



Northeast Fisheries Science Center Reference Document 26-14

Description of Oceanographic Conditions on the Northeast US Continental Shelf during 2024

August 2026



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Editorial Notes

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ABSTRACT

An overview is presented of the oceanographic conditions on the Northeast U.S. Continental Shelf during 2024. 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 significantly fresher in 2024 relative to the 1991–2020 climatological mean condition. While fresh anomalies were observed throughout the region, freshening was most pronounced in the Middle Atlantic Bight and in the upper layers in the Gulf of Maine. While cold and fresh anomalies were also observed in the deep Northeast Channel for the second year in a row, conditions in the deep basins of the Gulf of Maine downstream of this inflow suggest that the freshening observed in 2024 did not result directly from this deep inflow. Notably, the deep waters were near normal to slightly warm, and the salinity was saltier than the climatological average. Together, this suggests that the freshening observed on the Northeast U.S. Shelf reflects a shift in source water contributions to the region in 2024, with Scotian Shelf Water dominating slope water sources.

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 (NOAA'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. In 2024, unexpected vessel repairs and vessel staffing delays led to a loss of sea days and truncation of the winter, spring and summer EcoMon surveys, resulting in reduced seasonal resolution (Fig 2). Overall, roughly 10% of planned stations were left unsampled for the year, with notable gaps throughout the Northeast U.S. Shelf in the winter, in the Gulf of Maine during March/April, on Georges Bank and southern Gulf of Maine in November/December, and in the Middle Atlantic Bight during July/August (Fig. 2a).

During 2024, hydrographic data were collected on 15 individual NEFSC cruises, totaling 1,487 profiles of temperature and salinity and 1,172 profiles falling within the NEUS shelf region (Table 1). Data were collected aboard the NOAA ships *FSV Henry Bigelow*, *FSV Pisces*, *R/V Gloria Michelle*, in addition to the *F/V Saints and Angels*, *F/V Dyrsten*, *M/V Joseph E. Pearce*, and *M/V Eagle Eye II* using a combination of Seabird Electronics SBE-19+ SEACAT profilers and SBE 9/11 Conductivity Temperature Depth (CTD) units. Sampling covered spring, summer and fall seasons but was limited during winter (Fig 2).

All NEFSC CTD measurements are subject to rigorous quality control protocols following community standards (Melrose et al., 2026). In brief, CTD data are processed using software provided by the manufacturer (Seabird Scientific Inc.), with steps applied to ensure sensor alignment, factory calibrations are applied and measurements are within expected ranges. Measurements are bin-averaged to 1-decibar resolution and profiles are visually inspected for inversions and spikes. The up or down cast data are chosen depending on which is cleanest and based on the deployment method (Melrose et al., 2026). Obviously bad measurements are flagged with a reversible QC flag. Water samples collected at sea are analyzed and used to apply corrections to conductivity.

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 NEFSC at: https://comet.nefsc.noaa.gov/erddap/tabledap/ocdbs_v_erddap1.html

The hydrographic conditions over the Northeast U.S. Shelf vary significantly on seasonal timescales, particularly temperature. As such, any attempt to resolve year-to-year changes requires that this seasonal variability be quantified and removed to avoid bias. This process is complicated by the fact that the majority of NEFSC hydrographic surveys conform to a random stratified sampling design, meaning that stations are not repeated at fixed locations year after year so that variability cannot be assessed at fixed station locations. Instead, time series of *in situ* 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). Near-surface and near-bottom temperature and salinity are examined within each region, defined as the shallowest measurement made within 5 meters of the surface and the deepest measurement made within 10 meters of the bottom for each profile respectively. An area-weighted average temperature and salinity is calculated for each survey in the database using all of the observations falling within a given regional polygon. The result of this calculation is a time series of regional average surface and bottom temperature and salinity having a temporal resolution that matches the survey frequency in the database. To remove the seasonal variability, a reference annual cycle is defined for each sub-region by fitting an annual harmonic with a 365-day period to the collection of regional average observations collected between 1991–2020. The reference period corresponds with the standard recommended by the World Meteorological Organization (WMO, 2021). The anomaly time series is calculated as the difference between each regional mean temperature and salinity in the time series and the expected temperature or salinity as predicted by the reference annual cycle for the corresponding time of the year. Annual anomalies are averages of the anomalies across the year and a final normalized anomaly is reported by dividing the anomaly time series by the standard deviation calculated for the reference annual cycle fit. In some cases, we report anomalies as calculated in the upper 30 meters of the water column as an indicator of water column variability. In this case, a volume-weighted average temperature and salinity replaces the area-weighted average described above.

Observations made as part of the fall and spring NEFSC Ground fish Survey provide spatial context to the regional average anomalies described above. In this case, the observations from a single survey are treated as synoptic and anomalies are calculated on a station by station basis before mapping their distribution. Surface and bottom temperature for all available NEFSC CTD profiles collected between 1991 and 2020 were interpolated onto a 0.05-degree latitude and longitude grid using ordinary kriging. The results for all cruises were fitted to a sinusoidal seasonal cycle model (Mountain 1989) to allow daily climatological values to be estimated for each grid location. The spring and fall trawl survey temperature data were interpolated to the same 0.05-degree grid. The climatological

values at each grid location and interpolated sampling date were subtracted from the interpolated survey temperature data to produce corresponding anomaly grids.

Gridded reanalysis products describing basin-scale atmospheric and oceanographic conditions are presented as context for the interpretation of regional *in situ* observations. Monthly maps of surface air temperature anomaly calculated relative to the 1991–2020 reference period are extracted from the NCEP-NCAR Reanalysis product (Kulnay et al., 1996) provided by NOAA Physical Sciences Laboratory (PSL, <https://psl.noaa.gov>). A timeseries of regional average sea surface temperature is calculated by spatially averaging observations falling within the NEUS shelf region from NOAA’s global monthly Extended Reconstructed Sea Surface Temperature dataset (Huang et al., 2017), provided by NOAA PSL (<https://psl.noaa.gov>). Finally, the principal component-based index of the North Atlantic Oscillation (NAO) produced by NCAR’s climate Analysis Section (Hurrell, 2003) is used to track the variability in Sea Level Pressure patterns over the North Atlantic.

RESULTS

Basin-Scale Conditions in 2024

Warm surface air temperatures prevailed over most of the western North Atlantic through the majority of 2024 (Fig. 4). Isolated cold anomalies were observed during spring and fall, while the entire region was blanketed by very warm anomalies in March. Sea surface temperatures remain notably warm on the Northeast U.S. Shelf (Fig. 5), with annual average temperatures in 2024 measuring slightly cooler than the last 4 years but remaining in the top 11 warmest years since measurements began 1860. Consistent with air temperature patterns, sea surface temperature anomalies were largest during the spring transition (March–June), 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 2023–24, following from a more strongly negative state in 2023 (Fig. 6). The negative index was associated with a weakening of both the subpolar (Icelandic) low and of the subtropical (Azores) high, and the action centers for the low-pressure anomaly were shifted northeast of their typical positions (IROC, 2025). As is expected with a negative NAO, some weakening of the westerly winds was observed at mid-latitudes over the east coast of the

U.S. and Canada. However, wind speeds were in fact stronger than average over almost the entire southern North Atlantic, driven by a cyclonic anomaly in the south (IROC, 2025). 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, winter air temperature anomalies in 2024 were in fact warmer than normal along the entire east coast of North America (IROC, 2025).

Hydrographic Conditions in 2024

Temperature

Relative to historical values (1991–2020), regional ocean temperatures across the NEUS shelf were warmer than normal during 2024 (Fig. 7). Annual average temperatures measured more than 0.5 standard deviation (SD) warmer than the 1991–2020 reference value at the sea surface and bottom in every region except in the eastern Gulf of Maine, where near bottom temperatures were near normal (Fig. 7a). Surface temperature anomalies were warmest in the Gulf of Maine, approaching 2 SD and warm anomalies penetrated the water column in the Middle Atlantic Bight, with similar magnitudes observed at the surface and bottom. A statistically significant long-term warming trend is observed in every region, measuring $\sim 0.03\text{--}0.05$ °C/year since 1977 (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 2024 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 upper ocean temperatures in 2024 measured near the long-term mean over much of the shelf (Fig. 8a). Notable differences were in August in the eastern Gulf of Maine and northern Middle Atlantic Bight and in fall in the northern and southern Middle Atlantic Bight, when temperatures were more than 1 SD above/below the reference temperature. Surface temperature records from an NDBC buoy located south of Nantucket Shoals, corroborate the anomalously warm temperatures observed in the upper water column during summer in the shipboard observations (Fig. 9) and the enhanced warming observed during the spring transition as observed in satellite derived SST records (Fig. 5). Records show that surface temperatures were 2° C warmer than the long-term mean from May through September. Significant warm anomalies (> 1SD) were also observed near the bottom in the western Gulf of Maine during April, June and August and during October and November in the northern Middle Atlantic Bight (Fig. 8b). Elsewhere, bottom temperatures were warm to near-normal (Fig. 8b). Synoptic maps from the spring NEFSC Ground Fish Survey show that the warmer regional averages are reflective of warm conditions that encompass the entire shelf, except in a narrow band

along the outer shelf where cooler anomalies prevail (Fig 10). In contrast, the distribution of temperature anomalies during fall shows greater spatial variation, with warm anomalies observed in the northern Middle Atlantic Bight and western Gulf of Maine and cold anomalies in the southern Middle Atlantic Bight and along the outer shelf edge offshore of Georges Bank and in the bottom waters within the eastern Gulf of Maine (Fig. 10).

Salinity

On average, waters at the sea surface and bottom were fresher than normal in 2024, particularly in the north, measuring up to 1.5–2.0 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 normalized annual salinity anomaly for the upper 30 meters in 2024 measured -1.5 SD, representing a significant freshening over the anomalous conditions observed in the previous year (Fig. 11b). Fresh anomalies of similar scale were observed near the bottom in the Middle Atlantic Bight (~1.0 SD, Fig. 11a). However, bottom waters in the Gulf of Maine were less fresh in 2024 than 2023, suggesting that the enhanced freshening observed in the upper layers did not result from changes in the composition of slope water entering the Gulf of Maine (Fig. 11c). Indeed, deep inflow through the Northeast Channel was slightly fresh in 2024 (<0.5 SD), with anomalies of similar magnitude to those observed in 2023 (Fig 11c).

Relative to the annual cycle, large negative salinity anomalies (> 1 SD) were observed in the upper water column throughout 2024 in the Gulf of Maine and during winter and early spring in the northern Middle Atlantic Bight (Fig. 12a). Salinity anomalies in the upper 30 meters measured up to 1.5 units fresher than the long-term average in these regions (Fig. 12a). Some freshening was also observed near the bottom in the Middle Atlantic Bight, suggesting that the anomalous conditions observed during spring penetrated the water column in these regions (Fig. 12b). Synoptic maps from the spring NEFSC Ground fish Survey show that fresh conditions were pervasive across the Northeast Shelf during spring except in the deep basins in the Gulf of Maine (Fig. 13). The strongest negative anomalies were observed in the Middle Atlantic Bight and are present at both surface and bottom.

Gulf of Maine Hydrography

Conditions in the deep Northeast Channel – a primary conduit for source waters entering the Gulf of Maine – suggest an apparent departure from the dominance of warm and salty slope water sources to the region. However, the absence of fresh anomalies downstream in the deep basins of the Gulf of Maine seems to negate this as the cause of the extreme freshening in 2024 (Fig. 13 and Fig. 14).

The strong springtime fresh anomalies observed in the Gulf of Maine penetrated from the surface to 150 m depth in the western Gulf of Maine (Fig. 15 & 16). The spring temperature distribution is characterized by very warm anomalies at the surface bounded below by a sharp seasonal thermocline (Fig. 16). Below the seasonal thermocline, the minimum temperature in the Cold Intermediate layer, a mid-depth water mass formed seasonally as a product of convective mixing driven by winter cooling, was slightly colder than the long-term average (Fig. 16). However, this feature, distinguished by its mid-depth temperature minimum and the temperature threshold of 6C, measured just 50 meters thick in 2024. Below 75 meters, temperatures were warmer than normal and beneath 150 meters waters were both warmer and saltier than normal. Composite vertical sections of temperature and salinity from observations collected in May and June 2024 along an east-west transect crossing the Gulf of Maine show that the freshening observed in the upper 150 m extended from the western boundary across the width of the basin (Fig. 17).

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 $\sim 0.03\text{--}0.05$ °C/year. While significant seasonal to interannual variations are superimposed on this trend, annual average temperatures throughout the region were warmer than normal in 2024. More notably, waters on the Northeast U.S. Shelf were anomalously fresh in 2024 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 2024. The fact that the freshening is confined to the upper ocean in the Gulf of Maine, with positive temperature and salinity anomalies prevalent at depth, suggests that we may be observing a shift in source water contributions to the region, with Scotian Shelf Water dominating slope water sources. In general, large interannual variations in the temperature and salinity on the Northeast U.S. Shelf have the potential to cause significant changes in the ecosystem, leading to the seasonal elimination of critical habitats or the disruption of seasonal migration cues and may be suggestive of changes in nutrient loading on the shelf as well as changes in community structure and species diversity.

SUMMARY

- On average, waters on the Northeast U.S. Continental Shelf were anomalously fresh and warmer than the climatological mean in 2024.

- Notable fresh anomalies were observed in the upper layers of the Gulf of Maine and throughout the water column in the MAB during Spring 2024, likely caused by advection of Scotian Shelf Water from the north.
- Slightly cold and fresh anomalies were present in the deep Northeast Channel in 2024, reflective of a shift in the composition of source water entering the deep Gulf of Maine, although these do not appear to be the cause of the broader freshening within the basin.
- In the western Gulf of Maine, the Cold Intermediate Layer was very thin in the spring of 2024 with colder minimum temperatures at its core, while underlying layers were warmer and saltier.

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Table 1: Listing of the stations sampled by the Oceanography Branch on NOAA Northeast Fisheries Science Center Surveys, grouped by geographic region and survey type. The Geographic regions are described by the polygons shown in Figure 3, including the eastern Gulf of Maine (GME), western Gulf of Maine (GMW), northern Middle Atlantic Bight (MBN), southern Middle Atlantic Bight (MBS) and Georges Bank (GB). The month of sampling and survey sampling design are also indicated.

Geographic Region	Month(s) ¹	Sampling Design ²	Survey Type	No. Stations
GME	4,5	S	Bottom trawl survey	37
	6	S	Ecosystem monitoring survey	22
	8	S	Ecosystem monitoring survey	27
	9	O	North Atlantic Right Whale Prey Studies	1
	10,11	S	Bottom trawl survey	37
GMW	2	S	Ecosystem monitoring survey	9
	4,5	S	Bottom trawl survey	53
	6	S	Ecosystem monitoring survey	29
	8	S	Ecosystem monitoring survey	28
	9	O	North Atlantic Right Whale	3
	10,11	S	Bottom trawl survey	60
MBN	1,2	O	Passive Acoustic Monitoring/eDNA Studies	13
	1,2,3	O	North Atlantic Right Whale Prey Studies	37
	2	S	Ecosystem monitoring survey	23
	3,4,5	S	Bottom trawl survey	57
	4	O	North Atlantic Right Whale Prey Studies	65
	5,6	S	Ecosystem monitoring survey	30
	7	O	Passive Acoustic Monitoring/eDNA Studies	11
	8	S	Ecosystem monitoring survey	26
	9,10	S	Bottom trawl survey	44
	10,11	S	Ecosystem monitoring survey	34
	12	O	North Atlantic Right Whale Prey Studies	1
	12	O	Passive Acoustic Monitoring/eDNA Studies	12
MBS	2	S	Ecosystem monitoring survey	7
	3,4	S	Bottom trawl survey	107
	5,6	S	Ecosystem monitoring survey	35
	6	O	Longfin Squid Survey	12
	9,10	S	Bottom trawl survey	105
	10,11	S	Ecosystem monitoring survey	49
GB	4,5	S	Bottom trawl survey	61
	6	S	Ecosystem monitoring survey	35
	7	O	Passive Acoustic Monitoring/eDNA Studies	1
	8	S	Ecosystem monitoring survey	37
	9	O	North Atlantic Right Whale	1
	10	S	Bottom trawl survey	63

¹ 1 to 12 for month. ² S indicates random-stratified survey design and O indicates ‘other’.

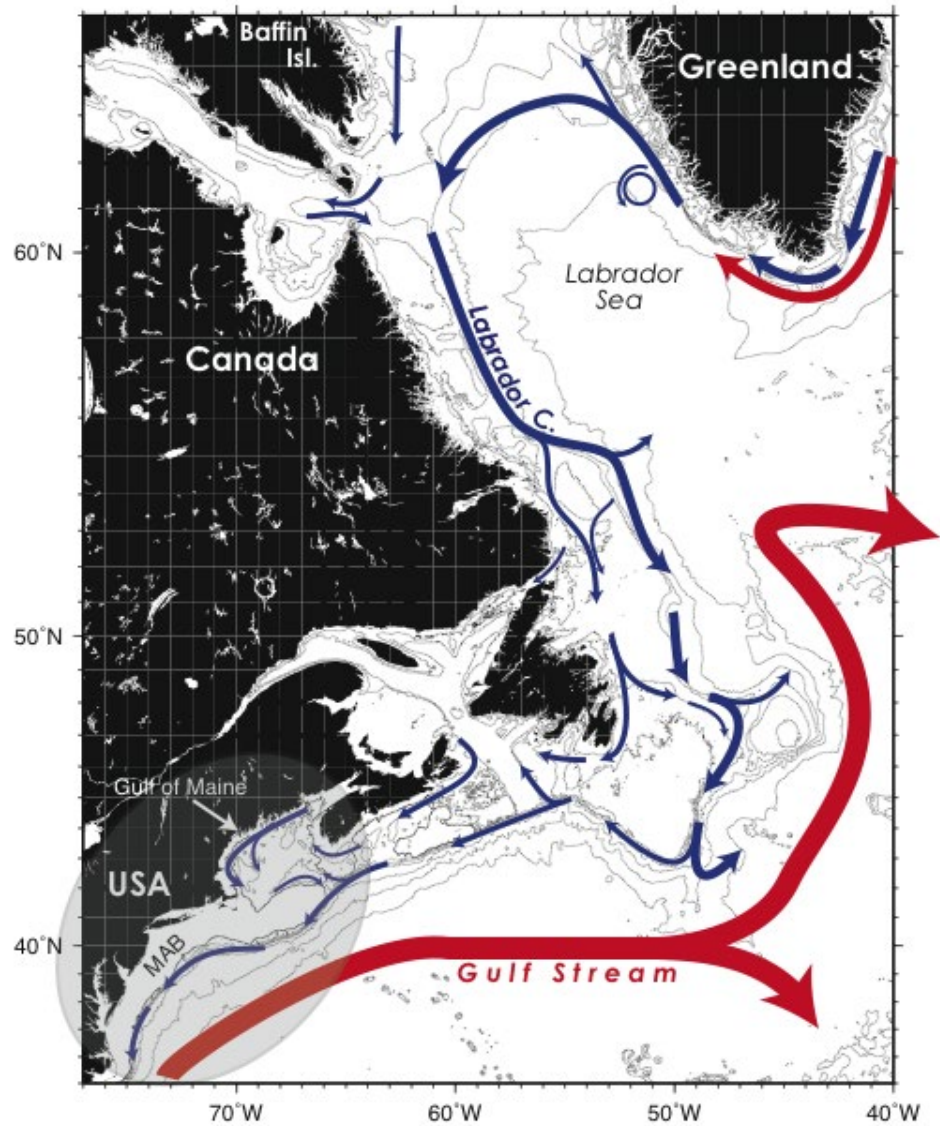


Figure 1a: Circulation schematic of the western North Atlantic. The Northeast U.S. Shelf region is identified by the shaded oval. Contours for the 100-, 200-, 500-, 1000-, 2000-, 3000-and 4000-meter isobaths are shown.

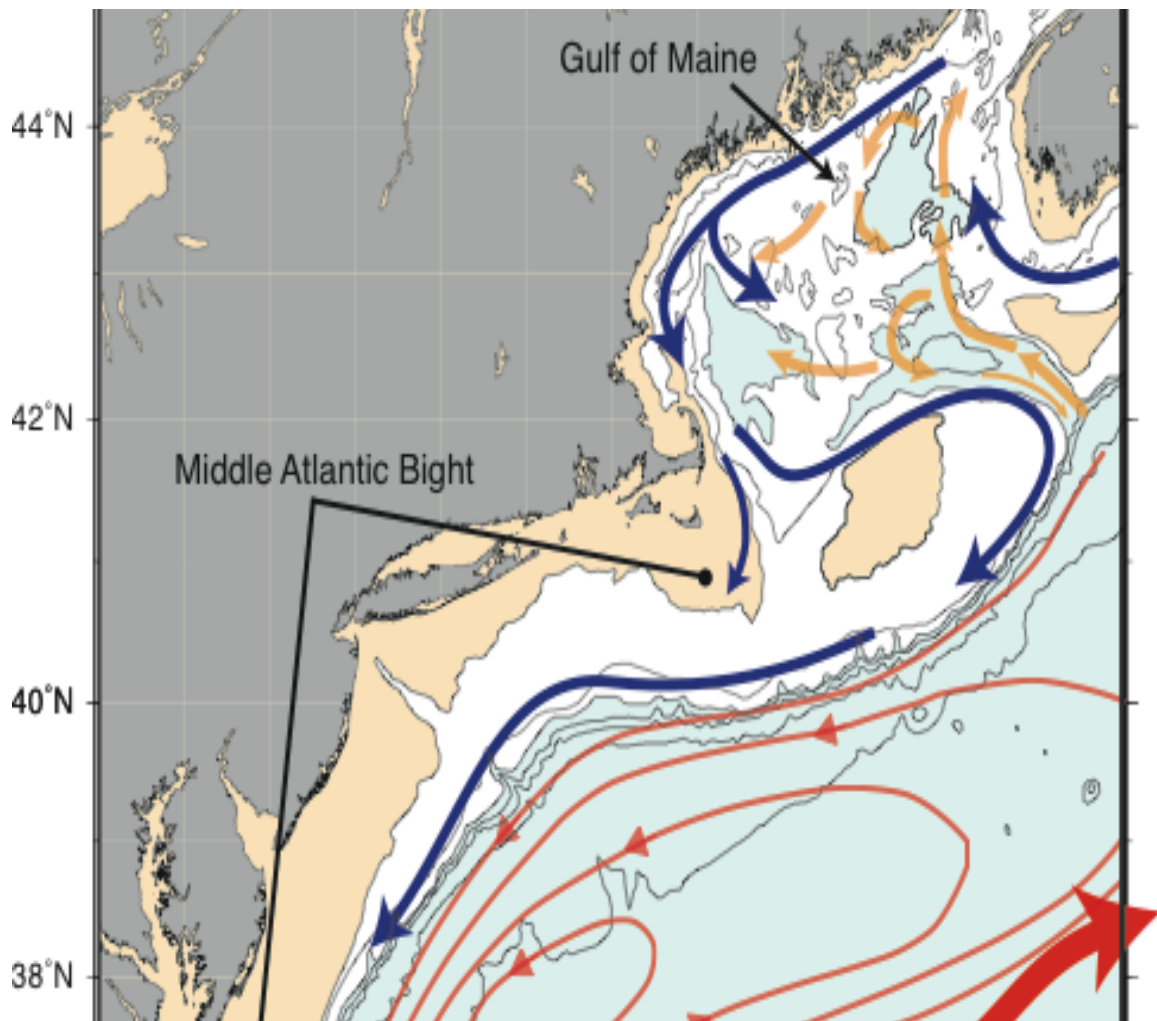


Figure 1b: Circulation schematic for the Northeast U.S. Shelf region, where blue arrows represent shelf water circulation and orange arrows represent deeper slope water circulation pathways. Water depths deeper than 200 meters are shaded blue. Water depths shallower than 50 meters are shaded tan.

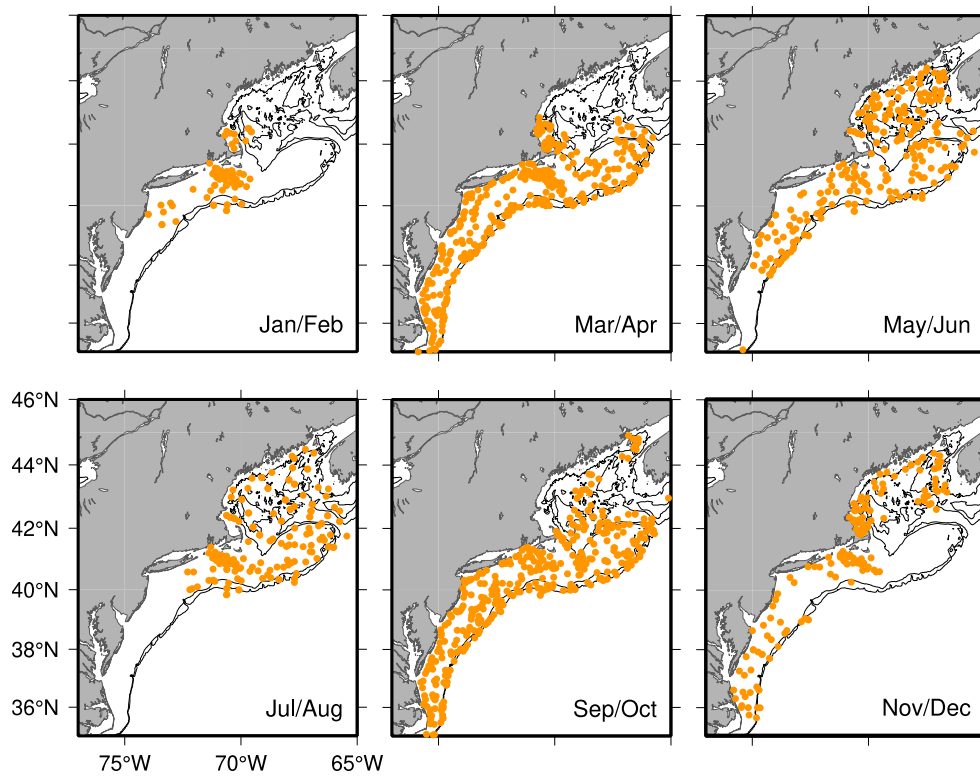


Figure 2a: Distribution of hydrographic stations occupied in 2024. Contours show the 100 m and 200 m isobaths.

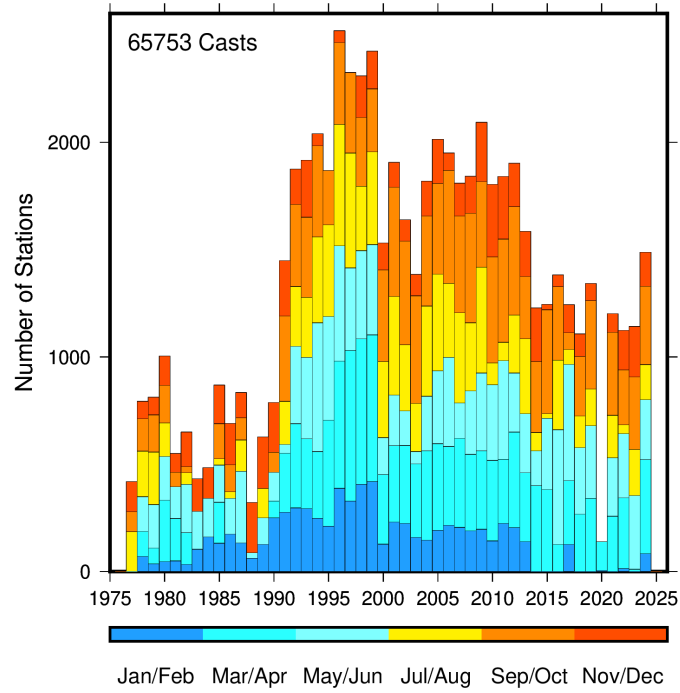


Figure 2b: Histogram of hydrographic stations sampled as part of NEFSC operational oceanography programs as a function of year and season.

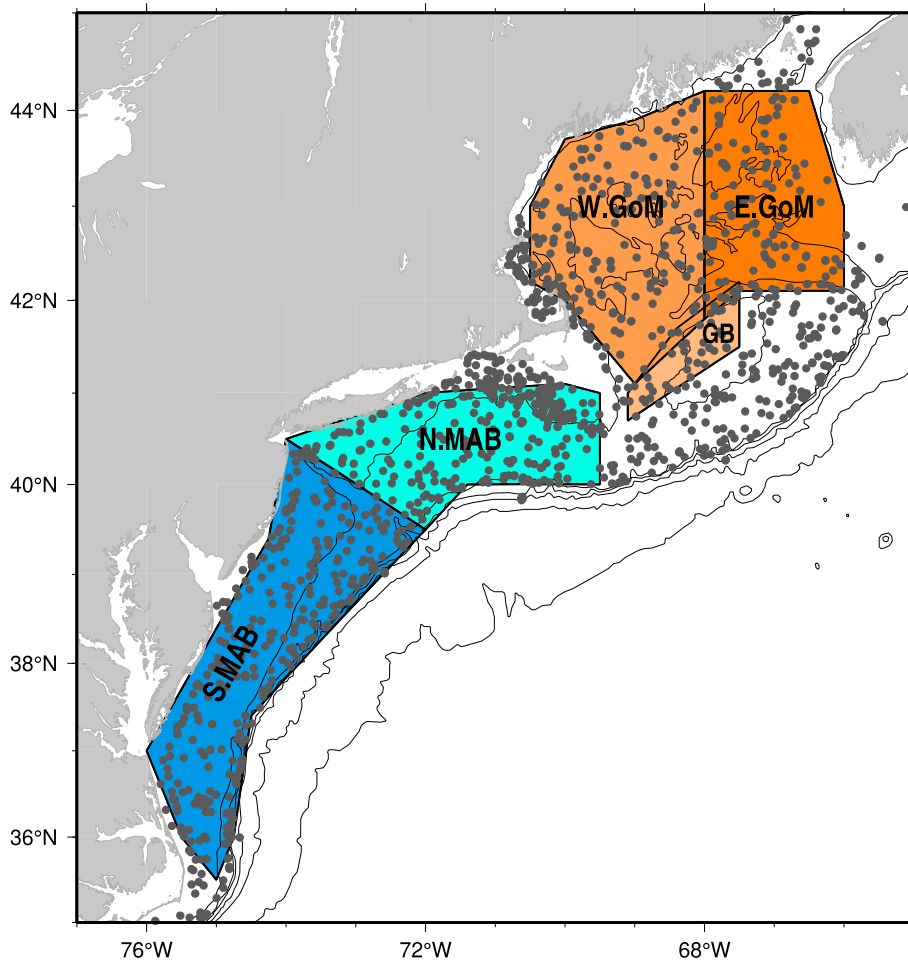


Figure 3: Hydrographic sampling conducted in 2024 by NOAA's Northeast Fisheries Science Center (circles). The colored polygons denote regional polygons used to calculate regional average conditions, corresponding to the Southern Middle Atlantic Bight (SMAB), Northern Middle Atlantic Bight (NMAB), northwest Georges Bank (GB), Western Gulf of Maine (WGOM) and Eastern Gulf of Maine (EGOM). Depth contours are shown for the 50, 200, 500, 1000, 2000, and 3000-meter isobaths.

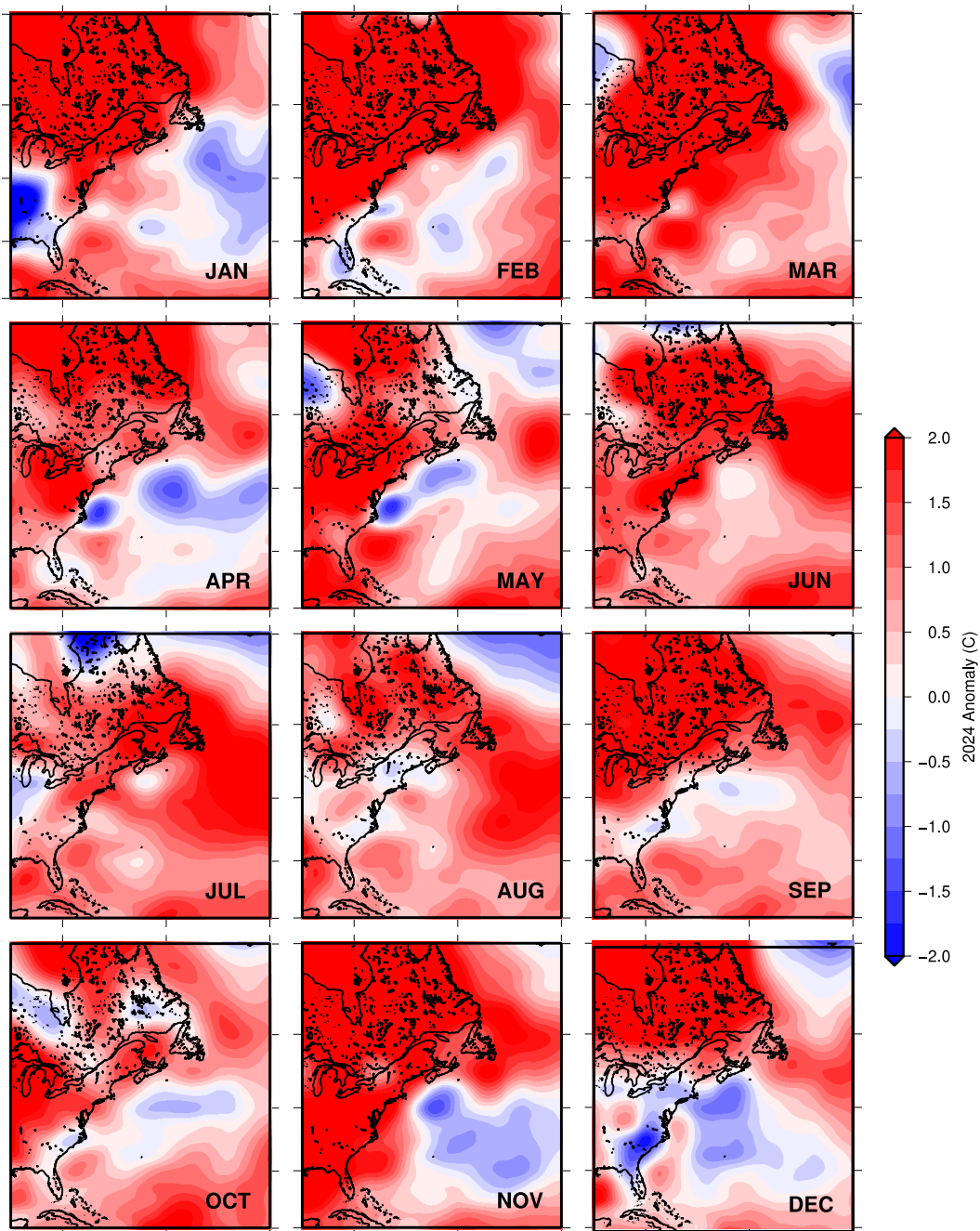


Figure 4: Surface air temperature anomaly derived from the NCEP/NCAR Reanalysis product (<http://www.esrl.noaa.gov/psd/data/composites/day/>). Positive anomalies correspond to warming in 2024 relative to the reference period (1991–2020).

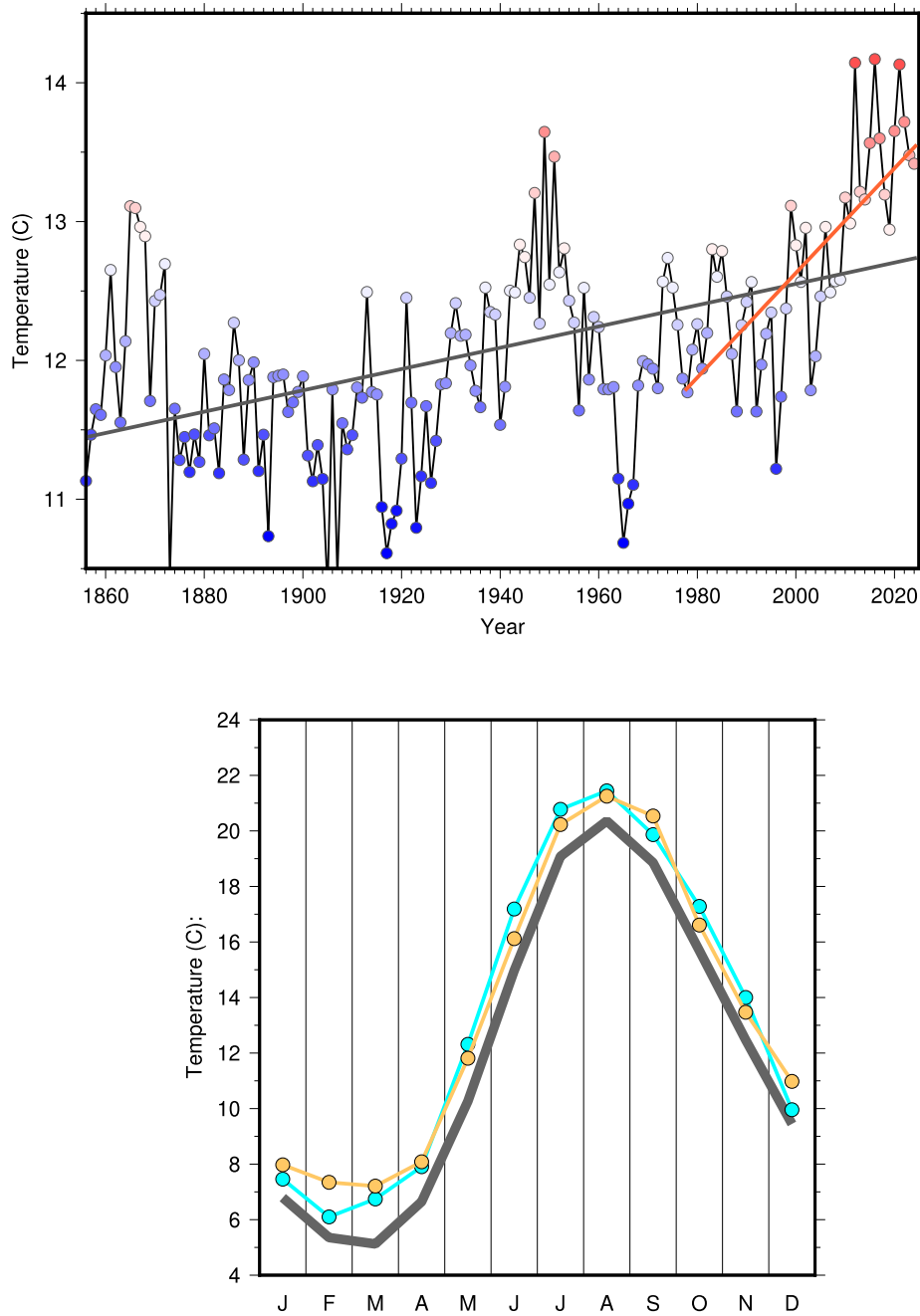


Figure 5: Top: Regional average annual sea surface temperature for the NEUS shelf region calculated from NOAA’s extended reconstructed sea surface temperature product (<https://psl.noaa.gov/data/gridded/data.noaa.ersst.v5.html>). Colors correspond with the anomaly magnitude where darker colors correspond to larger values. Bottom: Regional average monthly mean SST for the NEUS shelf for 2024 (cyan), 1951 (orange) and 1991–2020 (gray) calculated from the same product.

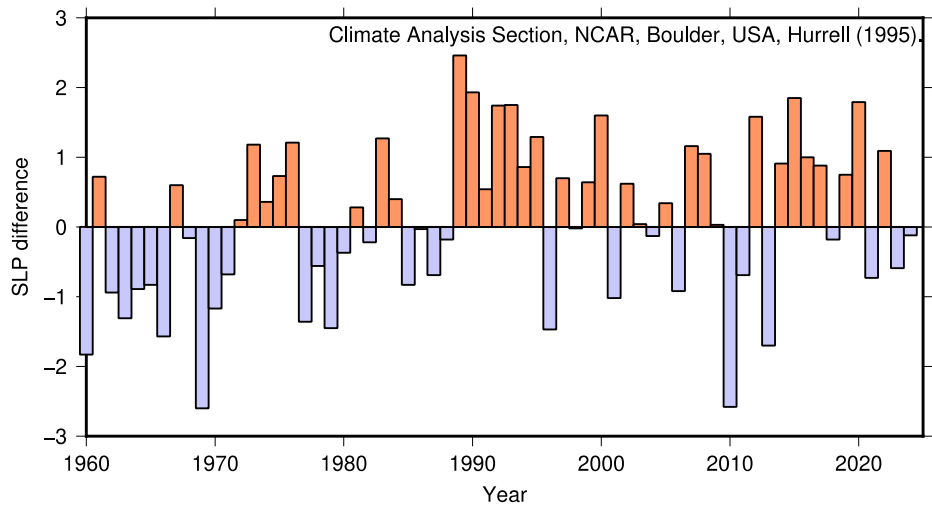


Figure 6: North Atlantic Oscillation index computed from principal component analysis of sea level pressure in the North Atlantic (see Hurrell, 1995).

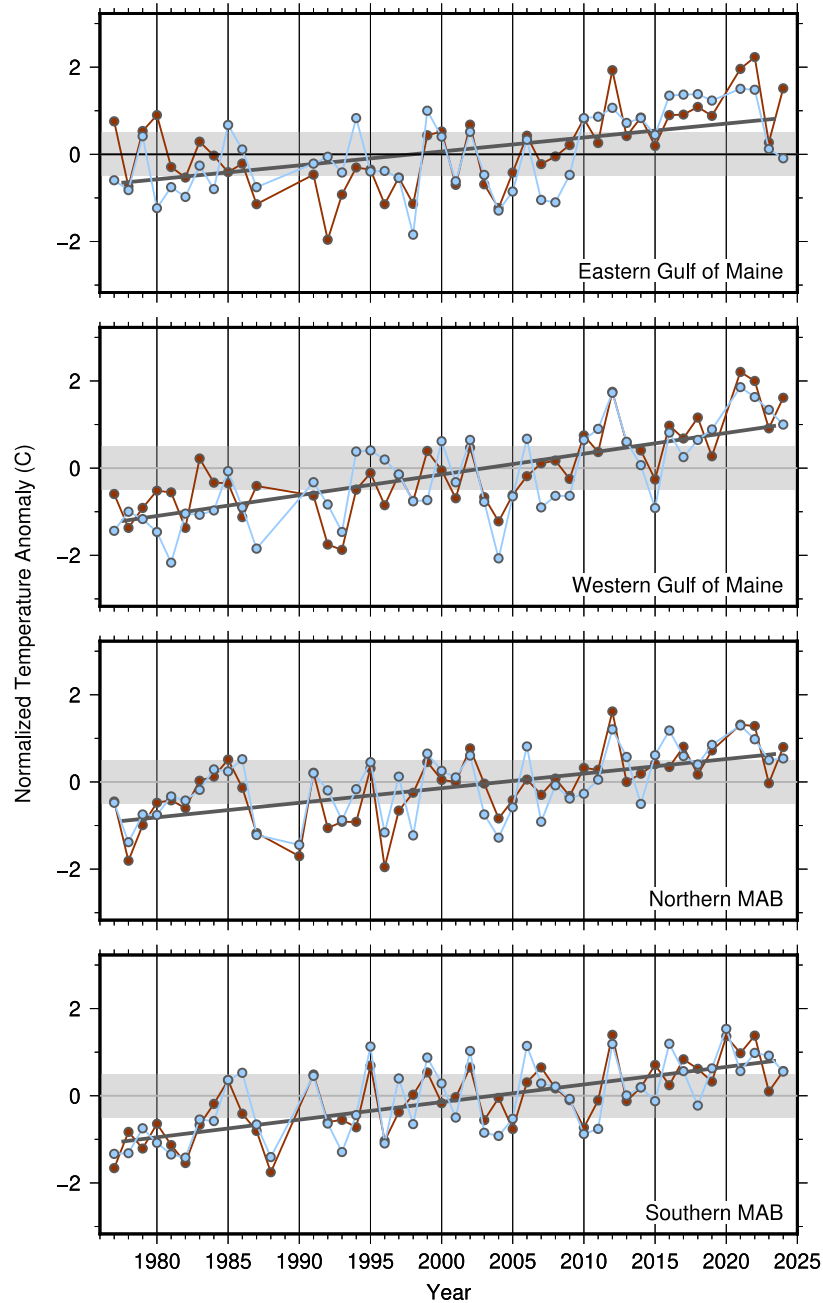


Figure 7a: Time series of surface (red) and bottom (blue) regional annual average normalized sea temperature anomaly ($^{\circ}\text{C}$). Positive anomalies correspond to warming relative to the reference period (1991–2020). Gray line shows the temporal trend based on linear regression where significance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

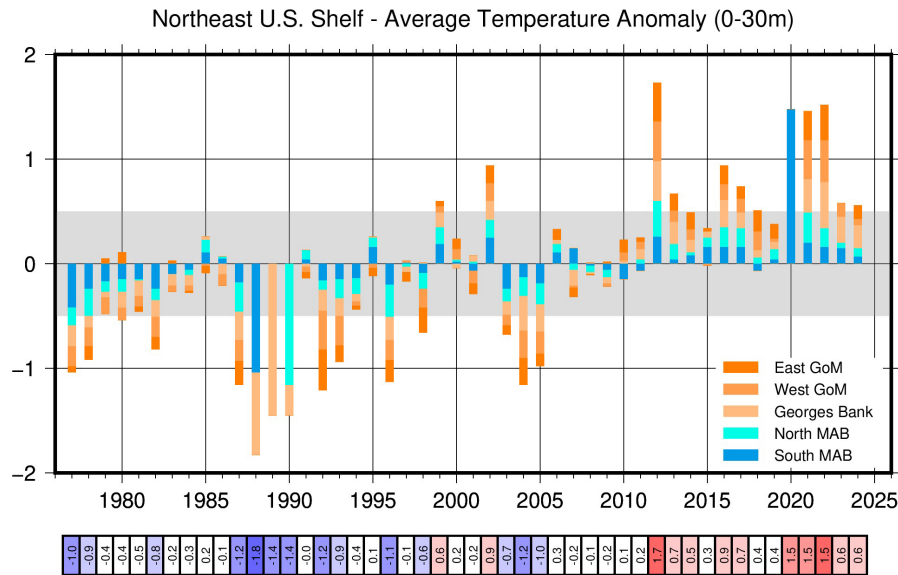


Figure 7b: Normalized annual sea temperature anomaly for the upper 30 meters of the Northeast U.S. Shelf, inclusive of the eastern and western Gulf of Maine, Georges Bank, and northern and southern Middle Atlantic Bight. The bars show the average of the five regions, where the length of each bar corresponds 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.

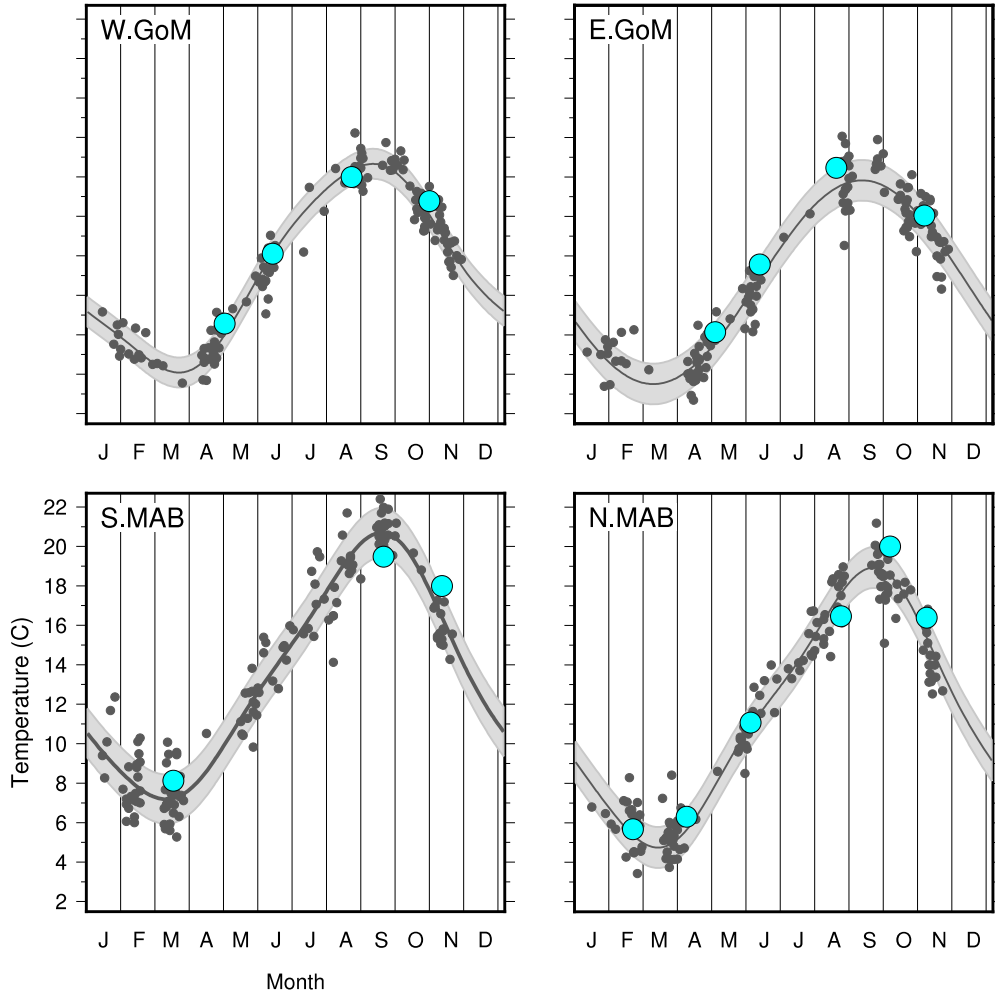


Figure 8a: Regional average 0–30-meter temperature (°C) as a function of calendar day for the western and eastern Gulf of Maine (top panels) and the southern and northern Middle Atlantic Bight (bottom panels). Each dot represents a volume-weighted average of all observations from a single survey falling 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 2024 surveys are shown in cyan.

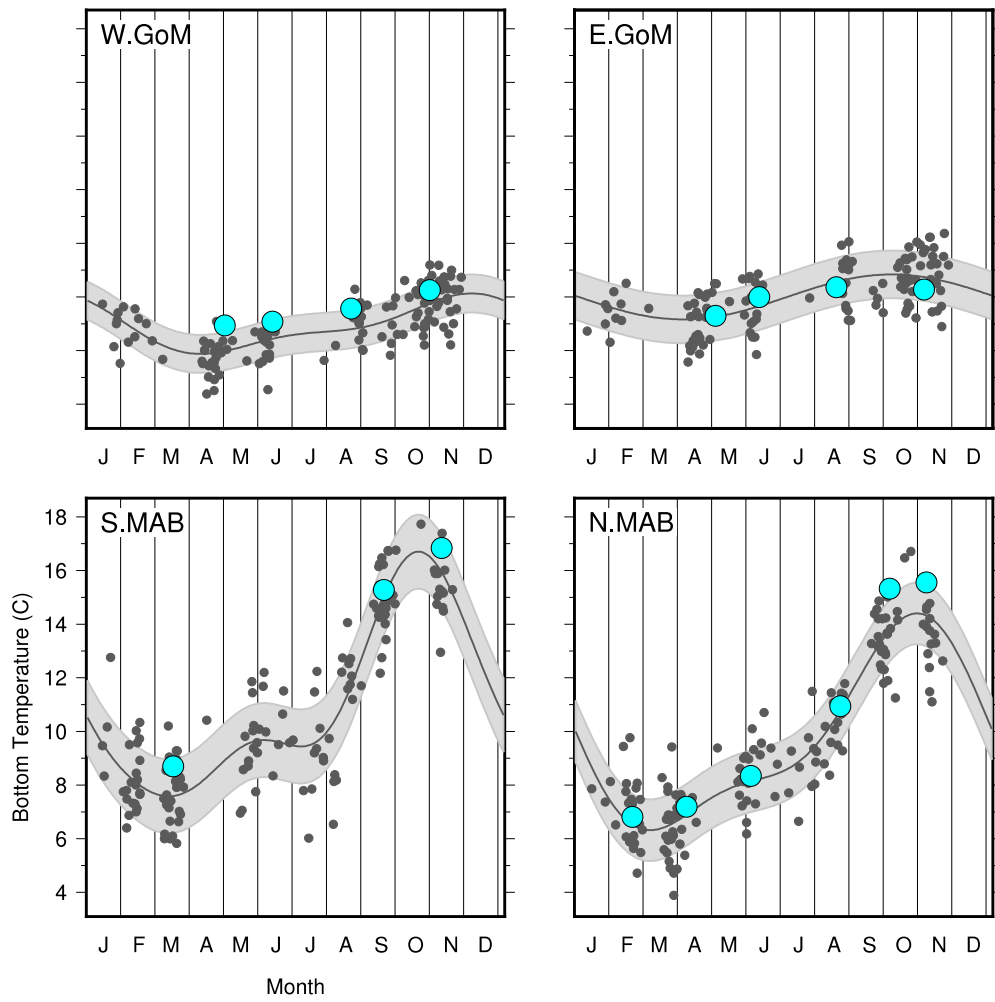


Figure 8b: As in Fig. 8a, but for bottom temperatures.

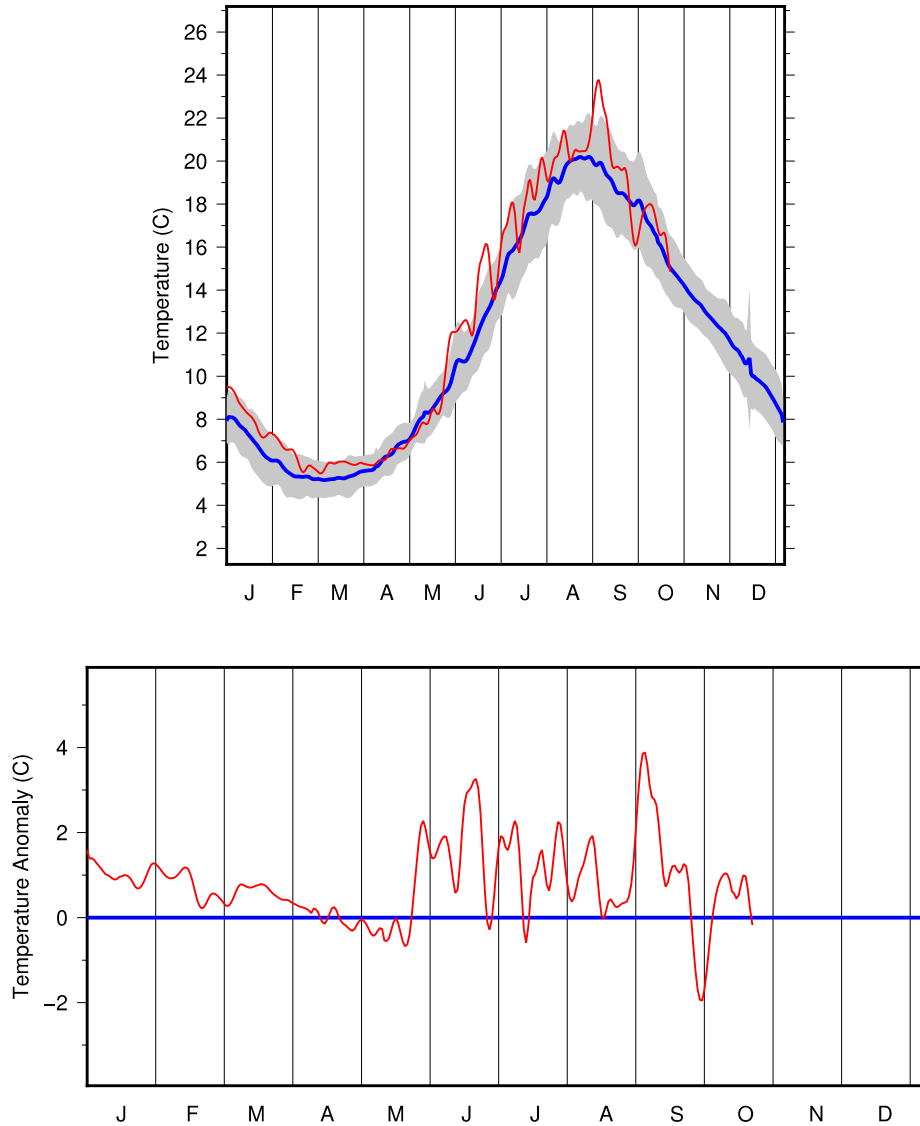


Figure 9: (top) Time series of surface ocean temperature from NDBC buoy 44008 located south of Nantucket Shoals in the northern Middle Atlantic Bight. Temperatures observed in 2024 (red) are compared with average temperatures (1991–2020, blue) in the top panel. The gray shading indicates one standard deviation about the long-term mean. The lower panel shows the difference between 2024 and the long-term mean temperature, where positive values indicate warmer conditions in 2024.

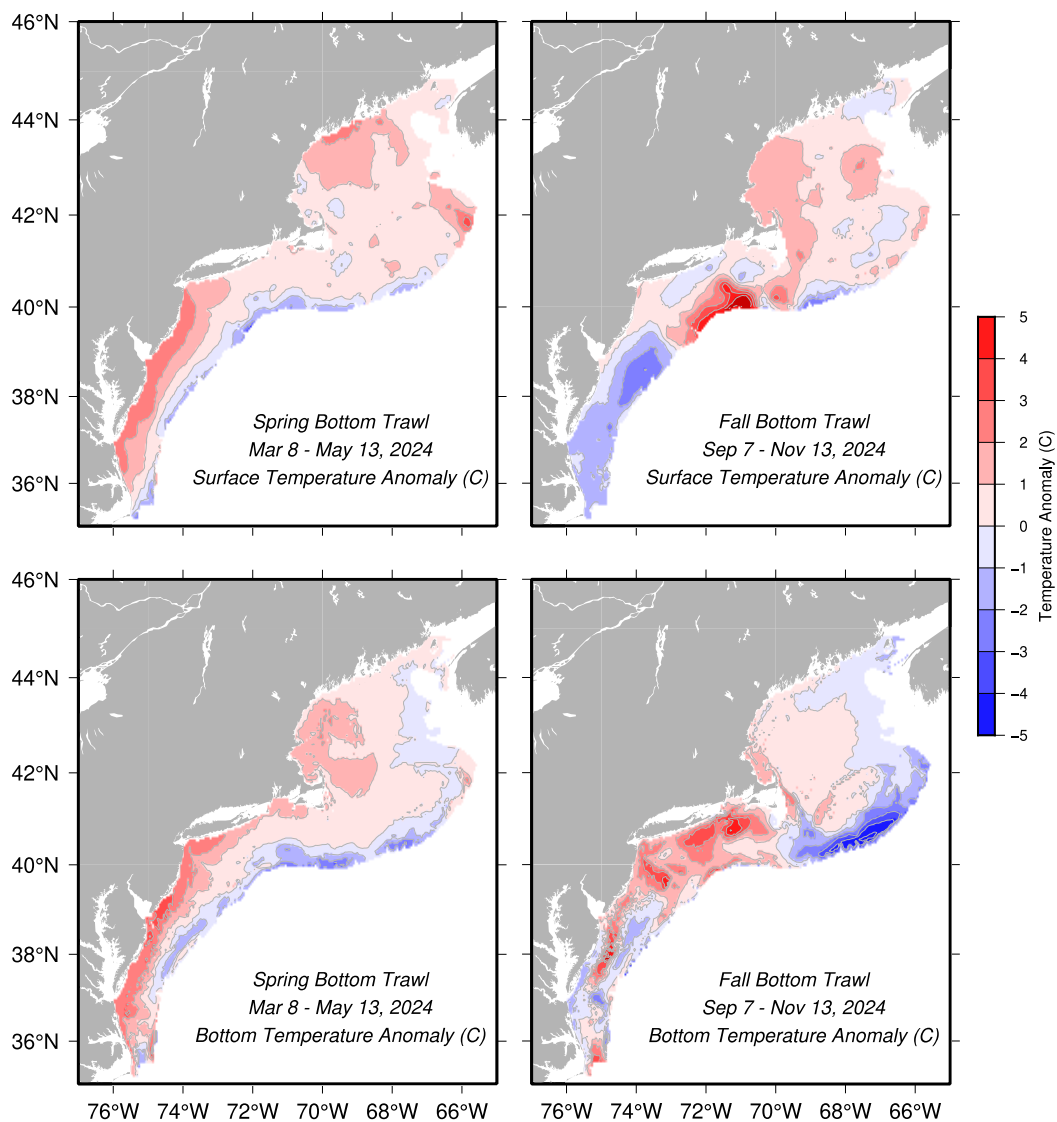


Figure 10: Surface (upper panels) and bottom (lower panels) temperature anomaly from the Spring (left) and Fall (right) 2024 ground fish surveys. Contour interval is 1 C. Positive anomalies correspond to warming in 2024 relative to the reference period (1991–2020).

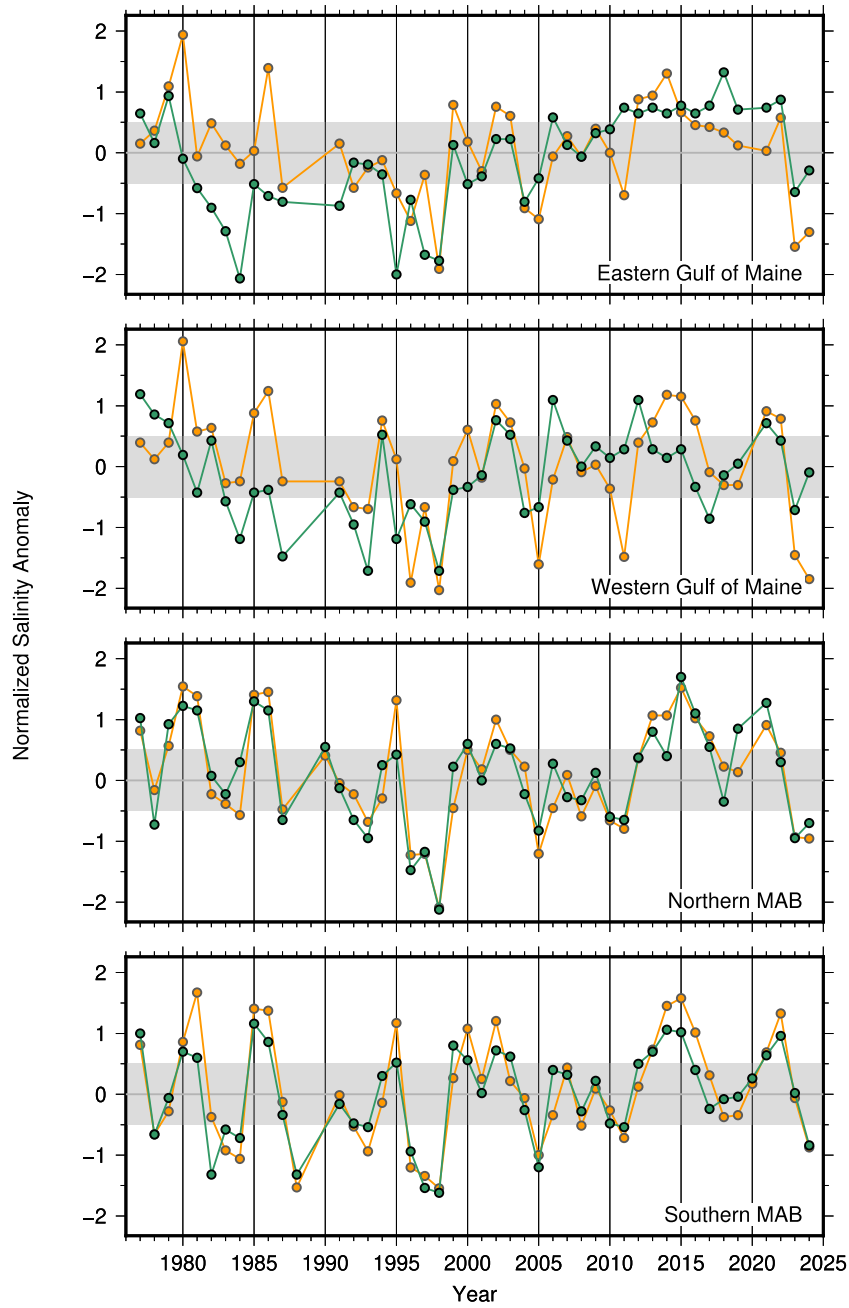


Figure 11a: Time series of surface (orange) and bottom (green) normalized annual average sea salinity anomaly. Positive anomalies correspond to more saline conditions relative to the reference period (1991–2020). Gray shading indicates the normalized anomalies falling within ± 0.5 standard deviation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

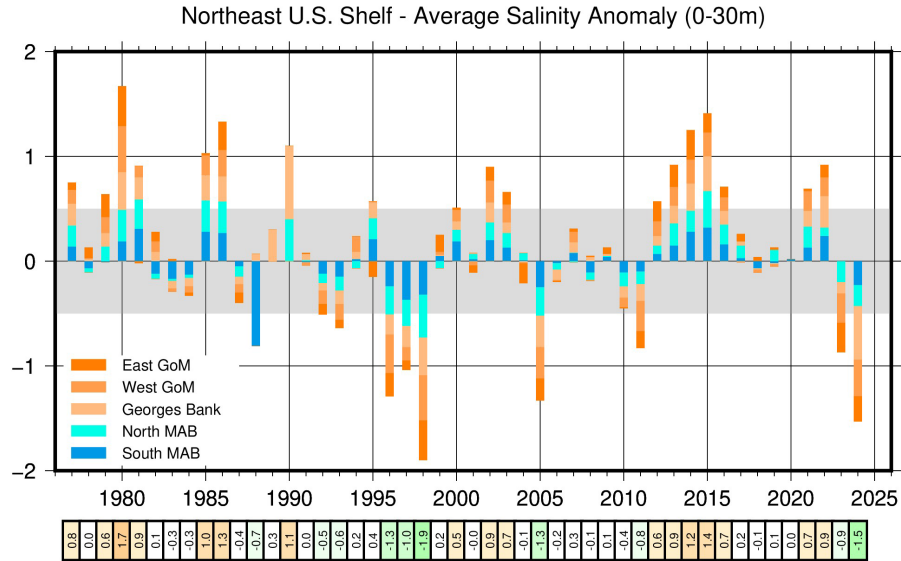


Figure 11b: Normalized annual salinity anomaly for the upper 30 meters of the Northeast U.S. Shelf (upper panel, incorporating the Gulf of Maine, Middle Atlantic Bight and Georges Bank regions). The bars show the relative contribution of each regional anomaly to the average. Positive anomalies correspond 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.

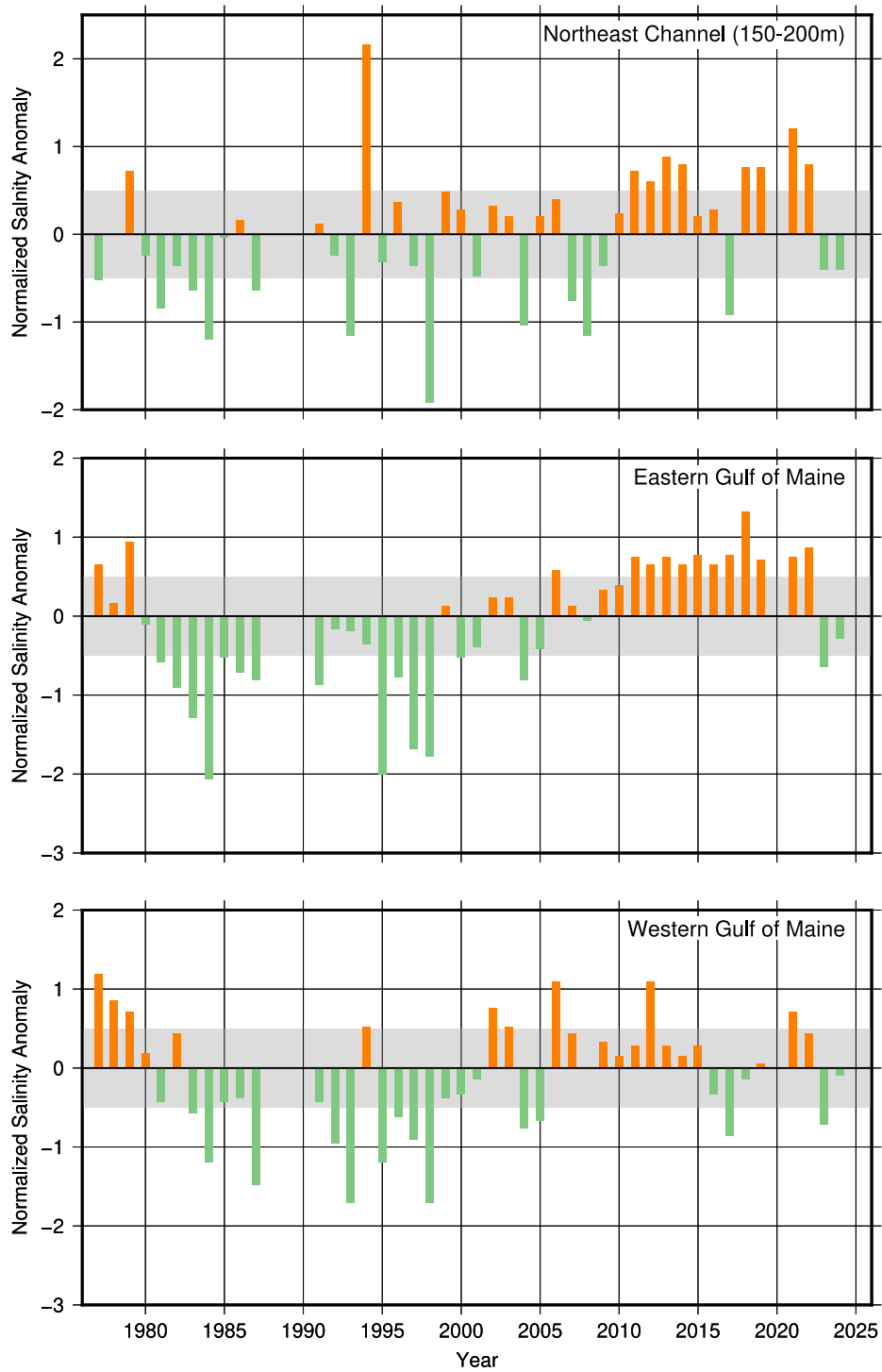


Figure 11c: Normalized annual salinity anomaly in the deep Northeast Channel (top panel) and near the seafloor for the eastern (middle panel) and western (lower panel) Gulf of Maine.

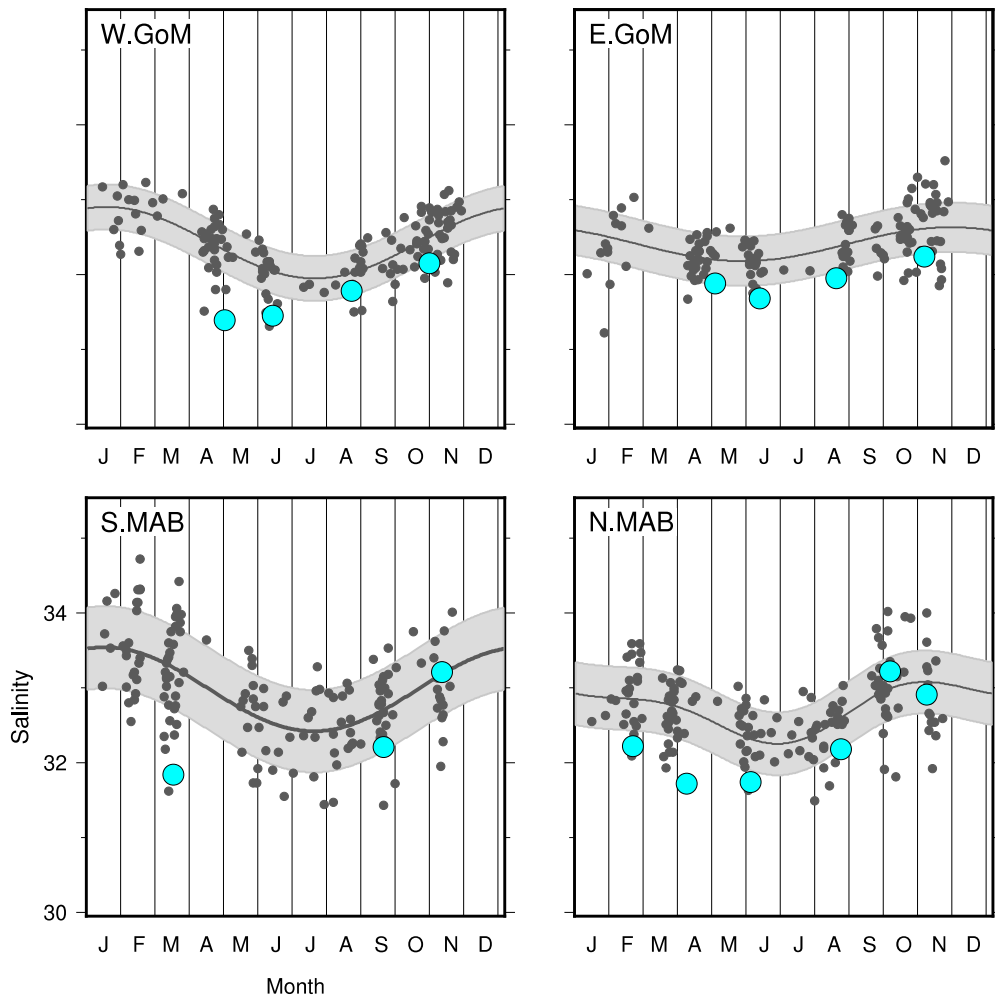


Figure 12a: Regional average 0–30-meter salinity as a function of calendar day for the western and eastern Gulf of Maine (top panels) and the southern and northern Middle Atlantic Bight (bottom panels). Each dot represents a volume-weighted average of all observations from a single survey falling within 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 2024 surveys are shown in cyan.

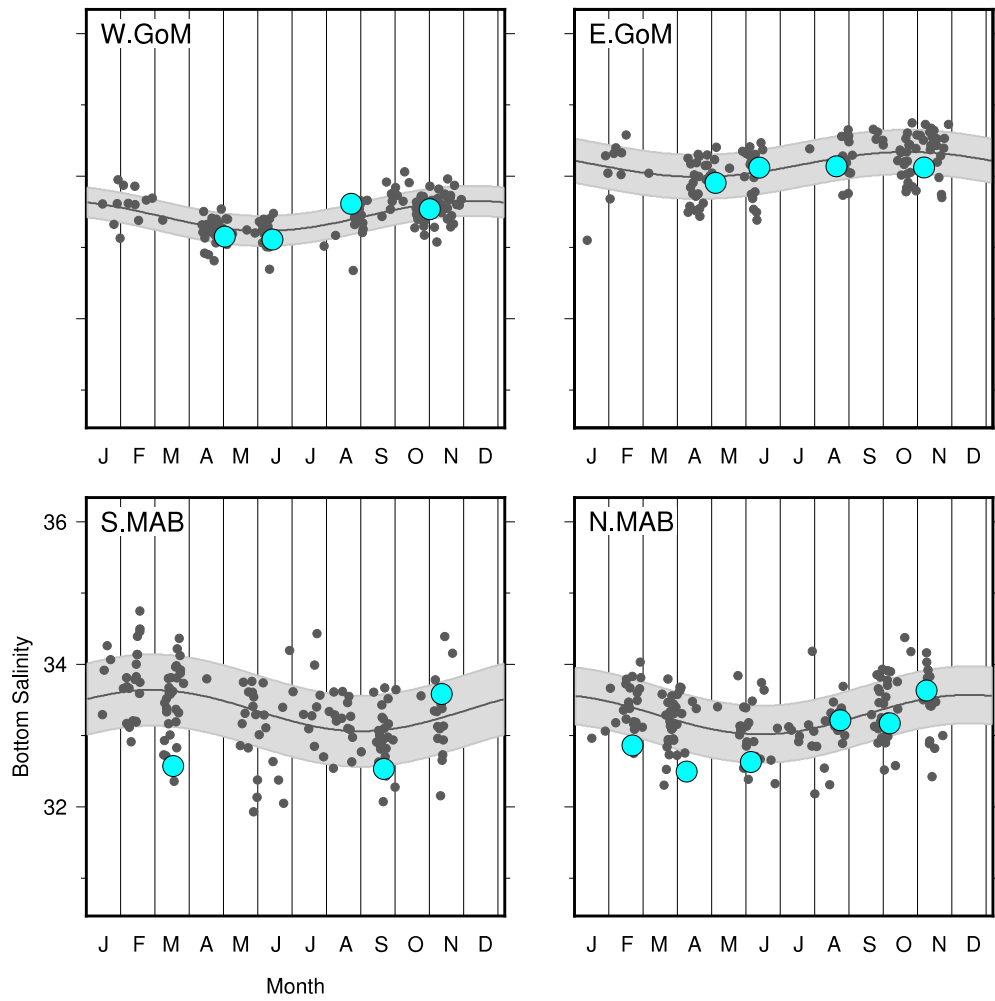


Figure 12b: As in Fig. 12a, but for bottom salinities.

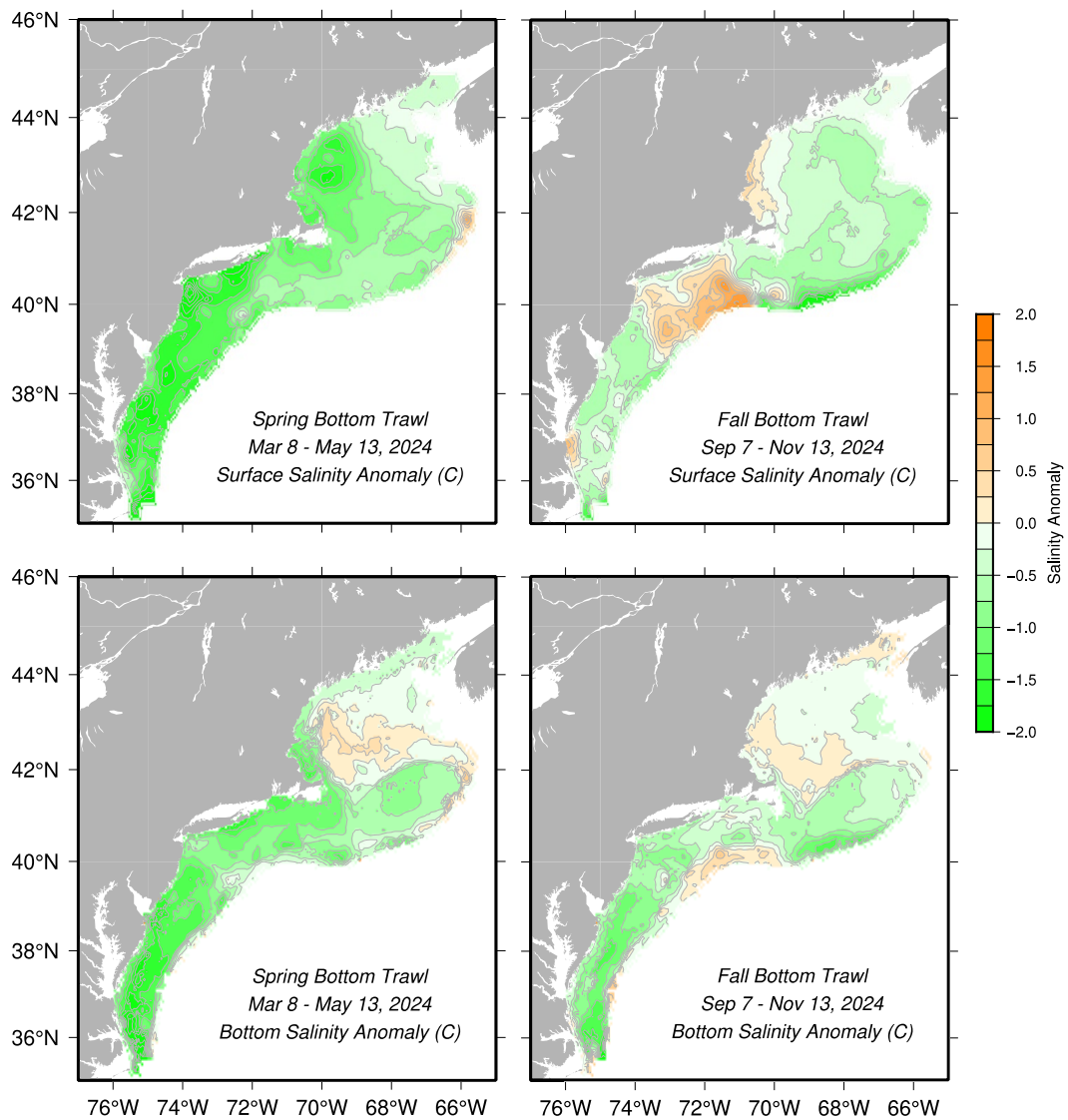


Figure 13: Surface (upper panels) and bottom (lower panels) salinity anomaly from the Spring (left) and Fall (right) 2024 ground fish survey. Contour interval is 0.25 psu. Negative anomalies correspond to less saline conditions in 2024 relative to the reference period (1991–2020).

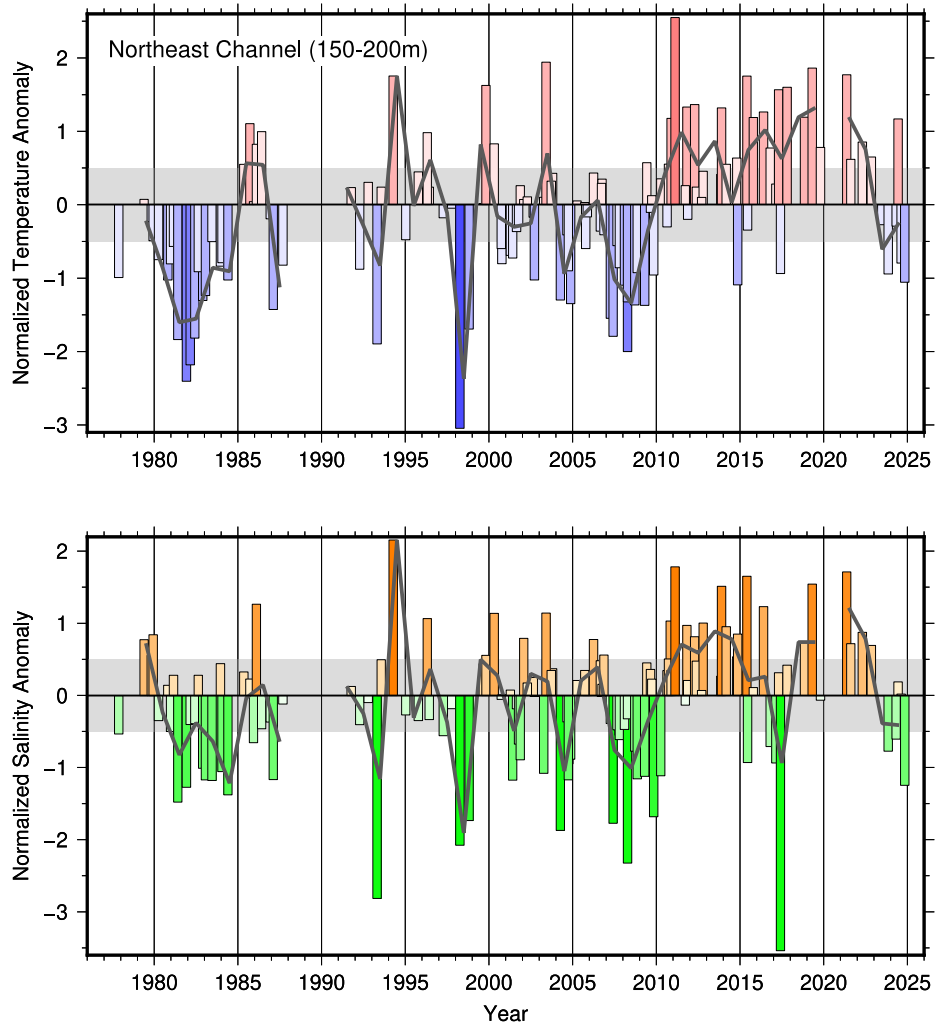


Figure 14: Time series of normalized temperature and salinity anomaly in the deep Northeast Channel. Each bar represents a volume-weighted average of all observations from a single survey collected between 150–200 meters in the Northeast Channel. The grey curve shows the annual average anomaly time series. 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.

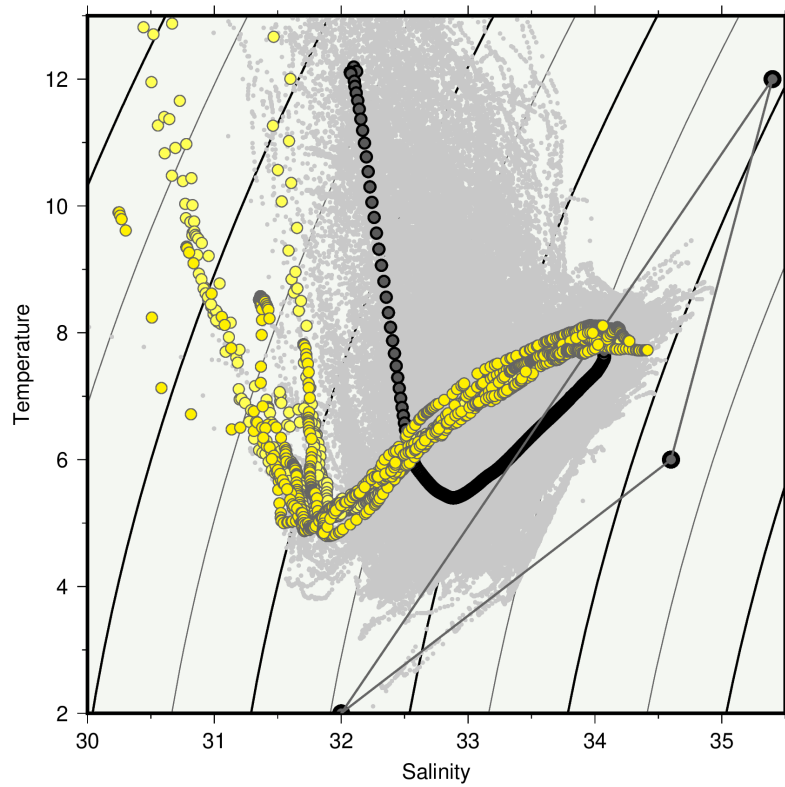


Figure 15: Temperature-salinity diagram showing water properties in Wilkinson Basin in the western Gulf of Maine. All observations from May–June (yellow) 2024 are shown along with the spring climatological average profile (1991–2020, dark gray). The lightest gray dots show the historical range encompassed 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.

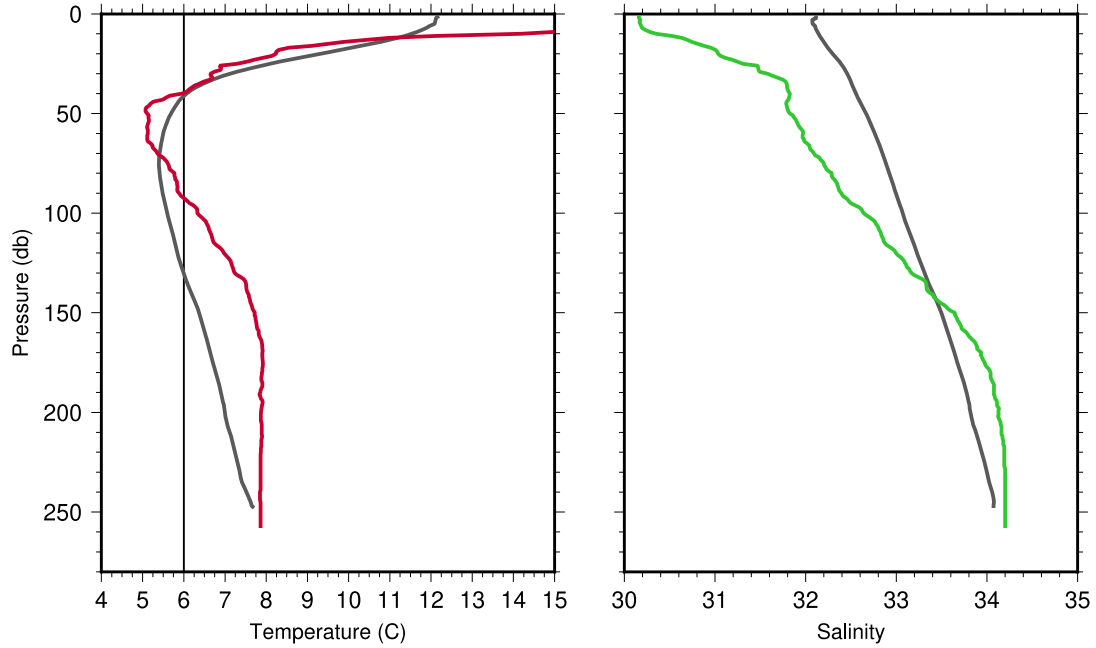


Figure 16: Average profiles of temperature (left) and salinity (right) from repeated observations collected during June in Wilkinson Basin in the western Gulf of Maine. The average of all profiles from June 2024 (red and green) are shown along with the climatological average profile for the same month (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.

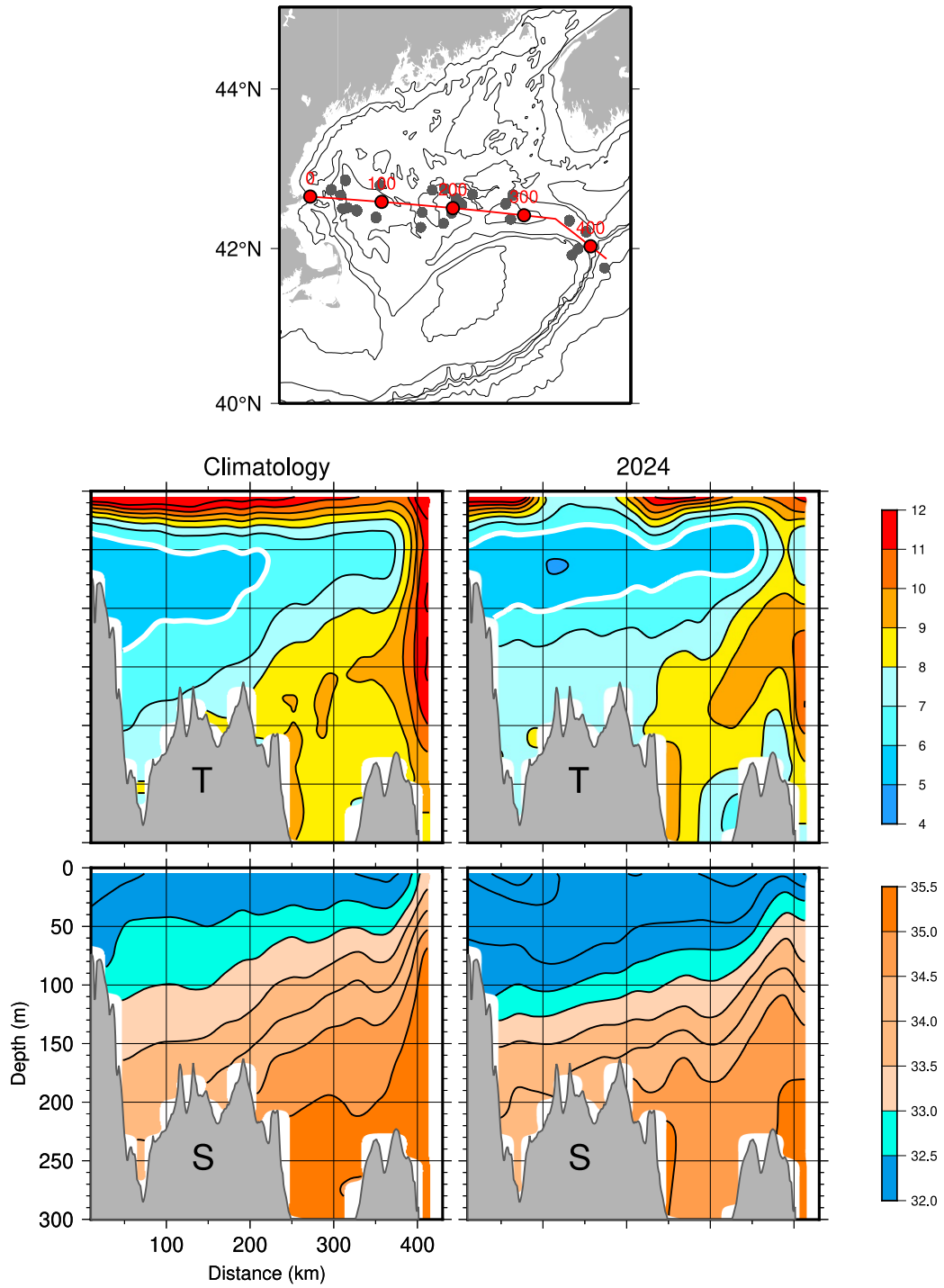


Figure 17: Vertical sections of temperature (top) and salinity (bottom) crossing the Gulf of Maine along a zonal transect shown in the map. The left panels show the climatological average for June spanning the years 1991–2020. The right panels show the synoptic mean section for May–June 2024. The heavy white contour highlights the 6°C isotherm as an indicator of the boundary of the Cold Intermediate Layer. Along-transect distances and the May–June 2024 station distribution are shown on the map for reference.

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