NOAA Atlas NESDIS 11

OBJECTIVE ANALYSES OF TEMPERATURE AND SALINITY FOR THE WORLD OCEAN ON A 1/4° GRID

Washington, D.C.
March 1997

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Environmental Satellite, Data, and Information Service

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Preface

This atlas continues and extends earlier works including *Climatological Atlas of the World Ocean* and the *World Ocean Atlas 1994* series. These earlier works have proven to be of great utility to the international oceanographic, climate research, and operational forecasting communities. The objectively analyzed fields of temperature and salinity have been used in a variety of ways including: 1) use as boundary and/or initial conditions in numerical ocean circulation models; 2) for verification of numerical simulations of the ocean; 3) as a form of "sea truth" for satellite measurements such as altimetric observations of sea surface height; 4) for planning oceanographic expeditions. We have expanded these earlier works to include high spatial resolution analyses (1/4° grid) of temperature and salinity for the world ocean.

The production of global analyses of oceanographic data is a major undertaking. Such work benefits from the input of many individuals and organizations. The production of works like this atlas series is becoming easier because of advances in computer hardware and software. These include: 1) the development of relatively inexpensive but powerful workstations that can be dedicated to data processing and analysis and 2) the development of high resolution printers and interactive graphics software that minimize the need for expensive, time consuming manual drafting and photographic processing.

The objective analyses in this atlas, and data on which they are based, are being made available internationally without restriction via CD-ROMs as well as the Internet. This is to insure the widest possible distribution.

An atlas such as this is only made possible through international cooperation of scientists, data managers, and scientific administrators throughout the international community. I would also like to thank the staff of the Ocean Climate Laboratory of NODC for their dedication to the project leading to publication of this atlas series. Oceanography is a field of increasing specialization, and it is my belief that the development of national and international oceanographic data archives is best performed by scientists who are actively working with the historical data. Margarita Conkright, Todd O'Brien, Linda Stathoplos, John Antonov, and Igor Belkin receive my particular thanks.

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January, 1997

Acknowledgments

The establishment of a research group at the National Oceanographic Data Center to focus on the preparation of research quality oceanographic data sets and their objective analyses sets has been made possible by a grant from the NOAA Climate and Global Change Program. Substantial amounts of historical oceanographic data used in this study were located and digitized (Data Archaeology and Rescue projects) with funding from the NOAA Climate and Global Change Program and the NOAA Environmental Services Data and Information Management Program.

The work described in this atlas was made possible by scientists, technicians, ships' crew, data managers, and science administrators from the international scientific community. This atlas represents the results of several different research/data management projects of the NODC Ocean Climate Laboratory at the National Oceanographic Data Center (NODC), Washington, D.C. The products in this atlas are all based on the master oceanographic data archives maintained by NODC/WDC-A as well as data acquired from the IOC/IODE Global Oceanographic Data Archaeology and Rescue (GODAR) project. These archives and data sets exist because scientists of the international scientific community have submitted their data to national and regional data centers. In turn these centers have submitted data to the World Data Center system established under the International Council of Scientific Unions and the Intergovernmental Oceanographic Commission. This atlas and similar works would not exist without these international efforts. In particular we would like to thank data managers at these centers and the administrators and staff of these international organizations. The archiving of oceanographic data at international data centers means that the substantial expenditures in human and capital resources devoted to oceanographic measurement programs will be fully exploited, both for present and future scientific studies. Dr. Iouri Oliounine of the IOC Secretariat has been responsible for much of the success of the GODAR project and hence the scientific data sets products produced from the enhanced global data bases made available as a result of the GODAR project.

Although many data managers from the international community have been instrumental in the building of global oceanographic data bases we would like to thank in particular Harry Dooley, Hydrographer of the International Council for Exploration of the Sea (ICES). The work of the ICES ocean data center that is directed by Dr. Dooley has been outstanding.

Jeff Burney provided excellent system administration and programming support. Daphne Johnson provided invaluable assistance in unpacking numerous data sets used in this project. Robert Gelfeld was instrumental in the acquisition of numerous data sets as part of the GODAR Project. Our colleagues at NODC/WDC-A provided support for various data management projects related to this atlas. Jennifer Campbell helped in preparing the manuscript for publication. The support of GregWithee and Bruce Douglas, former directors of NODC is appreciated, as well as the support of Bob Winokur, Associate Administrator of NOAA for the National Environmental Satellite , Data, and Information Service.

The data sets and products represented by this atlas are distributed internationally without restriction in accordance with ICSU/IOC data management policies and U.S. Climate and Global Change policy in support of Global Change Research.

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Objective Analyses of Temperature and Salinity for the World Ocean on a 1/4° Degree Grid

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ABSTRACT

Objectively analyzed mean temperature and salinity fields have been calculated on a 1/4° grid using techniques previously used to calculate 1° grid mean fields. In comparison with the previous 1° temperature and salinity fields, the large scale oceanic circulation is similar, but smaller scale features, such as the Loop Current in the Gulf of Mexico, the Agulhas Retroflection, the Norwegian Sea overflow, and the Sulu Sea, are more clearly defined in the 1/4° mean analyzed fields.

1. INTRODUCTION

Climatological Atlas of the World Ocean (Levitus, 1982) has proved to be a valuable tool for studying the world ocean. In 1994, revised temperature and salinity climatologies were released as part of the *World Ocean Atlas 1994* series(Levitus and Boyer, 1994; Levitus *et al.,* 1994a, henceforth referred to collectively as WOA94). The main improvement in these new climatologies was the addition of significant amounts of data, both from archives of the United States National Oceanographic Data Center (NODC), and from the Global Ocean Data Archeology and Rescue (GODAR) project (Levitus *et al.*, 1994b). The earlier works were computed on a one-degree grid, the present work is computed on a one-quarter-degree grid for temperature and salinity for the "all-data" annual compositing period.

The quarter-degree analysis resolves small-scale features such as the Loop Current in the Gulf of Mexico, which were not present in the earlier one-degree analyses. Also, small, isolated regions, such as the Sulu Sea, are more accurately delineated on the higher resolution grid so that analyses at this resolution better reflect the physical property distributions of the area. The high-resolution analyses we present in this atlas will allow for more realistic initial and boundary conditions for numerical ocean models as well as provide improved fields for verification of these models. Satellite altimetry studies will benefit from better sea-truth provided by these high resolution fields. Increases in the speed of vector supercomputers and the development of fast, massively parallel computers has allowed for increased resolution in numerical ocean simulations on regional (Yamagata and Iizuka (1995), basin (Doscher *et al.*, (1994); Bryan *et al.* (1995), Boning *et al.* (1996); Sparrow *et al.*, (1996); Doos (1996)) and global (Semtner and Chervin (1988, 1992); Wilkin *et al.* (1995); Stammer *et al.*, (1996) Fu and Smith, (1996)) scales.

Problems due to the lack of data in some regions, as noted in WOA94, are magnified in the quarter-degree analysis, since a much smaller area (the influence region), and hence number of data points, is used to produce an analyzed value at each grid point. This drawback has been bypassed in some measure by using the one-degree analyzed fields as first-guess fields for the quarter-degree analysis. Thus, in areas with little or no data on the quarter-degree grid, the one-degree analysis is the dominant signal.

2. METHOD

The method for objectively analyzing the data is basically the same as outlined by WOA94 for temperature and salinity. One major difference is that the size of the radius of influence around each grid point used for analysis was 557 km for WOA94 and is 134 km for the high-resolution analyses. The higher-resolution grid allows us to use this smaller influence of radius and resolve features on the order of 220 kilometers with seven or eight gridpoints.

The second major difference is the land/ocean bottom topography used. ETOP05 is the altitude and bathymetry of the entire world at five-minute position intervals available from the United States National Geophysical Data Center (NGDC). A modified version of ETOP05 was used to define a quarter-degree grid in two steps. The first step consisted of defining a land point as any quarter-degree latitude-longitude box in which more than three-fourths of the five minute grid points were greater than or equal to zero meters (positive values being altitude). Land points were given a value of 1. All remaining points were then assigned a value between 2 and 33, for the 33 standard depths defined by Levitus (1982), by taking the average of the five-minute ocean depth values for a quarter-degree square and assigning the number of the standard depth nearest to this average value.

Another difference between the one-degree and quarter-degree analyses is the choice of first-guess field for each analysis. Instead of using a zonal average as the starting point for analyzing the data as was previously done, objectively analyzed one-degree climatological values were used as the first-guess for the quarter-degree analysis. The one-degree field had to be modified in two ways, however. First, in order to better reflect the new topography, the same procedure as outlined above was performed to create a one-degree bathymetry more similar in character to the quarter-degree field. The data prepared and previously used for the one-degree annual temperature and salinity analyses in WOA94 were then analyzed using the new one-degree bathymetry. This one-degree analysis was then imposed on the quarter-degree grid by distributing the one-degree value over each of the sixteen quarter-degree grid points. Where there was no one-degree value because the one-degree square was defined as land or below ocean bottom, the nearest present one-degree value was used. Finally, defined ocean subareas were redefined to fit the new bathymetry. Each distinct ocean area, beginning with the Pacific, Atlantic, and Indian Ocean basins, and extending to sub-basins is assigned a unique number. This area number is used to keep water masses which are separated by land or ocean bottom from being used when analyzing values of an adjacent water mass which is within the defined radius of influence, but geographically separated. (For a full explanation of area numbers, see Appendix A)

The greater resolution provided by the quarter-degree grid allows us to define more sharply distinct ocean subareas. To insure that the first-guess field is consistent with our definition of distinct subareas, when the one-degree analysis is not well-defined enough to differentiate subareas we used the following procedure. When a one-degree square contains quarter-degree squares from more than one subarea, only the quarter-degree squares from the most represented subarea are given the first-guess value. The idea is that the most representative area will have dominated in the analysis of the one-degree square. The remaining quarter-degree squares are filled in with the closest values from within their own area.

The method of preparing the measured data for the objective analysis is basically the same as outlined in WOA94. The same method of final quality control was used in the quarter-degree analysis as in the previous one degree analyses. 'Bull's-eyes', anomalous values which cause large concentric gradients in the analyzed fields, were identified after an initial analysis. The values and/or anomalous profile(s) causing each bullseye were flagged and not used in a recalculation of the quarter-degree mean values. The fields were then reanalyzed. Due to the smaller radius of influence in the quarter-degree analysis, a great many addition problem profiles and cruises were identified this way, in addition to those already found in the 1994 one-degree temperature and salinity analyses. Some of the problems identified are: a number of XBT cruises which were in the middle of the southern Pacific were found to have the wrong longitude sign, and were actually cruises south of Australia and New Zealand. Some CTD cruises were found with negative signs missing in the temperature data, giving deep basin values in the southern Atlantic positive values where negative values were expected. A disproportionate amount of GTSPP (Global Temperature and Salinity Pilot Project) XBT data were found to be problematic. The same is true of data from the Southern Ocean Atlas provided by the Alfred Wegner Polar Institute (due to the use of linear interpolations of data to standard levels) and DBT (Digital Bathythermograph) data from Japan. After the problems were identified and flagged, both the one-degree first-guess field and the quarter-degree analysis were reanalyzed.

3. RESULTS

Thirty-three levels of high resolution analyzed temperature and salinity for the world's ocean are the results of our work. Six levels have been mapped and presented here for both temperature and salinity for the Atlantic, Pacific, and Indian Oceans (Appendices A and B, C and D, and E and F, respectively). The depth levels shown are at the surface, 100, 500, 1000, 2000, and 3000 meters. Examination of these figures reveals that the quarter-degree depict the same basic large-scale oceanic features as the one-degree analysis results (not shown here), but are somewhat noisier because of the reduced smoothing due to the use of the smaller influence region around each gridpoint. Numerous small-scale features are represented by the high resolution analyses as will be described shortly.

The limitations of the quarter-degree analysis are apparent in low data density areas, such as the Indian Ocean (salinity at 2000 meters). A large number of bullseyes are created due to the inability of the meager amount of data within the influence region surrounding each gridpoint to adequately represent the mean at each gridpoint. With this in mind, we have provided, along with the data, files containing the number of grid-points used to analyze each value (such files were also provided with the WOA94 analyses). Note that the file containing the number of surrounding grid-points used to analyze a value does not usually reflect the total number of measurements in the area, since the value at each grid-point is a mean of all measurements in the quarter-degree square.

One of the more striking features resolved by the high resolution analyses is the Loop Current in the Gulf of Mexico. Fig. 1a shows the quarter-degree analyzed salinity field in and around the Gulf of Mexico at 250 meters depth. Fig. 1b shows the same area for the one-degree analyzed salinity from Levitus *et al.* (1994) in which the Loop Current is smoothed out, revealing itself only as a gradual intrusion spanning the entrance to the Gulf of Mexico. In Fig. 1a, the Loop Current assumes more of its characteristic form, with the salinity distributions associated with the inflowing Yucatan Current, the Loop itself, and the outgoing Florida Current. Note also, the increased coherence in the climatological Gulf Stream and its separation at about 38°N latitude from the North American coast in Fig. 1a. A concern raised by the appearance of the Loop Current in the quarter-degree analyzed fields is whether a seasonal bias in data collection has caused a seasonal phenomena to dominate the annual average. In the case of the Loop Current this appears not to be the case. Hurlburt and Thompson (1980) note that "the Loop Current can penetrate into the Gulf, bend westward, and shed anticyclonic eddies at almost an annual frequency, with no time variation in the inflow." The distribution of data spatially does not appear to bias these results. Fig. 1c shows the distribution of data used in the high resolution analysis revealing no large data-void areas.

Another area of the Atlantic which shows improvement in the quarter-degree analysis is the Norwegian Sea. Fig. 2a is the quarter-degree temperature analyzed field for the northern North Atlantic and the Norwegian Sea at 500 meters depth; Fig. 2b shows the same area for the one-degree analysis. The higher resolution allows the Iceland-Faroe Front to be resolved. In addition, at this depth there are only two major connections between the North Atlantic and the Norwegian Sea, through the Denmark Strait between Greenland and Iceland, and through the Faroe Channel. The one-degree bathymetry used in WOA94 does not properly resolve a narrow portion of the Iceland-Faroe Ridge and so a third channel exists in those analyses. Even though the area masks we described keep the northern North Atlantic water from being used to analyze the waters north of this ridge, and vice-versa, the one-degree squares which span the ridge contain measurements from both water types, biased towards the North Atlantic water, and thus the one-degree analysis created an artificial high temperature area north of Iceland. This spurious high-temperature area does not exist in the quarter-degree analysis, as the Iceland-Faroe Ridge is more fully resolved, the quarter-degree grid-squares more fully separate the two basins, and the water types are kept from influencing the analysis in adjacent but separated areas. In Fig. 2a, the water pool with below-zero temperature in the mid-Norwegian Sea area extends all the way south to Iceland.

The North Atlantic water inflow through the Faroe-Shetland Channel hugs the continental shelf before curling off-shore and sinking (Worthington, 1970). This process is reflected both in Figs. 2a and 2b, but the pool of warm North Atlantic water is warmer and more defined in the quarter-degree analysis. The quarter-degree analysis results compare well with results presented in the atlas by Dietrich (1969).

Another notable feature of the high resolution analyses is that the limited inflow of the North Atlantic Current into the Labrador Sea (near 51°N, 43°W), known as the 'Northwest Corner' is distinct but was practically nonexistent in the one-degree analyses. Tongues in the temperature distribution in the western subarctic that are associated with the flow of water from the Labrador Sea to the Irminger Sea and eastward along 52°N are clearly resolved in the high-resolution analyses.

Although the southern hemisphere is relatively data poor, there are some areas which exhibit considerable differences between the one-degree and quarter-degree analyses. One such area is the region south of southern Africa known as the Agulhas Retroflection, where the Agulhas Current reaches its most westward extension before abruptly turning east. It is an area characterized by large warm-core eddies which transport warm, saline water from the South Indian to the South Atlantic Ocean (Duncombe Rae *et al.*, 1996); a minimum of 4-6 eddies per year enter the Cape Basin. Also advection of Agulhas filaments (50 km wide and 50 m deep) into the South Atlantic occurs which also transport warm, salty water into the Cape Basin (Lutjeharms and Cooper, 1996).

Fig. 3a shows this area for the quarter-degree analysis at 500 meters depth; Fig. 3b shows this same area for the one-degree analysis. Fig. 3c shows the data distribution for this region on the one-quarter-degree grid. The stippled regions in both figures are areas with salinities between 34.8 and 35.0 (pss). The westward extension of the Agulhas Current is seen in the quarter-degree analysis as a tongue of high-salinity water off the southern and eastern coast of Africa., with the furthest westward extension represented by the stippled 34.8 to 35.0 salinity water. This high-salinity tongue is not apparent in the one-degree analysis salinity. The tongue, as represented in the quarter-degree analysis salinity field, is also seen in atlases of the southern ocean by Gordon *et al.* (1982) and Olbers *et al.* (1992). Also apparent in Fig. 3a are isolated areas west of Africa between 35°S and 25°S of salinities greater than 34.8. Salinities do not reach this value until much further west in the one-degree analysis. These isolated areas may be the result of measurements in warm core eddies spun off from the Agulhas Retroflection. Fig. 3c shows areas with little or no data southwest of Africa. Sampling problems will clearly have a large impact in this area. Lack of data weakens the semipermanent signal of the warm core eddies that often occur in this region. However, if the historical database in this region consists primarily of samples from a few eddies, the analyses will be biased towards these few data, thus suggesting that these warm core eddies are permanent features. The representativeness of our analyses of historical data in this region should be viewed with caution.

One last example of differences between the quarter-degree and one-degree analysis is the analyzed temperature field at 600 meters in and around the Sulu Sea (Figs. 4a, 4b) for the quarter-degree and one-degree results, respectively. The Sulu Sea, below its sill depth of 420 meters, is nearly homogenous in temperature and salinity. The temperature values are above 9.8°C to the bottom of the basin, while the surrounding areas are much cooler (Quadfasel *et al.*, 1990). Since the basin is so small, spanning little more than 2°

in latitude and 4° in longitude, it is not an easy basin to effectively resolve in the one-degree analysis. The large differences between temperatures inside the basin and outside exacerbate the situation. The stippled area in both figures indicates temperatures greater than 10°C, representative of the Sulu Sea at 600 meters. The one-degree field shows temperatures of this magnitude only in the very center of the Sea. The values near the borders of the basin are influenced by values from outside the basin, which are at least 2.5°C lower. Furthermore, since the small ridge enclosing the sea to the southeast is not resolved in the one-degree bathymetry, a large artificial gradient is present. None of these problems are apparent in the quarter-degree results.

4. DISCUSSION

The quarter-degree analyzed temperature and salinity fields retain the large-scale oceanic features that exist in their one-degree counterparts but with more noise. At smaller scales and in small isolated areas, the better resolution afforded by the quarter-degree analysis results in substantial improvements over the one-degree analysis results. However, many data deficient areas are better represented by the one-degree analysis, since there is not enough data to average out anomalous or erroneous measurements in the quarter-degree fields. Also, the quarter-degree analyses may amplify biases in the data introduced by large numbers of measurements in certain seasons or of anomalous features. Overall, the quarter-degree analysis can be improved greatly by the addition of more data in data deficient areas of the worlds ocean.

5. FUTURE WORK

In the future we intend to produce new versions of these high resolution analyses based on the expanded historical ocean data bases of temperature and salinity that are becoming available. Seasonal, ,high-resolution analyses will be computed. Suggestions and comments from the user community are welcomed, in particular regarding the adequacy of our definition of sea floor topography. For example, we expect that the definition of narrow channels that are important for the exchange of deep and bottom water between various basins may need to be refined. Although this atlas deals with results from high-resolution analyses of the ocean, it is also appropriate to discuss vertical resolution at which analyses are performed. There is no question that finer vertical resolution for the analysis levels will improve our representation of the ocean. However, we are limited by the available data. Certainly we can use bathythermograph data to provide data at finer vertical resolution in the upper ocean. As the database of high resolution CTD profiles builds up we can do the same for salinity. At present the high resolution database may provide enough data for regional analyses but not for global analyses. Many older S/CTD measurements were archived at standard analysis levels. In part, we believe this occurred because storage media did not have the capacity for easily storing large volumes of data. It appears that many older S/CTD profiles were never sent to any data center.

6. APPENDIX A: AREA NUMBERS AND MIXING NUMBERS DEFINED

The 'Area Number' is a number assigned to each gridpoint, which defines distinct water masses, and is used in our objective analysis software to keep gridpoints of one distinct water mass region. This problem occurs gridpoints from another distinct water mass region during the objective analysis computations where these gridpoints are physically separated by land or ocean bottom. For instance, the Atlantic and Pacific Oceans are separated by the Isthmus of Panama. The Area Number of the Atlantic Ocean and the Area Number of the Pacific Ocean are different thus, data from the Atlantic Ocean are not used to analyze grid-points in the Pacific Ocean, even though the radius of influence for a gridpoint may cross the isthmus. As basins become increasingly separated by ocean bottom at deeper levels, the number of such areas increases. At the sea surface, we have defined 13 distinct areas. At a depth of 5500 meters (depth level 33) we have defined 54 such regions. But area numbers are not sufficient by themselves. For example the Atlantic Ocean and the Mediterranean Sea have different area numbers, so there is no unrealistic mixing across the Iberian Peninsula,. However, the Atlantic and Mediterranean do mix through the Straits of Gibraltar. Similarly, the Atlantic and Pacific Oceans do mix south of South America, but not across the narrow Argentina-Chile region. To account for this, another parameter, which we term the 'Mixing Number', is needed. Each grid-point has been assigned a mixing number, -2 through 2. If two area numbers are equal, each data value may be used to analyze the other's grid-point. If two area numbers are not equal, but the mixing numbers add up to be greater than zero, the data values may still be used to analyze the other's grid-point. So, the Atlantic and Pacific Oceans both have a mixing number of one, except in special regions such as the aforementioned Isthmus of Panama, where the mixing number of the Pacific is -1. Thus mixing will occur between areas where appropriate.

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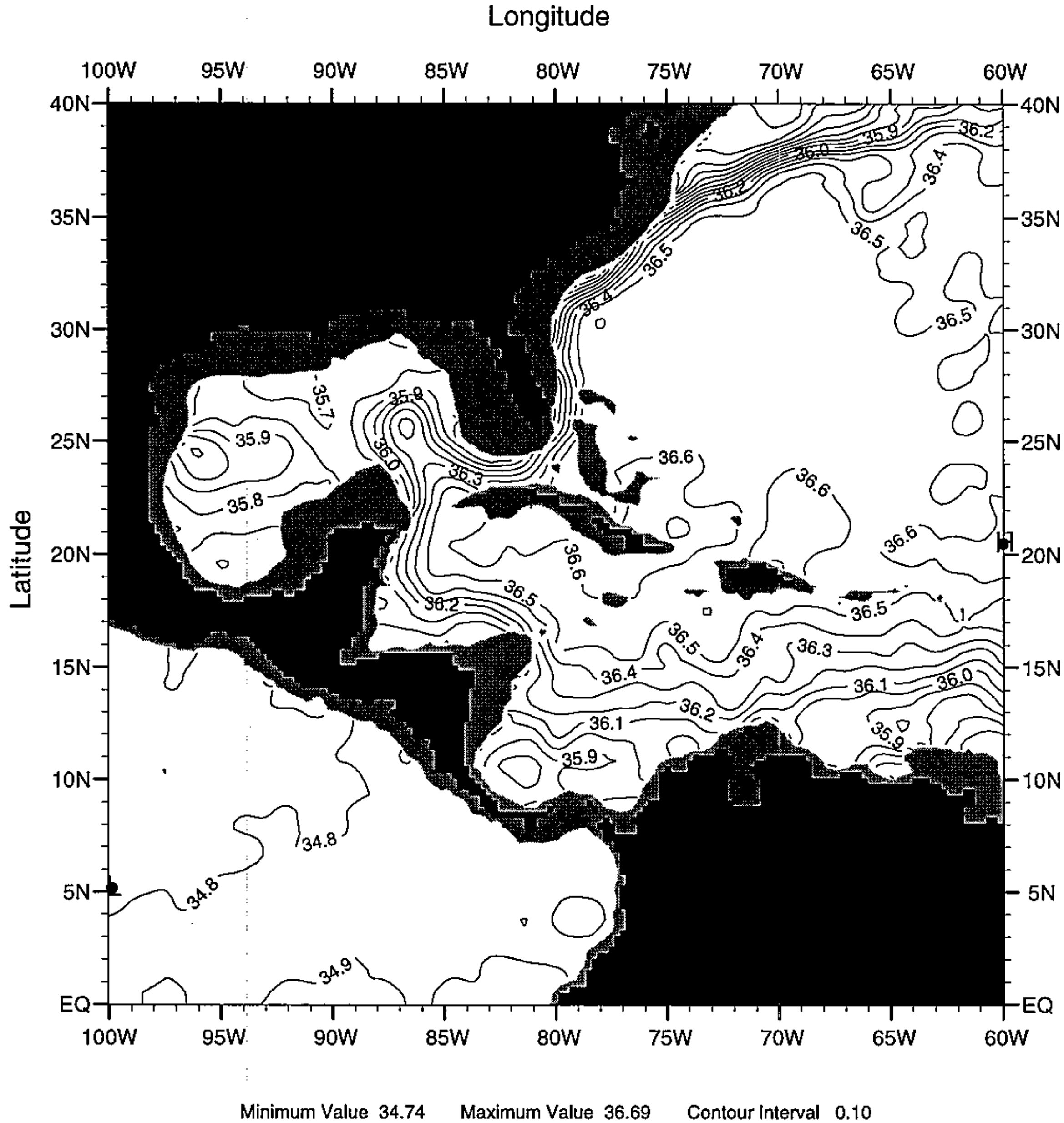


Fig. 1a High resolution salinity at 250 meters depth in the Gulf of Mexico.

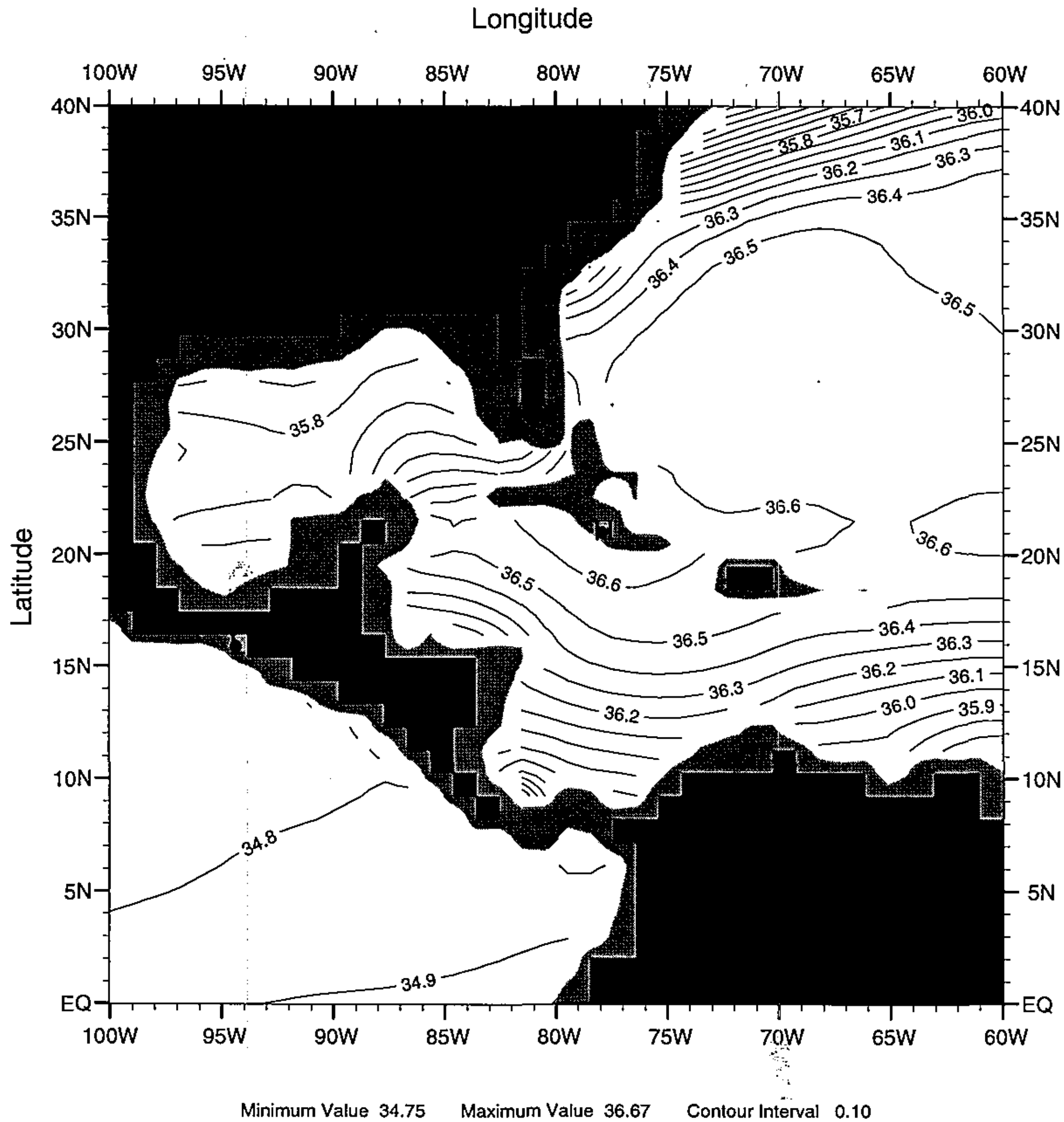


Fig. 1b Low resolution salinity at 250 meters depth in the Gulf of Mexico.

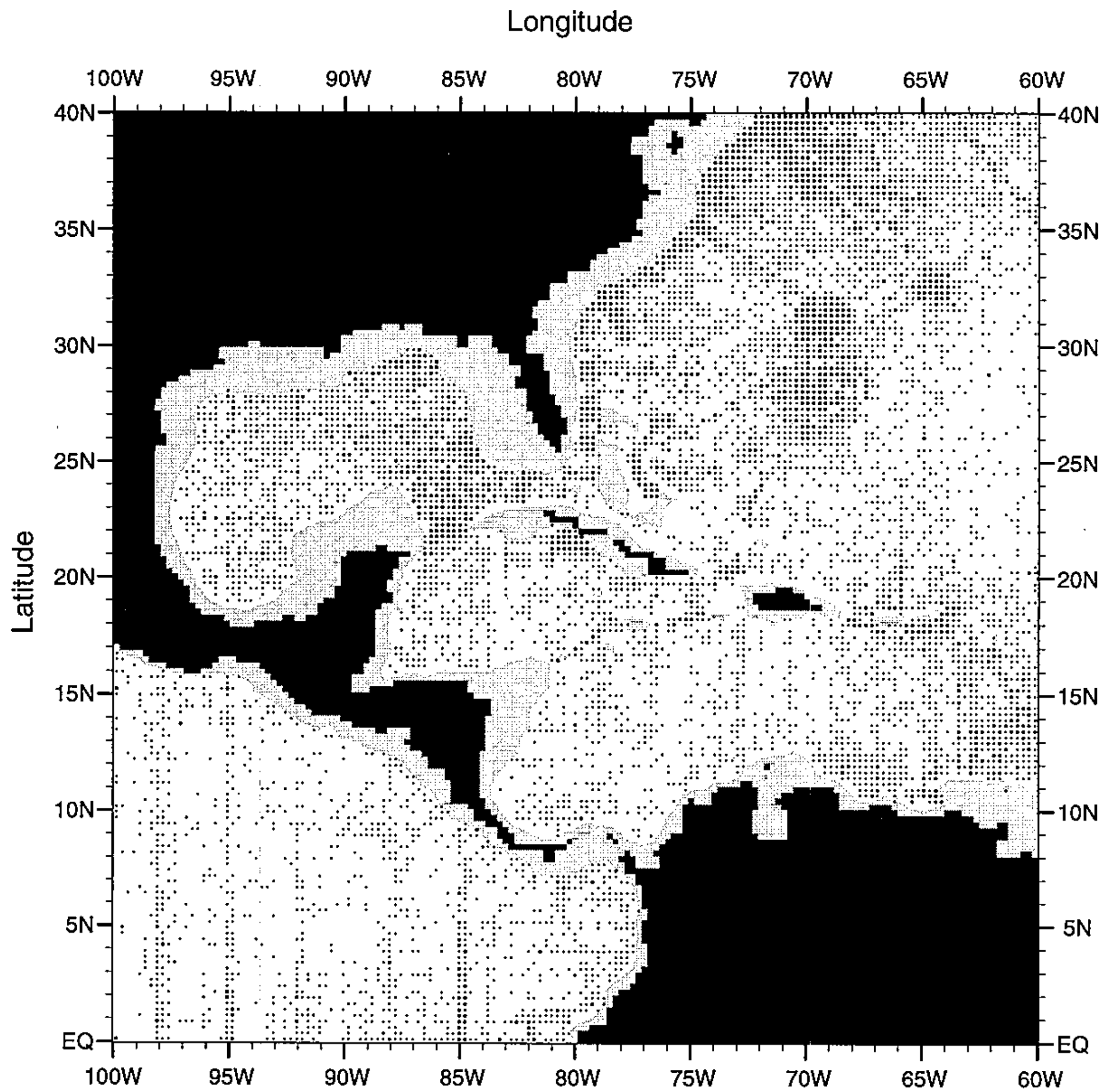
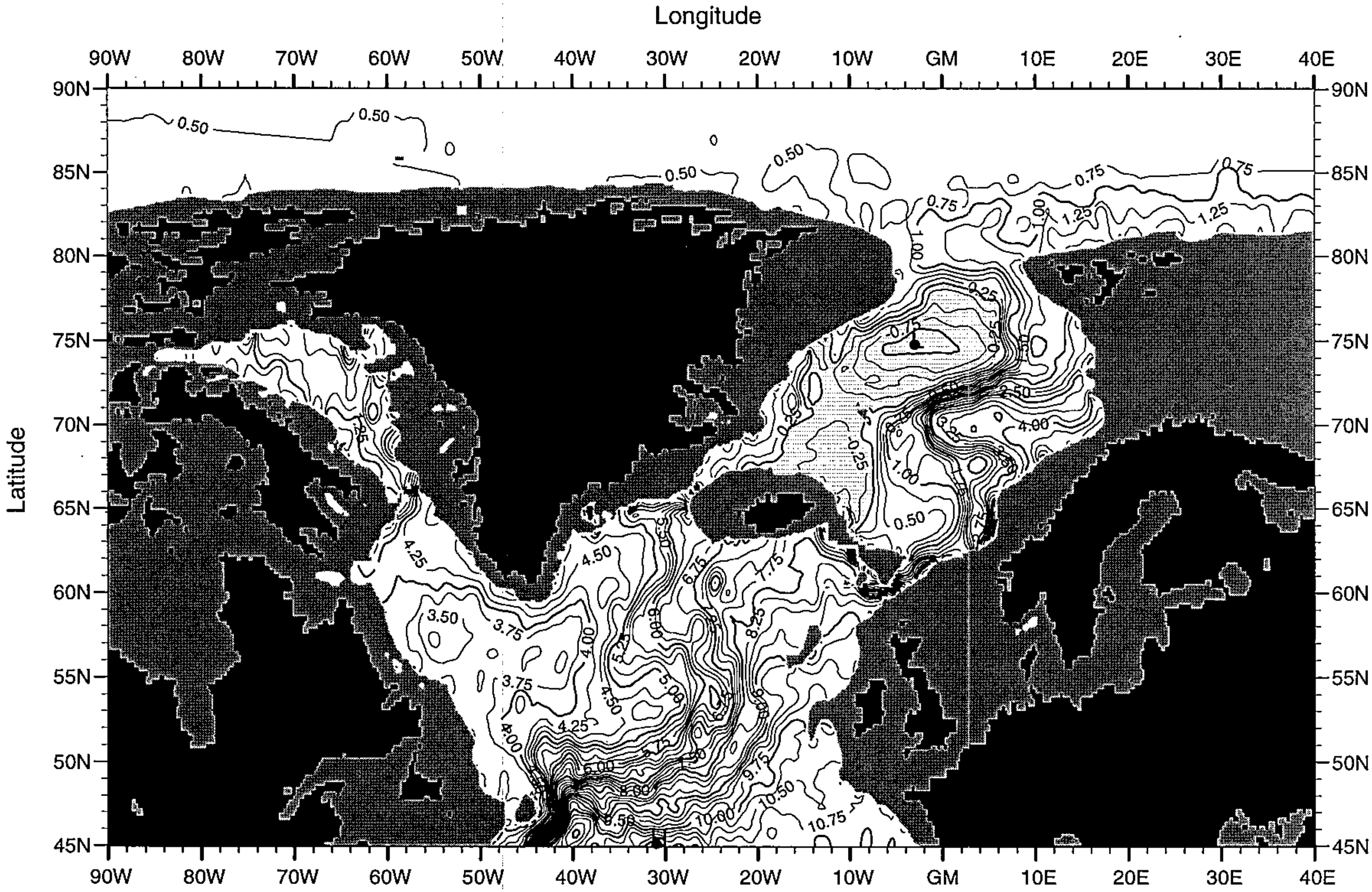


Fig. 1c Salinity data distribution at 250 meters depth in the Gulf of Mexico and surrounding areas on a one-quarter-degree grid. Small dots indicate from 1 - 4 observations, large dots indicate 5 or more observations.



Minimum Value -1.08 Maximum Value 11.29 Contour Interval 0.25

Fig. 2a High resolution temperature at 500 meters in the northern North Atlantic. Stippling indicates temperatures less than 0°C.

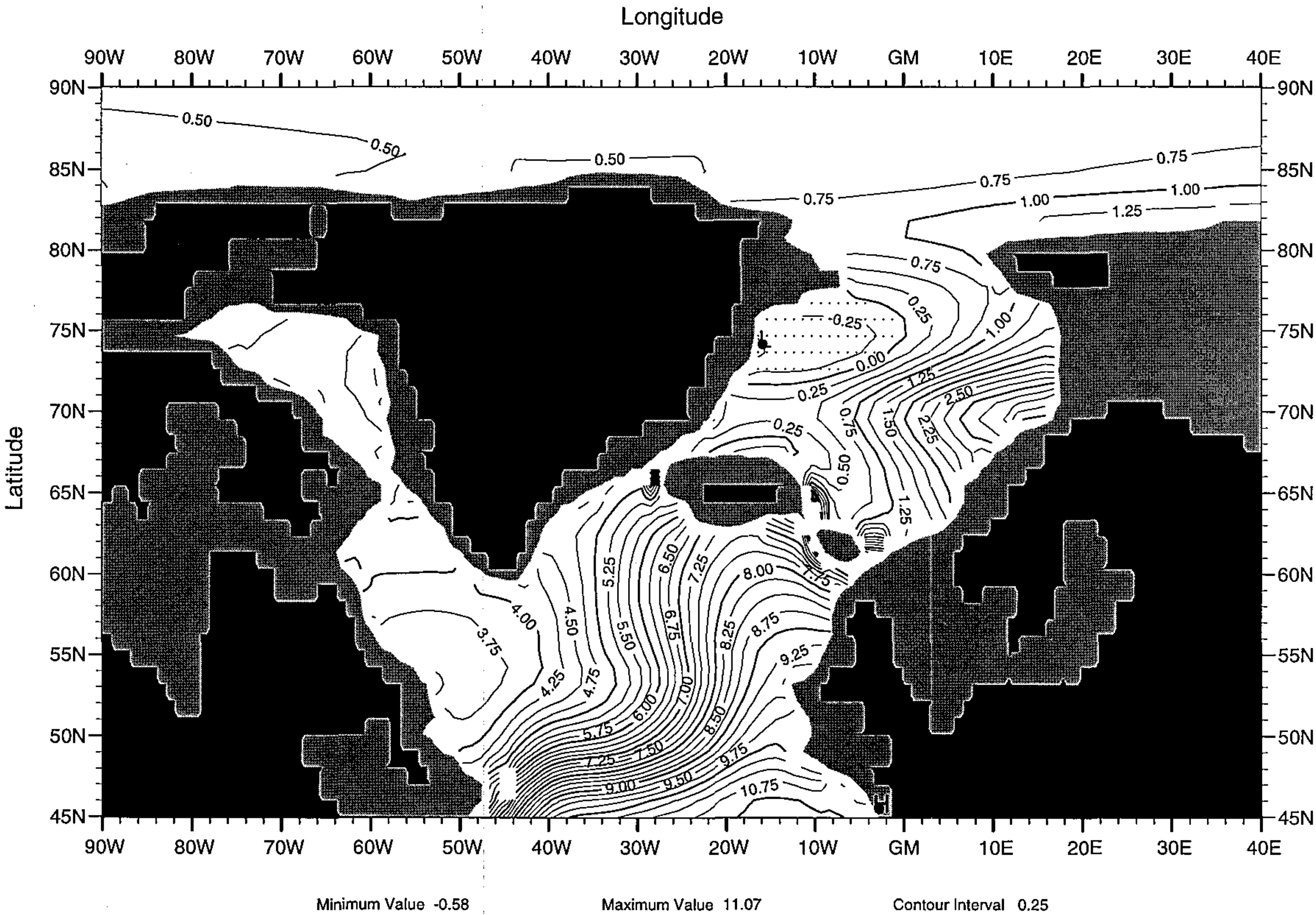
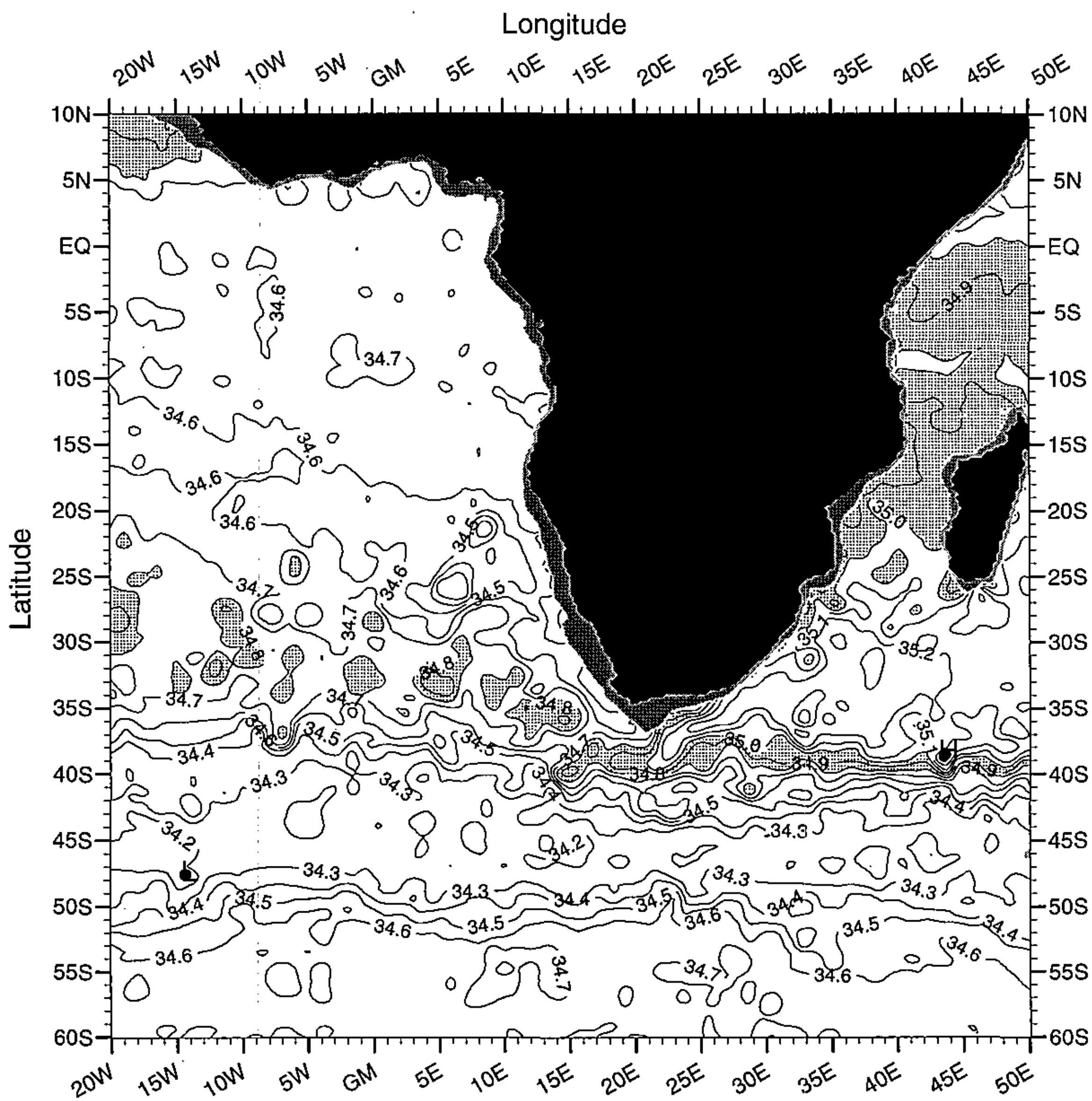
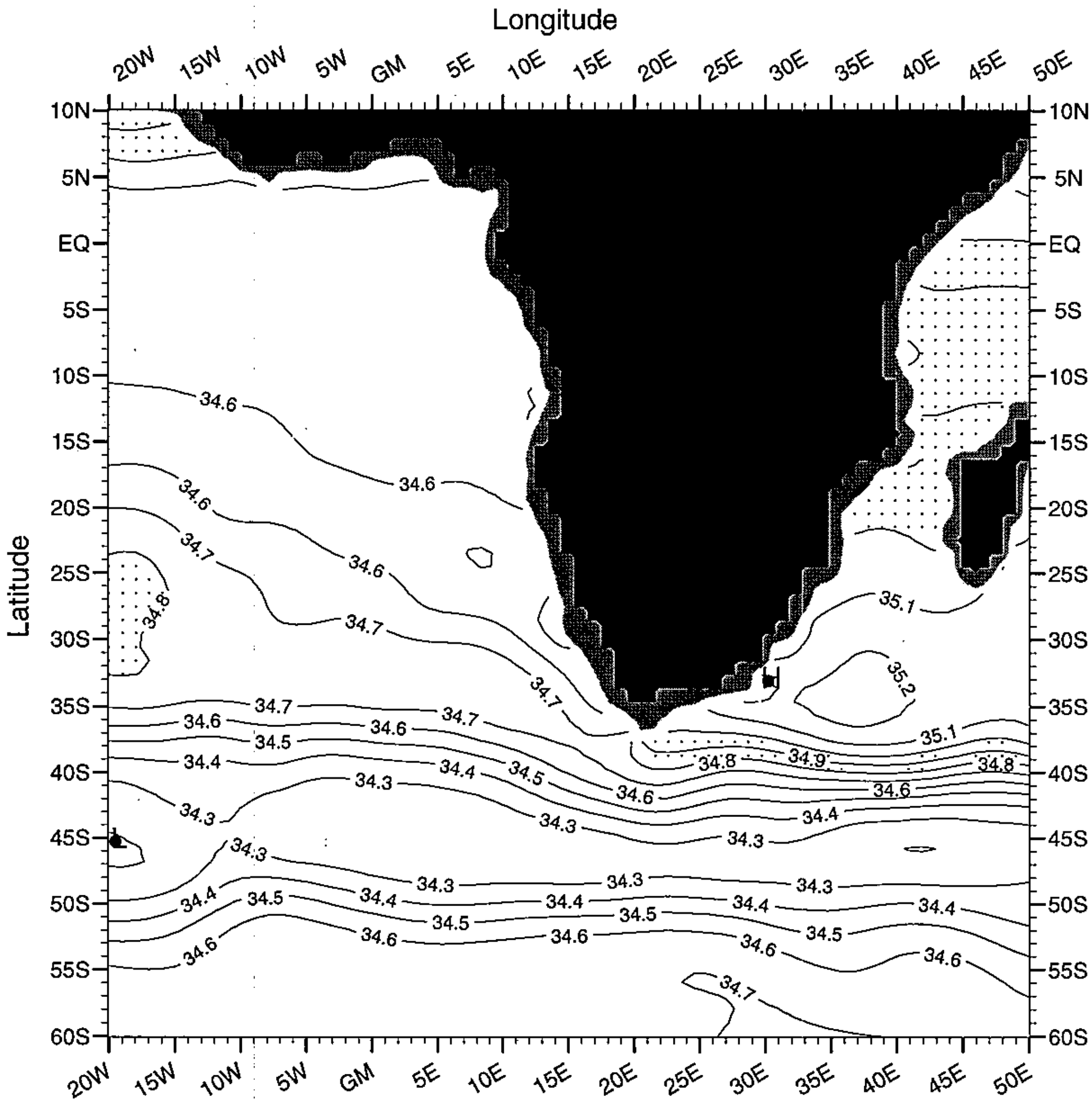


Fig. 2b Low resolution temperature at 500 meters in the northern North Atlantic. Stippling indicates temperatures less than 0°C.



Minimum Value 34.15 Maximum Value 35.36 Contour Interval 0.10

Fig. 3a High resolution salinity at 500 meters depth in the Agulhas Retroflection and surrounding area. Stippling indicates salinities between 34.8 and 35.0 psu.



Minimum Value 34.19 Maximum Value 35.24 Contour Interval 0.10

Fig. 3b Low resolution salinity at 500 meters depth in the Agulhas Retroflection and surrounding area. Stippling indicates salinities between 34.8 and 35.0 psu.

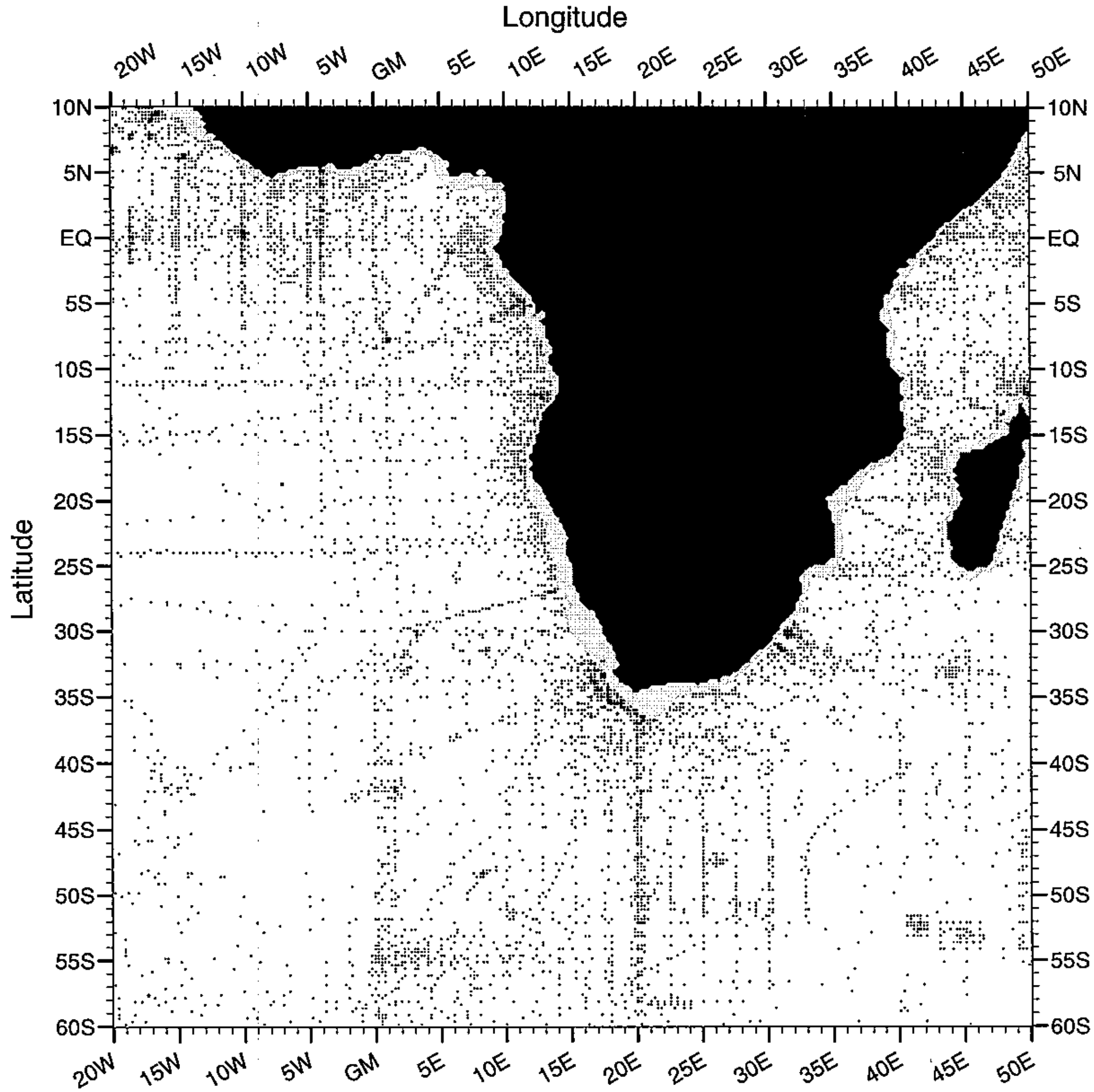


Fig 3c Salinity data distribution at 500 meters depth in the Alguhas Retroflection and surrounding areas on a one-quarter-degree grid. Small dots indicate from 1 - 4 observations, large dots indicate 5 or more observations

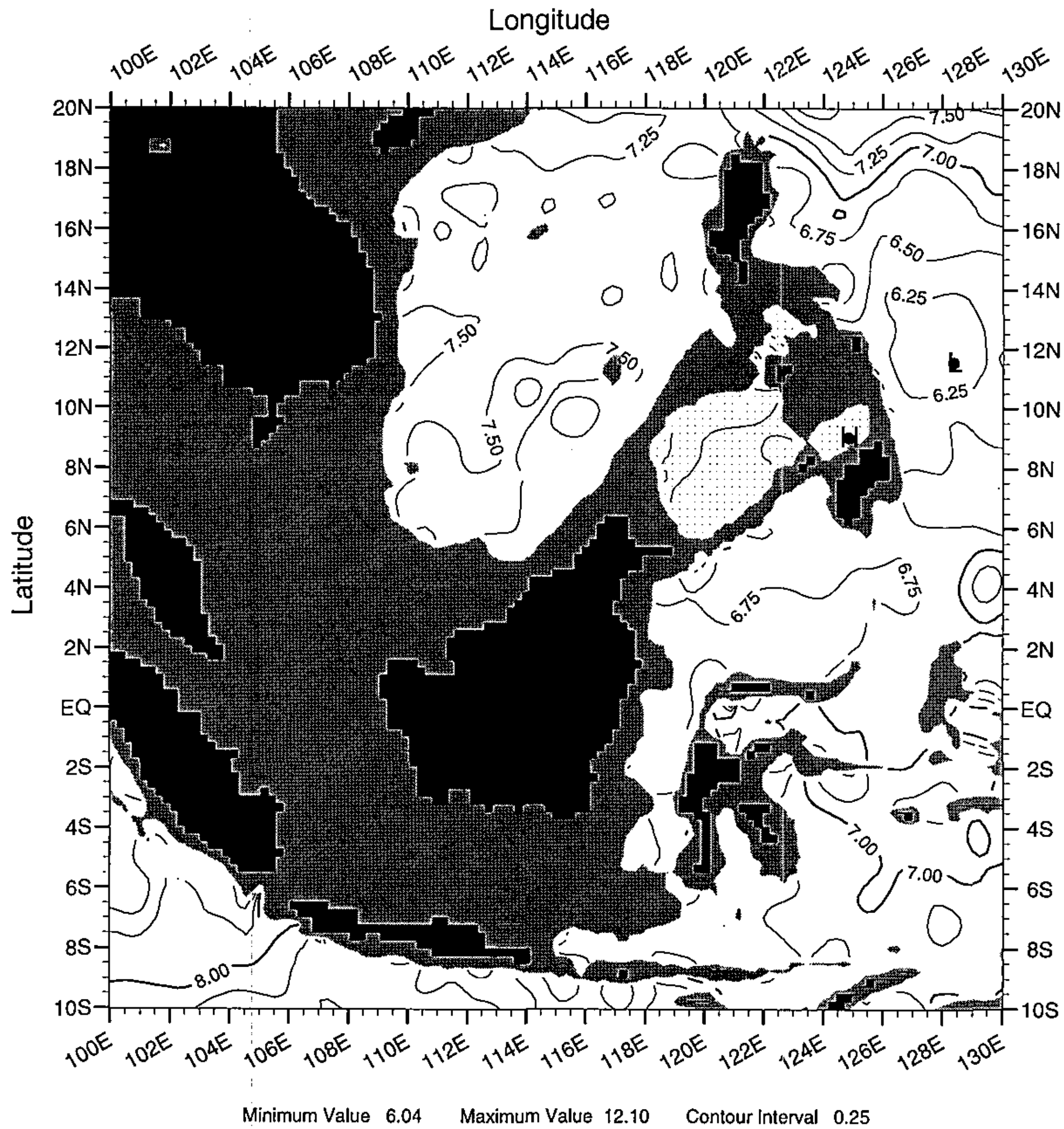


Fig. 4a High resolution temperature at 600 meters depth in the Sulu Sea and surrounding area. Stippling indicates temperature > 10°C

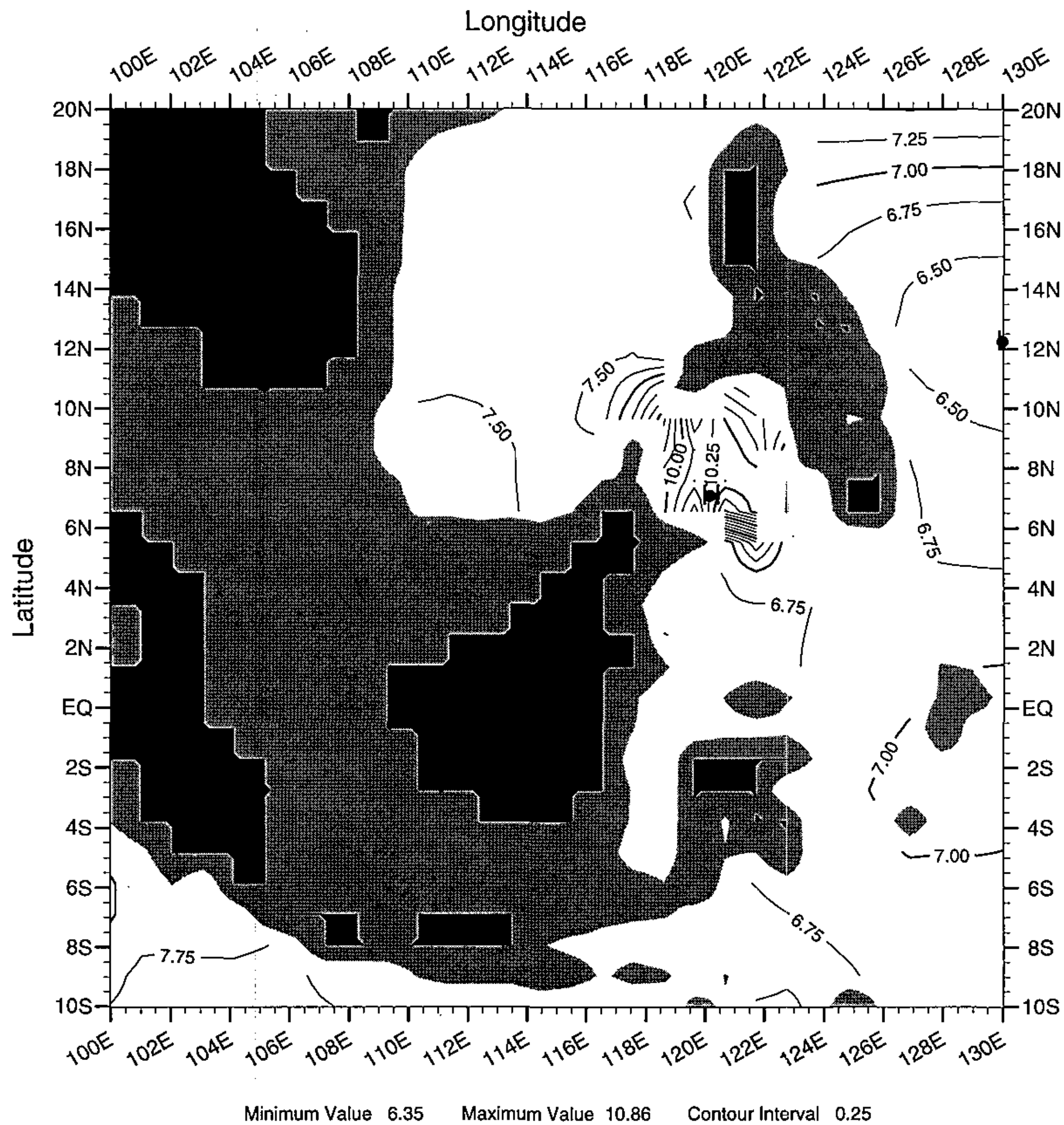
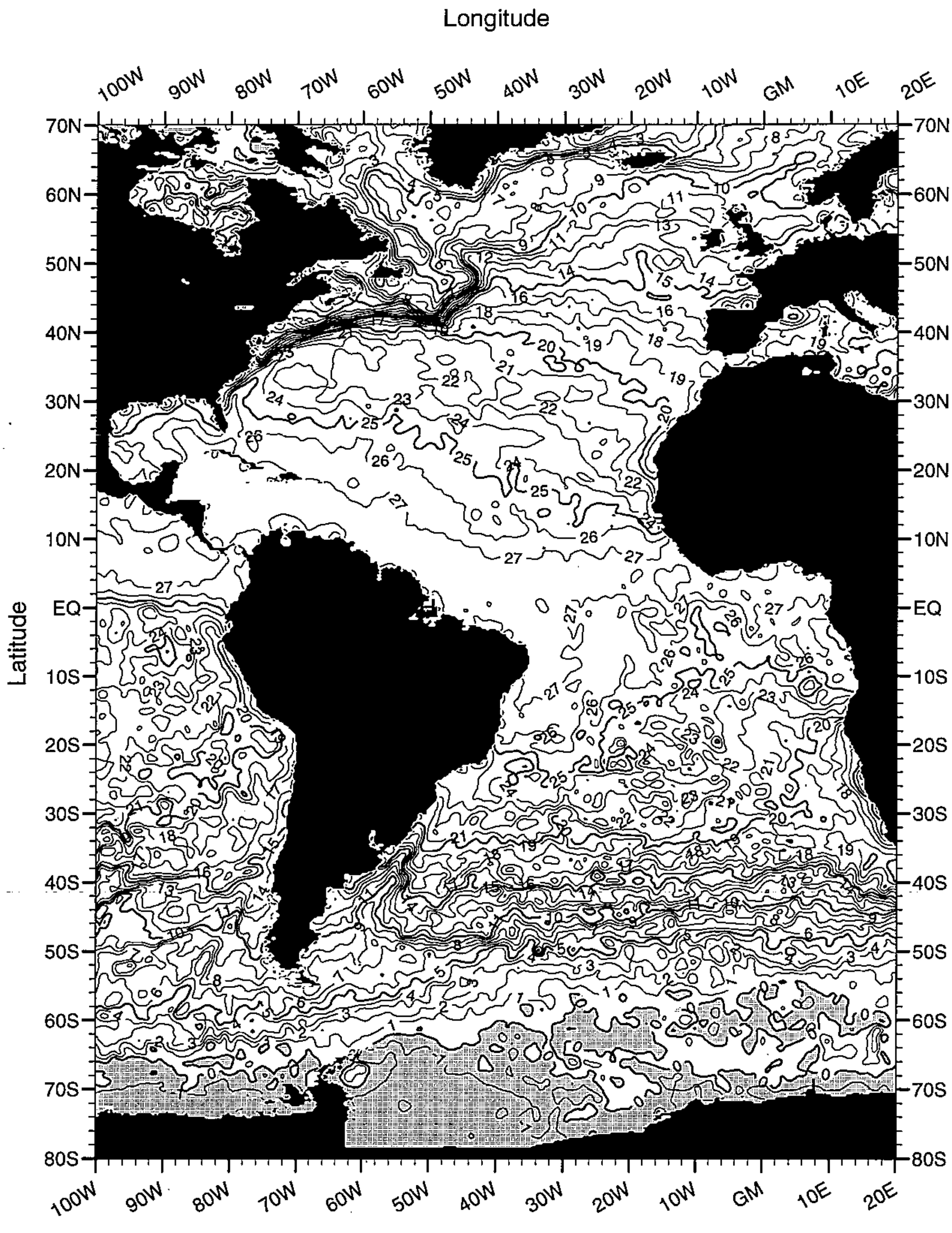
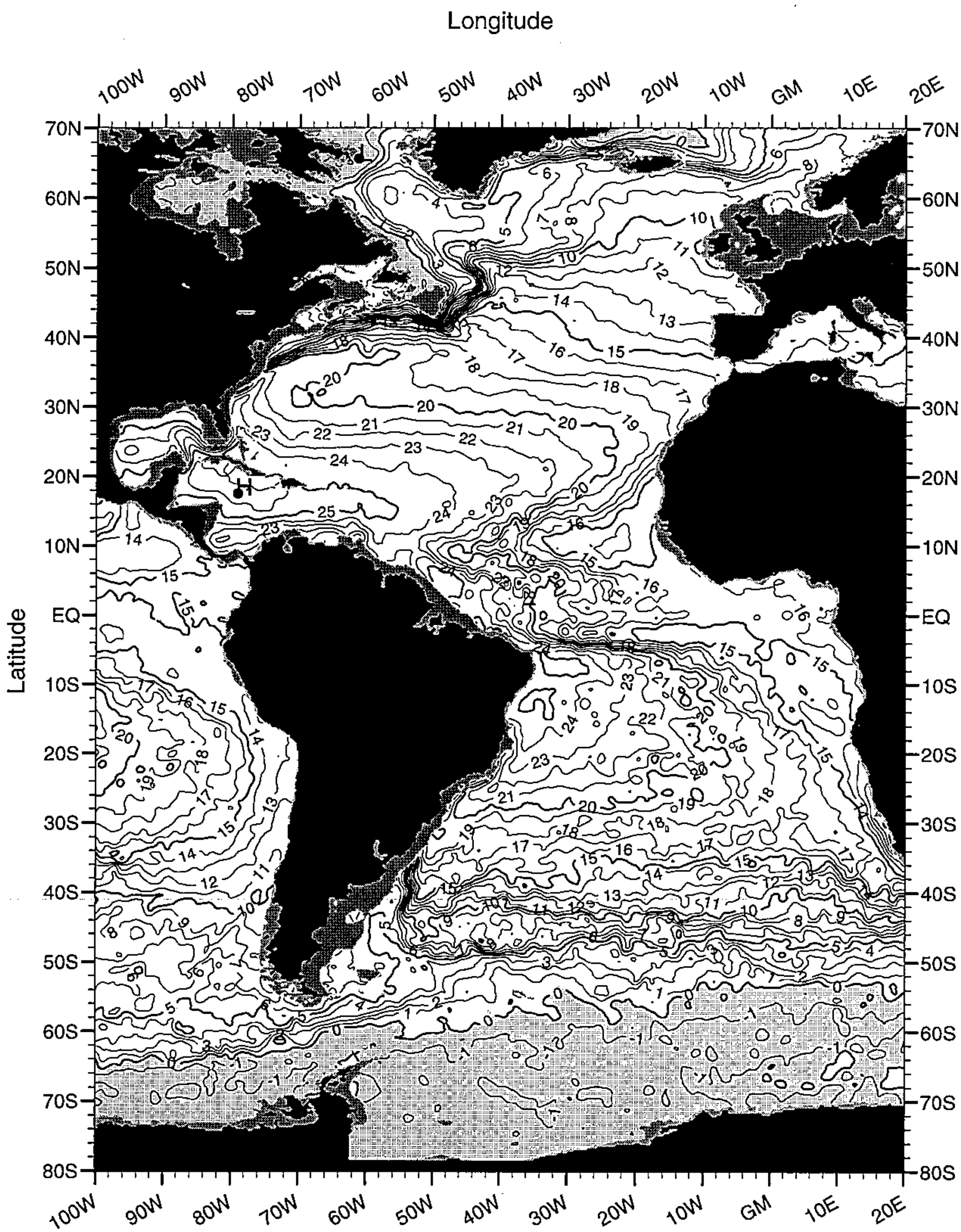


Fig. 4b Low resolution temperature at 600 meters depth in the Sulu Sea and surrounding area. Stippling indicates temperature > 10°C



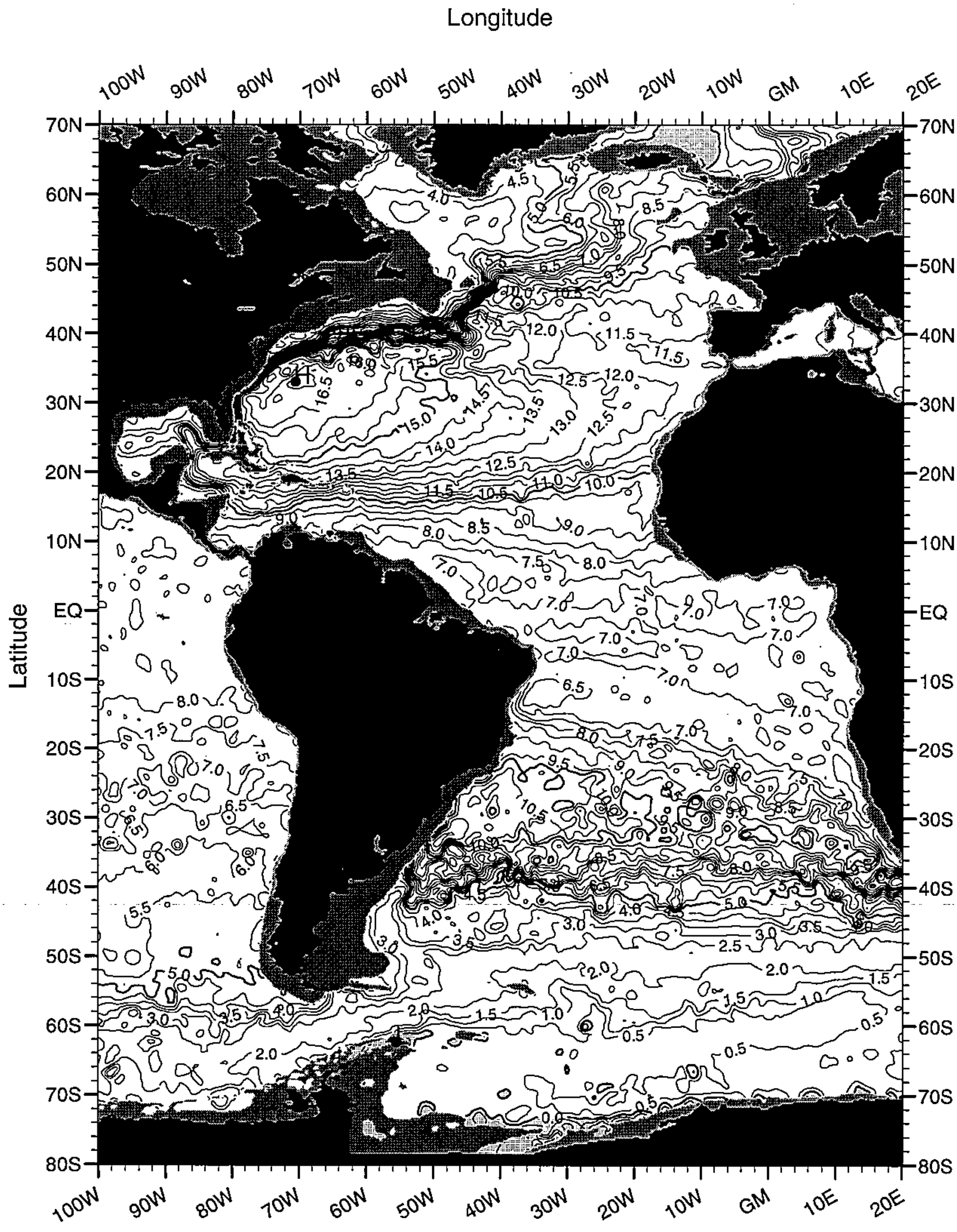
Minimum Value -2.24 Maximum Value 29.50 Contour Interval 1.00

Fig. B1 High resolution temperature in the Atlantic Ocean at the sea surface. Stippling indicates temperature less than 0°C.



Minimum Value -2.20 Maximum Value 26.57 Contour Interval 1.00

Fig. B2 High resolution temperature in the Atlantic Ocean at 100 meters depth. Stippling indicates temperature less than 0°C.



Minimum Value -2.39 Maximum Value 17.19 Contour Interval 0.50

Fig. B3 High resolution temperature in the Atlantic Ocean at 500 meters depth. Stippling indicates temperature less than 0°C.

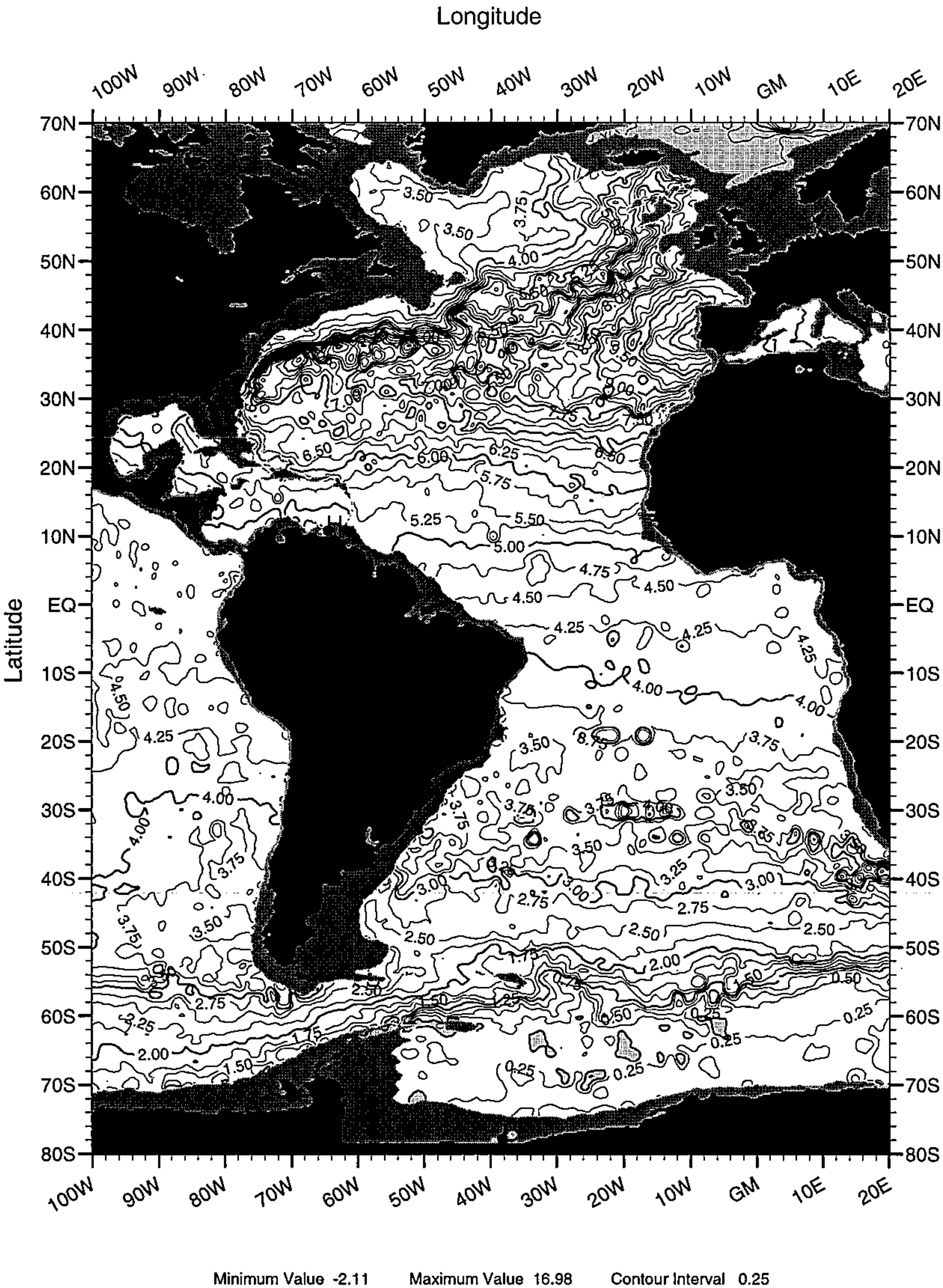


Fig. B4 High resolution temperature in the Atlantic Ocean at 1000 meters depth. Stippling indicates temperature less than 0°C.

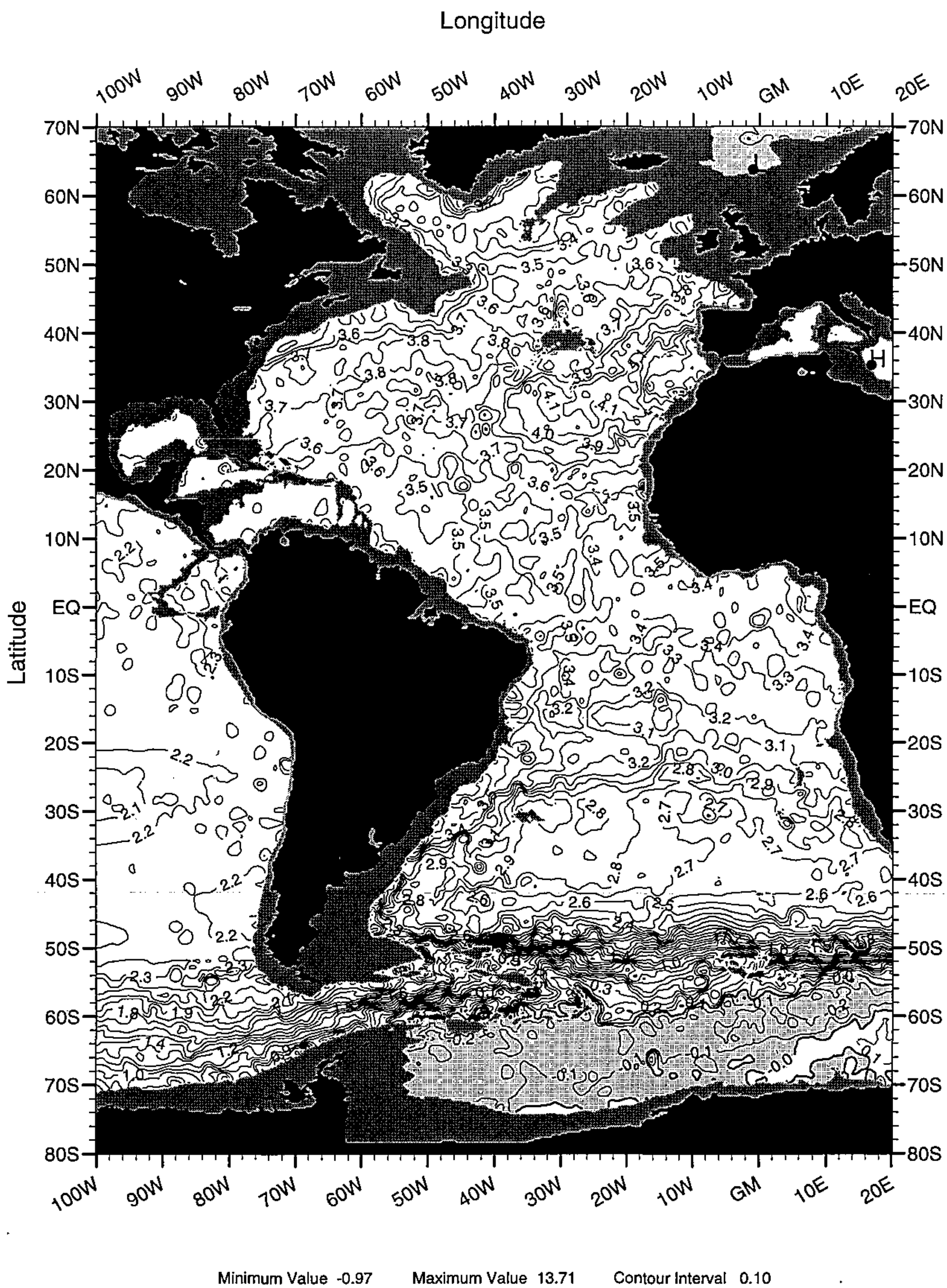
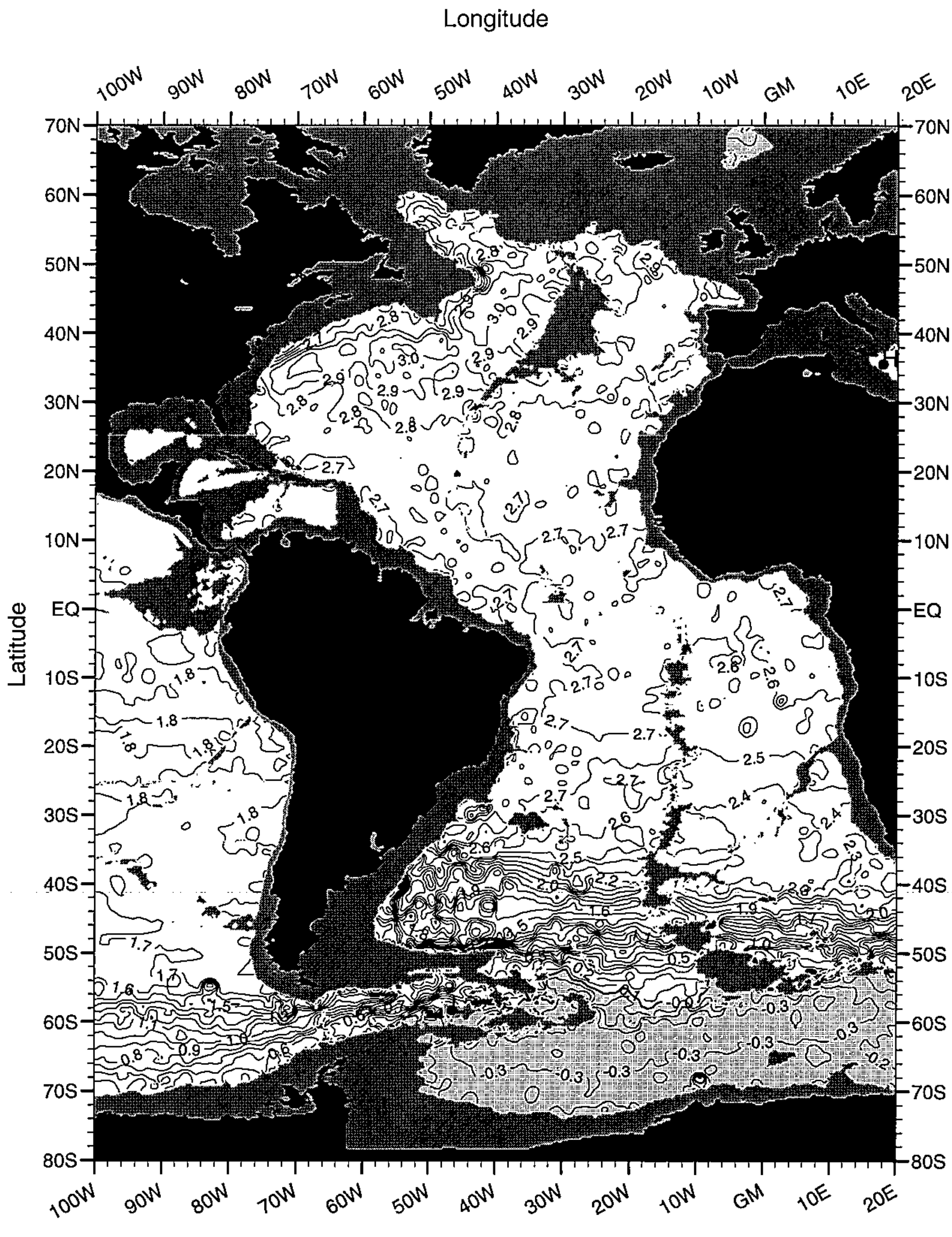
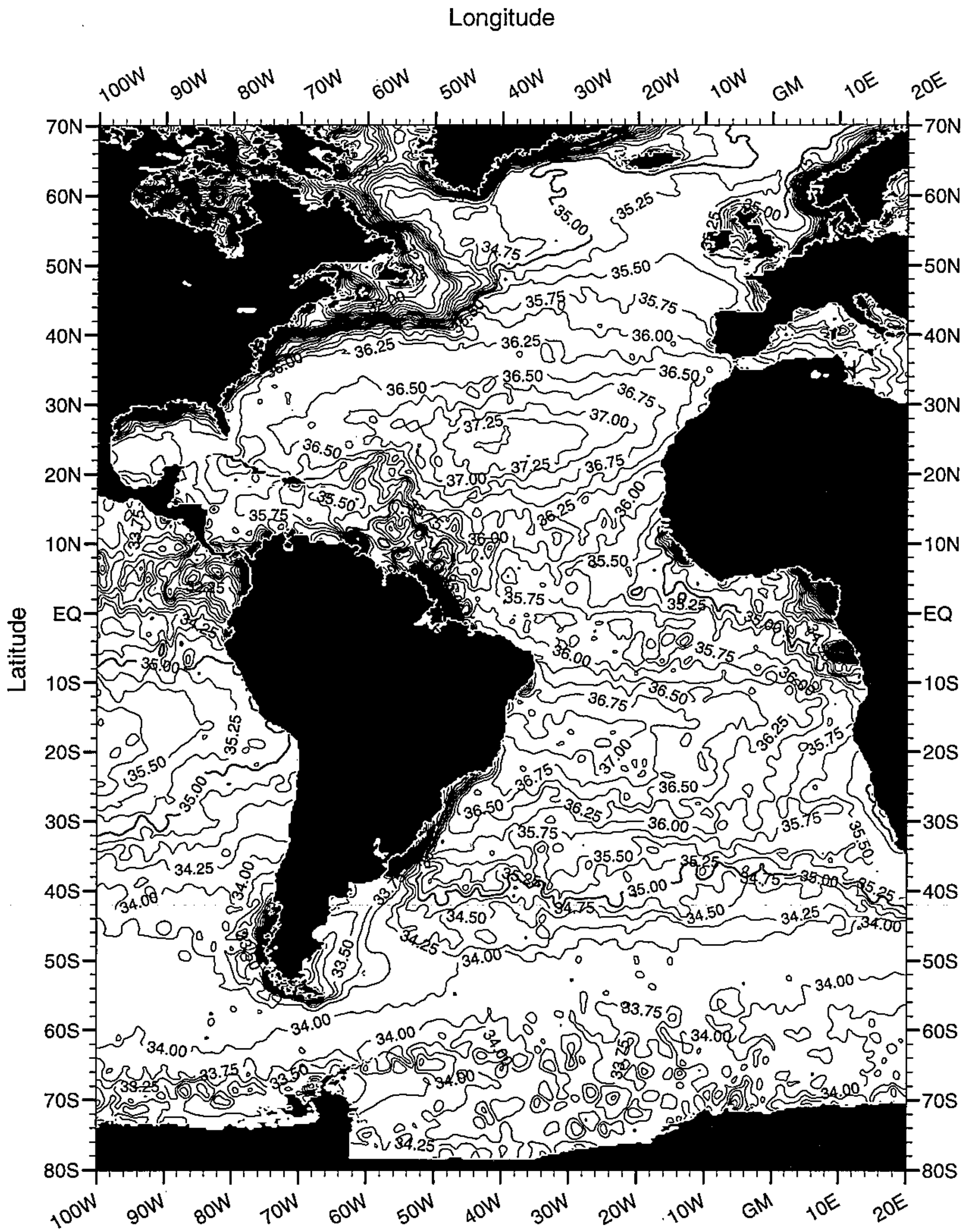


Fig. B5 High resolution temperature in the Atlantic Ocean at 2000 meters depth. Stippling indicates temperature less than 0°C.



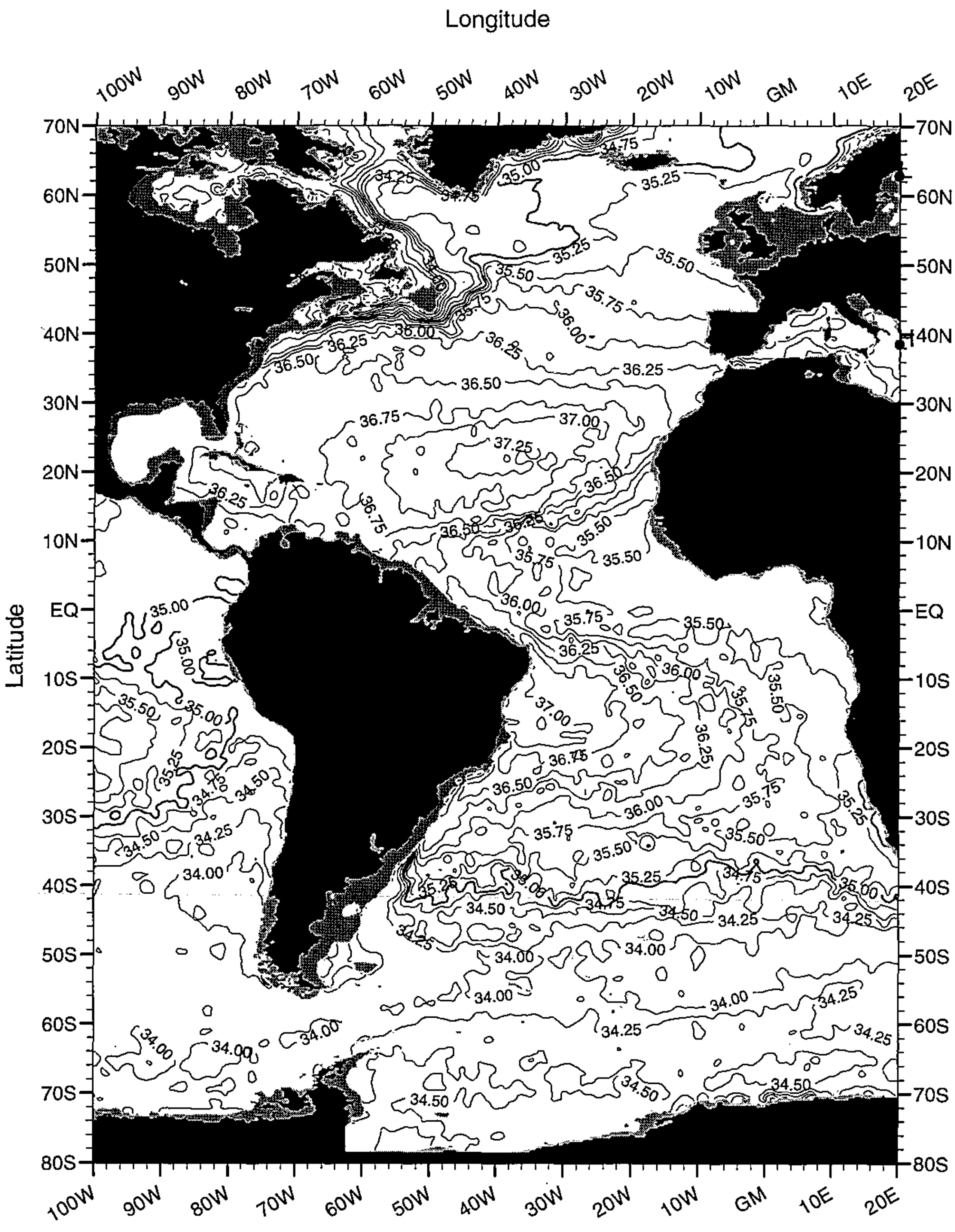
Minimum Value -1.04 Maximum Value 13.81 Contour Interval 0.10

Fig. B6 High resolution temperature in the Atlantic Ocean at 3000 meters depth. Stippling indicates temperature less than 0°C.



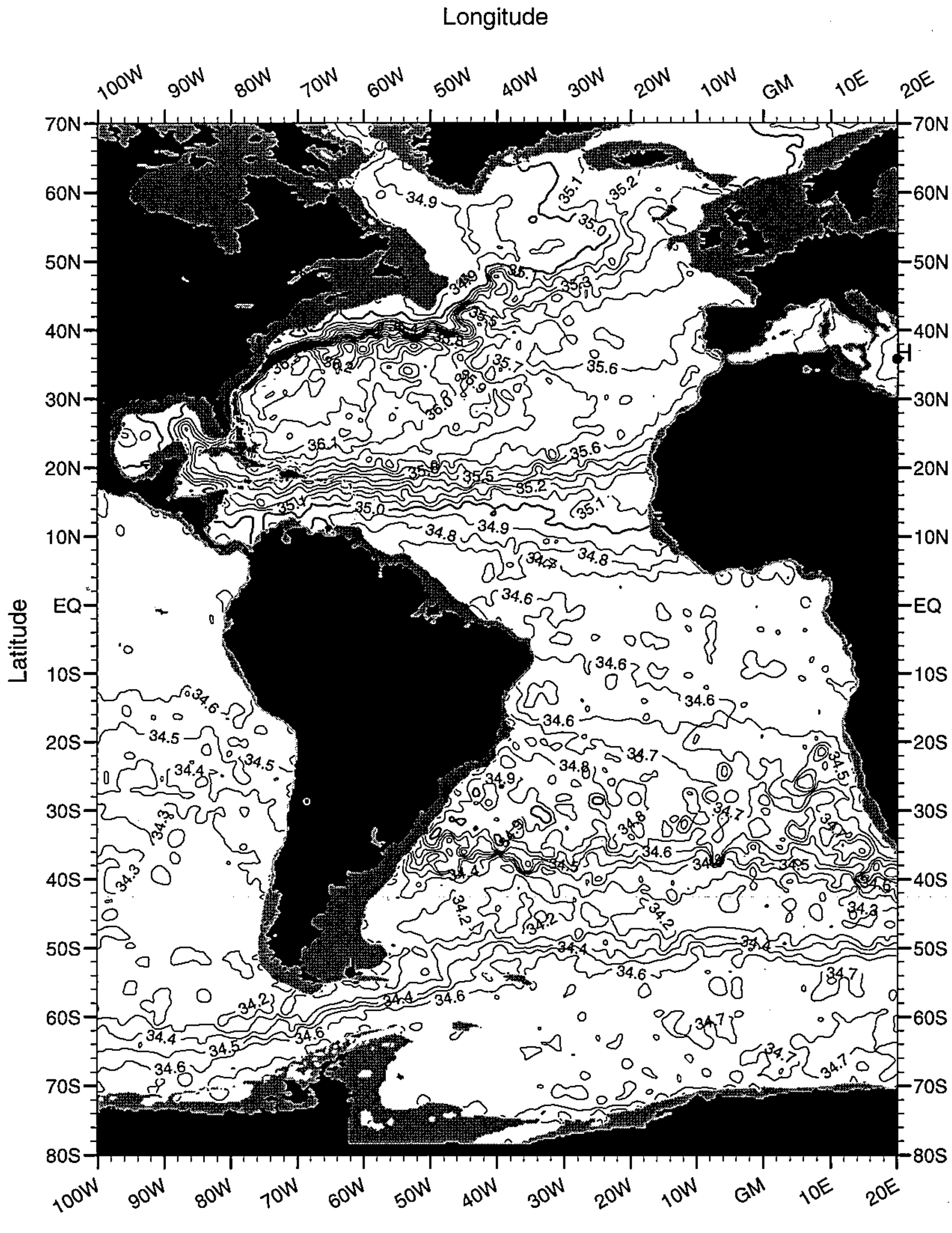
Minimum Value 0.07 Maximum Value 38.89 Contour Interval 0.25

Fig. C1 High resolution salinity in the Atlantic Ocean at the sea surface.



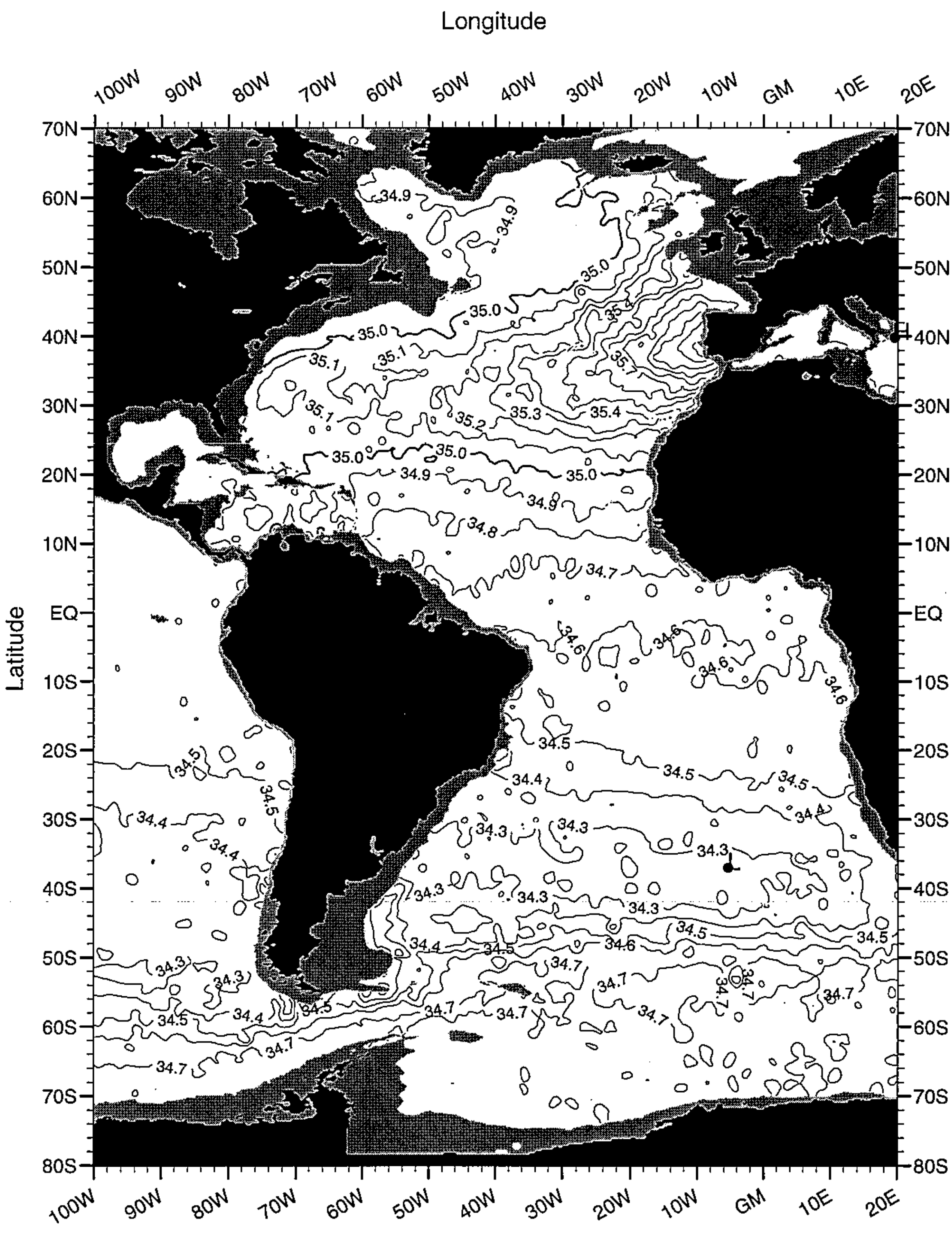
Minimum Value 6.36 Maximum Value 38.74 Contour Interval 0.25

Fig. C2 High resolution salinity in the Atlantic Ocean at 100 meters depth.



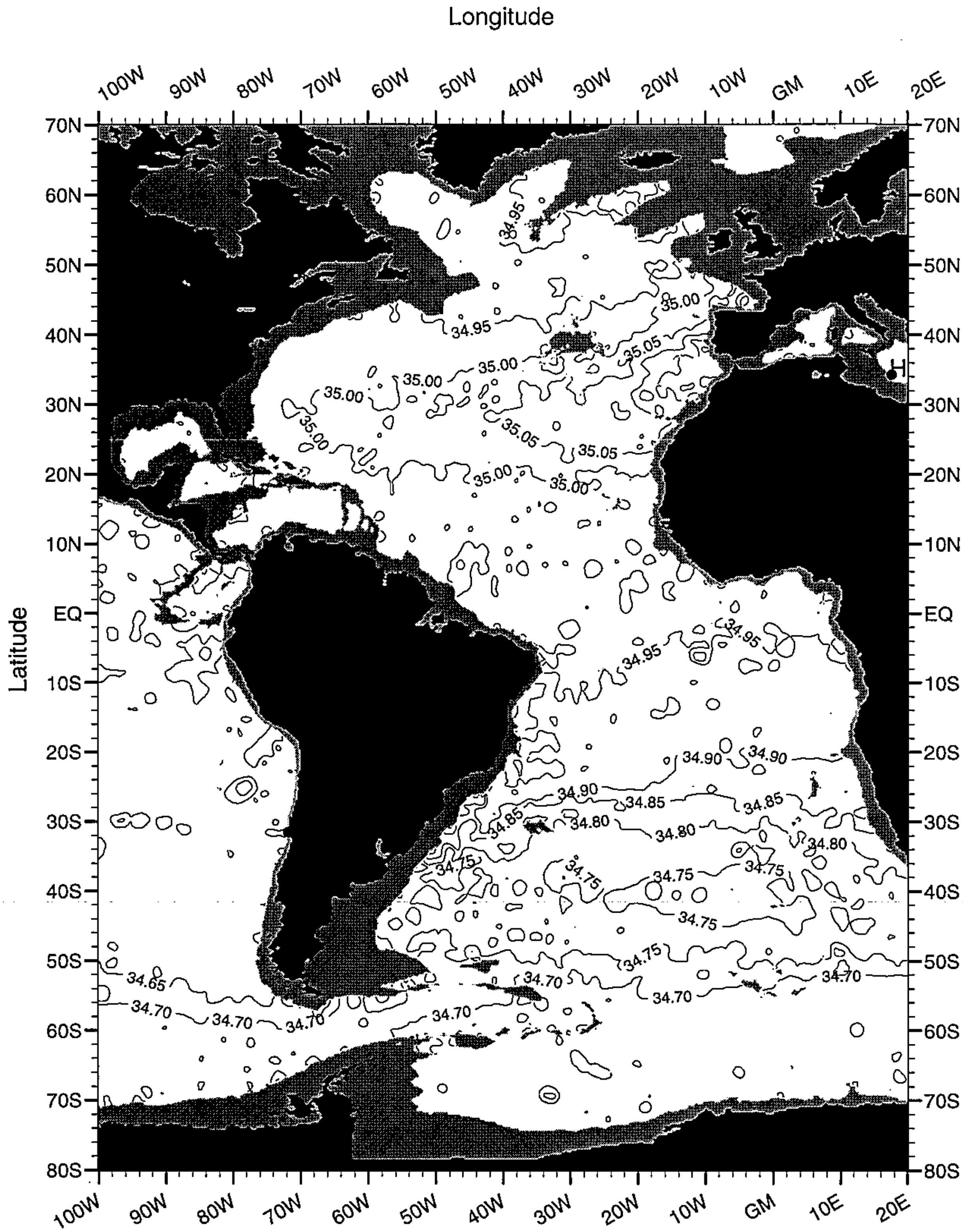
Minimum Value 33.86 Maximum Value 38.87 Contour Interval 0.10

Fig. C3 High resolution salinity in the Atlantic Ocean at 500 meters depth.



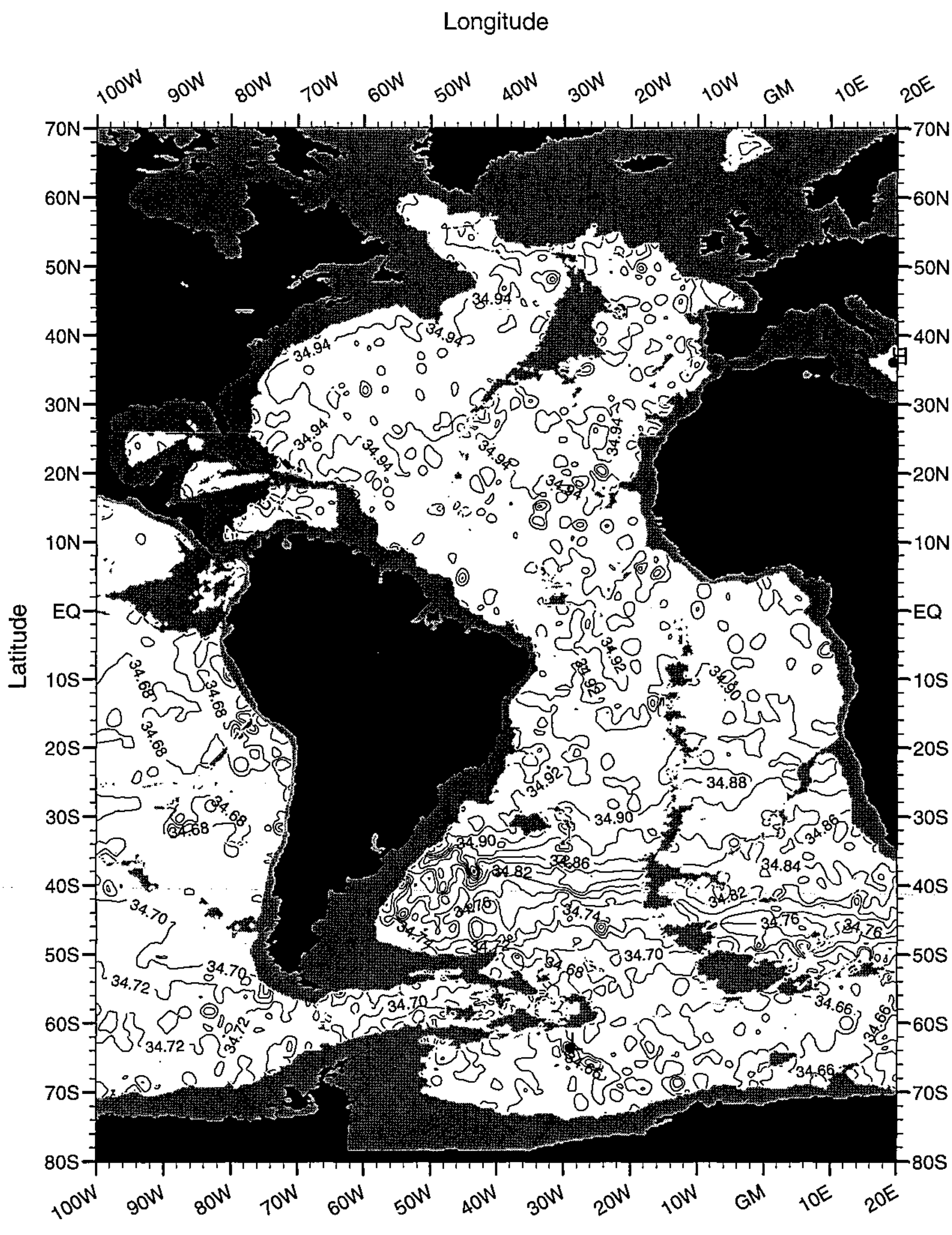
Minimum Value 34.20 Maximum Value 38.84 Contour Interval 0.10

Fig. C4 High resolution salinity in the Atlantic Ocean at 1000 meters depth.



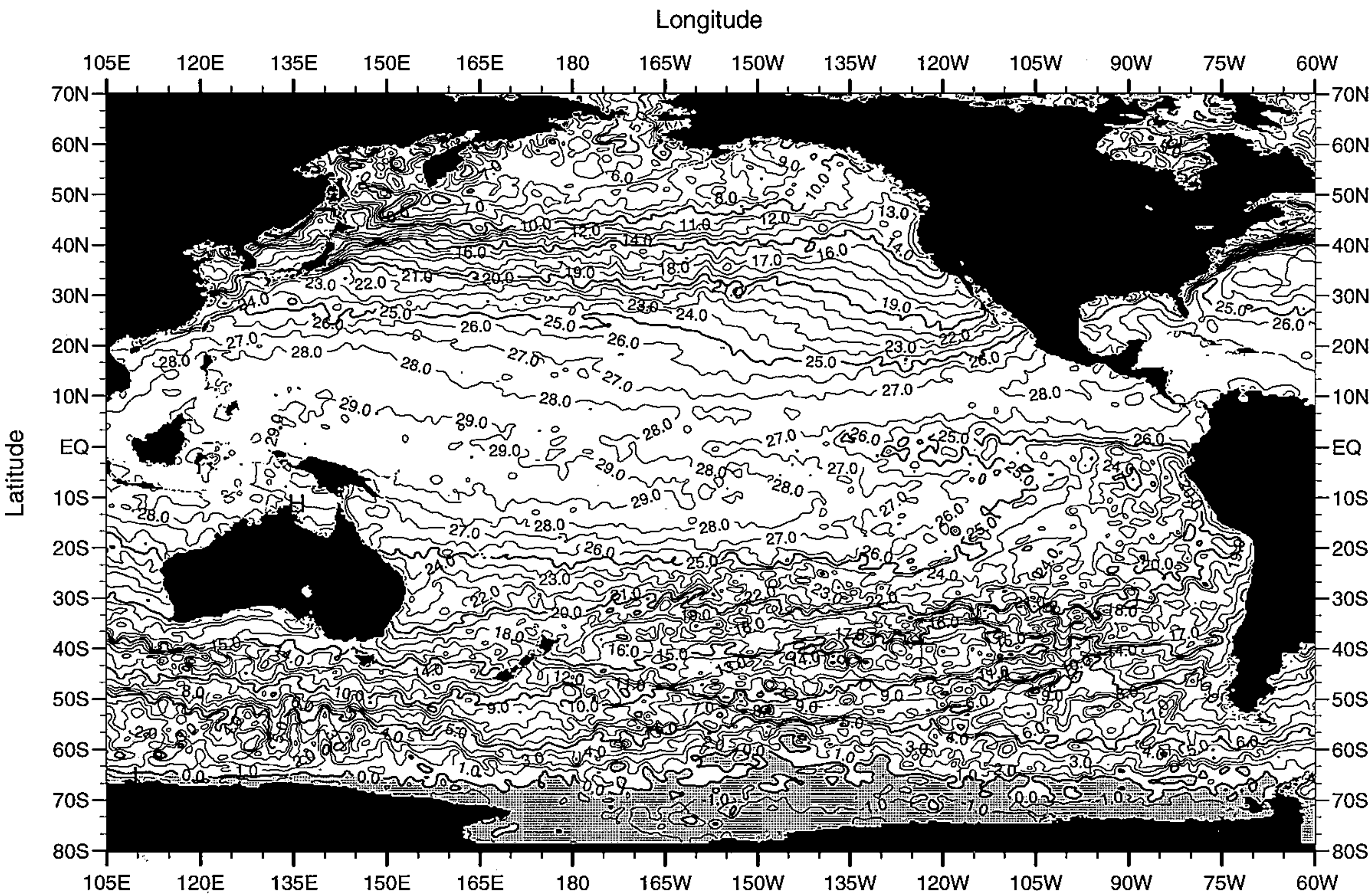
Minimum Value 34.55 Maximum Value 38.71 Contour Interval 0.05

Fig. C5 High resolution salinity in the Atlantic Ocean at 2000 meters depth.



Minimum Value 34.60 Maximum Value 38.68 Contour Interval 0.02

Fig. C6 High resolution salinity in the Atlantic Ocean at 3000 meters depth.



Minimum Value -2.65   Maximum Value 30.41   Contour Interval 1.00

Fig. D1 High resolution temperature in the Pacific Ocean at the sea surface. Stippling indicates temperature less than 0°C.

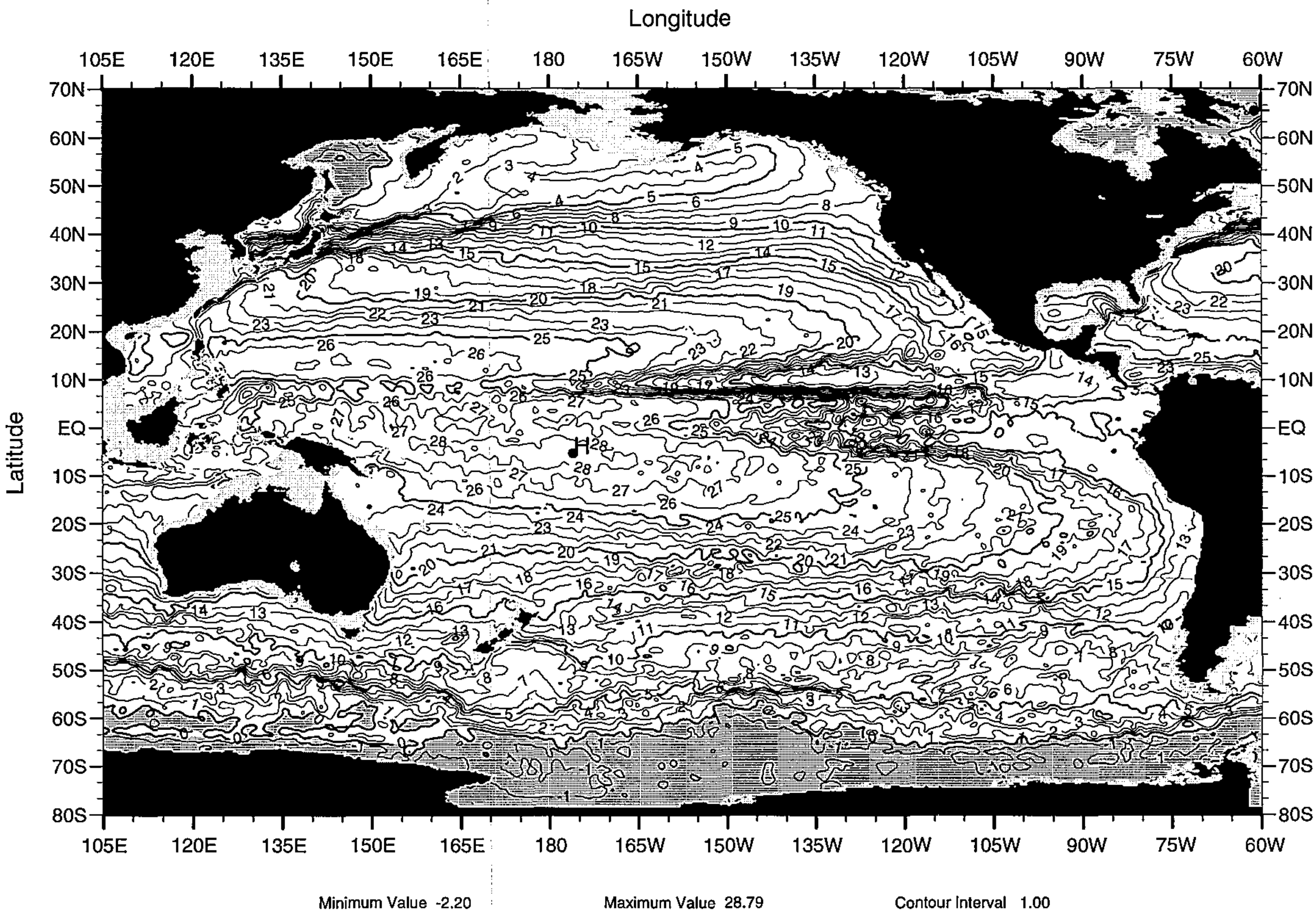
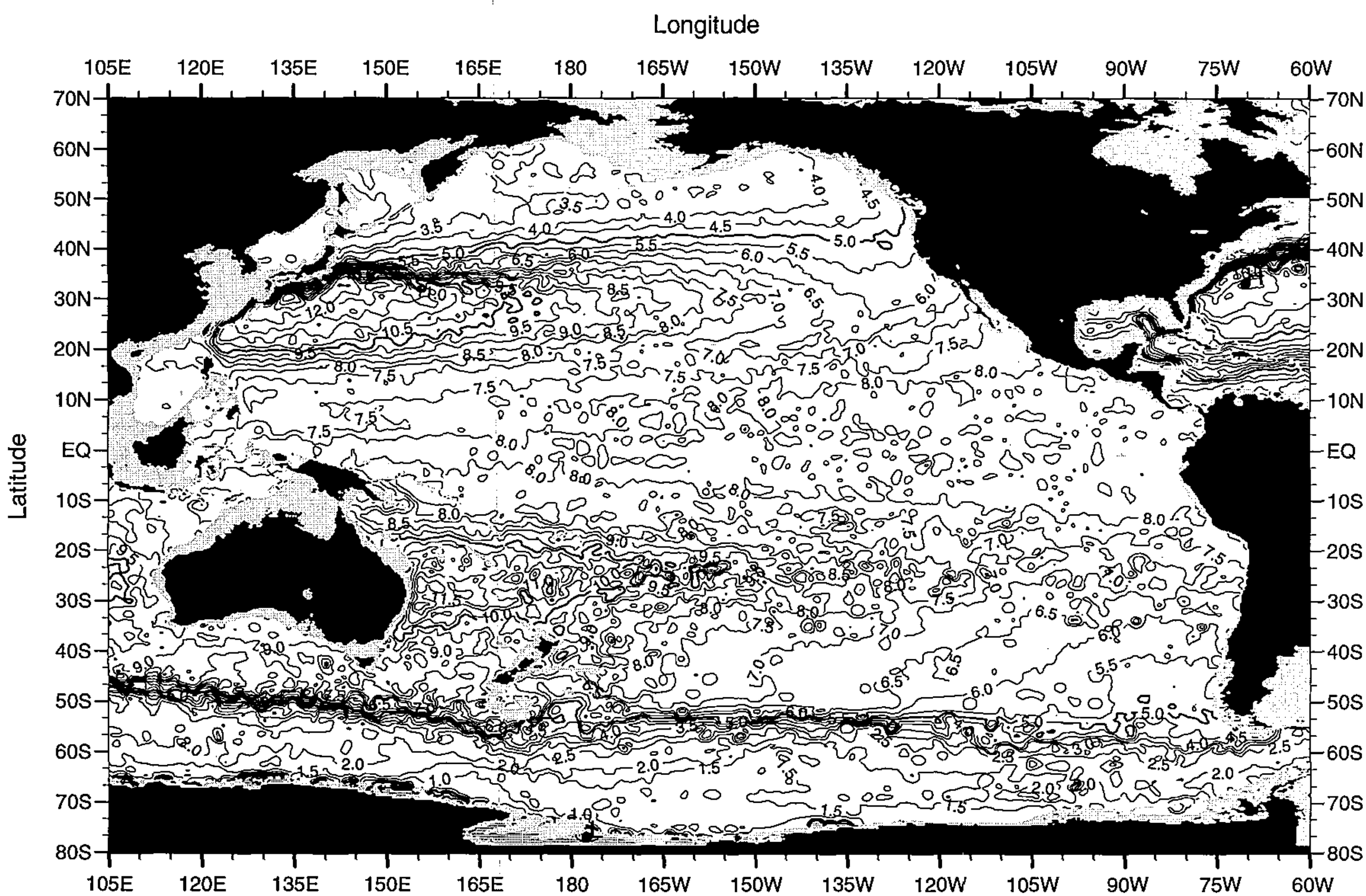
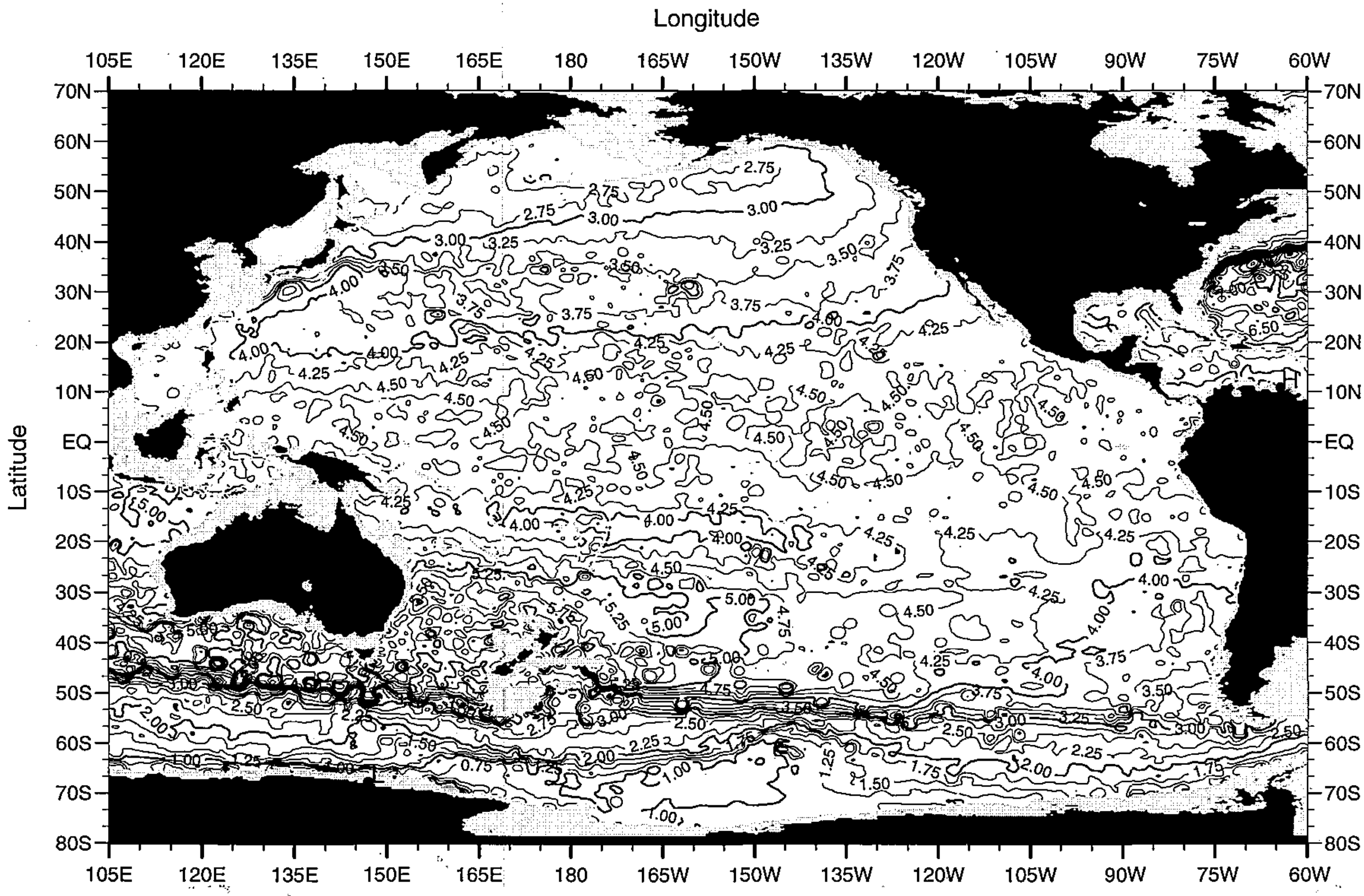


Fig. D2 High resolution temperature in the Pacific Ocean at 100 meters depth. Stippling indicates temperature less than 0°C.



Minimum Value -2.65 Maximum Value 17.19 Contour Interval 0.50

Fig. D3 High resolution temperature in the Pacific Ocean at 500 meters depth. Stippling indicates temperature less than 0°C.



Minimum Value -1.89 Maximum Value 16.98 Contour Interval 0.25

Fig. D4 High resolution temperature in the Pacific Ocean at 1000 meters depth. Stippling indicates temperature less than 0°C.

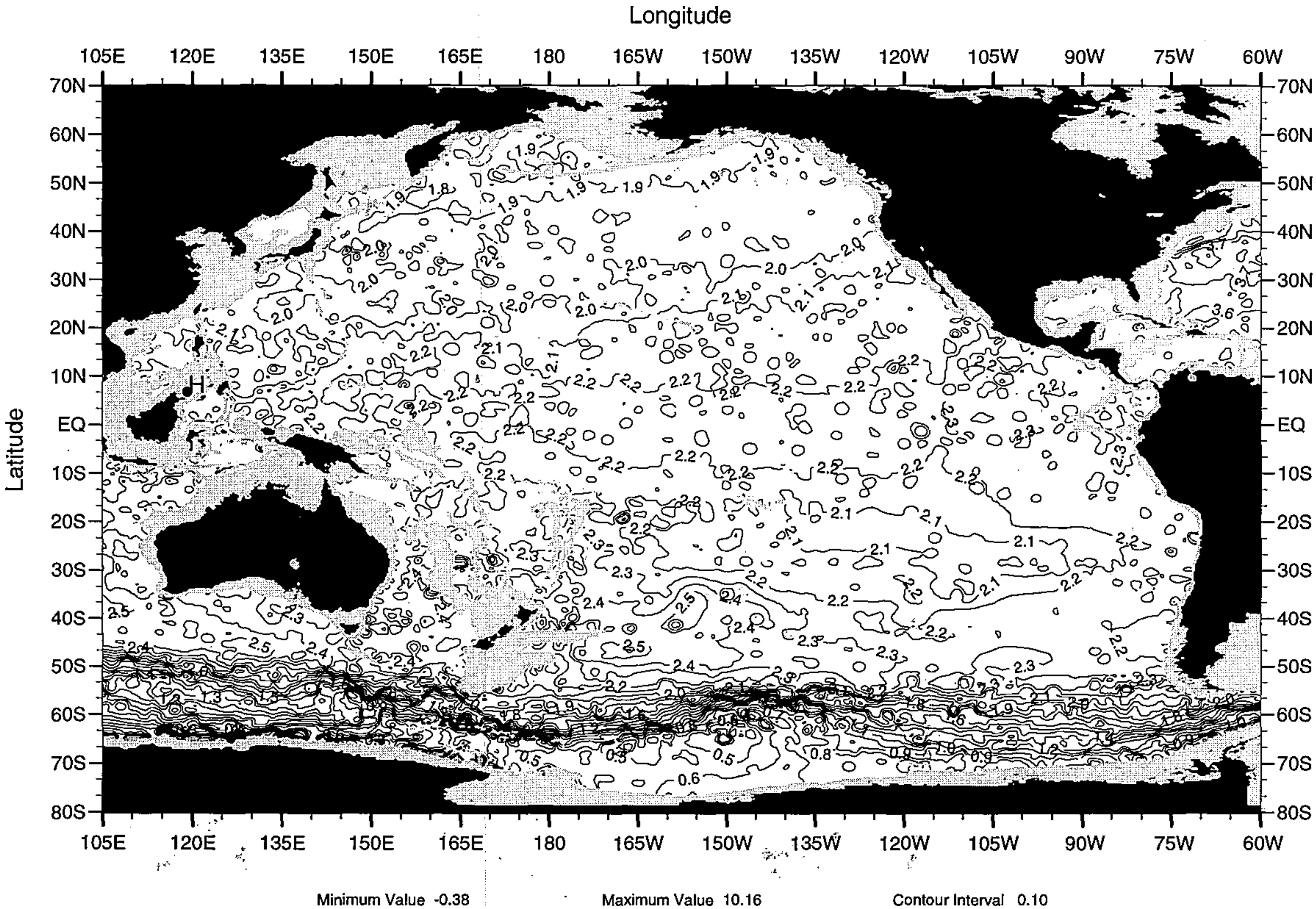
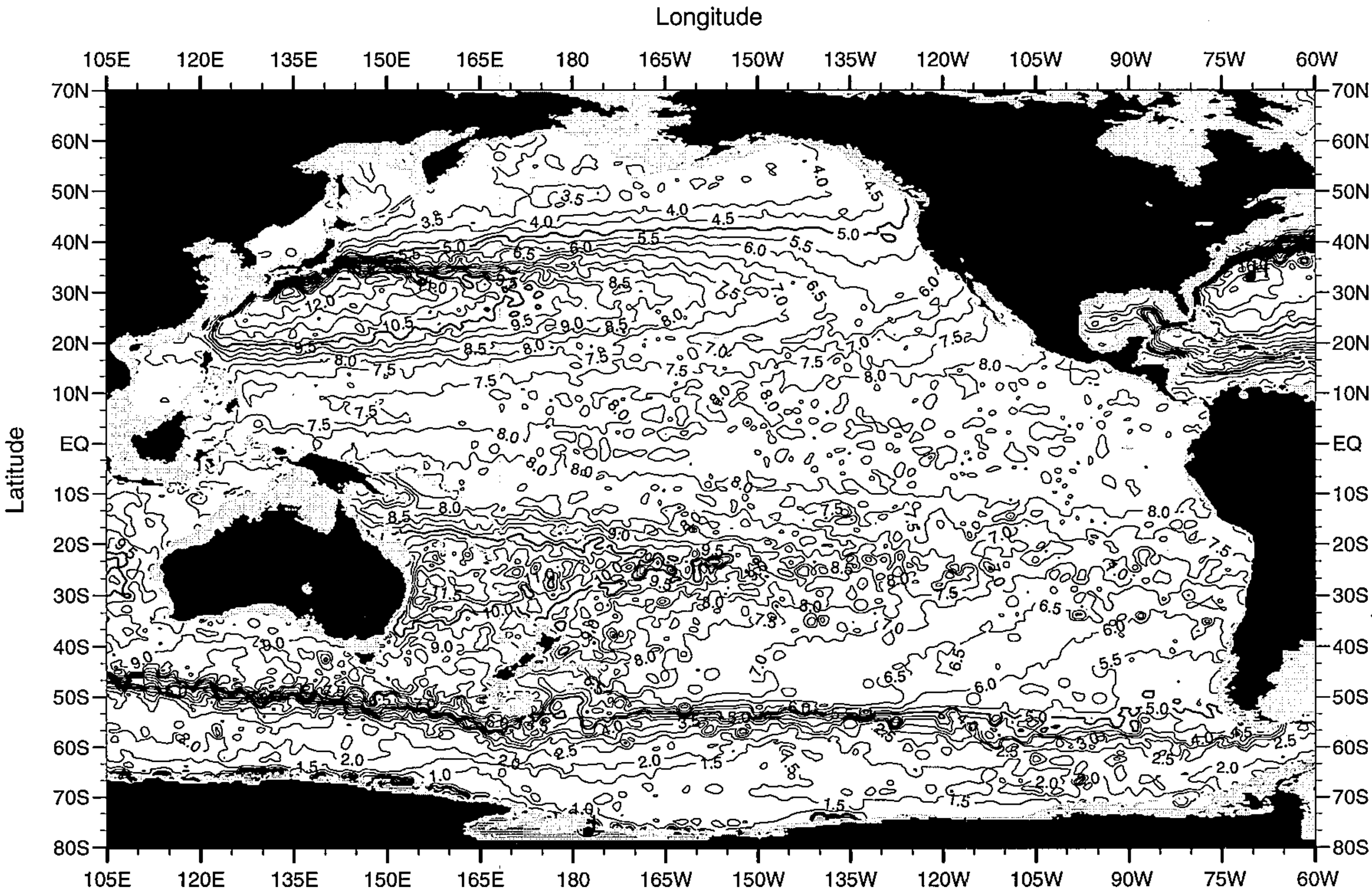
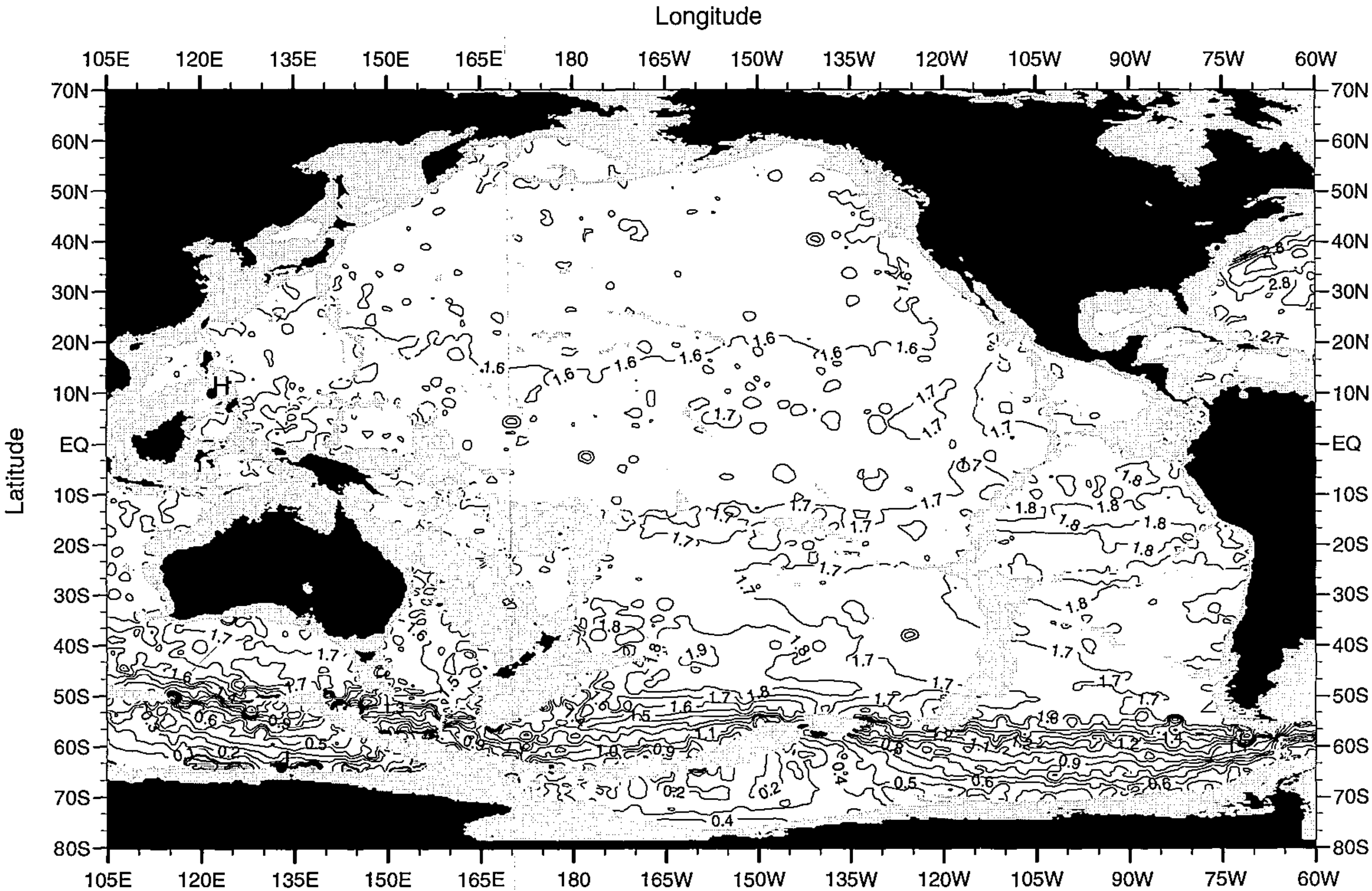


Fig. D5 High resolution temperature in the Pacific Ocean at 2000 meters depth. Stippling indicates temperature less than 0°C.



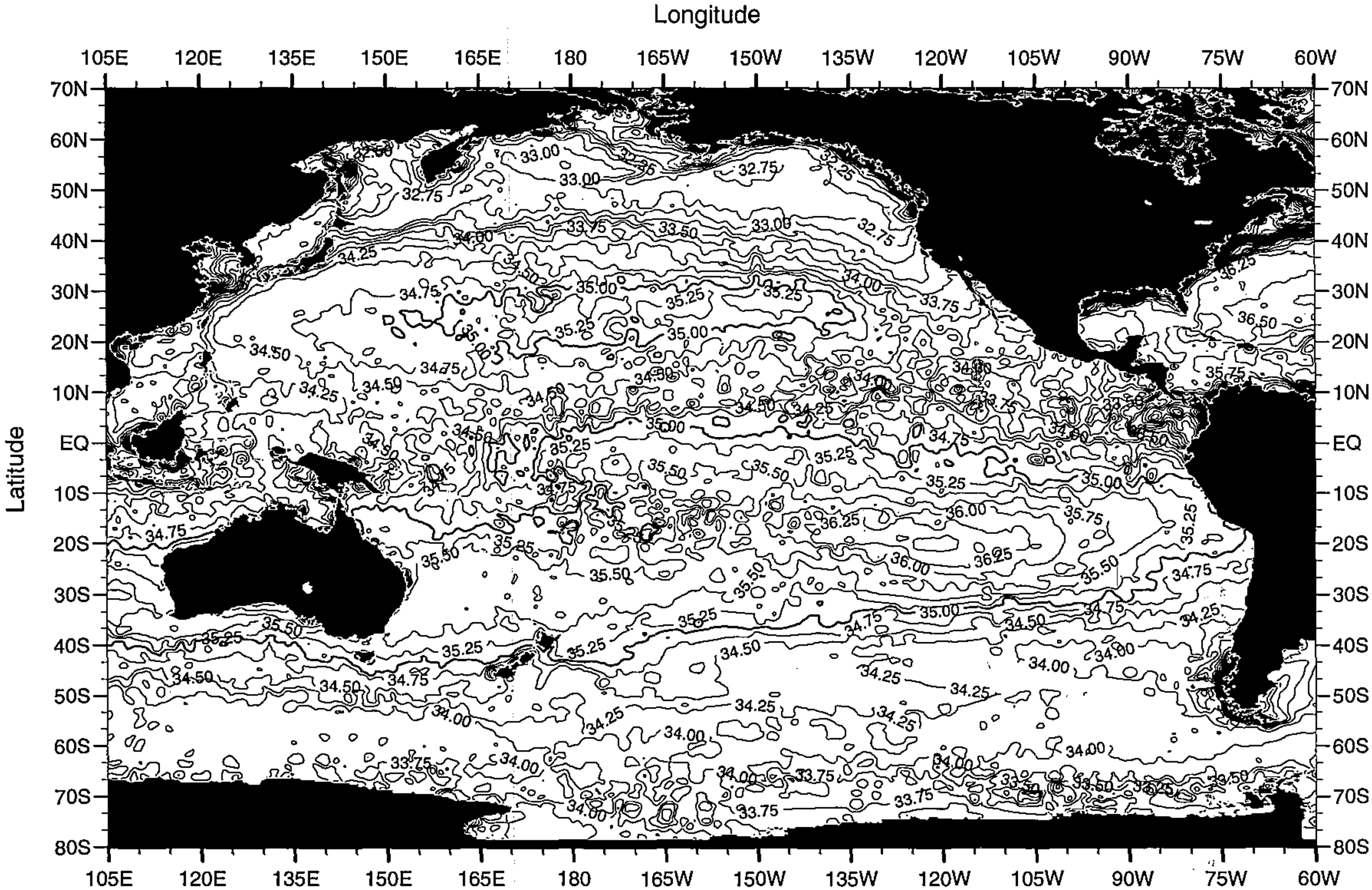
Minimum Value -2.65 Maximum Value 17.19 Contour Interval 0.50

Fig. D3 High resolution temperature in the Pacific Ocean at 500 meters depth. Stippling indicates temperature less than 0°C.



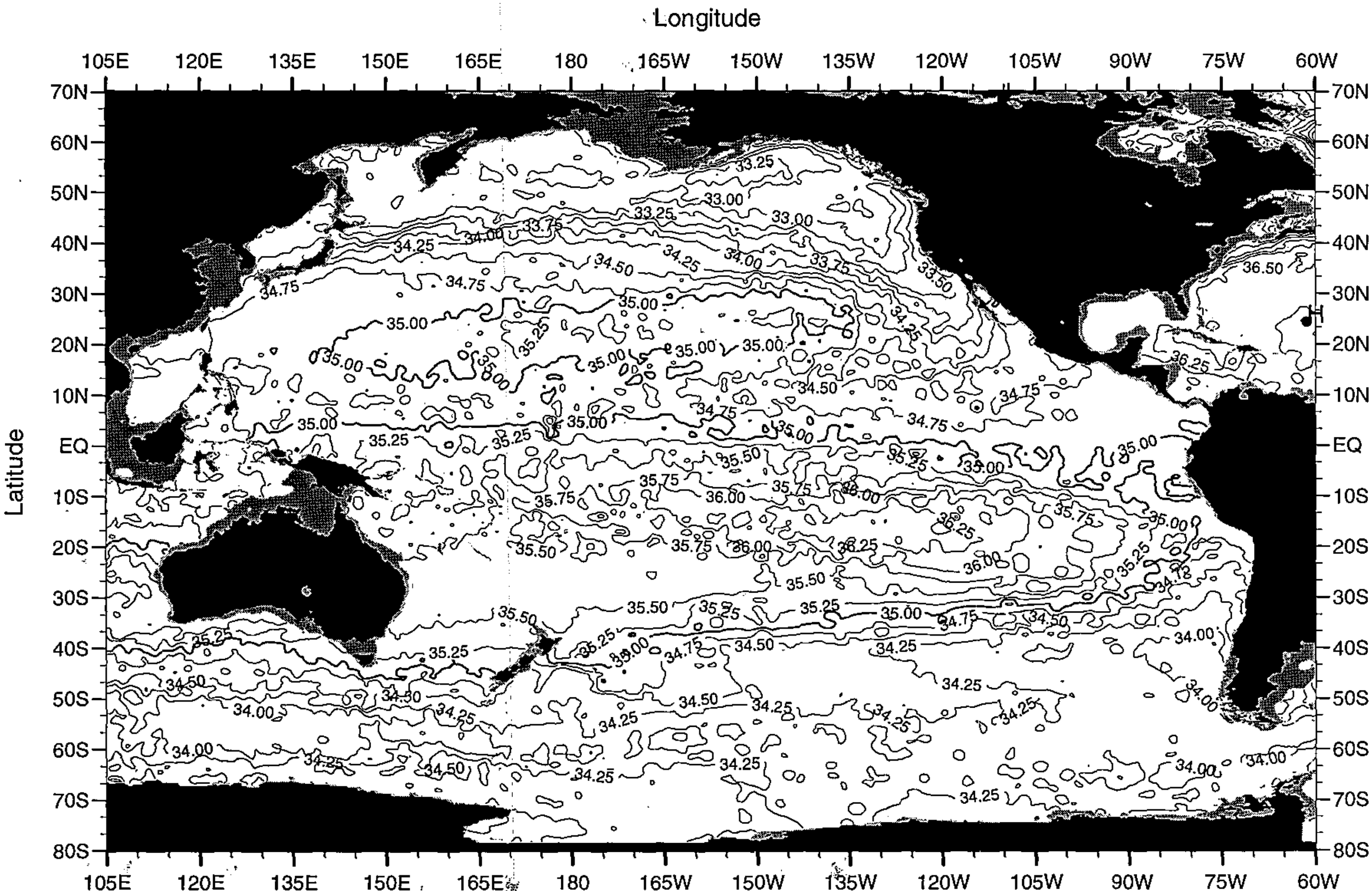
Minimum Value -0.38 Maximum Value 10.30 Contour Interval 0.10

Fig. D6 High resolution temperature in the Pacific Ocean at 3000 meters depth. Stippling indicates temperature less than 0°C.



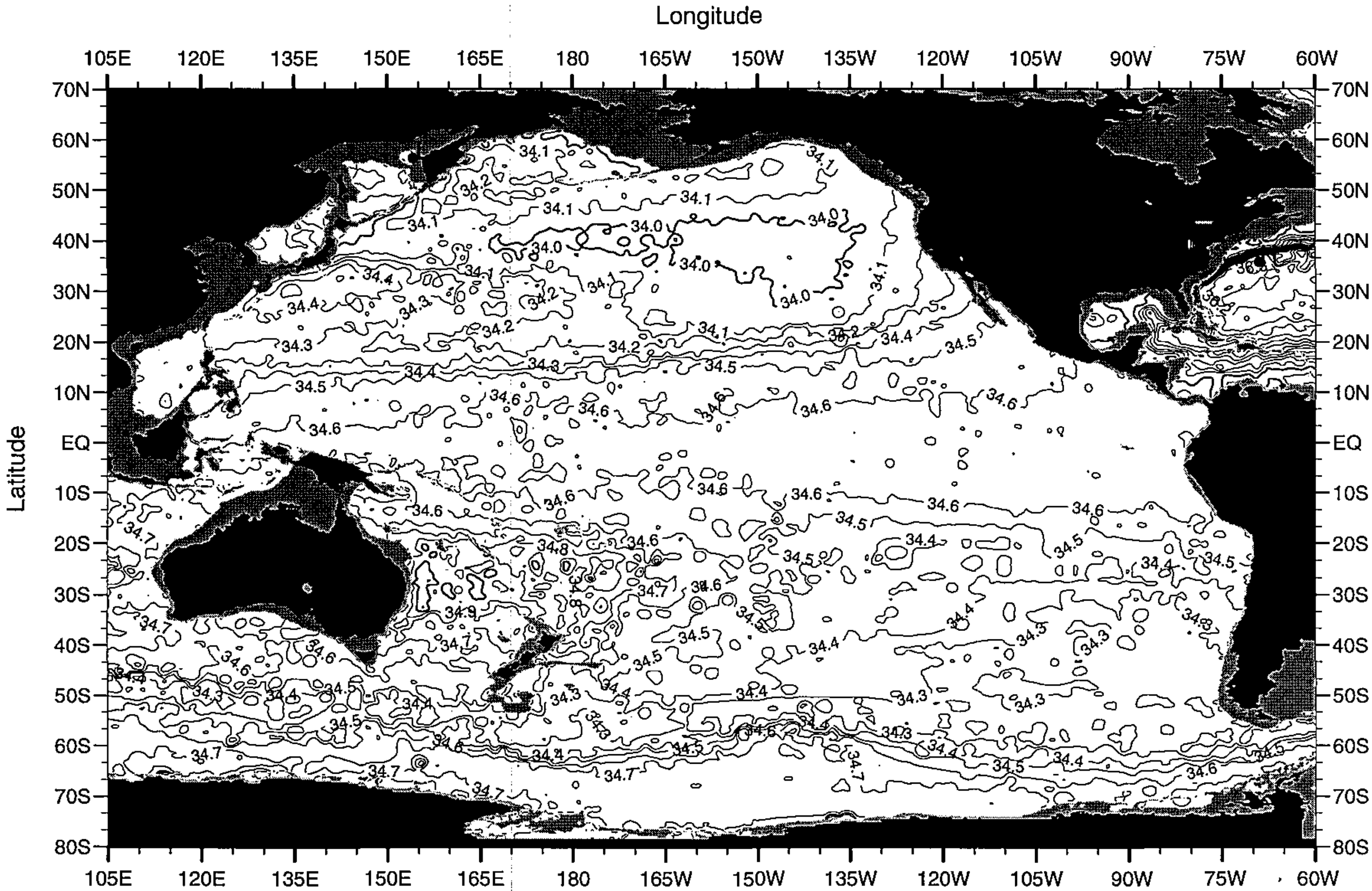
Minimum Value 2.13 Maximum Value 37.55 Contour Interval 0.25

Fig. E1 High resolution salinity in the Pacific Ocean at the sea surface.



Minimum Value 28.57 Maximum Value 37.05 Contour Interval 0.25

Fig. E2 High resolution salinity in the Pacific Ocean at 100 meters depth.



Minimum Value 33.61 Maximum Value 36.44 Contour Interval 0.10

Fig. E3 High resolution salinity in the Pacific Ocean at 500 meters depth.

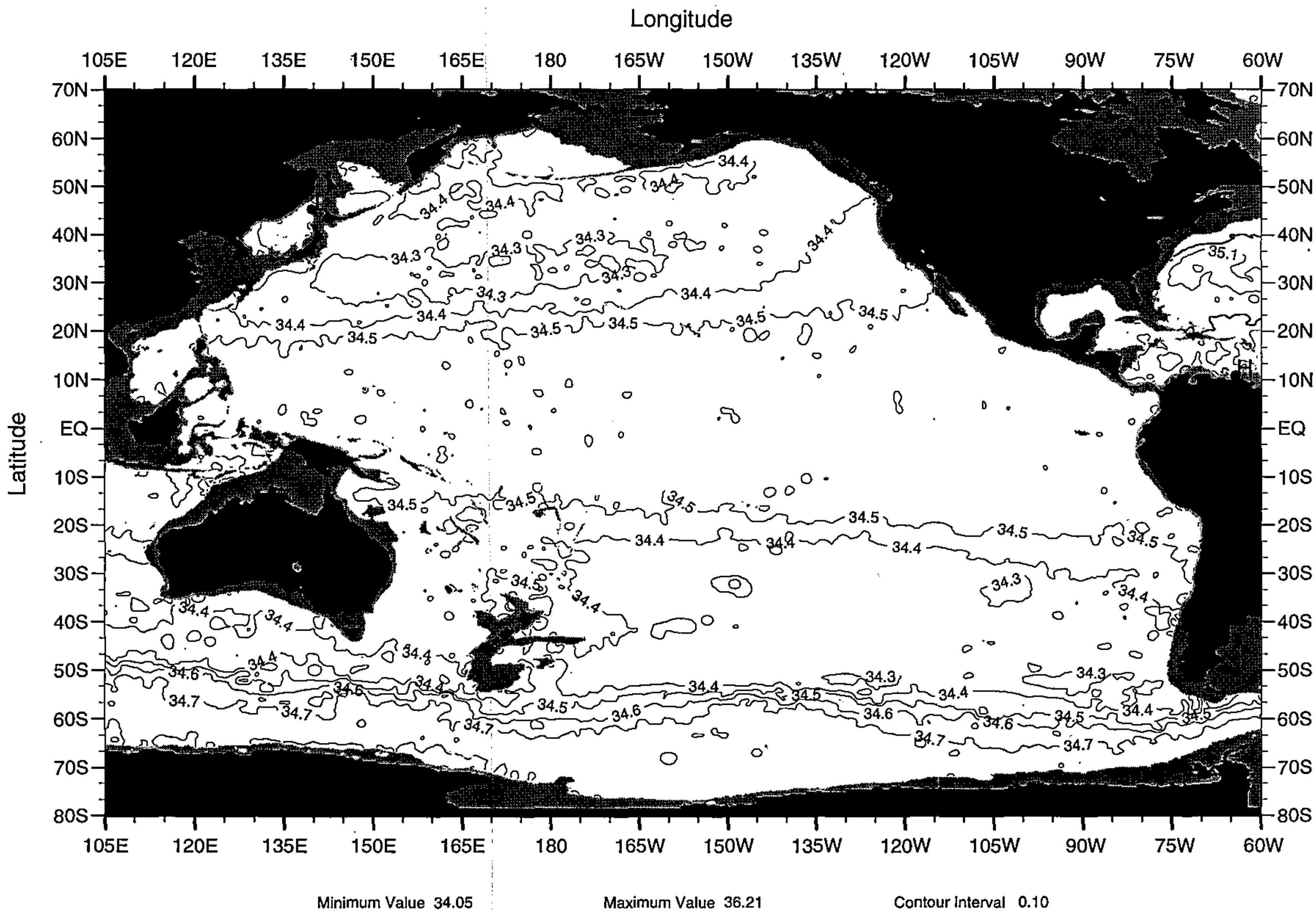


Fig. E4 High resolution salinity in the Pacific Ocean at 1000 meters depth.

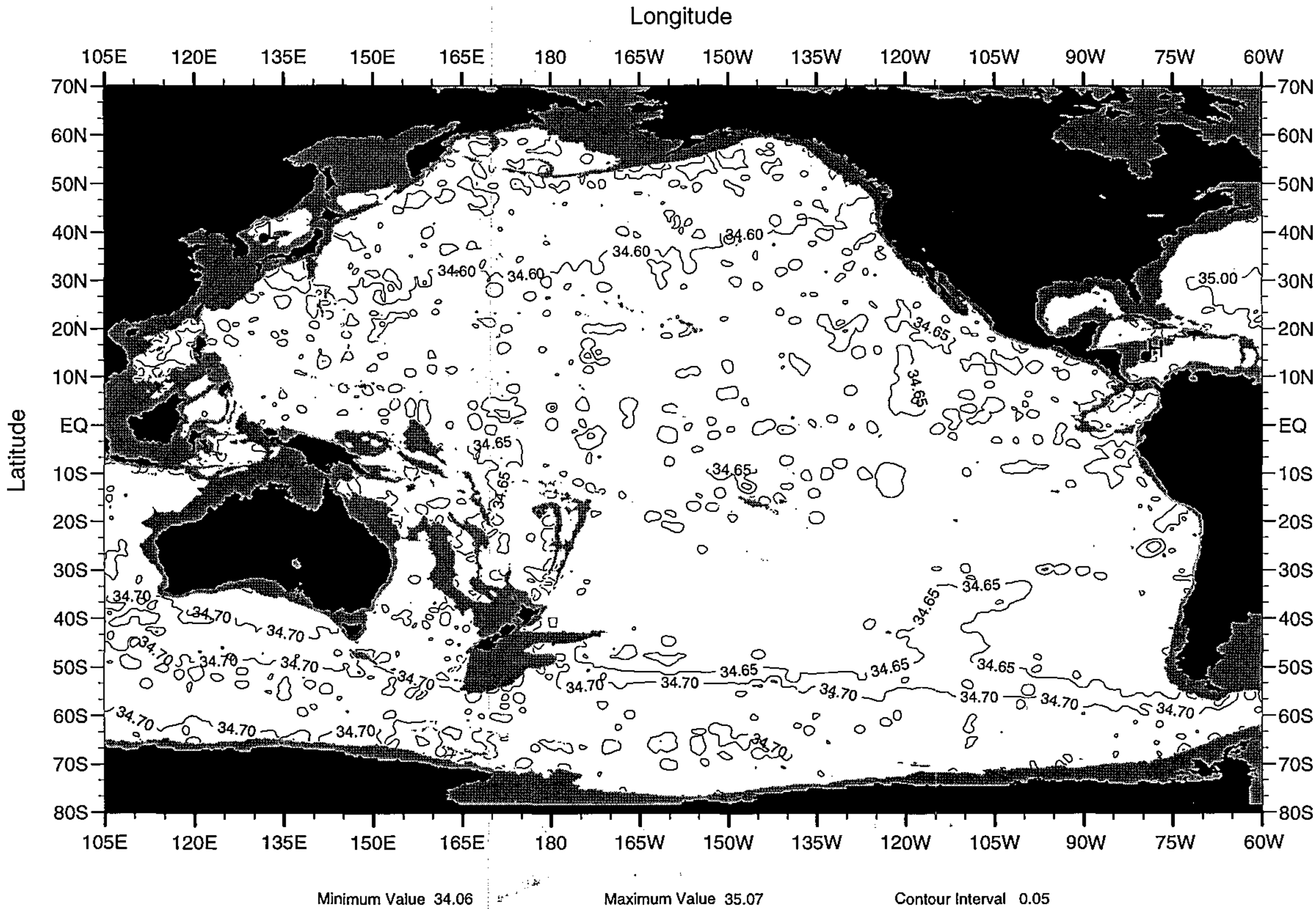
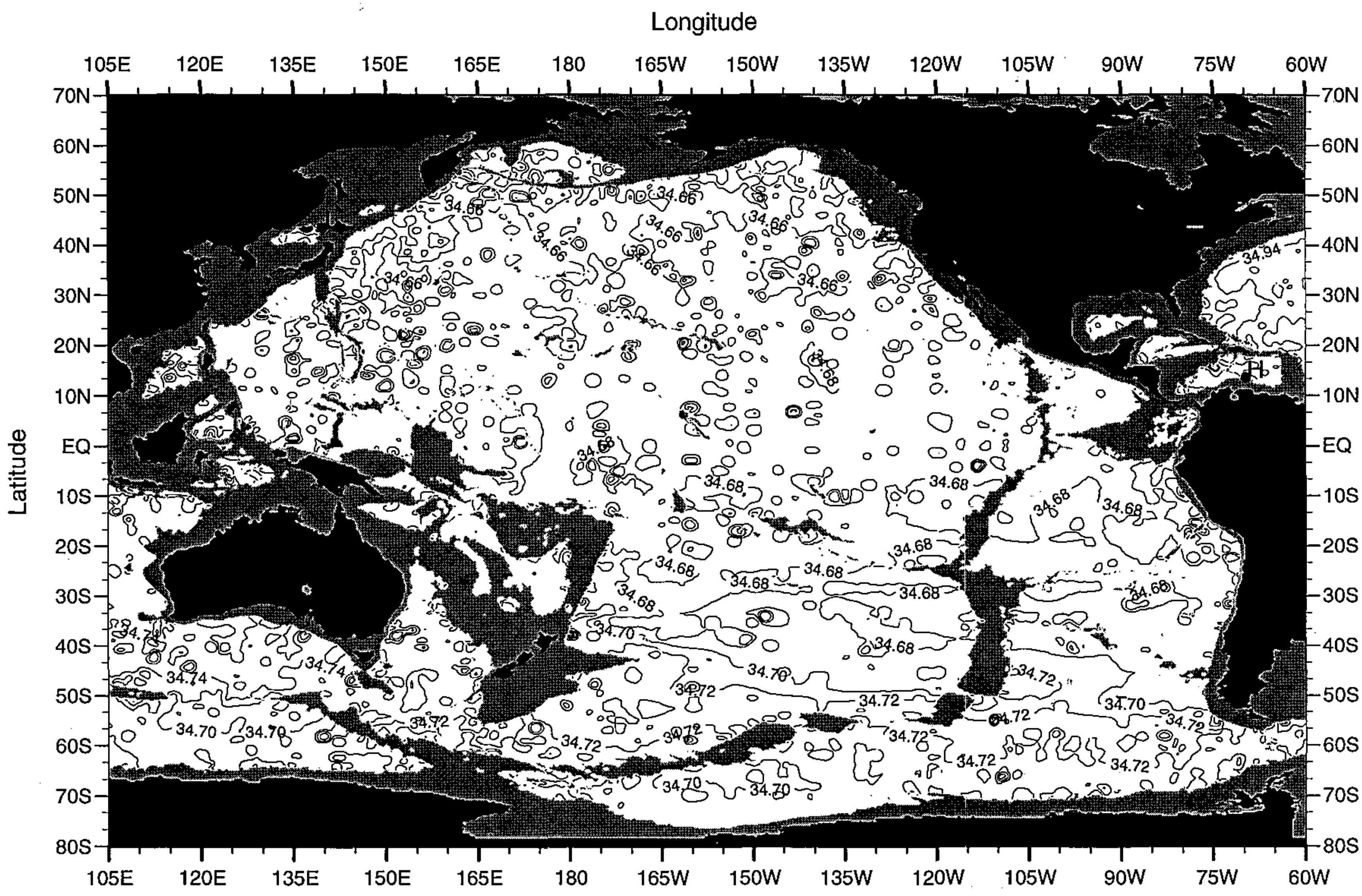
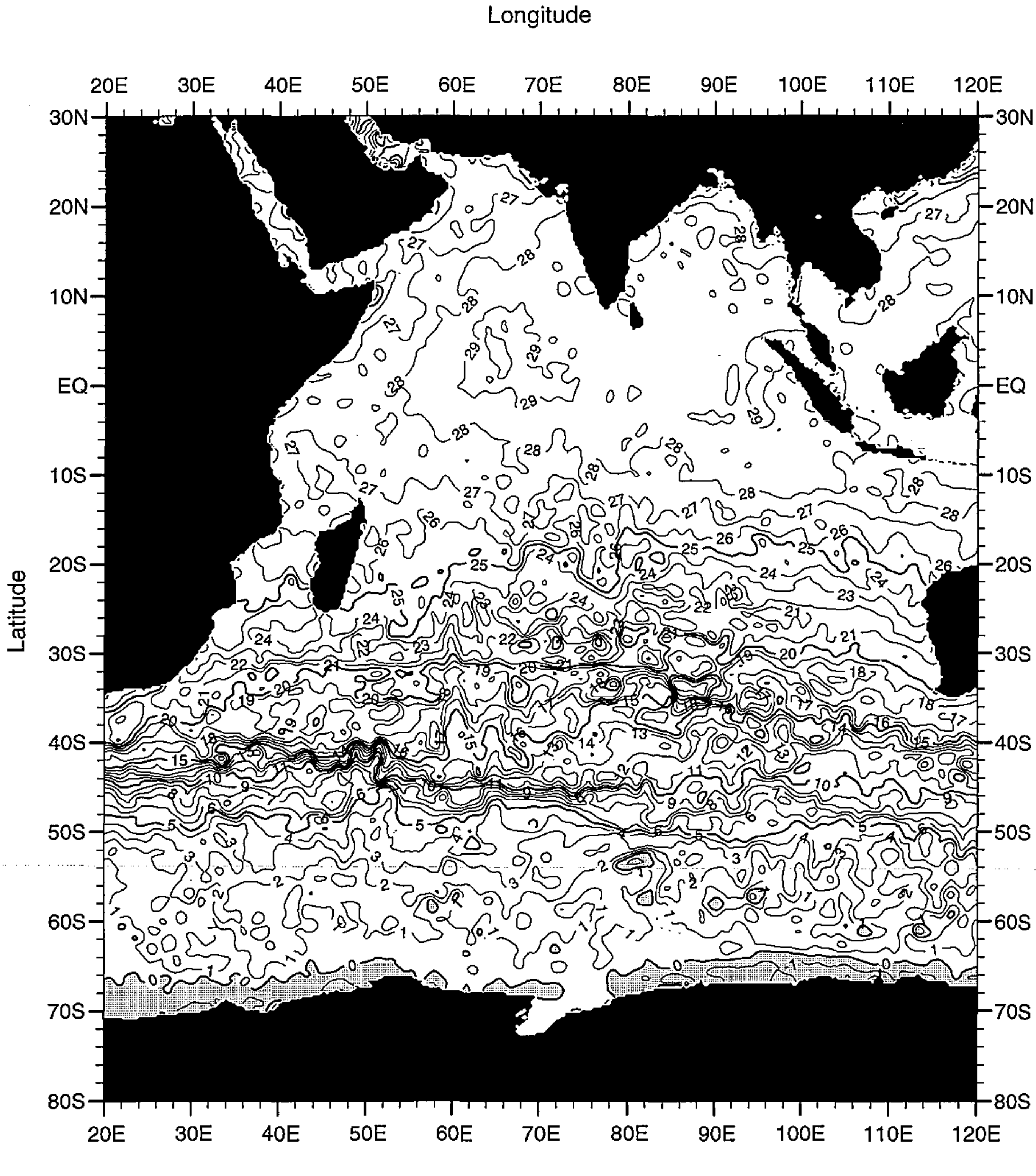


Fig. E5 High resolution salinity in the Pacific Ocean at 2000 meters depth.



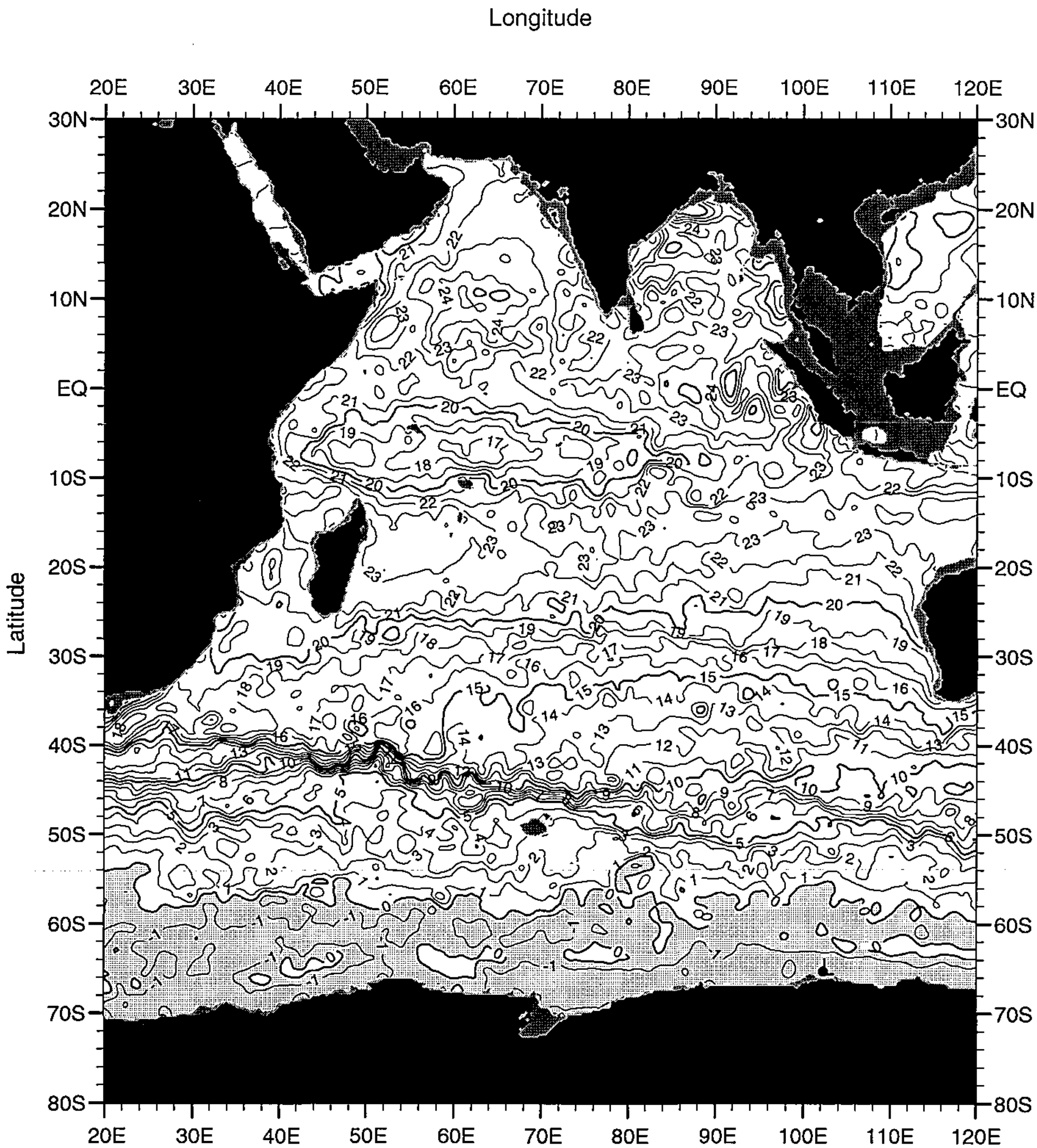
Minimum Value 34.06 Maximum Value 35.02 Contour Interval 0.02

Fig. E6 High resolution salinity in the Pacific Ocean at 3000 meters depth.



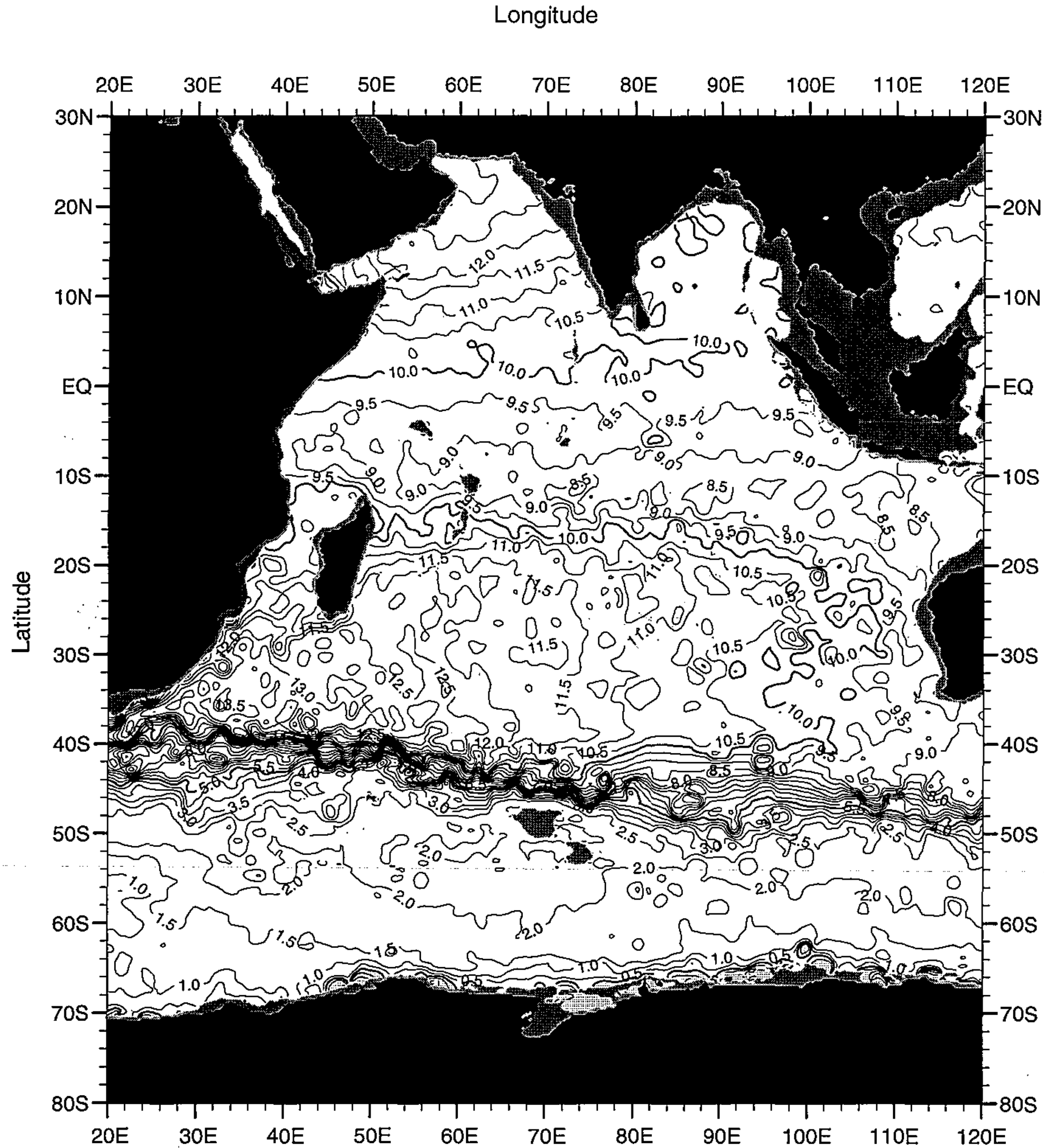
Minimum Value -2.65 Maximum Value 31.14 Contour Interval 1.00

Fig. F1 High resolution temperature in the Indian Ocean at the sea surface. Stippling indicates temperature less than 0°C.



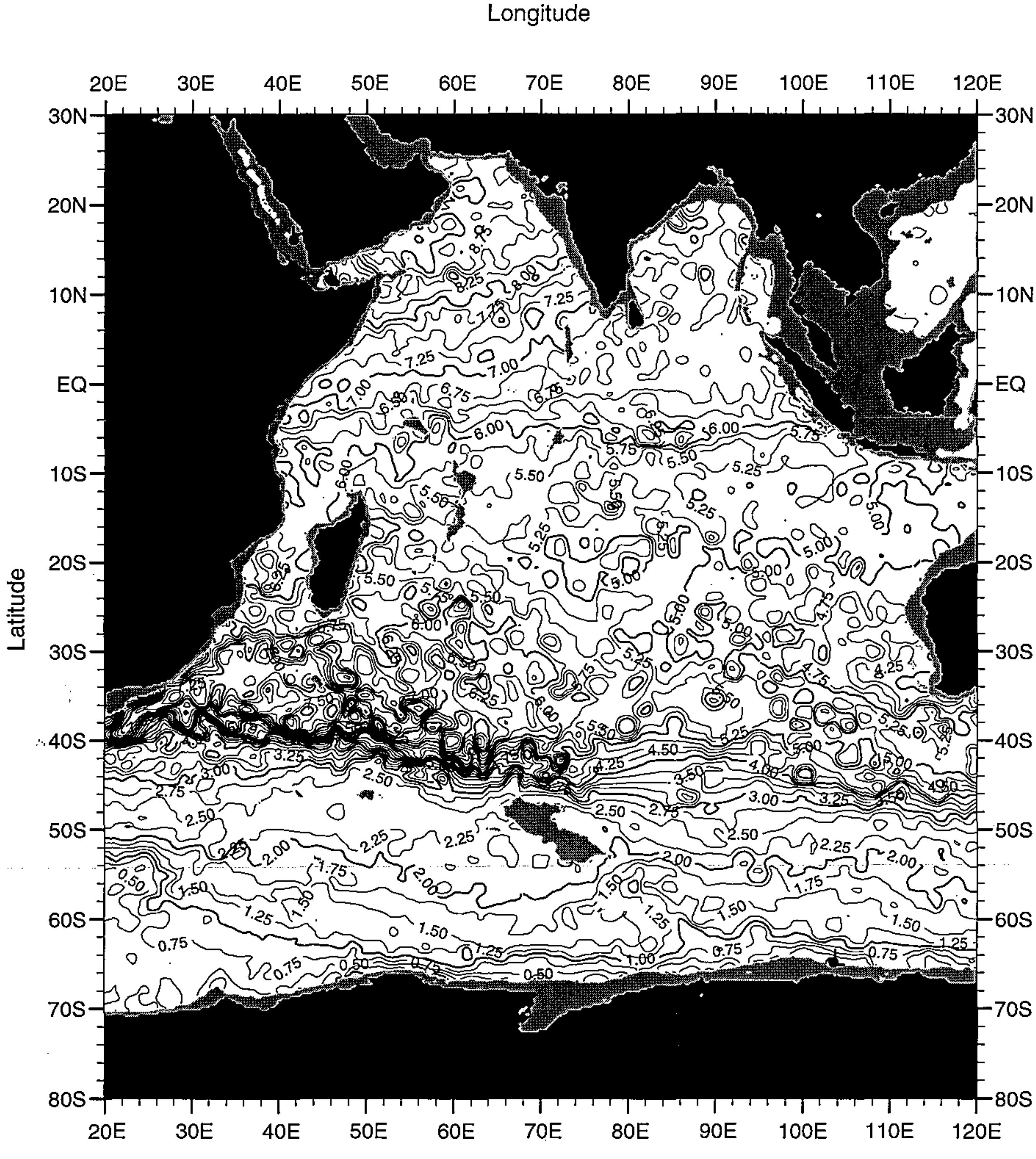
Minimum Value -2.00 Maximum Value 27.62 Contour Interval 1.00

Fig. F2 High resolution temperature in the Indian Ocean at 100 meters depth. Stippling indicates temperature less than 0°C.



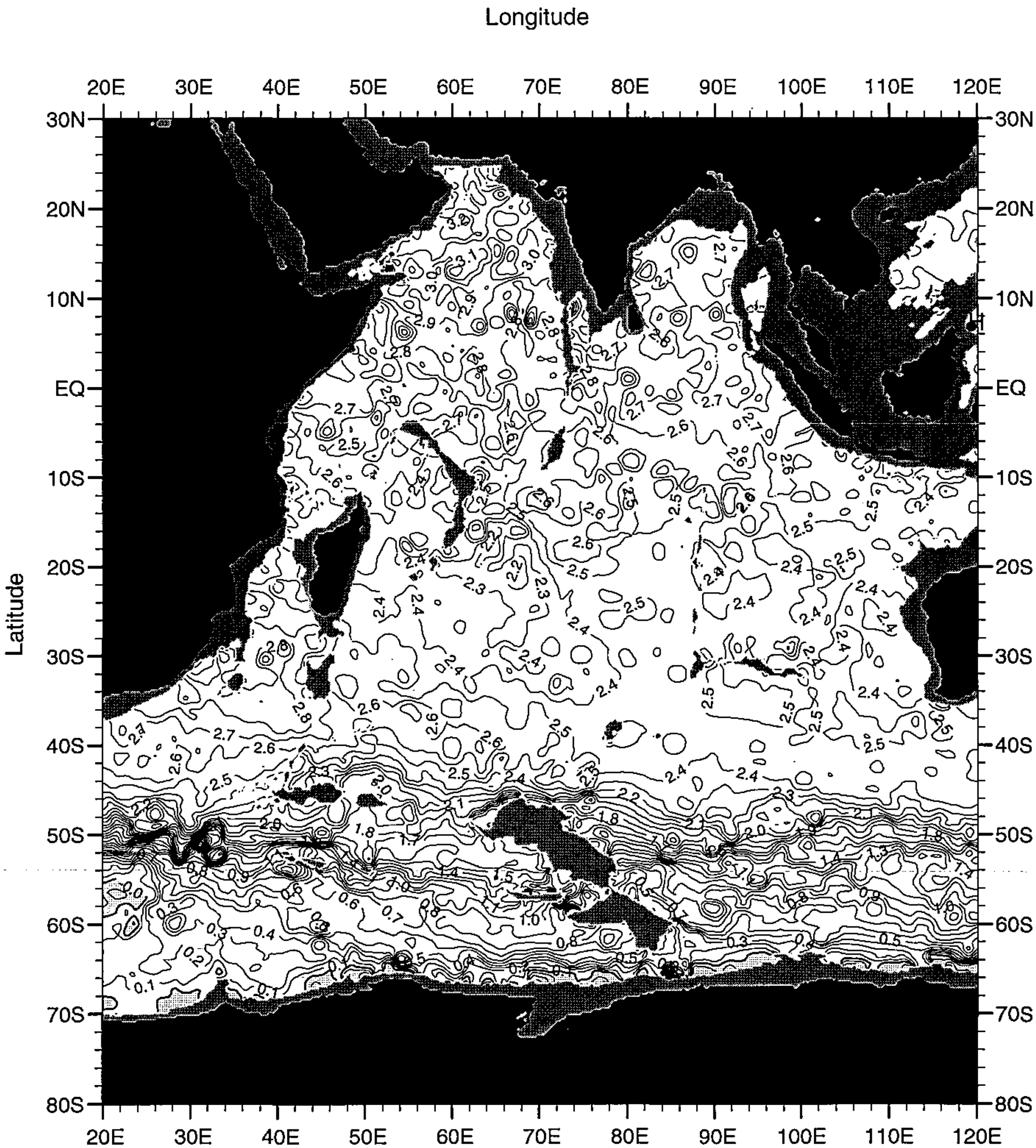
Minimum Value -2.65 Maximum Value 22.28 Contour Interval 0.50

Fig. F3 High resolution temperature in the Indian Ocean at 500 meters depth. Stippling indicates temperature less than 0°C.



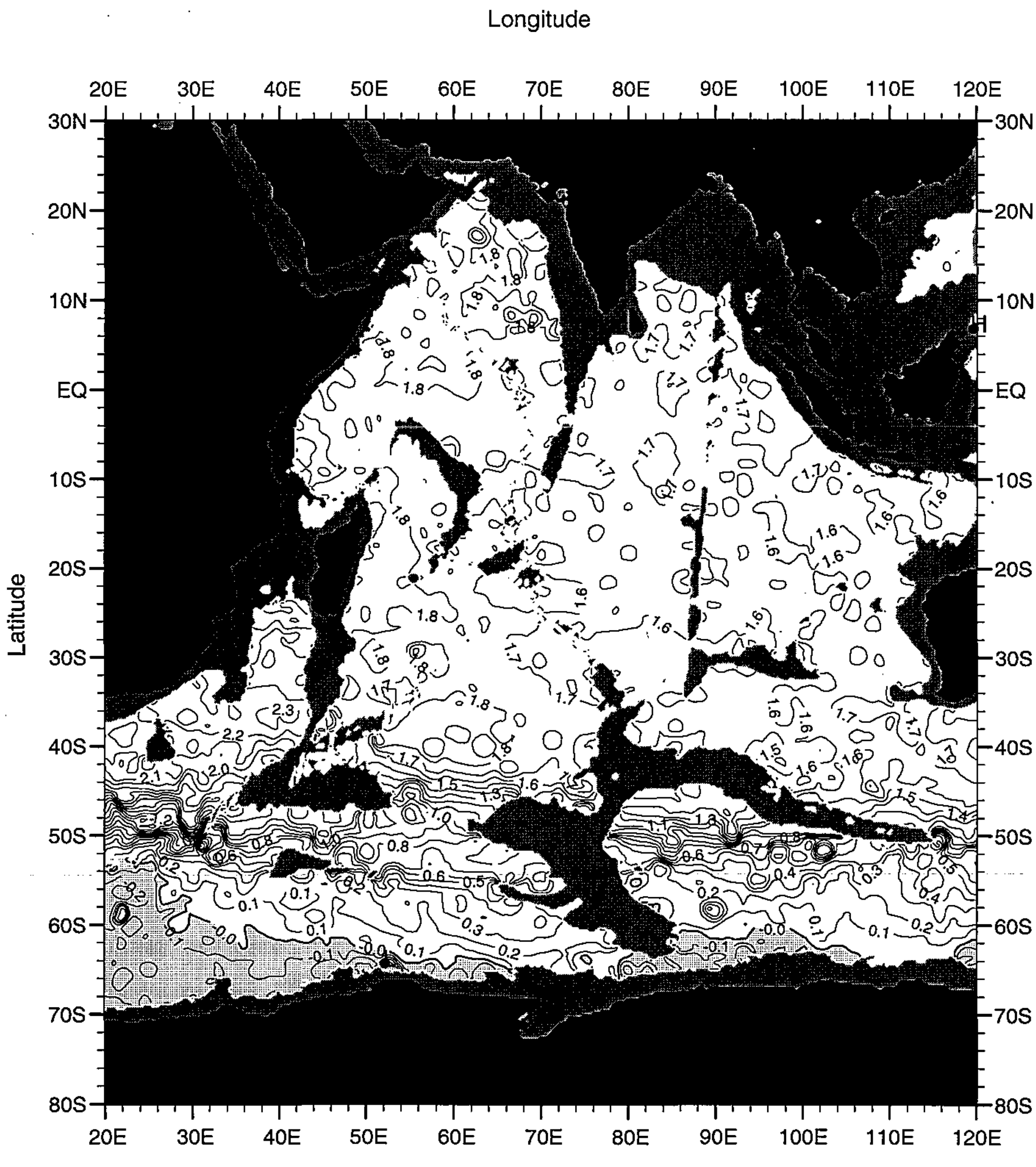
Minimum Value -0.26 Maximum Value 21.81 Contour Interval 0.25

Fig. F4 High resolution temperature in the Indian Ocean at 1000 meters depth. Stippling indicates temperature less than 0°C.



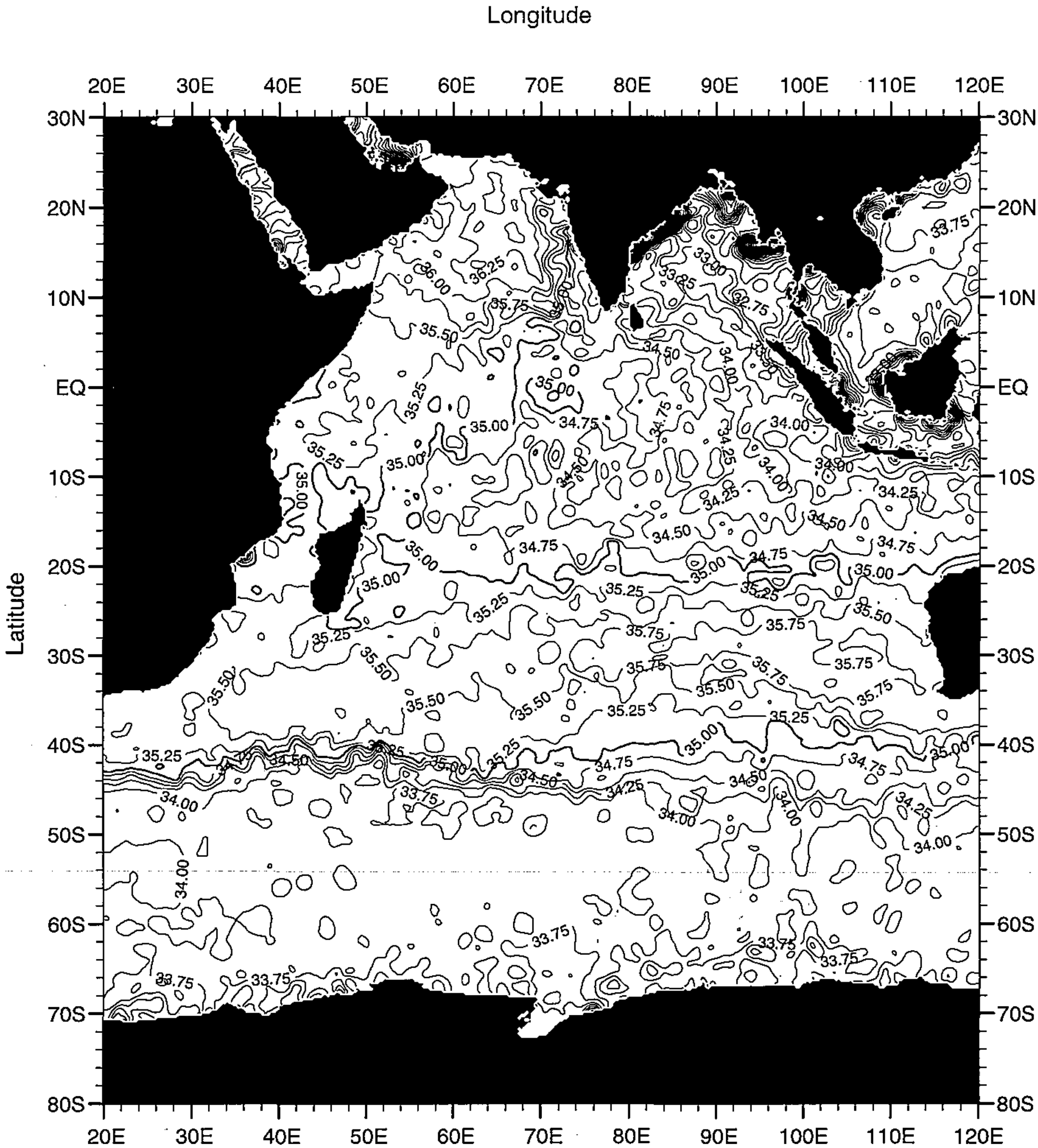
Minimum Value -0.48 Maximum Value 10.16 Contour Interval 0.10

Fig. F5 High resolution temperature in the Indian Ocean at 2000 meters depth. Stippling indicates temperature less than 0°C.



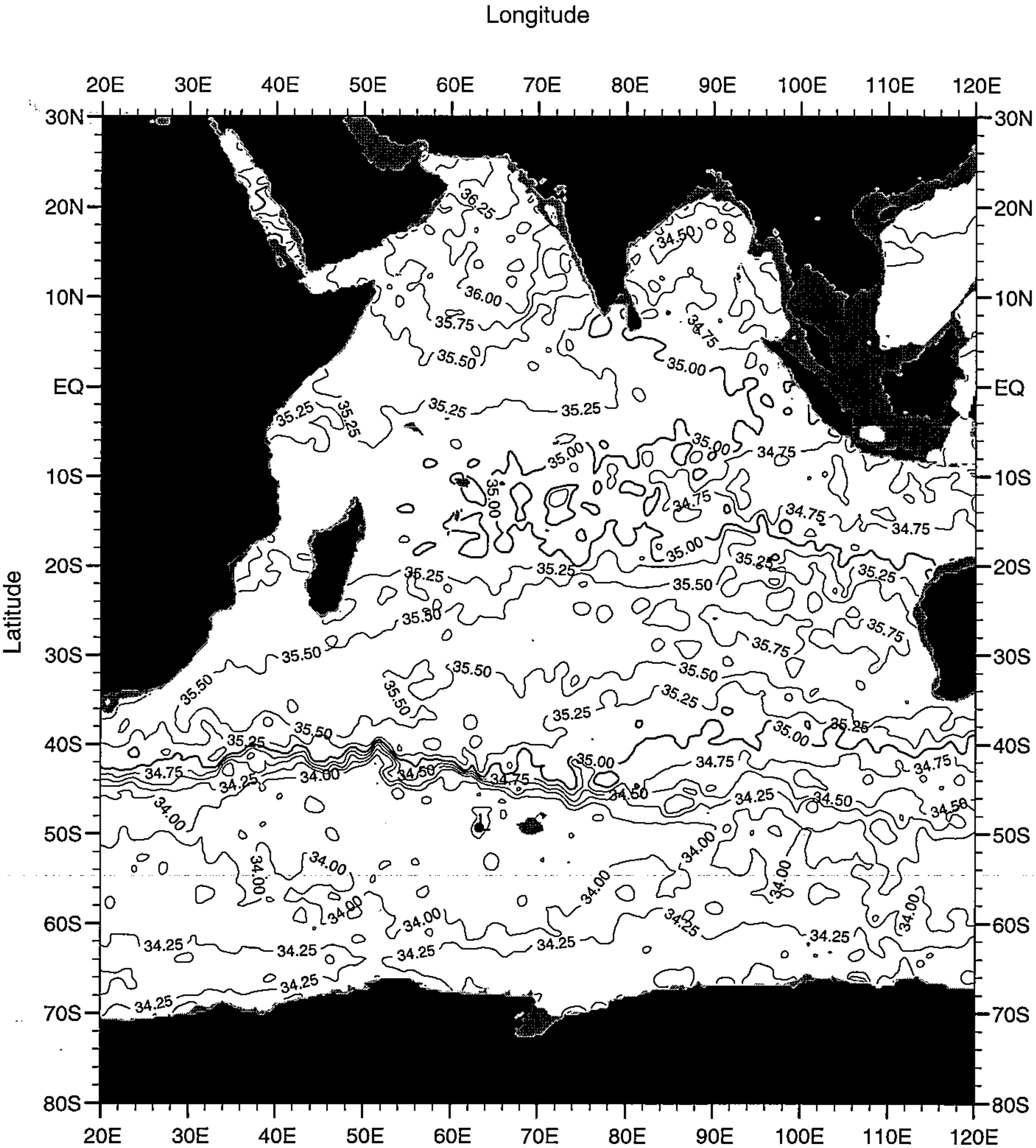
Minimum Value -0.46 Maximum Value 10.29 Contour Interval 0.10

Fig. F6 High resolution temperature in the Indian Ocean at 3000 meters depth. Stippling indicates temperature less than 0°C.



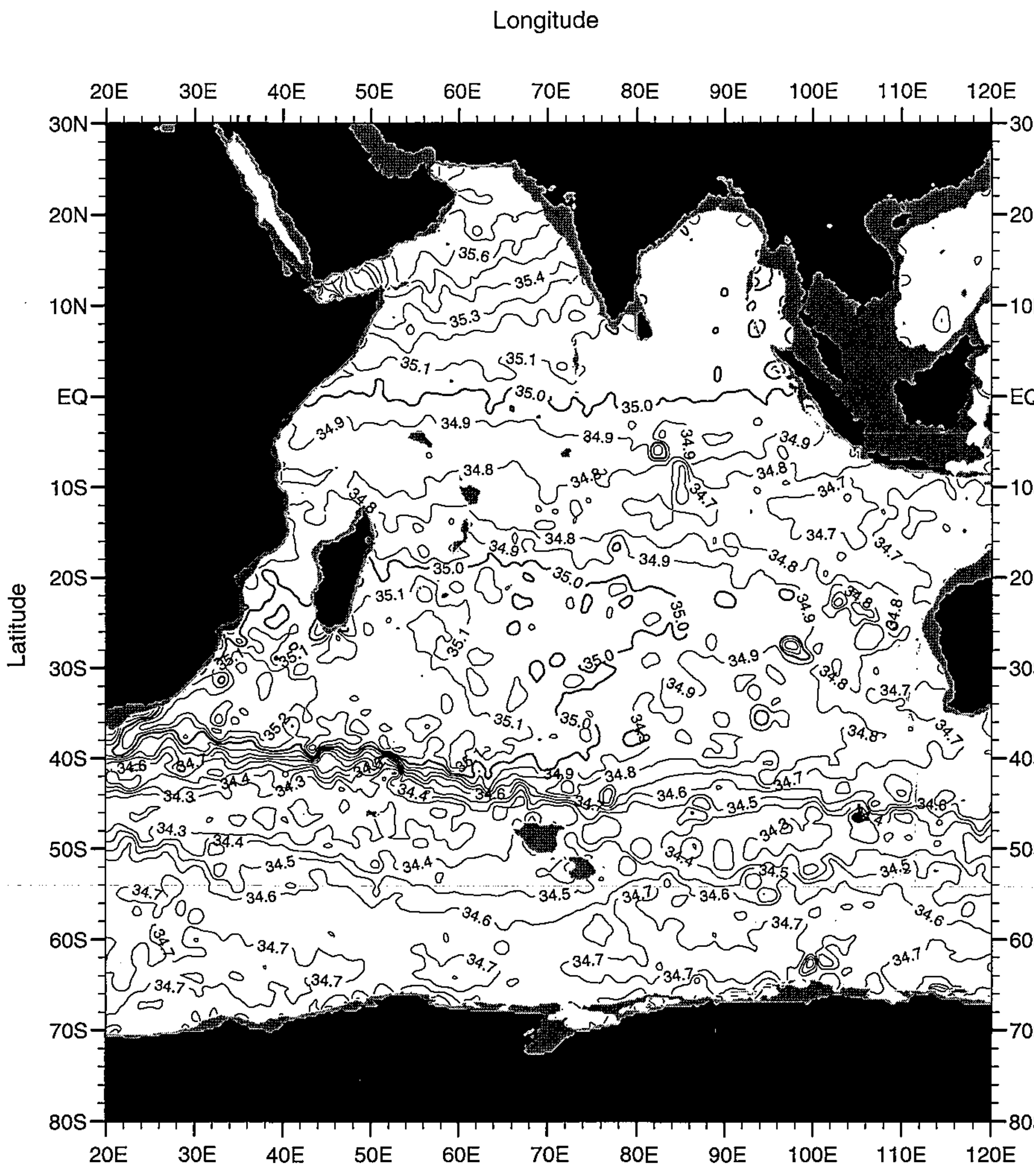
Minimum Value 22.62 Maximum Value 42.82 Contour Interval 0.25

Fig. G1 High resolution salinity in the Indian Ocean at the sea surface.



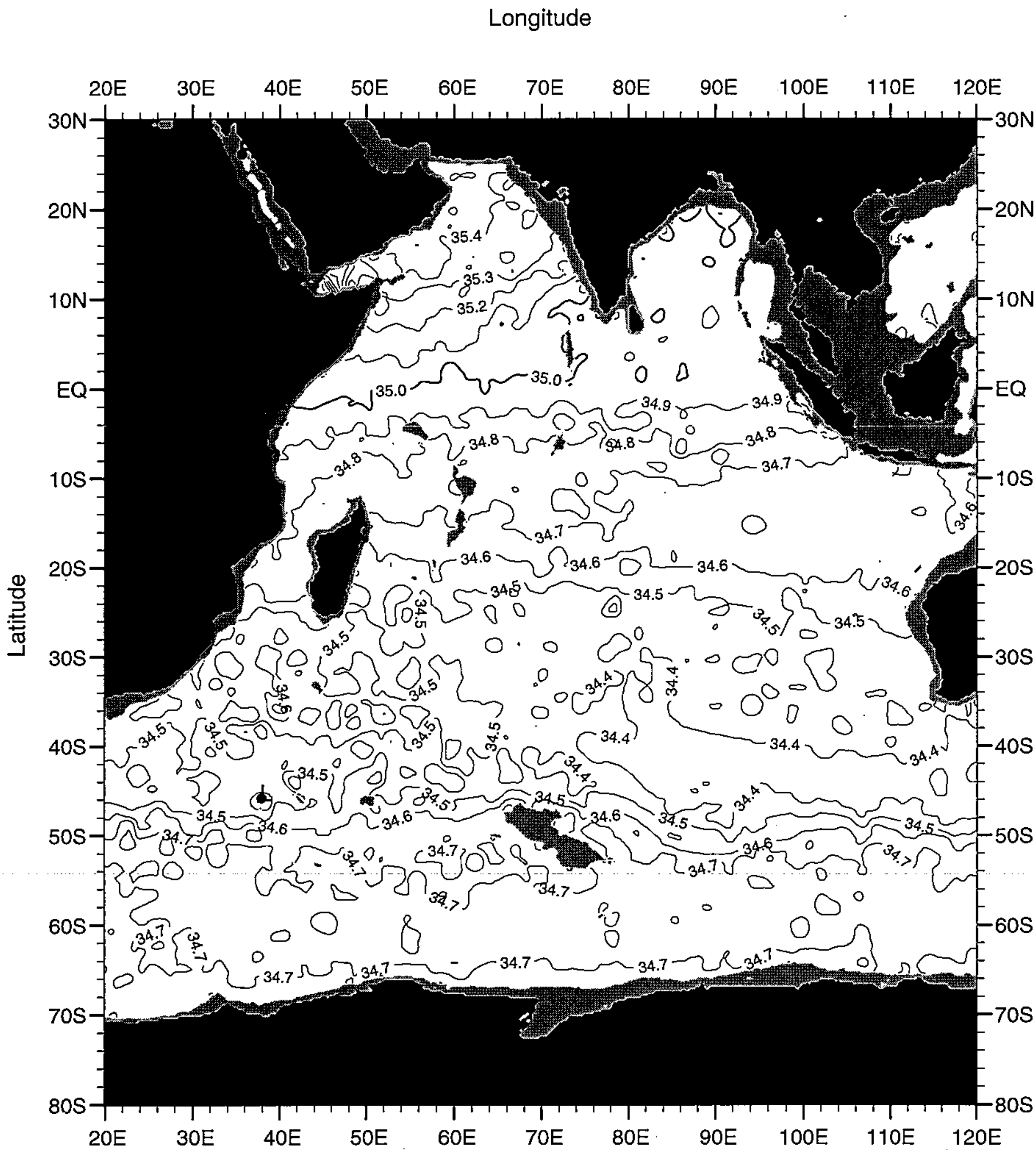
Minimum Value 33.58 Maximum Value 40.56 Contour Interval 0.25

Fig. G2 High resolution salinity in the Indian Ocean at 100 meters depth.



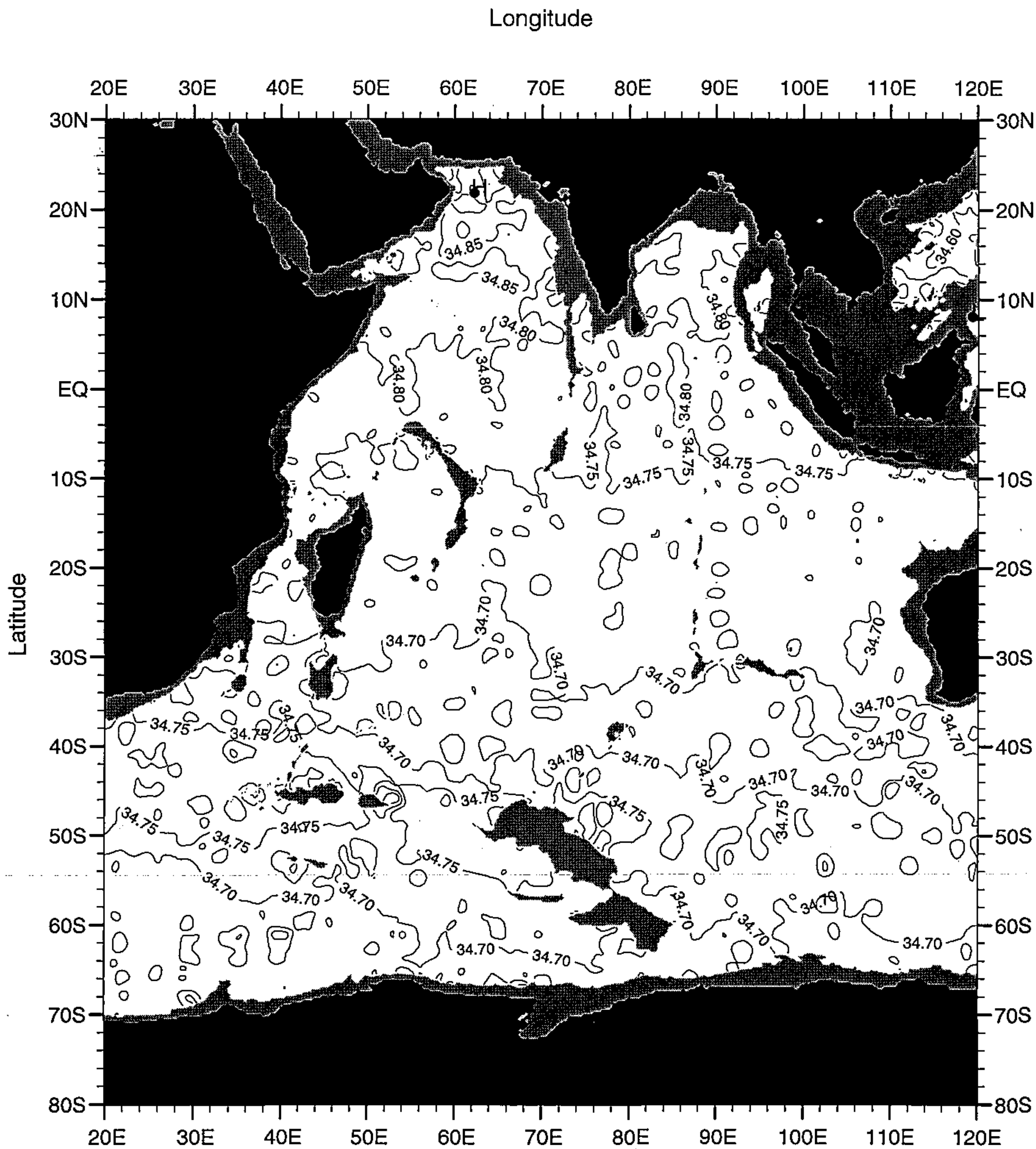
Minimum Value 34.15 Maximum Value 40.74 Contour Interval 0.10

Fig. G3 High resolution salinity in the Indian Ocean at 500 meters depth.



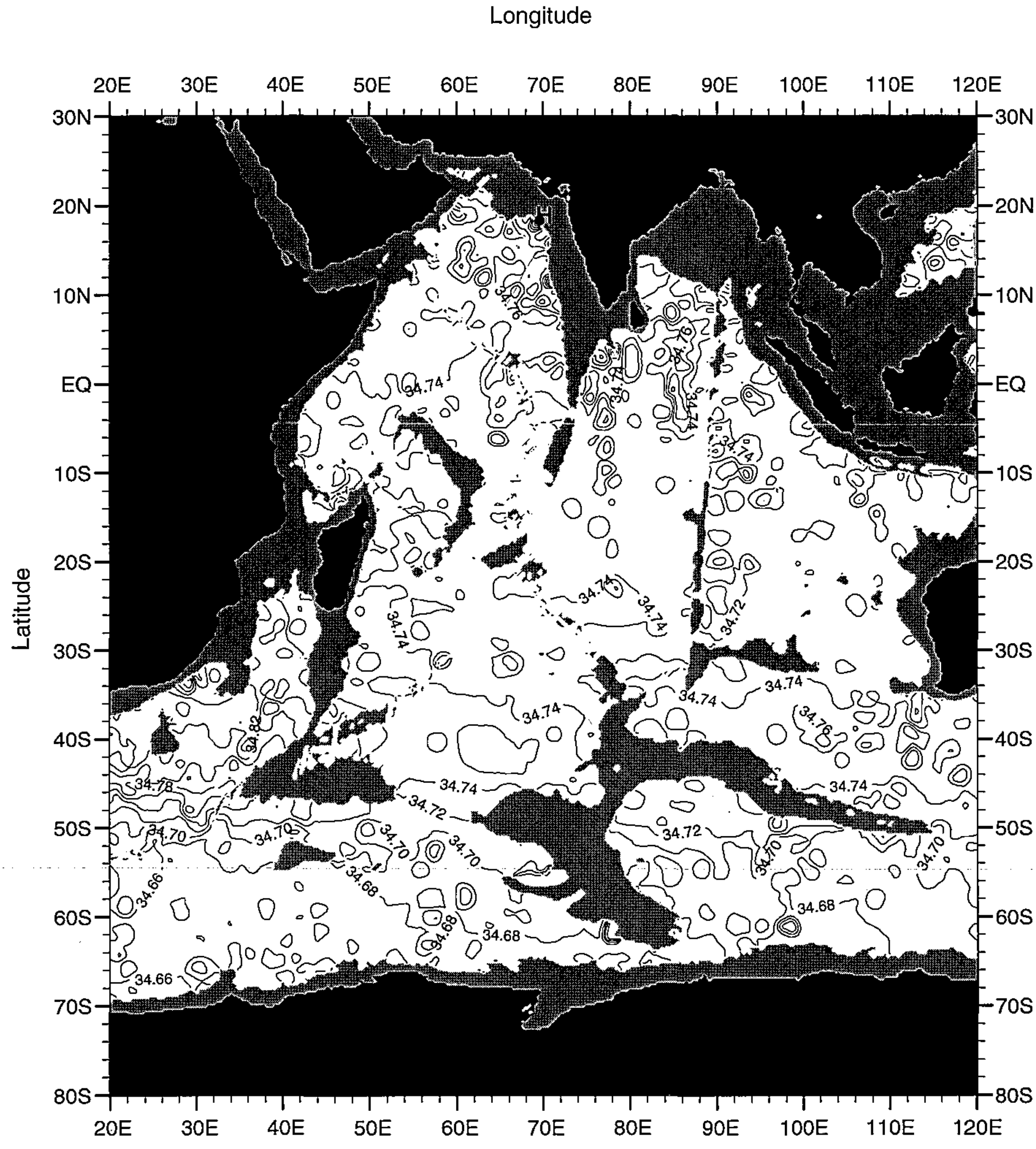
Minimum Value 34.29 Maximum Value 40.64 Contour Interval 0.10

Fig. G4 High resolution salinity in the Indian Ocean at 1000 meters depth.



Minimum Value 34.461 Maximum Value 34.913 Contour Interval 0.050

Fig. G5 High resolution salinity in the Indian Ocean at 2000 meters depth.



Minimum Value 34.465 Maximum Value 34.896 Contour Interval 0.020

Fig. G6 High resolution salinity in the Indian Ocean at 3000 meters depth.

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