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Hydrographic Conditions on the Northeast United States Continental Shelf in 2021 – 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 2021. 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. Overall, 2021 was characterized by warmer than average water temperatures observed across the entire Northeast US Shelf. Extreme warm and salty anomalies observed in the northern Middle Atlantic Bight are linked to a shoreward displacement of the shelf-slope front. Deep (slope) waters entering the Gulf of Maine continue to be warmer and saltier than average, marking two full decades that southern source waters have dominated the slope water composition in the region. The Cold Intermediate Layer in the western Gulf of Maine was warmer than normal, while the underlying water mass was warmer and saltier than normal.

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. Typically, the NEFSC completes 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. Limited sea day allocations in 2021 eliminated the winter Ecosystem Monitoring (EcoMon) Survey and led to truncation of others. Overall, roughly 20% of the stations were left unsampled for the year, with notable gaps in the far northern (Gulf of Maine) and far southern (southern Middle Atlantic Bight) survey areas (Fig. 2).

During 2021, hydrographic data were collected on 9 individual NEFSC cruises, amounting to 1201 profiles of temperature and salinity and 11070 in NAFO subareas 5 and 6 (Table 1). Data were collected aboard the NOAA ships *Henry Bigelow, Gordon Gunter, Pisces*, and *Gloria Michelle*, in addition to the R/V *HR Sharp, R/V Warren Jr. and F/V Eagle Eye II* using a combination of Seabird Electronics SBE-19+ SEACAT profilers and SBE 9/11 CTD units. Cruise reports are accessible at: https://www.fisheries.noaa.gov/resource/data/2010-2019-ecosystem-monitoring-northeast-us-continental-shelf-cruise-reports. Data are publicly available from the World Ocean Database

maintained by NOAA's National Centers for Environmental Information at:
http://www.nodc.noaa.gov/OC5/SELECT/dbsearch/dbsearch.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. 7 for regional delineations). 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 2021 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 2021

Surface air temperatures over the western North Atlantic basin were very warm in the north and cooler in the south during the first third of 2021 (Fig. 3). Notable exceptions were in February when the eastern US was blanketed by extreme cold anomalies. Air temperature anomalies weakened in May, yielding to cooler conditions over the entire region by July. Warmer conditions returned across the region in August, remaining through October. Very warm air temperatures were observed across the southeastern US in December following cooling in the same region the previous month. A tongue of very warm sea surface temperature was observed during winter 2021, extending eastward from the Gulf of Maine to the Tail of the Grand Banks of Newfoundland (Fig. 4). The warm anomaly persisted, albeit weaker through summer. Fall sea surface temperatures were anomalously warm across the entire Northeast US Shelf and into the Gulf of St. Lawrence. Annually, sea surface temperature on the Northeast US Shelf was equivalent to the record warming observed in 2012, with monthly anomalies exceeding 2C in March-April, June and October-November (Fig. 5).

It has been suggested that an index measuring the atmospheric sea level pressure difference between Iceland and the Azores is a reliable indicator of atmospheric conditions and oceanic response in the North Atlantic. The North Atlantic Oscillation (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 negative during 2020-21, marking the first strong negative index measured since 2013 (Fig. 6). The negative index was associated with a typical sea level pressure anomaly pattern, involving a weakening of both the subpolar (Icelandic) low and the subtropical (Azores) high, as well as reduced wind speeds along the east coast of North America (IROC, 2022). The distribution of winter air temperature anomalies observed in 2021 (Fig. 3) was consistent with expected patterns under negative NAO conditions, with warm anomalies to the north and cold anomalies to the south.

A negative NAO is also typically associated with a more zonally oriented atmospheric Jet Stream and North Atlantic storm track, stronger cold-air outbreaks and increased storminess over eastern North America, a southward shift in the Gulf Stream, a predominance of cooler Labrador slope water in the Northeast Channel and colder bottom waters in the Gulf of Maine (Petrie, 2007; Mountain, 2012; Joyce *et al.*, 2000). However, observations indicate that the Gulf Stream was shifted north of its average position in 2021 (NEFSC State of the Ecosystem Report, 2022), bottom waters in the Gulf of Maine were anomalously warm and water masses in the Northeast Channel contained a proportionally small volume of Labrador slope water (see below).

Hydrographic Conditions in 2021

Relative to historical values (1991-2020), regional ocean temperatures across the NEUS shelf were warm during 2021 (Fig. 7). Annually, waters in the upper 30 meters were between 1.3-1.5°C warmer than normal everywhere. Enhanced warming was observed throughout the year, but particularly in summer and early fall in the northern Middle Atlantic Bight (Fig. 8a). Extremely warm conditions were also observed near the bottom across the entire region, with warm anomalies measuring more than one standard deviation above normal throughout the year in the Gulf of Maine and northern Middle Atlantic Bight (Fig. 8b). Most notably, anomalies exceeded 2.5°C throughout the water column during September in the northern Middle Atlantic Bight and reached 2°C at the surface and bottom in the western Gulf of Maine in November (Fig. 8b) The spatial distribution of the seasonal differences are revealed in synoptic maps compiled from the spring and fall ground fish surveys (Fig. 9). Warm anomalies were observed at the surface across the entire Northeast Shelf in spring and fall. A shoreward intrusion of warm water in the northern Mid-Atlantic Bight during fall is evident in enhanced warm anomalies, particularly near the bottom. This is suggestive as a shoreward intrusion of slope waters. Cooling observed near the bottom in the southern Mid-Atlantic Bight is consistent with an apparent southward displacement of Cold Pool (winter-mixed) water (Fig. 9). Time series observations of near-surface temperature from NDBC buoy 44008, located south of Nantucket Shoals, observed reported an extended period of anomalously warm conditions during summer (August-October), returning to near-normal or slightly warm conditions in Fall (Fig. 10). The ocean temperature anomalies reach an impressive 4-5°C during summer, which is suggestive of an oceanic driver.

Annually, in 2021 surface waters in the upper 30 meters were saltier than normal everywhere except the eastern Gulf of Maine, where they were near-normal (Fig. 11). Seasonally, large positive anomalies were observed during September and October in the northern Middle Atlantic Bight, where anomalies exceeded 0.7 psu (Fig. 12a). Similar patterns were observed near the bottom, with more saline conditions observed in the northern Middle Atlantic Bight and eastern Gulf of Maine (Fig. 11). Bottom waters in the northern Middle Atlantic Bight were saltier than normal throughout the year, although anomalies were particularly enhanced during September and October (Fig. 12b). Synoptically, saline conditions were pervasive during spring across the Northeast Shelf (Fig. 13). Large positive salinity anomalies at the surface and bottom extended onshore nearly to the coast in the northern Middle Atlantic Bight during fall (Fig. 13). These were coincident with enhanced warm anomalies (Fig. 9) and are associated with a significant shoreward shift in the shelf-slope front (Fig. 14). These observations are consistent with independent observations collected by moored instruments deployed in the Ocean Observatories Initiative Coastal Pioneer Array and subsequent measurements made in the region, which confirm that the front shifted shoreward as early as June, 2021 and remained inshore into the Fall when NEFSC Bottom Trawl observations were made (Glen Gawarkiewicz, personal communication).

Deep inflow through the Northeast Channel continues to be dominated by Warm Slope Water, marking two decades that southern source waters have dominated the slope water composition in the region (Fig. 15). Springtime temperature-salinity and temperature-depth profiles indicate the presence of a weak Cold Intermediate layer in the western Gulf of Maine, a mid-depth water mass formed seasonally as a product of convective mixing driven by winter cooling (Fig. 16 & 17). Remnant winter water in this layer was roughly 1.5°C warmer than average and capped by very warm surface waters in 2021 (Fig. 18). Deep waters below the Cold Intermediate Layer in Wilkinson Basin were much warmer and more saline than average (Fig. 17 & 18). Similarly, Georges Basin and the Northeast Channel were flooded with warm, salty water (Fig. 18). Vertical mixing during winter is an important process in the Western Gulf of Maine. Deeper mixing has greater potential to tap into nutrient rich slope water at depth resulting in a thicker intermediate layer during spring, both potentially having an impact on the timing or intensity of spring phytoplankton blooms.

Impacts

Our in situ observations continue to show that the Northeast U.S. Continental Shelf has been warming at a rate of ~.03-.05 °C/year since 1977, with significant interannual variations in temperature and salinity superimposed on this trend. As a result, the habitats of fish and invertebrate species in this region have experienced change on a variety of temporal and spatial scales, driving changes in distribution and abundance. Observations suggest that the NEUS Continental Shelf is being influenced more frequently by the Gulf Stream (Gawarkiewicz et al., 2018) and that the increased interactions may be related to changes in the meandering character of the current (Andres, 2016) and an increase in the frequency of warm core ring formation by the Gulf Stream (Gangopadhyay, et al., 2019). Northward shifts in the Gulf Stream path (NEFSC State of the Ecosystem Report, 2022) and extreme diversions and meanders in its path (e.g. Gawarkiewicz et al., 2012) and detached Gulf Stream Warm Core Rings (e.g. Zhang and Gawarkiewicz, 2015) directly and indirectly influence the hydrography on the shelf, often leading to intrusions of comparatively warm and salty water onto the shelf. These episodic intrusions have the potential to cause significant changes in the ecosystem, for instance leading to significant changes in nutrient loading on the shelf, the seasonal elimination of critical habitats such as the cold pool and shelf-slope front, disruption of seasonal migration cues, and an increase in the concentration of offshore larval fish on the shelf.

Summary

- Waters on the Northeast U.S. Continental Shelf were warmer than average in 2021
- Extreme warm anomalies were observed in the northern Middle Atlantic Bight linked to shoreward incursions of the shelf-slope front
- In the western Gulf of Maine, the Cold Intermediate Layer was warmer than normal, and the underlying water mass in Wilkinson Basin warmer and saltier than normal.
- Deep waters entering the Gulf of Maine continue to be warm and salty, marking two decades that southern source waters have dominated the slope water composition in the region

References

Andres, M., 2016. On the recent destabilization of the Gulf Stream Path downstream of Cape Hatteras, *Geophysical Research Letters*. 43, doi:10.1002/2016GL069966.

Davis, X., T.M. Joyce, and Y-O. Kwon, 2017. Prediction of silver hake distribution on the Northeast U.S. shelf based on the Gulf Stream path index. *Continental Shelf Research*, 138, 61-64.

Gangopadhyay, A., G. Gawarkiewicz, E.N.S. Silva, M. Monim and J. Clark, 2019. An observed regime shift in the formation of Warm Core Rings from the Gulf Stream, Scientific Reports, 9, 12319 (2019). https://doi.org/10.1038/s41598-019-48661-9.

Gawarkiewicz, G. G., R. E. Todd, A. J. Plueddemann, M. Andres, and J. P. Manning, 2012. Direct interaction between the Gulf Stream and the shelfbreak south of New England, *Scientific Reports*, 2(553), doi:10.1038/srep00553.

Gawarkiewicz, G., R.E. Todd, W. Zhang, J. Partida, A. Gangopadhyay, M.-U.-H. Monim, P. Fratantoni, A. Malek Mercer, and M. Dent. 2018. The changing nature of shelfbreak exchange revealed by the OOI Pioneer Array. *Oceanography* 31(1): 60–70, https://doi.org/10.5670/oceanog.2018.110.

Holzwarth TJ and Mountain DG. 1990. Surface and Bottom Temperature Distributions from the Northeast Fisheries Center Spring and Fall Bottom Trawl Survey Program, 1963- 1987. NEFSC Reference Document 90-03, 62 pp.

Hurrell JW. 1995. Decadal trends in the North Atlantic Oscillation and relationships to regional temperature and precipitation. *Science*. 269, 676-679.

ICES Report on Ocean Climate (Highlights), 2022. https://ocean.ices.dk/iroc/#.

NEFSC State of the Ecosystem Report for the Mid-Atlantic, 2022. https://www.fisheries.noaa.gov/new-england-mid-atlantic/ecosystems/state-ecosystem-reports-northeast-us-shelf

Petrie, B., 2007. Does the North Atlantic Oscillation Affect Hydrographic Properties on the Canadian Atlantic Continental Shelf? *Atmosphere-Ocean*, 45, 141-151.

Visbeck, M., E.P. Chassignet, R. Curry, T. Delworth, B. Dickson and G. Krahmann, 2003. The Oceans's Response to North Atlantic Osciallation Variability, In: J. Hurrell, Y. Kushner, G. Ottersen and M. Visbeck (Eds.), *The North Atlantic Oscillation: Climatic Significance and Environmental Impact*. Geophysical monograph 134, Washington: American Geophysical Union, pp. 113-145.

Zhang, W. G. and G. G. Gawarkiewicz, 2015. Dynamics of the direct intrusion of Gulf Stream ring water onto the Mid-Atlantic Bight Shelf, *Geophys. Res. Lett.,* 42, 7687-7695, doi:10.1002/2015GL065530.

World Meteorological Organization (WMO), 2021. Updated 30-year reference period reflects changing climate. https://public.wmo.int/en/media/news/updated-30-year-reference-period-reflects-changing-climate.

Table 1. Inventory of hydrographic monitoring on the Northeast U.S. Shelf during 2021

Sub-area	Division(s)	Month(s)	Type[1]	Description	Station count
4	X	5	S	Bottom trawl survey	22
4	X	5	S	Ecosystems monitoring survey	13
4	X	8	S	Ecosystems monitoring survey	20
4	X	11	S	Bottom trawl survey	21
5	Y,Z	3,4,5	S	Bottom trawl survey	189
5	Y,Z	3	O	North Atlantic Right Whale	11
5	Y,Z	5	S	Ecosystems monitoring survey	83
5	Y,Z	6,7	O	Sea scallop survey	21
5	Y,Z	8	S	Ecosystems monitoring survey	126
5	Y,Z	8	O	North Atlantic Right Whale	21
5	Y,Z	9,10,11	S	Bottom trawl survey	193
5	Y,Z	10	S	Ecosystems monitoring survey	44
6	A,B,C	3,4	S	Bottom trawl survey	112
6	A,B,C	5	S	Ecosystems monitoring survey	30
6	A,B,C	5	O	Apex Predator survey	7
6	A,B,C	8	S	Ecosystems monitoring survey	28
6	A,B,C	9,10	S	Bottom Trawl survey	147
6	A,B,C	10	S	Ecosystems monitoring survey	58

[1] Sampling design: S refers to stratified-random and O to other survey designs.

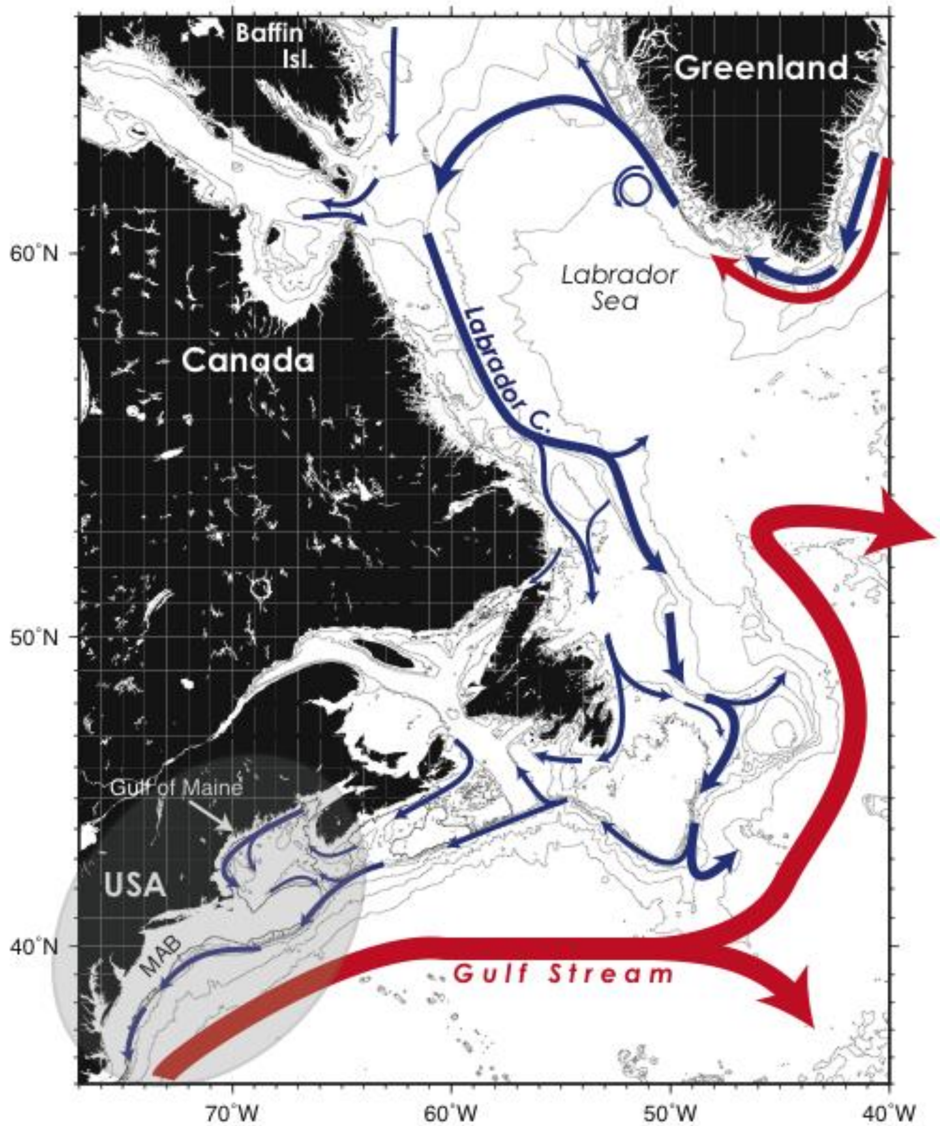

Figure 1a. Circulation schematic of the western North Atlantic. The Northeast U.S. Shelf region is identified by the shaded oval. The 100, 200, 500, 1000, 2000, 3000 and 4000 meter isobaths are shown.

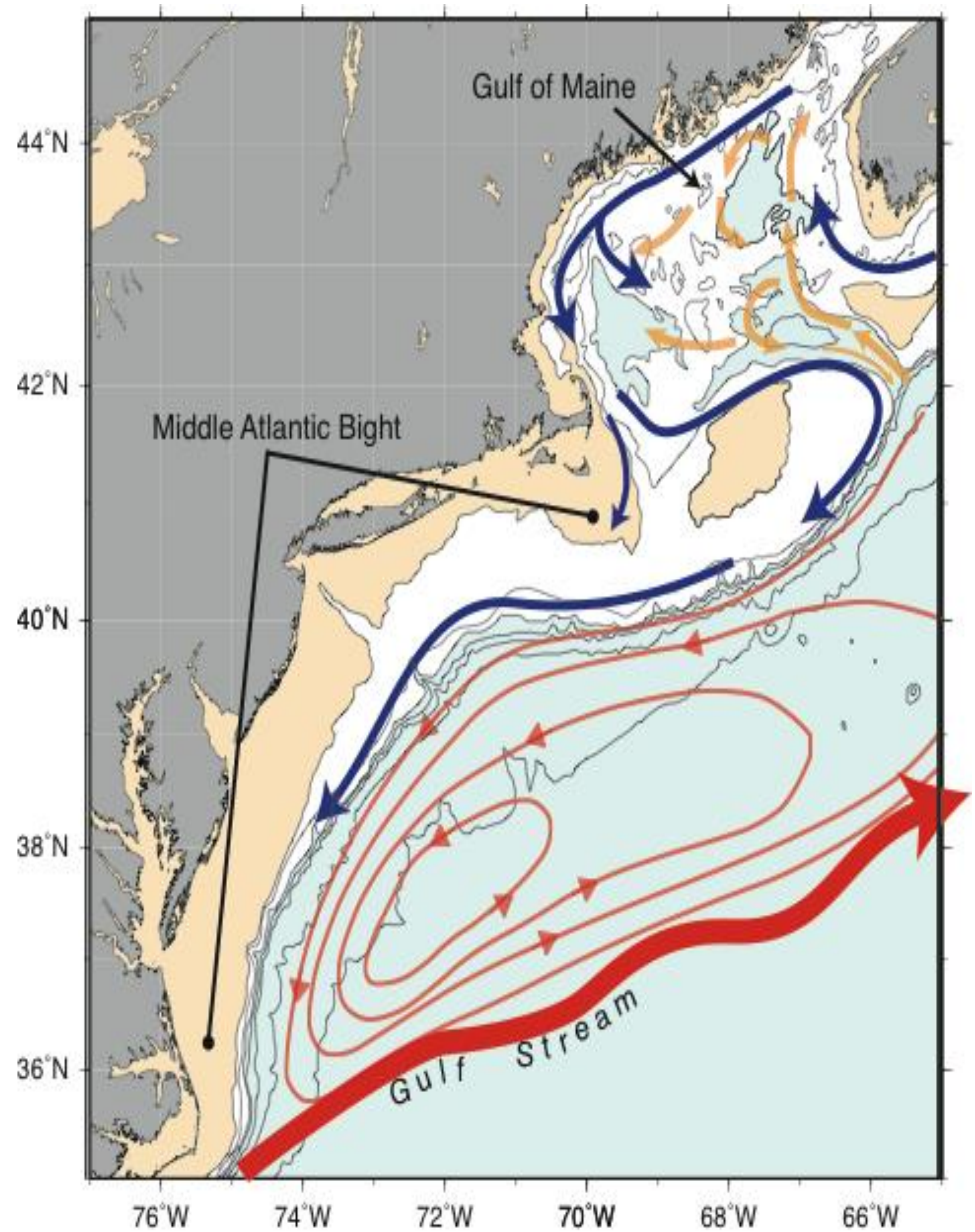

Figure 1b. Circulation schematic for the Northeast U.S. Shelf region, where blue arrows represent shelf water circulation and orange arrows represent deeper slope water circulation pathways. Water depths deeper than 200 meters are shaded blue. Water depths shallower than 50 meters are shaded tan.

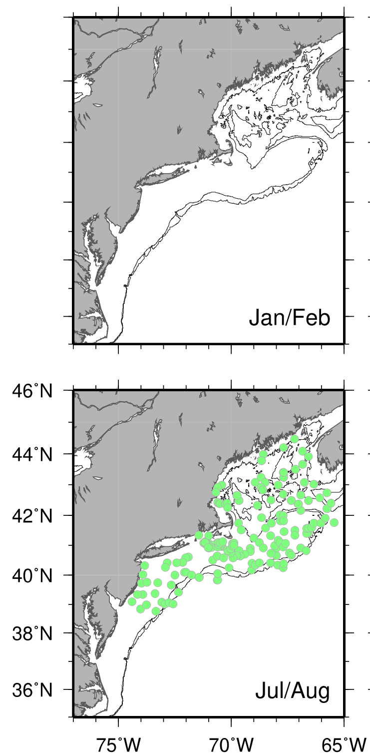

Figure 2. Distribution of hydrographic stations occupied in 2021. Contours show the 100 m and 200 m isobaths.

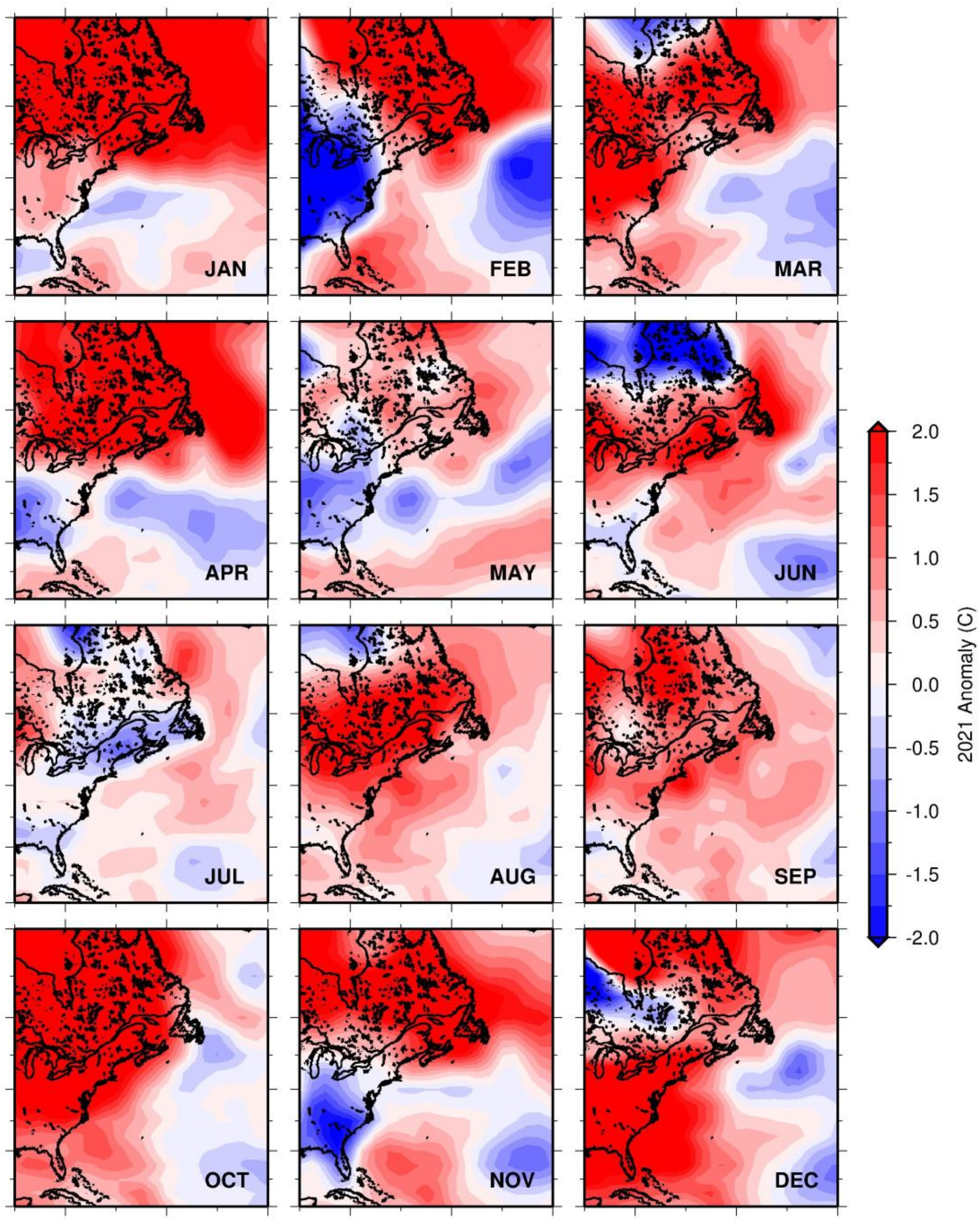

Figure 3. Surface air temperature anomaly derived from the NCEP/NCAR Reanalysis product (http://www.esrl.noaa.gov/psd/data/composites/day/). Positive anomalies correspond to warming in 2021 relative to the reference period (1991-2020).

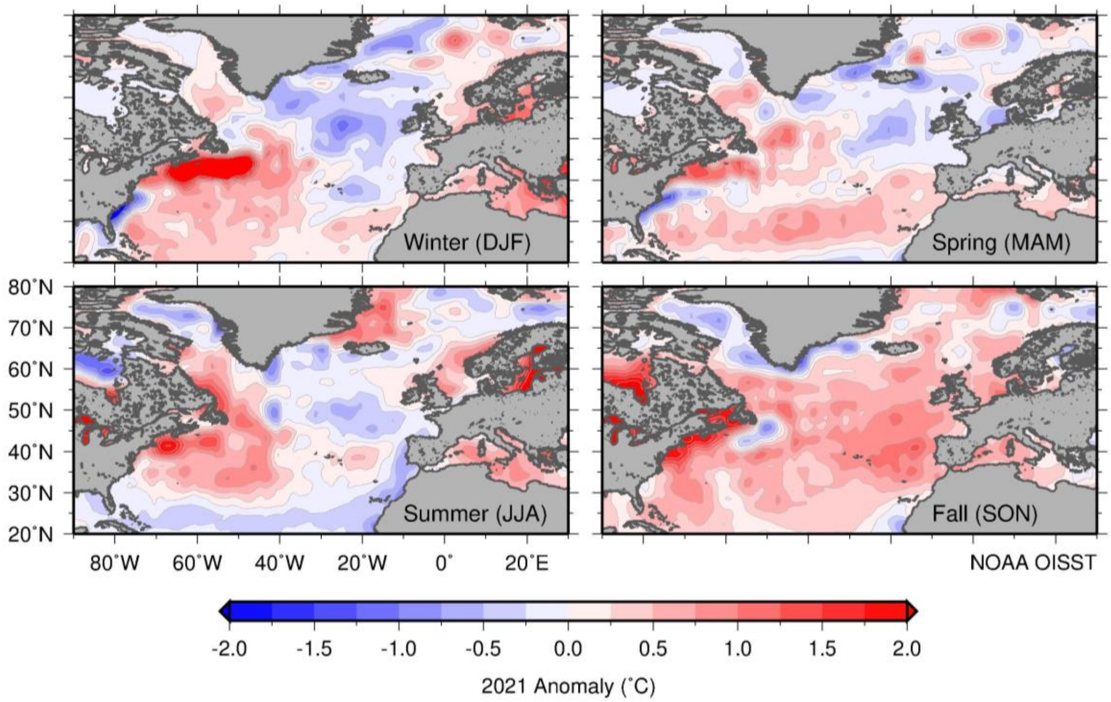

Figure 4. Sea surface temperature anomaly derived from the NOAA's Optimum Interpolation (OI) SST product (http://www.esrl.noaa.gov/psd/data/gridded/data.noaa.oisst.v2.html). Seasons are made up of 3-month periods where winter spans December-February. Positive anomalies correspond to warming in 2021 relative to the reference period (1991-2020).

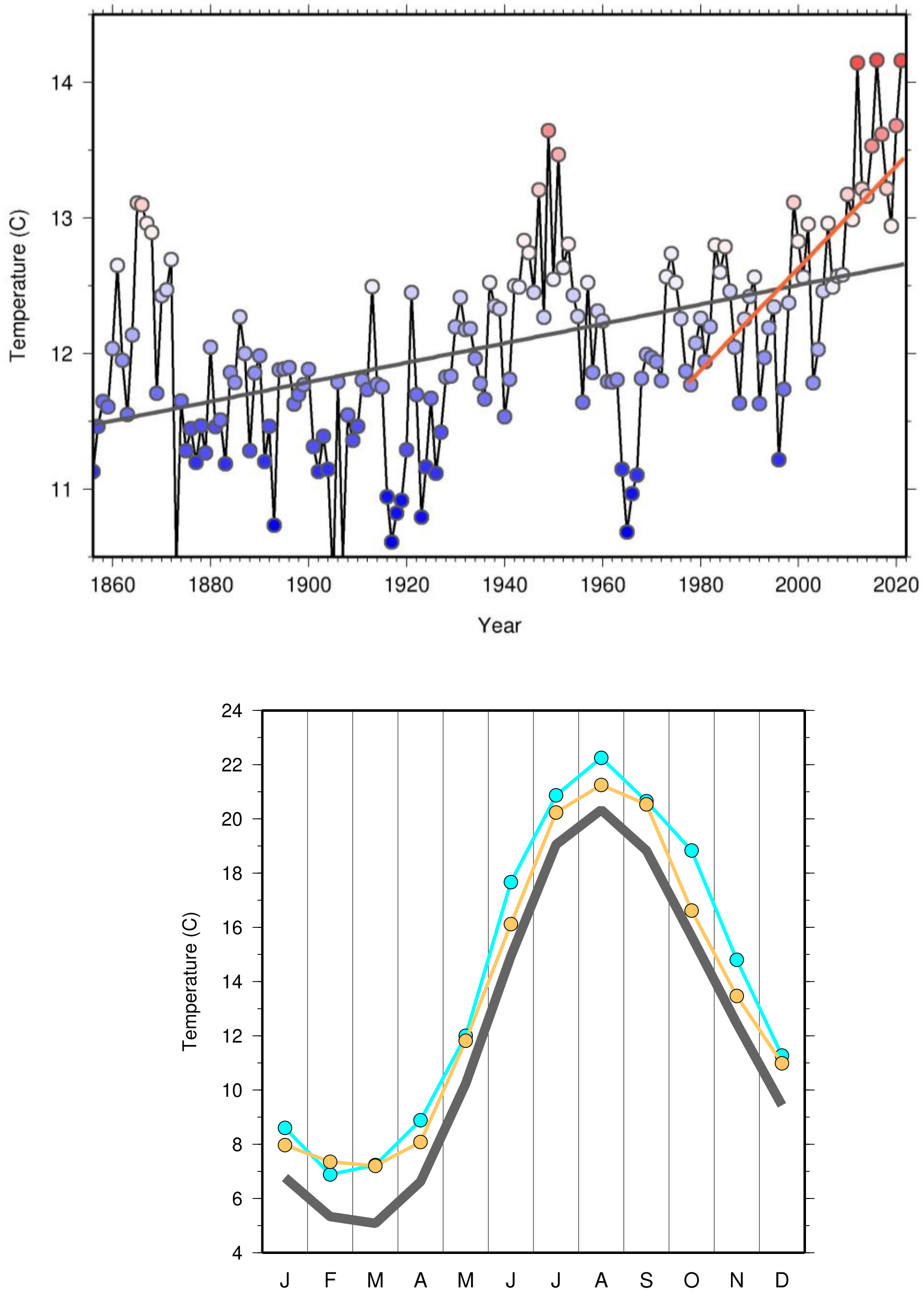

Figure 5. Top: Regional average annual sea surface temperature for the NEUS shelf region calculated from NOAA's extended reconstructed sea surface temperature product (http://www.esrl.noaa.gov/psd/data/gridded/data.noaa.ersst.html). Colors correspond with the anomaly scale in Figure 4. Bottom: Regional average monthly mean SST for the NEUS shelf for 2021 (cyan), 1951 (orange) and 1991-2020 (gray) calculated from the same product.

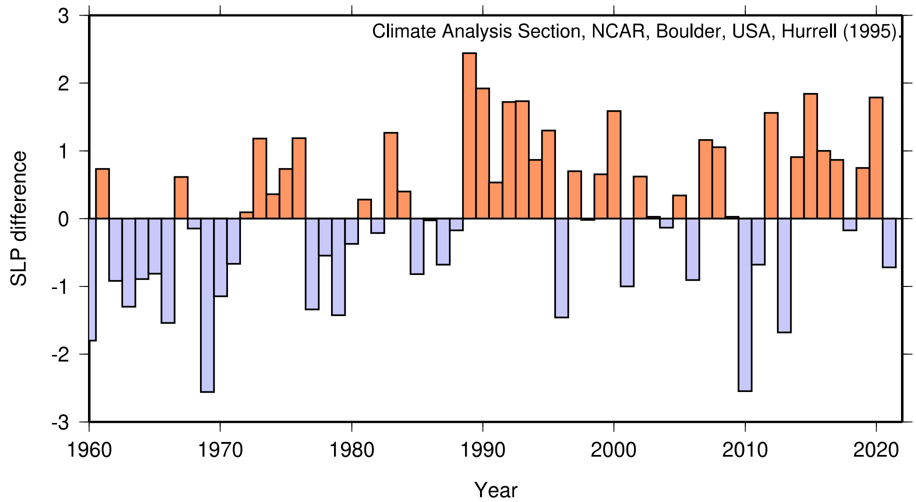

Figure 6. North Atlantic Oscillation index computed from principal component analysis of sea level pressure in the North Atlantic (see Hurrell, 1995).

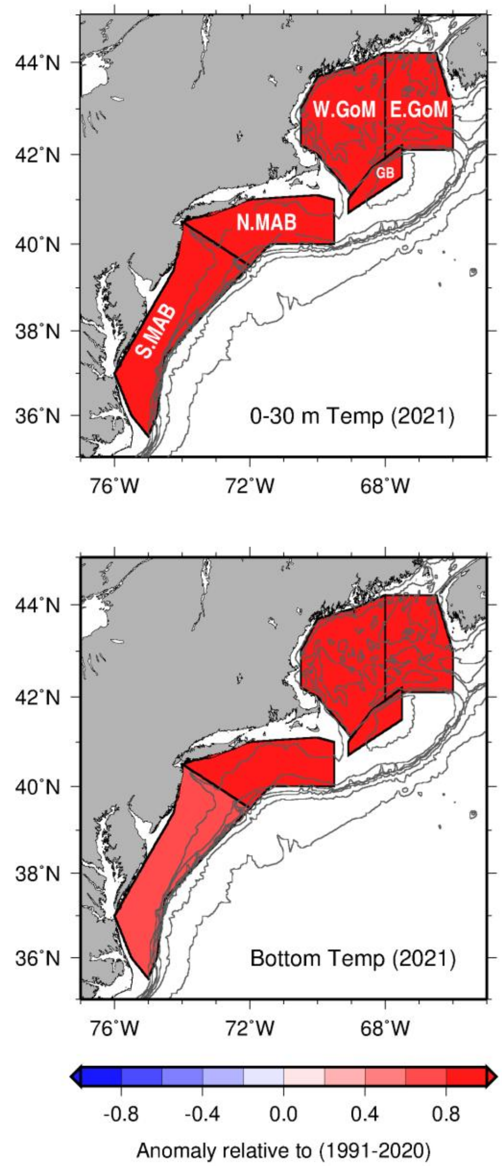

Figure 7. Surface (upper panel) and bottom (lower panel) regional annual temperature anomaly (°C). Positive anomalies correspond to warming in 2021 relative to the reference period (1991-2020). The region labels correspond to the panels in Figure 8.

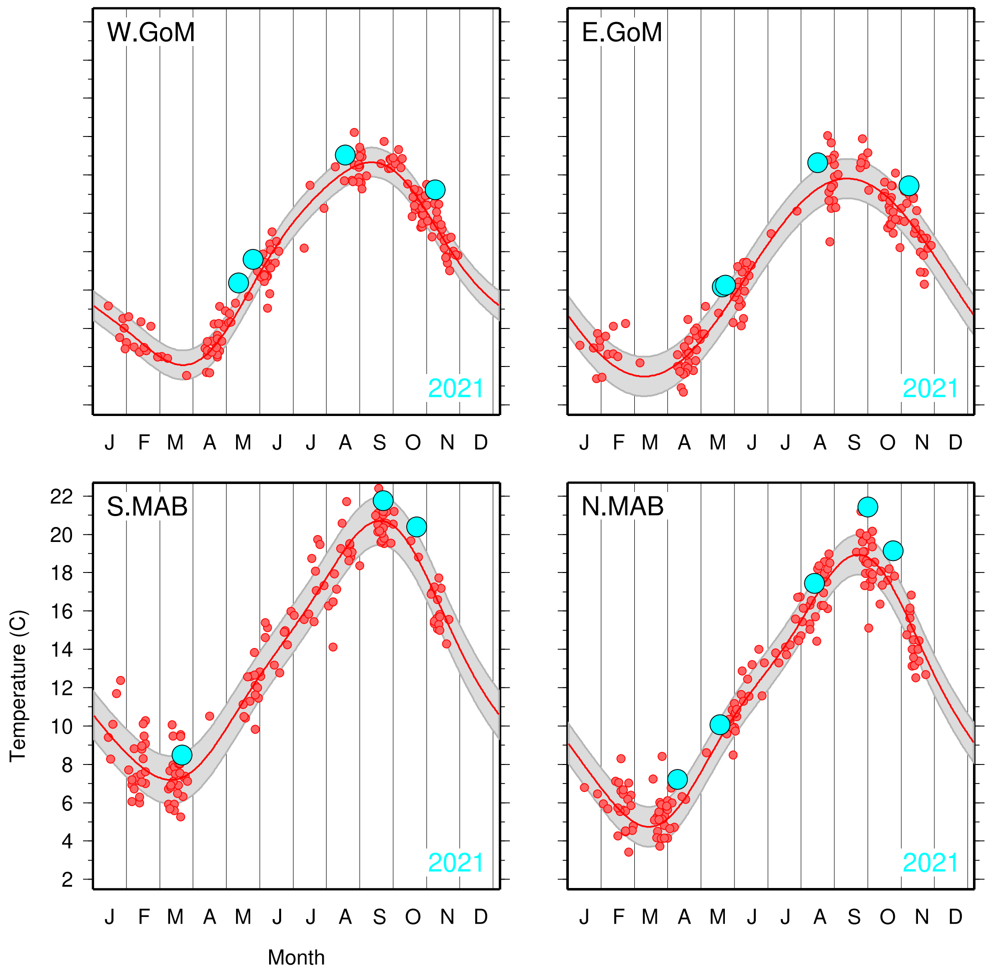

Figure 8a. Regional average 0-30 meter temperature (°C) as a function of calendar day. Each dot represents a volume-weighted average of all observations from a single survey falling within the regions delineated in Fig. 7. An annual harmonic fit to the regional average temperatures from 1991-2020 is shown by the red curve with the points contributing to the fit also shown in red. The gray shading depicts one standard deviation around this fit. The regional average temperatures from 2021 surveys are shown in cyan.

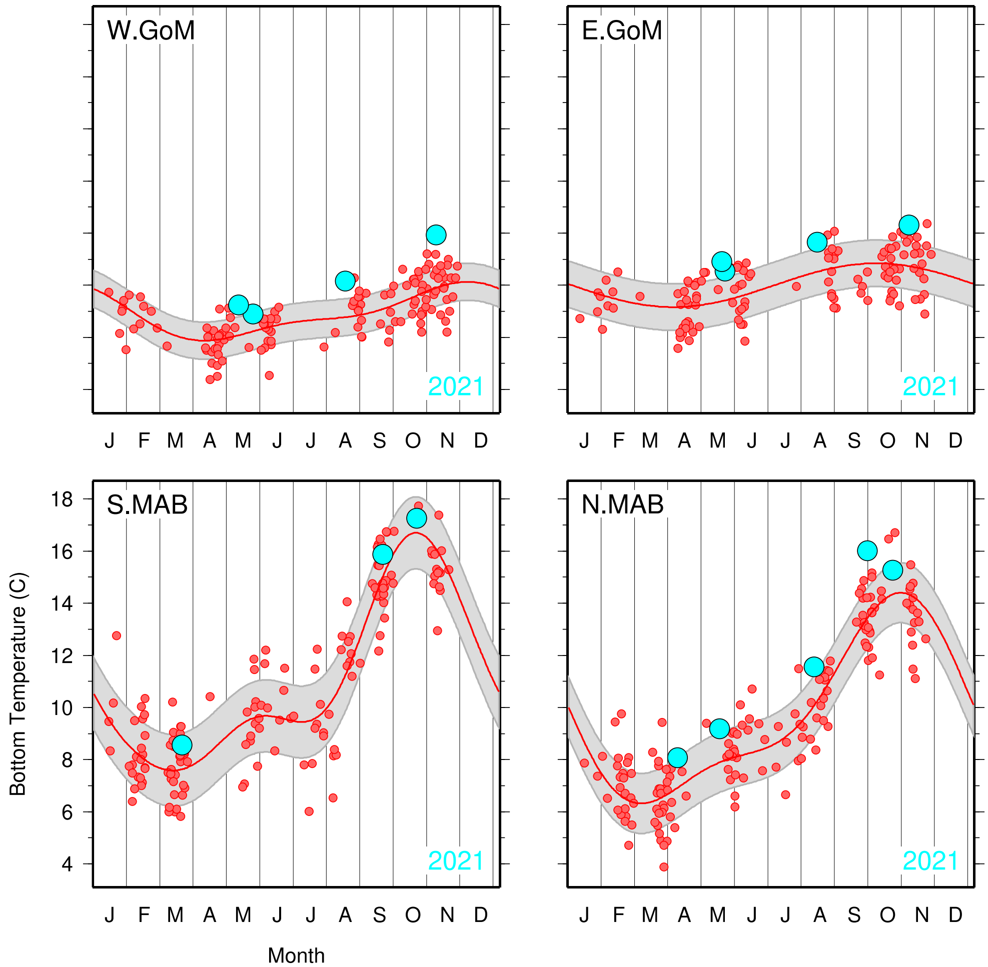

Figure 8b. As in Fig. 8a, but for bottom temperatures.

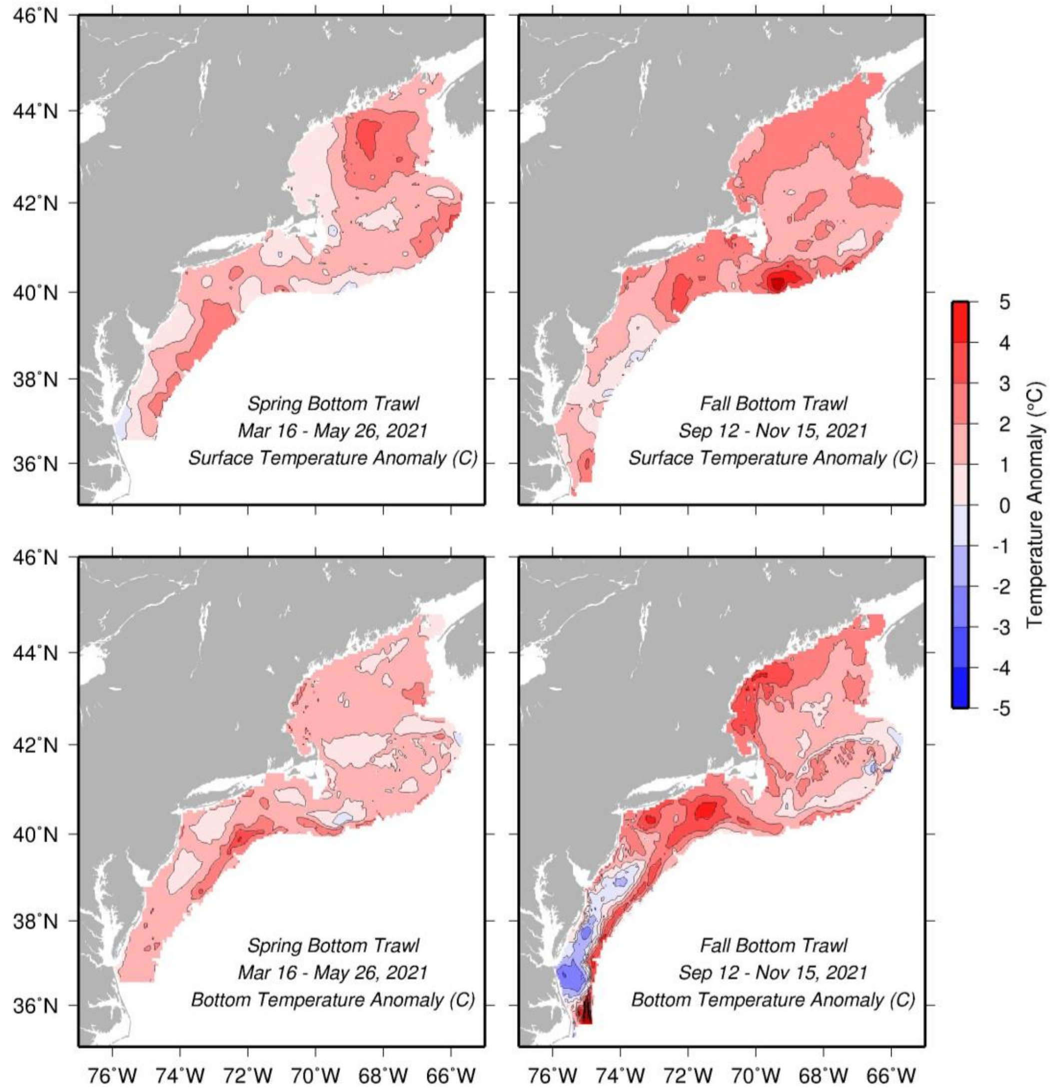

Figure 9. Surface (upper panels) and bottom (lower panels) temperature anomaly from the spring 2021 (left) and fall 2021 (right) ground fish surveys. Positive anomalies correspond to warming in 2021 relative to the reference period (1991-2020).

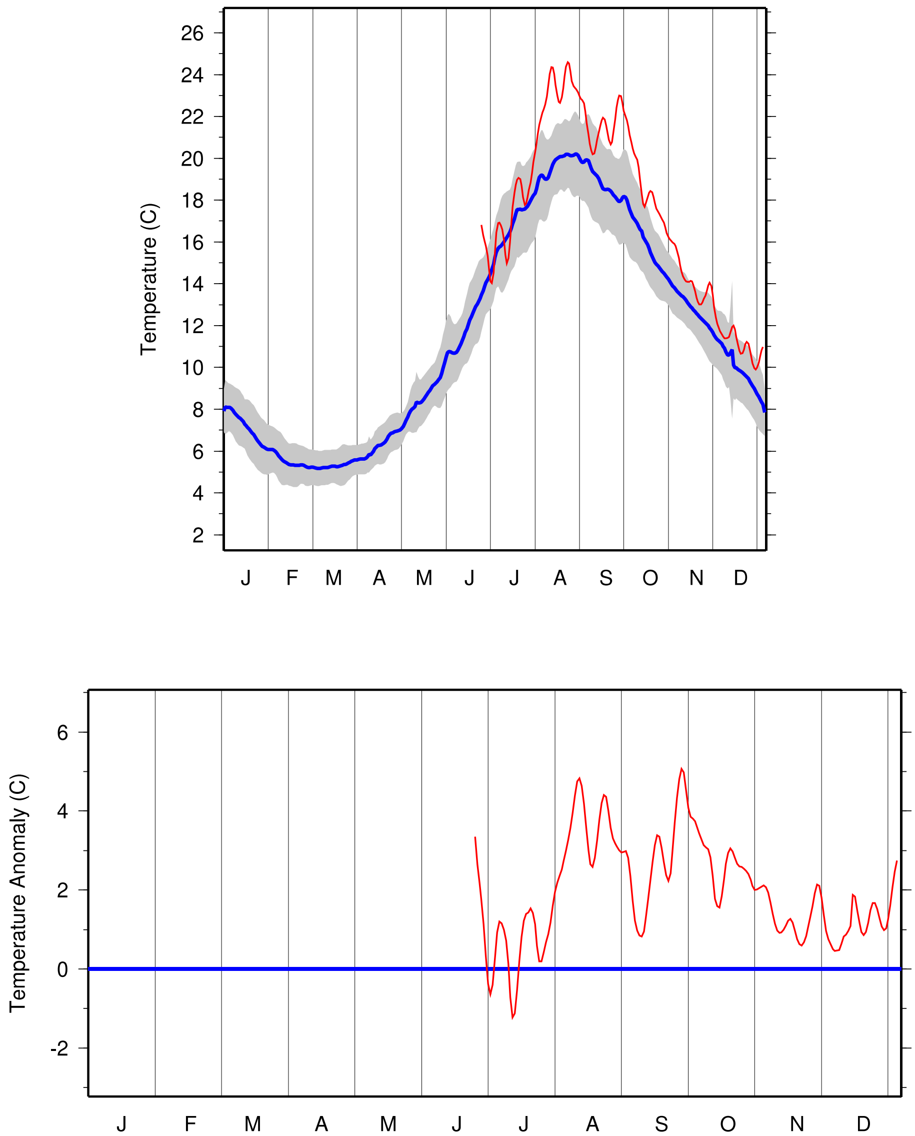

Figure 10. (top) Time series of surface ocean temperature from NDBC buoy 44008 located south of Nantucket Shoals in the northern Middle Atlantic Bight. Temperatures observed in 2021 (red) are compared with average temperatures (1991-2020, blue) in the top panel. The gray shading indicates one standard deviation about the long-term mean. The lower panel shows the difference between 2021 and the long-term mean temperature, where positive values indicate warmer conditions in 2021.

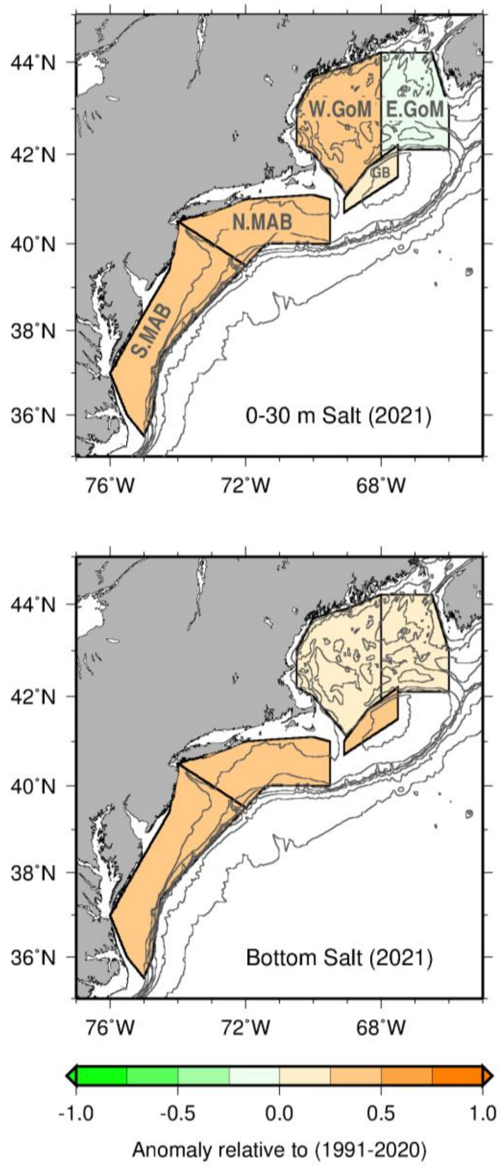

Figure 11. Surface (upper panel) and bottom (lower panel) regional annual salinity anomaly. Positive anomalies correspond to more saline conditions in 2021 relative to the reference period (1991-2020). The region labels correspond to the panels in Figure 12.

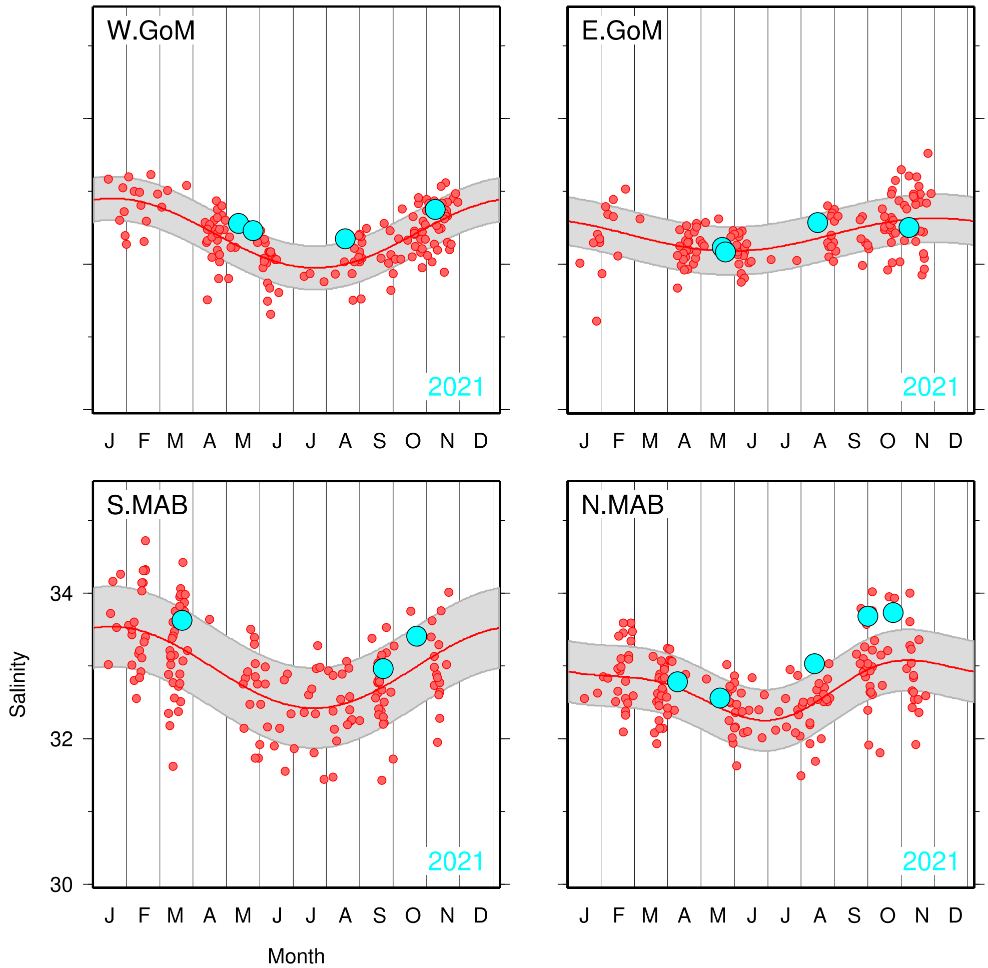

Figure 12a. Regional average 0-30 meter salinity as a function of calendar day. Each dot represents a volume-weighted average of all observations from a single survey falling within the regions delineated in Fig. 11. An annual harmonic fit to the regional average salinities from 1991-2020 is shown by the red curve with the points contributing to the fit also shown in red. The gray shading depicts one standard deviation around this fit. The regional average salinities from 2021 surveys are shown in cyan.

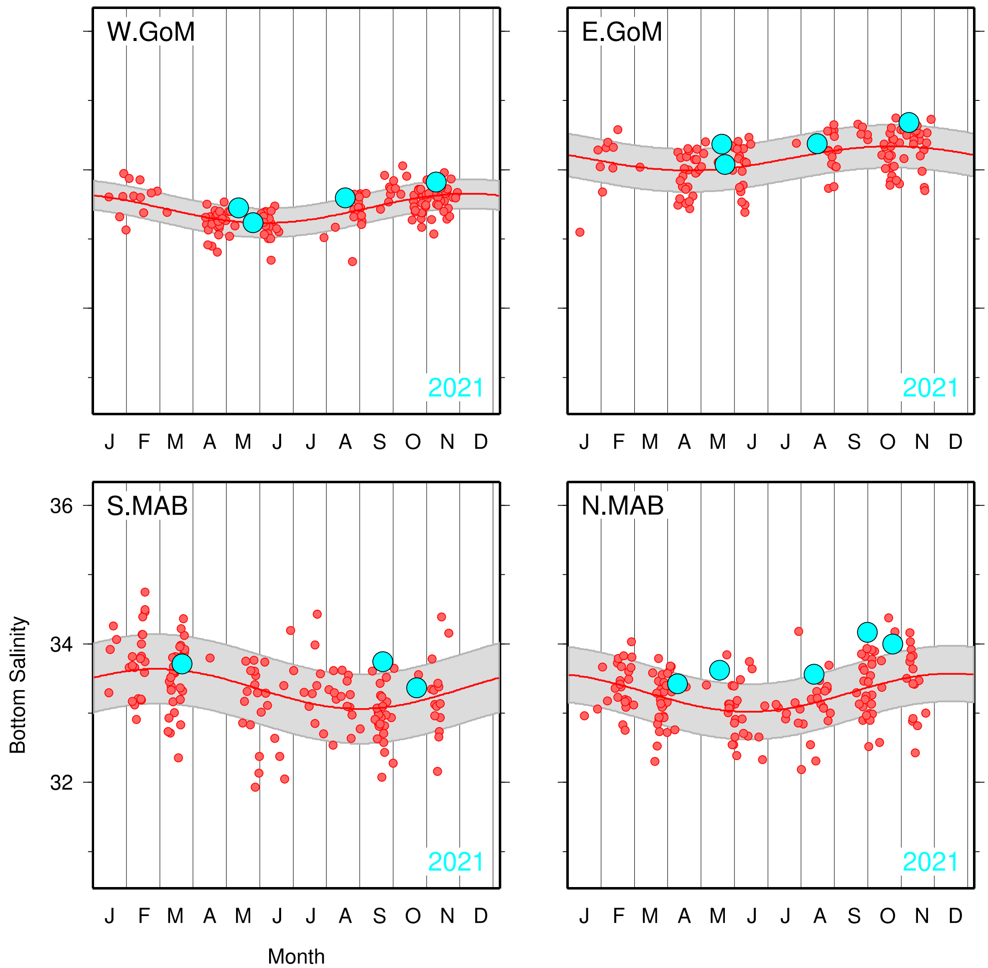

Figure 12b. As in Fig. 12a, but for bottom salinities.

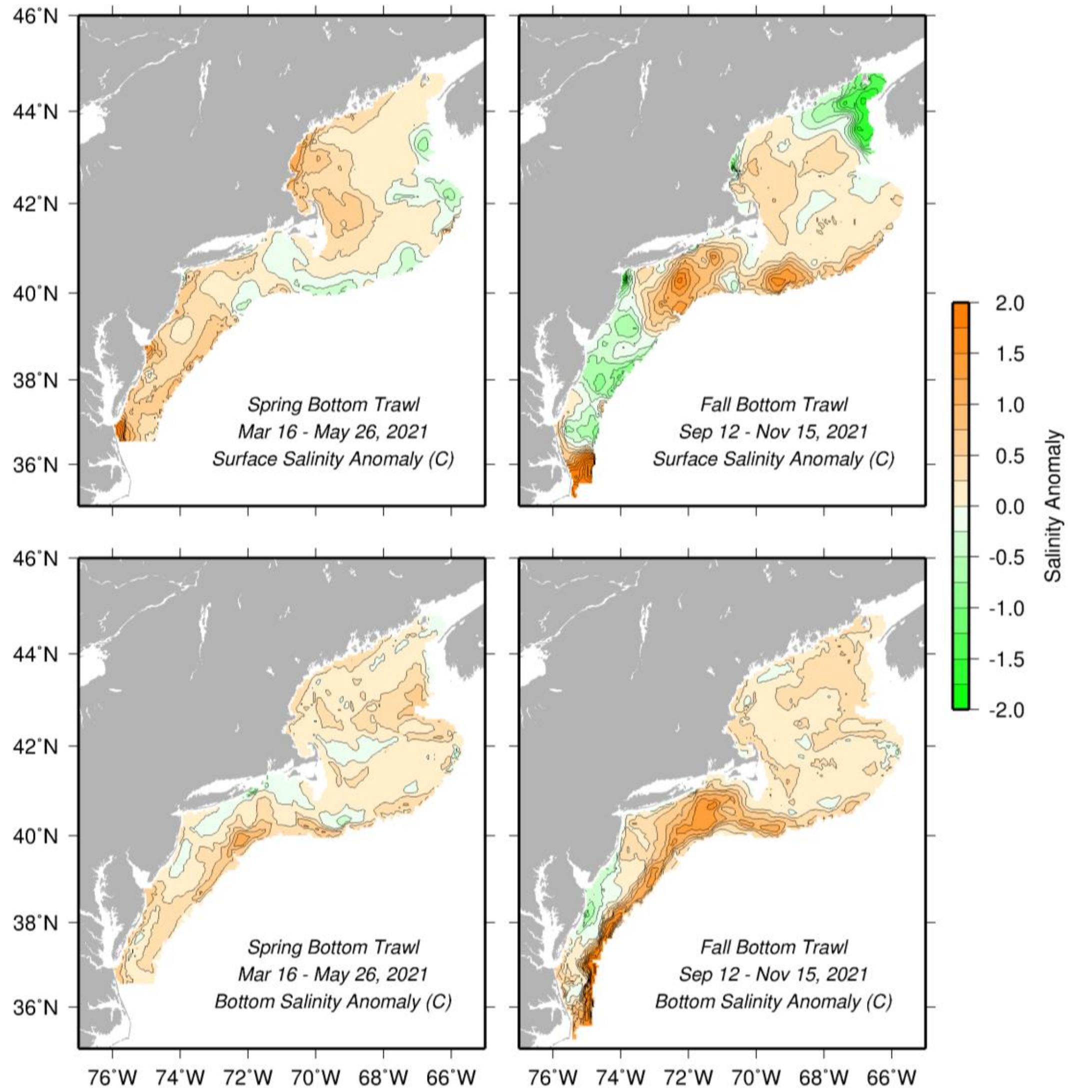

Figure 13. Surface (upper panels) and bottom (lower panels) salinity anomaly from the spring 2021 (left) and fall 2021 (right) ground fish surveys. Positive anomalies correspond to more saline conditions in 2021 relative to the reference period (1991-2020).

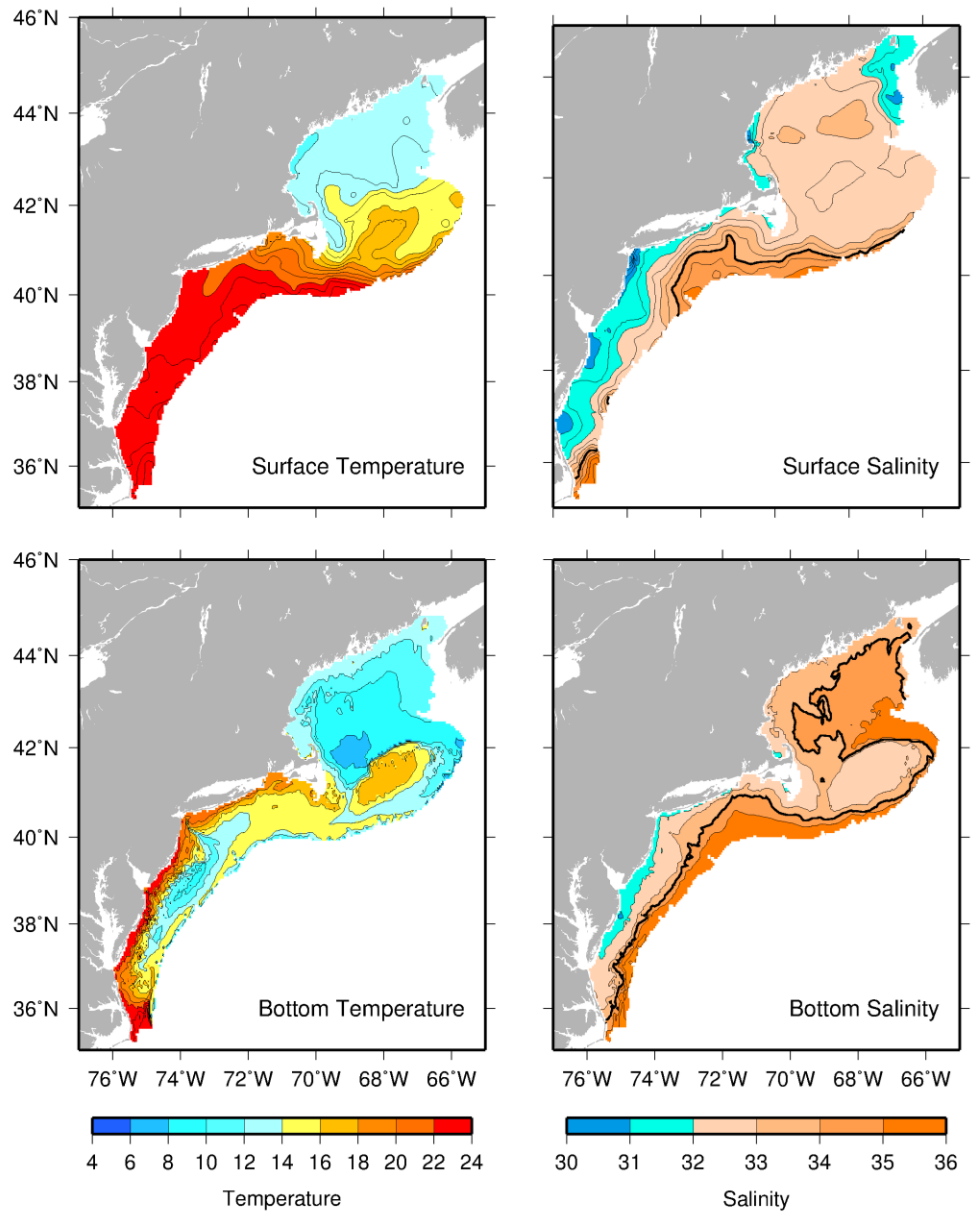

Figure 14. Surface (upper panels) and bottom (lower panels) temperature (left) and salinity (right) distribution from the fall 2021 ground fish surveys (Sep 12 – Nov 15, 2021). The heavy black contour shows the 34 isohaline, typically associated with the center of the shelf-slope front.

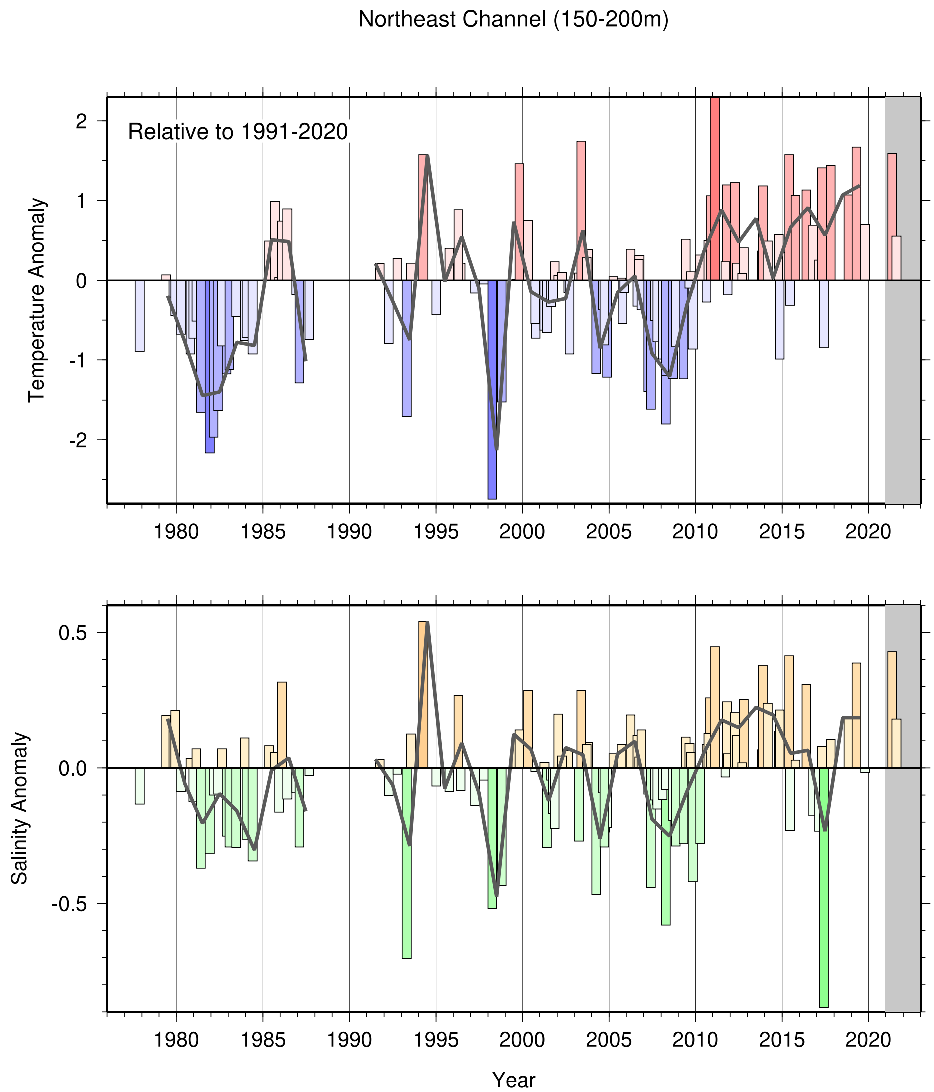

Figure 15. Time series of temperature and salinity anomaly in the deep Northeast Channel. Each bar represents a volume-weighted average of all observations from a single survey collected between 150-200 meters in the Northeast Channel. The grey curve shows the annual average anomaly time series. Positive values are warmer and saltier than the long-term mean calculated for 1991-2020. The gray shading highlights sampling done in 2021.

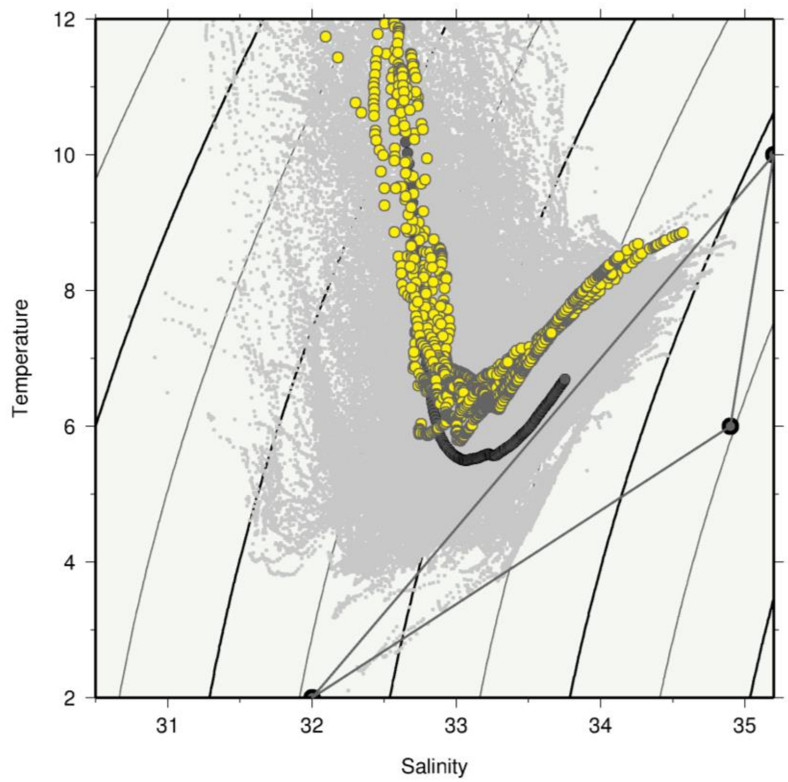

Figure 16. Temperature-salinity diagram showing water properties in Wilkinson Basin in the western Gulf of Maine. All observations from May (yellow) 2021 are shown along with the spring climatological average profile (1991-2020, dark gray). The lightest gray dots show the historical range encompassed 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.

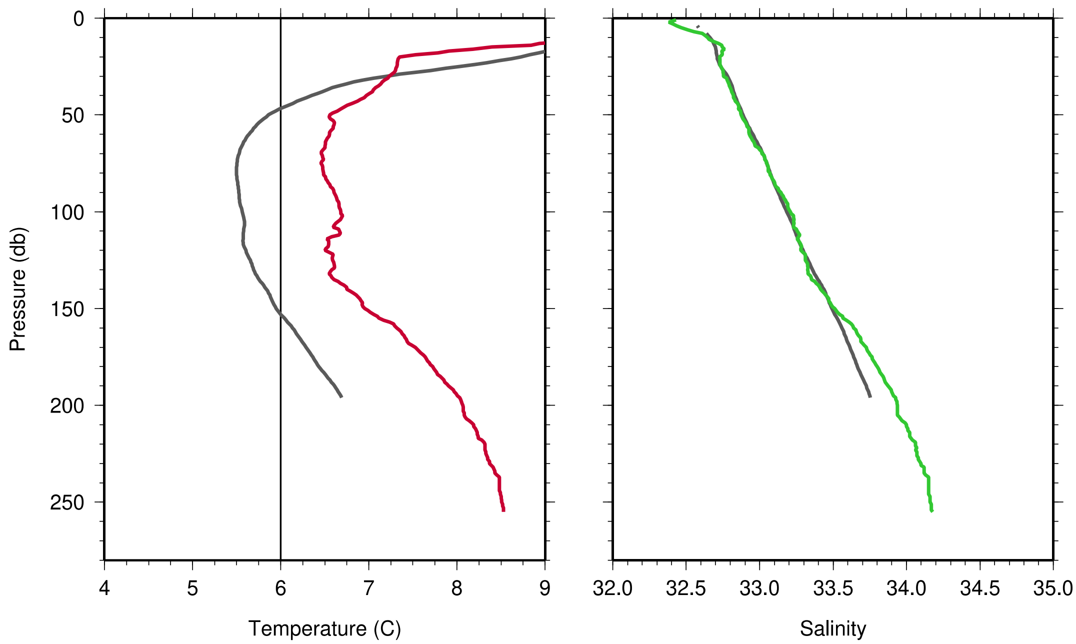

Figure 17. Average profiles of temperature (left) and salinity (right) from repeated observations collected during May in Wilkinson Basin in the western Gulf of Maine. All observations from May 2021 (red and green) are shown along with the climatological average profile for the same month (1991-2020, 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.

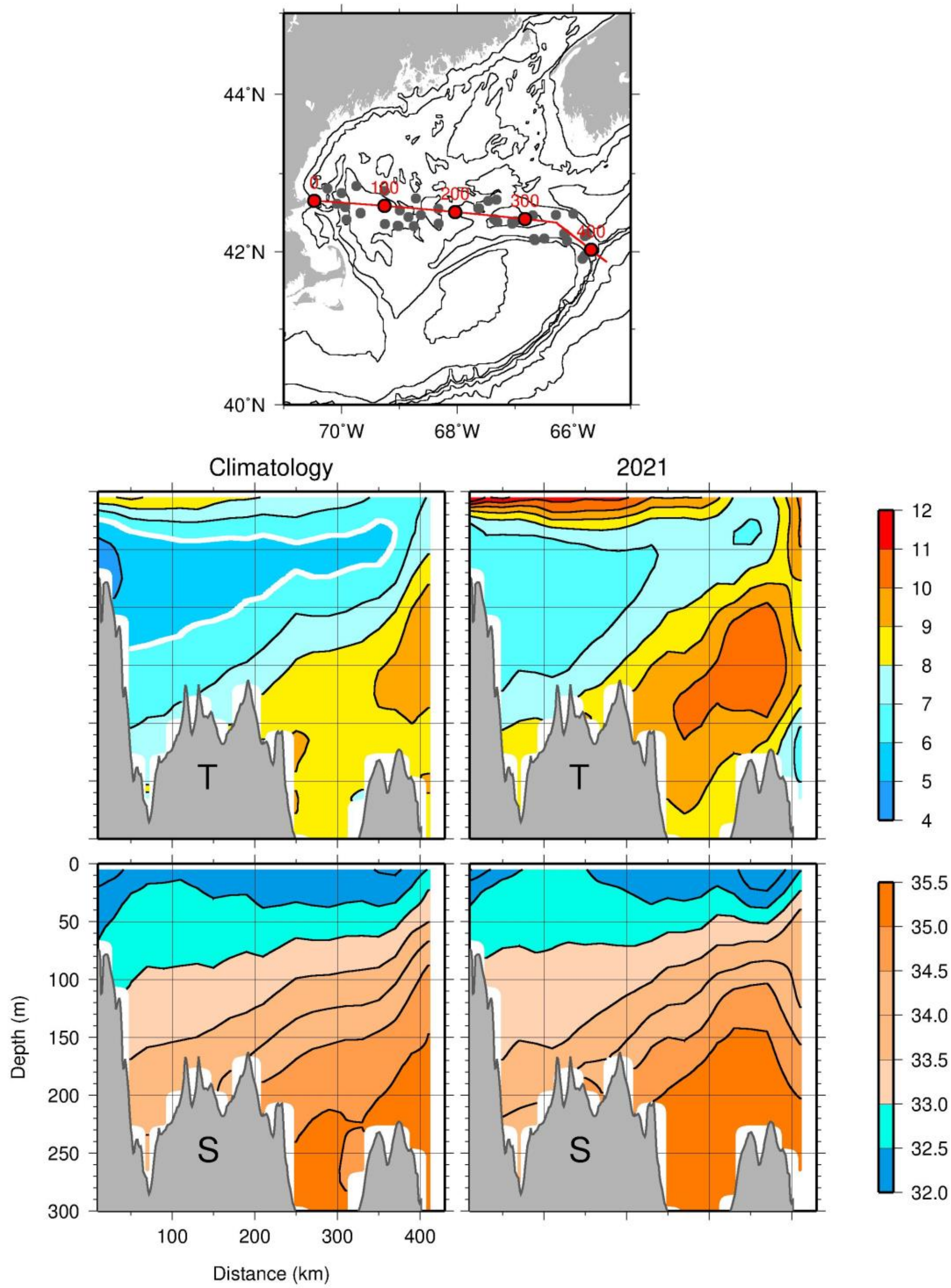

Figure 18. Vertical sections of temperature (top) and salinity (bottom) crossing the Gulf of Maine along a zonal transect shown in the map. The left panels show the climatological average for May spanning the years 1991-2020. The right panels show the synoptic mean section for May 2021. The heavy white contour highlights the 6°C isotherm as an indicator of the boundary of the Cold Intermediate Layer. Along-transect distances and the May 2021 station distribution are shown on the map for reference.