NOAA Atlas NESDIS 55

ATLAS OF TEMPERATURE-SALINITY FREQUENCY DISTRIBUTIONS: North Atlantic Ocean

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National Oceanic and Atmospheric Administration
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World Data Center for Oceanography, Silver Spring
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АТЛАС ЧАСТОТНЫХ РАСПРЕДЕЛЕНИЙ ТЕМПЕРАТУРЫ И СОЛЁНОСТИ:
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International Ocean Atlas and Information Series, Volume 4
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Moscow – Silver Spring
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Atlas of Temperature-Salinity Frequency Distributions: North Atlantic Ocean

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Abstract

This atlas presents statistical temperature-salinity characteristics of the North Atlantic Ocean. This is accomplished through the presentation of empirical frequency distribution functions of temperature and salinity, both joint and individual distribution functions, as well as estimates of some other empirical statistics. The Atlas contains more than 80,000 plots of empirical distributions of temperature and salinity for 5-degree squares in the North Atlantic. The distributions were constructed for all standard levels, for each of four seasons for the upper (0-400 m) ocean and annual distributions for deeper (500-5500 m) ocean standard levels. Additional statistics are given for each 5-degree square including estimates of the mean and standard deviation based on the arithmetic mean, the median, and Median Absolute Deviation (MAD), winsorized estimates of the mean and standard deviation, quartiles, skewness, and skewness estimated from the quartiles. Some of these statistics are presented in both "normalized" as well as "natural" coordinates.

1. Introduction

In performing quality control of temperature and salinity data from the world ocean, some researchers assume a probability density function (PDF) that has a traditional bell symmetrical form, the "Normal Distribution". For example, as part of quality control procedures, data are flagged based on the number of standard deviations that each datum differs from the mean of all data at each standard depth level in a five-degree square (Boyer and Levitus, 1994). Some earlier works (Winterfeld and Stommel, 1972; Kim and Rossby, 1979) have noted that empirical temperature distribution functions in some parts of the world ocean clearly deviate from a normal distribution. Winterfeld and Stommel (1972) noted bimodality in the deep temperature structure in the Kuroshio region due to the presence or absence of the Kuroshio large meander (Uda, 1964). Kim and Rossby identified bimodality of temperature in the Gulf Stream region due to the presence or absence of Gulf Stream Rings and/or other mesoscale phenomenon.

Our experience indicates that statistical characteristics of the world ocean deviate from normality more than may have been previously recognized. The importance of global, integrated, comprehensive, scientifically quality-controlled ocean profile databases is increasing due to the importance of determining the role of the ocean in climate change. Investigators need access to such databases for other purposes such as quality control of real-time data used in operational forecasting.

We emphasize that there are no "set" statistical rules for assessing the quality of data in a global oceanographic database. The purpose of this atlas is to begin examining the frequency distributions of temperature and salinity data in the world ocean and other summary statistics in a systematic way. Our goal is to begin the effort of quantifying the statistics of ocean variables on a global basis and to improve the statistical quality control of ocean profile data which is applied to the data in such databases as *World Ocean Database 1998* (Levitus *et al.*, 1998) *and World Ocean Database 2001* (Conkright *et al.*, 2002).

Some of the statistics we present in this Atlas have been computed as part of the COADS (Comprehensive Ocean Atmosphere Data Set) database (Slutz *et al.*, 1985; Woodruff *et al.*, 1987, 1998). Given the paucity of data in some regions, and the interannual-to-decadal variability that has been documented in parts of the world ocean, we emphasize that quality control assessments of specific data can easily change with increased sampling in space and time. For example, Wolter (1997) has documented problems associated with trimming of surface marine data in the COADS database.

The statistics and discussions in this atlas follow the work of Kleiner and Graedel (1980), Graedel and Kleiner (1985), and Wilks (1995).

The hard copy part of this Atlas is published as a guide to the two CD-ROM's containing the statistics and distributions described in this Atlas.

2. Data Analysis

One-dimensional frequency distribution plots given in this Atlas are traditional. Temperature or salinity values are marked on the abscissa (horizontal) axis with equal interval equal bin sizes (for any particular 5-degree square), and relative frequency (in units of percent) – is given along the ordinate (vertical) axis.

Two-dimensional joint temperature-salinity distributions are represented as contours, constructed by means of a triangulation method. The contours are drawn with a preset interval (as a rule = 0.005), and temperature and salinity are marked on the horizontal and vertical axes respectively.

Frequency distribution plot representations in natural coordinates (°C and pss) provide information on distribution specifications and make it possible to evaluate modes and limit positions, as well as to compare the variation of frequency distributions with depth, season, *etc.*

The bin sizes we have selected for computing frequency distributions in natural coordinates varied with depth as follows:

Depths (m)	Standard levels	T (°C) bin width	S (pss) bin width
0 - 400	1 -13	1.0	0.25
500 - 900	14 - 18	1.0	0.1
1000 - 2500	19 - 27	0.5	0.1
3000 - 5500	28 - 33	0.25	0.05

Another method to represent empirical distributions (which we display in this Atlas) is to represent them in a normalized (dimensionless) form. Normalized distributions make it possible to visually evaluate important distribution characteristics such as skewness, tail length, and actual distribution limits, which are far beyond +/- three root-mean-square deviations.

Let $x'_{(i)}$, for $i = 1, 2, \ldots, n$ represent the n sample observations of a series of numbers sorted into ascending order. Thus $x'_{(1)}$ is the smallest element of the series and $x'_{(n)}$ is the largest element. Normalized values of a series of numbers are then defined as:

$$x_{(i)} = (x'_{(i)} - m_x) / s_x \qquad (1)$$

where:

m_x = estimation of the mean (location), and
s_x = estimation of standard deviation (scale) of the sample.

In constructing our figures of normalized distributions we used a constant bin width equal to 0.4 root-mean-square deviations.

3. Statistics and robust/resistant estimators

In addition to frequency distribution plots to describe a set of data it is useful to have numerical estimates of statistics which describe the data values that comprise a distribution pattern (*e.g.*, "summary statistics") . Large databases usually have "outliers" due to measurement error or natural variability. Even after implementing a statistical quality control process which flags and eliminates from further consideration what we believe to be erroneous and/or non-representative values, the samples may be non-normal due to skewness in one or both tails of the empirical distribution. This raises the questions of how summary statistics should be computed and how representative they are. For further information about some historical experiences dating back centuries we refer the reader to the book by Hampel *et al.* (1986).

In making statistical estimates, such skewness may cause "dramatic" results, such as a location estimation offset and a significant increase of a scale estimation. Robust/resistant estimators are frequently used for computing the statistical descriptors of such samples. Quoting Kleiner and Graedel (1980) "estimates which may not be optimal for any given distribution but remain quite good under a variety of circumstances; such estimates are called 'robust'. Estimates which are not unduly influenced by a small number of outliers are called 'resistant'."

There are no unambiguous rules in the application of such robust/resistant estimators. We have computed and present in this Atlas some simple robust/resistant estimators along with more classical estimators, which allows one to estimate advantages and disadvantages of the various estimators.

"Trimming" is a procedure that reduces the effect of outliers on the estimate of the mean of a series of numbers by ignoring a set percentage of the highest and lowest values in a series of numbers. However, the process of trimming reduces the variance of the series of numbers. The process of "winsorization" restores some of the variance by

a) substituting in the highest value of the series (after trimming) for the –k "highest" values that were ignored during estimate of the trimmed mean

b) substituting in the lowest value of the series (after trimming) for the –k "lowest" values that were ignored during estimate of the trimmed mean.

The mean and variance resulting from a winsorization procedure are dependent on the number of outliers in a series of numbers, but are not dependent on their actual values.

Although this atlas provides estimates of the mean and variance of the winsorized series of temperature and salinity in each 5-degree square at each standard depth level, for completeness we present equations defining the mean and variance of a trimmed as well as a winsorized time series of numbers.

We denote the means of a trimmed series of numbers as $\bar{x}_t$, and the mean of a winsorized series of numbers as $\bar{x}_w$. We define α as the fraction of the data in a series that will be trimmed at each end of a series of numbers. Quoting Kleiner and Graedel (1980) "The choice of α depends on the actual situation, in which the non-normality of the data and the amount of protection against outliers play important roles.". We use a value of $\alpha = 0.04$ in this atlas and define $k = \alpha n$. Then,

$$\bar{x}_t = \frac{1}{n-2k} \sum_{i=k+1}^{n-k} x_i \tag{2}$$

$$\bar{x}_w = \frac{1}{n} \left[\sum_{i=k+1}^{n-k} x_i + \left(k x_{k+1} \right) + \left(k x_{n-k} \right) \right] \tag{3}$$

$$Variance(\bar{x}_t) = \frac{1}{(n-2k)} \sum_{i=k+1}^{n-k} (x_i - \bar{x}_t) \tag{4}$$

Note that the trimmed variance may be multiplied by an adjustment factor (Kleiner and Graedel, 1980) to make it consistent with the classically defined sample variance.

$$Variance(\bar{x}_w) = \frac{1}{n} \left[\sum_{i=k+1}^{n-k} (x_i - \bar{x}_w)^2 + k\left(x_{k+1} - \bar{x}_w\right)^2 + k\left(x_{n-k} - \bar{x}_w\right)^2 \right] \tag{5}$$

To further describe each distribution pattern we have computed and present in this atlas several summary statistics which we present in the following list:

m_x	=	arithmetic mean;
s_x	=	standard deviation;
μ_x	=	sample median;
s_{MAD}	=	robust estimator for standard deviation based on MAD (median absolute deviation from median), MAD = median $_i\|x_{(i)}$-median$_i(x_{(i)})\|$, s_{MAD}= 1.483MAD; The factor 1.483 results from the fact as described by Kleiner and Graedel (1980) that "MAD has to be divided by a normalizing constant c_{MAD} to make it a biased-free estimate of the standard deviation";
m_w	=	estimate of the mean based on the winsorized series of data;
s_w	=	estimate of the standard deviation based on the winsorized series of data
$Q_{0.25}$	=	lower quartile;
$Q_{0.5}$	=	median
$Q_{0.75}$	=	upper quartile;
a3	=	direct estimation of the coefficient of skewness, m_3/s_x^3, where $m_3= \Sigma(x_i-m_x)^3 /n$;
a3q	=	quartile coefficient of skewness (a robust estimator), a3q = $(Q_{0.25}+Q_{0.75}-2Q_{0.5})/(Q_{0.75}-Q_{0.25})$. Note that $Q_{0.5}$ = median.

It is obvious, that the distribution mode (or modes) would be an additional valuable statistic for evaluation. However, we do not know methods of sufficiently accurate determination of distribution mode, especially in the case of a polymodal distribution given the considerable sample variability we observe in parts of the Atlantic Ocean

4. Data

To construct empirical frequency distributions of climatological temperature and salinity data for the Atlantic Ocean we used data from the *World Ocean Database 1998* (WOD98) (Levitus *et al.*, 1998) for the region bounded by latitudes 80°N and 30°S. The distributions were constructed based on all historical data available for all standard depth levels for all 5-degree squares by seasons for the depth range 0 – 400 m and for a climatic year for the depth range 500-5500 m. The samples contain all the available observation data, considered as independent (*e.g.*, formally for the upper depths we accept a cyclo-stationary model (Hasselmann, 1976); and consider the temperature and salinity observation data or T-S pairs as an ensemble of realizations of a stochastic climate variable, whose distribution features should be estimated).

The minimum sample size for computation of our distributions and statistics was 25. We believe this criteria allows evaluation of a distribution form, although in the areas of considerable sample variability the distribution plots are fractured.

For the above criteria the data in WOD98 makes it possible to provide estimates for most 5-degree squares of the North Atlantic.

A matrix smoothing was carried out to achieve more matched dimensionless 2-D distributions.

5. Guide to the CD-ROM

We present eleven figures as part of the hard-copy version of this Atlas and use them as a guide to what users can expect from the CD-ROM version of this Atlas.

Fig. 1 shows the 5-degree square coordinate system we use for referencing individual 5-degree squares in this atlas. It is the same system used in the *World Ocean Atlas 1998* series (Ocean Climate Laboratory, 1999).

Fig. 2 is a scatterplot matrix of the joint temperature (°C)-salinity (pss) frequency distributions (natural coordinates) for the North Atlantic Ocean at 600 m depth for the all-data climatological annual compositing period. There is a similar map for each standard depth level. This figure provides a "thumbnail" view of the distributions at this level. As a historical note we point out that Emery and O'Brien (1978) published scatterplot matrices of T-S distributions for the North Pacific Ocean. In the CD-ROM part of this Atlas the distribution in an individual 5-degree square can be "clicked" on and the joint T-S frequency distribution in natural co-ordinates for that single square will be displayed on a computer monitor as exemplified by Fig. 3.

Fig. 3 shows the T-S distribution for the 5-degree square with grid co-ordinates I=59 and J=26 as given just below the figure. The next line gives the climatological compositing period (in this case Annual), the depth in meters, the standard level number and the number of T-S pairs plotted in the figure. The latitude and longitude boundaries for this square are given in the next line. The statistics described in section 3 of the text are given in table form. Finally, the bin widths of temperature and salinity used in constructing the distribution are given.

Not shown in figure 3 but part of the on-screen display of this distribution and statistics are buttons that when clicked, allow one to see the individual frequency distributions for T and S in this 5-degree square in natural coordinates as displayed in Fig. 4.

Similarly buttons appear that allow the user to display the joint frequency distribution of T-S in "normalized" coordinates as shown in Fig. 5 and the individual normalized distributions of T and S as shown in Fig. 6.

In Figs. 7-11 we repeat the sequence of Figs. 2-5 but for the climatological Spring season data distributions at the sea surface.

The Atlas shell is based on HTML 4.0/Java Script code, which runs using Microsoft Internet Explorer 3.0 or higher and Netscape Navigator 4.0 or higher.

6. Discussion

The frequency distributions presented in this Atlas make it clear that the 5-degree square distributions of temperature and salinity are not normally distributed over fairly large regions of the North Atlantic Ocean. The non-normality may be due to several phenomenon including the passage of mesoscale phenomenon such as eddies and rings through a region, the existence of strong fronts bisecting a 5-degree square, the occurrence of rainfall and river outflow, and the fact that the North Atlantic is influenced by water masses formed in several distinct regions to cite just a few possibilities. The non-normality of frequency distributions of salinity in the North Atlantic has been used by Richardson *et al.* (1991) to search for the existence of eddies and/or lenses in the Mediterranean outflow of the North Atlantic. In addition, as noted earlier in this Atlas, large-scale currents such as the Kuroshio may occupy different positions in time which results in bimodal distributions of temperature and salinity. Insufficient sampling of the temporal varying large-scale distributions of temperature and salinity may also lead to non-normal distributions. The works by Levitus (1989a,b,c), Levitus *et al.* (2000), Shaffer *et al.* (2000), Arbic and Owens (2001) represent just a few of the many papers documenting such changes in parts of the world ocean. The flattening of the permanent thermocline in the Pacific Ocean during El Nino is another example. The global deployment (Roemmich and Owens, 2000) of profiling floats that provide vertical profiles of temperature and salinity to 2000 m depth at nominal intervals of 10 days will provide data that will greatly improve our knowledge of the statistics of these variables as well as our understanding of the variability of the world ocean.

The non-normality of the distributions of temperature, salinity, and other ocean variables also is an important factor in the preparation of climatologies of the world. Such climatologies attempt to represent the large-scale permanent and semi-permanent features of the world ocean (Levitus, 1982). The expectation that a single climatology can represent the state of the world ocean is not realistic. Levitus (1982) discussed this issue and the limitations of ocean climatologies based on composites of historical data. Nevertheless, climatologies have found widespread use by the scientific community who often find novel ways to utilize such analyses. For example, work by Holland and Hirschman (1975) noted the sensitivity of ocean diagnostic models to even small insensitivities in climatological temperature-salinity fields. Sarmiento and Bryan (1992) addressed this problem by introducing Newtonian damping terms into an ocean general circulation model which allowed the model temperature-salinity fields to depart from the internal climatological temperature-salinity fields used to drive the model.

We expect non-normality to occur even as we average data on finer scale grids. The non-normality indicates care must be taken when interpreting climatological mean fields of these variables. Computation of objectively analyzed fields of ocean variables for compositing periods other than climatological periods will reduce the problem of non-representativeness of data due to temporal variability. Yearly upper-ocean temperature anomaly fields have been produced as part of *World Ocean Atlas 1994* and *World Ocean Atlas 1998*. Five-year running composite fields of temperature and salinity have been produced for intermediate and deep ocean levels as part of these series also. The *World Ocean Database 2001* (Conkright *et al.*, 2002) will also be used to generate such fields. It must be recognized however, that compositing data for shorter periods means that it is more likely that some ocean regions for some compositing periods may have such reduced data coverage that it is not possible to produce a "global" analysis if that is desired.

As the historical ocean database builds up the scientific community will be able to improve the quality control of both historical as well as real-time oceanographic data. In this way the research and operational communities that use historical data for research and operational forecasting will be able to more accurately diagnose, model, and forecast the state of the world ocean.

7. Future Work

Distributions and estimates for the world ocean similar to those presented in this atlas are in preparation. This new work will be based on *World Ocean Database 2001* (Conkright *et al.*, 2002).

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Each element F (i,j) of an analyzed field F, where F is dimensioned F(72,36), is considered to represent the value at the center of a five-degree latitude longitude square.

Longitude denoted by the variable "i", varies from 1 at 2.5° E to 72 at 2.5° W

Latitude denoted by the variable "j", varies from 1 at 87.5° S to 36 at 87.5° N

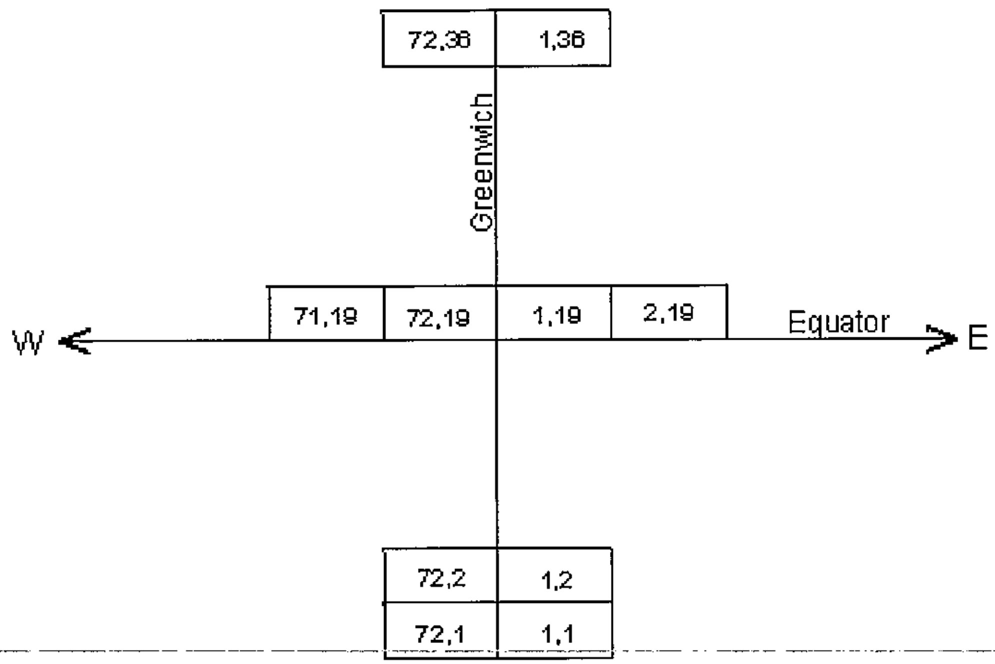


Fig. 1. Description of the five-degree square numbering system for the world ocean.

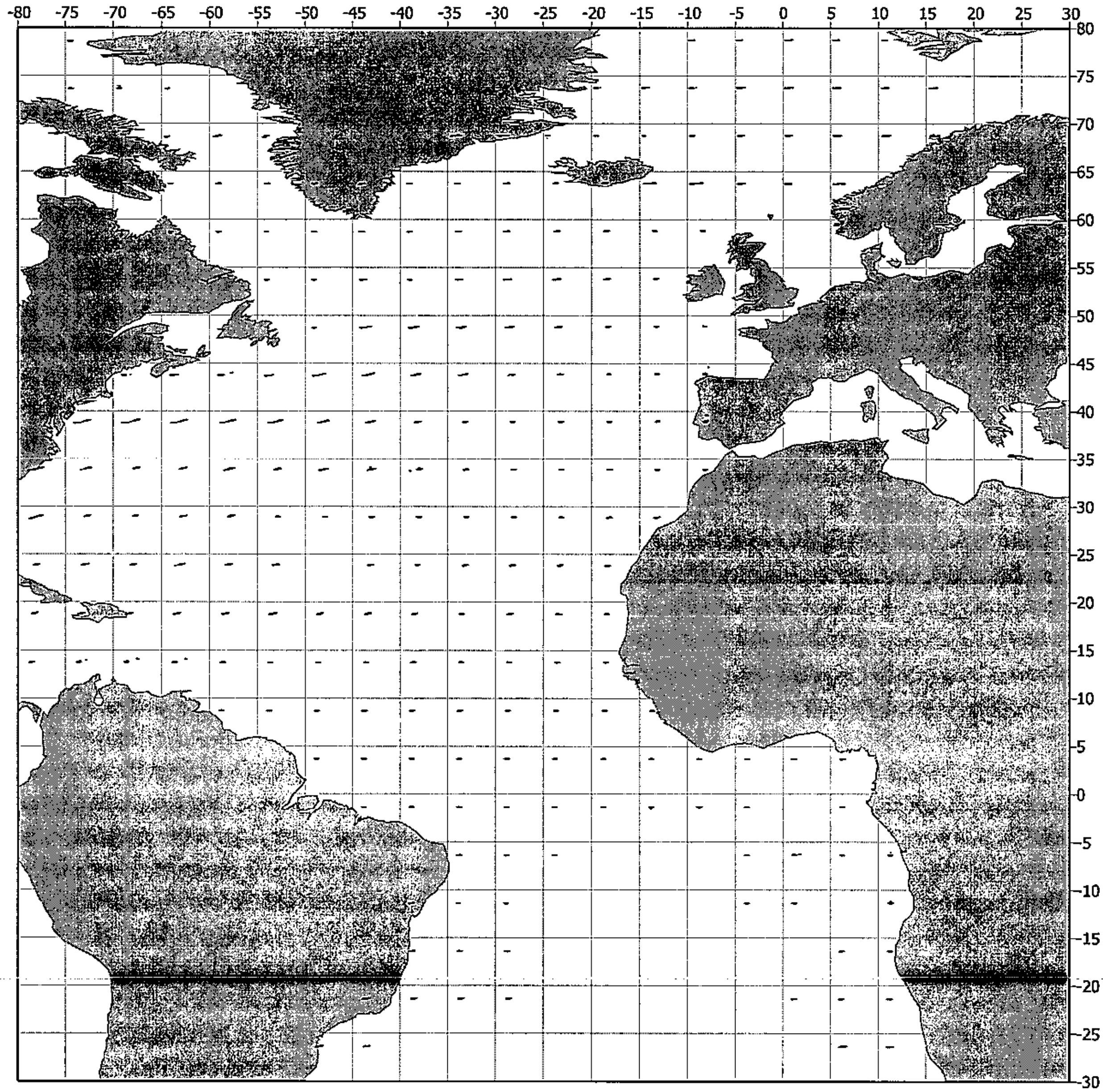
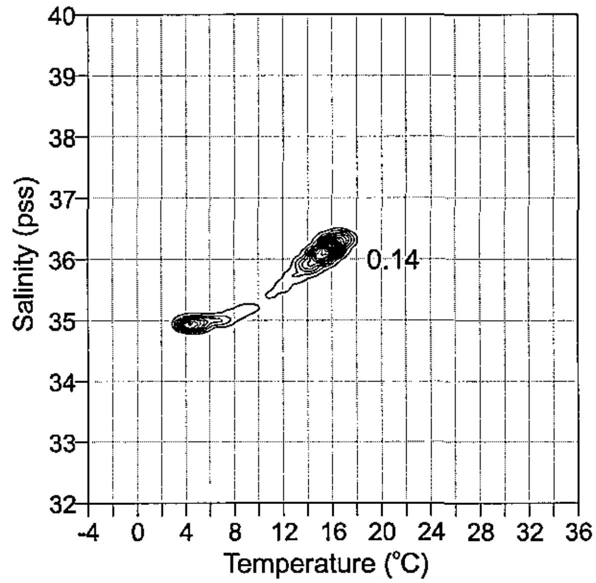


Fig. 2 Scatterplot matrix by 5-degree squares of joint temperature-salinity frequency distributions at 600 m depth in the North Atlantic for the annual compositing period. Salinity is plotted along the ordinate (vertical axis) and temperature along the abscissa (horizontal) of each plot in the matrix.

T-S Joint Distribution - 2-D Plot

(each isoline corresponds to 0.005)



I= 59, J = 26

Annual , Depth=**600** m (Standard level # **15**), Number of T,S pairs= **1774**

N. boundary - 40°N, S. boundary - 35°N, W. boundary - 70°W, E. boundary - 65°W

Statistics:

	m_x	s_x	μ_x	s_{MAD}	m_w	s_w	a3	$a3_q$
Temperature	12.83	4.54	15.19	2.32	12.83	4.53	-0.81	-0.71
Salinity	35.79	0.54	36.03	0.42	35.79	0.53	-0.55	-0.63

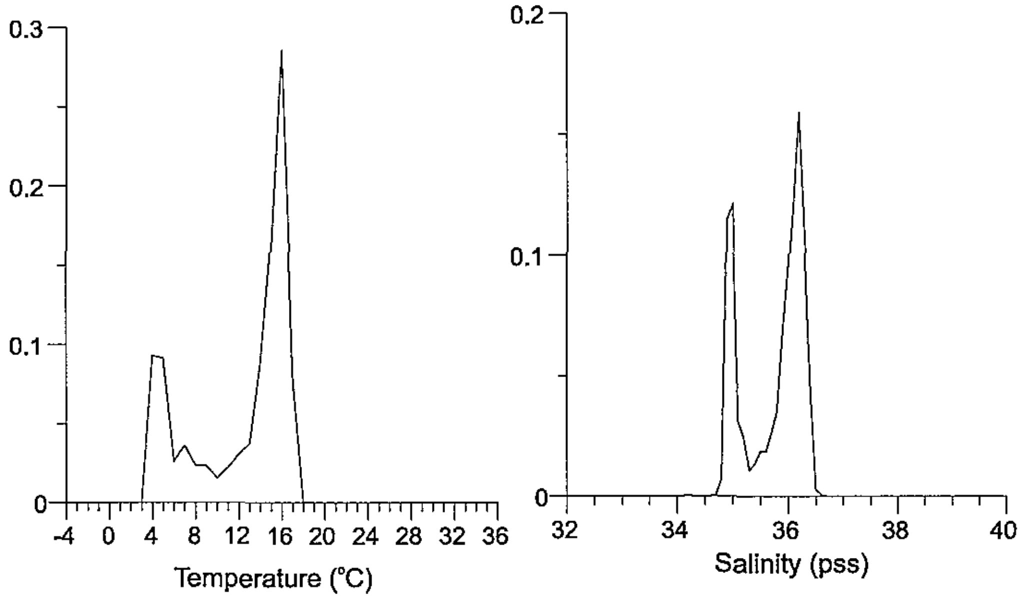
Additional Statistics:

	Natural				Normalized			
	$Q_{0.25}$	$Q_{0.75}$	min	max	$Q_{0.25}$	$Q_{0.75}$	min	max
Temperature	8.43	16.35	4.28	18.06	-2.92	0.50	-4.71	1.24
Salinity	35.13	36.23	34.27	36.60	-2.11	0.48	-4.15	1.35

Bin width: 1.0°C x 0.1 pss

Fig. 3 Empirical joint temperature-salinity frequency distribution (natural coordinates) for the 5-degree square noted below the figure. Statistics shown are those described in the text of this atlas.

T and S Individual Distributions - 1-D Plot



I= 59, J = 26

Annual , Depth=**600** m (Standard level # **15**), Number of T,S pairs= **1774**

N. boundary - 40°N, S. boundary - 35°N, W. boundary - 70°W, E. boundary - 65°W

Statistics:

	m_x	s_x	μ_x	s_{MAD}	m_w	s_w	a3	$a3_q$
Temperature	12.83	4.54	15.19	2.32	12.83	4.53	-0.81	-0.71
Salinity	35.79	0.54	36.03	0.42	35.79	0.53	-0.55	-0.63

Additional Statistics:

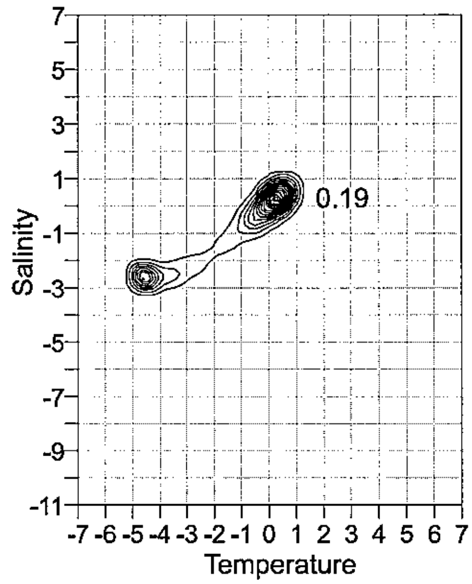
	Natural				Normalized			
	$Q_{0.25}$	$Q_{0.75}$	min	max	$Q_{0.25}$	$Q_{0.75}$	min	max
Temperature	8.43	16.35	4.28	18.06	-2.92	0.50	-4.71	1.24
Salinity	35.13	36.23	34.27	36.60	-2.11	0.48	-4.15	1.35

Bin width: 1.0°C x 0.1 pss

Fig. 4 Empirical individual temperature and salinity frequency distributions (natural coordinates) for the same 5-degree square shown in figure 2. Statistics shown are those described in the text of this atlas.

T-S Joint Normalized Distribution - 2-D Plot

(each isoline corresponds to 0.005)



I= 59, J = 26

Annual , Depth=**600** m (Standard level # **15**), Number of T,S pairs= **1774**

N. boundary - 40°N, S. boundary - 35°N, W. boundary - 70°W, E. boundary - 65°W

Statistics:

	m_x	s_x	μ_x	s_{MAD}	m_w	s_w	a3	$a3_q$
Temperature	12.83	4.54	15.19	2.32	12.83	4.53	-0.81	-0.71
Salinity	35.79	0.54	36.03	0.42	35.79	0.53	-0.55	-0.63

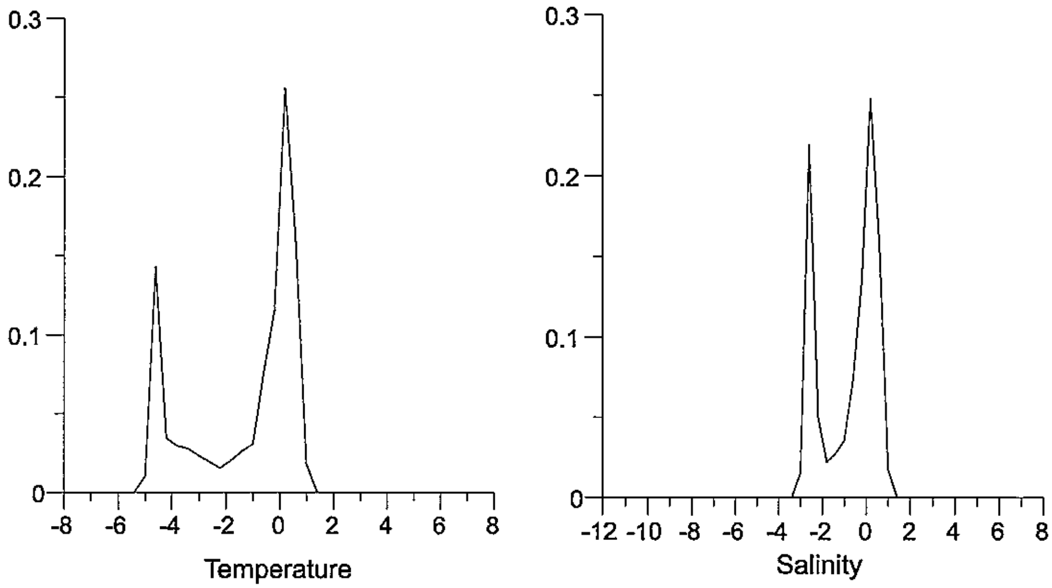
Additional Statistics:

	Natural				Normalized			
	$Q_{0.25}$	$Q_{0.75}$	min	max	$Q_{0.25}$	$Q_{0.75}$	min	max
Temperature	8.43	16.35	4.28	18.06	-2.92	0.50	-4.71	1.24
Salinity	35.13	36.23	34.27	36.60	-2.11	0.48	-4.15	1.35

Bin width: 1.0°C x 0.1 pss

Fig. 5 Empirical joint temperature-salinity frequency distribution (normalized coordinates) for the same 5-degree square shown in figure 2. Statistics shown are those described in the text of this atlas.

T and S Individual Normalized Distributions - 1-D Plot



I= 59, J = 26
Annual , Depth=**600** m (Standard level # **15**), Number of T,S pairs= **1774**
N. boundary - 40°N, S. boundary - 35°N, W. boundary - 70°W, E. boundary - 65°W

Statistics:

	m_x	s_x	μ_x	s_{MAD}	m_w	s_w	a3	$a3_q$
Temperature	12.83	4.54	15.19	2.32	12.83	4.53	-0.81	-0.71
Salinity	35.79	0.54	36.03	0.42	35.79	0.53	-0.55	-0.63

Additional Statistics:

	Natural				Normalized			
	$Q_{0.25}$	$Q_{0.75}$	min	max	$Q_{0.25}$	$Q_{0.75}$	min	max
Temperature	8.43	16.35	4.28	18.06	-2.92	0.50	-4.71	1.24
Salinity	35.13	36.23	34.27	36.60	-2.11	0.48	-4.15	1.35

Bin width: 1.0°C x 0.1 pss

Fig. 6 Empirical individual temperature and salinity frequency distributions (natural coordinates) for the same 5-degree square shown in figure 2. Statistics shown are those described in the text of this atlas.

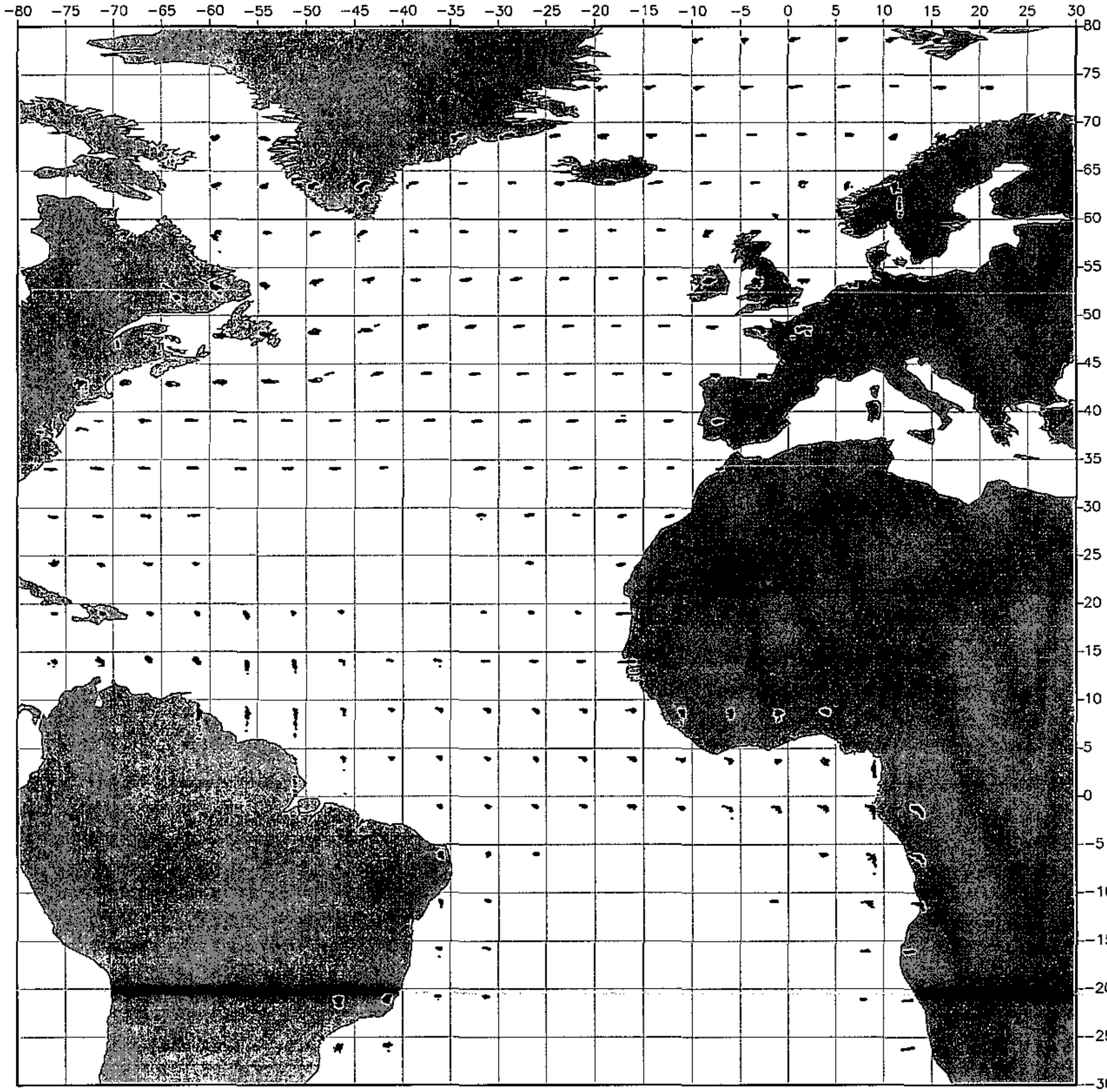
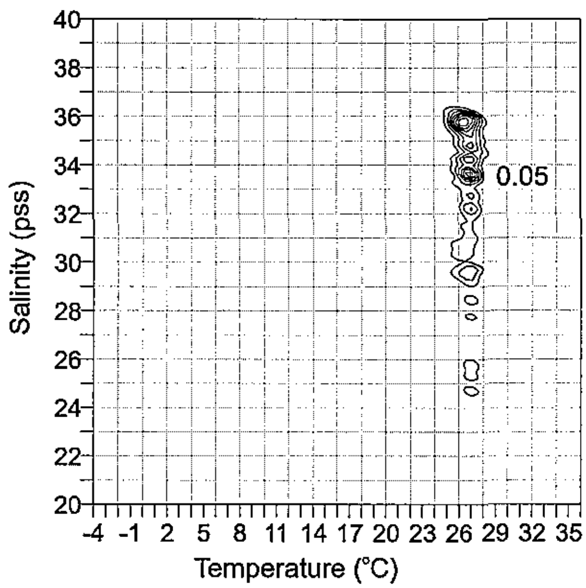


Fig. 7 Scatterplot matrix by 5-degree squares of joint temperature-salinity frequency distributions at the sea surface in the North Atlantic for the Spring compositing period. Salinity is plotted along the ordinate (vertical axis) and temperature along the abscissa (horizontal) of each plot in the matrix.

T-S Joint Distribution - 2-D Plot

(each isoline corresponds to 0.005)



I = 62, J = 20

Spring (Apr - Jun),Depth **0** m (St.level # **1**), Number of T,S pairs **136**

N. boundary - 10°N, S. boundary - 5°N, W. boundary - 55°W, E. boundary - 50°W

Statistics:

	m_x	s_x	μ_x	s_{MAD}	m_w	s_w	a3	$a3_q$
Temperature	27.23	0.45	27.28	0.39	27.23	0.44	-0.49	-0.13
Salinity	32.82	3.25	33.81	2.88	32.83	3.21	-1.07	-0.28

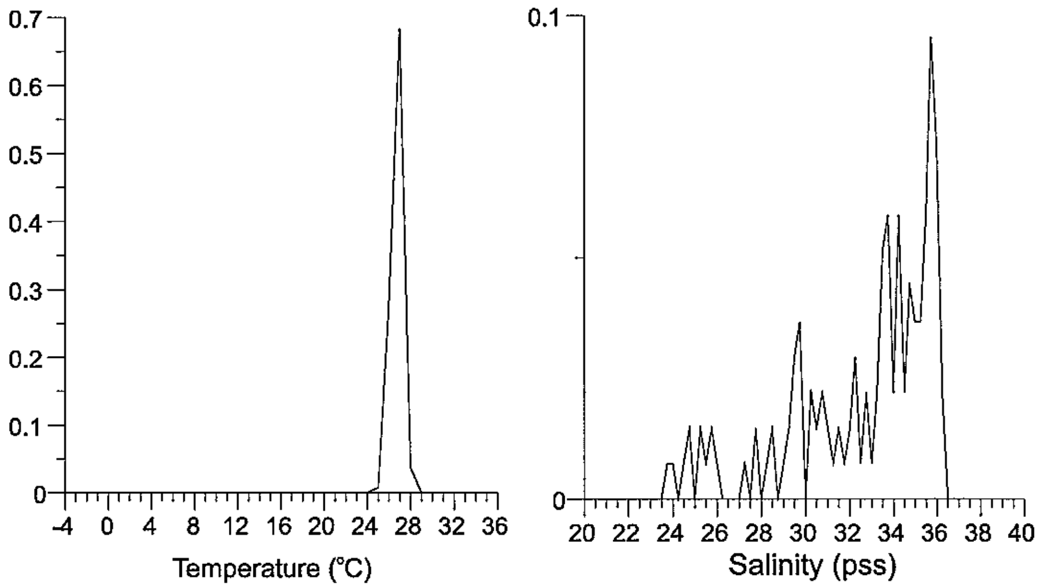
Additional Statistics:

	Natural				Normalized			
	$Q_{0.25}$	$Q_{0.75}$	min	max	$Q_{0.25}$	$Q_{0.75}$	min	max
Temperature	26.97	27.52	25.77	28.17	-0.79	0.61	-3.84	2.28
Salinity	30.84	35.46	23.77	36.29	-1.03	0.57	-3.48	0.86

Bin width: 1.0°C x 0.25 pss

Fig. 8 Empirical joint temperature-salinity frequency distribution (natural coordinates) for the 5-degree square noted below the figure. Statistics shown are those defined in the text of this atlas.

T and S Individual Distributions - 1-D Plot



I = 62, J = 20
Spring (Apr - Jun),Depth **0** m (St.level # **1**), Number of T,S pairs **136**
N. boundary - 10°N, S. boundary - 5°N, W. boundary - 55°W, E. boundary - 50°W

Statistics:

	m_x	s_x	μ_x	s_{MAD}	m_w	s_w	a3	$a3_q$
Temperature	27.23	0.45	27.28	0.39	27.23	0.44	-0.49	-0.13
Salinity	32.82	3.25	33.81	2.88	32.83	3.21	-1.07	-0.28

Additional Statistics:

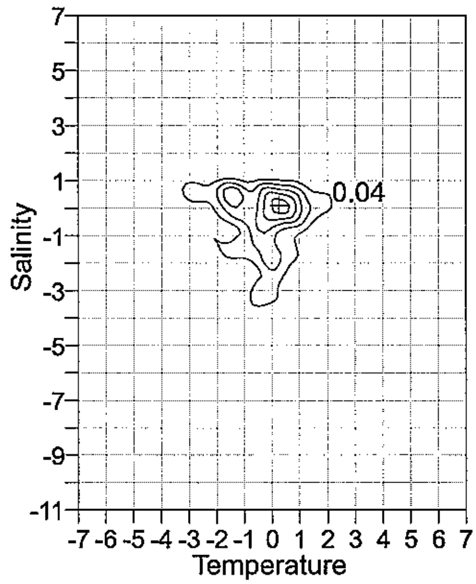
	Natural				Normalized			
	$Q_{0.25}$	$Q_{0.75}$	min	max	$Q_{0.25}$	$Q_{0.75}$	min	max
Temperature	26.97	27.52	25.77	28.17	-0.79	0.61	-3.84	2.28
Salinity	30.84	35.46	23.77	36.29	-1.03	0.57	-3.48	0.86

Bin width: 1.0°C x 0.25 pss

Fig. 9. Empirical individual temperature and salinity frequency distributions (natural coordinates) for the same 5-degree square shown in figure 8. Statistics are those described in the text of this atlas.

T-S Joint Normalized Distribution - 2-D Plot

(each isoline corresponds to 0.005)



I = 62, J = 20

Spring (Apr - Jun),Depth **0** m (St.level # **1**), Number of T,S pairs **136**

N. boundary - 10°N, S. boundary - 5°N, W. boundary - 55°W, E. boundary - 50°W

Statistics:

	m_x	s_x	μ_x	s_{MAD}	m_w	s_w	a3	$a3_q$
Temperature	27.23	0.45	27.28	0.39	27.23	0.44	-0.49	-0.13
Salinity	32.82	3.25	33.81	2.88	32.83	3.21	-1.07	-0.28

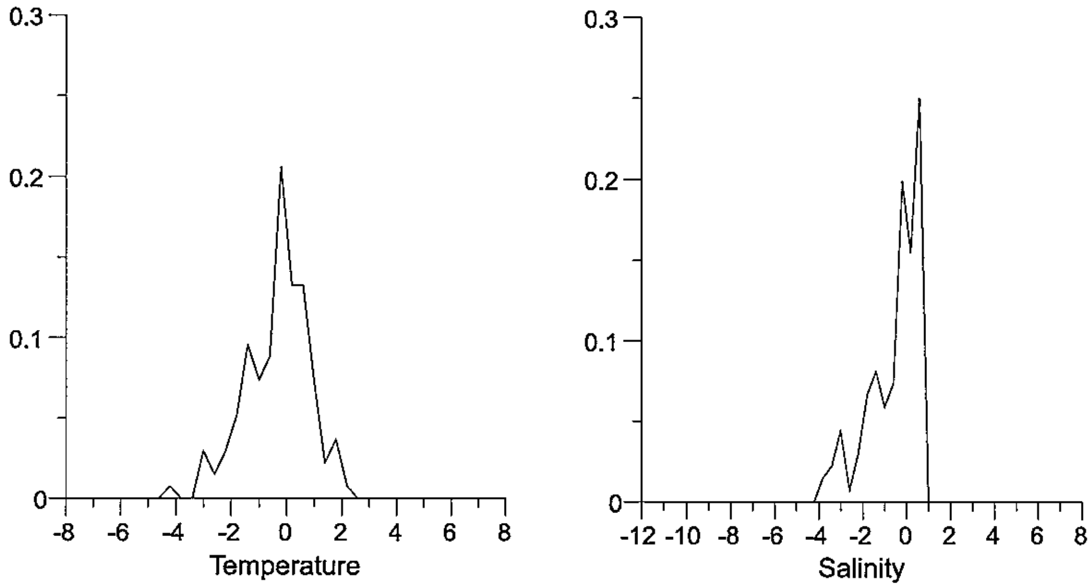
Additional Statistics:

	Natural				Normalized			
	$Q_{0.25}$	$Q_{0.75}$	min	max	$Q_{0.25}$	$Q_{0.75}$	min	max
Temperature	26.97	27.52	25.77	28.17	-0.79	0.61	-3.84	2.28
Salinity	30.84	35.46	23.77	36.29	-1.03	0.57	-3.48	0.86

Bin width: 1.0°C x 0.25 pss

Fig. 10. Empirical joint temperature-salinity frequency distribution (normalized coordinates) for the same 5-degree square shown in figure 8. Statistics are those described in the text of this atlas.

T and S Individual Normalized Distributions - 1-D Plot



I = 62, J = 20
Spring (Apr - Jun),Depth **0** m (St.level # **1**), Number of T,S pairs **136**
N. boundary - 10°N, S. boundary - 5°N, W. boundary - 55°W, E. boundary - 50°W

Statistics:

	m_x	s_x	μ_x	s_{MAD}	m_w	s_w	a3	$a3_q$
Temperature	27.23	0.45	27.28	0.39	27.23	0.44	-0.49	-0.13
Salinity	32.82	3.25	33.81	2.88	32.83	3.21	-1.07	-0.28

Additional Statistics:

	Natural				Normalized			
	$Q_{0.25}$	$Q_{0.75}$	min	max	$Q_{0.25}$	$Q_{0.75}$	min	max
Temperature	26.97	27.52	25.77	28.17	-0.79	0.61	-3.84	2.28
Salinity	30.84	35.46	23.77	36.29	-1.03	0.57	-3.48	0.86

Bin width: 1.0°C x 0.25 pss

Fig. 11. Empirical individual temperature and salinity frequency distributions (natural coordinates) for the same 5-degree square shown in figure 8. Statistics are those described in the text of this atlas.