Northeast Fisheries Science Center Reference Document 95-11

Water - Column Thermal Structure in the Middle Atlantic Bight and Gulf of Maine for 1993 and 1994

by

Robert L. Benway
and
Jack W. Jossi

NOAA/National Marine Fisheries Service
Northeast Fisheries Science Center
Environmental Processes Division
Plankton Ecology Investigation
Narragansett, RI 02882-1199

March 1995

Northeast Fisheries Science Center Reference Document 95-11

Water - Column Thermal Structure in the Middle Atlantic Bight and Gulf of Maine for 1993 and 1994

by

Robert L. Benway
and
Jack W. Jossi

NOAA/National Marine Fisheries Service
Northeast Fisheries Science Center
Environmental Processes Division
Plankton Ecology Investigation
Narragansett, RI 02882-1199

March 1995

The Northeast Fisheries Science Center Reference Documents are a series of informal reports produced by the Center for timely transmission of results obtained through work at the various NEFSC labs. The documents are reviewed internally before publication, but are not considered formal literature. The National Marine Fisheries Service does not endorse any proprietary material, process, or product mentioned in these reports. To obtain additional copies of this report contact, Information Services Unit, Northeast Fisheries Science Center, Woods Hole, MA 02543 (508-548-5123, ext. 260).

The correct citation for the document is: Benway, Robert L. and Jack W. Jossi. 1995. Water-column thermal structure in the Middle Atlantic Bight and Gulf of Maine for 1993 and 1994. Woods Hole, MA: NOAA/NMFS/NEFSC. *Center Ref. Doc.* 95-11. Available from: NMFS/NEFSC, 166 Water Street, Woods Hole, MA 02543.

TABLE OF CONTENTS

Abstract 1
Introduction 1
Methods 1
Study Area 1
Data and Sample Processing 1
Generation of Contoured Vertical Sections 2
Results 2
References 3

LIST OF TABLES

Table 1. List of all MARMAP Ships of Opportunity Program (SOOP) cruises through the Route MB (Middle Atlantic Bight) polygon from the *C/V Oleander* (OL) during the period 1993-1994 4

Table 2. List of all MARMAP Ships of Opportunity Program (SOOP) cruises through the Route MC (Gulf of Maine) polygon from the *C/V Yankee Clipper* (YC) or *C/V Skogafoss* (SK) during the period 1993-1994 4

LIST OF FIGURES

Figure 1. The (A) Middle Atlantic Bight (MAB), and (B) Gulf of Maine (GOM) Route MC polygons, within which monitoring transects occurred, showing reference positions and distances, location of Ambrose tower, and major geographical features through which all sampling took place 5

Figure 2. Water-column thermal structure (degrees Celsius) along the Middle Atlantic Bight transect during January and February 1993 6

Figure 3. Water-column thermal structure (degrees Celsius) along the Middle Atlantic Bight transect during March and April 1993 7

Figure 4. Water-column thermal structure (degrees Celsius) along the Middle Atlantic Bight transect during May and June 1993 8

Figure 5. Water-column thermal structure (degrees Celsius) along the Middle Atlantic Bight transect during July and August 1993 9

Figure 6. Water-column thermal structure (degrees Celsius) along the Middle Atlantic Bight transect during September and October 1993 10

Figure 7. Water-column thermal structure (degrees Celsius) along the Middle Atlantic Bight transect during November and December 1993 11

Figure 8. Water-column thermal structure (degrees Celsius) along the Middle Atlantic Bight transect during January and February 1994 12

Figure 9. Water-column thermal structure (degrees Celsius) along the Middle Atlantic Bight transect during March and April 1994 13

Figure 10. Water-column thermal structure (degrees Celsius) along the Middle Atlantic Bight transect during May and June 1994 14

Figure 11. Water-column thermal structure (degrees Celsius) along the Middle Atlantic Bight transect during July and August 1994 15

Figure 12. Water-column thermal structure (degrees Celsius) along the Middle Atlantic Bight transect during September and October 1994 16

Figure 13. Water-column thermal structure (degrees Celsius) along the Middle Atlantic Bight transect during November and December 1994 17

Figure 14. Water-column thermal structure (degrees Celsius) along the Gulf of Maine transect during January, February, and March 1993 18

Figure 15. Water-column thermal structure (degrees Celsius) along the Gulf of Maine transect during April, May, and June 1993 19

Figure 16. Water-column thermal structure (degrees Celsius) along the Gulf of Maine transect during July, August, and September 1993 20

Figure 17. Water-column thermal structure (degrees Celsius) along the Gulf of Maine transect during October, November, and December 1993 21

Figure 18. Water-column thermal structure (degrees Celsius) along the Gulf of Maine transect during January, February, and March 1994 22

Figure 19. Water-column thermal structure (degrees Celsius) along the Gulf of Maine transect during April, May, and June 1994 23

Figure 20. Water-column thermal structure (degrees Celsius) along the Gulf of Maine transect during July, August, and September 1994 24

Figure 21. Water-column thermal structure (degrees Celsius) along the Gulf of Maine transect during October, November, and December 1994 25

ABSTRACT

This report presents water-column temperature data collected in the Middle Atlantic Bight and Gulf of Maine for 1993 and 1994, and extends a similar compilation for data collected during 1978-1992 of the Northeast Fisheries Service Ships of Opportunity Program (Benway *et al.* 1993a). Data were collected by expendable bathythermographs deployed by merchant vessels during monthly transects within both bodies of water. Data are presented as contoured vertical sections. Methods of data collection, management, and portrayal are discussed.

INTRODUCTION

In 1970, the National Marine Fisheries Service (NMFS) and the Maritime Administration (MARAD) initiated a cooperative expendable bathythermograph (XBT) survey to identify and describe seasonal and year-to-year variations of temperature, salinity and circulation in major currents of the Gulf of Mexico and western North Atlantic. This survey, conducted in support of the NMFS's Marine Resources Monitoring, Assessment, and Prediction (MARMAP) Program, used merchant ships, cooperating in MARAD's Ship of Opportunity Program (SOOP), as inexpensive collection platforms, and relied on Kings Point Maritime Academy cadets to gather the XBT data.

In the mid-1970s, the continuous plankton recorder (CPR) survey (Glover 1967; Jossi *et al.* 1982), also using ships of opportunity, merged with the XBT survey. The combined surveys concentrated on water masses, circulation, and plankton of the Middle Atlantic Bight and Gulf of Maine, with particular interest in the continental shelf and slope waters.

This report portrays monthly water-column thermal conditions along MARMAP Routes MB (Middle Atlantic Bight) and MC (Gulf of Maine) for 1993 and 1994. During hte monthly cruises, CPR data were also collected, but are not presented here because of delays in data processing. Analyses of SOOP hydrographic data regarding long-term mean conditions and interannual variability in surface temperature, surface salinity, and bottom temperature are presented in Benway *et al.* (1993b). Additional analyses of the data collected in 1993 are presented in Benway *et al.* 1994.

METHODS

STUDY AREA

Ship routes were selected in regions of interest to fisheries research to provide regular sampling and to allow the characterization of oceanographic conditions. Repeated coverage is important for comparative analyses, so ships with the most regular schedules were chosen whenever possible. The cooperating ship's included research, commercial, and U.S. Coast Guard vessels outfitted with data sampling hardware and software from the National Marine Fisheries Service Narragansett (Rhode Island) Laboratory; The National Ocean Service Office of Ocean Observations, Washington D.C.; and the Environmental Research Laboratory, Atlantic Oceanographic and Meteorological Laboratory, Miami, Florida.

Track lines varied on different occupations of a route. This variability made it necessary to develop route polygons with shapes such that only variations along the long axis were considered significant relative to program goals (Figures 1a and 1b).

The Middle Atlantic Bight sampling originates at Ambrose Light (40°27.5'N, 73°49.6'W) and extends offshore 500 km (270 nm) towards Bermuda (Figure 1a). The route polygon is termed MARMAP Route MB, the corners of which are: 40°34'N, 74°00'W; 40°20'N, 74°00'W; 38°30'N, 69°00'W; and 34°44'N, 70°30'W. This route traverses waters of the continental shelf, continental slope, and Gulf Stream.

The Gulf of Maine sampling extends from Boston, Massachusetts, on the western side, to Cape Sable, Nova Scotia on the eastern portion (Figure 1b), for approximately 452 km (244 nm). This route polygon is termed MARMAP Route MC, the corners of which are: 43°30'N, 71°00'W; 43°30'N, 65°37'W; 43°00'N, 65°37'W; and 42°00'N, 71°00'W. This route traverses waters of Massachusetts Bay, Wilkinson Basin, the central gulf ledges, Crowell Basin, southern Jordan Basin and western Scotian Shelf.

DATA AND SAMPLE PROCESSING

On all SOOP vessels, XBT and meteorological data were recorded and logged following the methods of Benway *et al.* (1993a). Temporal coverage by data type is shown in Tables 1 and 2. Middle Atlantic Bight SOOP vessels cast XBT's at 1 hr

intervals (about each 26 km or 14 nm), whereas Gulf of Maine SOOP vessels dropped XBT's at 2-hr intervals (about each 44 km or 24 nm). In both regions, surface temperature was recorded hourly via bucket thermometer, and surface salinity was sampled whenever an XBT was deployed. In the Gulf of Maine, however, at the end of 1993 the *C/V Yankee Clipper* was replaced by the *C/V Skogafoss* and surface salinity sampling ceased. A thermosalinograph has been installed on the *C/V Skogafoss* and is currently going through calibration.

Temperature and depth data collected aboard SOOP vessels were processed and quality controlled by personnel at the NMFS Narragansett Laboratory, following the methods in Benway *et al.* (1993a).

The CPR data were collected and processed following the methods of Thomas (1992). In brief, CPRs were towed at a fixed depth of 10m. Seawater entering the front of the CPR was filtered through a mechanically driven belt of Swiss bolting silk with a wet mesh aperture of 225 microns x 234 microns. In the laboratory, the silk was divided into sections ("stations") corresponding to 10 nautical-mile segments (18.52 km) of a tow track. Geographic position and reference distance were calculated for each geometric center of each silk section, and successive silk sections were assigned sequential station numbers. Zooplankton and phytoplankton atlases are in preparation for both MB and MC Routes.

GENERATION OF CONTOURED VERTICAL SECTIONS

The method of generating contoured vertical sections, or grids, was designed at the NMFS Narragansett Laboratory to overcome problems associated with irregular sampling in time and space (Thomas 1992). Both XBT and bucket data from a single cruise were used to create a contoured grid of monthly, interpolated water-column temperatures.

All contoured sections of water-column temperatures (in degrees Celsius) have been constructed with route polygon reference distances (in kilometers) along the x-axis, and water-column depths along the y-axis. Grid intersections were chosen at intervals of 17.38 km distance and 10 m depth.

A search was performed of the elliptical space (100 km by 50 m) around every grid intersection, and all raw data values within the search ellipses were fitted to the grid by interpolation, using inverse distance squared weighting. In the event of fewer than four raw data values within the search ellipse at a given grid intersection, no interpolation was performed, resulting in a blank region within the interpolated surface.

RESULTS

During 1993 and 1994 the total number of cruises conducted was 29 for the Middle Atlantic Bight and 26 for the Gulf of Maine. Cruises are listed in Table 1 (Middle Atlantic Bight) and Table 2 (Gulf of Maine) along with information on the types of data collected on each cruise.

Portrayals of monthly water-column temperatures for the Middle Atlantic Bight(Route MB) are shown in Figures 2-13, and for the Gulf of Maine (Route MC) in Figures 14-21. *Not* included in these portrayals are the locations of concomitant CPR stations.

Temperature data for any SOOP transect are available from the National Oceanographic Data Center (NODC) in a variety of forms. Requests for and inquiries about SOOP data held by NODC, as well as data products, should be directed to:

National Oceanographic Data Center
National Environmental Satellite, Data and Information Service/NOAA
1825 Connecticut Ave., N.W.
Washington, DC 20235
U.S.A.

For information about CPR plankton collections, please contact:

Plankton Ecology Investigation
Northeast Fisheries Science Center
National Marine Fisheries Service
28 Tarzwell Drive,
Narragansett, R.I. 02882
U.S.A.

intervals (about each 26 km or 14 nm), whereas Gulf of Maine SOOP vessels dropped XBT's at 2-hr intervals (about each 44 km or 24 nm). In both regions, surface temperature was recorded hourly via bucket thermometer, and surface salinity was sampled whenever an XBT was deployed. In the Gulf of Maine, however, at the end of 1993 the *C/V Yankee Clipper* was replaced by the *C/V Skogafoss* and surface salinity sampling ceased. A thermosalinograph has been installed on the *C/V Skogafoss* and is currently going through calibration.

Temperature and depth data collected aboard SOOP vessels were processed and quality controlled by personnel at the NMFS Narragansett Laboratory, following the methods in Benway *et al.* (1993a).

The CPR data were collected and processed following the methods of Thomas (1992). In brief, CPRs were towed at a fixed depth of 10m. Seawater entering the front of the CPR was filtered through a mechanically driven belt of Swiss bolting silk with a wet mesh aperture of 225 microns x 234 microns. In the laboratory, the silk was divided into sections ("stations") corresponding to 10 nautical-mile segments (18.52 km) of a tow track. Geographic position and reference distance were calculated for each geometric center of each silk section, and successive silk sections were assigned sequential station numbers. Zooplankton and phytoplankton atlases are in preparation for both MB and MC Routes.

GENERATION OF CONTOURED VERTICAL SECTIONS

The method of generating contoured vertical sections, or grids, was designed at the NMFS Narragansett Laboratory to overcome problems associated with irregular sampling in time and space (Thomas 1992). Both XBT and bucket data from a single cruise were used to create a contoured grid of monthly, interpolated water-column temperatures.

All contoured sections of water-column temperatures (in degrees Celsius) have been constructed with route polygon reference distances (in kilometers) along the x-axis, and water-column depths along the y-axis. Grid intersections were chosen at intervals of 17.38 km distance and 10 m depth.

A search was performed of the elliptical space (100 km by 50 m) around every grid intersection, and all raw data values within the search ellipses were fitted to the grid by interpolation, using inverse distance squared weighting. In the event of fewer than four raw data values within the search ellipse at a given grid intersection, no interpolation was performed, resulting in a blank region within the interpolated surface.

RESULTS

During 1993 and 1994 the total number of cruises conducted was 29 for the Middle Atlantic Bight and 26 for the Gulf of Maine. Cruises are listed in Table 1 (Middle Atlantic Bight) and Table 2 (Gulf of Maine) along with information on the types of data collected on each cruise.

Portrayals of monthly water-column temperatures for the Middle Atlantic Bight(Route MB) are shown in Figures 2-13, and for the Gulf of Maine (Route MC) in Figures 14-21. *Not* included in these portrayals are the locations of concomitant CPR stations.

Temperature data for any SOOP transect are available from the National Oceanographic Data Center (NODC) in a variety of forms. Requests for and inquiries about SOOP data held by NODC, as well as data products, should be directed to:

National Oceanographic Data Center
National Environmental Satellite, Data and Information Service/NOAA
1825 Connecticut Ave., N.W.
Washington, DC 20235
U.S.A.

For information about CPR plankton collections, please contact:

Plankton Ecology Investigation
Northeast Fisheries Science Center
National Marine Fisheries Service
28 Tarzwell Drive,
Narragansett, R.I. 02882
U.S.A.

REFERENCES

Benway, Robert· L.,and Jack W. Jossi. 1994. Surface and bottome temperatures, and salinities; New York to the Gulf Stream, Massachusetts to Capr Sable, N.S., 1993 *NAFO SCR Doc.,94/15, 16p.*

Benway, Robert L., Kevin P. Thomas, and Jack W. Jossi. 1993a. Water-column thermal structure in the Middle Atlantic Bight and Gulf of Maine during 1978-1992. U.S. Dept. of Commerce, NOAA Tech. Mem., NMFS-F/NEC-97, 154 p.

Benway, Robert L., Jack W. Jossi, Kevin P. Thomas, and Julien R. Goulet. 1993b. Variability of temperature and salinity in the Middle Atlantic Bight and Gulf of Maine. MARMAP Atlas Monograph No. 4. U.S. Dep. Commerce, NOAA Tech. Rep., NMFS 112, 108 p.

Benway, Robert L., Jack W. Jossi, and Carolyn A. Griswold. 1993c. Surface and bottom temperatures, and \surface salinities: New York to the Gulf Stream, Massachusetts to Cape Sable, N.S., 1992. NAFO SCR Doc. 93/27, 15 p.

Glover, R.S. 1967. The continuous plankton recorder survey of the Norht Atlantic. *Symp. Zool. Soc. Lond. 19: 189-210.*

Thomas, K.P. 1992. Initiation and decline of *Ceratium tripos* blooms in the Gulf of Maine; dependence upon water column structure. Kingston, RI: Univ. of Rhode Island. M.Sc. Thesis 127p.

Jossi, J.W.;Smith, D.E.;White, G.A. 1982. Continuous plankton records: the sampling program of the U.S. National Marine Fisheries Service. *Ann. Biol. 38: 66-68.*

Table 1. List of all MARMAP Ships of Opportunity Program (SOOP) cruises through the Route MB (Middle Atlantic Bight) polygon from the *C/V Oleander* (OL) during the period 1993-1994.

CRUISE	DATE	XBT	SST	SSS	CPR
1993					
OL9301	8 Jan 1993	-	X	X	X
OL9302*	6 Feb 1993	X	X	X	X
OL9303	6 Mar 1993	-	-	X	X
OL9304*	3 Apr 1993	X	X	X	X
OL9305*	7 May 1993	X	X	X	X
OL9306*	12 Jun 1993	X	X	X	X
OL9307*	2 Jul 1993	X	X	X	X
OL9308*	6 Aug 1993	-	X	X	X
OL9309	4 Sep 1993	-	X	X	X
OL9310	8 Sep 1993	-	-	-	X
OL9311*	24 Sep 1993	X	X	X	-
OL9312*	15 Oct 1993	X	X	X	X
OL9313*	6 Nov 1993	X	X	X	-
OL9314	20 Nov 1993	-	-	-	X
OL9315*	4 Dec 1993	X	X	X	X
1994					
OL9401*	7 Jan 1994	X	X	X	X
OL9402*	5 Feb 1994	X	X	X	X
OL9403*	5 Mar 1994	X	X	X	X
OL9404*	13 May 1994	X	X	X	-
OL9405	21 May 1994	-	-	-	X
OL9406*	10 Jun 1994	X	X	X	X
OL9407*	9 Jul 1994	X	X	X	X
OL9408	15 Jul 1994	-	-	-	X
OL9409*	5 Aug 1994	X	X	X	X
OL9410*	2 Sep 1994	X	X	X	X
OL9411	7 Oct 1994	X	X	X	-
OL9412*	21 Oct 1994	X	X	X	X
OL9413*	4 Nov 1994	X	X	X	X
OL9414*	10 Dec 1994	X	X	X	X

Notes: An "X" indicates collection of a particular data type (XBT = expendable bathythermograph drop; SST = sea surface temperature (bucket); SSS = sea surface salinity (bucket) sample; CPR = continuous plankton record. Cruises with * are presented as verticle sections in this report.

Table 2. List of all MARMAP Ships of Opportunity Program (SOOP) cruises through the Route MC (Gulf of Maine) polygon from the *C/V Yankee Clipper* (YC) or *C/V Skogafoss* (SK) during the period 1993-1994

CRUISE	DATE	XBT	SST	SSS	CPR
1993					
YC9301*	16 Jan 1993	X	X	X	X
YC9302*	20 Feb 1993	X	X	X	X
YC9303*	13 Mar 1993	X	X	X	X
YC9304*	22 Apr 1993	X	X	X	X
YC9305*	14 May 1993	X	X	X	X
YC9306*	11 Jun 1993	X	X	X	X
YC9307*	3 Jul 1993	X	X	X	-
YC9308*	6 Aug 1993	X	X	X	-
YC9309	27 Aug 1993	-	-	-	X
YC9310	10 Sep 1993	X	X	X	-
YC9311*	24 Sep 1993	X	X	X	X
SK9301*	11 Nov 1993	X	X	-	X
SK9302	12 Dec 1993	-	-	-	X
1994					
SK9401*	4 Jan 1993	X	X	-	X
SK9402	31 Jan 1993	X	X	-	-
SK9403*	28 Feb 1994	X	X	-	X
SK9404*	28 Mar 1994	X	X	-	X
SK9405*	8 May 1994	X	X	-	X
SK9406	5 Jun 1994	-	-	-	X
SK9407	2 Jul 1994	X	X	-	X
SK9408*	30 Jul 1994	X	X	-	X
SK9409*	27 Aug 1994	X	X	-	X
SK9410	24 Sep 1994	-	-	-	X
SK9411*	22 Oct 1994	X	X	-	-
SK9412*	20 Nov 1994	X	X	-	X
SK9413*	18 Dec 1994	X	X	-	X

Notes: An "X" indicates collection of a particular data type (XBT = expendable bathythermograph drop; SST = sea surface temperature (bucket); SSS = sea surface salinity (bucket) sample; CPR = continuous plankton record. Cruises with * are presented as verticle sections in this report.

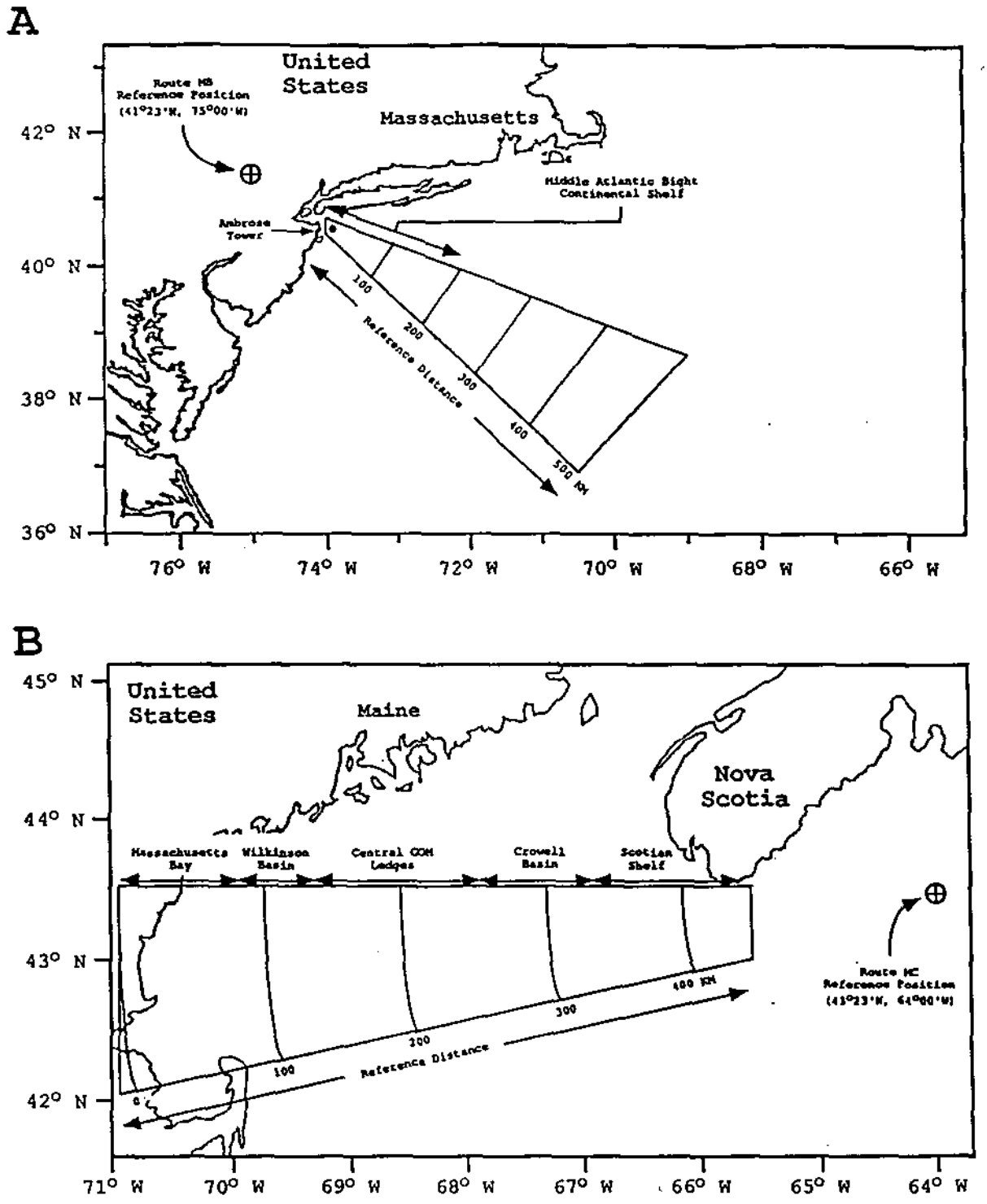

Figure 1. The (A) Middle Atlantic Bight (MAB), and (B) Gulf of Maine (GOM) Route MC polygons, within which monitoring transects occurred, showing reference positions and distances, location of Ambrose tower, and major geographical features through which all sampling took place.

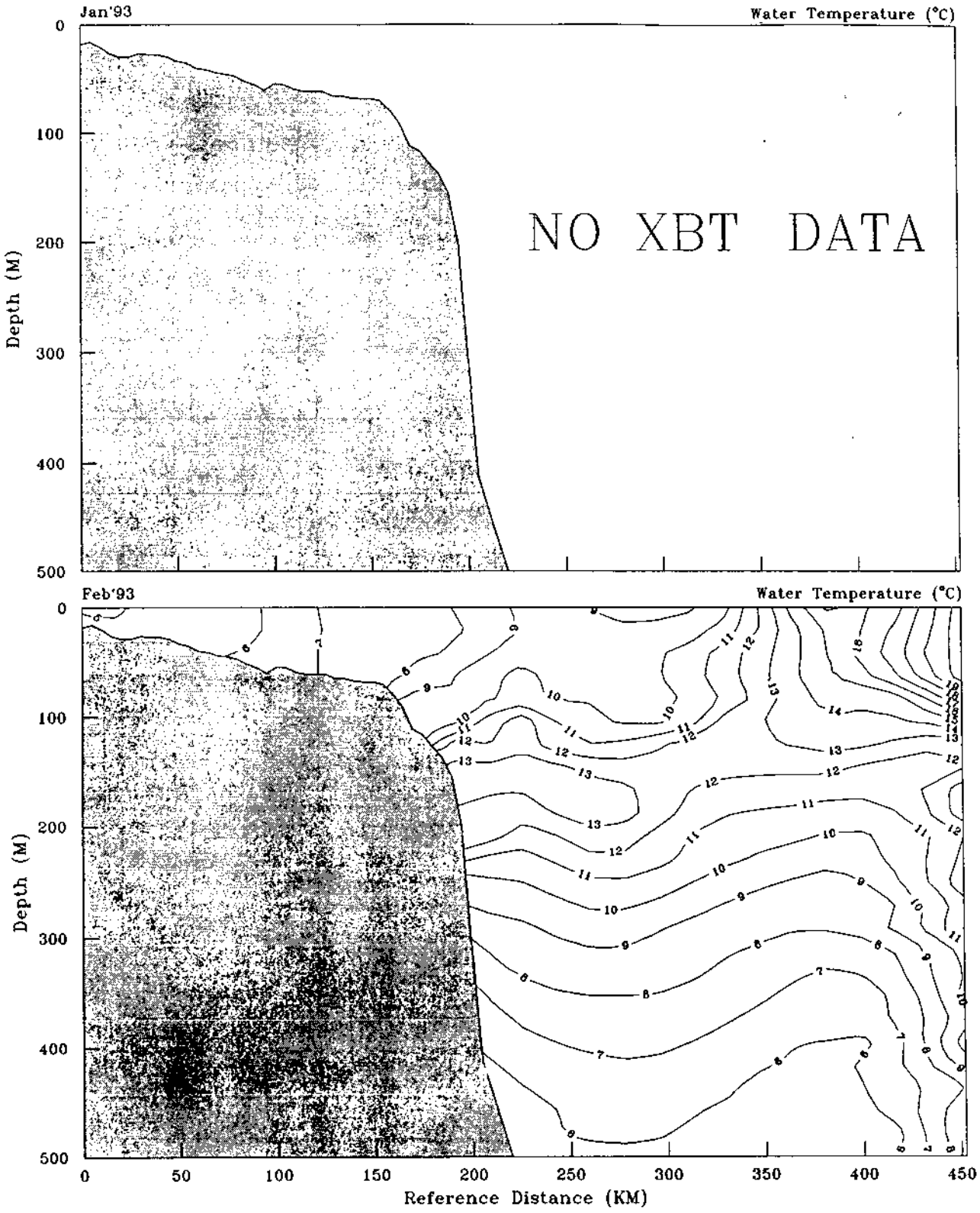

Figure 2. Water-column thermal structure (degrees Celsius) along the Middle Atlantic Bight transect during January and February 1993.

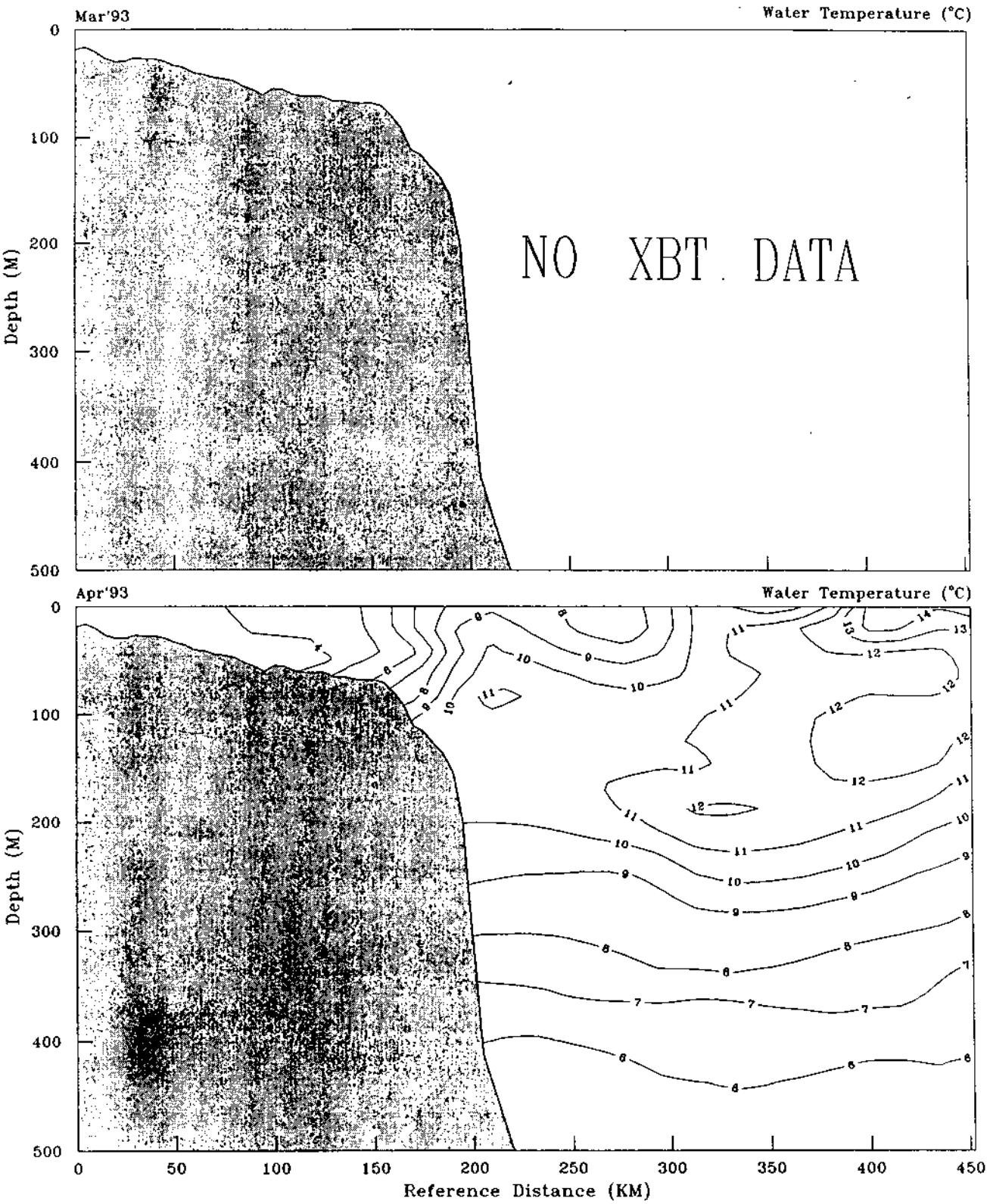

Figure 3. Water-column thermal structure (degrees Celsius) along the Middle Atlantic Bight transect during March and April 1993.

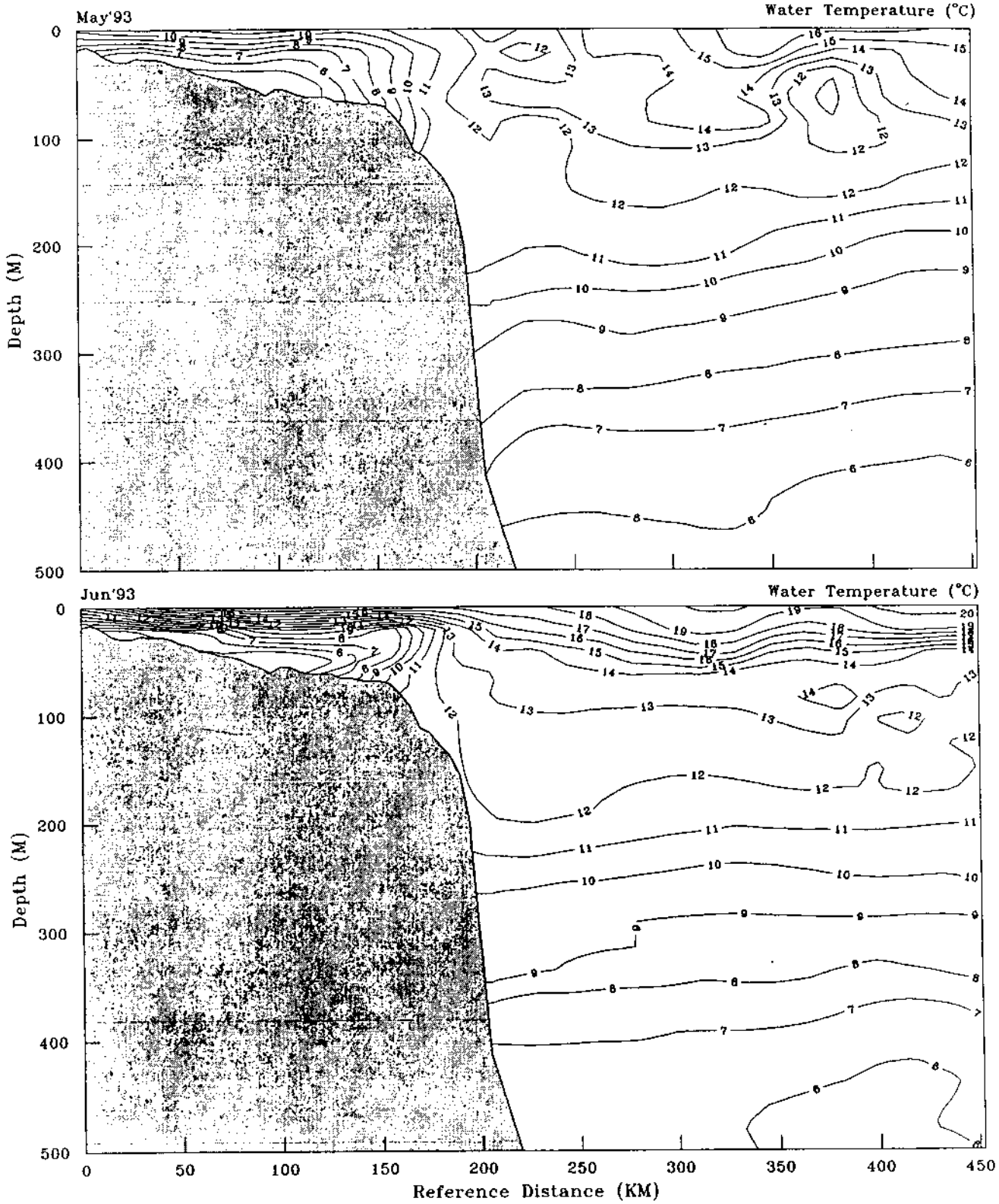

Figure 4. Water-column thermal structure (degrees Celsius) along the Middle Atlantic Bight transect during May and June 1993.

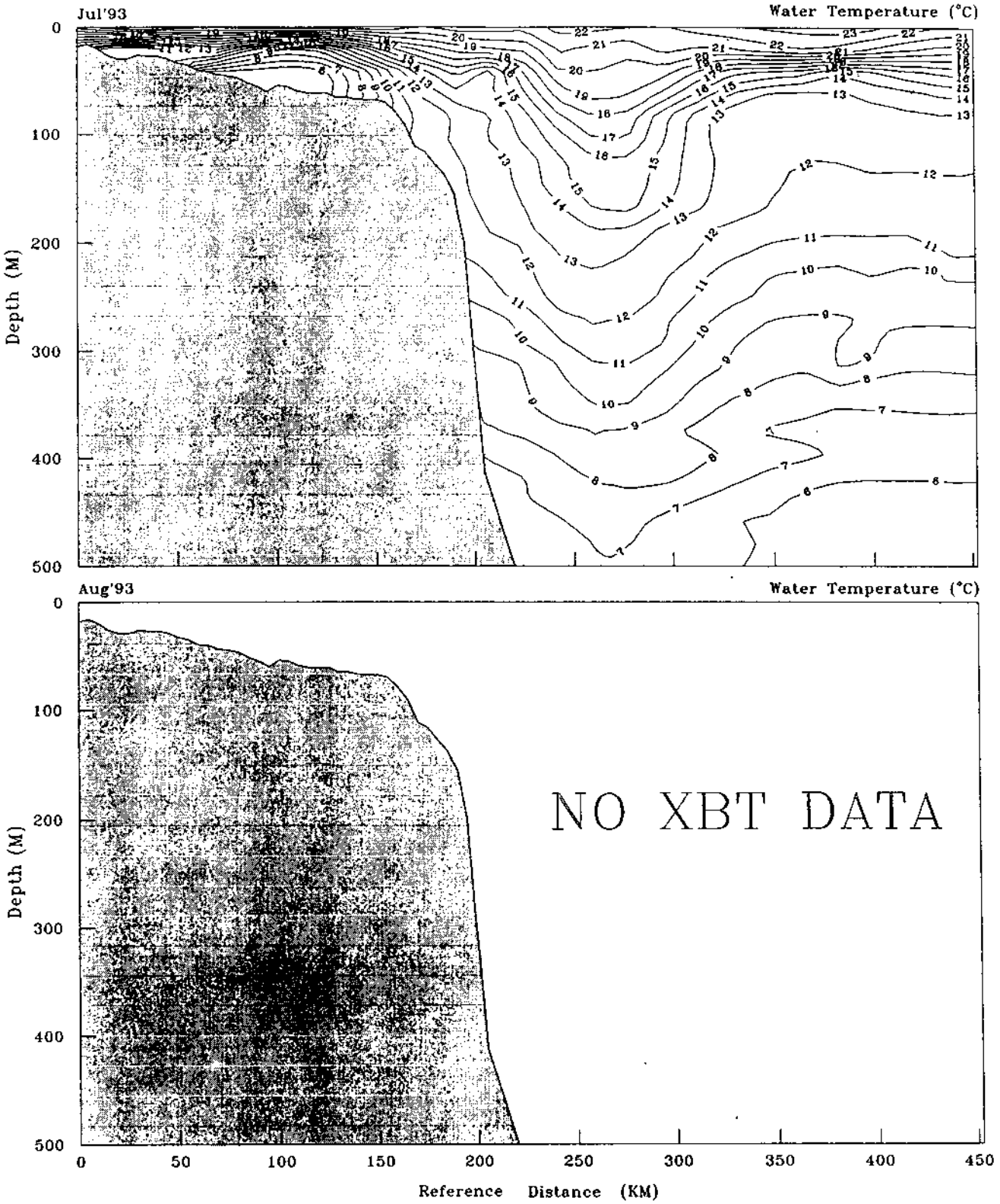

Figure 5. Water-column thermal structure (degrees Celsius) along the Middle Atlantic Bight transect during July and August 1993.

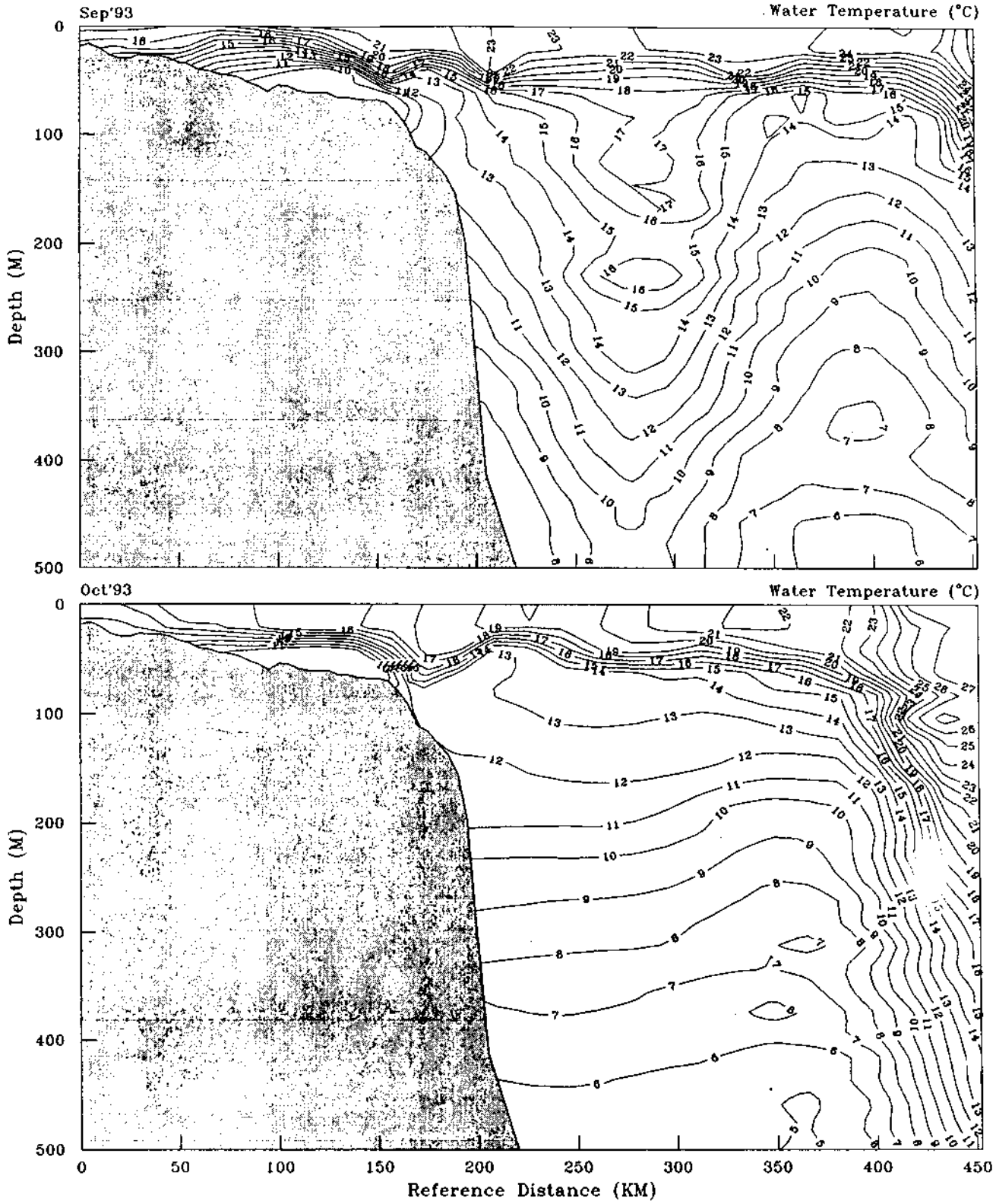

Figure 6. Water-column thermal structure (degrees Celsius) along the Middle Atlantic Bight transect during September and October 1993.

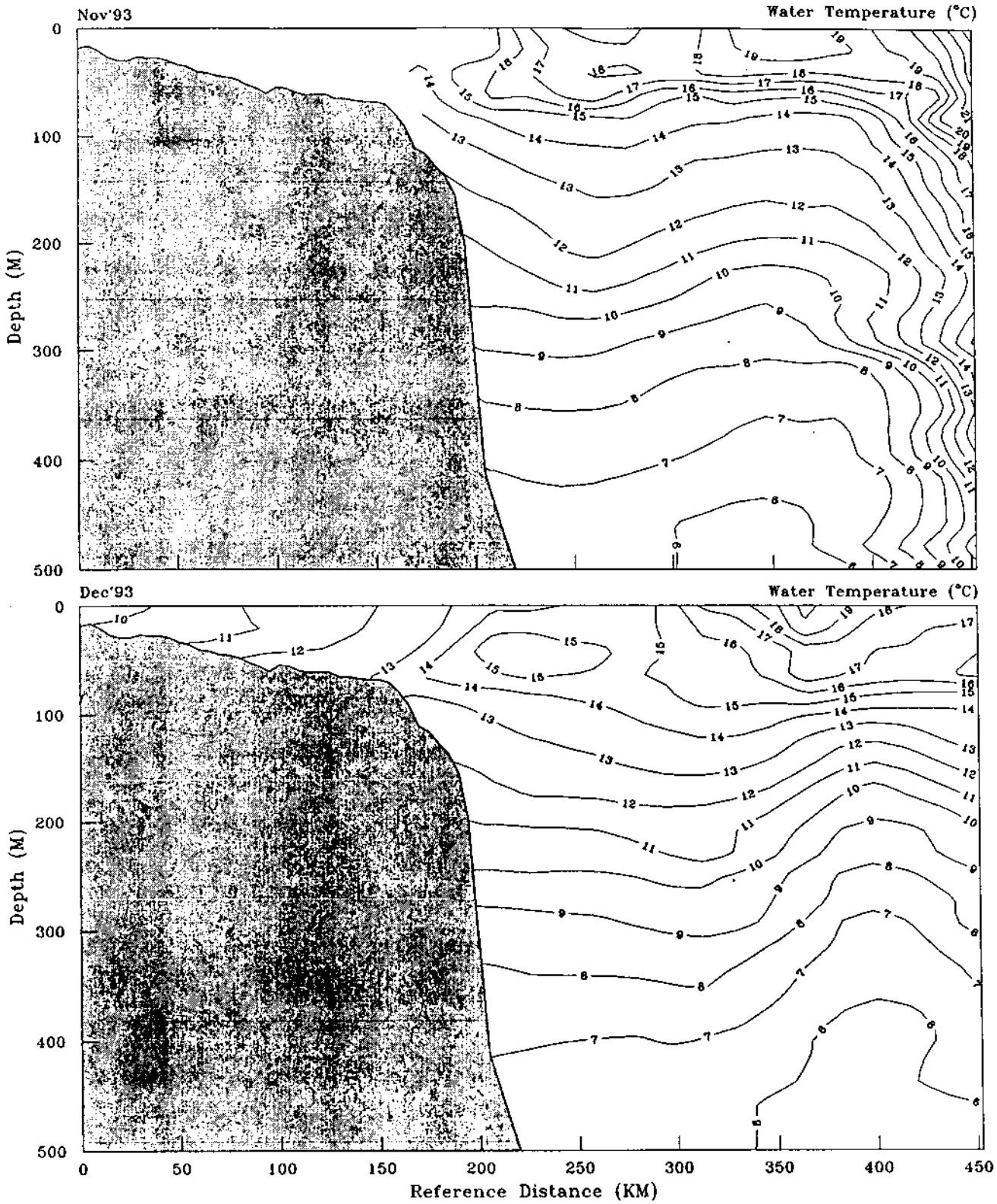

Figure 7. Water-column thermal structure (degrees Celsius) along the Middle Atlantic Bight transect during November and December 1993.

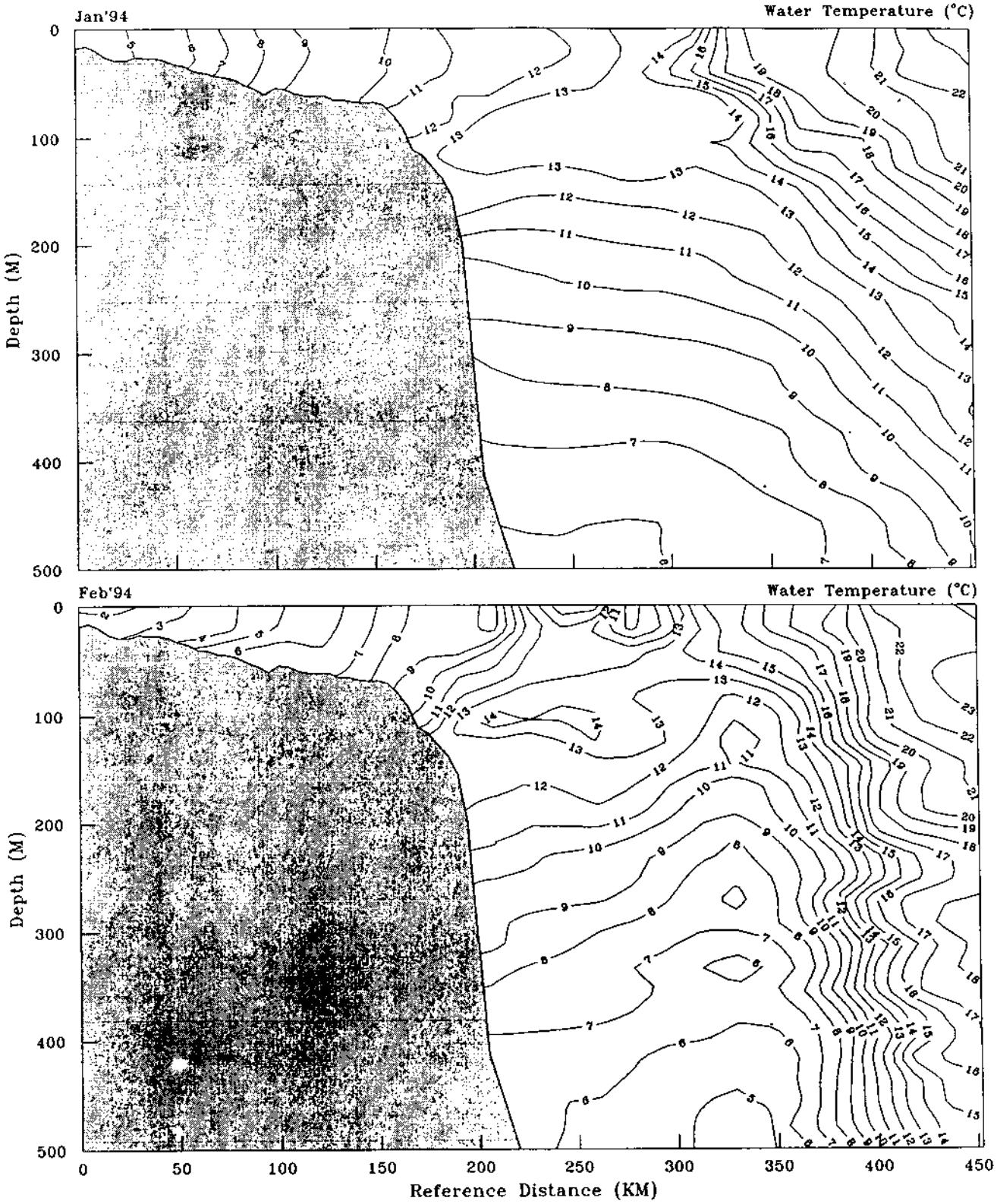

Figure 8. Water-column thermal structure (degrees Celsius) along the Middle Atlantic Bight transect during January and February 1994.

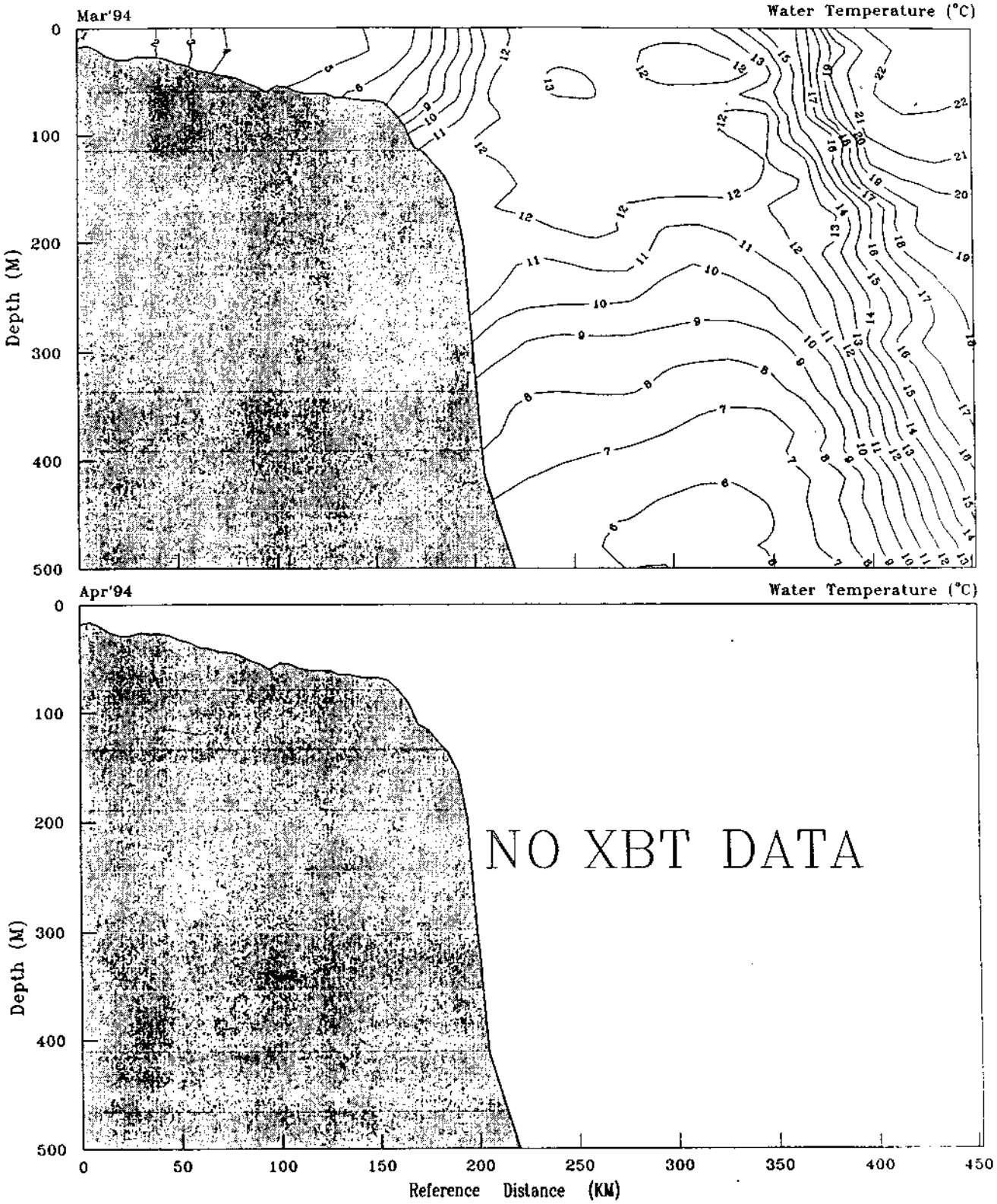

Figure 9. Water-column thermal structure (degrees Celsius) along the Middle Atlantic Bight transect during March and April 1994.

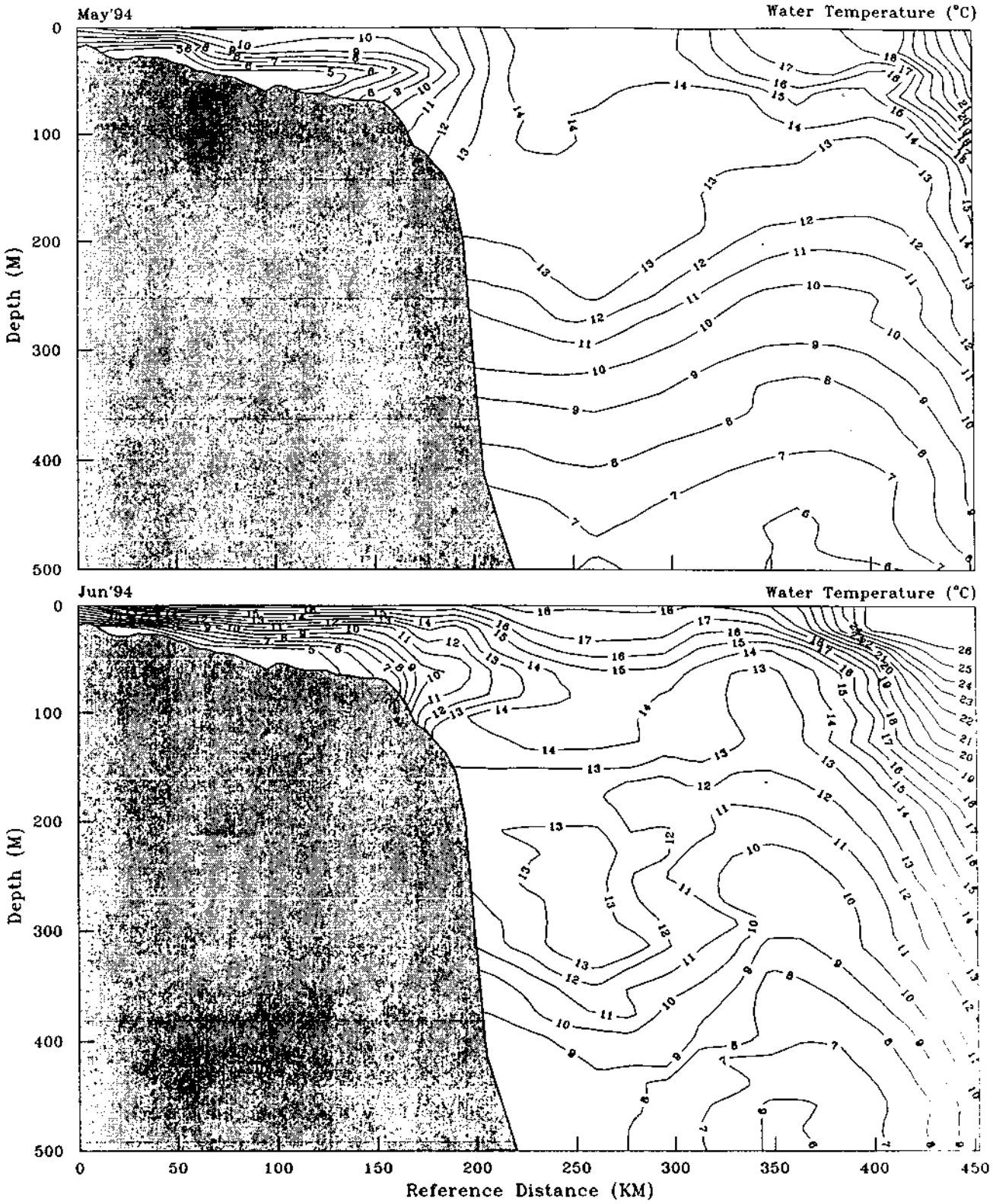

Figure 10. Water-column thermal structure (degrees Celsius) along the Middle Atlantic Bight transect during May and June 1994.

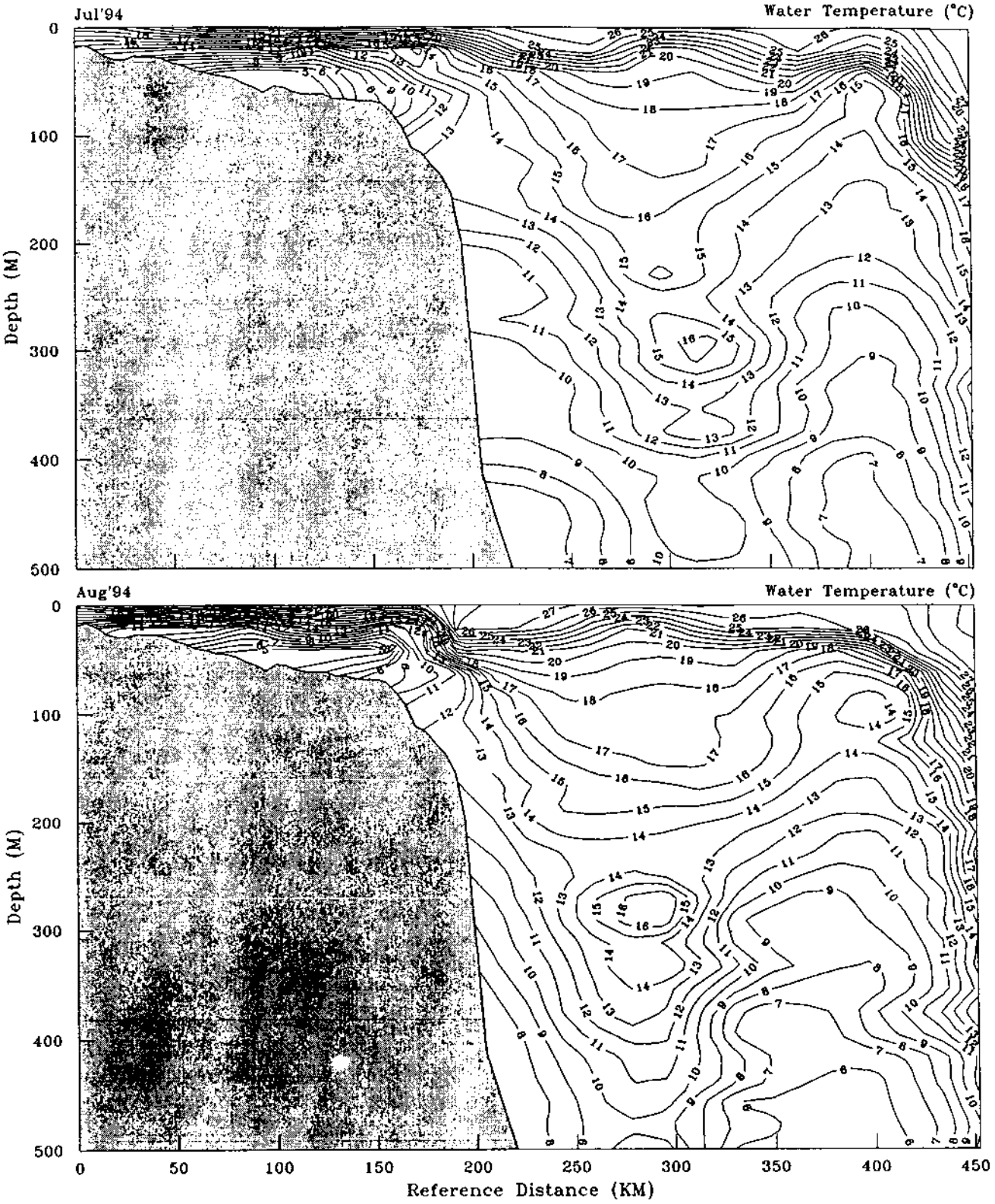

Figure 11. Water-column thermal structure (degrees Celsius) along the Middle Atlantic Bight transect during July and August 1994.

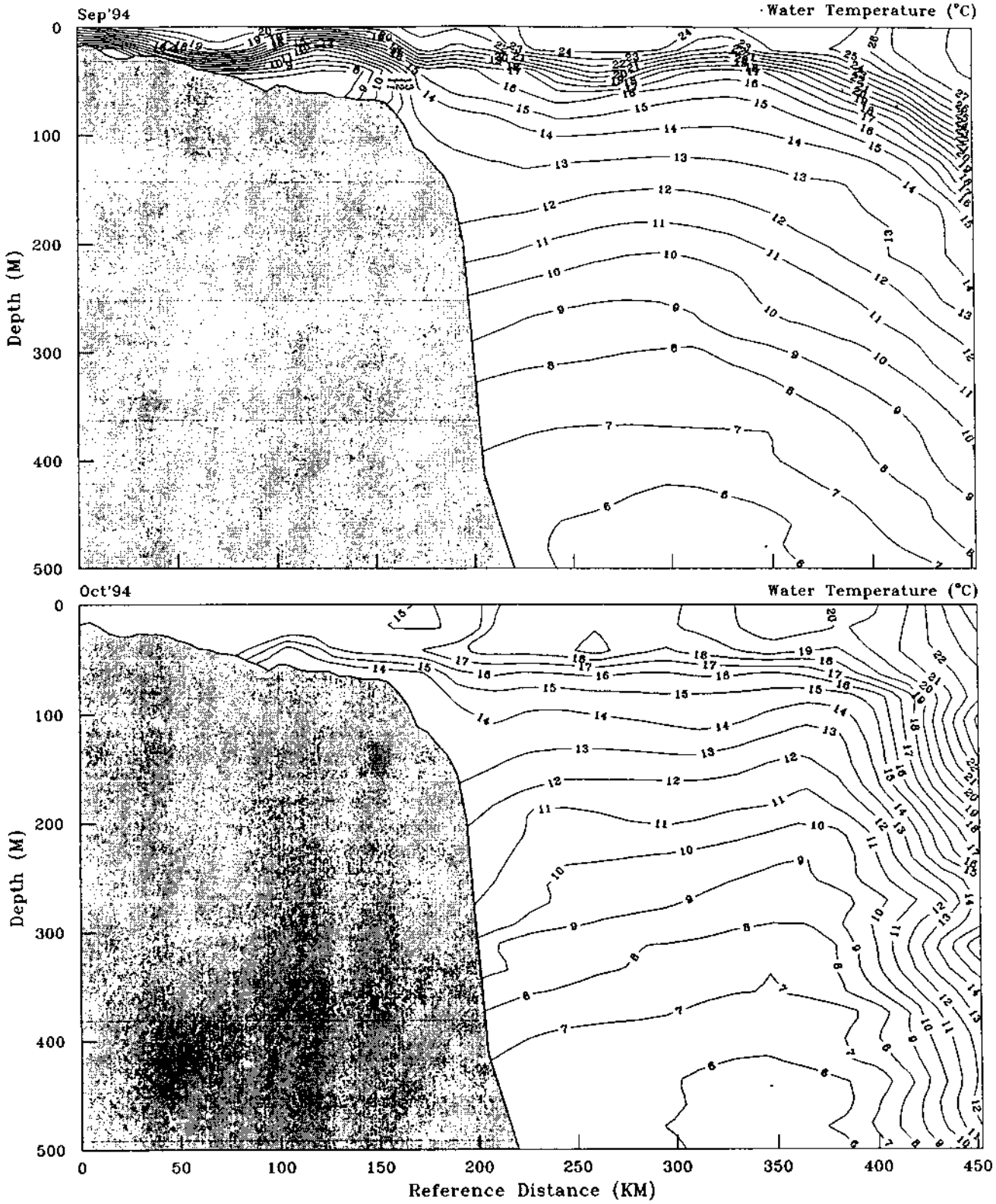

Figure 12. Water-column thermal structure (degrees Celsius) along the Middle Atlantic Bight transect during September and October 1994.

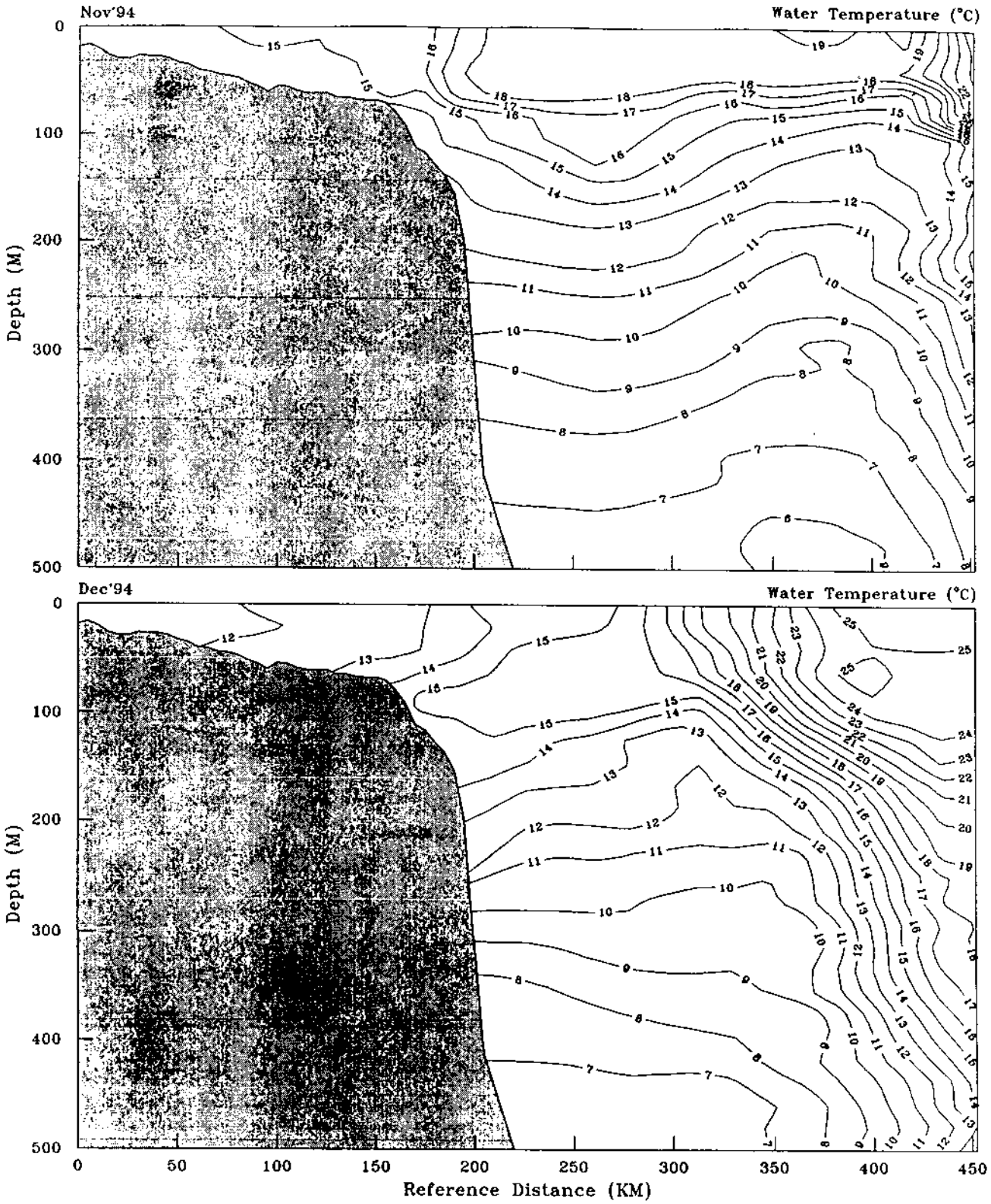

Figure 13. Water-column thermal structure (degrees Celsius) along the Middle Atlantic Bight transect during November and December 1994.

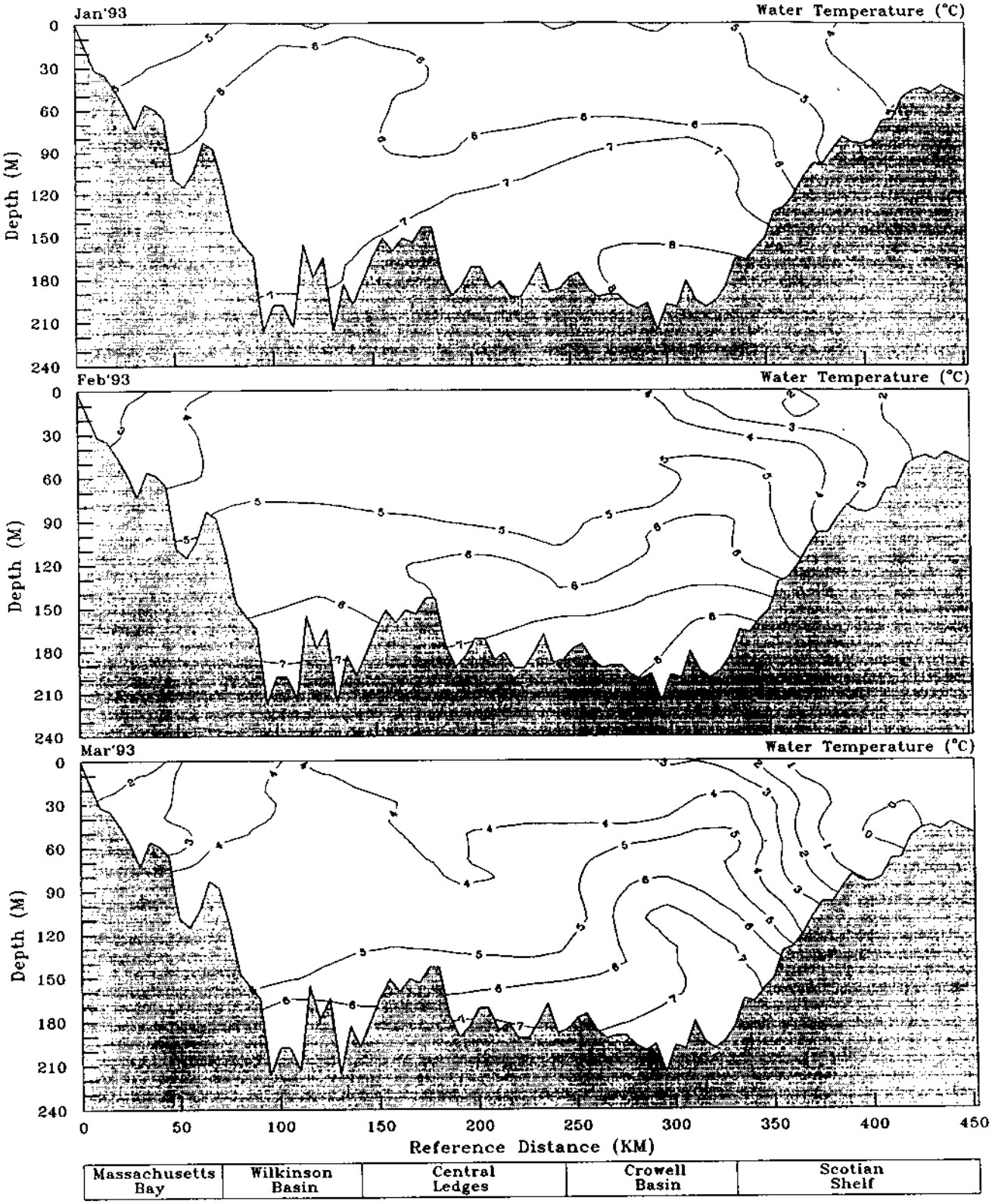

Figure 14. Water-column thermal structure (degrees Celsius) along the Gulf of Maine transect during January, February, and March 1993.

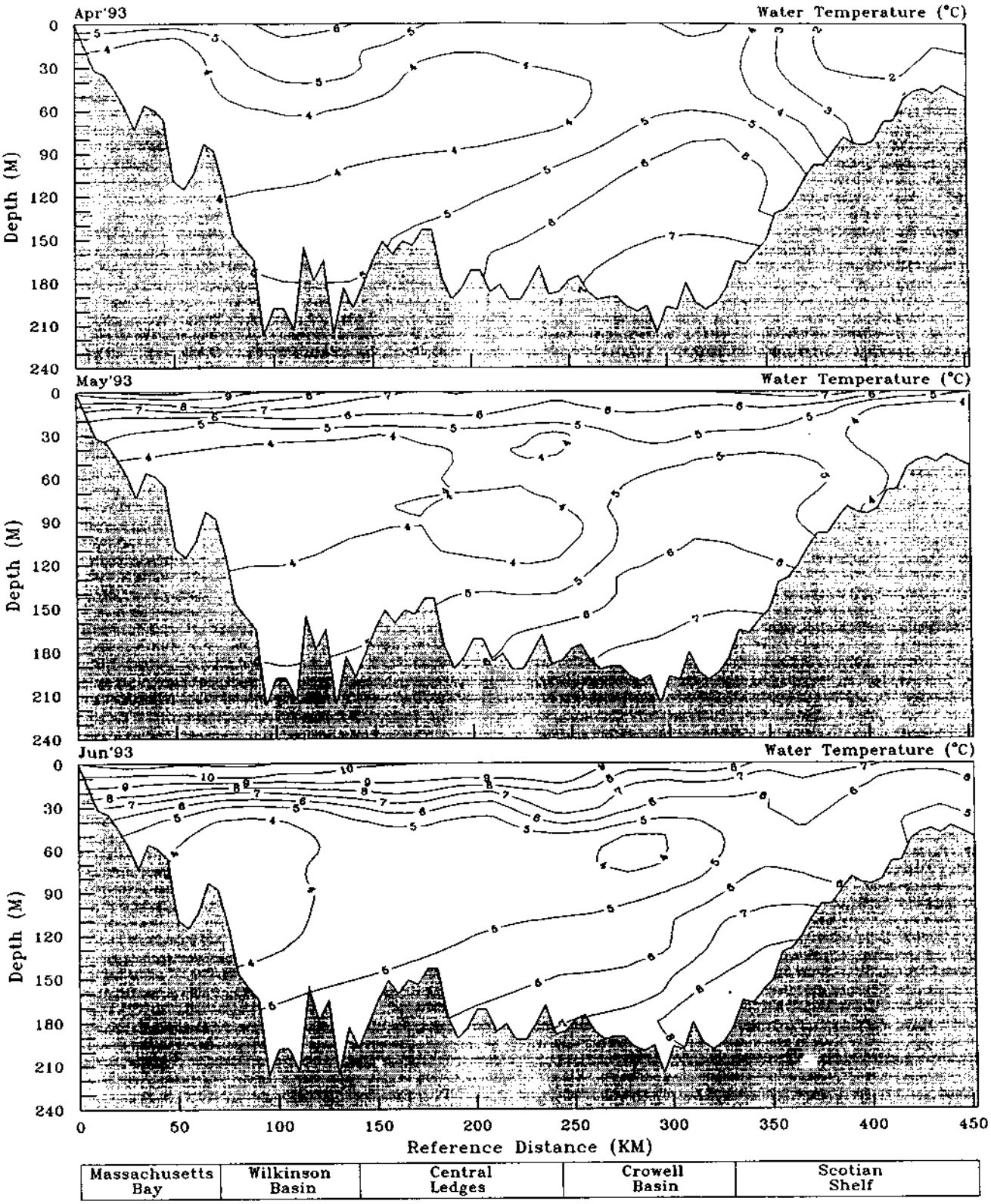

Figure 15. Water-column thermal structure (degrees Celsius) along the Gulf of Maine transect during April, May, and June 1993.

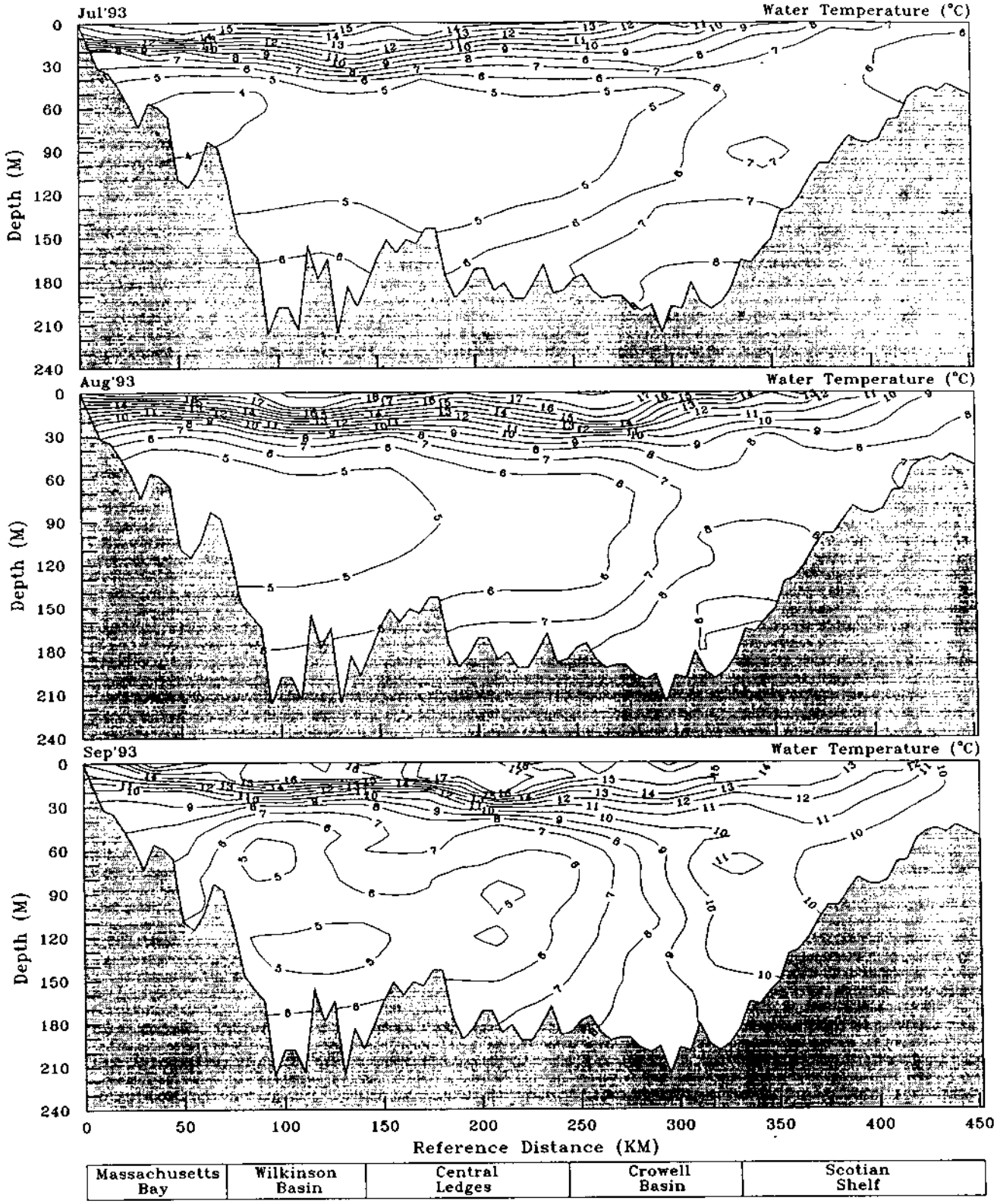

Figure 16. Water-column thermal structure (degrees Celsius) along the Gulf of Maine transect during July, August, and September 1993.

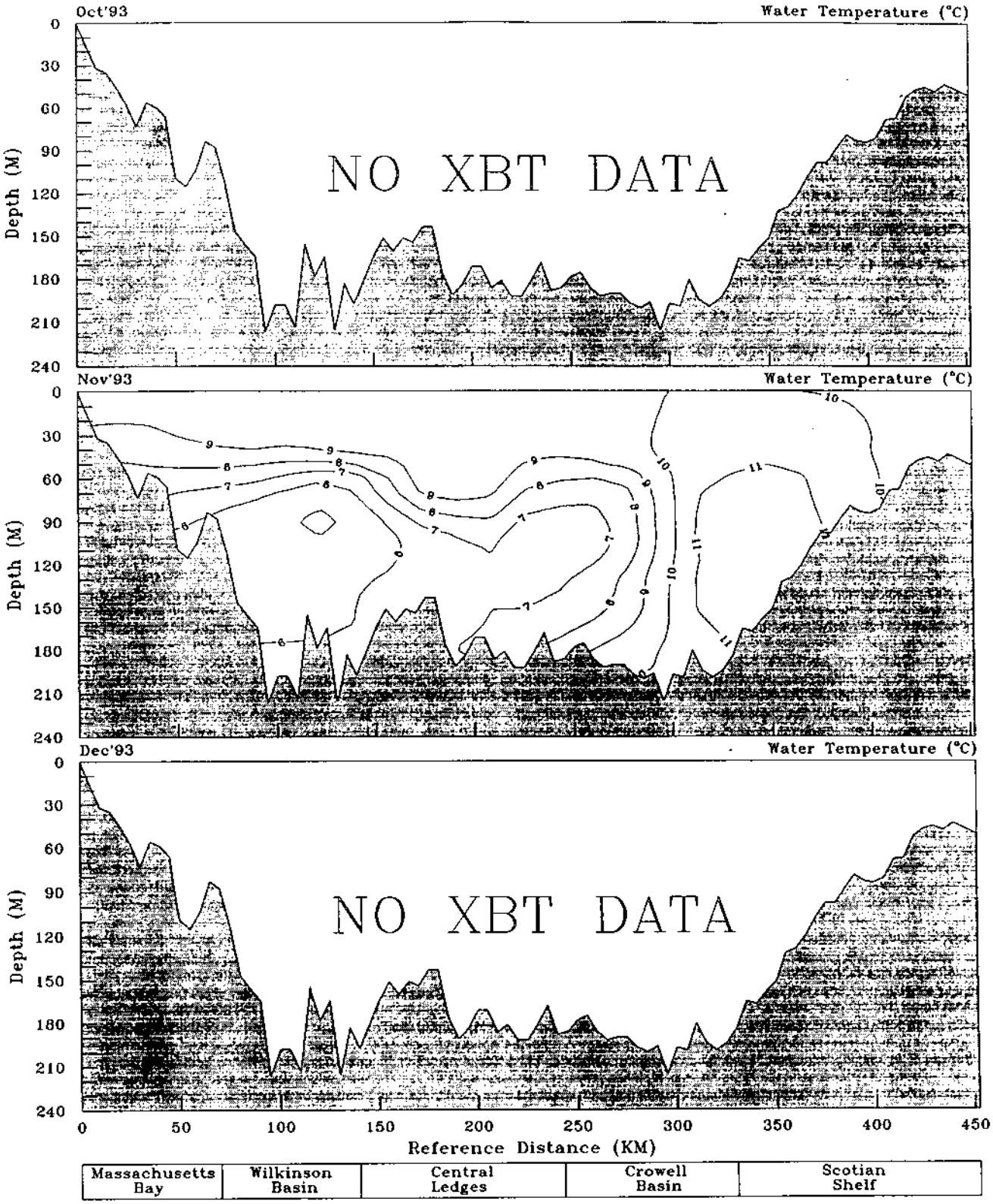

Figure 17. Water-column thermal structure (degrees Celsius) along the Gulf of Maine transect during October, November, and December 1993.

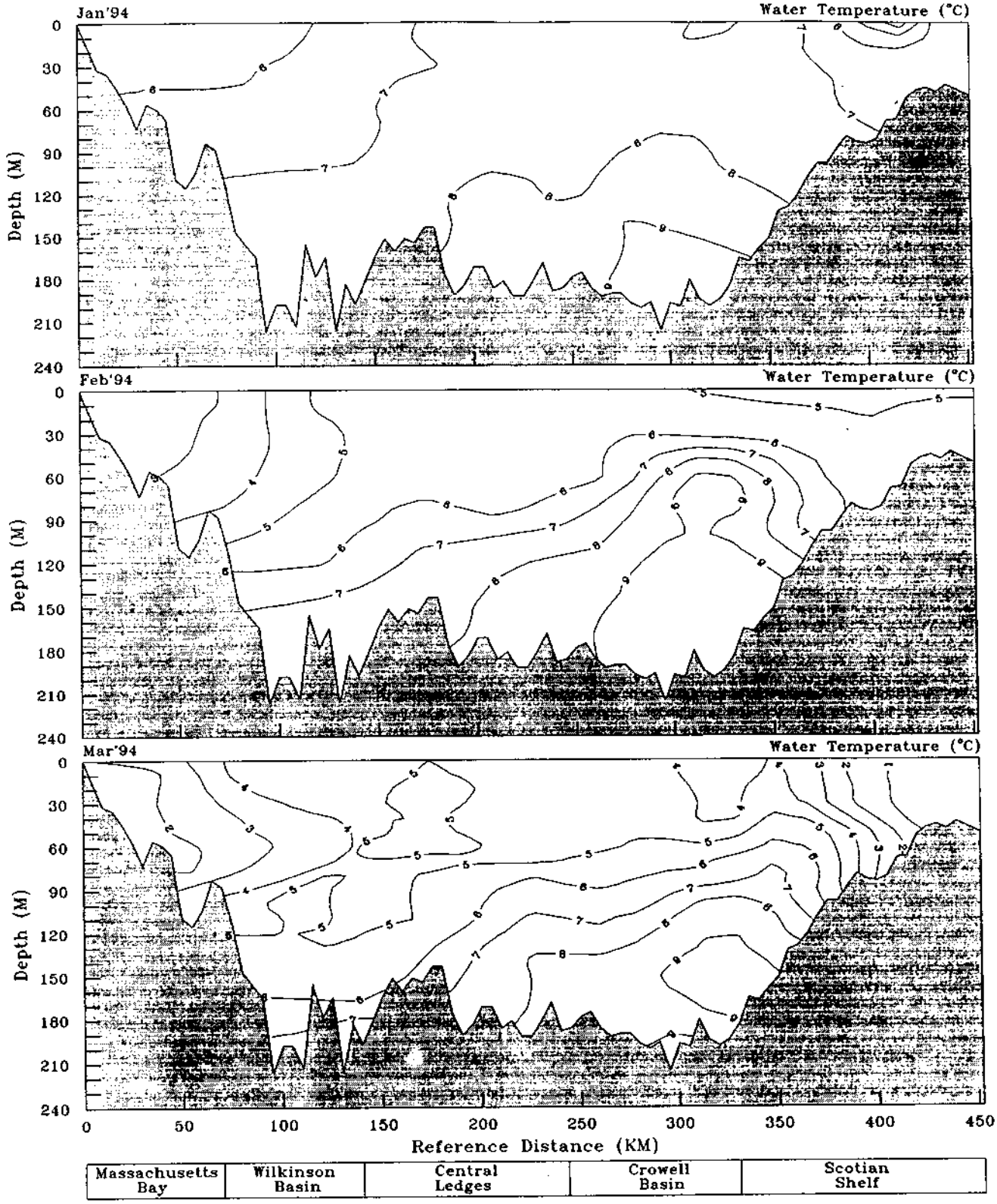

Figure 18. Water-column thermal structure (degrees Celsius) along the Gulf of Maine transect during January, February, and March 1994.

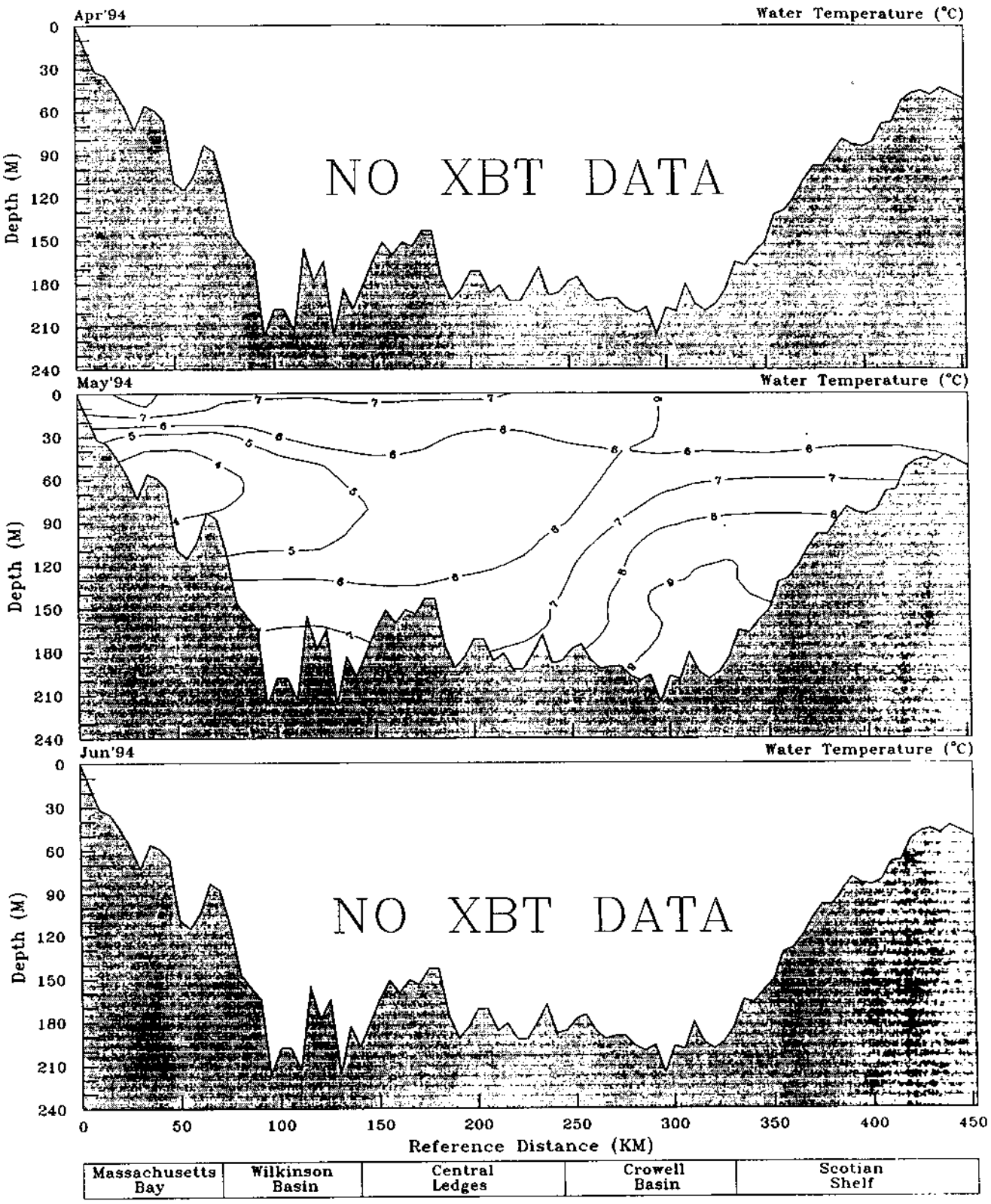

Figure 19. Water-column thermal structure (degrees Celsius) along the Gulf of Maine transect during April, May, and June 1994.

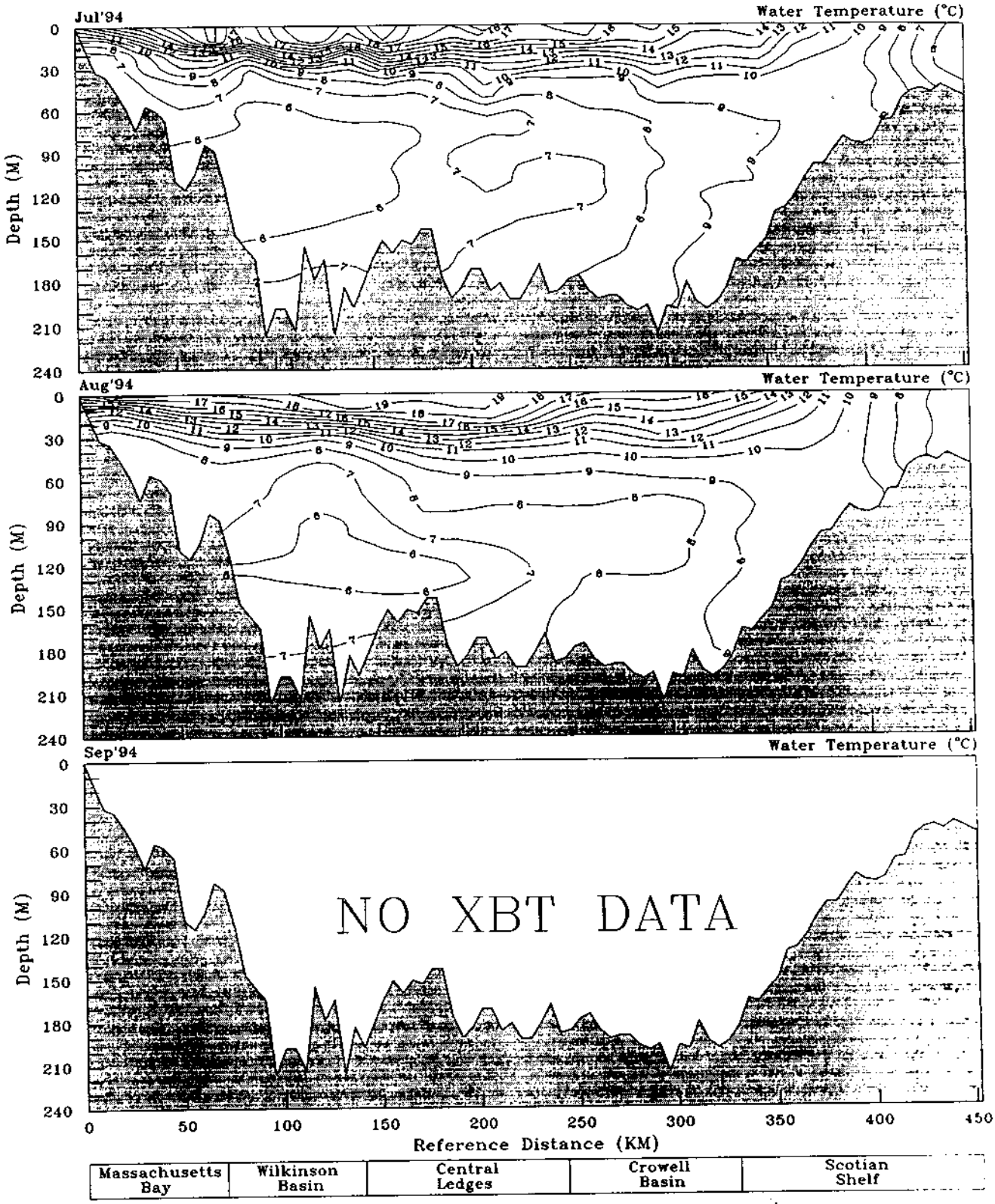

Figure 20. Water-column thermal structure (degrees Celsius) along the Gulf of Maine transect during July, August, and September 1994.

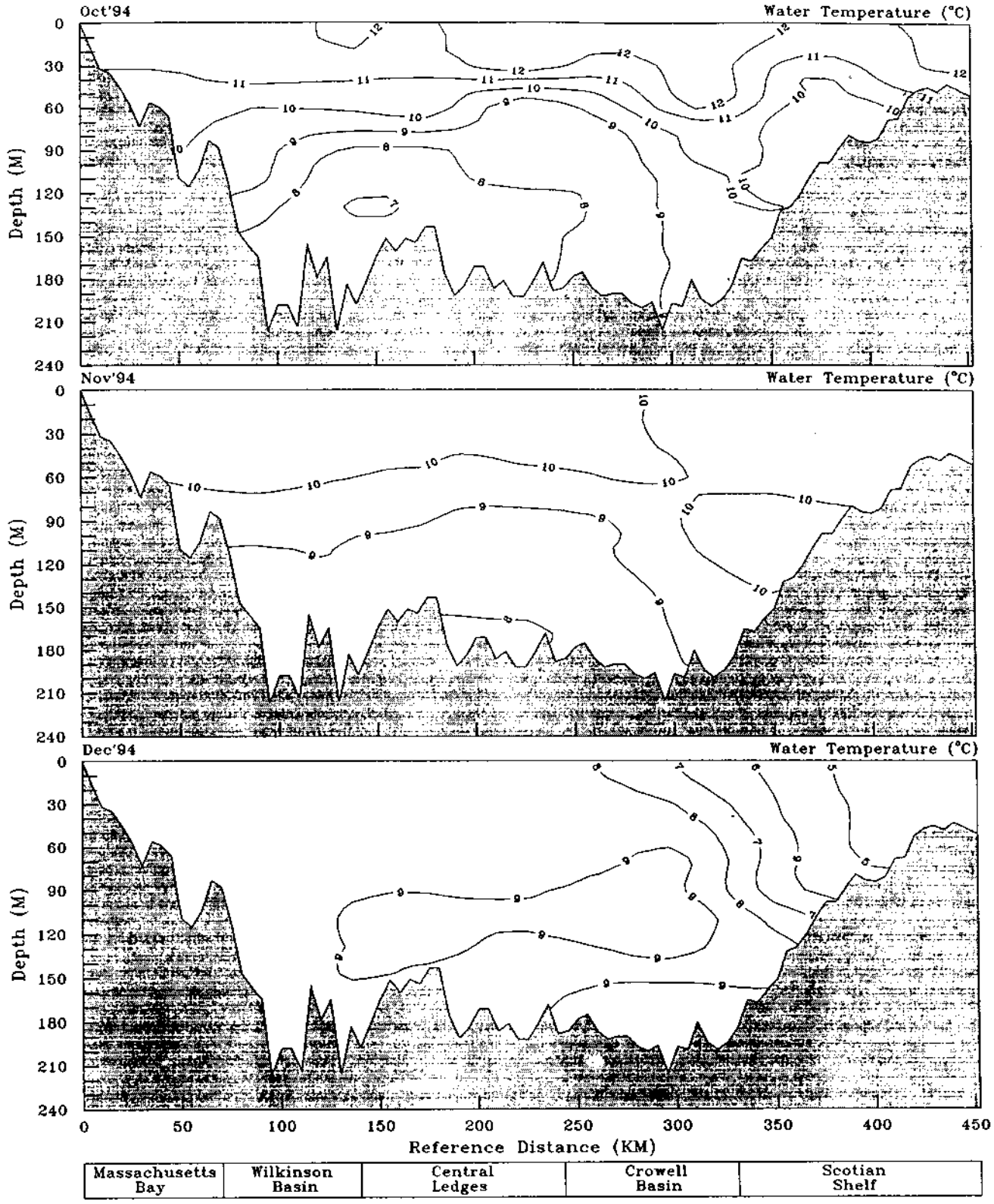

Figure 21. Water-column thermal structure (degrees Celsius) along the Gulf of Maine transect during October, November, and December 1994.