Objective Analyses of Annual, Seasonal, and Monthly Temperature and Salinity for the World Ocean on a 1/4° Grid

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ABSTRACT

Objectively analyzed climatological mean fields of temperature and salinity have been calculated on a 1/4° grid for the world ocean for the annual, seasonal, and monthly compositing periods using data from the *World Ocean Database 2001* (WOD01). The annual and seasonal fields are calculated at standard levels from the surface to 5500 meters. The monthly fields are calculated at standard levels from the surface to 1500 meters. In comparison with similarly computed climatologies calculated on a 1° grid, ocean circulation features such as the Gulf of Mexico Loop Current are more clearly represented. The new 1/4° climatologies preserve most of the spatial resolution of earlier 1/4° temperature and salinity climatologies, while reducing noise by additional smoothing in horizontal space (geographically at each depth), vertically (along depth at each grid), as well as in time (through Fourier filtering).

1. INTRODUCTION

The temperature and salinity climatologies presented as part of the *Climatological Atlas of the World Ocean* (Levitus, 1982) and its atlas updates in 1994 (Levitus and Boyer, 1994; Levitus *et al.*, 1994), 1998 (Antonov *et al.*, 1998a;b;c; Boyer *et al.*, 1998 a;b;c), and 2001 (Stephens *et al.*, 2002, hereafter referred to as W01t for the temperature analyses; Boyer *et al.*, 2002, hereafter referred to as W01s for the salinity analyses, W01 collectively) have proven to be valuable tools for studying the temperature and salinity structure of the World Ocean, as initial and boundary conditions for ocean circulation models, and for sea truth for remote sensing data, such as Sea Surface Temperature (SST). The main improvement of the atlas updates released since 1982 has been the addition of significant amounts of data assembled from international data management projects including the Intergovernmental Oceanographic Commission (IOC) sponsored Global Ocean Data Archeology and Rescue (GODAR) project, the World Ocean Database project (Conkright *et al.*, 2002; Levitus *et al.*, 2004), the MEDAR/MEDATLAS project sponsored by the European Community as well as routine international ocean data exchange carried out under the auspices of the IOC.

All of the above climatological mean fields were calculated on a 1° latitude/longitude grid. Boyer and Levitus (1997, hereafter BL97) calculated "all-data" annual fields of climatological mean temperature and salinity on a 1/4° grid, which greatly improved the spatial resolution of these climatological fields. However, Chang and Chao (2001) noted that the BL97 fields are quite noisy spatially. Noise here refers to small variations on the scale of 2-5 grid-boxes which are an artifact of temporal and spatial discrepancies in measurement distributions rather than a true reflection of the climatological mean. The present work details the calculation of new, improved annual, seasonal, and monthly fields of climatological mean temperature and salinity on a 1/4° grid (hereafter collectively referred to Q01) and compares the results to W01 and BL97. The Q01 fields have increased spatial smoothing over BL97, reducing noise while still preserving tight spatial gradients. Other improvements over BL97 include the addition of significant amounts of data and the calculation of seasonal and monthly climatologies.

W01 and Q01 used the same data set, the *World Ocean Database 2001* (WOD01), so the major improvement of the new 1/4° climatologies over the W01 1° climatologies is primarily due to increased spatial resolution. The 1/4° climatological fields resolve features such as the climatological Loop Current in the Gulf of Mexico, which are not as well defined in the previous 1° analyses. Also, small, isolated regions, such as the Sulu Sea, are better resolved on the high resolution grid, so that analyses at the high resolution better reflect the regional physical property distributions of the area compared to the 1° grid analyzed fields. Month-to-month and season-to-season variations in small-scale features and in small distinct oceanic regions can also be better discerned by comparison of the seasonal and monthly climatological mean fields on the 1/4° grid to their 1° counterpart fields.

Problems due to little or no data in some oceanic regions are magnified in the 1/4° grid, since a reduced area (the influence region) and hence number of data points, is used to produce an analyzed value in each grid-box. This drawback has been bypassed to some extent by using the 1° grid analyzed climatological mean fields as first-guess fields for the 1/4° calculations. A first-guess field is a best guess of the structure of a climatological mean field. Thus, in areas with little or no data on the 1/4° grid, the 1° grid climatological field is the dominant signal.

2. METHODS

The Q01 1/4° grid climatological mean fields of temperature and salinity for the annual, seasonal, and monthly time periods were calculated using data from WOD01 using objective analysis techniques which were essentially the same as those detailed in W01t and W01s for the 1° grid climatological mean fields, with differences described below. The Q01 annual and seasonal fields were calculated at standard levels from the surface to 5500 meters. The seasons are defined as three month periods starting with winter, defined as January, February, and March. The Q01 monthly fields were calculated at standard levels from the surface to 1500 meters.

The smaller spatial resolution for Q01 increases greatly the number of temperature and salinity measurements used to calculate climatologies , even when using the same dataset as W01t and W01s. In a coastal area, a 1° grid-box could be designated land when up to half of the sixteen 1/4° grid-boxes contained within the 1° grid-box are designated ocean. Since a large percentage of oceanographic data in WOD01 is near-shore data and climatologies are only calculated for grid-boxes designated as ocean grid-boxes, a large increase in data is available data for the 1/4° climatologies. Approximately 18% of all temperature data in WOD01 are in 1° grid-boxes designated as land grid-boxes. Only 3% of all data in WOD01 are in 1/4° grid-boxes designated as land grid-boxes.

Our objective analysis procedure produces estimates of climatological mean values at each grid-box based on the cumulative weighted difference between the means and first-guess fields at all grid-boxes within a given "radius of influence" around the center of a grid-box. In the present case, for both 1° grid and 1/4° grid, the procedure was repeated three times, each time with a diminishing radius of influence. The reduced grid-box size for the 1/4° grid allows us to define smaller scale features than the 1° grid. To preserve this advantage, the radii of influence for each pass through the analysis procedure were reduced as well, so as to limit the number of grid-boxes which would affect the climatological mean value. The size of the radii of influence for each pass through the analysis for each grid size were:

Pass	1° grid radius of influence (W01)	1/4° grid radius of influence (Q01)
1	892 km	321 km

2	669 km	267 km
3	446 km	214 km

For both the 1° and 1/4° cases, there are still areas of the ocean for which we have little or no data, and as such, our analyses within these areas should be used with caution. We define an area as data sparse if there are ≤ 3 mean temperature (or salinity) values within the largest radius of influence around a grid-box.

Another major difference between our 1° and 1/4° analyses is the degree of smoothing. The 1° climatologies were smoothed using one pass of a Shuman gridpoint smoother (Shuman, 1957) followed by one pass of a gradient preserving median smoother (Rabiner *et al.*, 1975). The median smoother uses the data from grid-boxes directly to the west, east, north and south, in addition to the datum from the grid-box itself. The 1/4° climatologies were smoothed using only the median smoother, but using data from five grid-boxes on either side of a datum in addition to the datum itself.

The first-guess field for the 1° climatological mean fields was the 1° zonal average of all data within a subarea (*e.g* Atlantic Ocean, Pacific Ocean, Mediterranean Sea, small marginal basins). As previously stated, for the 1/4° climatological analysis, we used the corresponding analyzed climatological mean fields on a 1° grid as the first-guess field. To do this, the climatological value from a 1° grid-box was assigned to the sixteen 1/4° grid-boxes contained therein. For those 1/4 ° grid-boxes defined as ocean where there was no 1° analyzed mean value because the

1° grid-box was defined as land or ocean bottom, the analyzed mean value from the nearest 1° grid-box not defined as land or ocean bottom and within the same ocean basin was used. If no data existed in the defined ocean basin for the 1° analysis, the average of all 1/4° grid mean values for the basin was used. This last situation only occurred in small deep basins, such as the northeast Sulu Sea, which is not resolved at the 1° resolution (defined as ocean bottom for the 1° analysis), but for which data does exist and there is sufficient resolution to define ocean grid-boxes for this basin in the 1/4° analysis.

The increased resolution provided by the 1/4° grid allows for more sharply defined ocean subareas, so the first-guess field for the 1/4° grid must be consistent within these subareas. When a 1° grid-box contained 1/4° grid-boxes from more than one subarea, only the 1/4° grid-boxes from the most representative subarea were assigned the first-guess value from the 1° grid-box. The remaining 1/4° grid-boxes were assigned the analyzed mean value from the closest 1° grid-box from within their own ocean subarea.

As previously noted, calculations on a 1/4° grid result in more noise in the climatological mean fields as compared to the fields calculated on the 1° grid. To remove some of this noise, the 1/4° monthly climatological mean fields were further smoothed by reconstructing the fields using the annual mean and the first three harmonics from a Fourier analysis of the twelve monthly climatological mean fields of temperature and salinity. The resultant 12 monthly fields, from the surface to 1500 meters, were averaged at each grid-box to provide the mean annual climatological mean field to this depth. The appropriate three monthly fields from the surface to 1500 meters were averaged to provide the final mean fields for each seasonal climatological mean field. Below 1500 meters, the four seasonal climatological mean fields were averaged to yield the final mean annual climatological field for all standard depths down to 5500 meters. The seasonal climatological mean fields below 1500 meters (to 5500 meters depth) had no Fourier smoothing applied.

Our last step was to stabilize each temperature and salinity field in the vertical with respect to their calculated density. Thus, all temperature and salinity fields yield a vertically stable density structure. The stabilization process is a modification of the method detailed by Jackett and McDougal (1995). Since density is a nonlinear function of temperature and salinity (and pressure), objectively analyzing temperature and salinity separately on depth surfaces causes the relationship between temperature and salinity with respect to density to change, which can result in small instabilities between adjacent levels at some grid-boxes. To rectify this problem, temperature and salinity values are minimally altered to create a nonnegative stability, $\mathbf{E} \geq 0$, where stability **E** is the Hesselberg-Sverdrup criteria described by Lynn and Reid (1968) and Neumann and Pierson (1966), defined as

in which:

z=depth

ρ= *in situ* density

ρ_0=1020 kg m^{-3}, and

$\delta\rho$=vertical density difference between adjacent depth surfaces

The method for preparing the observed data for the objective analysis procedure was basically the same as outlined in W01t and W01s. All measurements excluded from the 1° mean calculations based on checks against the standard deviation and based on subjective checks were also excluded from the 1/4° mean calculations. No further checks against standard deviation were performed for the 1/4° grid. However, further quality control checks on the initial data were necessary, as the reduced area over which means were calculated revealed additional non-representative data. Once these checks were performed, and additional suspect data were flagged, the 1° mean calculation and objective analysis procedures were rerun excluding the newly flagged data. Then the 1/4° mean calculation and objective analysis were rerun until no more exclusion of data was necessary.

Here, our discussion follows that given by Levitus (1982). The weight function of Barnes (1964) is based on the principle that "the two-dimensional distribution of an atmospheric variable can be represented by the summation of an infinite number of independent harmonic waves, that is, by a Fourier integral representation". Any gridded field has the limitation that it takes 7 or 8 Δx to adequately describe a Fourier component, where Δx is the distance between adjacent gridpoints. So, the ideal interpolation procedure would remove all wavelengths shorter than $8\Delta x$ completely, while preserving completely all longer wavelengths. For our 1° climatologies, Δx is ~111 kilometers at the equator, so the ideal cutoff wavelength would be 888 kilometers. For our 1/4° climatologies, Δx is ~27.5 kilometers, and the cutoff wavelength would be 222 kilometers.

This is a lower limit, and applies to an ideal case. Barnes (1964) derived a response function for finite objective analysis. The response function is a measure of the response of the data to one iteration of the interpolation procedure. Barnes' response function (**D**) is

$$\mathbf{D=exp(\pi^2R^2/4\lambda^2)}$$

where:

R=radius of influence

λ=wavelength of a Fourier component

The response function is dependent on the radius of influence used and we want to resolve as many wavelengths as possible (down to the ideal limit). Due to the irregular distribution of data geographically, it is necessary to use a radius of influence large enough to contain sufficient data to interpolate meaningful climatological values. Use of multiple passes with successively smaller radii of influence, along with additional smoothing between passes, is necessary due to the irregularity of the data.

Barnes' response function is defined for one pass through the objective analysis, and does not account for any additional smoothing. To approximate the response function for our full three pass analysis procedure with additional smoothing, we created a perfect data set of summations of only integral wavelength components on our grid. This perfect data set was then run through the analysis procedure and Fourier analyzed. The resultant set of amplitudes is the response function for our analysis. The amplitudes are between zero and one and give a measure of the spatial features resolved by our analyzed fields.

Figure 1 shows the response functions (with wavelengths in kilometers) for the 1° analyzed fields, for BL97, and for Q01. Table 1 gives numerical values at selected wavelengths for each case. Looking first at 8Δx, roughly, 40 % (0.40) of an 888 kilometer wave is retained in the 1° fields, while less than 1% (0.002) of a 222 kilometer wave is retained in Q01. Using 60% (0.60) as a threshold beyond which we can have confidence in the spatial resolution of the given Fourier component, features of ~1110 kilometers or greater are well resolved in our 1° analyses, while features of ~666 kilometers or greater are well resolved in Q01. This is a significant improvement in spatial resolutio. between the Q01 and the W01 analyses.

Results

We present some examples of the new 1/4° temperature and salinity climatologies to illustrate the enhanced spatial resolution of Q01 in comparison to W01t and W01s. We also compare Q01 to BL97. The first example is on a basin scale at the surface and 100 meters depth to show the similarities and differences between the climatologies at a large scale and in the upper ocean. The other examples are of smaller scale features at depths and in areas that highlight dramatic differences between climatologies. Figure 2 shows the Atlantic Ocean annual climatological temperature field at the surface and 100 meters depth from W01t and Q01. The large scale patterns in the temperature field are similar in each. However, many small-scale features that are poorly defined or absent in W01t are clear and evident in Q01. For instance, the Florida Current is represented in Q01 at 100 meters while it is not fully resolved in W01t. The temperature gradients associated with the northern edge of the subpolar gyre around Greenland are smoothed out in some places in W01t, but are clearly visible in Q01 at both the surface and 100 meters. The Gulf Stream is characterized by tighter gradients in Q01. Sharper temperature gradients off the coast of Argentina and southern Africa improve upon their smoothed counterpart in W01t. Overall, many features which are smoothed out in the 1° degree climatology are better resolved in the 1/4° climatology. Data sparse areas, which are hatched in all figures, are non-existent in the W01t and found only in small areas of the South Atlantic in Q01 in Figure 2.

Q01 also offers improvements over the previous version of the 1/4° climatology, BL97, as demonstrated in Figure 3. Figure 3a shows the Agulhas Retroflection region for the W01s annual salinity climatology at 500 meters depth. Figure 3b shows the same area for BL97, while Figure 3c shows the present 1/4° climatology (Q01). BL97 used one pass through the objective analysis with a radius of influence of 134 km. This resulted in sharp horizontal gradients, but more noise in parts of the World Ocean. This noise was cited by Chang and Chao (2001) as a problem with BL97, while the sharp gradients were an advance over 1° climatologies. Q01 uses three passes through the objective analysis procedure, as well as additional smoothing in time and space. Our new work achieves a reasonable balance between W01s and BL97. While the large scale features are quite similar between W01s and Q01, the western tail of the Agulhas Retroflection is preserved in Q01, whereas it is truncated in W01s.

A notable difference between BL97 and Q01 is the representation of areas of relatively high salinity in the southeast Atlantic. These areas, represented by the red shading in Figure 3b (BL97) may be due to observations of Agulhas rings. These are rings which break off from the Agulhas Retroflection and bring warm, high salinity waters northwestward in the South Atlantic. Agulhas rings are a common feature of the southeastern Atlantic Ocean (see Richardson *et al.*, 2003 for an overview). The relatively high salinity areas in the South Atlantic in BL97 (Fig. 3b) are absent in Q01 (Fig. 3c). However, the monthly fields of Q01 (not shown) display areas of similar relatively high salinity water in different areas of the southeast Atlantic and of different sizes. Thus, it is not the larger radius of influence in Q01, nor the Fourier reconstruction or increased use of median smoothing that removes or reduces the traces of the high salinity from southeast Atlantic in the annual field for Q01. It is the averaging of the twelve monthly fields used to create the annual field for Q01 which removes the high salinity traces. This procedure was not carried out in BL97 since the monthly fields were not calculated. In BL97, the point was made that these features are resolvable in a 1/4° climatology. But, since Agulhas rings are transient features which pass through a given southeastern Atlantic grid-box, we believe that an all data annual climatology is better served by representing the mean ocean without the rings, thus representing the average state of the ocean which is then interrupted by the passage of the high salinity rings. As Levitus (1982) discussed, our analyses are an attempt to represent large-scale permanent or semi-permanent ocean features.

Another notable difference between BL97 and Q01 is the amount of data sparse areas, the hatched regions in Figures 3. Much of the area south and west of southern Africa is data sparse in BL97 salinity, while very little of the annual Q01 salinity field is data sparse. This is due both to the larger radius of influence applied in Q01 and to additional salinity measurements added for use in Q01.

Figures 4a,b show annual mean salinity at a depth of 250 meters for the Caribbean for W01s and Q01. Q01 clearly delineates the climatological Loop Current entering and exiting the Gulf of Mexico. W01s (Fig. 4a) does not have sufficient resolution to resolve the Loop Current. For example, the 36.0 isohaline spans the entire entrance to the gulf in W01s. In contrast, Q01 (Fig. 4b) reveals the 36.0 isohaline entering seaward of the Yucatan shelf, penetrating some distance into the Gulf of Mexico before looping back and exiting seaward of the Florida shelf. Figures 4a,b also show that the gradients associated with the Florida Current are not well resolved at 250 meters in W01s while they are better resolved in Q01. Further north, the gradient across the Gulf Stream is sharper in Q01 than in W01s. The gradient across the Gulf Stream in BL97 (not shown) is sharper still than Q01, again illustrating the compromise between preserving gradients and presenting reasonably smooth fields.

In addition to the annual climatological fields of temperature and salinity, Q01 also includes temperature and salinity climatologies for each season and month. BL97 did not include seasonal or montly fields due to lack of data, especially salinity data. But the salinity profile data on WOD01 represents an 80% increase over the salinity profile data used for BL97. However, this large increase in overall number of salinity profiles is not evenly distributed geographically or temporally. There are still ocean areas, especially in the southern hemisphere, which are data sparse for some months or all months in Q01. Even in the western north Atlantic, there are some months for which there are large data sparse areas. Figures 4c and 4d show the 1/4° salinity fields at 250 meters depth in the Caribbean for the months of June and December.. The Gulf of Mexico is well sampled historically in June, but has data sparse areas in December, by our definition. The eastern Caribbean is better sampled in December than June, as is the portion of the Pacific Ocean shown. The corresponding 1° climatologies have no data sparse areas in the region shown in Figures 4, nor do the Q01 annual climatologies. In regions which are data sparse for only a few months of the year, our Fourier analysis provides some revision of the first-guess field at each grid-box based on the annual mean and the first three harmonics. The use of the 1° climatology as the first-guess field also insures that when data is sparse at the 1/4° resolution, a valid value will still be available for analysis, albeit from a larger radius of influence. So, in areas with more available data, the monthly 1/4° climatology is an improvement over the 1° climatology. Where there is not sufficient data, the 1/4° climatology is heavily influenced by the 1° climatology.

Discussion

The 1/4° climatological temperature and salinity fields are an improvement over their 1° counterparts. The increased spatial resolution and reduced area over which smoothing is performed resolves small-scale features and prevents oversmoothing in high horizontal gradient areas. Features such as the Loop Current, which are not well represented in the 1° climatologies are clearly represented in the 1/4° climatology, resulting in a more realistic representation of mean oceanographic characteristics. In addition, the present 1/4° climatology is an improvement over a previous 1/4° climatology (BL97) because Q01 reduces noise by smoothing in horizontal space (increased radius for median smoothing and radius of influence for objective analysis), in the vertical (stabilizing temperature and salinity fields with respects to density), and in time (Fourier analysis of monthly mean climatologies, averaging monthly mean climatologies for annual, seasonal climatologies).

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The data on which this atlas is based are in *World Ocean Database 2001* and are distributed on-line and CD-ROM by NODC/WDC. Many data were acquired as a result of the NODC *Oceanographic Data Archaeology and Rescue* (NODAR) project, the IOC/IODE *Global Oceanographic Data Archaeology and Rescue* (GODAR) project, and the IOC/IODE *World Ocean Database* project (WOD). At NODC/WDC, "data archaeology and rescue" projects are supported with funding from the NOAA Environmental Science Data and Information Management (ESDIM) Program and the NOAA climate and Global Change Program with some support from NASA. Support for some of the regional IOC/GODAR meetings was provided by the MAST program of the European Union. The European Community has also provided support for the MEDAR/MEDATLAS project which has resulted in the inclusion of substantial amounts of ocean profile data from the Mediterranean and Black Seas into *World Ocean Database 2001.*

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Figures

Figure 1. Response function for W01, Q01, BL97 for wavelengths up to 4000 kilometers**.**

Figure 2. Atlantic Ocean mean temperatures Data sparse grid-boxes are hatched.
- a. surface from 1° annual climatology (W01t).
- b. 100 meters depth from 1° annual climatology (W01t).
- c. surface from 1/4° annual climatology (Q01).
- d. 100 meters from 1/4° annual climatology (Q01).

Figure 3. Agulhas Retroflection area salinity at 500 meters depth. Salinities greater than 34.8 are shaded red to mark boundary between high salinity Indian Ocean water and Atlantic Ocean water. Data sparse grid-boxes are hatched.
- a. from 1° annual climatology (W01s).
- b. from 1/4° annual climatology (BL97).
- c. from 1/4° annual climatology (Q01).

Figure 4. Gulf of Mexico salinity at 250 meters depth. Salinities greater than 36.0 are shaded to highlight the Loop Current entering the gulf. Data sparse grid-boxes are hatched.
- a. from 1° annual climatology (W01s).
- b. from 1/4° annual climatology (Q01).
- c. from 1/4° June climatology (Q01).
- d. from 1/4° December climatology (Q01).

Table

Table 1. Response function for W01, Q01, BL97. Only integral wavelengths for the W01 (1°) case are shown.

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Table 1

Wavelength (km)	WO1 response	Q01 response	BL97 response
39960	1.000	1.000	1.000
19980	0.999	1.000	1.000
13320	0.998	0.999	1.000
9990	0.997	0.998	0.999
7992	0.996	0.997	0.999
6660	0.994	0.996	0.998
4995	0.989	0.993	0.997
4440	0.986	0.991	0.996
3996	0.983	0.989	0.995
3330	0.974	0.984	0.992
2664	0.958	0.975	0.988
2220	0.937	0.964	0.983
1998	0.919	0.956	0.979
1665	0.873	0.937	0.970
1332	0.776	0.900	0.953
1110	0.655	0.856	0.934
999	0.566	0.822	0.919
888	0.455	0.775	0.898
666	0.195	0.608	0.825
555	0.081	0.464	0.757
444	0.014	0.270	0.645
333	0.001	0.080	0.452
222	0.000	0.002	0.151

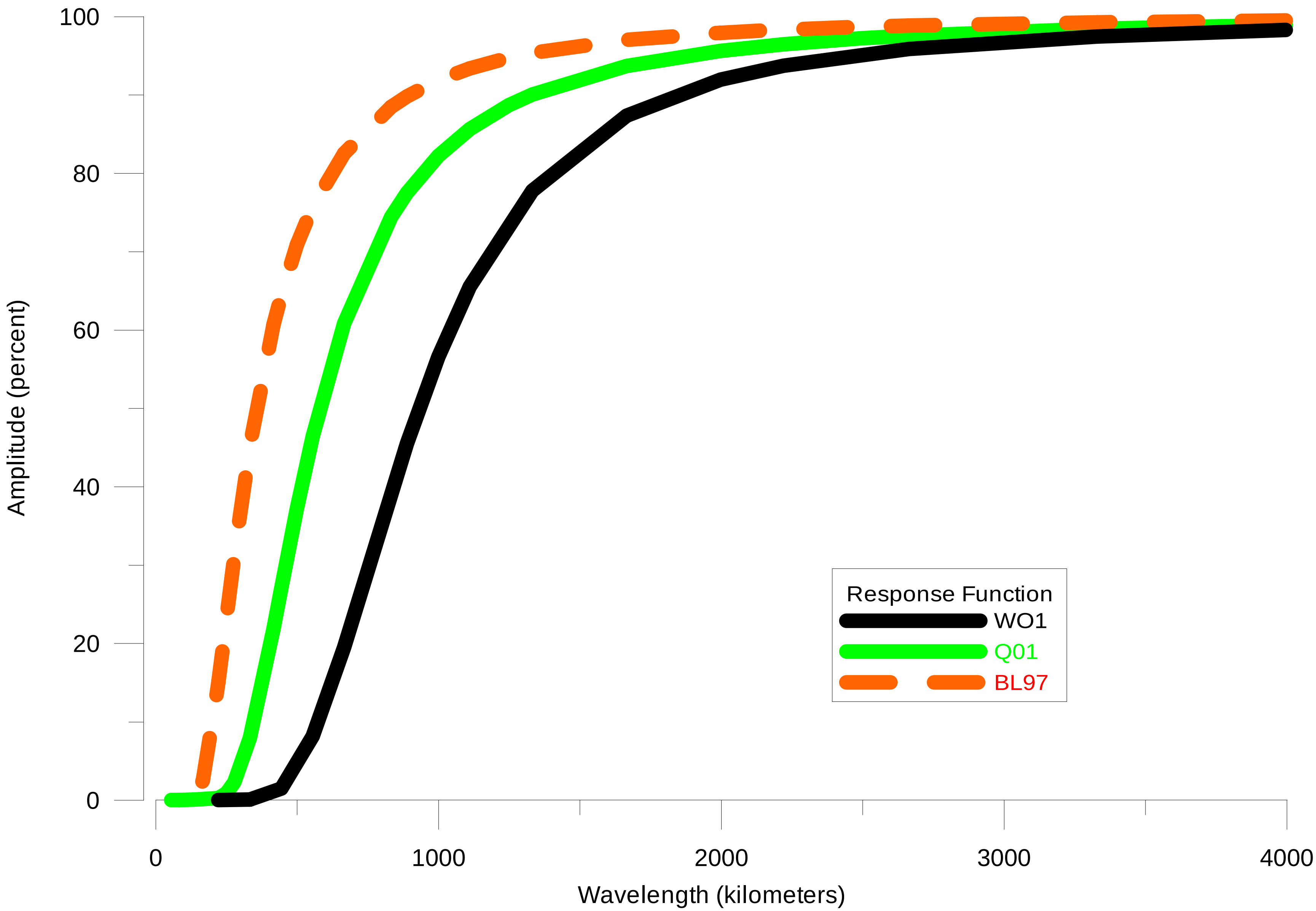

100
80
60
40
20
0
Amplitude (percent)
0
1000
2000
3000
4000
Wavelength (kilometers)
Response Function
WO1
Q01
BL97

Figure 1

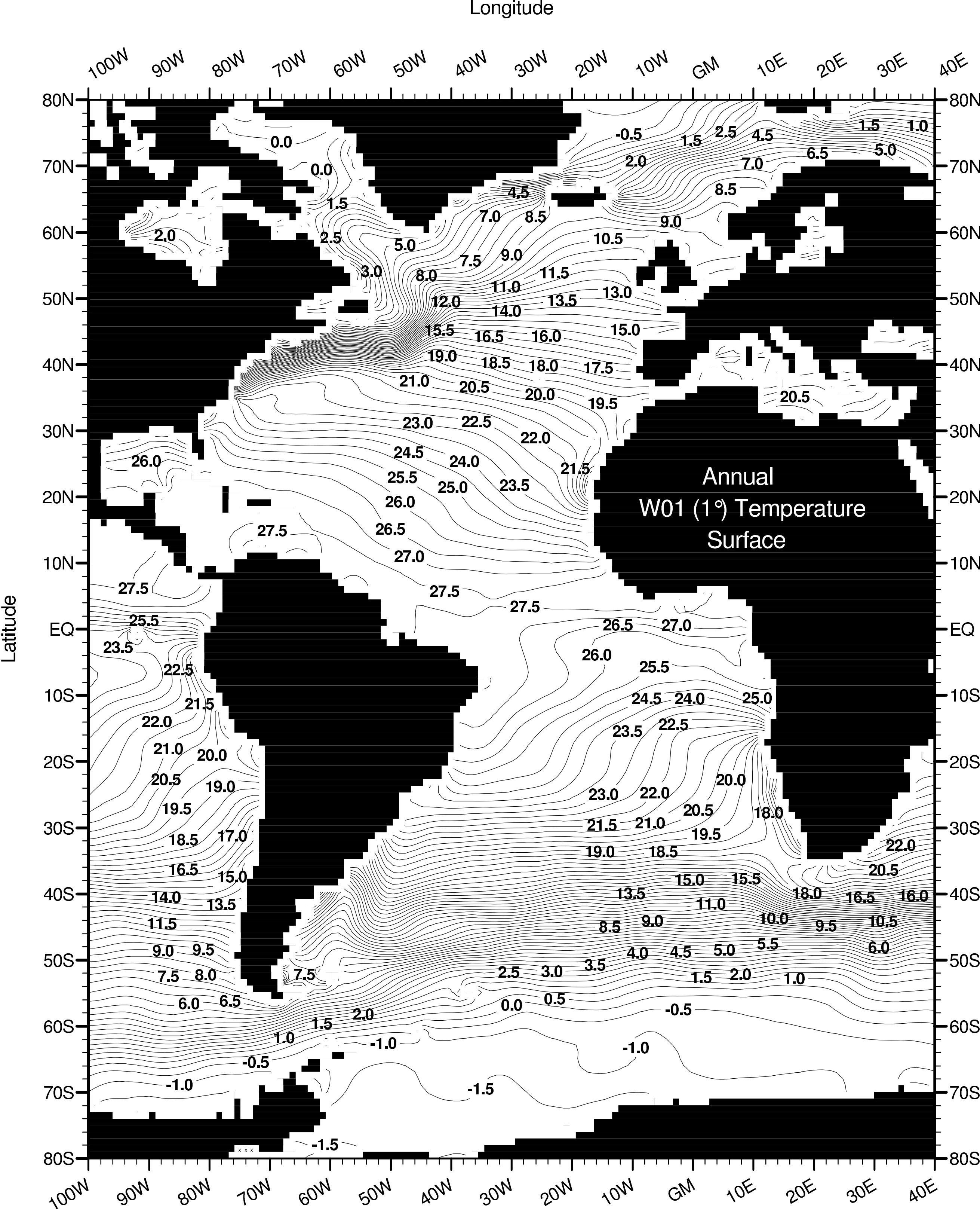

Longitude
100W 90W 80W 70W 60W 50W 40W 30W 20W 10W GM 10E 20E 30E 40E
Latitude
80N 70N 60N 50N 40N 30N 20N 10N EQ 10S 20S 30S 40S 50S 60S 70S 80S
Annual
W01 (1°) Temperature
Surface

Figure 2a

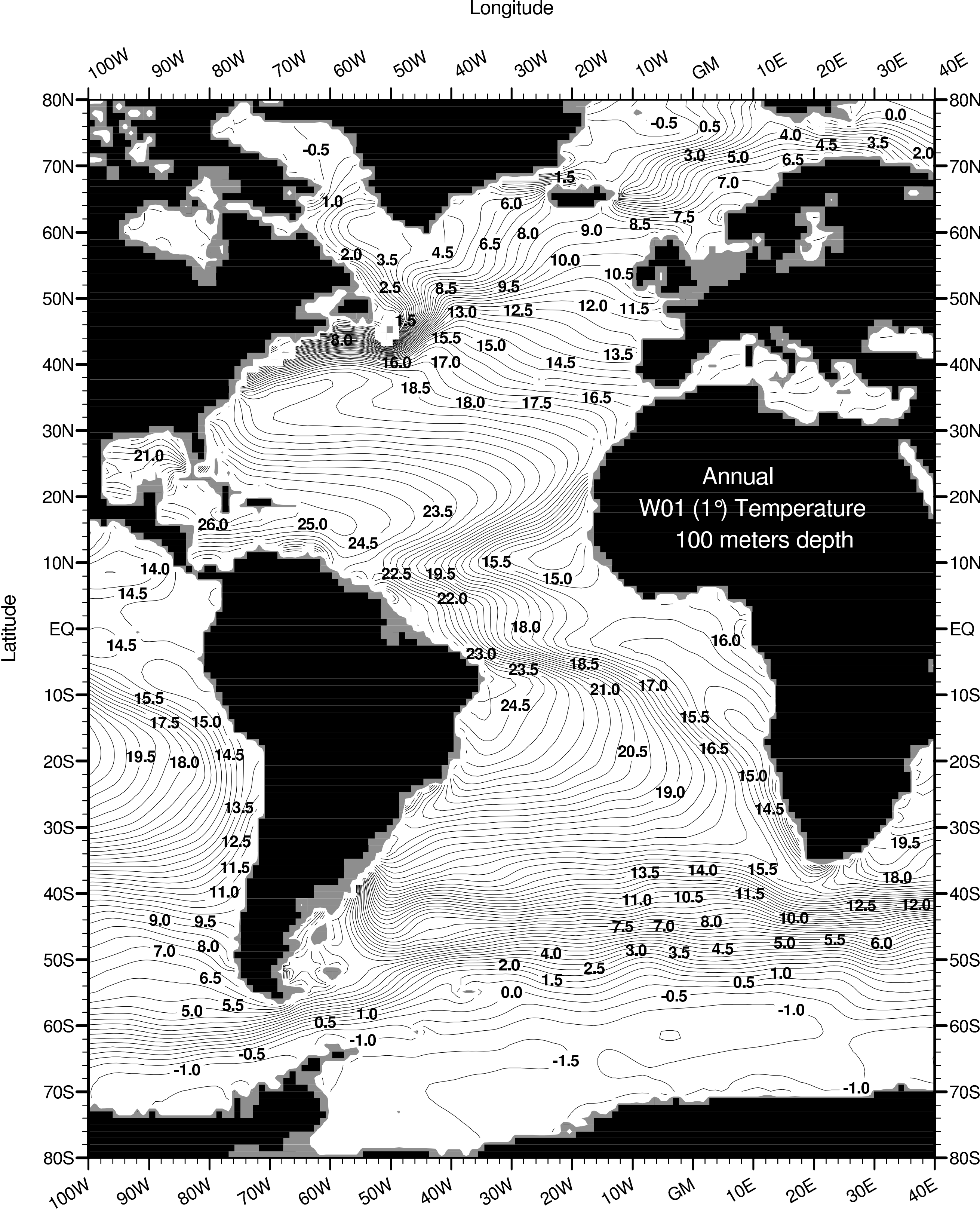

Annual
W01 (1°) Temperature
100 meters depth
Longitude
Latitude

Figure 2b

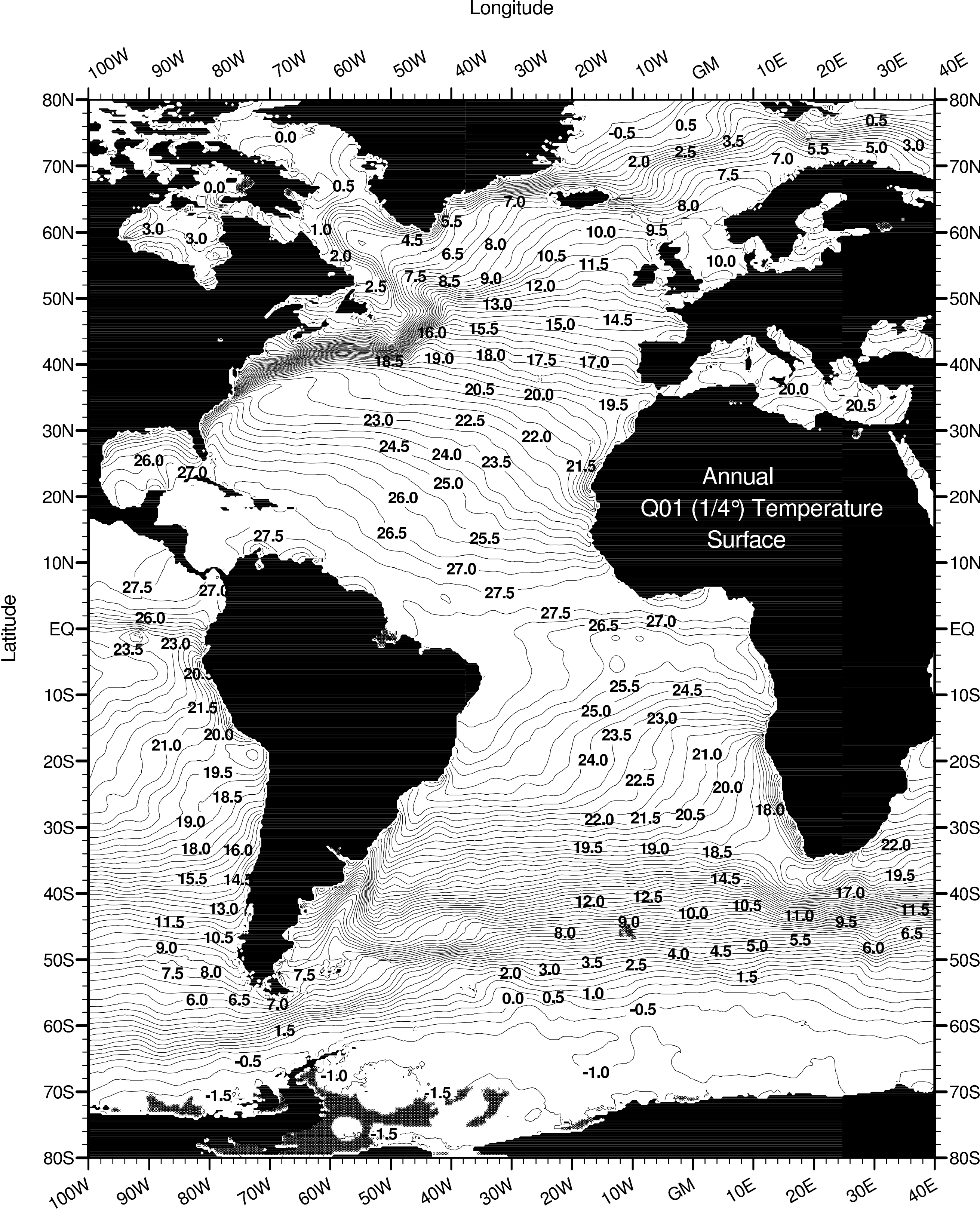

Longitude
Latitude
Annual
Q01 (1/4°) Temperature
Surface
100W
90W
80W
70W
60W
50W
40W
30W
20W
10W
GM
10E
20E
30E
40E
80N
70N
60N
50N
40N
30N
20N
10N
EQ
10S
20S
30S
40S
50S
60S
70S
80S

Figure 2c

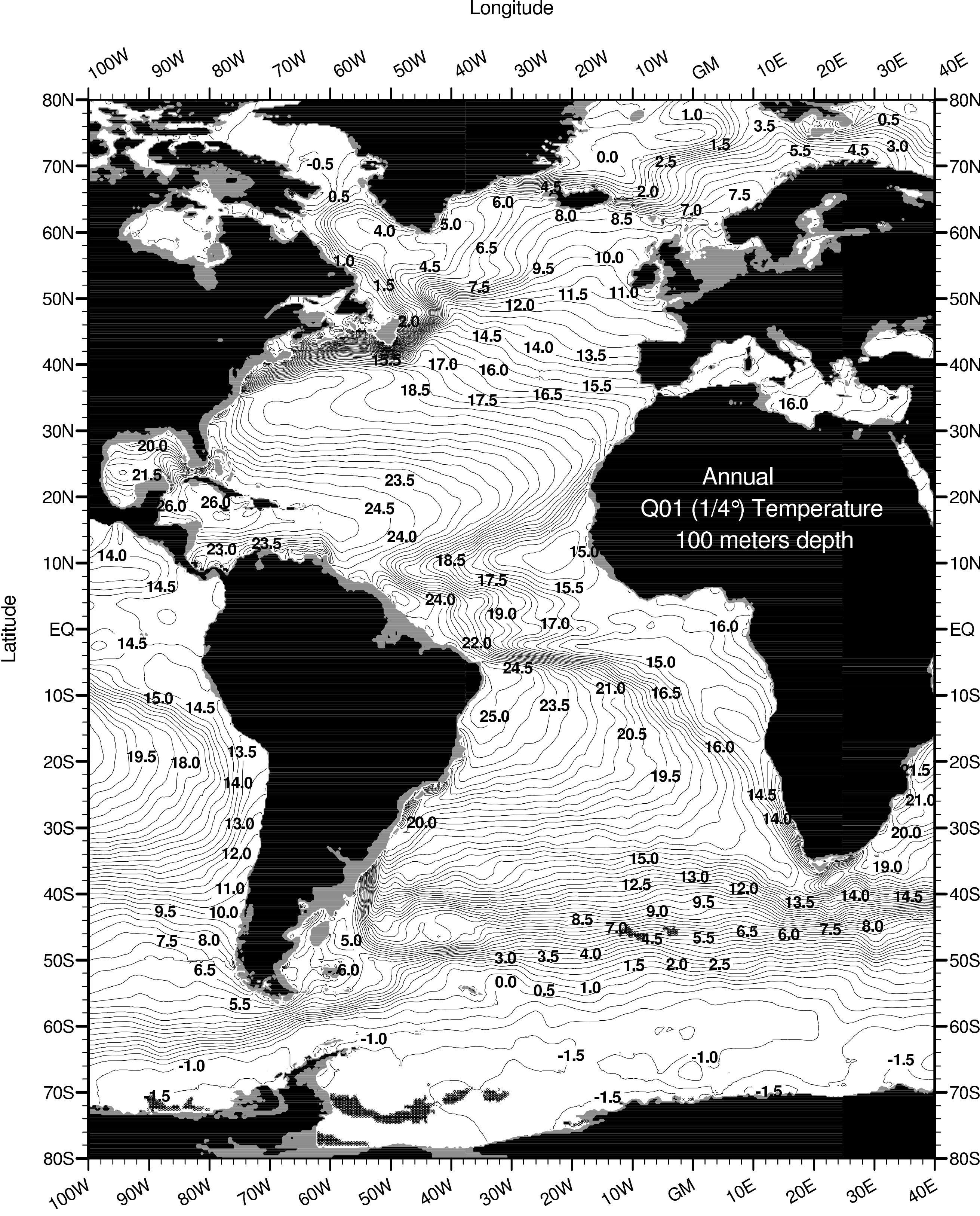

Longitude
Latitude
100W
90W
80W
70W
60W
50W
40W
30W
20W
10W
GM
10E
20E
30E
40E
80N
70N
60N
50N
40N
30N
20N
10N
EQ
10S
20S
30S
40S
50S
60S
70S
80S
Annual
Q01 (1/4°) Temperature
100 meters depth

Figure 2d

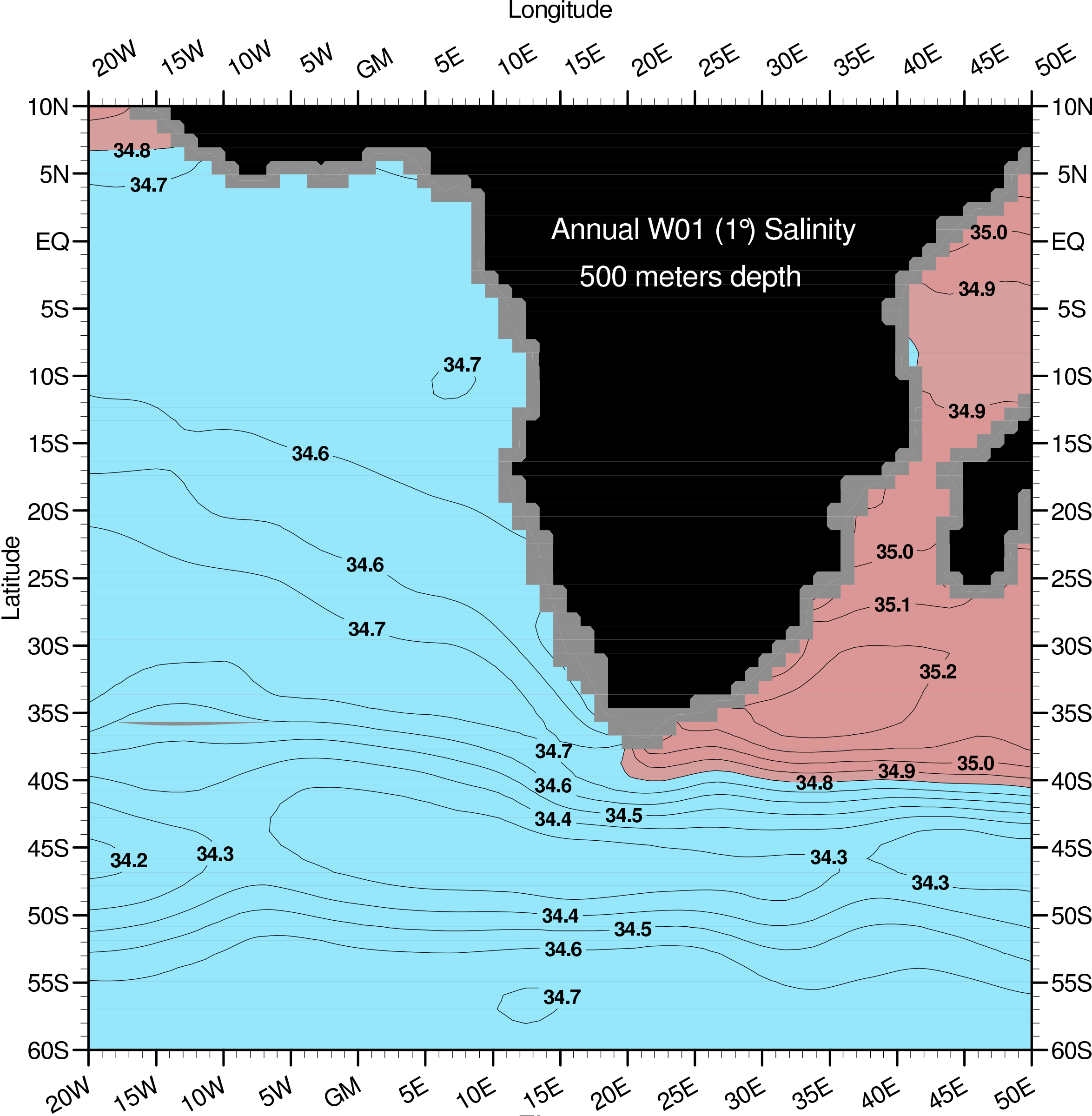

Longitude
Latitude
Annual W01 (1°) Salinity
500 meters depth
20W
15W
10W
5W
GM
5E
10E
15E
20E
25E
30E
35E
40E
45E
50E
10N
5N
EQ
5S
10S
15S
20S
25S
30S
35S
40S
45S
50S
55S
60S
34.8
34.7
35.0
34.9
34.7
34.9
34.6
34.6
35.0
35.1
34.7
35.2
34.7
35.0
34.9
34.6
34.8
34.5
34.4
34.2
34.3
34.3
34.3
34.4
34.5
34.6
34.7

Fig 3a

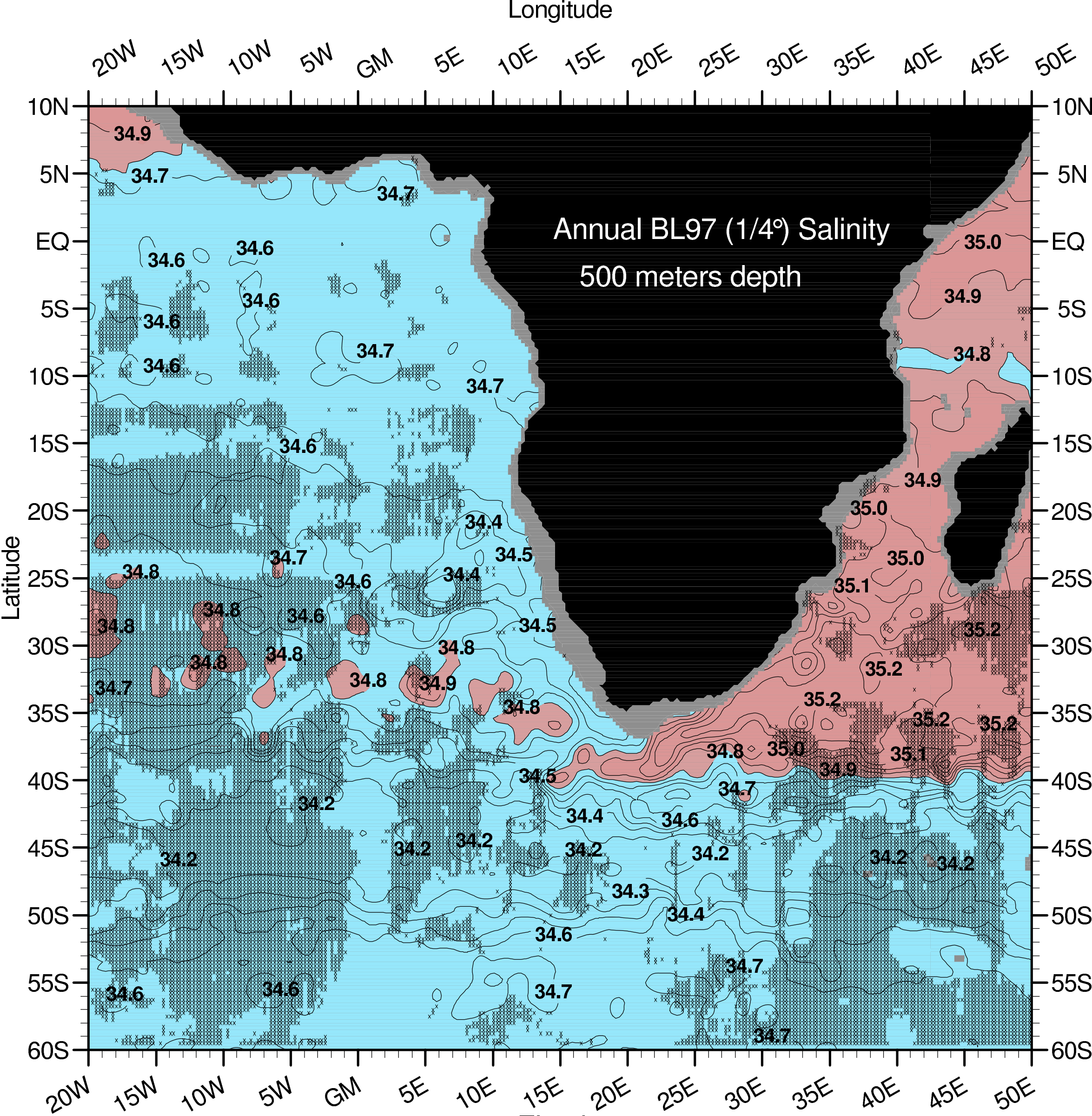
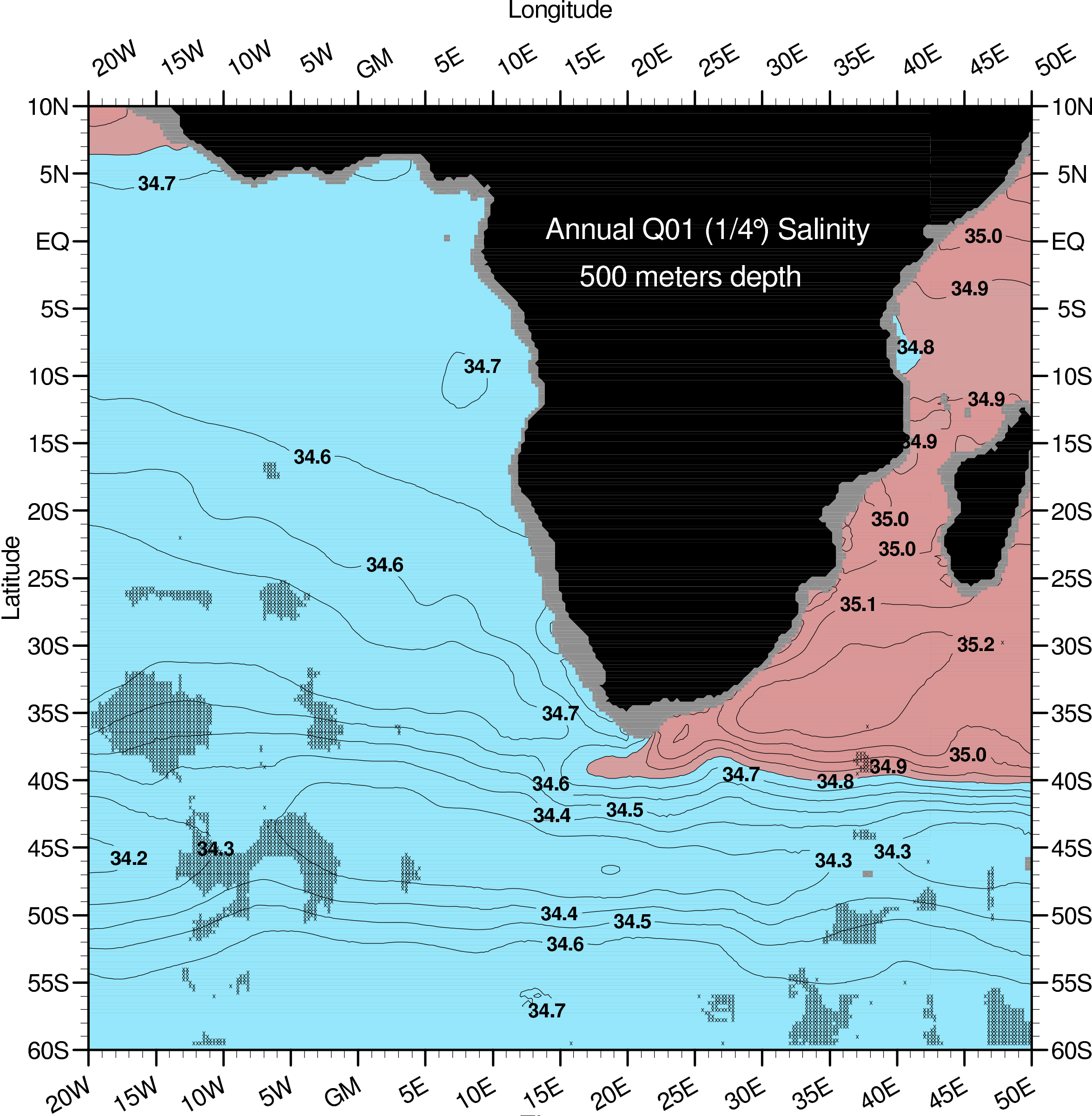

Longitude
Latitude
Annual BL97 (1/4°) Salinity
500 meters depth

Fig 3b


Longitude
Latitude
Annual Q01 (1/4°) Salinity
500 meters depth
20W
15W
10W
5W
GM
5E
10E
15E
20E
25E
30E
35E
40E
45E
50E
10N
5N
EQ
5S
10S
15S
20S
25S
30S
35S
40S
45S
50S
55S
60S
34.7
35.0
34.9
34.8
34.7
34.9
34.6
34.9
35.0
35.0
34.6
35.1
35.2
34.7
35.0
34.6
34.7
34.9
34.8
34.4
34.5
34.2
34.3
34.3
34.3
34.4
34.5
34.6
34.7
Fig 3c

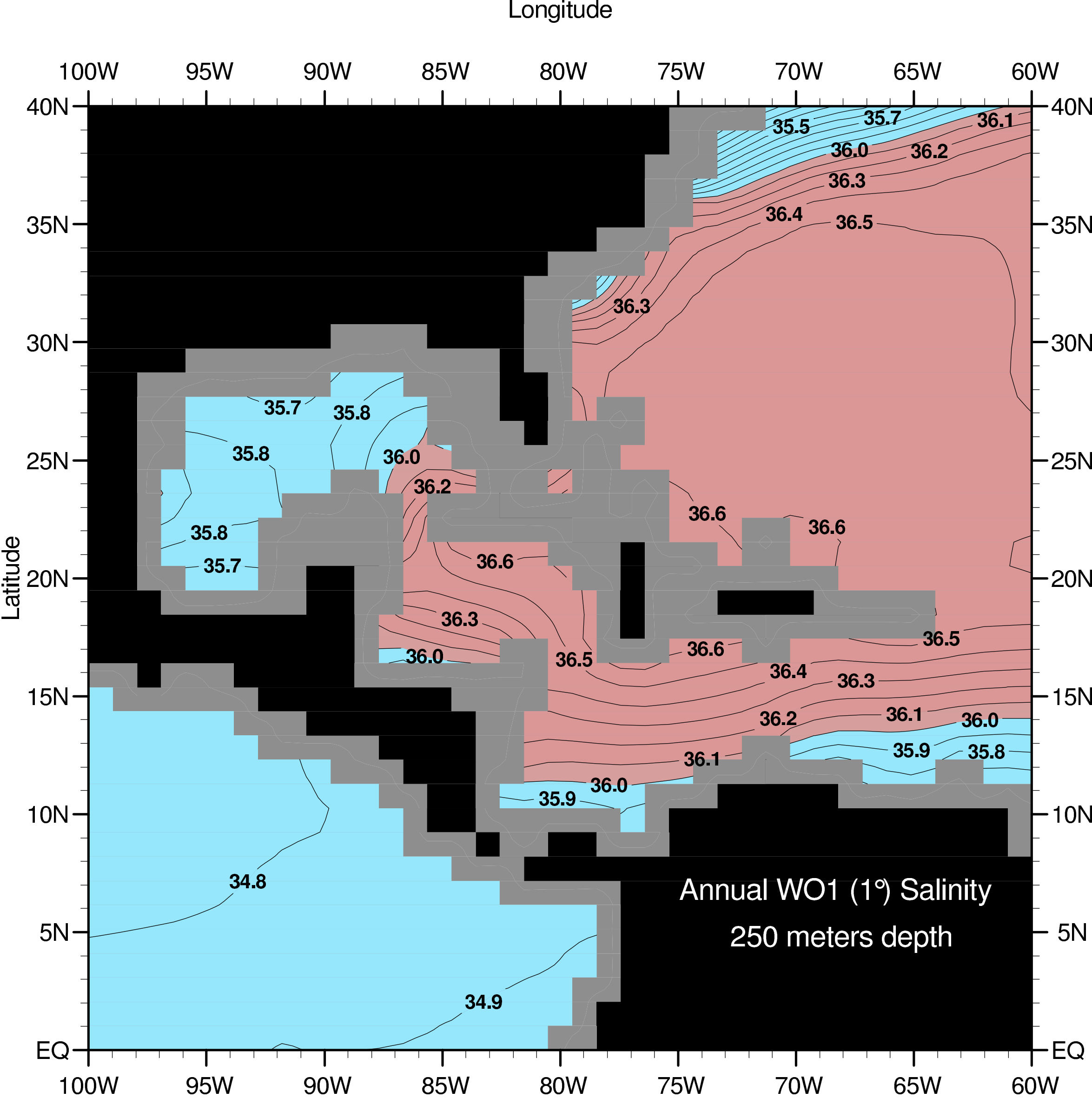

Longitude
Latitude
100W
95W
90W
85W
80W
75W
70W
65W
60W
40N
35N
30N
25N
20N
15N
10N
5N
EQ
35.5
35.7
36.1
36.0
36.2
36.3
36.4
36.5
35.7
35.8
35.8
36.0
36.2
35.8
35.7
36.6
36.6
36.6
36.3
36.0
36.5
36.6
36.5
36.4
36.3
36.2
36.1
36.0
35.9
35.8
36.1
36.0
35.9
34.8
34.9
Annual WO1 (1°) Salinity
250 meters depth

Figure 4a

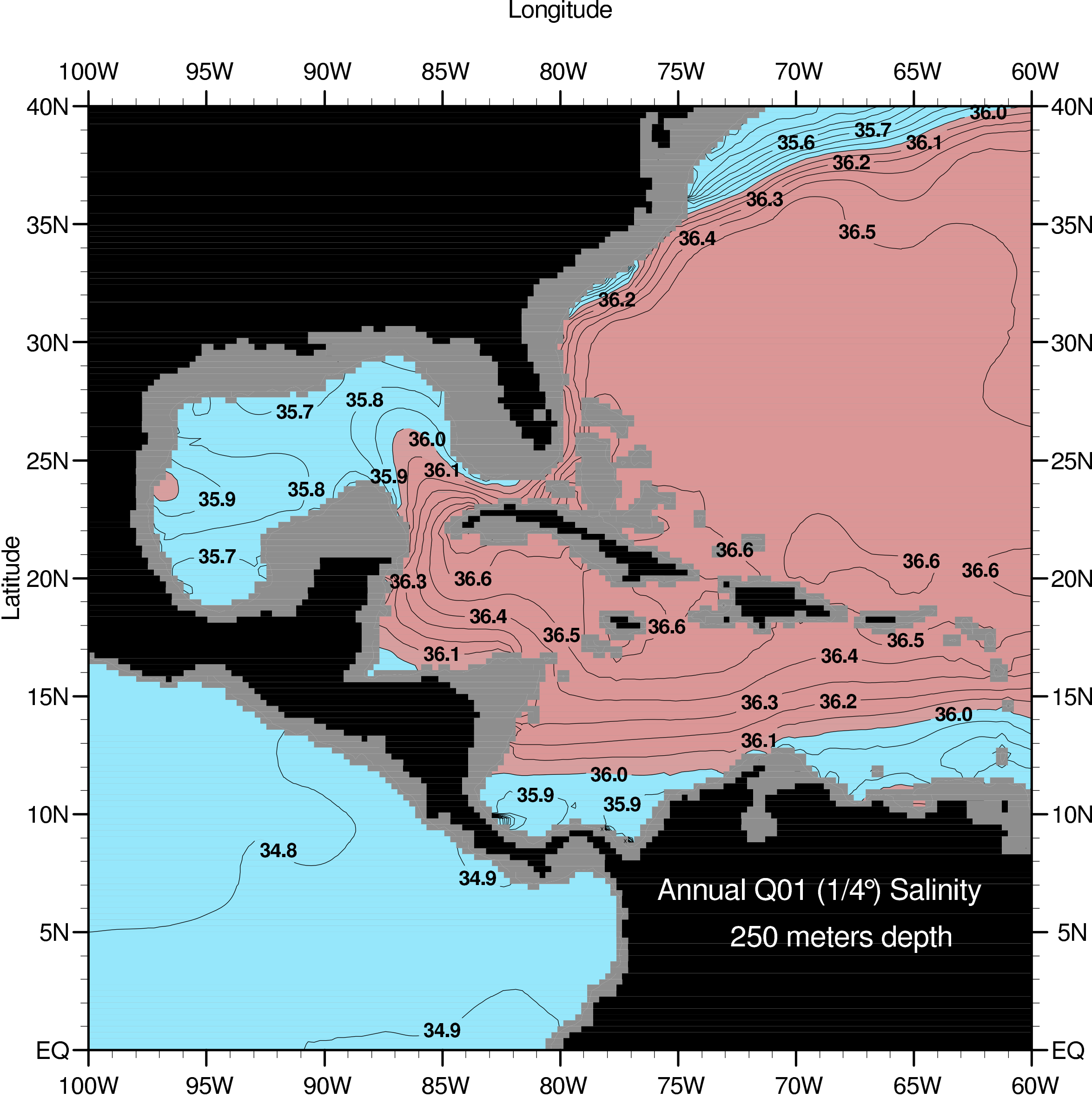

Longitude
Latitude
100W
95W
90W
85W
80W
75W
70W
65W
60W
40N
35N
30N
25N
20N
15N
10N
5N
EQ
Annual Q01 (1/4°) Salinity
250 meters depth
36.0
35.7
35.6
36.1
36.2
36.3
36.5
36.4
36.2
35.8
35.7
36.0
36.1
35.9
35.8
35.9
35.7
36.6
36.3
36.6
36.6
36.6
36.4
36.5
36.6
36.5
36.1
36.4
36.3
36.2
36.0
36.1
36.0
35.9
35.9
34.8
34.9
34.9

Figure 4b

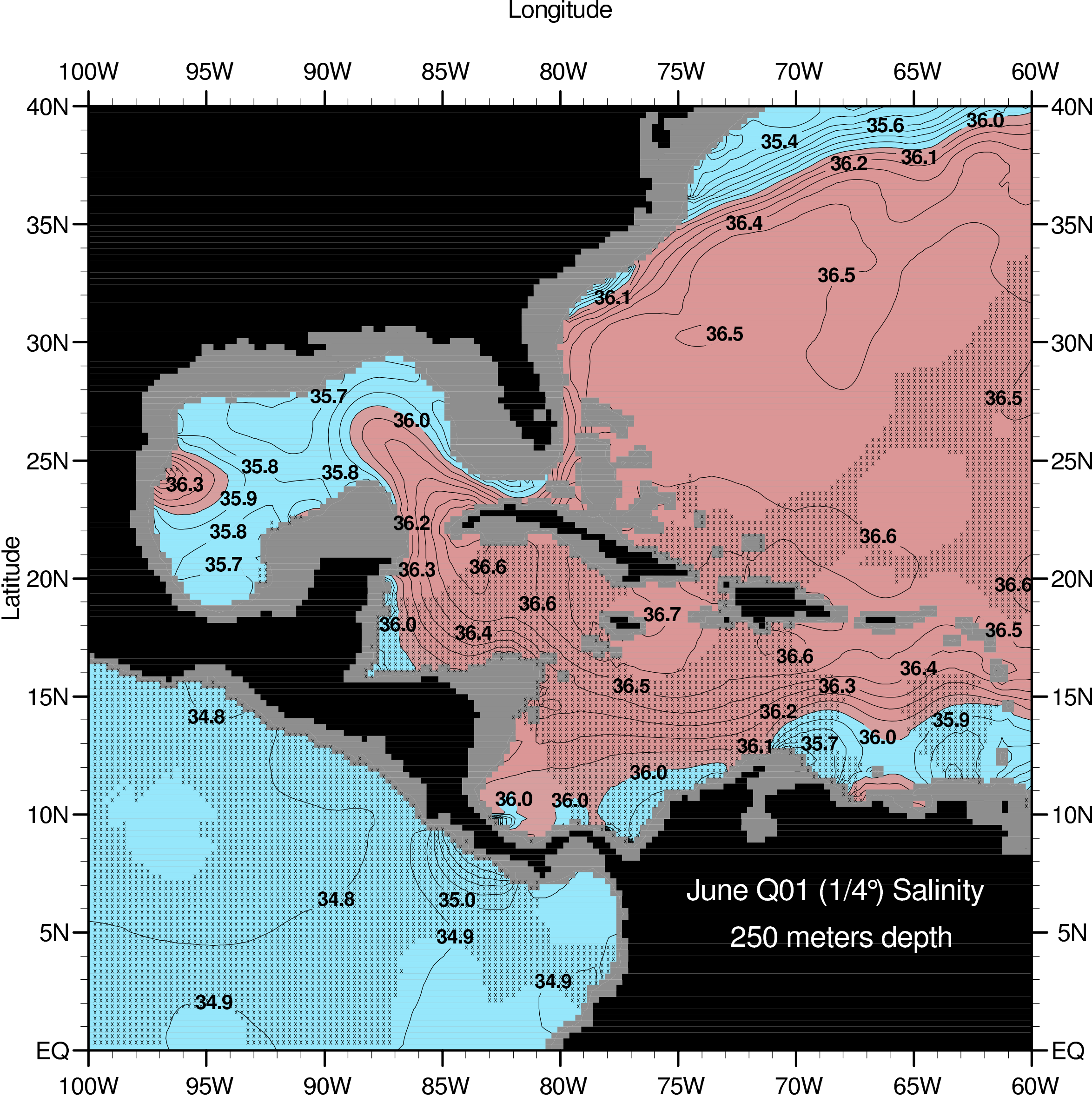

Longitude
Latitude
100W
95W
90W
85W
80W
75W
70W
65W
60W
40N
35N
30N
25N
20N
15N
10N
5N
EQ
35.4
35.6
36.0
36.2
36.1
36.4
36.5
36.1
36.5
35.7
36.0
36.5
35.8
35.8
36.3
35.9
35.8
36.2
36.6
35.7
36.3
36.6
36.6
36.6
36.7
36.0
36.4
36.5
36.6
36.4
36.5
36.3
34.8
36.2
35.9
36.1
35.7
36.0
36.0
36.0
36.0
34.8
35.0
34.9
34.9
34.9
June Q01 (1/4°) Salinity
250 meters depth

Figure 4c

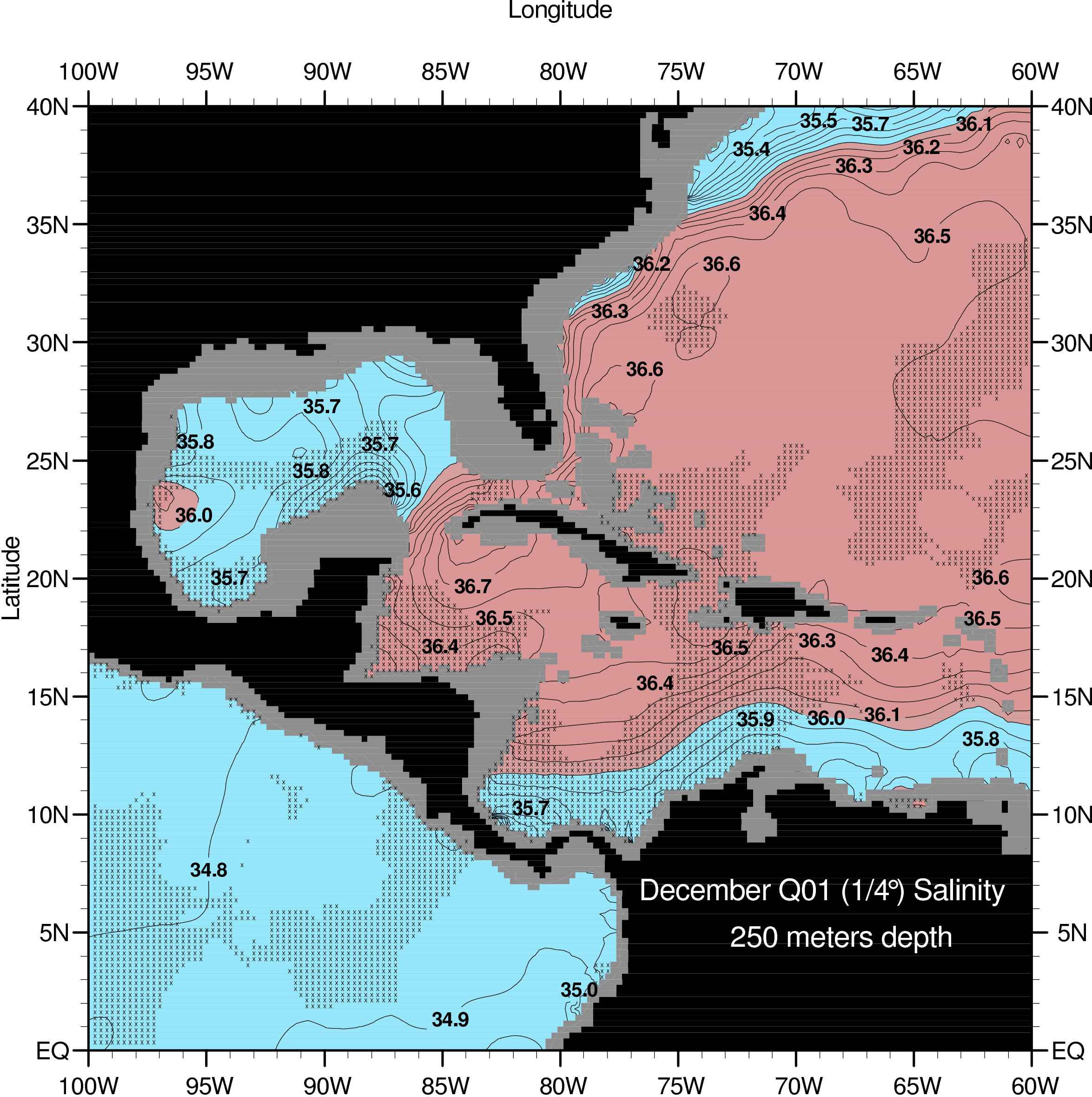

Longitude
Latitude
100W
95W
90W
85W
80W
75W
70W
65W
60W
40N
35N
30N
25N
20N
15N
10N
5N
EQ
35.5
35.7
36.1
35.4
36.2
36.3
36.4
36.5
36.2
36.6
36.3
36.6
35.7
35.8
35.7
35.8
35.6
36.0
35.7
36.7
36.6
36.5
36.5
36.4
36.3
36.5
36.4
36.4
35.9
36.0
36.1
35.8
35.7
34.8
35.0
34.9
December Q01 (1/4°) Salinity
250 meters depth

Figure 4d