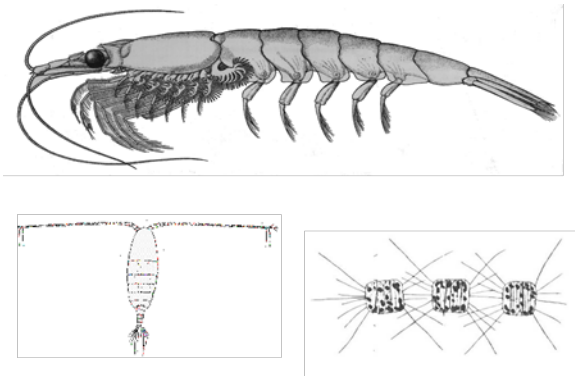
Fisheries and Oceans Canada | Pêches et Océans Canada
Ecosystems and Oceans Science | Sciences des écosystèmes et des océans

OCEANOGRAPHIC CONDITIONS IN THE ATLANTIC ZONE IN 2020



Key taxa of the pelagic food web: euphausiids (top), phytoplankton (bottom right), and copepods (bottom left).
Images: Fisheries and Oceans Canada

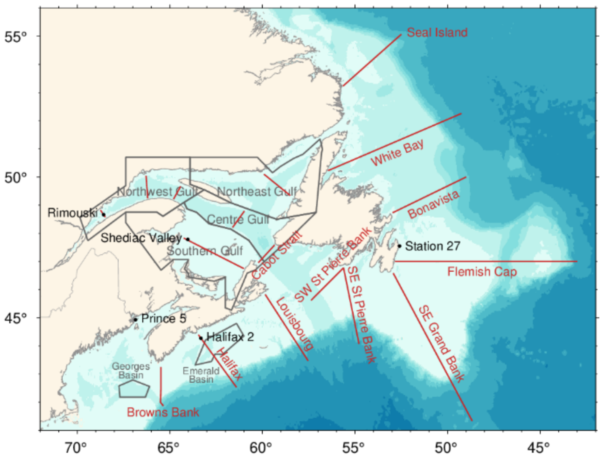


Figure 1. Atlantic Zone Monitoring Program high-frequency sampling stations (black), selected section lines (red) and averaging areas (gray).

Context:

The Atlantic Zone Monitoring Program (AZMP) was implemented in 1998 with the aim of increasing Fisheries and Oceans Canada (DFO's) capacity to understand, describe, and forecast the state of the marine ecosystem and to quantify the changes in the ocean's physical, chemical and biological properties.

A description of the seasonal patterns in the distribution of phytoplankton (microscopic plants) and zooplankton (microscopic animals) in relation to the physical environment provides important information about organisms that form the base of the marine food web. An understanding of the production cycles of plankton and their interannual variability is an essential part of an ecosystem approach to stock assessment and marine resource management.

This Science Advisory Report is from the March 22–26, 2021 Twenty-third Annual Meeting of the Atlantic Zone Monitoring Program (AZMP) held via video-conference. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

July 2021

SUMMARY

- Monthly average sea surface temperatures were generally normal to above normal in ice-free areas until May when they were below normal to normal. After being mostly near-normal in June, temperatures increased to mostly above-normal in July, including a series record (since 1982) in the St. Lawrence Estuary. Temperatures remained normal to above normal in August but reached a series record low in the Estuary in September, after strong winds. While temperatures remained below normal in the Estuary, the Gulf and 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.
- Sea surface temperatures averaged over the ice-free months were normal to above normal across the zone except for the Northern Gulf. They were above normal on the Newfoundland and Labrador Shelf for the first time since 2014.
- Winter average sea ice conditions were below normal in the Gulf of St. Lawrence and also for the first time since 2013 on the Newfoundland and Labrador Shelf.
- Summer cold intermediate layer (CIL) metrics indicated normal to warmer-than-normal conditions across the zone. The CIL and sea ice index for the zone was the 3rd warmest of the time series (since 1980), after 2011 and 2006.
- Bottom temperatures were above normal across the zone except in NAFO Divisions 2J and 3K where they were near normal; There were however no measurements in 3Ps and 3LNO due to a cancelled survey. Warm conditions included 100+ year record highs in the deeper waters of the northern Gulf of St. Lawrence and in Cabot Strait at 300 m, as well as a series record on the Magdalen Shallows in waters deeper than 30 m in September. The zonal average index was highest of the time series (since 1980).
- At the high-frequency stations, 0-50 m seasonal average and bottom temperatures were mostly above normal, including a series record at Rimouski Station.
- The Labrador Current weakened to normal during 2019 and 2020 on the Newfoundland and Labrador slope, and has been below normal fairly consistently since 2014 on the Scotian slope.
- Deep nitrate inventories were above or near normal on the Newfoundland and Labrador Shelf and in the northern Gulf of St. Lawrence, but mainly below normal in the southern Gulf of St. Lawrence and across the Scotian Shelf, including a record low on Browns Bank.
- Annual chlorophyll *a* inventories were above normal over most of the Newfoundland and Labrador Shelf and Gulf of St. Lawrence, but near or below normal on the Scotian Shelf.
- The onset of the spring phytoplankton bloom was highly variable across the Atlantic Zone, but mostly close to normal. It was later than normal in the Labrador Sea, the latest on record on the Central Scotian Shelf and the earliest on record on Georges Bank. The magnitude of the bloom was mostly above normal on the Newfoundland shelf, including a series record in Hibernia, normal to above normal in the Gulf, and variable on the Scotian Shelf with a record low on the Central Scotian Shelf. Bloom duration was variable and close to normal in most regions across the zone but included a record high on Georges Bank.
- The zooplankton community shift observed in recent years (2014–2019), characterized by lower abundance of the large energy-rich copepod *Calanus finmarchicus* and higher abundance of small copepods and non-copepods, moderated in 2020 with increases in

Calanus finmarchicus and declines in some small copepods, although the overall abundance of copepods and non-copepods remained elevated. There were below normal abundances of copepods in the Gulf of St. Lawrence and a record minimum on the Halifax Line section. There were below normal abundances of *Pseudocalanus* spp. in most regions with a record low in the Southern Gulf and on the Cabot Strait section, but a record high on the Bonavista section. Non-copepods were at a record low at Halifax 2 station but at a record high at Prince 5. Seal Island section saw record high abundances of copepods, non-copepods and *Calanus finmarchicus*.

- Zooplankton biomass was generally normal to above normal on the Newfoundland and Labrador shelves and below normal to normal elsewhere.
- Near-bottom pH and aragonite saturation are generally much lower in the Gulf of St. Lawrence than on the Grand Banks and Scotian Shelf. Near-bottom aragonite is under-saturated throughout most of the Gulf of St. Lawrence, including the shallow waters of the Southern Gulf. From 2019 to 2020, near-bottom pH across the Newfoundland Shelf and Gulf of St. Lawrence has shown a general decline, with undersaturation state for aragonite occurring in 2020 on the Grand Banks and in the Avalon channel on the Newfoundland shelf.
- New record low concentrations of deep dissolved oxygen were measured in the Lower St. Lawrence Estuary.
- In the Labrador Sea, convection reached the depth of 1600 m and possibly deeper, exceeding depths observed in 2019. Despite the NAO index being relatively high, the convection depths were noticeably shallower than the depths reported for the 2015-2018 period (which reached 2000 m). Winter and spring air temperatures over the Labrador Basin were near normal and above normal. Both winter and spring sea surface temperatures in the Labrador Basin were above normal, while sea ice extent was below normal.
- In the Labrador Sea, the late timing of the mission, in July rather than in May, induced a bias in the *in situ* measurements that prevented comparisons with the biochemical and surface observations collected in most other years. However, compared to those collected around the same time of year, 2020 appeared to be a warmer than normal year as in 2003. Nutrients and chlorophyll *a* concentration were lower than the seasonal average with the exception of nutrients in the surface layer in the Central Labrador Sea and chlorophyll *a* concentration on the Greenland Shelf.

BACKGROUND

The Atlantic Zonal Monitoring Program (AZMP) was implemented in 1998 (Therriault et al. 1998) with the aim of:

1. Increasing Department of Fisheries and Oceans' (DFO's) capacity to understand, describe, and forecast the state of the marine ecosystem; and
2. Quantifying the changes in ocean physical, chemical, and biological properties.

A critical element in the observation program of AZMP is an annual assessment of the physical oceanographic properties and of the distribution and variability of nutrients, phytoplankton and zooplankton.

A description of the distribution in time and space of nutrients and gases dissolved in seawater (nitrate, silicate, phosphate, oxygen) provides important information on the water-mass movements and on the locations, timing, and magnitude of biological production cycles. A description of the distribution of phytoplankton and zooplankton provides important information on the organisms forming the base of the marine food web. An understanding of the production cycles of plankton is an essential part of an ecosystem approach to stock assessment and fisheries management.

The AZMP derives its information on the state of the marine ecosystem from data collected at a network of sampling locations (high-frequency sampling stations, cross-shelf sections, ecosystem surveys) in each of DFO's administrative regions in Eastern Canada (Quebec, Maritimes, Gulf, Newfoundland and Labrador) sampled at a frequency of weekly to once annually (Figure 1). The sampling design provides for basic information on the natural variability in physical, chemical, and biological properties of the Northwest Atlantic continental shelf. Multispecies trawl surveys and cross-shelf sections provide detailed geographic information, but are limited in their seasonal coverage. Strategically placed high-frequency sampling stations complement the broad scale sampling by providing more detailed information on temporal (seasonal) changes in pelagic ecosystem properties. This annual assessment of the State of the Atlantic Zone has included Labrador Sea observations resulting from the Atlantic Zone Off-Shelf Monitoring Program (AZOMP) since the report on 2015 conditions, and included information on ocean acidification since the report on 2018 conditions.

Environmental conditions are usually expressed as anomalies, i.e., deviations from their long-term mean. The long-term mean or normal conditions are calculated when possible for the 1991–2020 reference period for physical parameters, and for 1999–2020 for biogeochemical parameters. Furthermore, because these series have different units (°C, km^3, km^2, etc.), each anomaly time series is normalized by dividing by its standard deviation (SD), which is also calculated using data from the reference period. This allows a more direct comparison of the various series. Missing data are represented by grey cells, and near normal conditions are designated by white cells. These are values within ± 0.5 SD of the average for physical parameters while a threshold of 0.3 SD is used for biological parameters. Conditions corresponding to warmer than normal (higher temperatures, reduced ice volumes, reduced cold-water volumes or areas) are shown as red cells, with more intense reds corresponding to increasingly warmer conditions or greater levels of biogeochemical variables. Similarly, blue represents colder than normal conditions or lower levels of biogeochemical variables. Higher than normal freshwater inflow, salinity or stratification are shown as red, but do not necessarily correspond to warmer than normal conditions.

ASSESSMENT

Climatology shift

This year's report sees the climatological reference period changed from 1999–2015 to 1999–2020 for biogeochemical variables, a 5 year period increase, and from 1981–2010 to 1991–2020 for physical variables, a 10 year shift.

The 5-year increase in the number of years included in the biogeochemical climatologies increases stability and generally reduces the amplitude of anomalies. For example, the zooplankton community shift observed since 2014, characterized by lower abundance of the large energy-rich copepod *Calanus finmarchicus* and higher abundance of small copepods and non-copepods, is currently fully integrated into the climatological period. The very large anomalies reported up to last year's report for recent years will appear diminished somewhat, and the closer-to-normal and variable anomalies reported for the period that preceded the community shift will now change to either above or below normal.

The 10-year shift in the physical climatology is done following the World Meteorological Organization standards (World Meteorological Organization 2017) and allows, over subsequent decadal shifts, the comparison over the same climatological period of an increasing number of time series. It has the disadvantage of masking long-term trends, including those caused by global warming. In our zone, the effects of the shift are large for sea surface temperature since the cold 1981–1990 period is removed and the warm 2011–2020 period is added to the climatological period. Previously reported very high anomalies for 2012 will be reduced in this report. Similarly, bottom temperatures have been greatly increasing in the last decade, even exceeding the past known range of variability. Therefore, not only has the mean of the climatology changed, but in many cases the variance as well, which also affects normalized anomalies. A good example is the zonal average bottom temperature anomaly for 2018 (bottom panel of Fig. 10): in last year's report, it was highly above normal (+0.8 SD) and it appears normal (+0.1 SD) in this report. The normalized anomaly for the northern Gulf deep bottom temperature went from +4.8 SD to +1.7 SD for that year, greatly reducing its impact on the zonal average. Many of these changes are documented by comparing the mean and standard deviations listed for the variables in Figure 7 with those reported last year, and core Newfoundland & Labrador times series are examined using both climatologies in Cyr and Galbraith (2021).

While we often describe the environment in terms of anomalies relative to the climatological period, it remains important to look at the long-term trends. We also often speak in terms of rank and series records which help to paint a broader picture.

Physical Oceanographic Conditions

This is a summary of physical oceanographic conditions during 2020 for eastern Canadian oceanic waters (Figures 1 and 2) as reported annually by the AZMP in three reports (e.g. Hebert et al. 2021, Cyr et al. 2021 and Galbraith et al. 2020 for conditions in 2019). Exceptionally, a primary publication is already available that includes conditions in 2020 on the Newfoundland and Labrador Shelf (Cyr and Galbraith 2021).

The North Atlantic Oscillation

The North Atlantic Oscillation (NAO) index is based on the sea-level atmospheric pressure difference between the sub-equatorial high and sub-polar low and quantifies the dominant winter atmospheric forcing over the North Atlantic Ocean. The winter index used here is the December-March average of the monthly time series from the National Oceanic and Atmospheric Administration (NOAA). It affects winds, air temperature, precipitation, and the hydrographic properties on the eastern Canadian seaboard either directly or through advection. Strong northwest winds, cold air and sea temperatures, and heavy ice in the Labrador Sea area have usually been associated with a high positive NAO index, with opposite effects occurring with a negative NAO index. The minimum value on record was reached in 2010 at -1.5, coinciding with warmer than normal conditions. In 2020, the winter NAO index was +1.2, positive for a 7th consecutive year (including the largest value on record of +1.6 in 2015). This positive streak has however not coincided with colder than normal conditions.

Annual Temperature Cycle

Temperature varies vertically through the seasons in the Atlantic Zone (Figure 3). The summertime temperature (T) structure consists of three distinct layers: the summertime warm surface layer, the cold intermediate layer (CIL), and the deeper water layer. During fall and winter, the surface layer deepens and cools mostly from wind-driven mixing prior to ice formation, but also partly because of cooling, reduced runoff and brine rejection associated with sea ice formation where it occurs. The surface winter layer extends to an average depth of about 50 m on the Scotian Shelf, 75 m in the Gulf of St. Lawrence (GSL) by March, and can extend to the bottom (>150 m) on the Labrador and Newfoundland Shelves. It reaches near-freezing temperatures in the latter two areas. During spring, surface warming, sea ice melt waters, and continental runoff lead to a lower salinity and higher temperature surface layer, below which cold waters from the previous winter are partly isolated from the atmosphere and form the summer CIL. This layer persists until the next winter, gradually warming and deepening during summer. The CIL is, for the most part, locally formed in winter in separate areas around the zone. For example, the temperature minimum of the winter mixed layer occurs at about the same time in March both on the Scotian Shelf and in the GSL, reaching different minimum temperatures; an indication of local formation rather than advection from one region to the other. However, transport occurs later in the year from the Labrador Shelf to the GSL and Newfoundland Shelf and from the GSL to the St. Lawrence Estuary and to the Scotian Shelf. The temperature minimum in Southern parts of the Newfoundland Shelf (e.g. at Station 27) can occur well after winter; for example, in 2016 it was observed in early August. Deep waters are defined here as those below the CIL that have only weak seasonal cycles.

Sea surface Temperature

The satellite-based sea surface temperature product used since last year’s report blends data from Pathfinder version 5.3 (1982–2020), Maurice Lamontagne Institute (1985–2013) and Bedford Institute of Oceanography (1997–2020) and monthly temperature composites are calculated from averaged daily anomalies to which monthly climatological average temperatures are added (Galbraith et al. 2021). New this year, the Gulf of St. Lawrence was divided into two regions that delimit the Southern and Northern Gulf along a boundary chosen by an Ecosystem Approach working group (Figure 1).

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, and 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. 2020). 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. After being mostly near-normal in June, temperatures increased to mostly above-normal in July, including a series record (since 1982) in the St. Lawrence Estuary. There, temperatures increased nearly as much as in the northeast Gulf, a very unusual occurrence. Upwelling and mixing that occurs at the head of the Laurentian Channel usually keeps Estuary surface water cool, but North-easterly winds appear to have created a circulation that capped the mixing region with warmer waters. 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 the Estuary and Gulf of St. Lawrence. Surface temperatures then reached a series record low in the Estuary in September. While temperatures remained below normal in the Estuary, the Gulf and 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 except for the Northern Gulf. They were above normal on the Newfoundland and Labrador Shelf for the first time since 2014.

Cold Intermediate Layer

For the Newfoundland and Labrador Shelf, the CIL indices shown here (Figure 7) are the cross-sectional areas of waters with T<0°C during summer along the Seal Island, White Bay, Bonavista and Flemish Cap AZMP sections (Cyr et al. 2021). For the Gulf, the CIL volume with T<1°C observed in August-September is used (Galbraith et al. 2020). Because the CIL reaches to the bottom on the Magdalen Shallows in the Southern Gulf, the area of the bottom occupied by waters colder than 1°C during the September survey is also used as a CIL index specific to that area (Galbraith et al. 2020). On the Scotian Shelf, the volume of water having T<4°C in July is used (limited data prior to 1990 is compensated for by the use of a 5-year running mean to achieve extended temporal coverage; however, this results in a loss of high-frequency variability from that part of the time series) (Hebert et al. 2021). The CIL indices reported here are taken at about the same time within their respective annual cycles, although not simultaneously.

Both the Gulf of St. Lawrence and Scotian Shelf CIL volumes were at record lows in 2012, representing record warm conditions. While conditions were warmer than normal in the Newfoundland and Labrador sections in 2011 and 2013, they were followed by mostly normal to colder-than-normal conditions during 2014–17. In 2020, CIL conditions were normal to warmer-than-normal across the zone, by +1.2 SD on the Bonavista section, +1.8 SD on the Seal Island section and +2.4 SD in the Southern Gulf where the September bottom area with temperatures colder than 1°C was at a near record low of only half of the climatological mean. There were no measurements of the usually reported CIL metrics on the White Bay section because of limited sampling.

Sea ice

Because the CIL and sea ice cover are both formed in winter, it is not surprising that indices for both are well correlated with each other and with winter air temperature, and show the North-South advective nature of properties on the Newfoundland and Labrador Shelf. Seasonal average sea ice volume on the Southern Labrador Shelf is correlated with the CIL area further South along the Bonavista section (1980–2020, $R^2 = 0.70$) whereas Newfoundland Shelf sea ice metrics are correlated with December-March air temperature further North at Cartwright (1969–2019, $R^2 = 0.65$–0.81; Cyr et al. 2021). In the Gulf of St. Lawrence, the correlation between the December-March air temperature averaged over multiple coastal meteorological stations and the annual maximum ice volume reaches $R^2 = 0.73$ (1969–2020). Air temperature is similarly well correlated to sea ice cover area and duration ($R^2 = 0.79$–0.82; Galbraith et al. 2020). Sensitivity of the Gulf of St. Lawrence ice cover to climate change can be therefore estimated using past patterns of change in winter air temperature and sea ice features, which indicate losses of 18 km^3, 31,000 km^2 and 13 days of sea ice season for each 1°C increase in winter air temperature (Galbraith et al. 2020).

New this year, sea ice conditions on the Newfoundland and Labrador Shelf are provided by an index that encompasses duration and seasonal maximum area in three regions: Northern and Southern Labrador Shelf and Newfoundland Shelf (Cyr and Galbraith 2021).

For the past decade, ice volumes on the Newfoundland and Labrador Shelf, the Gulf of St. Lawrence and the Scotian Shelf have generally been lower than normal reaching a record low value in the Gulf of St. Lawrence in 2010 and on the Newfoundland and Labrador Shelf in 2011 (Figure 7). In the eleven year period between 2010 and 2020, the Gulf seasonal average sea ice volume had seven of the eleven lowest values of the series (but 2020 was not among them, ranking 13th), while the Newfoundland and Labrador shelf had only four of the eleven lowest indices (including 2020). In 2020, the Newfoundland and Labrador sea ice index was below normal on the Newfoundland and Labrador Shelf (-0.6 SD) for the first time since 2013. The seasonally averaged sea ice volume in the Gulf of St. Lawrence was also below normal (-0.7 SD), as was the seasonally averaged volume of ice exported onto the Scotian Shelf.

Bottom and Deep Water Temperatures

Interdecadal changes in temperature, salinity, and dissolved oxygen of the deep waters of the GSL, Scotian Shelf, and Gulf of Maine are related to the varying proportion of their source waters: cold–fresh/high-dissolved-oxygen Labrador Current water and warm–salty/low-dissolved oxygen Warm Slope Water. The >150 m water layer of the GSL below the CIL originates from an inflow at the entrance of the Laurentian Channel which circulates towards the heads of the Laurentian, Anticosti, and Esquiman Channels in up to roughly three to four years at 300 m after reaching Cabot Strait, with limited exchange with shallower upper layers. Deeper portions of the Scotian Shelf and Gulf of Maine are similarly connected to the slope through deep channels that cut into the shelves from the shelf break. Variations in the westward transport of Labrador Slope Water from the Newfoundland region along the shelf break have been shown to have a strong effect on water masses of the Scotian Shelf deep basins, with increased transport through Flemish Pass associated with below normal deep temperatures and salinities on the Scotian Shelf and in the Gulf of Maine. Deep basins such as Emerald Basin undergo very large interannual and interdecadal variability of the bottom water temperature associated with deep renewal events. More regular changes associated with circulation are observed in bottom water temperature over the central and eastern Scotian Shelf (NAFO Divisions 4W and 4Vs respectively). Bathymetry in these areas is fairly evenly distributed between 30 m and 170 m, with 4Vs including some 400–450 m depths from the Laurentian Channel. Both these areas are therefore affected somewhat by CIL waters as well as the waters underneath.

In 2020, bottom temperatures averaged over large areas in the Atlantic Zone ranged from normal in NAFO Divisions 2J and 3K to above normal elsewhere. There were however no spring measurements in 3Ps and 3LNO due to a cancelled survey. There were new 100+ year high-temperature records for the Gulf at 200, 250 and 300 m that are reflected in the average bottom temperature of the northern Gulf deeper than 200 m (Figure 7), and a record high in Cabot Strait at 300 m. The recent warming of the Gulf deep waters began as a warm anomaly first observed in Cabot Strait in 2010 that has propagated towards the heads of the channels, sustained by later warm water inflows. At intermediate depths, there was a September series record on the Magdalen Shallows bottom water temperature average for depths greater than 30 m, but this appears to be partly caused by a storm that mixed near surface heat into the bottom layer at the end of August.

Runoff and Stratification

Freshwater runoff in the Gulf of St. Lawrence, particularly within the St. Lawrence Estuary, strongly influences the circulation, salinity, and stratification (and hence upper-layer temperatures) in the Gulf and, via the Nova Scotia Current, on the Scotian Shelf. The runoff product is based on daily runoffs estimated at Québec City that are then lagged by 3 weeks to account for transport time to the Estuary, then combined with output from a hydrological watershed model for rivers flowing into the Estuary (Galbraith et al. 2020). The inter-annual variability of the seasonal (May–October) stratification (0–50 m) at Rimouski Station in the Estuary is correlated with the seasonally averaged runoff of the St. Lawrence river (1991–2020; $R^2 = 0.57$, Figure 8). The 2020 annual runoff was above normal (19,000 m^3s^{-1}, +0.9 SD).

Stratification on the Scotian Shelf decreased to below normal in 2020 (-1.2 SD). Since 1948, there has been an increase in the mean stratification on the Scotian Shelf, resulting in a change in the 0–50 m density difference of 0.33 kg m^{-3} per 50 years (Figure 8). This change in mean stratification is due mainly to a decrease in the surface density, composed equally of warming and freshening. Stratification was near normal at Rimouski station (-0.2 SD) in spite of the above normal runoff (Figure 8).

Conditions at AZMP High Frequency Sampling Stations

Station 27 was the only AZMP high-frequency sampling station with above normal seasonal stratification. It was below normal at Halifax 2 and Prince 5. There was no clear relation with 0-50 m seasonal average salinity as it was above normal at Rimouski station and at Shediac Valley and near normal at the other sites. The seasonal average 0-50 m temperature was normal or above normal at all stations. Bottom temperature was normal to above normal at all stations, and at Rimouski station the last seven years were the warmest of the time series, reaching a new record high in 2020.

Labrador Current Transport Index

The annual-mean Labrador Current transport index shows that the Labrador Current transport over the Labrador and northeastern Newfoundland Slope is generally out of phase with the shelf-break current transport over the Scotian Slope (Figure 7). The transport was strongest in the early 1990s and weakest in the mid-2000s over the Labrador and northeastern Newfoundland Slope, and opposite over the Scotian Slope. The transport index is positively and negatively correlated with the winter NAO index over the Labrador and northeastern Newfoundland Slope and over the Scotian Slope, respectively. The annual mean transport weakened to normal during 2019 and 2020 over the Labrador and northeastern Newfoundland Slope (+0.2 SD) and has been below normal fairly consistently since 2014 on the Scotian slope (-0.7 SD in 2020).

Summary

Surface oceanic waters in the Atlantic zone during ice-free months have been mostly tracking the climate-change driven warming trends observed in the atmosphere. Warming winters have also led to less sea ice cover and weaker cold intermediate layers. The 2010–20 period was characterized by record lows in 2012 for both the Gulf of St. Lawrence and Scotian Shelf CIL volumes, representing record warm conditions. For the past decade, ice volumes on the Newfoundland and Labrador Shelf, the Gulf of St. Lawrence and the Scotian Shelf have generally been lower than normal reaching a record-low value in the Gulf of St. Lawrence in 2010 and on the Newfoundland and Labrador Shelf in 2011.

The deep water temperatures on the Scotian Shelf and Gulf of St. Lawrence were greatly influenced by an increasing proportion of Gulf Stream Water relative to Labrador Water. While the Newfoundland Shelf and Labrador Shelf were characterized by normal to above normal bottom temperatures in the early and late period of 2011–20 with some below normal temperatures in 2014–17, nearly all anomalies were above normal on the Scotian Shelf and the northern Gulf of St. Lawrence during this time period in spite of the climatology change to 1991-2020. Series records were observed during this period in central (4W) and western (4X) Scotian Shelf, Georges Basin (200 m), Emerald Basin (250 m) as well as a 100+-year record in the northern Gulf of St. Lawrence and in Cabot Strait (300 m).

Three annual composite index time series were constructed as the average of anomalies shown earlier, and represent the state of different components of the system, with each time series contribution shown as stacked bars (Figure 10). The components describe sea surface and bottom temperatures, as well as the cold intermediate layer and sea ice volume, which are both formed in winter. These composite indices measure the overall state of the climate system with positive values representing warm conditions and negative representing cold conditions (e.g. less sea ice and CIL areas and volumes are translated to positive anomalies). Cumulated indices also give a sense of the degree of coherence between the various metrics of the environmental conditions and different regions across the zone. Sea surface anomalies are weighted to their spatial area (although not by the numbers of months in the season) and all three panels are weighted for missing values. On average over the zone, conditions in 2020 were near normal for surface temperatures, and warmer than normal for Cold Intermediate Layer and sea ice anomalies as well as for bottom temperatures. Average conditions were third warmest of the time series for Cold Intermediate Layer and sea ice and warmest of the time series for bottom temperature. A total of 47 indices listed in Figures 7 and 9 describe ocean conditions related to temperature within the AZMP area in 2020 (SST; ice; summer CIL areas, volumes, and minimum temperature; bottom temperature; 0–50 m average temperature). Of these, only one was colder than normal, 15 were within normal values (± 0.5 SD) and 31 were above normal, indicating a continuation of warmer than normal oceanographic conditions in 2020 across much of the Atlantic Zone despite a 7th consecutive year of positive winter NAO index, a situation generally known to lead to colder than average conditions in the Zone.

Biogeochemical Environment

Lower trophic levels are the components of marine food webs that channel the sun’s energy to higher trophic level animals such as shellfish (e.g., crabs, lobsters, scallops, and mussels), finfish (e.g., cod, herring, and halibut), marine mammals (e.g., seals and whales) and seabirds. Lower trophic level organisms include phytoplankton and zooplankton. Phytoplankton are microscopic plants that form the base of the aquatic food web and occupy a position in the marine food web similar to that of plants on land. Zooplankton are a broad variety of small animals ranging from 0.2 to 20 mm in length that drift with ocean currents. There is a wide variation in the size of phytoplankton, from the large diatoms to the smaller flagellates, each taxon fulfilling a different ecological function. Phytoplankton are the primary food source for zooplankton, which are the critical link between phytoplankton and larger organisms. The zooplankton community includes animals such as copepods, gelatinous filter feeders and predators, and ephemeral larval stages of bottom-dwelling and planktonic invertebrates. As with phytoplankton, there is a broad range of sizes of zooplankton. Smaller stages and species are the principal prey of young stages of fish and larger copepods are eaten predominantly by juvenile and adult fishes that forage near the surface.

Productivity of marine ecosystems depends on photosynthesis, the synthesis of organic matter from carbon dioxide and dissolved nutrients by phytoplankton. Light provides the energy necessary for the transformation of inorganic elements into organic matter. The growth rate of phytoplankton is dependent on the availability of light and nutrients in the form of nitrogen (nitrates, nitrites, and ammonium), phosphorous (phosphate), and silica (silicate), with the latter being essential for production of diatoms. During springtime, phytoplankton undergoes an explosion in abundance known as the spring bloom. The spring bloom occurs principally in near-surface waters. In fall, a secondary bloom, less intense than the spring bloom, also contributes to the functioning of the marine ecosystem. We report on the amount of nutrients available for phytoplankton, the overall abundance of phytoplankton and important features of the spring bloom, and the abundance of zooplankton species based on the data available from 1999 to present.

Indices representing nitrate inventories, phytoplankton standing stock, features of the spring phytoplankton bloom derived from satellite observations, and zooplankton abundance and biomass from the Newfoundland Shelf (Maillet et al. 2019), Gulf of St. Lawrence (GSL) (Blais et al. 2021) and Scotian Shelf (Casault et al. 2020) are summarized as time series (1999–2020) of annual values in matrix form in Figures 11–14. Anomalies for biogeochemical parameters were calculated using a climatological reference period of 1999-2020.

Although the relatively short time series of biogeochemical variables from the program tend to highlight the high degree of interannual variability in the information rather than the long-term trends that are apparent for the physical environment, there have been distinct shifts across several variables in recent years. There is a degree of synchrony in the patterns of variation of individual biogeochemical variables at adjacent locations, and the sign of anomalies tends to persist for several years, although in some instances there may be considerable variability among locations within a region.

Nutrients

In continental shelf waters, nitrate, the dominant form of nitrogen, is usually the limiting nutrient for phytoplankton growth. The amount of nitrate contained in waters below the surface mixed layer at depths of 50–150 m is called the “deep water nitrate inventory”. Generally, this inventory is not greatly influenced by the growth of phytoplankton, so it provides a good indicator of resources that can be mixed into the water column during winter or summer and fall through upwelling to become available for phytoplankton growth. Nitrate inventories, and the relative abundances of other nutrients, are mostly dependent on the source waters that make up the deep water on continental shelves, which can vary from year to year. Deep nutrient inventories (50–150 m) in 2020 were above or near normal on the Newfoundland and Labrador Shelf and in the northern Gulf of St. Lawrence, but mainly below normal in the southern Gulf of St. Lawrence and across the Scotian Shelf, including a record low on the Browns Bank section (Figure 11).

Phytoplankton

Chlorophyll inventories in the upper ocean (between 0–100 m) represent phytoplankton biomass. They demonstrated a high degree of year-to-year variability including exceptional values either above or below the long-term average (Figure 11). Part of this variation is explained by the relatively fixed timing of the program's oceanographic surveys throughout the zone while the production cycle may vary annually depending on environmental conditions. Annual chlorophyll *a* inventories in 2020 showed a similar pattern to 2018 and 2019 with anomalies mostly above normal in the northern regions (Newfoundland and Labrador Shelf, Northwest and Northeast GSL) in contrast to southern regions where they were near or below normal (Center Gulf of St. Lawrence and Scotian Shelf). Because of the reliance of phytoplankton on nutrient availability, coupled with increasing length of the respective time series, the variation in nutrient inventories appears to be associated with general trends in phytoplankton biomass at regional scales. Although nutrient inventories provide some threshold to limit seasonal production dynamics across the zone, additional factors are likely to be influencing local nutrient-phytoplankton dynamics and the balance of these factors is likely to differ when considered at the very large spatial scale from the Gulf of Maine to southern Labrador, which includes estuarine to oceanic environments.

The magnitude (total production) of the spring bloom is partly dependent on the amount of nutrients that are mixed into surface waters over the course of the winter. The characteristics of the bloom (magnitude, timing, and duration) provide important information about regional variations in ecosystem productivity and are linked to the productivity of organisms that depend on lower trophic levels. Characteristics of the spring phytoplankton bloom were derived from daily composite observations of the concentration of chlorophyll at the ocean surface based on satellite observations (Moderate Resolution Imaging Spectroradiometer [MODIS] 2003–20; Figure 12). The onset timing of the spring phytoplankton bloom was highly variable across the Atlantic Zone, but mostly close to normal. It was later than normal in the Labrador Sea, the latest of the time series in Central Scotian Shelf and the earliest in Georges Bank. The magnitude of the bloom was mostly above normal on the Newfoundland shelf, including a series record in Hibernia, normal to above normal in the Gulf, and variable on the Scotian Shelf with a record low on the Central Scotian Shelf. Bloom duration was variable and close to normal in most regions across the zone but included a record high on Georges Bank.

Zooplankton

Zooplankton community structure is strongly influenced by depth, temperature, and season, and the complexity of the community differs substantially among the three bioregions of the Northwest Atlantic. Despite its complexity and diversity in different parts of the zone, four indices of abundance provide good indicators of the state of the zooplankton community. Zooplankton abundance indices demonstrate a high degree of large spatial scale coherence in their signal across different parts of the Atlantic zone. Two copepod taxa serve to represent different broad groups with similar life histories: *Calanus finmarchicus* and *Pseudocalanus* spp. *Calanus finmarchicus* is a large, ubiquitous copepod that develops large energy reserves in later developmental stages and is therefore a rich source of food for pelagic fish and a dominant species by biomass throughout much of the region. *Pseudocalanus* spp. are small copepods that are widespread throughout the Atlantic zone and have much smaller energy reserves relative to *C. finmarchicus,* but their life history features are generally representative of smaller taxa in the copepod community. The other indices provide information on the total abundance of copepods and non-copepod taxa, and the biomass (dry weight) of the zooplankton in the 0.2–10 mm size fraction typically dominated by copepods.

The zooplankton community shift observed in recent years (2014–2019), characterized by lower abundance of the large energy-rich copepod *Calanus finmarchicus* and higher abundance of small copepods and non-copepods, moderated in 2020 with increases in *Calanus finmarchicus* and declines in some small copepods, although the overall abundance of copepods and non-copepods remained elevated (Figure 13). There were below normal abundances of copepods in the Gulf of St. Lawrence and a record minimum on the Halifax Line section. There were below normal abundances of *Pseudocalanus* spp. in most regions with a record low in the Southern Gulf and on the Cabot Strait section, but a record high on the Bonavista section. Non-copepods were at a record low at Halifax 2 station but at a record high at Prince 5. Seal Island section saw record high abundances of copepods, non-copepods and *Calanus finmarchicus*.

Zooplankton biomass was generally normal to above normal on the Newfoundland and Labrador Shelf and below normal to normal elsewhere (Figure 14). The exception was Browns Bank where zooplankton biomass was above normal. Overall, recent changes in zooplankton community structure continue to indicate that important shifts in the flow of energy among lower trophic levels of the marine ecosystem in Atlantic Canadian waters are taking place, but the consequences to higher trophic levels will require further investigation.

Ocean Acidification

Ocean acidification (OA) parameters are collected as part of the AZMP since fall 2014. In addition to pH, the calcium carbonate saturation states with respect to calcite and aragonite (Ω_{cal} and Ω_{arg}) are measures of ocean acidification that indicate the potential to precipitate/dissolve carbonate. Below the threshold of 1, the environment is considered undersaturated with respect to calcium carbonate and potentially corrosive to organisms that build biogenic carbonate shells. The Ω typically decreases with depth, and thus deep slope waters tend to have lower Ω than the bottom waters of the shallower shelf waters. From 2019 to 2020, near-bottom pH across the Newfoundland Shelf and Gulf of St. Lawrence has shown a general decline, with undersaturation state for aragonite occurring in 2020 on the Grand Banks and in the Avalon channel on the Newfoundland shelf (Figure 15).

For the Scotian, Newfoundland, and Labrador shelves, bottom pH values ranged from 7.8 to above 8 and demonstrated considerable spatial variability. Ω_{arg} was slightly undersaturated in the Avalon channel, on the Grand Banks, in the deepest part of the Newfoundland Shelf slope and the eastern Scotian Shelf. All bottom waters of the Gulf of St. Lawrence, including the shallower southern Gulf, was also undersaturated with respect to aragonite. The only exceptions were inflowing waters in the Strait of Belle Isle and the Cabot Strait. The lowest pH and Ω values were however observed along the deep Laurentian channel, especially in the St. Lawrence Estuary where most of the deep layer (>300 m) was undersaturated with respect to aragonite and calcite (pH values were below 7.6 throughout the Estuary) and represents increased acidification relative to the conditions in 2019. In addition, oxygen saturation at many sampling locations is well below 20% (even below 15% at some stations; Figure 15, bottom panel) and has generally declined compared to 2019. These correspond to new low oxygen concentration records for the Lower St. Lawrence Estuary, reaching <1mL/L at Station Rimouski during the fall.

At the surface, pH and Ω_{arg} (not shown) are generally lower on the Newfoundland and Labrador Shelf and in the Gulf (especially in the Lower Estuary) compared to the Scotian Shelf, principally because of lower temperature and/or salinity.

Labrador Sea Environment

The Atlantic Zone Off-Shelf Monitoring Program (AZOMP) provides observations of variability in the ocean climate and plankton affecting ecosystems off Atlantic Canada and climate systems at a regional and global scale. In July-August of 2020, the Atlantic Repeat 7-West (AR7W) line was occupied by the Bedford Institute of Oceanography for the 33rd time since 1990. Additionally, the network of profiling Argo floats provided temperature and salinity data to 2000 m used for monitoring of year-round variability of the oceanographic conditions in the Labrador Sea.

While the winter (Dec–Mar) NAO index in 2020 was above-normal and the highest since 2015 (Figure 16), the sea level atmospheric pressure pattern was not associated with strong westerly winds along the Labrador coast. This led to, respectively, near-normal and above-normal winter and spring air temperatures in the Labrador Basin domain. Both winter and spring sea surface temperatures in the Labrador Basin were above normal. Winter sea ice extent was below normal in the Davis Strait and Northern Labrador Shelf regions, and below normal in the Labrador Shelf region. Spring sea ice extent was below normal in all three regions.

In the Labrador Sea, intense vertical mixing induced by high surface heat losses in winter resulted in the formation of a characteristic dense water mass, Labrador Sea Water, which consequently spread across the ocean ventilating its deep layers and essentially driving the global ocean overturning circulation. The most remarkable event in the entire history of oceanographic observations in the North Atlantic was the production of a record cold dense deep gas-saturated voluminous class of Labrador Sea Water between the late 1980s and mid-1990s. Over about 20 years that followed this well-documented water mass development, the strength of wintertime cooling notably declined (upward/positive trend in the low-pass filtered annual surface heat loss values in Figure 16), while the sea, especially at its mid-depth (200-2000 m; Figure 16), was gradually warming, gaining more saline and less dense waters.

Starting in the winter of 2014, a year before the Labrador Sea incurred the highest heat loss in more than two decades (Figure 16), and ending in the winter of 2018~~,~~ winter convection progressively deepened from 1600 to 2000 m (Figure 17), becoming the deepest since the winter of 1994. In the winter of 2020, the Labrador Sea convection reached the depth of 1600 m and possibly deeper, exceeding the depths observed in the previous year (Figure 16). The deepening of convective mixing and slight cooling of the deep mixed layer are mainly attributed to increases in the North Atlantic Oscillation index and net cumulative surface cooling from the previous winter. However, despite the NAO index being relatively high, the convection depths were noticeably shallower than the depths reported for the 2015-2018 period.

Similar to the previous year, the upper 15–100 m layer of the central Labrador Sea had its temperature above normal and salinity about normal in 2020 (Figure 16). The intermediate, 200–2000 m, layer reached its warmest state since 1972 in 2011 and then started to cool. The cooling of the intermediate layer that followed was a direct result of persistently deepening convection during the winters of 2012 through 2018. The warming of the upper and intermediate layers of the Labrador Sea in 2019 and 2020 concurs with the reduced heat loss and shallowed convection in the winter of 2019.

With respect to interdecadal variability, the Labrador Sea has recently (2019 and 2020) completed a cooling cycle, 2012–2018, similar to those observed during 1987–1994 and in the late 1950s. Each of these cooling events coincided with strengthening of winter convection and production of large volumes of Labrador Sea Water, while the trends of subsurface warming were associated with accumulation of relatively warm and saline Atlantic waters in the deep Labrador Sea reservoir.

The late timing of the survey in the Labrador Sea, in July rather than in May, induced a bias in the *in situ* measurements that prevents comparisons with the biochemical and surface observations collected in most other years. However, compared to those collected around the same time of year, 2020 appeared to be a warmer than normal year as in 2003 (Figure 18). Nutrients and chlorophyll *a* concentration were lower than the seasonal average with the exception of nutrients in the surface layer in the Central Labrador Sea and chlorophyll *a* concentration on the Greenland Shelf.

Sources of Uncertainty

The general spatial and seasonal patterns of physical, chemical and biological oceanographic indices in the Northwest Atlantic monitored by AZMP have remained relatively consistent since the start of the program. Although there are seasonal variations in the distribution of water masses, plants and animals, these variations show generally predictable patterns. However, there is considerable uncertainty in estimates of overall abundance of phytoplankton and zooplankton. This uncertainty is caused in part by the life cycle of the animals, their patchy distribution in space, and by the limited coverage of the region by the monitoring program.

Physical (temperature, salinity) and chemical (nutrients) oceanographic variables are effectively sampled, because they exhibit fairly conservative properties that are unlikely to show precipitous changes either spatially or from year-to-year. In addition, measurements of these variables are made with a good degree of precision. The only exception occurs in surface waters where rapid changes in the abundance of phytoplankton, particularly during the spring bloom, can cause rapid depletion of nutrients.

The greatest source of uncertainty comes in our estimates of phytoplankton abundance because of the difficulties in determining the inter-annual variations in the timing, magnitude and duration of the spring phytoplankton bloom. Phytoplankton may undergo rapid changes in abundance, on time scales of days to weeks. Because our sampling is limited in time, and occasionally suffers from gaps in coverage as a result of vessel unavailability or weather, which often occurs in the sampling at our high-frequency sampling stations during the winter months, we may not sample the spring phytoplankton and other important variables adequately. Also, variations in the timing of the spring phytoplankton bloom across a region and in relation to spring oceanographic surveys may limit our ability to determine inter-annual variations in maximum phytoplankton abundance. In contrast, we are better capable of describing inter-annual variations in the abundance of dominant zooplankton species because their seasonal cycle occurs at time scales of weeks to months as a result of their longer generation times relative to phytoplankton. However, zooplankton show greater variability in their spatial distribution. Although inter-annual variations in the abundance of dominant groups, such as copepods, can be adequately assessed, variations in the abundance of rare, patchily distributed or ephemeral species cannot be reliably estimated at this time.

In several areas, the occupation of high frequency sampling stations during the winter and early spring is particularly limited, causing us to sometimes miss major events in the seasonal cycle (e.g. the onset of the spring phytoplankton bloom). Additionally, reductions in vessel scheduling within regions have also reduced the number of full observations at some sites.

CONCLUSION

While a shift to warmer ocean conditions occurred prior the implementation of the AZMP, the past decade has seen further increases in water temperatures with sea surface temperatures that reached record values across the zone in summer 2012. In 2020, they returned to above normal overall for the zone after two below-normal years. Winter average sea ice volume was below normal in the Gulf of St. Lawrence and sea ice conditions were below normal (i.e., warmer) on the Newfoundland and Labrador Shelf for the first time since 2013. Consistent with this, summer cold intermediate layer conditions were near normal to warmer and thinner than normal across the zone. Bottom temperatures in the Atlantic Zone ranged from normal in NAFO Divisions 2J and 3K to above normal elsewhere, including a new 100+ year high-temperature record for the Gulf at 200, 250 and 300 m, and in Cabot Strait at 300 m.

Patterns of variation in biogeochemical variables appear dominated by short-term fluctuations, due to the relatively short duration of the time series, initiated in 1999, but there is evidence of multi-year trends in recent years. The current state of the biogeochemical environment demonstrates some spatial structuring across the Atlantic Zone. Overall, there appear to have been important changes in general patterns of productivity of lower trophic levels in recent years. General declines in nutrient and chlorophyll inventories and overall zooplankton biomass may be indicative of lower ecosystem production potential than in the previous decade. Despite some evidence that the shift in zooplankton community structure from large lipid-rich copepods to smaller taxa has moderated, the high abundance of small copepods and non-copepods may be indicative of changes in the transfer efficiency from primary producers to higher trophic levels.

In the Labrador Sea, convection reached the depth of 1600 m and possibly deeper, exceeding depths of 2019. Despite the NAO index being relatively high, the convection depths were noticeably shallower than the depths reported for the 2015-2018 period (which reached 2000 m).

LIST OF MEETING PARTICIPANTS

Name	Affiliation
Allain, Renée	DFO, Science – Gulf Region
Beazly, Lindsay	DFO, Science – Maritimes Region
Bélanger, David	DFO, Science – Newfoundland and Labrador Region
Bishop, Charlie	DFO, Science – Newfoundland and Labrador Region
Blais, Marjolaine	DFO, Science – Quebec Region
Boivin, Brian	DFO, Science – Quebec Region
Brickman, David	DFO, Science – Maritimes Region
Bujold, Luc	DFO, Science – National Capitol Region
Cardoso, Diana	DFO, Science – Maritimes Region
Casault, Benoit	DFO, Science – Maritimes Region
Caverhill, Carla	DFO, Science – Maritimes Region
Chassé, Joël	DFO, Science – Gulf Region
Clay, Stephanie	DFO, Science – Maritimes Region
Cyr, Frederic	DFO, Science – Newfoundland and Labrador Region
Devred, Emmanuel	DFO, Science – Maritimes Region
Dumas, Jacqueline	DFO, Science – Quebec Region
Fife, Jack	DFO, Science – Maritimes Region
Gaboury, Isabelle	DFO, Science -- National Capitol Region
Gabriel, Carrie-Ellen	DFO, Science – Maritimes Region
Galbraith, Peter	DFO, Science – Quebec Region
Gibb, Olivia	DFO, Science – Newfoundland and Labrador Region
Greenan, Blair	DFO, Science – Maritimes Region, ARGO Canada, OSOM
Hebert, Dave	DFO, Science – Maritimes Region
Johnson, Catherine	DFO, Science – Maritimes Region
Lambert, Nicolas	DFO, Science – Gulf Region
Lavoie, Diane	DFO, Science – Quebec Region
Layton, Chantelle	DFO, Science – Maritimes Region
Lehoux, Caroline	DFO, Science – Quebec Region
Lewis, Sara	DFO, Science – Newfoundland and Labrador Region
Maillet, Gary	DFO, Science – Newfoundland and Labrador Region
Ma, Zhimin	DFO, Science, -- Newfoundland and Labrador Region
Michaud, Sonia	DFO, Science – Quebec Region
Niven, Sherry	DFO, Science – Maritimes Region
Pepin, Pierre	DFO, Science – Newfoundland and Labrador Region
Plourde, Stéphane	DFO, Science – Quebec Region
Proudfoot, Maddison	DFO, Science – Maritimes Region
Riche, Olivier	DFO, Science – Quebec Region
Ringuette, Marc	DFO, Science – Maritimes Region
Shaw, Jean-Luc	DFO, Science – Quebec Region
Snook, Stephen	DFO, Science – Newfoundland and Labrador Region
St-Pierre, Félix	DFO, Science – Quebec Region
Starr, Michel	DFO, Science – Quebec Region
Sun, Krista	Special guest -- OSDM, MEDS
Tran, Anh	DFO, Science – National Capitol Region
Villeneuve, François	DFO, Science – Quebec Region

Name	Affiliation
Wan, Di	DFO, Science – Pacific Region
Yashayaev, Igor	DFO, Science – Maritimes Region

SOURCES OF INFORMATION

This Science Advisory Report is from the March 22–26, 2021 Twenty-third Annual Meeting of the Atlantic Zone Monitoring Program (AZMP) held via video-conference. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

Blais, M., Galbraith, P.S., Plourde, S., Devine, L. and Lehoux, C. 2021. Chemical and Biological Oceanographic Conditions in the Estuary and Gulf of St. Lawrence during 2019. DFO Can. Sci. Advis. Sec. Res. Doc. 2021/002. iv + 66 pp

Casault, B., Johnson, C., Devred, E., Head, E., Cogswell, A., and Spry, J. 2020. Optical, Chemical, and Biological Oceanographic Conditions on the Scotian Shelf and in the eastern Gulf of Maine during 2019. DFO Can. Sci. Advis. Sec. Res. Doc. 2020/071. v + 64 p.

Cyr, F., Snook, S., Bishop, C., Galbraith, P.S., Pye, B., Chen, N., and Han, G. 2021. Physical Oceanographic Conditions on the Newfoundland and Labrador Shelf during 2019. DFO Can. Sci. Advis. Sec. Res. Doc. 2021/017. iv + 52 p.

Cyr, F. and Galbraith, P.S. 2021. A climate index for the Newfoundland and Labrador shelf. Earth Syst. Sci. Data, 13, 1807-1828. 2021.

Galbraith, P.S., Chassé, J., Shaw, J.-L., Dumas, J., Caverhill, C., Lefaivre, D. and Lafleur, C. 2020. Physical Oceanographic Conditions in the Gulf of St. Lawrence during 2019. DFO Can. Sci. Advis. Sec. Res. Doc. 2020/030. iv + 84 p.

Galbraith, P. S., Larouche, P., Caverhill. C. 2021. A sea-surface temperature homogenization blend for the Northwest Atlantic. Can. J. Remote Sensing. DOI: 10.1080/07038992.2021.1924645.

Hebert, D., Layton, C., Brickman, D. and Galbraith, P.S. 2021. Physical Oceanographic Conditions on the Scotian Shelf and in the Gulf of Maine during 2019. DFO Can. Sci. Advis. Sec. Res. Doc. 2021/040. iv + 58 p.

Maillet, G., Bélanger, D., Doyle, G., Robar, A., Fraser, S., Higdon, J., Ramsay, D. and P. Pepin. 2019. Optical, Chemical, and Biological oceanographic conditions on the Newfoundland and Labrador Shelf during 2016-2017. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/055.viii + 35 p.

Therriault, J.-C., Petrie, B., Pepin, P., Gagnon, J., Gregory, D., Helbig, J., Herman, A., Lefaivre, D., Mitchell, M., Pelchat, B., Runge, J., and Sameoto, D. 1998. Proposal for a northwest Atlantic zonal monitoring program. Can. Tech. Rep. Hydrogr. Ocean Sci. 194: vii+57p.

World Meteorological Organization 2017. WMO guidelines on the calculation of climate normals, Tech. rep., Geneva, Switzerland, 2017.435.

APPENDIX – FIGURES

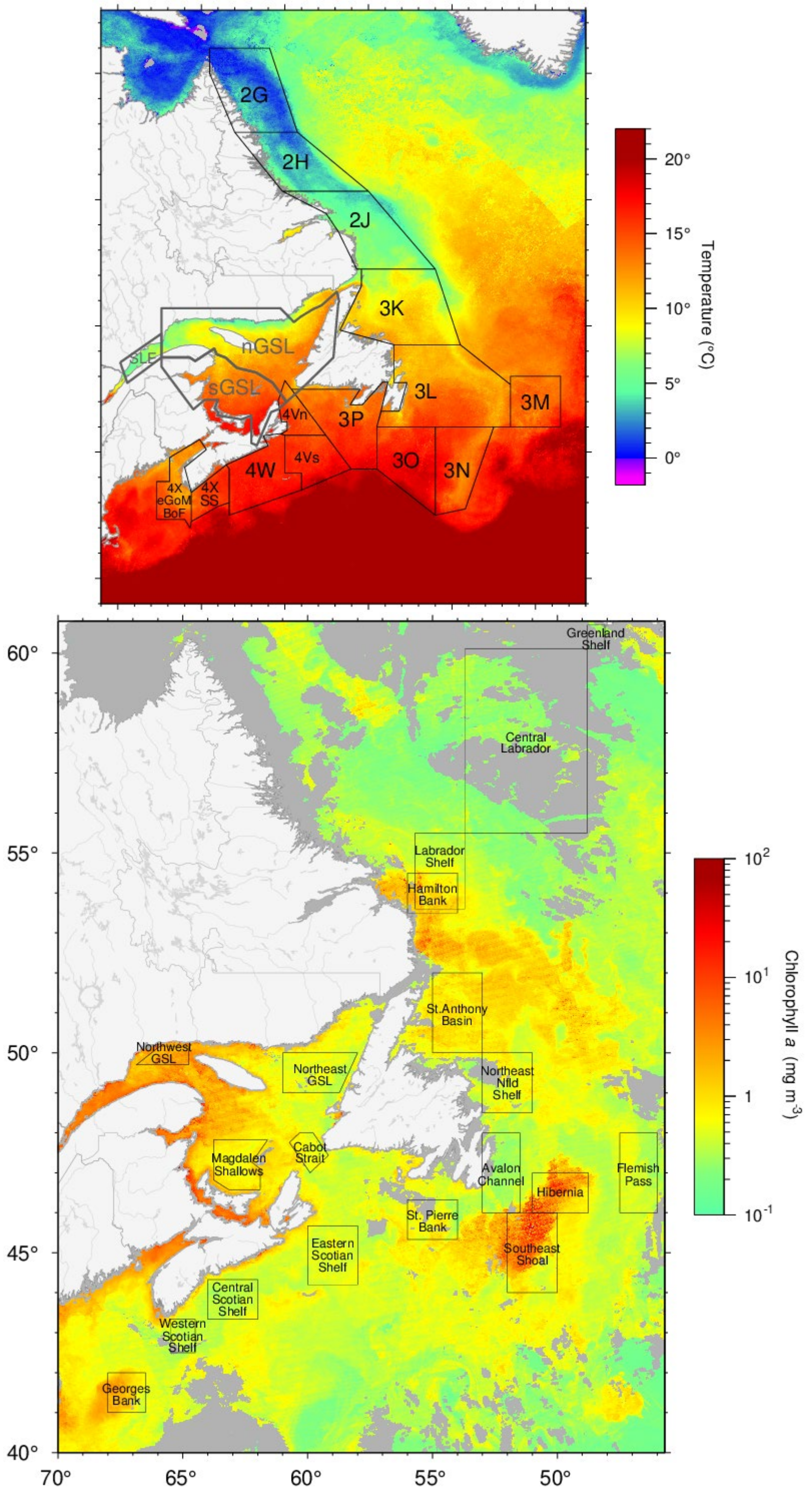


Figure 2. Areas used for (top) temperature and (bottom) ocean color averages. (Top) North Atlantic Fisheries Organization Divisions are cut off at the shelf break. The acronyms GSL and SLE are Gulf of St. Lawrence and St. Lawrence Estuary respectively. Sea surface temperatures are shown for September 2020 and ocean colour chlorophyll a concentrations are for the first half of May 2020.

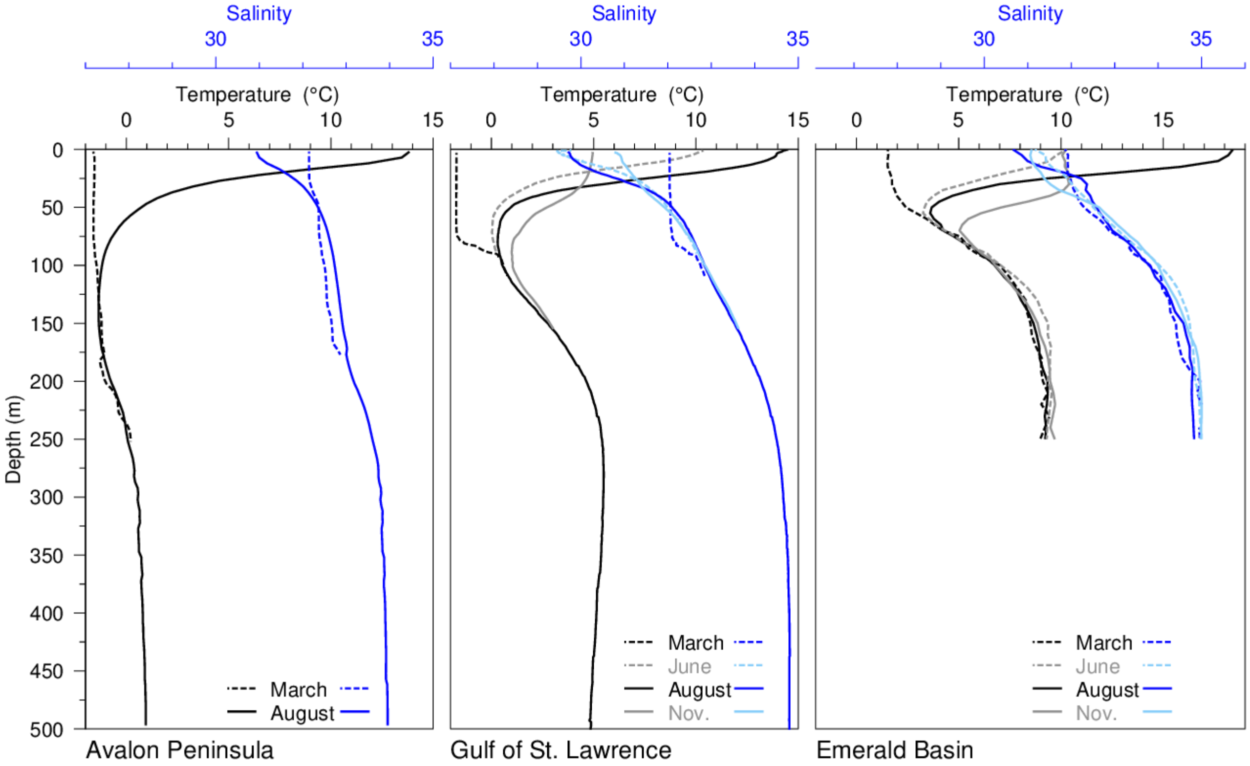


Figure 3. Typical seasonal progression of the depth profile of temperature and salinity observed in three representative regions across the zone. The Avalon Peninsula region is delimited by 45–50°N and 50–55°W and shown are the averages of profiles for March and August between 2015 and 2017, calculated from 5 and 302 profiles respectively. The Gulf of St. Lawrence profiles are averages of observations in June, August and November 2007 in the northern Gulf, while the March profile shows a single winter temperature profile (March 2008), with near-freezing temperatures in the top 75 m. The Emerald Basin profiles are monthly climatological averages for 1981–2010.

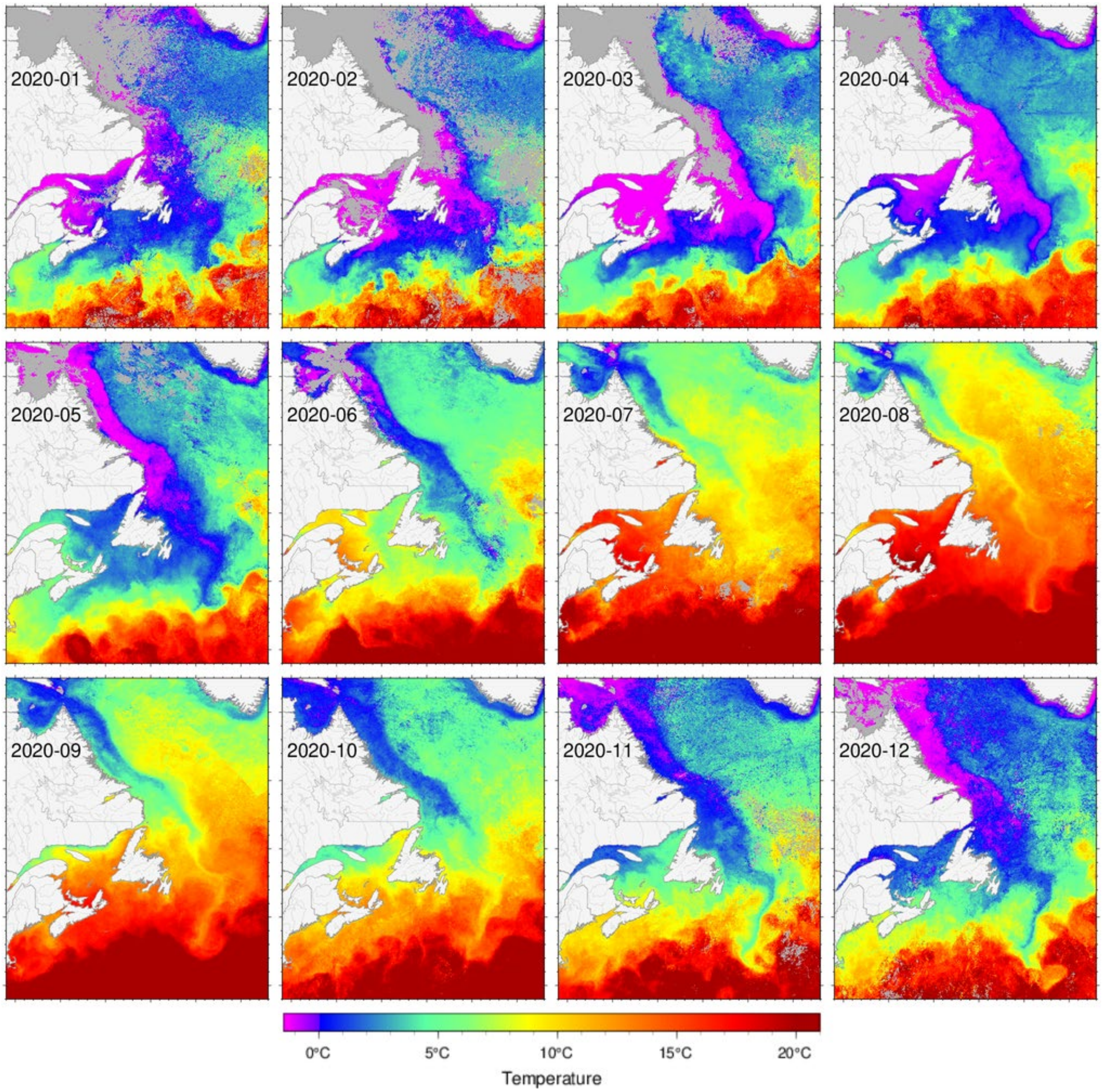


Figure 4. Sea surface temperature monthly averages for 2020 in the Atlantic zone.

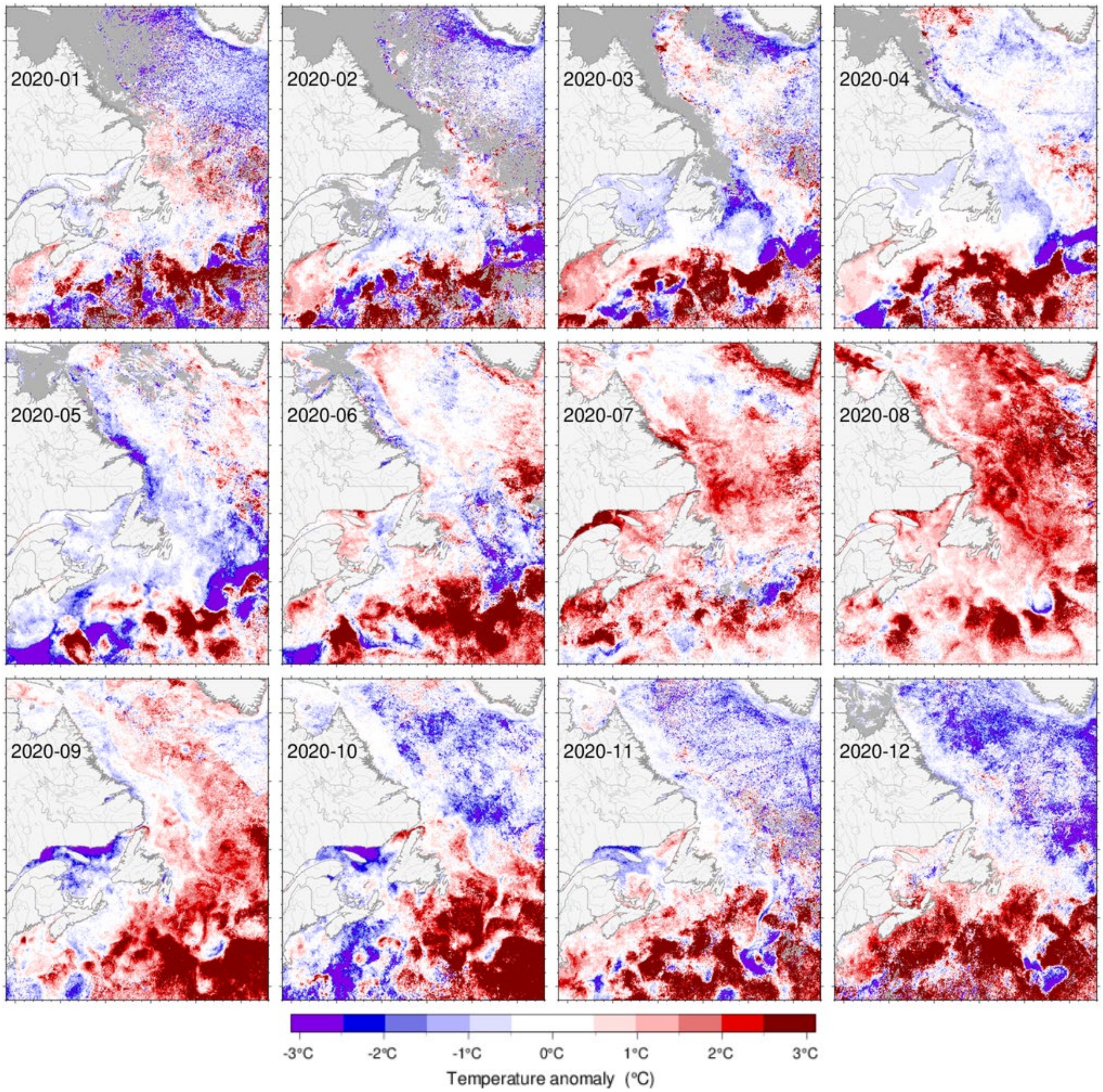


Figure 5. Sea surface temperature monthly anomalies for 2020 in the Atlantic zone. Temperature anomalies are based on a 1985–2010 climatology and not the 1991-2020 used elsewhere in this document.

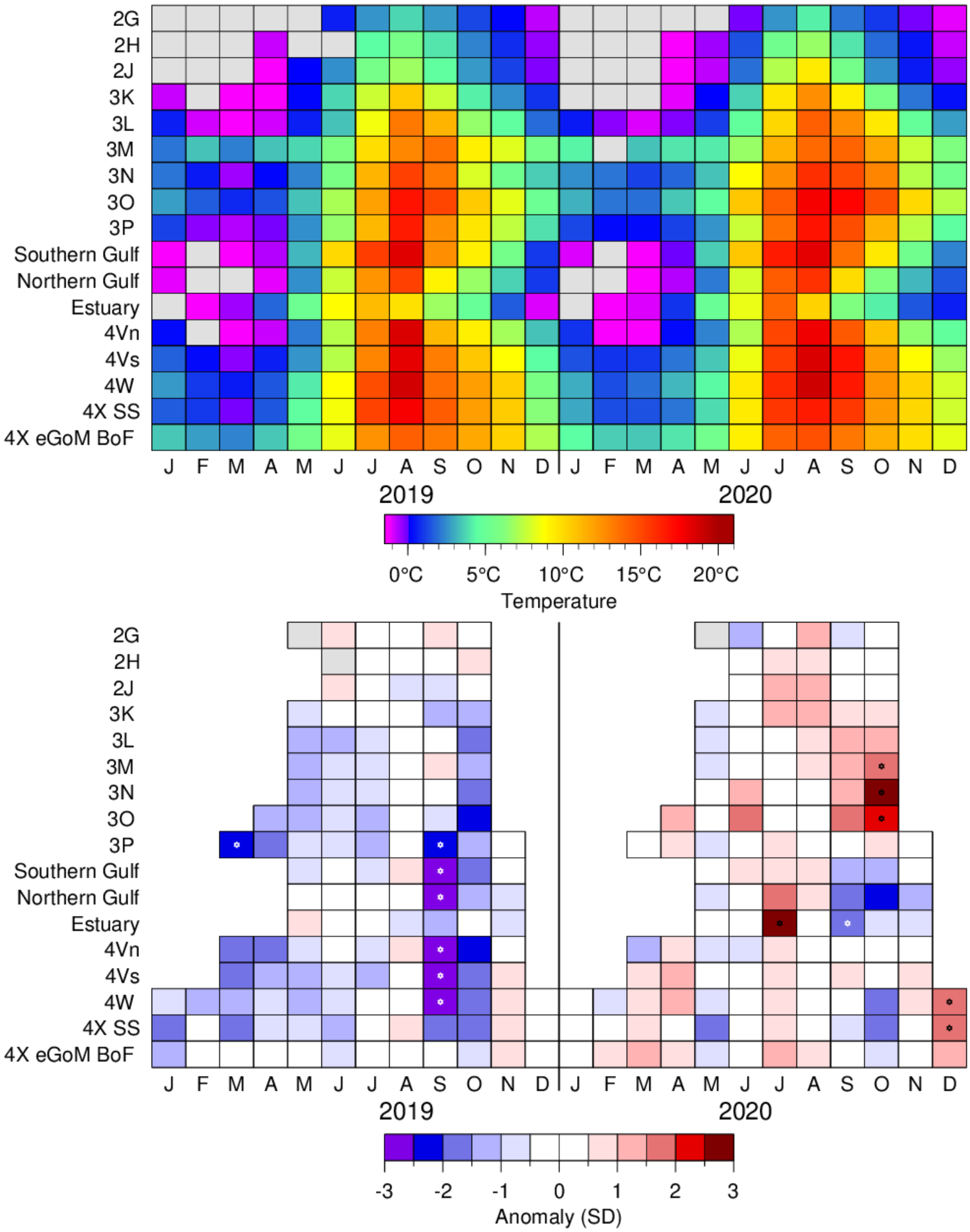


Figure 6. Monthly sea surface temperature temperatures (top) and anomalies (bottom) for ice-free months of 2019–20, averaged over the 17 regions shown in Figure 2. Regions and months for which the average temperature was at a record high or low are indicated by a star. Grey squares have insufficient data coverage to yield a monthly average anomaly (<7%).

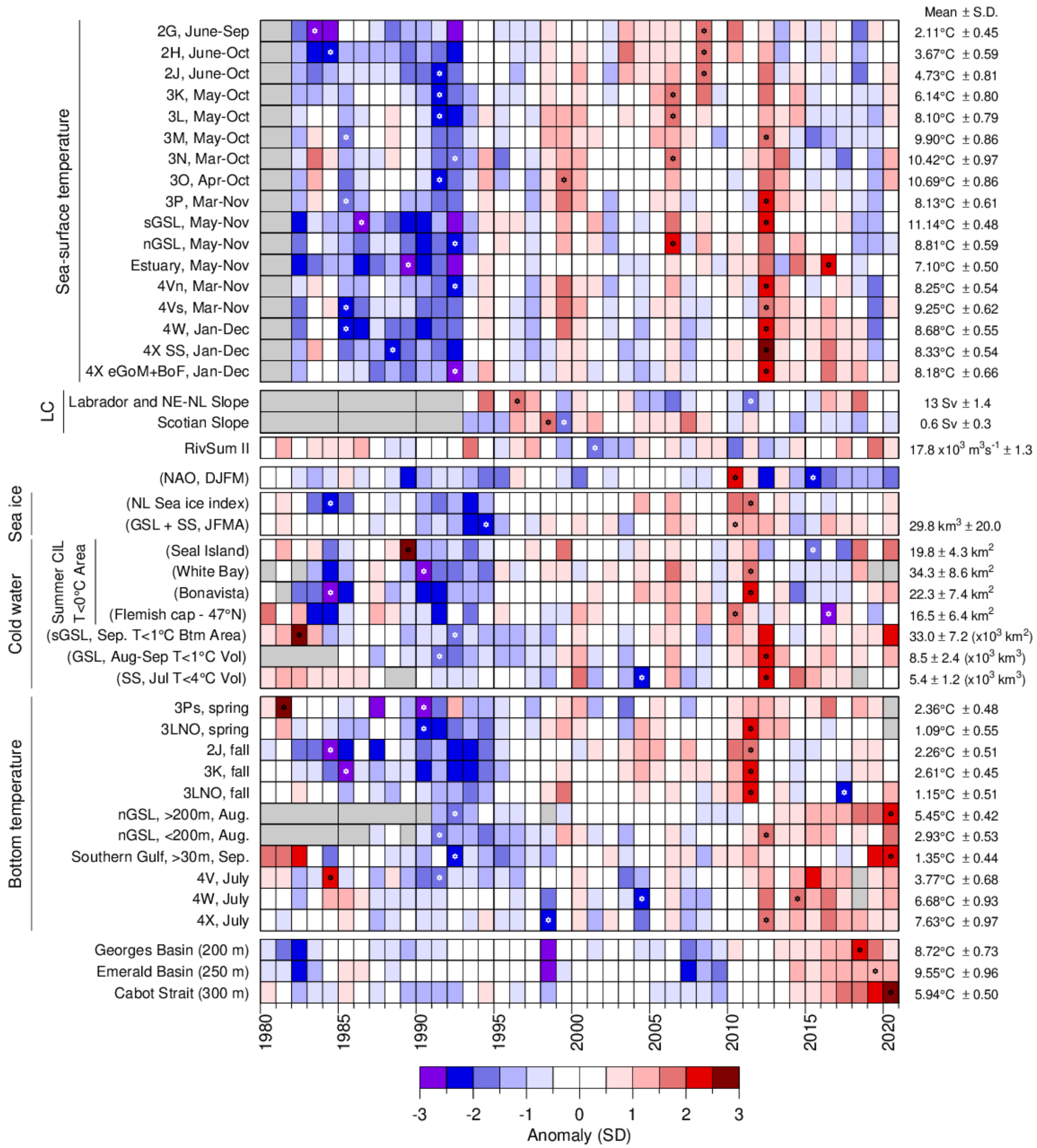


Figure 7. Time series of oceanographic variables, 1980–2020. A grey cell indicates missing data, a white cell is a value within 0.5 SD of the long-term mean based on data from 1991–2020 when possible; a red cell indicates above normal conditions, and a blue cell below normal. Variables whose names appear in parentheses have reversed colour coding, whereby reds are lower than normal values that correspond to warm conditions. More intense colours indicate larger anomalies. Series minimum and maximums are indicated by a star when they occur in the displayed time span. Long-term means and standard deviations are shown on the right-hand side of the figure. (LC is Labrador Current transports. RivSum II is the combined runoff flowing into the St. Lawrence Estuary. North Atlantic Oscillation [NAO], GSL [Gulf of St. Lawrence], SS [Scotian Shelf], sGSL [southern Gulf of St. Lawrence], nGSL [northern Gulf of St. Lawrence], cold intermediate layer [CIL]).

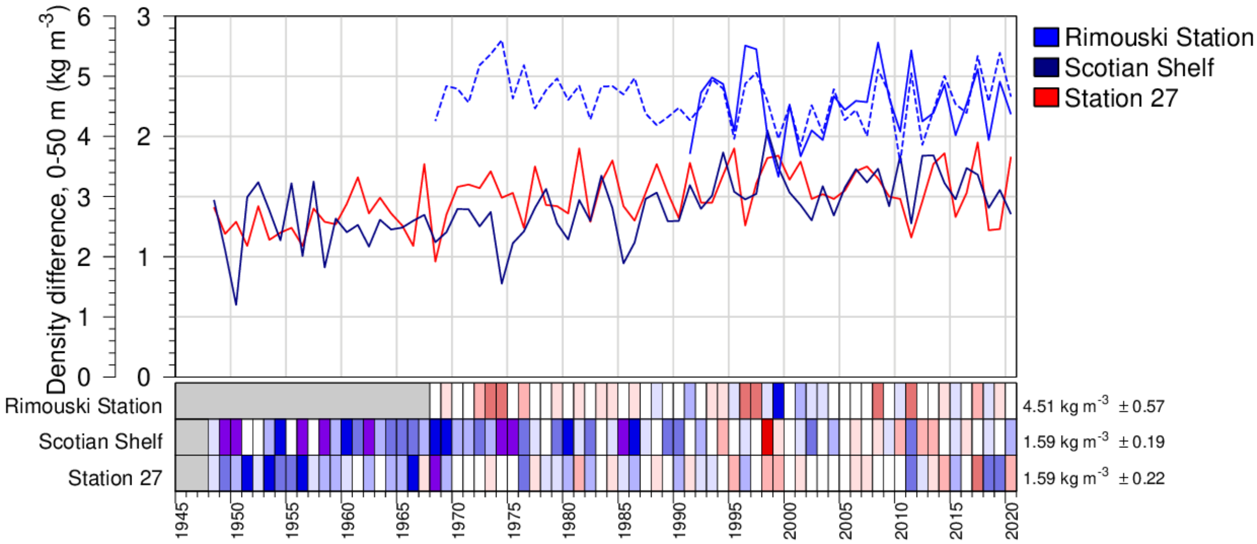


Figure 8. Stratification trends on the southern Newfoundland-Labrador Shelf (May-Nov average at Station 27), Scotian Shelf and St. Lawrence Estuary (May–Oct average at Rimouski Station). The inner y-axis is for Station 27 and Scotian shelf, while the outer y-axis is for Rimouski Station. The dashed line for Rimouski Station is a proxy based on May–October freshwater runoff. The three bottom lines show normalized anomalies based on the 1991–2020 period. A grey cell indicates missing data, a white cell is a value within 0.5 SD of the long-term mean, a red cell indicates above normal conditions, and a blue cell below normal.

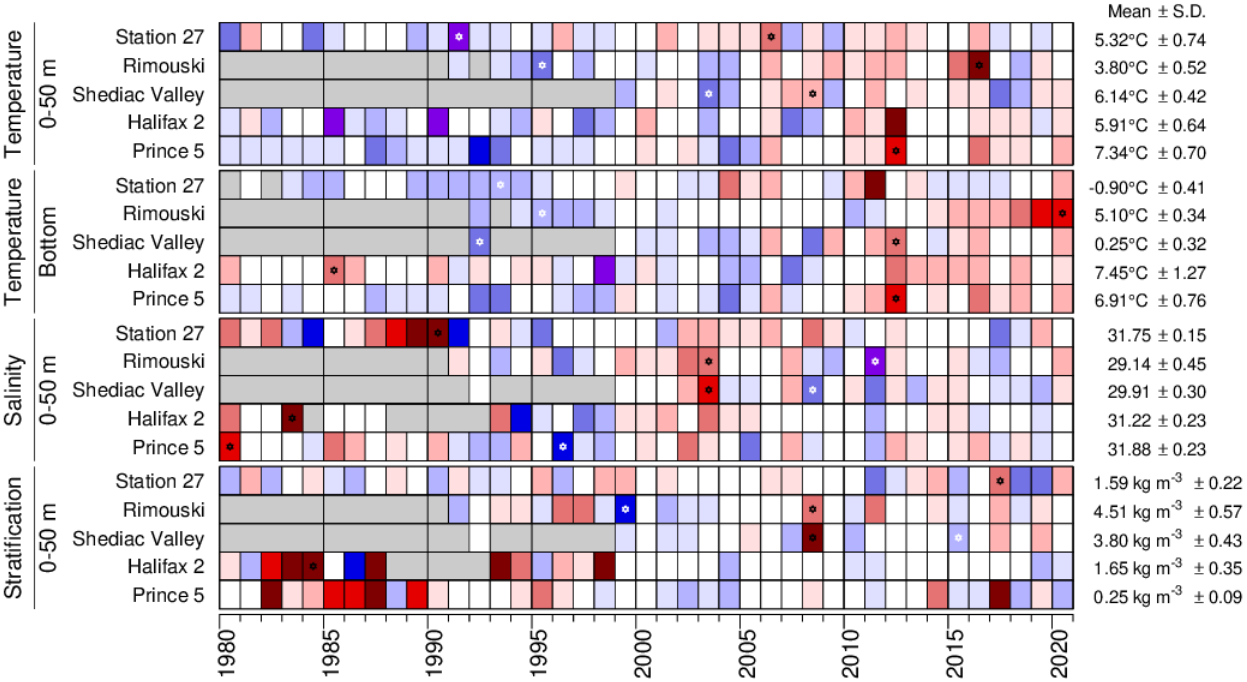


Figure 9. Time series of oceanographic variables at AZMP high-frequency sampling stations, 1980–2020. Values are annual averages at Halifax 2 and Prince 5, May–November at station 27 and May-October at Rimouski station. A grey cell indicates missing data, a white cell is a value within 0.5 SD of the long-term mean based on data from 1991–2020 when possible; for high-frequency station depth-averaged temperature, a red cell indicates warmer than normal conditions, a blue cell colder than normal. More intense colours indicate larger anomalies. For salinity and stratification, red corresponds to above normal conditions. Series minimum and maximums are indicated by a star when they occur in the displayed time span. Climatological means and standard deviations are shown on the right-hand side of the figure. Palette as in Figures 6 and 7.

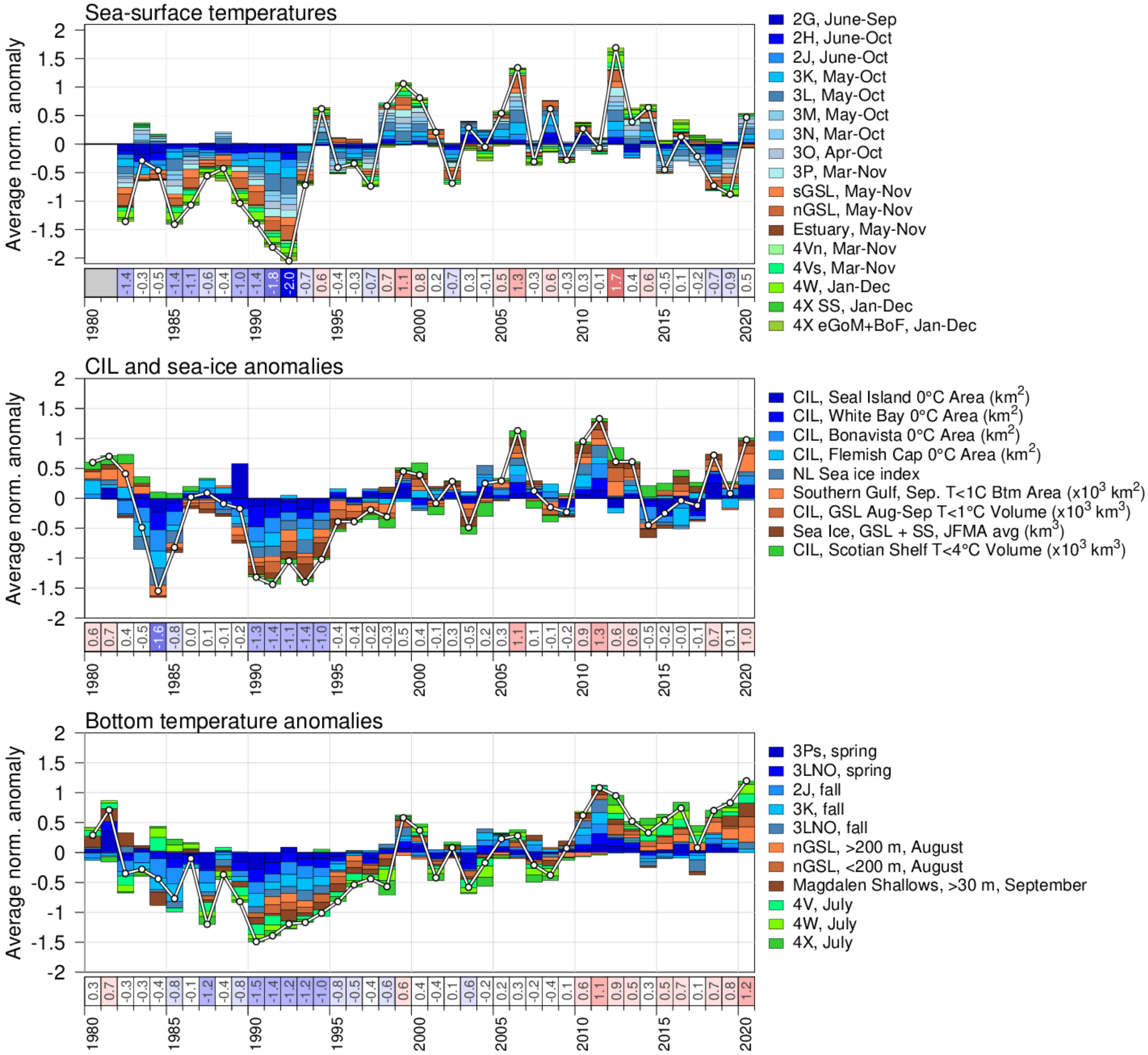


Figure 10. Composite climate indices (white lines and dots) derived by averaging various normalized anomalies from different parts of the environment (colored boxes stacked above the abscissa are positive anomalies, and below are negative). Top panel shows averages sea surface temperature anomalies weighted by area, middle panel averages cold intermediate layer and sea ice anomalies with areas and volumes in reversed scale (positive anomalies are warm conditions) and bottom panel averages bottom temperature anomalies.

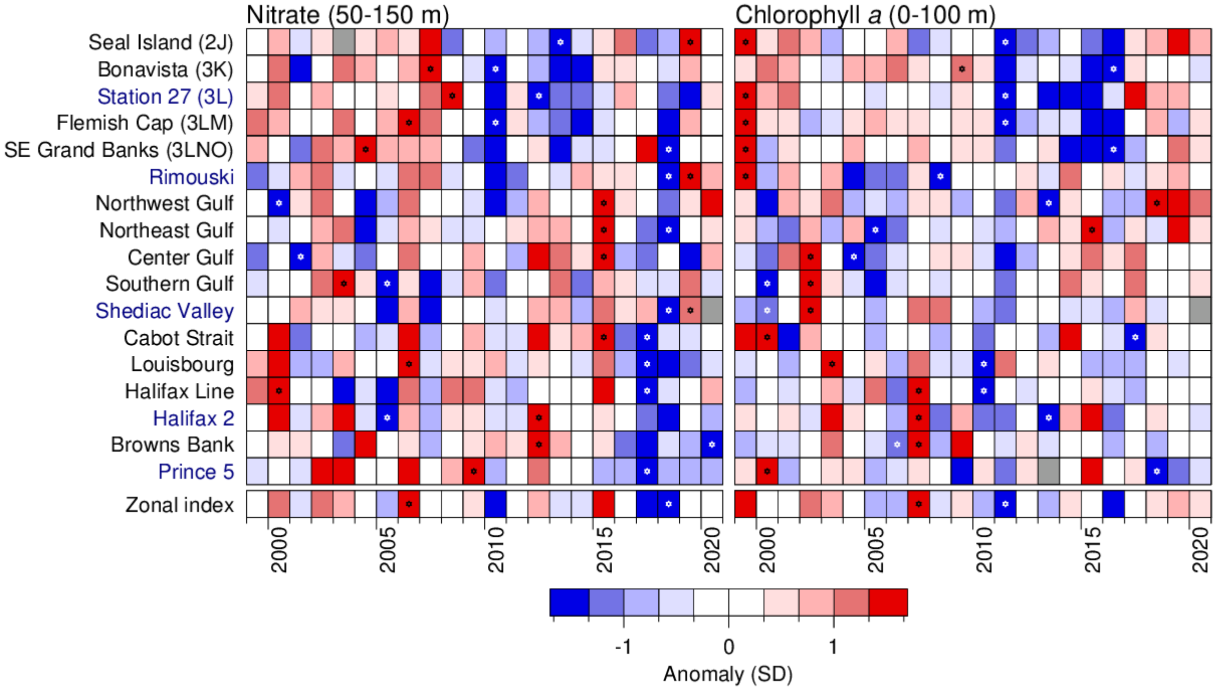


Figure 11. Time series of deep water nitrate inventories (50–150 m) and surface phytoplankton standing stocks (expressed as chlorophyll a 0–100 m mean concentration) at AZMP sections (labelled in red in Figure 1) and high-frequency sampling stations (labelled in blacks in Figure 1), 1999–2020. A grey cell indicates missing data. Note change in colour palette: a white cell is a value within 0.33 SD of the long-term mean based on data from 1999–2020; a red cell indicates above normal inventories, a blue cell below normal. More intense colours indicate larger anomalies. Series minimum and maximums are indicated by a star. The "zonal index" is created as the average of all normalized anomalies, and that result is again normalized.

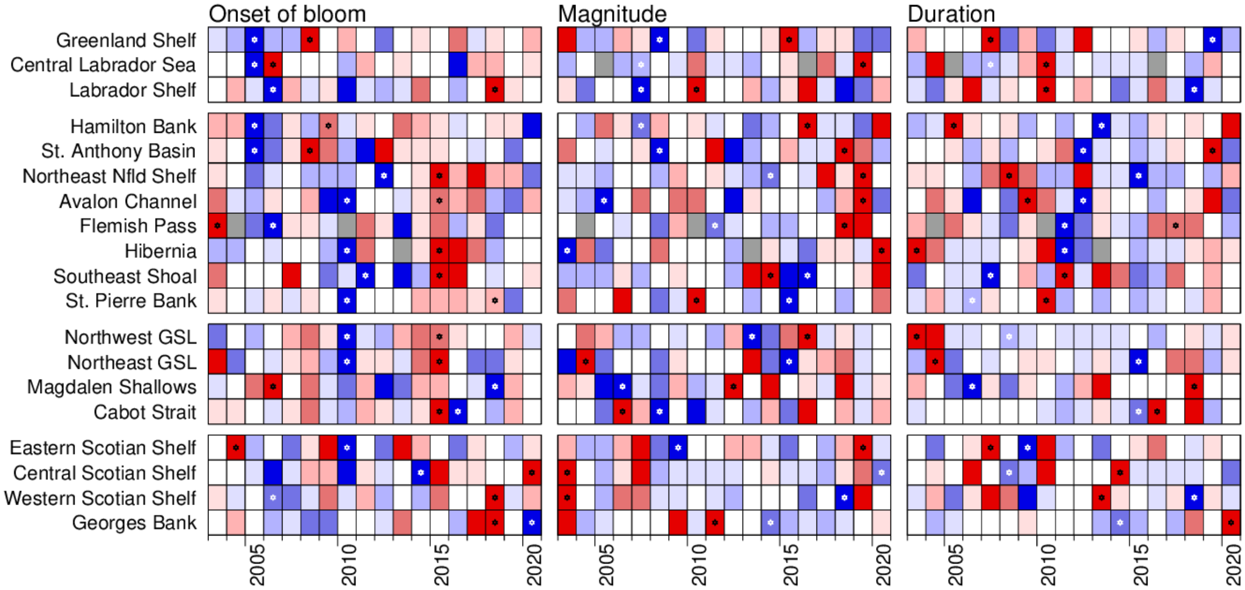


Figure 12. Time series of remotely sensed bloom parameter anomalies in various regions (onset of bloom, magnitude and duration) 1998-2020. Data are MODIS. Series minimum and maximums are indicated by a star. See Figure 2 for area definitions. Palette as in Figure 11.

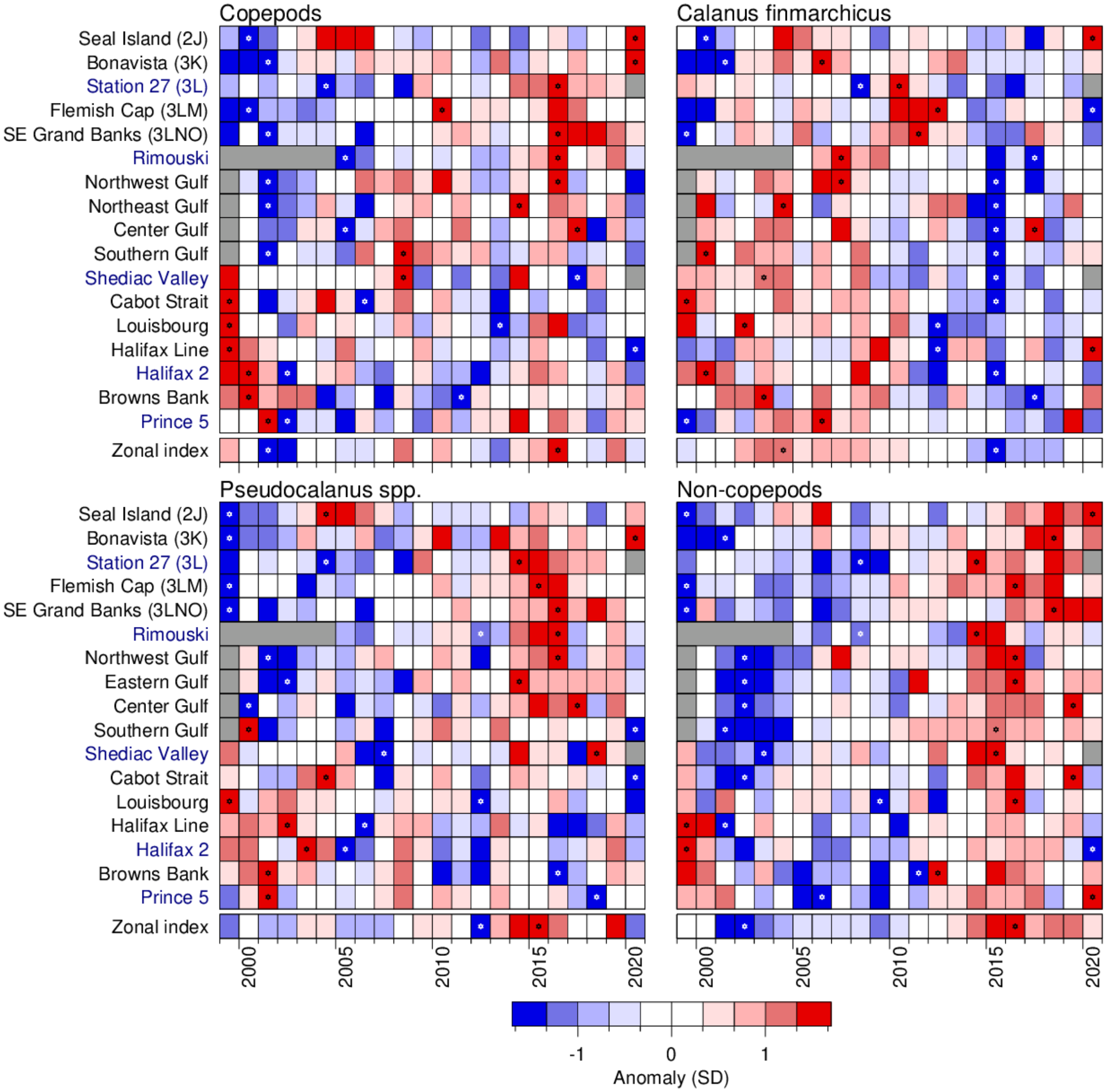


Figure 13. Time series of the standing stocks of total copepods, Calanus finmarchicus, Pseudocalanus spp., and non-copepod zooplankton, 1999–2020. A grey cell indicates missing data, a white cell is a value within 0.33 SD of the long-term mean based on data from 1999–2020; a red cell indicates above normal inventories, a blue cell below normal. More intense colours indicate larger anomalies. Series minimum and maximums are indicated by a star. The "zonal index" is created as the average of all normalized anomalies, and that result is again normalized.

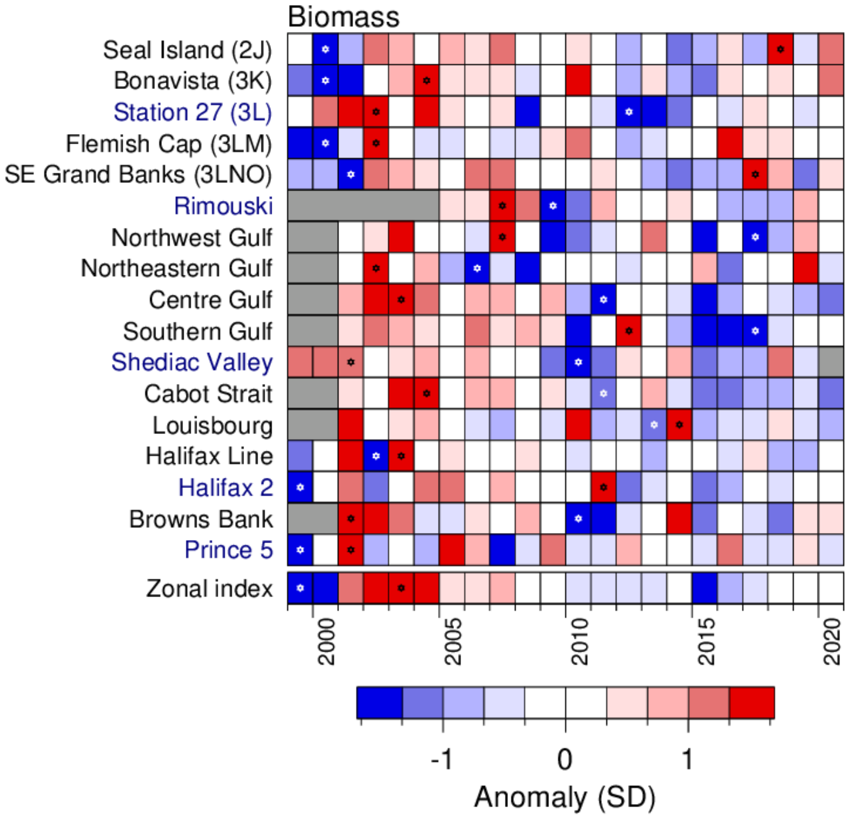


Figure 14. Time series of zooplankton biomass (dry weight), 1999 to 2020. Biomass is measured on the 0.2–10 mm size fraction which is usually dominated by copepods. A grey cell indicates missing data, a white cell is a value within 0.33 SD of the long-term mean based on data from 1999–2020; a red cell indicates above normal inventories, a blue cell below normal. More intense colours indicate larger anomalies. Series minimums and maximums are indicated by a star. The lowest row is the averaged (anomaly across all sections and fixed stations in a given year. The "zonal index" is created as the average of all normalized anomalies, and that result is again normalized.

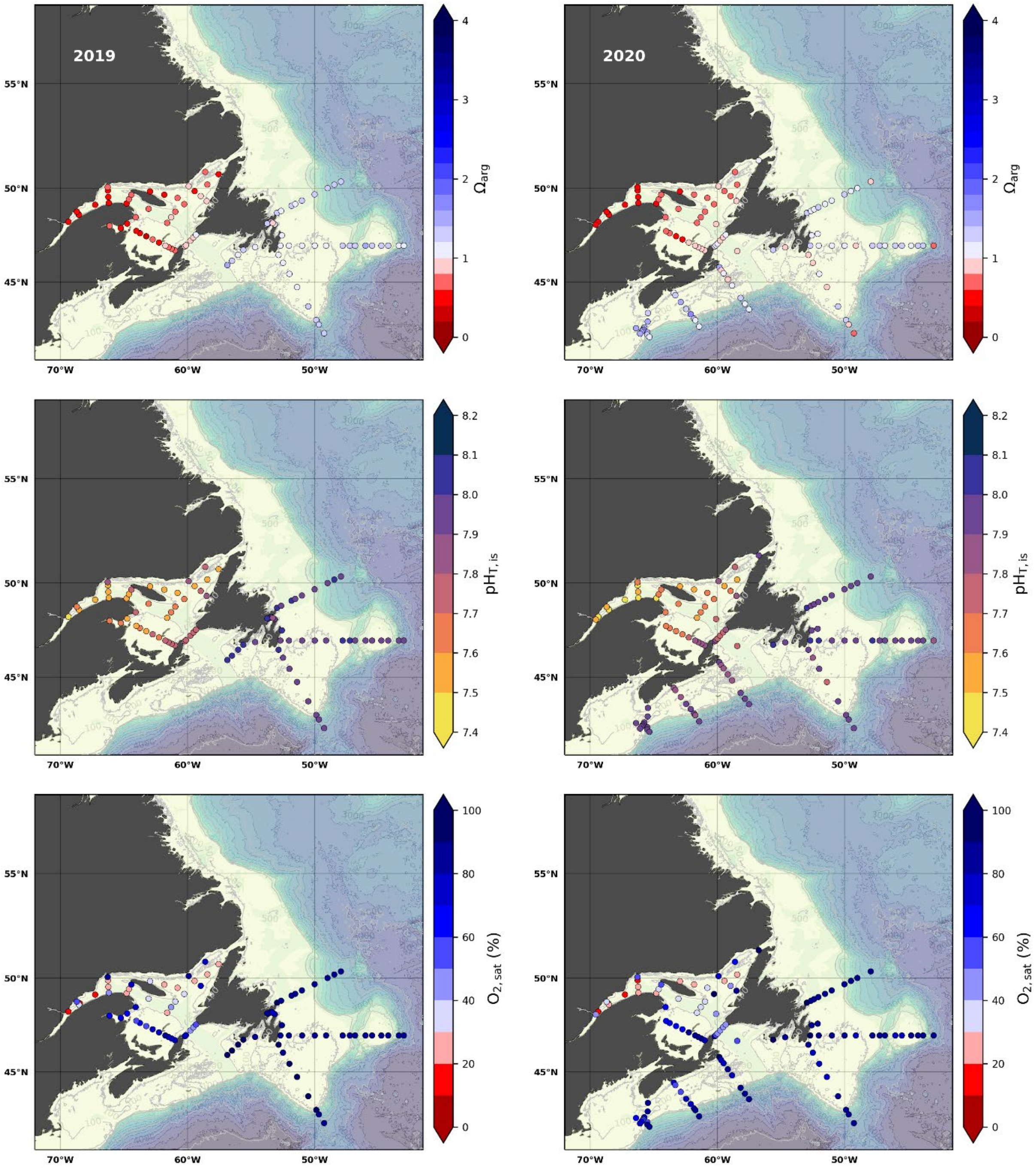


Figure 15. Bottom ocean acidification conditions during fall 2019 (left) and 2020 (right) for the Gulf of St. Lawrence, Scotian Shelf and Newfoundland Shelf: aragonite saturation state (top), in situ pH using total scale (center) and dissolved oxygen saturation (lower). Undersaturated conditions relative to aragonite and hypoxic oxygen conditions are plotted in red colors.

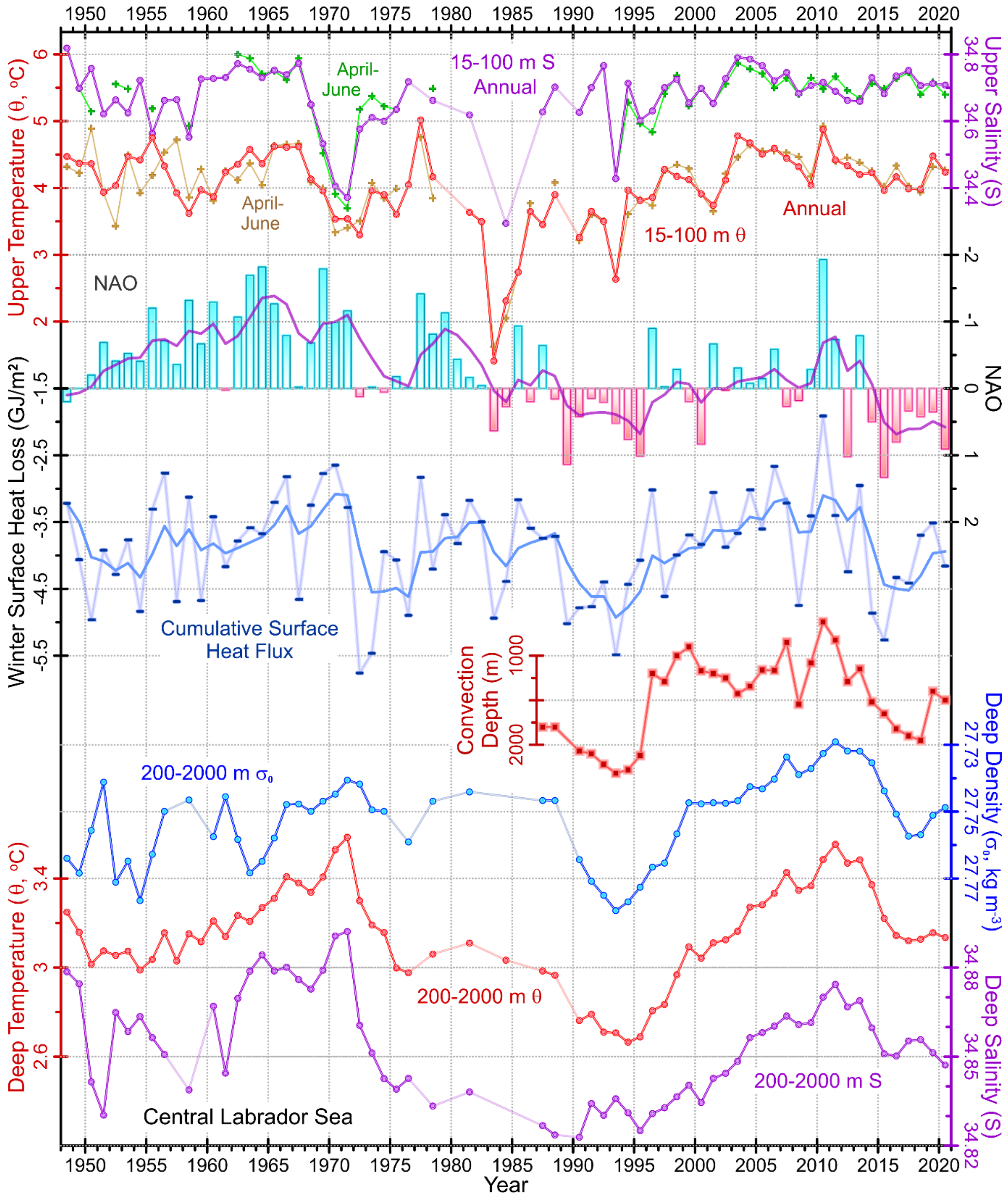


Figure 16. Key Labrador Sea environmental indices since 1948. From top to down: Annual and spring mean salinity (S) and temperature (θ) averaged over the 15-100 m depth range; The normalized winter NAO index (bar graph, inverted vertical scale); The NCEP reanalysis-based cumulative surface heat flux computed for the central Labrador Sea over individually-defined annual cooling seasons (blue); The solid lines overlaying the NAO and heat flux graphs indicate five-back-point filtered series; Annual mean seawater density (σ₀), θ and S averaged over the 200–2000 m depth range in the central Labrador Sea.

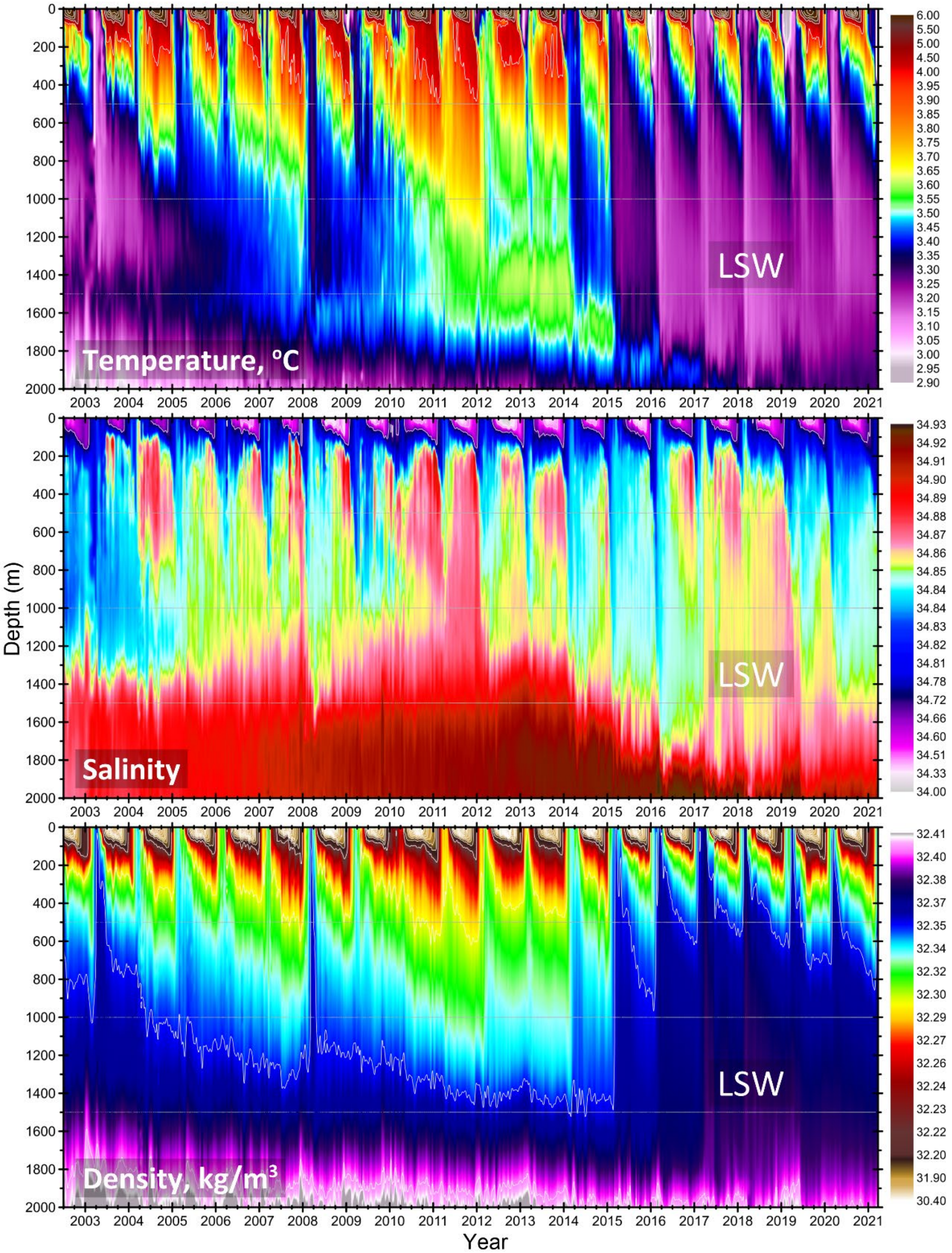


Figure 17. Annual temperature (upper panel), salinity (middle panel) and density (referenced to 1000 dbar, lower panel) means in the central region of the Labrador Sea between 200 and 3500 m based on profiling Argo float and shipboard observations and averaged in 10-day time bins spaced at 5-day intervals over the time period of 2002-2020. LSW-indicates Labrador Sea Water.

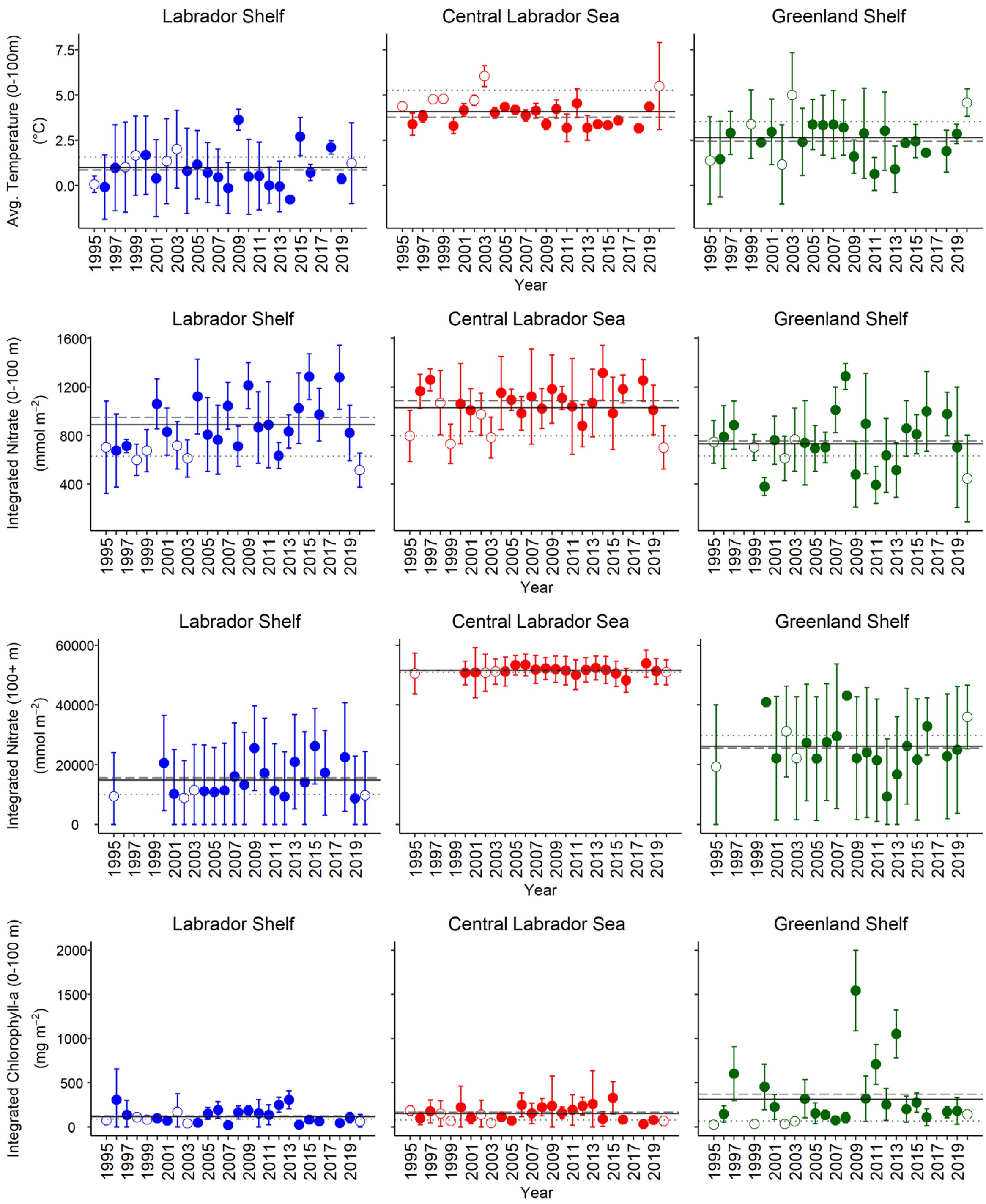


Figure 18. Labrador Sea 0–100 m averages of observations from oceanographic station data. Top to bottom panels show the average temperature from 0 to 100 m (°C), the integrated nitrate for the top 100 m, the integrated nitrate below 100 m to the bottom (mmol m^{-2}) and the integrated chlorophyll a from 0 to 100 m (mg m^{-2}). From left to right the panels are divided in 3 regions with the Labrador Shelf in Blue, the Central Labrador Sea in Red and the Greenland Shelf in green. Open symbols correspond to late surveys (after 19 June).The reference period is from 1999 to 2020 and the solid line represents the average for all years, the dashed line corresponds to the summer average and the dotted line corresponds to the spring period.

THIS REPORT IS AVAILABLE FROM THE:

Center for Science Advice (CSA)
Quebec Region
Fisheries and Oceans Canada
Maurice Lamontagne Institute
850 route de la Mer
P.O. Box 1000
Mont-Joli (Quebec)
Canada G5H 3Z4

Telephone: (418) 775-0825
E-Mail: bras@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

ISSN 1919-5087
ISBN 978-0-660-39502-9 Cat. No. Fs70-6/2021-026E-PDF

Correct Citation for this Publication:

DFO. 2021. Oceanographic Conditions in the Atlantic Zone in 2020. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2021/026.

Aussi disponible en français :

MPO. 2021. Conditions océanographiques dans la zone atlantique en 2020. Secr. can. de consult. sci. du MPO. Avis sci. 2021/026.