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Hydrographic Conditions on the Northeast United States Continental Shelf in 2023 – NAFO Subareas 5 and 6

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Abstract

An overview is presented of the atmospheric and oceanographic conditions on the Northeast U.S. Continental Shelf during 2023. The analysis utilizes hydrographic observations collected by the operational oceanography programs of the Northeast Fisheries Science Center (NEFSC), which represents the most comprehensive consistently sampled ongoing environmental record within the region. On average, waters on the Northeast U.S. Continental Shelf were anomalously fresh and slightly warmer in 2023 relative to the 1991-2020 climatological mean condition. Notable cold and fresh anomalies were observed in the northern Middle Atlantic Bight and Gulf of Maine during fall, likely caused by advection of water from the north. Cold and fresh anomalies dominated the properties in the deep Northeast Channel, reflective of a shift in the composition of source water entering the Gulf of Maine. In the western Gulf of Maine during spring, the entire water column was warmer and fresher than normal, including the Cold Intermediate Layer.

Introduction

The Northeast United States (NEUS) Continental Shelf extends from the southern tip of Nova Scotia, Canada, southwestward through the Gulf of Maine and the Middle Atlantic Bight, to Cape Hatteras, North Carolina (Fig. 1a). Contrasting water masses from the subtropical and subpolar gyres influence the hydrography in this region. Located at the downstream end of an extensive interconnected coastal boundary current system, the NEUS shelf is the direct recipient of cold/fresh arctic-origin water, accumulated coastal discharge and ice melt that has been advected thousands of kilometers around the boundary of the subpolar North Atlantic. Likewise, subtropical water masses, advected by the Gulf Stream, slope currents and associated eddies, also influence the composition of water masses within the NEUS shelf region. The western boundary currents of the subpolar and subtropical gyres respond to variations in basin-scale forcing through changes in position, volume transport and/or water mass composition and it is partly through these changes that basin-scale climate variability is communicated to the local NEUS shelf.

To first order, hydrographic conditions along the NEUS shelf are determined by the relative proportion of two main sources of water entering the region: cold/fresh arctic-origin water advected by the coastal boundary current from the north and warmer, more saline slope waters residing offshore of the shelf break. The source waters first enter the NEUS shelf region through the Gulf of Maine, a semi-enclosed shelf sea that is partially isolated from the open Northwest Atlantic by two shallow banks, Browns and Georges Banks. Below 100 meters, exchange between the Gulf of Maine and the deeper North Atlantic is restricted to a single deep channel, the Northeast Channel, which bisects the shelf between the two banks. This deep channel interrupts the continued flow of cold, fresh arctic-origin water along the slope, redirecting the majority of this flow into the Gulf of Maine. In the meantime, denser slope waters enter the basin through the same channel at depth, gradually spreading into a network of deep basins within the Gulf of Maine (Fig. 1b). In the upper layers of the Gulf of Maine, the shelf waters circulate counter-clockwise around the basin before continuing southwestward through the Middle-Atlantic Bight (Fig. 1b). The shelf water is progressively modified by atmospheric fluxes of heat and salt and through mixing with both deeper slope waters and the discharge of several local rivers. In this way, the Gulf of Maine represents the gateway to the NEUS shelf region, responsible for setting the initial hydrographic conditions for water masses entering the Middle Atlantic Bight further downstream.

The pronounced seasonal cycle of heating and cooling over the region drives seasonal variations in water mass composition that are typically larger than interannual variations. During fall and winter, intense cooling at the surface removes buoyancy, resulting in overturning and vertical homogenization of a significant portion of the water column. During spring and summer, surface heating re-stratifies the surface layer, isolating a remnant of the previous winter's cold/fresh mixed water at depth. In the Gulf of Maine, this remnant water mass is isolated at intermediate depths, bounded at the surface by the seasonal thermocline and at depth by warmer slope water masses. In the Middle Atlantic Bight where waters are shallower, this remnant water mass is trapped at the bottom, bounded at the surface by the seasonal thermocline. Variations in these seasonal processes (e.g. less cooling in winter or shifts in the timing of springtime warming) can result in interannual variations in the composition and distribution of water masses. In addition, fluctuations in the composition and volume of source waters entering the Gulf of Maine may also drive interannual variations in water properties relative to this seasonal mean picture.

The slope water that enters the Gulf of Maine is a mixture of two water masses: warm, saline, relatively nutrient-rich Warm Slope Water (WSLW) originating in the subtropics and cooler, fresher, relatively nutrient-poor Labrador Slope Water (LSLW) originating in the subpolar region. Seaward of the Gulf of Maine, the relative proportion of these two water masses varies over time. However, in general, the volume of each decreases with increasing along-slope distance from their respective sources; LSLW (WSLW) volume decreases from north to south (south to north). Decadal shifts in the position of the Gulf Stream appear to be closely tied to changes in slope water temperature offshore of the NEUS shelf and to the composition of slope water entering the Gulf of Maine (Davis et al., 2017). Cooling in the slope water offshore is accompanied by a southward shift in the Gulf Stream and a predominance of northern source water (LSLW) in the deep layers of the Northeast Channel.

Data and Methods

The U.S. National Oceanic and Atmospheric Administration's Northeast Fisheries Science Center (NEFSC) conducts multiple shelf-wide surveys every year in support of its mission to monitor the NEUS ecosystem. Monitoring efforts have been ongoing since 1977. The NEFSC aims to complete six full-shelf hydrographic surveys per year, in addition to several more regionally focused surveys – the minimum required to resolve the dominant seasonal cycle in this region. Reduced sea day allocations in 2023 eliminated the winter Ecosystem Monitoring (EcoMon) Survey and vessel maintenance issues led to the truncation of the spring Bottom Trawl Survey, resulting in a significant loss in seasonal resolution (Fig 2). Overall, roughly 20% of planned stations were left unsampled for the year, with notable gaps in the far northern (Gulf of Maine, Sep/Oct) and far southern (southern Middle Atlantic Bight, Nov/Dec) survey areas (Fig. 2a).

During 2023, hydrographic data were collected on 10 individual NEFSC cruises, amounting to 1142 profiles of temperature and salinity and 1048 in NAFO subareas 5 and 6 (Table 1). Data were collected aboard the NOAA *ships FSV Henry Bigelow, FSV Pisces, R/V Gloria Michelle*, in addition to the R/V *HR Sharp, F/V Saints and Angels and M/V Warren Jr.* using a combination of Seabird Electronics SBE-19+ SEACAT profilers and SBE 9/11 CTD units. Sampling covered spring, summer and fall seasons but was notably absent during winter (Fig 2). Cruise reports are accessible at: https://www.fisheries.noaa.gov/new-england-mid-atlantic/science-data/ecosystem-monitoring-northeast-us-continental-shelf-survey. Data are publicly available from the World Ocean Database maintained by NOAA's National Centers for Environmental Information and via an ERDDAP server maintained by NOAA's Northeast Fisheries Science Center at: https://comet.nefsc.noaa.gov/erddap/tabledap/ocdbs_v_erddap1.html

Absent fixed station observations, time series of surface and bottom temperature and salinity are constructed from area-weighted averages of profile data within five sub-regions spanning the Northeast U.S. Continental Shelf (Fig. 3). Anomalies are calculated relative to a reference annual cycle, defined by a harmonic fit to regional average temperature and salinity collected between 1991-2020. The reference period corresponds with the standard recommended by the World Meteorological Organization (WMO, 2021). Anomalies are defined as the difference between the observed 2023 value at an individual station and the expected value for each location and time of year based on the reference annual cycle, while regional anomalies are the area-weighted average of these anomalies within a given subarea. The methods used and an explanation of uncertainties are presented in Holzwarth and Mountain (1990).

Basin-Scale Conditions in 2023

Surface air temperatures over the western North Atlantic were colder than normal in November, February (Newfoundland and Labrador coastline) and in May and June (Northeast US Shelf, Fig. 4). During the rest of 2023, warm air temperature anomalies prevailed, with particularly warm anomalies prevalent in January, July and December. In January, the entire western North Atlantic was blanketed by extreme warm air temperature anomalies. Sea surface temperatures remain notably warm on the Northeast U.S. Shelf (Fig. 5), with annual average temperatures in 2023 measuring slightly cooler than the last 3 years but remaining in the top 10 warmest years since measurements began 1860. Sea surface temperature anomalies were largest during winter and summer, but warmer than the climatological mean in every season (Fig. 5).

The North Atlantic Oscillation (NAO) index measures the atmospheric sea level pressure difference between Iceland and the Azores and is considered an indicator of atmospheric conditions and oceanic response in the North Atlantic. The NAO has been related (with lags) to the intensity, frequency and pathway of storms crossing the North Atlantic; the intensity of westerly winds; the depth of convection and amount of sea ice in the Labrador Basin; the temperature and salinity of waters on the Canadian and U.S. continental shelves; and the position of the north wall of the Gulf Stream (e.g. Visbeck *et al.*, 2003; Petrie, 2007). The winter NAO index was weakly negative during 2022-23, reversing from a more strongly positive state in the preceding year (Fig. 6). The negative index was associated with a weakening of both the subpolar (Icelandic) low and of the subtropical (Azores) high, although action centers are shifted west of their typical positions (IROC, 2024). As is expected with a negative NAO, westerly winds at mid-latitudes were weaker across much of the North Atlantic and North Sea (IROC, 2024). While a negative NAO would normally predict warmer than average air temperatures over the Labrador Sea and cooler temperatures to the south over North America and over Europe, winter air temperature anomalies in 2023 were in fact warmer than normal along the entire east coast of North America and over Europe, with cold anomalies observed over a limited region in the Greenland Sea (IROC, 2024).

Hydrographic Conditions in 2023

Relative to historical values (1991-2020), regional ocean temperatures across the NEUS shelf were near normal during 2023 (Fig. 7). Annual average temperatures measured within 0.5 standard deviation (SD) of the 1991-2020 reference value at the sea surface and bottom in every region except the western Gulf of Maine, where temperatures were 1 SD above the reference mean (Fig. 7a). While this is the first time in more than 4 years that temperatures have returned to near-normal range across much of the NEUS shelf, there remains a statistically significant long-term warming trend in every region. Warming trends measure ~.03-.05 °C/year since 1977, with interannual variations superimposed on this trend (Fig. 7a). Warming trends are consistent from top to bottom in all regions and interannual variability is coherent, particularly in the Middle Atlantic Bight where water depths are shallower than in the Gulf of Maine (Fig. 7a). Shelf-wide, the average temperature observed in the upper 30-meters in 2023 was 0.6 SD, continuing a period of anomalously warm years that stretches back to 2012 (Fig. 7b).

Relative to the annual cycle, regional average temperatures measured near the long-term mean over much of the shelf (Fig. 8a). Notable differences were in Spring in the northern and southern Middle Atlantic Bight, when temperatures were more than 1 SD above the reference temperature, and Fall in the northern Middle Atlantic Bight, when temperatures were more than 1 SD below the reference temperature. Surface temperature records from an NDBC buoy located south of Nantucket Shoals, corroborate the cold temperatures observed during Fall in the shipboard observations (Fig. 9). Records show that surface temperatures were 2-3 C warmer than the long-term mean from January through August, but then dropped suddenly in mid-September and remained cold until the end of October before returning to reference values and remaining there through the end of the year. The cold anomalies observed at the surface during fall reached an impressive 3 C in late-September to early-October (Fig. 9). Cold anomalies were also observed near the bottom during early-November in the northern Middle Atlantic Bight, suggesting that the cold event penetrated the water column (Fig. 8b). Elsewhere, bottom temperatures were warm to near-normal, with significant warming (> 1 SD) observed in the western Gulf of Maine during spring, summer and fall and during spring and summer in the Middle Atlantic Bight (Fig. 8b). Synoptic maps from the fall NEFSC Groundfish Survey show that the cooler regional averages are reflective of cold anomalies extending along the outer shelf between Georges Bank and 72W near the surface and from the Northeast Channel to 72 W near the bottom (Fig 10). In contrast, waters over the mid- and inner-shelf were notably warm across then entire southern Middle Atlantic Bight region (Fig. 10).

On average, waters at the sea surface and bottom were fresher than normal in 2023, particularly in the north, measuring up to 1.5 SD fresher than the reference salinity near the surface in the Gulf of Maine and 1 SD fresher in the Middle Atlantic Bight (Fig. 11a). Shelf-wide, the average salinity observed in the upper 30-meters in 2023 was -0.9 SD, representing the first fresh conditions to be observed since 2011 (Fig. 11b). Similar patterns were observed near the bottom, with fresher conditions observed in 2023 in the Gulf of Maine (> 0.5 SD) and northern Middle Atlantic Bight (1 SD) (Fig. 11a & 11c). In fact, the fresh conditions observed in the eastern Gulf of Maine represent the first of their kind since 2008 (Fig 11c). The fresh conditions in the deep Gulf of Maine reflect trends observed in the deep Northeast Channel, where salinities between 150-200 meters were slightly fresh in 2023 relative to the reference period, representing only the second time fresh conditions have been observed since 2010 (Fig 11c).

Relative to the annual cycle, large negative salinity anomalies were observed during August and October/November in the Gulf of Maine and northern Middle Atlantic Bight (Fig. 12a). Salinity anomalies in the upper 30 meters measured up to 1.2 units fresher than the long-term average in these regions and were coincident with cold anomalies (Fig. 8a and 9). Similar patterns were observed near the bottom, with freshening concentrated in October/November in these same regions (Fig. 12b). Synoptic maps from the fall NEFSC Groundfish Survey show that fresh conditions were pervasive across the Northeast Shelf, encompassing the surface of the Gulf of Maine and northern Middle Atlantic Bight and extending southwest along the outer shelf in the southern Middle Atlantic Bight (Fig. 13). The strongest negative anomalies were observed in Northeast Channel and along the outer shelf, tracing the predominant advective pathways in this region. Near the bottom, fresh anomalies also dominate, with the largest anomalies concentrated in the northern Middle Atlantic Bight (Fig. 13). The fresh anomalies at surface and bottom were coincident with enhanced cold anomalies (Fig. 10) and appear to be associated with a pulse of Scotian shelf water flooding the region from the north. These patterns are also reflected in the properties of deep waters within the Northeast Channel – a primary conduit for source waters entering the Gulf of Maine – and suggestive of an apparent departure from the dominance of warm and salty slope water sources to the region (Fig. 14). Maps of sea surface temperature constructed from satellite observations provide spatial and temporal context for the fall cooling and freshening, showing cold water flooding into the Gulf of Maine in September with a tongue protruding southwest along the shelf edge (Fig. 15). In fact, the coldest waters extend well offshore of the shelfbreak suggesting that the event involved a significant pulse of northern source water. This is consistent with observations further north showing the volume transport along the Scotian Slope, south of the Grand Banks, was above normal for the first time in a decade (Cyr, et al. 2024).

While the largest fresh anomalies were observed during fall in the Gulf of Maine, fresh conditions were also observed earlier in the year. Springtime temperature-salinity and temperature-depth profiles from June indicate that freshening was present throughout the water column in the western Gulf of Maine and accompanied by uniform warming (Fig. 16 & 17). As a result, the Cold Intermediate layer, a mid-depth water mass formed seasonally as a product of convective mixing driven by winter cooling, was slightly warmer and much fresher than climatology (Fig. 16). Composite vertical sections of temperature and salinity from June 2023 along an east-west transect crossing the Gulf of Maine show that freshening extended from the western boundary up to 250 km into the central basin, while colder/fresher water was observed in the upper 100 m at the entrance to the Northeast channel (Fig. 18).

Impacts

The habitats of fish and invertebrate species on the Northeast U.S. Shelf continue to experience change on a variety of temporal and spatial scales. In situ observations collected since 1977 continue to show that the Northeast U.S. Continental Shelf is warming at a rate of ~.03-.05 °C/year. However, significant seasonal to interannual variations are superimposed on this trend, and annual average temperatures throughout the region in 2023 were close to the climatological mean. More notably, waters on the Northeast U.S. Shelf were anomalously fresh in 2023 relative to the previous two decades. While recent observations have suggested that the NEUS Continental Shelf is being influenced more frequently by the Gulf Stream (Gawarkiewicz et al., 2018) with increased interactions leading to more warm and salty water influencing the shelf (Silver et al., 2023; Gawarkiewicz et al., 2022), it appears that northern sources like the Labrador Current were more influential to the regional hydrography in 2023. This is corroborated by observations that the transport of northern source waters south of the Grand Banks of Newfoundland increased in 2023 (Cyr, et al., 2024). In general, large interannual variations have the potential to cause significant changes in the ecosystem, leading to changes in nutrient loading on the shelf, changes in community structure and species diversity, the seasonal elimination of critical habitats and the disruption of seasonal migration cues.

Summary

- On average, waters on the Northeast U.S. Continental Shelf were anomalously fresh and slightly warmer than the climatological mean.
- Notable cold and fresh anomalies were observed throughout the Gulf of Maine and northern MAB during Fall, likely caused by advection of Scotian Shelf Water from the north.
- Cold and fresh anomalies dominated the properties in the deep Northeast Channel, reflective of a shift in the composition of source water entering the deep Gulf of Maine
- In the western Gulf of Maine, the entire water column was warmer and fresher than normal including the Cold Intermediate Layer

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INVENTORY OF ALL CTD SURVEYS, 2023

Sub-area	Division(s)	Month(s)[1]	Type of survey[2]	Nature of survey	No. of sets
4	X	6	S	Ecosystems monitoring survey	23
4	X	8	S	Ecosystems monitoring survey	22
4	X	10,11	S	Bottom trawl survey	16
4	X	11	S	Ecosystems monitoring survey	21
5	Y,Z	4	O	North Atlantic Right Whale Prey Studies	11
5	Y,Z	5	S	Bottom trawl survey	72
5	Y,Z	5,6	O	North Atlantic Right Whale	16
5	Y,Z	6	O	Sea scallop survey	1
5	Y,Z	9	O	North Atlantic Right Whale	14
5	Y,Z	6	S	Ecosystems monitoring survey	169
5	Y,Z	8	S	Ecosystems monitoring survey	128
5	Y,Z	10,11	S	Bottom trawl survey	176
5	Y,Z	10,11	S	Ecosystems monitoring survey	118
5	Y,Z	11	O	North Atlantic Right Whale Prey Studies	4
6	A,B,C	6	S	Ecosystems monitoring survey	63
6	A,B,C	8	S	Ecosystems monitoring survey	64
6	A,B,C	9,10	S	Bottom trawl survey	143
6	A,B,C	10,11	S	Ecosystems monitoring survey	69

[1] 1 to 12 for month. [2] S indicates stratified-random survey design and O indicates 'other'.

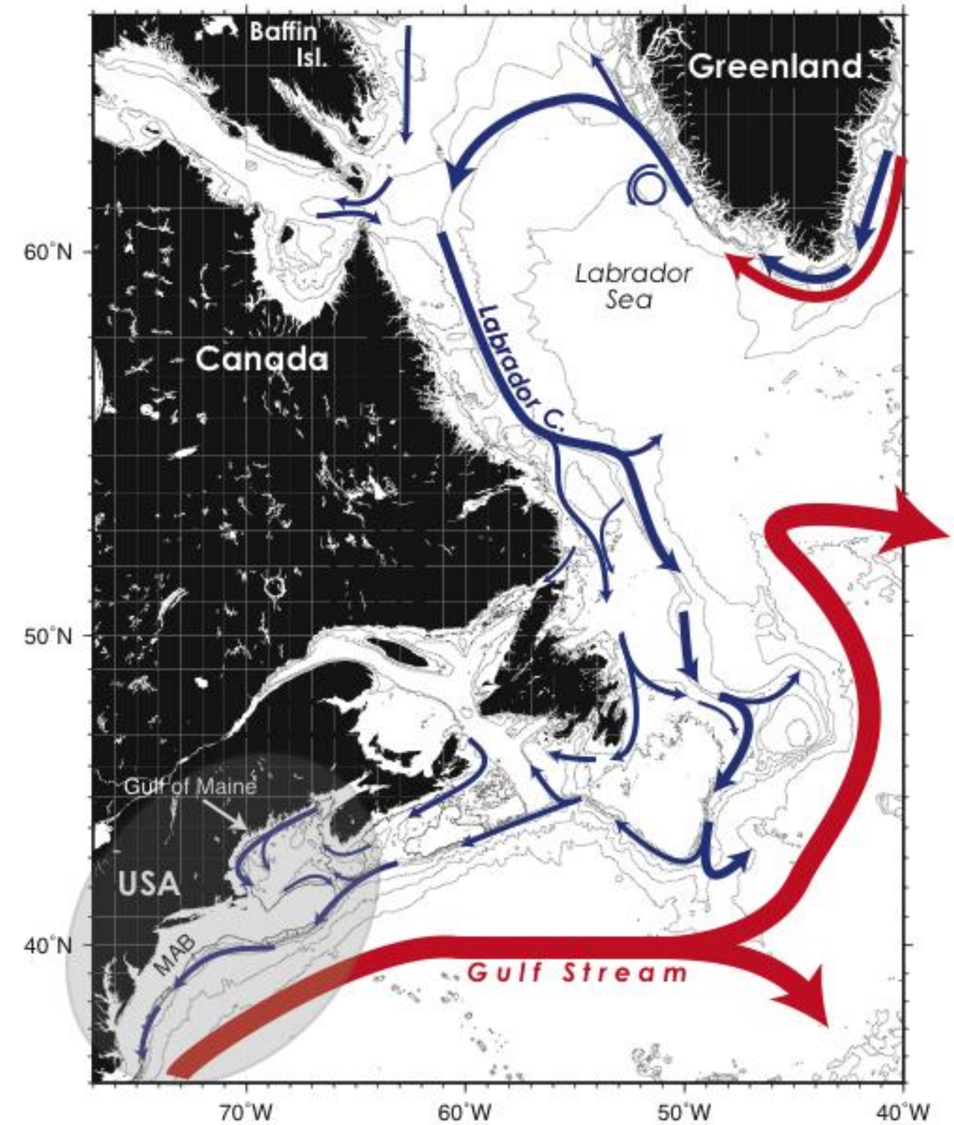


Figure 1a. Circulation schematic of the western North Atlantic. The Northeast U.S. Shelf region is identified by the shaded oval. The 100, 200, 500, 1000, 2000, 3000 and 4000 meter isobaths are shown.

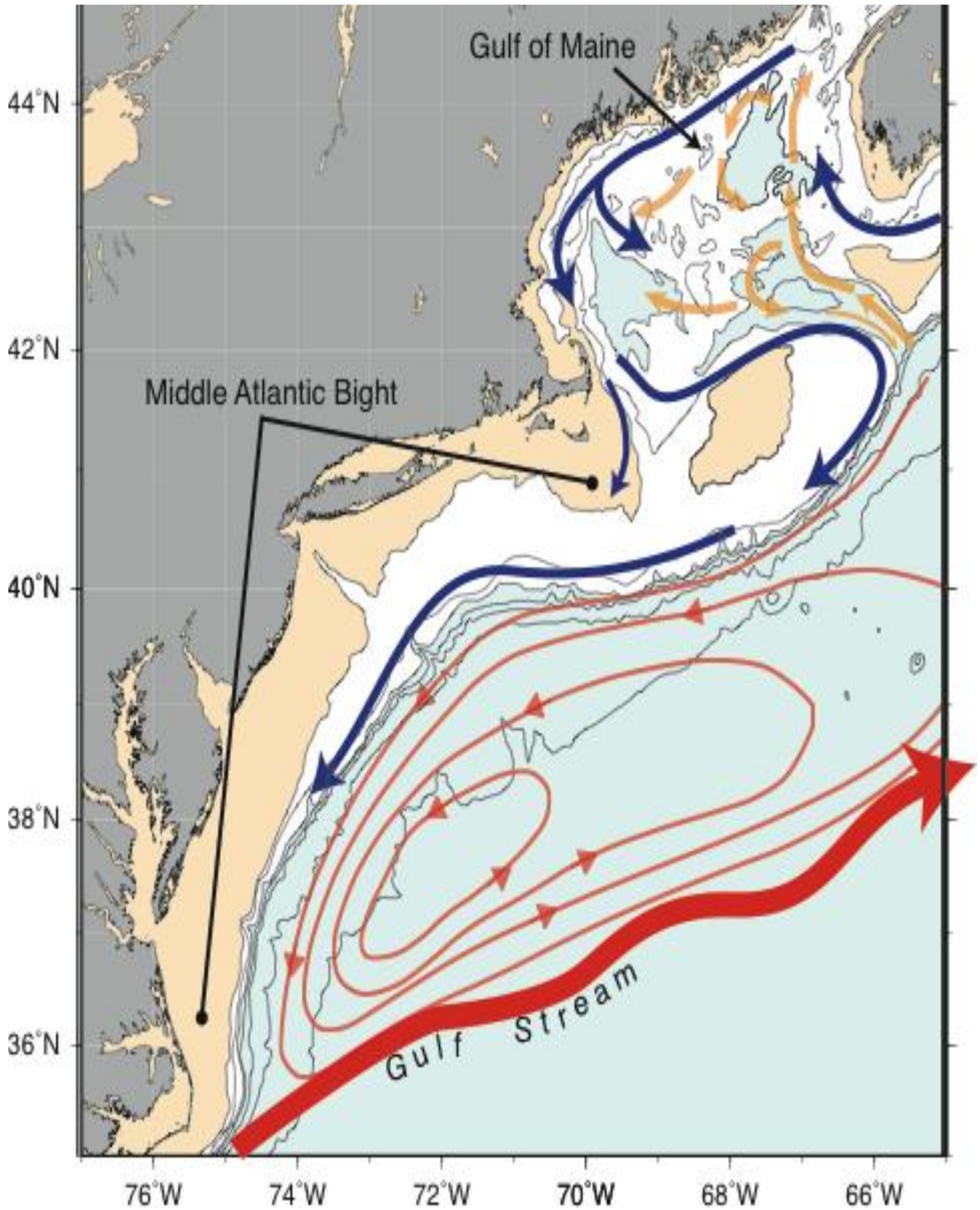


Figure 1b. Circulation schematic for the Northeast U.S. Shelf region, where blue arrows represent shelf water circulation and orange arrows represent deeper slope water circulation pathways. Water depths deeper than 200 meters are shaded blue. Water depths shallower than 50 meters are shaded tan.

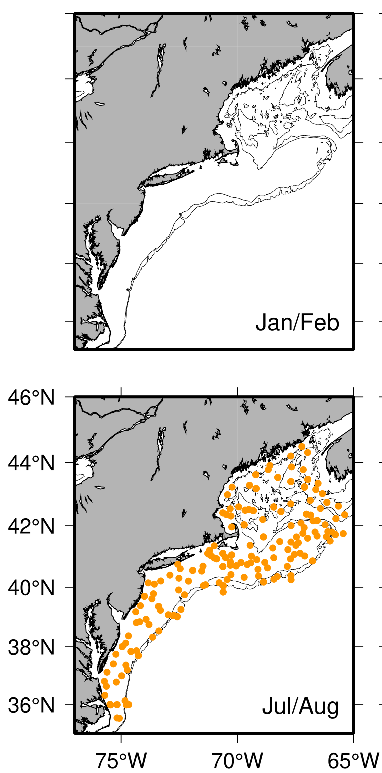


Figure 2a. Distribution of hydrographic stations occupied in 2023. Contours show the 100 m and 200 m isobaths.

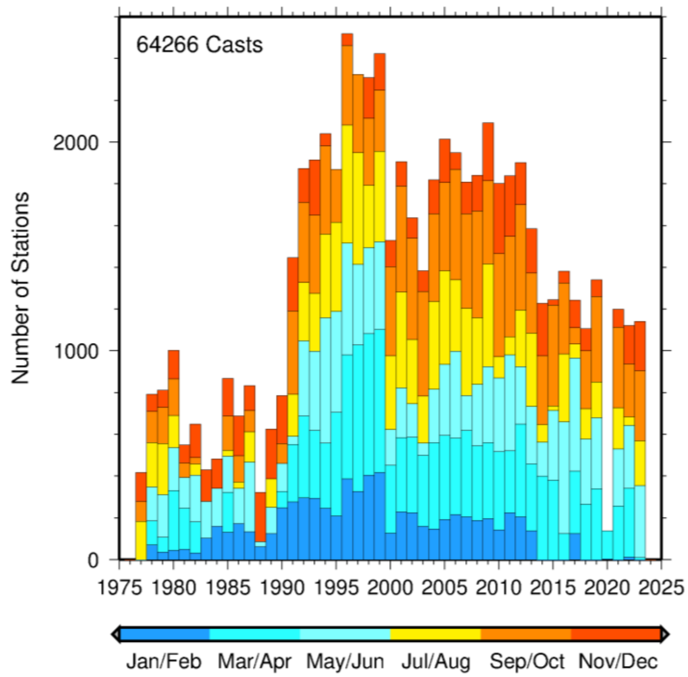


Figure 2b. Histogram of hydrographic stations sampled as part of NEFSC operational oceanography programs as a function of year and season.

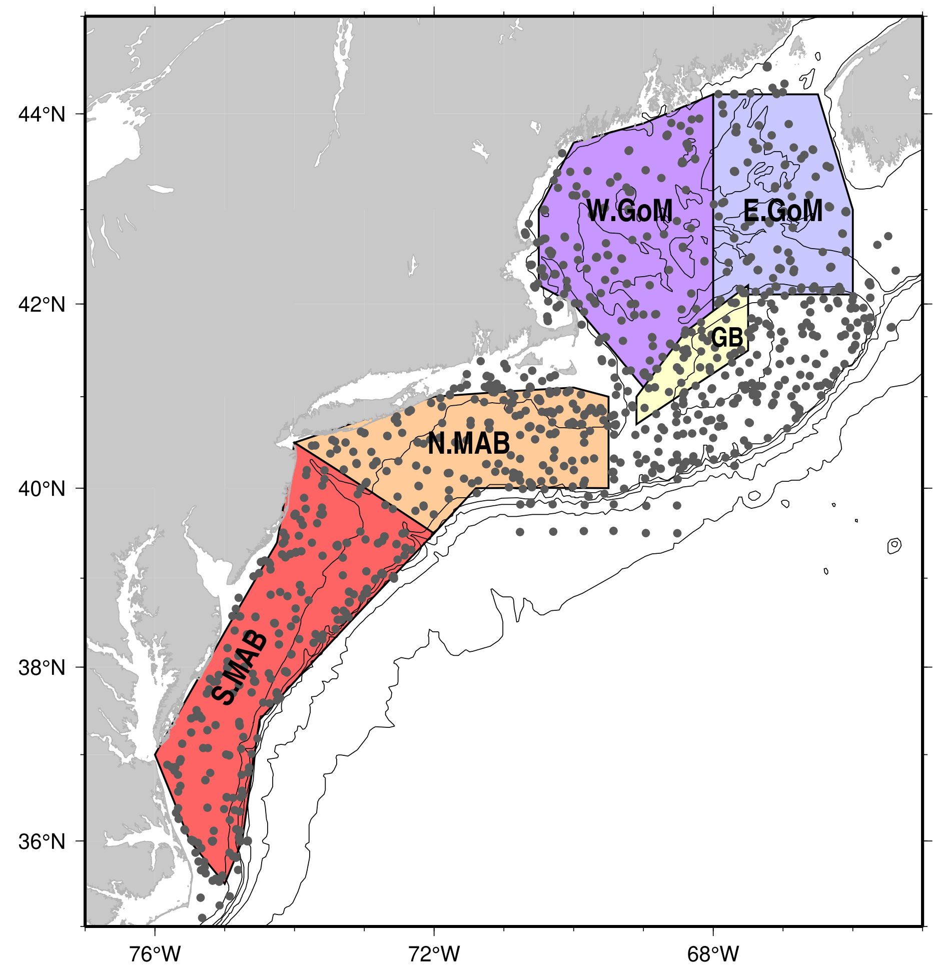


Figure 3. Hydrographic sampling conducted in 2023 by NOAA's Northeast Fisheries Science Center (circles). The colored polygons denote regional polygons used to calculate regional average conditions, corresponding to the Southern Middle Atlantic Bight (SMAB), Northern Middle Atlantic Bight (NMAB), northwest Georges Bank (GB), Western Gulf of Maine (WGOM) and Eastern Gulf of Maine (EGOM). Depth contours or shown for the 50, 200, 500, 1000, 2000, and 3000-meter isobaths.

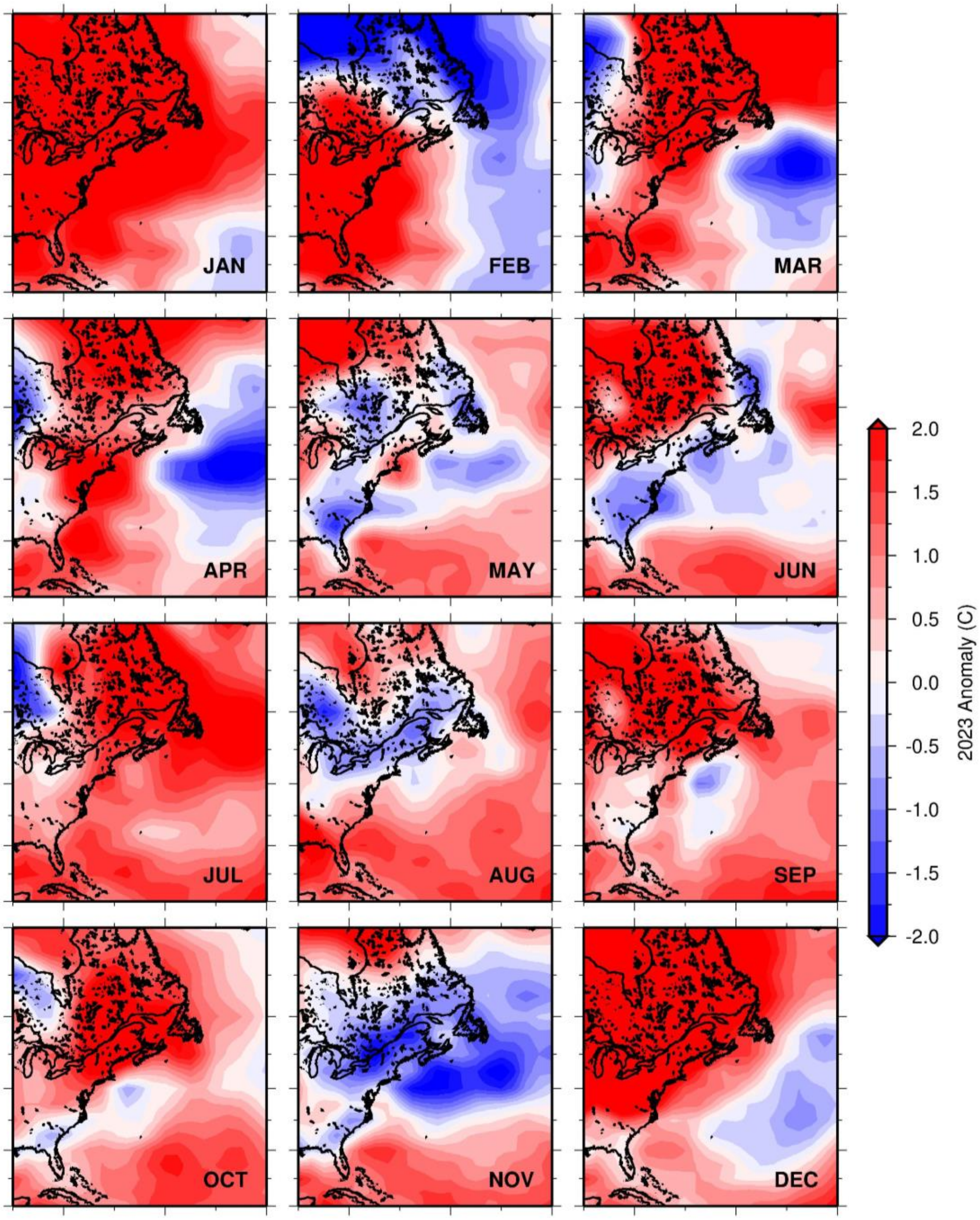
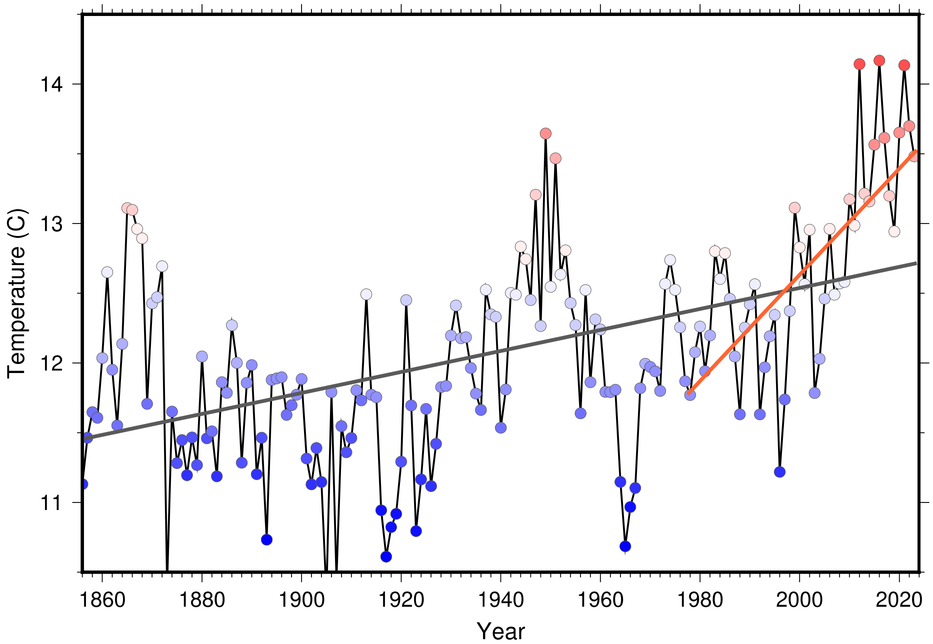


Figure 4. Surface air temperature anomaly derived from the NCEP/NCAR Reanalysis product (http://www.esrl.noaa.gov/psd/data/composites/day/). Positive anomalies correspond to warming in 2023 relative to the reference period (1991-2020).



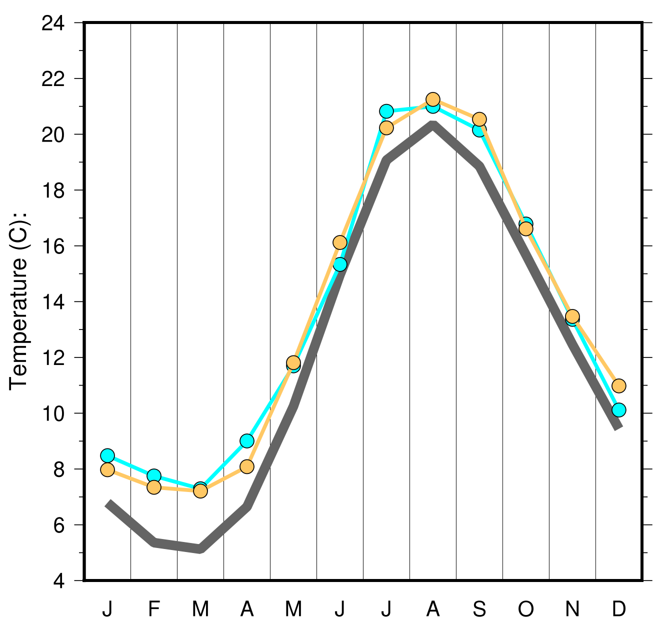


Figure 5. Top: Regional average annual sea surface temperature for the NEUS shelf region calculated from NOAA's extended reconstructed sea surface temperature product (http://www.esrl.noaa.gov/psd/data/gridded/data.noaa.ersst.html). Colors correspond with the anomaly scale in Figure 4. Bottom: Regional average monthly mean SST for the NEUS shelf for 2023 (cyan), 1951 (orange) and 1991-2020 (gray) calculated from the same product.

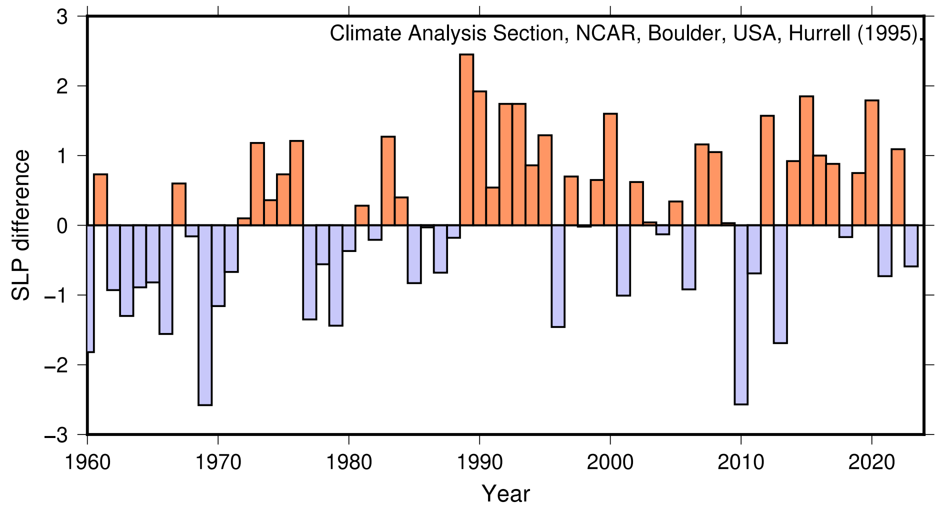


Figure 6. North Atlantic Oscillation index computed from principal component analysis of sea level pressure in the North Atlantic (see Hurrell, 1995).

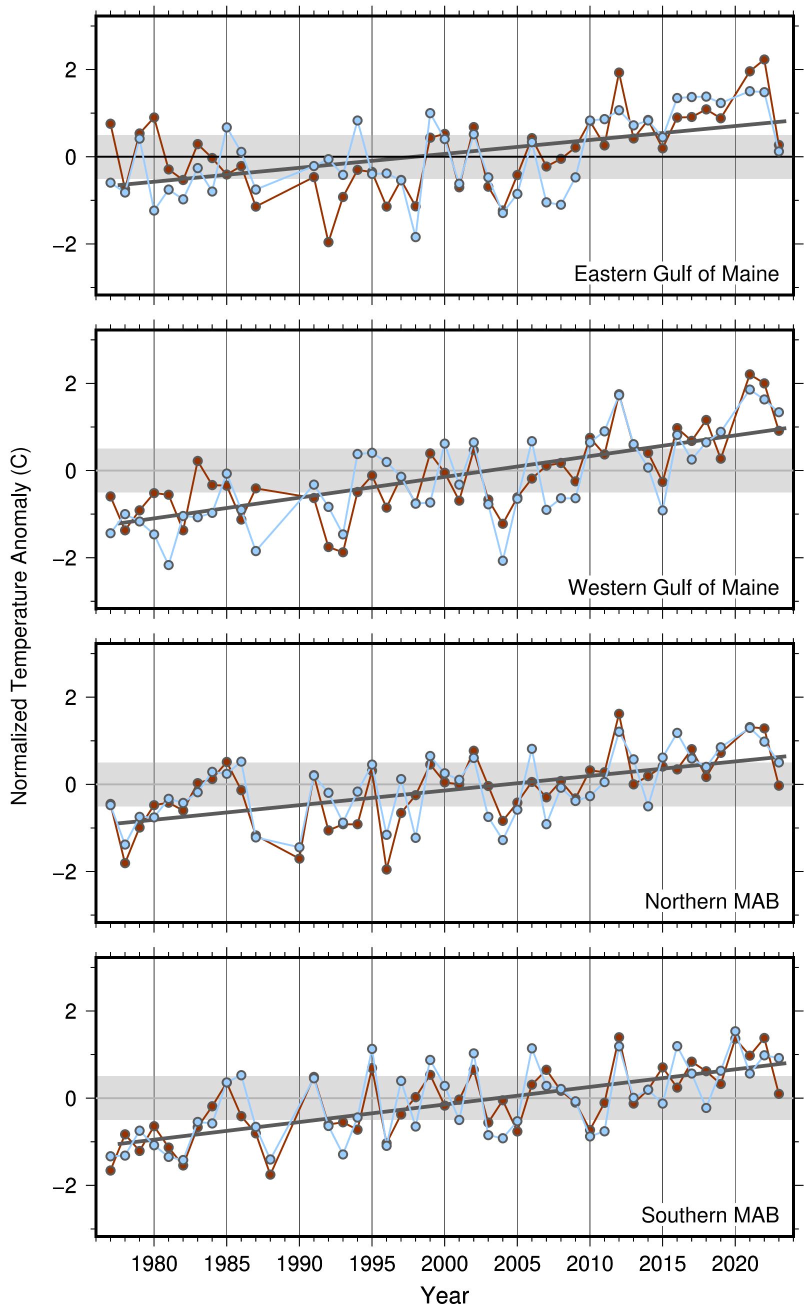


Figure 7a. Time series of surface (red) and bottom (blue) regional annual average normalized sea temperature anomaly (°C). Positive anomalies correspond to warming relative to the reference period (1991-2020). Gray line shows the temporal trend based on linear regression where significance is confirmed based on p-value ≤ 0.05. Gray shading indicates the normalized anomalies falling within 0.5 standard deviation of the reference value.

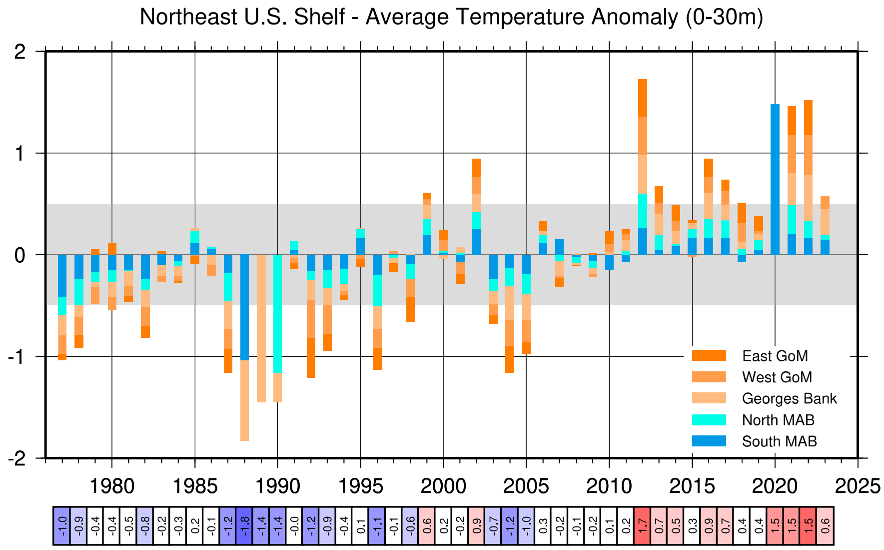


Figure 7b. Normalized annual sea temperature anomaly for the upper 30 meters of the Northeast U.S. Shelf, inclusive of the eastern and western Gulf of Maine, Georges Bank, and northern and southern Middle Atlantic Bight. The bars show the average of the five regions, where the length of each bar corresponds to the relative contribution of each regional anomaly to the shelf-wide average. Positive anomalies correspond to warmer conditions relative to the reference period (1991-2020). Regions are as identified in Fig. 3. The magnitude of the anomaly for each year is reported in the color-coded scorecard at the bottom of the figure. Positive anomalies (>0.5 SD) are colored red while negative anomalies (<0.5 SD) are colored blue. Darker colors correspond with stronger anomalies and white corresponds with the climatological average, within +/- 0.5 SD.

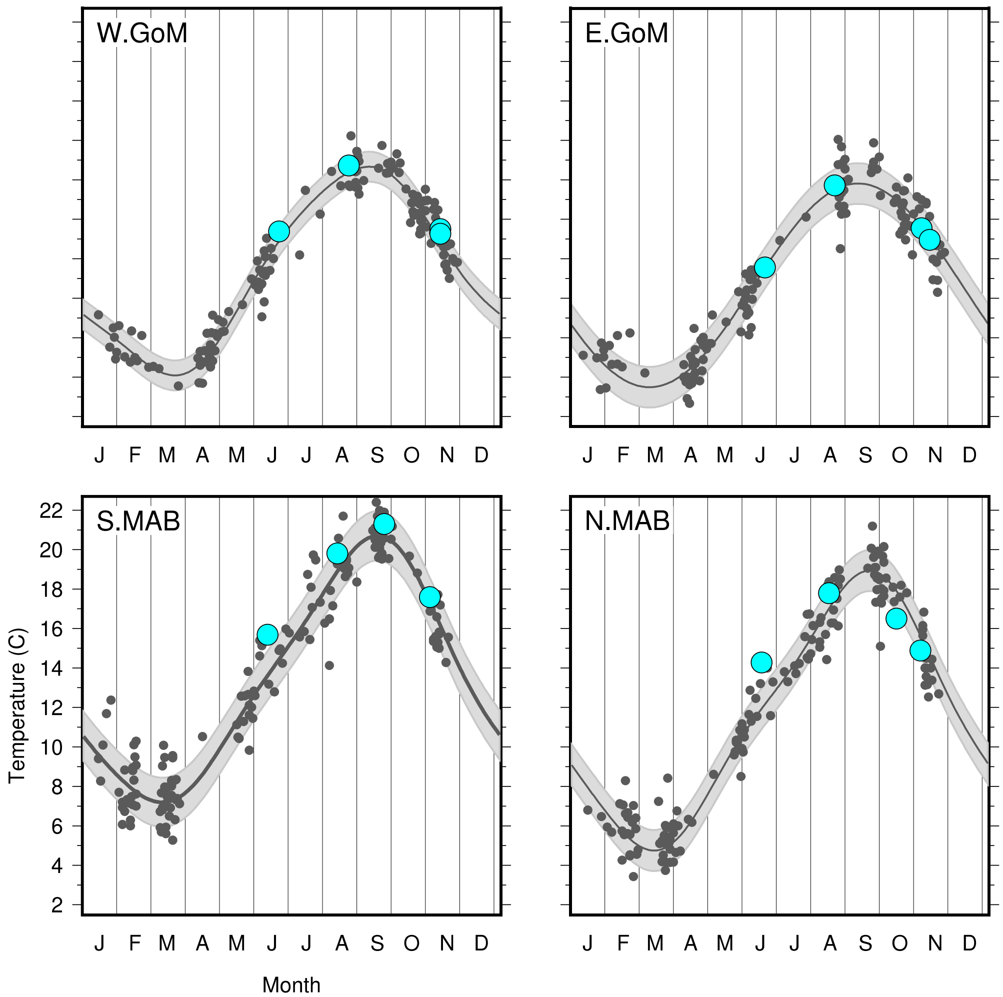


Figure 8a. Regional average 0-30 meter temperature (°C) as a function of calendar day for the western and eastern Gulf of Maine (top panels) and the southern and northern Middle Atlantic Bight (bottom panels). Each dot represents a volume-weighted average of all observations from a single survey falling within the regions defined in Fig. 3. An annual harmonic fit to the regional average temperatures from 1991-2020 is shown by the gray curve with the points contributing to the fit also shown in gray. The shading depicts one standard deviation around this fit. The regional average temperatures from 2023 surveys are shown in cyan.

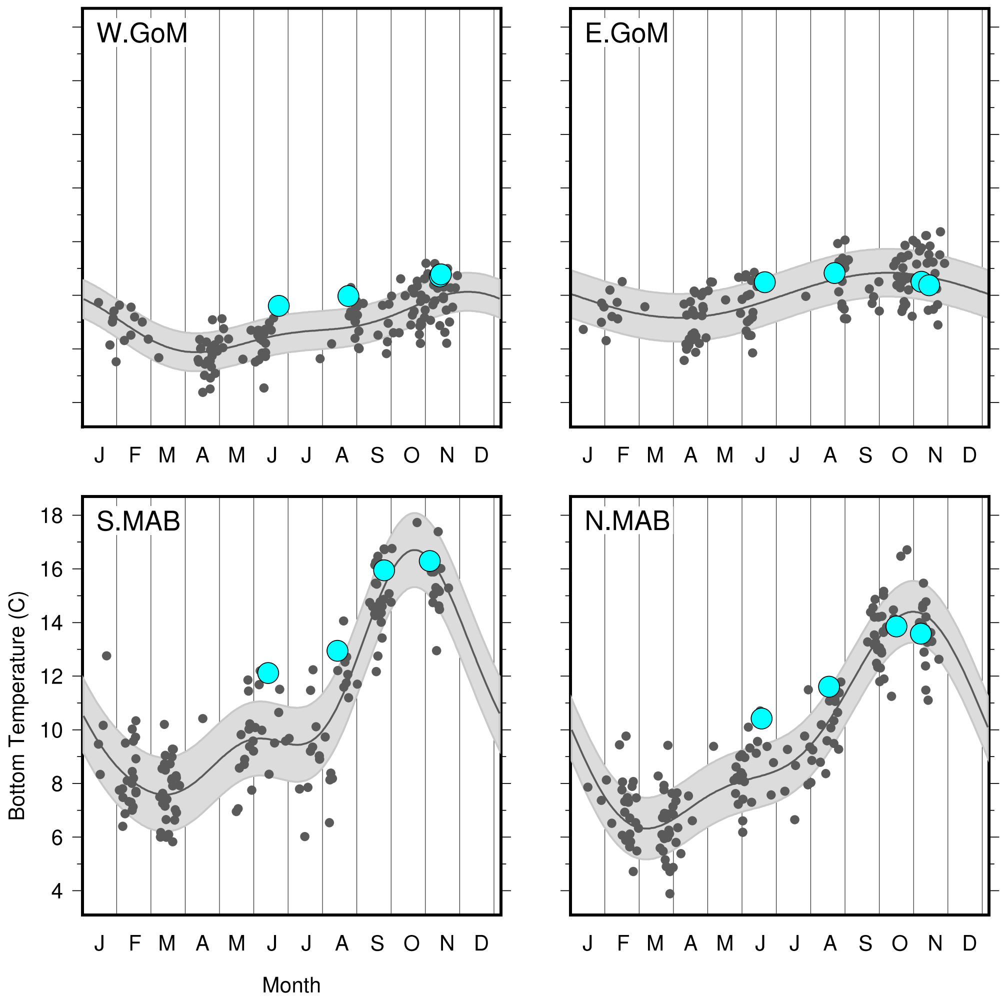


Figure 8b. As in Fig. 8a, but for bottom temperatures.

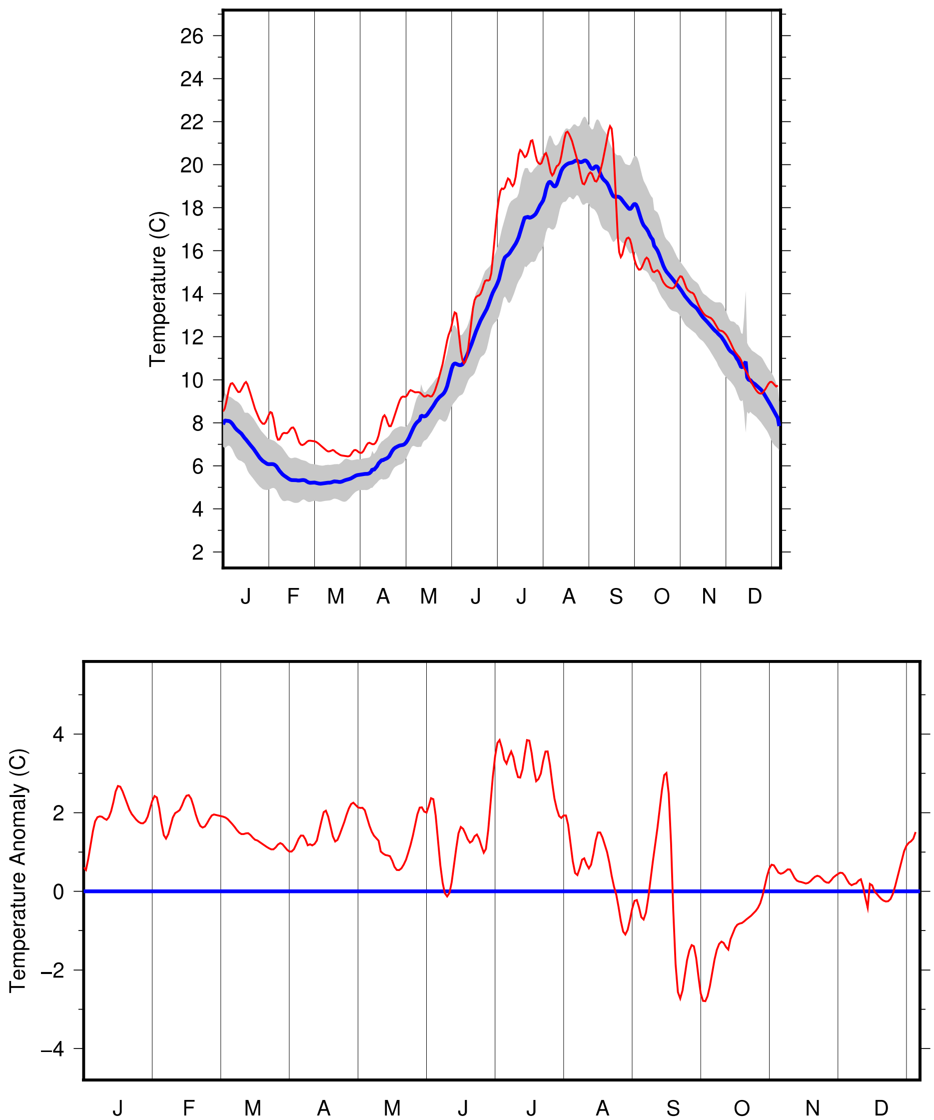


Figure 9. (top) Time series of surface ocean temperature from NDBC buoy 44008 located south of Nantucket Shoals in the northern Middle Atlantic Bight. Temperatures observed in 2023 (red) are compared with average temperatures (1991-2020, blue) in the top panel. The gray shading indicates one standard deviation about the long-term mean. The lower panel shows the difference between 2023 and the long-term mean temperature, where positive values indicate warmer conditions in 2023.

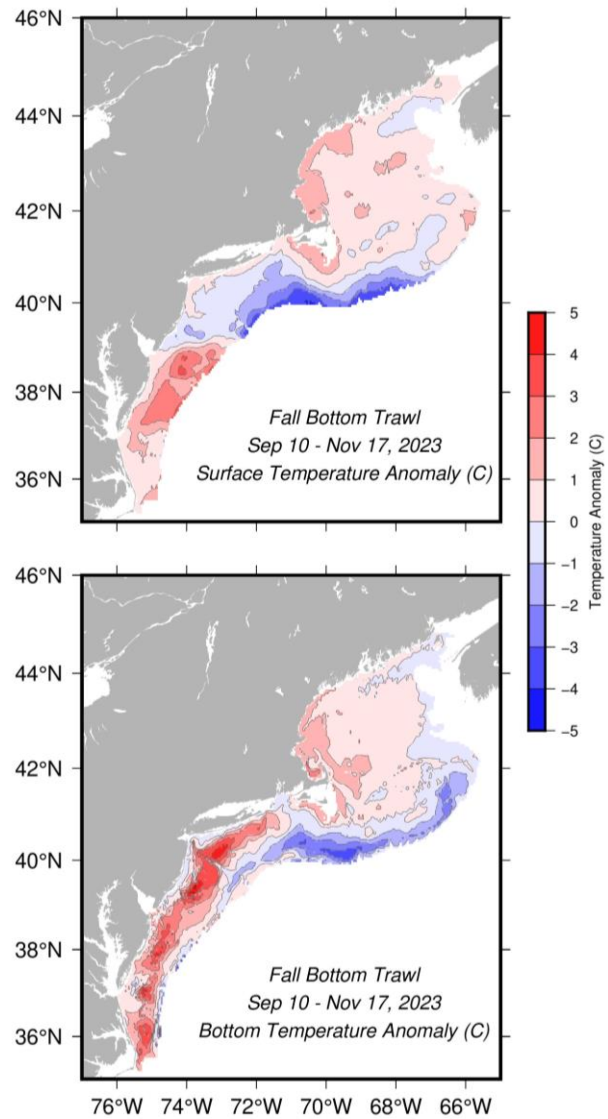


Figure 10. Surface (upper panels) and bottom (lower panels) temperature anomaly from the Fall 2023 ground fish surveys. Contour interval is 1 C. Positive anomalies correspond to warming in 2023 relative to the reference period (1991-2020).

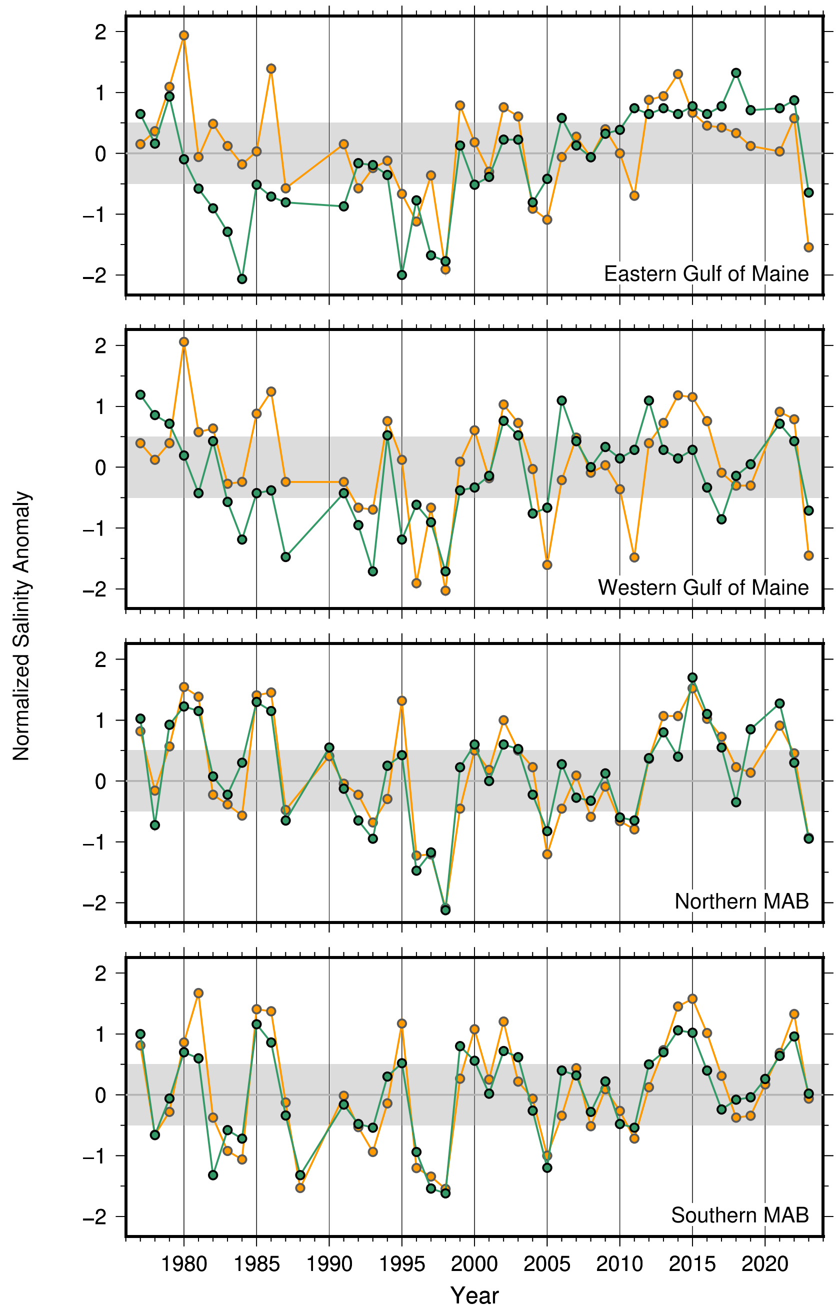


Figure 11a. Time series of surface (orange) and bottom (green) normalized annual average sea salinity anomaly. Positive anomalies correspond to more saline conditions relative to the reference period (1991-2020). Gray shading indicates the normalized anomalies falling within +/-0.5 standard deviation of the climatological average.

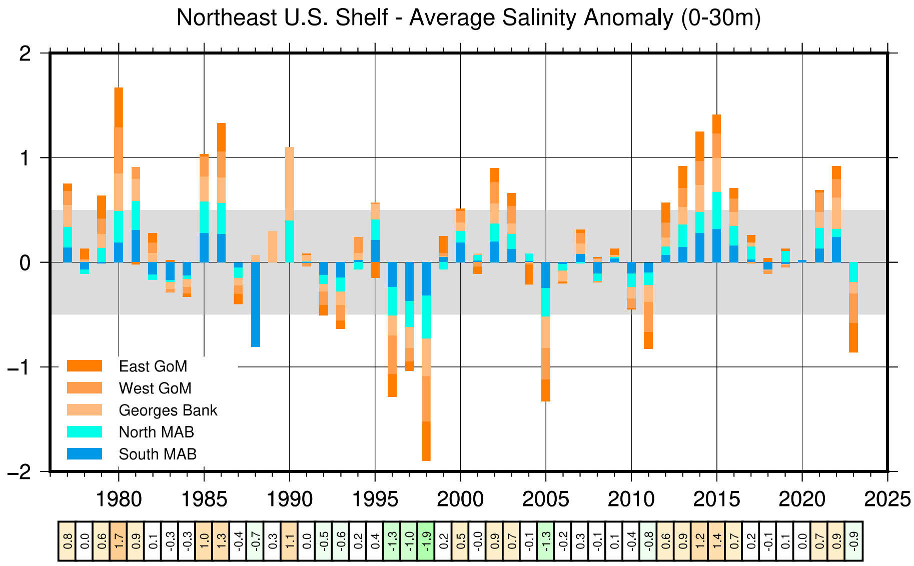


Figure 11b. Normalized annual salinity anomaly for the upper 30 meters of the Northeast U.S. Shelf (upper panel, incorporating the Gulf of Maine, Middle Atlantic Bight and Georges Bank regions). The bars show the relative contribution of each regional anomaly to the average. Positive anomalies correspond to more saline conditions relative to the reference period (1991-2020). The magnitude of the anomaly for each year is reported in the color-coded scorecard at the bottom of the panels. Positive anomalies (>0.5 SD) are colored orange while negative anomalies (<0.5 SD) are colored green. Darker colors correspond with stronger anomalies and white corresponds with the climatological average, within +/- 0.5 SD.

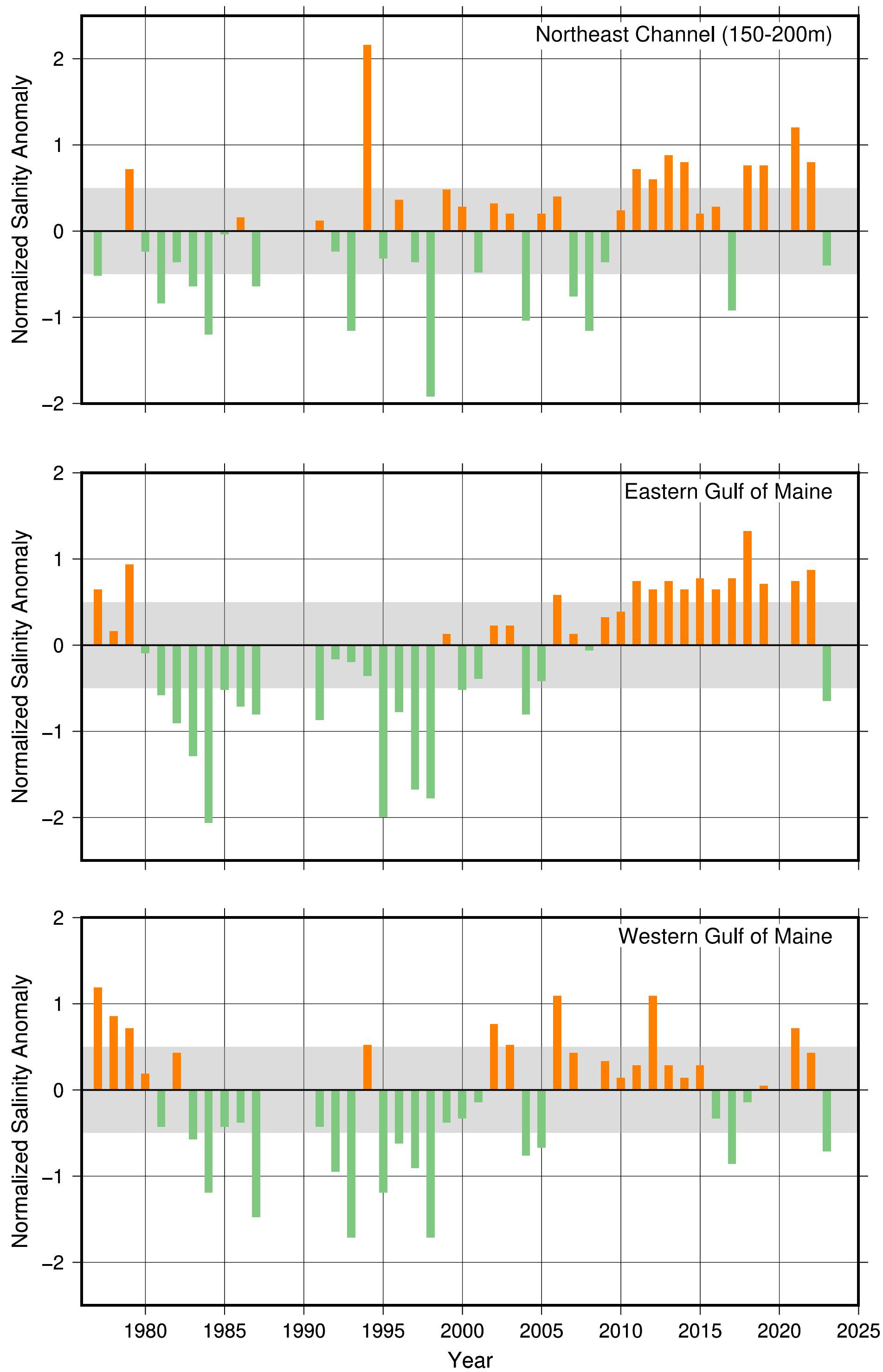


Figure 11c. Normalized annual salinity anomaly in the deep Northeast Channel (top panel) and near the seafloor for the eastern (middle panel) and western (lower panel) Gulf of Maine.

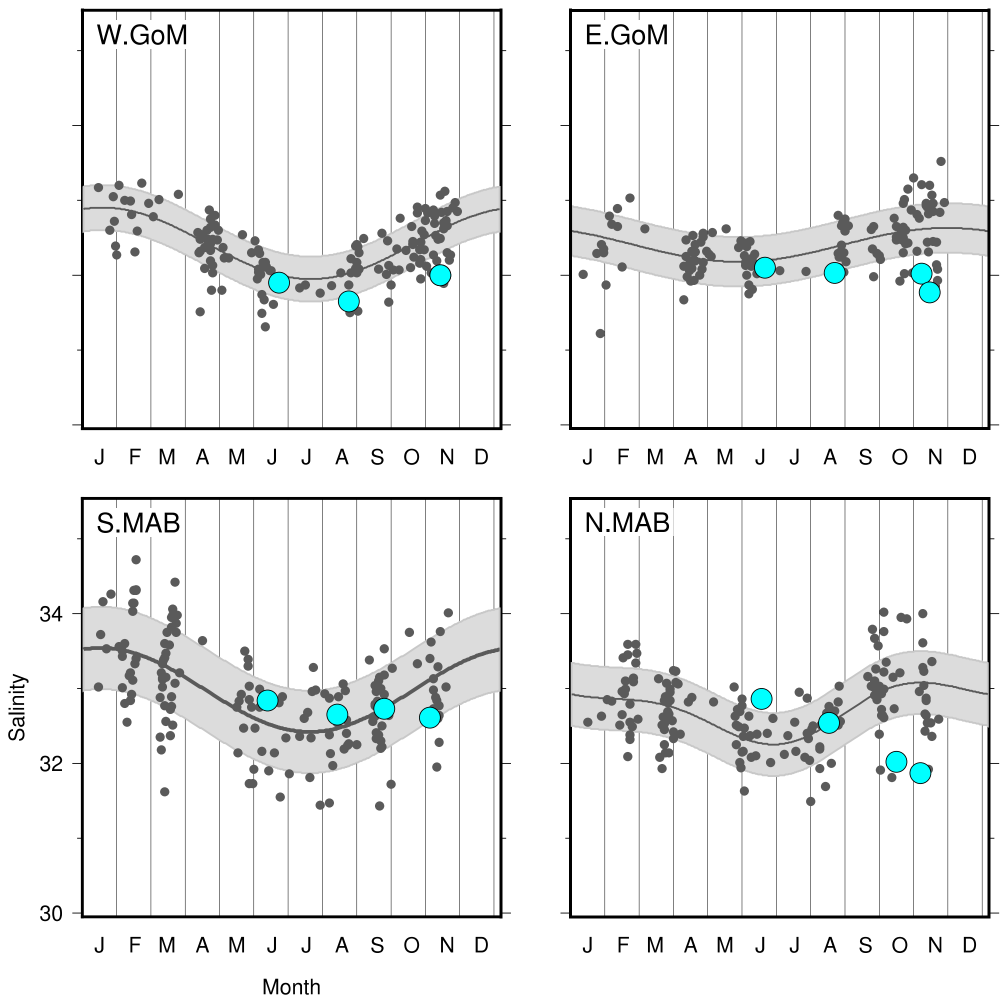


Figure 12a. Regional average 0-30 meter salinity as a function of calendar day for the western and eastern Gulf of Maine (top panels) and the southern and northern Middle Atlantic Bight (bottom panels). Each dot represents a volume-weighted average of all observations from a single survey falling within the regions defined in Fig. 3. An annual harmonic fit to the regional average salinities from 1991-2020 is shown by the gray curve with the points contributing to the fit also shown in gray. The shading depicts one standard deviation around this fit. The regional average salinities from 2023 surveys are shown in cyan.

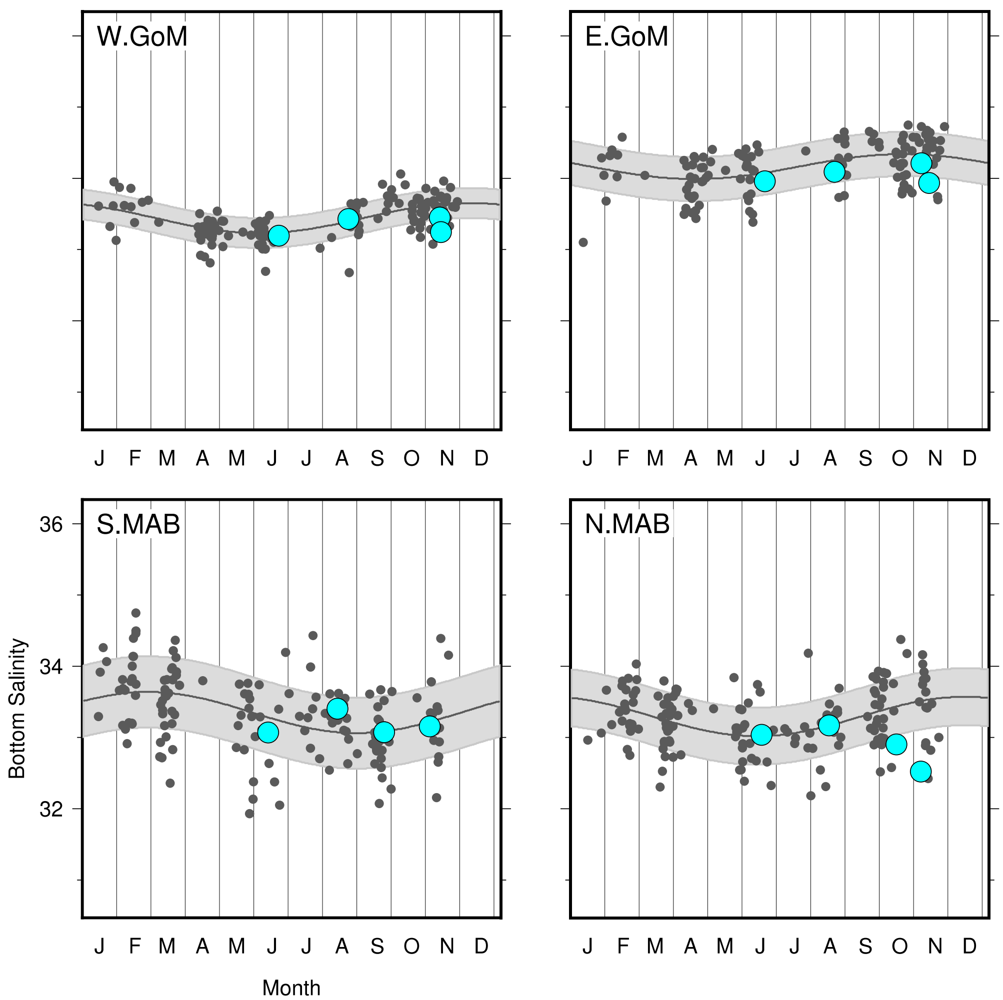


Figure 12b. As in Fig. 12a, but for bottom salinities.

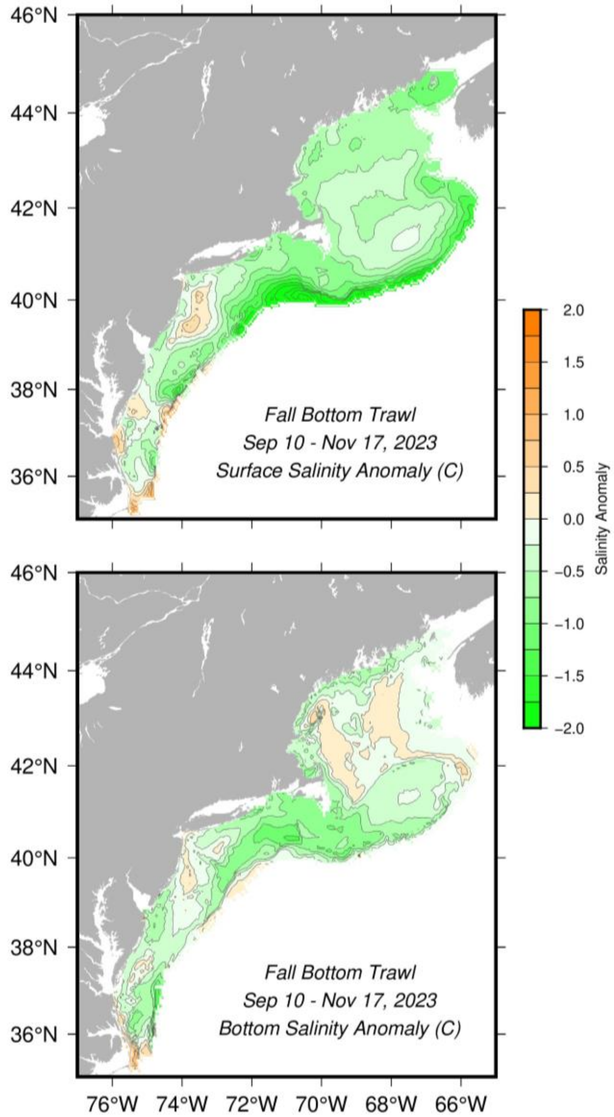


Figure 13. Surface (upper panels) and bottom (lower panels) salinity anomaly from the Fall 2023 ground fish survey. Contour interval is 0.25 psu. Negative anomalies correspond to less saline conditions in 2023 relative to the reference period (1991-2020).

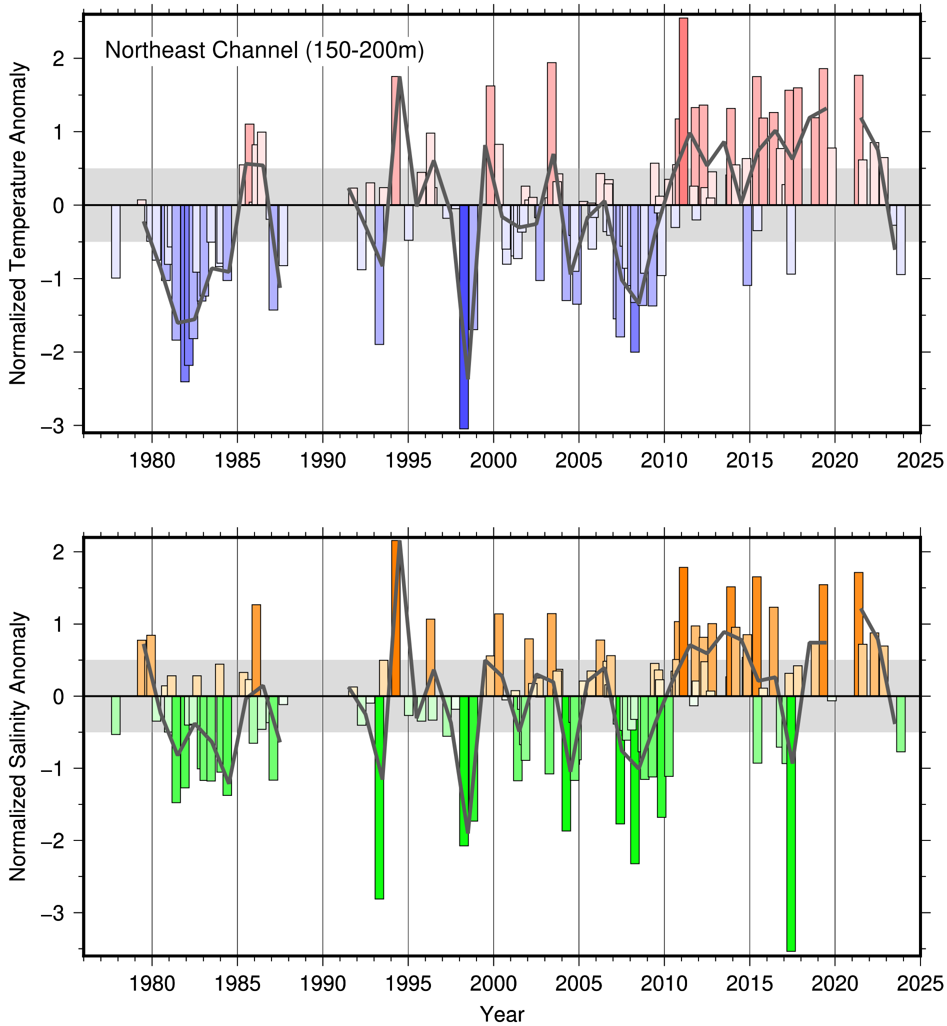


Figure 14. Time series of normalized temperature and salinity anomaly in the deep Northeast Channel. Each bar represents a volume-weighted average of all observations from a single survey collected between 150-200 meters in the Northeast Channel. The grey curve shows the annual average anomaly time series. Positive values are warmer and saltier than the long-term mean calculated for 1991-2020. The gray shading shows the envelope wherein anomalies are within +/- 0.5 standard deviation of the climatological average.

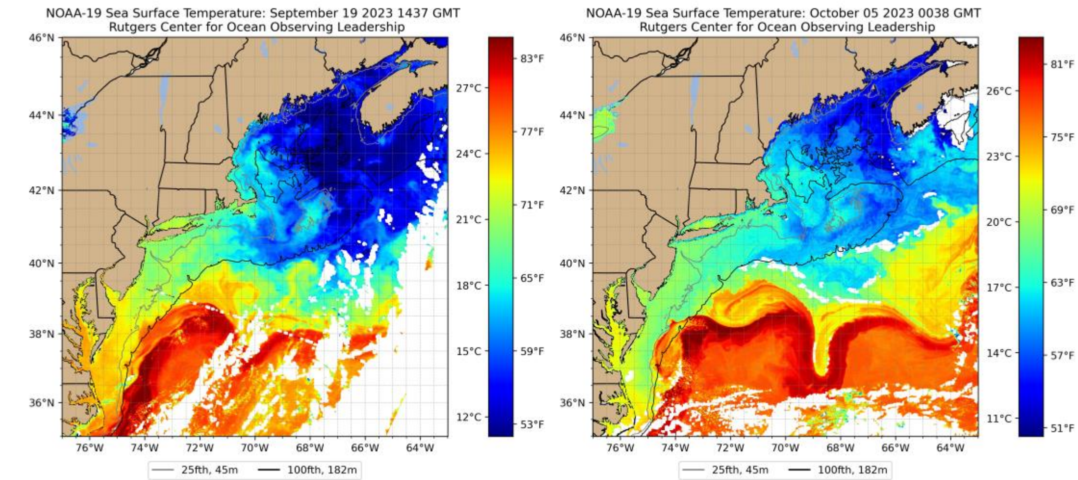


Figure 15. Daily composite sea surface temperature derived by the Rutgers University Coastal Ocean Observations Laboratory produced from data collected by NOAA's Advanced Very High-Resolution Radiometer on September 19, 2023 (left) and October 5, 2023 (right).

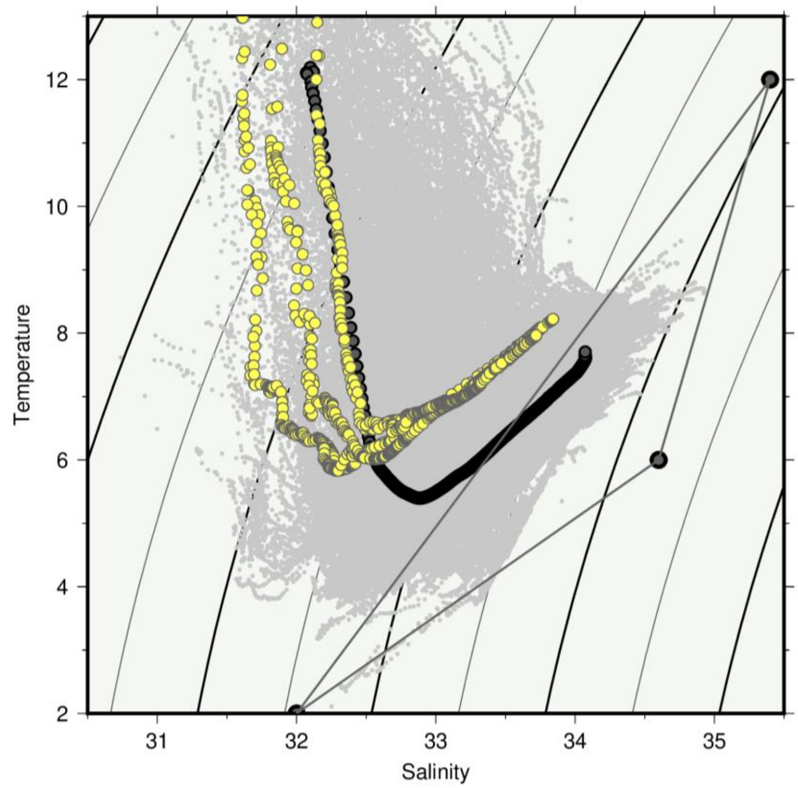


Figure 16. Temperature-salinity diagram showing water properties in Wilkinson Basin in the western Gulf of Maine. All observations from June (yellow) 2023 are shown along with the spring climatological average profile (1991-2020, dark gray). The lightest gray dots show the historical range encompassed by observations from the reference period, 1991-2020. Temperature and salinity properties representative of source waters entering the Gulf of Maine are shown by the mixing triangle.

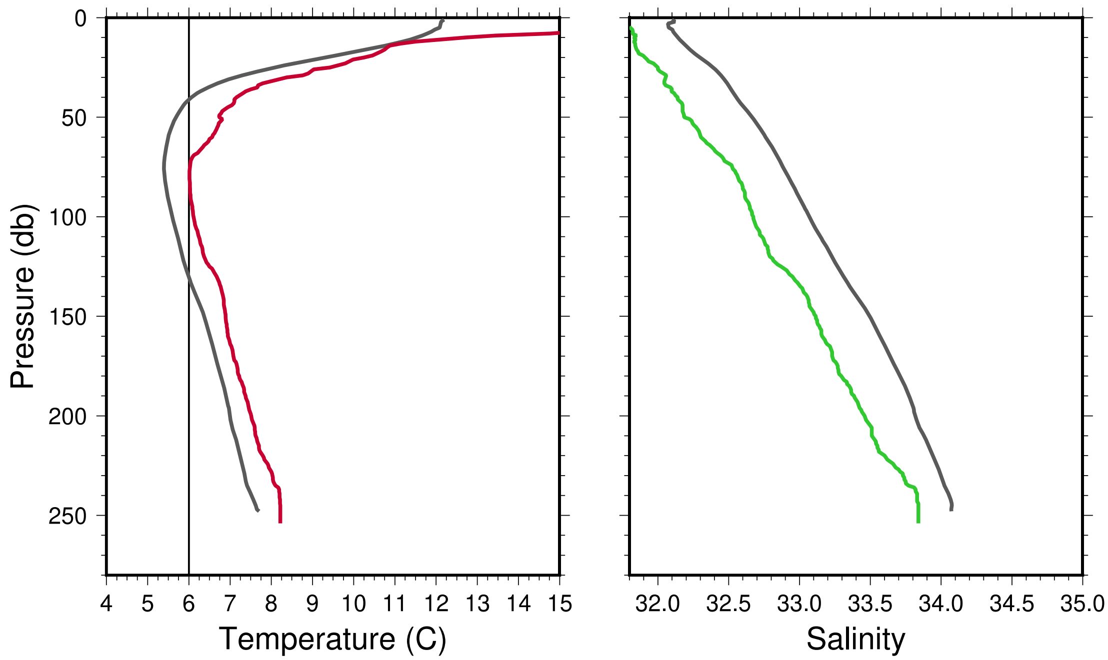


Figure 17. Average profiles of temperature (left) and salinity (right) from repeated observations collected during June in Wilkinson Basin in the western Gulf of Maine. All observations from June 2023 (red and green) are shown along with the climatological average profile for the same month (1991-2020, dark gray). Waters in the Cold Intermediate Layer in the western Gulf of Maine are typically colder than 6°C, denoted by the vertical line.

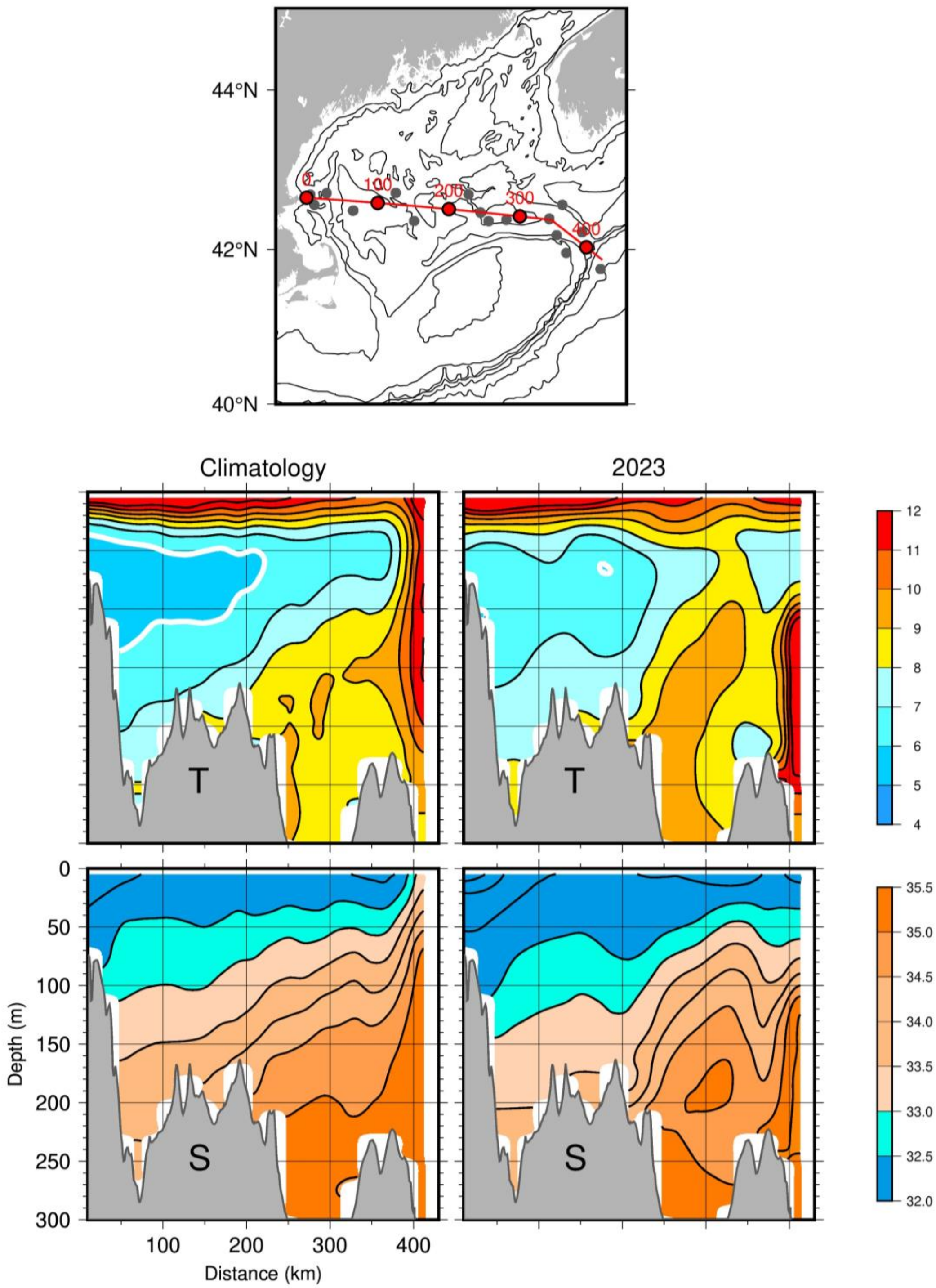


Figure 18. Vertical sections of temperature (top) and salinity (bottom) crossing the Gulf of Maine along a zonal transect shown in the map. The left panels show the climatological average for June spanning the years 1991-2020. The right panels show the synoptic mean section for June 2023. The heavy white contour highlights the 6°C isotherm as an indicator of the boundary of the Cold Intermediate Layer. Along-transect distances and the June 2023 station distribution are shown on the map for reference.