NAFO Northwest Atlantic Fisheries Organization

2021–2024 Regime Change in the Labrador Sea hydrography

Fisheries and Oceans Canada / Pêches et Océans Canada

Bedford Institute of Oceanography
Deep-Ocean Observation and Research Synthesis

DEEP-OCEAN OBSERVATION DOORS AND RESEARCH SYNTHESIS

Objective:

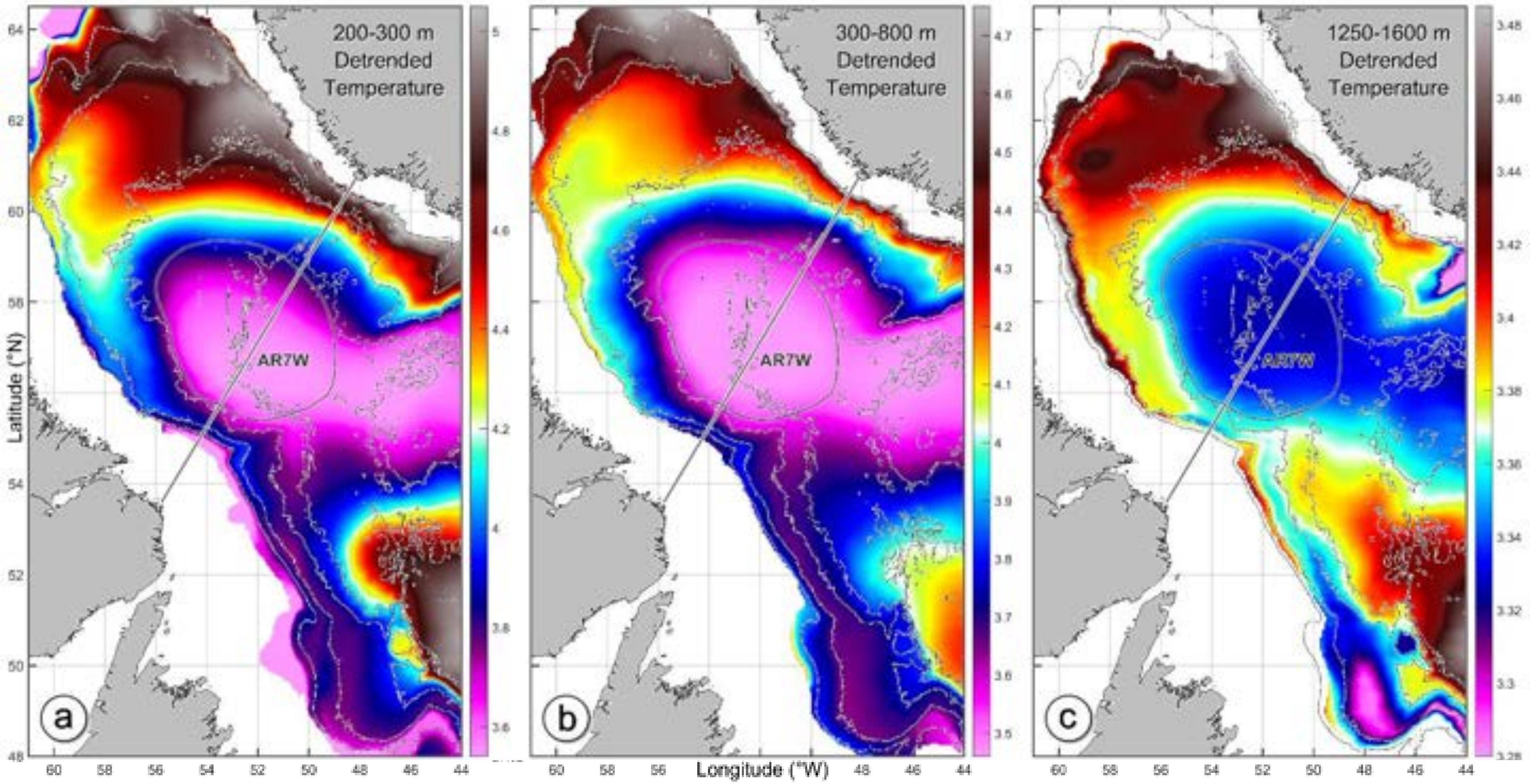
The purpose of this presentation is to highlight some of the new results presented in the recent publication dedicated to Labrador Sea convection and seasonal-to-interannual variability in its major characteristics, including a long-term Labrador Slope mooring record, the 2024 NAFO Report, and a look into the 2024 oceanographic conditions.

Elements of the Labrador Sea
climate observing network

To refamiliarize ourselves
with the Labrador Sea
we will walk through
three slices extracted
from its new climatology.

Practical applications of this climatology
include regional partitioning and
optimization of observations.

2002-2023 Multiplatform Vertically-Averaged Temperature Climatology

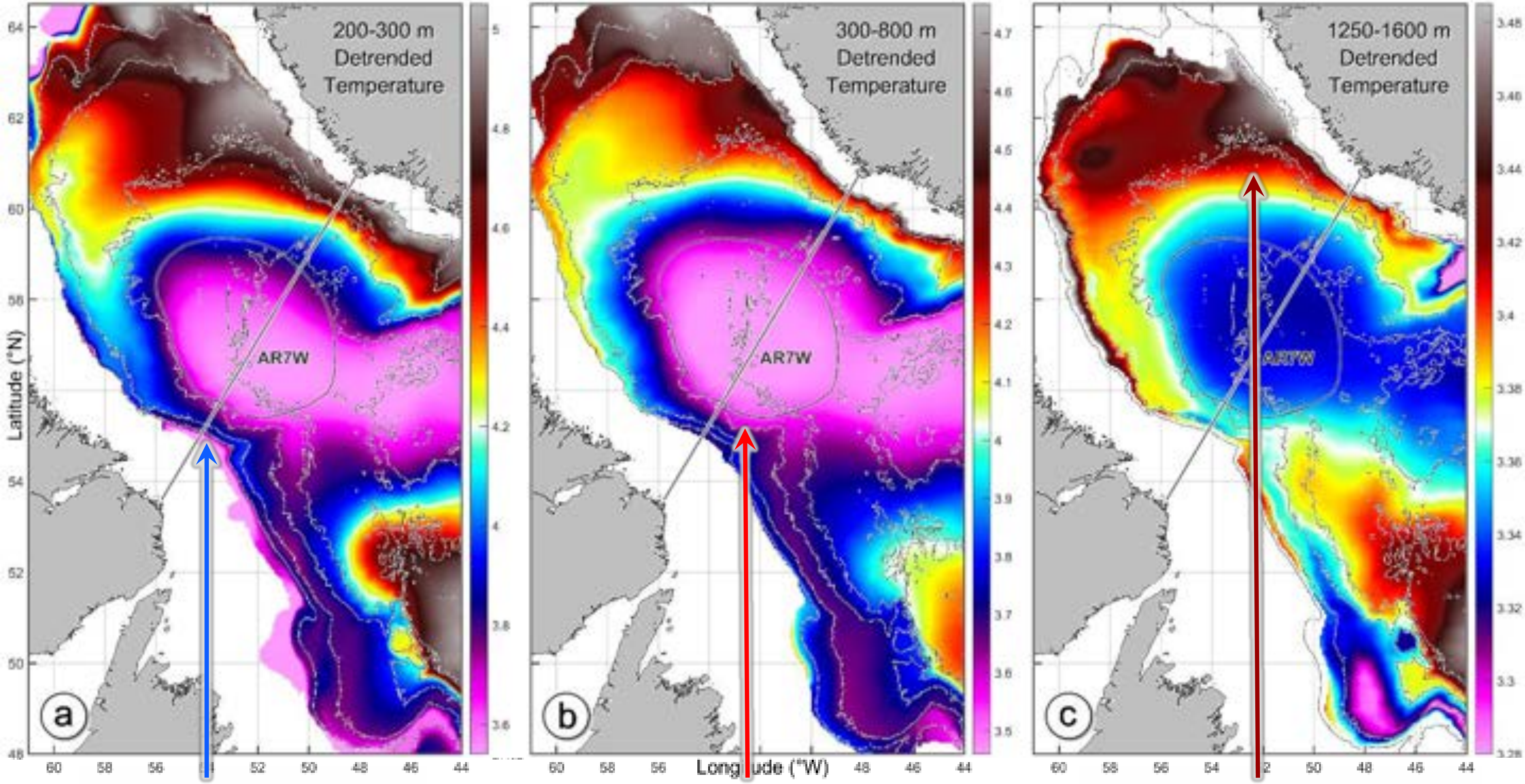


Hydrographic measurements from all platforms (e.g., profiling floats, ships) pass thorough multistep quality control, problem (e.g., drift) detection and correction.

Seasonal and interannual signals removed before spatial gridding.

Here, 2002-2023 was chosen because of spatiotemporal uniformity of data.

2002-2023 Multiplatform Vertically-Averaged Temperature Climatology

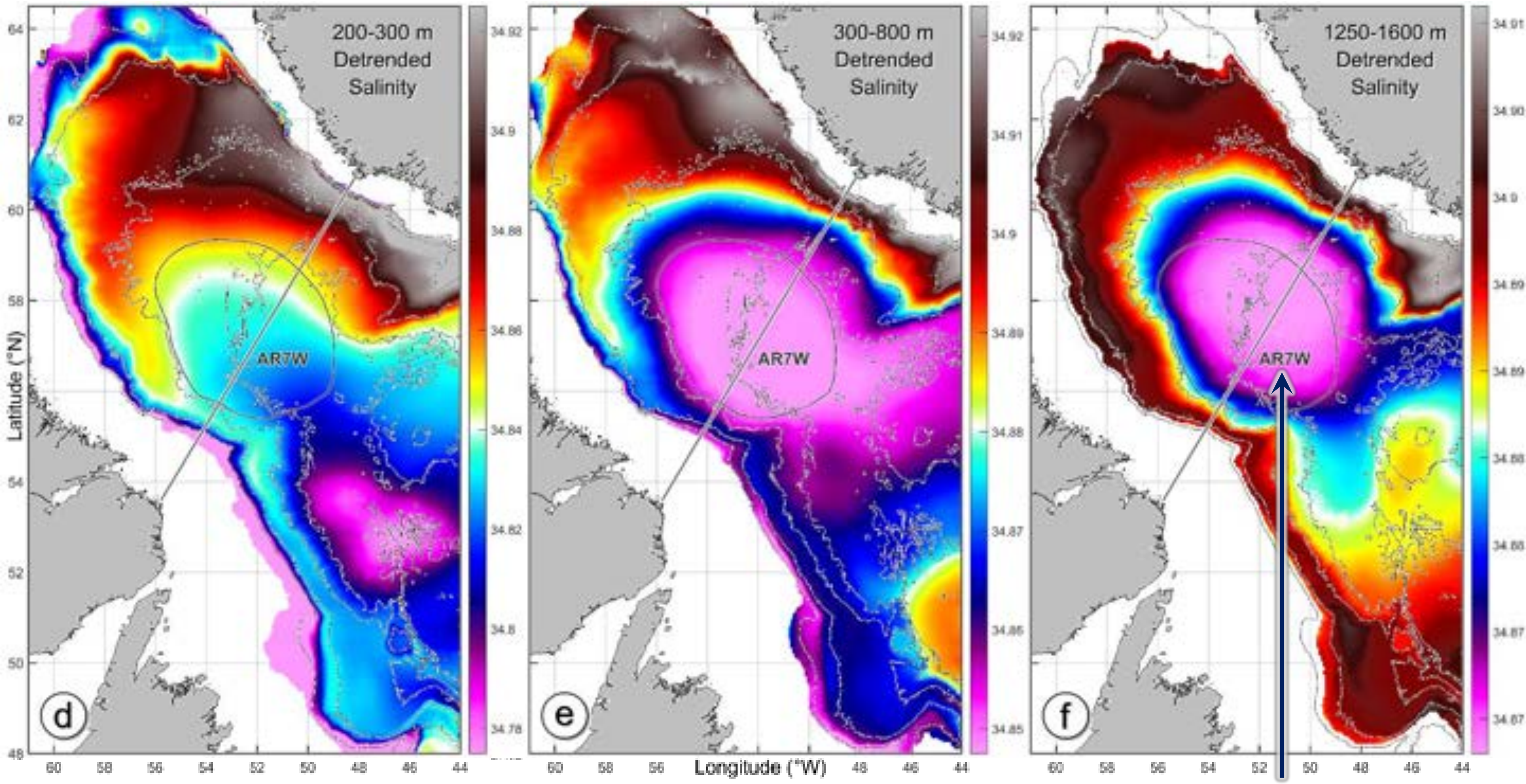


AR7W Atlantic Repeat hydrography line 7-West

Central Labrador Sea (**CLS**)

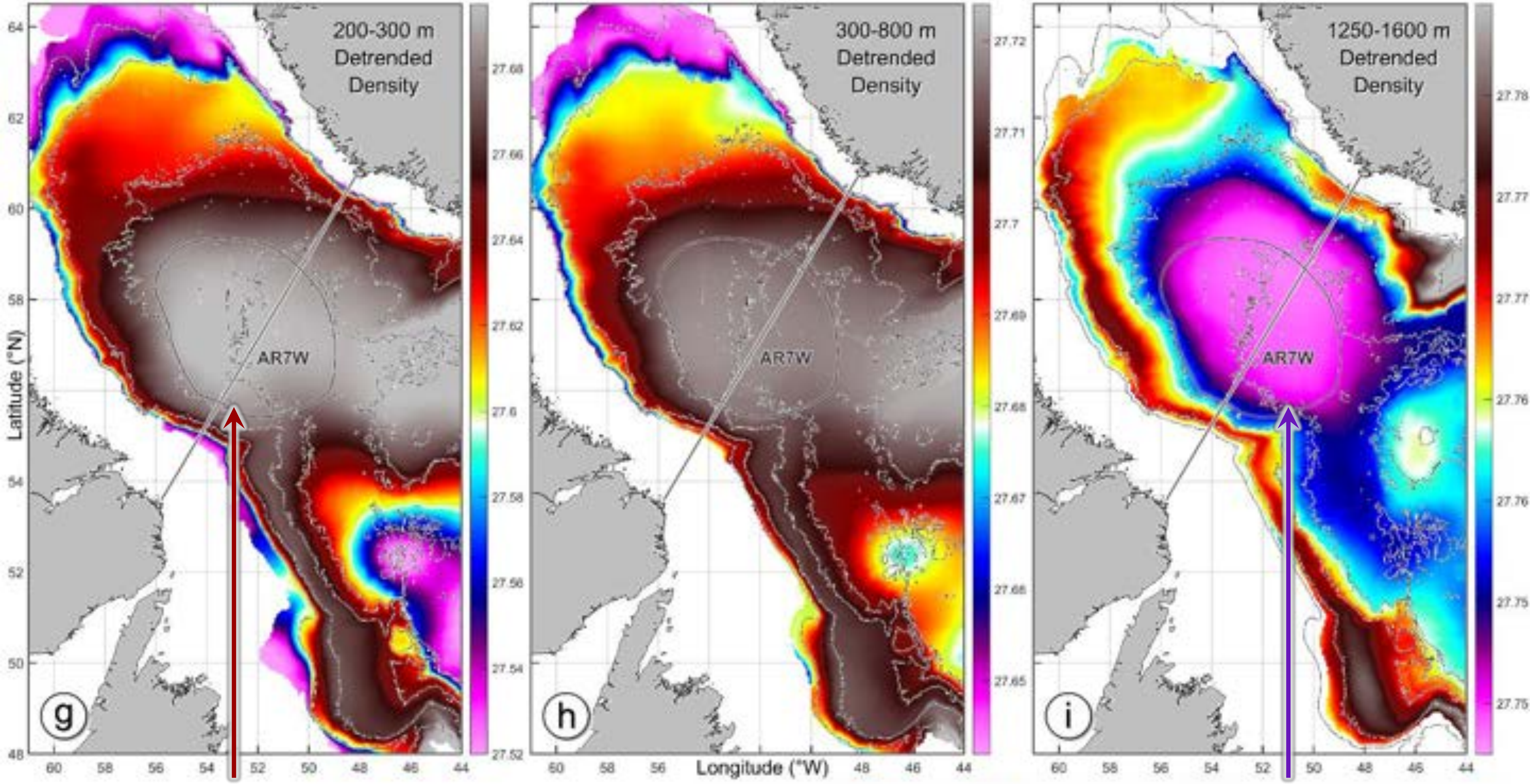
A reservoir of warm Atlantic Water in the northern Labrador Sea

2002-2023 Multiplatform Vertically-Averaged Salinity Climatology



Here freshwater
and gases sink deeper
than anywhere else in the
subpolar North Atlantic

2002-2023 Multiplatform Vertically-Averaged Density Climatology

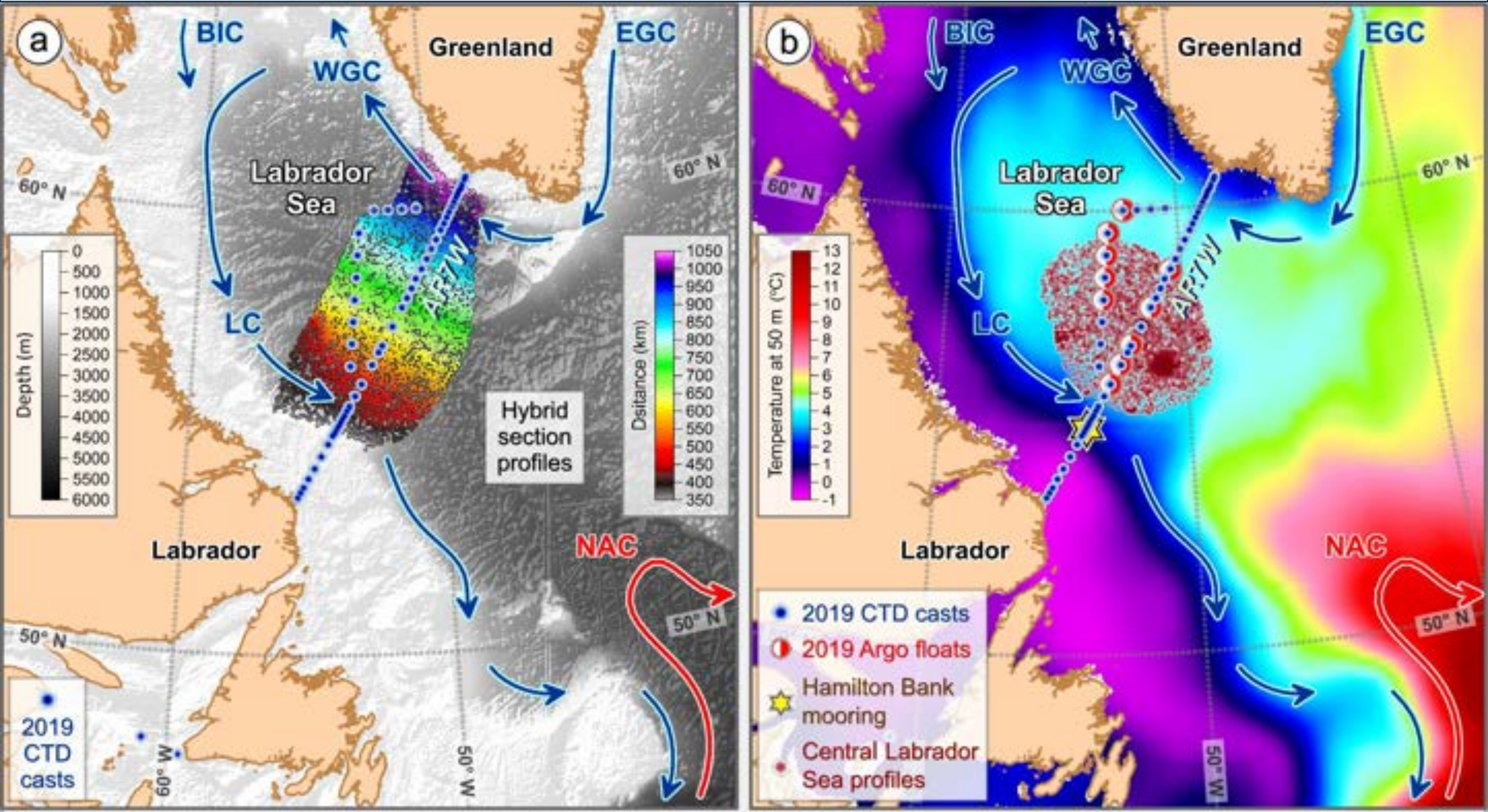


In the top 1000 m, the densest water is found in the center

Below 1000 m, the central Labrador Sea showcases a density minimum, explaining low stratification of the 200-1600 m layer.

This means that salinity dominates density at depth.

The Labrador Sea Deep-Ocean Observation and Research Synthesis (DOORS)
Oceanographic data uptake, quality control, analysis and synthesis platform



EGC - East-Greenland Current | **WGC** - West-Greenland Current | **LC** - Labrador Current | **BIC** - Baffin Island Current | **NAC** - North Atlantic Current

Distance color-coded locations of profiles used to construct the composite sections

Locations of the central Labrador Sea (CLS) profiles

The first destination of our magical Labrador Sea mystery tour is a 75-year record of the regional environmental changes. It will leave us with one big question to answer through the course of this Journey.

The Labrador Sea oceanographic record contains water sample, reversing thermometer, CTD and Argo float data

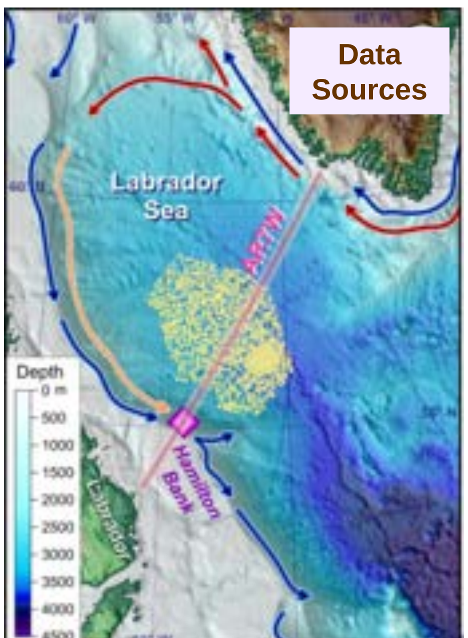
Vertical profile averaging:

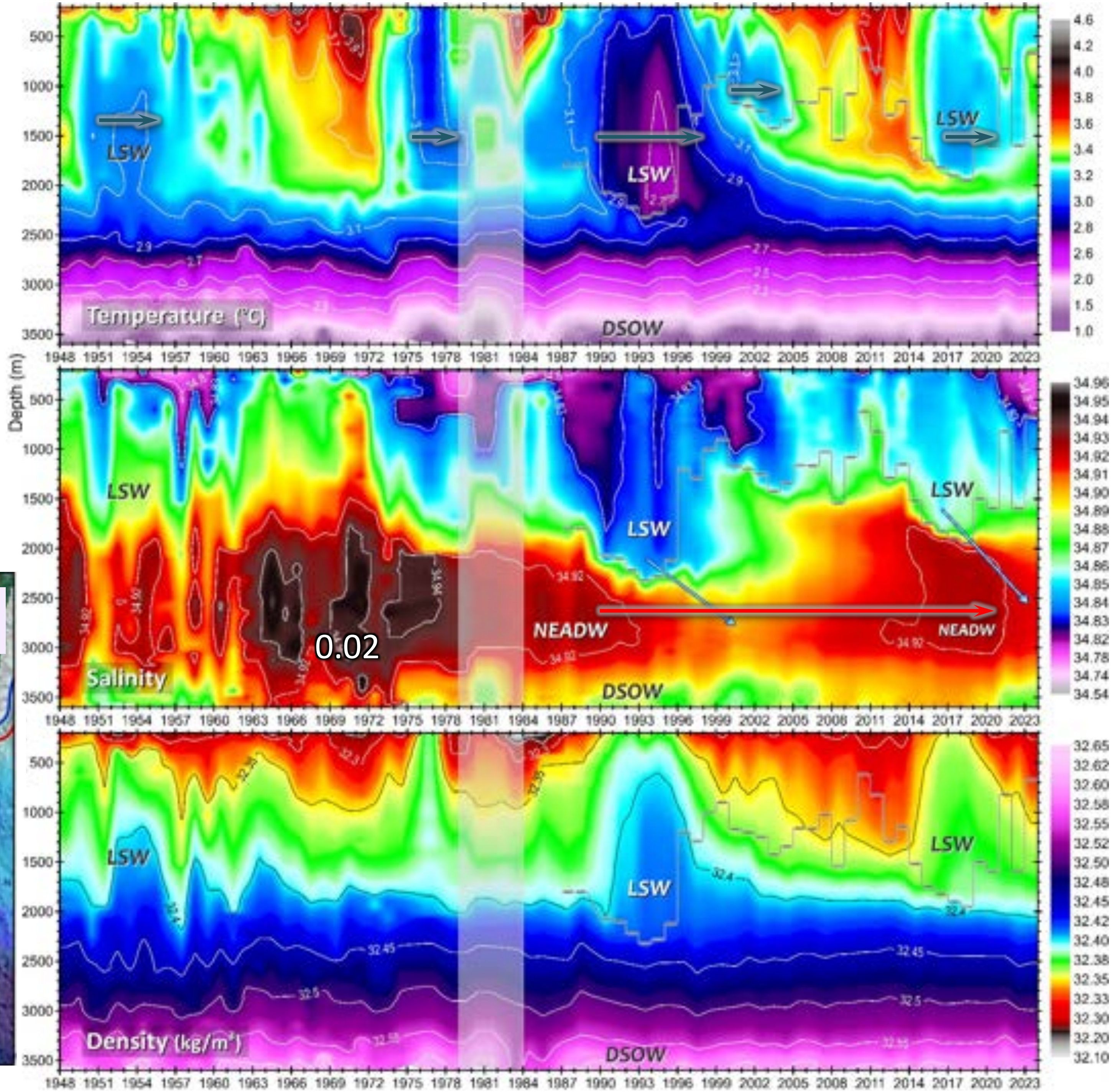
Early years – isobaric;

1948-1975 – isobaric-isopycnic hybrid;

1976-2023 – isopycnic;

Argo-only – isobaric 2017 & 2021





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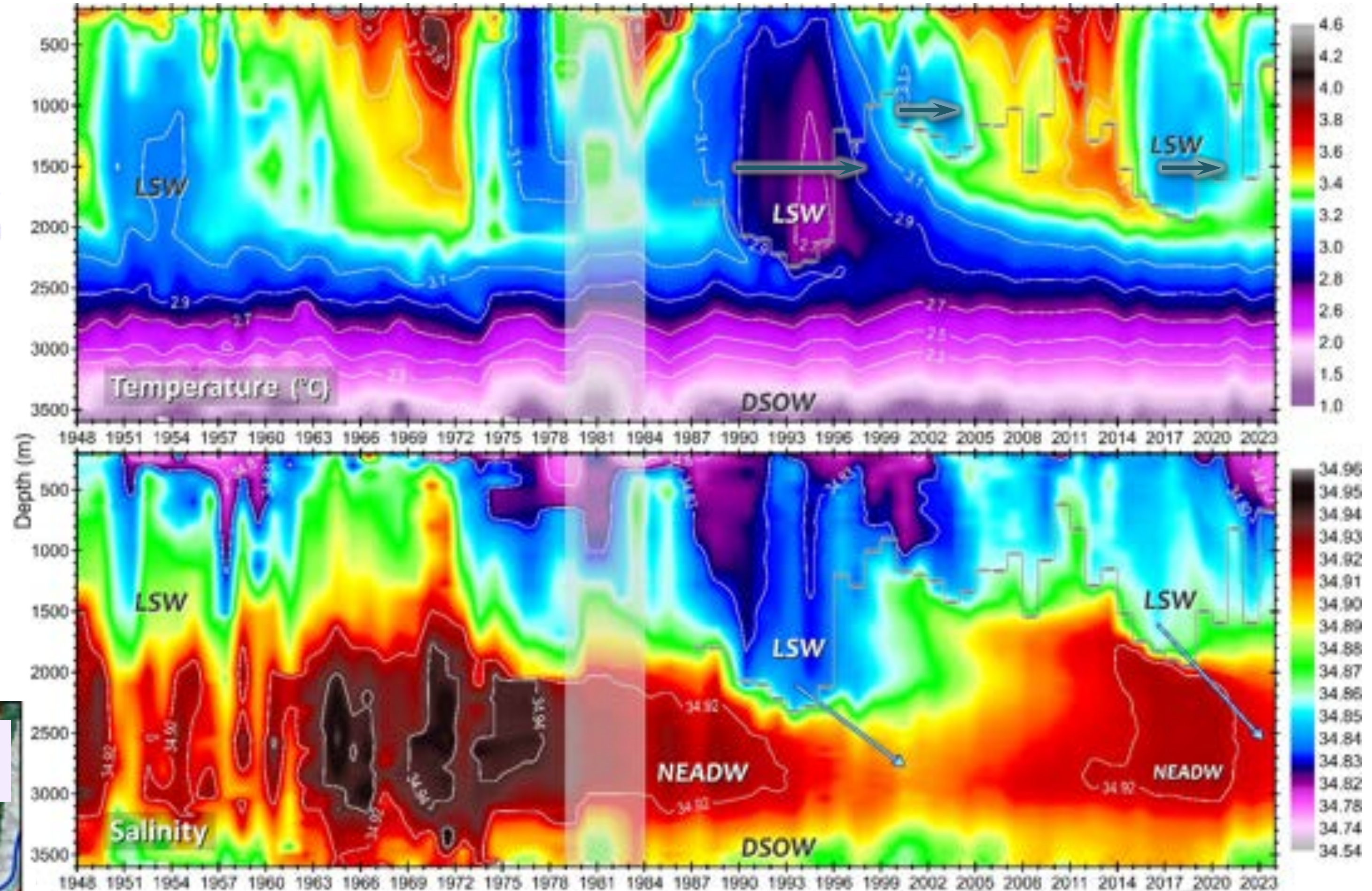
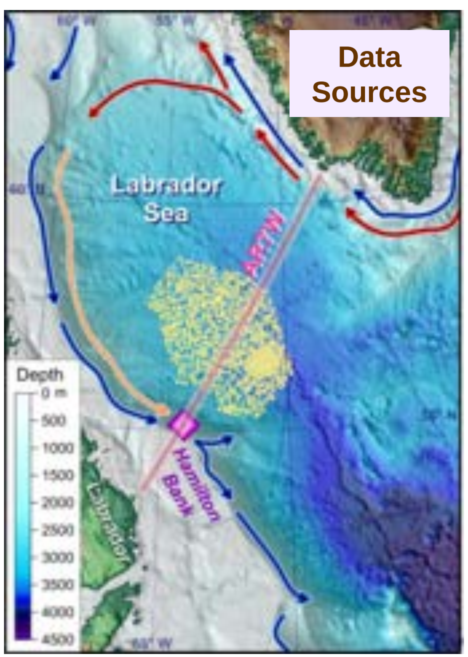
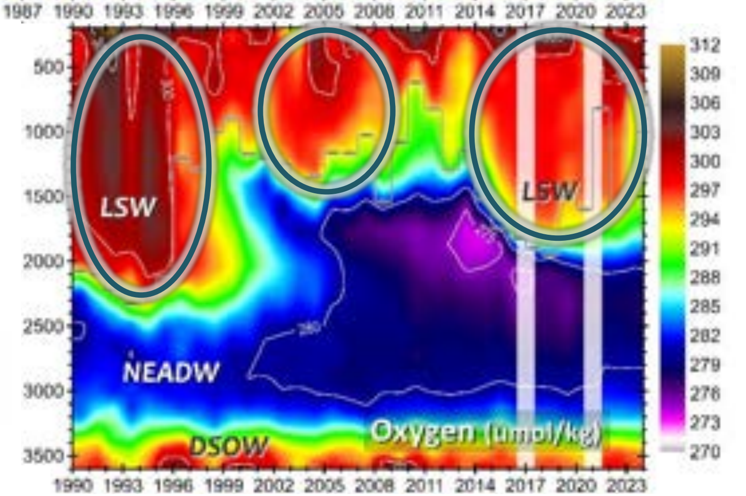




The impact of convection on ventilation based on corrected dissolved oxygen

Similarly to 1996, the 2023 shutdown of deep convection triggered a decline in the oxygen concentrations below 700 m.



Is
the North Atlantic Oscillation
the sole driver of
the winter atmospheric forcing
in the Labrador Sea?

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Progress in Oceanography

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Hydrographic changes in the Labrador Sea, 1960–2005

Igor Yashayaev *

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The agreement between convection and the NAO is not perfect for several reasons:

(1) The high correlation between the NAO index and net air-sea heat flux over the Labrador Sea is mainly a response to "the low frequency shift in the atmospheric conditions between the 1960s and the early 1990s". Removing this trend from the input series, lowers the correlation.

(2) Convective preconditioning – NAO's memory is short, while the sea's is much longer. Mild winters and upper layer freshening can inhibit convection.

(3) A high NAO is about a stronger mean westerly wind over the central North Atlantic, which may likely affect the Labrador Sea one way or the other, but not necessarily. Significant variations in atmospheric fields over the North Atlantic weaken the response of the winter conditions in the Labrador Sea, including convection, to changes in NAO.

The nature of both
station-based and PC/NAO/SVD-based
North Atlantic Oscillation indices is such
that a plethora of diverse 3D atmospheric
situations is routinely projected on either
a single line or a single standing pattern.

Who is the prime suspect of committing the act of Labrador Sea overturning ~~in winter?~~

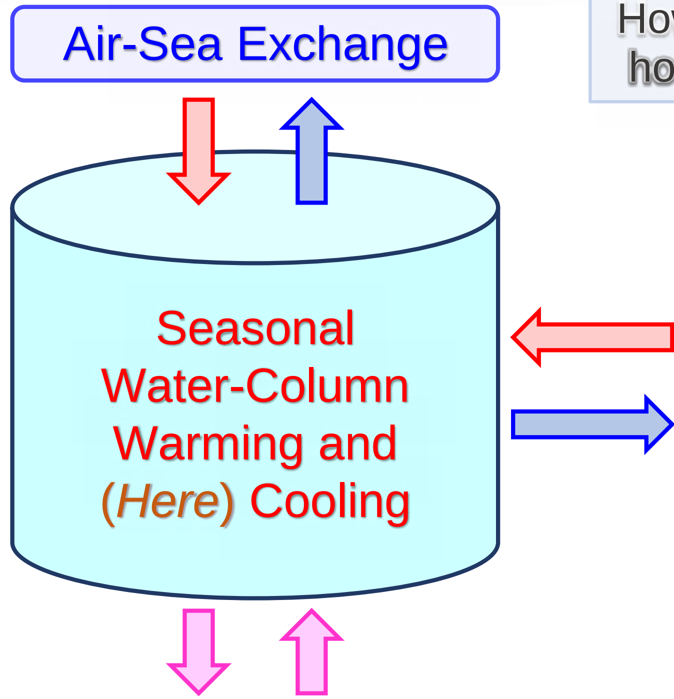
IN SOME WINTERS?

Water Column Cooling in response to cumulative Winter Surface Heat Loss

What is the main cause and driver of winter convection?

How can we measure the net horizontal heat flux *for free*?

Winter Surface Heat Loss *(known)*
=
Water-Column Cooling *(known)*
+
Net Horizontal Heat Flux *(unknown)*



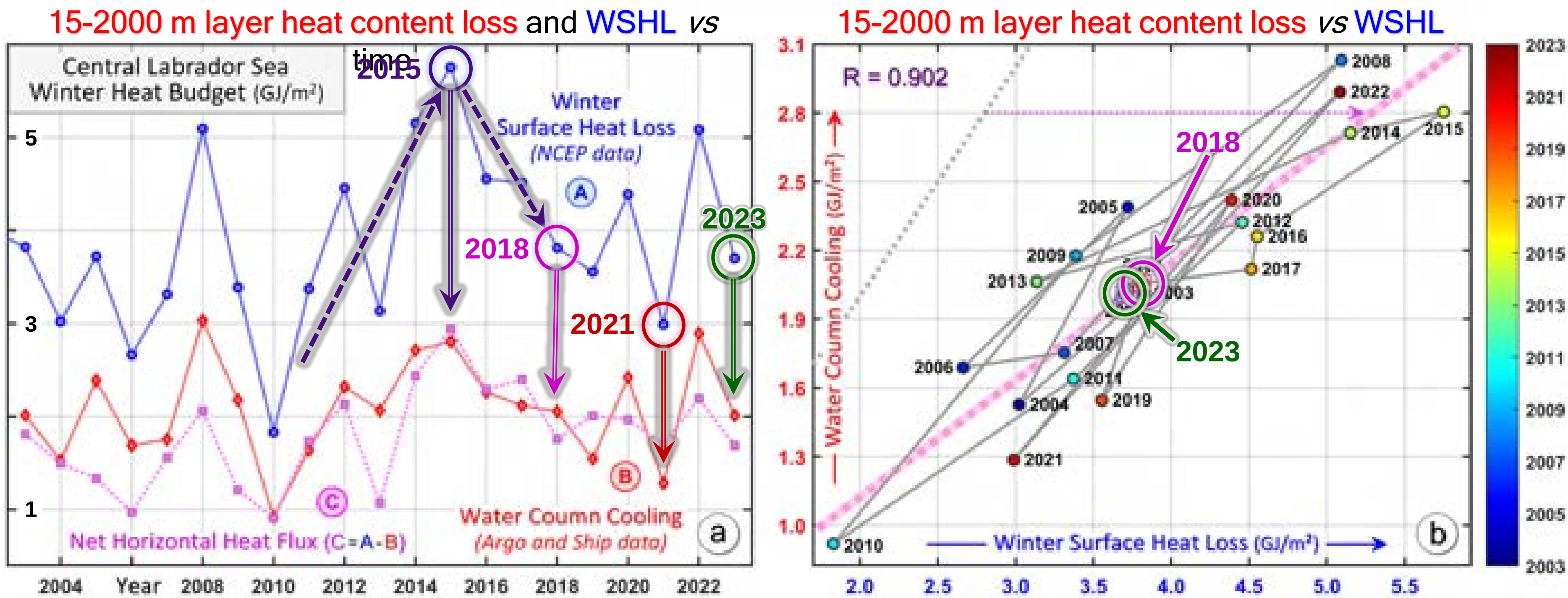
Net Horizontal Heat Flux
=
Advection
+
Diffusion
=
Convergence of Heat

Winter Surface Heat Loss (WSHL) is a sum of the latent and sensible heat, incoming and outgoing shortwave and longwave radiation fluxes Integrated over a sea surface cooling season.

WSHL, through convection, cools the water column.
The same water column is simultaneously warmed by the advective and diffusive horizontal flux or convergence of heat.

WSHL is based on NCEP/NCAR Reanalysis.
Water column heat loss is mainly based on the Argo float profiles.

Water Column Cooling in response to cumulative Winter Surface Heat Loss



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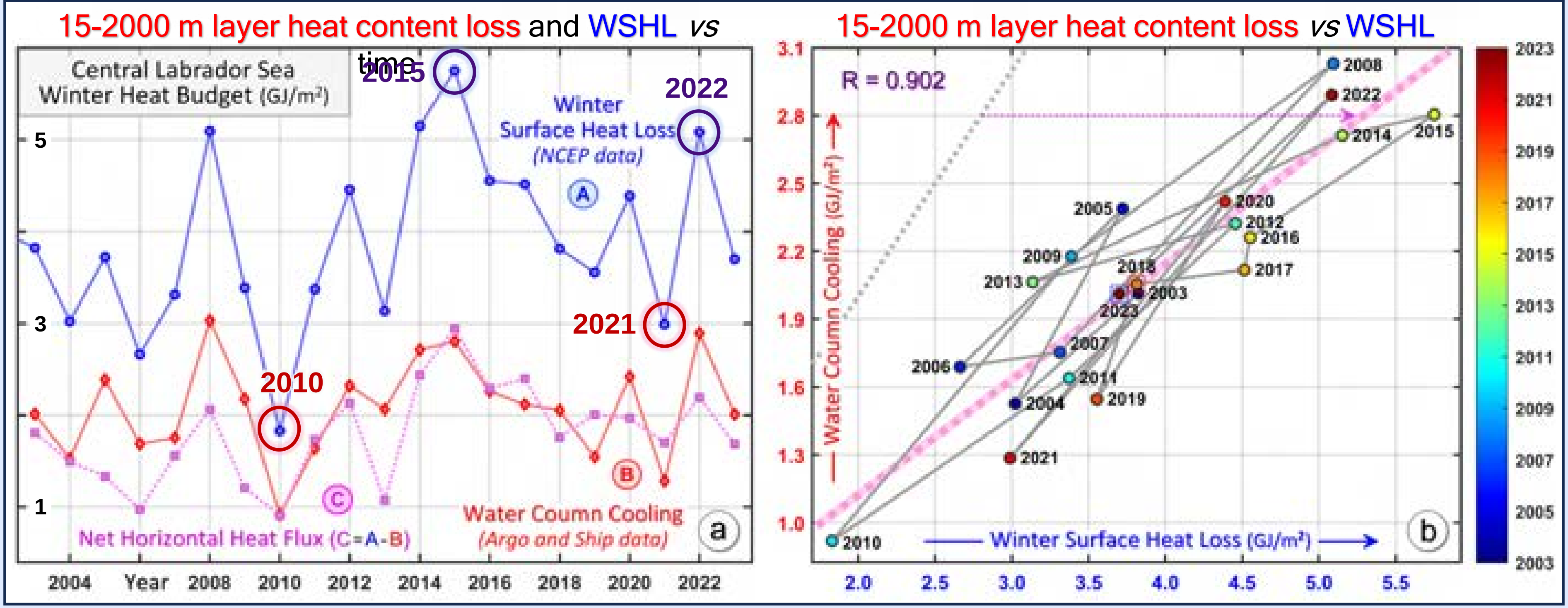
How do the stratospheric and tropospheric dynamics control winter cooling and convection in the Labrador Sea?

We will select two extreme warm and two extreme cold years, and analyze all four years individually.

Water Column Cooling in response to cumulative Winter Surface Heat Loss



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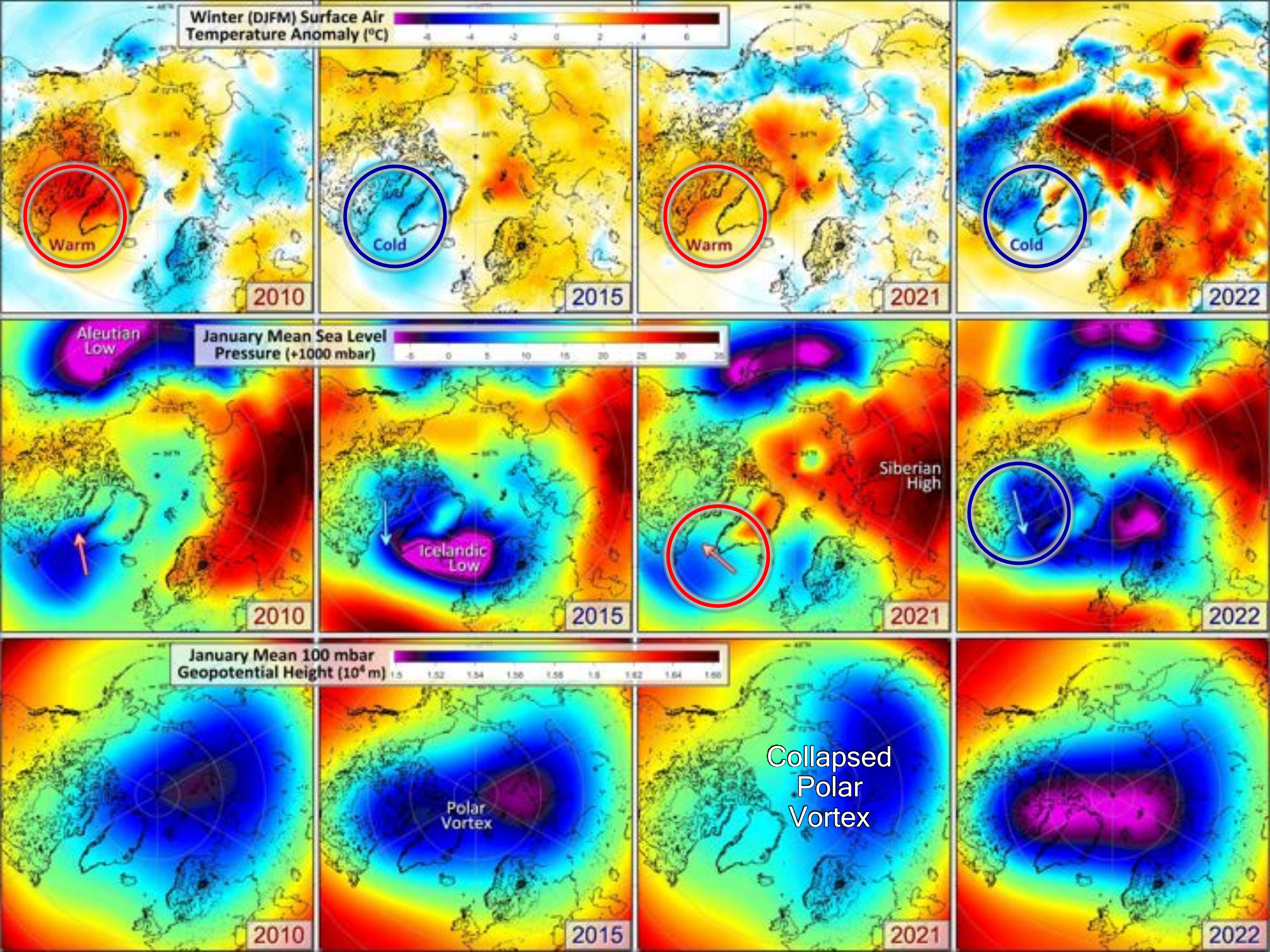
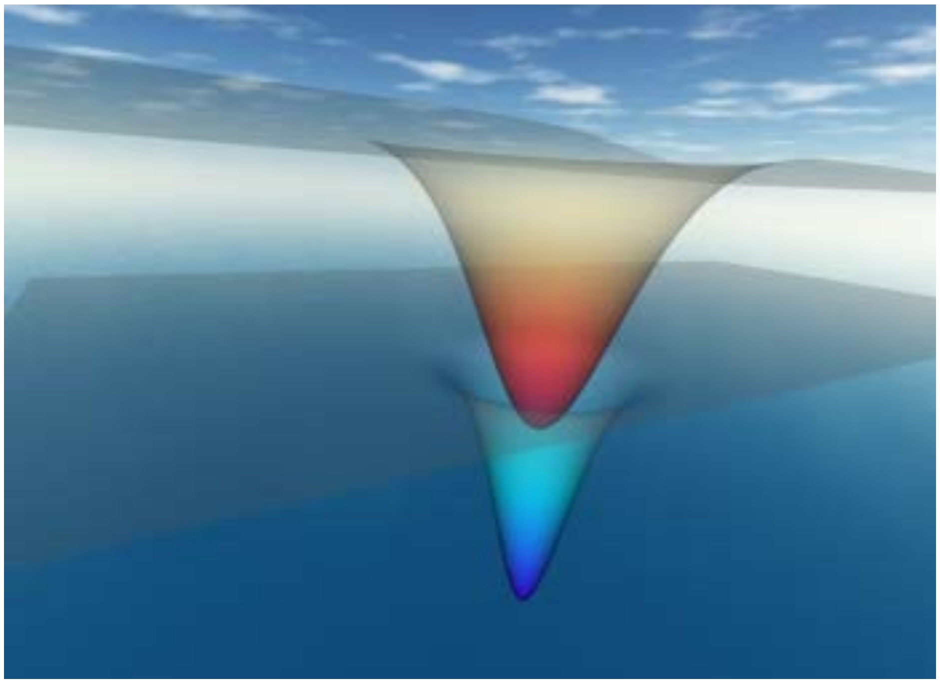

Winter (DJFM) Surface Air Temperature Anomaly (°C)
-6
-4
-2
0
2
4
6
Warm
Cold
Warm
Cold
2010
2015
2021
2022
January Mean Sea Level Pressure (+1000 mbar)
-5
0
5
10
15
20
25
30
35
Aleutian Low
Icelandic Low
Siberian High
2010
2015
2021
2022
January Mean 100 mbar Geopotential Height (10⁴ m)
1.5
1.52
1.54
1.56
1.58
1.6
1.62
1.64
1.66
Polar Vortex
Collapsed Polar Vortex
2010
2015
2021
2022

Polar vortex and Icelandic Low aligned

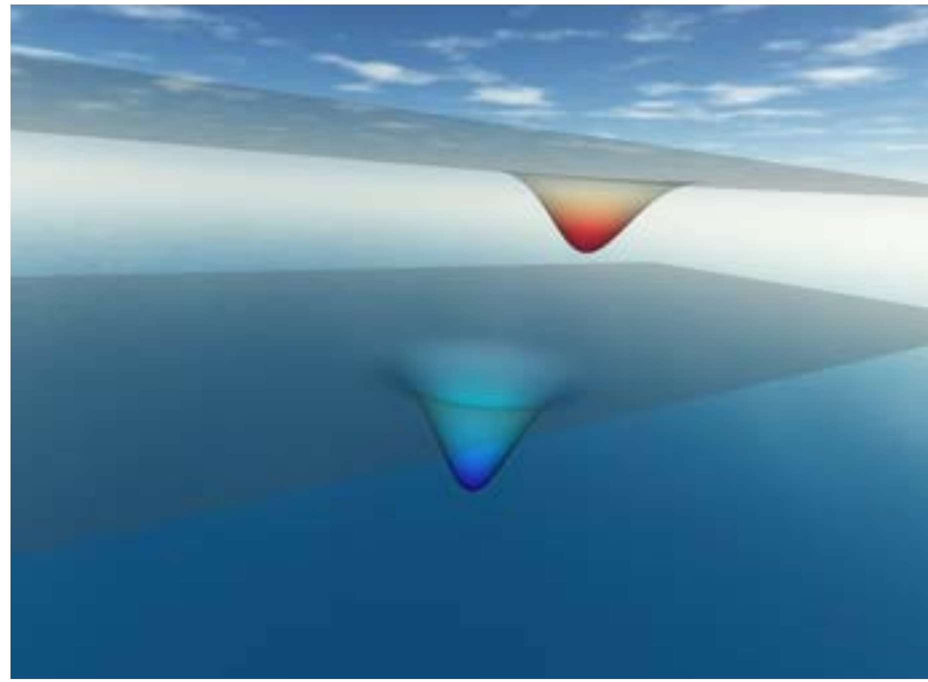
Strong polar vortex



Strong Icelandic Low → High NAO

Polar vortex shifted east and Icelandic Low shifted west

Disrupted and/or weak polar vortex

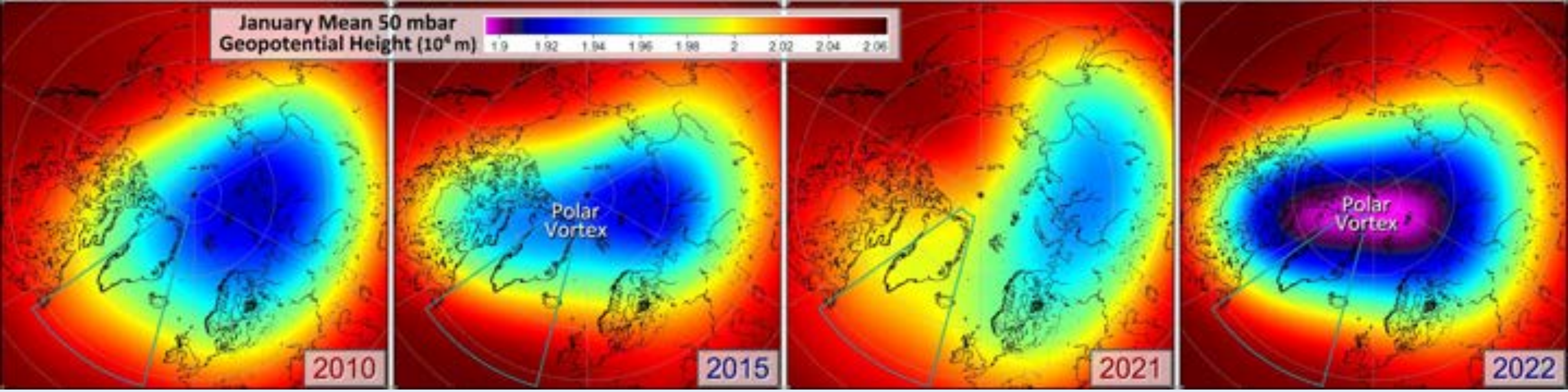


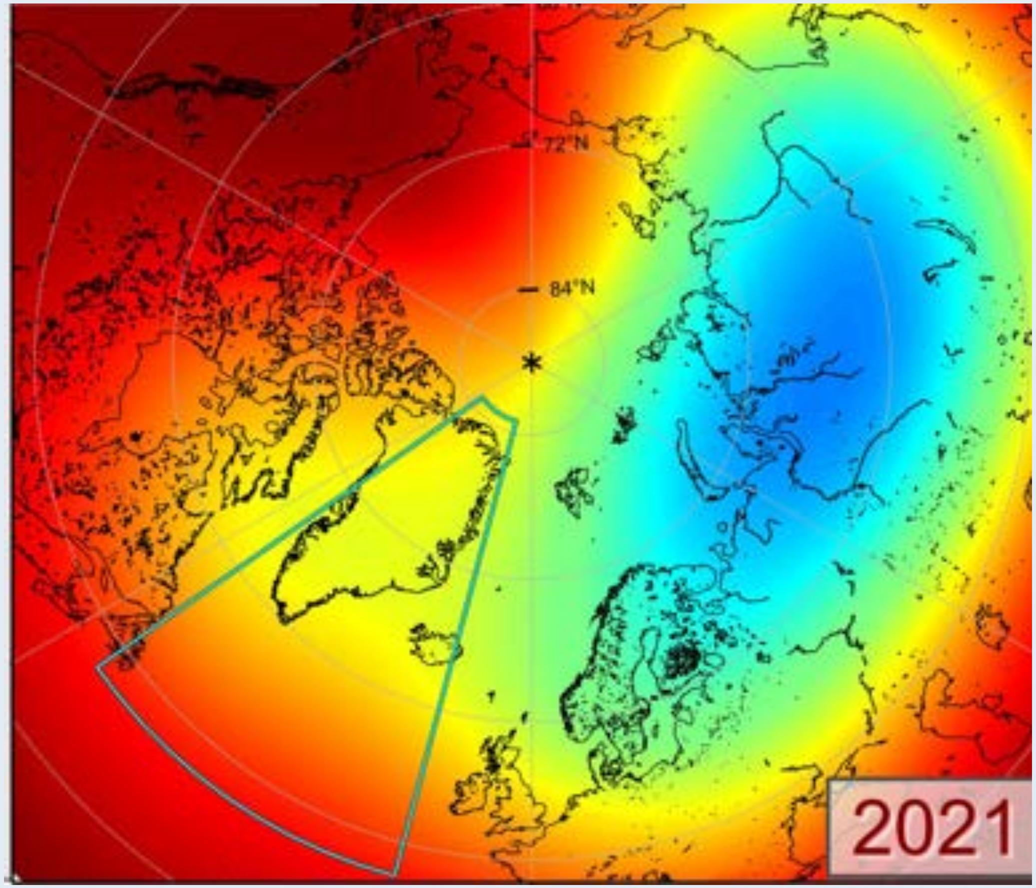
Weak Icelandic Low → Low NAO

Conclusion of the atmospheric data analysis:

Stratospheric and tropospheric circulation changes shut down Labrador Sea convection in 2010 and 2021

The next two slides introduce a new polar vortex index





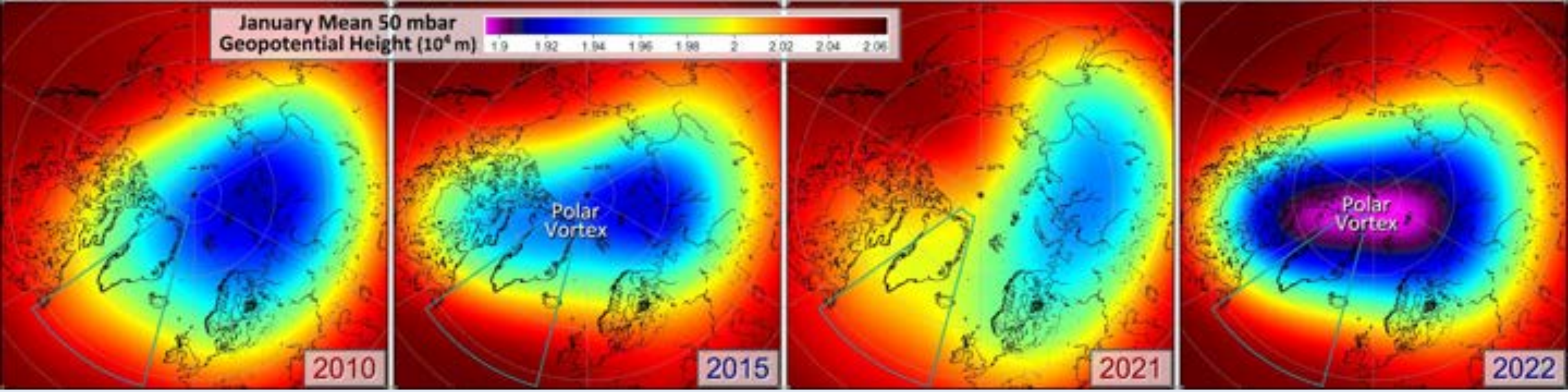
North Atlantic Polar Vortex Index

(1) Define the Trapezoid;

(2) Zonal (longitudinal) mean geopotential heights (GPH) for each latitude inside the Trapezoid;

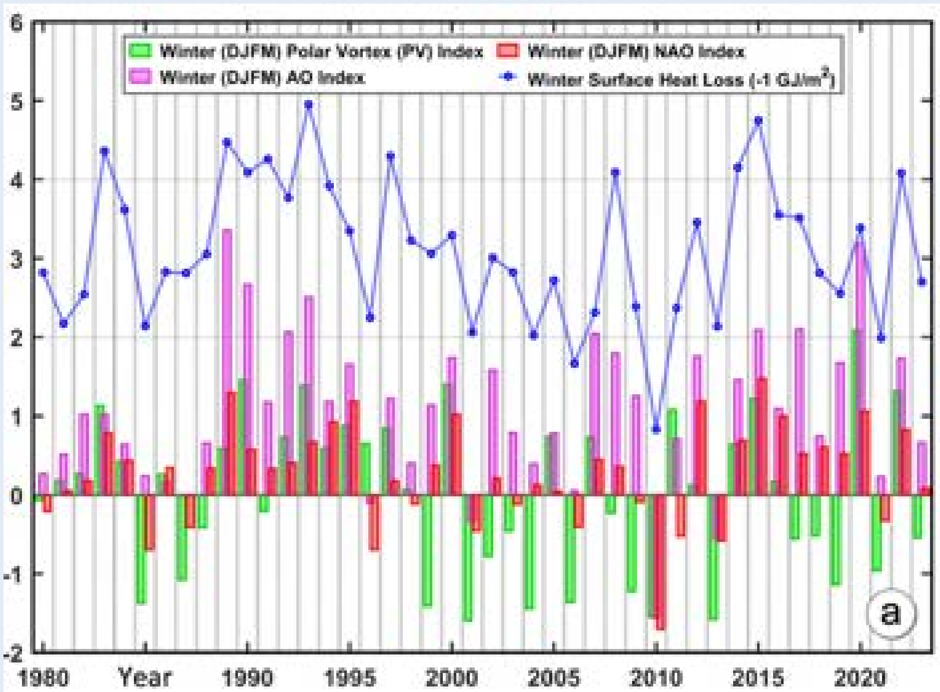
(3) Linear least-square fit of the zonal mean GPH values as function of latitude with the Trapezoid or any latitudinal range of interest;

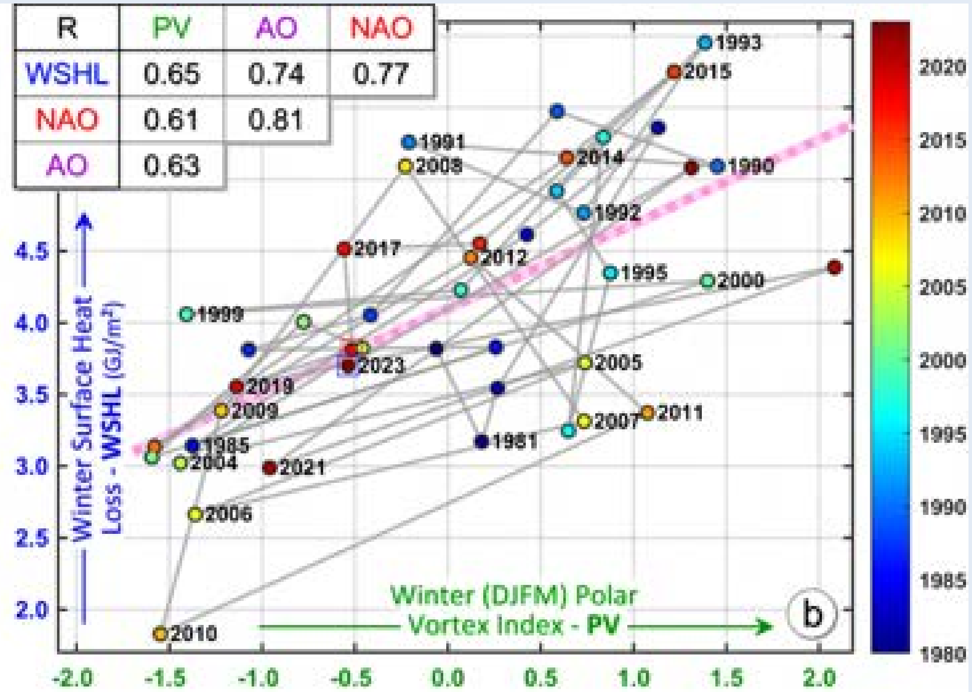
(4) The zonal mean GPH slope (gradient) is negative with latitude, thus multiple by -1.



Polar-subpolar winter atmospheric circulation indices and surface heat loss in the Labrador Sea

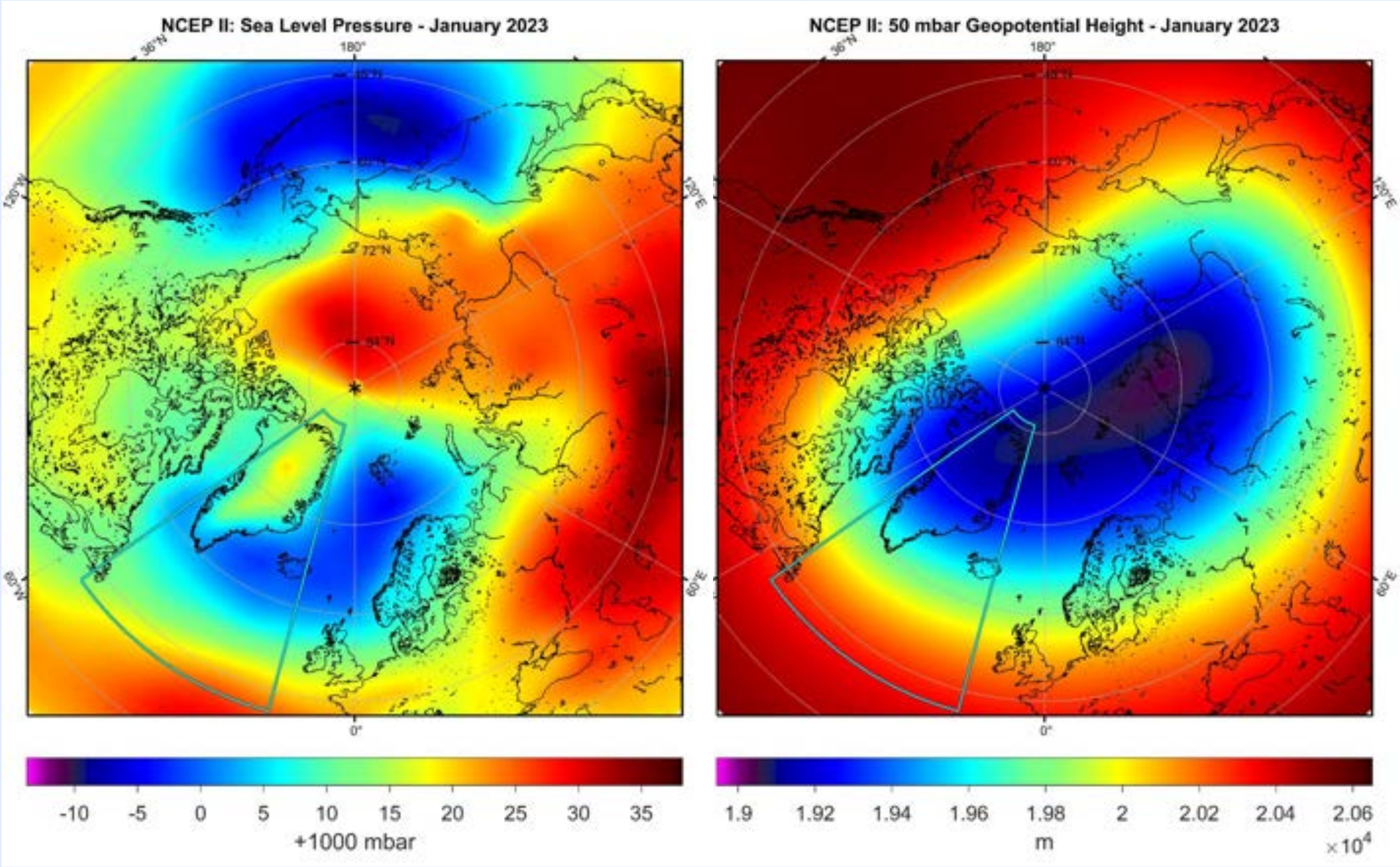
The North Atlantic Polar Vortex index is correlated with the Labrador Sea winter forcing



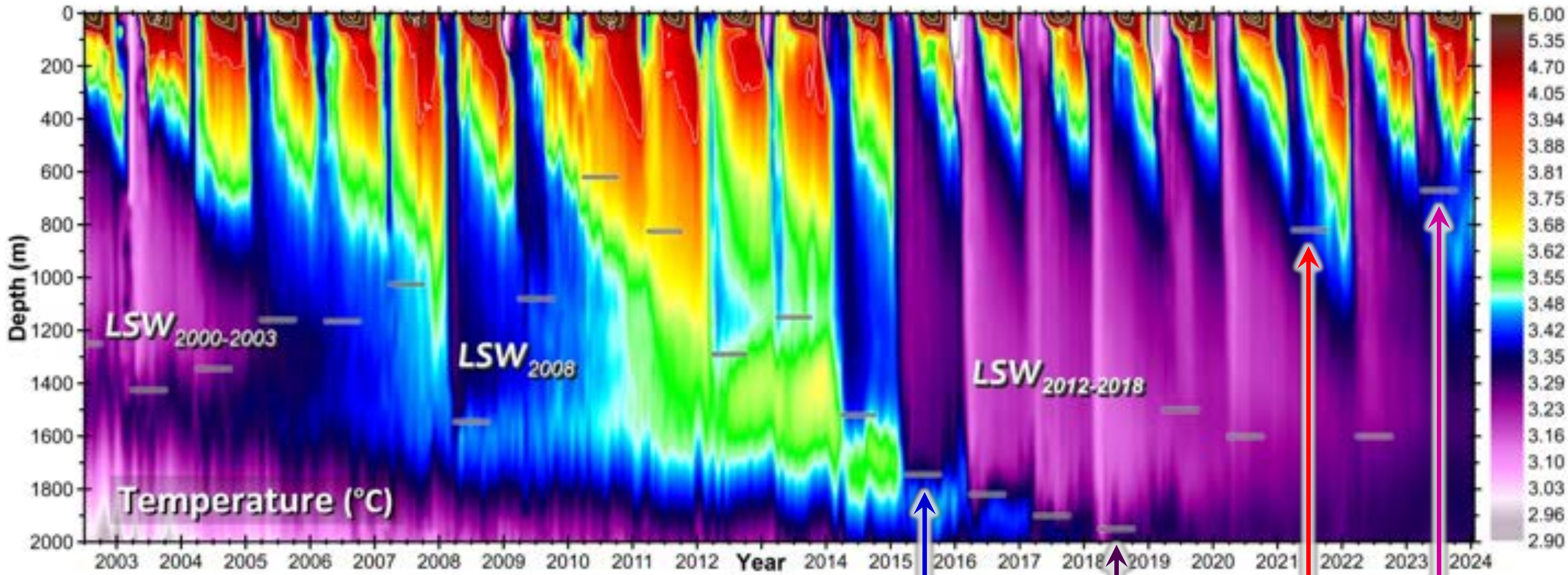


R	PV	AO	NAO
WSHL	0.65	0.74	0.77
NAO	0.61	0.81	
AO	0.63		

What about 2023?



So far, we reported
a high winter heat loss in 2015,
a low winter heat loss in 2021.
We have not seen
the response of the sea yet.
How much did these events
change the water column
of the Labrador Sea?



2002 June – 2024 January

Temporal averaging is limited to maximum of two weeks, nominally – one week.

This is why the seasonality is resolved in all years from surface to bottom.

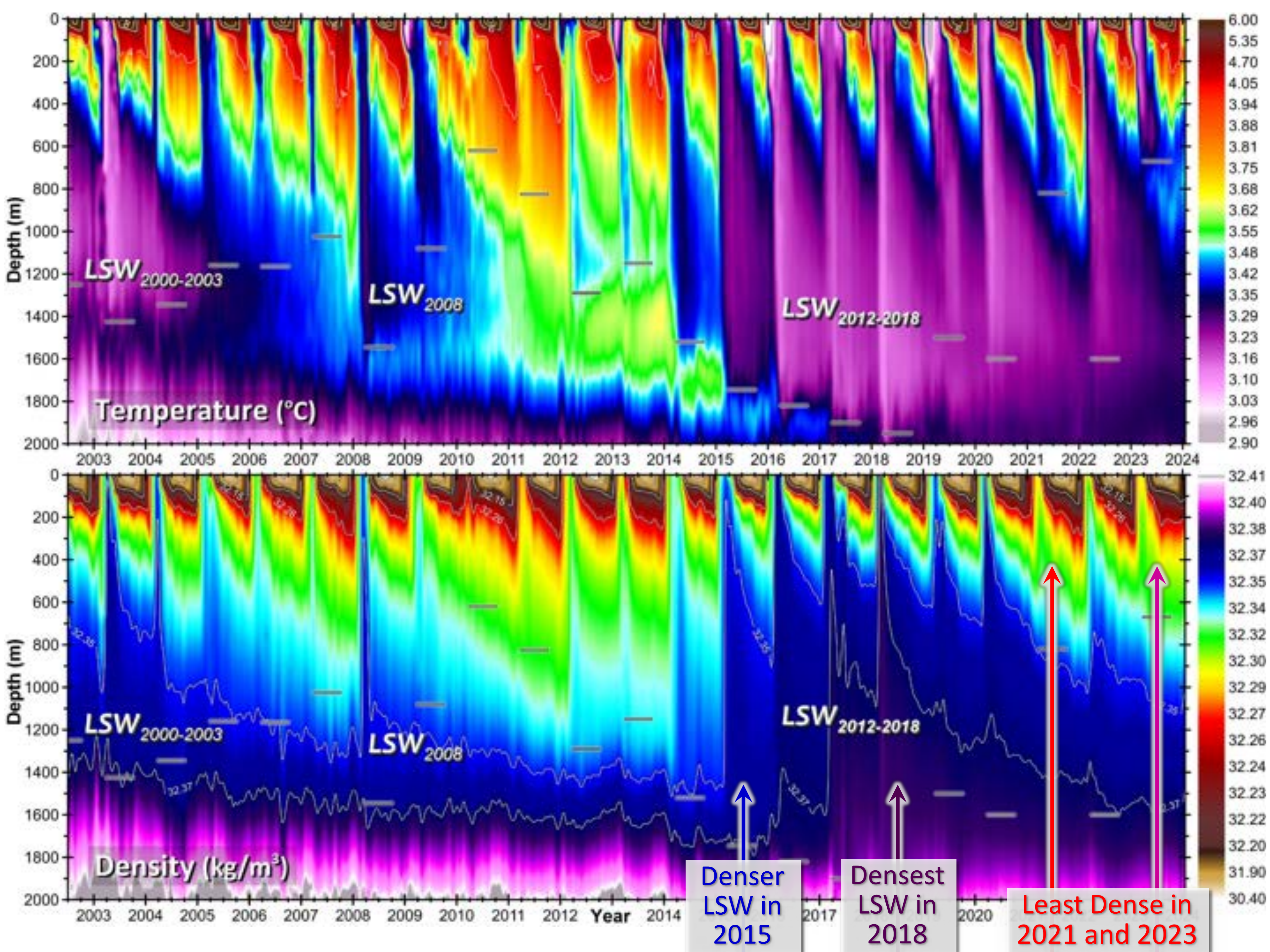
The ship-based data alone do not resolve the seasonal and interannual changes in the top 700 m layer.

Strongest Cooling in 2015

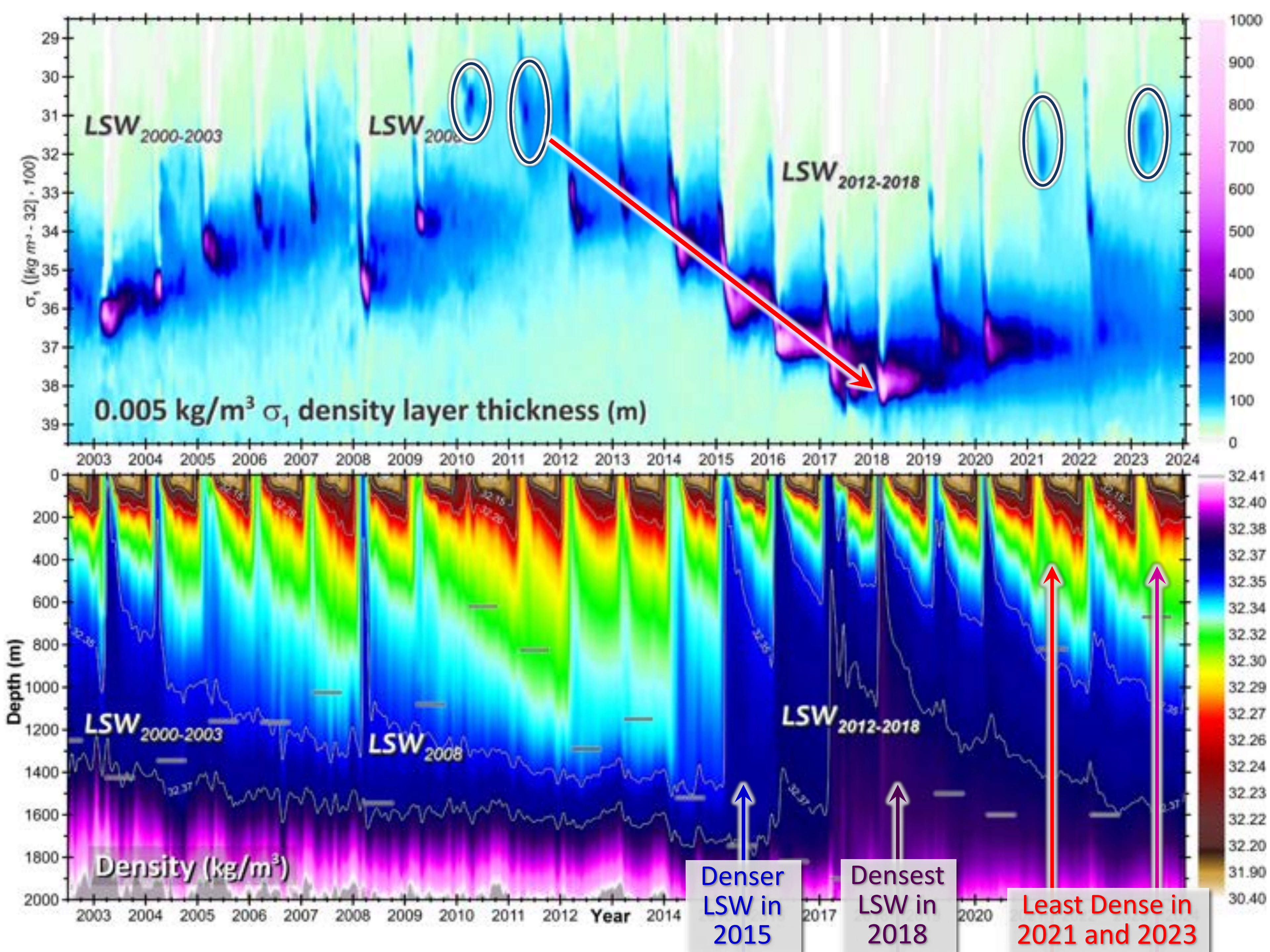
Deepest Mixing in 2018

Rapid Warming in 2021

Shallowest but Cold Mixed Layer in 2023



LSW2000-2003
LSW2008
LSW2012-2018
Temperature (°C)
Density (kg/m³)
Depth (m)
Year
Denser LSW in 2015
Densest LSW in 2018
Least Dense in 2021 and 2023

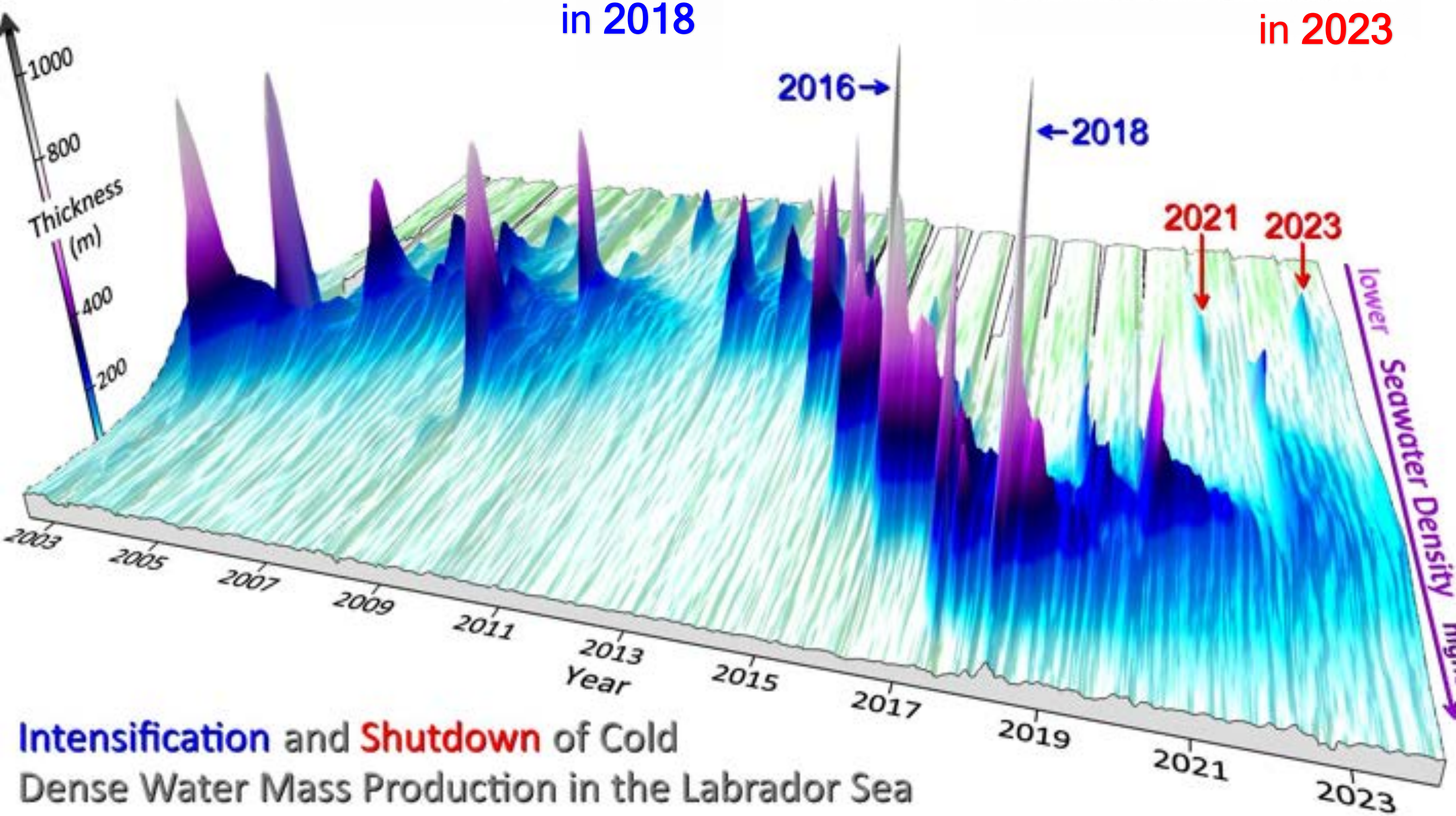

LSW 2000-2003
LSW 2008
LSW 2012-2018
0.005 kg/m³ σ1 density layer thickness (m)
σ1 ([kg m⁻³ - 32] · 100)
Depth (m)
Year
Density (kg/m³)
Denser LSW in 2015
Densest LSW in 2018
Least Dense in 2021 and 2023

These features could be discovered only with Argo!

The densest and thickest mixed layer formed in **2018**

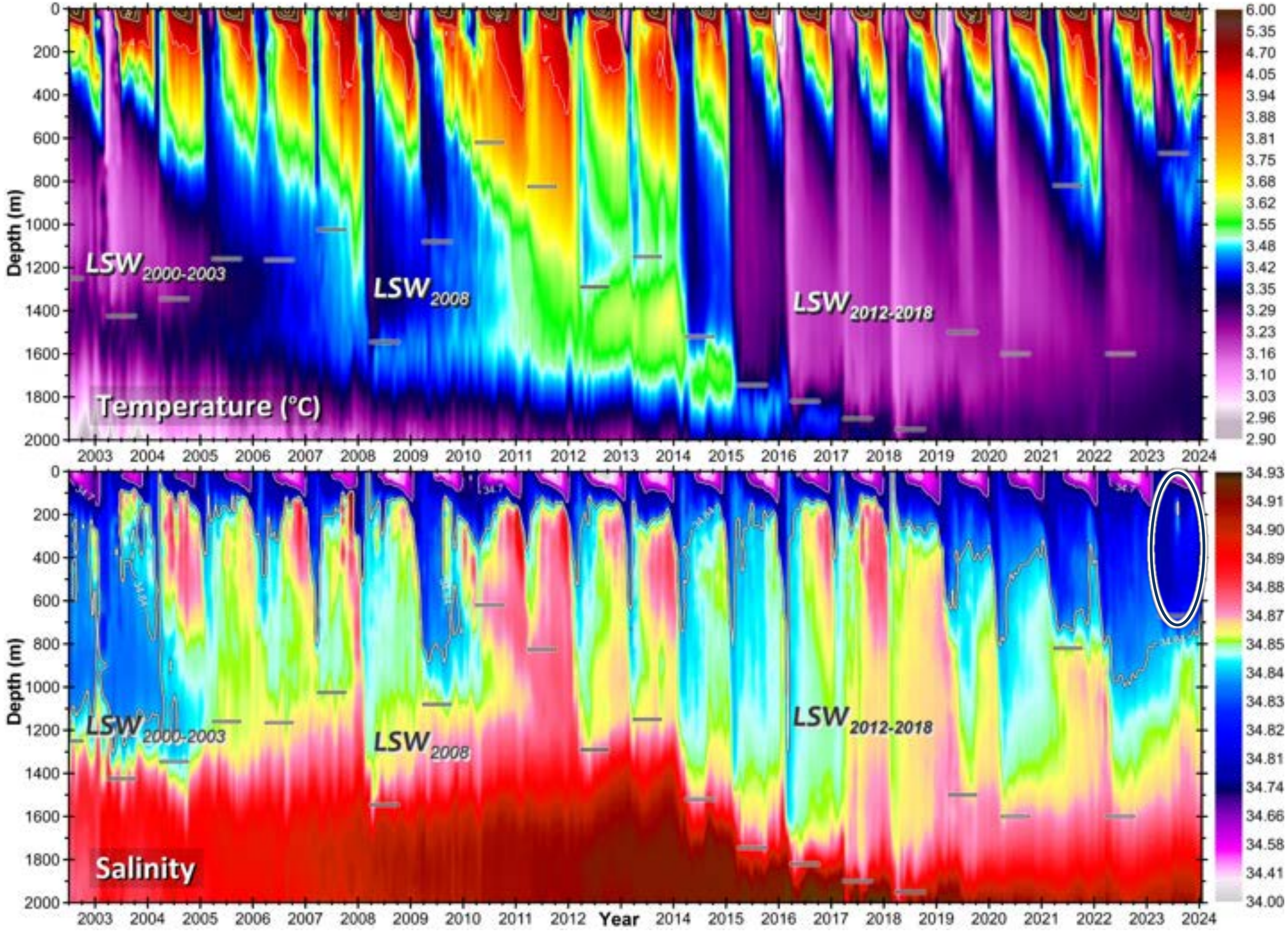
Shoaled convection in **2021**

Convective shutdown in **2023**

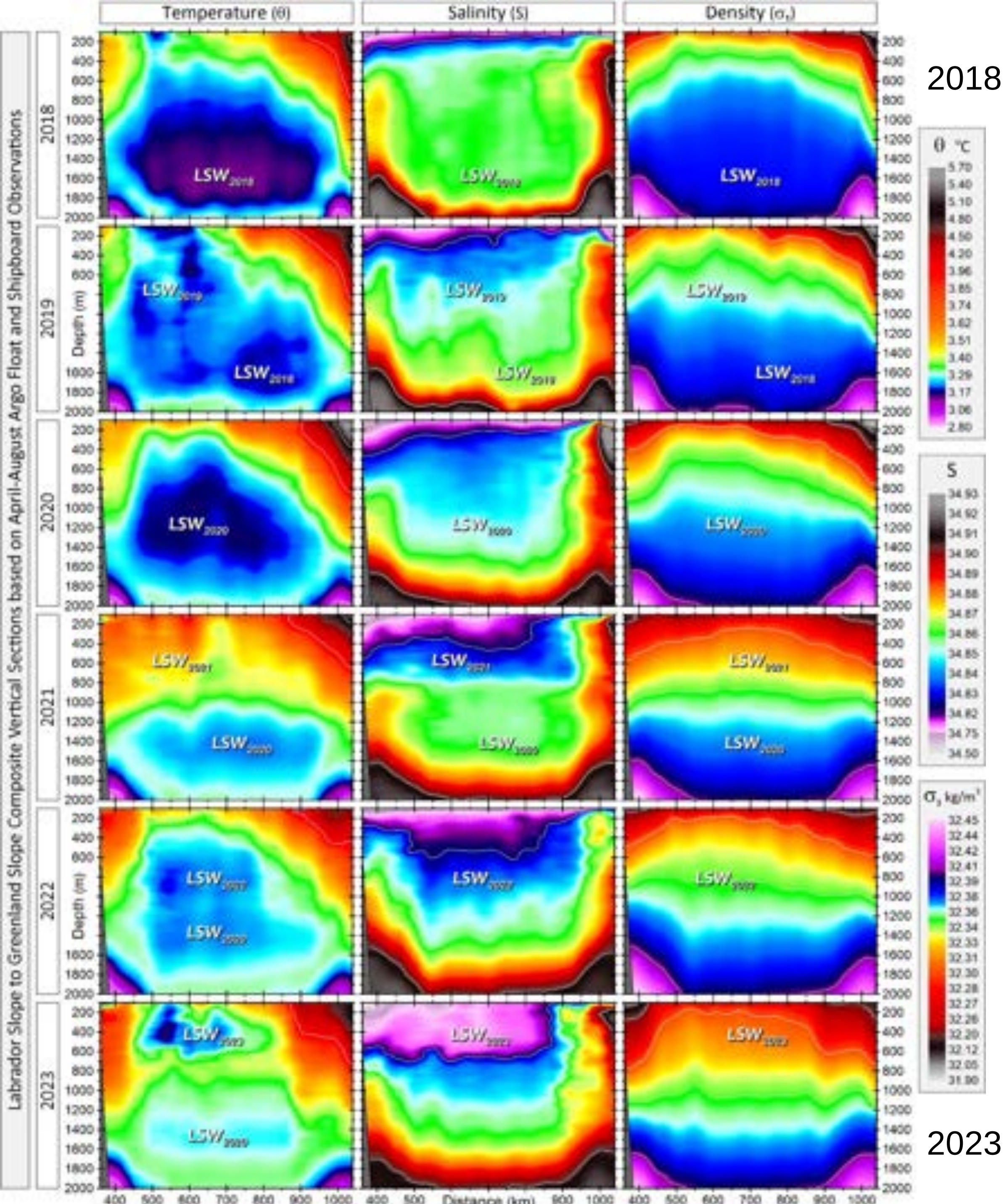


Intensification and **Shutdown** of Cold Dense Water Mass Production in the Labrador Sea

… and now we are going to see how a rapid change in summer-fall salinity can inhibit winter convection



Temperature (°C)
Salinity
Depth (m)
Year
LSW2000-2003
LSW2008
LSW2012-2018



April-August Temperature, Salinity and Density on AR7W from Multiplatform Observations

The sections were constructed using the hybrid coordinate method.

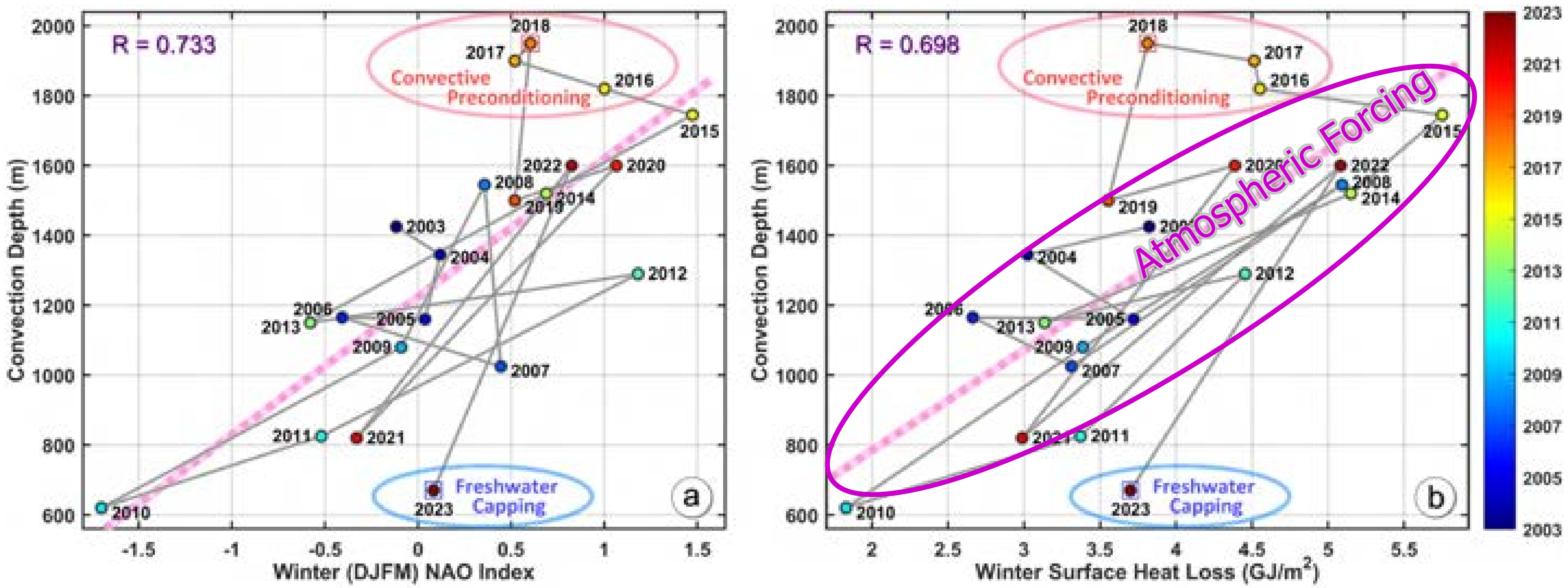
In the first year in this series, 2018, convection (large cold blob - **LSW$_{2018}$**) reached 2000 m.

LSW$_{2018}$ was still present in 2019, when convection was much shallower, making the sea more stratified.

Most remarkable changes occurred in 2021 and 2023: **warm fresh low-density 800 m deep layer in 2021**, and **massive layer of fresher colder low-density water in 2023**.

So far, we reported
a high winter heat loss in 2015,
a low winter heat loss in 2021,
a massive freshening in 2022.
But why winter convection
of 2018 was the deepest?

How can we determine the cause for each deepening or shoaling of convection?



Year-colored convection depth as function of
(a) the winter NAO index representing the dynamical winter forcing, and
(b) winter surface heat loss representing the thermal winter forcing.

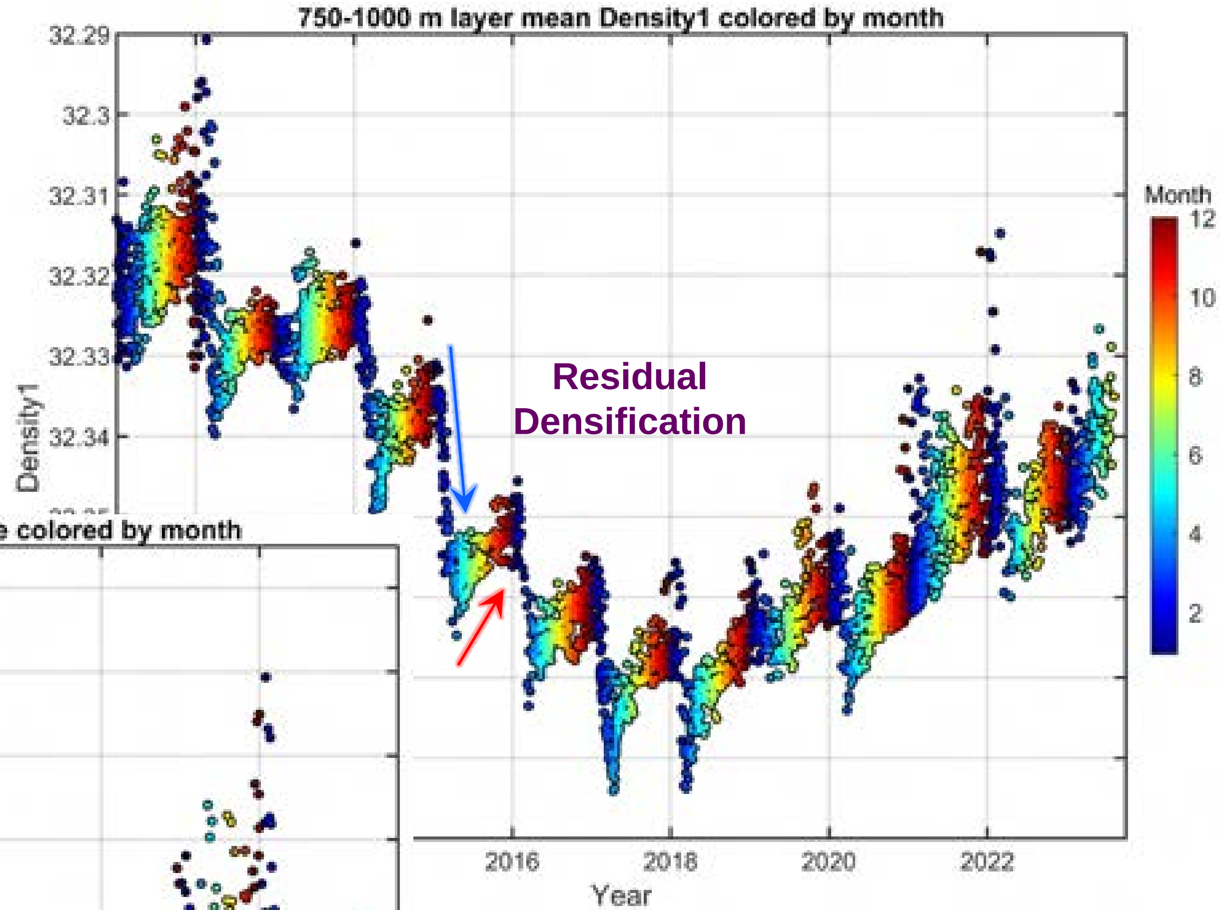
Even thought 2018 and 2023 had similar WSHL,
2018 had record deep convection, while 2023 - record shallow.

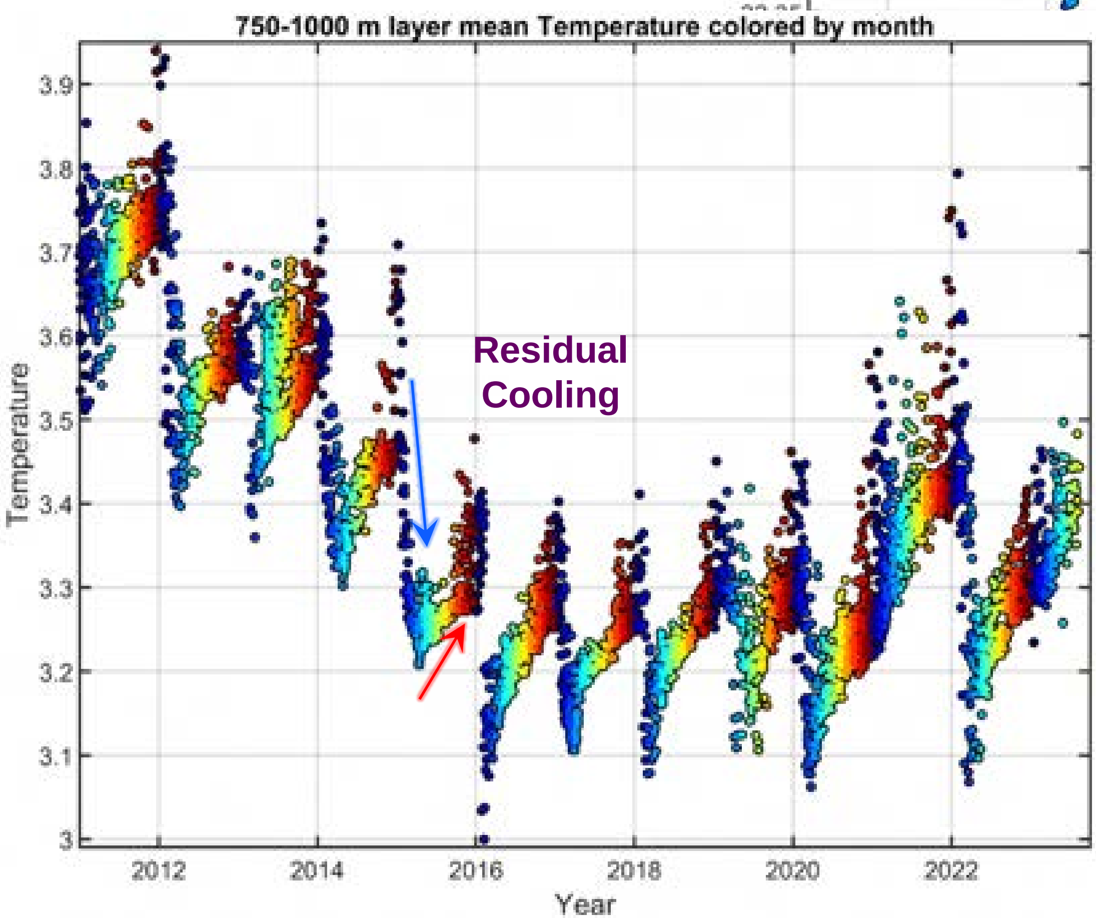
The 2018, 2017 and 2016 convections were deeper than expected due to convective preconditioning retaining weak stratification left by the previous (2012-2015) mixing events.

This method of analyzing of convection depths I defined as ***Convection Understanding Diagrams*** *(CUD)*

There are two more ways to assess the effect of the water-column preconditioning on future deep-sea state

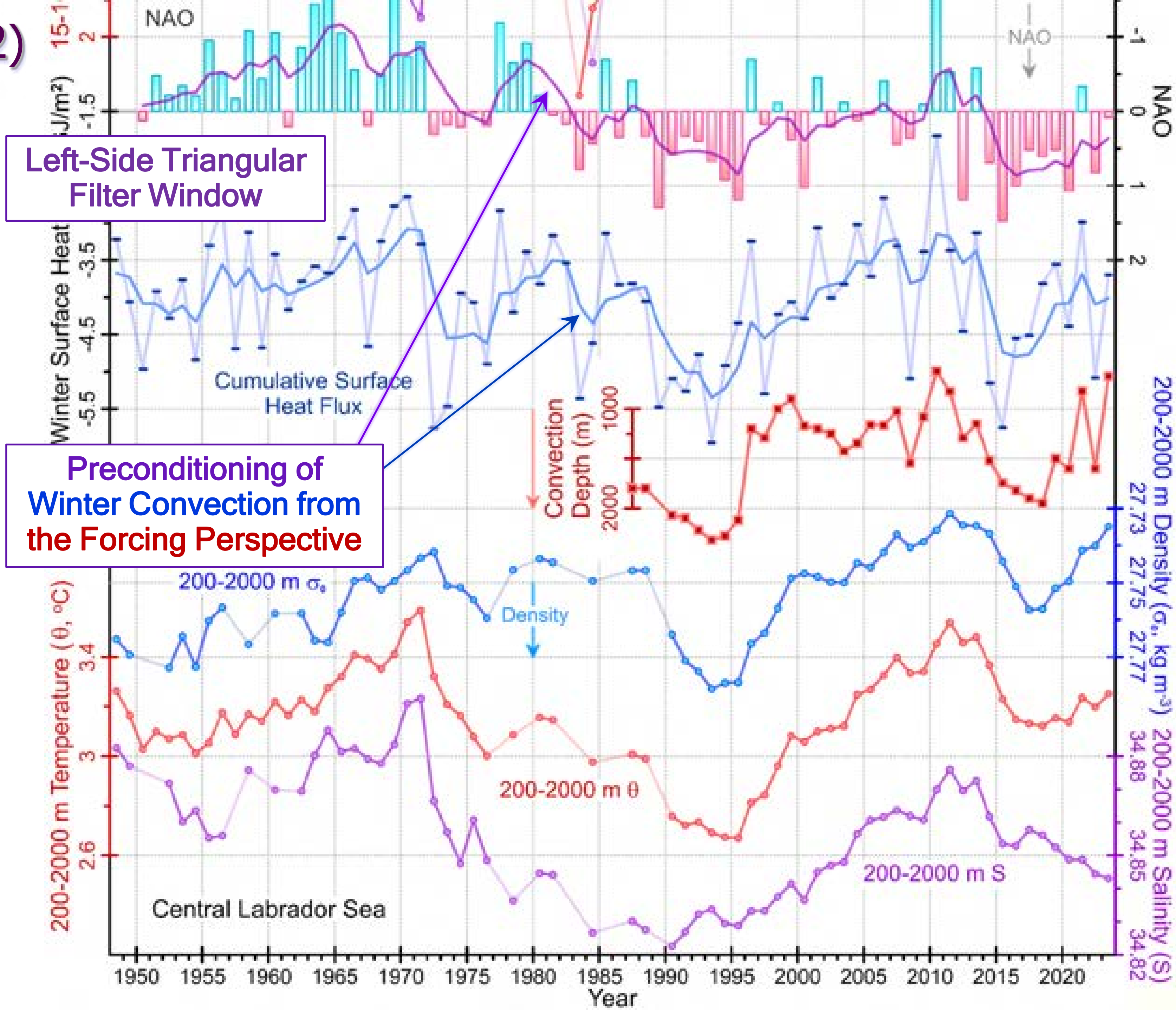
(1)





Preconditioning of
Winter Convection from
the Oceanic Perspective

(2)



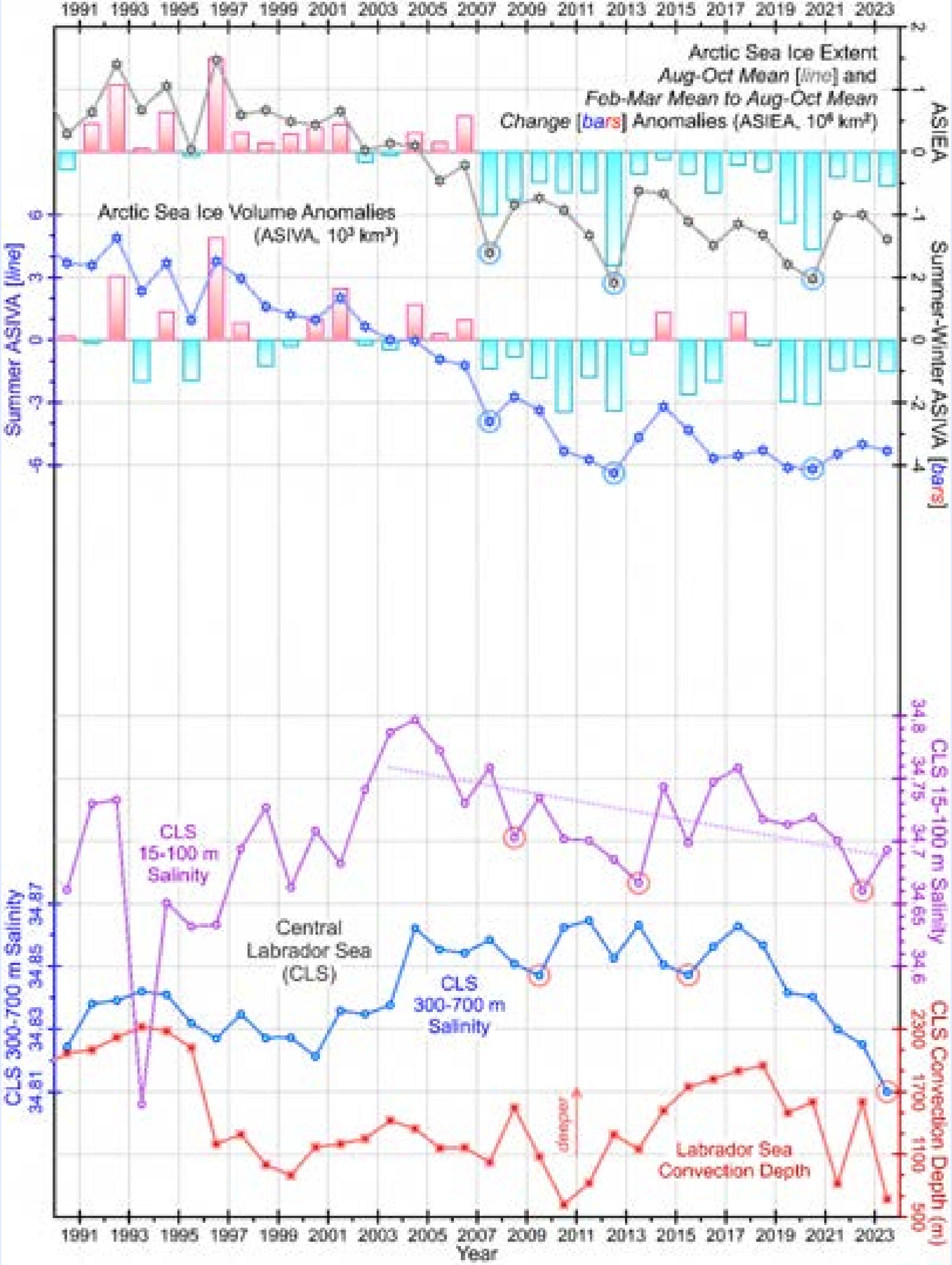
Left-Side Triangular Filter Window
Preconditioning of Winter Convection from the Forcing Perspective
NAO
Cumulative Surface Heat Flux
Convection Depth (m)
200-2000 m σ_θ
Density
200-2000 m θ
200-2000 m S
Central Labrador Sea
Winter Surface Heat
200-2000 m Temperature (θ, °C)
200-2000 m Density (σ_θ, kg m^{-3})
200-2000 m Salinity (S)
Year

We just explained how an alignment in the tropospheric and stratospheric pressure/geopotential systems made the winters of 2010 and 2021 much warmer than usual.

We also showed that the 0-700 m layer of the Labrador Sea freshened in 2023.

Next, we will answer the question:

"What is/are the source/sources of the 2021-2023 Labrador Sea freshening?"

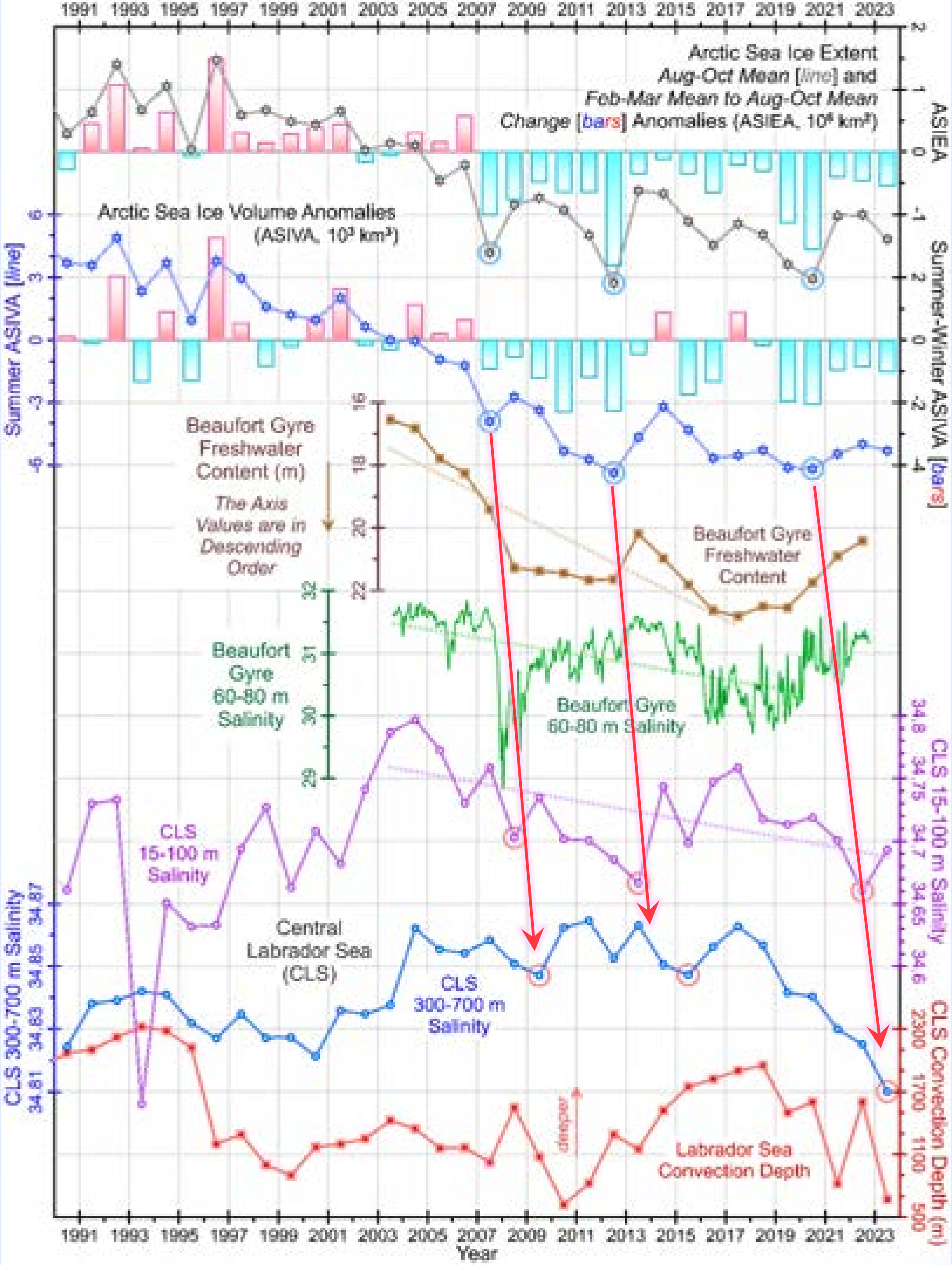


Summer Arctic sea ice extent and winter-to-summer sea ice extent change

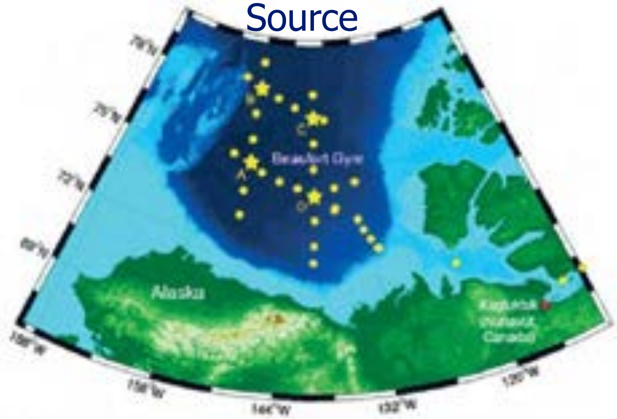
Summer Arctic sea ice volume and winter-to-summer sea ice volume change

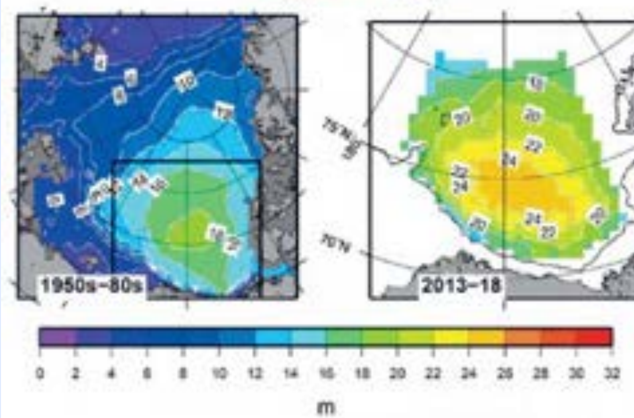
Labrador Sea upper (15-100 m) and upper-intermediate (300-700 m) layer salinity series

Labrador Sea Convection Depth

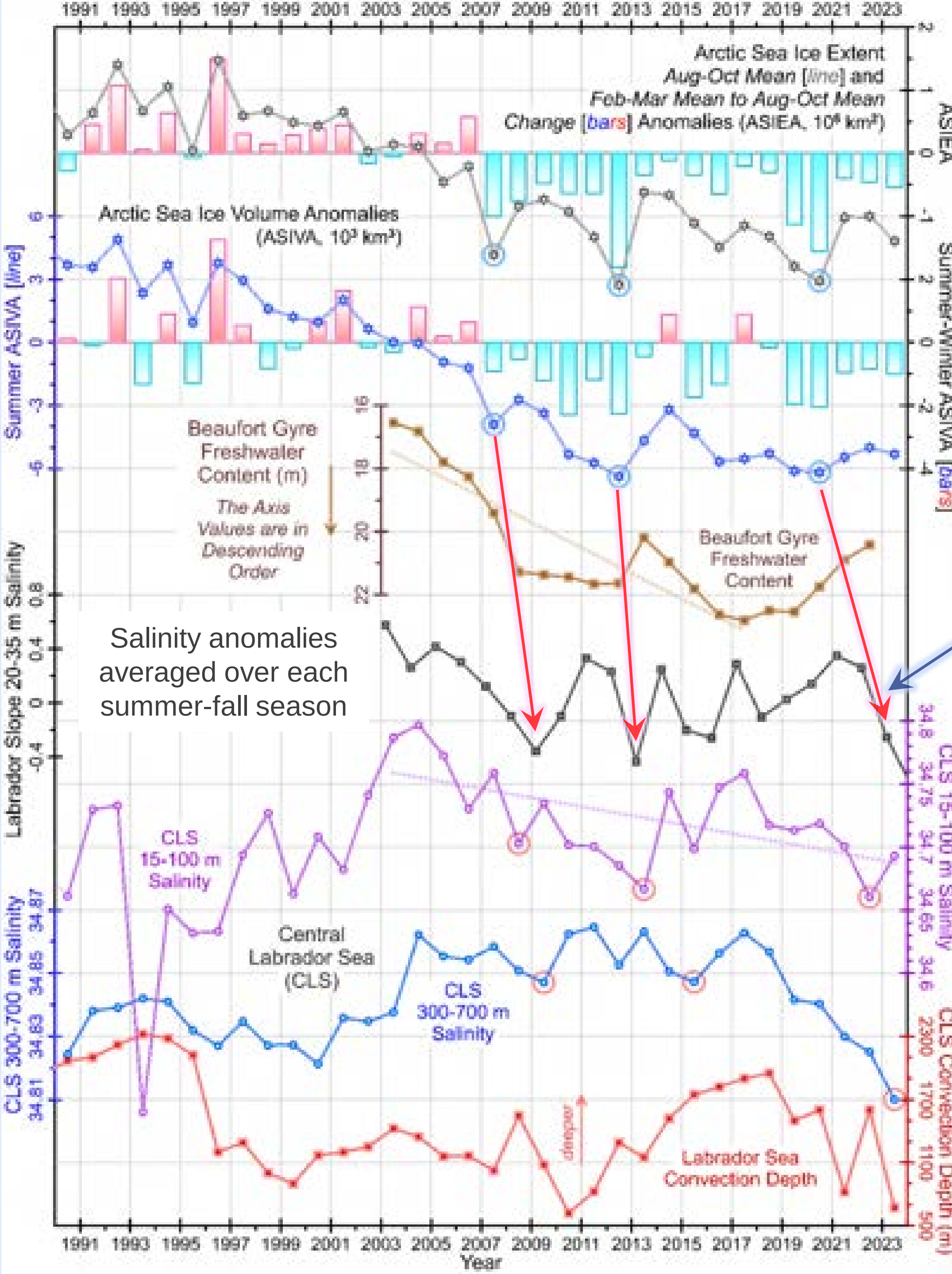


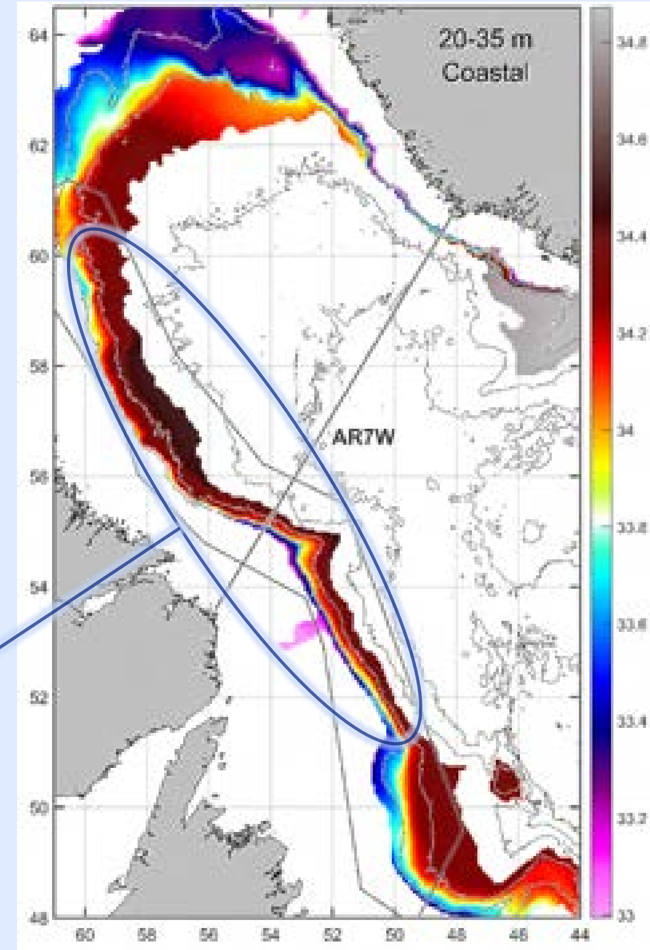
Beaufort Gyre as a Freshwater Source





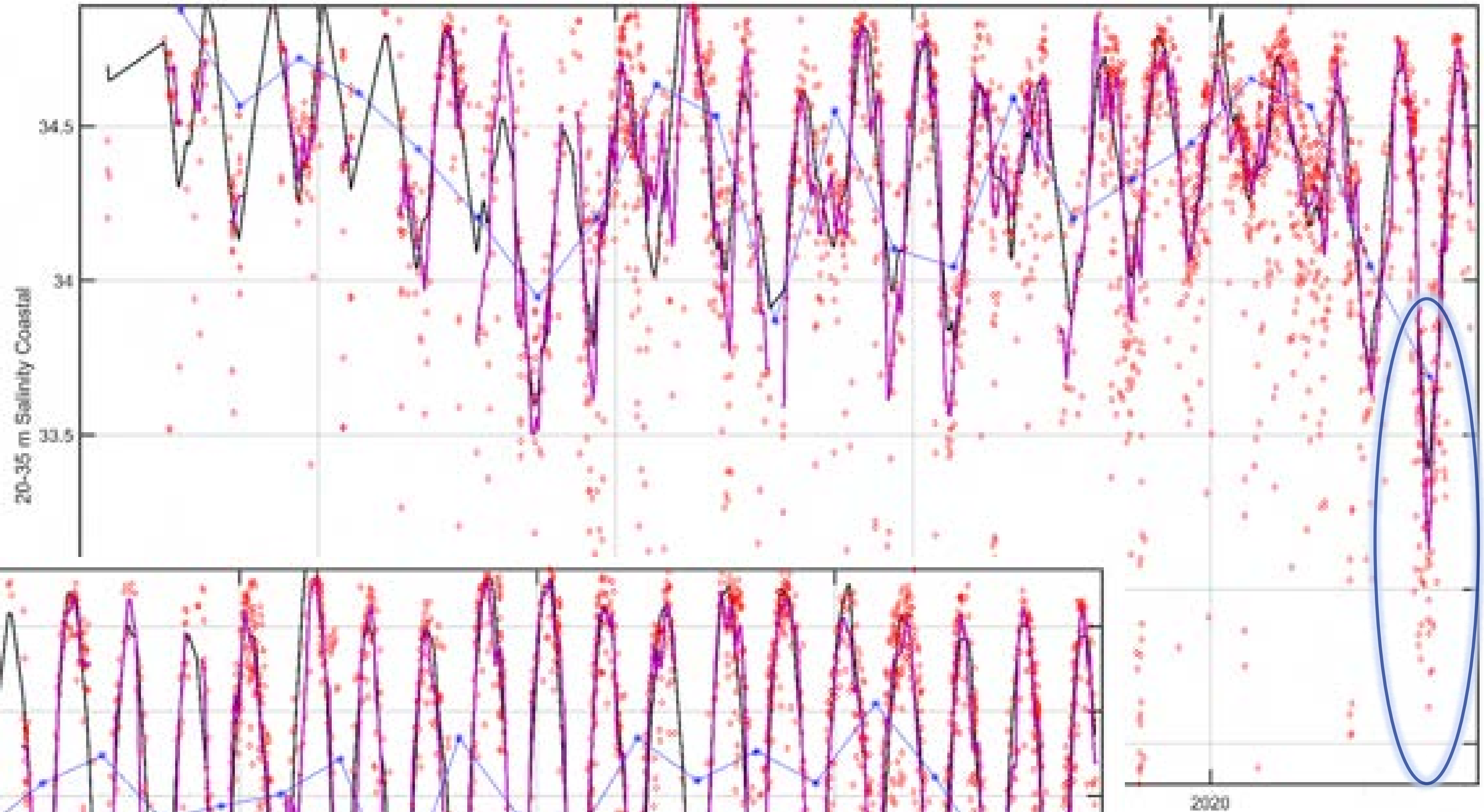
Proshutinsky et al, 2020

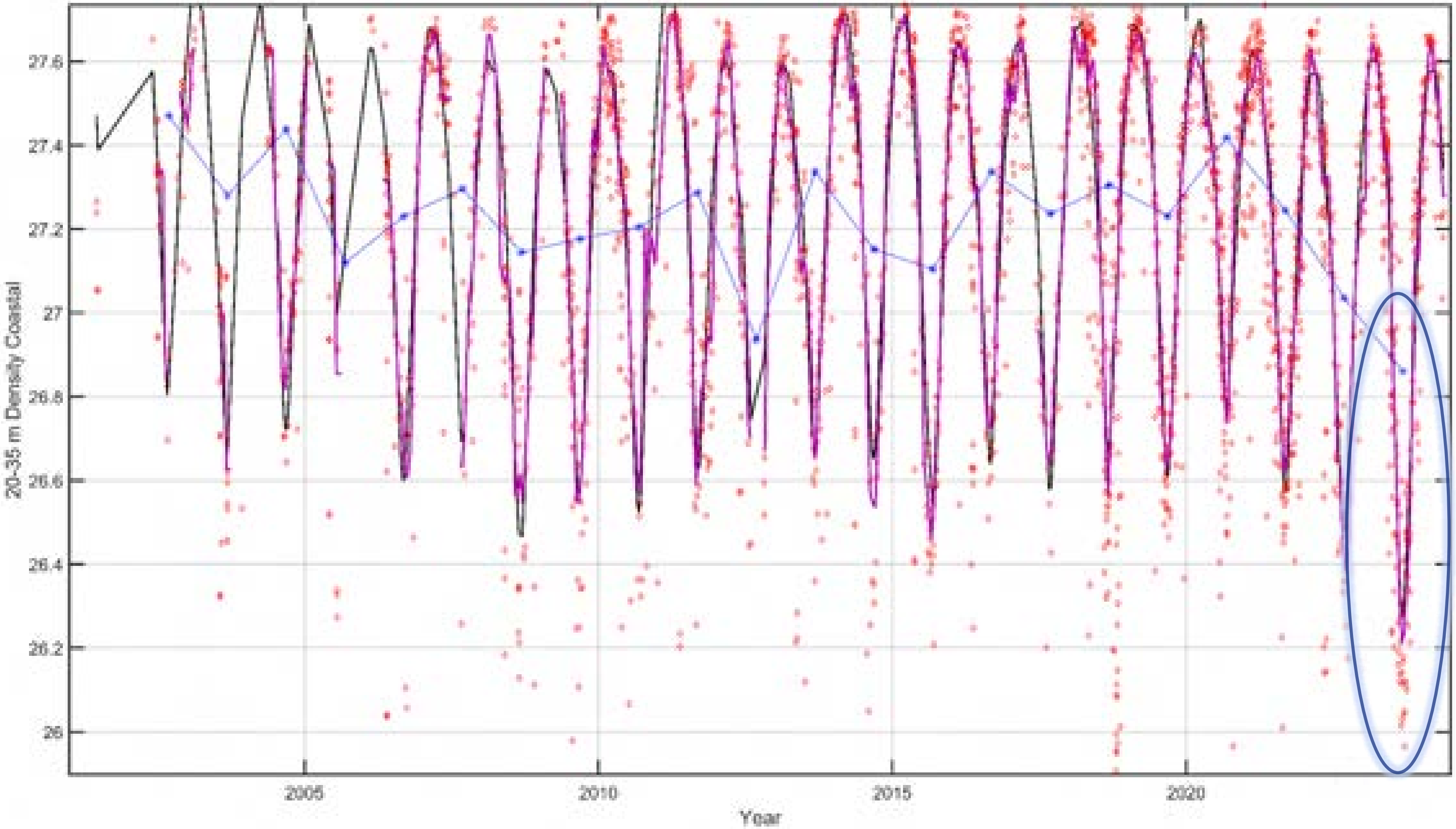




Labrador Slope
20-35 m Average
De-seasoned Salinity

Labrador Slope
20-35 m Average
De-seasoned
Salinity

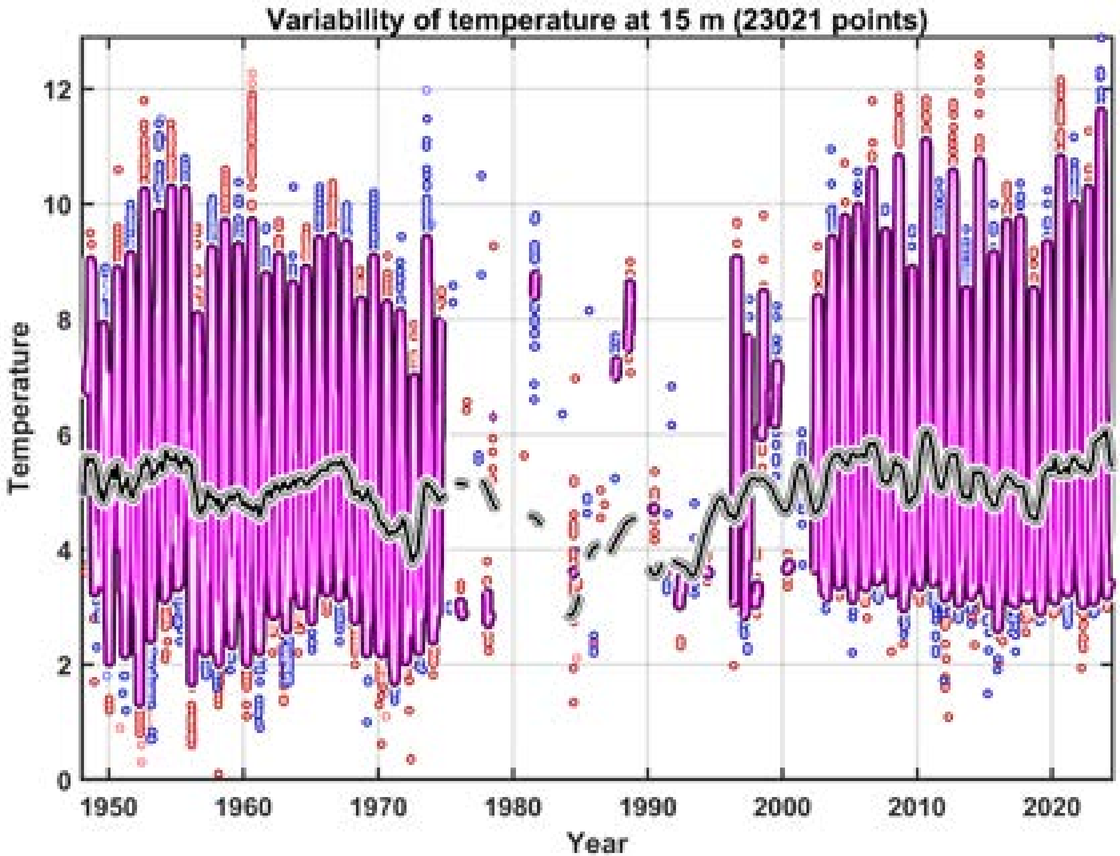


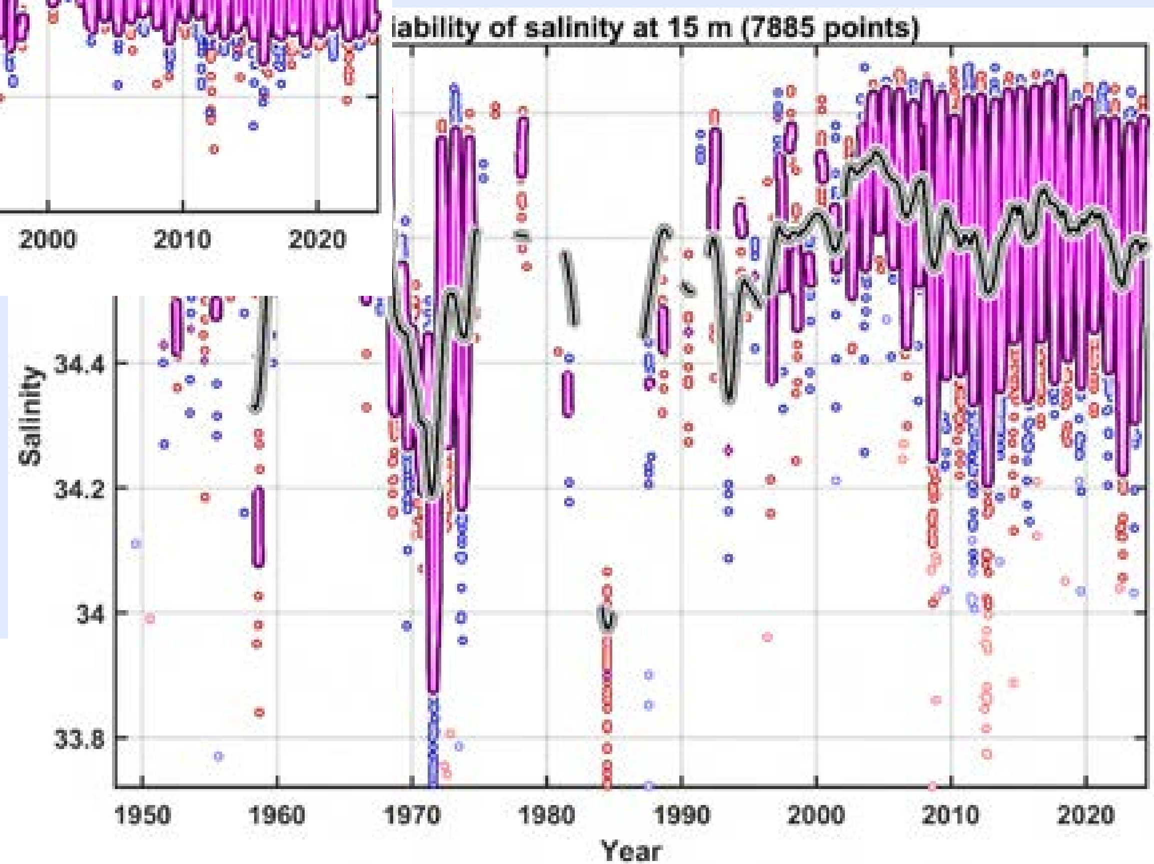


Labrador Slope
20-35 m Average
De-seasoned
Density

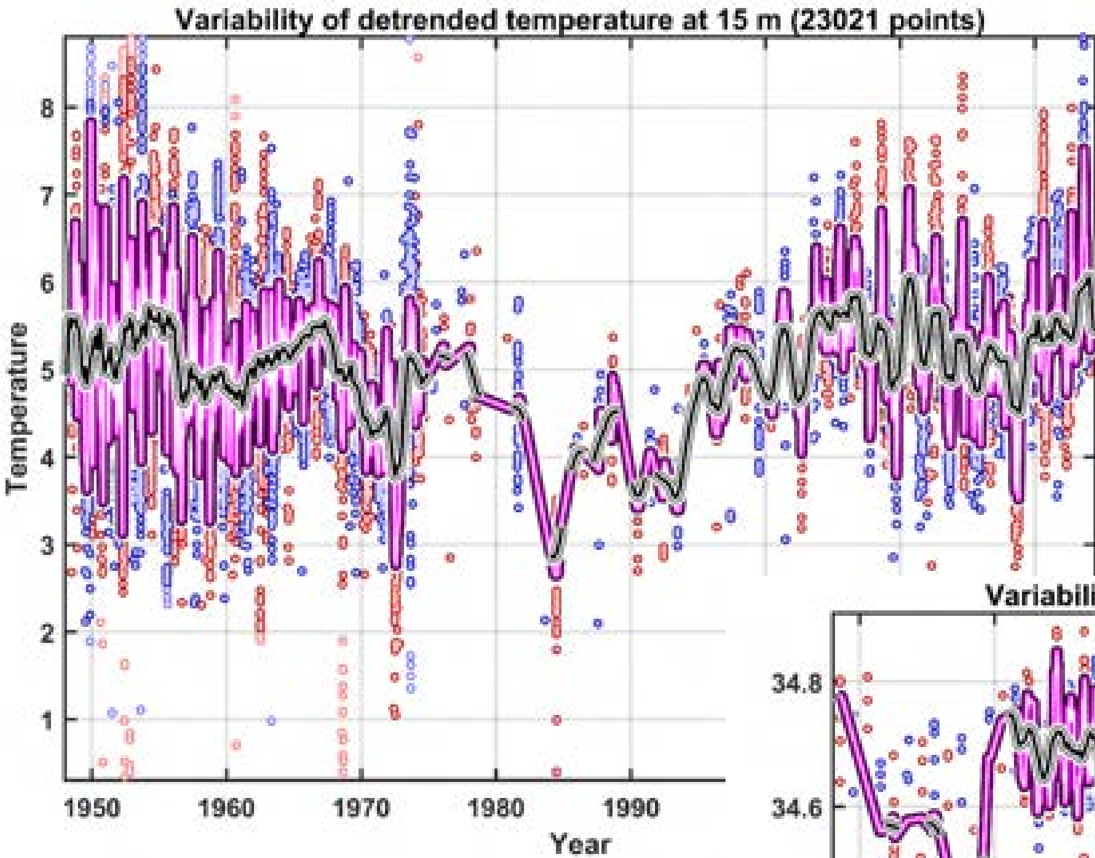
A heatwave visited the upper layer of the Labrador Sea in the summer of 2023

Central Labrador Sea 15 m Measured Temperature

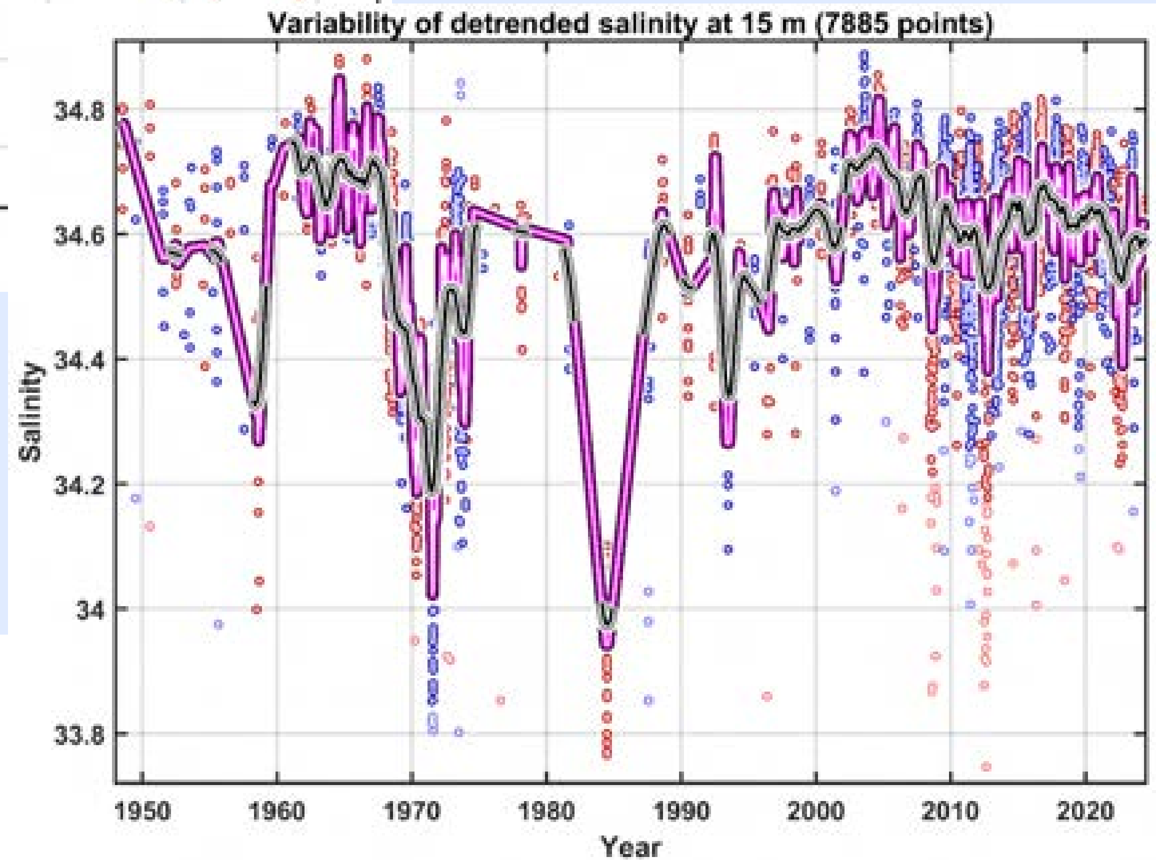




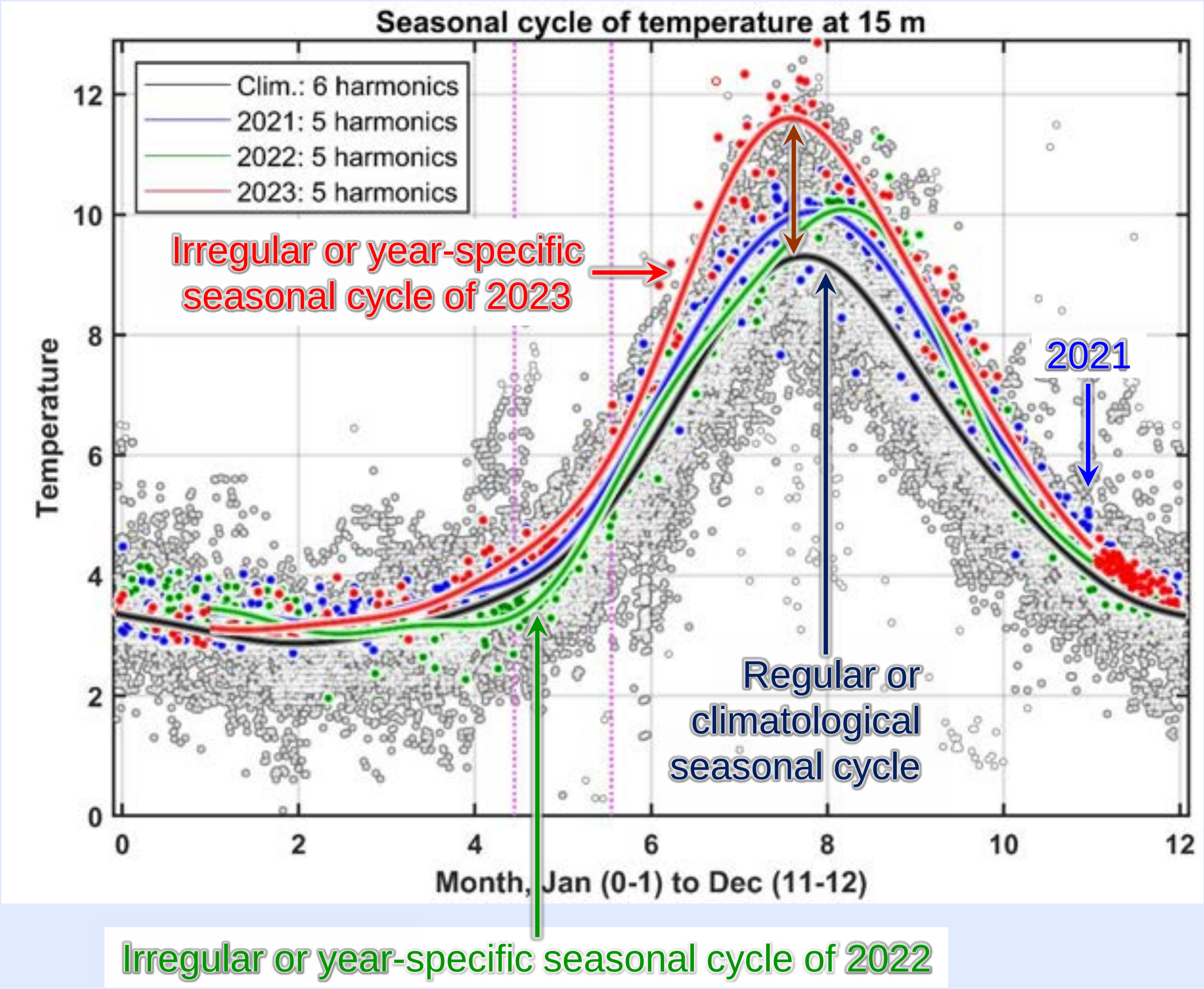
Central Labrador Sea 15 m Measured Salinity



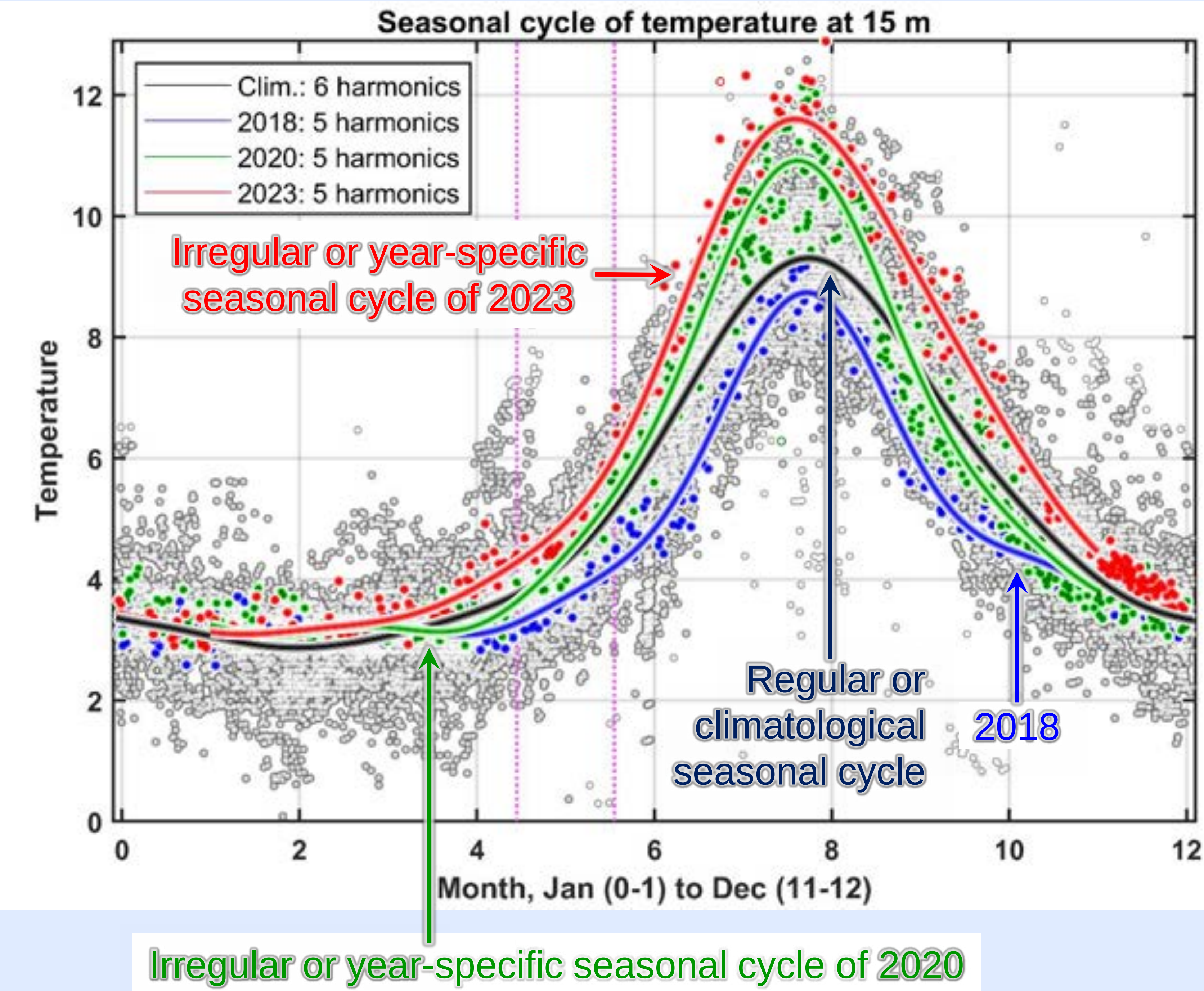
Central Labrador Sea 15 m
De-seasoned Temperature



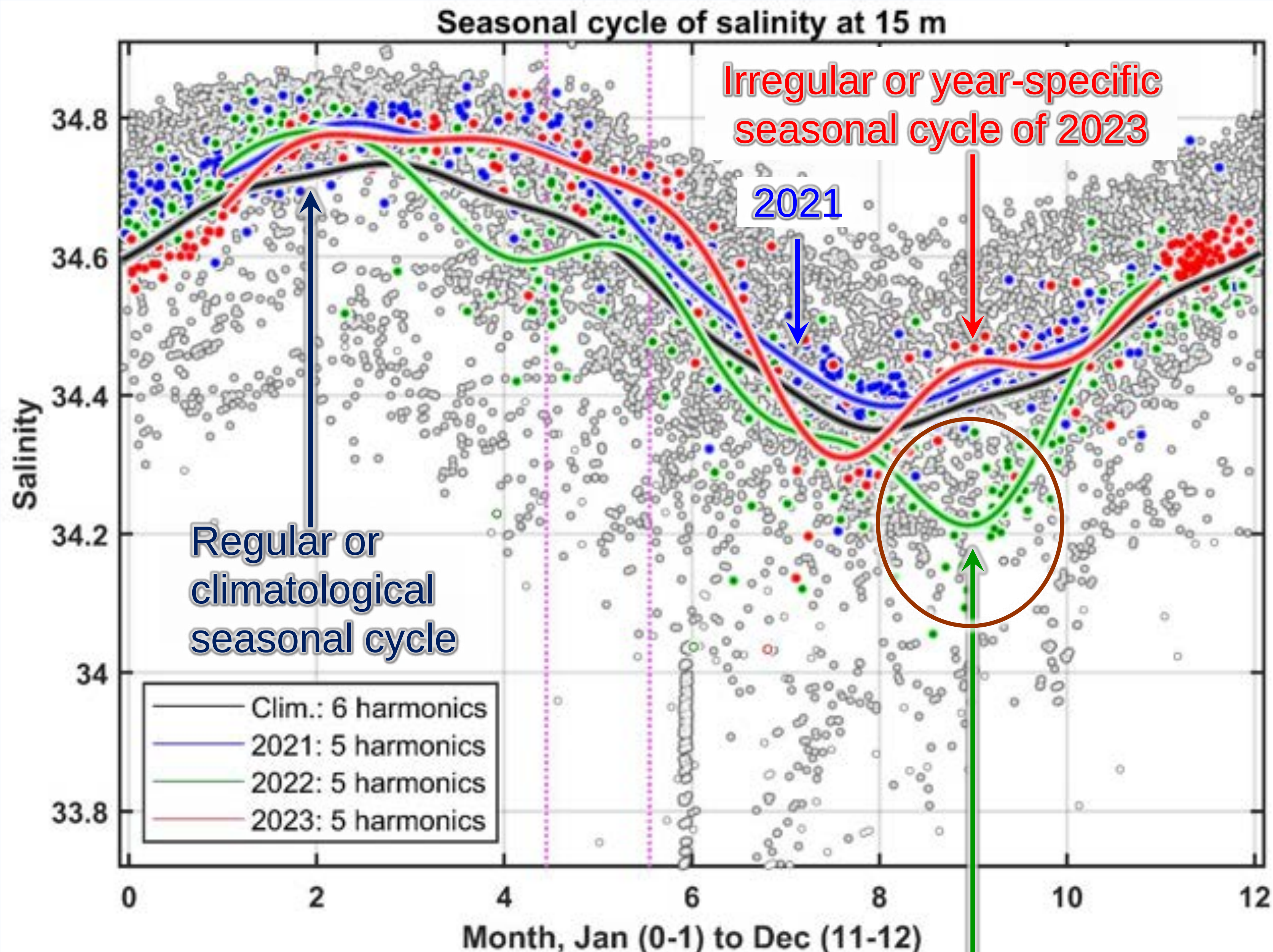
Central Labrador Sea 15 m
De-seasoned Salinity



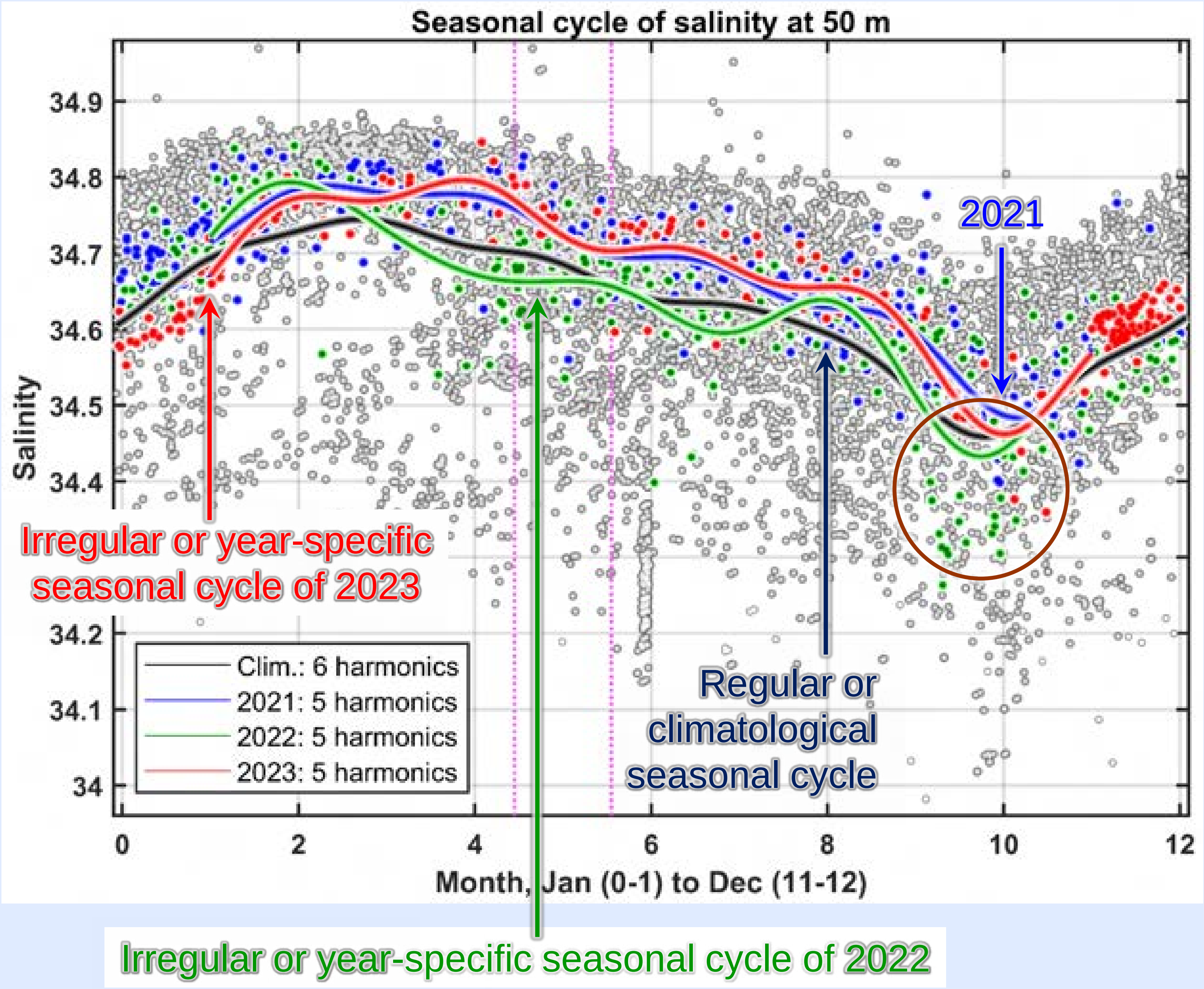
Seasonal cycle of temperature at 15 m
Clim.: 6 harmonics
2021: 5 harmonics
2022: 5 harmonics
2023: 5 harmonics
Irregular or year-specific seasonal cycle of 2023
2021
Regular or climatological seasonal cycle
Temperature
Month, Jan (0-1) to Dec (11-12)
0
2
4
6
8
10
12
Irregular or year-specific seasonal cycle of 2022

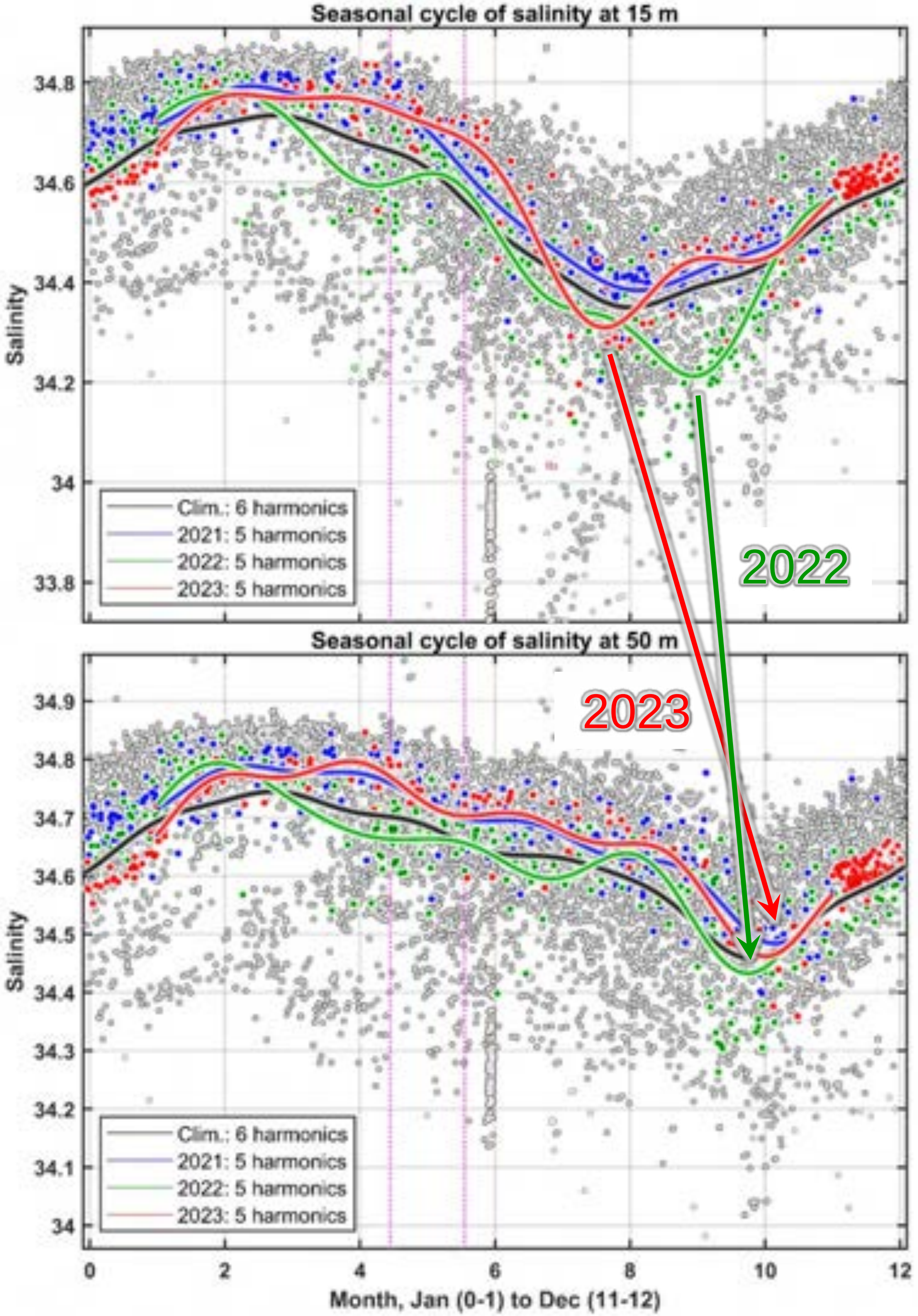


Seasonal cycle of temperature at 15 m
Clim.: 6 harmonics
2018: 5 harmonics
2020: 5 harmonics
2023: 5 harmonics
Irregular or year-specific seasonal cycle of 2023
Regular or climatological seasonal cycle
2018
Temperature
Month, Jan (0-1) to Dec (11-12)
0
2
4
6
8
10
12
Irregular or year-specific seasonal cycle of 2020



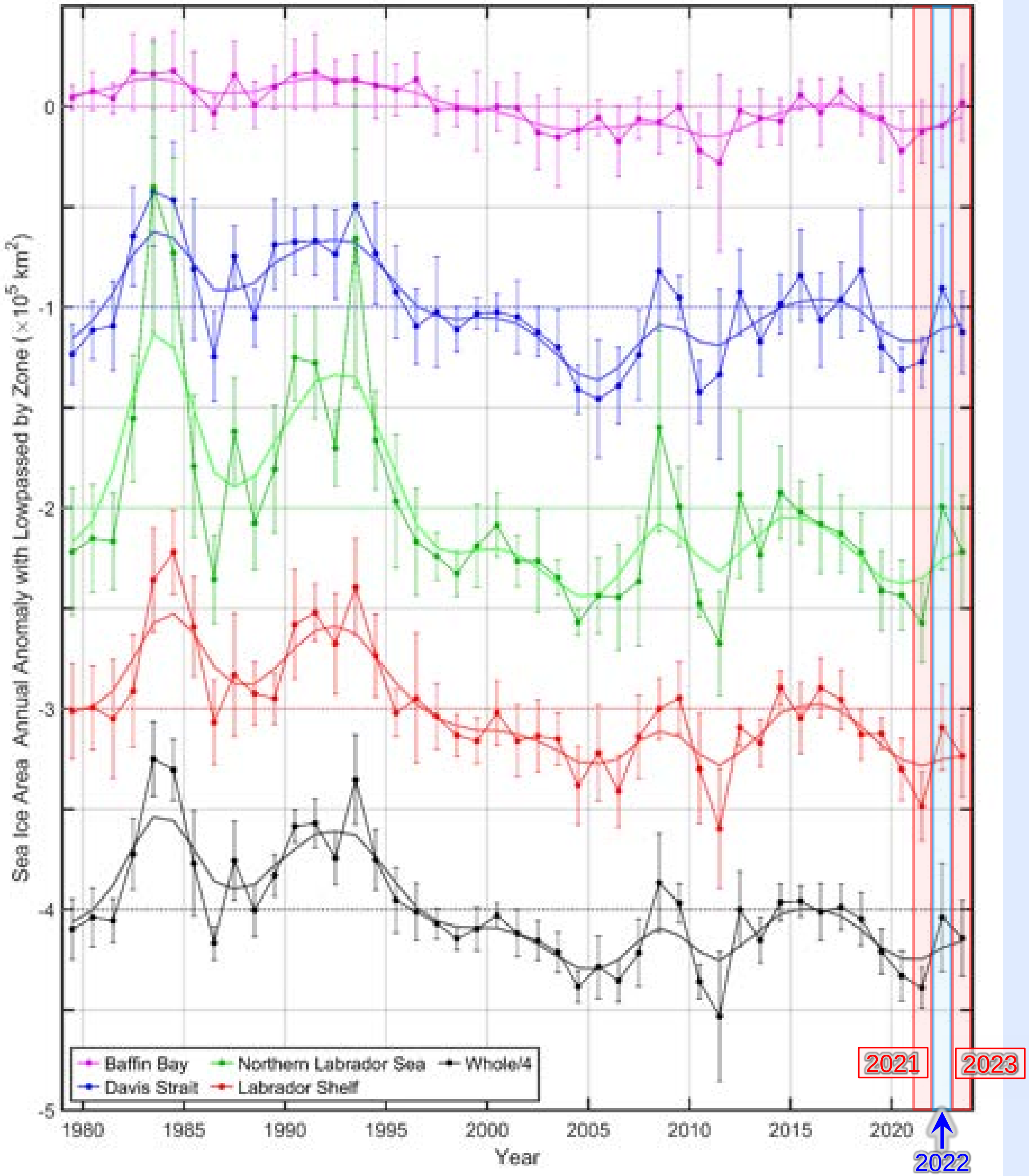
Irregular or year-specific seasonal cycle of 2022


Seasonal cycle of salinity at 50 m
Salinity
34.9
34.8
34.7
34.6
34.5
34.4
34.2
34.1
34
0
2
4
6
8
10
12
Month, Jan (0-1) to Dec (11-12)
Clim.: 6 harmonics
2021: 5 harmonics
2022: 5 harmonics
2023: 5 harmonics
2021
Irregular or year-specific seasonal cycle of 2023
Regular or climatological seasonal cycle
Irregular or year-specific seasonal cycle of 2022

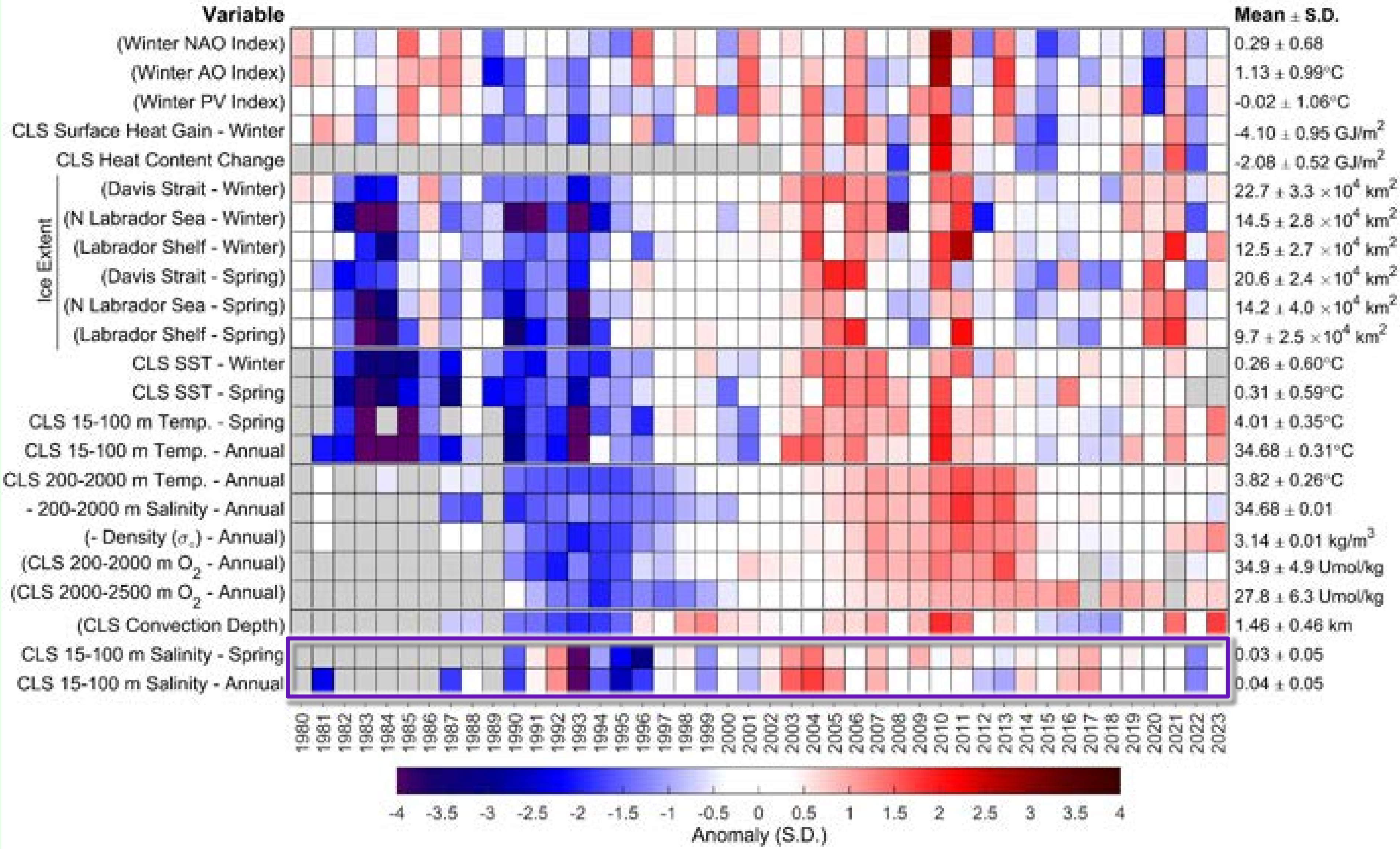

Seasonal cycle of salinity at 15 m
Salinity
Clim.: 6 harmonics
2021: 5 harmonics
2022: 5 harmonics
2023: 5 harmonics
2022
2023
Seasonal cycle of salinity at 50 m
Salinity
Clim.: 6 harmonics
2021: 5 harmonics
2022: 5 harmonics
2023: 5 harmonics
Month, Jan (0-1) to Dec (11-12)

Why?

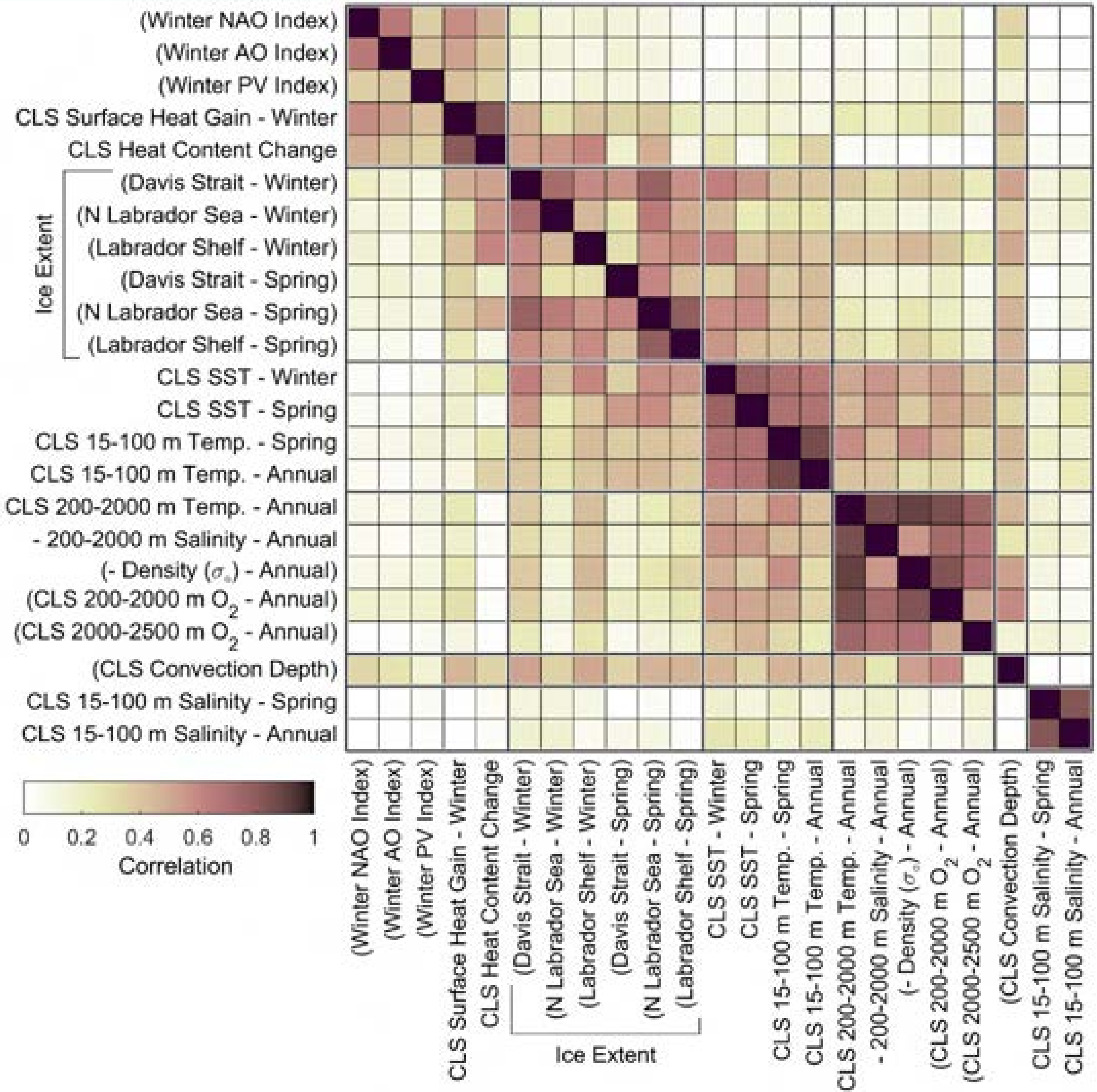
Sea Ice



Sea Ice Area Annual Anomaly with Lowpassed by Zone ($\times 10^5$ km^2)
0
-1
-2
-3
-4
-5
1980
1985
1990
1995
2000
2005
2010
2015
2020
Year
Baffin Bay
Davis Strait
Northern Labrador Sea
Labrador Shelf
Whole/4
2021
2022
2023

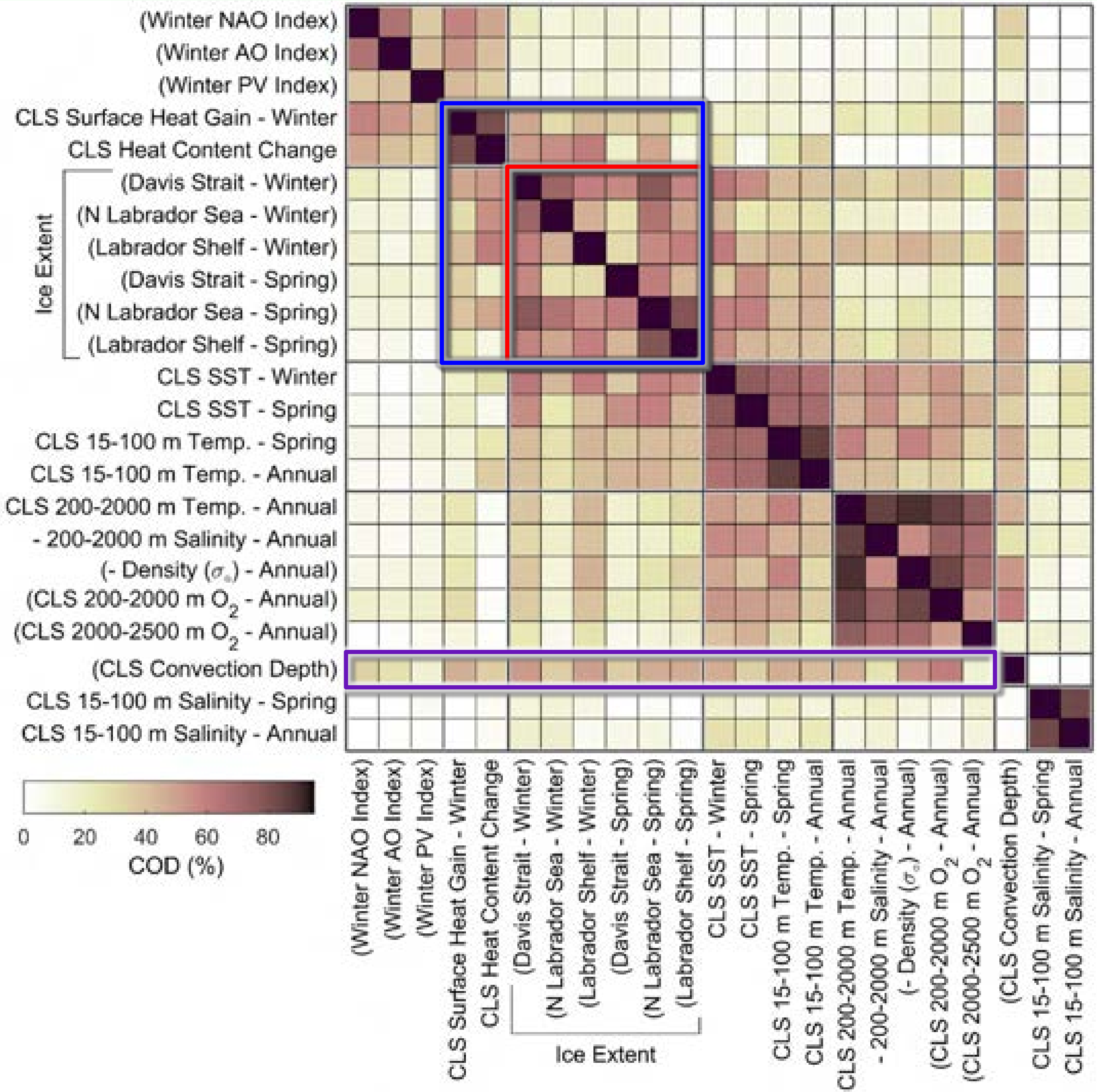


Labrador Sea DOORS Scorecard



Labrador Sea DOORS Correlation Matrix

Labrador Sea DOORS Coefficient of Determination Matrix (%)



~~Outlook~~

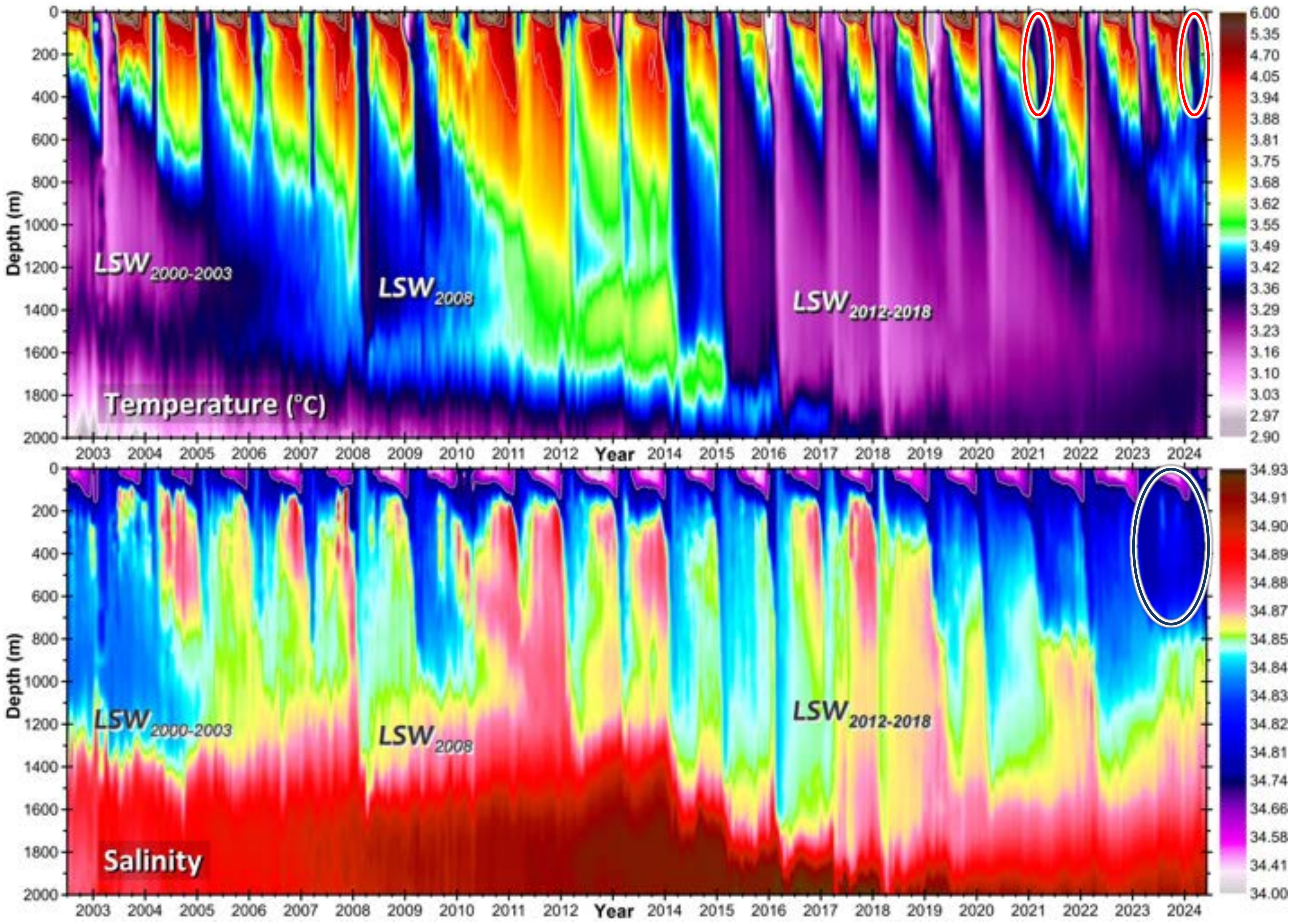
communications earth & environment **Article**

https://doi.org/10.1038/s43247-024-01296-9

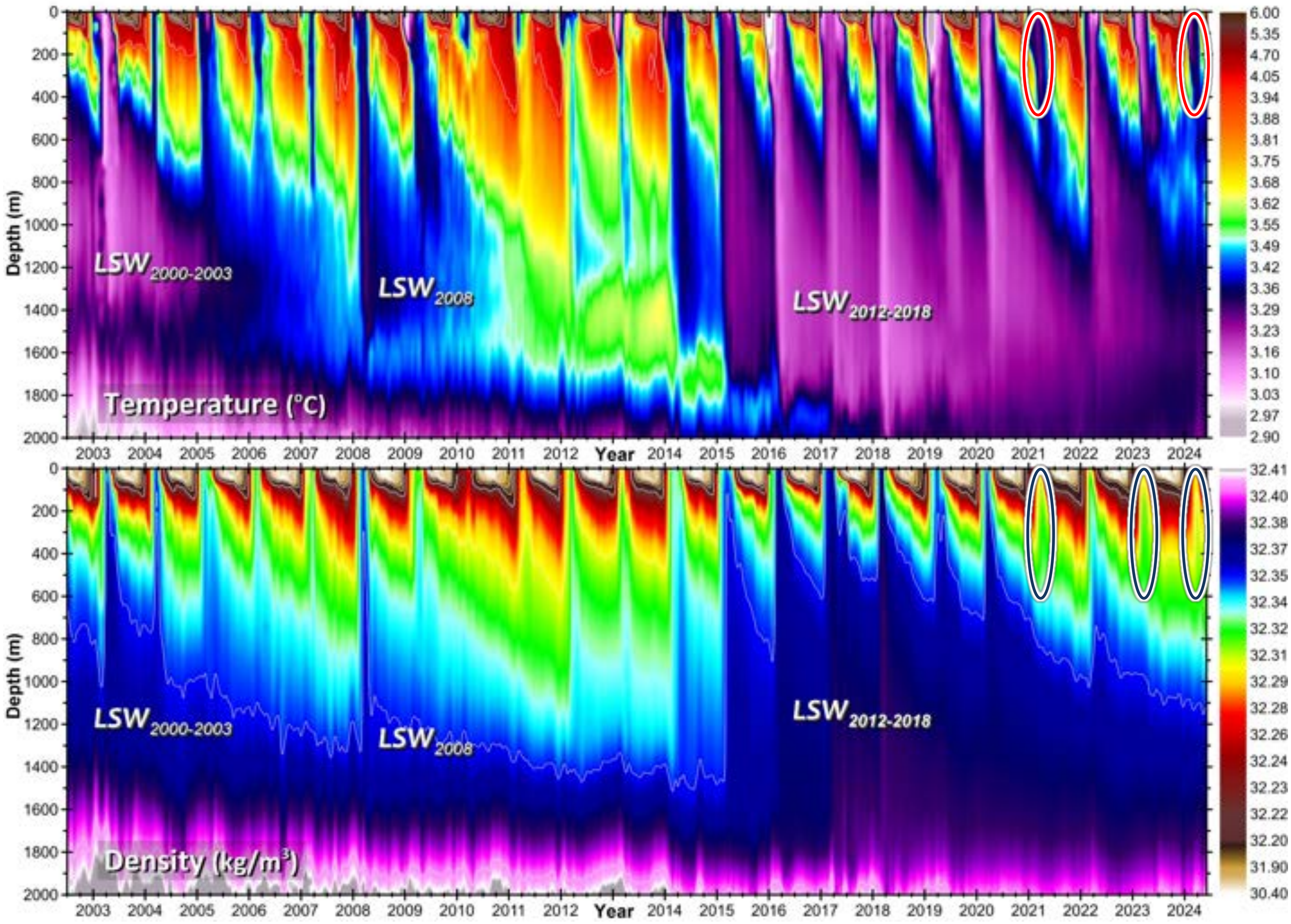
Intensification and shutdown of deep convection in the Labrador Sea were caused by changes in atmospheric and freshwater dynamics

This study predicted that deep convection would not be possible in 2024.

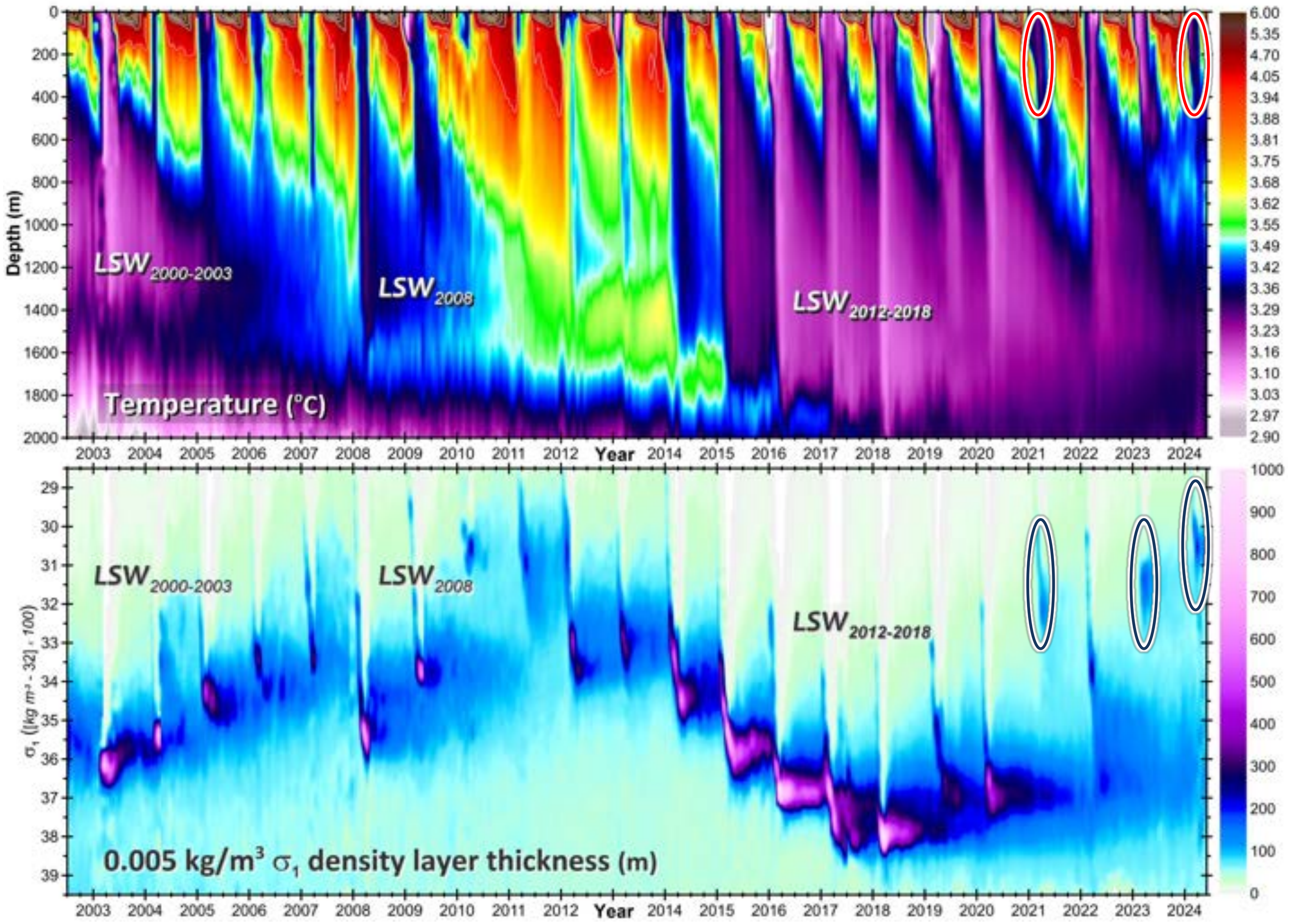
Today we either validate or reject the stated prediction!



Temperature (°C)
LSW2000-2003
LSW2008
LSW2012-2018
Depth (m)
Year
6.00
5.35
4.70
4.05
3.94
3.88
3.81
3.75
3.68
3.62
3.55
3.49
3.42
3.36
3.29
3.23
3.16
3.10
3.03
2.97
2.90
Salinity
34.93
34.91
34.90
34.89
34.88
34.87
34.85
34.84
34.83
34.82
34.81
34.74
34.66
34.58
34.41
34.00



Temperature (°C)
LSW2000-2003
LSW2008
LSW2012-2018
Depth (m)
Year
Density (kg/m³)



Depth (m)
LSW2000-2003
LSW2008
LSW2012-2018
Temperature (°C)
Year
0.005 kg/m3 σ1 density layer thickness (m)
σ1 ([kg m-3 - 32] - 100)

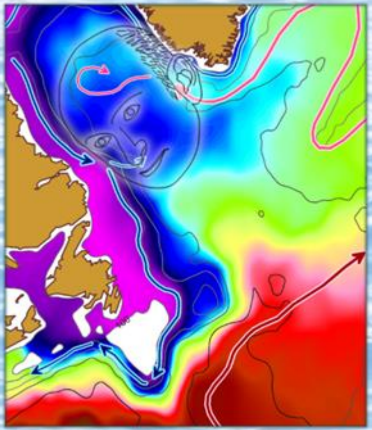
Highlights

- The deepening phase of the 2012-2023 Labrador Sea convective cycle was sustained by **winter surface cooling in the first four years** (2012-2015) and by **preconditioning in the following three years** (2016-2018).
- In 2019, the Labrador Sea post-convective relaxation phase began.
- Stratospheric and tropospheric circulation changes led to the shutdown of convection in 2021. The polar vortex disrupted, collapsed and shifted east in January of 2021. The weakened Icelandic Low shifted southwest. The displacement of the two lows reversed the westerly winds, reducing winter surface cooling.
- The massive Labrador Sea freshening that followed the extreme Arctic sea ice losses and Beaufort Gyre freshwater release caused the shutdown of convection in 2023 (and now we can say for sure in 2024).
- This shutdown can be regarded as the **first significant impact of Global Warming on Labrador Sea convection and** associated environmental **conditions**.

Next Steps:

Causes and impacts of
the 2021-2024 environmental
extremes in the Labrador Sea:

Extreme salinity, temperature,
density, sea level (and T-S
contributions),
winter cooling, summer warming,
convection depth, …



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B2Y 4A2, Canada

DEEP-OCEAN OBSERVATION
DOORS
AND RESEARCH SYNTHESIS

Source:

I. Yashayaev, (2024), 2024 Oceanographic Conditions in the Labrador Sea in the Context of Seasonal, Interannual and Multidecadal Changes, NAFO SCR Doc. 24/014.

NAFO Northwest Atlantic Fisheries Organization

Additional information:

Yashayaev, I., (2024), Intensification and shutdown of deep convection in the Labrador Sea were caused by changes in atmospheric and freshwater dynamics, *Nature Communications Earth & Environment*, 5:156 https://doi.org/10.1038/s43247-024-01296-9