2009

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Gatner, P. (2009) 'Labrador Sea Water formation in the Irminger Basin and its dependence on the North Atlantic Oscillation', The Plymouth Student Scientist, p. 199-269.
http://hdl.handle.net/10026.1/13878

The Plymouth Student Scientist
University of Plymouth

*The Plymouth Student Scientist, 2009, **2**, (2), 199-217*

# Labrador Sea Water formation in the Irminger Basin and its dependence on the North Atlantic Oscillation

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**Abstract**

Historical temperature and salinity data from the Irminger basin were analysed to determine if Labrador Sea Water forms in the Irminger Basin and if deep convection in the region is dependent on the North Atlantic Oscillation. This was undertaken by analysing the Surface Mixed Layer depth during the Boreal winter (December-March) and comparing it to the North Atlantic Oscillation Index. We find there is evidence of LSW formation in the region and there is a weak to moderate correlation with the North Atlantic Oscillation Index.

## Introduction

### History and Background

Deep convection in the open ocean is widely accepted to take place in the following locations: the Greenland, Labrador, Mediterranean, Ross and Weddell Seas (Marshall and Schott 1999). In the early twentieth century an additional location was thought to be the Irminger Sea, east of Cape Farewell (southern tip of Greenland, Fig. 1.1). A hypothesis of deep water formation in the Irminger Sea was first published by Nansen (1912), who also suggested that this deep water formation played a major part in North Atlantic circulation.

Expeditions to the Irminger Sea followed Nansen's suggestions (Defant 1936) and found evidence of a weakly stratified, ventilated water column in the Irminger Sea, and high oxygen concentrations at depth (Wattenburg 1938; Sverdrup et al. 1942; Wust 1943). West of Cape Farewell, however, the Labrador Sea is more easily identifiable as an area of potential deep convection due to the meteorological and thermohaline conditions (Pickart et al. 2003a), and the scientific community focused exclusively on this area, overlooking *Defant's* research undertaken in the Irminger basin. However, in recent years a number of papers have been published suggesting the Irminger basin as a possible location for deep convection and Labrador Sea Water (LSW) formation (Bacon et al. 2003; Pickart et al. 2003a,b; Deshayes et al. 2007; Falina et al. 2007; Våge et al. 2008). Due to the lack of previous interest in the Irminger Sea and the constraints of operating in this environment during winter, there is little winter data available for the region, and most studies have relied on modelling.

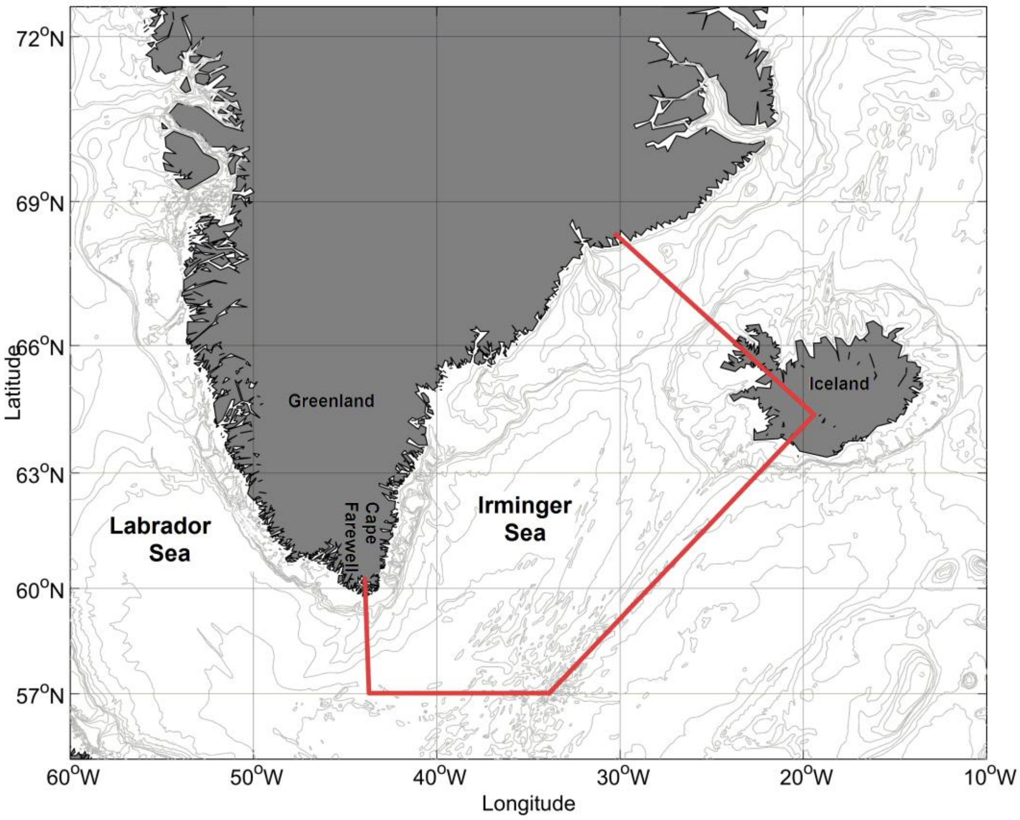


Fig. 1.1. Map showing the location of the Irminger Sea and the local region.

This study will assess whether LSW formation occurs in the Irminger basin by using historical temperature and salinity data. It will also investigate the possible dependence of convection on the North Atlantic Oscillation (NAO), as previously hypothesised (Dickenson et al. 1996; Pickart et al. 2003ab). This shall be undertaken by comparing the depth of the surface mixed layer (SML) in the Boreal Winter (December – March) with the North Atlantic Oscillation Index (NAOI). It should be noted that winter in this study shall be defined as the Boreal winter (December – March).

**Labrador Sea Water (LSW) formation in the Irminger basin**

Similarities in the thermohaline properties of the two seas are shown in Fig. 1.2. The two seas are very similar in terms of potential density, oxygen saturation, and potential vorticity[1] (PV), which is a key identifier of LSW (Dickson et al. 1996). In addition, PV should be close to zero or negative for convection to occur (DiBattista and Majda 2002). The profiles shown in Fig. 1.2 were collected as part of the World Ocean Circulation Experiment (WOCE). It should be noted that for the Irminger Sea the data shown is not winter data, while the

[1] Planetary Potential vorticity is defined as PV=$(f/\rho)(\partial\rho/\partial z)$, where $f$ is the Coriolis parameter, $\rho$ is the potential density and $z$ is the depth (positive upwards) (Pedlosky, 1996).

Labrador Sea data is and this is the most probable cause for the surface difference between the two seas. During non-winter months the water column becomes more stratified in the region (Labsea Group 1998). Increased atmospheric forcing would provide a stronger air-sea buoyancy flux and would alter the surface layer sufficiently to be more comparable with the data shown for the Labrador Sea. Hence sufficient preconditioning and atmospheric forcing should cause LSW formation in the Irminger basin. Despite these similarities the Irminger basin was overlooked as a site for possible deep convection. This was primarily because meteorological analyses, such as the National Centre for Environmental Predictions (NCEP) regional field analysis, indicated that there was insufficient atmospheric forcing in the region to cause deep convection.

Lavender et al. (2000) demonstrated that the required preconditioning already exists in the Irminger Basin. Preconditioning refers to the state of the water column that allows convection to occur below the normal mixed layer depth. The most conducive conditions for downwelling in the open ocean are when the water is in an anticyclonic gyre. At the centre of the gyre horizontal flow should be as close to zero as possible and PV will be negative, inducing vertical downward flow at the centre of the gyre (DiBattista and Majda 2002). Combined with increased surface cooling, denser surface waters sink below the normal surface mixed layer depth (deep convection). If the water column is already weakly stratified, or the pycnocline is eroded, then this will also increase the probability of deep convection (DiBattista and Majda 2002).

Lavender et al. (2000) identified recirculation of intermediate water in both the Irminger and Labrador basins. As part of the WOCE and the Labrador Sea Deep Convection Experiment, 200 PALACE and SOLO floats were deployed in the North Atlantic at depths of 400m, 700m and 1500m. An anti-cyclonic cell was identified in the Irminger Sea. When taking into account atmospheric conditions (Pickart et al. 2002) and regional specific anomalies such as the Greenland tip jet[2] (Doyle & Shapiro 1999), a region for potential convection can be identified in the Irminger Basin. The Greenland Tip Jet (GTJ) also induces wind-driven anti-cyclonic circulation to the east of Cape Farewell, amplifying preconditioning (Pickart et al. 2003b).

[2] The Greenland Tip Jet (GTJ) is a high velocity localised wind event that forms in the lee of Cape Farewell (Doyle & Shapiro 1999; Cappelen et al. 2001).

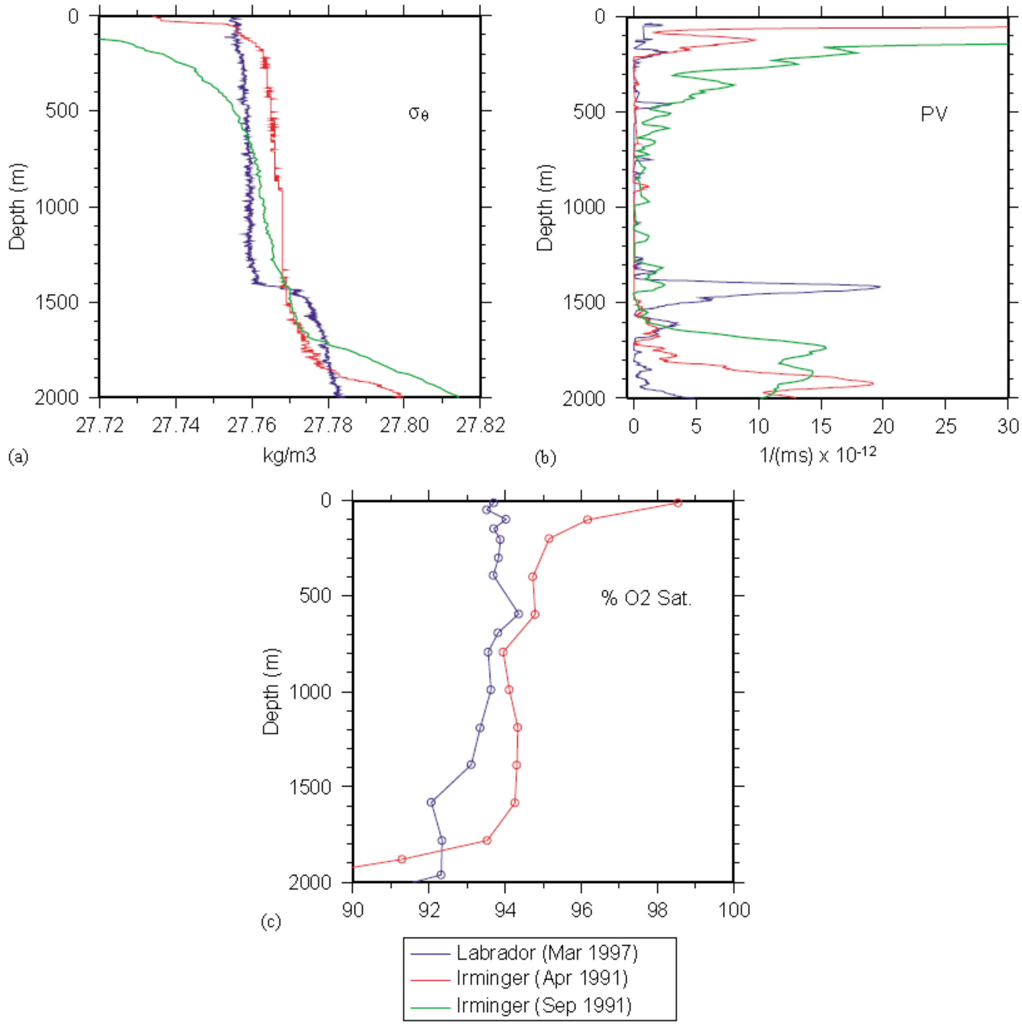


Fig. 1.2. Adapted from Pickart et al. (2003a), Vertical profiles of (a) potential density, (b) potential vorticity (PV), (c) percentage oxygen saturation from the Labrador and Irminger Seas.

## Greenland Tip Jet (GTJ)

NCEP reanalysis of global meteorological fields did not show the atmospheric conditions for deep convection required as were seen in the Labrador Sea (Pickart et al 2003b). Specifically, it did not show sufficient wind velocities to create the air-sea buoyancy fluxes required for deep convection events. However a tip jet was identified in the late 1990s in the lee of Cape Farewell by Doyle & Shapiro (1999) which NCEP analysis models were unable to resolve due to their low resolution. Fig. 1.3, shows a tip jet event in 2002. NCEP re-analysis only resolved a maximum wind speed for the same event of $24ms^{-1}$ (Vage et al. 2008). This event periodically occurs when north-westerly winds descend orographically on the eastern side of Greenland and accelerate due to the conservation of the Bernoulli function (1), *B*,

$$B = fT + \frac{v^2}{2} + gz \qquad (1)$$

where *T* is the temperature, *v* is the wind velocity, *z* is the height, *f* is the Coriolis parameter, and *g* is acceleration due to gravity (Doyle and Shapiro

1999). This draws colder high velocity air over the southern Irminger Sea (Doyle and Shapiro 1999) producing a high buoyancy loss (Pickart et al. 2003b).

The frequency of GTJ events and their effect on the ocean was first investigated in 2003 (Pickart et al. 2003b). As the tip jet curls off the coast of Cape Farewell it produces a region of anti-cyclonic circulation with strong wind and buoyancy forcing, which allows convection to occur over a broad region (Pickart et al. 2003b). Models of the southwest Irminger Sea when the effect of the GTJ is included show convection 500m deeper than when it is not considered (Pickart et al. 2003b). In winters with significant GTJ events, coupled with a high NAO, convection can occur to depths below 1700m (Våge et al. 2008).

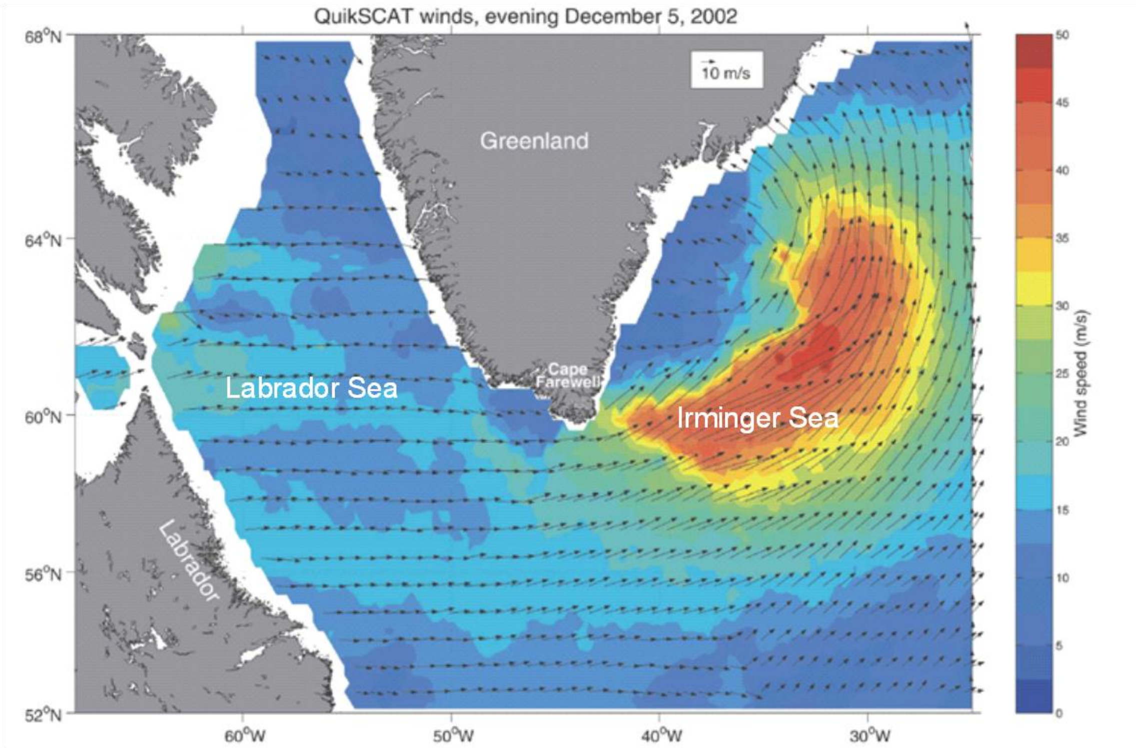


Fig. 1.3. QuickSCAT analysis of wind speeds (colour) and vectors (arrows), adapted from Våge et al. (2008).

**North Atlantic Oscillation (NSO)**

Bakalian et al. (2007), studied the relationship between GTJ events and the NAO. It was found that 32% of tip jet events could be explained due to the effect of the NAO. A high NAO produces more northerly storm tracks hence stronger atmospheric forcing along western Greenland, inducing GTJ events (Cappelen et al. 2001; Pickart et al. 2003b; Bakalian et al. 2007). It was found that during high NAO periods tip jet events increased in frequency and magnitude (Bakalian et al. 2007). If the effect of the change in latitude of the Icelandic low is also considered, then 48% of tip jet events can be explained.

The NAO is a hemispheric meridional oscillation with centres of action over the subtropical Atlantic and Iceland. Studies have demonstrated that NAO-related impacts extend from Florida to Greenland and from north-western Africa across Europe and into northern Asia (Visbeck et al. 2001).

During a positive phase NAOI it has been shown that the frequency and depth of convection events increases in the Labrador Sea (Dickson et al. 1996). The hypothesis of a relationship between a high NAO and possible convection in the Irminger basin was put forward by both Bacon et al. (2003) and Pickart et al. (2003a). Convection events occurring in correlation with high NAO events have been noted in a variety of models of differing types and resolution (Pickart et al. 2003b; Deshayes et al. 2007; Våge et al. 2008).

## Methods

### NAOI data

Monthly mean NAOI data were obtained from NOAA. The mean for the winter months for a given year was then calculated. The data is shown in Fig. 2.1. A three year smoothing filter was applied to allow ease of comparison with other works (Picart et al. 2003a). The NAOI data uses the Icelandic low and the Azores's high as used by others investigating similar relationships in the region (Pickart et al. 2003ab; Bakalian et al. 2007).

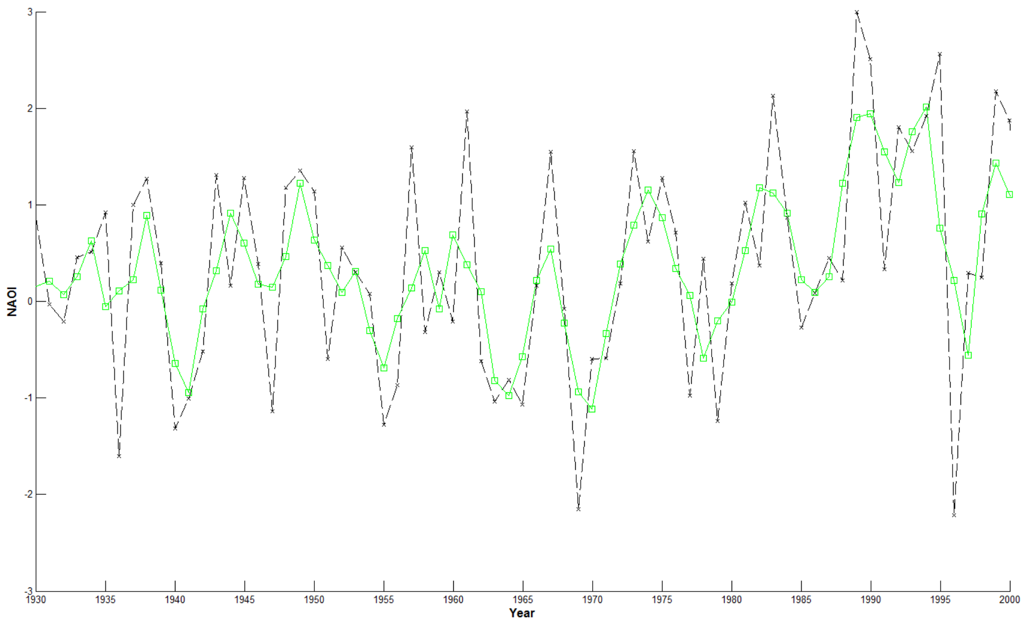


Fig. 2.1. Time series of the NAO winter time index from 1930 to 2000. Raw data shown with black dashed line. Three year mean smoothed data shown in green.

### Oceanographic Data

To investigate the relationship between deep convection and the NAO, oceanographic data were analysed and compared to the NAOI. Vertical temperature and salinity profiles were obtained for the Irminger basin from the International Council for the Exploration of the Seas Oceanographic Database (ICES). There is limited publicly available CTD data for the region; to expand the data set, data obtained from bottle sampling in the database were also used. ICES data were selected as the database has stringent data policies and validation procedures in place (ICES 2006). The area of data selected was 55°N - 64°N, 30°W - 45°W (Fig. 2.2). The region was selected as it was identified as an area of low PV during winter periods by Pickart et al. (2003a) and within the area affected by GTJ events (Bakalina et al. 2007; Våge et al. 2008).

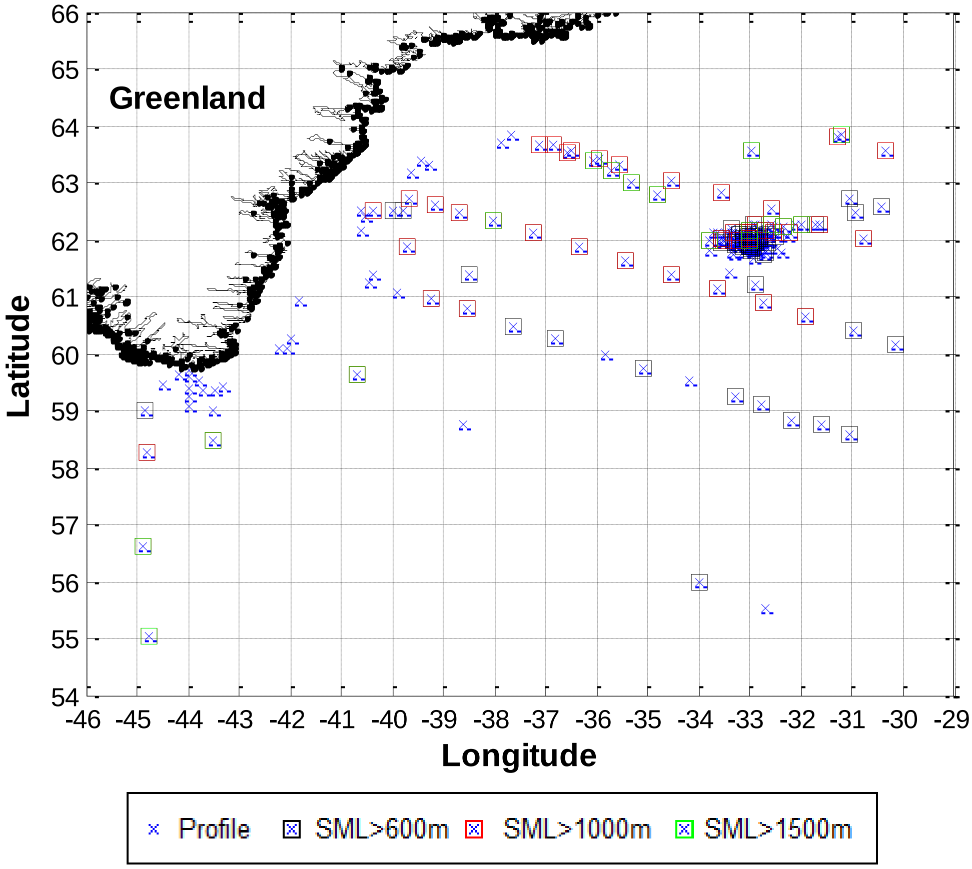


Fig.2.2. Map showing the location of the profiles used in this study (blue x). Box surrounding x identifies depth of the SML, no box less than 600m, black box more than 600m, red box more than 1000m, green box more than 1500m.

The data were separated into individual profiles and the winter profiles were then selected. Winter has been identified as the most likely period for convection events to take place (Labsea Group 1998; Visbeck et al. 2001; Pickart et al. 2003a). The potential densities for each profile were then calculated using the equation of state for seawater at atmospheric pressure (Millero and Possion 1981).

## SML Depth & Deep Convection

Deep convection is where the water column is homogeneous from the surface to below the normal mixed layer depth allowing for vertical mixing of the water column to depth. The base of the surface mixed layer (SML), by definition, is the point where the water column is no longer homogenous, and therefore the depth of convection was defined using SML depth. The SML depth was defined as the depth at which the potential density is 0.1 greater than at the surface (Brainerd and Gregg 1995; Hosegood et al. 2006). While Brainerd and Gregg (1995) show that the SML could be defined between 0.05 and 0.5 greater than the surface potential density, 0.1 was used in this investigation to allow for comparison with other works. Deep convection in this study will be considered to be taking place or to have recently taken place where the SML is greater than 600m. This depth was selected by taking the mean SML depth of all the non Winter data for the selected region (179.8m) and multiplying by 3, as LSW forms between 500m and 2500m (Pickart et al. 2003a), Taking a depth of 600m as the SML required for deep convection is more conservative than necessarily required.

Due to the fact that oceanographic data were collected originally for a variety of different studies, the resolution of each profile varied considerably. The data were processed as follows:-

- Data were separated into individual profiles, and winter data selected.
- Potential temperature and density were calculated for each profile.
- Profiles without data for the surface were removed as it would not be possible to calculate the depth of the SML.
- Depth of the SML for each profile was then calculated.
    - If a data point did not exist exactly 0.1 greater than the surface potential density, the first point greater than 0.1 of the surface potential density was used with the previous point, and the depth of the SML was linearly interpolated.
    - If the SML was not found by the end of the profile and the maximum depth in the profile was less than 600m, the profile was removed from the data set.
    - If the SML was not found by the end of the profile and the maximum depth in the profile was more than 600m, the maximum depth of the profile was considered to be the SML since deep convection would be considered to be taking place.

These restrictions reduced the overall availability of data for the final study to only 277 profiles. The distribution of the data available shows that a large proportion of the data is pre 1970s and will therefore be bottle data (Fig. 2.3).

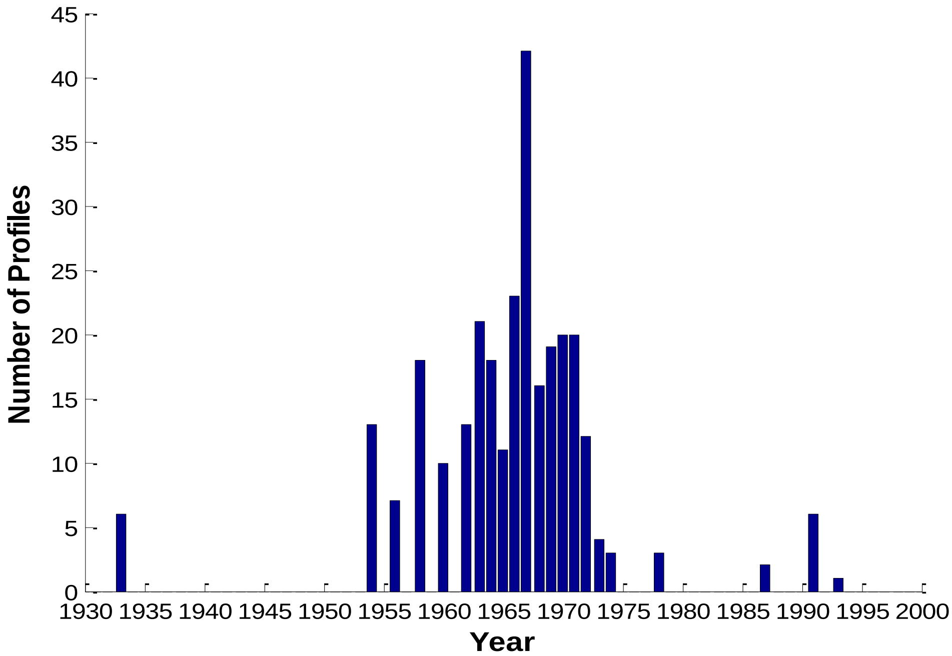


Fig. 2.3. Number of profiles available for each year that were used in this study.

## Results

### Evidence of deep convection

Previous studies have demonstrated that LSW formation is taking place in the Irminger basin (Bacon et al. 2003; Falinia et al. 2007). Fig. 3.1 shows a typical deep convection profile from the dataset analysed in this study showing a convection event. Table 1 shows the percentage of profiles that show SML depths depicted as being deep enough for deep convection to be considered to be taking place. This shows that slightly less than half the data set has an SML below 600m.

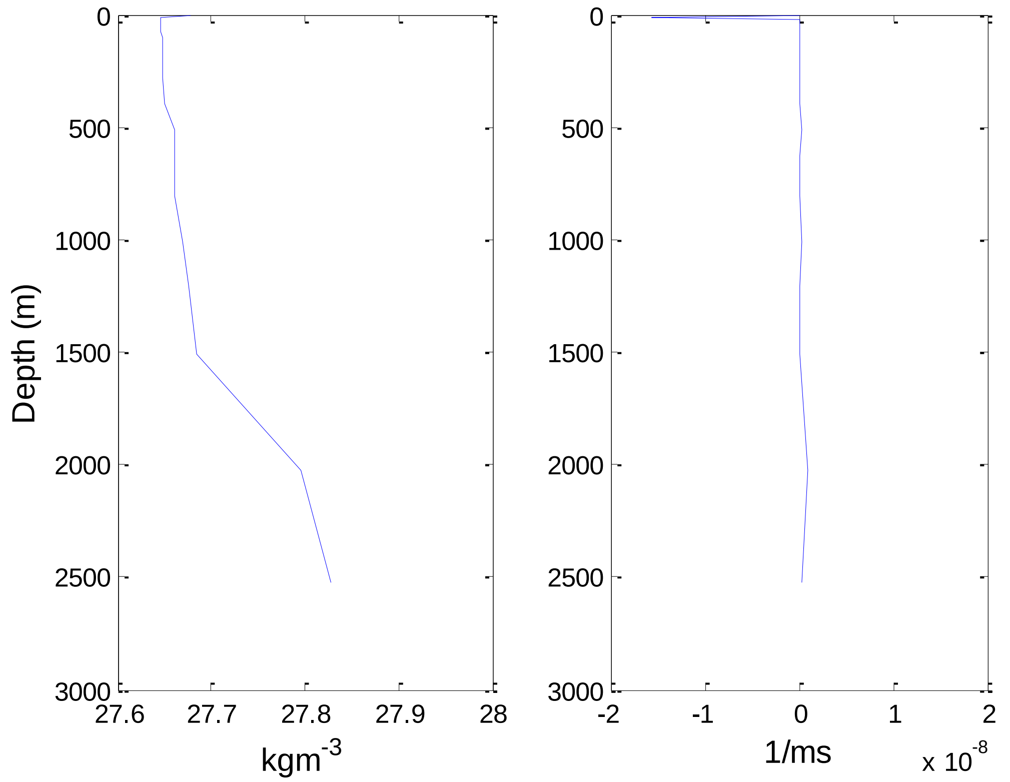


Fig 3.1. A typical deep convection profile from the data set, this profile is from March 1973.

| Depth of SML | Percentage of data set |
|---|---|
| Less than 600m | 52% |
| More than 600m | 48% |
| More than 1000m | 21% |
| More than 1500m | 6% |

Table 1. Percentage of profiles in the data set with a SML identified as deep convection.

### Investigation of deep convection dependence on NAOI

Identifying the dependence of deep convection on the NAOI was undertaken by directly comparing the depth of the SML with the NAOI for that period. This was statistically tested by identifying a linear correlation coefficient (2), R,

$$R(i,j) = \frac{\Sigma(i,j)}{\sqrt{\Sigma(i,i)\,\Sigma(j,j)}} \qquad (2)$$

where i and j are the variables being compared. The p-values of the correlations were then found to identify the significance of the correlation. There was a linear but weak correlation between the SML depth data for each year compared to the NAOI (Fig. 3.2). Due to the variability in the availability of data in terms of both time and space, the SML depths for each winter were then annually averaged (mean) and compared to the NAOI (Fig. 3.3). The correlation in this case was moderate. The coefficient of determination in this case ($R^2$) would suggest that 31% of the annual variability in the mean depth of the SML over the region is due to the variation of the NAOI.

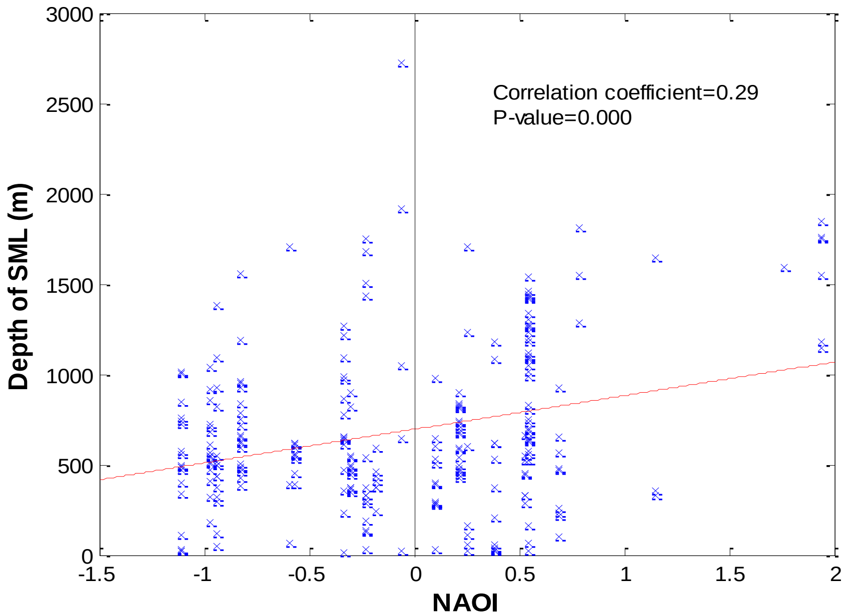


Fig. 3.2. Raw SML depth against NAOI showing correlation coefficient and relevant p-values with line of best fit (red).

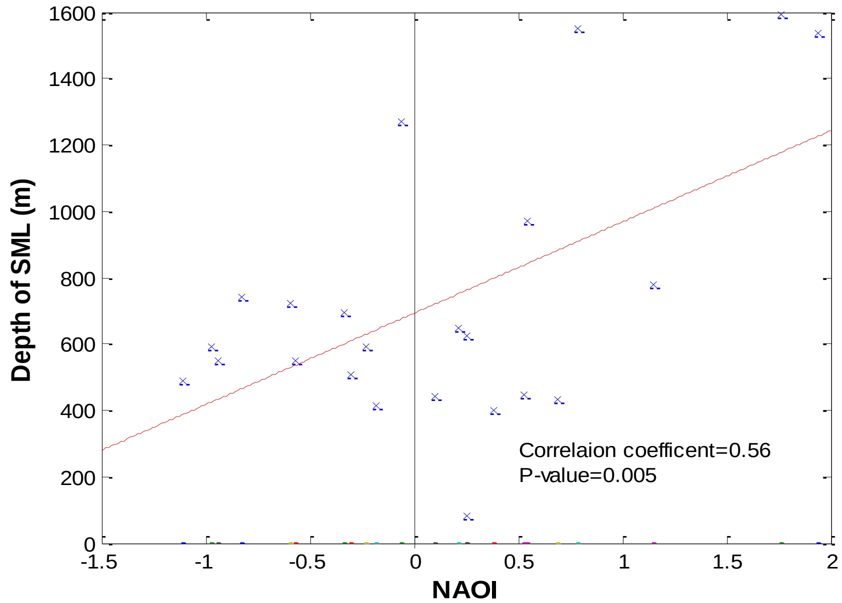


Fig. 3.3. Mean SML depth for each winter against NAOI showing correlation coefficient and relevant p-values with line of best fit (red).

It may be considered that taking the entire region and treating it as if it was all affected equally by the NAOI was unrealistic due to the variability in conditions across the region. This variability includes boundary currents, atmospheric forcing and vertical variability in the water column. Three areas were identified and investigated to see if there was any change in the correlation with the NAOI (Fig. 3.4). The regions were selected based on availability of data and the variability in conditions at these stations. Area one is located in the open ocean, area two is south of Cape Farewell, while area three is close to the east coast of Greenland in an area that is less affected by the GTJ (Fig. 1.3).

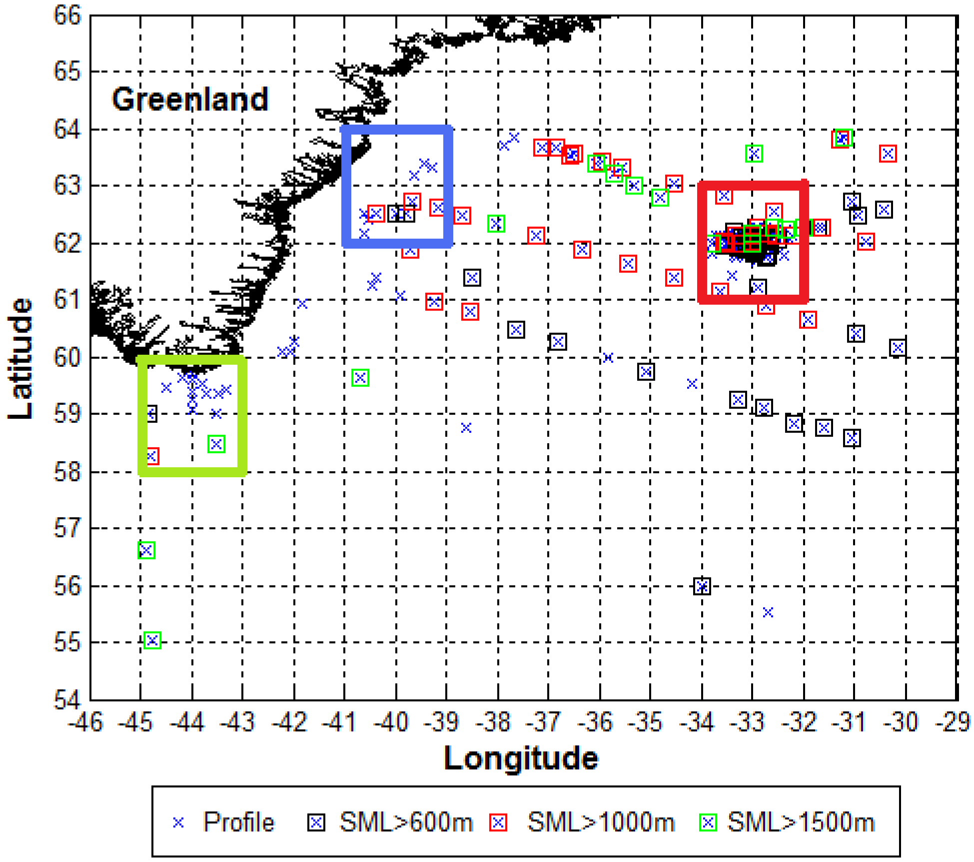


Fig. 3.4. Map showing location of three areas taken separately, with the location of profiles used profiles marked (x). Area one (red), area two (green) and area three (blue).

Area one is located offshore in a region identified by Våge et al. (2008) to be affected by the GTJ and having a low PV (Pickart et al. 2003a). It also had the highest concentration of available data. The time period and quantity of data available is shown in Fig. 3.5. The data has both positive and negative phase NAOI data in it with a spread over several years. There was found to be no statistically significant correlation with the NAOI either when the raw data was linearly compared pr when the mean SML depth for each year was compared. This would suggest that the NAOI phase does not affect the deep convection in this region.

Area two is located south of Cape Farewell and area three is located close to the east coast of Greenland. Both of these locations had a significant lack of available data and were only spread over a few years (Table 2 and Table 3).

Any comparison therefore between the NAOI and the depth of the SML would be insufficient for one to reach a valid conclusion. In both cases no correlation was found between the NAOI and depth of the SML. Investigating other areas was considered; however the restrictions of the data spread in both terms of time and space inhibited this.

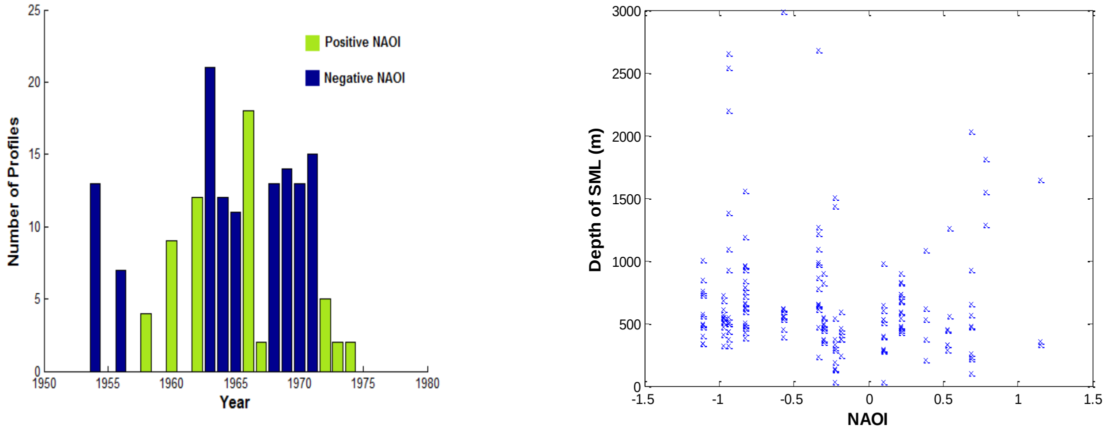


Fig 3.5. Spread of data over time (left) and data correlation (right) for area one.

| Year | No. Profiles | NAOI |
|---|---|---|
| 1935 | 1 | -0.0567 |
| 1971 | 2 | -0.3333 |
| 1972 | 4 | 0.3833 |
| 1978 | 3 | -0.59 |
| 1987 | 2 | 0.2517 |

Table 2. Spread of data in area two.

| Year | No. Profiles | NAOI |
|---|---|---|
| 1933 | 1 | 0.2525 |
| 1964 | 5 | -0.9717 |
| 1967 | 1 | 0.545 |
| 1969 | 1 | -0.94 |
| 1933 | 1 | 0.2525 |

Table 3. Spread of data in area three.

Våge et al. (2008) and Pickart et al. (2003) both demonstrated that the area depicted by area one in this study is both strongly affected by the GTJ and is the most likely area for convection in the region. GTJ events do occur in periods of low NAOI (Bakalian et al. 2007) and would be the most likely reason for the non-dependence on the NAOI for this region. There is insufficient data for the rest of the region for one to investigate if any other areas are similar to area one. However, when the data from area one were removed from the whole dataset, the correlation between the NAOI and the depth of the SML substantially increased. The correlation between the raw SML depth data and the NAOI increases from 0.29 to 0.37 and the mean SML depth and NAOI data increase from 0.56 to 0.65. In both cases these remain statistically significant. This would suggest that convection for the rest of the region, excluding area one, is more dependent on the NAOI for deep convection events to occur.

**Deep convection in low NAOI periods**

Data presented here suggests that deep convection is also taking place in low NAOI periods. This is contrary to the hypothesis of Pickart et al. (2003a). This would indicate that deep convection events are taking place in periods with a negative NAOI. There are 11 years in the dataset with a negative NAOI. In each of these years there is at least one profile with an SML depth below 600m (Fig. 3.6). The mean SML depth for positive NAOI data is higher than that for negative NAOI data, at 744m and 623m respectively, where 46% of the dataset represents positive NAOI data, and 54% represents negative NAOI data.

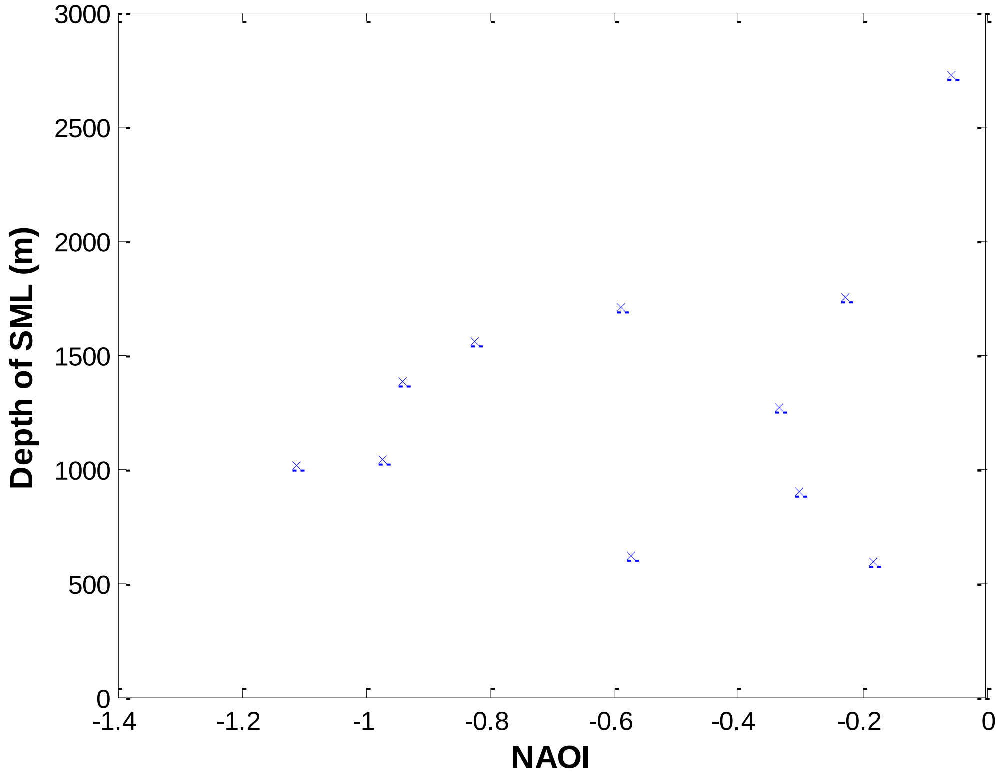


Fig. 3.6. Plot showing the maximum depth of convection for years in the data set with negative NAOI compared to the NAOI.

**Comparison with LSW**

LSW is known to form in the Labrador Sea and spread into various regions in the North Atlantic including the Irminger basin. It would therefore not be valid to take the entire dataset and show that the temperature salinity properties of LSW exist in the Irminger basin. Instead profiles with an SML depth of greater than 600m were plotted as these were profiles identified as having convection occurring (Fig. 3.7). The core properties of LSW are highly variable (LabSea Group 1998). One of the most widely used definitions of LSW is a temperature between 3$^{o}$C and 4$^{o}$C and a salinity less than 34.93 (Talley and McCartney 1982; Wright and Worthington 1970). Results within this range are depicted in the grey box in Fig. 3.5.

In order to identify that LSW exists across the region, the data for area one (black), two (green), and three (red) were plotted in separate colours along with the remaining data from the dataset (blue). This would suggest that LSW exists across the region, while there is also denser more saline water in the region.

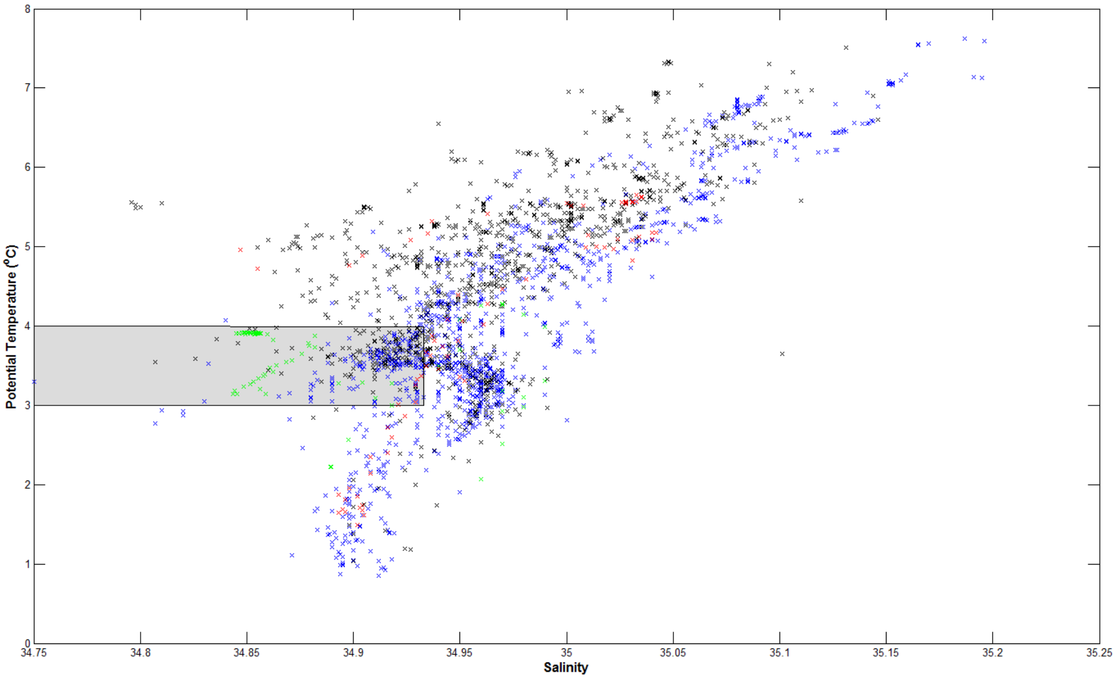


Fig 3.7. Temperature salinity plot of data with SML depth greater than 600m. Data for area one (black), area two (green), area three (red), rest of region (blue). Grey box shows data that can be considered LSW.

## Discussion

It would appear that LSW formation occurs across the entire region with some more saline denser water also being formed with similar properties to LSW. It has also been shown that deep SML depths greater than 600m occur in periods with a low NAOI. There is a weak correlation between the NAOI and the depth of the SML with a moderate correlation between the mean annual depth of the SML and the NAOI. There appears to be a limited dependence between convection in the region and the NAOI, with 31% of the mean annual variance in the SML depth explained by the NAOI. This is similar to the dependence of the GTJ on the NAOI which is 32% (Bakalian et al. 2007). It would appear that the GTJ is the limiting factor for convection in the Irminger basin (Pickart et al. 2003b; Bakalina et al 2007; Våge et al. 2008). This would suggest that the NAOI is affecting the GTJ which in turn affects deep convection events in the Irminger basin. Further studies of the region may consider a more in-depth analysis of the dependence between the NAOI and the GTJ, and the dependence of LSW formation on the GTJ. Unfortunately this study is unable to investigate the effect of the GTJ, as data for this event does not exist in a historical dataset that could be compared with the historical oceanographic data in this study. However, any such study would require either significantly more data than currently publicly available or possible computer modelling to provide any robust conclusions.

The data used in this study are primarily from bottle data. Temperature measurements are derived from mercury thermometers, and salinity from titrations or salinometers. This could possibly have more errors associated with it in comparison to CTD data due to increased chance of human error, and inaccuracies in some earlier methods (Gourstski and Jancke 2001). A study into the errors and variability of historical and modern data by Gourstski and Jancke (2001) demonstrated that while there were many possible errors in the data collection method in historical oceanographic datasets, it was not possible to quantify these without having the information on the collection methods at the time of collection. It was also noted that the same can be true of modern CTD data, although it is less likely. Data in the ICES database has been collected by research cruises for the purpose of science and is validated and checked stringently in accordance with international consensus (ICES 2006). While it is accepted that there may be errors in the data set such error would not significantly impact this study.

Fig 4.1 shows a profile from 1935 that would have been collected with the use of Nansen bottles (Gourstski and Jancke 2001). The profile has an SML depth of 2700m when the SML depth is identified as being 0.1 greater than the surface. However, the profile has variability at the surface and spikes in the PV at 200m and 300m, which may suggest that deep convection is not taking place to this depth. However, the minor fluctuations in the potential density could be accounted for by considering the errors in the collection method, especially the minor fluctuations that would suggest there is denser water above less dense water. Hence such a profile would be considered to be showing a deep convection event.

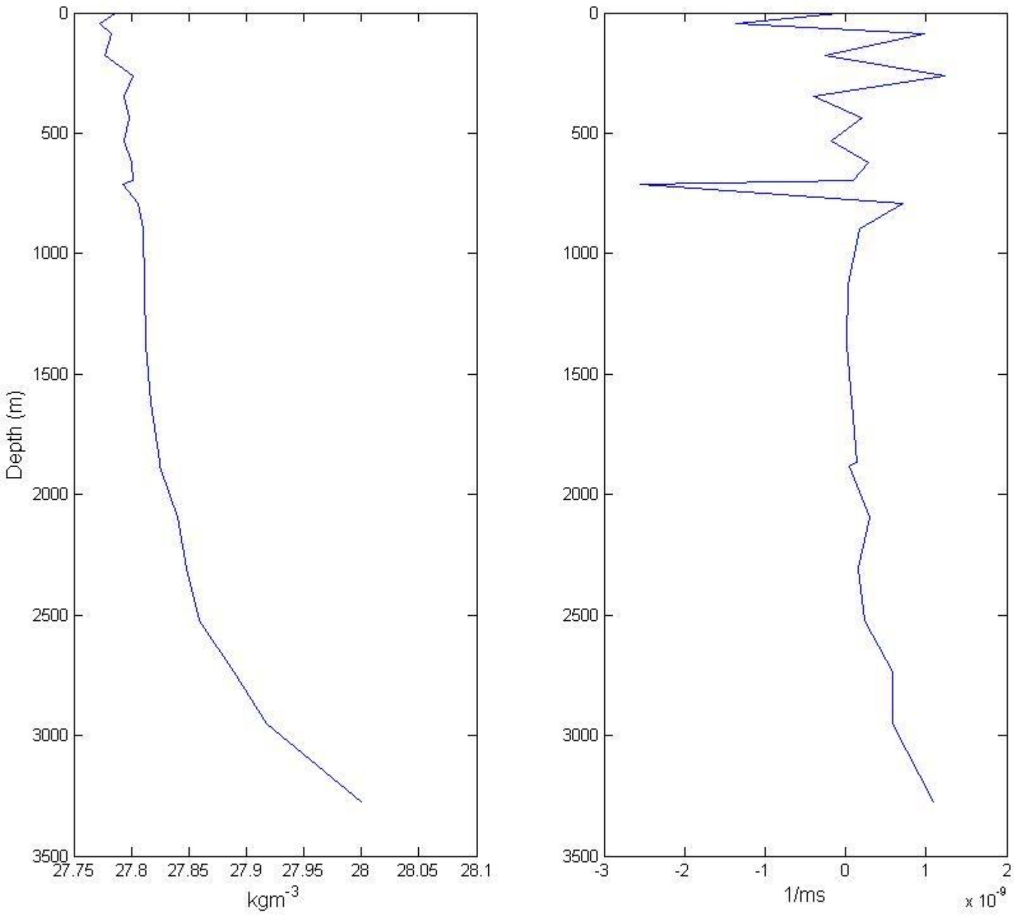


Fig 4.1. Profile indentified as a deep convection event. Potential density (right), PV (left), with evidence of errors taken in March 1935.

The variability in the vertical resolution of the data, however, will produce considerable error in some of the profiles' SML depth. Profiles where measurements were only taken, for example, every 250m, indicate that when the SML depth is calculated, the first point more than 0.1 greater than the surface potential density is then used with the previous point in the profile to linearly interpolate the depth of the SML. However, realistically, a halocline or thermocline could exist anywhere between these two points, and as such there could be error in the SML depth. Dispensing with data of a low vertical resolution was unrealistic, as too much data would have had to be removed from the dataset.

The SML as an identifier of the depth of convection was used as it was relatively simple to derive this from the dataset. This is the mixed layer and shows the depth to which mixing has taken place, not the depth in the profile to which mixing is currently taking place. This was due to the probability of capturing a deep convection event, since convective plumes are normally only a few kilometres across (DiBattista and Majda 2002). However, the region being analysed is in the order of thousands of kilometres across. Convection will have taken place to, or close to, the depth of the SML (Brainerd and Gregg 1995), and hence it is sufficient for us to identify the depth of convection in the region. However, a visual inspection of a number of profiles showed that the SML was significantly shallower than that calculated by using a 0.1 difference from the surface density. Fig. 5.2, is an example of such a profile. While the SML calculated is 1600m, the high PV and sudden change in potential density at 500m indicates that the SML is actually 500m. This would indicate that it may have been more appropriate to use the lower end of the potential density definition of the SML of 0.05 (Brainerd and Gregg 1995). However, the project has demonstrated that deep convection is taking place in the Irminger basin. Further, it has demonstrated that there is a deepening of the mean SML in a positive phase of the NAOI.

The greatest restriction on this study and other studies in the region is the lack of available data in terms of both spatial and temporal resolution. This is especially restrictive with studies such as this one that look at deep convection. As convection events require specific conditions to take place and deep convective plumes are relatively small in comparison to the region being studied (LabSea Group 1998; Våge et al. 2008).

To better understand the region, a long term data collection programme should be implemented so that future studies will be able to have a larger data set that has a high resolution in terms of both spatial, temporal, and vertical profiling. This would allow for better modelling of the effect of atmospheric changes on the input of water into global circulation from this region, and on long term climate change impacts.

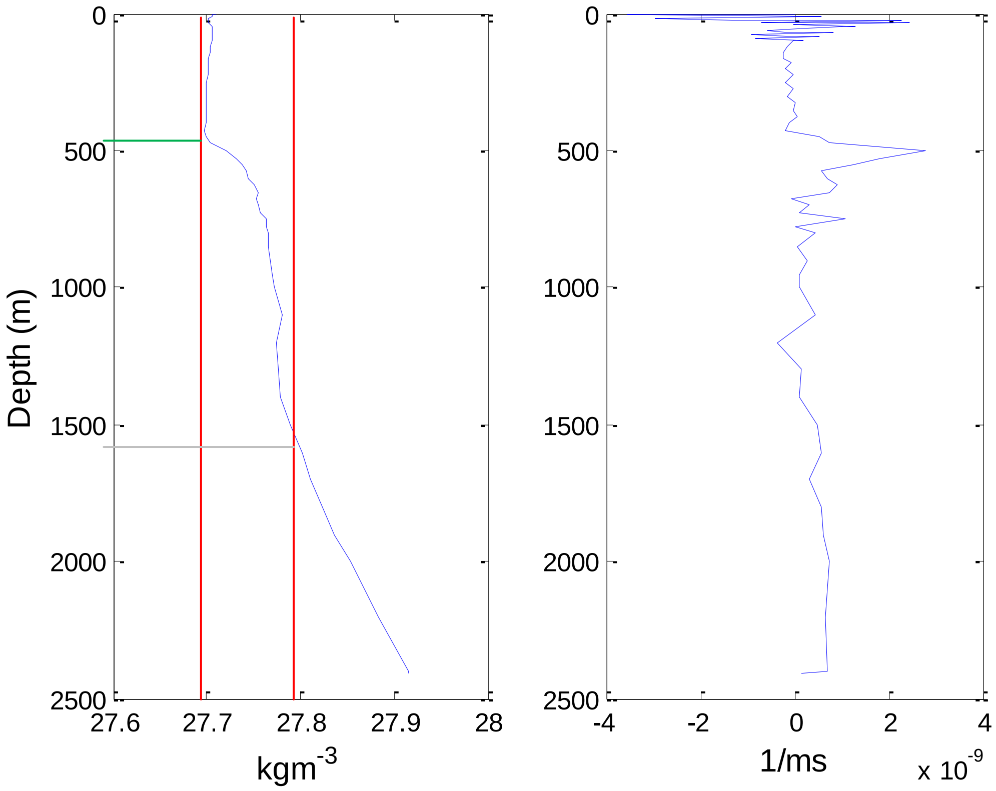


Fig 4.2. Profile from March 1978 with an incorrectly calculated SML depth. Red lines show surface potential density and the point 0.1 greater than this. Grey line shows calculated SML green line actual SML. PV (Right) with high PV spike at 500m where actual SML depth is.

## Conclusion

An analysis of historical temperature and salinity data from the Irminger basin, and comparison with the NAOI for winter periods has shown that there is a limited minor dependence on the NAO for deep convection. Convection was considered to be where the SML depth was greater than 600m. This study has shown that:-

- LSW formation takes place in the Irminger basin.
- There is a weak linear correlation between the winter SML depth and the winter NAOI, with a moderate correlation between the annual mean depth of the winter SML and the winter NAOI.
- 31% of the variance in the annual mean winter SML depth can be accounted for by variations in the NAOI. This suggests only a minor dependence on the NAO for convection in the Irminger basin.
- Convection events do in fact take place in low phases of the NAOI as well as in high phases.

## Acknowledgements
This work was undertaken with the guidance and advice of Dr. P. Hosegood from the University of Plymouth and we are indebted to him or this. We would also like to thank Mr. E. Davies and Mr. E Steele for their advice and guidance with the use of MatLab.

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