NOT TO BE CITED WITHOUT PRIOR
REFERENCE TO THE AUTHOR(S)

Northwest Atlantic Fisheries Organization

Serial No. N6798 **NAFO SCR Doc. 18/014**

SCIENTIFIC COUNCIL MEETING – JUNE 2018

Hydrographic Conditions on the Northeast United States Continental Shelf in 2017 – NAFO Subareas 5 and 6

Paula Fratantoni
NOAA National Marine Fisheries Service
Northeast Fisheries Science Center
166 Water Street, Woods Hole, MA, 02543 USA

Abstract

An overview is presented of the atmospheric and oceanographic conditions on the Northeast U.S. Continental Shelf during 2017. 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, 2017 was characterized by warmer than average conditions across the region. Fall water temperatures were notably warm, consistent with anomalously warm air temperatures. The upper 30 meters throughout the Middle Atlantic Bight were more saline than normal, particularly during winter and spring, while surface waters in the Gulf of Maine were regionally delineated, with persistent salty conditions in the east and fresh conditions in the west. Observations indicate that rings and eddies in the Slope Sea facilitated cross-shelf flow, setting up localized anomalies in the northern Middle Atlantic Bight during spring and in the deep Northeast Channel during early summer. Overall, deep (slope) waters entering the Gulf of Maine were predominantly warmer and saltier than average, and their temperature and salinity suggest a subtropical source. Near bottom waters in the eastern Gulf of Maine were more than one standard deviation warmer and saltier than average throughout the year, while the western Gulf of Maine was consistently warm and fresh. Warm winter air temperatures and late onset storms suppressed winter mixing in the western Gulf of Maine, leading to a warmer Gulf of Maine intermediate water mass.

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. However, ship maintenance issues in 2017 led to the elimination of the summer Ecosystem Monitoring (EcoMon) Survey and truncation of the fall ground fish and EcoMon surveys. While reinstatement of the winter EcoMon survey saw a return to winter sampling for the first time in 4 years, overall roughly half as many stations were occupied, leading to a loss of seasonal resolution.

During 2017, hydrographic data were collected on 8 individual NEFSC cruises, amounting to 1146 profiles of temperature and salinity and 1085 in NAFO subareas 4, 5 and 6 (Table 1). Data were collected aboard the NOAA ships *Henry Bigelow, Pisces* and *Gordon Gunter,* and the R/V *HR Sharp* using a combination of Seabird Electronics SBE-19+ SEACAT profilers and SBE 9/11 CTD units. All processed hydrographic data, cruise reports and annual hydrographic summaries are accessible at: http://www.nefsc.noaa.gov/epd/ocean/MainPage/index.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. 6 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 1981-2010. The reference period corresponds with the standard recommended by the World Meteorological Organization. Anomalies are defined as the difference between the observed 2017 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 2017

Surface air temperatures were warmer than average (1981-2010) over the western North Atlantic basin during winter and fall. (Fig. 2). A series of late-winter storms resulted in anomalously cold air temperatures over the NEUS Shelf in March, ending a 10-month streak of warm anomalies. Air temperatures were weakly negative between May and August, while anomalously warm conditions returned in autumn. Sea surface temperature mirrored these patterns, with warmer than average SST over the NEUS Shelf during winter and fall (Fig. 3). Annually, the magnitude of the warming was comparable to that observed in the 1950s (Fig 4).

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 so-called 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 NAO index was positive for the fourth consecutive year during the winter of 2017, the first persistent positive NAO observed since the early 1990s (Fig. 5). While this is indicative of a deepening of the Icelandic low and a strengthening of the Azores high, the 2017 distribution of sea level pressure anomalies did not resemble the pattern typically observed under positive NAO conditions (IROC, 2018). A positive NAO is typically associated with stronger northwesterly winds over the shelves, warmer bottom waters in the Gulf of Maine, a northward shift in the Gulf Stream, and a predominance of Warm Slope Water in the Northeast Channel (Petrie, 2007; Mountain, 2012; Joyce *et al.*, 2000). However, wind anomalies were more northerly over the Labrador Sea as a result of the sea level pressure anomaly pattern (IROC, 2018).

Hydrographic Conditions in 2017

Relative to historical values, regional ocean temperatures across the NEUS shelf were warm during 2017 (Fig. 6). Annually, waters in the upper 30 meters were between 0.9-1.2°C warmer than normal everywhere. Of the seasons sampled, warming was most pronounced during fall in the Middle Atlantic Bight and Gulf of Maine, where regional temperature anomalies approached 2°C (Fig. 7a). Extremely warm conditions were also observed near the bottom across the entire region, with anomalies exceeding those at the surface in most seasons (Fig. 7b). During fall, the bottom temperature measured more than one standard deviation above normal across the entire NEUS Shelf, while similarly large anomalies were observed near bottom in the eastern Gulf of Maine year-round. The exception was during March and April in the northern Middle Atlantic Bight, where cold anomalies were observed near the bottom. The details of the seasonal differences are revealed in synoptic maps compiled from the spring and fall ground fish surveys (Fig 8). Warm anomalies were pervasive across the Gulf of Maine at the surface and bottom during fall. Whereas, in spring, a mix of warm and cold anomalies were observed at the surface across the NEUS while notably cold anomalies were observed in the Middle Atlantic Bight near the bottom at the shelf edge during March and April (Fig 8). Time series observations of near-surface temperature from NDBC buoy 44008, located south of Nantucket Shoals, observed near normal conditions during spring (April-June), followed by highly variable conditions during summer (July-September), and finally persistent warming from October to November (Fig. 9). In general, this is consistent with the time history of atmospheric warming observed in Fig 2.

Annually, surface waters in the upper 30 meters were saltier than normal in 2017, particularly in the northern Middle Atlantic Bight (Fig. 10). Seasonally, large positive anomalies were observed during February and March in the southern and northern Middle Atlantic Bight, where anomalies exceeded 0.6 psu, and in the eastern Gulf of Maine during fall, where anomalies exceeded 0.8 psu (Fig. 11a). Bottom waters in the eastern Gulf of Maine were saltier than average year round, while freshening was observed in the western Gulf of Maine (Fig. 10 and 11b). Bottom water conditions were more seasonally variable in the southern Middle Atlantic Bight. Synoptically, saline conditions were pervasive during spring throughout the Middle Atlantic Bight (Fig 12). Extremely fresh anomalies were also observed near the bottom at the shelf edge, coincident with cold anomalies observed along the shelf edge during spring (Fig 8). Satellite derived observations of sea surface temperature suggest offshore forcing is responsible for this cold fresh shelfbreak anomaly. Satellite images reveal a prominent filament of cold shelf water protruding offshore in the region, likely having been advected offshore by the circulation of a large warm core ring impinging on the shelf (Fig 13).

Deep inflow through the Northeast Channel continues to be dominated by Warm Slope Water, except in June when cool very fresh water was observed (Fig. 14a,b). The fresh anomaly is likely related to the presence of several eddies offshore and the formation of two large filaments drawing cold/fresh shelf water offshore around the eddy's periphery (Fig. 15). One of the filaments is roughly aligned with the western edge of the Northeast Channel, suggesting that cold anomalies observed in the channel may be associated with outflow through the southwest side of the channel. Springtime temperature-salinity and temperature-depth profiles indicate the presence of a warmer, thinner 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). The remnant winter water in the Cold Intermediate Layer was over 0.5°C warmer than average in 2017, suggesting that convective mixing was suppressed in the preceding winter (Fig. 16). In Wilkinson Basin, the entire water column below 50 meters was warmer than average, with anomalies increasing toward the bottom (Fig. 17 & 18). It is expected that extremely warm air temperatures over the North American continent during January and February suppressed wintertime convective mixing in the western Gulf of Maine, and the mild spring / summer to follow led to weaker than normal seasonal stratification (Fig 2). 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 observations suggest 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). Extreme diversions and meanders in the Gulf Stream's 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

- Observations indicate that ocean temperatures on the NEUS shelf continue to increase
- Near bottom waters in the eastern GoM were more than one standard deviation warmer and saltier than average throughout the year, while the western GoM was warm and fresh
- Warm winter air temperatures and late onset storms suppressed winter mixing in the western Gulf of Maine, leading to a warmer Gulf of Maine intermediate water mass

- Exclusive of June, slope waters entering the Gulf of Maine through the Northeast Channel were anomalously warm and salty, consistent with the properties characteristic of Warm Slope Water derived from subtropical origins

References

Armi, L., Bray, N.A., 1982. A standard analytic curve of potential temperature versus salinity for the Western North Atlantic. Journal of Physical Oceano- graphy 12, 384–387.

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.

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), 2018. https://ocean.ices.dk/iroc/#.

Joyce, T.M., C. Deser, and M.A. Spall, 2000. The relationship between decadal variability of Subtropical Mode Water and the North Atlantic Oscillation. *J. Climate*, 13, 2550-2569.

Mountain, D.M., 2012. Labrador Slope Water entering the Gulf of Maine – Response to the North Atlantic Oscillation, *Continental Shelf Research*, 47, 150-155.

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*.*

Table 1: Inventory of hydrographic monitoring on the Northeast U.S. Shelf during 2017

Sub-area	Division(s)	Month(s)	Type[1]	Description	Station count
5	Y,Z	2	S	Ecosystems monitoring survey	78
5	Y,Z	3,4,5	S	Bottom trawl survey	203
5	Y,Z	5,6	S	Ecosystems monitoring survey	102
5	Y,Z	5,6	O	Sea scallop survey	38
5	Y,Z	6	S	Tuna Slope Sea Survey	6
5	Y,Z	7	O	Marine Mammal (AMAPPS) survey	27
5	Y,Z	10,11	S	Bottom trawl survey	120
5	Y,Z	11	S	Ecosystems monitoring survey	59
6	A,B,C	2	S	Ecosystems monitoring survey	43
6	A,B,C	3,4,5	S	Bottom trawl survey	146
6	A,B,C	5,6	S	Ecosystems monitoring survey	59
6	A,B,C	6	S	Tuna Slope Sea Survey	112
6	A,B,C	7	O	Marine Mammal (AMAPPS) survey	9
6	A,B,C	11	S	Ecosystems monitoring survey	21

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

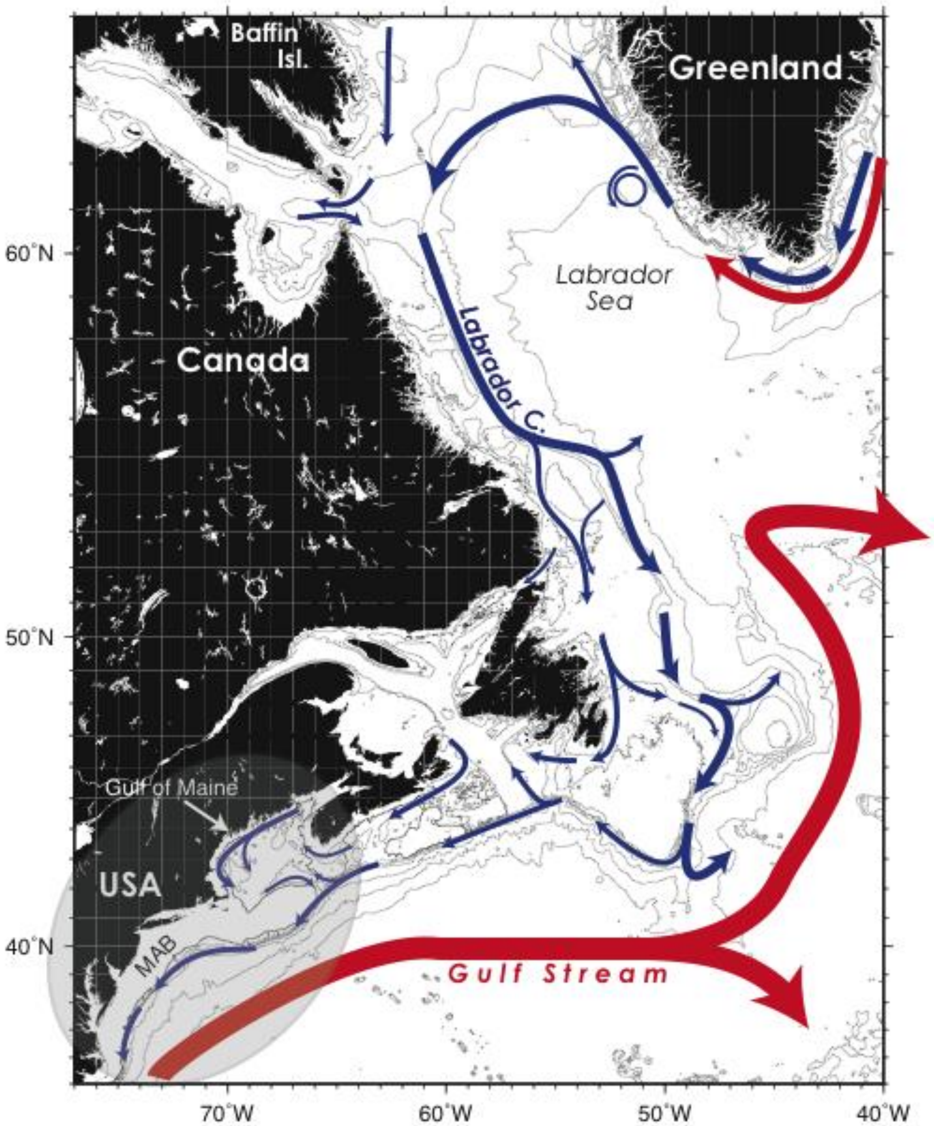


Fig.1a. Circulation schematic of the western North Atlantic. The Northeast U.S. Shelf region is identified by the shaded oval. The 100, 200, 500, 1000, 2000, 3000 and 4000 meter isobaths are shown.

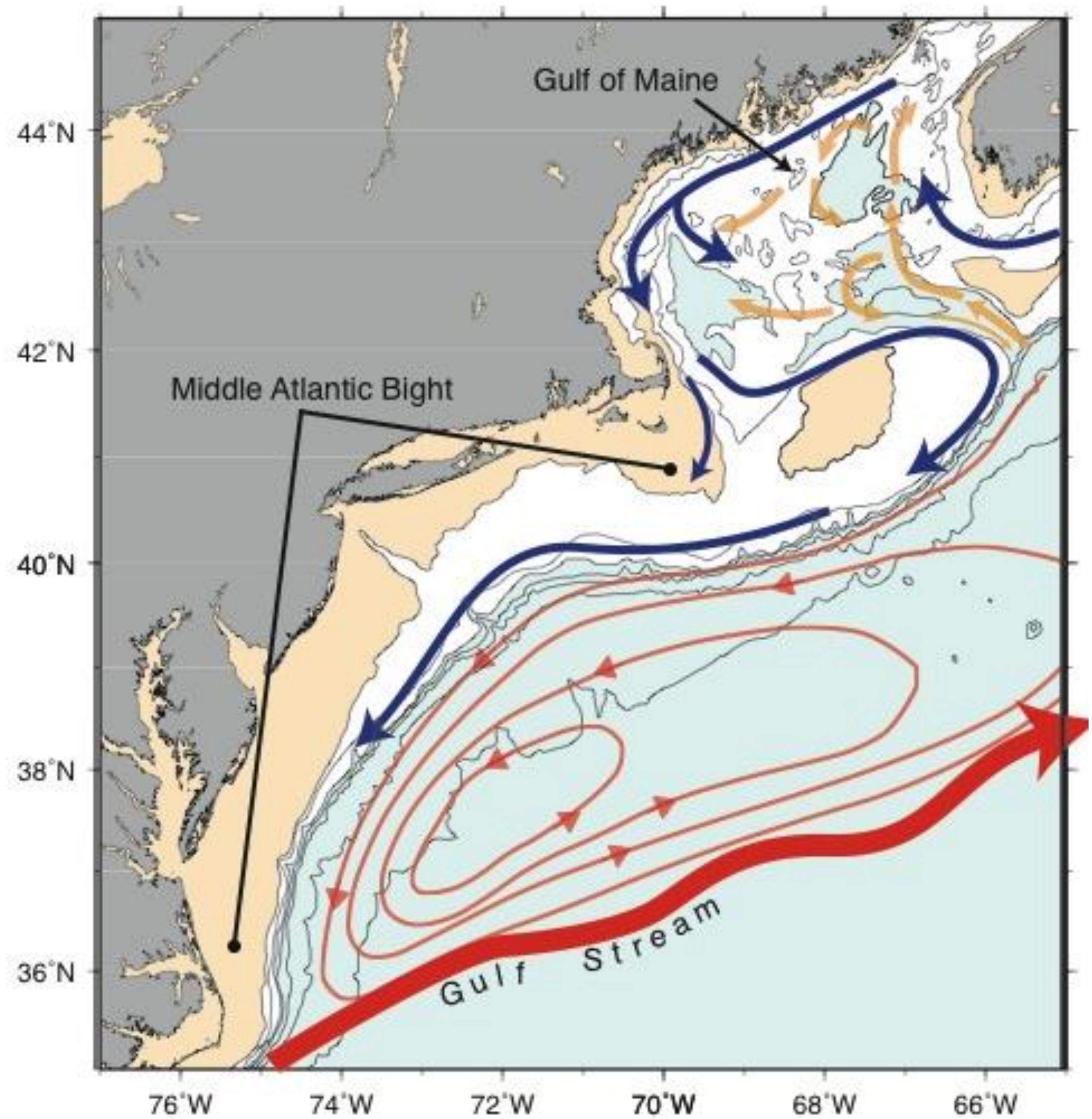


Fig. 1b. Circulation schematic for the Northeast U.S. Shelf region, where blue arrows represent shelf water circulation and orange arrows represent deeper slope water circulation pathways. Water depths deeper than 200 meters are shaded blue. Water depths shallower than 50 meters are shaded tan.

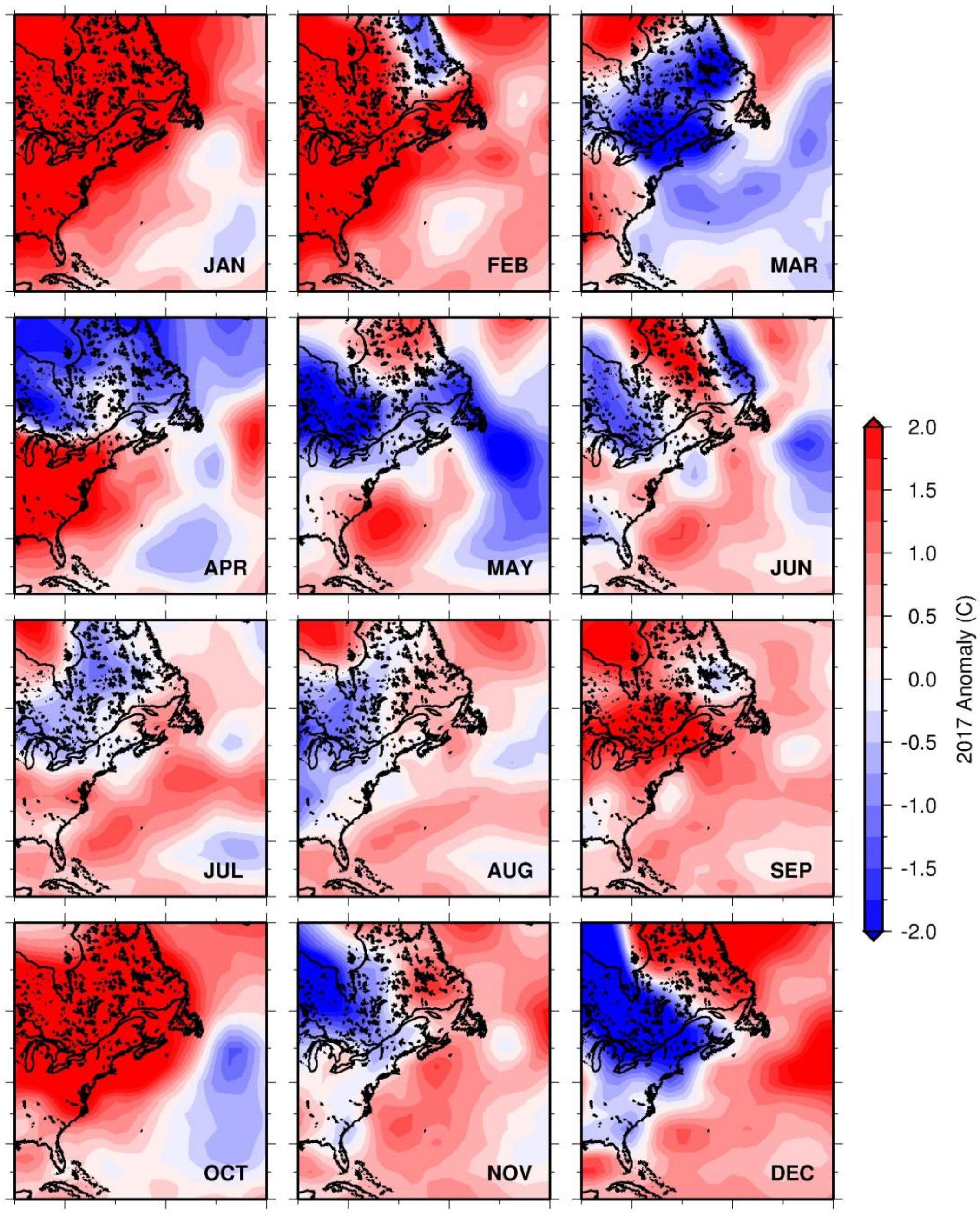


Fig. 2. Surface air temperature anomaly derived from the NCEP/NCAR Reanalysis product (http://www.esrl.noaa.gov/psd/data/composites/day/). Positive anomalies correspond to warming in 2017 relative to the reference period (1981-2010).

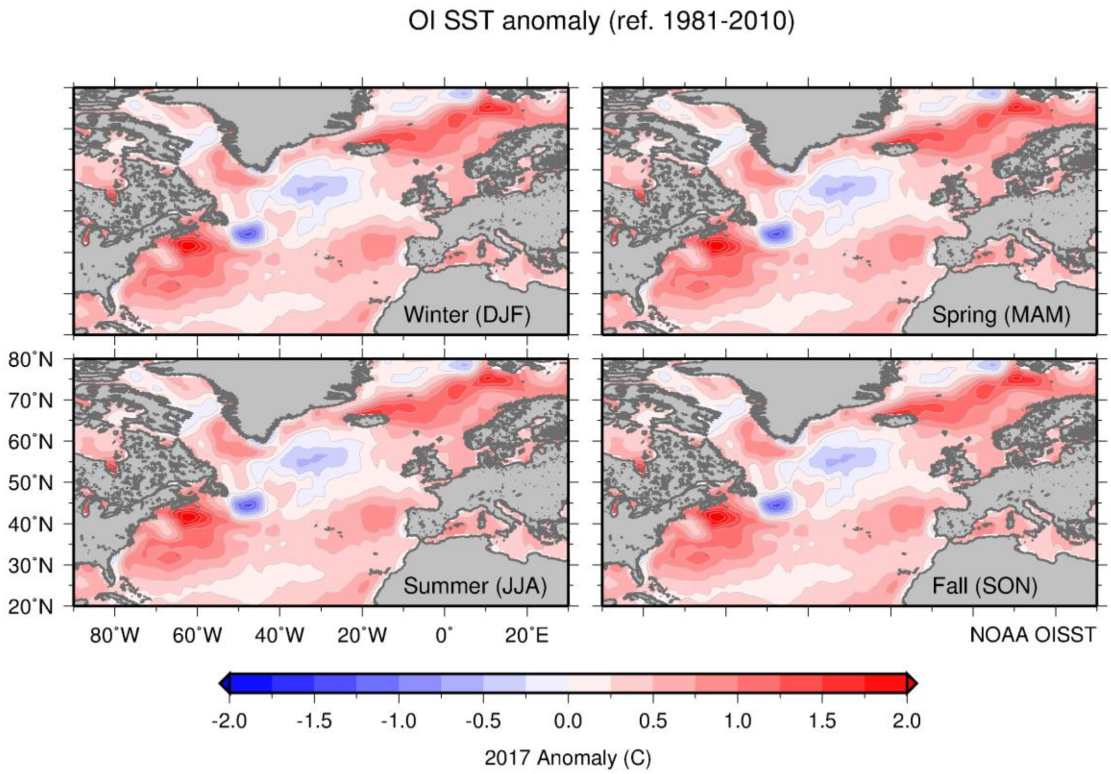
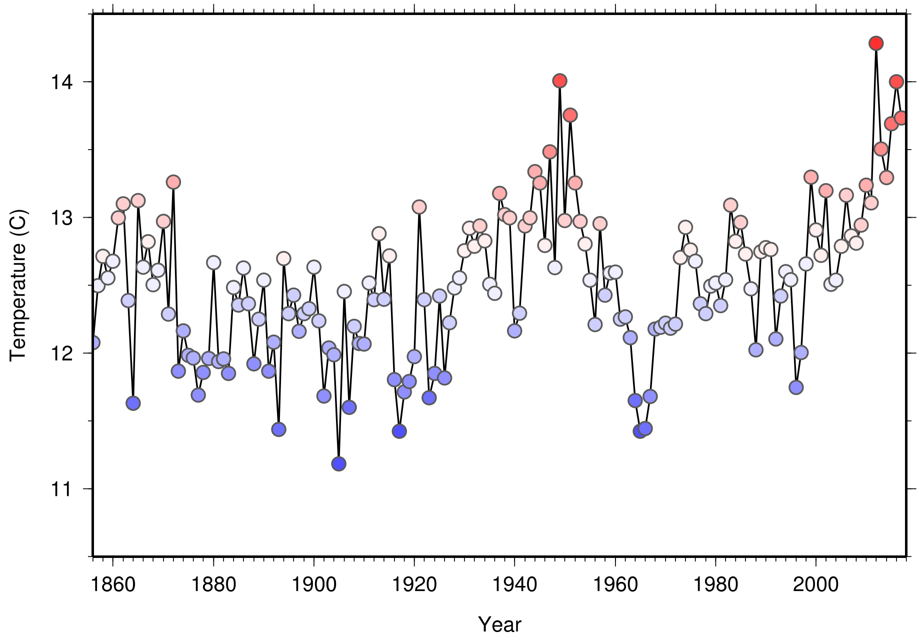


Fig. 3. Sea surface temperature anomaly derived from the NOAA's Optimum Interpolation (OI) SST product (http://www.esrl.noaa.gov/psd/data/gridded/data.noaa.oisst.v2.html). Seasons are made up of 3-month periods where winter spans December-February. Positive anomalies correspond to warming in 2017 relative to the reference period (1981-2010).



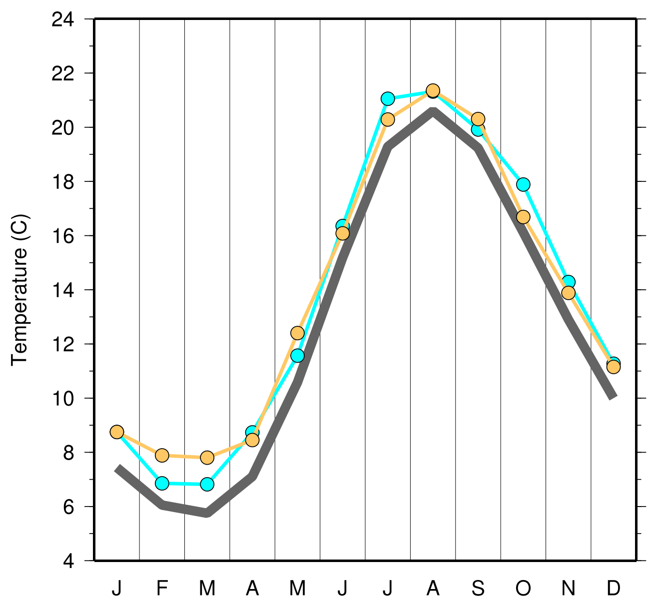


Fig. 4. Top: Regional average annual sea surface temperature for the NEUS shelf region calculated from NOAA's extended reconstructed sea surface temperature product (http://www.esrl.noaa.gov/psd/data/gridded/data.noaa.ersst.html). Colors correspond with the anomaly scale in Figure 3. Bottom: Regional average monthly mean SST for the NEUS shelf for 2017 (cyan), 1951 (orange) and 1981-2010 (gray) calculated from the same product.

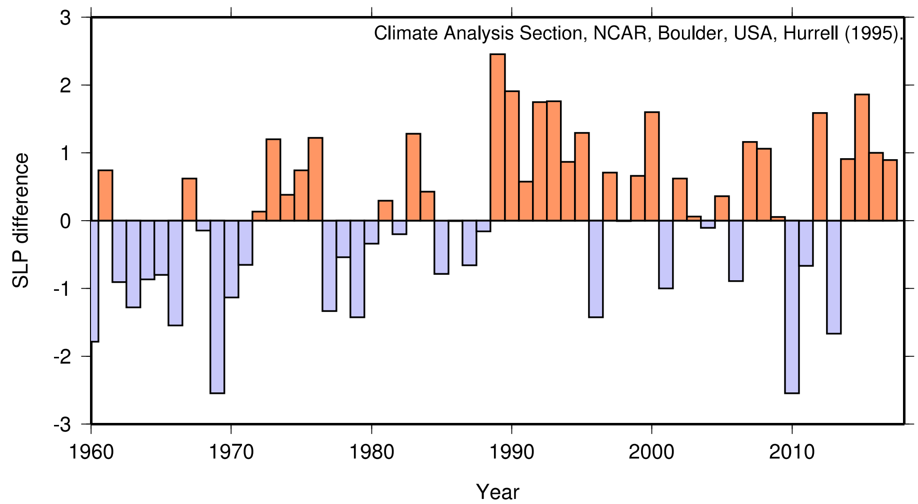


Fig.5. North Atlantic Oscillation index computed from principal component analysis of sea level pressure in the North Atlantic (see Hurrell, 1995).

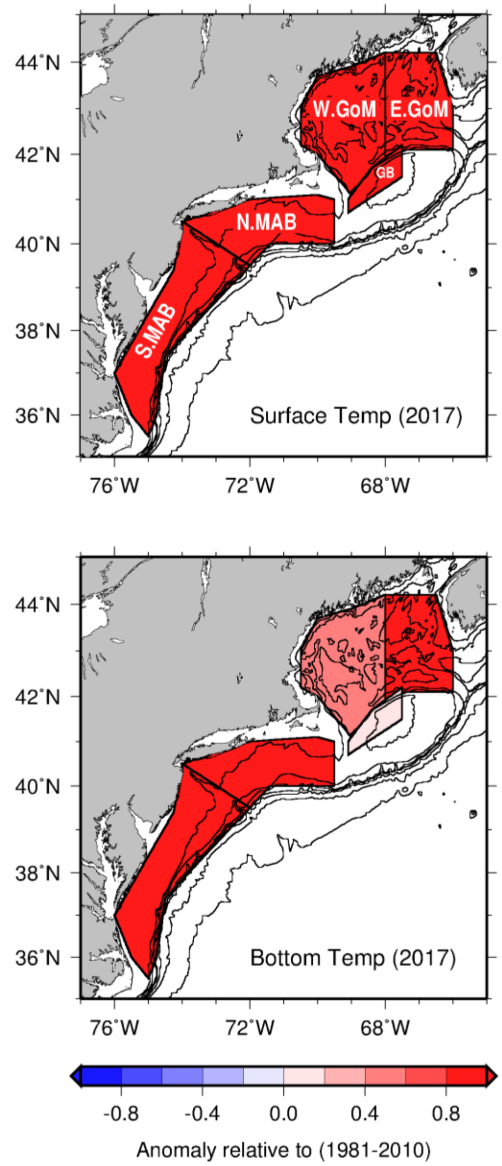


Fig. 6. Surface (upper panel) and bottom (lower panel) regional annual temperature anomaly (°C). Positive anomalies correspond to warming in 2017 relative to the reference period (1981-2010). The region labels correspond to the panels in Figure 7.

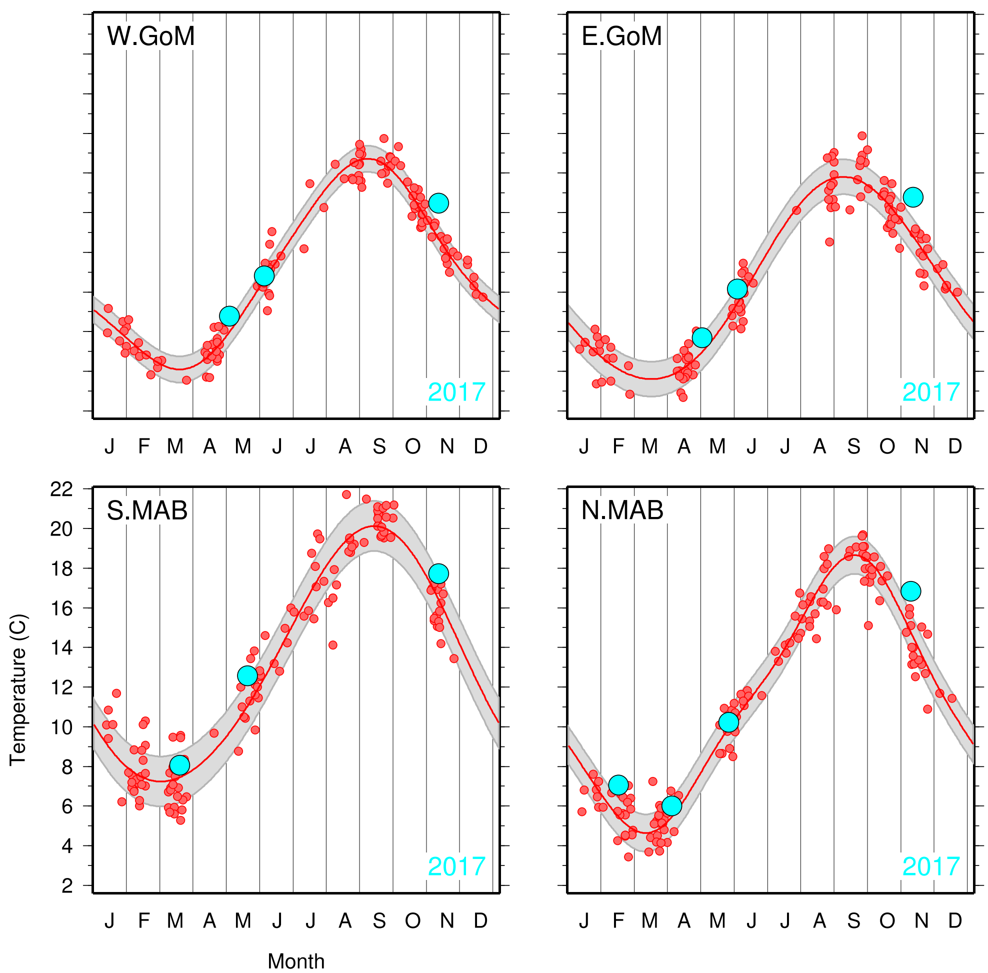


Fig. 7a. Regional average 0-30 meter temperature (°C) as a function of calendar day. Each dot represents a volume-weighted average of all observations from a single survey falling within the regions delineated in Fig. 6. An annual harmonic fit to the regional average temperatures from 1981-2010 is shown 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 2017 surveys are shown in cyan.

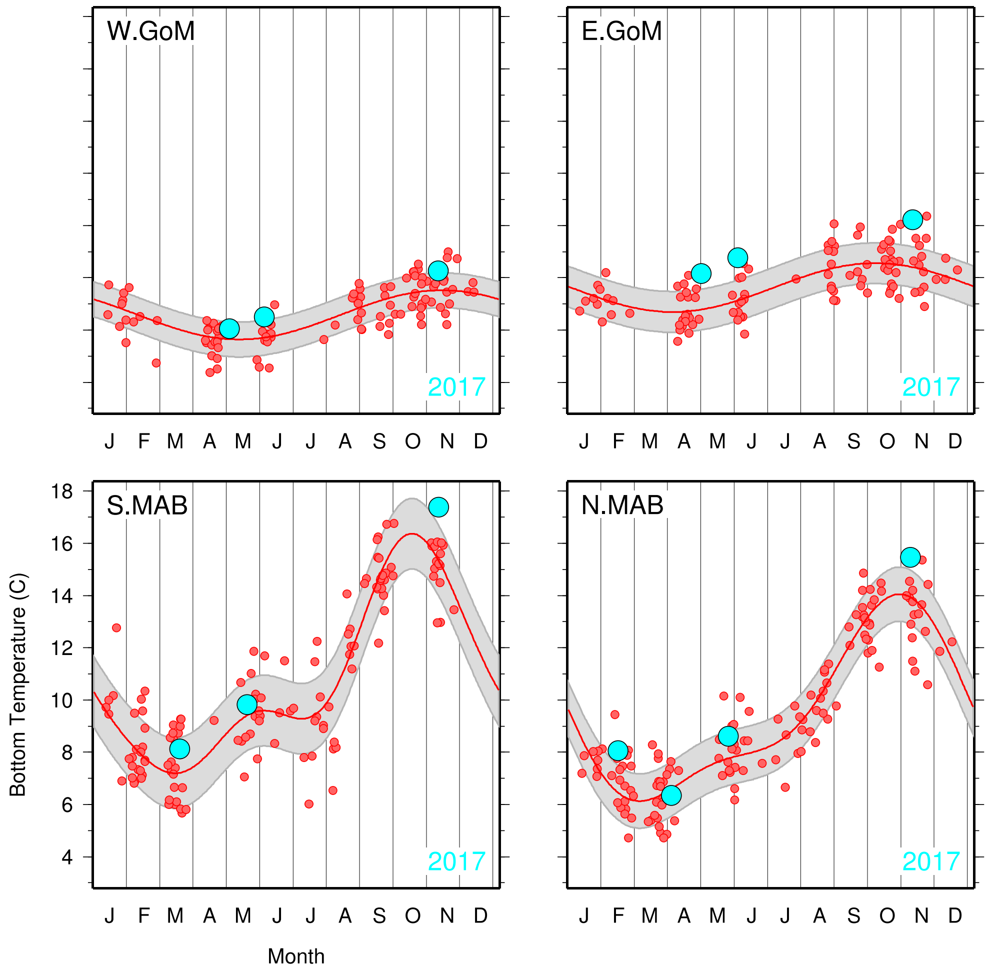


Fig.7b. As in Fig. 7a, but for bottom temperatures.

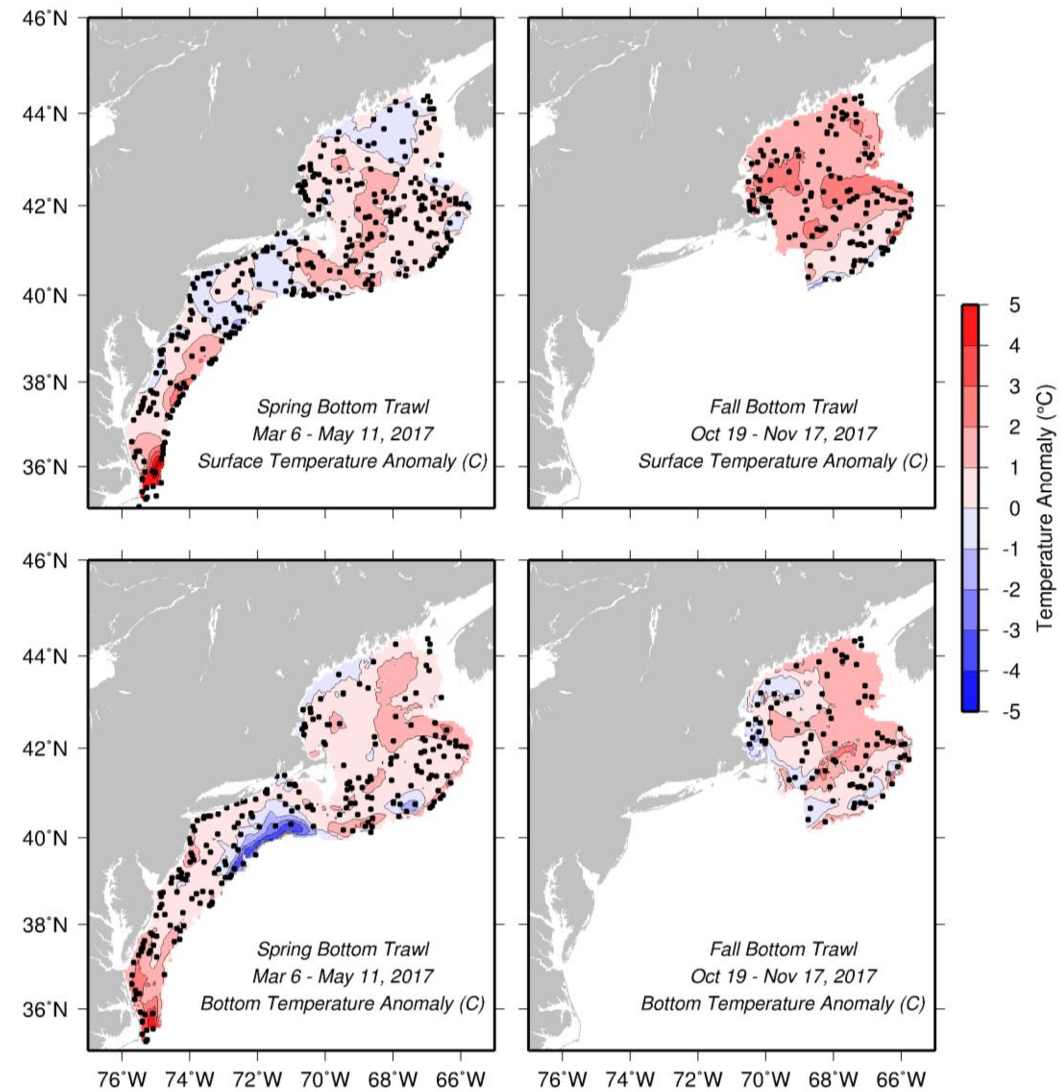


Fig. 8. Surface (upper panels) and bottom (lower panels) temperature anomaly from the spring 2017 (left) and fall 2017 (right) ground fish surveys. Positive anomalies correspond to warming in 2017 relative to the reference period (1977-1987).

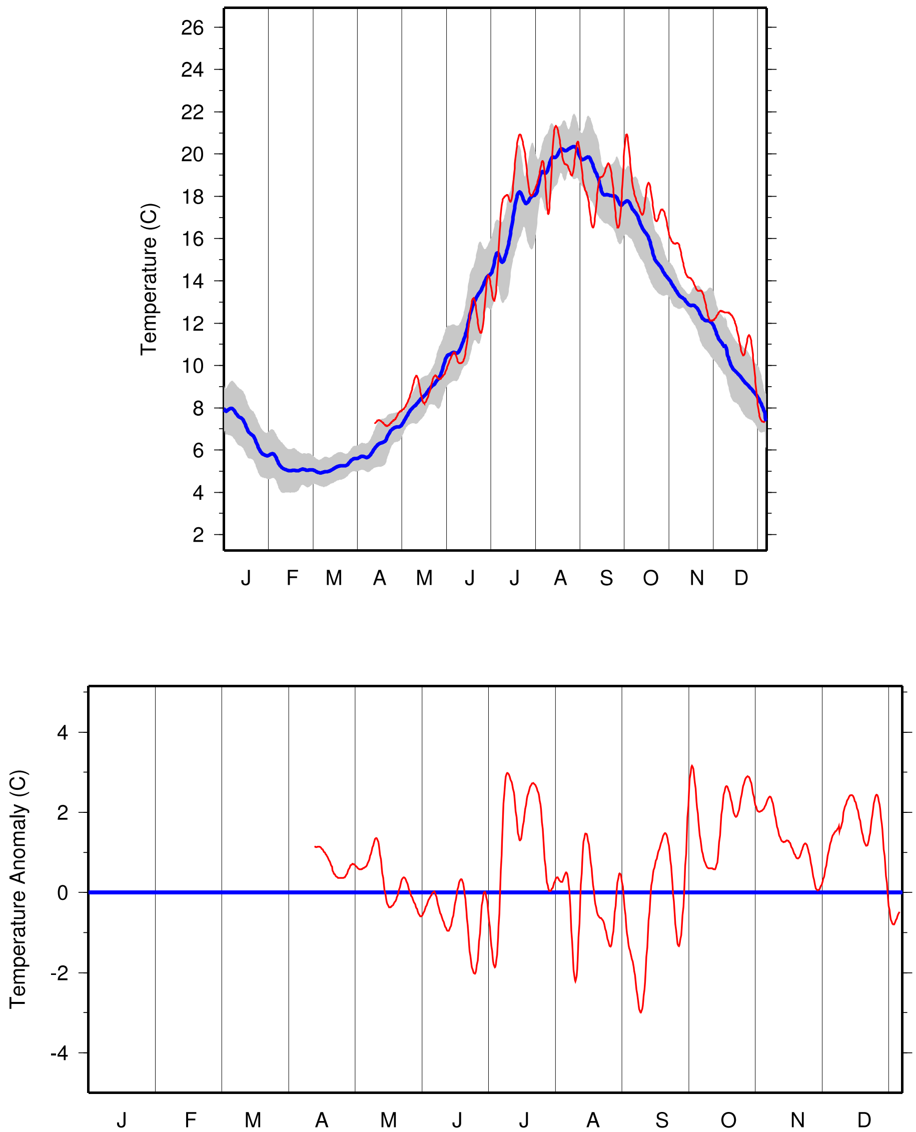


Fig. 9. (top) Time series of surface ocean temperature from NDBC buoy 44008 located south of Nantucket Shoals in the northern Middle Atlantic Bight. Temperatures observed in 2017 (red) are compared with average temperatures (2000-2010, blue) in the top panel. The gray shading indicates one standard deviation about the long-term mean. The lower panel shows the difference between 2017 and the long-term mean temperature, where positive values indicate warmer conditions in 2017.

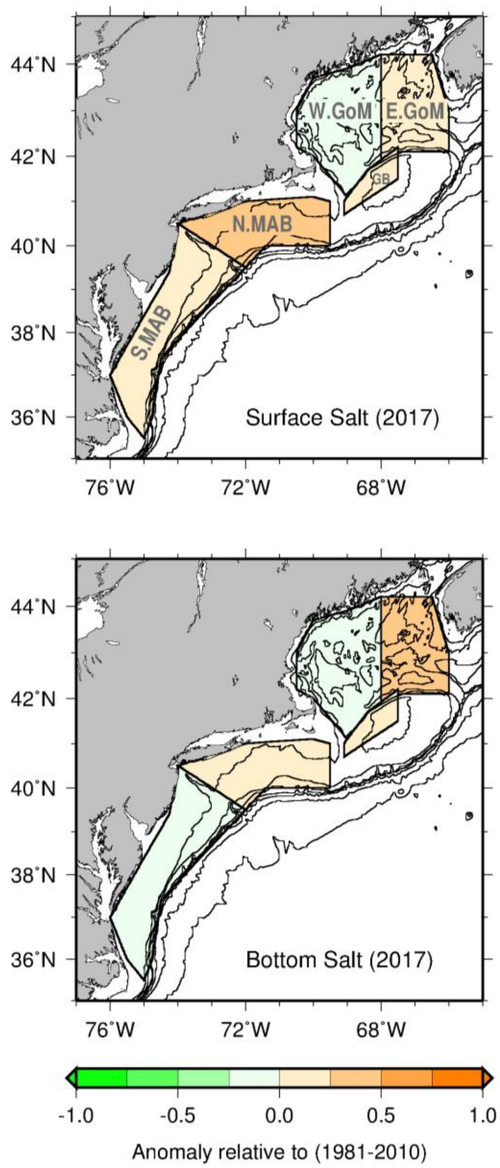


Fig. 10. Surface (upper panel) and bottom (lower panel) regional annual salinity anomaly. Positive anomalies correspond to more saline conditions in 2017 relative to the reference period (1981-2010). The region labels correspond to the panels in Figure 11.

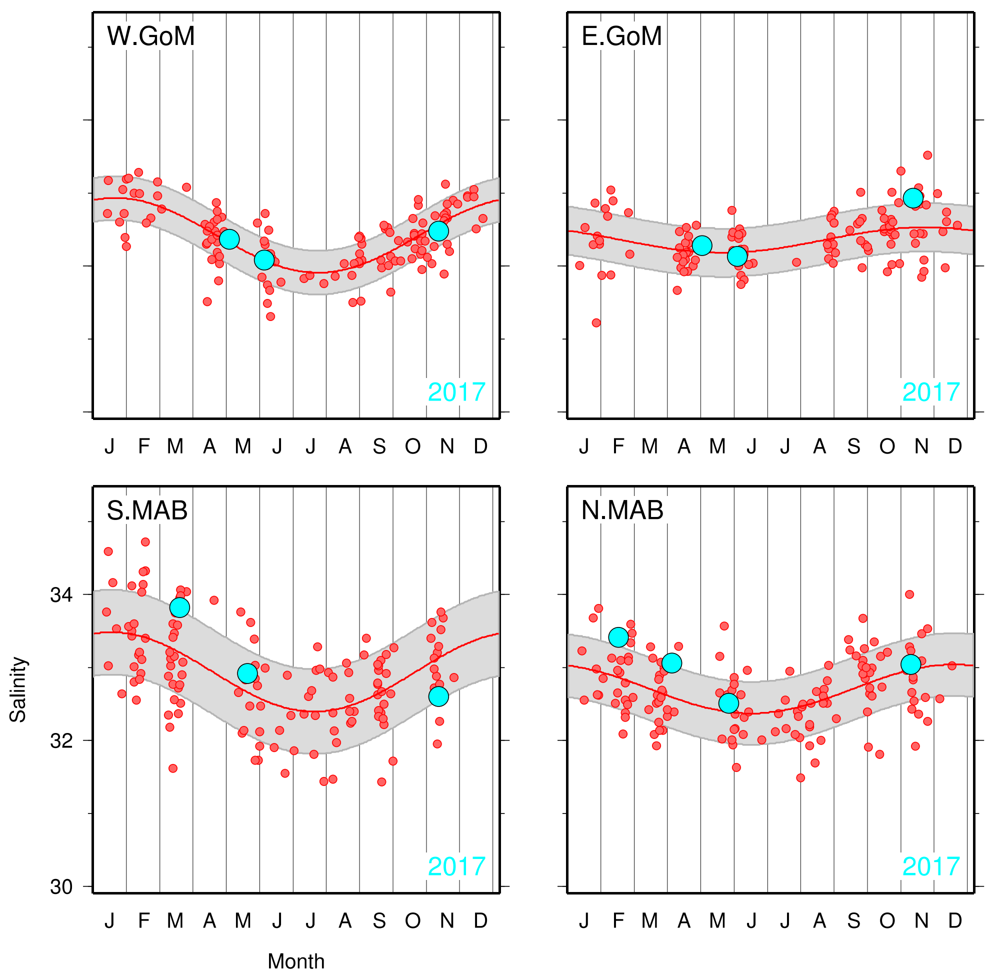


Fig. 11a. Regional average 0-30 meter salinity as a function of calendar day. Each dot represents a volume-weighted average of all observations from a single survey falling within the regions delineated in Fig. 10. An annual harmonic fit to the regional average salinities from 1981-2010 is shown by the 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 2017 surveys are shown in cyan.

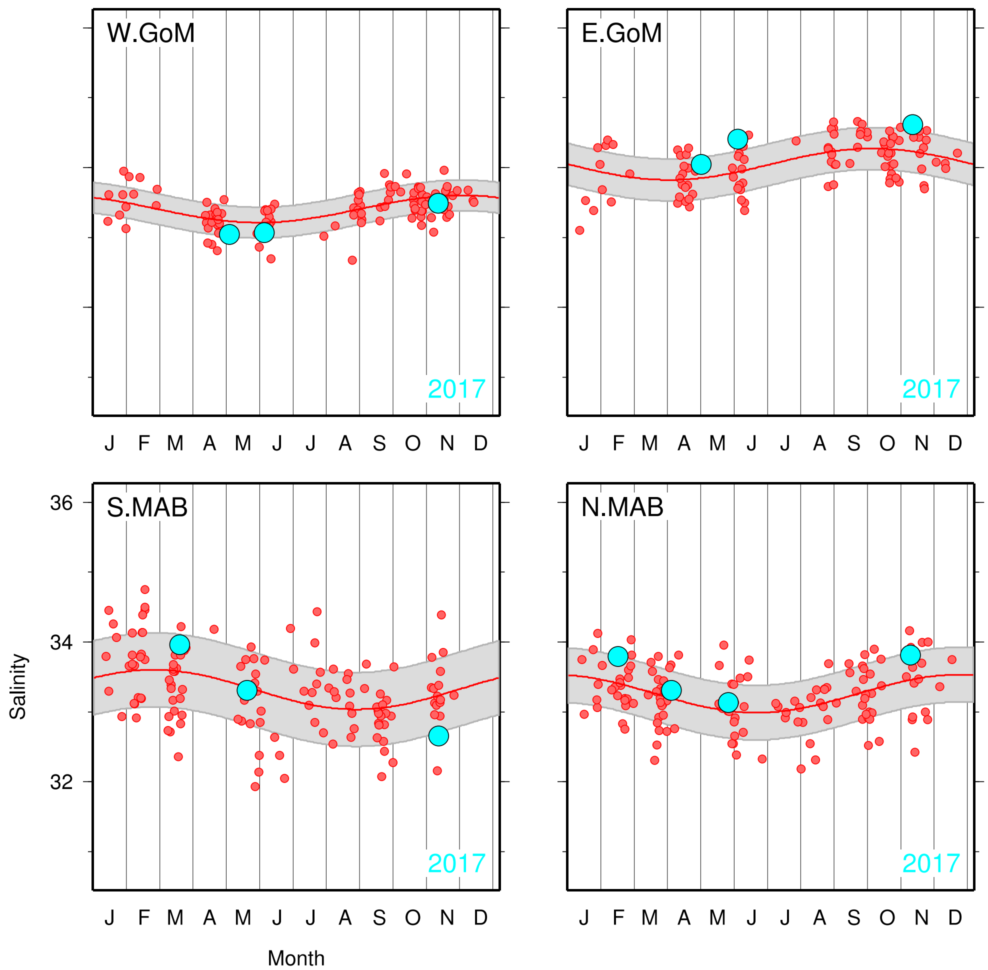


Fig. 11b. As in Fig. 11a, but for bottom salinities.

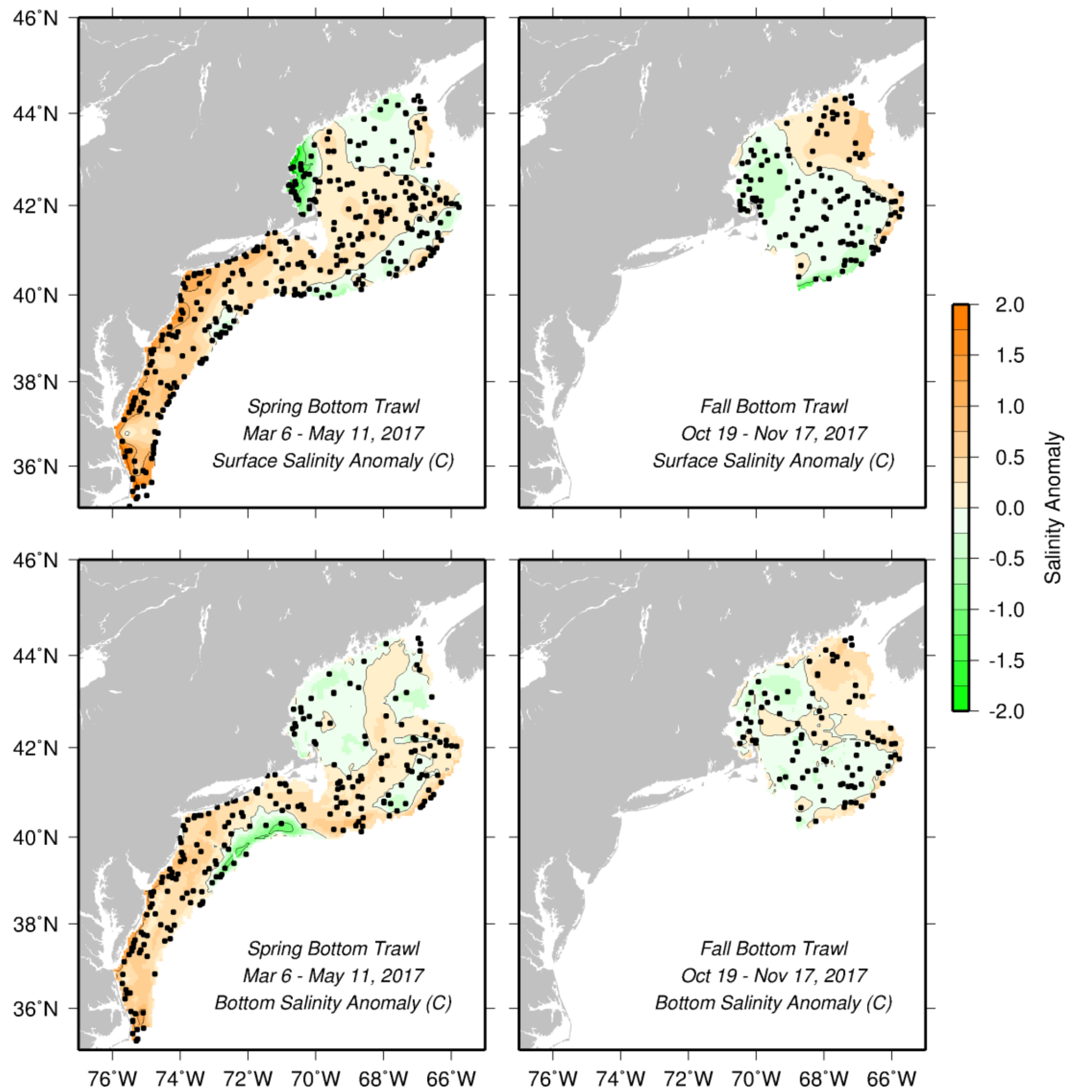


Fig. 12. Surface (upper panels) and bottom (lower panels) salinity anomaly from the spring 2017 (left) and fall 2017 (right) ground fish surveys. Positive anomalies correspond to more saline conditions in 2017 relative to the reference period (1977-1987).

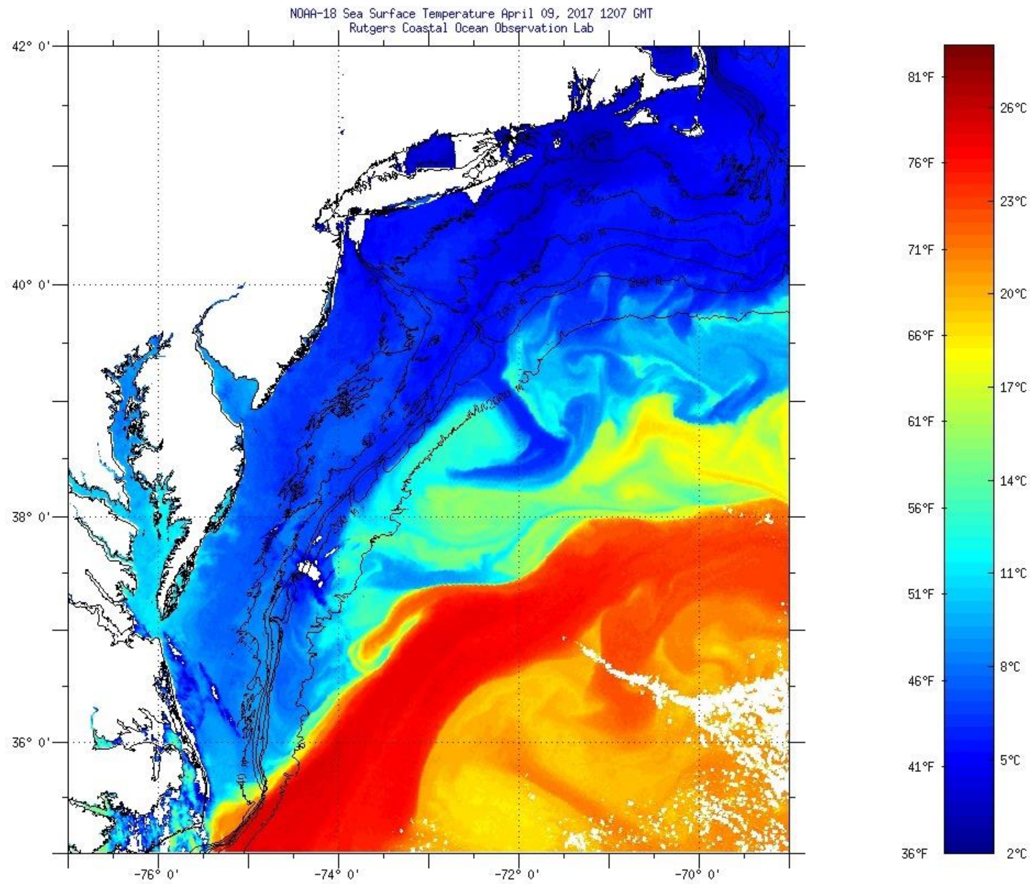


Fig. 13. Daily composite sea surface temperature derived by the Coastal Ocean Observations Lab, Rutgers University, from data collected by the Advanced Very High Resolution Radiometer on April 9, 2017.

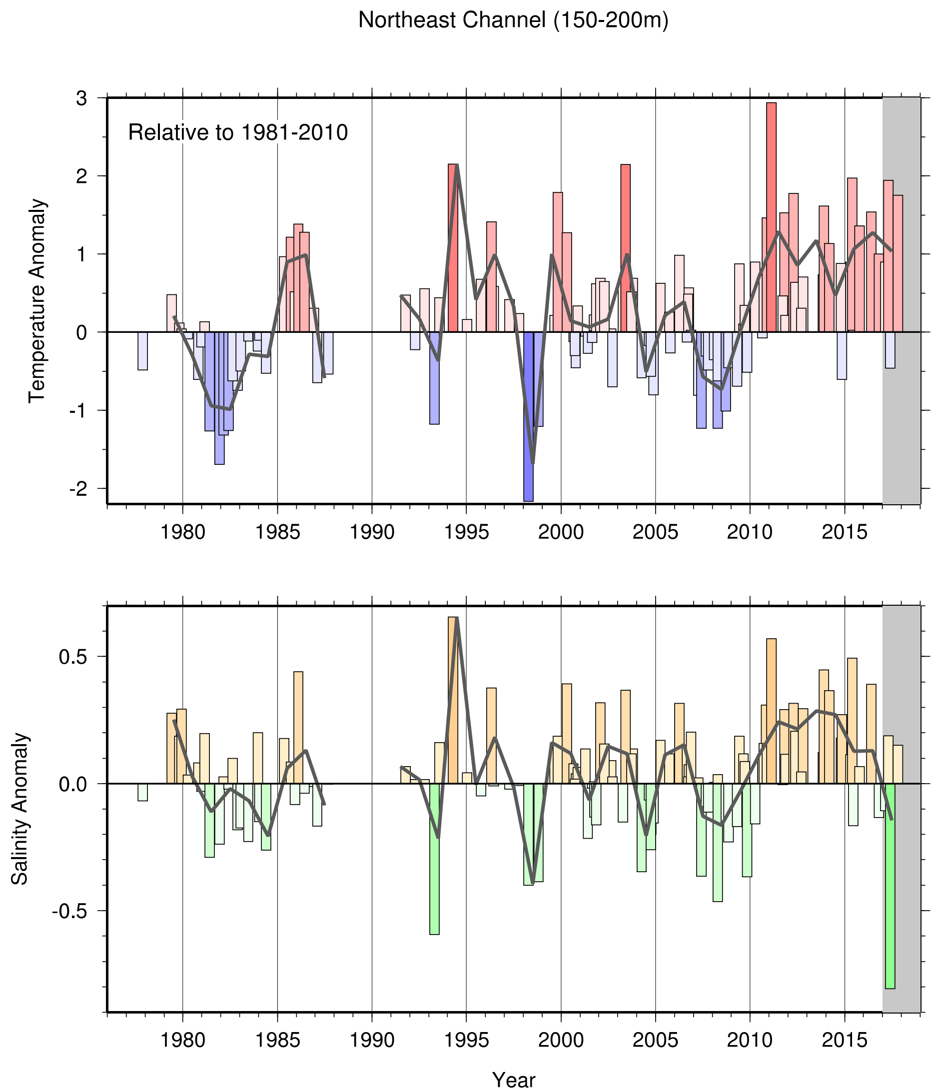


Fig. 14a. Time series of temperature and salinity anomaly in the deep Northeast Channel. Each bar represents a volume-weighted average of all observations from a single survey collected between 150-200 meters in the Northeast Channel. The grey curve shows the annual average anomaly time series. Positive values are warmer and saltier than the long-term mean calculated for 1981-2010. The gray shading highlights sampling done in 2017.

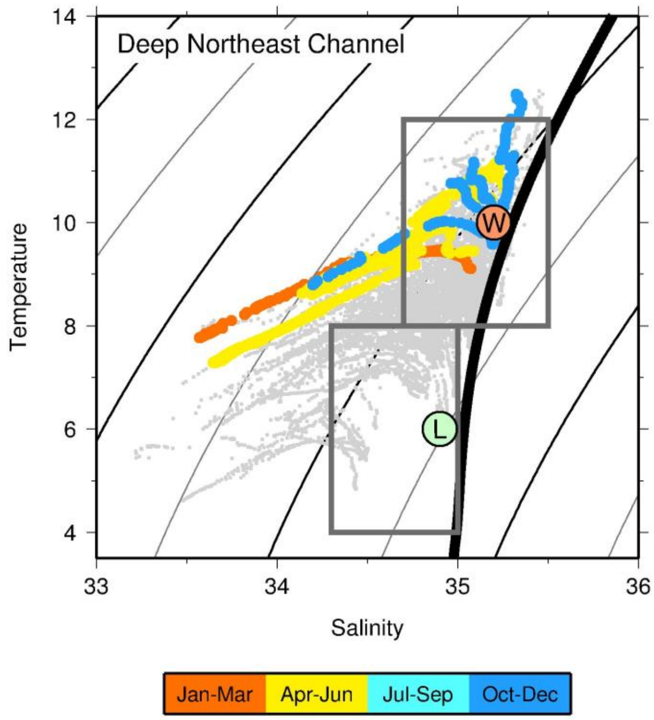


Fig. 14b. Temperature-salinity profiles extracted from the deep Northeast Channel (150-250 m). Profiles from 2017 (shown in color, with colors corresponding to time of year) are compared with all profiles observed between 1981-2010 (grey). The boxes delineate the property range typically associated with Labrador Slope Water (L) and Warm Slope Water (W). The heavy black curve is the standard T–S curve constructed by Armi and Bray (1982) for Western North Atlantic Central Water, the saltiest water mass we expect to influence the Northeast U.S. Shelf.

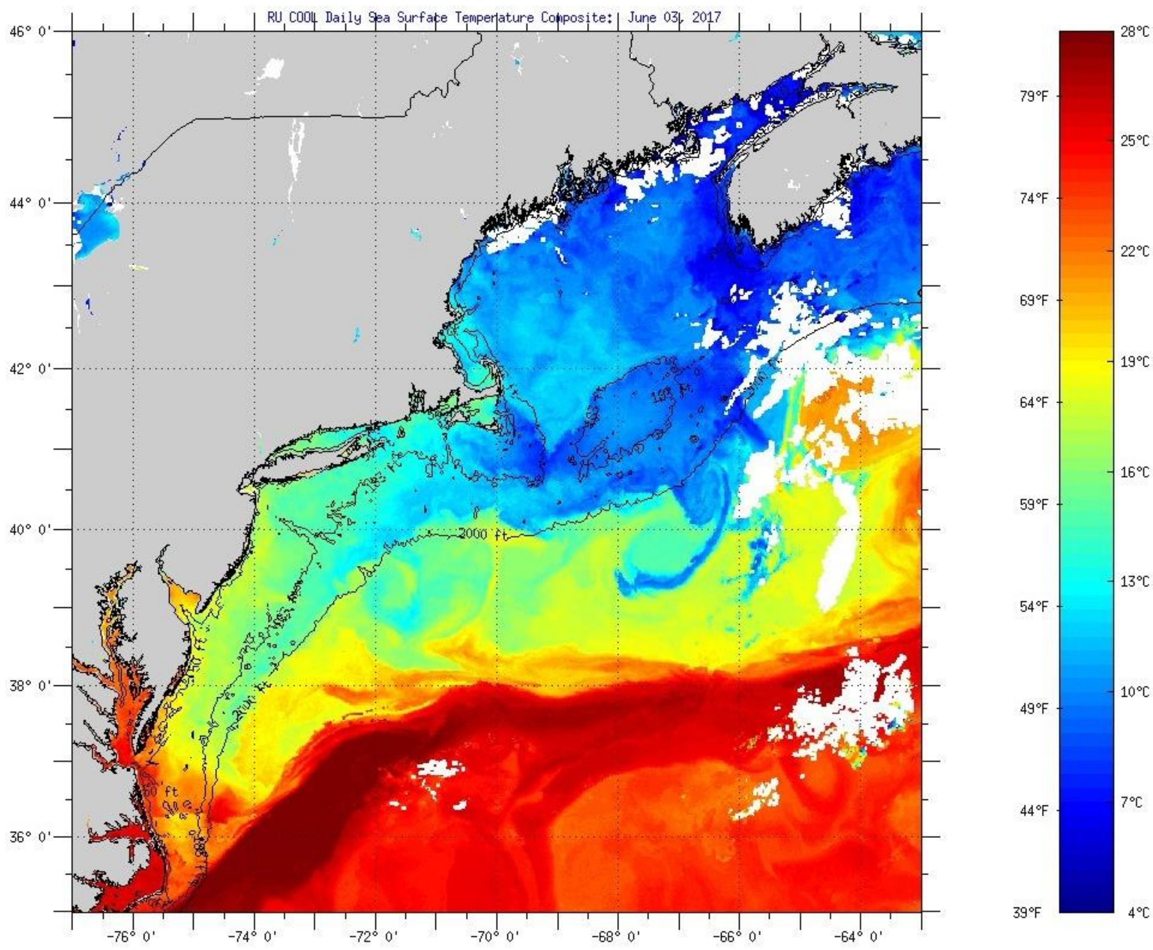


Fig. 15. Daily composite sea surface temperature derived by the Coastal Ocean Observations Lab, Rutgers University, from data collected by the Advanced Very High Resolution Radiometer on June 3, 2017.

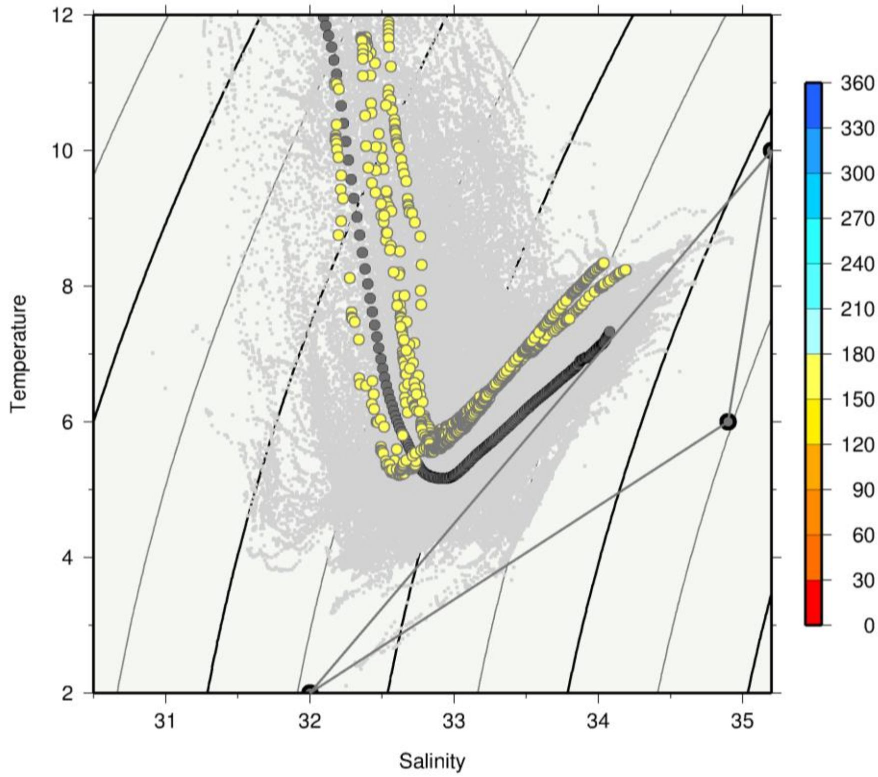


Fig. 16. Temperature-salinity diagram showing water properties in Wilkinson Basin in the western Gulf of Maine. All observations from spring 2017 (yellow) are shown along with the spring climatological average profile (1981-2010, dark gray). The lightest gray dots show the historical range encompassed by observations from the reference period, 1981-2010. Temperature and salinity properties representative of source waters entering the Gulf of Maine are shown by the mixing triangle.

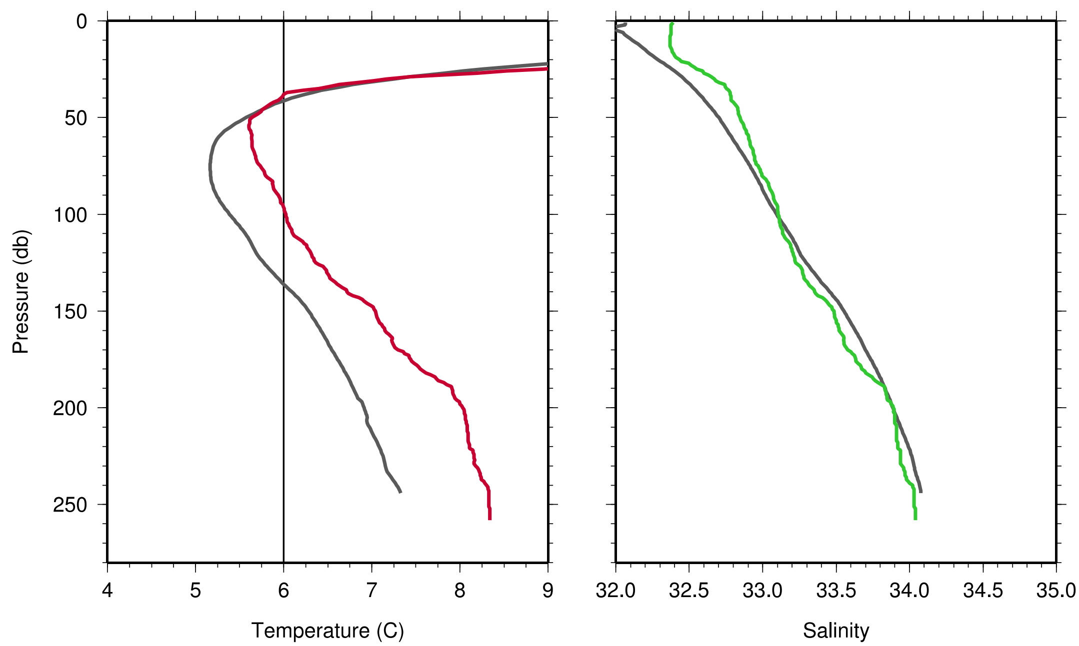


Fig.17. Average profiles of temperature (left) and salinity (right) from repeated observations collected during June in Wilkinson Basin in the western Gulf of Maine. All observations from June 2017 (red and green) are shown along with the climatological average profile for the same month (1981-2010, 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.

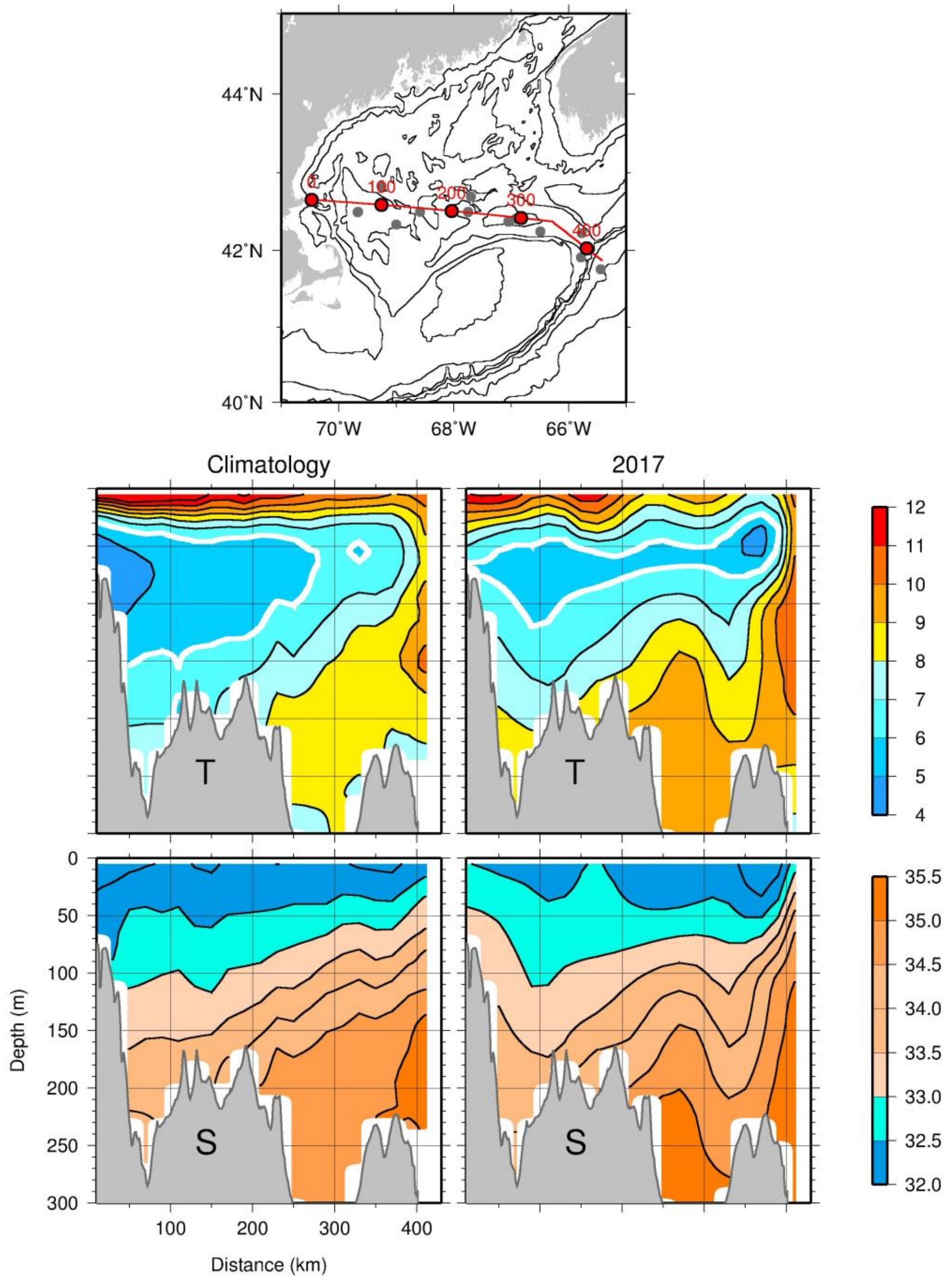


Fig. 18. Vertical sections of temperature (top) and salinity (bottom) crossing the Gulf of Maine along a zonal transect shown in the map. The left panels show the climatological average for June spanning the years 1981-2010. The right panels show the synoptic mean section for June 2017. The heavy white contour highlights the 6°C isotherm as an indicator of the boundary of the cold intermediate layer. Along-transect distances and the June 2017 station distribution are shown on the map for reference.