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State of the eastern North Atlantic subpolar gyre: The Extended Ellett Line Programme Annual Report No. 1

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ABSTRACT

The Extended Ellett Line is a hydrographic section between Iceland and Scotland that is occupied annually by scientists from the National Oceanography Centre (NOC) and the Scottish Association for Marine Science (SAMS), UK. The measurement programme began as a seasonally-occupied hydrographic section in the Rockall Trough in 1975, building on early surface observations made underway from ocean weather ships. In 1996 the section was extended to Iceland, sampling three basins: the Rockall Trough, the Hatton-Rockall Basin and the Iceland Basin. This report presents a summary of data from the Extended Ellett Line programme. The data are analysed to calculate time series of temperature and salinity of the upper ocean and Labrador Sea Water in the eastern subpolar gyre. The most recent Extended Ellett Line cruise (August 2012) is shown as temperature, salinity and density sections.

KEYWORDS:

ISSUING ORGANISATION **National Oceanography Centre**
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1. Introduction

The Extended Ellett Line is a hydrographic section between Iceland and Scotland that is occupied annually by scientists from the National Oceanography Centre (NOC) and the Scottish Association for Marine Science (SAMS), UK. The measurement programme began as a seasonally-occupied hydrographic section in the Rockall Trough in 1975, building on early surface observations made underway from ocean weather ships. In 1996 the section was extended to Iceland, sampling three basins: the Rockall Trough, the Hatton-Rockall Basin and the Iceland Basin (Figure 1). These three basins form the main routes though which warm saline Atlantic water flows northwards into the Nordic Seas and Arctic Ocean. The section crosses the eastern North Atlantic subpolar gyre; as well as the net northward flow there is a large recirculation of the upper layers as part of the wind-driven gyre. During its passage through the region, the warm saline water is subjected to significant modification by exchange of heat and freshwater with the atmosphere. The two deep basins (Rockall Trough and Iceland Basin) contain southward flowing dense northern overflow waters, and Labrador Sea Water in the intermediate layers.

This report presents a summary of temperature and salinity data from the Extended Ellett Line programme. The historical data set is analysed to calculate time series of temperature and salinity of the upper ocean and Labrador Sea Water in the eastern subpolar gyre. The most recent Extended Ellett Line cruise (August 2012) is shown as temperature, salinity and density sections.

From autumn 2012 the Extended Ellett Line programme is jointly led by Penny Holliday at NOC and Stuart Cunningham at SAMS. Thanks to Jane Read (NOC) and Toby Sherwin (SAMS) for their work maintaining the section over recent years.

2. Current Research

Research highlights in 2012 from the Extended Ellett Line include an analysis of how changes in the subpolar gyre on a basin scale impact the water mass properties in the Rockall Trough (Sherwin et al, 2012), a review of the variability of the subpolar North Atlantic over the past 60 years (Hughes et al, 2012), and a study of multidecadal variability and trends in the temperature of the northwest European continental shelf (Holt et al, 2012).

3. The August 2012 Iceland-Scotland hydrographic section

The 2012 Iceland-Scotland section was carried out on RRS *Discovery* cruise D379 in August (RRS *Discovery* was retired after 50-years of service a few months later). Colin Griffiths (SAMS) was principle scientist and details of the full suite of data collected can be found at *www.bodc.ac.uk/data/information_and_inventories/cruise_inventory/report/11412/*. The cruise enjoyed excellent weather throughout and the section was completed without interruption. Figure 2 shows the potential temperature, salinity and potential density for the full section.

4. Temperature and salinity time series for the upper ocean

The Extended Ellett Line upper ocean data are presented as time series of potential temperature and salinity (Table 1 and Figure 3). The Rockall Trough time series is well-established (eg Holliday et al, 2000, Dye et al, 2012); the "upper ocean" is calculated as an average of data from 30-800 dbar between Rockall and the outer Scottish continental shelf (black dots in Figure 1). The 800 dbar limit is selected because it marks the top of the permanent thermocline, or the base of the dominant water mass, the Eastern North Atlantic Water. By ignoring the very surface layer we hope to reduce temporal aliasing. However it should be noted that the upper ocean is subject to a seasonal cycle in properties (deep winter mixing to 600-800m depth, and spring/summer surface warming), and some

aliasing of the seasonal cycle is inevitable. The Rockall Trough part of the Extended Ellett Line began in 1975 (black dots in Figure 1); present day conditions are warm and saline in the upper ocean compared to the long-term mean (black lines in Figure 3). Between 1975 and 1995 the mean temperature of the upper ocean in the Rockall Trough was 9.2±0.3 °C. A warming trend from 1995 to 2005 reached a peak of 10.1°C before cooling to 9.5°C in 2011. Upper ocean salinity in the Rockall Trough was at a minimum in the late 1970s (35.27) during the Great Salinity Anomaly, rose to a maximum around 1983 (35.37), decreased in the 1990s, then rose again to a maximum of 35.41 in 2010. The salinity and temperature of the Rockall Trough do not always co-vary.

The upper ocean in the Hatton-Rockall Bank (red dots in Figure 1) is defined in the same way (30-800 dbar) because the permanent thermocline is found at similar depths (Figure 2). The shorter time series shows the same pattern of variability as the Rockall Trough though the amplitude of the interannual variability is higher (red lines in Figure 3). In the Iceland Basin (blue dots in Figure 1), the upper ocean is defined as 30-600 dbar since the permanent thermocline is shallower here (Figure 2). Different water masses are present in the Iceland Basin, and the region is an area of active modification of mode waters. The time series of temperature and salinity show similar patterns of variability as the other two basins, but the multi-year trend is less clear (blue lines in Figure 3). In the Hatton-Rockall Basin and Iceland Basin the waters have warmed rapidly since 2010.

The Hatton-Rockall Basin and Iceland Basin time series are shown here as a first look at the evolution of the properties as observed by the Extended Ellett Line; these data have not been presented before. It may be that some of the variability in the time series is an artefact of the method to average the data (note, for example, that the upper ocean isopycnals are significantly sloping in the Iceland Basin). However the data as presented show that a similar pattern of change to that in the Rockall Trough is observed in both the Hatton-Rockall Basin and the Iceland Basin.

3. Temperature and salinity time series for intermediate waters

The intermediate layers of the two deep basins, the Rockall Trough and Iceland Basin, are filled with Labrador Sea Water (LSW). The core of the LSW can be identified by a layer of well mixed, low-stratification water; the signature of its origins as a surface water mass subjected to very deep convective mixing in winter. Formally this can be detected as a minimum in potential vorticity calculated at the two deepest stations, Station M in the Rockall Trough (57.30°N 10.38°W) and at station IB12 in Iceland Basin (60.0°N 20.0°W). The evolution of the LSW properties in the two basins is rather different (Table 2 and Figure 4); in the Rockall Trough, temperature and salinity has been rather stable over the past 15 years, and both remain low compared to the early part of the time series. In the Iceland Basin, there is a slight trend of increasing temperature and salinity of LSW since the late 1990s.

Table 1. Time series of temperature and salinity of the upper ocean in the Rockall Trough (30-800 dbar), Rockall-Hatton Basin (30-800 dbar) and Iceland Basin (30-600 dbar).

Date	Rockall Trough		Hatton-Rockall Basin		Iceland Basin	
	Potential Temp °C	Salinity	Potential Temp °C	Salinity	Potential Temp °C	Salinity
1975.34	8.84	35.304				
1975.51	9.14	35.284				
1975.86	9.50	35.303				
1976.25	8.96	35.271				
1976.39	9.02	35.269				
1977.29	8.83	35.281				
1977.35	8.78	35.274				
1977.64	9.22	35.280				
1978.30	8.84	35.297				
1978.43	8.89	35.301				
1978.61	9.14	35.288				
1978.69	9.24	35.322				
1978.85	9.54	35.307				
1979.39	8.88	35.309				
1979.71	9.54	35.344				
1979.83	9.33	35.340				
1980.34	8.98	35.338				
1981.08	9.14	35.364				
1981.30	9.14	35.347				
1981.53	9.50	35.331				
1981.79	9.56	35.334				
1983.40	9.22	35.363				
1983.63	9.35	35.373				
1984.90	9.52	35.357				
1985.07	9.25	35.368				
1985.36	9.06	35.353				
1985.64	9.46	35.352				
1987.03	9.17	35.329				
1987.33	8.87	35.341				
1988.47	9.30	35.332				
1989.07	9.32	35.322				
1989.35	8.81	35.297				
1989.60	9.18	35.321				
1989.90	9.52	35.339				
1990.49	9.08	35.320				
1990.67	9.29	35.308				
1992.74	9.26	35.314				
1993.37	9.09	35.313				
1993.69	9.38	35.305				
1994.21	8.85	35.320				
1994.35	8.60	35.298				
1994.63	9.10	35.303				
1994.90	9.42	35.321				
1995.58	9.35	35.338				
1996.75	9.12	35.277	8.46	35.194	8.75	35.210
1997.70	9.72	35.358	9.01	35.272	8.76	35.218
1998.40	9.38	35.369	9.07	35.320	8.66	35.263

1999.70	9.65	35.370	9.07	35.288	8.93	35.226
2000.11	9.56	35.372				
2000.38	9.28	35.353				
2001.35	9.26	35.350	8.62	35.263	8.11	35.207
2003.30	9.60	35.401				
2003.56	9.91	35.407				
2004.54	9.88	35.402	9.41	35.332	8.96	35.265
2005.80	9.93	35.391			8.67	35.237
2006.82	10.13	35.390	9.70	35.332	8.97	35.227
2007.66	10.02	35.396	9.57	35.333	8.92	35.243
2008.39	9.90	35.409				
2009.46	9.77	35.411	9.16	35.344	8.44	35.261
2010.38	9.63	35.412	9.02	35.313	8.28	35.230
2011.42	9.56	35.401	9.05	35.311	8.49	35.246
2012.59	9.68	35.374	9.37	35.290	9.03	35.230

Table 2. Time series of temperature and salinity of the Labrador Sea Water in the Rockall Trough (Station M, 57.30°N 10.38°W) and Iceland Basin (Station IB12 60.0°N 20.0°W).

Date	Rockall Trough		Iceland Basin	
	Potential Temp °C	Salinity	Potential Temp °C	Salinity
1975.34	8.84	35.304		
1975.51	9.14	35.284		
1975.34	3.76	34.983		
1975.51	3.63	34.967		
1975.86	3.71	34.986		
1976.25	3.96	34.981		
1976.39	3.55	34.951		
1977.29	3.54	34.967		
1977.35	3.59	34.965		
1977.64	3.71	34.953		
1978.30	3.48	34.972		
1978.61	3.61	34.962		
1978.69	3.99	34.999		
1978.85	3.80	34.971		
1979.39	3.86	35.001		
1979.71	3.62	34.981		
1980.34	3.47	34.991		
1981.08	3.89	34.974		
1981.30	3.44	34.979		
1981.79	3.37	34.978		
1983.63	3.45	34.972		
1985.36	3.67	34.944		
1985.64	3.81	34.946		
1987.03	3.46	34.952		
1987.33	3.48	34.952		
1988.47	3.67	34.961		
1989.07	3.93	34.968		
1989.35	3.70	34.971		
1989.60	4.02	34.974		
1989.90	3.64	34.955		
1990.49	3.61	34.947		
1990.67	3.47	34.917		
1992.74	3.24	34.942		
1993.37	3.42	34.941		
1993.69	3.67	34.925		
1994.21	3.51	34.940		
1994.35	3.38	34.943		
1994.63	3.73	34.931		
1994.90	3.81	34.937		
1995.58	3.61	34.931		
1996.75	3.49	34.932		
1997.70	3.46	34.927	3.45	34.888
1998.40	3.62	34.936	3.22	34.891
1999.70	3.39	34.931	3.42	34.898
2000.11	3.31	34.926		
2000.38	3.15	34.931		
2001.35	3.27	34.924	3.11	34.890

2003.30	3.38	34.924		
2003.56	3.33	34.929		
2004.54	3.37	34.912	3.46	34.894
2005.80	3.23	34.940		
2006.82	3.30	34.923	3.54	34.908
2007.66	3.21	34.927		
2008.39	3.88	34.942		
2009.46	3.47	34.931	3.55	34.912
2010.38	3.53	34.930	3.56	34.910
2011.42	3.53	34.929	3.80	34.918
2012.59	3.27	34.924	3.70	34.914

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Figures

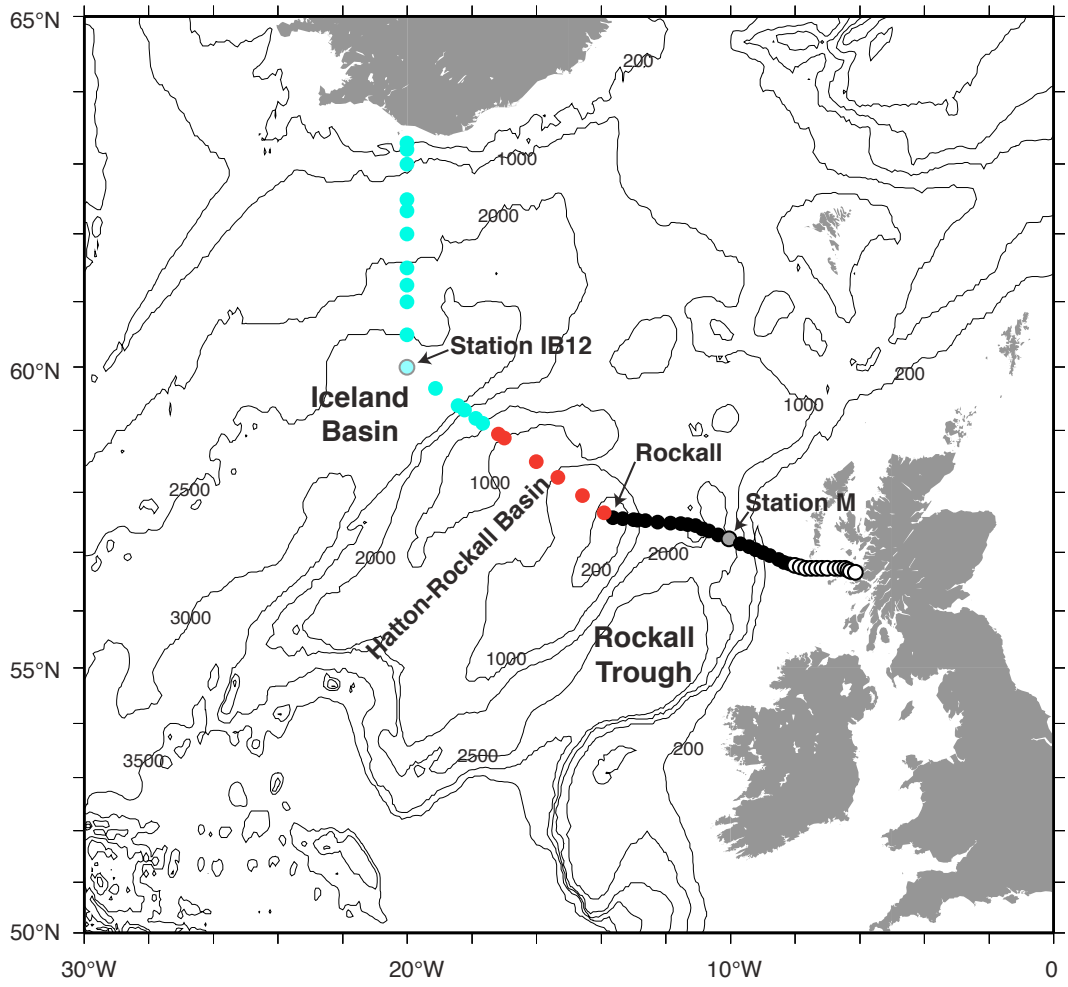

Figure 1. Location of the Extended Ellett Line, a hydrographic section between Iceland and Scotland. Each dot represents the position of a standard station, and the different colours indicate the stations used in calculating the time series shown here. Open circles are continental shelf stations, filled black dots are Rockall Trough stations, red dots are Hatton-Rockall Basin stations, blue dots are Iceland Basin Stations. Stations M and IB12 are labelled; these are the deep stations where Labrador Sea Water properties are examined. Bathymetry contours are labelled in metres (200, 1000, 2500, 3000, 3500m).

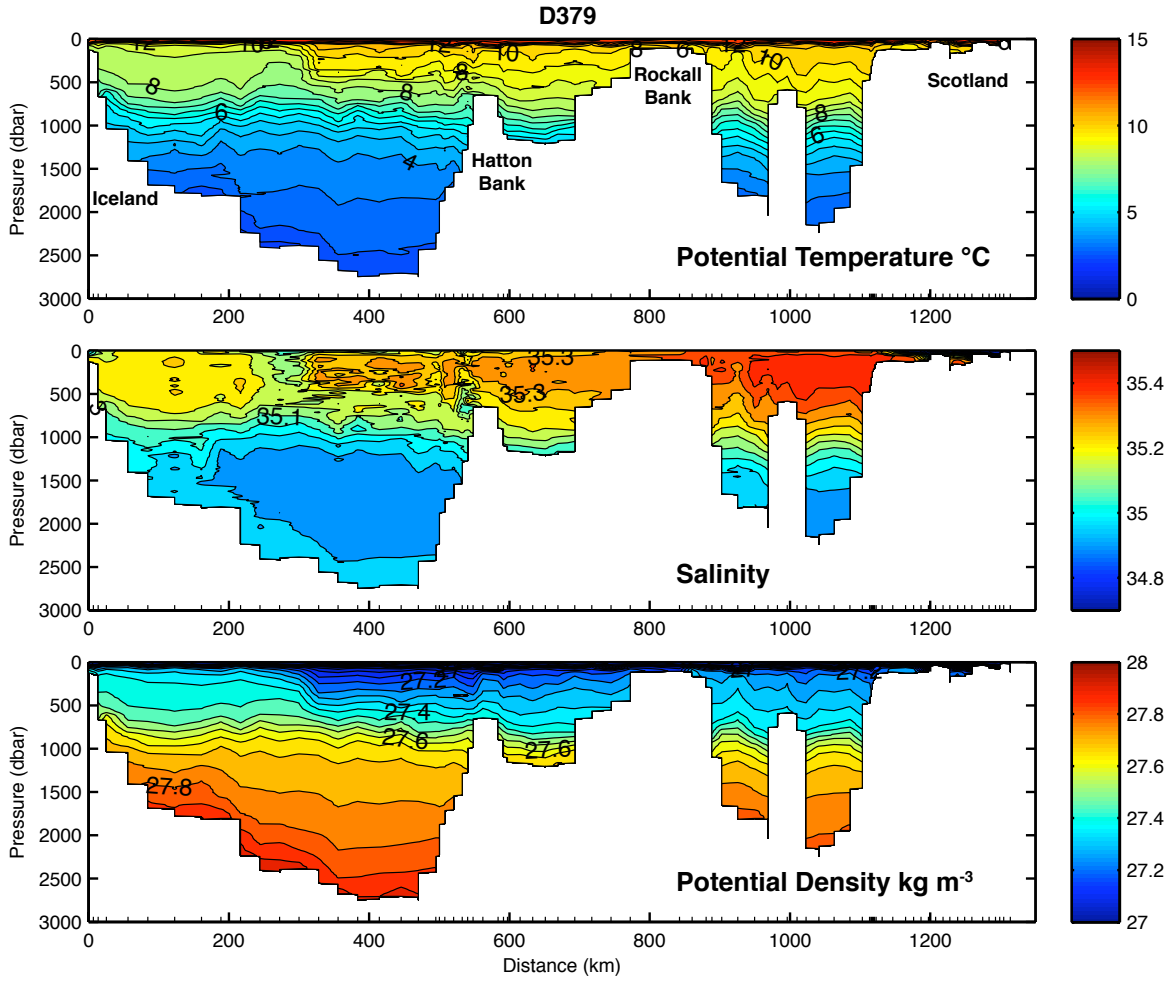

Figure 2. Temperature, salinity and density of the eastern North Atlantic subpolar gyre; the Extended Ellett Line in August 2012. The section runs north to south, horizontal axis given in kilometres from the first station off the Iceland coast, last station is on the Scottish continental shelf.

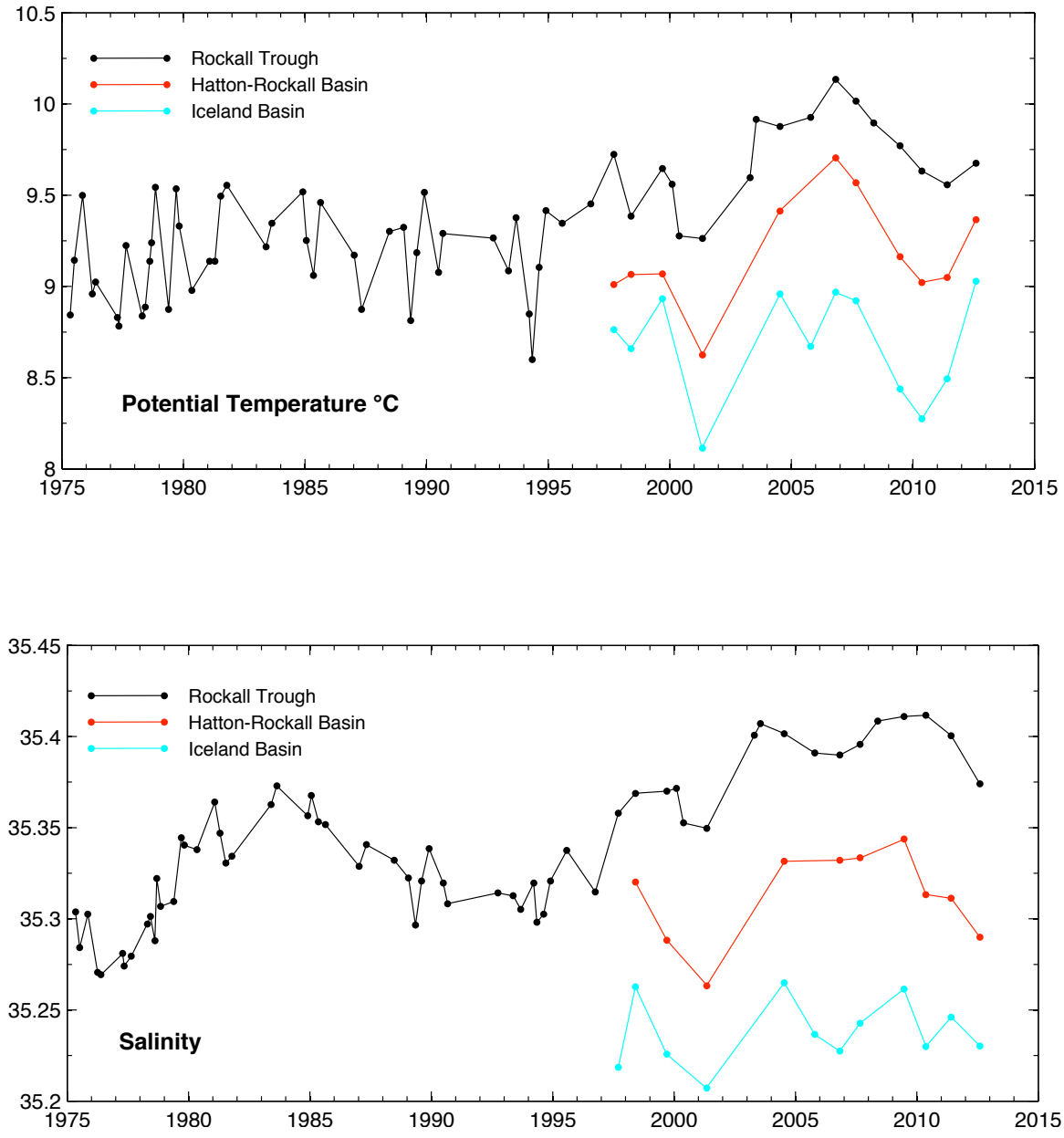

Figure 3. Temperature (top panel) and salinity of the upper ocean in the Rockall Trough (black), Hatton-Rockall Basin (red), and Iceland Basin (blue). Upper ocean defined as 30-800m in Rockall Trough and Hatton-Rockall Basin, and as 30-600m in Iceland Basin. Continental shelf stations are not shown (see Figure 1).

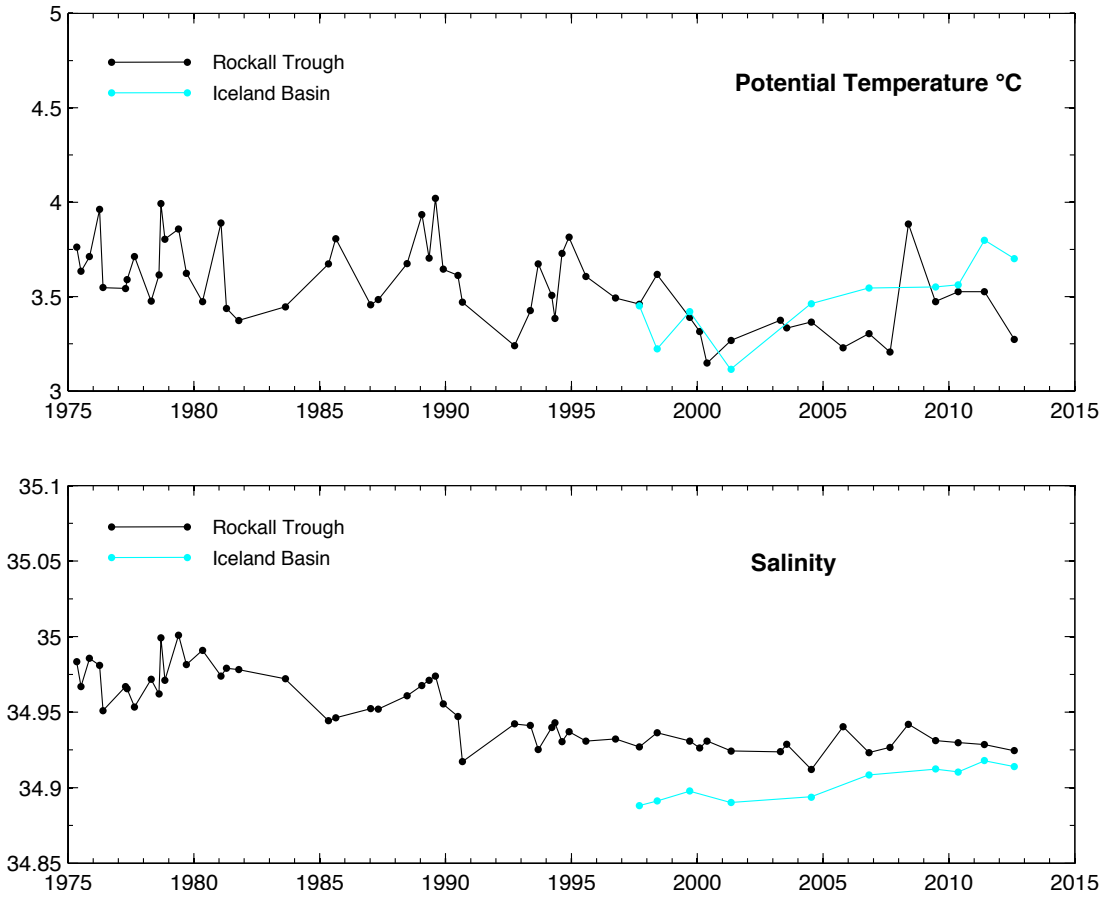

Figure 4. Temperature (top panel) and salinity of the Labrador Sea Water in the Rockall Trough (black) and Iceland Basin (blue). Properties extracted from deep (1800-2000 dbar) potential vorticity minimum at station M in Rockall Trough (57.30°N 10.38°W) and at station IB12 in Iceland Basin (60.0°N 20.0°W).