A GRIDDED DATA SET OF TEMPERATURE AND SALINITY FOR THE NORTWEST ATLANTIC OCEAN

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TABLE OF CONTENTS

ABSTRACT

Tang, C.L. and C.K. Wang. 1996. A gridded data set of temperature and salinity for the northwest Atlantic Ocean. Can. Data Rep. Hydrogr. Ocean Sci. 148: iv + 45 pp.

Temperature and salinity data from the AFAP data base are objectively analyzed to produce a data set at 33 depths on a $1/6^0 \times 1/6^0$ grid for each of the four seasons. The areas of coverage include the Labrador Sea, the N.E. Newfoundland Shelf, the Grand Banks, the Newfoundland Basin, the Gulf of St. Lawrence, the Scotia Shelf, the Gulf of Maine and the Gulf Stream. The method of analysis is described in detail. Horizontal contour plots at selected depths are presented.

RÉSUMÉ

Tang, C.L. and C.K. Wang. 1996. A gridded data set of temperature and salinity for the northwest Atlantic Ocean. Can. Data Rep. Hydrogr. Ocean Sci. 148: iv + 45 pp.

Les données de température et de salinité de la base de données AFAP sont analysées de façon objective pour produire un ensemble de données à des profondeurs de 33 sur une grille de $1/6^0 \times 1/6^0$ pour chacune des quatre saisons. Les zones couvertes comprennent la mer du Labrador, le plateau continental du N.-E. de T.-N, les Grands Bancs, le Bassin de Terre-Neuve, le Golfe du Saint-Laurent, le plateau continental de Scotian, le Golfe du Maine et le Gulf Stream. L'étude décrit en détail la méthode d'analyse et présente les tracés de contour horizontaux.

1. Introduction

There has been a growing interest among Canadian oceanographers in recent years in regional-scale modeling of the northwest Atlantic Ocean and the continental shelf. To satisfy the need of the modeling community for a high resolution temperature and salinity data set capable of resolving frontal structure at the shelf edge, a project was undertaken to analyze the hydrography data archived at the Bedford Institute of Oceanography. This data report describes the method of analysis and presents the analyzed seasonal temperature and salinity fields in contour plots.

In the shelf areas off Newfoundland and Nova Scotia and in the Gulf of St. Lawrence, abundant data exist for all seasons. From the data, various statistical parameters such as mean, error, spatial and temporal scales can be extracted using optimal interpolation or other advanced techniques (O'Neal and Bodner, 1995). Modelers can choose the most suitable method of analysis to obtain the hydrographic fields required by a particular modeling project. By contrast, in areas with sparse data such as northern Labrador Sea, we face a problem of an entirely different nature. There are not enough data even for the most basic parameters required for modeling. To overcome the problem, we must rely on assumptions based on empirical relationships and oceanographic principles rather than rigorous statistical theories in making optimal estimates of the oceanographic parameters.

2. Data source

All the data used in this report are from the AFAP (Atlantic Fisheries Adjustment Program) historical temperature and salinity data base. This data base covers a large area from northern Baffin Bay to Cape Hatteras and from the coast to 42^0 W, and includes data from a variety of sources dating back to 1910. A detailed description of the data base is given in Petrie et al. (1996).

3. Method of analysis

The methods developed by Levitus (1982) for the world ocean and Reynaud et al. (1995) for the northwest Atlantic are the basis of our analysis. The main features of the analysis include an iterative difference-correction procedure and a depth dependent domain of averaging. This method is particularly suitable for areas with sparse data such as northern and eastern Labrador Sea. For areas with dense data, different methods of analysis are not likely to results in significant differences in the analyzed mean fields.

The area covered in the analysis is bounded by the 40^0 N, 70^0 N, 42^0W and 70^0 W latitude/longitude lines as shown in Fig.1. The major steps taken in the analysis are described in the following sub-sections.

(a) Data preparation and range check

Duplicate stations in the AFAP data base, and stations with data values outside the ranges 26 ~ 38 for salinity and $-2^0C \sim 35^0C$ for temperature were removed. This process eliminates stations with large measurement errors and stations located in rivers and upper estuaries.

(b) Sorting of raw data into bins

Following deYoung et al. (1994), the data were separated into four seasons according to:

Winter:	January, February, March
Spring:	April, May, June
Summer:	July, August, September
Autumn:	October, November, December.

This separation is different from that of the meteorological convention and in the Levitus data set in which each season starts one month earlier and one month later respectively. The breakdown used here is more reasonable for water properties in high latitudes.

The seasonal data were sorted into bins of $1/12^0$ x $1/12^0$ grid cells and 33 depth segments. Table 1 gives the upper and lower limits of the depth segments. Data in a given cell and depth segment are considered to be located at the center of the cell and at a standard depth (see Table 1) for the horizontal analysis described in sub-section **(d)**. For each bin, the means of the temperature and salinity in given years and seasons were calculated first. The means were then averaged over different years to produce the final means for each bin and season. Such a two-step averaging is necessary in order to remove bias caused by interannual variation if the numbers of data points are unevenly distributed over the years.

To obtain a best estimate of the means in the $1/12^0 \times 1/12^0$ cells, the means and standard deviations were calculated first from the raw data. Data points with extreme values lying outside the range (mean $\pm$ 3 $\times$ standard deviation) were discarded and the means were re-calculated. The procedure was repeated until all data values were within the tolerance limits. The final means were used in the vertical interpolation described below.

(c) Vertical interpolation

Small data gaps in the water column of non-empty cells were filled by averaging the data at the two adjacent standard depths. If both the adjacent depths had no data, the data at the next two adjacent depths were used. If no data were found in these depths, no further interpolation was attempted and the data gap would remain there. Vertical interpolation in this way, unlike data fitting with a prescribed function, has the advantage that even if the data have uneven depth distribution or very small number of depths, the interpolated data values are constrained by the adjacent data values and represent a best estimate.

(d) Analysis on the horizontal planes

An iterative difference-correction method was employed to smooth and interpolate the data horizontally. The vertically interpolated data were averaged horizontally with a distance and topography dependent weight on a $1/6^0 \times 1/6^0$ grid for each standard depth according to the following equation:

$$S = S_{guess} - \frac{\sum_i W_i (S_{guess} - S_i)}{\sum_i W_i} \qquad (1)$$

where S_{guess} is the initial guess, S_i is the data value and W_i is the weight.

Since the horizontal coherent scale of temperature and salinity is in general smaller at the shelf edge than in areas with gentle topography, data at locations having a water depth very different from the water depth of the grid point should not be included in the averaging. This condition is analogous to using anisotropic weights of average, but the computation involved is much simpler. The summation in (1) was applied only to data points satisfying

$$|H - H_i| < \delta h \qquad (2)$$

where H and H_i are the water depth of the grid point and data point respectively. A depth dependent δh was used to take into account the fact that variation of water properties is smaller in the deep ocean than in the coastal ocean:

$$\delta h = 500 + 0.14\, H$$

A Gaussian form was used for W_i:

$$W_i = 0, \qquad r_i > R$$

$$W_i = \exp\left(-\frac{4 r_i^2}{R^2}\right), \qquad r_i \le R$$

where r_i is the horizontal distance between the grid point and the data point, and R is the radius of influence.

The calculation for S was repeated for three iterations with a decreasing radius of influence. In each iteration, the S calculated in the previous iteration was used as the initial guess. In the first iteration, the mean of all data in a given standard depth were used as the initial guess. The radii of influence for the three iterations are 800 km, 500 km and 200 km if the depth is equal or less than 1100 m, and are 1000 m, 600 km, 400 km if the depth is greater than 1100 m.

The data in each iteration must pass a statistical check to ensure extreme data values were not included in the averaging. Data with values outside the range (mean $\pm$ 2 $\times$ standard deviation) were removed. This procedure was repeated till all data points were within the tolerance limits.

(e) Three-dimensional smoothing in areas with sparse data

In areas with sparse data, the horizontal temperature/salinity distributions calculated from step ***(d)*** may have large differences between neighboring depths. This is due to the fact that no spatial coherent was taken into consideration in the horizontal analysis. To incorporate the spatial coherence scales into the mean fields, a three-dimensional smoothing was performed for the following seasons and areas:

Winter: north of 50^0N not including the Gulf of St. Lawrence;
Fall: north of 50^0N and water depths equal to or greater than 2000 m.

The smoothed value at grid point j, $\bar{S}_j$, was computed from

$$\bar{S}_j = S_j - \frac{\sum_i w_i (S_j - S_i)}{\sum_i w_i}$$

where S_i is the horizontally interpolated data value from step ***(d)***. The summation is over data points satisfying (2). The weight, w_i, is given by

$$w_i = \exp\left(-\frac{4r_i^2}{L^2} - \frac{4z_i^2}{D^2}\right), \qquad r_i < R \text{ and } z_i < D$$

$$w_i = 0, \qquad r_i > R \text{ or } z_i > D$$

where r_i and z_i are the horizontal and vertical distances between points i and j respectively, and L and D are the horizontal and vertical coherence scales respectively. The following values were used for L and D:

$L = 100$ km, $\quad z_i \le 1000$ m

$L = 200$ km, $z_i \geq 1100$ m

$D = 100$ m, $z_i \leq 300$ m

$D = 200$ m, $300 \text{ m} < z_i \leq 1300$ m

For depths greater than 1300 m, only horizontal smoothing with L = 200 km was performed since the change of temperature and salinity in the deep water was very small. Applying a large D would distort the depth variation obtained in the horizontal analysis.

(f) Filling holes in the horizontal planes

Holes in the horizontal planes after step (***d***) or (***e***) were filled by averaging the data over a 5 x 5 grid. The number of holes are very small and exist mainly in northern Labrador Sea.

4. Contour plots at selected depths

Contour plots of temperature and salinity at 0 m, 50 m, 100 m, 200 m, 500 m, 1000 m, 2000 m and 3000 m are presented in the pages following fig.1. The binned and vertically interpolated data points on the $1/12^0 \times 1/12^0$ grid are shown as dots on each plot. The purpose is to allow the user to decide whether the analyzed data in a given area are suitable for a particular application. The number of points at selected depths is given in Table 2.

The NCAR plotting package was used to generate the contour plots. The letters "L", "H" and the number beside the symbols that appear in some plots indicate the local minimum (L) and maximum (H), and the value of the parameter at the minimum or maximum.

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Levitus, S., 1982. Climatological atlas of the world ocean. *NOAA Professional Paper, 13*, National Oceanic and Atmospheric Administration, Washington, D.C..

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Table 1. Standard depths

Standard depths (right column) and the depth ranges (first and second columns) for the gridded data set.

DATA DEPTH (m) lower limit	upper limit	STANDARD DEPTH (m)
0	5	0
5	15	10
15	25	20
25	40	30
40	62.5	50
62.5	87.5	75
87.5	112.5	100
112.5	137.5	125
137.5	175	150
175	225	200
225	275	250
275	350	300
350	450	400
450	550	500
550	650	600
650	750	700
750	850	800
850	950	900
950	1050	1000
1050	1150	1100
1150	1250	1200
1250	1350	1300
1350	1450	1400
1450	1625	1500
1625	1875	1750
1875	2250	2000
2250	2750	2500
2750	3250	3000
3250	3750	3500
3750	4250	4000
4250	4750	4500
4750	5250	5000
5250	5750	5500

Table 2. Data density

Numbers of $1/12^0 \times 1/12^0$ ocean grid cells, and binned and vertically interpolated data points at selected depths. The data are divided into three areas as shown in fig.1.

	Area I	Area II	Area II
No of cells	49464	28369	14772
Depth (m)		**Winter**	
0	636	2560	3444
50	634	2354	2727
100	618	2148	2087
500	472	1446	263
1000	373	1061	119
3000	145	51	7
		Spring	
0	1378	7269	4980
50	1291	7145	3838
100	1220	5894	2701
500	763	3476	440
1000	589	2695	267
3000	134	401	86
		Summer	
0	4285	3947	6143
50	4158	3828	4860
100	3893	3151	3352
500	1913	1479	453
1000	1083	1041	255
3000	263	135	55
		Autumn	
0	2230	2640	3743
50	2180	2597	2838
100	2137	2137	2025
500	1016	991	300
1000	454	663	177
3000	66	92	39

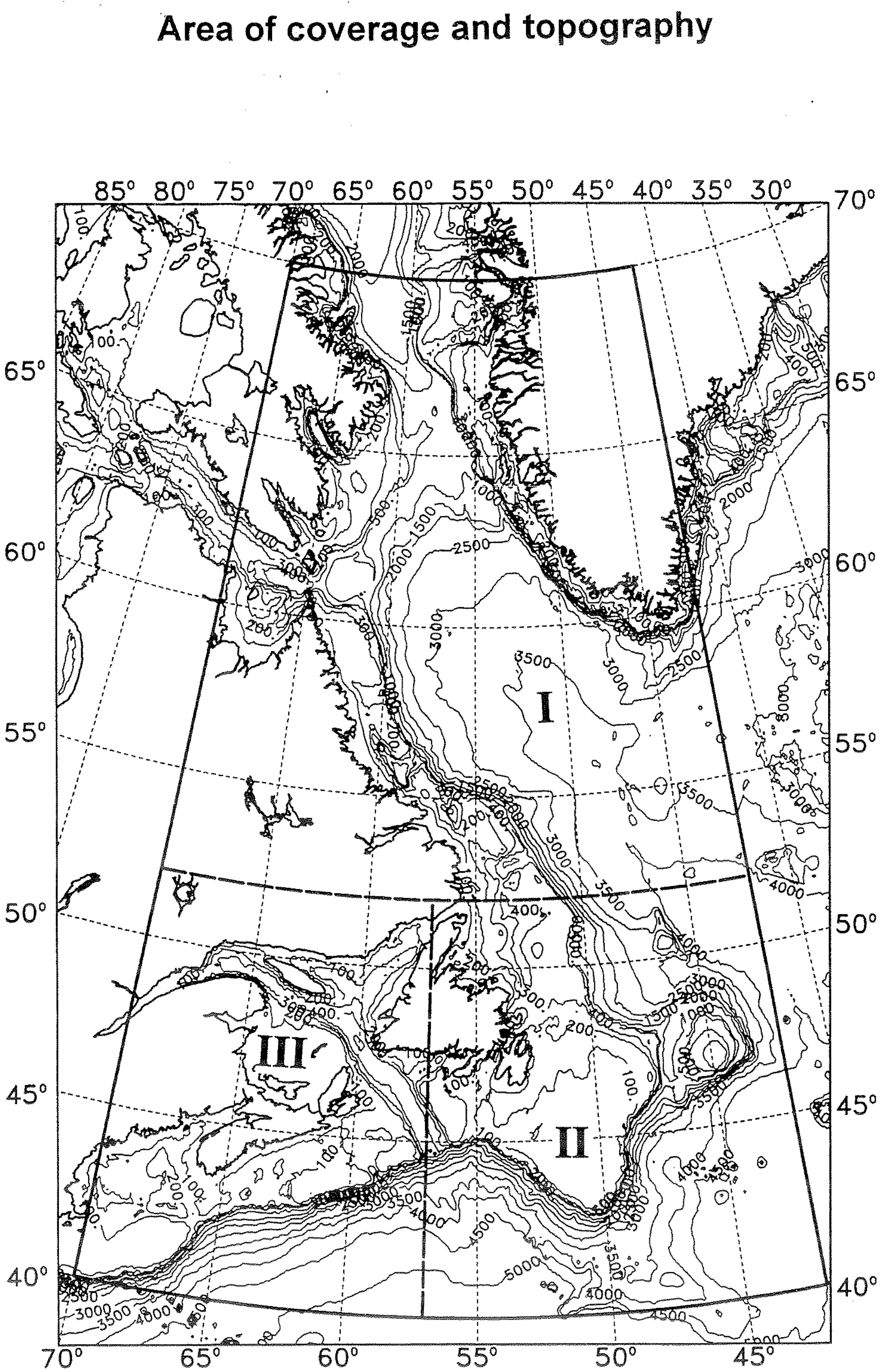
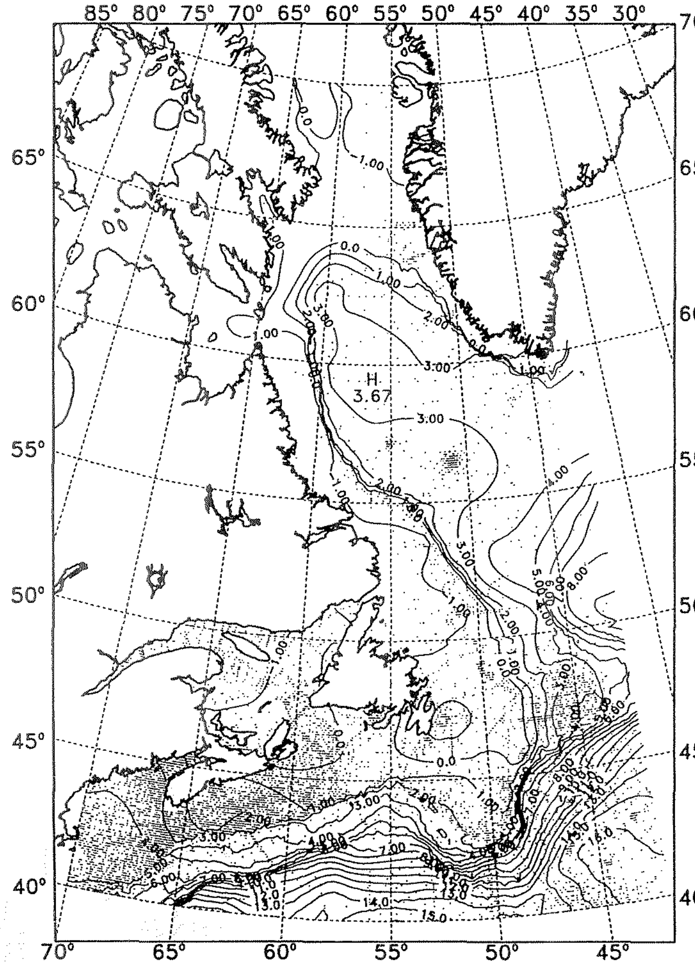


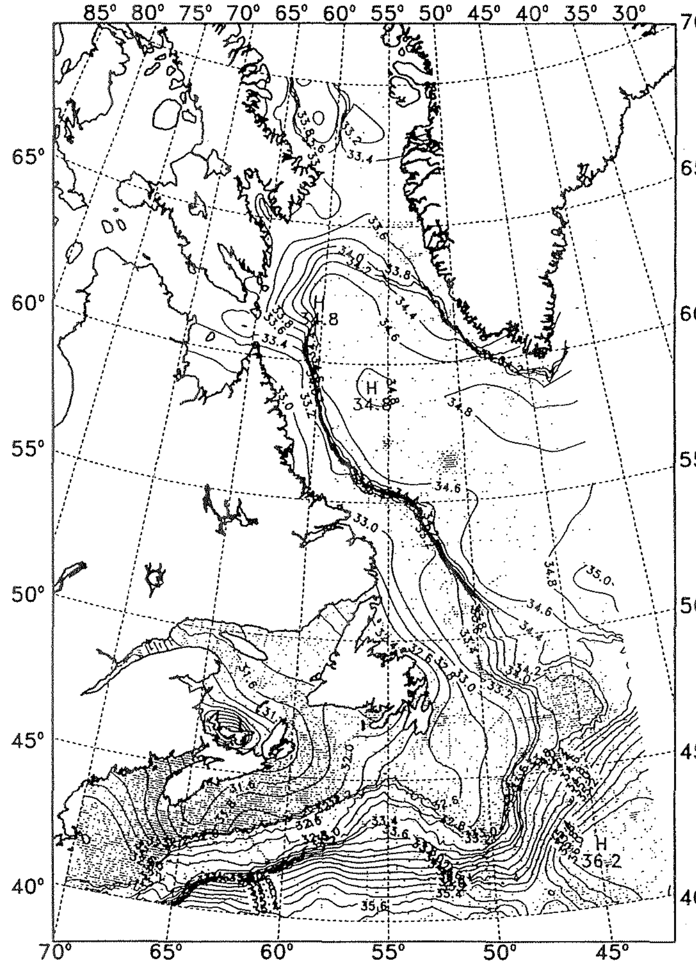
Figure 1. The area covered by objective analysis is indicated by the thick solid lines. The sub-areas denoted by "I", "II" and "III" are used in the statistics in Table 2.

Winter

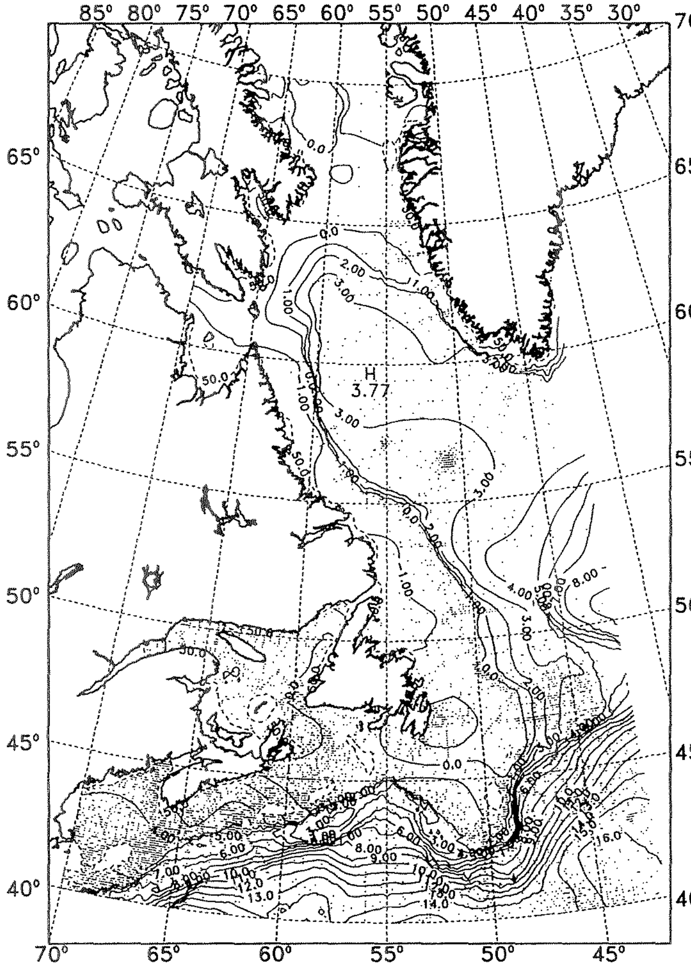
WINTER TEMPERATURE AT 0m



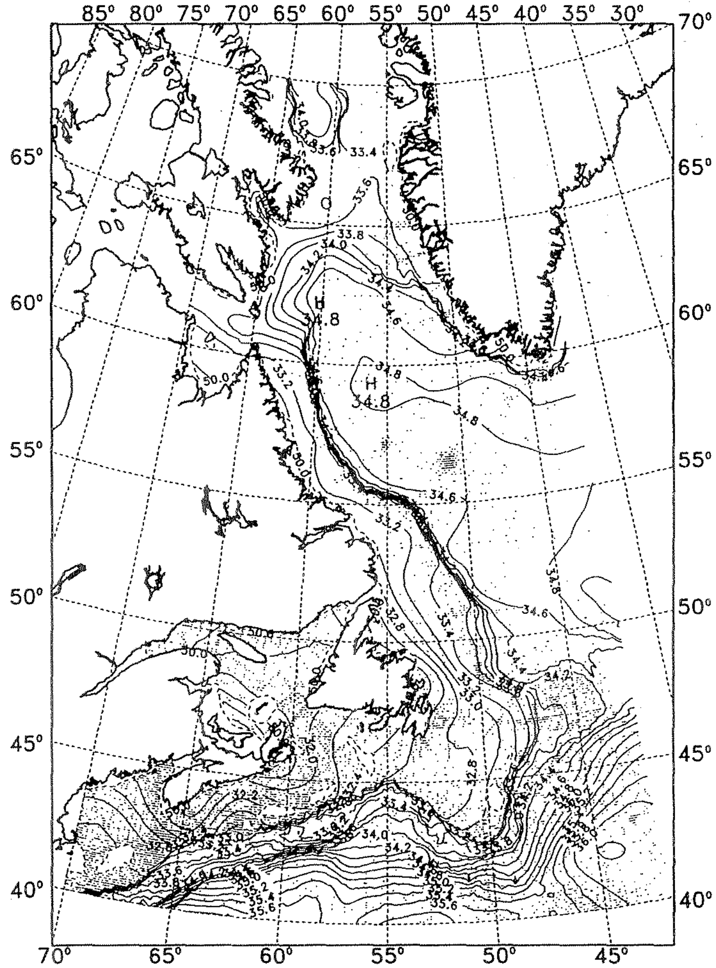
WINTER SALINITY AT 0m



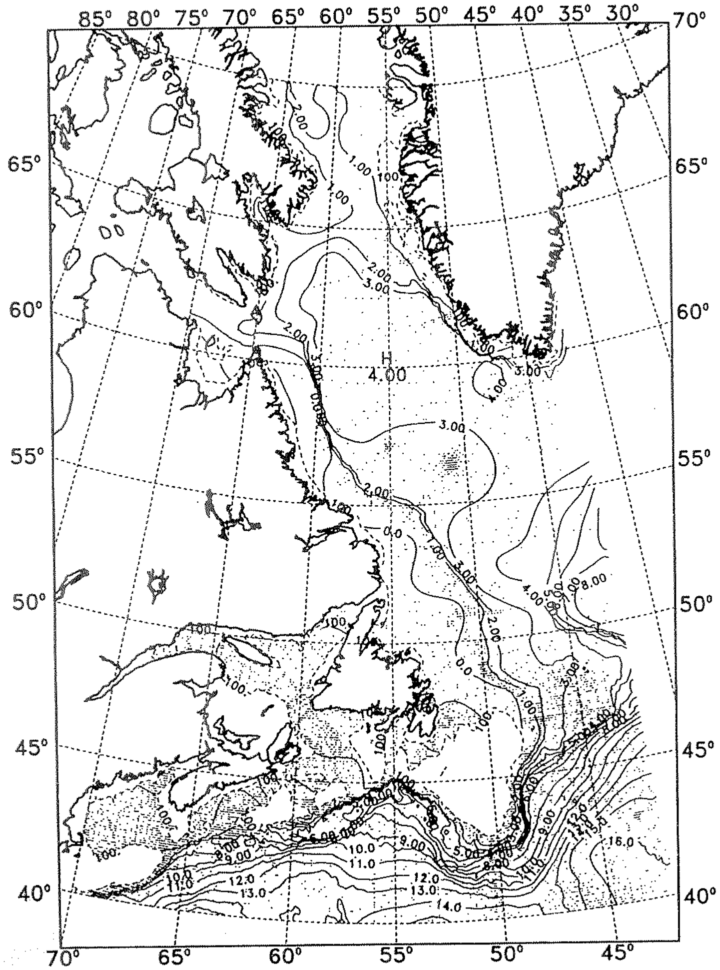
WINTER TEMPERATURE AT 50m



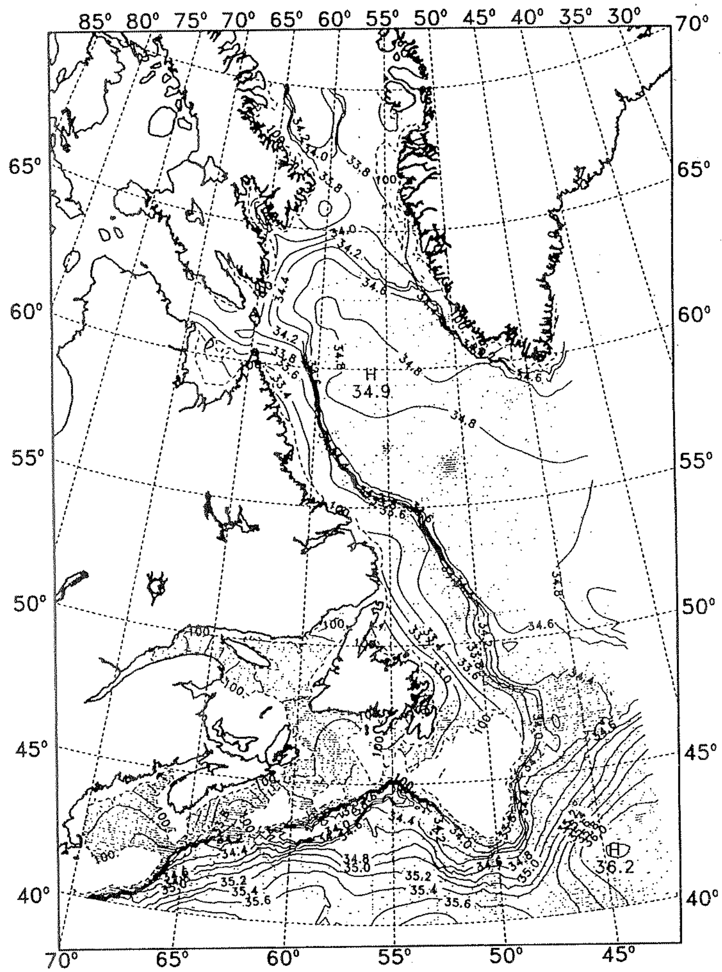
WINTER SALINITY AT 50m



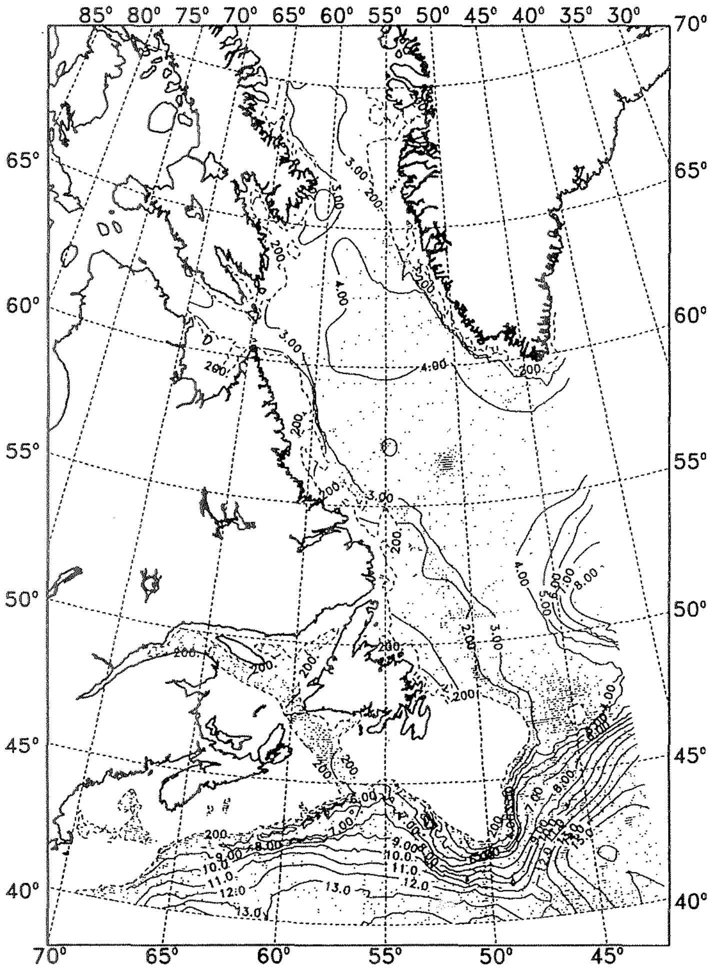
WINTER TEMPERATURE AT 100m



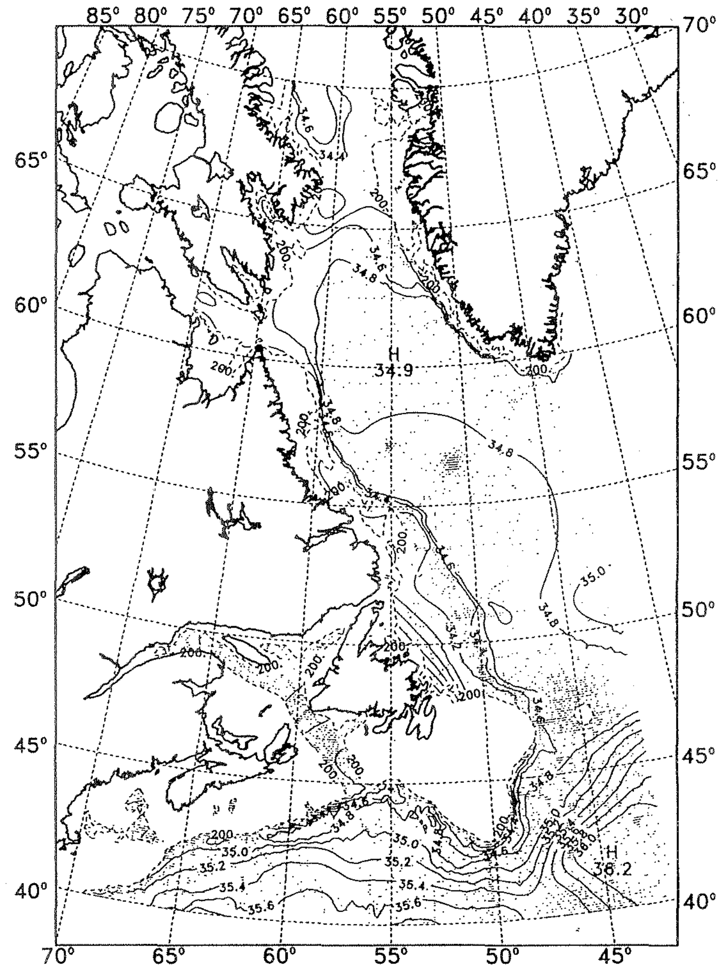
WINTER SALINITY AT 100m



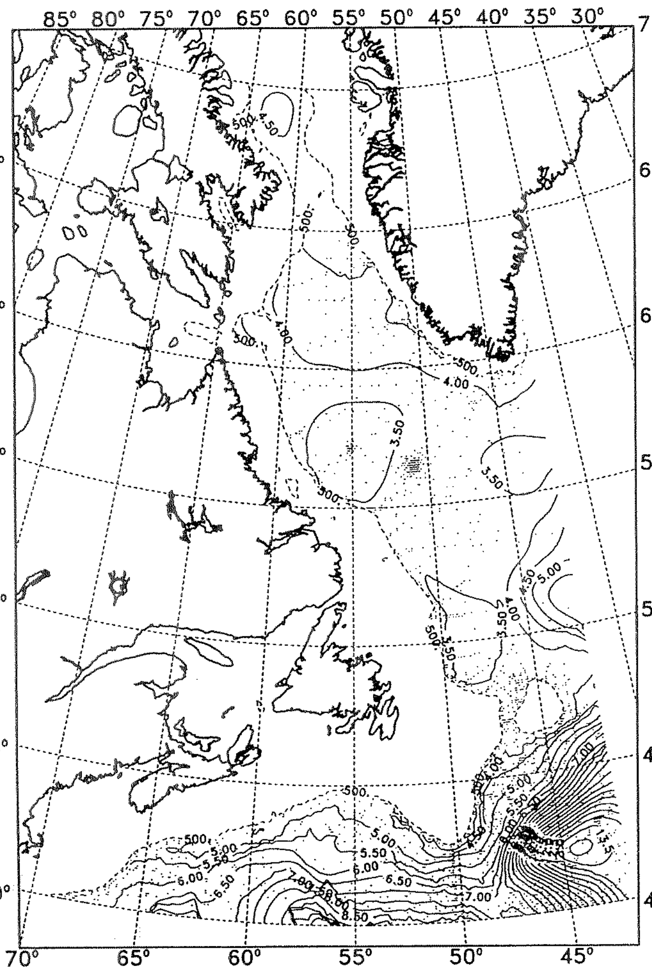
WINTER TEMPERATURE AT 200m



WINTER SALINITY AT 200m



WINTER TEMPERATURE AT 500m



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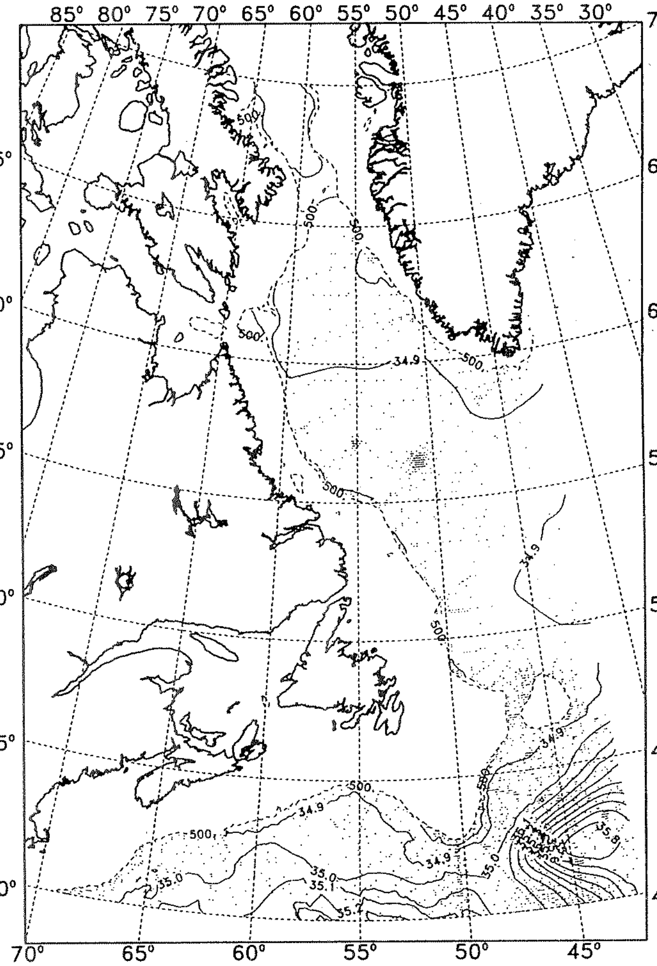
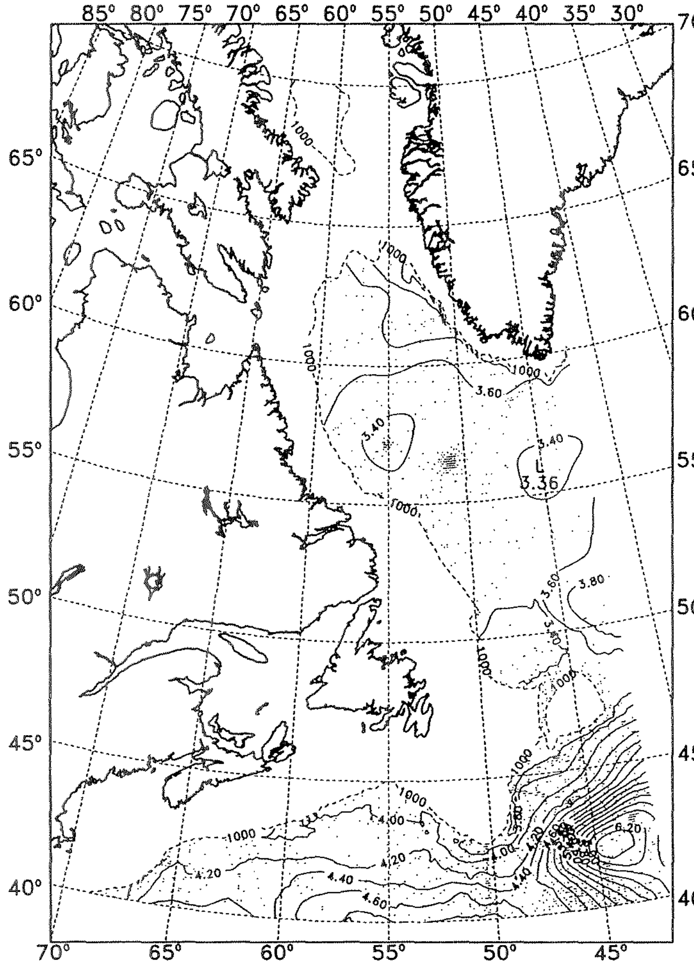
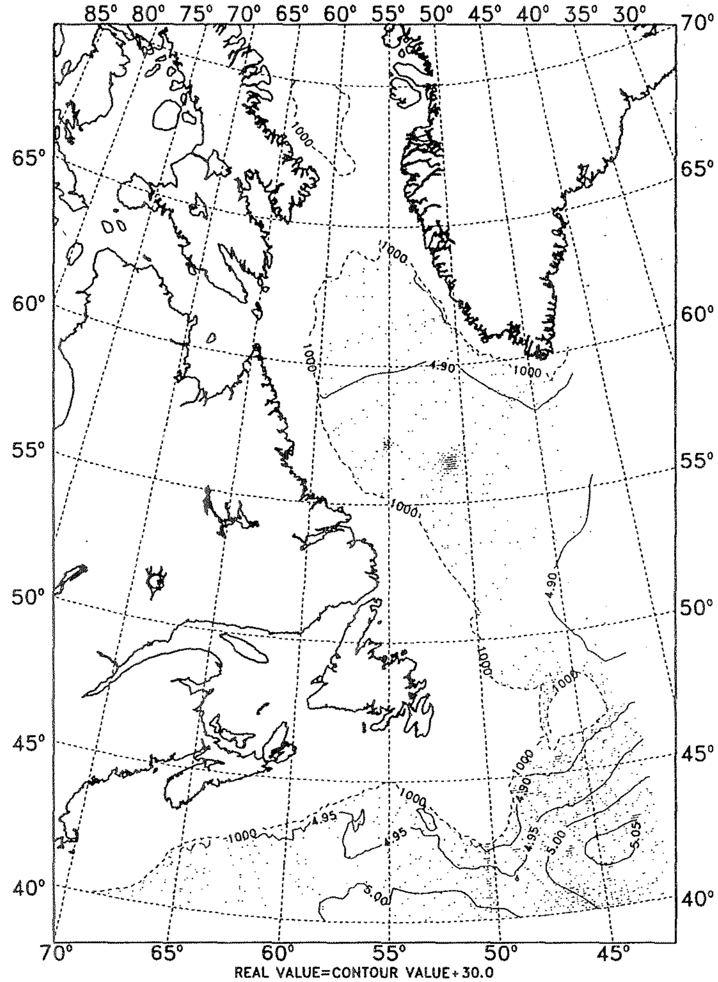


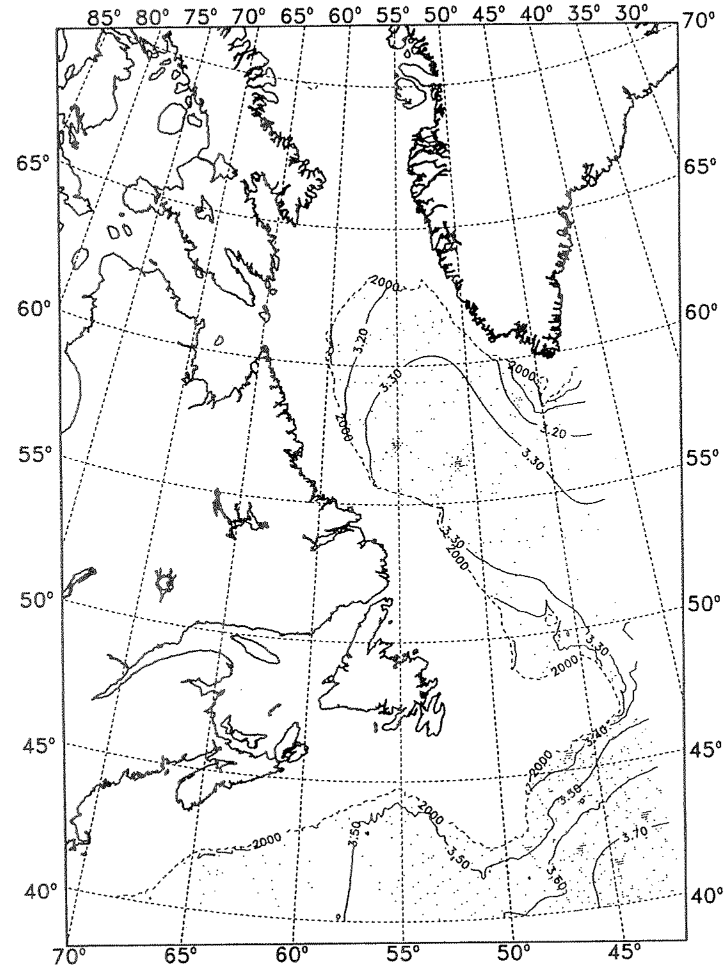
WINTER TEMPERATURE AT 1000m



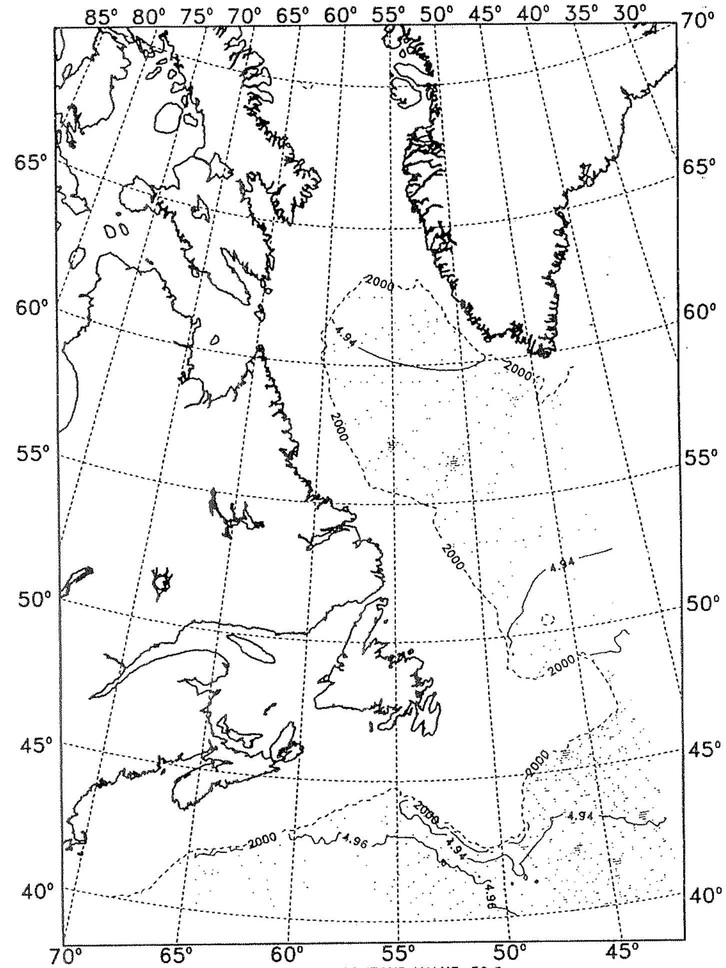
WINTER SALINITY AT 1000m



WINTER TEMPERATURE AT 2000m



WINTER SALINITY AT 2000m



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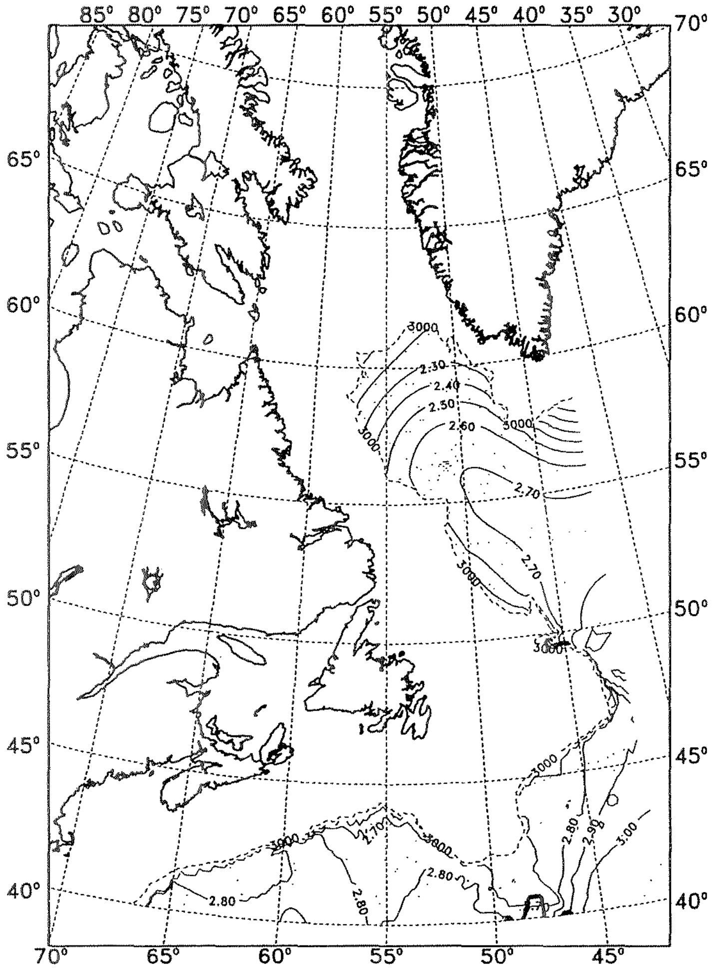
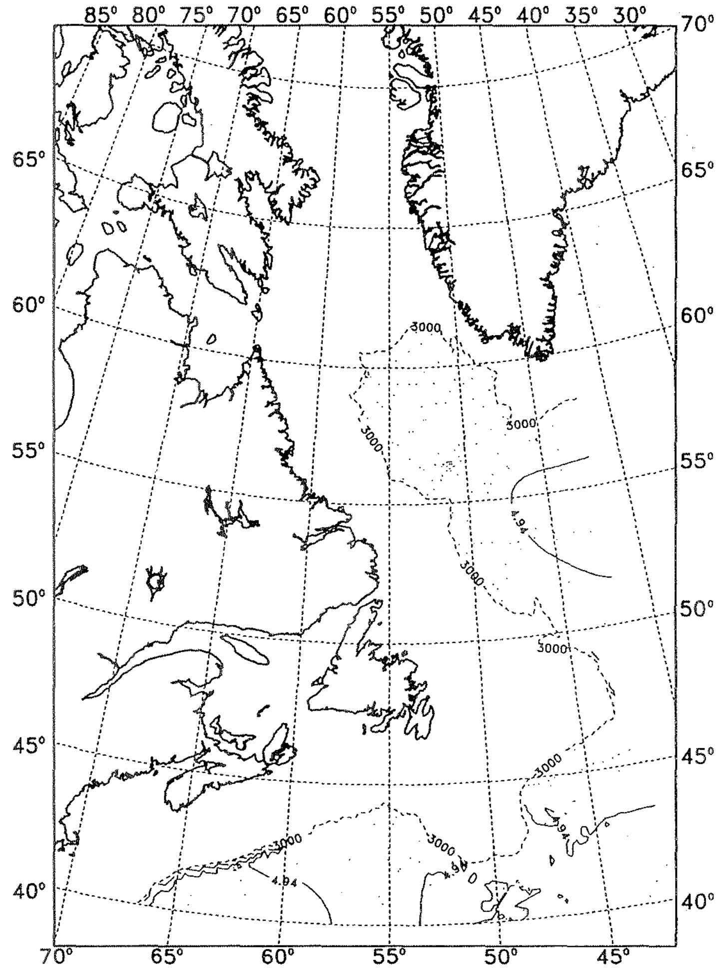
WINTER TEMPERATURE AT 3000m



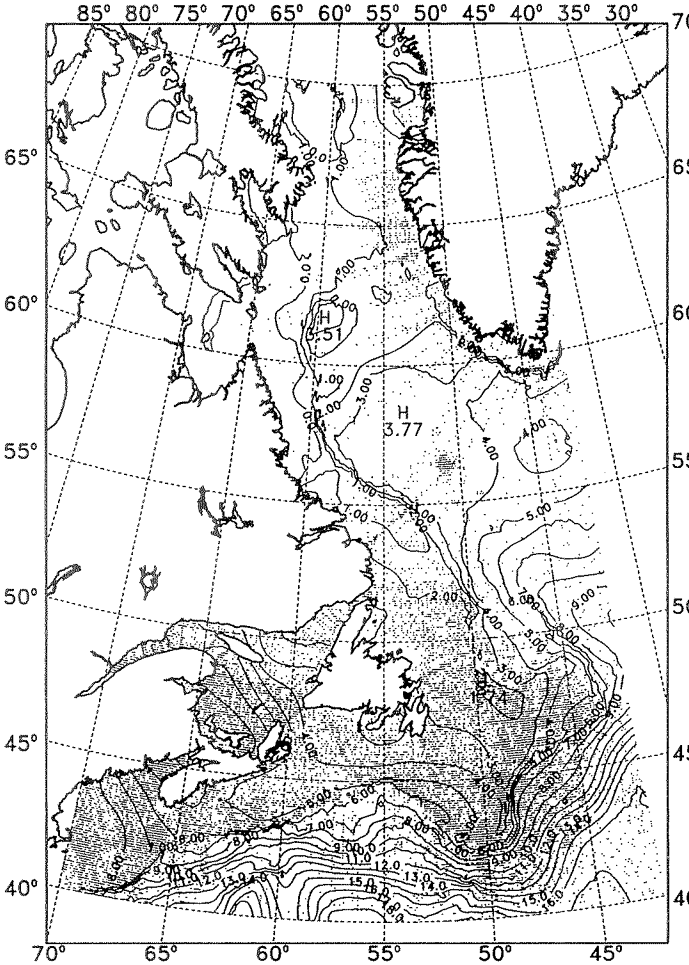
WINTER SALINITY AT 3000m



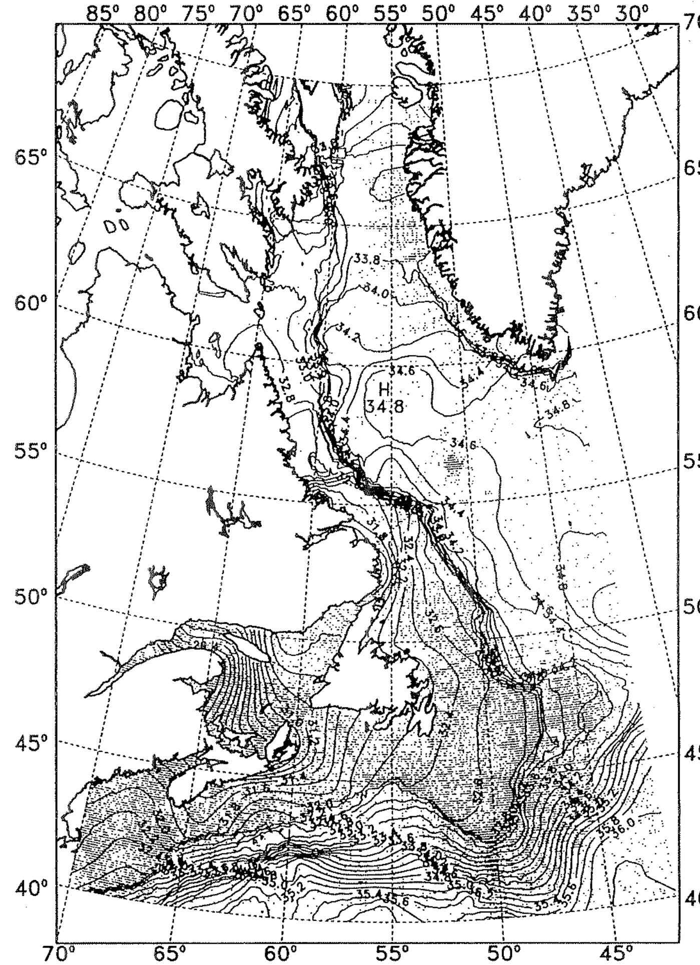
REAL VALUE=CONTOUR VALUE+30.0

Spring

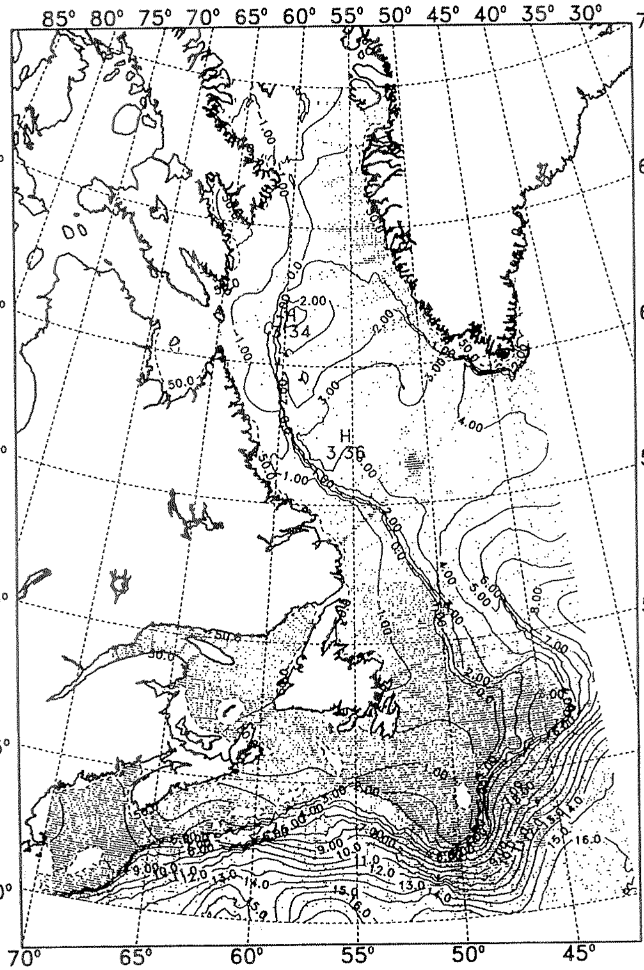
SPRING TEMPERATURE AT 0m



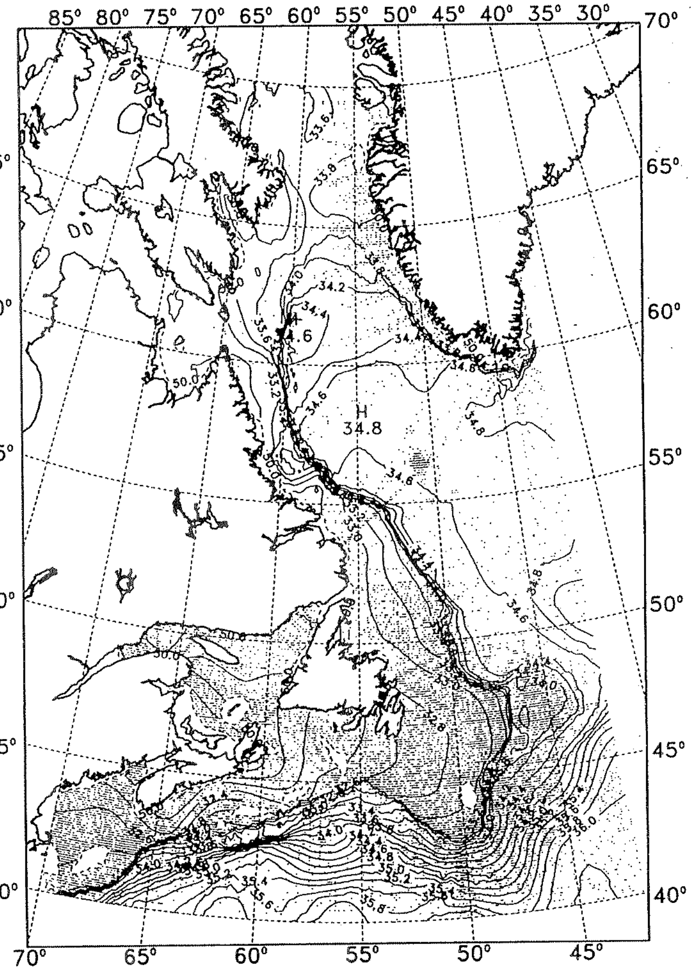
SPRING SALINITY AT 0m



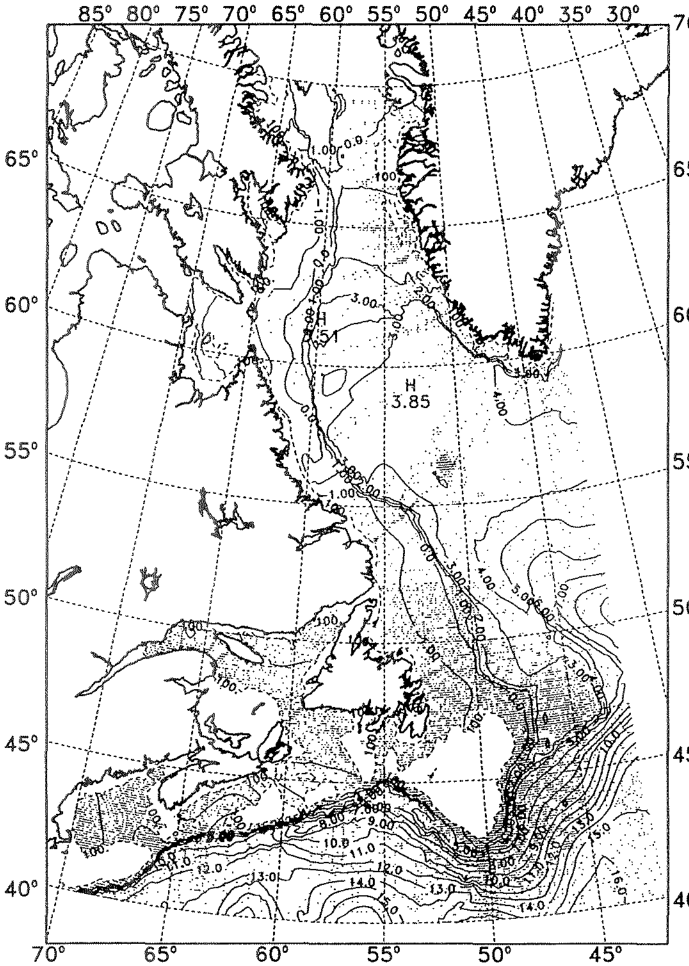
SPRING TEMPERATURE AT 50m



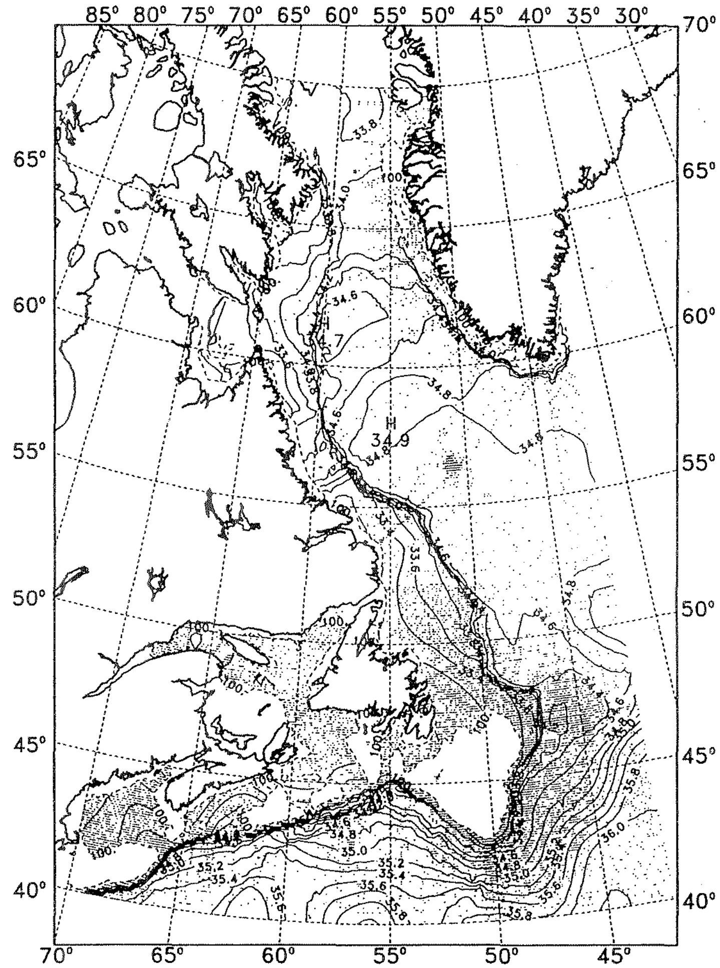
SPRING SALINITY AT 50m



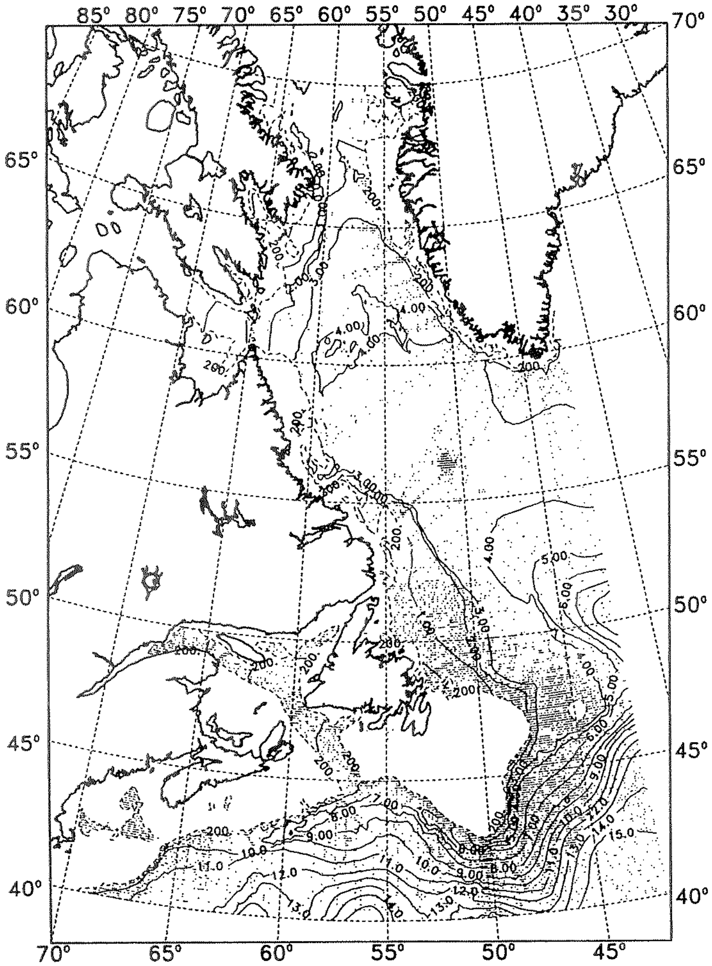
SPRING TEMPERATURE AT 100m



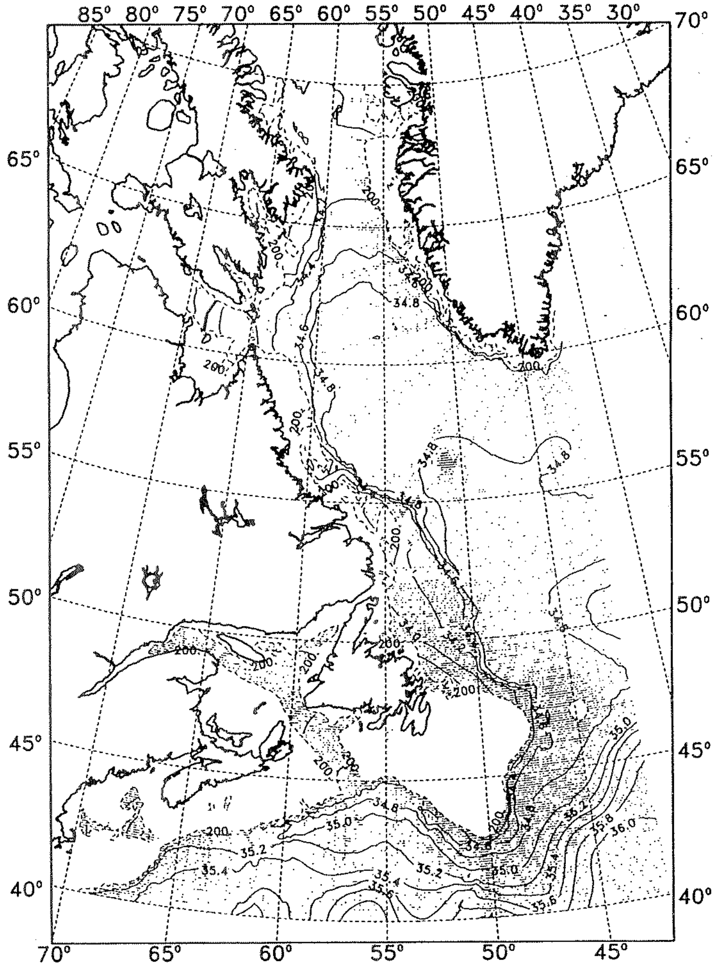
SPRING SALINITY AT 100m



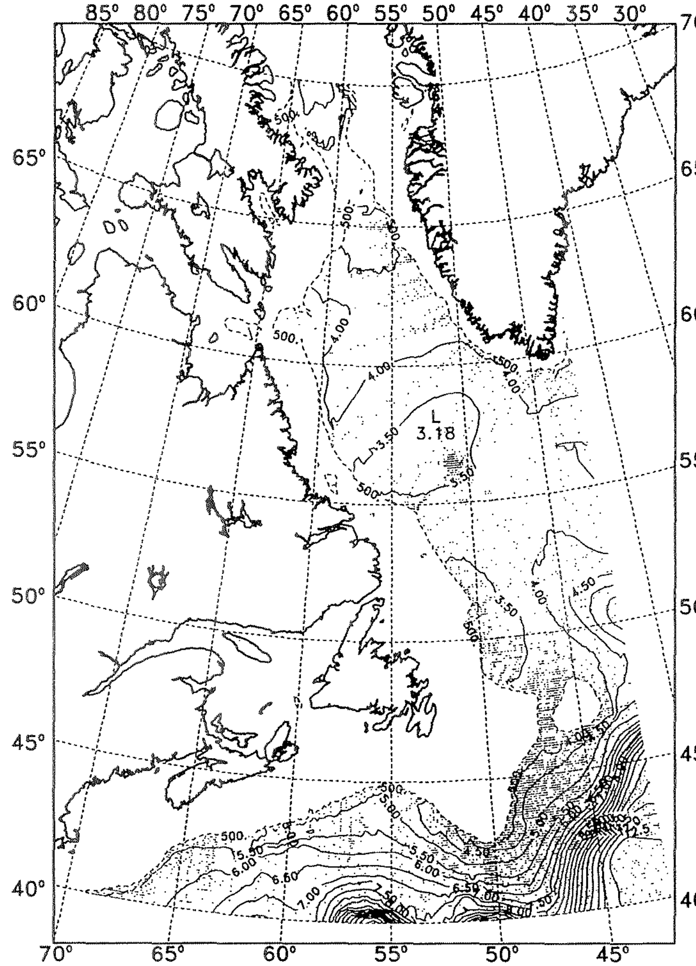
SPRING TEMPERATURE AT 200m



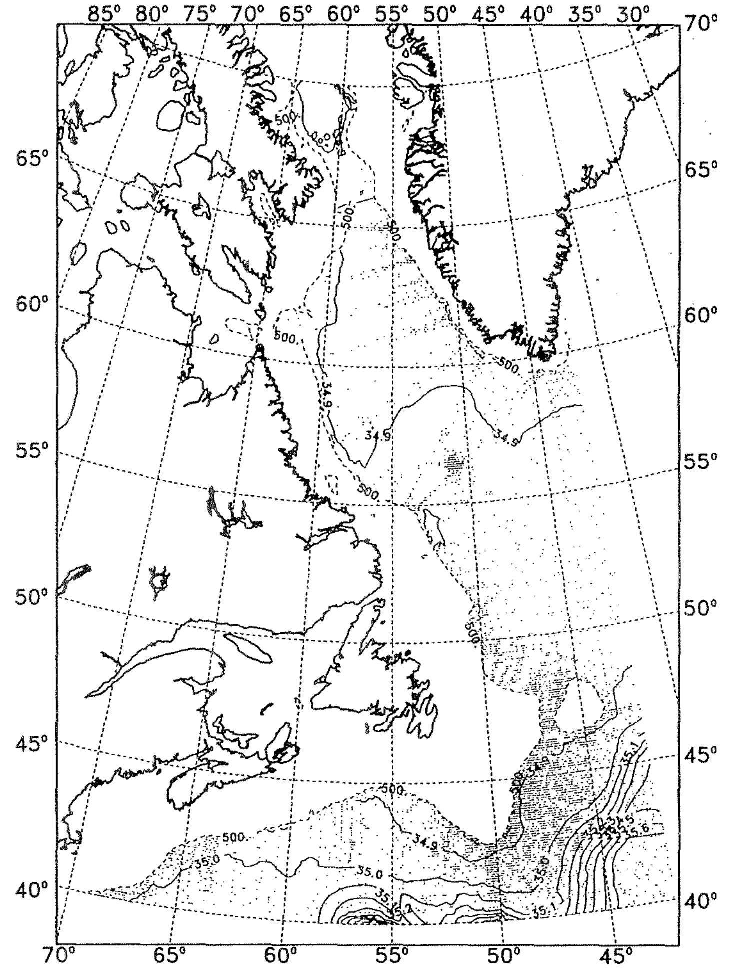
SPRING SALINITY AT 200m



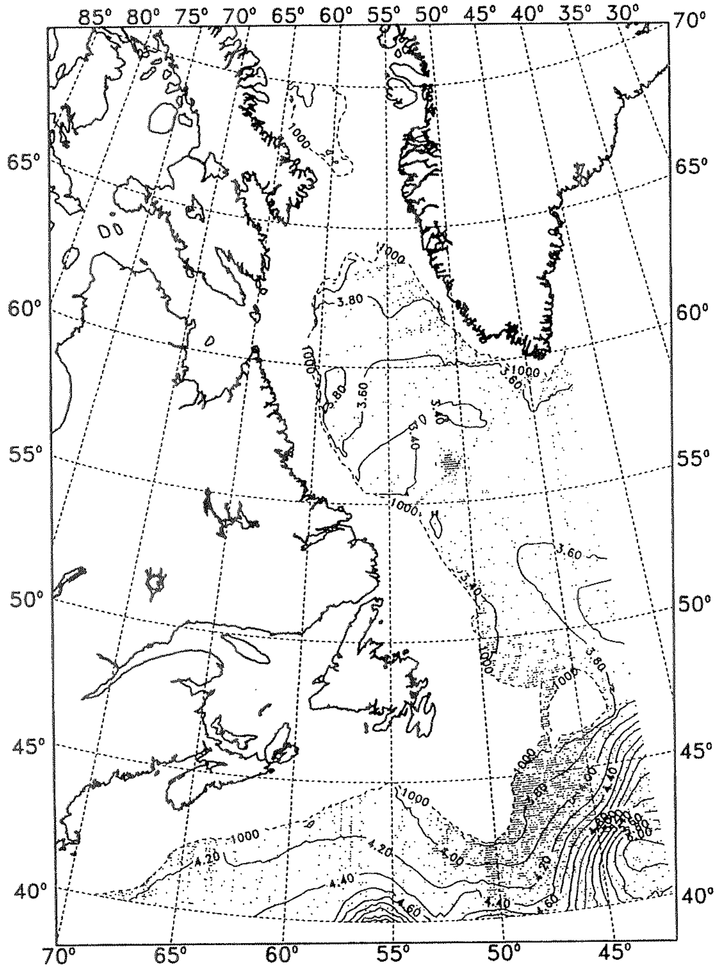
SPRING TEMPERATURE AT 500m



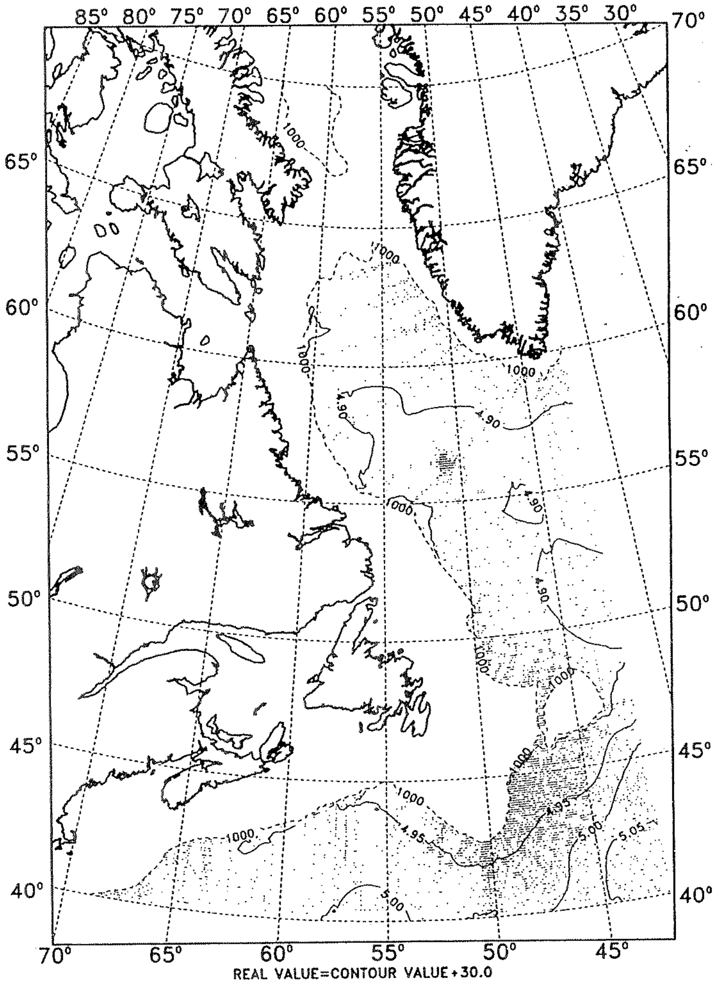
SPRING SALINITY AT 500m



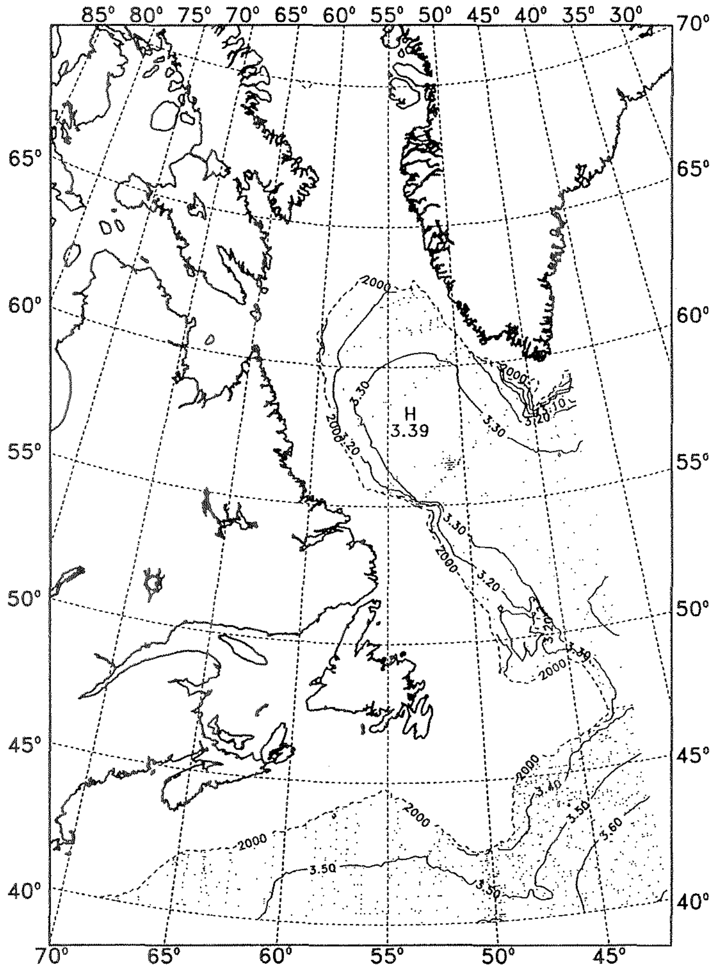
SPRING TEMPERATURE AT 1000m



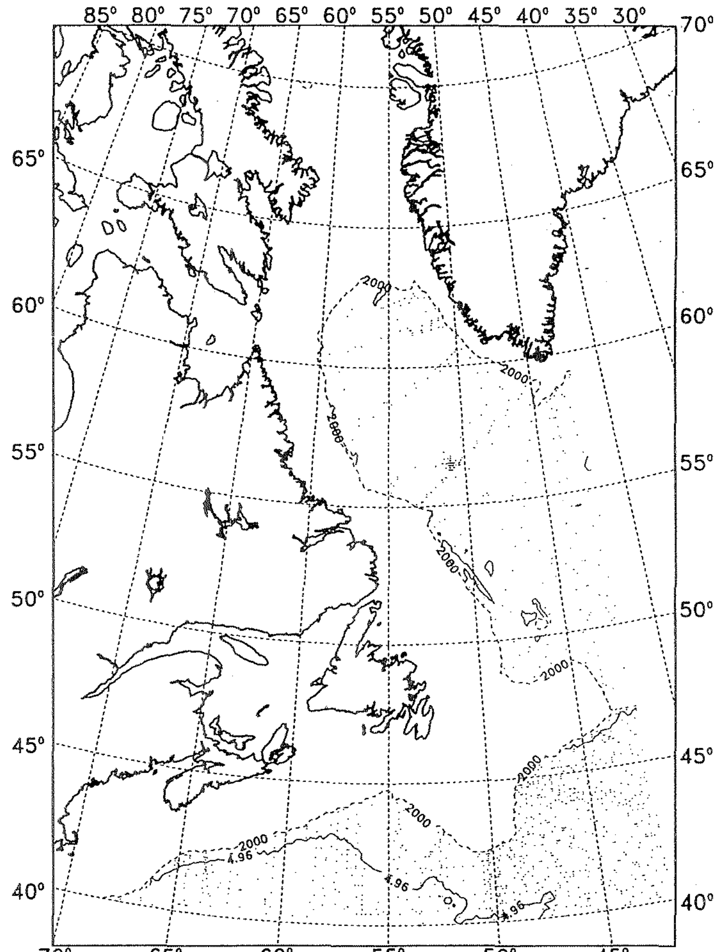
SPRING SALINITY AT 1000m



SPRING TEMPERATURE AT 2000m

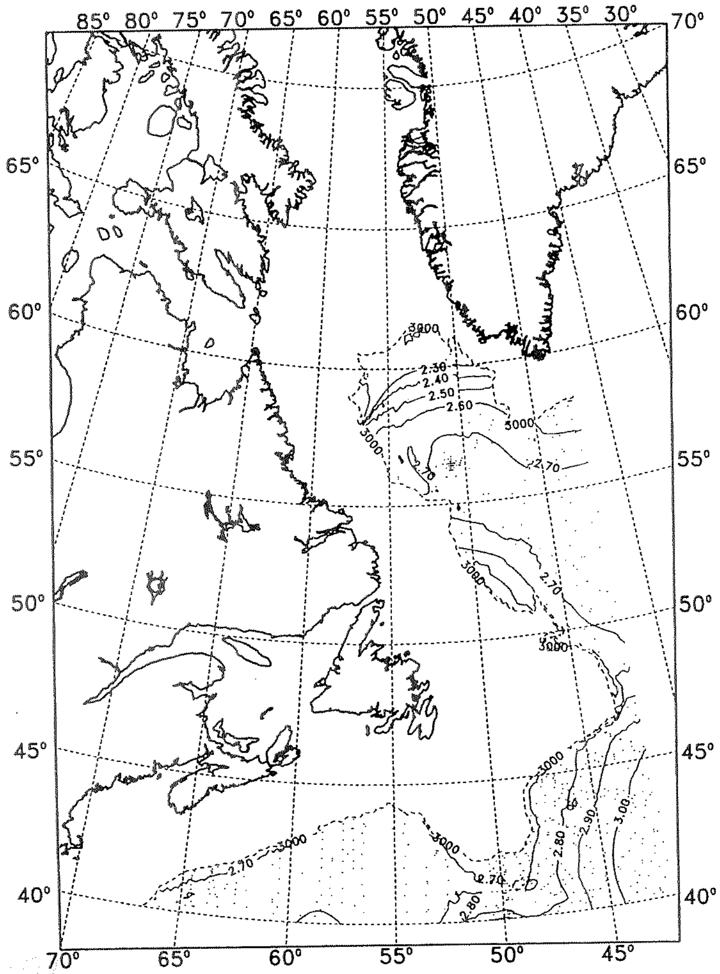


SPRING SALINITY AT 2000m

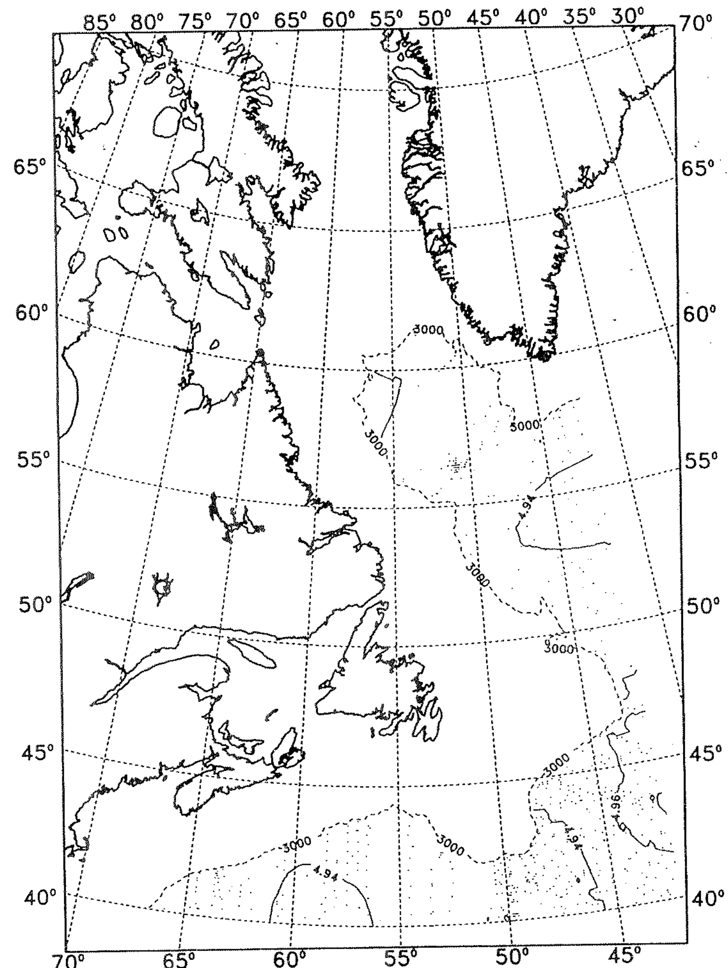


REAL VALUE=CONTOUR VALUE+30.0

SPRING TEMPERATURE AT 3000m



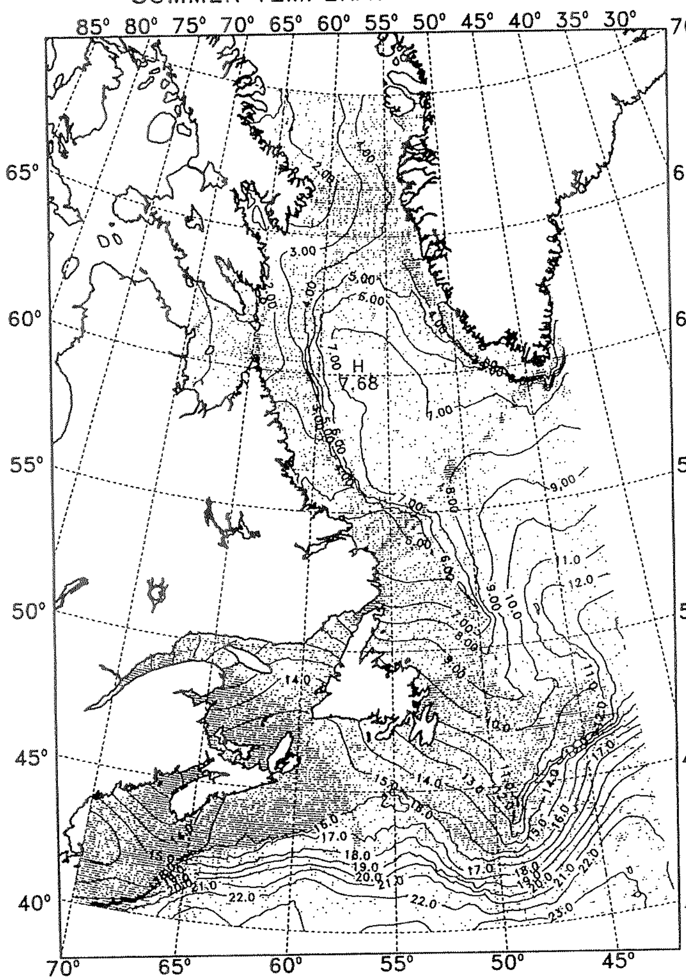
SPRING SALINITY AT 3000m



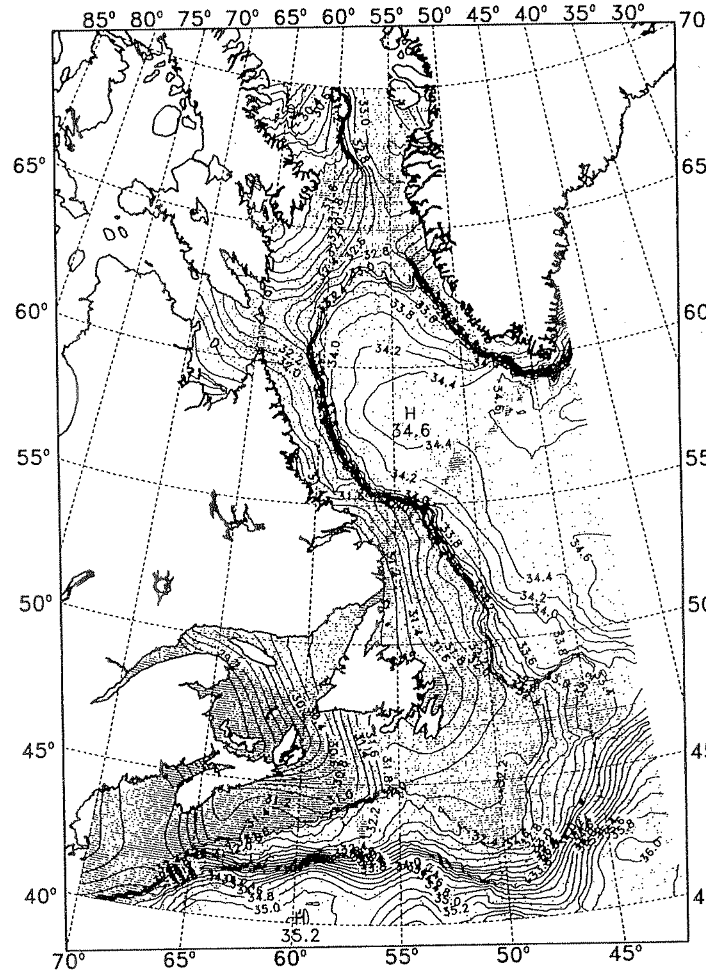
REAL VALUE=CONTOUR VALUE+30.0

Summer

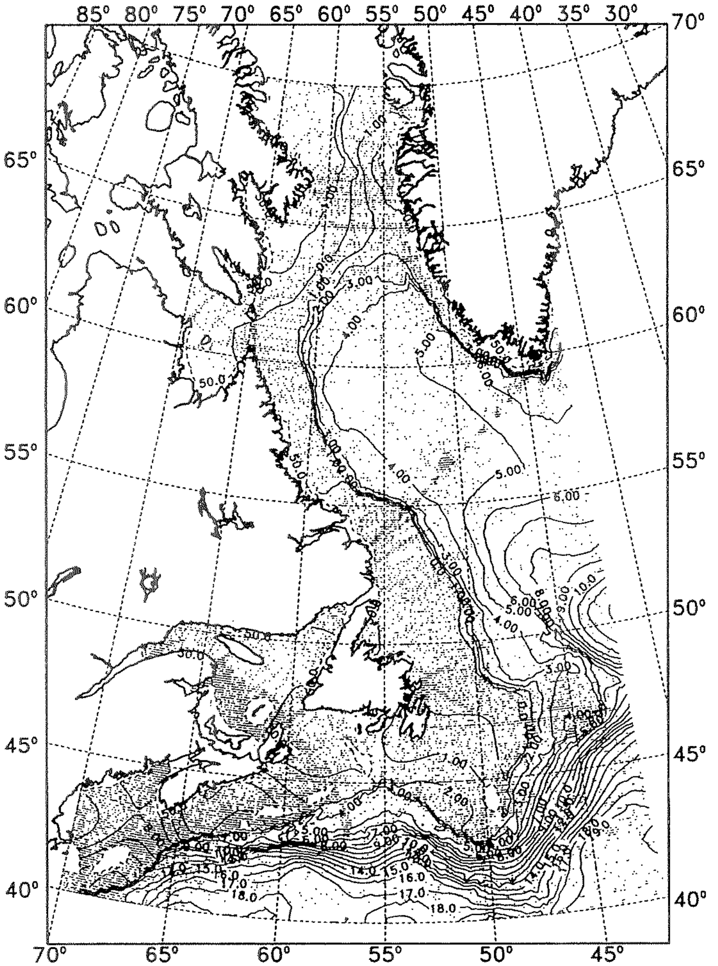
SUMMER TEMPERATURE AT 0m



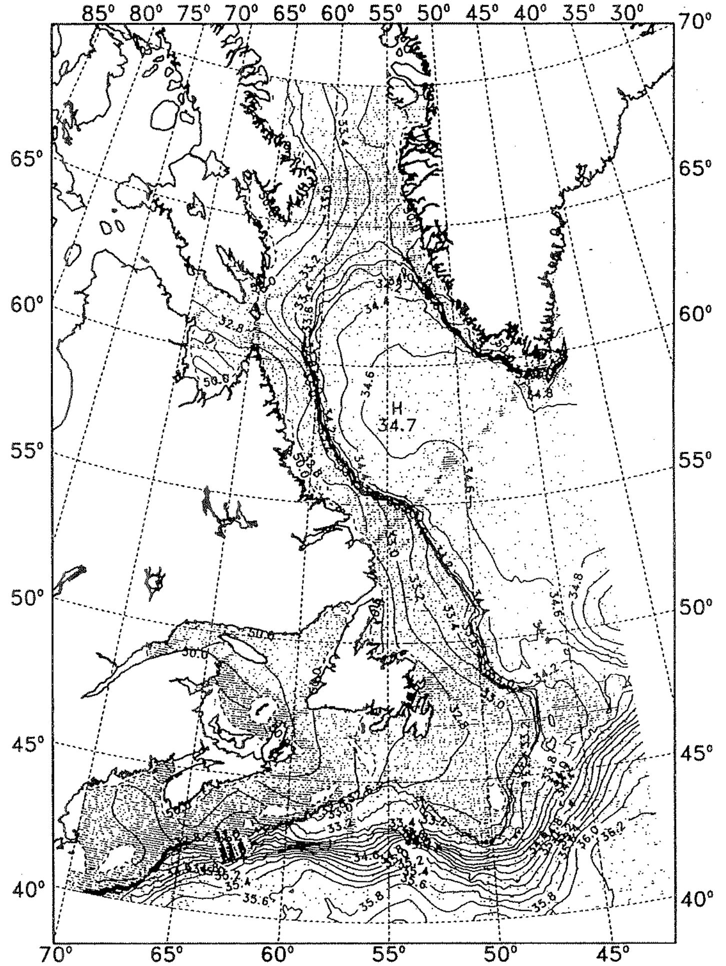
SUMMER SALINITY AT 0m



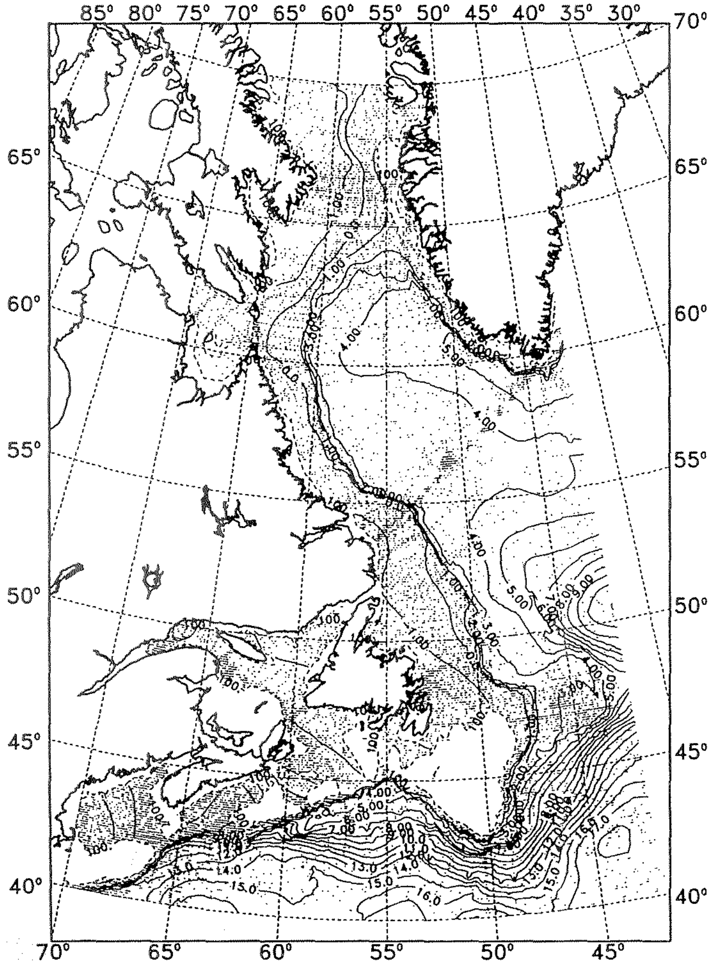
SUMMER TEMPERATURE AT 50m



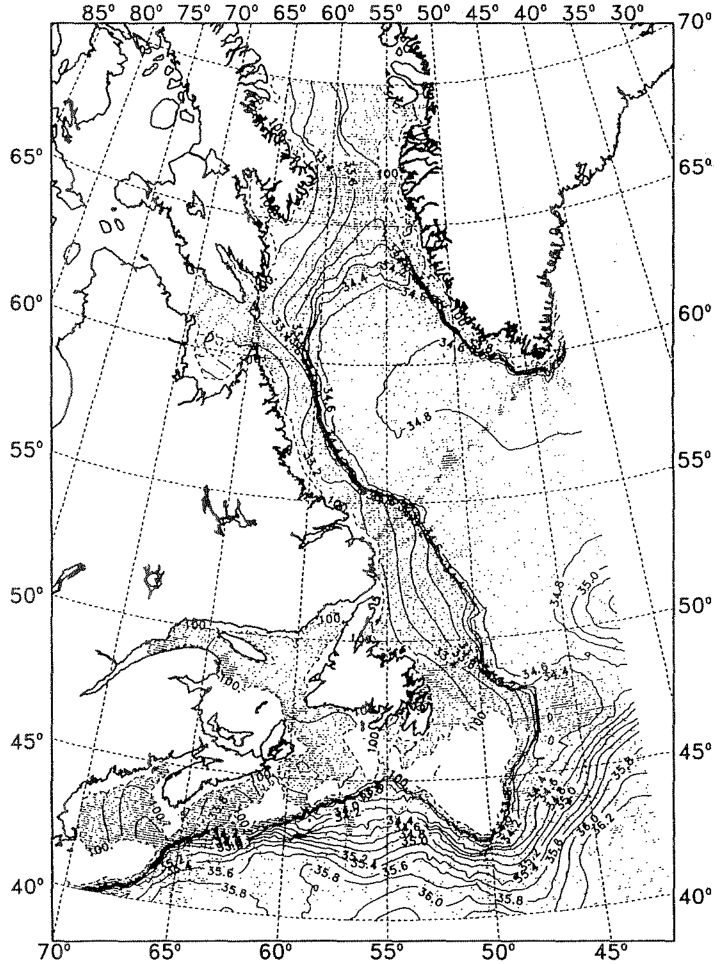
SUMMER SALINITY AT 50m



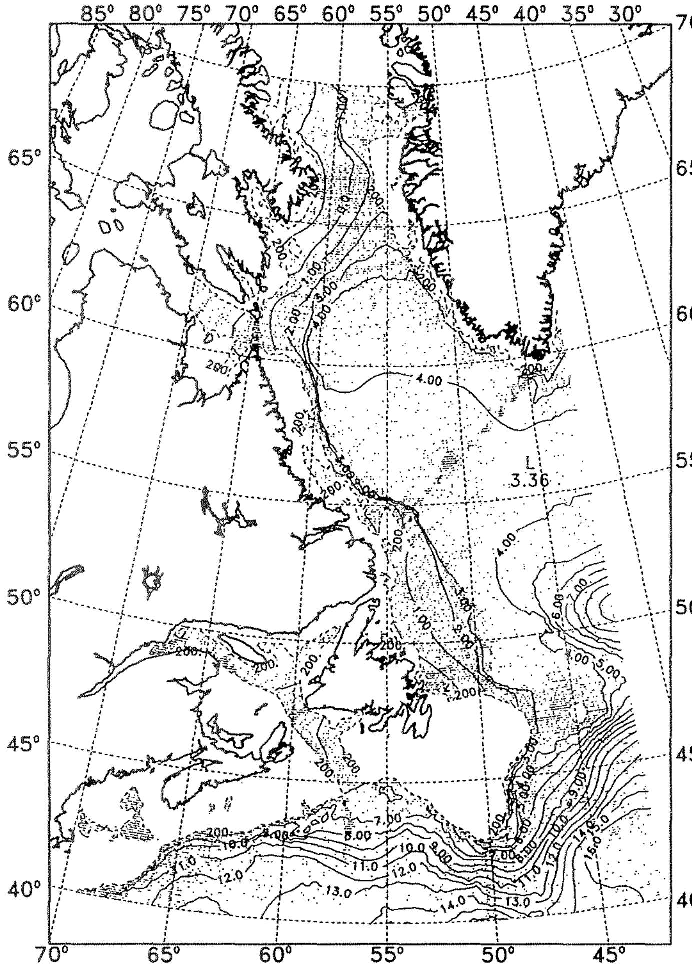
SUMMER TEMPERATURE AT 100m



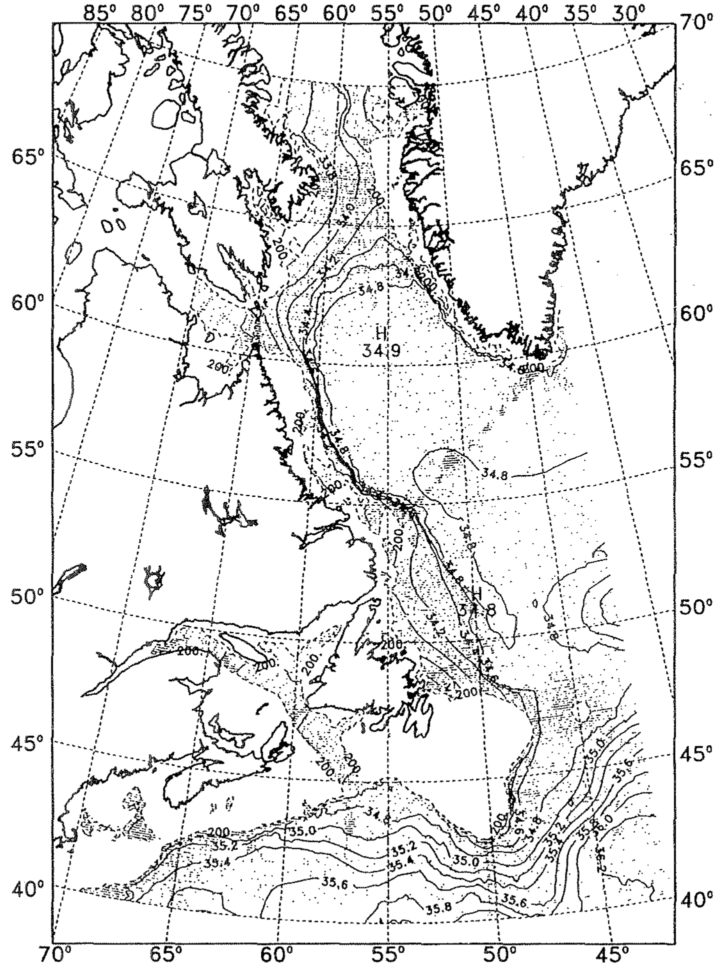
SUMMER SALINITY AT 100m



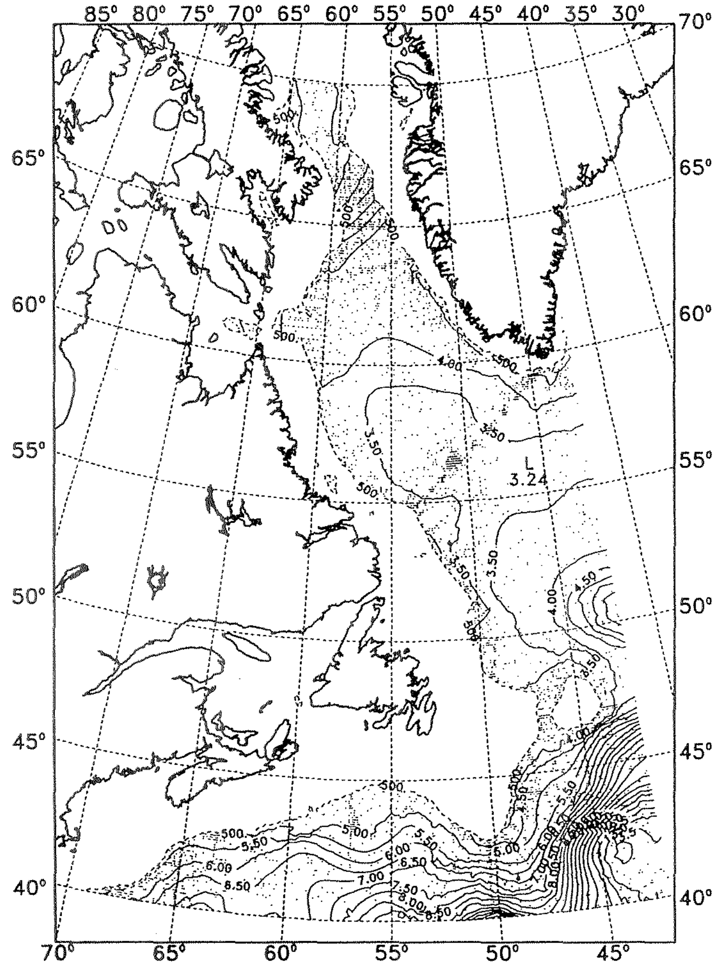
SUMMER TEMPERATURE AT 200m



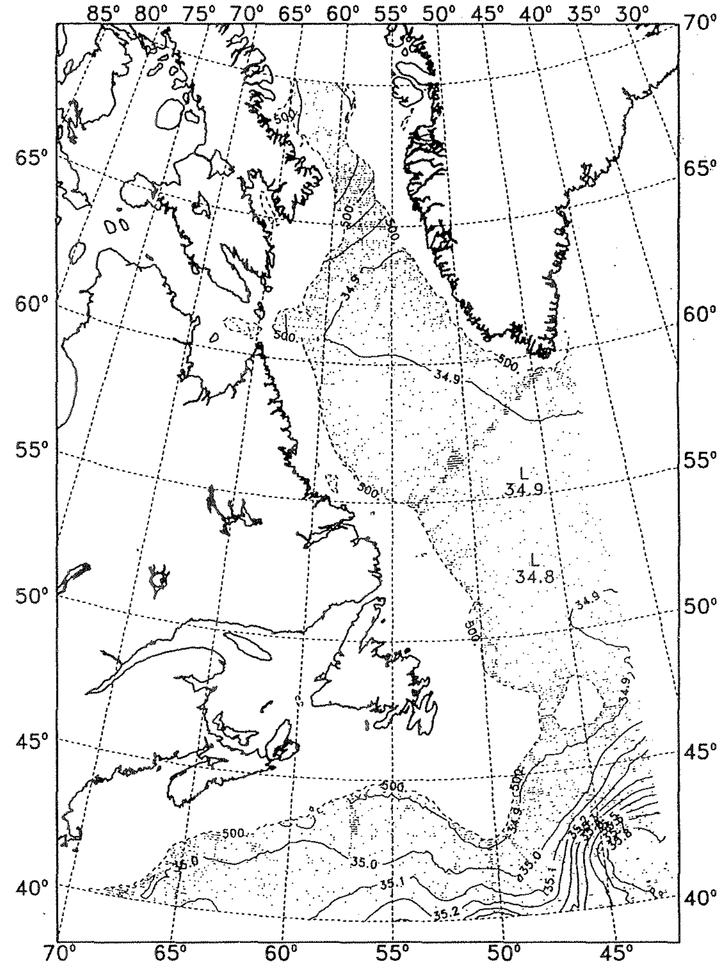
SUMMER SALINITY AT 200m



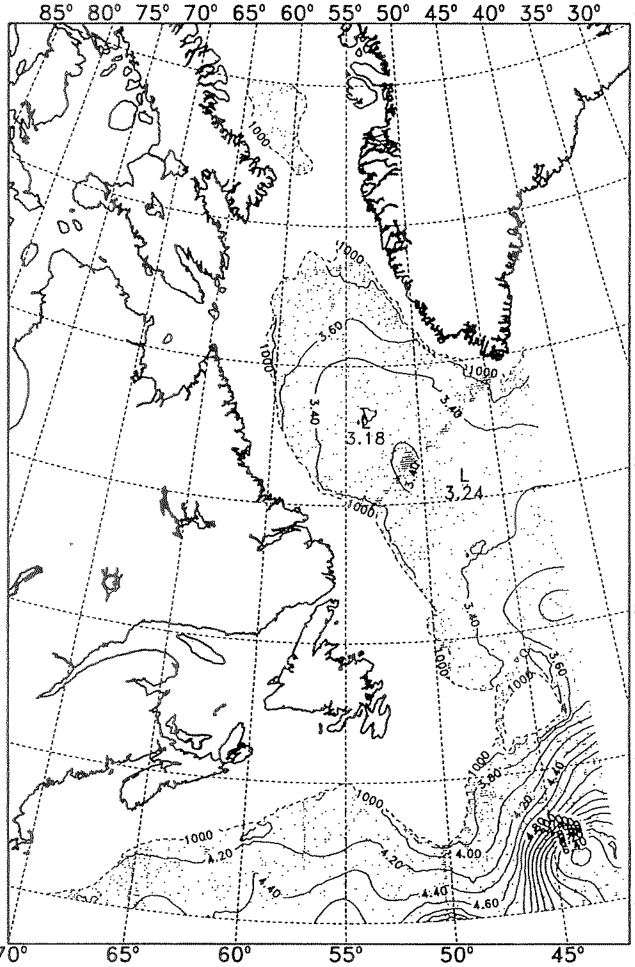
SUMMER TEMPERATURE AT 500m



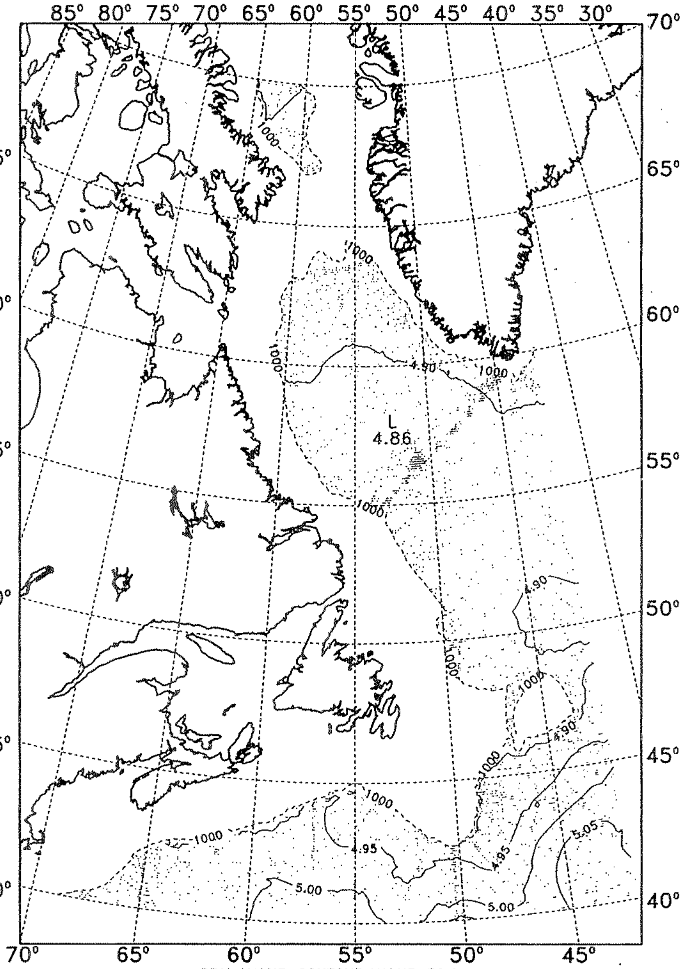
SUMMER SALINITY AT 500m



SUMMER TEMPERATURE AT 1000m

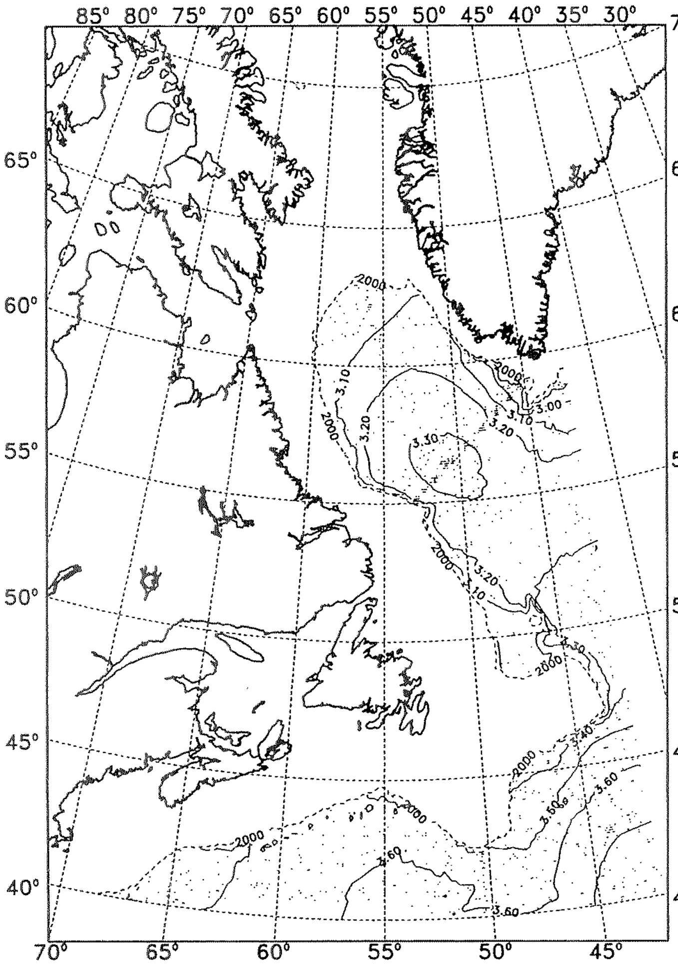


SUMMER SALINITY AT 1000m

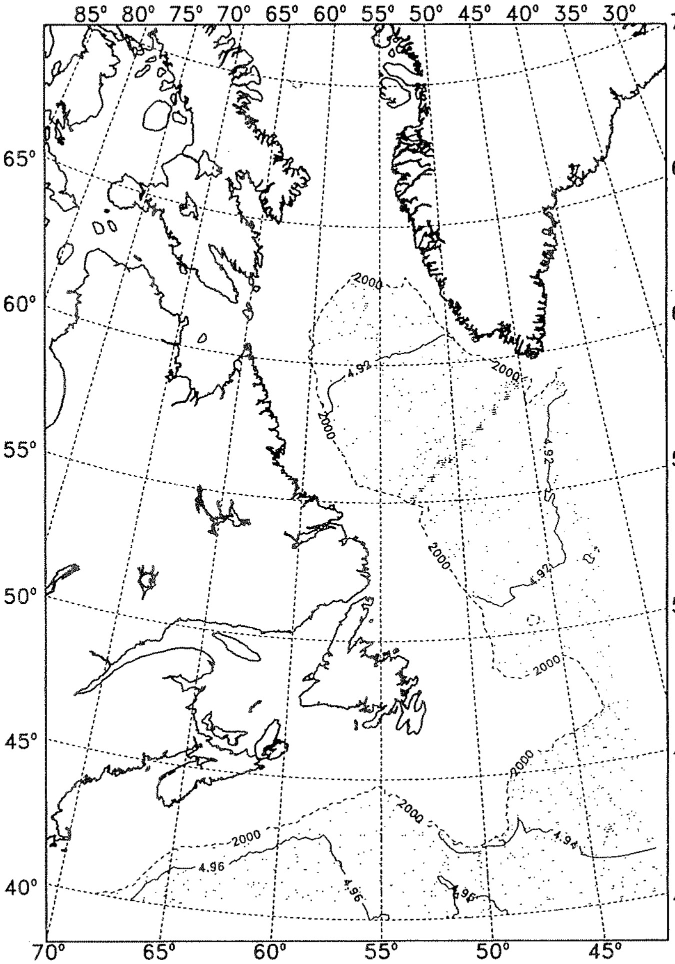


REAL VALUE=CONTOUR VALUE+30.0

SUMMER TEMPERATURE AT 2000m

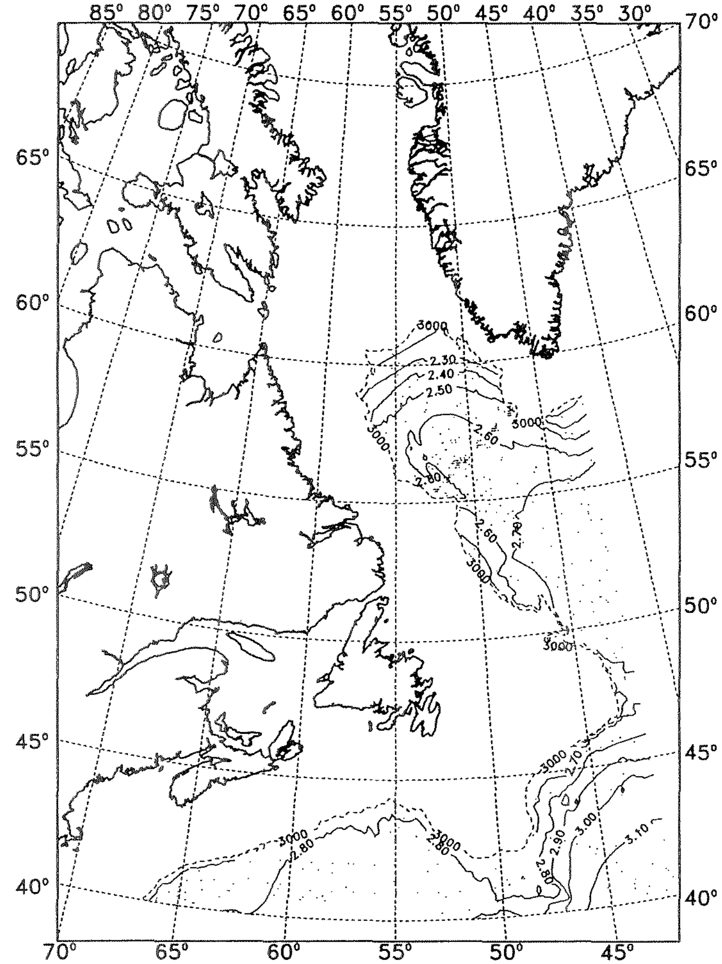


SUMMER SALINITY AT 2000m

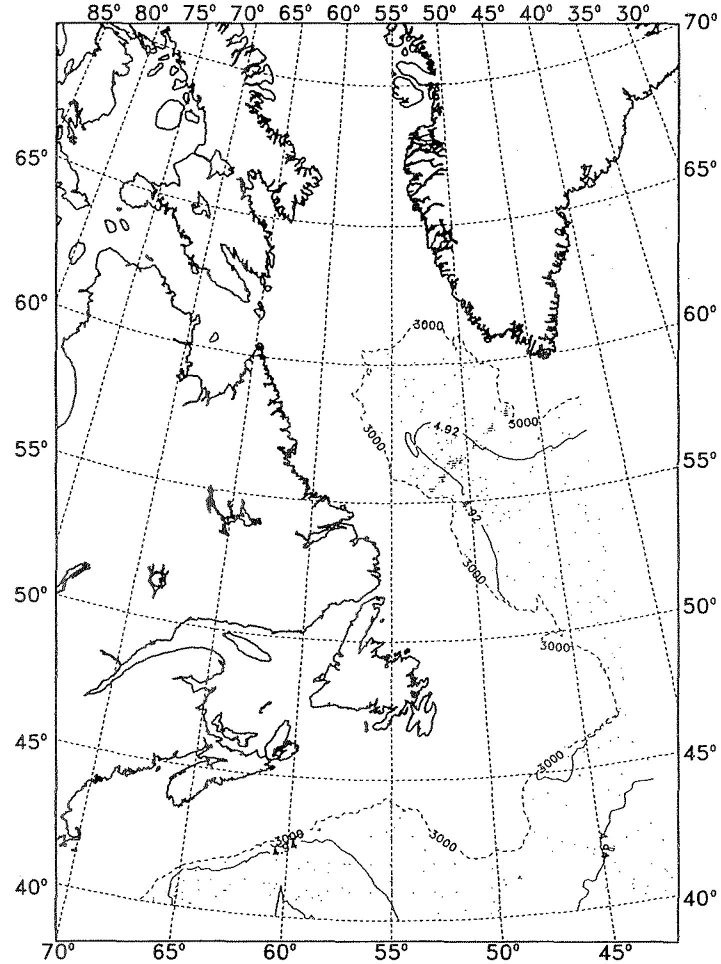


REAL VALUE=CONTOUR VALUE+30.0

SUMMER TEMPERATURE AT 3000m



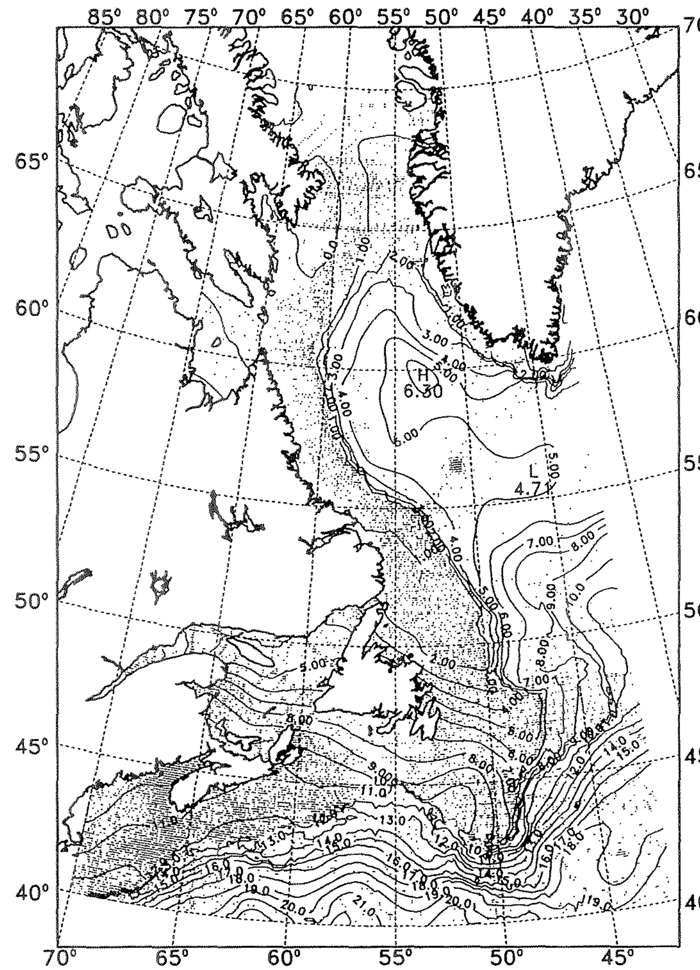
SUMMER SALINITY AT 3000m



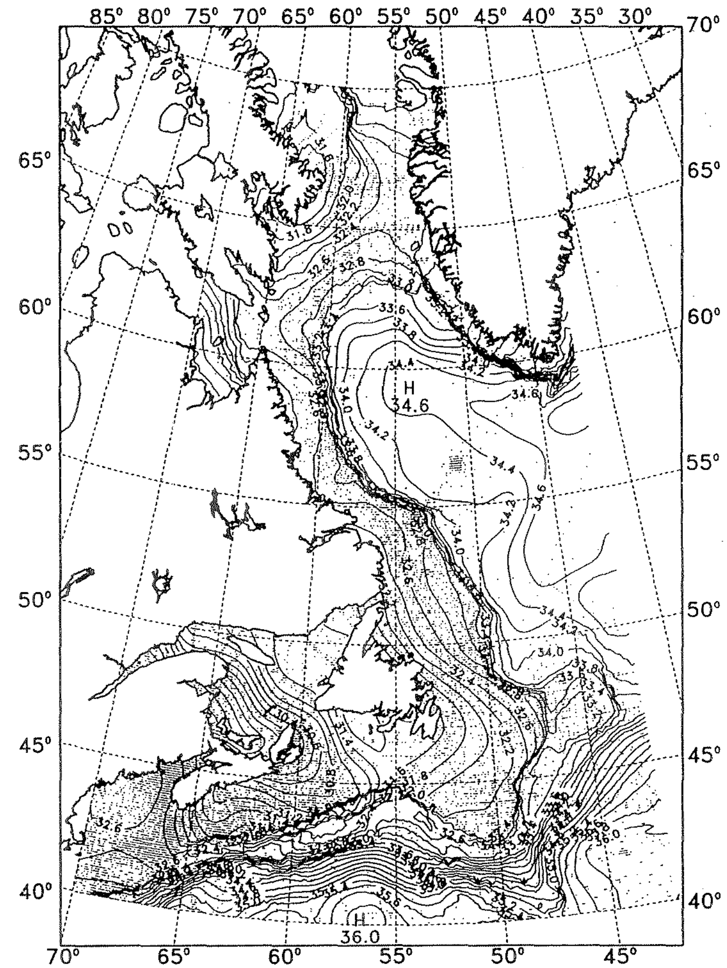
REAL VALUE=CONTOUR VALUE+30.0

Autumn

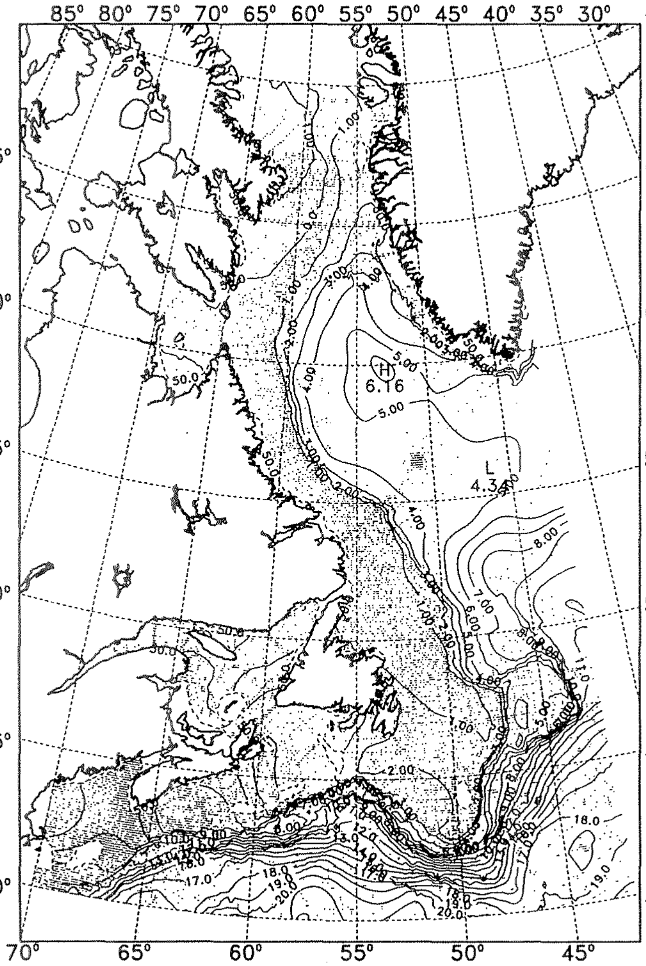
AUTUMN TEMPERATURE AT 0m



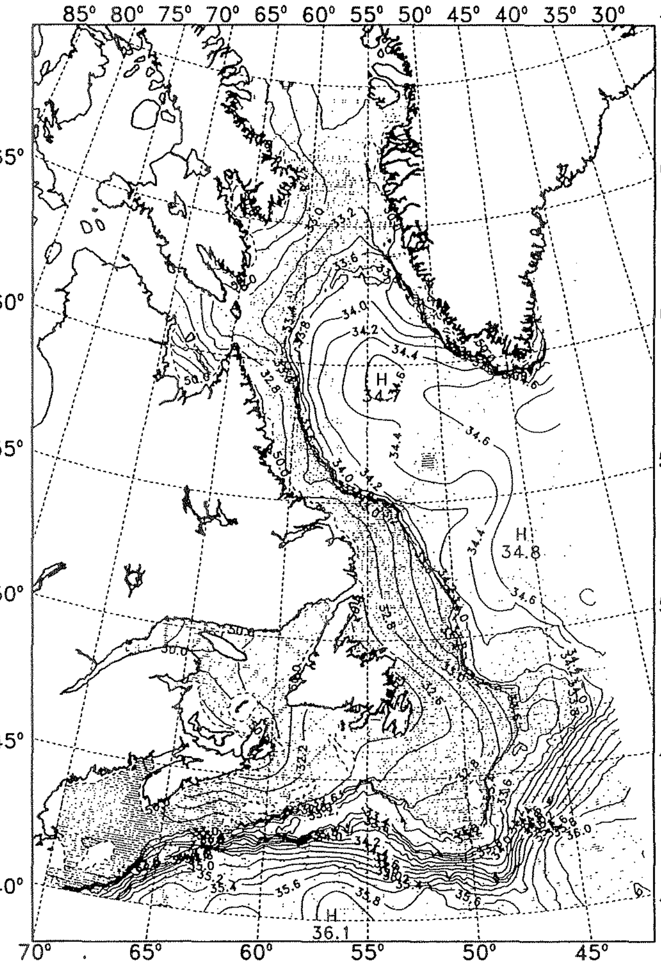
AUTUMN SALINITY AT 0m



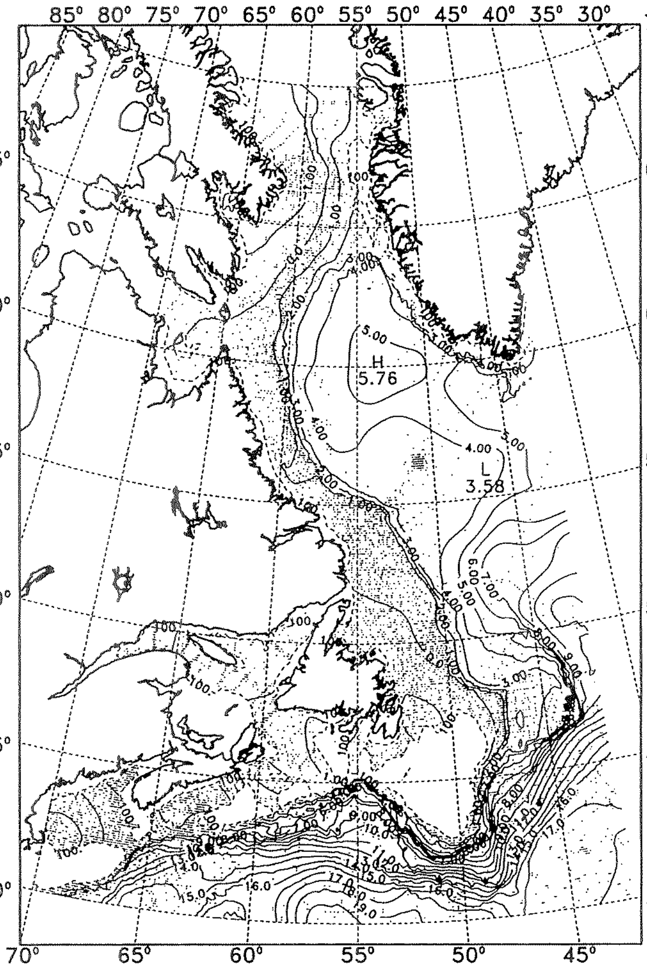
AUTUMN TEMPERATURE AT 50m



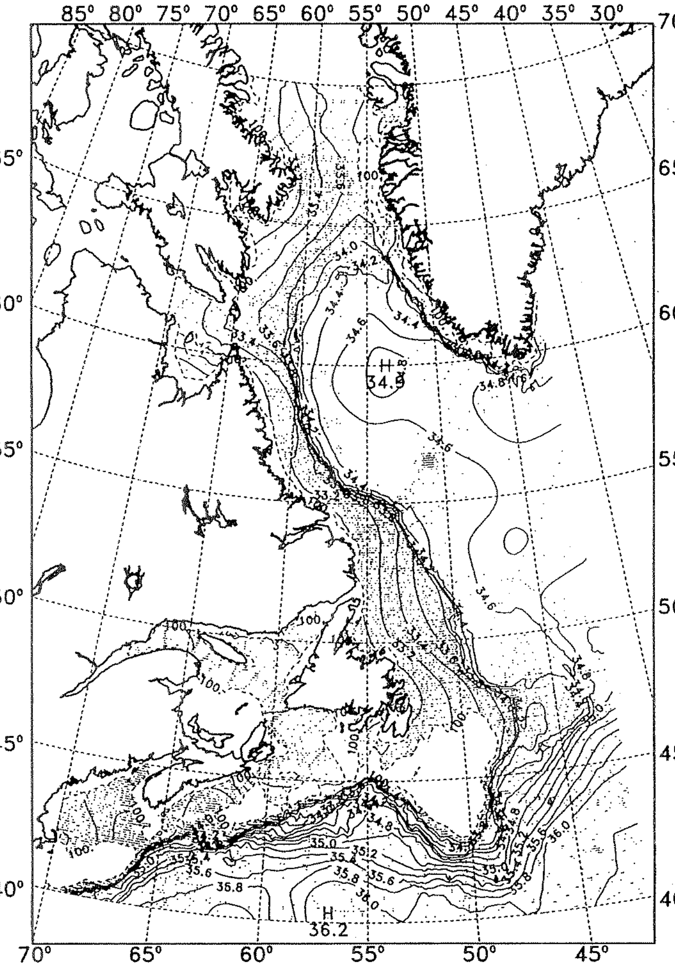
AUTUMN SALINITY AT 50m



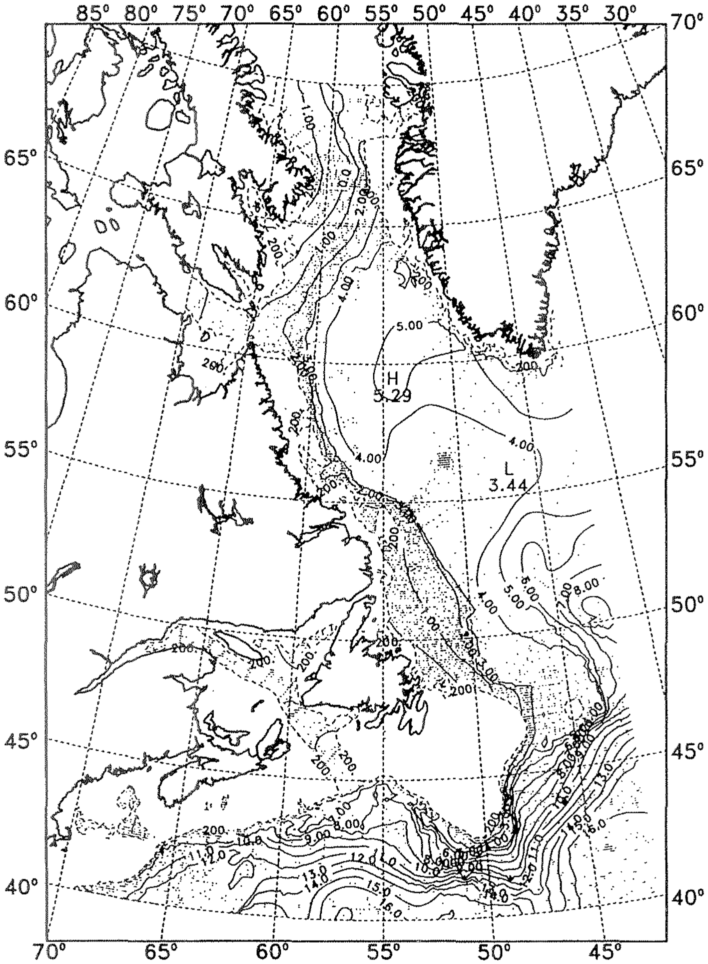
AUTUMN TEMPERATURE AT 100m



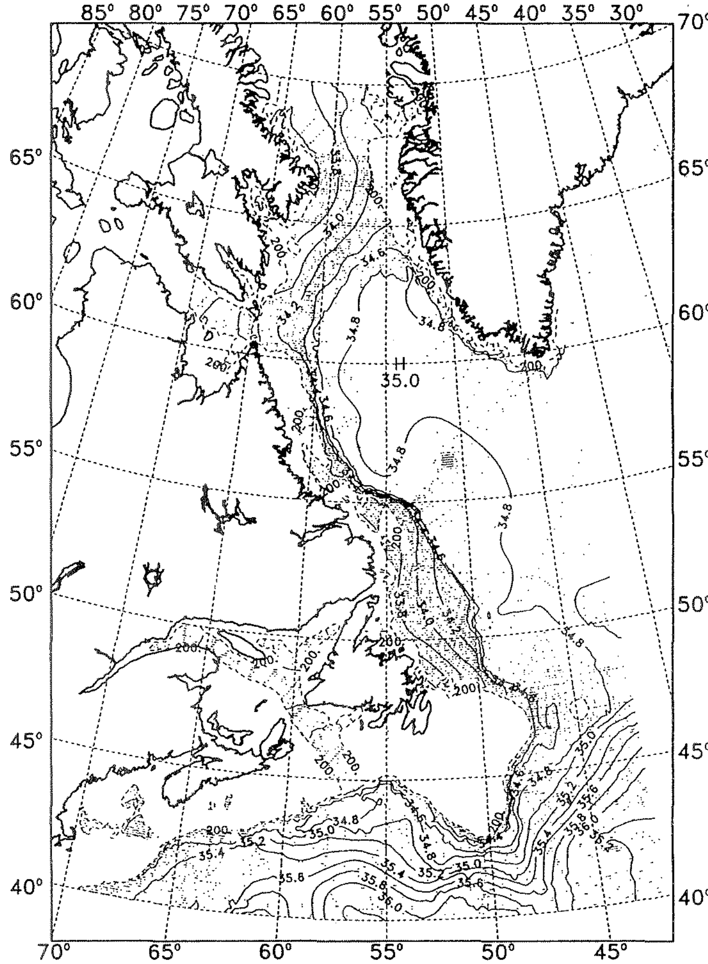
AUTUMN SALINITY AT 100m



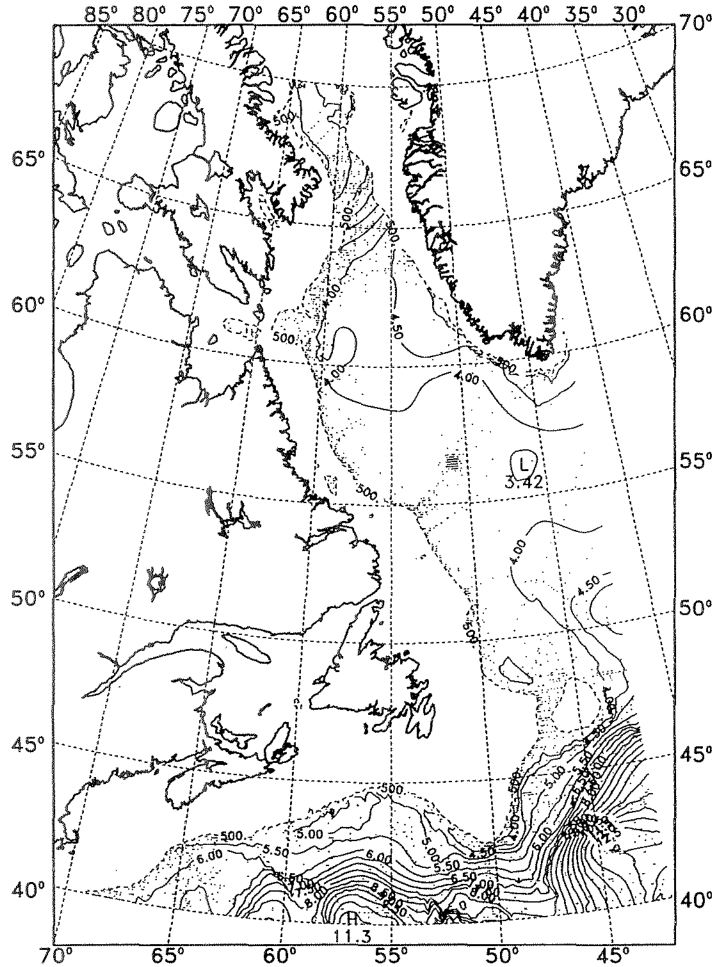
AUTUMN TEMPERATURE AT 200m



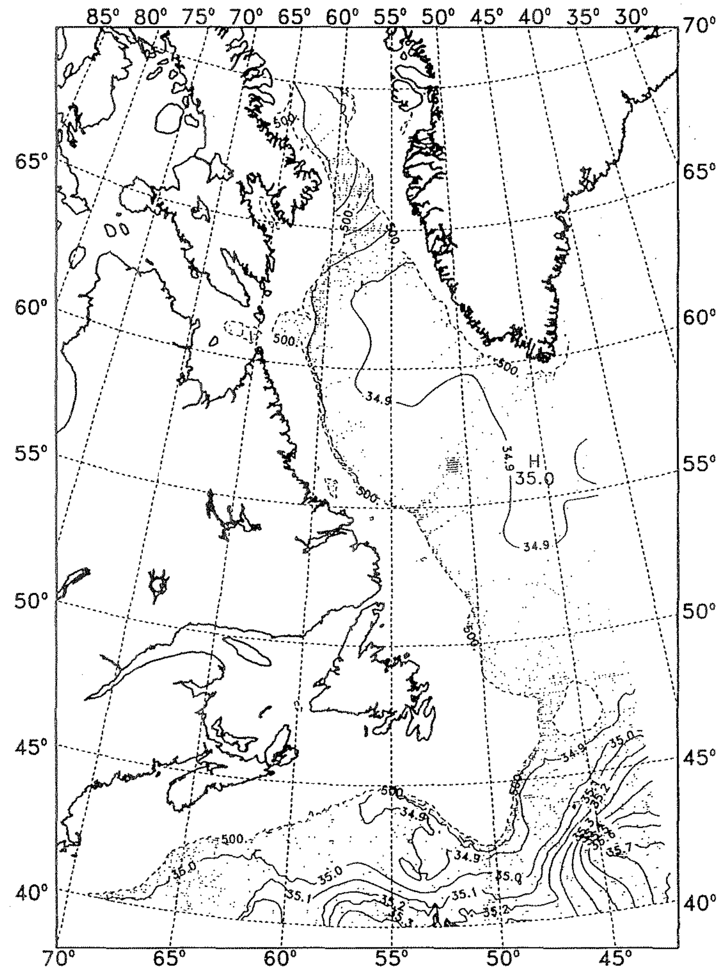
AUTUMN SALINITY AT 200m



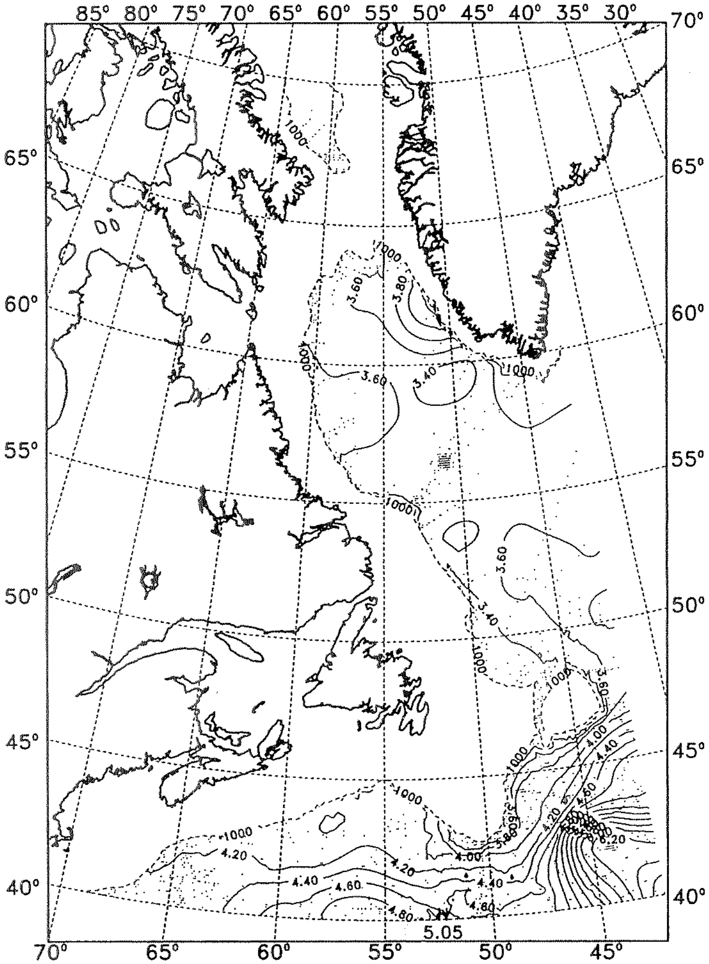
AUTUMN TEMPERATURE AT 500m



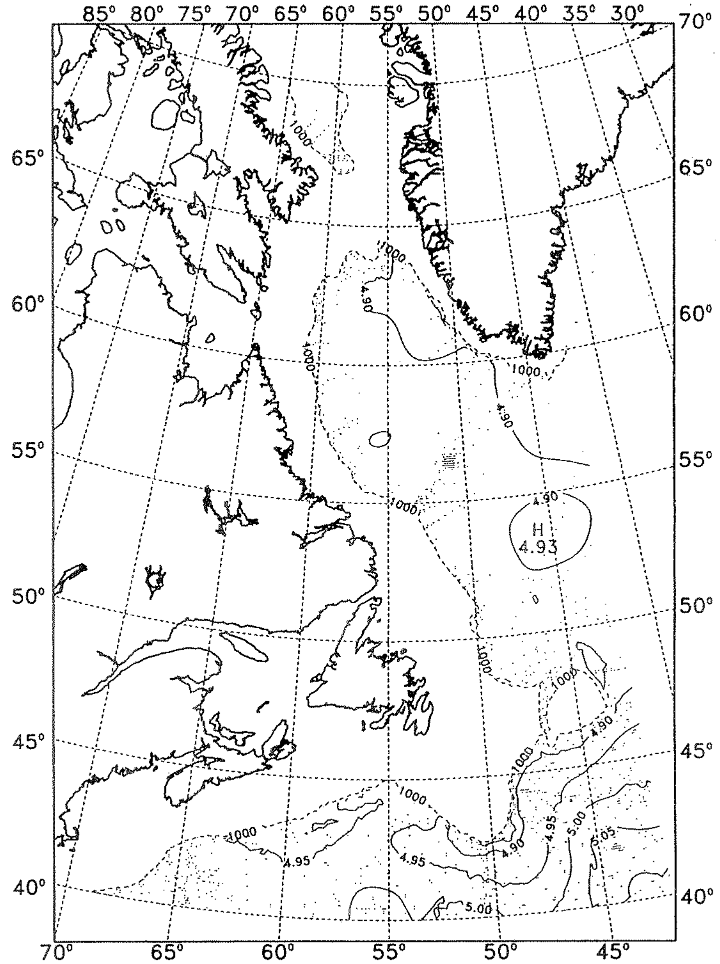
AUTUMN SALINITY AT 500m



AUTUMN TEMPERATURE AT 1000m

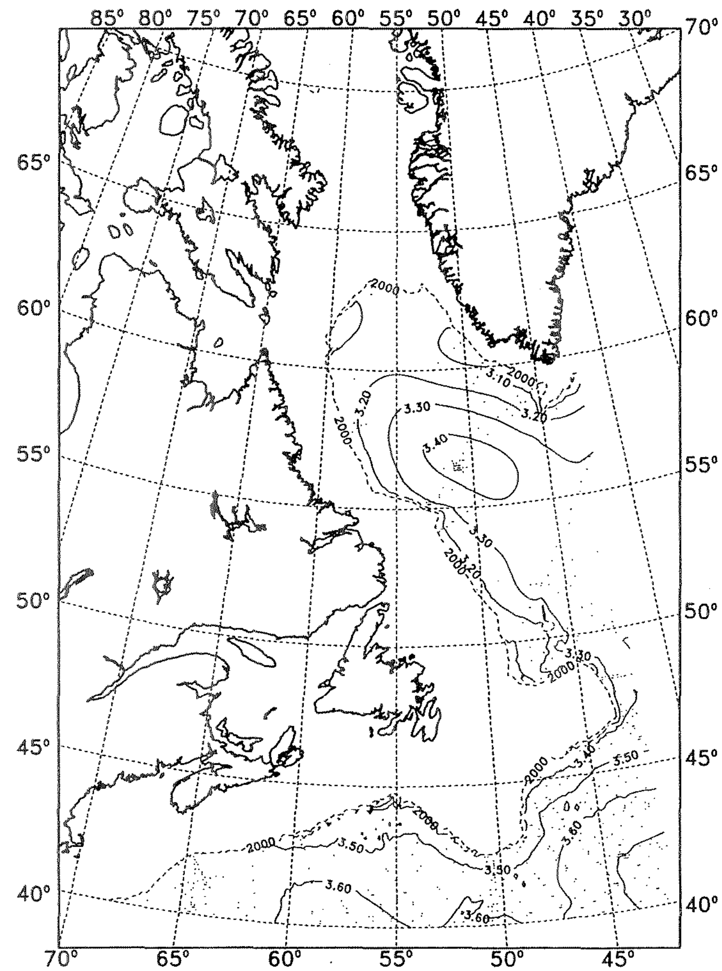


AUTUMN SALINITY AT 1000m

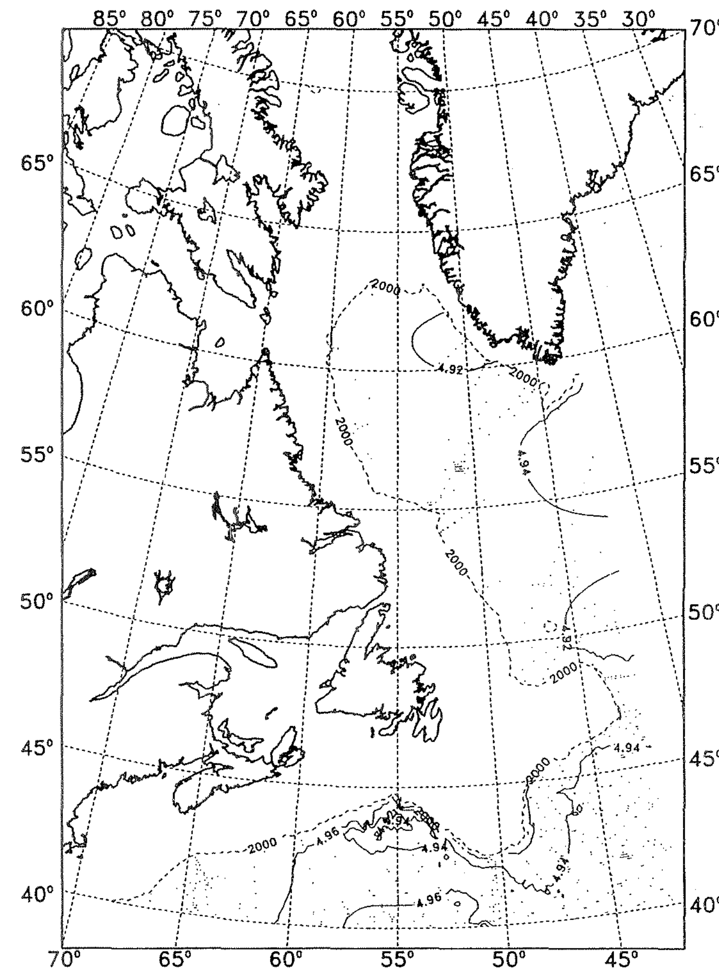


REAL VALUE=CONTOUR VALUE+30.0

AUTUMN TEMPERATURE AT 2000m

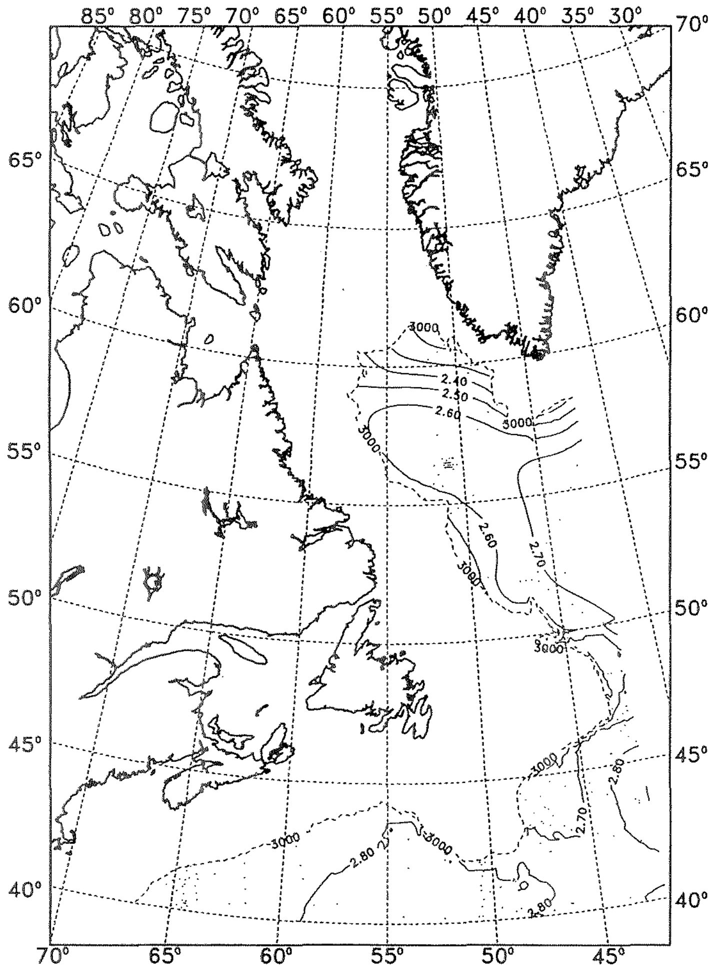


AUTUMN SALINITY AT 2000m

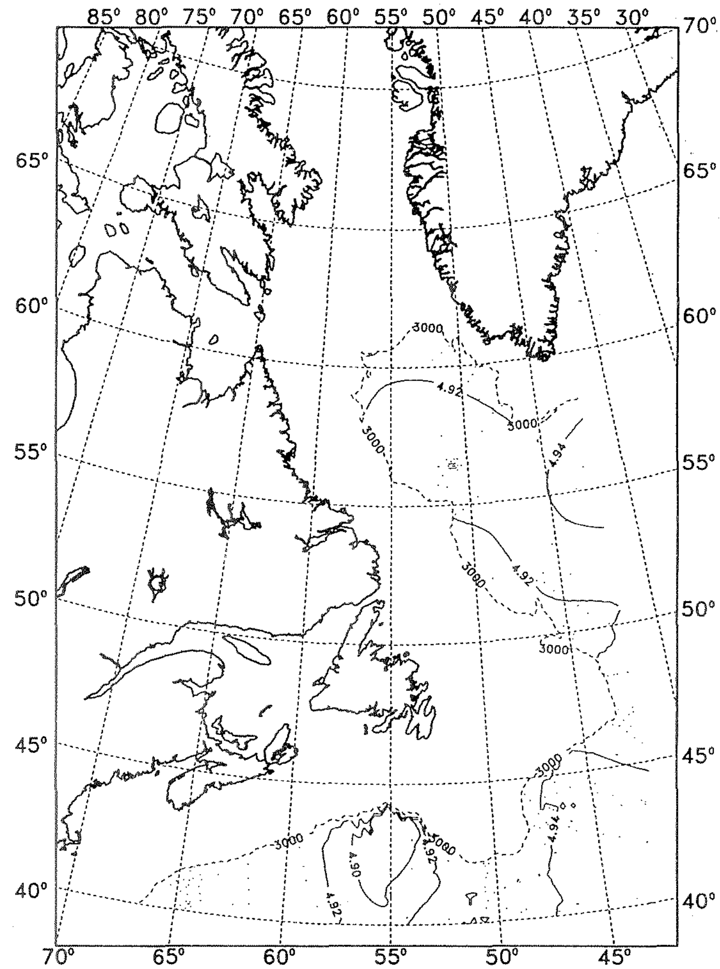


REAL VALUE=CONTOUR VALUE+30.0

AUTUMN TEMPERATURE AT 3000m



AUTUMN SALINITY AT 3000m



REAL VALUE=CONTOUR VALUE+30.0