Decadal coherence of thermohaline staircase layers in the Arctic Ocean's Canada Basin

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Key Points

- We detect 48 thermohaline staircase layers across the Beaufort Gyre Region that are coherent across 2005–2022 with nearly constant salinity.
- The temperature gradient across the staircase weakened by approximately 30% over 17 years, with warm layers cooling and cool layers warming.
- The total height of detected layers compressed by approximately 21.92 dbar in 17 years, with upper layers sinking faster than lower layers.

Introduction

The Canada Basin of the Arctic Ocean contains a staircase structure, a series of homogeneous layers separated by sharp gradient interfaces in temperature and salinity that impact vertical heat flux. Staircase layers have appeared in profiles from this region (Fig. 1a) since the beginning of measurements over 50 years ago [1]. However, previous studies have only tracked individual staircase layers for a few years at a time.

Timmermans et al. 2008 [2] noted that profiles from a wide area with staircases exhibit clusters in temperature–salinity space, demonstrating that layers can stretch 100's of km horizontally. We find these patterns persist when extending the time series by approximately a factor of 10 (Fig. 1c).

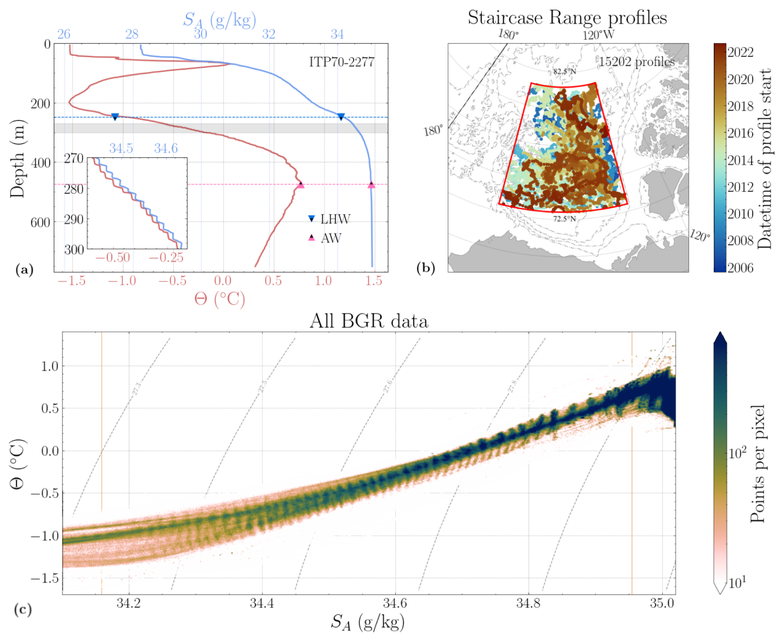

Figure 1. (a) An illustrative ITP temperature and salinity profile. (b) A map of the Beaufort Gyre Region (BGR) showing the locations and observation times of profiles. (c) A histogram of observations in temperature–salinity space for 2005–2022 BGR ITP data.

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Long-term layer coherence

In order to track individual staircase layers across time, we use Ice-Tethered Profiler (**ITP**) data from the Beaufort Gyre Region (**BGR**) between 2005–2022, taking profile sections between the Lower Halocline Waters (**LHW**) and the Atlantic Waters (**AW**). First, following Schee et al. 2024 [3], we apply the HDBSCAN clustering algorithm [4] to each year of data separately. Then, we create a salinity histogram of all clustered data and divide into layers based on the local minima.

We find staircase layers to be coherent across 17 years. Overall, salinity is stable and temperatures are converging; pressure is more variable, yet indicates the staircase is deepening and compressing (Fig. 2 & 3).

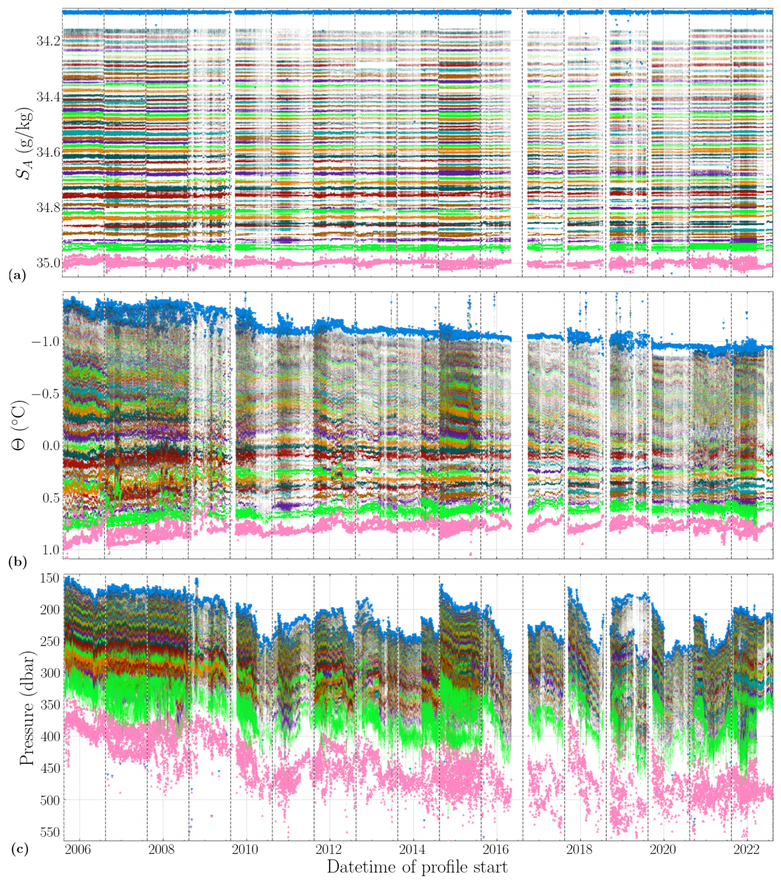

Figure 2. The temporal evolution of (a) salinity, (b) temperature, and (c) pressure of the detected layers. Blue and pink markers denote the values of the LHW and AW, respectively. The vertical dashed lines denote the boundary between time periods.

References

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Staircase trends

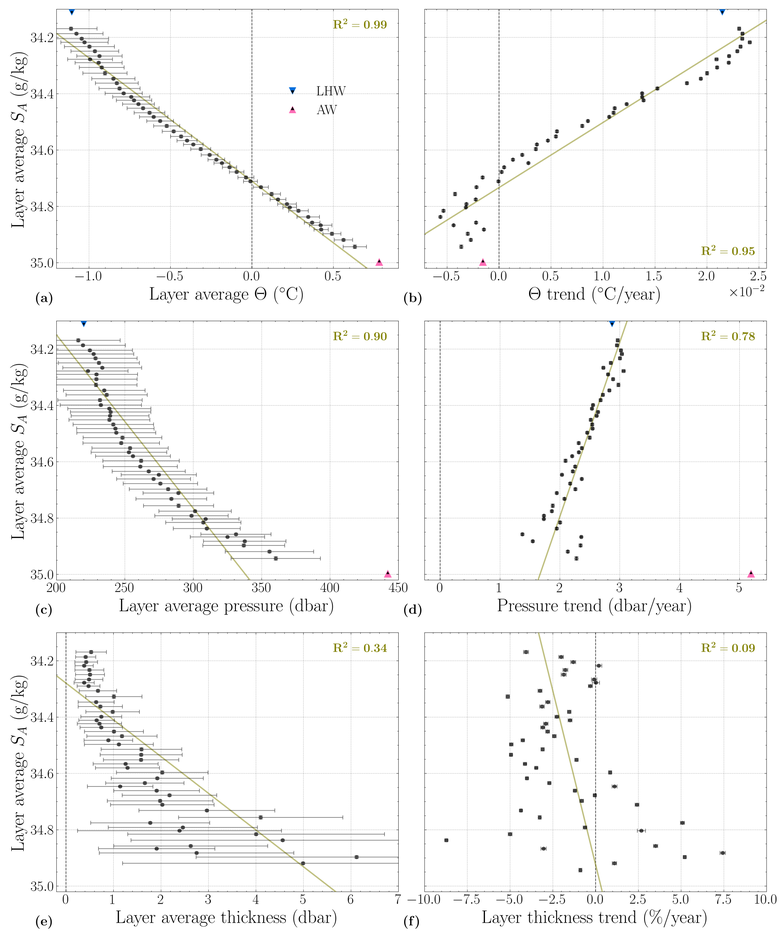

Figure 3. Averages and trends for all detected staircase layers over the entire 17-year period for (a,b) temperature, (c.d) pressure, and (e,f) thickness. Layer thickness trends in (f) are normalized to % changes relative to the average thicknesses in (c). Linear fits and R^2 values are noted in each panel. When taking temporal trends, we account for spatial variations using a 2D polynomial fit across latitude and longitude.

Discussion

This study establishes decadal-scale coherence of Arctic thermohaline staircase layers, allowing us to form novel estimates of how the staircase evolves over time.

- The rate of temperature gradient decrease implies **uniform temperature in 40 years**.
- Layers sinking at a rate matching that of reported cumulative downwelling in the BGR [5, 6].
- An overall compression implies the **total vertical range collapsing to 0 in 200 years**.
- Rates of layer thinning imply **at least 50 years before most layers disappear**.

These evolution time scales seem to suggest all observations to date of staircases in the BGR describe a single, slowly-evolving structure. They also raise the question as to whether staircases will continue to exist into the future as the Arctic Ocean continues to undergo rapid changes.