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TEMPERATURE, SALINITY AND SIGMA-T ALONG THE STANDARD FLEMISH CAP TRANSECT

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ABSTRACT

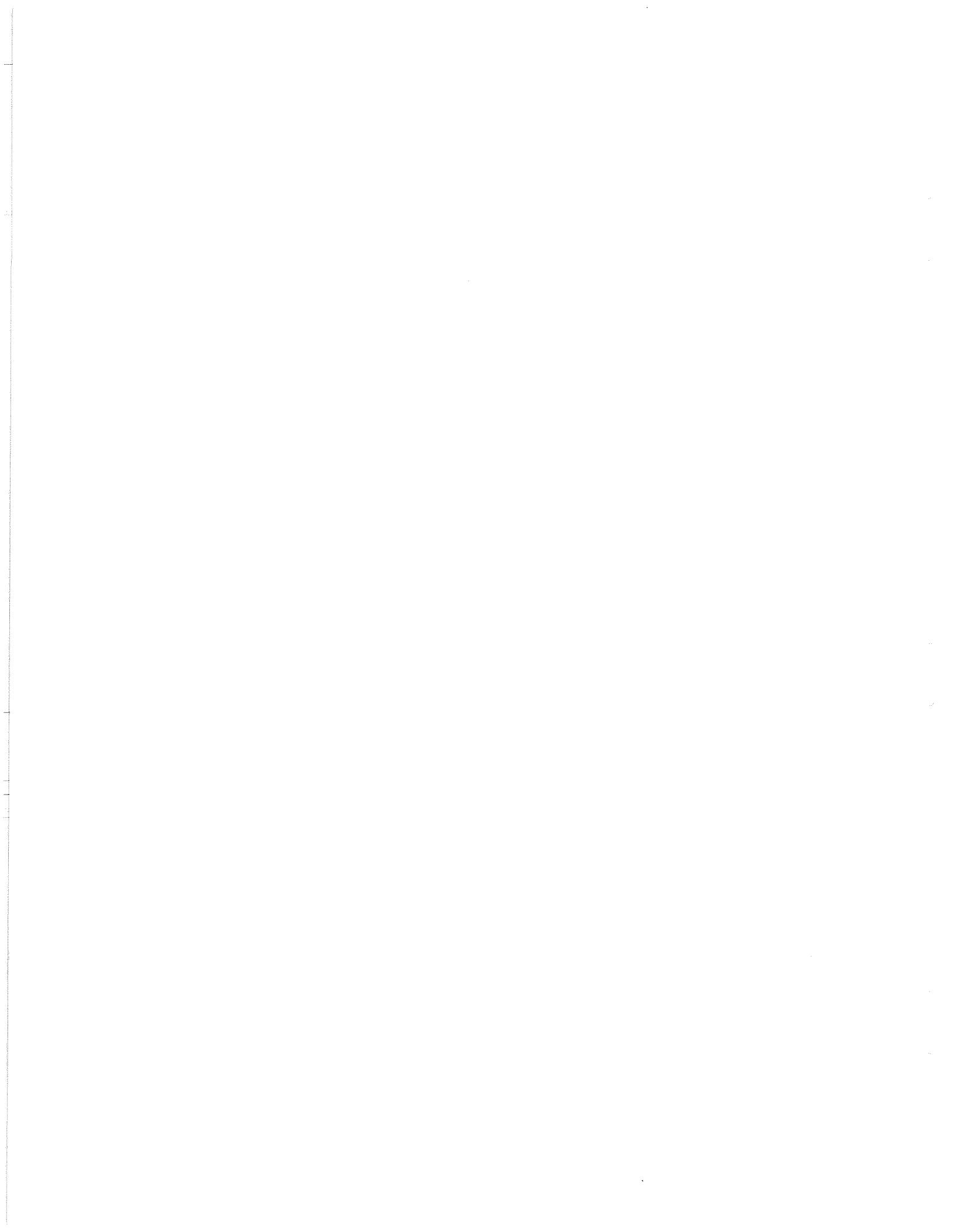
Colbourne, E. B., and D. R. Senciall. 1996. Temperature, Salinity and Sigma-T Along the Standard Flemish Cap Transect. Can. Tech. Rep. Hydrogr. Ocean Sci. 172: v + 222 p.

A review of the spatial and temporal distribution of the historical oceanographic data set on the Grand Banks of Newfoundland and on Flemish Cap along the standard NAFO Flemish Cap transect is presented. A brief descriptive analysis of various indices describing the temperature field along the transect is presented, including a discussion of the 1951 to 1995 time series of the cross-sectional area of the Cold Intermediate Layer (CIL). Annual time-series of temperature, salinity and density (σ_t) are presented for the Avalon Channel, central Grand Bank, shelf edge, Flemish Pass, Flemish Cap and Atlantic Ocean continental slope areas along the transect based on all data available from 1931 to 1995. In addition, the monthly averaged vertical cross-sections for the period 1931-1995 are presented, followed by monthly transects by year.

RÉSUMÉ

Colbourne, E. B., and D. R. Senciall. 1996. Temperature, Salinity and Sigma-T Along the Standard Flemish Cap Transect. Can. Tech. Rep. Hydrogr. Ocean Sci. 172: v + 222 p.

Le présent rapport examine la distribution spatiale et temporelle des données océanographiques sur les Grands Bancs de Terre-Neuve et sur le Bonnet Flamand le long de la ligne de transect standard du Bonnet Flamand établie par l'OPANO. Il contient une brève analyse descriptive de divers indices sur le champ de température le long du transect, y compris un examen des séries chronologiques de 1951 à 1995 de la section transversale de la couche intermédiaire froide (CIF). Il présente aussi les séries chronologiques annuelles de température, de salinité et de densité (σ_t) établies pour les zones du Chenal d'Avalon, du centre des Grands Bancs, de la limite supérieure du talus continental, du col Flemish, du Bonnet Flamand et du talus continental de l'océan Atlantique du transect, à partir de l'ensemble des données connues sur la période allant de 1931 à 1995. Enfin, on y trouvera des moyennes mensuelles des sections verticales entre 1931 et 1995, ainsi que les transects mensuels répartis selon les années.



1. INTRODUCTION

In 1976 the International Commission for the Northwest Atlantic Fisheries (ICNAF) adopted a suite of standard oceanographic stations along transects in the Northwest Atlantic ocean from Cape Cod (USA) to Egedesminde (West Greenland) (Anon. 1978). One of these crosses the Grand Banks of Newfoundland and continues across the Flemish Cap at 47.0 °N latitude (Fig. 1) and is referred to as the Flemish Cap transect. A considerable amount of oceanographic data are available for this particular area dating back to the 1930s. Oceanographically this region is distinct from most of the northeast Newfoundland Shelf in that sub-zero °C water extends from below the seasonally heated upper layer to the bottom for up to 300-400 km offshore throughout most of the year.

With the recent increase in ocean climate research on the continental shelf of Atlantic Canada a considerable effort under the Department of Fisheries and Ocean's Northern cod Science Program (NCSP) during the early 1990s was initiated to make available historical data in the region in a form where it can be easily referenced and used by the science community.

Previous studies of the oceanography on the continental shelf of Atlantic Canada have included analyses of temperature and salinity data at Station 27, located about 8.0 km east of St. John's Newfoundland (Colbourne and Fitzpatrick, 1994; Keeley, 1981a; Bailey, 1961; Huyer and Verney, 1975), and along the ICNAF standard Flemish Cap, Bonavista and Seal Island transects (Keeley, 1981b; Colbourne and Senciali, 1993; Colbourne et al. 1995). The International Ice Patrol of the U.S. Coast Guard have also conducted studies concentrated mainly in the offshore branch of the Labrador Current along the southeast slopes of the Grand Bank (Kollmeyer et al. 1965). Additional studies have included extensive analysis of temperature and salinity variability along the east and northeast Newfoundland shelves (Petrie et al. 1991; Petrie et al. 1992; Petrie et al. 1988; Templeman, 1975). Drinkwater and Trites (1986) compiled monthly averaged temperature and salinity for standard areas over the entire Grand Bank and most of the northeast Newfoundland shelf up to 1982. Colbourne and Foote (1994) and deYoung et al. (1994) have presented analyses of the historical temperature and salinity data over wide areas of the Northwest Atlantic at monthly and seasonal time scales.

The data products presented in this report complements and updates (to 1995) the previous study (Keeley, 1981b) of the Flemish Cap transect which provided data up to 1980. This report includes a brief summary of the data sources and temporal and spatial distribution of the data along the transect. Synoptic and monthly averaged temperature, salinity and density (σ_t) cross-sections are presented as well as time series of the monthly averages as functions of depth for selected positions along the transect. Various indices calculated from the horizontal transects such as cross-sectional areas of the cold intermediate layer (CIL) defined by various temperature ranges and minimum core temperatures or CIL intensities are also discussed.

2. DATA SOURCES

The results presented here are based on analyses of all available bottle, mechanical bathythermograph (MBT), expendable bathythermograph (XBT) and conductivity-temperature-depth recorder (CTD) data. These were collected along the standard Flemish Cap transect from the early 1930s to 1995 within a box with boundaries at ± 15 minutes of latitude of a line connecting 47 00.0 N, 52 02.0 W and 47 00.0 N, 42 00.0 W (the end points of the standard Flemish Cap transect). The positions and water depths of the stations along the transect are shown in Fig. 1 and listed in Table 1. The transect consists of 25 stations beginning about 25 km from the coastline at depths of 120 m and ending about 900 km offshore east of the Flemish Cap at water depths of over 3000 m. In recent years extra stations were added to increase the spatial resolution particularly inshore and on the continental slope areas.

A considerable amount of oceanographic data dating back to 1931 is available for this area, including data from the standard stations as well as data from fisheries assessment surveys, particularly during spring and autumn since the late 1970s. Most of these data were available from the Marine Environmental Data Service (MEDS) in Ottawa, Canada and from archives at the Northwest Atlantic Fisheries Center (NAFC) in St. John's, Newfoundland.

About 39 % of the data, mainly before the late 1970s, were collected at standard depths (0, 10, 20, 30, 50, 75, 100, 125, 150, 200, 250, 300 and 400 m) using water sampling bottles fitted with reversing thermometers. Since the 1960s and up to the present a considerable amount of data were collected using mechanical and electronic bathythermographs (39 %) and since the late 1970s conductivity-temperature-depth (CTD) recorders have become commonplace, accounting for 22 % of the data. The temperature data collected by these instruments have expected accuracies ranging from ± 0.2

°C for bathythermographs to ± 0.02 °C for reversing thermometers and ± 0.005 °C for CTDs. Accuracies in salinities range from ± 0.02 psu from bottle titrations to ± 0.005 psu from CTD measurements.

3. DATA ANALYSIS

The earliest known single observation along the Flemish Cap transect occurred in July 1910. From 1931 to 1950 many observations were made but a complete synoptic transect was not completed until 1951. Since then the transect has been occupied on a regular basis in July or August. Observations along the transect during other months, particularly the winter months (December to March), were irregular. The total number of profiles measured along the transect in the selected corridor from all sources for the years 1931 to 1994 are shown in Table 2 by month. The transect has been occupied every summer during the period July-August from 1951 and 1995 comprising 1818 temperature profiles (24 %) of a total of 7542 for all months. By contrast 1295 salinity profiles (28 %) were available during the same time period out of a total of 4613 profiles for all months.

The seasonal distribution of data (Fig. 2a and 3a) show most of the data collected during spring and early summer corresponding to the spring fisheries assessments surveys and the annual summer oceanographic surveys. During the winter months (January, February and March) about 16 % of the temperature data and 12 % of the salinity data were collected, about 42 % and 45 % in the spring (April, May and June), about 28 % and 32 % during summer and about 14 % and 11 % during autumn (October, November and December).

The distribution of data collected among years indicate that about 3 % of the temperature and 4 % of the salinity data were collected from 1910 to 1950, 10 % and 12 % from 1951 to 1960, 14 % and 17 % from 1961 to 1970, 23 % and 24 % from 1971 to 1980, 40 % and 30 % from 1981 to 1990 and 10 % and 13 % from 1991 to 1994 (Fig. 2b and 3b). A noticeable gap in the historical record is apparent during the period 1942 to 1947. There has been a large increase in data collection since 1975 particularly in temperature indicating the high usage of bathythermographs, particularly during the 1970s and 1980s. This increased effort was due mainly to the start up of the NAFO division 3L groundfish spring and autumn surveys during the latter half of the 1970s.

Temporal biasing in the calculation of monthly averages is likely when there are variations in the amount of data collected from year to year and when

the data for a particular month are not distributed evenly throughout the month. No attempts were made to adjust the data for the interannual variations in the sample distribution, hence the means calculated here will be temporally biased towards later years of the time period.

Spatial biasing of the average cross-sections also occurs when there is a significant amount of data confined to a particular area along the transect. The spatial distribution of all observations within ± 15 minutes of latitude of the standard transect over all years for each month are shown in Fig 4a and 4b. The symbols on these maps indicate a station occupation, as either a standard bottle cast, BT or CTD; both temperature and salinity may not be available for each station. These results indicate a reasonably well distributed data set along the transect from January to December, unlike the Seal Island transect where the data was mainly restricted to the continental slope area during winter due to the ice cover (Colbourne et al. 1995). The scatter in the station positions is more pronounced during spring and autumn corresponding to the fisheries assessment surveys where station locations are randomly selected as opposed to the standard locations occupied during the summer period. No attempts were made to adjust the results for possible spatial biasing arising from this data distribution.

The station positions of all observations in the corridor along the transect, for the purposes of the analysis, were assumed to lie along a straight line with offshore distance calculated from the shore. The data were quality controlled for obvious spikes and restricted in the range of -1.84 to 20.0 °C for temperature and from 29.0 to 36.0 psu for salinity. The profiles were not extrapolated beyond their depth range. Data profiles collected with the same instrument within one minute of latitude and within a 30 minute time interval were considered duplicates and only one was retained. In addition, in cases where a particular cast was repeated on the same station as described above with a different instrument the duplicate data were discarded, keeping CTD and bottle data over BTs. Densities are reported as sigma-t values calculated using the UNESCO equation of state for seawater (Millero et al. 1980). The data were linearly interpolated or decimated if necessary onto a 5.0 km horizontal by 5.0 m vertical grid and the arithmetic mean computed. In general there was a sufficient amount of data collected during each month to approximate the monthly means along the transect throughout the year. The plotting package used the averaged gridded data as input to a finite difference Laplacian interpolation contouring scheme.

4. DATA PRODUCTS

A dominant feature of the temperature structure on the continental shelf off Newfoundland and Labrador is the cold intermediate layer (CIL) (Petrie et al. 1988). The CIL is most apparent in summer when spring ice melt and seasonal heating increases the stratification in the upper layers to a point where heat transfer to the lower layers is inhibited. The result is a cold layer of water confined to the continental shelf with temperatures ranging from 0.0 to -1.8 °C sandwiched between the seasonally heated upper layer and warmer slope water near the bottom. Along the Flemish Cap transect the CIL intersects the bottom over most of the Grand Bank throughout most of the year.

In the winter months the intermediate layer effectively disappears as the upper layers cool down to between -1.0 and 0.0 °C from January to March due to winter cooling and mixing of surface water into the CIL. By late April and early May the warming of the surface layer commences and the cross-sectional area of water ≤ 0.0 °C decreases from the winter maximum to a minimum in the fall due to summer heating.

The geometry and areal extent of the CIL bounded by the 0.0 °C isotherm for the 1990s, which were cold years together with the July-August average are shown in Fig. 5a. Since 1990 the CIL has been above normal in total area with 1991 showing the greatest extent. The maximum variation in the CIL between a warm year (1966) and cold year (1991) is shown in Fig 5b. On average, sub-zero °C water covers all of the Grand Bank below the upper layer during the summer reaching more than 400 km offshore.

Time series of the CIL cross-sectional areas of water less than 1.0, 0.0 and -1.0 °C from 1951 to 1995 for the July-August period together with the mean (dashed line) are shown in Fig. 6. In general, the time series for all temperatures shows large variations with generally warm conditions from 1951 to 1970. Since the early 1970s the time series is characterized by three major cold periods with peaks in 1972, 1984 and in 1991. The average cross-sectional area for water less than 1.0, 0.0, and -1.0 °C are 33, 26, and 8 km² with standard deviations of 6, 7 and 8 km² respectively.

The bottom temperature across the Grand Bank ranges from sub-zero °C near the coast and over the Grand Bank to 1.0 - 3.0 °C near the shelf edge in water depths greater than 200 m throughout most of the year. Similar to Hamilton Bank a strong thermal front exists at the edge of the continental shelf, in contrast to the Bonavista transect where the bottom temperature gradient is very weak near the bottom in the offshore region (Colbourne and Senciali,

1993). Minimum temperatures at the core of the CIL (Fig. 7) range from -1.84 °C in a cold year (1971) to -0.66 °C in a warm year (1966) with an average of -1.52 °C and a standard deviation of 0.23 °C. The freezing point of seawater at salinities typically found on the continental shelf along this transect (ie. between 32.50 to 34.25) ranges from -1.78 to -1.88 °C. A summary of the various CIL summer indices discussed above are presented in Table 3.

Time series of the monthly mean temperature, salinity and density versus depth are shown in Appendix A for the Avalon Channel (25 km offshore), central Grand Bank (250 km offshore), shelf edge (400 km offshore), Flemish Pass (460 km offshore), Flemish Cap (615 km offshore) and the Atlantic Ocean (725 km offshore). These time series were formed by averaging all data for each month in a 5 km horizontal bin along the transect (centered at each offshore distance) over all years (from 1931 to 1995). The plots show the seasonal variations in the CIL; its winter formation, spring capping, gradual decay over the summer and rapid erosion during the autumn. At the edge of the continental shelf (about 400 km offshore) the temperature and salinity structure is typical of slope water which is quite different from water over the continental shelf and in the inshore regions.

Presented in Appendices B to D are the monthly average vertical distributions of temperature, salinity and density versus horizontal distance from shore to the edge of the shelf based on all available data for each month. Appendix E to G contain specific occupations of the transect by month beginning in 1951 to 1995.

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ICNAF #	Latitude	Longitude	Depth (M)
28 (28)	47 00.0	52 02.0	120
29 (34)	47 00.0	51 00.0	102
30	47 00.0	50 40.0	175
31 (35)	47 00.0	50 00.0	81
32 (36)	47 00.0	49 07.0	80
33	47 00.0	48 37.0	103
34 (37)	47 00.0	48 07.0	126
35 (37A)	47 00.0	47 30.0	220
36 (38)	47 00.0	47 15.0	603
37	47 00.0	47 01.0	1018
38	47 00.0	46 50.0	1024
39	47 00.0	46 40.0	1000
40 (39)	47 00.0	46 29.0	807
41 (40)	47 00.0	46 01.0	308
42	47 00.0	45 30.0	245
43 (41)	47 00.0	44 59.3	152
44	47 00.0	44 26.0	158
45	47 00.0	44 05.0	327
46 (42)	47 00.0	43 45.0	674
47 (42A)	47 00.0	43 24.0	1284
48	47 00.0	43 15.0	3000
49	47 00.0	43 00.0	3650
50	47 00.0	42 45.0	2100
51	47 00.0	42 30.0	2100
52	47 00.0	42 00.0	2450

Table 1. The position and water depth of the standard oceanographic stations along the Flemish Cap transect (from Anon. 1978).

YEAR	MONTH											
	J	F	M	A	M	J	J	A	S	O	N	D
1930	0	0	0	0	0	0	0	0	0	0	0	0
1931	0	0	0	0	0	4	0	0	2	0	0	0
1932	0	0	0	5	1	0	0	0	2	0	0	0
1933	0	0	0	0	2	4	0	0	2	0	0	0
1934	0	0	0	1	6	10	0	1	3	10	0	0
1935	0	1	8	1	13	1	7	0	2	1	0	0
1936	0	0	0	11	11	0	0	0	0	0	0	0
1937	0	0	0	12	11	0	7	0	0	0	0	0
1938	0	0	0	0	10	0	11	0	0	0	0	0
1939	0	0	0	0	0	0	0	0	0	0	0	0
1940	0	0	0	0	0	0	0	0	0	0	0	0
1941	0	0	10	0	0	0	0	0	0	0	0	0
1942	0	0	0	0	0	0	0	0	0	0	0	0
1943	0	0	0	0	0	0	0	0	7	0	0	0
1944	0	0	0	0	0	0	0	0	0	0	0	0
1945	0	0	0	0	0	0	0	0	0	0	0	0
1946	0	0	0	0	0	0	0	0	0	0	0	0
1947	0	0	1	0	0	0	0	0	0	0	0	0
1948	0	0	1	0	0	1	0	1	0	0	0	0
1949	0	0	0	0	1	0	2	10	4	0	0	0
1950	0	0	0	1	1	6	6	5	0	0	0	0
1951	1	0	1	8	18	23	11	2	0	0	4	0
1952	0	0	0	11	15	20	10	3	0	0	12	0
1953	1	2	6	3	16	13	10	2	5	0	0	0
1954	1	1	0	18	1	7	29	1	0	1	1	0
1955	0	10	0	8	5	6	12	1	0	23	1	0
1956	0	0	0	12	7	8	9	4	0	0	0	0
1957	0	0	0	12	11	0	13	8	0	0	0	0
1958	0	0	12	12	13	14	15	13	0	6	22	1
1959	0	0	11	10	15	45	29	33	5	0	0	0
1960	0	0	9	0	14	11	16	4	9	0	0	0
1961	0	0	14	22	0	31	21	22	11	0	0	0
1962	0	1	0	26	1	19	17	1	0	2	2	12
1963	0	0	0	15	15	6	20	1	0	21	0	0
1964	0	0	0	22	17	15	29	2	11	0	2	0
1965	0	6	0	14	15	3	29	5	0	0	1	0
1966	11	0	7	0	0	0	26	1	0	0	9	0
1967	0	8	6	8	7	9	23	9	2	11	0	2
1968	0	8	34	26	30	32	30	0	0	0	7	0
1969	0	19	9	19	23	2	27	2	8	4	9	0
1970	9	9	0	31	49	11	39	34	2	13	9	0
1971	0	3	9	13	37	12	32	10	0	9	9	0
1972	0	0	9	13	17	6	24	9	0	4	0	1
1973	7	1	0	25	31	29	77	10	4	0	0	0
1974	0	6	5	20	28	18	0	23	0	10	0	0
1975	0	9	0	0	7	0	23	10	1	1	7	0
1976	1	10	0	21	12	0	11	19	0	13	9	0
1977	2	17	3	20	45	3	25	0	0	28	4	0
1978	29	40	2	10	35	32	62	10	0	1	32	0
1979	36	31	19	35	98	20	49	13	20	4	0	2
1980	18	0	9	58	70	74	55	51	11	32	0	0
1981	89	0	21	96	67	58	57	8	16	12	32	10
1982	28	31	0	13	23	9	14	0	0	1	24	9
1983	0	71	16	13	32	0	19	26	3	27	31	8
1984	3	90	1	46	64	27	22	86	0	3	6	5
1985	48	149	43	49	102	69	6	101	2	86	19	1
1986	21	21	1	20	78	33	8	52	15	52	23	5
1987	0	0	25	24	52	48	1	40	9	34	8	1
1988	1	2	3	8	55	24	18	54	18	11	27	10
1989	0	3	0	2	85	36	21	0	17	33	4	0
1990	6	0	1	13	35	5	0	17	13	0	41	0
1991	0	0	7	8	53	6	18	28	18	0	39	4
1992	7	0	0	11	24	59	17	0	34	2	33	0
1993	1	0	0	16	35	22	38	7	41	10	25	13
1994	0	7	1	2	18	29	31	2	10	17	11	13

Table 2a. Summary of the total number of temperature profiles available along and near the Flemish Cap transect from 1931 to 1994.

YEAR	MONTH											
	J	F	M	A	M	J	J	A	S	O	N	D
1930	0	0	0	0	0	0	0	0	0	0	0	0
1931	0	0	0	0	0	4	0	0	1	0	0	0
1932	0	0	0	3	0	0	0	0	1	0	0	0
1933	0	0	0	0	2	2	0	0	1	0	0	0
1934	0	0	0	0	2	5	0	0	1	10	0	0
1935	0	0	8	1	11	0	5	0	0	0	0	0
1936	0	0	0	11	11	0	0	0	0	0	0	0
1937	0	0	0	12	10	0	7	0	0	0	0	0
1938	0	0	0	0	6	0	11	0	0	0	0	0
1939	0	0	0	0	0	0	0	0	0	0	0	0
1940	0	0	0	0	0	0	0	0	0	0	0	0
1941	0	0	10	0	0	0	0	0	0	0	0	0
1942	0	0	0	0	0	0	0	0	0	0	0	0
1943	0	0	0	0	0	0	0	0	0	0	0	0
1944	0	0	0	0	0	0	0	0	0	0	0	0
1945	0	0	0	0	0	0	0	0	0	0	0	0
1946	0	0	0	0	0	0	0	0	0	0	0	0
1947	0	0	1	0	0	0	0	0	0	0	0	0
1948	0	0	1	0	0	0	0	0	0	0	0	0
1949	0	0	0	0	1	0	0	9	1	0	0	0
1950	0	0	0	1	1	6	5	0	0	0	0	0
1951	0	0	1	8	10	19	10	2	0	0	0	0
1952	0	0	0	10	13	14	10	2	0	0	0	0
1953	0	0	0	2	11	12	10	2	0	0	0	0
1954	0	0	0	13	1	7	25	1	0	0	0	0
1955	0	0	0	8	1	1	12	1	0	11	1	0
1956	0	0	0	12	7	4	9	4	0	0	0	0
1957	0	0	0	12	11	0	9	4	0	0	0	0
1958	0	0	11	12	12	12	11	9	0	3	8	1
1959	0	0	10	10	12	34	11	11	1	0	0	0
1960	0	0	9	0	6	9	13	2	0	0	0	0
1961	0	0	0	18	0	21	12	2	8	0	0	0
1962	0	0	0	22	0	14	12	1	0	1	0	12
1963	0	0	0	12	12	0	12	1	0	0	0	0
1964	0	0	0	11	12	12	12	1	0	0	0	0
1965	0	6	0	14	10	3	13	1	0	0	0	0
1966	10	0	7	0	0	0	11	0	0	0	9	0
1967	0	8	6	8	7	7	12	7	0	8	0	1
1968	0	8	19	20	19	28	12	0	0	0	3	0
1969	0	18	8	19	20	0	16	1	8	0	9	0
1970	9	9	0	29	44	9	24	23	2	10	9	0
1971	0	3	9	13	30	0	19	6	0	0	9	0
1972	0	0	9	8	0	6	12	9	0	0	0	1
1973	7	1	0	25	24	28	56	9	0	0	0	0
1974	0	6	3	15	13	12	0	13	0	9	0	0
1975	0	9	0	0	0	0	12	9	0	0	7	0
1976	0	9	0	20	10	0	5	16	0	0	9	0
1977	0	0	0	18	10	0	20	0	0	15	1	0
1978	12	0	0	10	1	6	49	4	0	0	0	0
1979	18	0	15	9	30	0	42	11	15	3	0	2
1980	14	0	9	25	33	56	40	50	9	30	0	0
1981	64	0	21	79	51	32	28	8	0	7	15	5
1982	12	0	0	4	1	1	10	0	0	1	4	0
1983	0	21	13	13	8	0	4	14	0	5	15	5
1984	0	19	1	24	7	15	7	50	0	0	0	5
1985	1	20	6	12	28	11	0	69	0	6	1	0
1986	6	0	0	17	26	12	7	49	7	47	1	0
1987	0	0	11	12	12	14	0	10	7	5	8	0
1988	0	1	2	5	6	7	18	50	4	0	0	0
1989	0	0	0	0	0	0	21	0	0	0	0	0
1990	2	0	1	2	0	0	0	11	8	0	22	0
1991	0	0	1	8	25	4	0	22	6	0	25	2
1992	7	0	0	0	20	44	14	0	17	2	23	0
1993	1	0	0	16	21	3	29	6	29	0	10	0
1994	0	3	0	0	17	13	16	2	6	8	7	5

Table 2b. Summary of the total number of salinity profiles along and near the Flemish Cap Transect from 1931 to 1994.

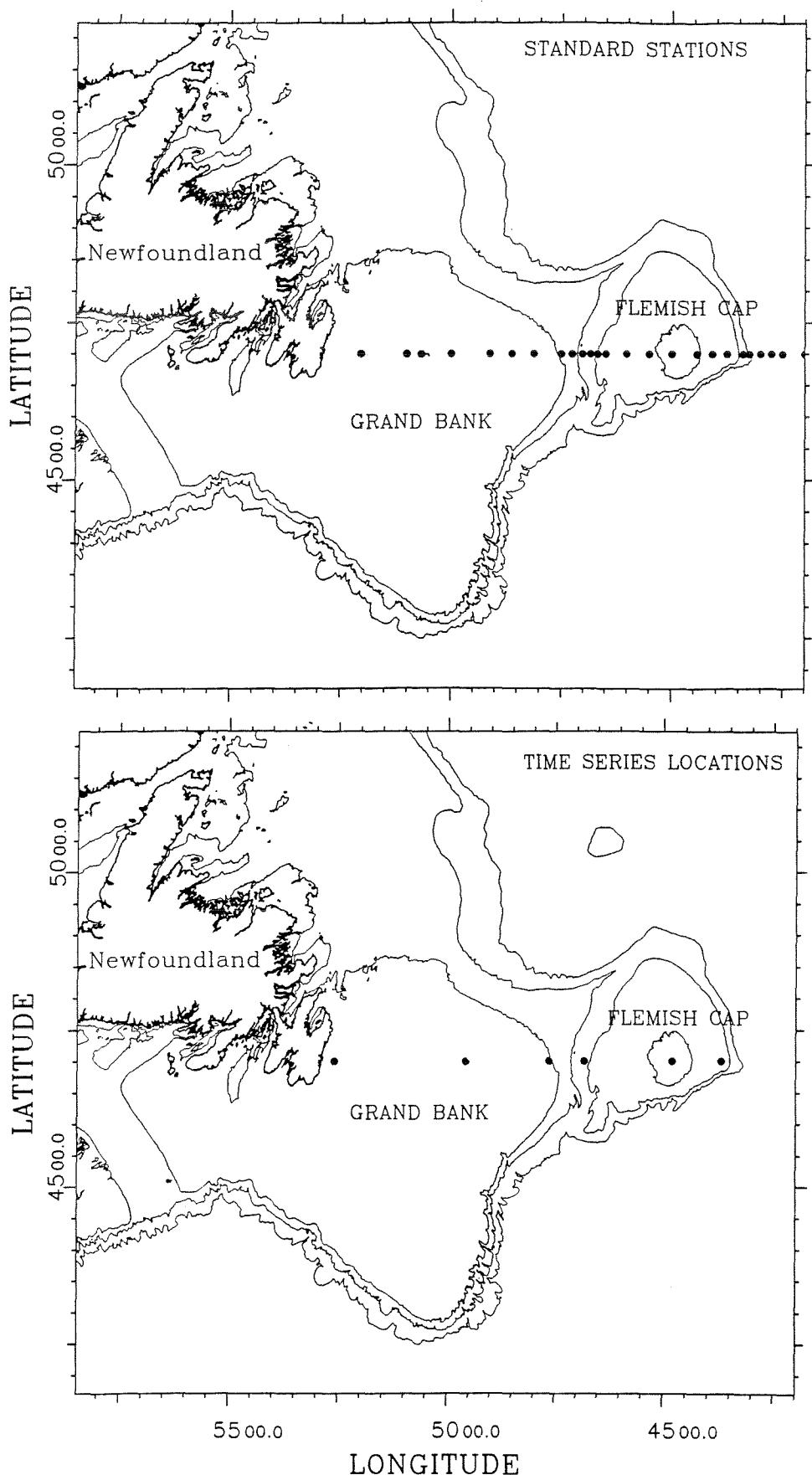


Fig. 1.

Location maps showing the positions of the standard stations and the locations where temperature, salinity and density annual time series were constructed along the Flemish Cap transect. The bathymetry lines are 200, 1000 and 2000 m.

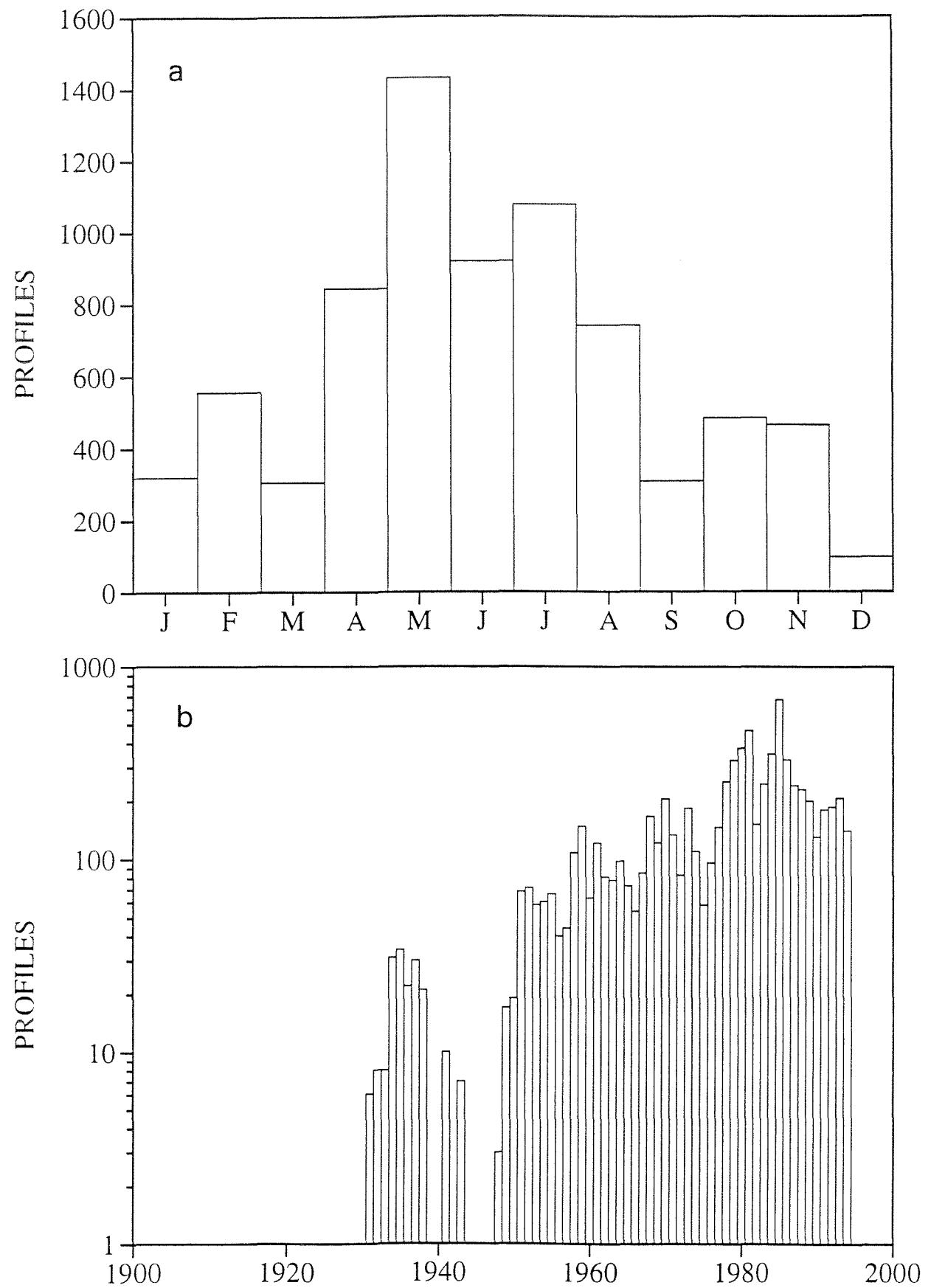


Fig. 2. (a) The total number of temperature profiles by month and (b) by year, occupied along and near the Flemish Cap transect since 1931.

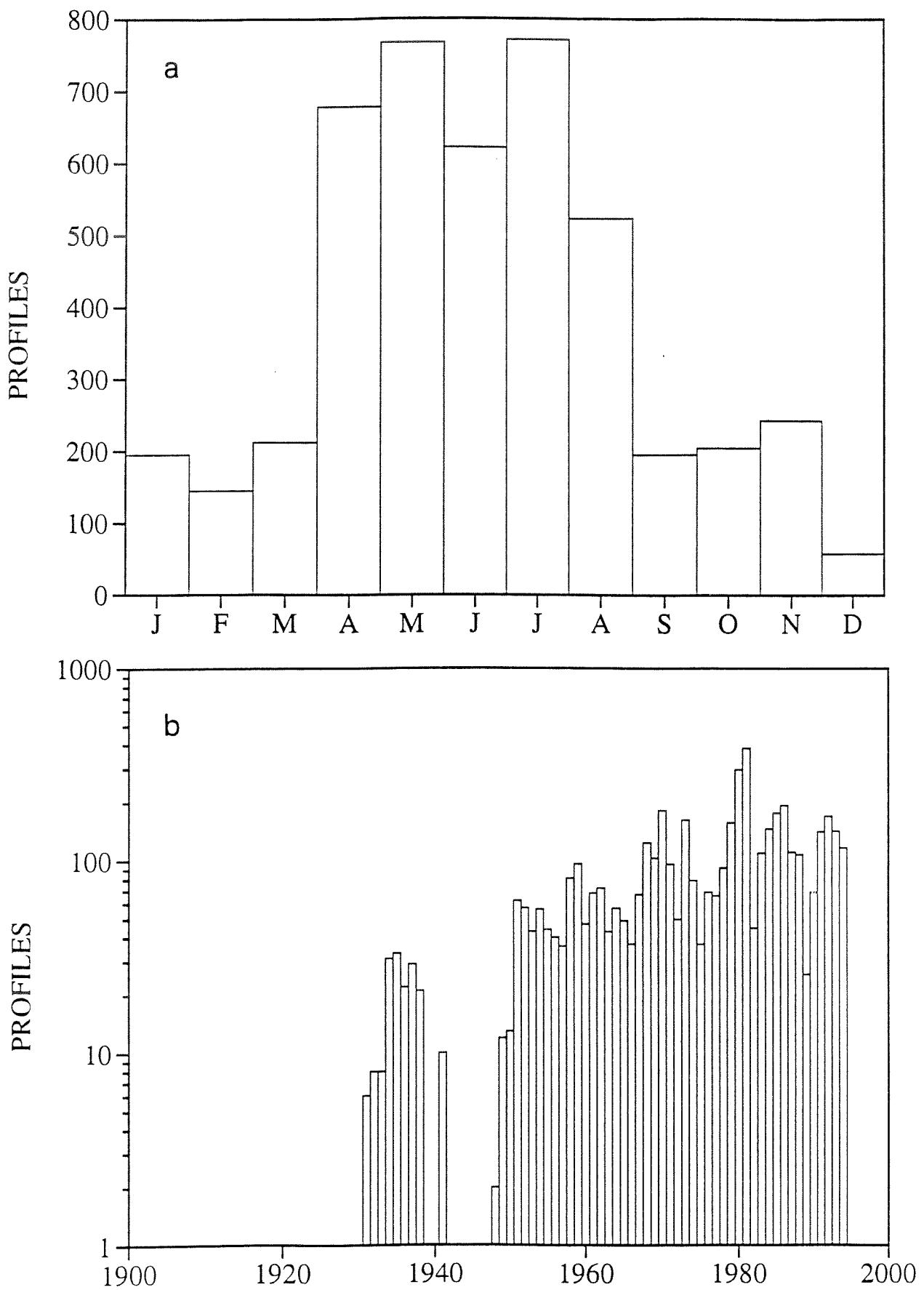


Fig. 3. (a) The total number of salinity profiles by month and (b) by year, occupied along and near the Flemish Cap transect since 1931.

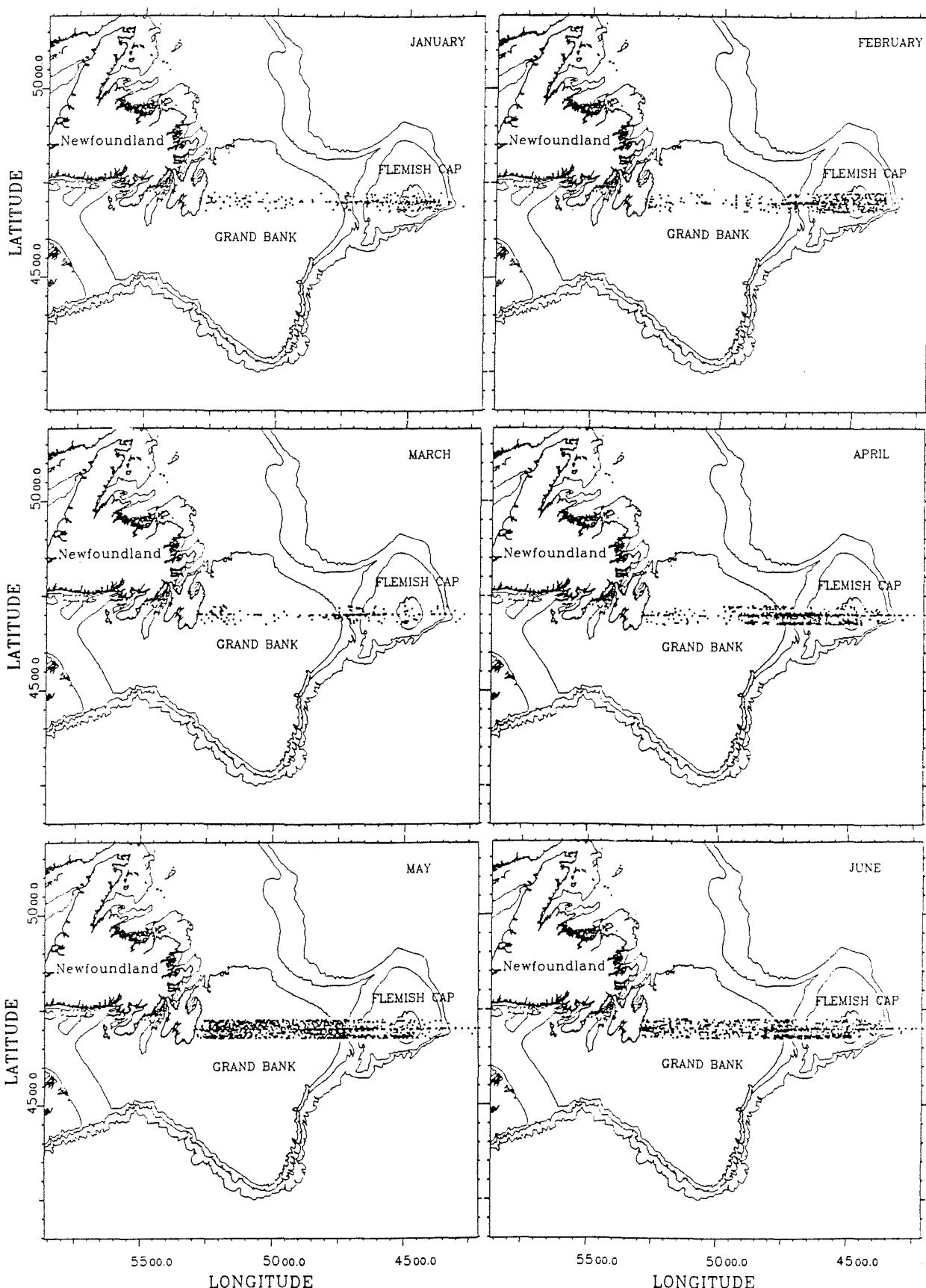


Fig. 4a. Location map showing the position of all stations occupied along and near the Flemish Cap transect since 1931 for January to June. Bathymetry lines are 200, 1000 and 2000 m.

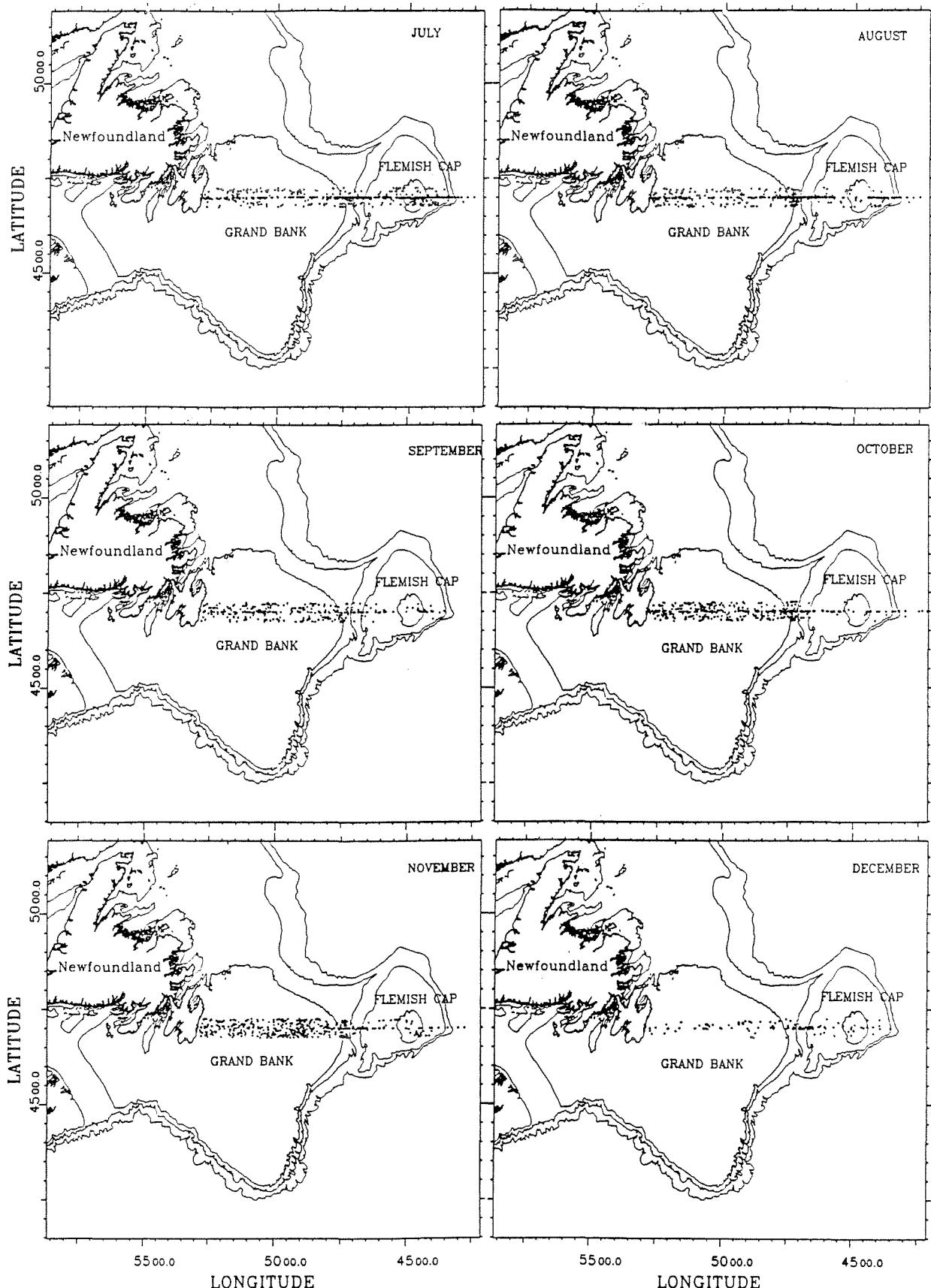


Fig. 4b. Location map showing the position of all stations occupied along and near the Flemish Cap transect since 1931 for July to December. Bathymetry lines are 200, 1000 and 2000 m.

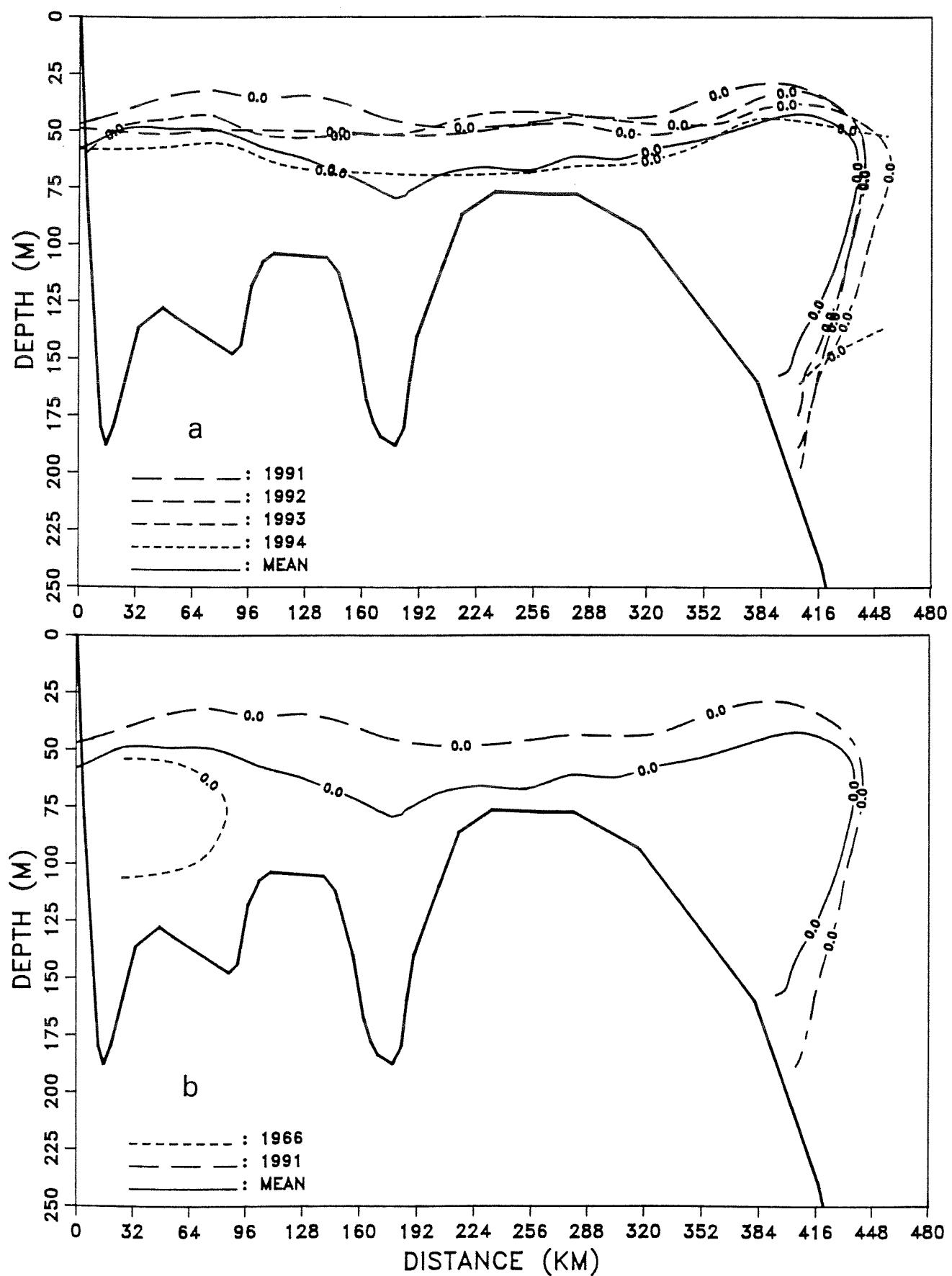


Fig. 5. (a) The geometry and extent of the CIL area less than 0.0 °C along the Flemish Cap transect for 1991 to 1994 and (b) for 1966 and 1991. The mean is shown as the solid line.

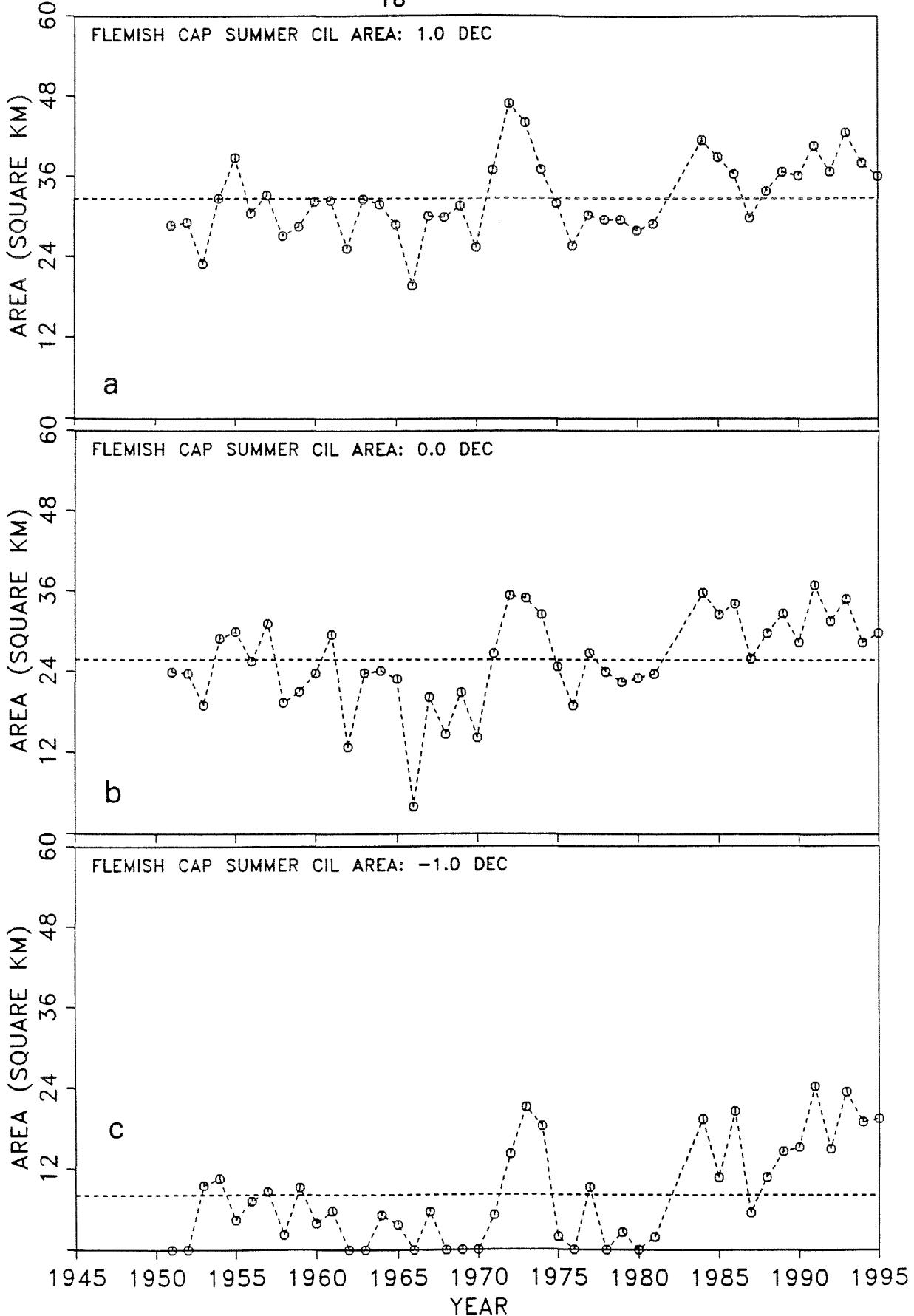


Fig. 6. (a) Time series of the Flemish Cap transect CIL area in km^2 less than (a) $1.0 \text{ } ^\circ\text{C}$, (b) less than $0.0 \text{ } ^\circ\text{C}$ and (c) less than $-1.0 \text{ } ^\circ\text{C}$.

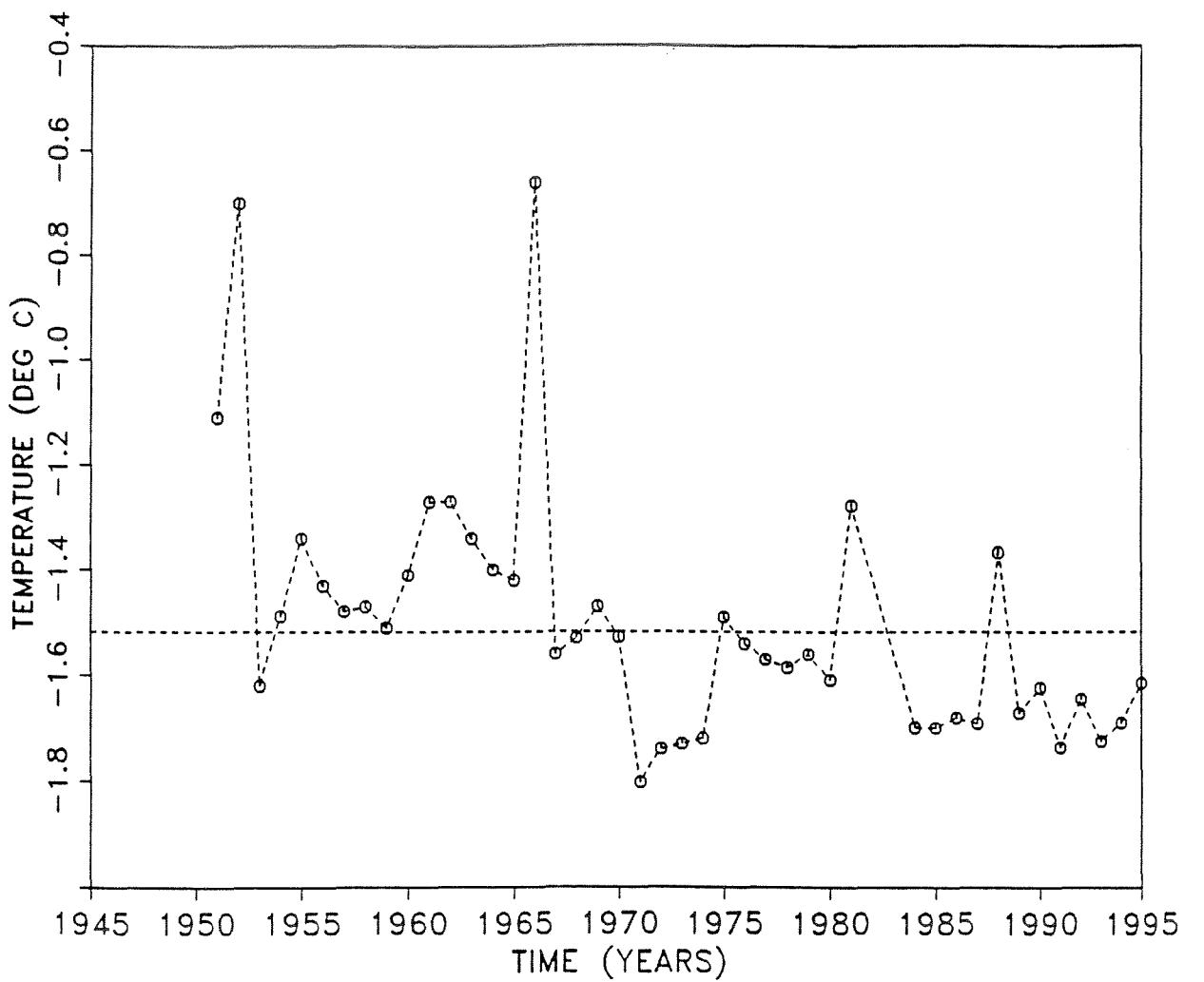


Fig. 7. Time series of the cold intermediate layer (CIL) intensities or minimum core temperatures.

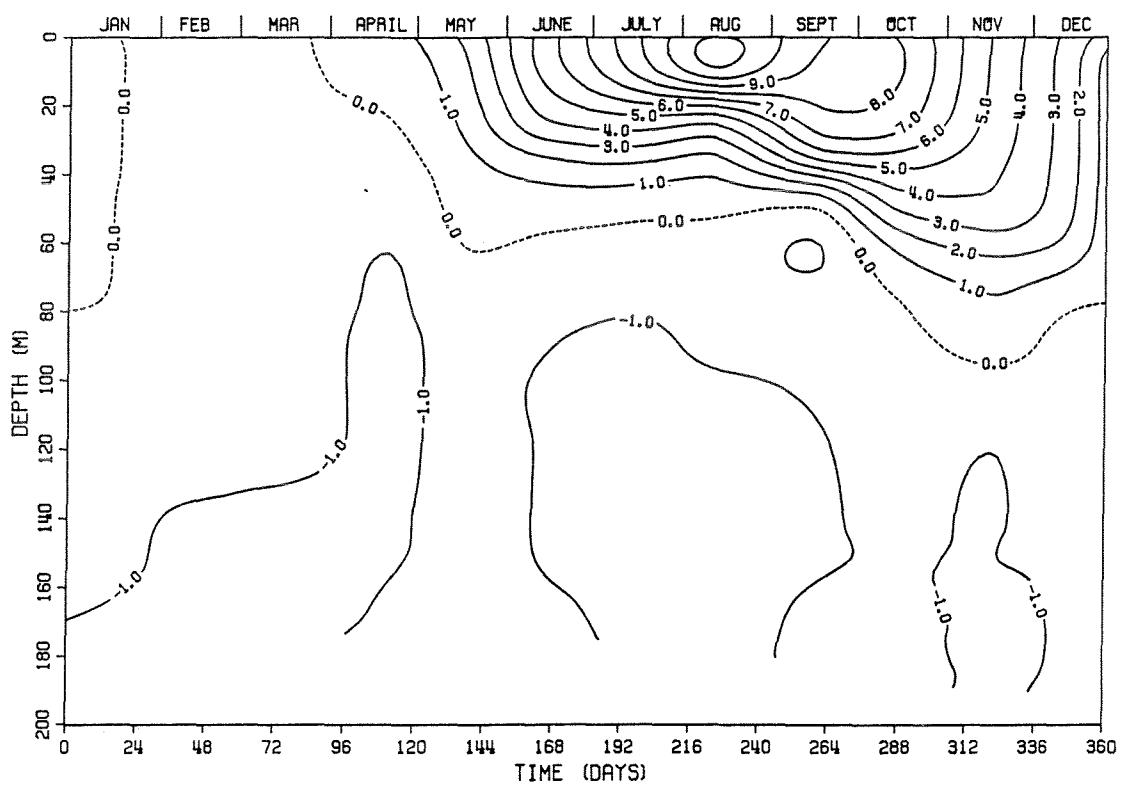
YEAR	CIL Indices				Min. Temp. (°C)	
	Cross Sectional Area. (KM) ²					
	1.0 °C	0.0 °C	-1.0 °C	-1.5 °C		
1951	28.7	23.9	0.0	0.0	-1.110	
1952	29.1	23.7	0.0	0.0	-.700	
1953	22.9	19.0	9.5	1.4	-1.620	
1954	32.7	28.9	10.5	0.0	-1.488	
1955	38.8	29.9	4.4	0.0	-1.340	
1956	30.5	25.5	7.2	0.0	-1.430	
1957	33.2	31.1	8.6	0.3	-1.479	
1958	27.1	19.4	2.2	0.0	-1.470	
1959	28.5	21.0	9.2	2.5	-1.510	
1960	32.2	23.7	3.9	0.0	-1.410	
1961	32.4	29.5	5.7	0.0	-1.270	
1962	25.2	12.8	0.0	0.0	-1.270	
1963	32.6	23.8	0.0	0.0	-1.340	
1964	31.8	24.1	5.1	0.2	-1.400	
1965	28.8	22.9	3.7	0.0	-1.420	
1966	19.7	4.0	0.0	0.0	-.660	
1967	30.1	20.2	5.6	1.4	-1.560	
1968	29.9	14.7	0.0	0.0	-1.530	
1969	31.6	20.9	0.0	0.0	-1.470	
1970	25.4	14.2	0.0	0.0	-1.528	
1971	36.9	26.7	5.1	1.1	-1.840	
1972	46.8	35.4	14.1	4.3	-1.740	
1973	44.0	35.0	21.1	5.7	-1.730	
1974	37.0	32.5	18.3	4.3	-1.720	
1975	31.9	24.7	1.9	0.0	-1.490	
1976	25.6	19.0	0.0	0.0	-1.540	
1977	30.2	26.8	9.2	0.0	-1.570	
1978	29.5	24.0	0.0	0.0	-1.585	
1979	29.5	22.5	2.6	0.0	-1.560	
1980	27.9	23.1	0.0	0.0	-1.609	
1981	28.9	23.7	1.9	0.0	-1.277	
1984	41.4	35.8	19.3	1.4	-1.699	
1985	38.9	32.6	10.7	0.2	-1.700	
1986	36.4	34.2	20.5	1.4	-1.680	
1987	29.8	26.0	5.5	0.0	-1.691	
1988	33.8	29.8	10.7	0.0	-1.367	
1989	36.7	32.7	14.5	0.0	-1.672	
1990	36.1	28.4	15.1	0.0	-1.624	
1991	40.6	37.0	24.2	3.1	-1.736	
1992	36.7	31.6	14.9	0.0	-1.645	
1993	42.5	34.9	23.4	6.8	-1.725	
1994	38.0	28.4	18.9	1.5	-1.690	

Table 3. Summary of the Flemish Cap transect (July-August) CIL indices.

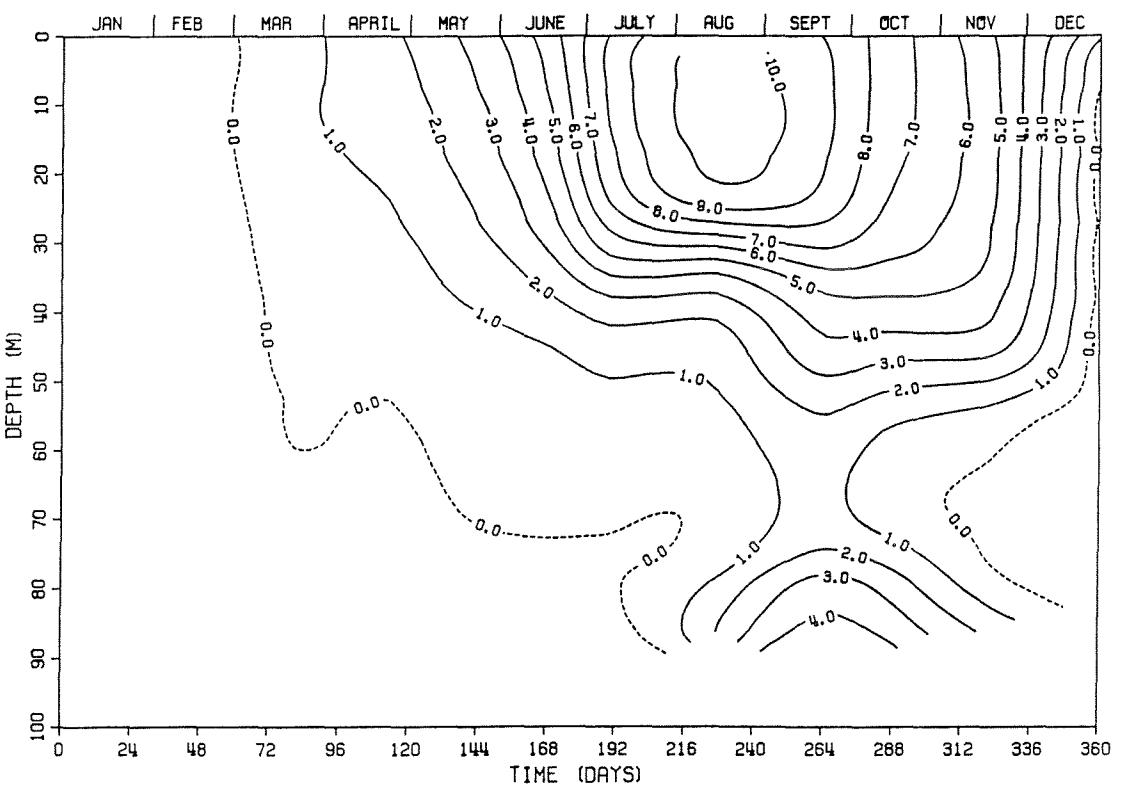
APPENDIX A.

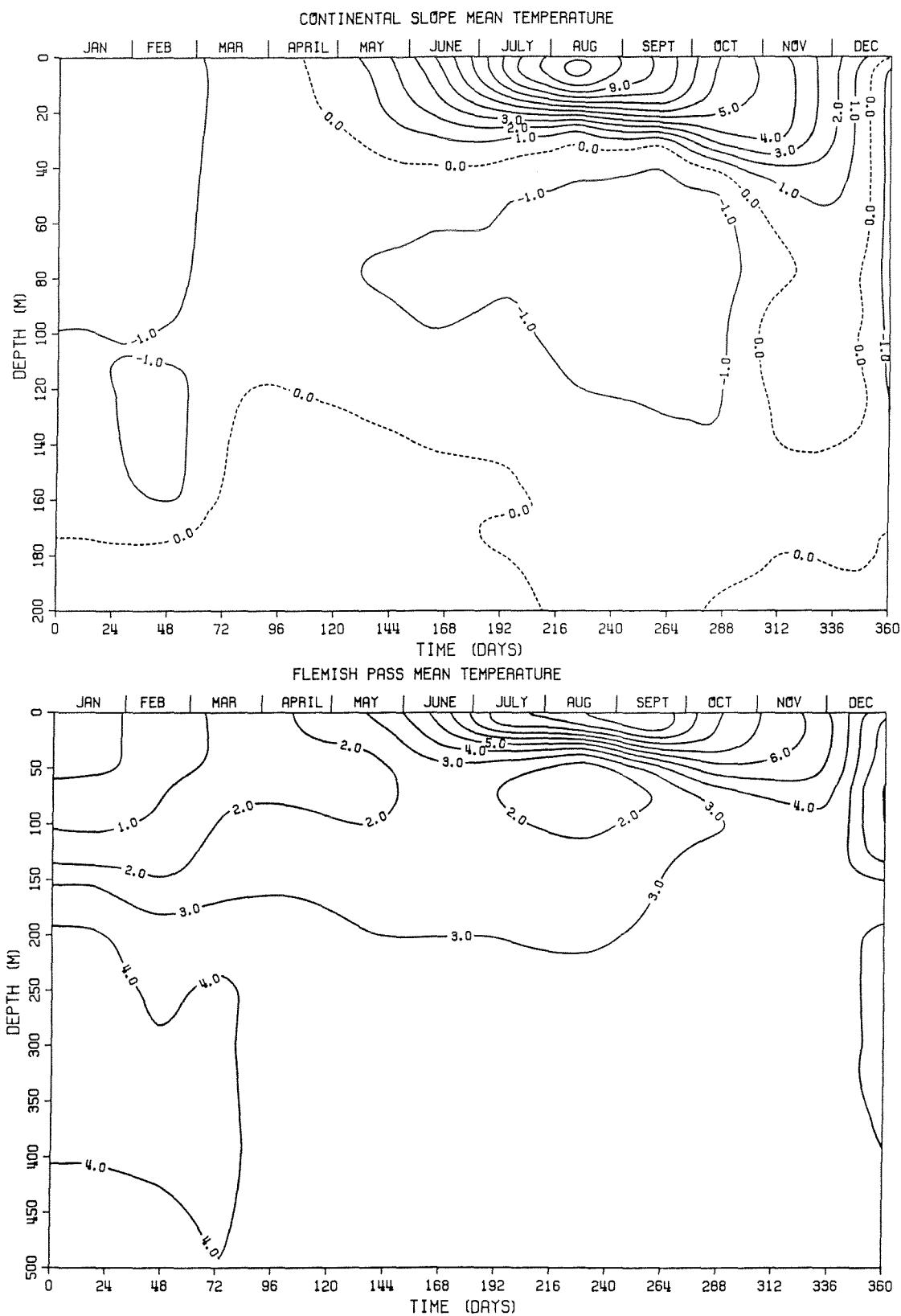
Time series of monthly mean temperature, salinity and density versus depth for the Avalon Channel, central Grand Bank, shelf edge, Flemish Pass, Flemish Cap and Atlantic Ocean areas along the Flemish Cap transect.

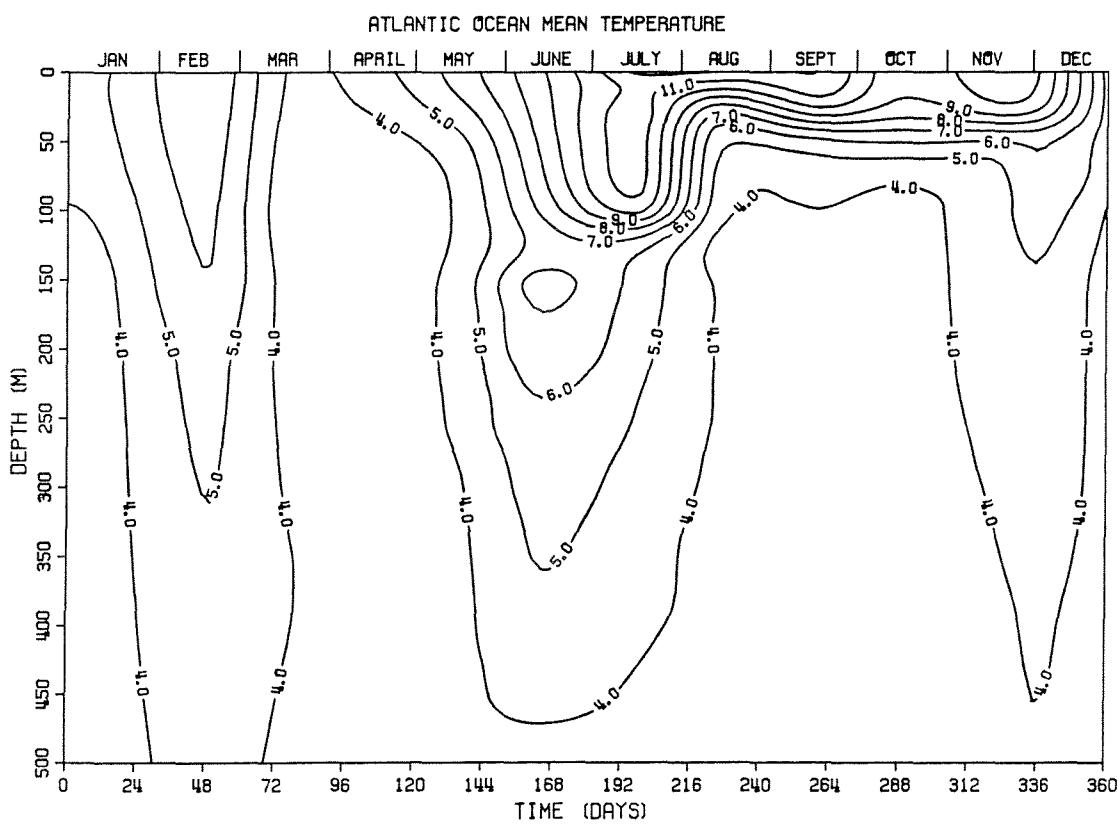
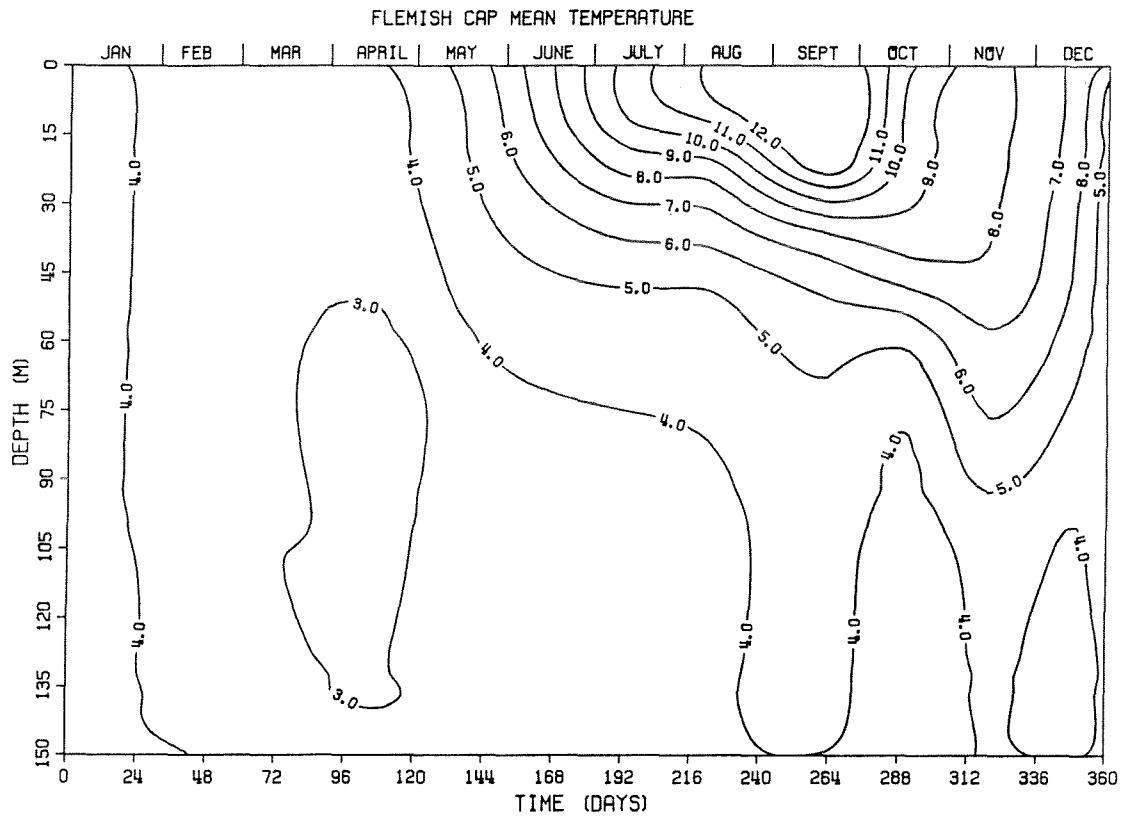
AVALON CHANNEL MEAN TEMPERATURE

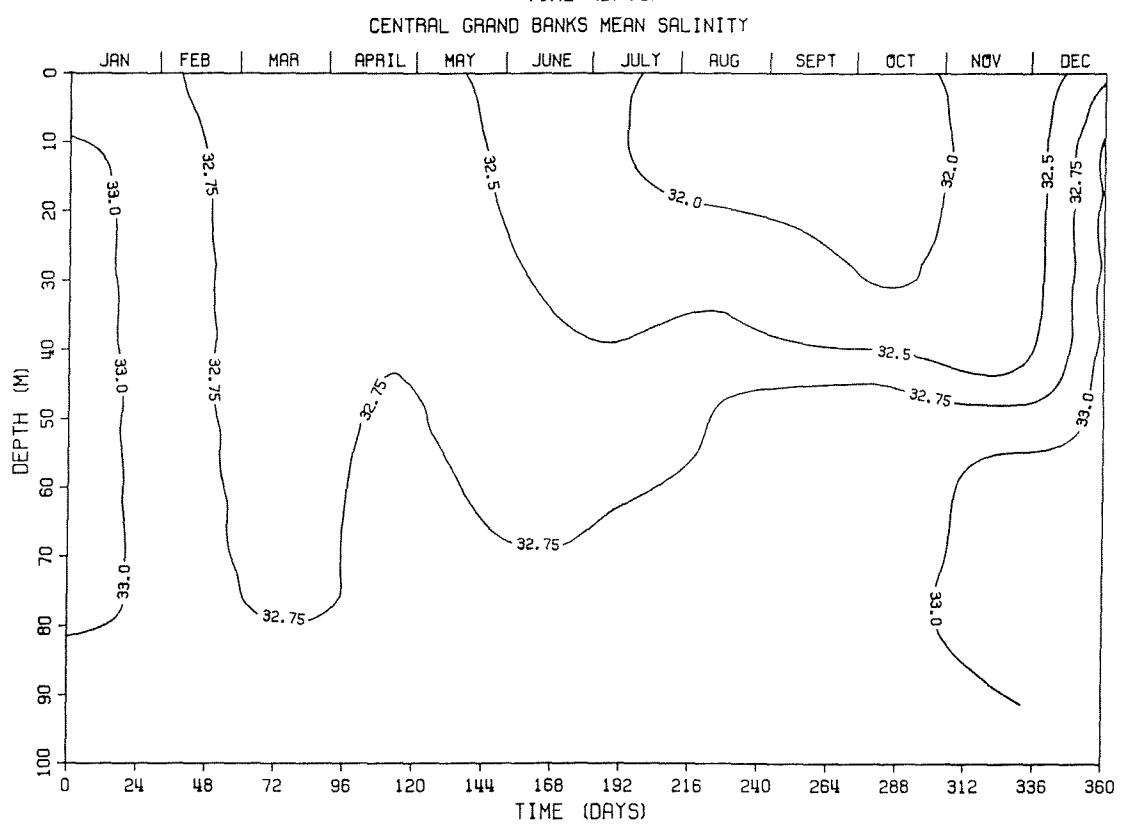
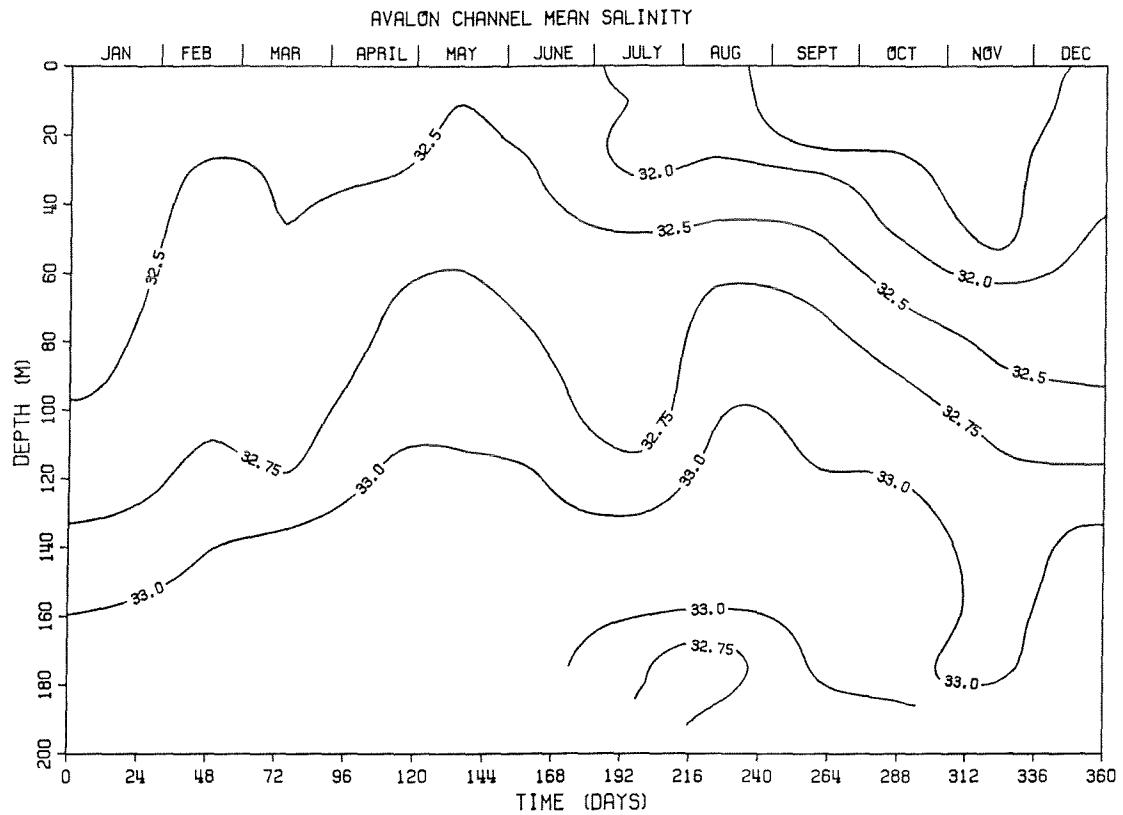


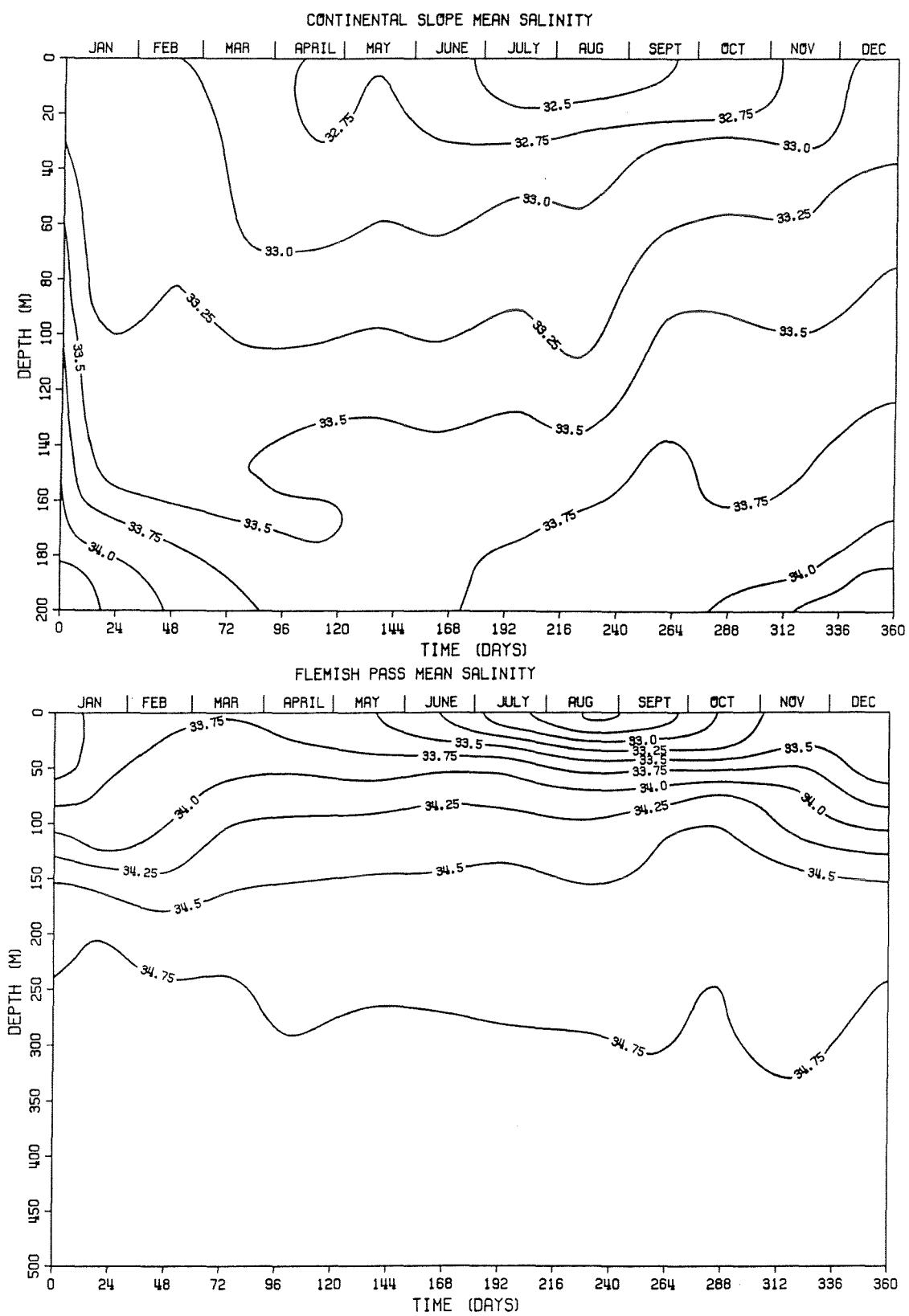
CENTRAL GRAND BANKS MEAN TEMPERATURE

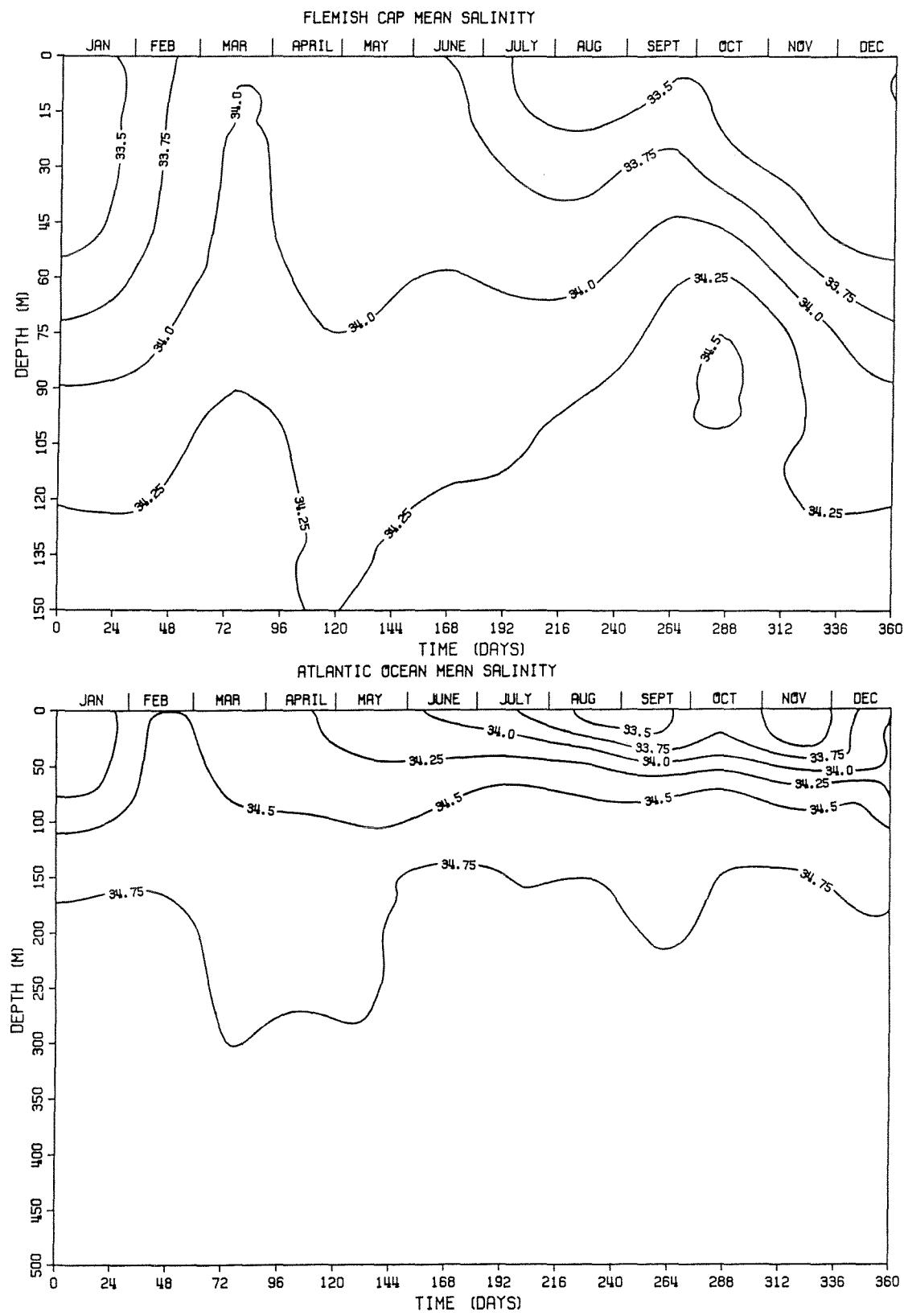


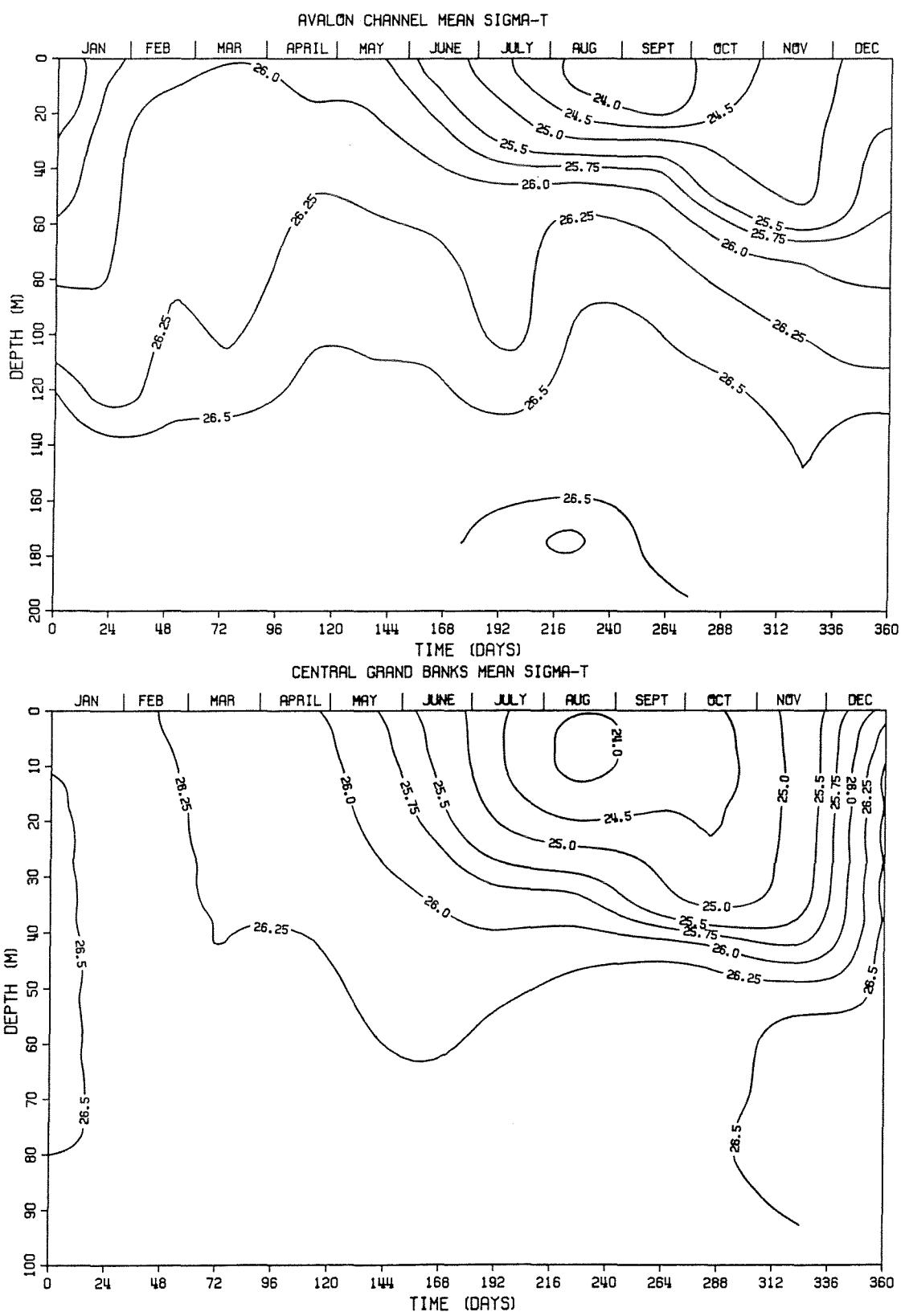


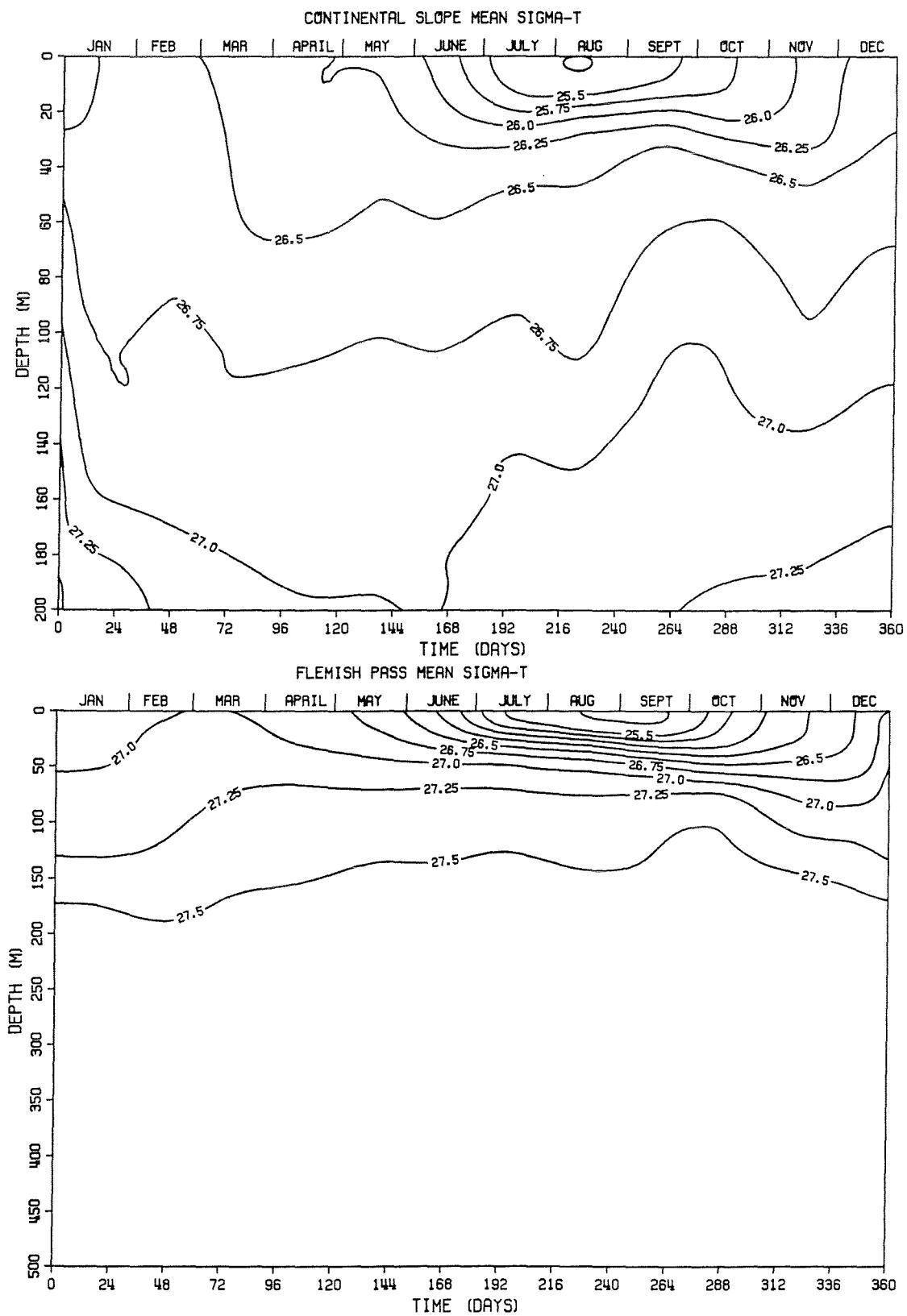


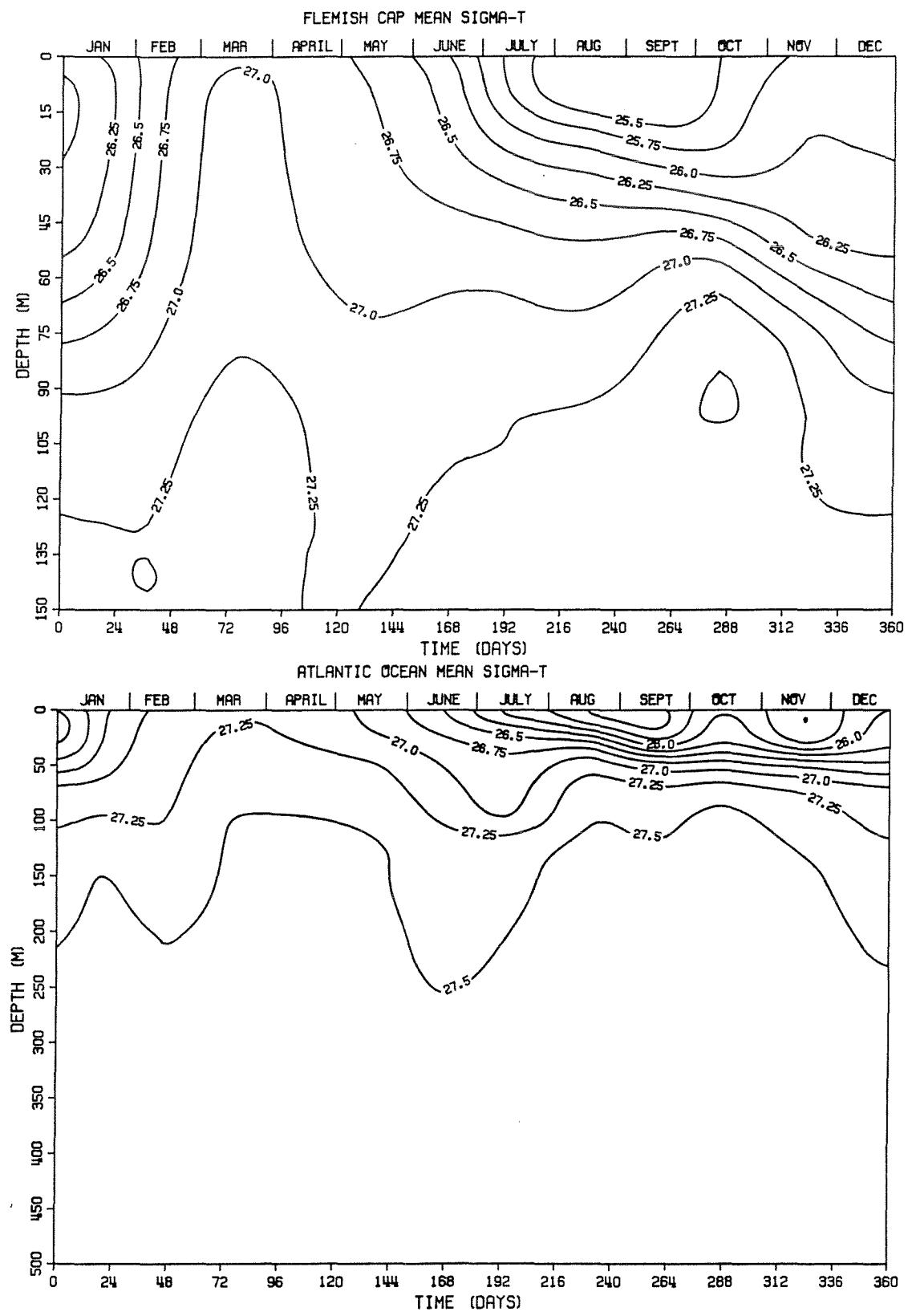






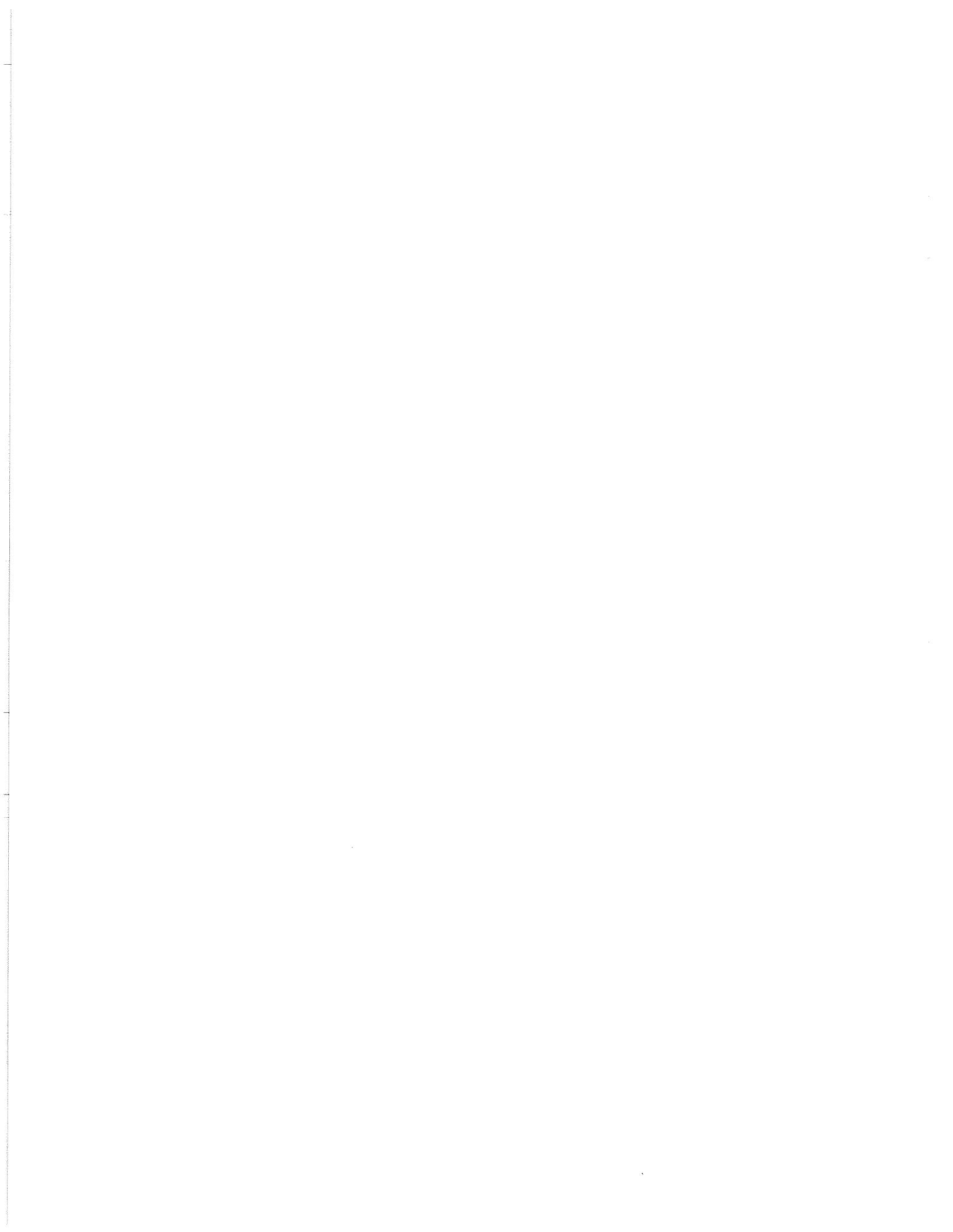


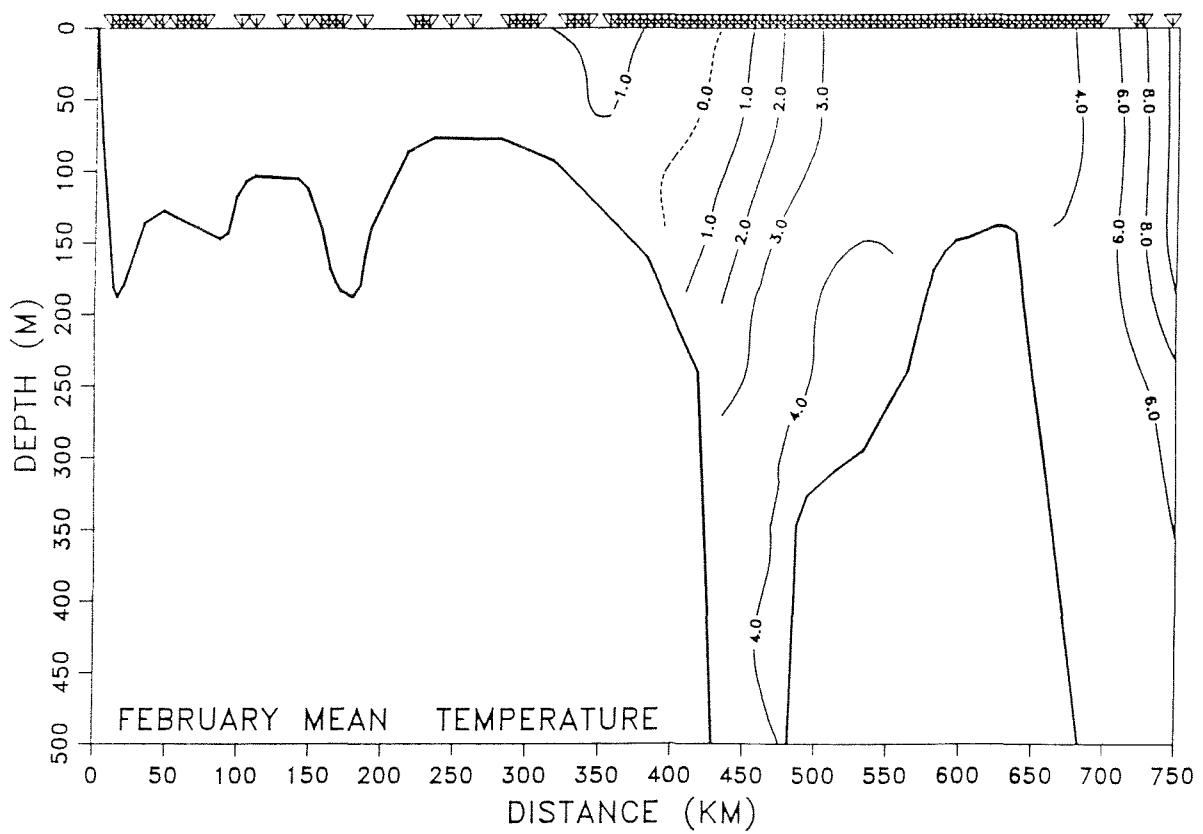
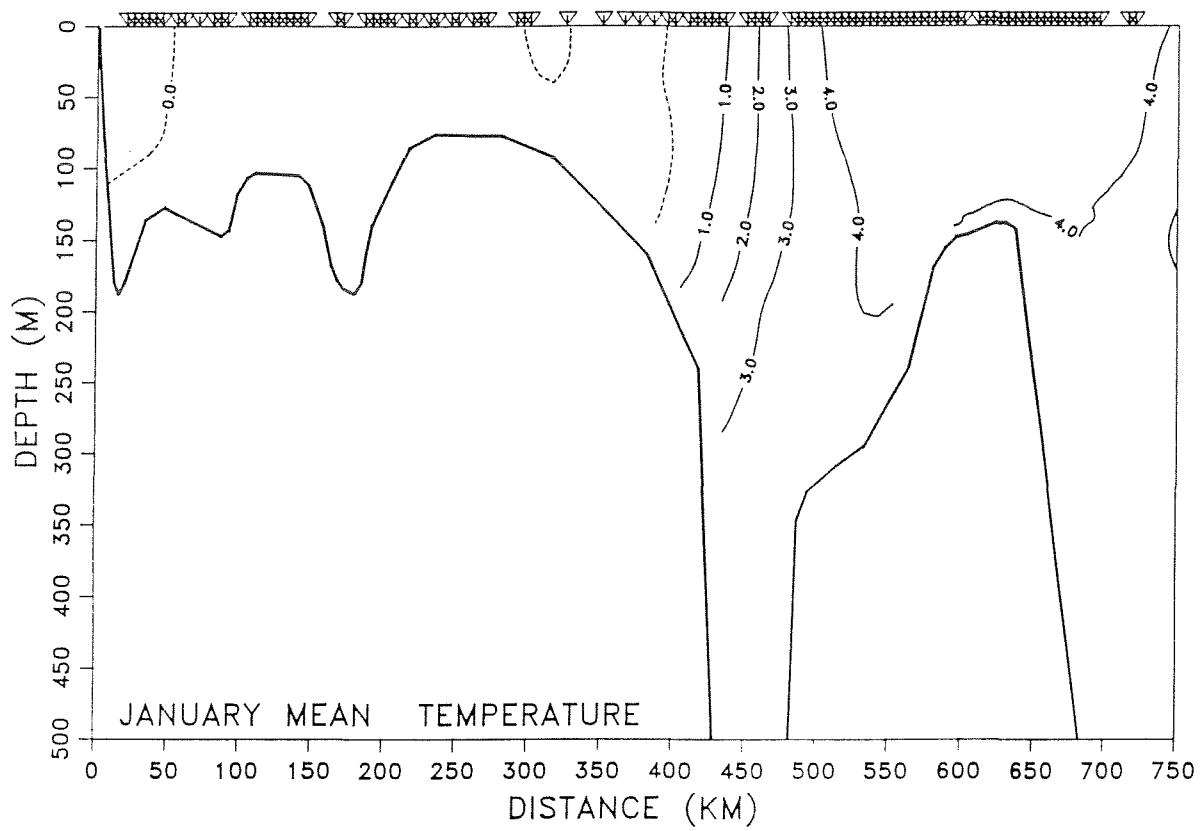


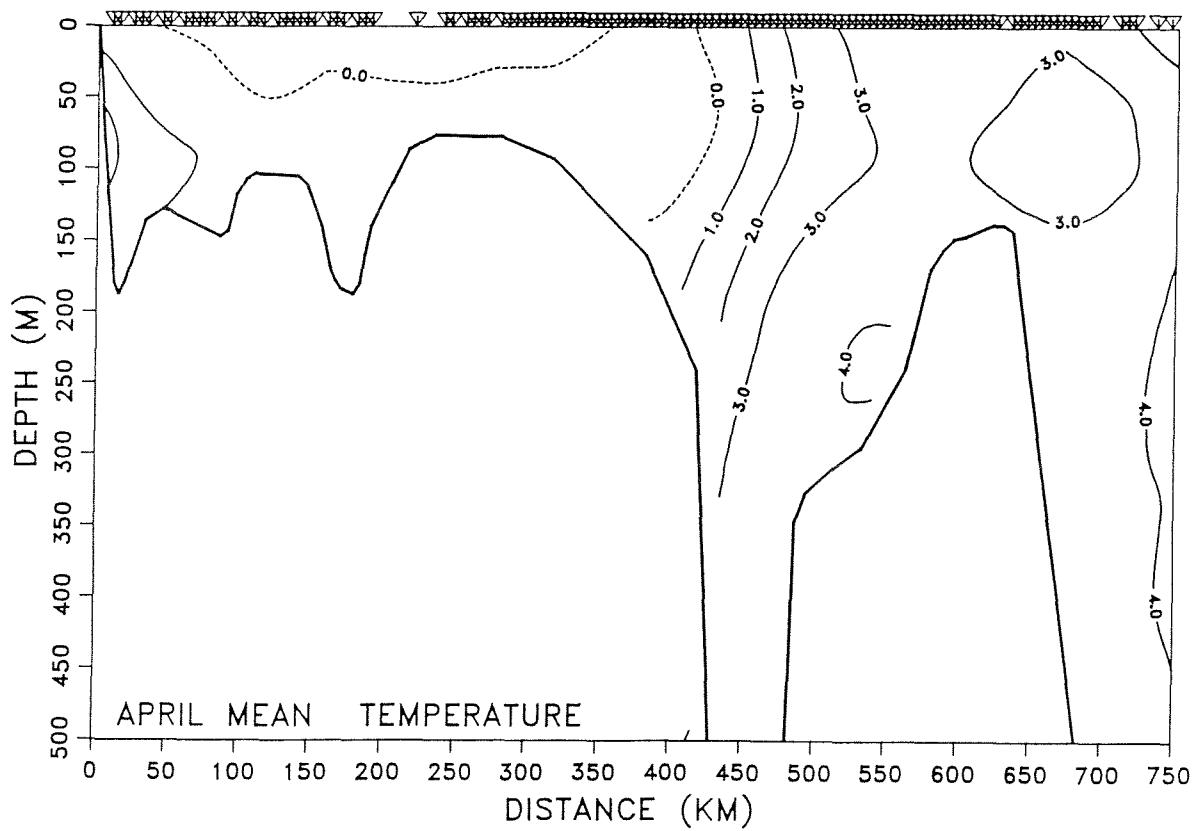
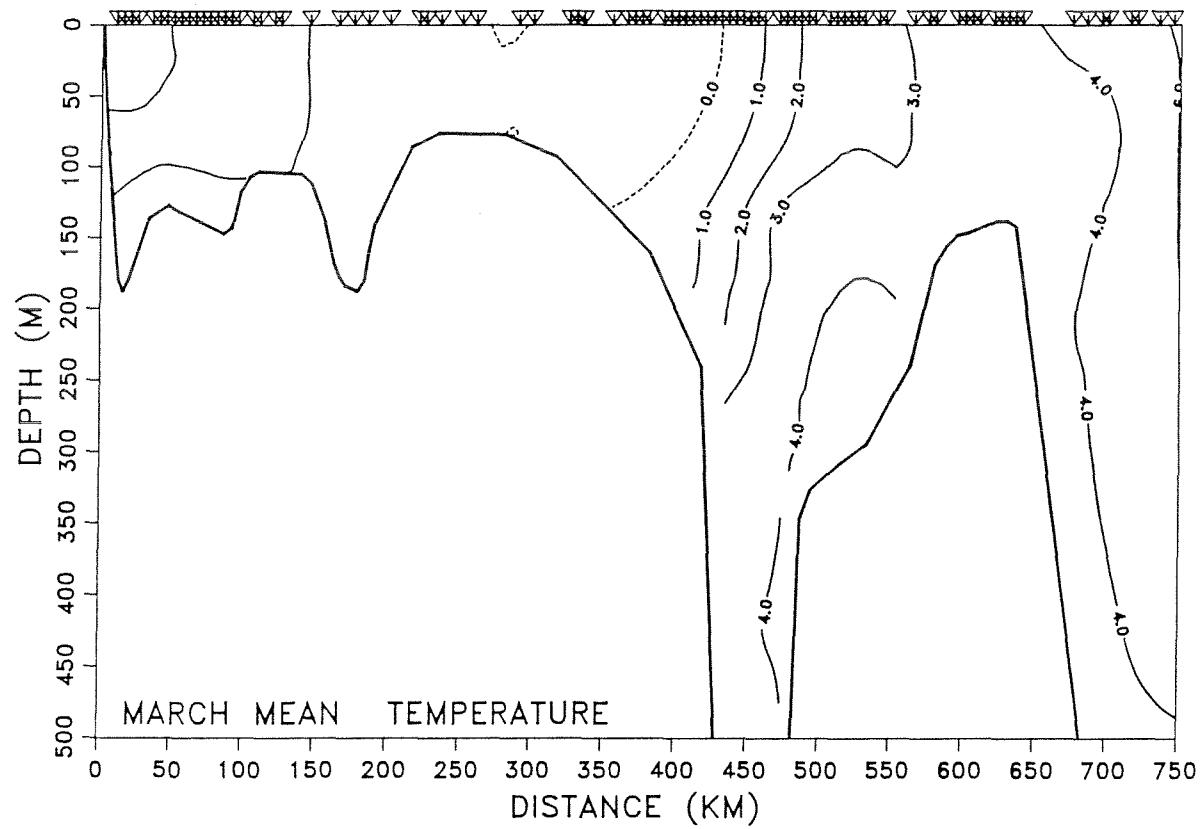


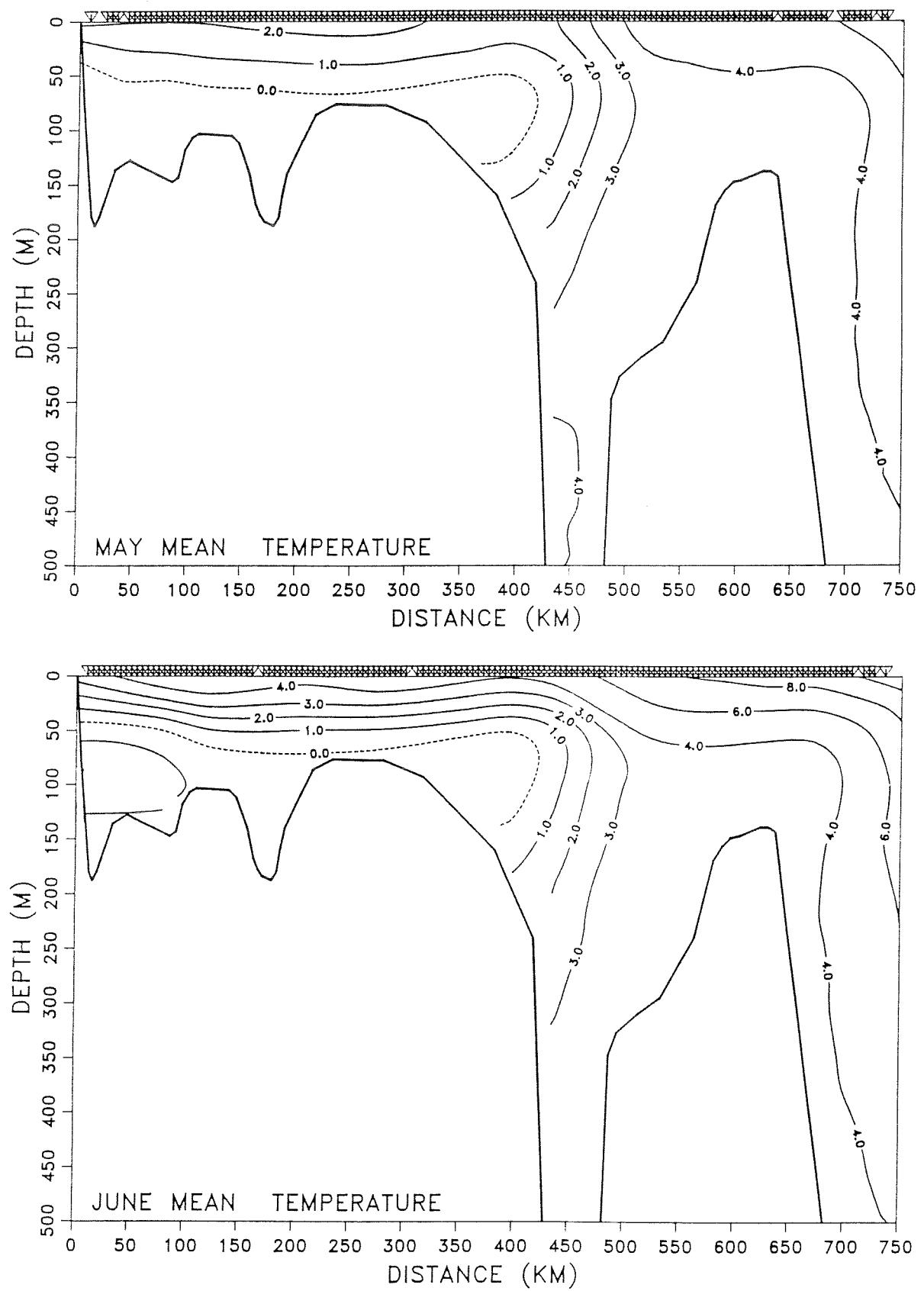


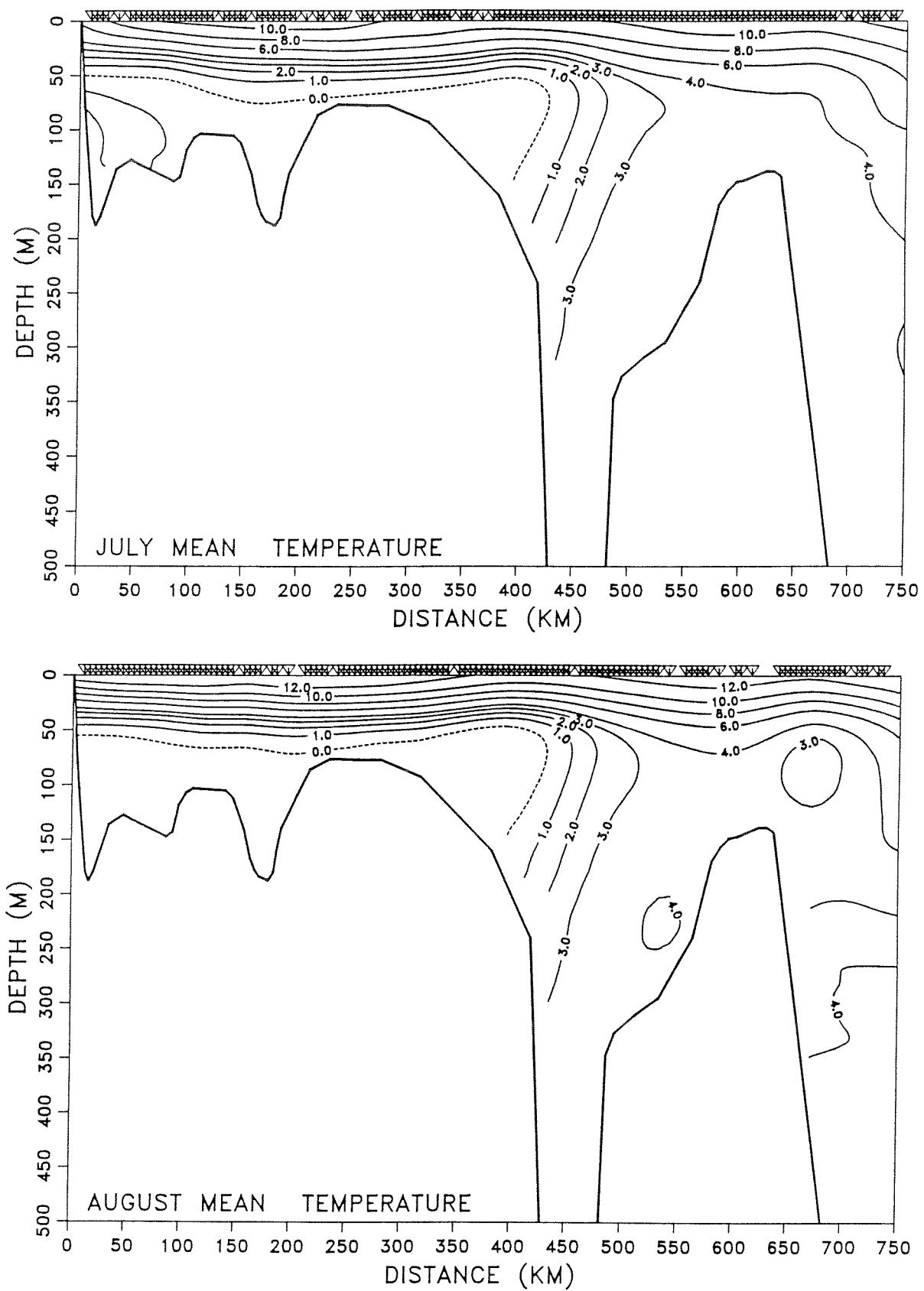
APPENDIX B. The monthly average vertical distributions of temperature.

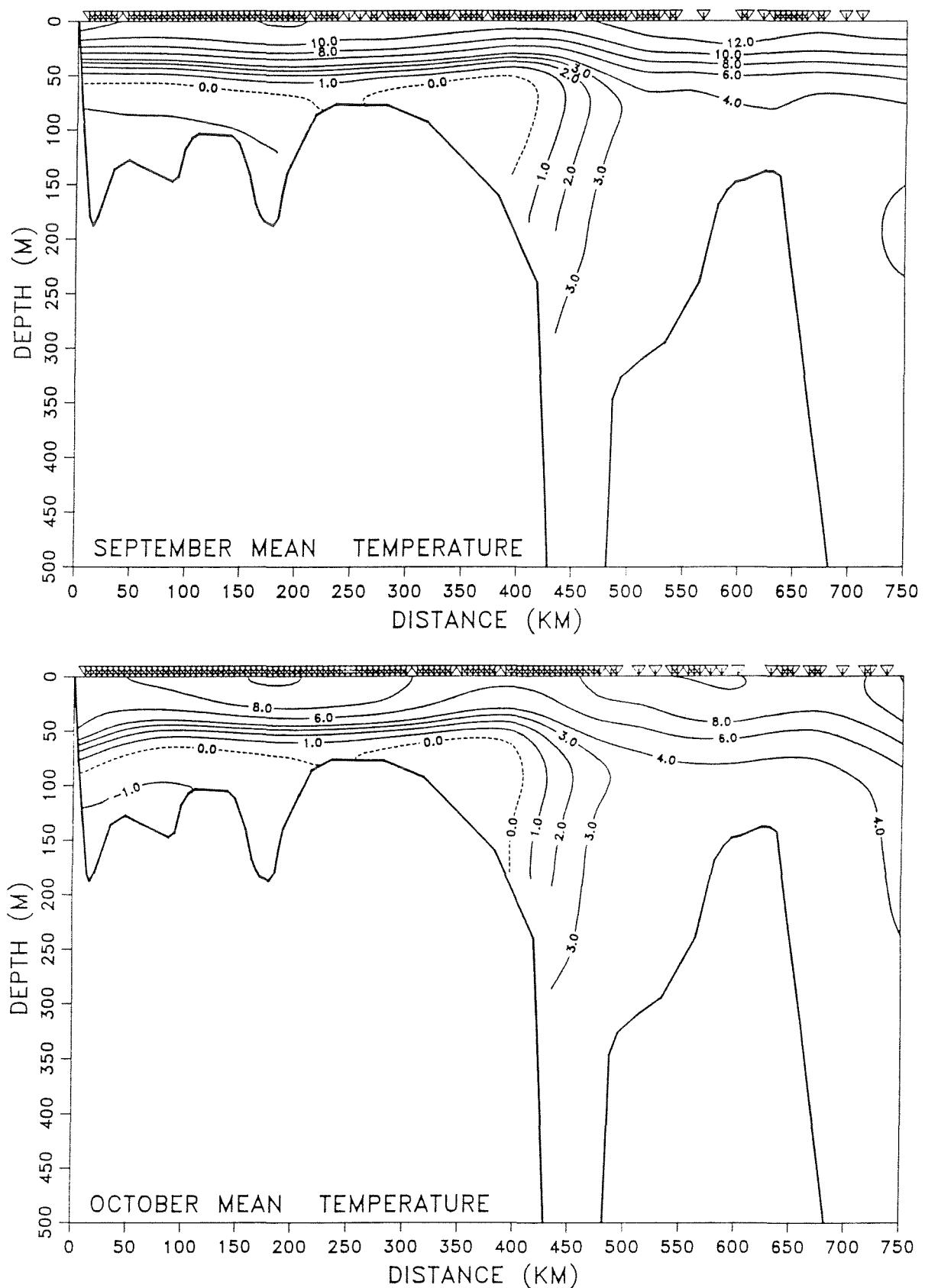


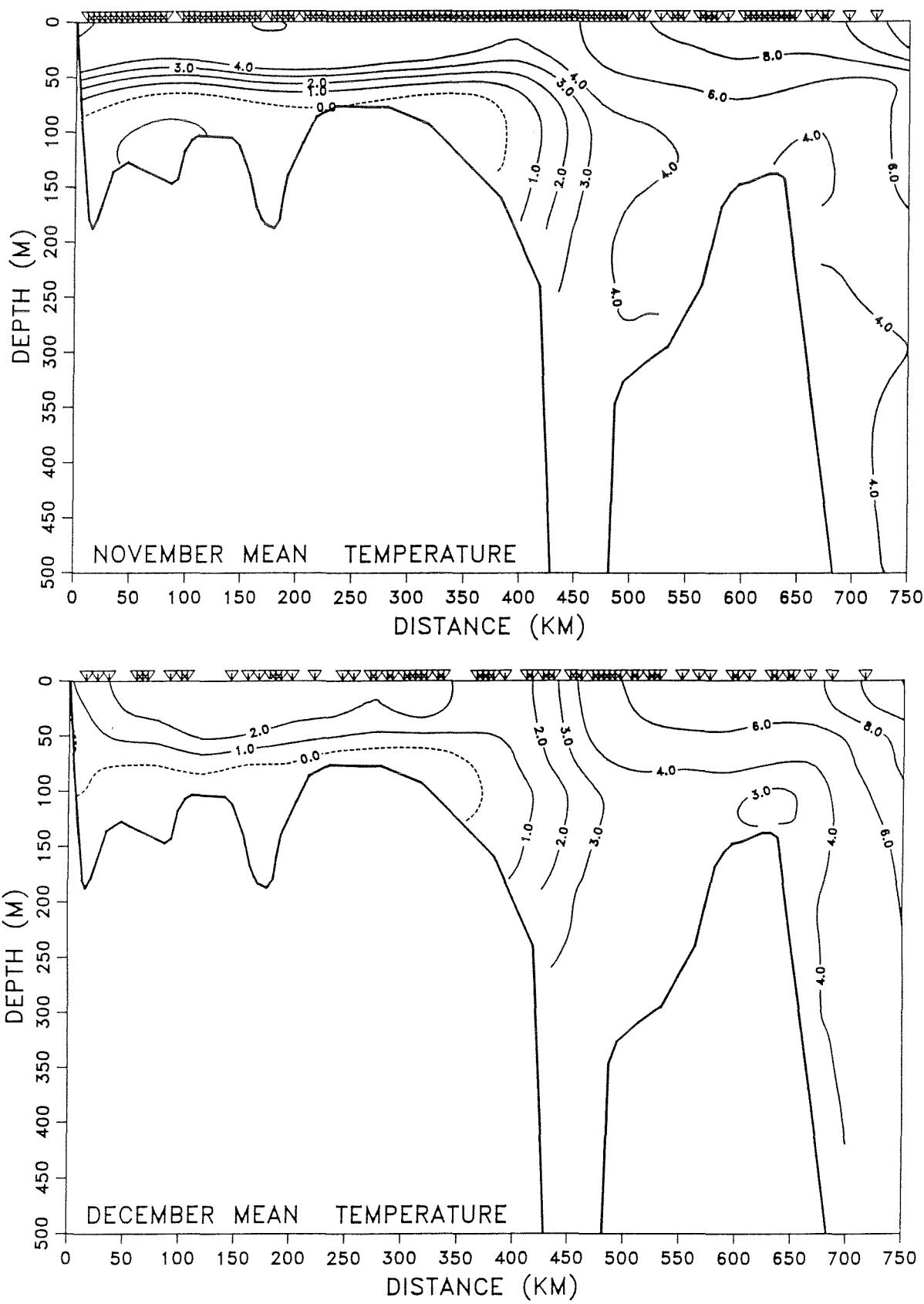




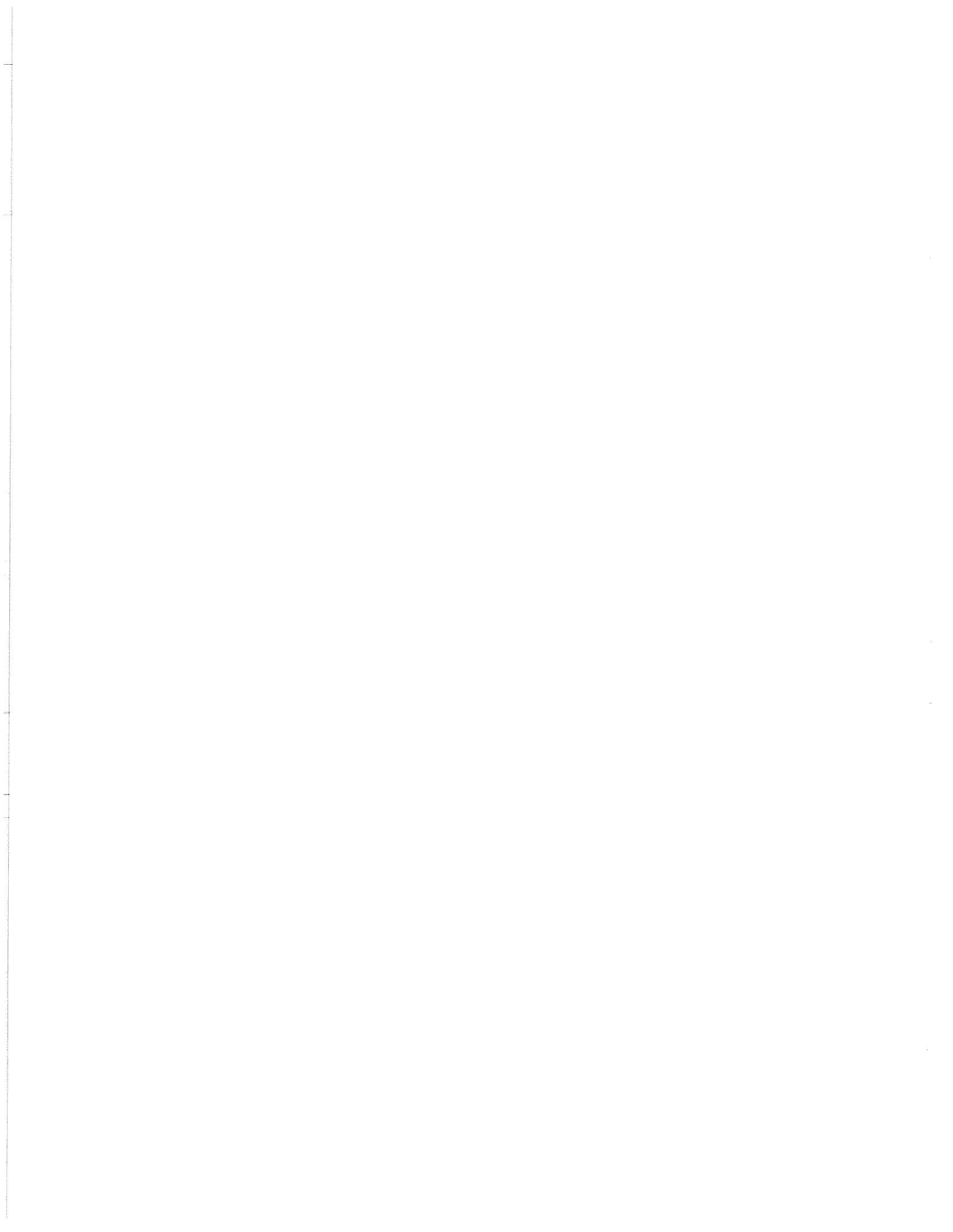


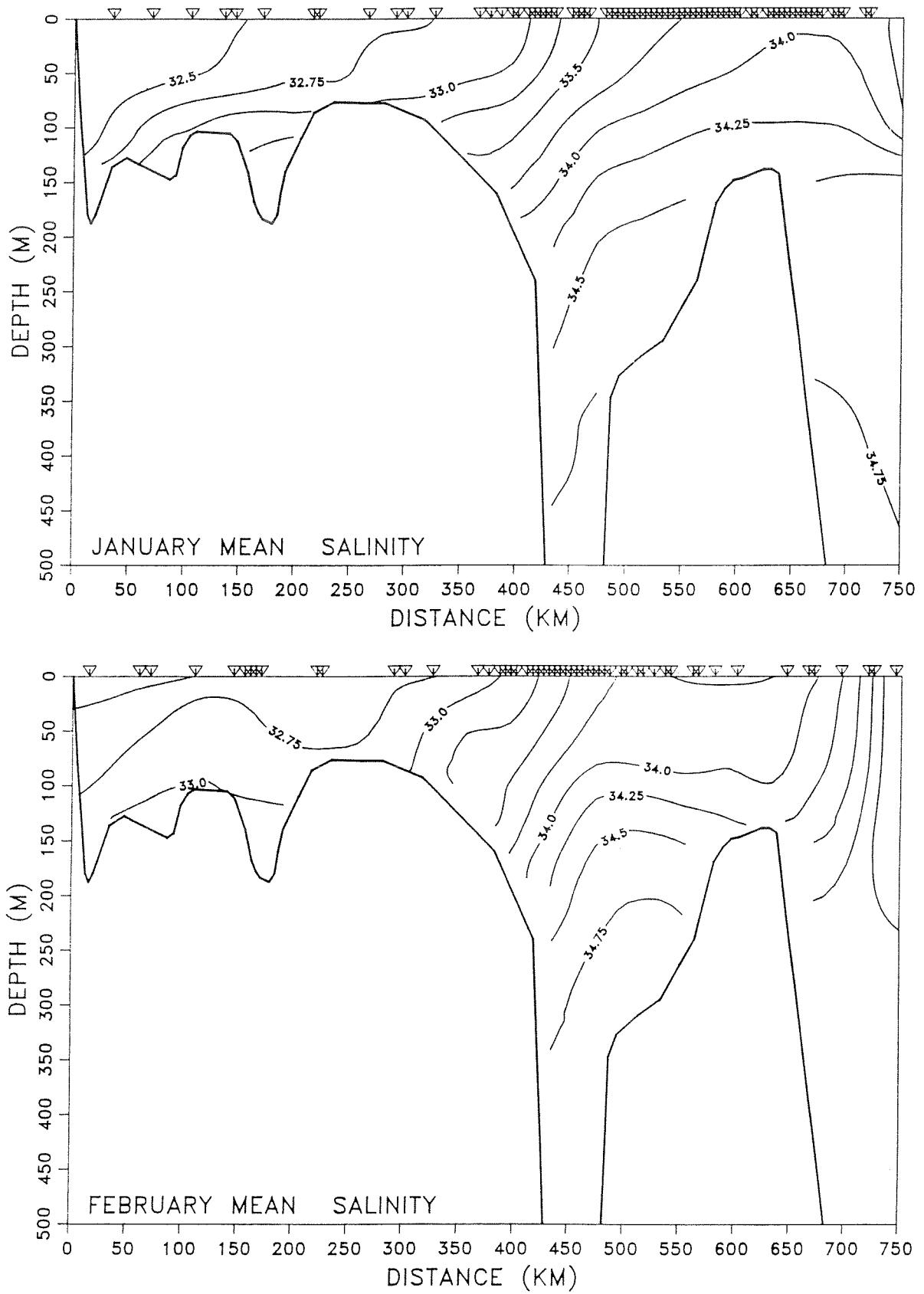


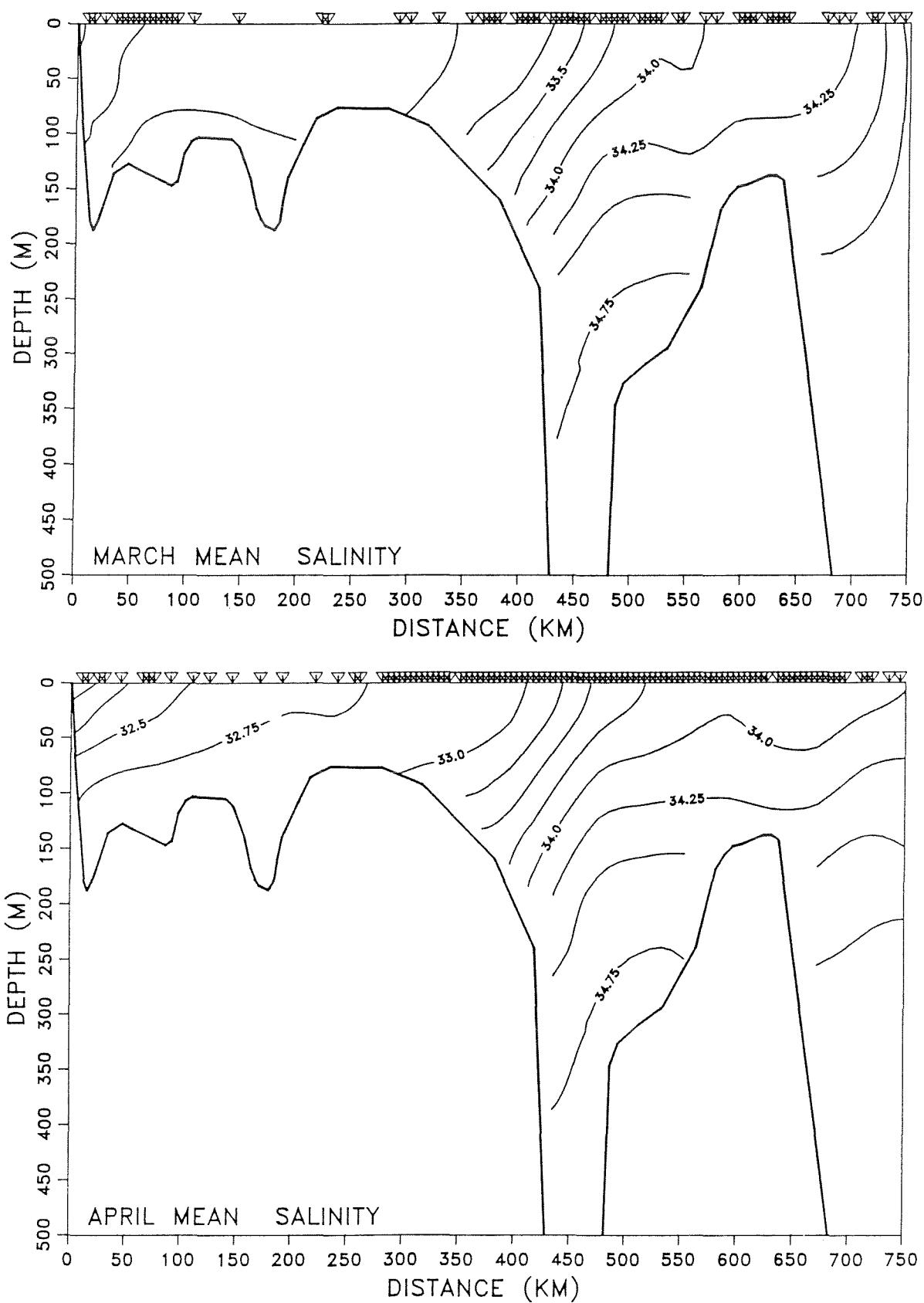


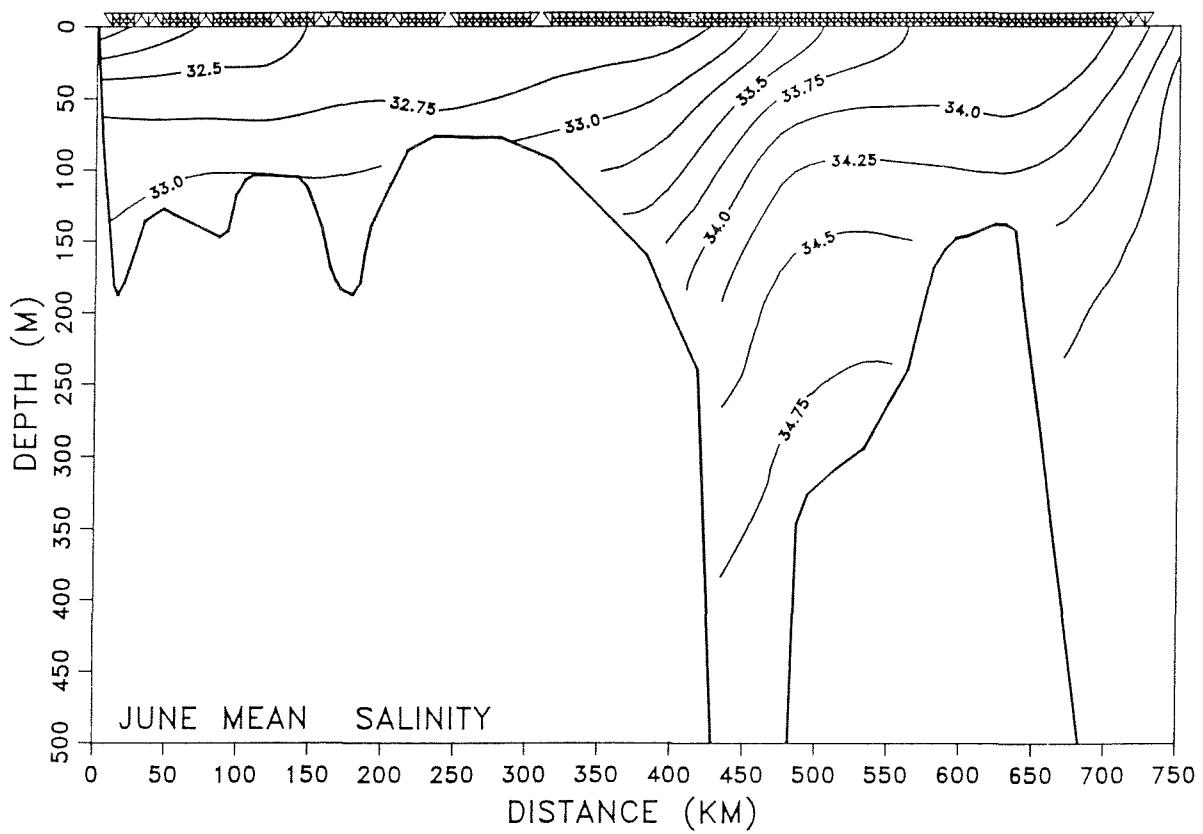
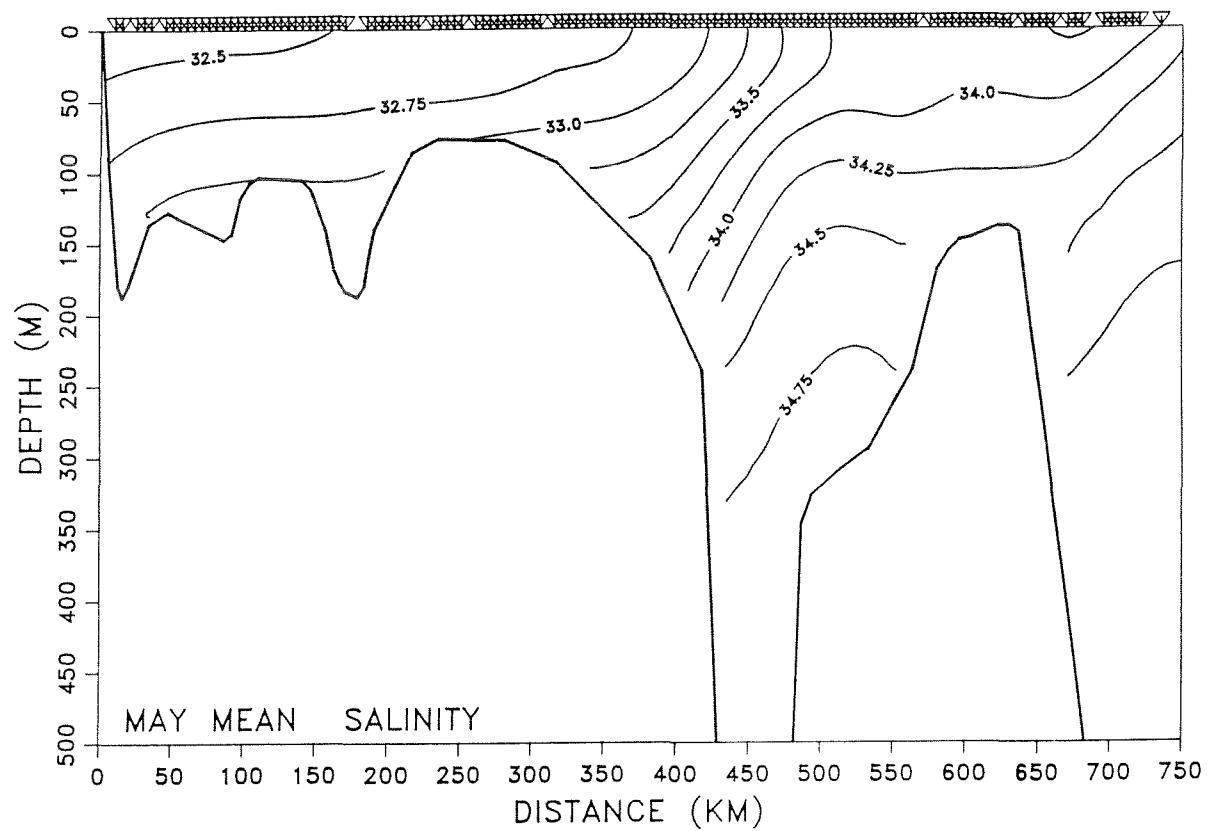


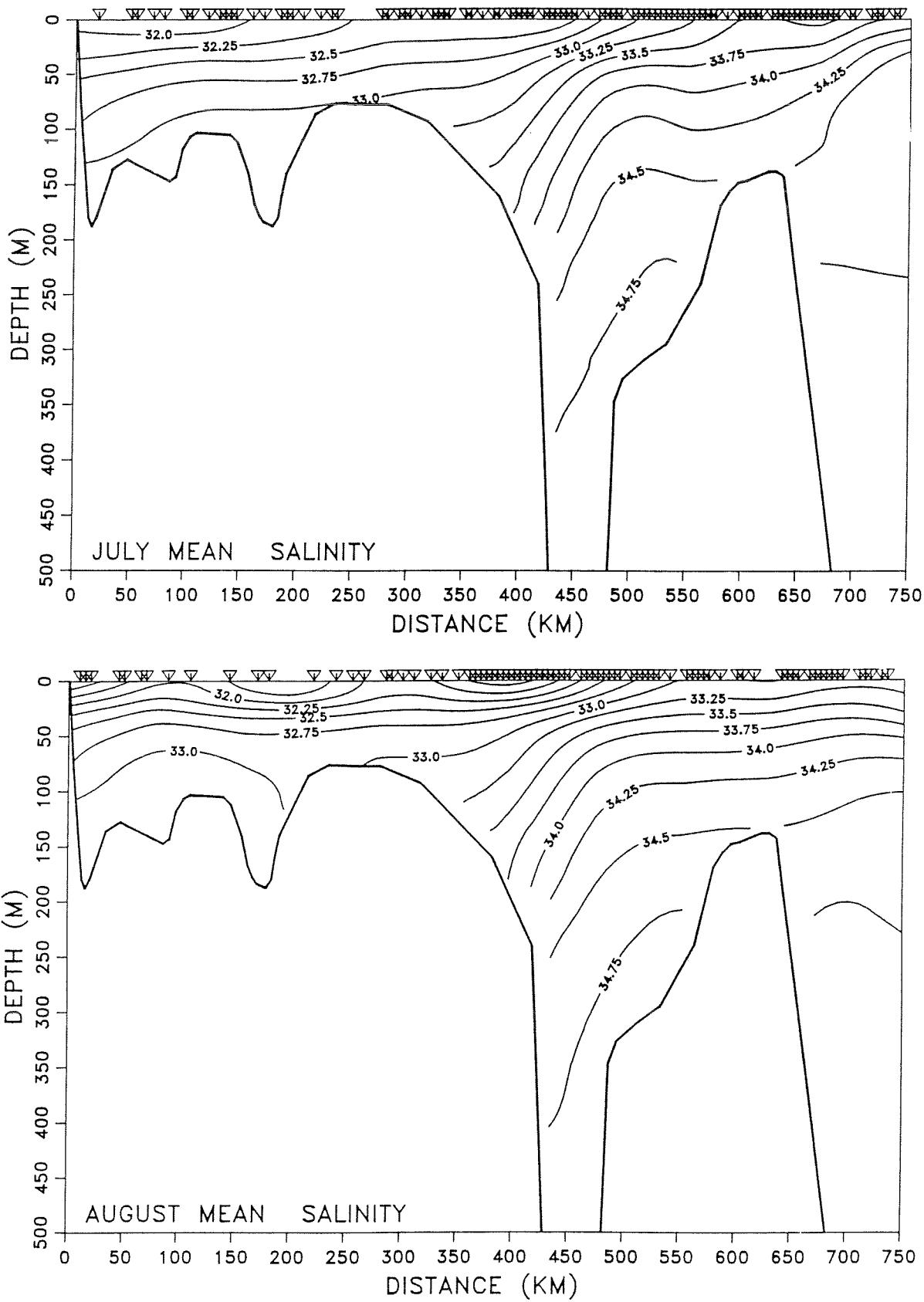
APPENDIX C. The monthly average vertical distributions of salinity.

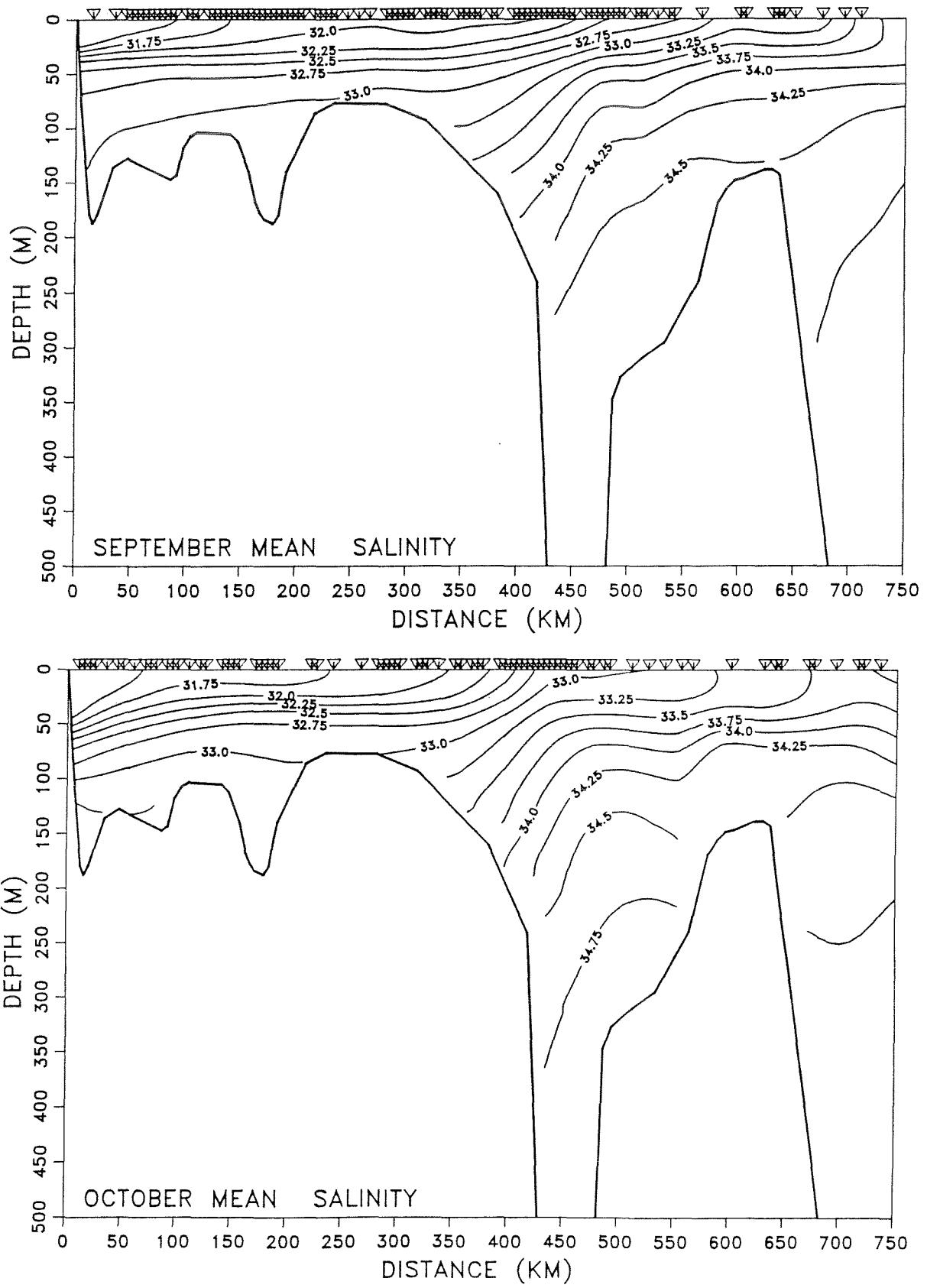


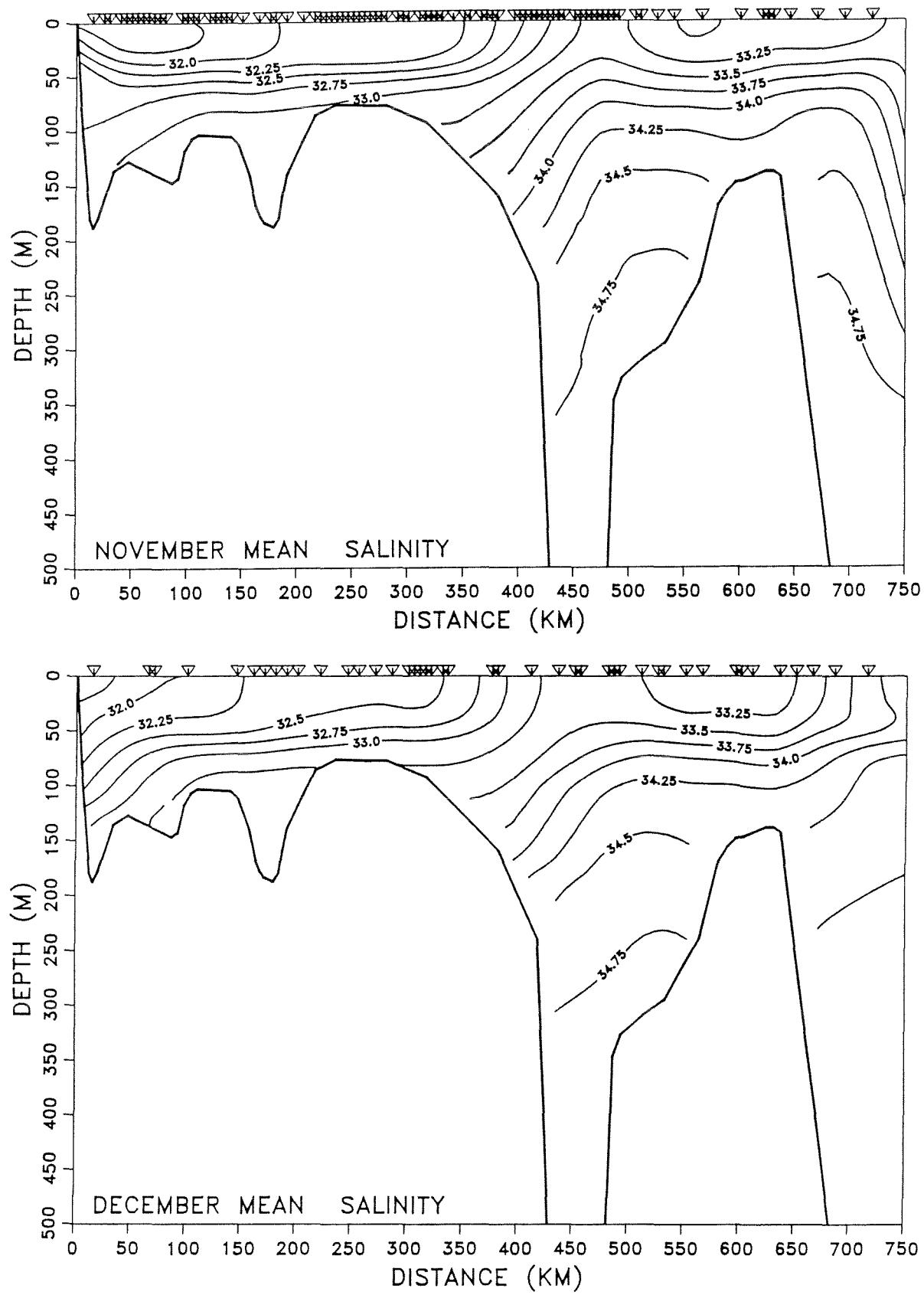




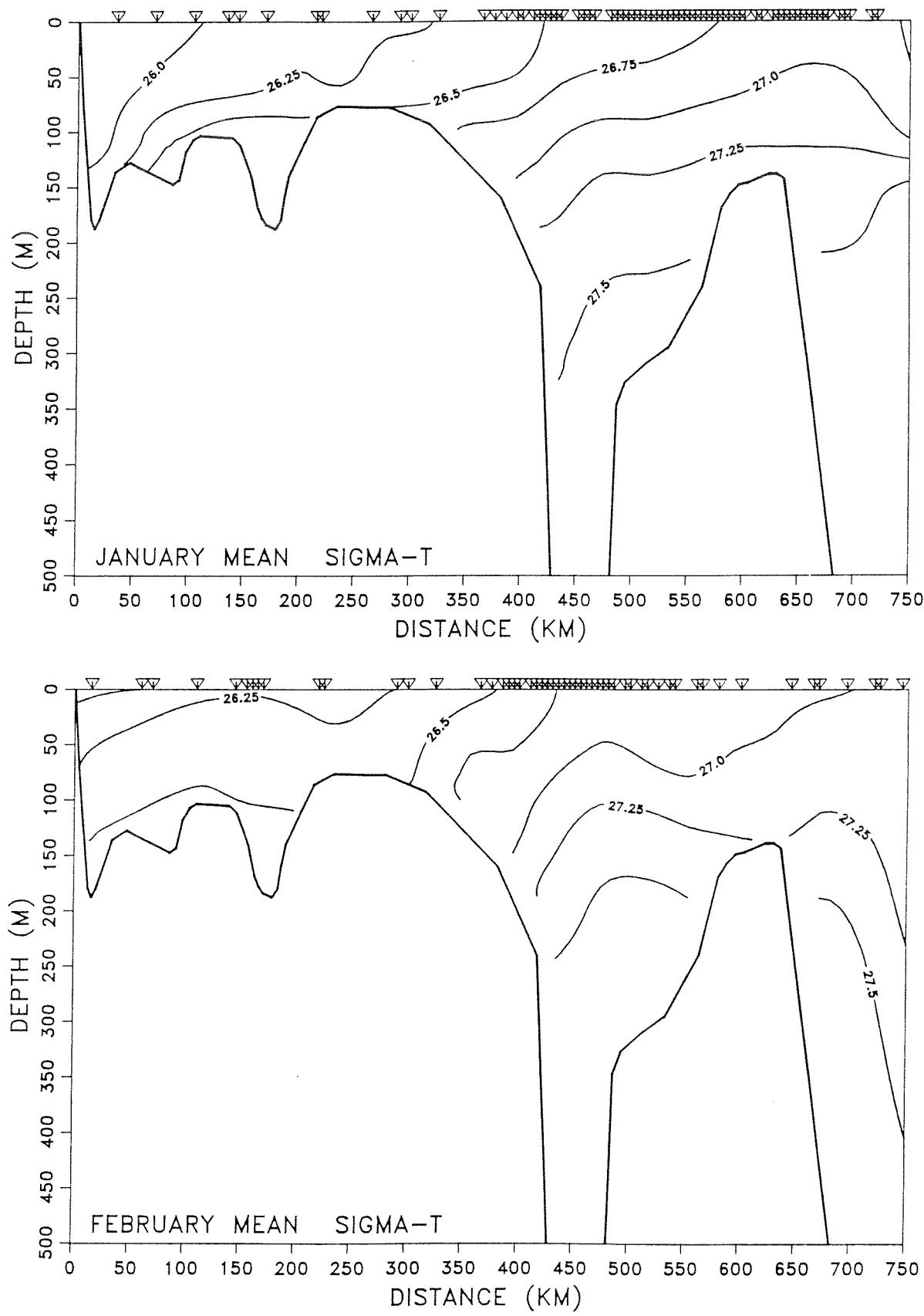


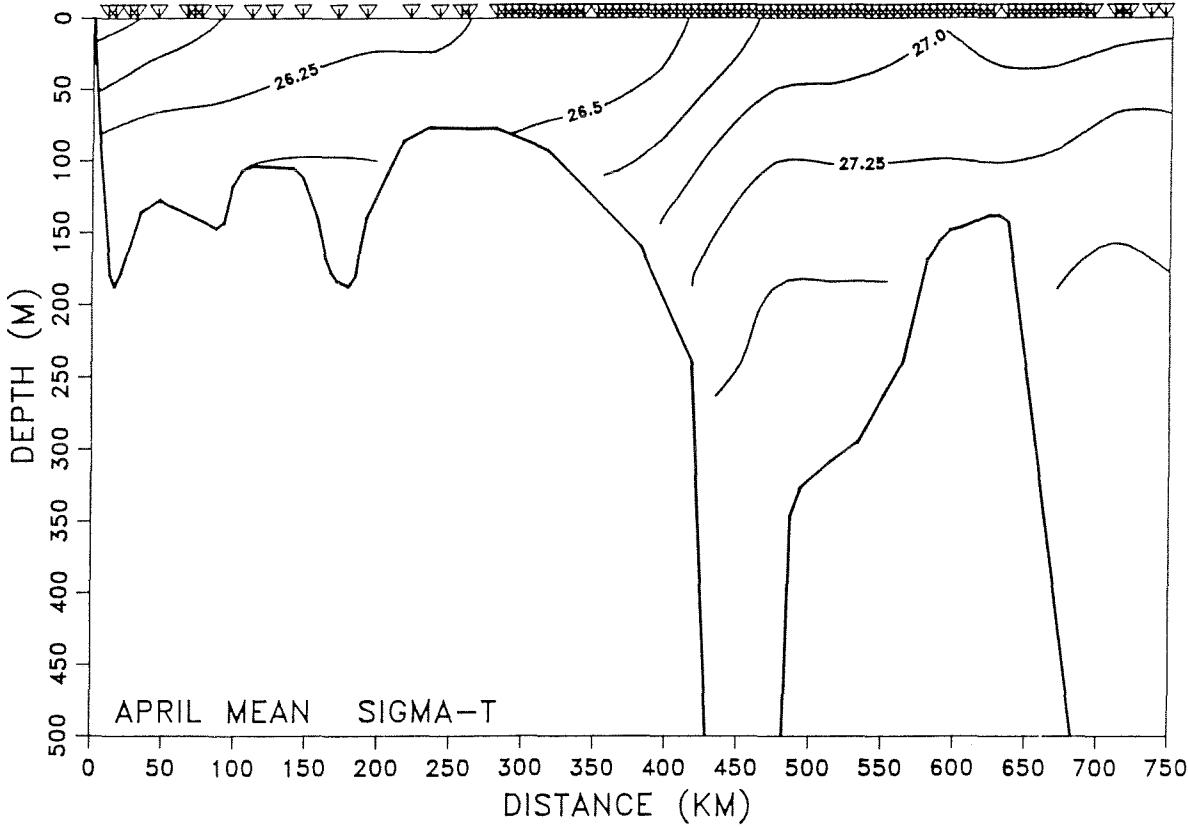
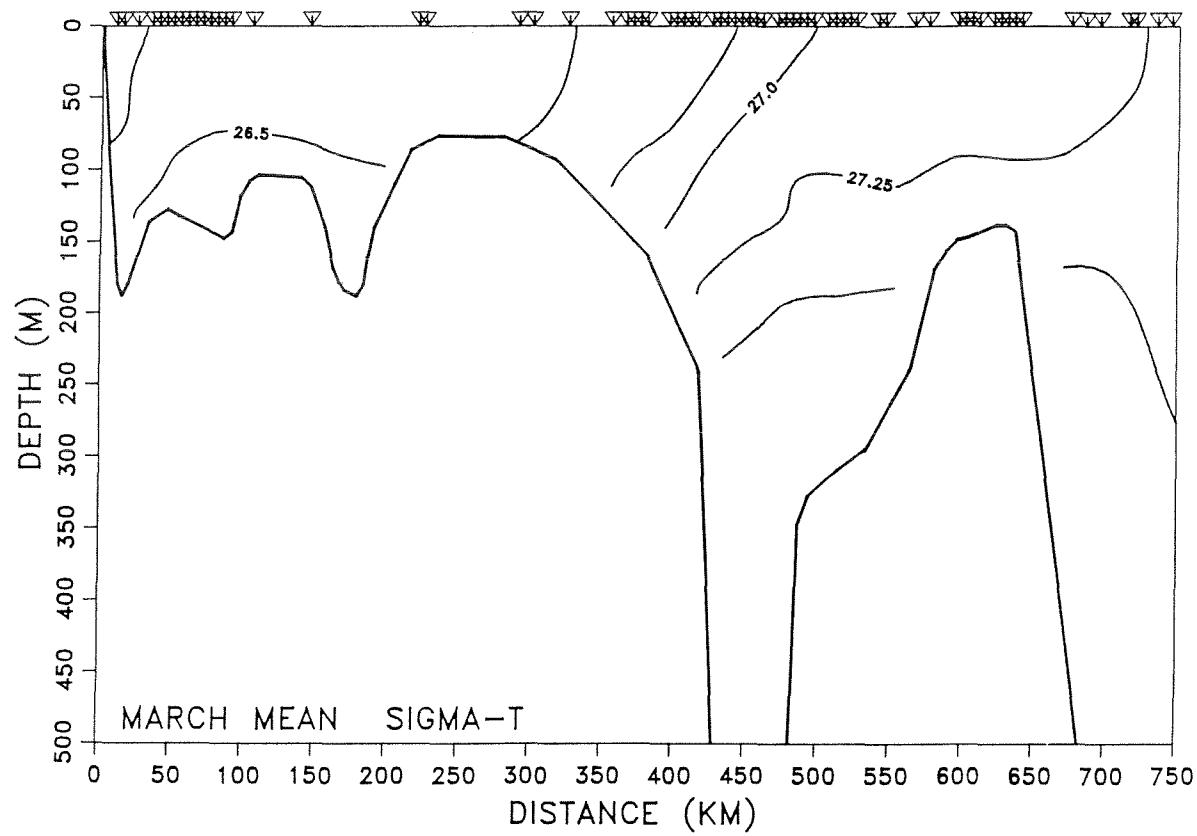


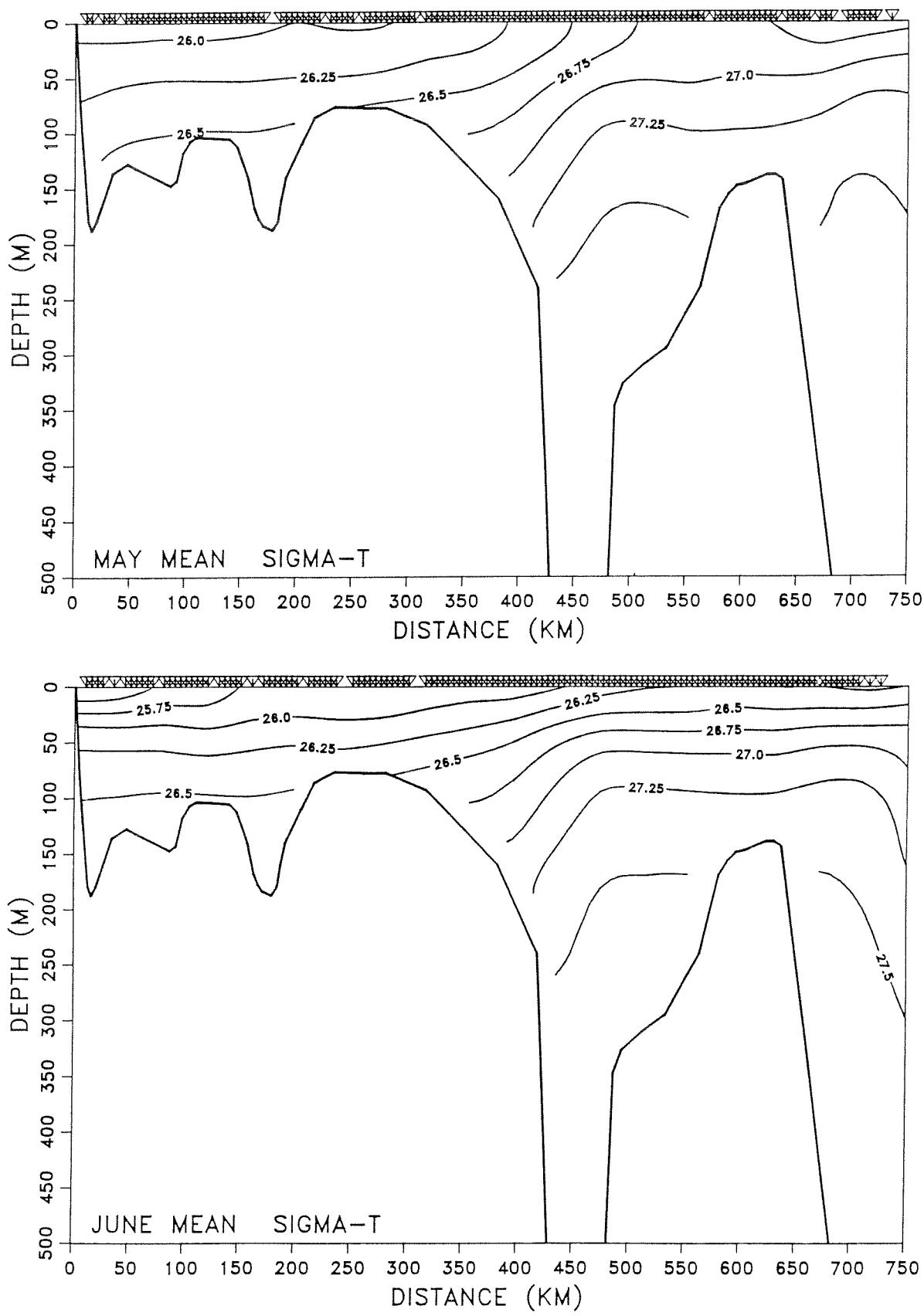


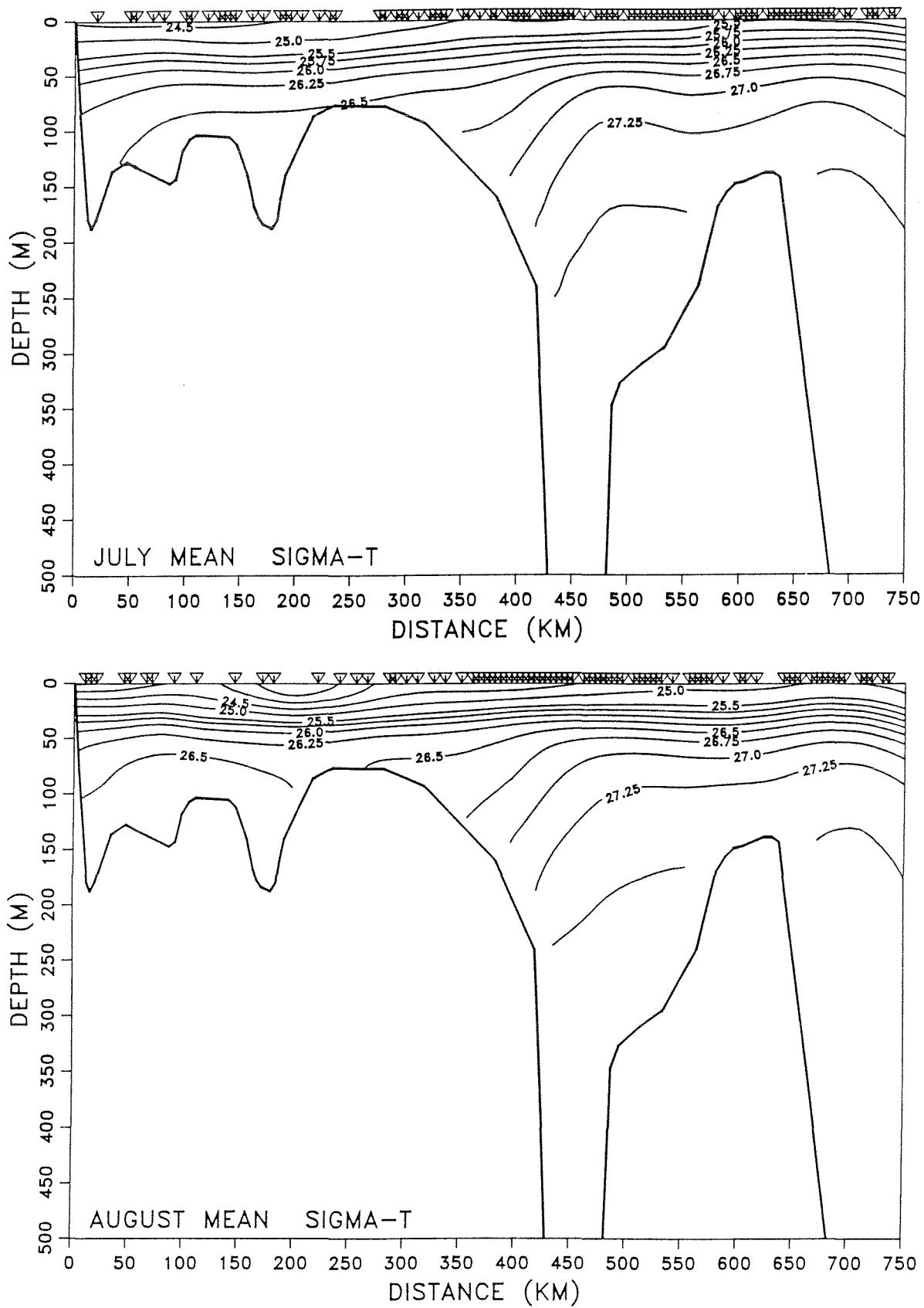


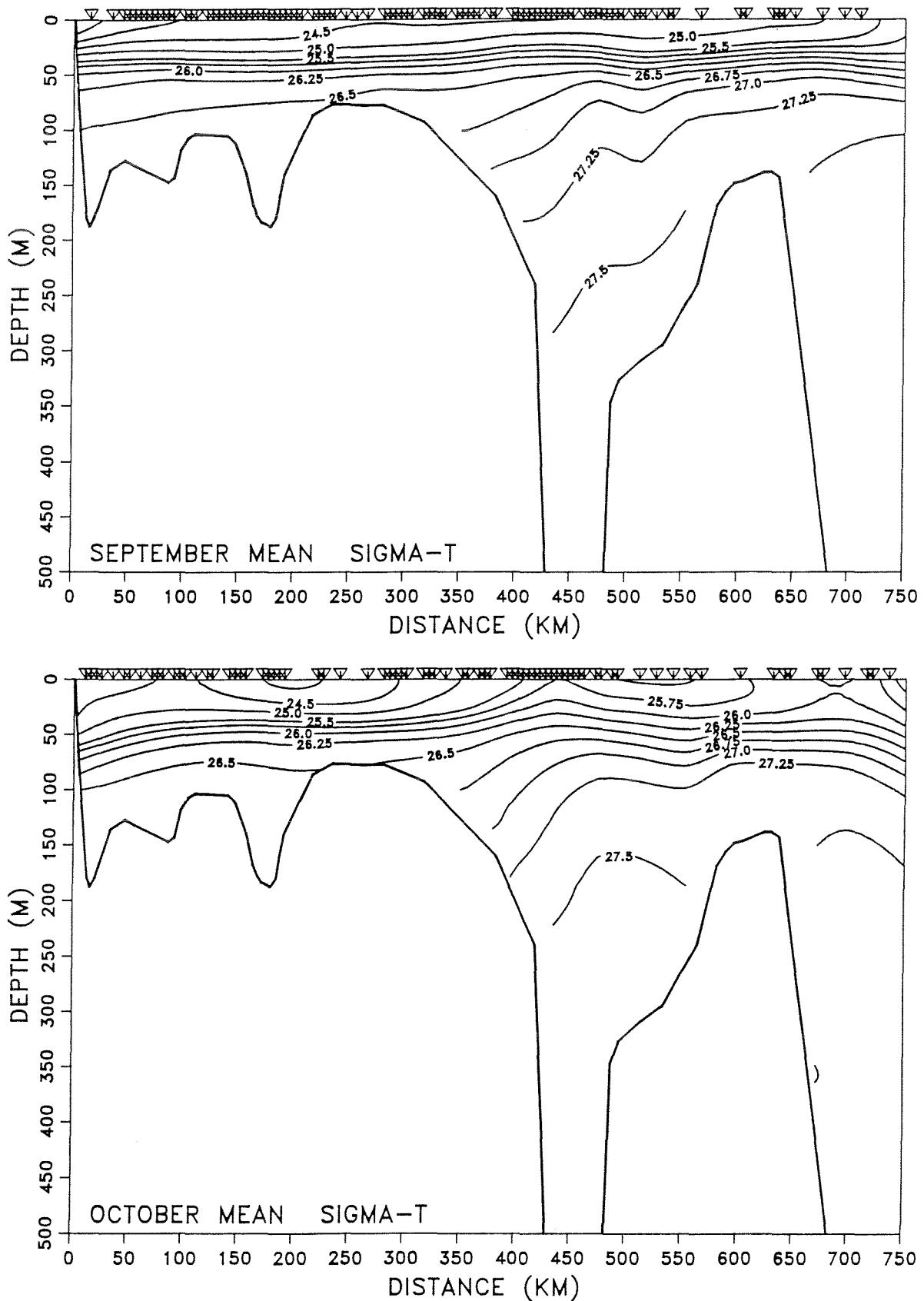
APPENDIX D. The monthly average vertical distributions of density.

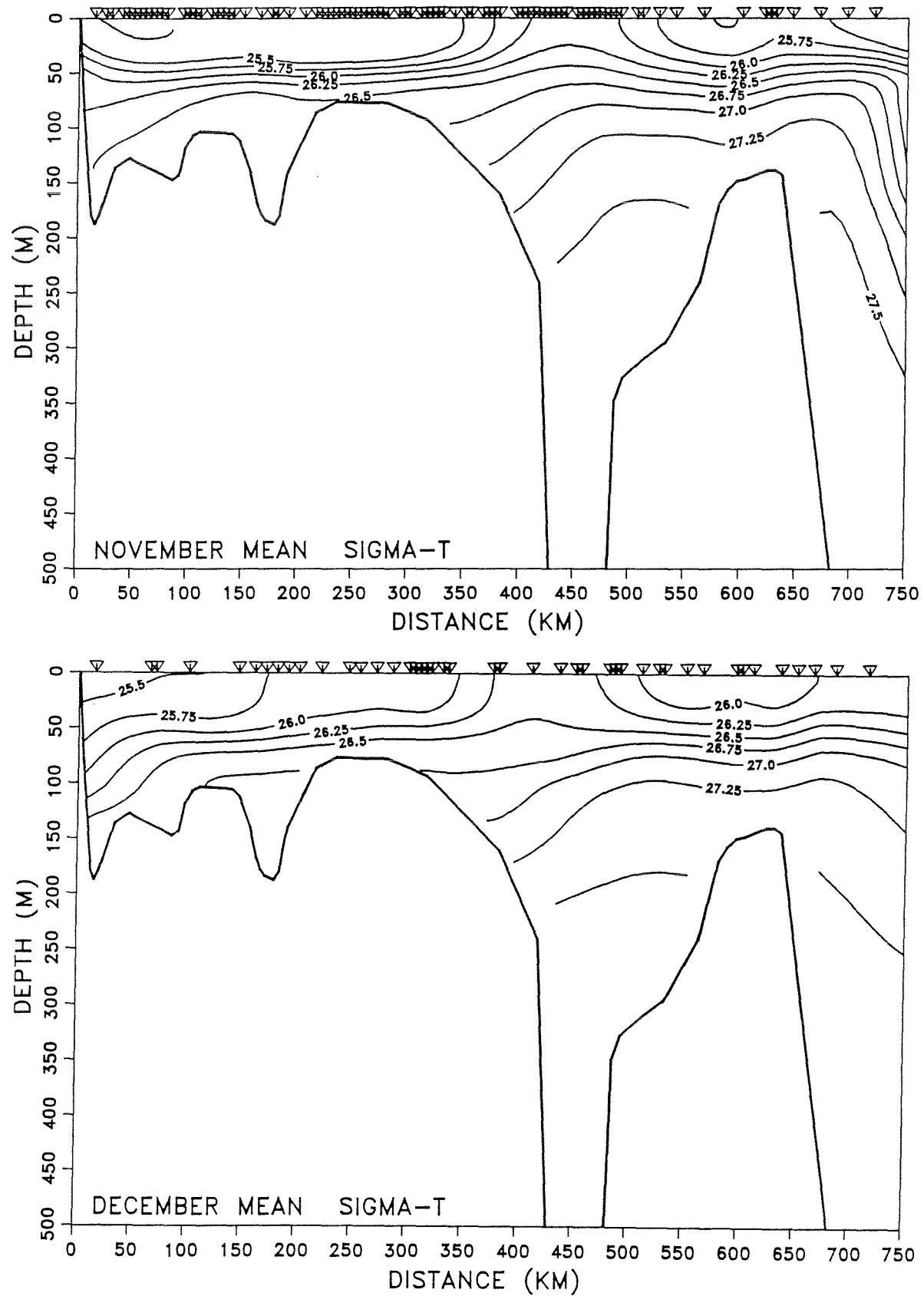




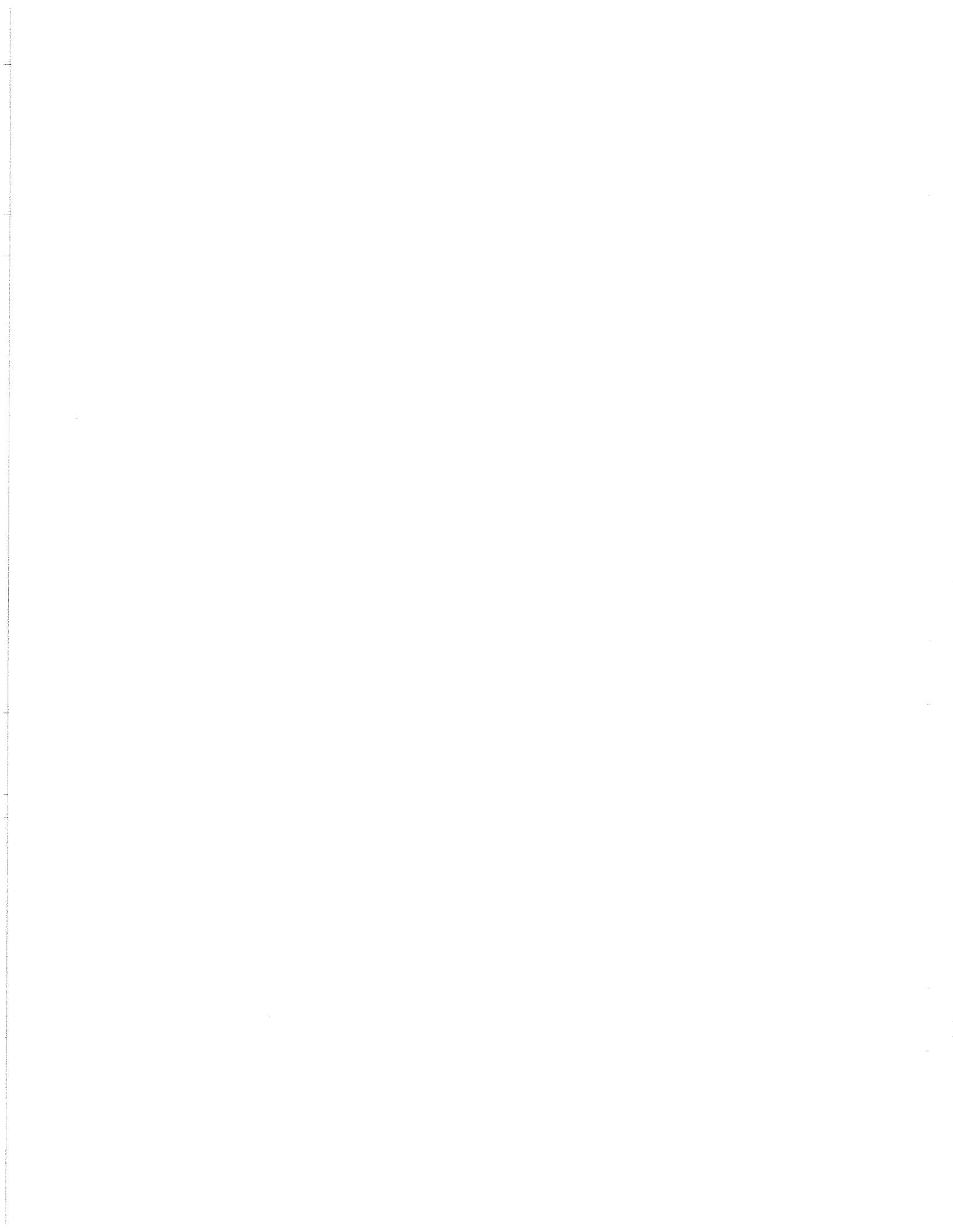


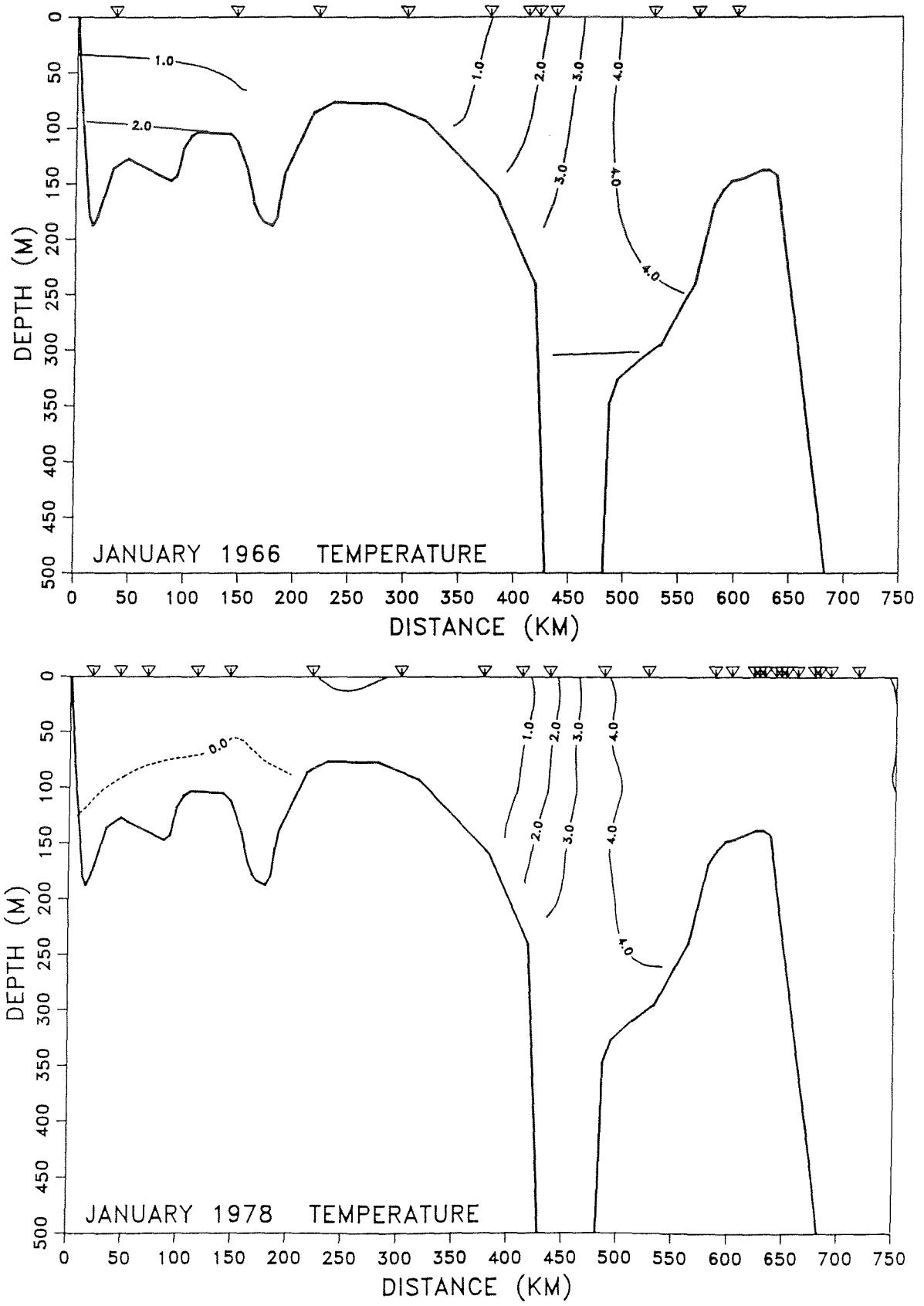


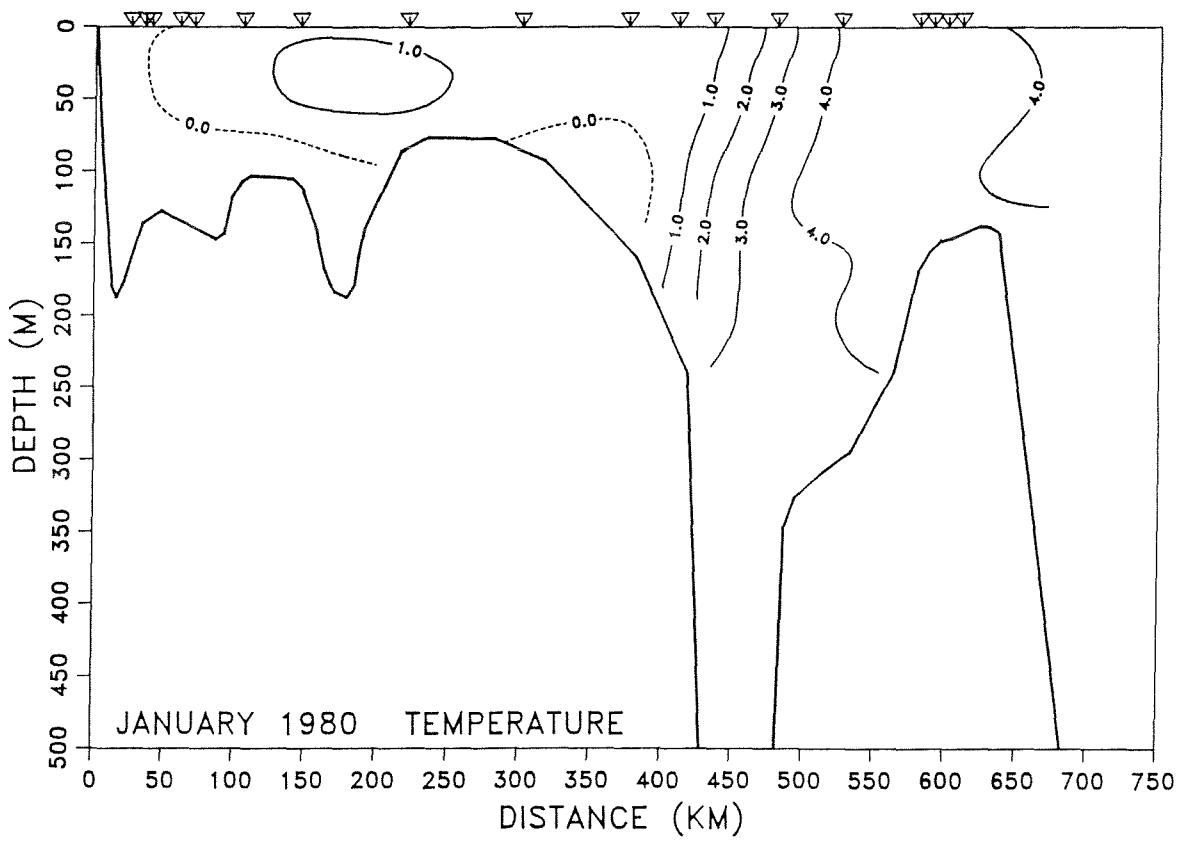
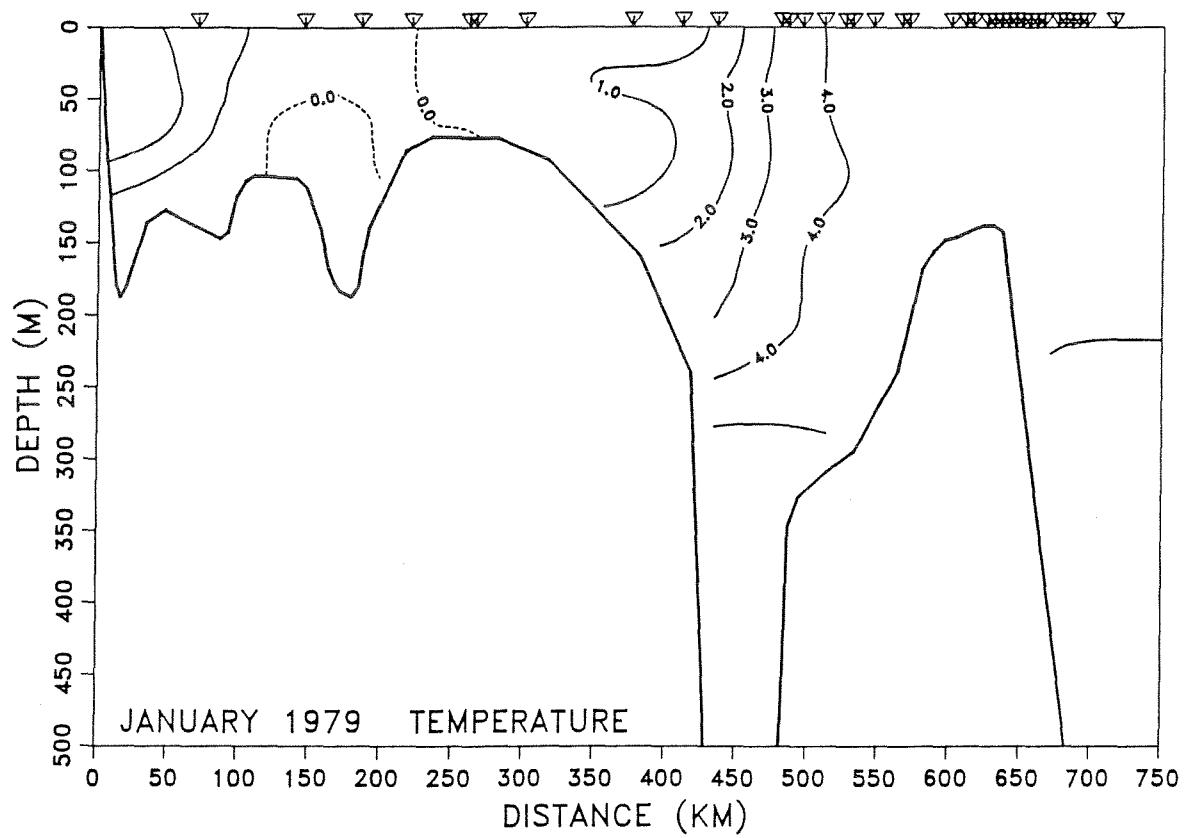


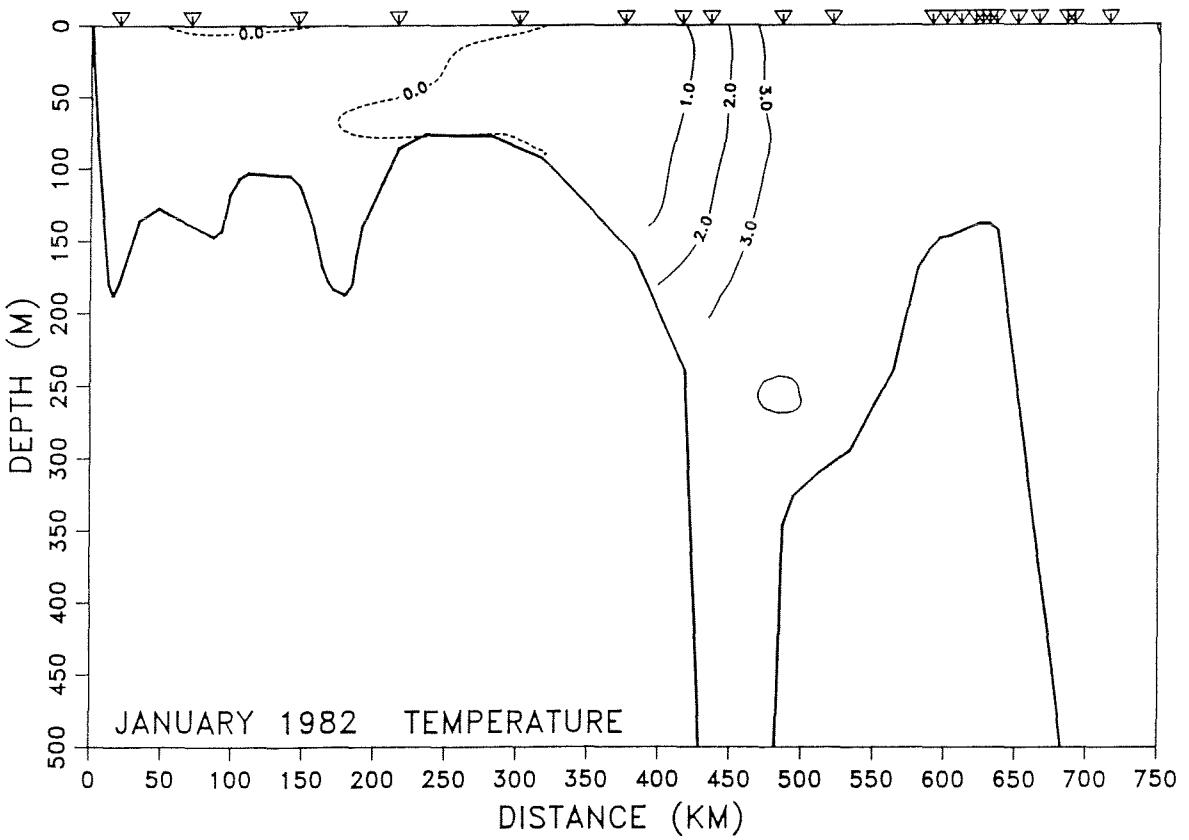
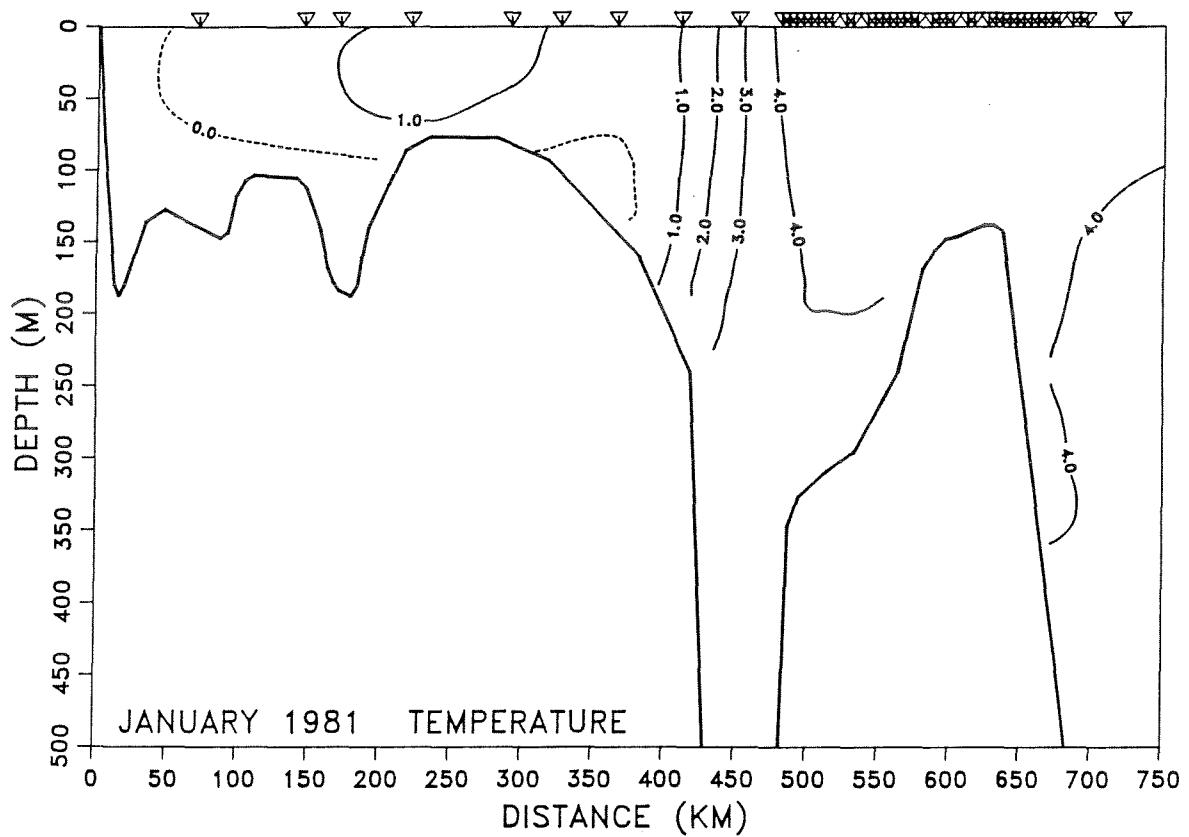


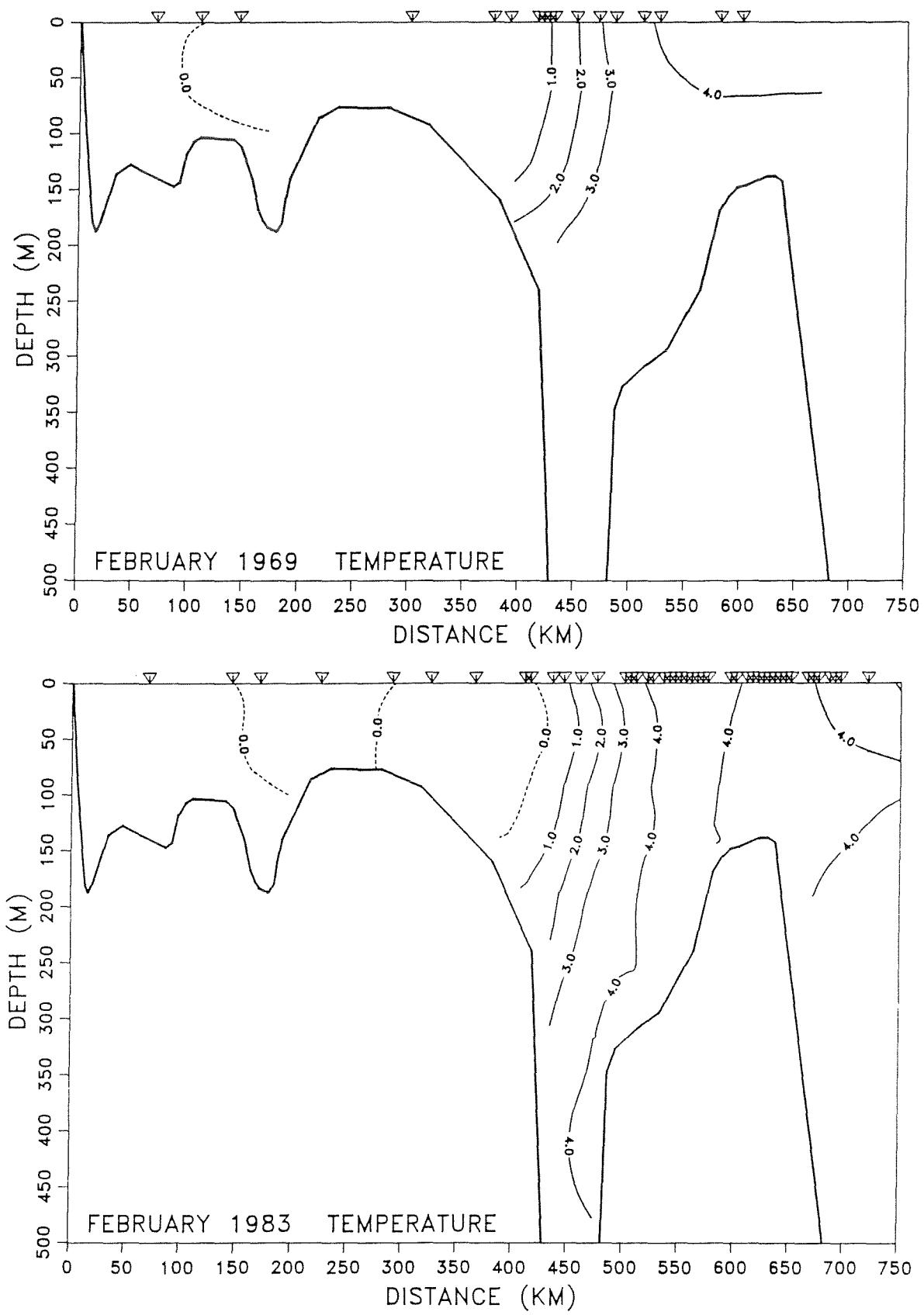
APPENDIX E. Flemish Cap Annual Temperature Transects.

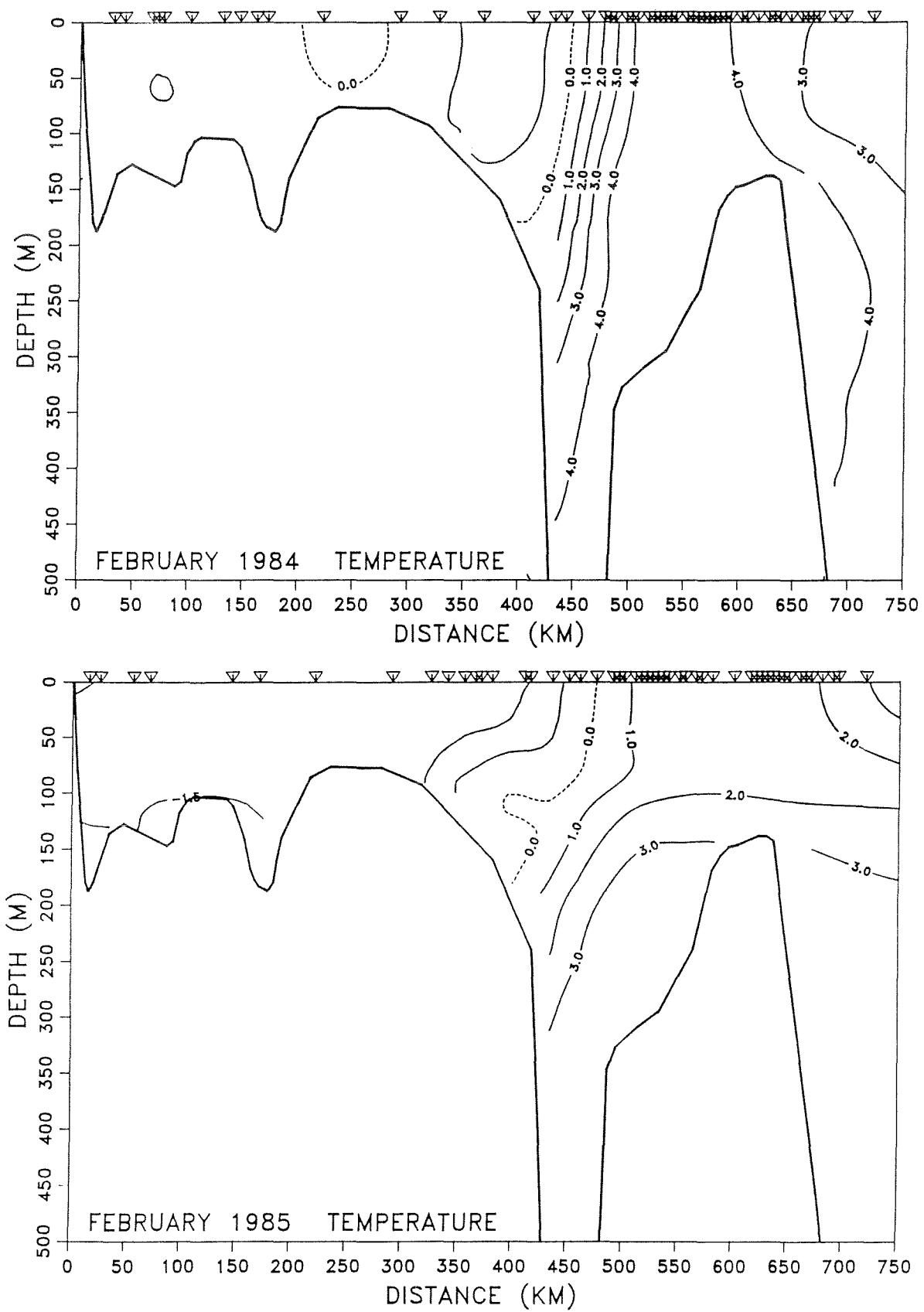


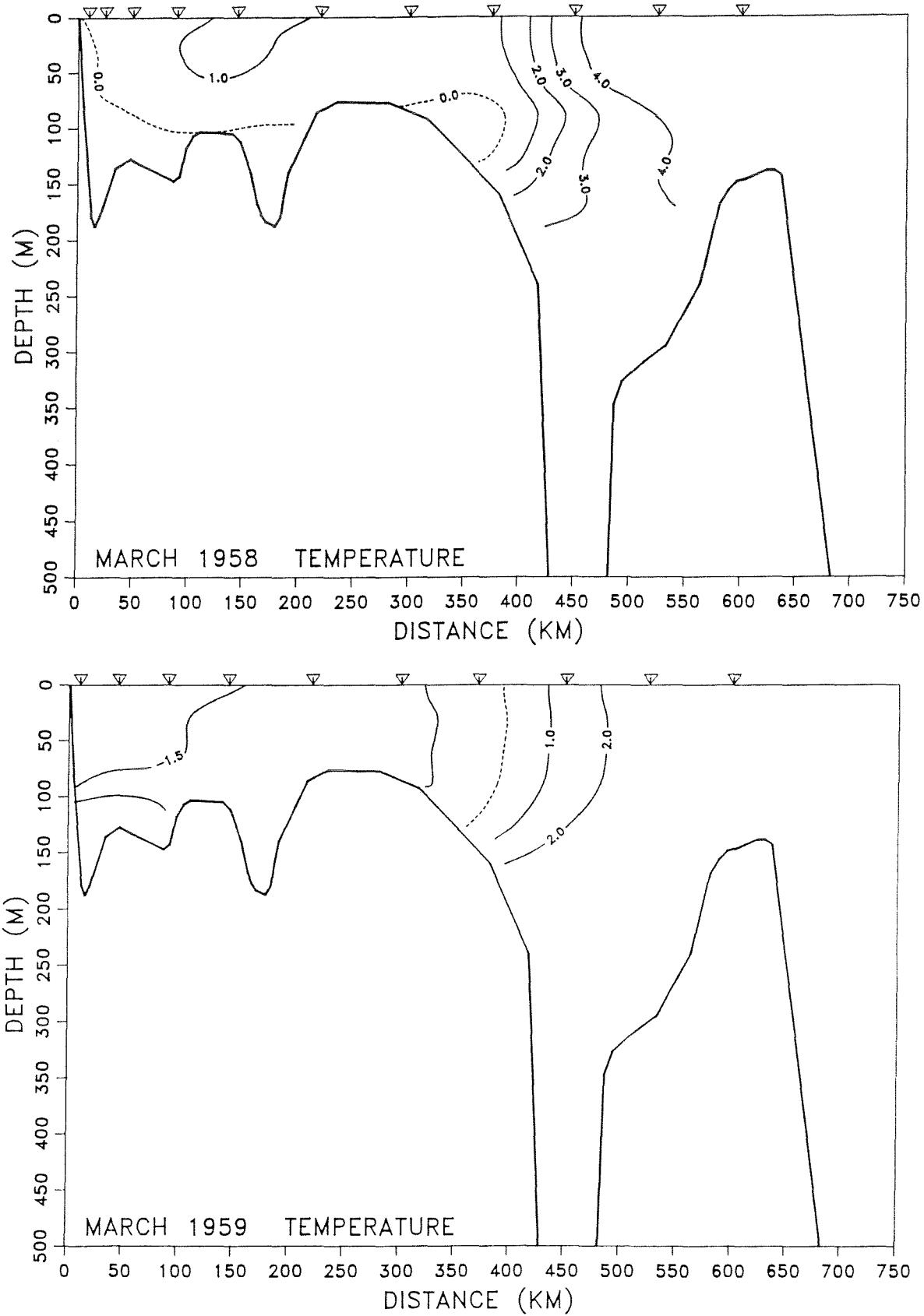


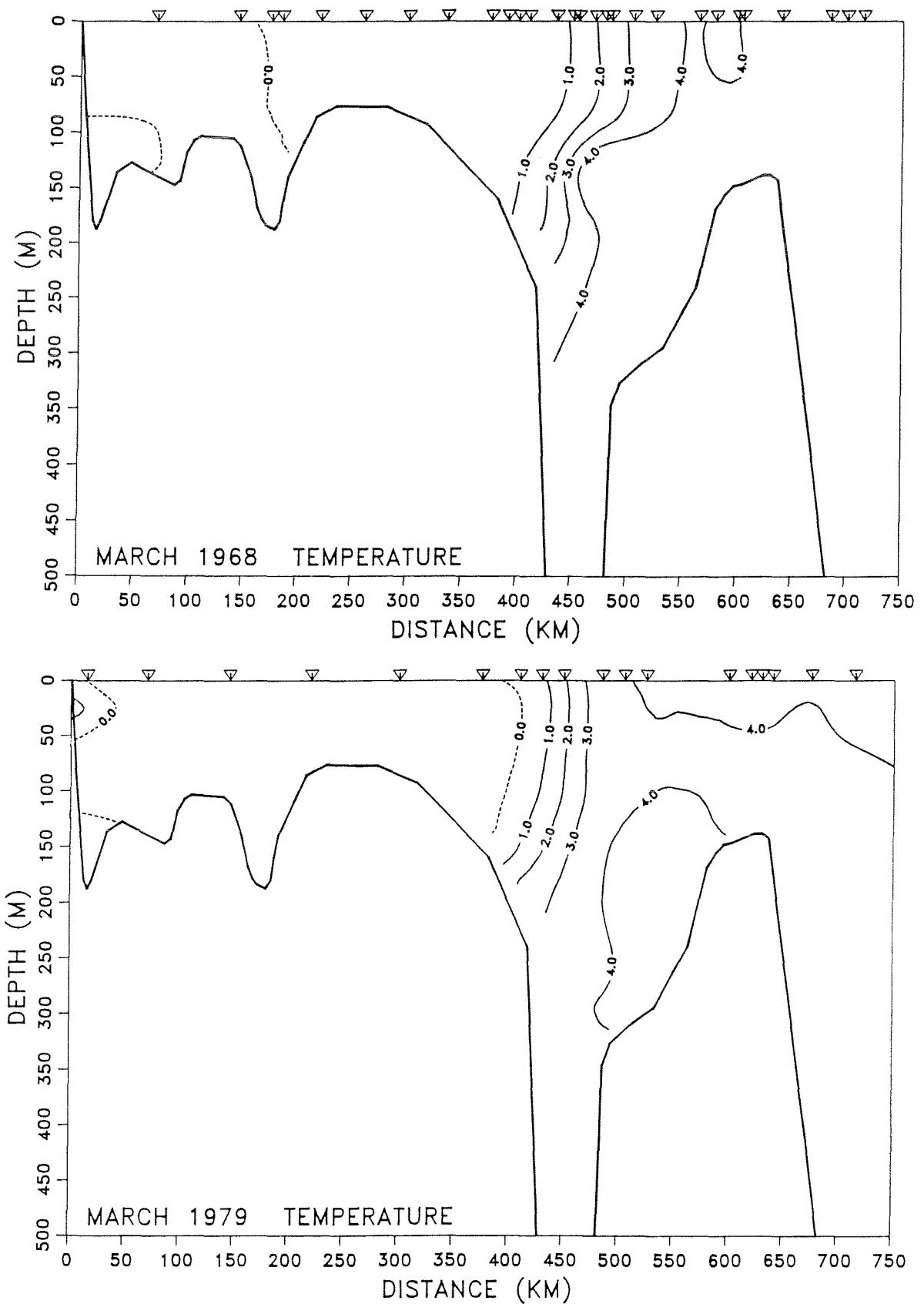


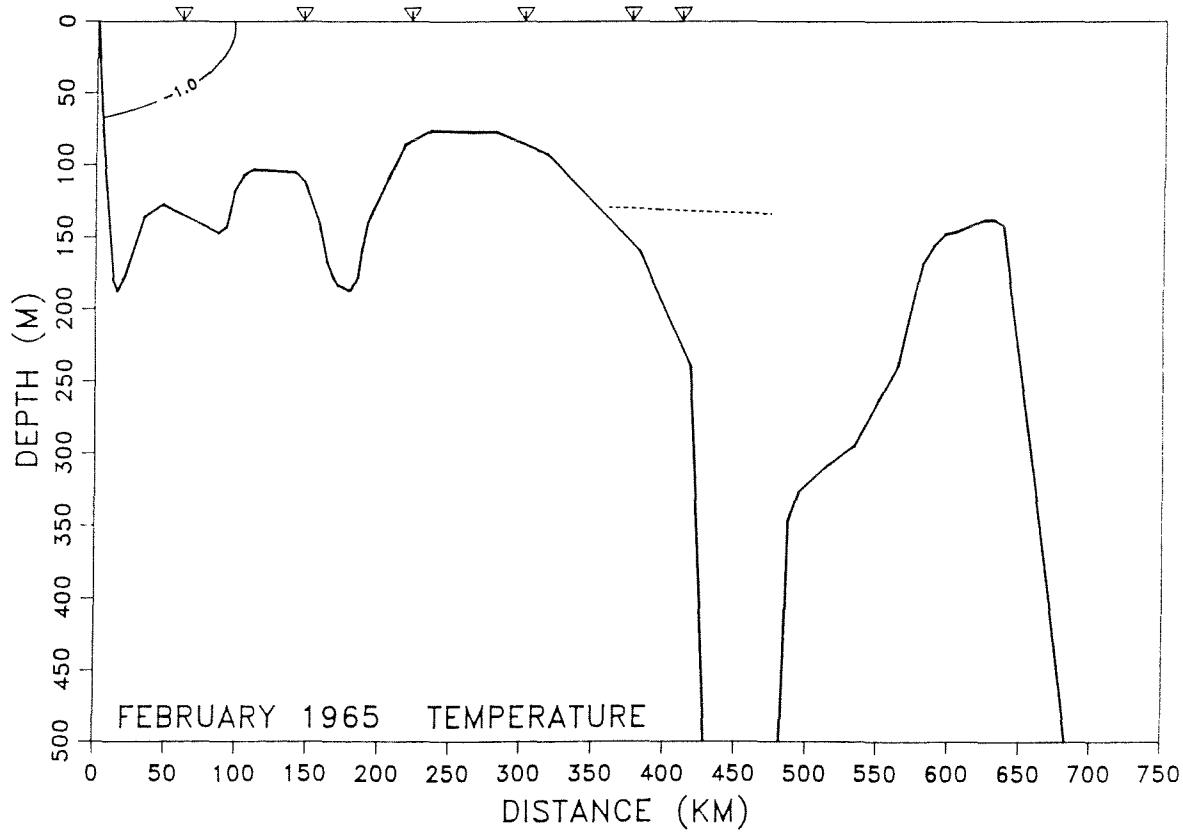
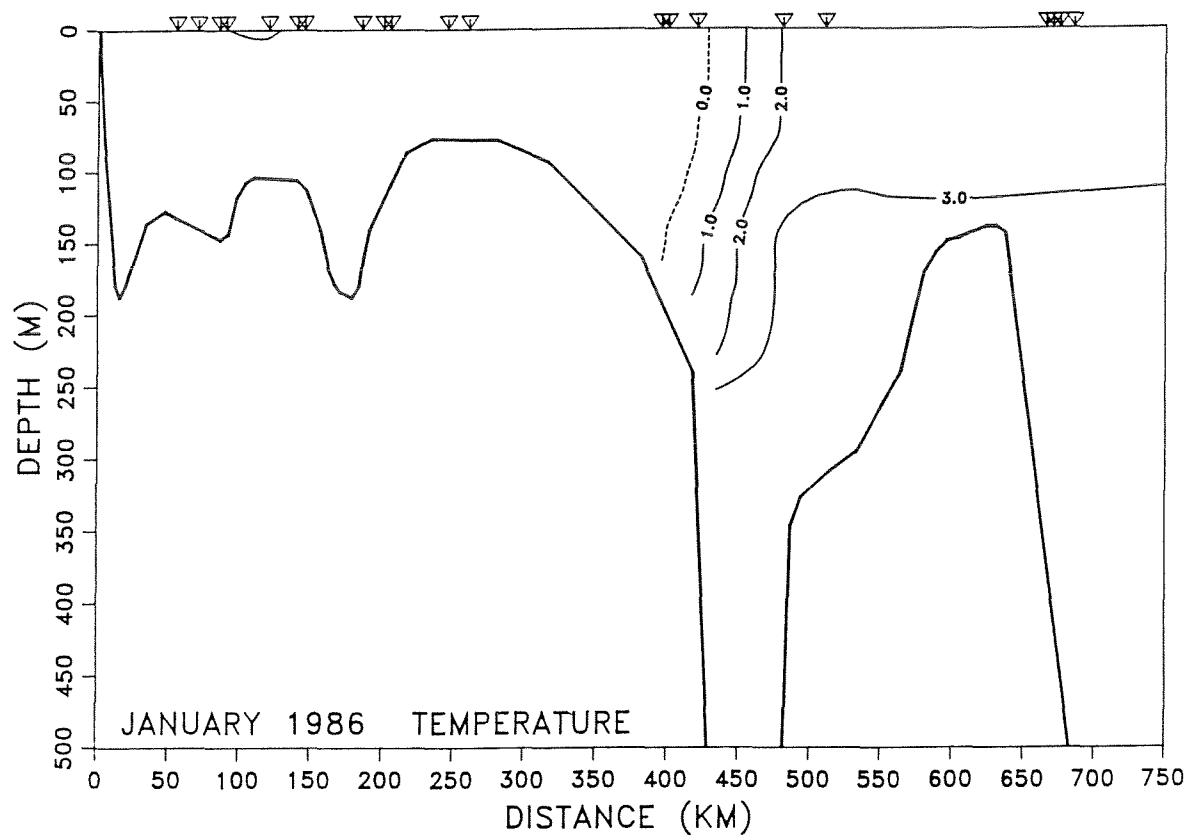


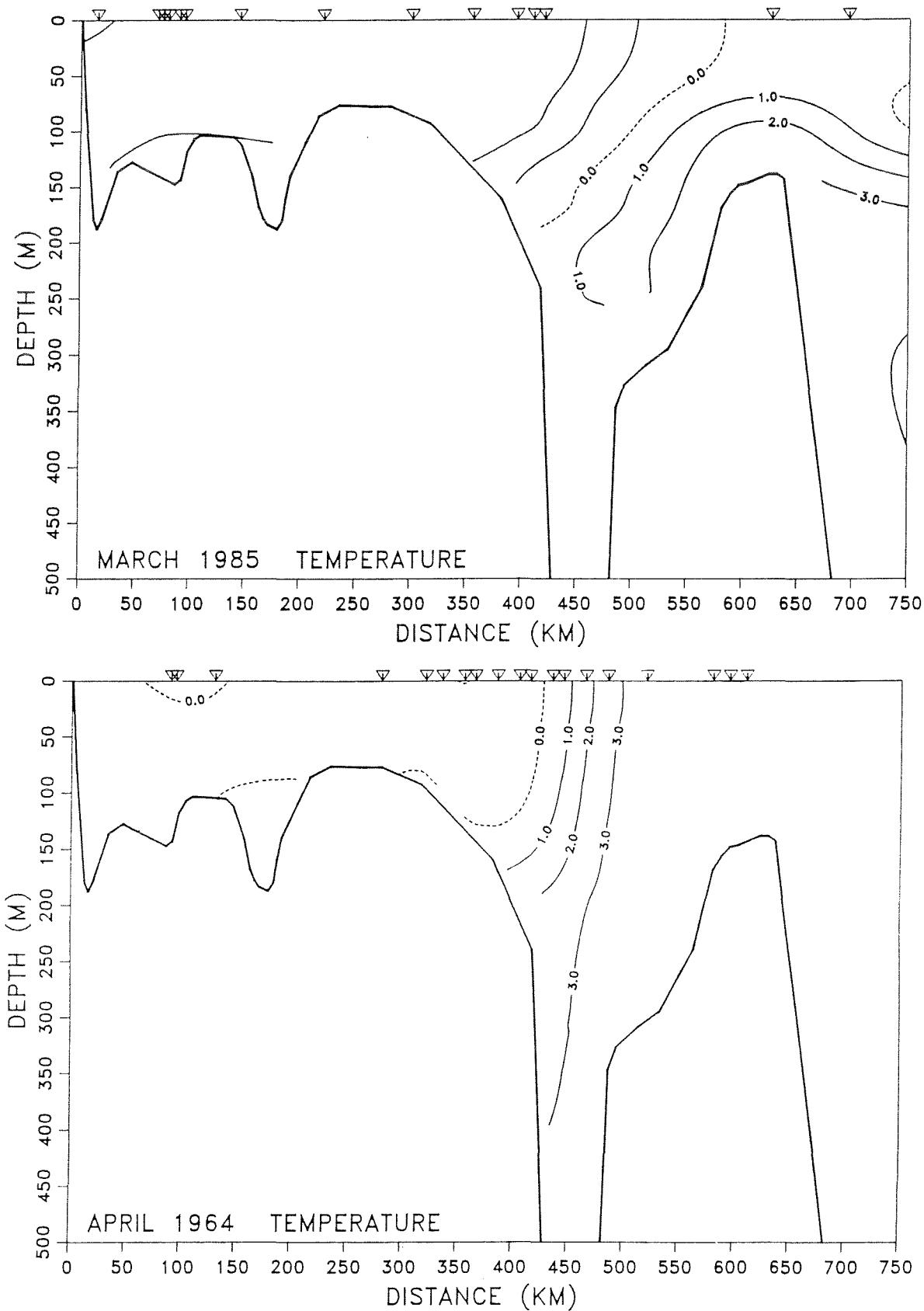


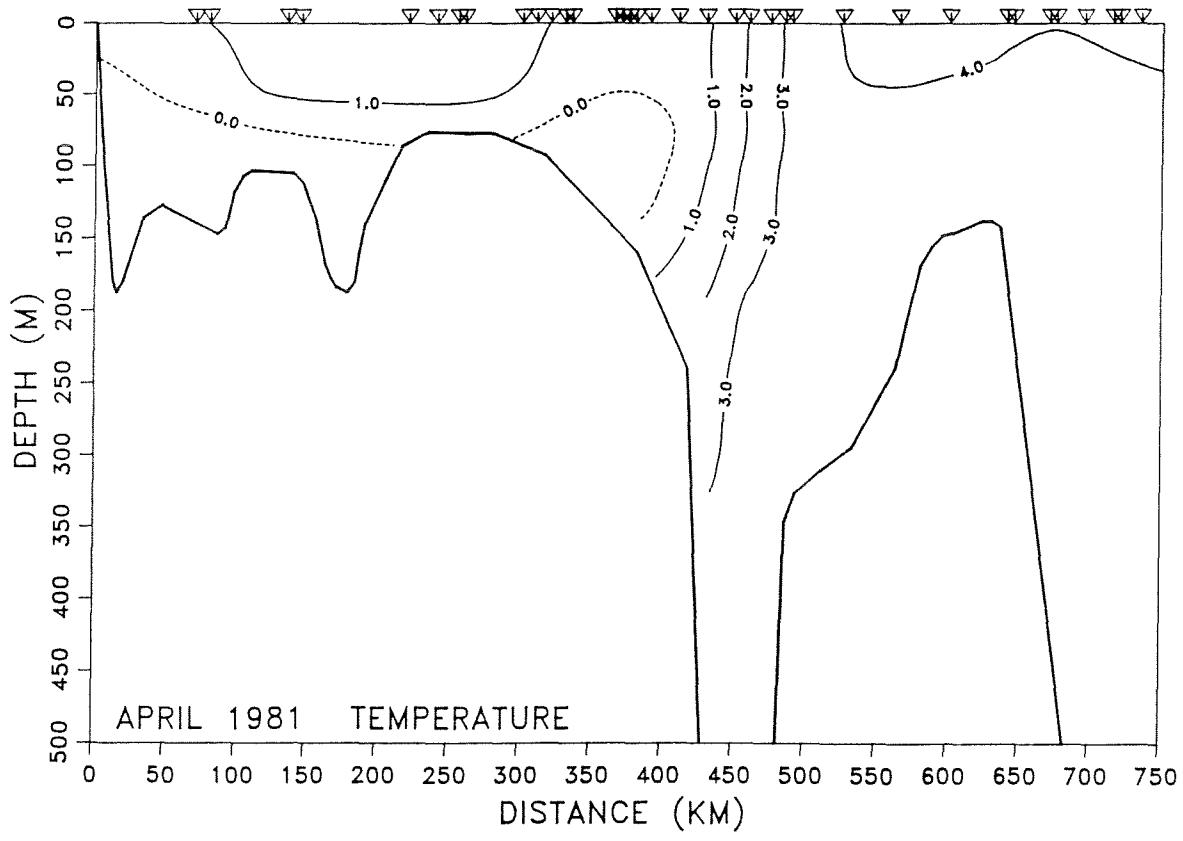
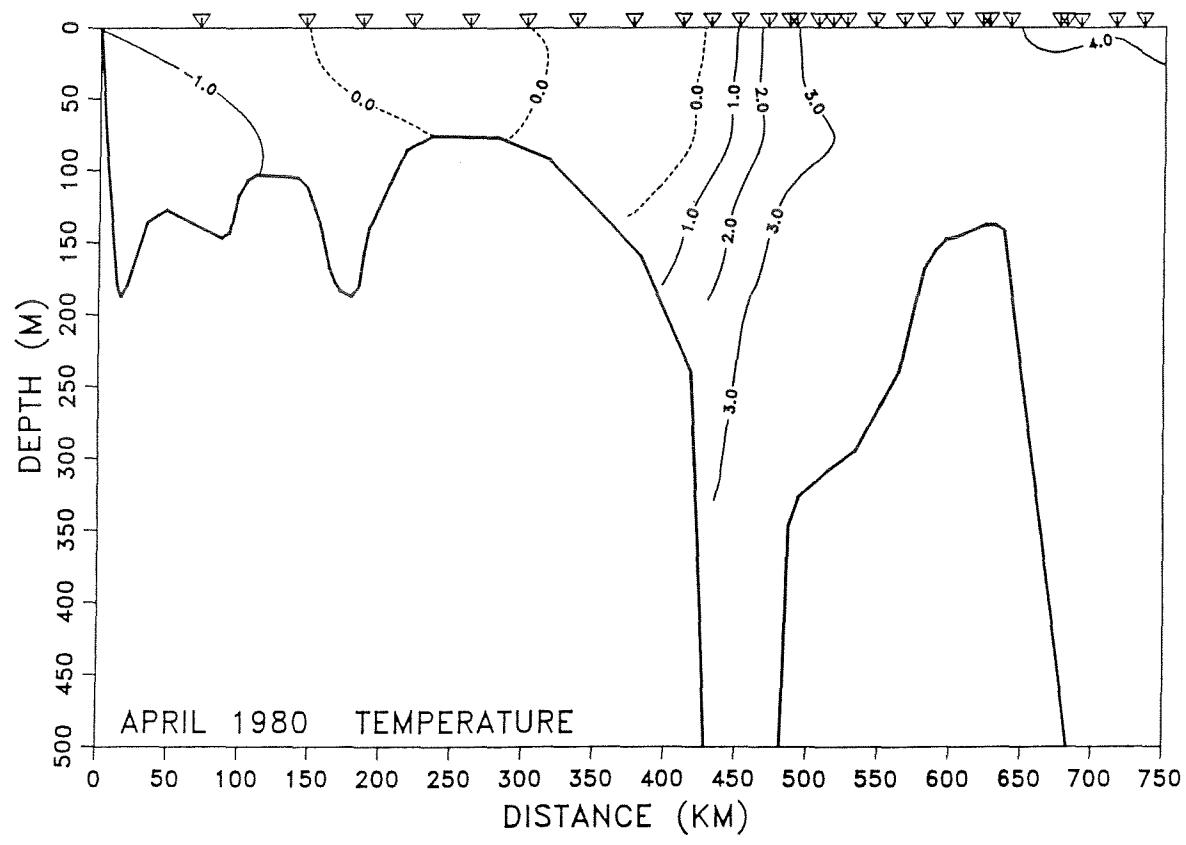


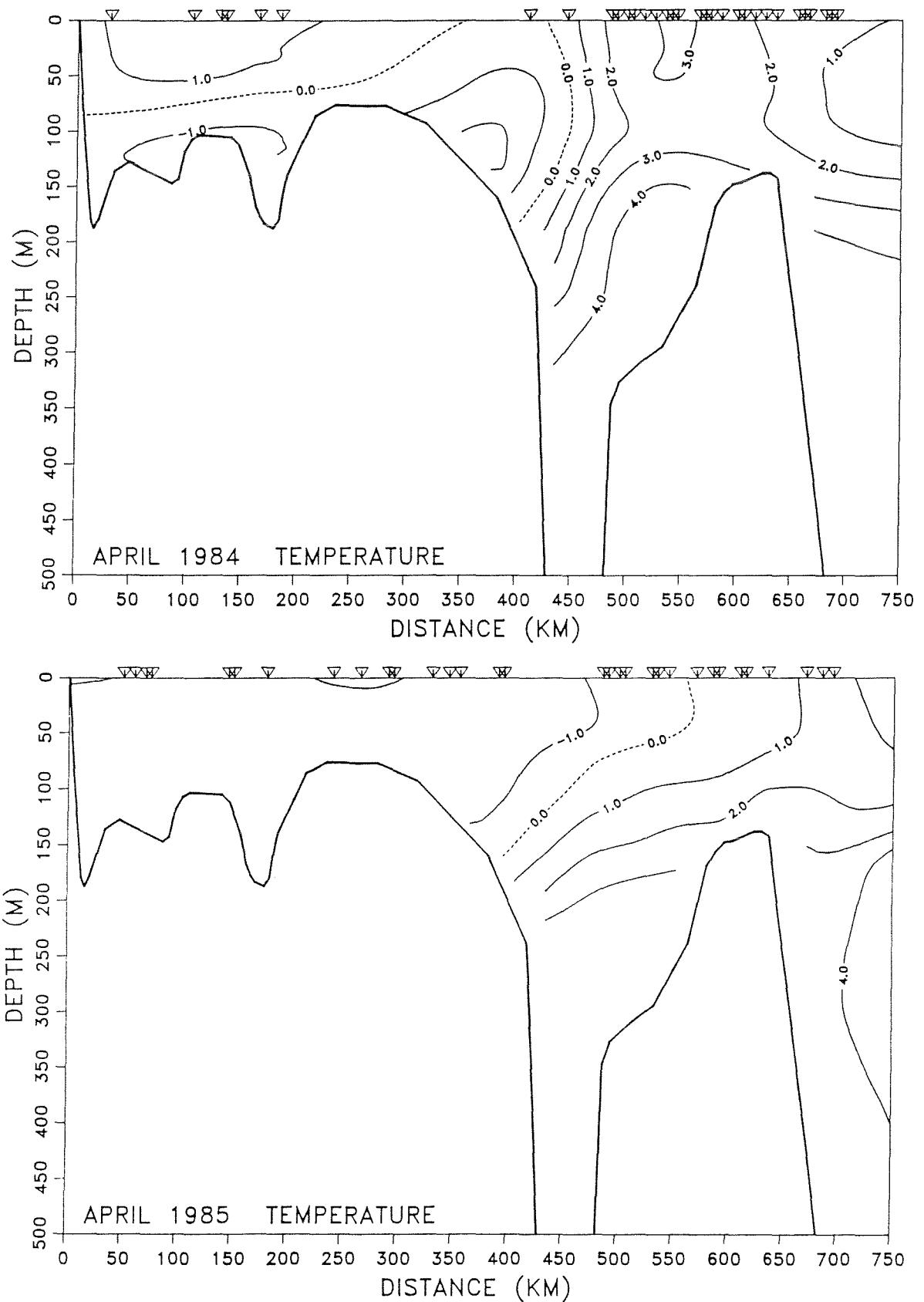


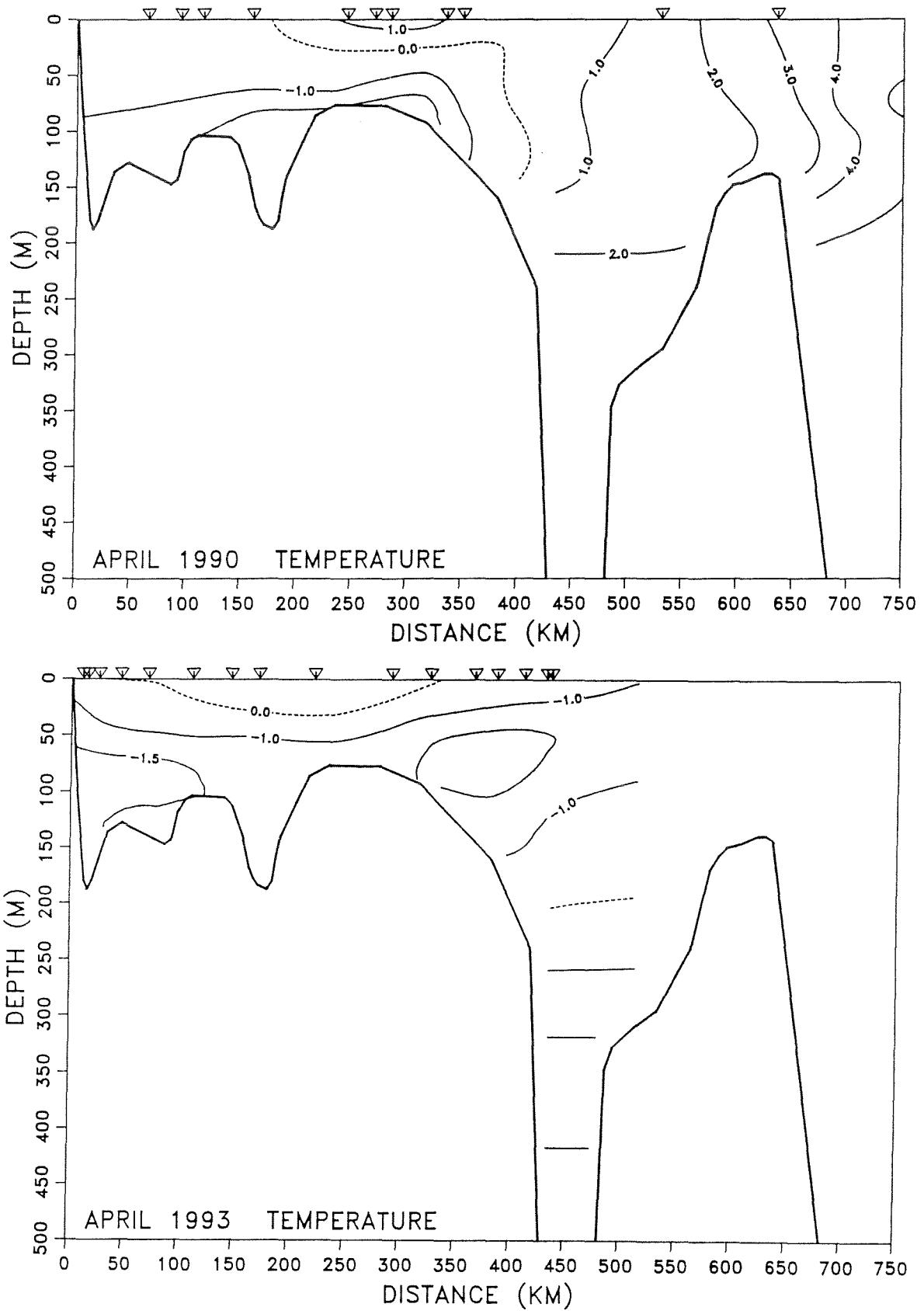


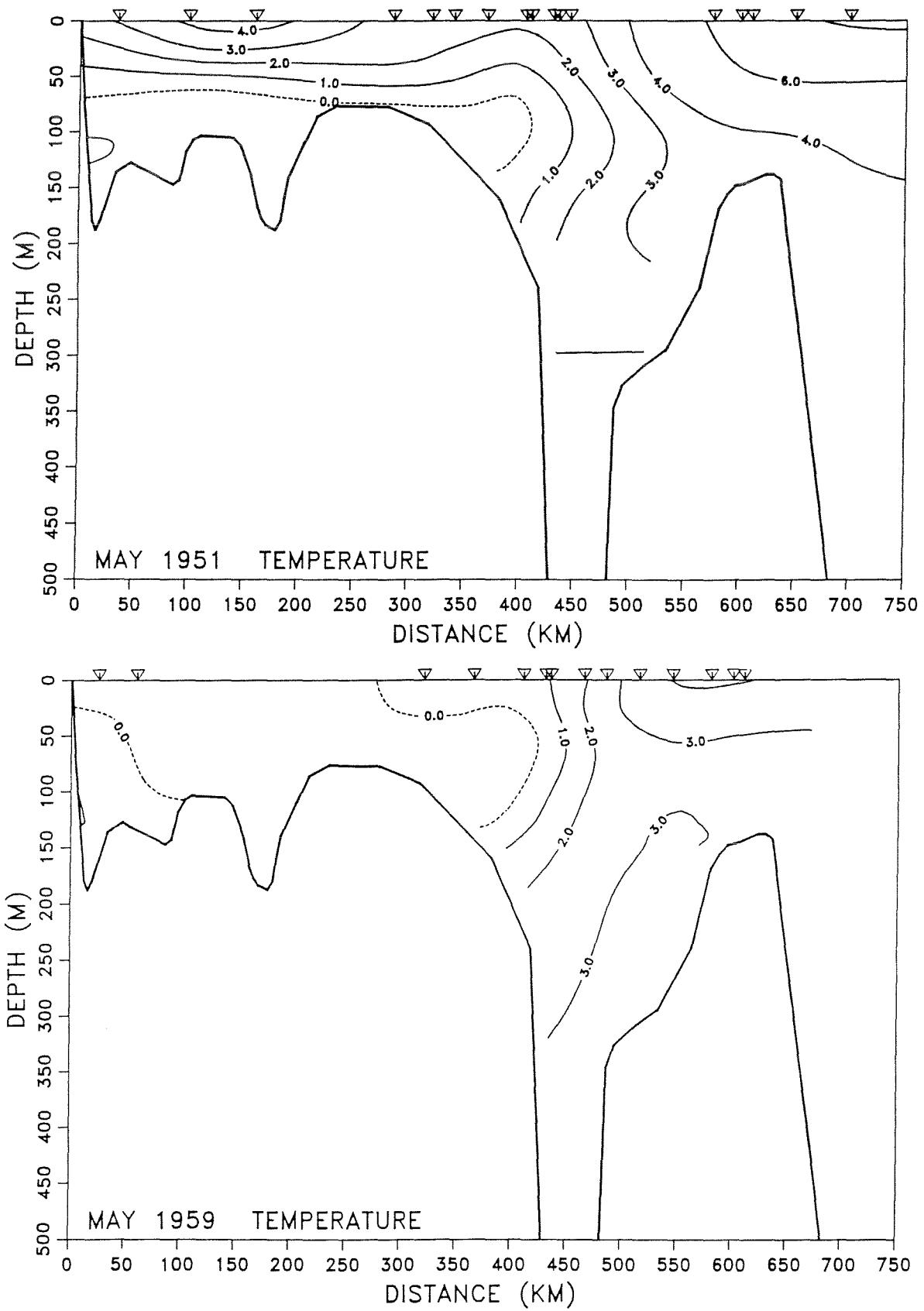


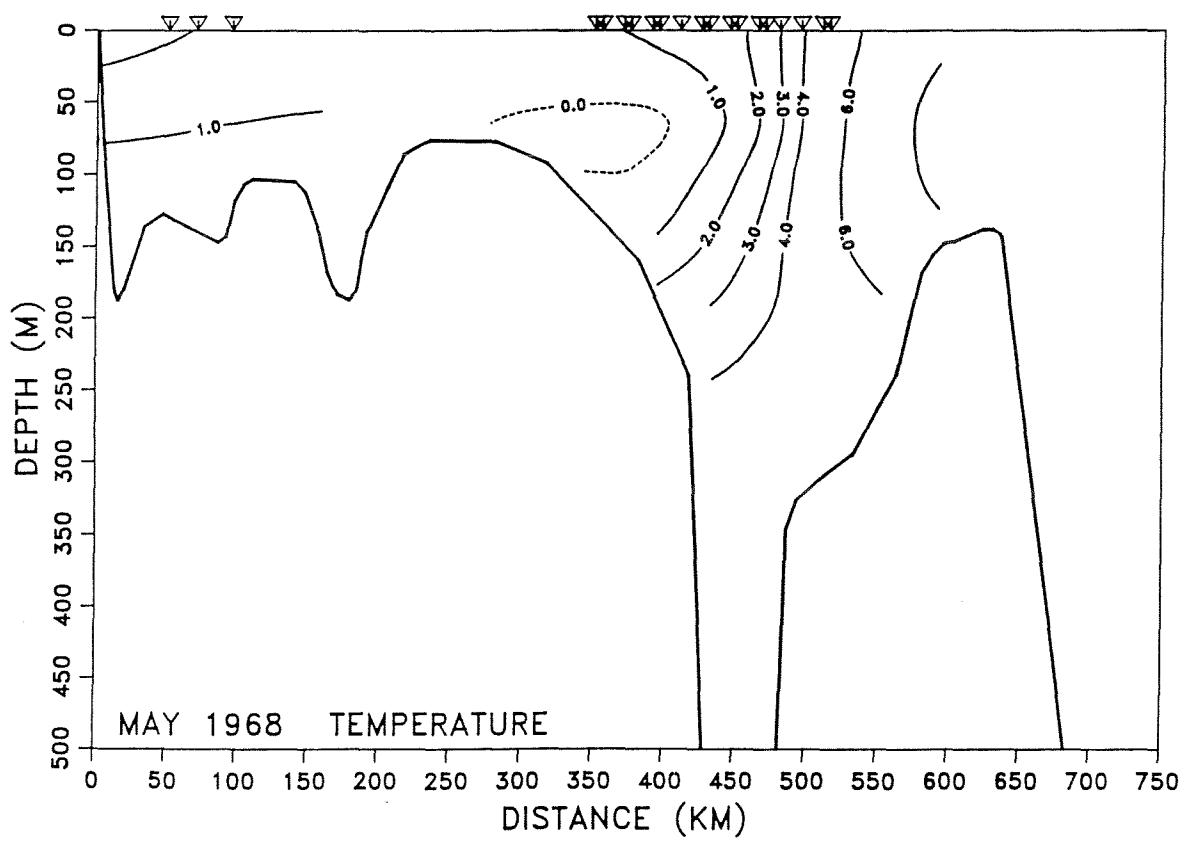
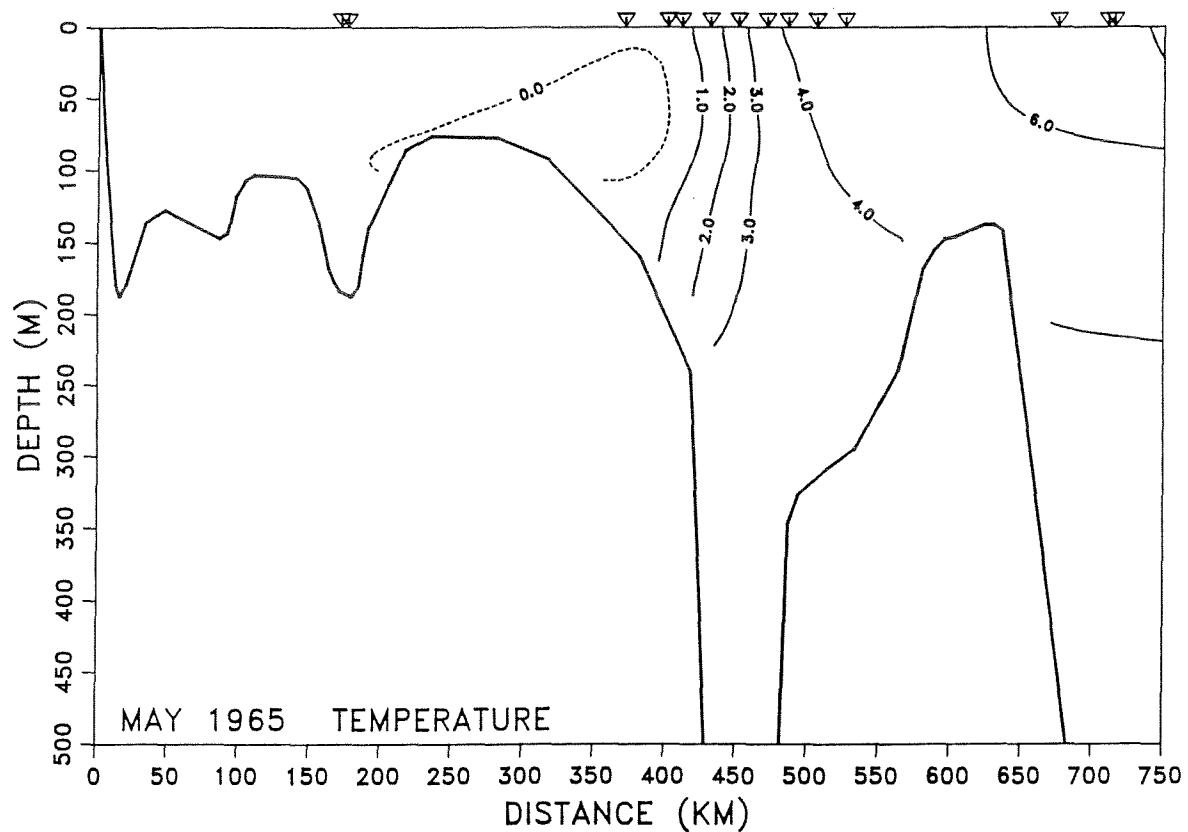


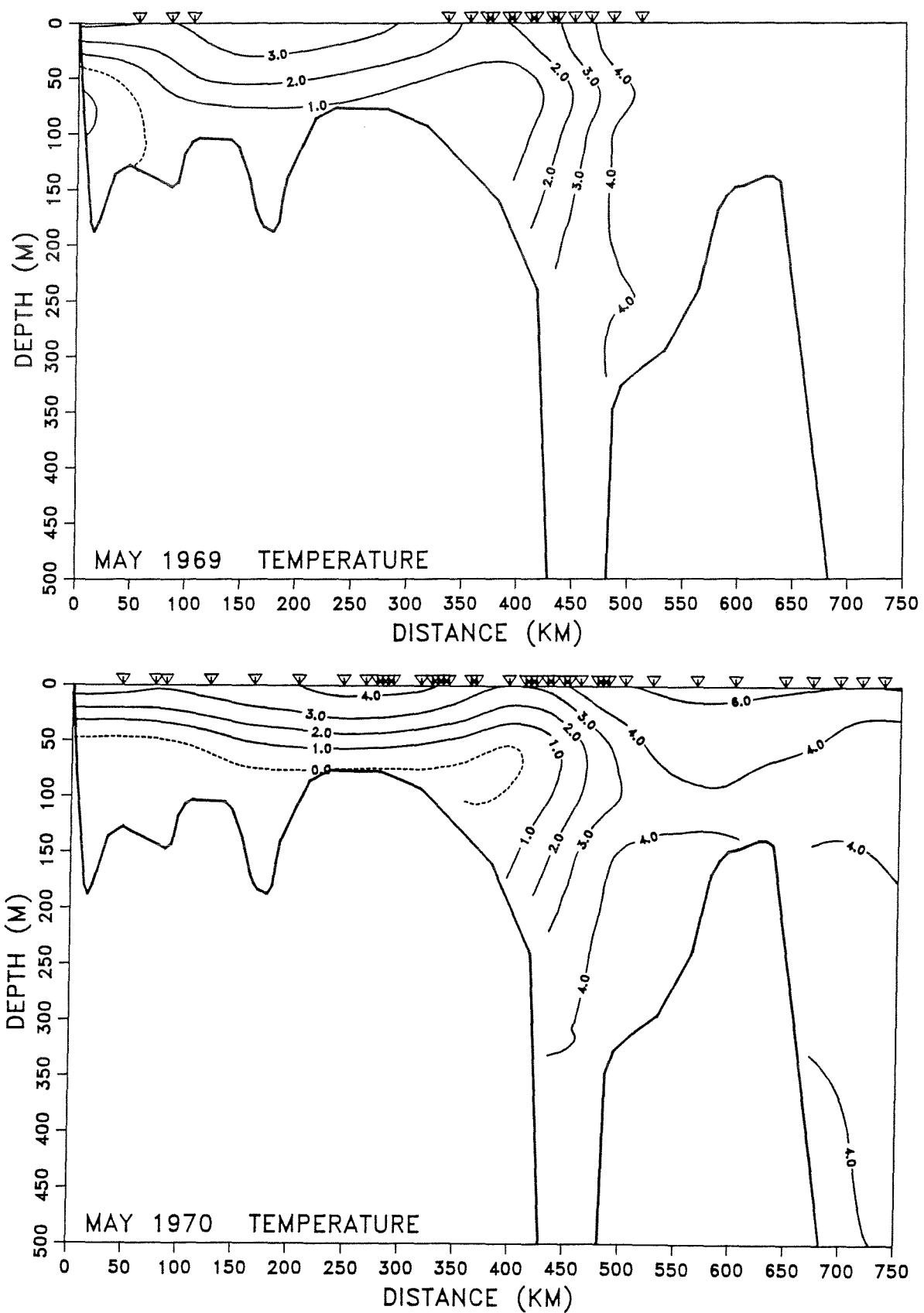


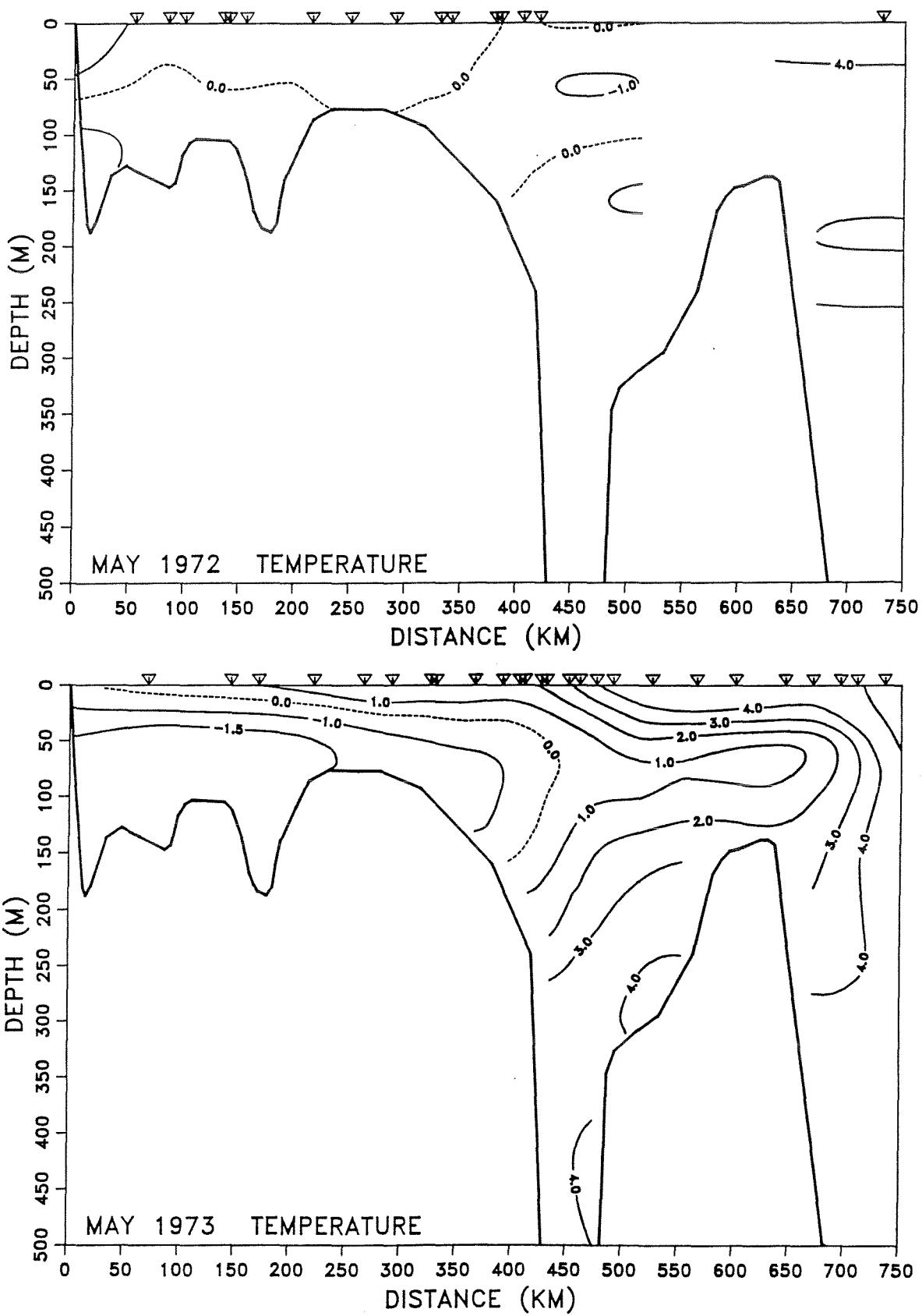


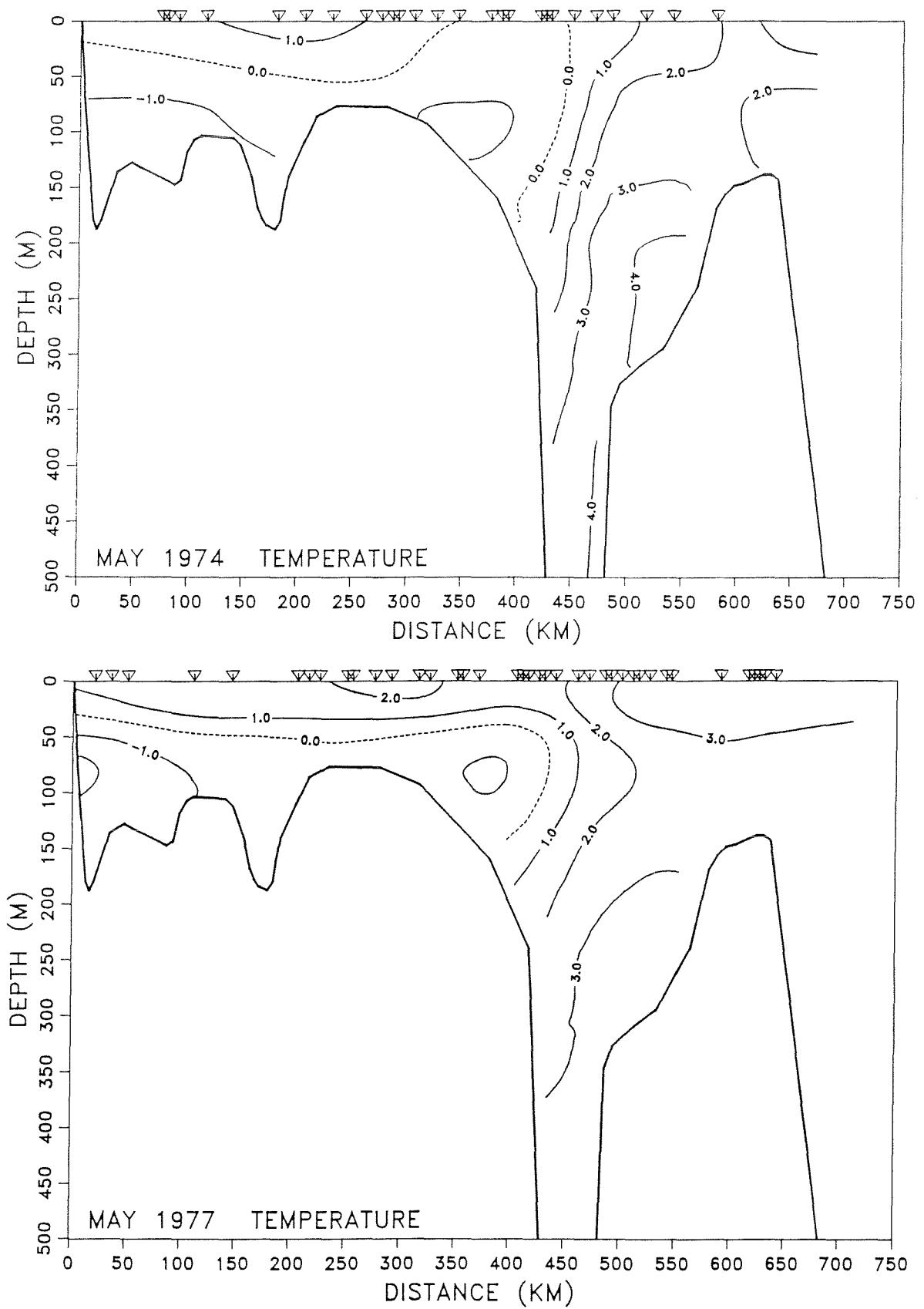


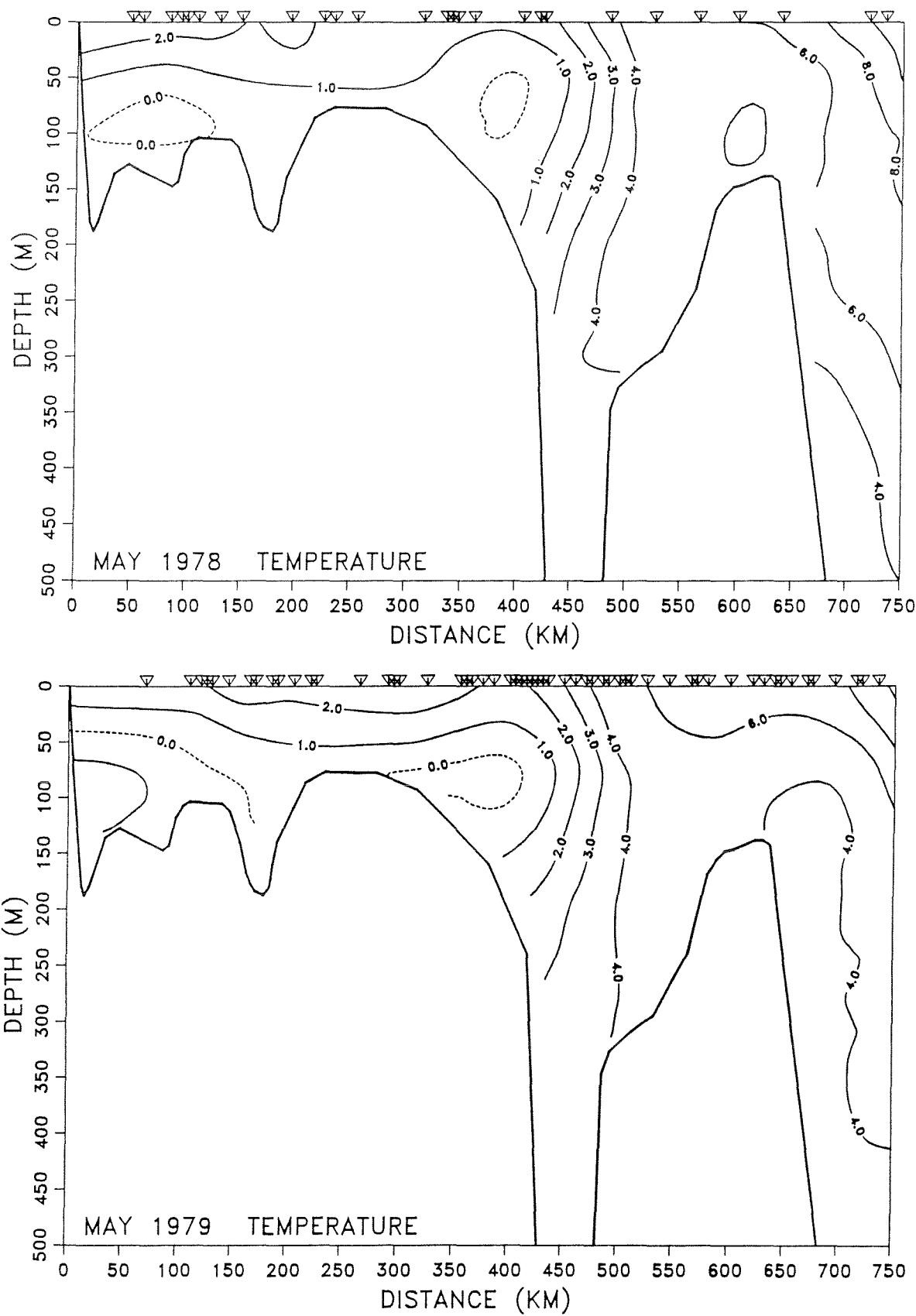


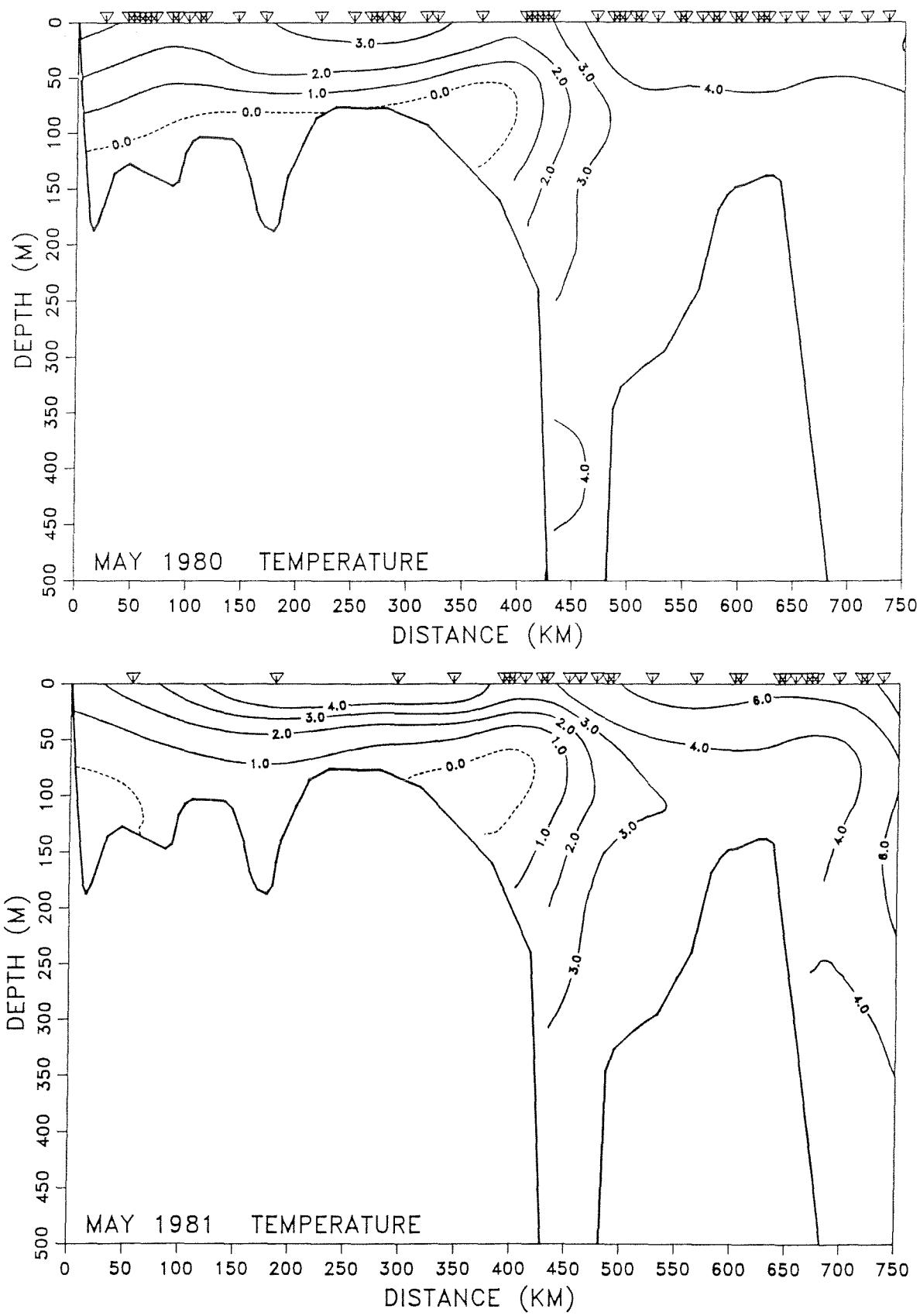


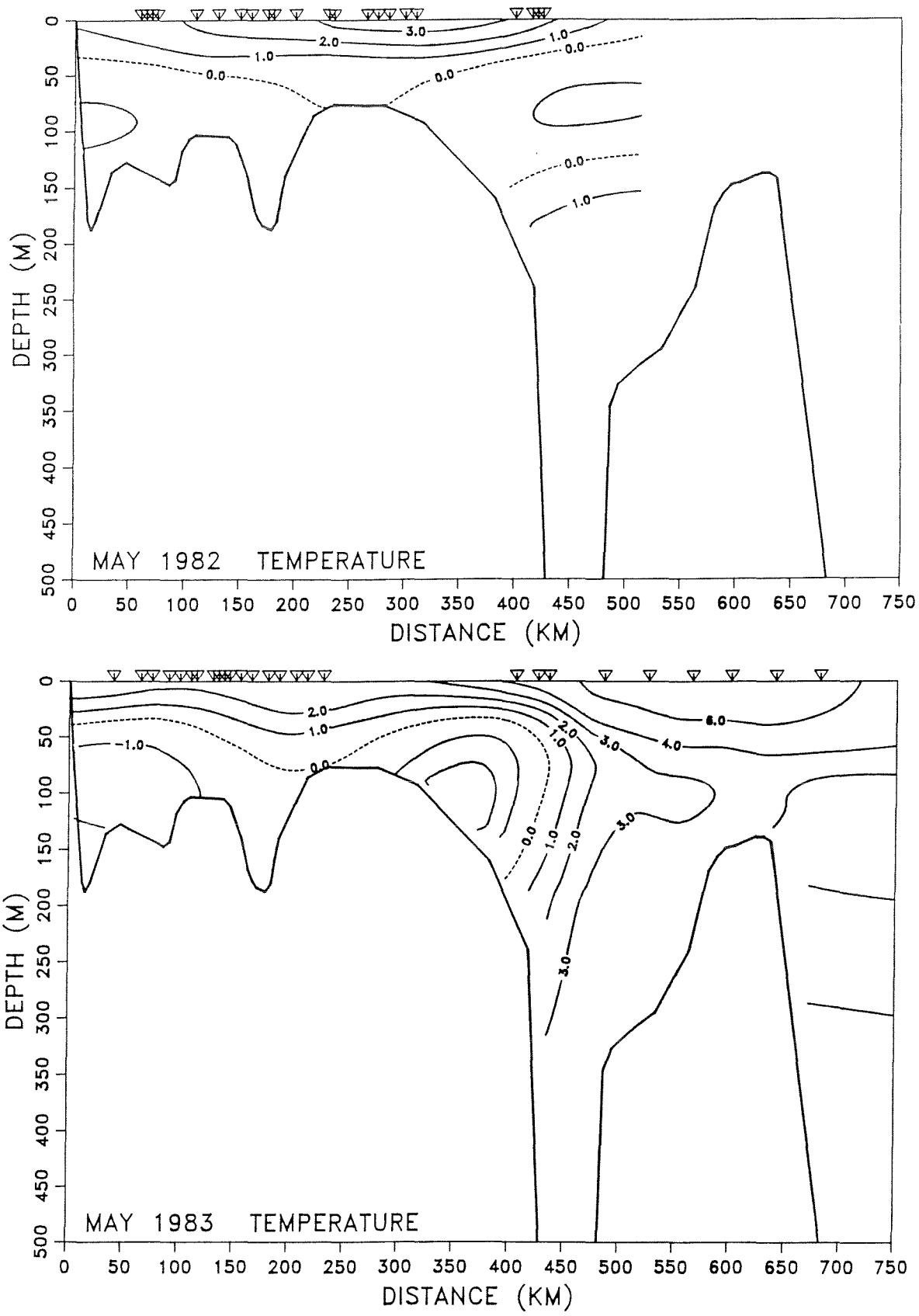


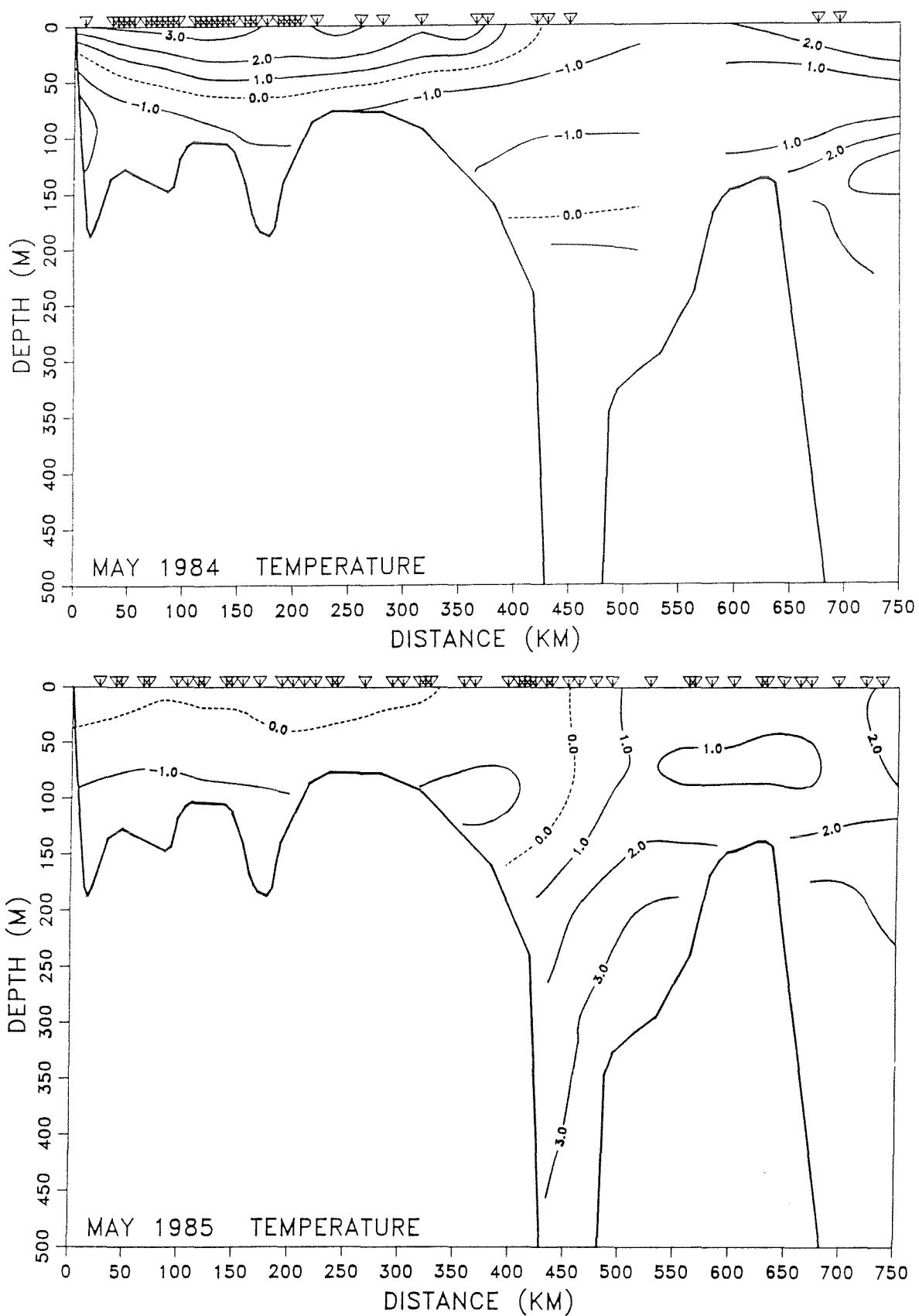


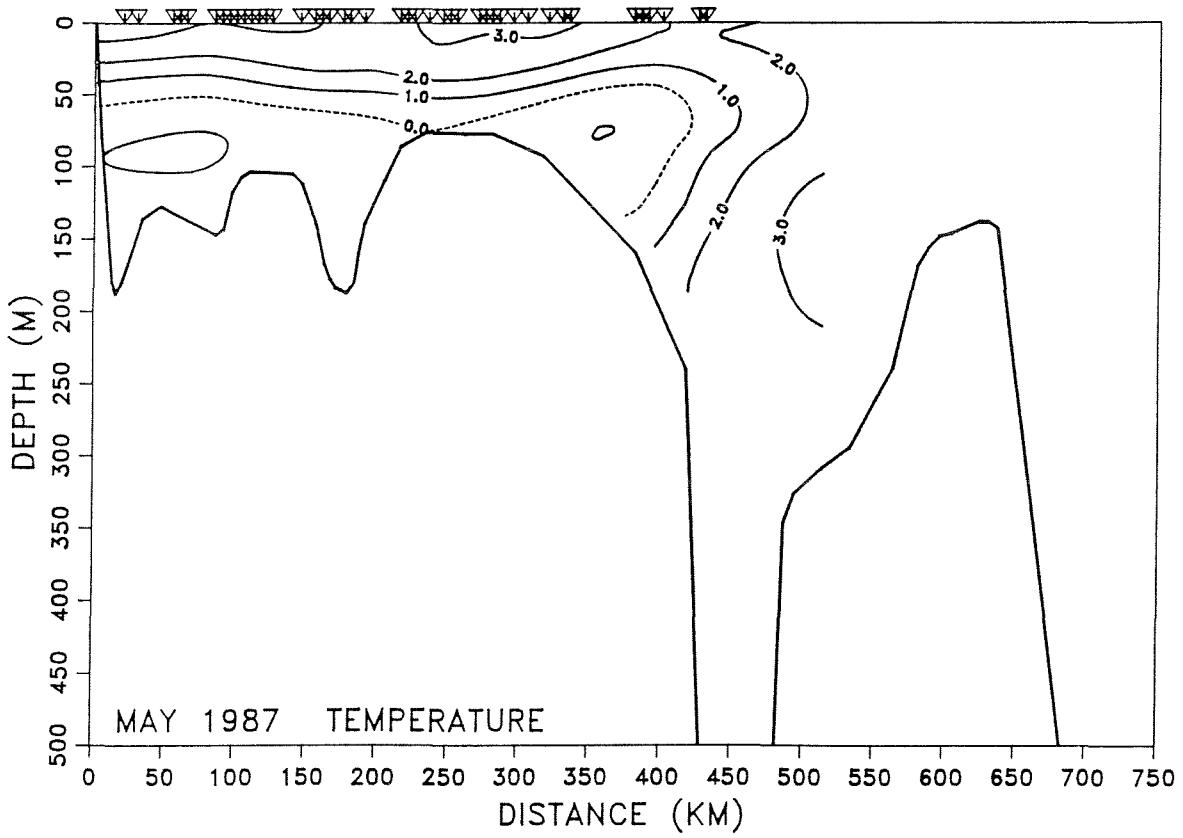
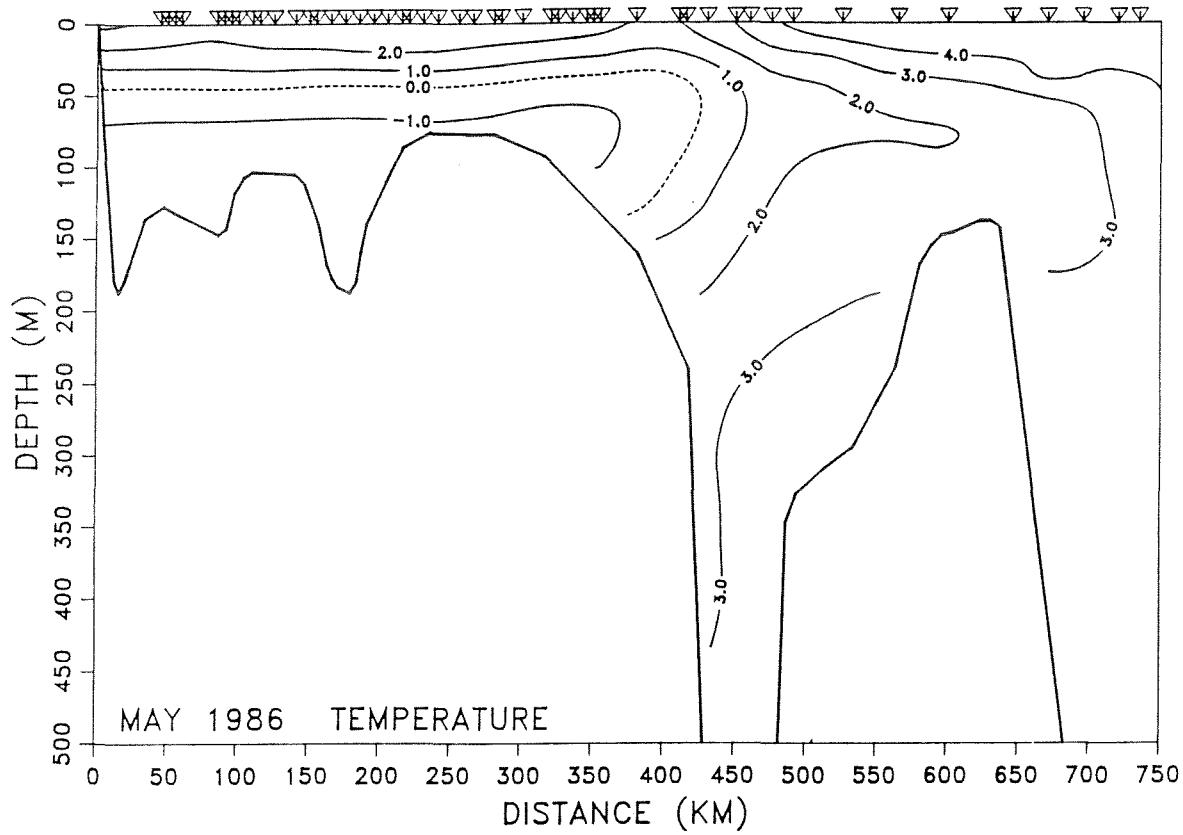


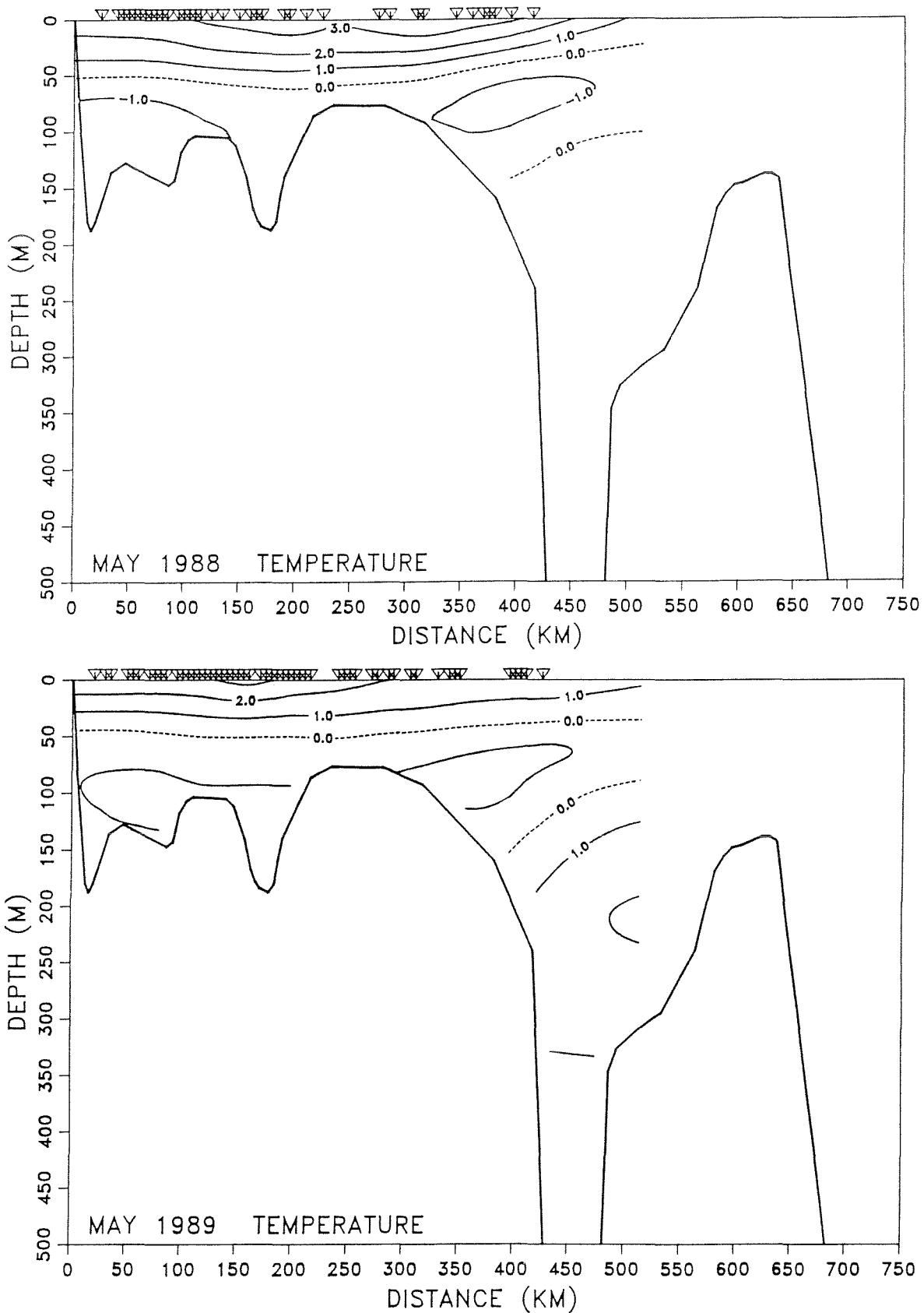


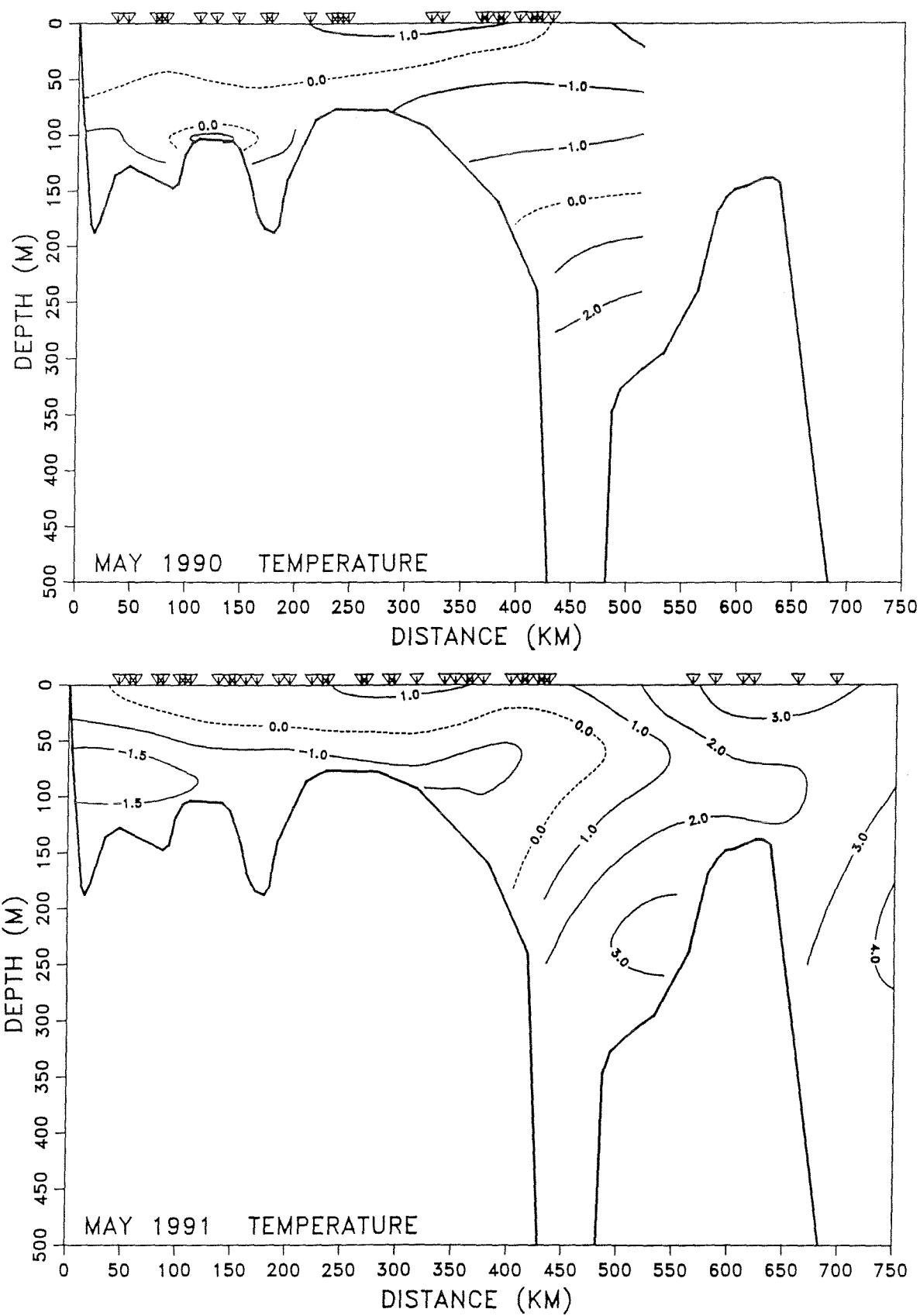


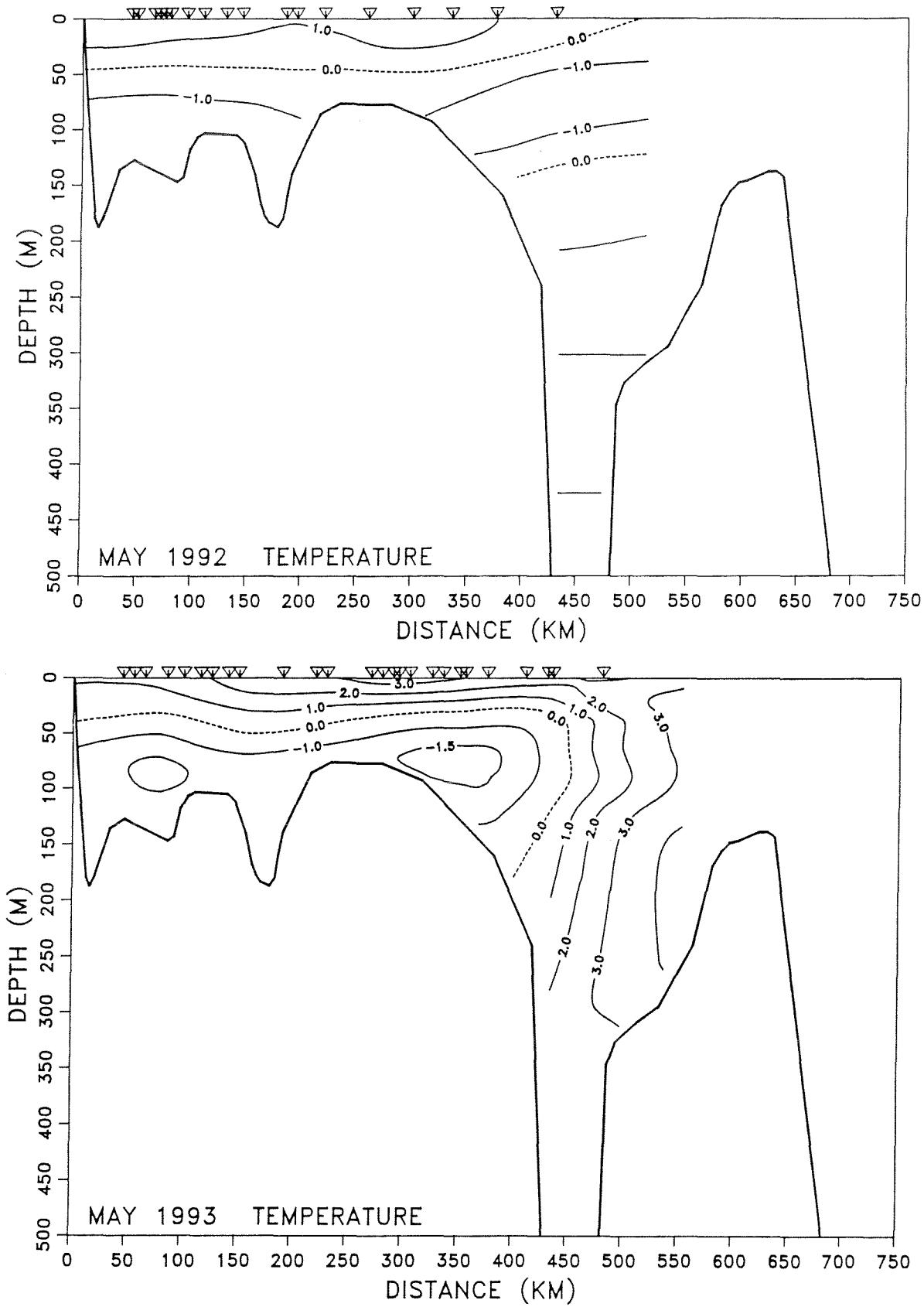


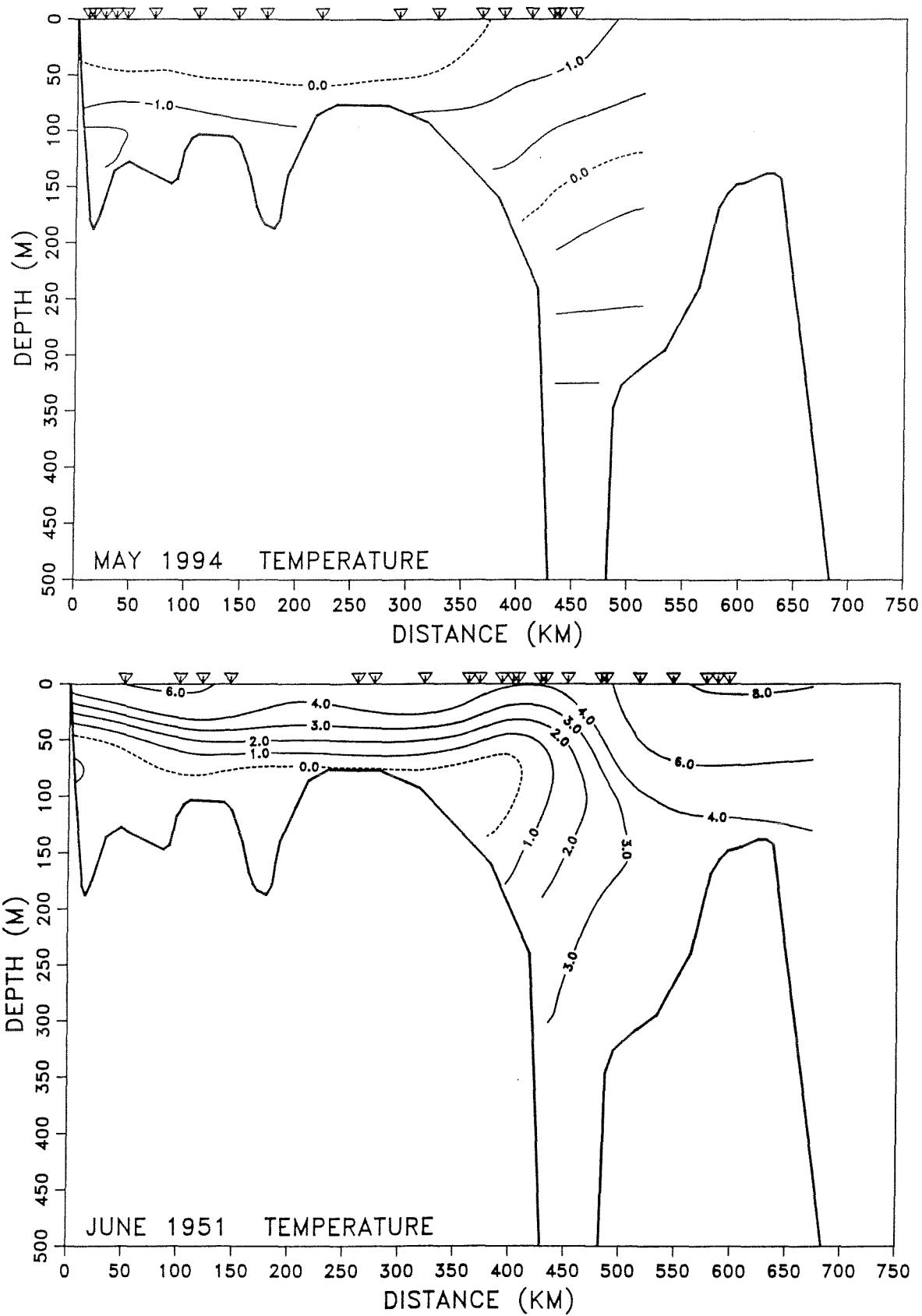


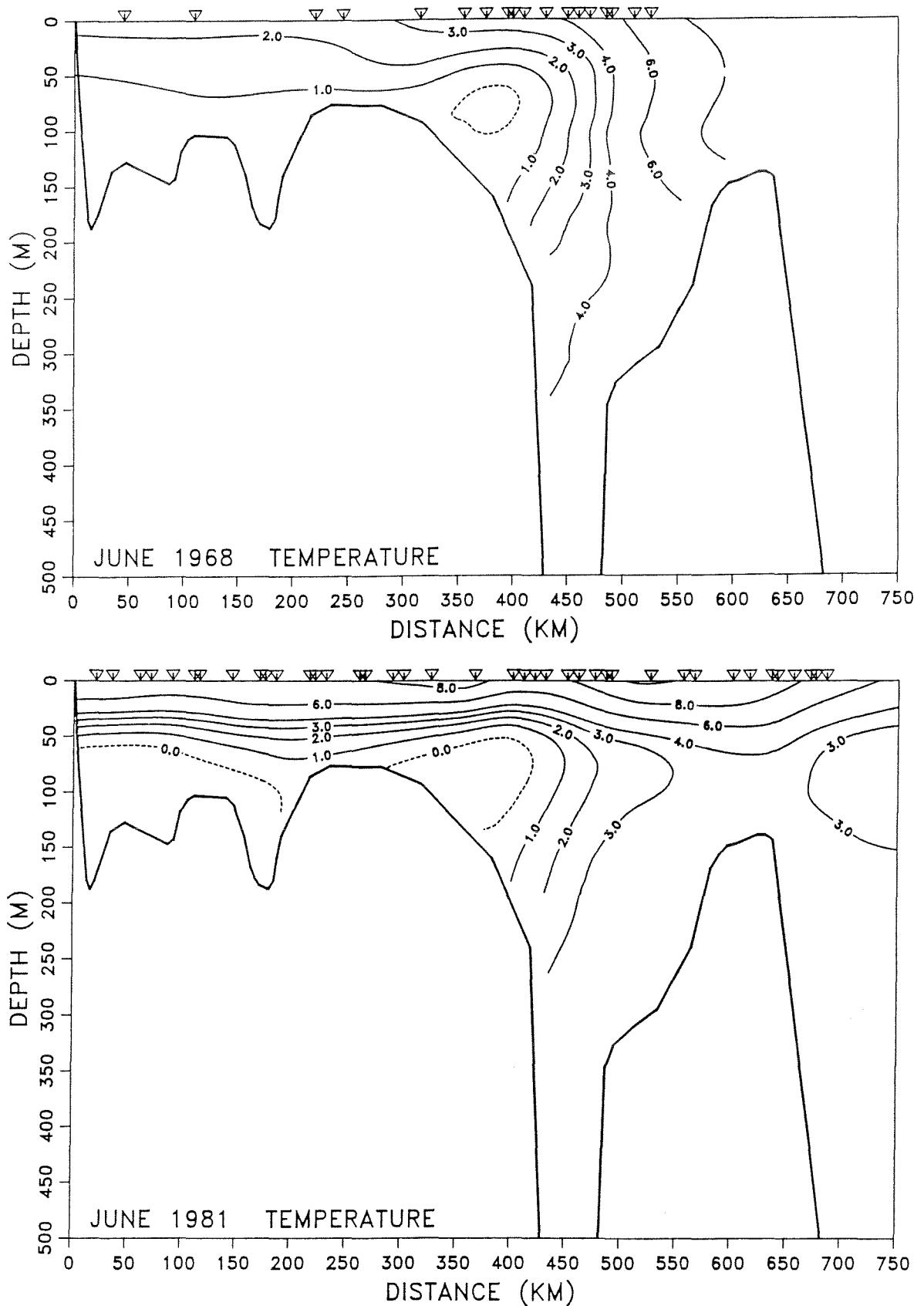


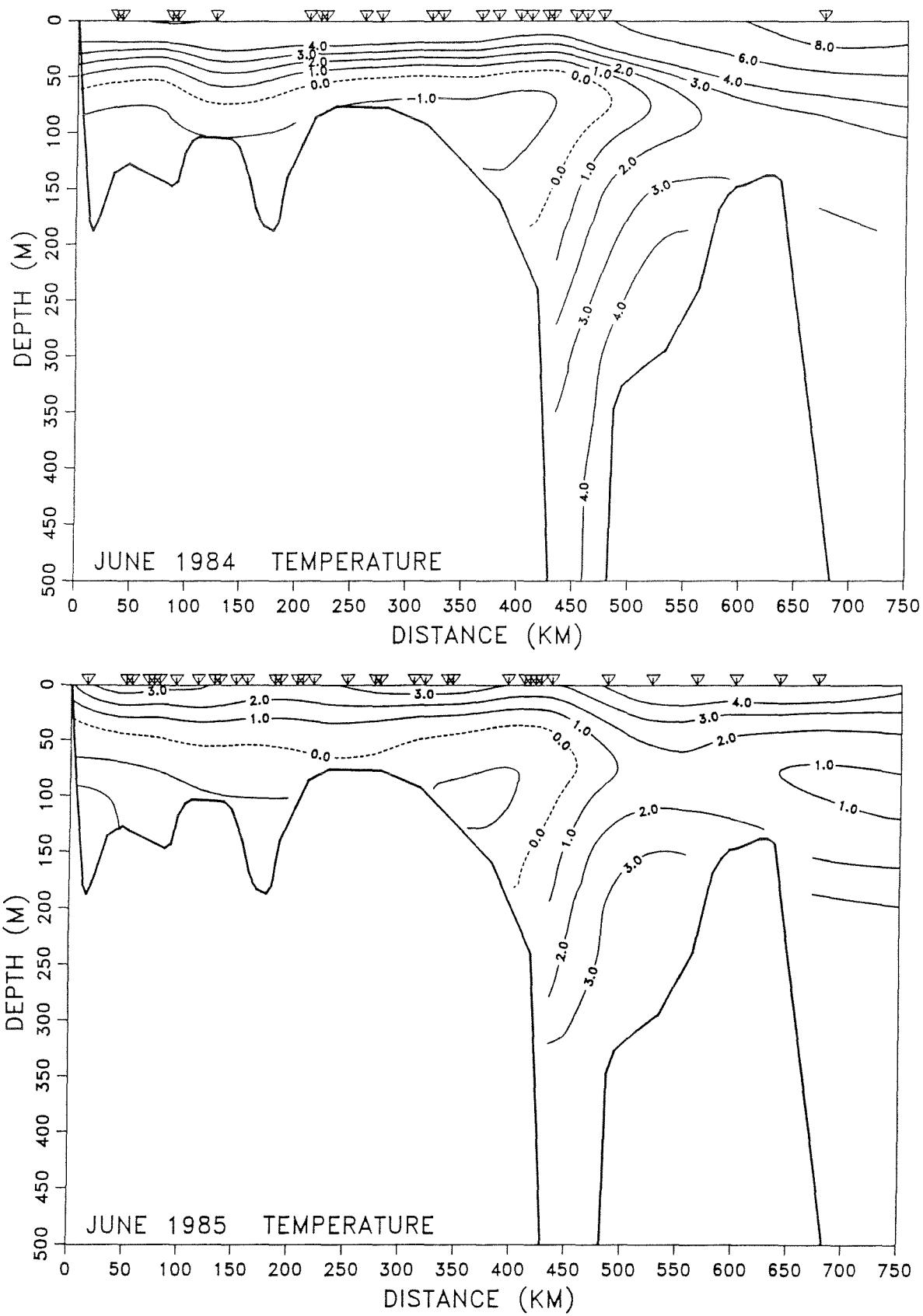


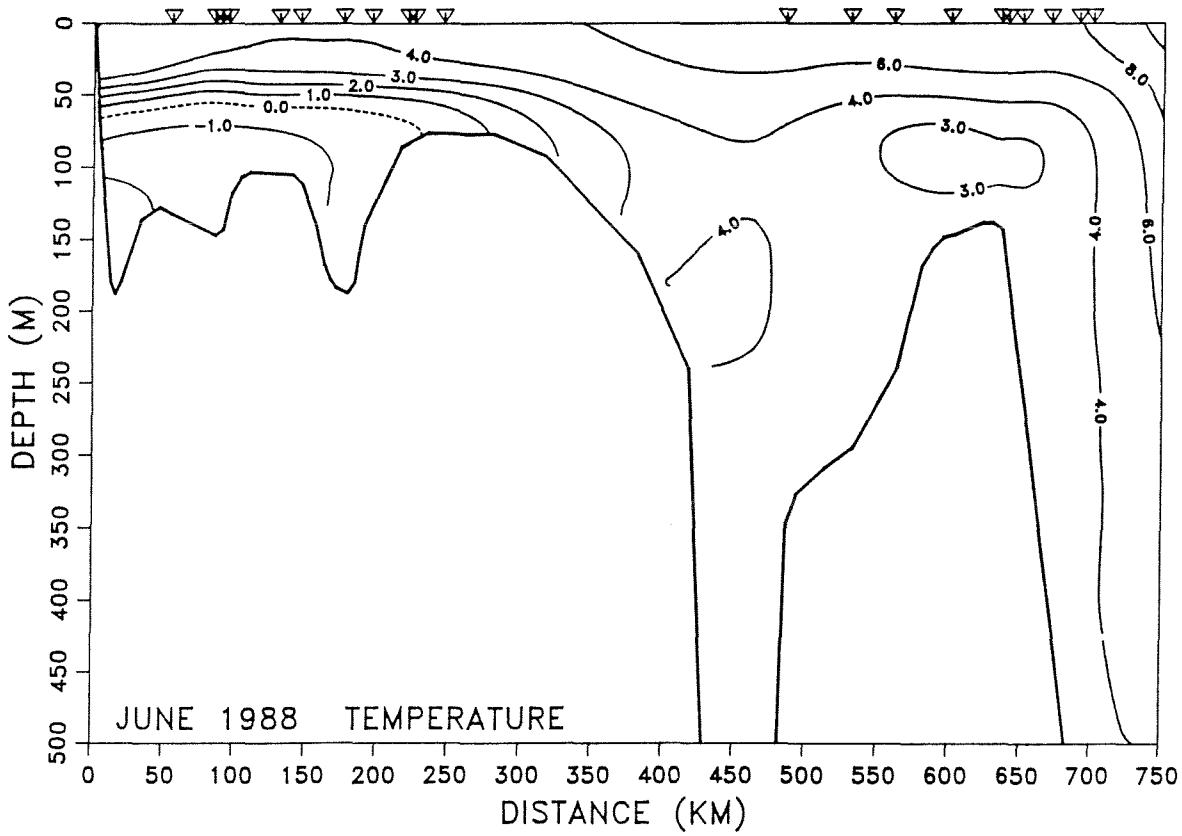
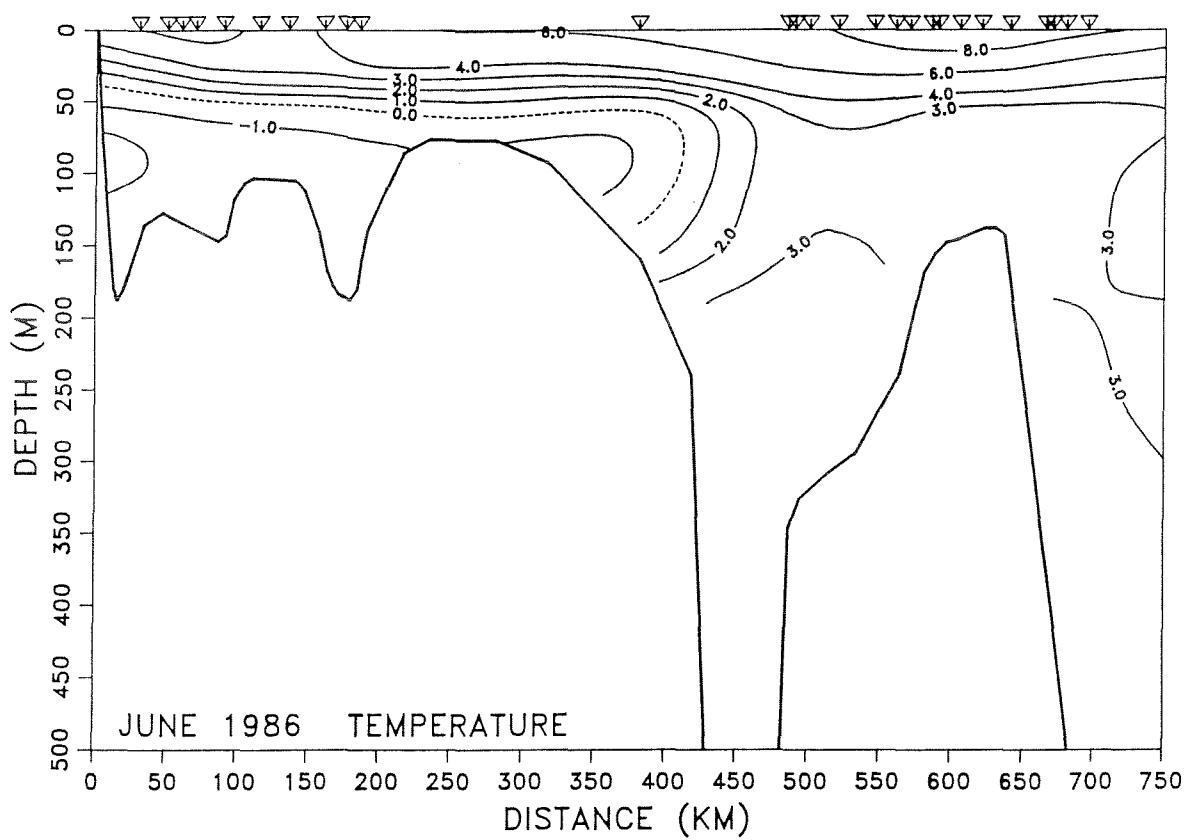


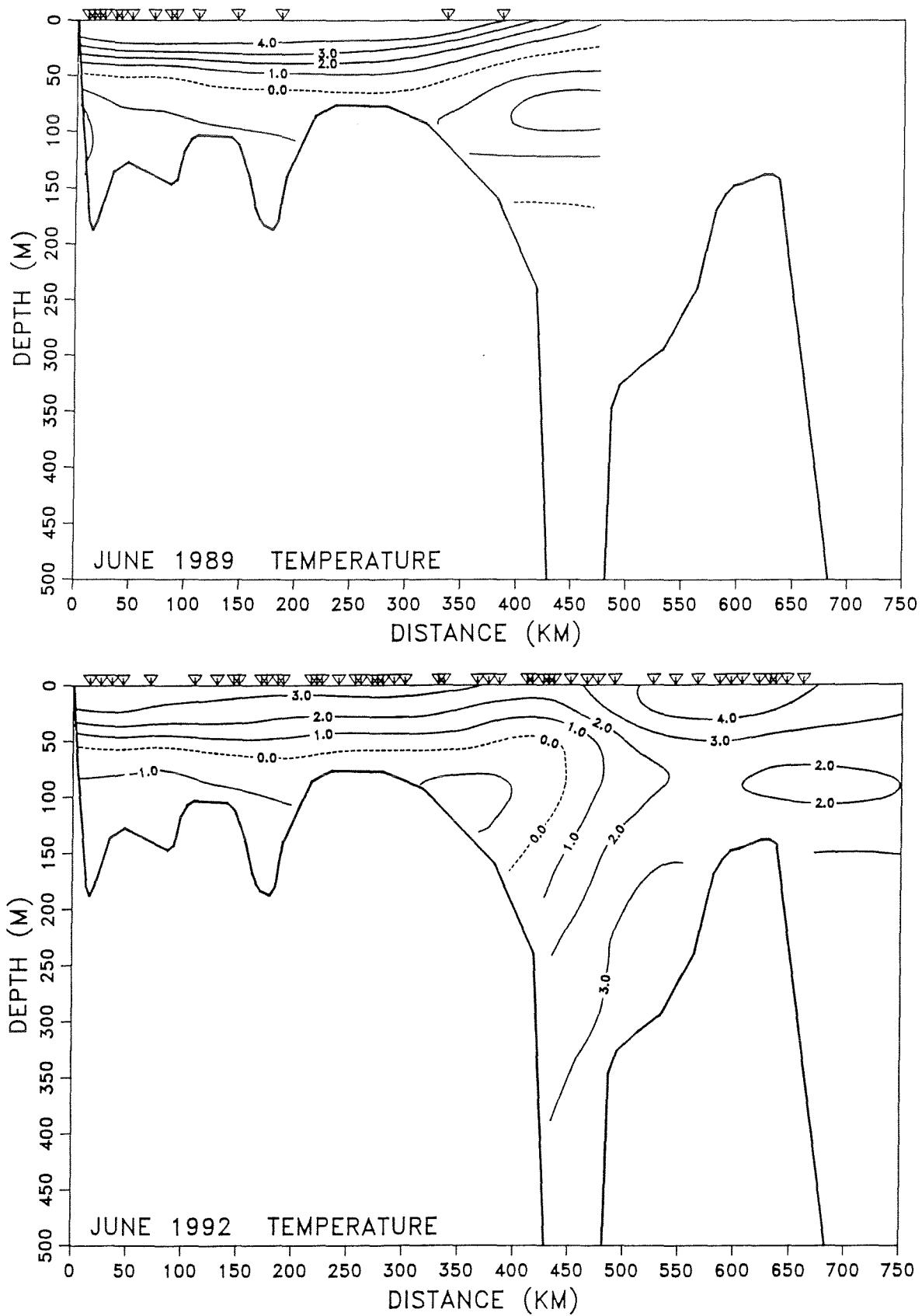


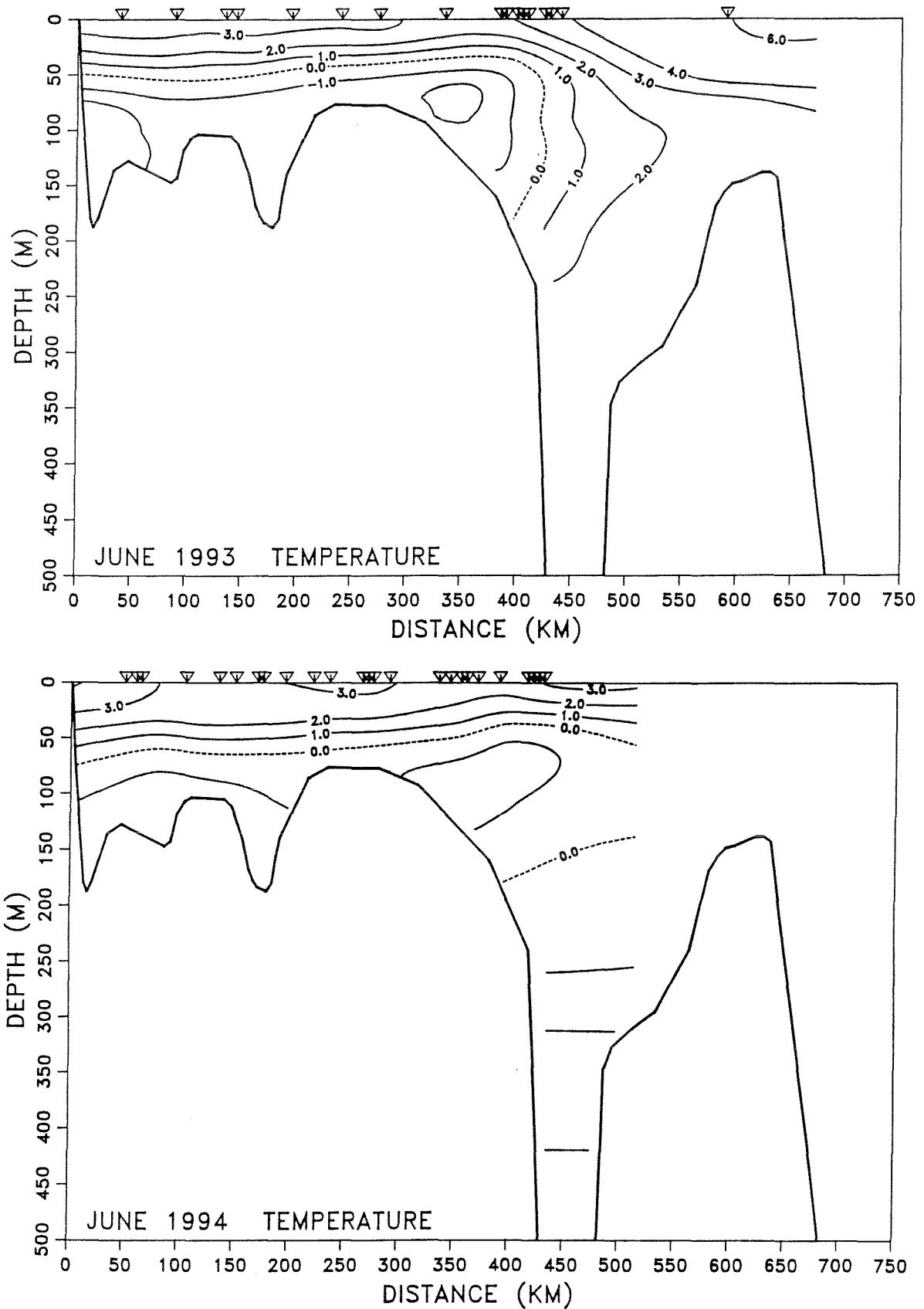


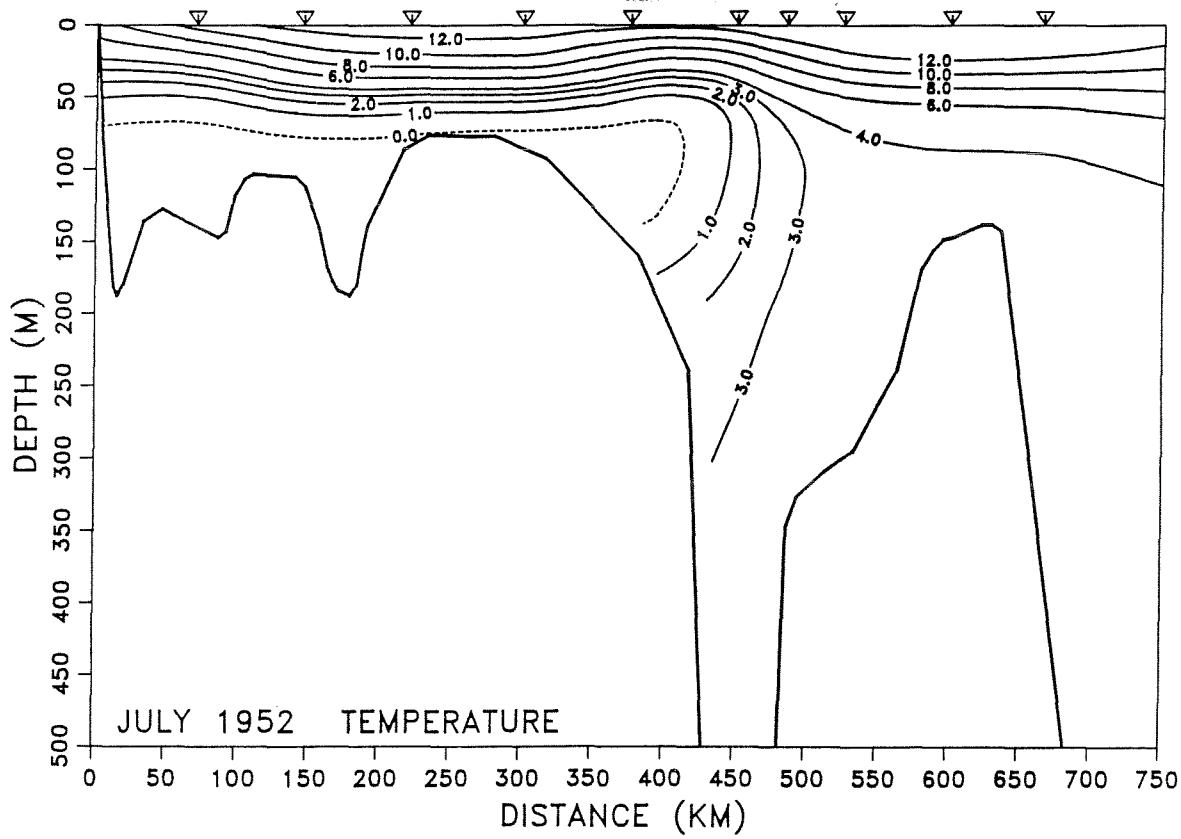
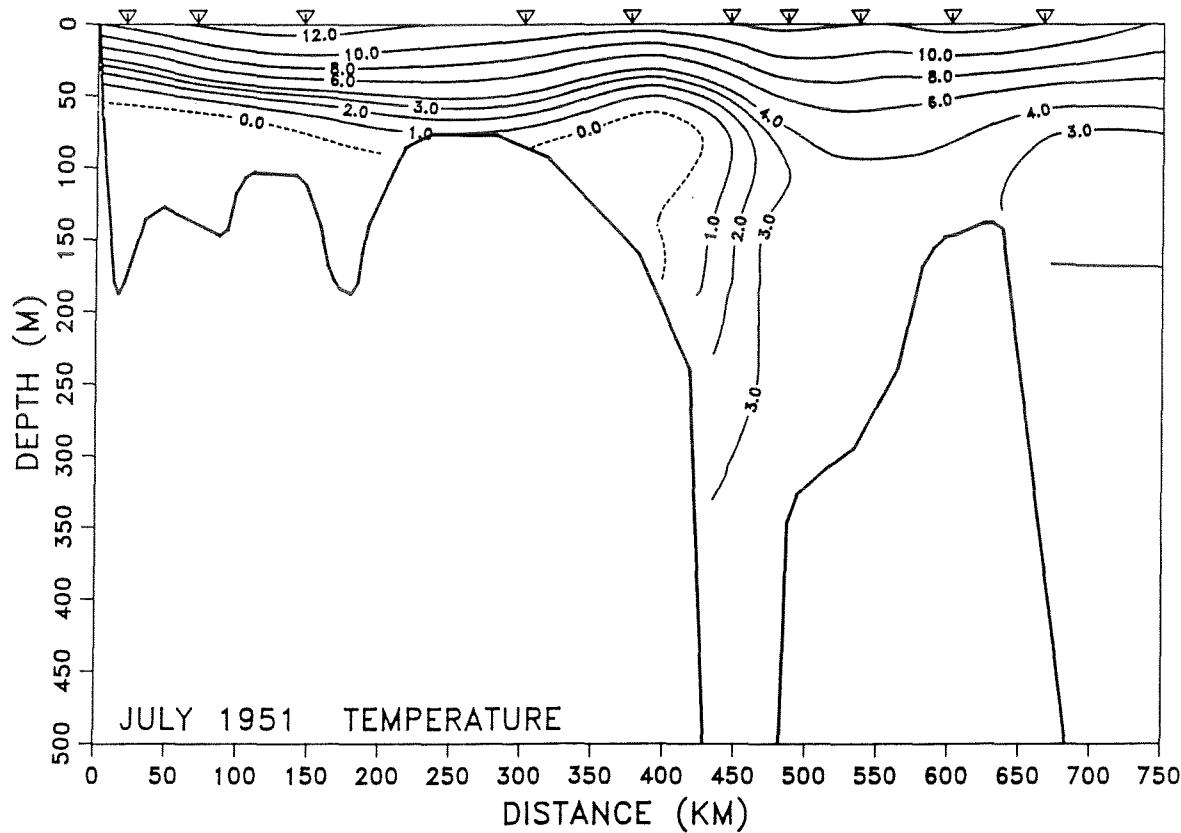


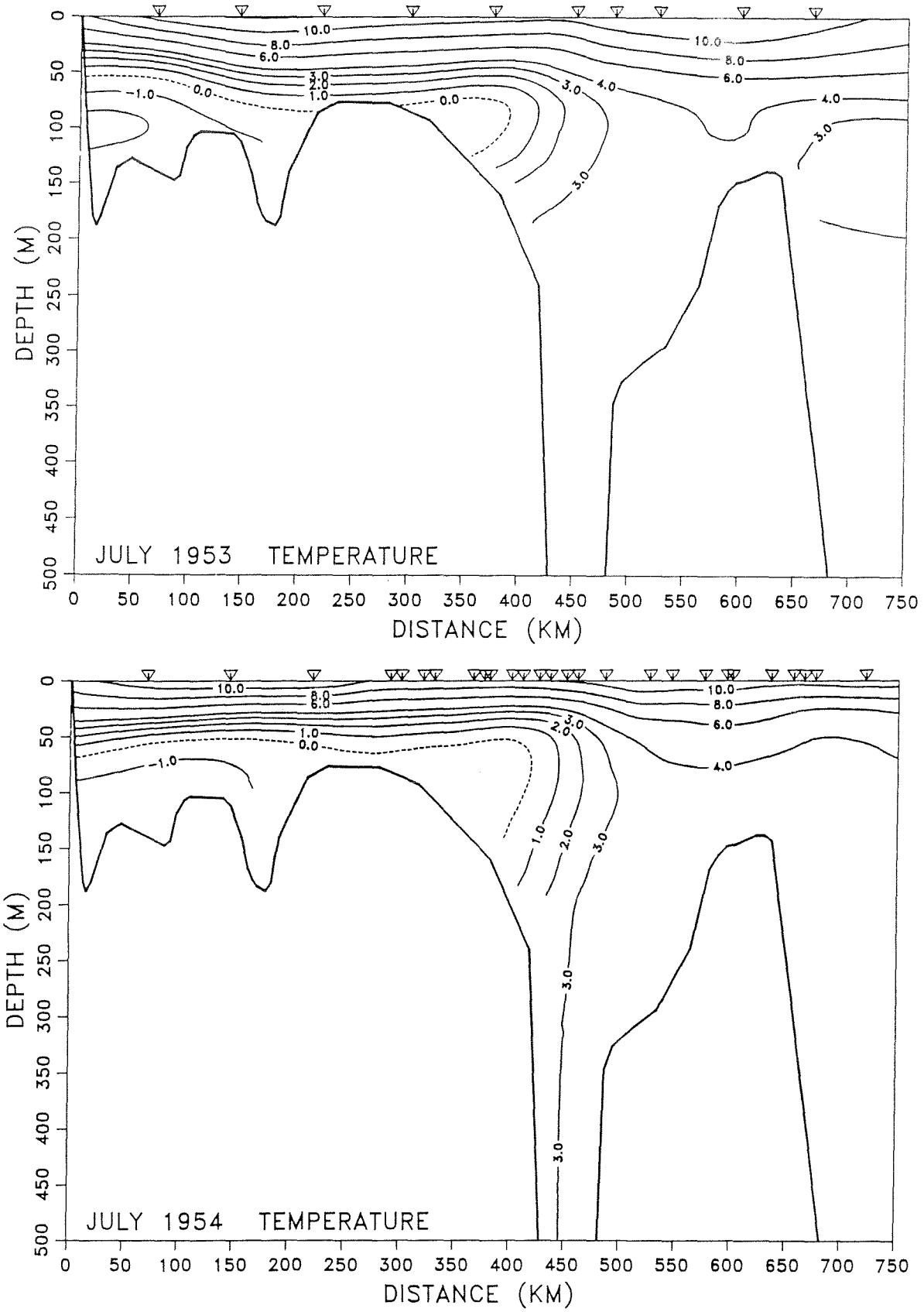


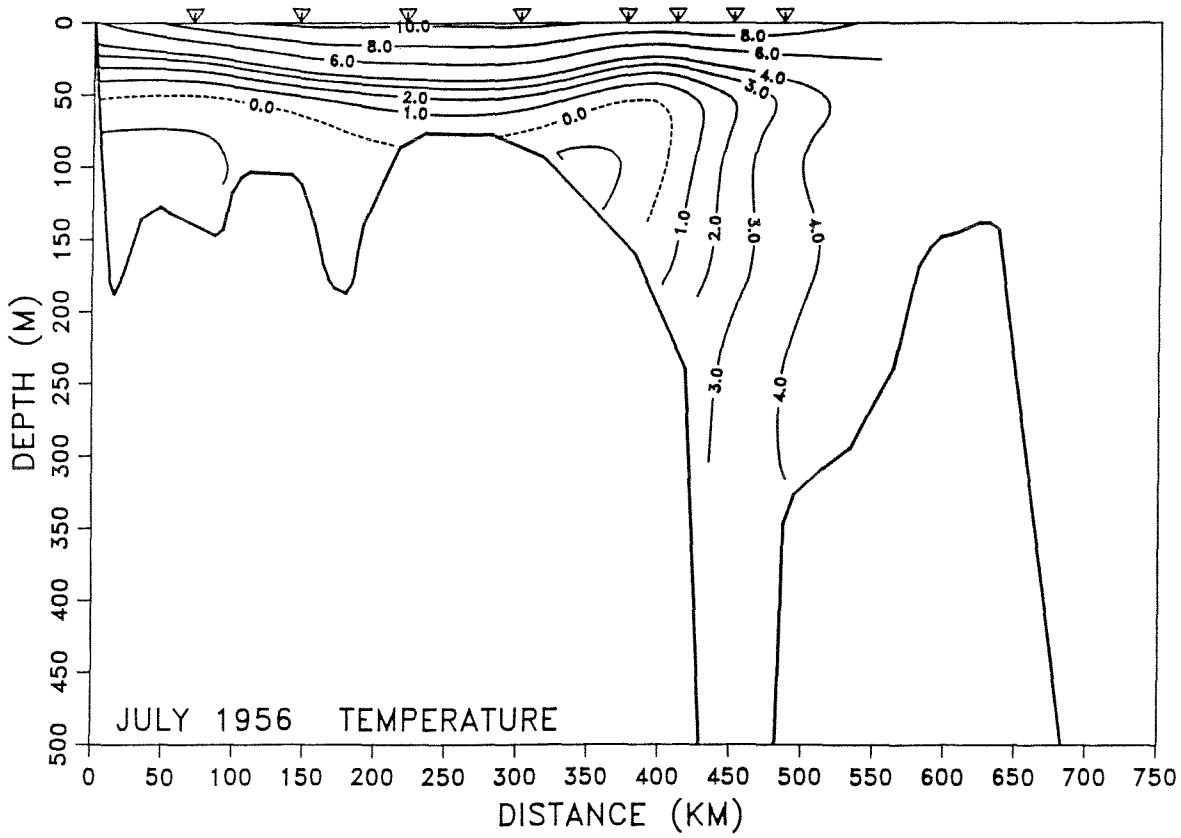
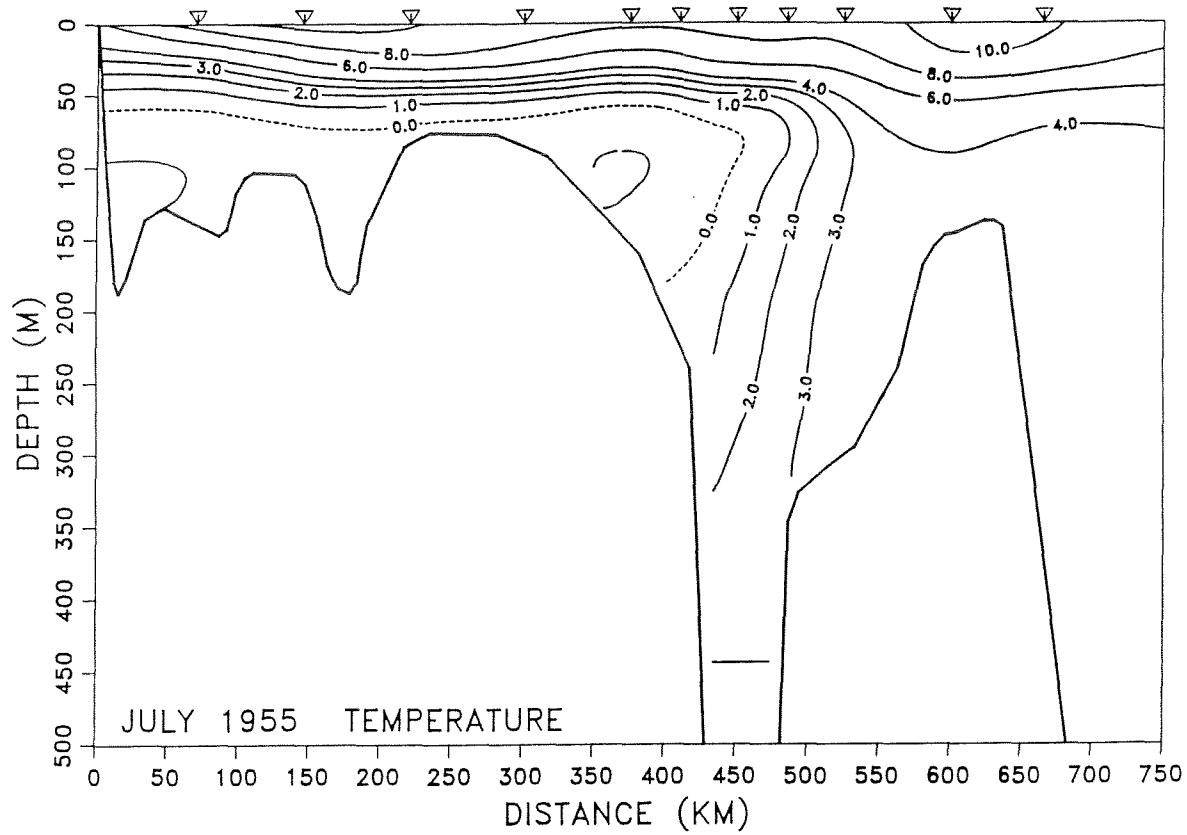


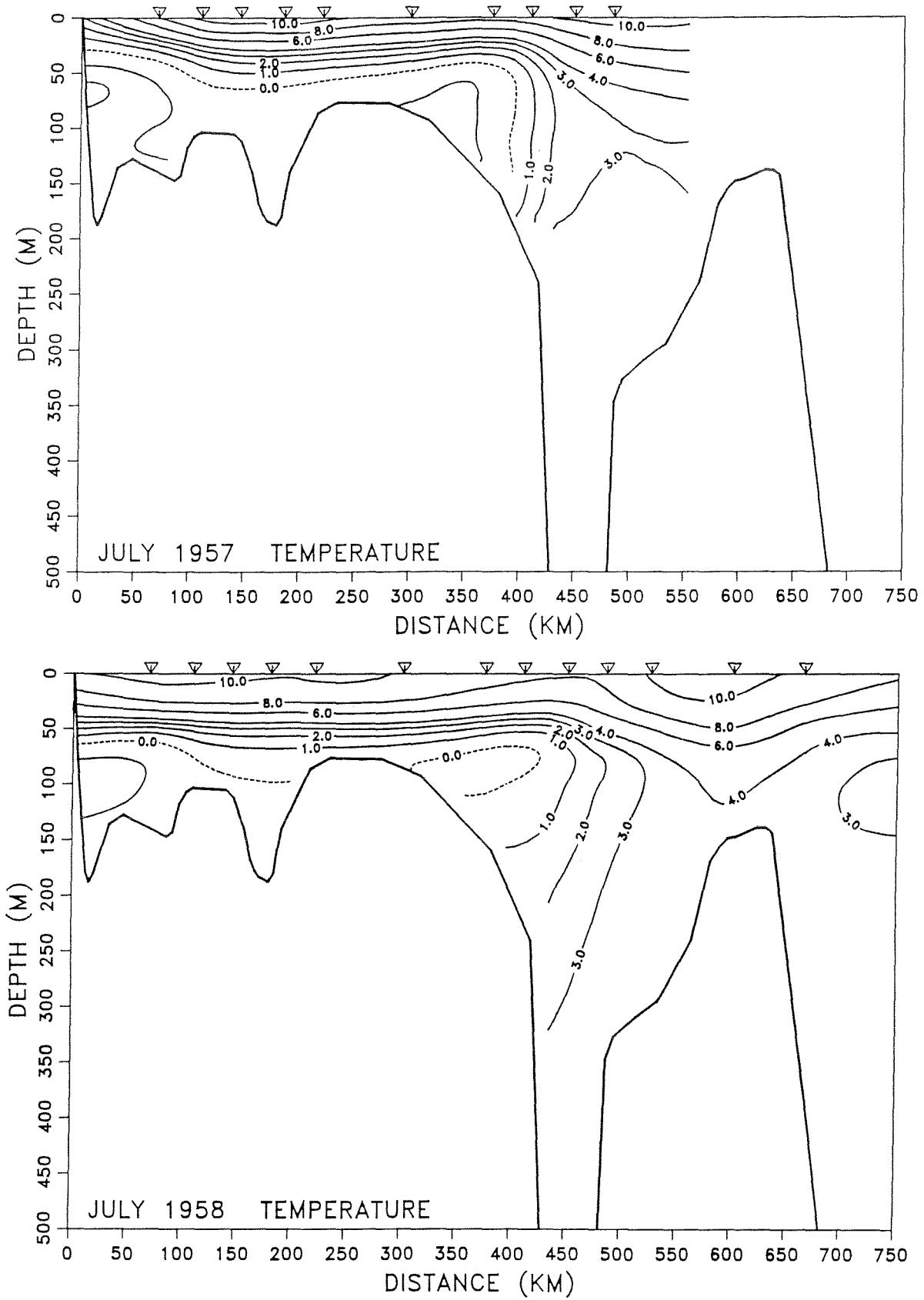


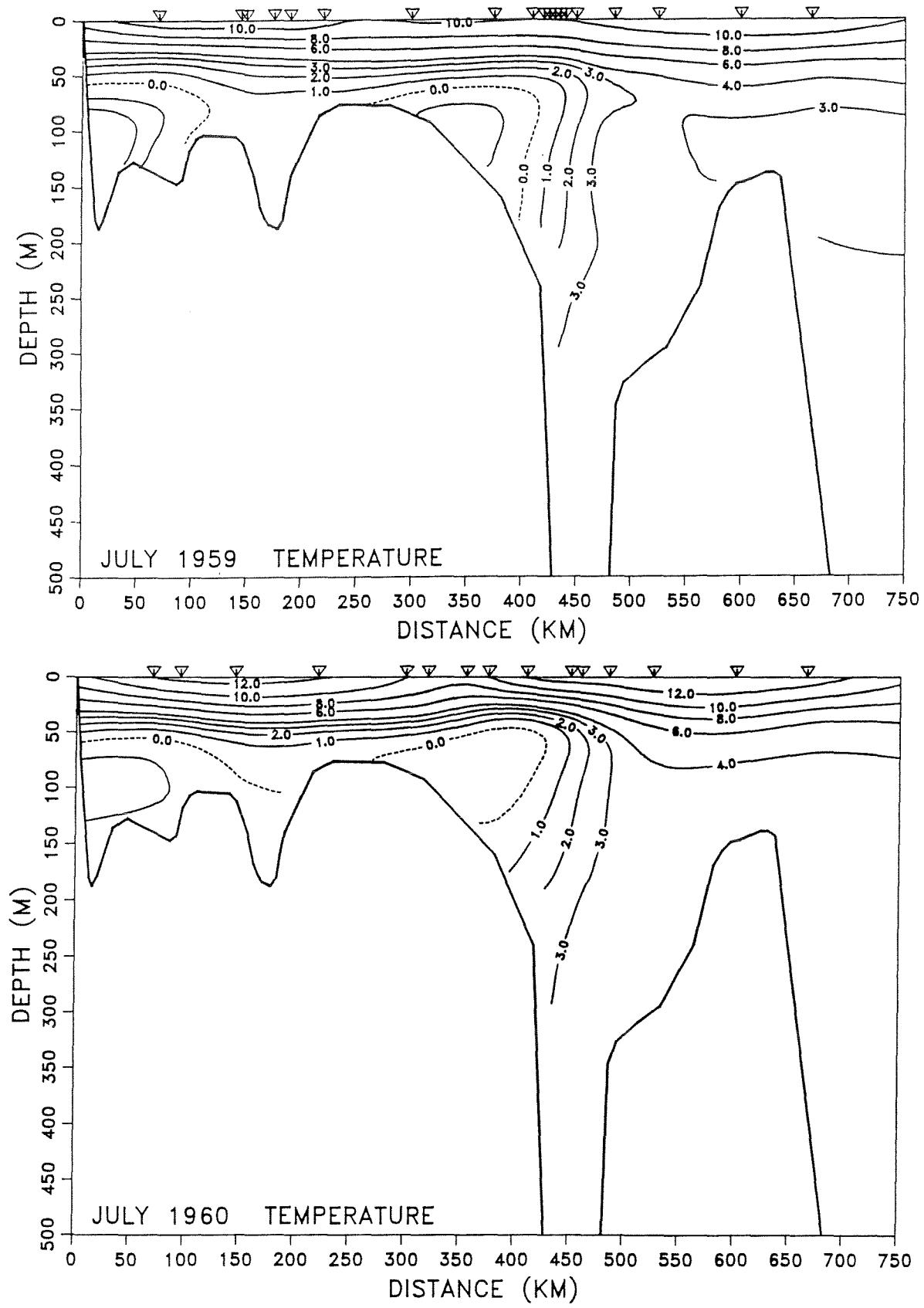


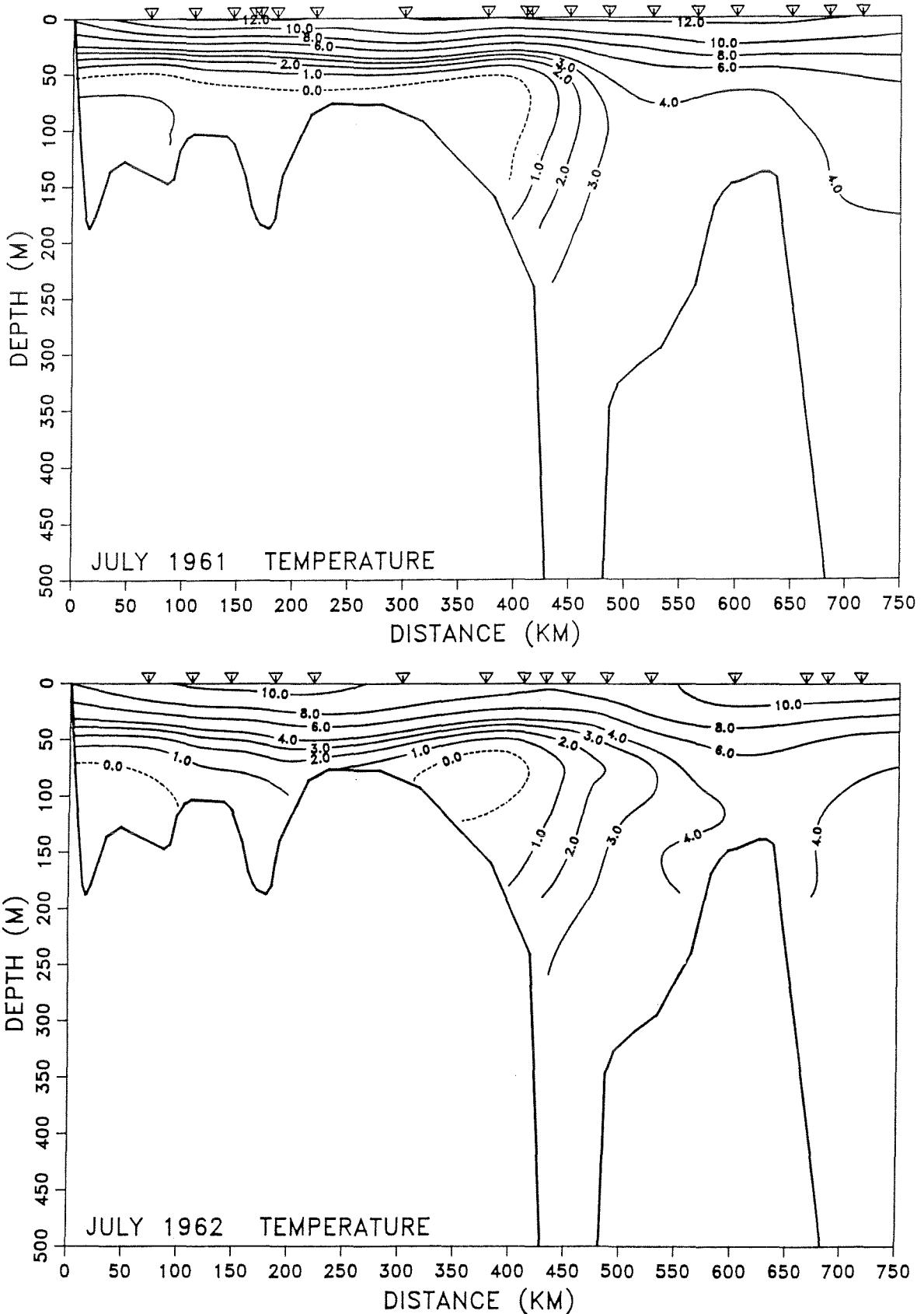


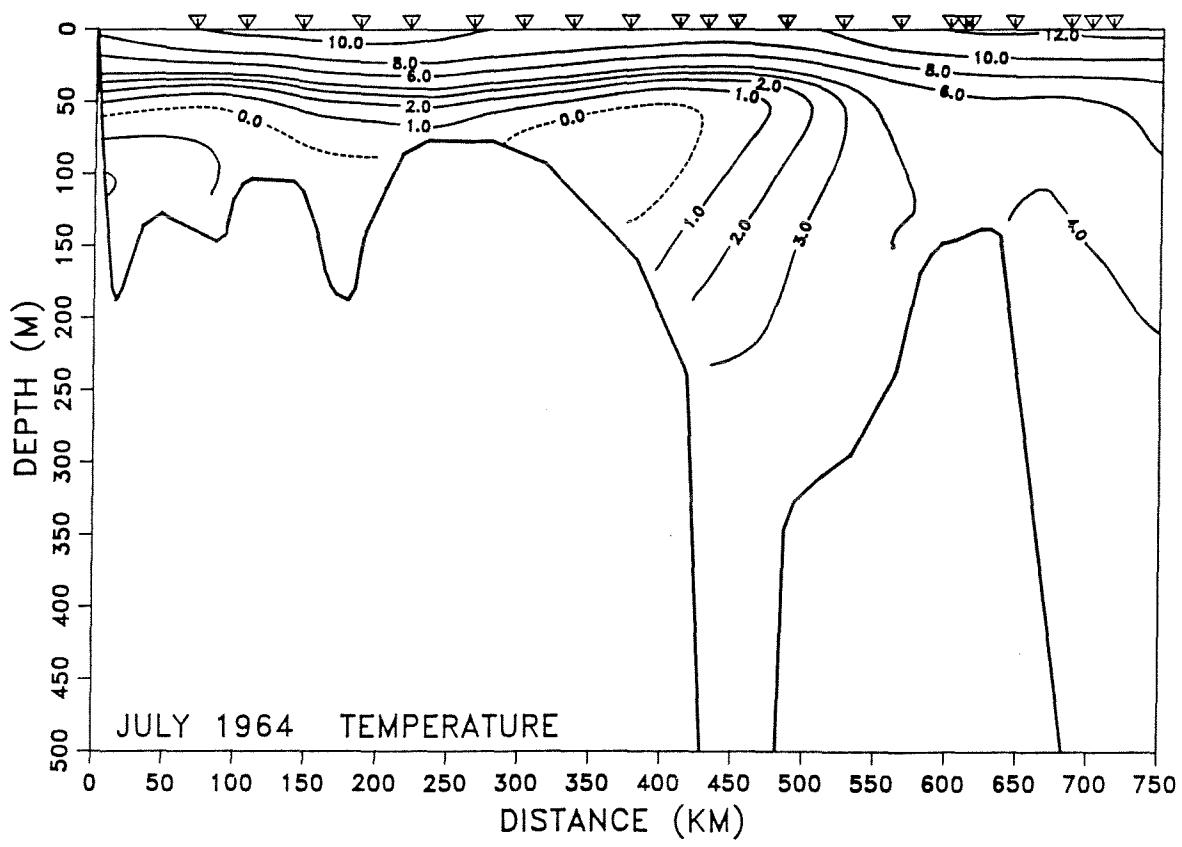
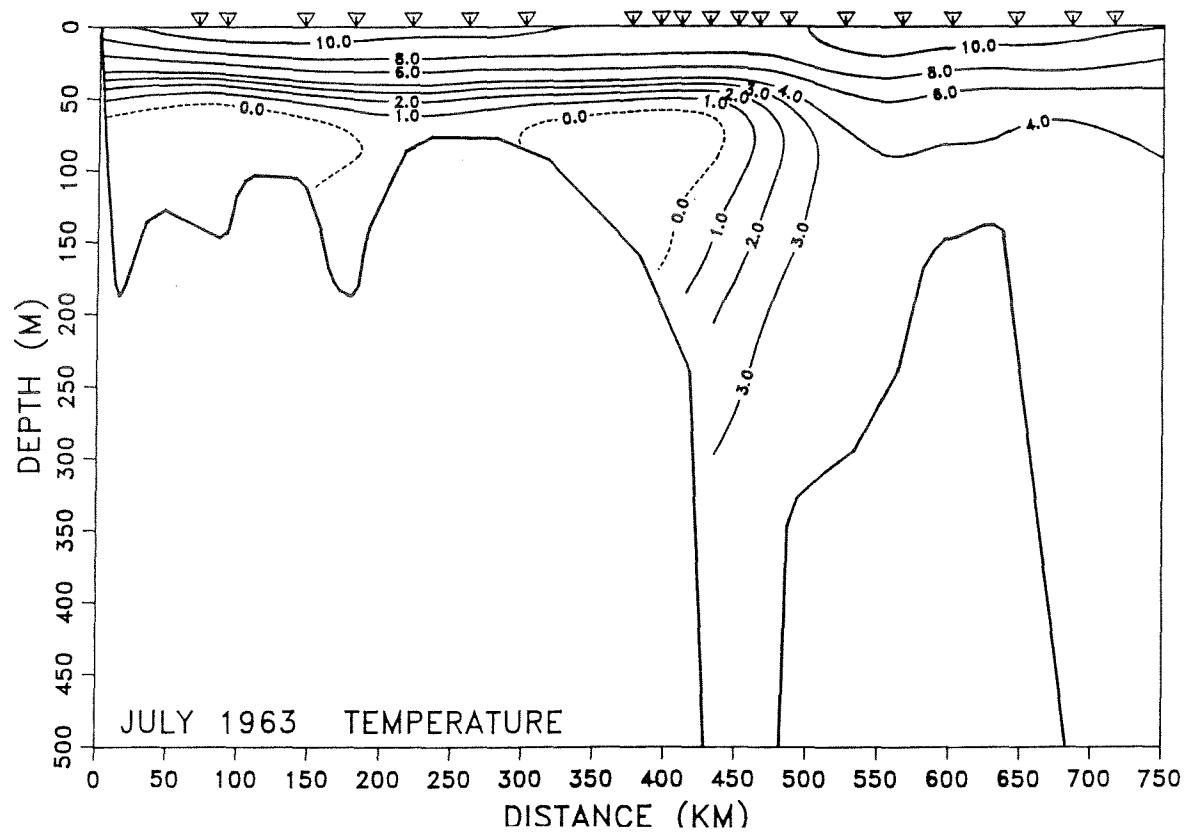


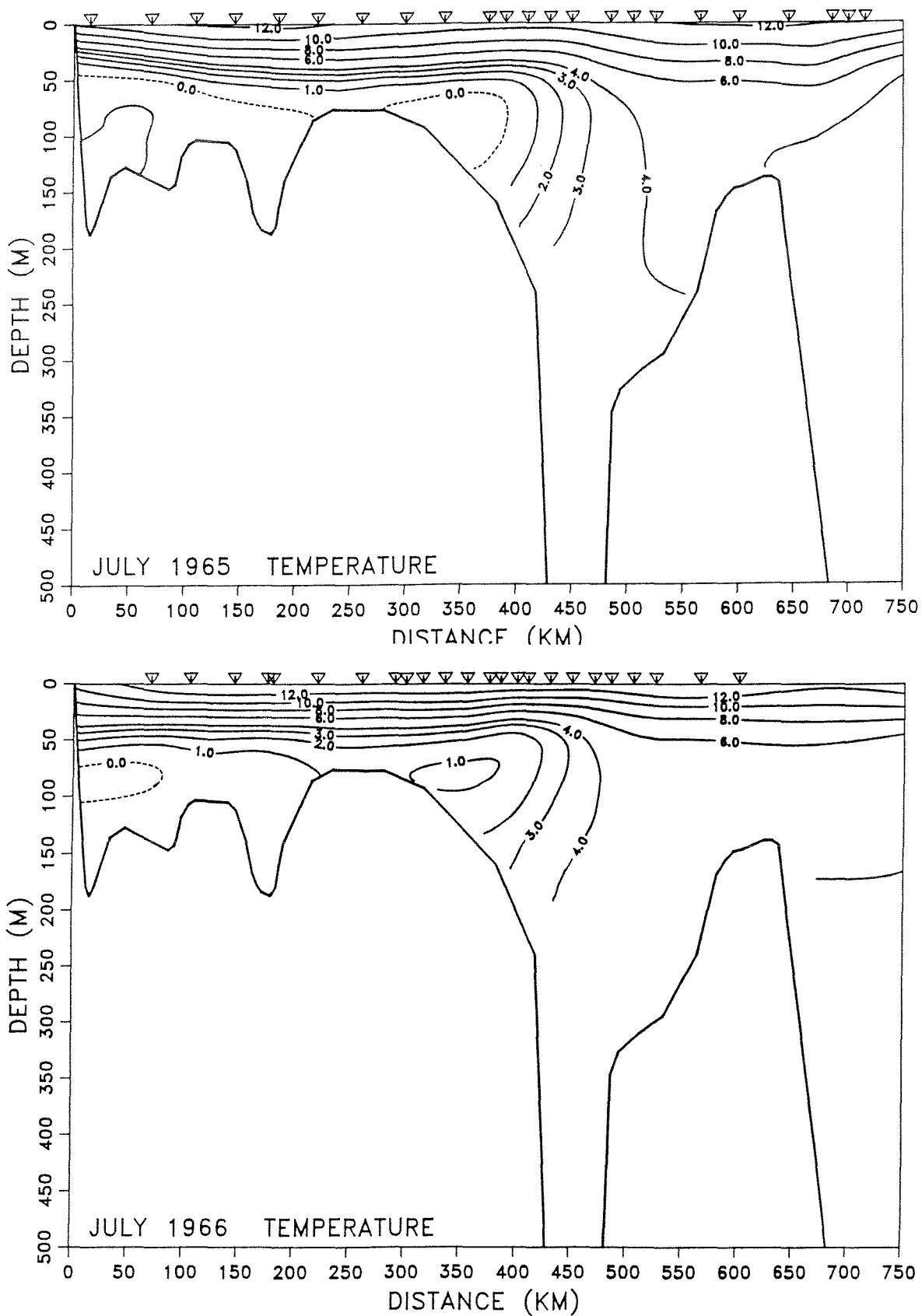


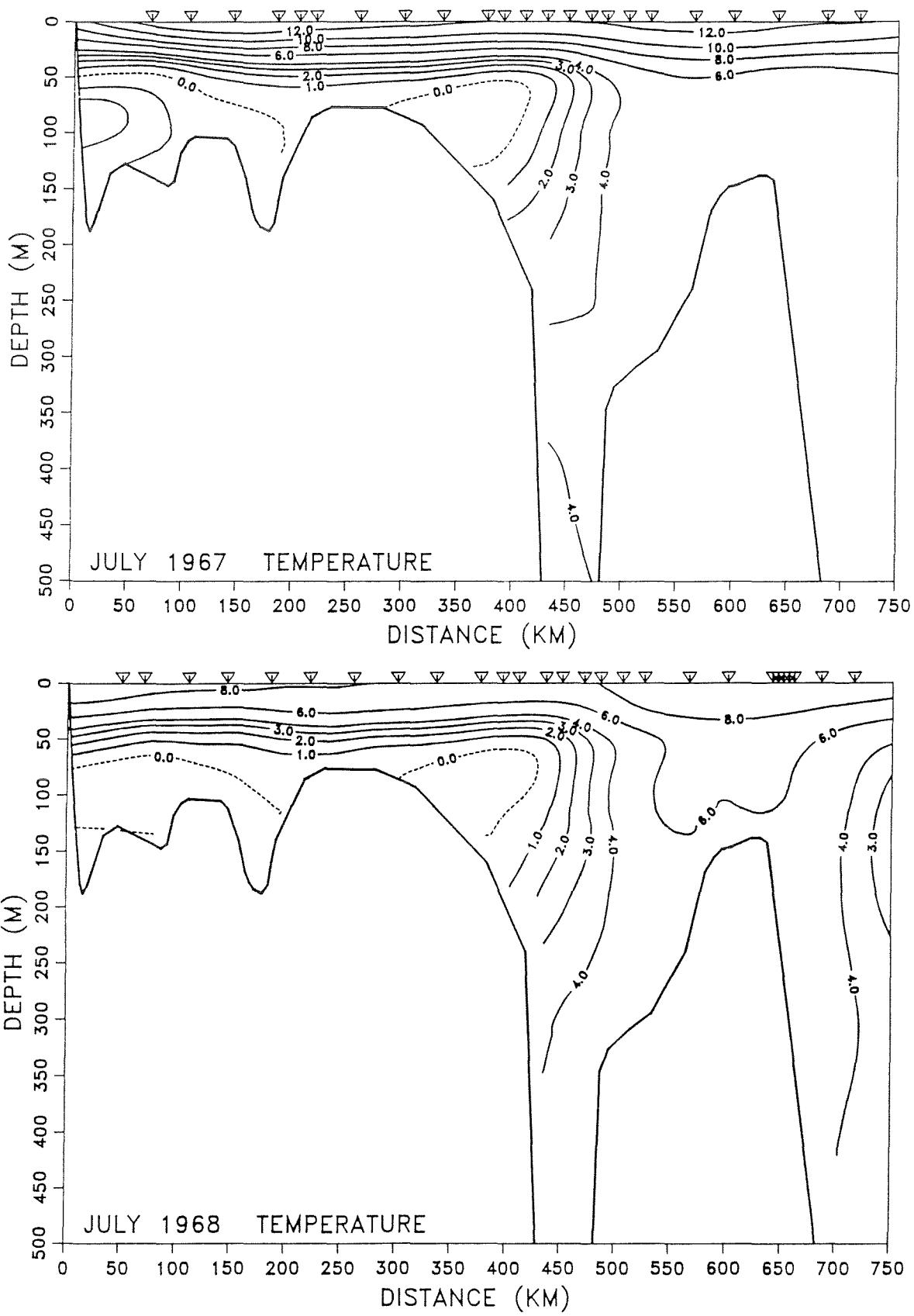


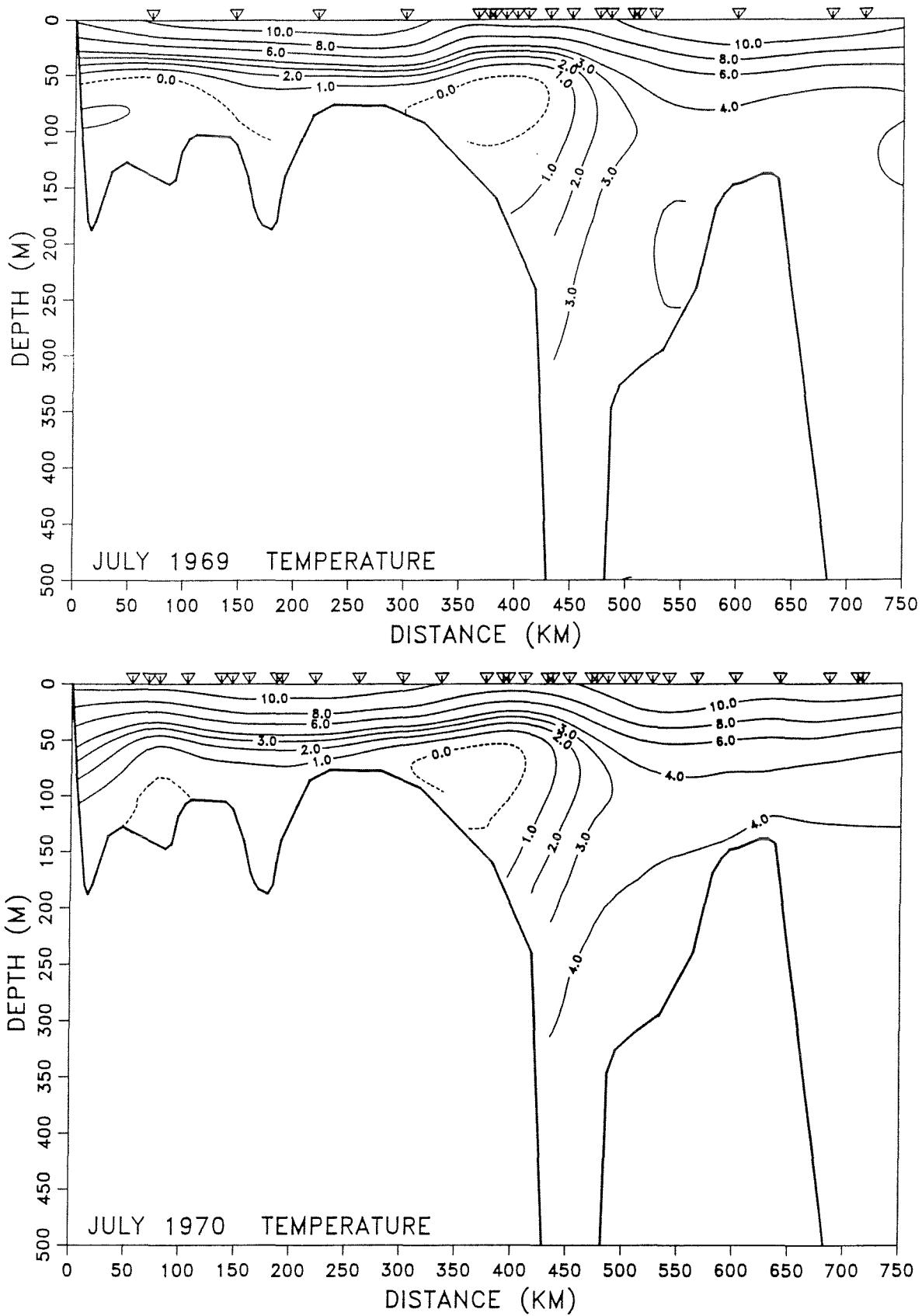




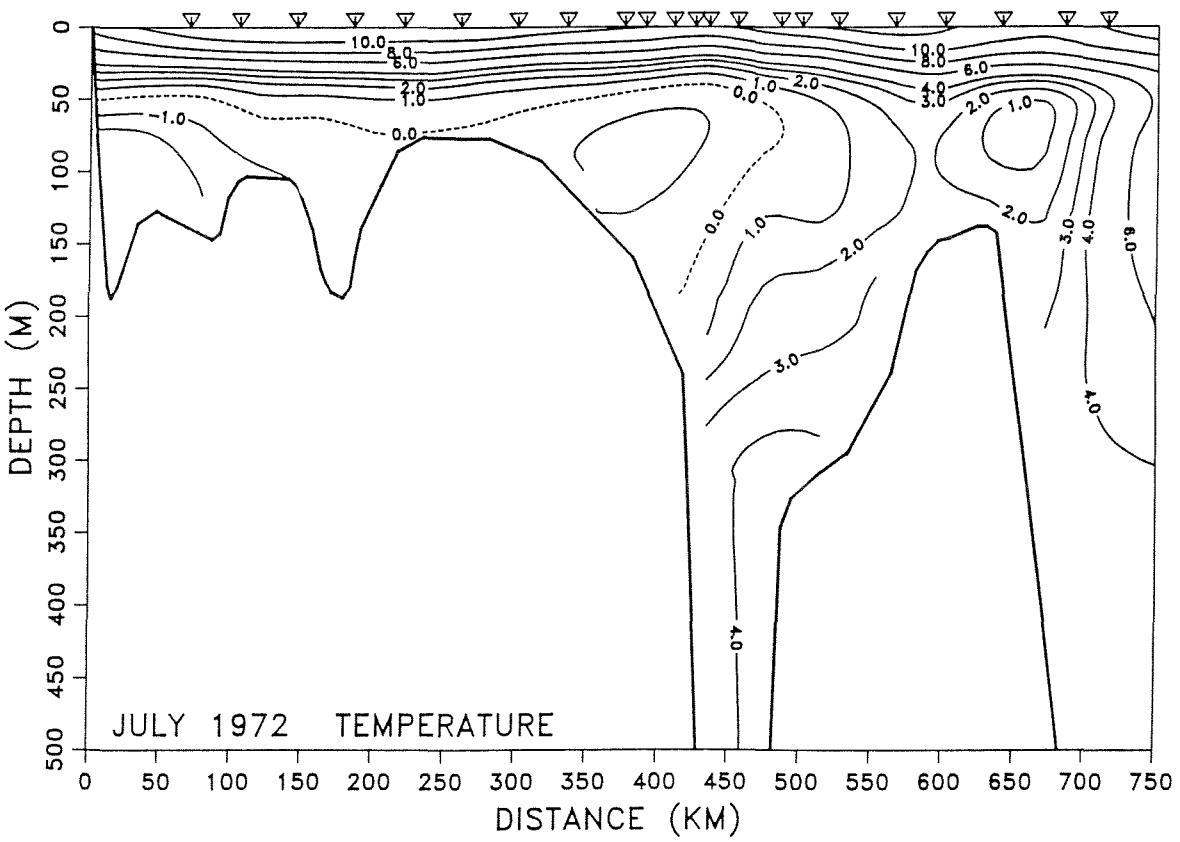
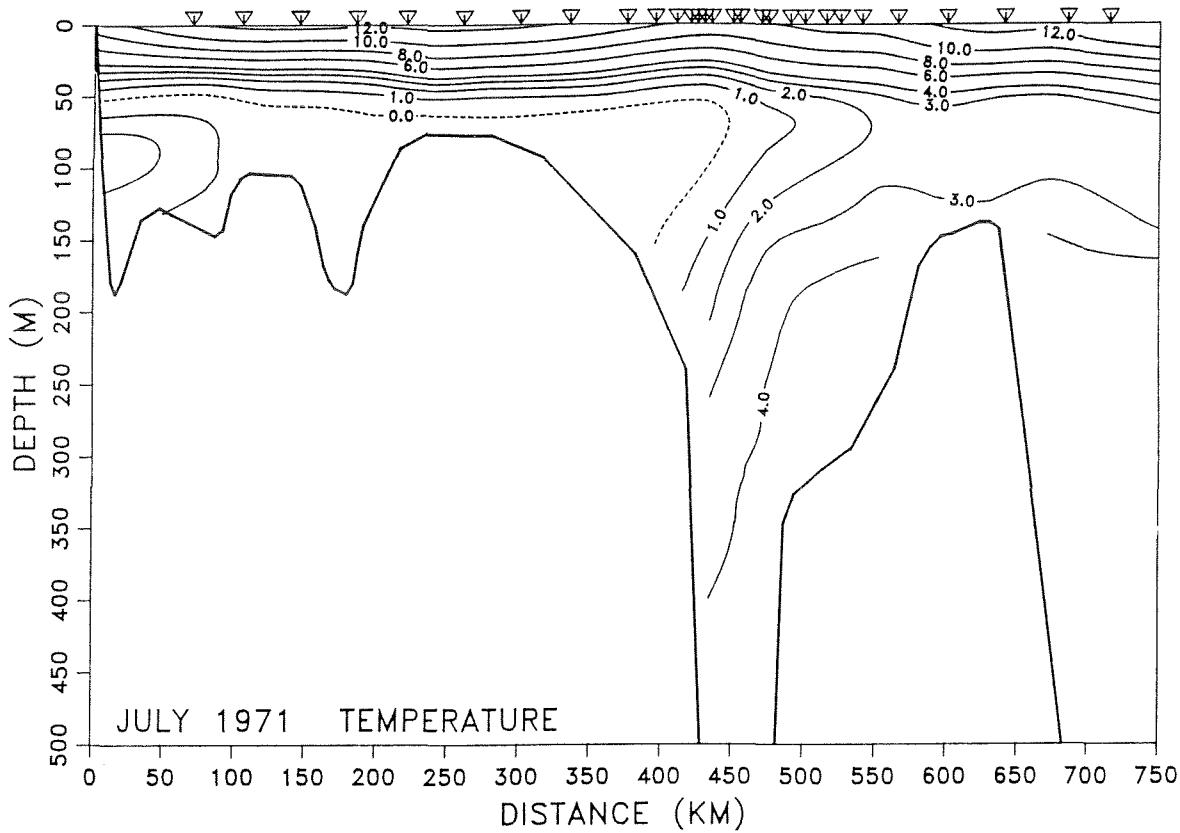


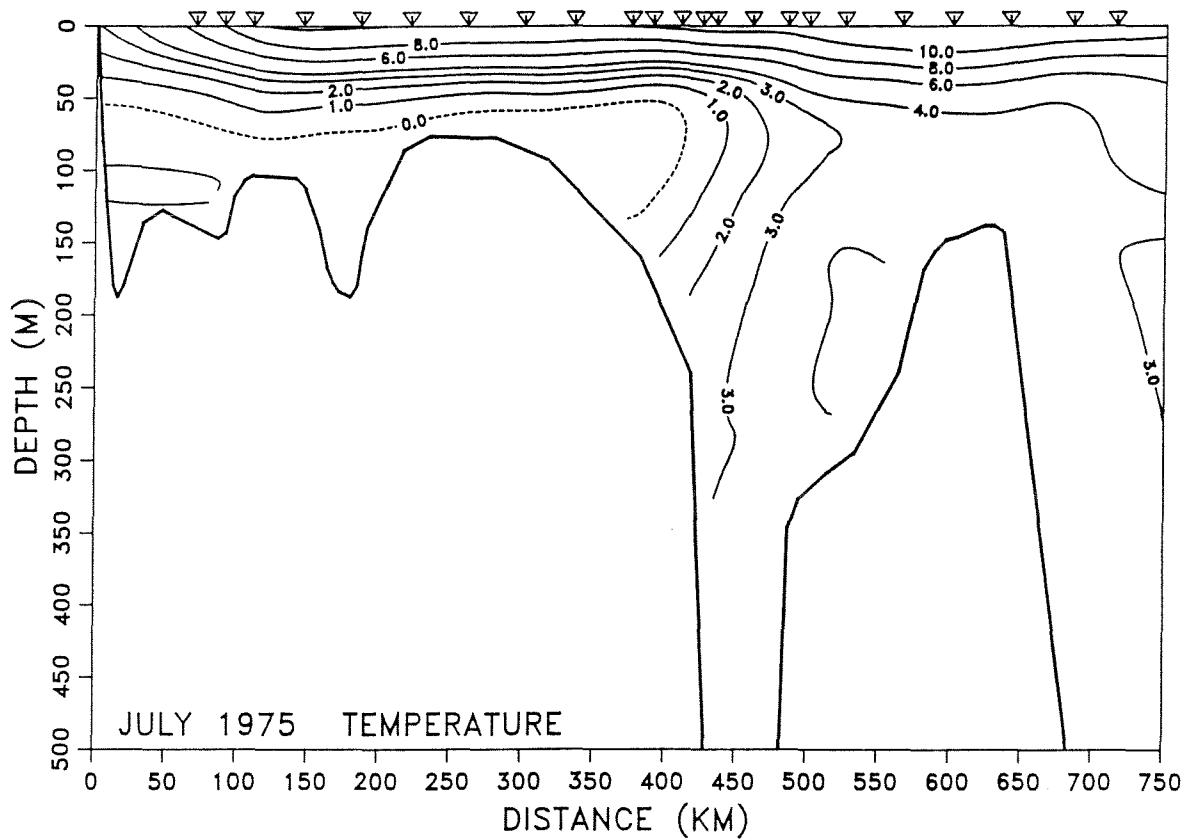
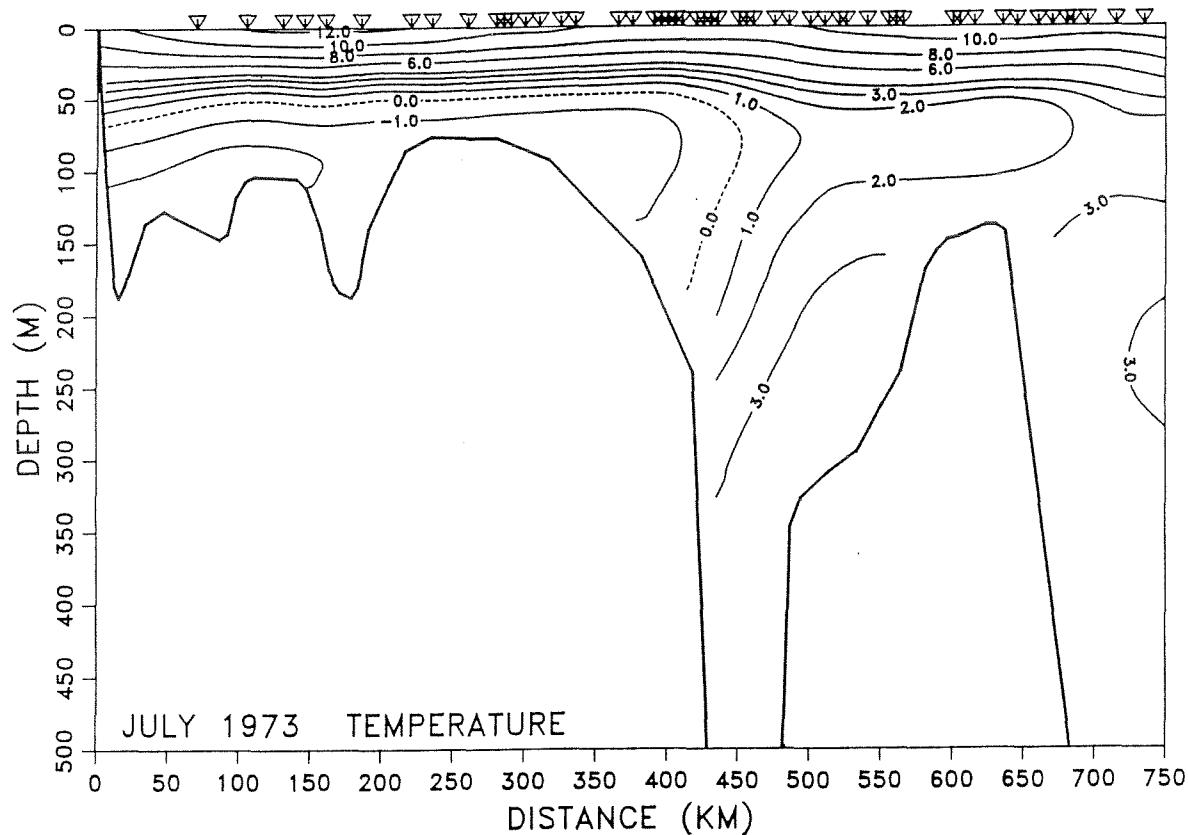


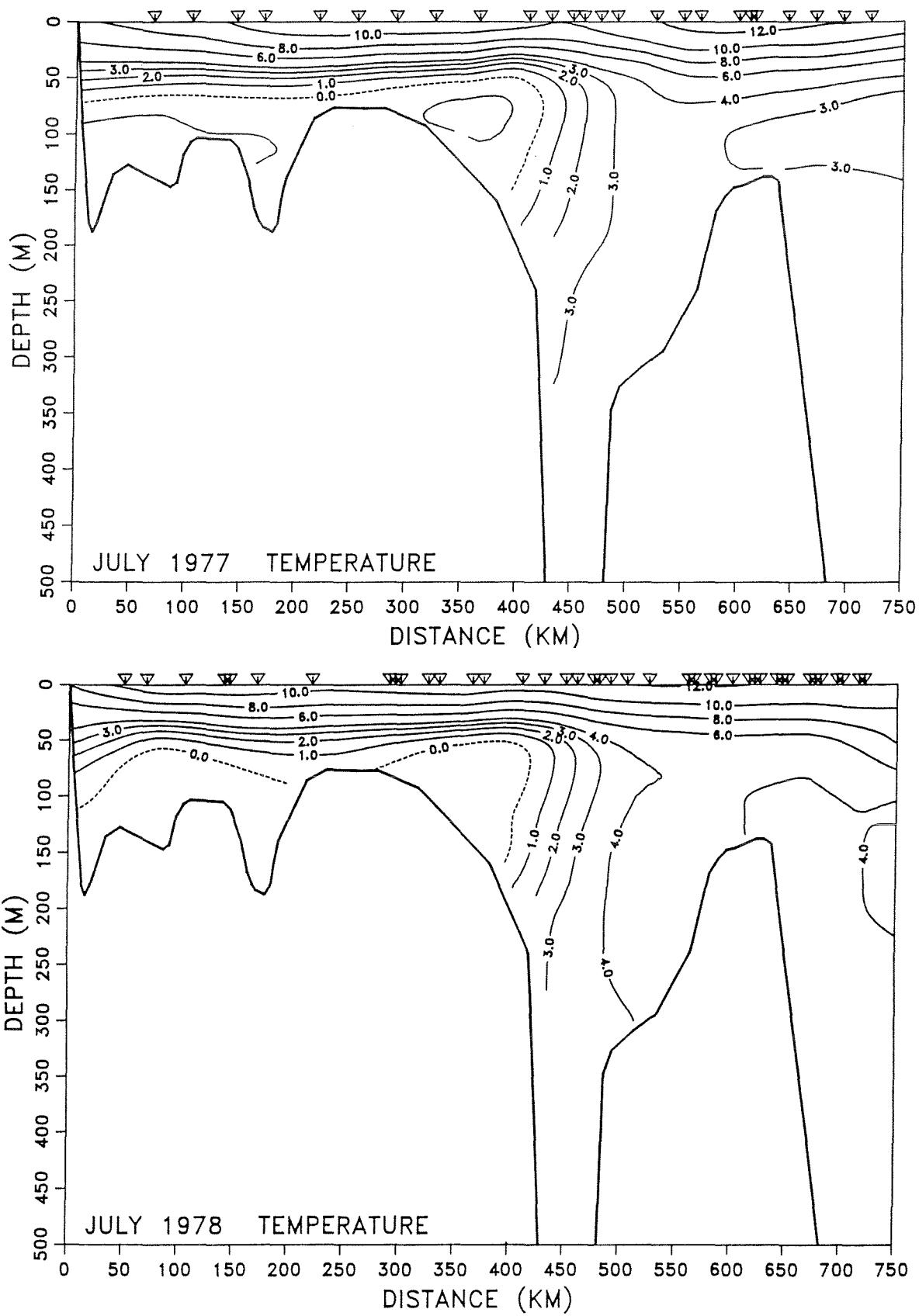


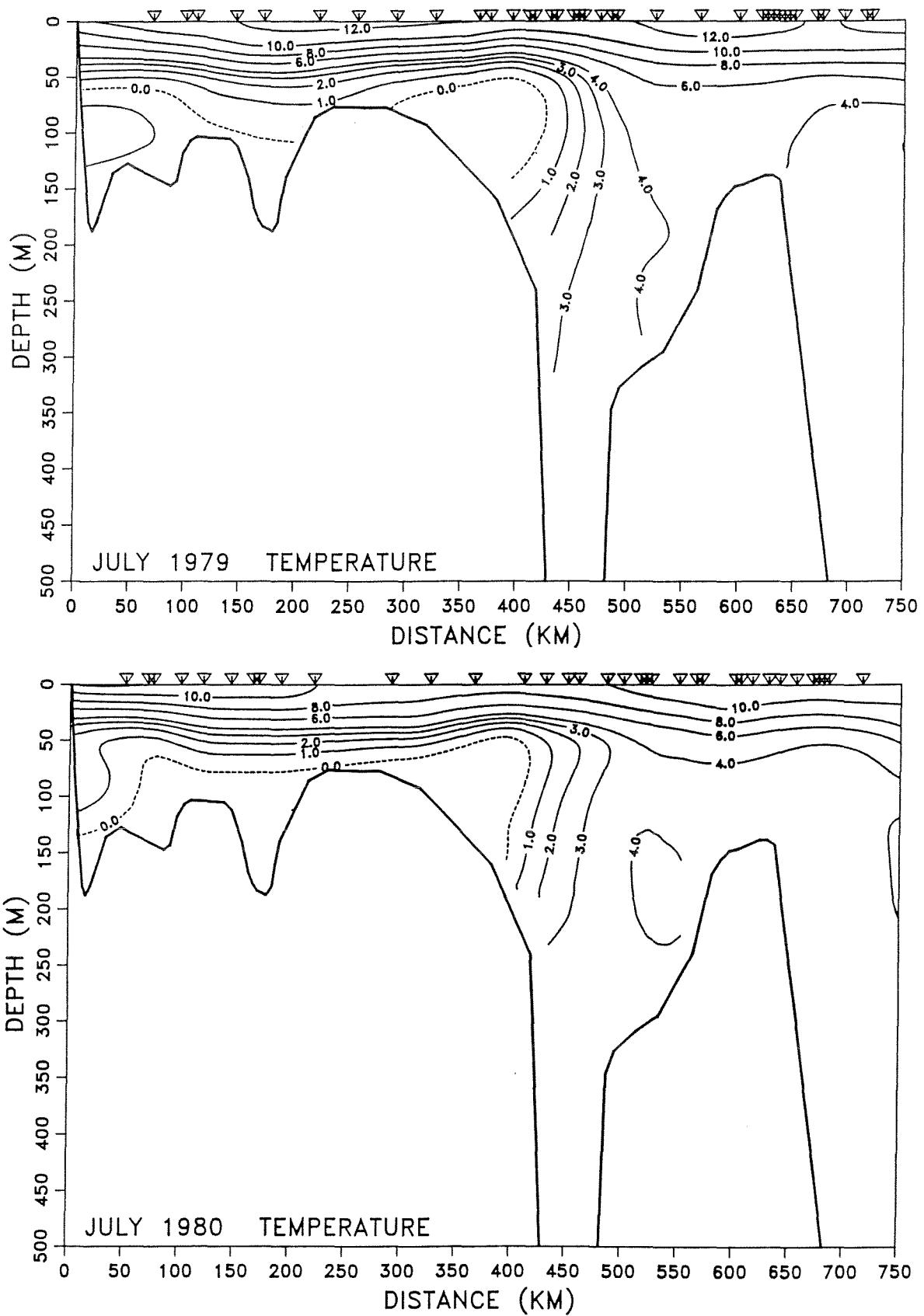


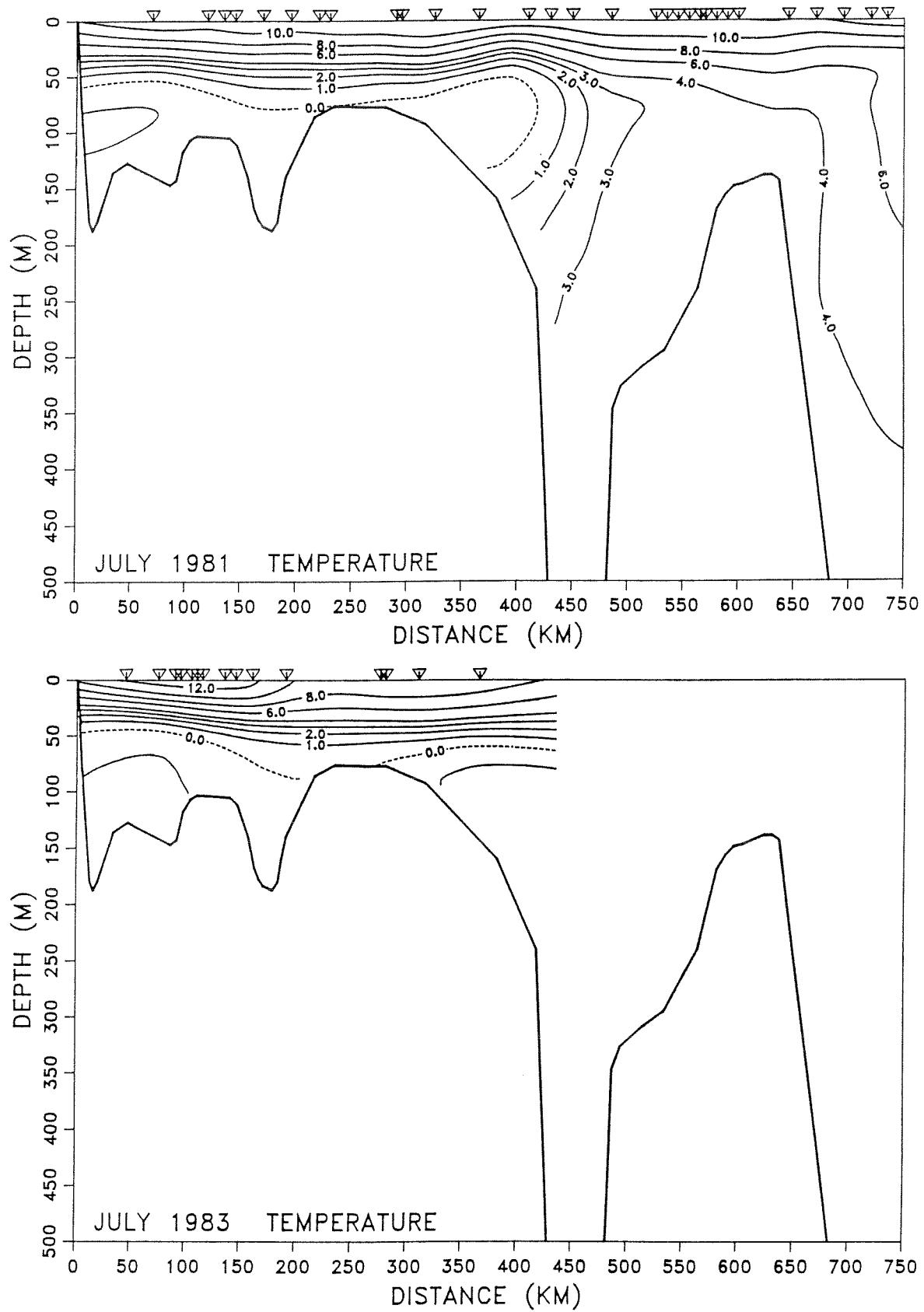
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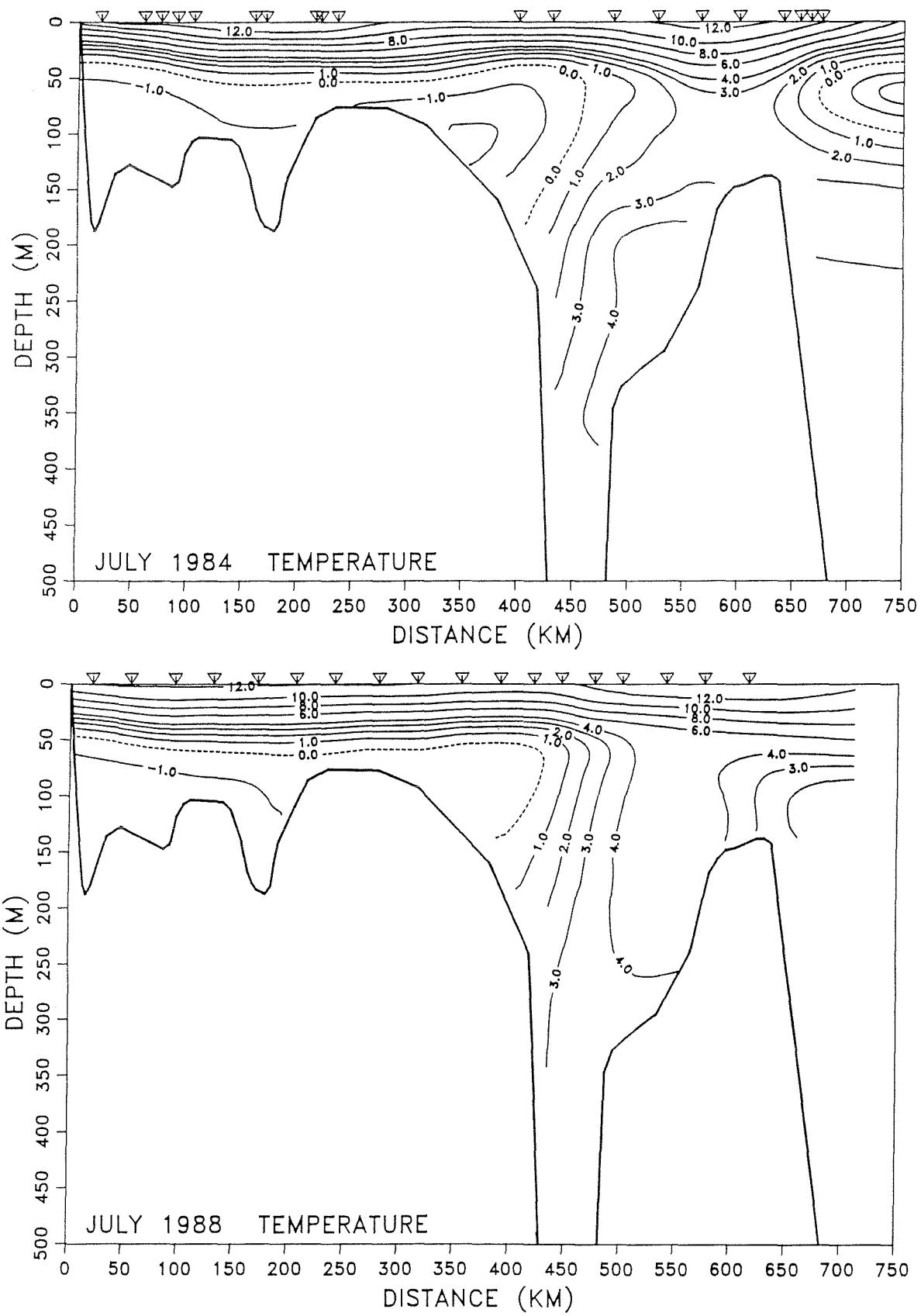


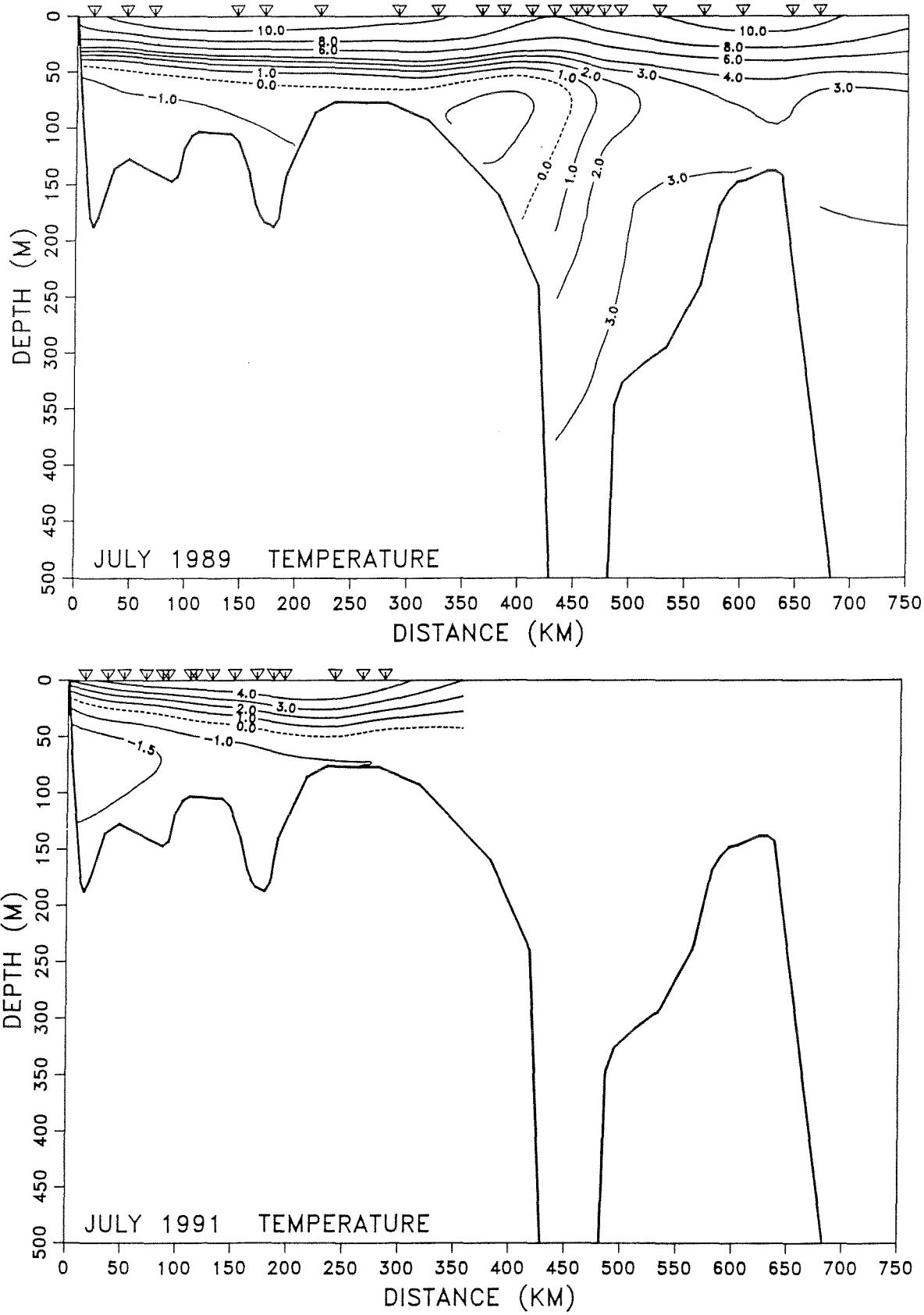


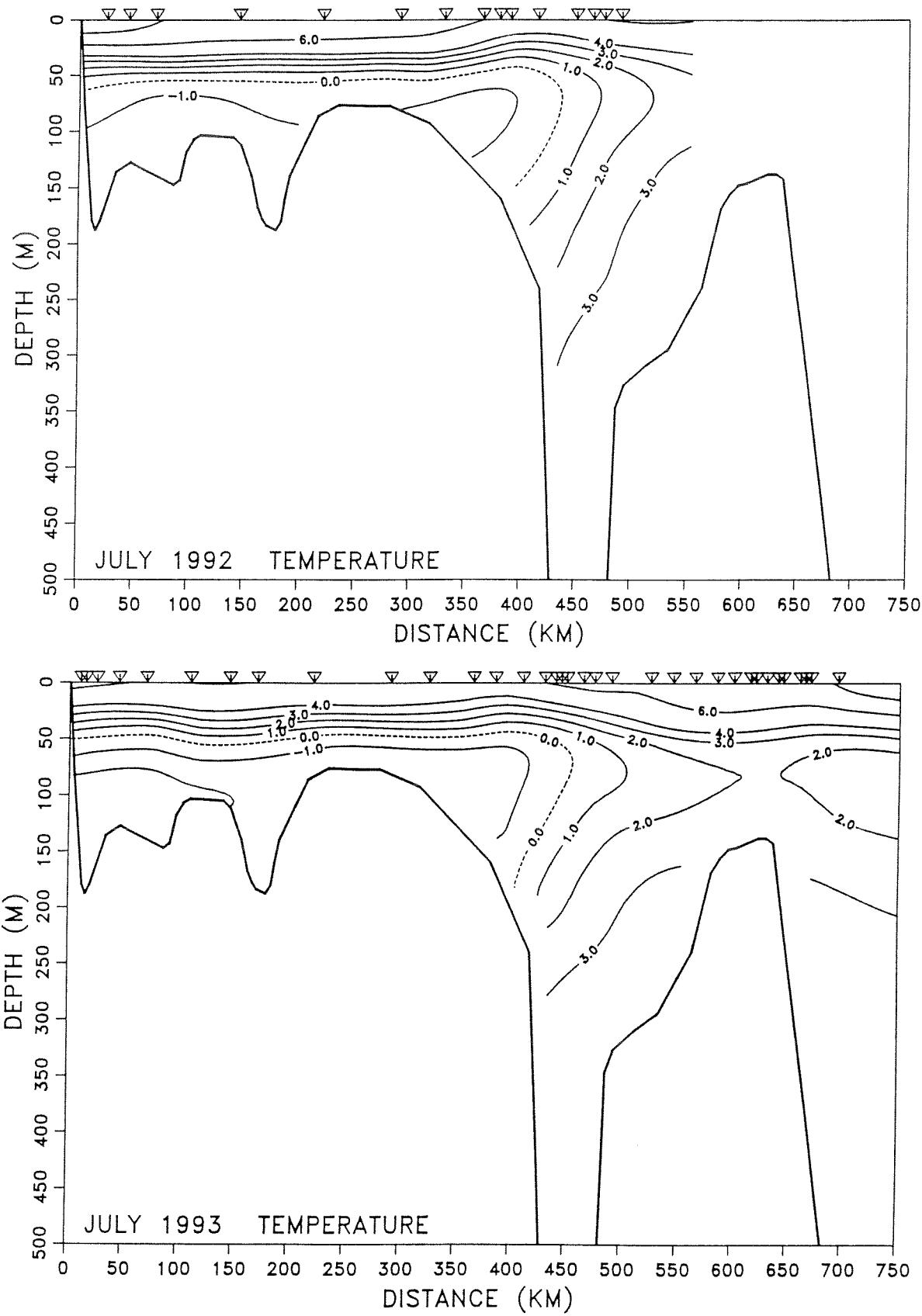


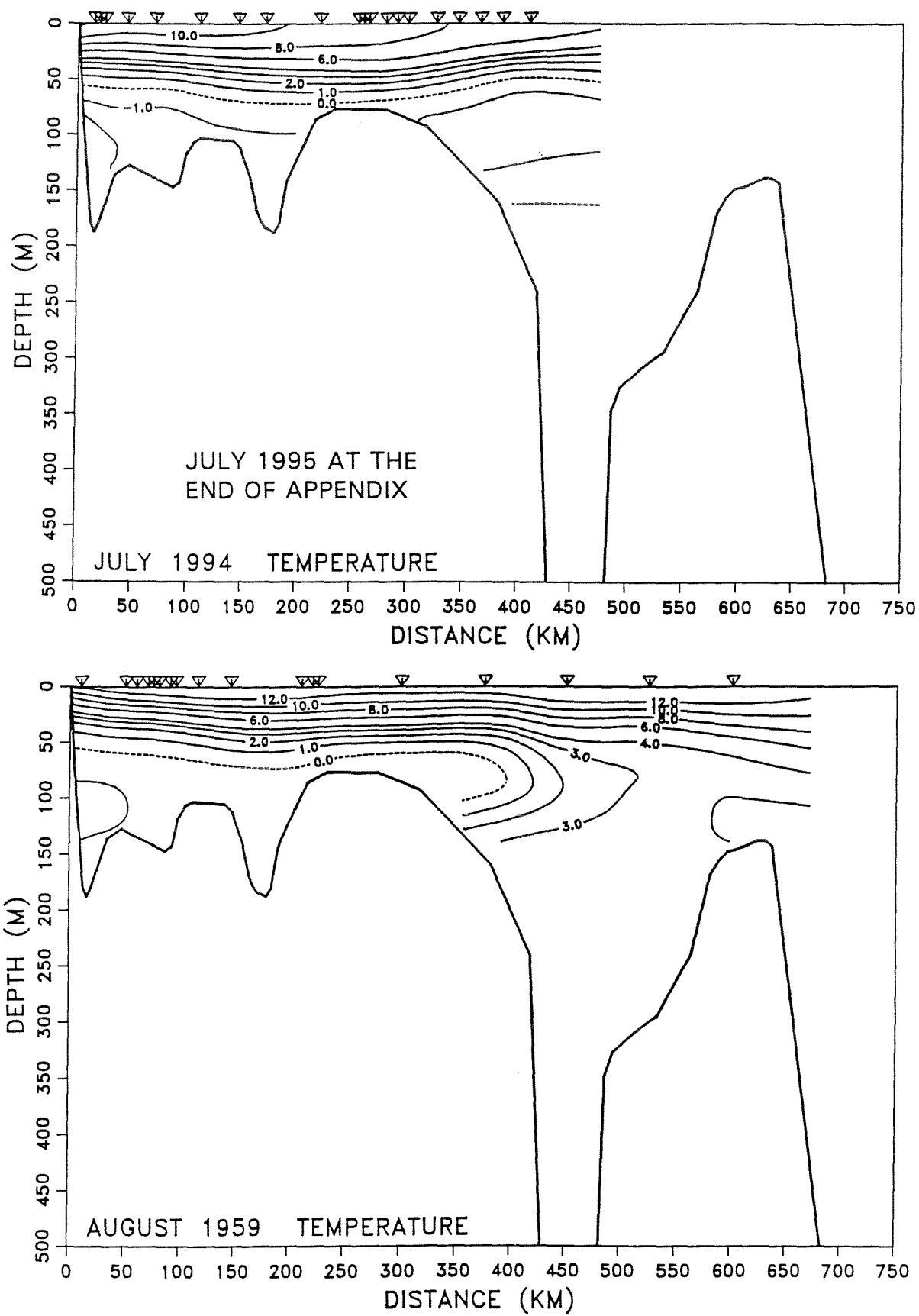


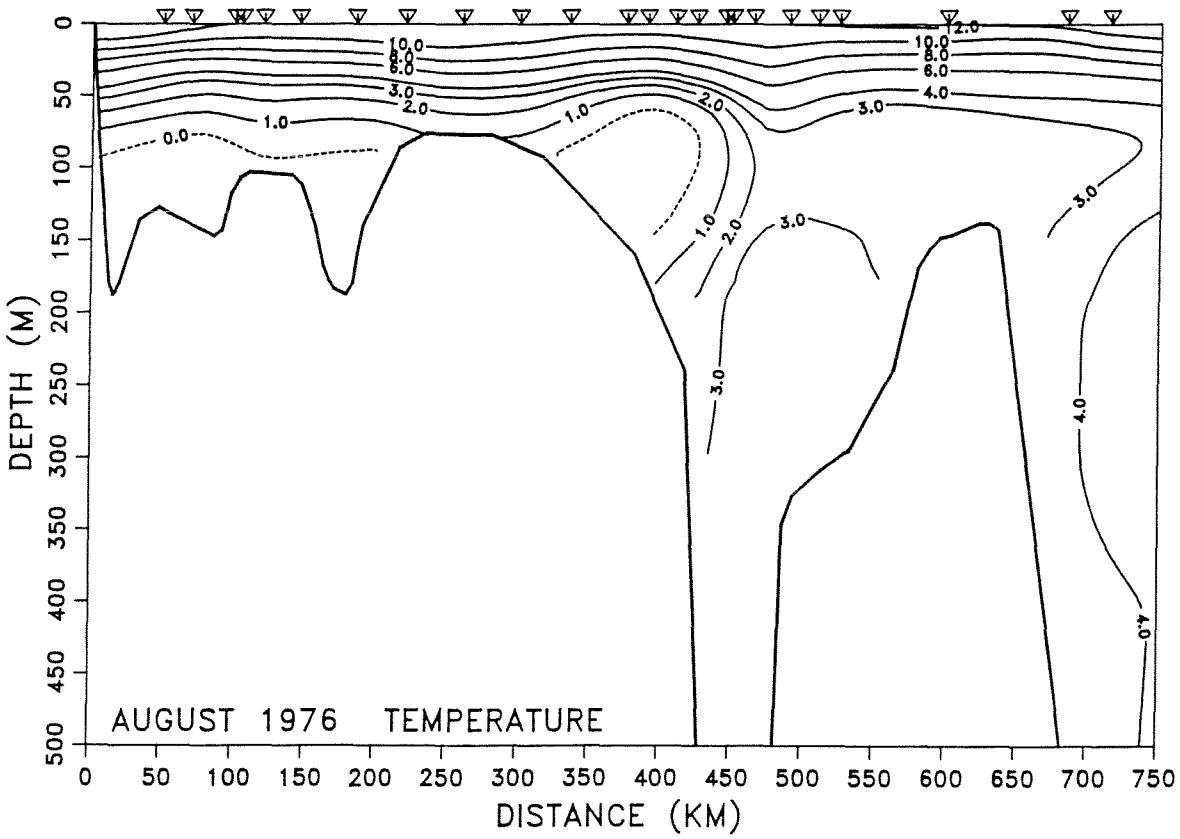
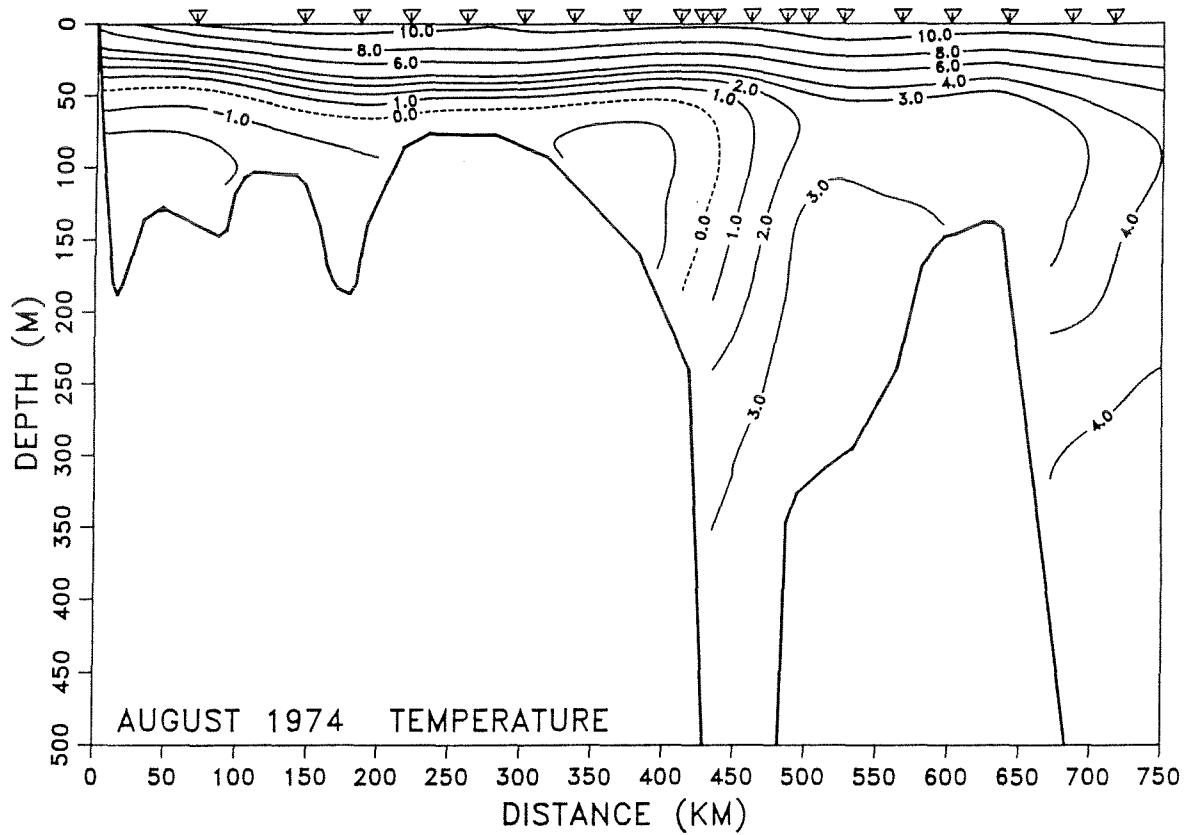


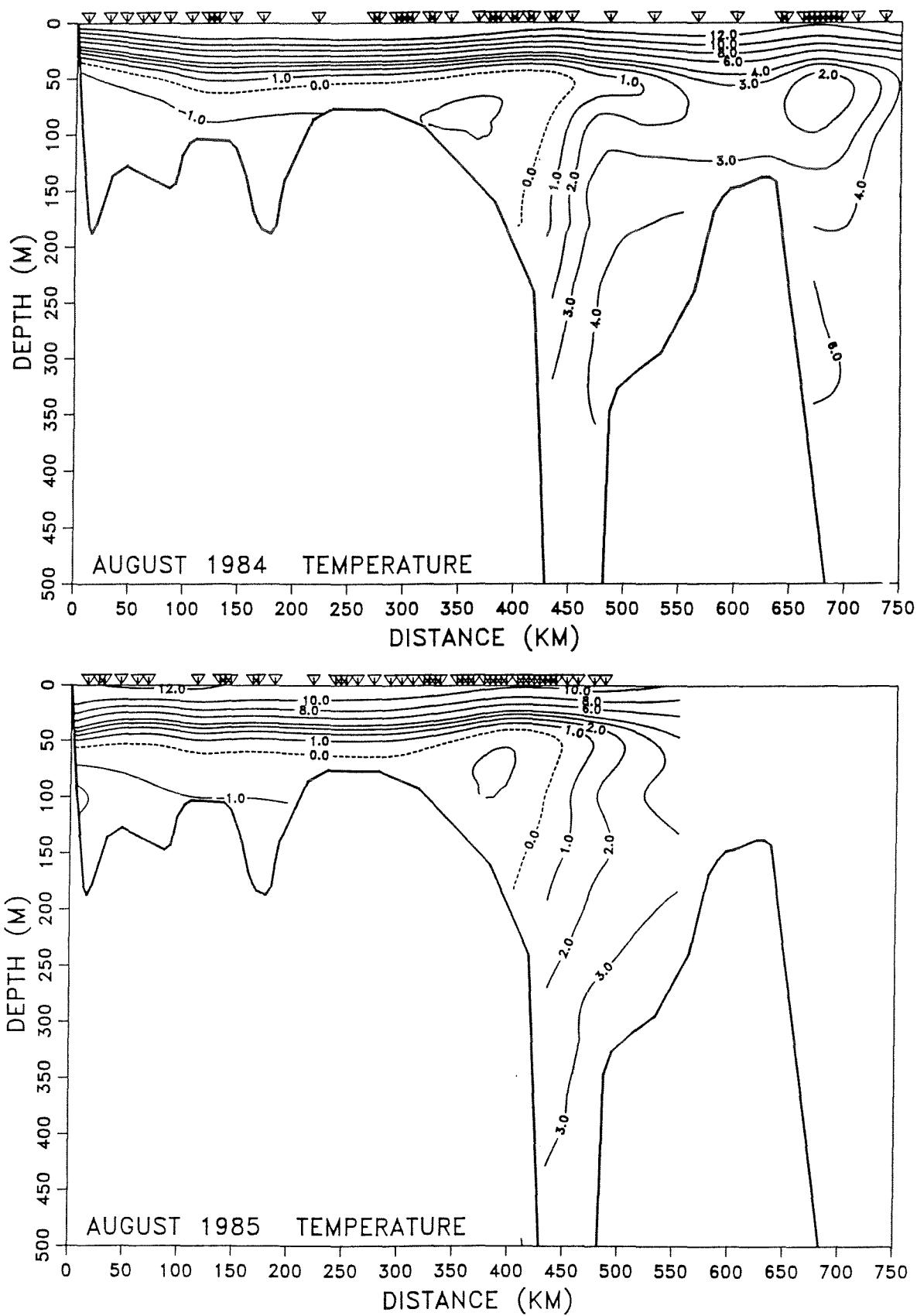


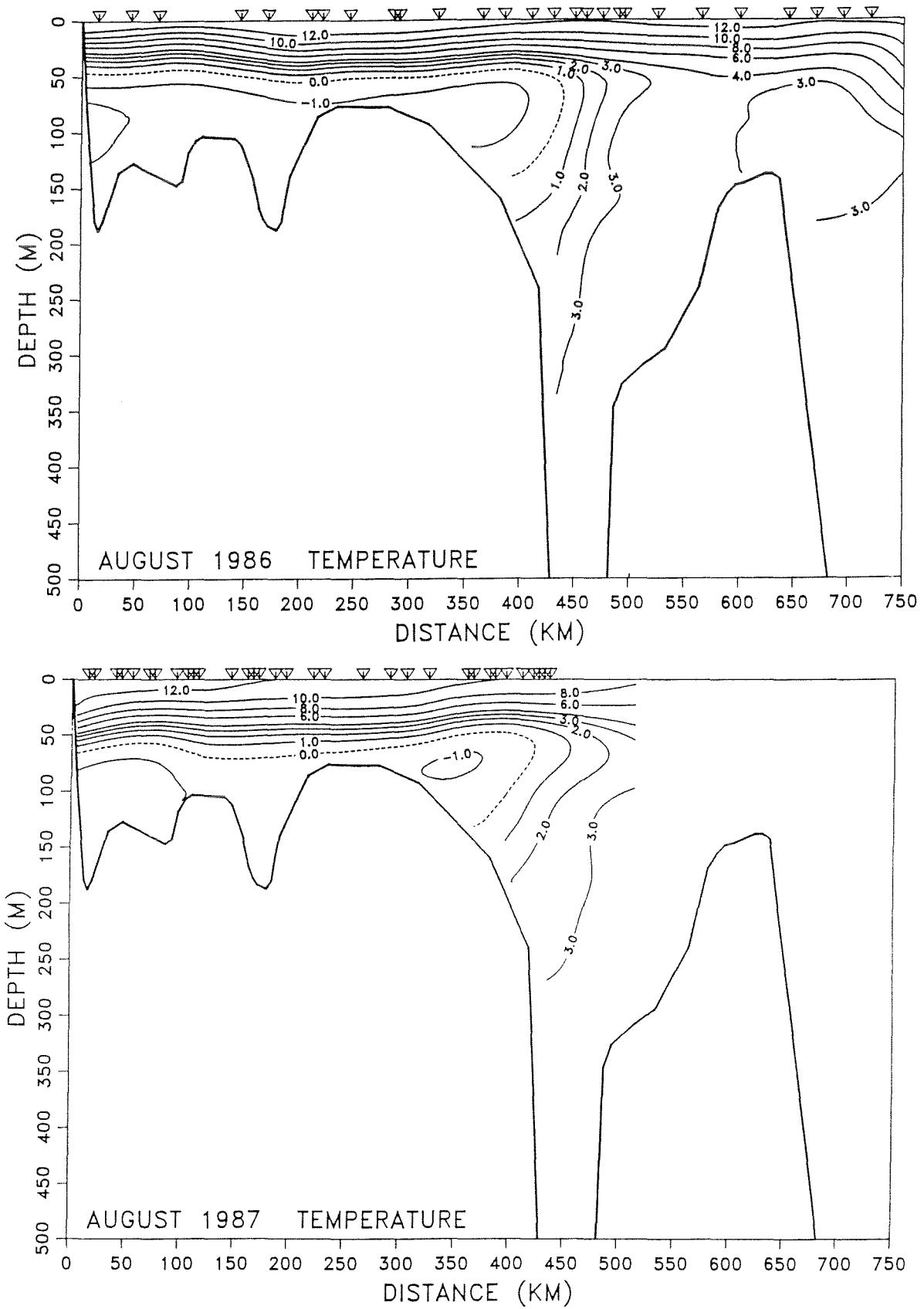


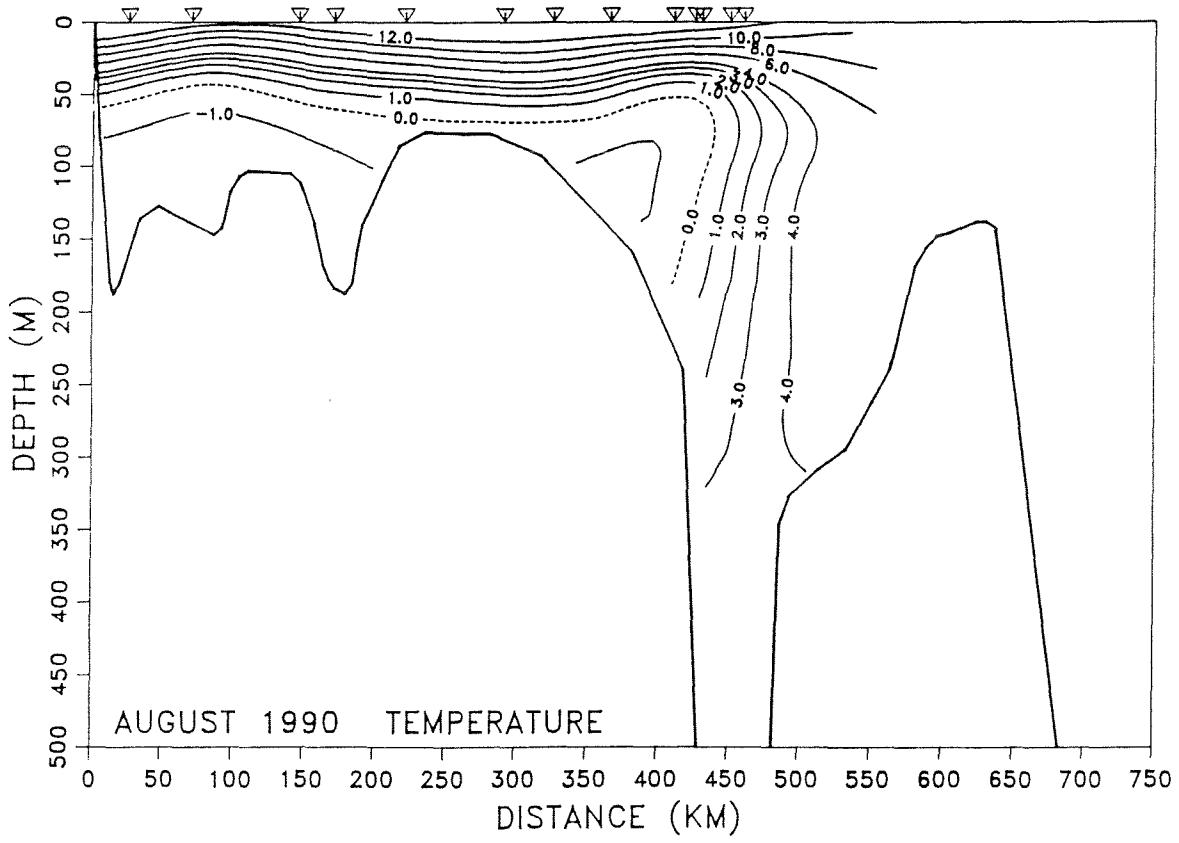
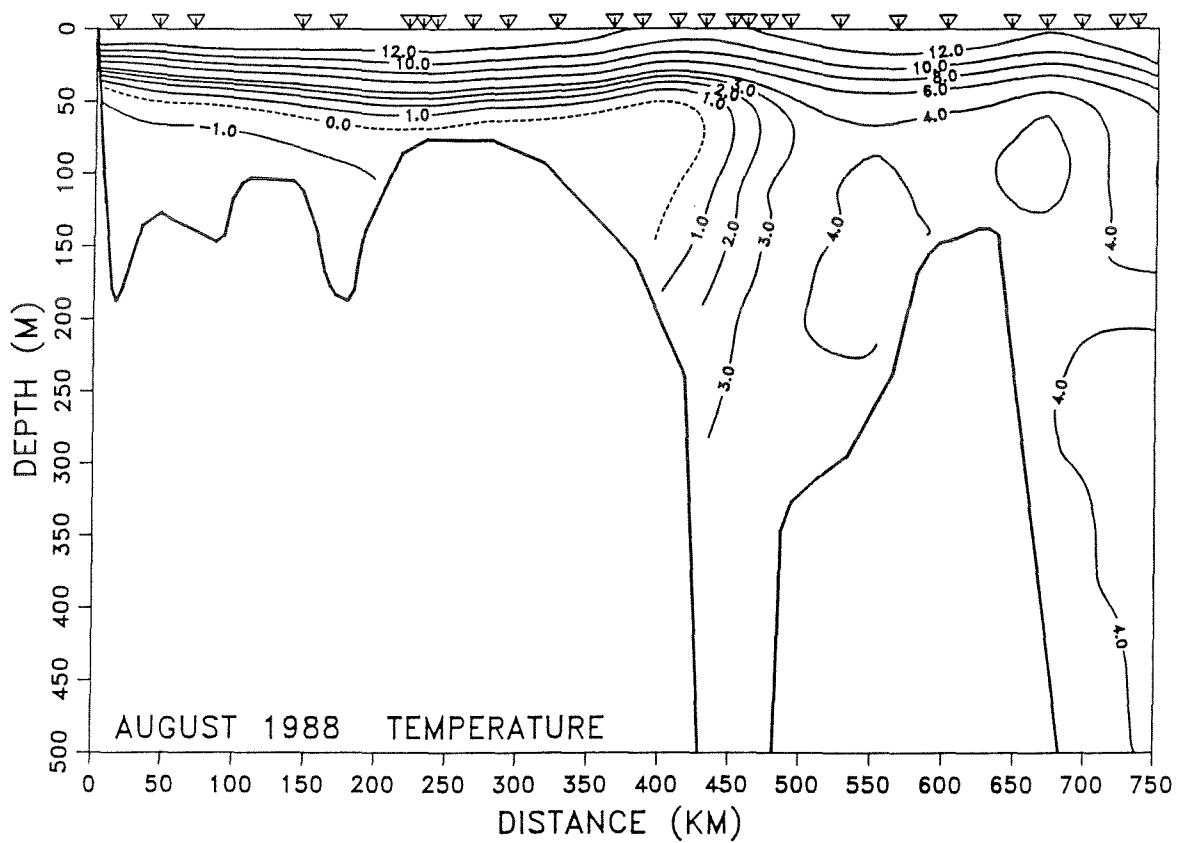


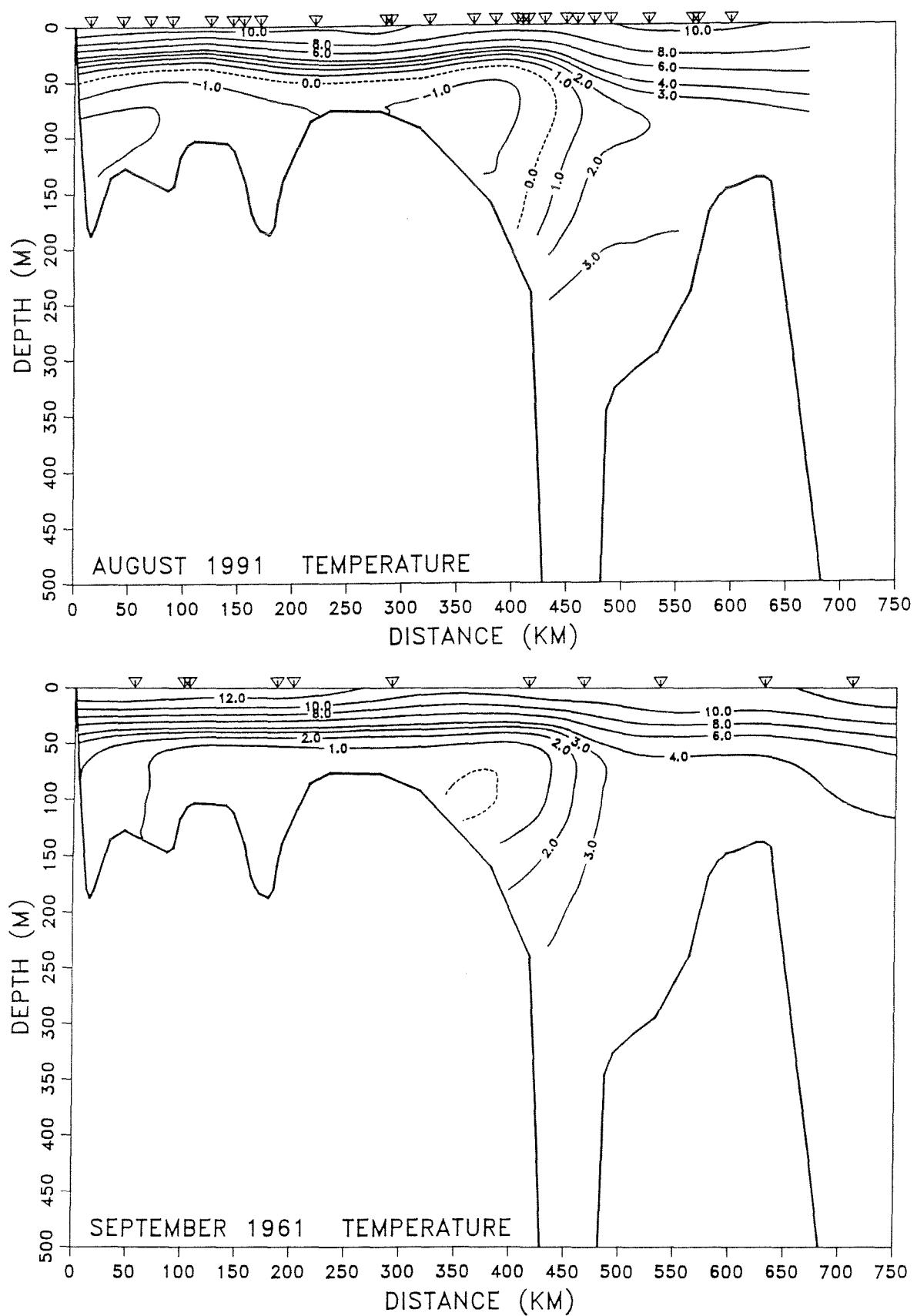


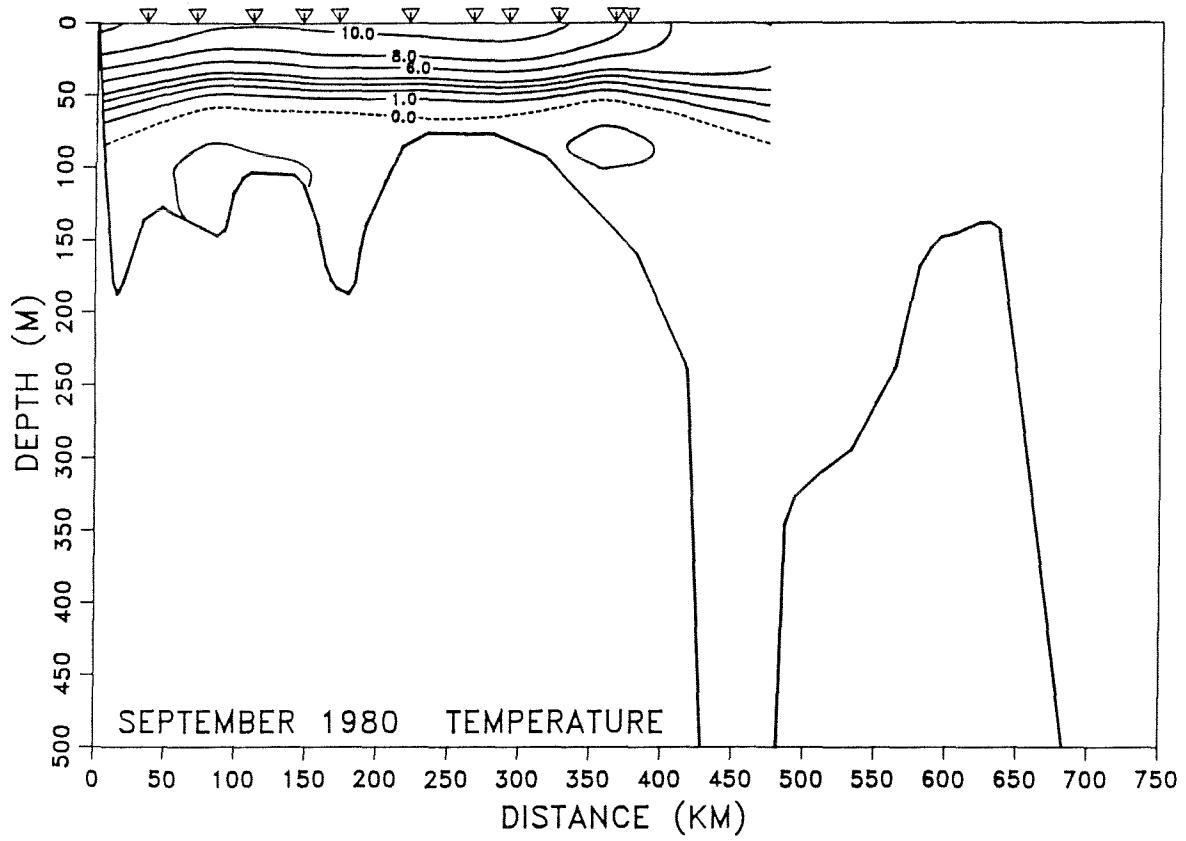
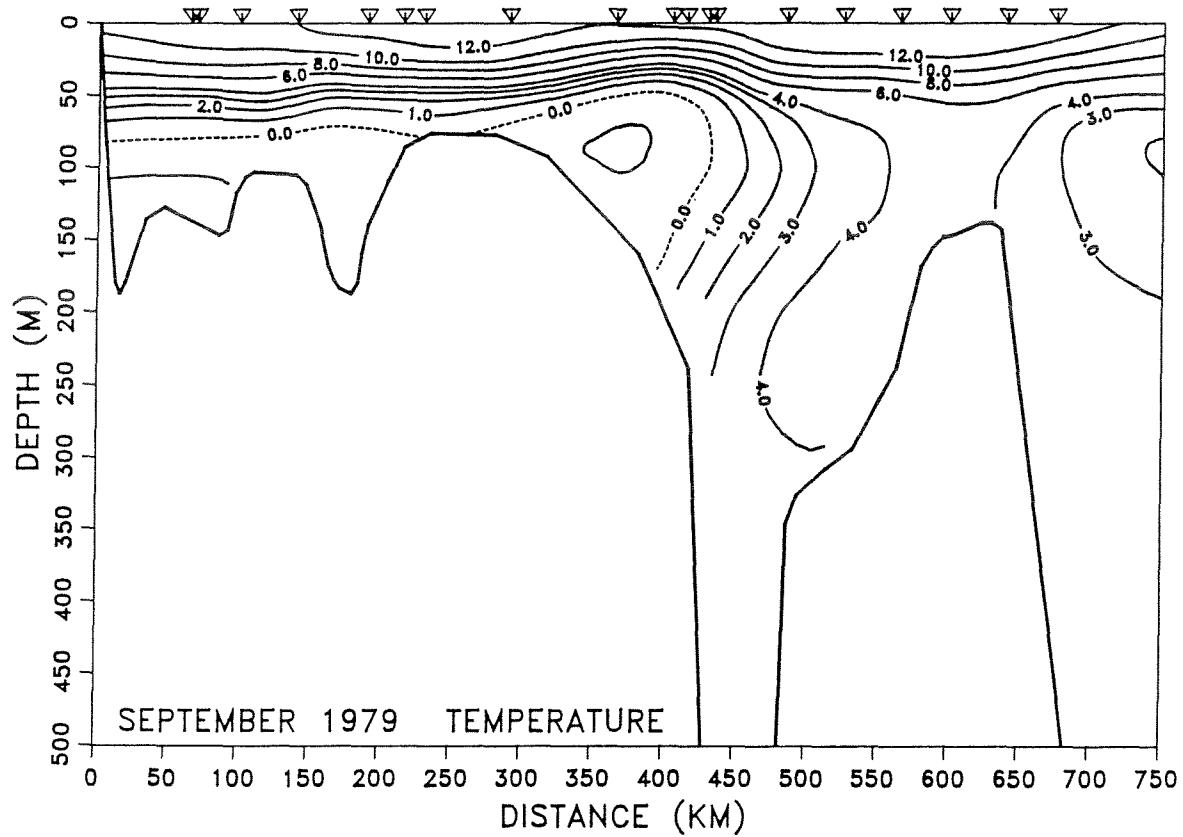


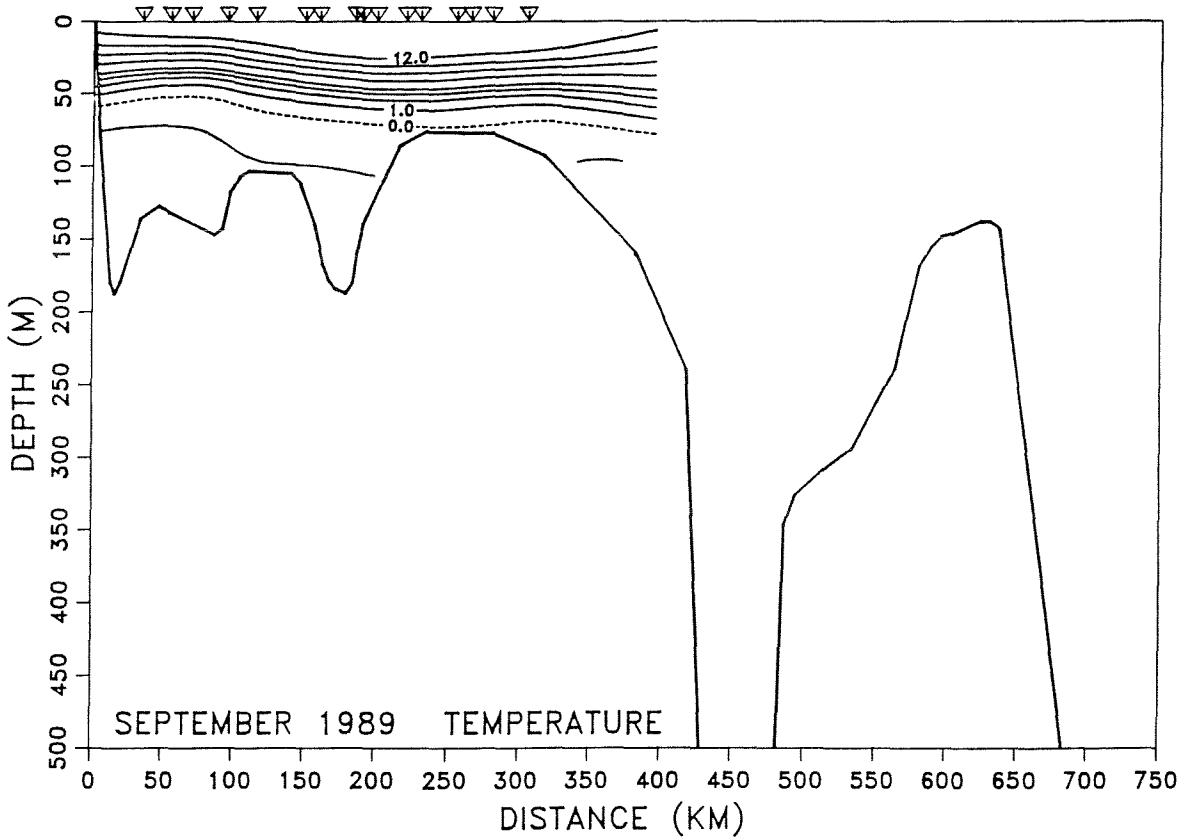
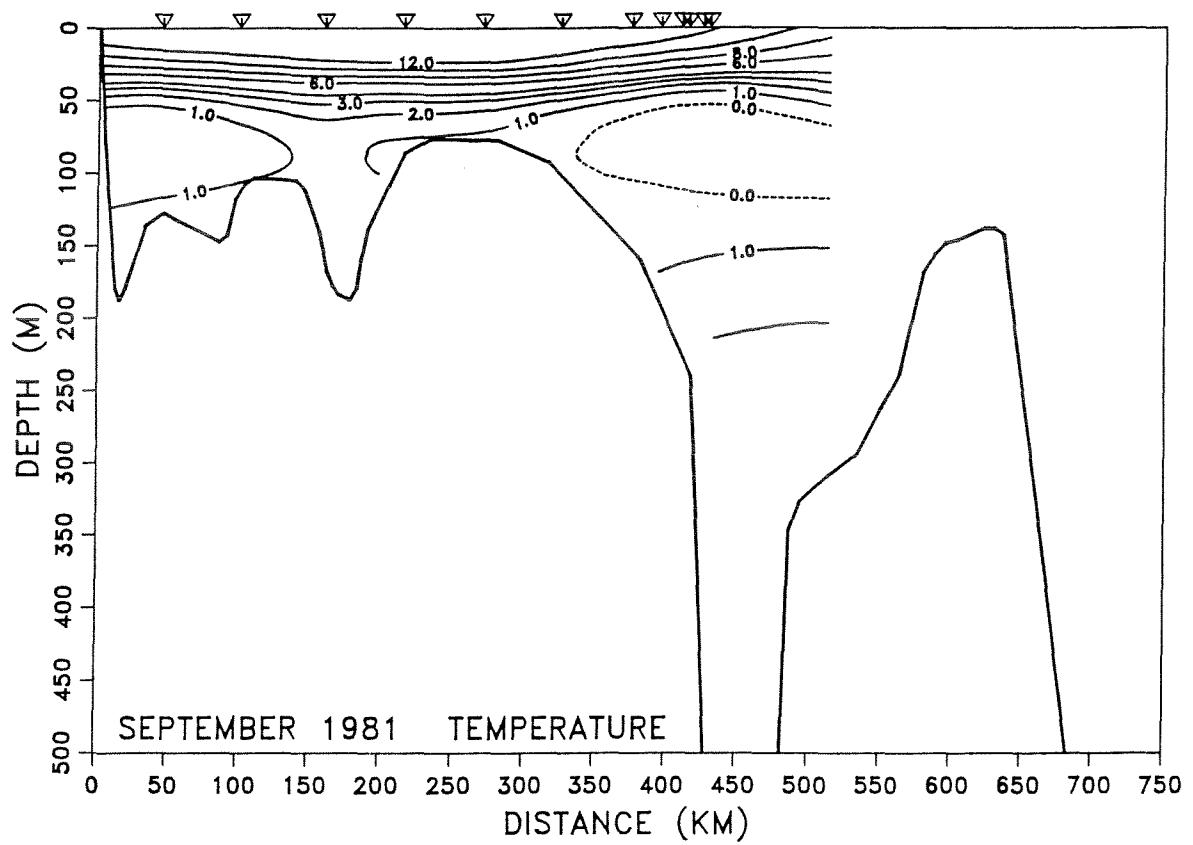


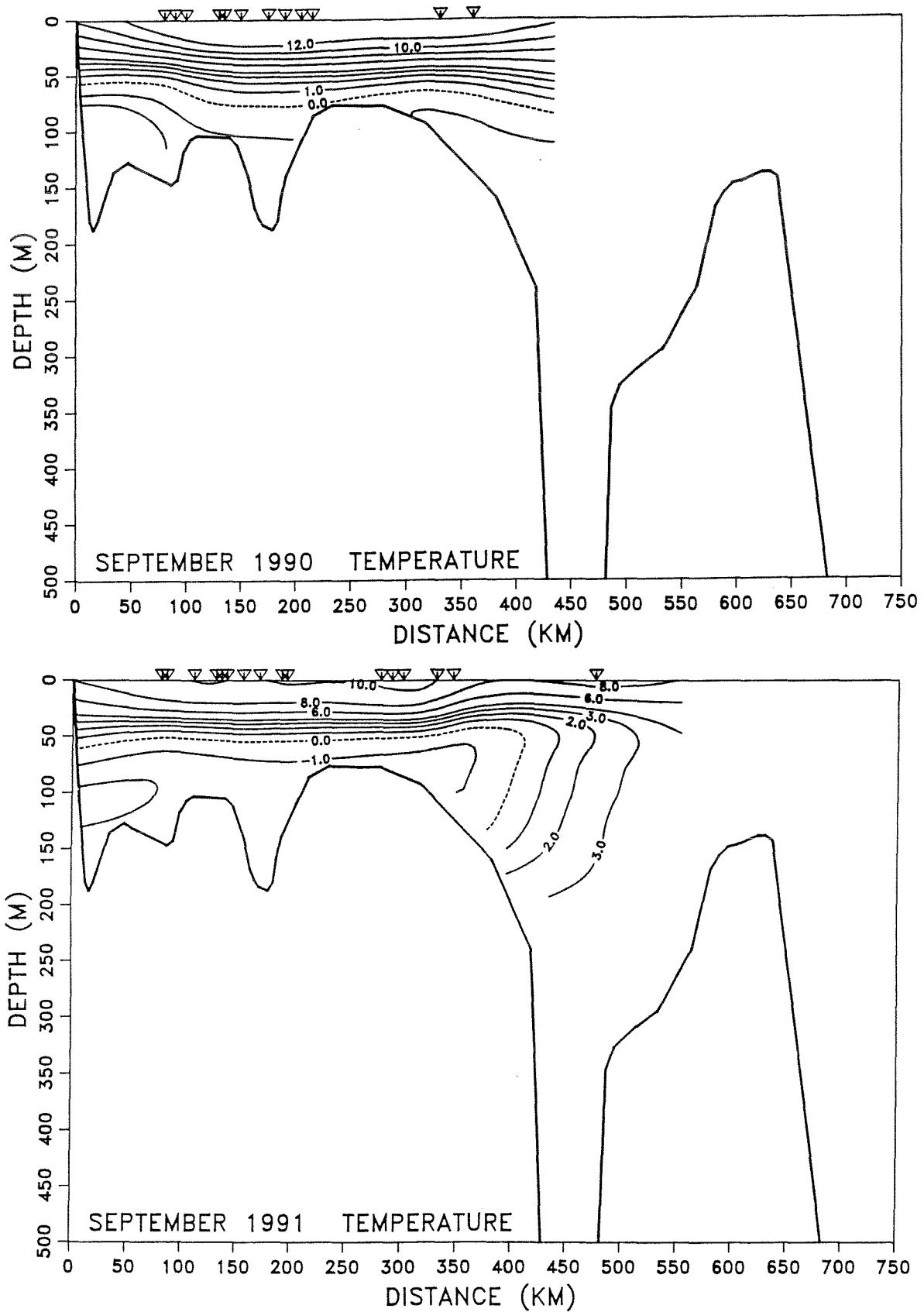


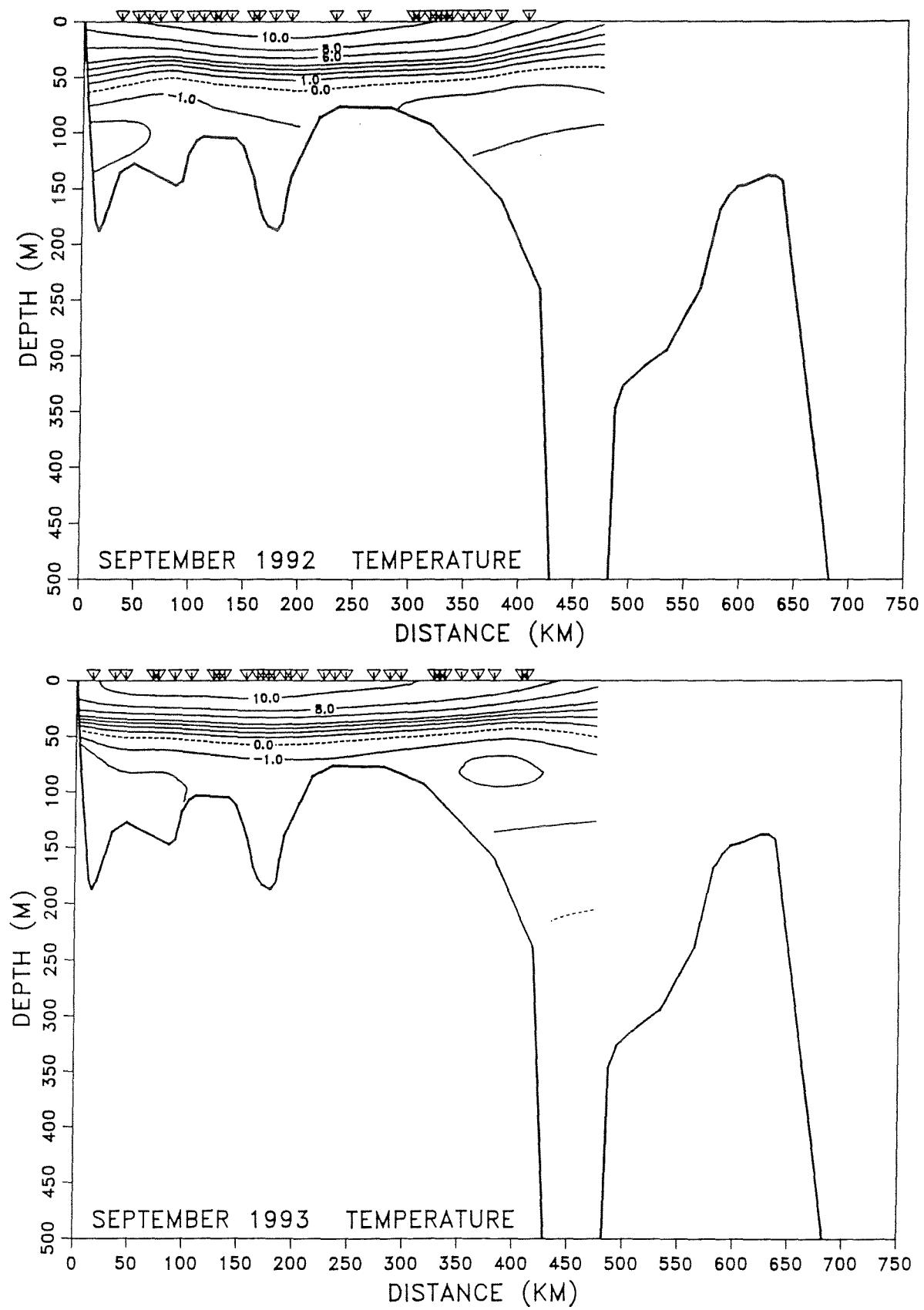


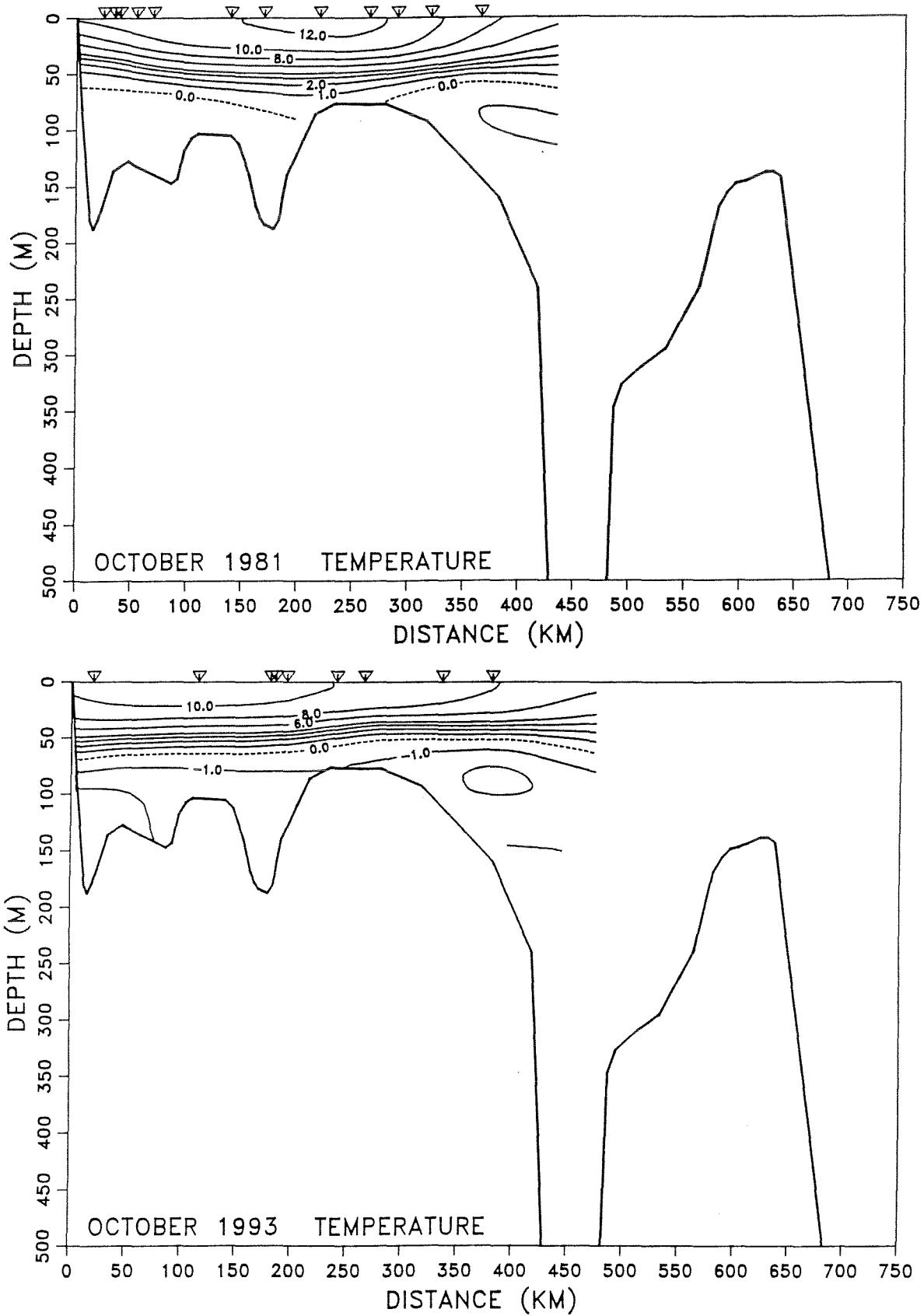


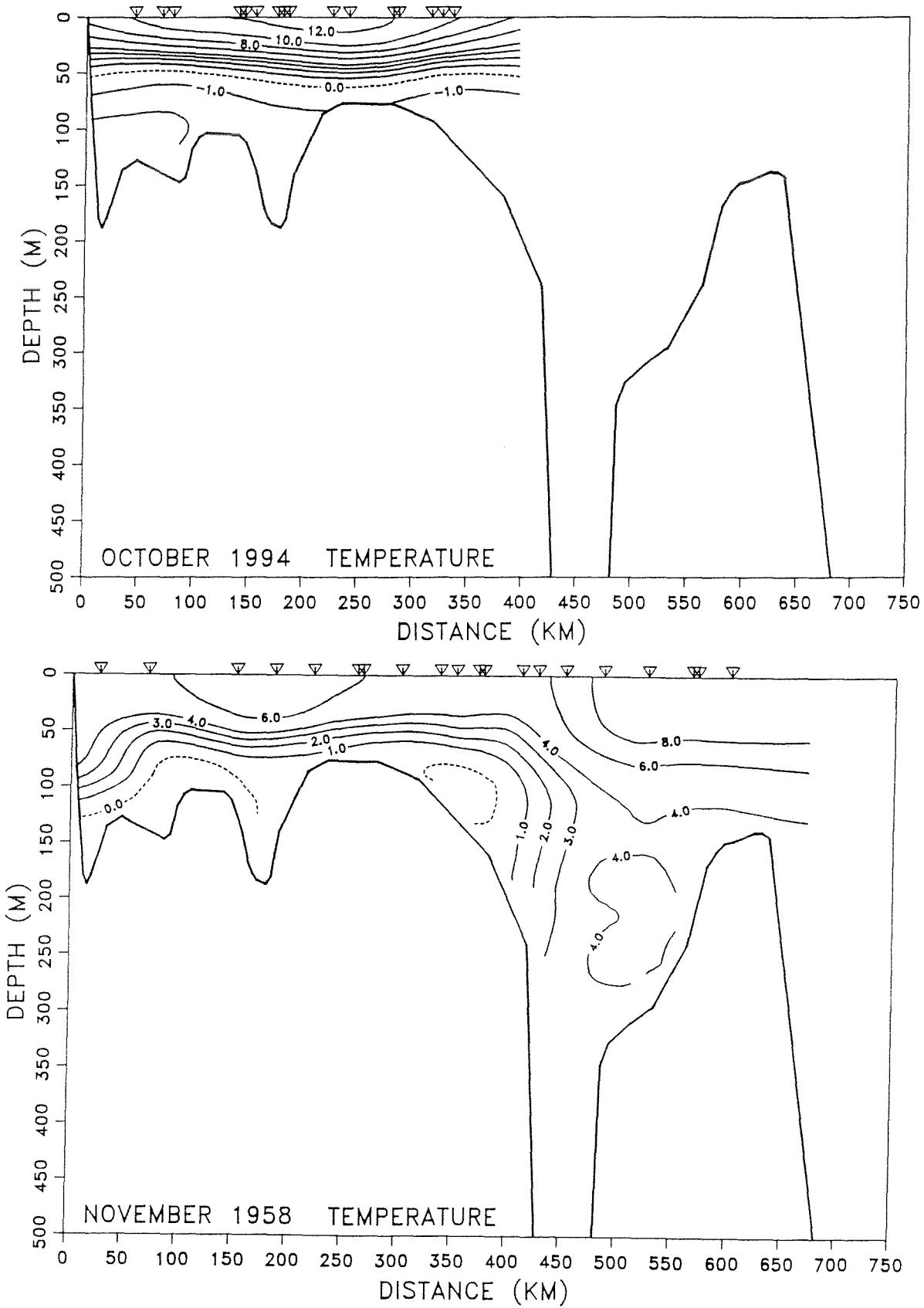


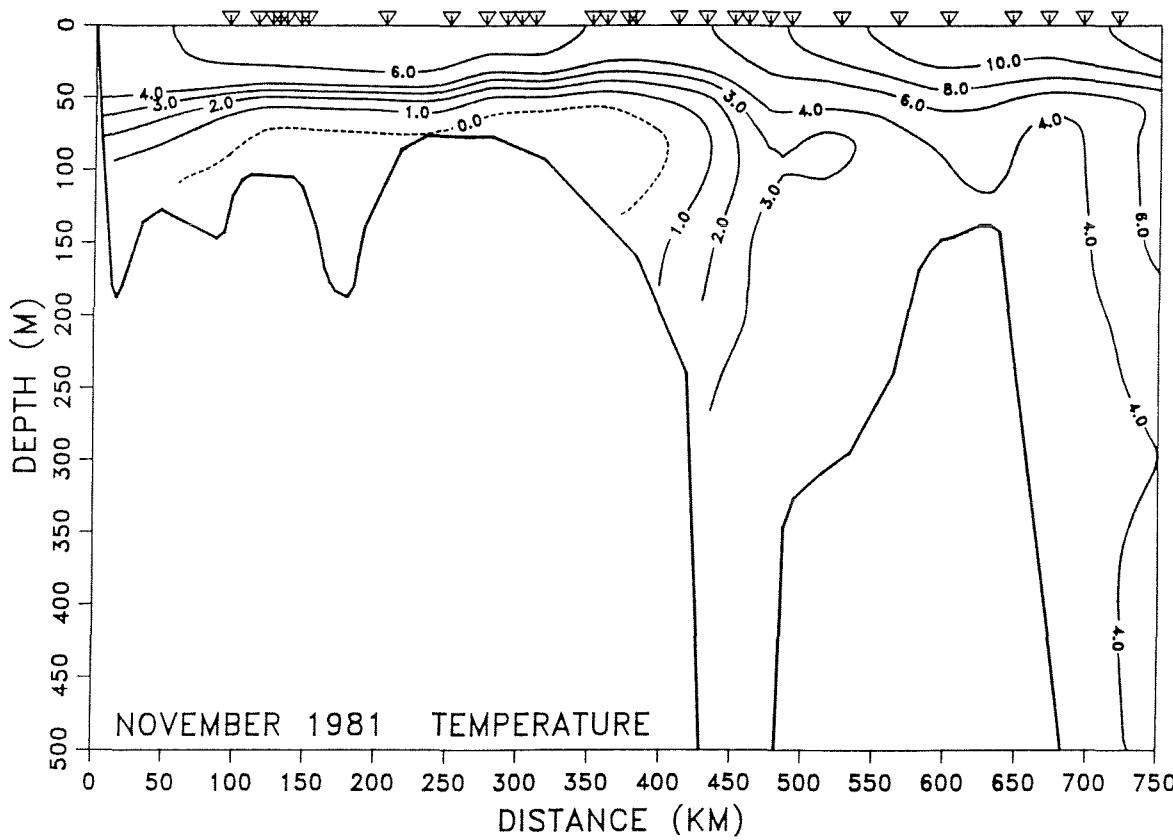
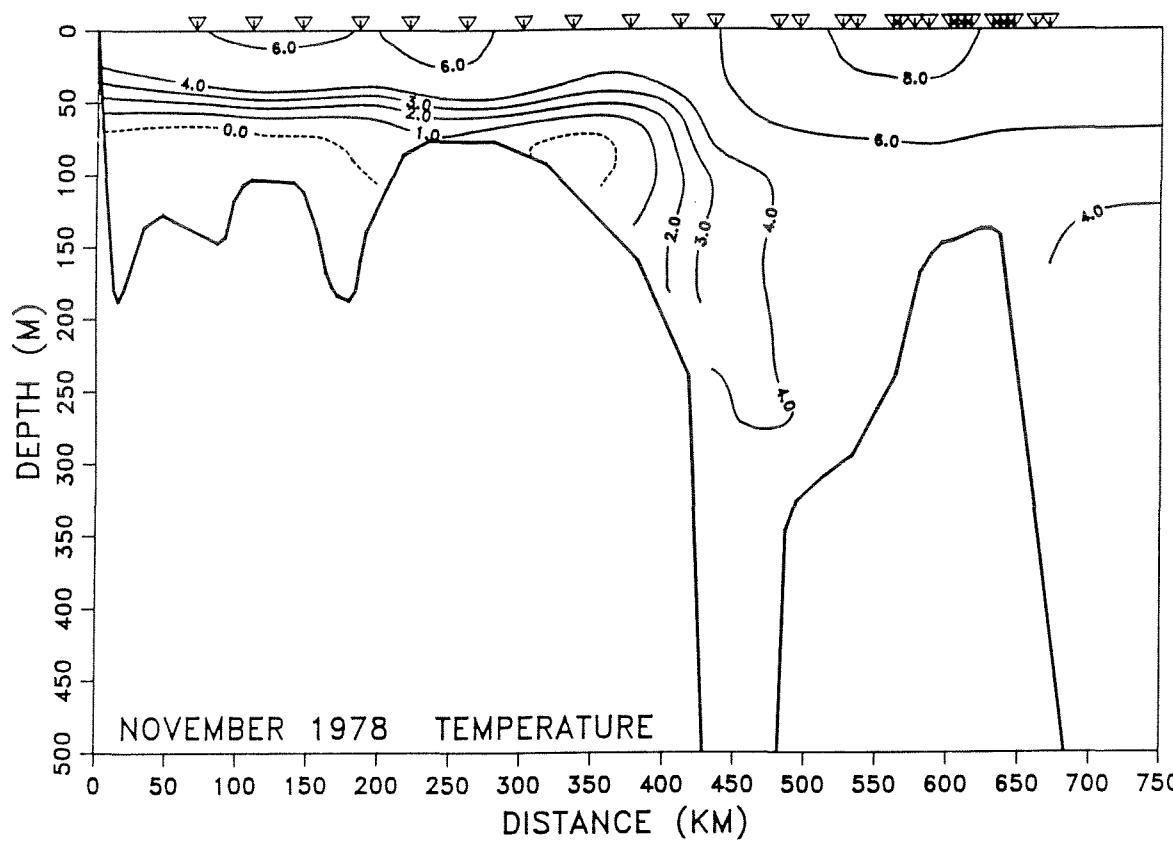


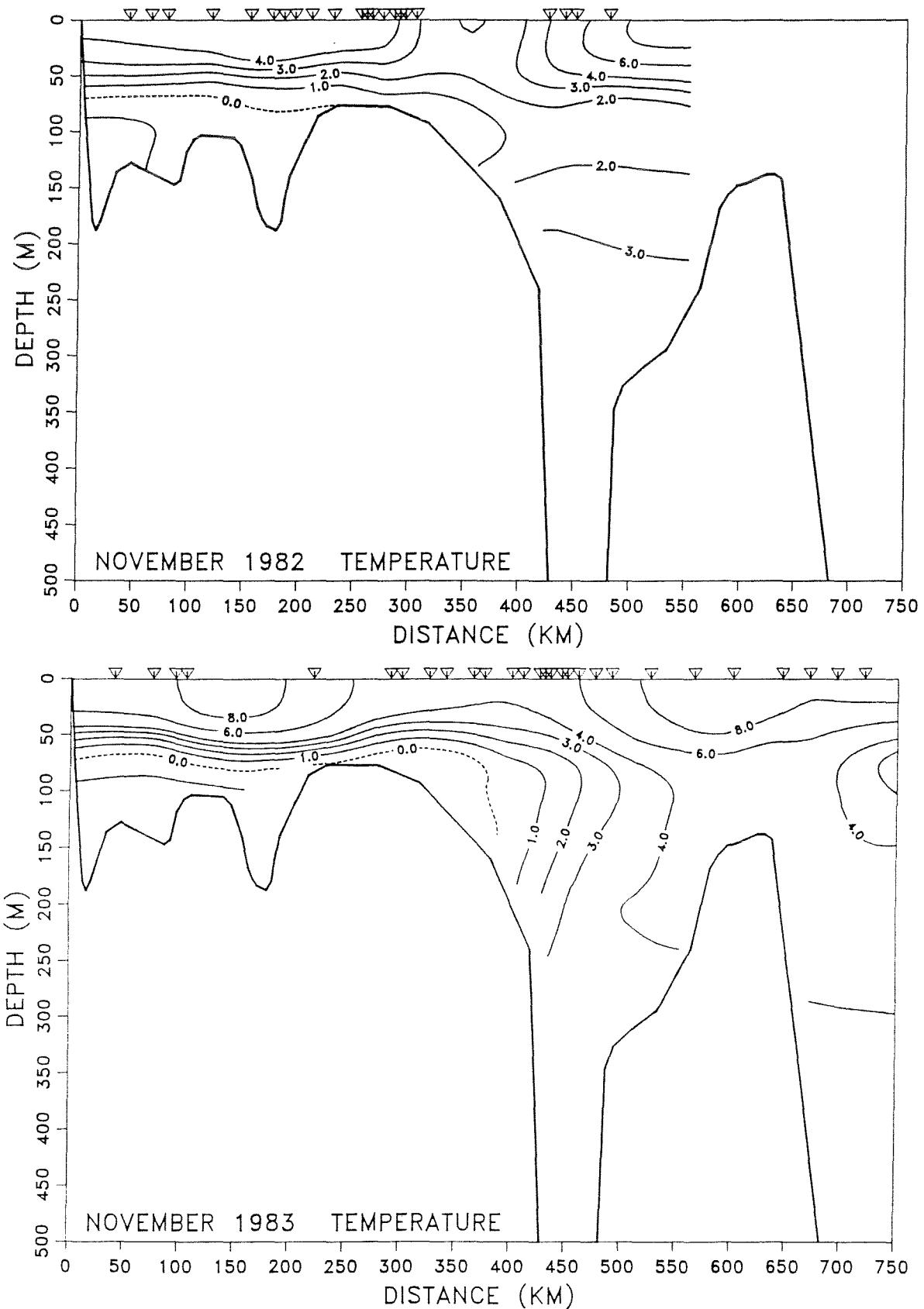


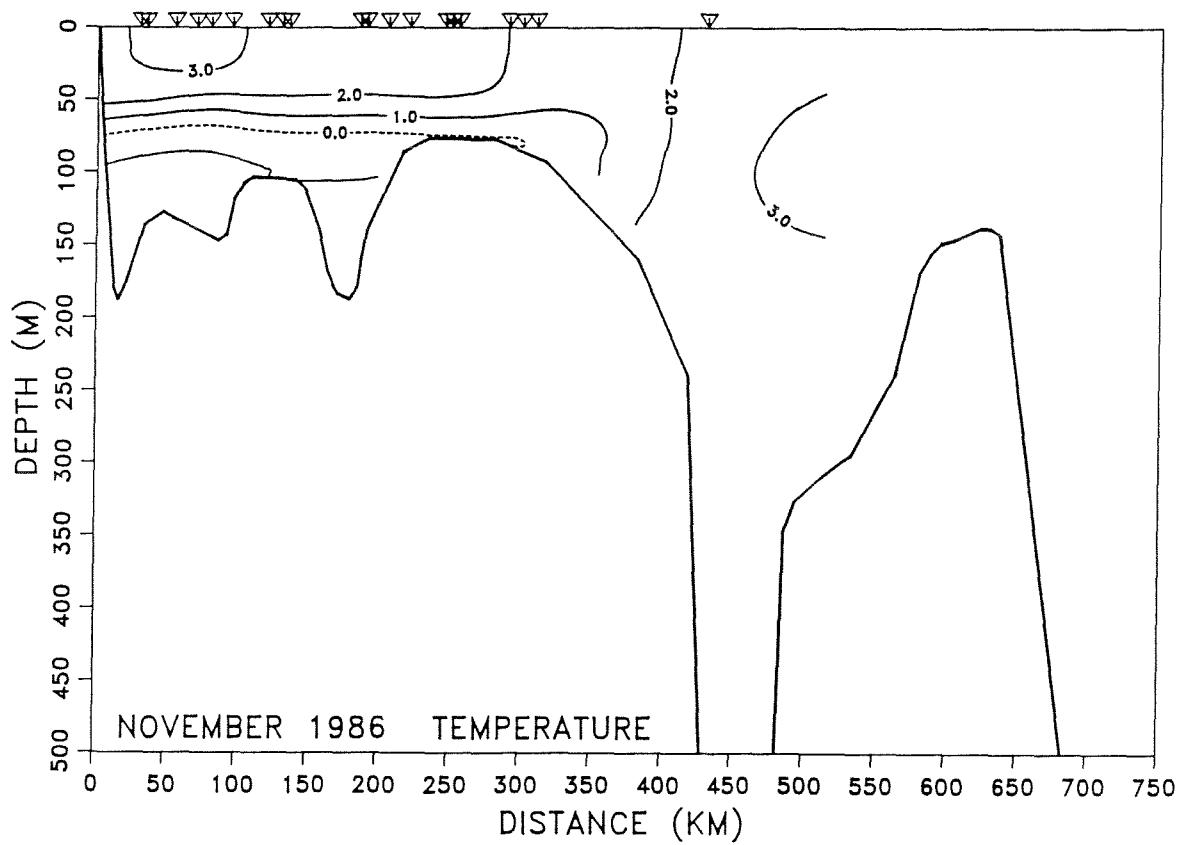
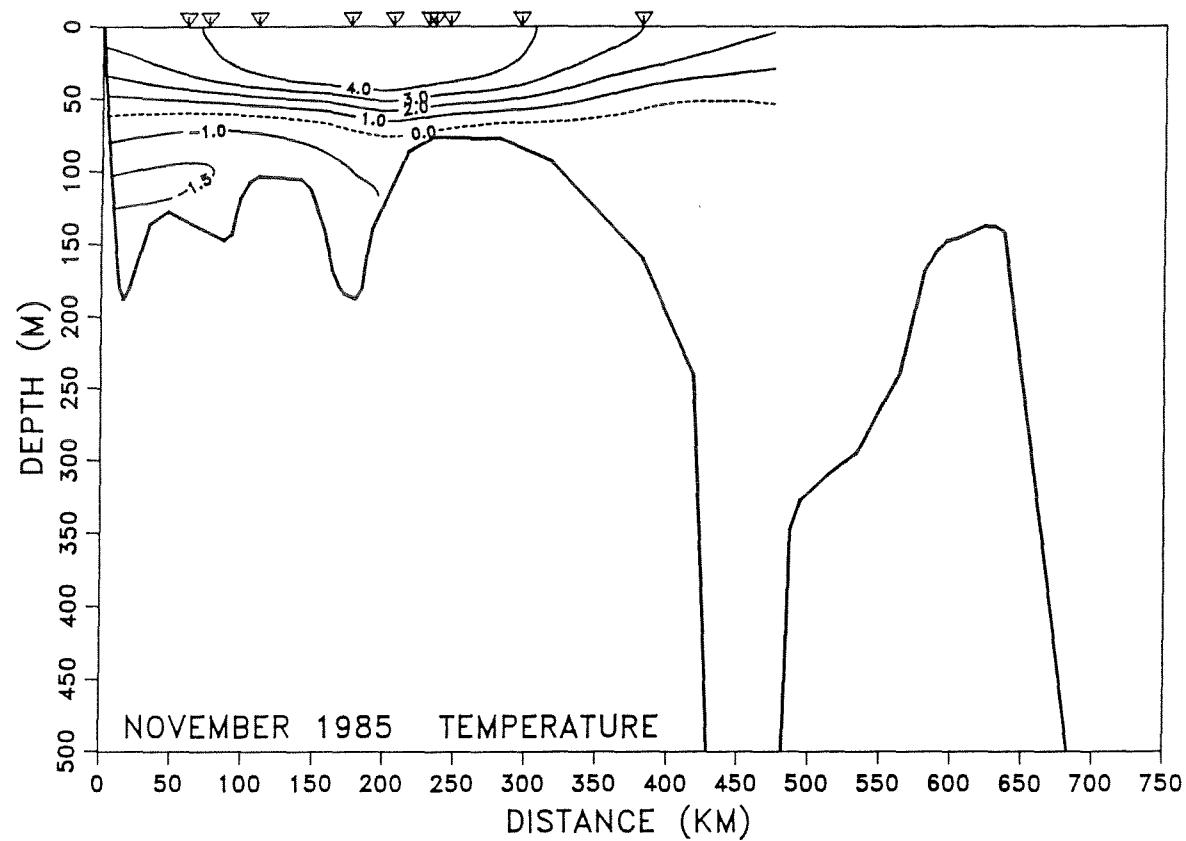


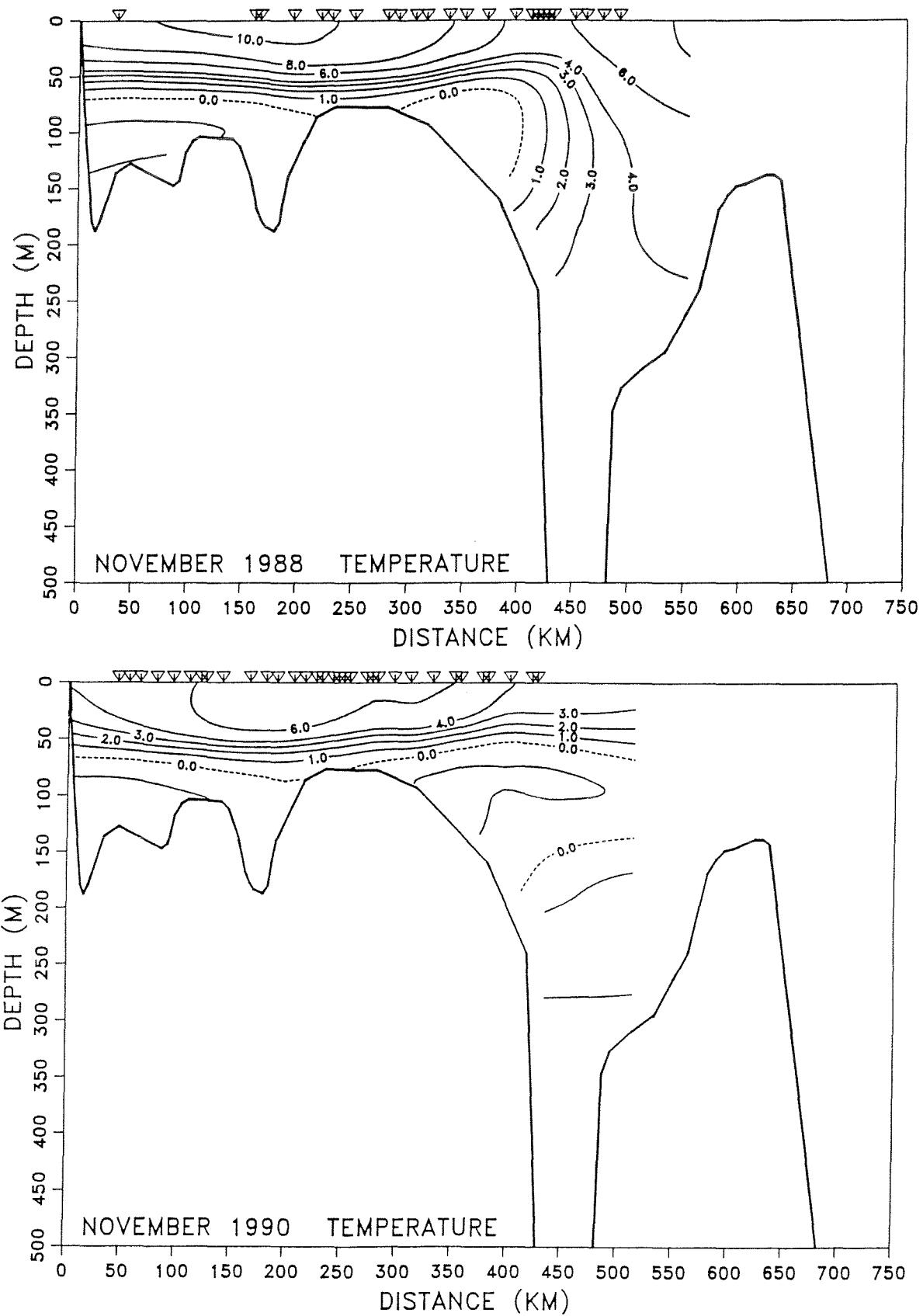


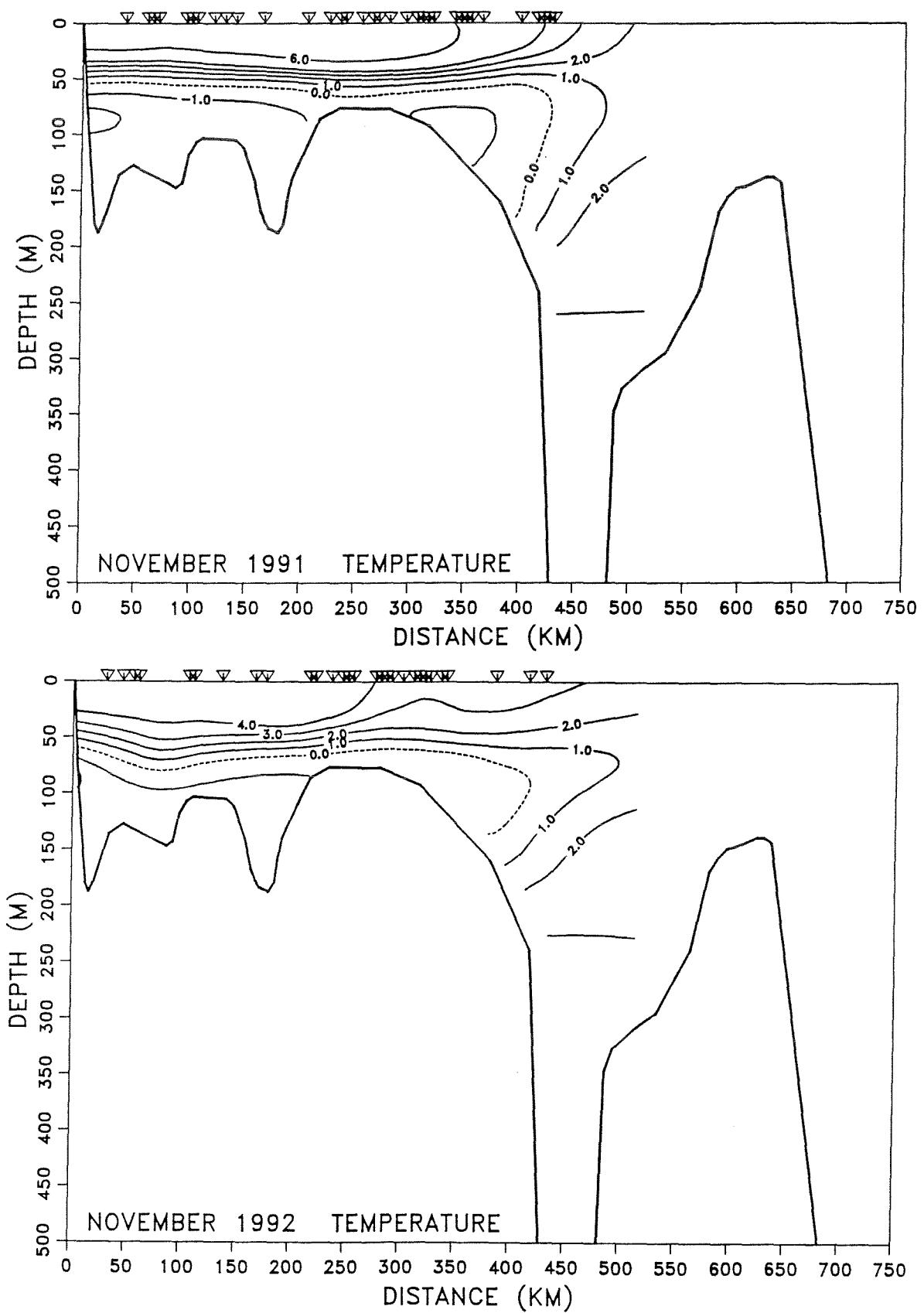


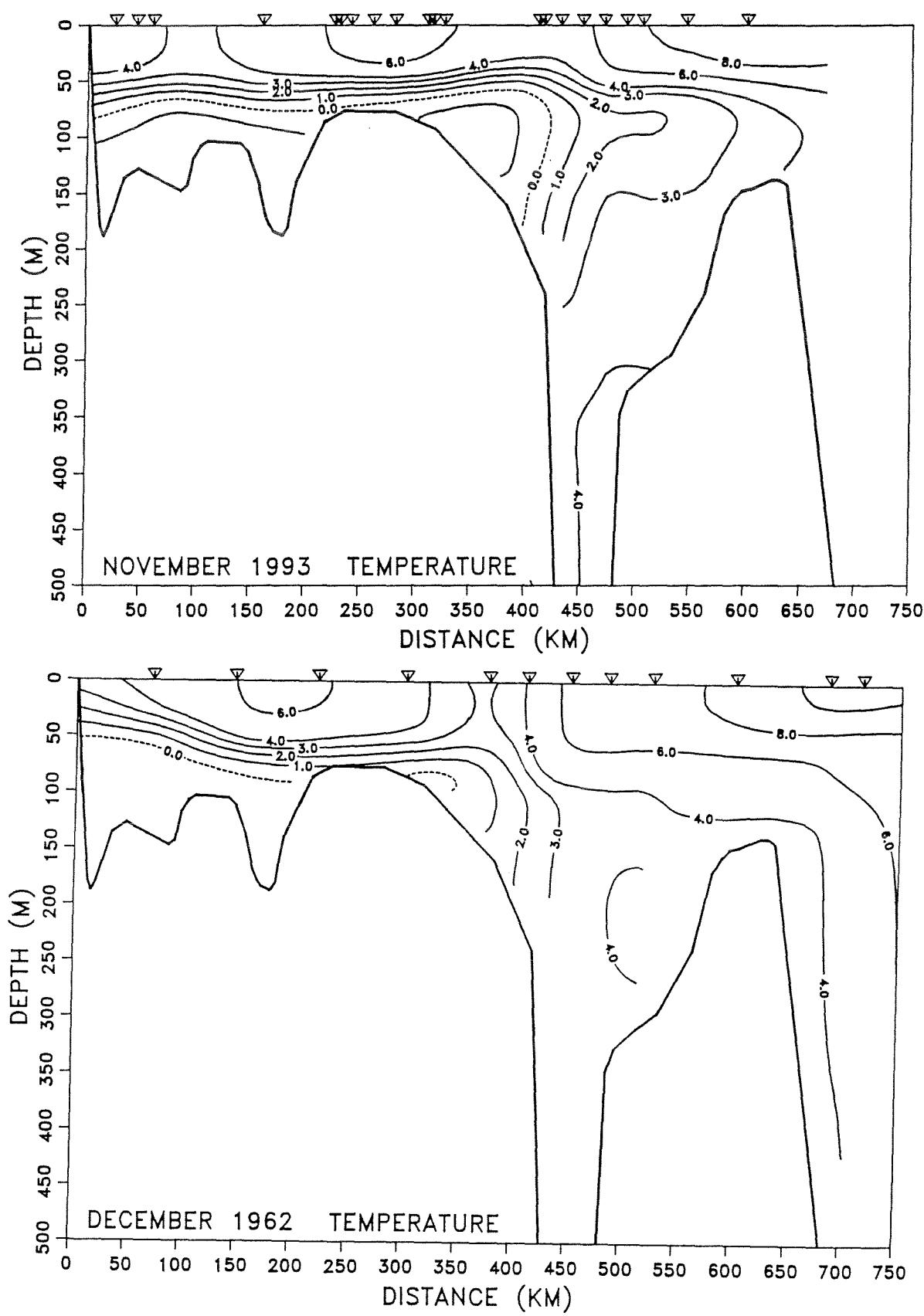


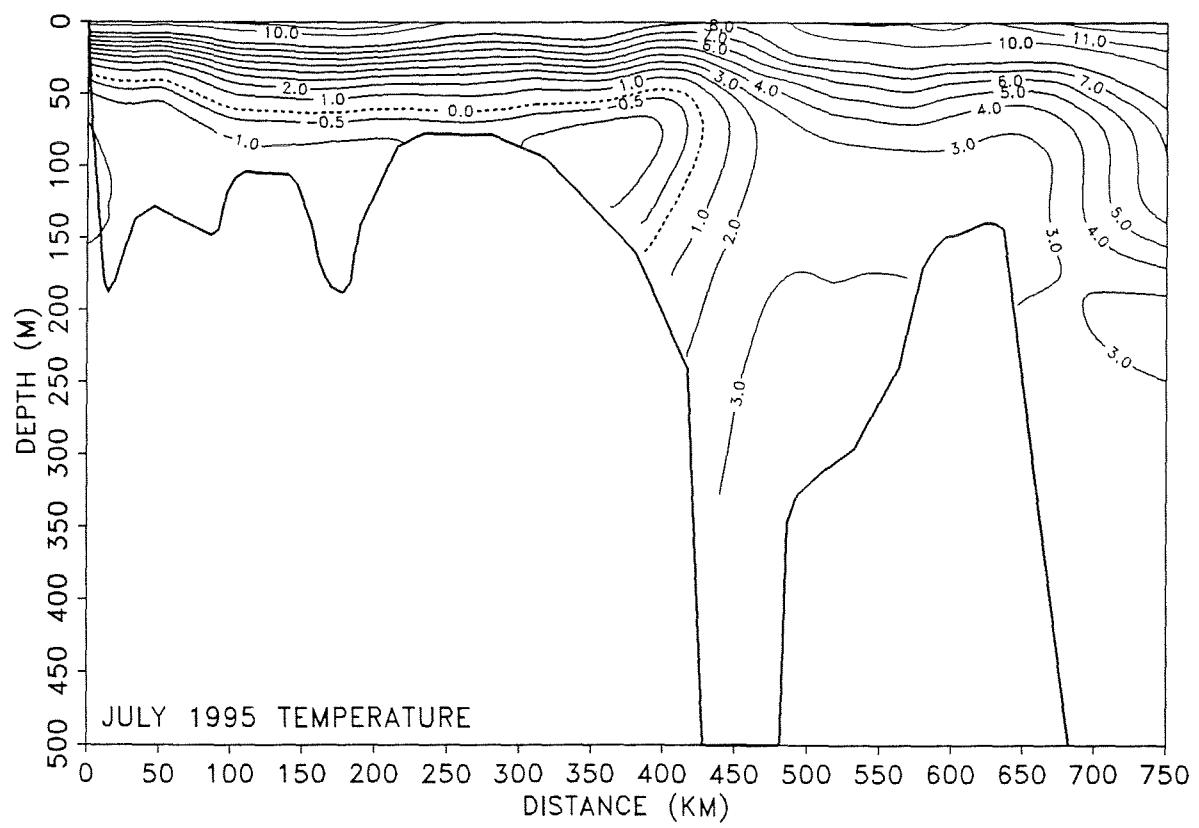
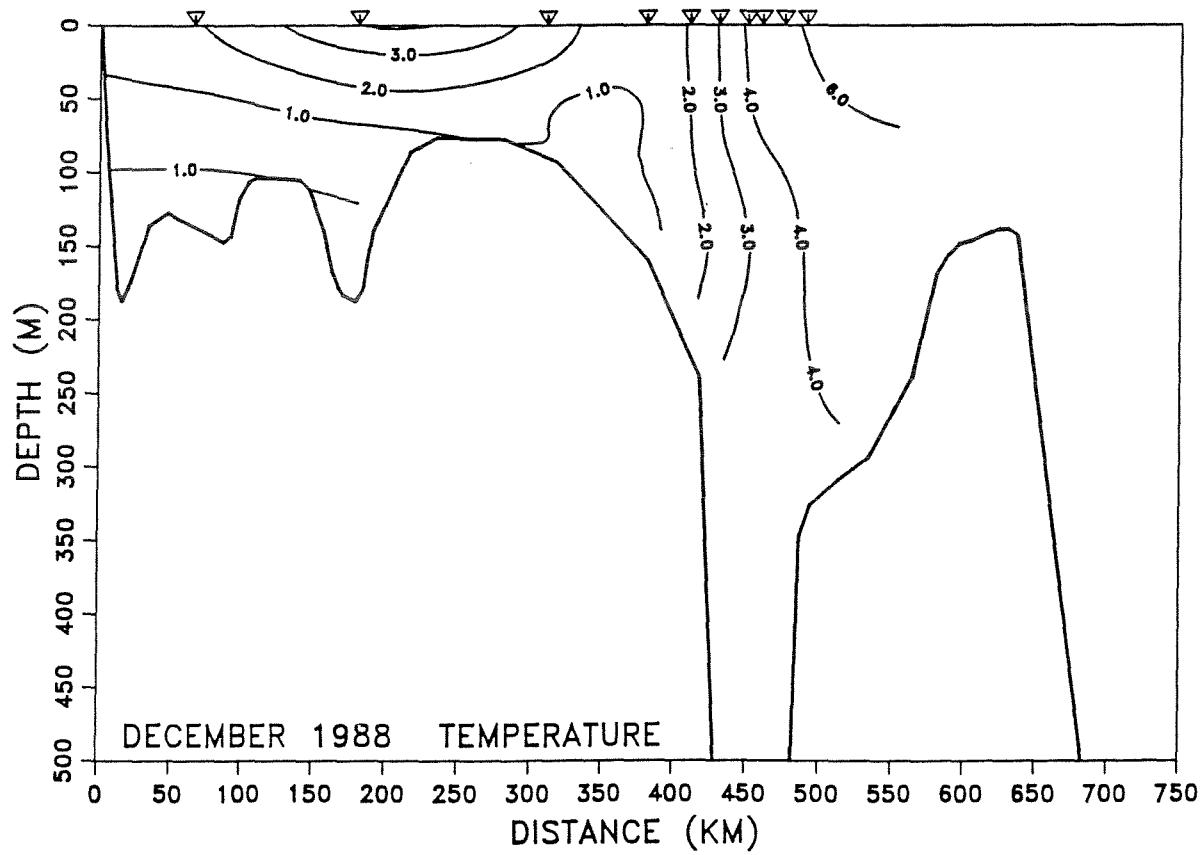




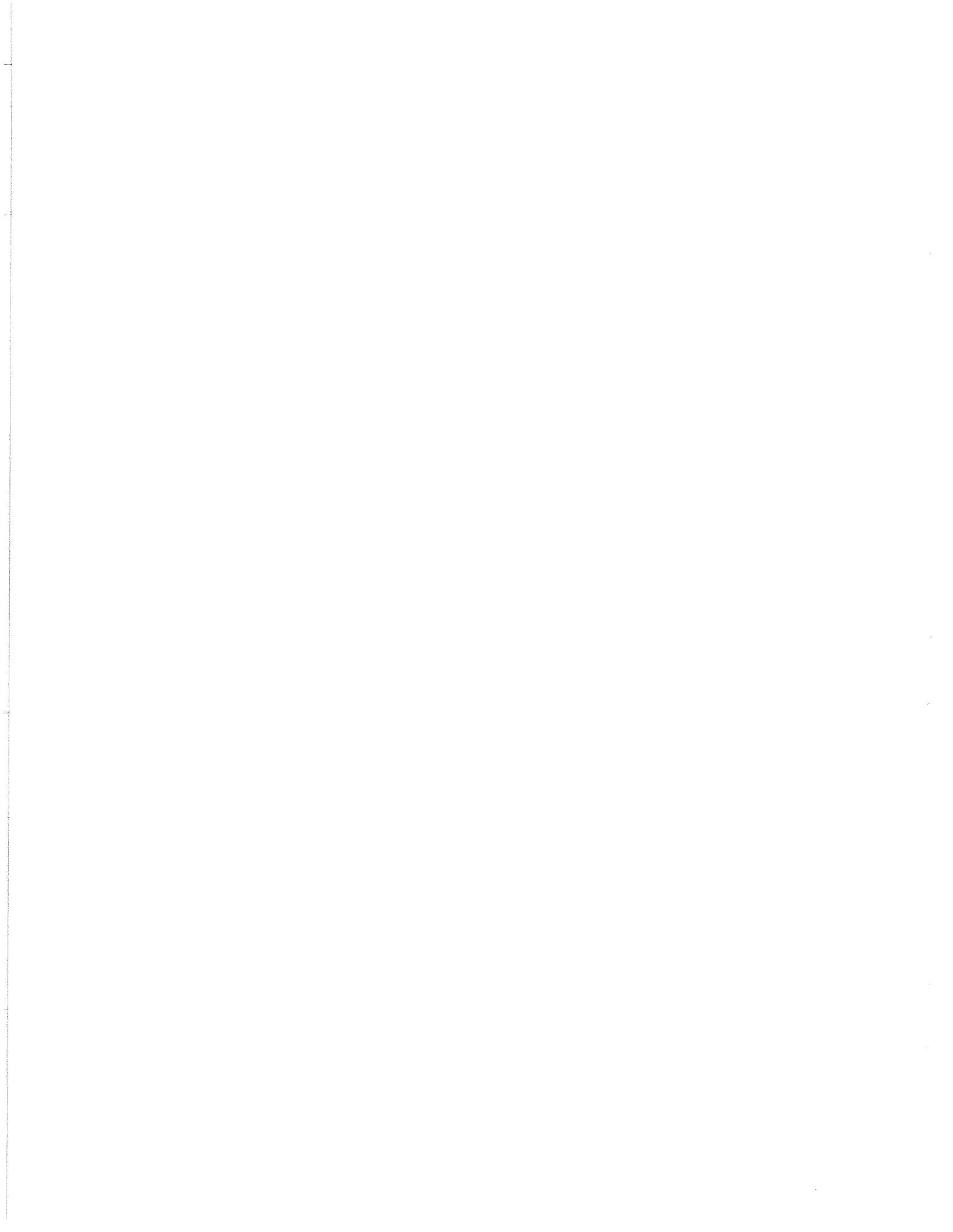


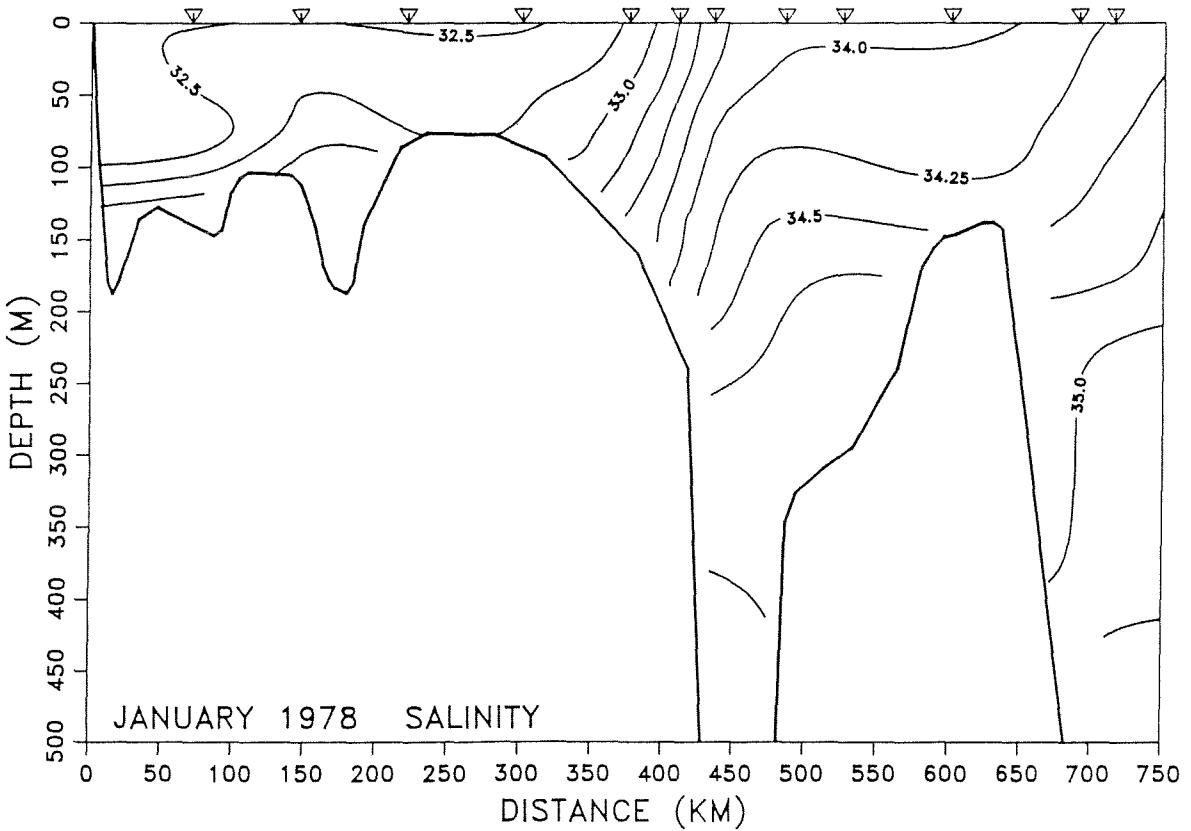
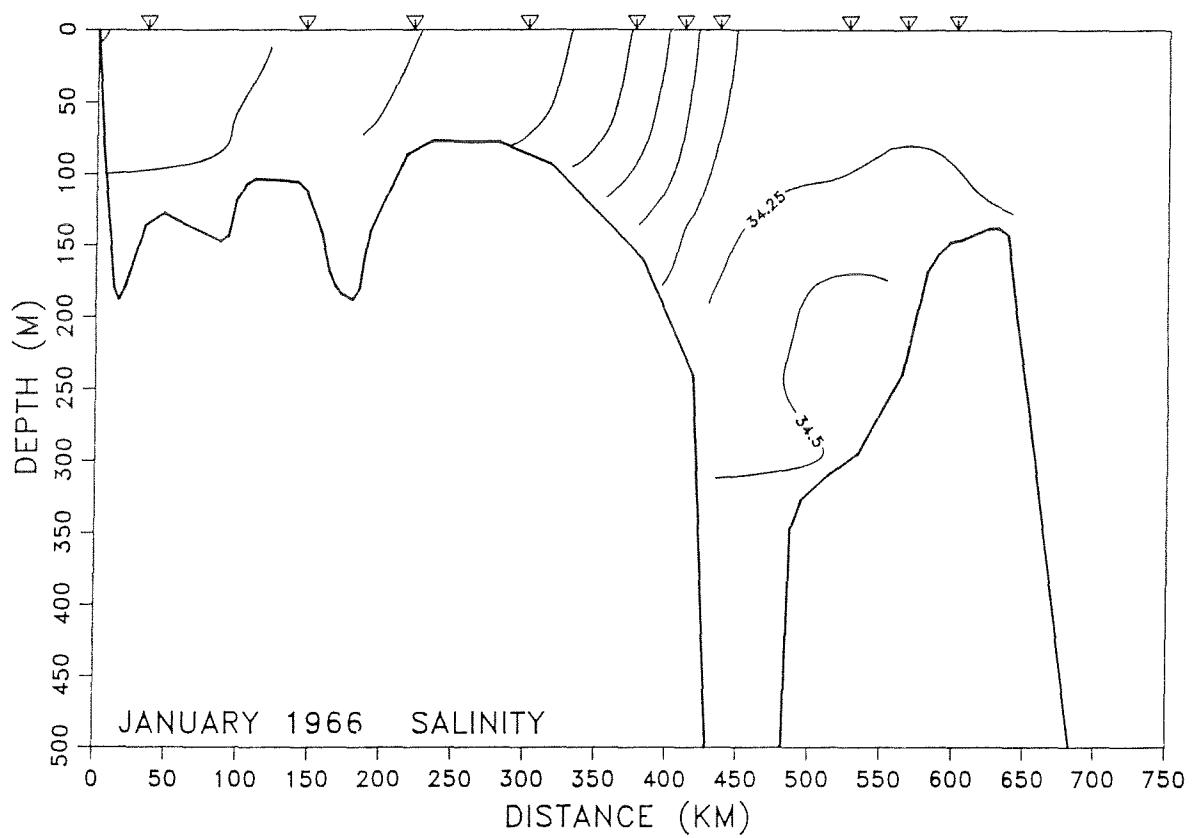


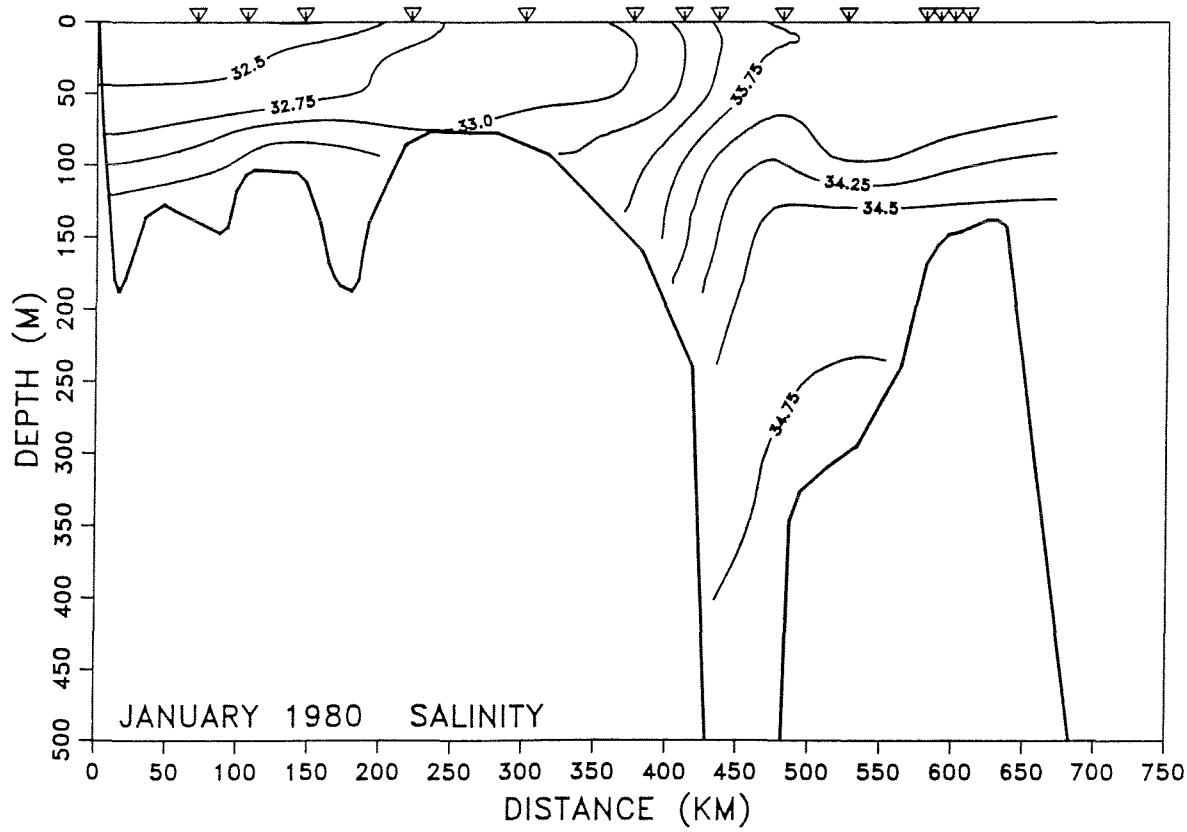
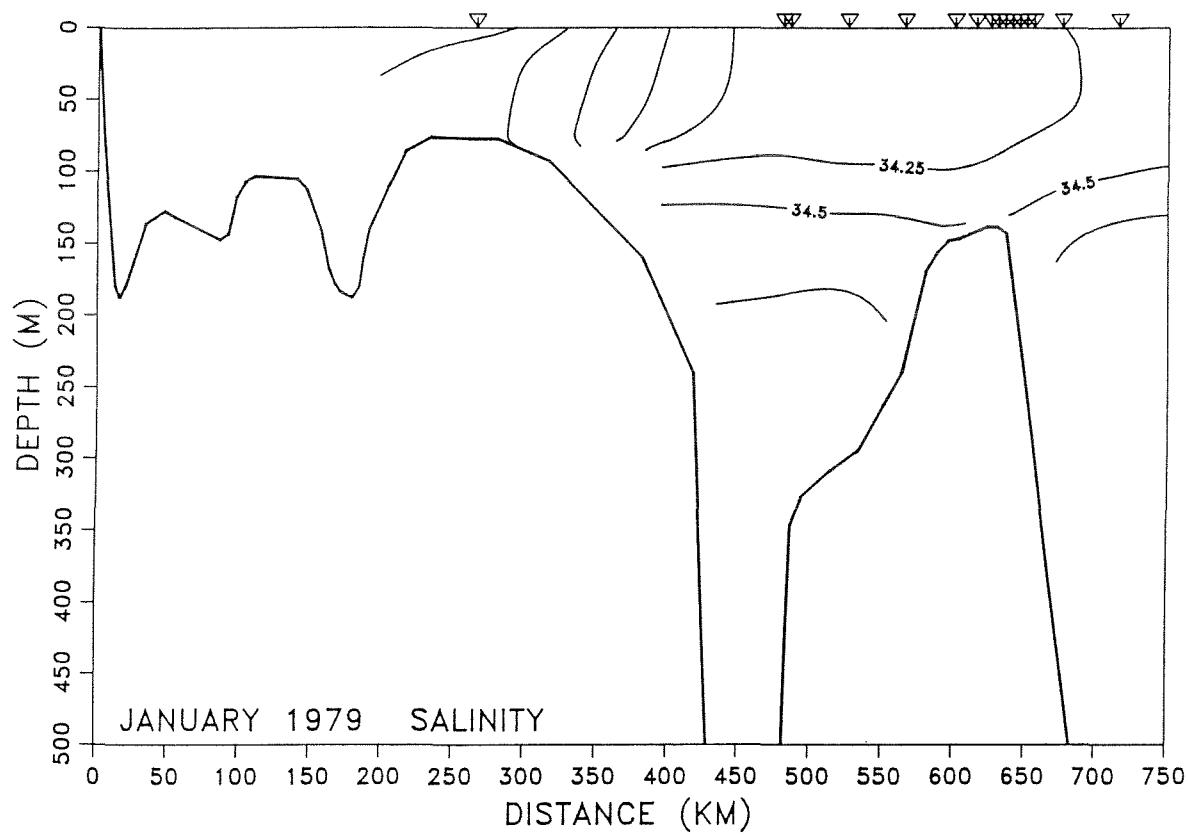


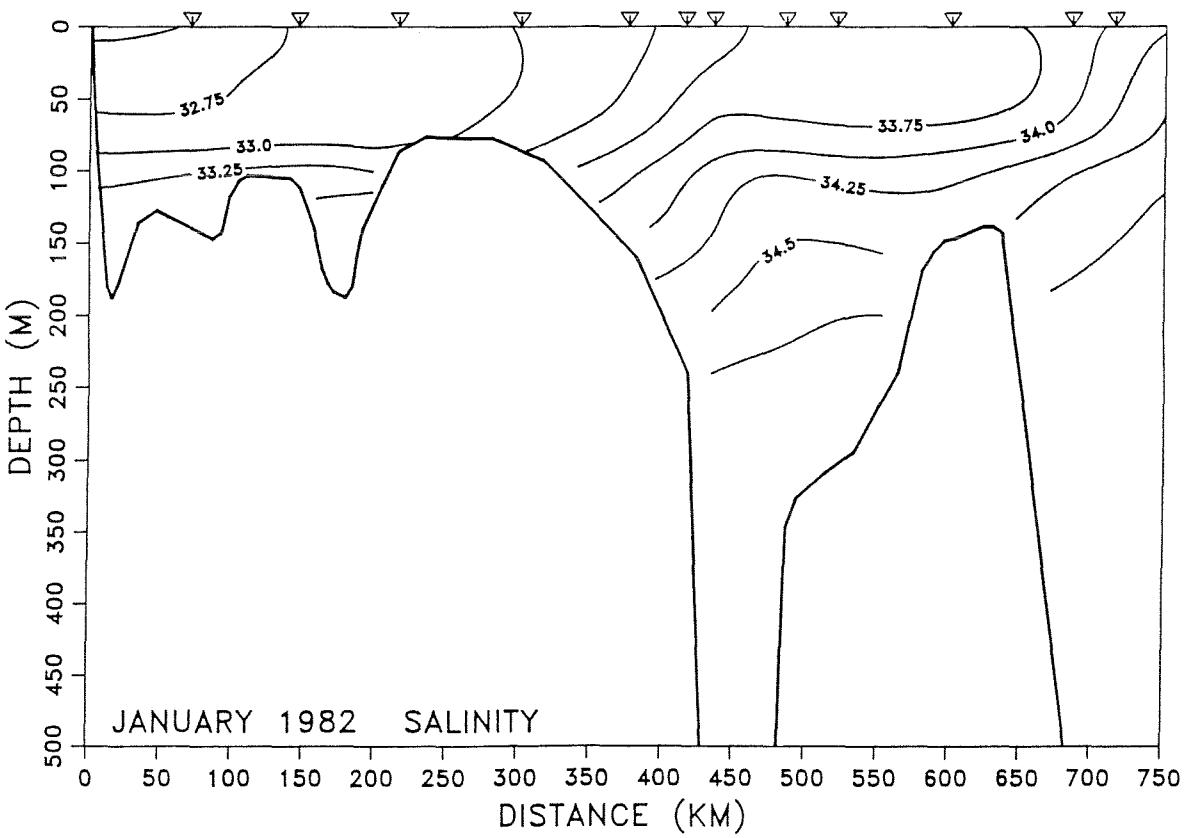
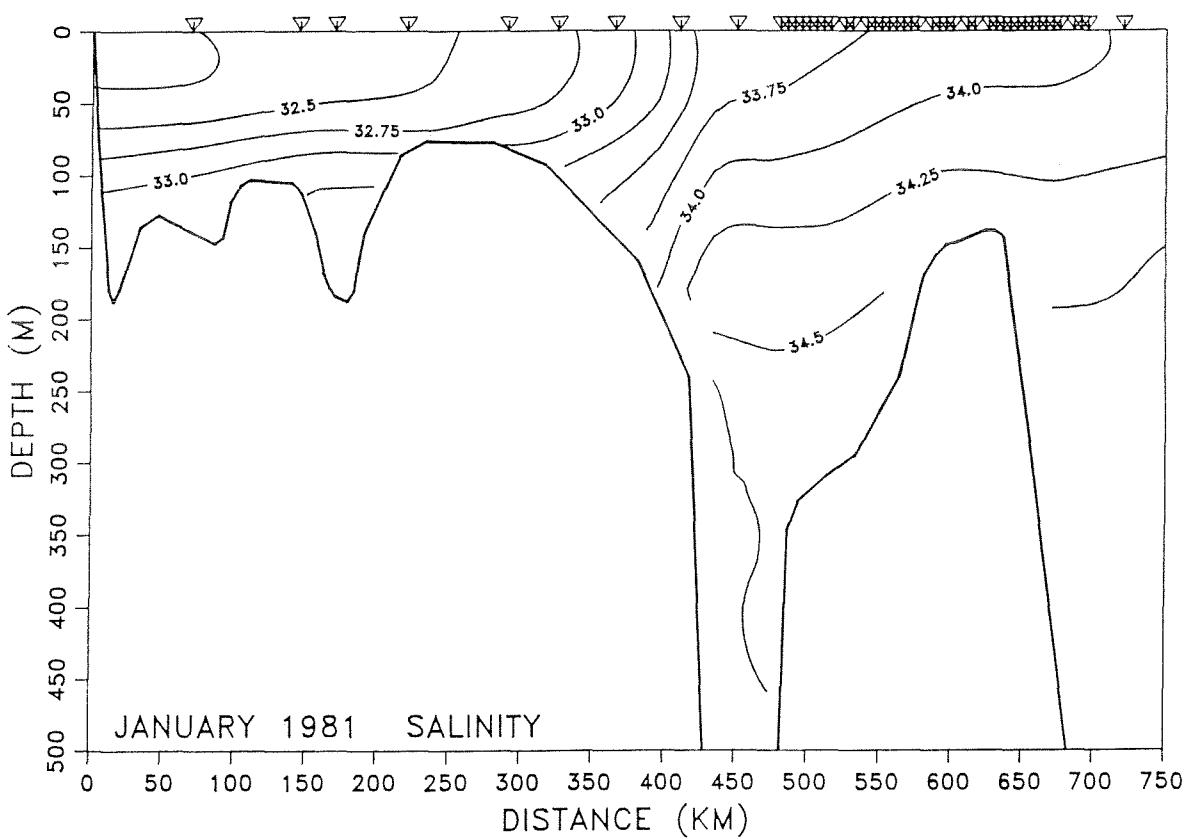


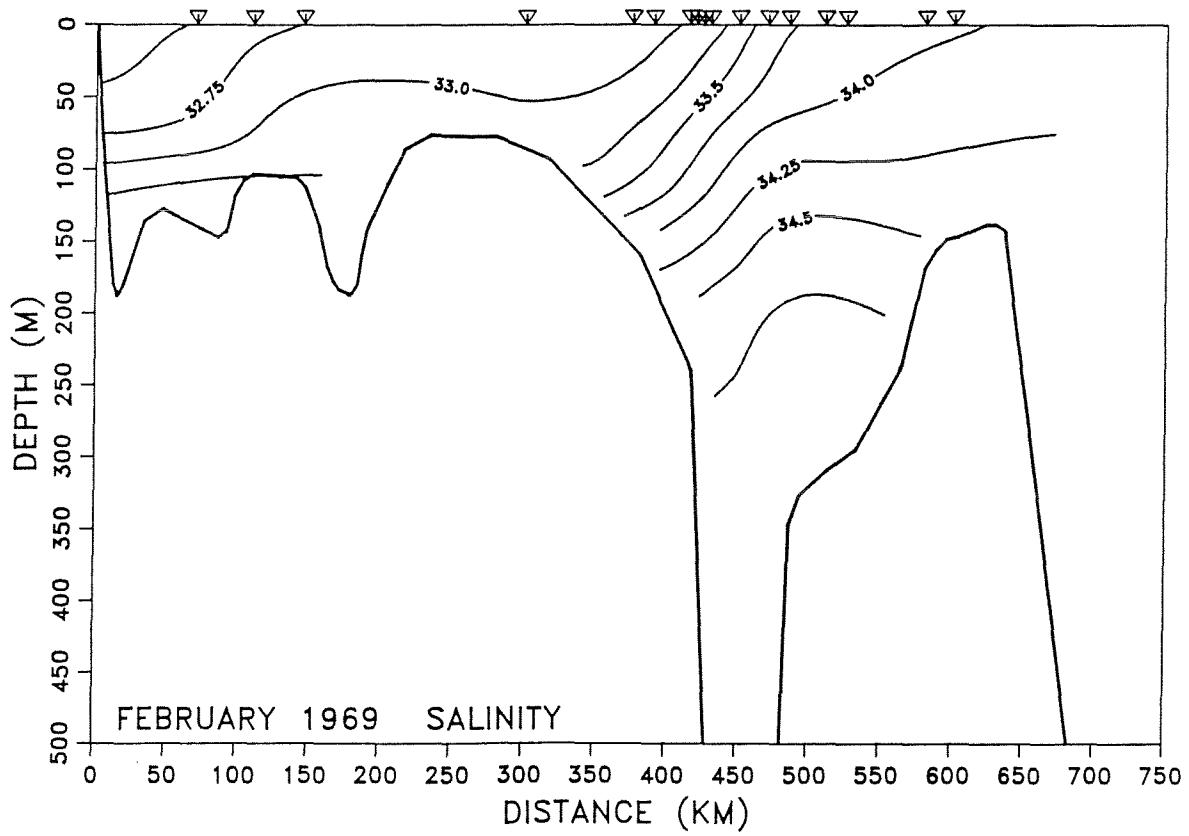
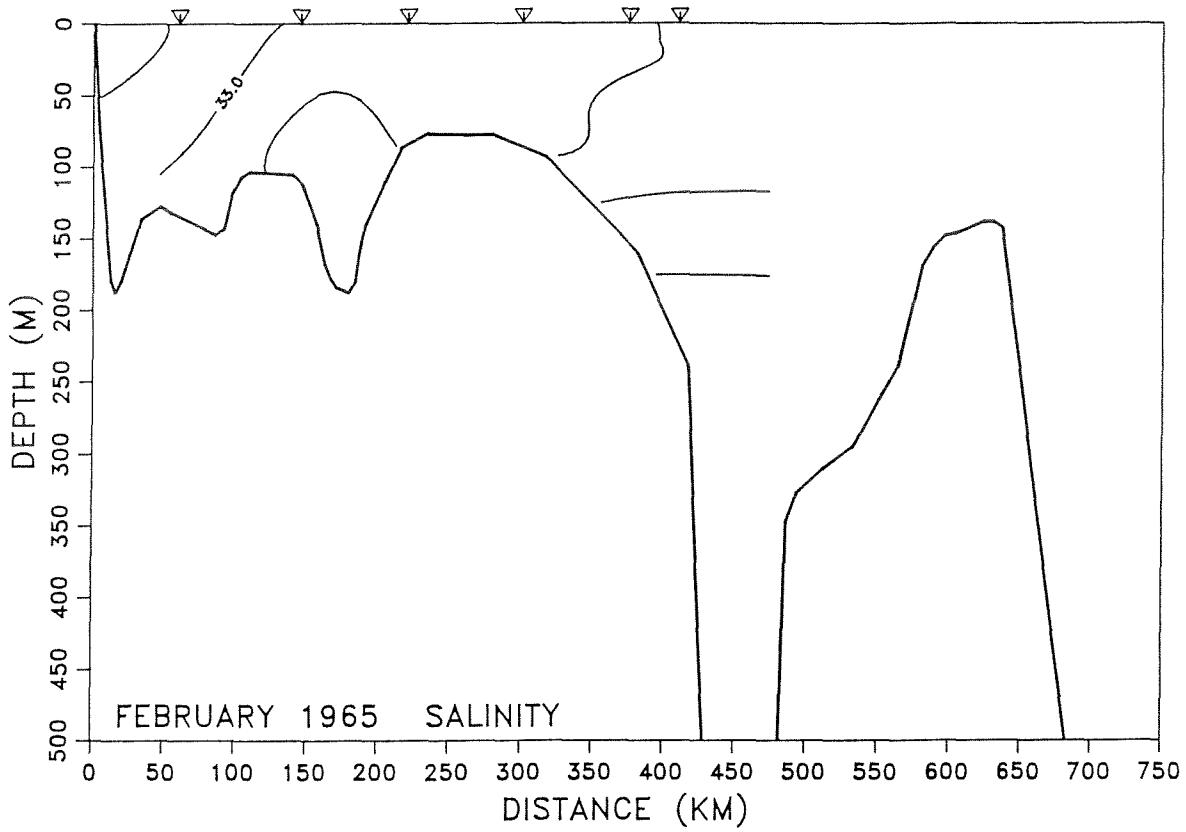
APPENDIX F. Flemish Cap Annual Salinity Transects

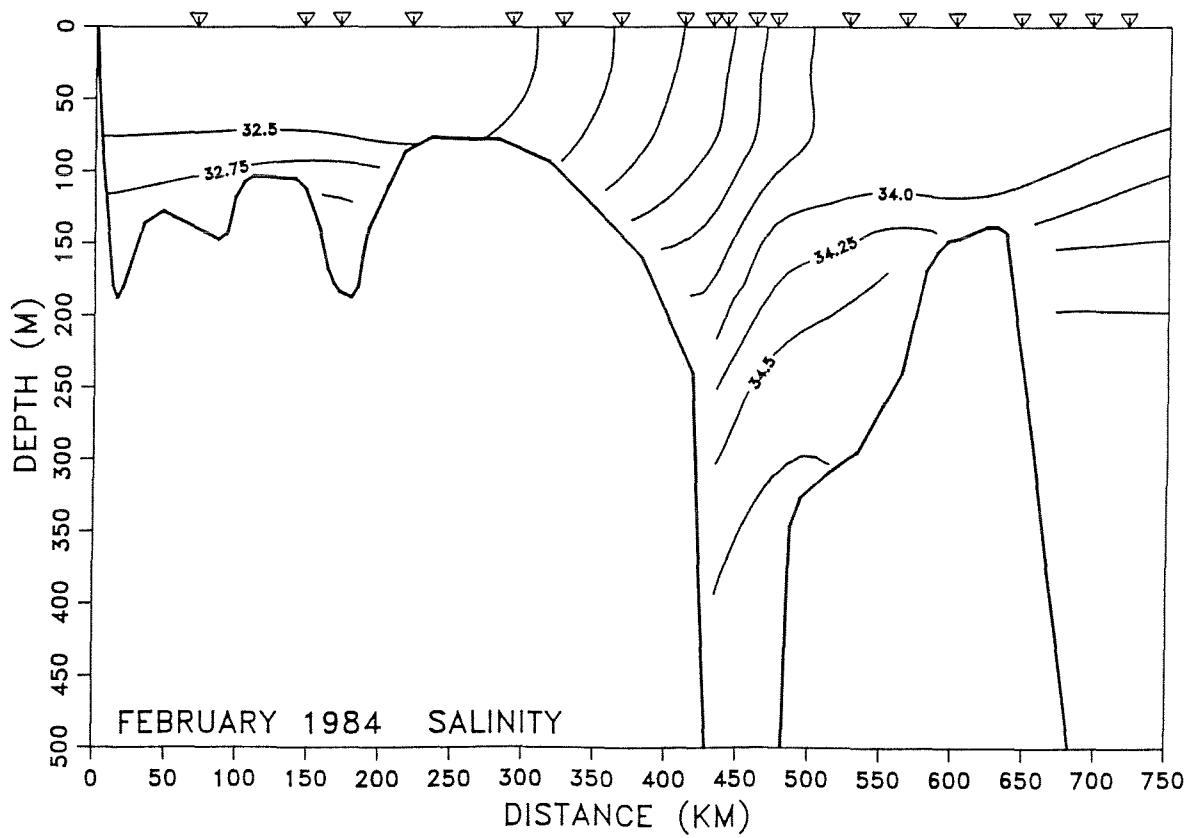
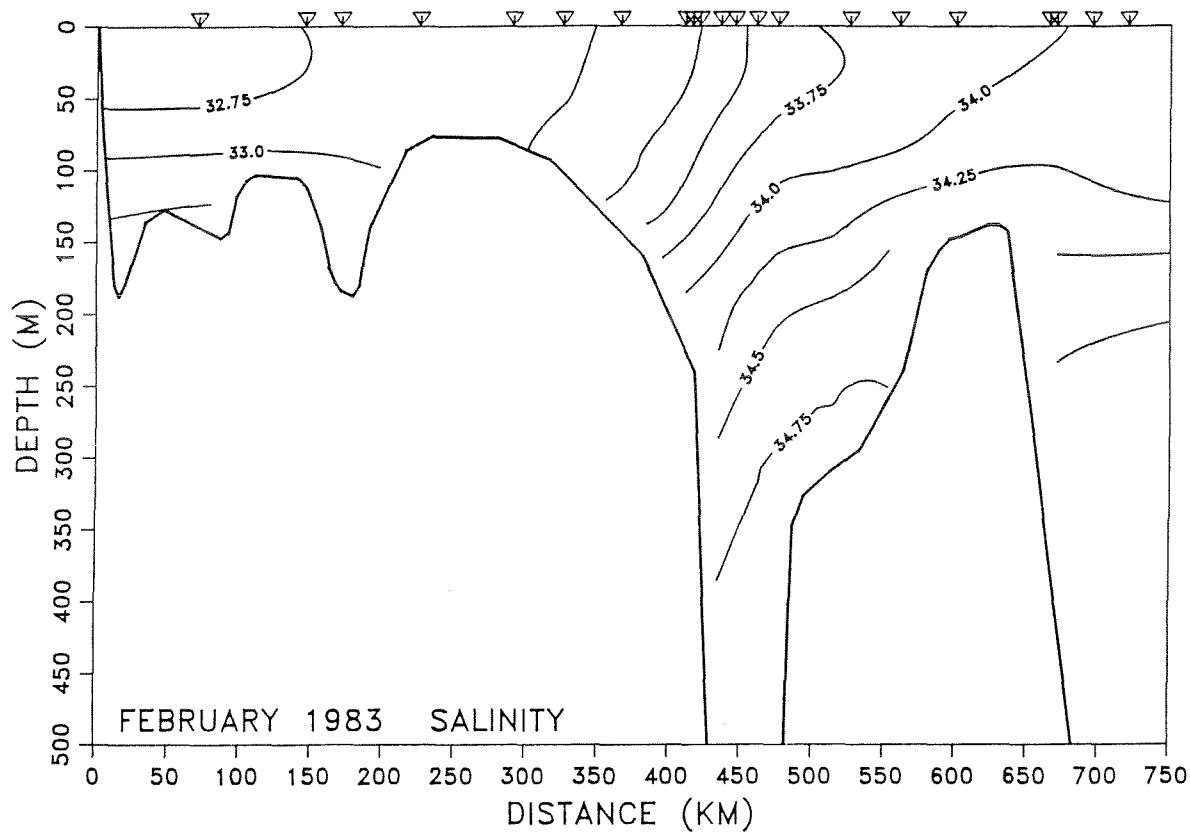


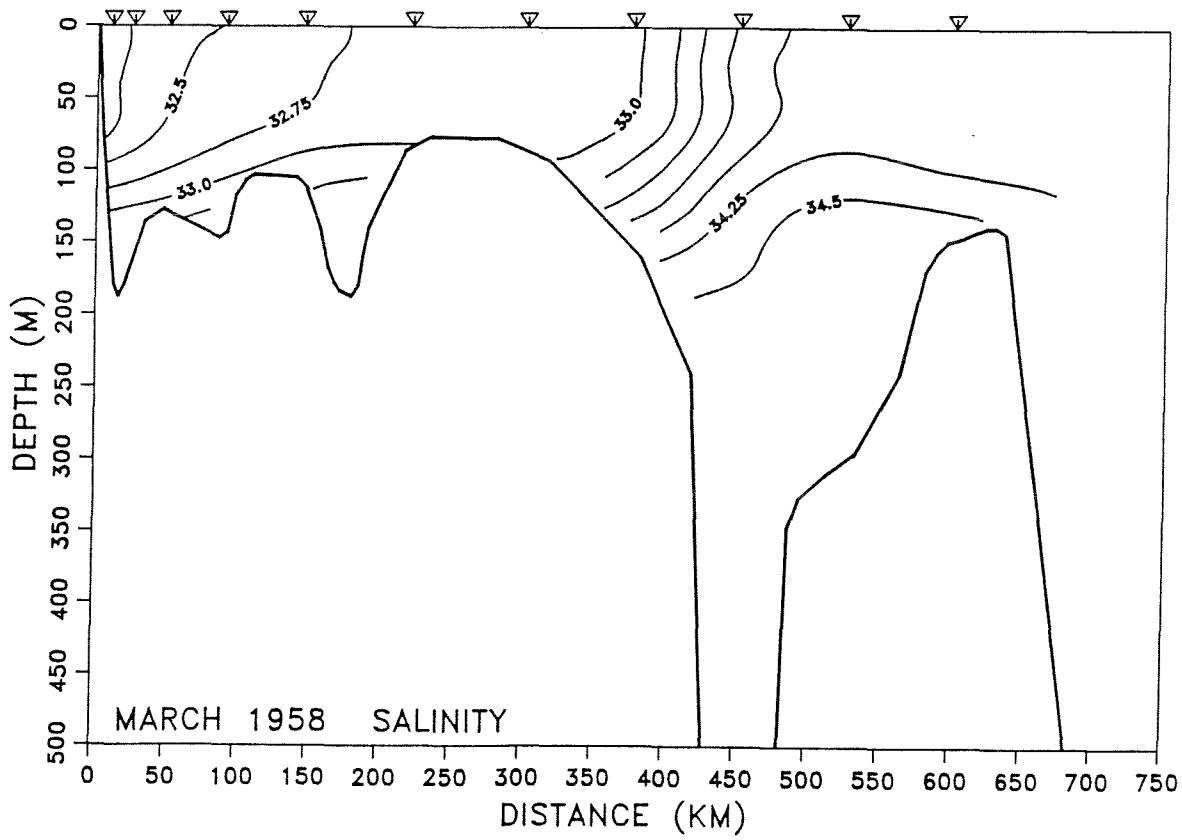
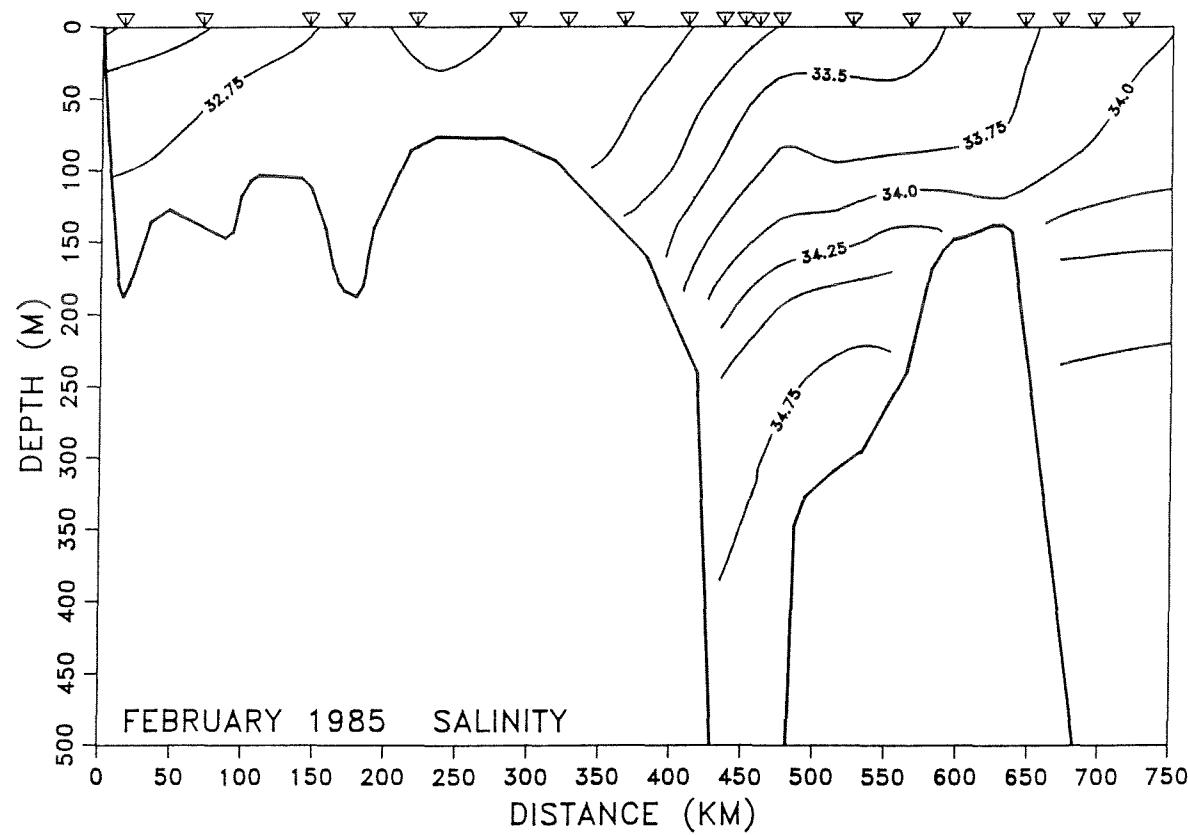


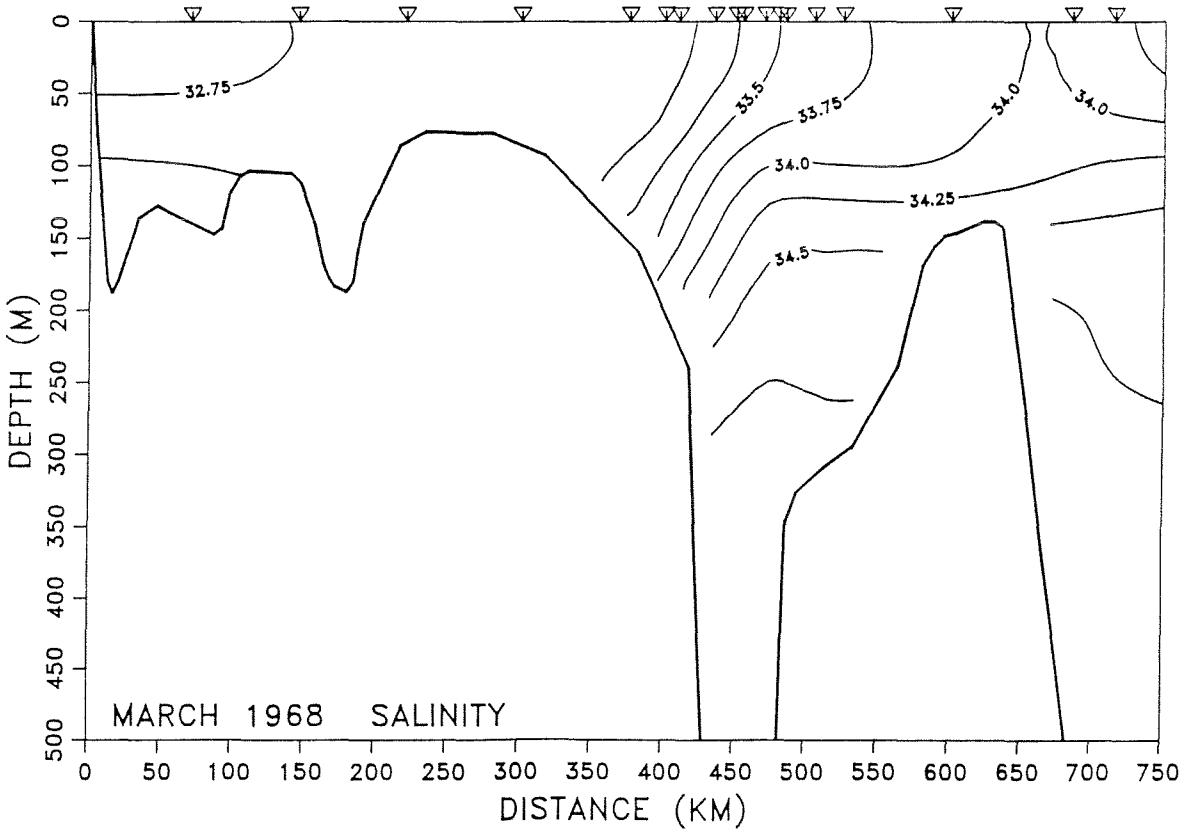
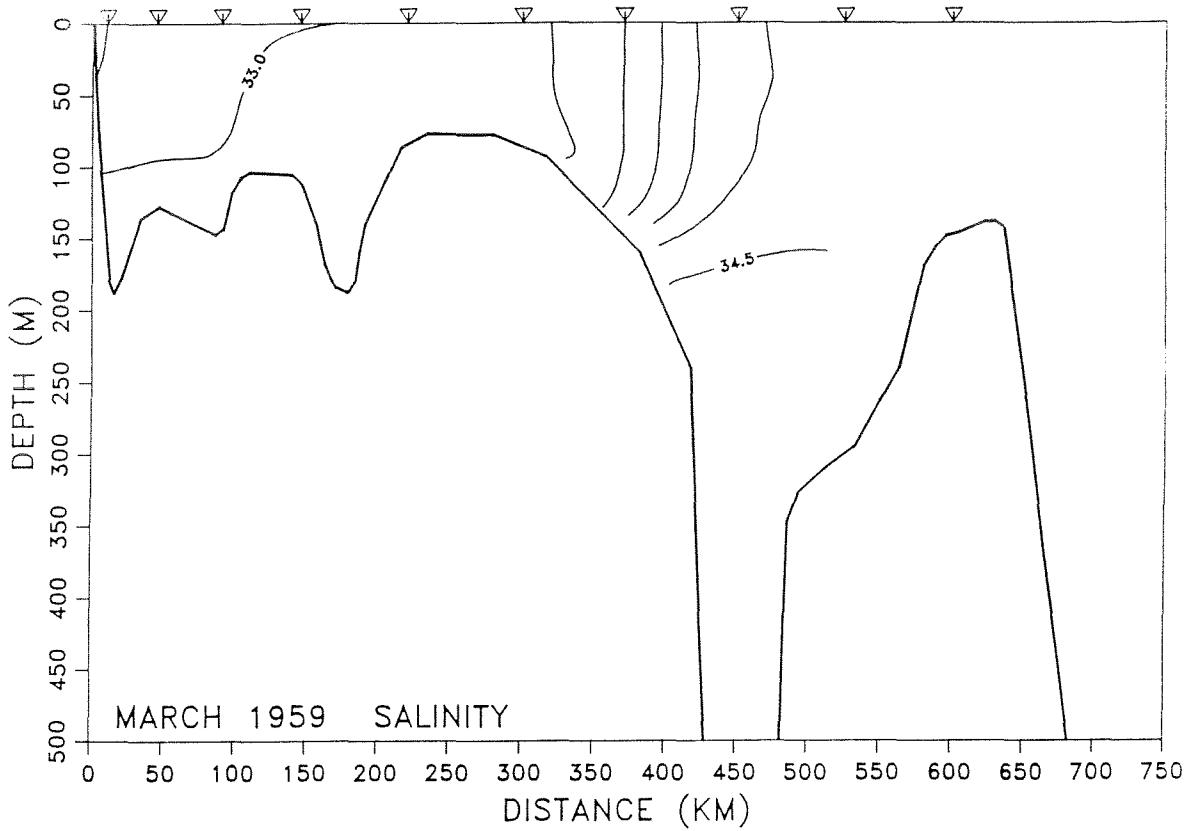


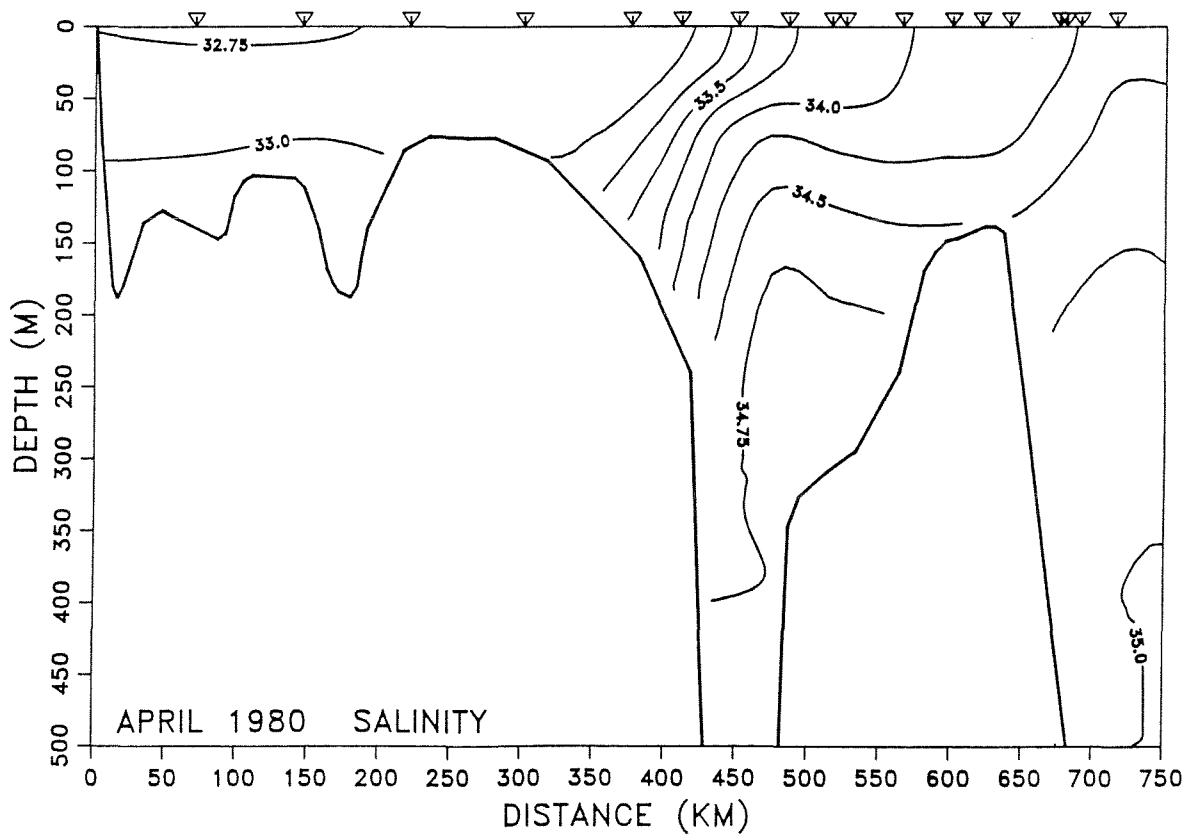
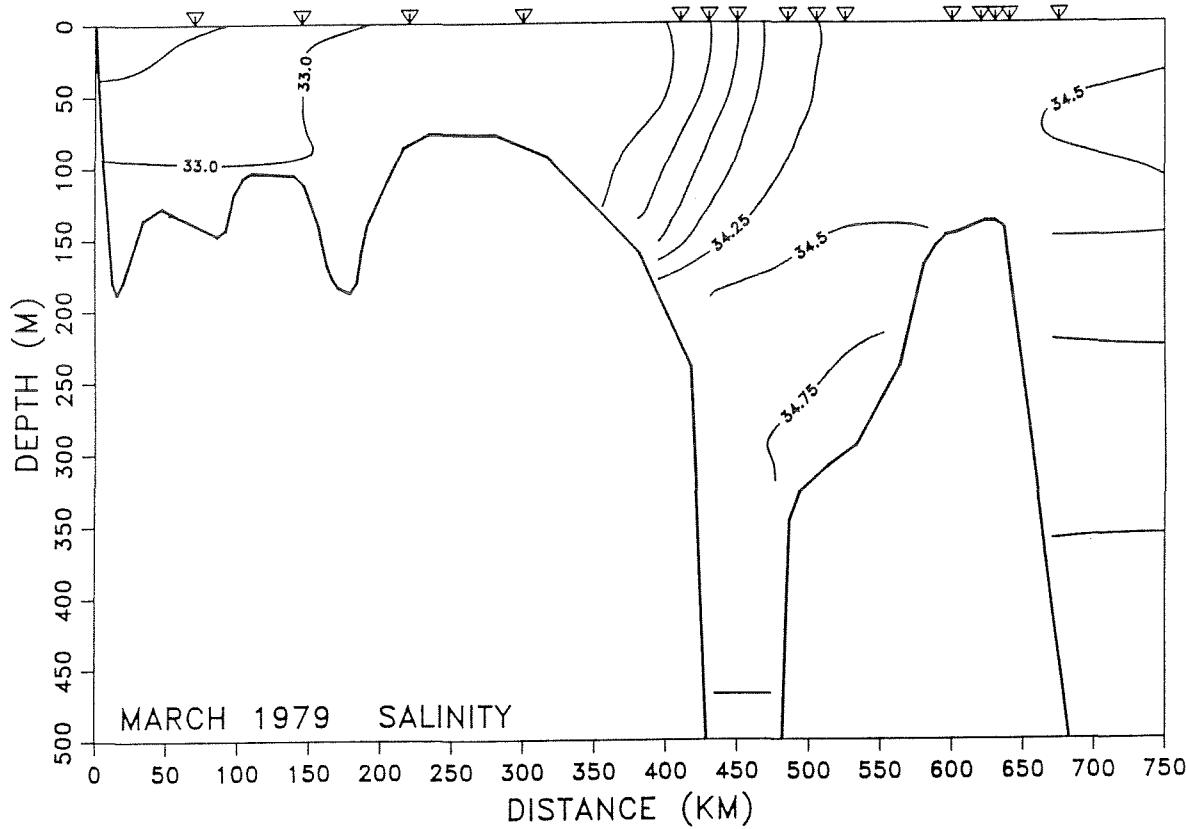


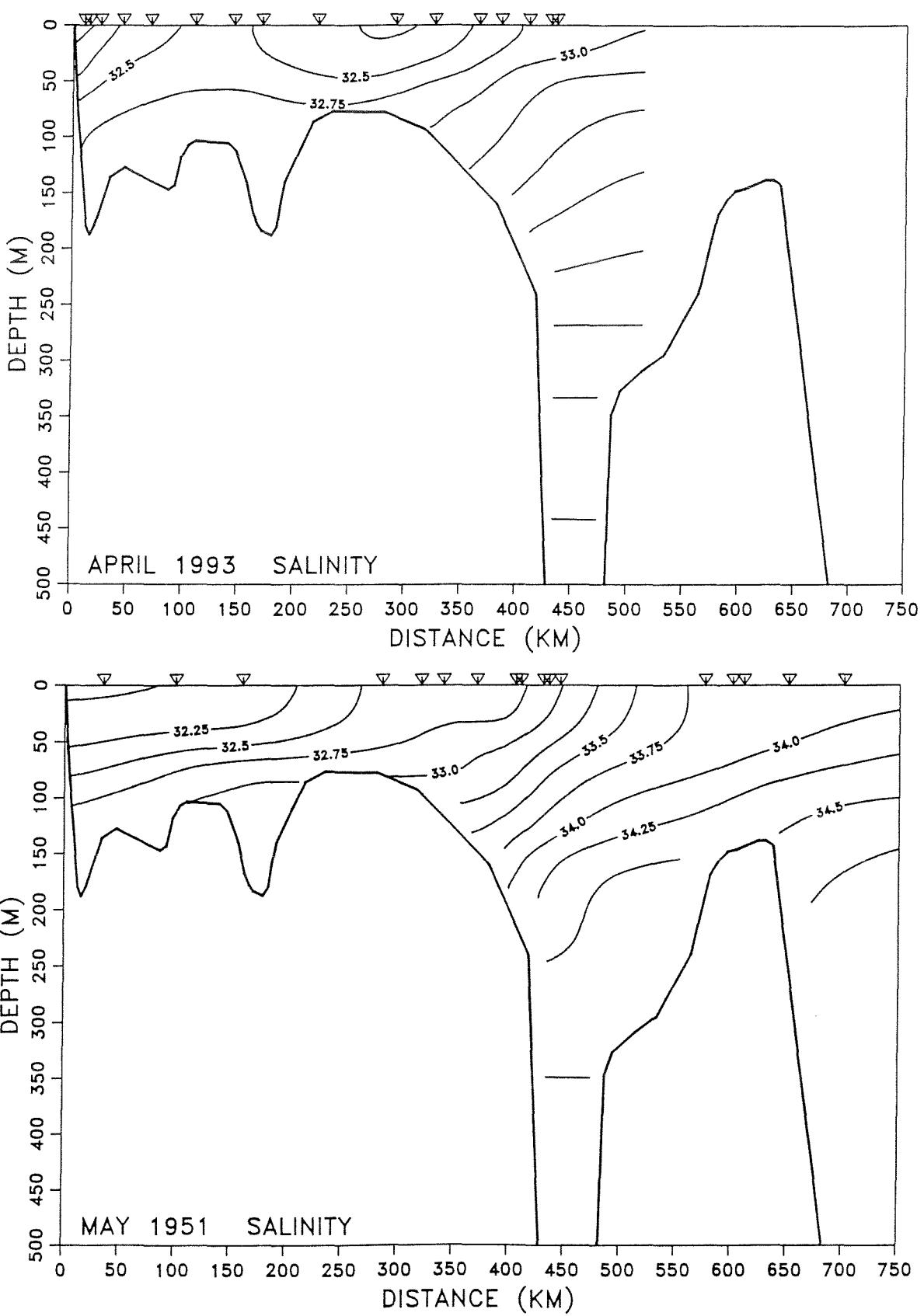


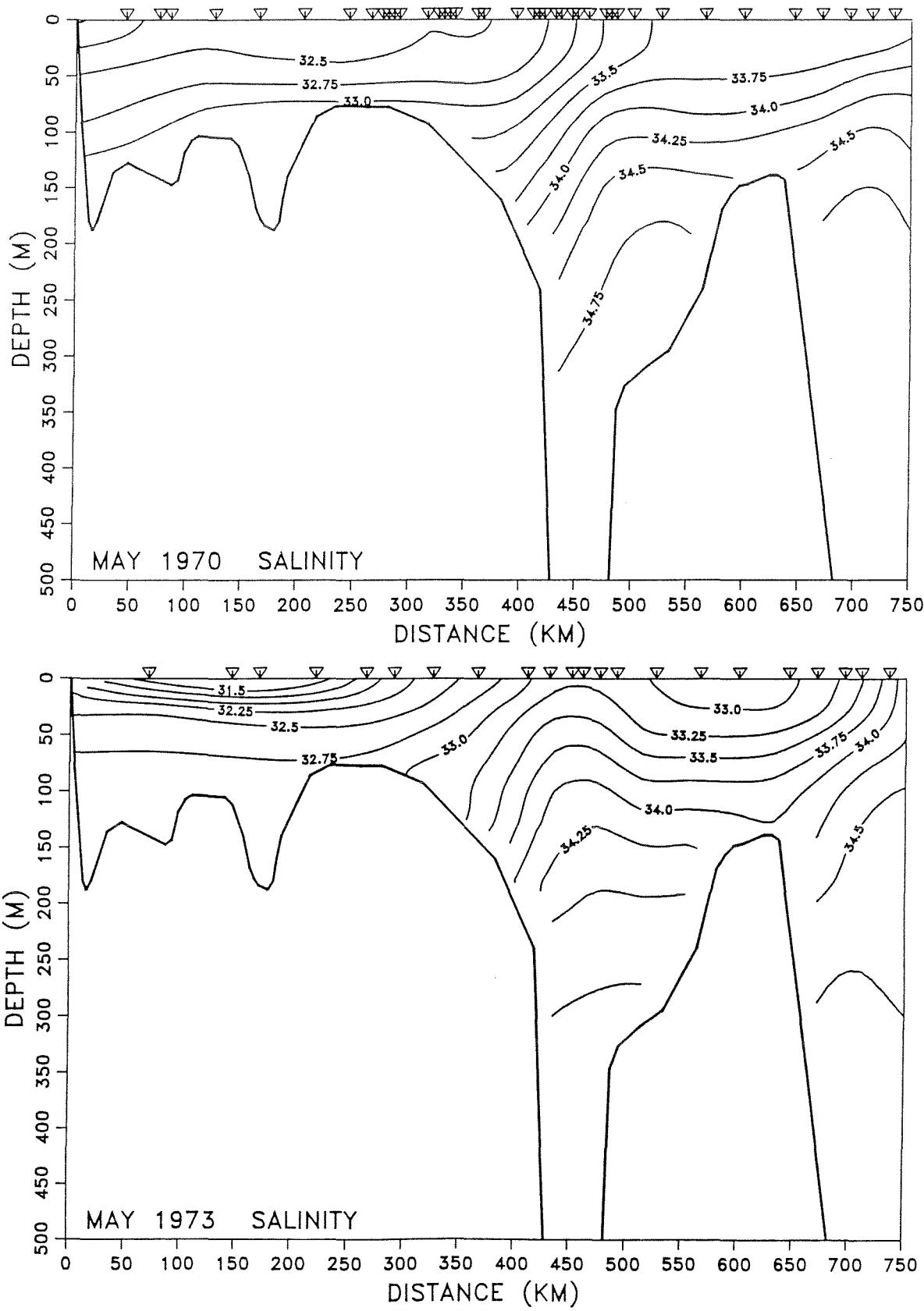


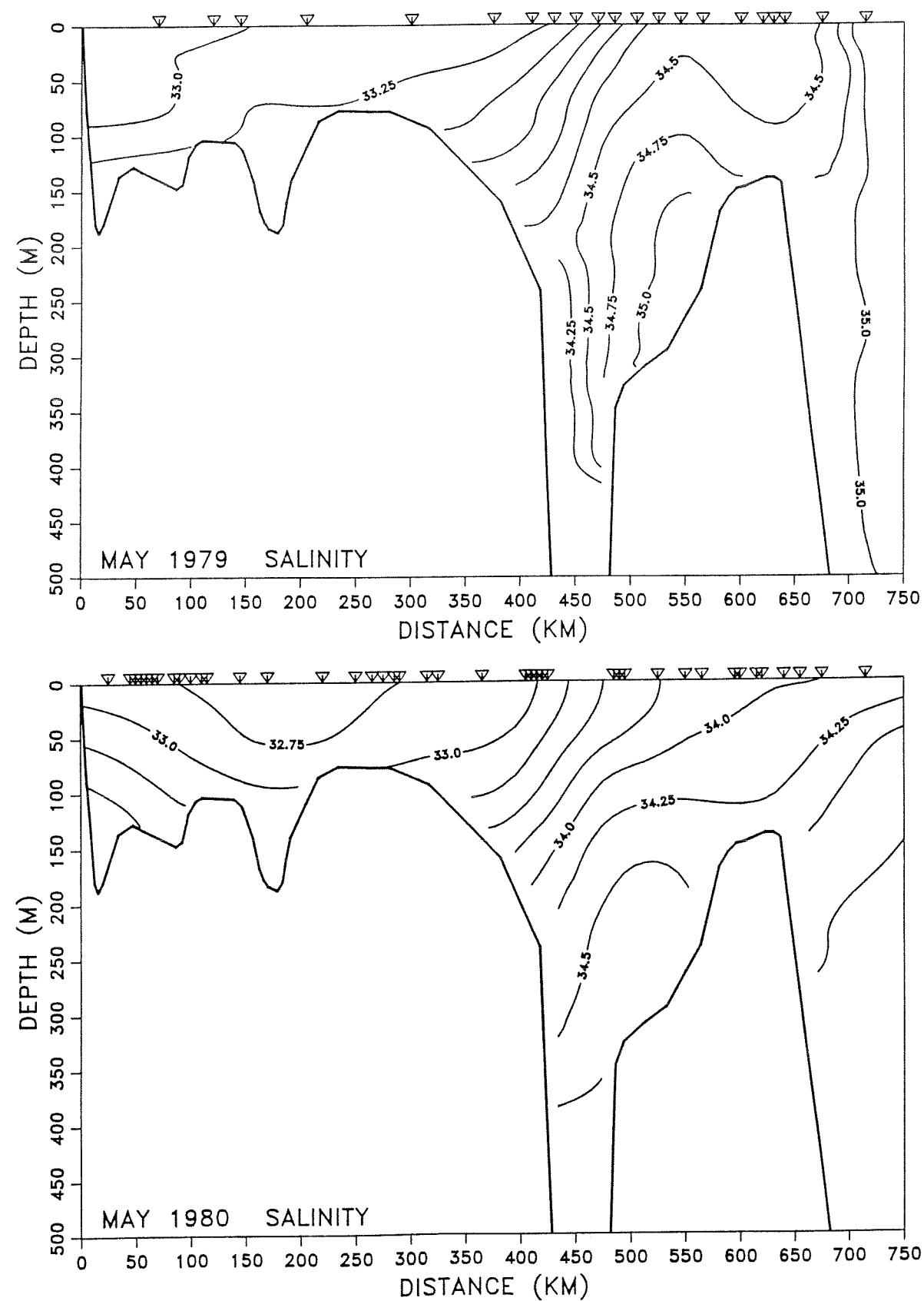


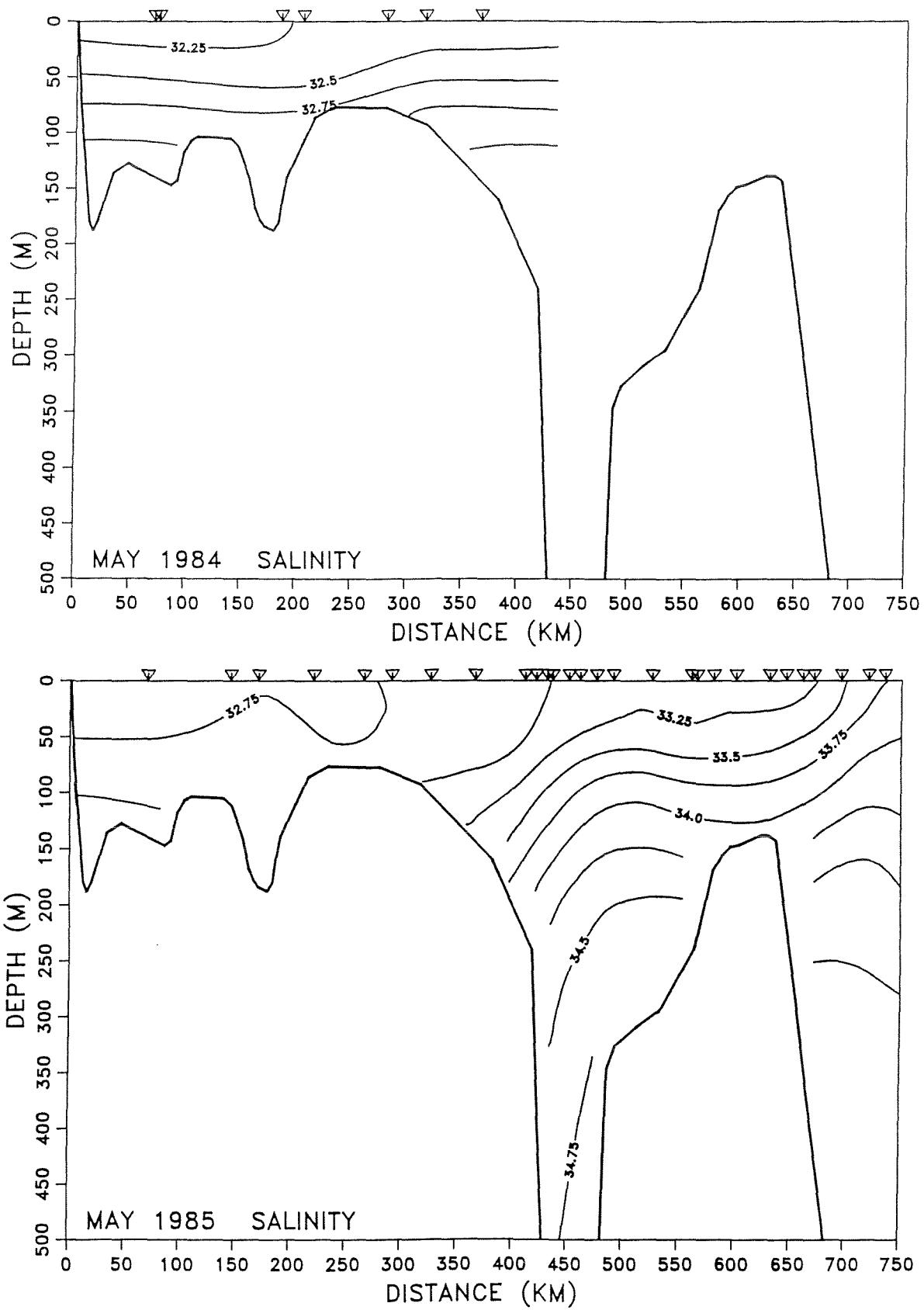


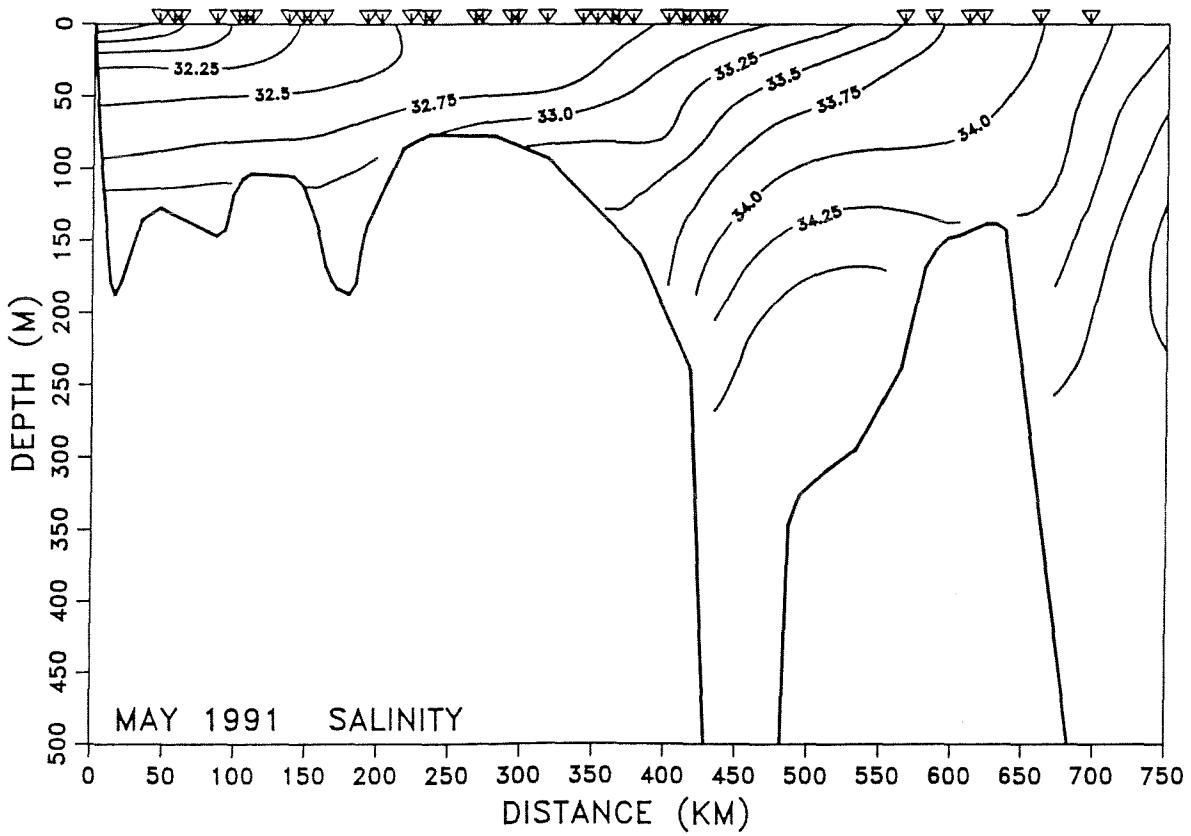
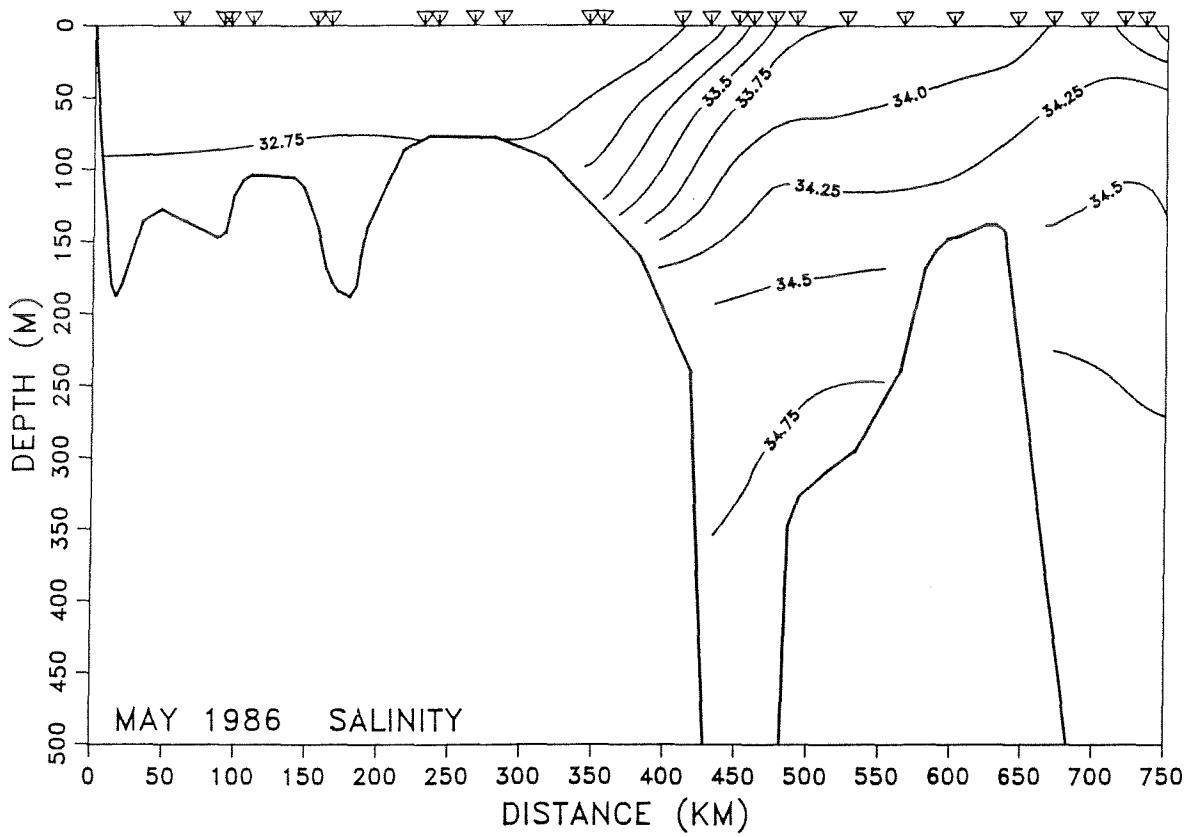


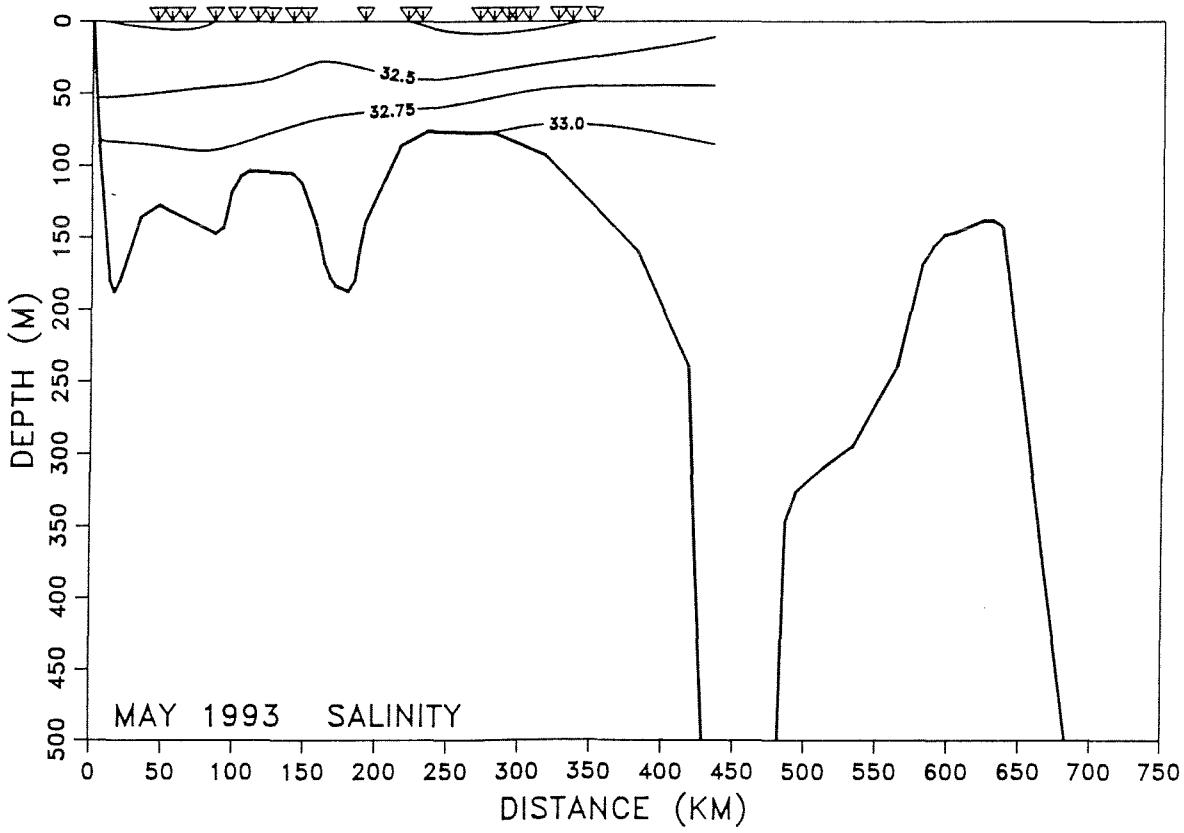
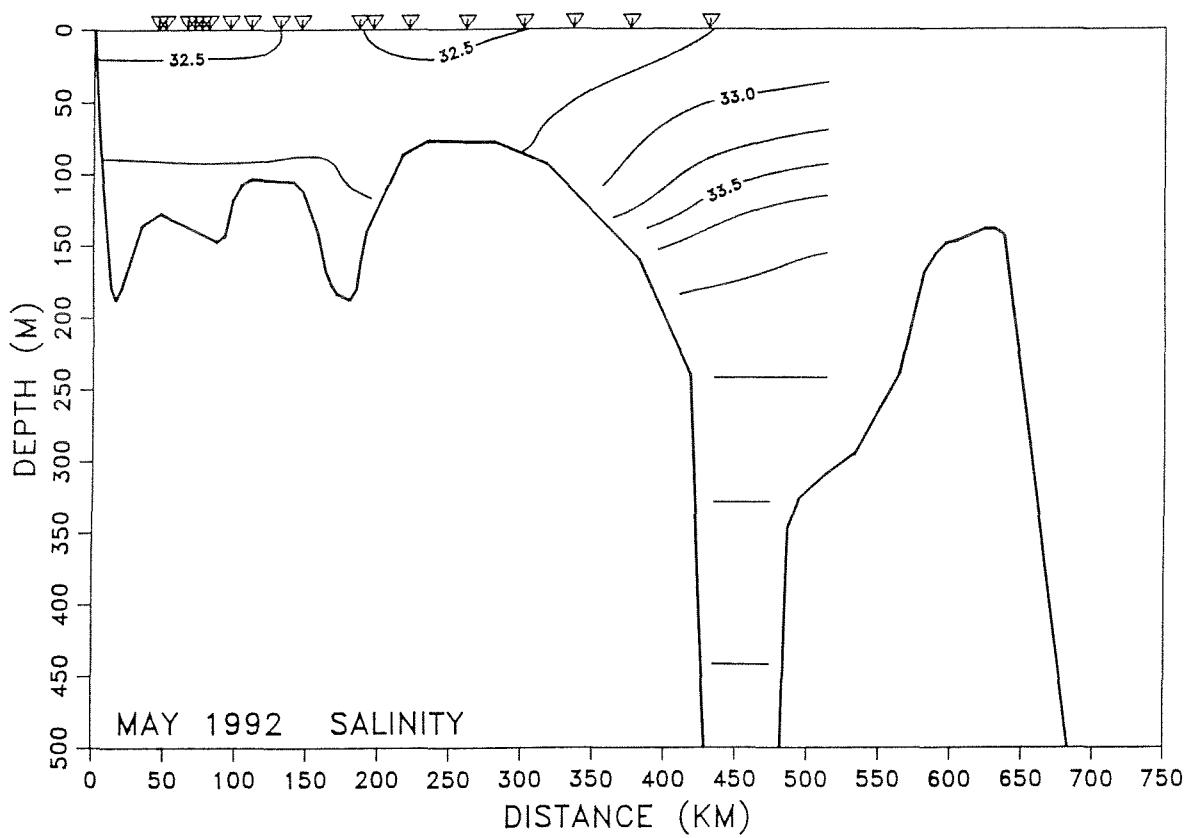


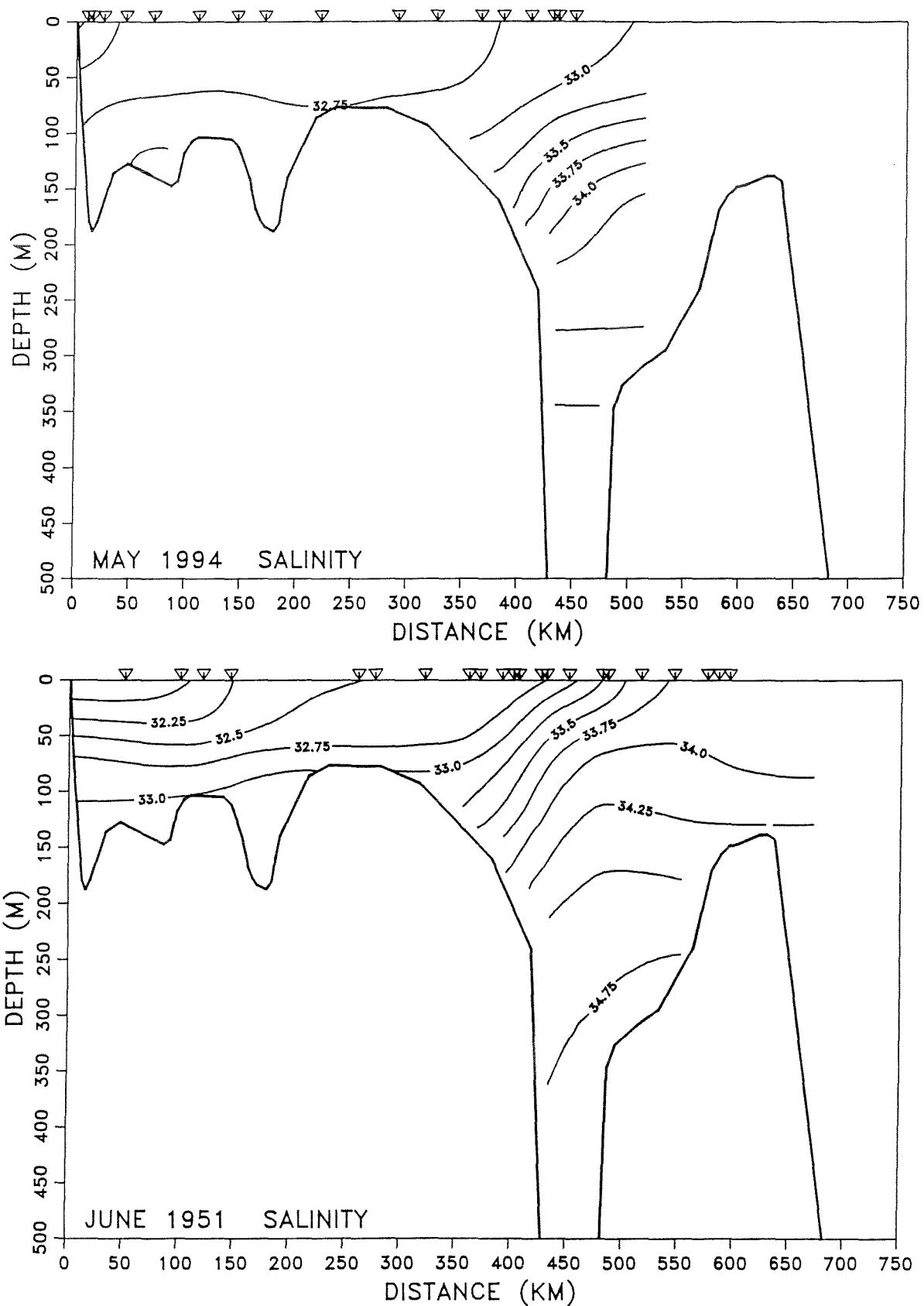


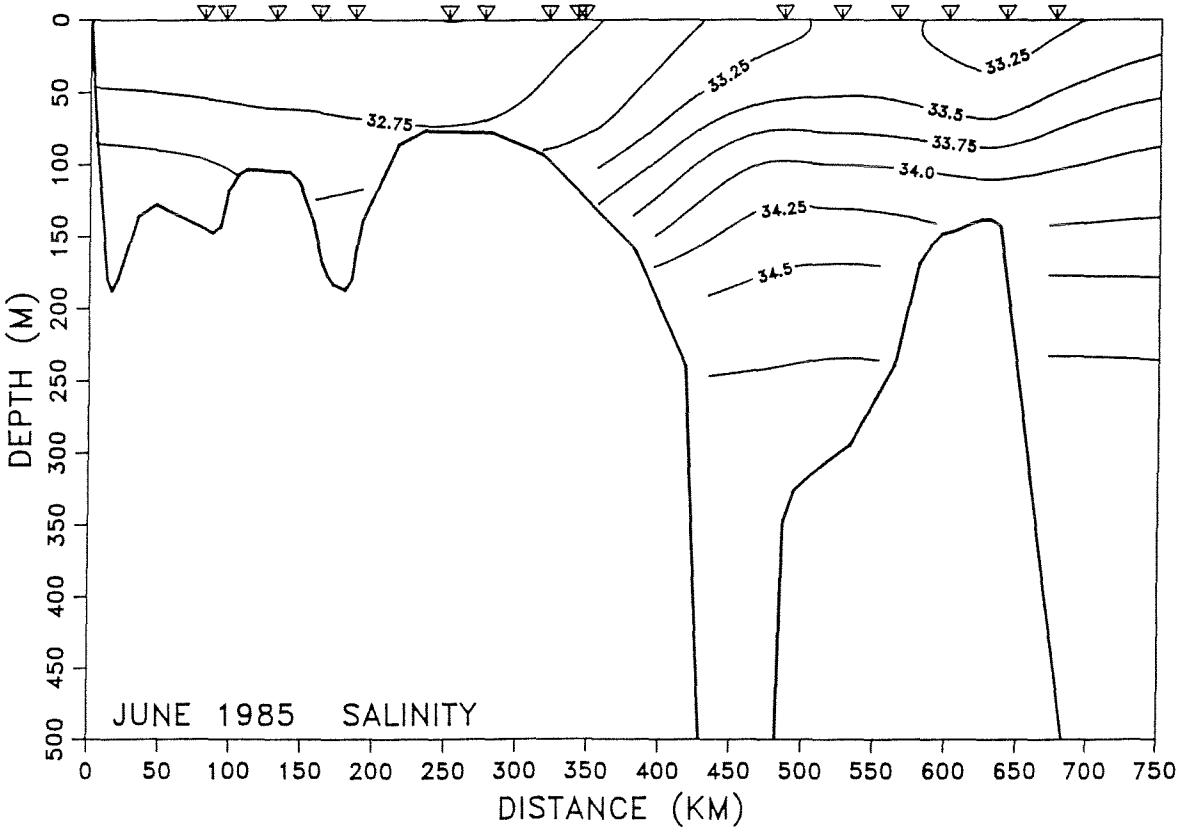
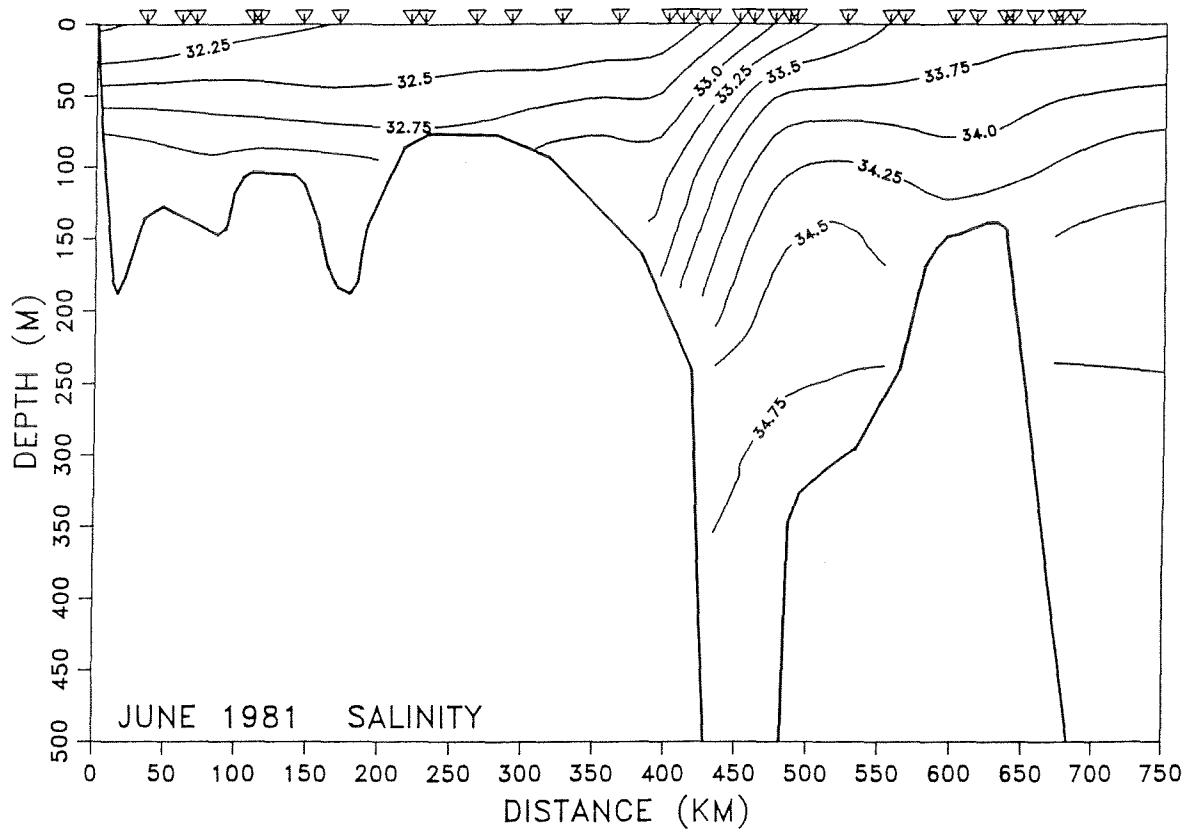


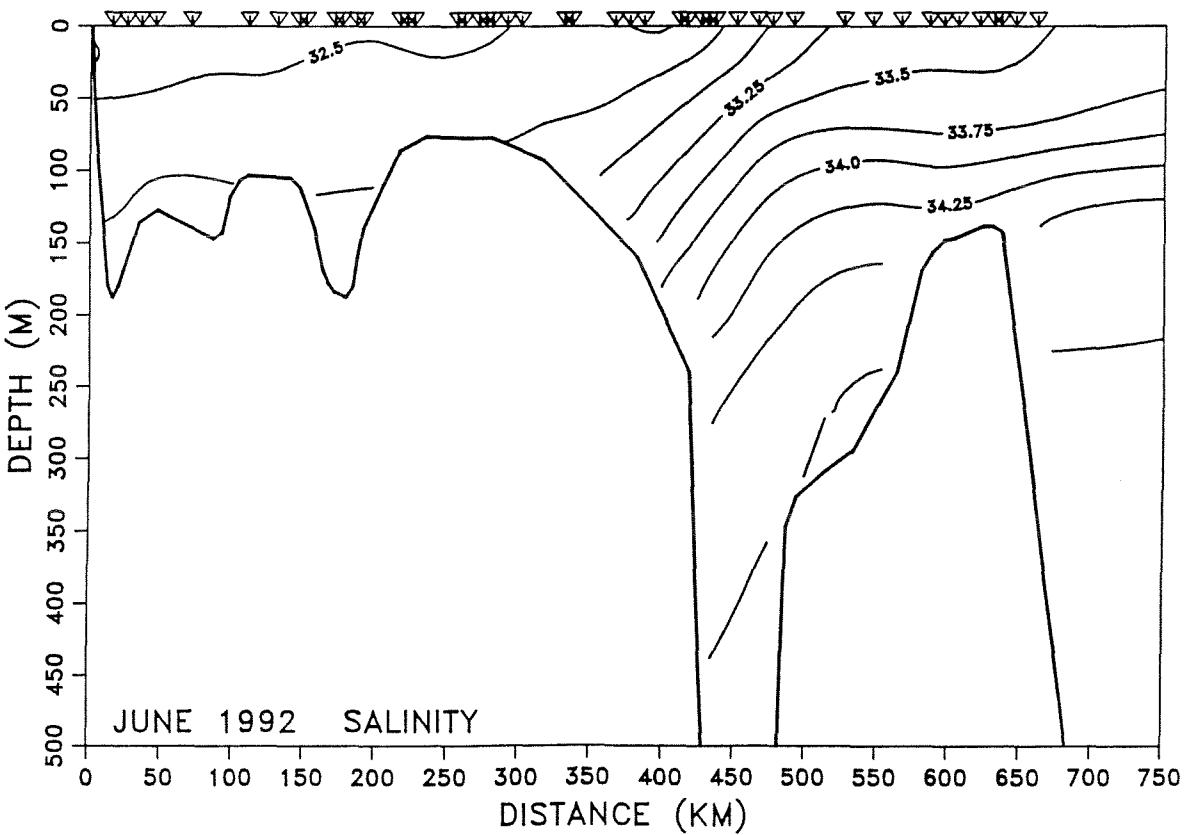
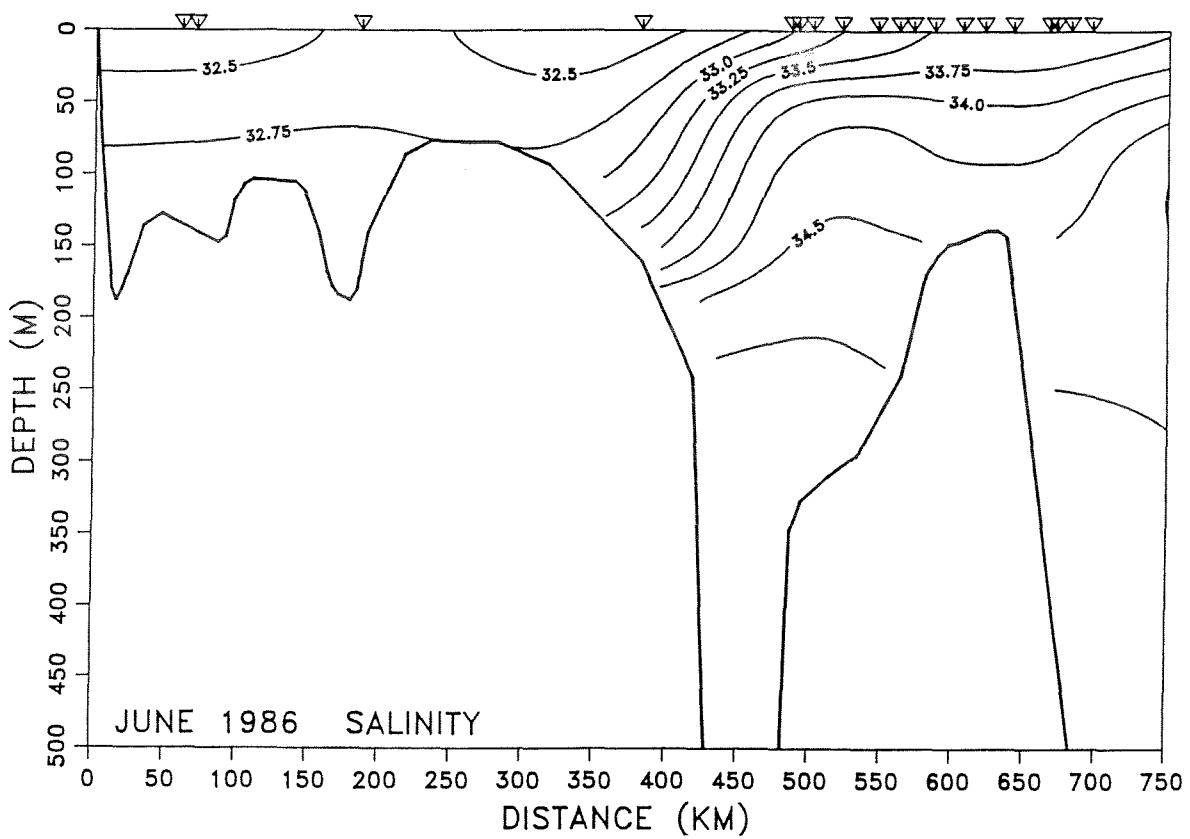


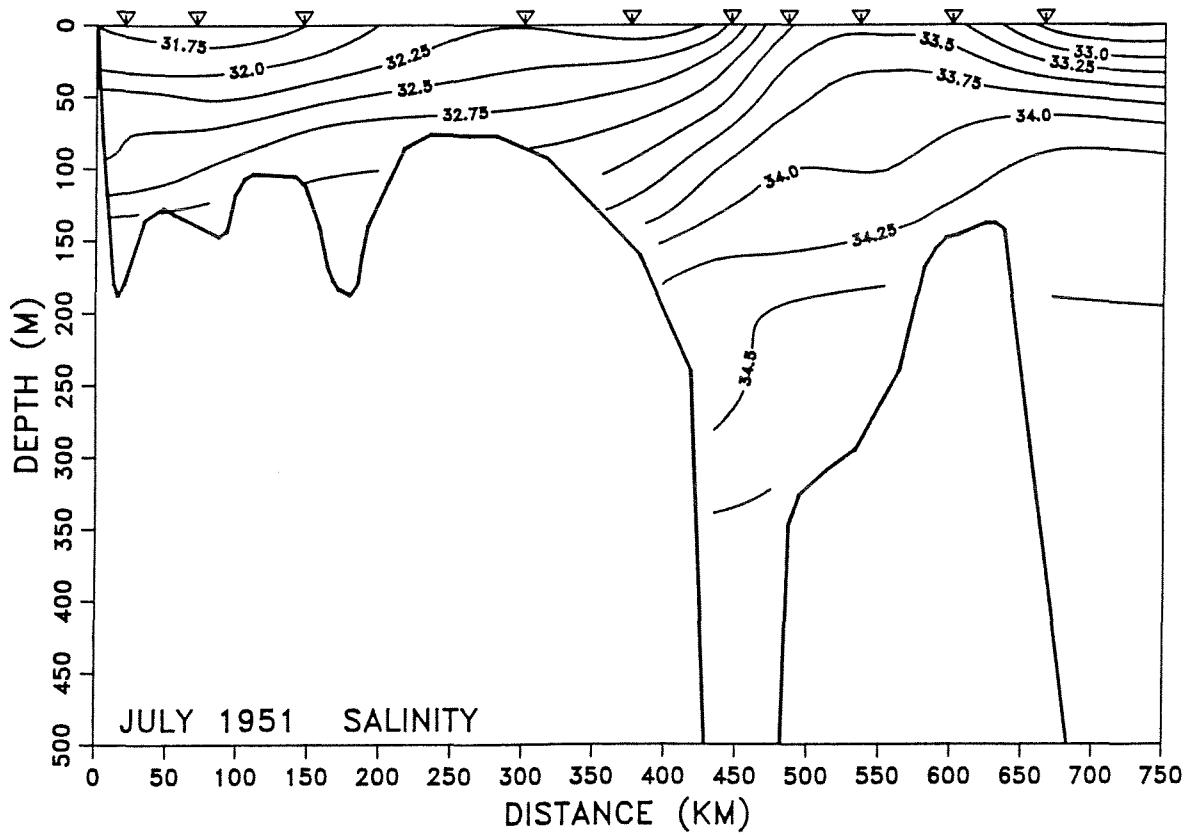
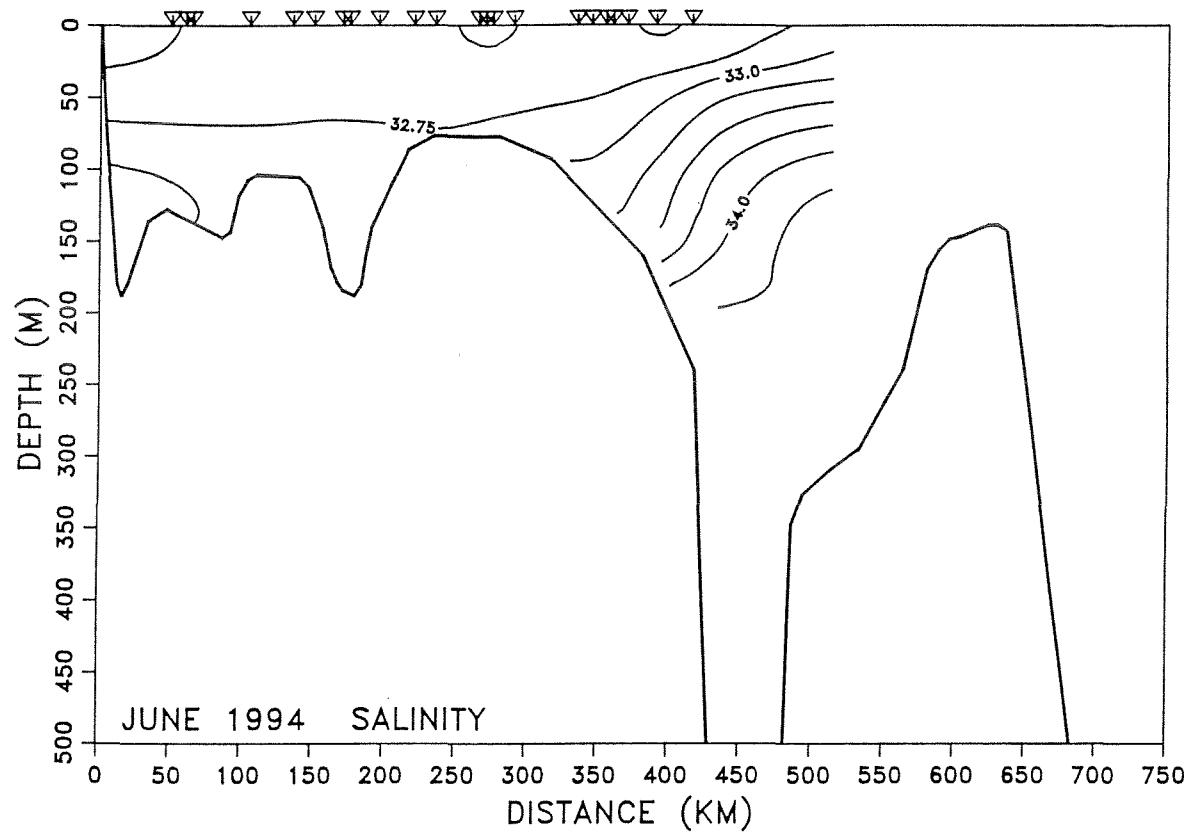


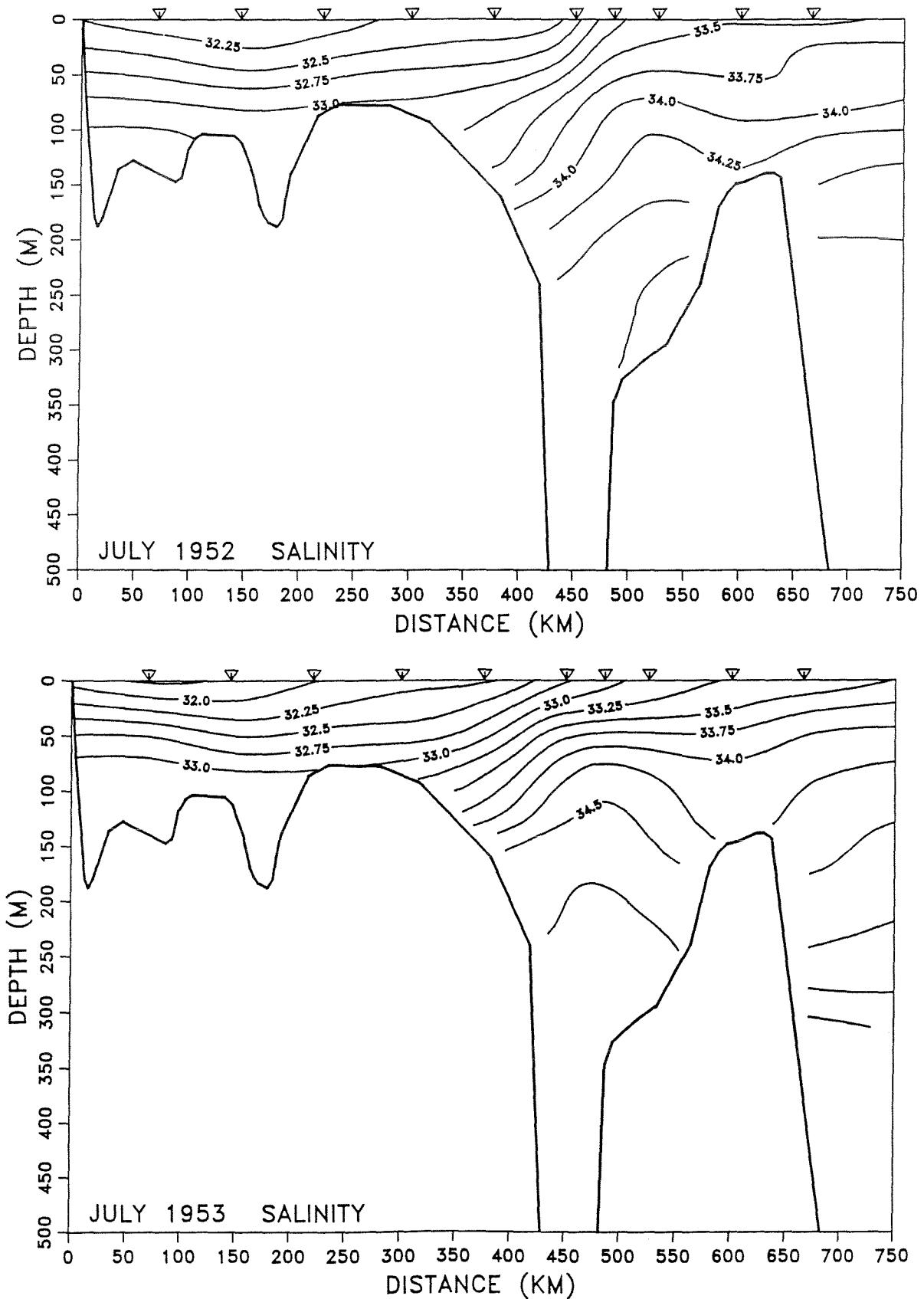


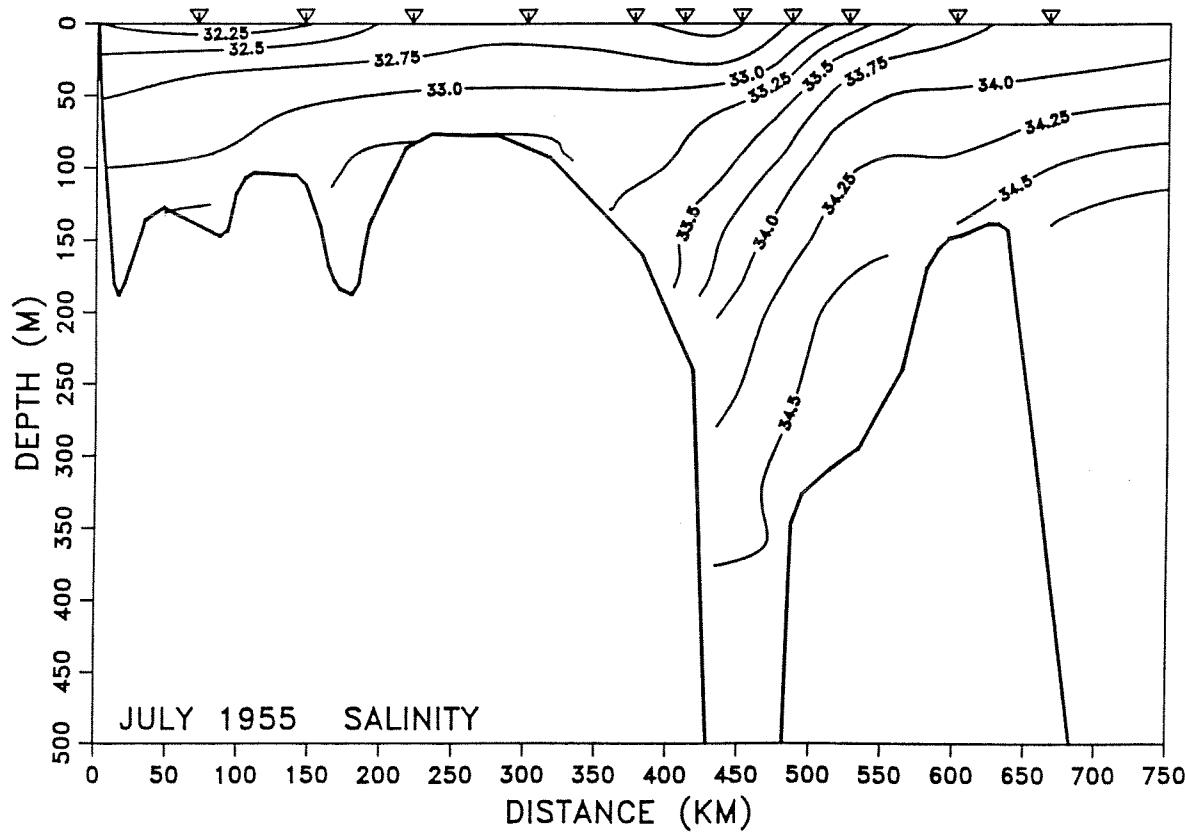
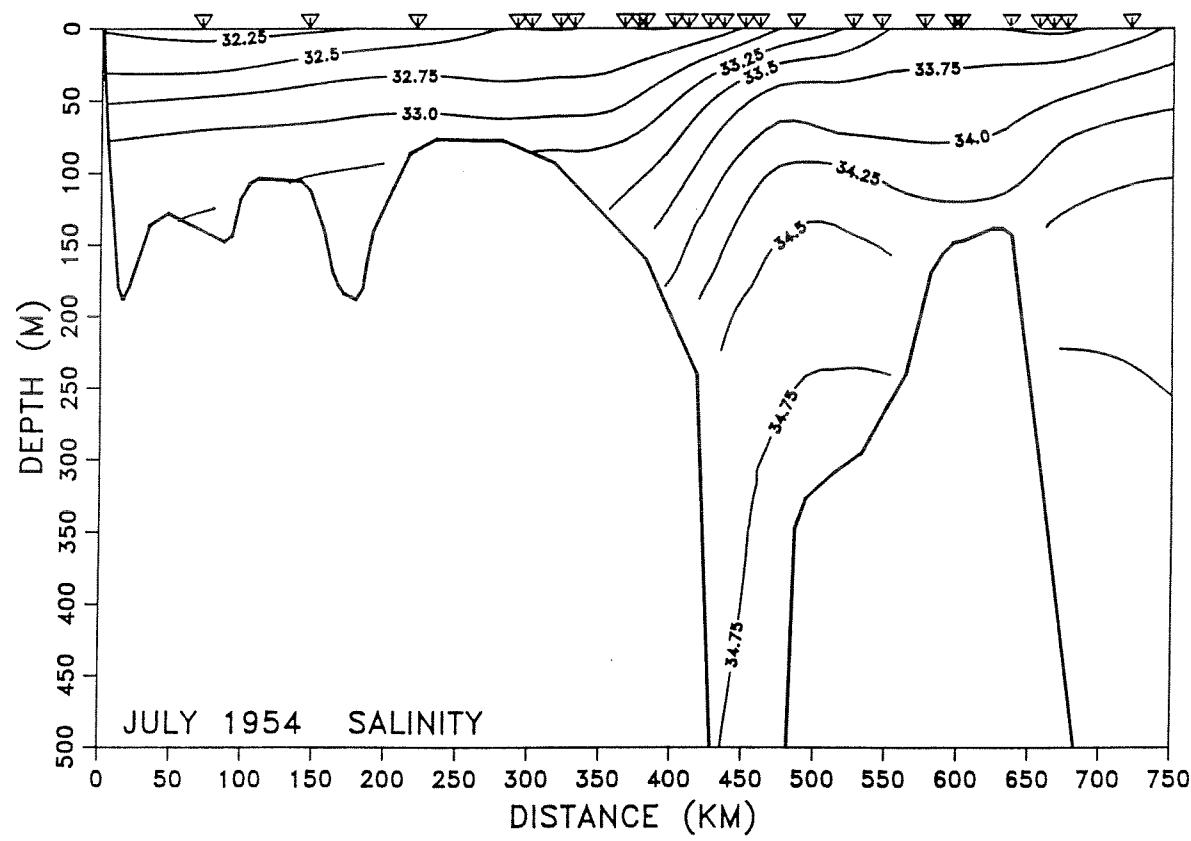


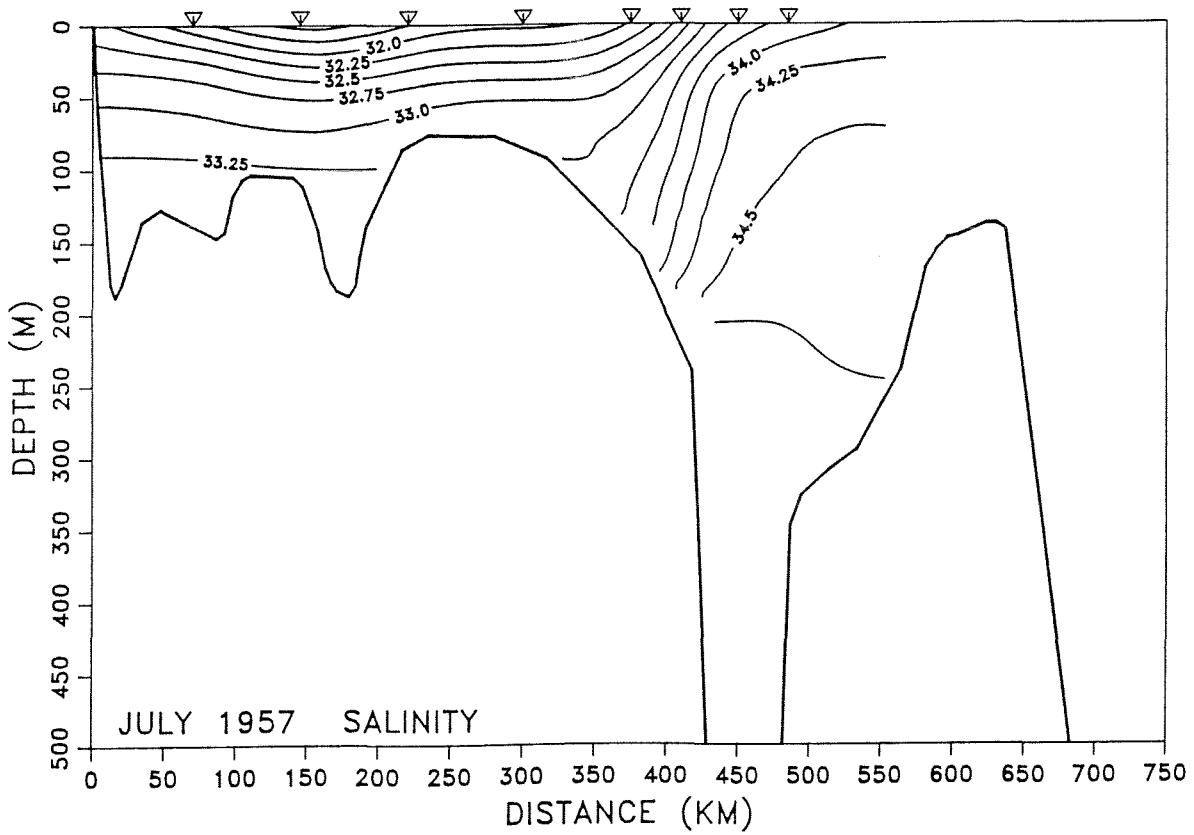
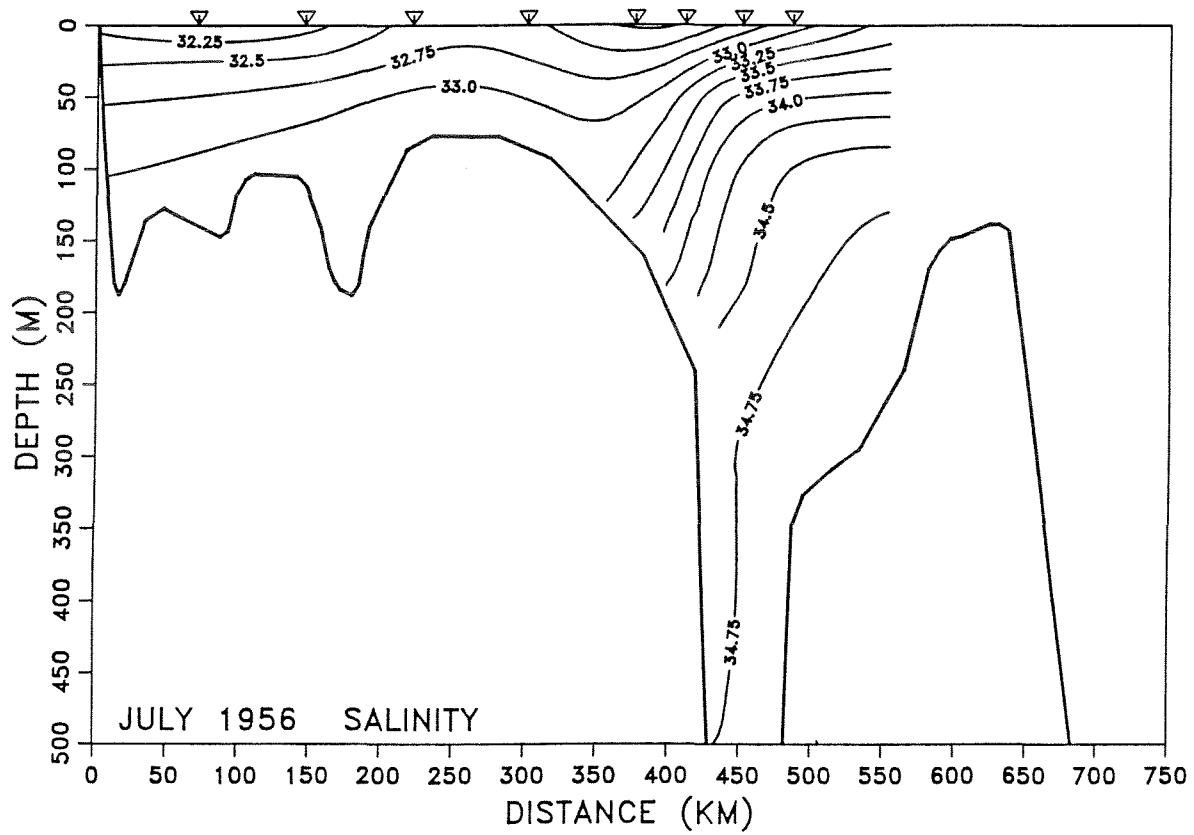




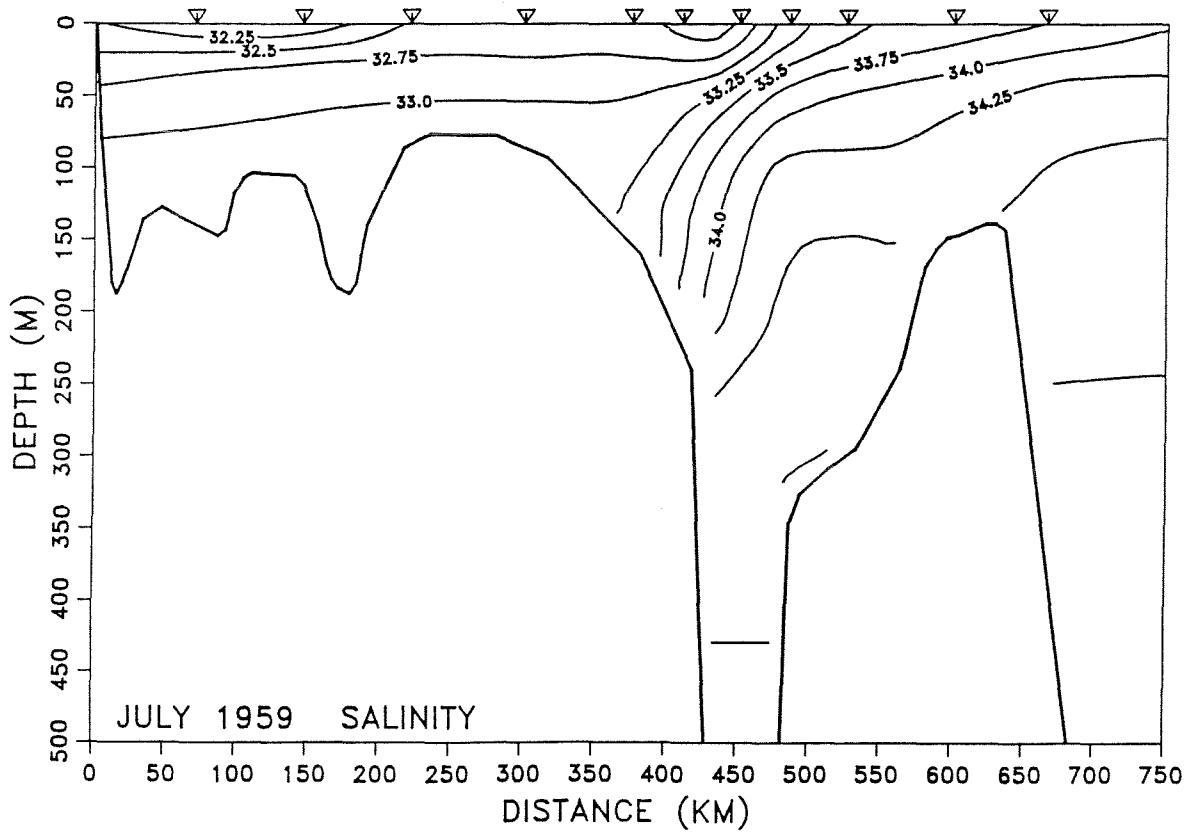
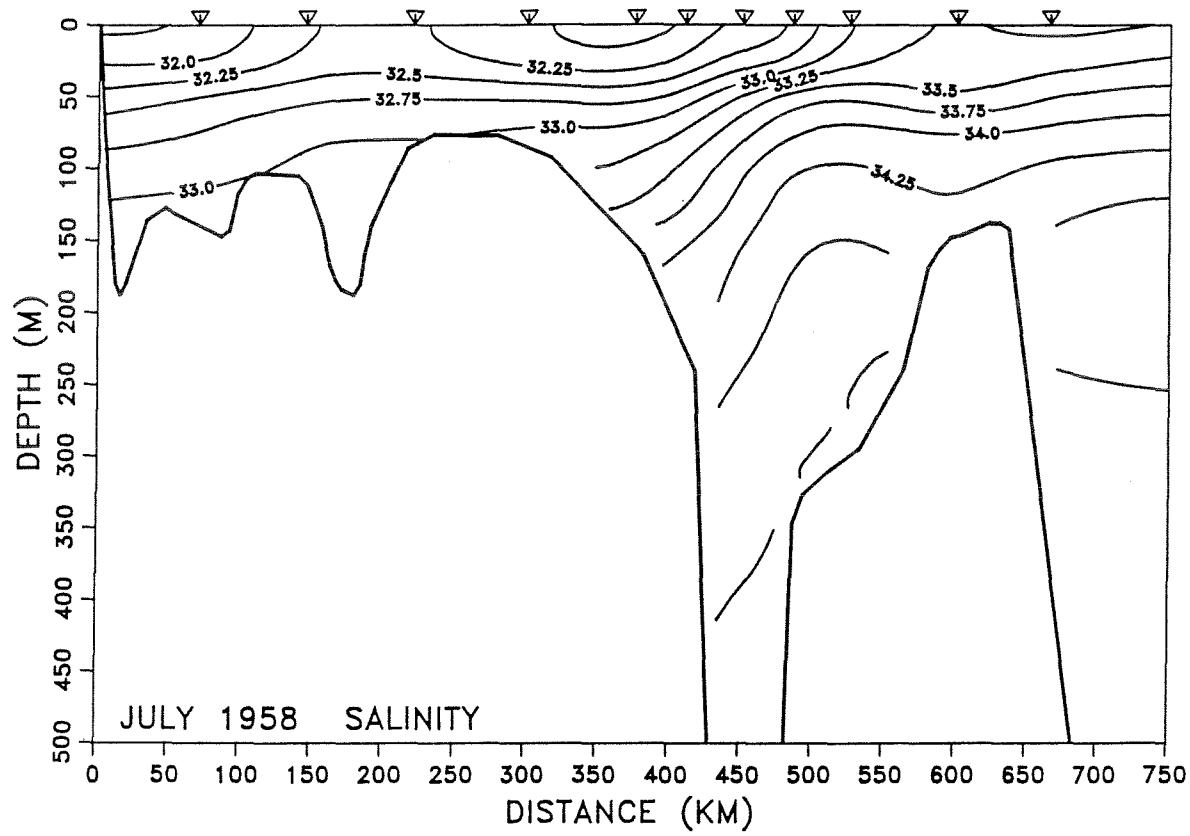


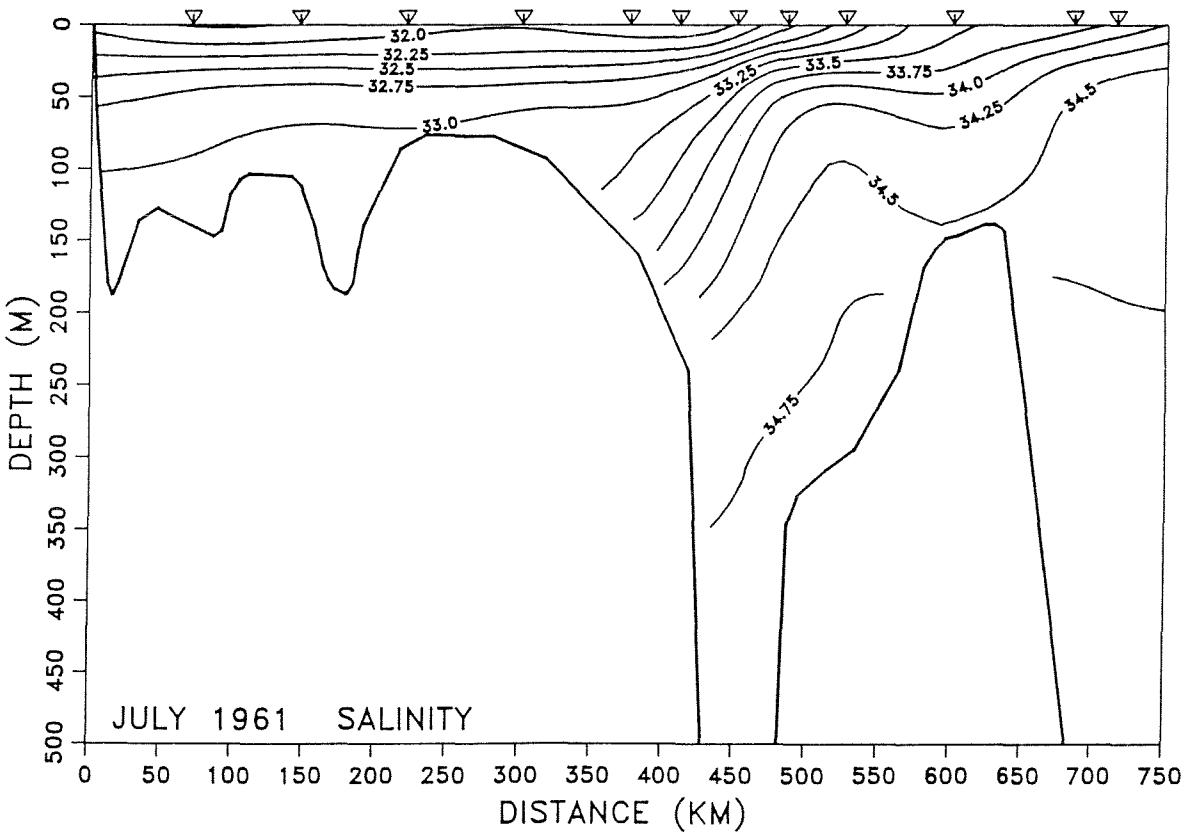
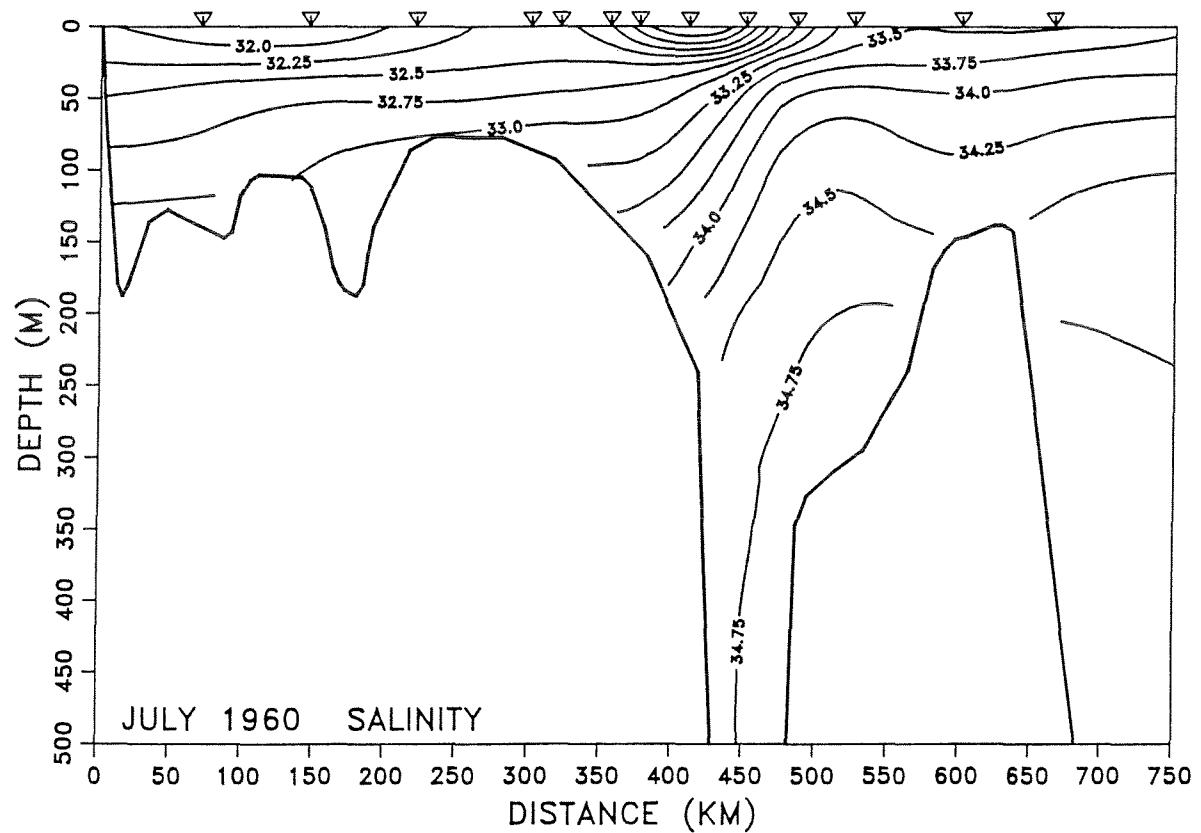


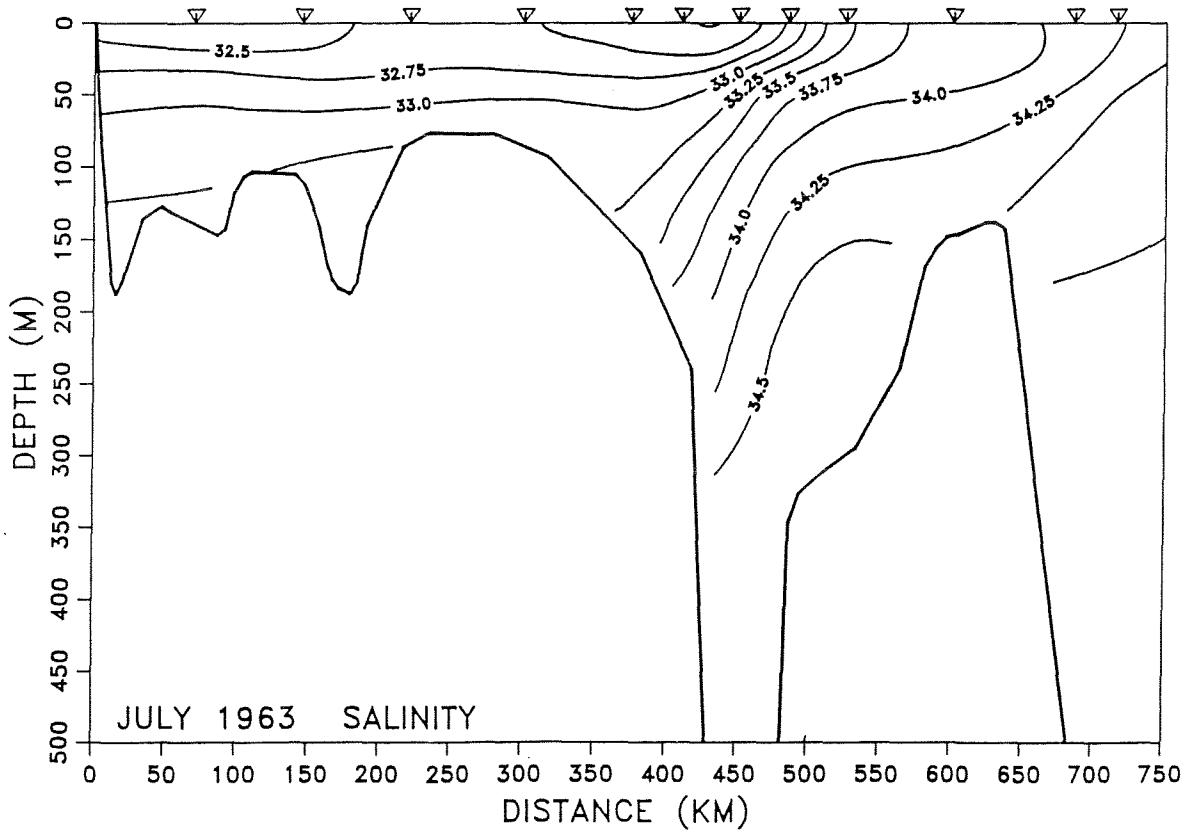
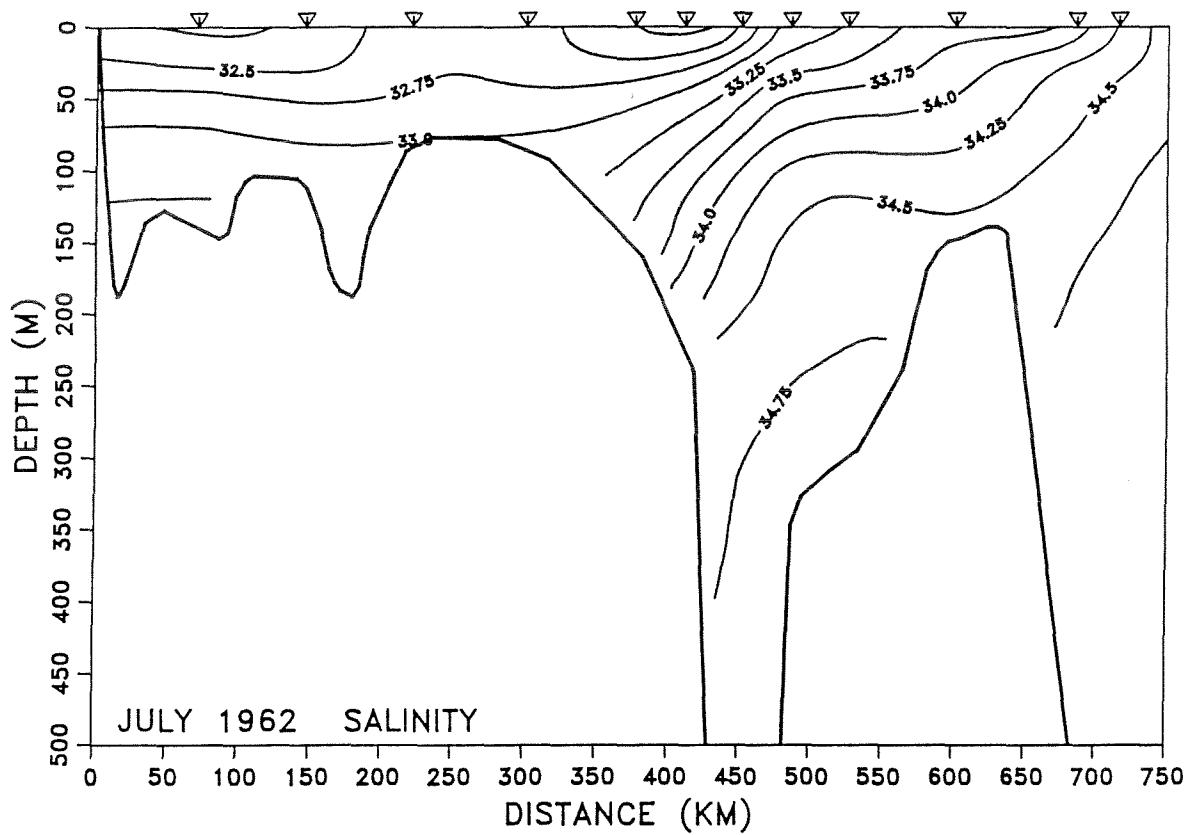


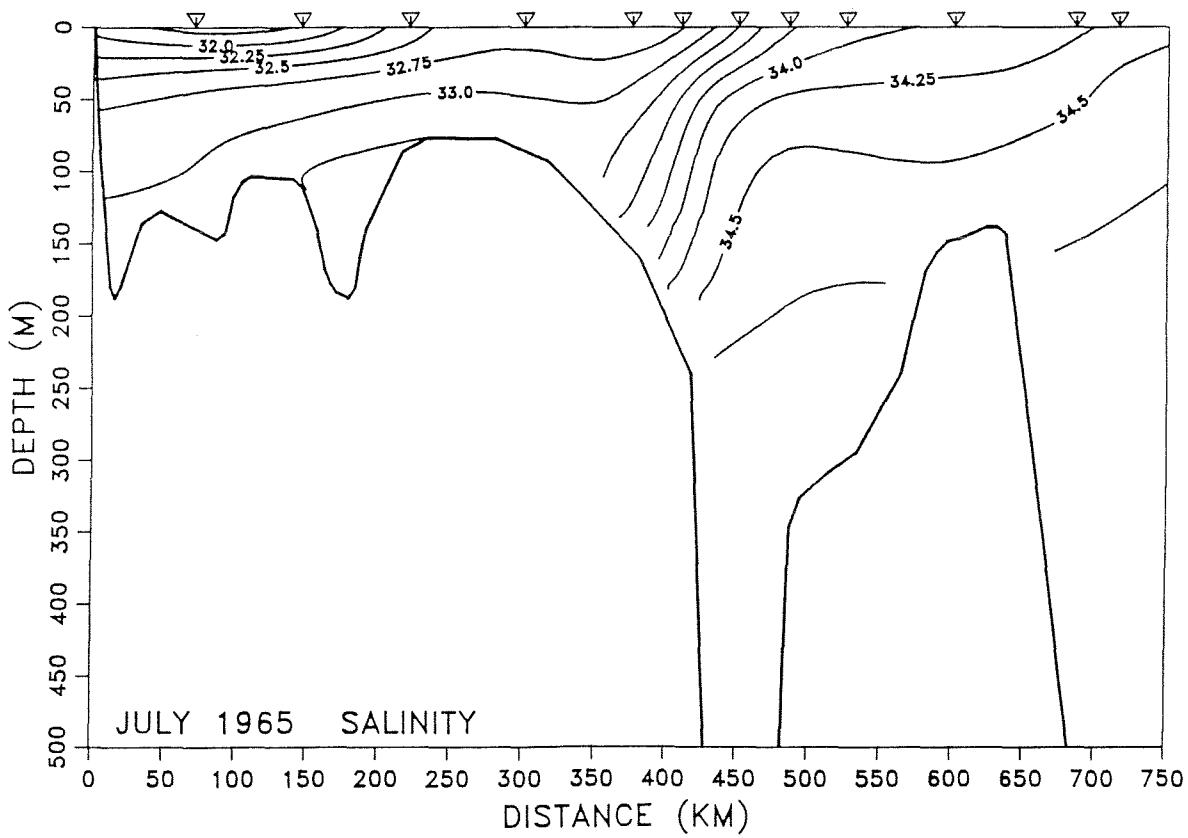
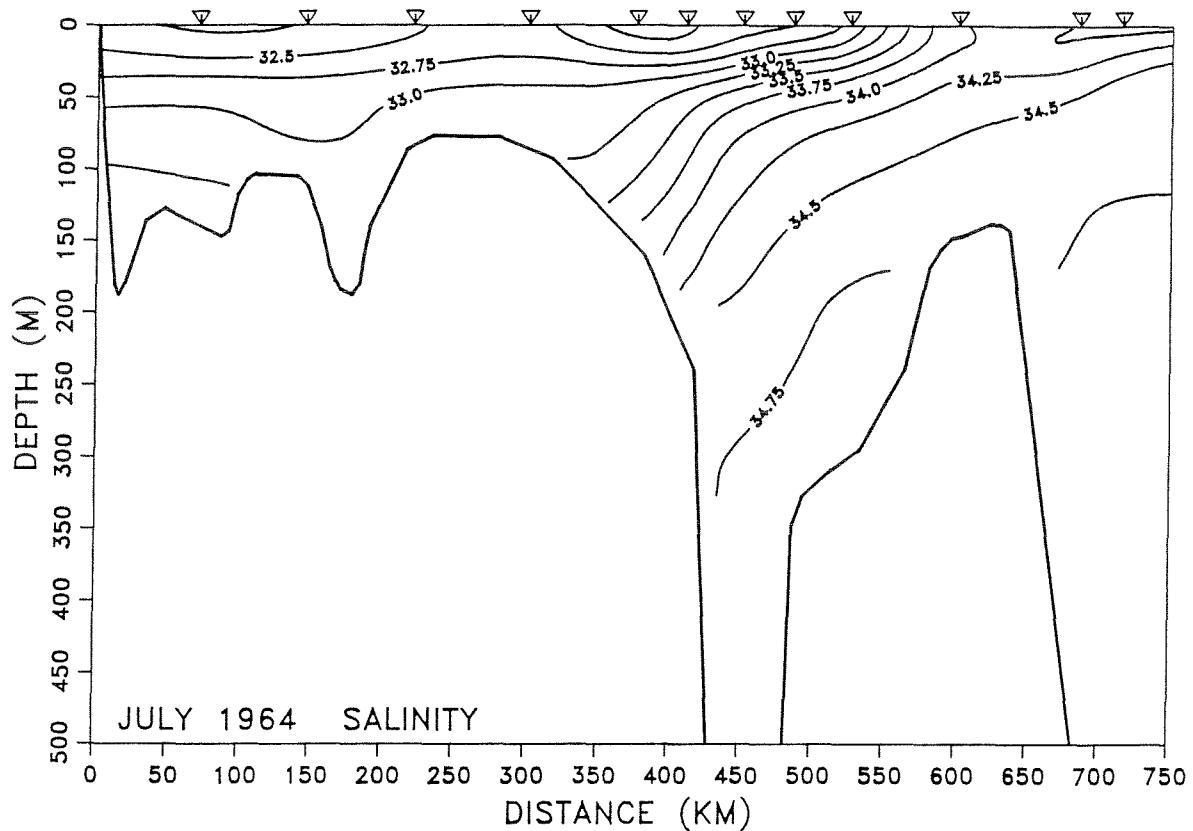


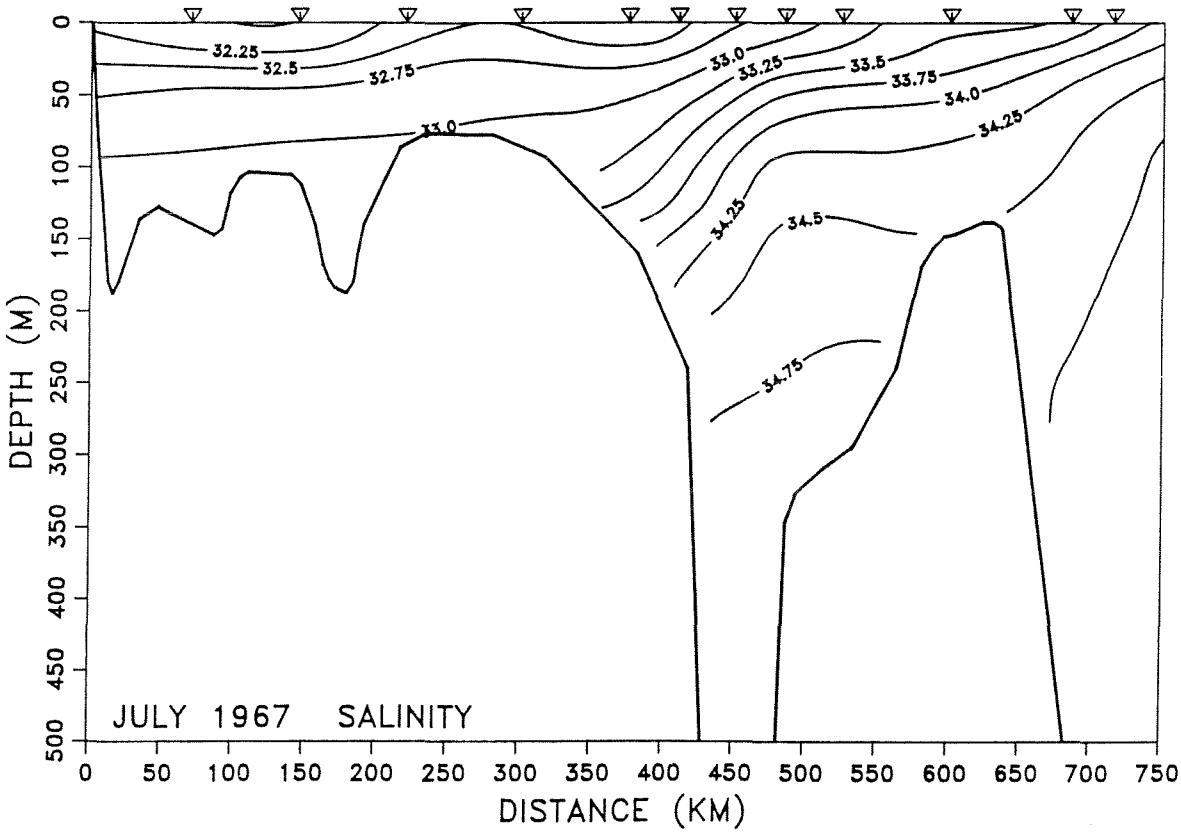
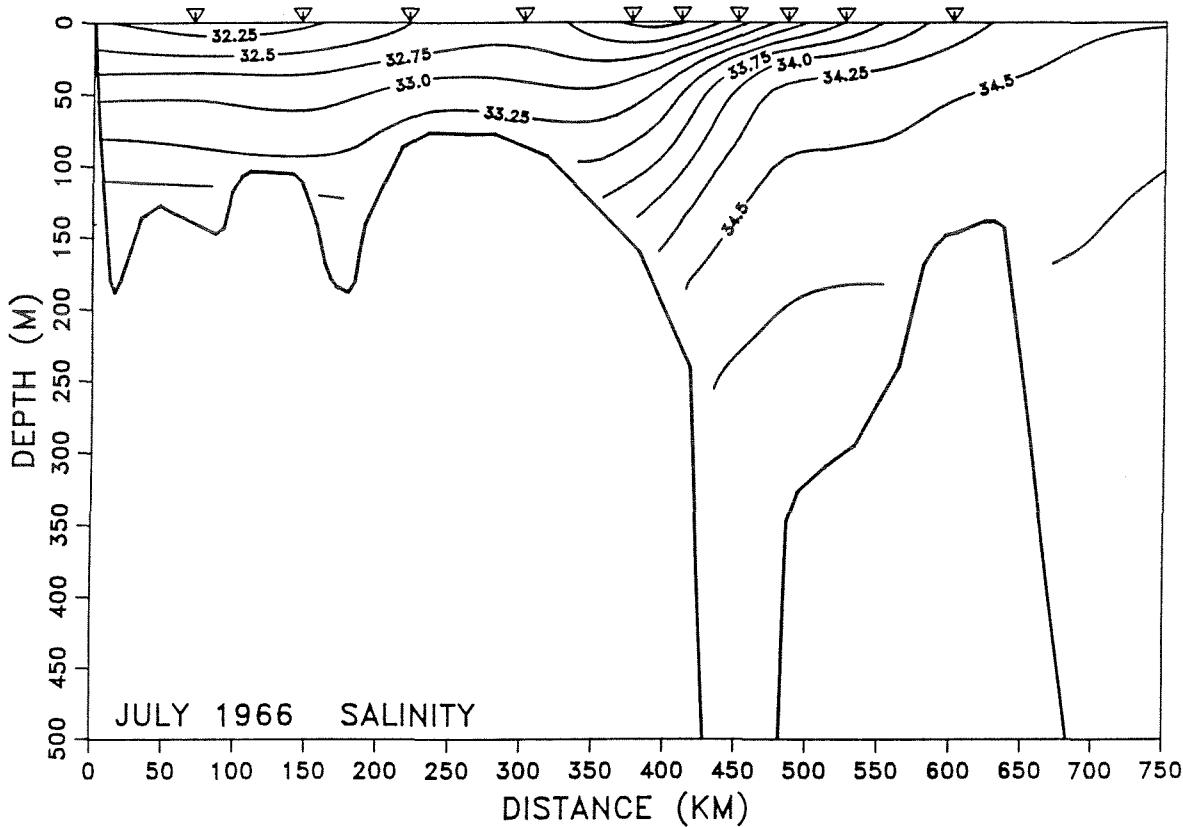
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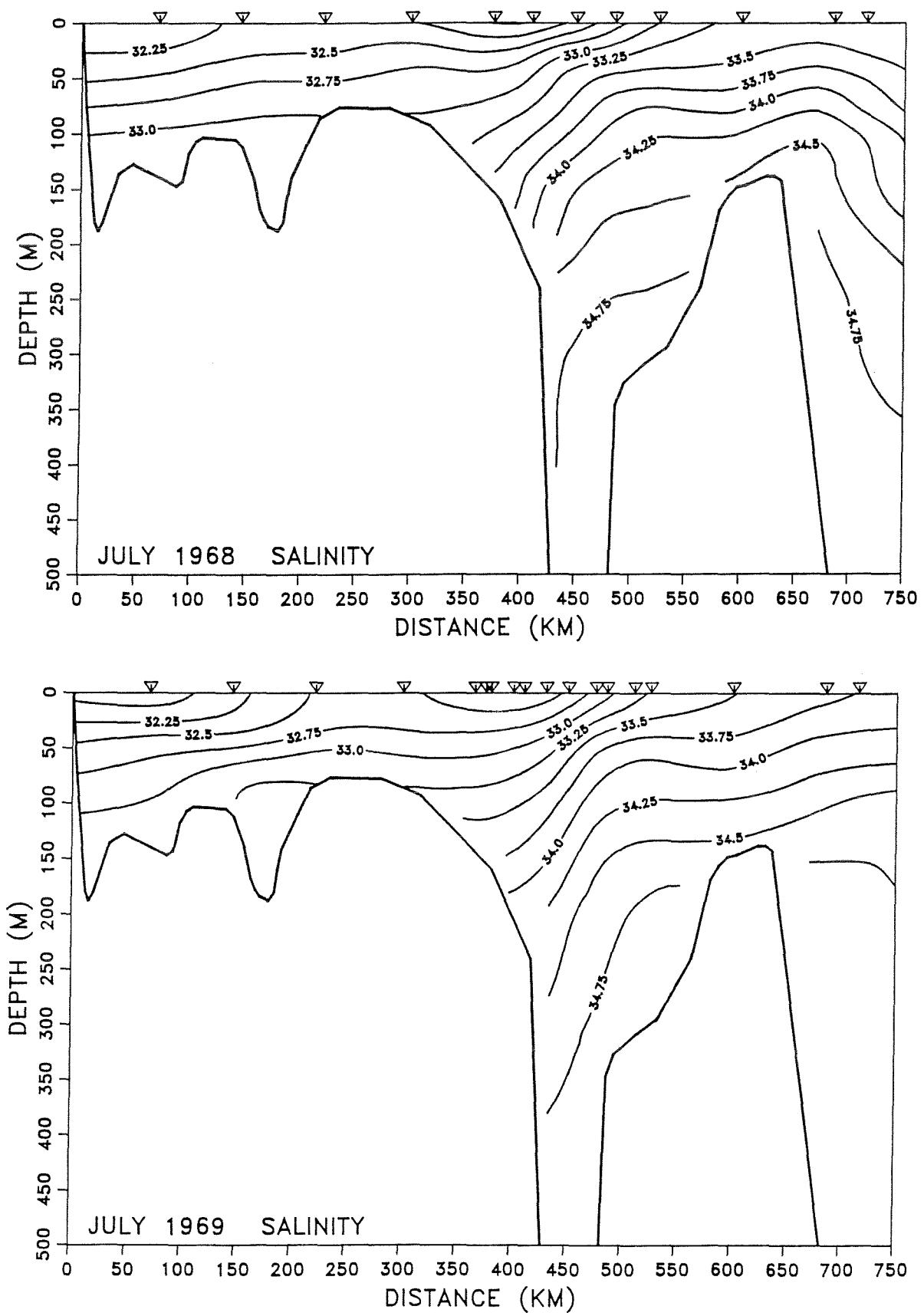


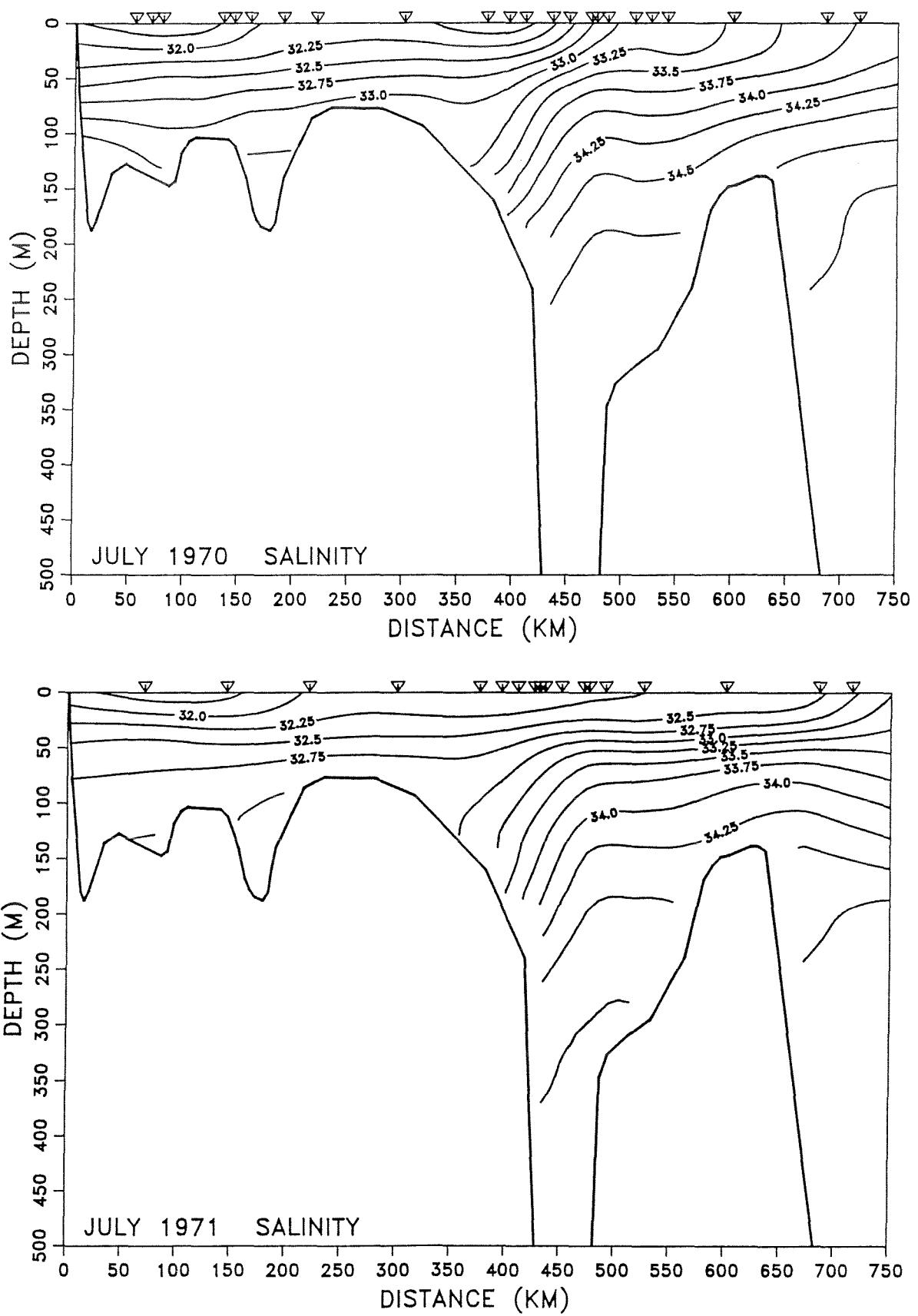


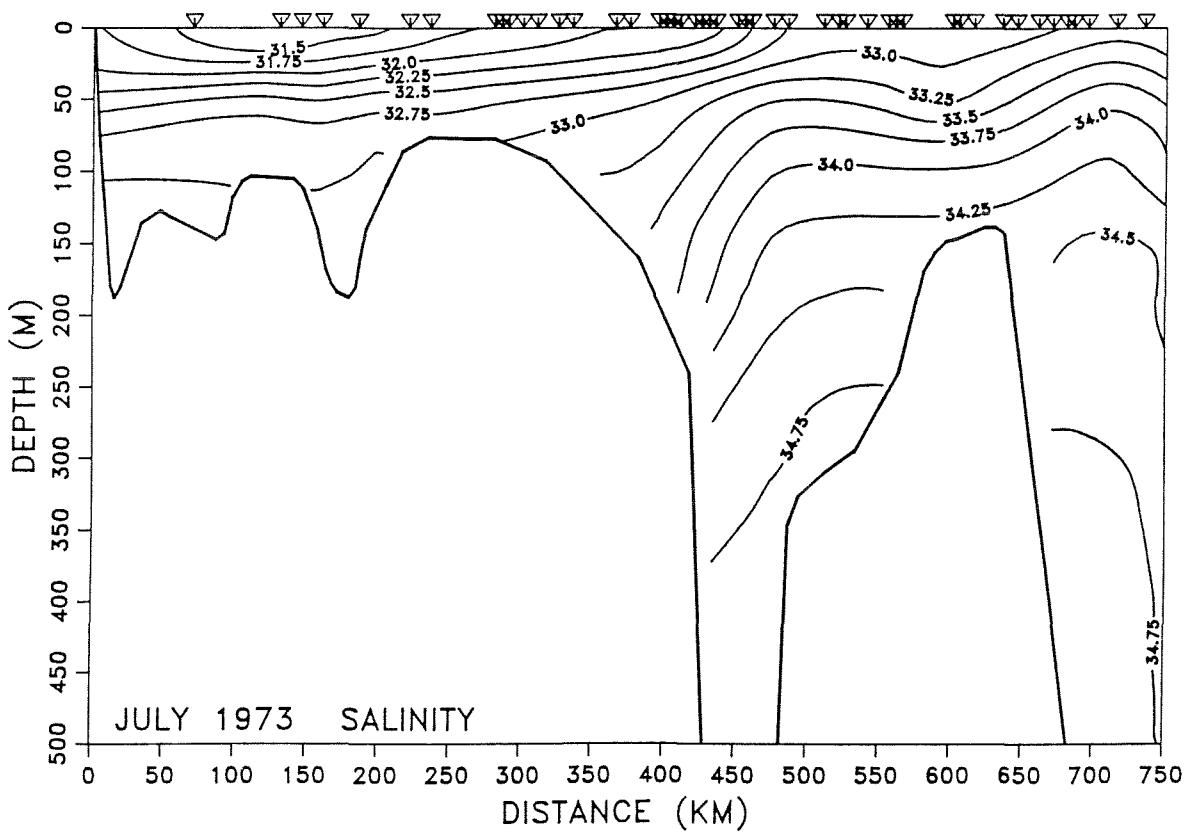
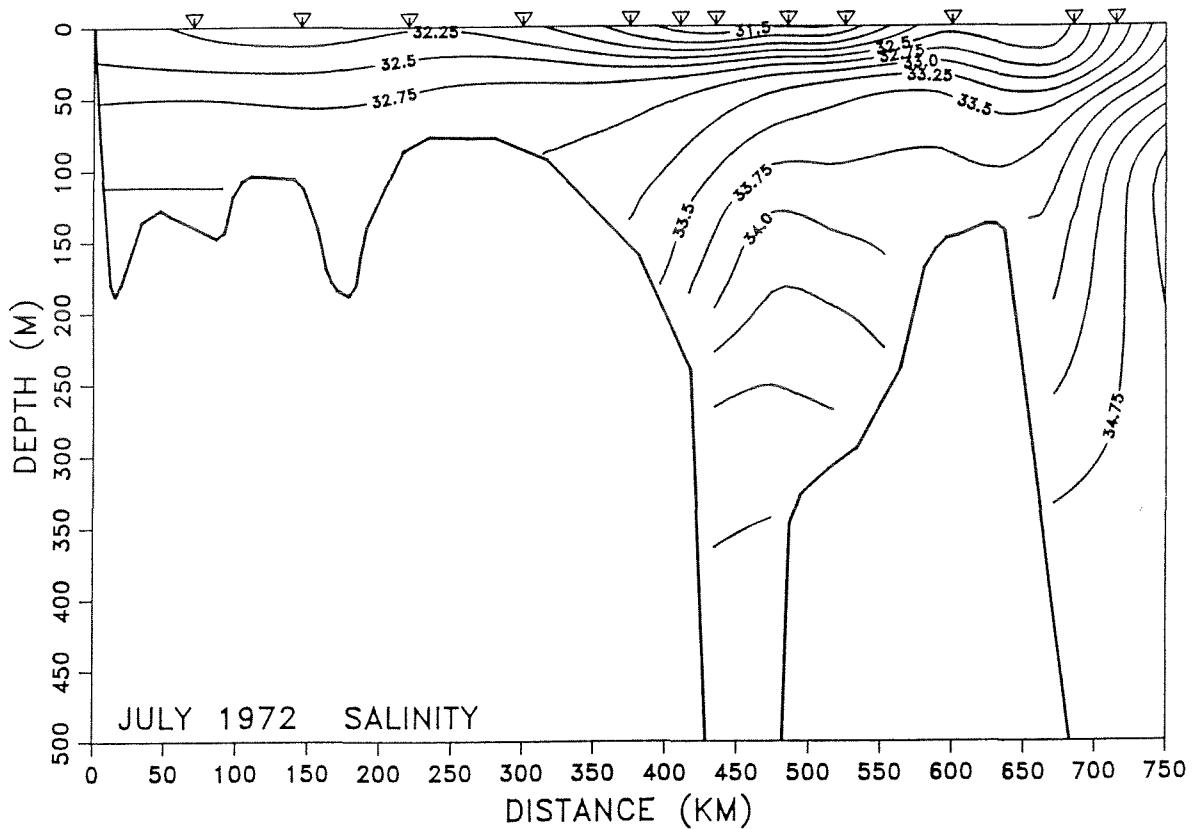


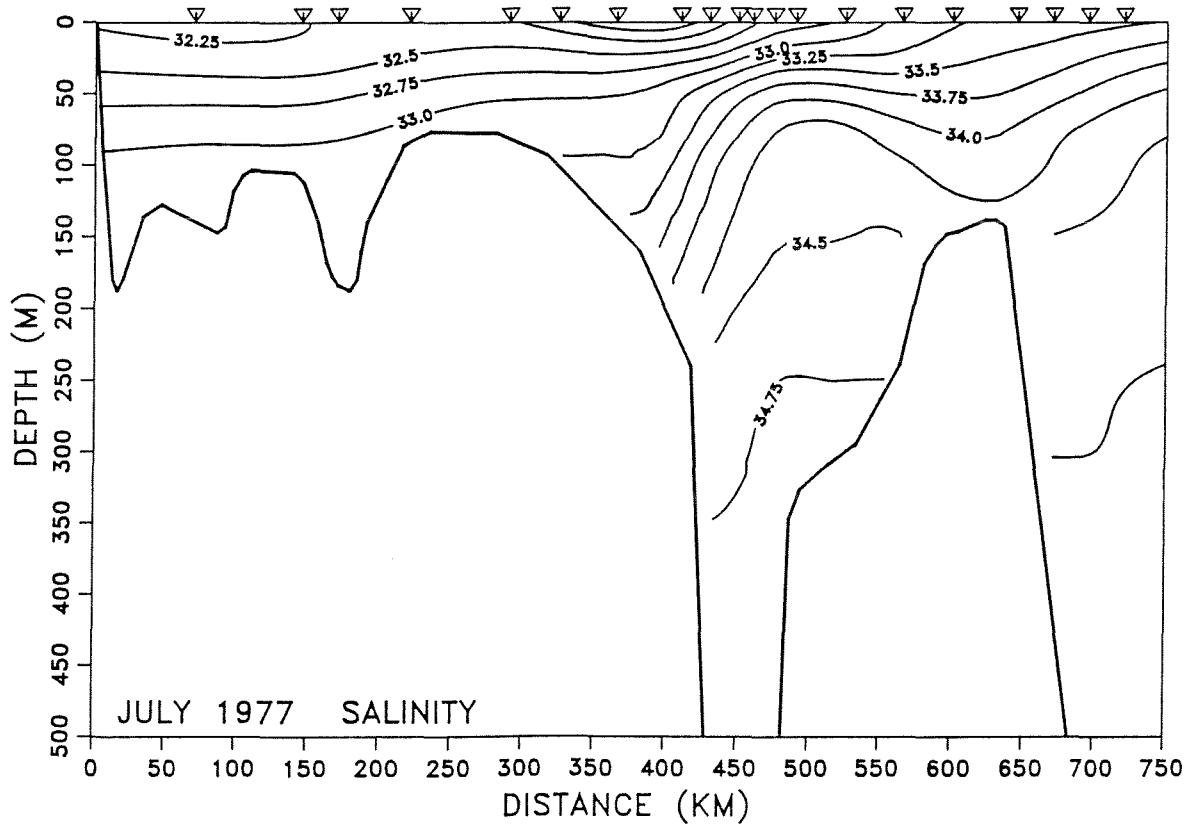
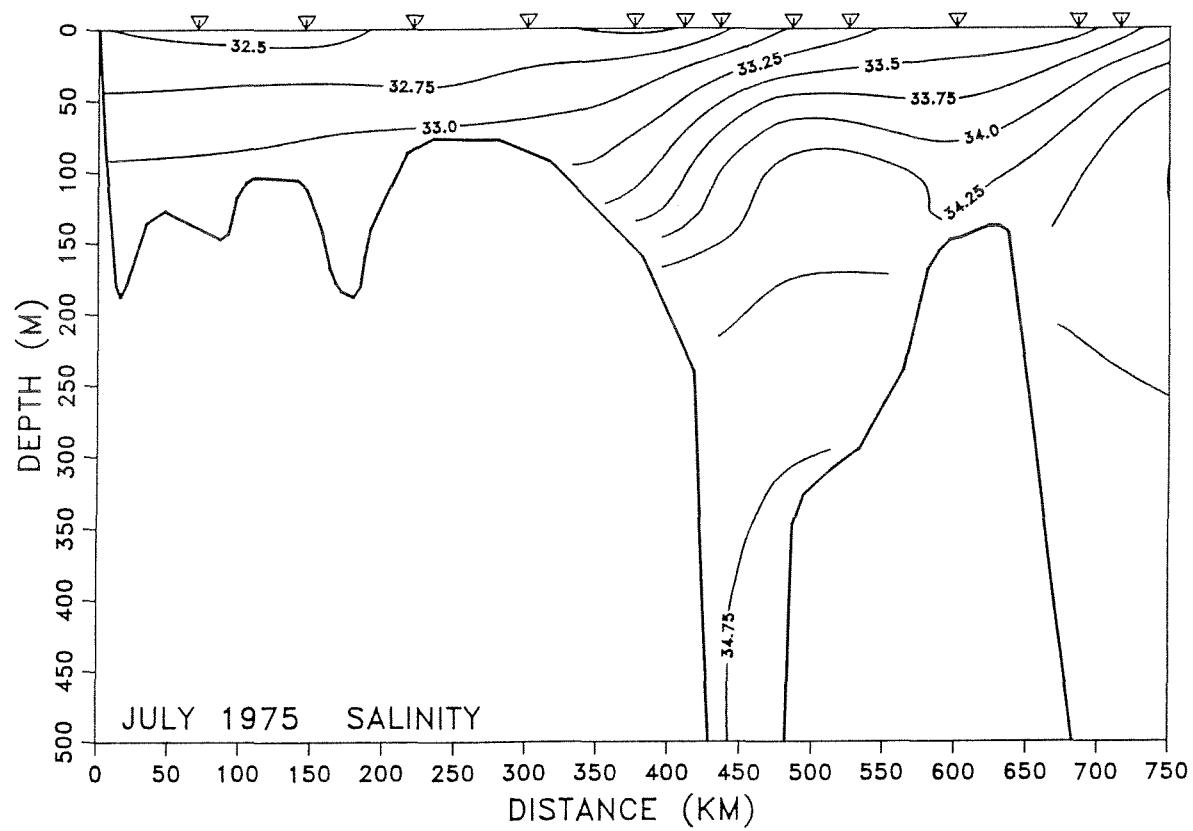


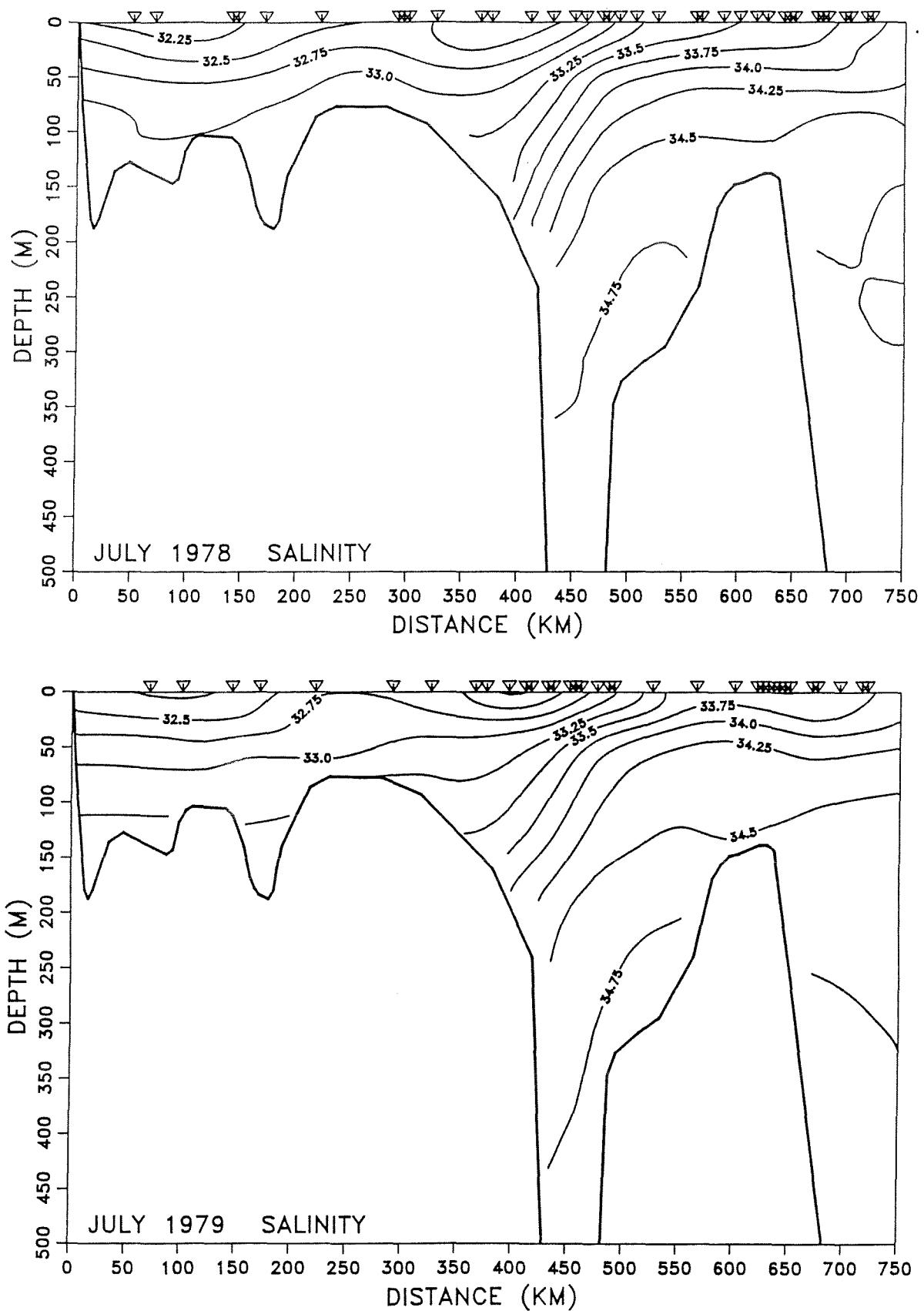


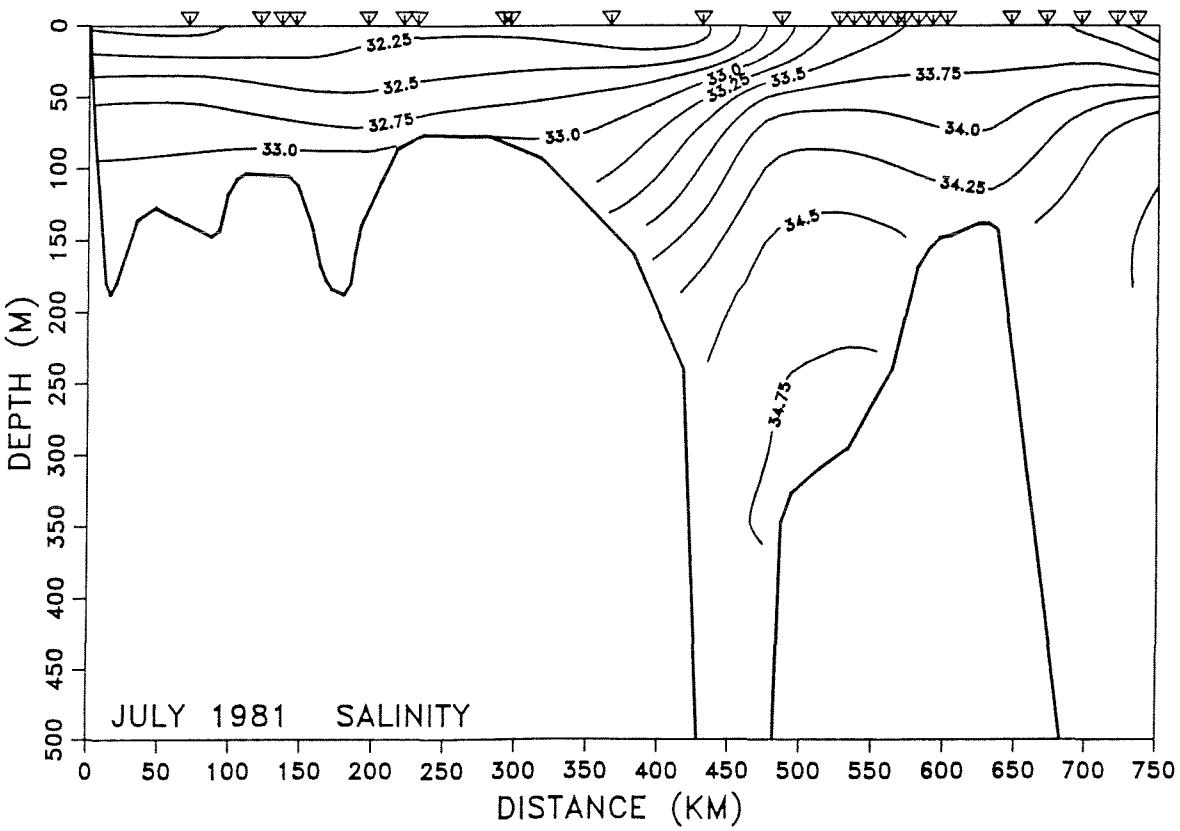
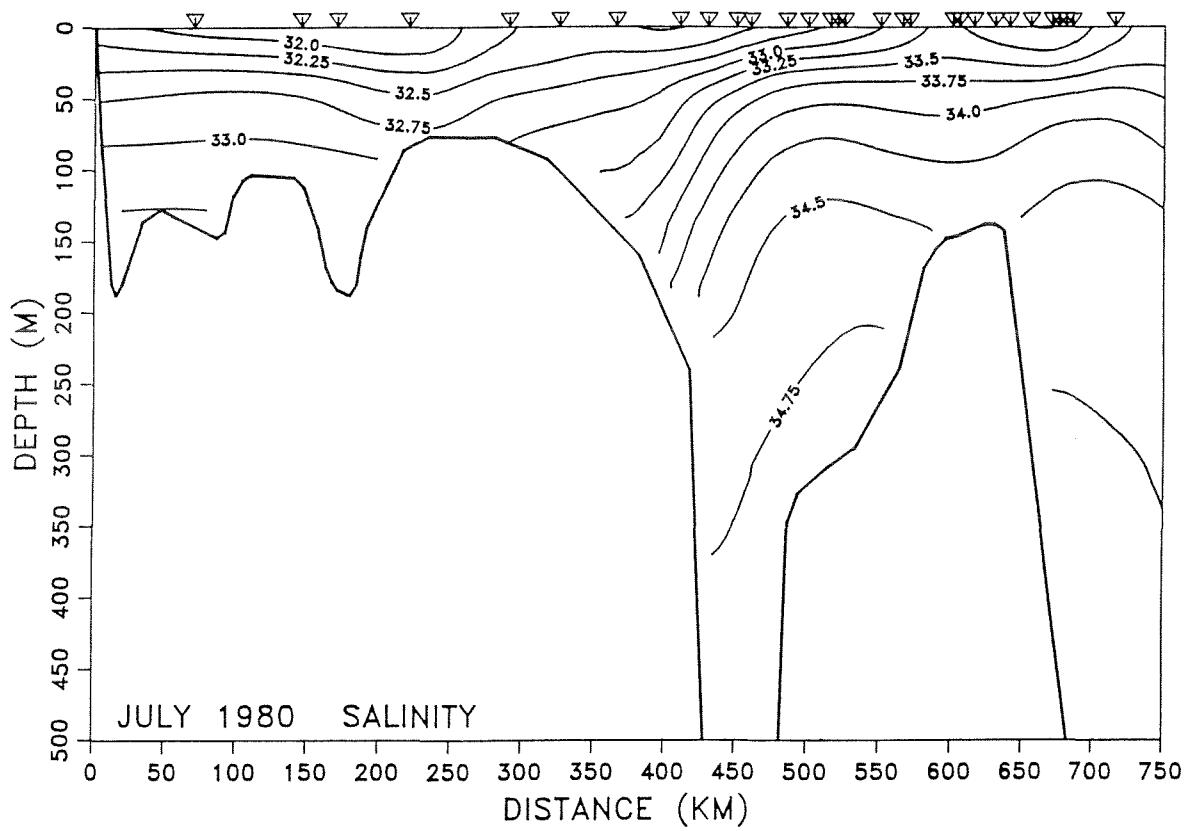


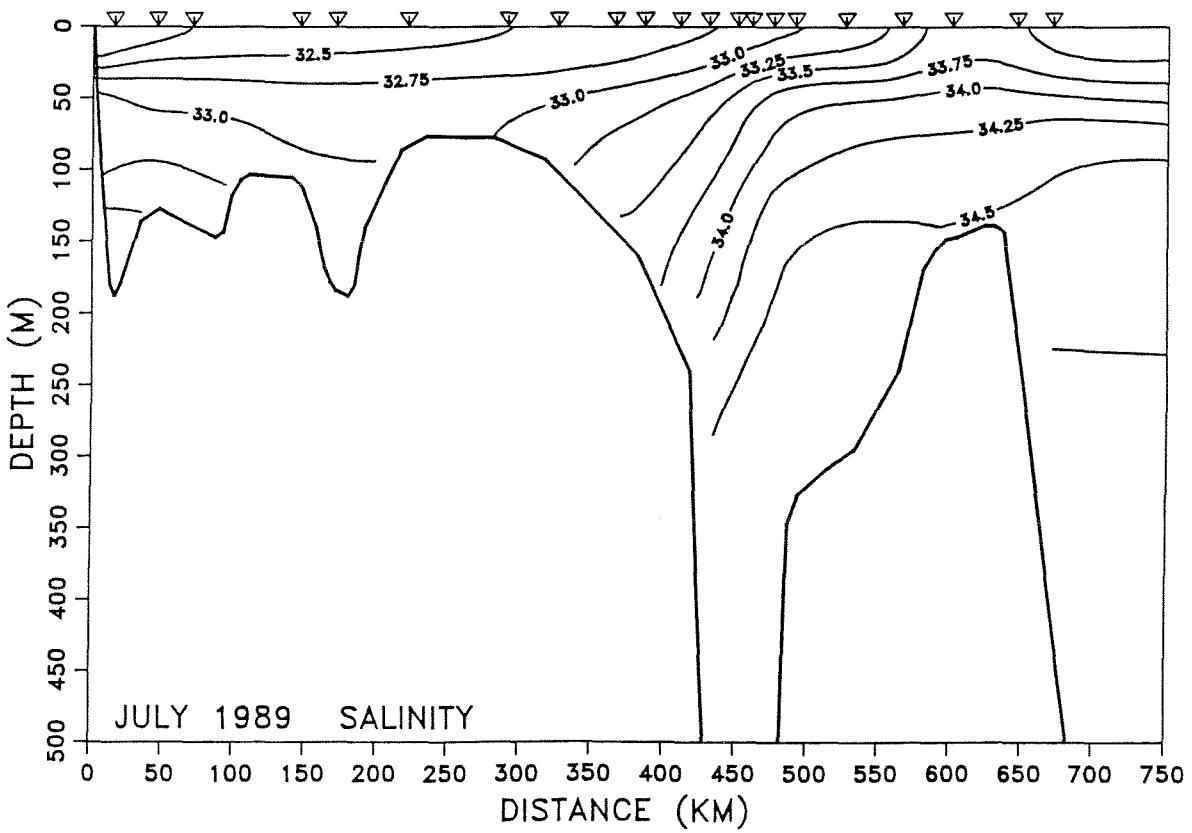
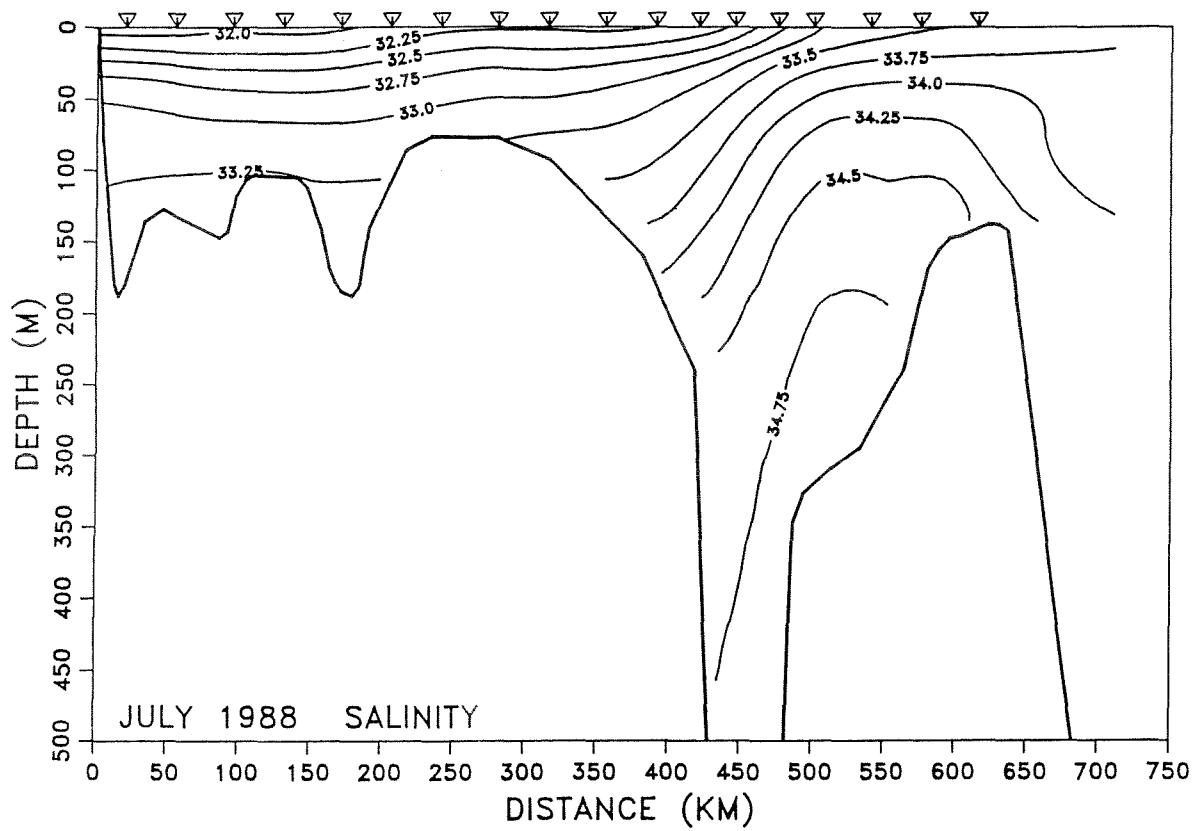


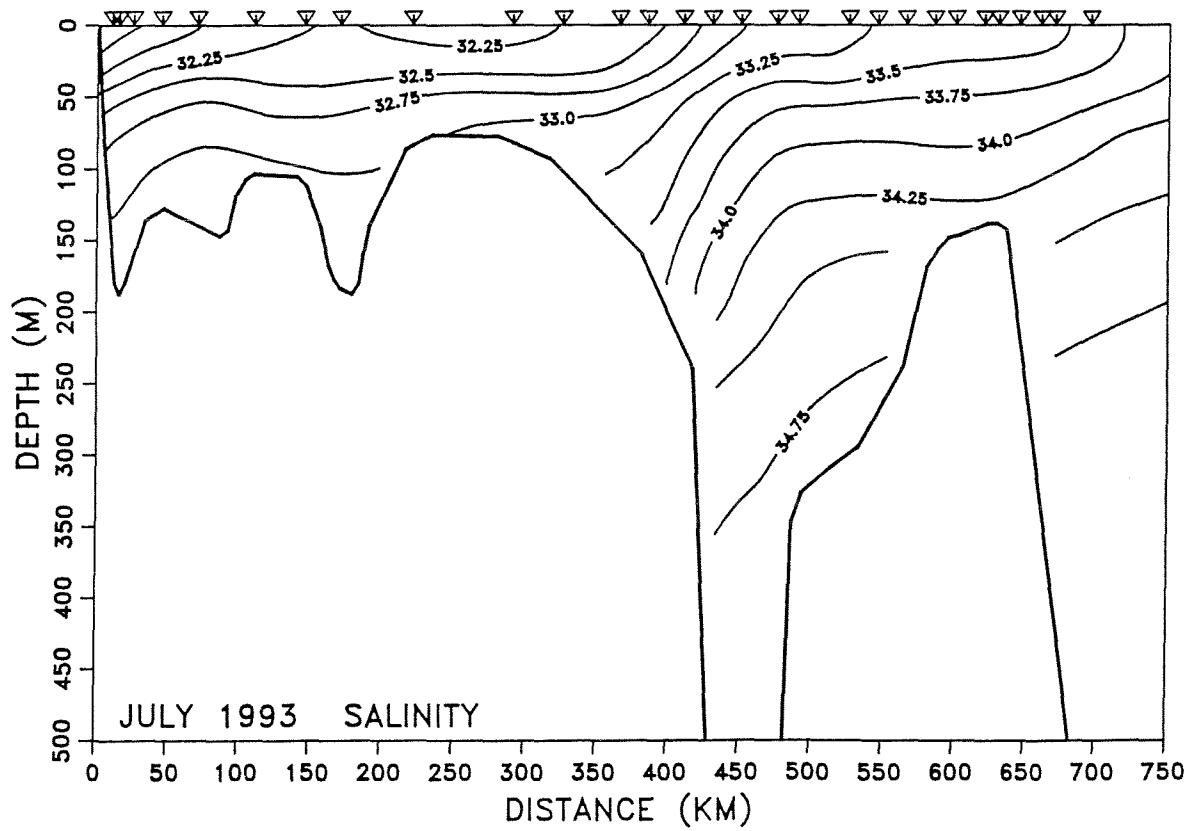
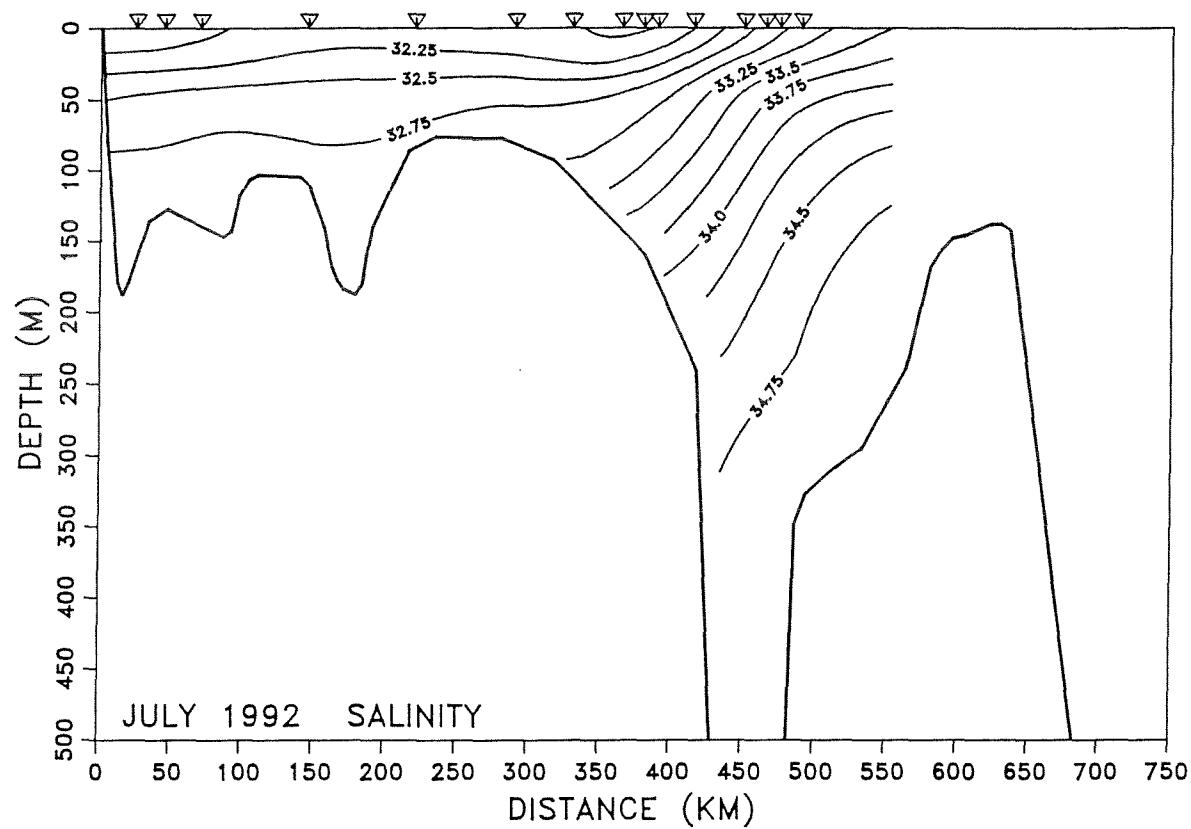


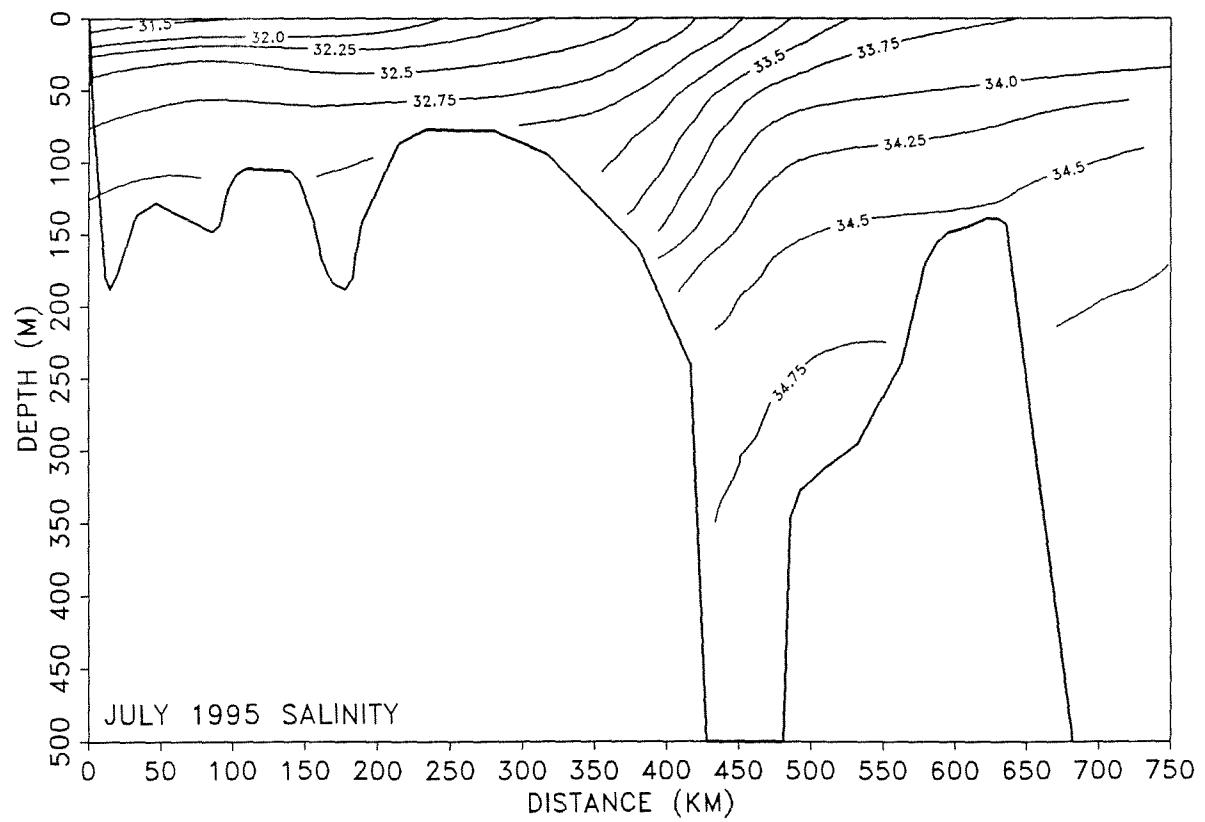
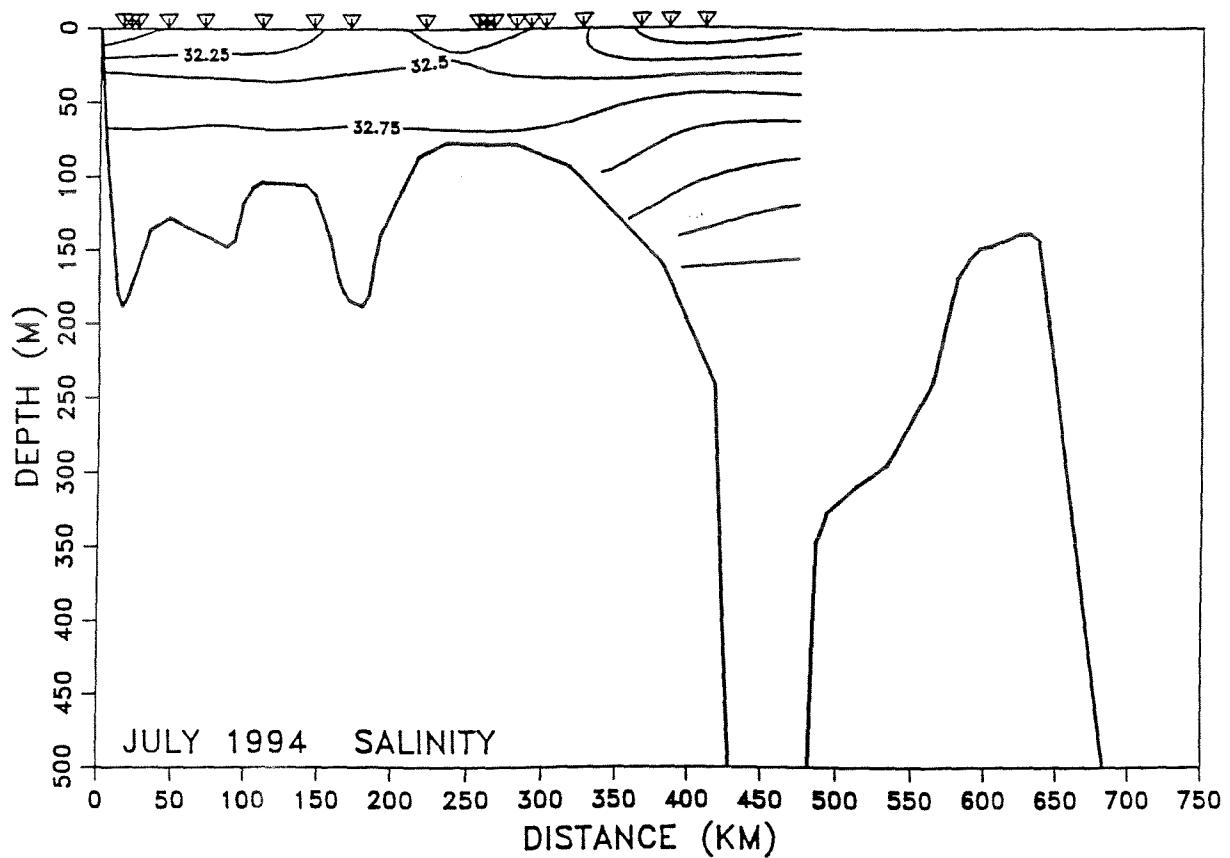


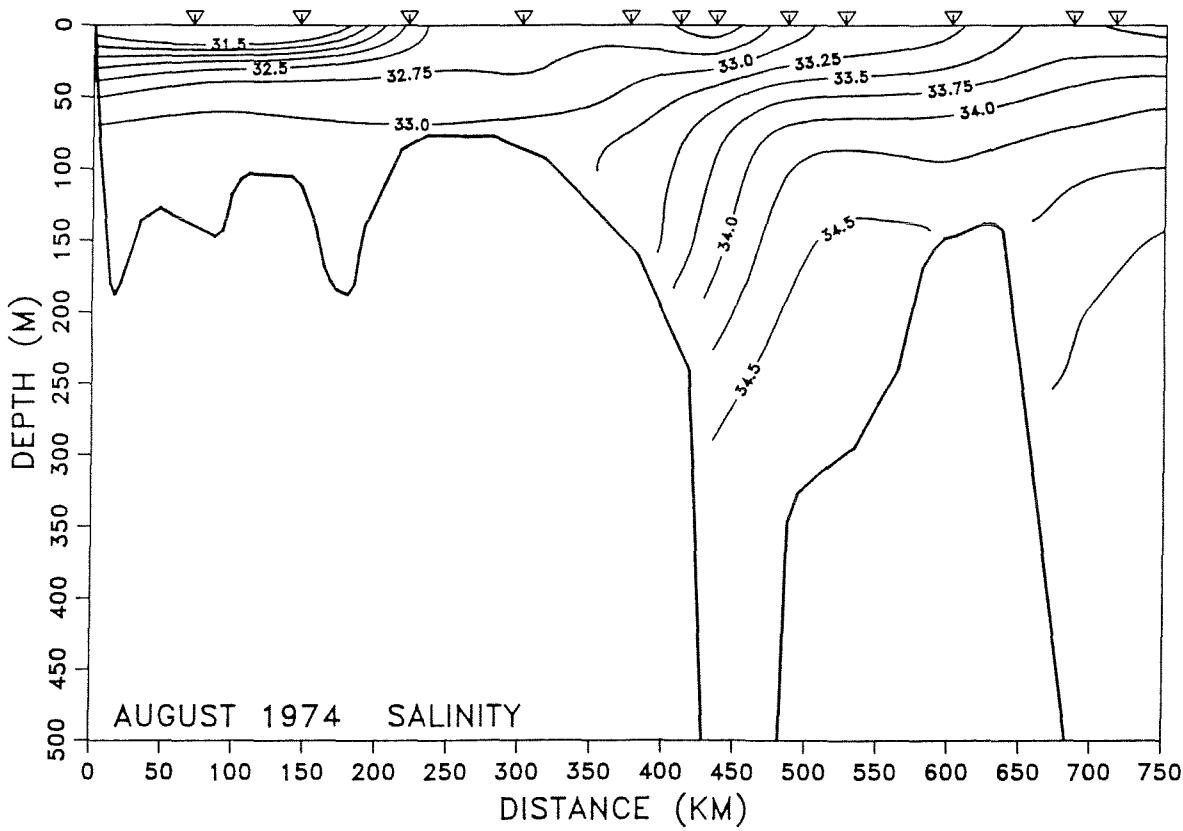
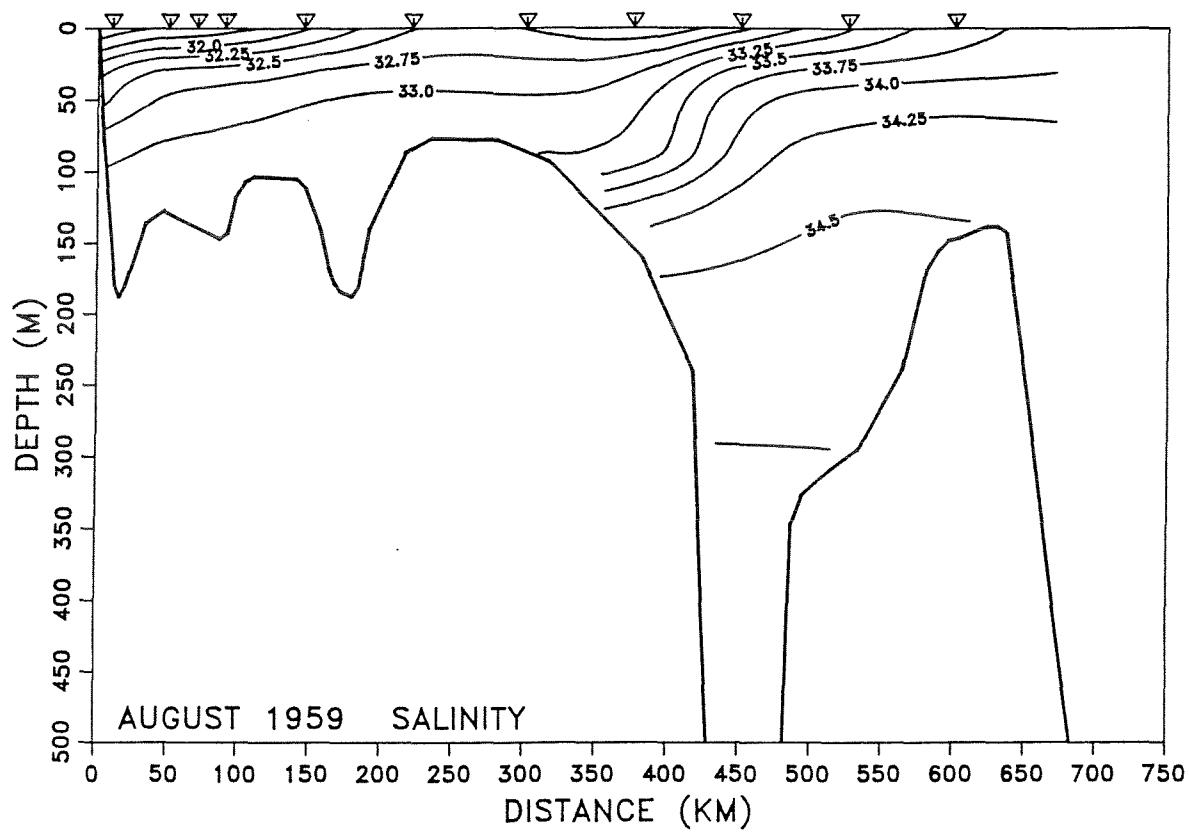


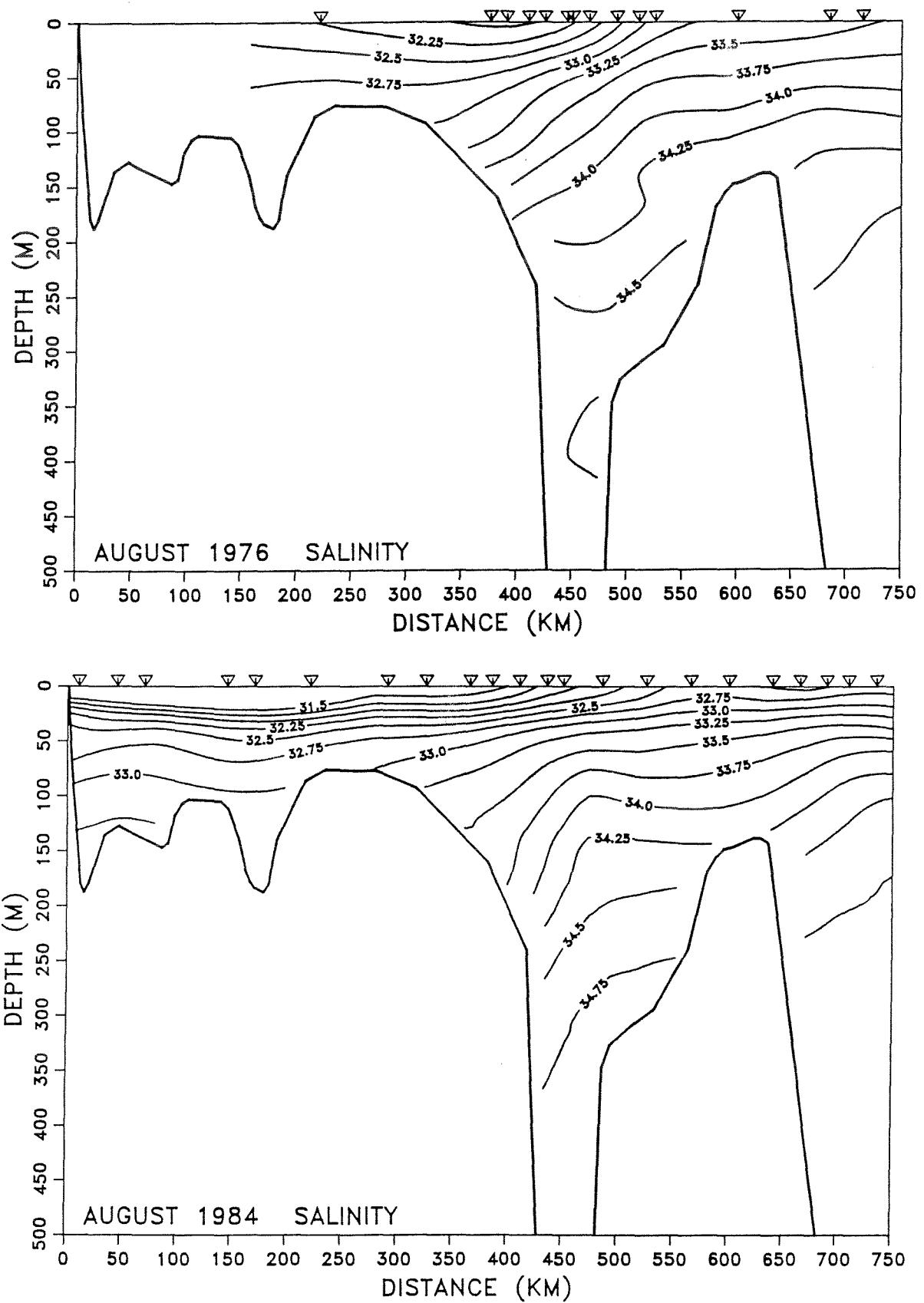


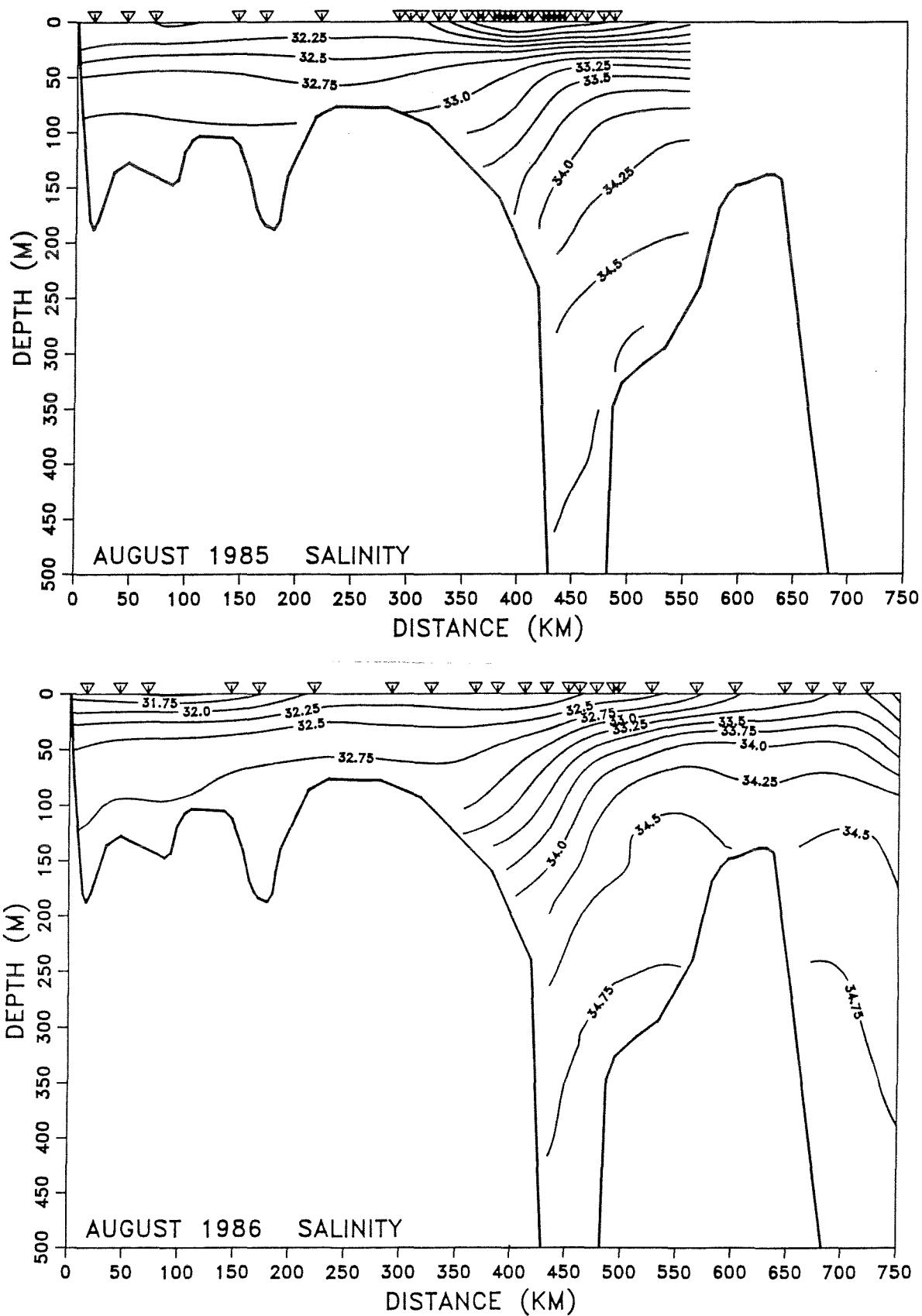


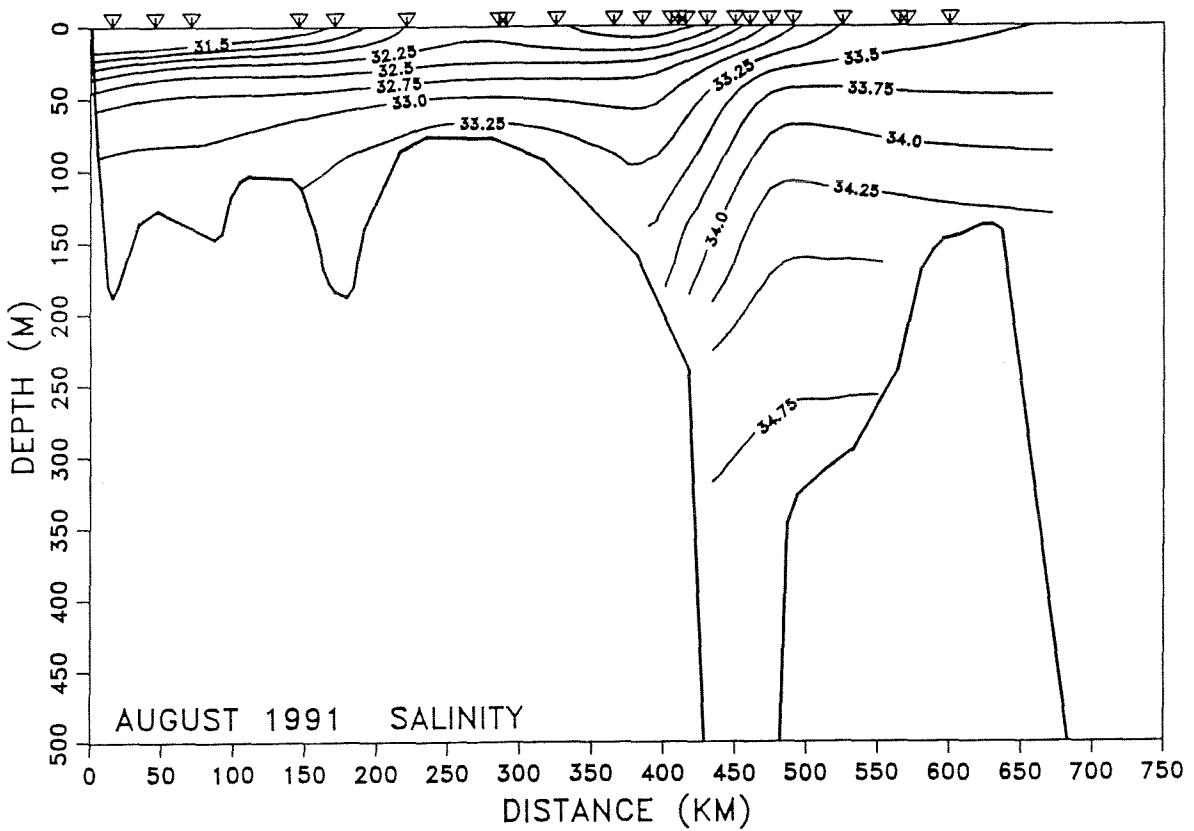
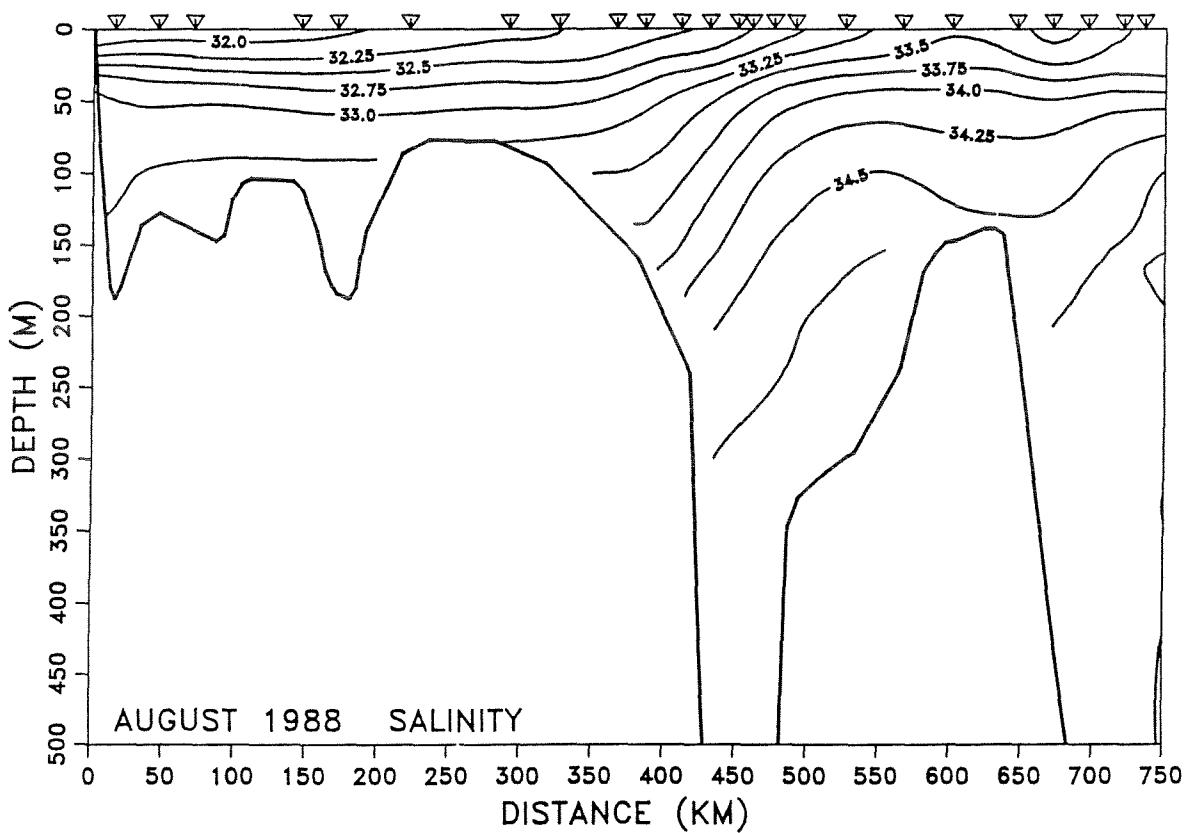


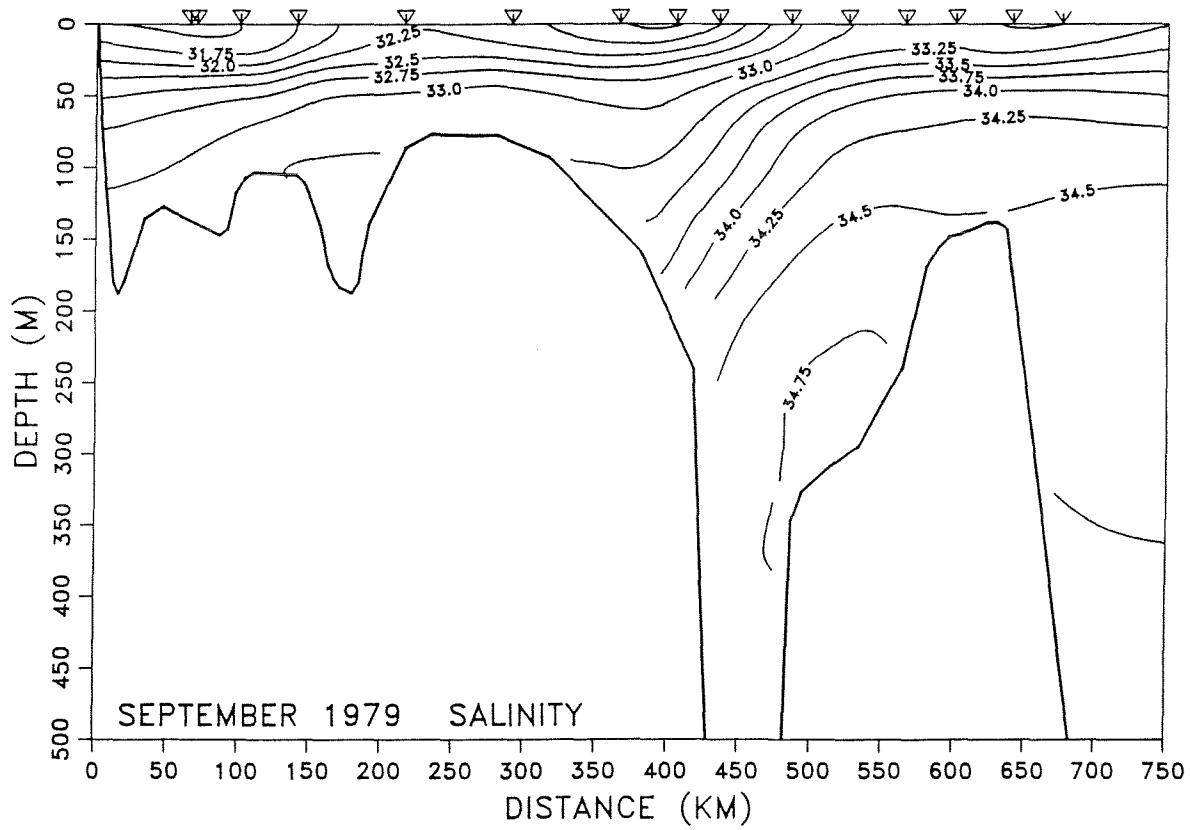
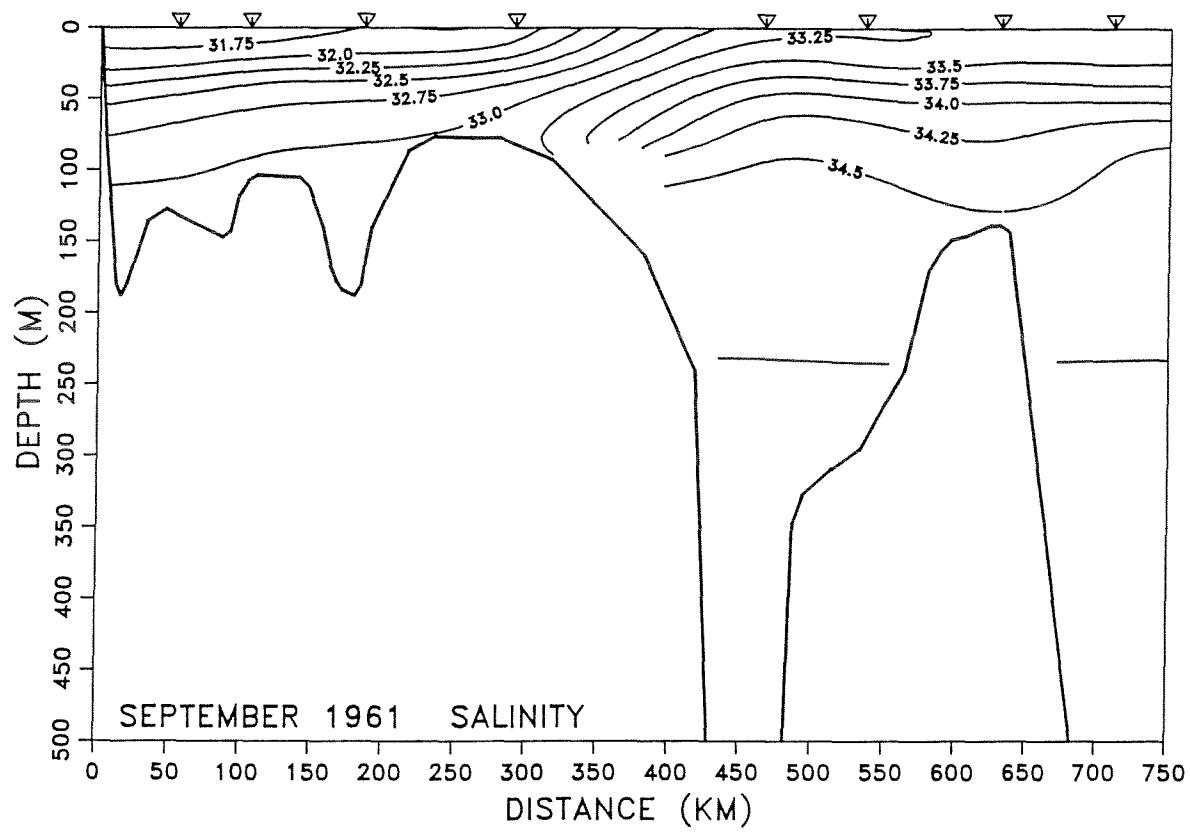


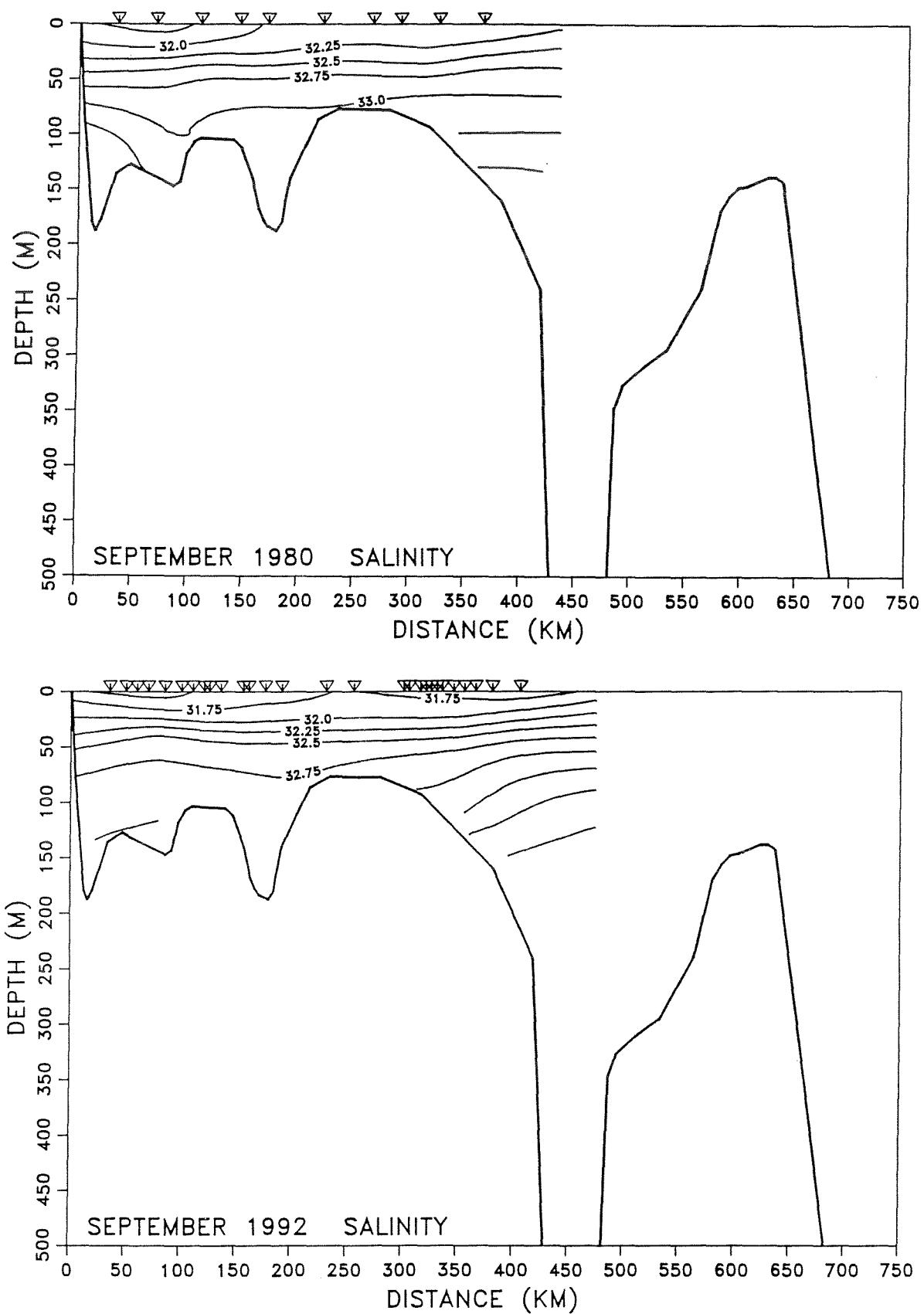


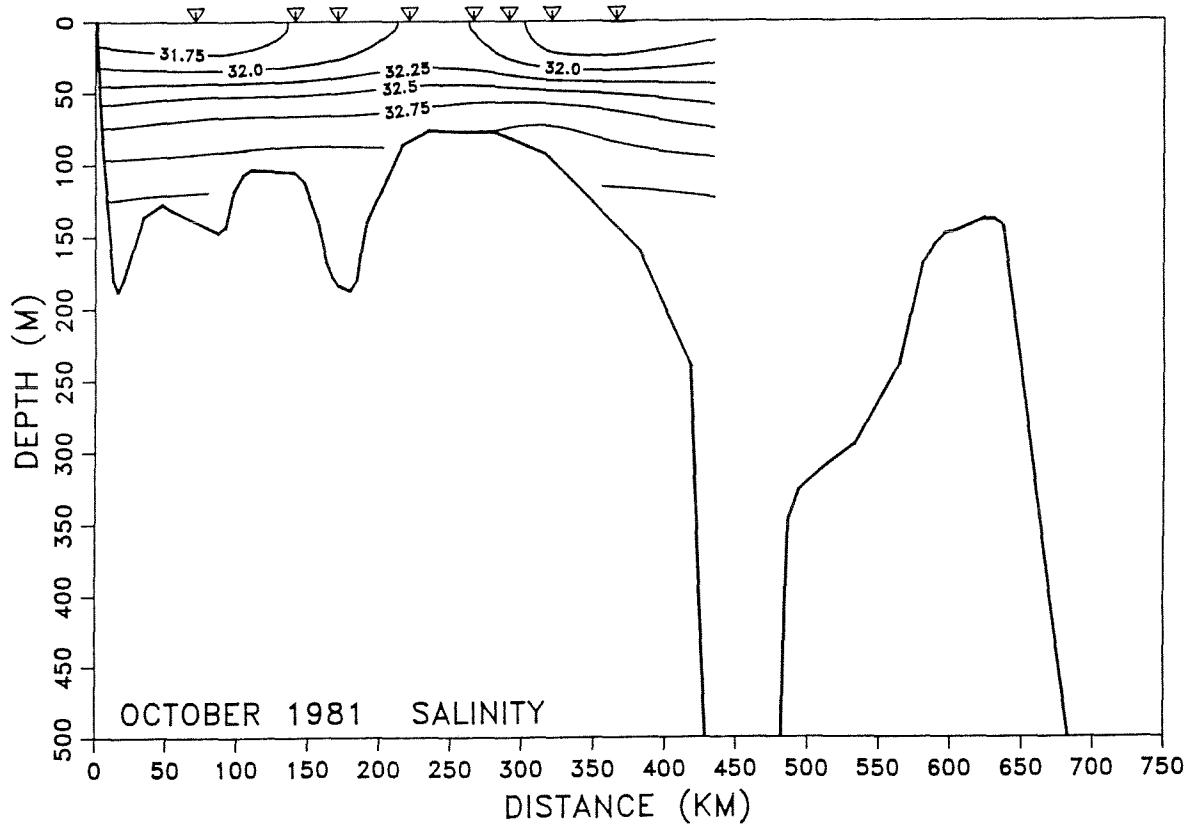
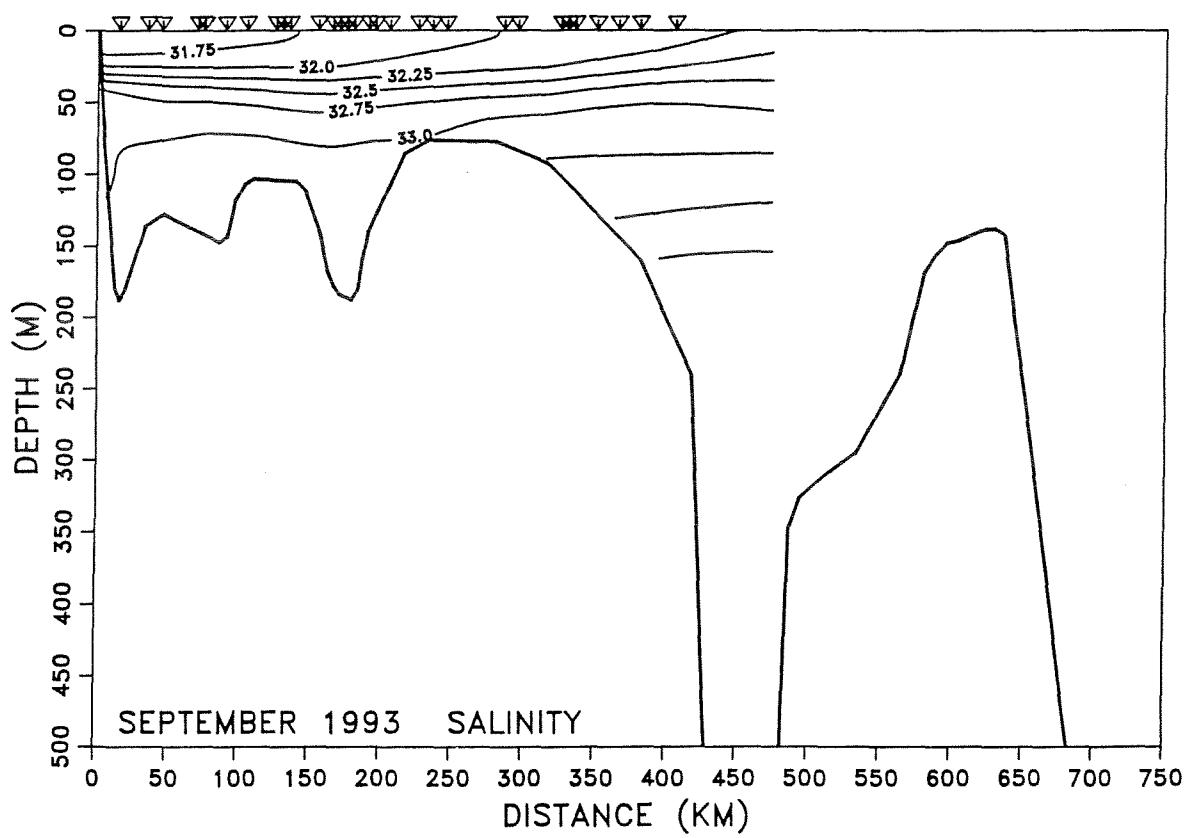


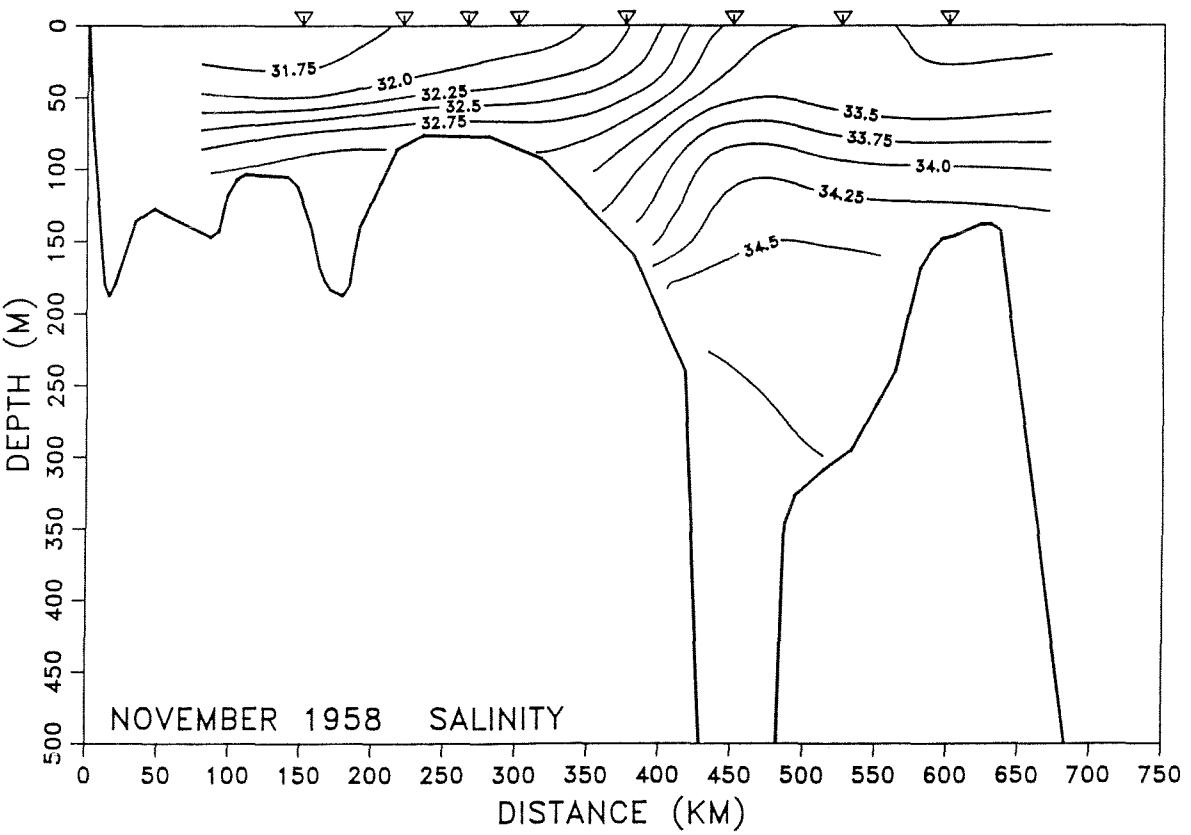
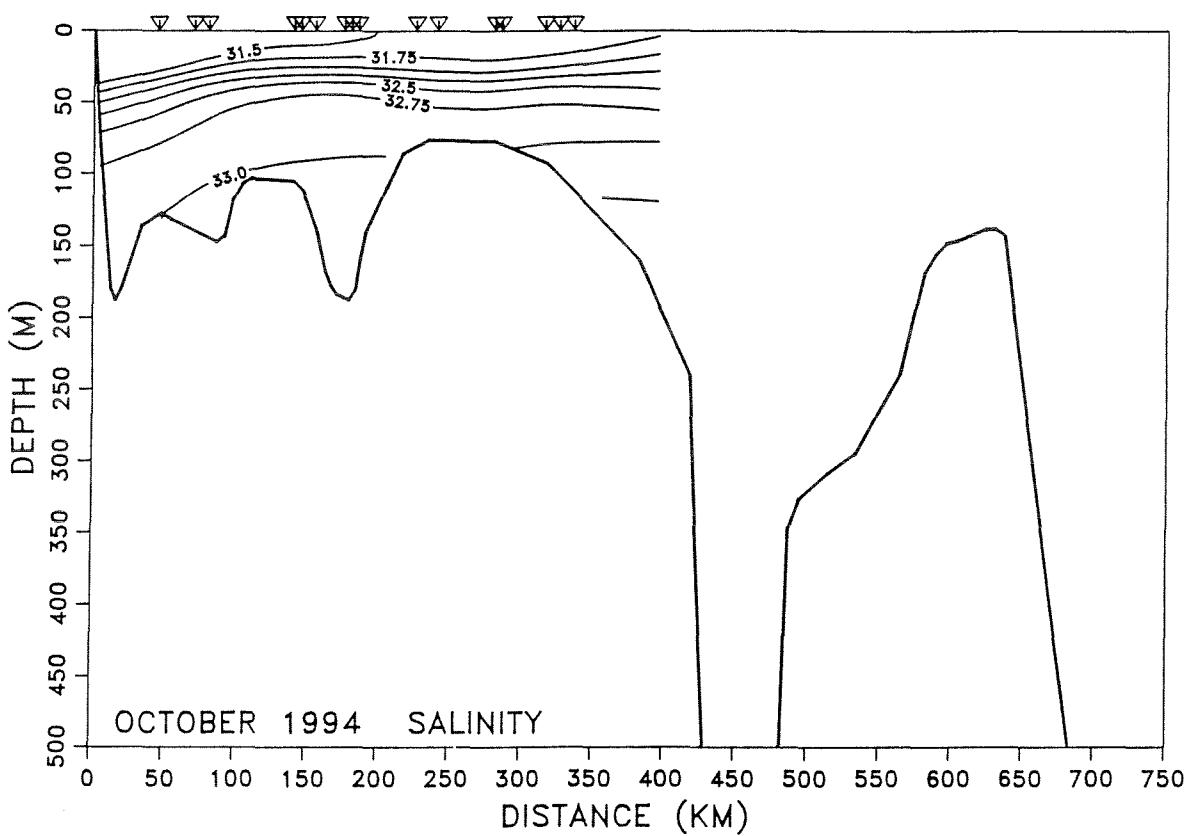


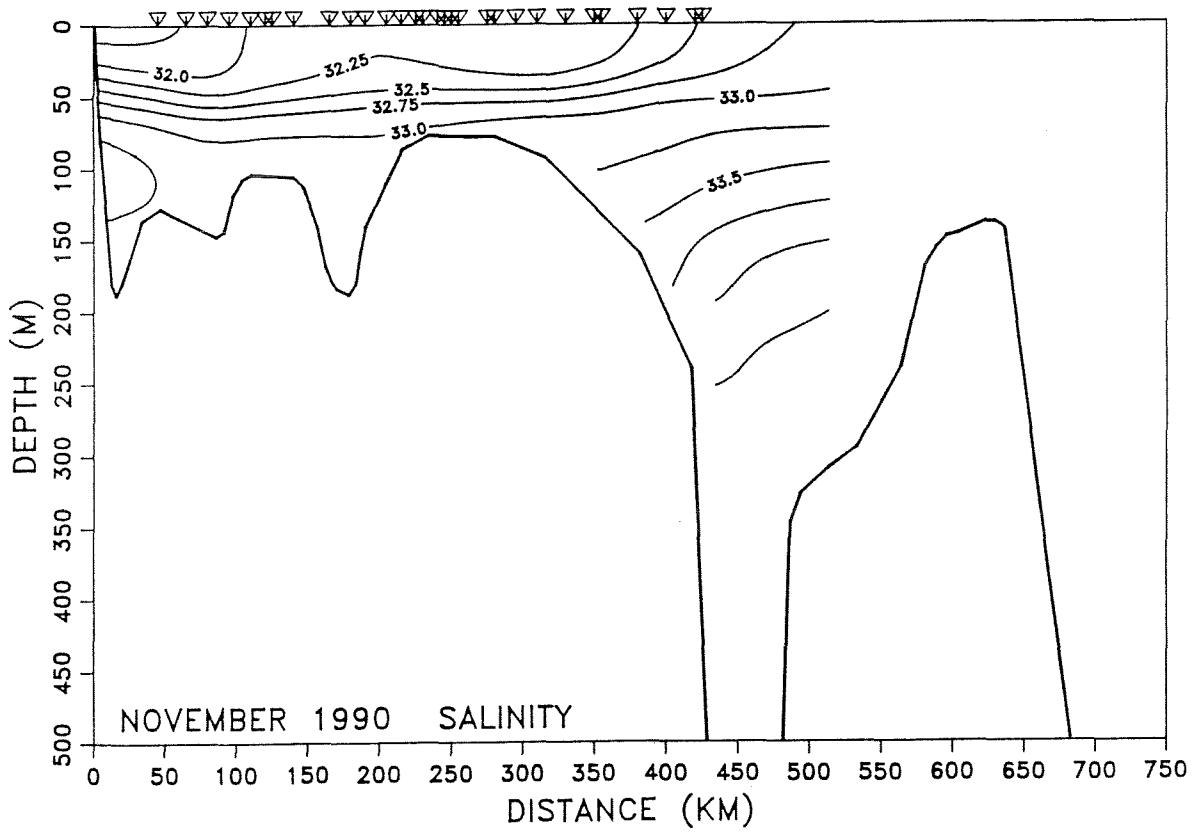
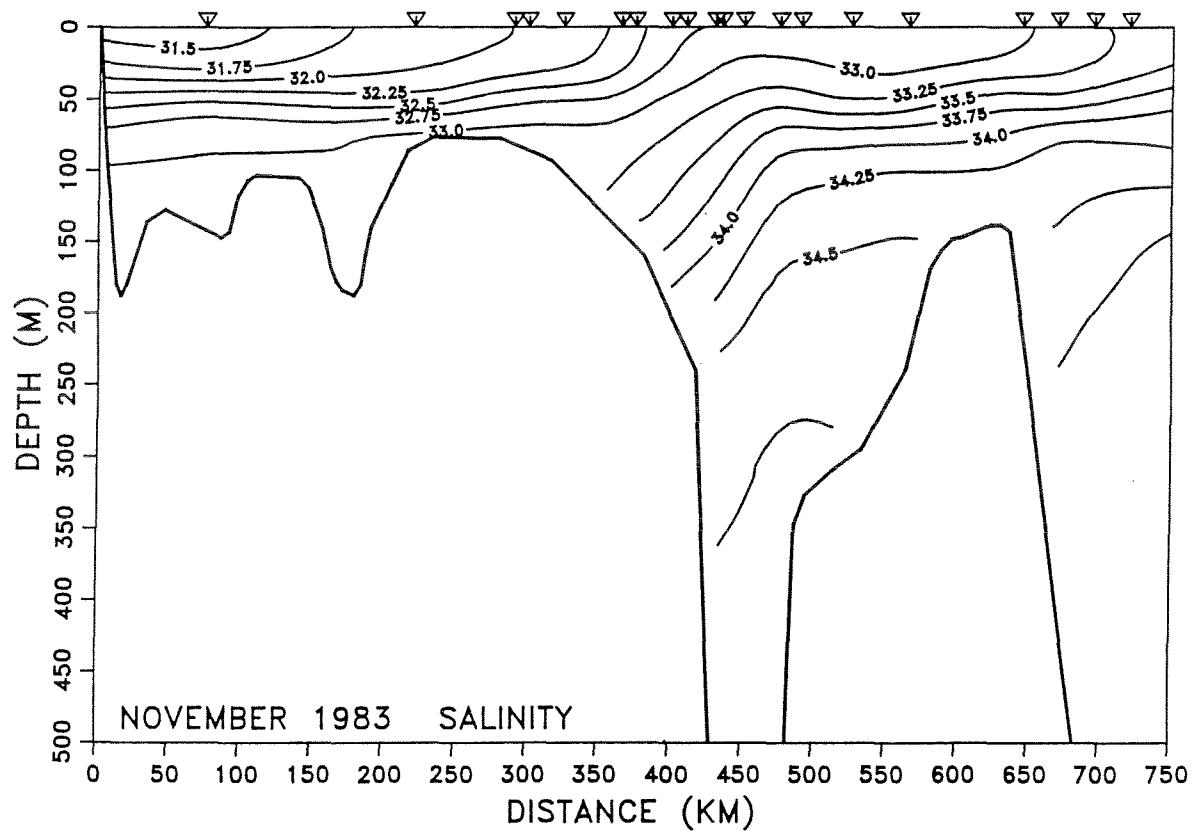


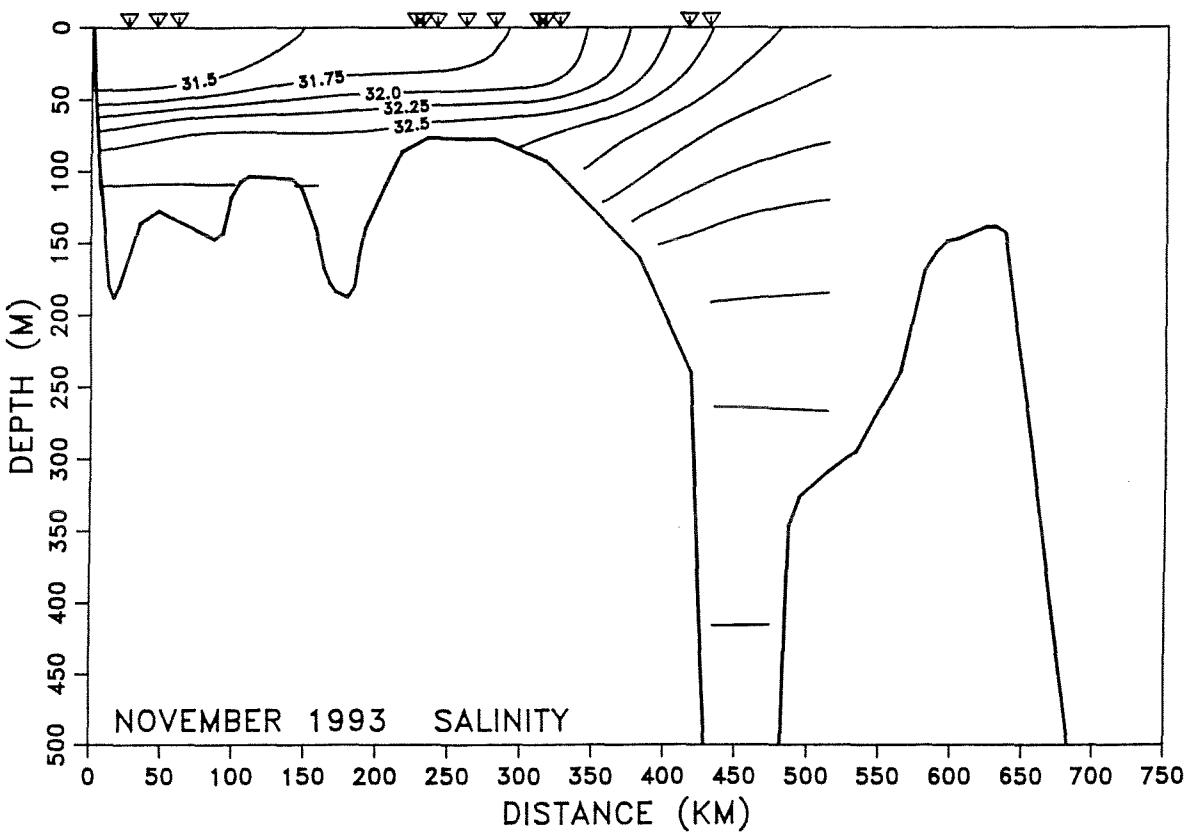
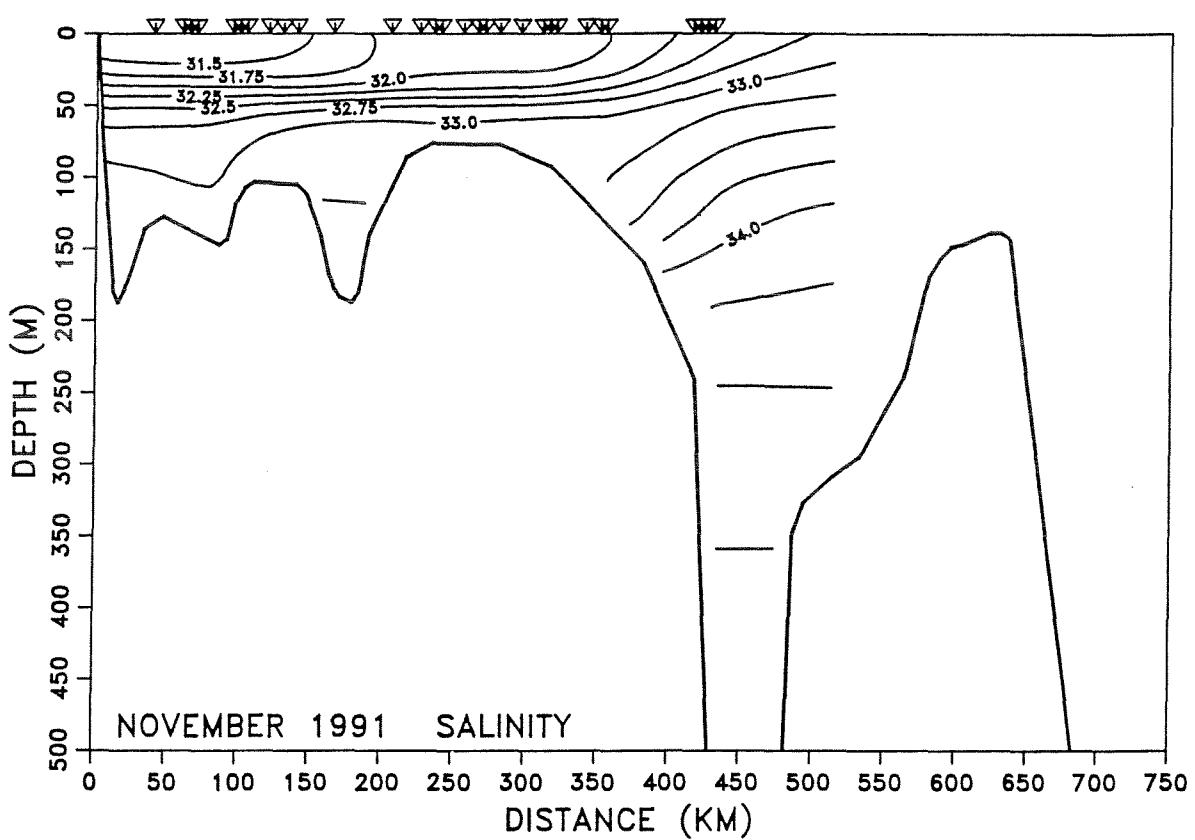


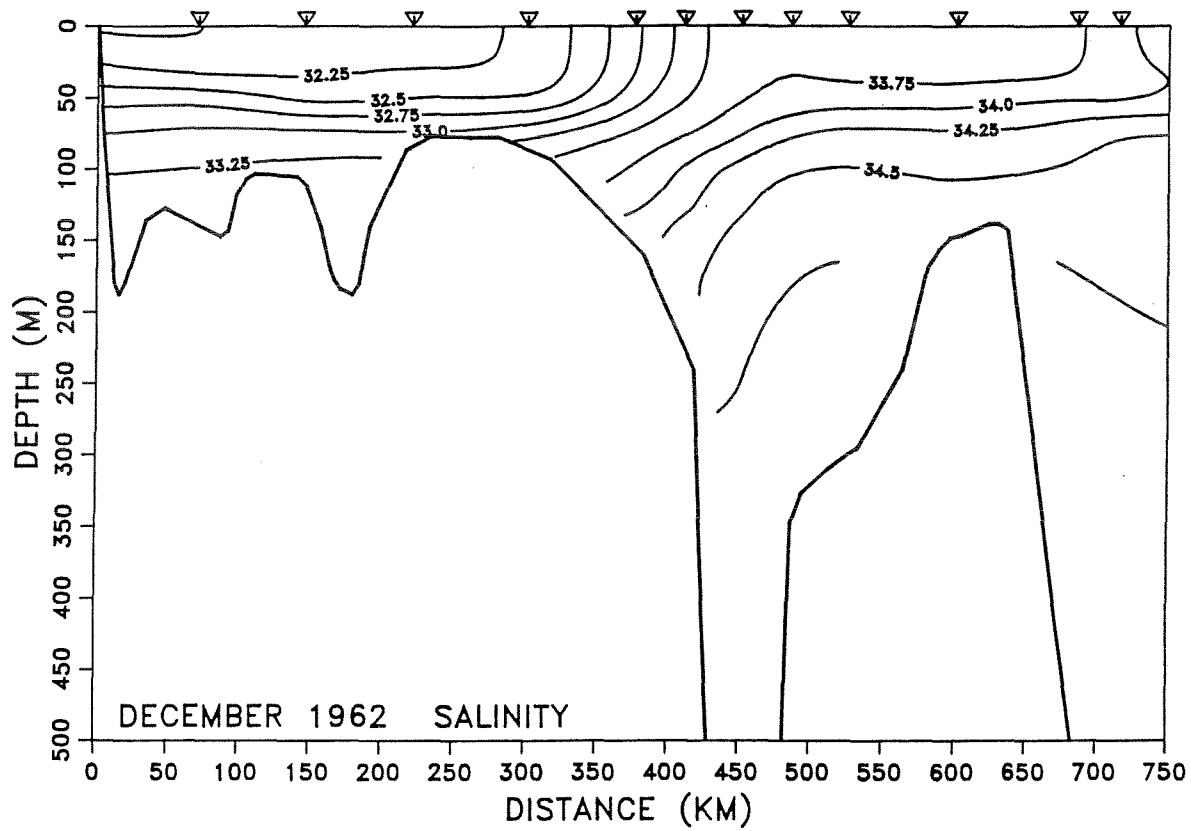




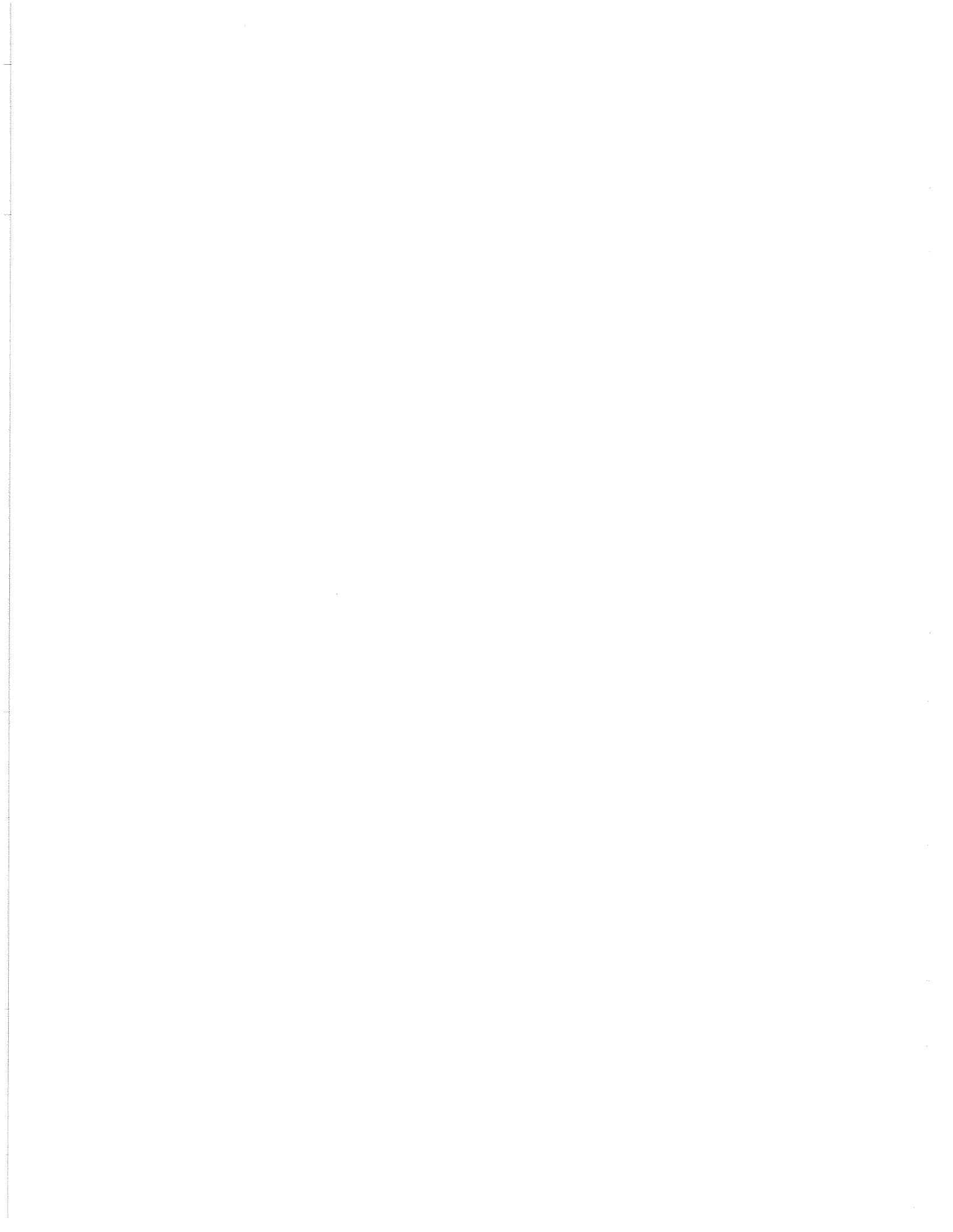


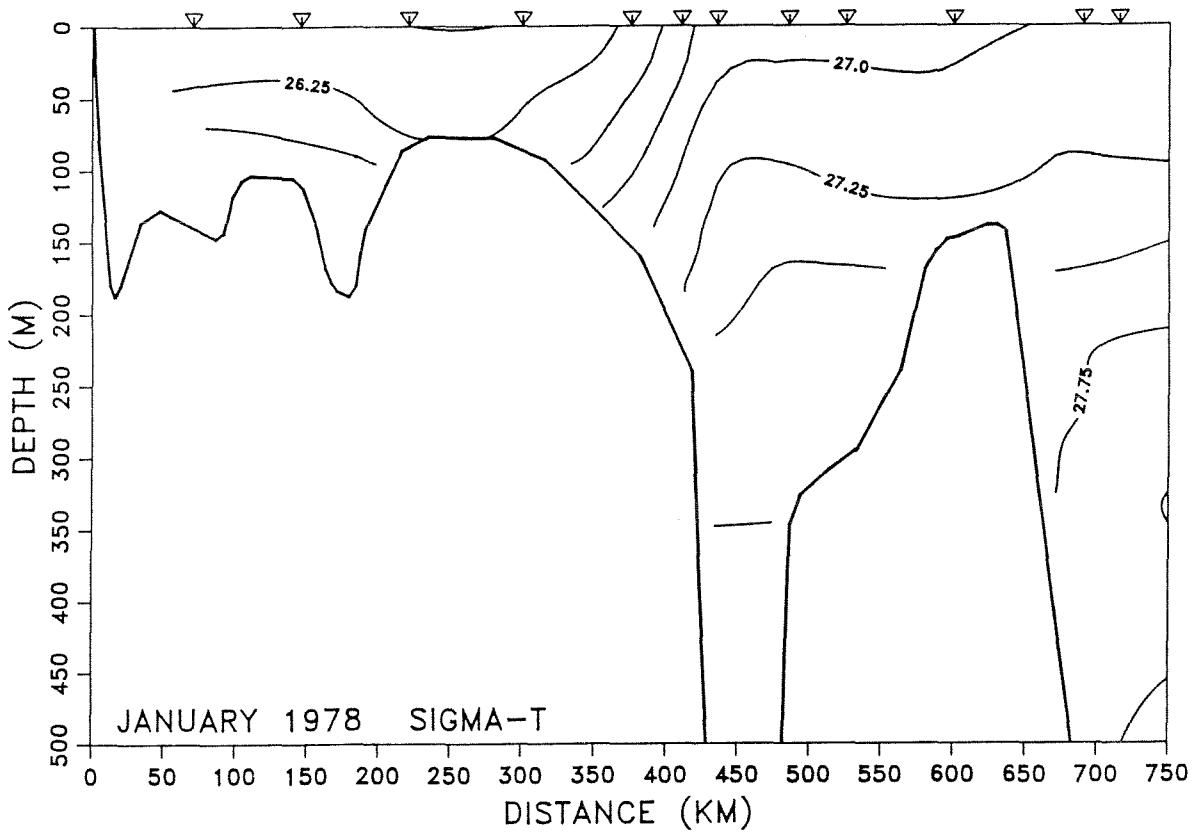
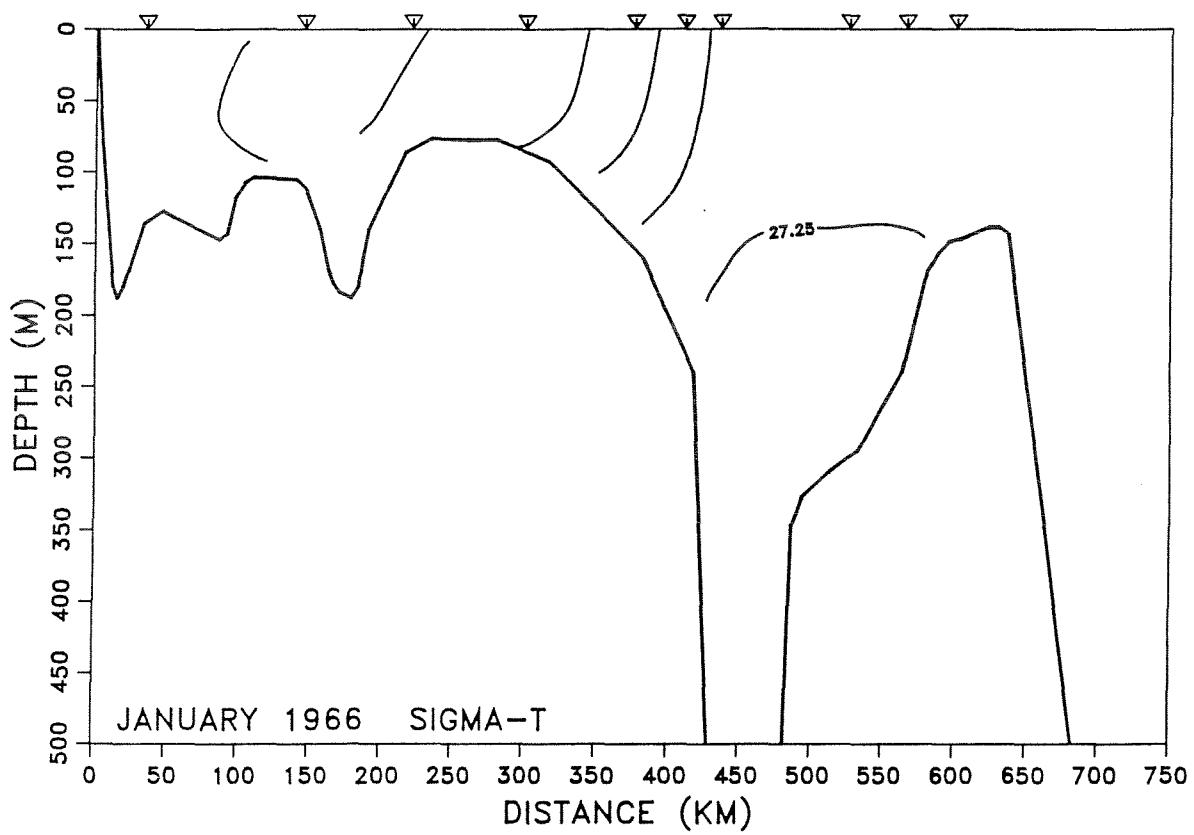


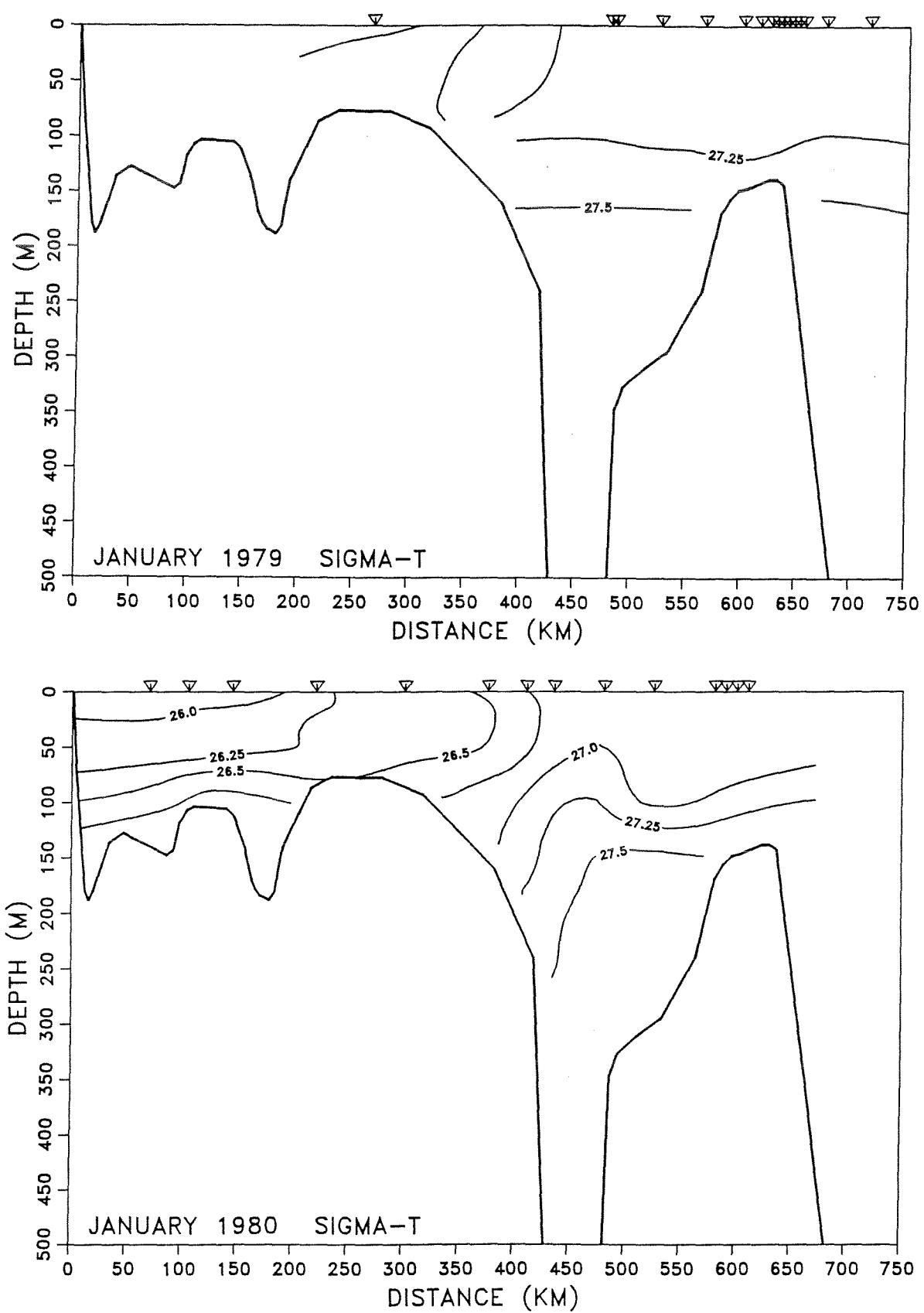


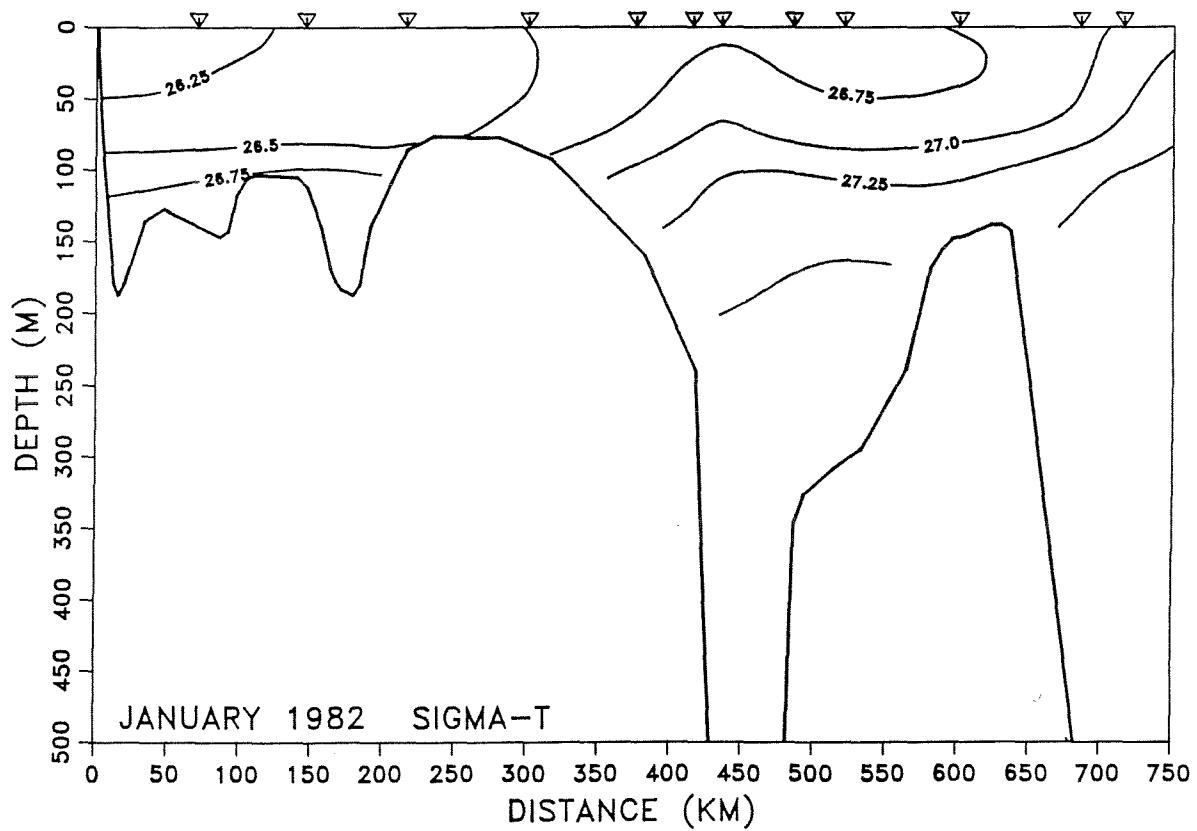
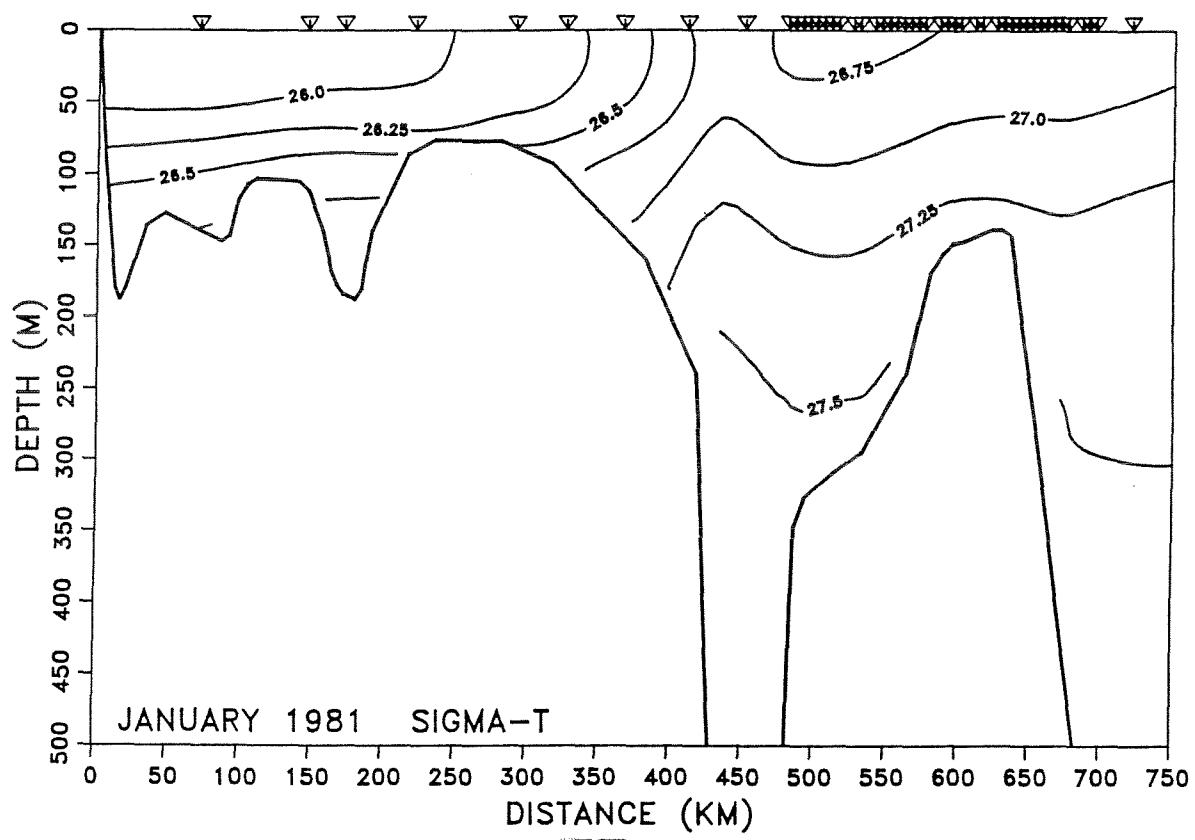


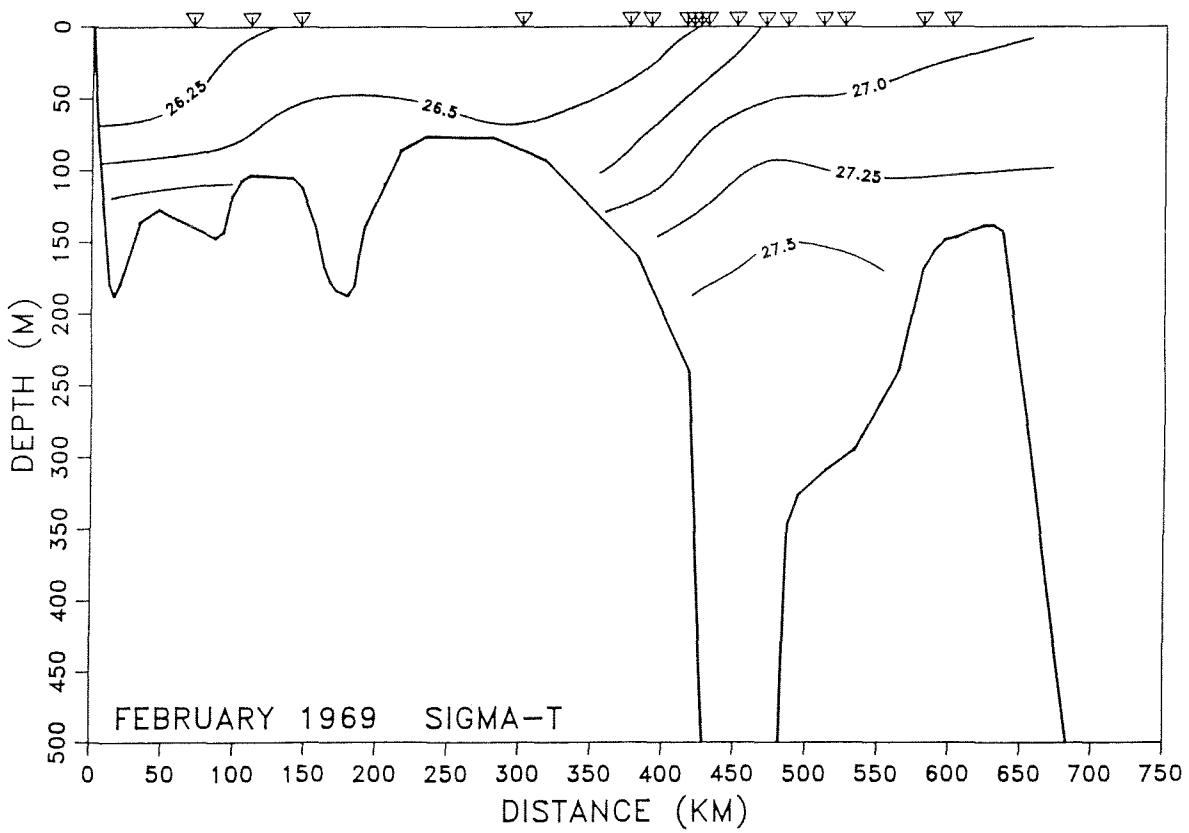
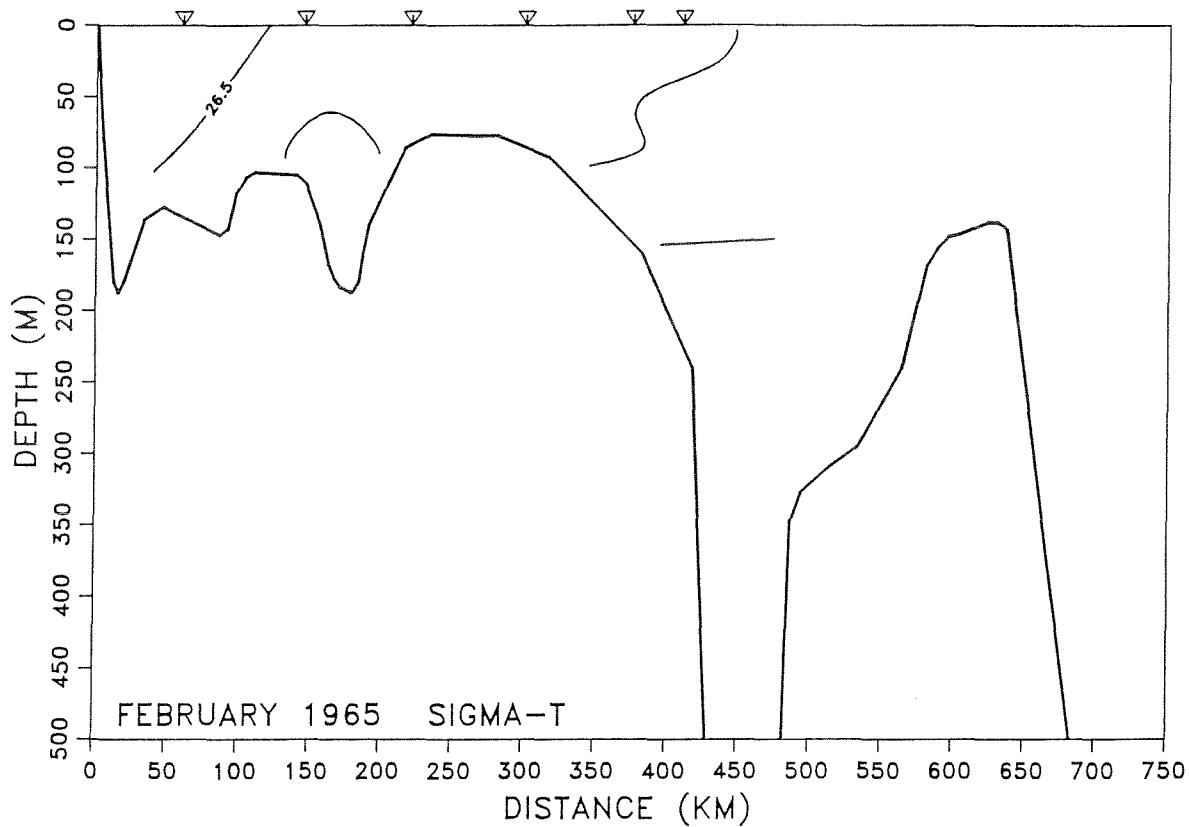
APPENDIX G. Flemish Cap Annual Sigma-t Transects.

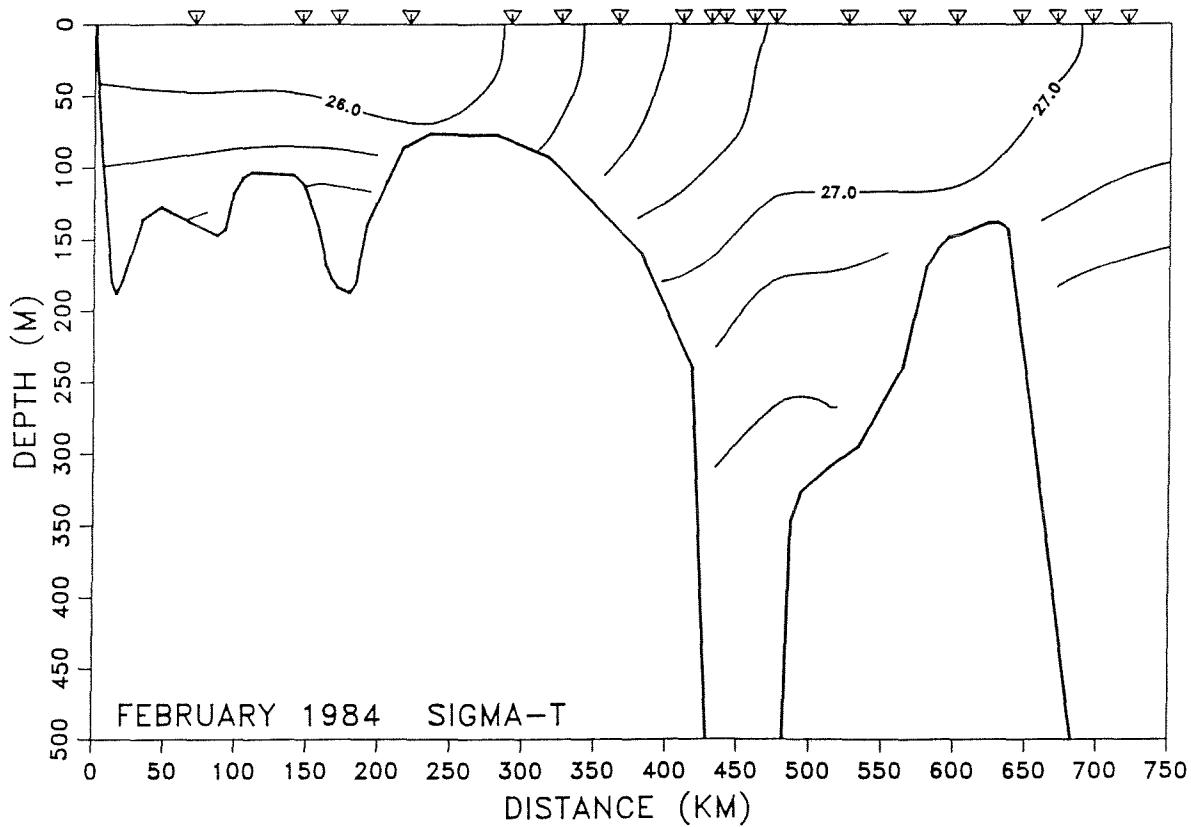
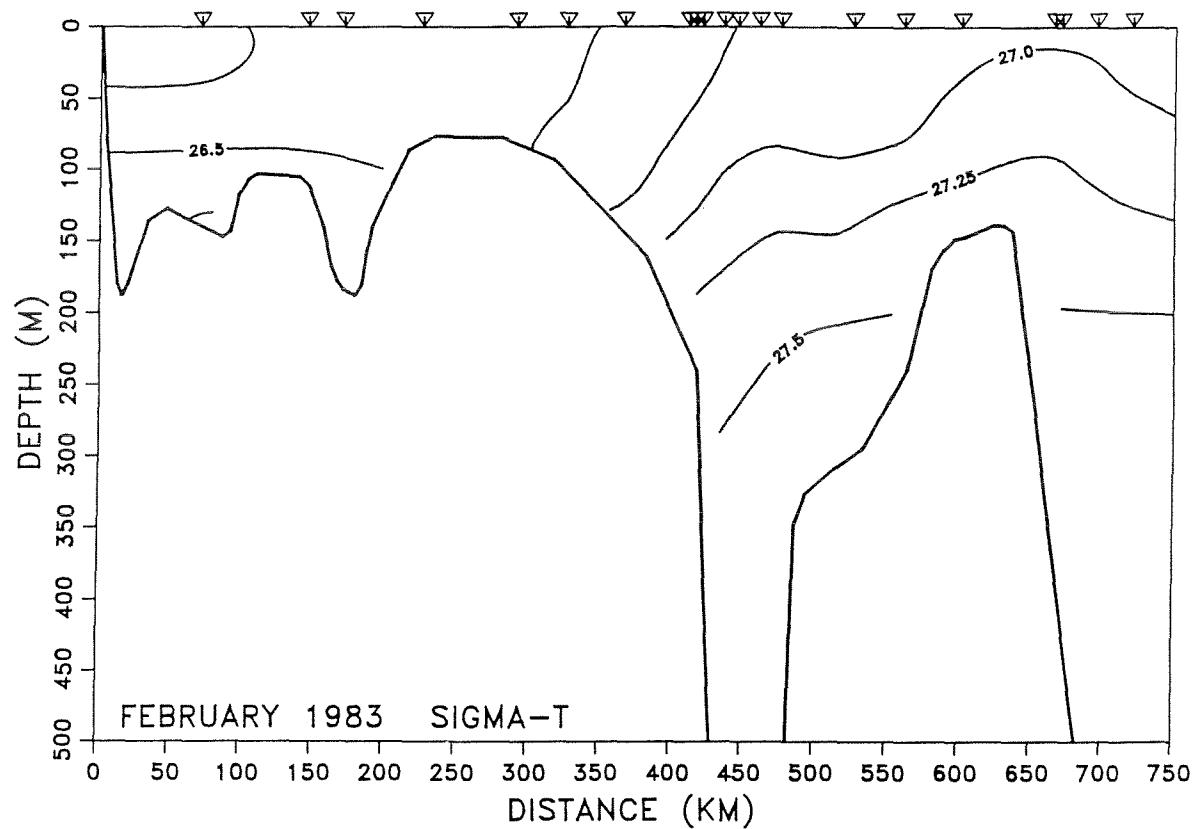


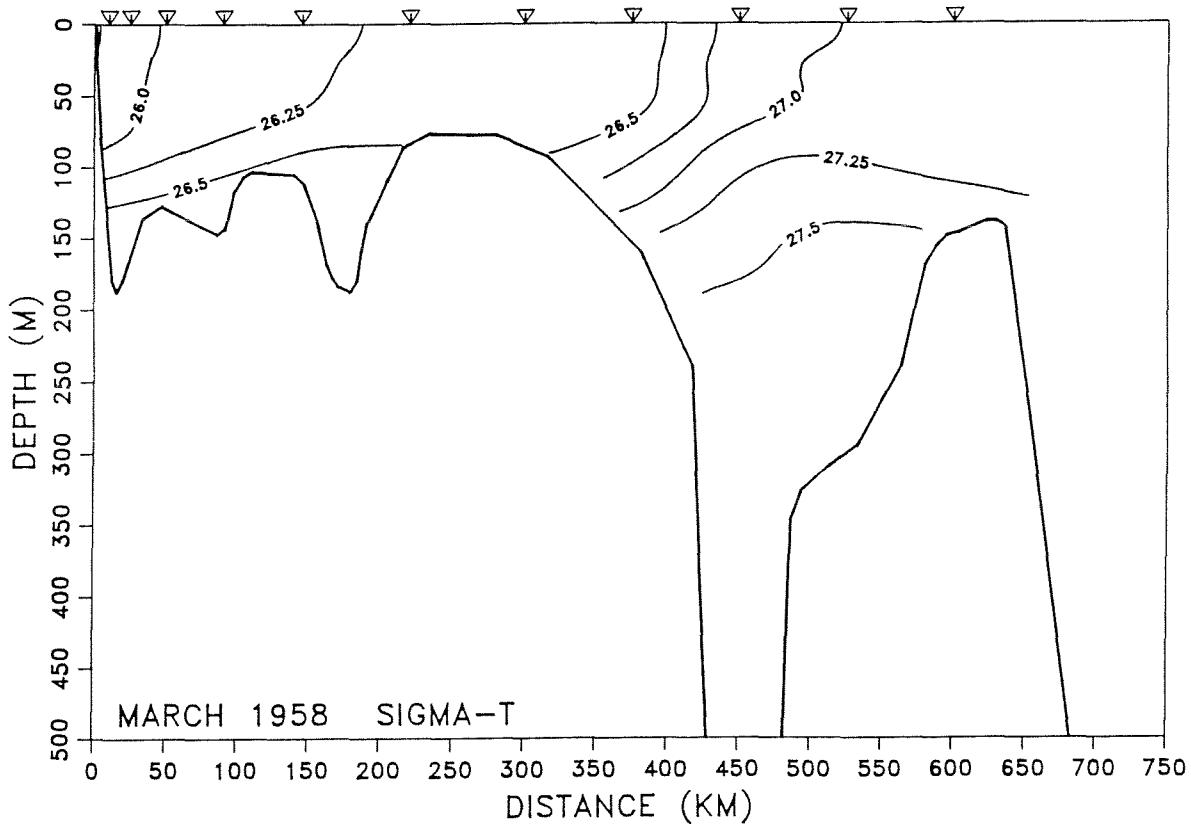
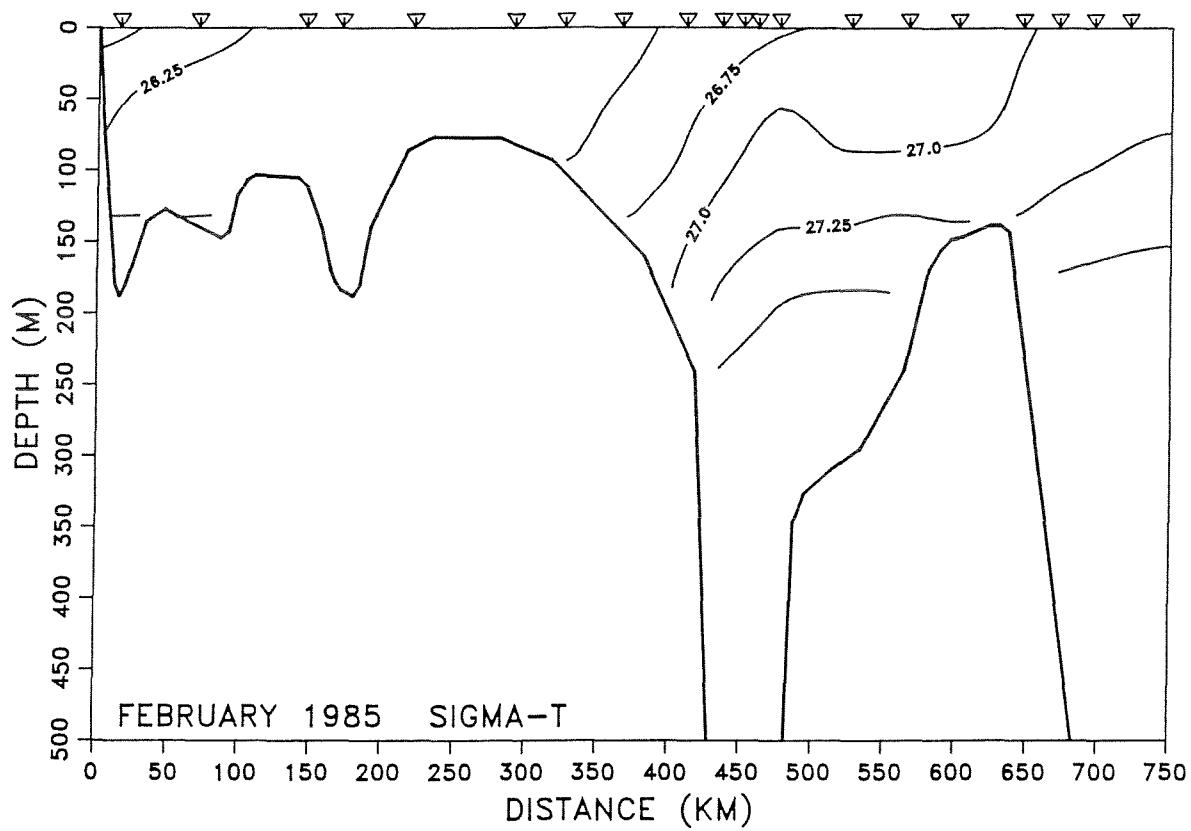


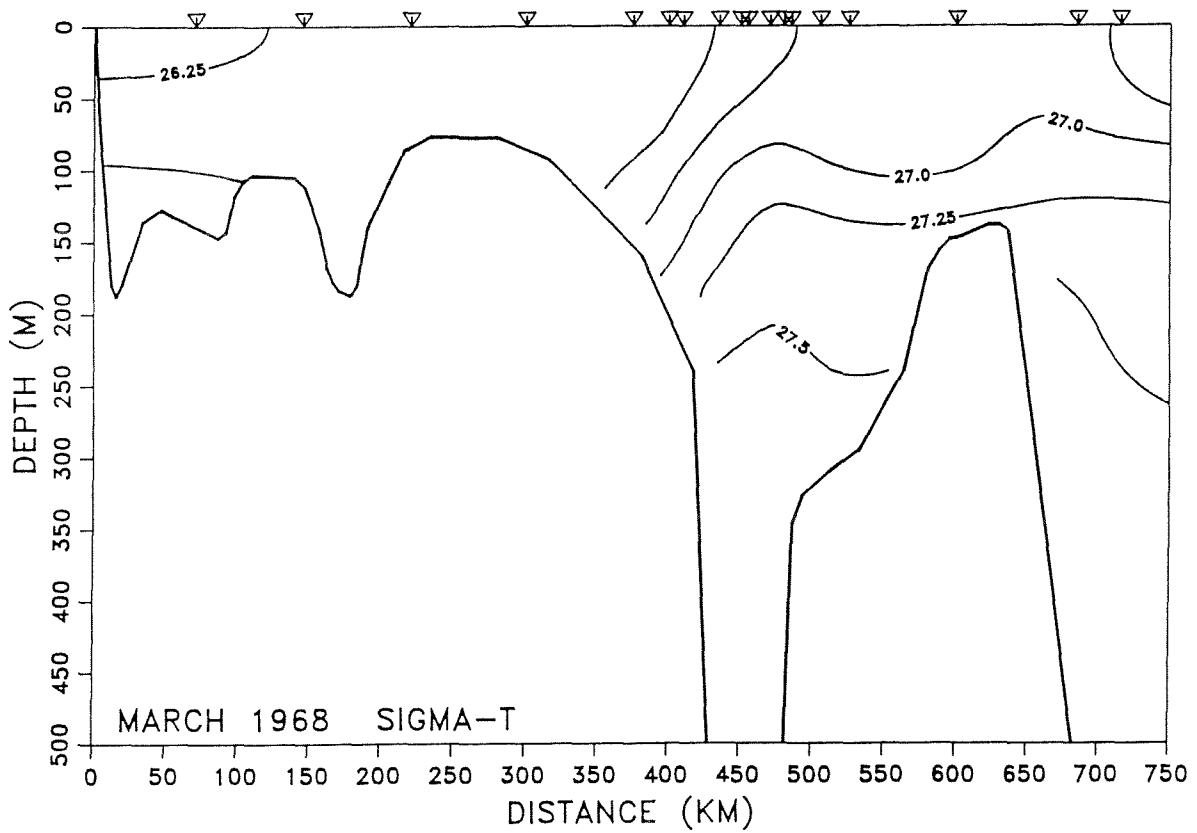
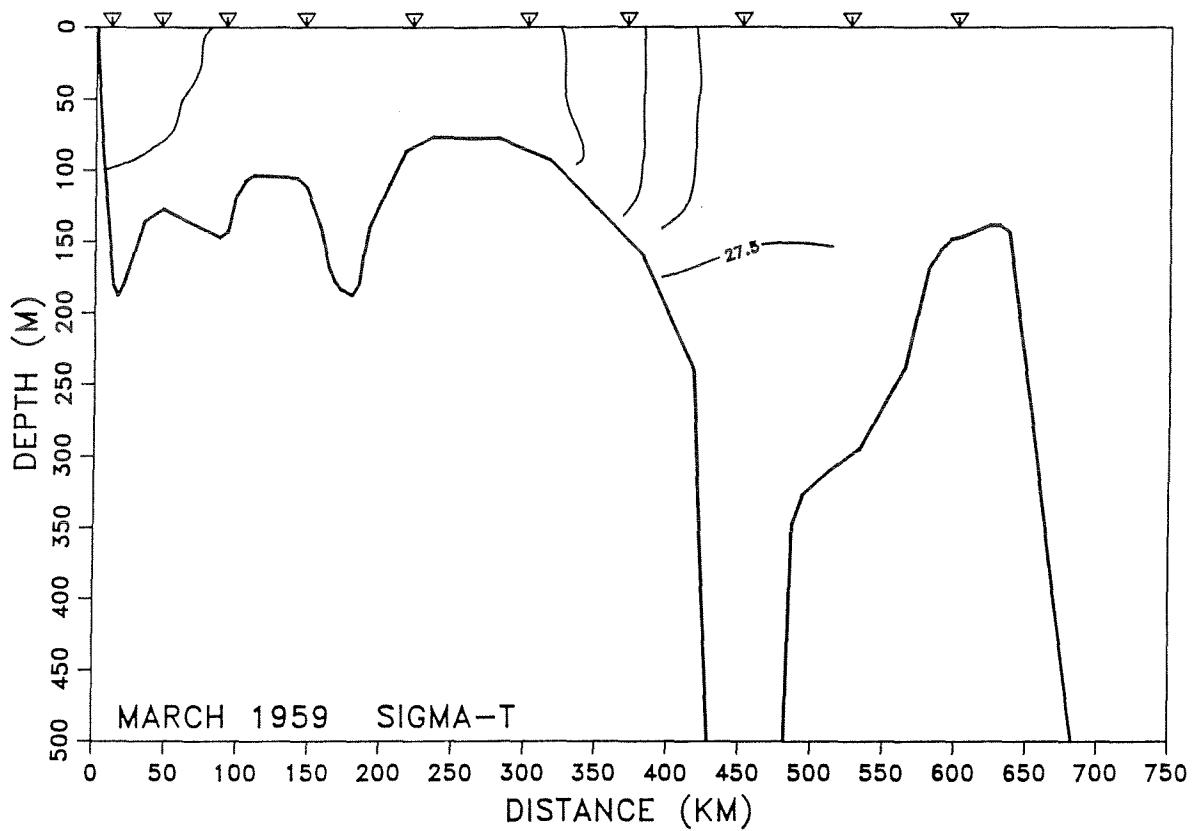


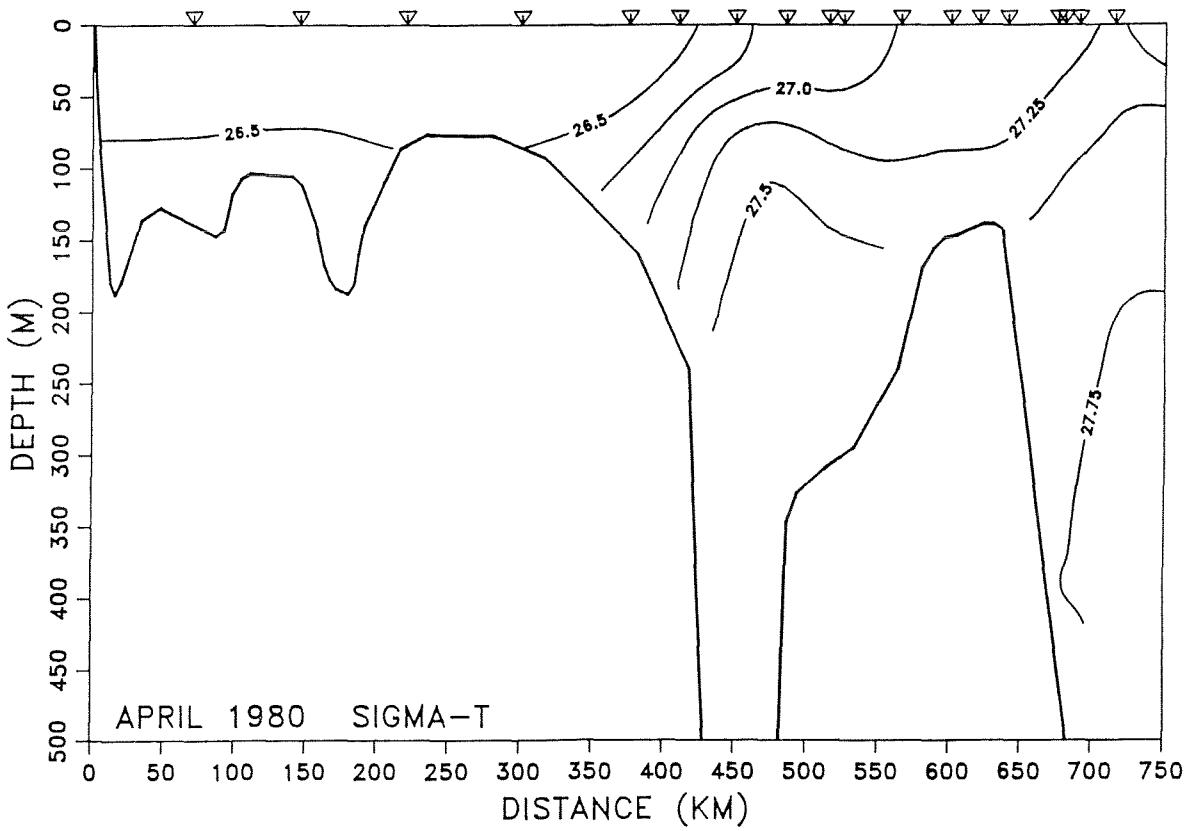
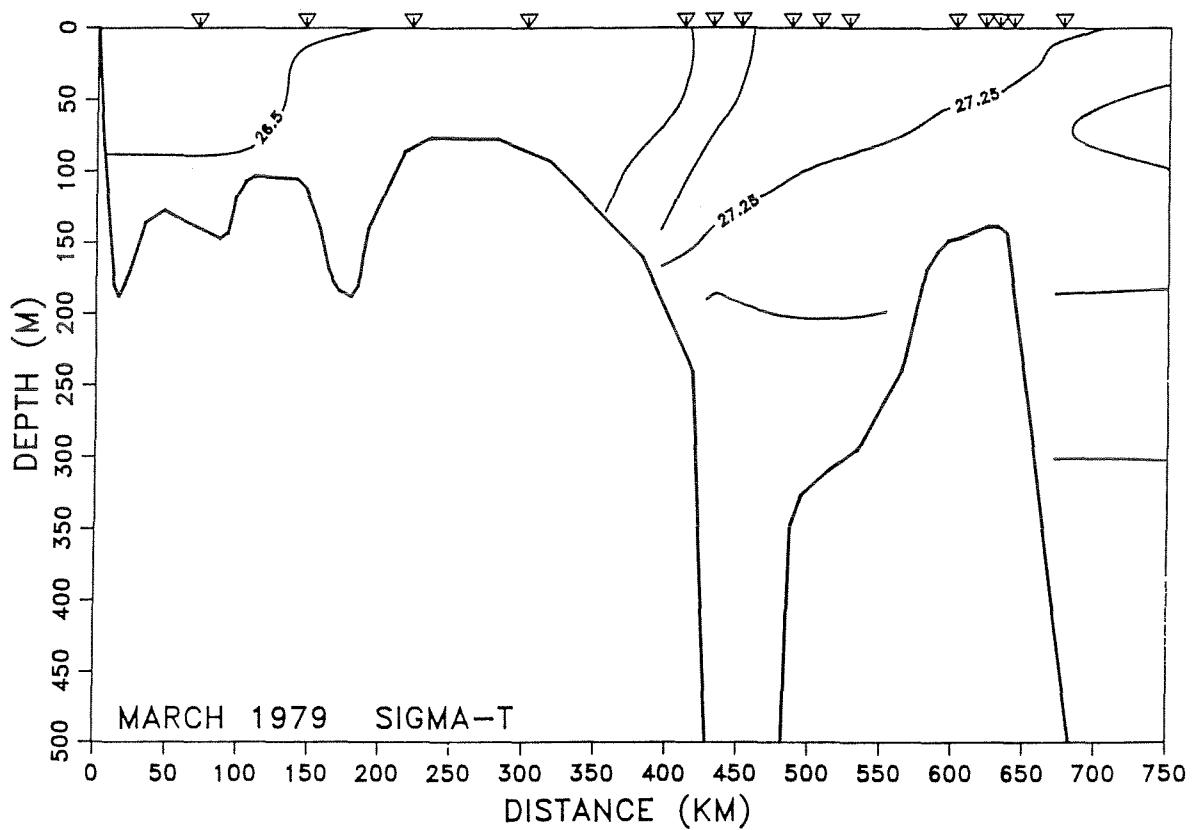


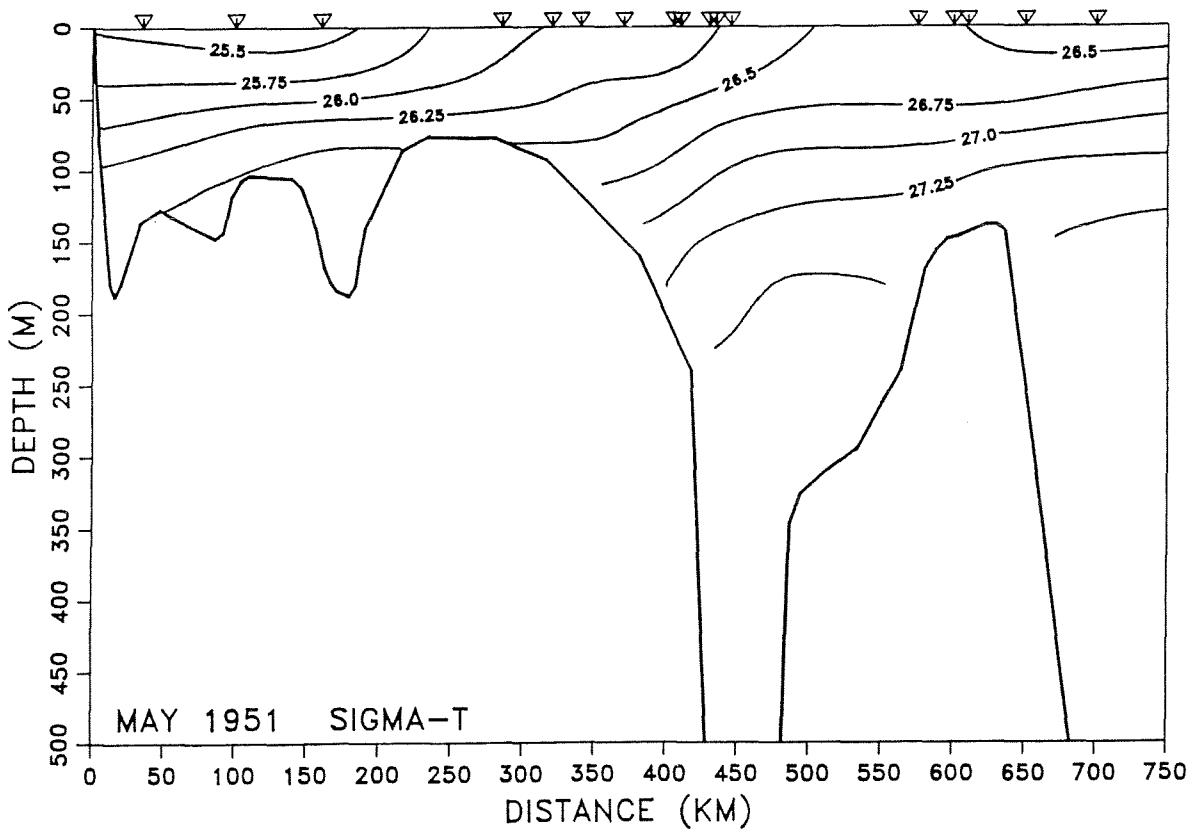
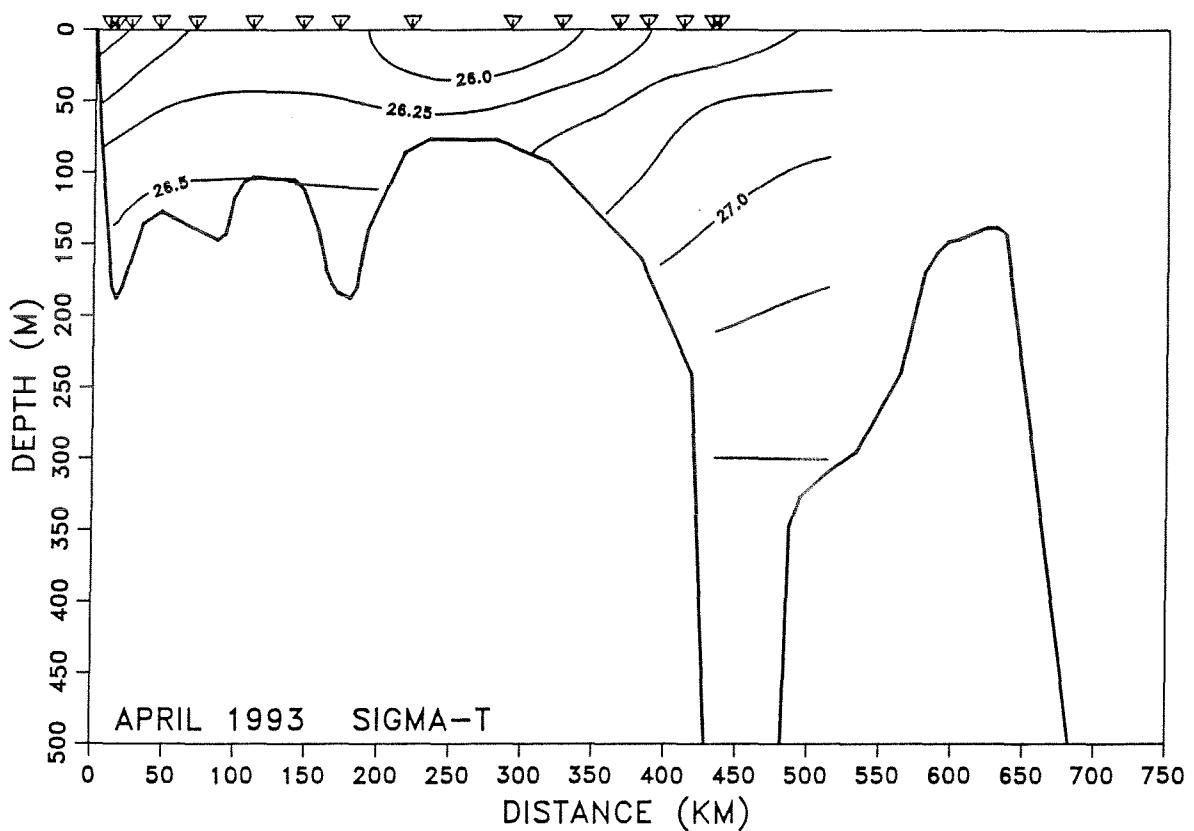


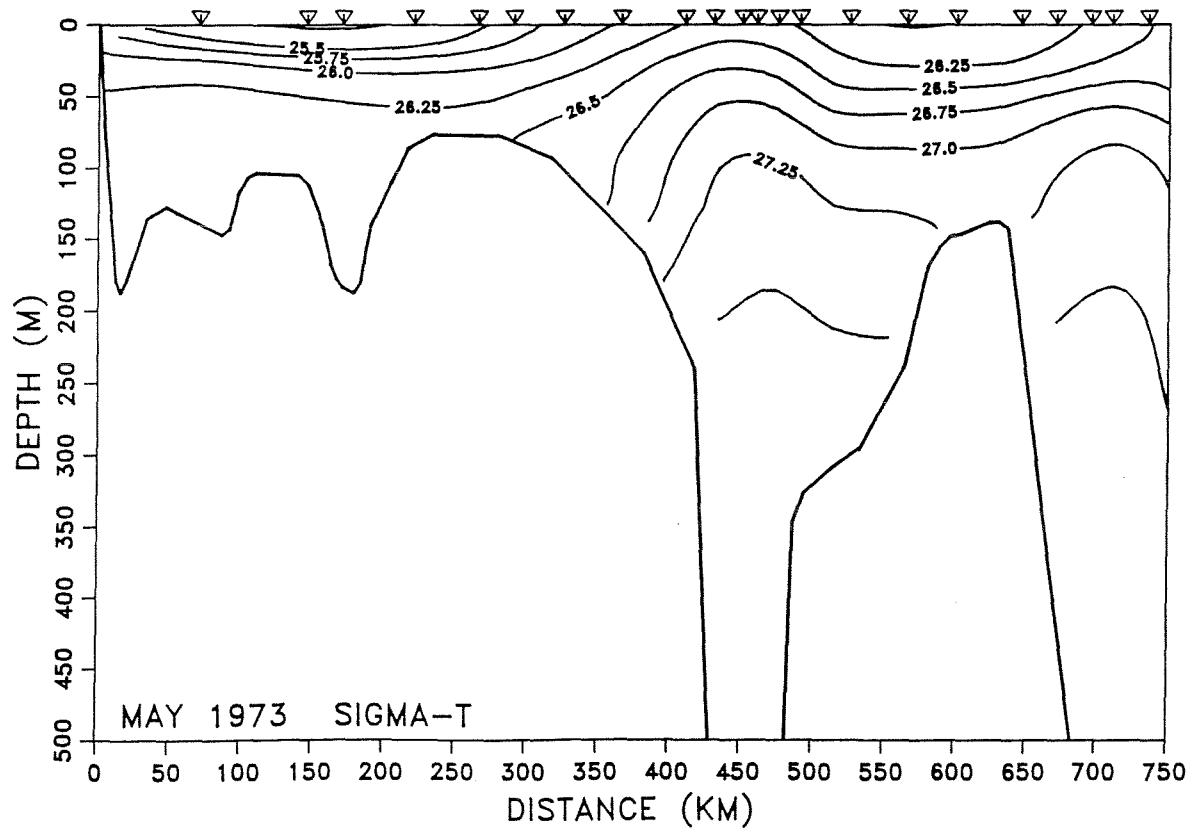
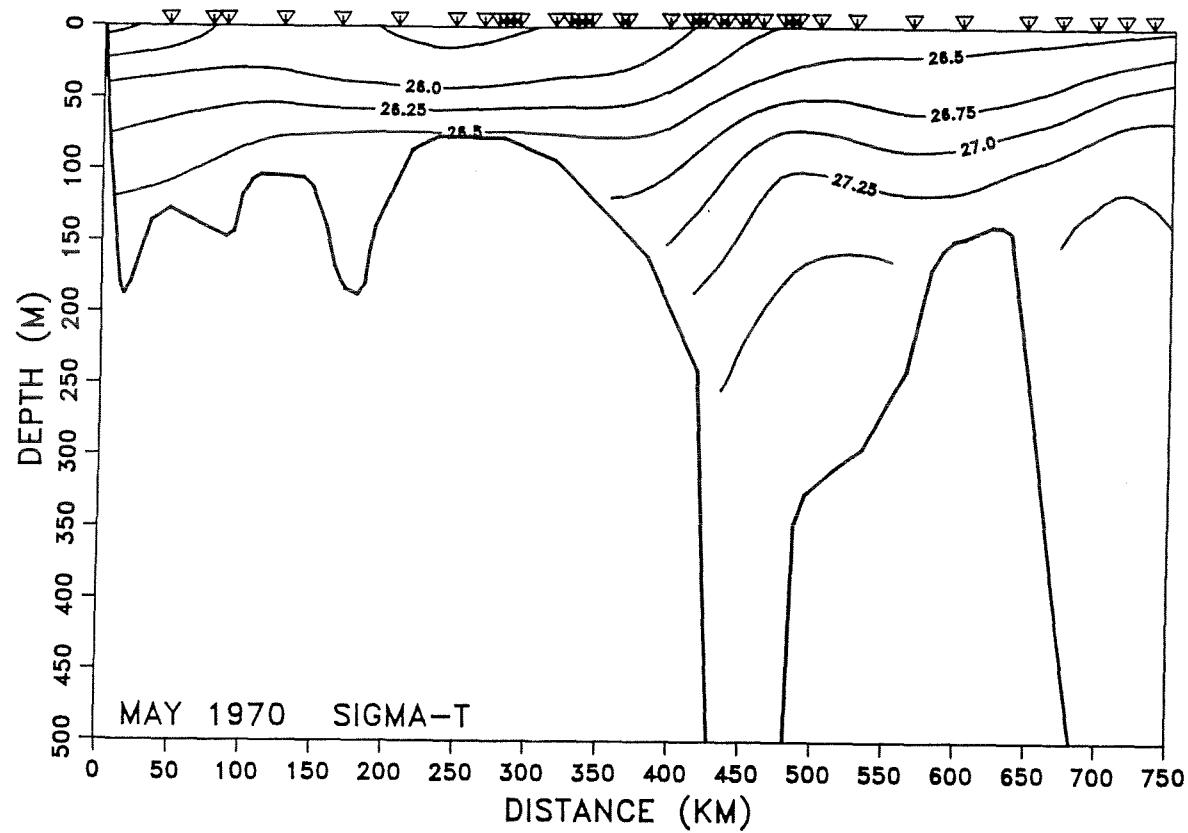


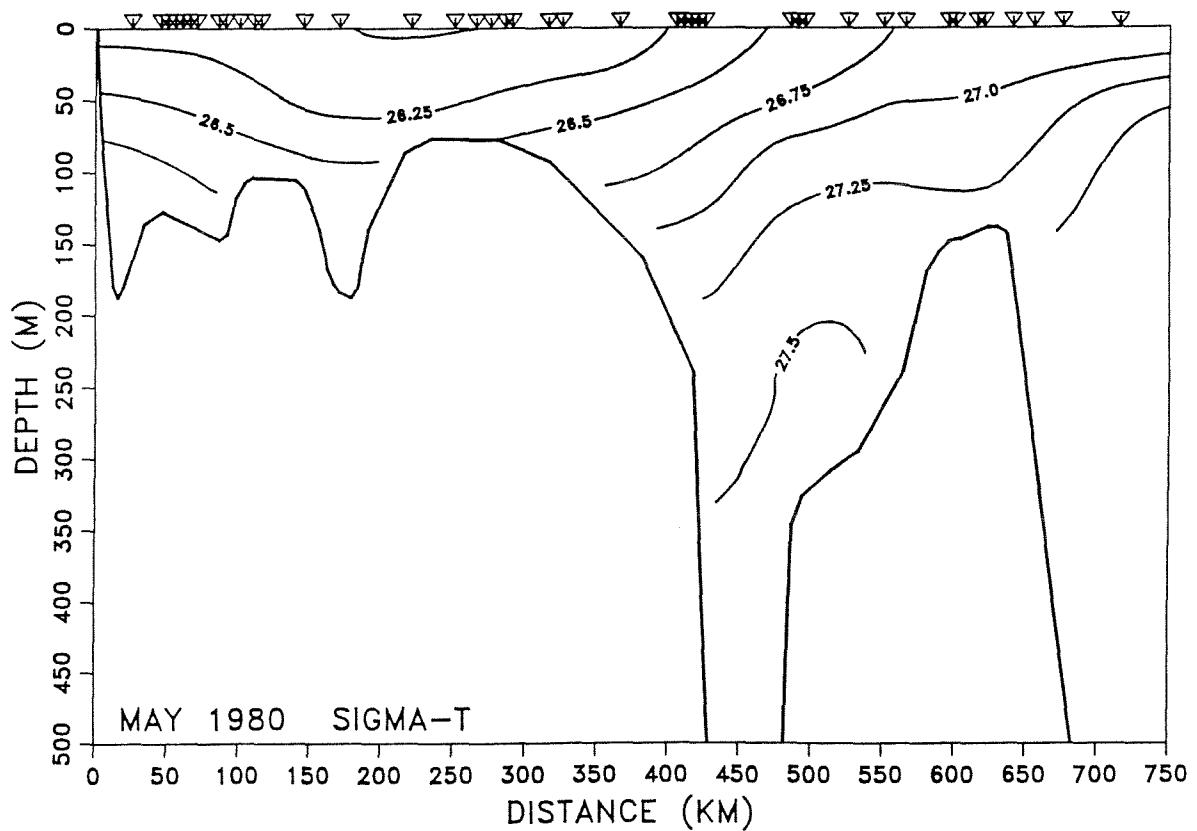
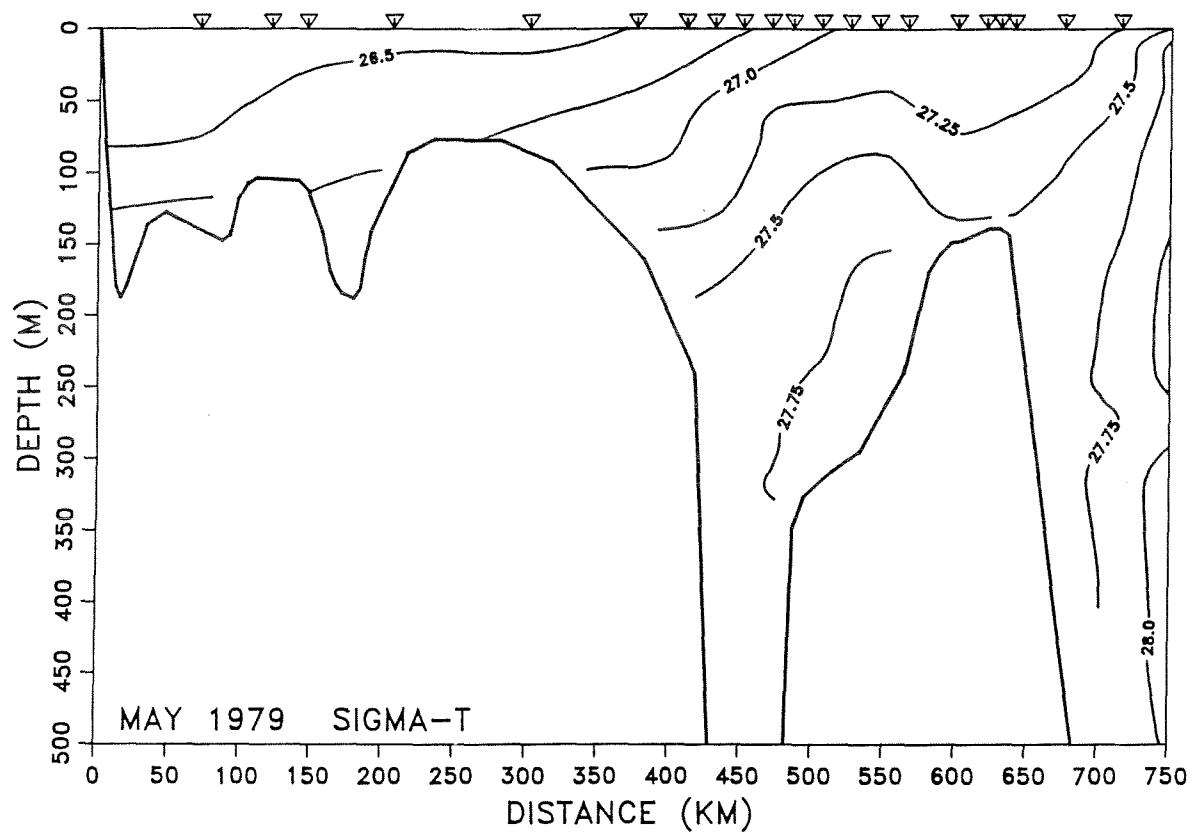


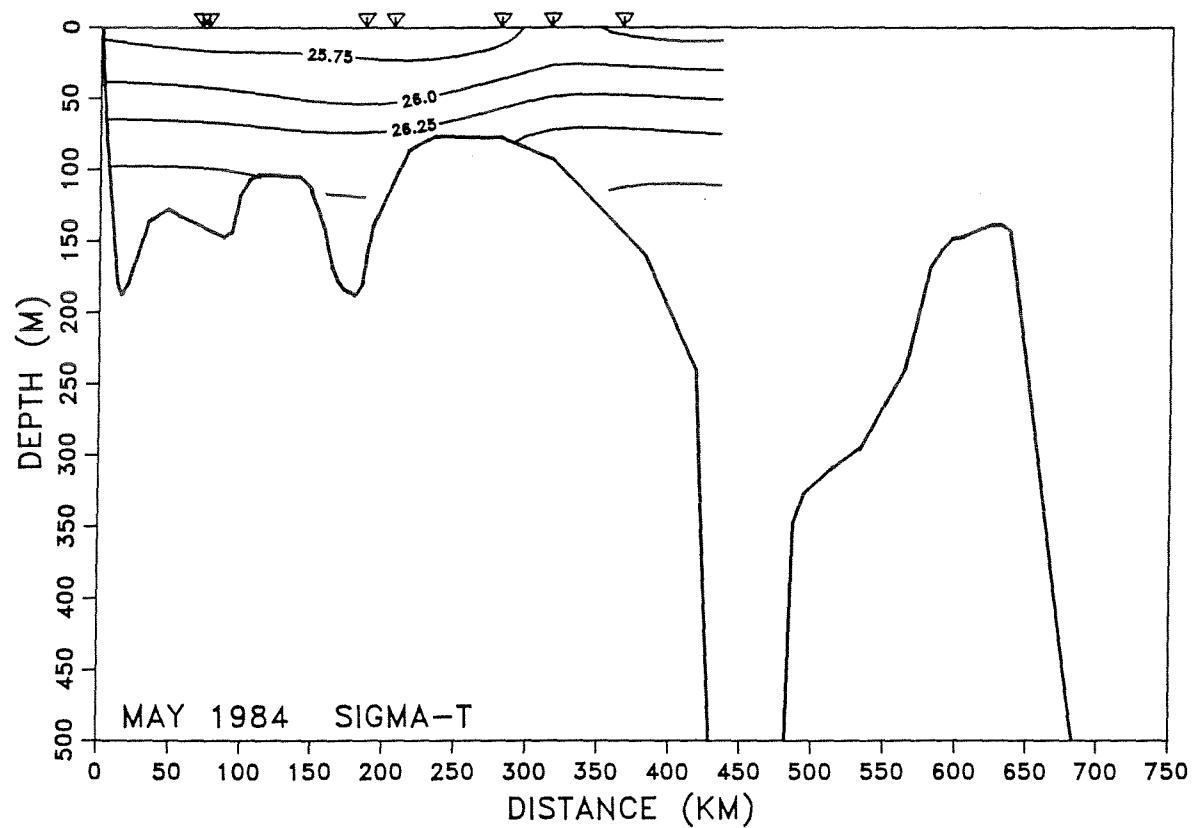






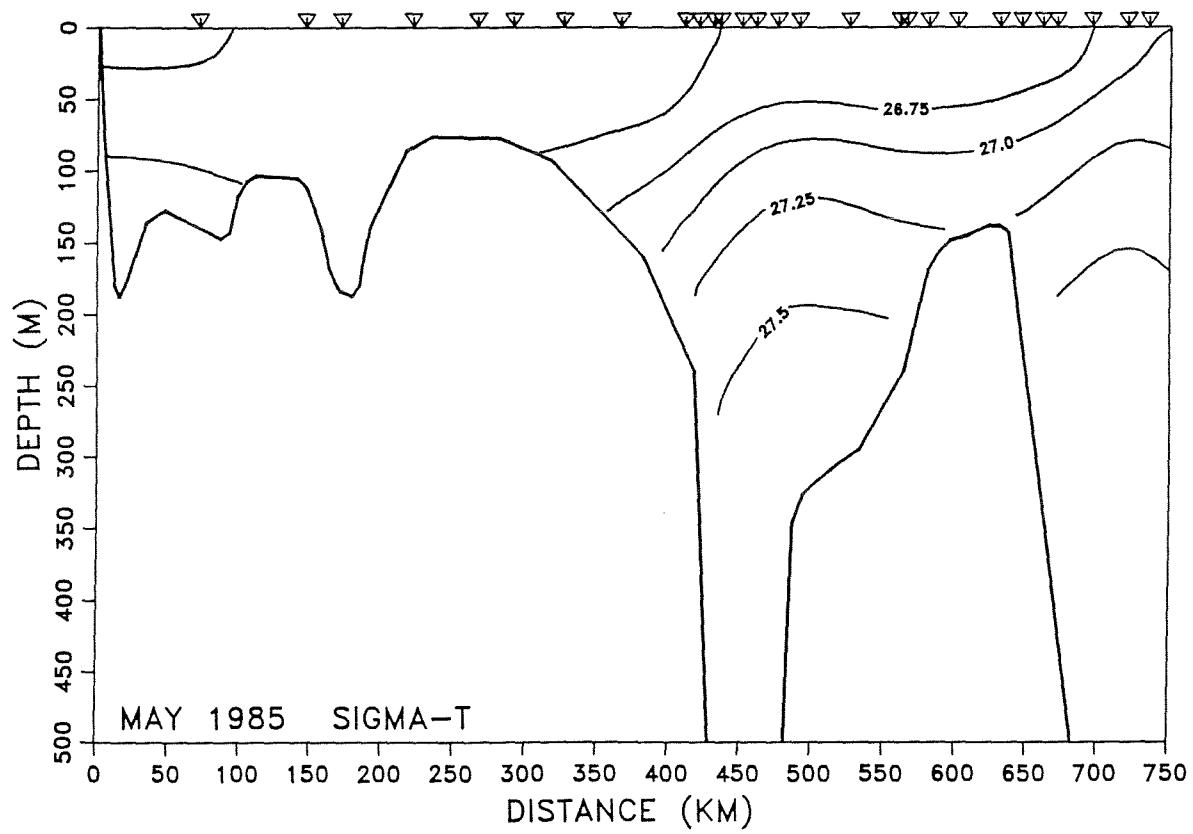






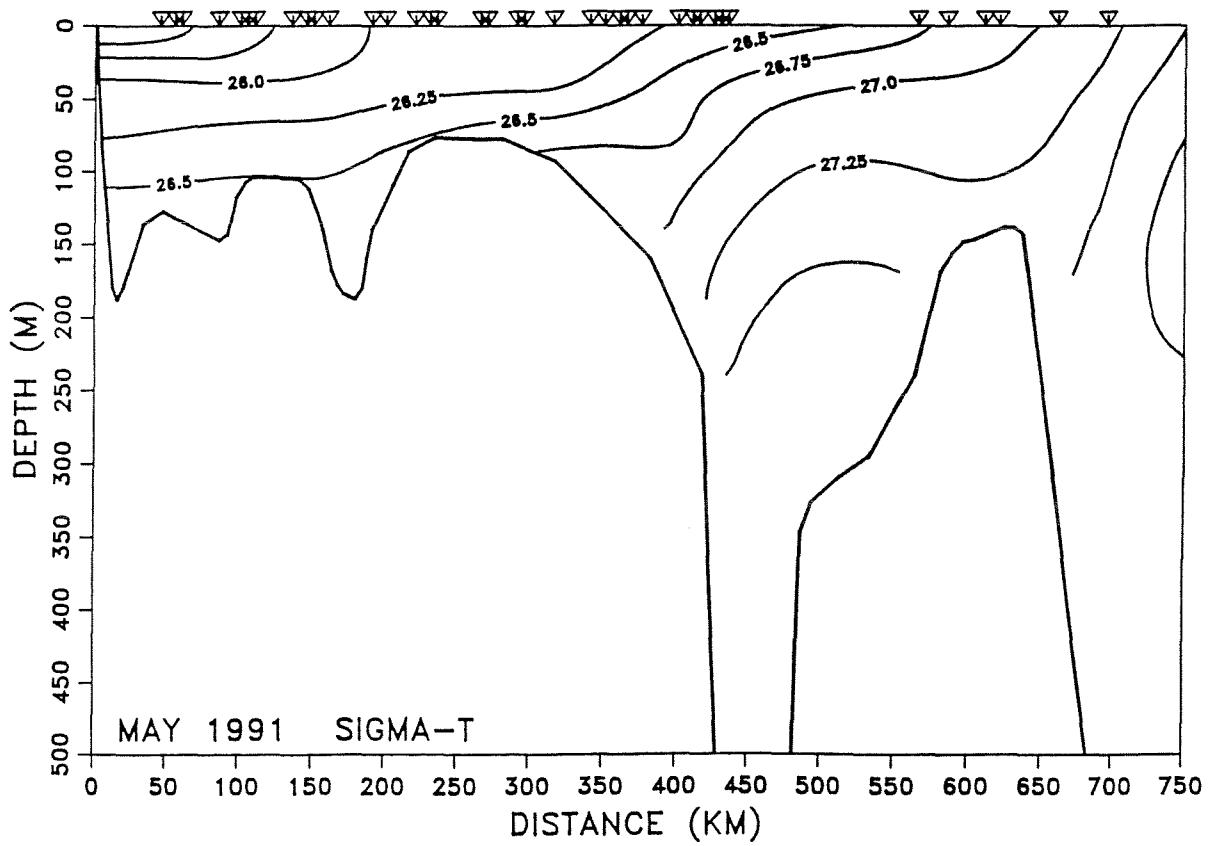
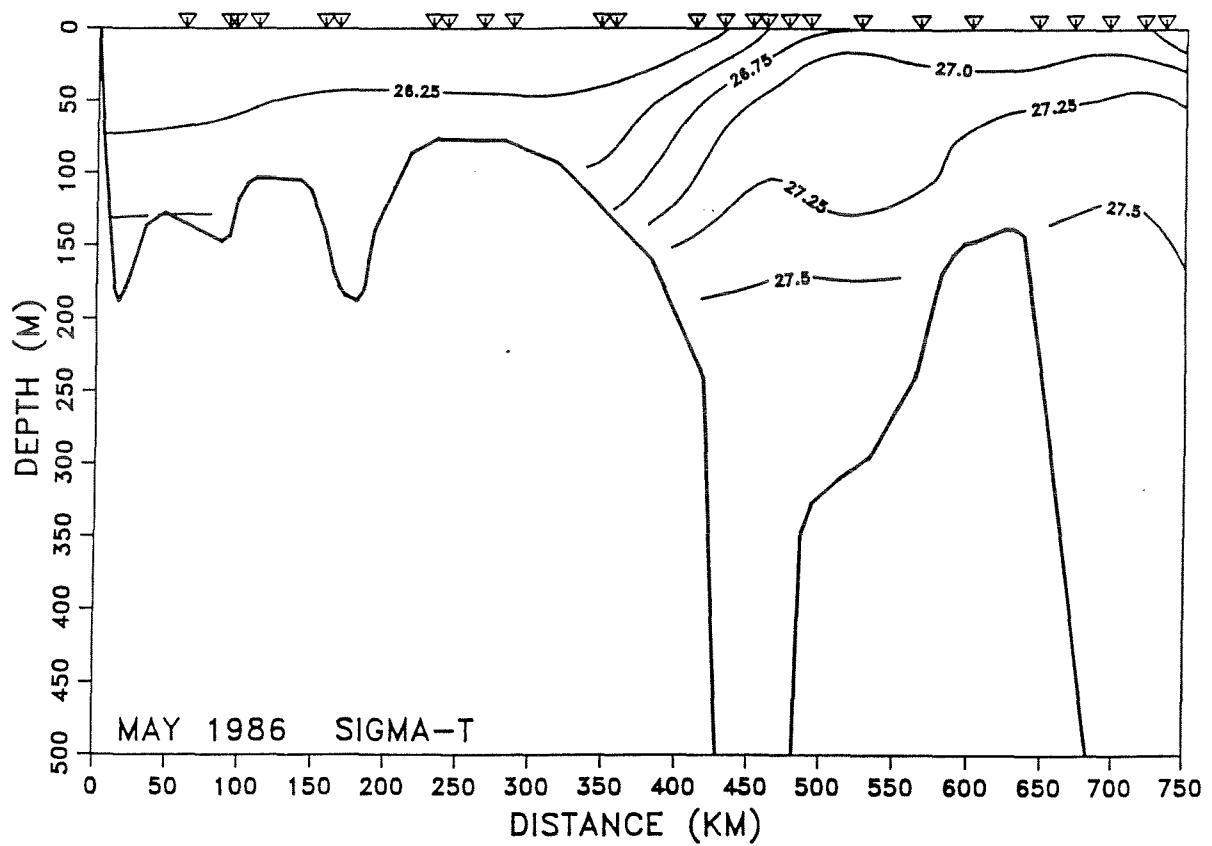
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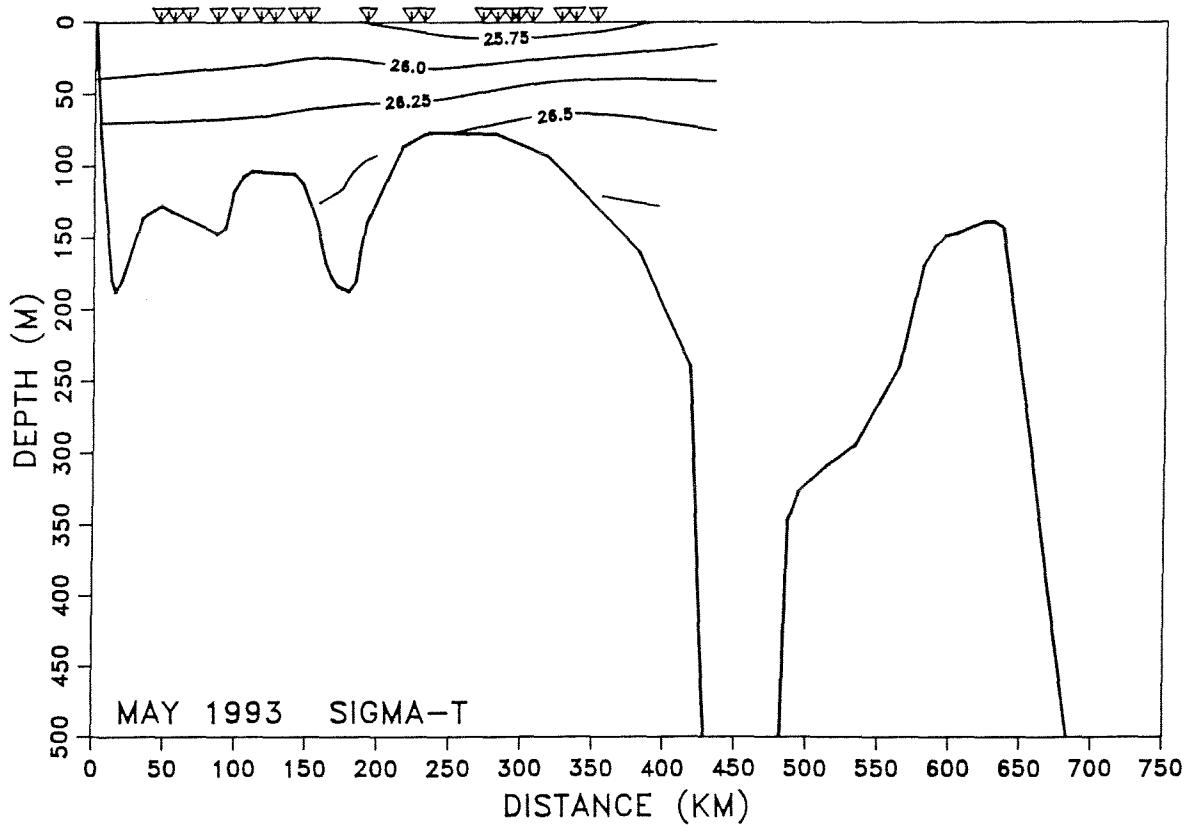
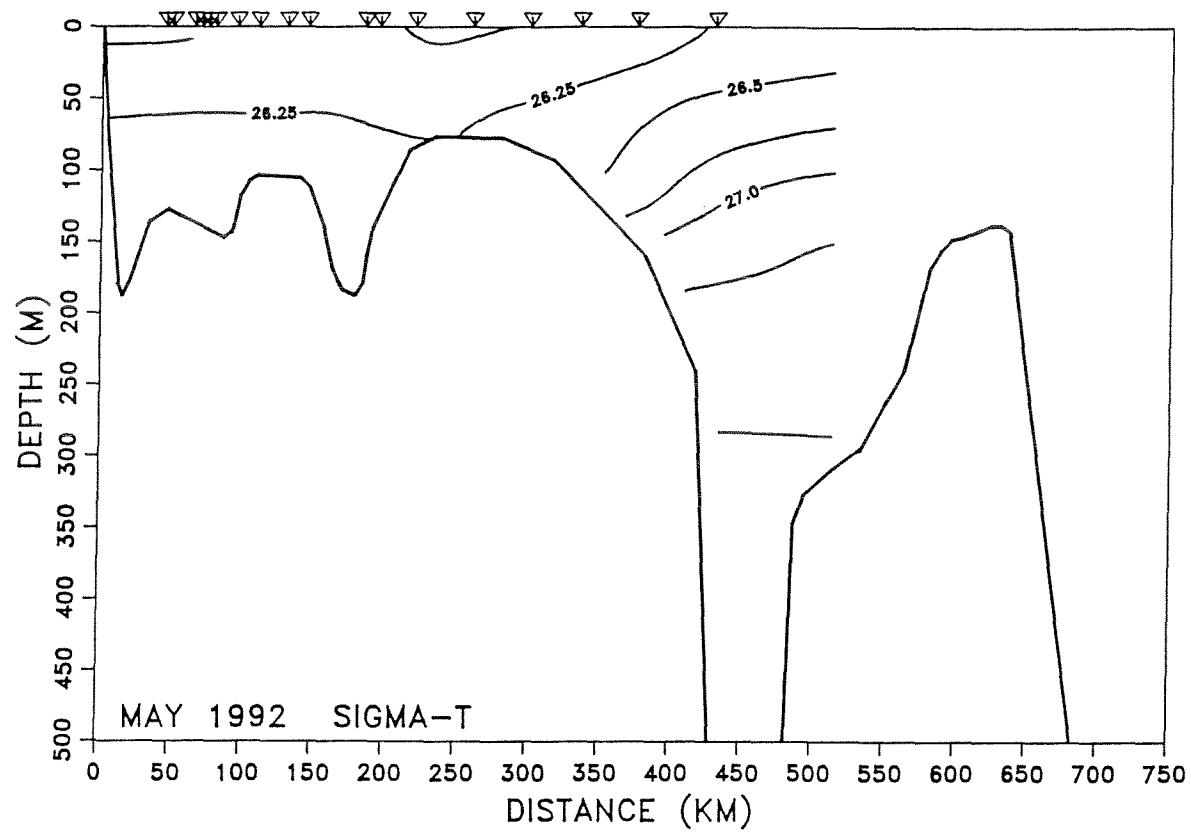
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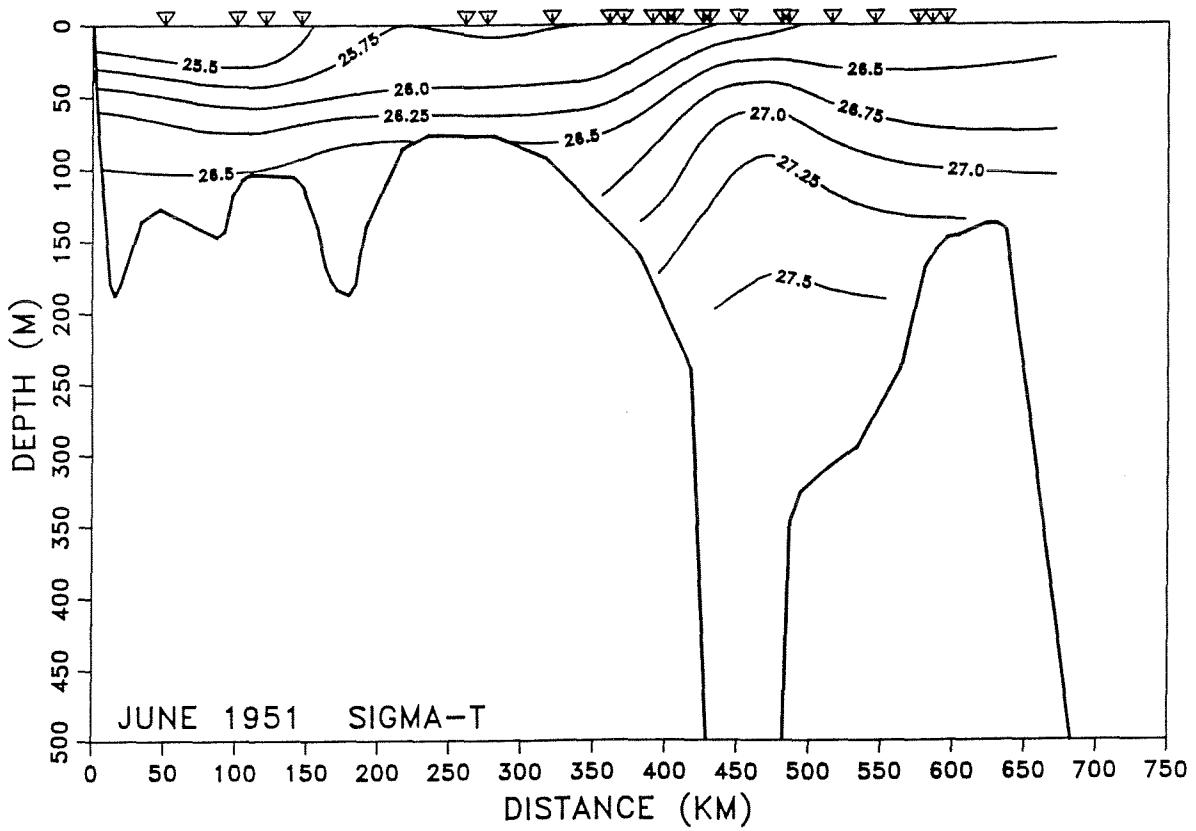
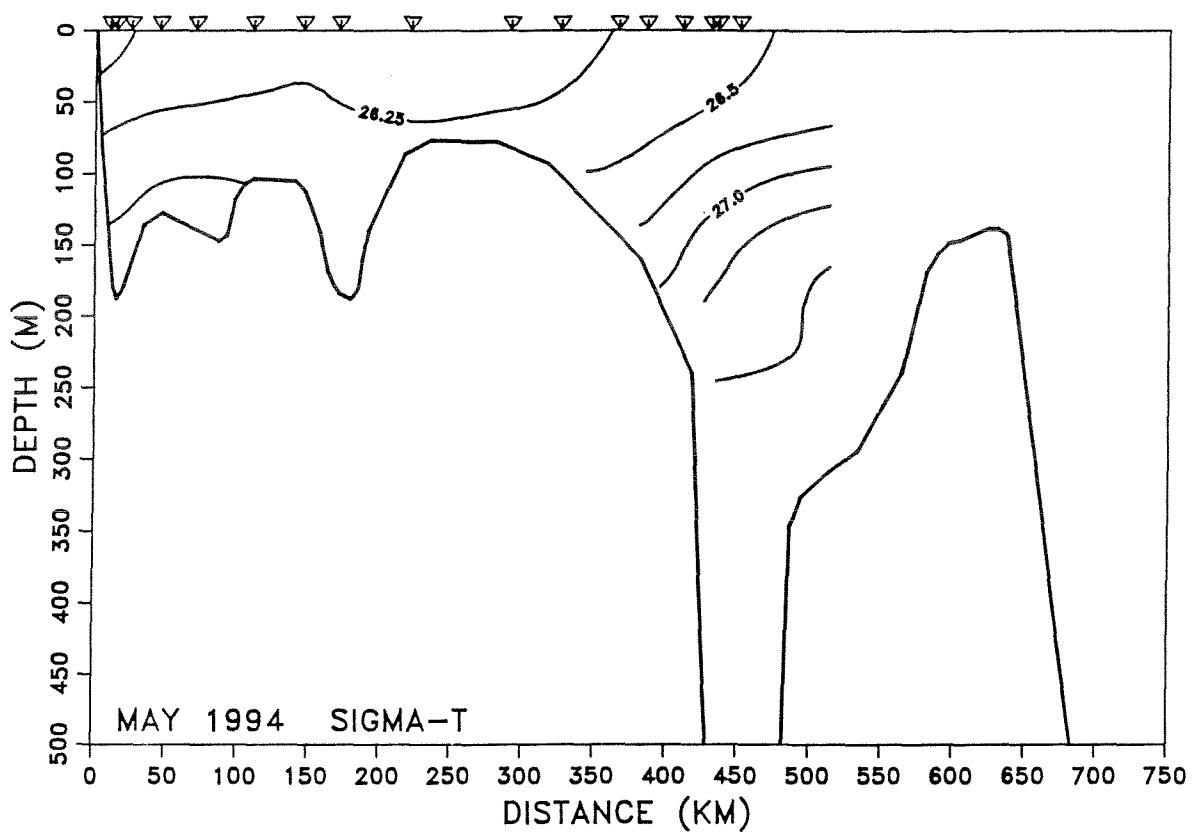


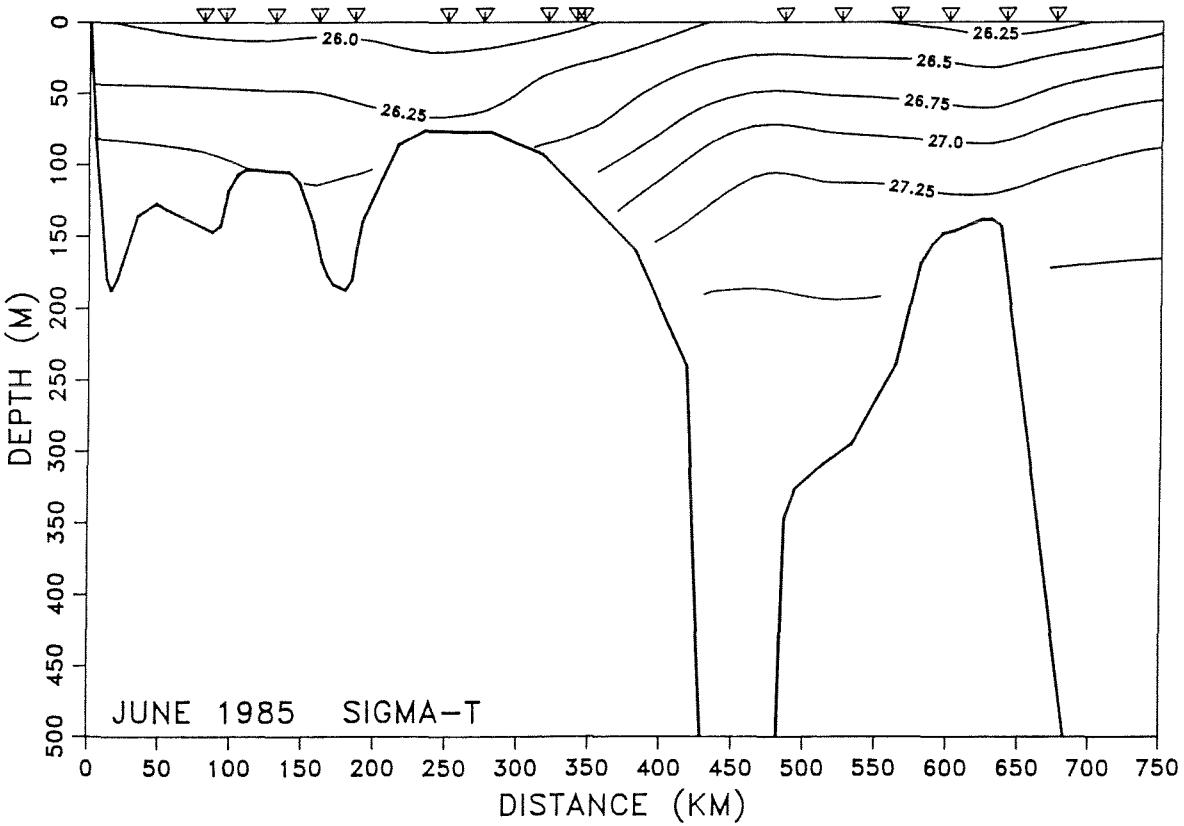
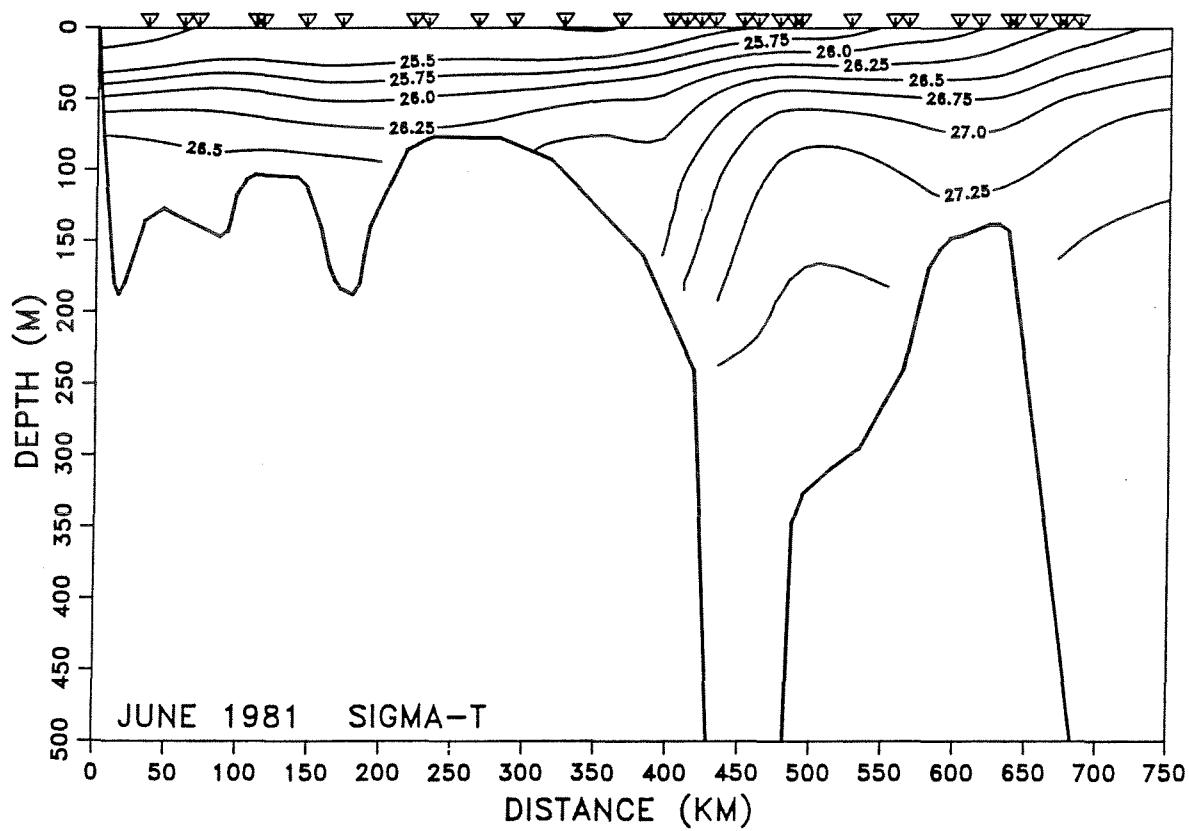
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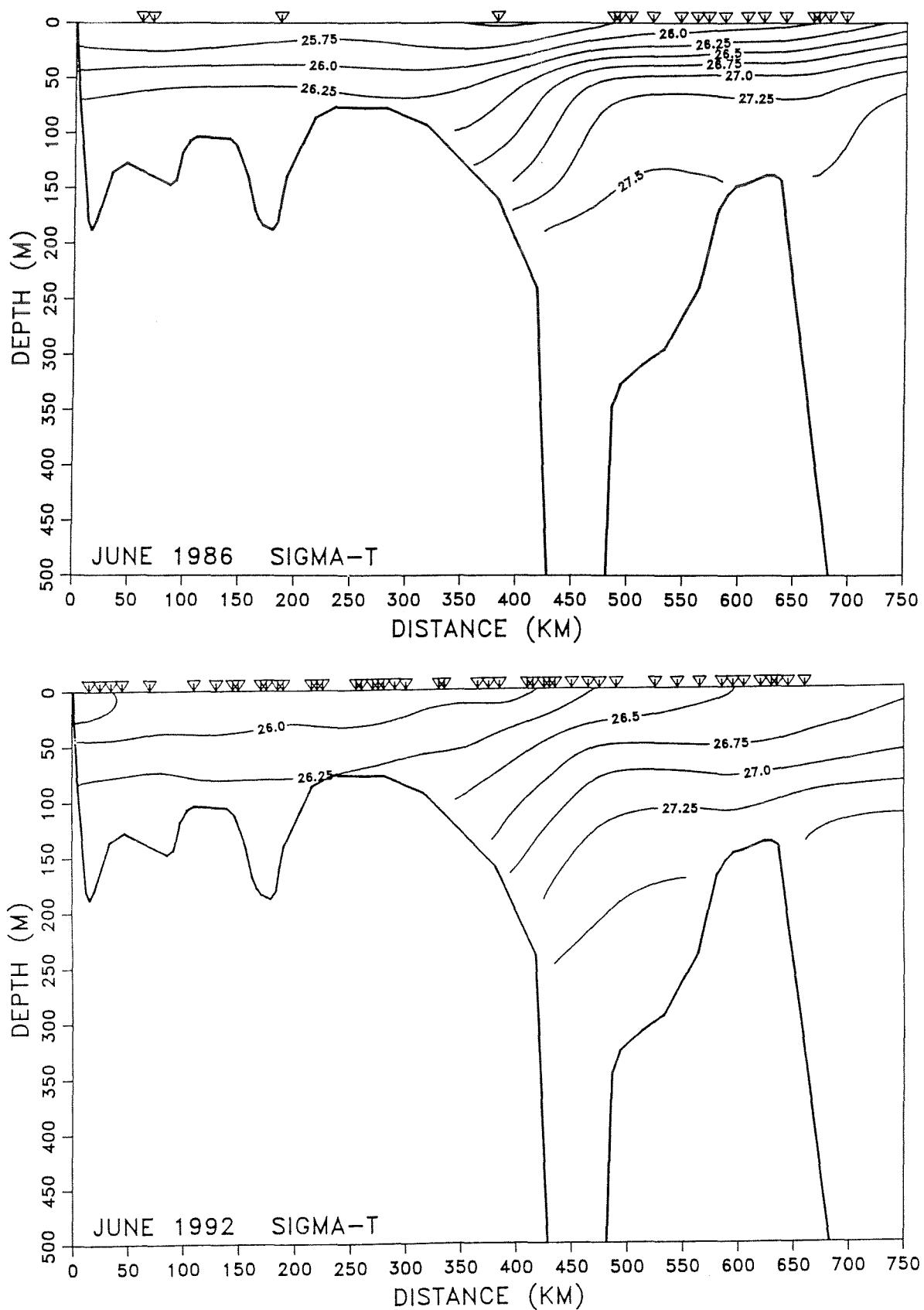
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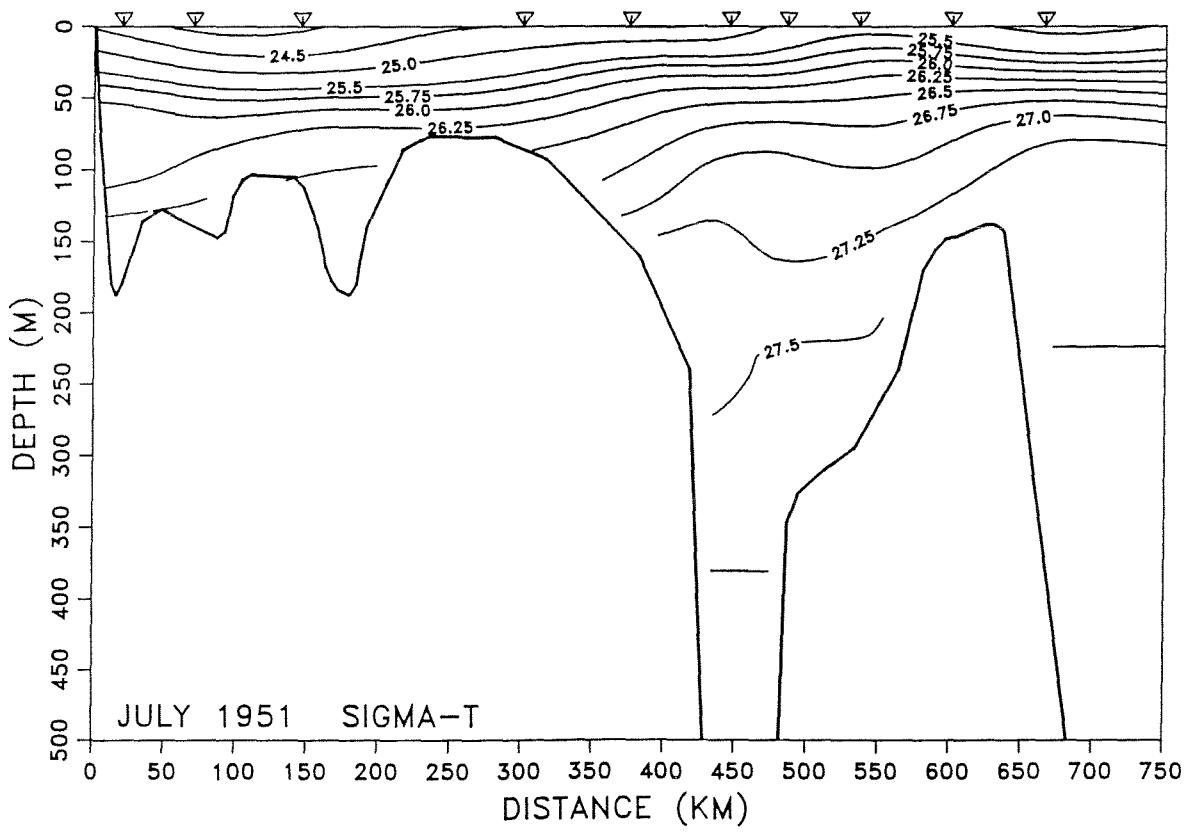
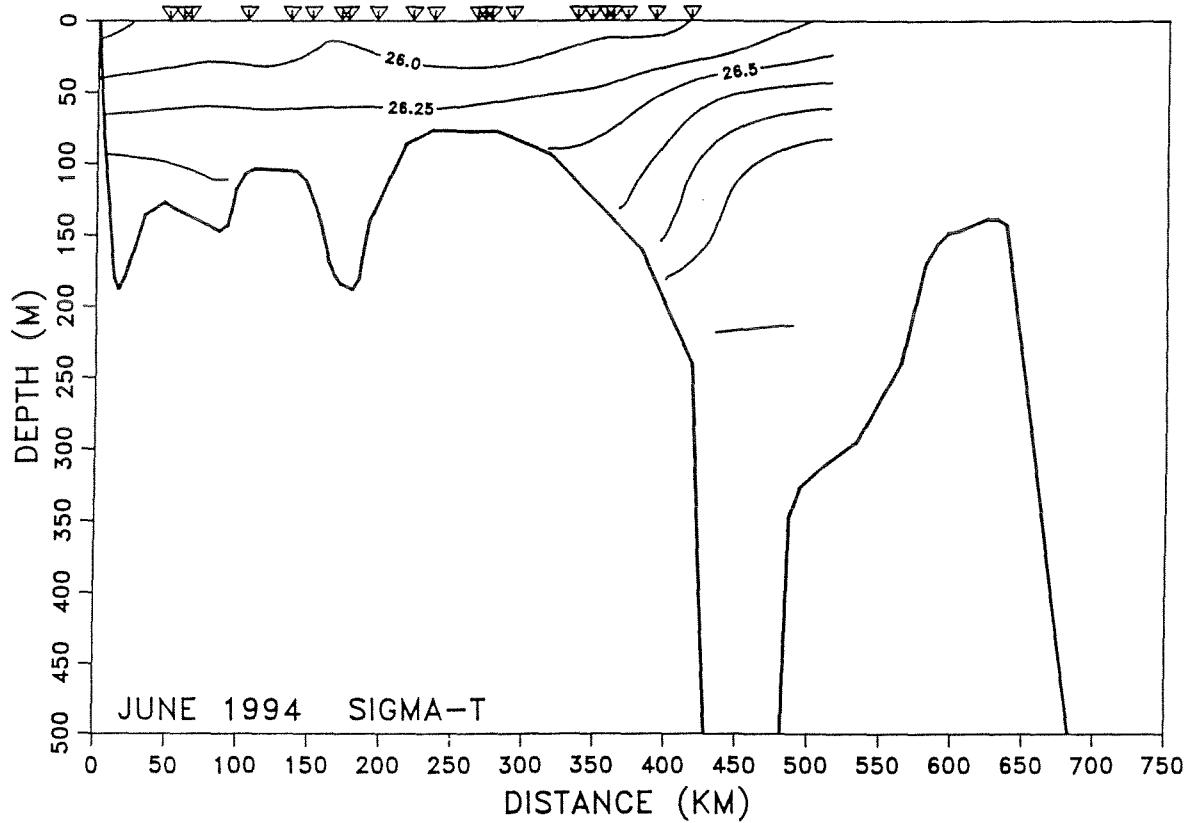


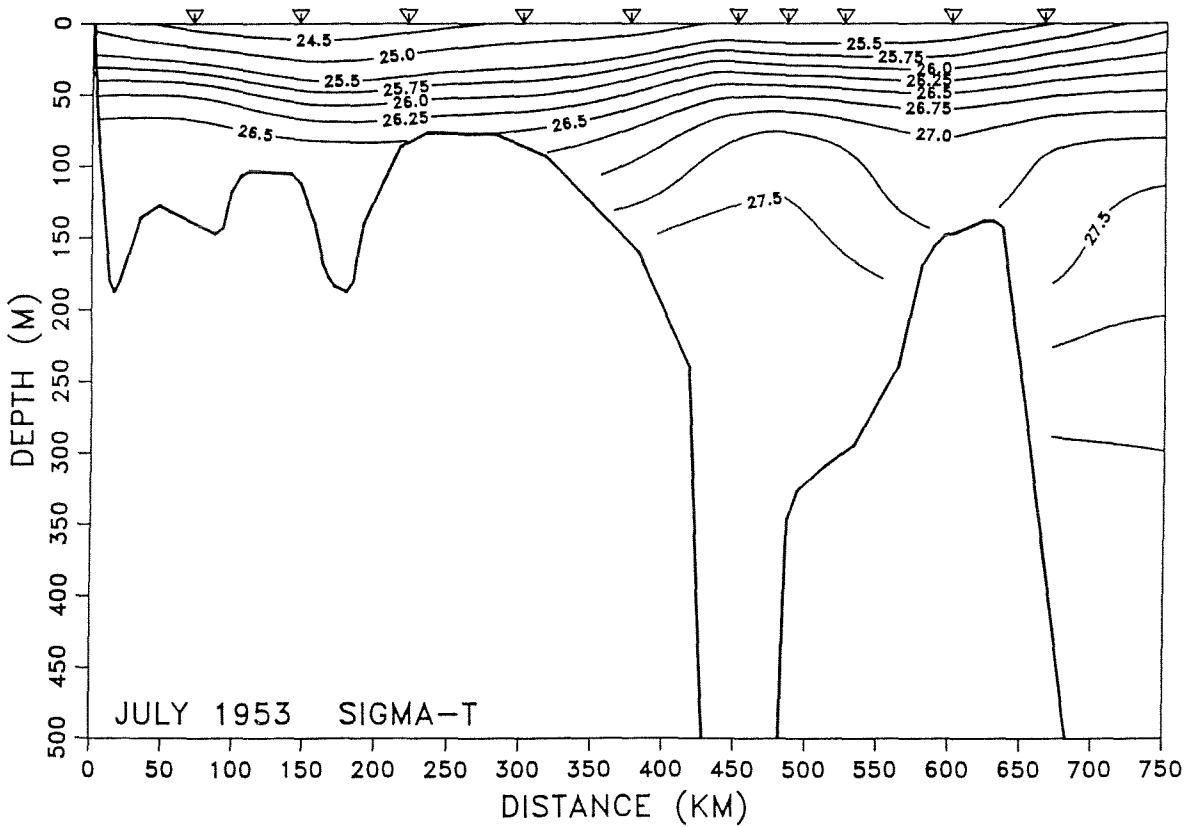
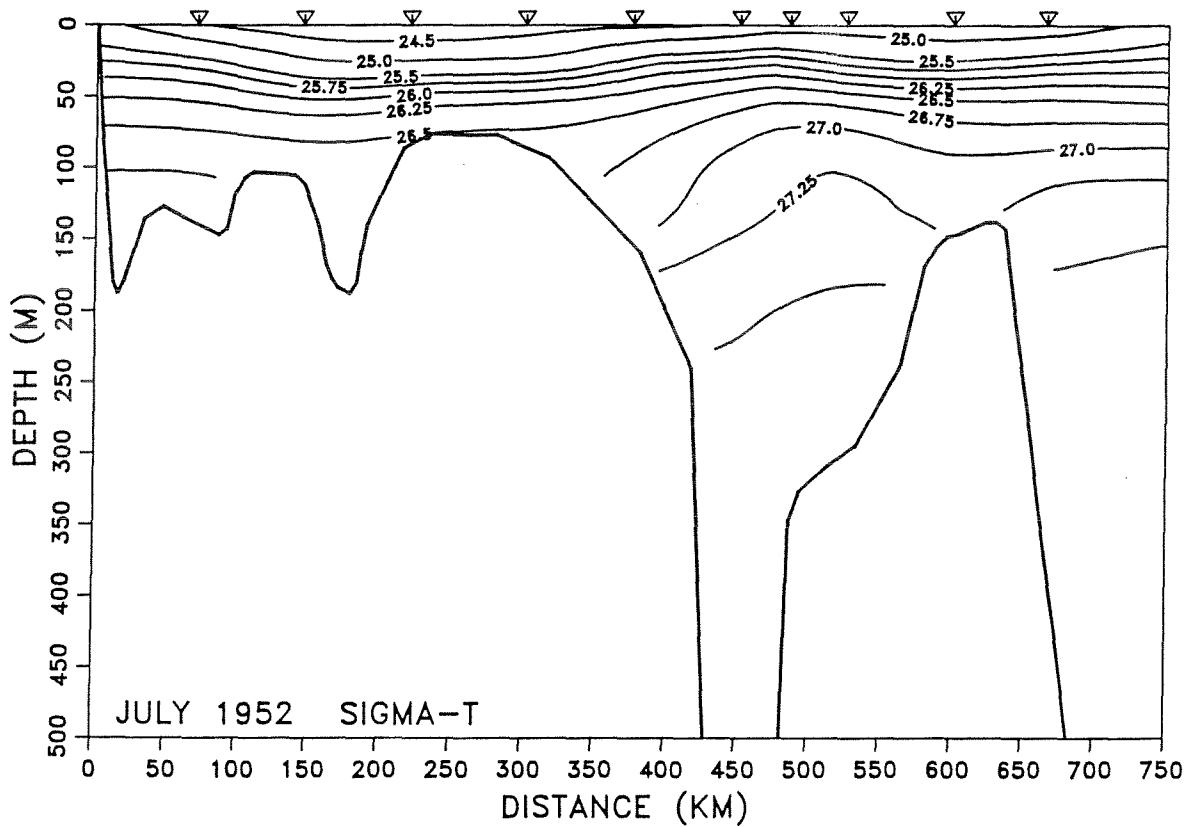


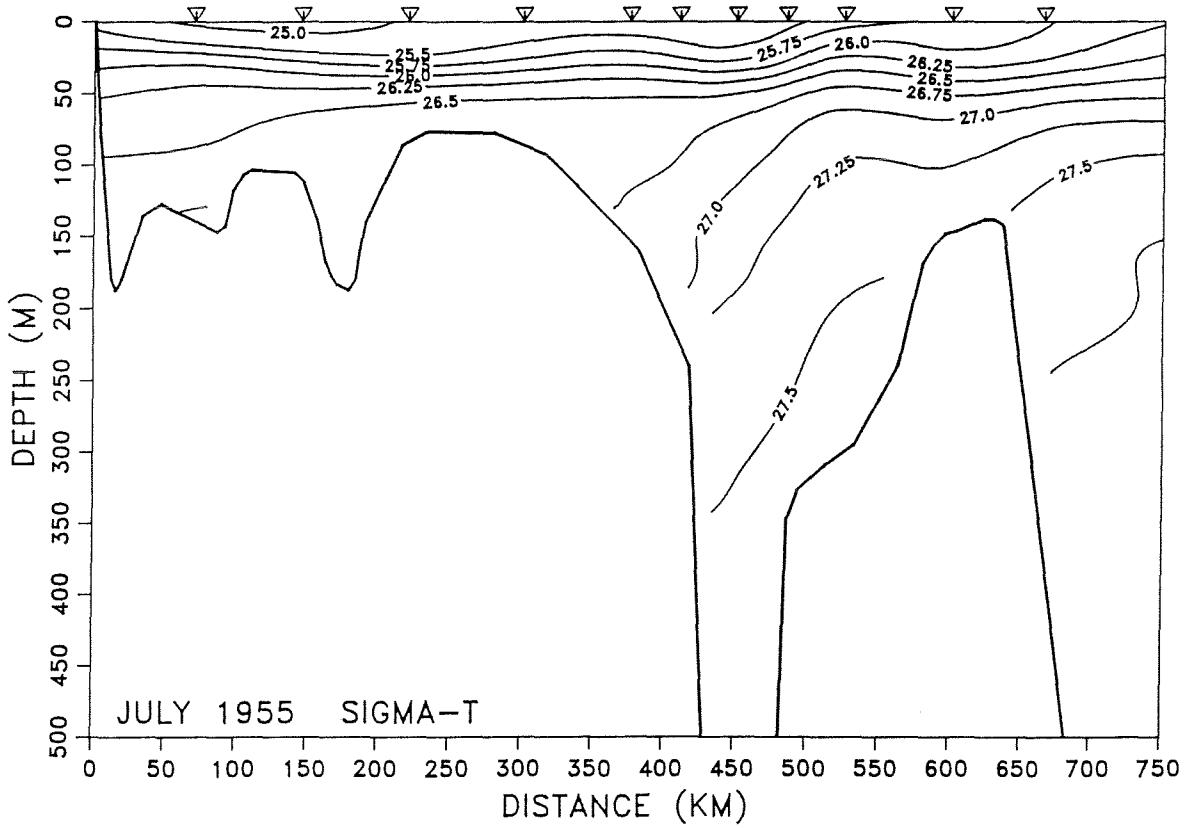
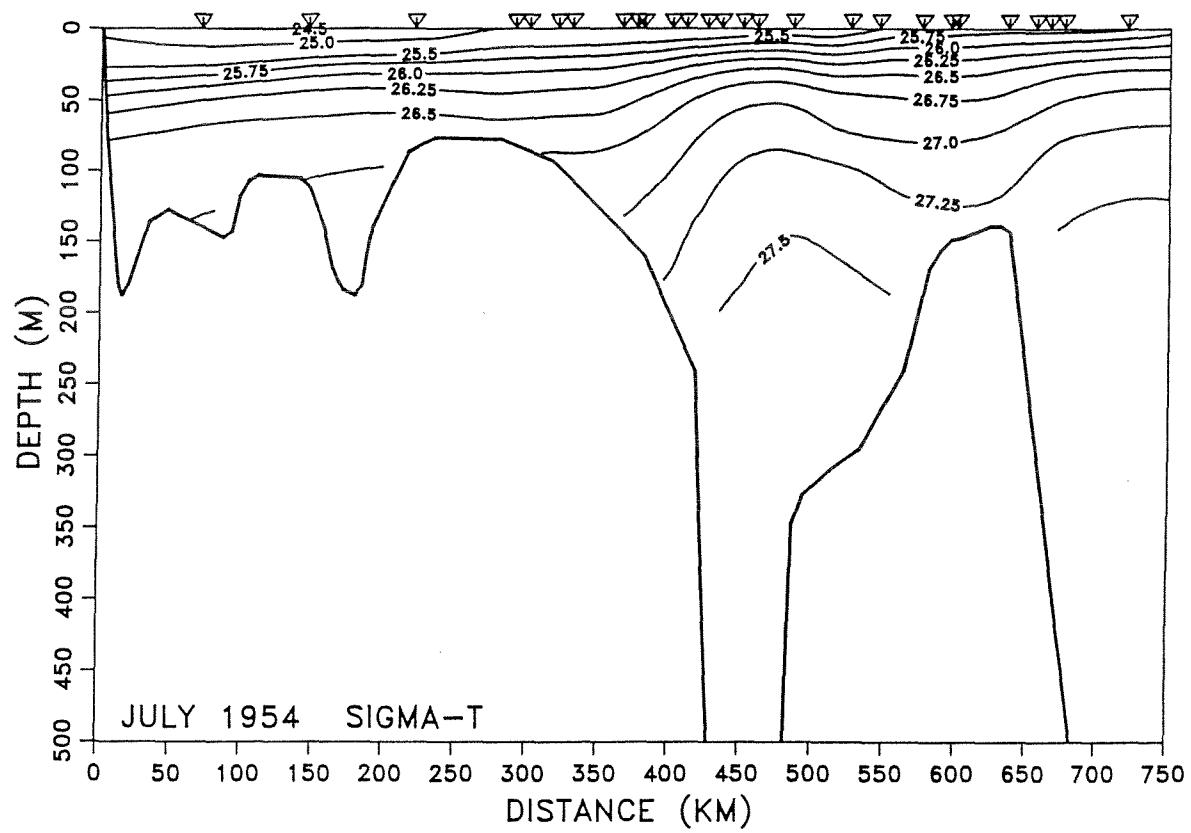


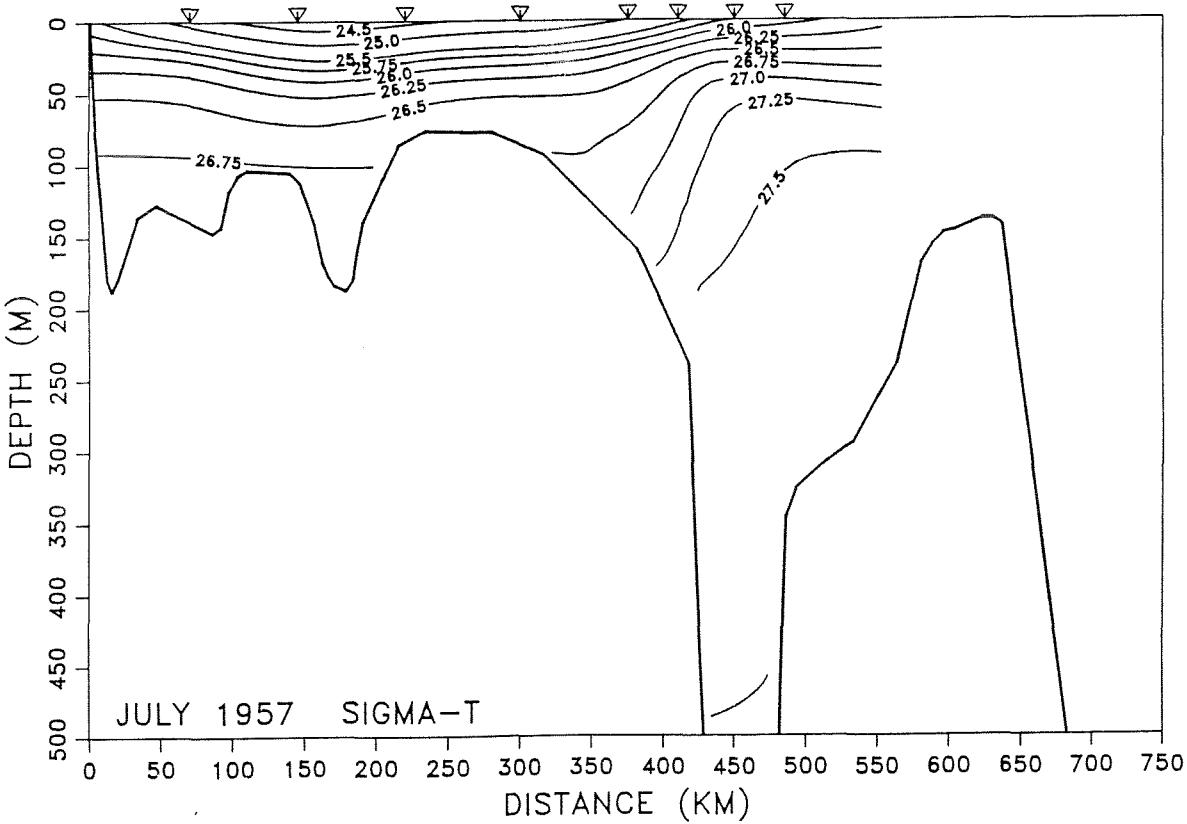
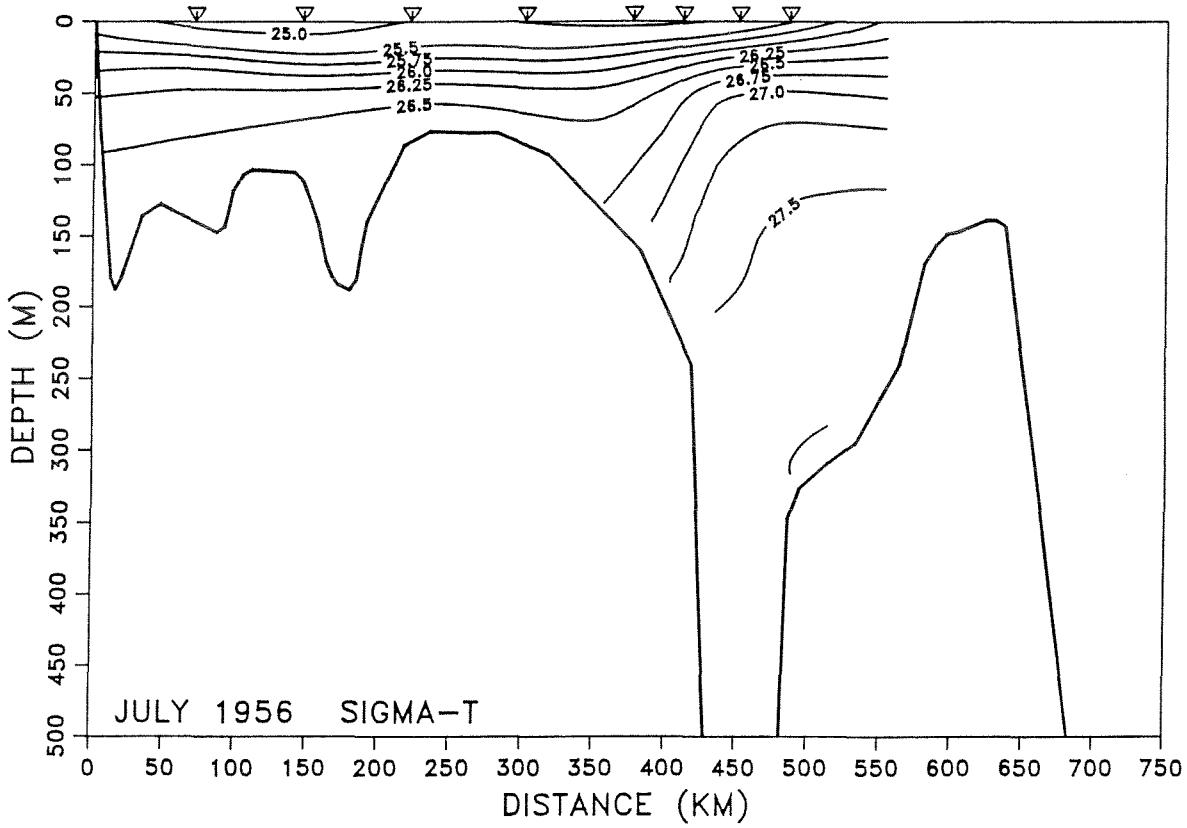


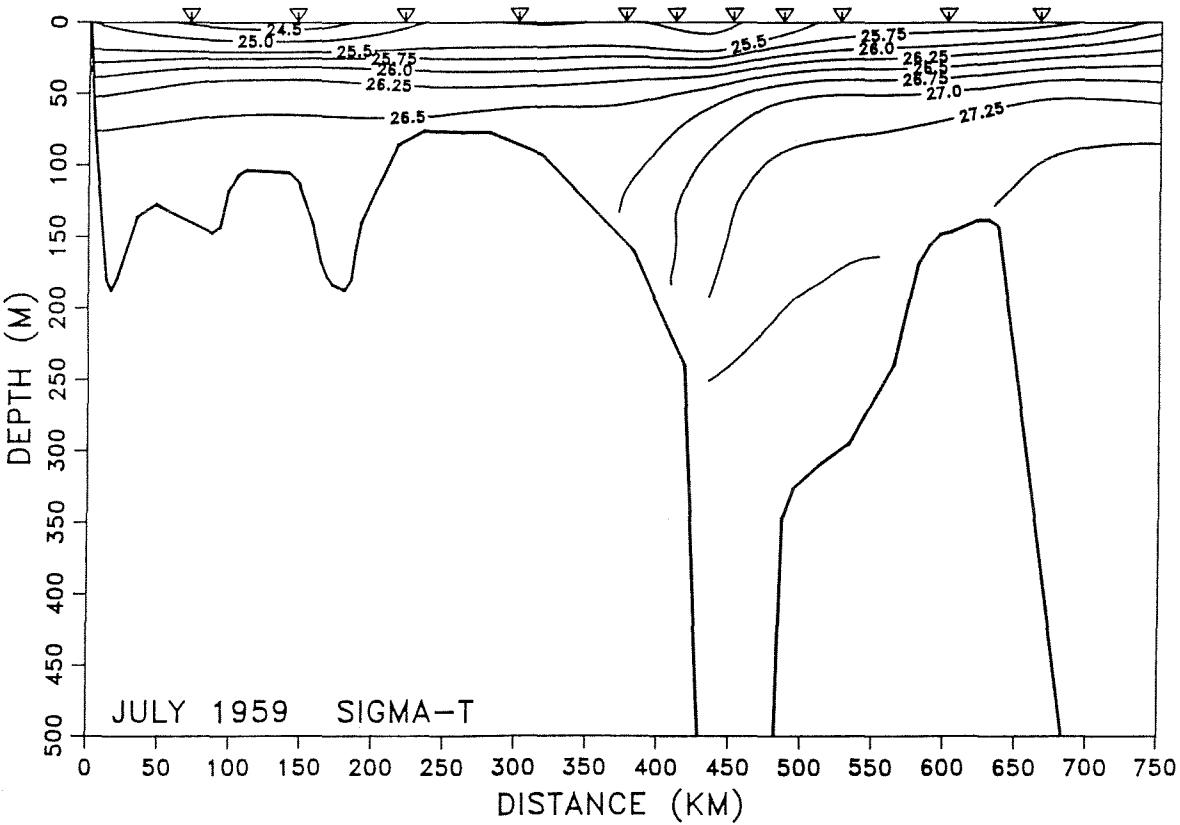
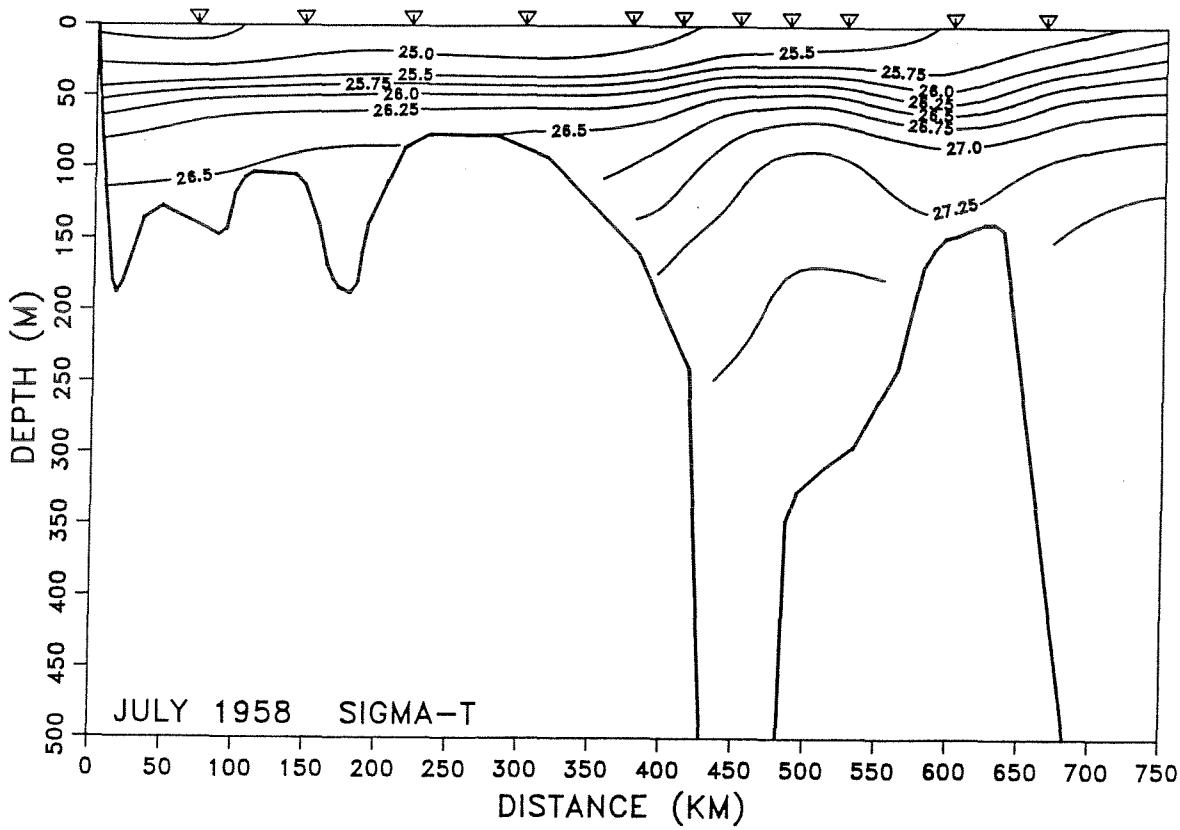


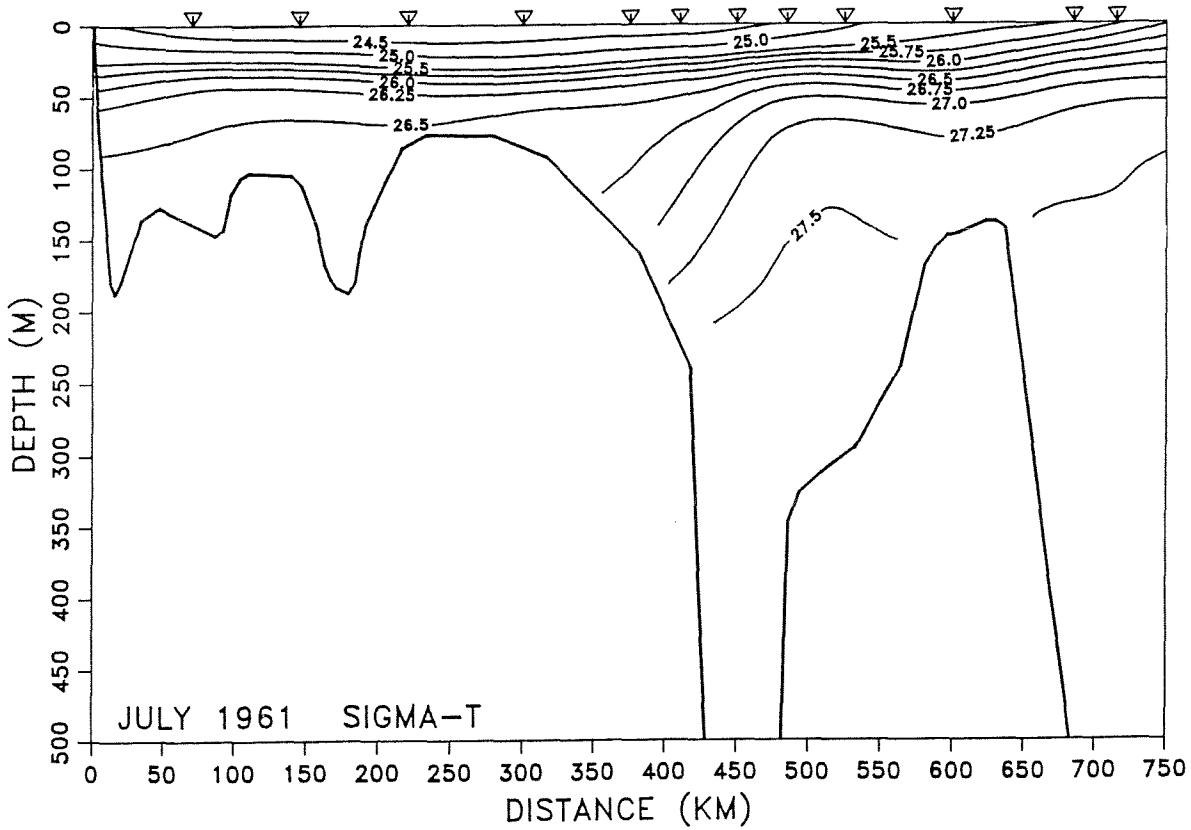
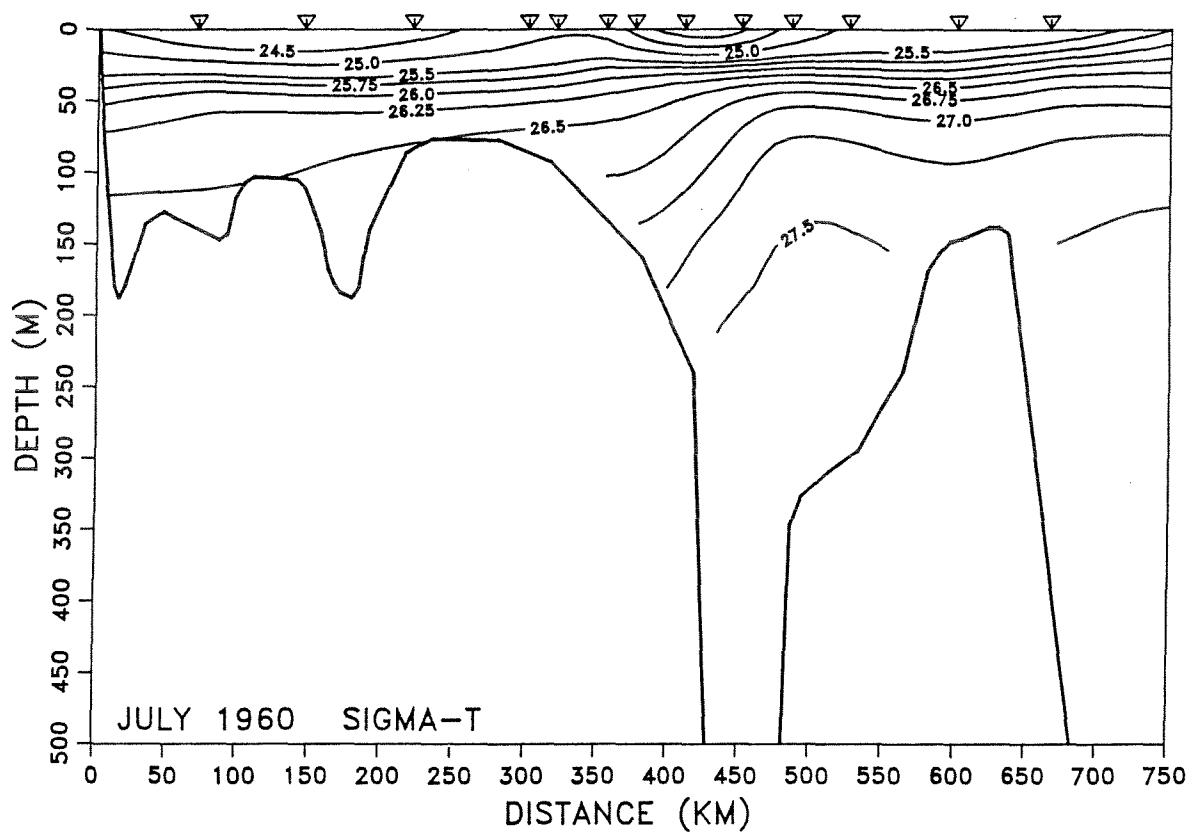




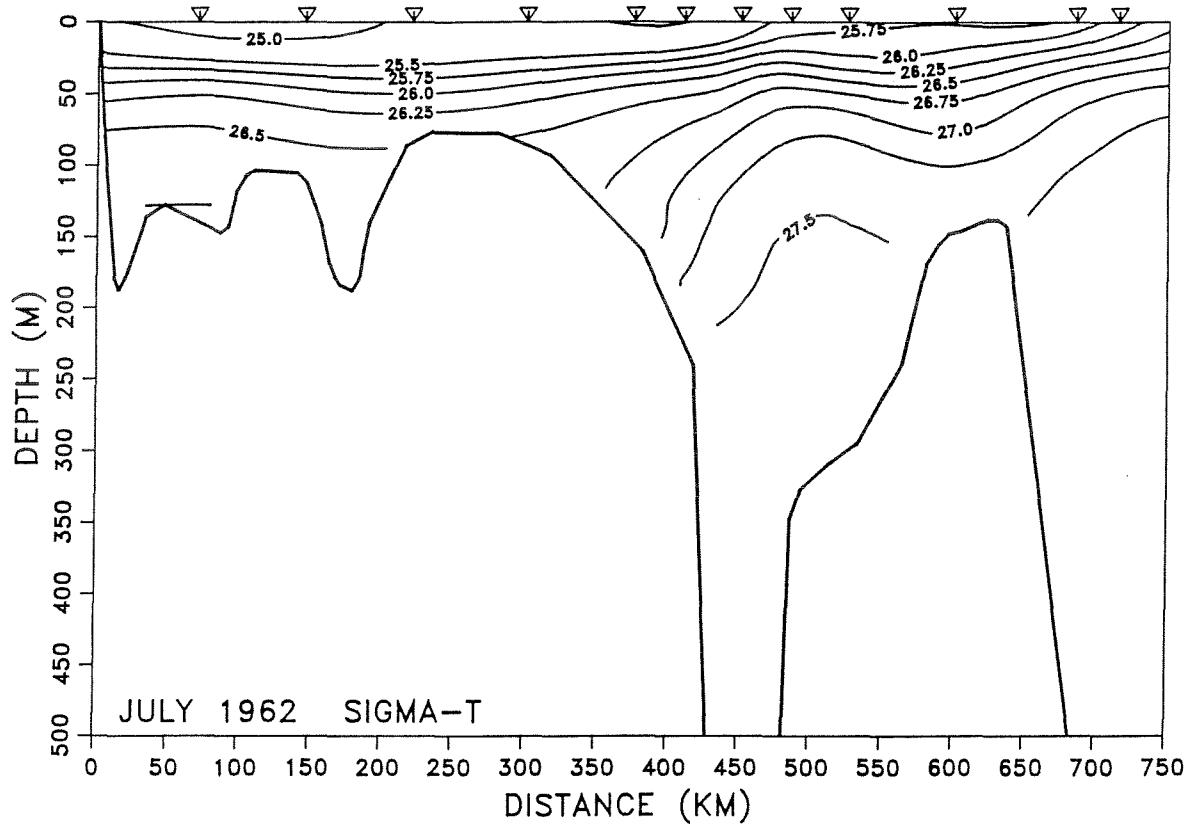




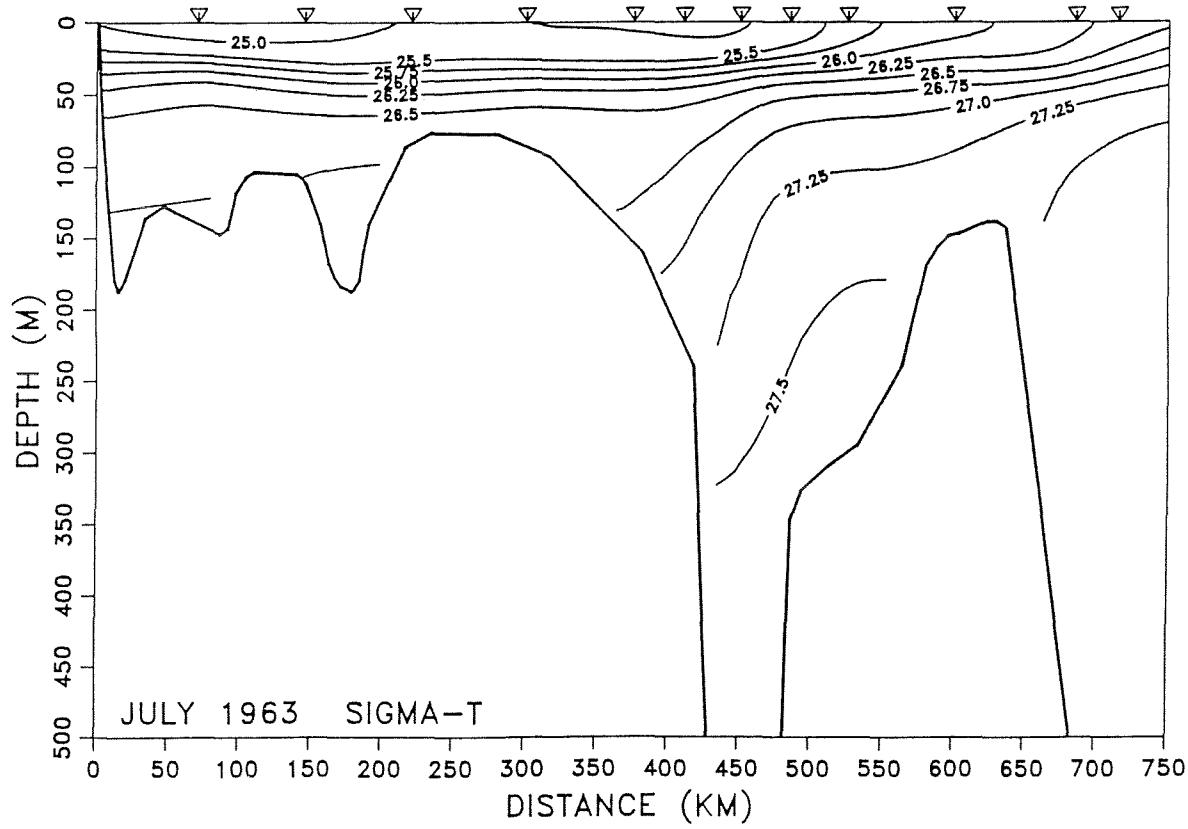




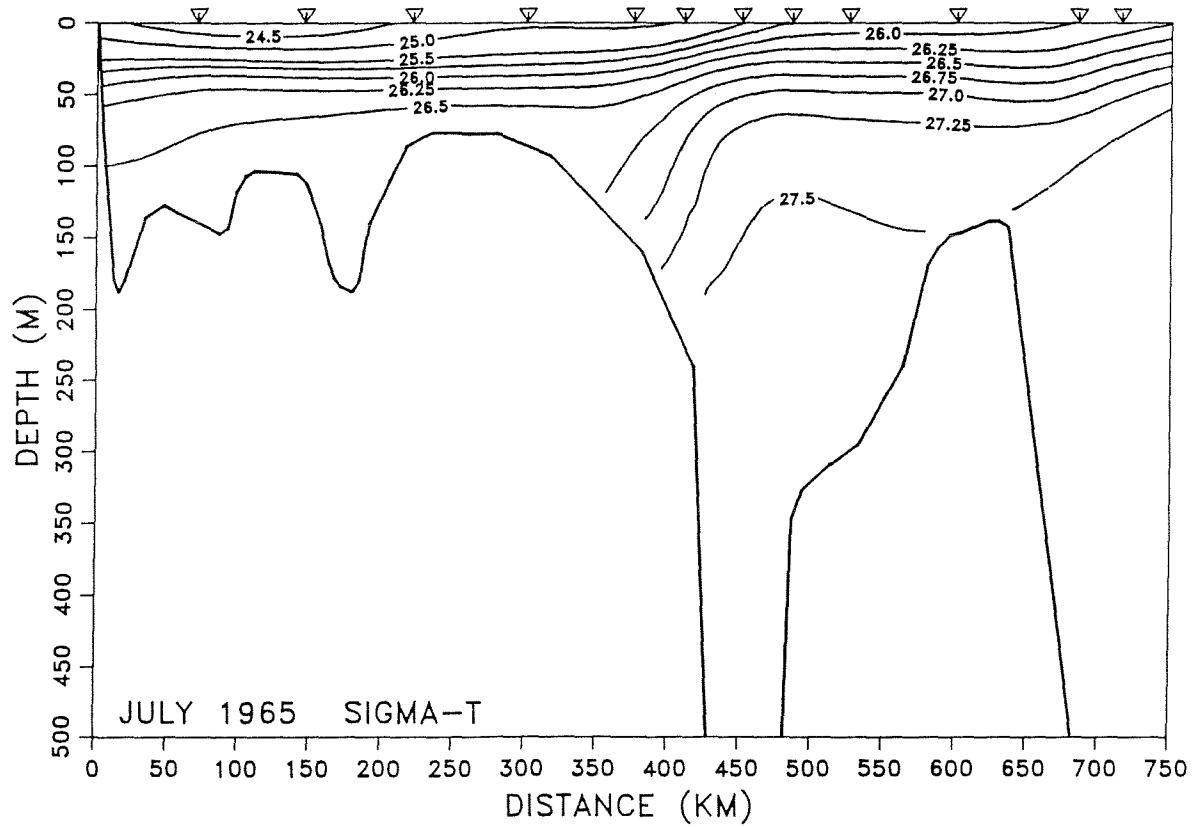
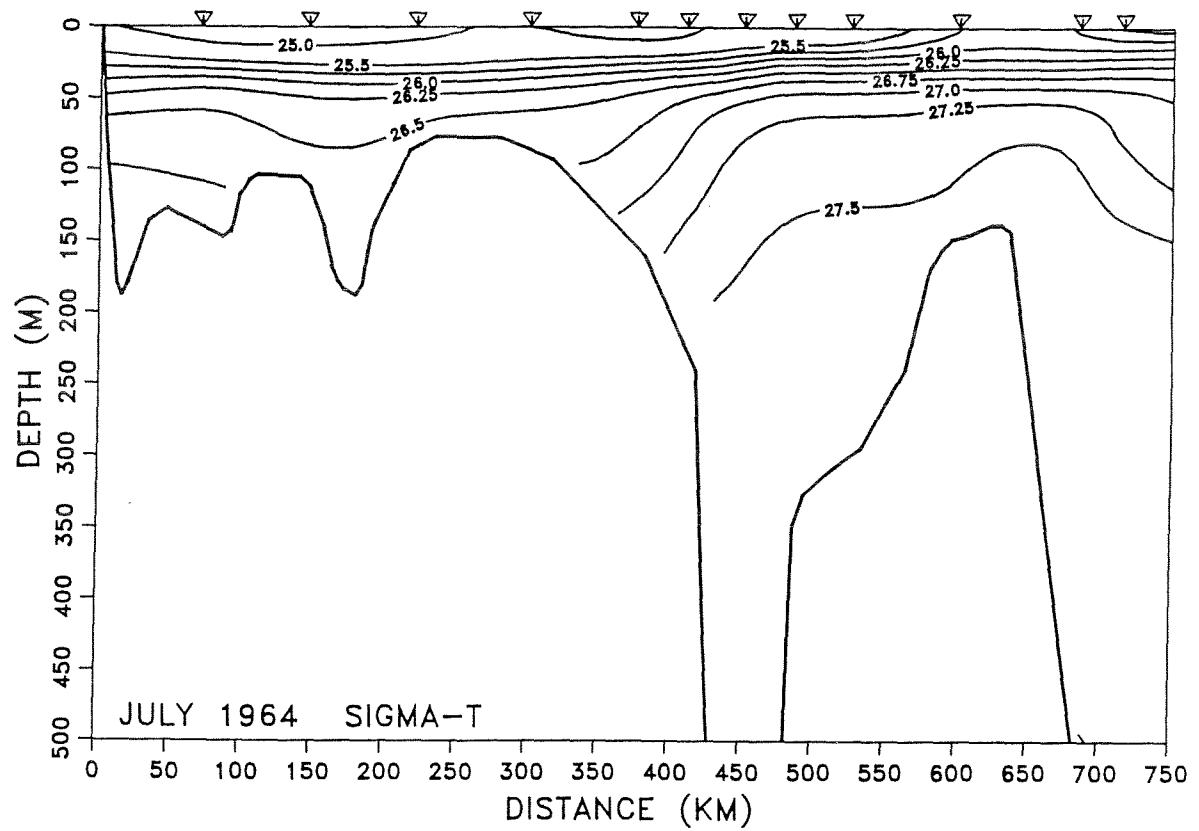
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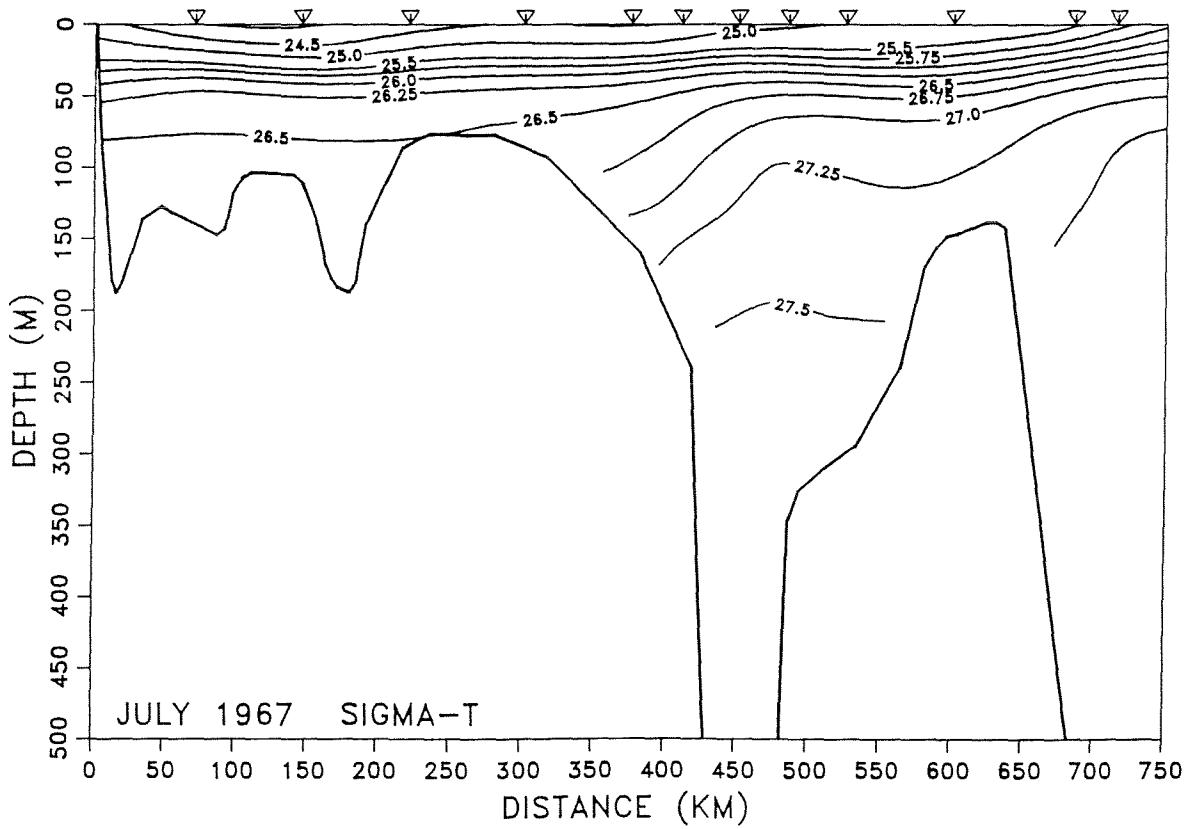
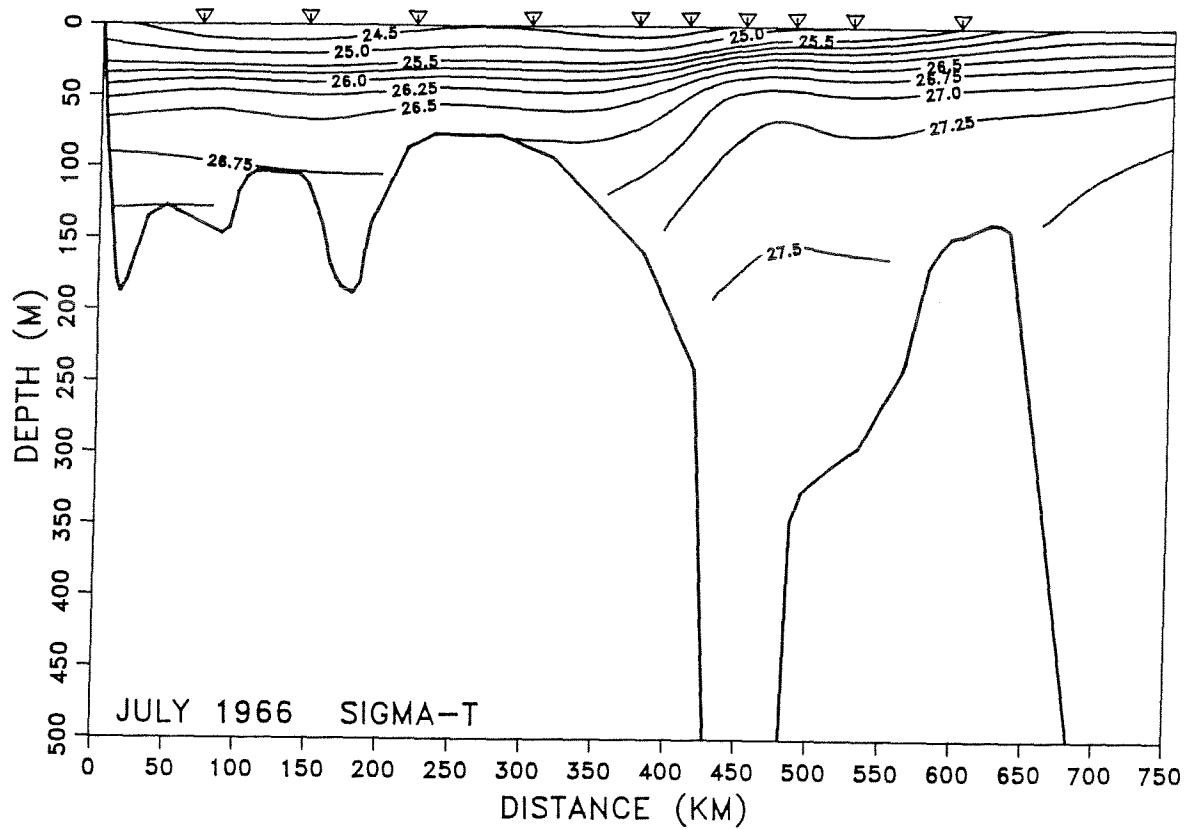


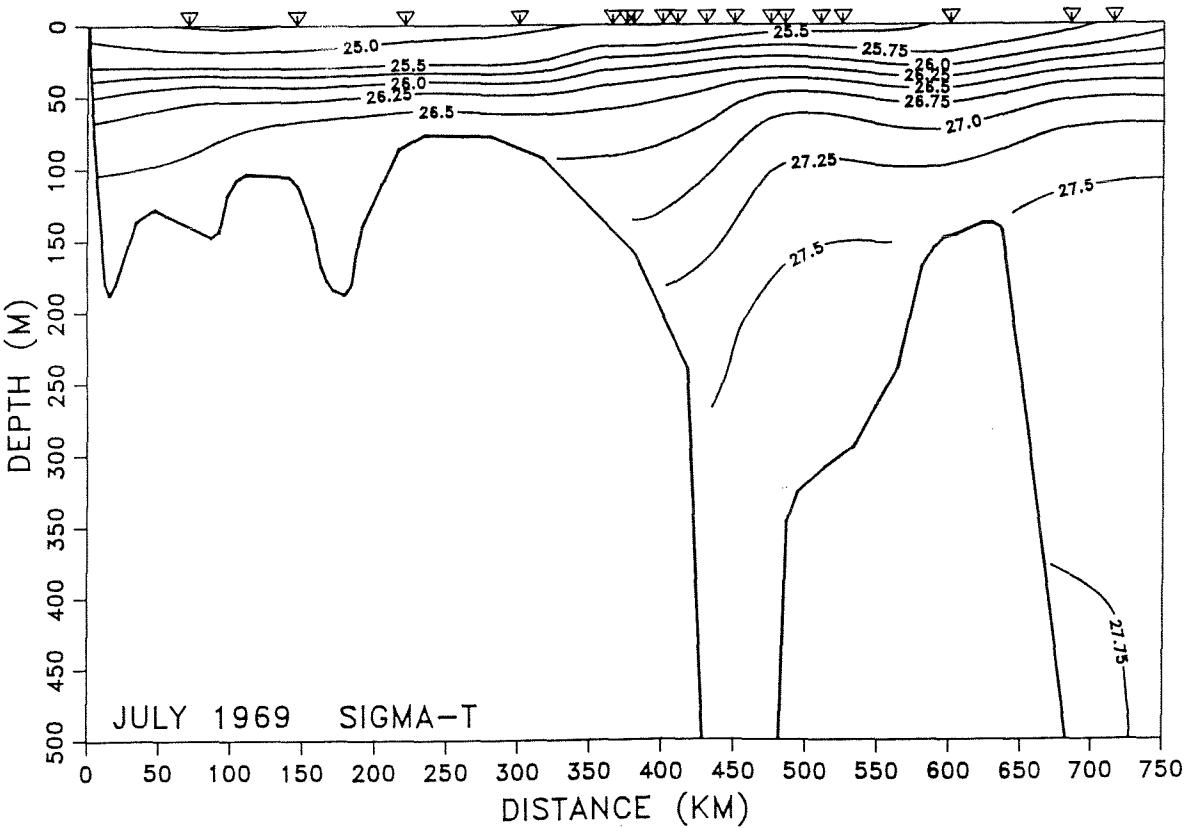
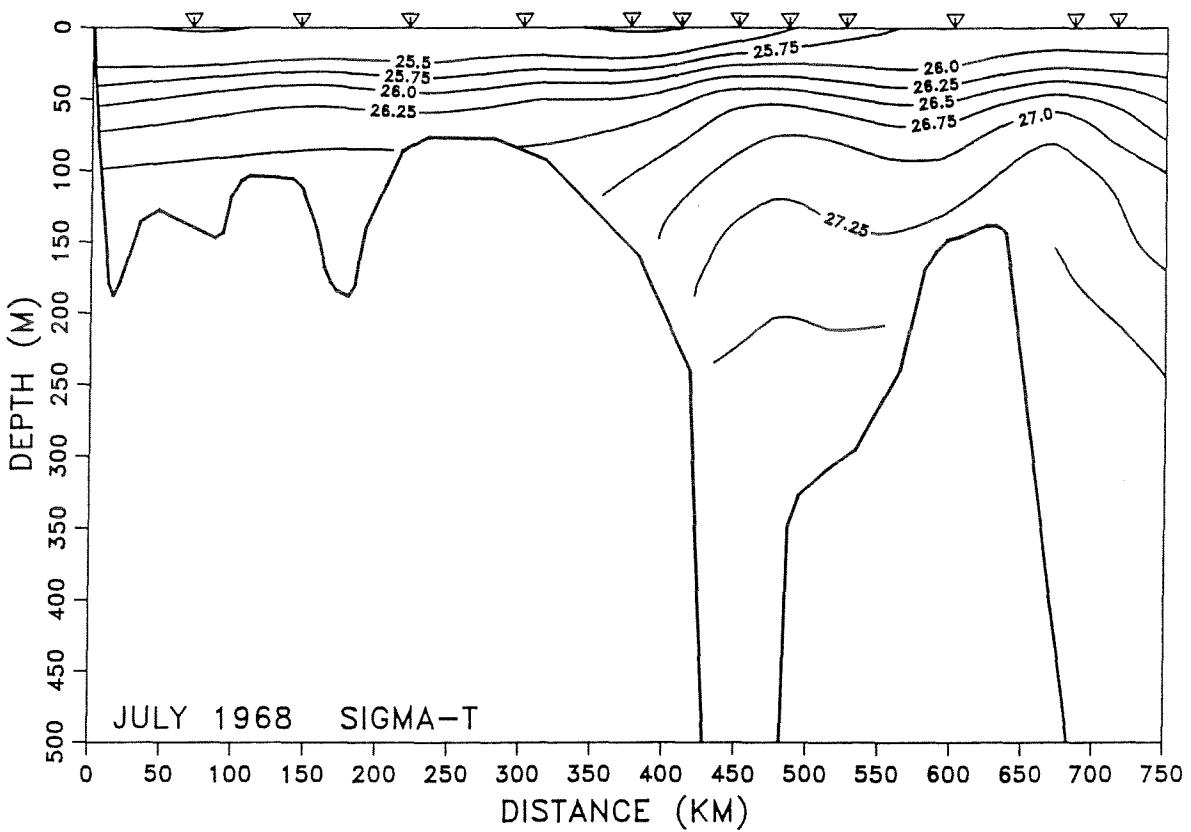
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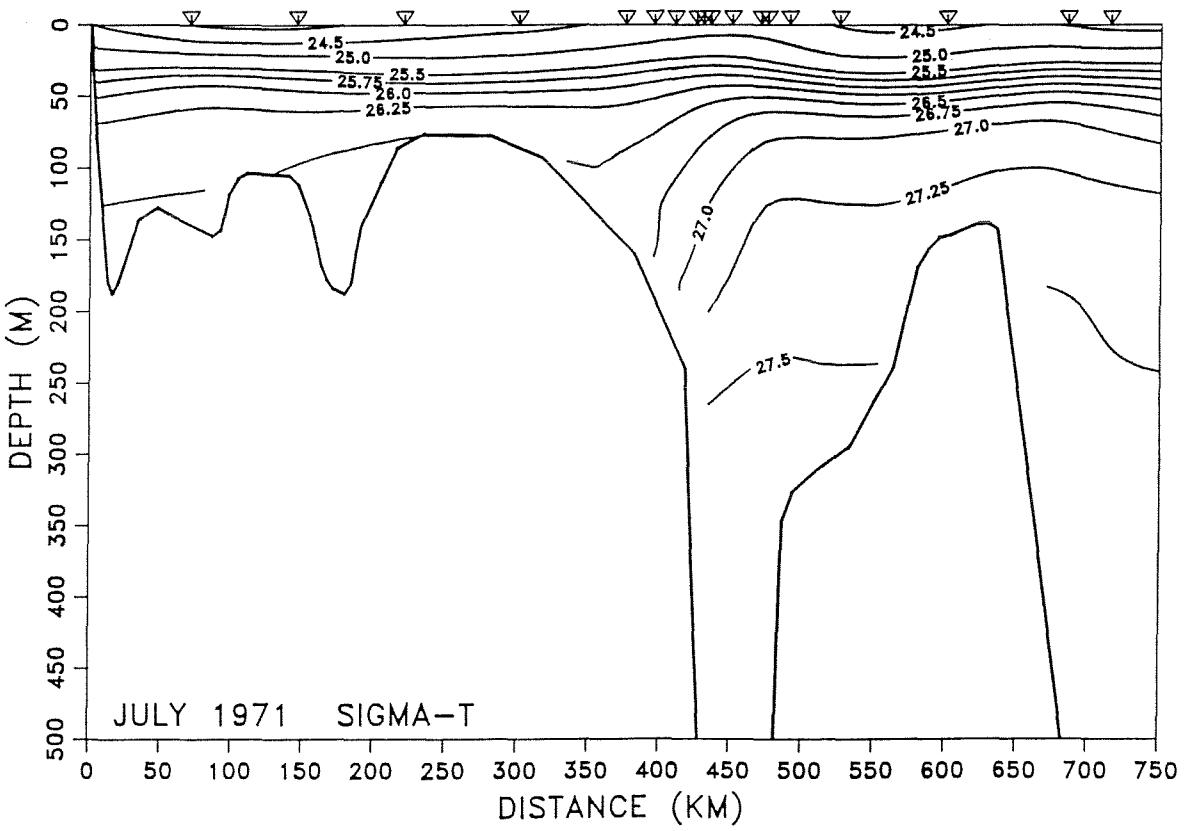
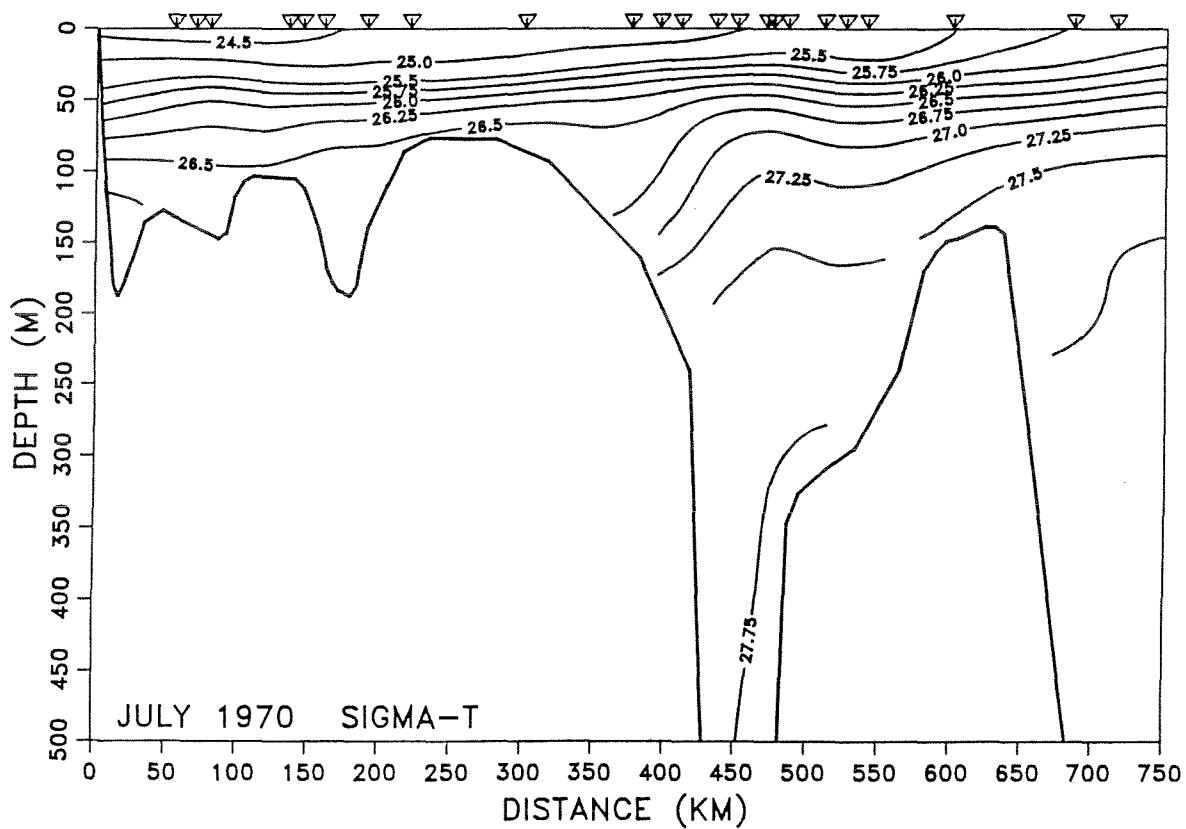


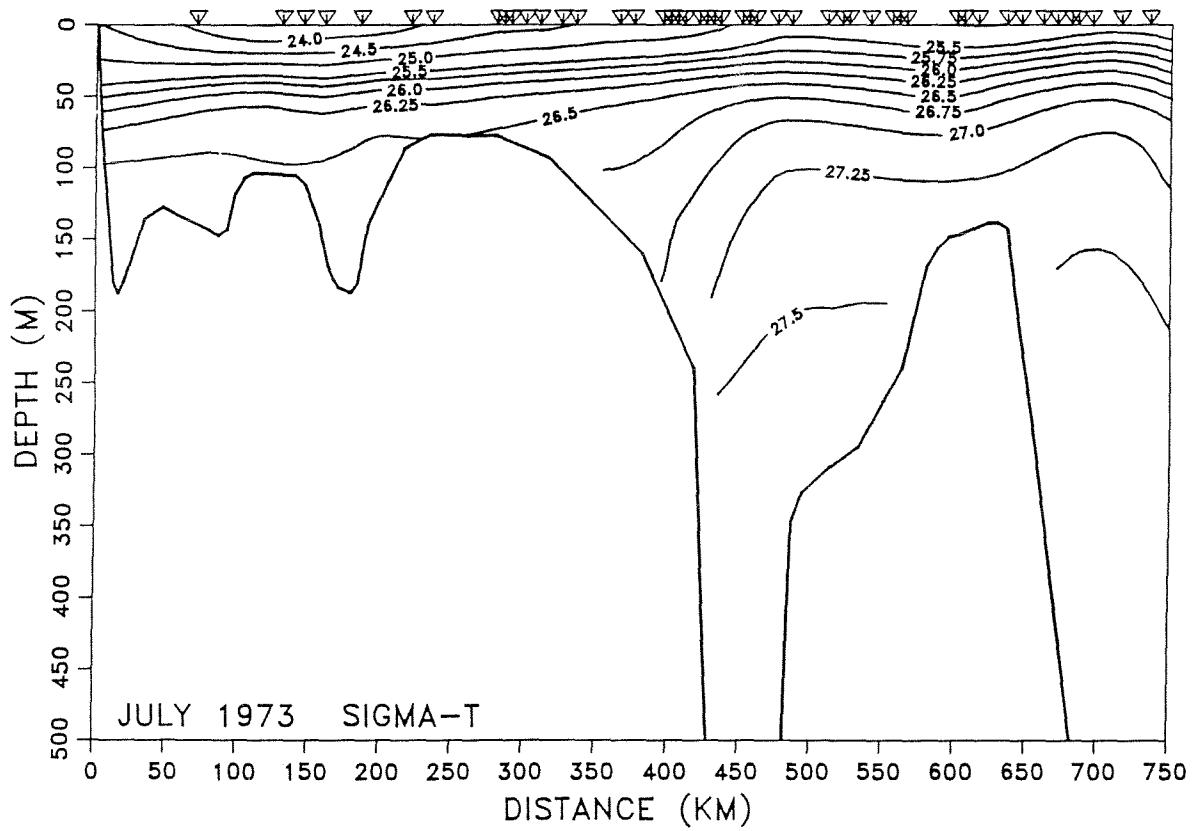
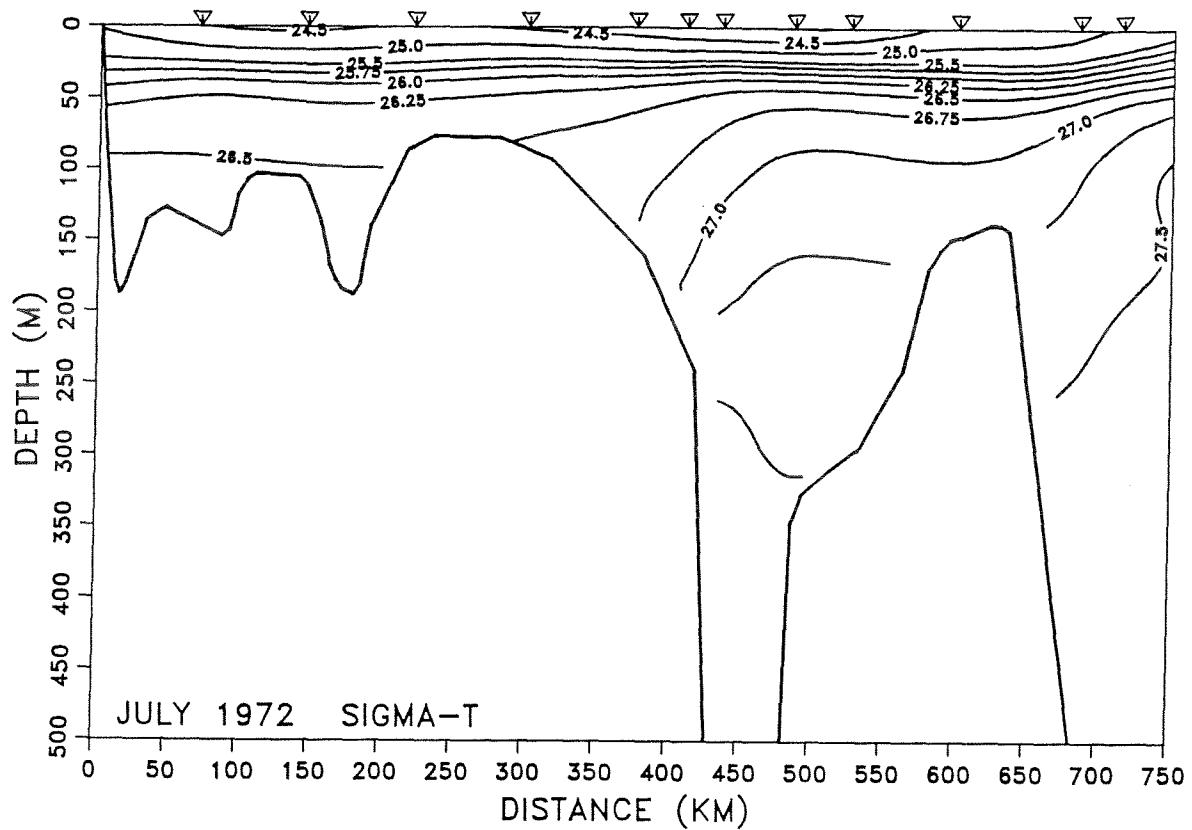
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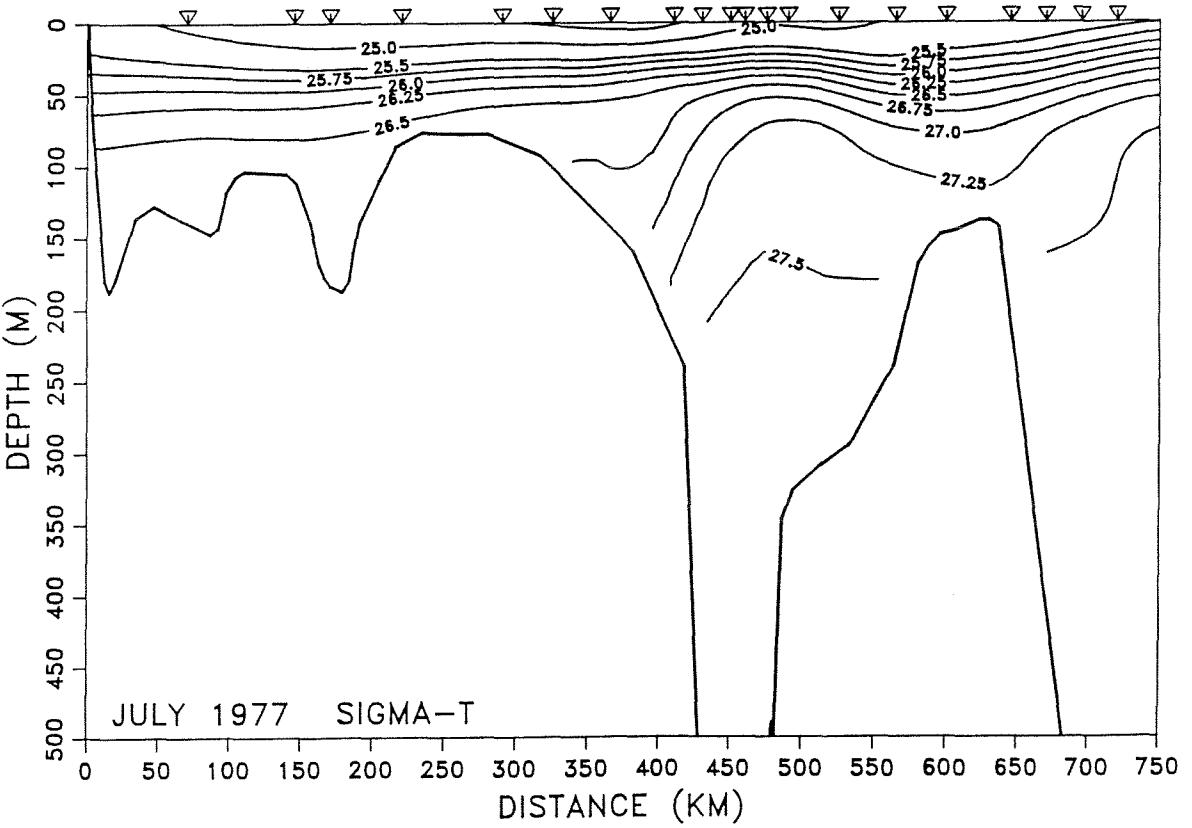
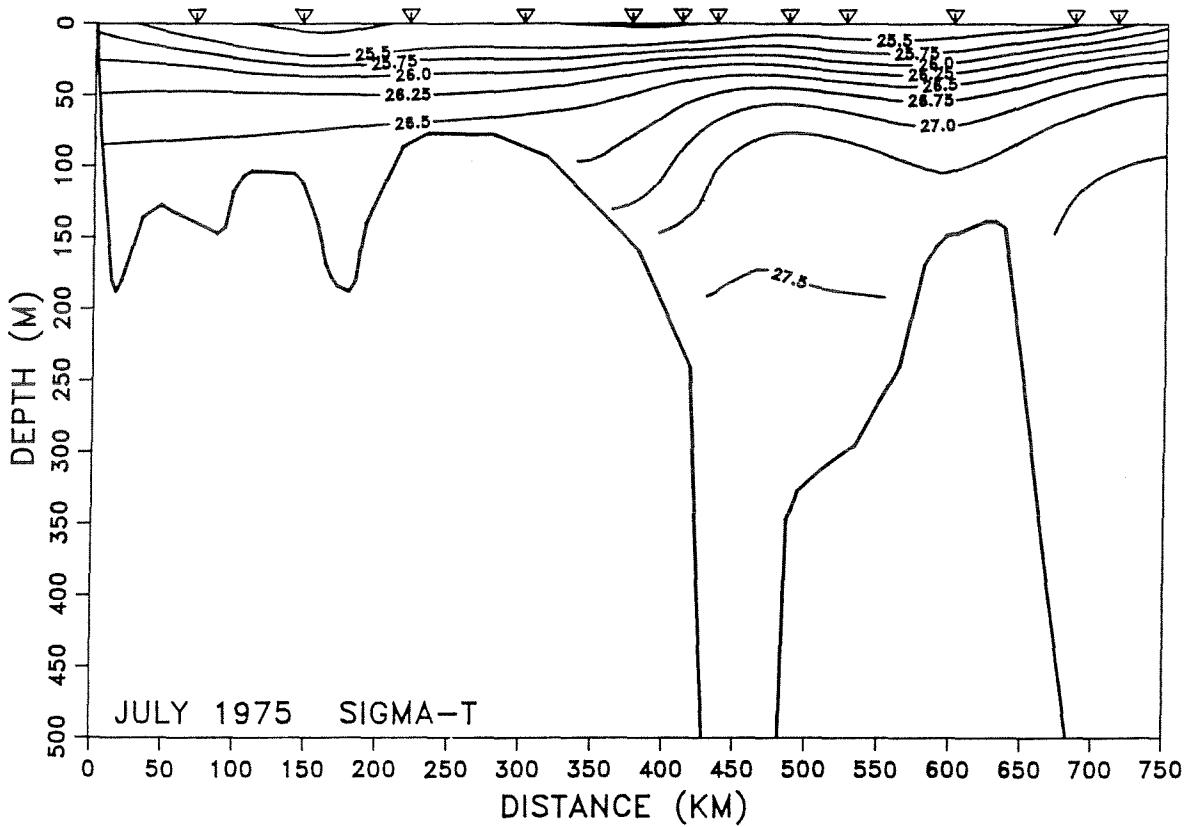


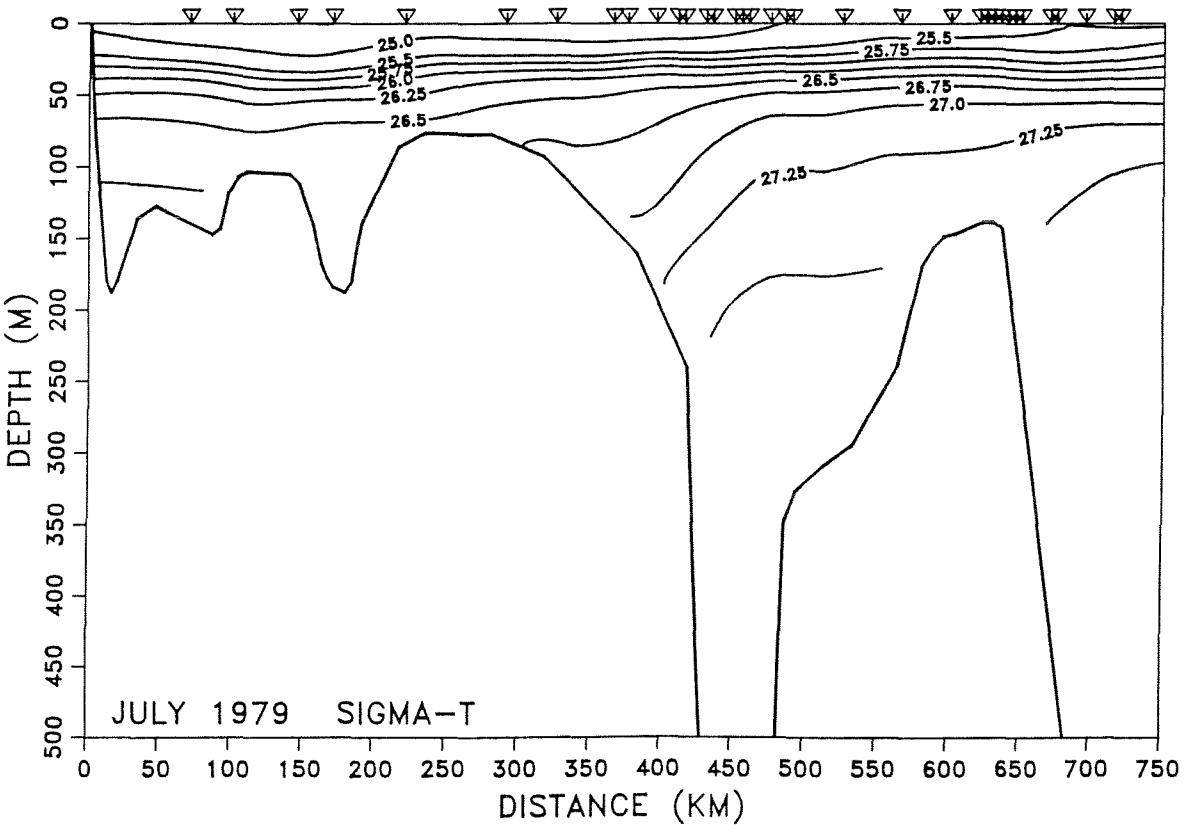
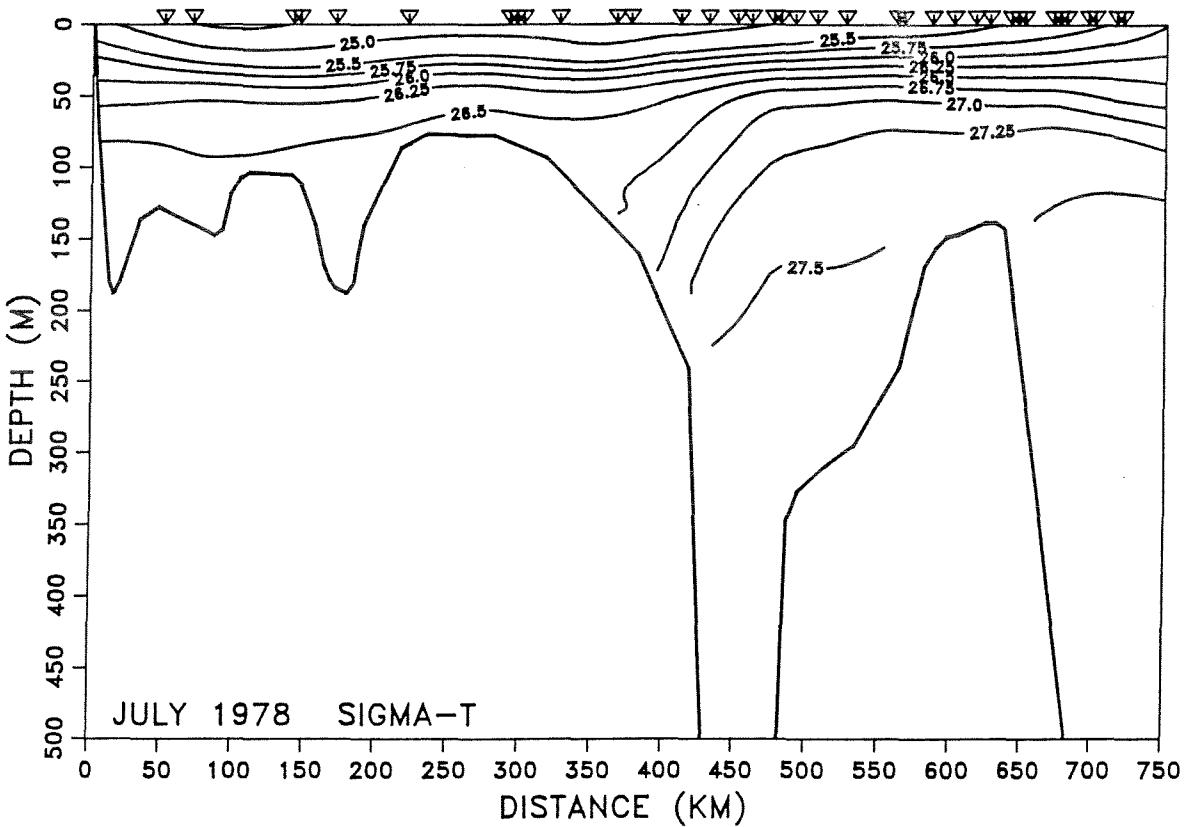


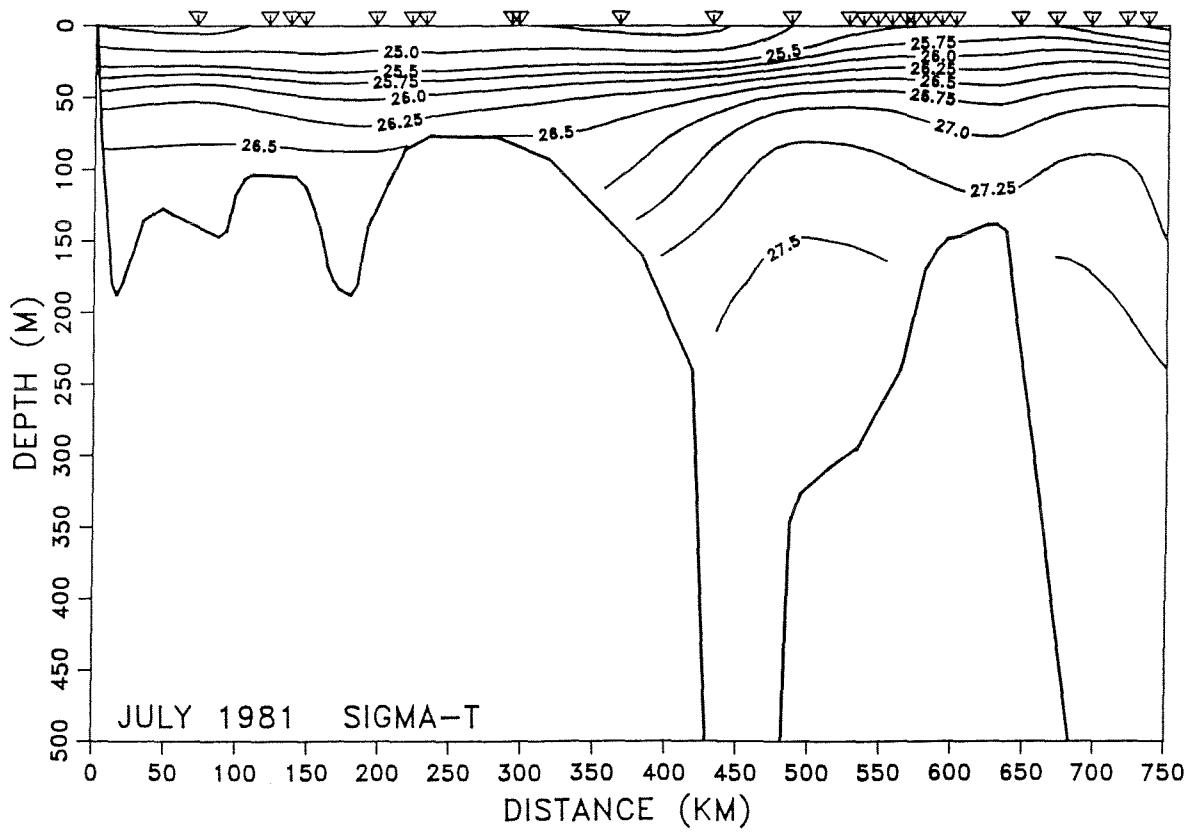
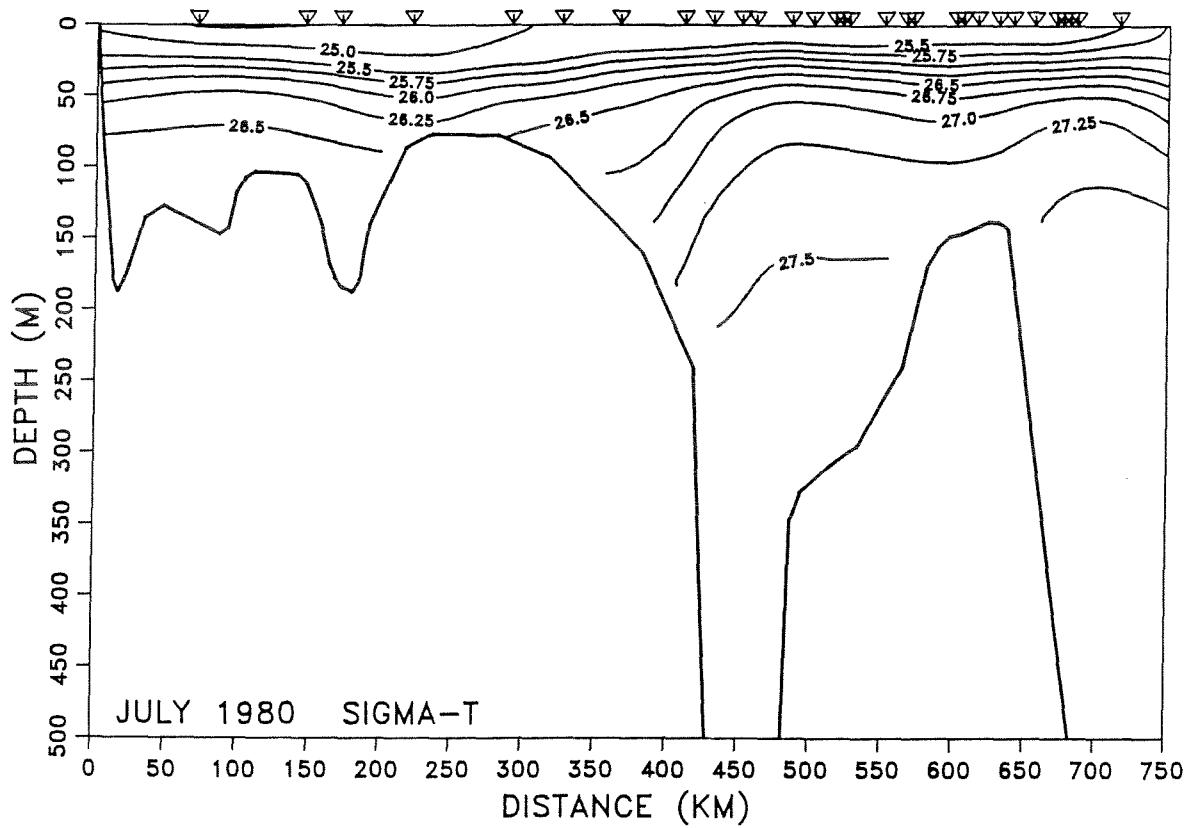


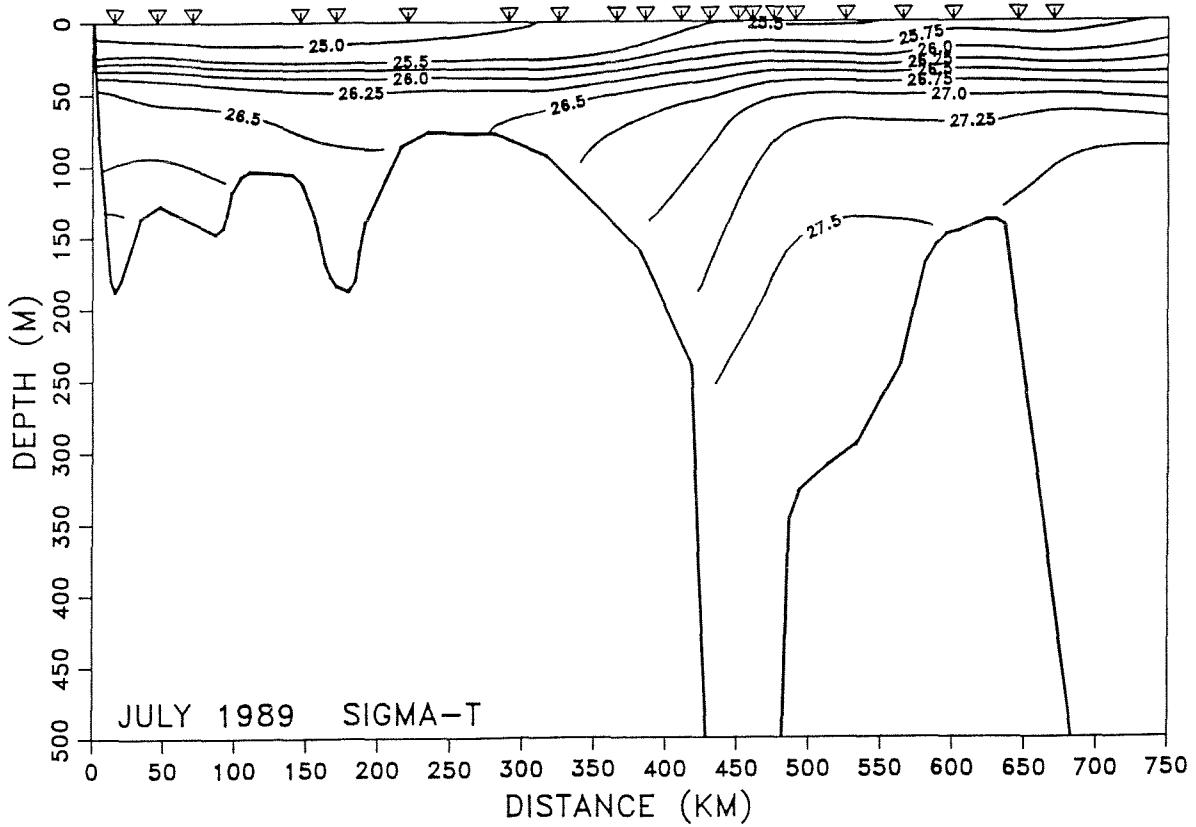
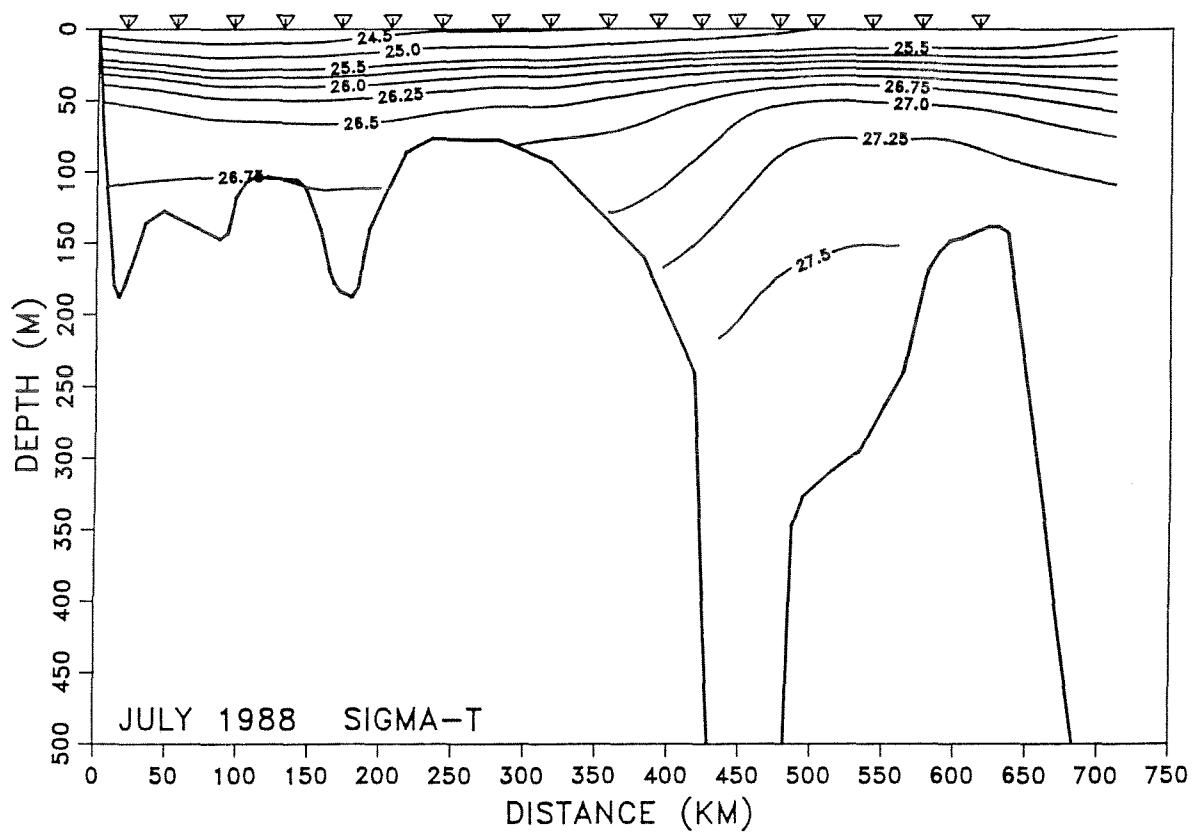


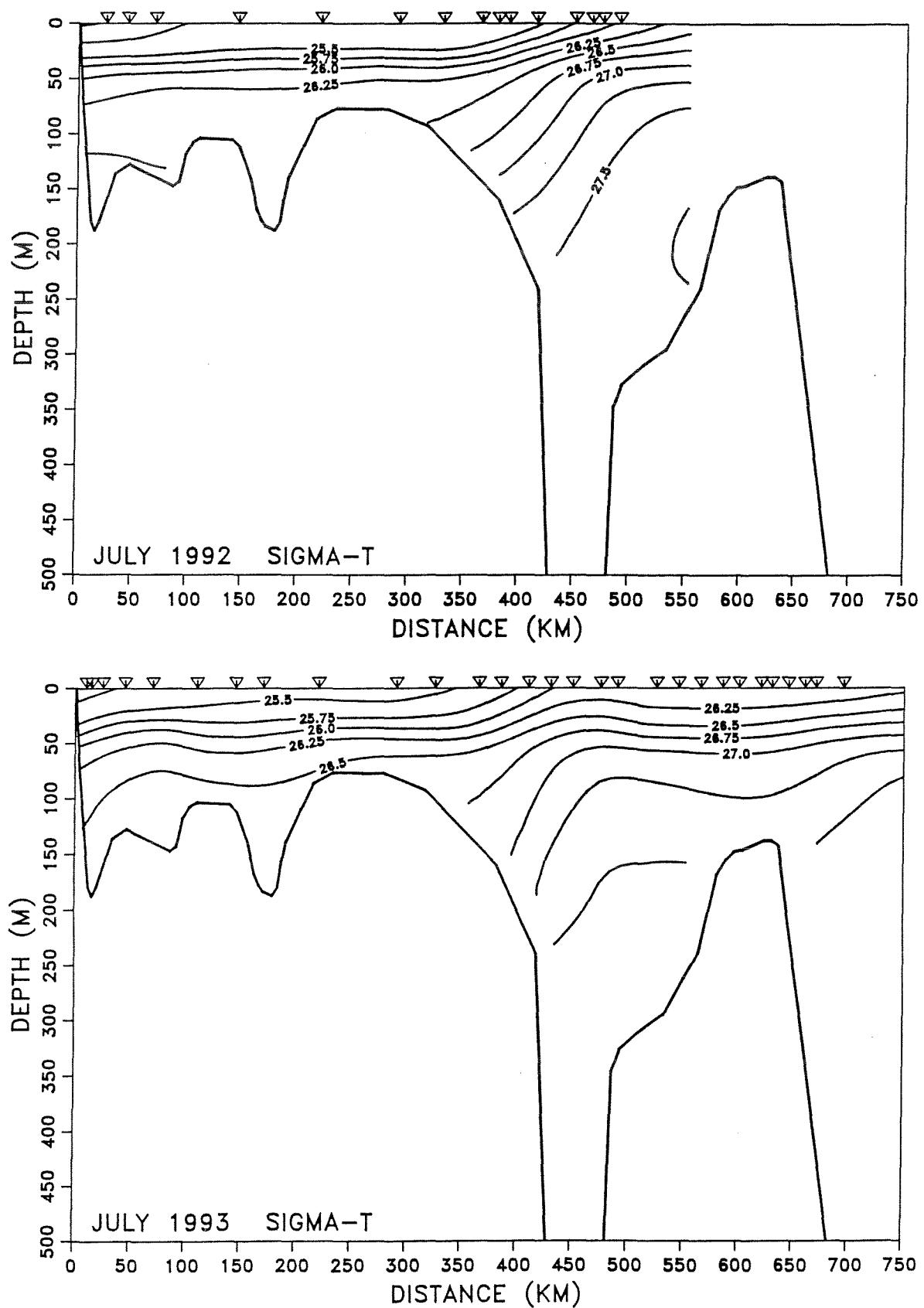


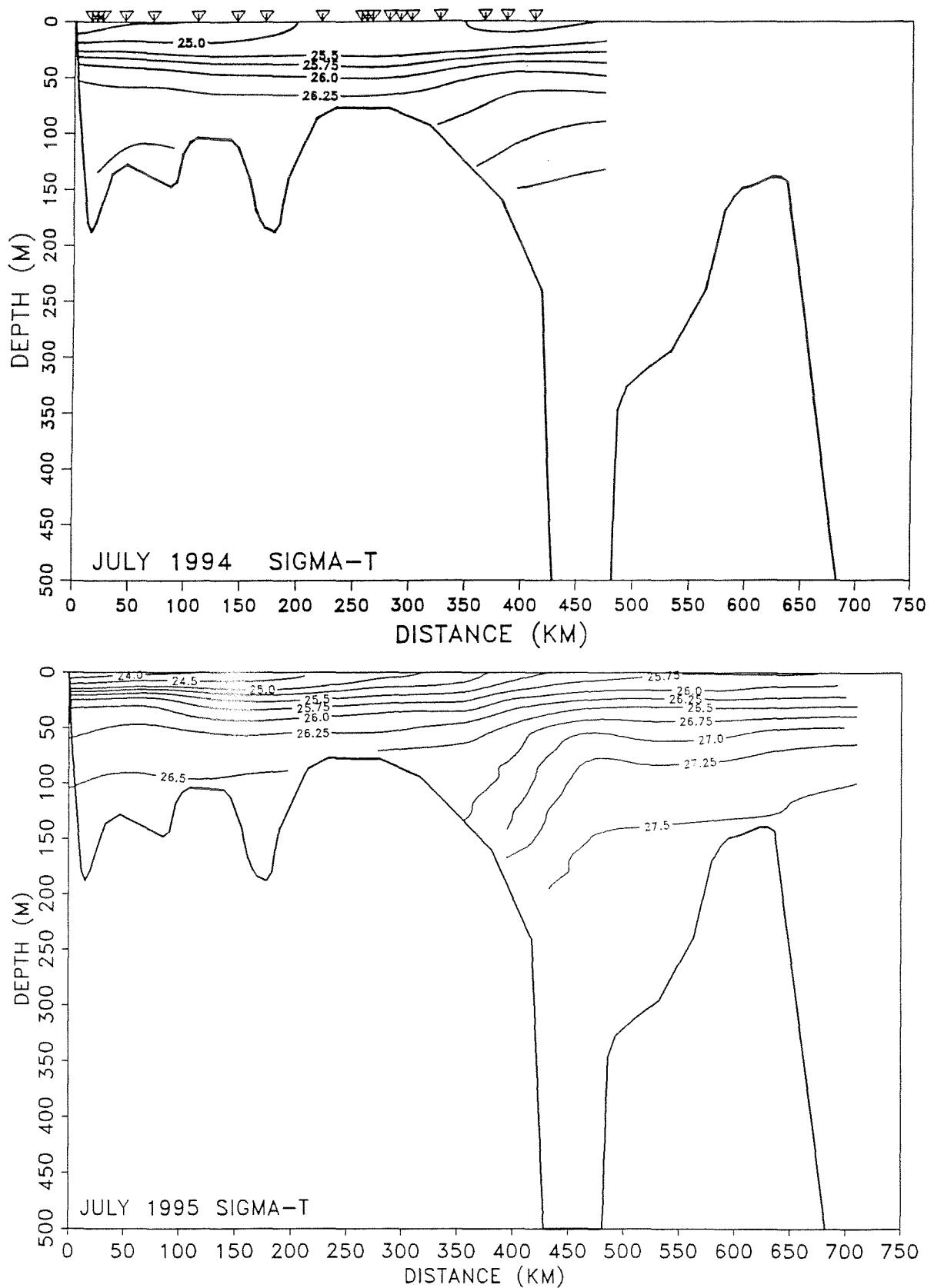


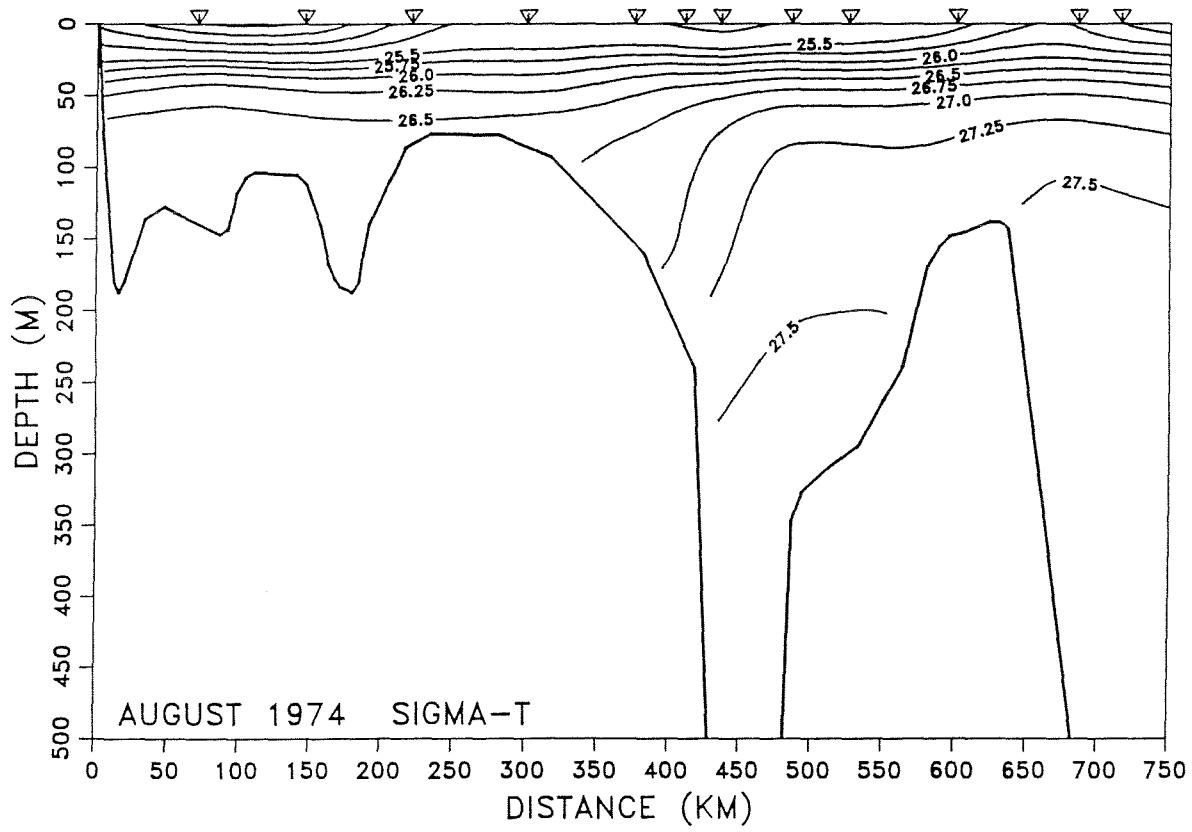
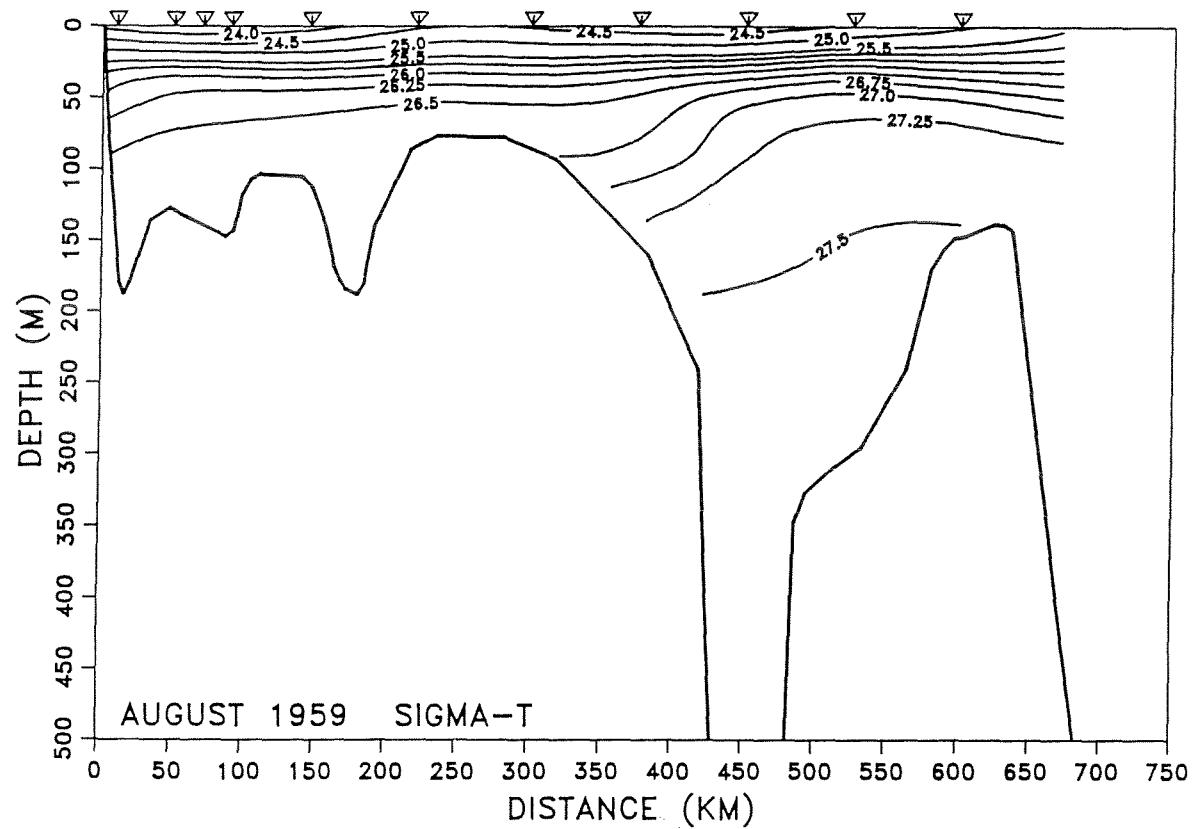


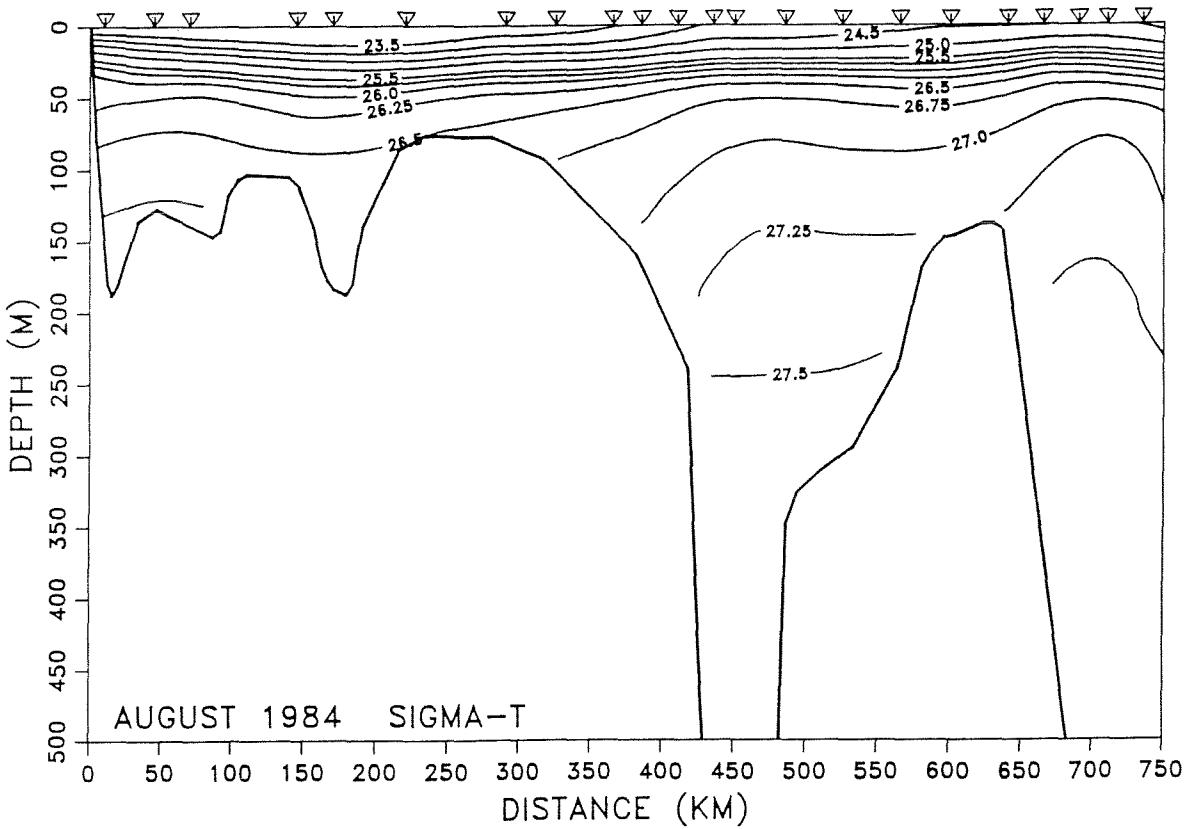
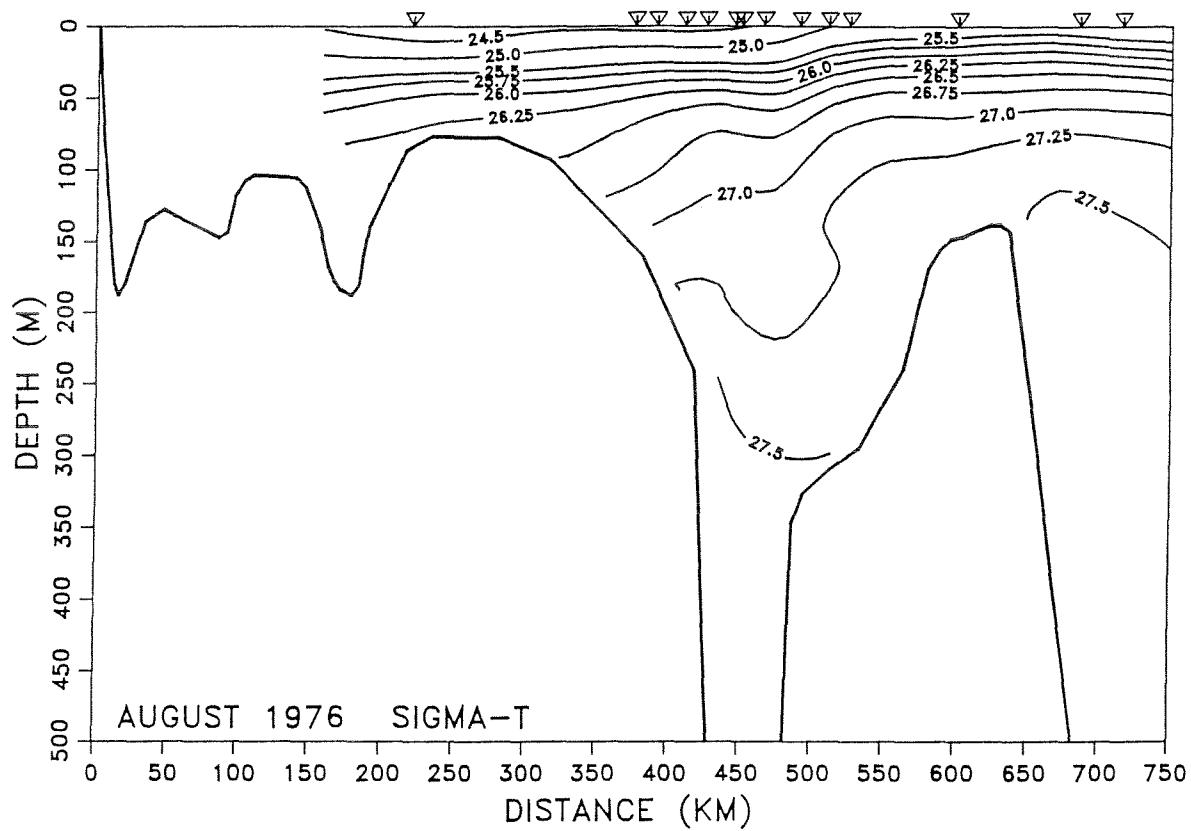


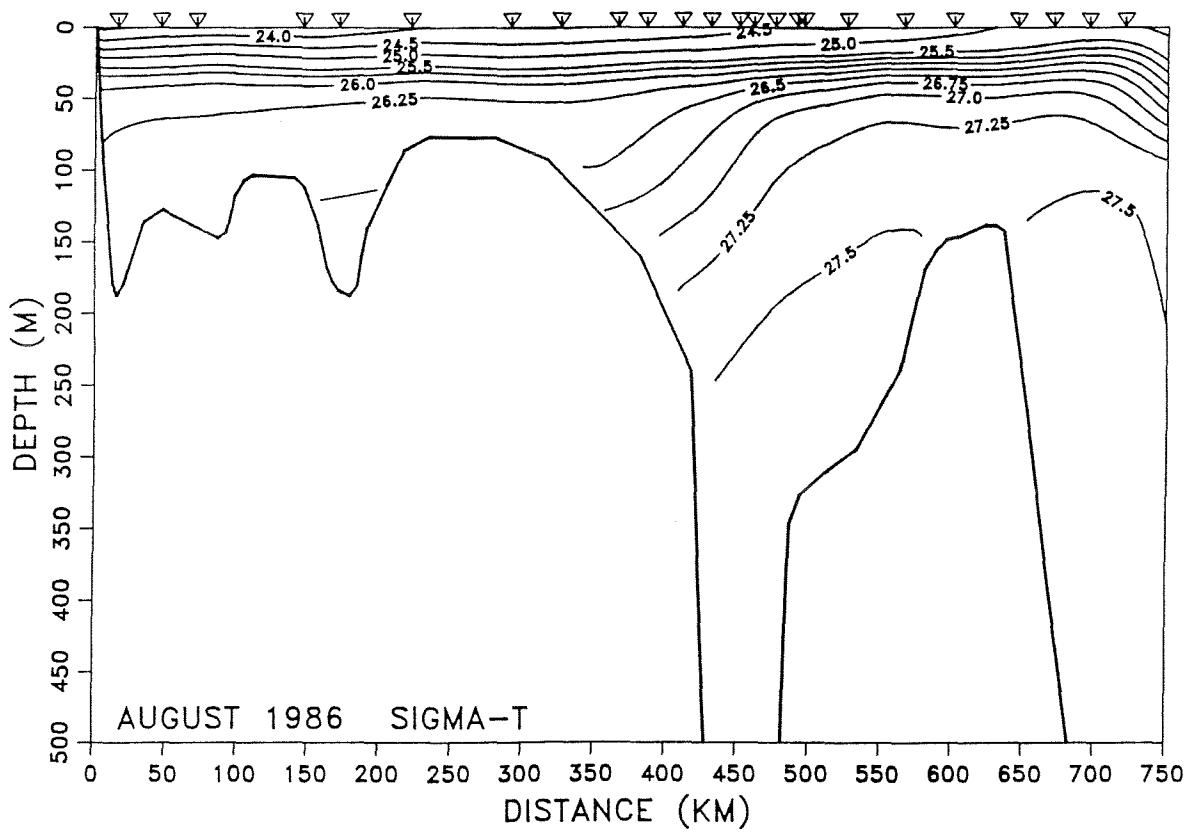
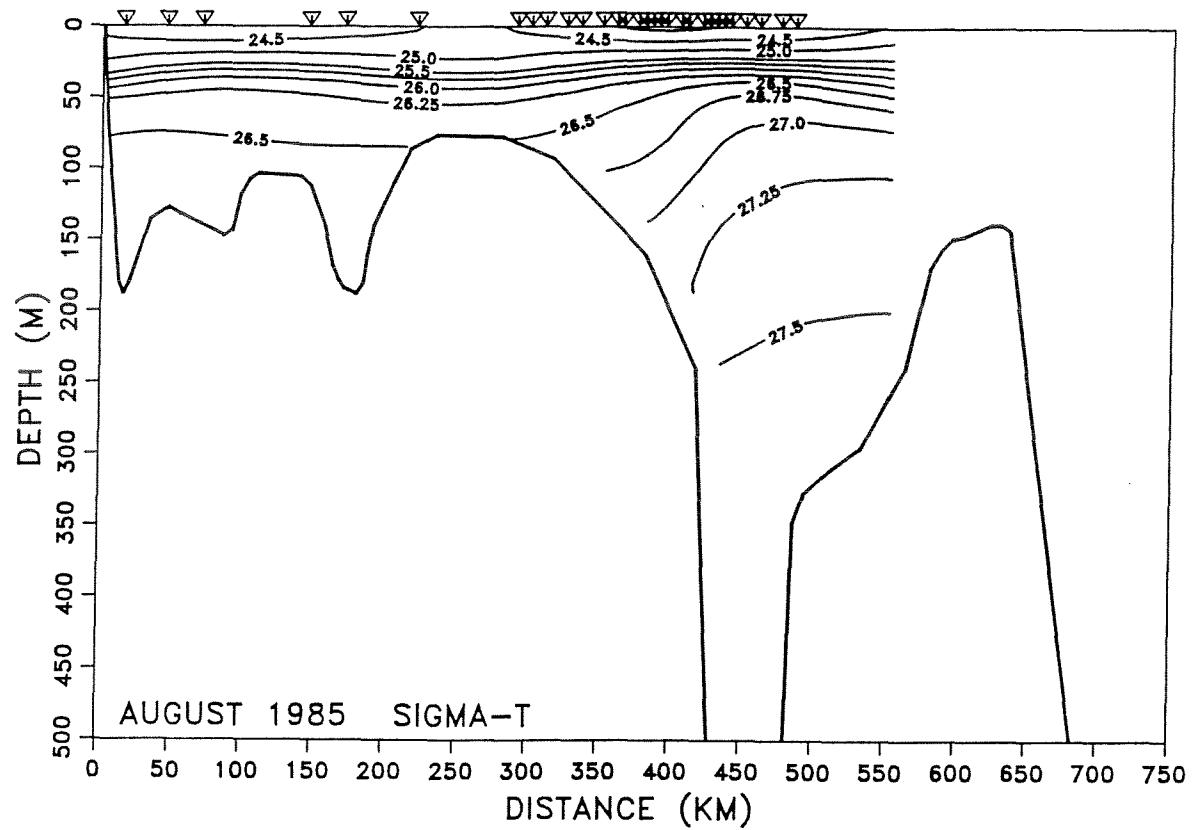


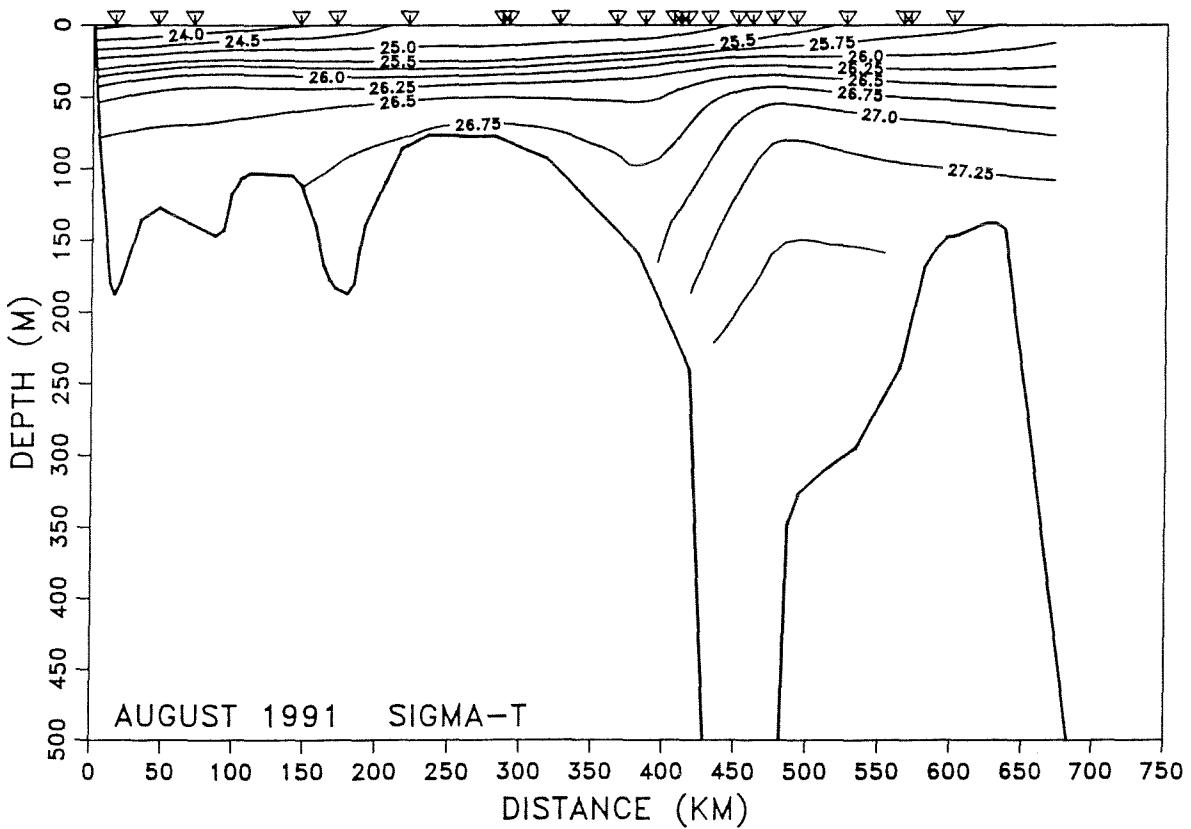
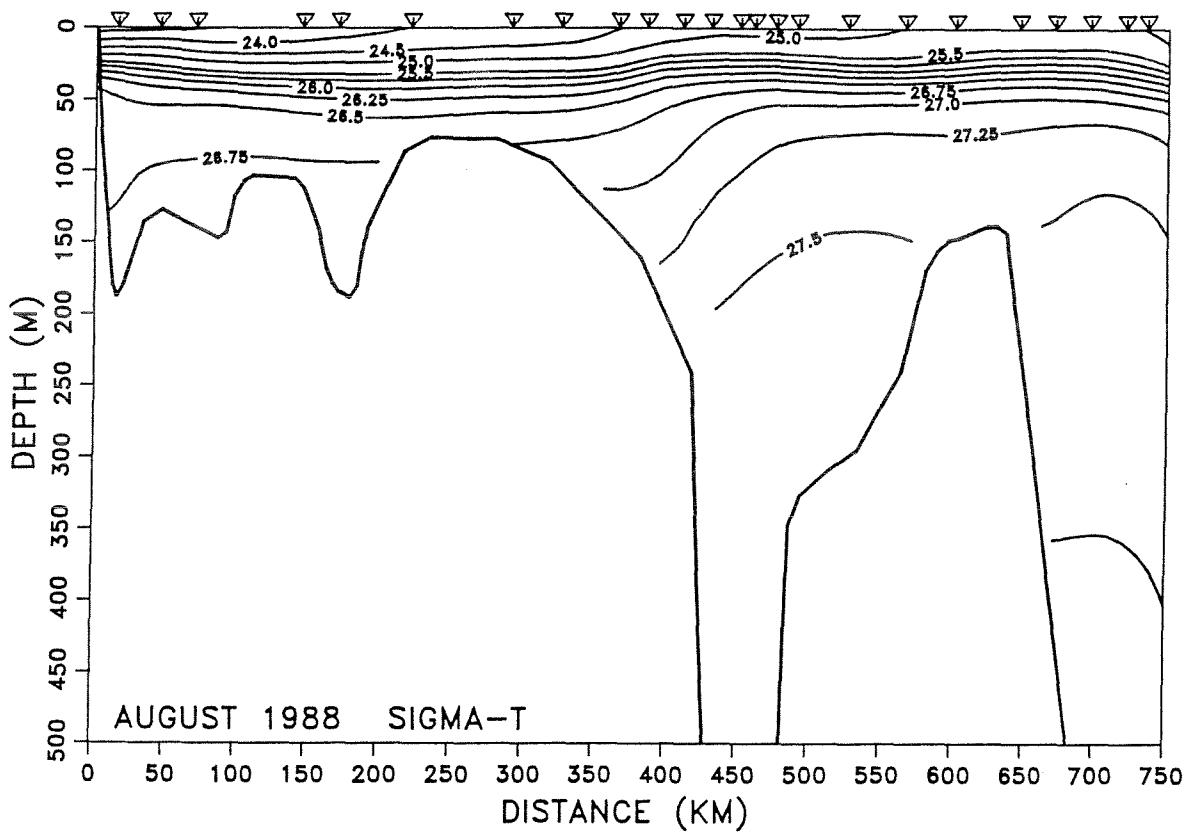


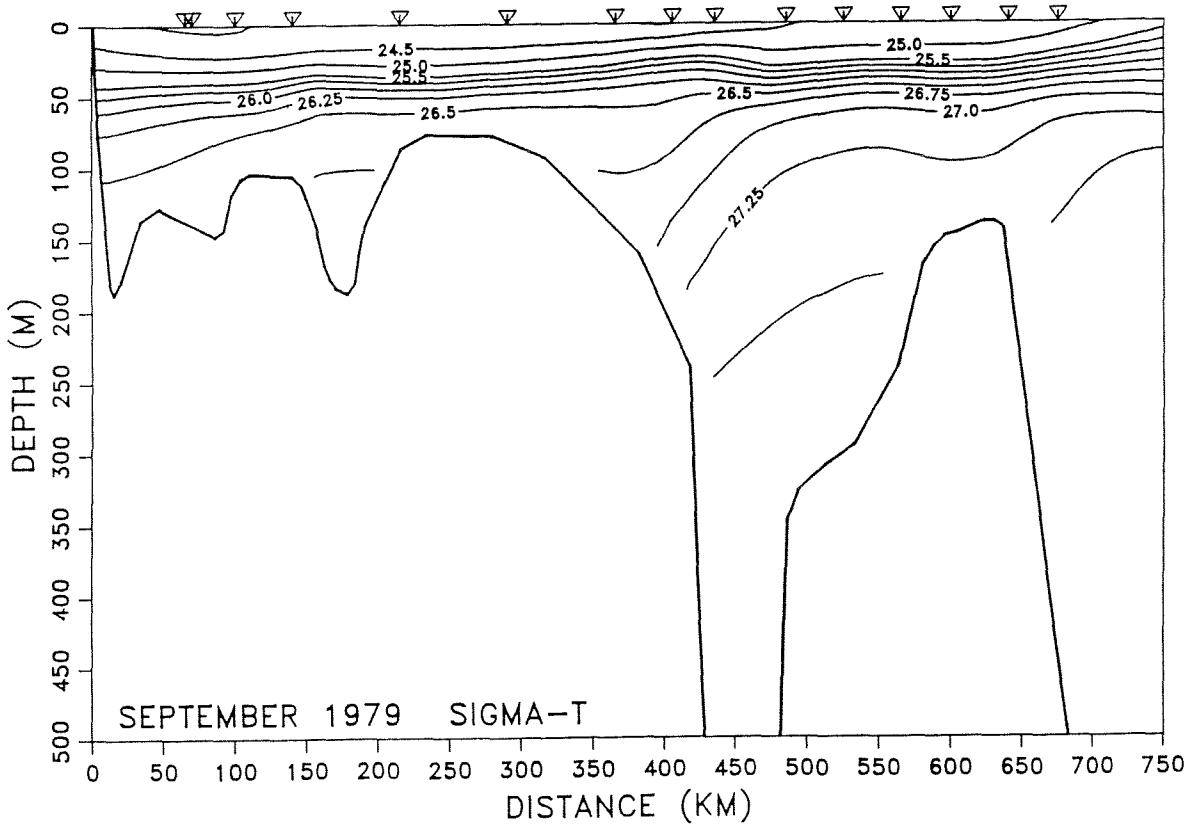
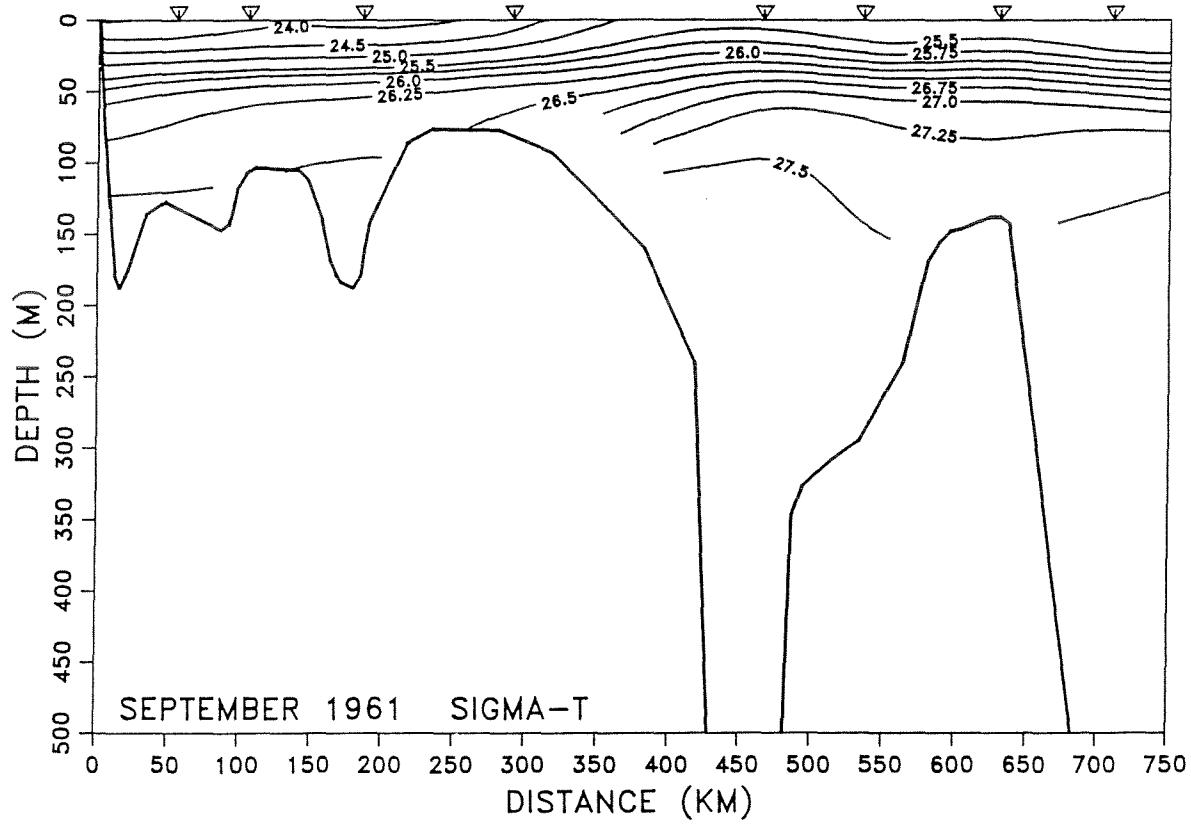


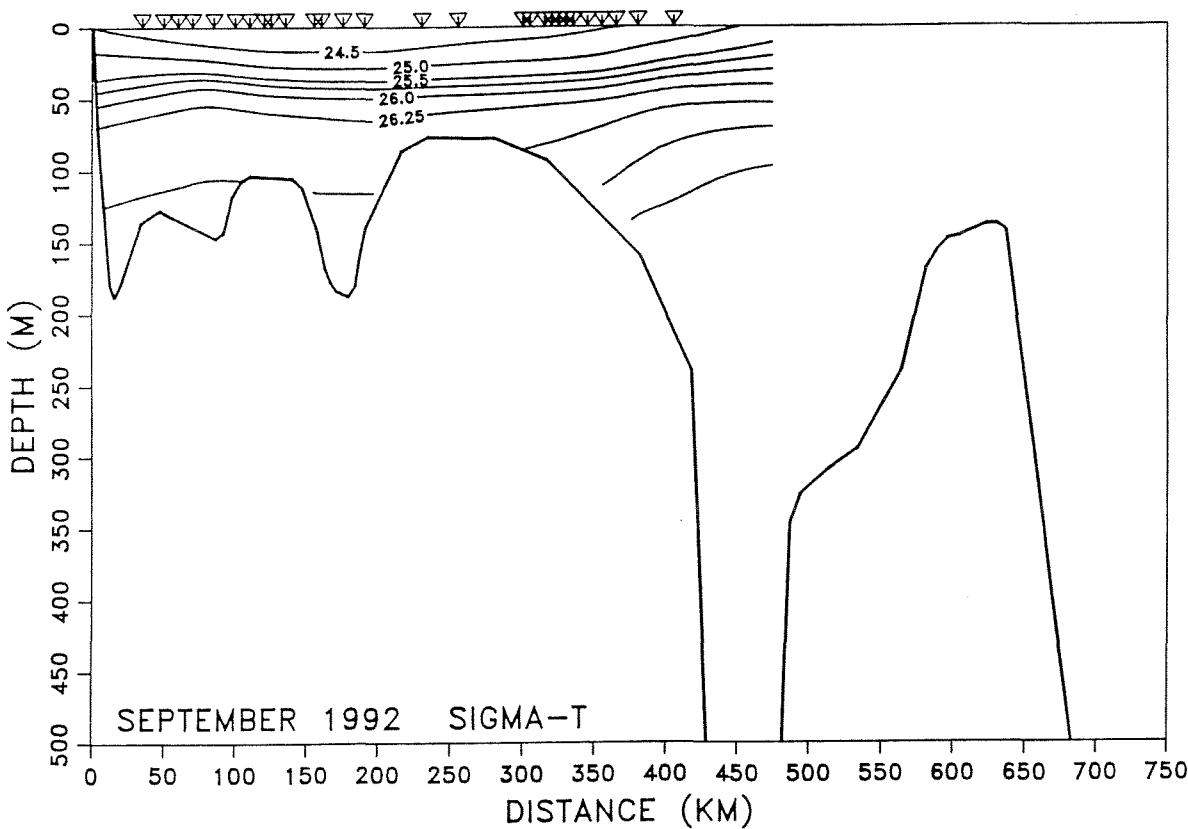
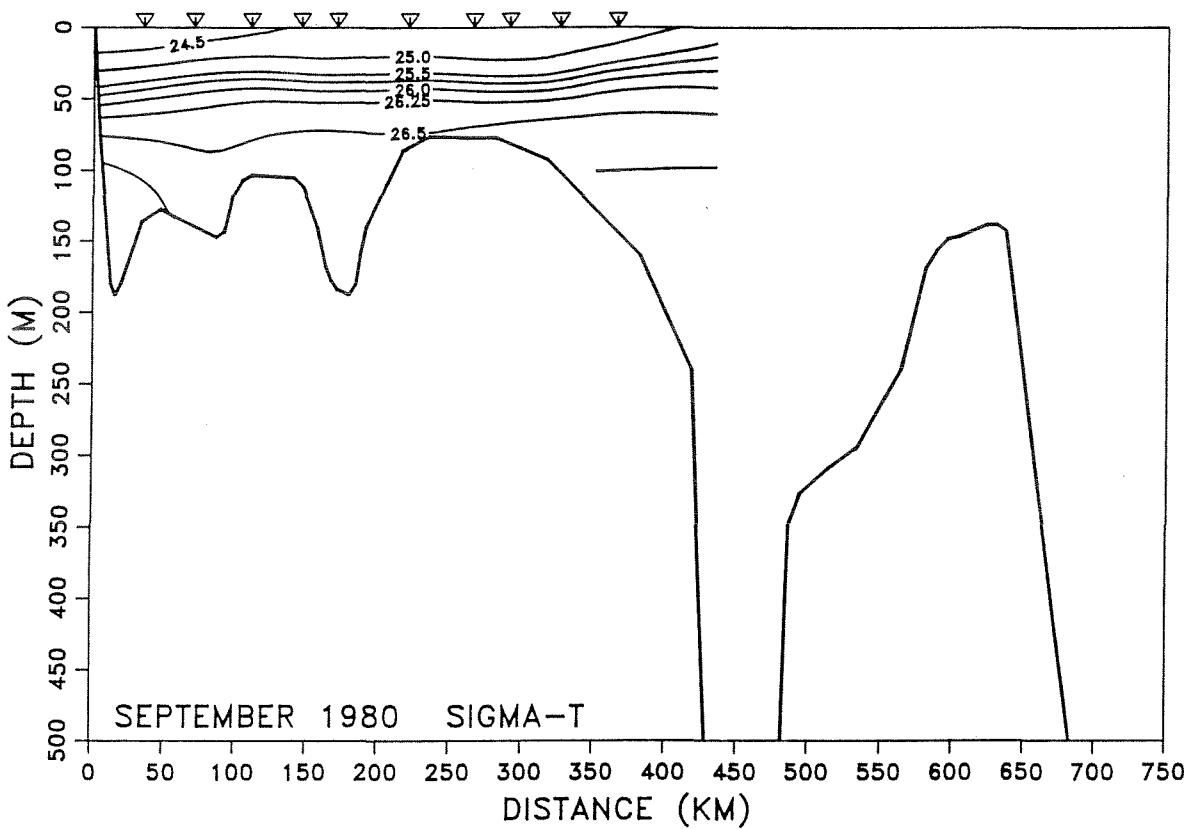


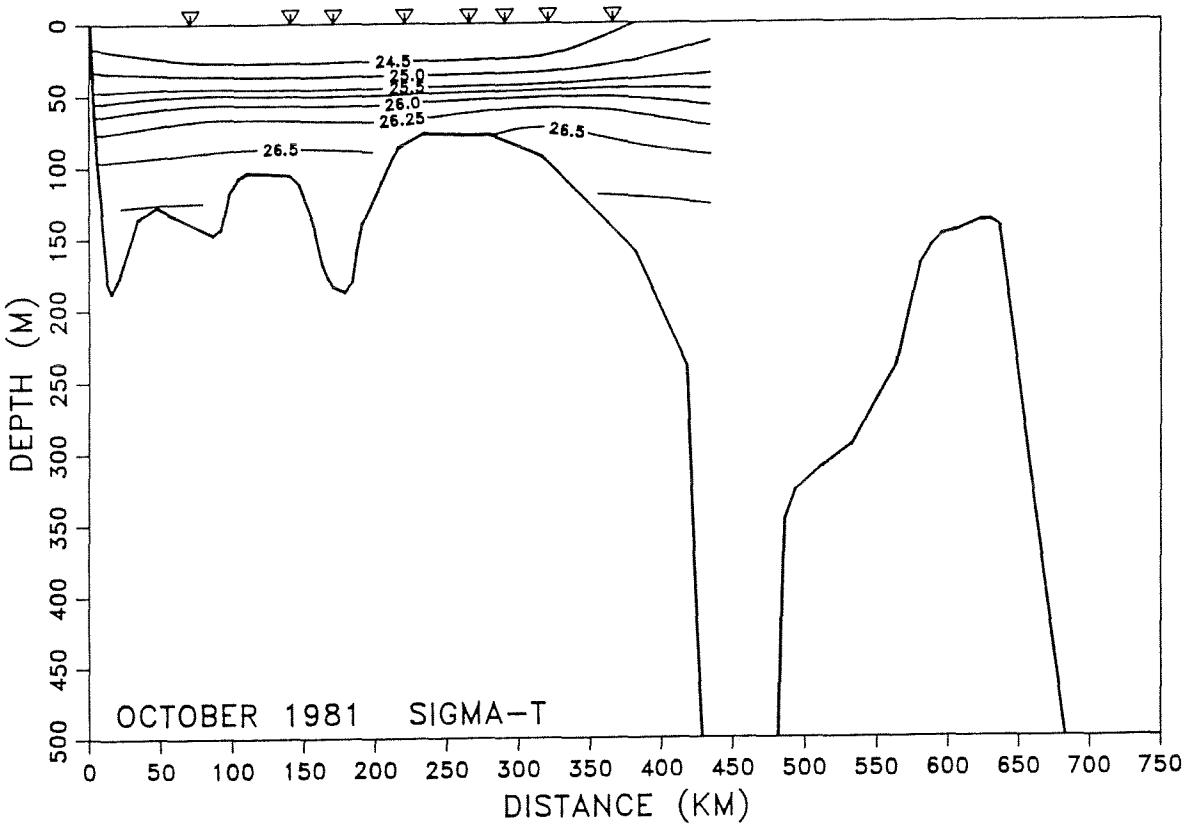
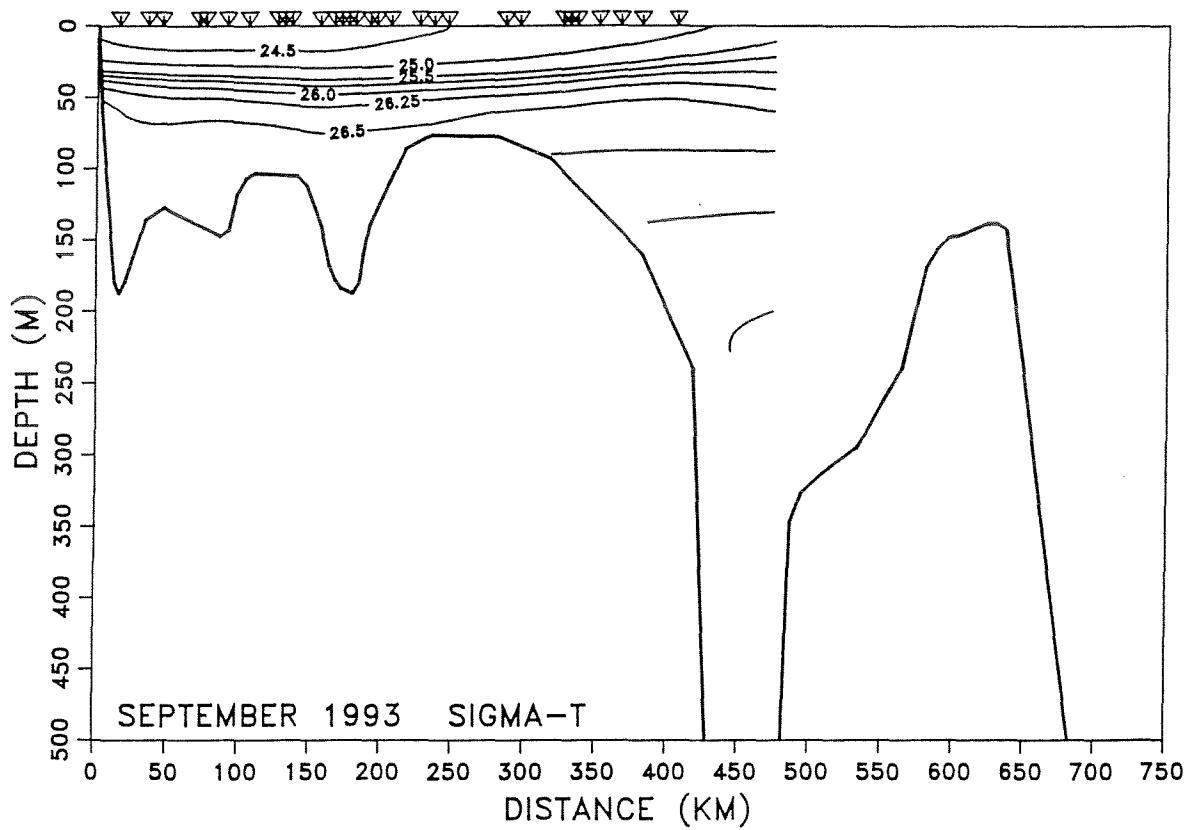


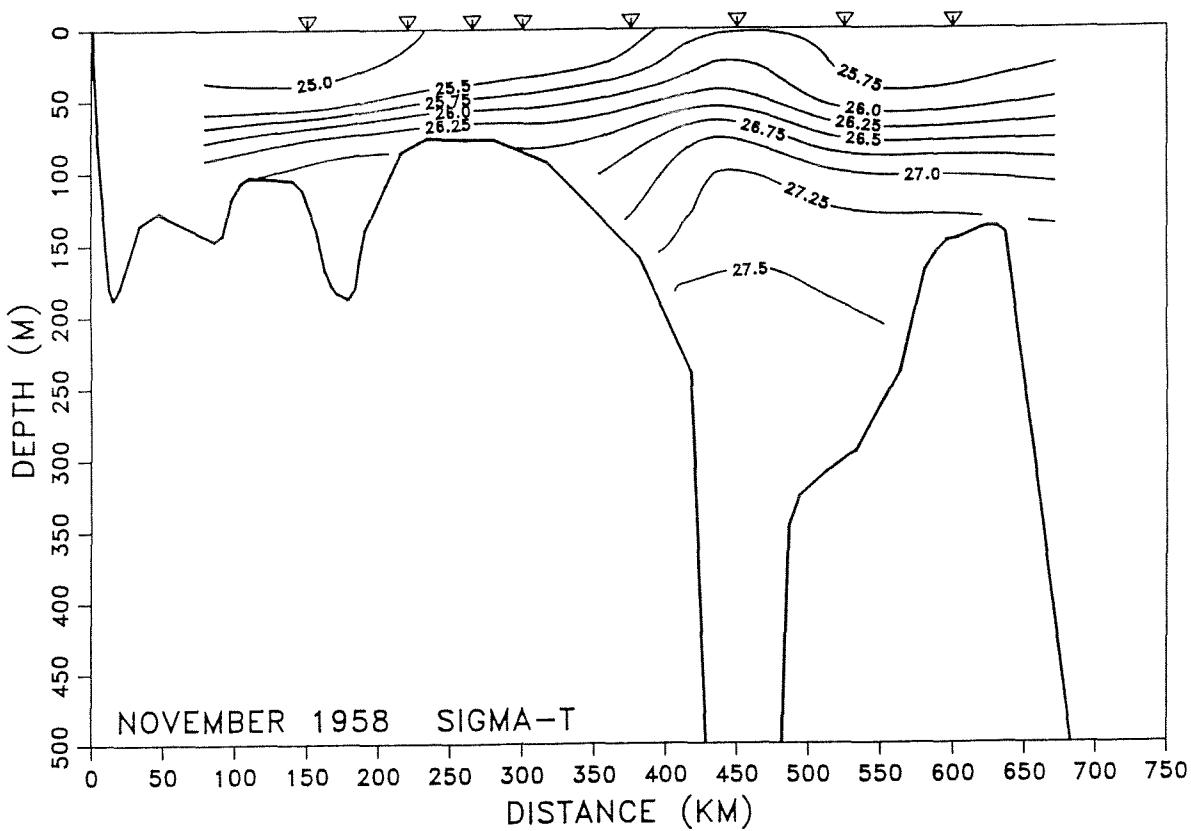
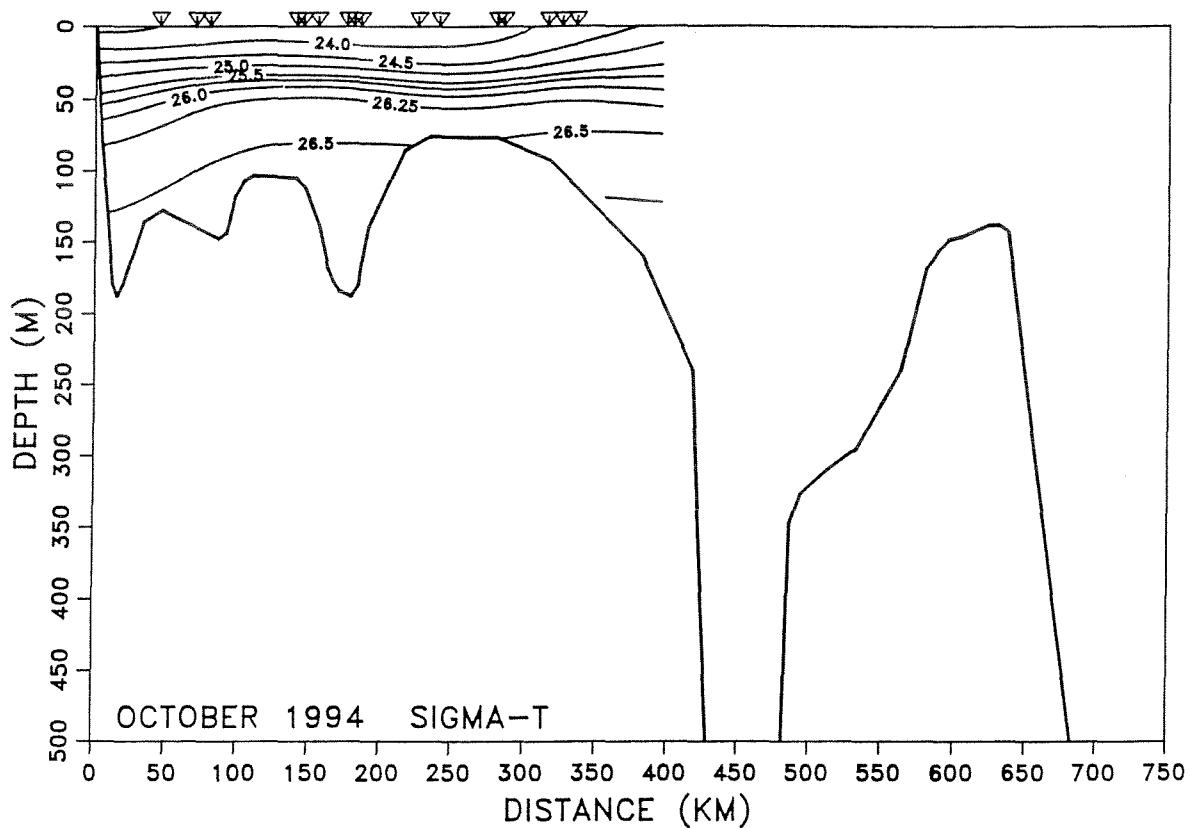




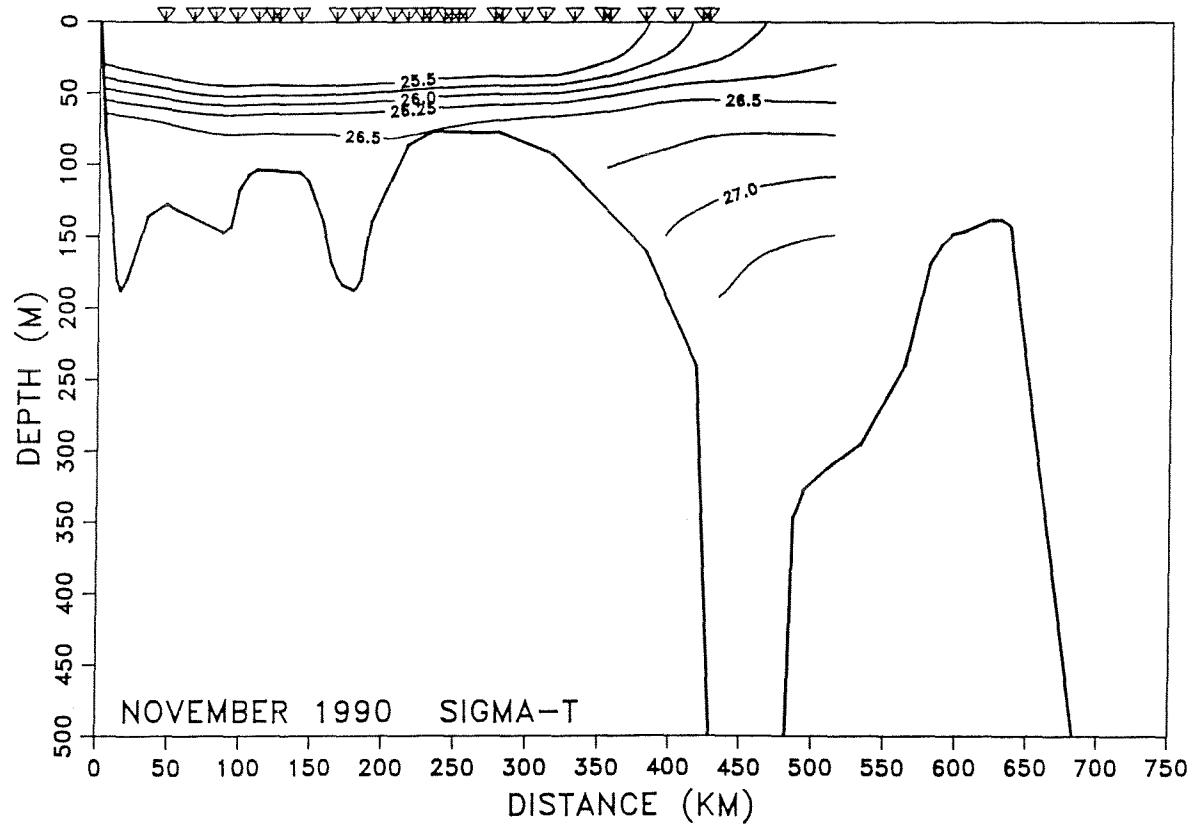
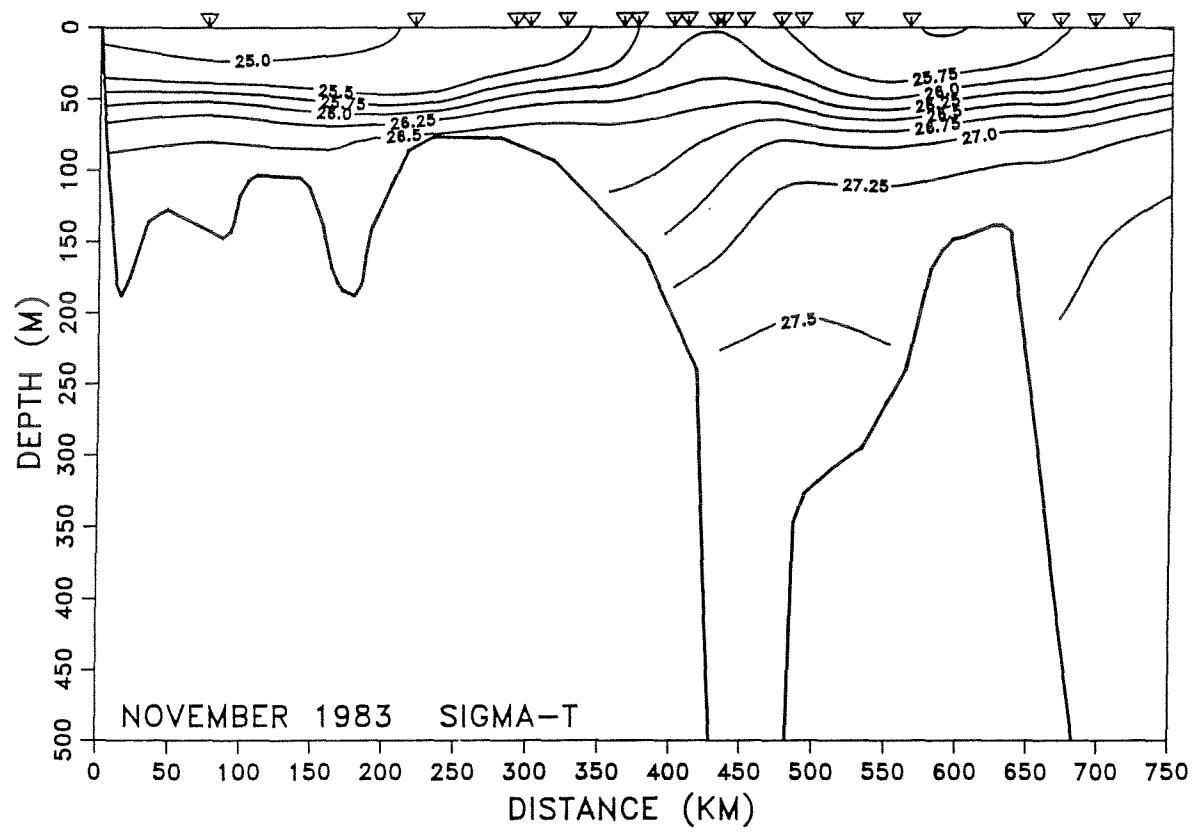


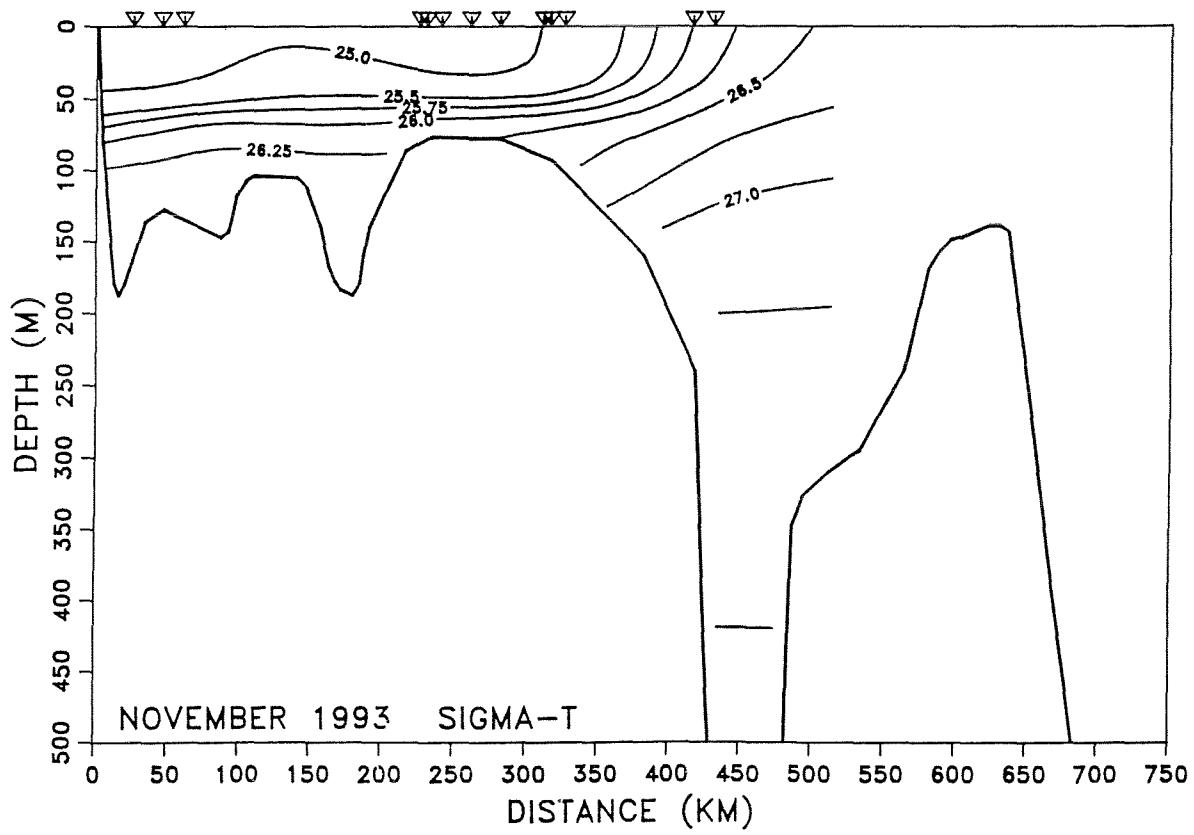
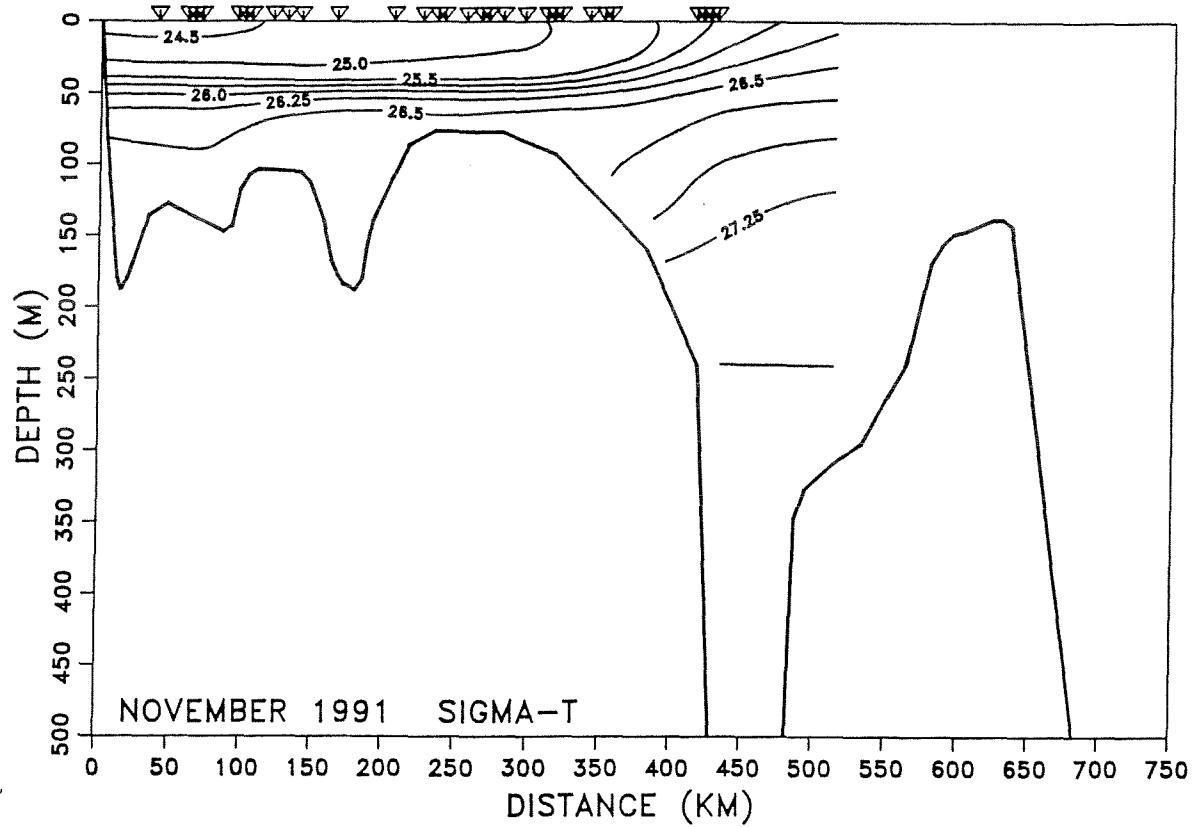






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