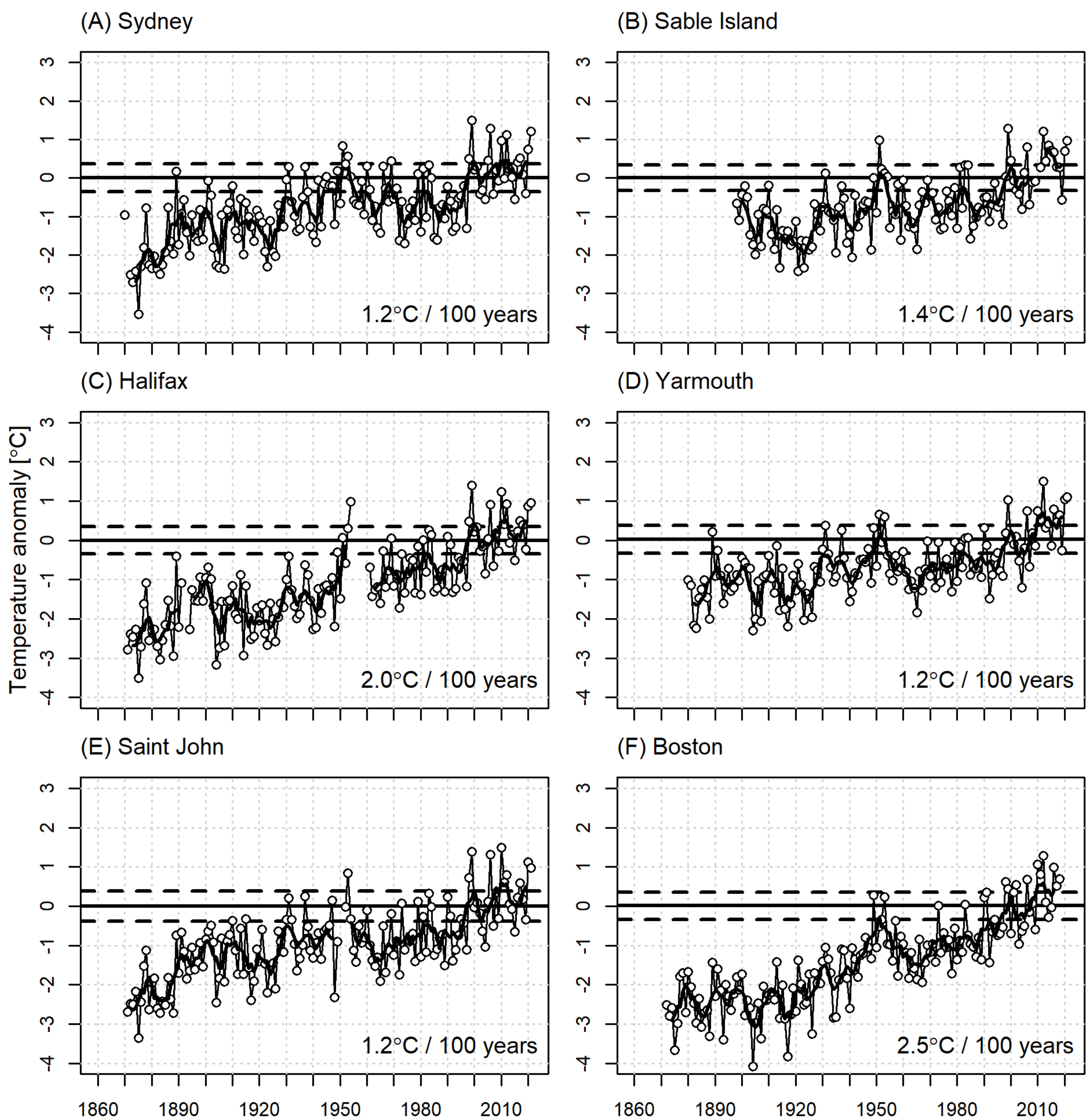

Figure 6. Annual air temperature anomalies in °C (dashed line) and five-year running means (solid line) at selected sites (Sydney, Sable Island, Halifax (Shearwater), Yarmouth, Saint John, and Boston) in Scotian Shelf/Gulf of Maine region (years 1860 to 2020). Horizontal dashed lines represent plus or minus 0.5 SD for the 1991–2020 period. Linear trends for 1900–present are shown.

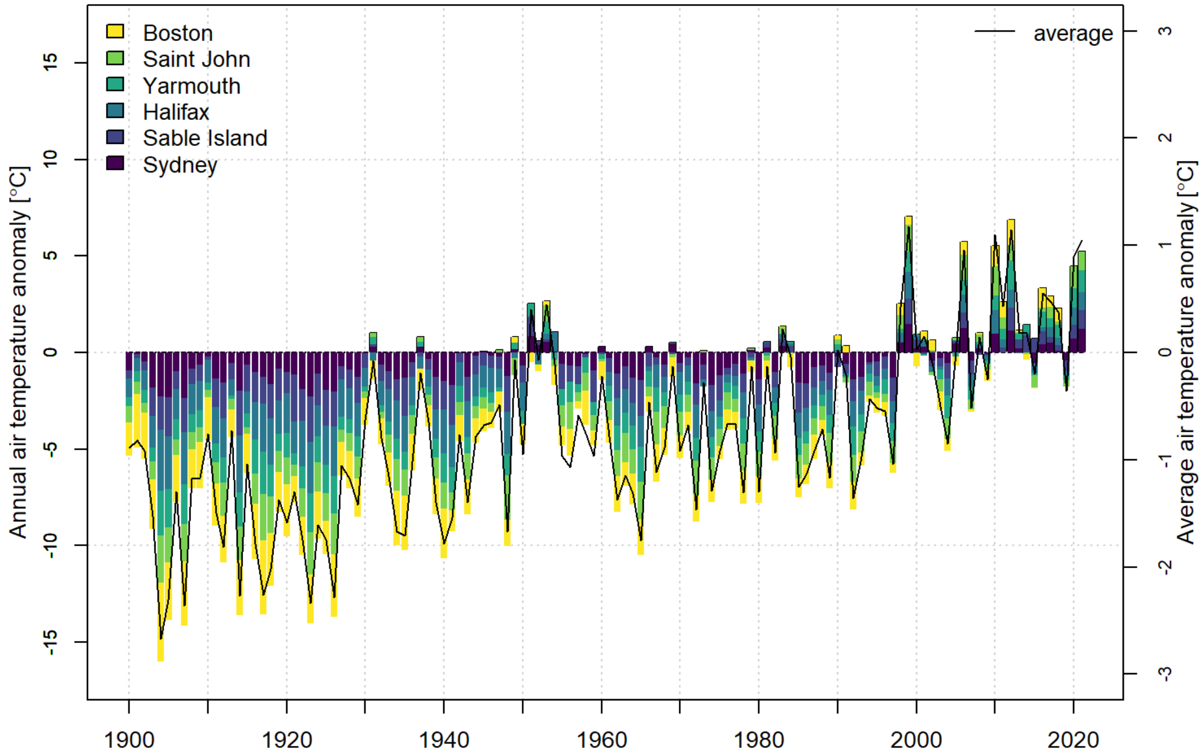

Figure 7. The contributions of each of the annual air temperature anomalies for six Scotian Shelf/Gulf of Maine sites (Boston, Saint John, Yarmouth, Halifax (Shearwater), Sable Island, and Sydney) are shown as a stacked bar chart. Anomalies referenced to 1991–2020.

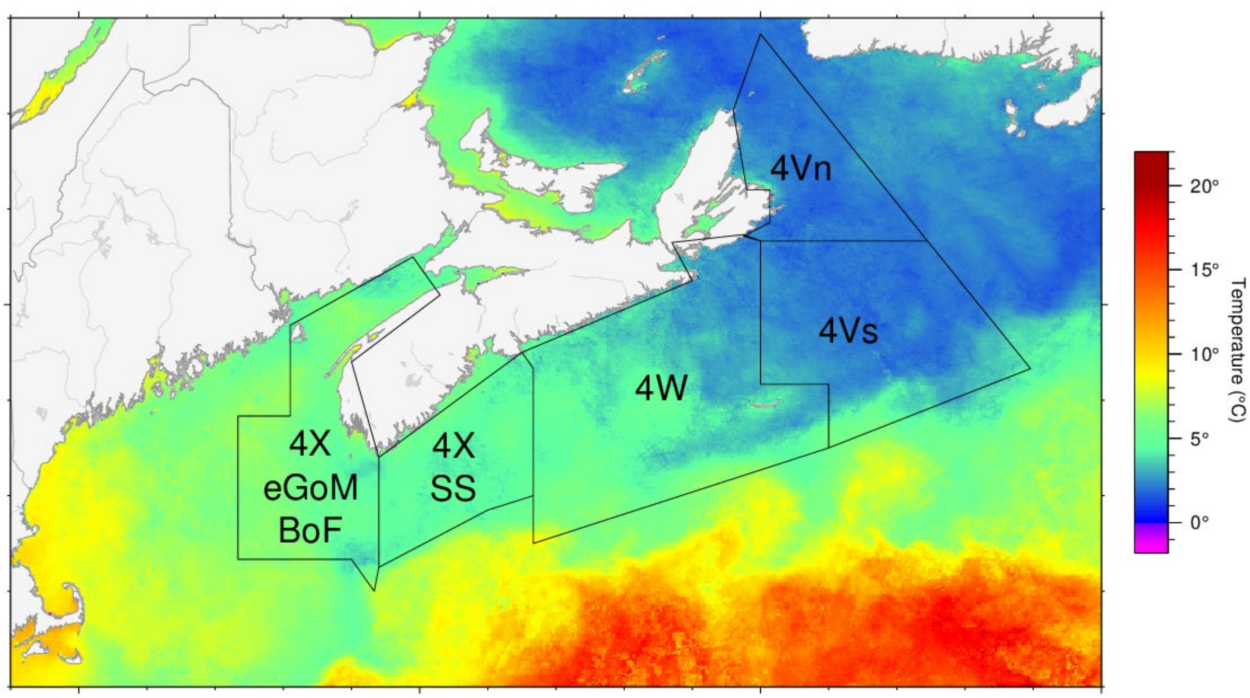

Figure 8. Scotian Shelf/Gulf of Maine areas (4Vn, 4Vs, 4W, 4X SS, and 4X eGoM-BoF) used for extraction of sea surface temperature.

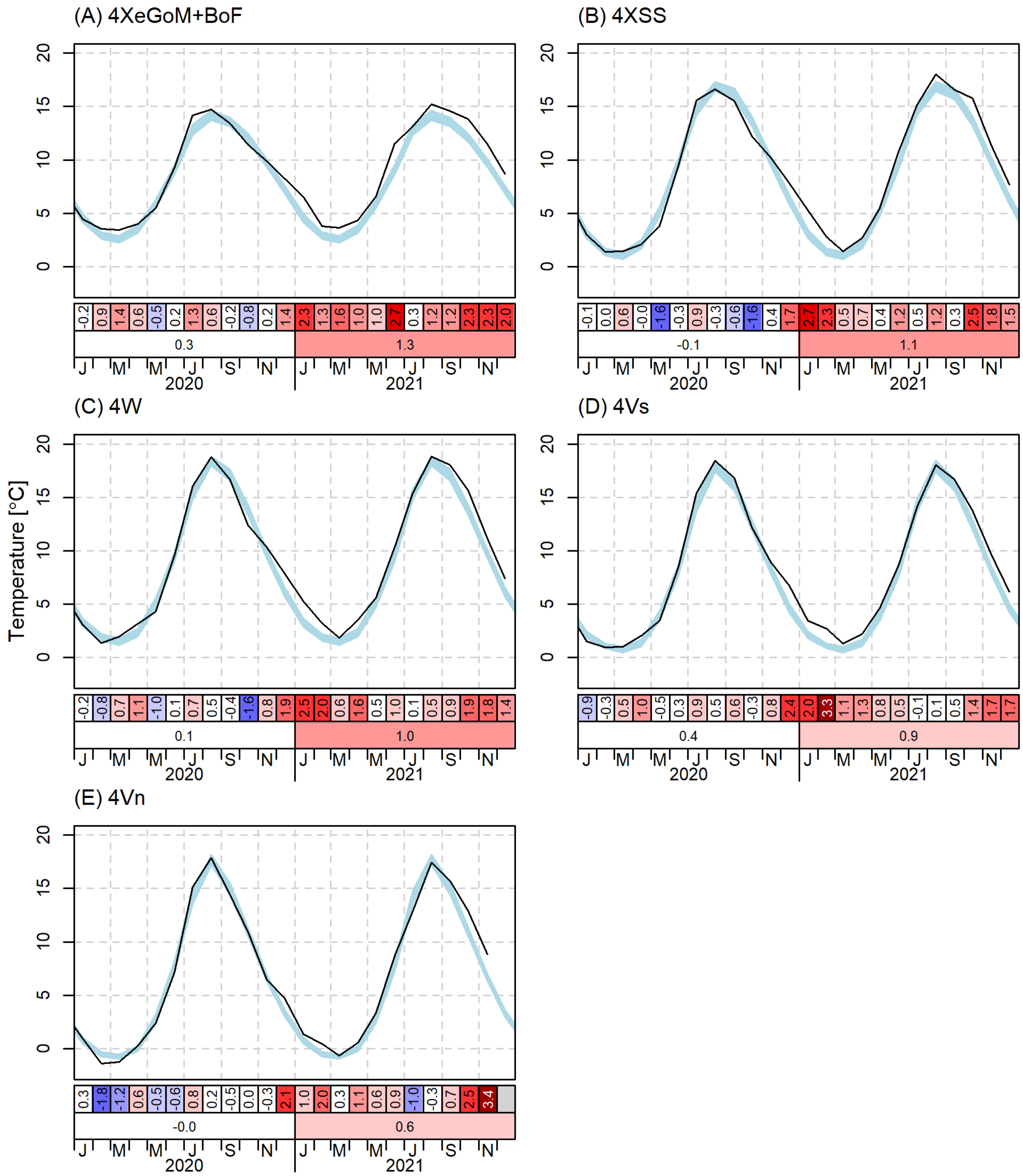

Figure 9. AVHRR SST weekly, monthly, and annual averages over the five regions of the Scotian Shelf and Gulf of Maine. The blue area represents the 1991–2020 climatological weekly mean ± 0.5 SD. The scorecards are colour-coded according to the normalized anomalies based on the 1991–2020 climatologies for each week (top row), month (middle row), or for the year (bottom row).

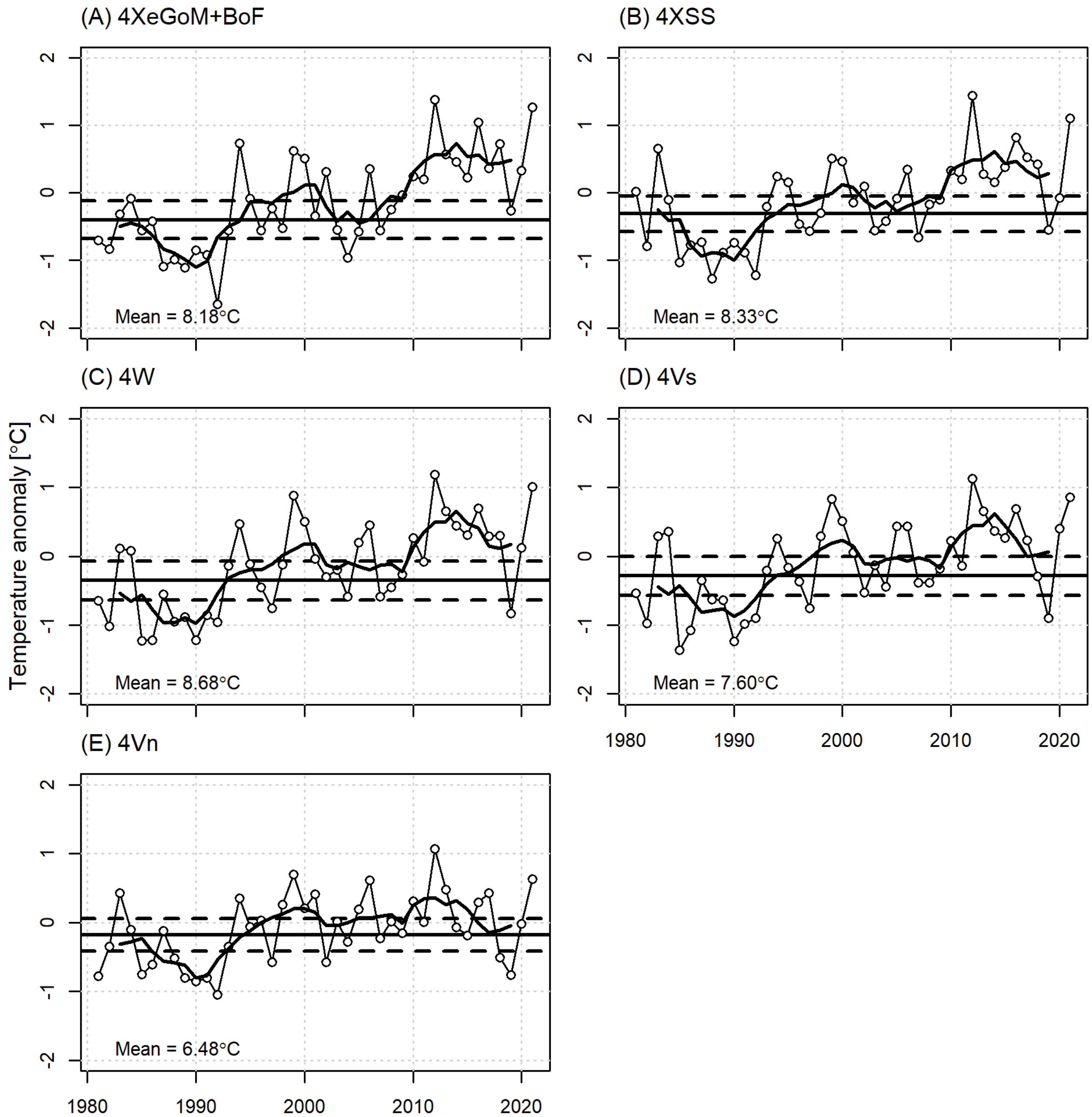

Figure 10. The annual sea-surface-temperature normalized anomalies derived from satellite imagery compared to their long-term monthly means (five Scotian Shelf and Gulf of Maine regions–4Vn, 4Vs, 4W, 4X Scotian Shelf, and 4X eastern Gulf of Maine/Bay of Fundy (Figure 8).

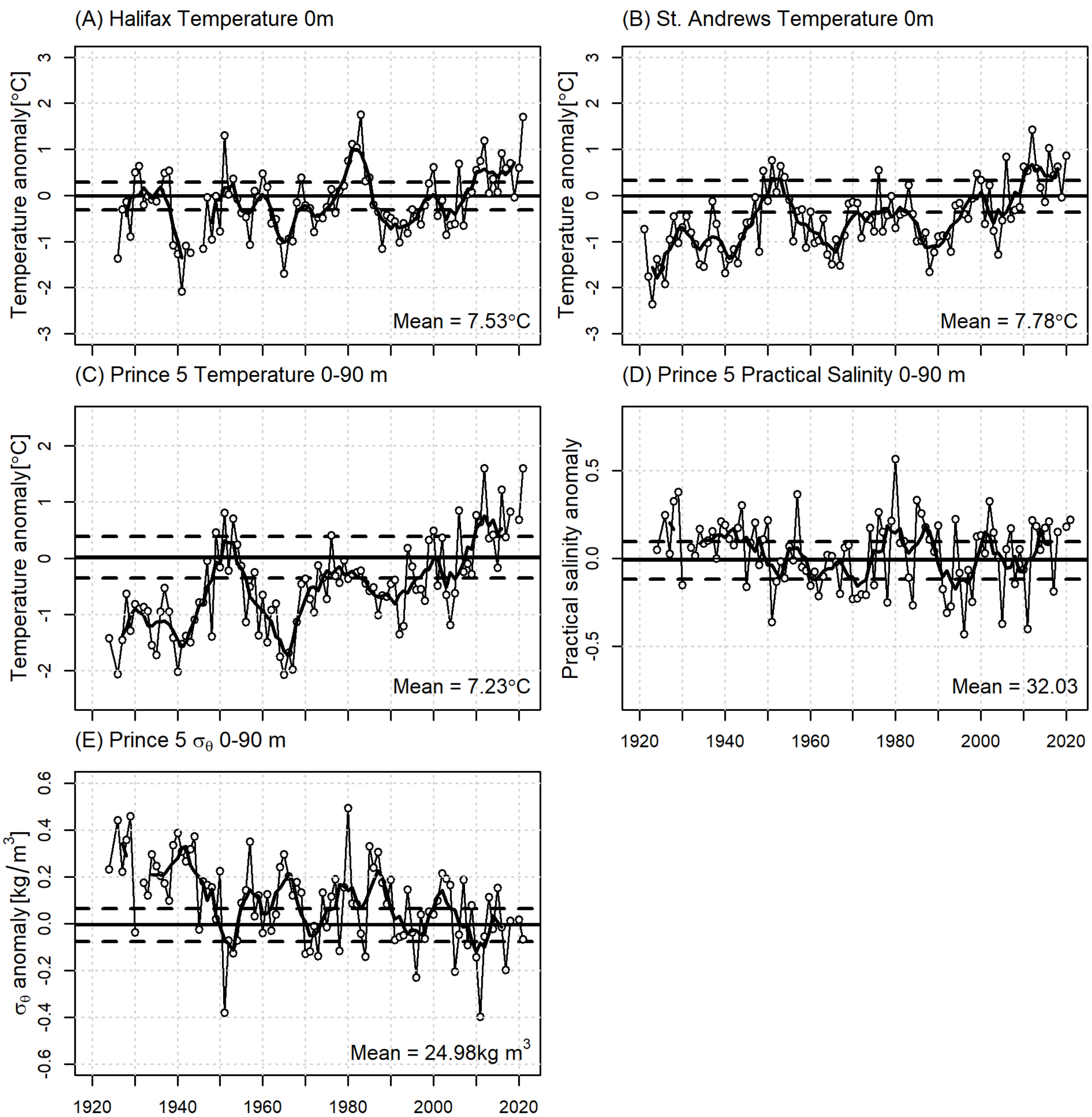

Figure 11. The annual surface-temperature anomalies (dotted line with circles) and their five-year running means (heavy black line) for (A) Halifax Harbour and (B) St. Andrews; and annual depth-averaged (0–90 m) temperature (C), salinity (D), and density (E) anomalies for the Prince 5 monitoring station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

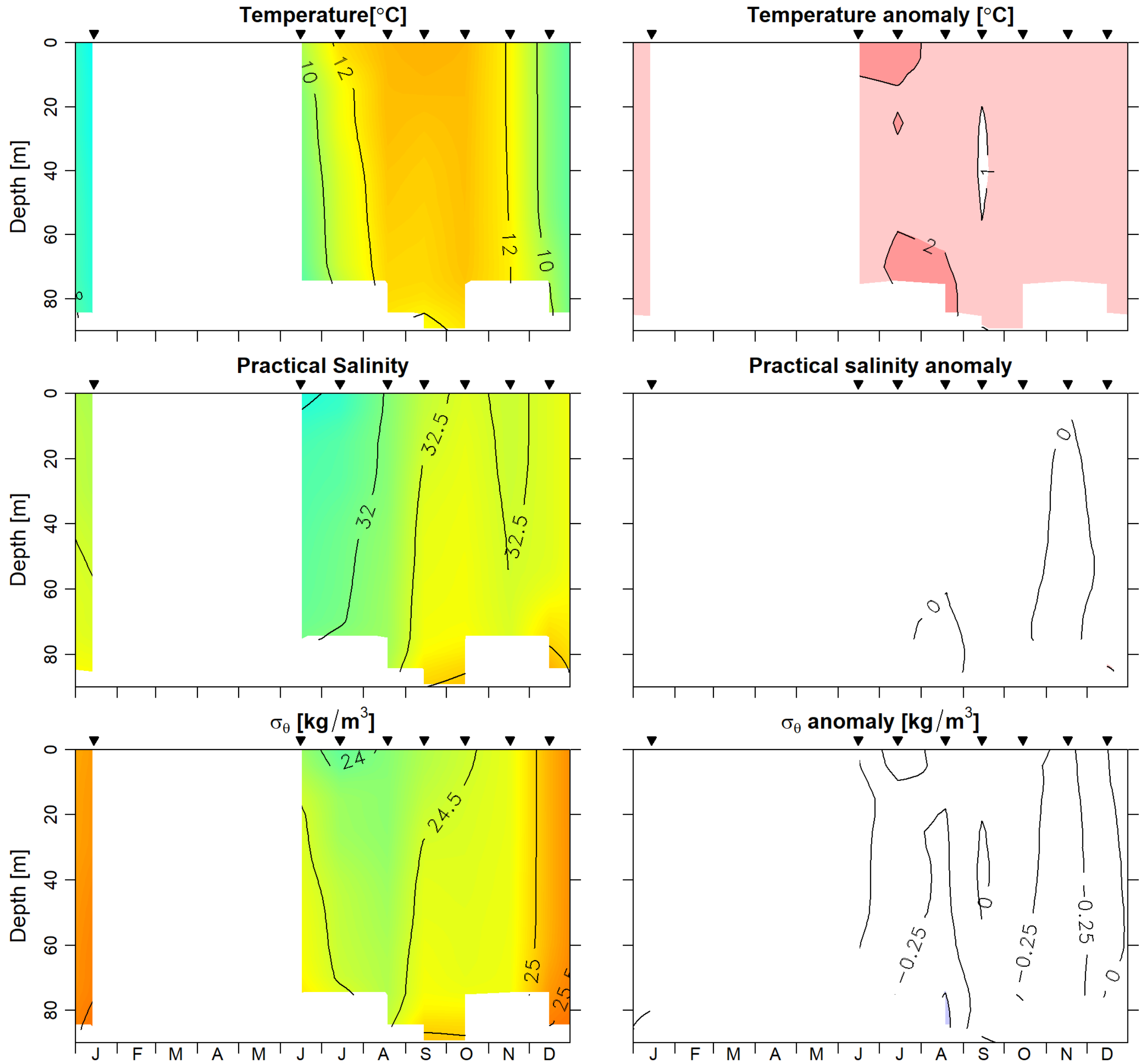

Figure 12. The 2021 annual cycle of temperature (top panel), salinity (middle panel), and density (lower panel) and their anomalies with respect to 1991–2020 monthly means (right panels) for the Prince 5 monitoring station at the mouth of the Bay of Fundy. Triangles indicate periods of sampling.

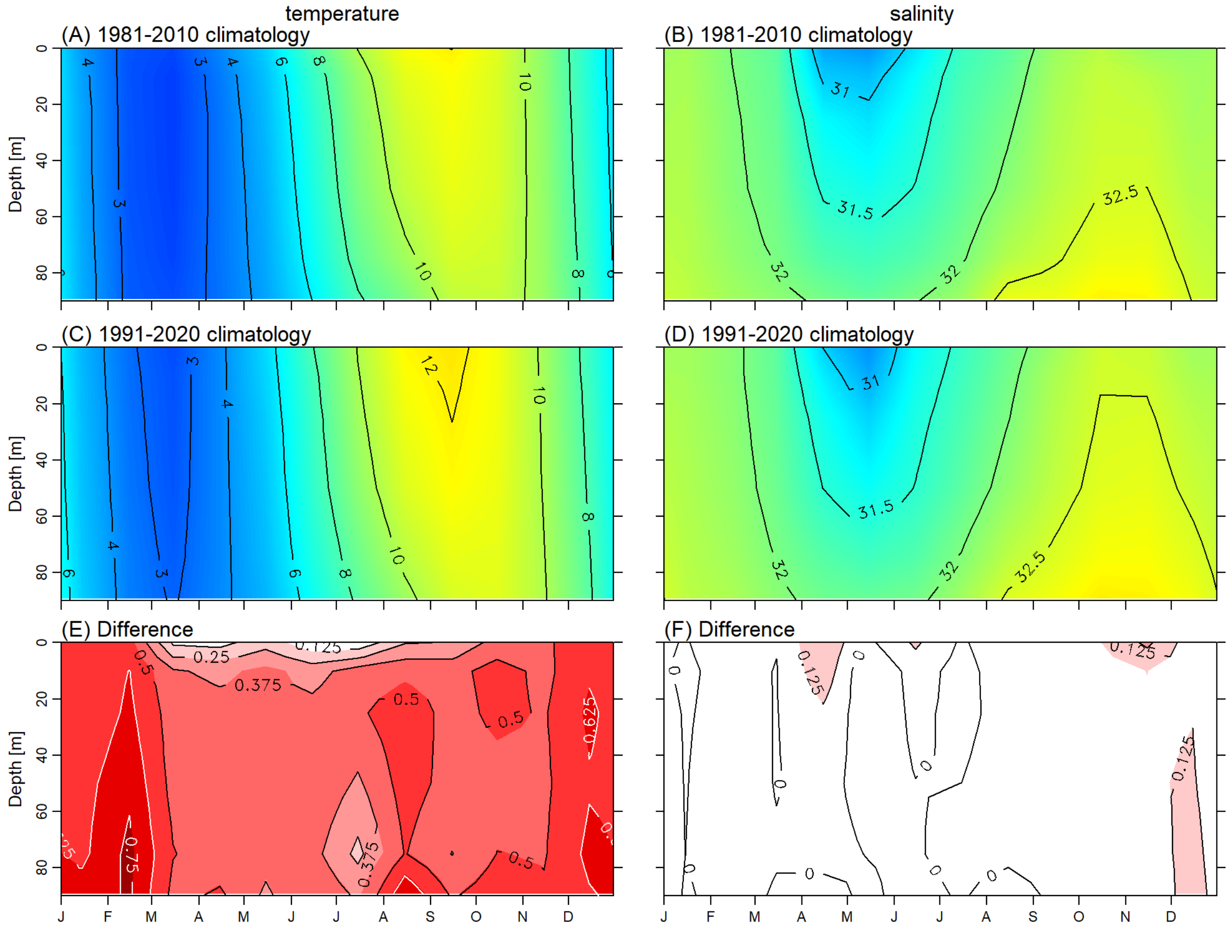

Figure 13. The 1981–2010 climatology of temperature (top left panel) and salinity (top right panel), the 1991–2020 climatology of temperature (middle left panel) and salinity (middle right panel). The lower panels difference between the two climatologies ([1991–2020]–[1981–2010]) for the Prince 5 monitoring station at the mouth of the Bay of Fundy. The daily climatology was determined from all data and loess filter applied.

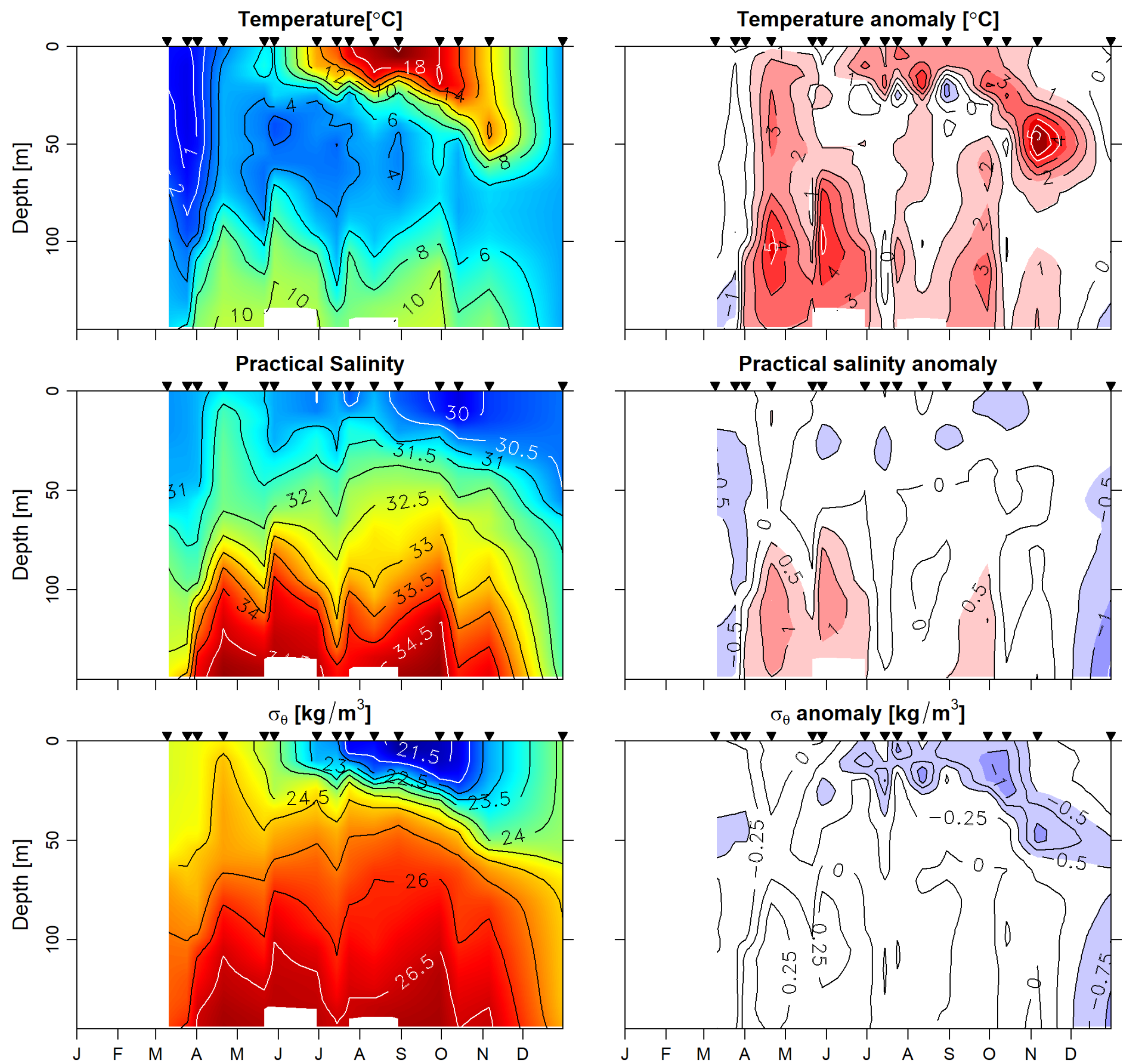

Figure 14. The 2021 annual cycles of temperature (top panel), salinity (middle panel), and density (lower panel) and their anomalies with respect to 1991–2020 monthly means (right panels) for Halifax station 2. Triangles indicate periods of sampling.

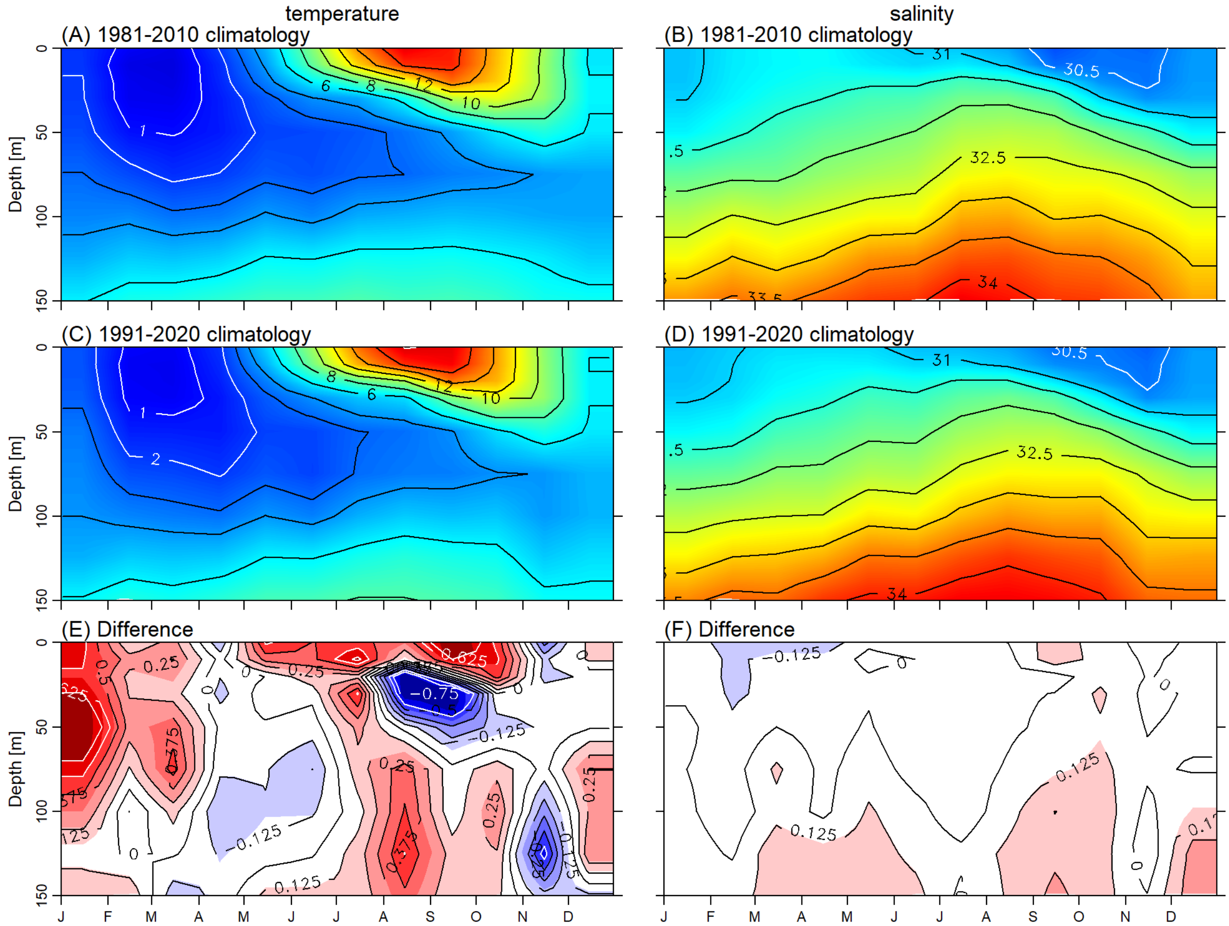

Figure 15. The 1981–2010 climatology of temperature (top left panel) and salinity (top right panel), the 1991–2020 climatology of temperature (middle left panel) and salinity (middle right panel). The lower panels difference between the two climatologies ([1991–2020]–[1981–2010]) for Halifax Station 2 (HL2) monitoring station at the mouth of the Bay of Fundy. The daily climatology was determined from all data and loess filter applied.

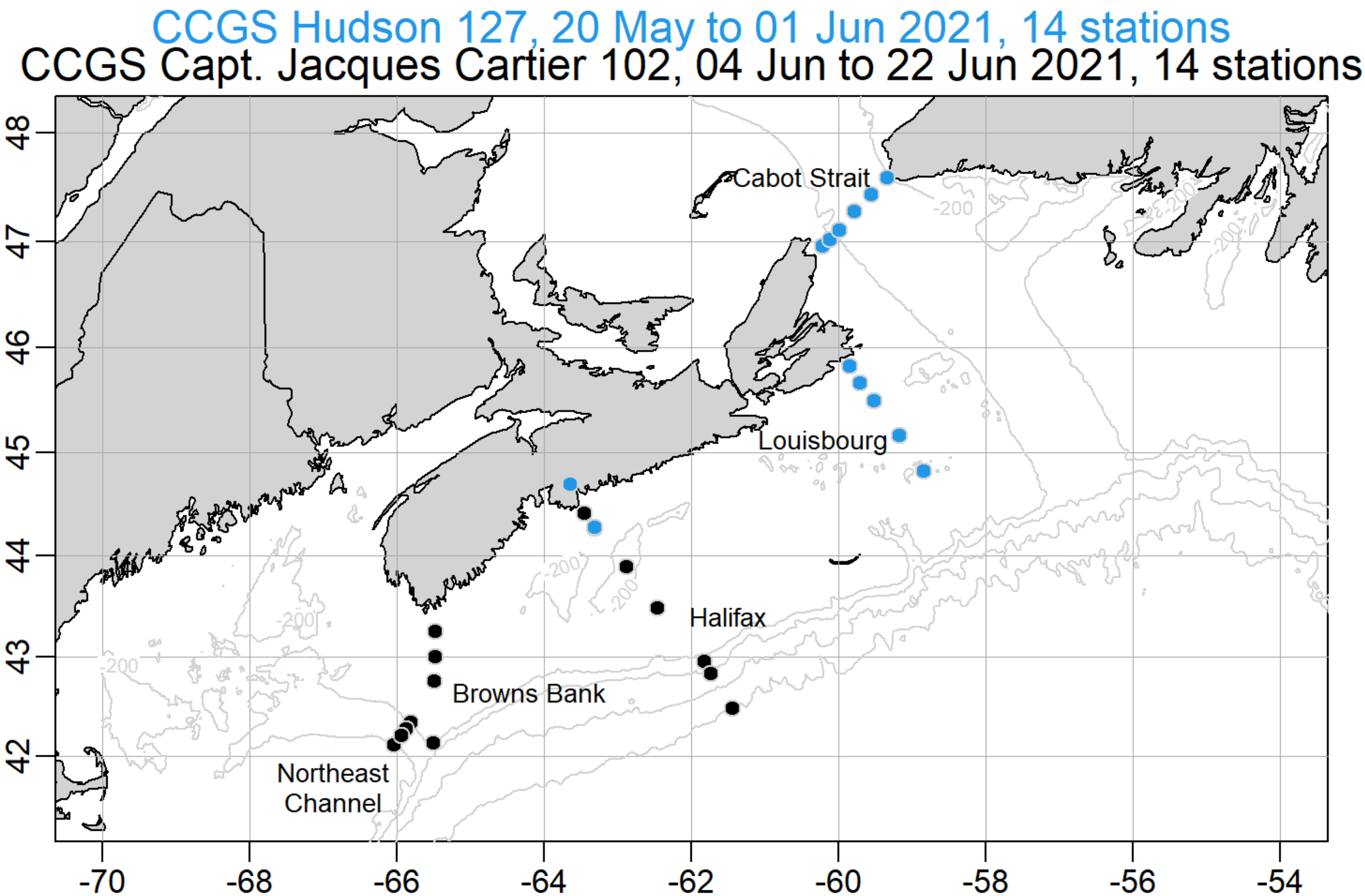

Figure 16. The 2021 sampling of the Scotian Shelf/Gulf of Maine for the late spring survey. This survey was later than normal to vessel availability.

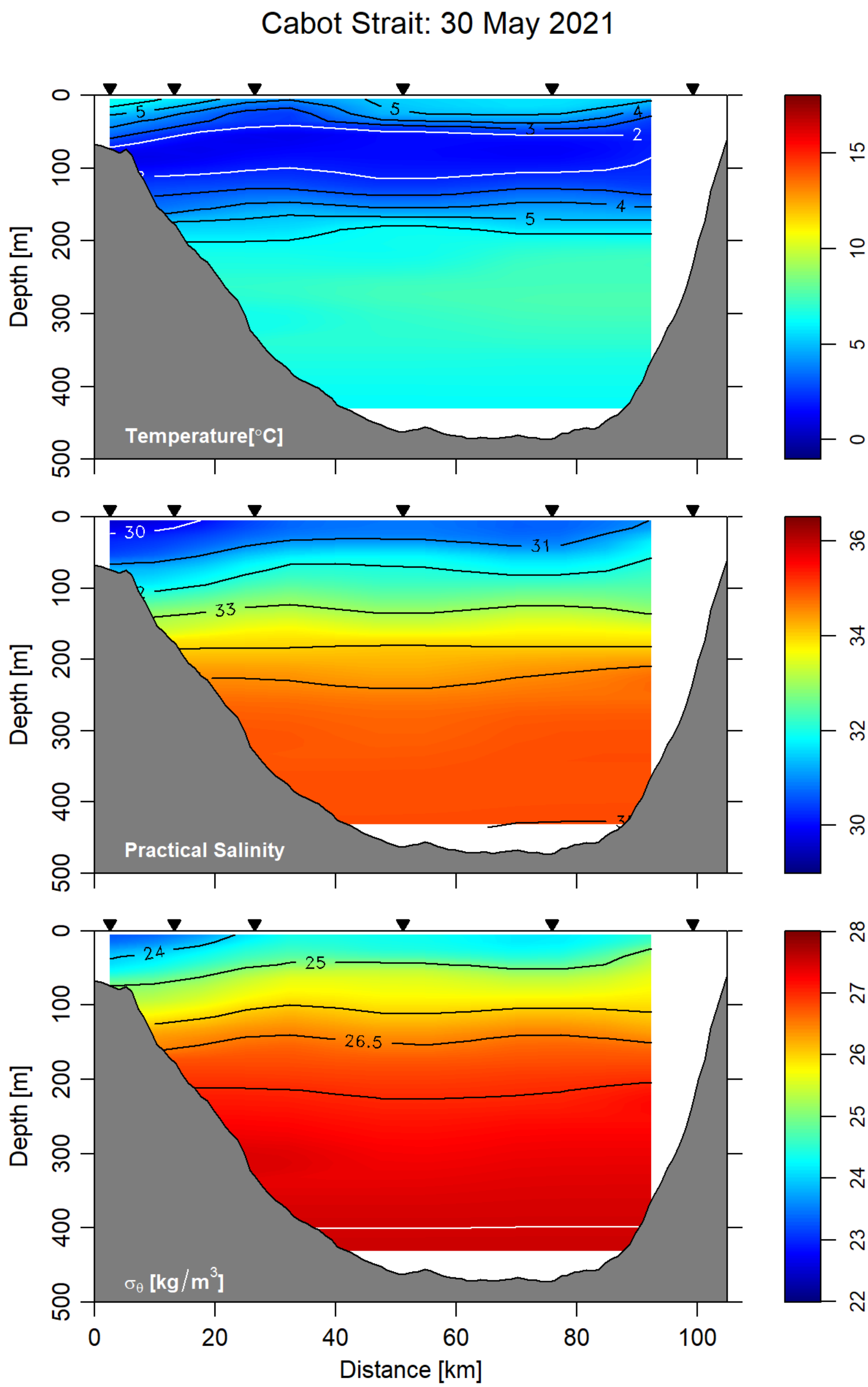

Figure 17. The 2021 sampling of the Cabot Strait Section for late spring. Temperature (top panel), salinity (middle panel), and density (lower panel). Anomalies could not be calculated due to no 1991–2020 climatology. Triangles indicate locations of sampling.

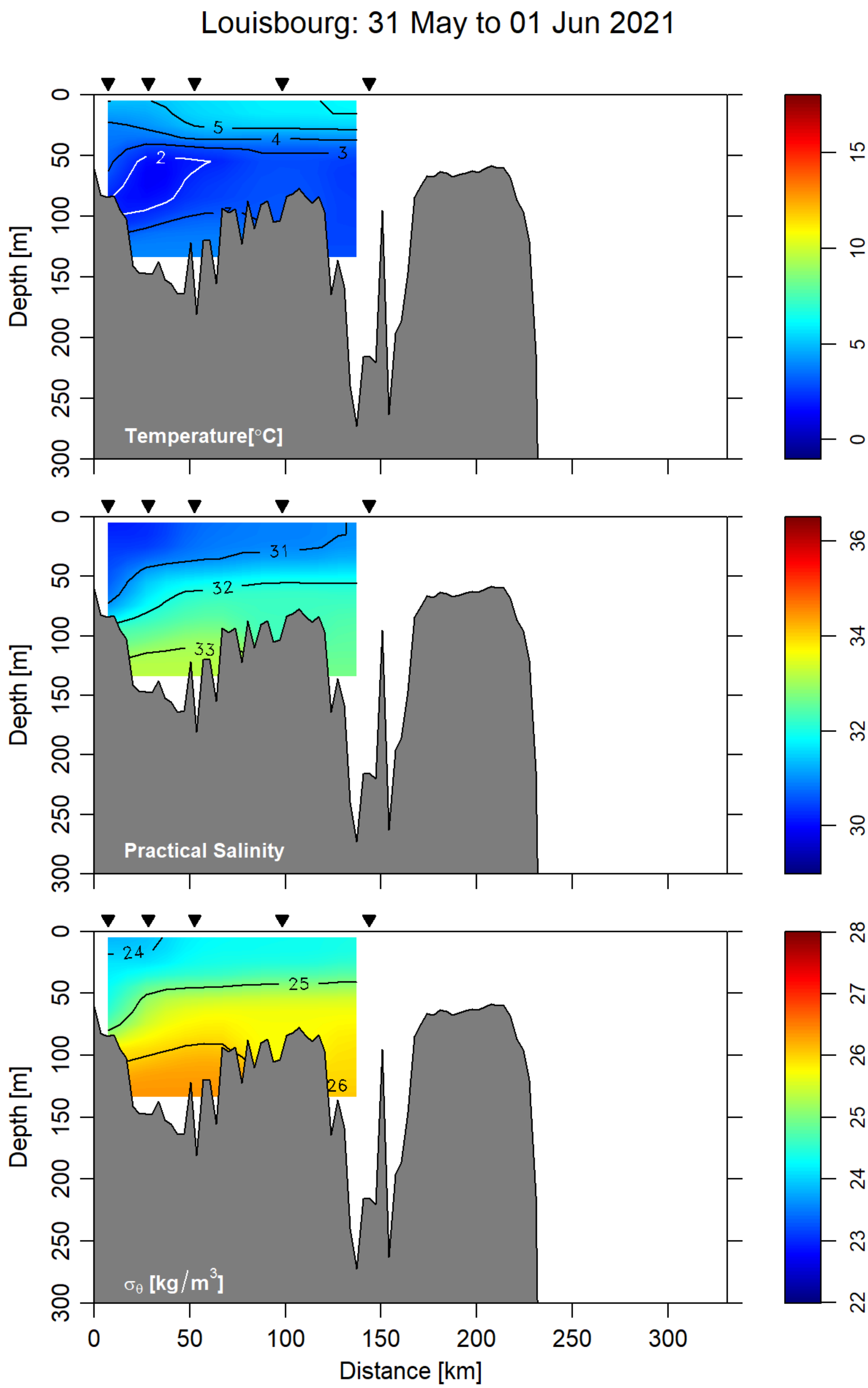

Figure 18. The 2021 sampling of the Louisbourg Section for late spring. Temperature (top panel), salinity (middle panel), and density (lower panel). Anomalies could not be calculated due to no 1991–2020 climatology. Triangles indicate locations of sampling.

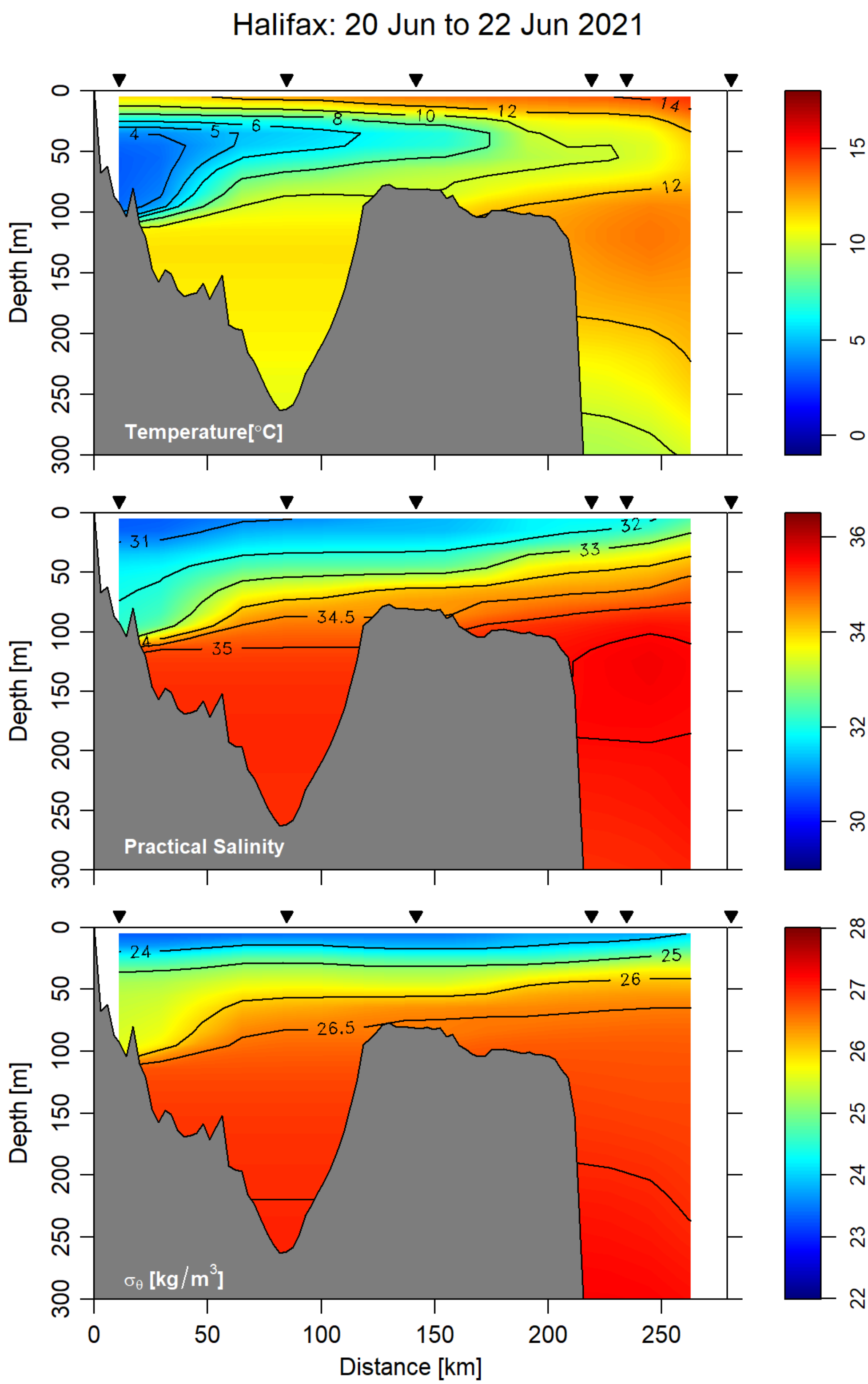

Figure 19. The 2021 sampling of the Halifax section for late spring. Temperature (top panel), salinity (middle panel), and density (lower panel). Anomalies could not be calculated due to no 1991–2020 climatology. Triangles indicate locations of sampling.

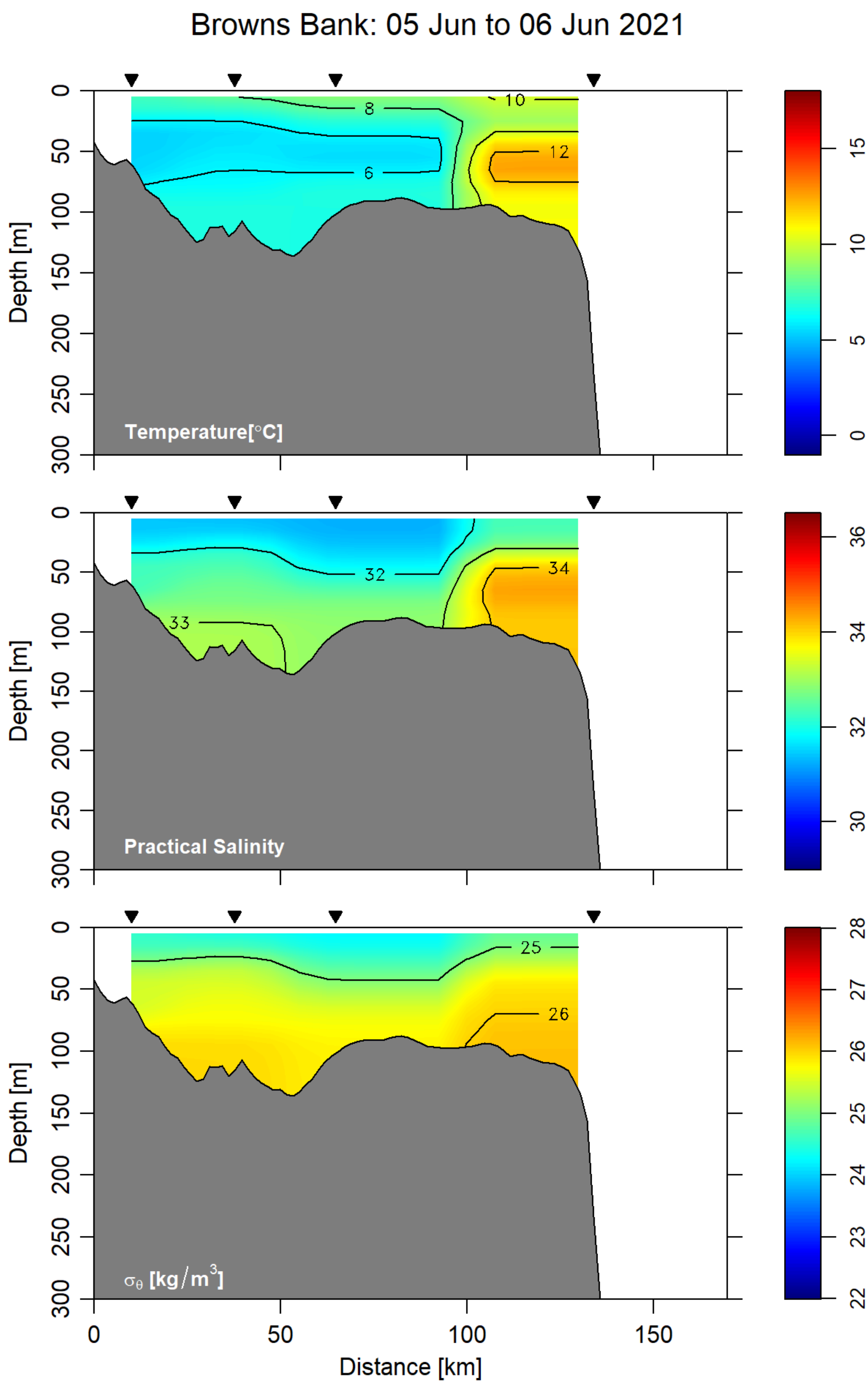

Figure 20. The 2021 sampling of the Browns Bank Section for late spring. Temperature (top panel), salinity (middle panel), and density (lower panel). Anomalies could not be calculated due to no 1991–2020 climatology. Triangles indicate locations of sampling.

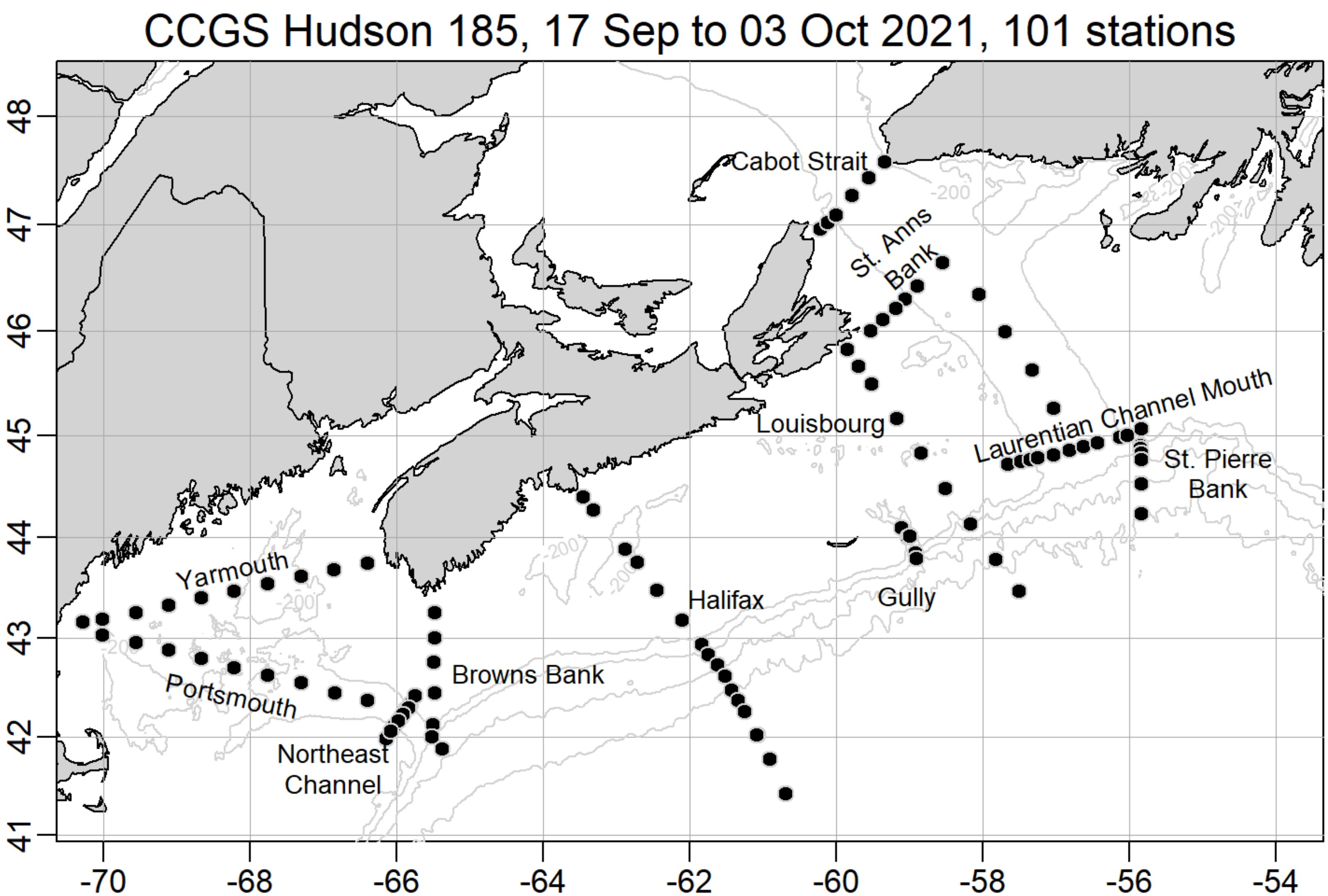

Figure 21. The 2021 sampling of the Scotian Shelf/Gulf of Maine for the fall survey.

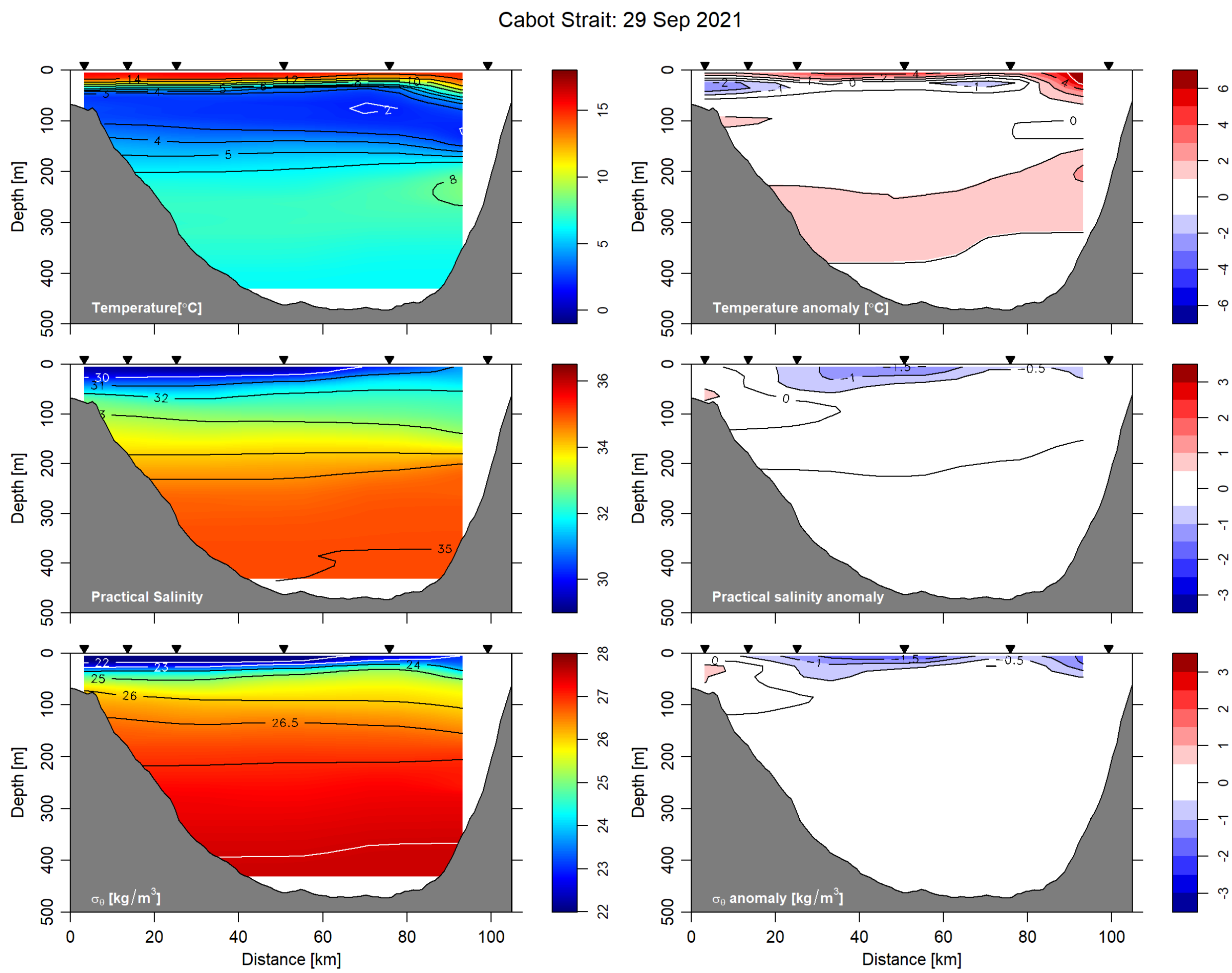

Figure 22. The 2021 sampling of the Cabot Strait Section for fall. Temperature (top panel), salinity (middle panel), and density (lower panel) and their anomalies with respect to 1991–2020 monthly means (right panels). Triangles indicate locations of sampling.

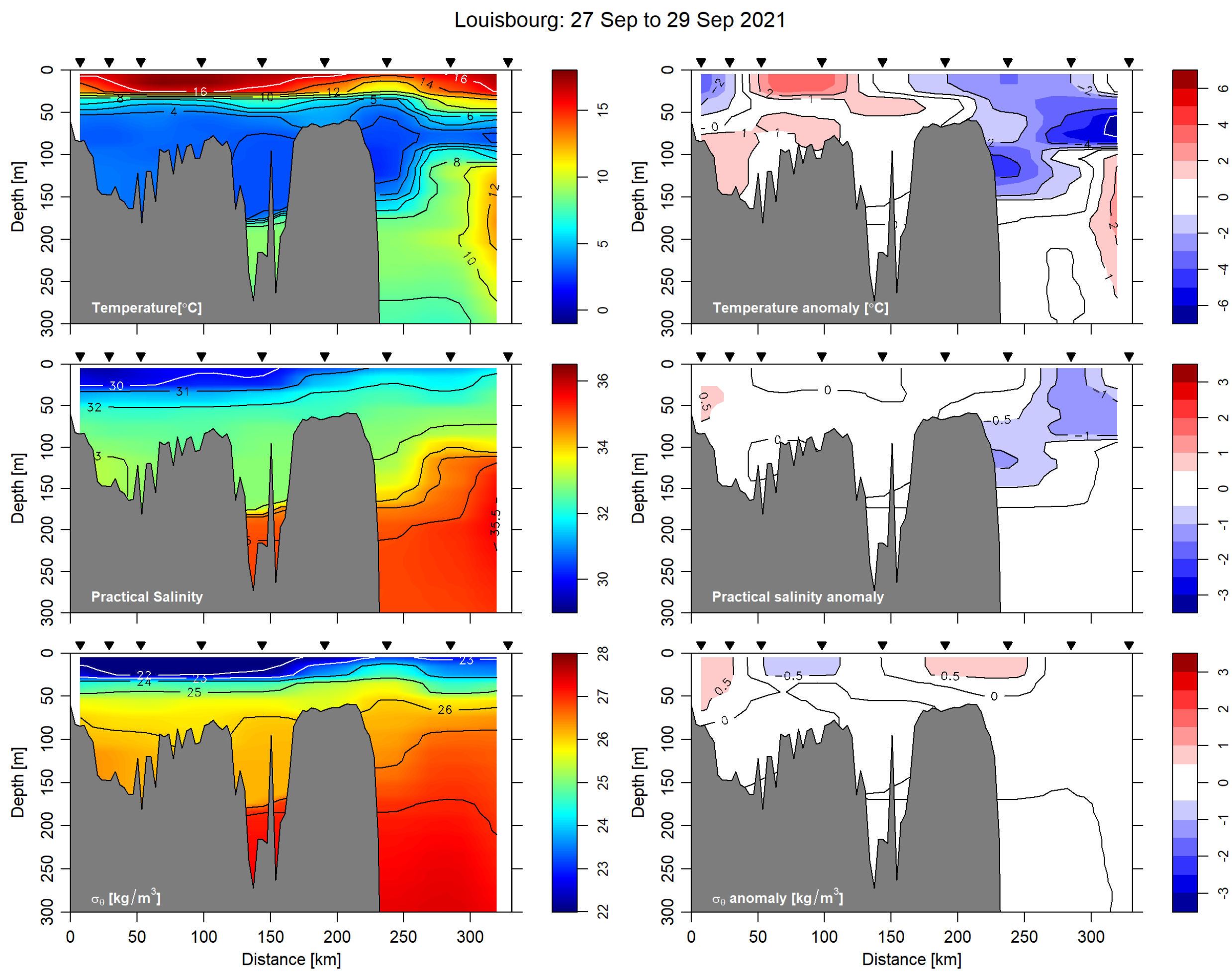

Figure 23. The 2021 sampling of the Louisbourg Section for fall. Temperature (top panel), salinity (middle panel), and density (lower panel) and their anomalies with respect to 1991–2020 monthly means (right panels). Triangles indicate locations of sampling.

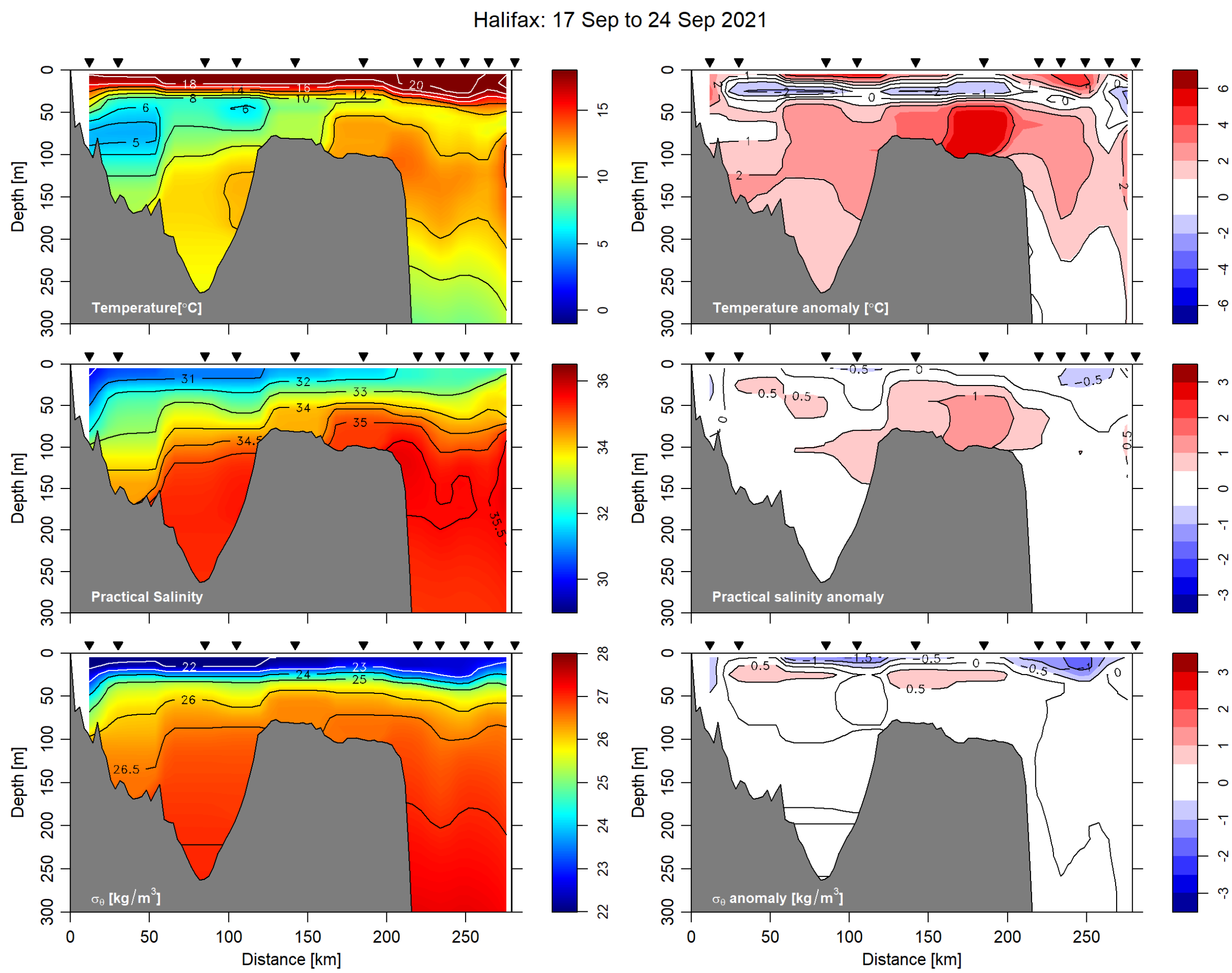

Figure 24. The 2021 sampling of the Halifax section for fall. Temperature (top panel), salinity (middle panel), and density (lower panel) and their anomalies with respect to 1991–2020 monthly means (right panels). Triangles indicate locations of sampling.

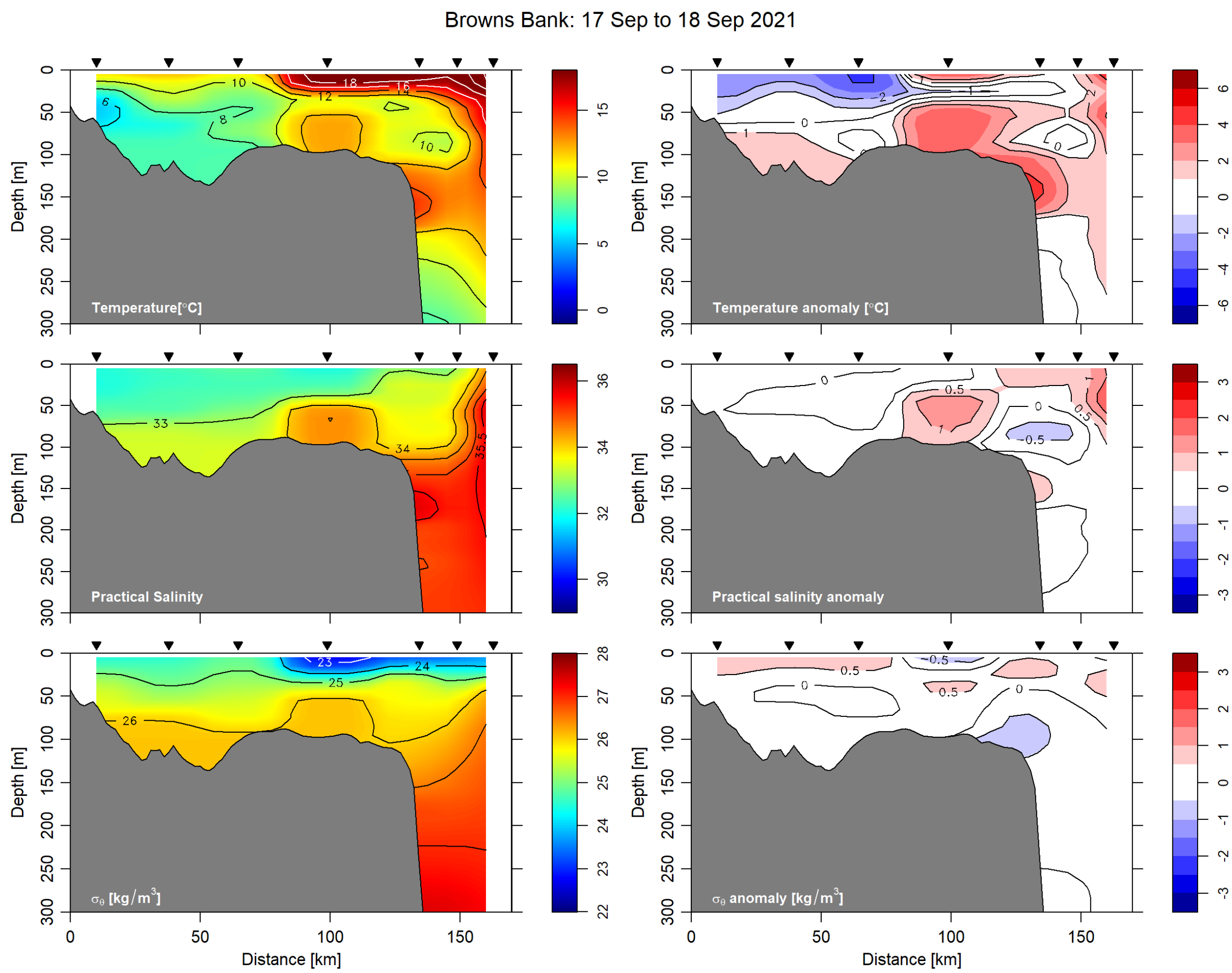

Figure 25. The 2021 sampling of the Browns Bank Section for fall. Temperature (top panel), salinity (middle panel), and density (lower panel) and their anomalies with respect to 1991–2020 monthly means (right panels). Triangles indicate locations of sampling.

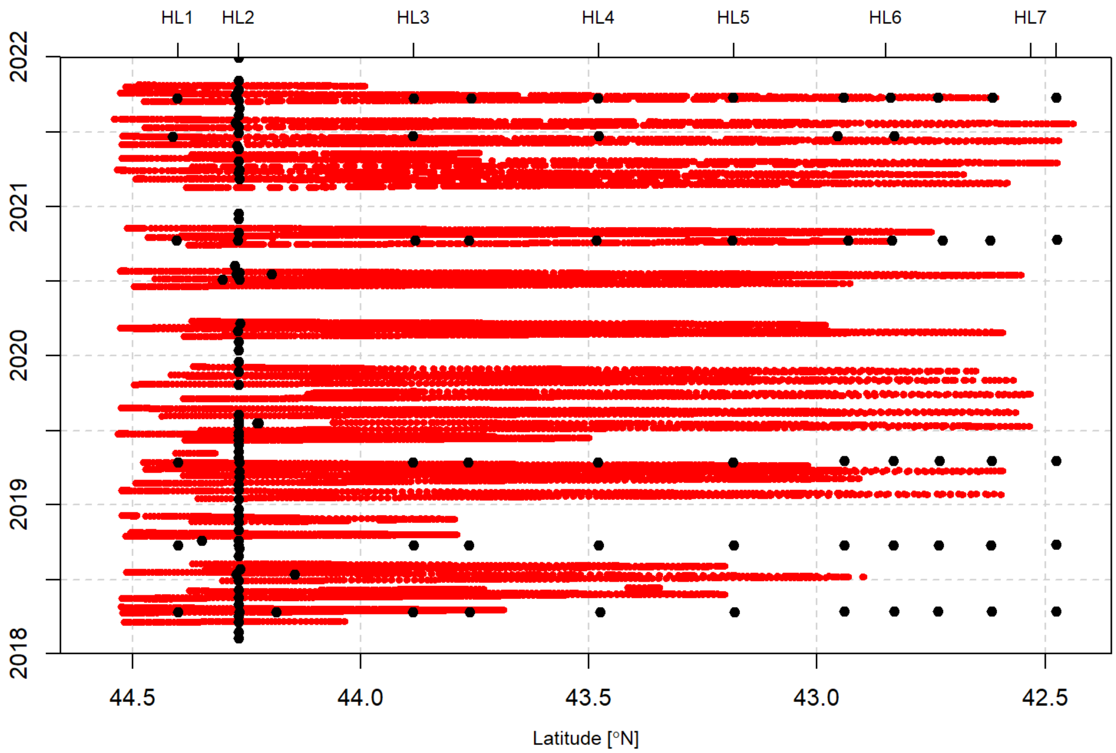

Figure 26. Hodograph of sampling on the Halifax Line for 2018–2021. Black dots represent the sampling by a vessel. Red dots represent sampling by the gliders.

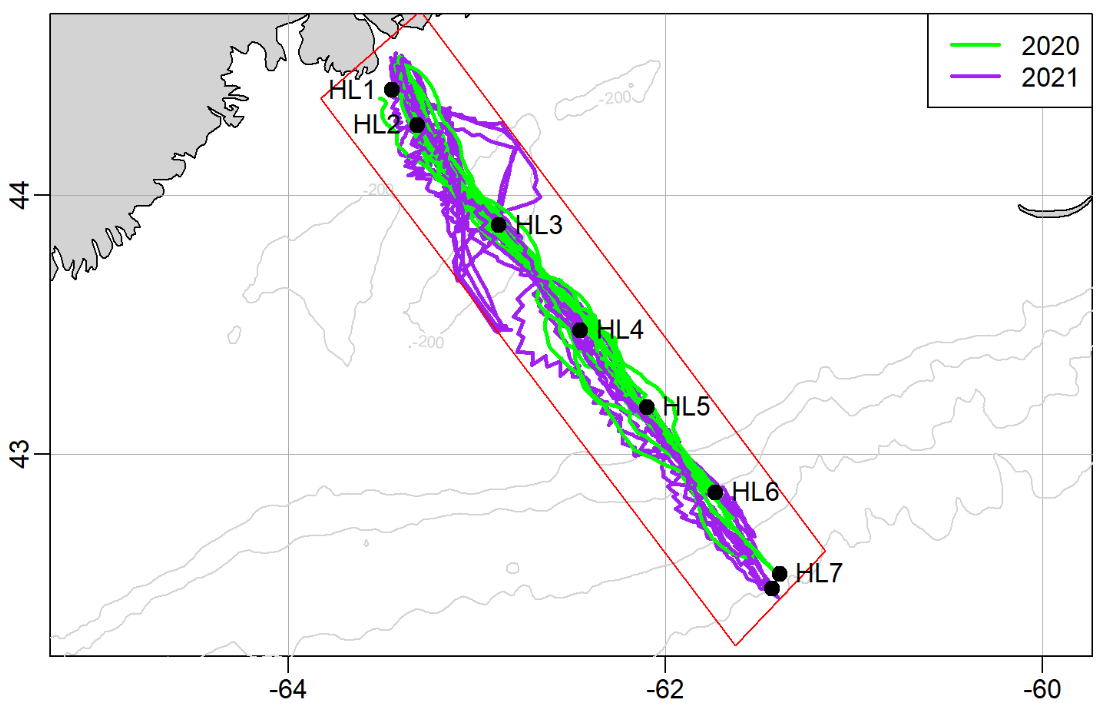

Figure 27. Glider trajectories on the Halifax Line (HL) for 2020 and 2021. Locations of the HL stations are shown by the black dots. Red box shows the limitations applied to glider data to be considered on HL.

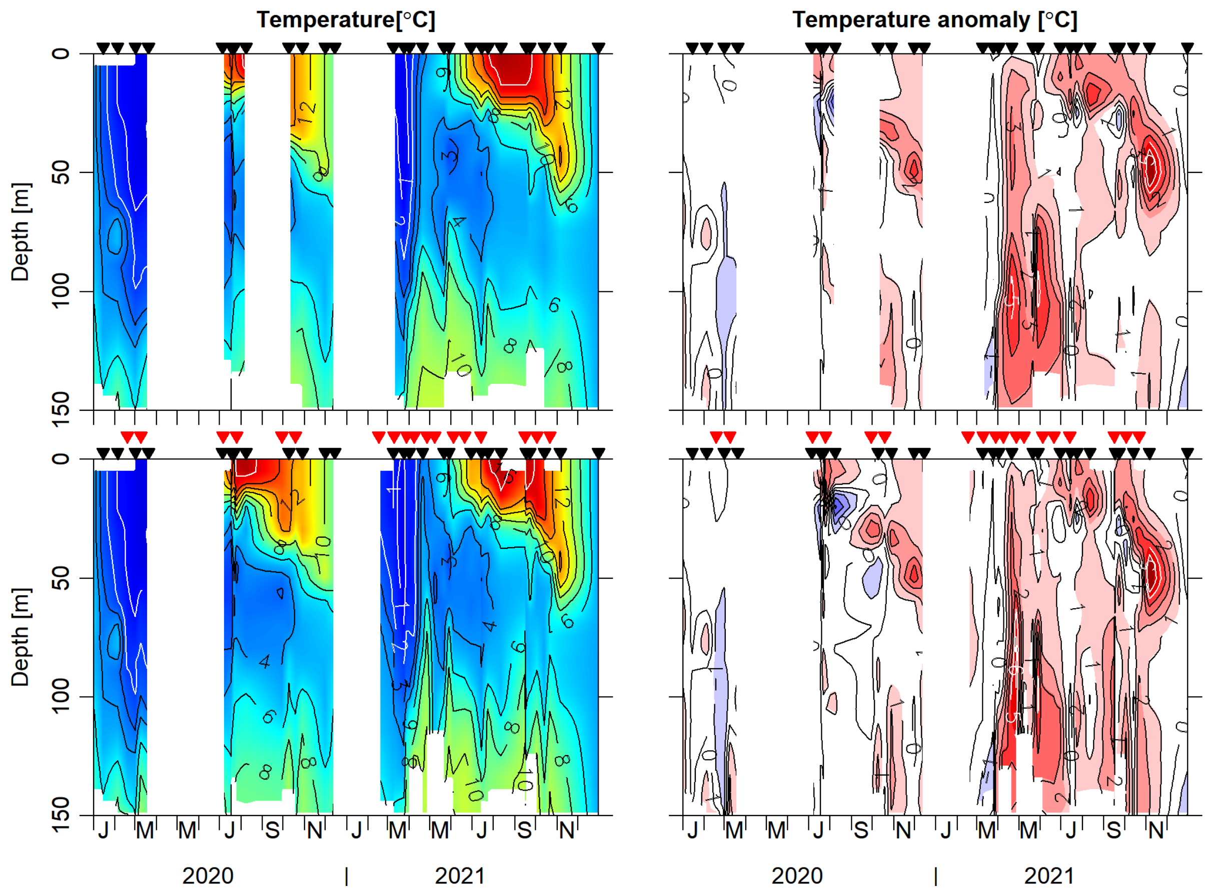

Figure 28. Top panels for temperature (left) and temperature anomaly (right) with standard vessel sampling at Station 2. Bottom panels include the additional glider data that has been averaged hourly. Times of vessel sampling (black triangles) and glider sampling (red triangles) are shown for each panel.

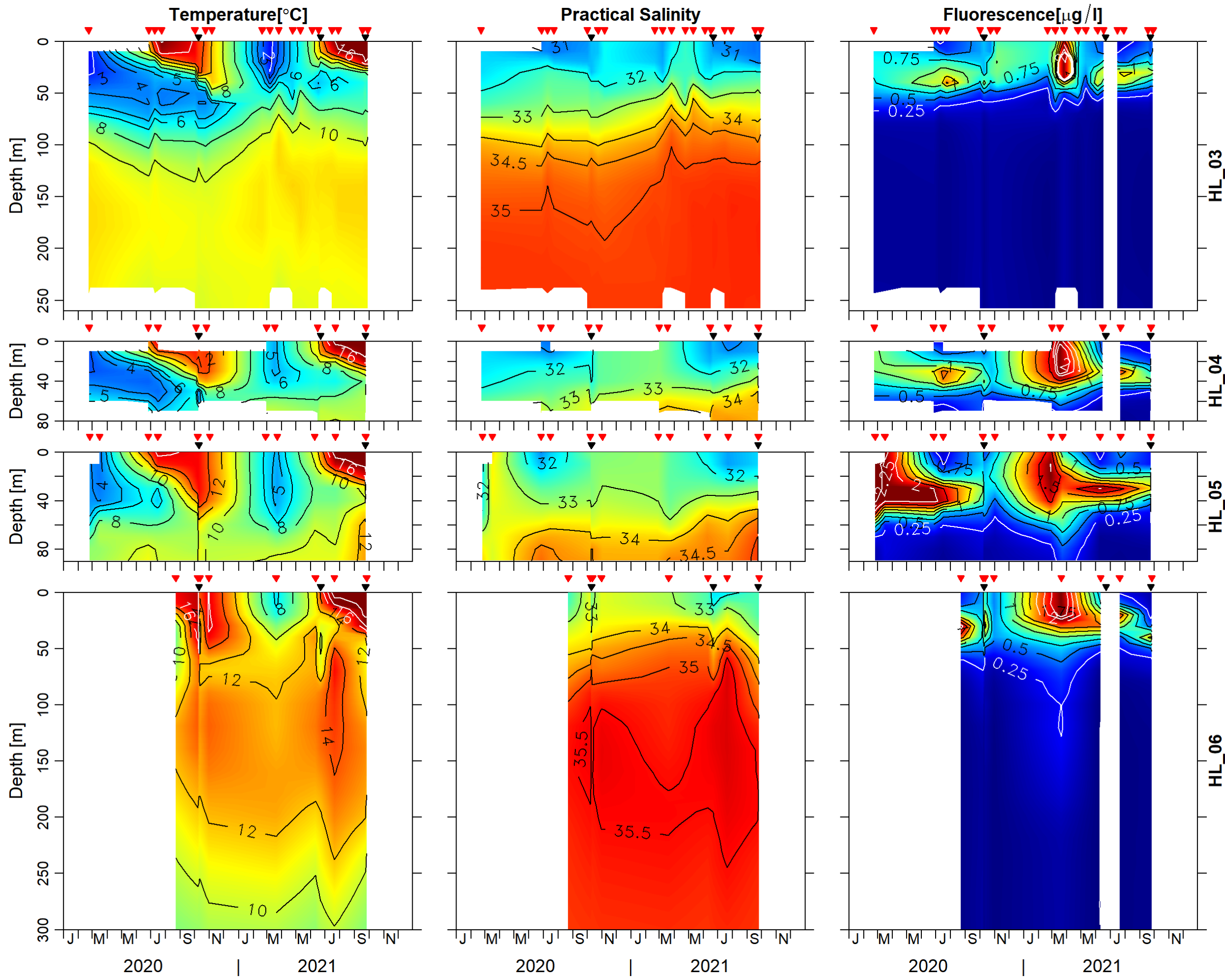

Figure 29. Temperature (left), salinity (middle), and chlorophyll fluorescence (right) for the standard hydrographic stations on the Halifax Line: HL3 (top panel), HL4 (second panel from the top), HL5 (third panel from the top), and HL6 (bottom panel). Only the top 300 m of HL data is shown. Times of vessel sampling (black triangles) and glider sampling (red triangles) are shown for each panel.

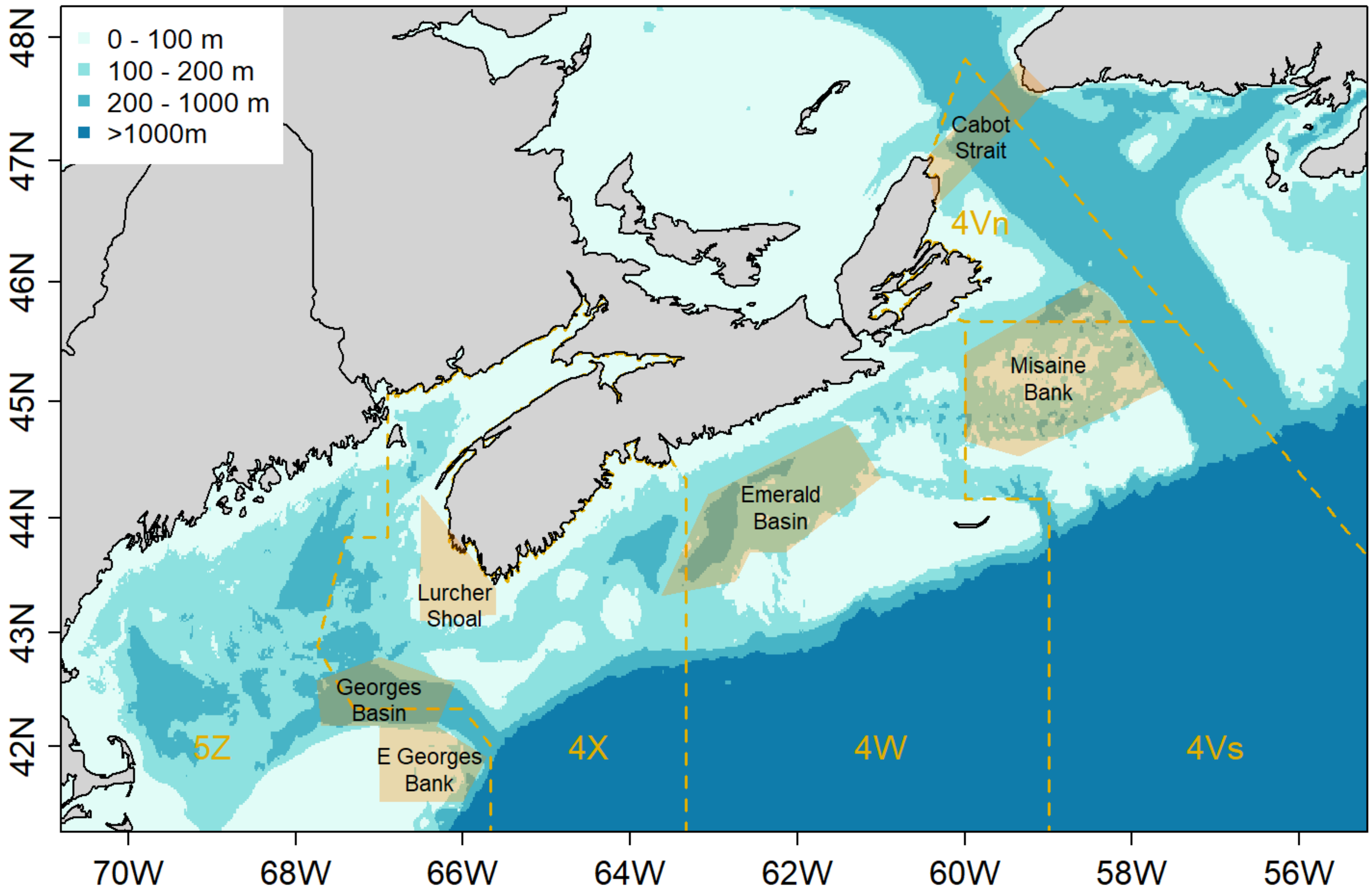

Figure 30. Areas on the Scotian Shelf and eastern Gulf of Maine depicting the different water masses: Cabot Strait; Misaine Bank; Emerald Basin; Lurcher Shoals; Georges Basin; and Eastern Georges Bank.

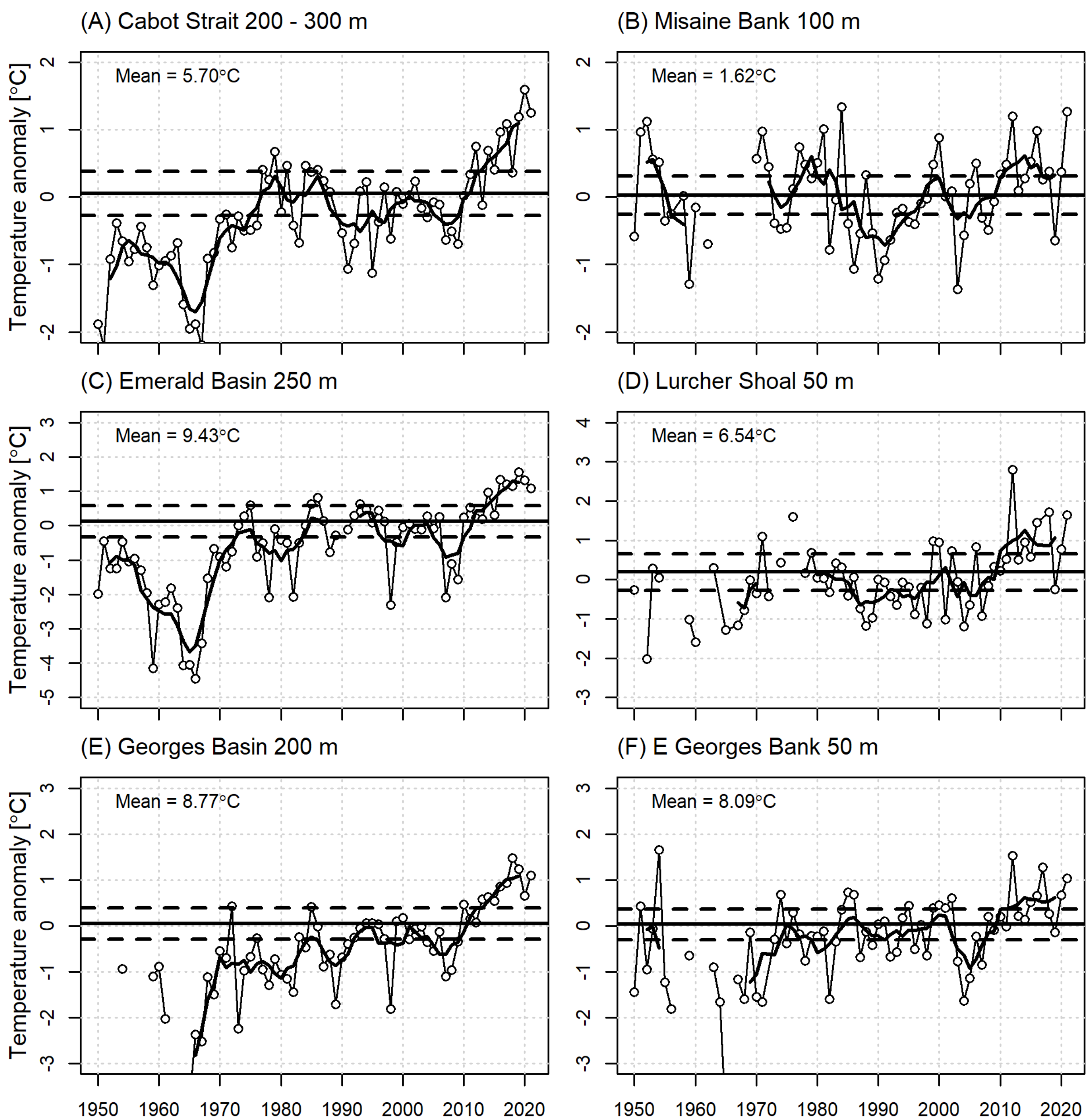

Figure 31. The annual mean temperature-anomaly time series (line with circles) and the five-year-running-mean filtered anomalies (heavy solid line) on the Scotian Shelf and in the Gulf of Maine at: (A) Cabot Strait at 200–300 m, (B) Misaine Bank at 100 m, (C) Emerald Basin at 250 m, (D) Lurcher Shoals at 50 m, (E) Georges Basin at 200 m, and (F) Eastern Georges Bank at 50 m (see Figure 23 for locations of regions). Horizontal dashed lines represent the mean ±0.5 SD for the 1991–2020 period.

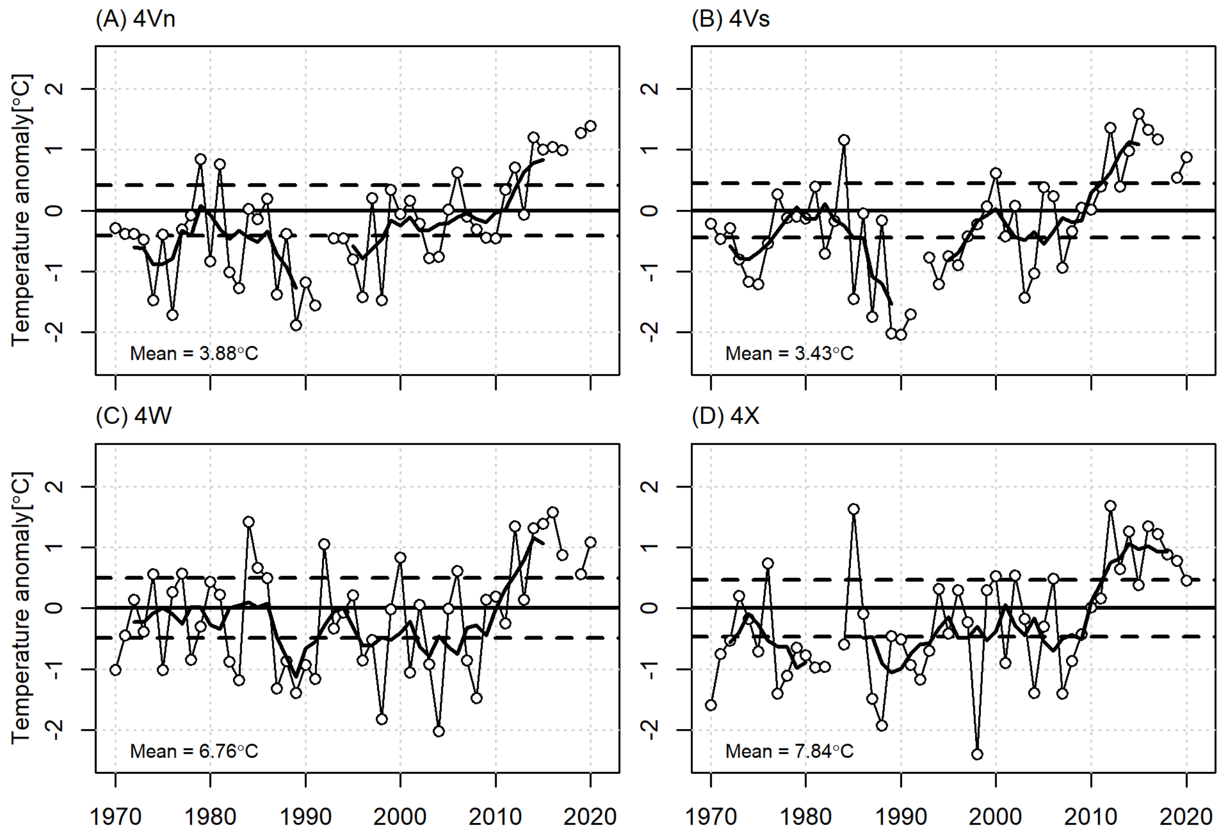

Figure 32. Time series of July bottom-temperature anomalies (thin lines with circles) and five-year-running-mean filtered series (heavy line) for NAFO Divisions: 4Vn, 4Vs, 4W, and 4X. In 2018, only 4X was sampled sufficiently to calculate bottom temperatures. The solid horizontal line is the 1991–2020 mean and dashed lines represent ±0.5 SD.

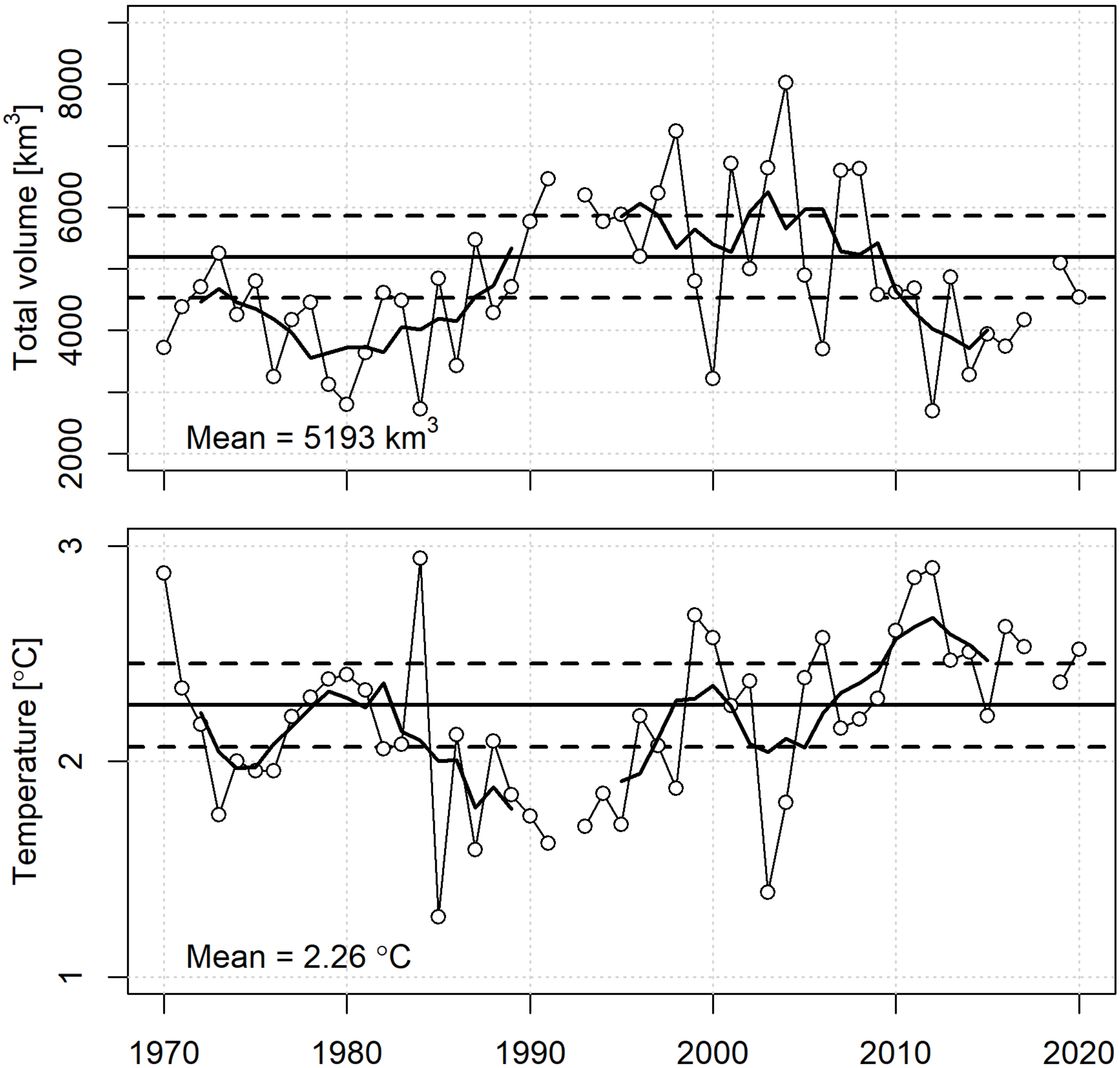

Figure 33. Time series of the Cold Intermediate Layer (CIL; defined as waters with temperature < 4°C) volume on the Scotian Shelf based on the DFO RV summer trawl survey (top pane). The area-weighted average minimum temperature in the CIL (bottom panel). The solid horizontal lines are the 1991–2020 means and dashed lines represent ±0.5 SD.

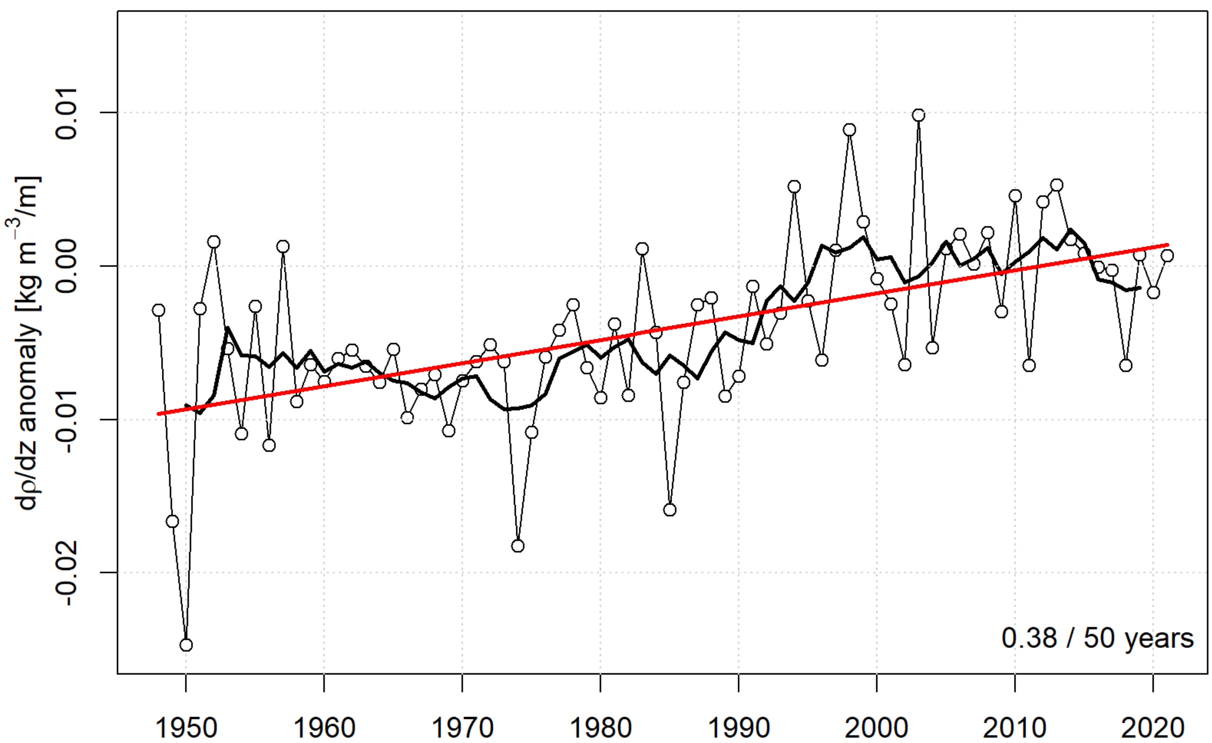

Figure 34. Stratification index (0–50 m density gradient) mean annual anomaly (black line with circles) and five-year running mean (black heavy solid line) averaged over the Scotian Shelf. The linear trend (red line) shows a change in the 0–50 m density difference of 0.38 kg m^{-3} over 50 years.

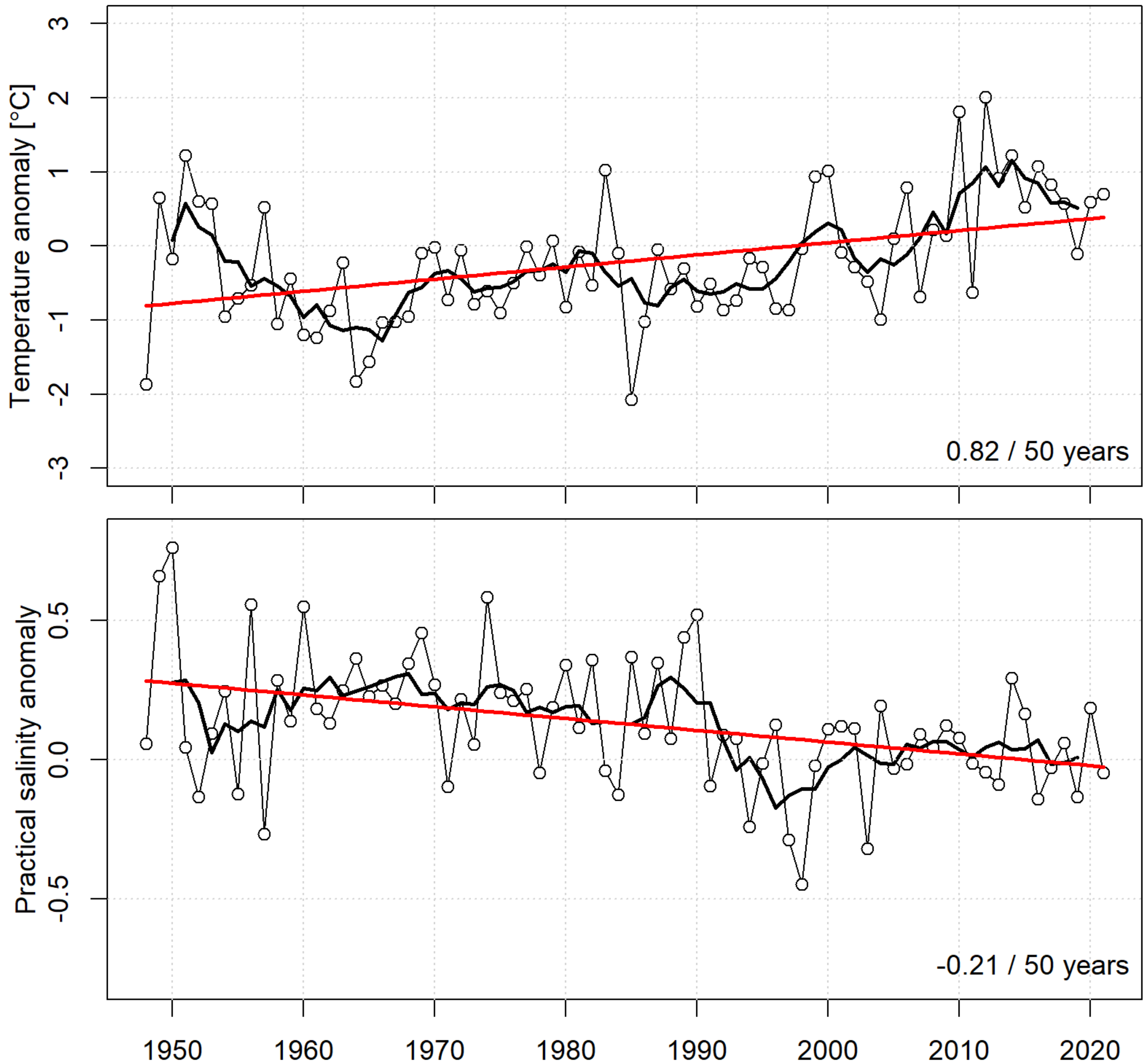

Figure 35. The mean-annual-surface-temperature (top panel) and salinity (lower panel) anomalies (black line with circles) and five-year running mean (black heavy solid line) averaged over the Scotian Shelf. Standard error estimates for each annual anomaly value are also shown. The linear trend (red line) shows a warming of 0.82 °C and a freshening of 0.21 over a 50-year period.

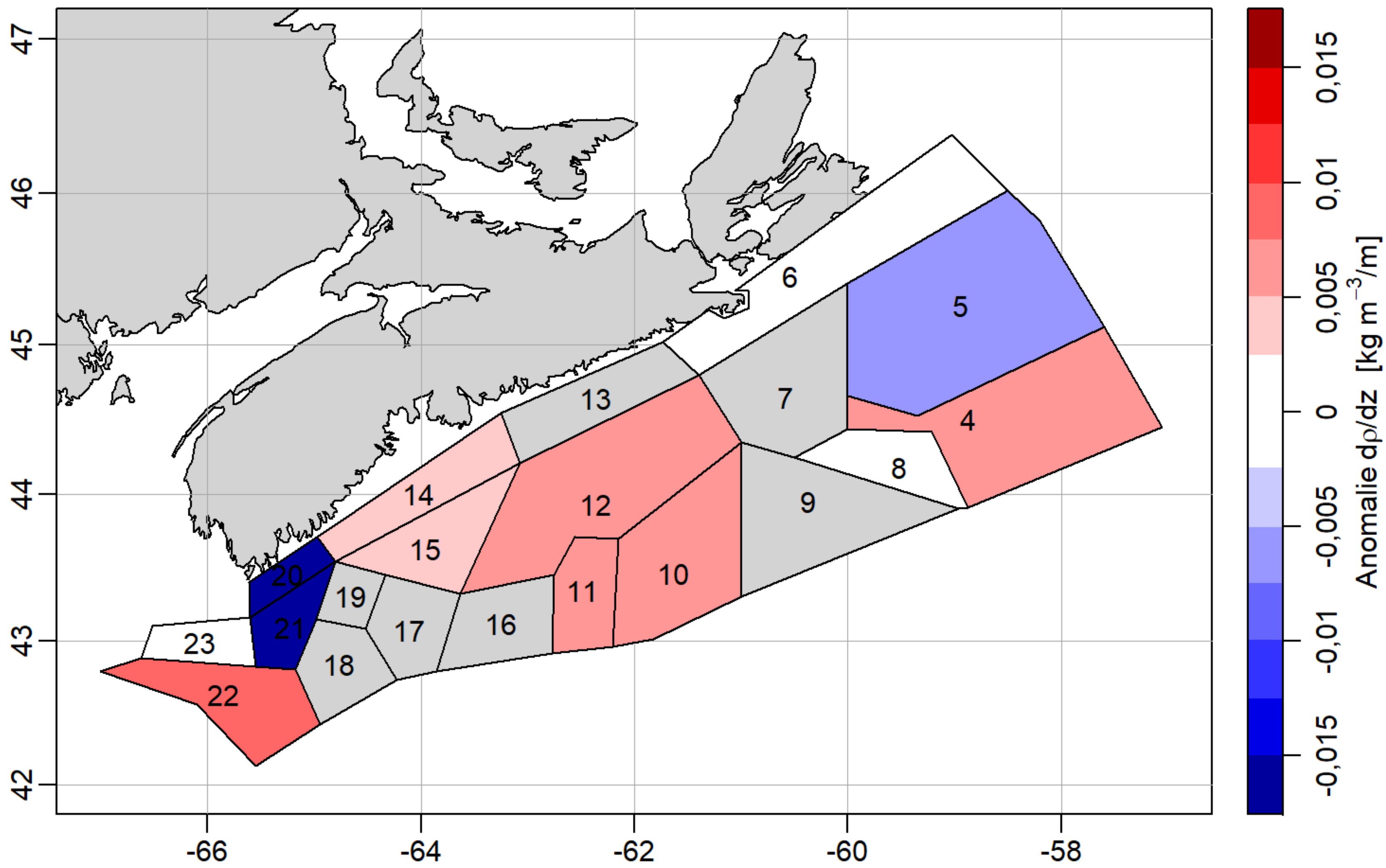

Figure 36. Stratification index (0–50 m density gradient) mean 2020 annual anomaly over the Scotian Shelf. The different areas were defined by Petrie et al. (1996).

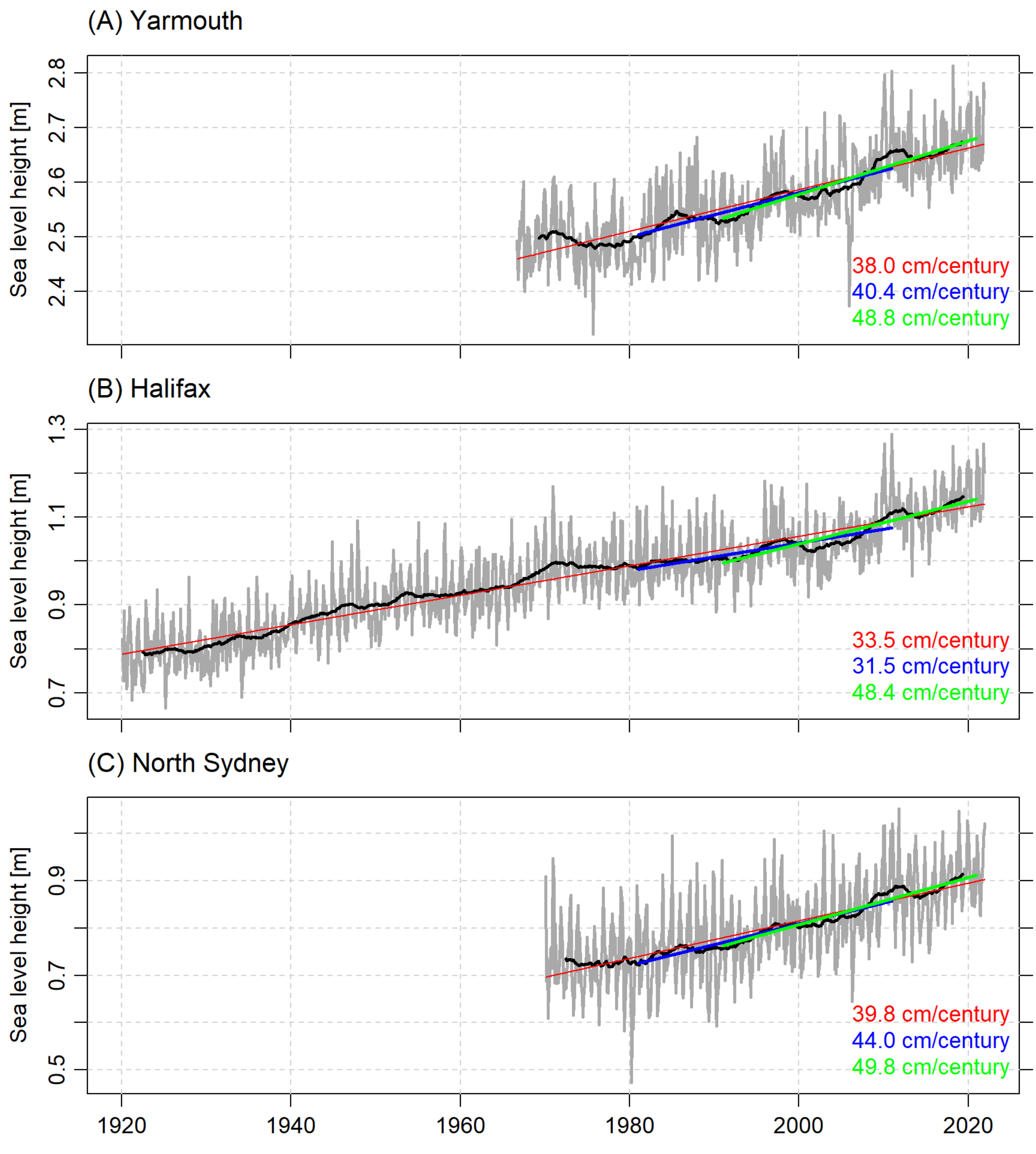

Figure 37. The time series of the monthly means (grey line) and a five-year running mean (black line) of the relative sea-level elevations at Yarmouth (top panel), Halifax (middle panel), and North Sydney (bottom panel), along with the linear trend (red line) over the observation period, over 1981–2010 (blue line) and over 1991–2020 (green line).

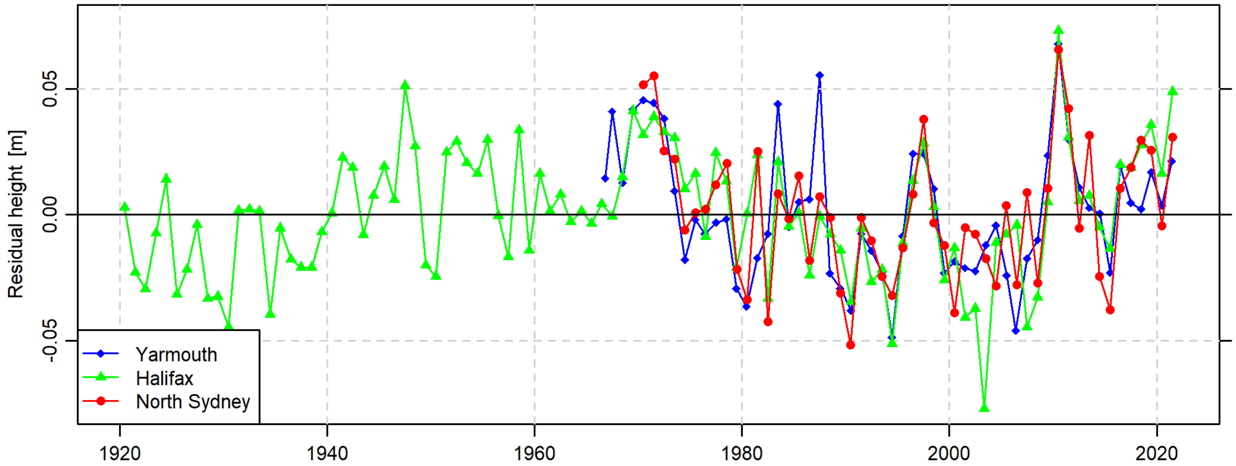

Figure 38. Residual relative sea level (annual observed values—linear trend based on the 1970–2021 period) for Yarmouth (blue line with diamonds), Halifax (green line with triangles), and North Sydney (red line with circles).

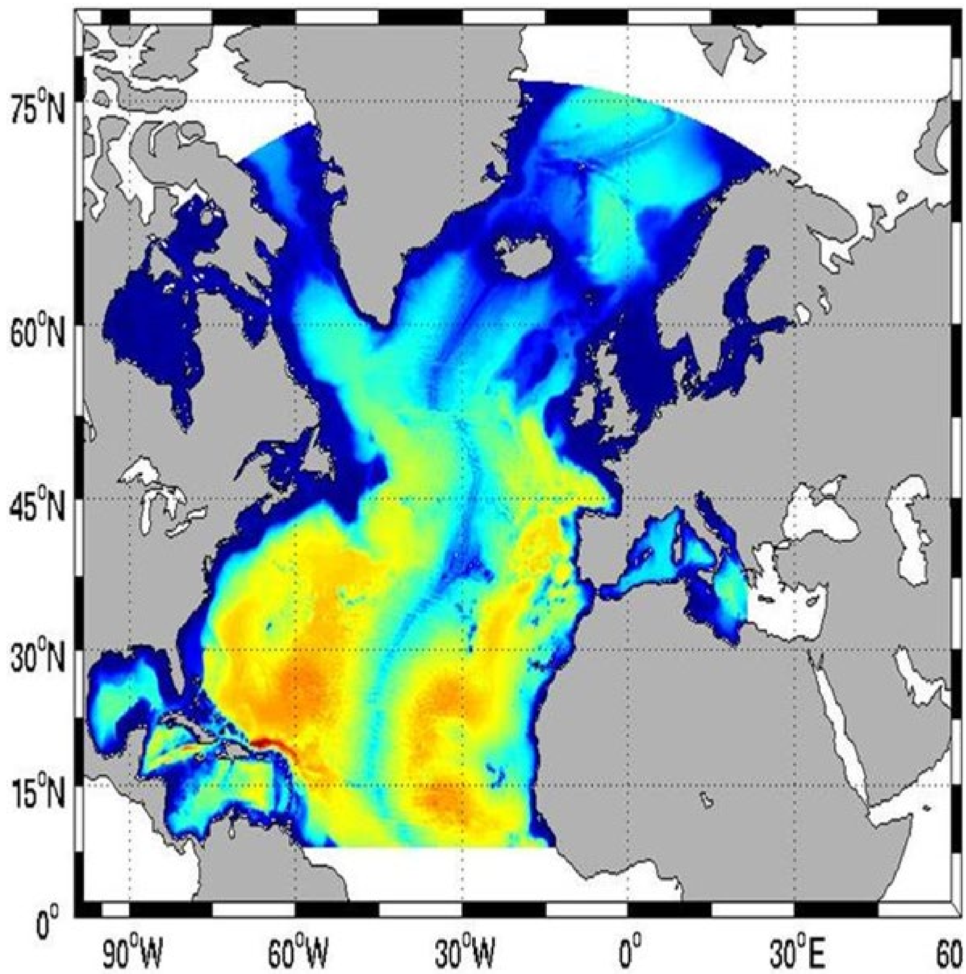

Figure 39. The BIO North Atlantic Model (BNAM) domain Bathymetry coloured from red (deep) to blue (shallow).

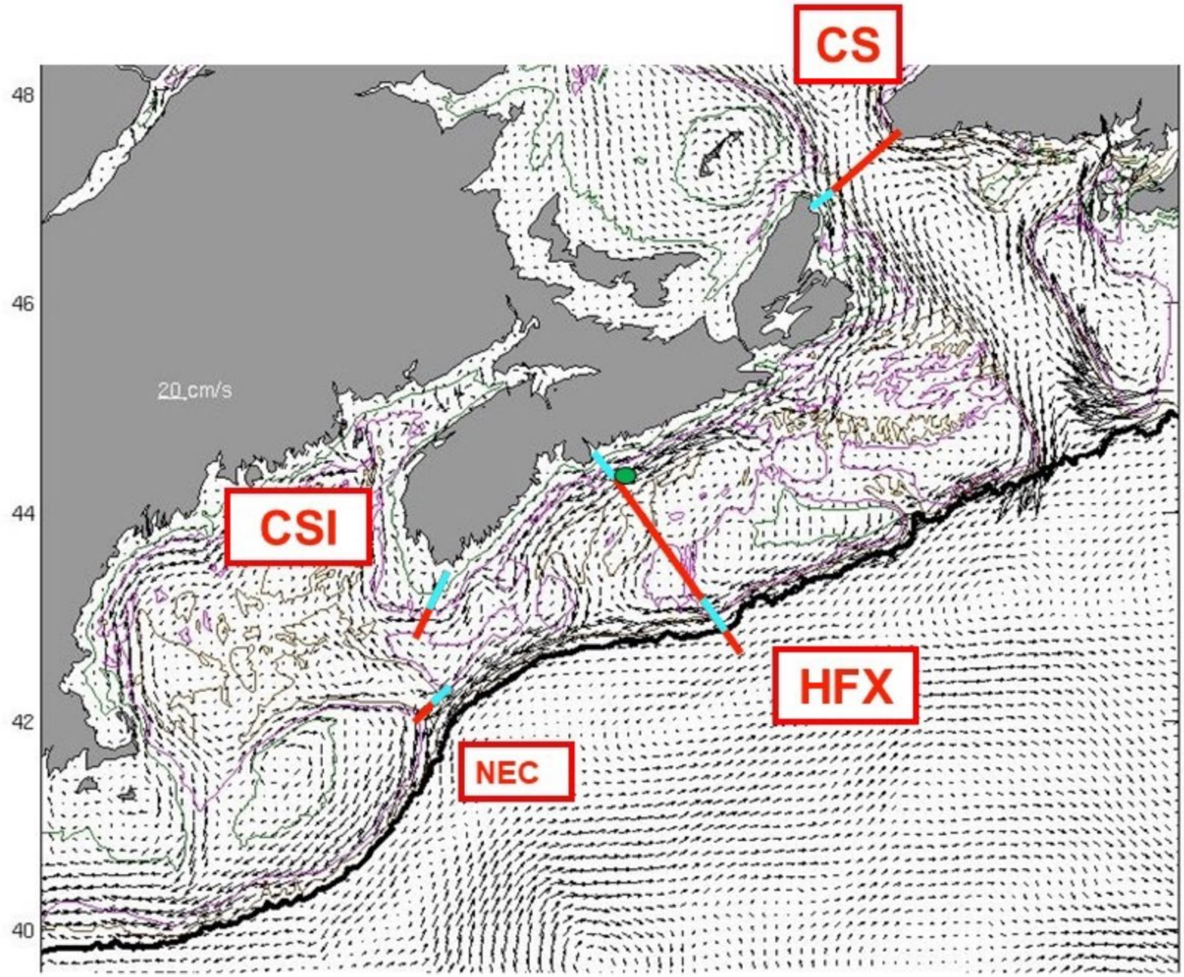

Figure 40. Climatological-annual and depth-averaged circulation illustrating the principal flow pathways from the southern Gulf of St. Lawrence to the Gulf of Maine and the subsections where transport calculations were made (cyan). CS = Cabot Strait; HFX = Halifax; CSI = Cape Sable Island/Browns Bank; NEC = Northeast Channel. Green circle shows the location off T2.

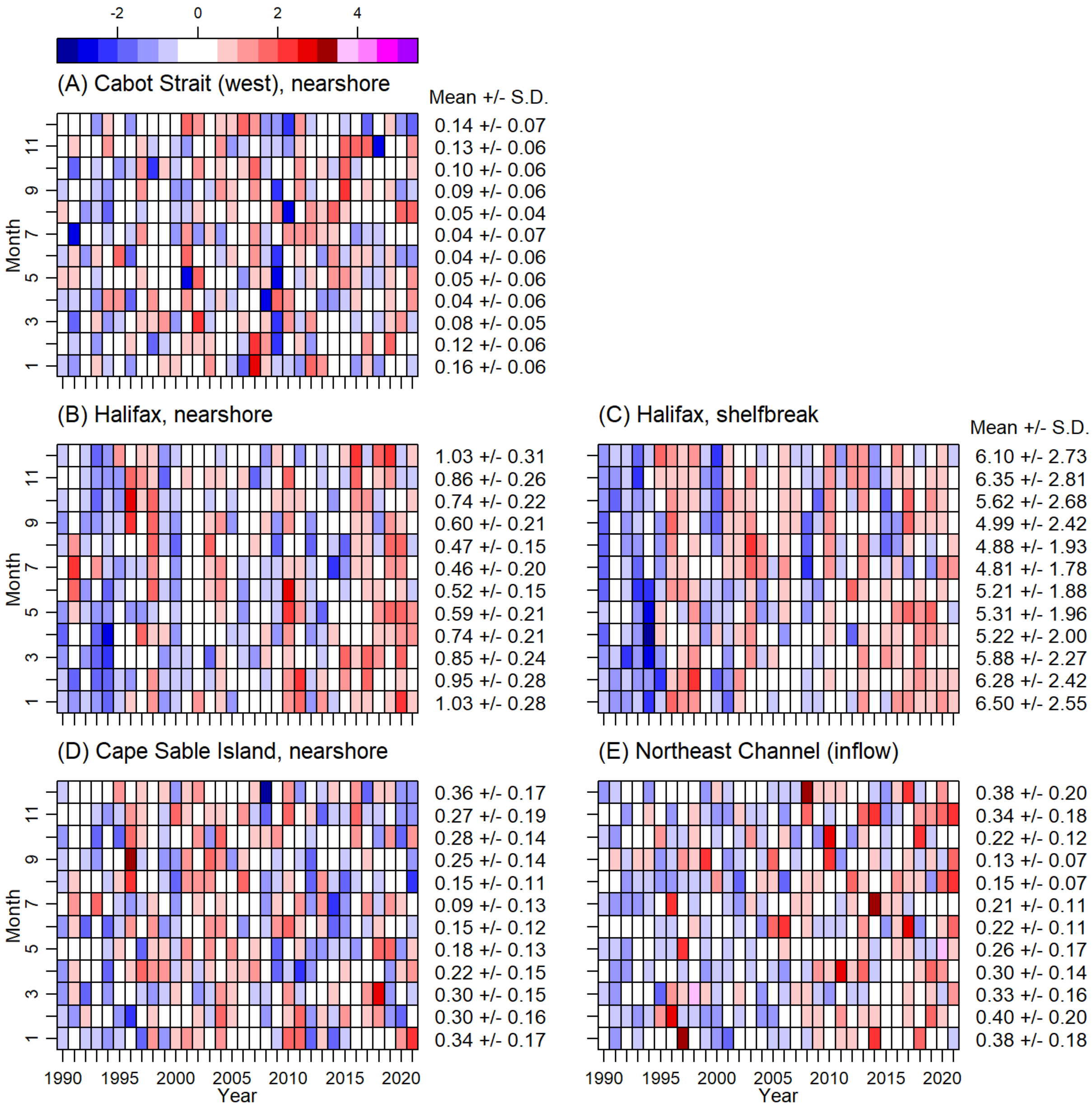

Figure 41. Standardized anomalies of the monthly transport relative to 1991–2020 for four Maritime sections: (A) Cabot Strait (CS) west nearshore; Halifax (HFX) (B) nearshore and (C) shelf break; (D) Cape Sable Island (CSI) nearshore; and (E) the Northeast Channel (NEC). Numbers to the right are monthly means and standard deviations in Sverdrups (1 Sv = 10^6 m^3s^{-1}).

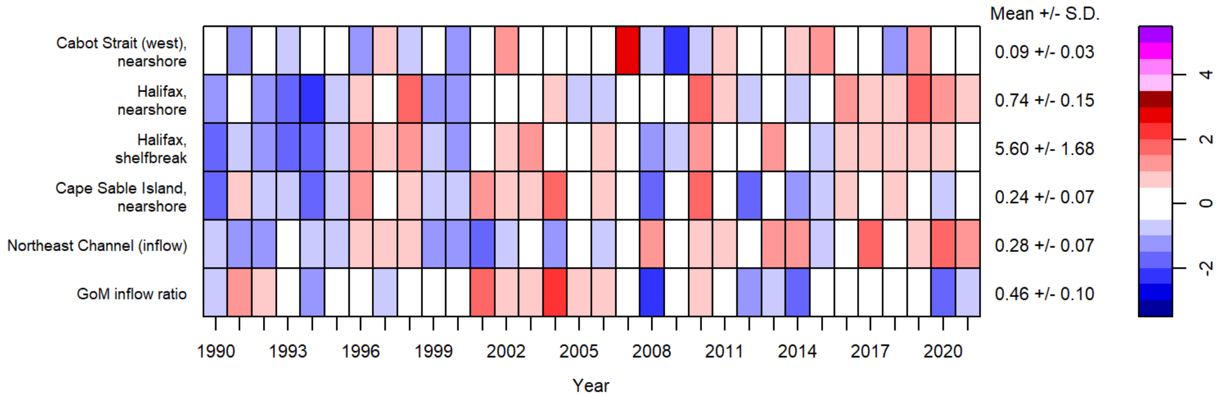

Figure 42. Annual transport anomalies scaled by the standard deviation for the monthly values shown in Figure 41 and Figure 44. Numbers to the right are climatological (1991–2020) annual means and standard deviations (in Sverdrups).

	2008		2010		2012		2014		2016		2018		2020		Mean +/- S.D.
Dec	-0.46	-0.59	-0.58	-0.33	-0.5	-0.83	-0.42	-0.53	-0.82	-0.4	-0.89	-0.76	-0.46		-0.58 +/- 0.19
Nov	-0.22	-0.34	-0.52	-0.49	-0.43	-0.3	-0.5	-0.38	-0.57	-0.21	-0.85	-0.28	-0.23		-0.41 +/- 0.18
Oct	-0.22	-0.51	-0.36	-0.3	-0.32	-0.22	-0.21	-0.17	-0.4	-0.33	-0.36	-0.24	-0.17		-0.29 +/- 0.10
Sep	-0.43	-0.21	-0.3	-0.12	-0.14	-0.03	-0.17	-0.13	-0.2	-0.28	-0.28	-0.22	-0.35		-0.22 +/- 0.11
Aug	-0.4	-0.26	-0.32	-0.23	-0.13	-0.08	-0.12	-0.18	-0.27	-0.05	-0.22	-0.26	-0.31	-0.16	-0.21 +/- 0.10
Jul	-0.04	-0.29	-0.39	-0.37	-0.11	-0.15	-0.07	-0.22	-0.31	-0.23	-0.34	-0.32	-0.3	-0.31	-0.25 +/- 0.11
Jun	-0.11	-0.31	-0.54	-0.4	-0.09	-0.16	-0.28	-0.35	0.05	-0.28	-0.23	-0.16	-0.17	-0.23	-0.23 +/- 0.15
May		-0.33	-0.52	-0.43	-0.22	-0.12	-0.26	0.04	-0.23	-0.35	-0.32	-0.34	-0.47	-0.43	-0.31 +/- 0.15
Apr		-0.34	-0.33	-0.48	-0.23	-0.37	-0.39	-0.32	-0.31	-0.33	-0.35	-0.39	-0.38	-0.32	-0.35 +/- 0.06
Mar		-0.48	-0.47	-0.55	-0.64		-0.53	-0.63	-0.4	-0.79	-0.31	-0.47	-0.58	-0.5	-0.53 +/- 0.12
Feb		-0.66	-0.68	-0.85	-0.59	-0.64	-0.44	-0.62	-0.46	-0.88	-0.66	-0.7	-0.42	-0.73	-0.64 +/- 0.14
Jan		-0.8	-0.65	-0.67	-0.38	-0.6	-0.45	-0.74	-0.6	-0.71	-0.78	-0.64	-0.75	-0.63	-0.64 +/- 0.12
Annual	-0.27	-0.43	-0.47	-0.43	-0.32	-0.32	-0.32	-0.35	-0.38	-0.4	-0.46	-0.4	-0.38	-0.41	-0.38 +/- 0.06

Figure 43. Monthly transport (Sv) for years 2008–2021 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.

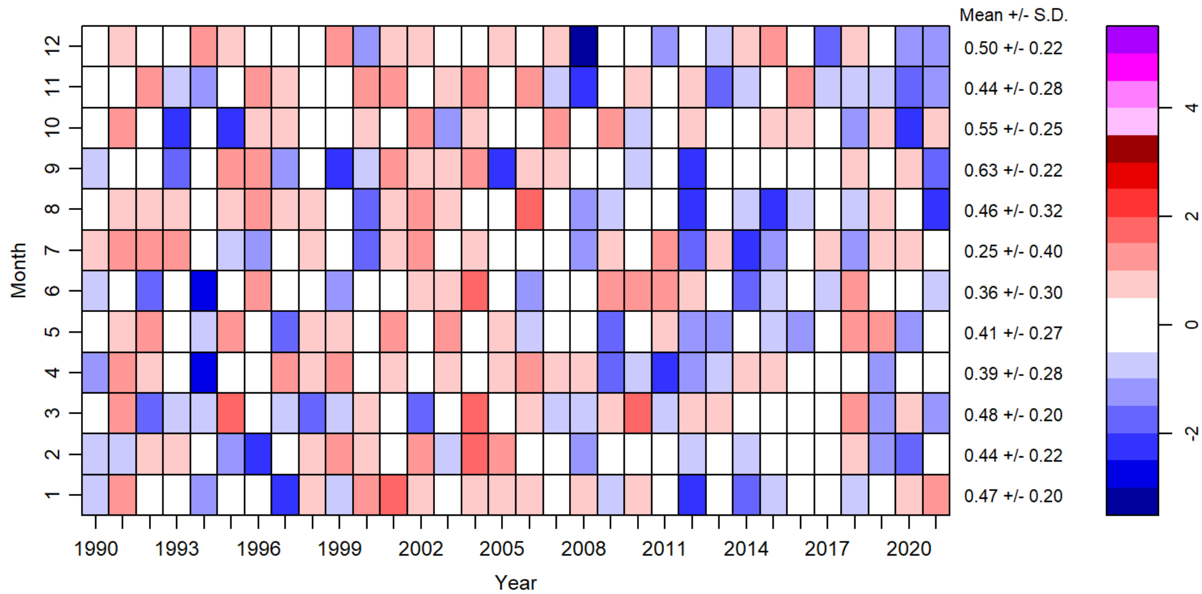

Figure 44. Standardized anomalies of the Gulf of Maine inflow ratio. Numbers to the right are 1991–2020 climatological monthly means and standard deviations.

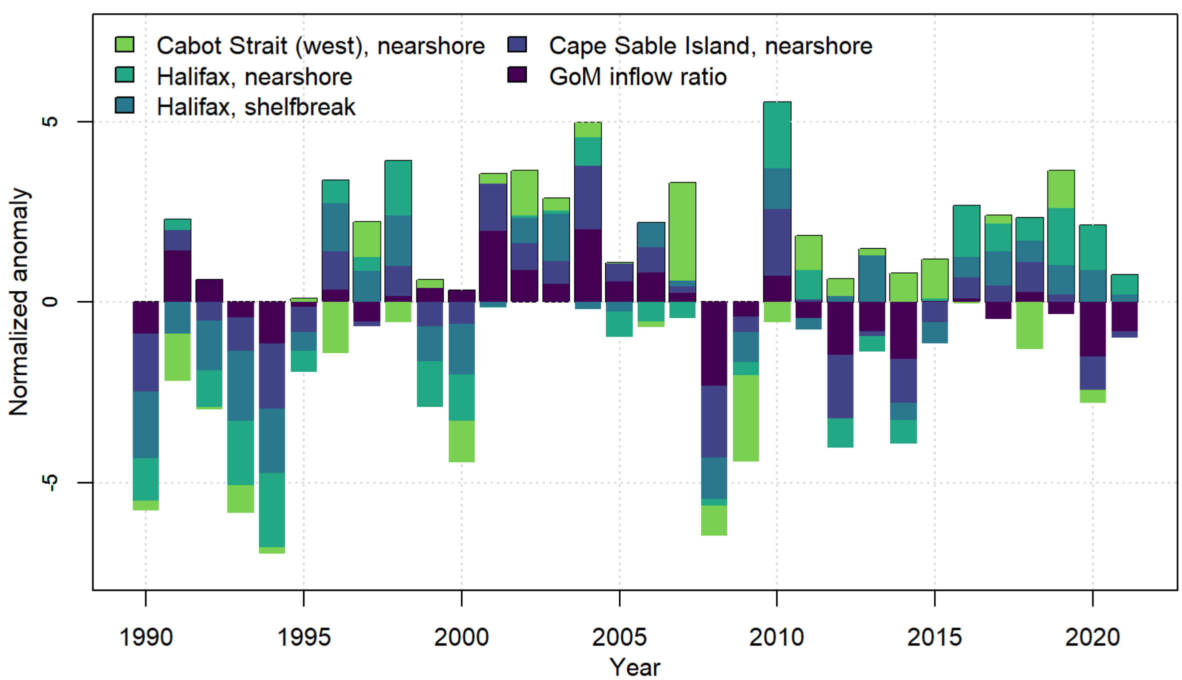

Figure 45. Sum of standardized transport anomalies for the variables in Figure 42.

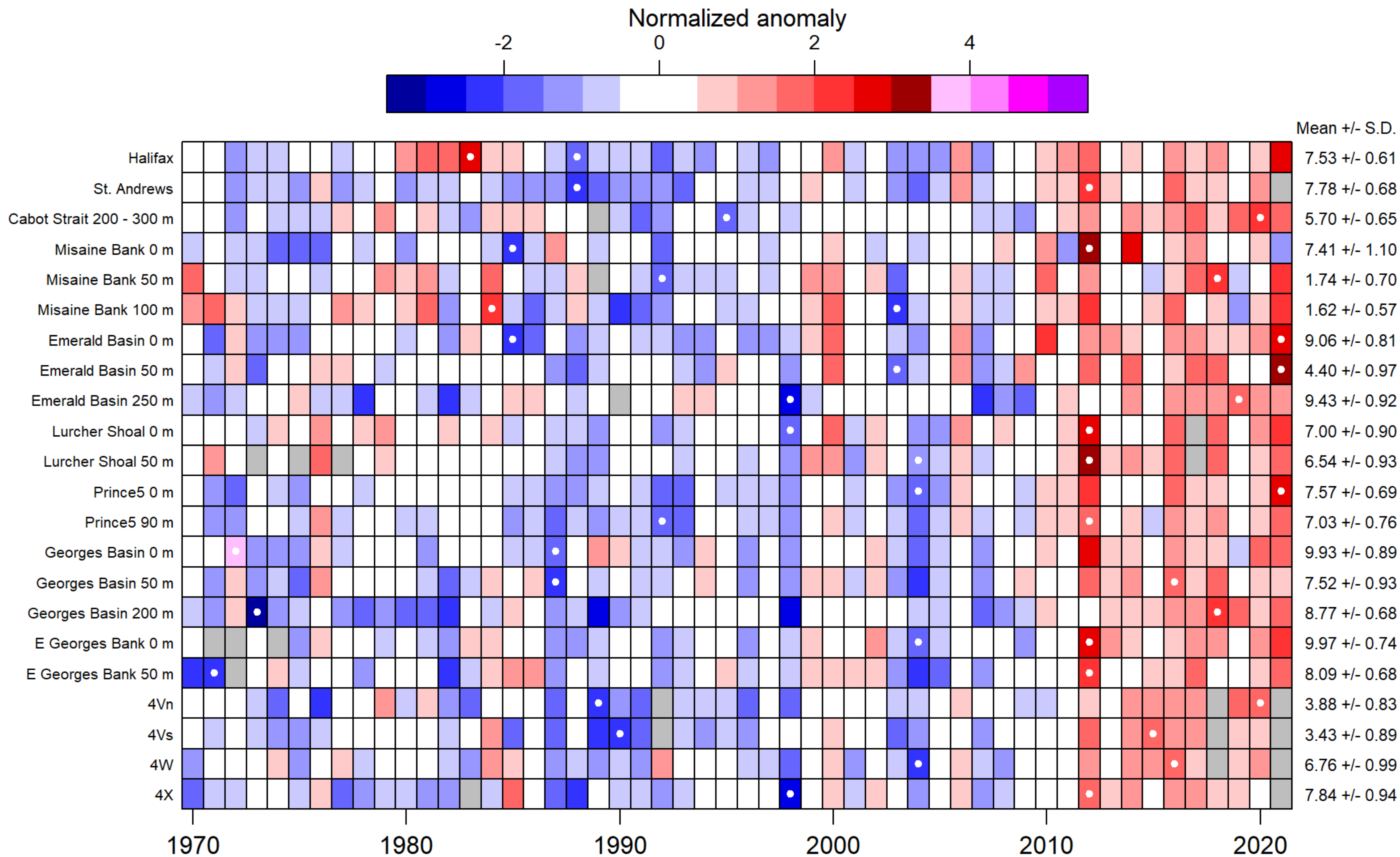

Figure 46. Normalized annual anomalies of temperatures at the bottom and discrete depths for the Scotian Shelf/Gulf of Maine region. These anomalies are based on the 1991–2020 means divided by the standard deviation. Blue colours indicate below-normal anomalies. Red colours indicate above-normal anomalies. White dots represent record minimum and maximum years for each parameter. Gray represents lack of data.

APPENDIX

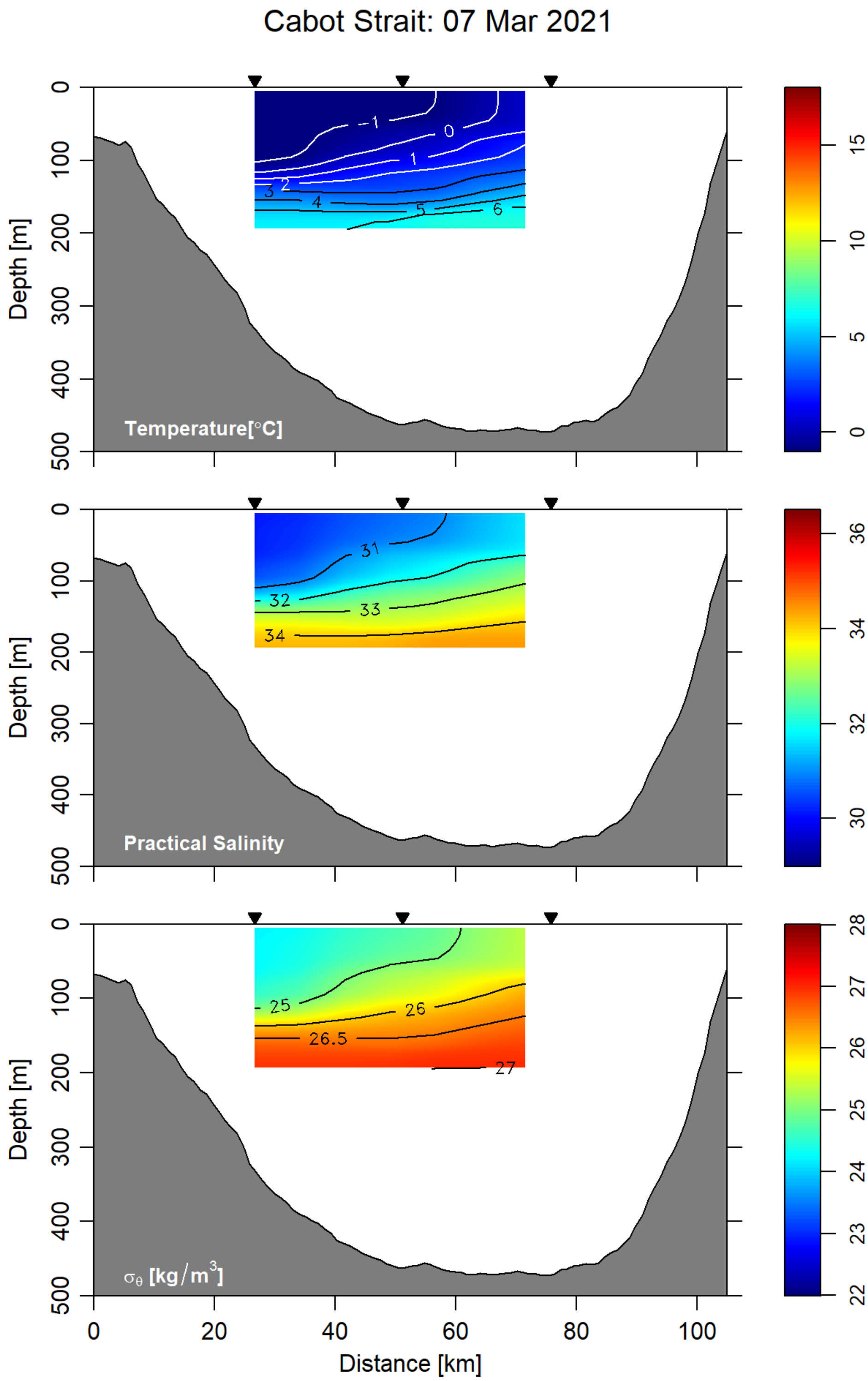

Figure A1. The 2021 sampling of the Cabot Strait Section for Winter collected by the Quebec Region AZMP. Temperature (top panel), salinity (middle panel), and density (lower panel). Triangles indicate locations of sampling.

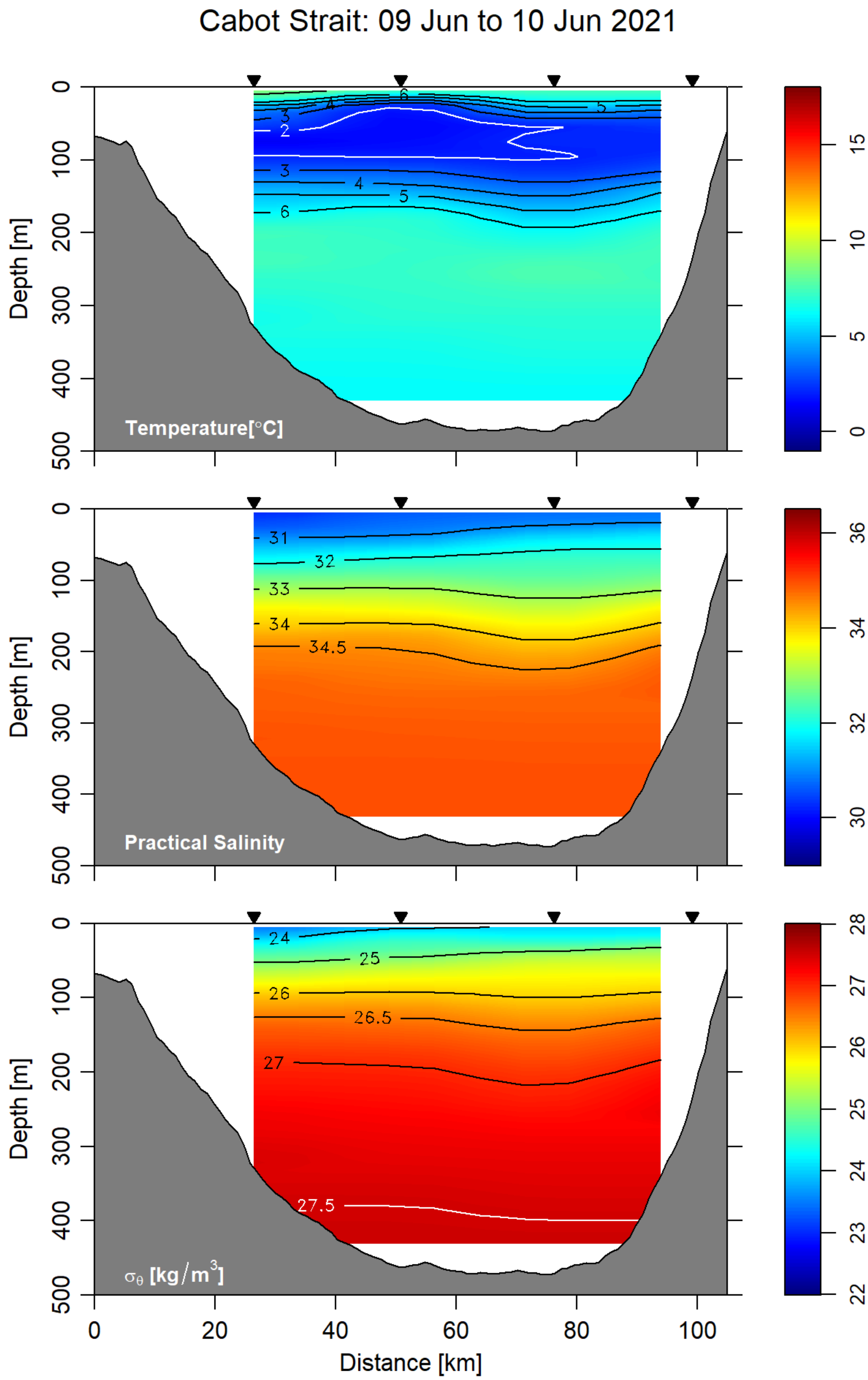

Figure A2. The 2021 sampling of the Cabot Strait Section for Summer collected by the Quebec Region AZMP. Temperature (top panel), salinity (middle panel), and density (lower panel). Triangles indicate locations of sampling.

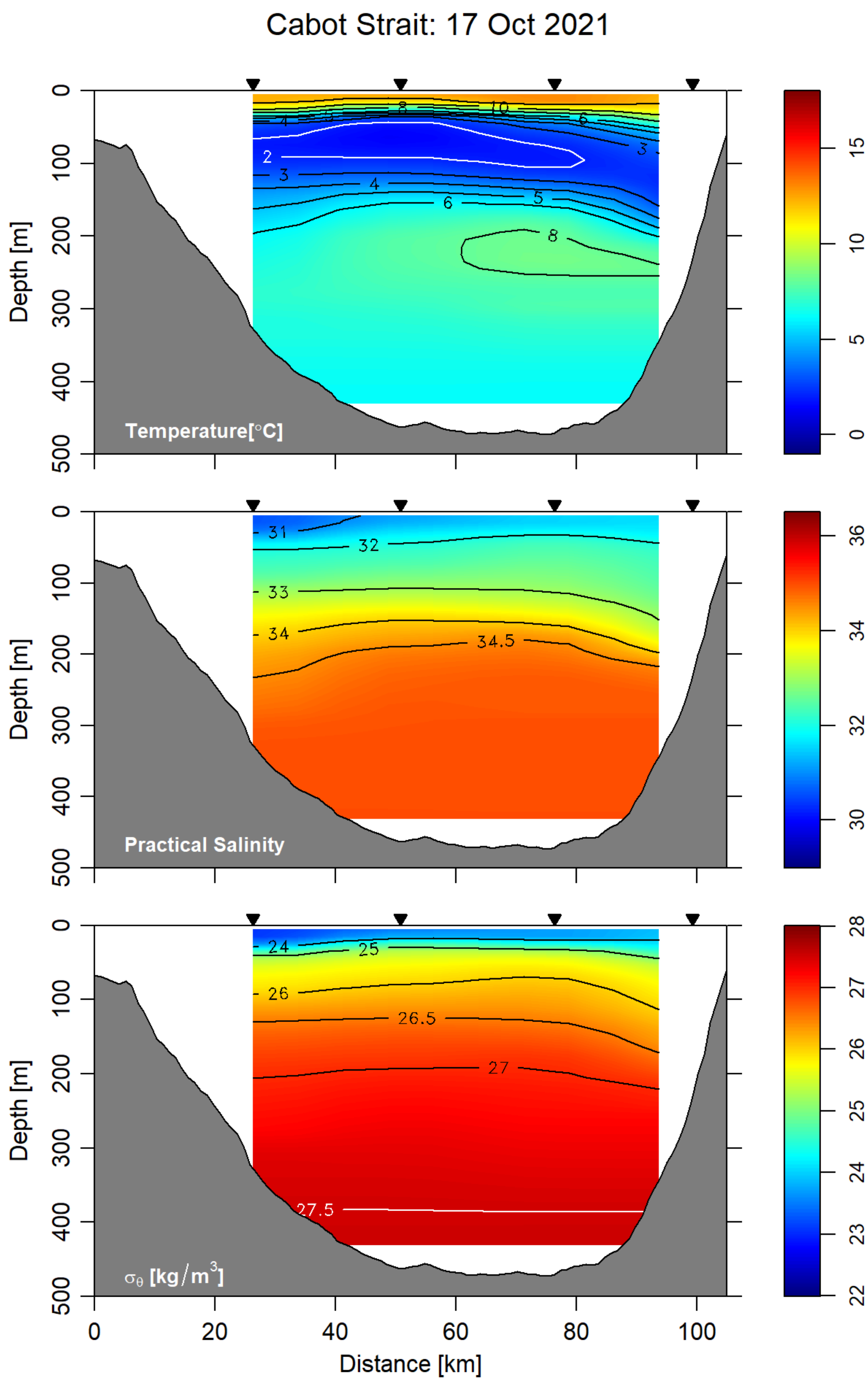

Figure A3. The 2021 sampling of the Cabot Strait Section for Fall collected by the Quebec Region AZMP. Temperature (top panel), salinity (middle panel), and density (lower panel). Triangles indicate locations of sampling.

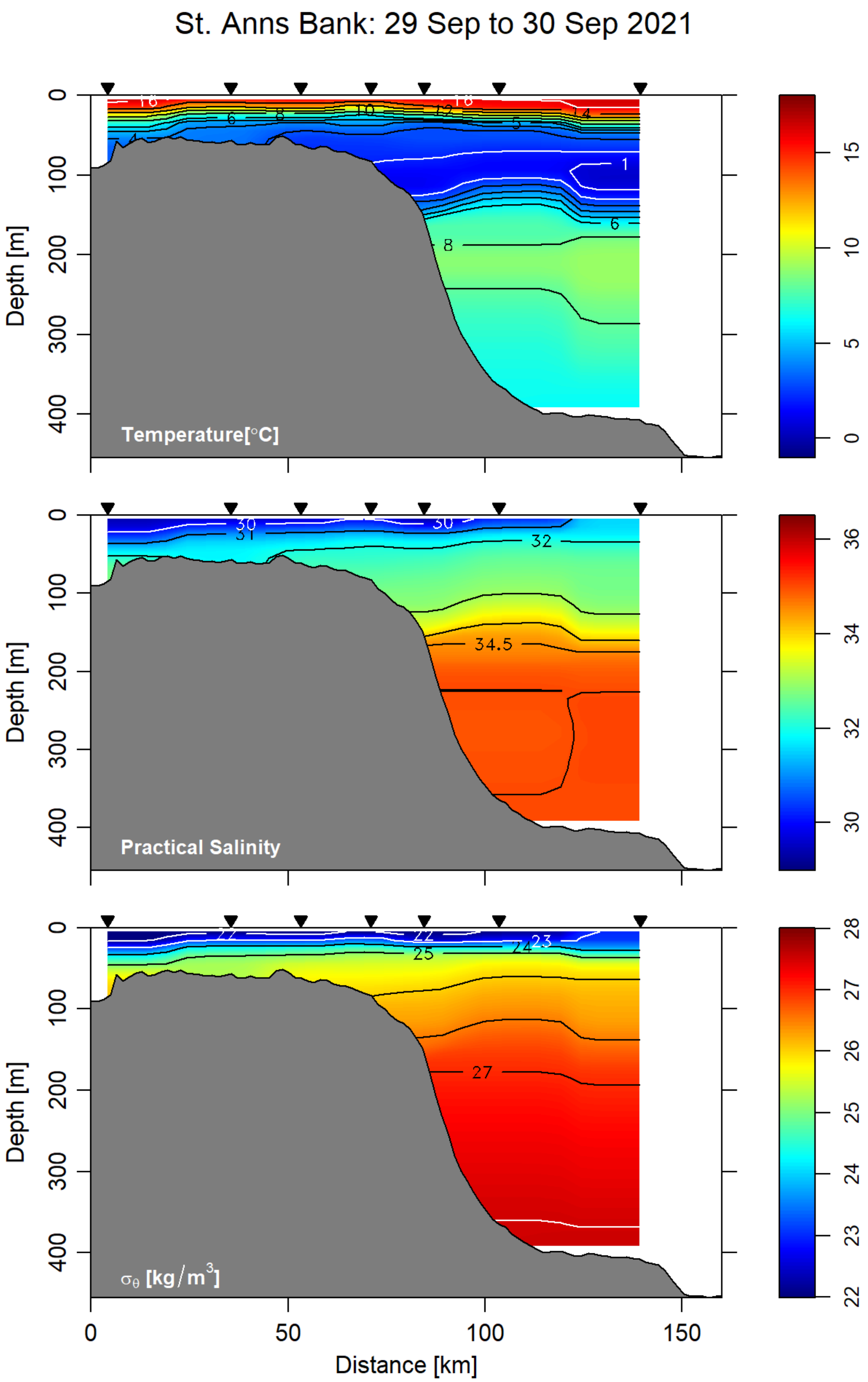

Figure A4. The 2021 sampling of the St Anns Bank Section for Fall collected by the Maritimes AZMP. Temperature (top panel), salinity (middle panel), and density (lower panel). Triangles indicate locations of sampling.

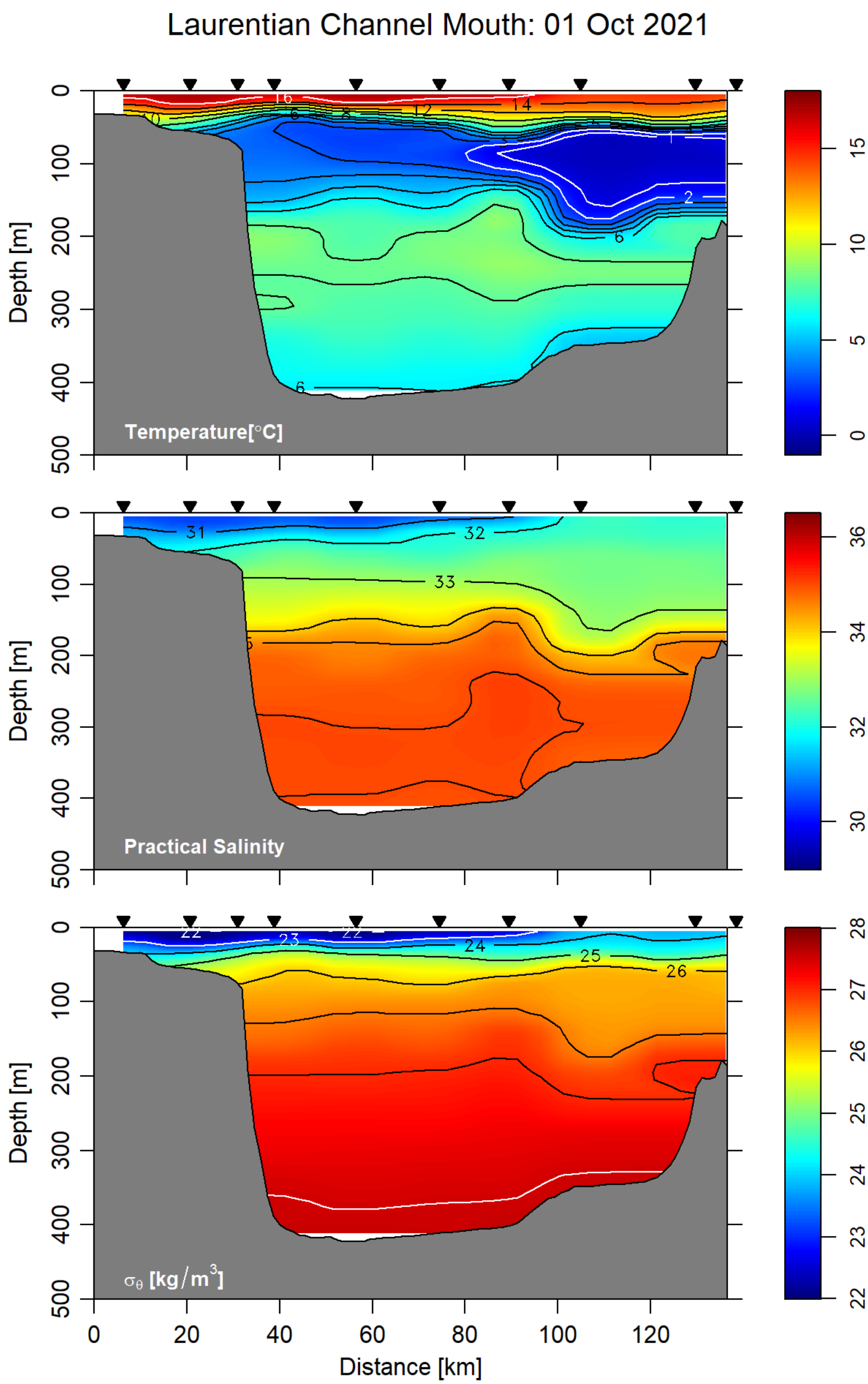

Figure A5. The 2021 sampling of the Laurentian Channel Mouth Section for Fall collected by the Maritimes AZMP. Temperature (top panel), salinity (middle panel), and density (lower panel). Triangles indicate locations of sampling.

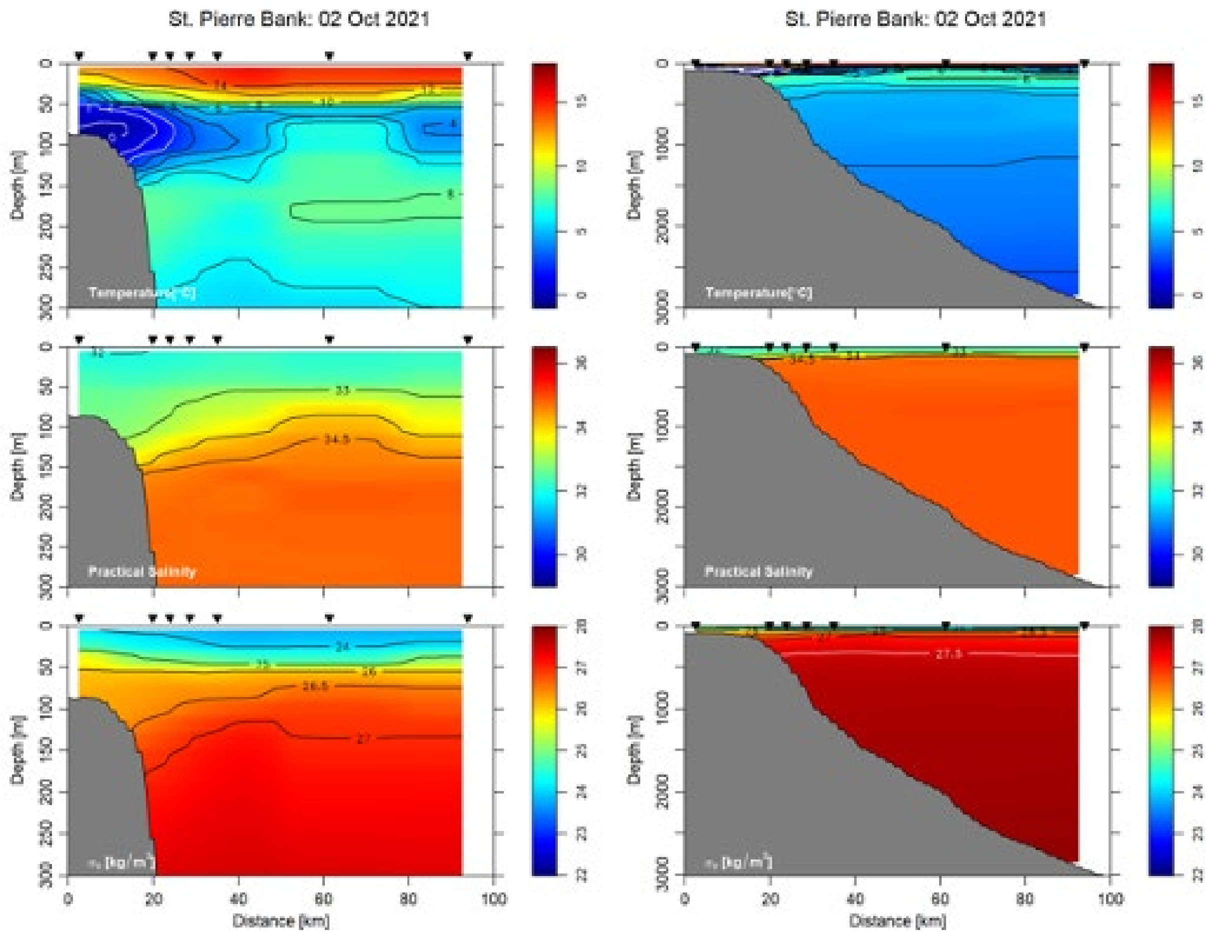

Figure A6. The 2021 sampling of the St Pierre Bank Section for Fall collected by the Maritimes AZMP. Temperature (top panel), salinity (middle panel), and density (lower panel). Triangles indicate locations of sampling.

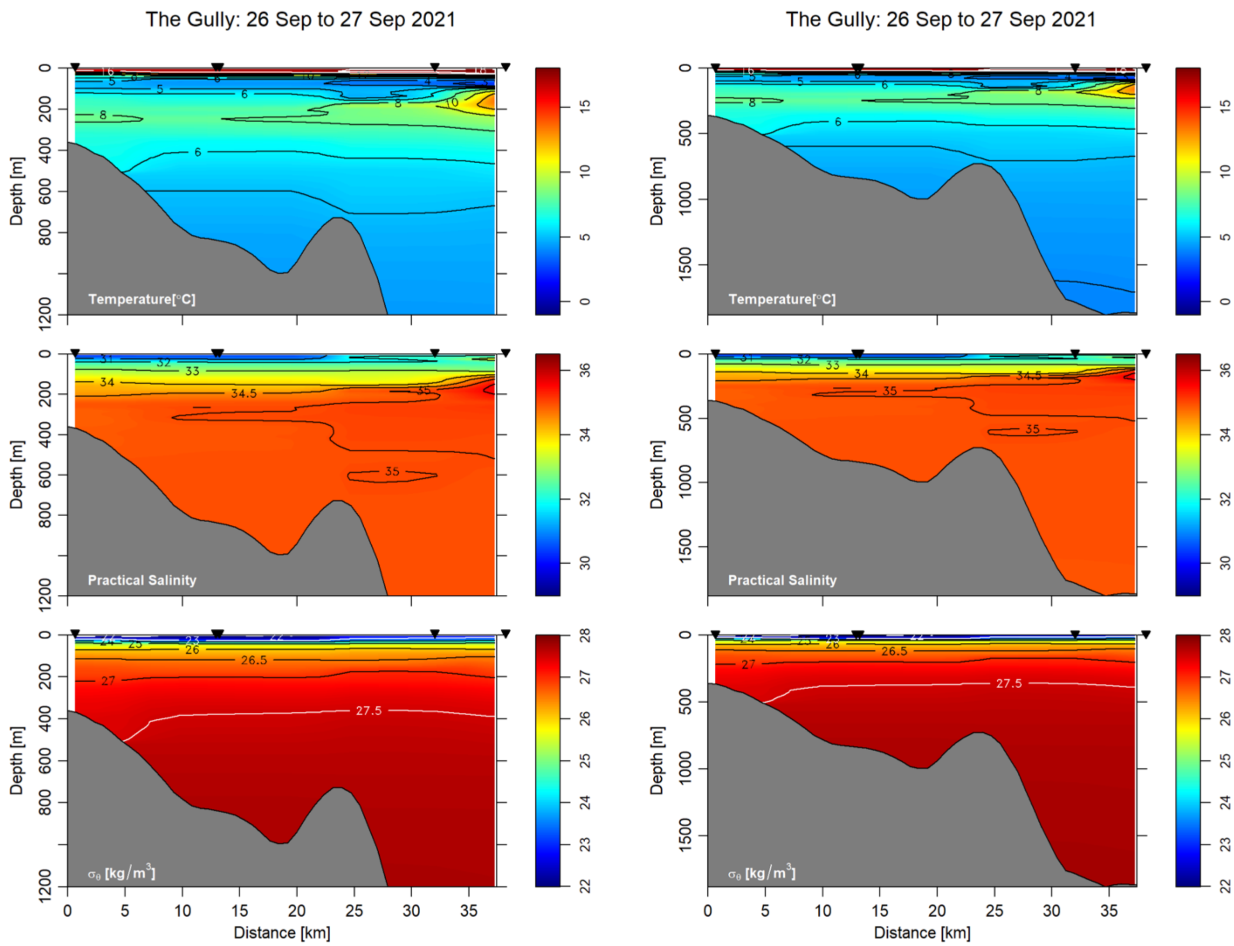

Figure A7. The 2021 sampling of the Gully Section for Fall collected by the Maritimes AZMP. Temperature (top panel), salinity (middle panel), and density (lower panel). Triangles indicate locations of sampling.

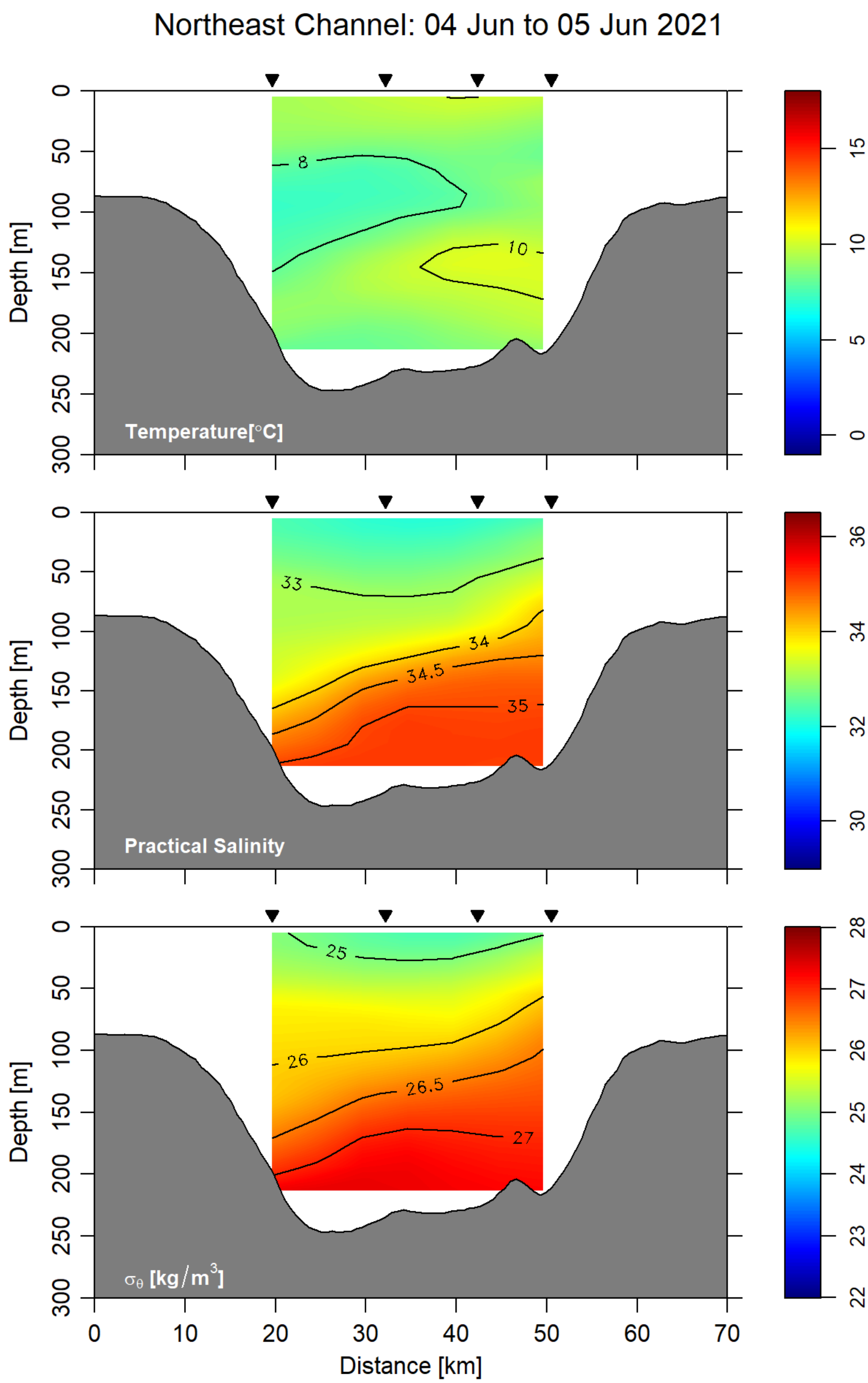

Figure A8. The 2021 sampling of the Northeast Channel Section for Summer collected by the Maritimes AZMP. Temperature (top panel), salinity (middle panel), and density (lower panel). Anomalies could not be calculated due to no 1991–2020 climatology. Triangles indicate locations of sampling.

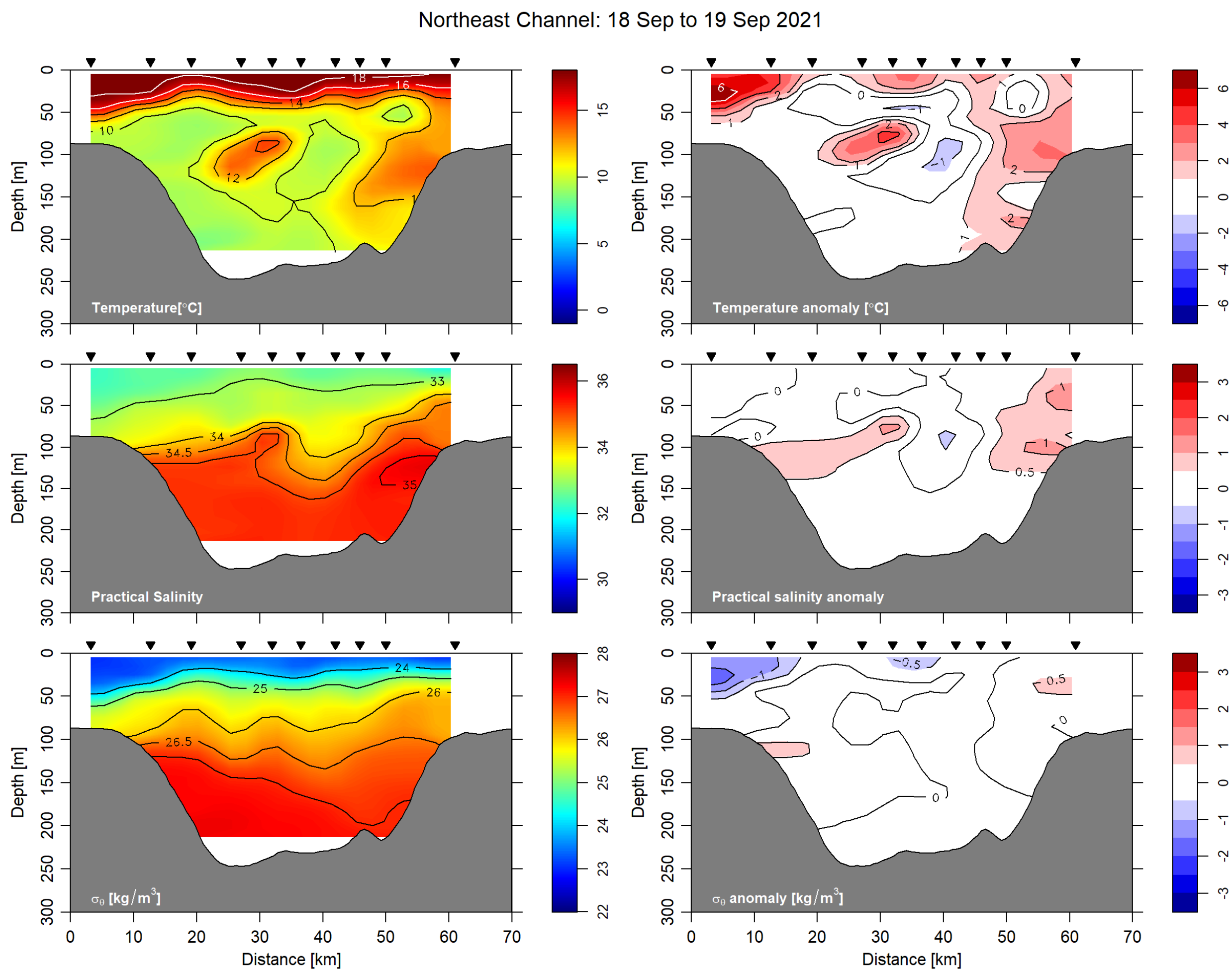

Figure A9. The 2021 sampling of the Northeast Channel Section for Fall collected by the Maritimes AZMP. Temperature (top panel), salinity (middle panel), and density (lower panel) and their anomalies with respect to 1991–2020 monthly means (right panels). Triangles indicate locations of sampling.

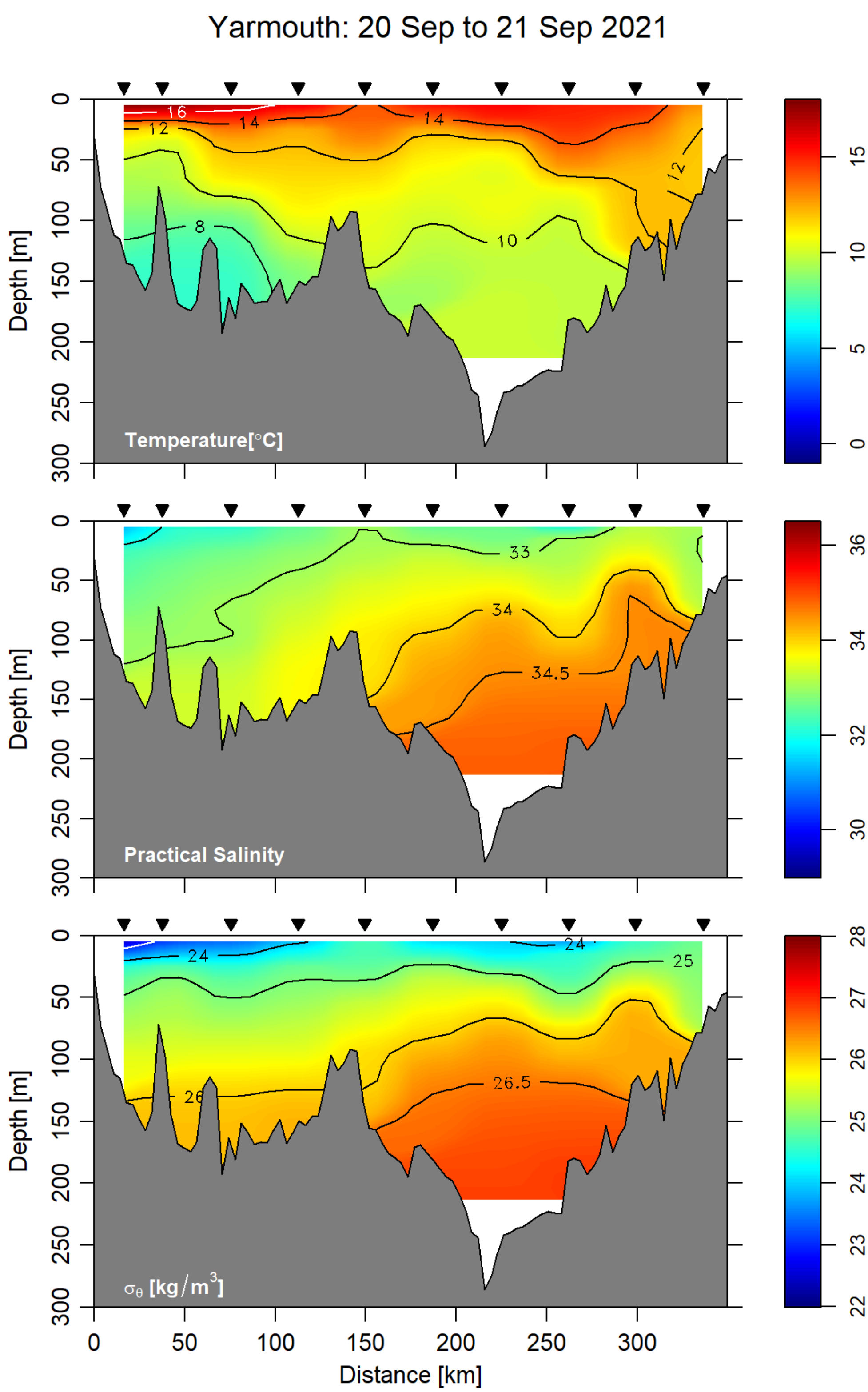

Figure A10. The 2021 sampling of the Yarmouth Section for Fall collected by the Maritimes AZMP. Temperature (top panel), salinity (middle panel), and density (lower panel). Anomalies could not be calculated due to no 1991–2020 climatology. Triangles indicate locations of sampling.

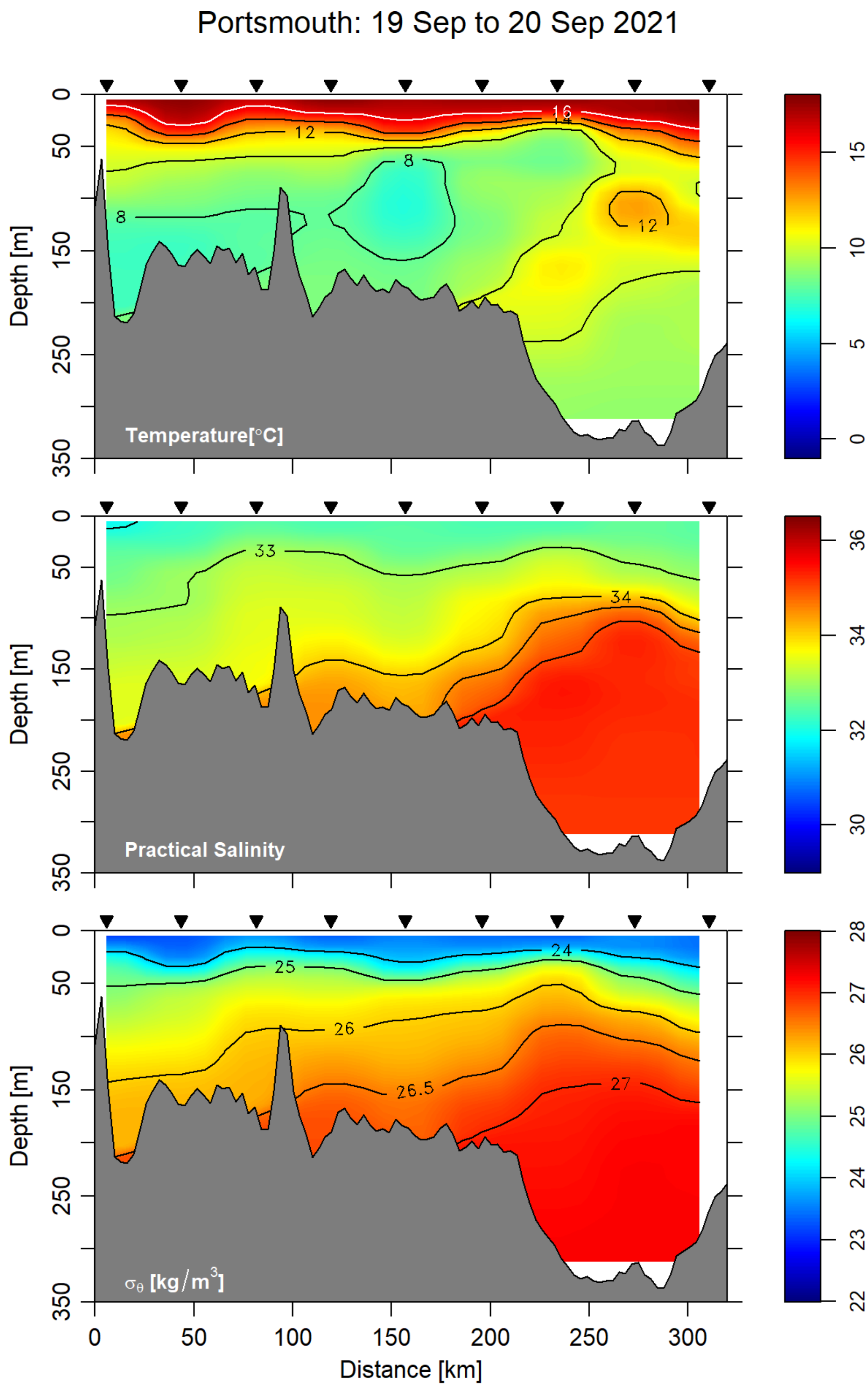

Figure A11. The 2021 sampling of the Portsmouth Section for Fall collected by the Maritimes AZMP. Temperature (top panel), salinity (middle panel), and density (lower panel). Anomalies could not be calculated due to no 1991–2020 climatology. Triangles indicate locations of sampling.