Water mass transformation in the Greenland Sea during the period 1986 - 2016

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Introduction

The Greenland Sea is among the few regions of the global ocean where deep convection, forming dense water masses, takes place during winter. This process replenishes the deep ocean with oxygen and is important for maintaining its thermohaline properties.

Several studies have documented significant changes in the convective activity during the past few decades. In particular, convection has been limited to the upper 2000 m since the cessation of deep and bottom convection in the 1980s.

In this study, we examine the evolution of convection and hydrographic properties in the Greenland Sea over the period 1986 to 2016 using historical hydrographic measurements.

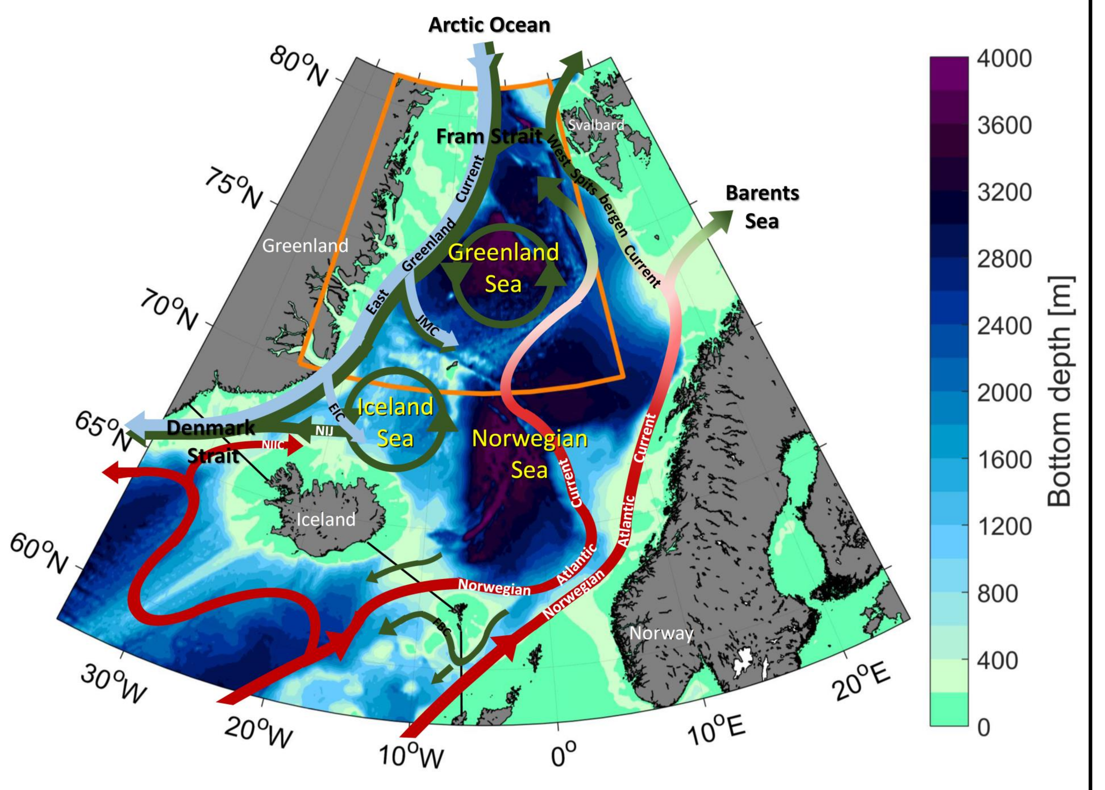


Fig 1: Bathymetry of the Nordic Seas (in colors) including schematics of the general circulation. Red colors indicate inflow of warm Atlantic Water while dark green colors indicate cold and dense waters. Fresh surface water is shown in light blue. The orange line outlines the region of interest in this study.

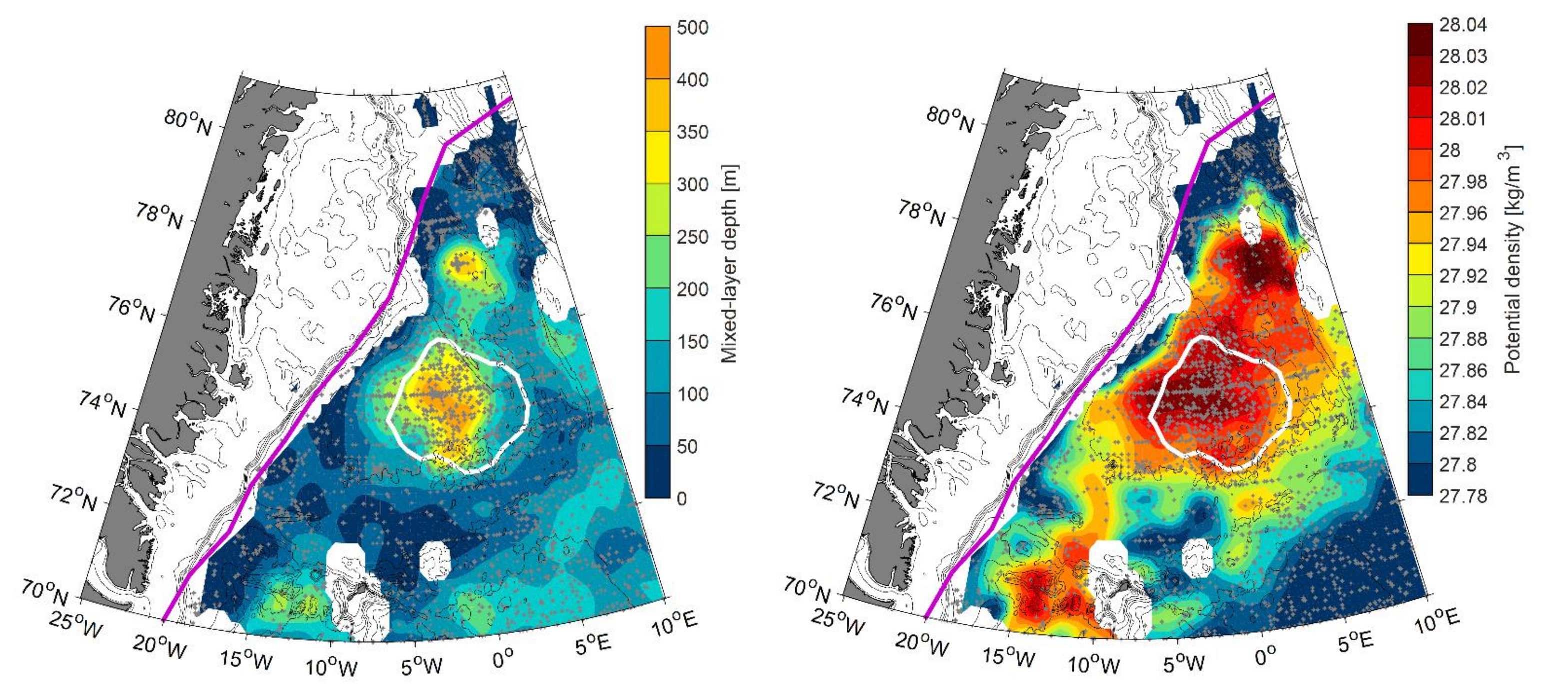


Fig 2: Mean late-winter (Feb-Apr) mixed-layer depth (left) and potential density (right) from 1986 to 2016. Data locations are indicated by gray dots. The white contour outlines the Greenland Sea gyre and the magenta curve denotes the 50 % sea ice concentration contour.

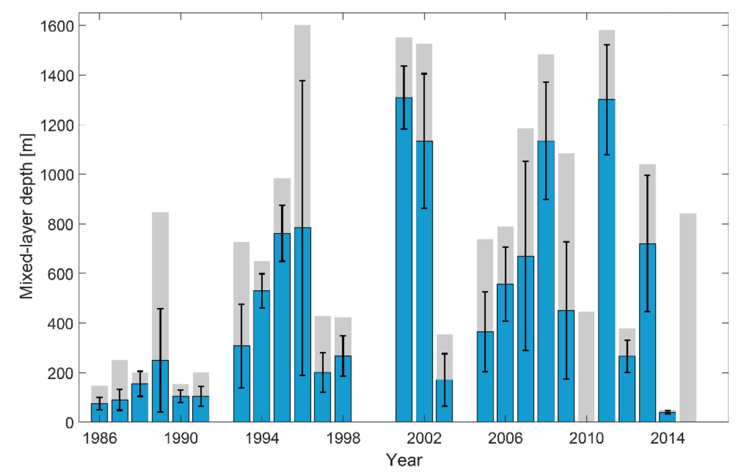
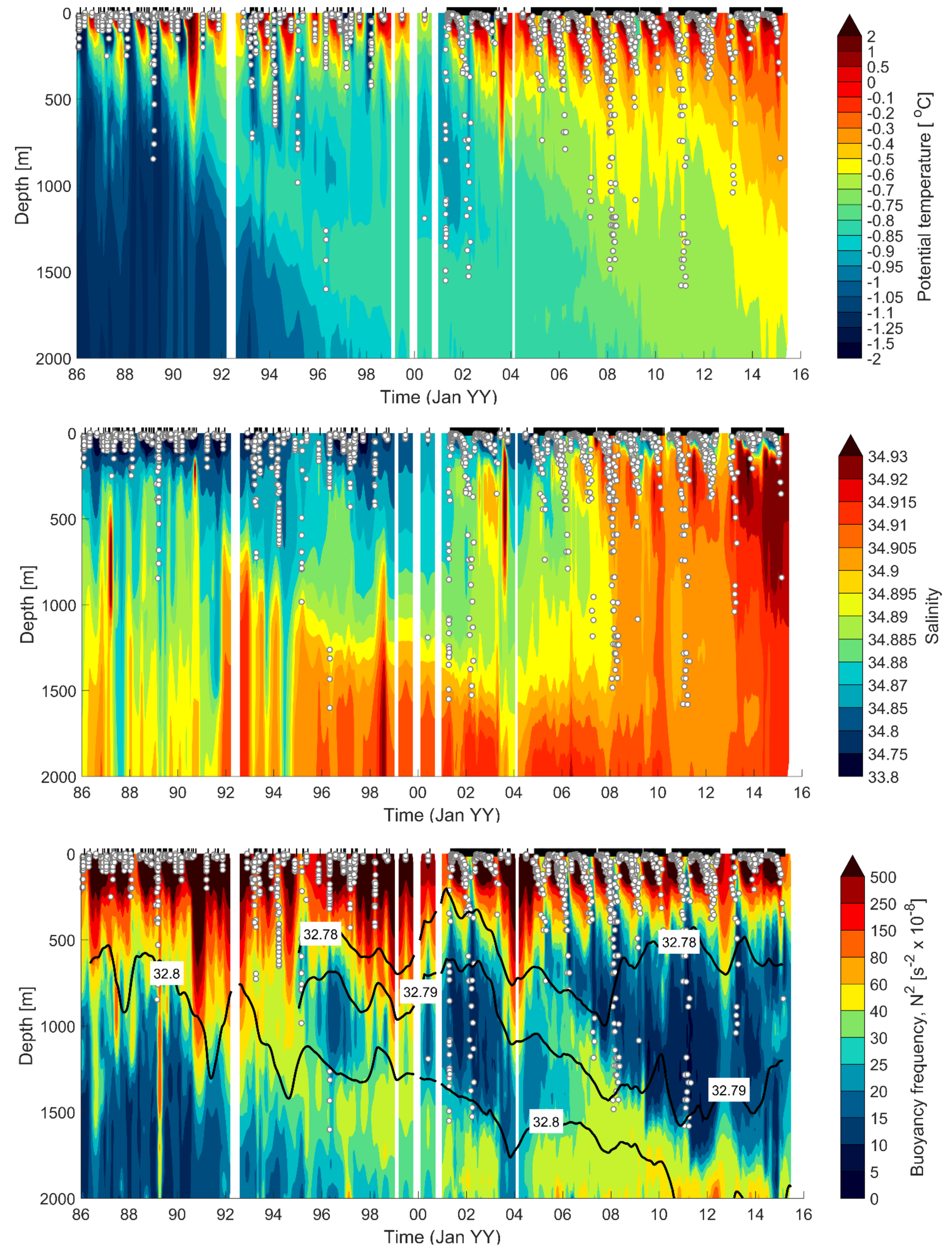


Fig 3: Mean late-winter mixed-layer depth (blue) and deepest mixed layer (gray) observed in the Greenland Sea gyre.

1) Mixed-layer depth:

- The deepest and densest mixed layers are located near the center of the cyclonic gyre.
- Substantial inter-annual variability.



2) Evolution of the intermediate water:

- Long term changes toward a warmer and more saline water column.
- Increasing volumes of weakly stratified water are associated with periods of deeper convection.

Fig 4: Evolution of potential temperature (top), salinity (middle), and buoyancy frequency (bottom) including estimated mixed-layer depths shown as white dots. The black bars along the top of each panel mark the time of each profile. The black contours in the bottom panel represent σ_1 isopycnals.

3) Water mass formation:

- The Greenland Sea Deep Water has not been ventilated since 1986 ➡ reduction in volume until it vanishes from the upper 2000 m in 2002.
- A new less dense class of intermediate water started forming in winters 1993-94 and 1994-95. Its volume has expanded in line with generally increased depths of convection.

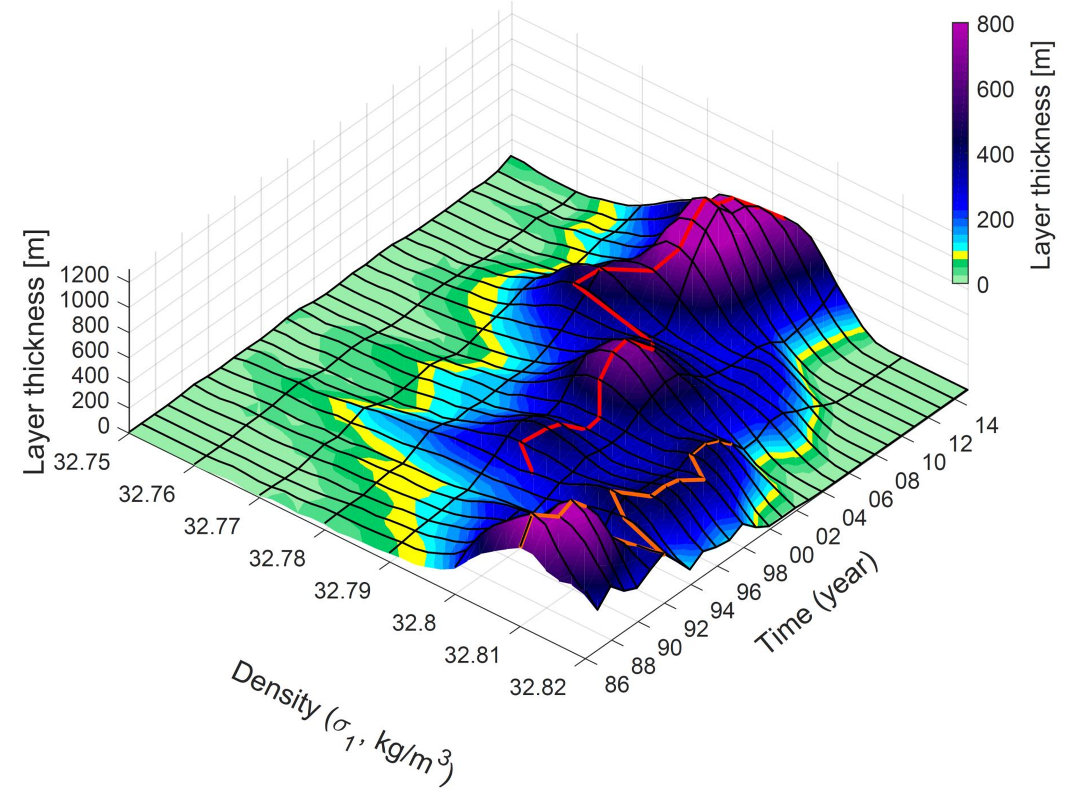


Fig 5: Evolution of annual mean thickness of given σ_1 layers ($\Delta\sigma_1$ = 0.01 kg/m³). Larger thickness means that the corresponding density layer occupies a larger part of the water column. The red and orange lines follow the maximum layer thickness associated with the ***Intermediate Water*** *and the* ***Greenland Sea Deep Water****, respectively.*

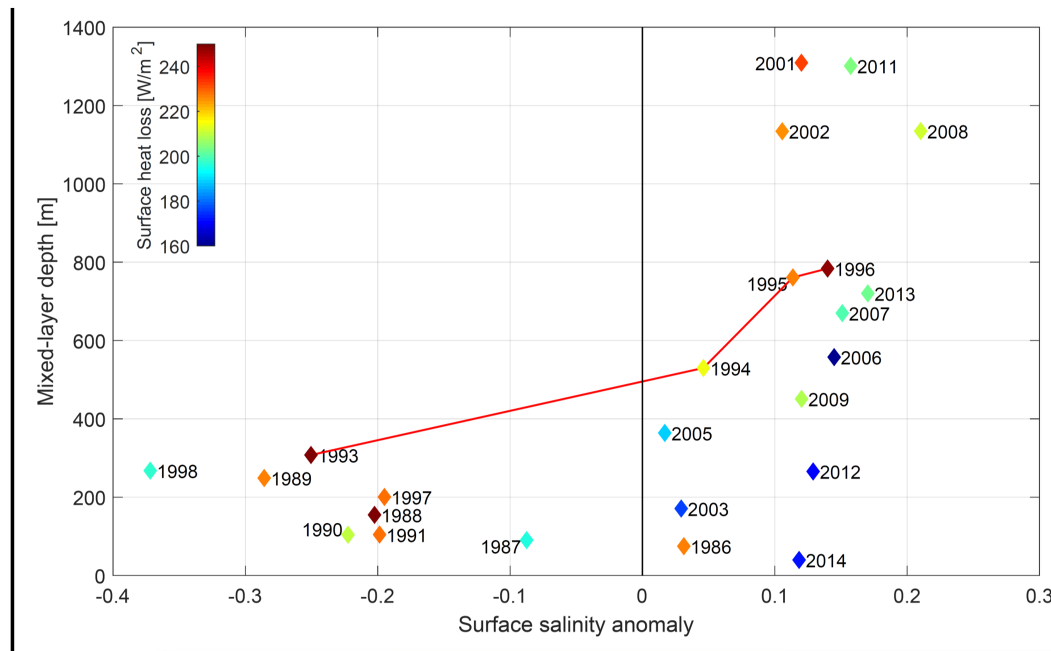


Fig. 6*: Mean late-winter (Feb-Apr) mixed-layer depths versus mean summer (Jun-Oct) near-surface salinity anomalies from 1985 to 2016. The anomalies are relative to the overall mean (34.71), indicated by the vertical black line. The red line marks the evolution from 1993 to 1996. Winter-mean surface heat loss is shown in color.*

4) Elements that limit the depth of convection:

- Anomalously fresh near-surface layers ➡ increased stability
- Weak atmospheric forcing

The convective response to various forcing and hydrographic conditions were examined by using a one-dimensional mixed-layer model.

5) Main result from mixed-layer model sensitivity studies:
Formation of the new class of intermediate water was primarily a result of reduced water column stability due to higher near-surface salinities.

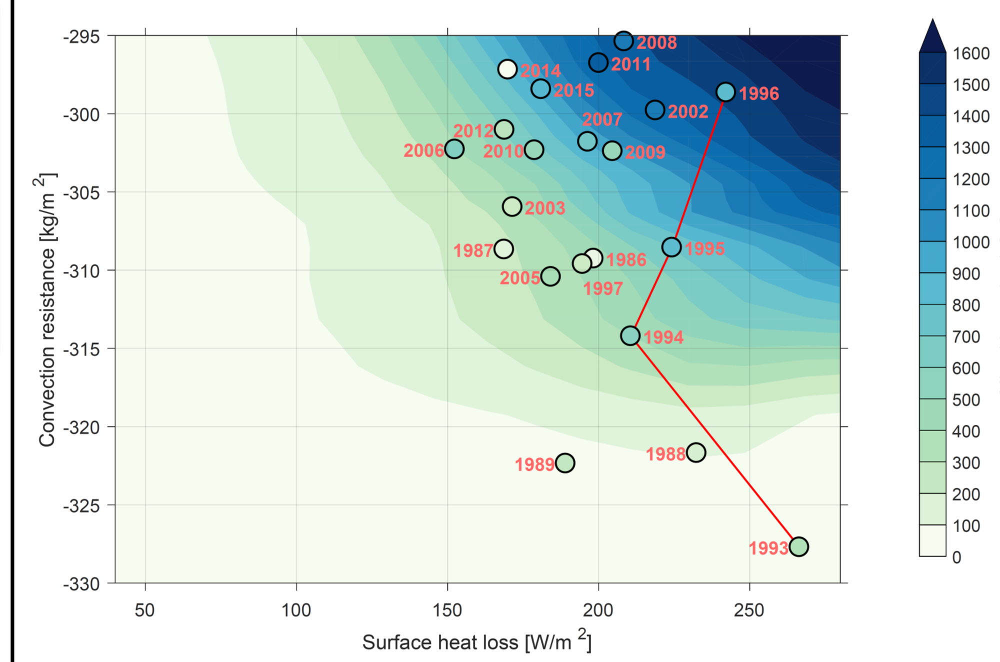


Fig. 7*: The background color shows simulated mixed-layer depth versus winter-mean surface heat loss and convection resistance (CR). CR is a measure of the mean fall stratification. More negative values indicate stronger stratification. The colored dots shows observed mean late-winter (Feb-Apr) mixed-layer depths and the red line indicates the large change in stratification over the time period 1993-1996.*

Concluding remarks

- Increased near-surface salinities during winters 1993-94 and 1994-95 resulted in the formation of a new class of intermediate water.
- Since it first started forming, this water mass has been the main product of convection in the Greenland Sea.
- The freshwater content in the upper layers has a great impact on the depth of convection ⟶ more work is needed to better understand the sensitivity of deep convection to the total content and distribution of freshwater.

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