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ABSTRACT

Galbraith, P.S., Blais, M., Lizotte, M., Bélanger, D., Casault, B., Clay, S., Layton, C., Penney, J., Gabriel, C.-E., Ringuette, M., Azetsu-Scott, K., Chassé, J., Coyne, J., Devred, E., Johnson, C.L., Maillet, G., Shaw, J.-L., Starr, M. 2026. Oceanographic conditions in the Atlantic Zone in 2025. Can. Tech. Rep. Hydrogr. Ocean. Sci. 420: v + 49 p.

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This summarizes oceanographic conditions for 2025 detailed in Atlantic Zone Monitoring Program (AZMP) reports. Sea surface temperatures were on average above normal, but anomalies were much weaker than the previous four years. The cold intermediate layer was generally warmer than normal, with conditions remaining similar for the past three years. Bottom temperatures in the deep channels of the Gulf of St. Lawrence and the Scotian Shelf, a mixture of Labrador Current water and Gulf Stream waters, show further decreases from the 2022 record highs. Zone-wide signals related to phytoplankton were mixed, with early spring blooms and late fall blooms, near-normal chlorophyll-*a*, and below-normal subsurface nitrate. *Calanus finmarchicus* had above-normal abundances across most regions for the third consecutive year. Total copepod, *Pseudocalanus* spp., and non-copepod abundances were near or above normal on the Newfoundland and Scotian Shelves, but near or below normal in the Gulf of St. Lawrence. Acidification metrics in near-bottom waters continued a pattern of inorganic carbon generally at normal to above-normal levels, and pH_T and calcium carbonate indices mostly at normal to below-normal levels, indicating ongoing carbon accumulation and acidification. The most critical chemical conditions are observed in near-bottom waters of the St. Lawrence Estuary and northwest Gulf, where hypercapnic conditions (pCO₂ >1,000 µatm) and hypoxic or nearly hypoxic conditions (oxygen saturation <30%) persist.

RÉSUMÉ

Galbraith, P.S., Blais, M., Lizotte, M., Bélanger, D., Casault, B., Clay, S., Layton, C., Penney, J., Gabriel, C.-E., Ringuette, M., Azetsu-Scott, K., Chassé, J., Coyne, J., Devred, E., Johnson, C.L., Maillet, G., Shaw, J.-L., Starr, M. 2026. Oceanographic conditions in the Atlantic Zone in 2025. Can. Tech. Rep. Hydrogr. Ocean. Sci. 420: v + 49 p.
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Ceci résume les conditions océanographiques 2025 détaillées dans les rapports du Programme de monitoring de la zone atlantique (PMZA). Les températures de surface de la mer étaient en moyenne supérieures à la normale, mais les anomalies étaient beaucoup moins marquées qu'au cours des quatre années précédentes. La couche intermédiaire froide était généralement plus chaude que la normale, et les conditions sont demeurées similaires ces trois dernières années. Les températures de fond dans les chenaux profonds du golfe du Saint-Laurent et du plateau néo-écossais, un mélange d'eaux du courant du Labrador et du Gulf Stream, ont continué de baisser par rapport aux records de 2022. Les signaux liés au phytoplancton à l'échelle de la zone étaient variables, avec des floraisons hâtives au printemps et tardives à l'automne, une chlorophylle-*a* proche de la normale et des nitrates inférieurs à la normale dans la couche de subsurface. *Calanus finmarchicus* a affiché des abondances supérieures à la normale dans la plupart des régions pour une troisième année consécutive. L'abondance totale de copépodes, de *Pseudocalanus* spp. et de non-copépodes étaient près ou supérieures à la normale sur le plateau de Terre-Neuve et le plateau néo-écossais, mais près de la normale ou inférieures à celle-ci dans le golfe du Saint-Laurent. Dans les eaux de fond, les indicateurs d'acidification traduisent une accumulation de carbone. Le carbone inorganique se situe généralement à des niveaux normaux ou supérieurs à la normale, alors que le pH_T et les indicateurs de carbonate de calcium sont majoritairement normaux ou inférieurs à la normale. Les conditions chimiques les plus critiques sont observées dans les eaux profondes de l'estuaire et du nord-ouest du golfe, où des conditions hypercapniques (pCO₂ > 1,000 µatm) et des conditions hypoxiques ou quasi hypoxiques (saturation en oxygène < 30%) persistent.

1. INTRODUCTION

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

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

A critical element of the AZMP is an annual assessment of the physical, biological, and chemical oceanographic conditions.

A description of the distribution in time and space of temperature, salinity, nutrients (nitrate, silicate, phosphate), gases dissolved in seawater (oxygen, carbon dioxide (CO₂)), and plankton provides important information on water-mass movements, on the locations, timing, and magnitude of biological production cycles, and ocean chemistry parameters. Understanding the production cycles of plankton, alongside changing physical and chemical conditions, is crucial for an ecosystem-based approach to stock assessment, marine protection and conservation, as well as fisheries and species at risk management.

The AZMP derives its information on the state of the marine ecosystem from data collected at a network of locations (high-frequency sampling stations, cross-shelf sections and ecosystem surveys) in each of DFO's administrative regions of Eastern Canada (Quebec, Maritimes, Gulf, Newfoundland and Labrador) sampled at frequencies ranging from weekly to annually (Figure 1). This annual assessment has included Labrador Sea observations collected by the Atlantic Zone Off-Shelf Monitoring Program (AZOMP) since the report on 2015 conditions. Information on ocean acidification was first presented in the report on 2018 conditions.

The sampling design provides information on the 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 at a greater temporal resolution. Sampling procedures are standardized across the zone and described in Mitchell et al. (2002). In addition, glider missions in 2025 sampled over 19,000 profiles of temperature, salinity, oxygen, optical backscatter, chlorophyll-*a* and coloured dissolved organic matter (CDOM) fluorescence, mostly on the Halifax section. Real time oceanographic buoys collected just over 450 vertical profiles throughout the zone in 2025, about half the usual number.

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, 1999–2025 for biological parameters and nutrients, and finally 2014–2025 for CO₂-carbonate system and oxygen saturation parameters. Furthermore, because these variables have different units (°C, km³, km², etc.) and ranges of variability, each annual anomaly in the time series is normalized by dividing it by the standard deviation (SD) of the annual anomaly values from the reference period for that variable. This allows to distinguish if a given anomaly is significantly different from normal conditions, and to directly compare the anomalies of the different variables. Missing data are represented by grey cells, and near-normal conditions by white cells. Conditions within ± 0.5 SD of the average are considered to be near normal. For biological and chemical parameters, the climatology used this year represents a 5-year extension relative to the previously used climatology that ended in 2020. While this tends to increase standard deviation, it also generally reduces the amplitude of

anomalies. Consequently, some of the large anomalies reported in previous reports, particularly oxygen and acidification parameters, will appear somewhat diminished.

Conditions with higher-than-normal values are shown as red cells. However, for quantities that decrease with warmer temperatures (e.g., ice volumes and cold water volumes or areas), red indicates reduced levels, with more intense reds representing greater reductions. Conversely, blue represents lower than normal values, except for increased sea ice and cold water areas and volumes. Higher than normal freshwater inflow, salinity or stratification are shown as red, but do not necessarily correspond to warmer than normal conditions. 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.

2. PHYSICAL OCEANOGRAPHIC CONDITIONS

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This is a summary of physical oceanographic conditions during 2025 for eastern Canadian oceanic waters (Figure 1 and Figure 2) as reported annually by the AZMP in technical reports (e.g., Galbraith et al. 2026 for conditions in 2025 in the Gulf of St. Lawrence, Coyne et al. 2025 for conditions in 2024 on the Newfoundland and Labrador Shelf, and Layton et al. 2025 for conditions in 2024 on the Scotian Shelf). Unless otherwise noted, the methodologies documented in these past reports are used here.

2.1 ANNUAL TEMPERATURE CYCLE

Ocean 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 and heat loss to the atmosphere prior to ice formation, but also partly because of 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 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 gradually warms and deepens in summer, persisting until the next winter (Gilbert and Pettigrew 1997, Cyr et al. 2011). The CIL is, for the most part, locally formed in winter in separate areas around the zone (Galbraith 2006, Umoh and Thompson 1994, Umoh et al. 1995). 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 Gulf of St. Lawrence, 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 Gulf of St. Lawrence (Galbraith 2006) and Newfoundland Shelf (Umoh et al. 1995) and from the Gulf of St. Lawrence to the St. Lawrence Estuary (Galbraith 2006) and the Scotian Shelf (Umoh and Thompson 1994). The temperature minimum in southern parts of the Newfoundland Shelf (e.g., at Station 27) can occur well after winter; for example, in 2021 it was observed in June-July. Deep waters are defined here as those below the CIL that have only weak seasonal cycles.

2.2 SEA SURFACE TEMPERATURE

The satellite-based sea surface temperature (SST) product blends data from three databases to bridge a longer time span: Pathfinder version 5.3 (4 km resolution for 1982–1985 and sparsely to 2020; Casey et al. 2010), Maurice Lamontagne Institute (MLI; 1.1 km resolution for 1985–2000 and sparsely to 2013; Larouche & Galbraith 2016), and NOAA STAR CoastWatch Advanced Clear-Sky Processor for Ocean (ACSPO) L3S-LEO-Daily “super-collated” v2.81 (0.02 degree resolution for 2000 to current; Jonasson et al. 2022). Details of the method are found in Galbraith et al. 2021 and of the regional calibration in Galbraith et al. 2026.

Monthly temperature composites are calculated from averaged daily anomalies to which monthly climatological average temperatures are added (Galbraith et al. 2021). Figures 4 and 5 show monthly temperature composites and anomalies, and Figures 6 and 7 show area-averaged values by month and for the ice-free season over the averaging areas shown in Figure 2 (top panel).

Averaged over ice-free periods of the year as short as June to November on the Labrador Shelf, May to November in the Gulf of St. Lawrence, to the entire year on the Scotian Shelf, air temperature has been found to be a good proxy of sea surface temperature. Therefore, the warming trend observed in air temperature since the 1870s of about 1 °C to 1.5 °C per century is also expected to have occurred in surface water temperatures across Atlantic Canada (Galbraith and Larouche 2013, Galbraith et al. 2021).

In 2025, monthly average sea surface temperatures were generally normal to above normal during ice-free periods, with larger anomalies during September to November (Figure 6). Of the 171 reported regional monthly averages, a total of 86 were above normal, but only 5 are series records. Only 13 monthly averages were below normal, 4 of them occurring in August. The Gulf had a 5th consecutive year with much warmer fall sea surface temperatures. Seasonal averages were normal to above normal (Figure 7). The spatially weighted zonal average anomaly was above normal (+0.7 SD), but less so than the four previous years (shown in later summary Figure 10).

2.1 THE NORTH ATLANTIC OSCILLATION

The North Atlantic Oscillation (NAO) index (Figure 7) is based on the sea-level atmospheric pressure difference between the sub-equatorial high and subpolar low and quantifies the dominant winter atmospheric forcing over the North Atlantic Ocean. Two versions of the winter NAO are used here. The first is the December-March average of the monthly time series from the National Oceanic and Atmospheric Administration ([NOAA](#)). The second is the [Hurrell](#) principal-component based index from the National Center for Atmospheric Research (NCAR). Both indices are similar in most years, but in some years, they differ markedly because of unusual pressure patterns. This has been the case more often in recent years, including in 2024 and to a lesser extent in 2025.

The atmospheric patterns described by the NAO affect winds, air temperature, precipitation, and 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 of the NOAA index was reached in 2010, coinciding with warmer than normal conditions. The recent positive streak of the NOAA index (normally indicative of colder conditions) has, however, not coincided with cold winter conditions as in the previous albeit more positive streak of the late-1980s/early-1990s. In 2025, the winter NOAA NAO index was positive (cold) at +0.7 while the Hurrell NAO index was near normal.

2.2 COLD INTERMEDIATE LAYER

For the Newfoundland and Labrador Shelf, the CIL indices shown in Figure 7 are the cross-sectional areas of waters with $T < 0^{\circ}\text{C}$ during summer along the Seal Island, White Bay, Bonavista and Flemish Cap AZMP sections (Coyne et al. 2025). For the Gulf, the CIL volume with $T < 1^{\circ}\text{C}$ observed in August-September (excluding the Mécatina Trough) is used (Galbraith et al. 2026). 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. 2026). For the Scotian Shelf, the volume with $T < 4^{\circ}\text{C}$ observed in July is used (Layton et al. 2025). The CIL indices reported here are taken at about the same time within their respective annual cycles, although not simultaneously.

The Gulf of St. Lawrence CIL volume was at record low in 2021, representing record-warm conditions. The volume in summer 2025, while over twice as large as in 2021, was fifth lowest. The CIL volume on the Scotian Shelf reached a record low in 2022, but has been near-normal every year since 2023. The CIL areas at the four AZMP sections on the Newfoundland and Labrador shelf were below normal (warm conditions) except for Bonavista, which was near normal.

2.3 SEA ICE

Because the CIL and sea ice cover are both formed in winter in the Gulf and on the Labrador Shelf, 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 (1977–2025, $R^2 = 0.71$; from data in this report) whereas Newfoundland Shelf sea ice metrics are correlated with December-March air temperature further north at Cartwright (1969–2024, $R^2 = 0.64$ – 0.78 ; Coyne et al. 2025). In the Gulf of St. Lawrence, the correlation between the December-March air temperature averaged over multiple coastal meteorological stations and the maximum annual ice volume reaches $R^2 = 0.76$ (1969–2024; Galbraith et al. 2024). December-March air temperature is similarly well correlated to sea ice cover area and duration ($R^2 = 0.82$ – 0.84 , 1969–2024; Galbraith et al. 2024). 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 , $32,000\text{ km}^2$ and 14 days of sea ice season for each 1°C increase in winter air temperature (Galbraith et al. 2024).

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 Labrador Shelf, southern Labrador Shelf and Newfoundland Shelf (Cyr and Galbraith 2021). The index was second lowest in 2010, reached a record low in 2011, and rebounded during 2014–2016 when heavy sea ice conditions were observed (Figure 7). It has been near or below normal since, notably 3rd lowest in 2021, and was below normal (-1.0 SD) in 2025.

Sea ice conditions in the Gulf of St. Lawrence and the Scotian Shelf have been below normal since 2010 except for a rebound in 2014 and 2015. The period includes four nearly ice-free winters (Galbraith et al. 2024). In the sixteen-year period between 2010 and 2025, the seasonal average sea ice volume had eleven of the sixteen lowest values of the 57-year time series. Record lows were reached in 2024 for both the seasonal weekly maximum (Galbraith et al. 2024) and the seasonal average volume (January to April; Figure 7). In 2025, this seasonal average volume was 4.9 km^3 and ranked 4th lowest. However, the maximum area of ice making

it south of Cabot Strait was 10 000 km², the first near-normal value (-0.4 SD) since 2018 (not shown).

2.4 LABRADOR CURRENT AND SCOTIAN SHELF TRANSPORT INDEX

The annual-mean Labrador Current transport index (Han et al. 2014, Coyne et al. 2025) shows that transport along the Newfoundland and Labrador shelf break is sometimes out of phase with transport on the Scotian Shelf break (Figure 7). Transport was strongest in the early 1990s and weakest in the mid-2000s over the Newfoundland and Labrador Shelf break, and opposite over the Scotian Shelf break. While there is a negative correlation between these two indices, the relationship is not statistically significant. 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 (e.g. Drinkwater & Gilbert 2004). The transport was at a record high along the Newfoundland and Labrador Shelf break (+2.4 SD) and above normal (+1.0 SD) for the third consecutive year along the Scotian Shelf break. The latter indicates increased input of cold and low salinity waters with high dissolved oxygen concentrations that may feed into the Gulf of St. Lawrence and Scotian Shelf at depth.

2.5 BOTTOM AND DEEP WATER TEMPERATURES

Interdecadal changes in temperature, salinity, and dissolved oxygen of the deep waters of the Gulf of St. Lawrence, 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 Slope Water, also called North Atlantic Central Waters (Gilbert et al. 2005, Jutras et al. 2020). The mixing ratio may be controlled by the retroreflection of the Labrador Current at the tip of the Grand Banks (Jutras et al. 2023a). The >150 m water layer of the Gulf of St. Lawrence 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 between three to five years at 300 m after reaching Cabot Strait, with limited exchange with shallower upper layers (Gilbert et al. 2004, Stevens et al. 2024, Rousseau et al. 2025). The mixing ratio of waters entering the Laurentian Channel was reported to have reached 100% of the warm component in 2021 (Jutras et al. 2023b). 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. 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 by both CIL waters and the waters underneath.

In 2025, bottom temperatures in areas affected by the CIL were above normal in nearly all regions of the Newfoundland and Labrador Shelf and Gulf of St. Lawrence (Figure 7), and reached a record high on the Grand Banks (3LNO) in the fall (+2.2 SD). Bottom temperatures in the deep channels of the Gulf of St. Lawrence and the Scotian Shelf, which are affected by the mixture of cold, fresh waters and warm, saline waters, show continued decreases from the 2022 record highs except in 4X where they remained stable and near normal. In the Gulf of St. Lawrence, temperatures decreased to values similar to those of 2018. On the Scotian Shelf, decreases in 4V and 4W led to temperatures remaining near normal and below normal (-1.2 SD) respectively.

2.6 RUNOFF AND STRATIFICATION

Freshwater runoff in the Gulf of St. Lawrence, particularly within the St. Lawrence Estuary, strongly influences 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 runoff estimated at Quebec City that is 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 to form the RIVSUM II index (Galbraith et al. 2026). Stratification is estimated from the simple metric of the density difference between 50 m and the surface, permitting its calculation in years preceding high resolution temperature-salinity casts. The inter-annual variability of seasonal (May–October) stratification (0–50 m) at Rimouski station in the Estuary is correlated with seasonally averaged RIVSUM II runoff (1991–2025; $R^2 = 0.65$, Figure 8). Run-off in the fall was very low. Stranded sailboats in marinas along the St. Lawrence river led to a 36-hour opening of the Cornwall dam to temporarily raise the St. Lawrence by 15 cm in mid-October. The 2025 annual runoff was below normal ($16,660 \text{ m}^3\text{s}^{-1}$, -0.7 SD ; Figure 7) but the stratification at Rimouski station was normal (Figure 8).

Stratification at Station 27 was below normal in 2025 (-1.0 SD ; Figure 8) and above normal at Prince 5 ($+2.5 \text{ SD}$). It was above normal at the Halifax 2 station ($+0.7 \text{ SD}$), but near normal over the Scotian Shelf as a whole ($+0.3 \text{ SD}$). 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 0.39 kg m^{-3} per 50 years (Figure 8). This change in mean stratification is due mainly to a decrease in the surface density, caused equally by warming and freshening.

2.7 CONDITIONS AT AZMP HIGH FREQUENCY SAMPLING STATIONS

At the high-frequency sampling sites (Figure 9), seasonal average 0–50 m temperature was above normal at all sites except Rimouski station. The last five years have generally had above normal values at these sites. Bottom temperature was below normal at Halifax 2 for the second consecutive year, 6th lowest, consistent with the cooling of deep waters in the zone; the previous below-normal year was in 2011. Bottom temperature was near normal at Prince 5 and above normal at the three other sites, including a record high at Rimouski station, which has not been reached yet by cooler deep water that has been entering the Laurentian Channel since 2022. Near-surface salinity (0–50 m) was normal at all sites. Stratification, as stated above, was variable across sites.

2.8 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. Sea surface temperatures averaged over the ice-free months were normal to above normal across the zone in 2025. The spatially weighted zonal average anomaly was above normal, but less so than the four previous years (Figure 10).

Warming winters have also led to less sea ice cover and warmer and thinner cold intermediate layers. The period since 2018 has seen only near-normal to warmer-than-normal CIL conditions across the zone. In 2025, CIL conditions and bottom waters affected by the CIL were warmer than normal across the Gulf of St. Lawrence and much of the Newfoundland and Labrador Shelf, but the Scotian Shelf had a near-normal CIL volume for the third consecutive year.

Deep-water temperatures on the Scotian Shelf and Gulf of St. Lawrence had been greatly influenced by an increasing proportion of warm saline waters (related to the Gulf Stream) relative to cold fresh Labrador Water in recent years, reaching record highs in 2022. However,

the transport along the Scotian Shelf break was above normal in 2023 for the first time since 2011, indicating possible increased input of cold waters with high dissolved oxygen concentrations that may feed into the Gulf of St. Lawrence and Scotian Shelf at depth. This transport was at a record high in 2024 and above normal in 2025. Below-CIL bottom temperatures of the Gulf of St. Lawrence and the Scotian Shelf showed continued decreases from the 2022 record highs except in 4X where they remained stable and near normal. In the Gulf of St. Lawrence, temperatures decreased to values similar to those of 2018 while remaining above normal. On the Scotian Shelf, decreases in 4V and 4W led to temperatures remaining near normal and below normal respectively.

Four 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. Two bottom temperature indices group areas with colder waters affected by CIL conditions and waters that are below the influence of the CIL. These four 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 smaller CIL areas and volumes are translated into 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 four panels are weighted for missing values. On average over the zone, conditions in 2025 were above normal for surface temperatures (Figure 10, top panel), for CIL and sea ice anomalies (e.g. thinner, warmer CIL and less severe ice conditions; Figure 10, second panel) as well as for bottom temperatures influenced by the CIL (Figure 10, third panel). The first two have been above normal since 2020 and the third since 2018. Bottom temperatures below the influence of the CIL (Figure 10, fourth panel) were near normal for the second consecutive year; the previous near normal year was 2013.

3. BIOGEOCHEMICAL ENVIRONMENT

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Lower trophic level organisms include phytoplankton and zooplankton. Together, they form the component 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., capelin, cod, herring, and halibut), marine mammals (e.g., seals and whales), reptiles (e.g., leatherback and loggerhead turtles) and seabirds. Phytoplankton are microscopic algae 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. There is a wide variation in the size of phytoplankton, from the small flagellates (<5 µm) to the large diatoms (300–500 µm), with 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. Zooplankton are a diverse group of small animals mostly ranging from 0.2 to 20 mm in length that primarily drift with ocean currents. The zooplankton community includes animals such as copepods, gelatinous filter feeders and predators, and ephemeral larval stages of bottom-dwelling and planktonic invertebrates (i.e., meroplankton). As with phytoplankton, there is a broad range of sizes of zooplankton. Smaller zooplankton species and developmental stages are the principal prey of larval fish, and larger copepods are prey for juvenile and adult fishes and some seabird and baleen whale species.

The productivity of marine ecosystems depends primarily 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 temperature and on the availability of light and nutrients in the form of nitrogen (nitrate, nitrite, and ammonium), phosphorous (phosphate), and silica (silicate), with the latter being essential for diatom production. During springtime, phytoplankton biomass increases rapidly, reaching a period of maximum biomass known as the spring bloom. The spring bloom occurs primarily in near-surface waters when the upper water column stabilizes, light and nutrients are available, and grazing by zooplankton is still low. In fall, a secondary bloom, usually less intense (i.e., lower biomass/shorter duration) than the spring bloom, can occur when upper water column stratification breaks down and nutrients are mixed into the surface layer. We report on the amount of nutrients available for phytoplankton, the concentration of chlorophyll-*a* (a proxy for phytoplankton biomass), features of the spring and fall blooms in terms of timing and intensity, and the biomass and abundances of key zooplankton taxa based on the data available from 1998 to 2025.

Indices of nitrate inventories, phytoplankton biomass, features of the spring and fall phytoplankton bloom derived from satellite observations, and zooplankton abundance and biomass from the Labrador Sea (Clay et al. 2026), Newfoundland Shelf and Grand Bank (Bélanger et al. 2025), Gulf of St. Lawrence (Blais et al. 2025) and Scotian Shelf (Casault et al. 2025) are summarized as time series of annual values in matrix form in Figure 11 to Figure 14. Anomalies were calculated using a climatological reference period of 1999–2025 for the biogeochemical parameters derived from in situ observations during seasonal oceanographic surveys. Unless otherwise noted, the regional citations provided above include the methodologies used in this current assessment. Descriptions of the aforementioned indices in 2025 will be published in similar regional reports.

In this report, characteristics of the phytoplankton blooms were derived from daily composites of chlorophyll-*a* concentration at the ocean surface derived from the Ocean-Colour Climate Change Initiative (OC-CCI, 1998–2025) dataset provided by the Plymouth Marine Laboratory, as recommended by the European Space Agency. The use of the OC-CCI product enhances spatial coverage, which improves the accuracy of our estimates (Sathyendranath et al., 2019) in comparison with the previously used dataset from the MODIS (Moderate Resolution Imaging Spectroradiometer) sensor. The metrics used to characterize the timing and intensity of the bloom follow the method updated in Galbraith et al. 2024 and include information on the fall bloom since that report. Intensity of the spring and fall blooms is expressed as the daily surface chlorophyll-*a* concentration averaged over spring and fall seasons, respectively.

The 28-year biogeochemical time series primarily captures interannual to multi-year cycles, in contrast to the interdecadal signals evident in the physical variables. Nevertheless, a few biological variables do show emerging long-term trends, and decadal-scale shifts are evident in recent years, with anomalies of consistent sign persisting over multiple years. Moreover, a high degree of synchronicity in biological variability at adjacent locations can also be observed, while spatial variability is also considerable in some instances.

3.1 NUTRIENTS

In the northwest Atlantic continental shelf waters, nitrate, the dominant form of nitrogen, is usually the limiting nutrient for phytoplankton growth. The subsurface nitrate inventory is the

amount of nitrate generally contained in waters below the surface mixed layer (depths of 50–150 m for Labrador and Newfoundland Shelf, Gulf of St. Lawrence and Scotian Shelf, and depths deeper than 100 m for the Labrador Sea). Generally, this inventory is independent of phytoplankton growth, so it provides a good indicator of resources that can be mixed into the surface mixed layer during winter and fall, or by episodic upwelling events throughout the year, to become available for phytoplankton growth. Subsurface nitrate inventories, and the relative abundances of other nutrients, are mostly dependent on the source waters that make up the deep water (> 150 m) on continental shelves (Lehmann et al. 2023), which can vary from year to year. Subsurface nitrate inventories in 2025 were near or below normal in most regions, except in the eastern and central Labrador Sea, and a record high was observed in the eastern Labrador Sea. The overall zonal index was negative (Figure 11). The 2025 conditions mark a return to near-normal conditions on the Newfoundland Shelf, Grand Bank, and Scotian Shelf, contrasting with the Gulf of St. Lawrence where the pattern of predominantly negative anomalies observed since 2016 persists. In the St. Lawrence Estuary, low oxygen levels may deplete the deep nitrate reservoir through anaerobic respiration (Pascal et al. 2025), which could in turn influence the subsurface inventory.

3.2 PHYTOPLANKTON

Chlorophyll-*a* inventories in the upper ocean (0–100 m) are used as a proxy for the overall phytoplankton biomass. They exhibit a high degree of year-to-year variability (Figure 11). Part of this variability is explained by the timing of the program's oceanographic surveys throughout the zone relative to the timing of spring and fall phytoplankton blooms.

Annual chlorophyll-*a* inventories in 2025 were near or above normal in most regions; however, strong negative anomalies were observed in the central Labrador Sea, at Halifax-2 station, and along the Browns Bank section, resulting in a near-normal zonal index (Figure 11). Anomalies of chlorophyll-*a* have mostly been normal or above normal on the Newfoundland Shelf and Grand Bank, and in the Gulf of St. Lawrence since 2017. Although subsurface nutrient inventories provide some threshold to limit seasonal production dynamics across the zone, additional factors are likely to influence local nutrient-phytoplankton dynamics, such as the phytoplankton community composition and the variability of the nutrient transfer from the subsurface layer to the surface waters where phytoplankton production occurs. The balance of these factors is likely to differ when considered at the very large spatial scale from the Labrador Sea to the Gulf of Maine, which includes estuarine to oceanic environments.

The timing and intensity of the spring and fall phytoplankton blooms provide important information about regional variations in ecosystem productivity and are linked to the production of organisms that depend directly on lower trophic levels. Bloom intensity (i.e., chlorophyll biomass production) partly depends on the amount of nutrients that are mixed into surface waters over the course of the winter and become available for the spring bloom, or through episodic upwellings or water column mixing events such as windstorms during fall. Peak biomass accumulation and bloom duration are also influenced by the extent of zooplankton grazing, among other controls.

The timing of the 2025 spring phytoplankton bloom was generally normal or earlier than normal, except in the eastern Labrador Sea, leading to an overall negative (early) zonal index (Figure 12). Spring bloom timing has generally been early on the Newfoundland Shelf and Grand Bank since 2021 and in the Gulf of St. Lawrence since 2016. The intensity of the spring bloom has

been dominated by interannual variability across the Atlantic Zone over the time series, with little spatial coherence in anomaly patterns. Both above- and below-normal spring bloom intensities were observed in 2025, including a record-high value in the northwest Gulf of St. Lawrence, and the zonal spring bloom intensity index was slightly above normal.

Around 2010, the timing of the fall bloom onset transitioned from mainly earlier to mainly later than normal in the Gulf of St. Lawrence and on the Scotian Shelf, largely driving the zonal index signal. A similar, although more recent, transition was also observed in the western Labrador Sea. In 2025, the timing of the fall bloom was predominantly near normal or later than normal across the Atlantic Zone, although slightly earlier-than-normal timing was observed in the eastern Labrador Sea and along the Flemish Pass and St. Pierre Bank sections (Figure 12). Since 2016, most regions have exhibited above-normal fall surface chlorophyll-*a* concentrations. Although a record high was observed in the central Labrador Sea, fall surface chlorophyll-*a* concentrations were near normal in most regions during 2025, and below normal on the Scotian Shelf, with a record low observed for George Bank (Figure 12).

3.3 ZOOPLANKTON

Zooplankton community composition and abundance are strongly influenced by bathymetry, temperature and season, and the community's composition differs greatly among the northwest Atlantic bioregions. Despite regional composition and diversity differences, four indices of abundance provide good indicators of the state of the zooplankton community. Zooplankton abundance indices exhibited a high degree of large-scale coherence in their signal across different parts of the Atlantic Zone (Figure 13). Copepods are by far the most abundant group, but non-copepods are also an important component of the zooplankton community in terms of abundance and ecological functions. Two copepod taxa are used to characterize trends in copepod groups representing different life history patterns: *Calanus finmarchicus* and *Pseudocalanus* spp. *Calanus finmarchicus* is a large, ubiquitous copepod that dominates zooplankton biomass throughout most of the zone. It develops large energy reserves in later developmental stages and is therefore a rich source of food for pelagic fish and certain species of whales. *Pseudocalanus* spp. are small copepods that are widespread throughout the Atlantic Zone and have smaller energy reserves relative to *C. finmarchicus*. Their life history features are generally representative of smaller taxa in the copepod community. We also report on the dry biomass of the zooplankton in the 0.2–10 mm size fraction, which is typically dominated by copepods (Figure 14).

A zooplankton community shift occurred in the mid-2010s across the Atlantic Zone, characterized by lower average zonal abundances of the large copepod *C. finmarchicus*, and higher abundances of the small copepod *Pseudocalanus* spp. and non-copepods. Although the abundance of *C. finmarchicus* was closer to normal between 2019 and 2022, the overall abundance of *Pseudocalanus* spp. and non-copepod zooplankton remained higher than normal during that period (Figure 13). Since 2023, zonal average conditions for most zooplankton indices have either returned to near-normal levels, or to levels similar to those observed prior to 2010. Total copepods and *Pseudocalanus* spp. abundances followed similar spatial patterns in 2025. They were mainly near normal on the Newfoundland Shelf and Grand Bank, below normal in the Gulf of St. Lawrence, and above normal on the Scotian Shelf, with a near-normal zonal index. Record-low abundances of *Pseudocalanus* spp. were observed at Rimouski station and in the center Gulf for a second consecutive year, while a record high was recorded along the Halifax section (including at Halifax-2 station), also for a second consecutive year. *Calanus*

finmarchicus showed near- or above-normal abundances at all locations in 2025, including record-high values in the southern Gulf and at Shediac Valley, leading to the third highest zonal average abundance over the time series, tied with the previous year. On the Newfoundland Shelf and Grand Bank, and on the Scotian Shelf, the abundance of non-copepods in 2025 continued the decade-long pattern of mostly positive anomalies that started in 2014. However, this pattern has shifted to mixed anomalies in the Gulf of St. Lawrence since 2023, bringing the zonal average to near-normal values since then. A record-low abundance of non-copepods was observed in the center Gulf in 2025 (Figure 13).

Despite the general increase in *C. finmarchicus* abundances, zooplankton biomass remained mainly near normal across the Atlantic Zone in 2025. On the Newfoundland Shelf and Grand Bank, zooplankton biomass anomalies have been primarily positive since the late 2010s, while they have been primarily negative in the Gulf of St. Lawrence and on the Scotian Shelf (Figure 14). Overall, the zonal index indicates that the highest zooplankton biomass was observed in the first half of the 2000s. The 2015–2017 period was marked by very low zooplankton biomass throughout most of the Atlantic Zone. Zonal biomass averages have been primarily near or below normal since then.

Recent findings in zooplankton community structure suggest that changes are taking place in the marine food web energy flow of the Atlantic Canadian waters (Blais et al. 2025, Casault et al. 2025, Bélanger et al. 2025). These changes are associated with shifts in the distribution of North Atlantic right whales in their northwest Atlantic shelf foraging areas (Brennan et al. 2021) and may be associated with declines in herring (Brosset et al. 2019) in the Atlantic Zone. However, the broader consequences to the marine ecosystem are not yet fully characterized.

4. CHEMICAL OCEANOGRAPHIC CONDITIONS

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The global ocean is undergoing profound chemical changes driven by planetary climate and environmental alterations associated with anthropogenic activities (IPCC, 2021). Among the most significant of these changes are shifts in the cycling of elements such as carbon and oxygen, leading to ocean acidification (OA) and deoxygenation, both of which have far-reaching consequences for marine ecosystems and the services they provide (IPBES 2019).

During the decade from 2014 to 2023, the global ocean has absorbed atmospheric CO₂ at a rate of 2.9 ± 0.4 gigatonnes of carbon per year, representing a sink for 26% of total CO₂ emissions (Friedlingstein et al. 2024). The uptake of anthropogenic CO₂ (C_{ant}) by the oceans, while mitigating some of the atmospheric CO₂ increase, triggers a series of chemical reactions that lower the concentration of bases in seawater and increase proton (H⁺) concentrations, thereby raising “acidity levels” (Gattuso & Hansson, 2020). This process, known as ocean acidification, lowers the pH. The current rates of oceanic chemical changes due to C_{ant} are 100 times faster than those during the last glacial period. Globally, the surface ocean’s average pH has decreased by approximately 0.11 units between 1750 and 2000, resulting in a 30% increase in acidity (Friedrich et al. 2012, Caldeira & Wickett 2003, Jiang et al. 2019, Orr et al. 2005). In Atlantic Canadian subsurface waters (50m and deeper), pH is declining even faster, by 0.03–0.04 units per decade, compared to the global surface average pH decline of 0.017–0.027 units per decade (Bernier et al. 2023).

Beyond the surface of the ocean, the downward transport of C_{ant} is intensifying acidification in the ocean interior, reaching depths of hundreds to thousands of meters (Müller & Gruber 2024). In some regions, sub-pycnocline waters are acidifying faster than surface layers (Lauvset et al. 2020, Fassbender et al. 2023). While C_{ant} accumulation is the primary driver of ocean interior acidification, variable rates of CO_2 -carbonate system changes can also arise from water mass redistributions and changing physical oceanographic conditions (Chen et al. 2017, Gruber et al. 2019, Müller & Gruber 2024). Modifications in biological and carbonate pumps, including changes in organic matter production, remineralization, and CaCO_3 mineral production and dissolution, may further impact key carbon parameters like total dissolved inorganic carbon (DIC) and total alkalinity (TA) (Gruber et al. 2023). These modifications can be particularly important in nearshore waters and ocean margin areas, where acidification is exacerbated by shifts in coastal and estuarine hydrographic (e.g., freshwater discharge) and biogeochemical processes (e.g., atmospheric deposition, nutrient loading and resulting eutrophication and remineralization of organic matter) (Cai et al. 2021, Doney 2010). The northwest Atlantic continental shelf is a region where many of these processes converge, though they do so in different ways across various areas. This convergence induces significant temporal and spatial variability in the CO_2 -carbonate system. While historical data on acidification parameters exist in the Atlantic Zone (e.g., Mucci et al. 2011), systematic measurements of OA parameters have been ongoing since fall 2014 as part of the AZMP and the Aquatic Climate Change Adaptation Services Program of DFO (Gibb et al. 2023, Galbraith et al. 2025, Lizotte et al. 2026).

The simultaneous alterations in seawater chemistry ($[\text{H}^+]$, $[\text{CO}_2]$, bicarbonate $[\text{HCO}_3^-]$, and carbonate $[\text{CO}_3^{2-}]$) associated with OA have complex and multifaceted effects on marine organism and ecosystem functions (Doney et al. 2020, Figuerola et al. 2021, Leung et al. 2022). Among these, reductions in the saturation state (Ω) of calcium carbonate (CaCO_3) minerals, such as calcite (Ω_{C}) and aragonite (Ω_{A}) below critical thresholds may impact marine organisms that build shells, skeletons, and structures from CaCO_3 , such as mollusks, crustaceans and corals. This is largely due to the increased energetic costs required to sustain net calcification under acidic conditions (Kroeker et al. 2010, 2013, Clements & Hunt 2017, 2018, Rheuban et al. 2018, Pousse et al. 2020). In addition, modifications in pH can directly impact physiological processes that rely on the transfer of protons (H^+), including olfactory senses in fish (e.g., Dixon et al. 2015), and biomineralization in calcifying organisms (Jokiel 2011, 2013, Thomsen et al. 2015, Toyofuku et al. 2017). Finally, a growing issue is the rise in water volumes with *in situ* partial pressure of CO_2 ($p\text{CO}_2$) surpassing 1,000 μatm , a condition termed ocean hypercapnia (McNeil & Sasse 2016). Ocean hypercapnia adversely affects the physiological, behavioural, and neurological functions of marine organisms by impairing their ability to expel CO_2 during respiration and disrupting their internal acid-base balance (Nilsson et al. 2012, Perry & Gilmour 2006, Pimentel et al. 2016, Feely et al. 2018). The increasing frequency and extent of ocean interior acidification and hypercapnic conditions may have detrimental implications for mesopelagic fisheries (Fassbender et al. 2023), including those in the Atlantic Zone. Fluctuations in each of these CO_2 -carbonate system variables can cause stress for marine organisms and may be compounded by concurrent stressors including, but not limited to, temperature fluctuations and oxygen availability (Kroeker et al. 2013, Arroyo et al. 2022).

The global ocean has lost about 2% of its oxygen content over the past 50 years (Schmidtke et al. 2017), with deoxygenation rates in the nearshore waters of the northwest Atlantic exceeding the global average (Gilbert et al. 2010). This oxygen loss spans estuaries, coastal waters, semi-enclosed seas, and the open ocean (Diaz et al. 2019, Falkowski et al. 2011, Limburg et al.

2020). Primarily driven by increased ocean warming and stratification, and changes in ocean circulation (Claret et al. 2018, Jutras et al. 2023b), deoxygenation also results from modifications in ocean biogeochemistry associated with eutrophication and organic matter remineralization, particularly in coastal, near-shore, and ocean margin areas (Keeling et al. 2010, Levin 2018, Oschlies et al. 2018, Rabalais 2019). Reductions in oxygen levels can cause significant alterations in the range of habitats for marine organisms, as well as modifications in oceanic productivity, biodiversity, and biogeochemical cycling (Breitburg et al. 2018). Deoxygenation has been shown to affect biological systems at all levels, from cells and organs, to individuals, populations, communities, and ecosystems (Roman et al. 2024, Woods et al. 2022). Additionally, deoxygenation through microbial respiration can exacerbate ocean acidification via the accumulation of metabolic CO₂, a phenomenon frequently observed in deep waters (e.g., Gobler & Baumann 2016, Mucci et al. 2011, Arroyo et al. 2022).

4.1 DISSOLVED OXYGEN SATURATION

Oxygen tolerance of marine organisms widely varies and because temperature influences the oxygen solubility, thresholds reflecting organism tolerances are generally better expressed in terms of oxygen saturation rather than oxygen concentration (Breitburg et al. 2018, Vaquer-Sunyer & Duarte 2008). In the nearshore waters of the northwest Atlantic Ocean, the hypoxia threshold is generally set at 30% oxygen saturation ($\approx 100 \mu\text{mol L}^{-1}$), although the more sensitive organisms may express a reduction in metabolic functions when saturation levels decrease below 70% ($\approx 215 \mu\text{mol L}^{-1}$; Plante et al. 1998, Chabot & Dutil 1999, Chabot & Claireaux 2008, Brennan et al. 2016).

Near-bottom dissolved oxygen saturations are generally above the 70% metabolic threshold across the zone over the time series, representing well-ventilated conditions, except in the deep channels of the Gulf of St. Lawrence, from Cabot Strait inward, and at the Halifax-2 coastal station. As deep waters slowly flow from the mouth of the Laurentian Channel to its head in the St. Lawrence Estuary, the dissolved oxygen content gradually decreases due to microbial respiration and the oxidation of sinking organic material. Consequently, the deepest waters of the estuary, particularly at the head of the Laurentian Channel, exhibit the lowest oxygen levels. In this area, dissolved oxygen levels ranged between 30 and 40% in the early 1970s and have consistently been hypoxic (below 30%) since 1984 (Gilbert et al. 2005, Blais et al. 2025).

Various factors may have driven the decadal alterations in dissolved oxygen concentration and saturation within the deep waters of the Gulf of St. Lawrence. Variations in the relative contributions of oxygen-rich Labrador Current Water (LCW) and oxygen-poor North Atlantic Central Waters (NACW) entering the Laurentian Channel could have exerted a predominant influence (Gilbert et al., 2005). Sudden swift reductions in oxygen levels observed since ca. 2016 in the deep waters of the Gulf of St. Lawrence could have arisen from a diminished influx of highly oxygenated LCW into the deep waters of the system, favouring the influx of low-oxygenated NACW (Jutras et al. 2020). These circulation alterations also likely accounted for the rapid rise in deep bottom temperatures in the Gulf of St. Lawrence and Estuary (Section 2). Part of the oxygen depletion likely stemmed from enhanced oxygen utilization in response to elevated temperatures and eutrophication in the St. Lawrence Estuary, as oxygen loss rates appear to exceed those expected from changes in water mass composition (Gilbert et al. 2005, Blais et al. 2025, Jutras et al. 2023b).

In 2025, oxygen saturation stayed above or very close to the metabolic threshold ($> 70\%$) in most locations of the Atlantic Zone (Figure 15). However, in the deep near-bottom waters of the Laurentian channel, the oxygen saturation levels approached 60% in Cabot Strait (which represents a time series record high), decreasing to 31% and below in the northwest Gulf and the Estuary. Although the annual average oxygen saturation levels remain below the hypoxic threshold in the Estuary, being as low as 15% in the near-bottom waters of Rimouski station, this represents a return to near-normal conditions (Figure 15). Monthly mean oxygen saturation values in the deep layer at Rimouski station during 2025 fell within the normal climatological range throughout the year, following the typical seasonal decline driven by remineralization of organic matter exported from the surface (Figure 16). The monthly means of oxygen saturation in the bottom waters of Station 27 in 2025 were near normal throughout the year and were all above 80% (Figure 16).

4.2 CO₂-CARBONATE SYSTEM

4.2.1 Inorganic Carbon State Variables

Variations in ocean inorganic carbon state variables (total alkalinity (TA) and total dissolved inorganic carbon (DIC)) provide insight into the ocean's buffering capacity against acidification, the overall health of marine ecosystems, and the dynamics of the carbon cycle. Total alkalinity is defined as the excess of proton acceptors over proton donors. Higher TA levels generally indicate a greater ability to neutralize acidity, which is crucial for maintaining stable pH levels amid rising atmospheric and ocean metabolic CO₂. Total dissolved inorganic carbon is the sum of all dissolved inorganic carbon species contents ([CO_{2(aq)}], [H₂CO₃], [HCO₃⁻], and [CO₃²⁻]). Monitoring DIC provides insights into how carbon is transported and transformed within the Atlantic Zone, which is crucial for assessing water quality changes driven by factors such as freshwater input, nutrient loading, organic matter decomposition, among other processes.

In the Atlantic Zone, near-bottom TA anomalies exhibit no coherent temporal patterns across regions and their sub-regions (Figure 15). Climatological means (2014-2025) range from a minimum in the southern Gulf ($2169 \pm 7 \mu\text{mol kg}^{-1}$) to a maximum in the Halifax section ($2306 \pm 9 \mu\text{mol kg}^{-1}$). In 2025, TA anomalies were normal in all reported sections of the Newfoundland and southern Labrador shelves. In the Gulf of St. Lawrence, 2025 TA anomalies were more heterogeneous, with mixed conditions across subregions and a time series record high observed at the high frequency Rimouski station. In the Scotian Shelf sections, 2025 TA anomalies were predominantly above normal across sub-regions, except at Browns Bank, where conditions remained within the normal range.

Unlike the relatively straightforward processes shaping TA in surface open-ocean waters, ocean margin areas—including estuaries, continental shelves, and upper slopes—are influenced by more complex TA sinks and sources (Cai et al. 2020). At depth, this complexity may result from upwelling of deep water enriched with alkalinity through enhanced carbonate mineral dissolution (Millero et al. 1998), removal through biological calcification (Cai 2003, Cai et al., 2020), and TA production via anaerobic organic matter degradation in nearby sediments (e.g., Chen & Wang 1999, Fennel & Wilkin 2009, Wang & Cai 2004). Finally, although research remains limited, dissolved organic matter (DOM) may contribute to TA in some environments, especially where higher concentrations of its recalcitrant fraction are present at depth (Lee et al. 2024).

Across the Atlantic Zone, the earlier part of the climatological record is characterized by a greater frequency of below-normal DIC anomalies (Figure 15). Since ~2020, near-bottom DIC

anomalies have shifted toward normal to above-normal conditions in the Newfoundland and southern Labrador Shelf sub-regions, predominantly above normal in the Gulf of St. Lawrence, and more frequent above-normal conditions on the Scotian Shelf, consistent with carbon accumulation across the regions. Highest climatological DIC averages (from 2241 ± 7 to $2309 \pm 7 \mu\text{mol kg}^{-1}$) are found in the deep (100m and deeper) near-bottom waters of the Gulf of St. Lawrence. In 2025, near-bottom DIC anomalies were normal in all sub-regions of the Newfoundland and Labrador shelves and the Gulf of St. Lawrence, except for the northwest Gulf (weakly above-normal). Anomalies were above-normal on the Scotian Shelf apart from a below-normal anomaly in Cabot Strait.

4.2.2 Potential of Hydrogen (pH)

The pH measures the potential of hydrogen ions (H^+) or the “acidity level” of seawater, expressed on a logarithmic scale. When employed, terms like “more acidic” or “acidification” indicate increasing H^+ levels. In reality, oceanic waters are typically mildly alkaline with $\text{pH} > 7.0$, and genuinely acidic conditions ($\text{pH} < 7.0$) are rarely encountered in marine systems. Throughout this document, pH is expressed on the total hydrogen ion scale (pH_T), unless otherwise specified.

Since about 2020, near-bottom water pH_T anomalies have been mostly normal to below normal across the Atlantic Zone (Figure 17), suggesting a tendency toward acidification. Over the zone, lowest climatological pH_T averages (from 7.54 ± 0.02 to 7.74 ± 0.01) are found in the deep (100m and deeper) near-bottom waters of the Gulf of St. Lawrence. The decline in pH_T is most clearly resolved at the high-frequency Rimouski station and Station 27, where enhanced temporal sampling improves the detection of statistically robust trends (Figure 16). These trends are supported by agreement between parametric and non-parametric slope estimates and remain robust after accounting for autocorrelation. Regression analyses of monthly averaged time series indicate significant declines in pH_T between 2014 and 2025, with rates of -0.004 and $-0.008 \text{ units year}^{-1}$ at Rimouski and Station 27, respectively. These results indicate that near-bottom waters at both stations are acidifying more rapidly than global basin-scale surface waters, where reported rates range from -0.0013 to $-0.0025 \text{ units year}^{-1}$ for 1982–2012 (Bates et al. 2014) and $-0.0017 \text{ units year}^{-1}$ for 1985–2022 (CMEMS 2025). This suggests an amplification of interior OA at these stations driven by factors that include seasonal changes in primary production, air-sea gas exchange, riverine inputs, and oceanographic processes like mixing and upwelling. No statistically significant decreases in surface pH_T values have been observed at Rimouski station and Station 27 over the past decade. In 2025, near-bottom pH_T conditions were mostly normal in Newfoundland and Labrador Shelf and Gulf of St. Lawrence sub-regions, except for weakly below-normal anomalies in southeast Grand Banks, northwest Gulf, and centre Gulf (Figure 17). The 2025 pH_T anomalies were mostly below-normal in the Scotian Shelf sub-regions apart from an above-normal anomaly in Cabot Strait.

4.2.3 Partial Pressure of CO_2

Ocean hypercapnia, which refers to elevated levels of CO_2 in seawater, can significantly impact marine organisms by affecting their physiology, behaviour, growth, reproduction, and survival (e.g., Michaelidis et al. 2005, Munday et al. 2009, Heuer & Grosell 2014). While direct pCO_2 measurements are crucial for understanding changing ocean interior levels of CO_2 , it is important to recognize that estimates derived from other CO_2 -carbonate system parameters (pH_T , TA and DIC, such as in this report) carry greater uncertainty, especially at depths below 100 m (Weiss 1974, Orr et al. 2015).

Climatological near-bottom $p\text{CO}_2$ mean values vary ca. 3-fold across the northwest Atlantic sub-regions for the 2014–2025 time series shown in Figure 15. Zonally, lowest and highest $p\text{CO}_2$ values are found in Newfoundland/Labrador and Gulf of St. Lawrence regions, respectively. Since about 2020, annual $p\text{CO}_2$ averages have exhibited mostly normal or above-normal conditions across sections of the Scotian and Newfoundland and Labrador Shelf regions, as well as in sub-regions of the Gulf of St. Lawrence. Near-bottom waters of the Estuary (including Rimouski station) have been consistently hypercapnic ($p\text{CO}_2 > 1,000 \mu\text{atm}$) since carbonate system measurements began in 2014. The Estuary is also host to the largest interannual variability in near-bottom $p\text{CO}_2$, reflective of the complex carbonate chemistry dynamics typical of estuarine environments (Cai et al., 2021). Near-bottom hypercapnic conditions have also been observed in the northwest Gulf (since 2020) and in the northeast Gulf (2021–2023). As a semi-enclosed oceanic region, the Gulf of St. Lawrence shows more pronounced CO_2 accumulation, consistent with observations that ocean margin areas may be more impacted by the phenomenon than open-ocean basins (Lee et al. 2011). While C_{ant} is continuously imported into the Gulf of St. Lawrence at depth, mainly from the North Atlantic through Cabot Strait, accumulation of metabolic CO_2 is also contributing to the long-term carbon build-up in near-bottom waters of the basin. In 2025, near-bottom $p\text{CO}_2$ anomalies were mostly normal in Newfoundland and Labrador Shelf and Gulf of St. Lawrence sub-regions, except for weakly above-normal anomalies in southeast Grand Banks and centre Gulf. The 2025 $p\text{CO}_2$ anomalies were above-normal in the Scotian Shelf sub-regions apart from a below-normal anomaly in Cabot Strait.

4.2.4 Calcium Carbonate Saturation States and Substrate-Inhibitor Ratio

The saturation state of CaCO_3 minerals (Ω_{CaCO_3}) is a dimensionless ratio comparing the concentration of dissolved CaCO_3 ions in seawater to their saturation concentration. It serves as a metric for dissolution thermodynamics: when $\Omega < 1$, dissolution of unprotected biogenic CaCO_3 structures is thermodynamically favoured (Morse et al. 2007). Biogenic CaCO_3 exists primarily as calcite or aragonite, which differ in crystal structure and solubility (Mann 2001). Calcite is mainly produced by coccolithophores, foraminifera, and some crustaceans, while aragonite is typically found in scleractinian corals and pteropods. Mollusks can form both calcite and aragonite, and echinoderms produce calcite that includes significant magnesium (Mg) within the crystal lattice (Mann 2001, Bach 2015). Aragonite's higher solubility generally results in lower saturation states in seawater compared to calcite, making aragonite-dependent marine organisms more susceptible to dissolution under changing ocean chemistry. Evidence shows that commercially important marine bivalves and crustaceans experience acute or chronic responses to OA when Ω levels for aragonite (Ω_A) and calcite (Ω_C) range between 1.0 and 2.0. This section reports on two key thresholds: $\Omega < 1.0$, indicating conditions that favour dissolution, and a conservative biological threshold of $\Omega < 1.5$, considered suboptimal for marine organisms due to its association with observed physiological effects (Gazeau et al. 2013, Waldbusser & Salisbury 2014, Dixon et al. 2010, Keppel et al. 2012, Long et al. 2016, Rodriguez-Dominguez et al. 2018, Siedlecki et al. 2021).

While dissolution due to acidification is primarily an inorganic process linked to undersaturation states of CaCO_3 minerals, marine calcification is biologically mediated and more complex. Biocalcification typically involves uptake of calcium ions (Ca^{2+}) and bicarbonate ions (HCO_3^-) as substrates (Allemand et al. 2004, Cyronak et al. 2016, Kahil et al. 2021, Mackinder et al. 2010, Mann 2001, Stumpp et al. 2012). The processes of biocalcification vary widely across taxa, each with unique mechanisms for inorganic carbon uptake and varying sensitivities to H^+ (Mann

2001). This inherent complexity makes it challenging to predict the net response of marine calcifiers based solely on the variability in the Ω metric (Bach 2015, Ninokawa et al. 2024). The substrate-inhibitor ratio (SIR), defined as the ratio of the substrate ($[\text{HCO}_3^-]$) to the waste product ($[\text{H}^+]$), has been proposed as an additional metric to assess the influence of changing carbonate chemistry on biocalcification (Bach 2015). In this report, while pH is presented on the total scale, the hydrogen ion concentrations in the $[\text{HCO}_3^-]/[\text{H}^+]$ ratio are on the free scale (SIR in $\text{mol } \mu\text{mol}^{-1}$) which better reflects the ionic environment experienced by marine organisms. A higher SIR indicates more favourable conditions for calcification (Bach 2015, Jokiel 2011, Cyronak et al. 2016, Roleda et al. 2012). Although SIR offers a straightforward numerical measure to understand CaCO_3 production and the effects of varying chemical conditions on calcifying organisms, it does not entirely capture the intricate interactions among carbonate system variables that are believed to influence calcification, as noted by others (Ninokawa et al. 2024).

Annual averages of near-bottom water Ω_A have been below the biological threshold of 1.5 since 2015 in all sections of the Newfoundland and Labrador and Maritimes regions, except for Browns Bank, for which average annual Ω_A values have oscillated between 1.39 to 1.94 since 2014 (Figure 17). In all areas of the Gulf of St. Lawrence, including at the high frequency station Rimouski, near-bottom water values of Ω_A have been consistently undersaturated ($\Omega_A < 1.0$) since monitoring began in 2014. The time series indicates an increase in the frequency of normal to below-normal Ω_A anomalies since approximately 2020 across all three regions of the Atlantic Zone. In 2025, near-bottom Ω_A conditions were mostly normal across Newfoundland and Labrador shelves and most Gulf of St. Lawrence sub-regions. Exceptions included a weakly below-normal anomaly in the centre Gulf and an above-normal anomaly at Rimouski station, where Ω_A was elevated relative to climatology but remained undersaturated ($\Omega_A < 1$). In contrast, Ω_A anomalies were predominantly below normal in 2025 across the Scotian Shelf sub-regions apart from an above-normal anomaly in Cabot Strait.

Zonal patterns of near-bottom Ω_C and Ω_A annual anomalies are similar in their overall trends. The time series indicates an increase in the frequency of normal to below-normal Ω_C anomalies since ~2020 across all three regions of the Atlantic Zone (Figure 17). The lowest annual averages are found in the Gulf of St. Lawrence, where near-bottom waters of all sub-regions have been below the biological threshold ($\Omega_C < 1.5$) since 2015. Annual averages Ω_C have been chronically undersaturated ($\Omega_C < 1.0$) at Rimouski station since 2014, and intermittently undersaturated in the Estuary. The rising frequency of low- Ω_A and Ω_C conditions in bottom waters of the St. Lawrence Estuary aligns with modelling projections of time-of-emergence for carbonate system changes (Lavoie et al. 2020). During 2025, near-bottom Ω_C conditions were generally within normal ranges across the Newfoundland and Labrador Shelf and Gulf of St. Lawrence sub-regions, aside from a weakly below-normal anomaly in the centre Gulf and an above-normal anomaly at Rimouski station. In the Scotian Shelf sub-regions, Ω_C anomalies were largely below normal, except for an above-normal anomaly in Cabot Strait.

The time series indicates an increase in the frequency of normal to below-normal SIR anomalies since about 2020 across all three regions of the Atlantic Zone (Figure 17). Annual averages of SIR ($[\text{HCO}_3^-]/[\text{H}^+]$ in $\text{mol } \mu\text{mol}^{-1}$) show considerable spatial variability, with a more than two-fold difference in climatological values between regions (ranging from 0.089 to 0.243 $\text{mol } \mu\text{mol}^{-1}$) (Figure 17). Calcification in certain marine organisms may drastically decline below a critical threshold equivalent to an SIR of 0.100 $\text{mol } \mu\text{mol}^{-1}$ (Thomsen et al. 2015). Time-series

observations indicate that SIR has remained chronically below this threshold at Rimouski station since 2014, and intermittently below it in the Estuary. This implies that near-bottom waters of the Gulf of St. Lawrence region that are already under or nearing this SIR threshold present a combination of co-occurring dissolution/biomineralization stressors (*i.e.*, low Ω_{CaCO_3} , Ω_A , Ω_C , and SIR). Overall, higher SIR values (mostly $>0.2 \text{ mol } \mu\text{mol}^{-1}$ found in the Scotian, Newfoundland and southern Labrador Shelf regions suggest more favourable conditions for biomineralization in near-bottom waters compared to the Gulf of St. Lawrence region, with values at the mid-range of oceanic SIR values (*e.g.*, ca from 0.050 to 0.350 $\text{mol } \mu\text{mol}^{-1}$, see Bach 2015). Near-bottom SIR conditions during 2025 were largely within normal ranges throughout the Newfoundland and Labrador Shelf and Gulf of St. Lawrence sub-regions, with weakly below-normal anomalies observed in the southeast Grand Banks and centre Gulf. Conversely, the Scotian Shelf sub-regions exhibited predominantly below-normal SIR anomalies, apart from an above-normal anomaly in Cabot Strait.

5. CONCLUSION

While a shift to warmer ocean conditions occurred prior to the implementation of the AZMP, the period since 2010 has seen further warming with sea surface temperatures reaching record values across the zone during various years since 2012, including in six of our reporting areas in 2024. Surface temperatures were not as high in 2025, but remained above normal for a sixth consecutive year. In 2025, the winter average sea ice volume was fourth lowest in the Gulf of St. Lawrence and sea ice conditions were below normal on the Newfoundland and Labrador shelf. The summer cold intermediate layer areas measured at four sections on the Newfoundland and Labrador shelf were below normal at three sections. Its volume was the fifth smallest on record in the Gulf of St. Lawrence, but near normal on the Scotian Shelf. Bottom temperatures in areas affected by the CIL were above normal in all but one region of the Newfoundland and Labrador Shelf and Gulf of St. Lawrence. Bottom temperatures in the deep channels of the Gulf of St. Lawrence and the Scotian Shelf, which are affected by the mixture of cold, fresh and warm, saline waters, show decreases from the 2022 record highs. In the Gulf of St. Lawrence, temperatures decreased to values similar to those of 2018. On the Scotian Shelf, they have remained near normal in regions 4V and 4X and below normal in region 4W.

Patterns of variation in biogeochemical variables were dominated by short-term fluctuations (1 to 5 years) over the course of the 25-year time series, and many demonstrated some spatial structure across the Atlantic Zone. While short-term fluctuations in certain indices (*e.g.*, *Calanus finmarchicus*) exhibit regionally coherent patterns across the Atlantic Zone, other indices (such as total copepods and non-copepods) show contrasting regional patterns. These differences underscore the influence of zonal-scale environmental gradients and oceanographic features that can affect lower trophic level responses differently across the Atlantic shelf bioregions. Taken together, the biogeochemical variables signal broad shifts in lower trophic level productivity and phenology: declining subsurface nitrate in several regions, a lengthening phytoplankton production season in some regions driven by earlier springs and later falls, and restructuring of the zooplankton community across the zone. This restructuring manifested over the past decade as a decline in overall zooplankton biomass driven by lower *C. finmarchicus* and higher *Pseudocalanus* spp. abundances, pointing to a community shift toward smaller copepods, an indicator of less efficient energy transfer to higher trophic levels. However, high abundance of *C. finmarchicus* over the past three years and a return to mostly near-normal zooplankton biomass in 2025 suggest a moderation of this pattern.

The Atlantic Zone is experiencing changes in its chemical conditions driven by alterations in hydrographic and biogeochemical processes that may impact the health and resilience of marine ecosystems. While oxygen saturation in deep near-bottom waters remained above the metabolic threshold of 70% in most locations of the Atlantic Zone in 2025, hypoxic conditions (<30%), or nearly hypoxic conditions, have been prevalent in the Estuary and northwest Gulf of St. Lawrence since 2015 and 2020, respectively. The proportionally greater influx of oxygen-poor NACW and reduced contributions from oxygen-rich LCW in the deep waters of the Laurentian Channel in the early 2020s have driven deep-water oxygen depletion and the accumulation of metabolic CO₂, which have been further exacerbated by increased microbial respiration under warmer temperatures. However, the actual return to near normal oxygen conditions in 2025 is consistent with a shift back toward more typical proportions of LCW and NACW in the deep water renewal of the Gulf. Hypercapnic conditions (pCO₂ >1,000 µatm) have been widespread in near-bottom waters of the St. Lawrence Estuary and northwest Gulf since 2014 and 2020, respectively. Over the Atlantic zone, the downward transport of anthropogenic CO₂ is also intensifying acidification in the ocean interior, leading to higher decreasing rates of pH compared to other parts of the world ocean. Overall, there has been a broad trend of normal to deteriorating conditions for proxies of calcium carbonate biocalcification and dissolution in deep near-bottom waters of the Atlantic zone since approximately 2020. This is particularly evident in aragonite saturation states, which were below the dissolution threshold ($\Omega_A < 1$) across all sub-regions of the Gulf of St. Lawrence.

5.1 SUMMARY

- Monthly average sea surface temperatures were generally near normal to above normal from March through November, with the highest anomalies from September to November.
- Sea surface temperature seasonal averages were near normal to above normal across the zone. The 2025 spatially weighted zonal average anomaly was above normal, but less so than the four previous years.
- Transport along the Newfoundland and Labrador Shelf break was at a record high. It was above normal for the third consecutive year along the Scotian Shelf break. The latter indicates increased input of cold and low salinity waters with high dissolved oxygen concentrations that may feed into the Gulf of St. Lawrence and Scotian Shelf at depth.
- Winter average sea ice conditions were below normal on the Newfoundland and Labrador Shelf and seasonal average volume was fourth lowest since 1969 in the Gulf of St. Lawrence.
- The cold intermediate layer (CIL) indices showed warmer than normal conditions in the Gulf of St. Lawrence and on the Newfoundland and Labrador Shelf (except for Bonavista, which was near normal), and still near normal on the Scotian Shelf. Conditions have been similar for the past three years, but the volume has been increasing on the Scotian Shelf.
- Bottom temperatures in shallower areas that are affected by the CIL were above normal in all regions of the Newfoundland and Labrador Shelf and Gulf of St. Lawrence including a record high on the Grand Banks (3LNO), but were near normal in 3Ps in the spring.
- Bottom temperatures in the deep channels of the Gulf of St. Lawrence and the Scotian Shelf, which are affected by the mixture of cold, fresh Labrador Current water and warm, saline waters related to Gulf Stream waters, show further decreases from the 2022 record highs. On the Scotian Shelf, these bottom temperatures remained near normal in regions 4V

and 4X and below normal in region 4W. The zonal average index was near normal for the second consecutive year; the previous near normal year was 2013.

- Near- or below-normal subsurface nitrate inventories were widespread across the Atlantic Zone, except for the central and eastern Labrador Sea, where there was a record-high inventory. This continues the post-2015 low-nitrate pattern in the Gulf of St. Lawrence and on the Scotian Shelf, and marks the end of a period of above-normal anomalies that had persisted since 2021 on the Newfoundland Shelf.
- Chlorophyll-*a* inventories were near or above normal across most of the Atlantic Zone, except in the eastern and central Labrador Sea and on the western Scotian Shelf. Since 2017, inventories have been predominantly near or above normal on the Newfoundland Shelf and in the Gulf of St. Lawrence.
- The timing of the spring phytoplankton bloom was near normal or earlier than normal across the Atlantic Zone, except in the eastern Labrador Sea. Spring bloom timing has generally been earlier than normal on the Newfoundland Shelf and in the Gulf of St. Lawrence since 2021 and 2016, respectively.
- Mean spring surface chlorophyll-*a* concentrations were generally near or above normal on the Newfoundland Shelf and in the Gulf of St. Lawrence, including a record high in the northwest Gulf, and near or below normal in the Labrador Sea and on the Scotian Shelf.
- The timing of the fall bloom was generally normal or later than normal across the Atlantic Zone, except in the eastern Labrador Sea, Flemish Pass, and St. Pierre Bank. At the zonal scale, a trend toward delayed fall bloom timing is emerging.
- Mean fall surface chlorophyll-*a* concentrations were generally near normal in the Labrador Sea, on the Newfoundland Shelf, and in the Gulf of St. Lawrence, and below normal on the Scotian Shelf. A record high was observed in the central Labrador Sea. At the zonal scale, a trend toward higher concentrations is emerging.
- Total copepod abundances were near normal on the Newfoundland Shelf, generally below normal in the Gulf of St. Lawrence, and above normal on the Scotian Shelf.
- Non-copepod abundances were near or above normal at most locations, consistent with a decade-long pattern of above-normal values, although a record low was recorded in the centre Gulf.
- *Pseudocalanus* spp. abundance showed contrasting regional patterns: mostly near normal on the Newfoundland Shelf, below normal in the Gulf of St. Lawrence, with record lows at Rimouski station and in the centre Gulf for a second consecutive year, and above normal on the Scotian Shelf, including a record high on the Halifax section for the second consecutive year.
- *C. finmarchicus* abundance was near or above normal across the Atlantic Zone, with record highs at Shediac Valley and in the southern Gulf. This marks a third consecutive year of widespread above-normal abundances, following a decade of near- to below-normal values.
- Zooplankton biomass was predominantly near or above normal on the Newfoundland Shelf, continuing a decade-long pattern. In the Gulf of St. Lawrence and on the Scotian Shelf, biomass was near or below normal, except in the southern Gulf, including Shediac Valley station, consistent with a pattern of mainly below-normal biomass observed since 2010.

- Near-bottom oxygen saturation was near or above normal across the Atlantic Zone, marking a notable recovery in the Gulf of St. Lawrence after a sharp decline since 2020. However, near-bottom waters of the St. Lawrence Estuary remained severely undersaturated (<20%), and those of the northwest Gulf remained near the hypoxia threshold (<30%).
- Since approximately 2020, above-normal anomalies in Dissolved Inorganic Carbon (DIC) and $p\text{CO}_2$ have been more frequent across near-bottom waters of the Atlantic Zone, particularly in the Gulf of St. Lawrence.
- Hypercapnic conditions ($p\text{CO}_2 > 1000 \mu\text{atm}$) have been present in the near-bottom waters of the Estuary since 2014, the northwest Gulf since 2020, and the northeast Gulf episodically from 2021 to 2023.
- Suboptimal calcification conditions have been sustained in near-bottom waters across the Atlantic Zone since 2014, with severity varying by region.
 - Aragonite undersaturation ($\Omega_A < 1$) has been widespread in the Gulf of St. Lawrence, while moderately reduced Ω_A (< 1.5) has characterized Newfoundland, southern Labrador, and most of the Scotian Shelf. Calcite undersaturation ($\Omega_C < 1$) has been present at Rimouski station, with moderately reduced Ω_C (< 1.5) elsewhere in the Gulf of St. Lawrence.
 - Substrate–inhibitor ratios have been below the critical threshold ($\text{SIR} < 0.1$), consistently at Rimouski station and episodically in the Estuary as a whole.
- At the high-frequency sampling stations (Figure 1):
 - Seasonal average 0–50 m temperature was above normal at all sites except Rimouski station. The last five years have generally had above normal values at these sites.
 - Bottom temperature was below normal at Halifax 2 for the second consecutive year, consistent with the cooling of deep waters in the region. It was near normal at Prince 5 and above normal at the three other sites, including a record high at Rimouski station.
 - Near-surface salinity (0–50 m) was normal at all sites but stratification was variable across sites.
 - Subsurface nitrate and chlorophyll-a inventories were near or below normal at most sites.
 - Zooplankton indices were normal or above normal across the stations, except at Rimouski station where they were mostly below normal.
 - The bottom waters of most stations were well-ventilated (oxygen saturation $\geq 68\%$), with hypoxic conditions (< 30 %) found only at Rimouski station.
 - Near-bottom waters show acidification trends between 2014 and 2025 with pH_T decline of 0.004 unit per year at Rimouski station and of 0.008 unit per year at Station 27.

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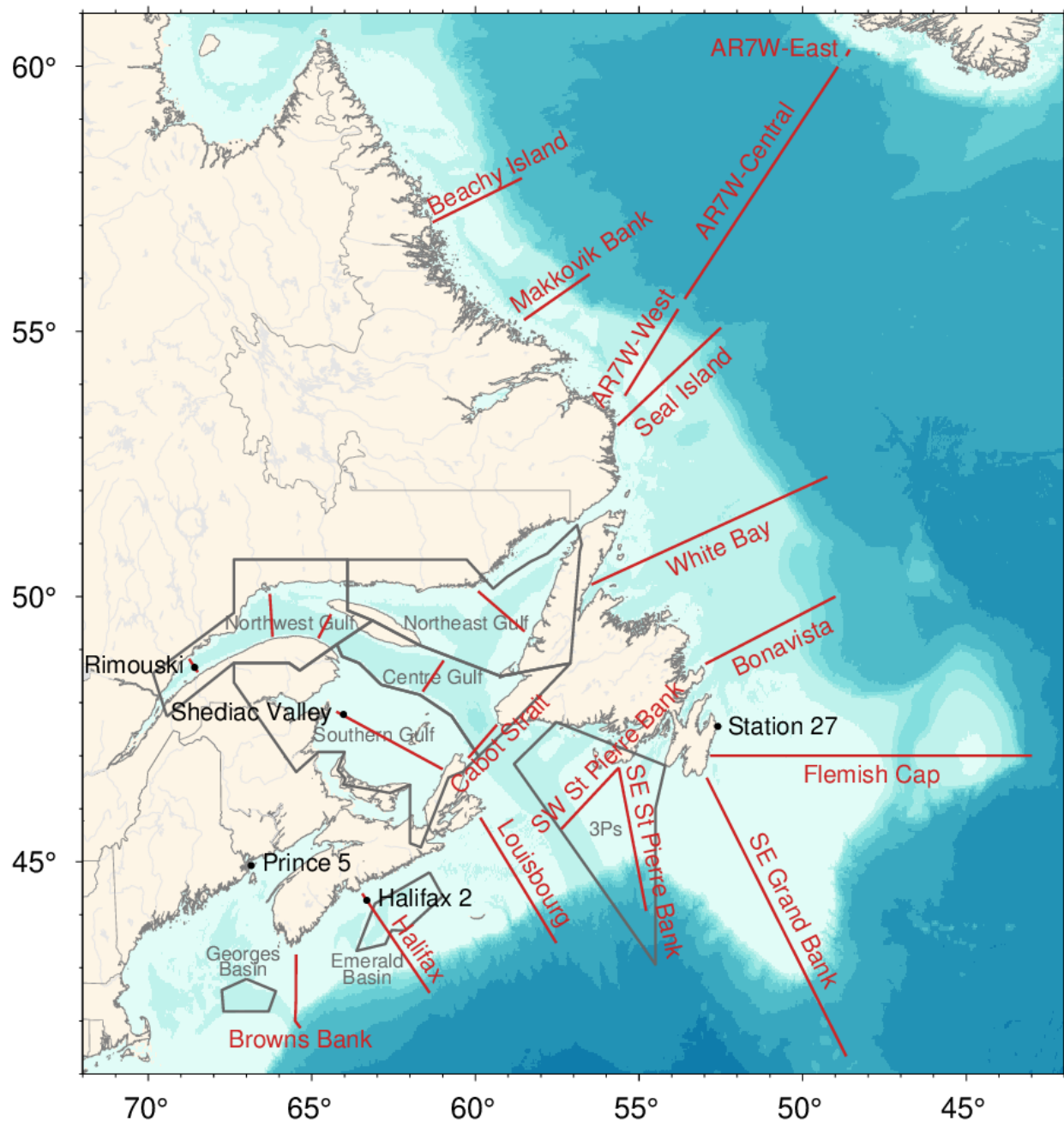


Figure 1. Atlantic Zone Monitoring Program high-frequency sampling stations (black), selected section lines (red) and averaging areas (gray).

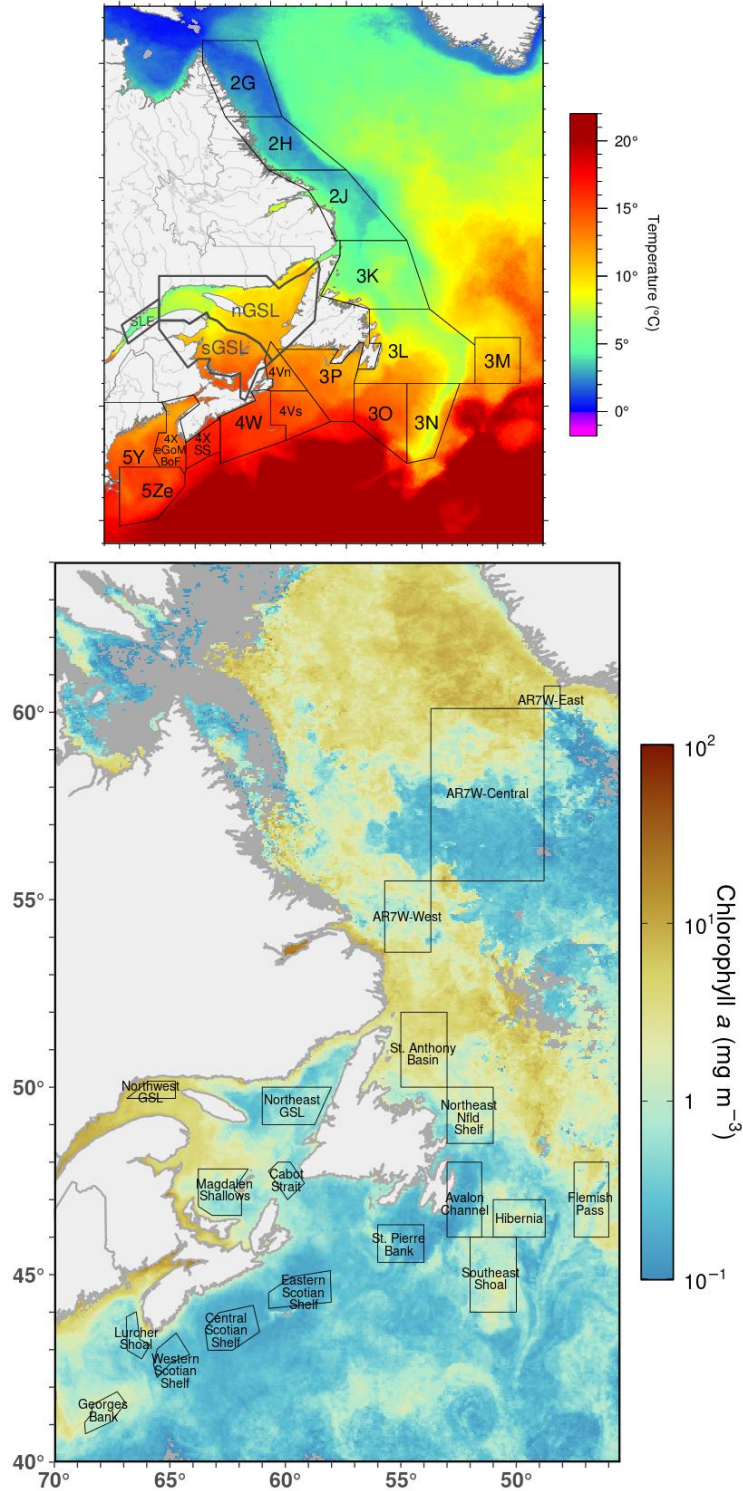


Figure 2. Areas used for (top) temperature and (bottom) ocean colour averages. (Top) North Atlantic Fisheries Organization Divisions are cut off at the shelf break. The acronyms GSL and SLE are Gulf of St. Lawrence and St. Lawrence Estuary respectively. Sea surface temperatures are shown for October 2025 and ocean colour chlorophyll a concentrations are for May 2025.

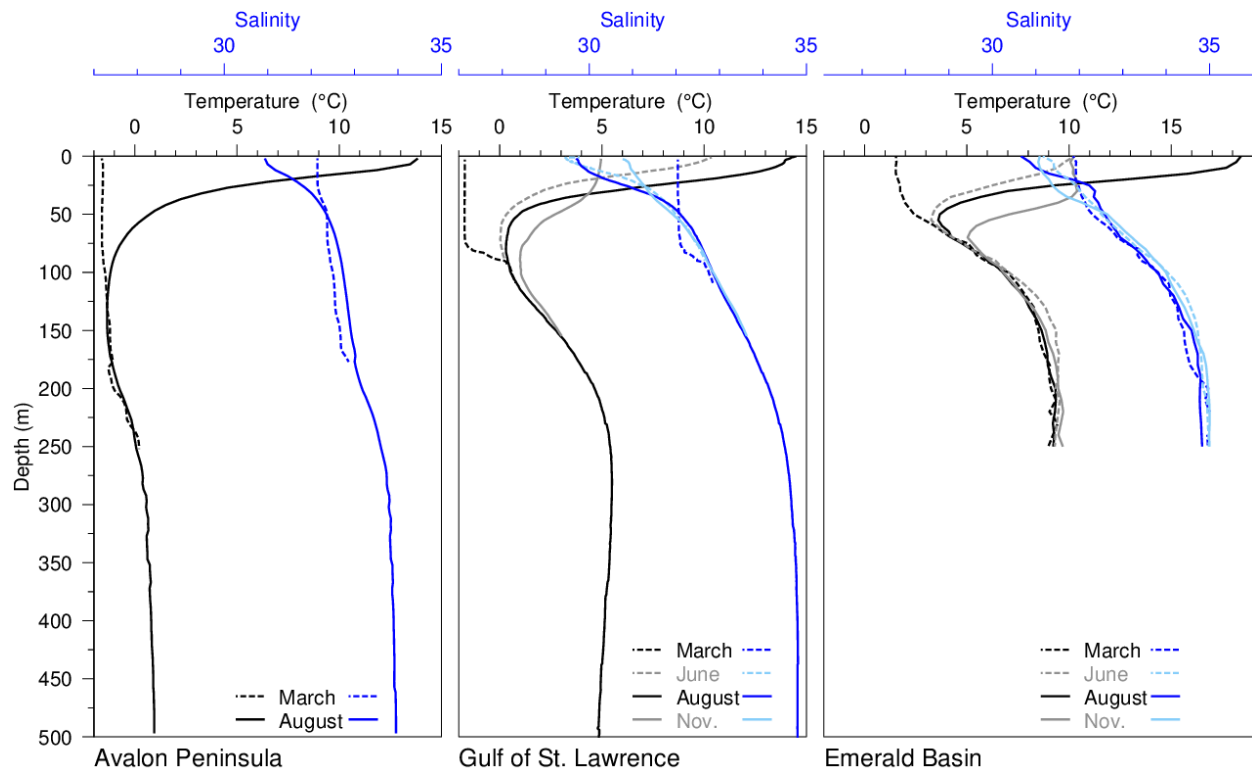


Figure 3. Typical seasonal progression of the depth profile of temperature and salinity observed in three representative regions across the zone. The Avalon Peninsula region is delimited by 45–50°N and 50–55°W and shown are the averages of profiles for March and August between 2015 and 2017, calculated 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.

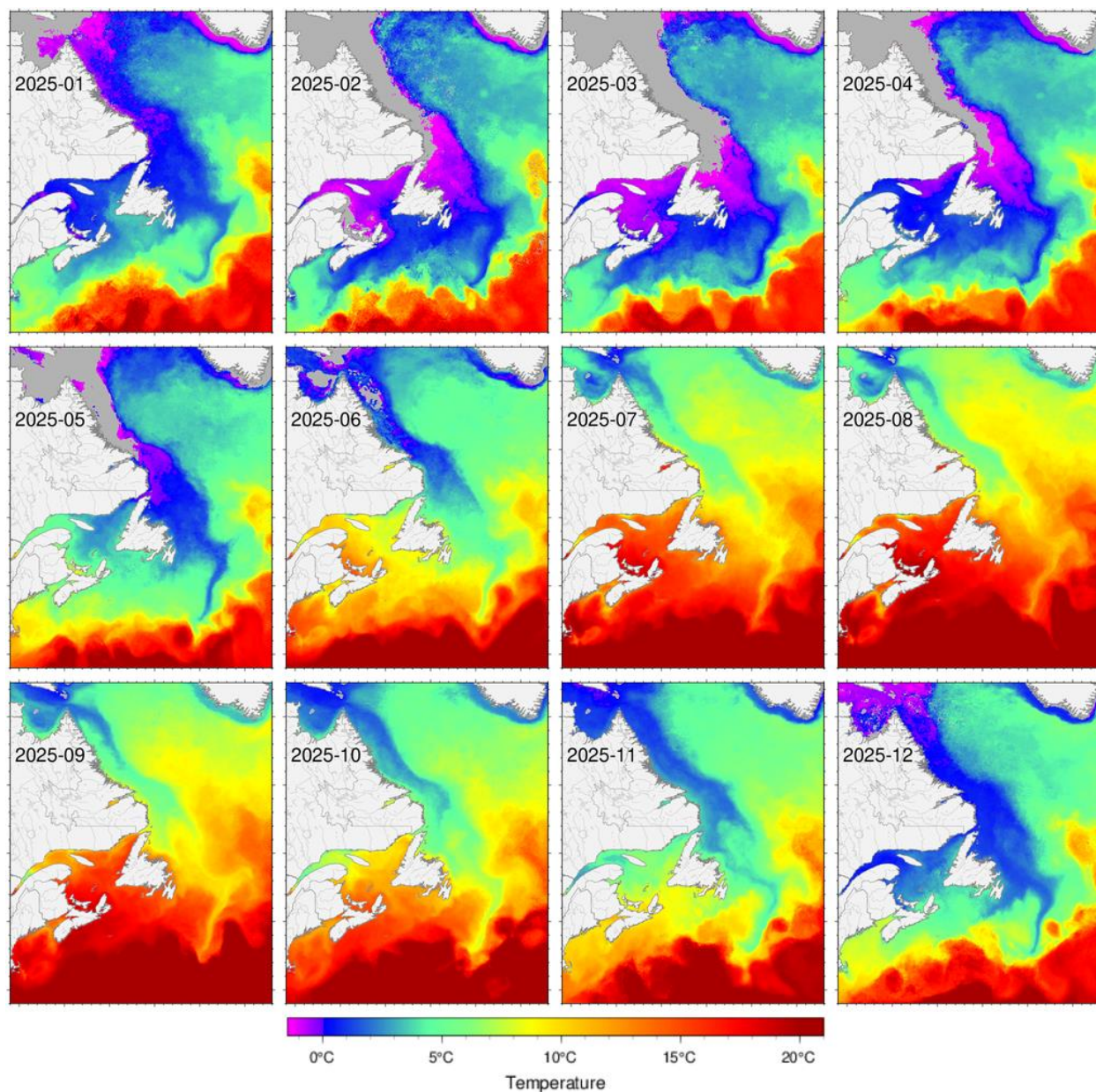


Figure 4. Sea surface temperature monthly averages for 2025 in the Atlantic zone. Grey areas have no data for the period due to ice cover or clouds. Temperatures are biased towards warmer ice-free conditions for all months affected by sea ice cover, as the freezing conditions of the ice-covered areas are not captured by satellite.

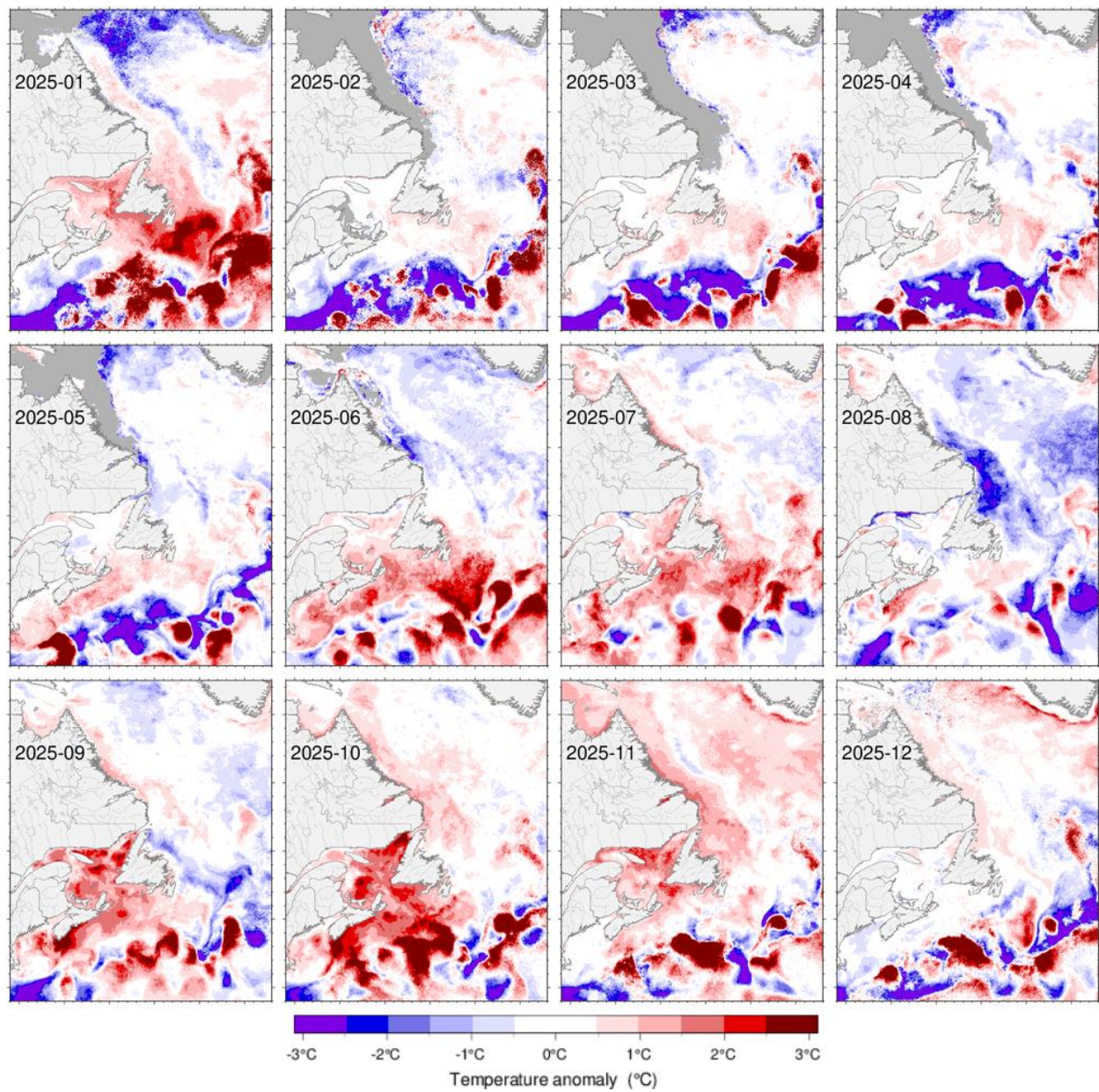


Figure 5. Sea surface temperature monthly anomalies for 2025 in the Atlantic Zone based on a 1991–2020 climatology. Areas often covered by sea ice in winter months, such as the Gulf of St. Lawrence, have monthly climatologies that are biased to warm ice-free conditions. Anomalies are not reliable in such areas and months.

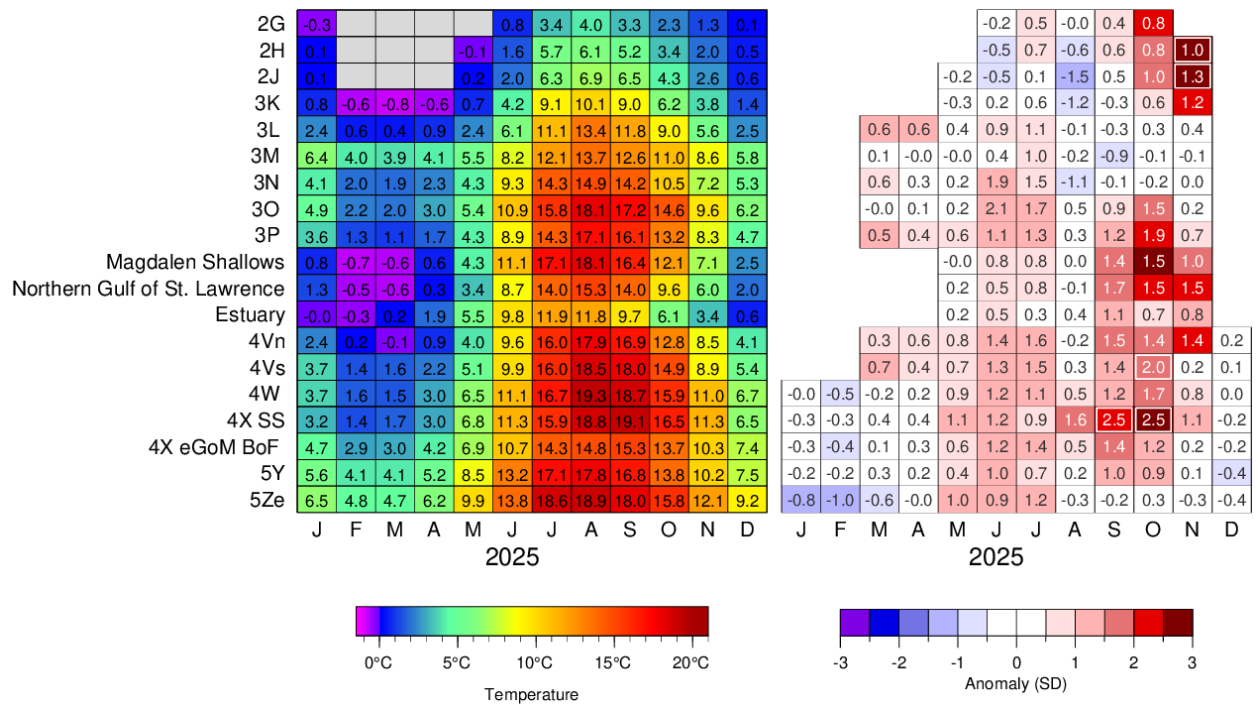


Figure 6. Monthly sea surface temperatures (left) and anomalies (right) for 2025, averaged over the 19 regions shown in the top panel of Figure 2. Regions and months for which the average temperature was at a record high or low are indicated by white outlines. Grey squares have insufficient data coverage to yield a monthly average anomaly (<7%) due to ice cover and clouds. Anomalies are only shown for months having a reliable climatology. Anomalies on the right panel are printed in °C and colour-coded according to the monthly normalized anomalies based on the 1991–2020 climatologies for each month.

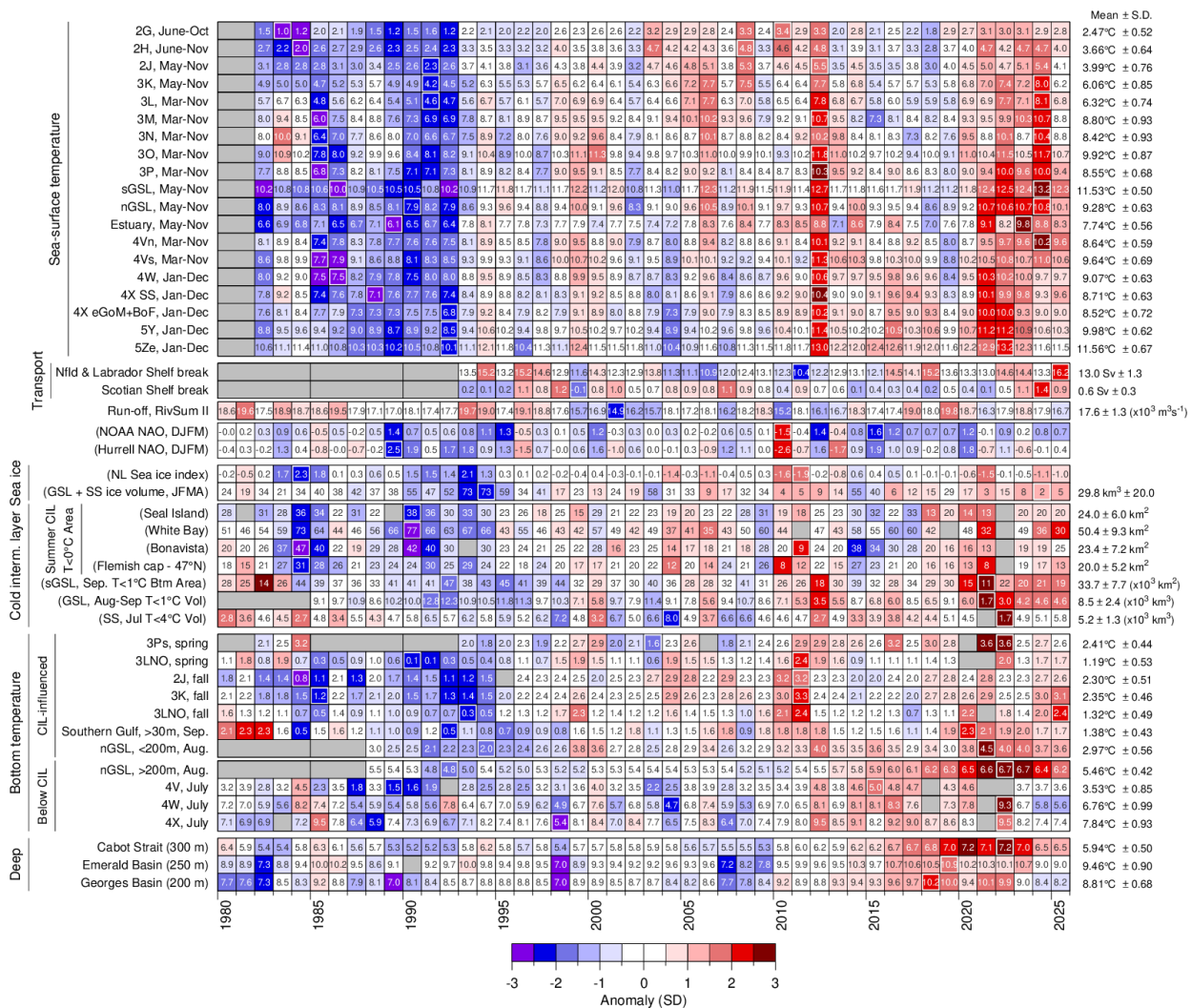


Figure 7. Time series of oceanographic variables 1980–2025. Numbers in the table are physical units, but the colour coding is according to normalized anomalies. A grey cell indicates missing data, a white cell is a value within 0.5 SD of the long-term mean based on data from 1991 to 2020 when possible; 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 minimums and maximums are indicated by a white outline when they occur in the displayed time span. Long-term means and standard deviations are shown on the right-hand side of the figure. RIVSUM II is the combined runoff flowing into the St. Lawrence Estuary. Abbreviations used: North Atlantic Oscillation (NAO), Gulf of St. Lawrence (GSL), Scotian Shelf (SS), southern Gulf of St. Lawrence (sGSL), northern Gulf of St. Lawrence (nGSL), cold intermediate layer (CIL).

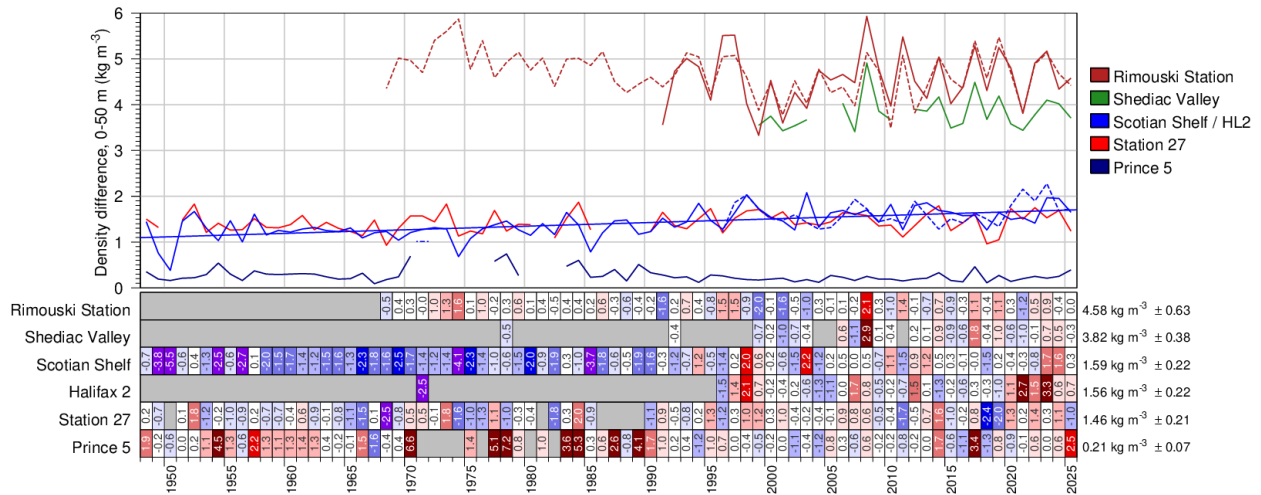


Figure 8. Stratification in the St. Lawrence Estuary (May–Oct average at Rimouski station), in the southern Gulf (May–Oct average at Shediac Valley station), on the Scotian Shelf (summer shelf average and annual average at Halifax 2 station), on the southern Newfoundland-Labrador Shelf (May–Nov average at Station 27), and in the Bay of Fundy (Prince 5 station annual average). The dashed line for Rimouski station is a proxy based on May–October RIVSUM II freshwater runoff. The solid dark blue line is for the Scotian Shelf average and the dashed line is for the Halifax 2 station. The bottom scorecard rows 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. The anomaly colour code is the same as in Figures 6 and 7.

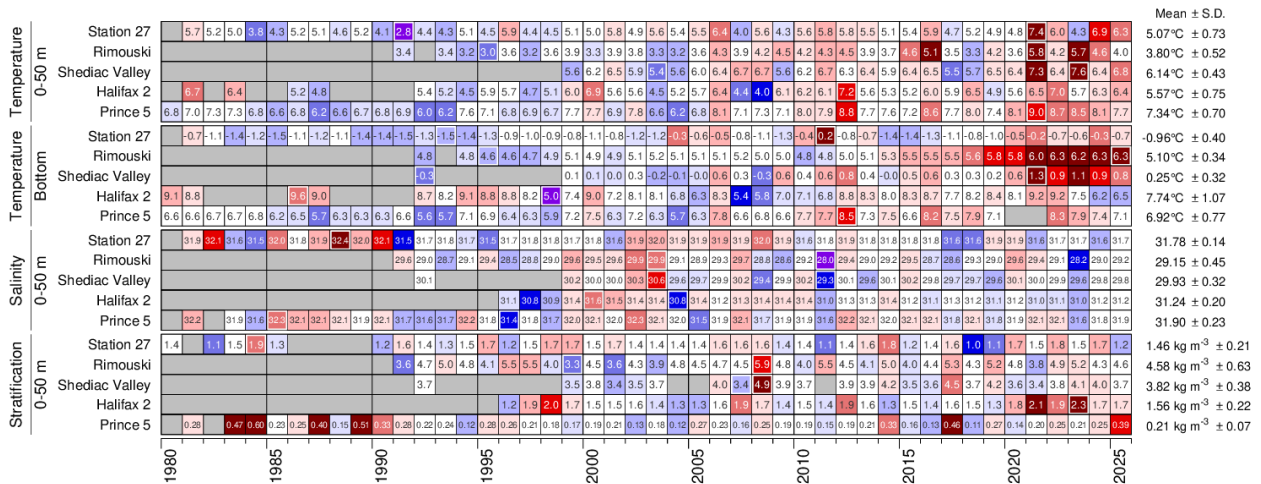


Figure 9. Time series of oceanographic variables at AZMP high-frequency sampling stations, 1980–2025. Values are annual averages at Halifax 2 and Prince 5, May–November at Station 27 and May–October at Rimouski station. A grey cell indicates missing data, a white cell is a value within 0.5 SD of the long-term mean based on data from 1991 to 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 minimums and maximums are indicated by a white outline when they occur in the displayed time span. Climatological means and standard deviations are shown on the right-hand side of the figure. The anomaly colour code is the same as in Figures 6 and 7.

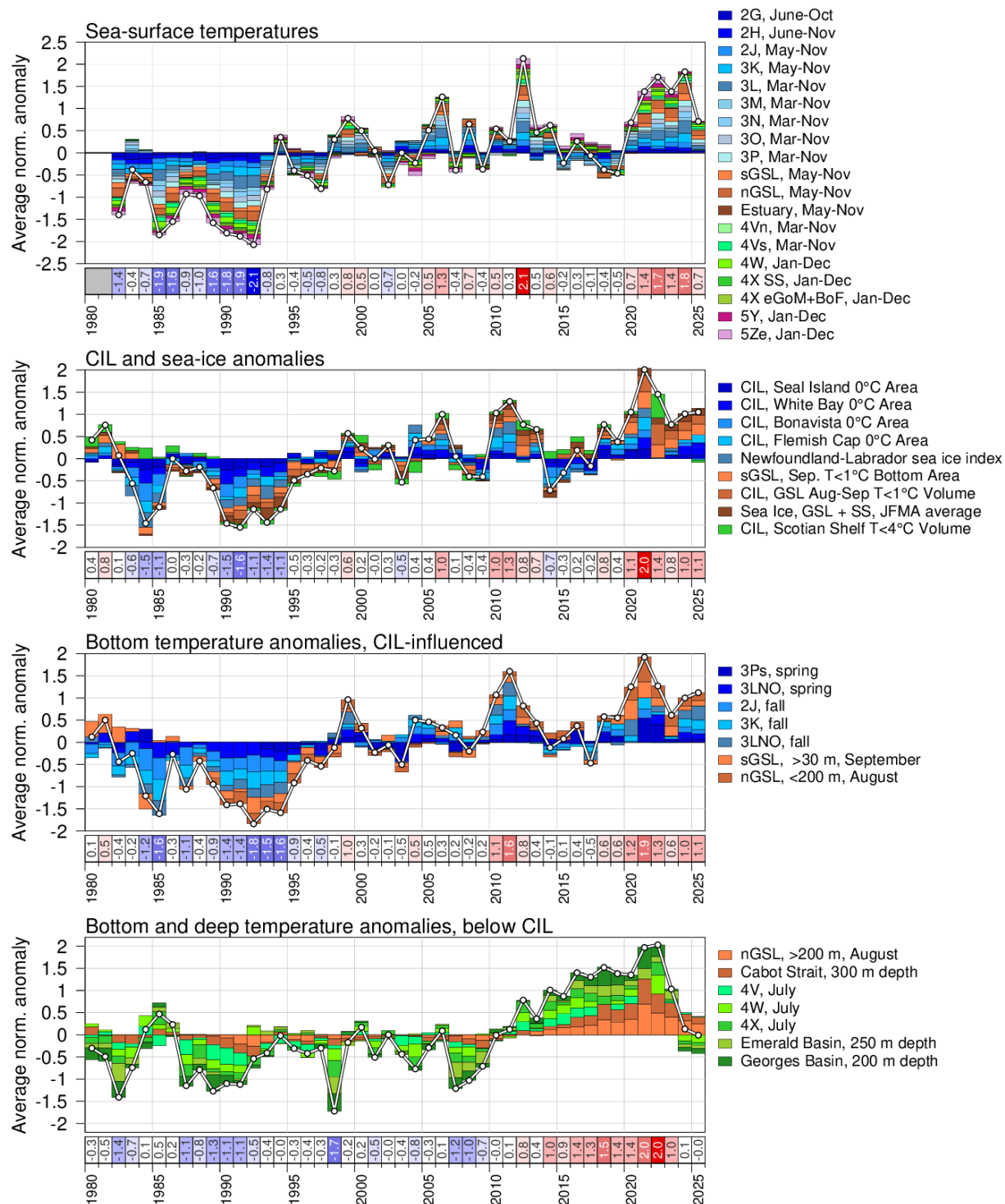


Figure 10. Composite climate indices (white lines and dots) derived by averaging various normalized anomalies from different parts of the environment (coloured boxes stacked above the abscissa are positive anomalies and below are negative). Top panel shows average sea surface temperature anomalies weighted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

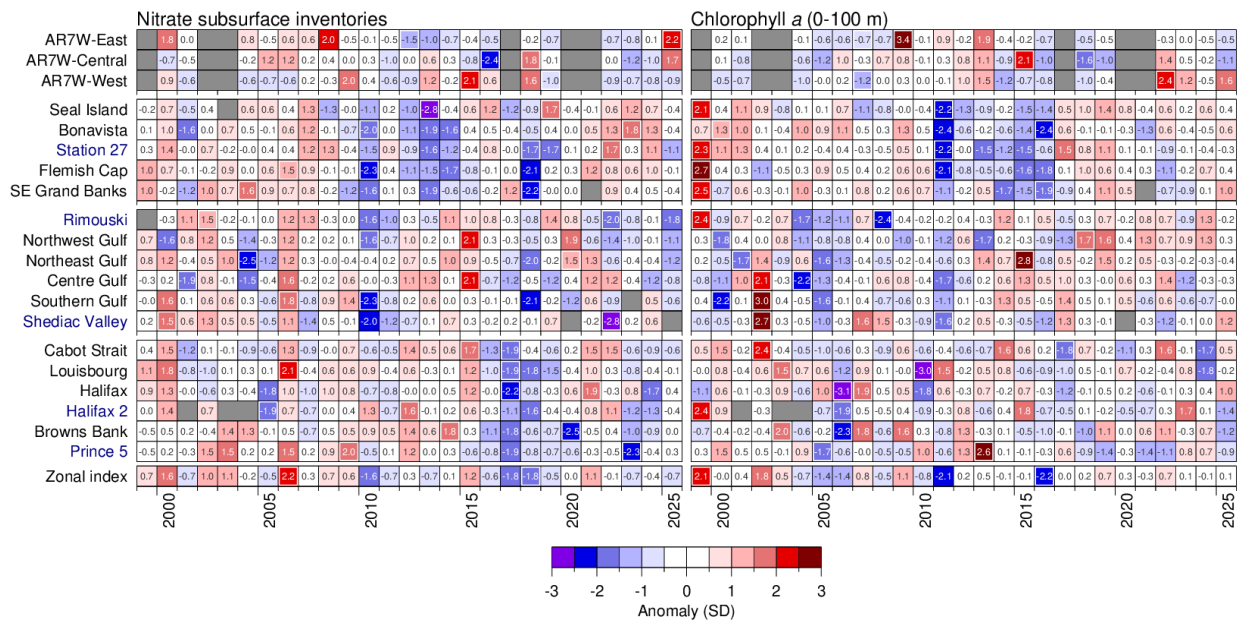


Figure 11. Time series of the subsurface nitrate inventories (100 m – bottom in Labrador Sea; 50–150 m in other regions) and phytoplankton biomass (expressed as chlorophyll-a 0–100 m inventory) in the Labrador Sea, at AZMP sections, in the Gulf of St. Lawrence averaging areas, and at high-frequency sampling stations (labelled in blue), 1999–2025. 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 1999–2025; a red cell indicates above normal inventories, a blue cell below normal. Darker shades indicate larger anomalies; anomaly values are indicated in each cell. Series minimums and maximums are framed in white. The “zonal index” is created as the average of all normalized anomalies, and that result is again normalized. See Figure 1 for the location of sections, averaging areas and stations.

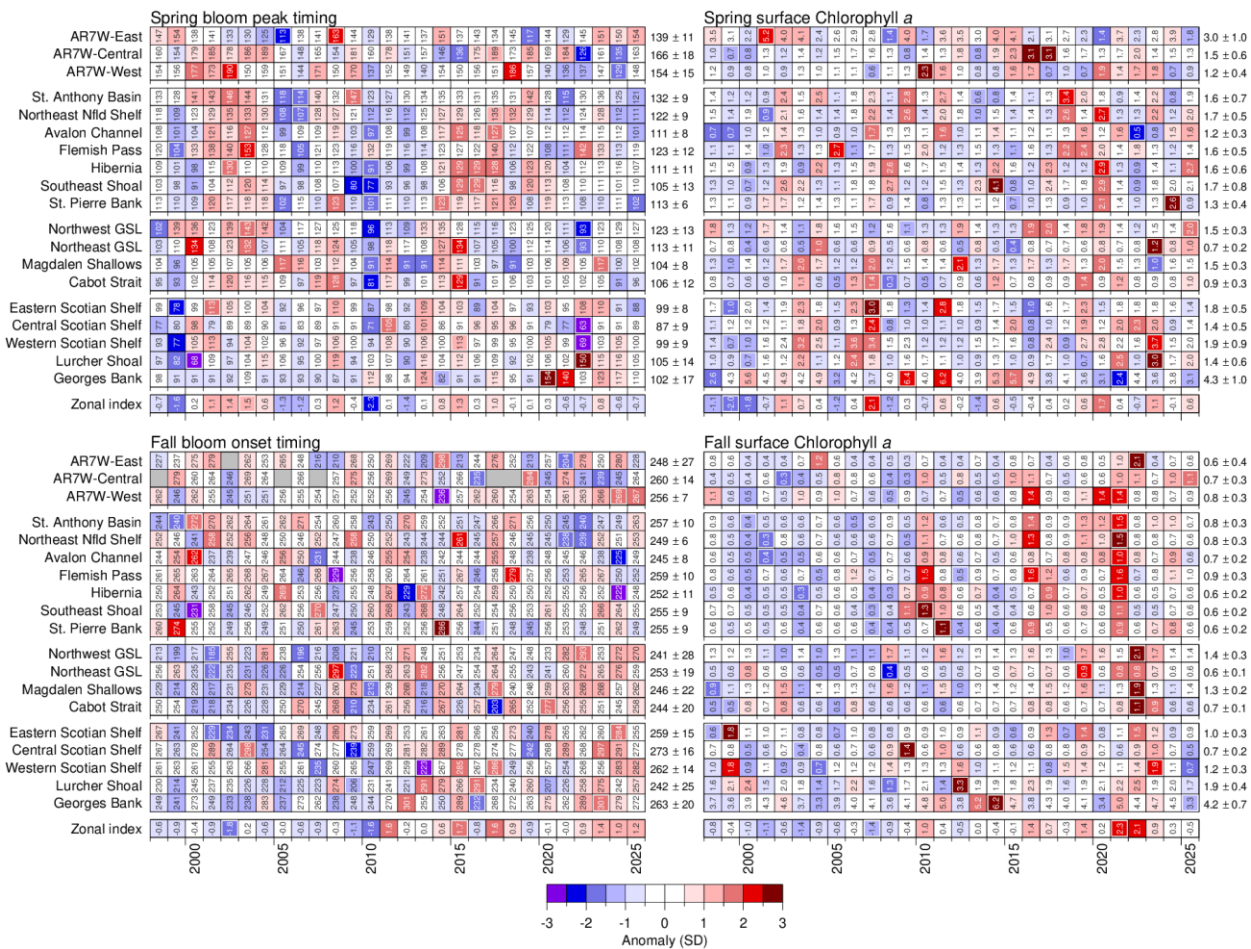


Figure 12. Time series of bloom parameter anomalies derived from remotely sensed surface chlorophyll-a measurements (spring bloom peak timing, spring chlorophyll-a, fall bloom onset timing, fall chlorophyll-a), 1998–2025. Seasonal anomalies are calculated from the daily surface chlorophyll-a concentration averaged over spring and fall. Data are from OC-CCI. 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 1999 to 2025; a red cell indicates late timing, or above normal inventories, and a blue cell early timing/below normal. Darker shades indicate larger anomalies. Values in cells are days of the year for bloom timing indices and surface chlorophyll-a concentration (mg m^{-3}) for seasonal averages. White-framed cells indicate series minima and maxima. The “zonal index” is created as the average of all normalized anomalies, and that result is again normalized. See Figure 2 for ocean colour subregion definitions.

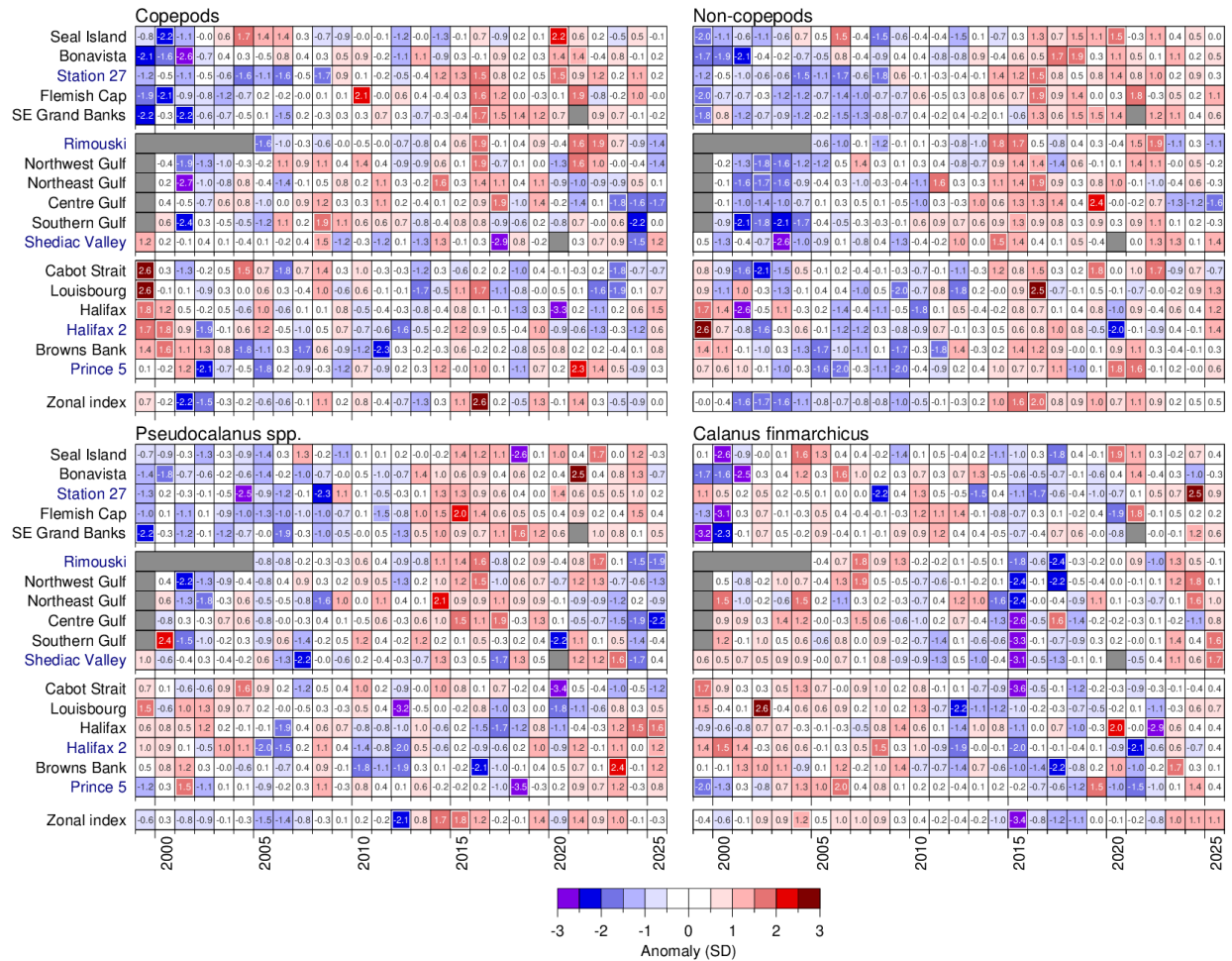


Figure 13. Time series of the abundance anomalies for total copepods, *Calanus finmarchicus*, *Pseudocalanus* spp., and non-copepod zooplankton at AZMP sections, in the Gulf averaging areas and at high-frequency sampling stations (labelled in blue), 1999–2025. A grey cell indicates missing data, a white cell is a value within 0.5 SD of the long-term mean based on data from 1999 to 2025; a red cell indicates above normal inventories, a blue cell below normal. Darker shades indicate larger anomalies. White-framed cells indicate series minima and maxima. The “zonal index” is created as the average of all normalized anomalies, and that result is again normalized. See Figure 1 for section, averaging areas and station positions.

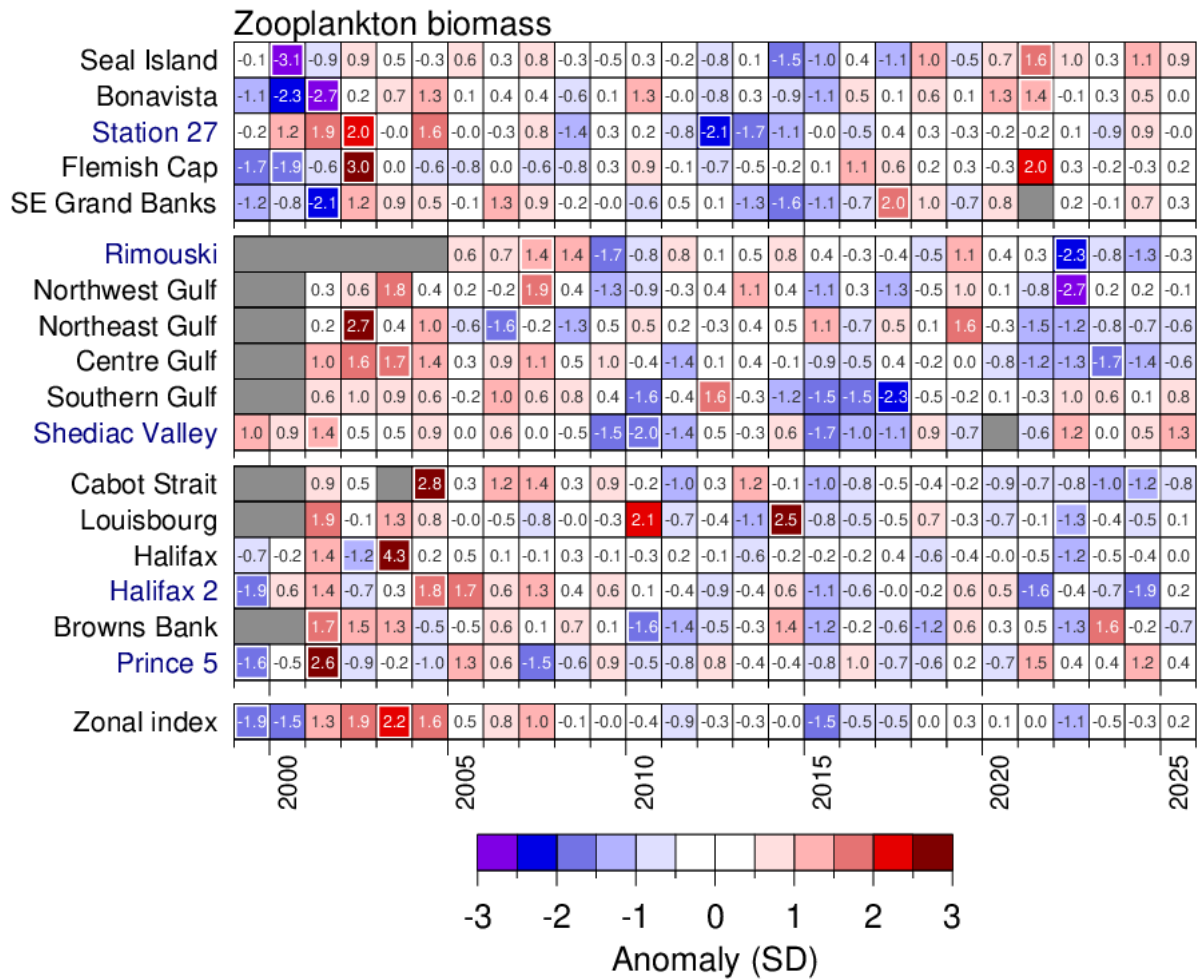


Figure 14. Time series of mesozooplankton dry biomass anomalies at AZMP sections, in the Gulf averaging areas and at high-frequency sampling stations (labelled in blue), 1999 to 2025. Biomass is measured on the 0.2–10 mm size fraction which is usually dominated by copepods. A grey cell indicates missing data, a white cell is a value within 0.5 SD of the long-term mean based on data from 1999 to 2025; a red cell indicates above normal inventories, a blue cell below normal. Darker shades indicate larger anomalies. White-framed cells indicate series minima and maxima. The “zonal index” is created as the average of all normalized anomalies, and that result is again normalized. See Figure 1 for section, averaging areas and station positions.

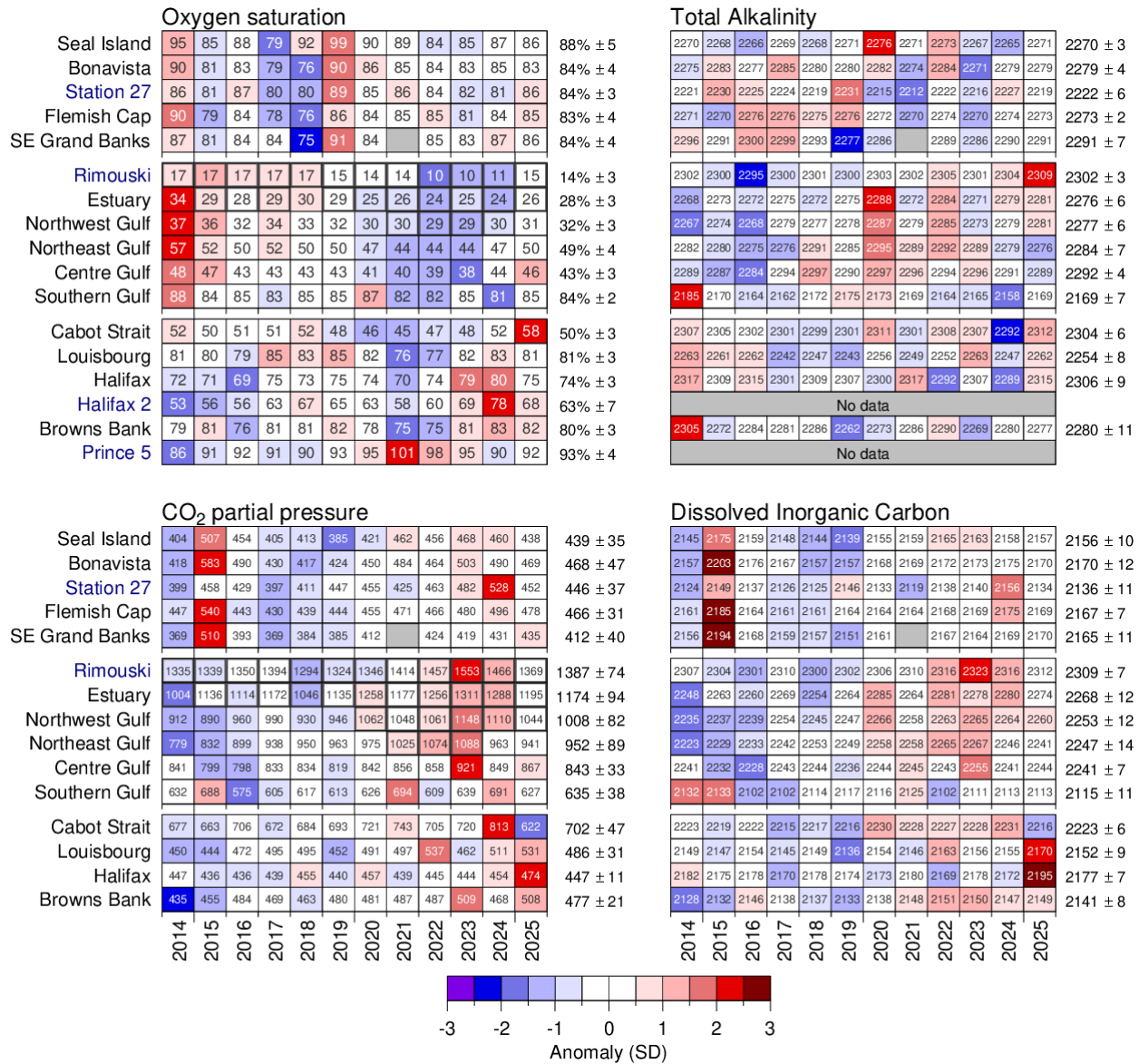


Figure 15. Time series of near-bottom water annual averages for: oxygen saturation (in %, upper left panel); total alkalinity (TA in $\mu\text{mol kg}^{-1}$, upper right panel); partial pressure of CO₂ (pCO₂ in μatm , lower left panel); and dissolved inorganic carbon (DIC in $\mu\text{mol kg}^{-1}$, lower right panel) at AZMP sections in the Newfoundland and Labrador and Maritimes regions, in the Gulf of St. Lawrence region averaging areas, and at high-frequency sampling stations (labelled in blue), from 2014 to 2025. A grey cell indicates missing data; a white cell is a value within 0.5 SD of the climatological mean based on data from 2014 to 2025 inclusively; a red cell indicates above normal values; a blue cell indicates below normal values. More intense colours indicate larger anomalies. Climatological means and standard deviations are shown on the right side of each panel. Boxes with thick borders in the oxygen saturation and pCO₂ panels correspond to values at or below the 30% saturation threshold, and above the 1000 μatm hypercapnia threshold. Near-bottom values represent the deepest observations; for all sub-regions except the southern Gulf, this corresponds to stations with depths >100 m, whereas in the shallower southern Gulf all near-bottom data were used. See Figure 1 for section, averaging area and station positions.

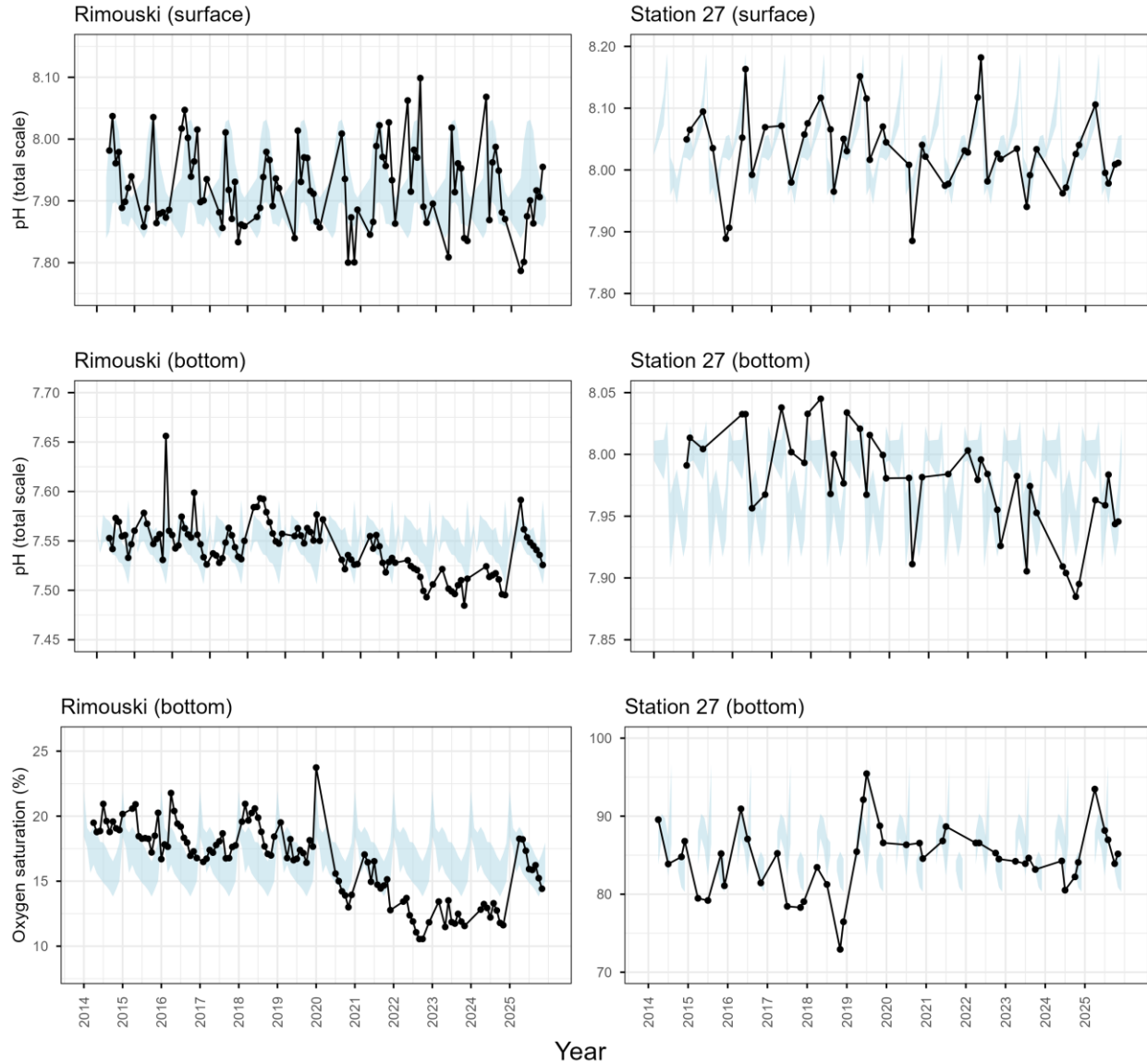


Figure 16. Time series of: (top panels) the monthly average *in situ* pH_T (pH on the total scale) in the surface waters (averaged within the top 15 m) at Rimouski station in the Gulf of St. Lawrence region (left) and at Station 27 on the Newfoundland Shelf (right); (middle panels) the monthly average *in situ* pH_T (pH on the total scale) in the bottom waters at Rimouski station (left, averaged between 270–320 m) and at Station 27 (right, averaged between 150–170 m); (bottom panels) the monthly average dissolved oxygen saturation (%) in the bottom waters at Rimouski station (left, averaged between 270–320 m) and at Station 27 (right, averaged between 150–170 m for pH_T and between 120–170 m for oxygen saturation). The shaded area in blue in each panel indicates the respective climatology for the 2014–2025 period. The relatively short time frame of the climatology, along with occasionally sparse data, may contribute to its noisier appearance. Note the different ranges in scales for pH_T and oxygen saturation in different panels.

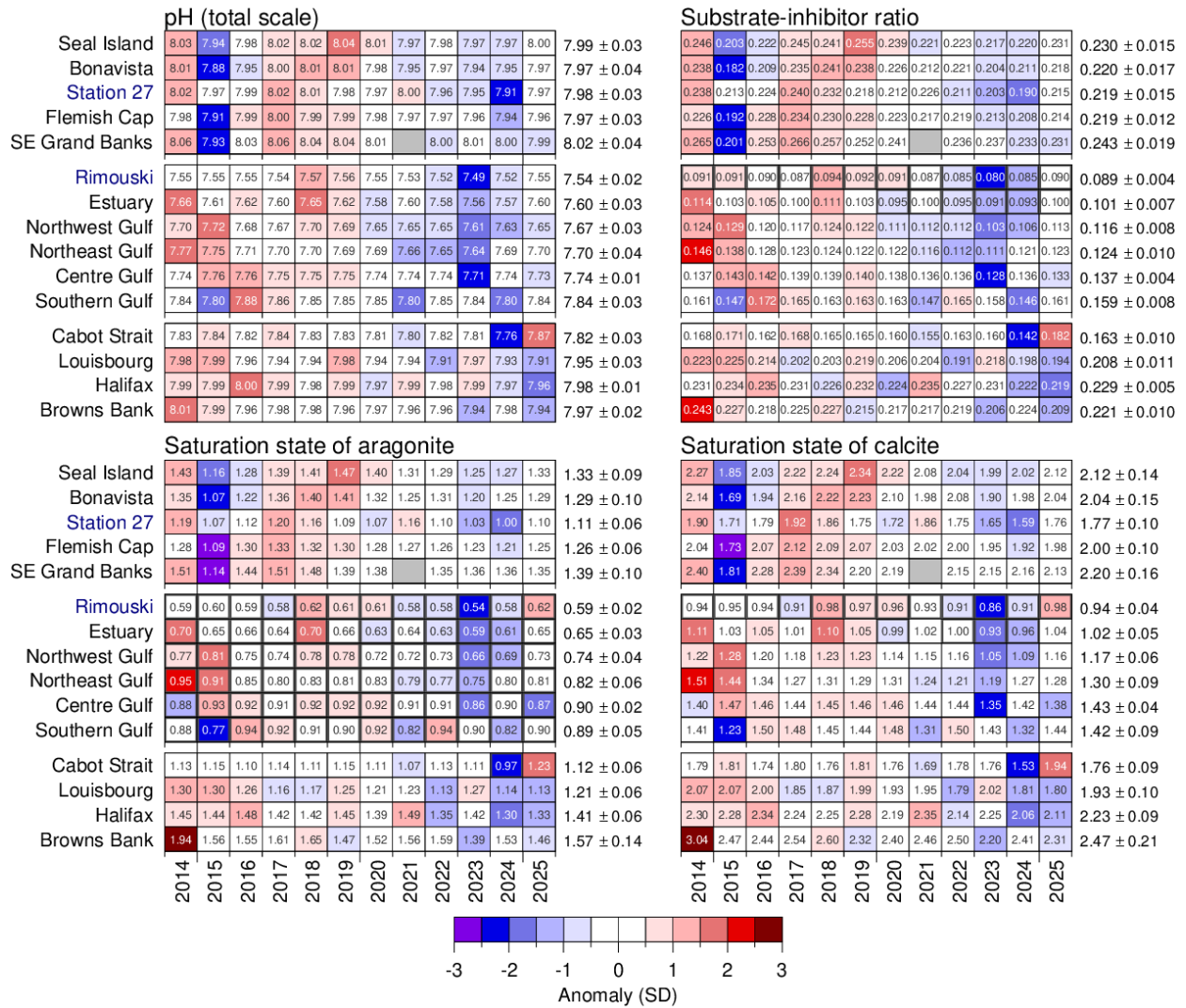


Figure 17. Time series of near-bottom water annual averages for: *in situ* pH_T (pH on the total scale, upper left panel); substrate-inhibitor ratio (SIR in mol μmol⁻¹, upper right panel); saturation state of aragonite (Ω_A - unitless, lower left panel); and saturation state of calcite (Ω_C - unitless, lower right panel) at AZMP sections in the Newfoundland and Labrador and Maritimes region, in the Gulf of St. Lawrence region averaging areas, and at high-frequency sampling stations (labelled in blue), from 2014 to 2025. A grey cell indicates missing data; a white cell is a value within 0.5 SD of the climatological mean based on data from 2014 to 2025 inclusively; a red cell indicates above normal values; a blue cell indicates below normal values. More intense colours indicate larger anomalies. Climatological means and standard deviations are shown on the right side of each panel. Boxes with thick borders in the substrate-inhibitor ratio, saturation state of aragonite and saturation state of calcite panels correspond to values at or below the thresholds of 0.1, 1 and 1, respectively. Near-bottom values represent the deepest observations; for all sub-regions except the southern Gulf, this corresponds to stations with depths >100 m, whereas in the shallower southern Gulf all near-bottom data were used. See Figure 1 for sections, averaging areas and station positions.