NOAA Technical Report NMFS 24

Temperature Conditions in the Cold Pool 1977-81: A Comparison Between Southern New England and New York Transects

Steven K. Cook

February 1985

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

NOAA TECHNICAL REPORTS NMFS

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John V. Byrne, Administrator
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William G. Gordon, Assistant Administrator for Fisheries

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Temperature Conditions in the Cold Pool 1977-81: A Comparison Between Southern New England and New York Transects

STEVEN K. COOK[1]

ABSTRACT

Expendable bathythermograph data collected by the Ships of Opportunity (SOOP) - Ocean Monitoring Program are analyzed for seasonal and inter-annual variations of the cold pool. Two major SOOP transects within the Middle Atlantic Bight (Southern New England and New York) have been analyzed for the years common to both (1977-81). During the years 1977-81, over 200 transects were occupied, and almost 3,000 XBT's were dropped.

Results show that the cold pool is formed with the onset of spring warming and persists until fall overturn, is consistent year to year in both area and weighted average annual temperature, and advects water from the northeast to the southwest. Results also show a 100-d lag in minimum temperature between the Southern New England and New York transects. Differences in bathymetry between the two transects and their influence on the cold pool are also discussed. Plots of average (1977-81) bottom temperature for both transects are discussed and show consistent annual weighted mean temperature and areas. Bottom temperature plots for individual years, as well as maximum and minimum bottom temperature plots, are presented as Appendix figures.

GENERAL DESCRIPTION OF THE COLD POOL

The cold pool, so named by Bigelow in 1933, is a continuous subsurface water type located on the continental shelf bottom between Georges Bank to the northeast and Cape Hatteras to the southwest. This feature was referred to as "remnant winter water" by Bigelow (1933), Ketchum and Corwin (1964), and Whitcomb (1970) who believed it to be formed from the winter cooling of mixed Middle Atlantic Bight shelf water. The cold pool feature has been traced in the north to the eastern edge of Georges Bank and into the Gulf of Maine (Colton et al. 1968; Limeburner et al. 1978) where temperature and salinity relationships suggest a possible source (Beardsley et al. 1976; Hopkins and Garfield 1979). To the south the cold pool feature has been traced past the offing of Chesapeake Bay to Cape Hatteras where three major water masses (shelf, slope, and Gulf Stream) converge.

The cold pool becomes an identifiable feature each year with the onset of spring surface warming and thermal stratification (generally in late April to early May) and lasts throughout the summer into early fall, until the normal seasonal overturn in October-December, but mostly in November, mixes away the vertical density structure and the water column again becomes isothermal.

Our SOOP - Vertical Temperature sections show that the cold pool normally covers an area on the bottom between the 40 and 110 m isobaths ($\cong$ 20-60 fathoms), an area of approximately 88,000 km^2 between Georges Bank and Cape Hatteras. The average thickness of the feature is about 35 m and extends from the bottom to the base of the thermocline (within 20-30 m of the surface). This represents a volume of about 3,100 km^3.

Wright (1976), from a volumetric analysis, calculated the total volume of shelf water within the Middle Atlantic Bight at about 11,000 km^3. Thus, the cold pool represents about 28% of the total volume of shelf water within the Middle Atlantic Bight.

The cold pool is a slowly moving feature (by virtue of its bathymetric location) when compared with the more active zones of mixing both seaward (shelf water/slope water front) and shoreward (tidal), and it has a general southwesterly flow of about 1 cm/s (0.02 kn) to 5 cm/s (0.10 kn), according to Mayer et al. (1979) and Houghton et al. (1982), respectively. However, it is acted on by several processes, either singly or simultaneously, some of which are as follows:

Wind Events can cause upwelling near shore, moving the shoreward edge of the cold pool toward the beach and sometimes even into the surf zone (Hicks and Miller 1980). Even relatively mild wind events (< 20 mph — 8.9 m/s) with the appropriate directional change can cause a significant change in sea surface temperature, mixed layer depth, and shoreward movement of the cold pool (Cook and Gardner 1978). The same wind events, if persistent enough, also can influence the offshore edge of the cold pool by forcing the shelf water/slope water surface front to move seaward (Csanady 1978).

Gulf Stream Rings migrating along the shelf edge to the southwest through the Middle Atlantic Bight can cause perturbations in the subsurface shelf water/slope water front. Advection of upper slope water (> 12°C) shoreward over the edge of the continental shelf can sometimes move the cold pool off the bottom and cause it to bulge seaward, eventually breaking off into slope water as parcels of shelf water. This process has been referred to as "calving" (Whitcomb 1970; Wright 1976).

Bathymetric Influences such as shoals (Nantucket), together with strong tidal currents, can mix away the cold pool locally. Fourteen major submarine canyons intersect the cold pool at several locations, from Corsair Canyon at the eastern edge of Georges Bank to Norfolk Canyon at the southern end of the Middle Atlantic Bight. Flow in the canyons can cause movement in the position of the cold pool. According to Mooers et al. (1979), down canyon trans-

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port of cold pool water was observed along the southwestern side of Wilmington Canyon, possibly leading to a calving event. In contrast to this, Han and Niedrauer (1981) observed that cold pool water did not sink into the Hudson Shelf Valley, but rather stayed at the same level as on the surrounding shelf. The proximity of the Gulf Stream at the southern edge of the cold pool (Cape Hatteras) entrains both surface shelf water and subsurface cold pool water (Ford et al. 1952; Fisher 1972; Kupferman and Garfield 1977), and limits its southern extent.

A standard bathymetric profile was derived for each route (see Fig. 2) that roughly bisects the transect envelopes shown on Figure 1. The transect envelopes shown on Figure 1 are, of course, diagrammatic and represent the worst case deviations from the "standardized" route. It should be pointed out that the majority of the actual transects collected were much closer to the "standardized" route than the outer edges of the envelope.

Comparison of the "standardized" bathymetry of the Southern New England and New York transects reveals the following:

1) The New York shelf break (120 m) is 43 km (23 nmi) farther seaward than is the break off Southern New England, yielding a 12% wider shelf.
2) Calculation of the distance across the bottom of the depth ranges, taken at 10 m intervals from the beach to the shelf break (120 m), shows significant differences between the two transects (Table 1 and Fig. 2). For example, between the depth ranges of 0-10 m and 10-20 m there is < 1% difference between New York and Southern New England. However, in the depth range of 20-30 m, there is almost 14% more bottom off New York than Southern New England. For the depth ranges pertinent to the Cold Pool (40-110 m), the differences between New York and Southern New England are predictable. Both occupy about the same distance across the bottom: 91 km (49 nmi) for New York compared with 85 km (46 nmi) for Southern New England. However, the bottom distance along the Southern New England transect, between the 40 and 110 m isobaths, represents about 10% more of the shelf width than does the similar distance along the New York transect. This is reflected off Southern New England as a slight shift to seaward into deeper (≅ 10 m) water of the approximate center of the cold pool.
3) The cross-sectional area of the water column from the beach out to 120 m depth along the New York transect is 8.91 km^2 and for the Southern New England transect 7.47 km^2; however, for the 40-110 m depth ranges pertinent to the cold pool, the cross-sectional areas were 2.34 km^2 and 2.41 km^2, respectively.

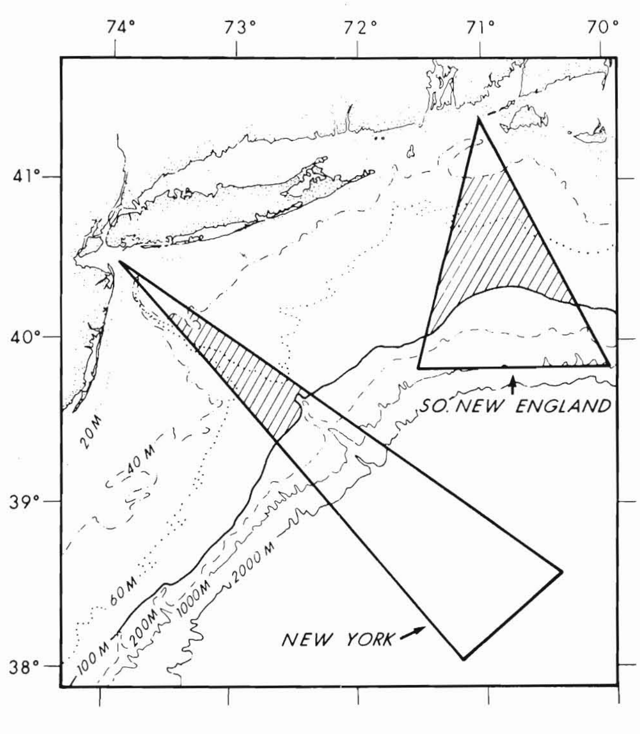

Figure 1.—Locator chart showing transect envelopes for Southern New England and New York. Shading indicates general area of cold pool occupation.

Table 1.—Bathymetric differences between Southern New England and New York. (Also, see Fig. 2.)

Depth ranges (m)	Southern New England nmi	Southern New England %	New York nmi	New York %	Southern New England Δ %	New York Δ %
0-10	3	3.9	3	3.0	+ .9	
10-20	3	3.9	3	3.0	+ .9	
20-30	5	6.5	20	20.2		+13.7
30-40	18	23.4	21	21.2	+ 2.2	
40-50	3	3.8	11	11.1		+ 7.3
50-60	15	19.5	6	6.1	+13.4	
60-70	8	10.4	11	11.1		+ .7
70-80	8	10.4	15	15.2		+ 4.8
80-90	6	7.8	3	3.0	+ 4.8	
90-100	4	5.2	2	2.0	+ 3.2	
100-110	2	2.6	1	1.0	+ 1.6	
110-120	2	2.6	3	3.0		+ .4
Totals	77	100.0	99	99.9	27.0	26.9

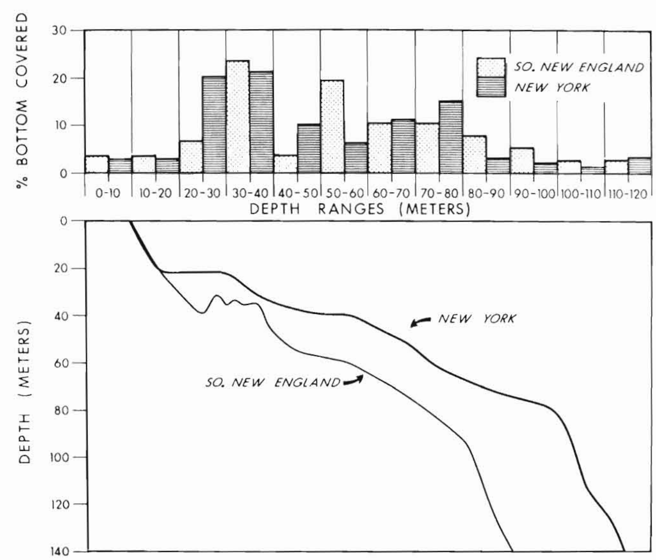

Figure 2.—Plot of standard bathymetry along the Southern New England and New York transects. The bar graph indicates percentage of bottom covered at 10 m intervals from 0 out to 120 m.

METHODS

Almost 3,000 expendable bathythermographs (XBT's) were dropped and over 200 transects collected along two routes (Fig. 1) monitored by the NMFS/AEG (Atlantic Environmental Group)

Ships of Opportunity (SOOP) - Ocean Monitoring Program during 1977-81 (Table 2). These two routes (Southern New England and New York) provide the basis of a unique set of subsurface temperature and sea surface salinity data. Analysis of the more than 200 vertical temperature sections collected during 1977-81 pointed out a need to summarize the data in a bottom temperature vs. time form that would more conveniently describe average conditions.

A detailed description of the construction of bottom temperature plots on a time-depth field can be found in Chamberlin (1978). Briefly, the plots are constructed from contoured vertical temperature sections plotted from XBT data collected by our SOOP - Ocean Monitoring Program. The points (depth) where the whole degree isotherms intersect the bottom are plotted on a depth vs. time grid bounded by depths of 0-200 m and time 0-360 Julian Days. For the shallower depths, from the shore out to the first XBT observation (usually about 30 m), we use temperature recorder (deployed at 20 m off Southern New England) data averaged and plotted by 10 Julian Day intervals and National Ocean Survey (NOS) coastal tide station data (0 m) averaged by month and plotted mid-month. The finished bottom temperature plot, consisting of the combination of XBT, temperature recorder, and NOS data, is then digitized at 10 m intervals, and interpolated temperature values at 10 Julian Day intervals are calculated to create the matrix that is contoured to produce bottom temperature plots (Appendix Figs. 1-10) and composite or averaged plots (Figs. 3, 4).

Additional detail concerning bottom temperatures outside the cold pool and water column characteristics for the years 1977-81 can be obtained from the annual reports in *Annales Biologiques*, Volumes 34-38, for Southern New England (Crist and Chamberlin 1979, 1980, 1981, 1983; Crist in press) and for New York (Cook 1979; Cook and Hughes 1980; Hughes and Cook 1981, 1983, in press).

RESULTS

The cold pool, defined here as temperatures of 10°C or less on the bottom temperature-depth vs. time plots, shows some similarities and major differences in the 5-yr averages for Southern New England and New York (Figs. 3, 4).

Cold pool water attains its minimum temperature near shore because of atmospheric winter cooling about Julian Day 30 (end of January) on both the Southern New England (< 1°C) and the New York (< 2°C) transects. At the center of the feature, (about 70 m depth on the Southern New England transect and 60 m on the New York) minimum temperatures of < 3°C are reached about Julian Day 40 for Southern New England and < 5°C about Julian Day 60 for New York.

The cold pool feature lasts until fall overturn which occurs about 10 d earlier along the Southern New England transect than off New York (Julian Day 265 vs. 275). It is at this time, when fall overturn is complete, that the area on the bottom previously occupied by the cold pool reaches maximum temperature (> 14°C on the Southern New England transect and > 12°C on the New York transect). It should be noted that we have observed fall overturn "maximum", on occasion, of more than 17°C on the New York transect.

The average maximum seaward extension of the cold pool is much less off Southern New England (130 m isobath) than off New York (175 m isobath). Maximum seaward expansion occurs about 20 d later off Southern New England than it does off New York (Julian Day 80 vs. 60).

The most obvious difference between the Southern New England and New York 5-yr average bottom temperature plots is in the variability of the cold pool temperature gradients with time. On the New York transect, periods of general warming in the cold pool are interrupted by shorter periods of cooling. These interruptions in seasonal warming are much less in evidence off Southern New England (see also Appendix Figs. 1 through 10). The cooling events are so prevalent off New York that they cannot be averaged out of the data set and even show up in the 5-yr average bottom temperature plot (Fig. 4). As stated by Houghton et al. (1982), these cooling interruptions on the New York transect are indicative of advective processes ongoing within the cold pool, where cooler water from the Southern New England transect area is transported southwestward into the New York transect area.

Table 2.—Annual distribution of XBT's collected on the Southern New England and New York transects.

	Southern New England					New York				
	1977	1978	1979	1980	1981	1977	1978	1979	1980	1981
Jan.	X	X	X	X	X	X	X	X	X	
Feb.	X	X	X			X	X		X	
Mar.	X	X	X	X	X	X	X	X	X	X
Apr.	X	X	X	X	X	X		X	X	X
May	X	X	X		X	X	X	X	X	X
June	X	X	X	X	X	X	X	X	X	X
July		X	X	X	X	X	X	X	X	X
Aug.	X	X	X	X	X	X	X	X	X	X
Sept.	X	X	X	X	X	X	X	X	X	X
Oct.	X	X	X	X	X	X	X	X	X	X
Nov.	X	X	X		X	X	X	X		X
Dec.	X	X	X	X	X	X	X	X	X	X
Total no. of transects	20	21	22	15	19	13	19	28	14	22
Total no. of XBT's	172	239	275	193	195	142	291	452	379	592
Average/year	19 Transects 214 XBT's					21 Transects 371 XBT's				

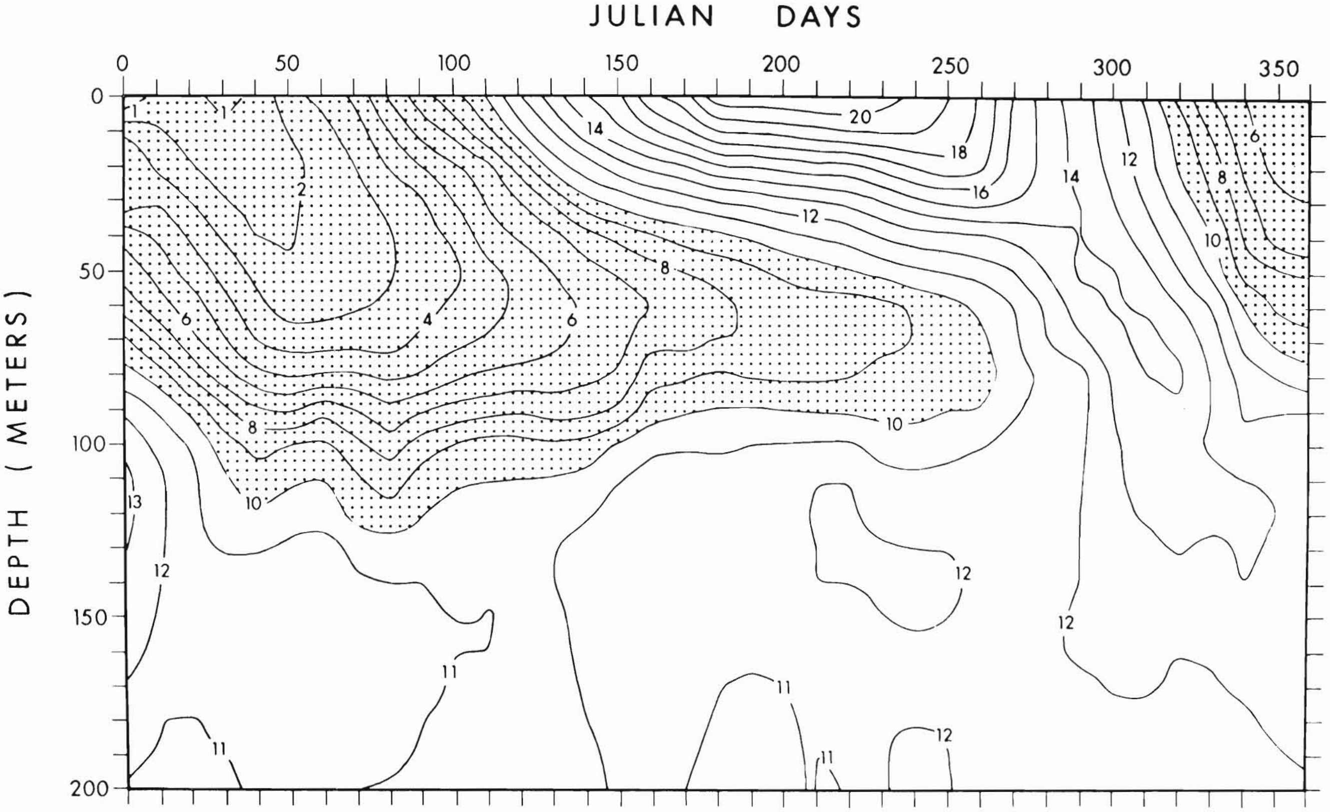

Figure 3.—Plot of average bottom temperature (°C) on depth-time grid for 1977-81 along the Southern New England transect. Shaded area is water of 10°C or less (cold pool).

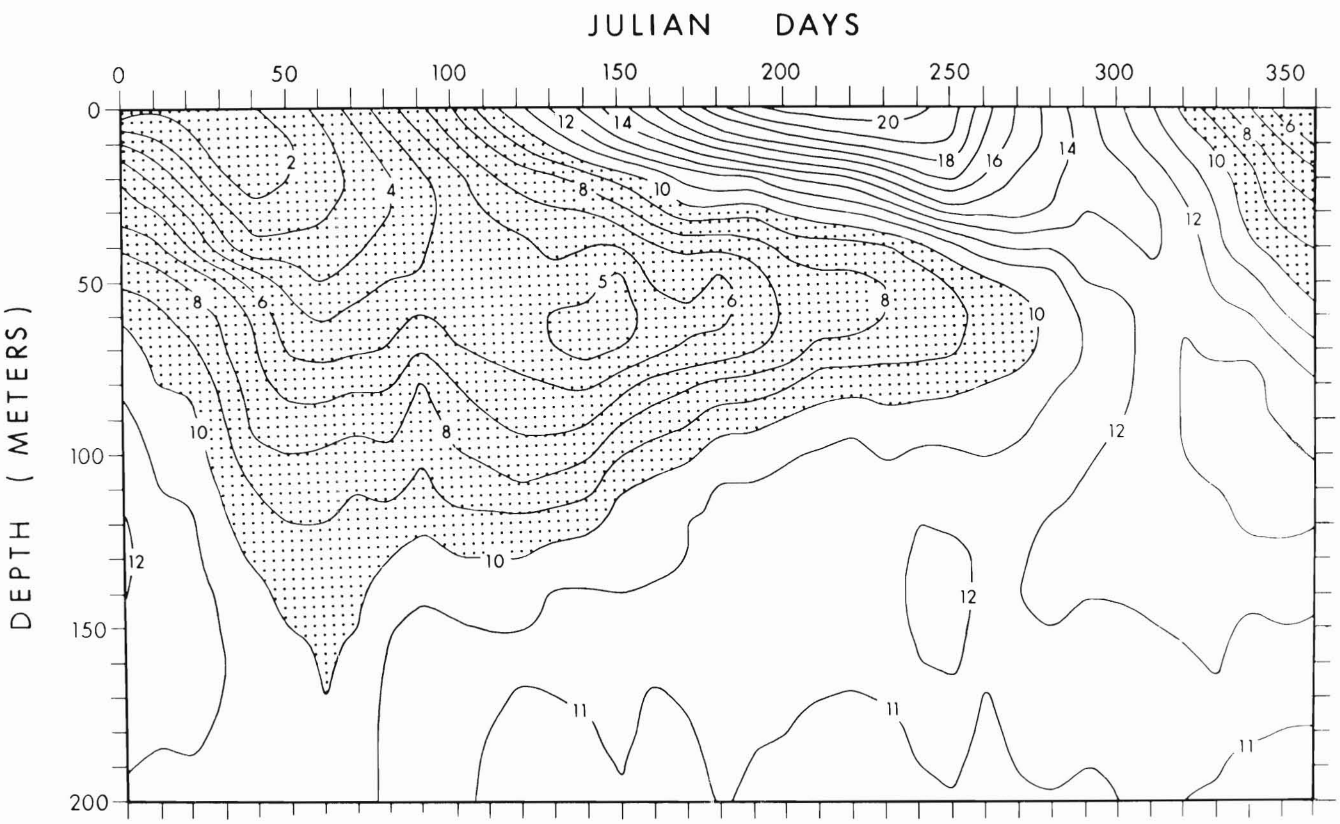

Figure 4.—Plot of average bottom temperature (°C) on depth-time grid for 1977-81 along the New тork transect. Shaded area is water of 10°C or less (cold pool).

Due to the closer proximity of the shelf/slope front to the 100 m isobath on the Southern New England transect and the higher occurrence of Gulf Stream warm core rings (Mizenko and Chamberlin 1979) impinging on the shelf break off Southern New England than off New York, one should expect to observe more "calving" incidents. Several temperature sections drawn from data collected off Southern New England and New York do show parcels of cold pool water at depths of 50 m and more apparently being drawn off the shelf into slope water. At other times, the cold pool has appeared as two cells which could be interpreted as being in two separate pieces or as a lobe of cold pool water such as might occur along a meander that was transected obliquely. In most of these "calving" instances, warm core Gulf Stream rings were present along the transect.

Another technique for portraying the extent and temperature of the cold pool was to calculate from the bottom temperature plots (Figs. 3, 4, and Appendix Figs. 1-5 and 8-12) the percentage of "area" covered by water of 10°C or less and the weighted mean temperature of the same parcel of water. In other words, 100% would equal the "area" (actually depth-time area) bounded by the depth range 0 to 200 m and time bounded by Julian Day 0 to 360. It is apparent from these calculations (Table 3) that there is 3.5% more "area" covered by 10°C or less water along the New York transect than there is along the Southern New England transect, and the New York transect averages about 0.7°C warmer than does the Southern New England transect.

Table 3.—Weighted mean temperature and percent of depth-time "area" covered by water of < 10°C.

	Southern New England			New York		
Years	Source	Weighted mean temp. (°C)	% Area	Source	Weighted mean temp. (°C)	% Area
1977	App. Fig. 1	6.7	26.0	App. Fig. 6	7.4	27.9
1978	App. Fig. 2	6.8	26.7	App. Fig. 7	7.5	30.3
1979	App. Fig. 3	6.6	22.1	App. Fig. 8	7.6	26.9
1980	App. Fig. 4	6.3	20.8	App. Fig. 9	7.6	27.2
1981	App. Fig. 5	6.5	20.1	App. Fig. 10	7.6	26.2
1977-81	Fig. 3	6.8	22.6	Fig. 4	7.5	26.[illegible]

Weighted mean bottom temperatures were calculated by measuring the relative areas of water bounded by whole degree isotherms (1°, 2°, 3°,. . ., 10°C) and using these area fractions as weighting terms in computing the mean temperatures (Table 3). This technique provides a single number for annual comparisons and is proportional to the heat content of the cold pool; and should show better than maximum or minimum temperatures the influence of a warm winter or cold winter on cold pool formation. If, for instance, the winter was very cold and long lasting, one would expect either lower bottom temperatures lasting longer, or usual bottom temperatures occupying a larger "area", or both. If the winter was unusually warm, then one would expect either warmer bottom temperatures or normally cool bottom temperatures occupying a smaller "area". The weighted mean temperature will reflect either condition.

The weighted mean temperatures (Table 3) show significant annual consistency. The maximum variation of weighted mean temperature off Southern New England was 0.5°C (≈ 8%) and 0.2° (≈ 3%) off New York. The only factors that would significantly influence a weighted cold pool temperature would be the intensiveness or mildness of winter and the timing of fall overturn. Overturn occurring either early or late would decrease or increase the overall duration of the cold pool. An unusually intense summer would not impact on the bottom signature of the cold pool, because the bottom is essentially sealed off from the surface by the thermocline until the fall overturn occurs. Increasing solar radiation at the surface would only serve to warm the surface mixed layer. However, other sources of heating to the cold pool as suggested by Ou and Houghton (1982) in the region of the Hudson Shelf Valley could be explained by the alongshelf variation of the heating rate. Other sources of heating can be attributed to slope water intrusions up the Hudson Canyon and eventually into the Hudson Shelf Valley.

Maximum and minimum average bottom temperatures for the 5-yr period at three depths (20 m—shoreward of the cold pool, 120 m—seaward of the cold pool, and 60 m—center of the cold pool) were compared for both Southern New England and New York transects.

Bottom temperatures at 20 m depths off Southern New England show a minimum (0°-3°C) occurring on Julian Day 50, while off New York the minimum (1°-2.5°C) occurred on Julian Day 60. Maximum temperatures (16°-18°C) off southern New England occurred on Julian Day 255, while off New York maximum temperatures (13°-18°C) occurred on Julian Day 260. Both transects, Southern New England and New York, are quite similar for waters inshore of the cold pool. For waters offshore of the cold pool (≥ 120 m), a similar pattern of temperature and timing occurs, only with a smaller overall range in temperature. This is to be expected, because the deeper or further offshore the less measurable the surface influence becomes.

However, an interesting difference occurs within the cold pool at 60 m depth (Fig. 5). Bottom temperatures plotted at 60 m off Southern New England show minimum temperatures (1°-3°C) occurring about Julian Day 66 (end of February) while off New York minimum temperatures (4°-5°C) occur about Julian Day 160 (mid-June). Maximum temperatures (13°-17°C) off Southern New England occur about Julian Day 312, while off New York, maximum temperatures (11°-14°C) occur about Julian Day 332 (Table 4).

From these plots (Fig. 5), it is apparent that timing of maximum cold pool temperatures between Southern New England and New York is controlled by the timing of fall overturn. Timing of minimum temperature on the two transects is controlled by several mechanisms, such as the timing and intensity of vernal warming, speed, volume, and temperature of advected water, and cross-frontal processes ongoing between Southern New England and New York (discussed earlier).

In the early part of the year (during minimum temperature formation), the ranges in temperature off Southern New England and New York do not overlap (Fig. 5), as they do for most of the rest of the year. The bottom water temperatures off Southern New England have the largest range, that is to say that Southern New England is both colder in the winter and hotter at fall overturn than New York. New York minimum temperatures, although not as cold as Southern New England, occur about 100 d after Southern New England—again indicative of advection of cooler water within the cold pool from Southern New England to New York.

NUMERICAL ANALYSIS

Several simple equations were developed in an effort to more easily describe the cold pool temperature cycles. Average bottom temperatures from 60 m depth taken from the 1977-81 bottom

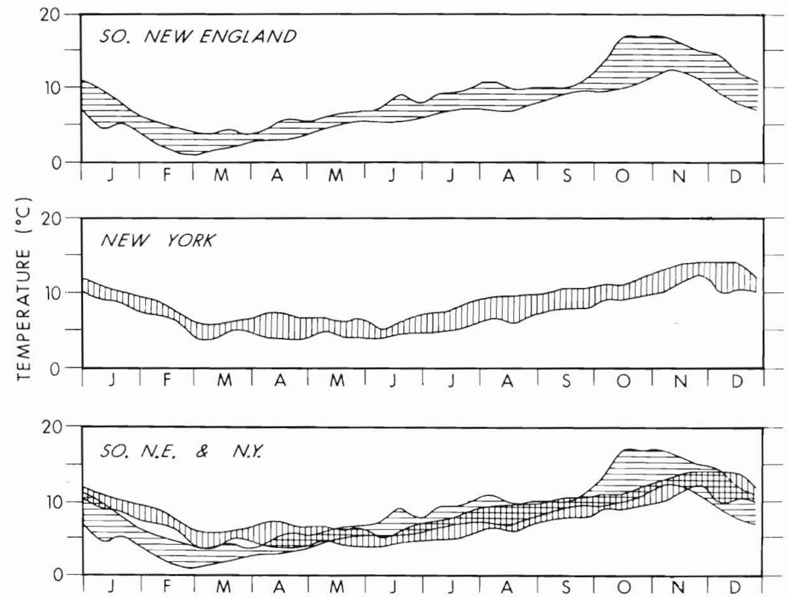

Figure 5.—Plot of maximum and minimum observed bottom temperature (°C) at 60 m depth (approximate core of the cold pool) for Southern New England transect (top), New York transect (middle), and composite of both transects (bottom). Based on 1977-81 data.

temperature plots (Figs. 3, 4) were used in the model development.

Linear regression equations relating A (average temperature 1977-81 at 60 m depth) to T (time-decad/pentad units 10-365) were developed for Southern New England and New York. In an effort to more accurately reflect the data via the regressions, we chose to break the year into seasonal warming (decads 10-250, Julian Day 70-310) and seasonal cooling (decads/pentads 260-365, Julian Day 320-60) periods. The use of neutral decad/pentad units (a common meteorological technique) was used to provide for an always increasing X-axis number in order to make the calculating of the simple statistics easier. The actual Julian Day counterpart and approximate month for the decad/pentad units are shown in Table 5.

The standard errors of coefficients are shown in parentheses for all equations. The standard errors for all equations were smaller than the slopes of the independent parameter (T) suggesting that the influence exerted by T has meaningful effect on the dependent parameter A.

A more acurate test of an independent parameter's significance is the Student t statistic, which was highly significant with $P > 0.0001$ for all equations. Another measure of how well the equation, as a whole, accounts for the dependent parameter's behavior is the F statistic, which was also highly significant for all equations with a $P > 0.0001$ (F statistic).

The correlation coefficient (R^2) measures how much variation in the dependent parameter can be accounted for by equation. Both Southern New England and New York indicate a strong linear association between average temperature and Julian Days. Sample size (N) is also shown for all equations.

Southern New England—warming (decad units 10-250)

$$A = \underset{(0.260)}{1.875} + \underset{(0.002)}{0.043}\,(T) \qquad R^2 = 0.96,\; N = 25$$

Southern New England—cooling (decad/pentad units 260-365)

$$A = \underset{(1.330)}{43.123} - \underset{(0.004)}{0.113}\,(T) \qquad R^2 = 0.99,\; N = 11$$

Due to the cooling lag that occurs off New York, the warming period is shortened to decads 110-250; and a quadratic equation was developed for the decads 10-100.

New York—warming (decad units 110-250)

$$A = \underset{(0.293)}{0.350} + \underset{(0.002)}{0.043}\,(T) \qquad R^2 = 0.98,\; N = 15$$

Table 4.—Derived maximum, minimum, and average of bottom temperatures at 60 m depth (mid-point of the cold pool) and their timing in Julian Days. Collected for 5 yr (1977-81) for the Southern New England and New York transects.

	Southern New England				New York			
Years	Min. temp. °C	Timing J. Day	Max. temp. °C	Timing J. Day	Min. temp. °C	Timing J. Day	Max. temp. °C	Timing J. Day
1977	1.3	60	17.0	310	3.8	150	14.1	330
1978	2.0	70	13.8	320	3.8	150	14.1	340
1979	1.9	60	14.9	330	3.8	160	12.6	350
1980	2.8	60	17.2	290	4.6	160	13.3	320
1981	3.3	80	12.7	310	4.9	160	11.4	320
Avg.	2.3	66	15.1	312	4.2	156	13.1	332

Table 5.—Comparison of Julian Day and decad/pentad units and approximate months for both warming and cooling periods. Decad/pentad units are used in calculating average temperatures from the equations used in the numerical analysis of the cold pool.

Julian Day	Decad/ Pentad units	Approximate months	
70	10		
80	20	March	
90	30		
100	40		
110	50	April	
120	60		
130	70		
140	80	May	
150	90		
160	100		Warming period
170	110	June	
180	120		
190	130		
200	140	July	
210	150		
220	160		
230	170	August	
240	180		
250	190		
260	200	September	
270	210		
280	220		
290	230	October	
300	240		
310	250		
320	260	November	
330	270		
340	280		
350	290	December	Cooling period
360	300		
10	315		
20	325	January	
30	335		
40	345		
50	355	February	
60	365		

New York—cooling (decad/pentad units 260-365)

$$A = 31.543 - 0.069\,(T) \qquad R^2 = 0.96$$
$$(1.442) \qquad (0.005) \qquad N = 11$$

New York—cooling lag (decad units 10-100)

$$A = 4.377 + 0.058\,(T) - 0.0006\,(T^2) \qquad R^2 = 0.91$$
$$(0.223) \quad (0.009) \qquad (0.00008) \qquad N = 10$$

CONCLUSIONS

Previously published information, in conjunction with the 5-yr time series presented here, leads to the following conclusions in describing the cold pool feature.

1) The cold pool is formed every year with the onset of vernal warming and persists until fall overturn. As summer progresses and the thermocline intensifies, the cold pool is sealed off from surface influence and becomes more identifiable as a thermal barrier. The timing of formation and destruction is consistent (±10 Julian Days) year to year.
2) The cold pool is a mostly continuous feature extending from the northeast point of Georges Bank (Gulf of Maine?) to the area between Chesapeake Bay and Cape Hatteras, where it is mixed away along with the slope water by interaction with the Gulf Stream. Along its course, the cold pool can vary in width across the bottom and thickness on the bottom but generally is located between 40 and 110 m depth, and represents about 28% of the total volume of shelf water within the Middle Atlantic Bight.
3) The cold pool is made up of winter-cooled mixed shelf and slope water, with an additional advective source from the Gulf of Maine.
4) The cold pool is consistent year to year in both "area" (occupying about 24% of the area on the depth vs. time plot) and weighted mean temperature (averaging a little more than 7°C).
5) The water within the cold pool flows from the northeast to the southwest at rates of 1-3 cm/s (0.5 to 1.4 nmi/d).
6) Several processes (wind, rings,. . . etc.) can influence the position, shape, and intensity of the cold pool. These processes can manifest themselves as cold pool meandering, calving, lobes, lenses, and high or low cross-frontal mixing rates.
7) The major differences in the cold pool off New York from that off Southern New England are the 100-d lag in the occurrence of minimum temperature along the New York transect from that of the Southern New England, and that the Southern New England transect is always cooler in the winter and warmer at fall overturn than the New York transect.
8) The cold pool along both transects can be described with a relatively simple numerical analysis, with the New York transect, due to its cooling lag, necessitating a more complex model.

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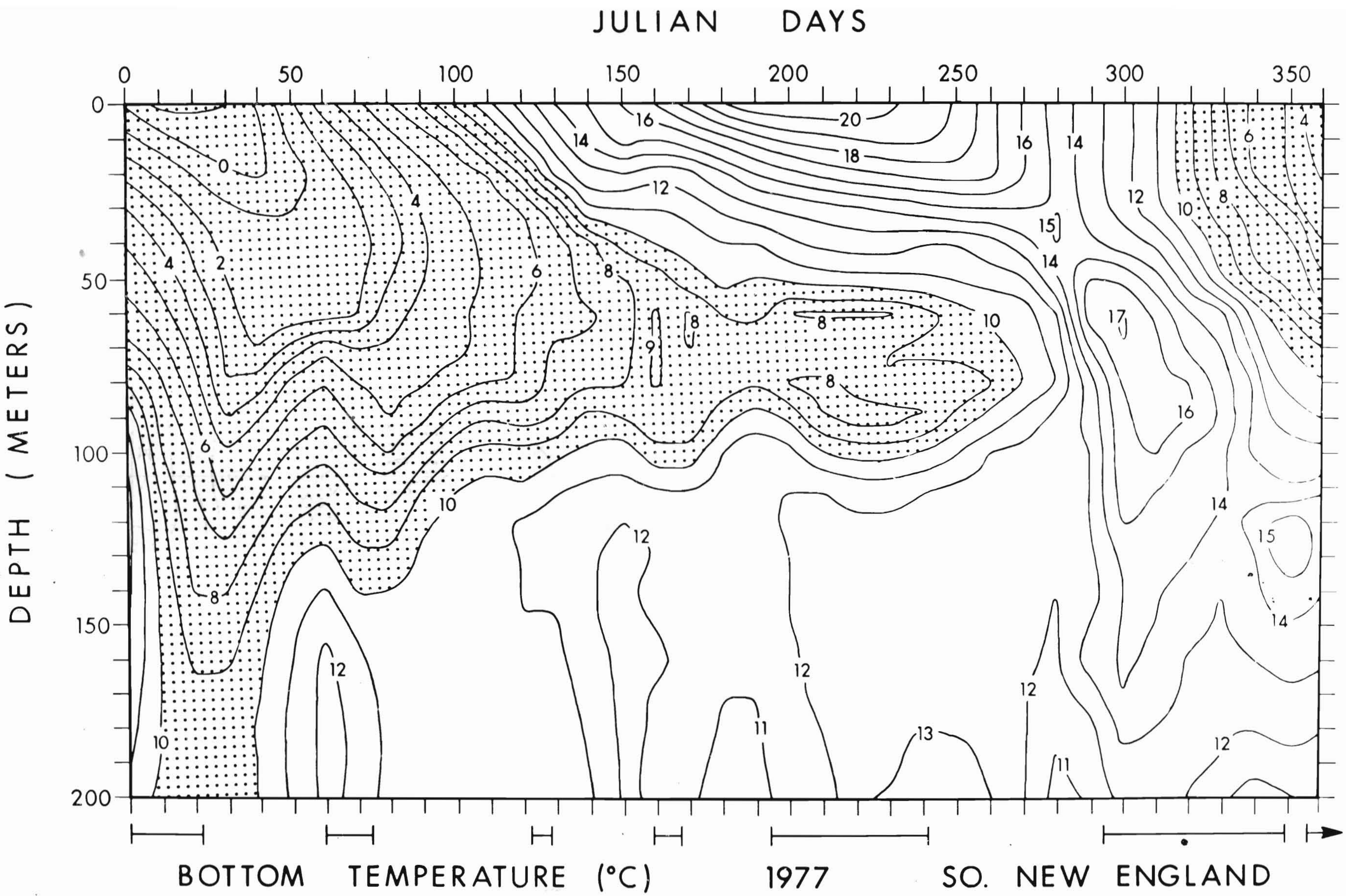
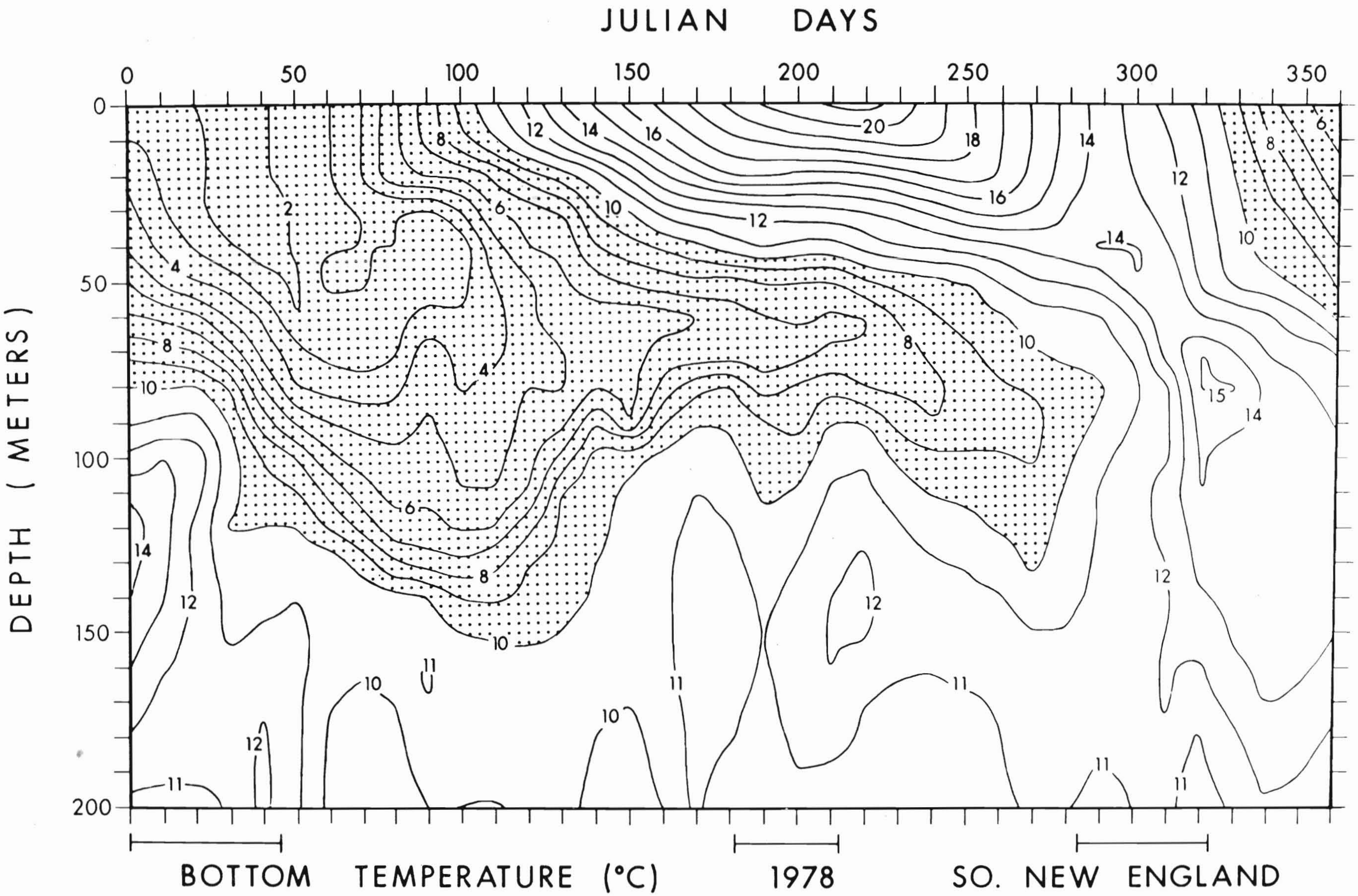
APPENDIX FIGURES

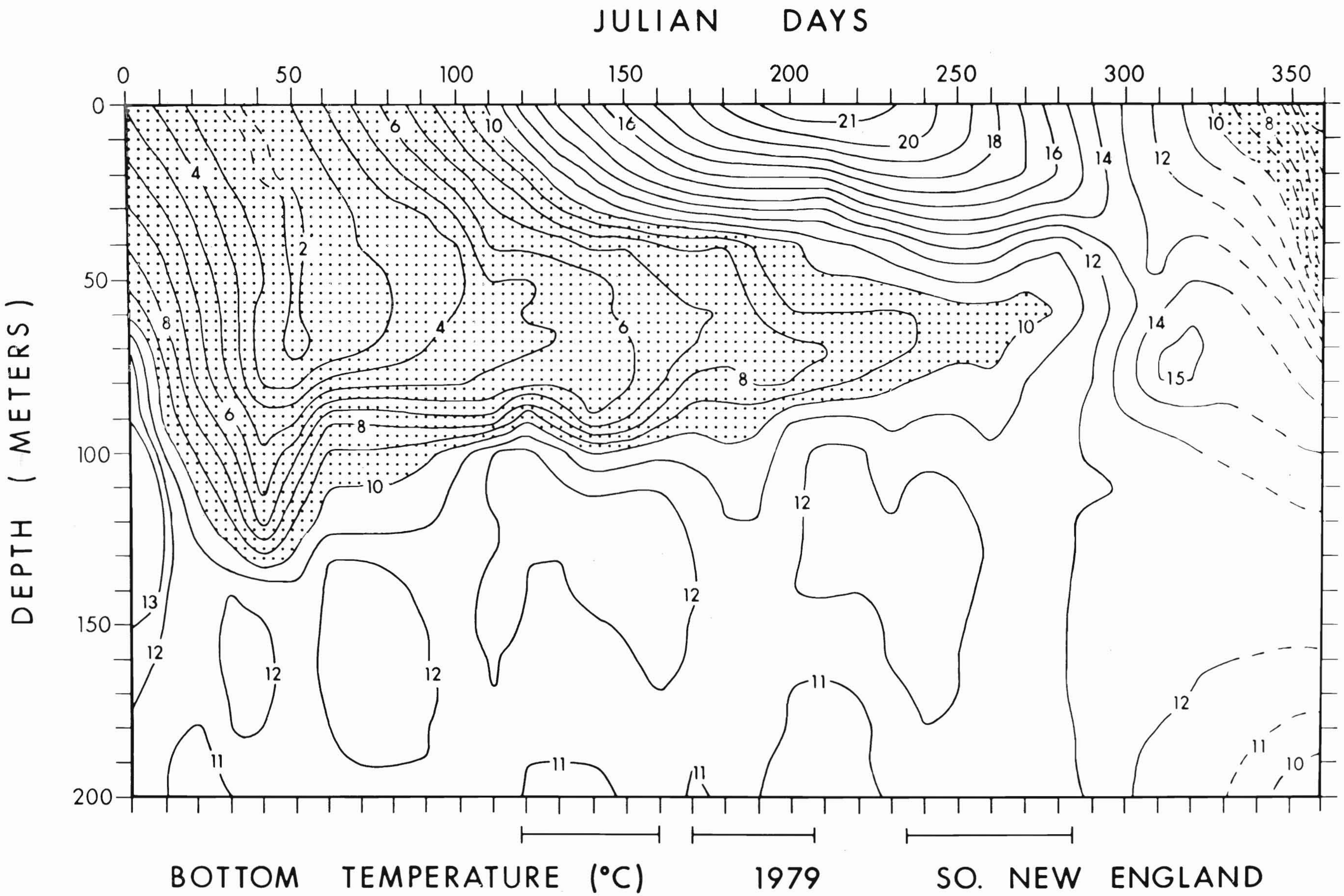
Bottom temperature plots for both the Southern New England and New York transects are presented for each year used in this time series study. Cold pool water (10°C or less) has been shaded for easier comparison with the averaged plots. The bracketed lines at the bottom of each plot represent those times and duration when rings were present along the transects.



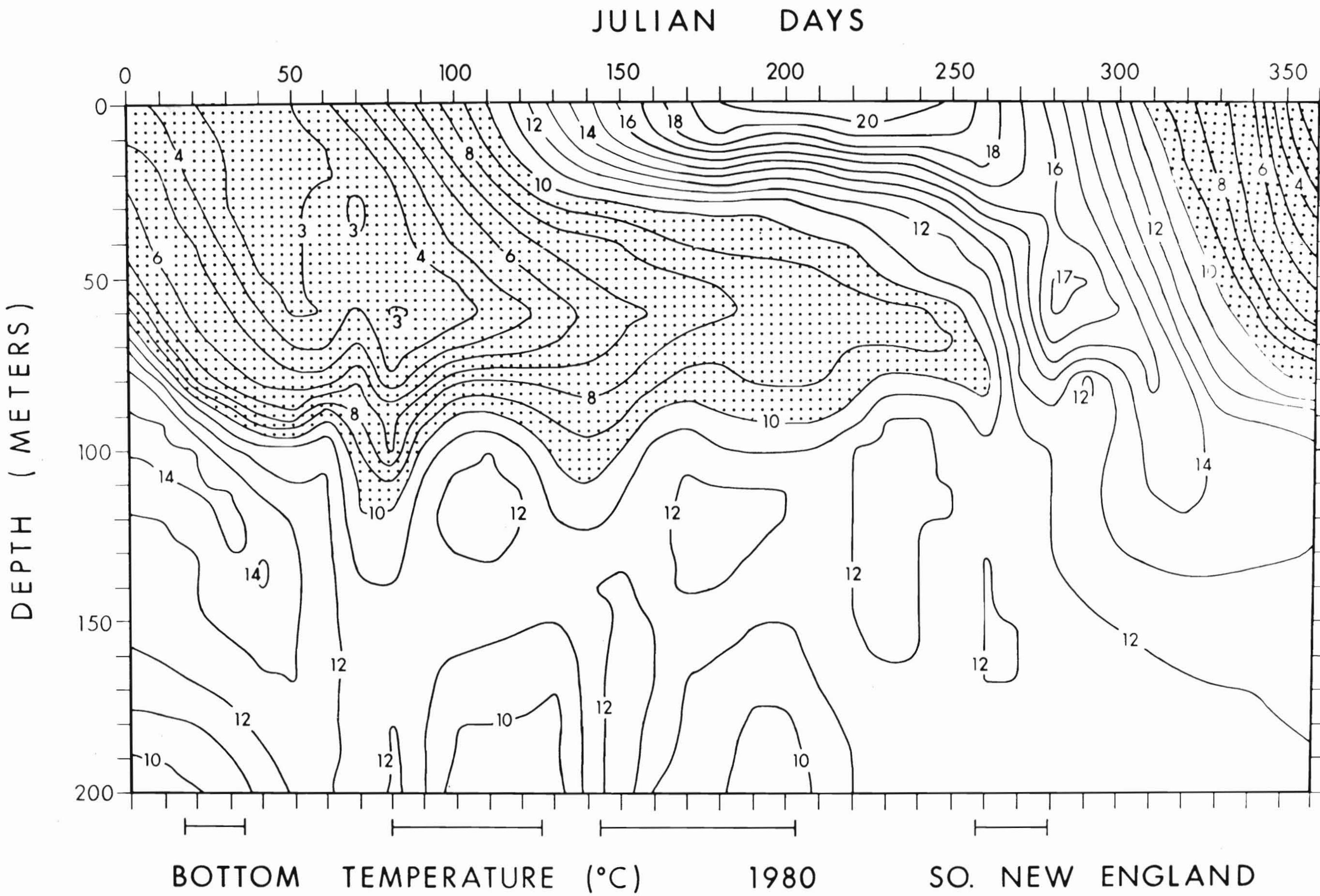
Appendix Figure 1.—Plot of bottom temperature (°C) on depth-time grid along the Southern New England transect for 1977.



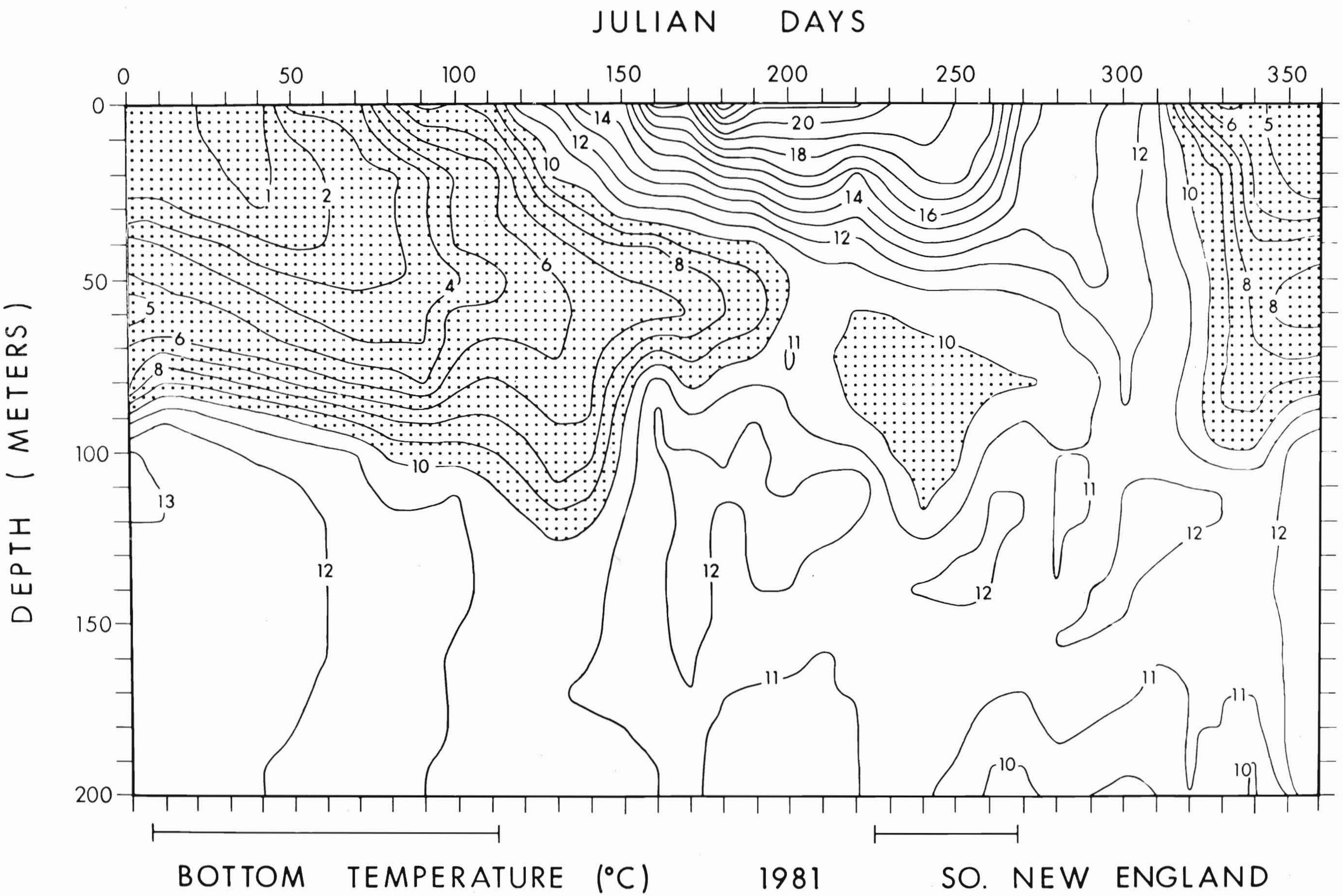
Appendix Figure 2.—Plot of bottom temperature (°C) on depth-time grid along the Southern New England transect for 1978.



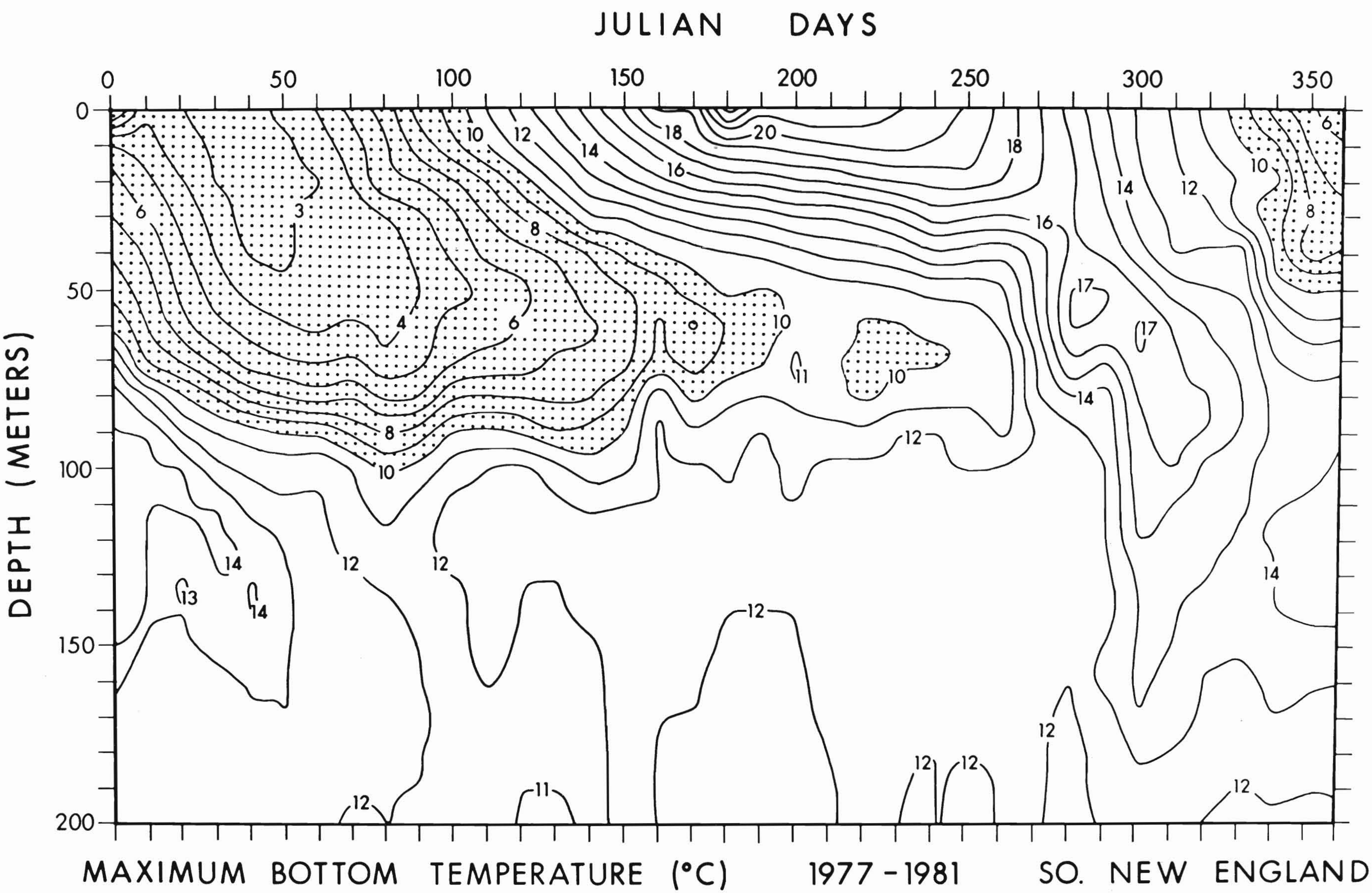
Appendix Figure 3.—Plot of bottom temperature (°C) on depth-time grid along the Southern New England transect for 1979.



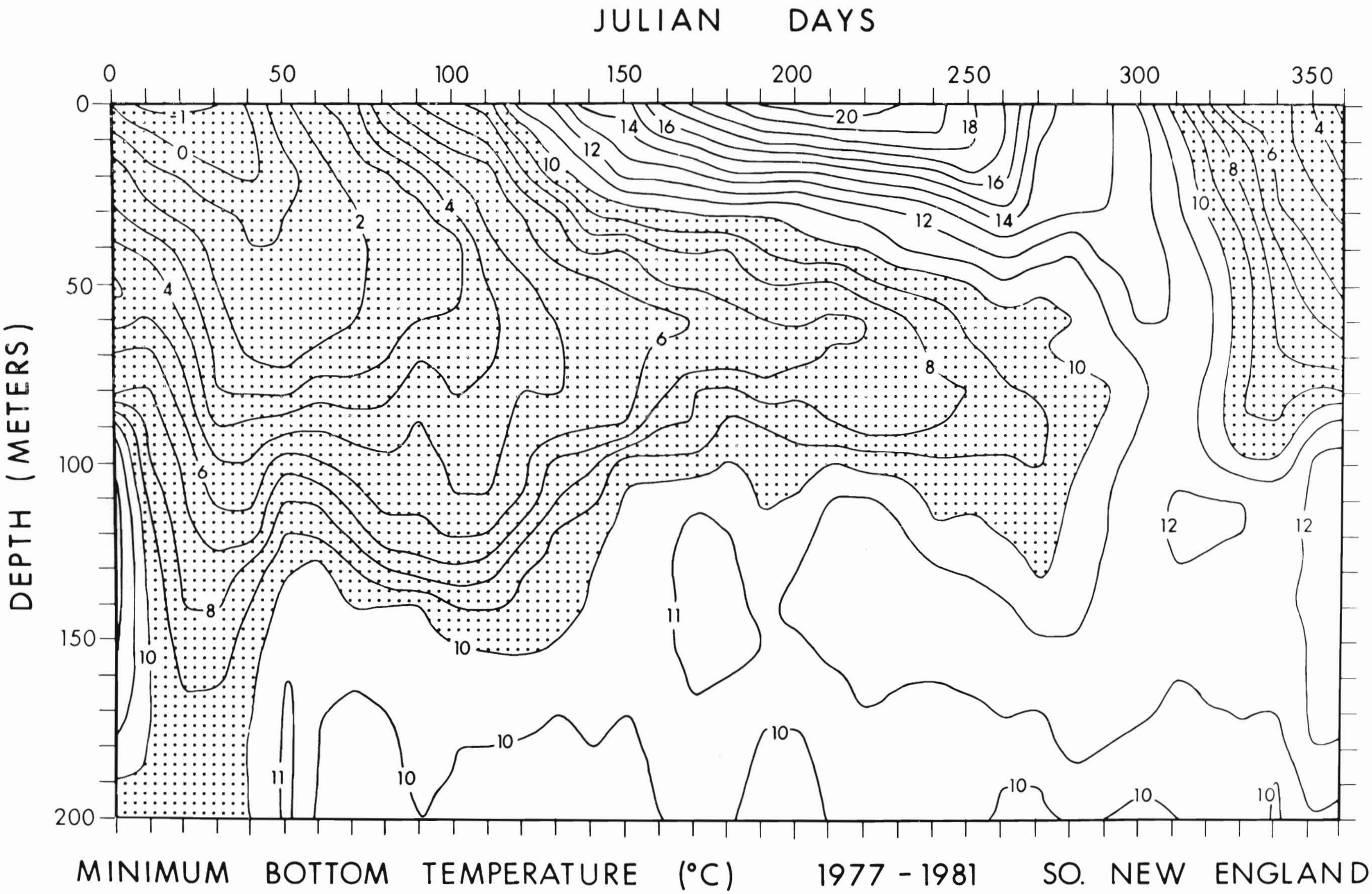
Appendix Figure 4.—Plot of bottom temperature (°C) on depth-time grid along the Southern New England transect for 1980.



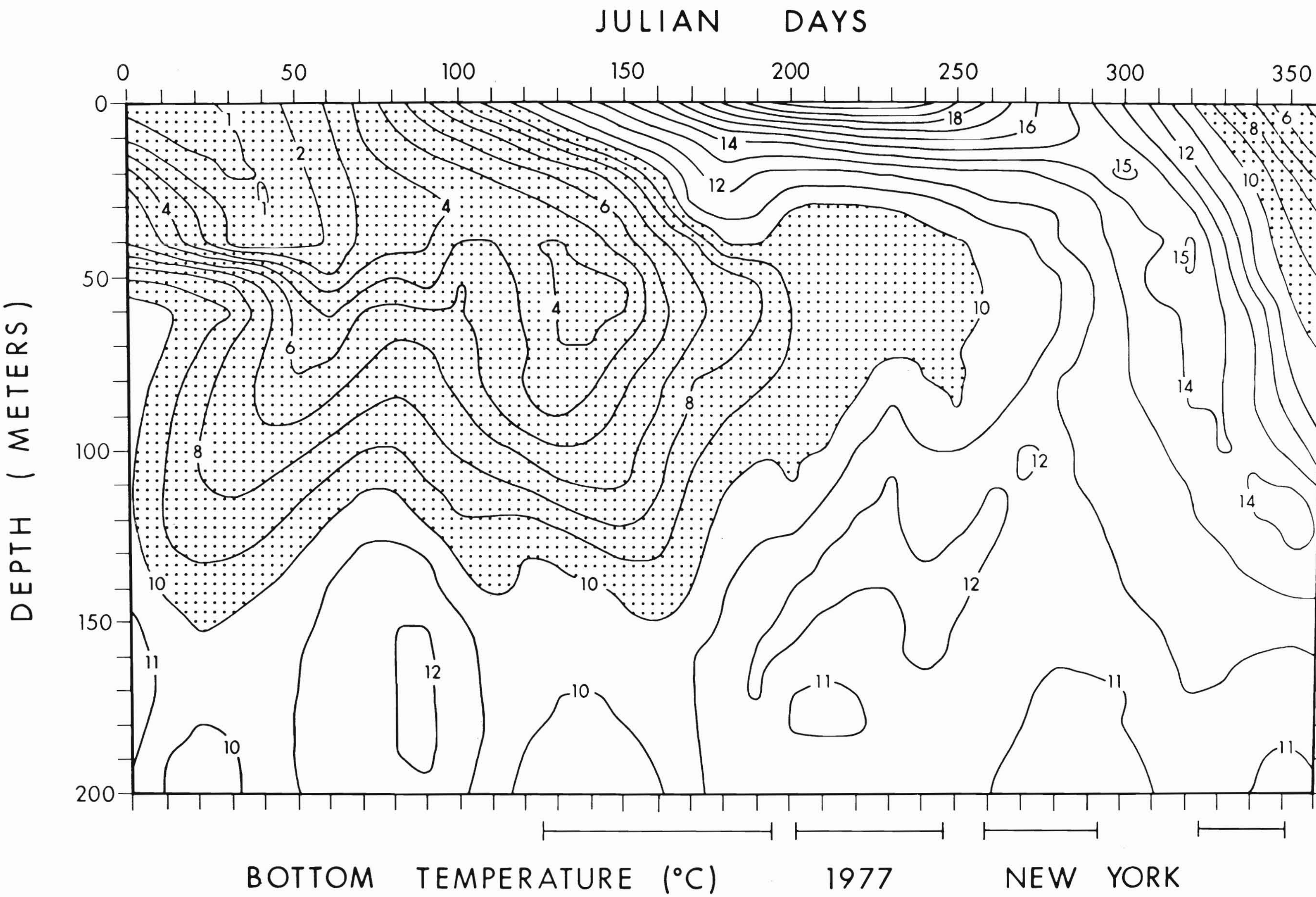
Appendix Figure 5.—Plot of bottom temperature (°C) on depth-time grid along the Southern New England transect for 1981.



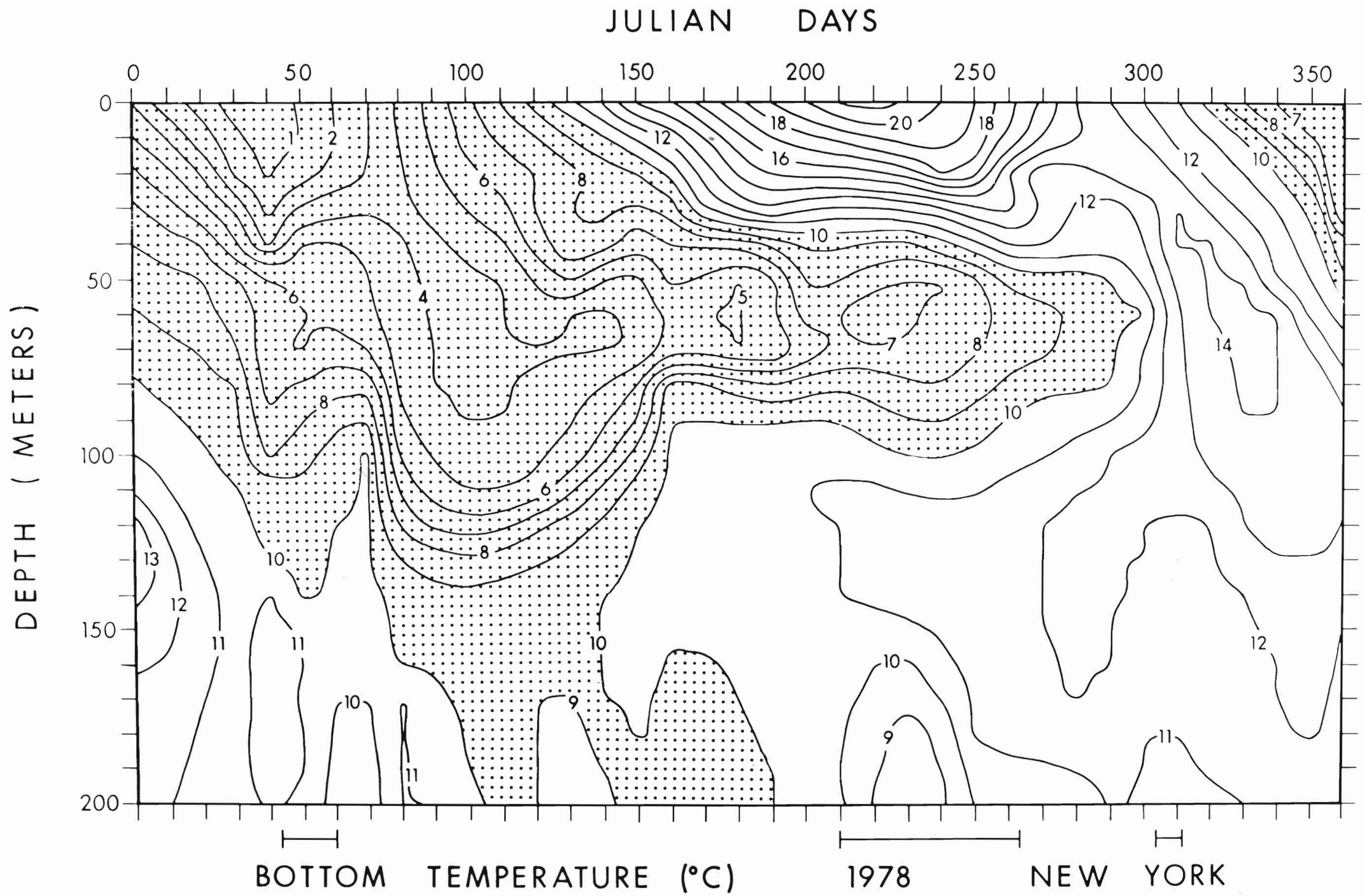
Appendix Figure 6.—Plot of maximum bottom temperature (°C) on depth-time grid for 1977-81 along the Southern New England transect.



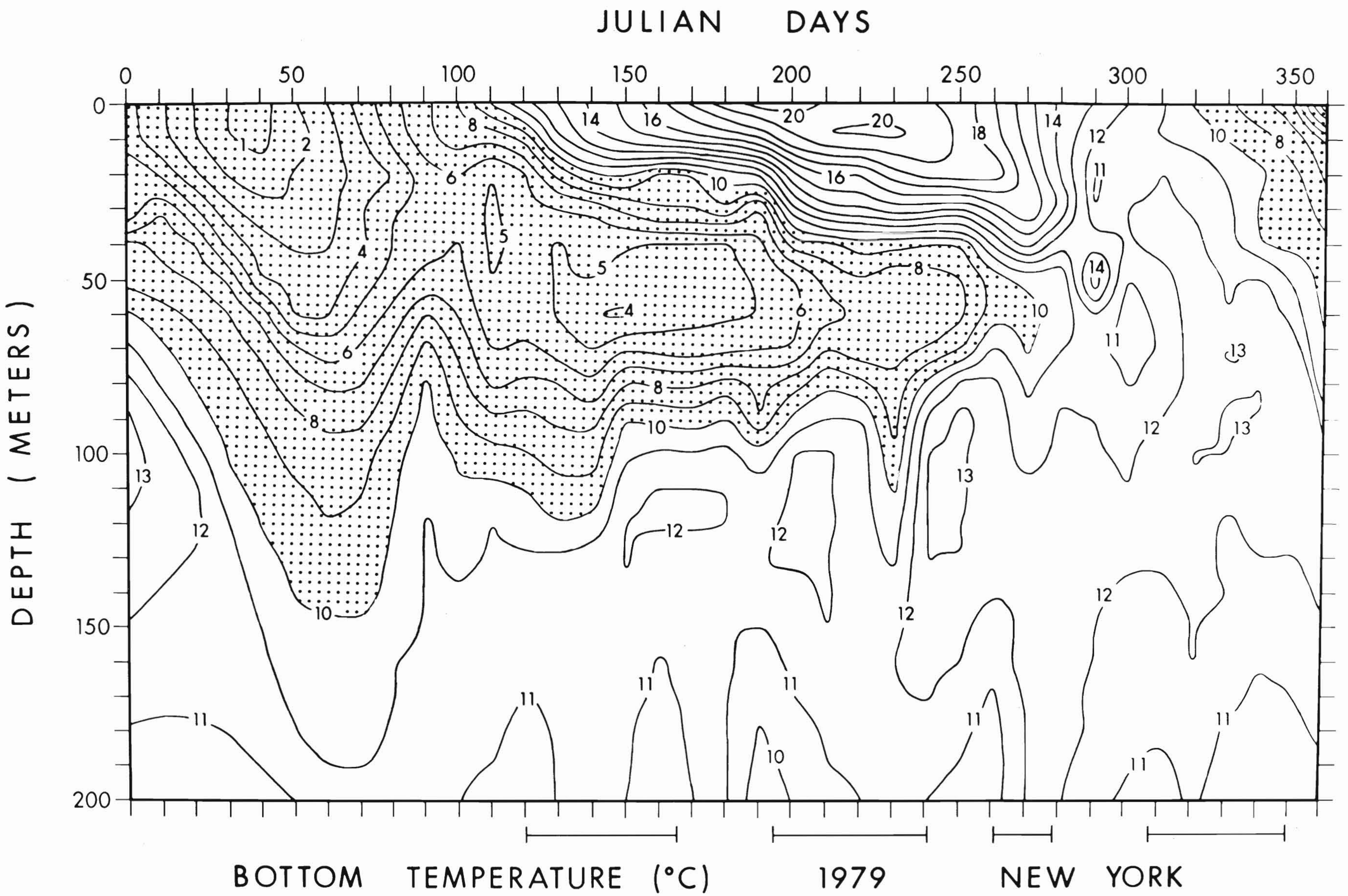
Appendix Figure 7.—Plot of minimum bottom temperature (°C) on depth-time grid for 1977-81 along the Southern New England transect.



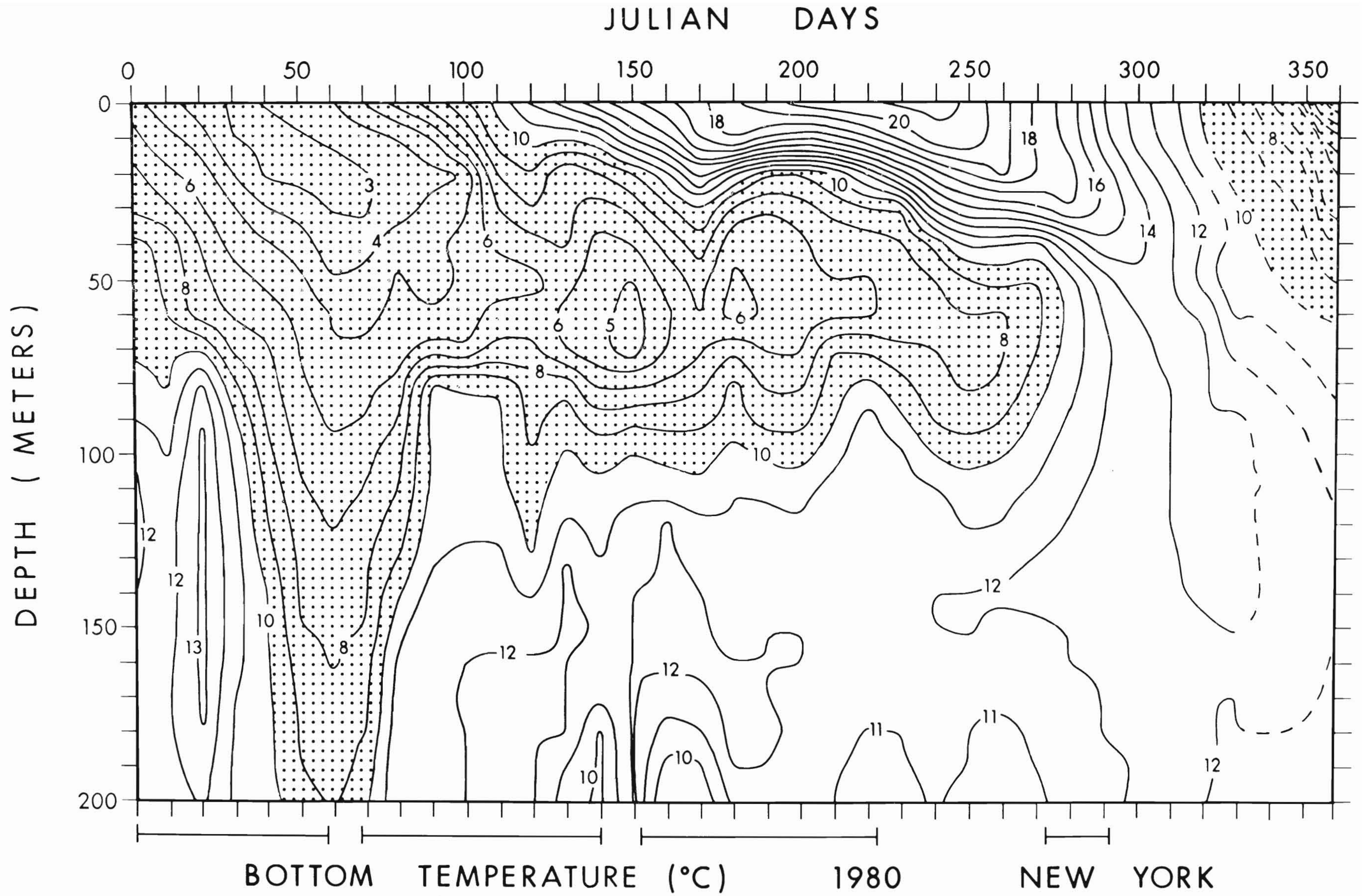
Appendix Figure 8.—Plot of bottom temperature (°C) on depth-time grid along the New York transect for 1977.



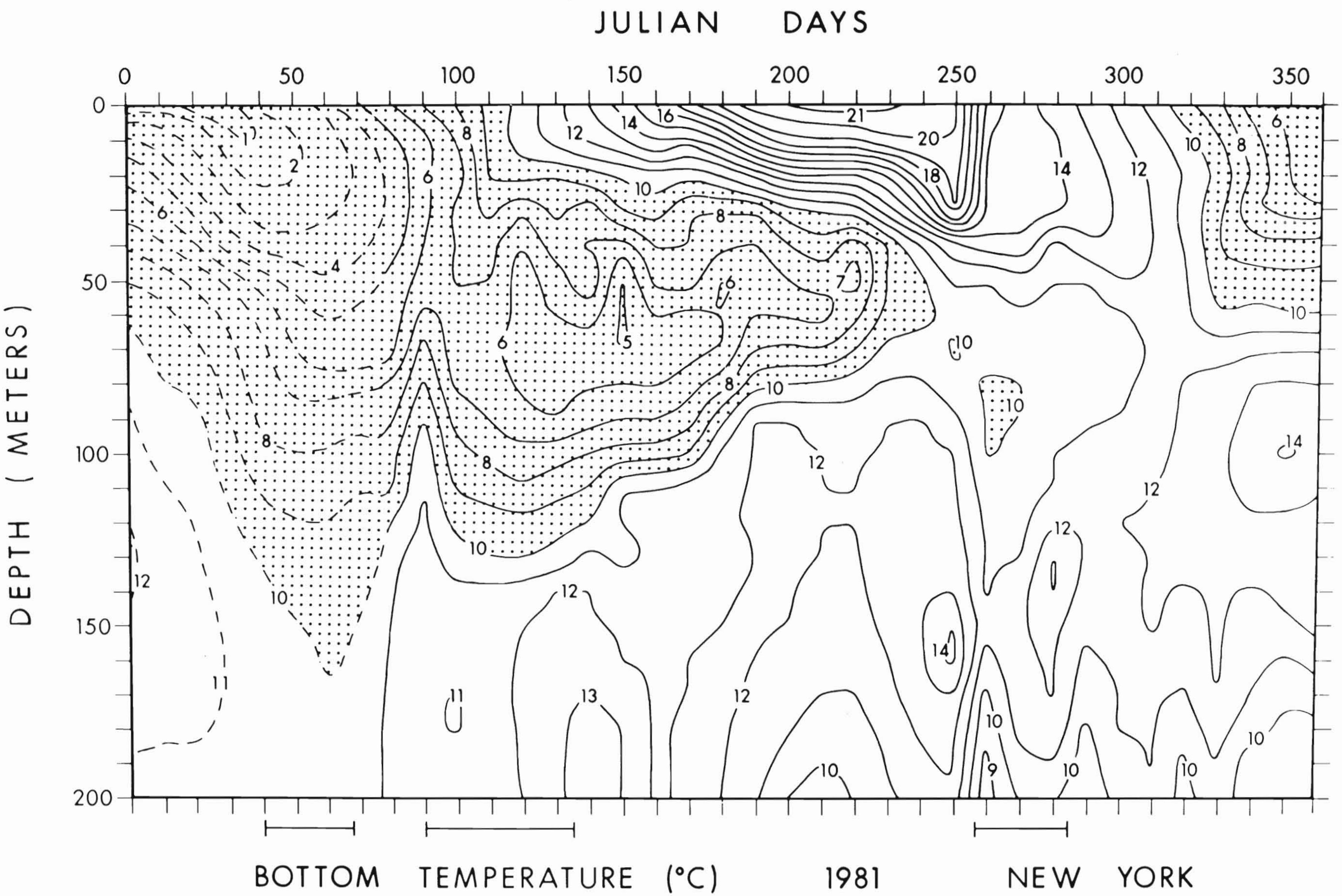
Appendix Figure 9.—Plot of bottom temperature (°C) on depth-time grid along the New York transect for 1978.



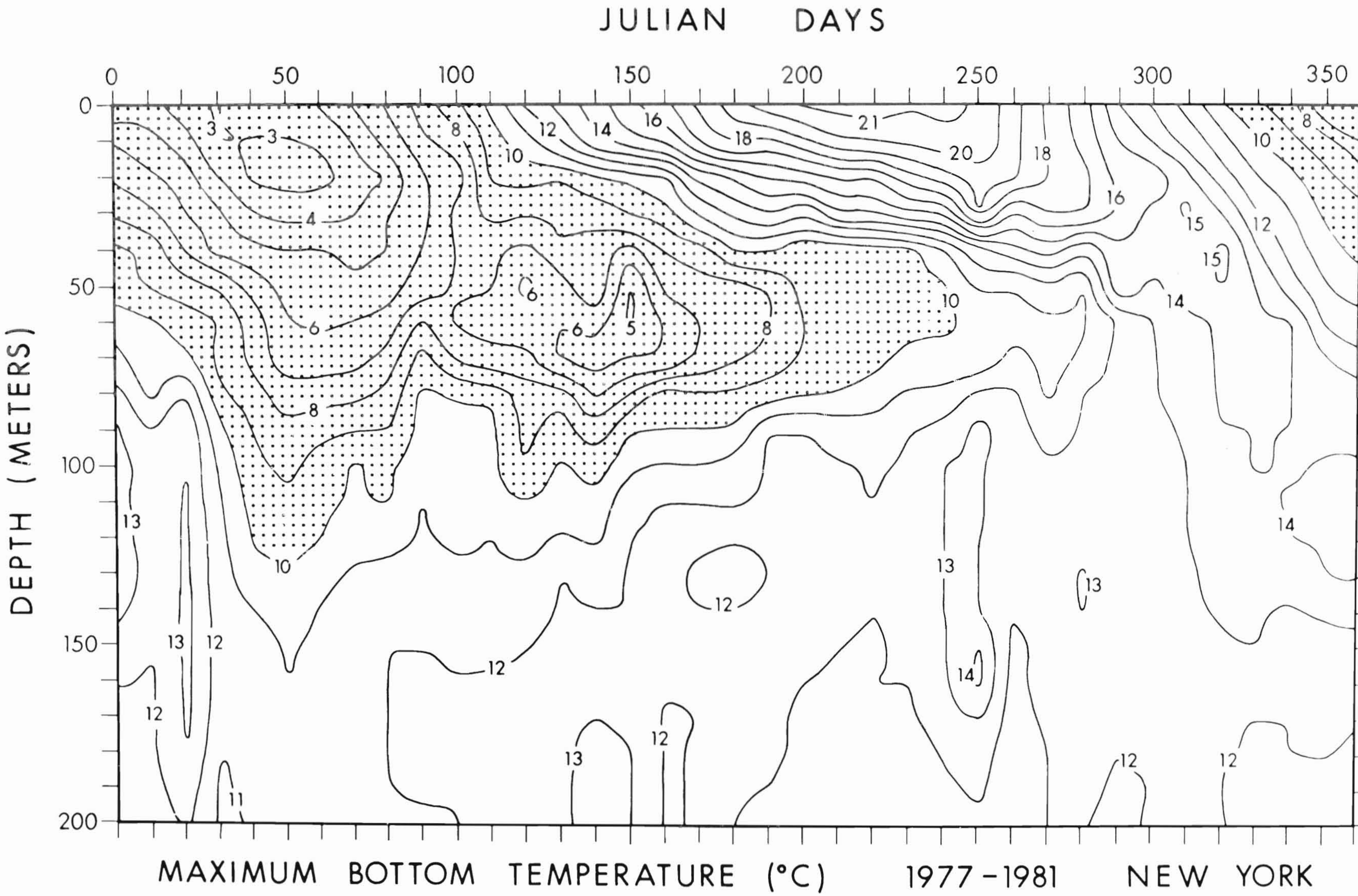
Appendix Figure 10.—Plot of bottom temperature (°C) on depth-time grid along the New York transect for 1979.



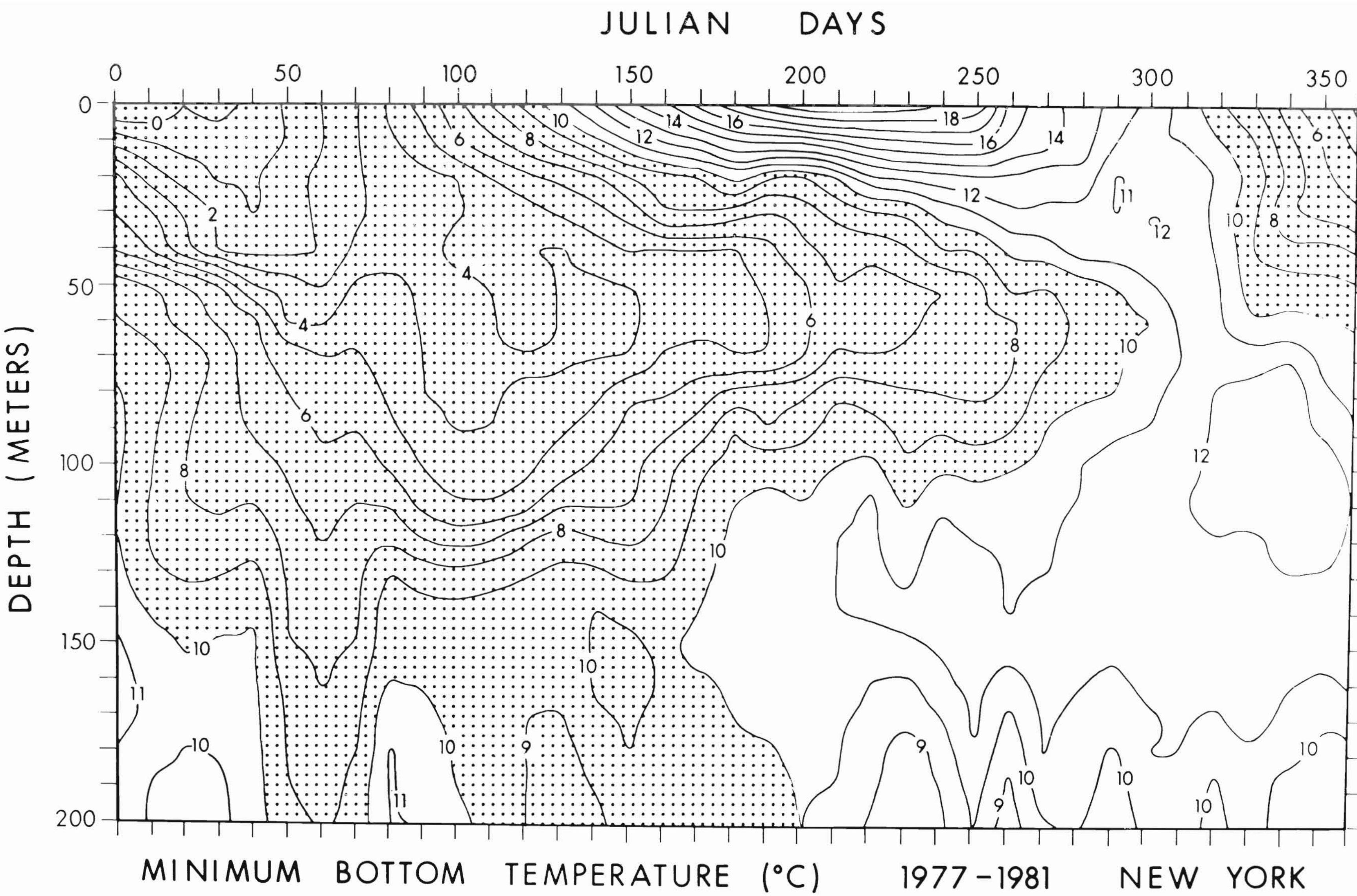
Appendix Figure 11.—Plot of bottom temperature (°C) on depth-time grid along the New York transect for 1980.



Appendix Figure 12.—Plot of bottom temperature (°C) on depth-time grid along the New York transect for 1981.



Appendix Figure 13.—Plot of maximum bottom temperature (°C) on depth-time grid for 1977-81 along the New York transect.



Appendix Figure 14.—Plot of minimum bottom temperature (°C) on depth-time grid for 1977-81 along the New York transect.