On peculiarities of ocean climate variability north of Gulf Stream

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The ocean climate variability in the Northwestern Atlantic region between the North Wall of the Gulf Stream and Nova Scotia coast is determined by interplay of two major circulation systems—the **Gulf Stream** and **Labrador Current**. We analyzed **all existing in-situ data** acquired from 1965 to 2017 in the World Ocean Database 2018 and confirmed continuous slow warming within the Gulf of Maine, Scotian Shelf, and Slope Sea areas over the last five decades. This warming has accelerated in the recent 10-12 years in concert with strengthened summer northward incursion of the Gulf Stream warm water, which was stronger than anything seen before since 1965.

We argue that the recent decadal-scale warming is unique and may signal that the shift of the thermal regime in this region might have been at least partially caused by altering of the Gulf Stream long-term variability in the Gulf Stream extension region, east of 50°N. We found that the **Scotian Shelf** and **Slope Water** regions have recently been **warming much faster** than the **Gulf of Maine** itself, implying that the probable cause of the faster warming in the most recent decade is due to the regime change in the Gulf Stream extension region (Seidov et al. 2021).

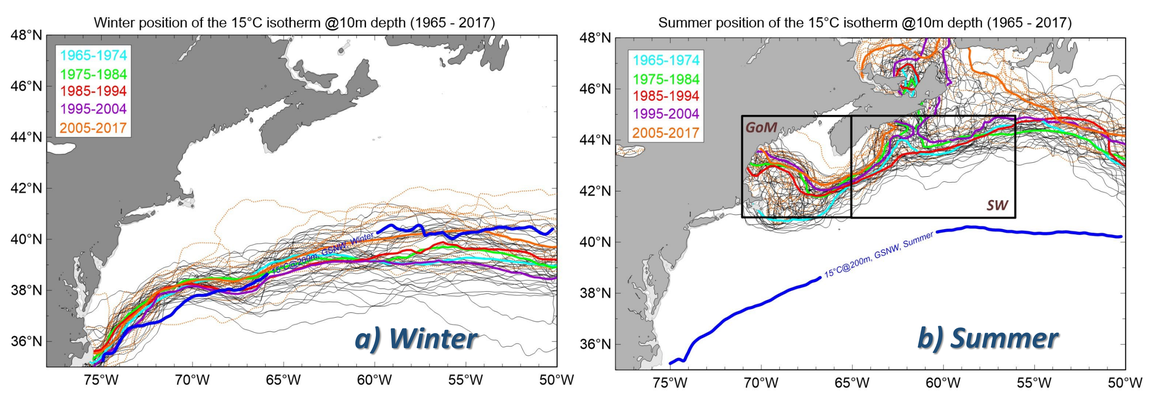


Figure 1. Seasonal positions of 15°C isotherm at 10 m depth for the 1965–2017 period. 1965–2004 yearly — gray lines, decadal - color lines. 2005-2017 yearly and decade – orange lines. Mean 1965–2017 position of the Gulf Stream North Wall (15°C at 200 m) - bold blue line. Rectangles are the areas where the Gulf of Maine and Slope Water box-averaged temperature was computed

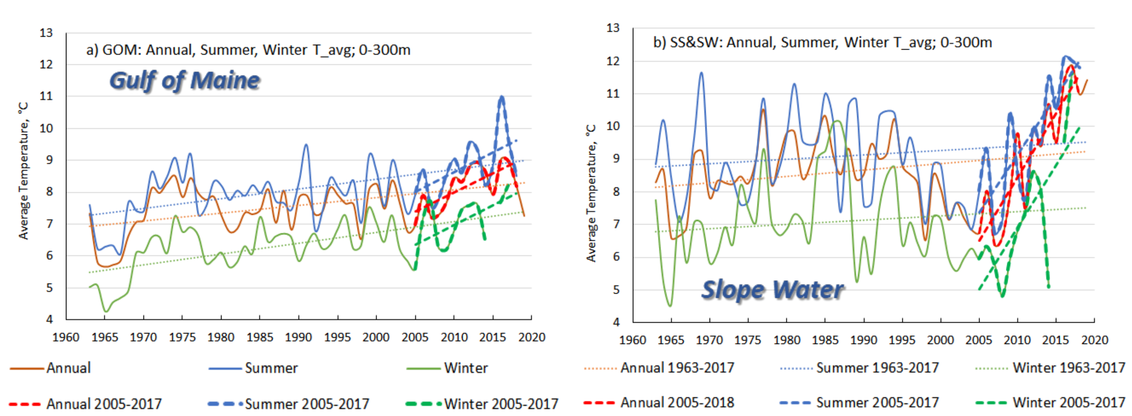


Figure 2. Annual, summer, and winter averaged temperatures in upper 300 m layer in the Gulf of Maine and Scotia Shelf/Slope Water regions

An analysis of the seasonal maps reveals that in winter the Gulf Stream pathways at 10 and 200 m depths coincide very closely (Fig. 1a). During summer, the situation is quite different (Fig. 1b). There is northwestward spreading of warm subsurface water with the maximum northward excursion spreads over the Scotian Shelf and reaching the southeastern part of the Gulf of Maine. In summer, and to some extent annually, in 1995–2004 and 2005–2017, the warm water expands northward very much farther north than in previous decades.

Averaged over the upper 300m, the summers, winters, and year-round temperature in the Gulf of Maine (Fig. 2a) and slope water (Fig. 2b) shows significant warming. The slope water and Gulf of Maine were both warming at a comparable rate for the extended period from 1963 to 2017. However, in the recent decade, slope water's warming is much steeper than that in the Gulf of Maine. The trends of vertically averaged temperature in the two domains illustrate the accelerated warming in 2005–2017, especially in the slope water (Table 1).

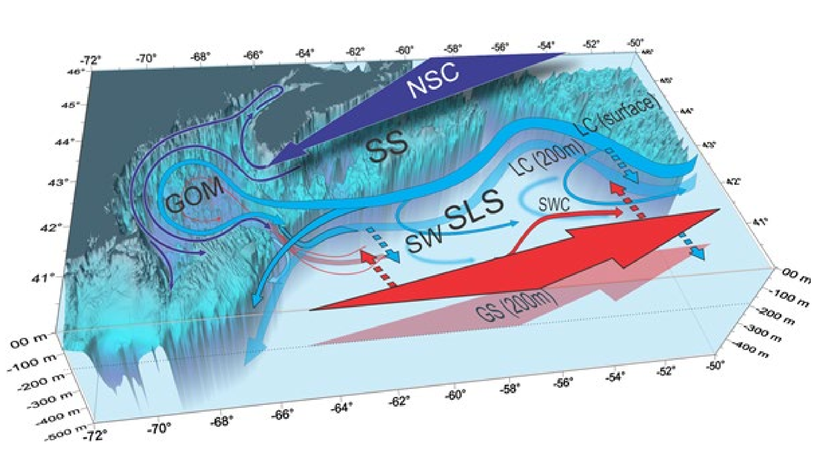


Figure 3. Ocean currents at the surface and seasonal thermocline (below 100 m depth): Gulf Stream (GS), Nova Scotia Current (NSC), Labrador Current (LC), Slope Water (SW), Slope Water Current (SWC), Scotian Shelf (SS), and the Slope Sea (SLS). Dashed red and blue arrows shows the GS path shifts to the north in summer and to the south in winter

Table 1. Gulf of Maine, Scotia Shelf & Slope Water temperature trends (°C/decade) in upper 300m layer

Years	1963-2017	2005-2017
Gulf of Maine		
Annual	0.23±0.01	**1.20**±0.36
Summer	0.29±0.01	**1.22**±0.58
Winter	0.32±0.01	**1.22**±0.55
Scotian Shelf and Slope Water		
Annual	0.20±0.23	**4.21**±0.77
Summer	0.14±0.27	**3.84**±0.96
Winter	0.13±0.27	**4.11**±1.19

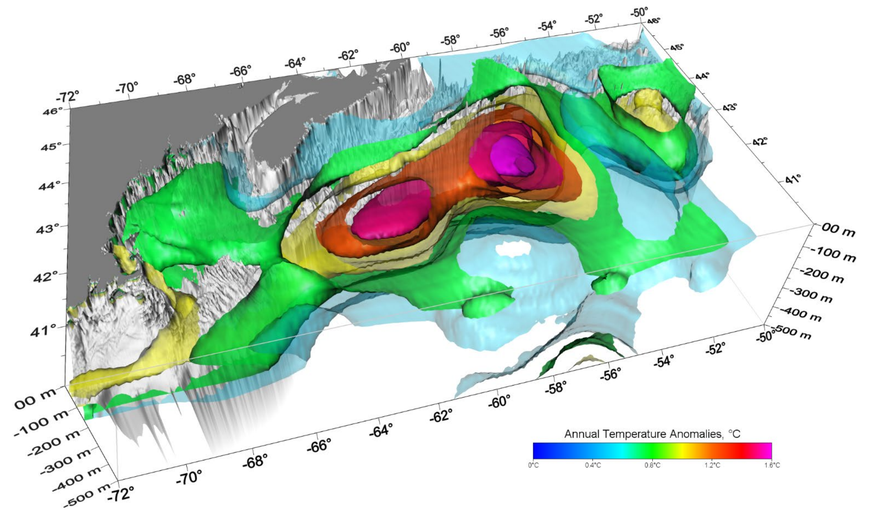


Figure 4. Annual temperature anomalies between the averages of 1995–2017 and 1965–1984 in Gulf of Maine/Scotia Shelf/Slope Water region

The overall decadal climatic change is centered in the Slope Sea (Fig. 3) and thus may be tied to the Gulf Stream path northward shift of ~0.45° in the main stretch and 2.6° in the Gulf Stream extension zone east of 50°W over the 2005-2017 (Seidov et al. 2019). This Gulf Stream shift could effectively squeeze the Slope Waters area and decrease propagation of the cold Labrador Current water southwestward along the shelf-break, thus causing relatively faster slope water warming in the last decade (Fig. 2b). The slope water region warmed annually more than Gulf of Maine (Fig.4).

Summer climate in the northeastern slope water became much warmer in 1995–2017 relative to 1965–1984 than the winters climate for the same periods (Fig. 5a, c). In the summers of 1995–2004, and especially in 2005–2017, the warm surface water of the Gulf Stream origin extends much further north than in 1965–1984 (Fig. 1b). However, this impacts only the northeastern slope water and the Gulf of St. Lawrence. The slope water warms more than the Scotian Shelf (Fig. 5a). Gulf's bottom layer warming caused by warmer water inflowing through the Northeast Channel (Fig. 5b).

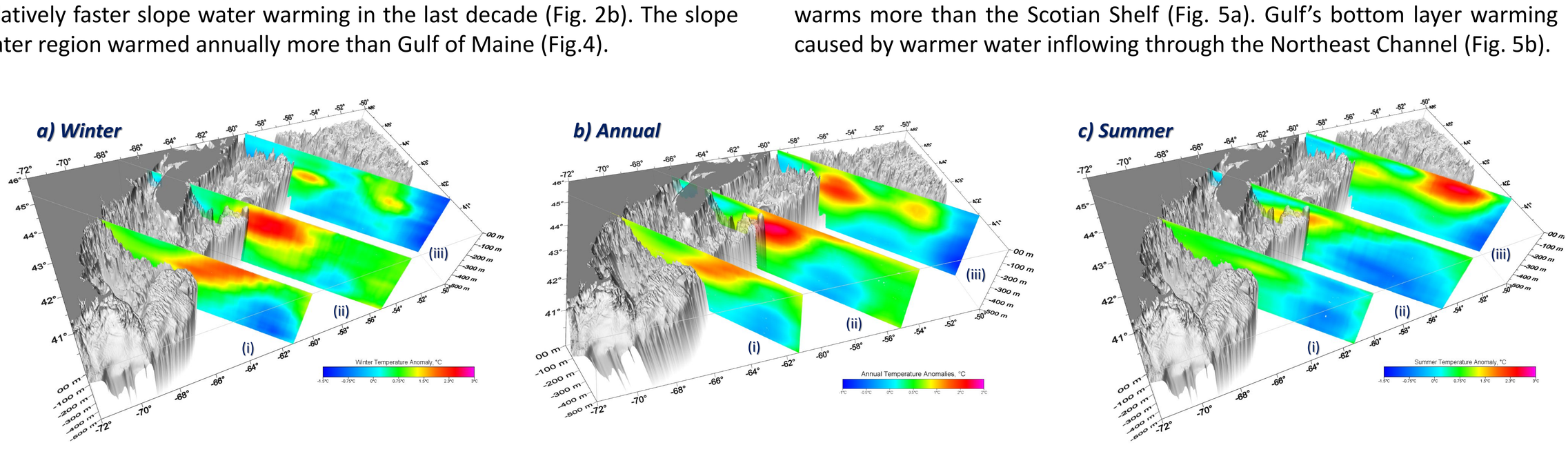
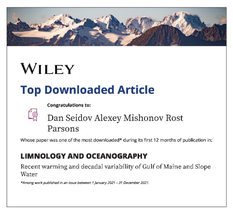


Figure 5. Winter, annual, and summer temperature anomalies between the averages: 1995–2017, and 1965–1984 along three cross-shelf sections:
(i) across the middle of the Gulf of Maine, (ii) across the middle of the Scotia Shelf and Slope Water area, and (iii) through the South of the Laurentian Channel outflow



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