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Northwest Atlantic Fisheries Organization

Serial No. N7176 **NAFO SCR Doc. 21/009**

SCIENTIFIC COUNCIL MEETING – JUNE 2021

Environmental and Physical Oceanographic Conditions on the Eastern Canadian shelves (NAFO Sub-areas 2, 3 and 4) during 2020.

by

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Abstract

Oceanographic and meteorological observations in NAFO Sub-areas 2, 3 and 4 during 2020 are presented and referenced to their long-term averages. The winter North Atlantic Oscillation (NAO) index, a key indicator of the direction and intensity of the winter wind field patterns over the Northwest Atlantic was positive for a 7th consecutive year (since 2012, only 2013 was negative). The air temperatures across the NW Atlantic were about normal in the Arctic and in Labrador, and warmer than average in Newfoundland and in sites on the coast of the Scotian Shelf and the Gulf of Maine. Winter average sea ice conditions were below normal on the Newfoundland and Labrador for the first time since from 2013. Annual sea surface temperature (SST) across the NAFO subareas 2, 3 and 4 were above normal overall for the zone for the first time since 2014. While SSTs remained below normal in parts of the Scotian Shelf in October, they were above normal on the Labrador and Newfoundland Shelf, reaching series records in 3MNO in October. The year ended with December record highs on the Scotian Shelf. The spatially averaged bottom temperature was above normal across the zone except in NAFO Divisions 2J and 3K where they were near normal. There were however no spring measurements in 3Ps and 3LNO due to a cancelled survey. The Labrador Current weakened to normal during 2019 and 2020 on the NL slope, and has been below normal fairly consistently since 2014 on the Scotian slope.

Introduction

This report presents an overview of the 2020 environmental and physical oceanographic conditions in NAFO sub-areas 2, 3 and 4 on eastern Canadian shelves (see Figure 1). It complements similar reviews of environmental conditions on the Northeast US Shelf, the Labrador Sea and West Greenland Waters as part of the Scientific Council's annual review of environmental conditions in the NAFO Convention Area.

The information presented for 2020 is derived from various sources:

1. Observations made throughout the year at historical monitoring stations 27 (near St. John's, NL), Prince-5 (Bay of Fundy) and Halifax-2 (Scotian Shelf);
2. Measurements made during the summer along standard NAFO and Atlantic Zone Monitoring Program (AZMP) (Therriault et al. 1998) cross-shelf sections (see Figure 1);
3. Oceanographic observations made during multi-species and ground fish resource assessment surveys (NAFO sub-areas 2 to 4);
4. SST data based on infrared satellite imagery (Advance Very High Resolution Radiometer, or AVHRR) of the Northwest Atlantic
5. Other multi-source historical data (ships of opportunity, international campaign, other DFO regions surveys, Argo program, etc.);
6. Ice data are from the Canadian Ice Service and meteorological data are from Environment Canada and other sources cited in the text.

Unless otherwise specified, these data are available from MEDS archives and maintained in a regional data archive at the Northwest Atlantic Fisheries Centre (NAFC) in St. John's, NL and at the Bedford Institute of Oceanography (BIO) in Dartmouth, NS.

Time series of temperature and salinity anomalies and other derived climate indices were constructed by removing the annual cycle computed over a standard climatological period. The "*Normal*" is defined here as the average over this period. This standard period has been updated this year from 1981-2010 to 1991 to 2020 for the time series in Newfoundland and Labrador (SA 2&3) and for the SSTs across the zone but has been kept to 1981-2010 for the Scotian shelf and the Gulf of Maine (SA 4). The reference period used to generate the different time series presented in this report is recalled in the figure captions. Annual or seasonal anomalies were sometimes normalized by dividing the values by the standard deviation (SD) of the data time series over the climatological period. A value of 2, for example, indicates that the index was 2 SD higher than its long-term average. As a general guide, anomalies within ±0.5 SD are considered to be normal.

The effects of the climatology shift where it occurred are large for SSTs since the cold 1981-1990 period is removed and the warm 2011-2020 period is added to the climatological period. Similar effects are observed for the bottom temperatures that have been greatly increasing in the last decade. The change in climatology generally tend to reduce the observed warm anomalies and emphasize the cold anomalies. Many of these changes and comparison for both climatologies are documented in Cyr & Galbraith (2021).

The normalized values of water properties and derived climate indices presented in this document are color-coded in "scorecards" with gradations of 0.5 SD (Figure 2). Shades of blue represent cold-fresh environmental conditions and reds warm-salty conditions. In some instances (NAO, ice and cold water areas or volumes, for example) negative anomalies may indicate warm conditions and hence are colored red. Most of the colormaps used in this report are taken from the *cmocean* colormaps package for oceanography (Thyng et al., 2016).

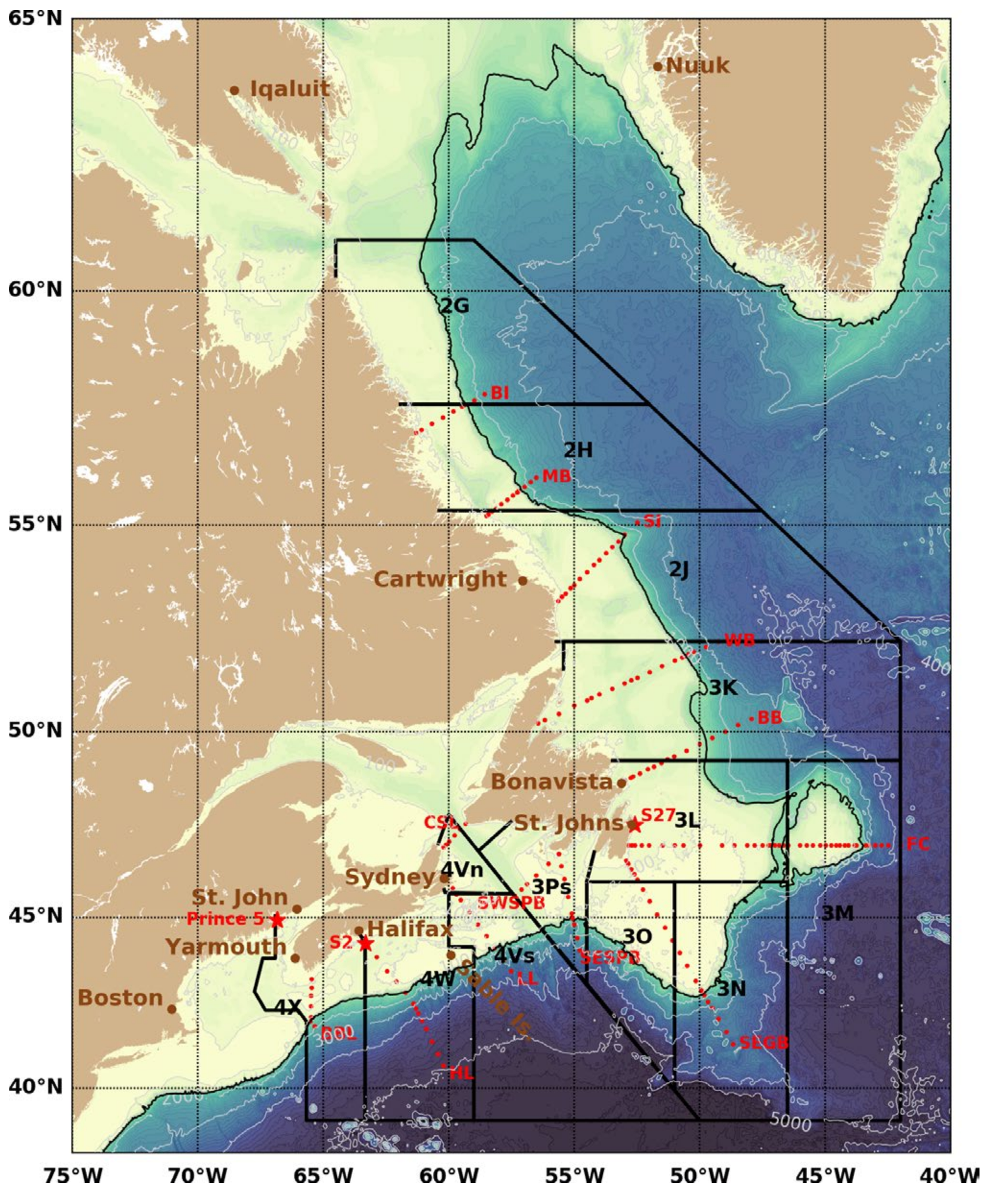

Figure 1. Map showing NAFO Divisions and main bathymetric features of the Northwest Atlantic. The hydrographic sections reported here are shown with red dots and the fixed stations by red stars. The stations used for air temperature time series and in brown. The black contour is the isobath 1000m that is used here to delimit the continental shelf.

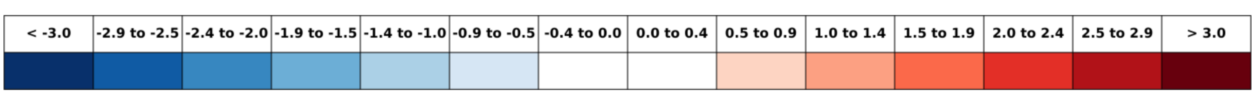

Figure 2. Color scale used for the presentation of normalized anomalies. Color levels are incremented by 0.5 standard deviations (SD), where blue is below normal and red above normal. Values between 0 and ±0.5 SD remain white indicating normal conditions.

Meteorological Conditions

The winter North Atlantic Oscillation (NAO) is defined as anomaly in the sea-level pressure (SLP) difference between the sub-tropical high (average location near the Azores) and the sub-polar low (average location near Iceland). Several definitions of the NAO exist and the definition used here is the one from the National Center for Environmental Information of the National Oceanic and Atmospheric Administration (NOAA) and available online. The winter NAO (defined here as the average of monthly values from December to March) is considered a measure of the strength of the winter westerly and north westerly winds over the Northwest Atlantic. A high NAO index (positive phase) occurs during an intensification of the Icelandic Low and Azores High. Except for some years for which the SLP patterns are spatially shifted (e.g., 1999, 2000 and 2018 where the location of high and low SLP were reversed in March), positive winter NAO years favor strong northwesterly winds, cold air and sea surface temperatures, and heavy ice conditions on the NL shelves (Colbourne et al., 1994; Drinkwater 1996; Petrie et al., 2007). In 2020, the winter NAO was positive (+1.2; first row in Figure 3) for a 7th consecutive year. A predominance of strongly positive winter NAO phase is ongoing since 2012 (all years except 2013 were positive), including the record high of +1.6 in 2015, whereas the record low of -1.5 was in 2010.

The Arctic Oscillation (AO) is a larger scale index intimately linked with the NAO. During a positive phase, the arctic air outflow to the Northwest Atlantic increases, resulting in colder winter air temperatures over much of the NL and adjacent shelf regions. In 2020, the AO was above normal for the first time since 2015 at +0.8 (Figure 3), generally indicative of cold air temperature.

The Atlantic Multidecadal Oscillation (AMO) is also provided in Figure 3. This index, based on the Sea Surface Temperature of the Atlantic Ocean, evolves as part of a 65-80 year cycle that influences the regional climate and has consequences on the ocean circulation in the North Atlantic (e.g., Kerr, 2000). The AMO is in a positive phase since 1996.

Air temperature anomalies (winter and annual values) from five coastal communities around the Northwest Atlantic (Nuuk Greenland, Iqaluit Baffin Island, Cartwright Labrador, Bonavista and St. John's Newfoundland) are shown in Figure 3 as normalized anomalies (referenced to the 1991-2020 period) between 1980 and 2020, and in Figure 4 and Figure 5 as cumulative annual and monthly anomalies, respectively. Except for Nuuk for which data are obtained from the Danish Meteorological Institute (Vinther et al., 2006), the air temperature data from Canadian sites are from the second generation of Adjusted and Homogenized Canadian Climate Data (AHCCD) that accounts for shifts in station location and changes in observation methods (Vincent et al., 2012).

On average, winter values in 2020 were normal or below normal for all 5 sites (coldest winter at Cartwright at -0.9 SD). The annual values show however normal to above normal for all Canadian sites and only Nuuk was below normal at -0.6 SD. The predominance of warmer-than-normal air temperatures at all sites from the mid-1990s to 2013 is evident in Figure 3 and Figure 4. The warmest period was the early 2010's, where values in 2010 at Cartwright and Iqaluit reached 2.2 and 2.9 SD above normal setting 77 and 65 year records, respectively. Averaged over the 5 sites, the annual air temperature was just about normal in 2020 (Figure 4). This was however characterized by December temperatures much above normal for all Canadian sites, especially in Cartwright (+4.8°C above normal) and for Iqaluit (+6.2°C above normal) as shown in Figure 5.

Annual air temperature anomalies for six sites in the Scotian Shelf-Gulf of Maine region (location in Figure 1) are shown in Figure 6 and in Table 1. In 2020, the mean annual air temperature anomalies compared to the 1981-2020 climatology were well above normal at all sites with anomalies ranging from +1.6 to +2.3 SD. The time series of annual anomalies indicates that all sites have increasing temperatures over the long term with decadal scale variability superimposed. Over 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, +1.5°C), +1.4°C (+1.0°C, +1.7°C), +1.9°C (+1.6°C, +2.3°C), +1.2°C (+0.8°C, +1.5°C), +1.2°C (+0.8°C, +1.6°C) and +2.6°C (+2.3°C, +3.0°C), respectively.

The anomalies for all 6 sites are displayed in Figure 7 as a composite sum. For most years the anomalies have the same sign. Since 1900, 97 of the 121 years had five or more stations with the annual anomalies having the same signs; for 68 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 among sites.

	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00
-- Climate indices --																					
NAO_{winter}	0.0	0.2	0.3	0.9	0.6	-0.5	0.5	-0.2	0.5	1.4	0.7	0.5	0.6	0.8	1.1	1.3	-0.5	0.3	0.0	0.5	1.2
AO	-0.6	-0.4	0.3	0.0	-0.2	-0.5	0.1	-0.5	0.0	1.0	1.0	0.2	0.4	0.1	0.5	-0.3	-0.5	0.0	-0.3	0.1	0.0
AMO	0.0	-0.1	-0.2	-0.1	-0.2	-0.3	-0.3	0.0	0.0	-0.1	-0.1	-0.2	-0.2	-0.2	-0.2	0.1	-0.1	0.0	0.3	0.1	0.0
-- Winter Air Temperature --																					
Nuuk	0.8	0.2	0.0	-3.0	-3.6	0.4	2.2	-0.4	0.4	-1.4	-0.6	-1.1	-1.4	-2.5	-0.7	-1.3	0.4	0.1	-0.1	-0.3	0.1
Iqaluit	0.4	0.8	0.9	-2.3	-2.0	0.6	1.7	-1.3	-0.4	-1.7	-1.1	-1.7	-0.9	-2.1	-0.8	-0.2	0.2	0.1	-1.9	-0.3	0.2
Cartwright	0.4	0.8	0.1	-1.3	-1.0	-0.2	0.0	-0.2	-0.1	-1.3	-1.3	-1.4	-1.6	-1.5	-1.1	-0.8	0.4	0.1	0.7	0.3	0.2
Bonavista	-0.3	0.6	-0.2	-0.3	-0.4	-1.0	-0.5	-0.9	-0.2	-1.5	-2.4	-1.5	-1.8	-2.1	-1.7	-1.0	0.4	-0.2	0.1	0.8	1.0
StJohns	-0.6	0.6	-0.4	0.6	0.4	-0.8	-0.3	-1.3	-0.4	-1.7	-2.4	-1.3	-1.9	-1.9	-1.5	-1.0	0.1	-0.1	-0.1	1.1	1.2
-- Annual Air Temperature --																					
Nuuk	0.4	-0.2	-1.6	-2.4	-2.7	1.0	-0.2	-0.4	0.0	-1.7	-1.2	-0.7	-2.0	-2.2	-1.1	-0.6	0.1	-0.2	0.0	-0.3	0.1
Iqaluit	0.4	1.2	-1.3	-2.1	-1.6	0.9	-1.1	-1.2	-0.4	-1.6	-1.7	-0.9	-2.3	-2.3	-0.7	0.3	0.3	0.6	-0.2	-0.5	0.2
Cartwright	-0.2	0.9	-1.3	-0.6	-1.1	-0.7	-1.0	0.3	-0.4	-0.6	-1.2	-1.5	-1.3	-1.3	-0.6	-0.5	0.3	-0.4	0.5	0.8	0.4
Bonavista	-1.1	0.6	-1.0	0.1	-0.4	-1.3	-0.9	-0.3	0.2	-0.2	-0.7	-1.7	-1.7	-1.6	-0.6	-0.7	0.5	-0.9	0.6	0.5	0.9
StJohns	-1.6	0.8	-1.3	0.3	0.1	-2.0	-1.3	-0.9	-0.1	-0.9	-0.8	-1.8	-2.2	-1.8	-0.7	-1.0	0.1	-1.4	0.4	1.8	0.8

	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	x̄	sd
-- Climate indices --																						
NAO_{winter}	-0.3	0.4	0.0	0.3	0.2	-0.2	0.6	0.5	0.1	-1.5	-0.4	1.3	-0.4	0.8	1.6	1.2	0.7	0.7	0.7	1.2		
AO	-0.2	0.1	0.2	-0.2	-0.4	0.1	0.3	0.2	-0.3	-1.0	0.5	-0.2	0.0	-0.1	0.6	-0.1	0.3	0.2	-0.1	0.8		
AMO	0.1	0.0	0.2	0.2	0.3	0.2	0.1	0.1	0.0	0.3	0.1	0.2	0.1	0.1	0.1	0.3	0.3	0.0	0.1	0.3		
-- Winter Air Temperature --																						
Nuuk	0.2	0.1	0.9	1.3	0.3	0.6	1.0	-1.5	0.6	2.3	1.3	-0.1	0.5	0.1	-1.0	0.1	0.1	-0.5	1.1	-0.5	-7.2	2.2
Iqaluit	0.4	-0.2	0.3	0.8	-0.6	0.4	1.1	-1.0	-0.1	2.2	2.1	0.6	0.6	0.5	-1.2	0.2	0.4	0.1	0.6	0.3	-23.9	3.0
Cartwright	-0.1	0.3	0.1	1.6	-0.1	0.6	0.8	-0.9	0.1	2.7	2.0	0.0	0.8	-0.8	-1.2	0.3	-0.2	0.2	-0.3	-0.9	-12.0	2.6
Bonavista	-0.3	0.1	-0.9	0.9	0.4	1.5	0.2	-0.5	0.4	1.0	1.9	0.8	0.6	-1.2	0.1	0.6	0.0	1.1	-0.7	0.0	-3.2	1.3
StJohns	-0.8	0.0	-1.0	0.7	0.5	1.4	-0.1	-0.4	0.9	0.9	2.0	0.7	0.4	-1.0	0.5	0.6	-0.1	1.2	-0.8	0.0	-3.0	1.2
-- Annual Air Temperature --																						
Nuuk	0.5	-0.1	1.1	0.4	1.0	0.6	0.4	-0.1	0.3	2.8	-0.6	0.9	0.5	0.1	-1.5	1.0	0.2	-0.9	1.0	-0.6	-1.0	1.3
Iqaluit	0.4	-0.5	0.6	-0.2	0.7	1.3	-0.1	-0.4	0.2	2.9	0.3	0.4	0.0	0.2	-1.7	0.1	0.5	-0.6	0.9	0.5	-8.3	1.5
Cartwright	0.5	-0.4	0.3	0.9	0.7	1.5	0.0	0.0	0.3	2.2	0.5	1.1	0.4	-0.1	-3.0	-0.4	0.1	-0.2	-1.1	0.4	0.2	1.4
Bonavista	0.5	-0.2	0.2	0.7	0.8	1.2	0.6	0.4	0.2	1.3	-1.6	1.4	0.7	-0.1	-0.7	0.3	0.9	-2.1	-0.5	0.9	5.0	1.0
StJohns	0.1	-0.7	0.1	0.3	0.5	1.4	-0.4	0.6	0.7	1.3	0.1	1.5	0.7	0.1	-1.0	0.2	0.1	0.2	-0.7	0.8	5.5	0.8

Figure 3. Scorecard of standardized air temperature anomalies (winter and annual) from 1980 to 2020.

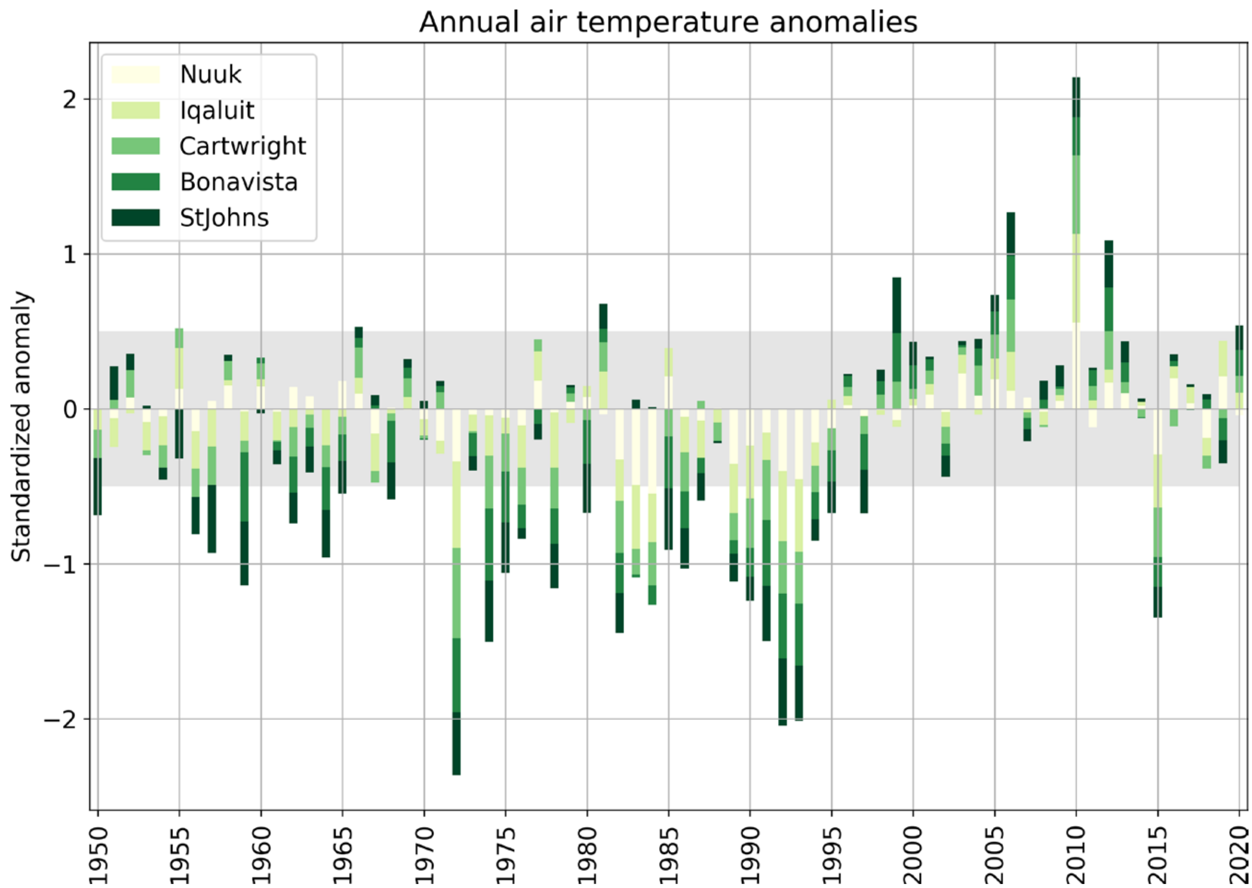

Figure 4. Cumulative standardized annual air temperature anomalies time series at Nuuk, Iqaluit, Cartwright, Bonavista and St. John's.

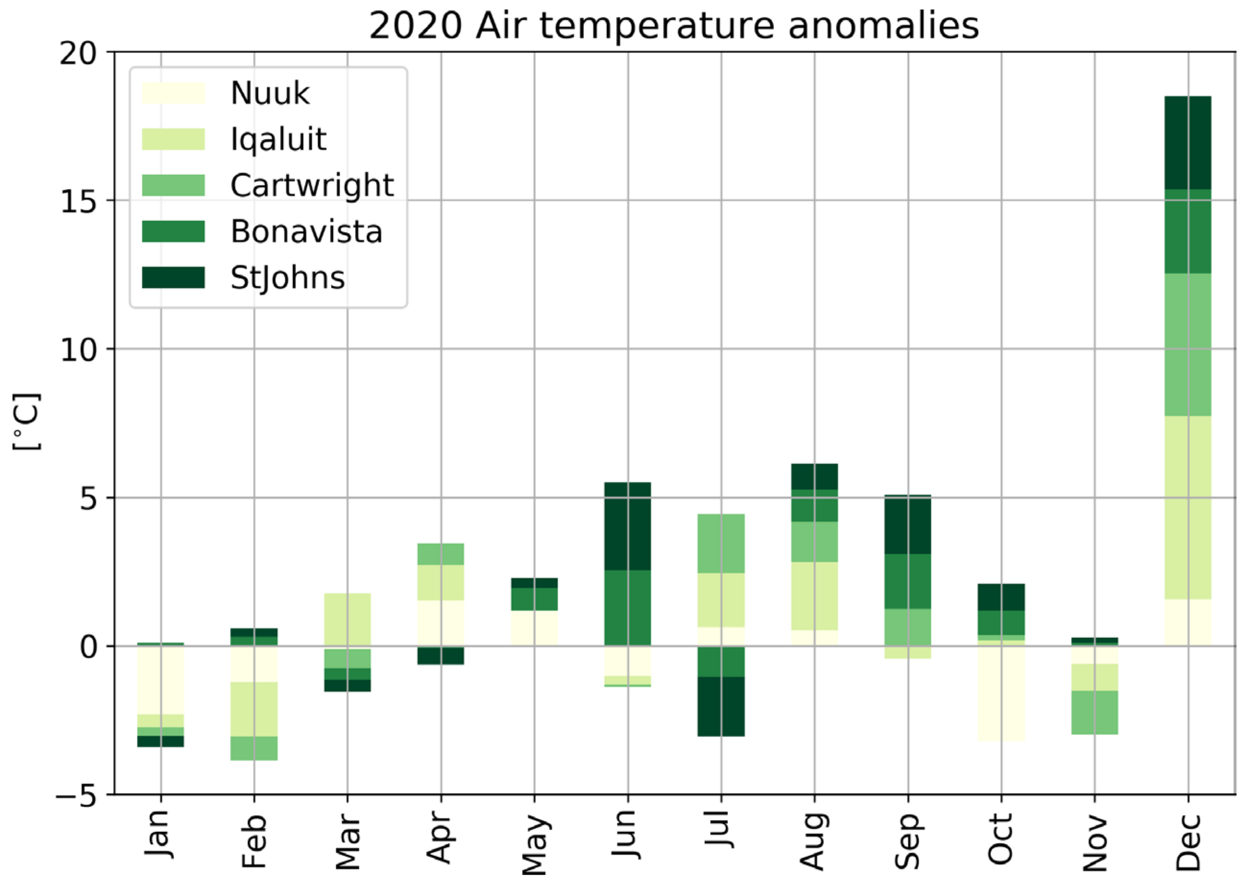

Figure 5. Cumulative monthly air temperature anomalies at Nuuk, Iqaluit, Cartwright, Bonavista and St. John's for 2020.

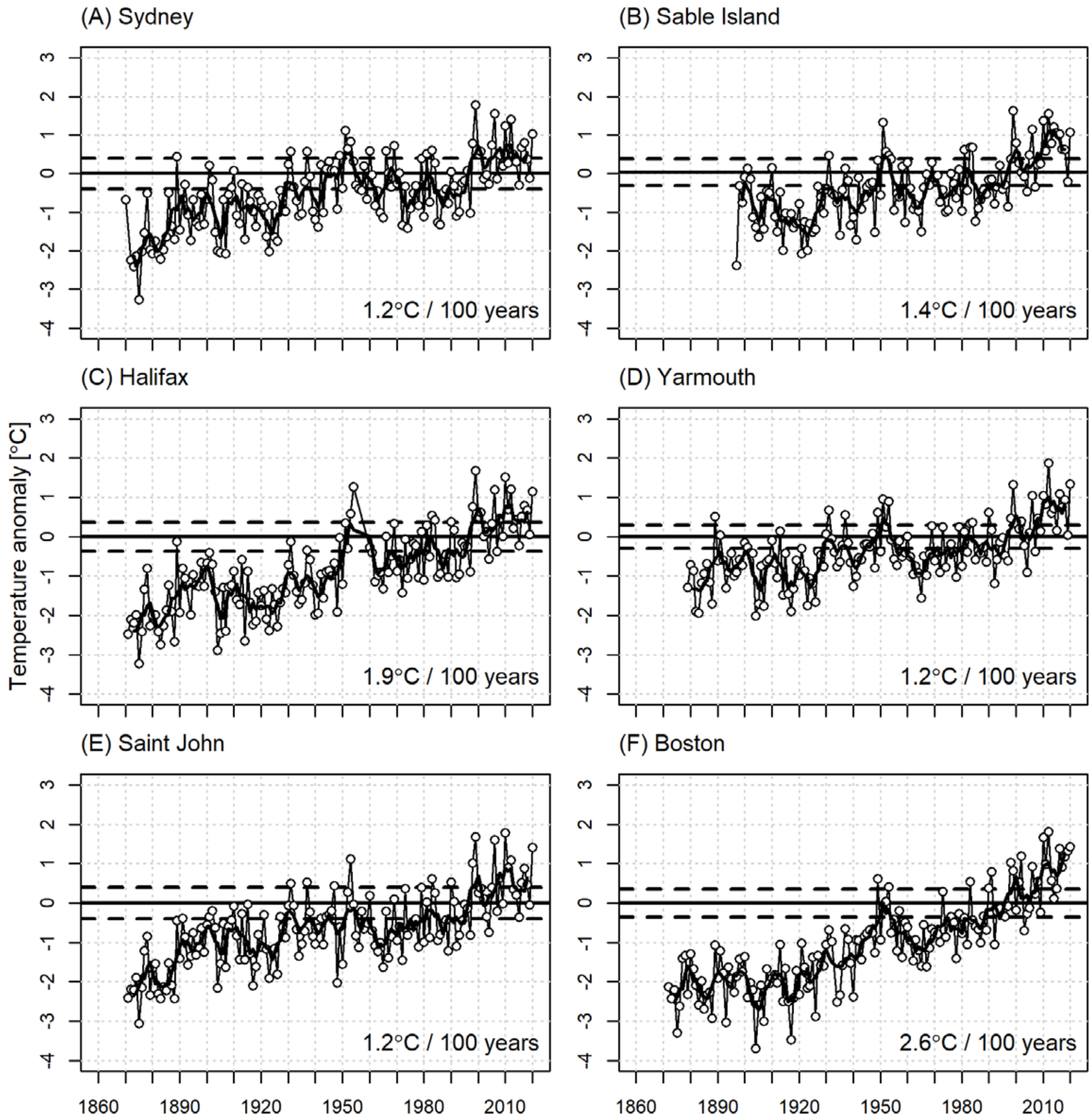

Figure 6. Annual air temperature anomalies in °C (dashed line) and five year running means (solid line) at selected sites (Sydney, Sable Island, Shearwater, Yarmouth, Saint John and Boston) in Scotian Shelf-Gulf of Maine region (years 1860 to 2020). Horizontal dashed lines represent the 1981-2010 climatological average ±0.5 SD.

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

Site	Annual Anomaly		1981-2010 Climatology	
	Observed (°C)	Normalized	Mean (°C)	SD (°C)
Sydney	+1.0	+1.3	5.87	0.81
Sable Island	+1.1	+1.6	7.88	0.68
Shearwater (Halifax)	+1.2	+1.5	6.99	0.74
Yarmouth	+1.3	+2.3	7.16	0.62
Saint John	+1.4	+1.8	5.19	0.74
Boston	+1.4	+2.0	10.91	0.60

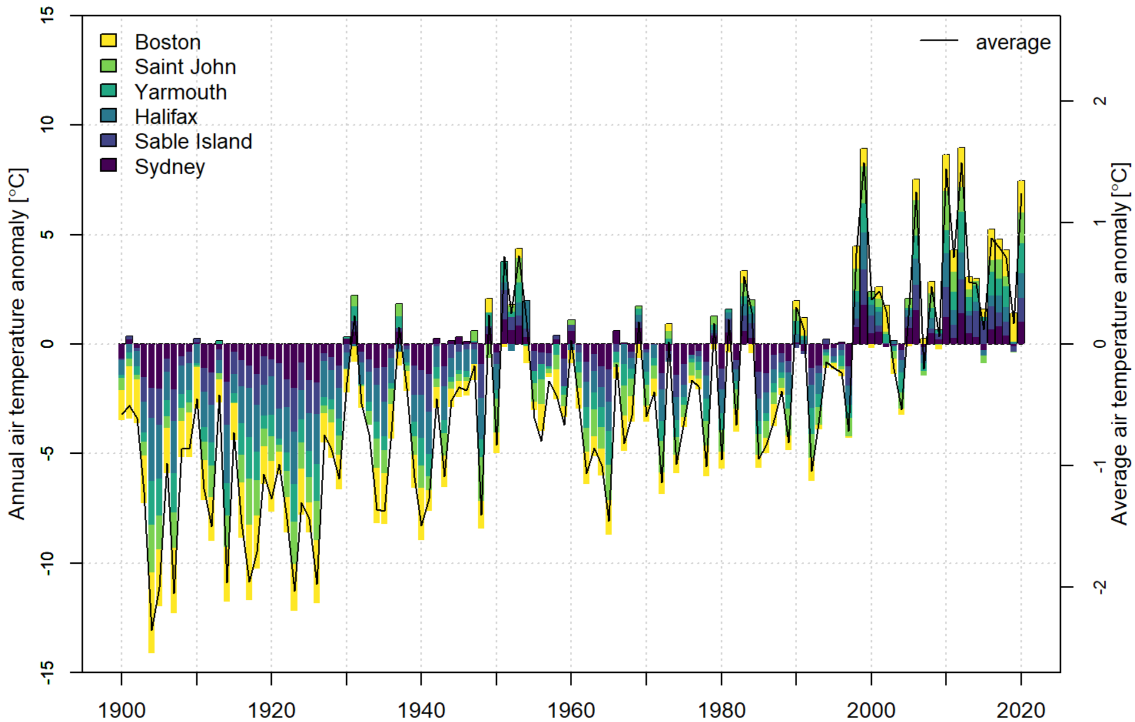

Figure 7. The contributions of each of the annual temperature anomalies for 6 Scotian Shelf-Gulf of Maine sites (Boston, Saint John, Yarmouth, Shearwater, Sable Island and Sydney) are shown as a stacked bar. Anomalies are referenced to the 1981-2010 period.

Sea-Ice Conditions

Ice cover area, volume and seasonal duration are estimated from ice cover products obtained from the Canadian Ice Service (CIS). These products consist of Geographic Information System (GIS) charts covering the East Coast, with weekly charts available for 1969-2020 and daily charts for 2009-2020, and 1980-2020 weekly charts for the Hudson Bay system that covers the Northern Labrador Shelf. All charts were further processed into regular 0.01° latitude by 0.015° longitude grids (approximately 1 km resolution), with ice concentrations and growth stages attributed to each grid point. Average thicknesses (and therefore regional volumes) are estimated from standard thicknesses attributed to each stage of ice growth from new ice and nilas (5 cm), grey ice (12.5 cm), grey-white ice (22.5 cm), thin first year ice (50 cm), medium first year ice (95 cm) and thick first year ice (160 cm). Prior to 1983, the CIS reported ice categories with fewer classifications, where a single category of first year ice (≥ 30 cm) was used with a suggested average thickness of 65 cm. We have found this value to lead to underestimates of the seasonal maximum thickness and volume based on high interannual correlations between the estimated volume of the weekly seasonal maximums and its area or sea-ice season duration. The comparisons of these correlations pre- and post-1983 provided estimates of first-year ice thickness of 85 cm in the Gulf of St. Lawrence and 95 cm on the Newfoundland and Labrador Shelf for this single first year ice category, which were used instead of the suggested 65 cm.

Several products were computed to describe the sea-ice cover inter-annual variability. The day of first and last occurrence, ice season duration (Figure 8) and distribution of ice thickness during the week of maximum volume (Figure 9) are presented as maps. These two figures combine information from the East Coast sea ice charts and Hudson Bay system charts, leading to a slight jump in the climatology maps of first occurrence and duration. The reason this occurs is because there are often missing weeks in the Hudson Bay charts around the period of first occurrence on the northern Labrador Shelf. Therefore, anomalies of these two parameters are not as good quality as the rest. Regional scorecards of anomalies in the first and last day of ice, duration of the sea ice season and maximum ice volume are presented in Figure 10 for the Labrador and Newfoundland shelves. Here, the areas defined as Northern and Southern Labrador shelves and Newfoundland Shelf are shown in Figure 9, with the Newfoundland Shelf and Gulf of St. Lawrence delimited at the Eastern end of the Strait of Belle Isle. Evolution of the ice volume during the 2020 ice season is presented in Figure 11 for the three regions in relation to the climatology and historical extremes. The Northern Labrador Shelf progression is shown using weekly data and the others are shown using daily data, extracted from East Coast charts. Time series of seasonal maximum ice volume, area (excluding thin new ice) and ice season are presented for the Northern (top left) and Southern (top right) Labrador Shelf and for the Newfoundland Shelf (bottom) in Figure 11. December-to-April air temperature anomaly at Cartwright is included with reversed scale in the Newfoundland Shelf panel. The durations shown in Figure 10 and Figure 12 are different products. The first corresponds to the number of weeks where the volume of ice anywhere within the region exceeded 5% of the climatological maximum, while the second is the average duration at every pixel of Figure 8, which is much shorter than the first.

Ice typically starts forming in December along the Labrador coast and only by late February at the southern extent of sea-ice presence (Figure 8). Last occurrence is typically in late June to early July on the Labrador coast, leading to sea-ice season durations of 23 weeks or more. There has been a declining trend in ice cover severity since the early 1990s reaching the lowest values in 2011 and 2010, with a rebound in 2014 (Figure 10 and Figure 12). On the Newfoundland Shelf, the sea ice metrics of annual maximum ice area, volume, and ice cover duration are well correlated with each other (R2 = 0.69 to 0.77; Figure 12). The best correlation with air temperature was found between the December-April air temperature anomaly at Cartwright and the sea-ice metrics of the Newfoundland Shelf (R2 = 0.62-0.80), indicative of the advective nature of sea ice on the Newfoundland Shelf, i.e., strong ice cover is associated with cold air temperatures in the source area. Sensitivity of the Newfoundland Shelf ice cover to air temperature increase (e.g., through anthropogenic climate change) can thus be estimated using 1969-2020 co-variations between winter air temperature and sea-ice parameters, which indicate losses of 14 km3, 26,000 km2 and 9 days of sea-ice season for each 1°C increase in winter air temperature.

In 2020, the sea-ice cover first appeared later than normal by a few weeks (Figure 8), leading to regional numbers that were also later than normal (Figure 10). Last occurrence varied between earlier than normal near the centre to later than normal at the northern and southern edges of the distribution (Figure 8). The regional last occurrences had near-normal timing except for the Newfoundland Shelf where it was earlier than normal by over 3 weeks (Figure 10). Sea ice volume progressed below normal until June on the Northern and Southern Labrador Shelf, and was always below normal on the Newfoundland Shelf (Figure 11). The seasonal maximum combined ice volume of the Southern Labrador Shelf and Newfoundland Shelf occurred during the week of March 30th and was below normal at 98 km^3 (-0.9 SD) (Figure 10). The bulk durations on the Northern and Southern Labrador and Newfoundland Shelves were respectively of 187 (-0.1 SD), 165 (-0.4 SD) and 88 days (-0.9 SD). An overview of sea ice conditions (volume and season duration) for NL since 1969 is presented in Figure 13 as the average of normalized anomalies. In 2020, this index was below normal at -0.6 SD.

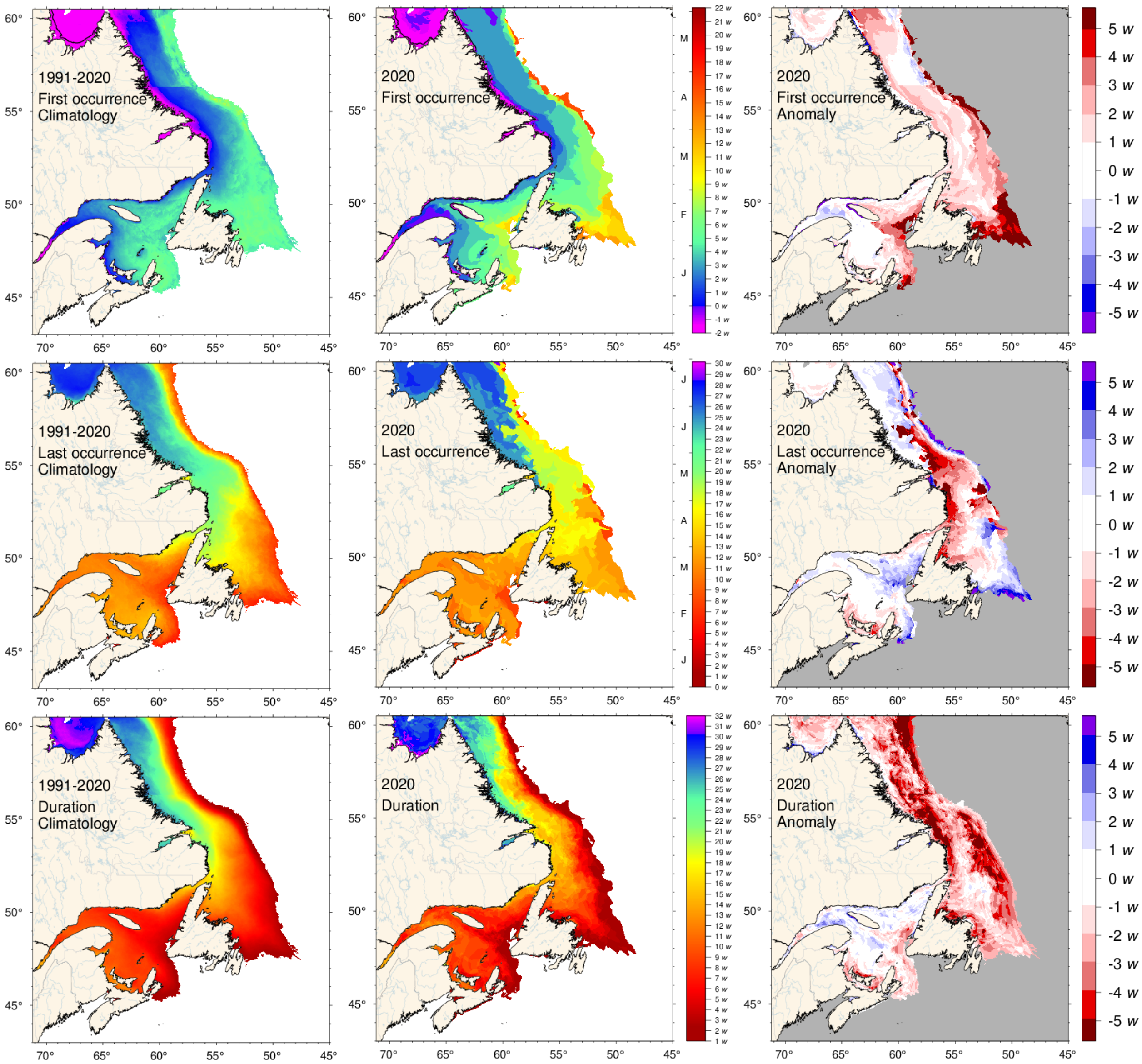

Figure 8. First (top) and last (middle) occurrence of ice and ice season duration (bottom) based on weekly data. The 1991-2020 climatologies are shown (left) as well as the 2020 values (middle) and anomalies (right). First and last occurrences are defined here as the first and last weekly chart in which any amount of ice is recorded for each pixel and are illustrated as day-of-year. Ice duration sums the number of weeks with ice cover for each pixel. Climatologies are shown for pixels that had at least 15 years out of 30 with occurrence of sea-ice, and therefore also show the area with 50% likelihood of having some sea-ice at any time during any given year. The duration anomaly map includes pixels with no ice cover where some was expected based on the climatology.

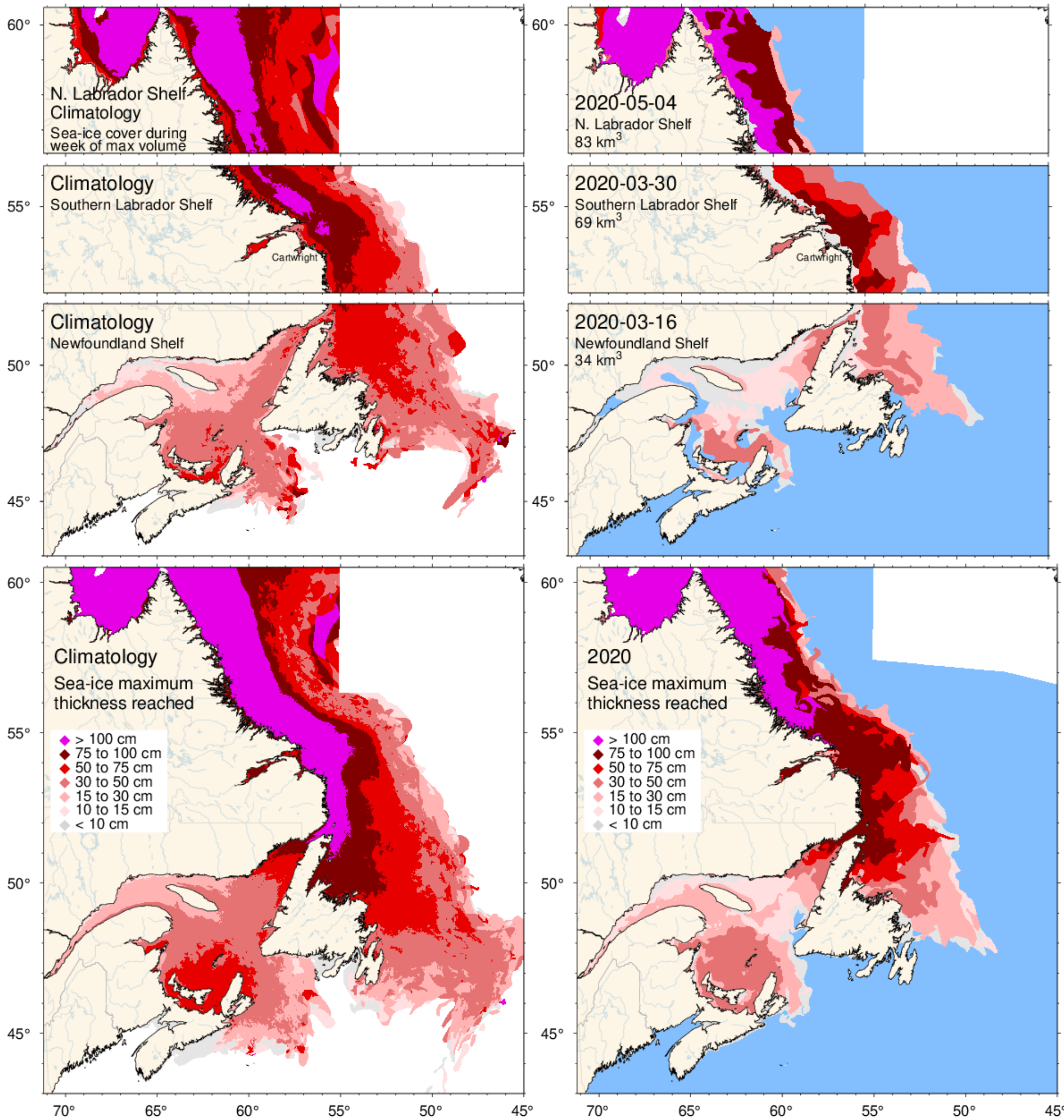

Figure 9. Ice thickness map for 2020 for the week with the maximum annual volume on the Newfoundland and Labrador Shelf (three upper right panel) and similarly for the 1991-2020 climatology of the weekly maximum (three upper left panel). Note that these maps reflect the ice thickness distribution on that week. The maximum ice thickness observed at any given location during the year is presented in the lower panels, showing the 1991-2020 climatology and 2020 distribution of the thickest ice recorded during the season at any location.

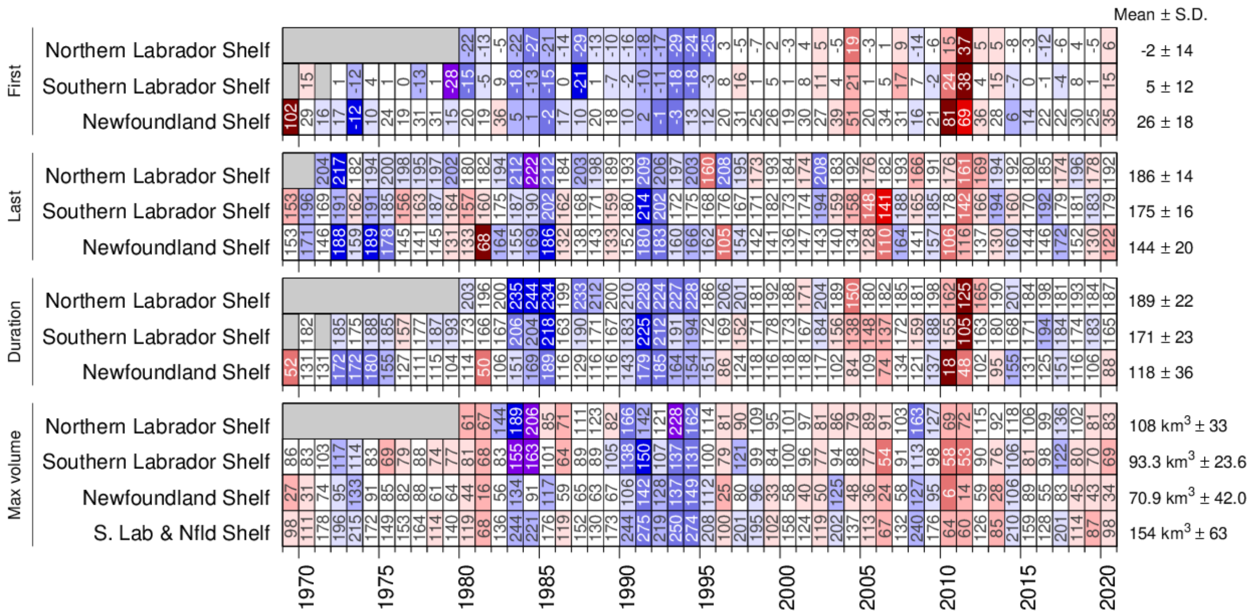

Figure 10. First and last day of ice occurrence, ice duration, and maximum seasonal ice volume by region. The moment when ice was first and last observed in days from the beginning of each year is indicated for each region, and the color code expresses the anomaly based on the 1991–2020 climatology, with blue (cold) representing earlier first occurrence and later last occurrence. The threshold is 5% of the climatological average of the seasonal maximum ice volume. Numbers in the table are the actual day of the year or volume, but the color coding is according to normalized anomalies based on the climatology of each region. Duration is the numbers of days that the threshold was exceeded.

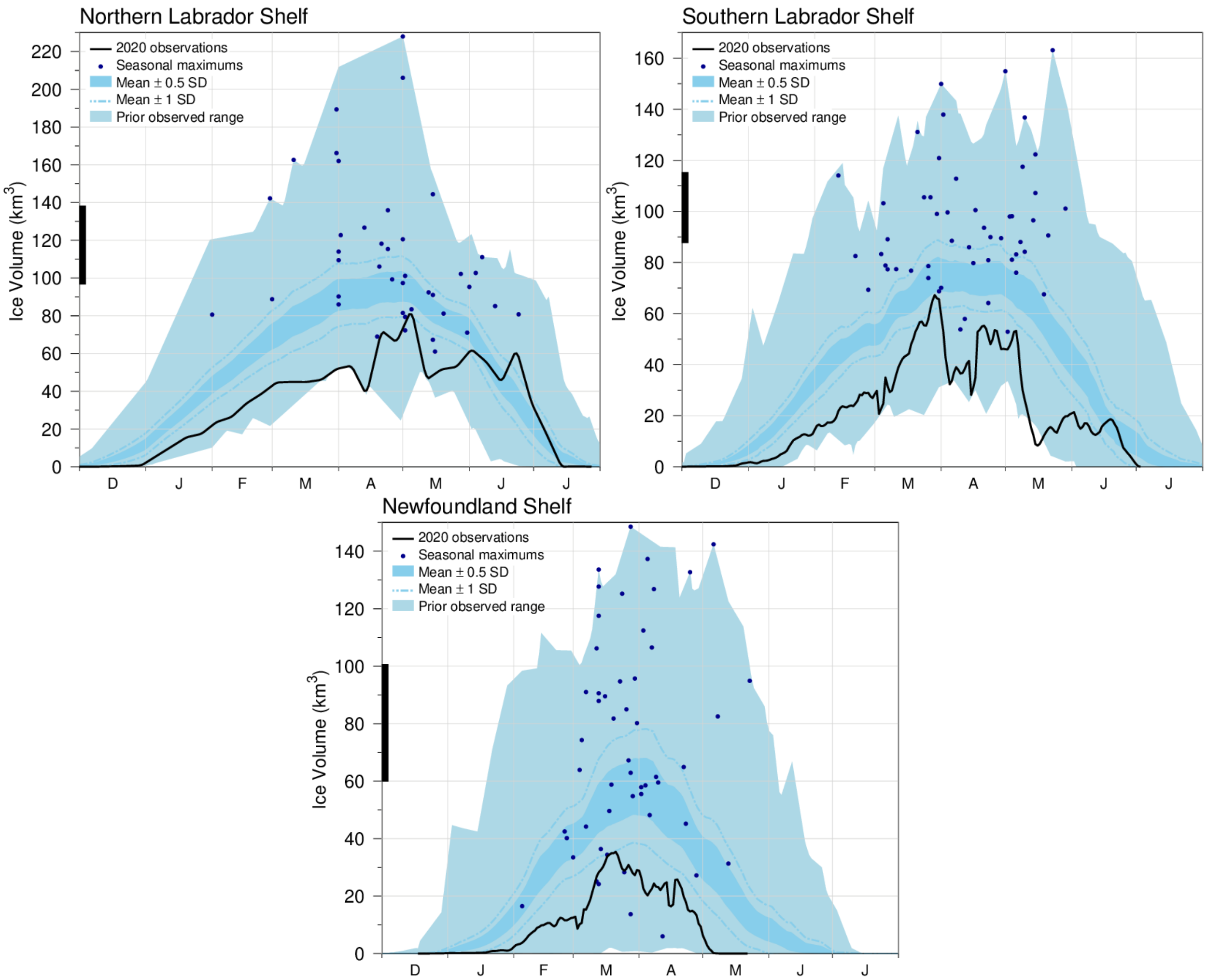

Figure 11. Time series of the 2019-2020 mean ice volume (black lines) for the Northern Labrador Shelf (top left), Southern Labrador Shelf (top right), and Newfoundland Shelf (bottom), the 1991-2020 climatological mean volume ±0.5 and ±1 SD (dark blue area and dashed line respectively), the minimum and maximum span of 1969-2020 observations (light blue), and the date and volumes of 1969-2020 seasonal maximums (blue dots). The thick black line on the left indicates the mean volume ±0.5 SD of the annual maximum ice volume, which is higher than the peak of the mean daily ice volume distribution.

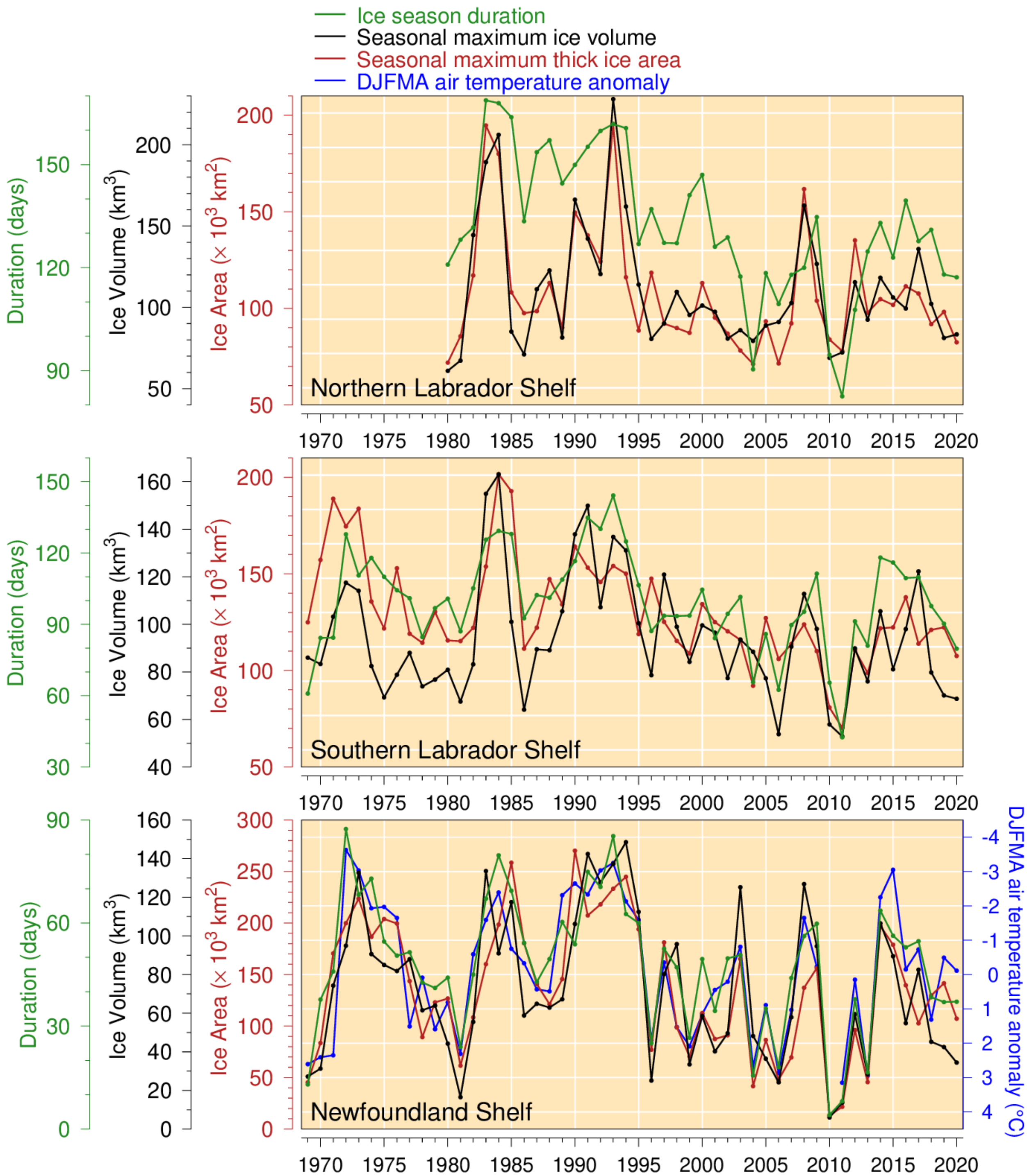

Figure 12. Seasonal maximum ice volume and area (excluding ice less than 15 cm thick), and ice season duration for the Northern and Southern Labrador Shelf (top and middle) and Newfoundland Shelf (bottom), and December-to-April air temperature anomaly at Cartwright.

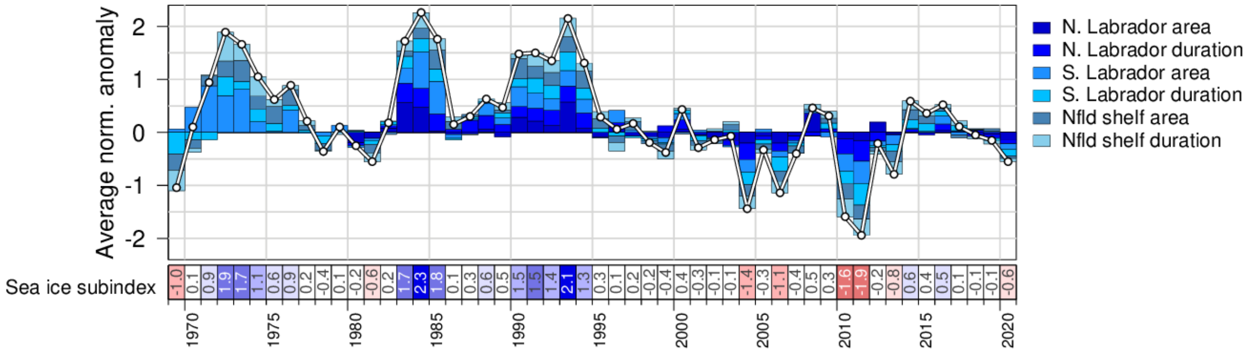

Figure 13. Newfoundland and Labrador sea ice index established by averaging the normalized anomalies of volume and duration of sea ice for Newfoundland and Labrador shelves (black and green time series in Figure 12).

Satellite Sea-Surface Temperature Conditions

Sea Surface Temperatures (SSTs) used here is a blend of data from Pathfinder version 5.3 (1982-2014), Maurice Lamontagne Institute (1985-2013) and Bedford Institute of Oceanography (1997-2019) and monthly temperature composites are based on averaged daily anomalies to which monthly climatological average temperatures are added (see Galbraith et al. 2021 for details).

Averaged over ice-free periods of the year as short as June to November on the Labrador Shelf, May to November in the Gulf, to the entire year on the Scotian Shelf, air temperature has been found to be a good proxy of sea surface temperature. The warming trend observed in air temperature since the 1870s of about 1°C per century is also expected to have occurred in surface water temperatures across Atlantic Canada (Galbraith et al. 2021). The Zone experienced its warmest surface temperatures in 2012 when all regions had positive anomalies over ice-free months, with records reached in the Bay of Fundy-Gulf of Maine (4X eGoM+BoF), Scotian Shelf (4X SS, 4W, 4Vn, 4Vs), St. Pierre Bank (3P) and Flemish pass (3M).

In 2020, monthly average sea surface temperatures were generally normal to above normal in ice-free areas until May when they were below normal to normal (Figure 14 to Figure 16). After being mostly near-normal in June, temperatures increased to mostly above-normal in July. Temperatures remained normal to above normal in August. At the end of August, high winds caused mixing to cool the surface waters and warm deeper waters in parts of the Scotian Shelf. While temperatures remained below normal in parts of the Scotian Shelf for the rest of the year, they were above normal on the Labrador and Newfoundland Shelf, reaching series records in 3MNO in October. The year ended with December record highs on the Scotian Shelf.

Sea surface temperatures averaged over the ice-free months were normal to above normal across the zone and on average above-normal for the first time since 2014 (Figure 17, scorecard at the bottom). Note that last year, Cyr et al. 2020 reported that 2020 was the first below normal anomaly throughout the zone since 1992. This finding based on the 1981-2010 climatology (1981-2010) has now disappeared with the introduction of the new climatology.

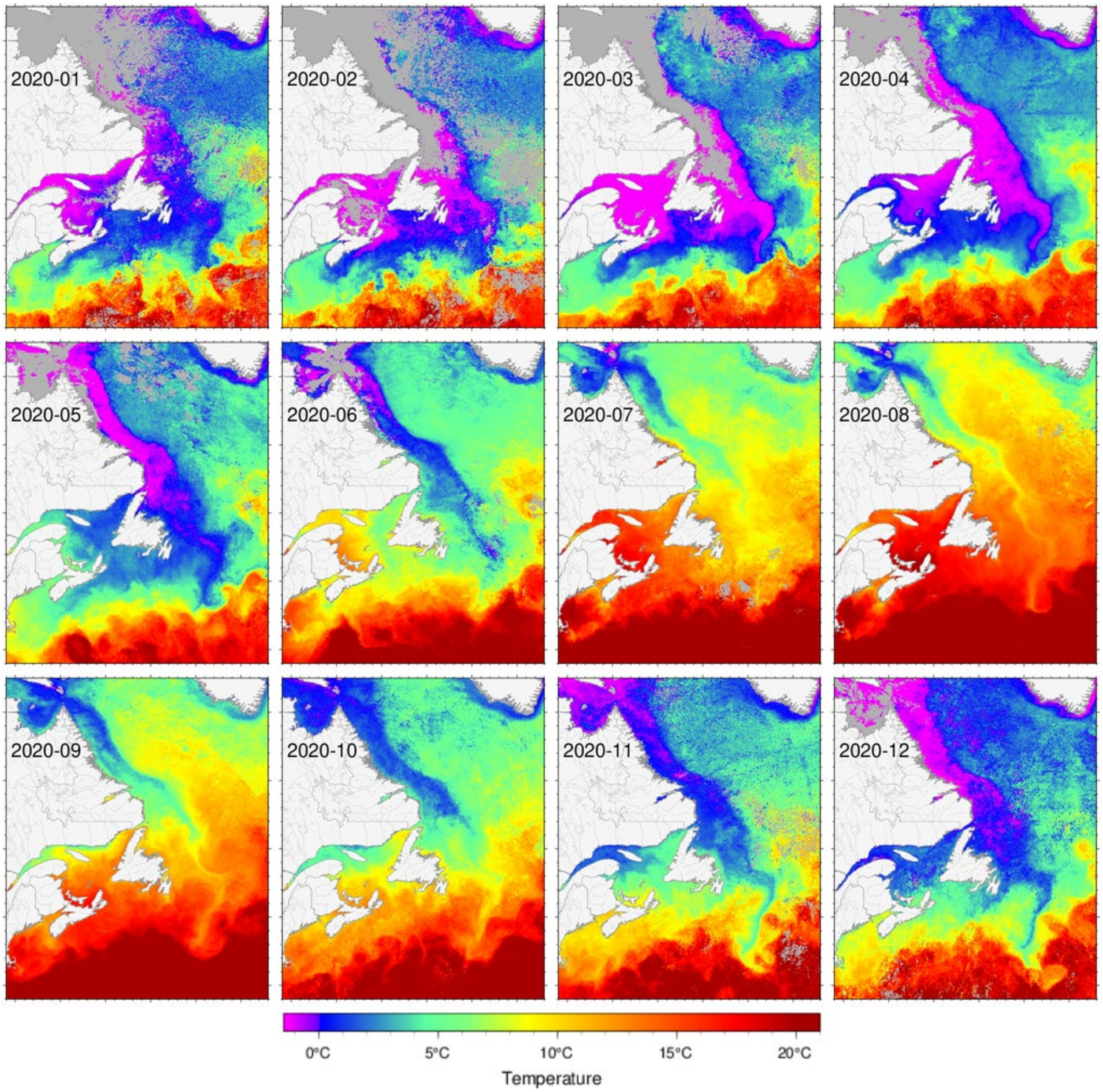

Figure 14. Sea-surface temperature monthly averages for 2020 in the Atlantic zone.

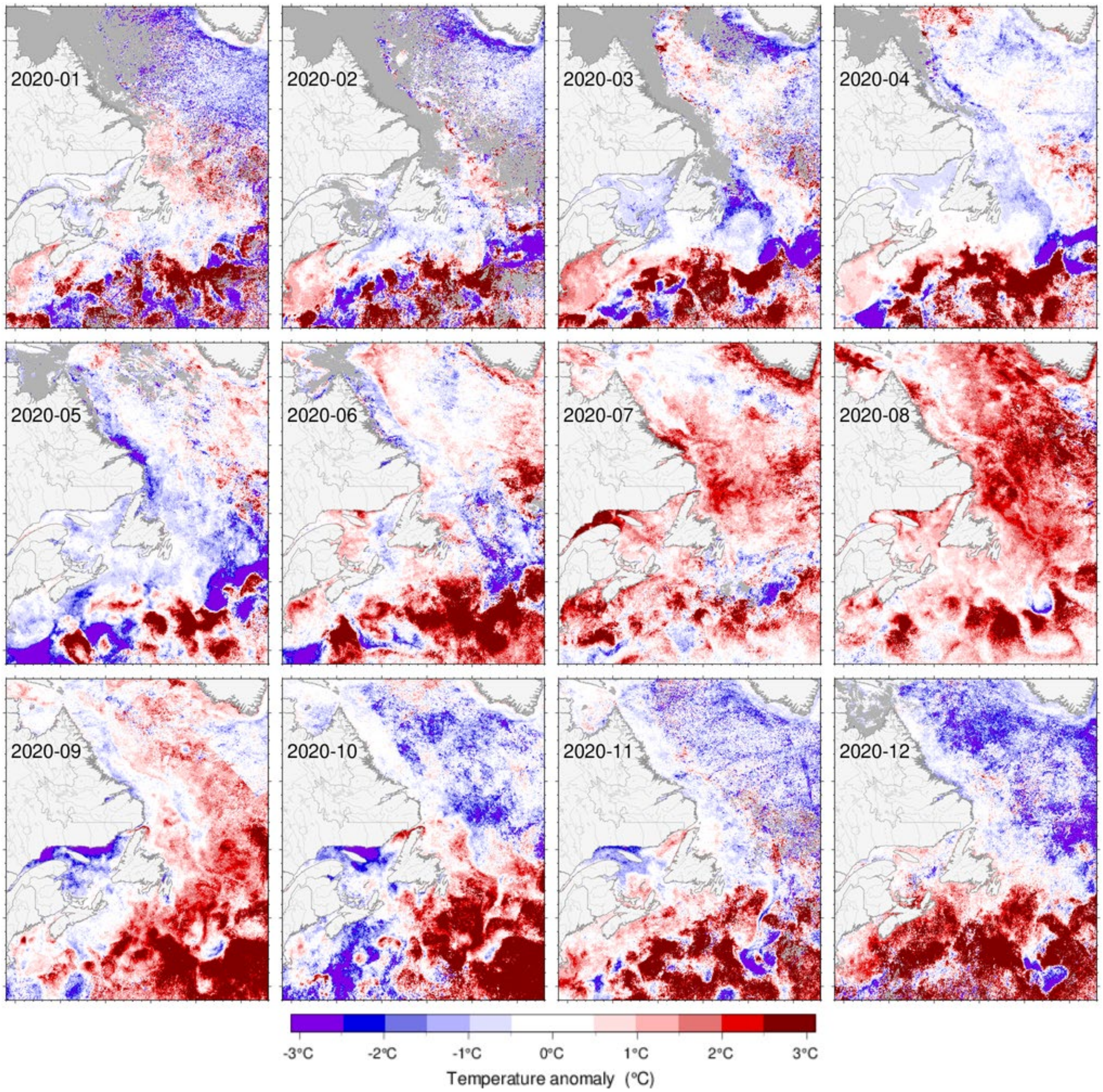

Figure 15. Sea-surface temperature monthly anomalies for 2020 in the Atlantic zone. Temperature anomalies are based on a 1985-2010 climatology.

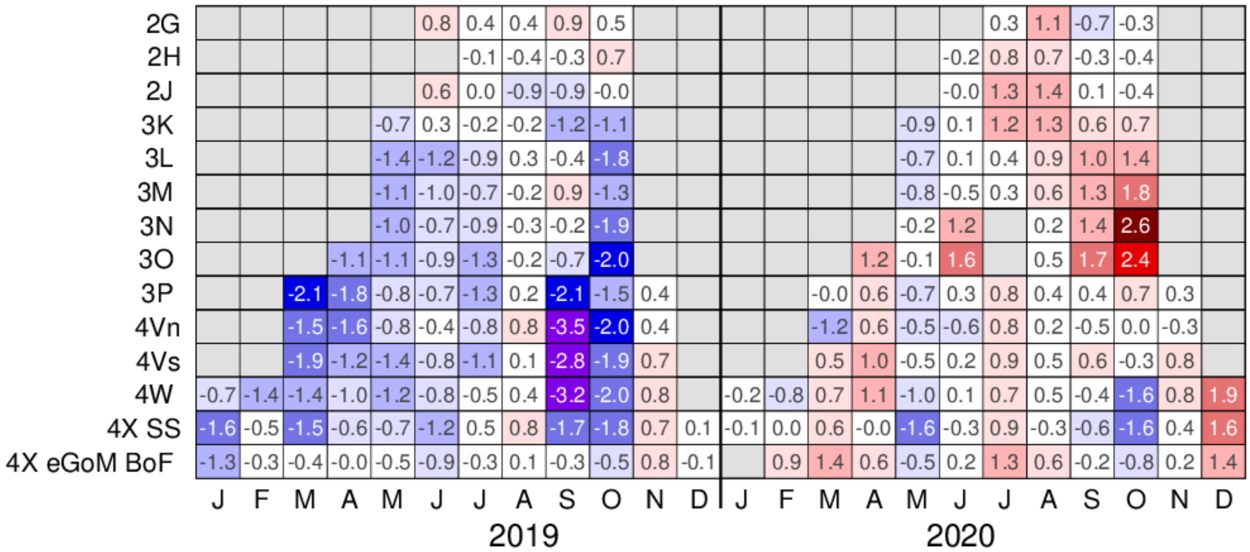

Figure 16. Monthly standardized anomalies of SST for NAFO subareas 2, 3 and 4 during 2019 and 2020 based on 1991-2020 climatologies. The area used for each division is limited to the continental shelf (see black contour in Figure 1). Grayed boxes represent months ignored either because of missing climatology due to ice cover or because coverage was less than 10%.

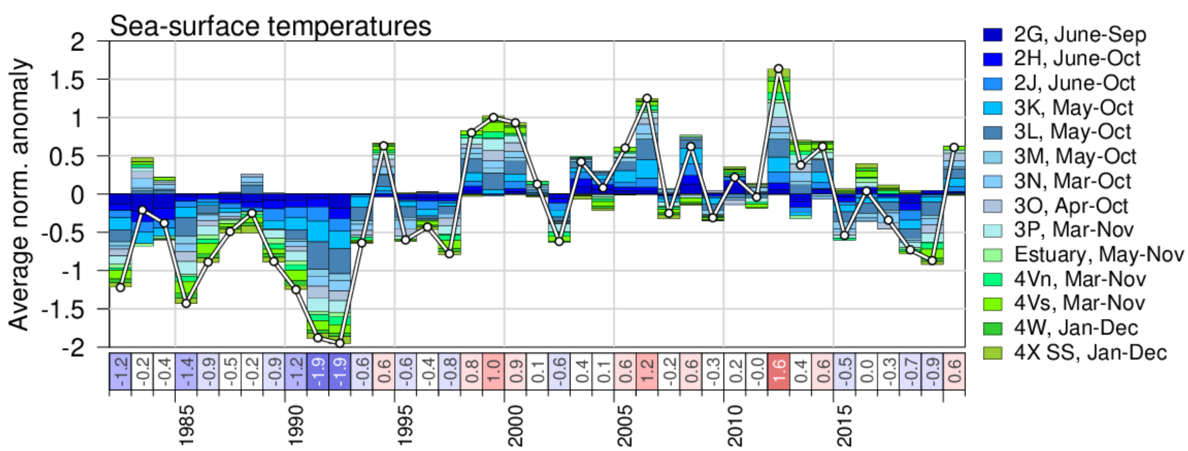

Figure 17. Sea Surface Temperature (SST) composite index in NAFO sub-areas 2 (dark blue), 3 (light blue) and 4 (green) since 1982. This index is built by performing a weighted average of the seasonal SST mean for each NAFO division (divisions and months used are provided on the right-hand side of the figure). The scorecard at the bottom of the figure represents the normalized anomaly of the seasonal average.

Ocean Conditions on the Newfoundland and Labrador Shelf (NAFO Sub-areas 2 and 3)

Long-term observations at Station 27

Station 27 (47° 32.8' N, 52° 35.2' W), is located in the Avalon Channel off Cape Spear, NL (Figure 1). It is one of longest hydrographic time series in Canada with frequent occupations (near-monthly basis) since 1948. In 2020, the station was occupied 27 times (26 CTD casts, including 19 biogeochemical sampling, and 1 XBT). Due to COVID-19 pandemic, no observations were made prior to July 14th, 2020, which represent the latest first occupation of the station since 1946.

In addition to the traditional hydrographic sampling described above, the addition of an automatic CTD profiling system on a surface buoy (type Viking) since 2017 really improved the sampling effort and our ability to detect short-term variations of ocean properties at Station 27. However, only 19 CTD profiles were collected from the Viking buoy in 2020 during the deployment that occurred between October 13th and December 28th. This number of profiles is much lower than the usual (e.g. 269 in 2019) and is due to the combination of a late deployment due to the COVID-19 pandemic, and to mechanical problems with the winch after the deployment.

Station occupation and Viking buoy automatic casts were combined to obtain the annual evolution of temperature and salinity at Station 27, as well as the anomaly compared to the 1991-2020 climatology, shown in Figure 18 and Figure 19. These figures demonstrate the seasonal warming of the top layer (~20m), with temperature peaking in August before being mixed during the fall. The cold intermediate layer (CIL; Petrie et al., 1988), a remnant of the previous winter cold layer and defined as temperature below 0°C (thick black line in Figure 18) is also evident below 100m throughout the summer. The surface layer is generally freshest between early-September and mid-October, with salinities <31 (Figure 19). These low near-surface salinities, generally from early summer to late fall, are a prominent feature of the salinity cycle on the Newfoundland Shelf and is largely due to the melting of coastal sea-ice.

In 2020, the surface layer was warmer than normal for the second half of the year where observations are available (Figure 18). The portion of the water column just above the CIL was however colder (Figure 18, bottom) and saltier (Figure 19, bottom). This suggests a shallower upper bound of the CIL in 2020. Overall, over the year, the vertically averaged temperature and salinity were normal in 2019 and 2020 (Figure 20). This contrasts with 2018 that exhibited the second largest fresh anomaly of the time series after 1970, a period commonly referred to as the Great Salinity Anomaly in the North Atlantic (Dickson et al., 1988).

The CIL summer (May-July) statistics at Station 27 since 1950 are presented in Figure 21. The striking feature in this figure is the very warm CIL anomaly from the early 1960s to the mid-1970s. The CIL core depth (bottom panel) seems uncorrelated to the two other panels that are well correlated between them. After the prevalence of a warm CIL in the early 2010s (with some of the warmest years since the mid-1970s), there has been a return to normal-to-cold CIL conditions between 2014 and 2017. The CIL was however warmer than normal in 2018 and 2019 (mean temperature 1.3 SD and 0.9 SD above normal, respectively), and normal in 2020.

The monthly mean mixed layer depth (MLD) at Station 27 was also estimated from the density profiles as the depth of maximum buoyancy frequency (*N*) calculated from the monthly averaged density profiles (ρ(z)) :

$$N^2 = -\frac{g}{\rho_0}\frac{\Delta\rho(z)}{\Delta z};$$

with g = 9.8 ms^{-2} as the gravitational acceleration, z the depth and ρ_0 as a reference density.

Climatological monthly MLD values, as well as for 2020, are presented in Figure 22. The climatological annual cycle shows a gradual decrease of the MLD between late fall and summer (mixed layer thickest in November-December and shallowest in July-August). During the second half of 2020 for which we have observations, the MLD was normal in July and August, but then shallower in October. The latter suggest that the water column remained stratified in the early fall, likely because of the warmer air conditions observed in September and October for Newfoundland (Figure 5) and warmer than normal SSTs in the region surrounding Station 27 (e.g. NAFO Divs 3LNO; see Figure 16). The mixed layer had however deepened to thicker than normal in November. Figure 23 shows a time series of the annual mean values of the MLD (solid gray line) and its 5-year moving average (dashed-black line). In general, there is a strong interannual and decadal oscillation in MLD, with an increase since the mid-1990's.

Stratification is an important characteristic of the water column since it influences, for example, the transfer of solar heat to lower layers and the vertical exchange of biogeochemical tracers between the deeper layers and the surface. The seasonal development of stratification is also an important process influencing the formation and evolution of the CIL on the shelf regions of Atlantic Canada. It essentially insulates the lower water column from the upper layers, thus slowing vertical heat flux from the seasonally heated surface layer.

The stratification index at Station 27 is computed from the density (ρ) difference between 8 and 50 m for each monthly average density profiles (i.e., $\Delta\rho/\Delta z$). Here 8 m is used as an upper bound for the calculation because most historical have their first observation around 5 m. The annual anomalies are then calculated as the average of monthly anomalies. The 2020 and climatological evolution of the stratification throughout the year are shown in Figure 24. The stratification is generally weakest between December and April, before rapidly increasing at the onset of spring until it peaks in August. In 2020, the stratification close to normal for most of the year that we have observations, except for a stronger stratification in October. This goes in line with what is discussed above for the MLD. The interannual evolution of the stratification anomaly since 1950 is shown in Figure 25. While strong decadal variations are observed, a positive trend is distinguishable since the mid-1970s, with the highest annual anomaly since 1950 observed in 1995 (+1.1 SD). After two years below normal (2018 and 2019), the annual stratification was normal in 2020. A scorecard of annual standardized anomalies since 1981 of all parameters discussed in this section is presented in Figure 26 (unlike other scorecards, 1980 was ignore because the annual coverage at Station 27 was weak).

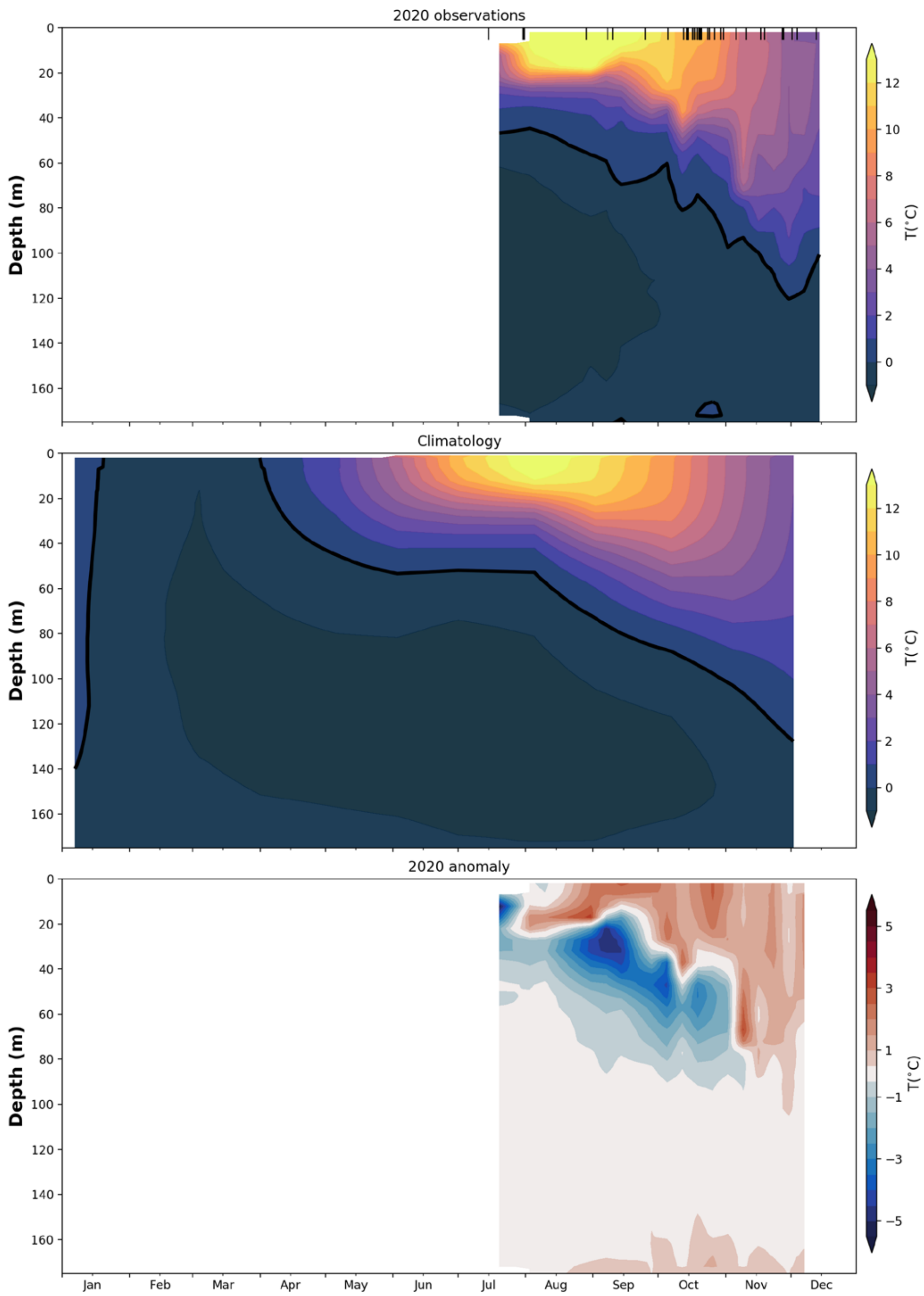

Figure 18. Annual evolution of temperature at Station 27. The 2020 contour plot (top panel) is generated from weekly averaged profiles from all available data, including station occupation and Viking buoy casts (indicated by black tick marks on top of panel). The solid black contour delineates the cold intermediate layer defined as water below 0°C. The 1991-2020 climatology (middle panel) is plotted from monthly-averaged temperature profiles. The anomaly (bottom panel) is the difference between the 2020 field and the climatology.

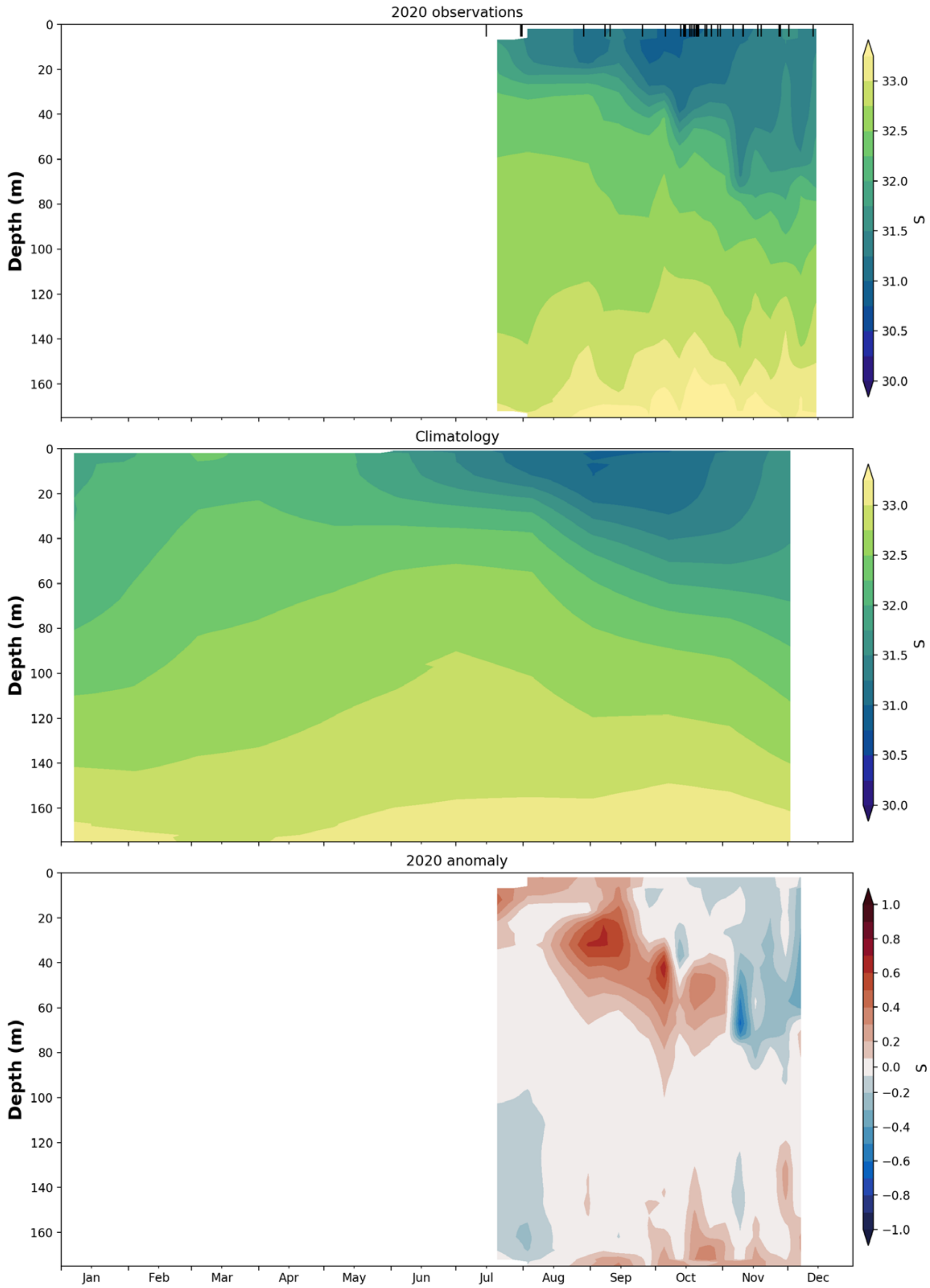

Figure 19. Same as in Figure 18, but for salinity.

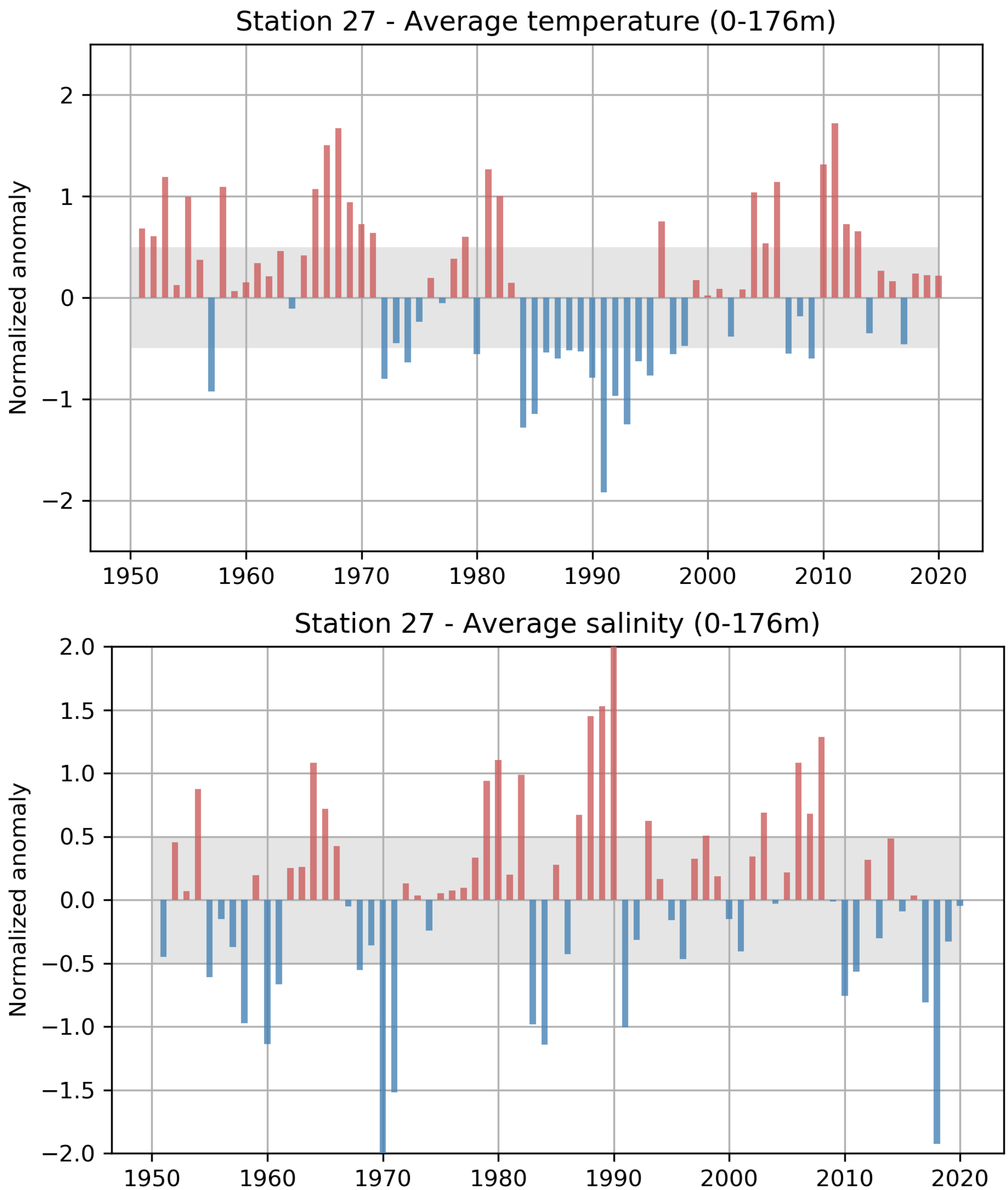

Figure 20. Annual normalized anomaly of vertically averaged (0-176m) temperature (top) and salinity (bottom) at Station 27 calculated from all occupations since 1950. Shaded gray areas represent the ±0.5 SD range considered "normal".

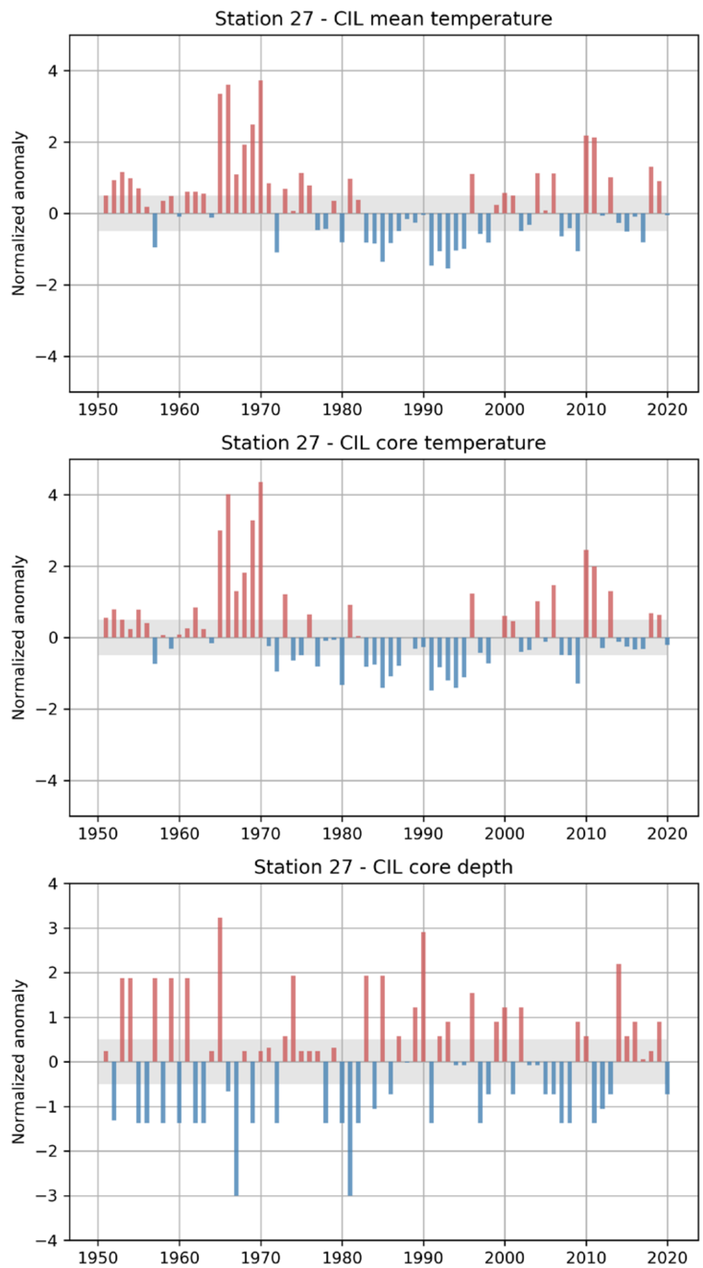

Figure 21. Normalized anomalies of summer (May-July) cold intermediate layer (CIL) statistics at Station 27 since 1950. The CIL mean temperature (top), its core temperature (minimum temperature of the CIL; middle) and the depth of the core (bottom) are presented. Shaded gray areas represent the ±0.5 SD range considered “normal”.

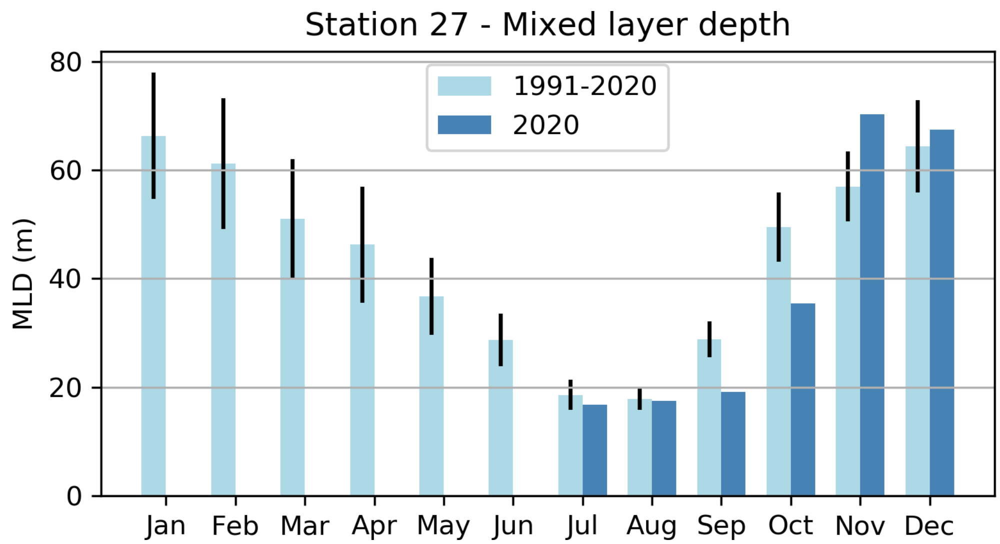

Figure 22. Bar plot of the monthly averaged mixed layer depth (MLD) at Station 27. The 1991-2020 climatology is shown in light blue while the update for 2020 is shown in dark blue. The black lines represent 0.5 SD above and below the climatology.

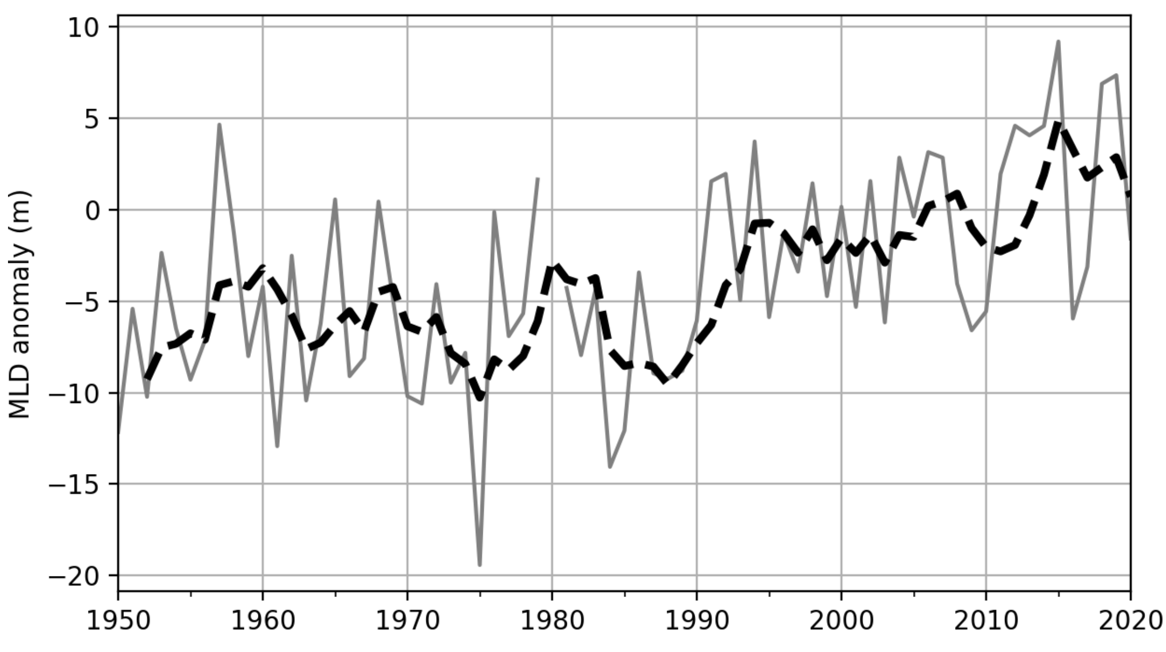

Figure 23. Time series of the annual mixed layer depth (MLD) average at Station 27 since 1950 (gray solid line) and its 5-year running mean (dashed-black line).

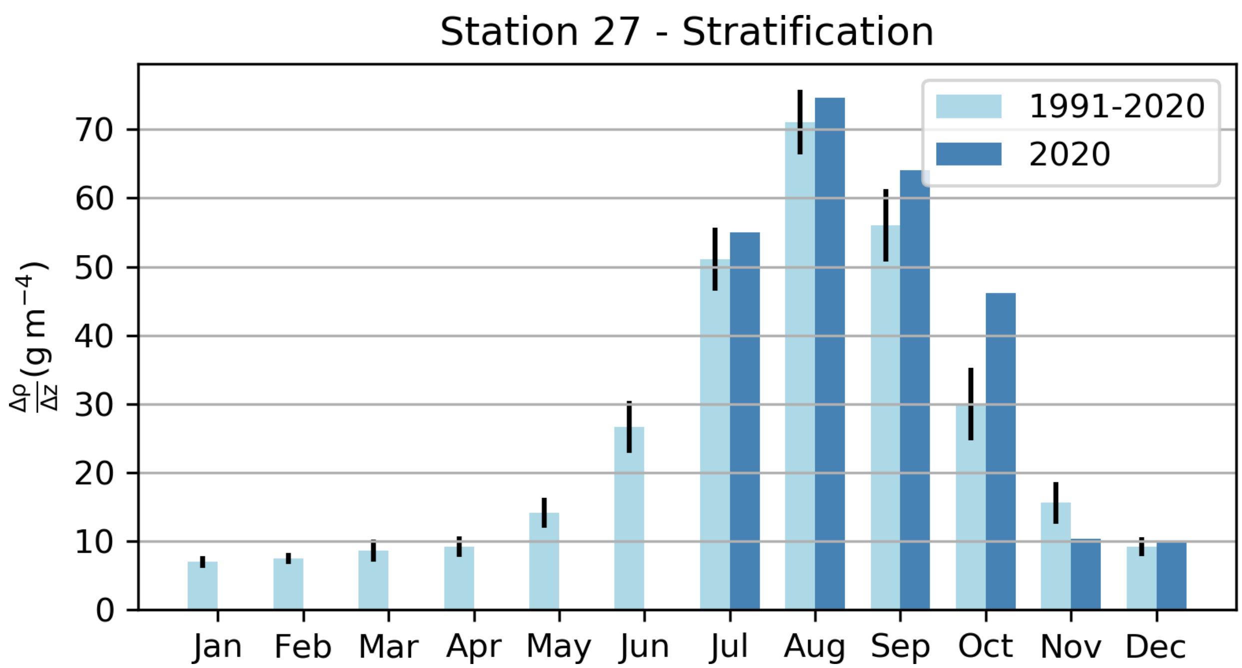

Figure 24. Bar plot of the monthly average stratification (defined as the density difference between 0 and 50 m) at Station 27. The 1991-2020 climatology is shown in light blue while the update for 2020 is shown in dark blue. The black lines represent 0.5 SD above and below the climatology.

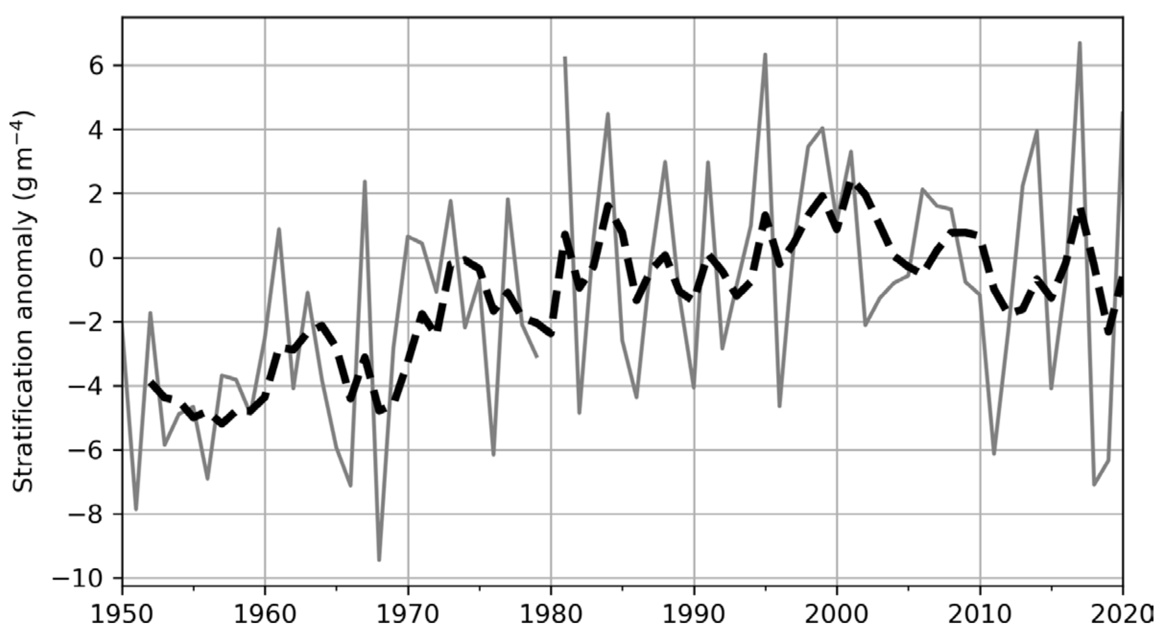

Figure 25. Time series of the annual average stratification at Station 27 since 1950 (gray solid line) and its 5-year running mean (dashed-black line).

	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	x̄	sd
-- Vertically averaged temperature --																																										
Temp 0-176m	1.3	1.0	0.1	-1.3	-1.1	-0.5	-0.6	-0.5	-0.5	-0.8	-1.9	-1.0	-1.2	-0.6	-0.8	0.8	-0.6	-0.5	0.2	0.0	0.1	-0.4	0.1	1.0	0.5	1.1	-0.6	-0.2	-0.6	1.3	1.7	0.7	0.7	-0.4	0.3	0.2	-0.5	0.2	0.2	0.2	0.6	0.5
Temp 0-50m	0.8	0.0	0.0	-1.3	-1.1	-0.5	-0.6	-0.6	-0.7	-0.7	-1.6	-0.8	-1.0	-0.3	-0.6	0.4	-0.6	-0.1	0.3	0.1	0.2	-0.6	0.1	0.6	0.5	1.2	-0.6	0.5	-0.9	0.9	1.1	0.9	0.7	-0.1	0.1	0.5	-0.4	-0.2	-0.4	0.1	3.5	0.8
Temp 150-176m	0.0	-0.6	-0.5	-1.0	-1.5	-0.6	-0.6	-0.5	-0.7	-1.1	-1.4	-1.1	-1.4	-1.2	-0.8	0.2	-0.2	0.1	0.3	0.1	0.3	-0.2	-0.3	1.3	0.9	1.0	0.1	-0.2	-0.6	1.1	2.5	0.4	0.6	-0.7	-0.7	-0.6	-0.7	0.5	0.2	1.0	-0.8	0.4
-- Vertically averaged salinity --																																										
Sal 0-176m	0.2	1.0	-1.0	-1.1	0.3	-0.4	0.7	1.4	1.5	2.4	-1.0	-0.3	0.6	0.2	-0.2	-0.5	0.3	0.5	0.2	-0.2	-0.4	0.3	0.7	0.0	0.2	1.1	0.7	1.3	0.0	-0.8	-0.6	0.3	-0.3	0.5	-0.1	0.0	-0.8	-1.9	-0.3	0.0	32.4	0.1
Sal 0-50m	0.4	1.7	-0.9	-1.4	0.6	0.6	1.0	1.3	1.9	1.9	-1.3	-0.2	0.2	0.0	-0.9	-0.1	0.0	-0.1	0.0	-0.5	-0.6	1.0	1.2	0.4	0.4	0.6	0.4	0.7	0.4	-0.9	-0.4	0.3	0.0	0.1	0.0	0.2	-1.0	-0.8	0.7	0.0	31.8	0.1
Sal 150-176m	0.0	-0.6	-0.5	-1.0	-1.5	-0.6	-0.6	-0.5	-0.7	-1.1	-1.4	-1.1	-1.4	-1.2	-0.8	0.2	-0.2	0.1	0.3	0.1	0.3	-0.2	-0.3	1.3	0.9	1.0	0.1	-0.2	-0.6	1.1	2.5	0.4	0.6	-0.7	-0.7	-0.6	-0.7	0.5	0.2	1.0	33.0	0.1
-- Cold intermediate layer (CIL) properties --																																										
CIL temp	1.0	0.4	-0.8	-0.8	-1.4	-0.8	-0.5	-0.2	-0.3	0.0	-1.5	-1.1	-1.5	-1.0	-1.0	1.1	-0.6	-0.8	0.2	0.6	0.5	-0.5	-0.3	1.1	0.1	1.1	-0.6	-0.4	-1.1	2.2	2.1	-0.1	1.0	-0.3	-0.5	-0.1	-0.8	1.3	0.9	-0.1	-1.0	0.2
CIL core T	0.9	0.0	-0.8	-0.8	-1.4	-1.1	-0.8	0.0	-0.3	-0.3	-1.5	-0.8	-1.2	-1.4	-1.1	1.2	-0.4	-0.7	0.0	0.6	0.5	-0.4	-0.4	1.0	-0.1	1.5	-0.5	-0.5	-1.3	2.5	2.0	-0.3	1.3	-0.1	-0.2	-0.3	-0.3	0.7	0.6	-0.2	-1.4	0.2
CIL core depth	-3.0	-1.4	1.9	-1.1	1.9	-0.7	0.6	0.0	1.2	2.9	-1.4	0.6	0.9	-0.1	-0.1	1.5	-1.4	-0.7	0.9	1.2	-0.7	1.2	-0.1	-0.1	-0.7	-0.7	-1.4	-1.4	0.9	0.6	-1.4	-1.1	-0.7	2.2	0.6	0.9	0.0	0.2	0.9	-0.7	123.2	15.4
CIL thickness	-1.1	-4.5	-0.1	0.7	0.6	0.1	-0.4	0.3	-1.2	-0.8	2.0	-0.2	0.0	1.0	0.3	-1.3	0.7	0.9	0.1	-0.1	0.2	0.4	-1.3	0.0	0.8	-0.2	1.1	0.9	0.9	-2.4	-1.7	-1.4	0.1	0.5	-0.1	-0.4	1.0	-1.6	-0.6	0.3	124.3	11.3
-- Mixed layer depth (MLD) --																																										
MLD winter	-0.8	-0.3		0.1	-1.1	-0.6	-0.2		-0.4	0.7	1.2		-0.6	0.6	-1.0	0.3	0.0	0.5	-0.3	0.0	-0.8	0.2	-0.3	0.7	0.3	1.1	0.1	-0.6	-1.8	-1.2	0.1	-0.3	1.9	0.3	0.8	-0.4			-1.1		59.5	7.8
MLD spring	0.4	-0.9	-0.8	-1.7	-1.4	-0.7	-1.0	-0.7	-0.8	-0.1	0.0	-0.5	-0.3	0.6	-0.8	-0.4	-0.6	-0.6	-0.9	0.2	0.1	0.1	-0.5	-0.2	-0.4	-0.1	0.4	0.0	-0.4	0.1	-0.4	1.3	0.3	0.5	0.0	-0.5	0.2	1.0	1.7		37.2	8.8
MLD summer	0.7	0.4	-0.3	-0.7	0.1	0.1	-0.6	-0.9	-1.3	-0.4	-0.6	1.4	1.2	0.6	0.7	1.0	0.4	-0.4	-0.3	-0.5	0.4	-0.5	-0.2	-0.7	-0.6	0.3	-0.7	-0.7	-0.3	-0.4	1.6	-1.0	-0.1	-0.9	0.5	0.9	-0.5	0.3	-0.5	-0.6	21.8	6.1
MLD fall			-0.2	-1.2	0.2	0.6	-0.7	-1.0	-0.4	-1.5	-0.2	0.9	-0.7	-0.6	-0.2	-0.7	-0.2	0.3	0.4	0.0	-0.6	0.2	-0.6	0.4	0.5	-0.6	0.4	-0.4	1.0	-0.5	0.5	1.1	-0.5	0.4	0.7	-0.9	-0.7	0.3	0.5	0.0	57.0	7.4
MLD annual	0.2	-0.4	-0.4	-1.1	-0.6	-0.2	-0.7	-0.8	-0.7	-0.4	-0.1	0.6	-0.1	0.3	-0.2	0.1	-0.1	-0.1	-0.3	-0.1	-0.2	0.0	-0.4	0.0	-0.1	0.1	0.0	-0.4	-0.2	-0.4	0.4	0.3	0.1	0.0	0.5	-0.2	-0.3	0.5	0.4	-0.3	43.9	17.3
-- Stratification --																																										
strat winter		-0.3		-0.1	0.7	-0.3	-0.6		-0.3	-1.0	-1.2		1.5	-1.4	1.5	-0.2	0.5	-0.8	0.4	0.2	0.2	0.5	0.4	-0.3	-0.5	0.0	-0.5	1.0	0.7	0.2	0.1	-0.8	-1.1	-1.0	0.0	-0.6			-0.1		0.008	0.001
strat spring	0.8	-0.1	2.6	1.6	-0.9	-0.2	2.4	0.5	-0.3	-1.1	0.4	-0.4	0.4	-0.5	2.2	-0.5	0.2	0.9	1.1	-0.1	0.2	-0.8	-0.7	0.1	0.2	0.6	0.1	-0.2	1.1	-0.3	-0.1	0.0	-0.3	-0.8	0.0	-0.4	0.3	-1.1	-1.1		0.017	0.009
strat summer	1.4	-1.4	-0.1	1.1	-0.1	-0.8	-1.2	0.0	-0.8	-0.4	-0.5	-0.5	-0.7	1.1	0.5	-1.4	-0.1	0.8	1.0	-0.1	0.4	0.1	-0.6	-0.2	0.3	0.0	0.9	0.1	0.3	-0.5	-1.9	0.0	0.9	1.9	-1.2	-0.5	1.5	-1.2	-1.0	0.5	0.059	0.01
strat fall			-1.0	0.2	-0.9	-1.3	-0.5	0.3	-0.1	0.3	1.8	-0.5	-0.6	0.0	0.6	-0.1	0.0	0.4	-0.2	0.6	1.1	-0.9	0.3	0.2	-0.5	0.7	-0.2	0.8	-1.1	0.6	-0.8	-0.8	-0.1	-0.4	-1.1	1.3	0.3	-0.6	-0.9	0.3	0.018	0.011
strat annual	0.9	-0.6	0.3	0.9	-0.2	-0.6	0.2	0.3	-0.3	-0.6	0.5	-0.4	0.2	-0.1	1.1	-0.6	0.1	0.4	0.6	0.2	0.4	-0.4	-0.2	-0.1	-0.1	0.4	0.1	0.4	0.1	0.0	-0.7	-0.4	0.0	0.1	-0.6	0.0	0.7	-1.0	-0.9	0.4	0.026	0.022

Figure 26. Annual normalized anomalies of hydrographic parameters for Station 27. The different boxes from top to bottom are: vertically averaged temperature and salinity for different depth ranges, cold intermediate layer (CIL) properties, mixed layer depth (MLD), and stratification for the 4 seasons and annual average. The cells are color-coded according to Figure 2. Gray cells indicate absence of data.

Standard Hydrographic Sections

In the early 1950s, several countries under the auspices of the International Commission for the Northwest Atlantic Fisheries (ICNAF) carried out systematic monitoring along hydrographic sections in Newfoundland and Labrador waters. In 1976, ICNAF normalized a suite of oceanographic monitoring stations along sections in the Northwest Atlantic Ocean from Cape Cod (USA) to Egedesminde (West Greenland) (ICNAF 1978). In 1998 under the Atlantic Zone Monitoring Program (AZMP) of Fisheries and Oceans Canada, the Seal Island (SI), Bonavista Bay (BB), Flemish Cap (47°N) (FC) and Southeast Grand Bank (SEGB) historical stations were selected as core monitoring sections. The White Bay section (WB) continued to be sampled during the summer as a long time series ICNAF/NAFO section (see Figure 1).

Two ICNAF sections on the mid-Labrador Shelf, the Beachy Island (BI) and the Makkovik Bank (MB) sections, were selected to be sampled during the summer if survey time permitted. Starting in the spring of 2009, a section crossing south-west over St. Pierre Bank (SWSPB) and one crossing south-east over St. Pierre Bank (SESPB) were added to the AZMP surveys.

After a significant loss of ship time in 2018 and 2019, our three annual surveys again suffered from significant reduction of various origins in 2020. The spring survey was canceled due to the COVID-19 pandemic. The summer survey was slightly reduced to 18 days instead of 21 (July 13th-31st) and we were able to sample FC, BB, SI and MB. The fall survey, scheduled for November 9th to December 1st was also reduced due to mechanical problems with the ship. We were only able to complete SEGB, FC and BB. In this manuscript we present the summer cross sections of temperature and salinity and their anomalies along the SI, BB and FC sections to represent the vertical temperature and salinity structure across the NL Shelf during 2020.

Temperature and Salinity Variability

The water mass characteristics observed along the standard sections crossing the NL Shelf are typical of subpolar waters with a subsurface temperature range of -1.5°C to 2°C and salinities from 31.5 to 33.5. Labrador Slope water flows southward along the shelf edge and into the Flemish Pass and Flemish Cap regions. This water mass is generally warmer and saltier than the subpolar shelf waters with a temperature range of 3° to 4°C and salinities in the range of 34 to 34.75. Surface temperatures normally warm to between 10° and 12°C during late summer while bottom temperatures remain < 0°C over much of the Grand Banks but increase to between 1° and 3.5°C near the shelf edge below 200 m and in the deep troughs between the banks. In the deeper (> 1000 m) waters of the Flemish Pass and across the Flemish Cap, bottom temperatures generally range from 3° to 4°C. In general, the near-surface water mass characteristics along the standard sections undergo seasonal modification from annual cycles of air-sea heat flux, wind forced mixing, and the formation and melting of sea ice. These mechanisms cause intense vertical and horizontal temperature and salinity gradients, particularly along the frontal boundaries separating the shelf and slope water masses. The seasonal changes in the temperature and salinity fields along the Bonavista section are presented in Colbourne et al. (2015).

The summer temperature and salinity structures along the Seal Island, Bonavista Bay and Flemish Cap (47ºN), hydrographic sections during 2020 are highlighted in Figure 27 to Figure 29. The dominant thermal feature along these sections is associated with the cold and relatively fresh waters overlying the shelf. This water mass is separated from the warmer and denser water of the continental slope region by strong temperature and salinity fronts. The cross sectional area of the CIL (i.e., an indication its volume) is bounded by the 0°C isotherm and highlighted as a thick black contour in the temperature panels. The CIL parameters are generally regarded as robust indices of ocean climate conditions on the eastern Canadian Continental Shelf. While the CIL area undergoes significant seasonal variability, the changes are highly coherent from the Labrador Shelf to the Grand

Banks. The CIL remains present throughout most of the summer until it gradually decays during the fall as increasing winds and storm episodes deepen the surface mixed layer.

During 2020, temperatures were above normal for all sections and at all depths (Figure 27 to Figure 29, bottom left), except for section FC offshore from Flemish Cap (Figure 29, bottom left, after x = 700 km). These warm anomalies are specifically strong near the surface at more than 3°C above the average. At depth, temperatures were also much warmer on inshore portion of the FC section, which signifies warmer bottom conditions in a large portion of the Grand Banks (see section on bottom observations).

The corresponding salinity cross sections show a relatively fresh upper water layer over the shelf with sources from arctic outflow and the Labrador Shelf with values < 33, in contrast to the saltier Labrador Slope water further offshore with values > 34 (Figure 27 to Figure 29, right panels). In 2020, salinities corresponding to the CIL and the inshore portion of the shelf were generally lower than normal for all sections, especially on FC section, while the slope waters were above normal (Figure 27 to Figure 29, bottom left). Like in 2019, this is likely due to an unusual extension of the saltier Labrador Current onto the slope in 2020 compared to the climatology. This is especially evident for sections BB and FC (see difference in salinity field between the top two right panels of all three figures).

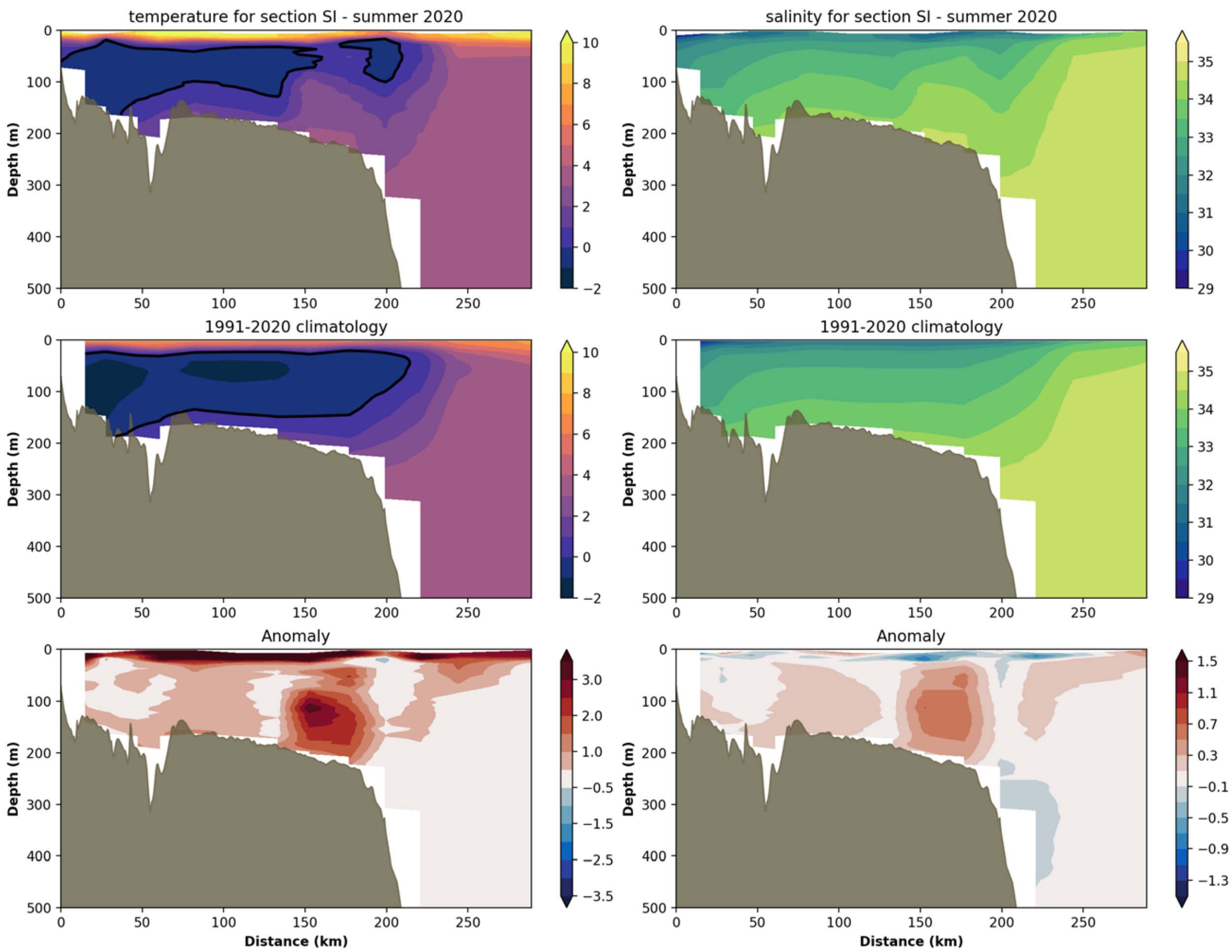

Figure 27. Contours of temperature (°C) and salinity during summer 2020 (top row) and climatological average (middle row) for Seal Island (SI) hydrographic section (see map Figure 1 for location). Their respective anomalies for 2020 are plotted in the bottom panels.

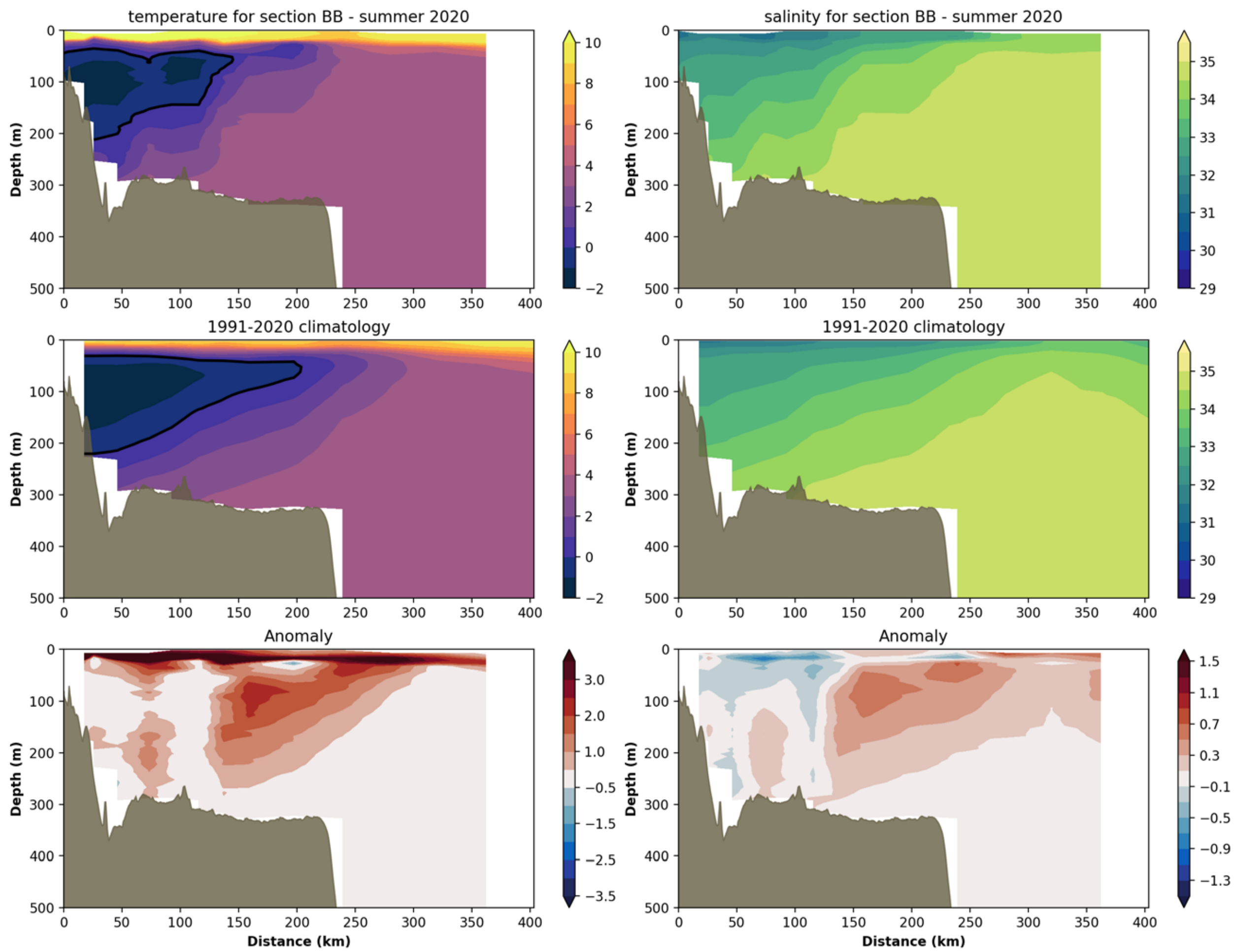

Figure 28. Same as in Figure 27, but for Bonavista (BB) hydrographic section (see map Figure 1 for location).

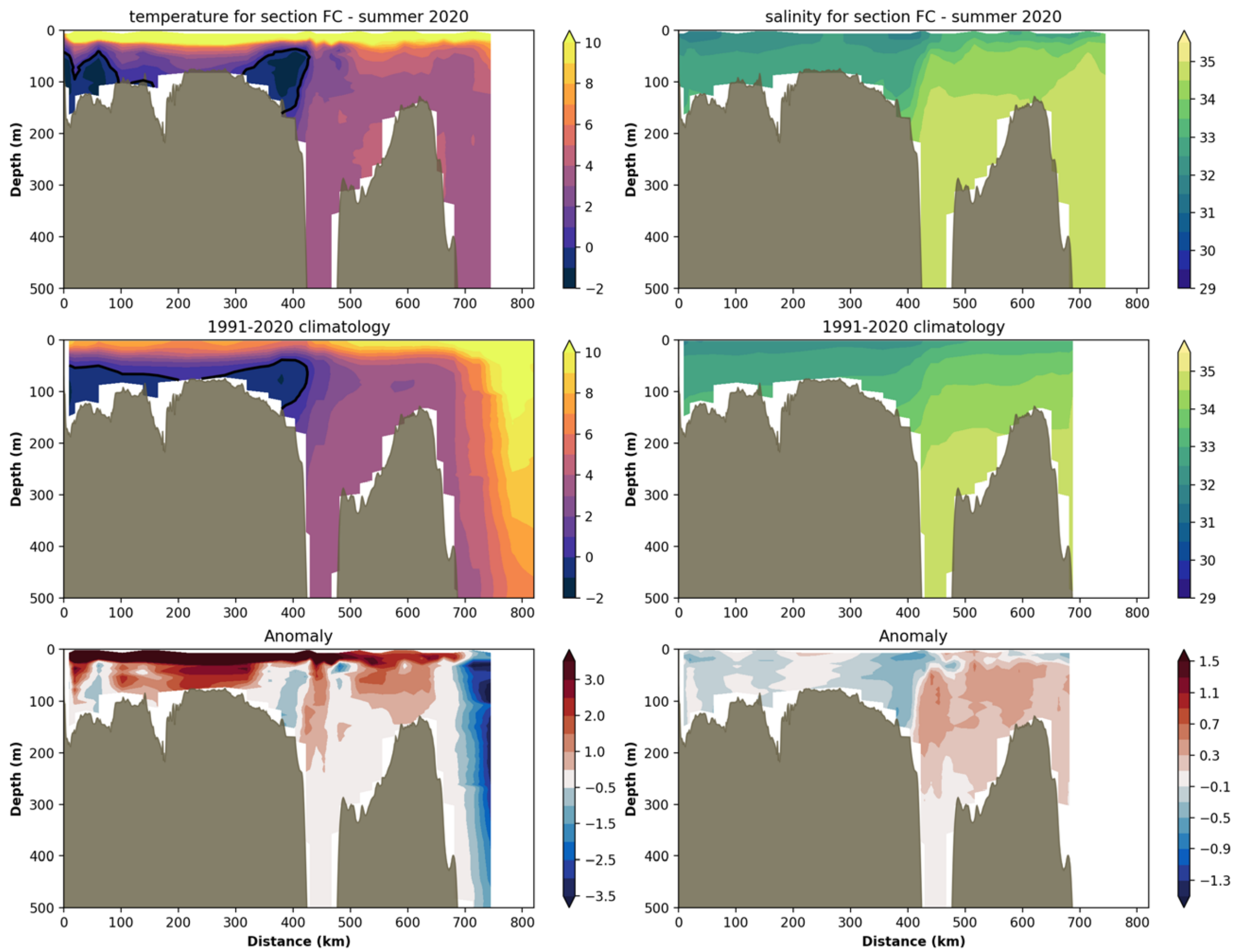

Figure 29. Same as in Figure 27, but for Flemish Cap (FC) hydrographic section (see map Figure 1 for location).

Cold Intermediate Layer Variability

Statistics of summer CIL anomalies for the three hydrographic sections discussed above (Seal Island, Bonavista and Flemish Cap) are presented in a scorecard in Figure 30. The climatological average cross sectional area of the summer CIL along these sections are 19.9 ± 4.1 km^2, 22.9 ± 7.6 km^2 and 16.5 ± 6.4 km^2, respectively. The averaged anomalies of the CIL core temperature (minimum temperature of this layer) and volume (defined as the cross sectional area) for these three sections are summarized in Figure 31 as a time series going back to 1950. In general, the summer CIL has been predominantly warmer/smaller than average since the mid 1990's, with a cooling trend emerging since about 2012 or 2014 to 2017. However, the most striking aspect of this long time series is the warm conditions that prevailed in the 1960's (that stands as a unique feature for this nearly 70-year time series, although measurements during this period were largely made from reversing thermometers that might have missed the CIL core), followed by a cold period that lasted from the mid-1980's to the mid-1990's. In 2020, the CIL area was smaller than normal at SI and BB and normal at FC. The CIL core temperature was colder than normal at SI and FC , and warmer at BB.

	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	x̄	sd
-- Seal Island section --																																											
CIL area (km²)	0.0		0.2	-0.3	2.0	0.7	-0.4	-0.1	-0.7		1.2	1.4	-0.1	1.7	0.0	-0.3	0.2	-0.7	0.5	-1.6	-0.1	0.5	0.0	0.9	-0.9	0.0	-0.5	0.1	0.2	0.6	-0.6	-1.2	0.6	-0.5	0.4	2.0	-0.1	1.9	-2.1	-0.4	-1.9	19.9	4.1
CIL core (°C)	0.9		1.2	-0.4	-0.8	-0.1	2.2	1.7	1.3		-0.5	-0.5	0.0	-0.6	-0.5	-0.5	0.7	-0.5	-0.5	-0.5	-0.5	2.6	-0.5	1.8	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	2.6	-0.5	-0.5	2.6	-0.1	-0.5	-0.5	-0.5	-0.5	0.5	-0.5	-1.7	0.1
core depth (m)	1.1		1.3	0.0	1.3	-1.4	1.1	1.3	-0.3		0.4	0.4	0.0	-1.2	0.4	0.4	-1.8	0.4	0.4	0.4	0.4	-2.3	0.4	0.6	0.4	0.4	1.3	0.4	0.4	0.4	-2.7	0.4	1.1	-0.7	-1.2	1.1	0.4	0.4	0.4	-1.6	0.4	87.4	22.5
-- Bonavista section --																																											
CIL area (km²)	-0.4	-0.2	1.5	1.7	3.2	2.0	-0.4	-0.7	0.9	0.7	1.8	2.4	1.2	1.4	1.0	-0.2	0.2	-0.4	0.3	-0.4	0.7	-0.4	-0.4	0.1	-1.4	-0.8	-1.2	-0.3	-0.9	0.5	-0.3	-2.1	-0.2	-0.6	1.8	1.0	0.8	0.5	-0.4	-0.9	-1.2	22.9	7.6
CIL core (°C)	1.2	0.6	-0.3	-1.7	-1.2	-1.0	0.3	-0.7	0.5	-1.0	-0.9	-1.3	-1.1	-1.1	-1.2	-0.6	0.8	-0.6	-0.6	0.0	-0.2	0.5	-0.1	-0.3	1.8	0.9	2.0	0.0	-0.3	-0.7	0.8	2.5	-0.8	0.4	-0.9	-1.0	-0.6	-0.8	0.8	0.4	1.2	-1.6	0.1
core depth (m)	0.5	-0.8	0.4	1.4	-1.5	-1.3	-0.1	1.4	-0.1	0.2	1.9	-1.3	0.4	1.1	0.4	-0.1	-0.3	-0.5	-1.3	0.7	0.9	-1.3	1.1	0.2	-0.5	-1.7	0.7	0.7	-0.1	-1.7	-1.7	0.2	1.1	-0.8	0.7	2.1	0.4	-0.5	-0.3	1.4	-0.1	92.7	20.8
-- Flemish Cap section --																																											
CIL area (km²)	-1.6	-0.3	-1.5	2.0	2.3	0.8	0.2	-1.2	-0.8	1.0	0.8	2.0	-0.5	1.7	0.0	-0.5	0.0	0.4	0.8	0.5	-1.1	-0.6	0.2	-0.5	-0.4	0.2	-1.5	-0.1	-1.1	0.4	-1.9	-0.9	0.8	-0.7	-0.2	-0.2	2.6	-0.9	0.1	1.3	0.2	16.5	6.4
CIL core (°C)	0.0	1.1	-0.3	-0.9	-0.9	-0.9	-0.7	-0.9	0.4	-1.2	-0.5	-1.1	-0.8	-1.1	-0.6	-1.4	1.2	0.1	-0.5	0.4	0.2	1.4	-0.8	-0.2	0.7	0.3	0.6	-0.4	-0.2	-0.9	2.4	1.9	-1.0	2.3	-0.8	-1.0	-0.2	0.2	-0.4	0.3	-0.7	-1.5	0.2
core depth (m)	1.4	2.9	1.4	-0.4	-1.0	0.1	0.6	0.9	3.0	-0.2	0.3	-1.0	-1.7	-0.4	0.6	1.4	-1.0	-1.0	0.3	1.1	-0.2	1.1	-0.4	0.9	0.6	-0.4	0.6	-0.2	-1.0	2.2	-1.0	-0.7	-0.2	1.1	-1.0	0.9	0.3	-1.7	1.6	-0.4	-0.4	75.0	19.3

Figure 30. Scorecards of the cold intermediate layer (CIL) summer statistics along Seal Island, Bonavista and Flemish Cap hydrographic sections. The CIL area is defined as all water below 0°C (see black contours in Figure 27 to Figure 29), and the CIL core temperature and depth are the minimum temperature of the CIL and the depth at which it is encountered respectively. Color codes for the area and depth have been reversed (positive is blue and negative is red) because they represent cold conditions. Grayed cells indicate absence of data.

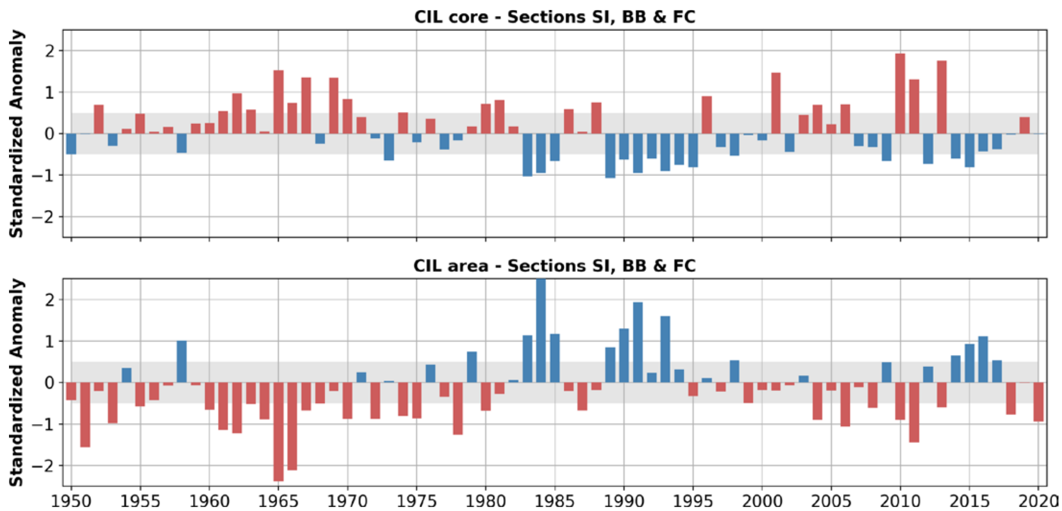

Figure 31. Mean normalized anomalies of the summer CIL core temperature (top) and area (bottom) over Seal Island, Bonavista and Flemish Cap sections since 1950 (values for each separate section since 1980 can be found in Figure 30). Shaded gray areas represent the ±0.5 SD range considered "normal".

Bottom Observations in NAFO sub-areas

Canada has been conducting stratified random bottom trawl surveys in NAFO Sub-areas 2 and 3 on the NL Shelf since 1971. Areas within each division, with a selected depth range, were divided into strata, and the number of fishing stations in an individual stratum was based on an area-weighted proportional allocation (Doubleday, 1981). Temperature profiles (and salinity profiles since 1990) are available for most fishing sets in each stratum. These surveys provide large spatial-scale oceanographic data sets for the Newfoundland and Labrador Shelf. NAFO Subdivision 3Ps on the Newfoundland south coast and Divisions 3LNO on the Grand Banks are surveyed in the spring, and Divisions 2HJ off Labrador in the north, 3KL off eastern Newfoundland, and 3NO on the southern Grand Bank are surveyed in the fall. The hydrographic data collected on these surveys are routinely used to assess the spatial and temporal variability in the thermal habitat of several fish and invertebrate species. A number of products based on the data are used to characterize the oceanographic bottom habitat. Among these are contour maps of the bottom temperatures and their anomalies, the area of the bottom covered by water in various temperature ranges, etc. In addition, species-specific *thermal habitats* indices are often used in marine resource assessments for snow crab and northern shrimp.

The current method to derive the bottom temperature was introduced by Cyr et al. (2019) and is similar to the approach presented in reports of the annual physical oceanographic conditions for the Gulf of St. Lawrence (Galbraith et al. 2020) and Newfoundland and Labrador Shelves (Cyr et al. 2021). First, all available annual profiles of temperature and salinity (from AZMP hydrographic campaigns, multi-species resources assessments, surveys from other DFO regions, international oceanographic campaigns, Argo program, etc.) are vertically averaged in 5 m bins and vertically interpolated to fill missing bins. Then, for each season (April-June for spring and September-December for fall), all data are averaged on a regular 0.1° x 0.1° (latitudinal x longitudinal) grid to obtain one seasonal profile per grid cell. Since this grid has missing data in many cells, each depth level is horizontally linearly interpolated. For each grid point, the bottom observation is considered as the data at the closest depth to the GEBCO_2014 Grid bathymetry (version 20141103), to a maximum 50 m difference. Lastly, bottom observations deeper than 1000 m are clipped. This method is applied for all years between 1980 and 2020 from which the 1991-2020 climatology is derived. Anomalies for 2020 are calculated as the difference between annual observations and the climatology.

Spring Conditions

The 2020 spring multispecies and AZMP surveys were cancelled because of the COVID-19 pandemic, and therefore no data are available for that season. The Spring climatological bottom temperature and salinity maps for NAFO divisions 3LNOPs are presented in Figure 32 and Figure 33, respectively. Bottom temperatures in 3L are generally below 0°C except in the northern part and near the shelf edge where they range from 2° to 4°C. Over the central and southern areas of the Grand Bank (3NO), bottom temperatures generally range from 0° on the bank (except above 3°C on the southeast shoal) to 6°C on the southwest slope of the Grand Bank. On St. Pierre Bank and most of eastern 3Ps, temperatures are generally below 0°, while they are above 5°C in the Laurentian Channel.

Spring bottom salinity in 3LNO generally range from 32 – 33 over the central Grand Bank, and from 33 – 35 closer to the shelf edge. In 3Ps, salinities are between 32 and 33 over shallower areas and above 34.5 in the Laurentian channel.

Climate indices based on normalized spring temperature anomalies between 1980 and 2019 (no 2020) are shown in a color-coded scorecard in Figure 34. Overall, the table colors visually highlight two main periods of this time series that are the cold period of the late 80's / early 90's (mostly blue cells) and the warm period of the early 2010's (mostly red cells). During the spring of 2011 in Divisions 3LNO, none of the bottom area was covered by <0°C water, the only such occurrence since the surveys began in the early 1970s, corresponding to -2.1 SD (little area covered by cold water). This warm period lasted between 2010 and 2013 before returning towards to normal/cold values. Between 2014 and 2017 the normalized anomalies in bottom temperature in 3LNO varied between -0.6 SD and -0.1 SD, while the area covered by water <0°C ranged between +0.8 SD and +0.2 SD.

In Division 3Ps bottom temperatures exhibit some similarities with 3LNO, with warm years of 1999-2000 and 2005-2006 separated by a colder period between 2001-2004 (2003 is the coldest year on record since 1991 at -2.1 SD). Contrary to 3LNO, 3Ps did not see a return to colder than normal conditions between 2014 and 2016, since no year was below normal since 2007, with the warmest year being 2016 at 1.6 SD above normal. The spring of 2011 had the lowest area of <0°C bottom water of the time series at -1.7 SD, also corresponding to little or no bottom waters with temperatures of <0°C.

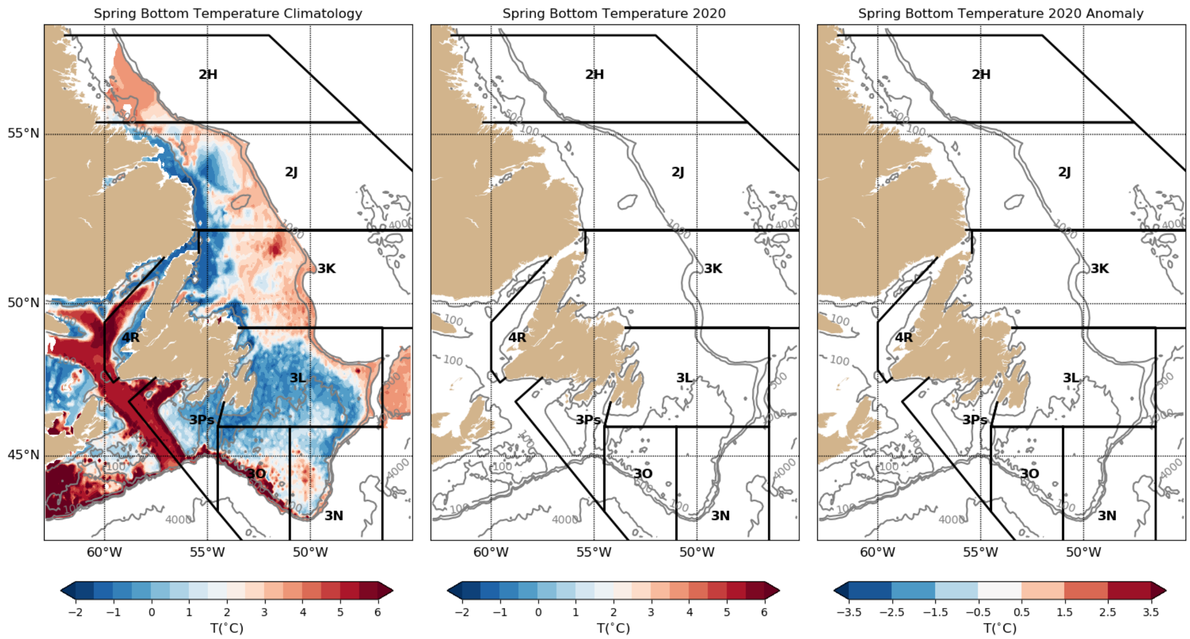

Figure 32. Maps of the mean 1991-2020 spring bottom temperature (left), and spring 2020 bottom temperature (center) and anomalies (right) for NAFO Divisions 3LNOPs only. The location of observations used to derive the temperature field is shown as black dots in the center panel.

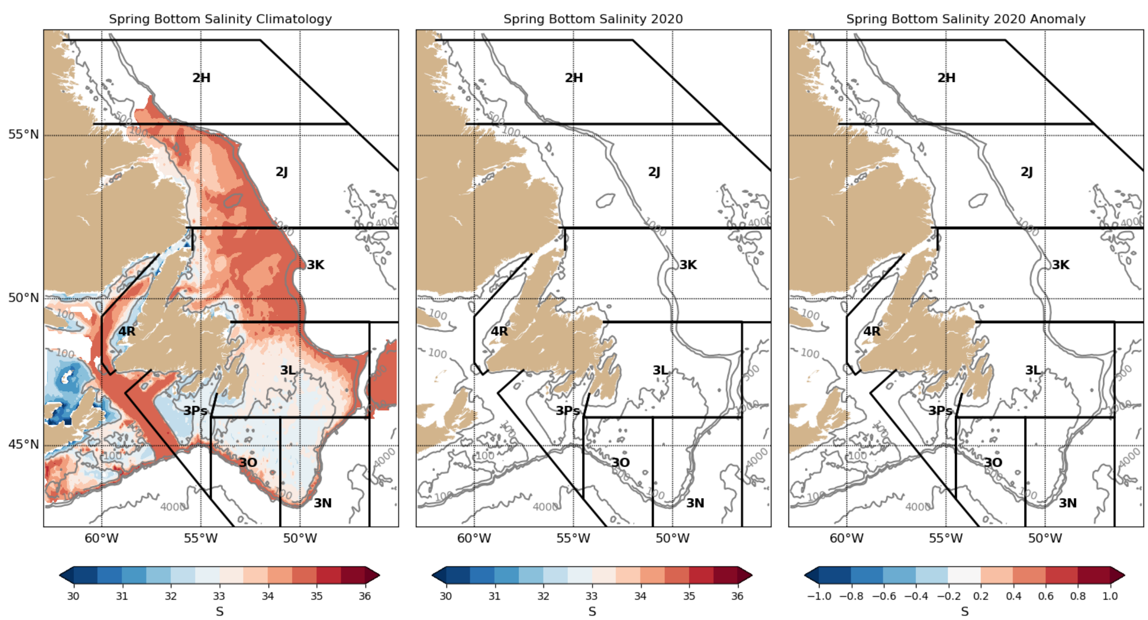

Figure 33. Maps of the mean 1991-2020 spring bottom salinity (left), and spring 2020 bottom salinity (center) and anomalies (right) for NAFO Divisions 2J3KLNO only. The location of observations used to derive the salinity field is shown as black dots in the center panel.

	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	$\bar{x}$	sd
-- NAFO division 3LNO --																																											
T_{bot}	-0.1	1.4	-0.8	0.4	-0.9	-1.5	-1.3	-0.5	0.0	-1.4	-2.1	-2.1	-1.7	-1.3	-1.6	-0.8	-0.1	-0.9	0.6	1.2	0.6	0.0	-0.2	-1.1	1.3	0.6	0.5	0.2	0.1	0.2	0.9	2.1	1.4	1.1	-0.5	-0.1	-0.6	-0.1	0.2	0.2		1.1	0.5
$T_{bot<200m}$	-0.3	1.6	-0.6	0.7	-0.9	-1.5	-1.3	-0.4	0.0	-1.2	-2.0	-2.0	-1.7	-1.2	-1.6	-0.9	0.0	-1.0	0.6	1.4	0.7	0.0	-0.2	-1.3	1.3	0.5	0.4	0.1	0.0	0.2	0.8	2.1	1.4	1.1	-0.6	-0.1	-0.3	-0.2	0.2	0.3		0.7	0.6
$Area_{>2^{\circ}C}$	-0.2	1.3	-1.5	0.6	-0.7	-1.6	-1.2	-0.4	0.0	-1.4	-2.1	-1.8	-1.8	-1.1	-1.4	-0.4	-0.1	-0.8	0.4	1.2	0.4	-0.6	-0.3	-1.0	1.8	0.6	0.3	0.3	0.5	0.7	0.4	2.4	1.5	0.4	-0.4	0.3	-1.0	0.0	-0.3	-0.1		69.3	20.8
$Area_{<0^{\circ}C}$	-0.3	-1.1	0.2	0.3	1.0	1.4	1.2	0.9	0.5	1.1	1.6	1.9	1.4	1.4	1.3	0.8	0.0	0.9	-0.6	-1.1	-0.1	0.0	0.2	1.0	-1.7	-0.7	-1.4	0.2	0.2	0.5	-1.6	-1.9	-0.8	-1.0	0.8	0.4	0.3	0.2	-0.2	-0.2		90.0	43.6
-- NAFO division 3Ps --																																											
T_{bot}			-0.5	0.1	0.2									-1.3	-1.3	-0.8	-0.2	-1.2	-0.2	0.8	1.1	-1.3	-0.5	-2.1	-0.4	0.6		-1.4	-0.3	0.2	0.5	1.4	1.2	0.7	0.3	0.5	1.6	0.3	1.1	0.7		2.4	0.5
$T_{bot<200m}$			0.2	0.5	0.9									-1.8	-1.5	-0.9	-0.1	-1.3	0.1	1.1	1.3	-1.0	-0.6	-2.0	0.0	1.0		-0.9	0.2	0.5	0.4	1.5	0.9	0.8	0.2	0.4	1.2	-0.4	0.9	0.0		0.9	0.6
$Area_{>2^{\circ}C}$			0.6	1.5	-1.0									-0.2	-0.5	0.5	-0.4	-0.7	0.6	2.4	2.0	-1.5	-0.7	-1.6	-1.0	0.1		-1.1	0.1	-0.1	0.1	1.8	0.2	0.5	-0.5	-0.2	-0.1	-0.3	1.4	-0.6		26.5	3.0
$Area_{<0^{\circ}C}$			-0.2	-0.4	-0.7									1.7	1.3	1.2	-0.3	1.5	0.1	-0.5	-0.9	0.8	0.4	2.2	-0.8	-1.2		0.7	0.2	-0.1	-0.7	-1.5	-1.2	-1.2	-0.2	-0.6	-0.9	0.4	-0.8	0.4		14.2	9.8

Figure 34. Scorecards of normalized spring bottom temperature anomalies for 3LNO and 3Ps.

Fall Conditions

Fall bottom temperature and salinity climatological maps, together with 2020 observations and anomalies for NAFO divisions 2HJ3KLNO, are presented in Figure 35 and Figure 36, respectively (see center panel for station occupation coverage). In 2020, most of the area was warmer than average, with a marked north-south gradient of bottom temperature anomalies in 2HJ3KLNO. While temperatures were only 0.5°C to 1.5°C above normal in 2HJ and 3K, temperatures were 1.5°C to 2.5°C above average in 3LN, and more than 3.5°C above average in 3O (Figure 35, left panel). The latter is probably due to an excursion of warm and salty Gulf Stream waters on the western part of the Grand Bank since there is a corresponding strong salinity anomaly (+1 salinity unit) in this area (Figure 36, left panel). Positive salinity anomalies are also found elsewhere on the NL shelf close to the coast and around the northern part of the Grand Bank.

Normalized bottom temperature and other derived indices anomalies are presented in the scorecard in Figure 37. After a generalized cold period between the mid 1980's and the mid-1990's, bottom temperature increased until about 2010 and 2011, the two warmest years on record. While the years 2012-2017 were generally marked by cooler than averaged conditions, the period 2018-2020 generally shows above normal conditions (none of the indices in Figure 37 is negative during this period).

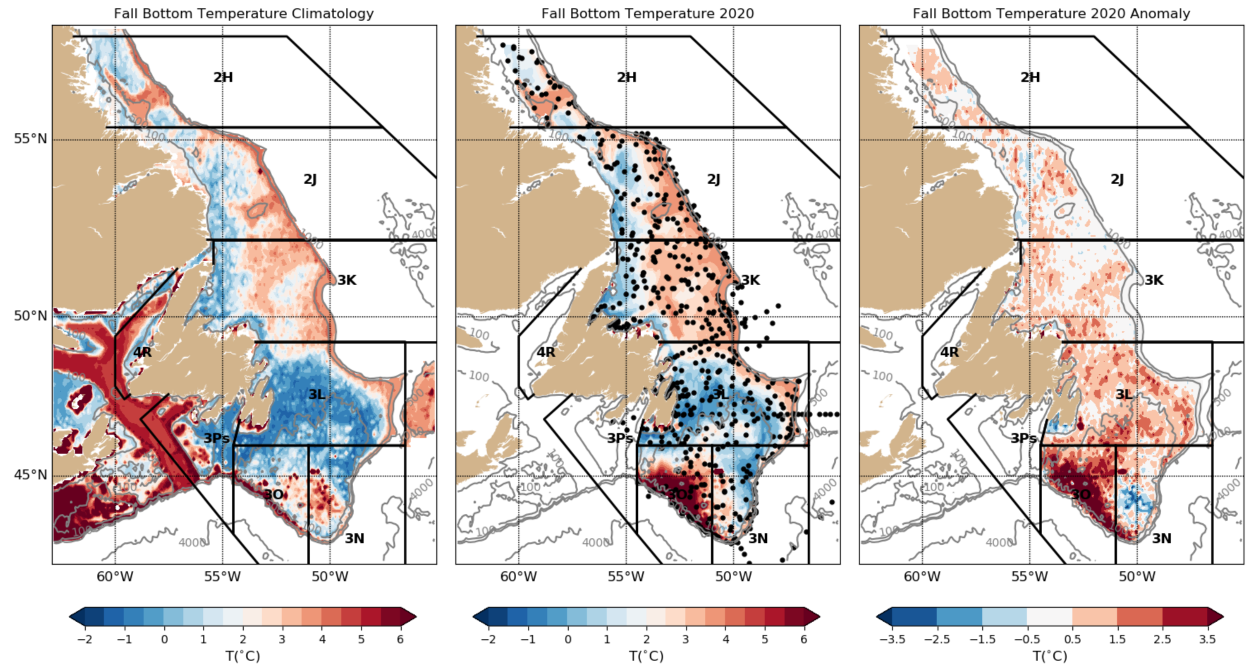

Figure 35. Maps of the mean 1991-2020 fall bottom temperature (left) and fall 2020 bottom temperature (center) and anomalies (right) for NAFO Divisions 2HJ3KLNO only. The location of observations used to derive the temperature field is shown as black dots in the center panel.

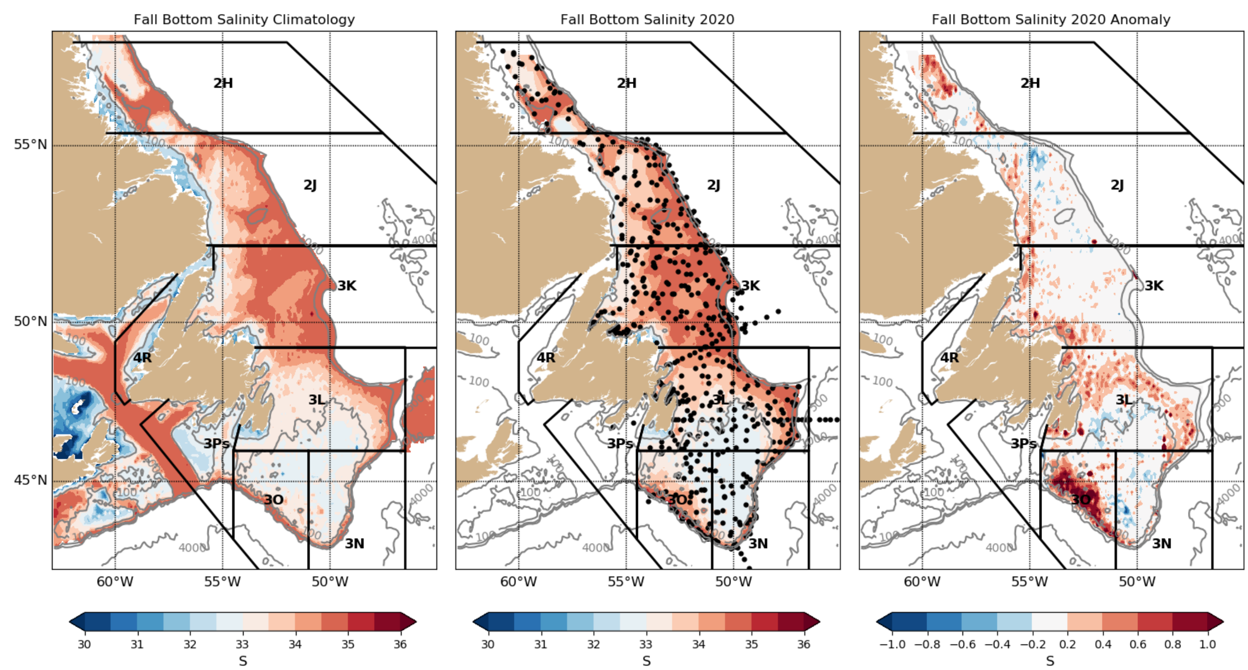

Figure 36. Maps of the mean 1991-2020 fall bottom salinity (left), and fall 2020 bottom salinity (center) and anomalies (right) for NAFO Divisions 2HJ3KLNO only. The location of observations used to derive the salinity field is shown as black dots in the center panel.

	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	x̄	sd
-- NAFO division 2H --																																											
T_{bot}		-0.5		-3.2								-2.2						-0.2	-0.2	0.2		-0.5			1.2		-0.3		0.1		1.8	2.0	0.3	-0.4	-0.1	-0.6	-0.4	-1.6	0.2	0.2	0.3	2.3	0.4
$T_{bot<200m}$		0.4		-2.7								-2.0						0.6	0.2	0.4		-1.5			1.0		-0.6		-0.6		1.5	1.9	0.4	-0.8	-0.5	0.1	0.0	-1.4	0.3	0.4	0.7	1.1	0.5
$Area_{>2^\circ C}$		-0.3		-1.4								-1.0						0.7	0.7	0.3		-1.2			1.5		0.0		-0.2		1.6	2.0	-0.2	-0.2	-0.5	-1.6	-0.4	-1.6	0.2	0.0	-0.2	20.9	4.1
$Area_{<1^\circ C}$		-0.9		2.9								2.6						-0.9	0.6	-0.6		0.4			-0.7		0.9		0.9		-1.3	-1.4	-0.2	0.9	0.1	-0.1	-0.1	1.0	-0.5	-0.7	-1.0	9.9	7.3
-- NAFO division 2J --																																											
T_{bot}	-0.8	-0.2	-1.7	-1.6	-2.9	-2.4	-0.2	-2.1	-0.4	-0.9	-1.9	-1.4	-2.3	-2.3	-1.6		0.3	0.0	0.0	0.3	-0.5	0.5	0.1	0.6	1.0	1.2	-0.4	1.2	-0.1	0.1	1.7	1.7	-0.1	0.0	-0.7	-0.7	0.2	-0.3	0.8	0.8	0.0	2.3	0.5
$T_{bot<200m}$	-0.4	0.0	-1.3	-1.8	-2.5	-1.8	0.0	-1.8	-0.3	-0.9	-1.5	-1.5	-2.1	-2.0	-1.3		0.5	-0.2	-0.2	0.4	-0.5	0.7	0.3	0.6	0.7	1.2	-0.7	1.2	-0.2	0.1	1.5	1.7	-0.3	-0.4	-1.0	-0.8	0.8	-0.3	0.6	1.2	0.0	1.0	0.7
$Area_{>2^\circ C}$	-0.5	-0.3	-1.8	-1.1	-2.2	-2.0	-0.1	-1.7	-0.4	-1.0	-1.8	-1.2	-1.6	-1.9	-1.3		0.7	0.1	-0.2	-0.3	-0.5	0.6	-0.6	0.5	0.9	1.4	-0.3	1.5	-0.7	-0.3	1.9	2.2	-0.6	-0.3	-0.7	-0.5	0.2	-0.4	0.6	0.9	0.1	52.4	13.3
$Area_{<1^\circ C}$	0.5	-0.1	1.8	1.7	2.2	2.0	-0.1	2.1	-0.1	1.0	1.8	1.6	1.9	2.0	1.4		-0.4	-0.1	0.3	-0.8	0.5	-0.7	-0.5	-0.7	-0.5	-1.3	0.7	-1.2	0.6	-0.1	-1.3	-1.3	0.5	0.4	1.0	0.8	-1.1	0.4	-0.6	-1.3	-0.2	19.5	14.6
-- NAFO division 3K --																																											
T_{bot}	-0.3	-0.4	-0.6	-1.0	-1.7	-2.6	-0.5	-1.5	-0.8	-0.7	-2.2	-1.3	-2.2	-2.2	-1.7	-1.1	-0.4	0.3	0.2	0.6	0.2	-0.2	0.4	0.5	1.3	0.7	0.0	0.8	0.5	0.0	1.4	2.1	0.1	0.3	-0.5	-0.2	-0.5	-0.9	0.6	0.7	0.5	2.6	0.4
$T_{bot<200m}$	-0.2	-0.5	-2.2	-1.9	-2.1	-2.0	-0.2	-1.8	-1.1	-0.9	-1.8	-1.7	-1.8	-2.0	-1.6	0.0	0.4	-0.3	-0.6	0.3	-0.6	0.2	0.4	0.4	1.1	0.7	-0.3	0.9	-0.3	-0.2	1.8	1.6	-0.1	-0.5	-0.9	-0.3	0.9	-0.5	0.8	1.5	1.0	0.6	0.7
$Area_{>2^\circ C}$	-0.3	-0.1	-0.3	-1.1	-1.4	-2.7	-0.2	-1.5	-0.8	-0.8	-2.1	-1.0	-2.1	-2.1	-1.8	-1.5	-0.4	0.6	0.4	0.6	0.4	-0.2	0.8	0.2	1.0	0.9	0.0	0.8	0.5	-0.5	1.6	1.4	0.0	0.5	-0.7	-0.1	-0.8	-0.9	0.8	0.8	0.9	77.7	13.0
$Area_{<1^\circ C}$	0.3	0.1	0.6	1.2	1.4	2.6	-0.4	0.8	0.2	0.3	2.8	1.4	2.0	2.5	1.8	0.2	-0.5	0.1	0.2	-0.3	0.4	0.0	-0.6	0.0	-1.2	-0.9	0.4	-1.0	0.2	0.3	-1.3	-1.4	0.3	-0.2	0.6	0.1	-0.7	0.8	-0.9	-1.3	-0.9	13.3	9.0
-- NAFO division 3LNO --																																											
T_{bot}	0.3	-0.1	1.0	0.1	-0.5	-1.0	0.0	-0.7	-1.1	0.1	-1.0	-1.4	-1.3	-2.0	-1.4	-0.3	0.1	-0.1	0.7	1.7	-0.3	0.0	0.0	-0.3	0.8	0.2	0.5	-0.1	-0.5	0.5	1.3	2.4	0.4	0.6	-0.8	-0.1	0.2	-2.1	0.2	0.1	1.1	1.2	0.5
$T_{bot<200m}$	0.5	-0.1	1.2	0.2	-0.4	-0.9	0.2	-0.7	-1.0	0.2	-0.7	-1.3	-1.1	-2.0	-1.3	-0.2	0.2	-0.2	0.7	1.8	-0.5	0.1	-0.1	-0.4	0.7	0.2	0.6	-0.3	-0.8	0.6	1.4	2.4	0.3	0.6	-0.9	-0.3	0.3	-2.0	0.1	0.2	1.2	0.8	0.5
$Area_{>2^\circ C}$	0.1	-0.3	0.5	0.5	0.1	-1.4	0.1	-0.6	-1.5	0.7	-1.1	-1.0	-1.3	-1.8	-1.3	-0.5	-0.1	-0.1	1.0	2.1	-0.1	-0.1	-0.2	-0.4	0.5	0.1	0.2	-0.1	-0.7	0.5	1.2	2.3	0.7	0.7	-1.0	0.0	0.3	-2.0	-0.1	0.1	1.3	73.5	22.3
$Area_{<0^\circ C}$	-0.6	0.8	0.1	0.8	1.1	0.4	0.0	0.5	0.4	0.2	0.6	1.4	1.1	2.0	1.4	-0.2	0.1	0.3	-0.2	-1.2	0.7	0.1	-0.3	0.0	-1.6	-0.5	-0.9	0.1	0.5	-0.1	-1.1	-2.5	0.2	0.0	0.0	0.2	0.3	2.0	-0.4	-0.1	-1.3	91.6	33.2

Figure 37. Scorecards of normalized fall bottom temperature anomalies for 2H, 2J, 3K and 3LNO.

Ocean Conditions on the Scotian Shelf and Gulf of Maine (NAFO Sub-area 4)

Coastal Temperatures and Salinities

Coastal sea surface temperatures have been collected at Halifax (Nova Scotia) and St. Andrews (New Brunswick) since the 1920s (Figure 38). In 2020, the SST anomalies were +0.9°C (+1.3 SD) for Halifax, an increase of 0.8°C from 2019 and +1.3°C (+2.2 SD) for St. Andrews, an increase of 0.9°C from 2019.

Temperature and salinity measurements through the water column, for the most part sampled monthly, have been taken since 1924 at Prince 5, at the entrance to the Bay of Fundy (Figure 38). 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). The depth-averaged (0-90 m) temperature, salinity and density anomaly time series are shown in x (C-E). In 2020, the annual temperature anomaly was +1.0°C (+1.9 SD) and the salinity anomaly was +0.2 (+1.1 SD). These represent changes of +0.6°C and +0.3 from the 2019 values. The below-normal density anomaly is accounted for by both positive temperature anomaly and negative salinity anomaly.

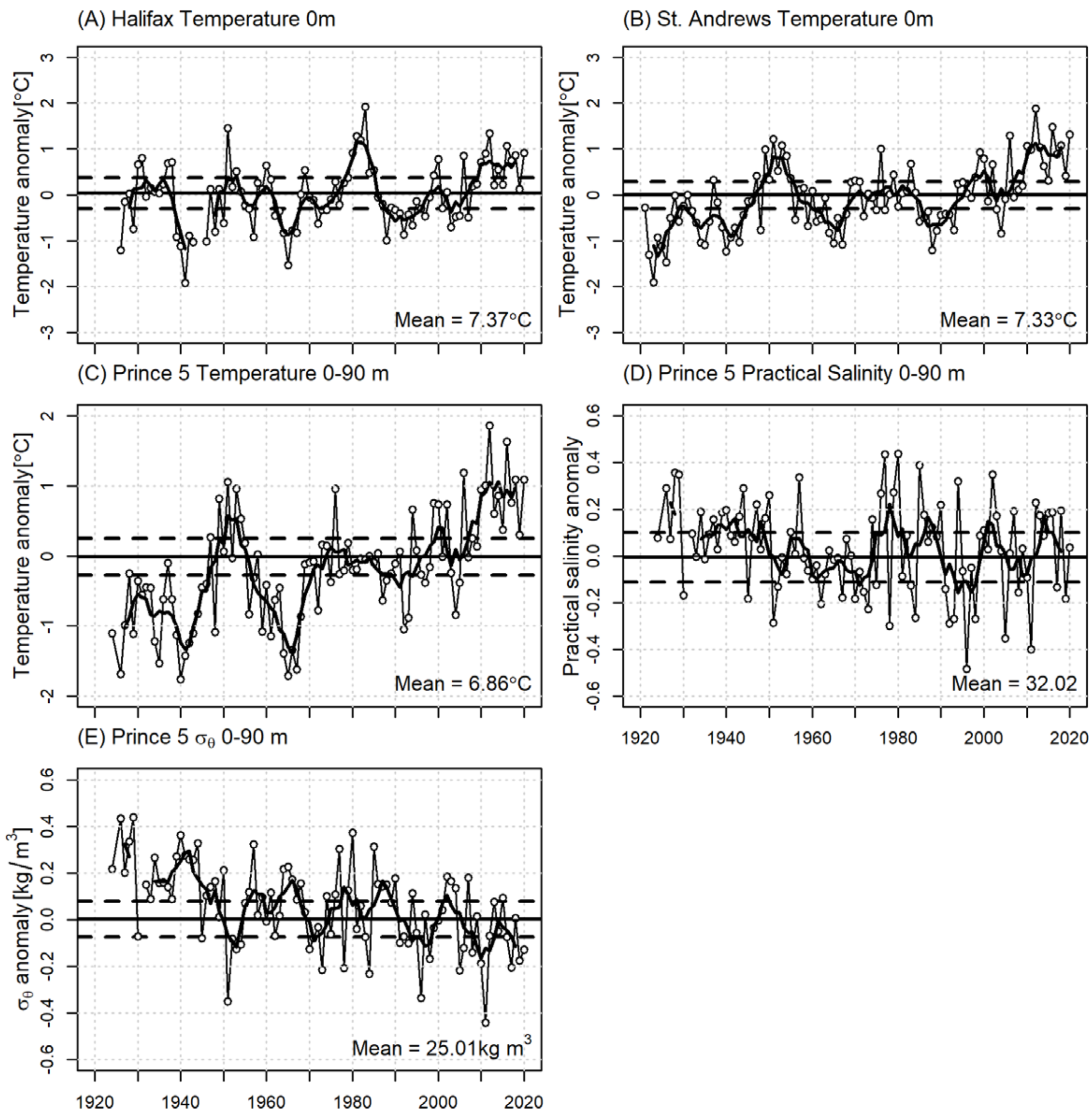

Figure 38. The annual surface temperature anomalies (dotted line with circles) and their 5-year running means (heavy black line) for (A) Halifax Harbour and (B) St. Andrews; annual depth-averaged (0-90 m) (C) Temperature, (D) salinity and (E) density anomalies for the Prince 5 monitoring station at the mouth of the Bay of Fundy. Horizontal dashed lines are the climatological average ±0.5 SD.

Temperatures from Long-term Stations

Drinkwater and Trites (1987) tabulated monthly mean temperatures and salinities from available bottle data for areas on the Scotian Shelf and in the eastern Gulf of Maine that generally correspond 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 (5 year running means) temperature anomalies at selected depths for six areas (see map Figure 39) is presented in Figure 40. The Cabot Strait temperatures represent a mix of Labrador Current Water and Warm Slope Water (e.g., Gilbert et al., 2005) entering the Gulf of St. Lawrence along Laurentian Channel; the Misaine Bank series characterizes the colder near bottom temperatures on the Eastern Scotian Shelf 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 anomalies represent the Slope Water intrusions onto the Shelf that are subsequently trapped in the deep inner basins (note the large anomaly “events” in Figure 40C, for example, around 1980 and 2009 indicative of pulse of Labrador Slope Water); the Lurcher Shoals observations define the ocean climate on the southwest Scotian Shelf and the shallow waters entering the Gulf of Maine via the Nova Scotia Current; last, the Georges Basin series indicates the slope waters entering the Gulf of Maine through the Northeast Channel. Annual anomalies are based on the averages of monthly values; however, observations may not be available for each month in each area. For Cabot Strait, Misaine Bank, Emerald Basin, Georges Basin, eastern Georges Bank and Lurcher Shoals, 2020 annual anomalies are based on observations from one, five, five, three, three and one month, respectively.

In 2020, the annual anomaly was +2.1°C (+6.3 SD) for Cabot Strait at 200-300 m (the largest anomaly; six of the last seven years were the warmest). For the shallow Misaine Bank on the eastern Scotian Shelf, the annual anomaly was +0.6°C (+0.9 SD) at 100 m. For the deep basins on the central Scotian Shelf and Gulf of Maine, the 2020 anomalies were +1.6°C (+1.9 SD) for Emerald Basin at 250 m (4th highest value, 2019 was a record high; the last seven years were the warmest in the record) and +1.1°C (+2.1 SD) for Georges Basin at 200 m (6th warmest, 2019 was the second warmest with 2018 the warmest; the last eight years were the warmest in the record). For the shallow banks in western Nova Scotia, the anomalies were +0.9°C (+1.6 SD) for eastern Georges Bank at 50 m and +1.6°C (+2.0 SD) for Lurcher Shoals at 50 m (2018 was the second highest with 2012 having the record). These values correspond to changes of +0.5˚C, +0.8˚C, -0.2˚C, -0.6˚C, +1.0˚C, and +1.2˚C, from the 2019 values.

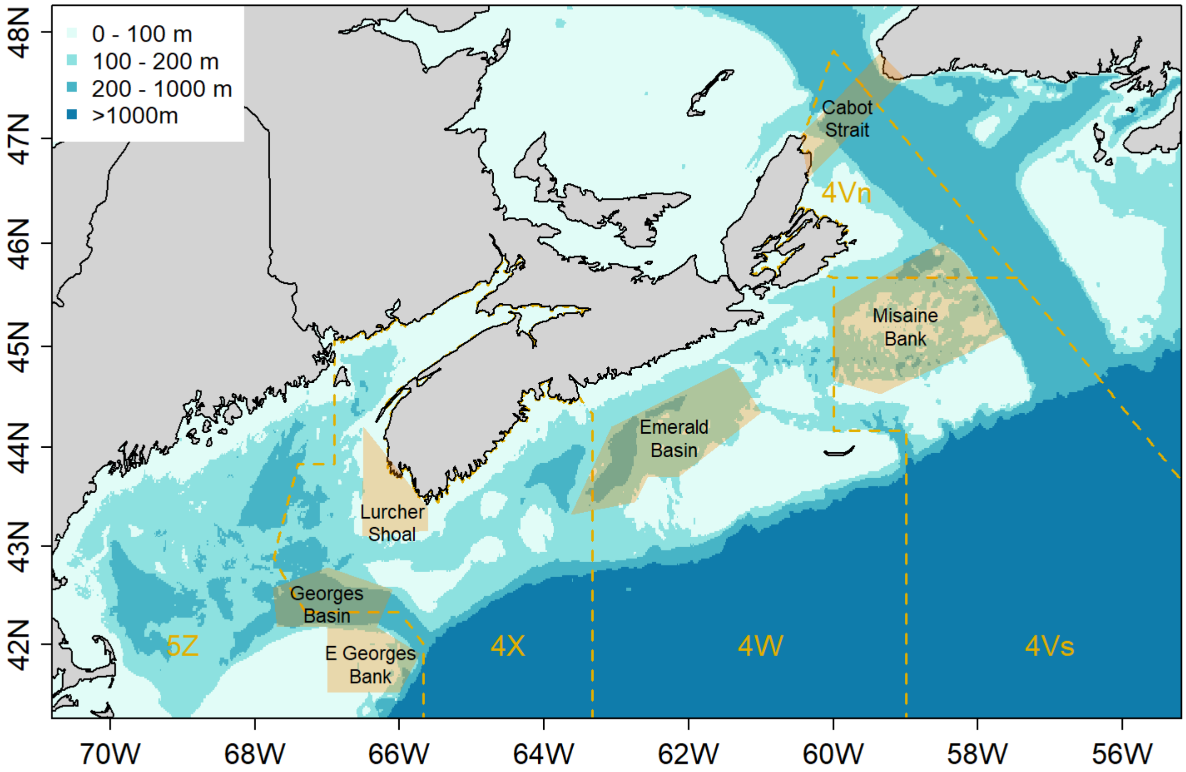

Figure 39. Areas on the Scotian Shelf and eastern Gulf of Maine used to characterize the different water masses.

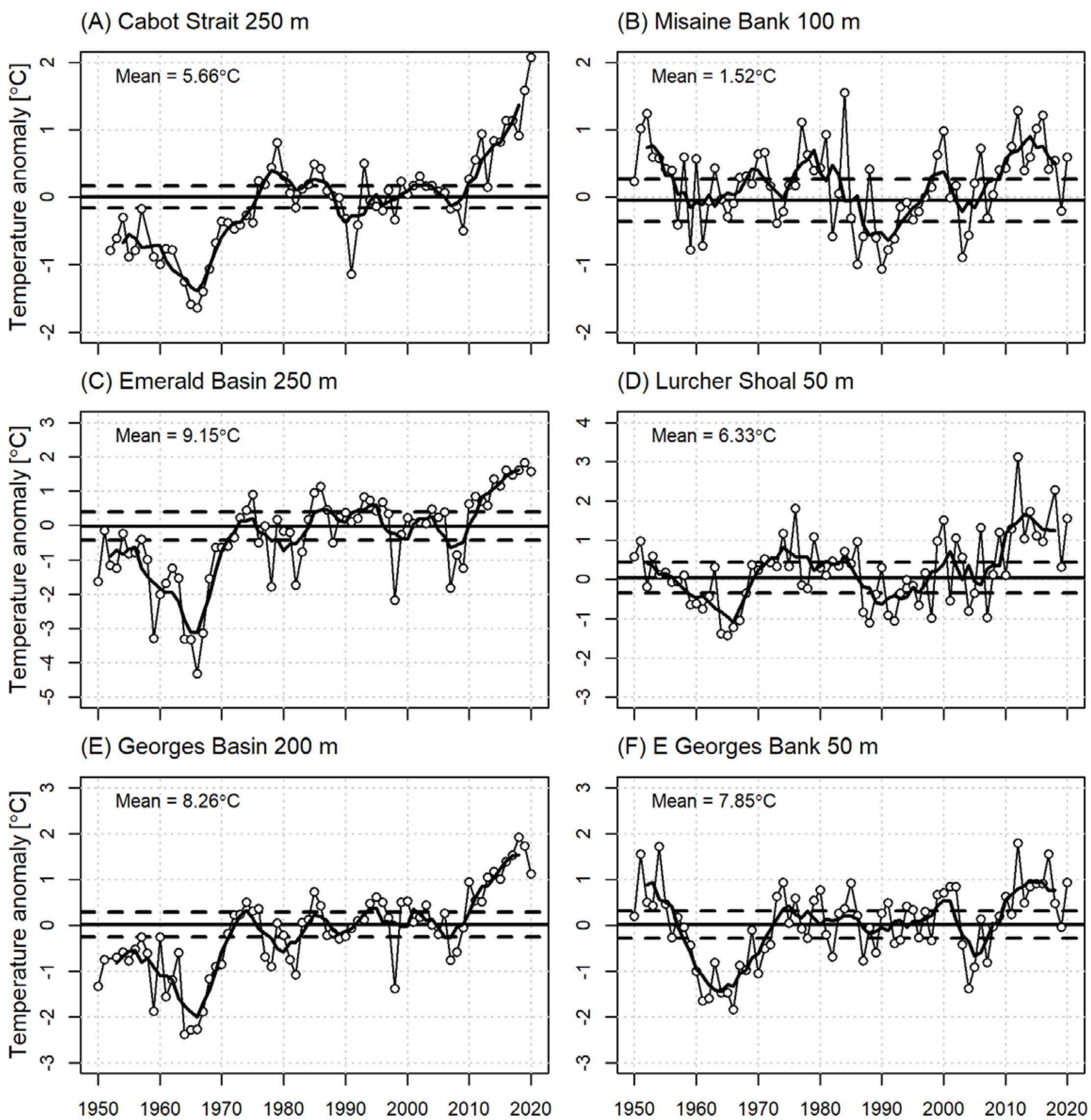

Figure 40. The annual mean temperature anomaly time series (dotted line with circles) and the 5 year running mean filtered anomalies (heavy solid line) on the Scotian Shelf and in the Gulf of Maine at (A) Cabot Strait (200-300 m); (B) Misaine Bank (100 m); (C) Emerald Basin (250 m); (D) Lurcher Shoals (50 m); and Georges Basin (200 m) (see Fig. 2). Horizontal dashed lines are the climatological average ±0.5 SD.

Temperatures during the Summer Groundfish Surveys

The broadest spatial temperature and salinity coverage of the Scotian Shelf is obtained during DFO's annual summer groundfish survey which covers the Scotian Shelf from Cabot Strait to the Bay of Fundy. The deep-water boundary of the survey is marked roughly by the 200 m isobath along the shelf break at the Laurentian Channel, at the outer Scotian Shelf, and at the Northeast Channel into the Gulf of Maine towards the Bay of Fundy. A total of 236 CTD stations were sampled during the 2020 survey. The groundfish survey normally takes one month to complete with the area west of Halifax sampled first and the area east of Halifax sampled last.

The temperatures from the survey were combined and interpolated onto a 0.2° by 0.2° latitude-longitude grid using an objective analysis procedure known as optimal estimation. 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 for at the standard depths (e.g., 0 m, 10 m, 20 m, etc.) and for near the bottom. Only the bottom temperatures are presented here (Figure 41).

Bottom temperatures anomalies for 2020 were positive for most of the region except for Browns Bank in 4X (Figure 42). The anomaly was positive for all of NAFO Divisions on the Scotian Shelf in 2020: +0.9°C (+2.3 SD) for 4Vn (the 3rd warmest in the record; 2019 was the warmest); +1.4°C (+2.0 SD) for 4Vs, the 4th warmest year; +1.6°C (+2.1 SD) for 4W, the 4th warmest year; and +0.9°C (+1.2 SD) for 4X (Figure 43). The volume of the Cold Intermediate Layer (CIL), defined as waters with temperatures <4°C, was estimated from the full depth CTD profiles for the region from Cabot Strait to Cape Sable (Figure 44). For the period 1970 to 1989, the number of CTD profiles per year was limited; therefore, 5-year blocks of data (e.g., 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 1 year and a new set of estimates made (i.e., 1970-74, 1971-75, …). This procedure is similar to filtering (5-year running mean) the data for the 1970-89 period, effectively reducing the variance. Thus, the long-term mean and particularly the SD (based on the 1981-2010 data in Figure 44) 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 44). The smallest volume was in 2012. In 2020, the CIL volume was slightly below normal. In the last six years, the CIL volume has been trending toward normal. The low-frequency variability of the area-weighted average minimum temperature mirrors the CIL volume.

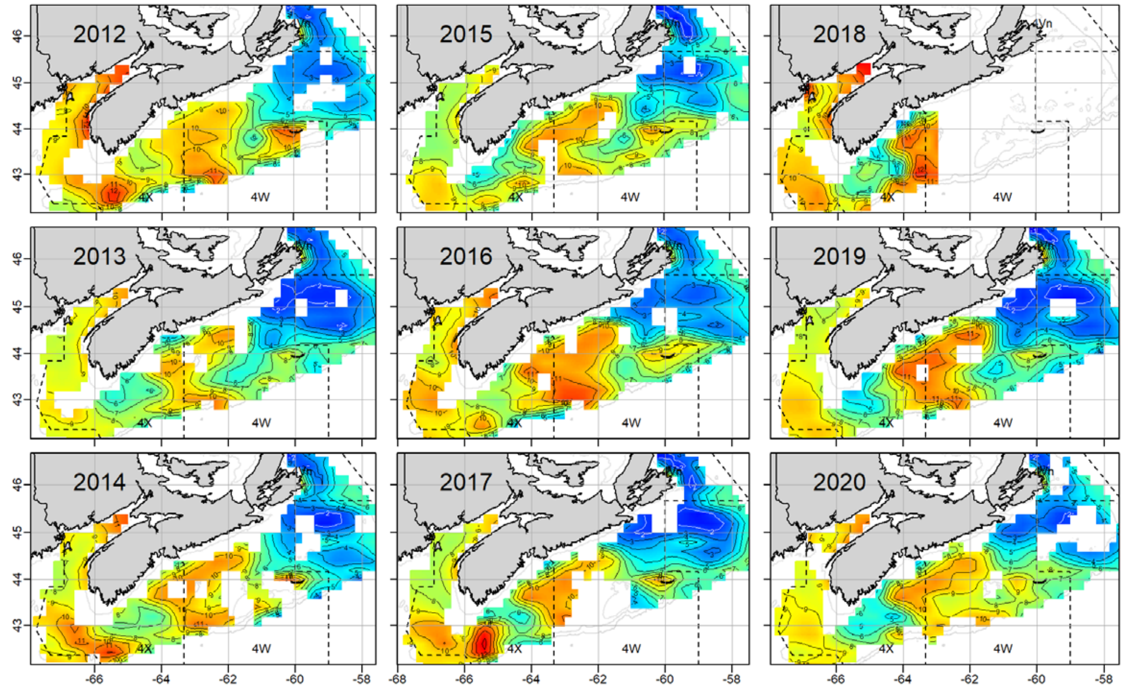

Figure 41. Bottom temperature determined from the July groundfish survey from 2012 to 2020. NAFO areas 4Vn, 4Vs, 4X and 4W are shown

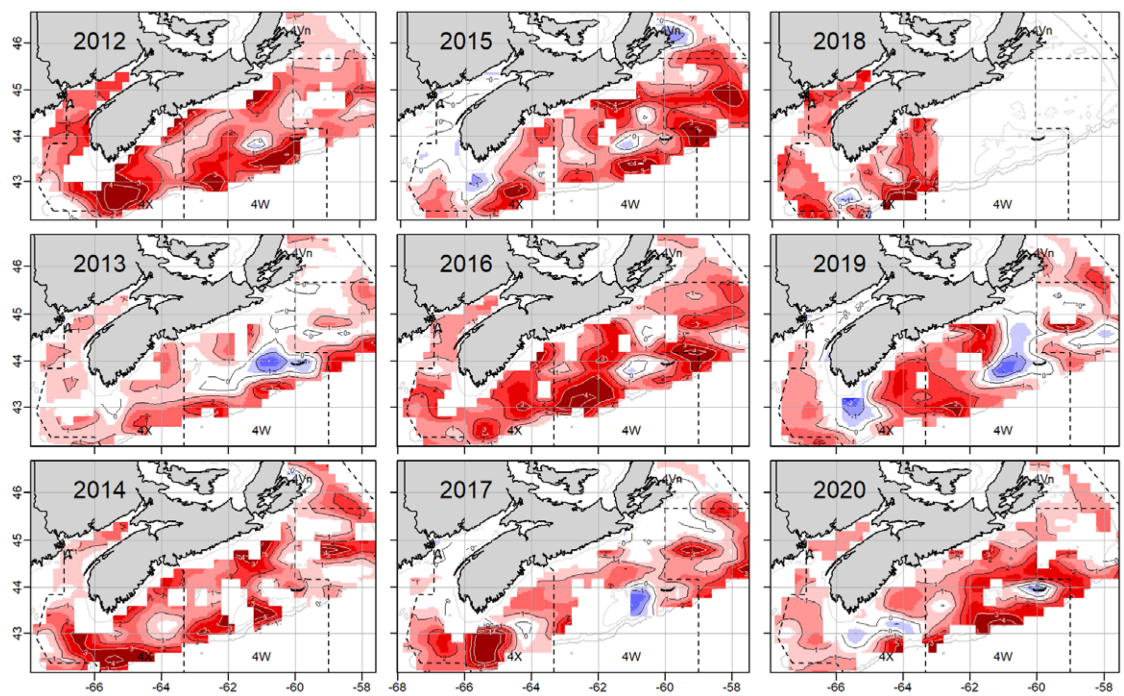

Figure 42. Bottom temperature anomalies determined from the July groundfish survey from 2012 to 2020. NAFO areas 4Vn, 4Vs, 4X and 4W are shown.

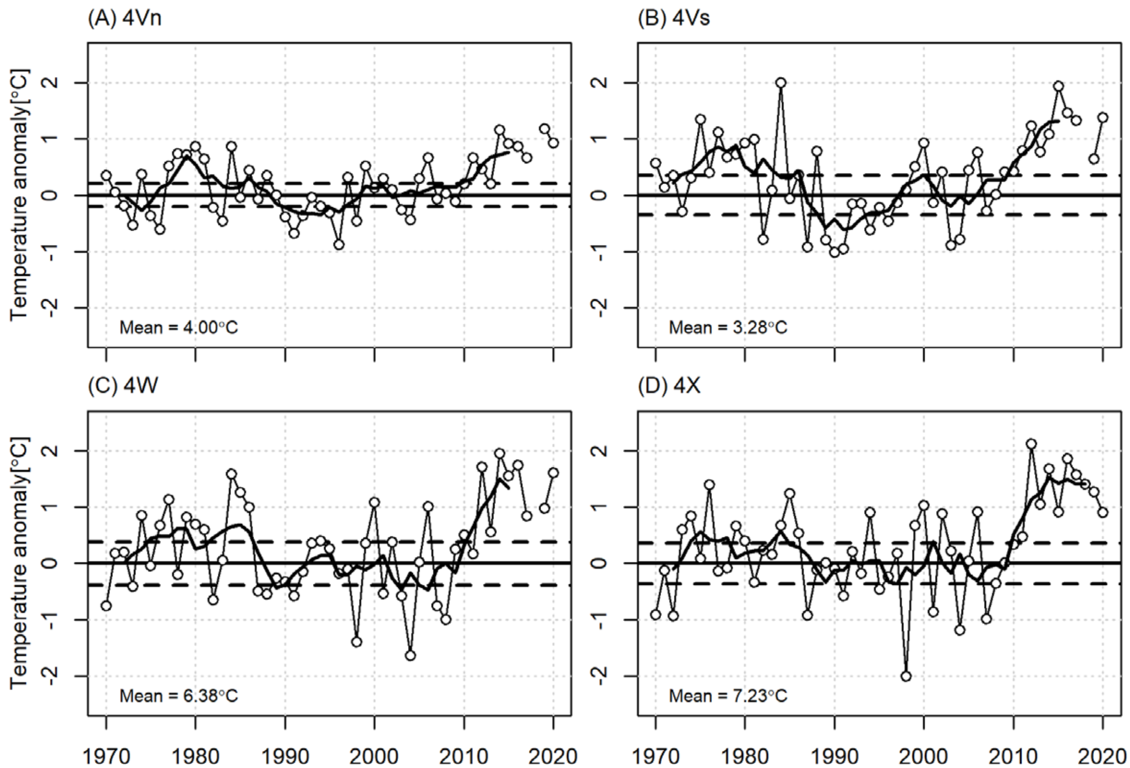

Figure 43. Time series of July bottom temperature anomalies (dashed lines with circles) and 5 year running mean filtered series (heavy line) for areas (A) 4Vn, (B) 4Vs, (C) 4W and (D) 4X. The solid horizontal line is the 1981-2010 mean CIL volume and dashed lines represent ±0.5 SD.

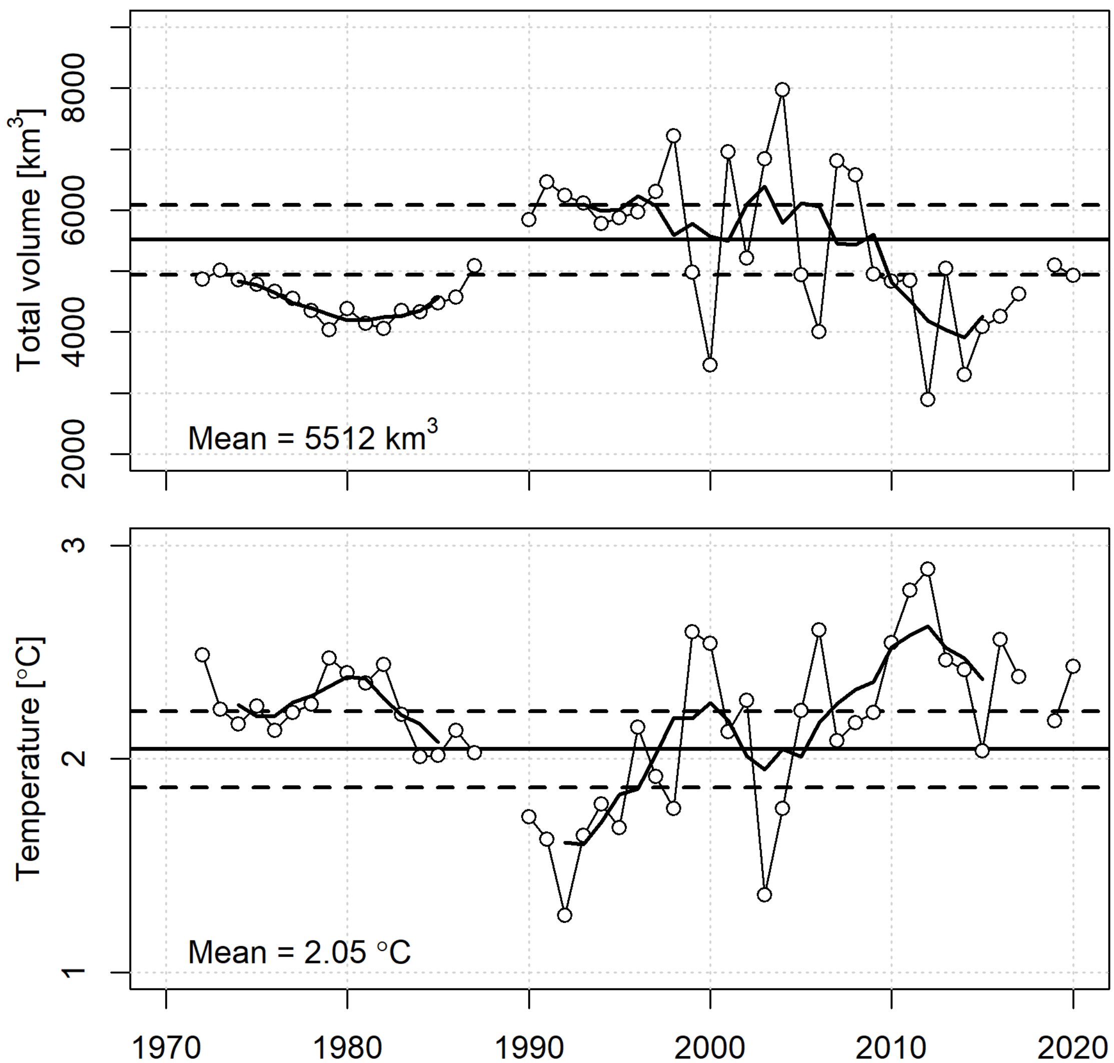

Figure 44. Time series of the Cold Intermediate Layer (CIL, defined as waters with T<4°C) volume on the Scotian Shelf based on the July ecosystem survey. The solid horizontal line is the 1981-2010 mean CIL volume and dashed lines represent ±0.5 SD.

Density Stratification

Stratification of the near surface layer influences physical and biological processes in the ocean such as 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 by calculating the density (σ_t) difference between 0 and 50 m was examined based on monthly mean density profiles on the Scotian Shelf. 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 were estimated by averaging all available monthly anomalies within a calendar year. This could be misleading if, in a particular year, most data were collected in months when stratification was weak, while in another year, sampling occurred when stratification was strong. However, initial results, using normalized monthly anomalies, were qualitatively similar to the plots presented here. The annual anomalies and their 5-year running means were for the Scotian Shelf. A value 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 that featured generally below average stratification in contrast to the past 25 years that is characterized by above normal values (Figure 45). Since 1948, there has been an increase in stratification on the Scotian Shelf, resulting in a change in the 0-50 m density difference of 0.33 kg m^{-3} over 50 years. This change in mean stratification is due mainly to a decrease in the surface density, composed of equally of warming and freshening. Stratification in 2020 was significantly lower than in 2019 due to the surface becoming saltier and warmer.

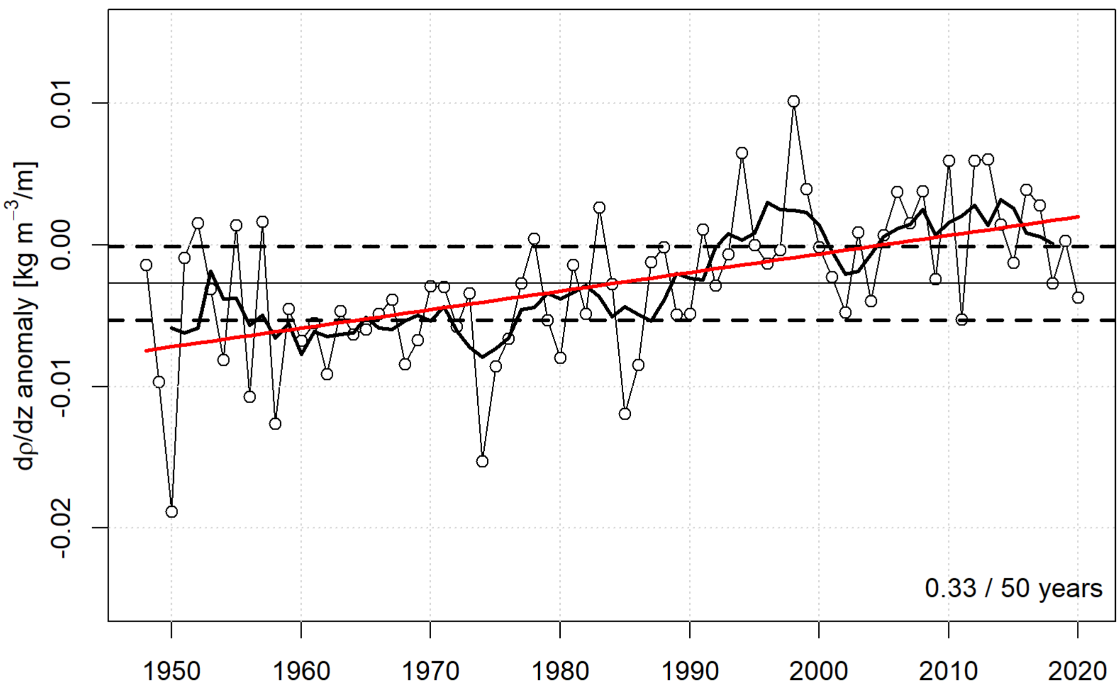

Figure 45. The mean annual anomaly (dashed line with circles) and 5-yr running mean (heavy solid line) of the stratification index (0-50 m density gradient) averaged over the Scotian Shelf. The solid horizontal line is the 1981-2010 mean stratification and dashed lines represent ±0.5 SD. The linear trend (red line) shows a change in the 0-50 m density difference of 0.33 kg m^{-3} over 50 years.

Labrador Current Variability in NAFO Sub-area 2,3 and 4

The circulation in NL region is dominated by the south-eastward flowing Labrador Current system, which floods the eastern shelf areas with cold and relatively fresh subpolar waters (Figure 46). This flow can significantly affect physical and biological environments off Atlantic Canada on seasonal and interannual time scales. The Labrador coastal current originates near the northern tip of Labrador where outflow through Hudson Strait combines with the eastern Baffin Island Current and flows southeastward along the Labrador coast where it is strongly influenced by the seabed topography, following the various cross shelf saddles and inshore troughs. A separate offshore branch flows southeastward along the western boundary of the Labrador Sea. This current is part of the large-scale Northwest Atlantic circulation consisting of the West Greenland Current that flows northward along the West Coast of Greenland, a branch of which turns westward and crosses the northern Labrador Sea forming the northwestern section of the Atlantic subpolar gyre.

Further south, near the northern Grand Bank, the inshore branch becomes broader and less defined. In this region, most of the inshore flow combines with the offshore branch and flows eastward, with a portion of the combined flow following the bathymetry southward around the southeast Grand Bank, and the remainder continuing east and southward around the Flemish Cap. A smaller inshore component flows through the Avalon Channel and around the Avalon Peninsula, and then westward along the Newfoundland south coast. Off the southern Grand Bank the offshore branch flows westward along the continental slope, some of which flows into the Laurentian Channel and eventually onto the Scotian Shelf. This extension of the Labrador Current on the Scotian Shelf (SS) slope is referred to as the Shelf Break Current. Additionally, there are strong interactions between the offshore branch of the Labrador Current and large-scale circulation. A significant portion of the offshore branch combines with the North Atlantic Current and forms the southern section of the subpolar gyre. Further east, the Flemish Cap is located in the confluence zone of subpolar and subtropical western boundary currents of the North Atlantic. Labrador Current water flows to the east along the northern slopes of the Cap and south around the eastern slopes of the Cap. In the eastern Flemish Pass, warmer high salinity North Atlantic Current water flows northward contributing to a topographically induced anticyclonic gyre over the central portion of the Cap. Satellite altimetry data are used over a large spatial area to calculate the annual-mean anomalies of the Labrador Current transport (Han et al., 2014). A total of nine cross-slope satellite altimetry tracks are used to cover the Labrador Current on the NL slope from approximately 47°N to 58°N latitude (Figure 46). Similarly, five tracks from approximately 55°W to 65°W longitude are used for the Shelf Break Current on the SS slope. The nominal cross-slope depth ranges used for calculating the transport are from 200 to 3,000 m isobaths over the NL slope and from 200 to 2,000 m isobaths over the SS slope.

An empirical orthogonal function (EOF) analysis of the annual-mean transport anomalies was carried out. An index was developed from the time series of the first EOF mode and normalized by dividing the time series by its standard deviation. The mean transport values are provided based on ocean circulation model output over the NL slope (Han et al. 2008) and over the SS slope (Han et al.1997). The mean transport of the Labrador Current along the NL slope is 13 Sv with a standard deviation of 1.4 Sv, and the mean transport of the Shelf Break Current on the SS slope is 0.6 Sv with a standard deviation of 0.3 Sv. The mean transport values will be updated as new model output becomes available. The standard deviation values will be updated as knowledge on nominal depth improves.

The reference period for the index calculation has been changed from 1993-2010 to 1993-2020. The annual-mean Labrador Current transport index shows that the Labrador Current transport over the Labrador and northeastern Newfoundland Slope was out of phase with that over the Scotian Slope for most of the years over

1993-2020 (Figure 47). The transport over the Labrador and northeastern Newfoundland Slope was strong in the early- and mid-1990s, weak in the mid-2000s and early- 2010s, and became strong again in past four years. In contrast, the transport over the Scotian Slope fluctuated in a nearly opposite way. The Labrador Current transport index was positively and negatively correlated with the winter North Atlantic Oscillation (NAO) index over the Labrador and northeastern Newfoundland Slope and over the Scotian Slope, respectively. In 2020 the annual-mean transport of the Labrador Current over the Labrador and northeastern Newfoundland Slope became weaker compared with that in the preceding four years but remained above normal. The transport on the Scotian Slope in 2020 remained below normal for seven consecutive years and was close to average in the preceding six years.

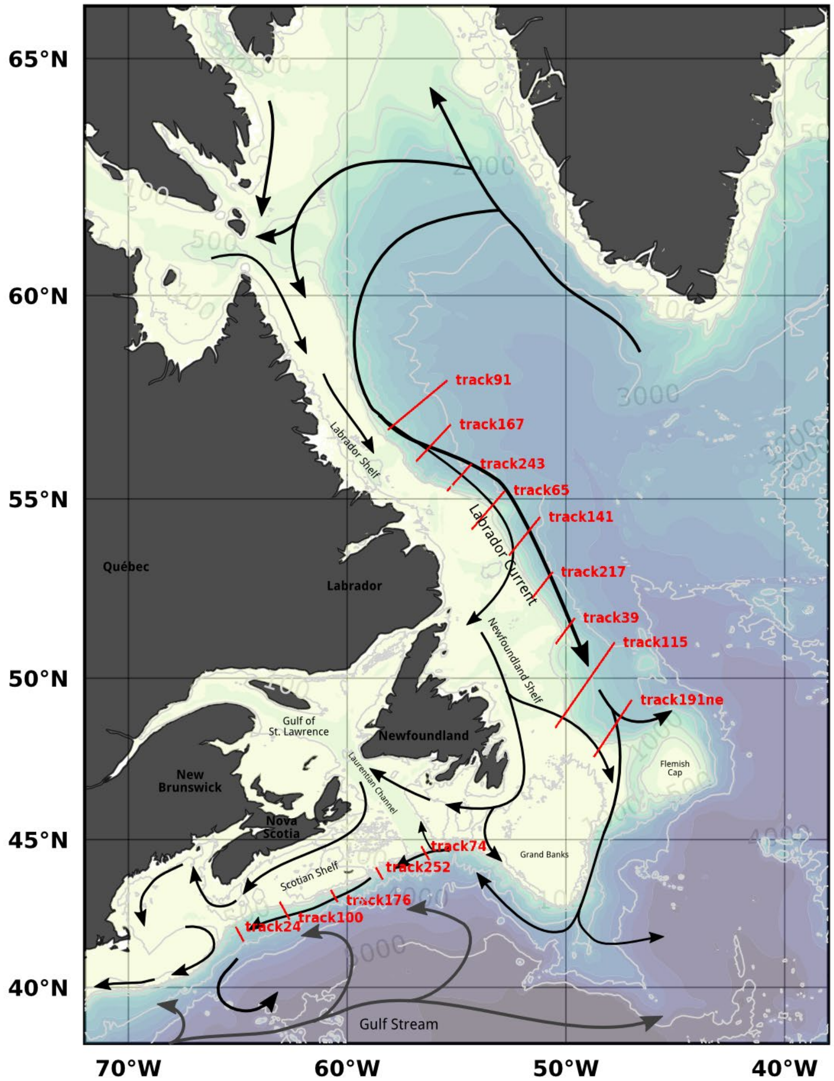

Figure 46. Map showing the Northwest Atlantic bottom topography (depth contour values in light gray) and schematic flow patterns (arrows). The transport is calculated across the cross-slope sections (red lines) identified by their satellite ground tracks numbers. The series of northern tracks are used for the Labrador Current calculation on the Newfoundland and Labrador slope, while the series of tracks in the south are used for the Shelf Break Current transport on the Scotian Shelf slope.

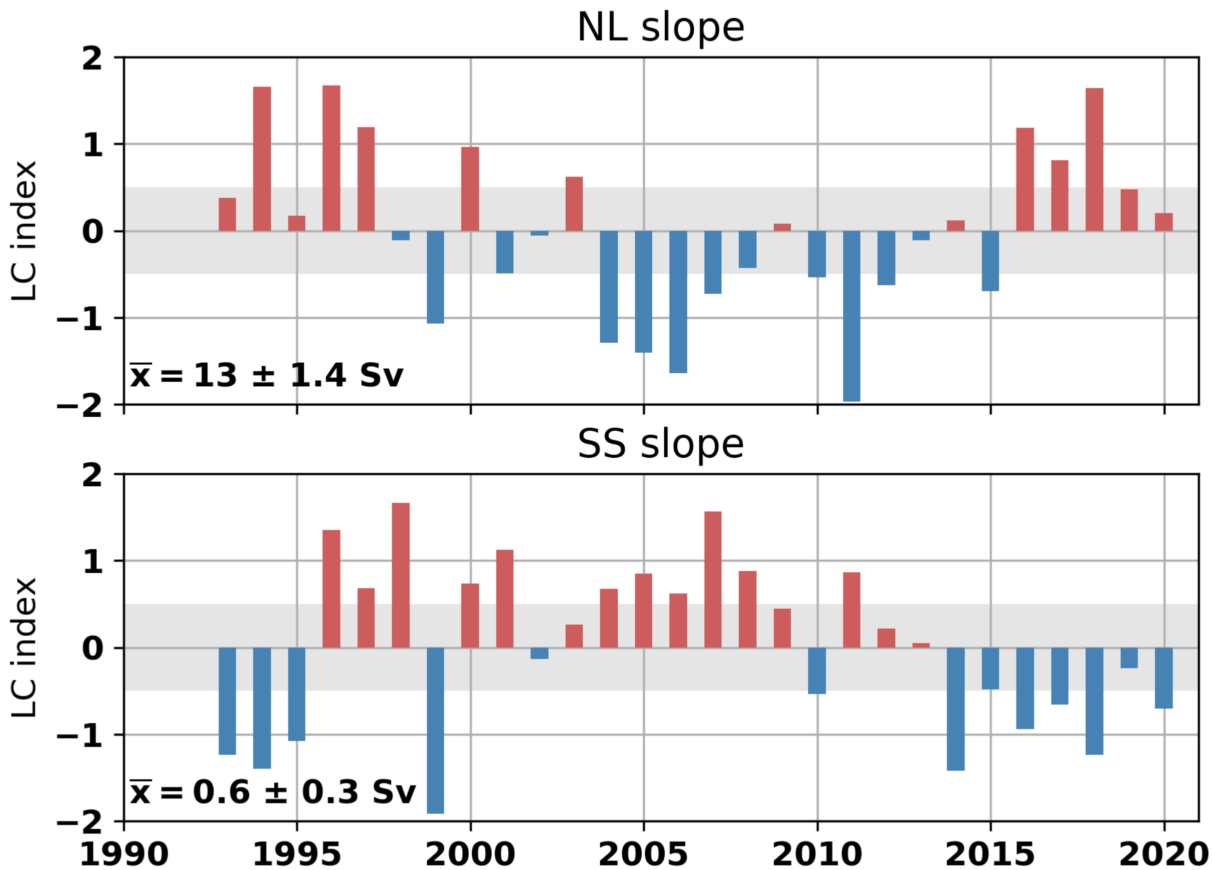

Figure 47. Normalized index of the annual-mean transport of the Labrador Current on the NL slope (top) and Shelf Break Current on the Scotian Shelf slope (bottom). Long-term averages over 1993-2020 (with standard deviation) are 13 ±1.4 Sv for the Labrador Current and 0.6 ±0.32 Sv for the Shelf Break Current. Shaded gray areas represent the ±0.5 SD range considered "normal".

Summary

An overview of physical environmental conditions for NAFO Divisions 2, 3 & 4 were presented. The highlights of 2020 can be summarized as follows:

- The winter North Atlantic Oscillation (NAO) index, a key indicator of the direction and intensity of the winter wind field patterns over the Northwest Atlantic was positive for a 7th consecutive year

- The annual air temperature was normal for the Arctic and Labrador sites, but generally warmer than average for sites in Newfoundland, and along the coast of the Scotian Shelf and Gulf of Maine.

- Winter average sea ice conditions were below normal on the Newfoundland and Labrador for the first time since 2013

- Sea surface temperatures averaged over the ice-free months were normal to above normal across the zone and on average above normal for the first time since 2014.

- Summer cold intermediate layer metrics indicated normal to warmer-than-normal conditions across the zone.

- Bottom temperatures were mainly above normal across the zone except in NAFO Divisions 2J and 3K where they were near normal.

- The Labrador Current weakened to normal during 2019 and 2020 on the NL slope, and has been below normal fairly consistently since 2014 on the Scotian slope.

Acknowledgments

We thank the many scientists and technicians at the Northwest Atlantic Fisheries Centre, Bedford Institute of Oceanography and St. Andrews Biological Station for collecting and providing much of the data contained in this analysis and to the Ocean Science Branch of Fisheries and Oceans in Ottawa for providing most of the historical data. Environment Canada provided the meteorological data. We also thank the captain and crew of the CCGS Teleost, CCGS Amundsen and CCGS Hudson and CCGS Alfred Needler for successful oceanographic survey during 2020. Finally, we thank the numerous technicians and scientists that contributed to the Atlantic Zone Monitoring Program for making this important work possible.

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