Seven decades of climate variability on the Newfoundland and Labrador shelf

Frédéric Cyr[1], D. Bélanger[1], P.S. Galbraith[2], N. Chen[1] & G. Han[3]

[1]Northwest Atlantic Fisheries Centre, Fisheries and Oceans Canada, St. John's, Canada
[2]Maurice-Lamontagne Institue, Fisheries and Oceans Canada, Mont-Joli, Canada
[3]Institute of Ocean Sciences, Fisheries and Oceans Canada, Sidney, Canada

Symposium on Decadal Variability of the North Atlantic and its Marine Ecosystems: 2010-2019

NAFO

ICES CIEM

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

Fisheries and Oceans Canada

Pêches et Océans Canada

Context

Systematic hydrographic observations on the Newfoundland and Labrador (NL) shelf have been carried out by Canada and other countries since the late 1940's. These observations were further augmented in 1998 (both with a better spatial and seasonal coverage, but also with the addition of biogeochemical sampling) after the creation of the Atlantic Zone Monitoring Program (AZMP) by Fisheries and Oceans Canada (Therriault et al., 1998). Seven decades of these observations have been collated into a single *Climate Index* presented below. The NL Climate Index (NLCI) aims to describe the environmental conditions on the NL shelf and in the Northwest Atlantic as a whole. It consists of the average of 10 normalized anomalies — or subindices — presented below in the central panel. This index now runs from 1951 to 2021 and will be updated annually. Such indices have been proven to be a useful tool for the production of advice for fisheries management and ecosystem status on the NL shelf. The NLCI and its subindices are available at https://doi.org/10.20383/101.0301 (Cyr and Galbraith, 2020). Here we put the NLCI in the context of the observed physical and biogeochemical changes on the NL shelf. Results suggest, for example, that the NL shelf climate undergoes large decadal variations. Winter conditions in the Northwest Atlantic largely set the stage for the ocean conditions on the NL shelf during the rest of the year. It is shown that decadal changes of the sea-level pressure above the North Atlantic influences the subpolar gyre, and thus the interactions between the Labrador and the North Atlantic currents, two major contributors to the NL shelf climate variability. This variability has in turn important consequences for the biogeochemistry and the overall productivity of the NL shelf ecosystem. **Follow the numbers starting from the central panel for a quick tour of the NLCI and its interpretation.**

2. Large decadal variability of the NL climate

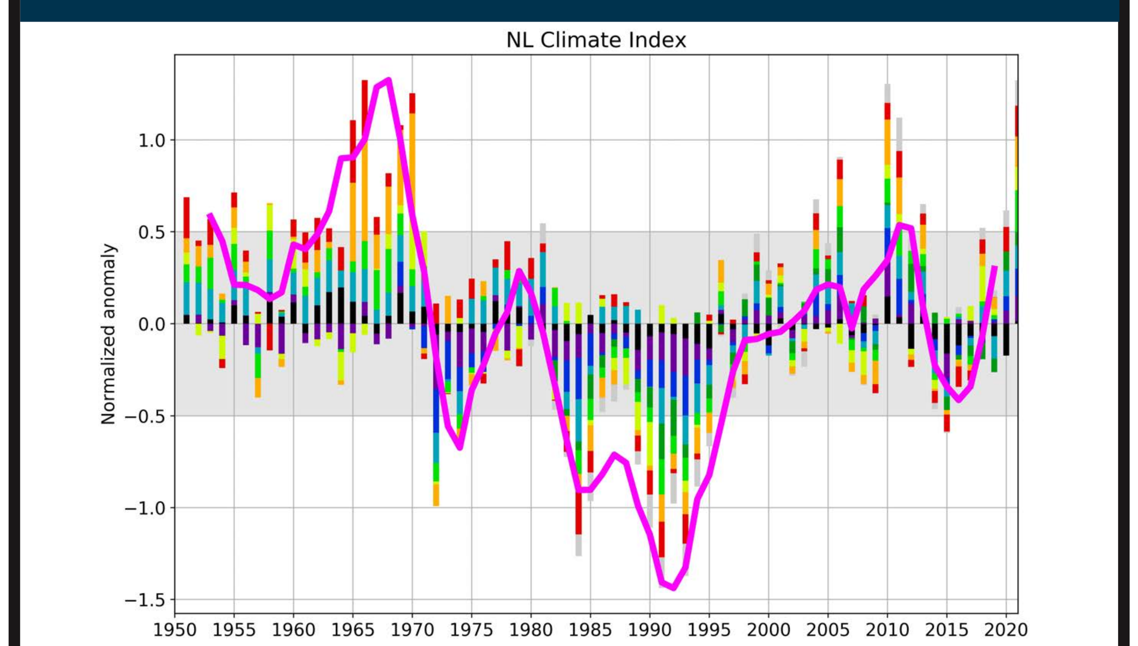


Figure 3. Decadal variability of the NL shelf are illustrated with a 5-year moving average overlaid on top of the NLCI. **The climate on the NL shelf is characterized by large decadal cycles.**

3. 1960s warmest period | 1990s the coldest

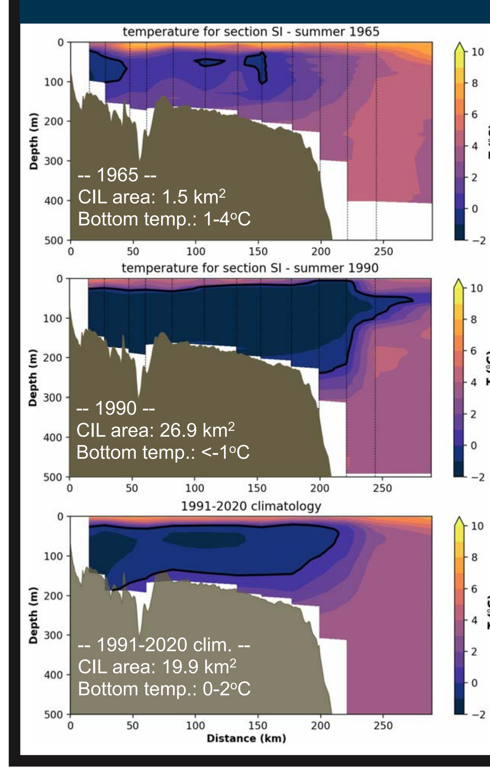


Figure 4. The **cold intermediate layer** (CIL) is defined as the water below 0°C (dark black contour in all panels). The area of the CIL along standard hydrographic sections (here Seal Island; see Figure 1) is a robust indicator of the state of the ocean climate in NL. Two extremes are presented: during the year 1965 (top), the CIL area was only 1.5 km^2. In 1990 (middle panel), this area was 26.9 km^2 and the CIL was much colder (darker shade of blue is -1°C). The bottom panel is the 1991-2020 climatology.

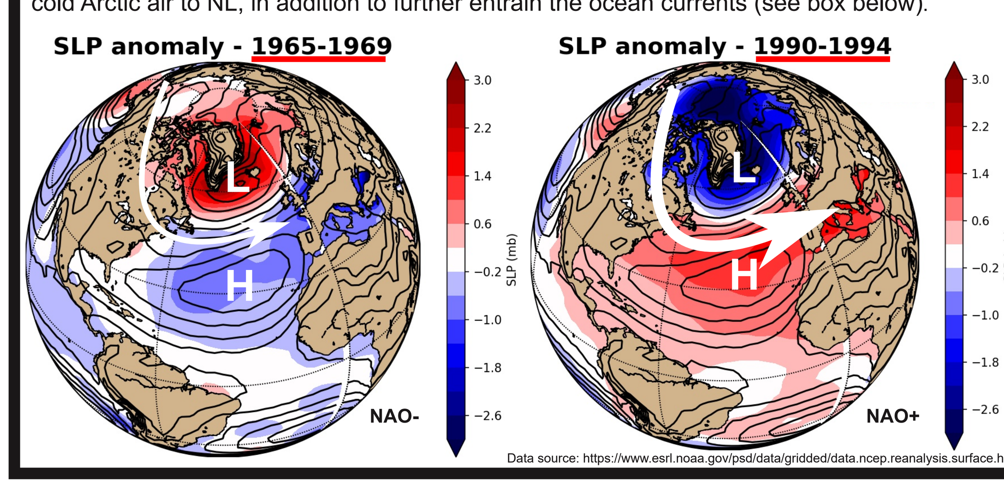
The CIL occupies most of the volume of the NL shelf. **The CIL properties will thus directly influence the thermal habitat of multiple pelagic and bethic species living on the NL shelf**, especially in the areas shallower than 250m.

Since the CIL is formed in the winter and corresponds to the remnant of the cold winter mixed layer, the **winter usually sets the stage for ocean conditions for the rest of the year.**

4. The atmospheric forcing sets the stage ...

Figure 5. Sea level pressure (SLP) anomalies (color scale) averaged over 5-year periods during the warm 1960s (left) and the cold 1990s (right). See also **BOX 3**. The long-term location of SLP contours are identified with black lines in both panels, with the approximate locations of the Icelandic low (L) and the Azores high (H) identified.

The bulk of this signal is captured by the winter NAO (see APPENDIX 1). When the Icelandic low is lower than normal and the Azores high is higer than normal (NAO+), the greater pressure differences drive an intensification of the westerlies winds above the north Atlantic (sketched with white arrows), and vice-versa. The intensification of the westeries will bring cold Arctic air to NL, in addition to further entrain the ocean currents (see box below).



1. The Newfoundland and Labrador Climate Index (NLCI) Cyr & Galbraith (2021)

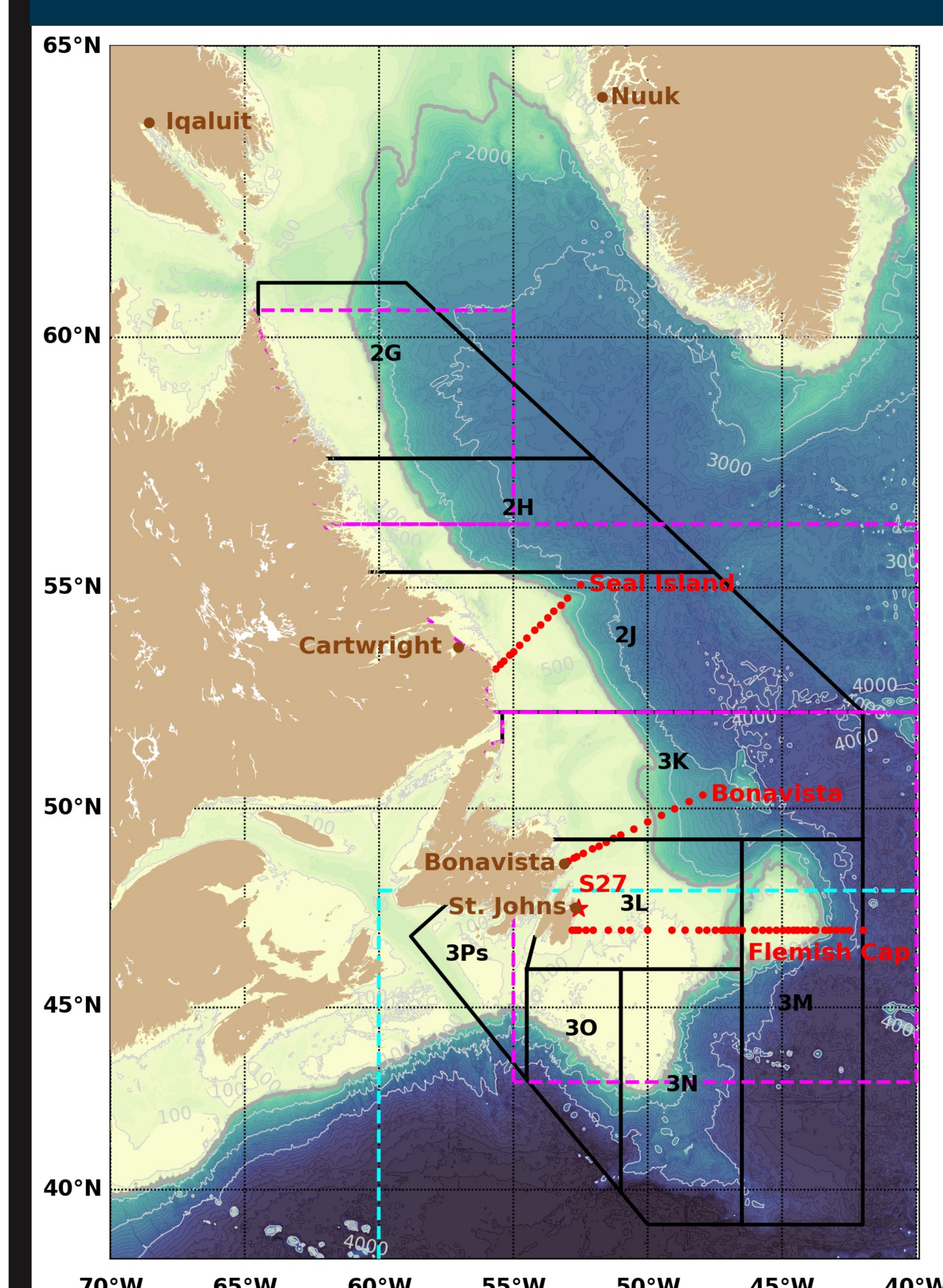


Figure 1. Map and main bathymetric features of the Northwest Atlantic ocean, together with geographical elements relevant for the NLCI (Figure 2). NAFO Divisions (sub-areas 2 and 3) on the Newfoundland and Labrador (NL) shelf are drawn. The AZMP hydrographic sections Seal Island, Bonavista Bay and Flemish Cap are shown with red dots. Long-term AZMP hydrographic Station 27 is highlighted with a red star. The five stations used for the air temperature time series are shown in brown. The three regions used for sea ice calculations are drawn with dashed magenta lines: northern Labrador shelf, southern Labrador shelf and Newfoundland shelf, respectively, from north to south. The region used by the International Ice Patrol for iceberg sightings south of 48°N is drawn in dashed cyan. The shelf break is delimited by a thicker and darker contour corresponding to the isobath 1000m (used to clip the SST and bottom temperature).

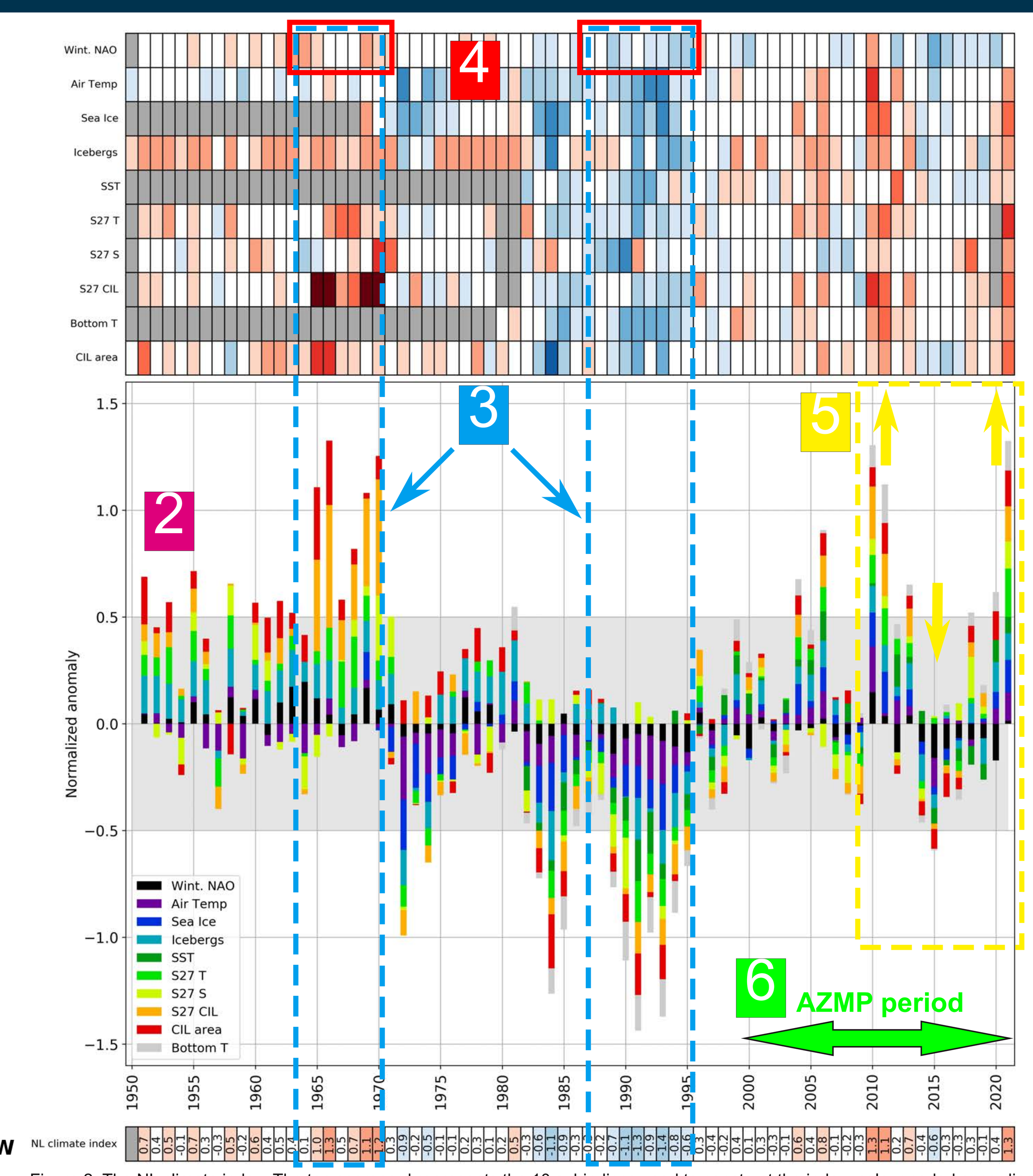


Figure 2. The NL climate index. The top scorecard represents the 10 subindices used to construct the index, colour coded according to their value (blue negative, red positive, white neutral). The sub-indices have been choosen to be relatively independent to each other (see APPENDIX 2). These time series are the following (see Figure 1 for geographical locations): winter NAO index (starts in 1951), the air temperature at five sites (starts in 1950), the sea ice season duration and maximum area for the northern Labrador, southern Labrador and Newfoundland shelves (starts in 1969), the number of icebergs (starts in 1950), SSTs in NAFO Division 2GHJ3KLNOP (starts in 1982), vertically averaged temperature and salinity at Station 27, CIL core temperature at Station 27 (starts in 1951), the summer CIL areas on the hydrographic sections Seal Island, Bonavista Bay and Flemish Cap (starts in 1950), and the spring and fall bottom temperature in NAFO Divisions 3LNOPs and 2HJ3KLNO, respectively (starts in 1980). The sign of some indices (NAO, ice, icebergs, salinity and CIL volume) has been reversed when positive anomalies are generally indicative of colder conditions. Grey cells in the scorecards indicate the absence of data. The main panel represents the climate index in a stacked-bar fashion, in which the total length of the bar is the average of the respective subindices and in which their relative contribution to the average is adjusted proportionally. The scorecard at the bottom of the figure shows the colour-coded numerical values of the NLCI.

6. NLCI is a good predictor of plankton bloom parameters

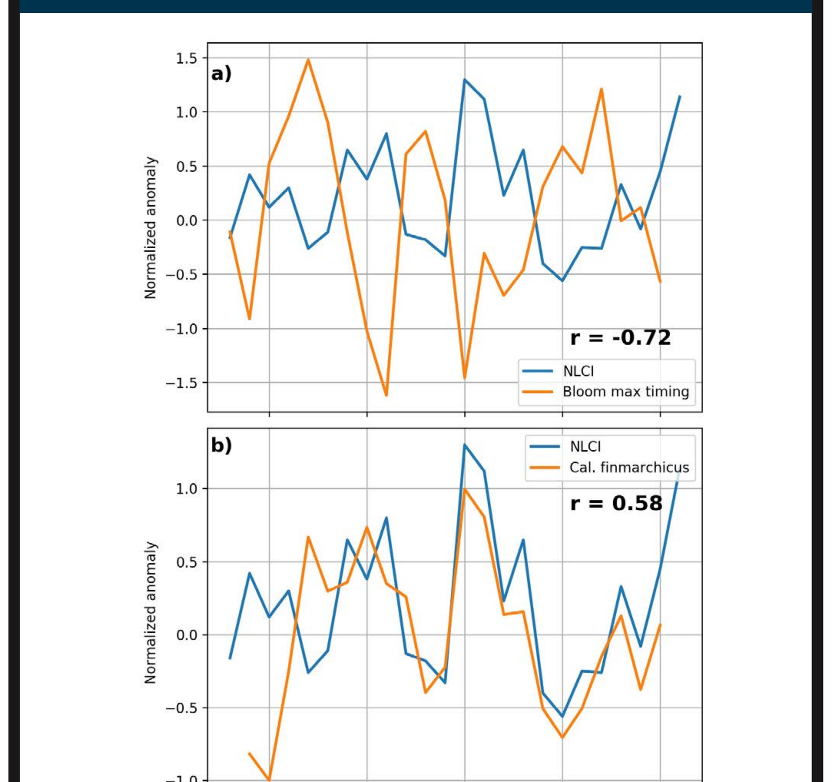


Figure 9. Comparision between the NLCI and a) the timing of the peak of the spring phytoplankton bloom, and b) the annual biomass of Calanus finmarchicus, a key zooplankton taxa for the NL ecosystem. Values presented correspond to the average of the normalized anomalies for NAFO divisions 2J, 3K and 3LNO. Pearson correlation coefficients are provided for both panels. The timing of the bloom is derived from daily images of surface ocean color obtained from SeaWiFS: (1998-2010) and MODIS (2003-2020) satellite and processed using the PhytoFit app (Clay & Layton, 2021) for each NAFO division. The Calanus finmarchicus biomass collected as part of the AZMP since 1998 has been normalized per NAFO divisions before being averaged here.

In a), it shows that periods with a **warmer climate** (milder winter, less sea ice, warmer SST, etc.) are associated with an **earlier bloom** accross the NL shelf. Note that there will still be a north-south gradient in the timing of the bloom, the latter being, for example, 40 days later in 2J compared to 3LNO (not shown; ongoing work).

In b), it shows that a **warmer climate (and thus an earlier bloom) favors the abundance of Calanus finmarchicus**. This may be related to a better match between the bloom and the emergence of spawning adults from winter diapause (on going work). Since Calanus finmarchicus is a key taxa relating primary producers to higher trophic levels (e.g. by being a favorite prey for capelin), the effect of late/early blooms can cascade through the whole NL ecosystem.

... and the ocean follows

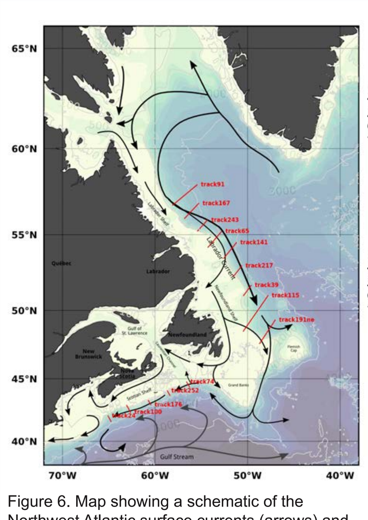


Figure 6. Map showing a schematic of the Northwest Atlantic surface currents (arrows) and the cross-slope altimetric track (red lines) used to calculate the transport of the Labrador Current on the NL shelf break and the transport of the Scotian shelf break current.

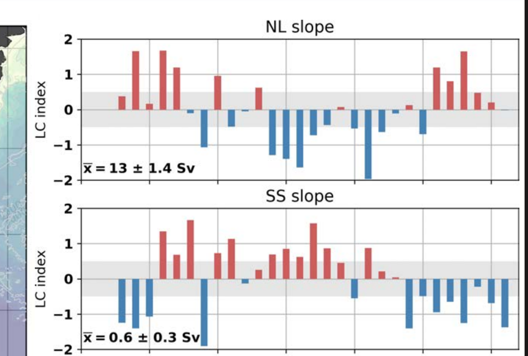


Figure 7. Normalized index of the annual-mean transport of the Labrador Current on the NL shelf break (top) and Scotian shelf break current (bottom).

Transports are generally out of phase between two slopes, with the positive transport on the NL slope (negative on the SS slope) generally associated with positive phases of the NAO (e.g. 2015-2020). This is in agreement with Holliday et al. (2020); see below.

The transport on the SS slope has been below normal for the last 8 years. This is partly responsible for record-high temperature and low oxygen concentration in the deep Gulf of St. Lawrence.

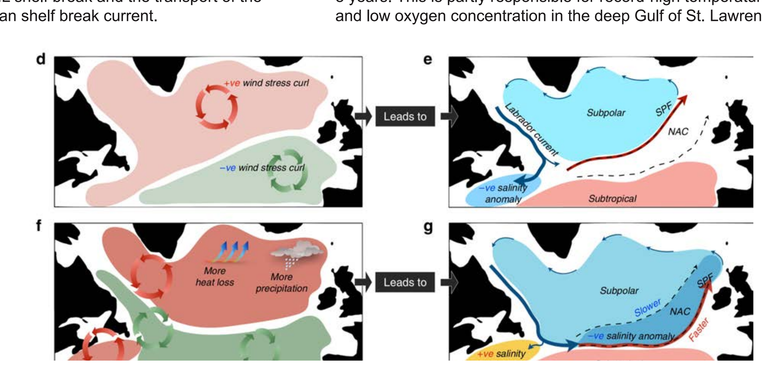
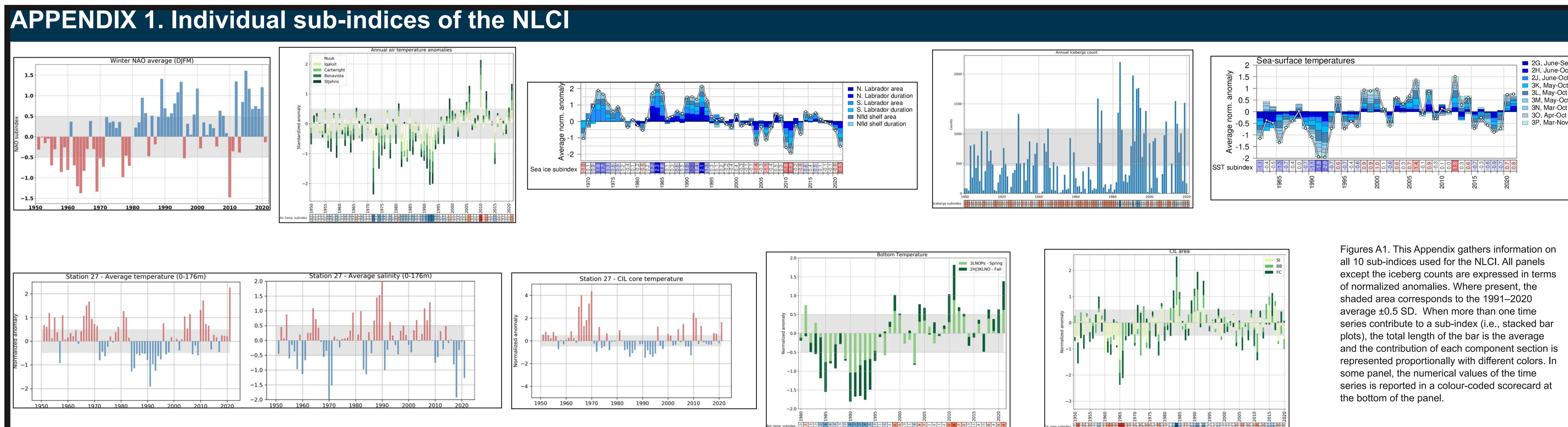


Figure 8. Schematic of the role of the wind on the subpolar gyre and the deflection of the Labrador current in the central North Atlantic (from Holliday et al., 2020).

5. Last decade: "cool" conditions (~2014-17) bracketed by some of the warmest years on record

The recent decade has seen some of the warmest years on record (2010 and 2021). Such a warm period has not been seen in NL since the mid-1960s. These record warm years are however separated by a normal-to-coolder-than-normal period between about 2014 and 2017 (see APPENDIX 1 for more details).

APPENDIX 1. Individual sub-indices of the NLCI



Figures A1. This Appendix gathers information on all 10 sub-indices used for the NLCI. All panels except the iceberg counts are expressed in terms of normalized anomalies. Where present, the shaded area corresponds to the 1991–2020 average ±0.5 SD. When more than one time series contribute to a sub-index (i.e., stacked bar plots), the total length of the bar is the average and the contribution of each component section is represented proportionally with different colors. In some panel, the numerical values of the time series is reported in a colour-coded scorecard at the bottom of the panel.

APPENDIX 2. Correlation between the NLCI sub-indices

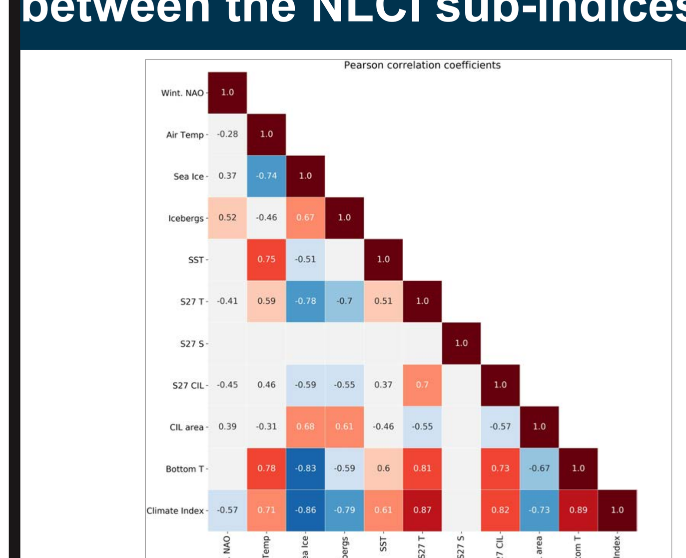


Figure A2. Pearson correlation (r) matrix between the different subindices of the NLCI and the NLCI itself. Red and blue colours denote a positive and negative correlation, respectively. Only significant correlations (p values <0.05) are shown. Correlations less than ±0.5 have been left white. The natural signs (not reversed) of the subindices have been used here in order to illustrate relationships in which positive (warm) anomalies in one variable (e.g. Station 27 temperature) are reflected by negative anomalies in another (e.g. sea ice)

Acknowledgements

This work is a contribution to the Atlantic Zone Monitoring Program (AZMP) of Fisheries and Oceans Canada (DFO). The authors thank the numerous scientists, technicians, captains and crew members who have participated in the sampling and analysis effort since 1951. The authors thank the Working Group on Oceanic Hydrography (WGOH) of the International Council for the Exploration of the Sea (ICES) for facilitating this research.

References

• Clay, S., & Layton, C. (2021). BIO-RSG/PhytoFit: First release. doi: 10.5281/433 zenodo.4770754
• Cyr & Galbraith (2020). Newfoundland and Labrador climate index. Federated Research Data Repository. https://doi.org/10.20383/101.0301
• Cyr & Galbraith (2021). A climate index for the Newfoundland and Labrador shelf. Earth System Science Data, 13, 1807–1828 doi: 10.5194/essd-13-1807-2021.
• Holliday et al. (2020). Ocean circulation causes the largest freshening event for 120 years in eastern subpolar North Atlantic. Nat Commun 11, 585. https://doi.org/10.1038/s41467-020-14474-y
• Theriault et al. (1998). Proposal for a Northwest Atlantic Zonal Monitoring Program. Can. Tech. Rep. Hydrogr. Ocean Sci. 194: vii+57 pp.

Questions or comments:

Frederic.Cyr@dfo-mpo.gc.ca

https://cyrf0006.github.io/