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# High-resolution monthly temperature and salinity climatologies for the northwestern North Atlantic Ocean

by

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## TABLE OF CONTENTS

**Page**



Figures

## ABSTRACT

Tang, C.C.L, 2007. High-resolution monthly temperature and salinity climatologies for the northwestern North Atlantic Ocean. Can. Data Rep. Hydrogr. Ocean Sci. No.169: iv + 55 pp.

Temperature and salinity data from the hydrographic data base at Bedford Institute of Oceanography are objectively analyzed to produce monthly climatologies at 33 depths on a $1/6^0$ x $1/6^0$ grid. The area of coverage is $35^0 – 80^0$ N, $40^0 – 100^0$ W, which includes Baffin Bay, the Labrador Sea, Hudson Bay, N.E. Newfoundland Shelf, the Grand Banks, Newfoundland Basin, the Gulf of St. Lawrence, Scotia Shelf, the Gulf of Maine and the Gulf Stream region. The analysis used an iterative difference-correction procedure with topography dependent domains of averaging. Horizontal contour plots of the analyzed temperature and salinity fields at selected depths are presented.



## RÉSUMÉ

Tang, C.C.L, 2007. High-resolution monthly temperature and salinity climatologies for the northwestern North Atlantic Ocean. Can. Data Rep. Hydrogr. Ocean Sci. No.169: iv + 55 pp.

Les données sur la température et la salinité de la base de données hydrographiques à l'Institut océanographique de Bedford sont analysées de façon objective afin de produire des climatologies mensuelles à 33 profondeurs sur une grille de $1/6^o$ sur $1/6^o$. La zone de couverture est $35^o – 80^o$ N et $40^o – 100^o$ O, ce qui comprend la baie de Baffin, la mer du Labrador, la baie d'Hudson, la plate-forme du nord-est de Terre-Neuve, les Grands Bancs, le bassin de Terre-Neuve, le golfe du Saint-Laurent, le plateau néo-écossais, le golfe du Maine et la région du Gulf Stream. L'analyse a consisté en l'utilisation d'une procédure itérative de correction des différences avec domaines d'établissement de moyennes dépendants de la topographie. Des tracés de contours horizontaux des champs de température et de salinité analysés aux profondeurs choisies sont présentés.

## 1. Introduction

Over the past 20 years, several temperature and salinity climatologies of the world ocean have been produced (Levitus, 1982; Conkright et al., 1998; Conkright et al., 2001; Locarnini et al., 2006). The horizontal resolution of these data sets is typically $1^0$ in latitude and longitude. Such a resolution cannot resolves small-scale features in coastal oceans such as sharp front over the shelf break, and is inadequate for regional-scale modeling. A high-resolution seasonal data set for the northwestern North Atlantic Ocean ($1/6^0$ x $1/6^0$) has been compiled by Tang and Wang (1996) to meet the needs of regional modeling. The monthly data set described in this report is a follow-up of the seasonal data set. In the report, the method of analysis is explained and the temperature and salinity fields from the analysis at selected depths are presented.

## 2. Data source

The data used in the analysis were taken from the hydrography data base at Bedford Institute of Oceanography. The data set encompasses the entire eastern Canadian seaboard and has a temporal coverage from 1910s to the present. The sources of the data base include Marine Environmental Data Service (MEDS) of Canada and National Ocean Data Center (NODC) of U.S..

In this work, data from the earliest date to 2005 in an area bounded by the $35^0$ N, $80^0$ N, $40^0$W and $100^0$ W latitude/longitude lines were retrieved for analysis.

## 3. Method of analysis

The method of analysis is a modification of the iterative difference-correction procedure developed by Levitus (1982) for the world ocean in which the domains of averaging are circular areas. In this analysis, depth dependent domains of averaging were used to reflect the anisotropic nature of the temperature and salinity fields, in particular, over steep slopes. The analyzed data were given on a $1/6^0$ x $1/6^0$ grid at 32 standard depths (Table 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 data base, and stations with data values outside the ranges 26 $^0/_{00}$ ~ 38 $^0/_{00}$ for salinity and $-2^0$C ~ $35^0$C 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 monthly bins*

The raw data for each month were sorted into bins of $1/12^0$ x $1/12^0$ cells and 33 depth segments. The depth range for each segment is given in Table 1. The exceptions were data

of the winter months (January, February, March) at 4500 m and 5000 m, for which the three months' data were combined to increase the data density. Data in a given bin are considered to be located at the center of the cell and at the standard depth for the horizontal analysis described in sub-section **(d)**. For each bin, the mean temperature and salinity in given years and months were calculated first. The means were then averaged over different years to produce the final means for each bin. Such a two-step averaging is necessary in order to remove the bias caused by the unevenly distribution of the data points over the years.

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

***(c) Vertical interpolation***

Small data gaps in the vertical were filled by averaging the data values at 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 at those depths. Vertical interpolation by this method has the advantage that even if the data have uneven depth distribution, the interpolated data values are constrained by the adjacent values and represent a reliable estimate.

***(d) Analysis on the horizontal planes***

An iterative difference-correction method was employed to smooth and interpolate the data horizontally. At each standard depth, the data were averaged with a distance and topography dependent weight for each grid point according to the following equation:

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

where $S_{guess}$ is the initial guess at a grid point, $S_i$ is the data value and $W_i$ is the weight. The summation is over data points within a given radius of influence and meeting a criterion for water depth.

Over a sloping ocean bottom, the horizontal coherent scale of temperature and salinity in the cross-slope direction is in general smaller that in the along-bottom slope direction. Data at locations with water depths much greater or smaller than the water depth of the grid point should not be included in the summation. 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 the data point respectively. A depth dependent $\delta h$ was used to take into account the fact that the 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 $W_i$:

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

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

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. For each iteration, S calculated in the previous iteration was used as the initial guess. For the first iteration, the mean of all data at the same standard depth was used as the initial guess. The radii of influence for the three iterations are set at 800 km, 500 km and 200 km if the depth is equal or less than 1100 m, and 1000 km, 600 km and 400 km if the depth is greater than 1100m.

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 x standard deviation) were removed. This procedure was repeated till all data points were within the tolerance limits.

In the horizontal analysis, a special treatment was applied to Baffin Bay and Hudson Bay. Since the water in Hudson Bay and in Baffin Bay below the sill depth of Davis Strait, 650 m, is not influenced by the Labrador Sea in a significant way, the temperature and salinity analysis in those areas and depths used data within Hudson Bay and Baffin Bay themselves.

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

In areas with sparse data, the temperature and salinity calculated from step ***(d)*** may have large differences between neighboring depths. This is due to the fact that vertical coherence was not taken into consideration in the horizontal analysis. To improve the results, three-dimensional smoothing was applied to the data from step ***(d)*** on a $1/6^0$ x $1/6^0$ grid (every other grid point of the $1/12^0$ x $1/12^0$ grid) for the following months and areas:

Winter (January, February, March): the entire area
Fall (October, November, December): north of $50^0$ and water depths greater or equal to 2000 m.

The temperature or salinity value at grid point j, $\overline{S_j}$, was computed from

$$\overline{S}_j = \frac{\sum_i w_i S_i}{\sum_i w_i}$$

where $S_i$ is the horizontally interpolated data value from step ***(d)***. The summation is over data point satisfying (2). The weights, $w_i$, 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, $z_i \leq 1000$ 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.

For all the other months and areas, a two-dimensional horizontal smoothing (i.e., $D = \infty$) was used. The main effect is to smooth the contour lines.

***(f) Filling holes in the horizontal planes***

Holes in the horizontal planes after steps ***(d)*** and ***(e)*** were filled by averaging the data over a $5^0 \times 5^0$ grid. A special treatment is applied to Baffin Bay and Hudson Bay (including Hudson Strait and Foxe Basin) where the water is covered by sea-ice most of the year. In areas with no data in Baffin Bay and Hudson Bay, the grid points have no temperature and salinity

values. The criterion of no data is no data point within $\pm 1^0$ in latitude and longitude from the grid point.

## 4. Contour plots at selected depths

Contour plots of the temperature and salinity fields at 0 m, 100 m, 500 m, and 1000 m are presented in the pages following Table 1. The binned and vertically interpolated data points on the $1/12^0$ x $1/12^0$ grid are shown as red dots. The purpose is to allow the user to judge whether the analyzed data in a given area are suitable for a particular application. The blue line is the bathymetry contour of the indicated depth. Since the maximum depth of the analyzed data (Table 1) may be greater that the bottom depth, the red dots may appear outside the bathymetry contour, i.e., in Laurentian Channel in the January 500 m map. These points should be ignored in applications.

## 5. Applications

The monthly temperature and salinity data can be used to study the annual variation of water properties, estimate geostrophic currents, volume/freshwater transports and mixed-layer depth. They can also be used to initialize and validate numerical models. A partial list of research papers using this data set are given in the references section.

## REFERENCES

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Conkright, M., S. Levitus, T. O'Brien, T. Boyer, J. Antonov, and C. Stephens, 1998. *World Ocean Atlas 1998 CD-ROM Data Set Documentation*, Tech. Rep. **15**, NODC Internal Report, Silver Spring, MD, 1998. 16pp.

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Wu, Y., T. Platt, C. L. Tang, S. Sathyendranath, 2007. Regional differences in the timing of the spring bloom in the Labrador Sea. *Marine Ecology Progress Series*. In press.

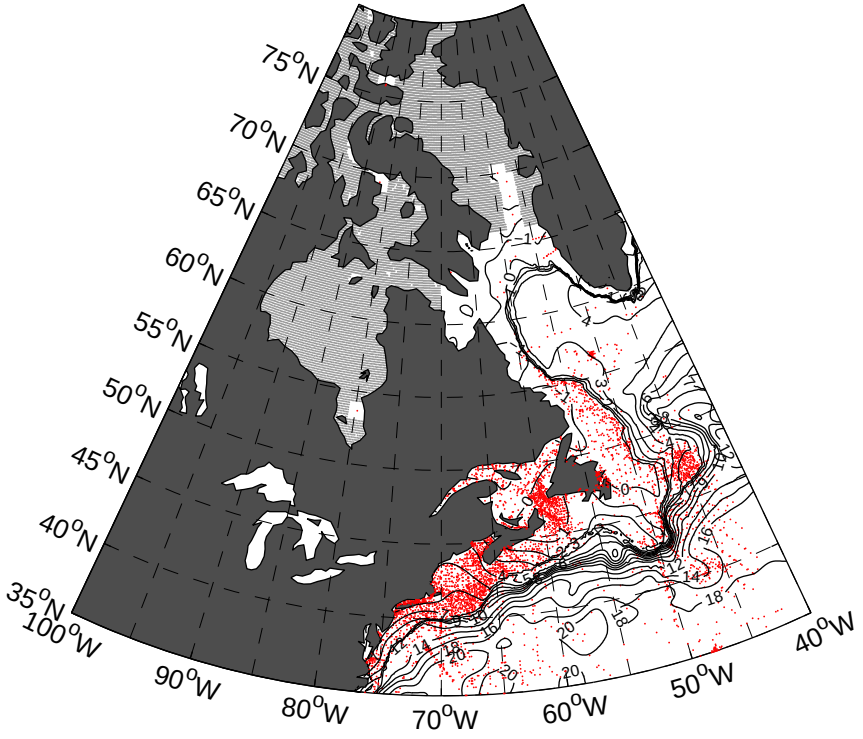
Yao, T. and C.L. Tang, 2003: The formation and maintenance of the North Water. *Atmosphere-Oceans*, **41**, 187-201.

**Table 1. Standard depths**

Standard depths (right column) and the associated depth ranges (first and second columns) for the analysis.

| DATA DEPTH (m) lower limit | DATA DEPTH (m) 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 |

## January Temperature at 0m

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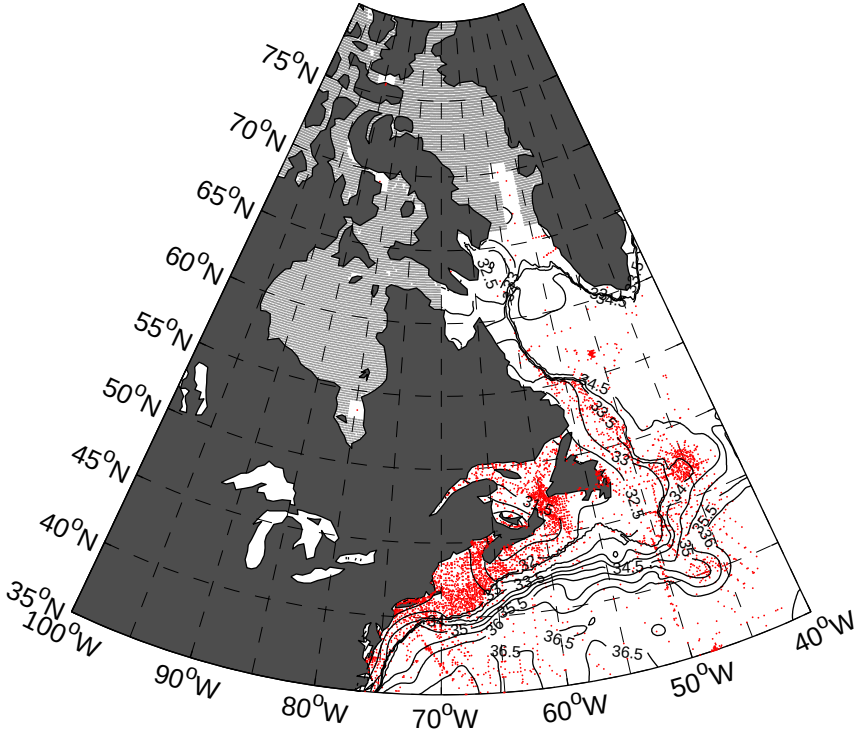

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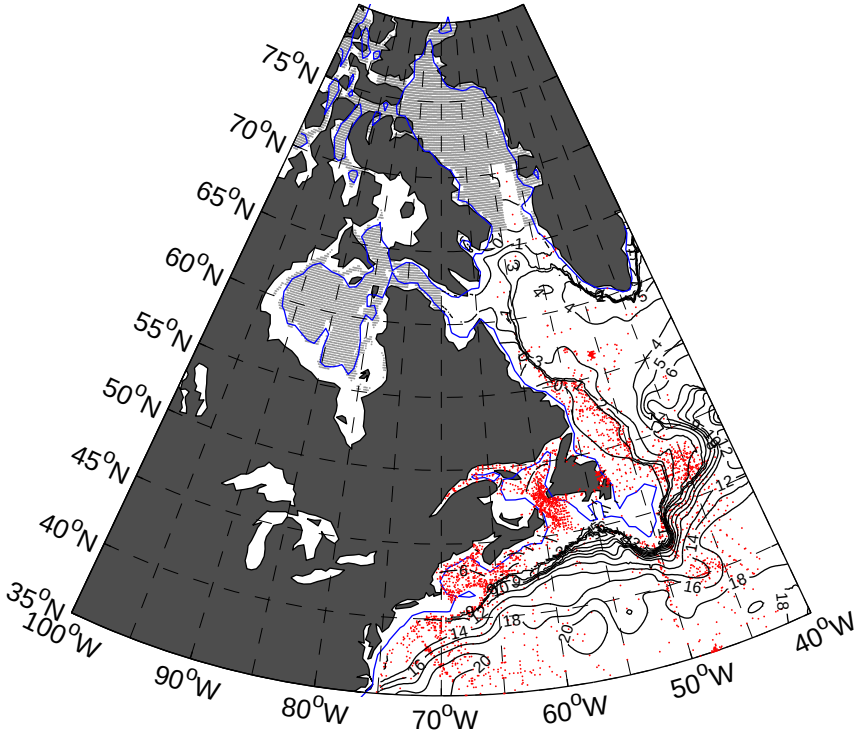


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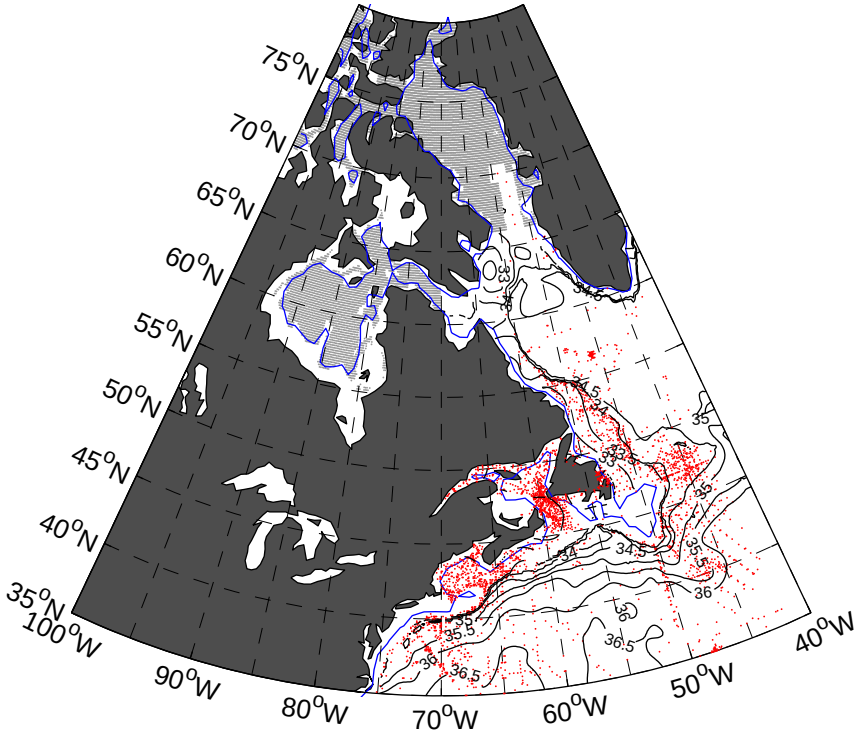

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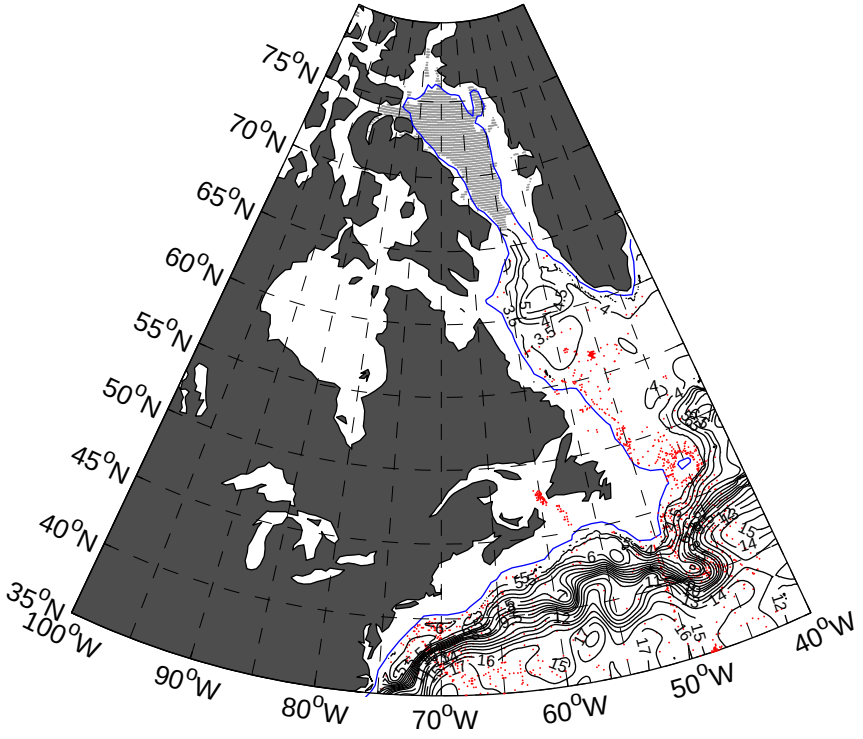


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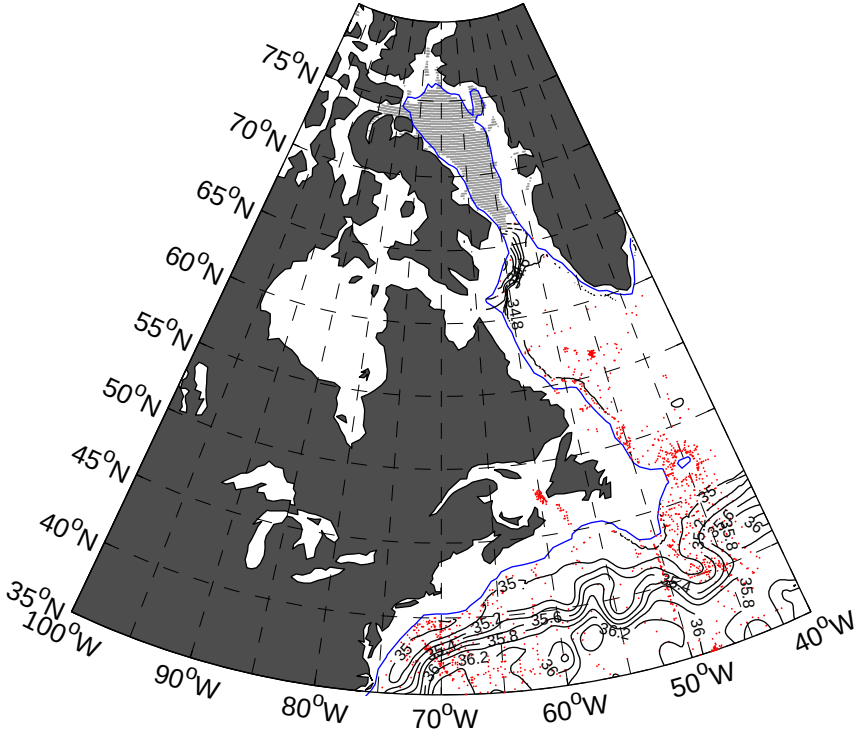

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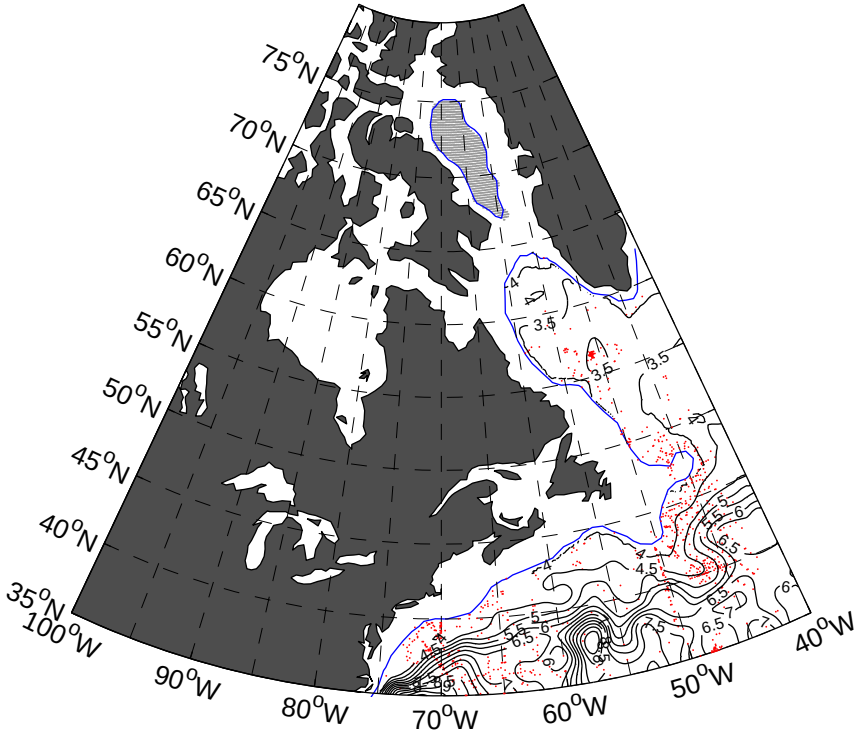


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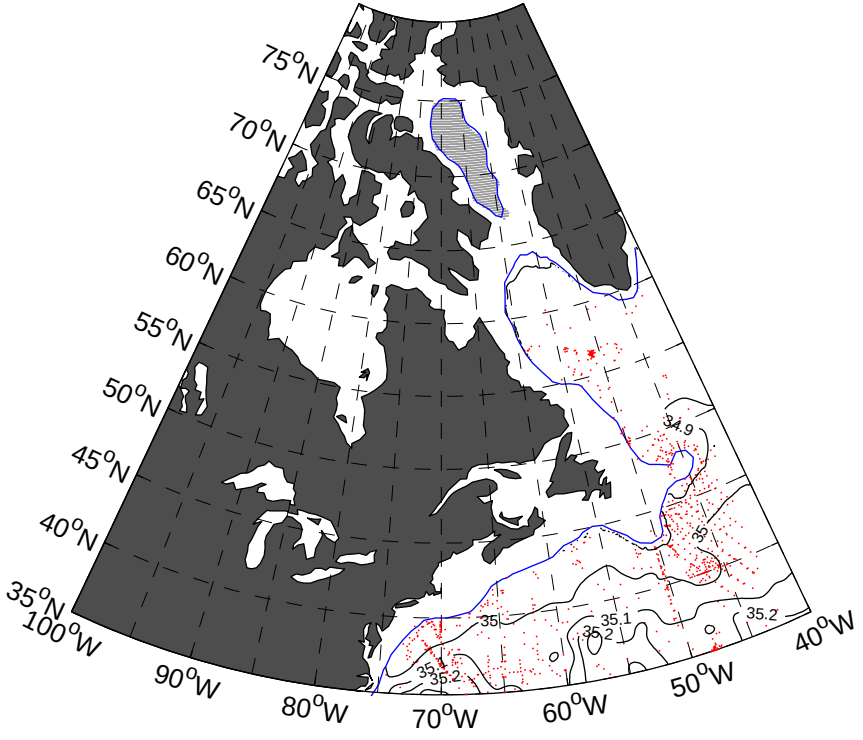

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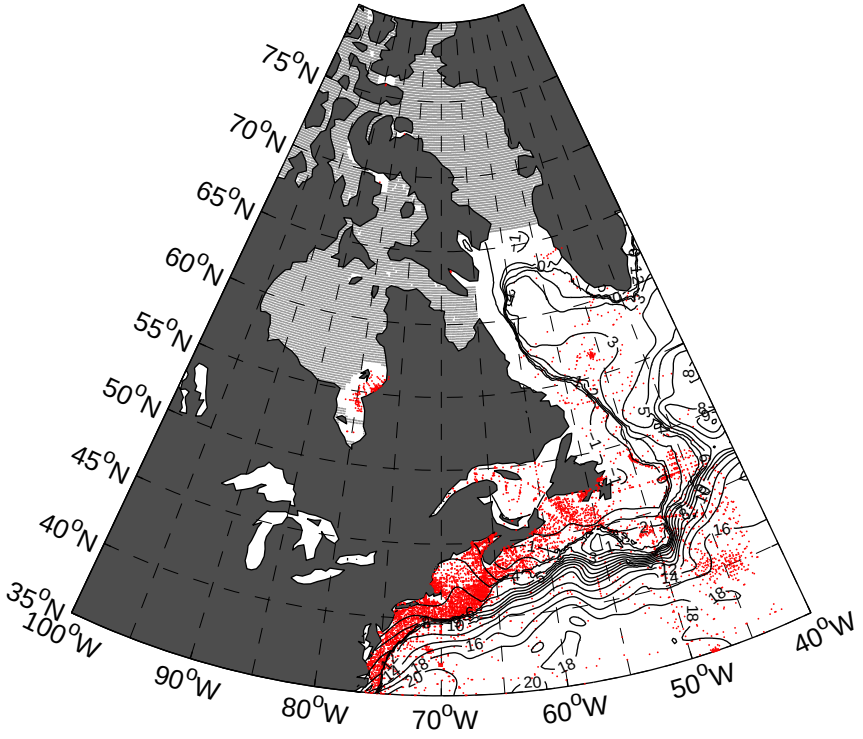


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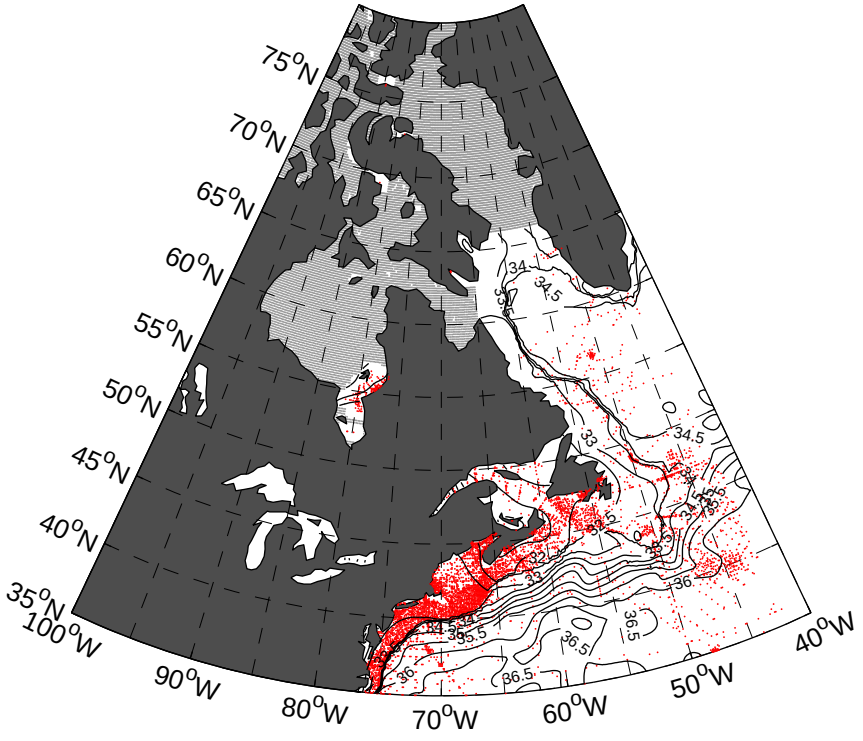

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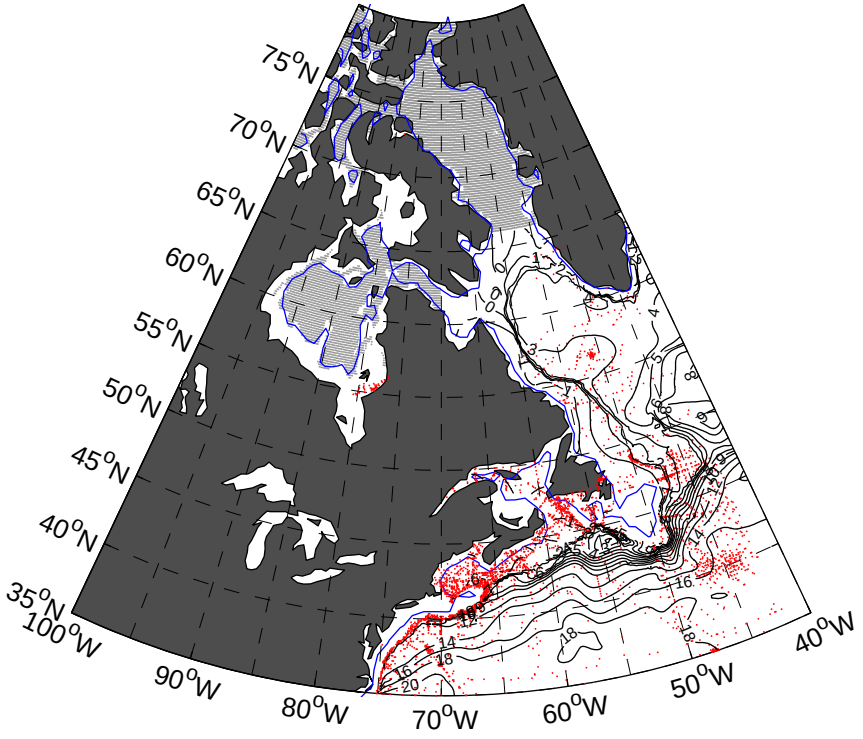


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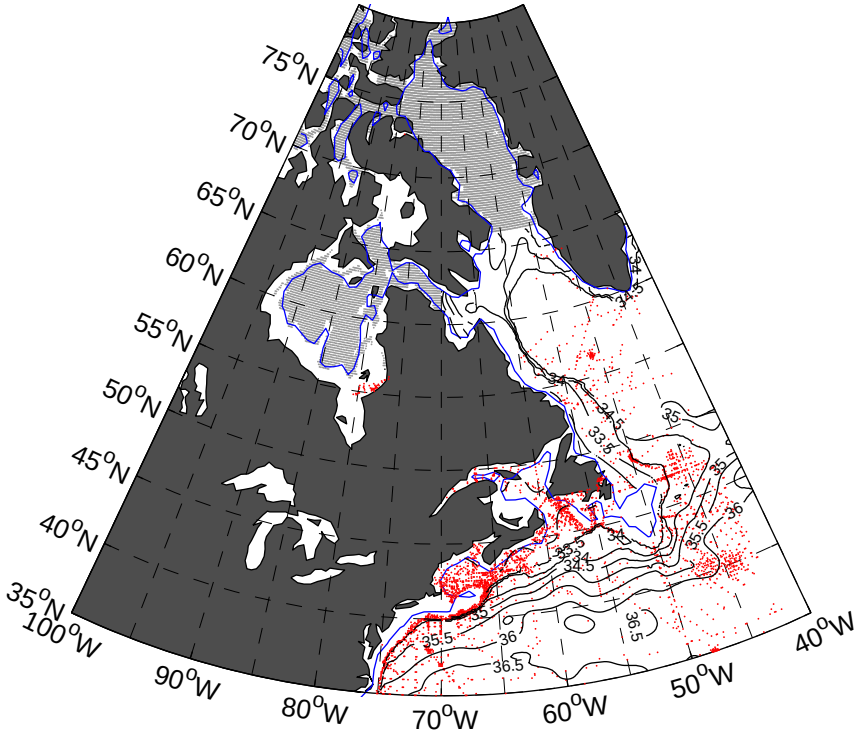

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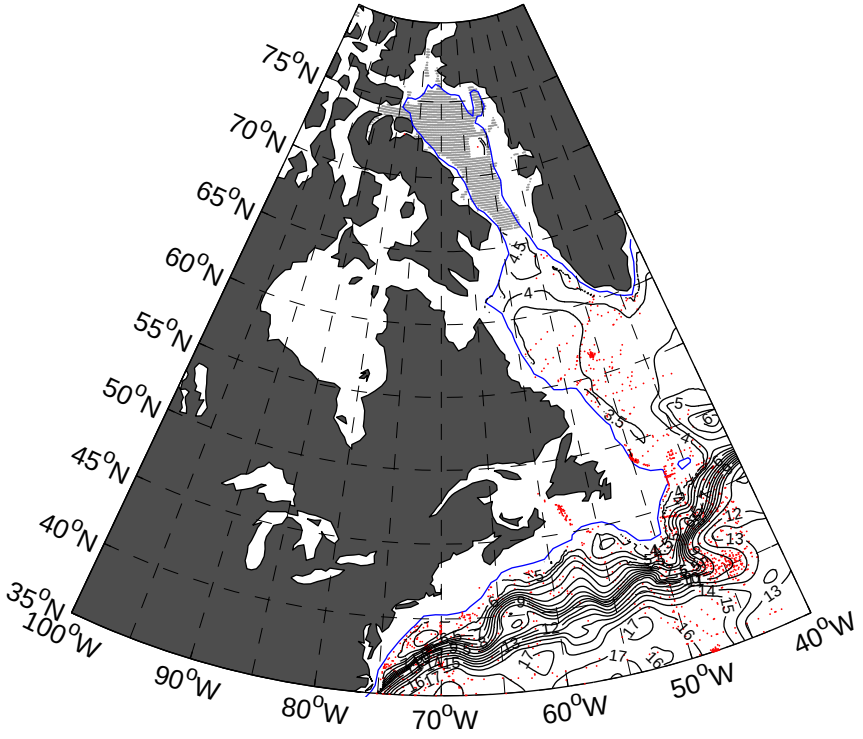


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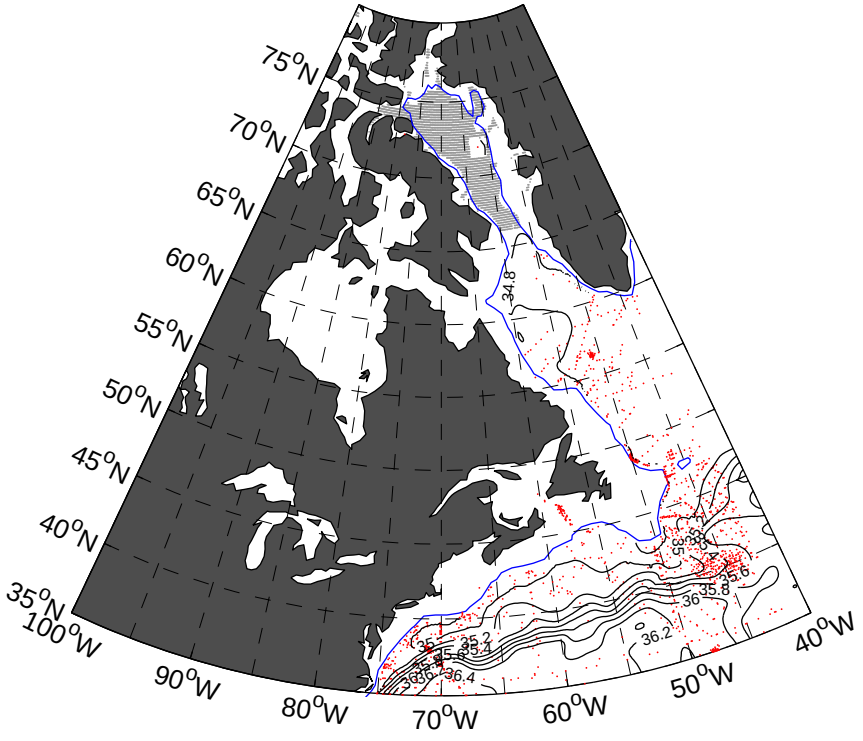

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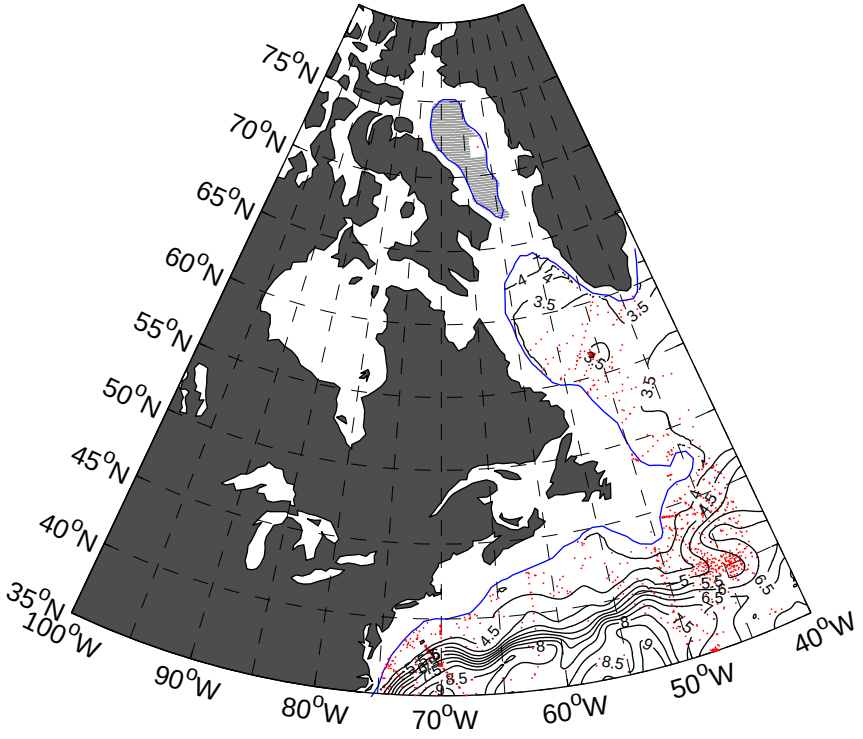


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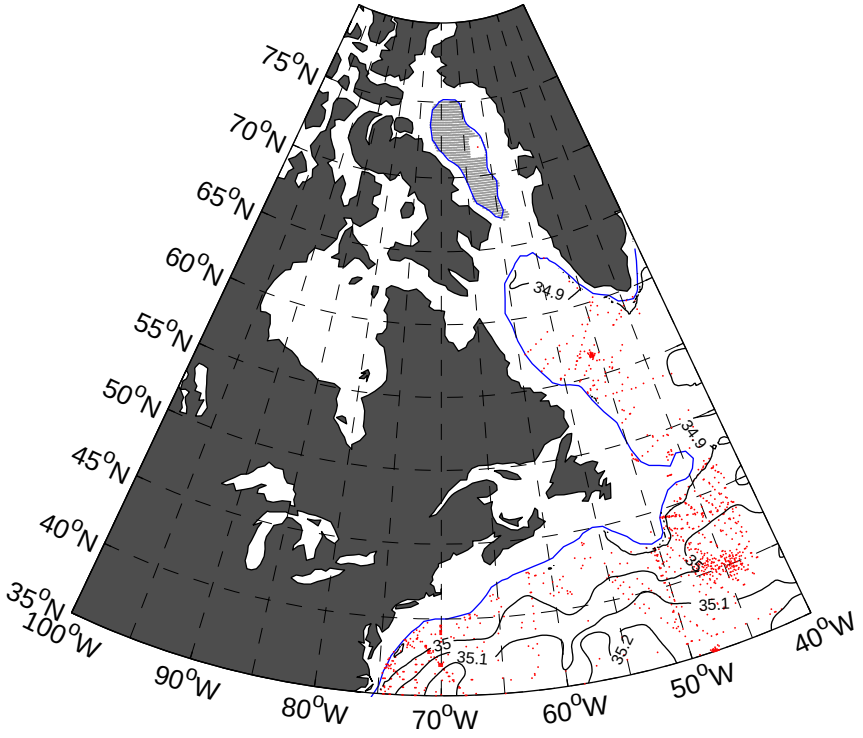

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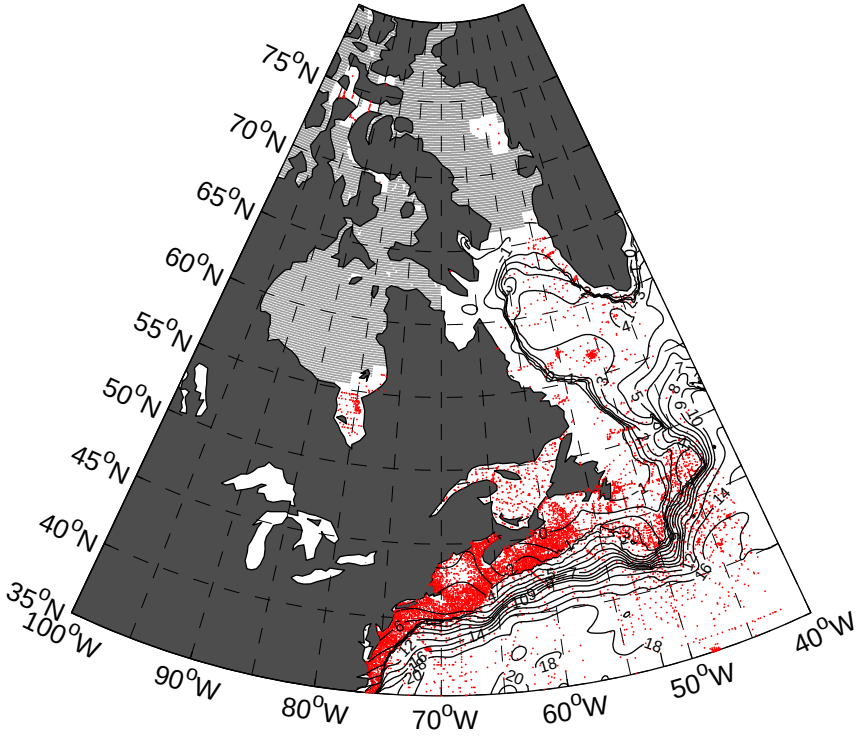


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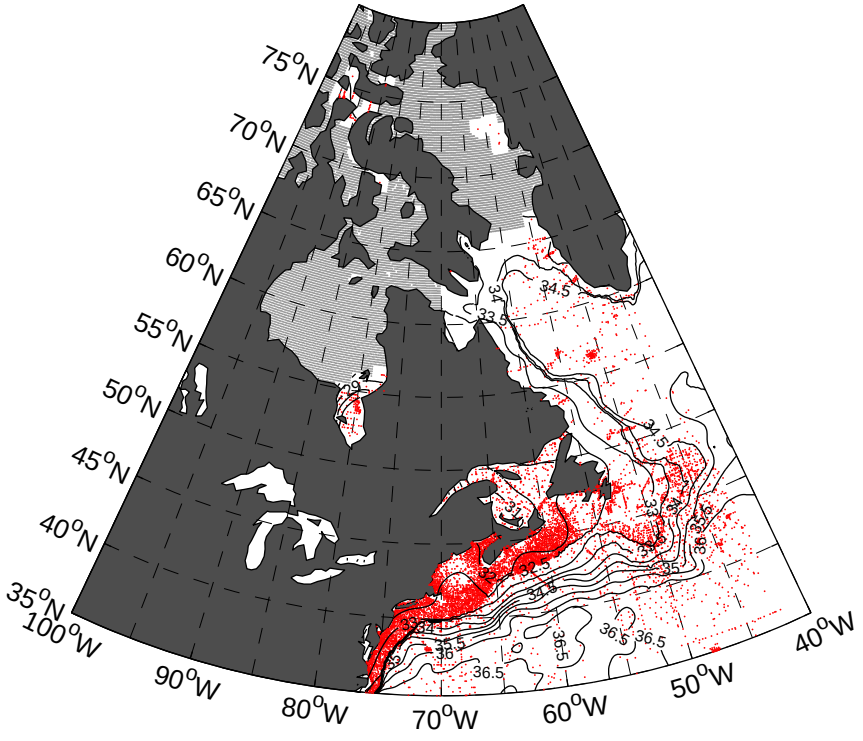

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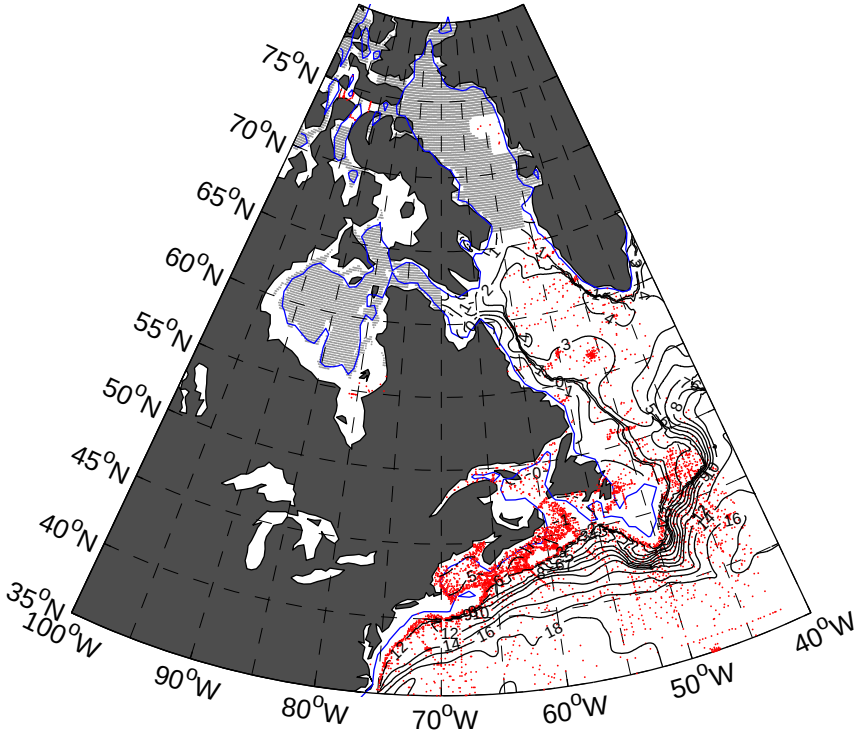


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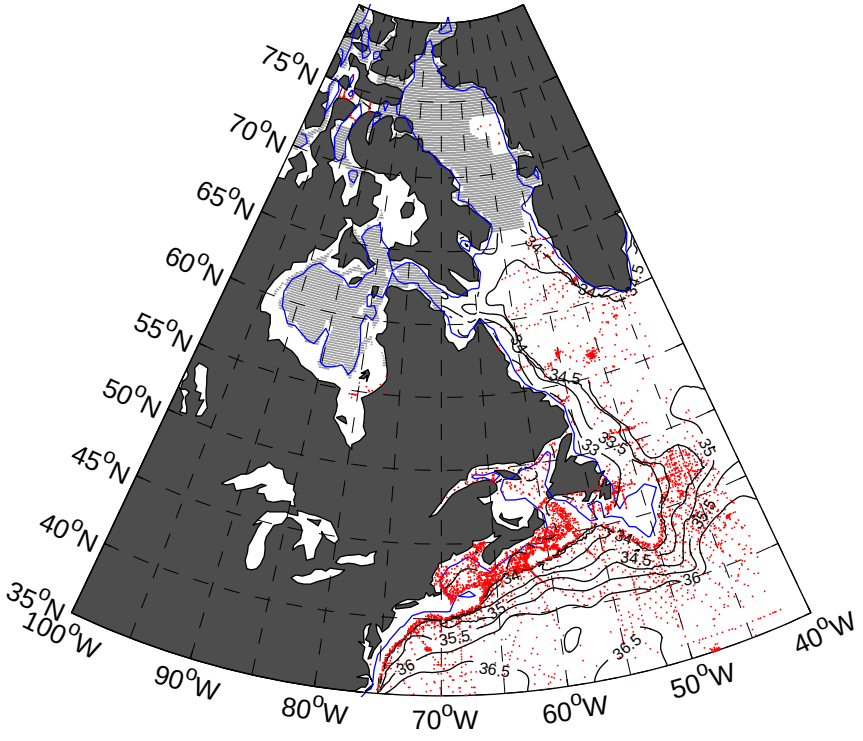

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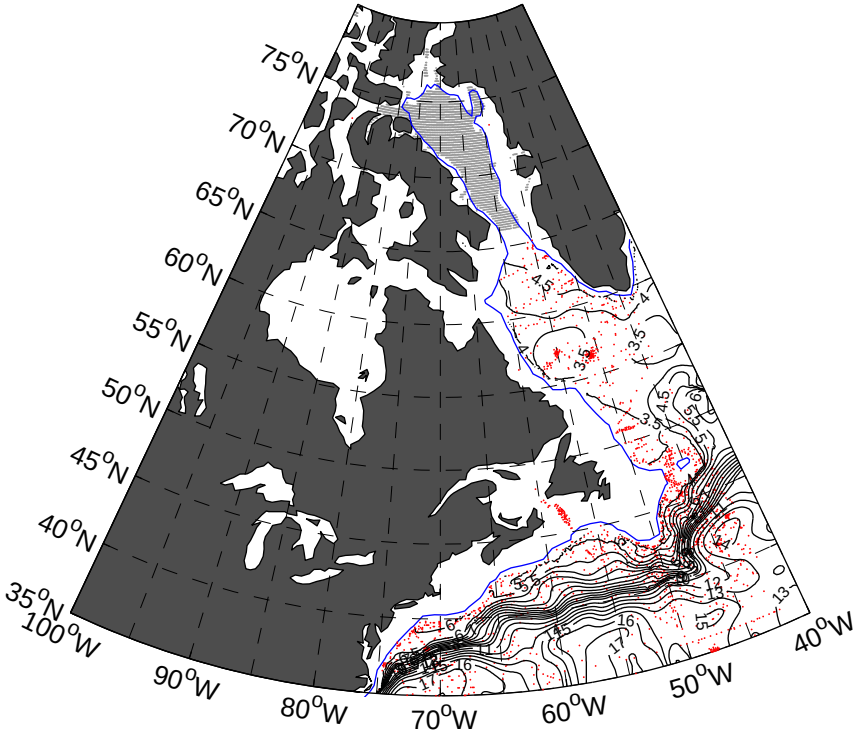


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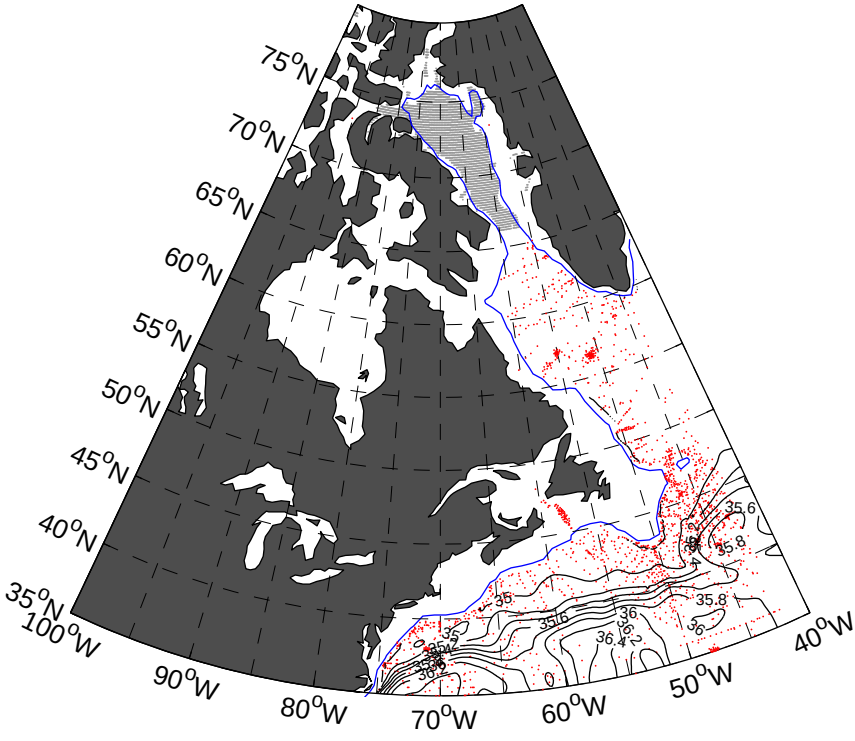

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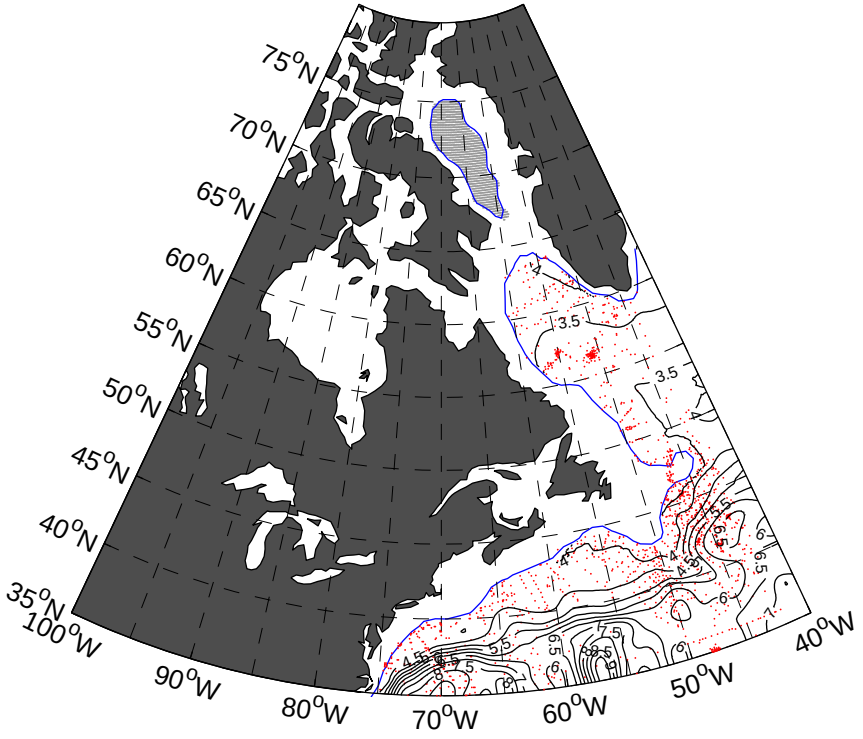


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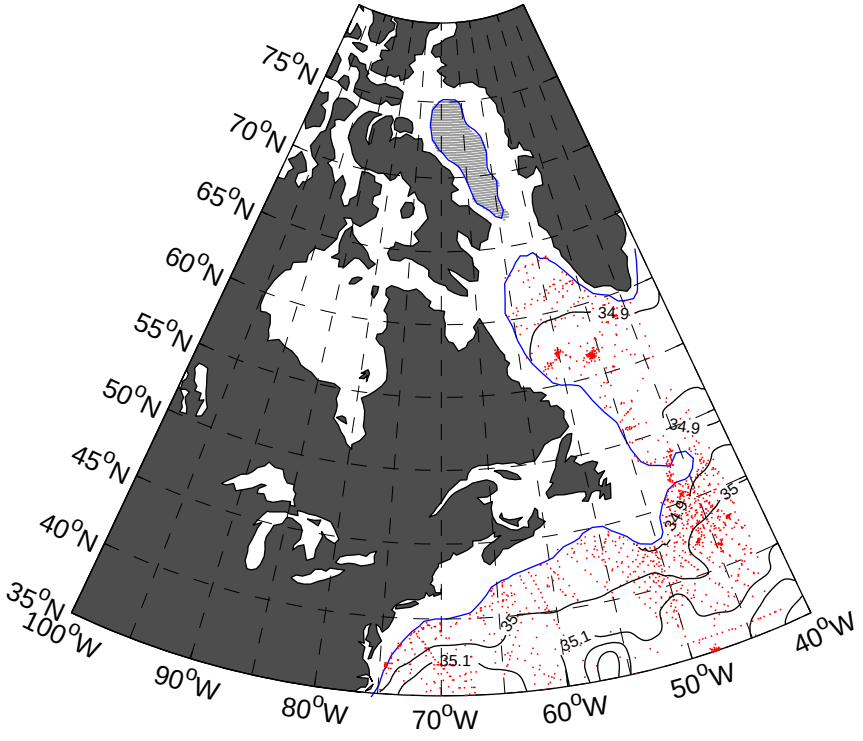

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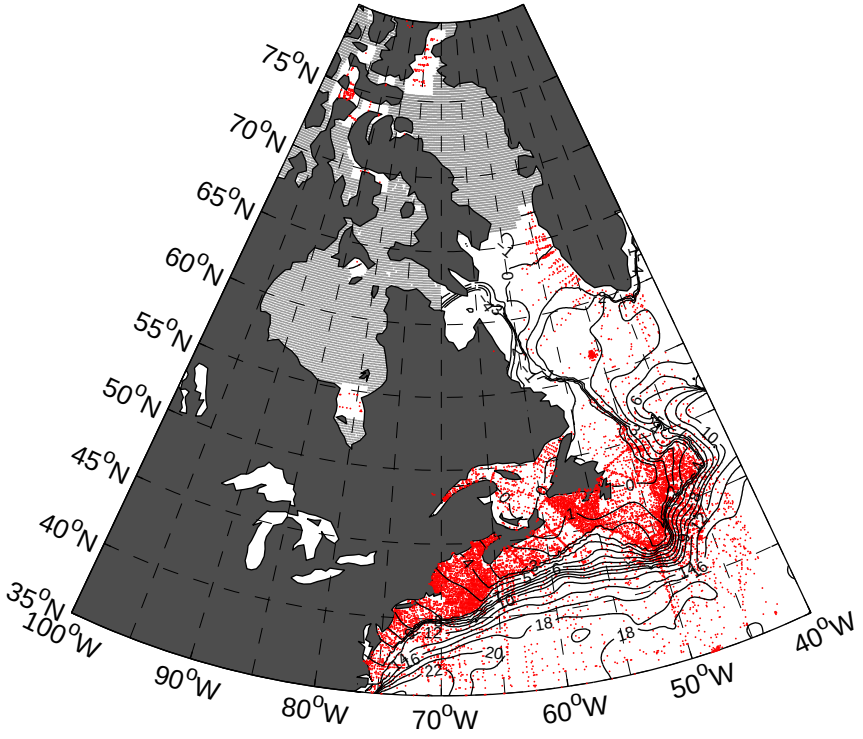


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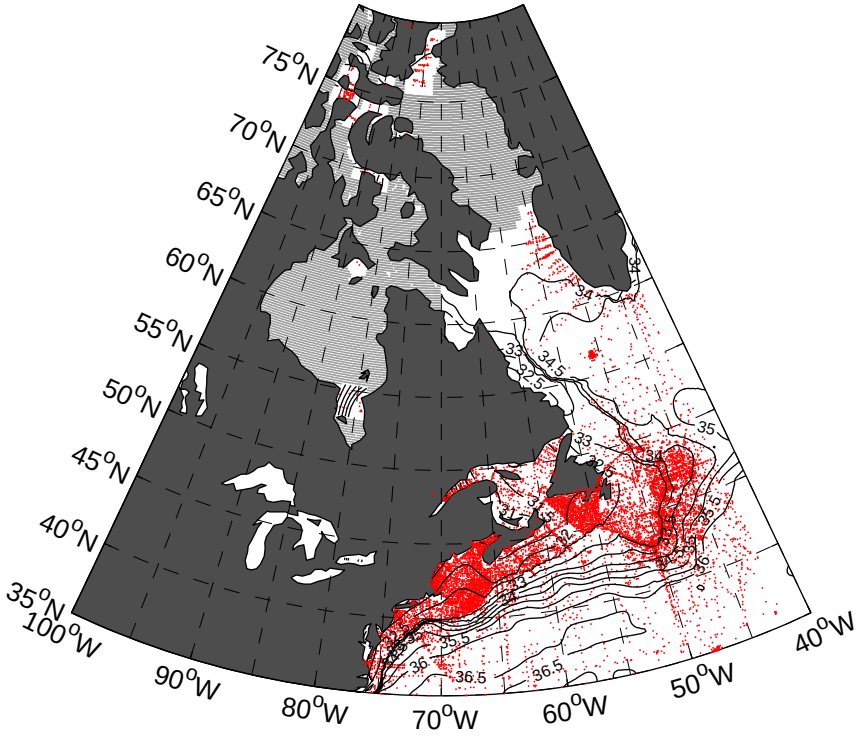

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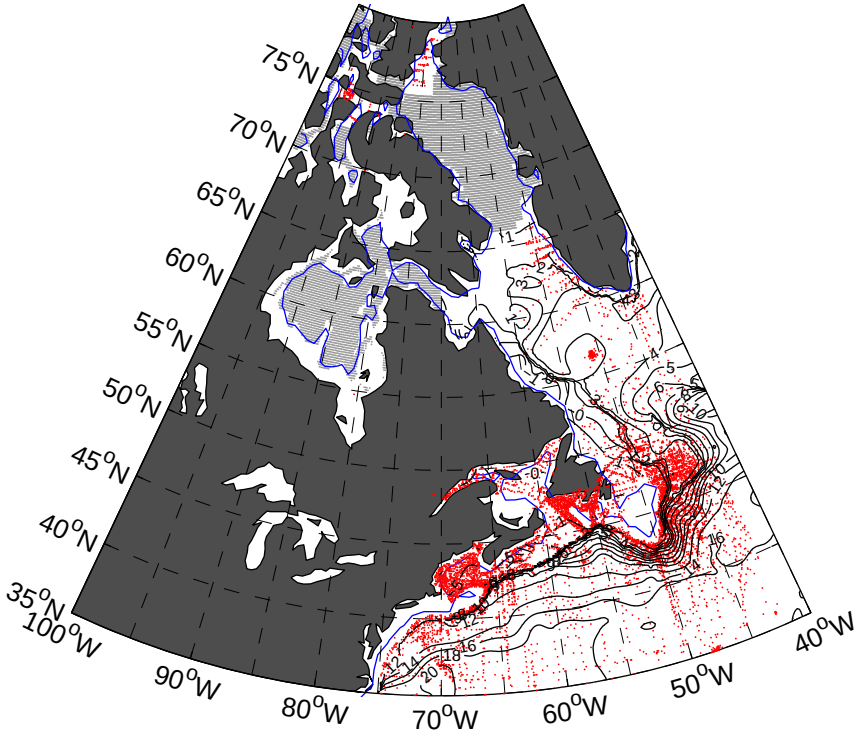
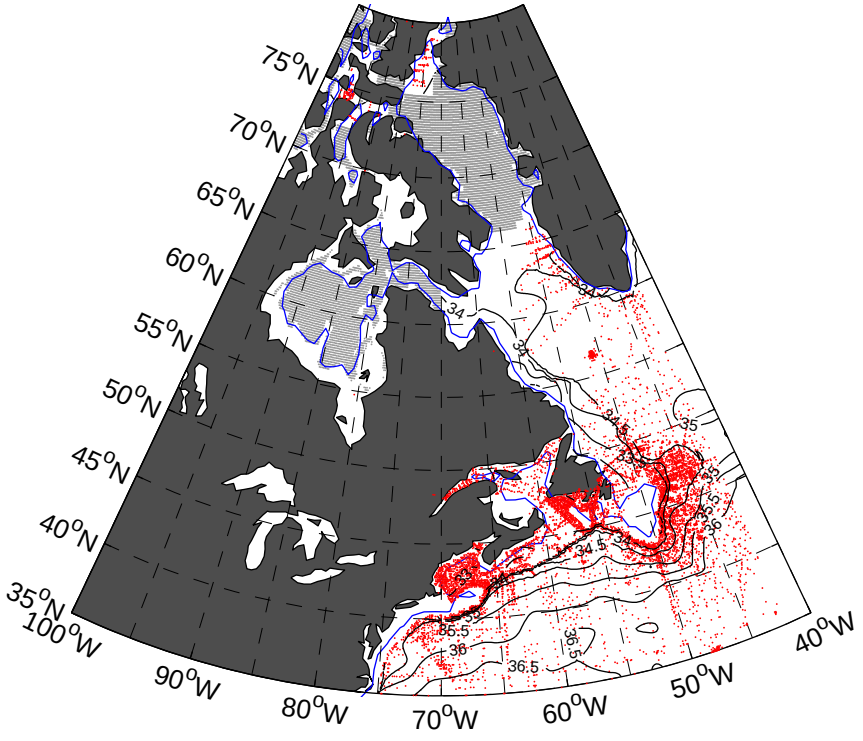
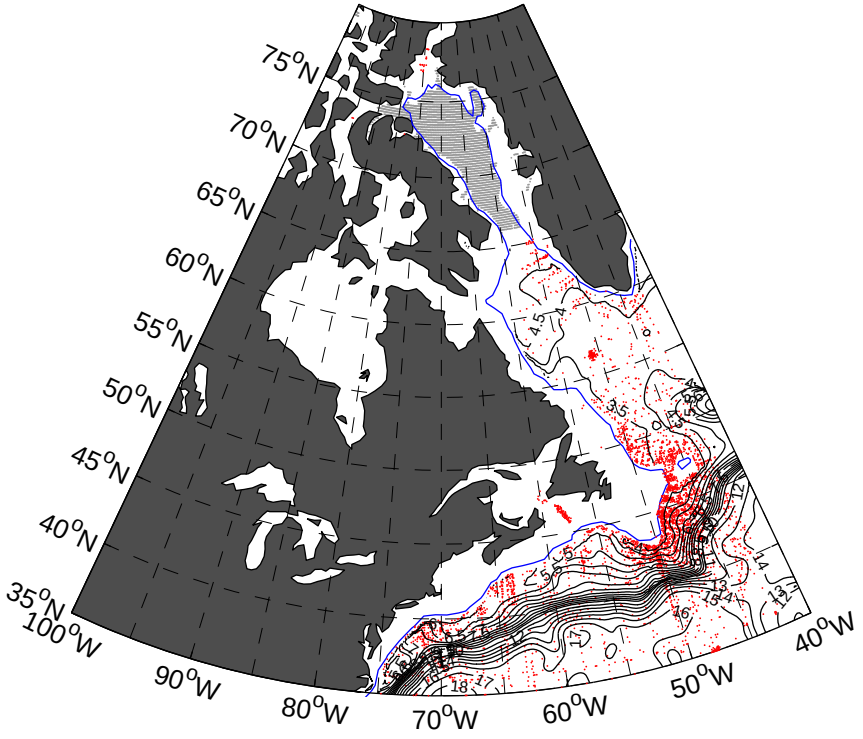


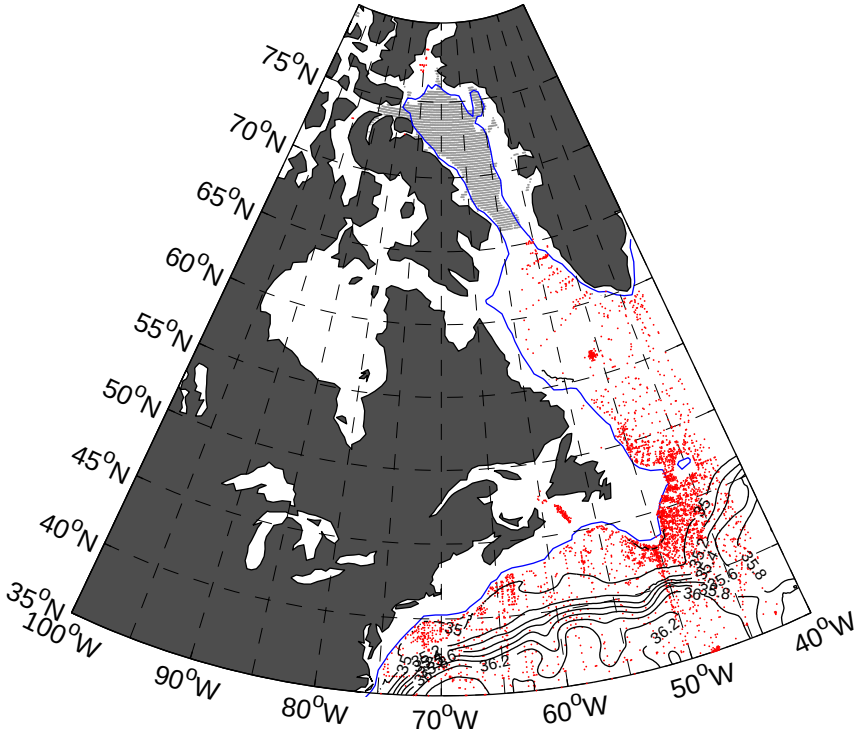

## April Salinity at 100m



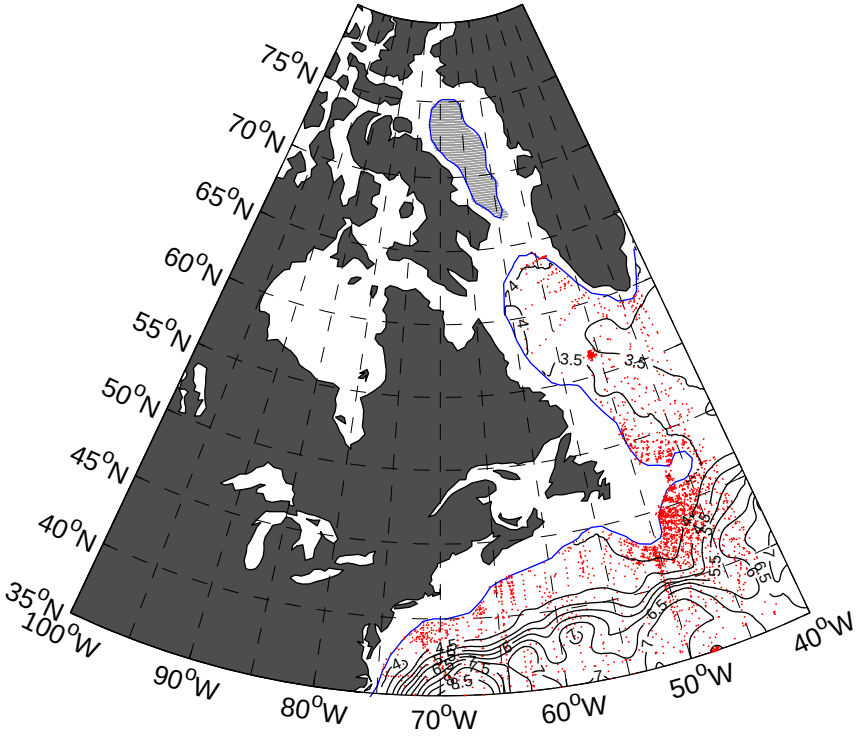
## April Temperature at 500m



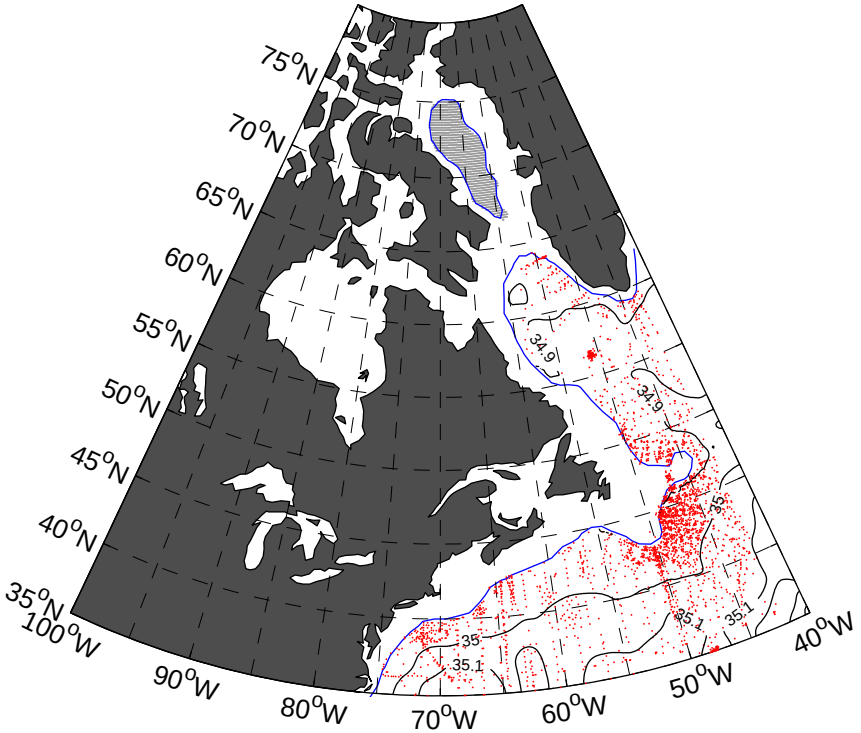

## April Salinity at 500m

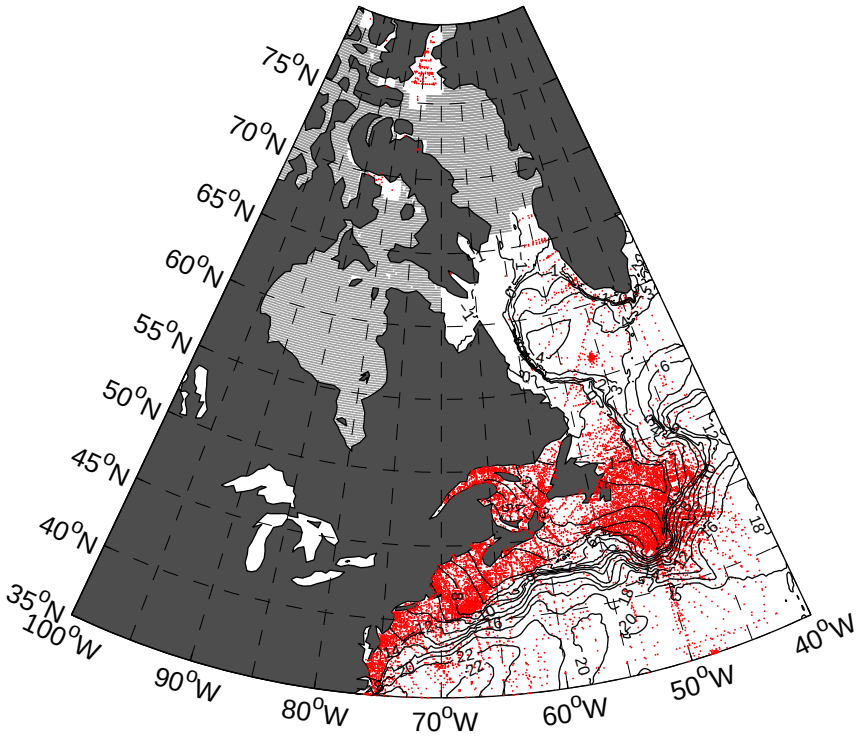


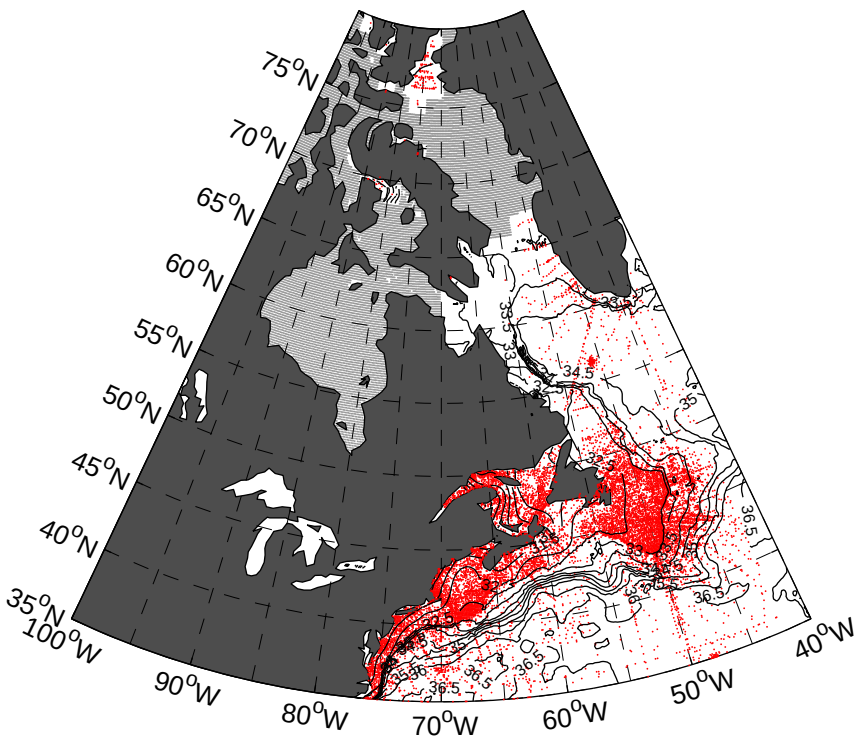
**April Temperature at 1000m**



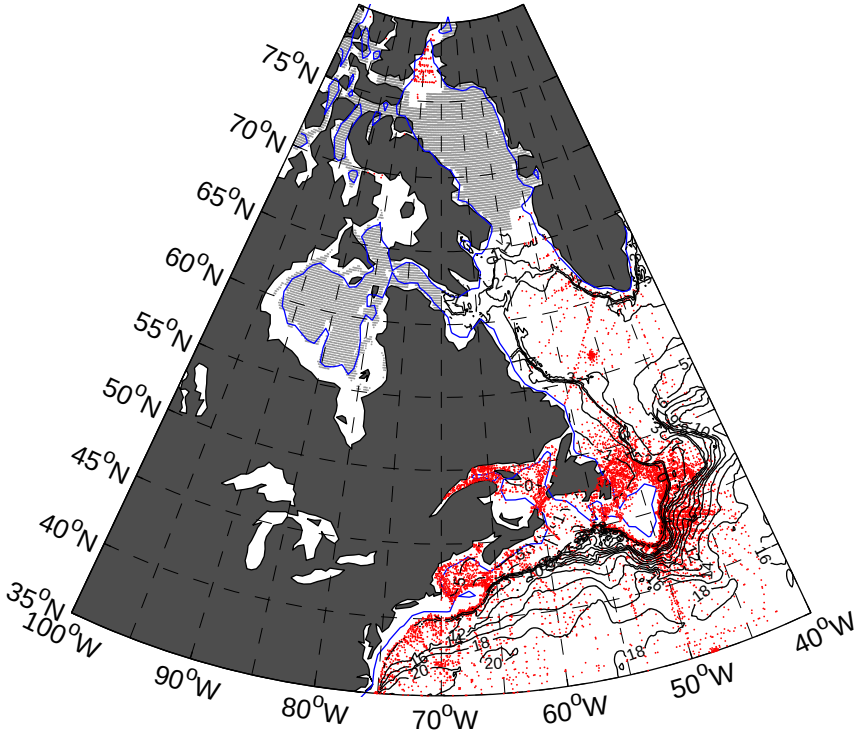

**April Salinity at 1000m**



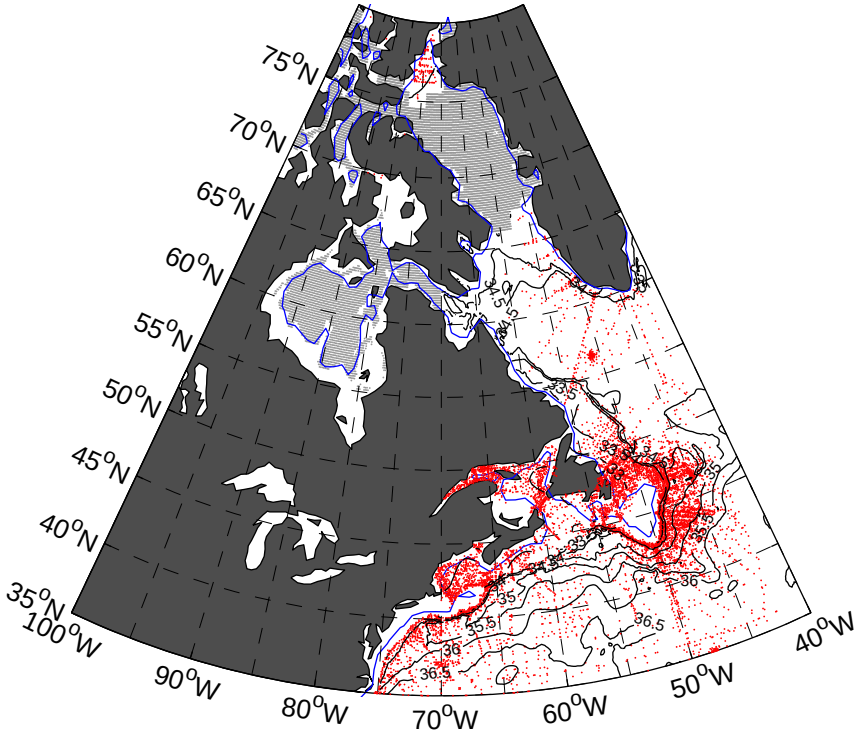

May Temperature at 0m
75°N
70°N
65°N
60°N
55°N
50°N
45°N
40°N
35°N
100°W
90°W
80°W
70°W
60°W
50°W
40°W


May Salinity at 0m
75°N
70°N
65°N
60°N
55°N
50°N
45°N
40°N
35°N
100°W
90°W
80°W
70°W
60°W
50°W
40°W

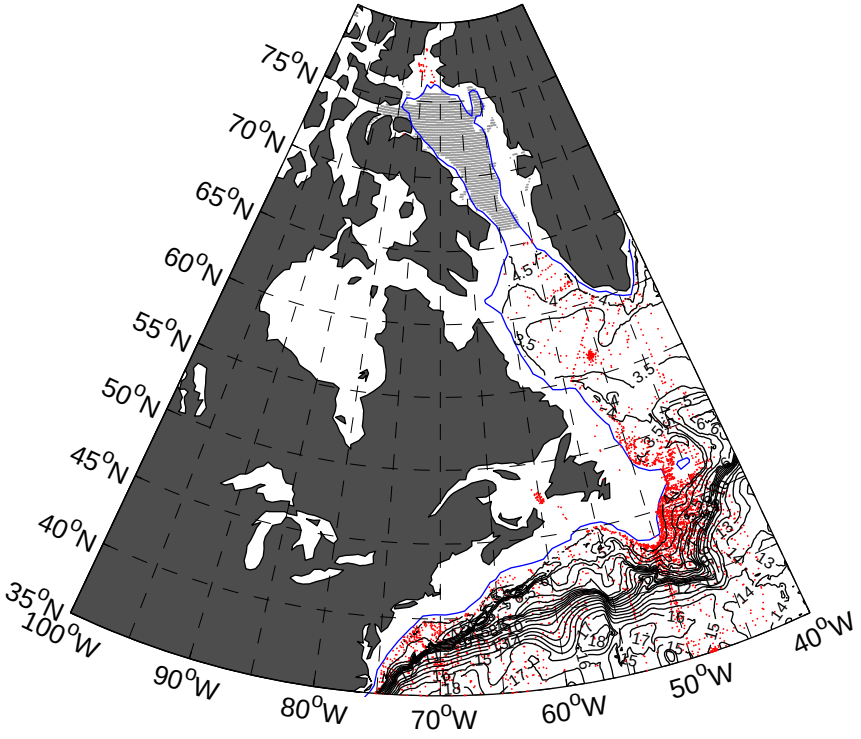
**May Temperature at 100m**



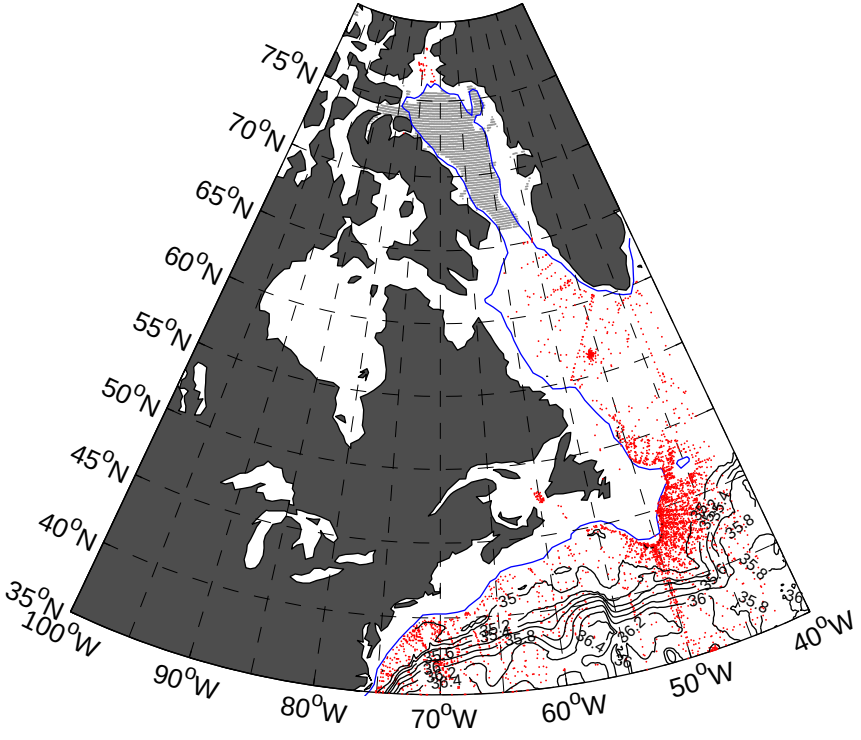

**May Salinity at 100m**



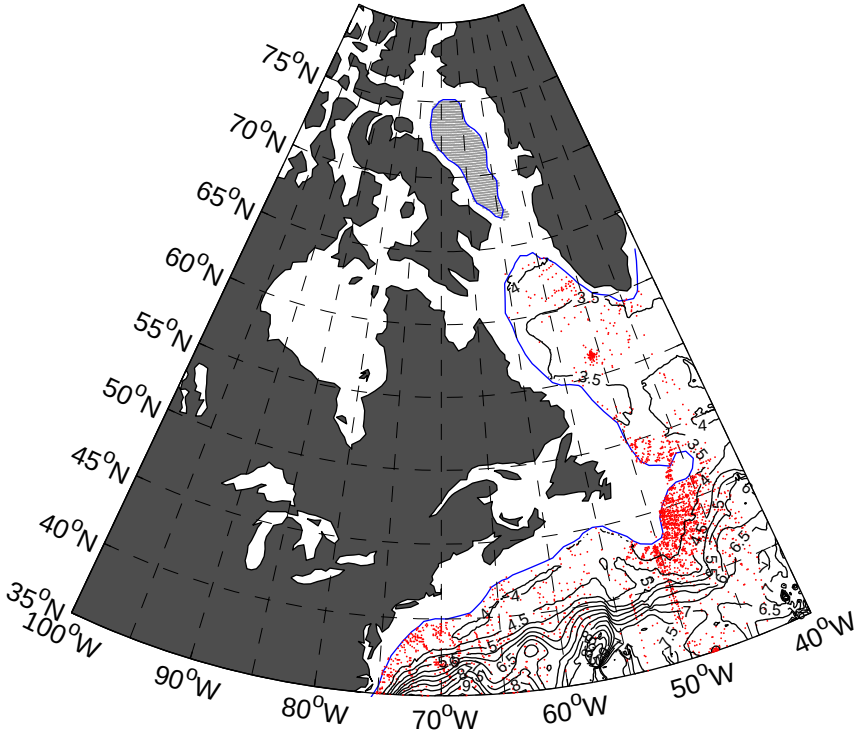
**May Temperature at 500m**



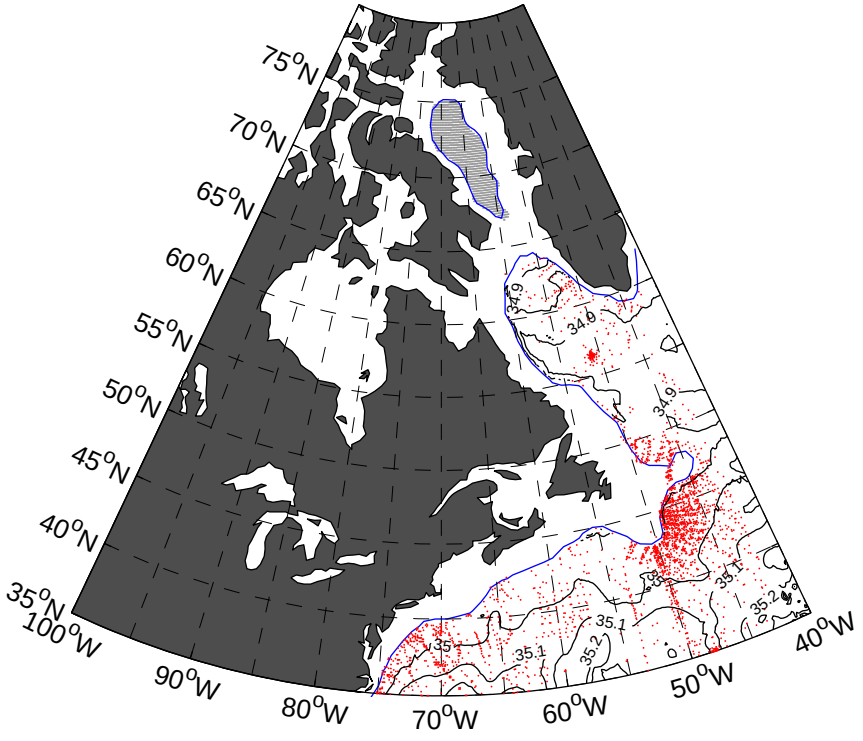

**May Salinity at 500m**

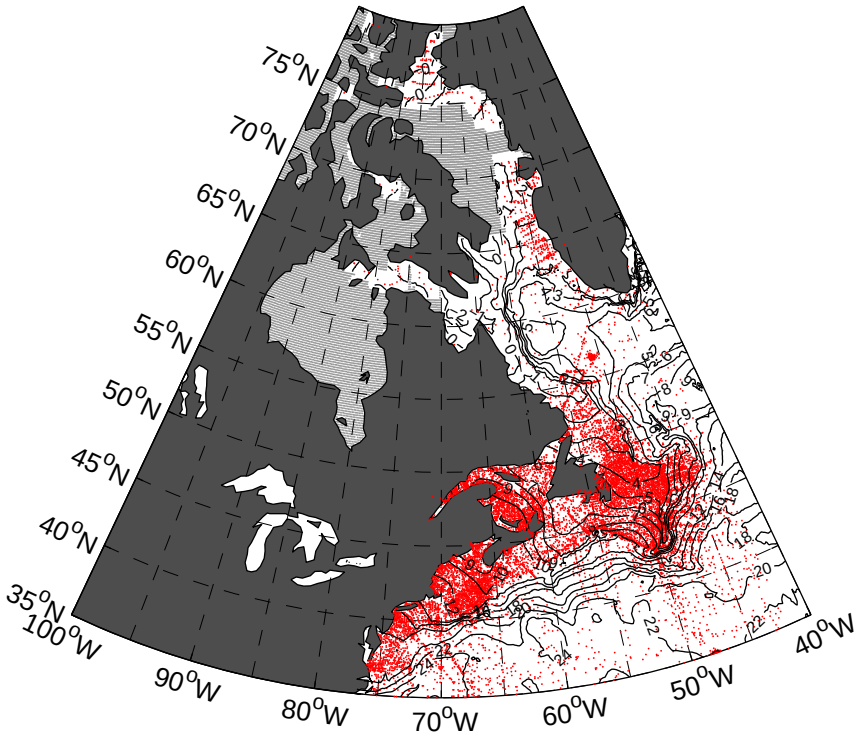


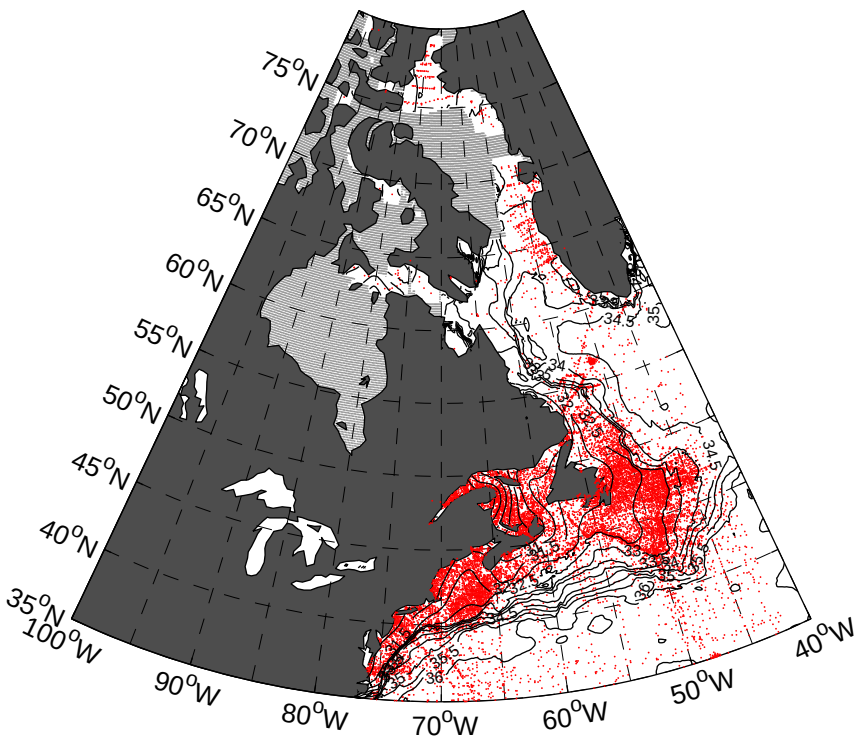
## May Temperature at 1000m



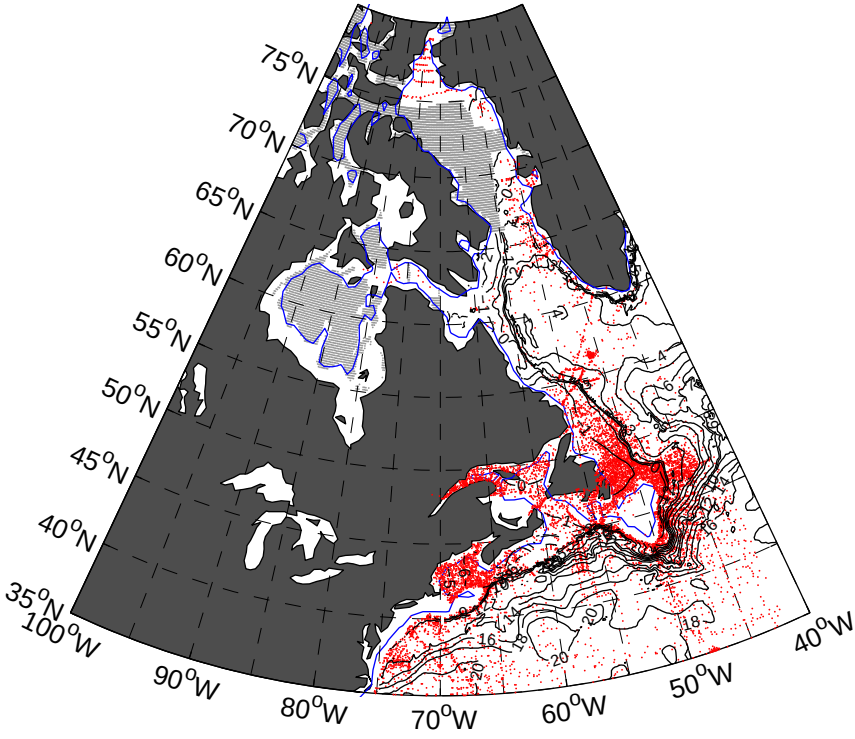

## May Salinity at 1000m



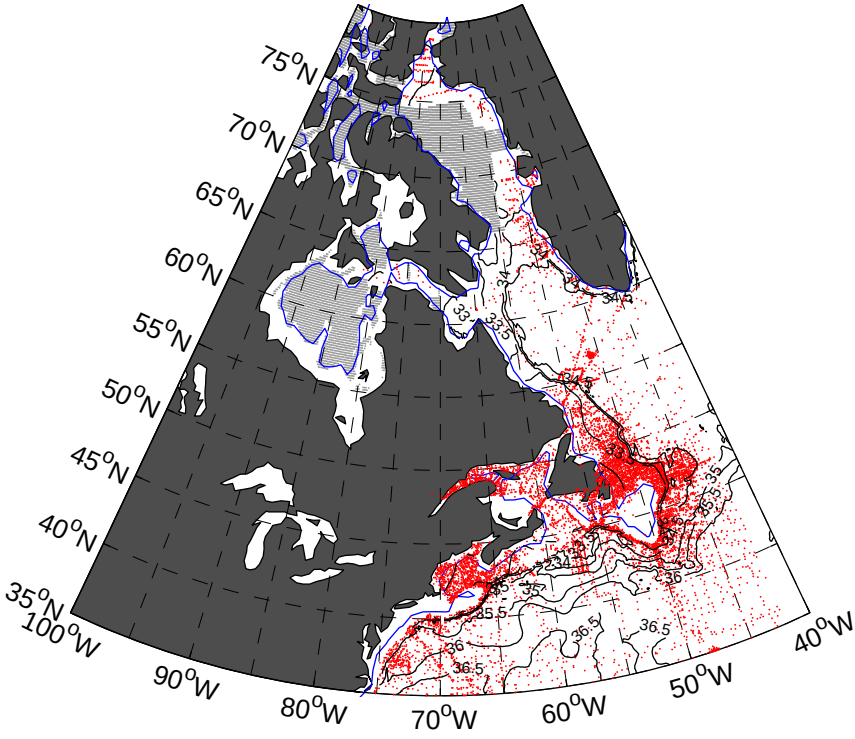

June Temperature at 0m
75°N
70°N
65°N
60°N
55°N
50°N
45°N
40°N
35°N
100°W
90°W
80°W
70°W
60°W
50°W
40°W


June Salinity at 0m
75°N
70°N
65°N
60°N
55°N
50°N
45°N
40°N
35°N
100°W
90°W
80°W
70°W
60°W
50°W
40°W

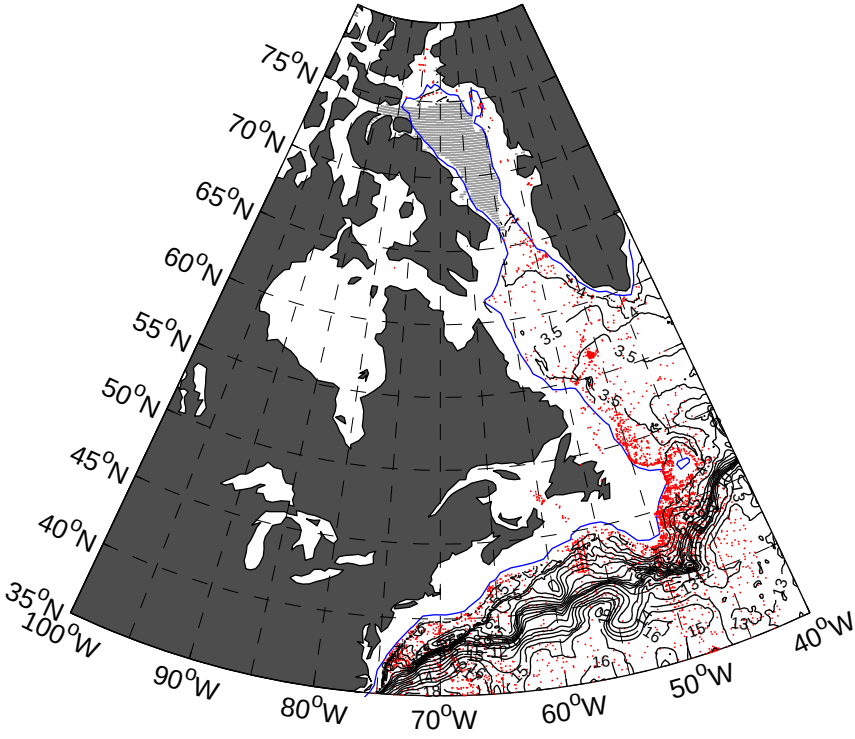
**June Temperature at 100m**



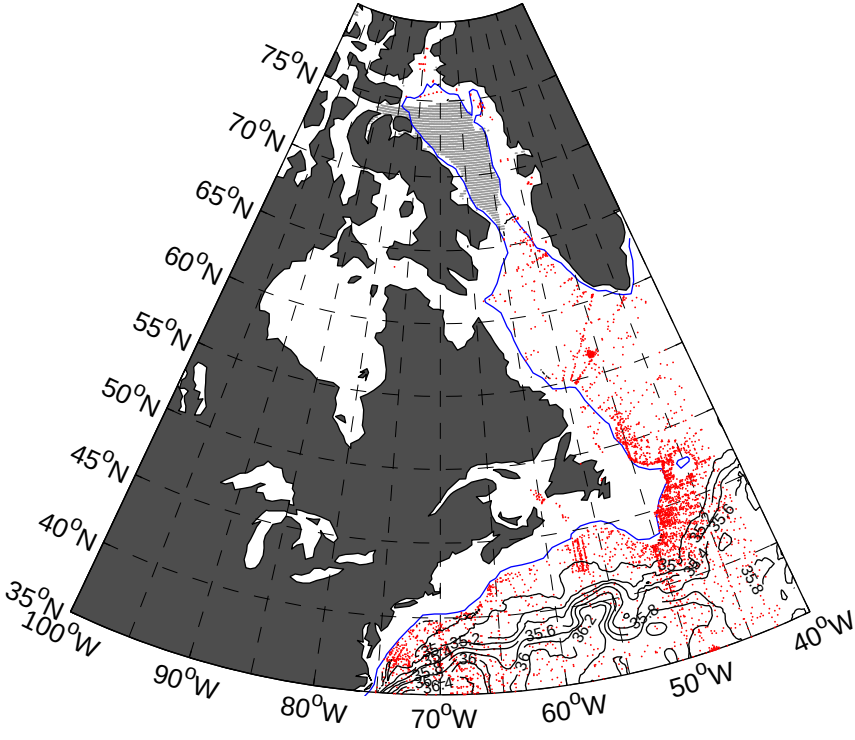

**June Salinity at 100m**



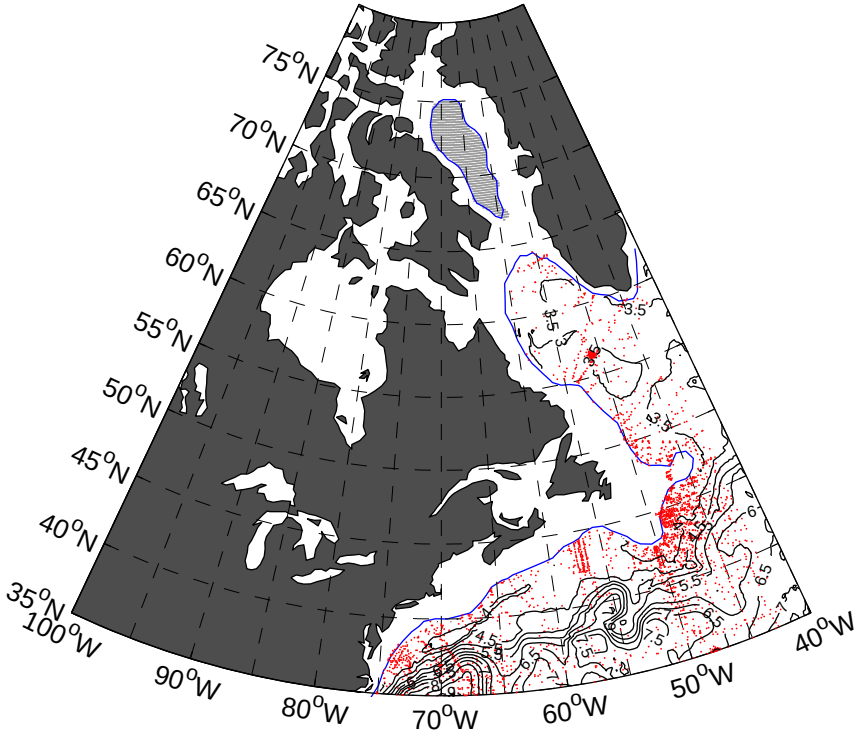
**June Temperature at 500m**



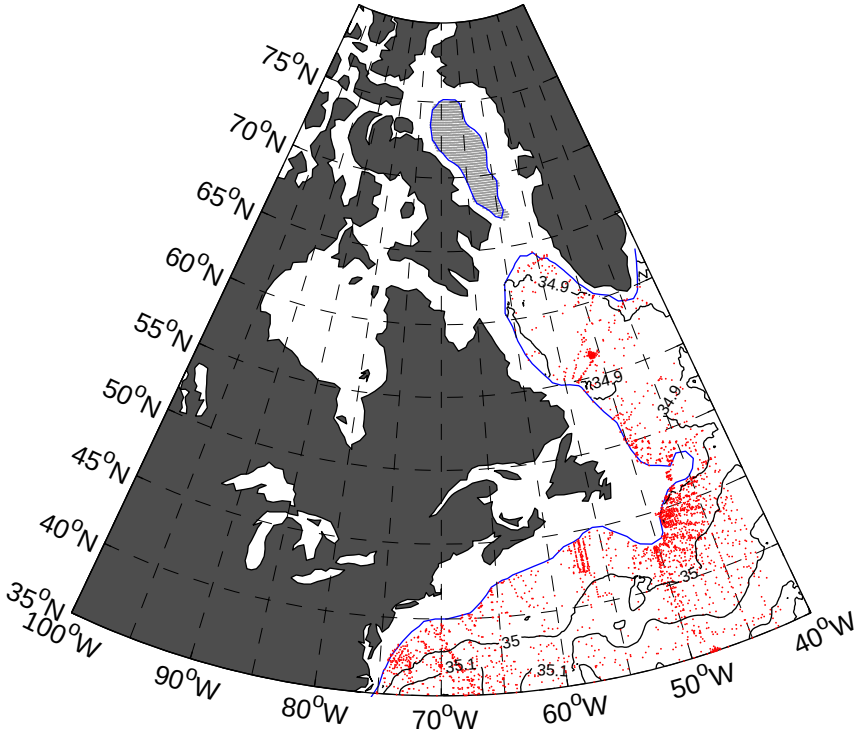

**June Salinity at 500m**



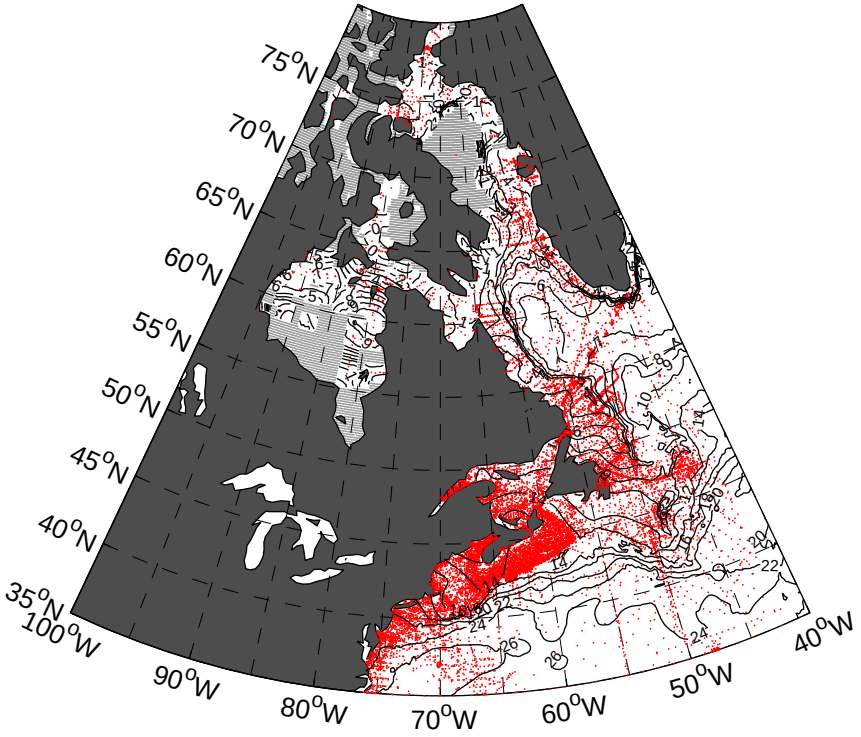
## June Temperature at 1000m



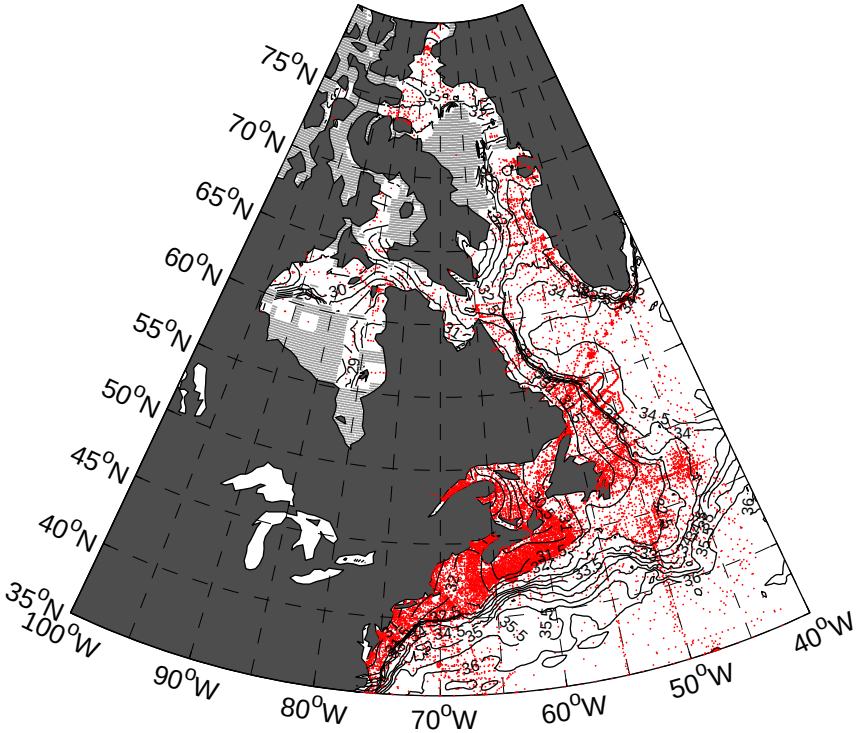

## June Salinity at 1000m



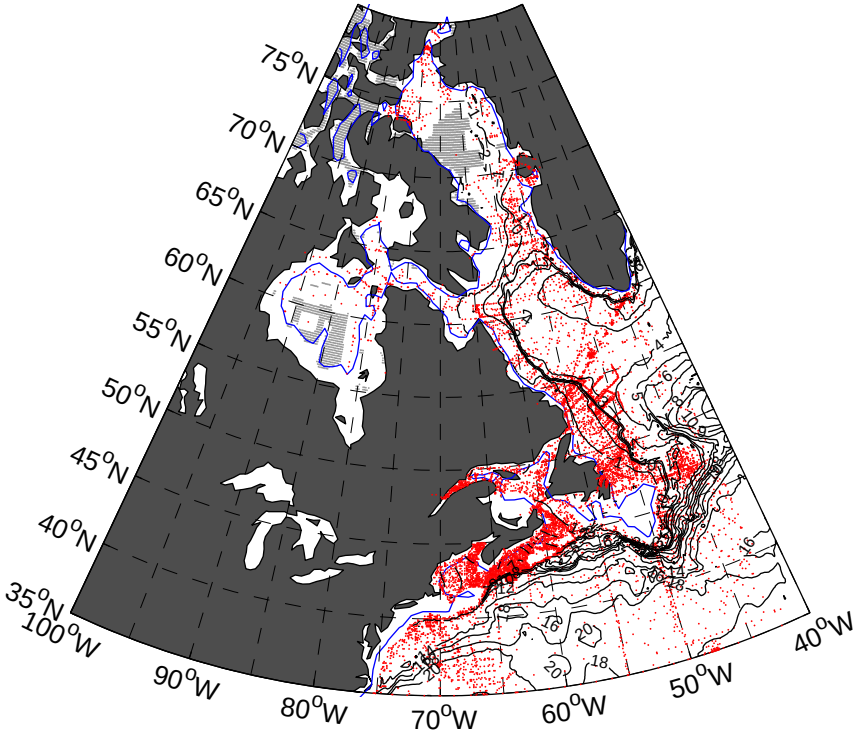
**July Temperature at 0m**



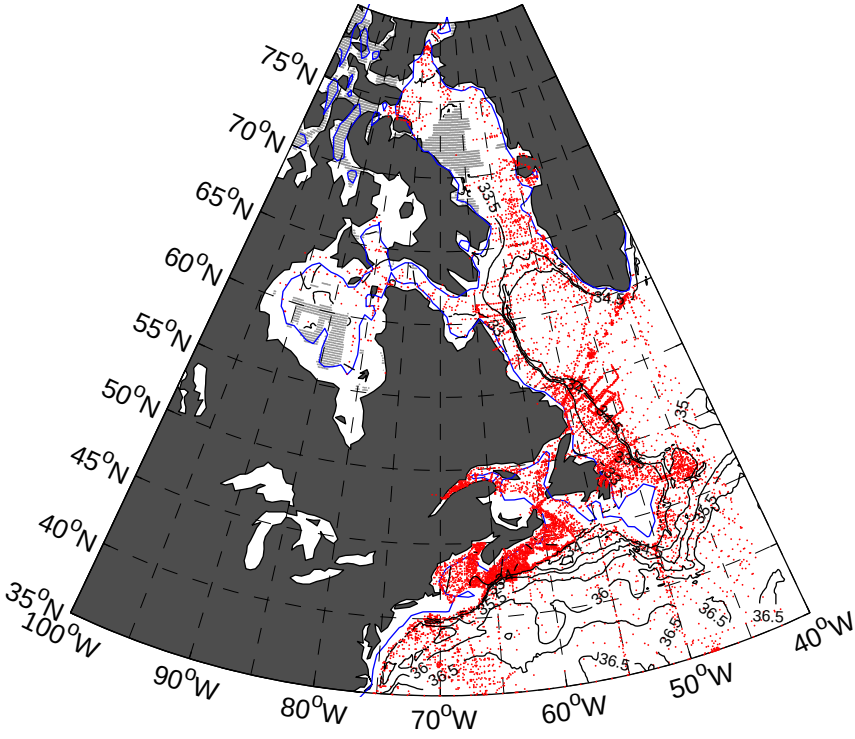

**July Salinity at 0m**



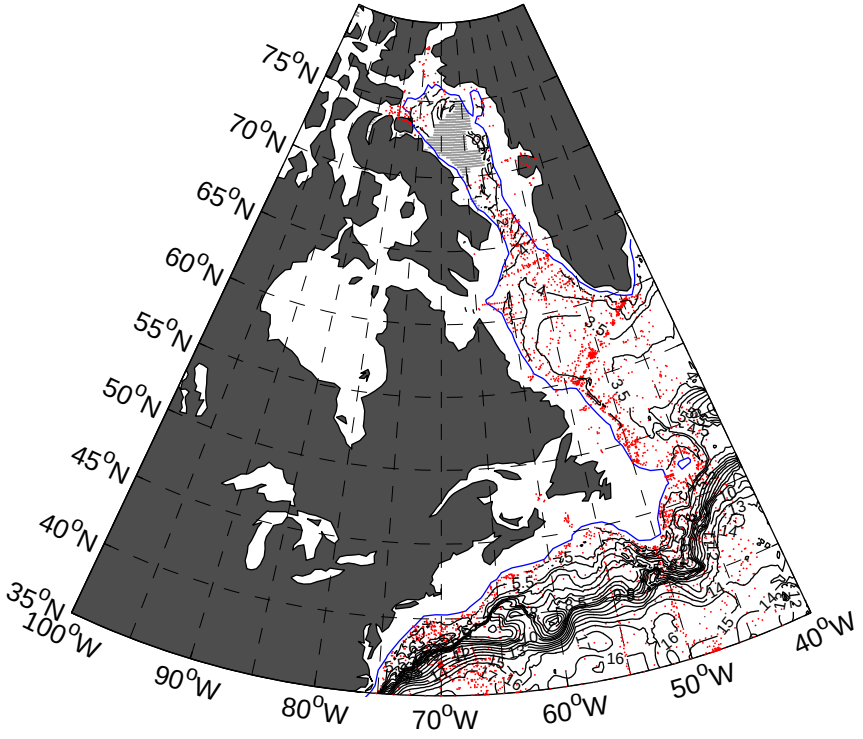
**July Temperature at 100m**



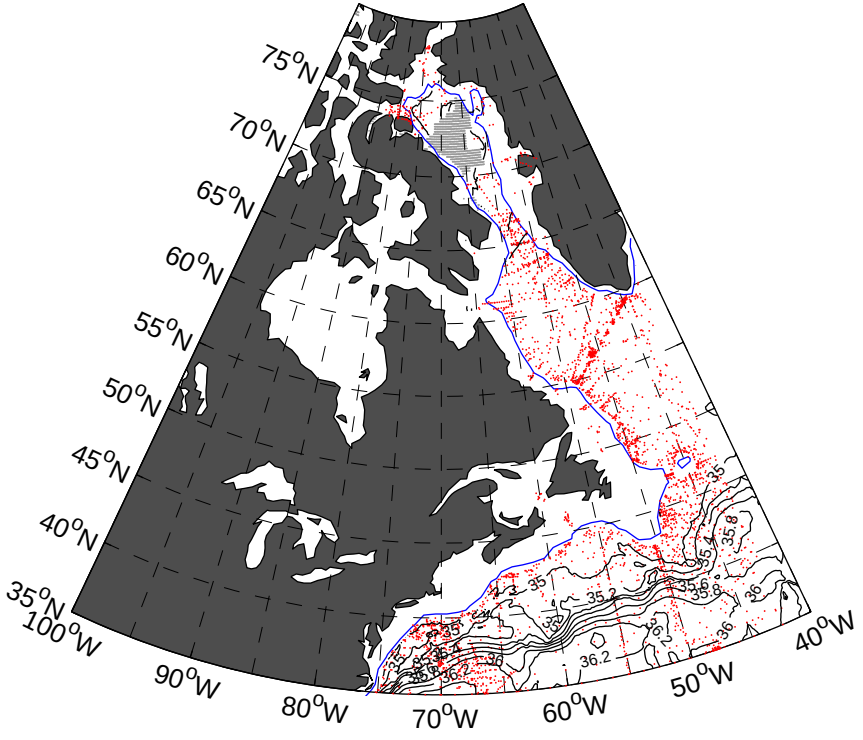

**July Salinity at 100m**



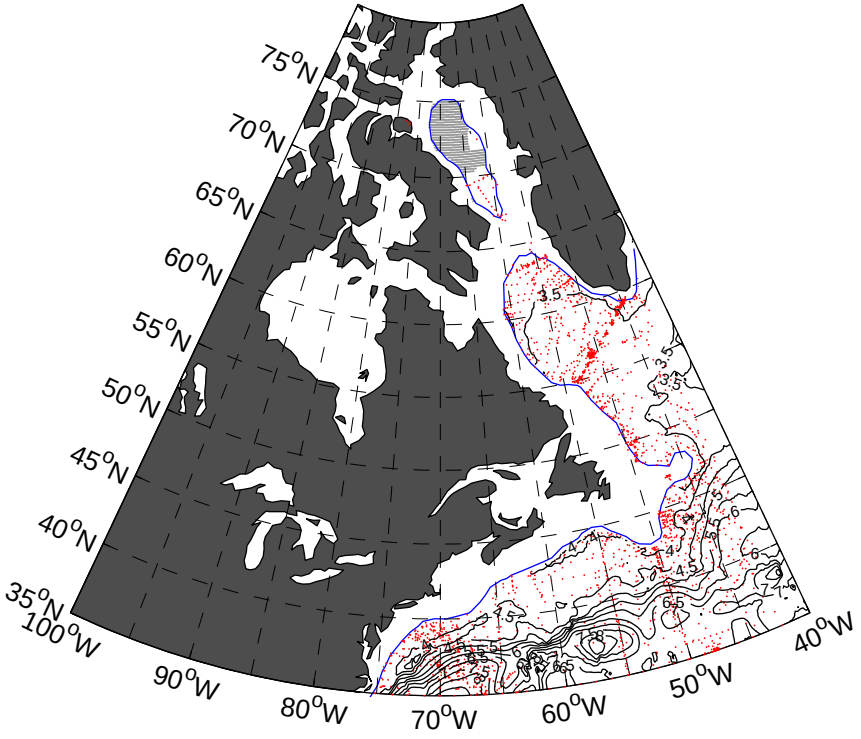
**July Temperature at 500m**



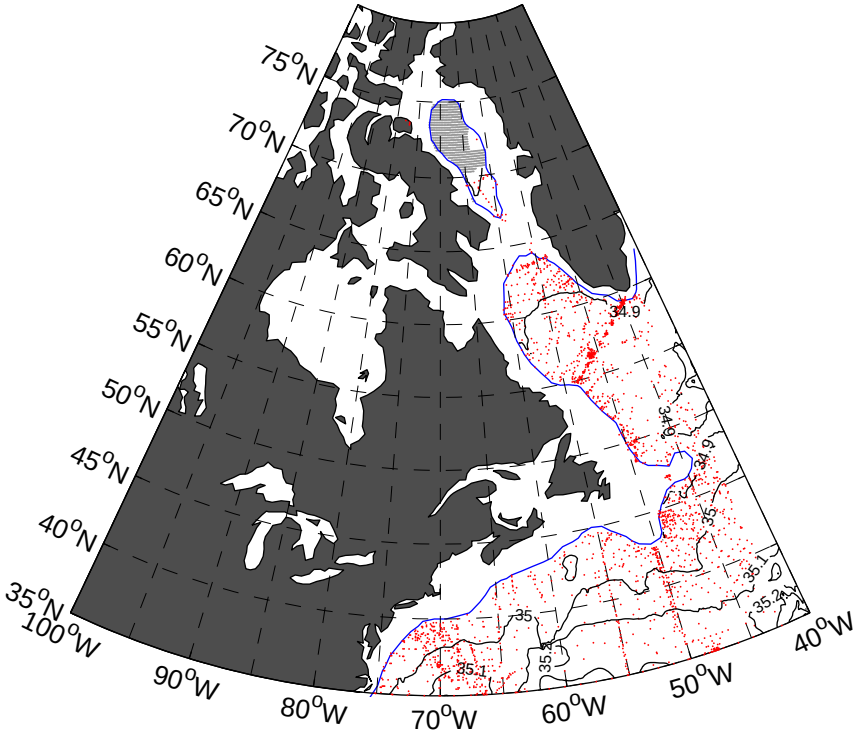

**July Salinity at 500m**



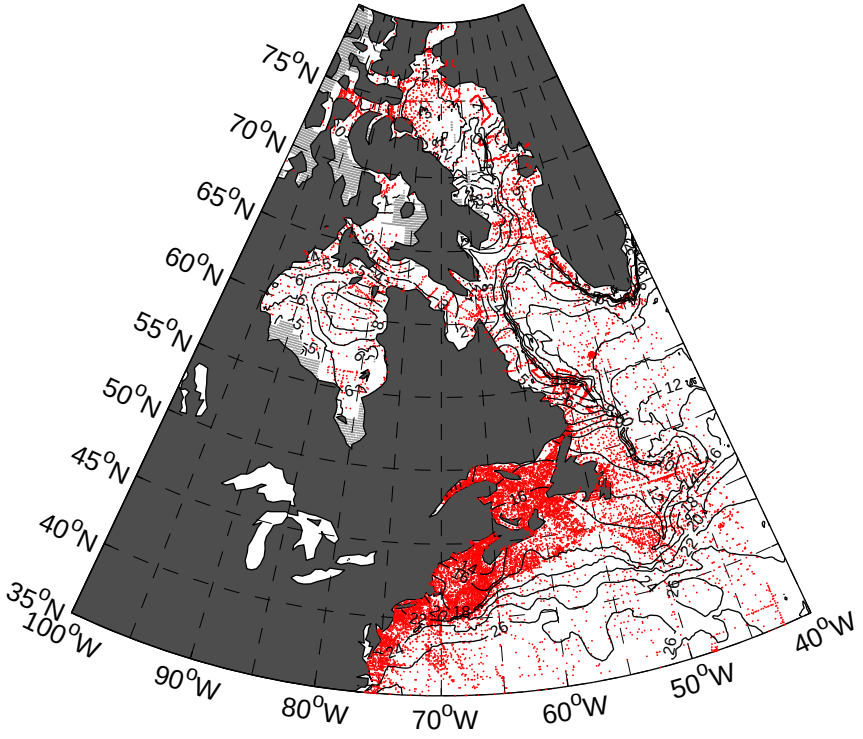
**July Temperature at 1000m**



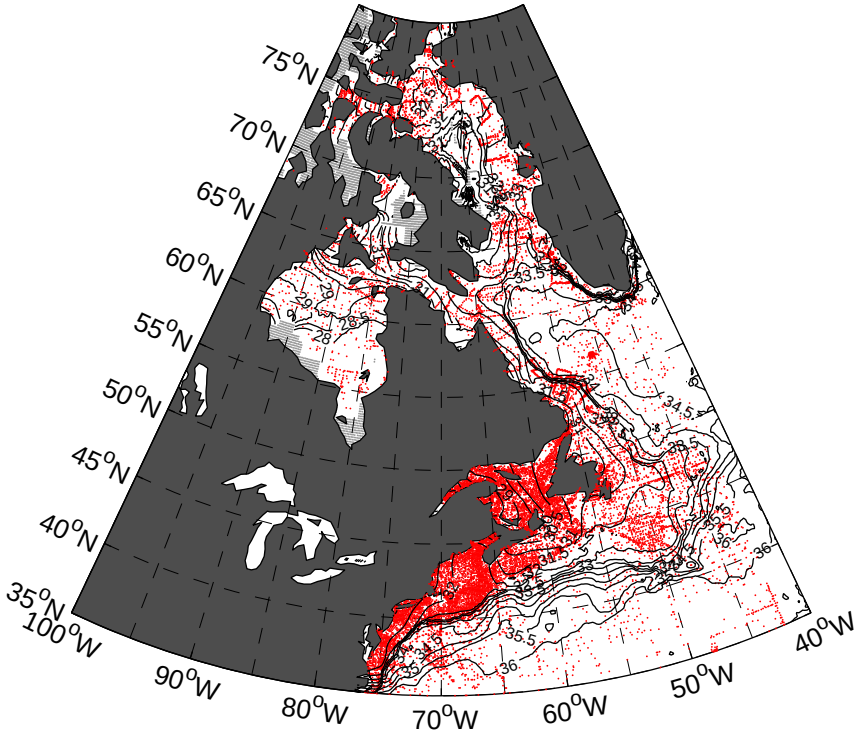

**July Salinity at 1000m**



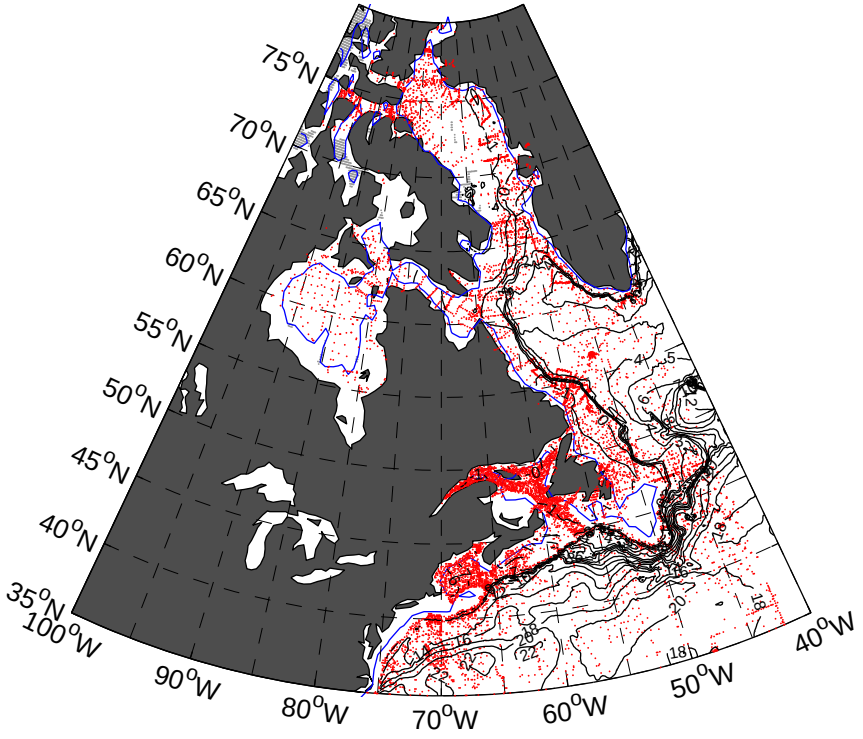
## August Temperature at 0m



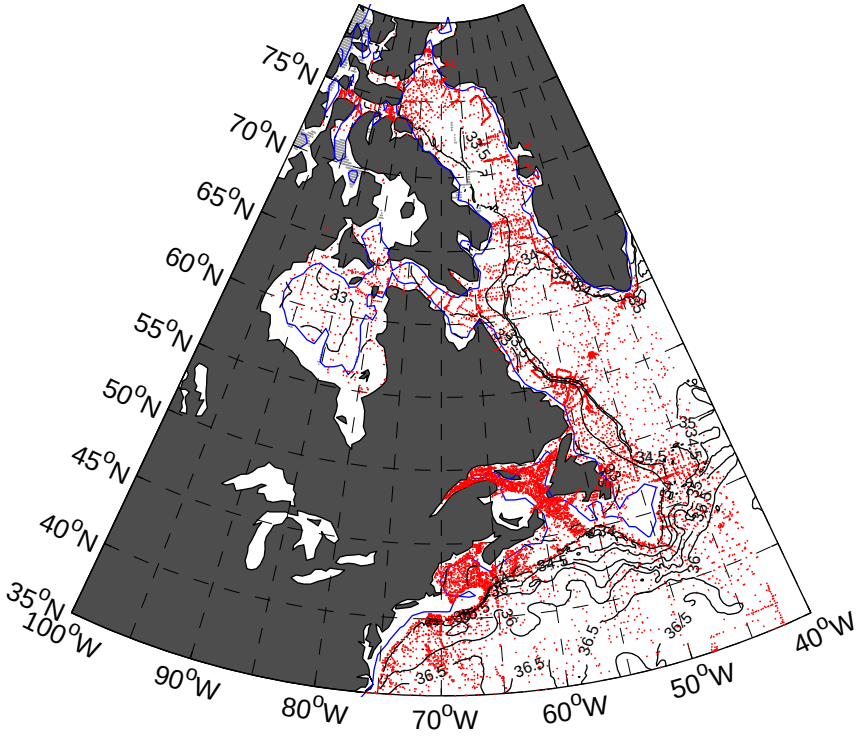

## August Salinity at 0m



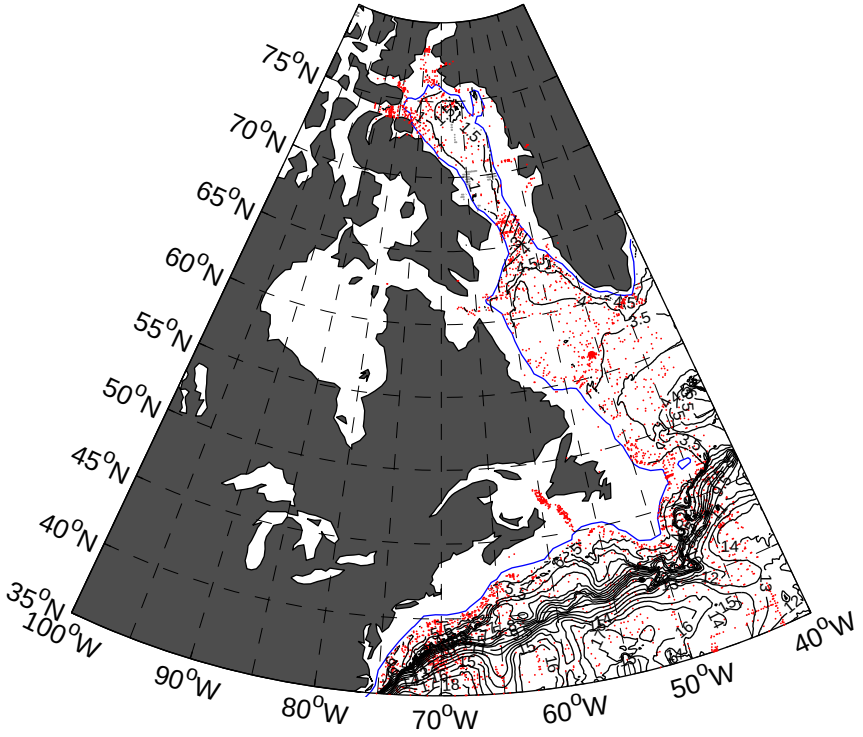
## August Temperature at 100m



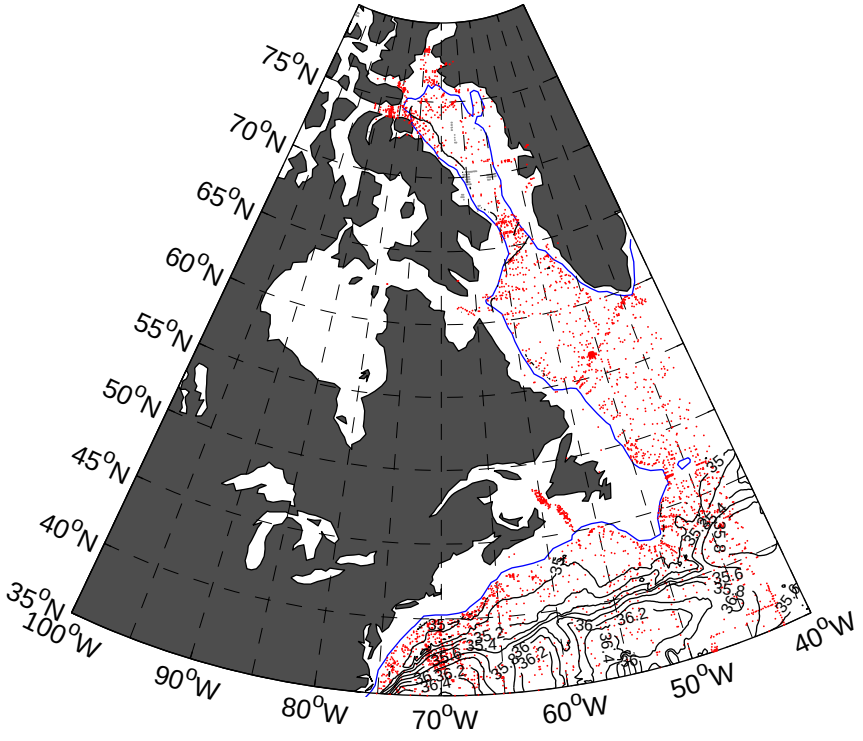

## August Salinity at 100m



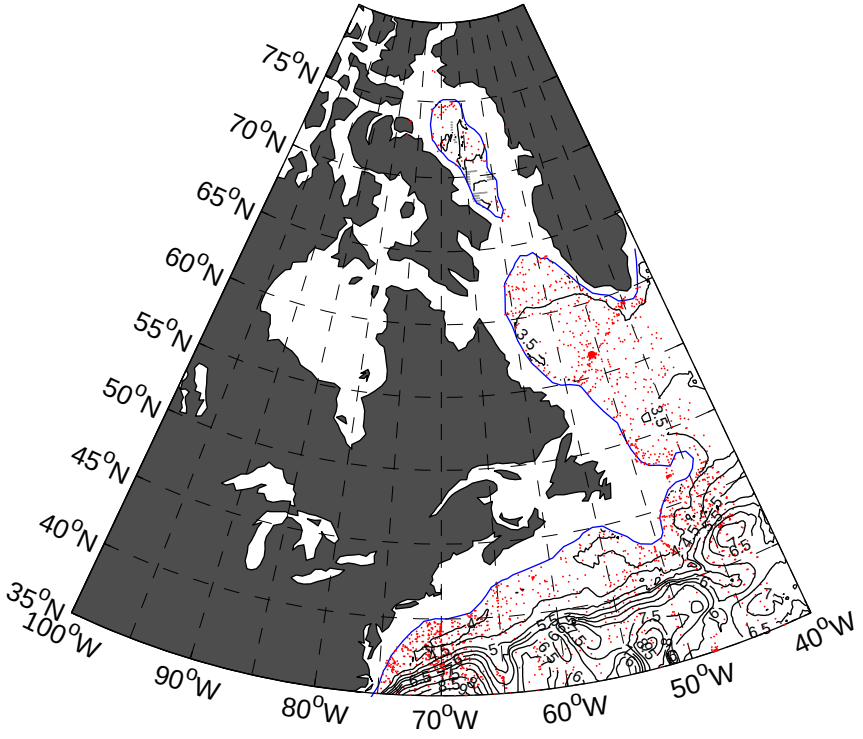
## August Temperature at 500m



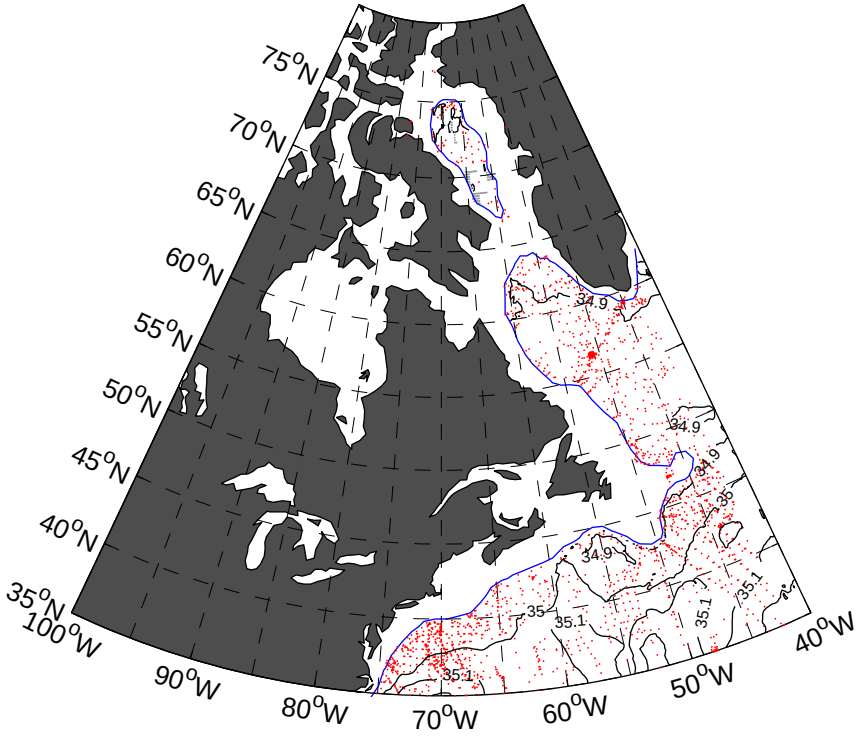

## August Salinity at 500m



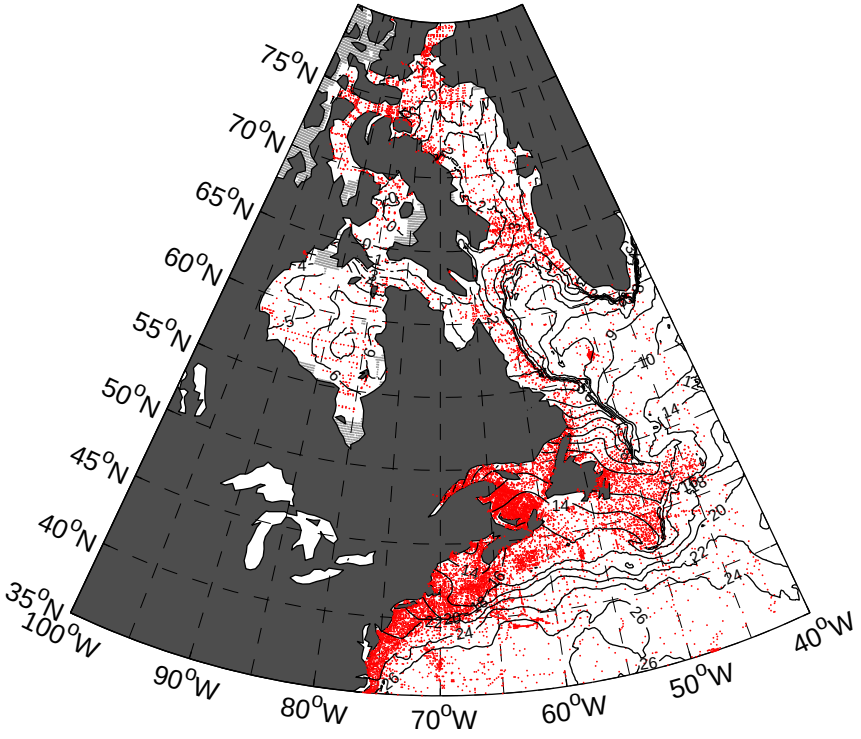
## August Temperature at 1000m



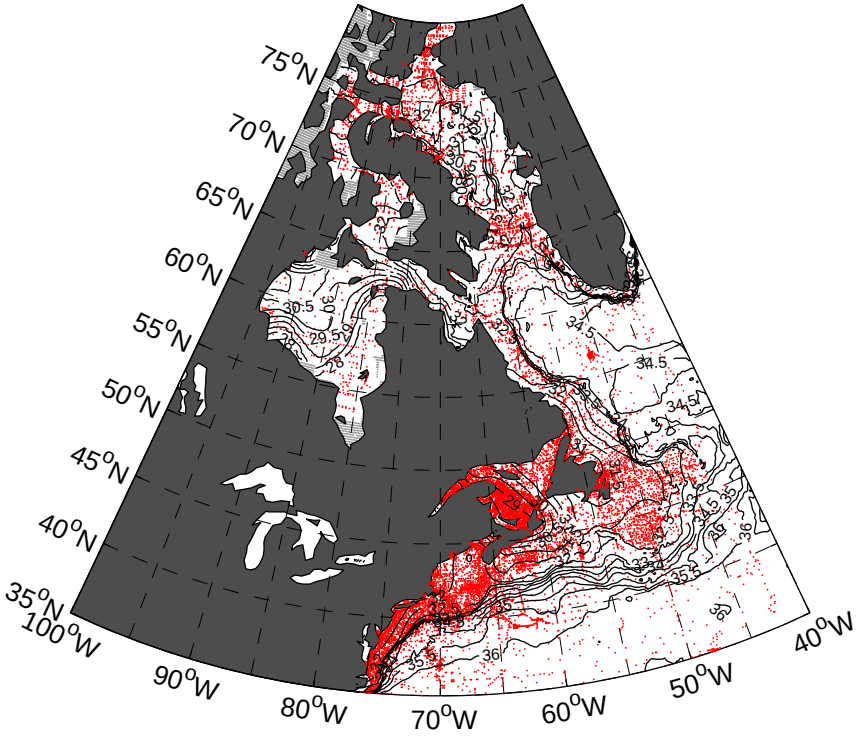

## August Salinity at 1000m



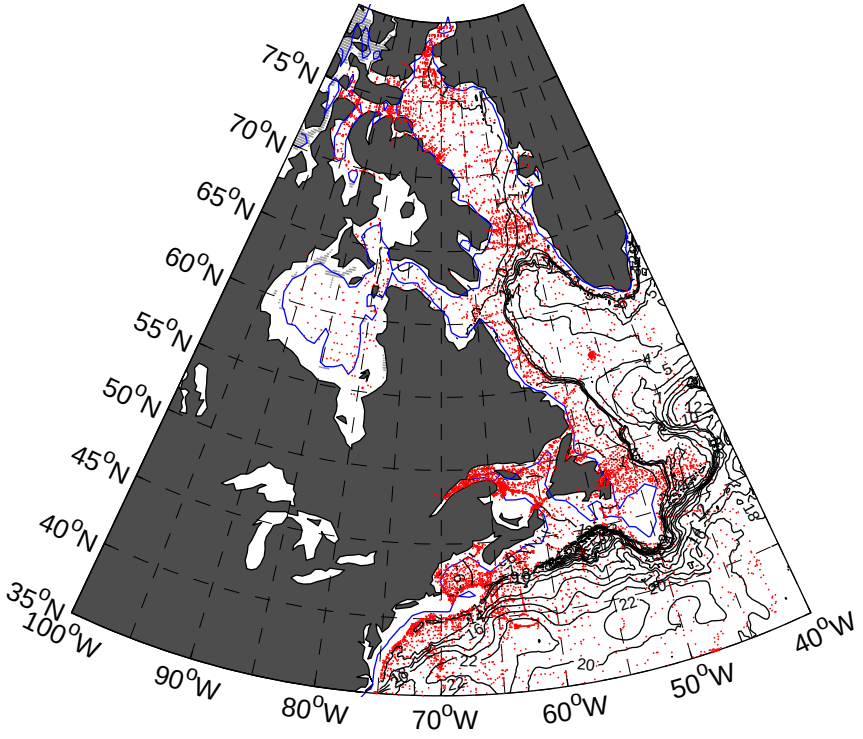
## SeptemberTemperature at 0m



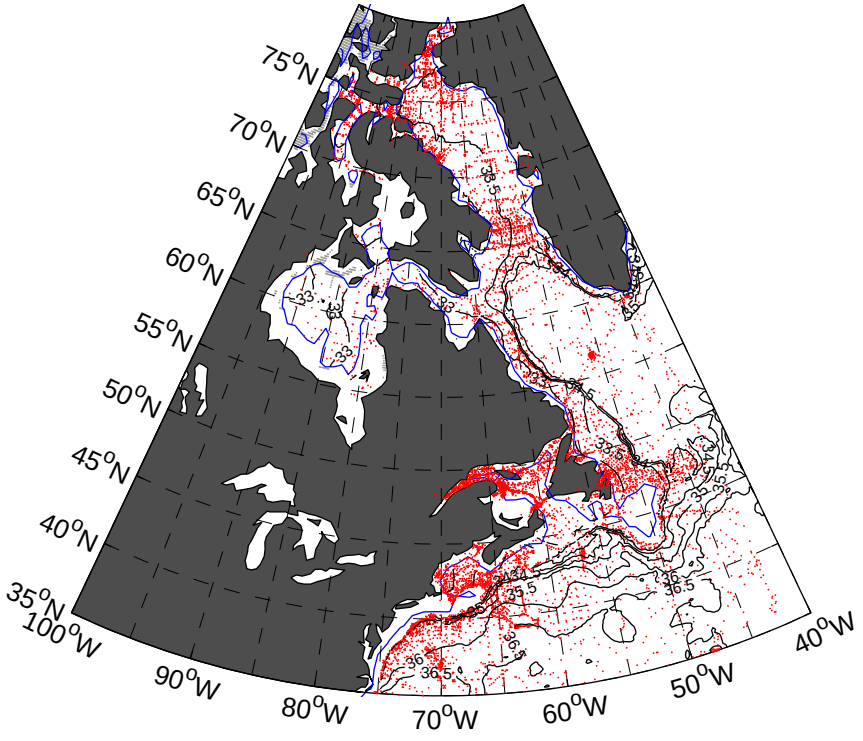

## September Salinity at 0m



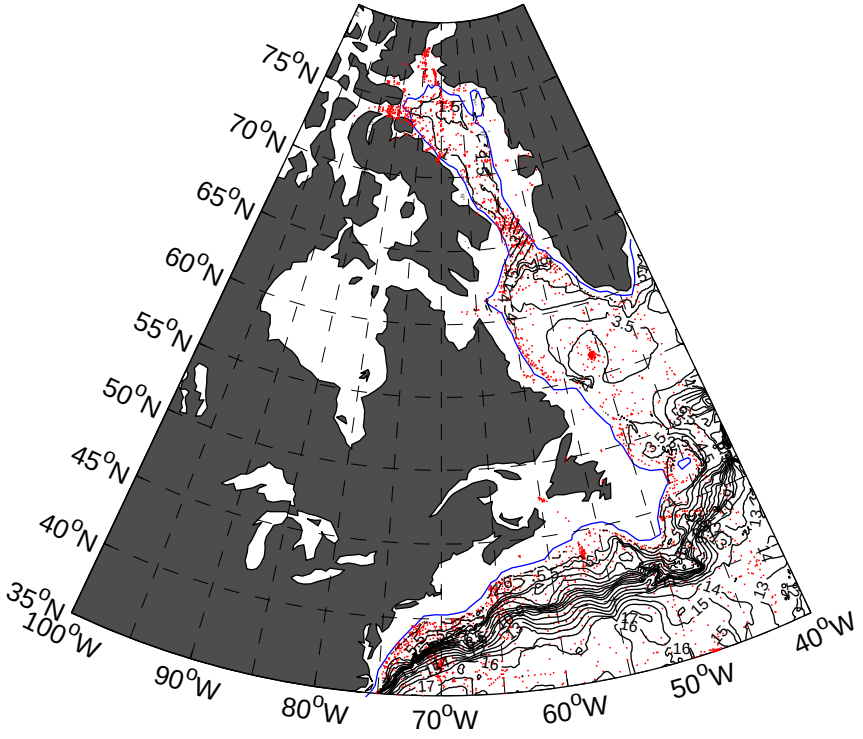
## SeptemberTemperature at 100m



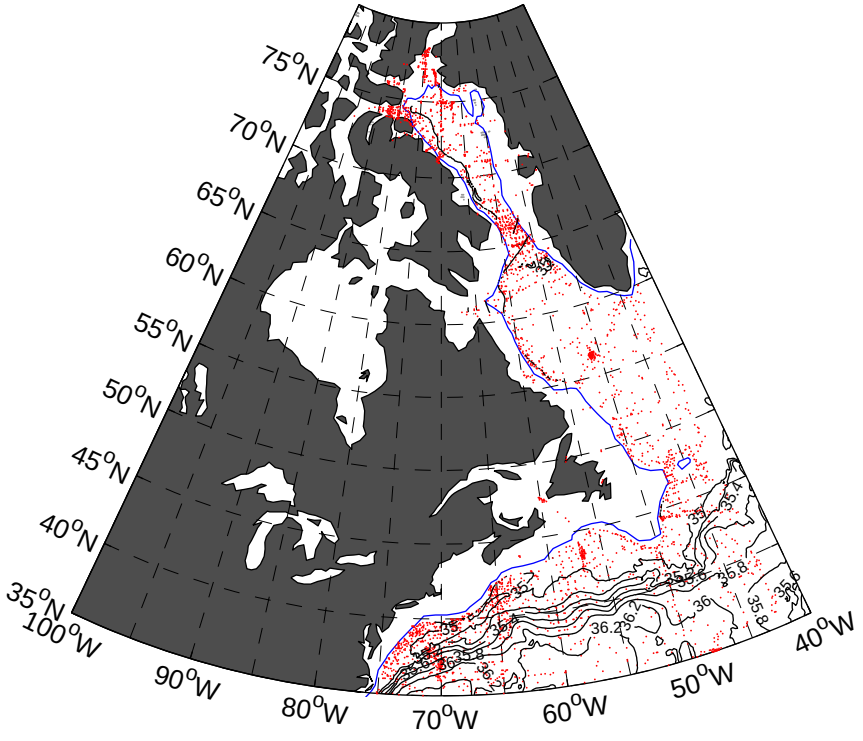

## September Salinity at 100m



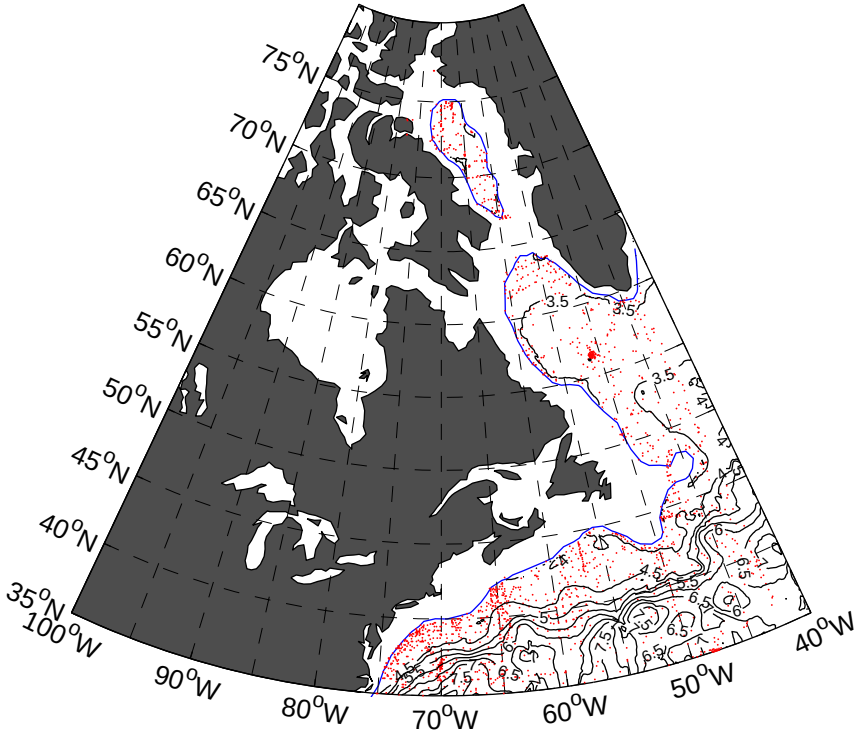
## SeptemberTemperature at 500m



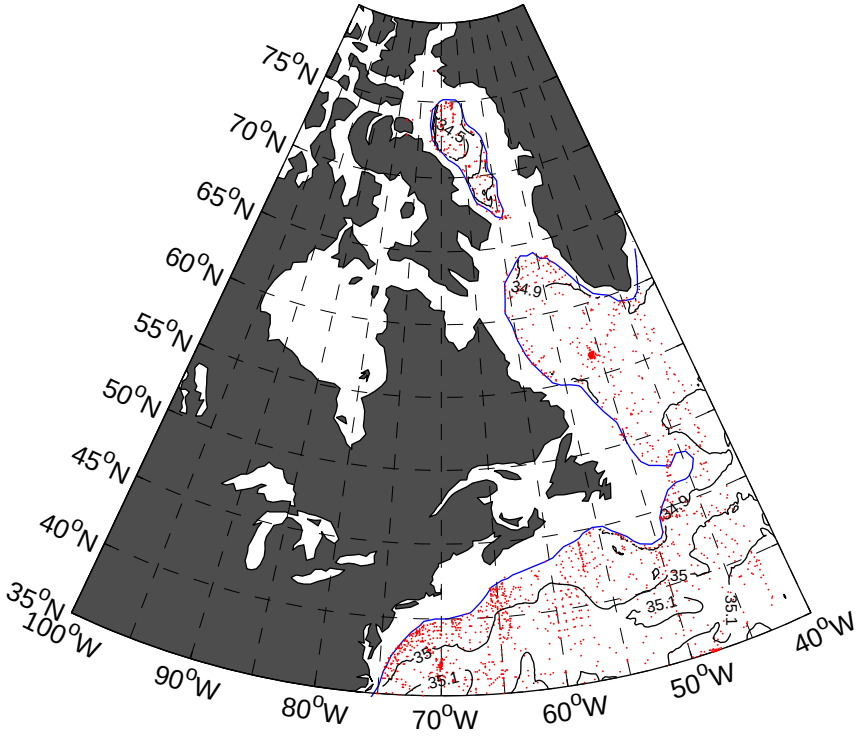

## September Salinity at 500m



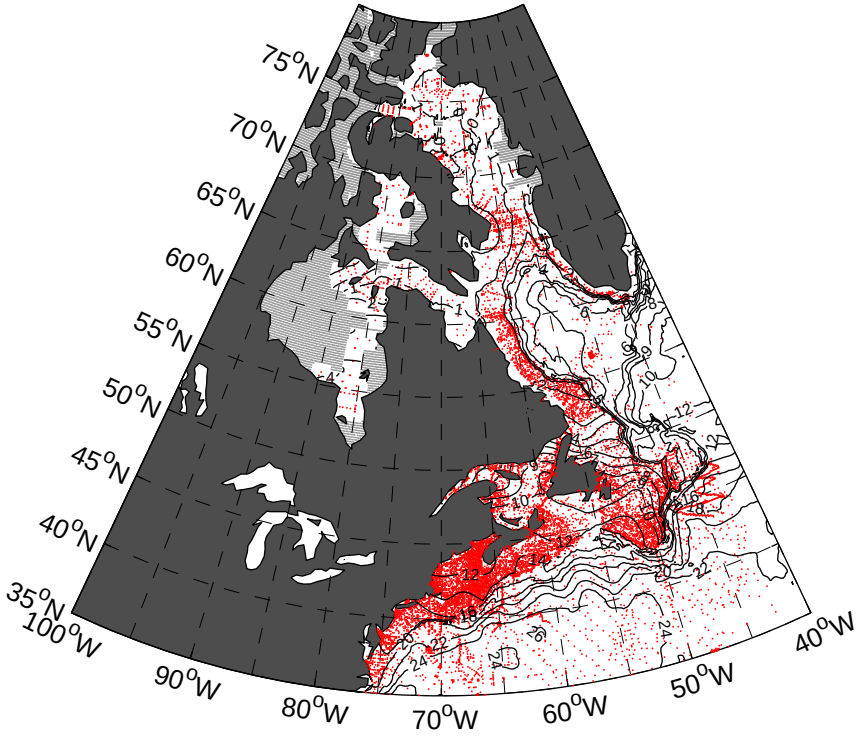
## SeptemberTemperature at 1000m



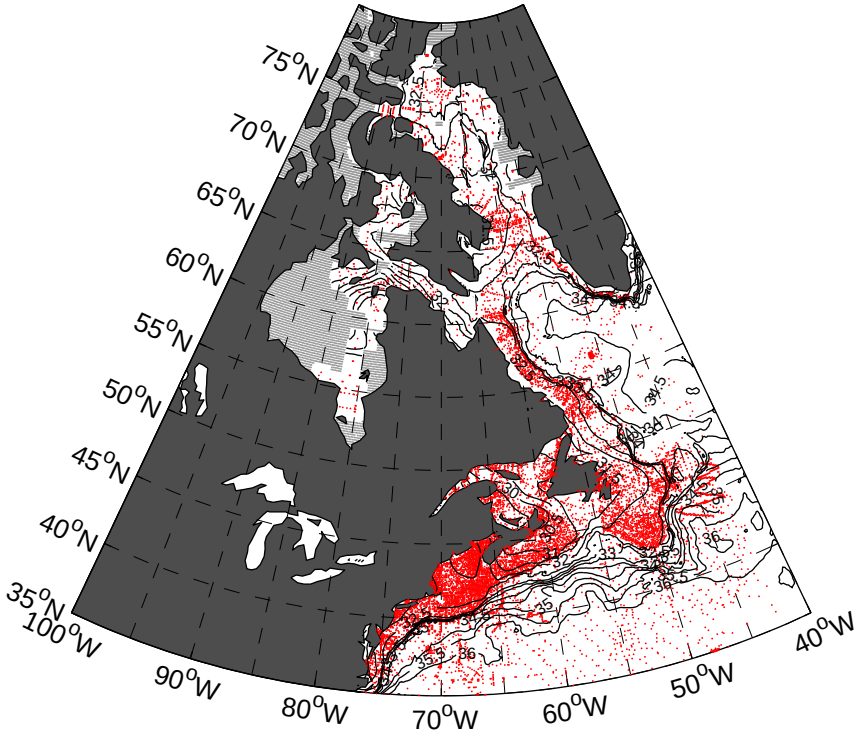

## September Salinity at 1000m



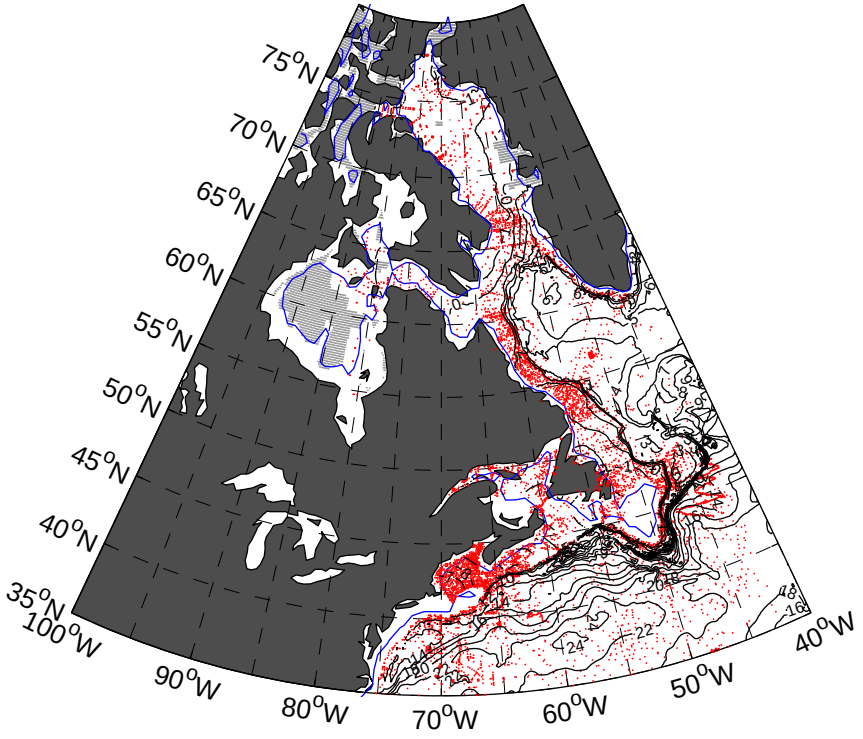
## October Temperature at 0m



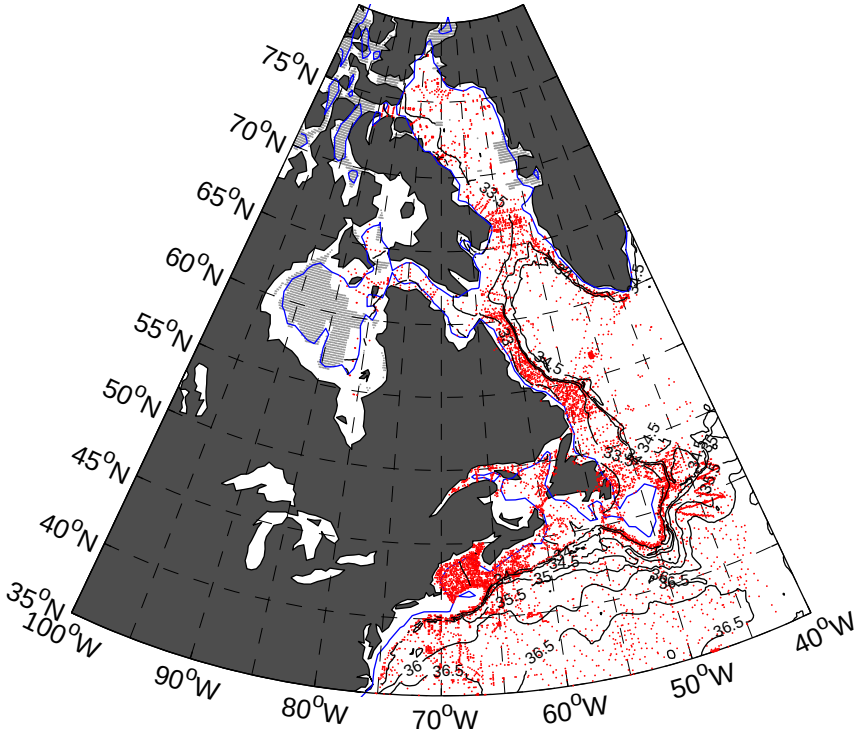

## October Salinity at 0m



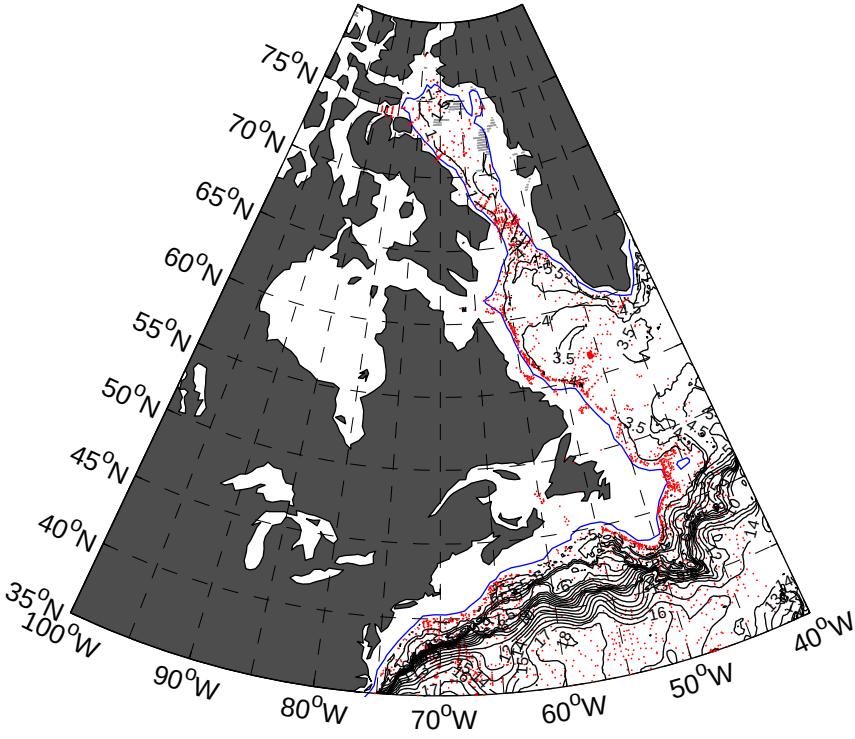
## October Temperature at 100m



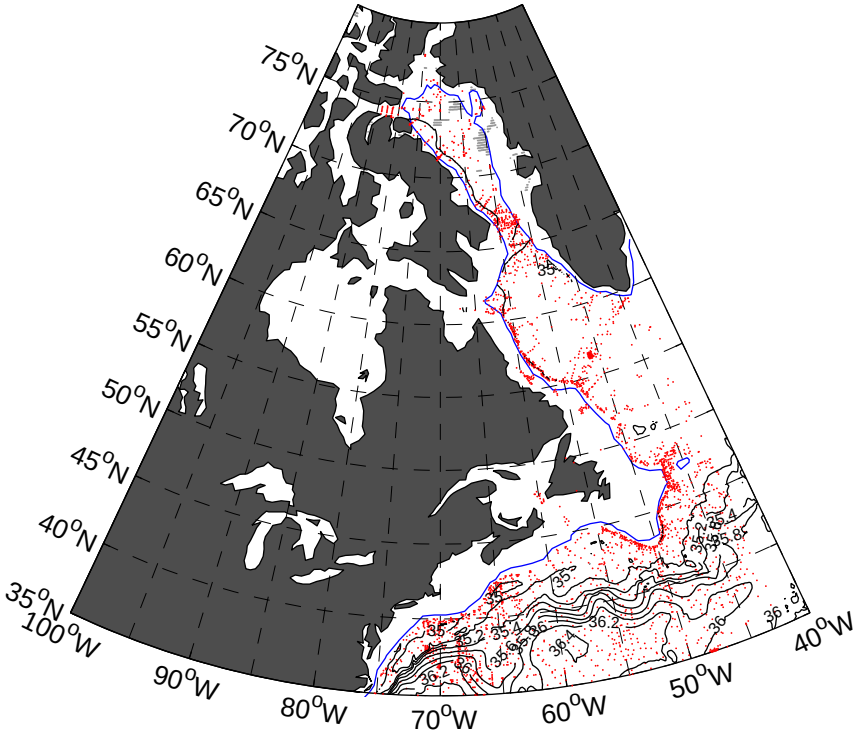

## October Salinity at 100m



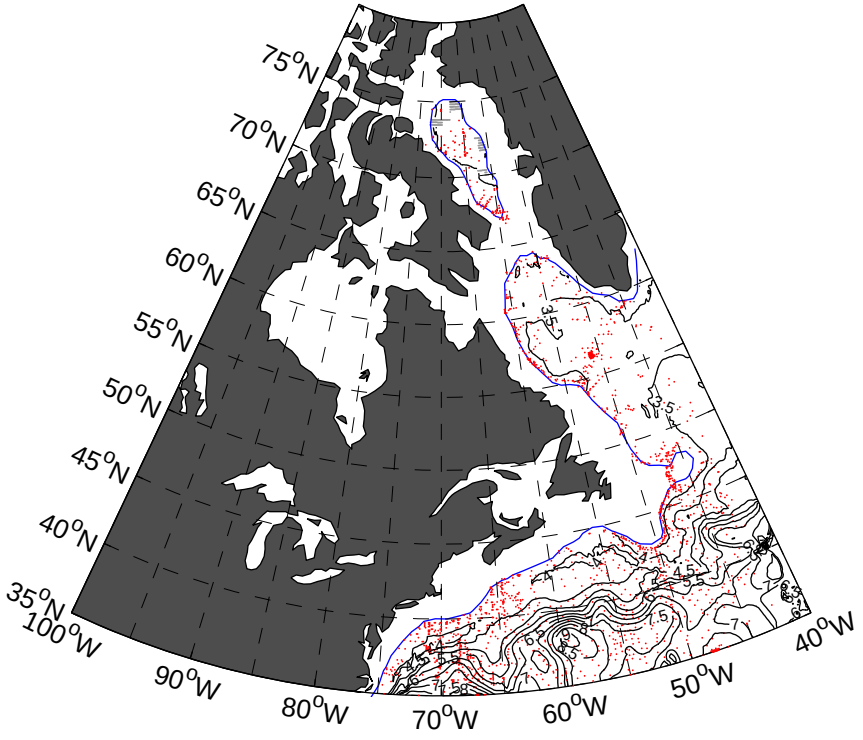
## October Temperature at 500m



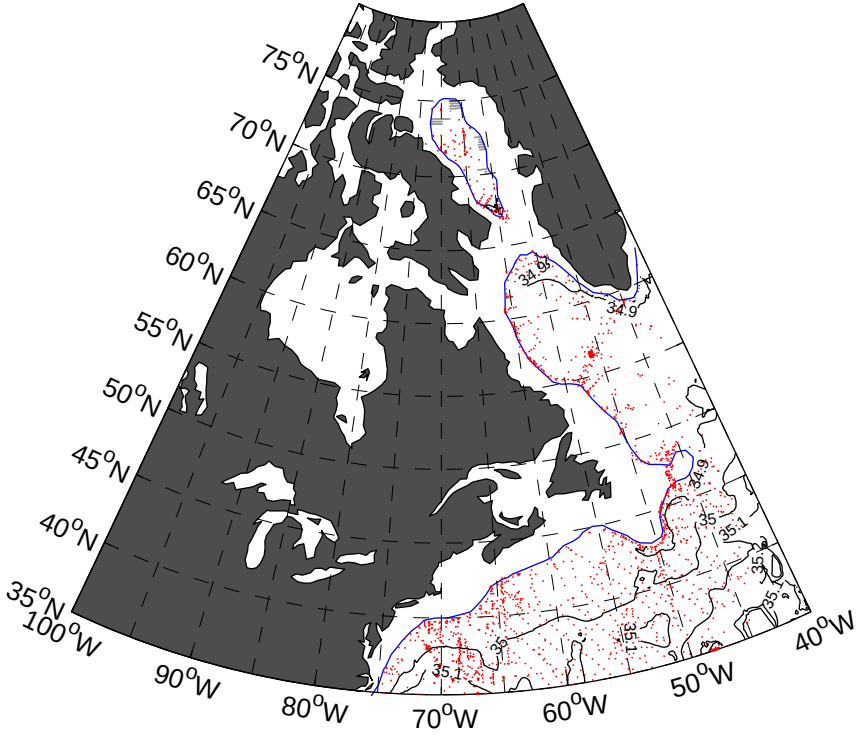

## October Salinity at 500m



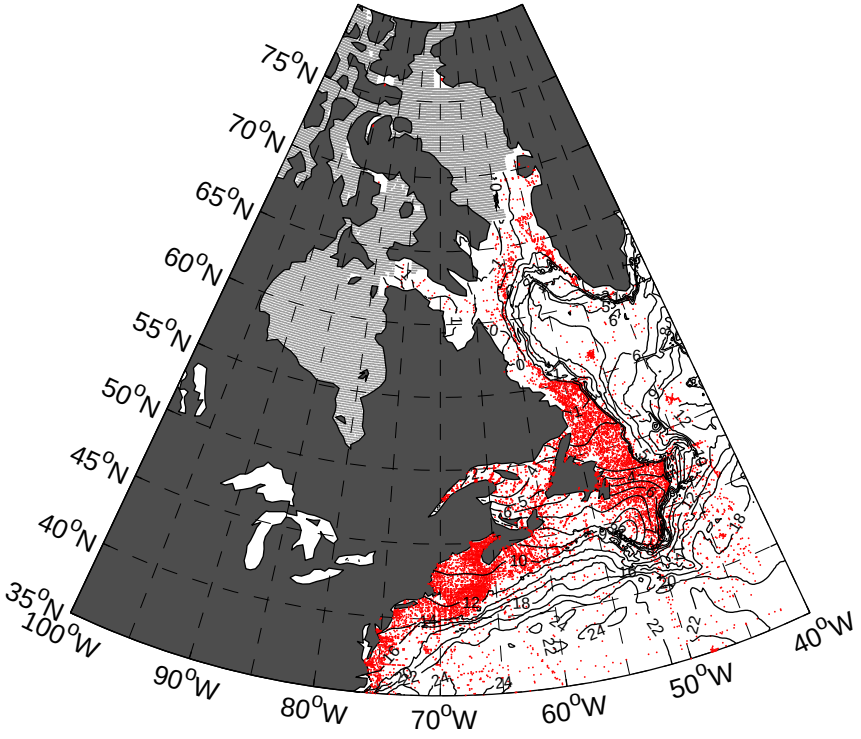
## October Temperature at 1000m



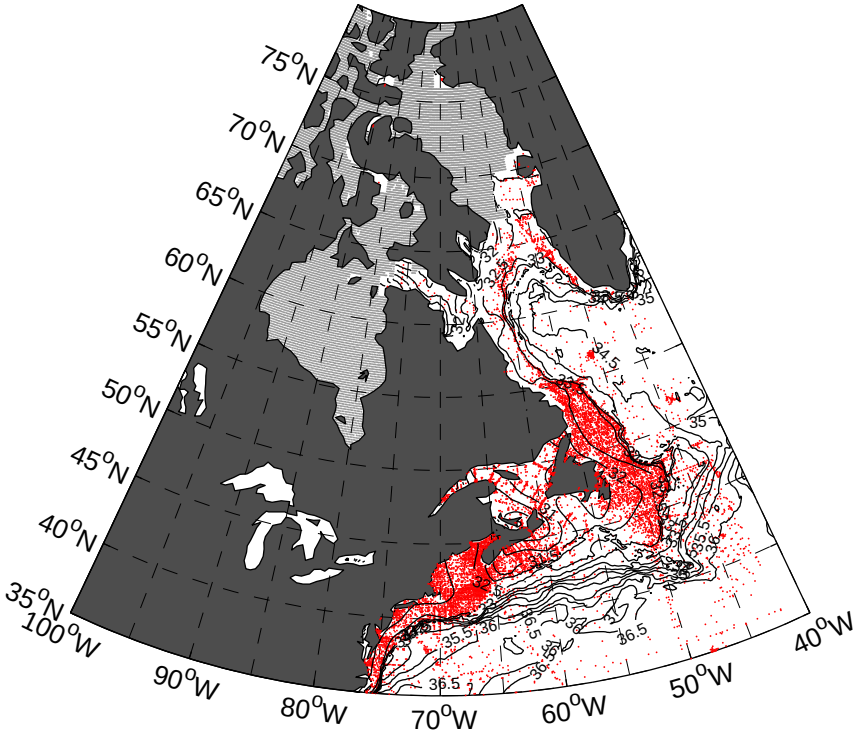

## October Salinity at 1000m



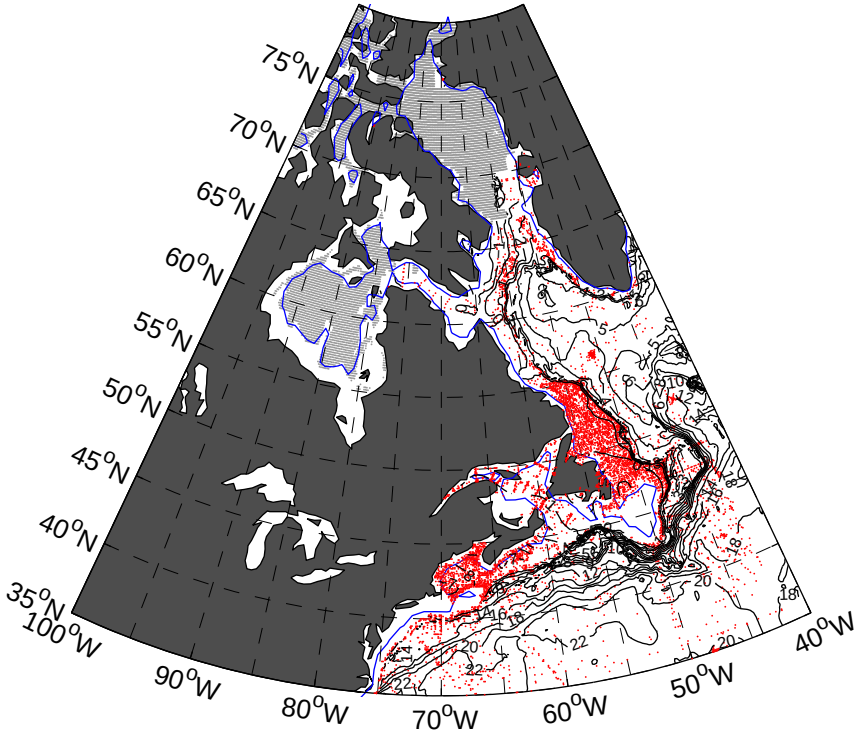
## November Temperature at 0m



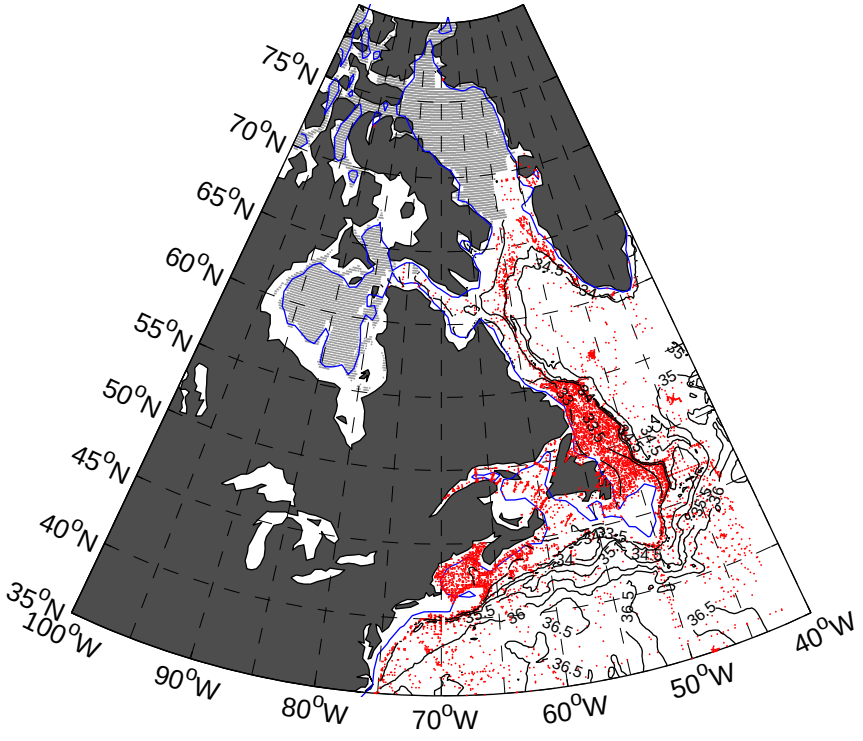

## November Salinity at 0m



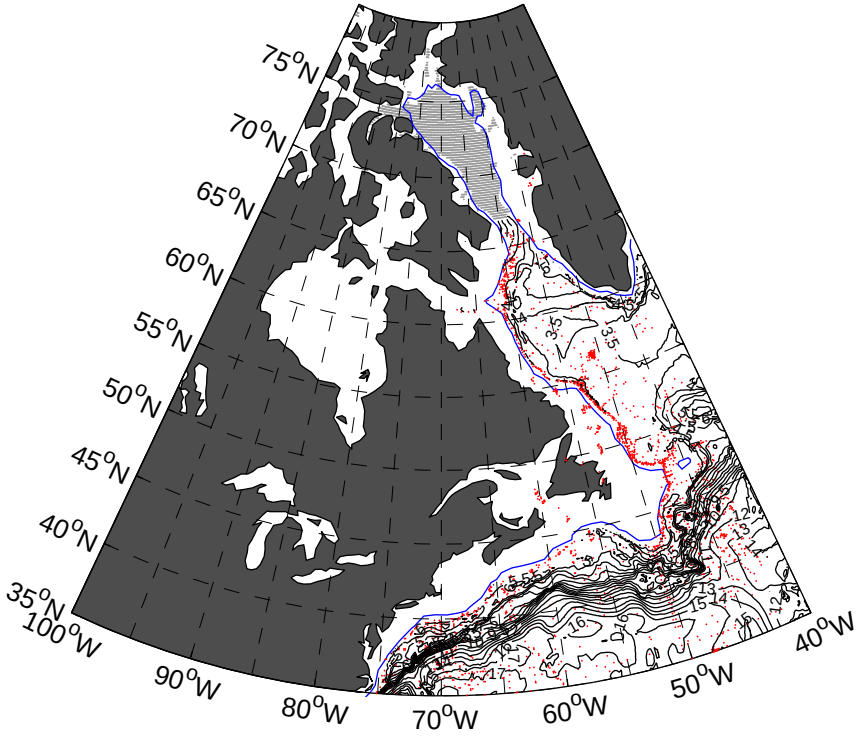
## November Temperature at 100m



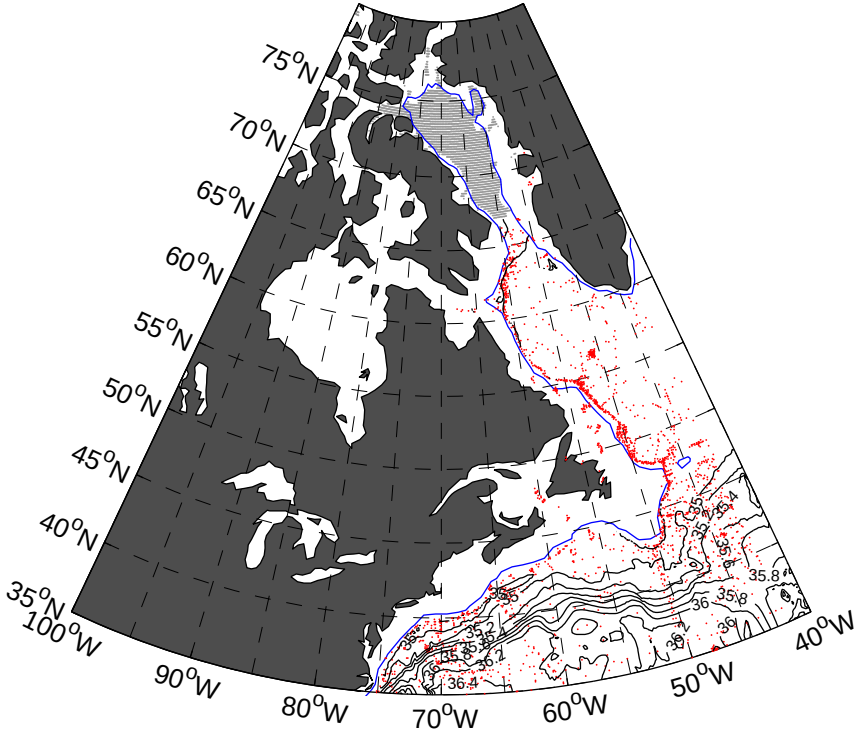

## November Salinity at 100m



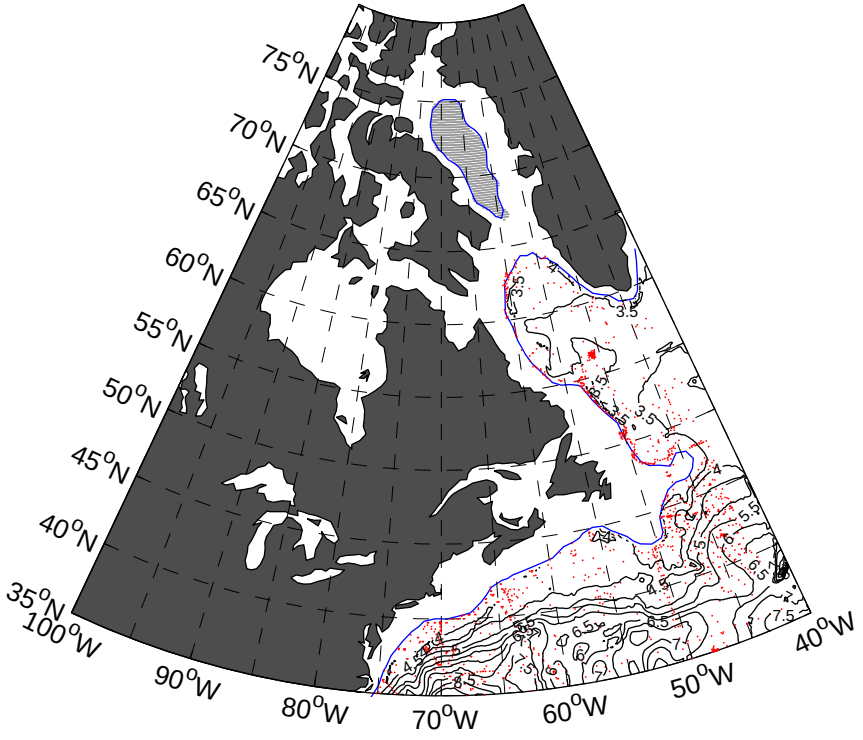
## November Temperature at 500m



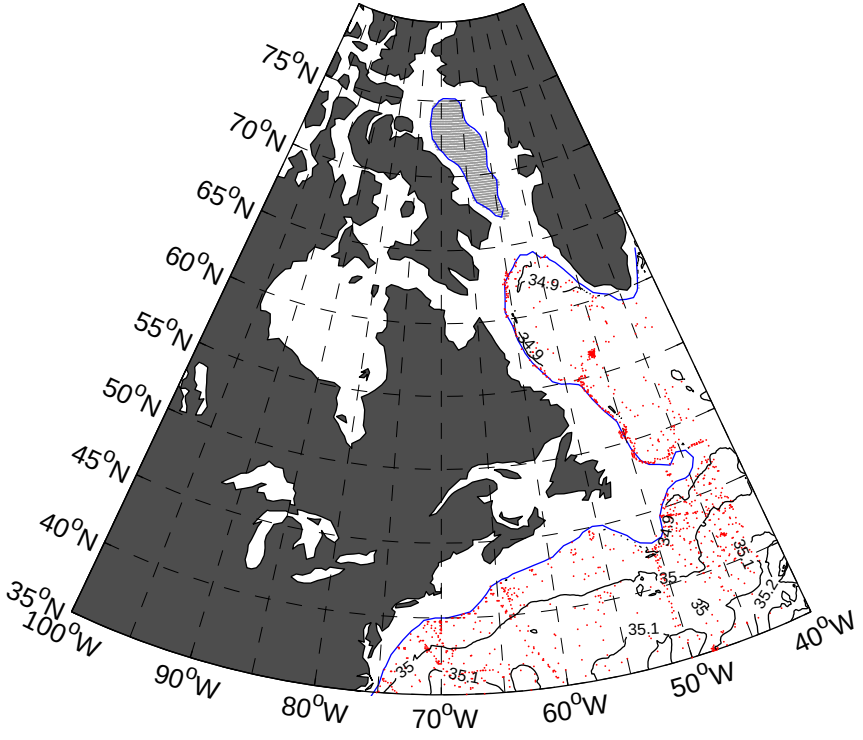

## November Salinity at 500m



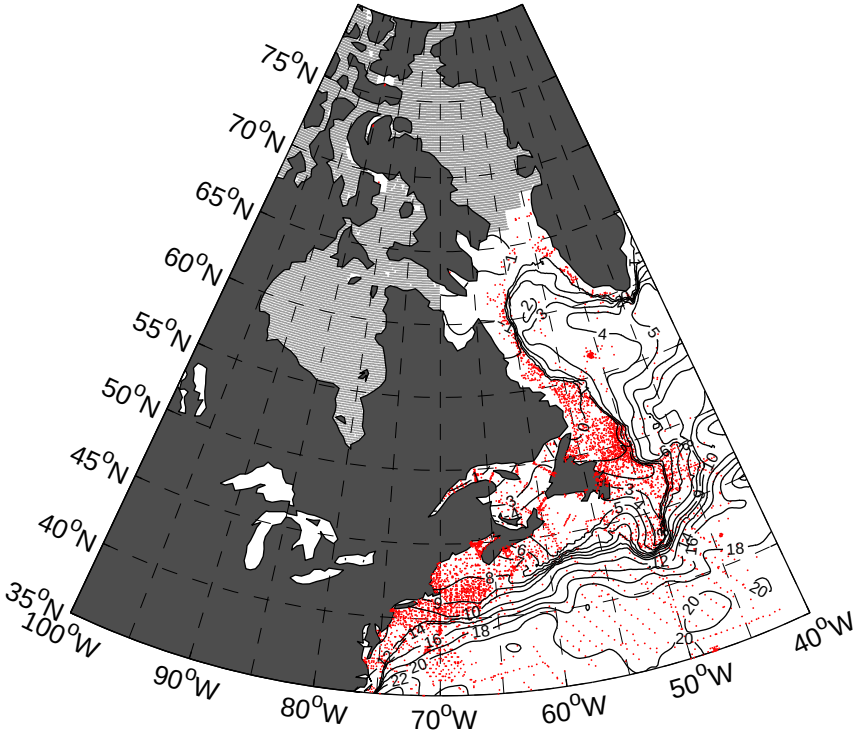
## November Temperature at 1000m



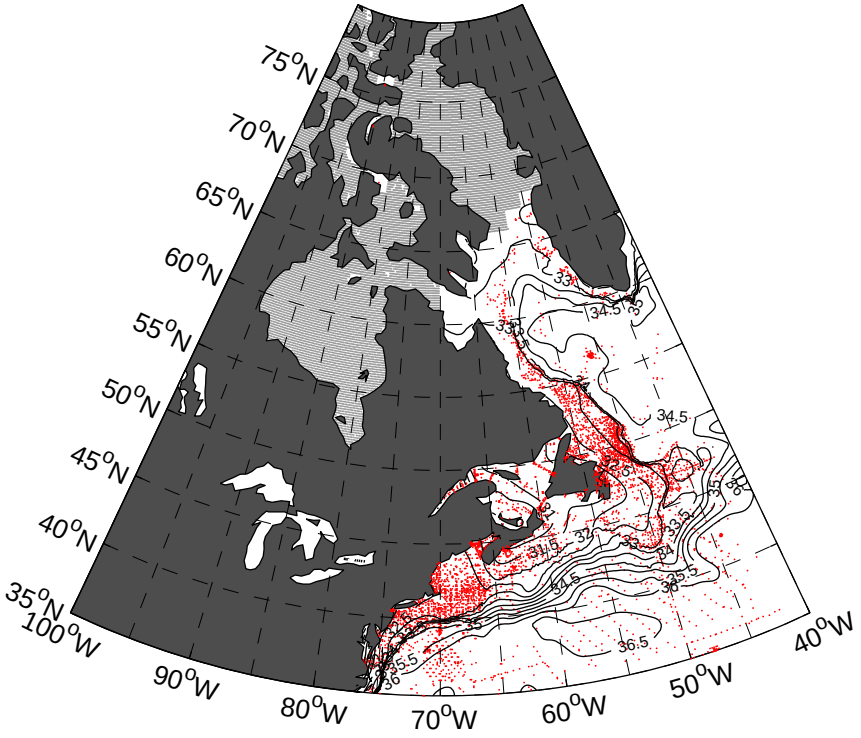

## November Salinity at 1000m



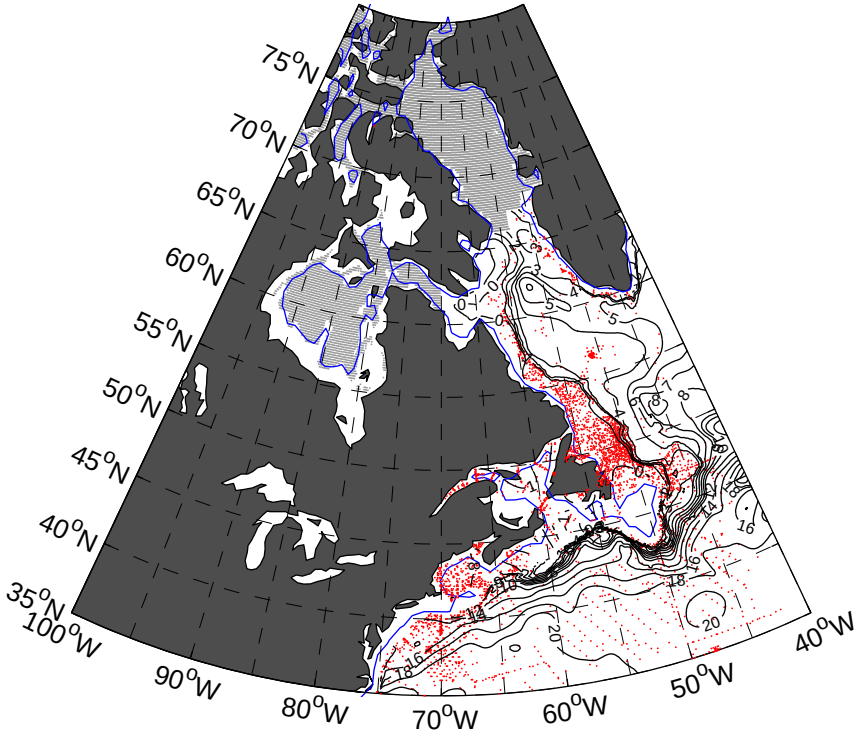
## December Temperature at 0m



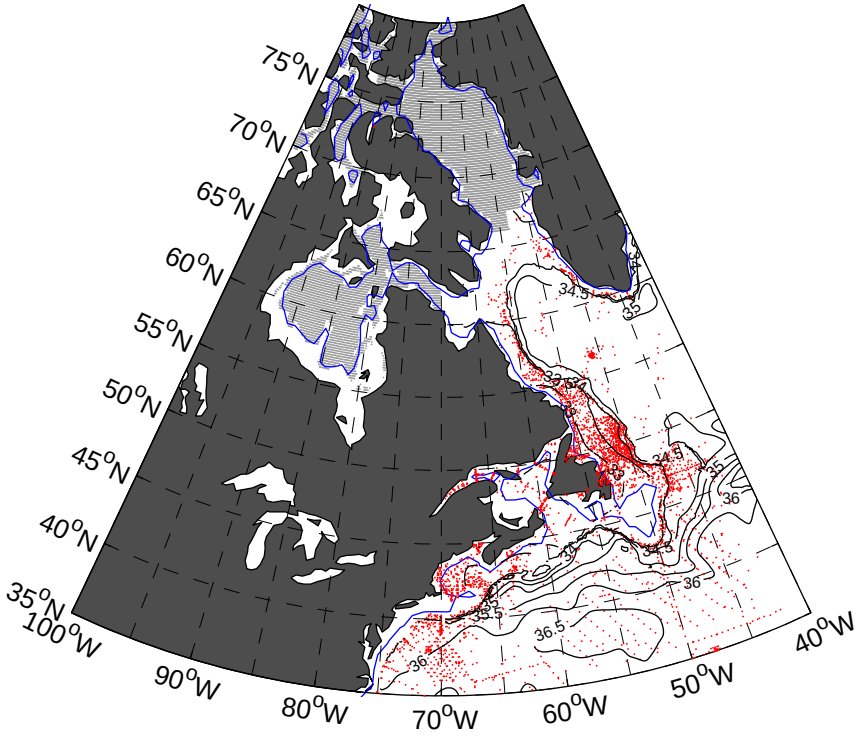

## December Salinity at 0m



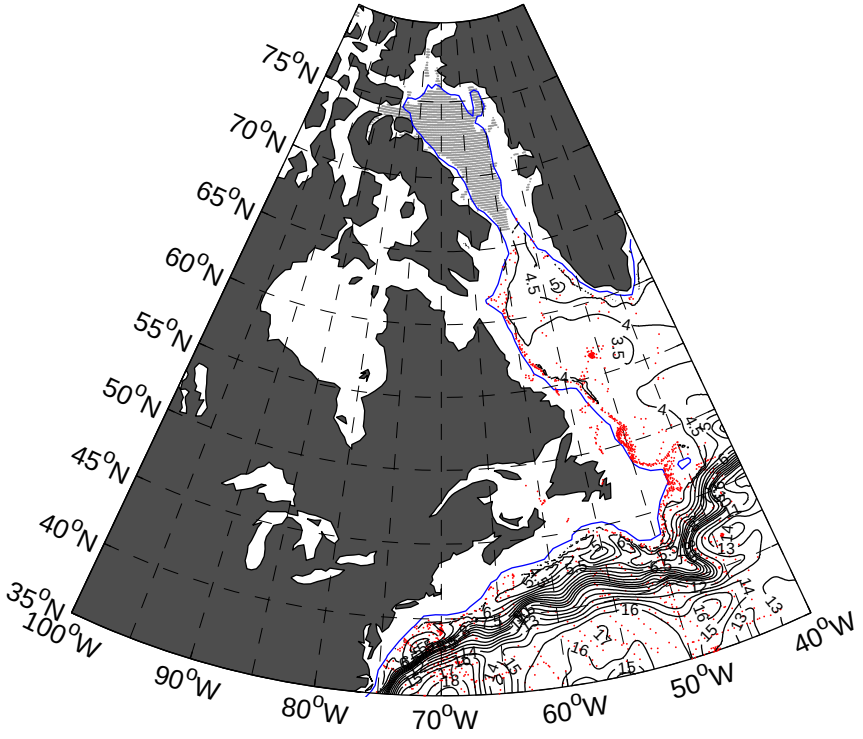
## December Temperature at 100m



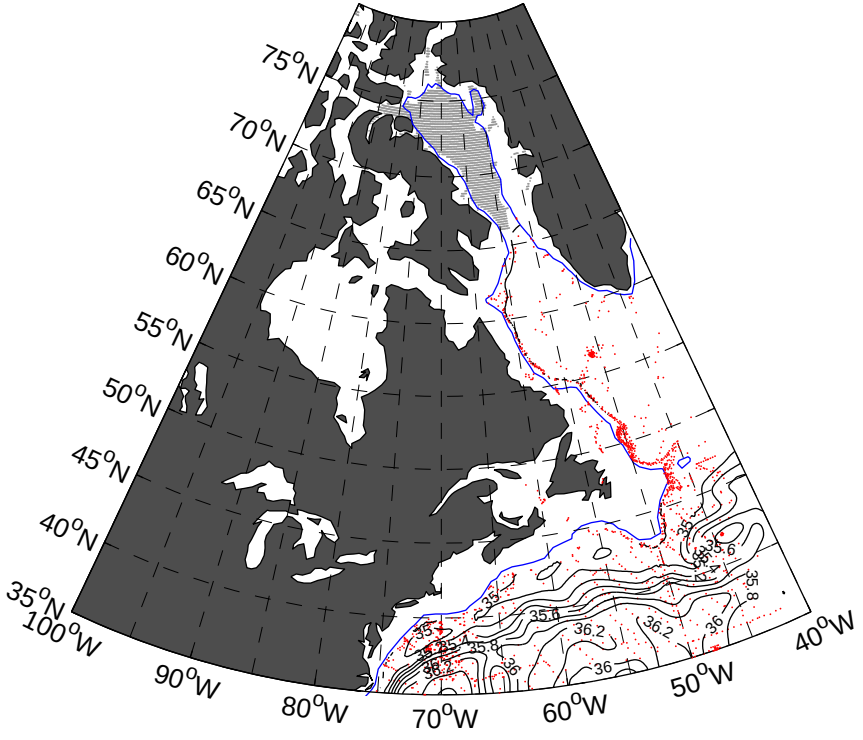

## December Salinity at 100m



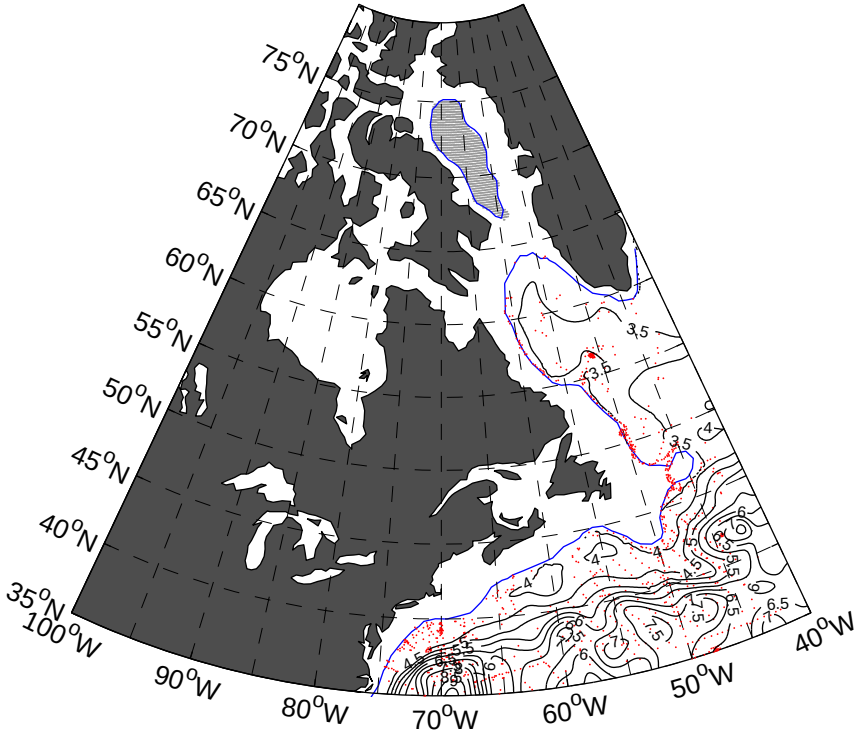
## December Temperature at 500m




## December Salinity at 500m



## December Temperature at 1000m




## December Salinity at 1000m