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TEMPERATURE, SALINITY AND SIGMA-T ALONG THE STANDARD SEAL ISLAND TRANSECT

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ABSTRACT

Colbourne, E. B., D. R. Senciall and K. D. Foote. 1995. Temperature, Salinity and Sigma-T Along the Standard Seal Island Transect. Can. Tech. Rep. Hydrogr. Ocean Sci. 164: vi + 241 p.

A review of the spatial and temporal distribution of the historical oceanographic data on Hamilton Bank along the standard NAFO Seal Island transect is presented. A brief descriptive analysis of various indices describing the temperature field along the transect is presented, including a discussion of the 1928 to 1994 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 inshore, mid-shelf and offshore areas of the transect based on all data available from 1928 to 1994. In addition, the monthly averaged vertical cross sections for the period 1928-1994 are presented, followed by monthly transects by year.

RÉSUMÉ

Colbourne, E. B., D. R. Senciall and K. D. Foote. 1995. Temperature, Salinity and Sigma-T Along the Standard Seal Island Transect. Can. Tech. Rep. Hydrogr. Ocean Sci. 164: vi + 241 p.

Le présent rapport examine la distribution spatiale et temporelle des données océanographiques sur le banc Hamilton le long de la ligne de transect standard de Seal Island 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 1928 à 1994 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 côtières, intermédiaires et hauturières du transect à partir de l'ensemble des données connues sur la période allant de 1924 à 1994. Enfin, on y trouvera les moyennes annuelles des sections verticales entre 1928 et 1994, 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 transects spans the Northwest Atlantic Ocean from Seal Island on the southern Labrador coast to the southern tip of Greenland (Fig. 1). The continental shelf portion of this transect on the Labrador side is referred to as the standard Seal Island transect. A considerable amount of oceanographic data dating back to the late 1920s is available for this particular area.

With the recent increase in oceanographic climatic research on the continental shelf of Atlantic Canada a considerable effort under the Northern cod Science Program (NCSP) 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 and Bonavista transects (Keeley, 1981b; Colbourne and Senciali, 1993). 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) have 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 complement the previous studies by providing the first detailed presentation of the historical data on the

southern Labrador shelf. The 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 area at various temperatures; maximum thickness, offshore extent of the cold intermediate layer (CIL); minimum core temperatures or CIL intensities and offshore bottom positions of various isotherms 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 Seal Island transect from 1928 to 1994 within a box with boundaries at ± 25 minutes of latitude of a line connecting 53 14.0 N, 55 39.0 W and 55 4.0 N, 52 30.0 W (the end points of the standard Seal Island 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 9 stations beginning about 5 km from the coast line at depths of 42 m and ending about 300 km offshore near the shelf slope at depths of 2686 m.

A considerable amount of oceanographic data dating back to 1928 is available for this area, including data from the standard stations as well as data from fisheries assessment surveys, particularly during autumn since 1978. 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 (42 %) and since the late 1970s conductivity-temperature-depth (CTD) recorders have become commonplace, accounting for 19% 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 occupation of the Seal Island transect occurred in July 1928. Since 1948 the transect has been occupied on a regular basis in July or August except for the period 1966 to 1967. 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 1928 to 1994 are shown in Table 2 by month. The transect has been occupied 68 times in the July-August period between 1928 and 1994 comprising 1137 temperature profiles of a total of 2922 (39 %) for all months. By contrast only 876 salinity profiles were available during the summer (July-August) out of a total of 1696.

The distribution of temperature and salinity data collected among years indicated that about 5 % and 9 % respectively were collected from 1928 to 1950, 12 % and 14 % from 1951 to 1960, 17 % and 18 % from 1961 to 1970, 21 % and 23 % from 1971 to 1980, 34 % and 24 % from 1981 to 1990 and 11 % and 12 % from 1991 to 1994 (Fig. 2a and 3a). 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 mainly in temperature indicating the high usage of bathythermographs, particularly during the 1970s and 1980s.

The seasonal distribution of data is bi-modal (Fig. 2b and 3b) with most of the data collected during summer (July, August and September) (43 %) corresponding to the annual oceanographic surveys and during autumn (October, November and December) (46 %) corresponding to the annual groundfish assessment surveys. Very little data were collected during the winter (4 %) (January, February and March) due to ice cover and about 7 % in the spring (April, May and June).

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.

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 \pm 25 minutes of latitude of the standard transect over all years for each month are shown in Fig 4a to 4l. 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 May to December, whereas data for January to April were mainly restricted to the outer portion of Hamilton Bank and the continental slope area due to the winter ice cover.

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 15.0 °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 a simple 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, except in the inshore regions during winter months. No attempts were made to adjust the data for possible temporal or spatial biasing arising from the data distribution discussed above. 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 shelves 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 warm seasonal upper layer and warmer slope water near the bottom.

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 ≤ 0.0 °C water 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 and for 1978, a relatively warm year, together with the July-August average are shown in Fig. 5. Since 1990 the CIL has been above normal in total area with 1991 showing the greatest extent. The maximum variation in the CIL in recent years is shown in Fig 5b. In general, sub-zero water covers most of the southern Labrador shelf during the summer reaching more than 200 km offshore.

Time series of the CIL cross-sectional areas of water less than 1.0, 0.0 and -1.0 °C from 1928 to 1994 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 1928 to the late 1960s. 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, -1.0 and -1.5 °C are 35, 28, 13 and 3 km² with standard deviations of 6, 7, 7 and 4 km² respectively.

The bottom temperature across the southern Labrador Shelf ranges from -1.0 °C near the coast to 2.0-3.0 °C in water depths greater than 200 m to the shelf edge throughout most of the year. The average bottom position (Fig. 7a) of the 1.0, 2.0 and 3.0 °C isotherms for the July-August period are located about 153, 177 and 192 km offshore respectively, indicating a strong thermal front near bottom at the edge of the continental shelf, unlike the Bonavista transect where the bottom temperature gradient is very weak near bottom in the offshore region (Colbourne and Senciarl, 1993). The mean offshore extent (Fig. 7b) of the CIL is about 214 km with a standard deviation of 26 km and a mean thickness about 227 m with a standard deviation of 53 m. Minimum temperatures at the core of the CIL (Fig. 8) range from -1.84 °C in cold years (mid 1970s) to -1.10 °C in warm years (1941) with an average of -1.55 °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 inshore (30 km offshore), mid-shelf (125 km offshore) and shelf edge (240 km offshore) areas along the transect. 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 1928 to 1994). 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 240 km offshore) the temperature and salinity structure is typical of slope water which is quite different from water at mid 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 F contain specific occupations of the transect by month beginning in 1928 to 1994.

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#	Latitude	Longitude	Depth (M)
1	53 14.0	55 39.0	42
2	53 20.0	55 30.0	124
3	53 37.0	55 00.0	300
4	53 55.0	54 30.0	185
5	54 12.0	54 00.0	215
6	54 30.0	53 30.0	340
7	54 38.0	53 15.0	610
8	54 47.0	53 00.0	1306
9	55 04.0	52 30.0	2686

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

YEAR	MONTH											
	J	F	M	A	M	J	J	A	S	O	N	D
1928	0	0	0	0	0	0	8	0	0	0	0	0
1929	0	0	0	0	0	0	0	0	0	0	0	0
1930	0	0	0	0	0	0	0	0	0	0	0	0
1931	0	0	0	0	0	0	8	0	1	0	0	0
1932	0	0	0	0	0	1	0	0	2	0	0	0
1933	0	0	0	0	0	0	10	0	3	0	0	0
1934	0	0	0	0	0	0	8	0	3	0	0	0
1935	0	0	0	0	0	0	2	11	1	0	0	0
1936	0	0	0	0	0	9	0	0	0	0	0	0
1937	0	0	0	0	0	0	2	0	0	0	0	0
1938	0	0	0	0	0	1	10	0	0	0	0	0
1939	0	0	0	0	0	0	11	0	0	0	0	0
1940	0	0	0	0	0	10	0	0	0	0	0	0
1941	0	0	0	0	0	0	10	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	0	0	0	0	0	0	0	0	0	0
1948	0	0	0	0	0	0	11	0	1	0	0	0
1949	0	0	0	0	0	0	11	2	0	0	0	0
1950	0	0	0	0	0	0	3	14	0	0	0	0
1951	0	0	0	0	0	0	21	5	8	0	0	0
1952	0	0	0	0	7	25	13	9	0	0	0	0
1953	0	0	3	0	0	6	11	13	4	0	0	0
1954	0	0	1	0	0	2	13	12	2	1	0	0
1955	0	0	0	0	0	0	17	6	17	0	0	0
1956	0	0	0	0	0	2	11	9	0	0	0	0
1957	0	0	0	0	0	0	12	17	0	0	0	0
1958	0	0	0	0	0	0	13	13	3	0	0	0
1959	0	1	0	0	0	1	0	32	1	0	2	0
1960	0	0	0	0	0	0	11	28	0	0	0	0
1961	0	0	0	0	0	0	15	10	5	0	0	0
1962	0	4	0	0	1	11	13	29	1	11	16	0
1963	0	0	0	5	2	1	13	19	12	20	0	0
1964	0	0	0	0	3	0	18	7	0	0	0	0
1965	0	0	0	0	0	0	15	15	0	0	0	0
1966	0	0	2	0	0	0	0	0	0	3	0	0
1967	0	0	0	0	0	0	1	2	0	57	9	0
1968	0	0	0	0	0	10	26	1	0	5	0	0
1969	0	0	0	0	8	1	12	22	0	15	0	1
1970	0	0	1	0	22	4	11	24	1	1	0	2
1971	0	0	0	3	5	0	13	17	1	1	24	0
1972	2	0	0	0	0	0	5	17	16	17	17	3
1973	0	0	0	0	0	12	16	7	18	0	10	0
1974	0	0	0	0	0	0	0	17	7	2	0	0
1975	0	0	0	0	0	18	13	9	0	0	0	21
1976	0	0	0	0	0	0	1	13	2	0	2	0
1977	0	0	0	0	0	0	0	17	0	1	20	0
1978	0	3	0	0	0	0	29	15	2	3	22	6
1979	0	0	0	0	10	0	0	9	0	13	38	7
1980	0	0	0	0	0	0	32	6	0	34	40	7
1981	5	0	34	0	0	0	5	14	0	23	28	0
1982	5	0	8	0	0	0	10	0	0	16	56	1
1983	0	0	0	0	0	0	0	18	0	19	58	2
1984	0	0	0	0	0	0	1	20	3	35	59	1
1985	0	0	0	0	0	0	3	20	2	44	49	0
1986	0	20	1	0	0	0	1	19	0	4	40	0
1987	0	0	0	0	0	0	8	17	0	16	34	0
1988	0	13	0	0	0	0	5	29	7	21	43	1
1989	0	0	0	0	0	0	2	0	8	49	0	
1990	0	2	0	0	0	0	21	2	0	10	71	0
1991	0	8	0	0	3	0	15	1	0	33	49	0
1992	0	4	0	9	0	0	16	0	0	28	38	0
1993	0	0	0	0	0	7	19	3	9	0	28	0
1994	0	0	0	0	0	2	12	0	0	11	29	0

Table 2a. Summary of the total number of temperature profiles available along and near the Seal Island transect from 1928 to 1994.

YEAR	MONTH											
	J	F	M	A	M	J	J	A	S	O	N	D
1928	0	0	0	0	0	0	8	0	0	0	0	0
1929	0	0	0	0	0	0	0	0	0	0	0	0
1930	0	0	0	0	0	0	0	0	0	0	0	0
1931	0	0	0	0	0	0	8	0	1	0	0	0
1932	0	0	0	0	0	1	0	0	2	0	0	0
1933	0	0	0	0	0	0	10	0	3	0	0	0
1934	0	0	0	0	0	0	8	0	3	0	0	0
1935	0	0	0	0	0	0	2	11	1	0	0	0
1936	0	0	0	0	0	9	0	0	0	0	0	0
1937	0	0	0	0	0	0	2	0	0	0	0	0
1938	0	0	0	0	0	1	10	0	0	0	0	0
1939	0	0	0	0	0	0	11	0	0	0	0	0
1940	0	0	0	0	0	10	0	0	0	0	0	0
1941	0	0	0	0	0	0	10	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	0	0	0	0	0	0	0	0	0	0
1948	0	0	0	0	0	0	11	0	0	0	0	0
1949	0	0	0	0	0	0	11	0	0	0	0	0
1950	0	0	0	0	0	0	3	14	0	0	0	0
1951	0	0	0	0	0	0	18	0	0	0	0	0
1952	0	0	0	0	0	3	13	9	0	0	0	0
1953	0	0	0	0	0	1	11	10	1	0	0	0
1954	0	0	0	0	0	1	10	11	0	0	0	0
1955	0	0	0	0	0	0	17	6	8	0	0	0
1956	0	0	0	0	0	1	11	9	0	0	0	0
1957	0	0	0	0	0	0	11	9	0	0	0	0
1958	0	0	0	0	0	0	11	9	1	0	0	0
1959	0	0	0	0	0	0	0	25	0	0	1	0
1960	0	0	0	0	0	0	11	15	0	0	0	0
1961	0	0	0	0	0	0	13	5	4	0	0	0
1962	0	4	0	0	0	11	11	8	0	11	7	0
1963	0	0	0	0	0	1	11	8	0	0	0	0
1964	0	0	0	0	0	0	15	4	0	0	0	0
1965	0	0	0	0	0	0	15	10	0	0	0	0
1966	0	0	2	0	0	0	0	0	0	0	0	0
1967	0	0	0	0	0	0	0	0	0	36	8	0
1968	0	0	0	0	0	9	24	0	0	5	0	0
1969	0	0	0	0	0	0	10	18	0	15	0	1
1970	0	0	1	0	5	4	10	14	1	1	0	2
1971	0	0	0	0	5	0	11	8	0	0	11	0
1972	2	0	0	0	0	0	0	8	11	11	17	3
1973	0	0	0	0	0	11	7	1	11	0	10	0
1974	0	0	0	0	0	0	0	8	7	0	0	0
1975	0	0	0	0	0	18	9	5	0	0	0	18
1976	0	0	0	0	0	0	0	8	0	0	0	0
1977	0	0	0	0	0	0	0	8	0	0	0	0
1978	0	3	0	0	0	0	22	8	0	0	10	3
1979	0	0	0	0	0	0	0	8	0	2	25	7
1980	0	0	0	0	0	0	29	6	0	34	22	0
1981	5	0	1	0	0	0	2	14	0	15	0	0
1982	5	0	0	0	0	0	8	0	0	7	19	1
1983	0	0	0	0	0	0	0	18	0	4	18	2
1984	0	0	0	0	0	0	0	18	3	0	15	1
1985	0	0	0	0	0	0	0	16	0	2	11	0
1986	0	0	0	0	0	0	0	16	0	2	12	0
1987	0	0	0	0	0	0	7	16	0	10	2	0
1988	0	0	0	0	0	0	0	27	1	0	6	1
1989	0	0	0	0	0	0	0	0	0	0	47	0
1990	0	0	0	0	0	0	20	0	0	0	62	0
1991	0	0	0	0	3	0	15	0	0	0	44	0
1992	0	0	0	0	0	0	16	0	0	13	37	0
1993	0	0	0	0	0	0	13	0	0	0	26	0
1994	0	0	0	0	0	0	12	0	0	0	28	0

Table 2b. Summary of the total number of salinity profiles along and near the Seal Island Transect from 1928 to 1994.

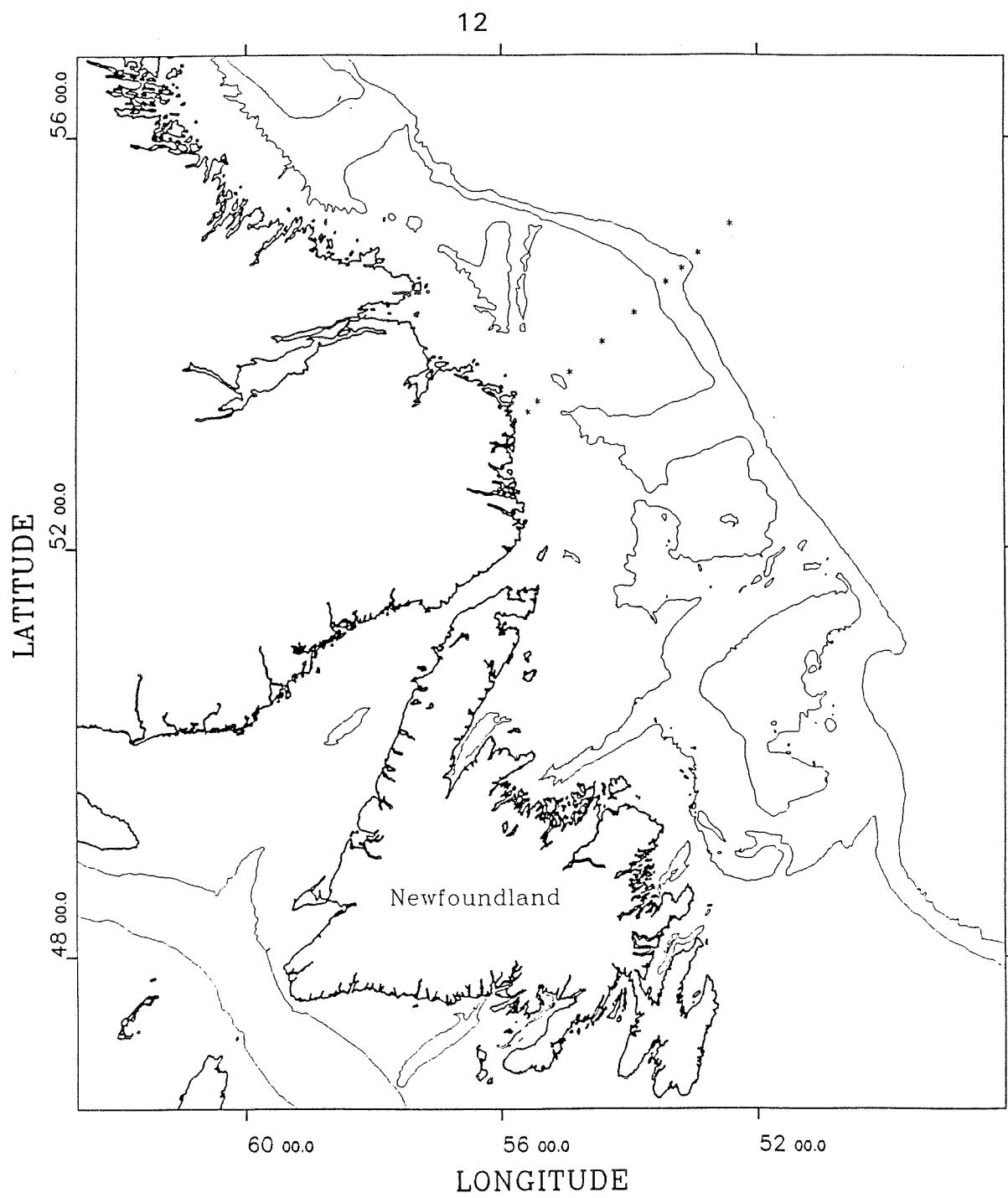


Fig. 1. Location map showing the position of the standard stations along the Seal Island transect. The bathymetry lines are 300 and 1000 m.

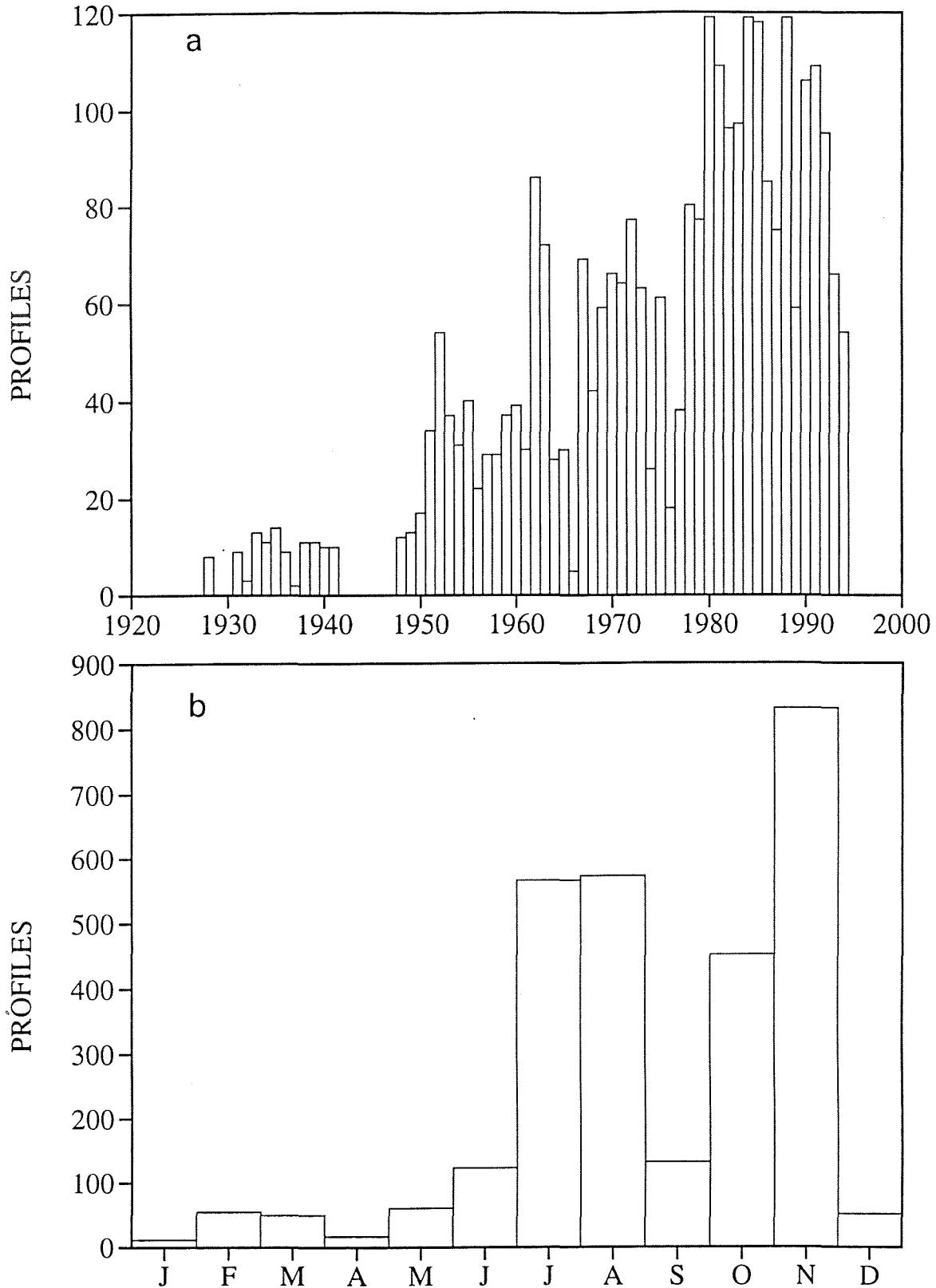


Fig. 2. (a) The total number of temperature profiles by year and (b) by month, occupied along and near the Seal Island transect since 1928.

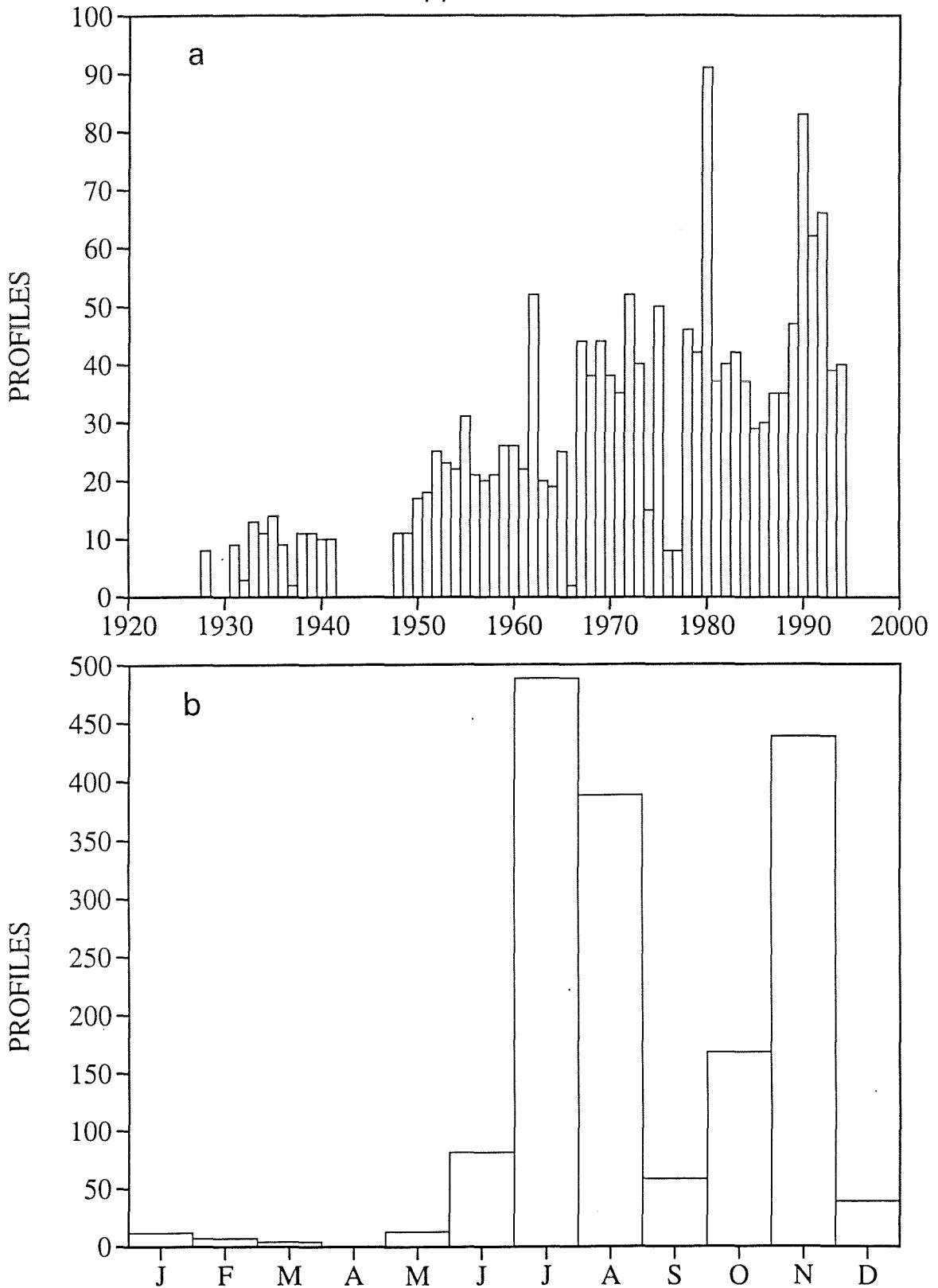


Fig. 3. (a) The total number of salinity profiles by year and (b) by month, occupied along and near the Seal Island transect since 1928.

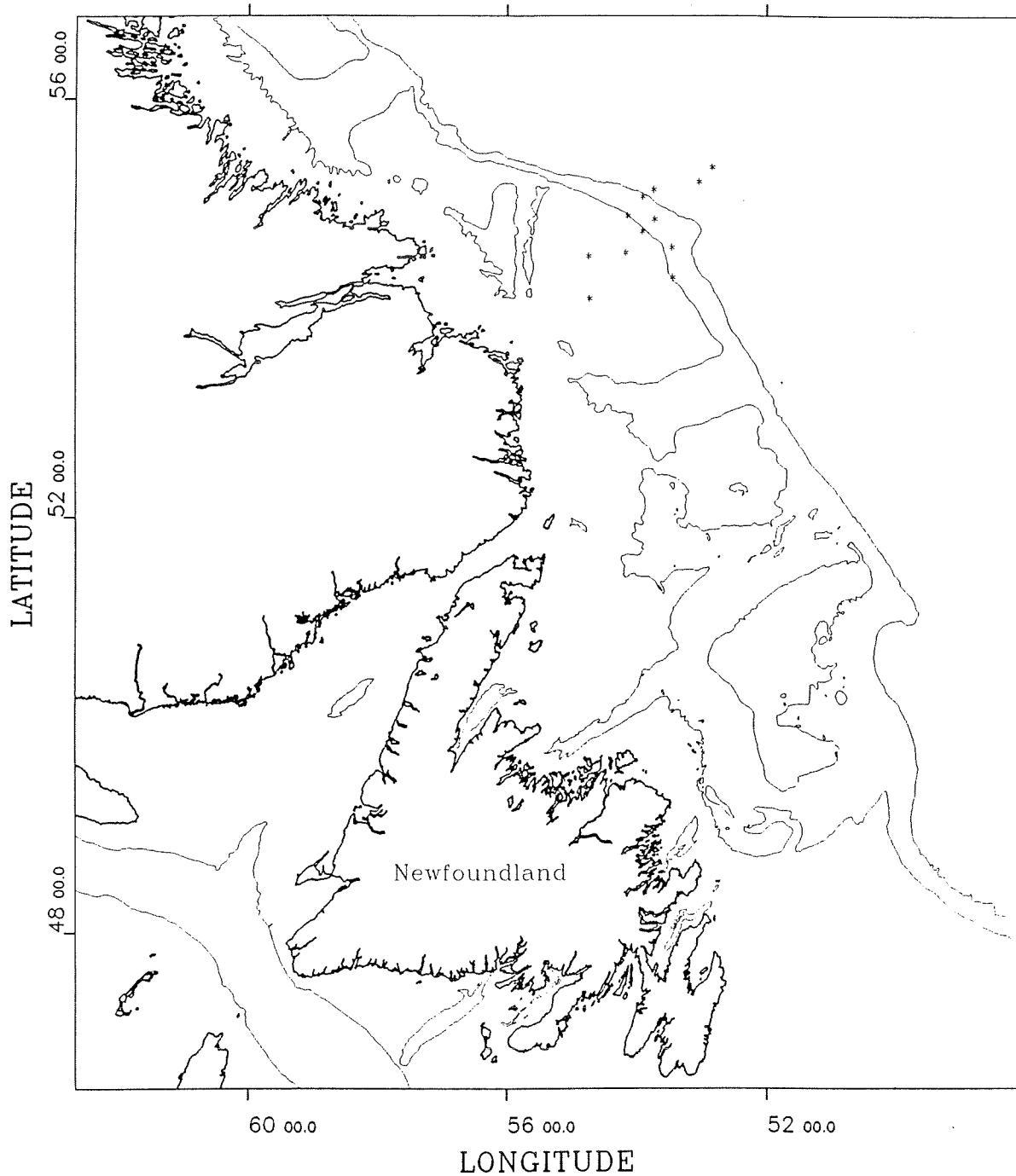


Fig. 4a. Location map showing the position of all stations occupied along and near the Seal Island transect since 1928 for the month of January.

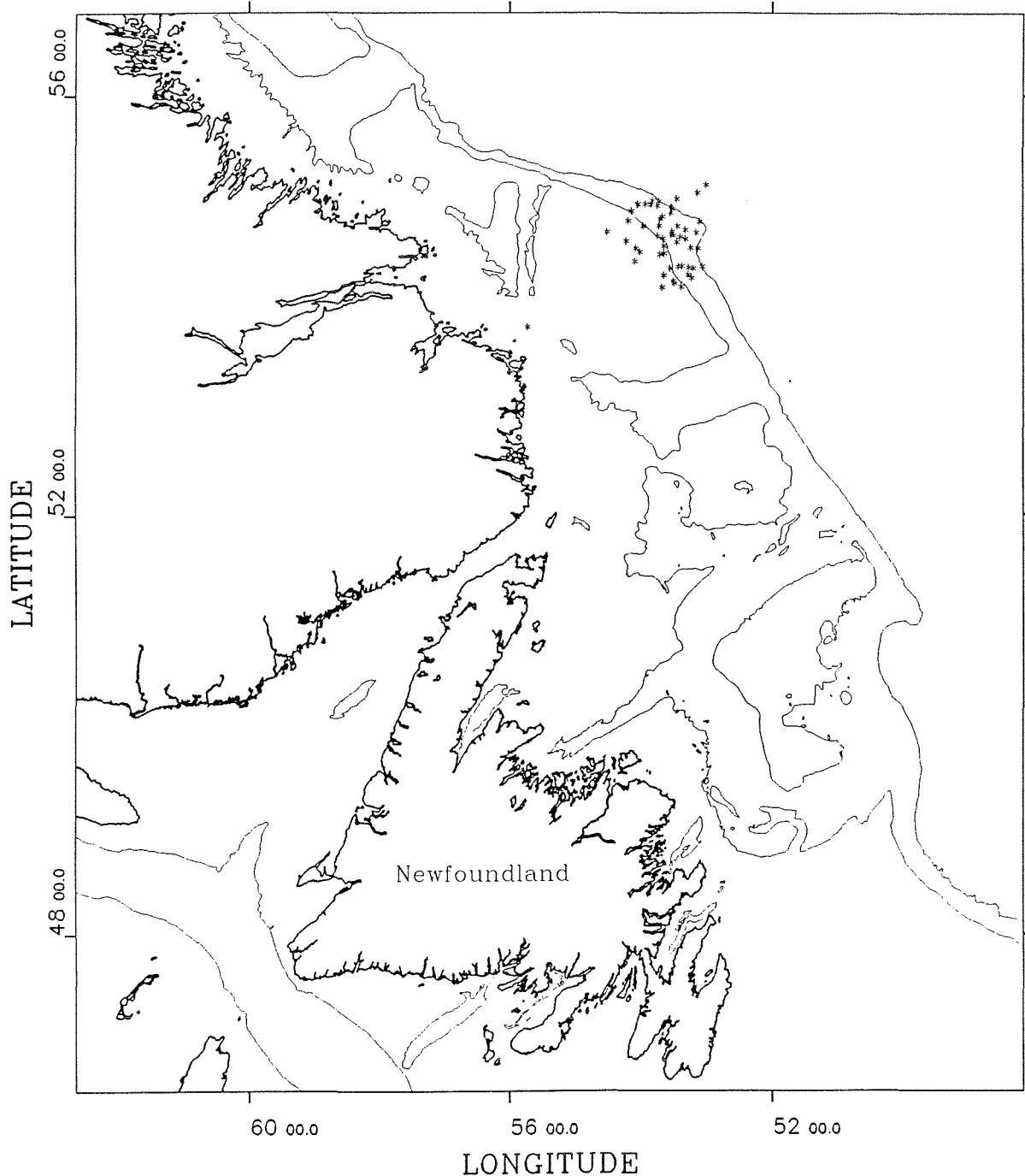


Fig. 4b. Location map showing the position of all stations occupied along and near the Seal Island transect since 1928 for the month of February.

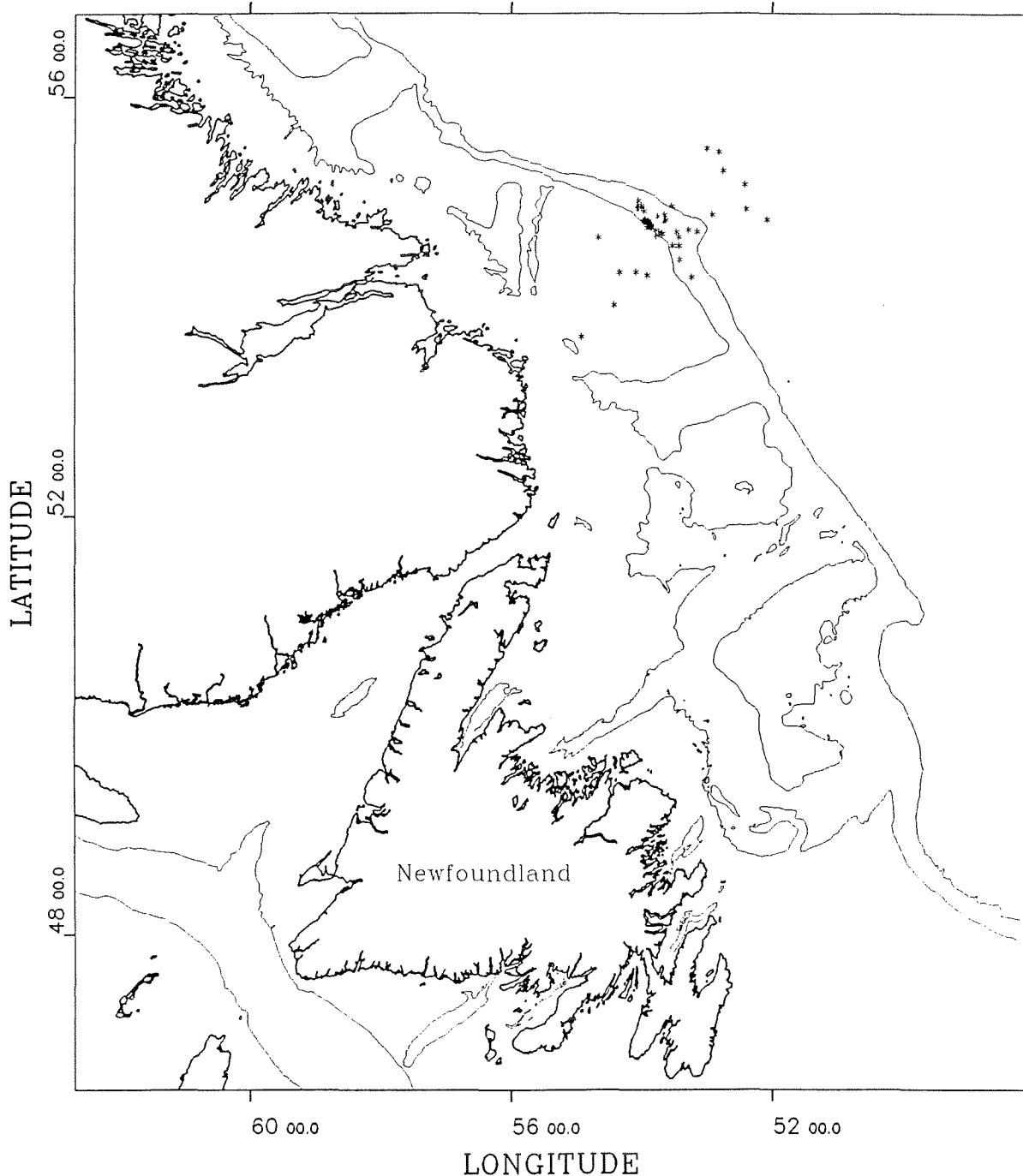


Fig. 4c. Location map showing the position of all stations occupied along and near the Seal Island transect since 1928 for the month of March.

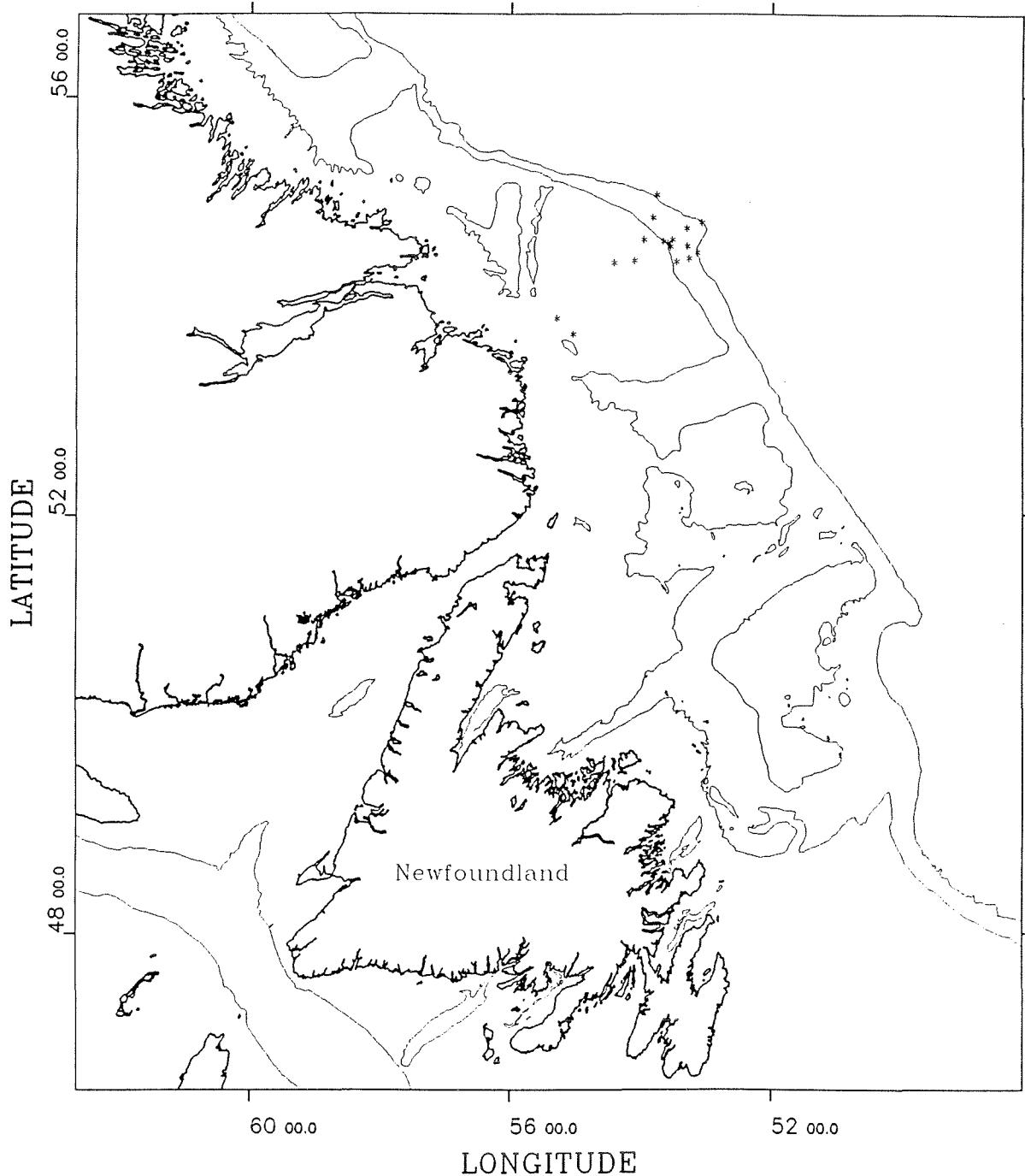


Fig. 4d. Location map showing the position of all stations occupied along and near the Seal Island transect since 1928 for the month of April.

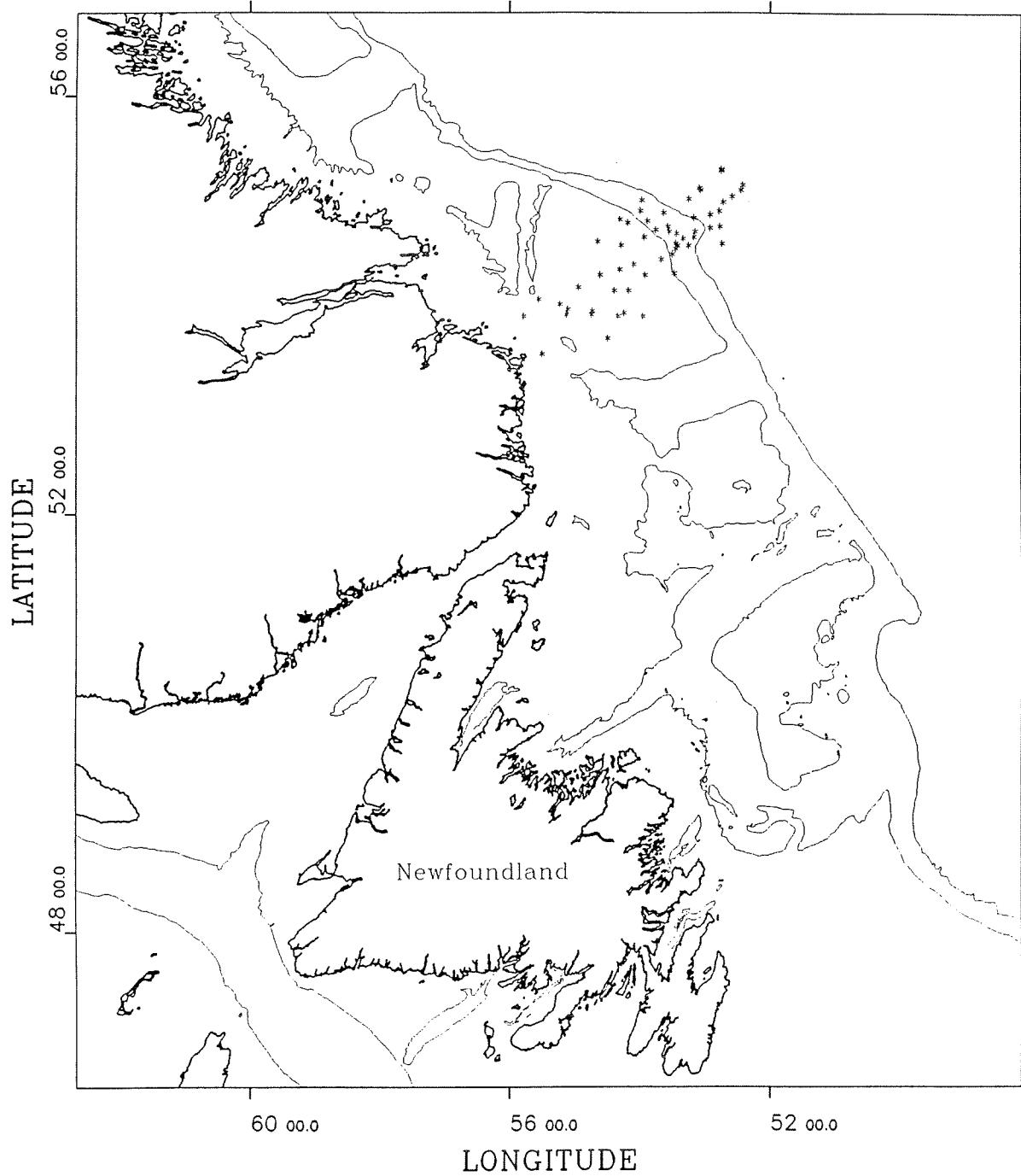


Fig. 4e. Location map showing the position of all stations occupied along and near the Seal Island transect since 1928 for the month of May.

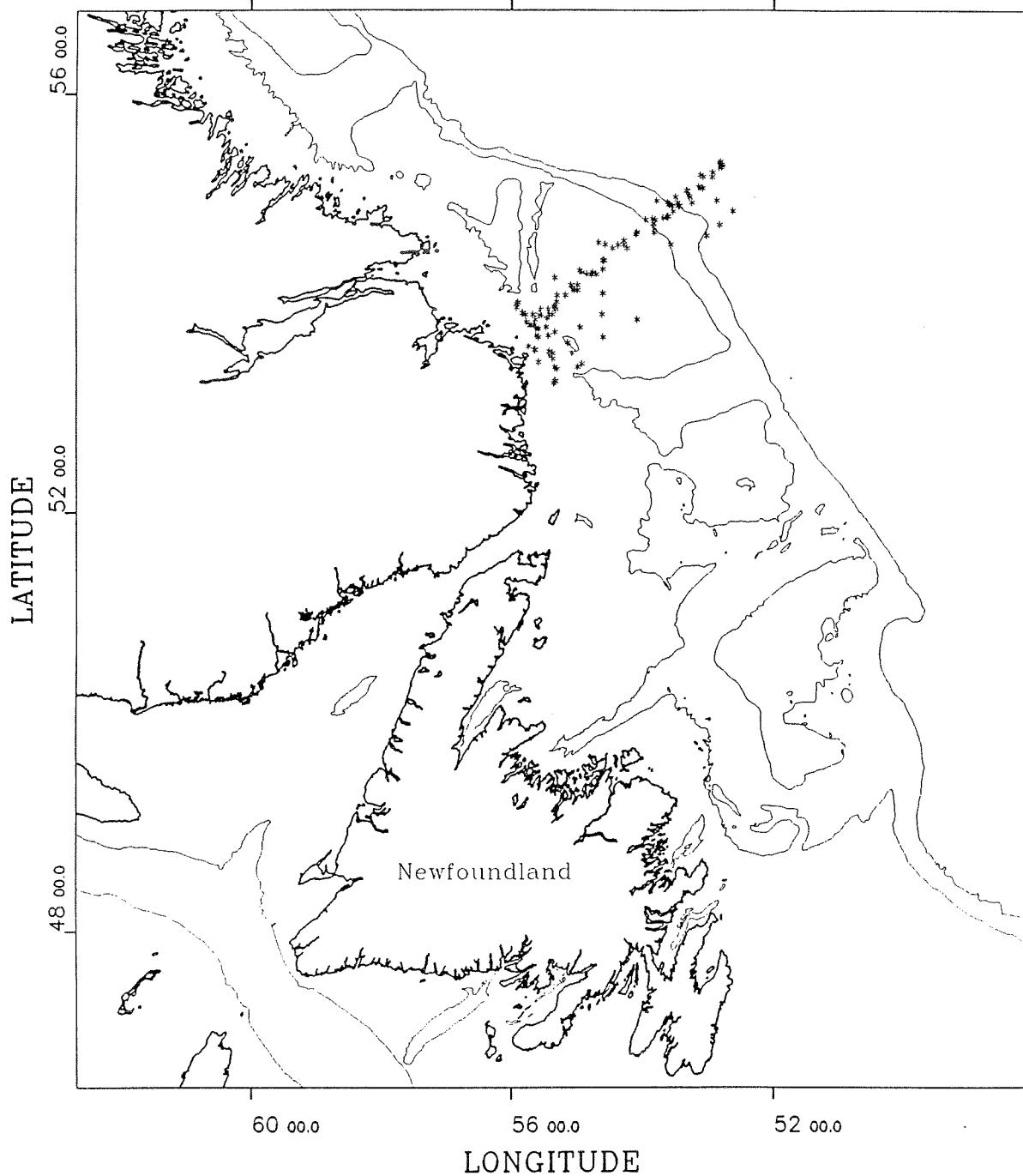


Fig. 4f. Location map showing the position of all stations occupied along and near the Seal Island transect since 1928 for the month of June.

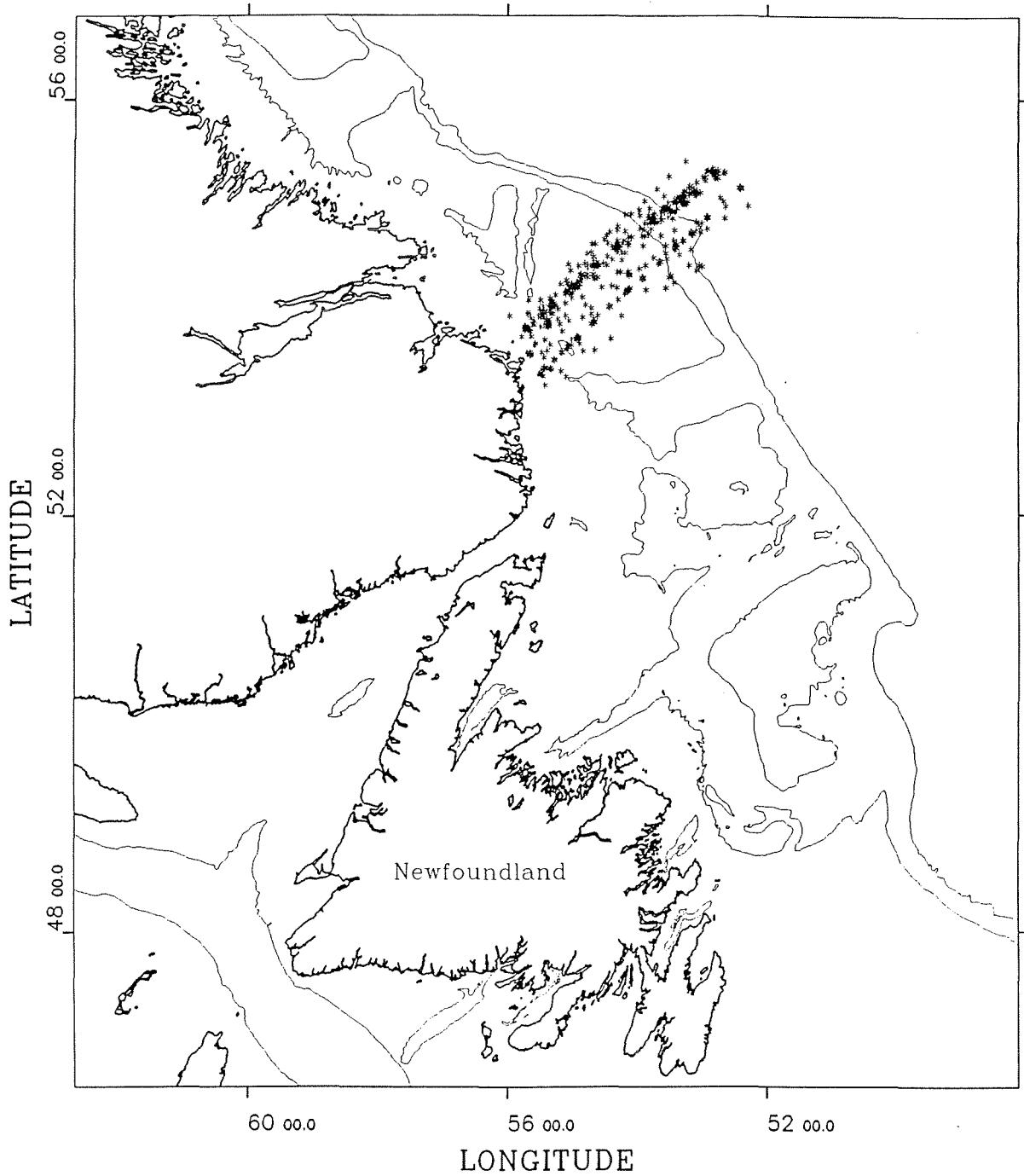


Fig. 4g. Location map showing the position of all stations occupied along and near the Seal Island transect since 1928 for the month of July.

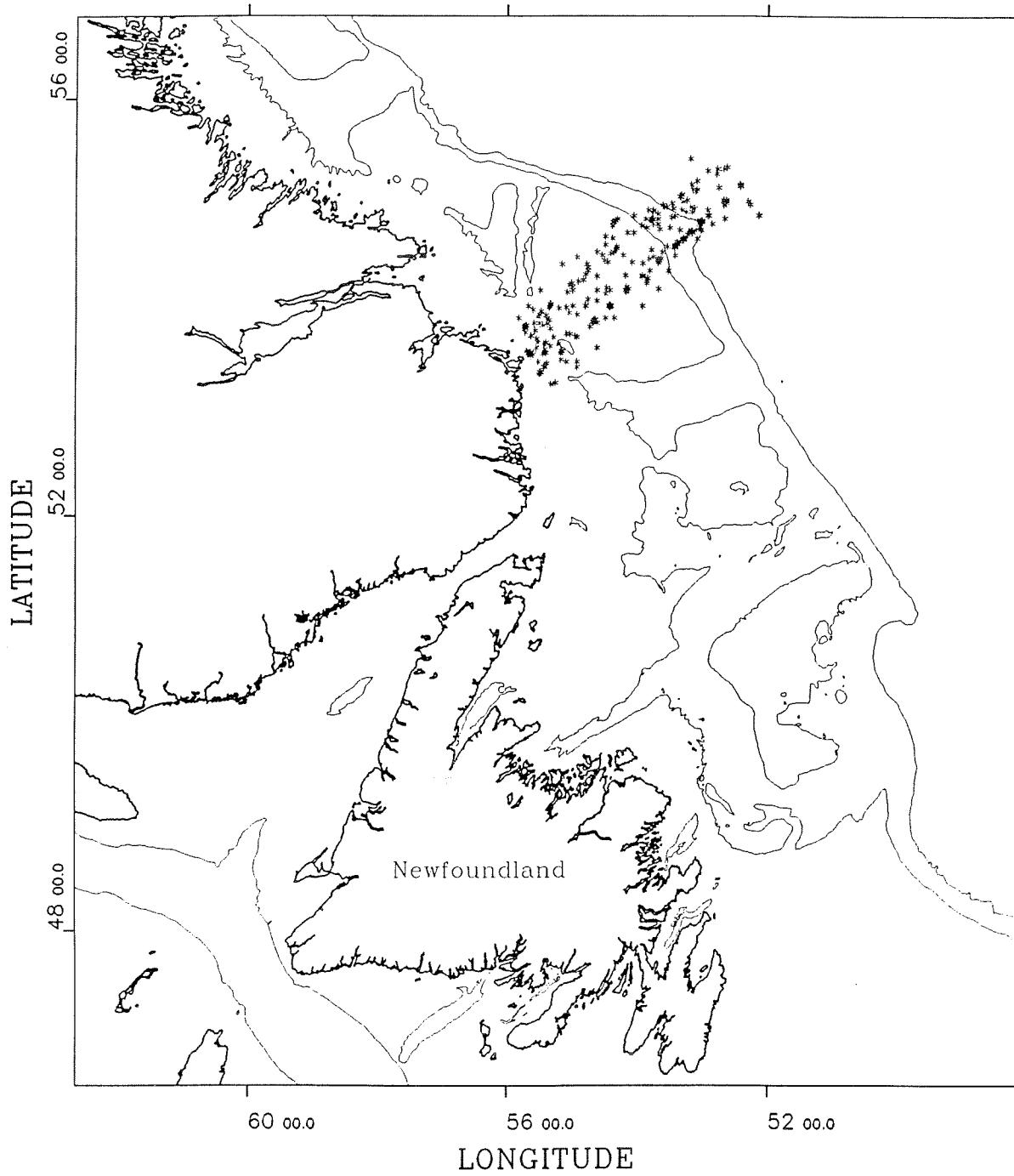


Fig. 4h. Location map showing the position of all stations occupied along and near the Seal Island transect since 1928 for the month of August.

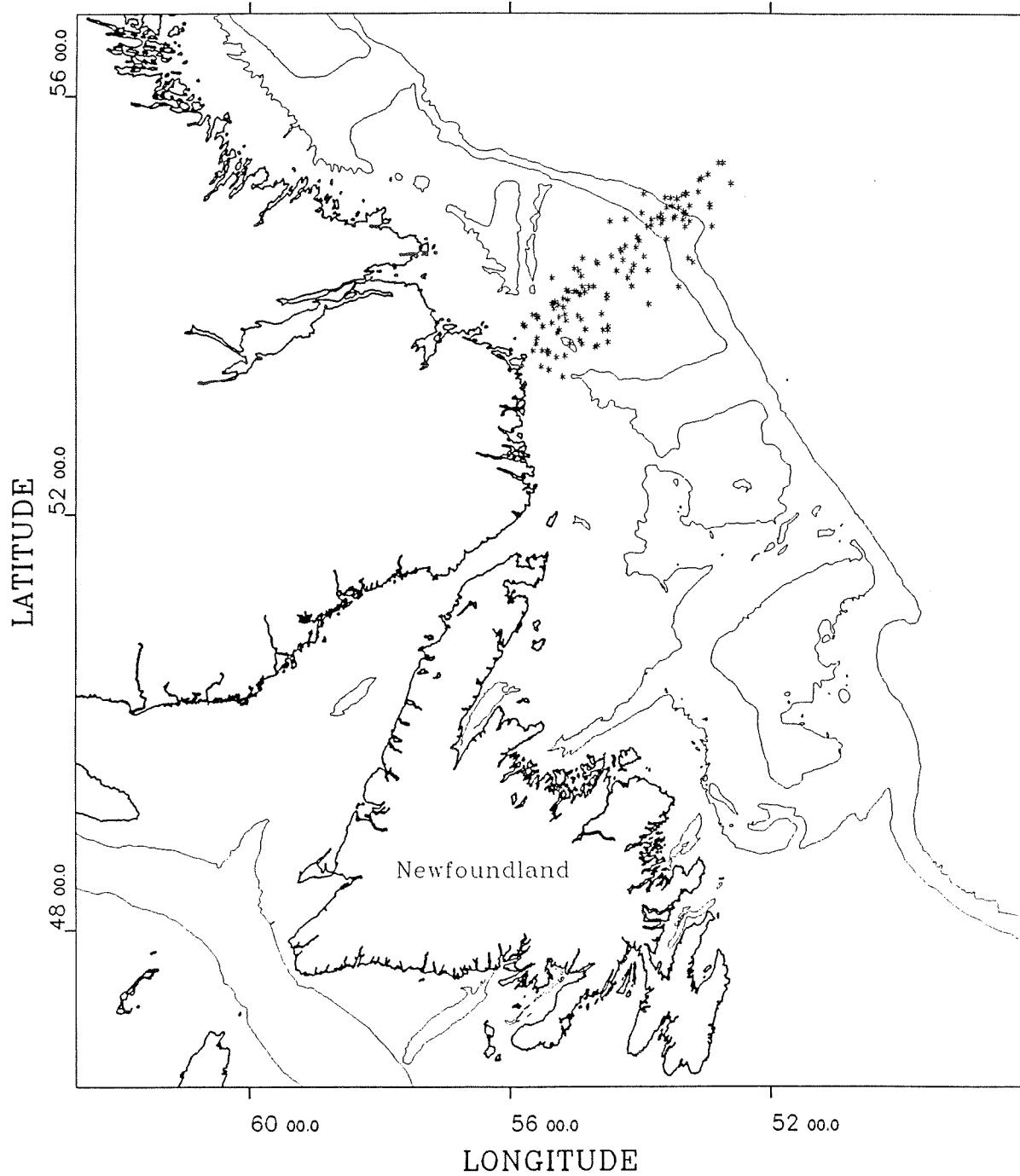


Fig. 4i. Location map showing the position of all stations occupied along and near the Seal Island transect since 1928 for the month of September.

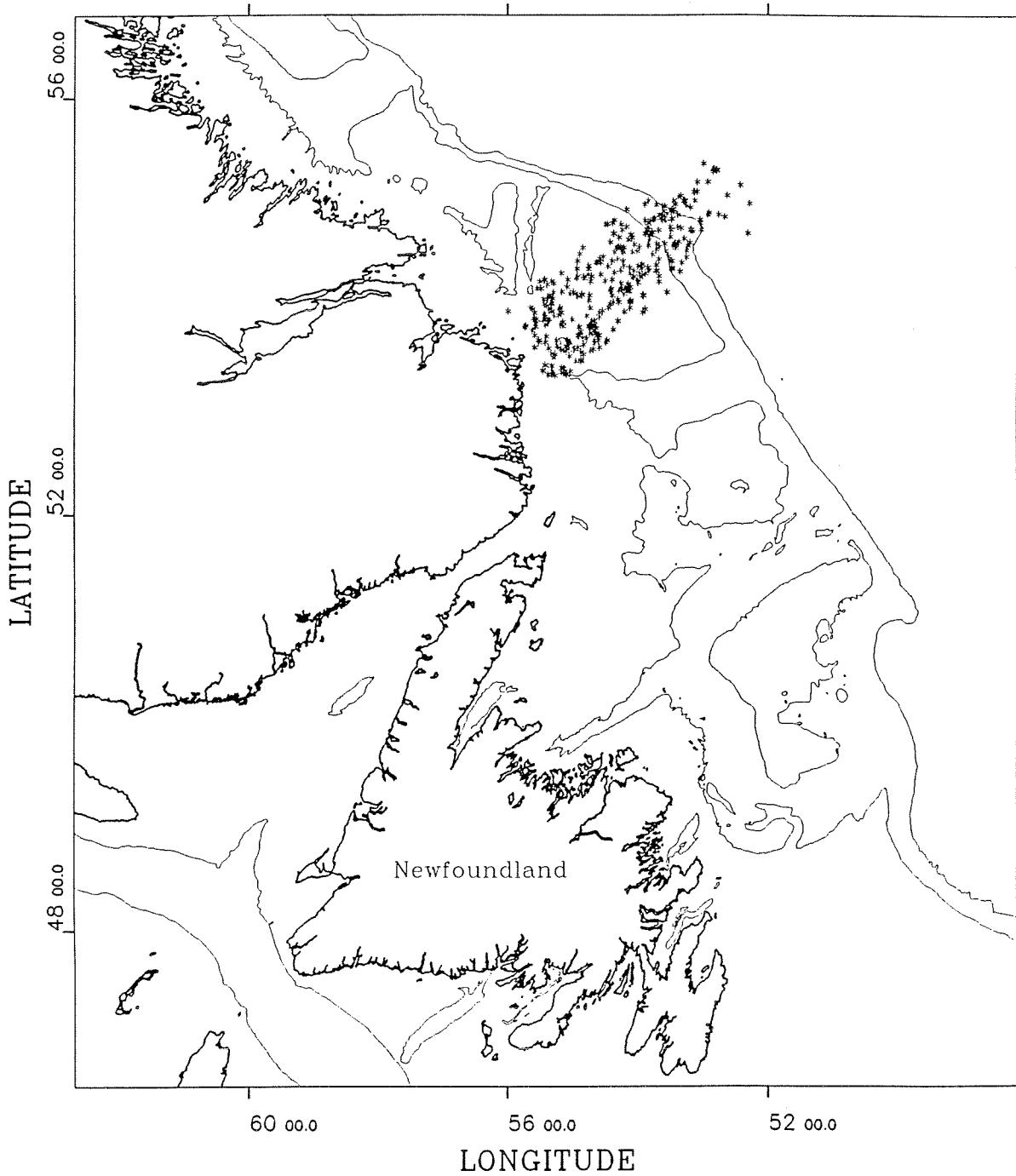


Fig. 4j. Location map showing the position of all stations occupied along and near the Seal Island transect since 1928 for the month of October.

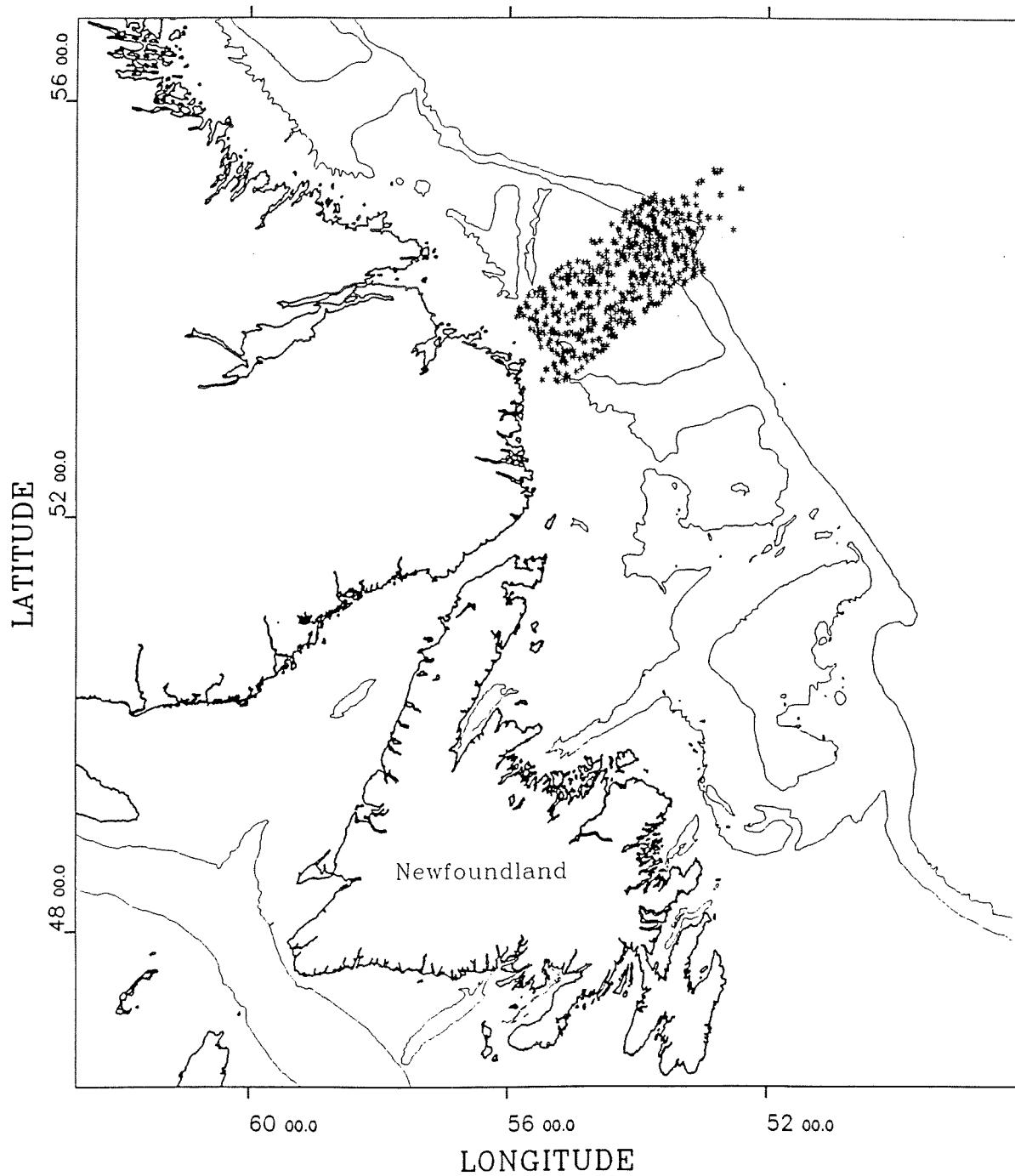


Fig. 4k. Location map showing the position of all stations occupied along and near the Seal Island transect since 1928 for the month of November.

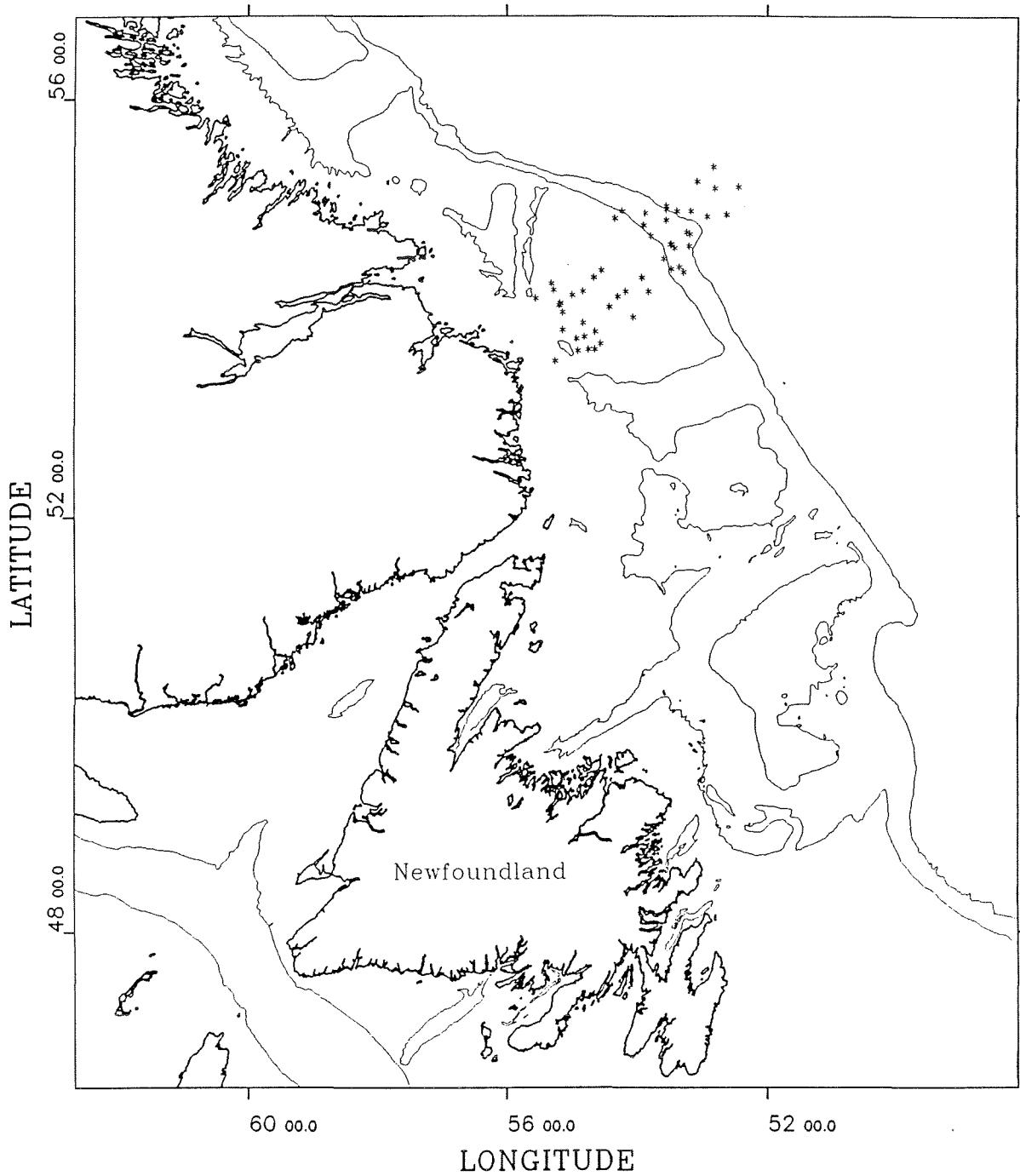


Fig. 4I. Location map showing the position of all stations occupied along and near the Seal Island transect since 1928 for the month of December.

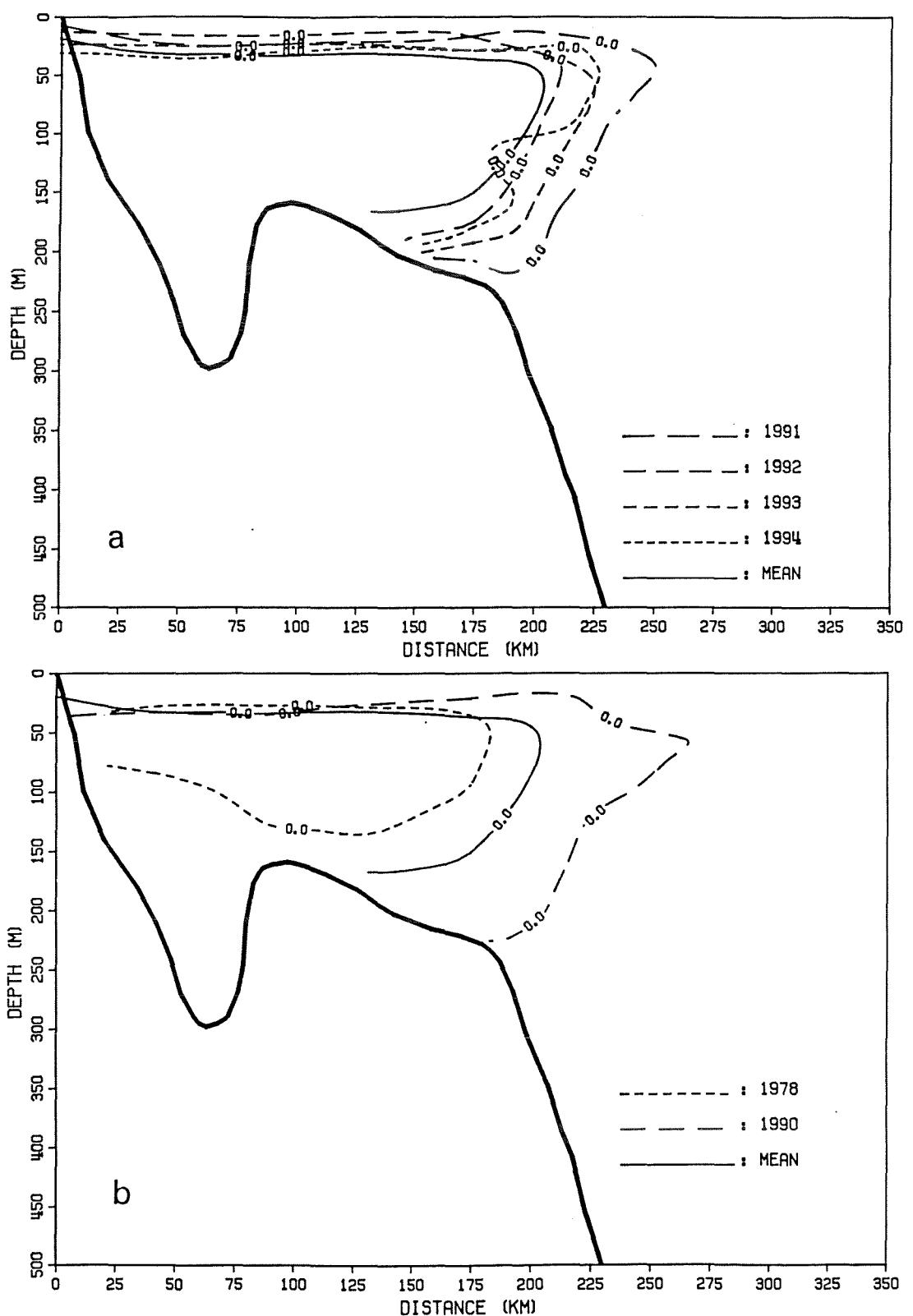
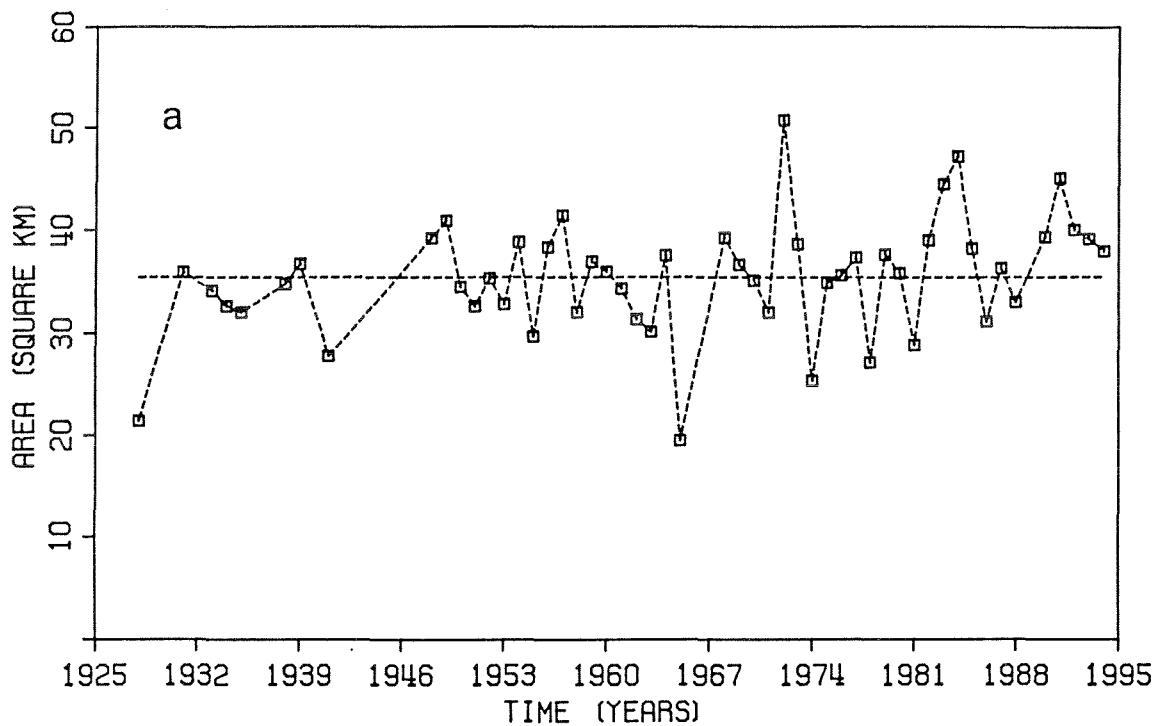


Fig. 5. (a) The geometry and extent of the CIL area less than 0.0 °C along the Seal Island transect for 1991 to 1994 and (b) for 1978 and 1990. The mean is shown as the solid line.

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SEAL ISLAND SUMMER CIL AREA : 1.0



SEAL ISLAND SUMMER CIL AREA : 0.0

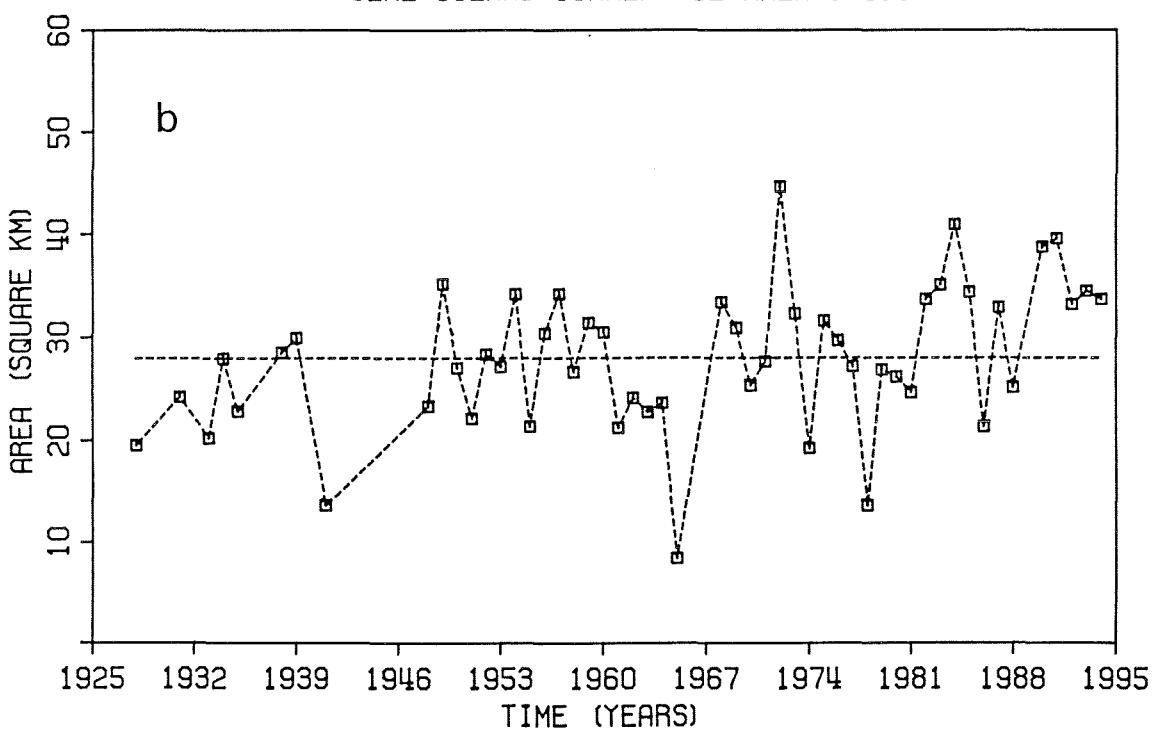


Fig. 6. (a) Time series of the Seal Island transect CIL area less than $1.0\text{ }^{\circ}\text{C}$ and (b) less than $0.0\text{ }^{\circ}\text{C}$ in km^2 .

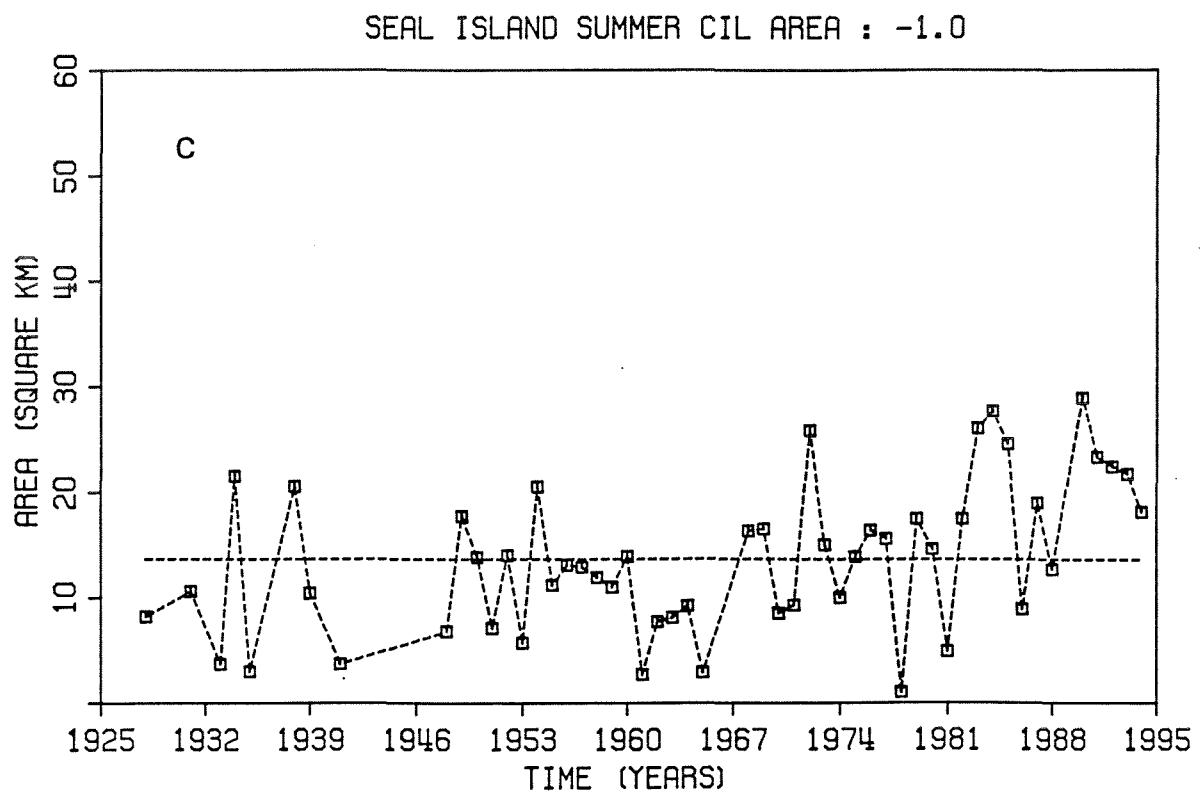


Fig. 6. (c) Time series of the Seal Island transect CIL area less than -1.0°C in km^2 .

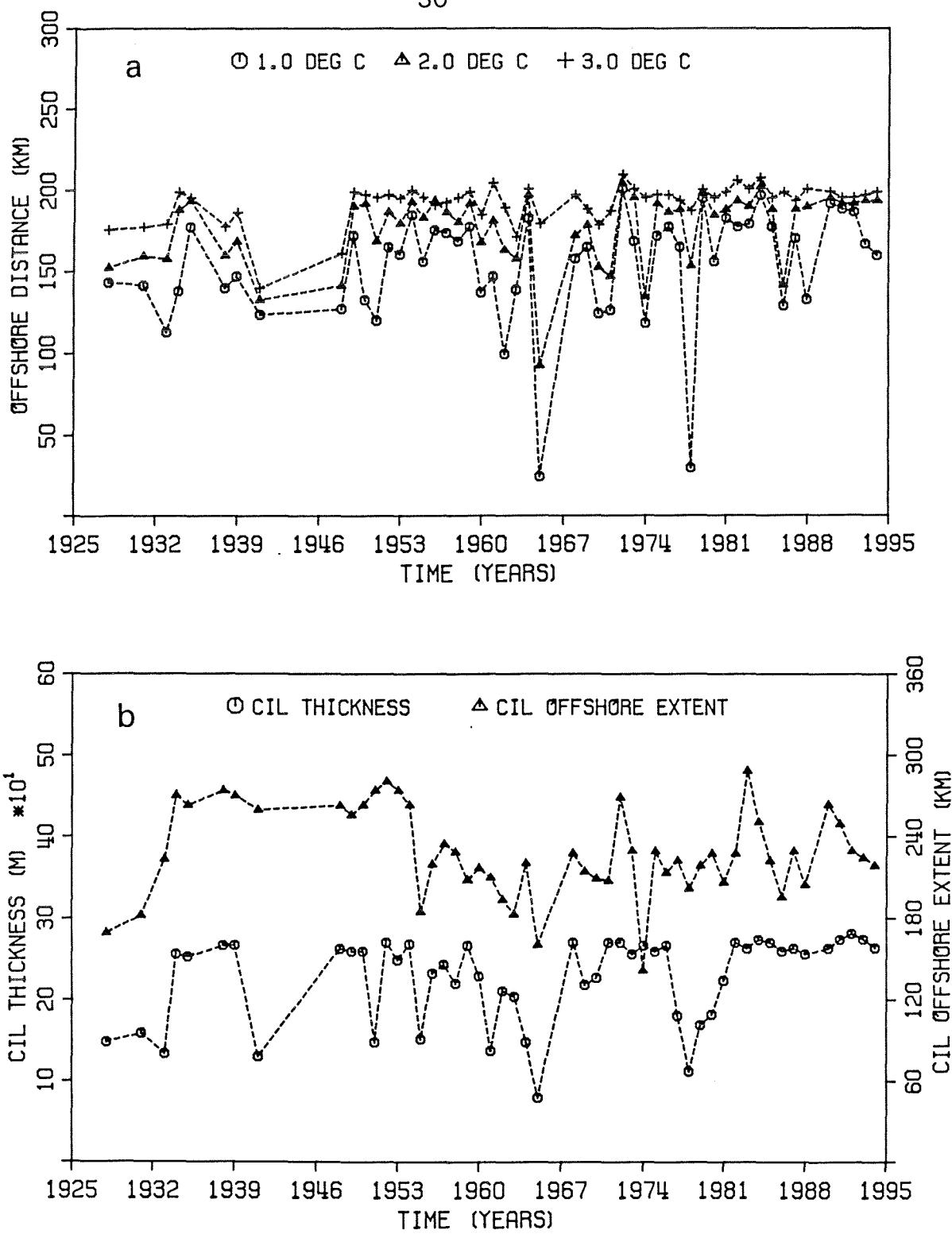


Fig. 7. (a) Offshore distance from shore of the bottom location of the 1.0, 2.0 and 3.0 °C isotherms and (b) the CIL thickness and offshore extent.

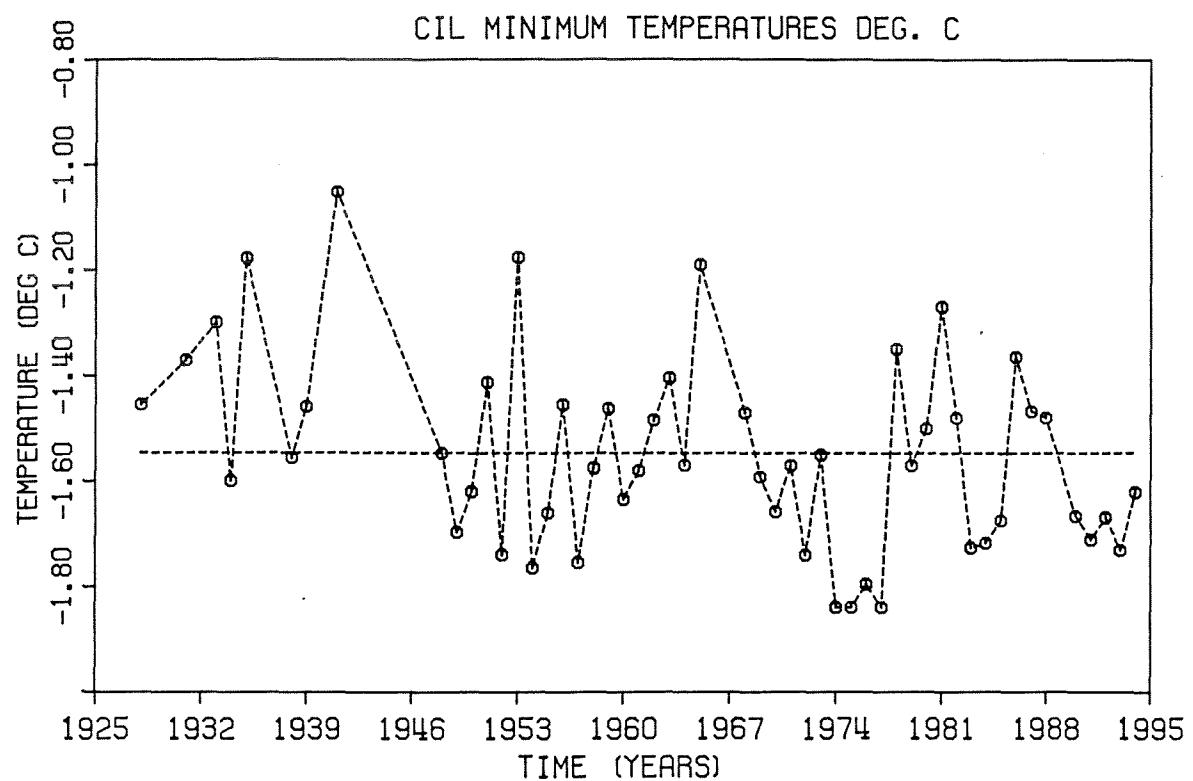
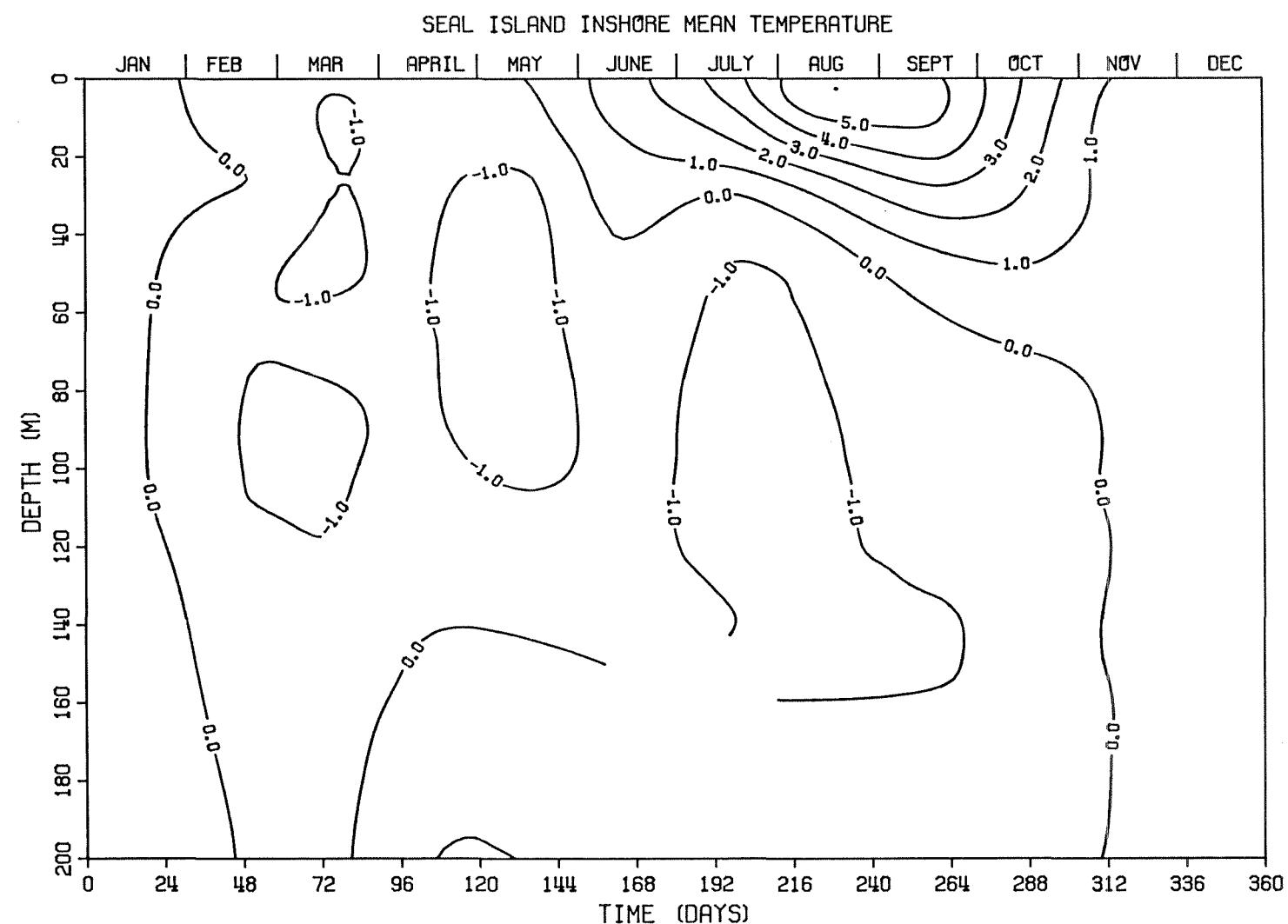


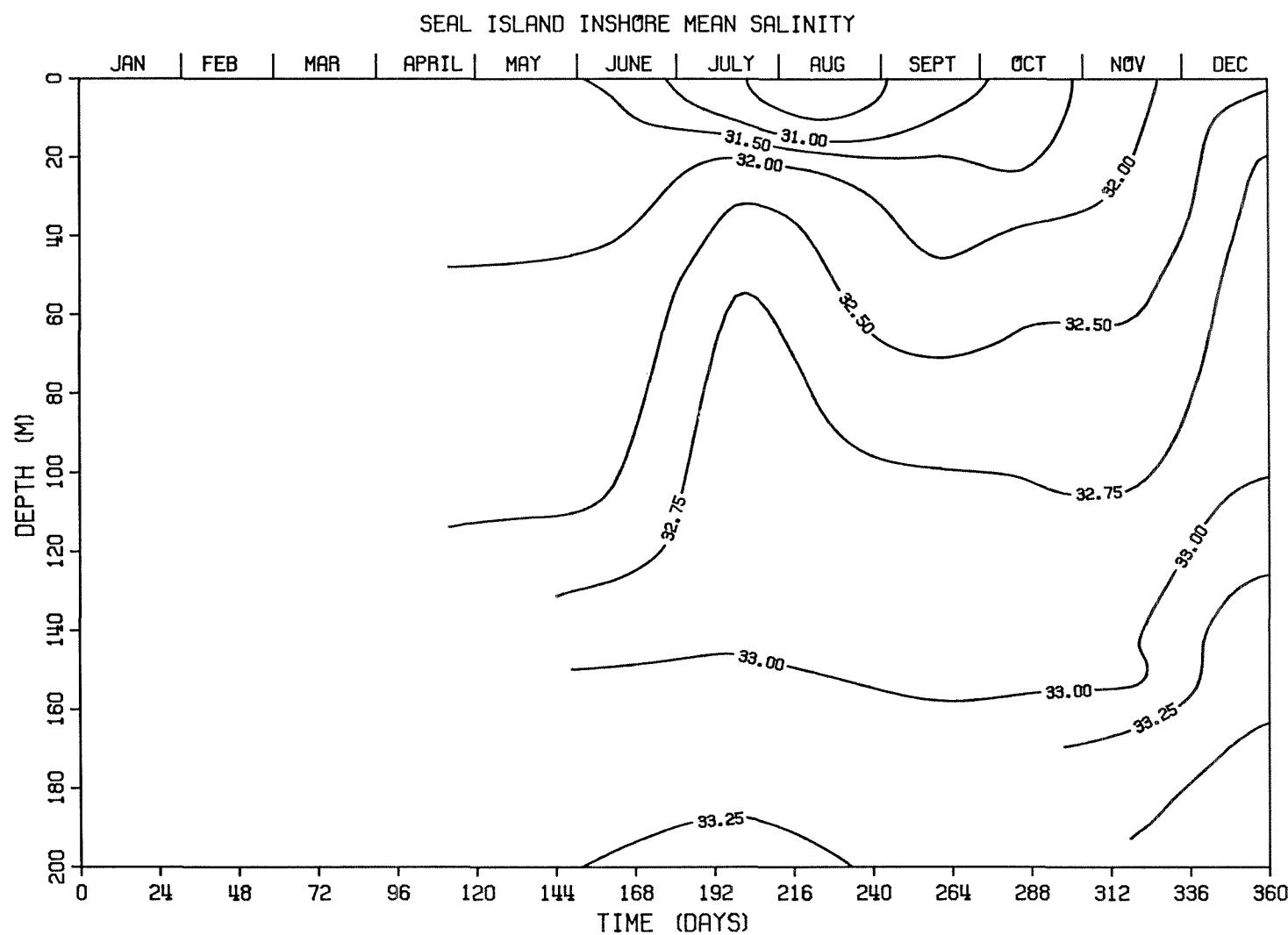
Fig. 8. Time series of the CIL intensities or minimum core temperatures.

YEAR	Seal Island CIL Indices				Min. Temp. (°C)	Thickness (M)	Extent (KM)
	1.0 °C	0.0 °C	-1.0 °C	-1.5 °C			
1928	21.4	19.5	8.2	0.0	-1.455	148	172
1931	35.9	24.2	10.6	0.0	-1.371	158	217
1933	34.1	20.2	3.7	0.0	-1.300	133	204
1934	32.6	27.9	21.5	7.6	-1.600	256	200
1935	32.0	22.8	3.0	0.0	-1.178	252	202
1938	34.8	28.5	20.5	3.9	-1.556	266	208
1939	36.7	29.9	10.4	0.0	-1.459	266	215
1941	27.7	13.6	3.7	1.1	-1.053	130	161
1948	39.2	23.3	6.8	2.7	-1.547	263	199
1949	40.9	35.1	17.7	5.8	-1.697	259	224
1950	34.5	27.0	13.8	1.2	-1.620	259	218
1951	32.6	22.1	7.1	0.0	-1.413	148	209
1952	35.3	28.3	14.0	0.0	-1.740	270	193
1953	32.8	27.1	5.7	0.0	-1.177	248	198
1954	38.8	34.1	20.5	0.9	-1.765	268	224
1955	29.6	21.3	11.2	1.2	-1.660	151	184
1956	38.3	30.3	13.1	1.6	-1.455	232	219
1957	41.4	34.1	12.9	2.8	-1.755	243	234
1958	32.0	26.6	11.9	0.9	-1.575	220	228
1959	36.9	31.3	11.0	0.0	-1.462	266	208
1960	35.9	30.4	13.9	1.8	-1.635	229	217
1961	34.3	21.2	2.7	0.0	-1.580	137	209
1962	31.3	24.1	7.7	0.0	-1.484	211	193
1963	30.1	22.7	8.1	0.0	-1.405	203	183
1964	37.5	23.6	9.2	0.0	-1.570	148	220
1965	19.4	8.4	2.9	1.0	-1.191	79	160
1968	39.2	33.3	16.3	1.1	-1.470	270	227
1969	36.6	30.8	16.5	3.2	-1.592	218	214
1970	35.1	25.3	8.5	1.8	-1.658	227	209
1971	32.0	27.6	9.3	1.6	-1.570	270	207
1972	50.7	44.6	25.8	0.0	-1.740	270	269
1973	38.6	32.2	15.0	0.0	-1.550	256	229
1974	25.3	19.2	10.0	2.5	-1.840	266	141
1975	34.9	31.5	13.9	1.5	-1.840	259	229
1976	35.6	29.6	16.4	1.9	-1.796	266	213
1977	37.3	27.1	15.6	3.2	-1.840	180	222
1978	27.1	13.6	1.0	0.0	-1.350	112	201
1979	37.6	26.8	17.5	0.0	-1.570	169	218
1980	35.8	26.1	14.6	0.0	-1.500	182	227
1981	28.8	24.6	4.9	0.0	-1.270	223	206
1982	39.0	33.6	17.5	0.9	-1.480	270	227
1983	44.5	35.0	26.1	11.8	-1.726	263	288
1984	47.2	40.9	27.7	14.9	-1.717	274	251
1985	38.2	34.3	24.6	12.5	-1.674	270	222
1986	31.1	21.3	8.9	0.0	-1.365	259	195
1987	36.3	32.8	19.0	0.0	-1.468	263	229
1988	33.0	25.1	12.7	0.0	-1.480	256	204
1990	39.3	38.7	29.0	14.1	-1.666	263	263
1991	45.1	39.5	23.4	2.9	-1.711	274	249
1992	40.0	33.1	22.5	8.2	-1.668	281	229
1993	39.1	34.4	21.8	11.9	-1.731	274	224
1994	37.9	33.6	18.2	4.3	-1.620	263	218

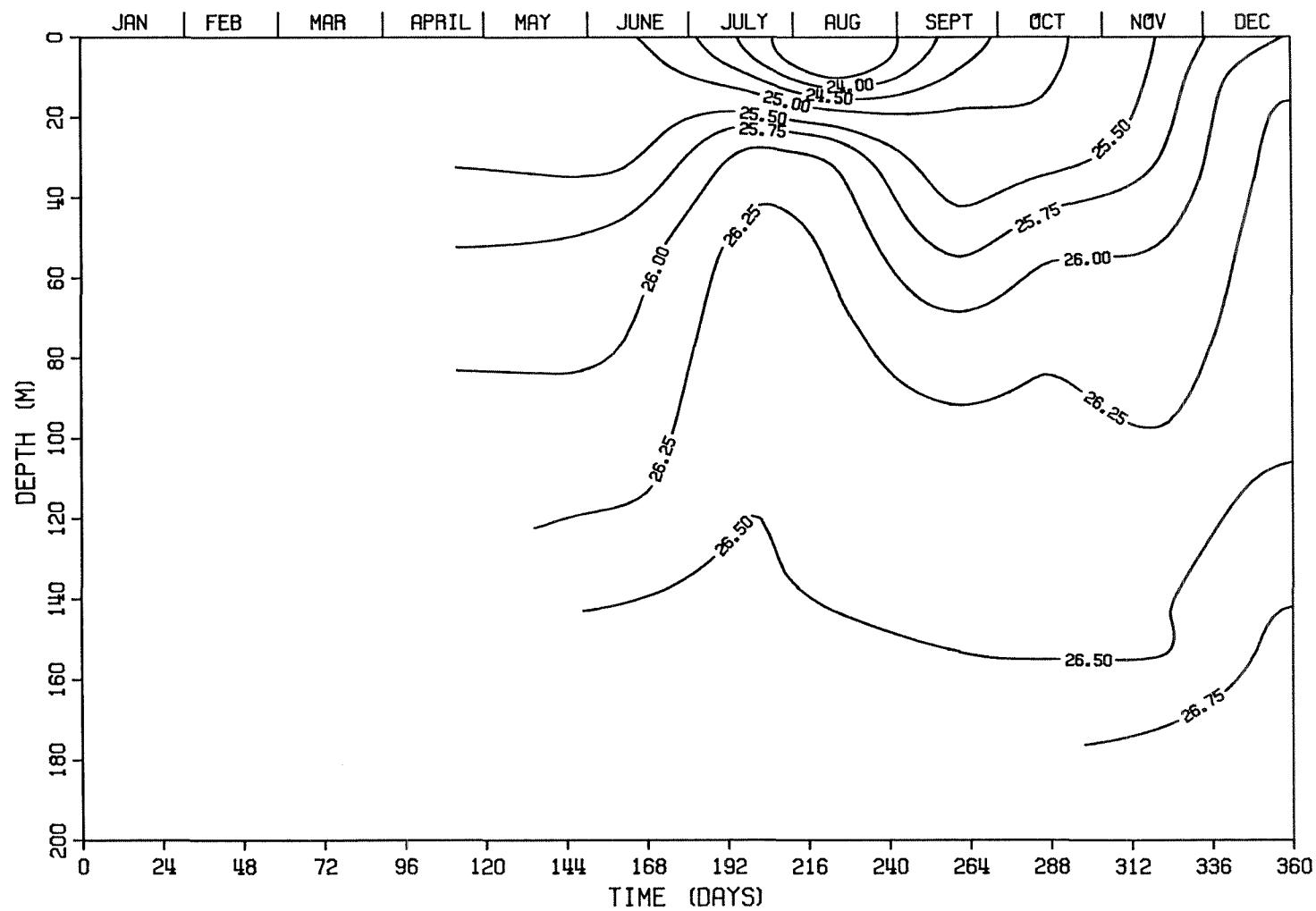
Table 3. Summary of the Seal Island transect (July-August) CIL indices.

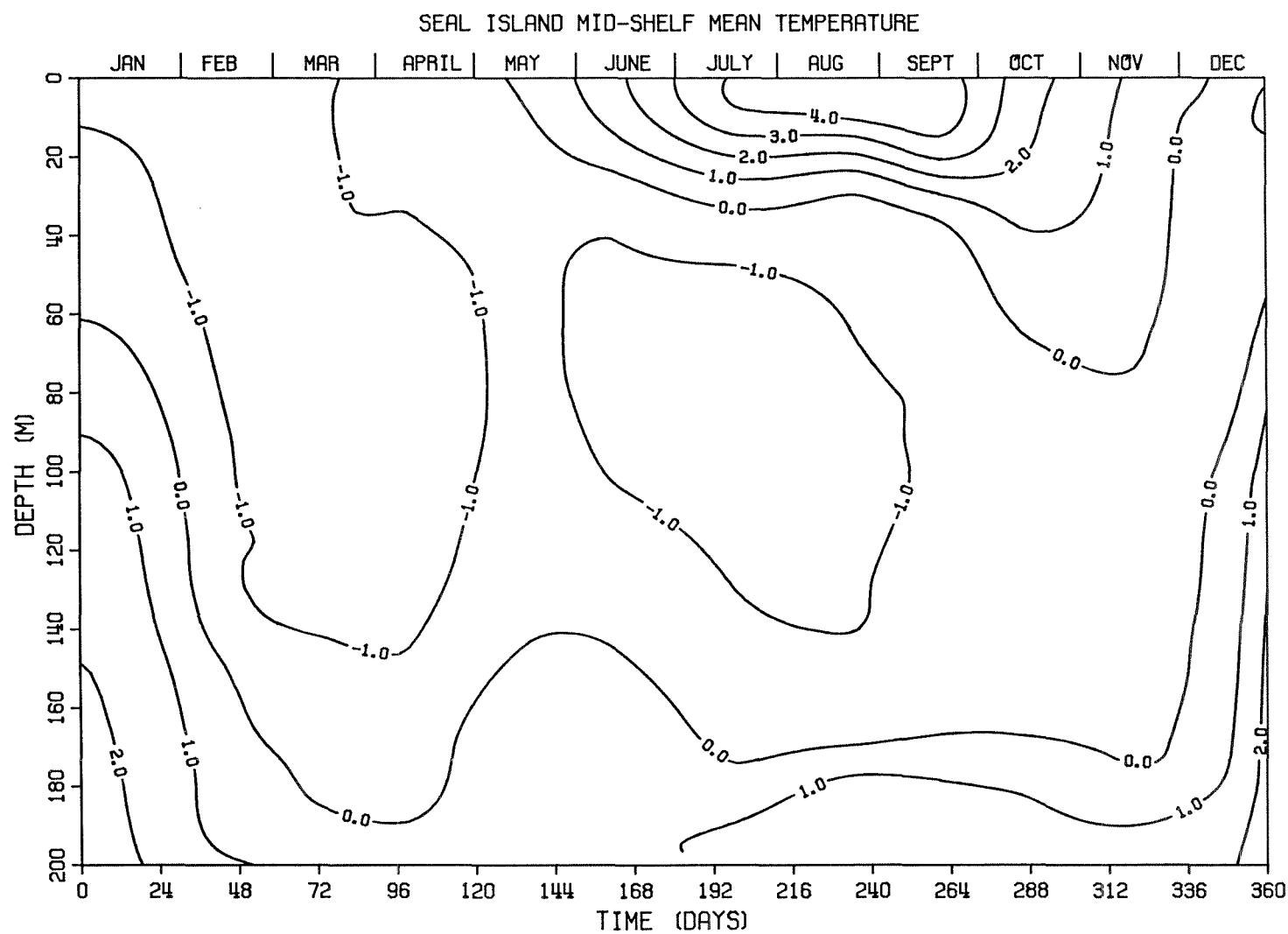
APPENDIX A. Time series of monthly mean temperature, salinity and density versus depth for the inshore, mid-shelf and shelf-edge areas along the Seal Island transect.

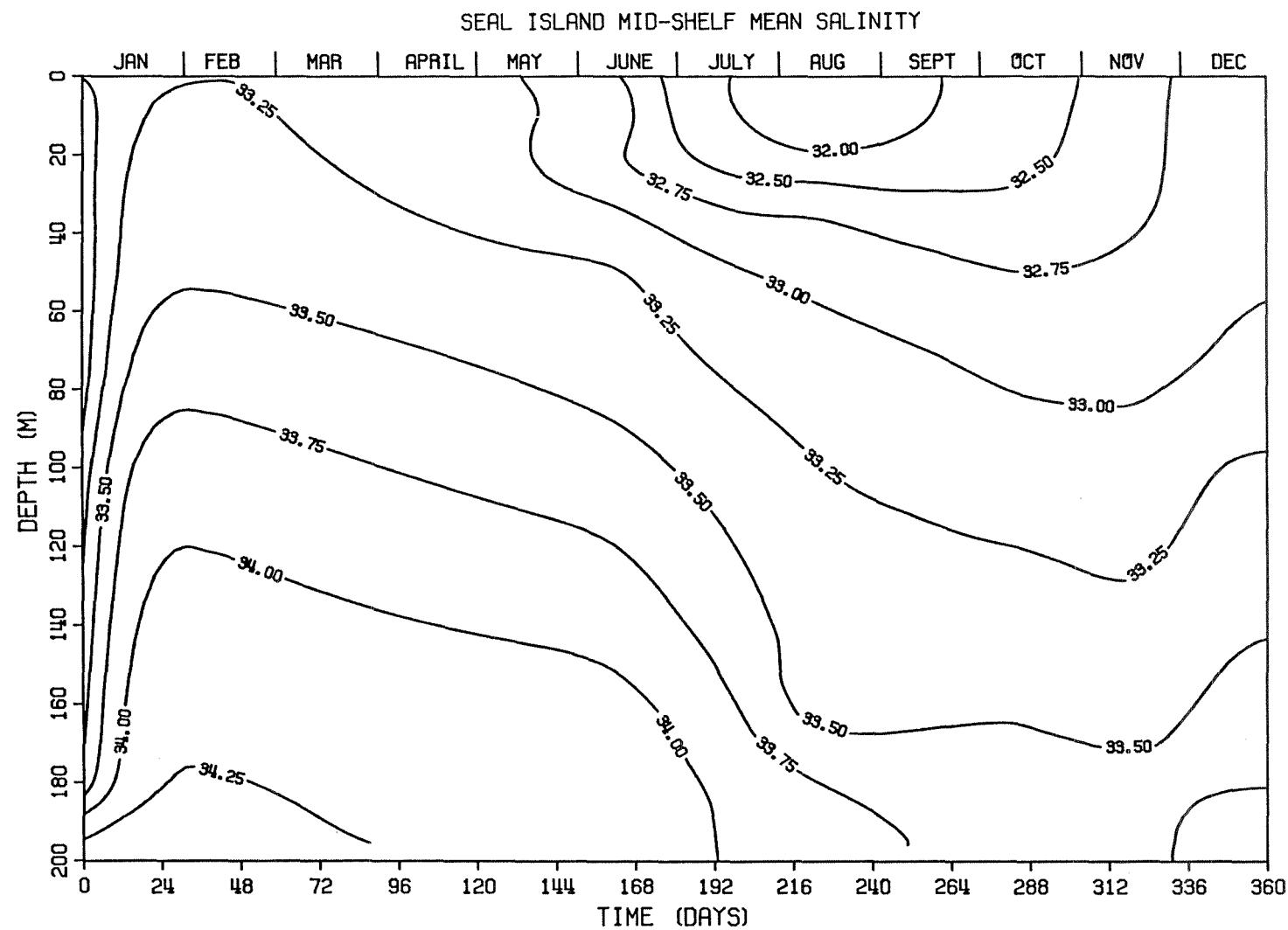


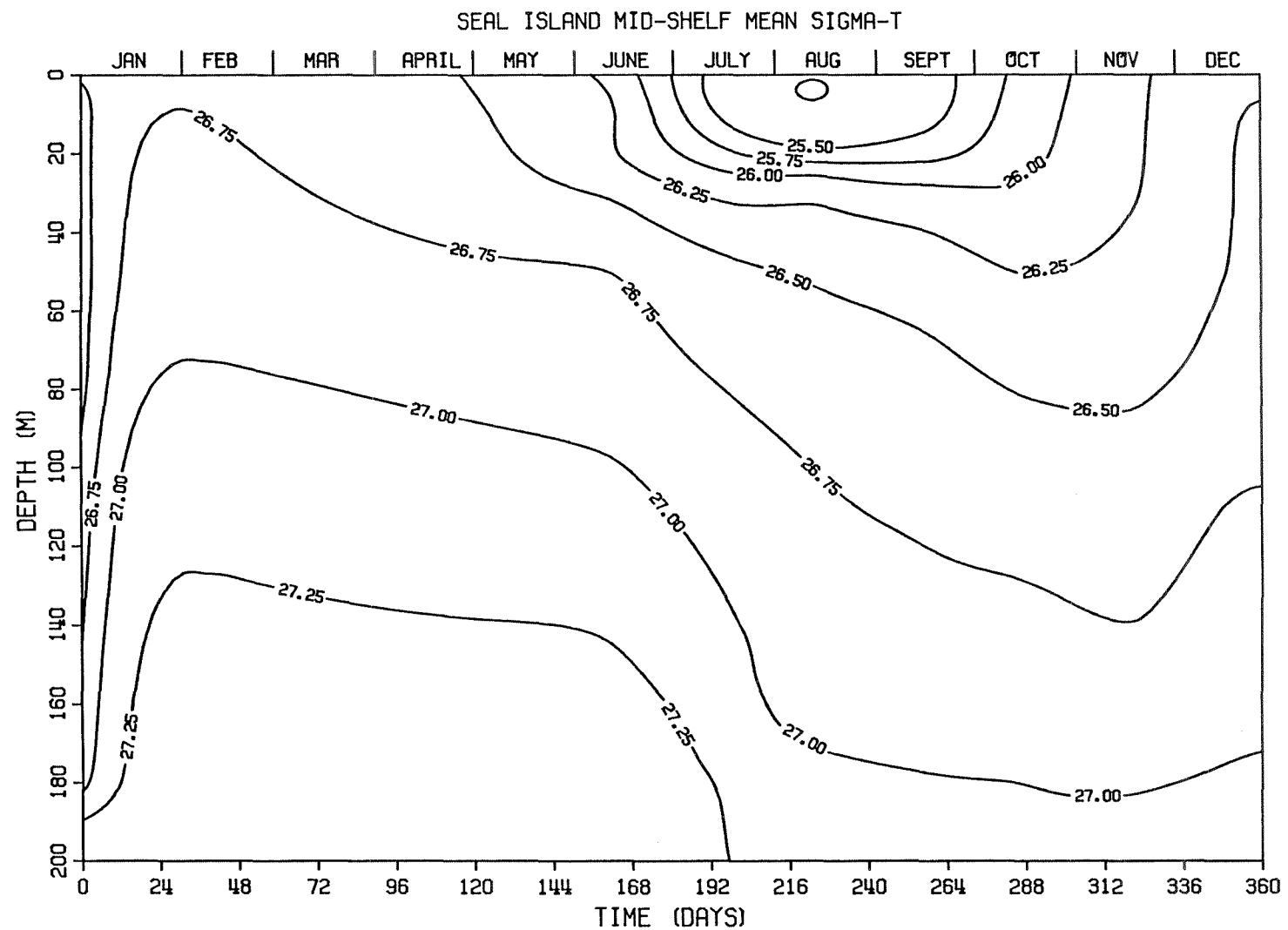


SEAL ISLAND INSHORE MEAN SIGMA-T

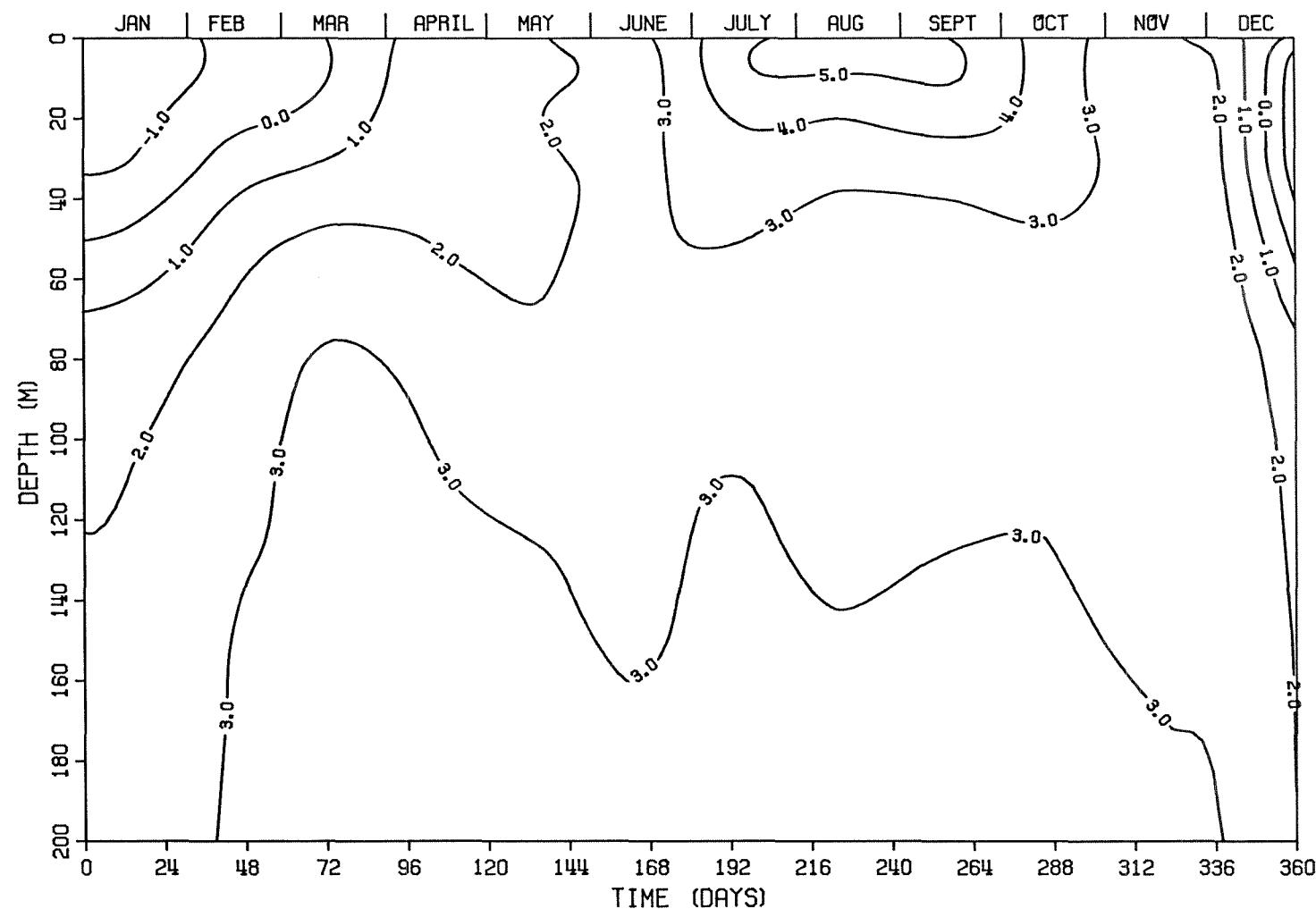


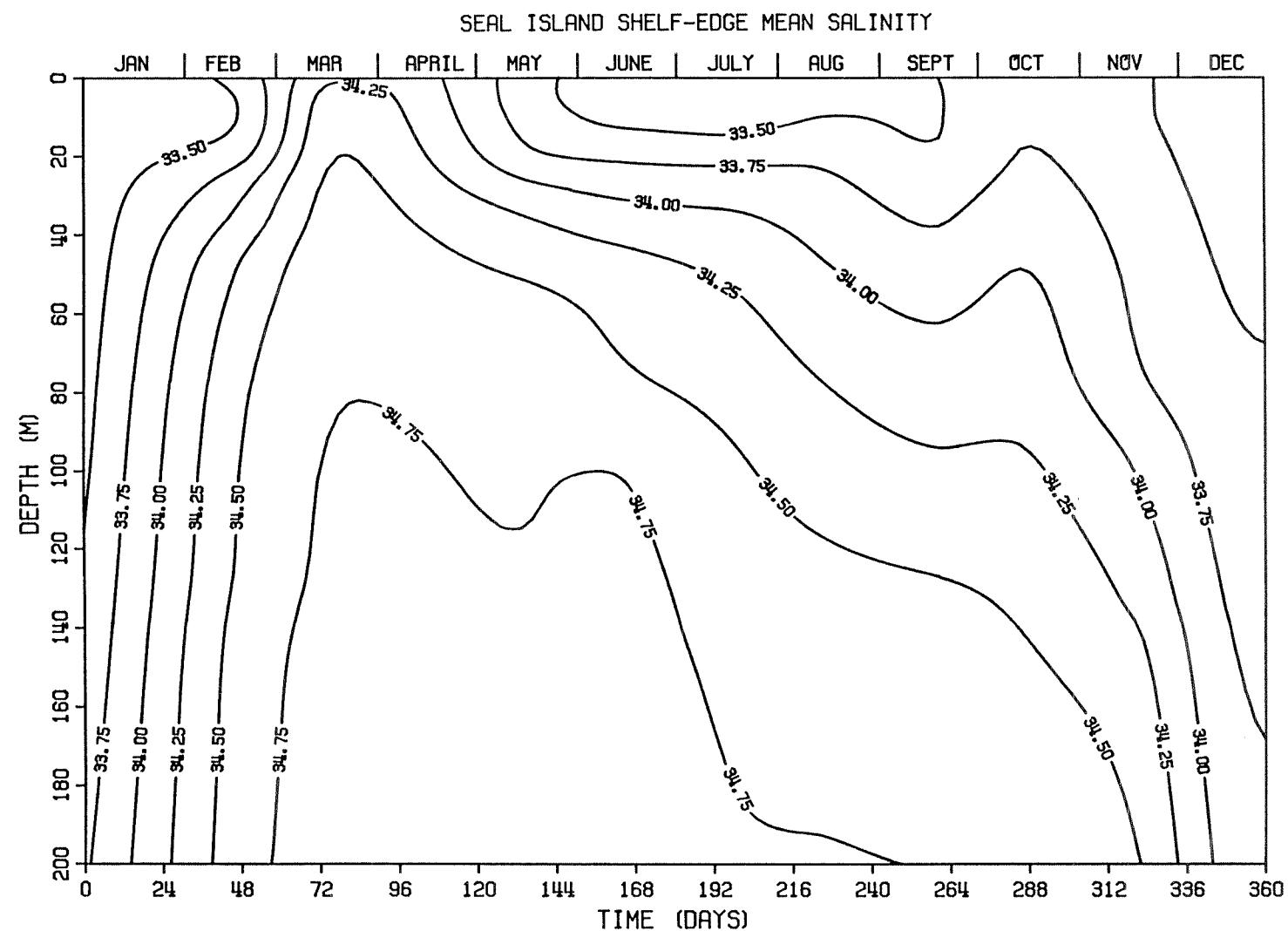


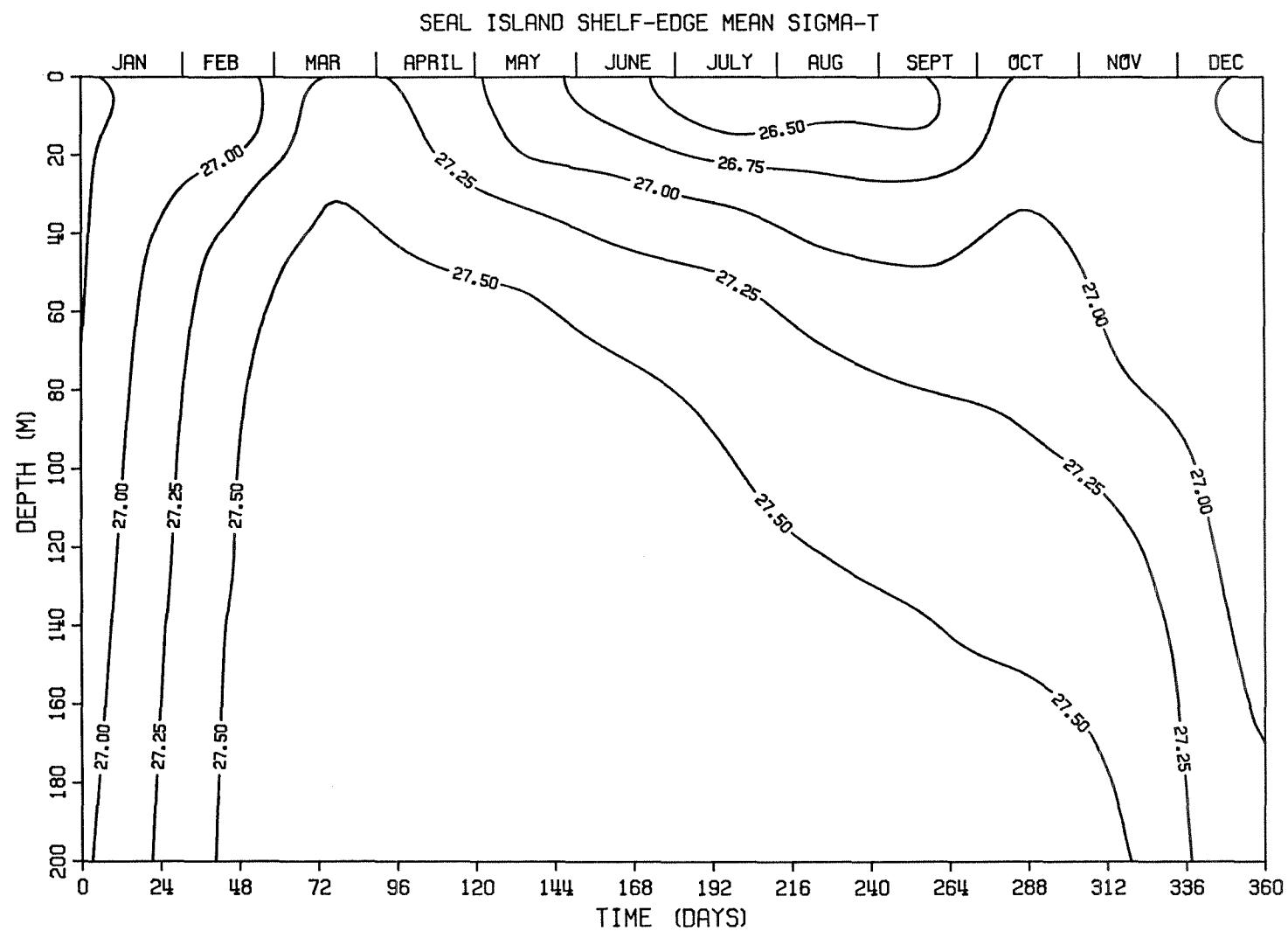




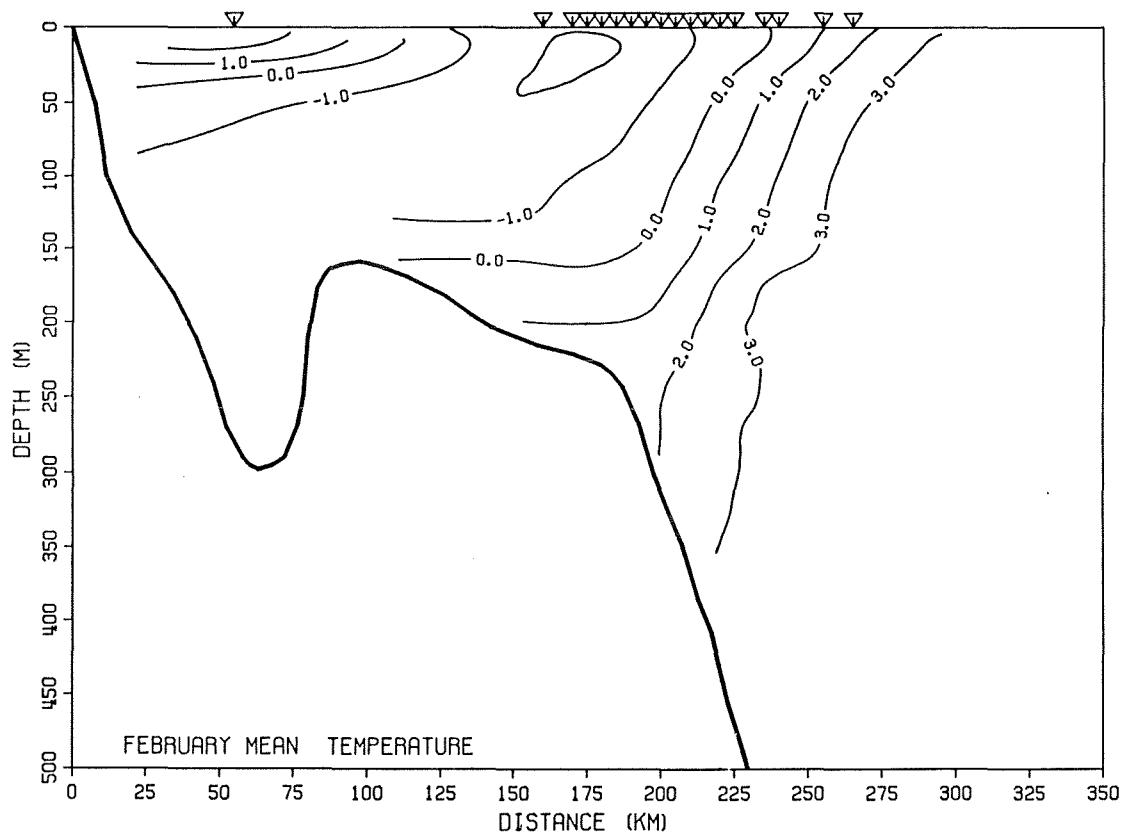
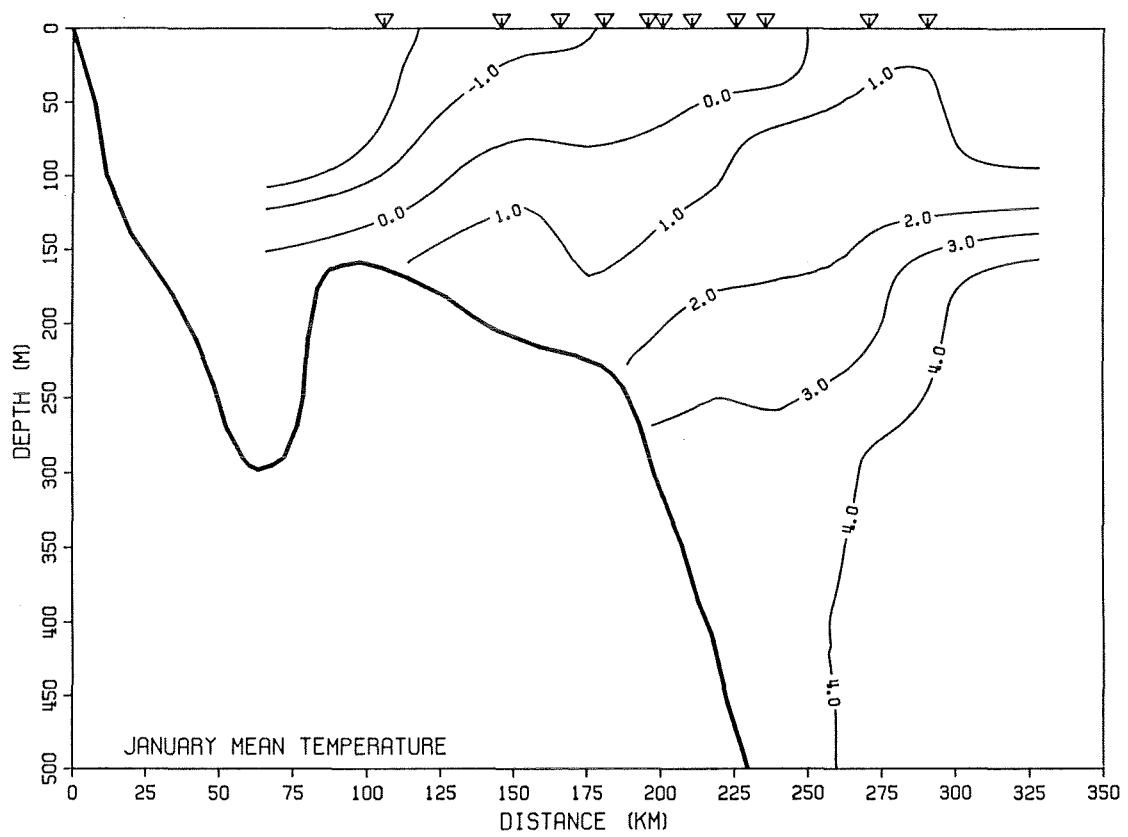
SEAL ISLAND SHELF-EDGE MEAN TEMPERATURE

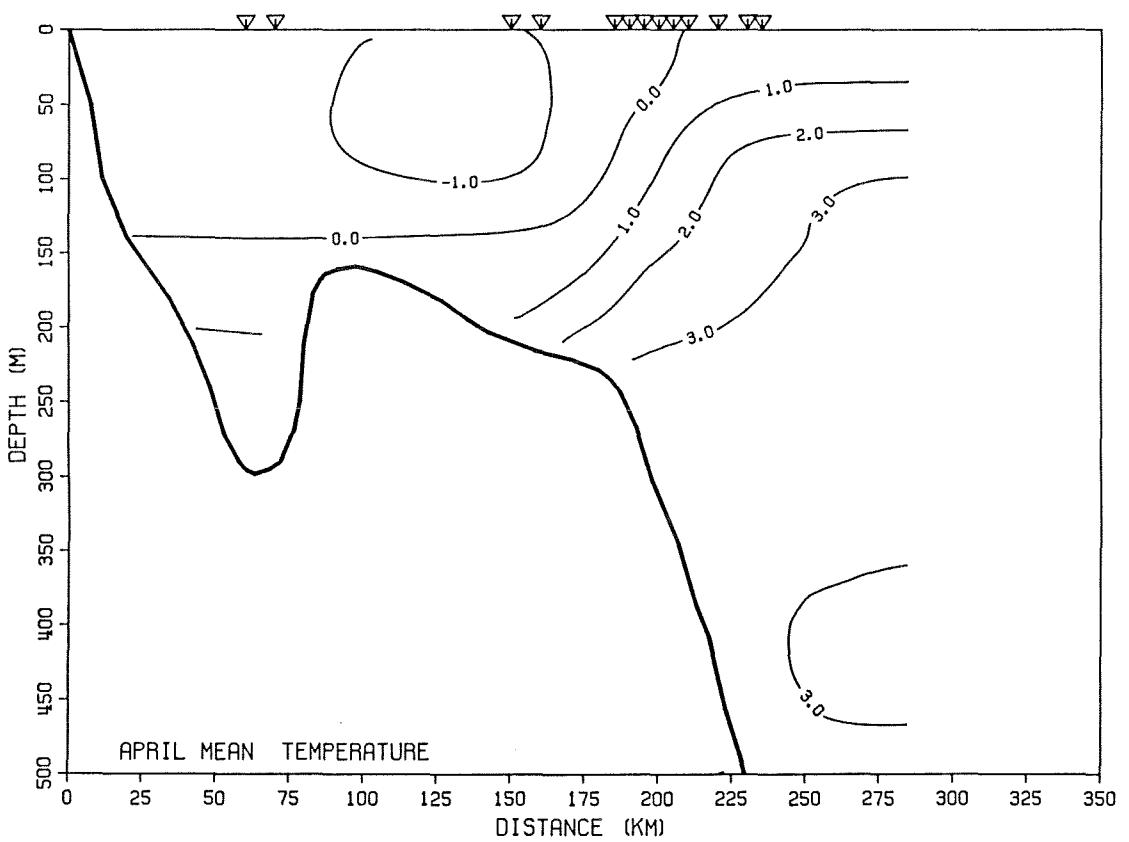
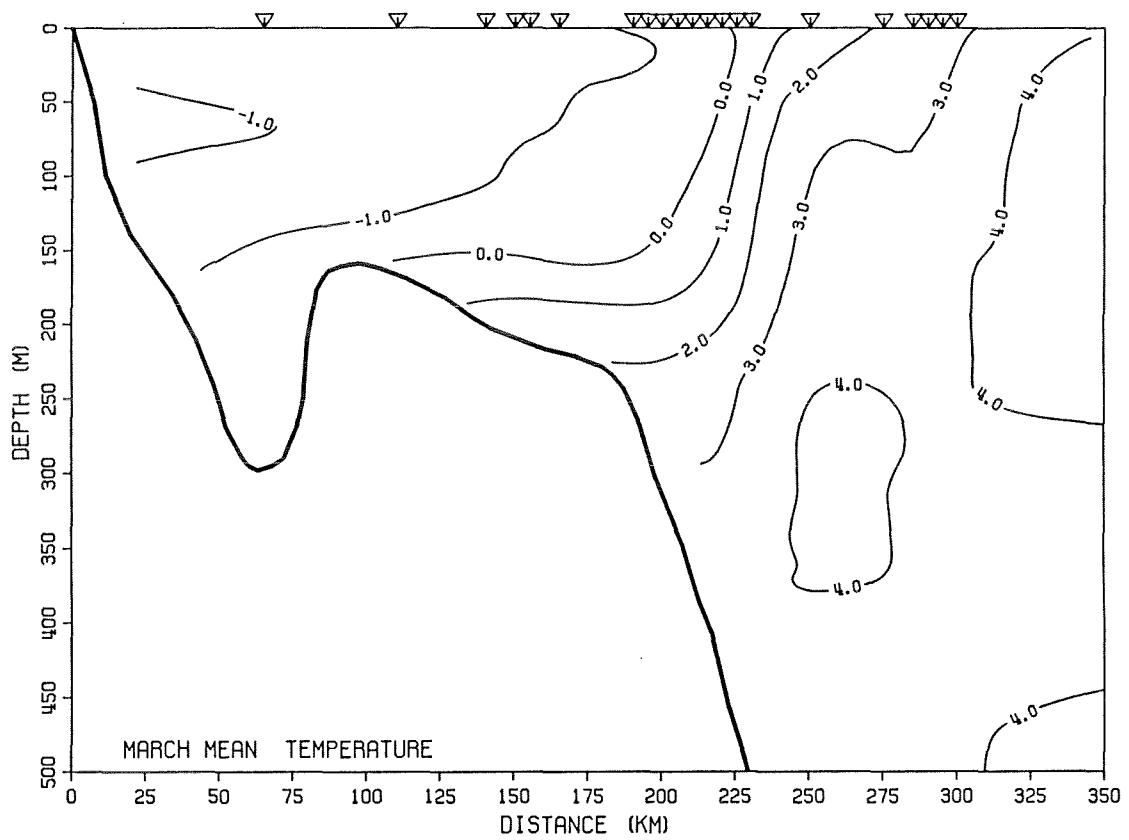


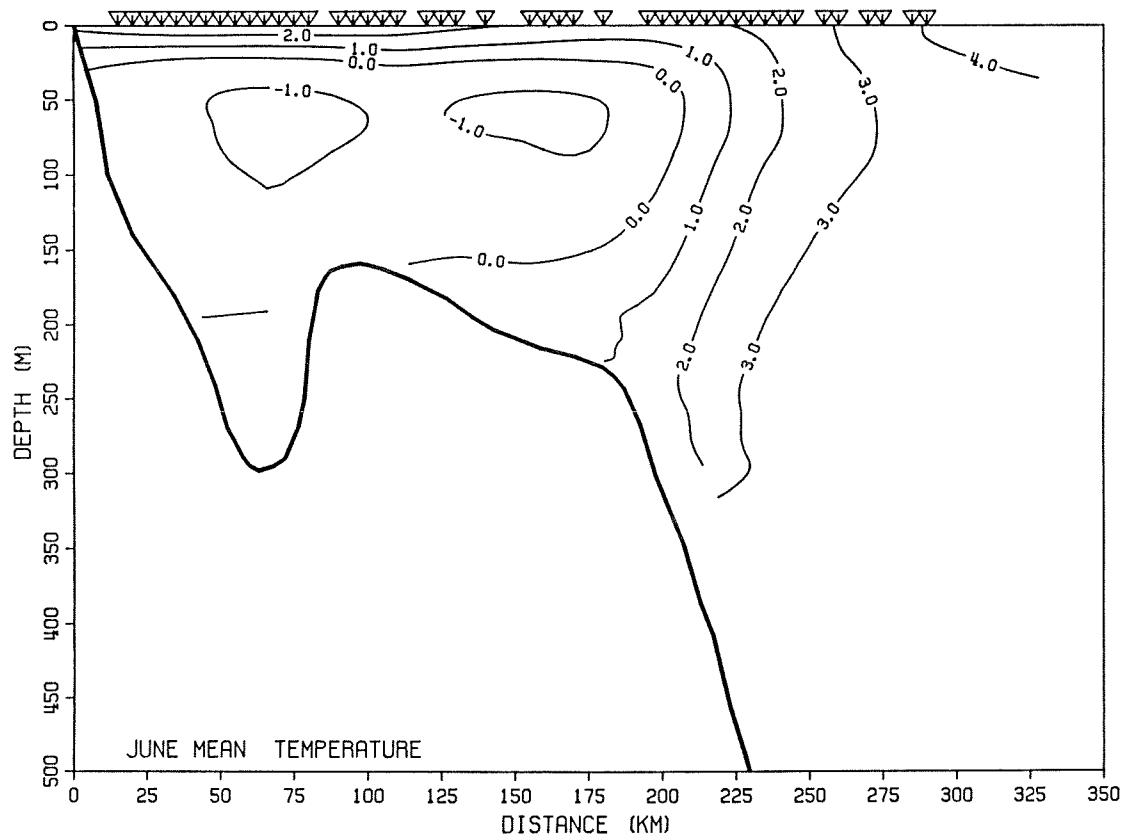
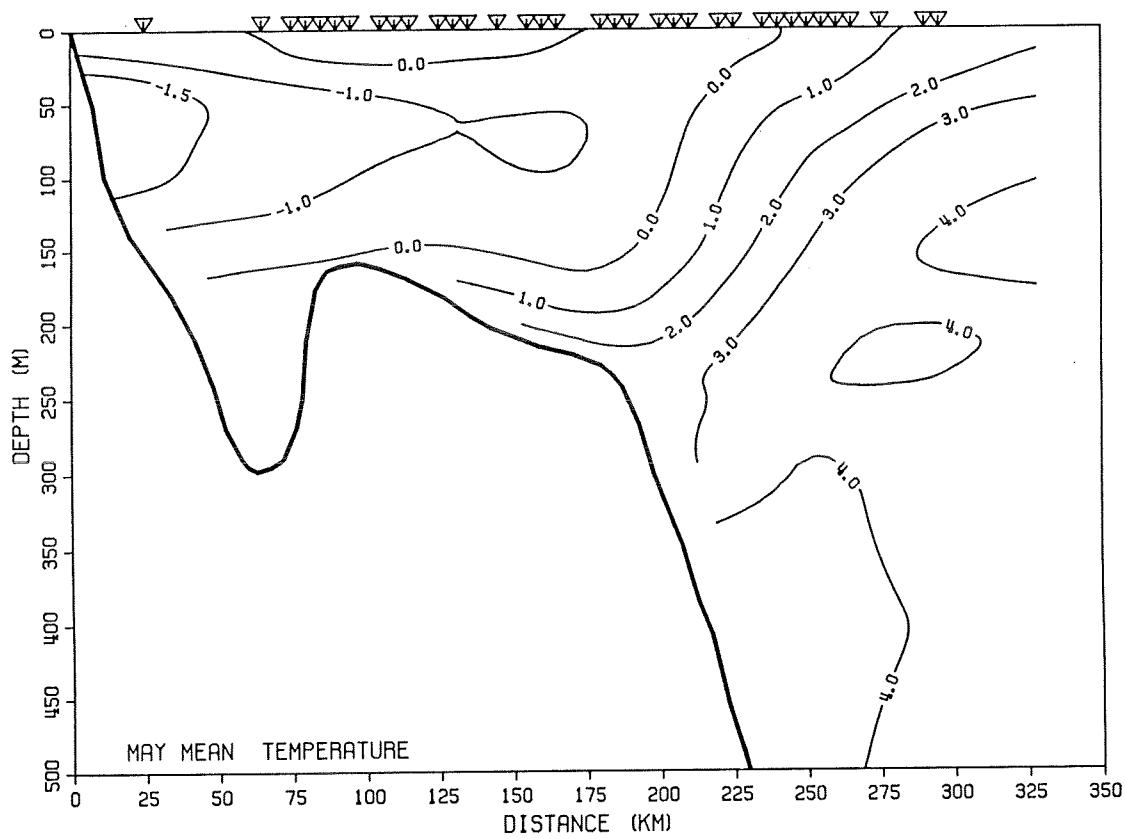




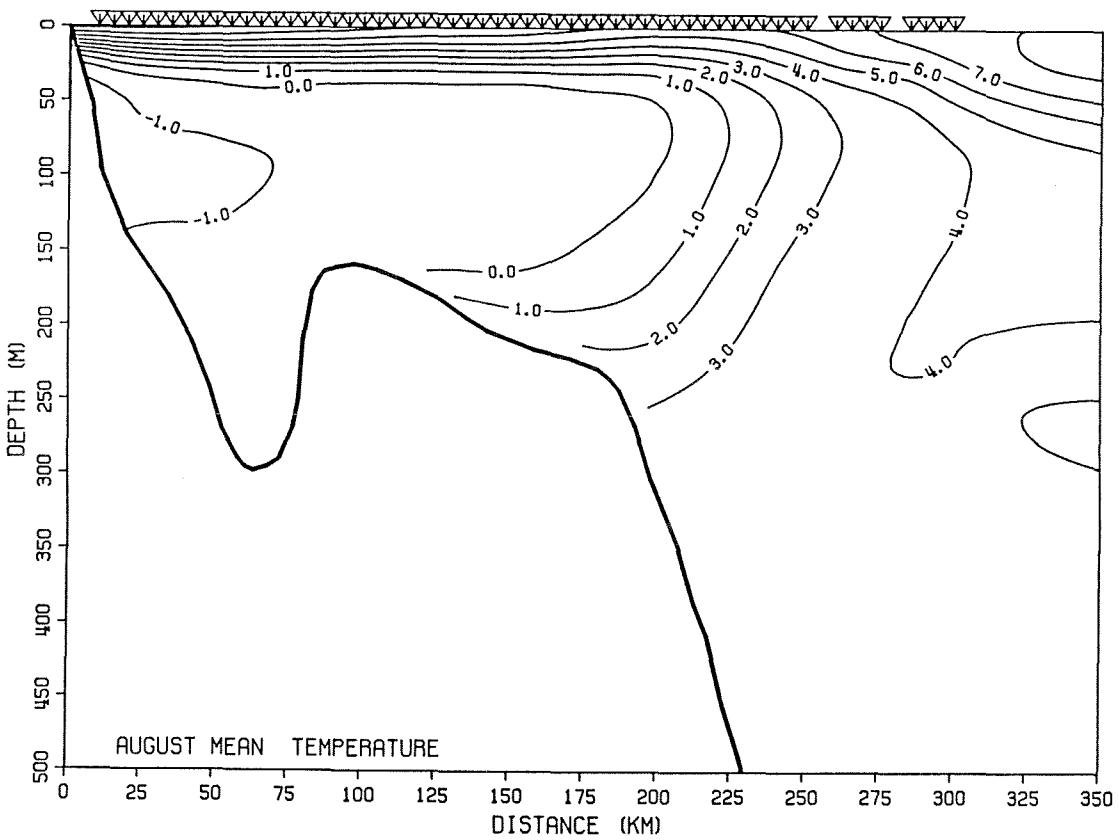
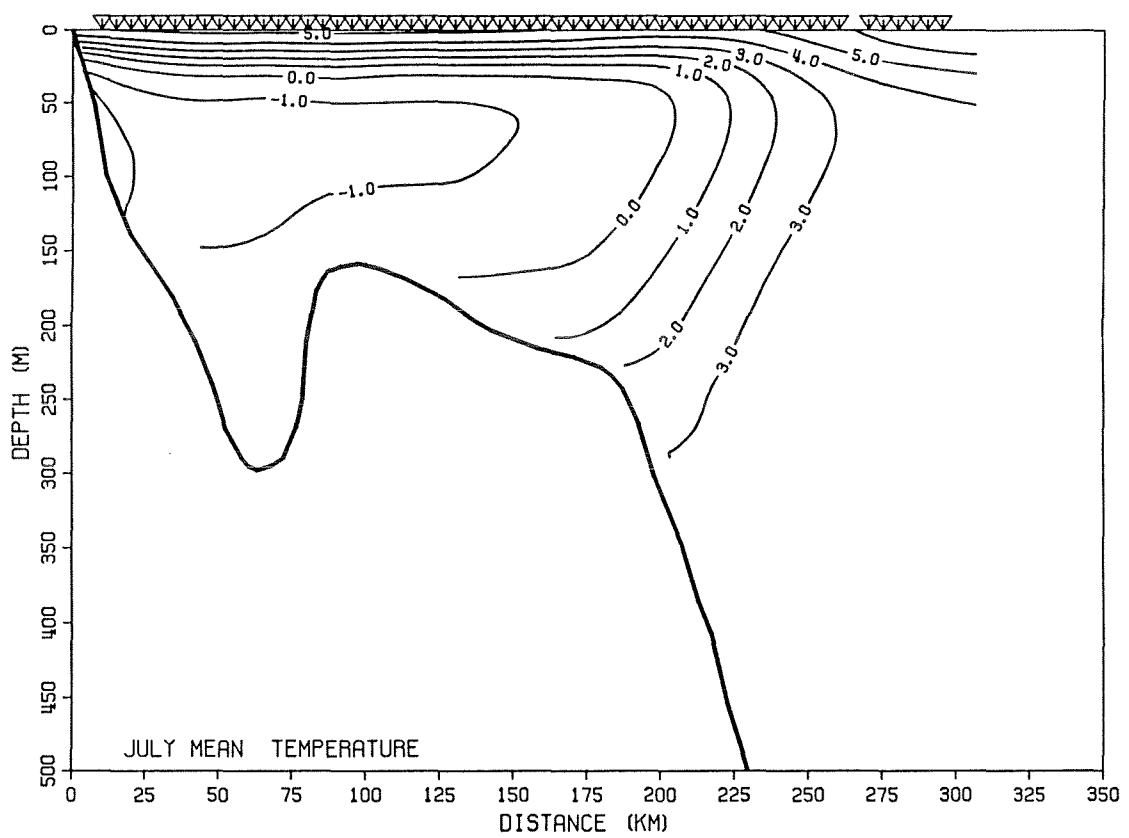
APPENDIX B. The monthly average vertical distributions of temperature.

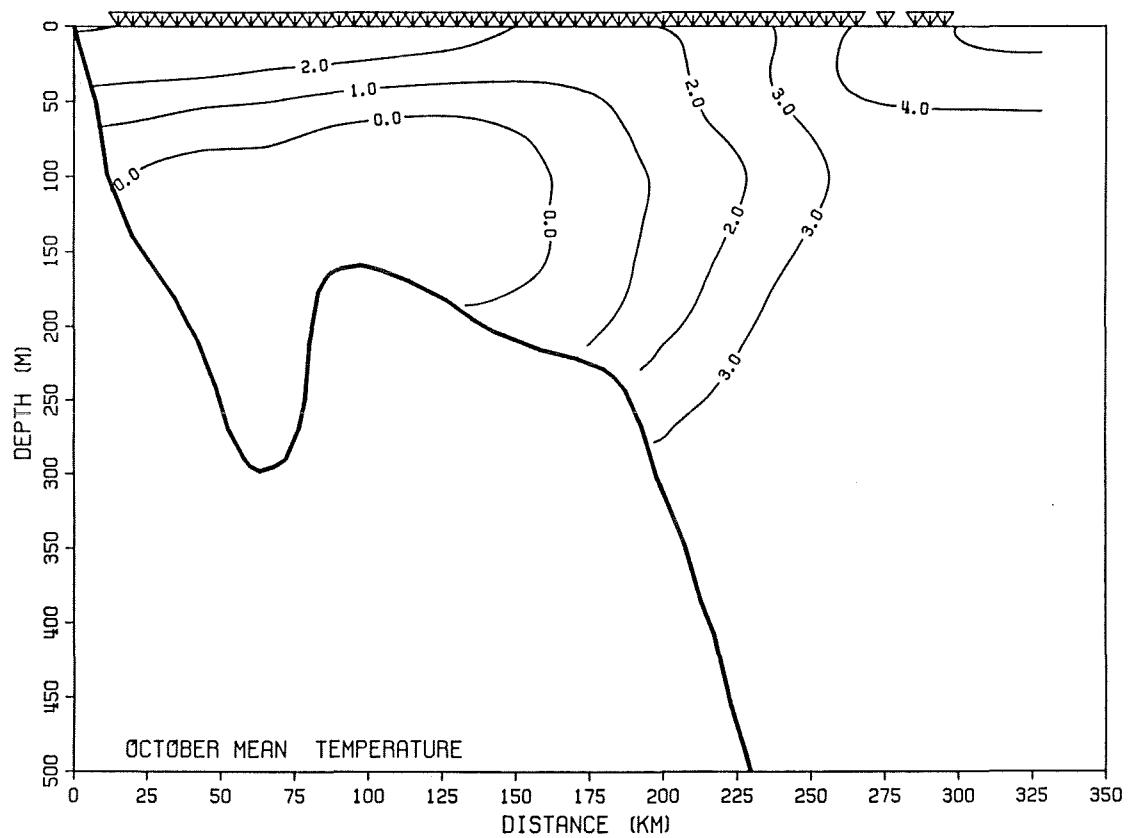
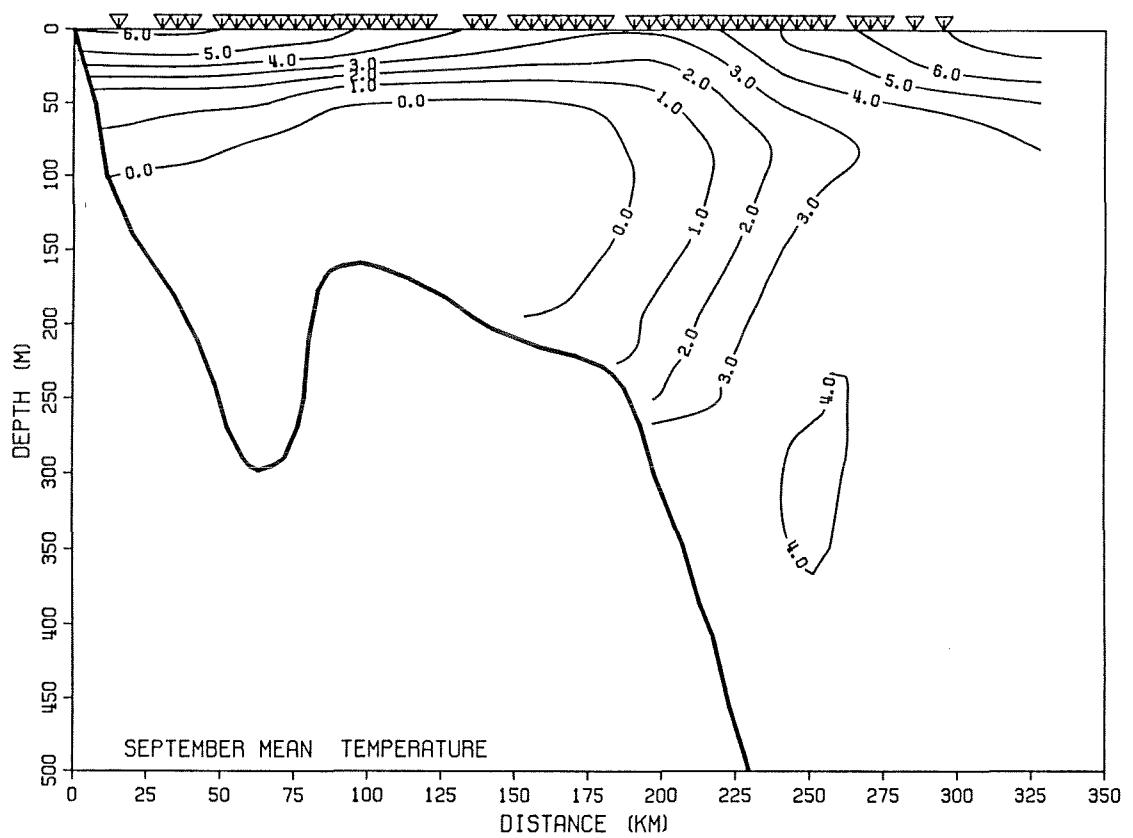


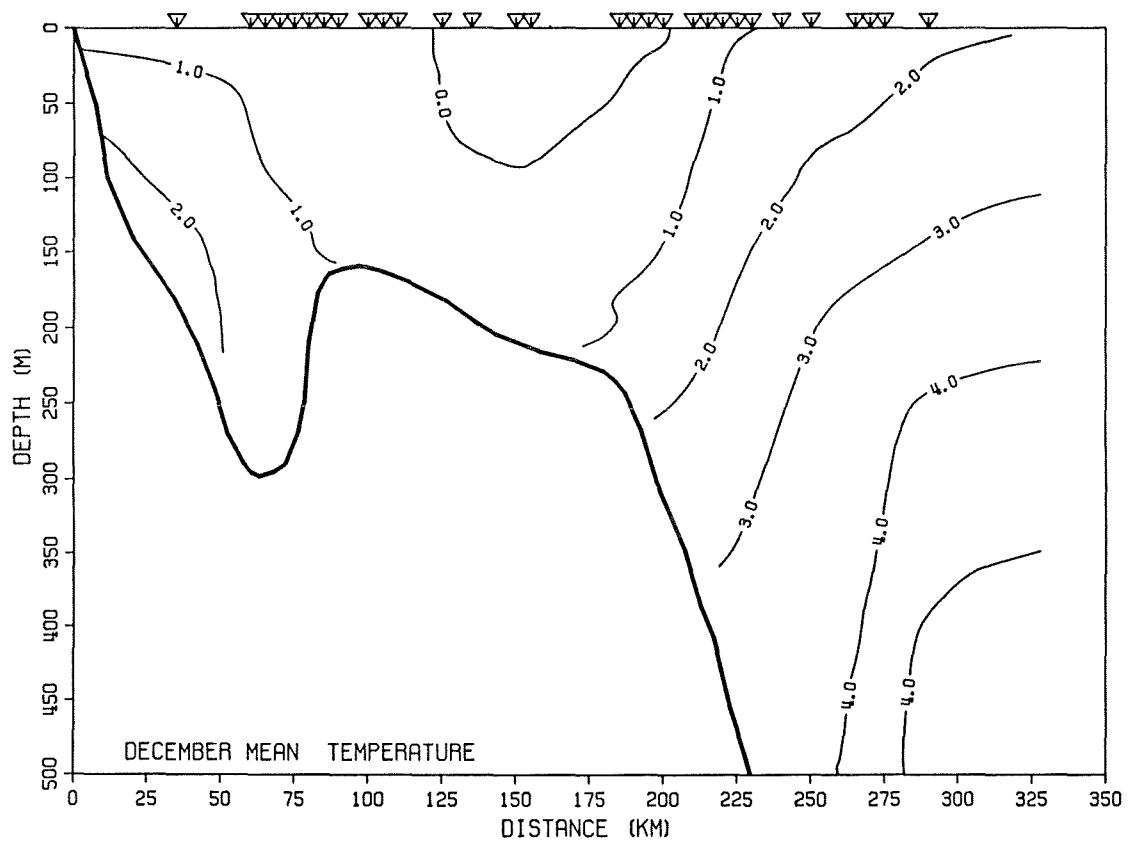
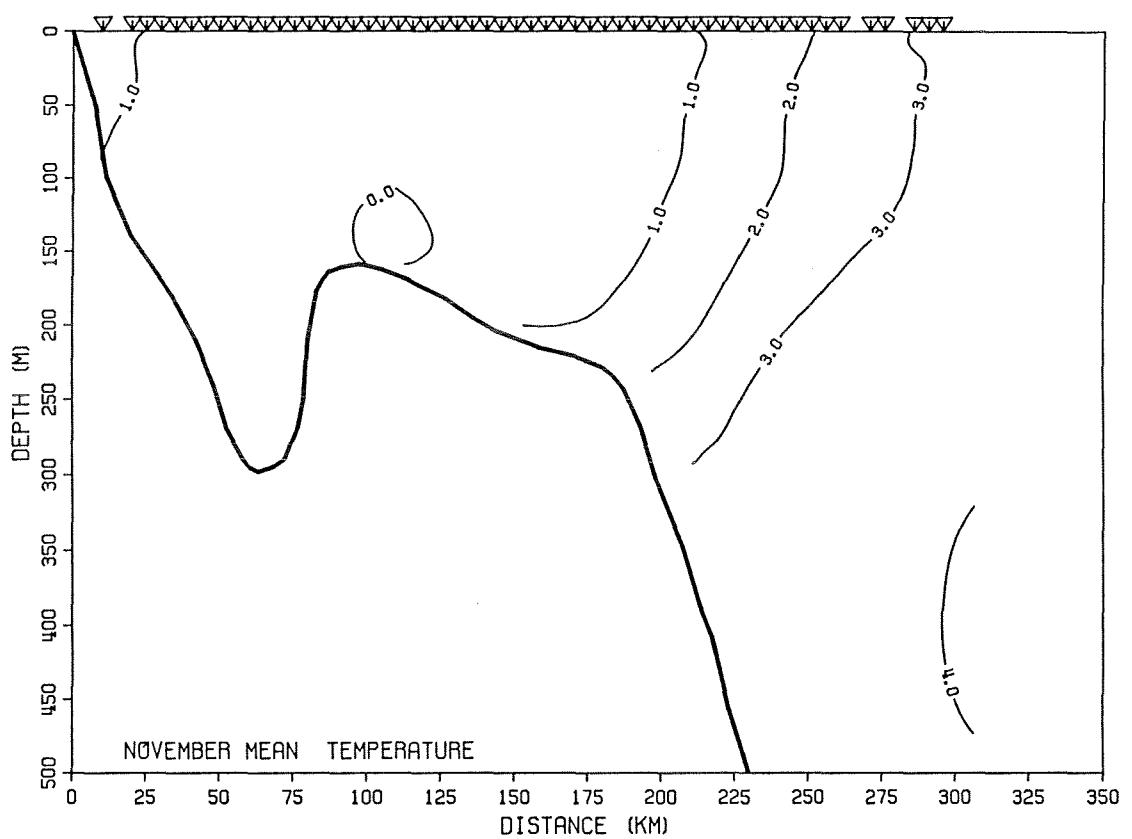




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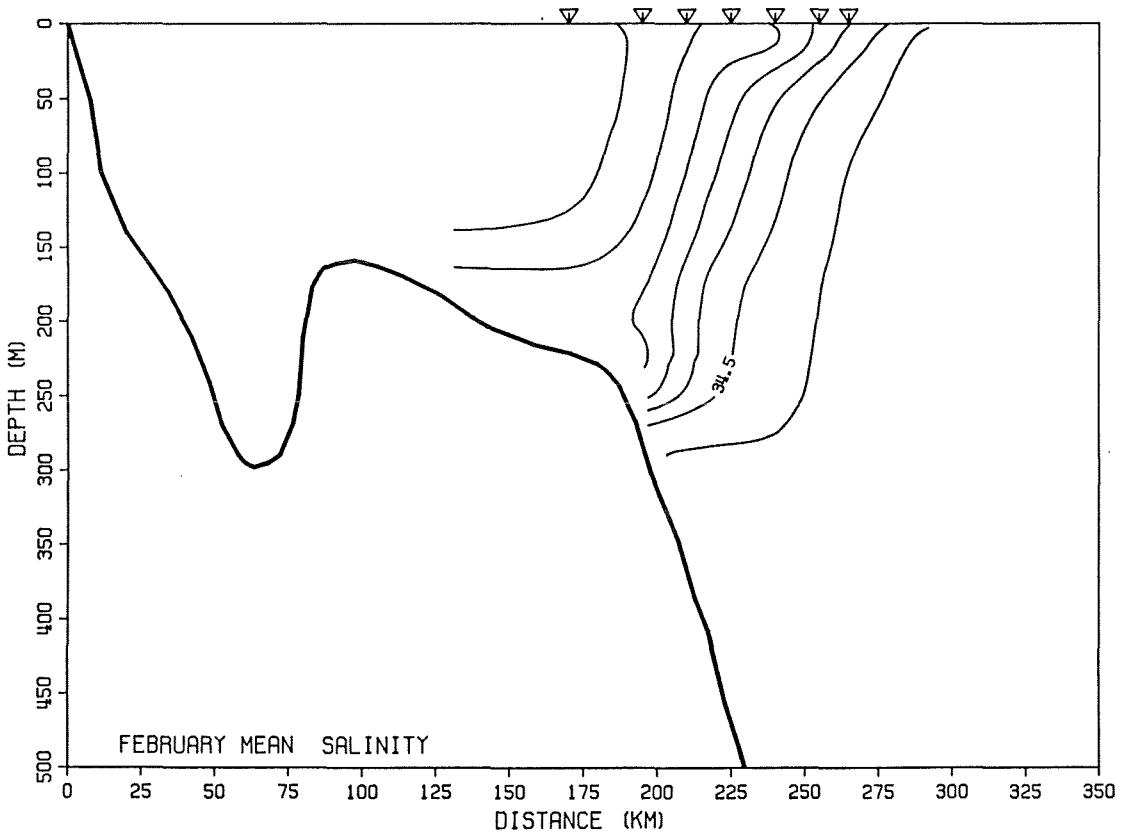
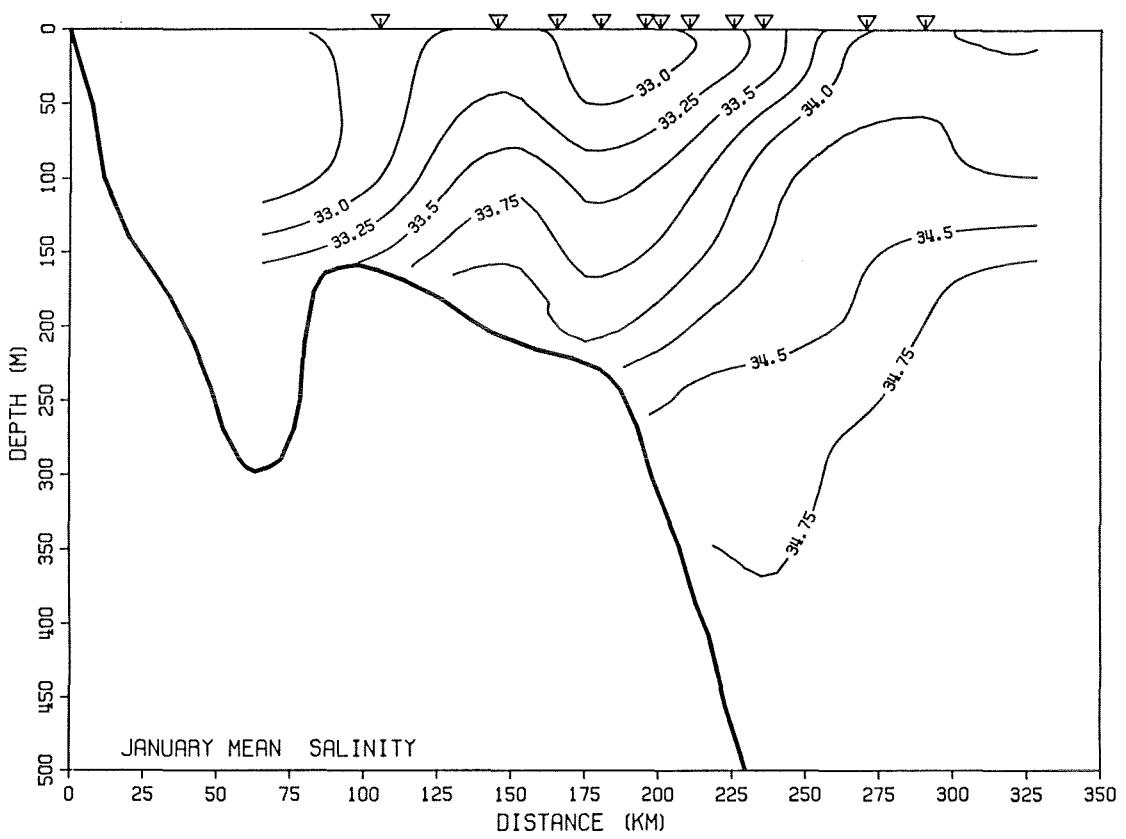


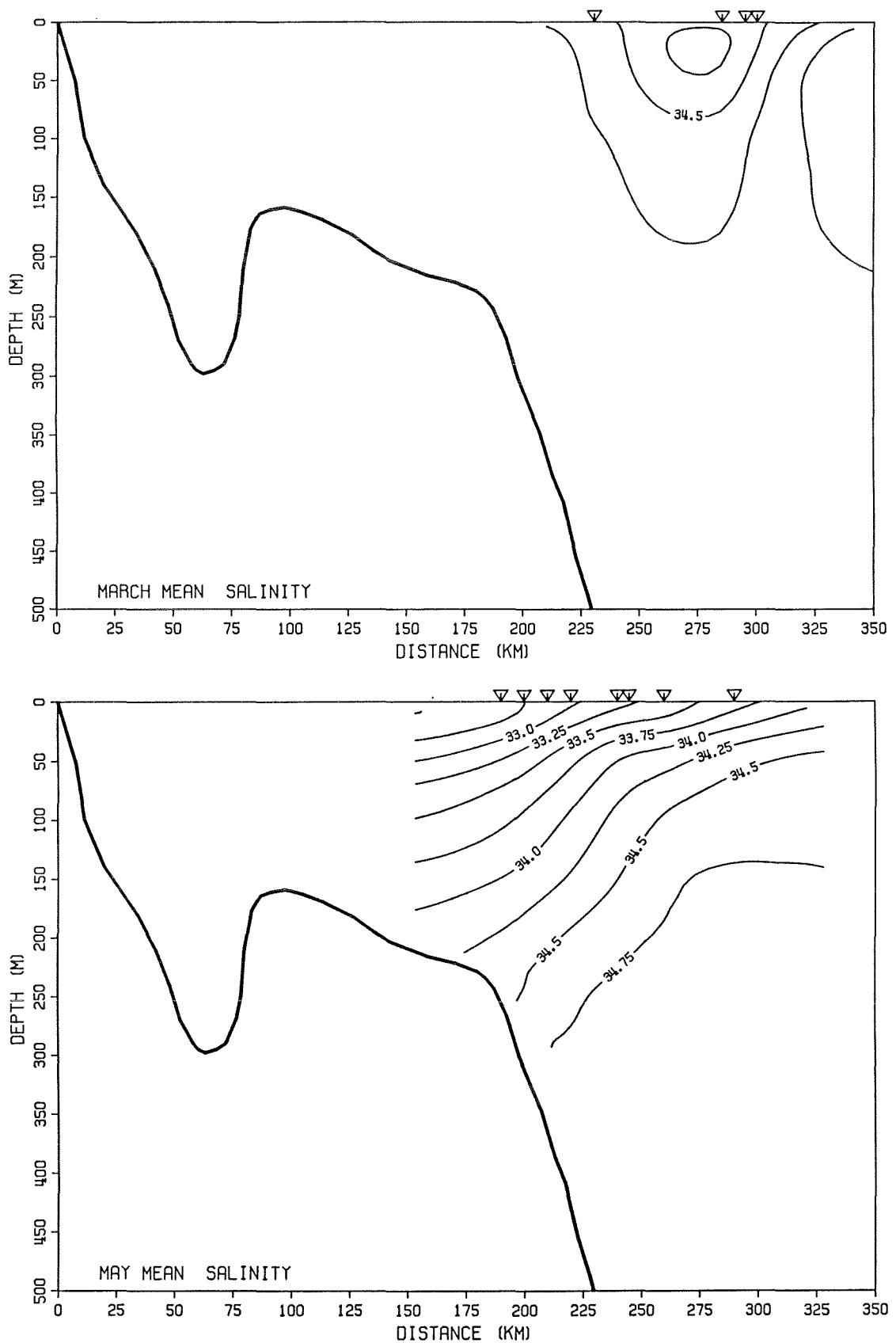


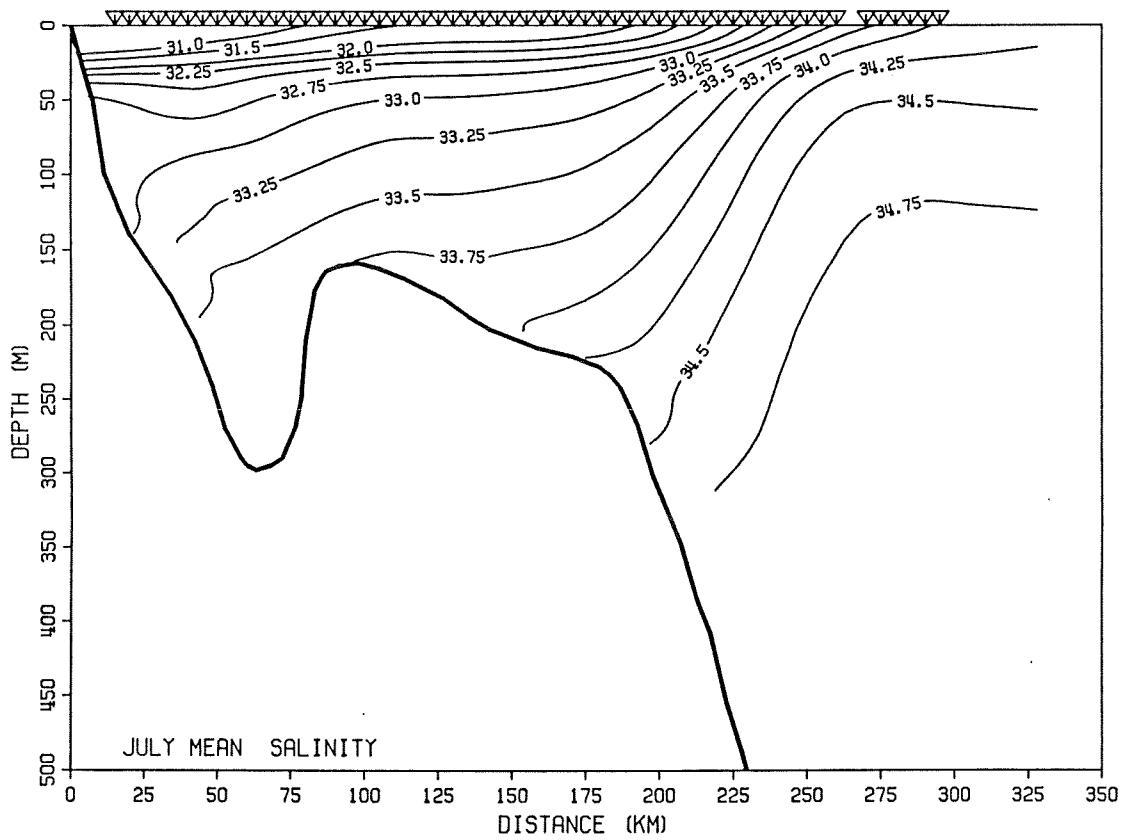
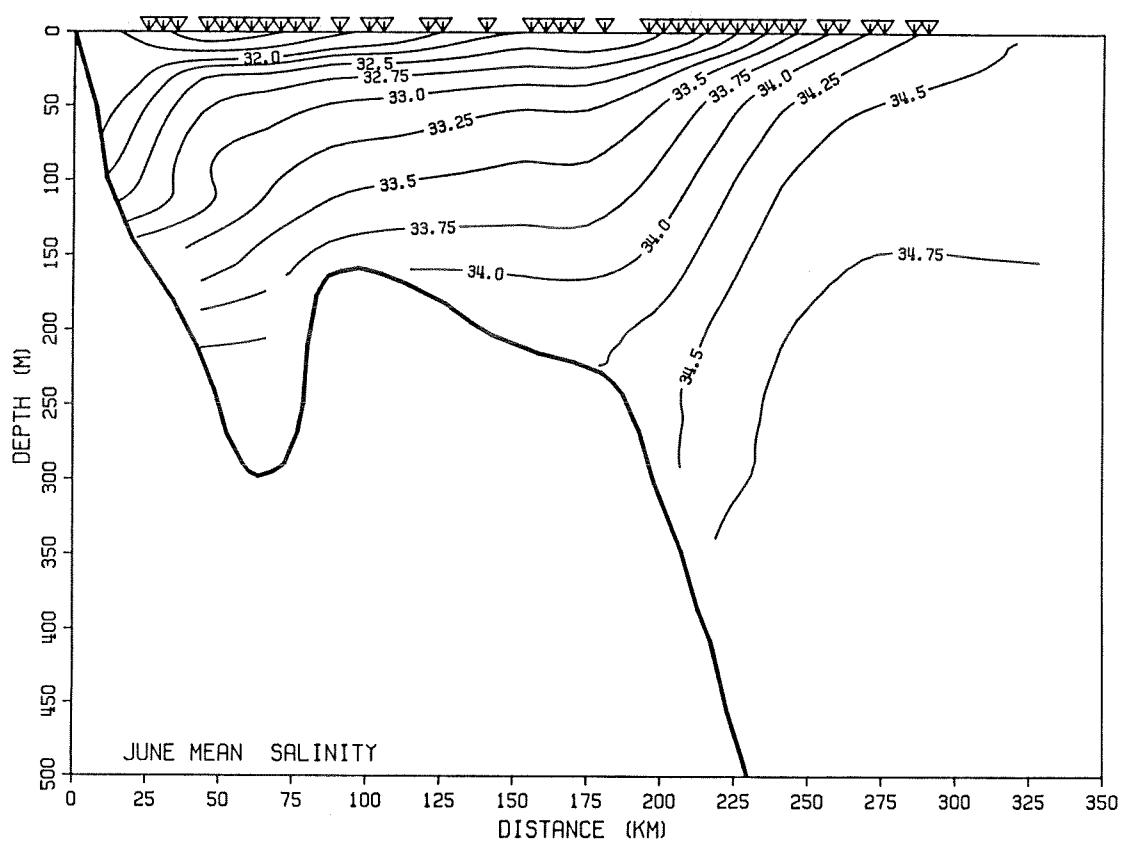


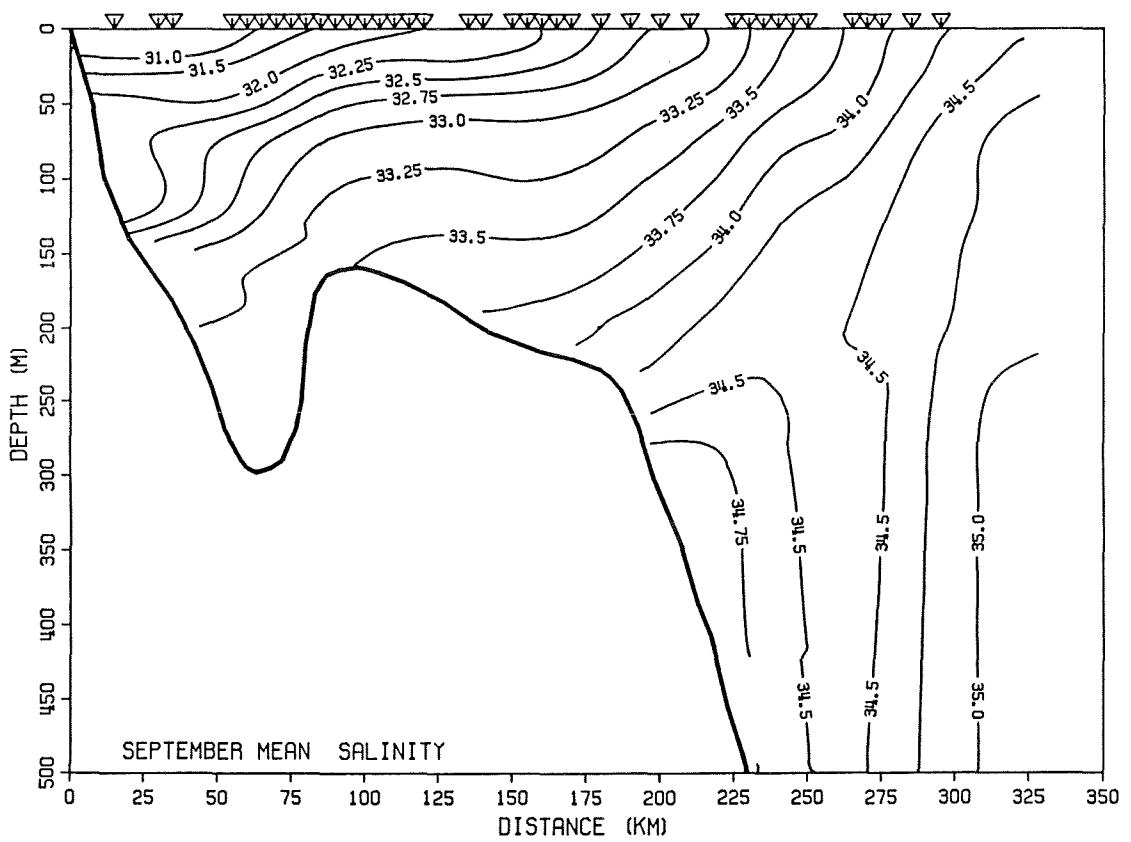
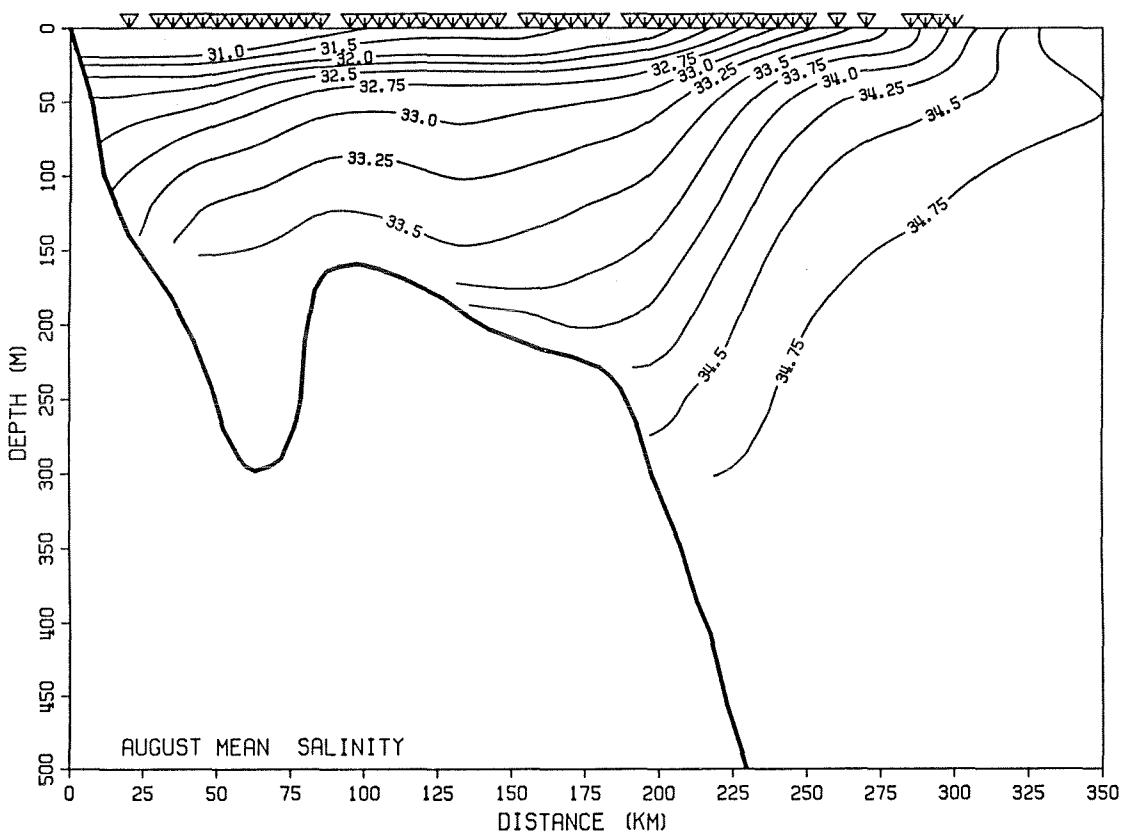
APPENDIX C. The monthly average vertical distributions of salinity.

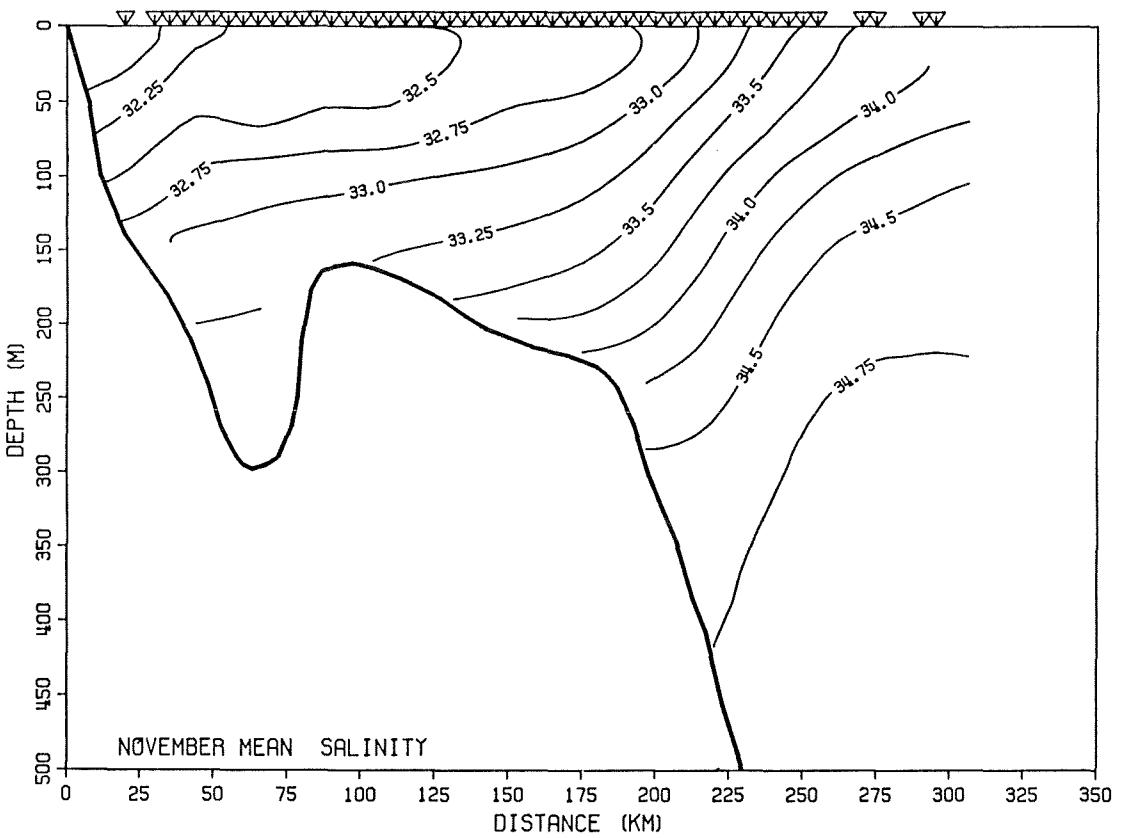
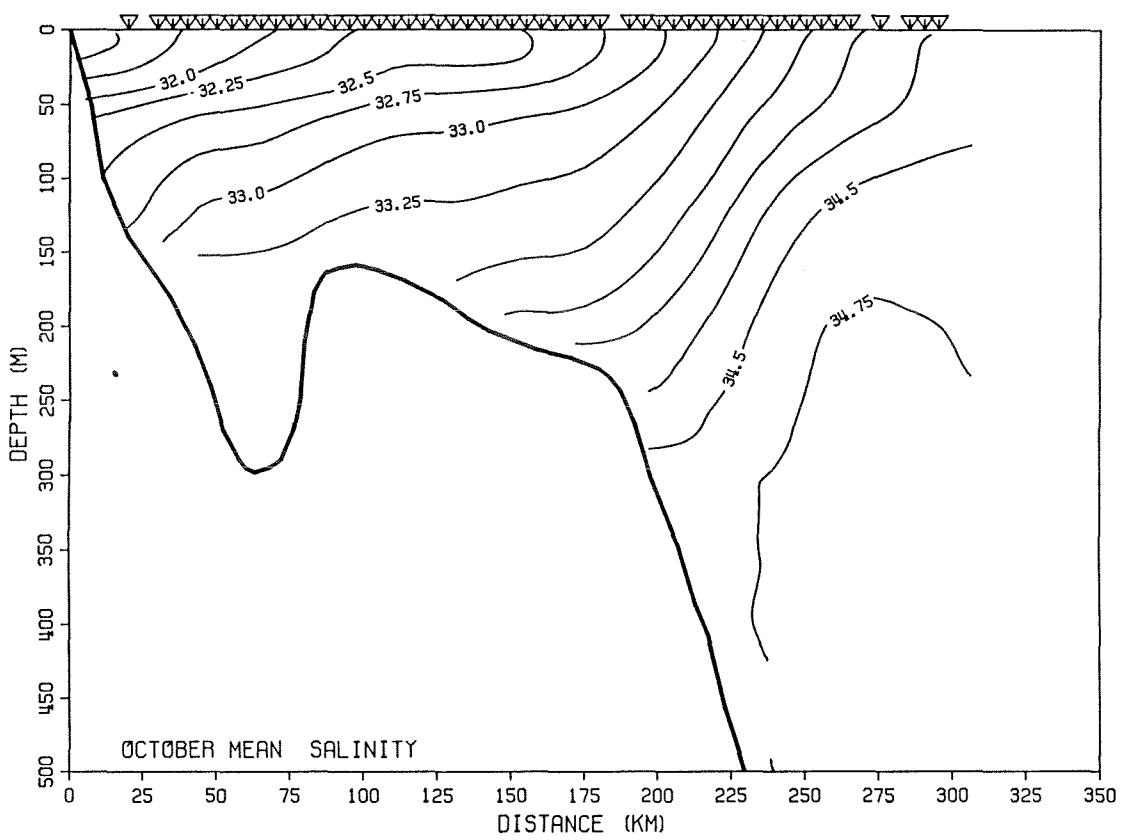
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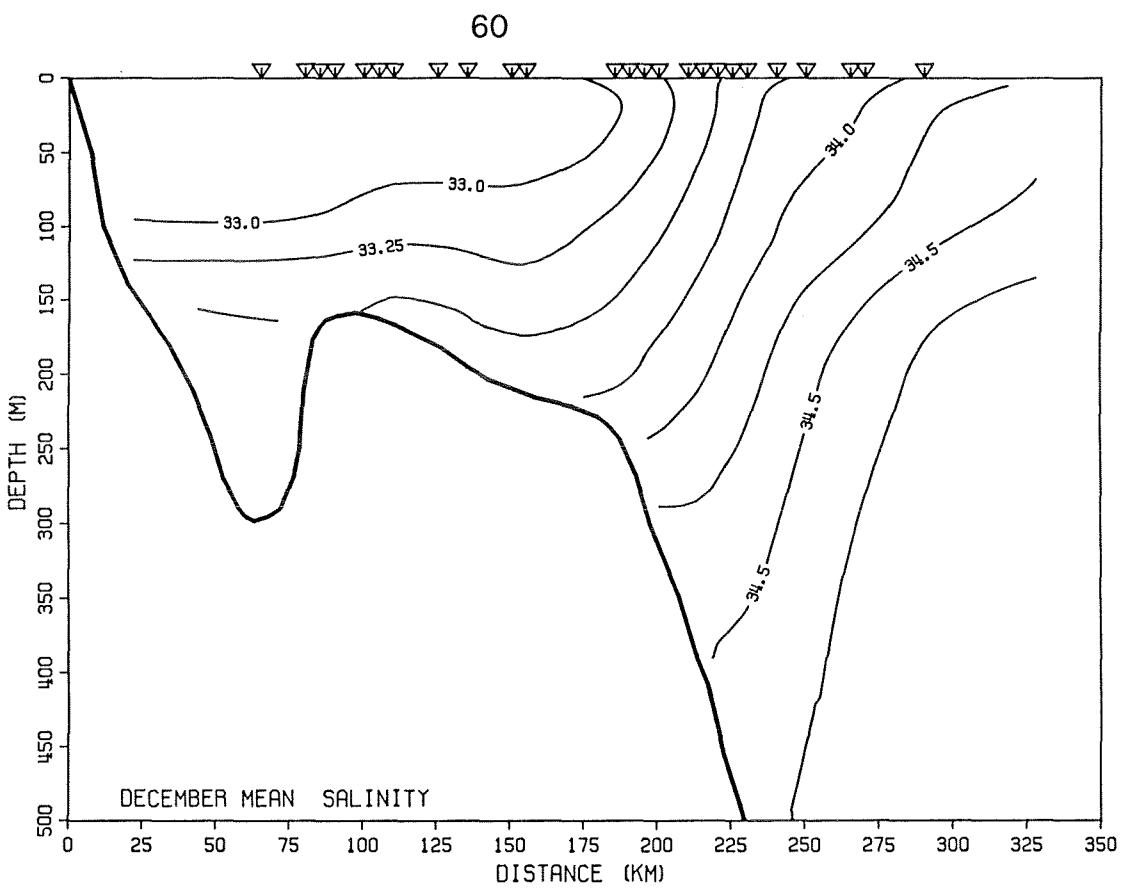




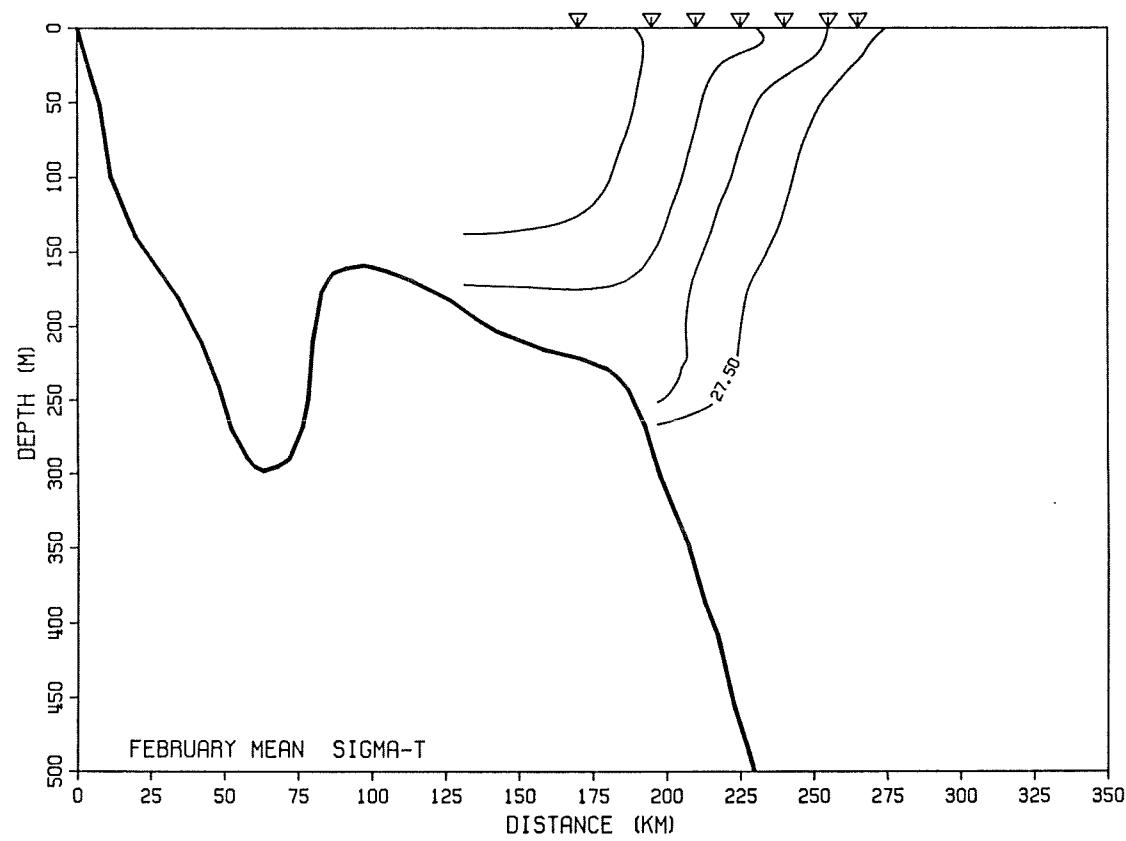
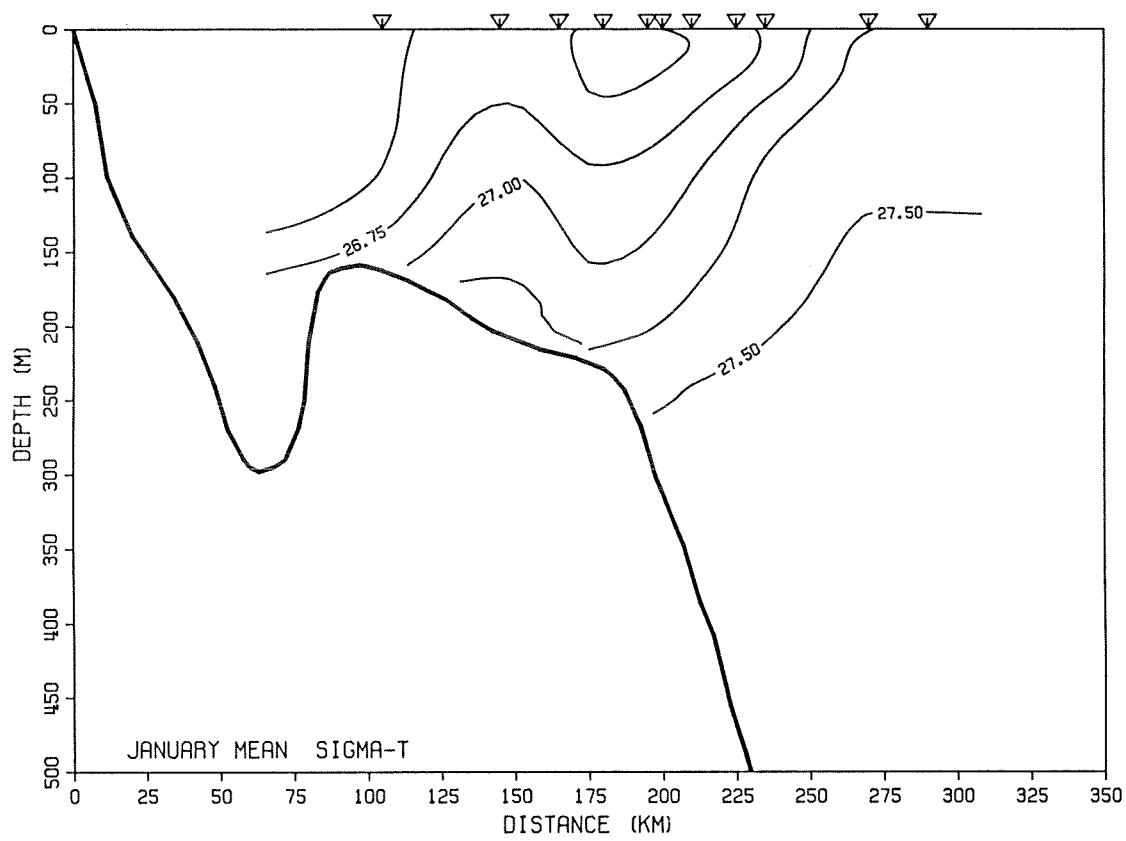


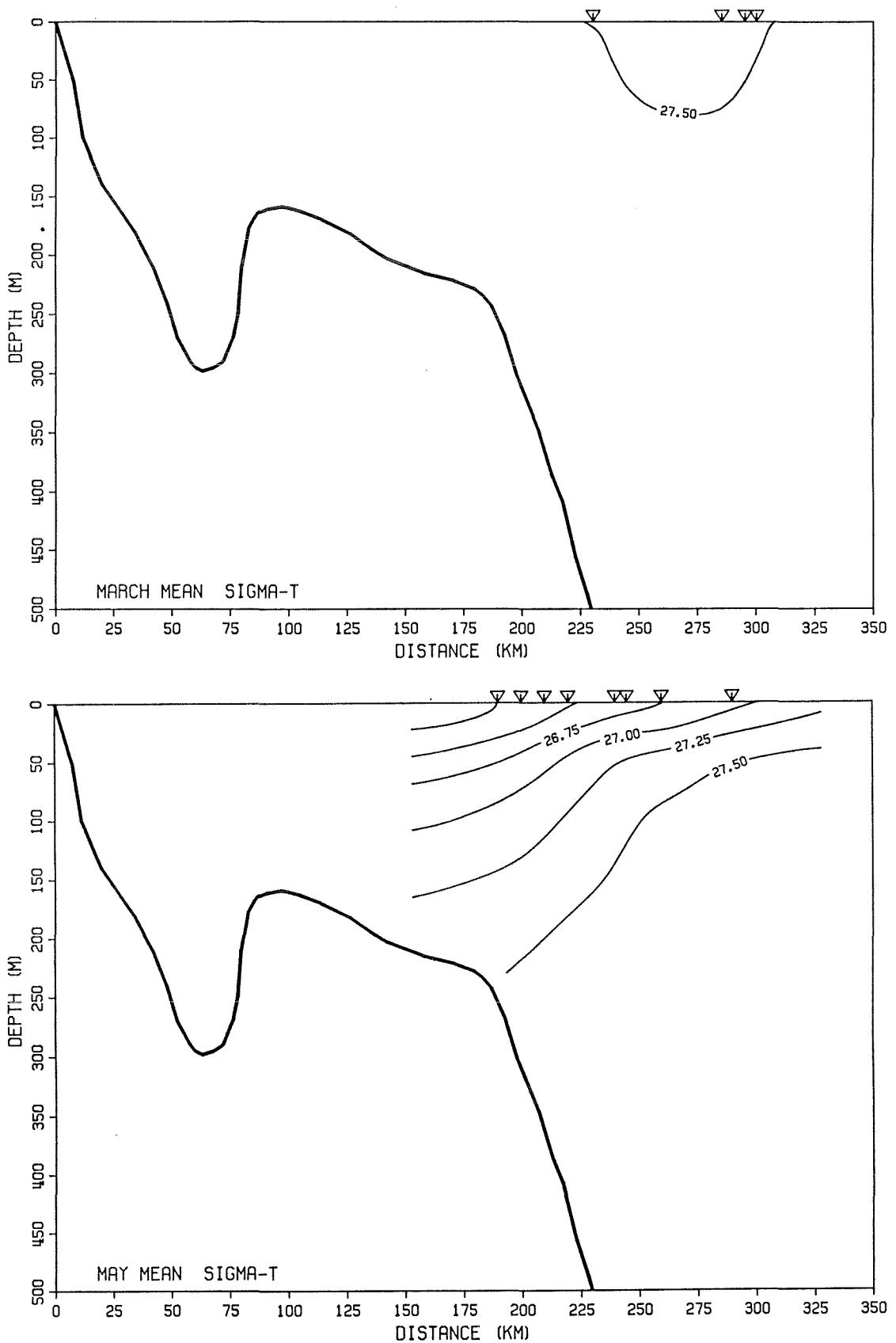




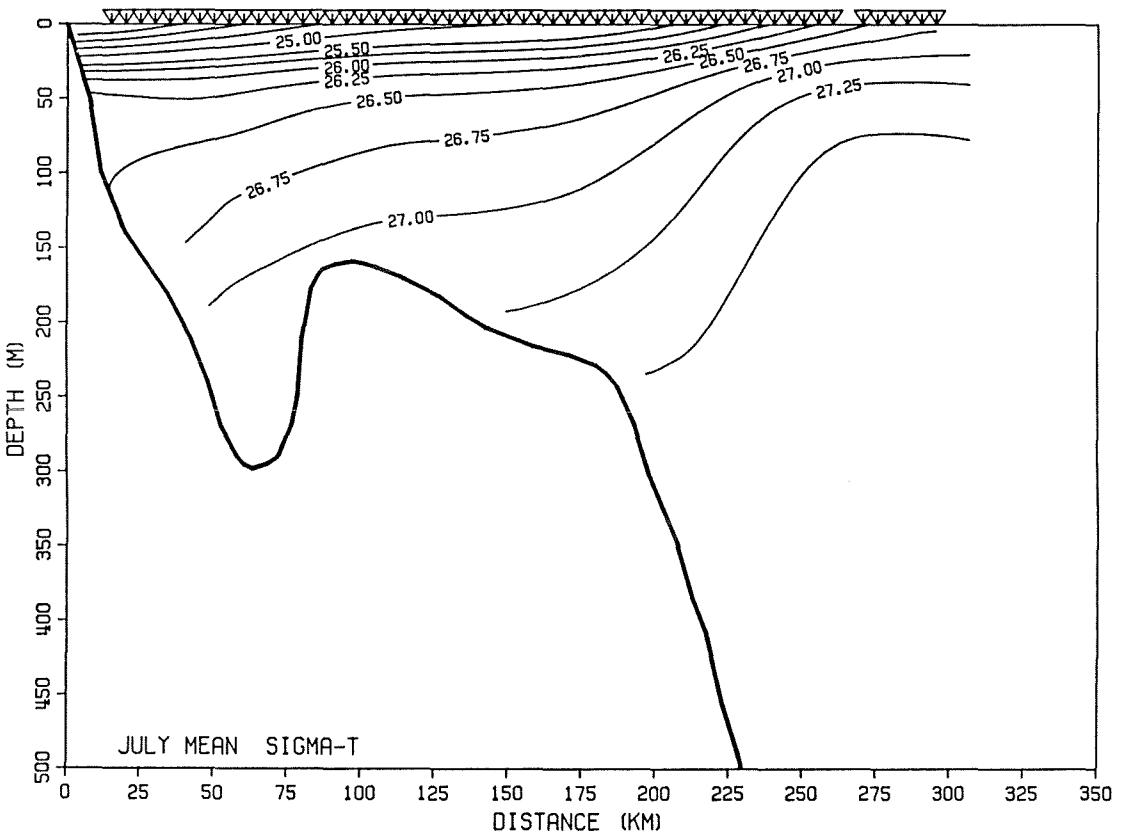
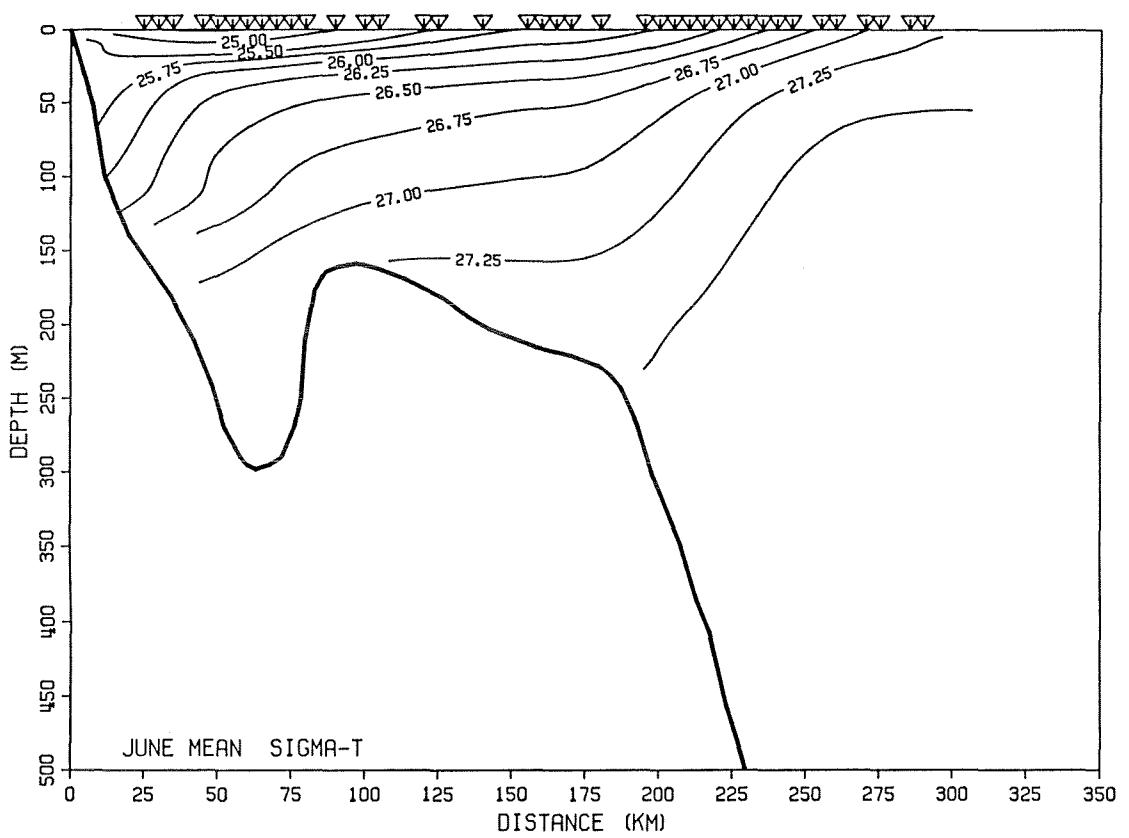


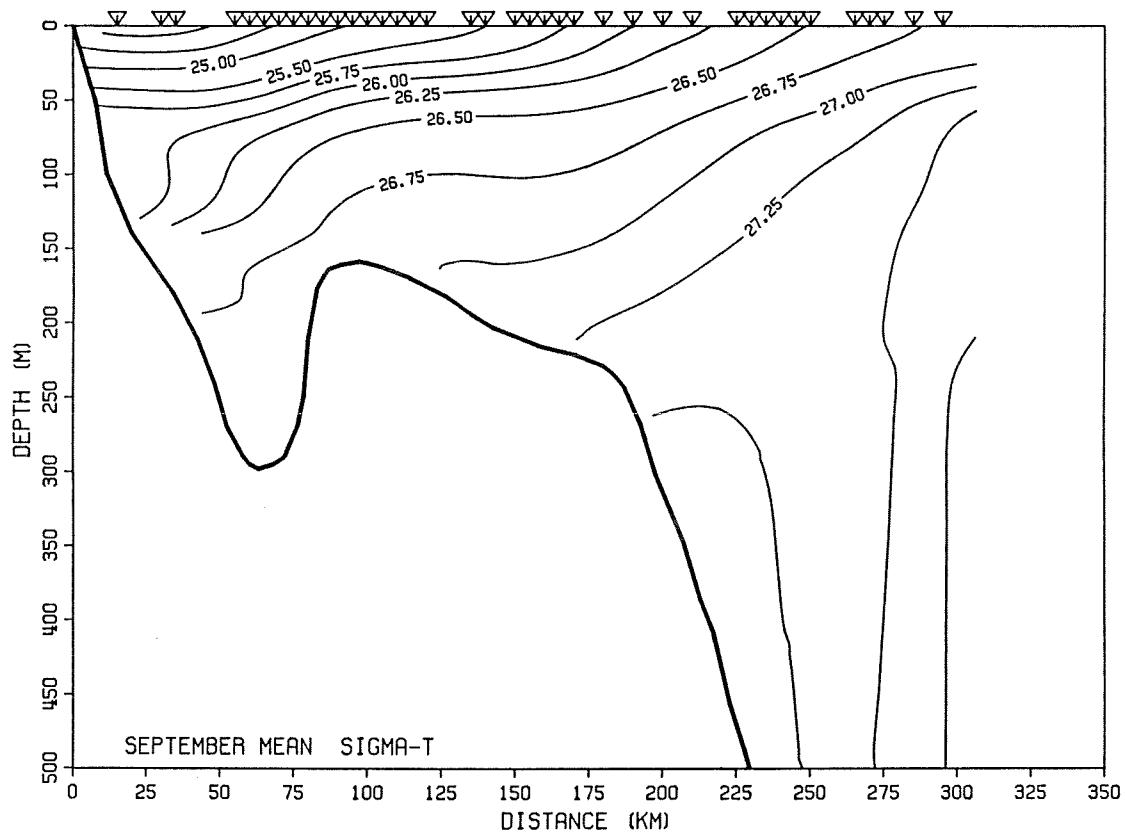
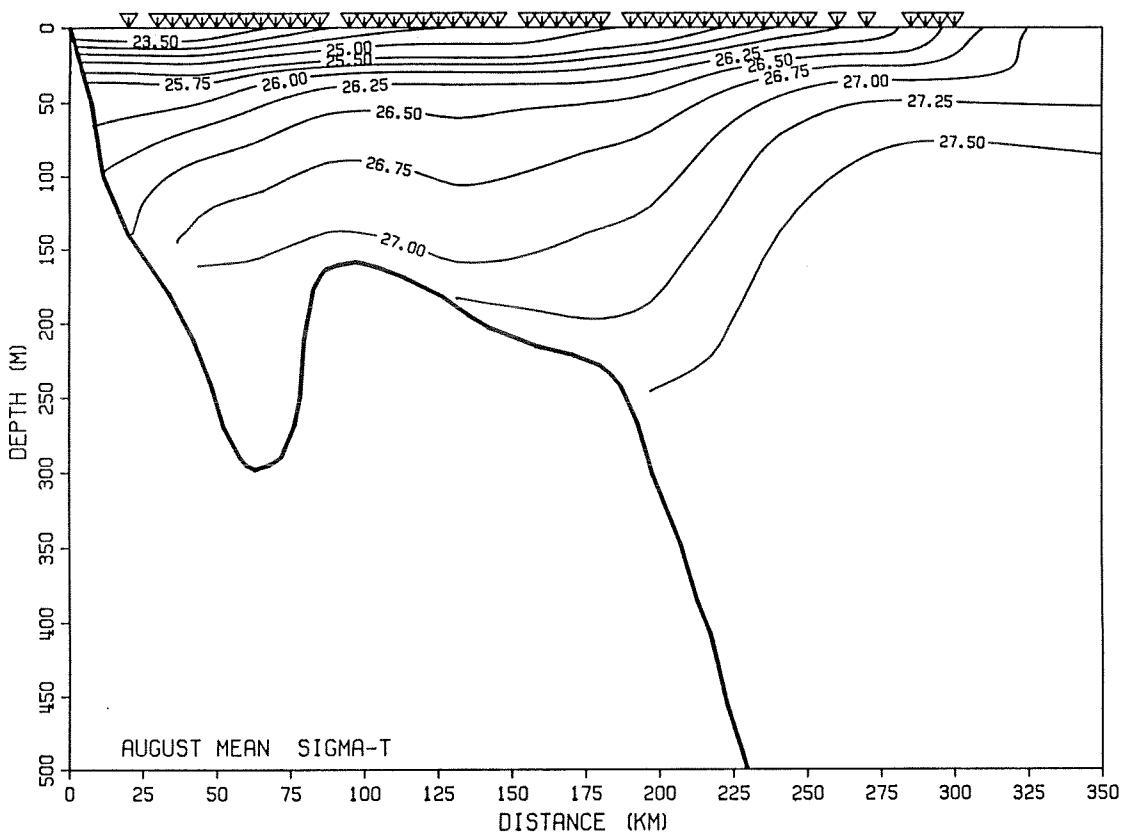
APPENDIX D. The monthly average vertical distributions of density.

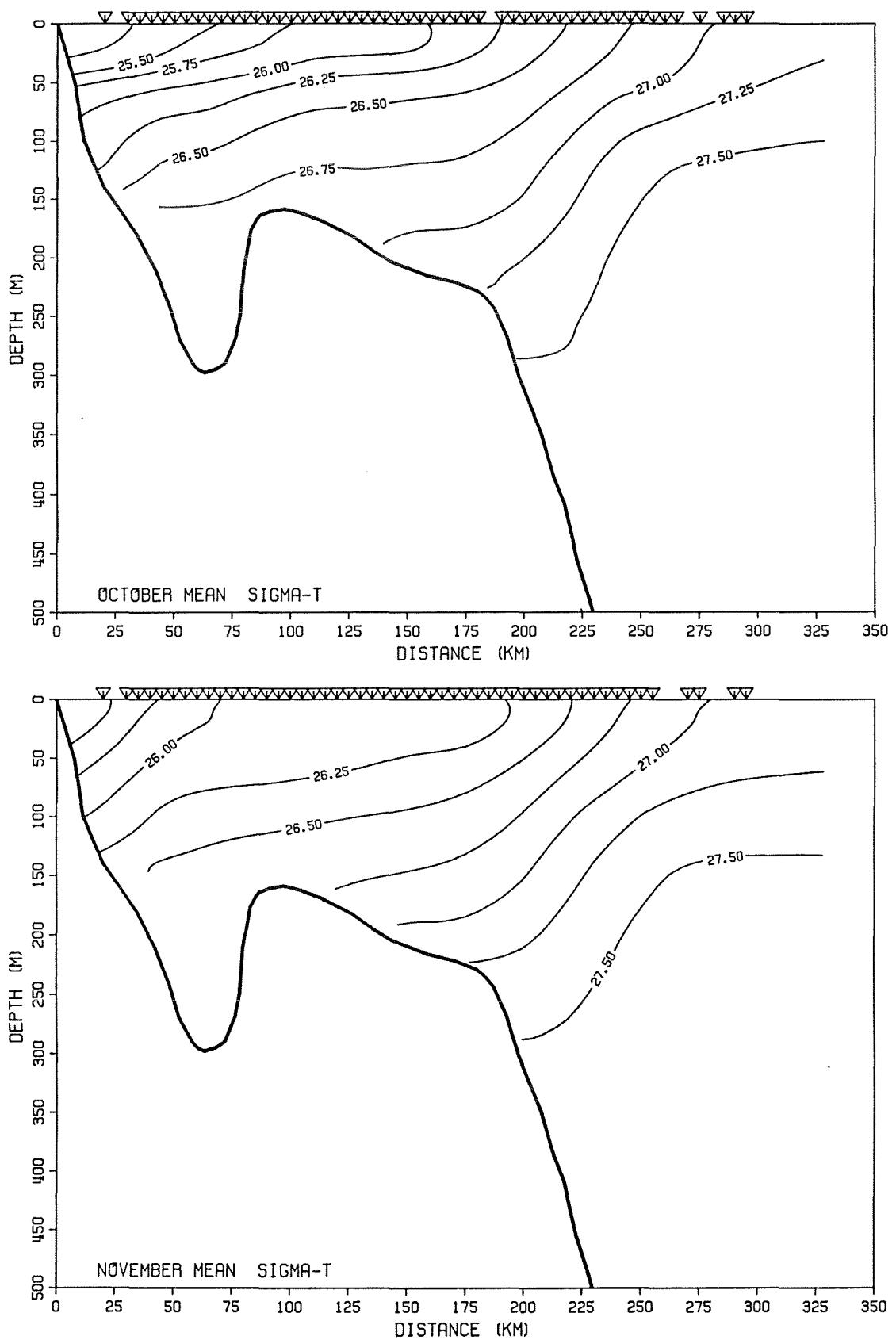


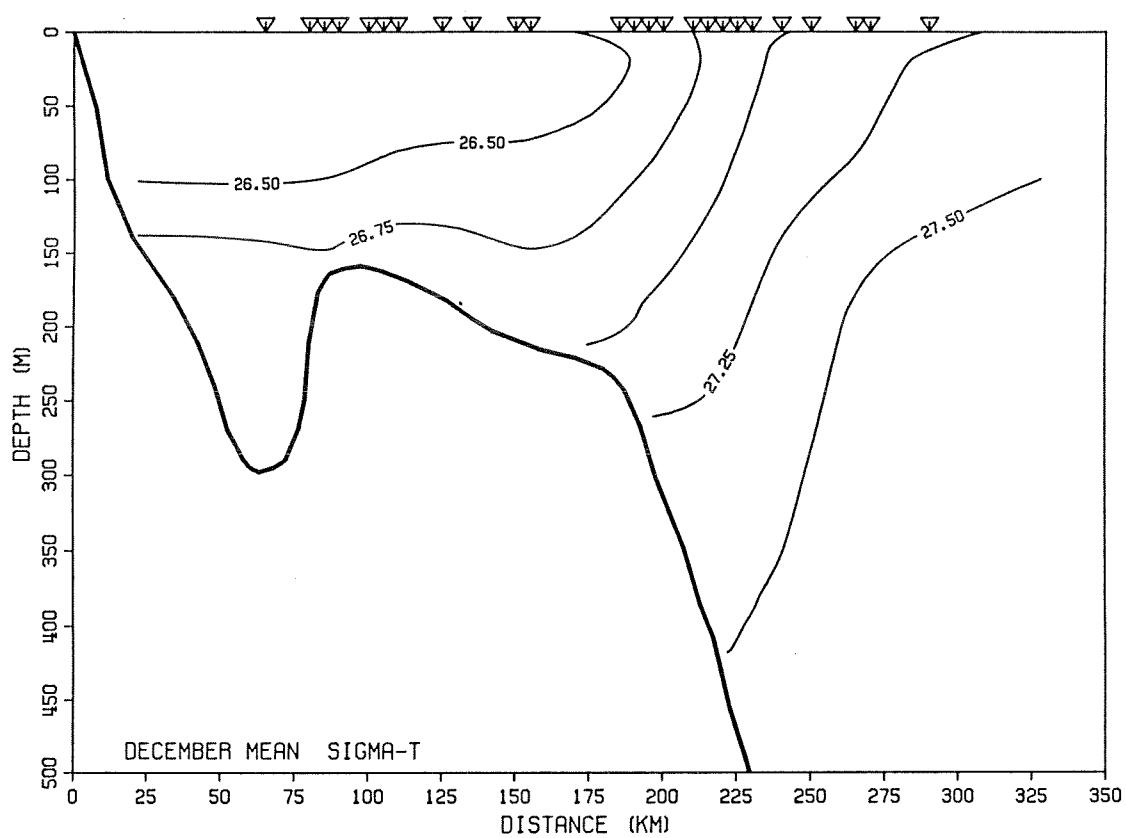


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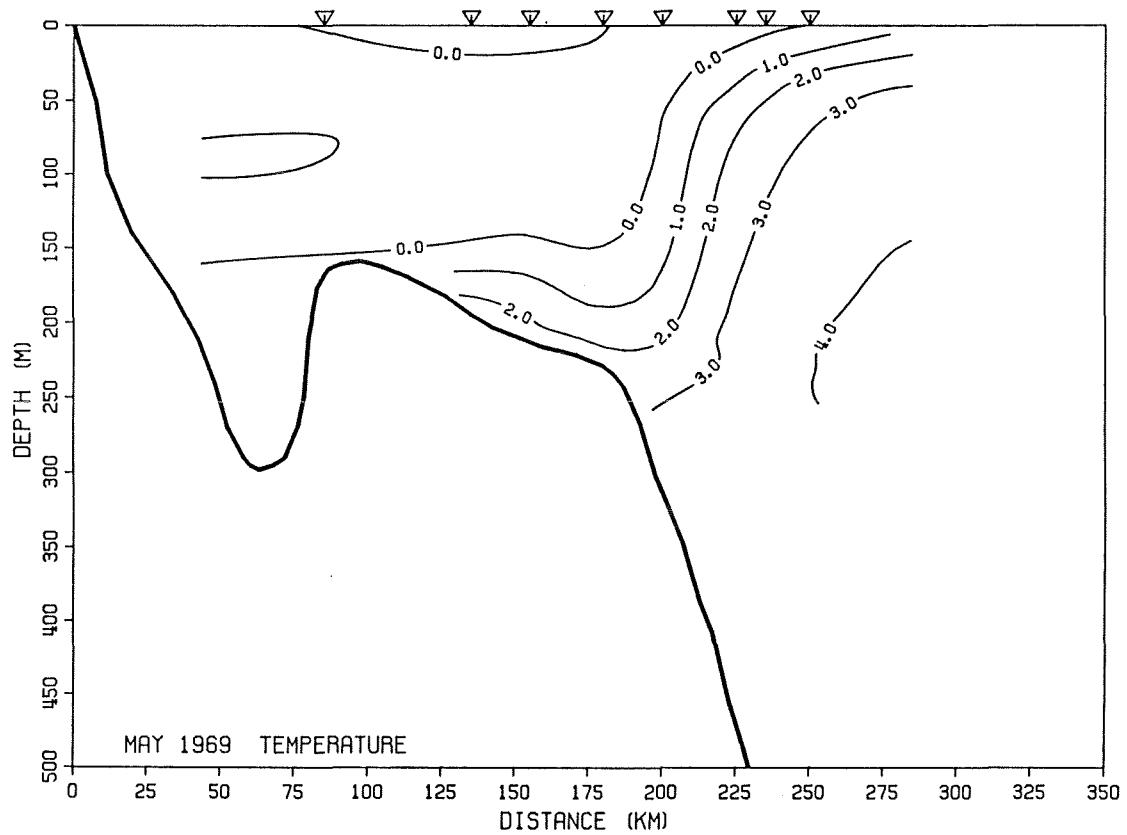
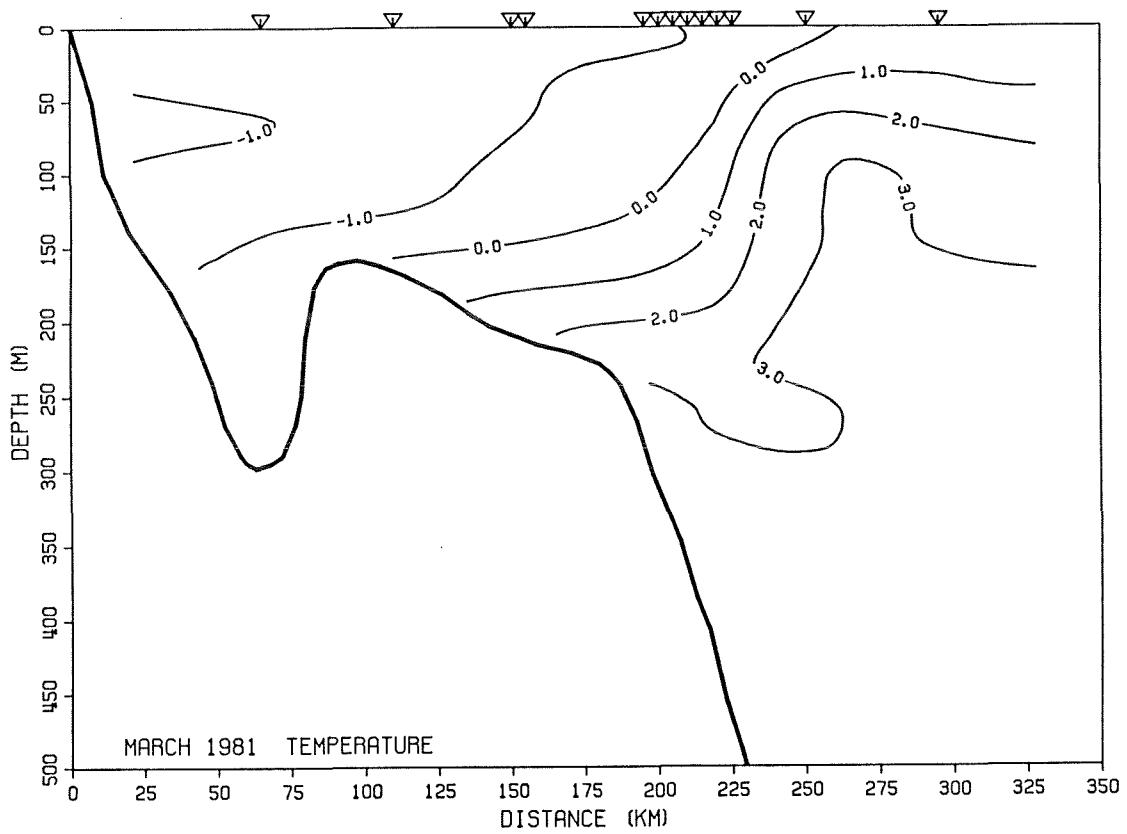


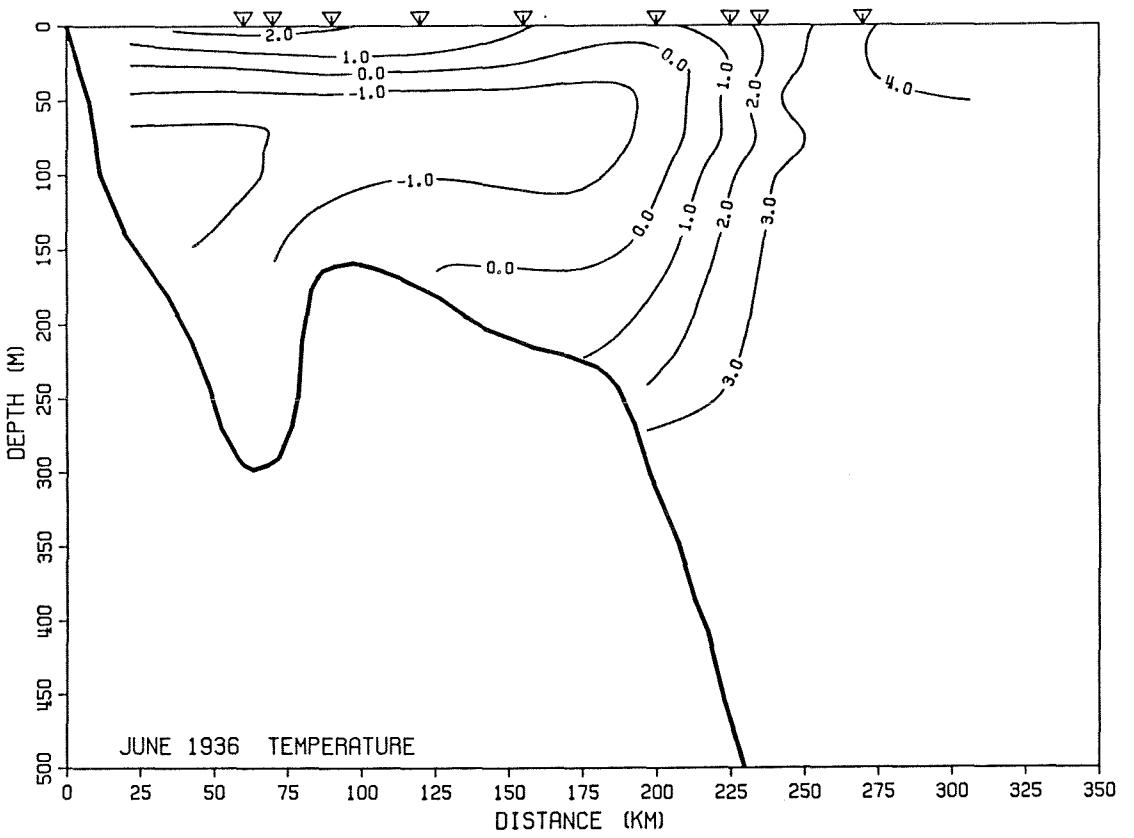
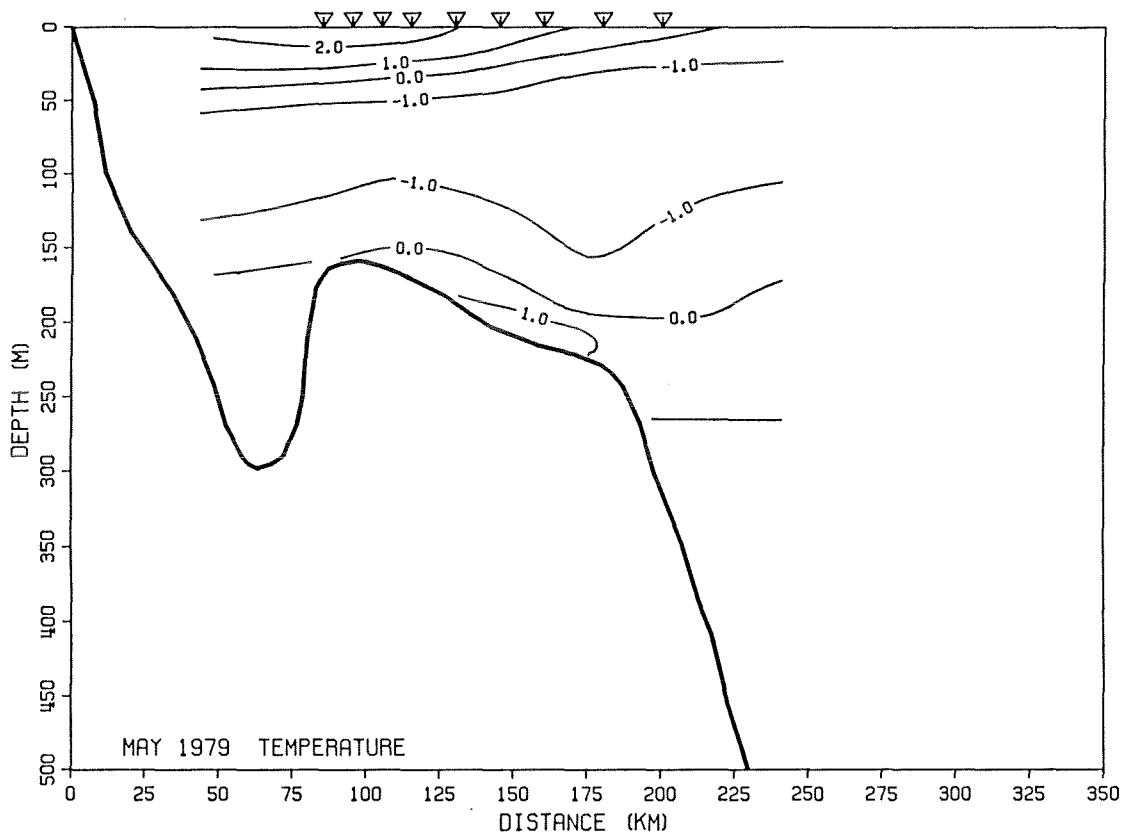


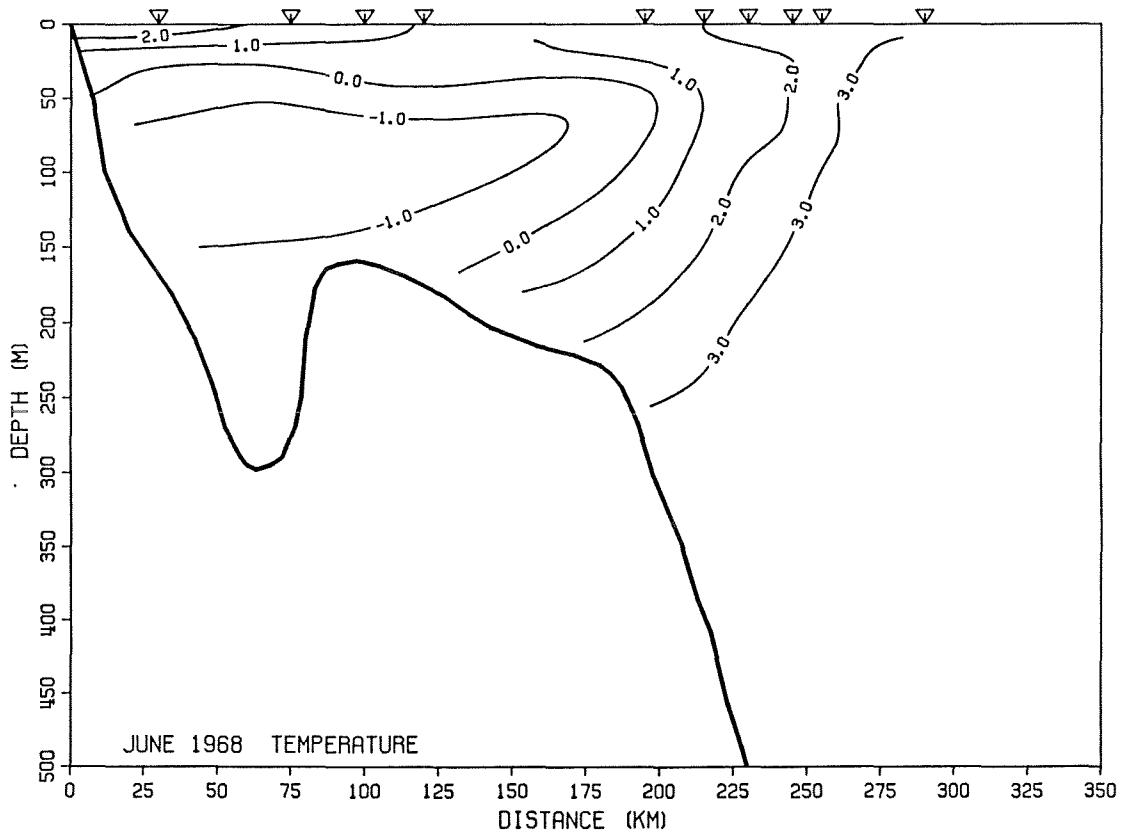
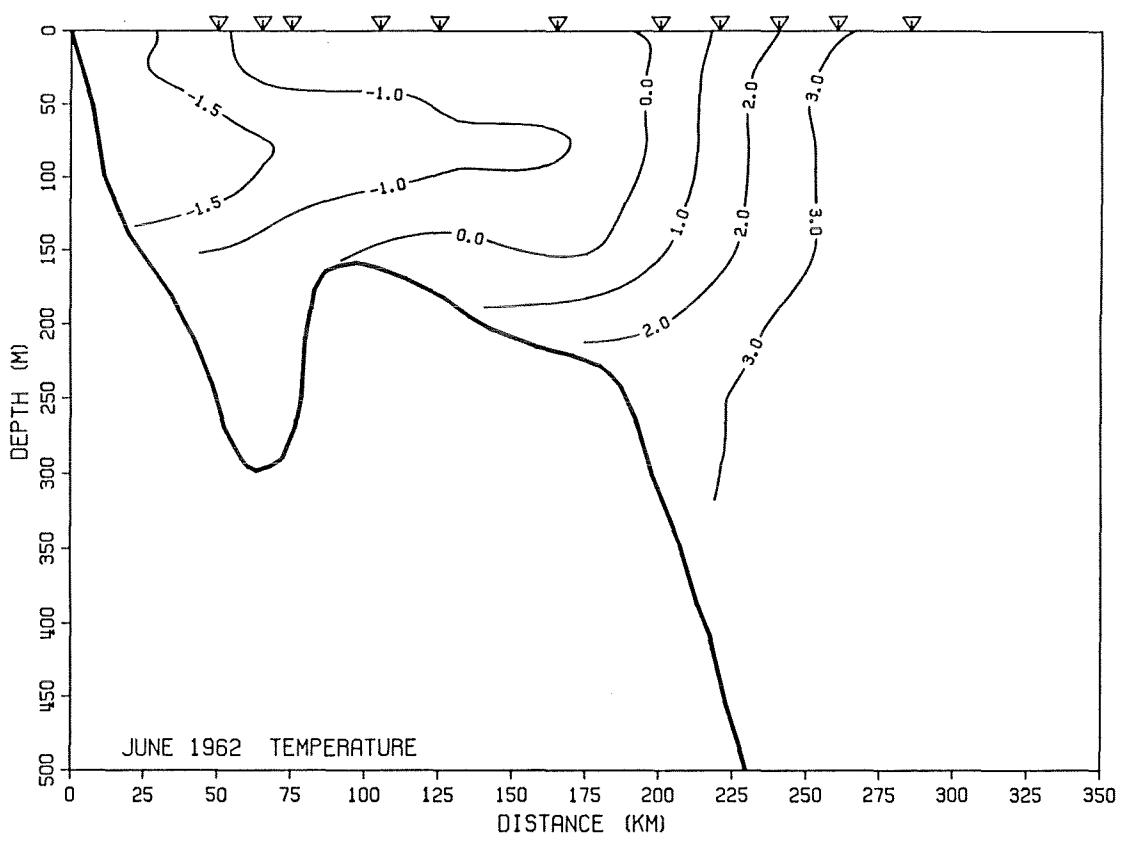




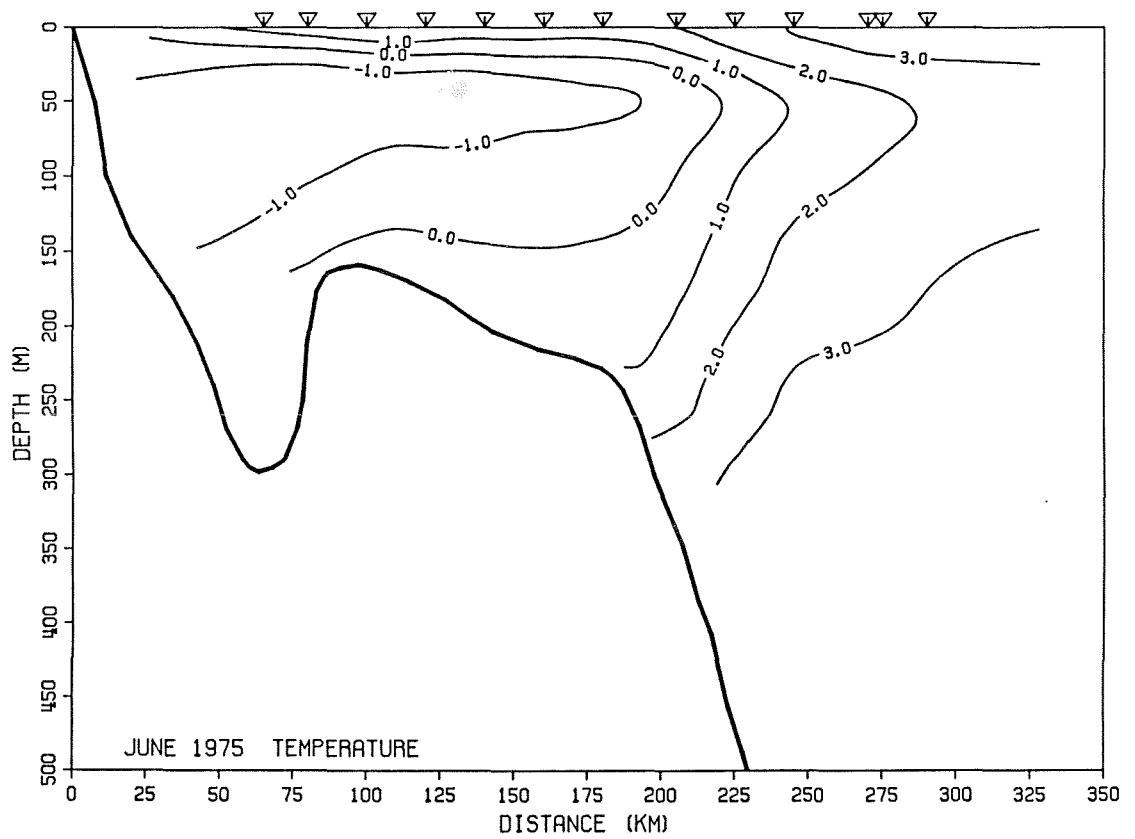
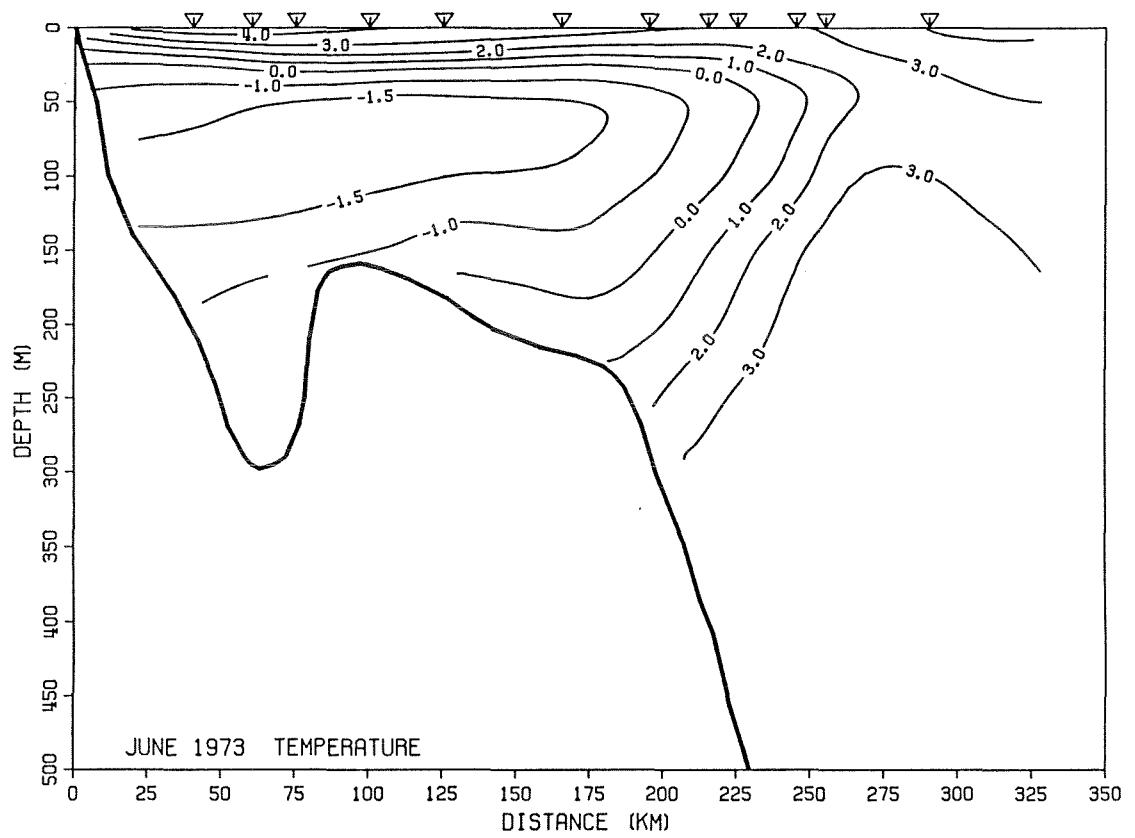
APPENDIX E. Seal Island Annual Temperature Transects.

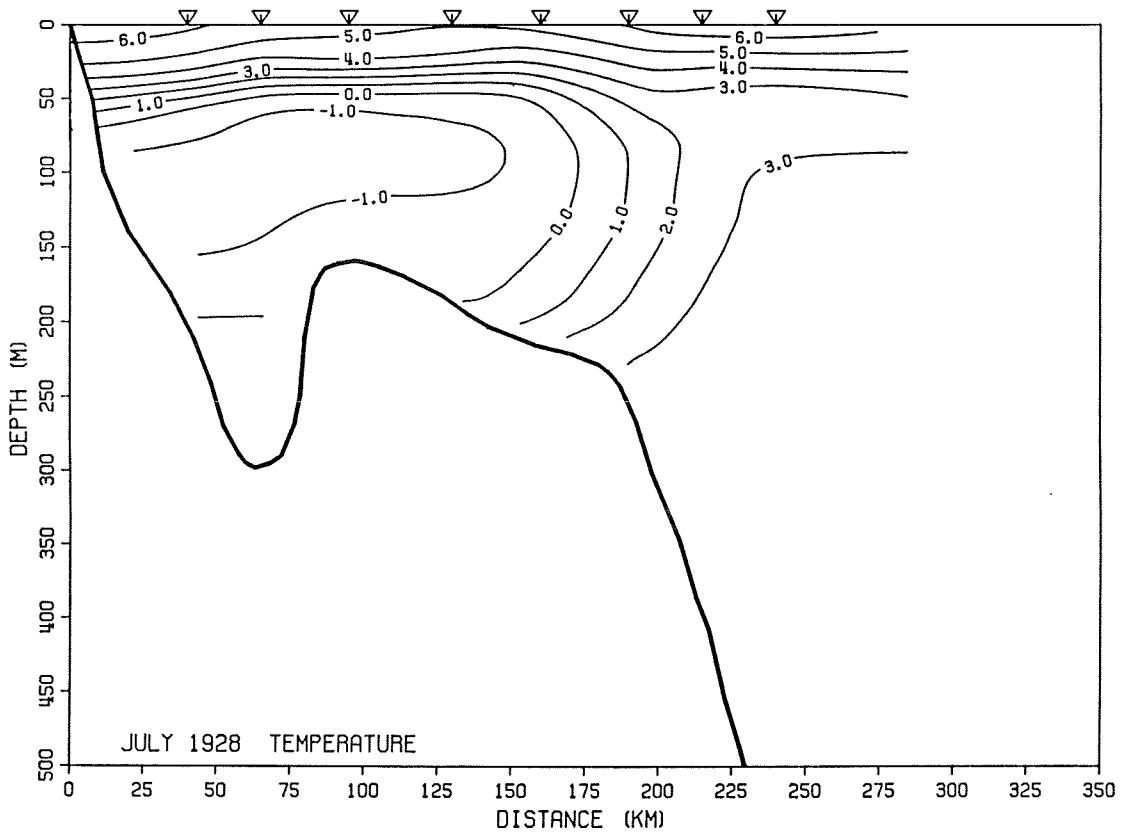
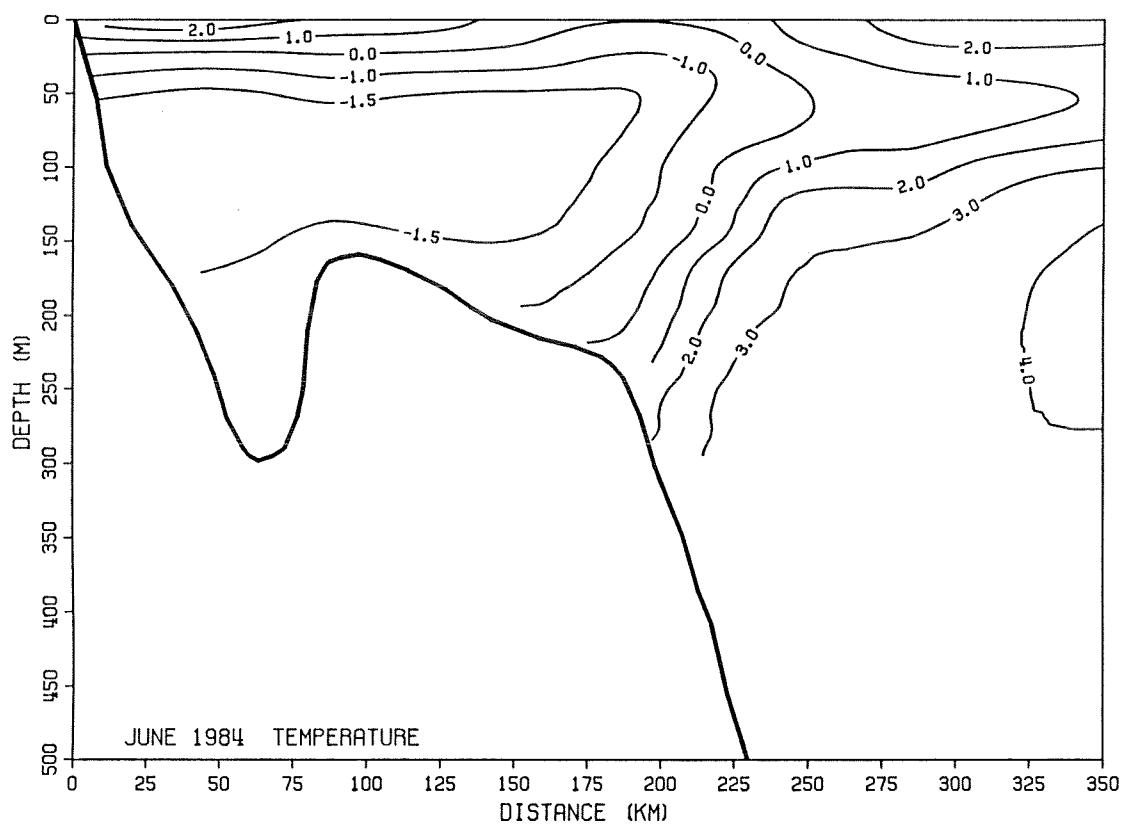


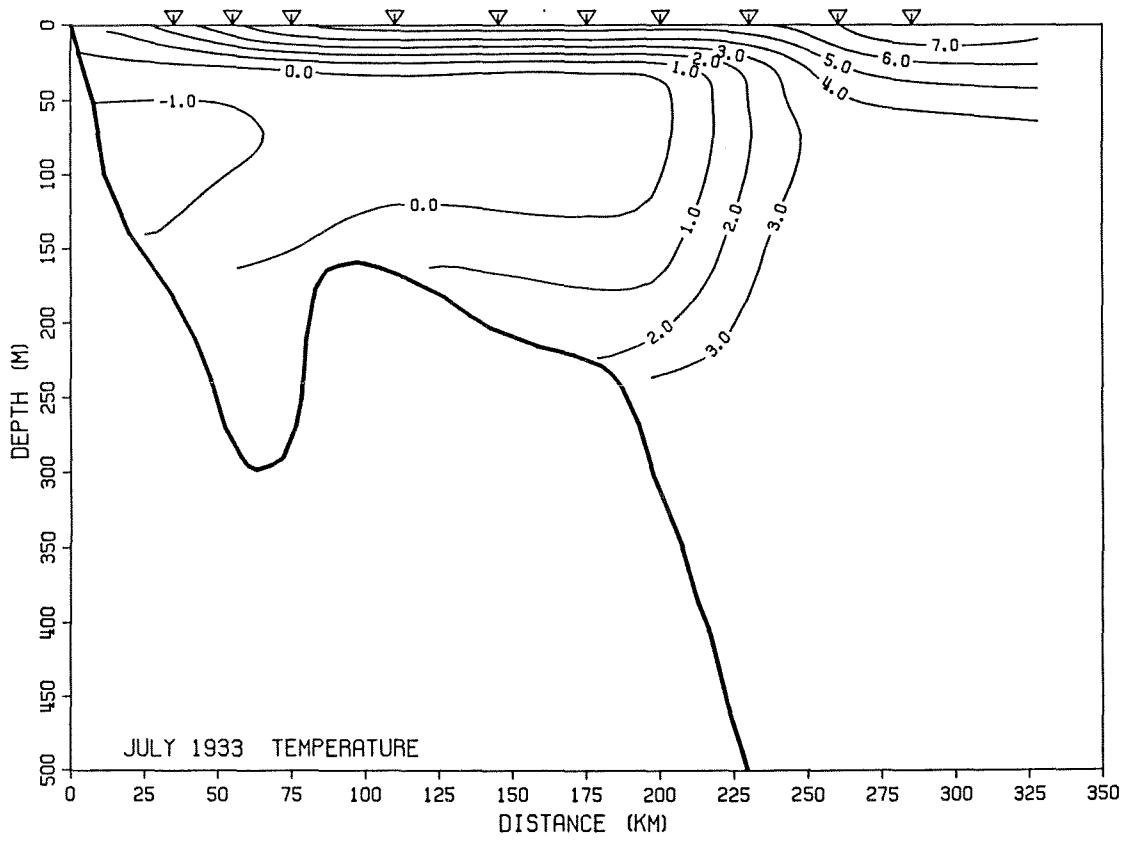
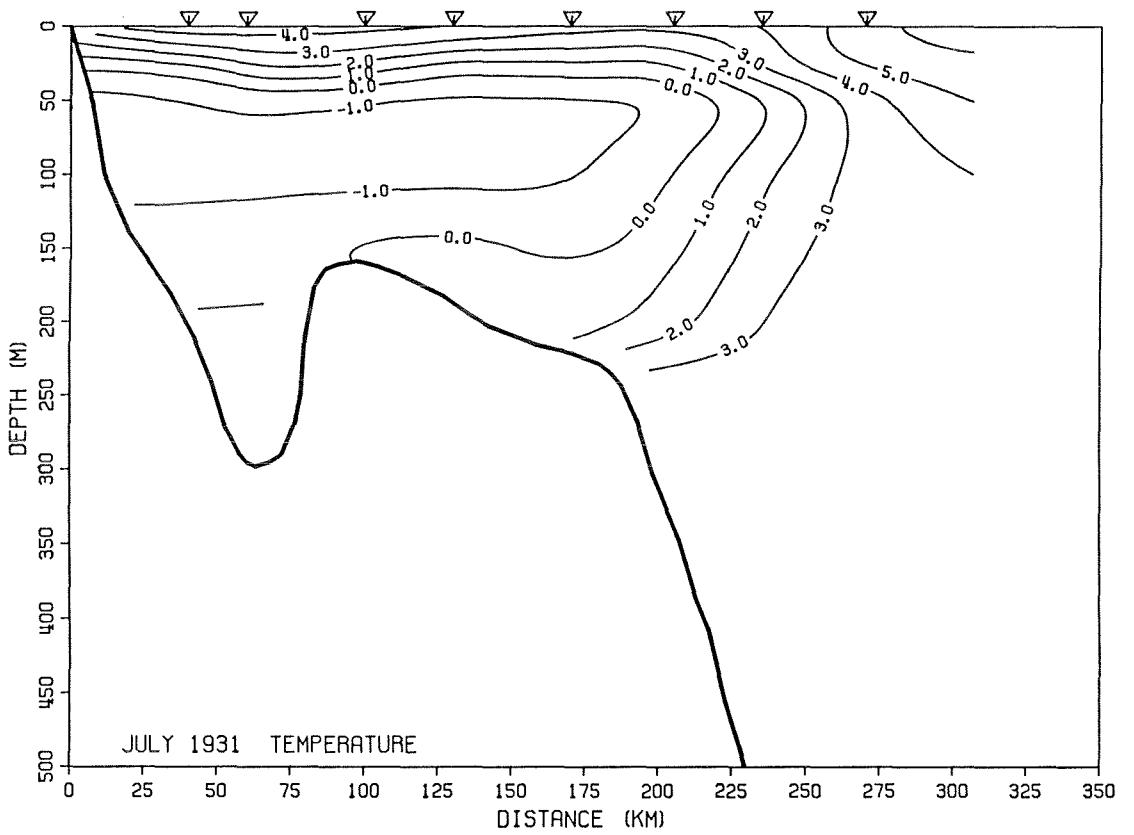


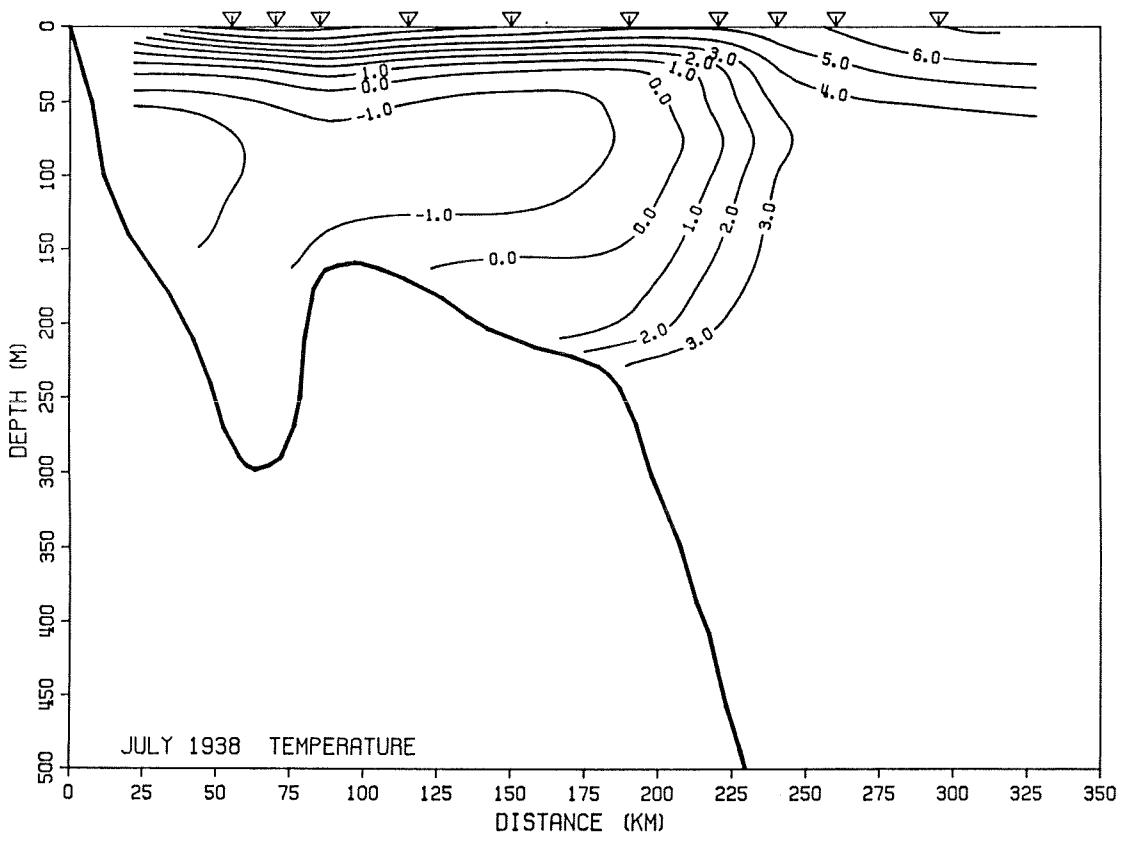
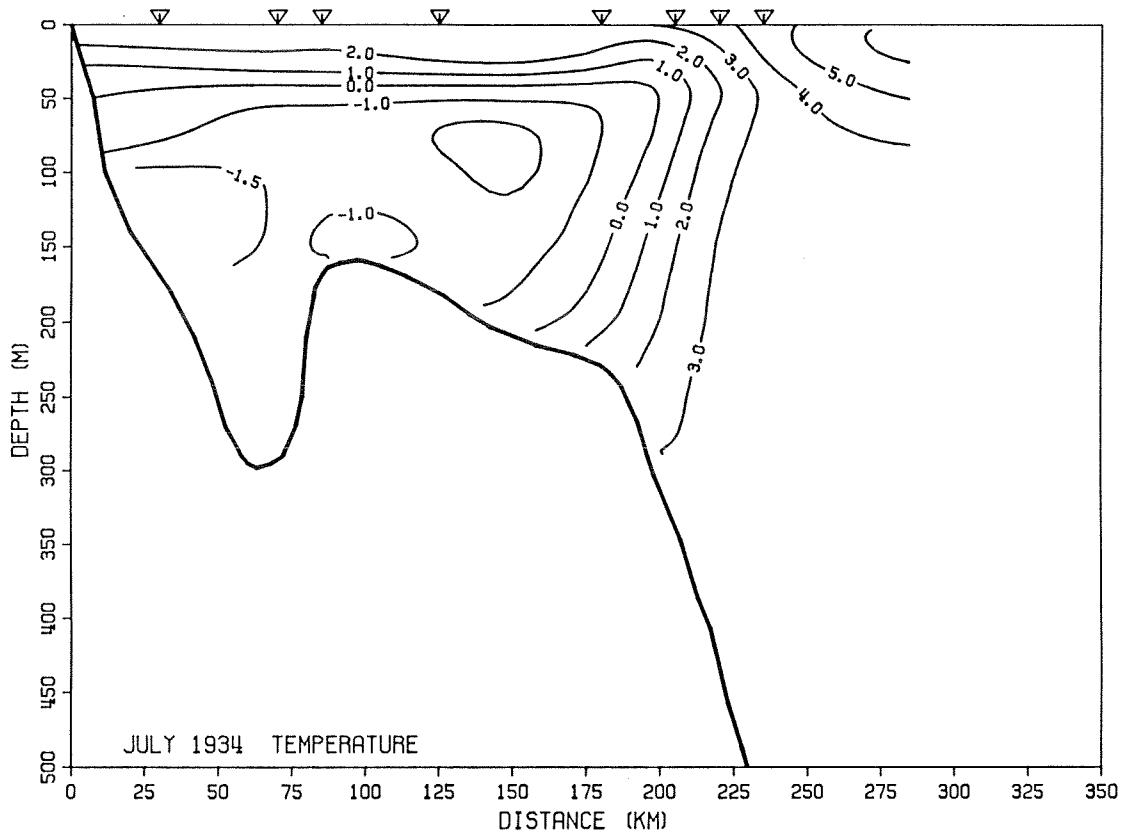


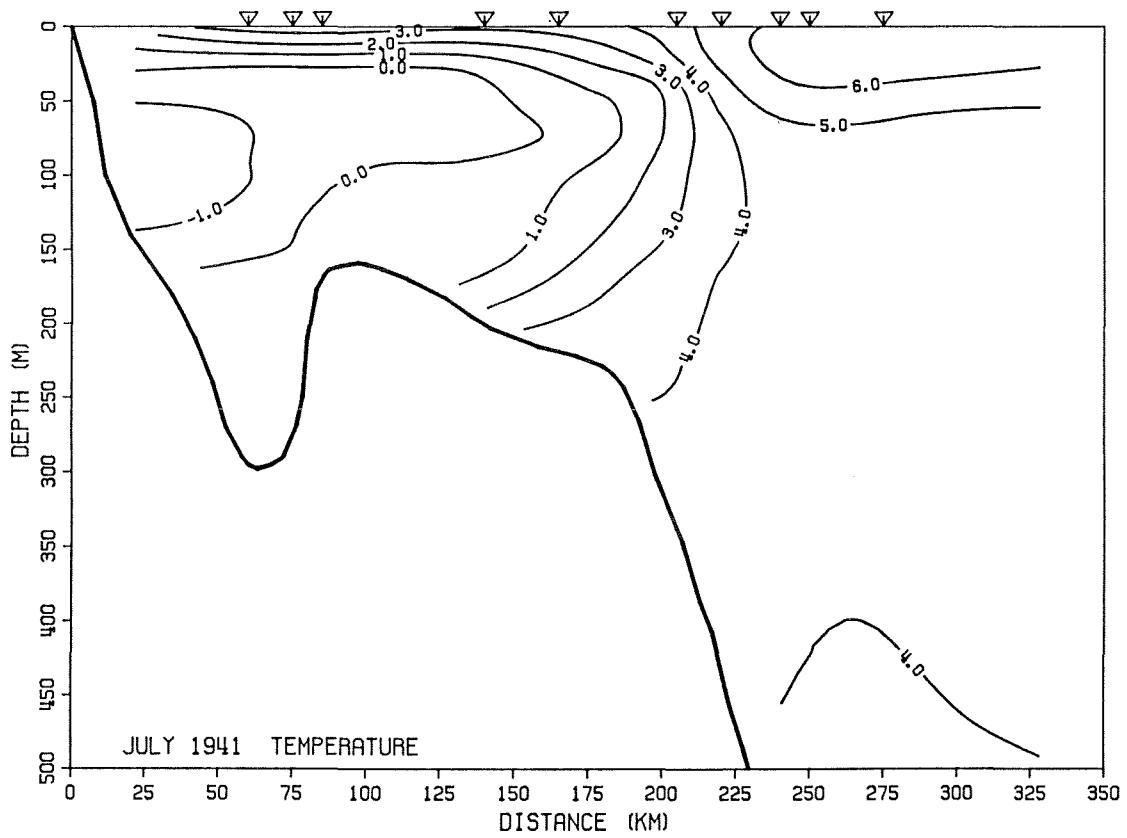
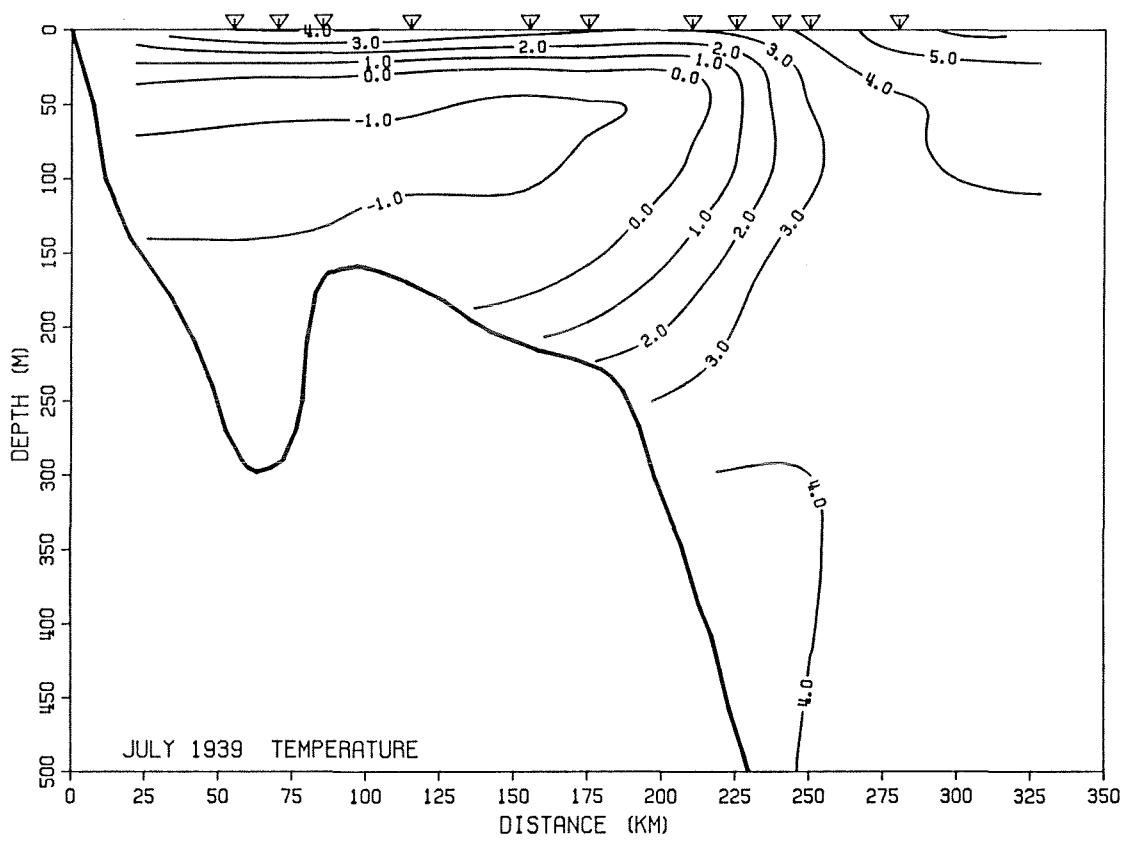
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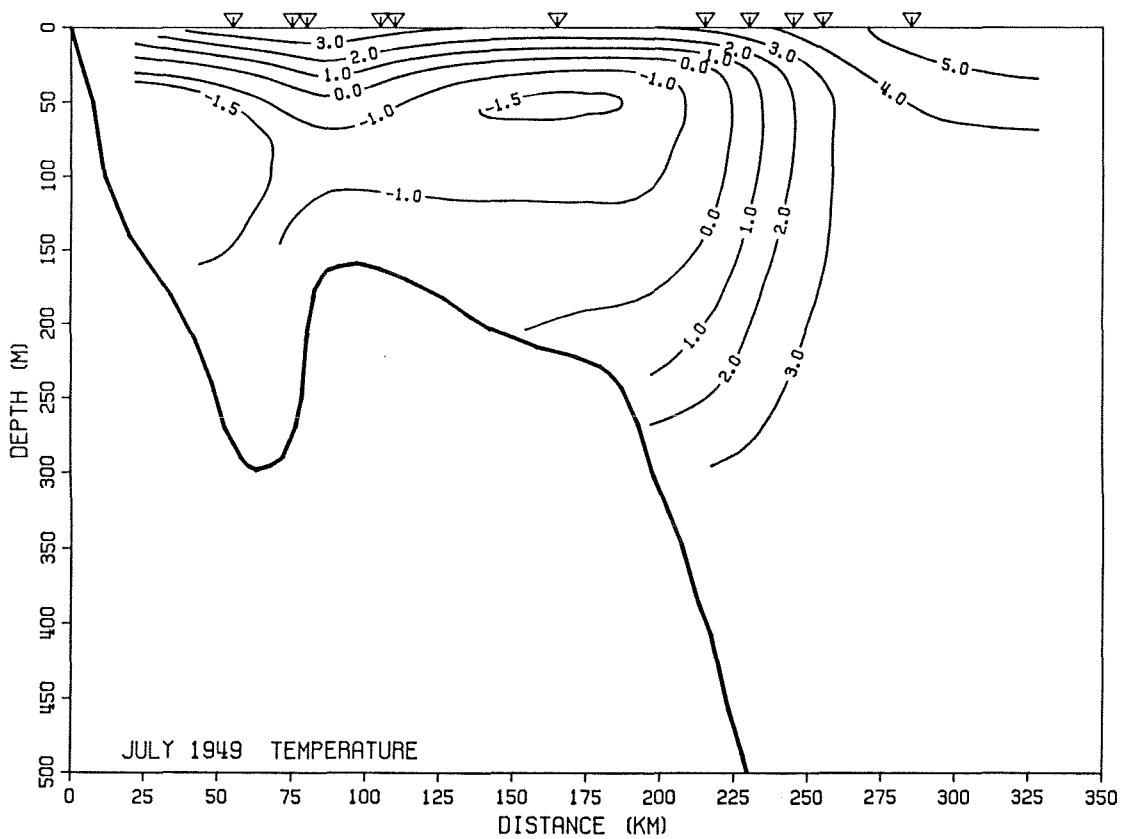
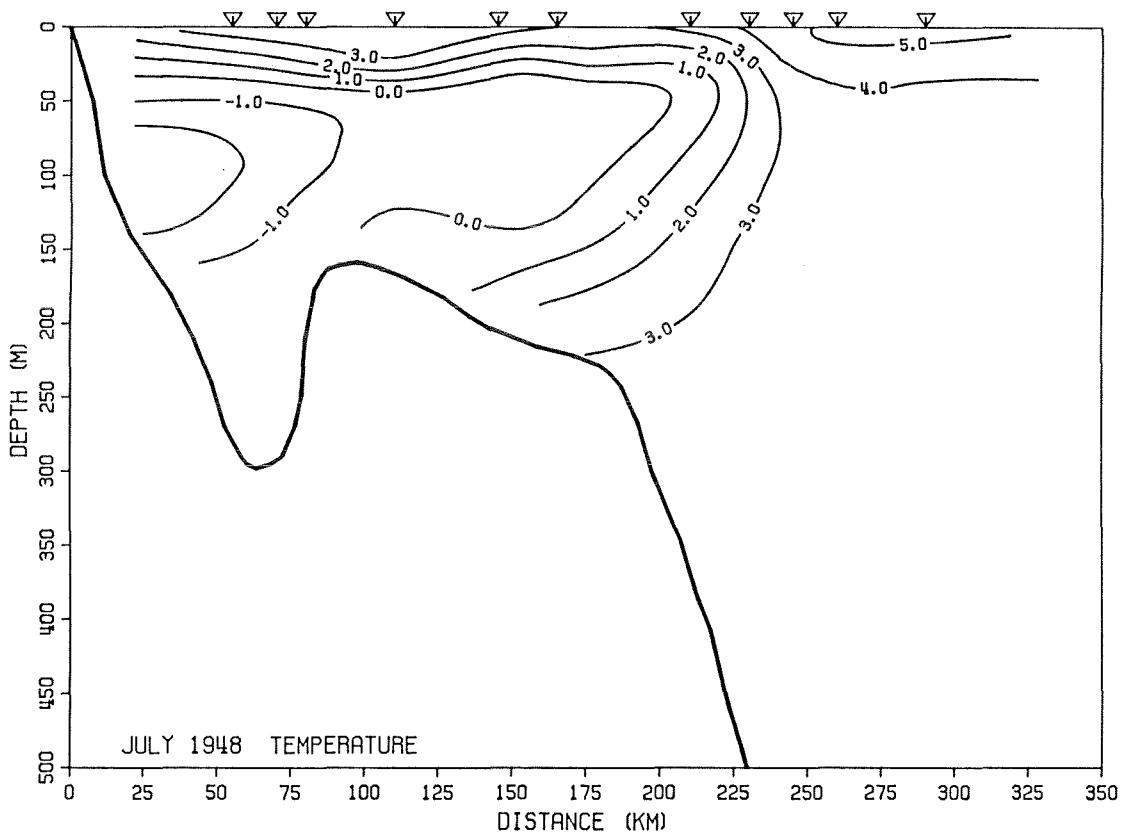




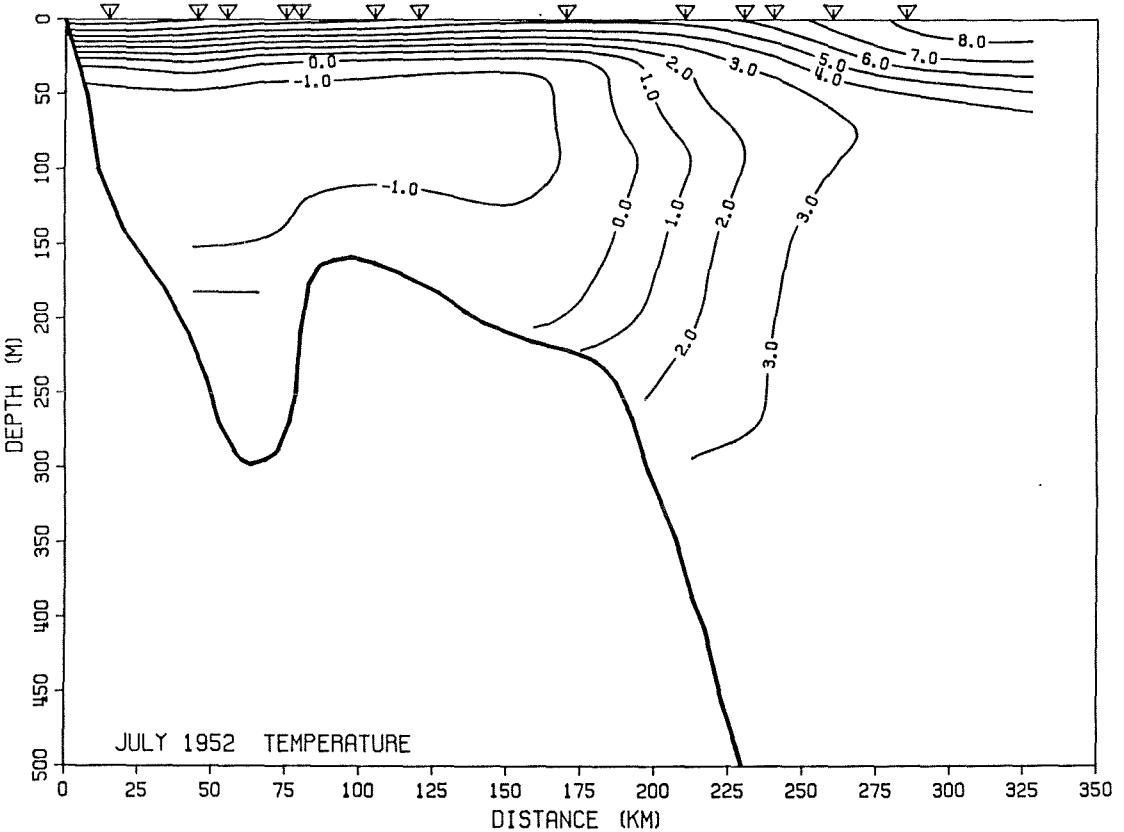
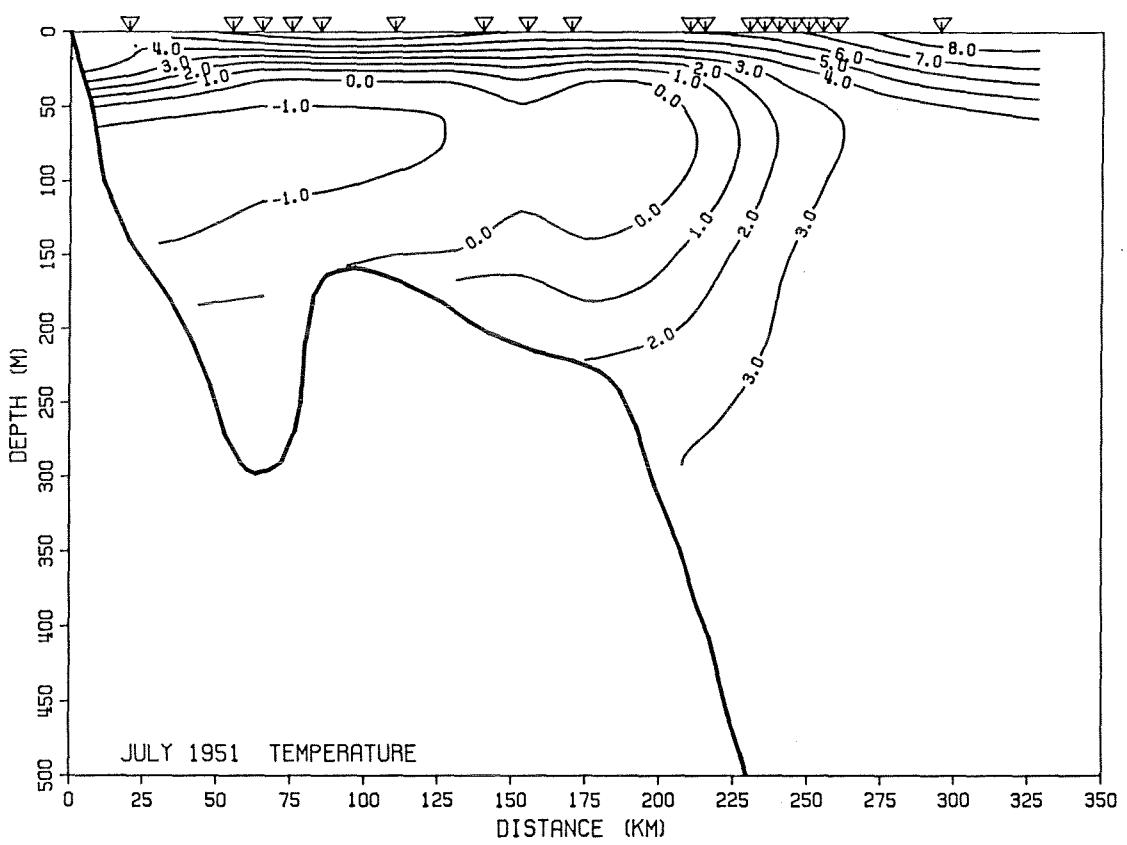


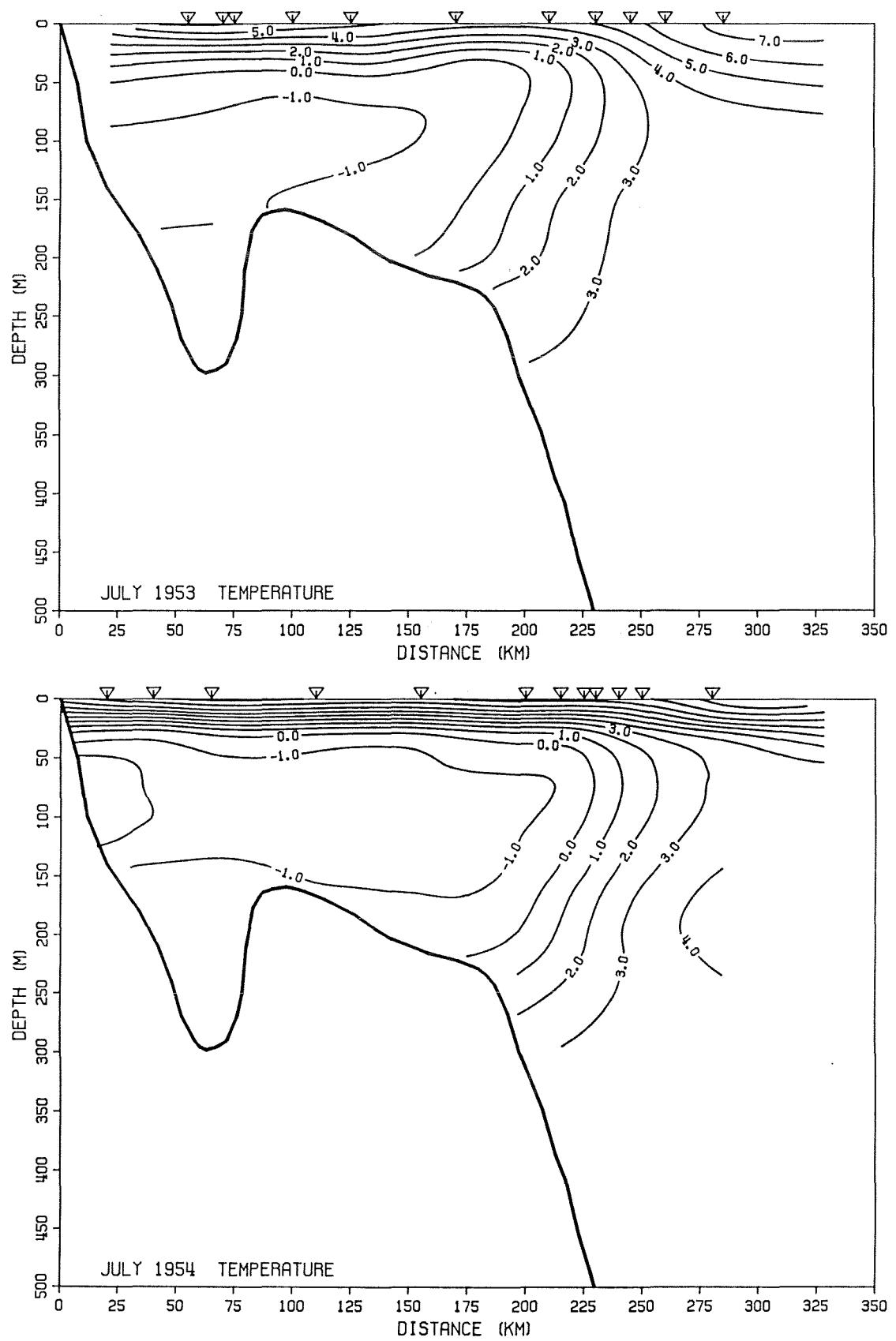


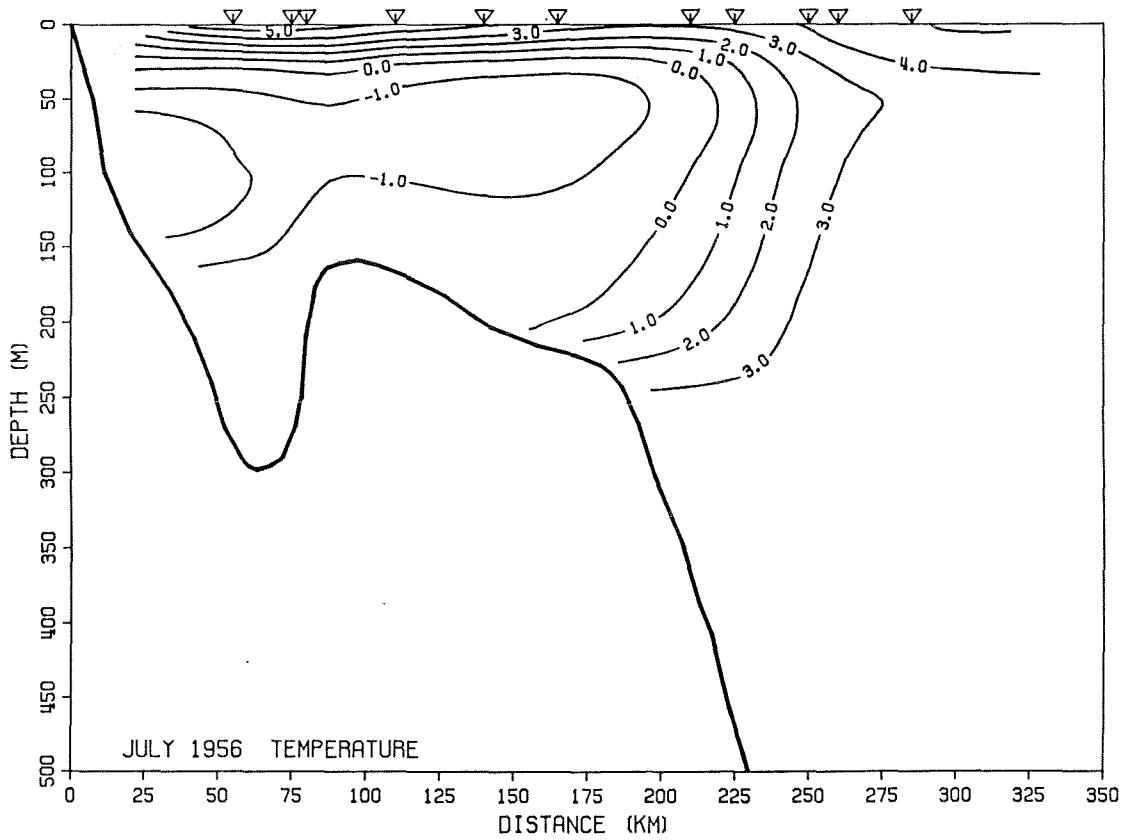
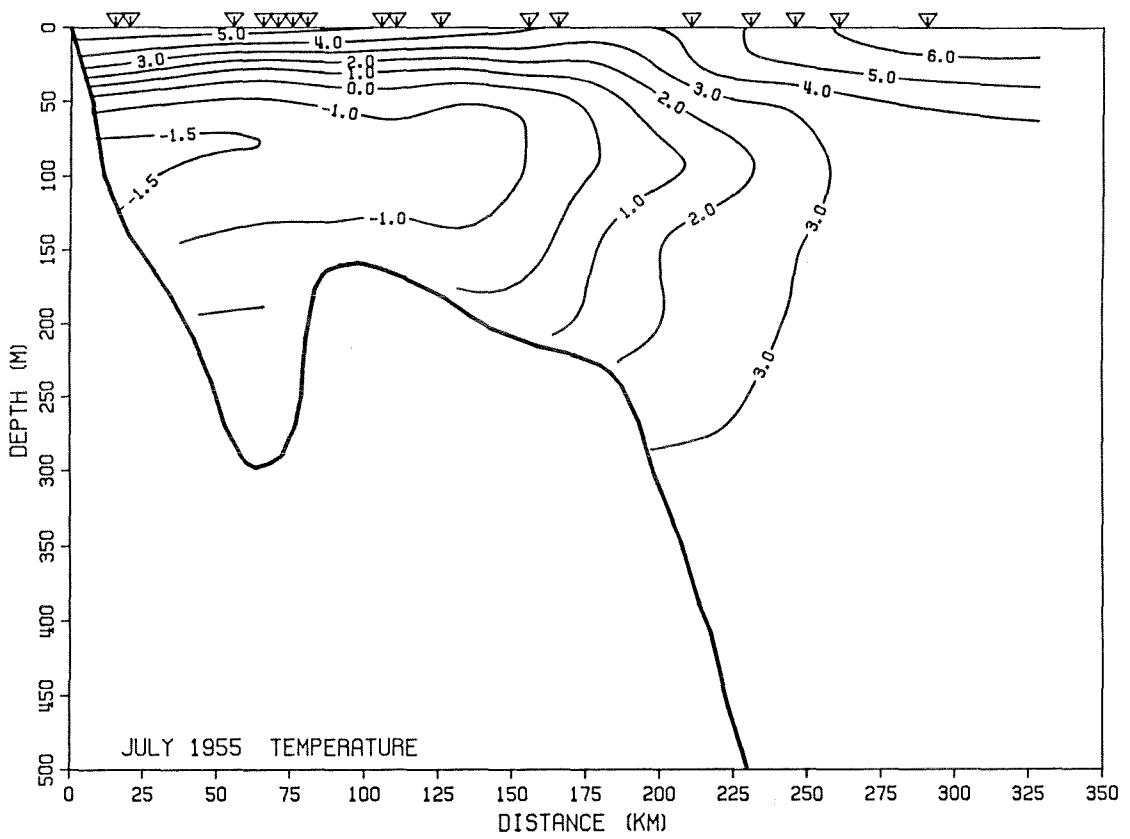


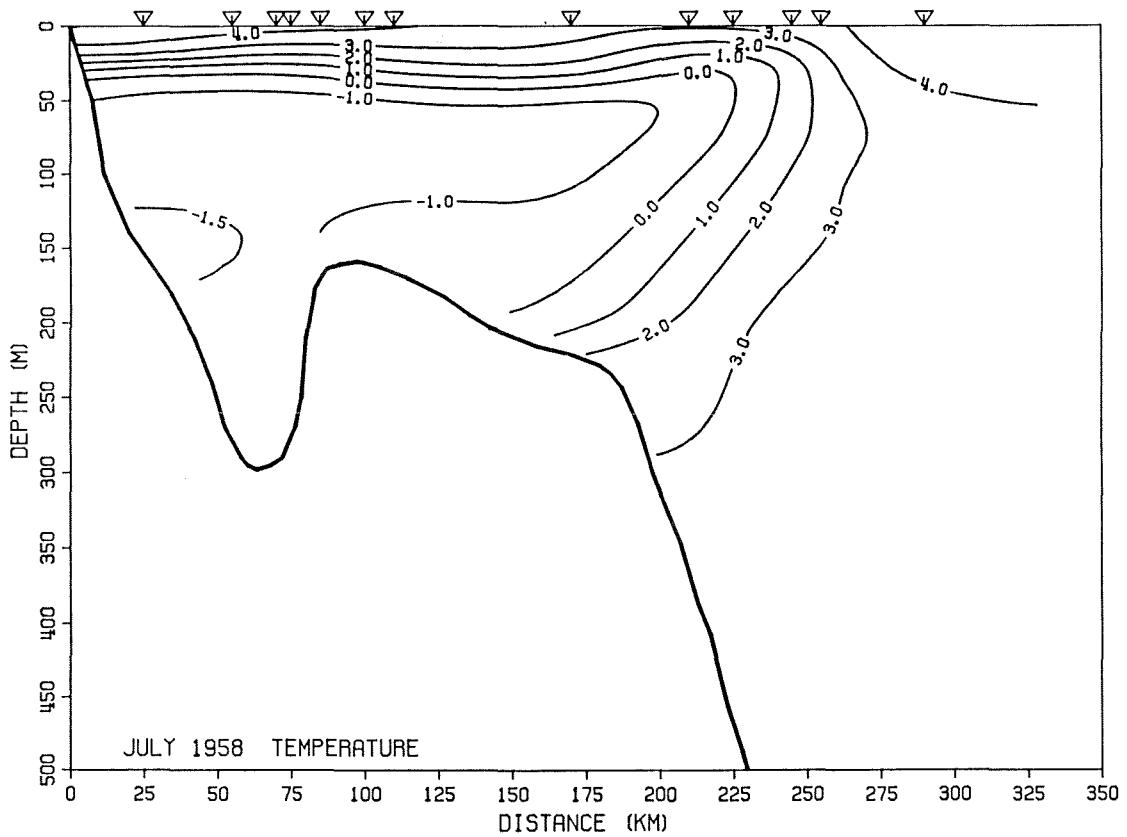
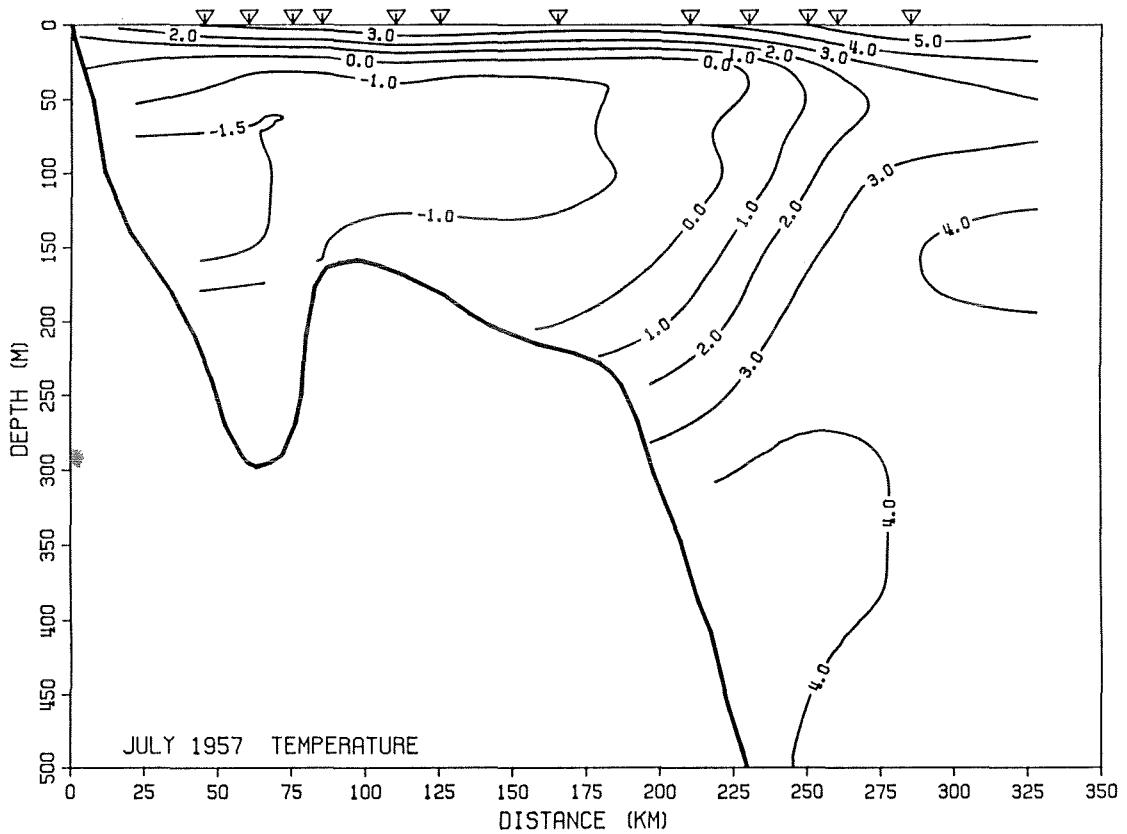


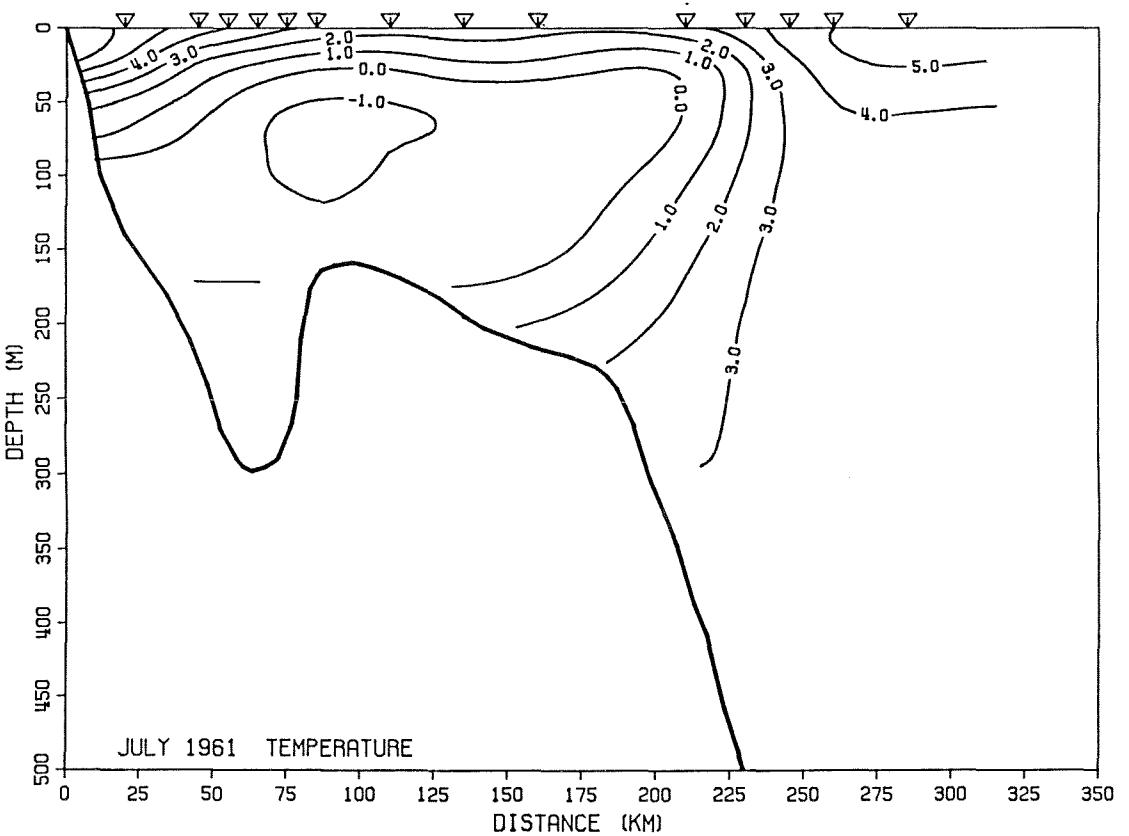
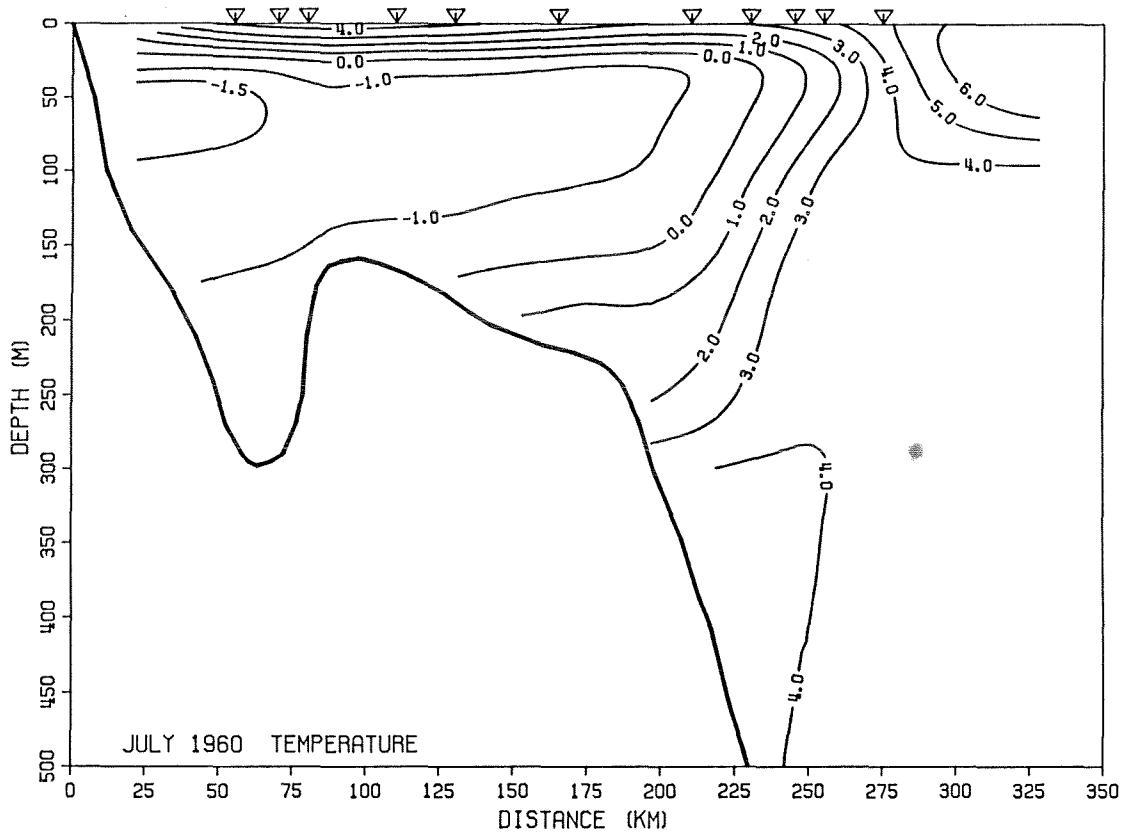
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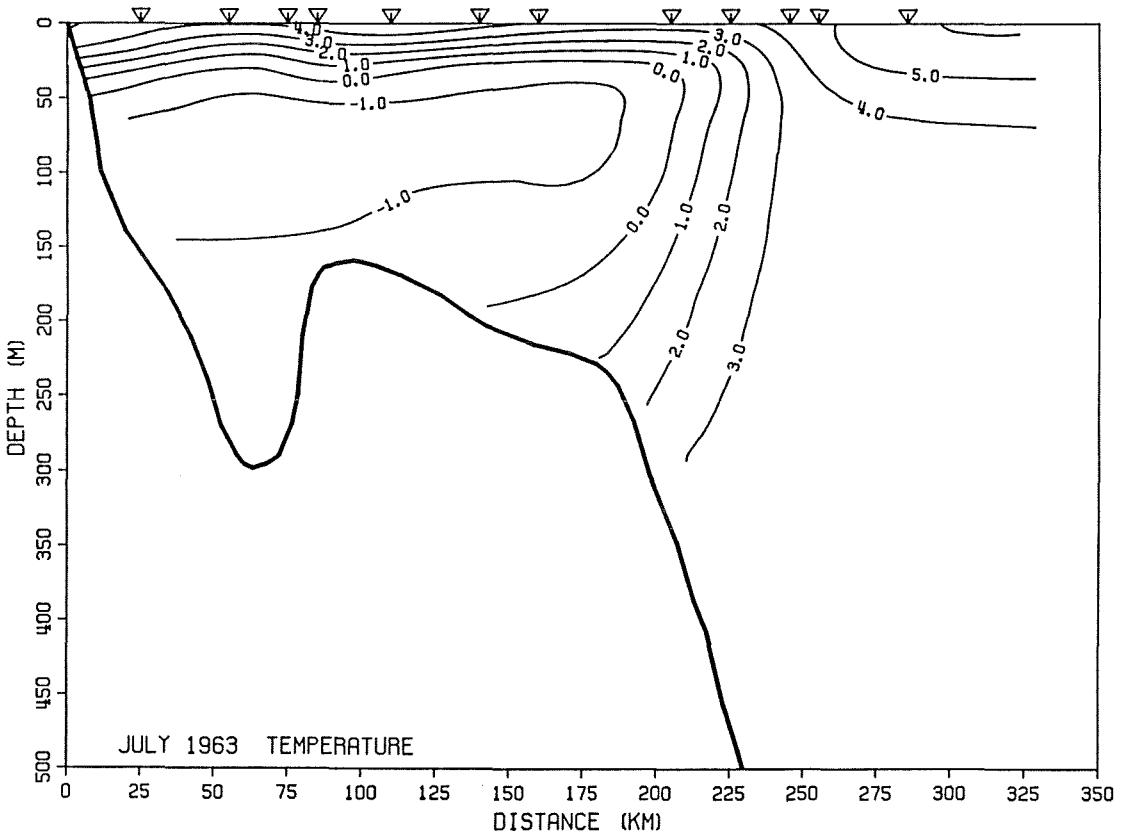
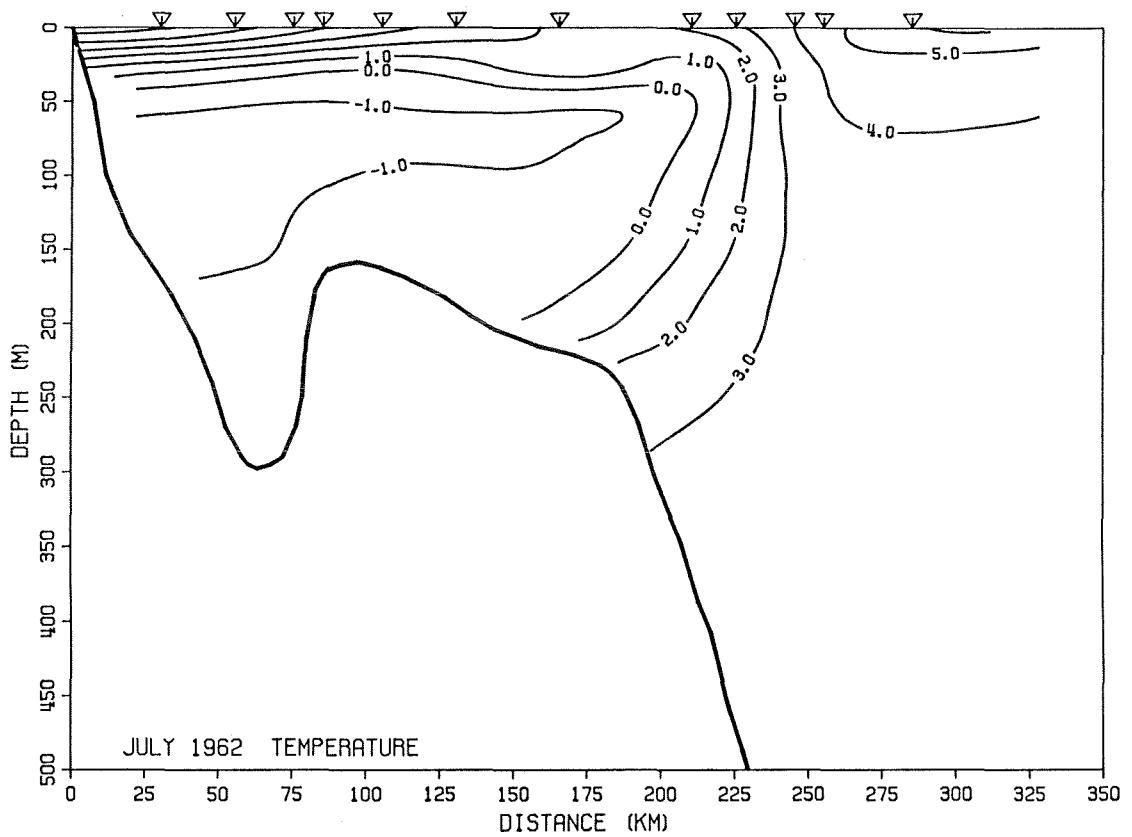


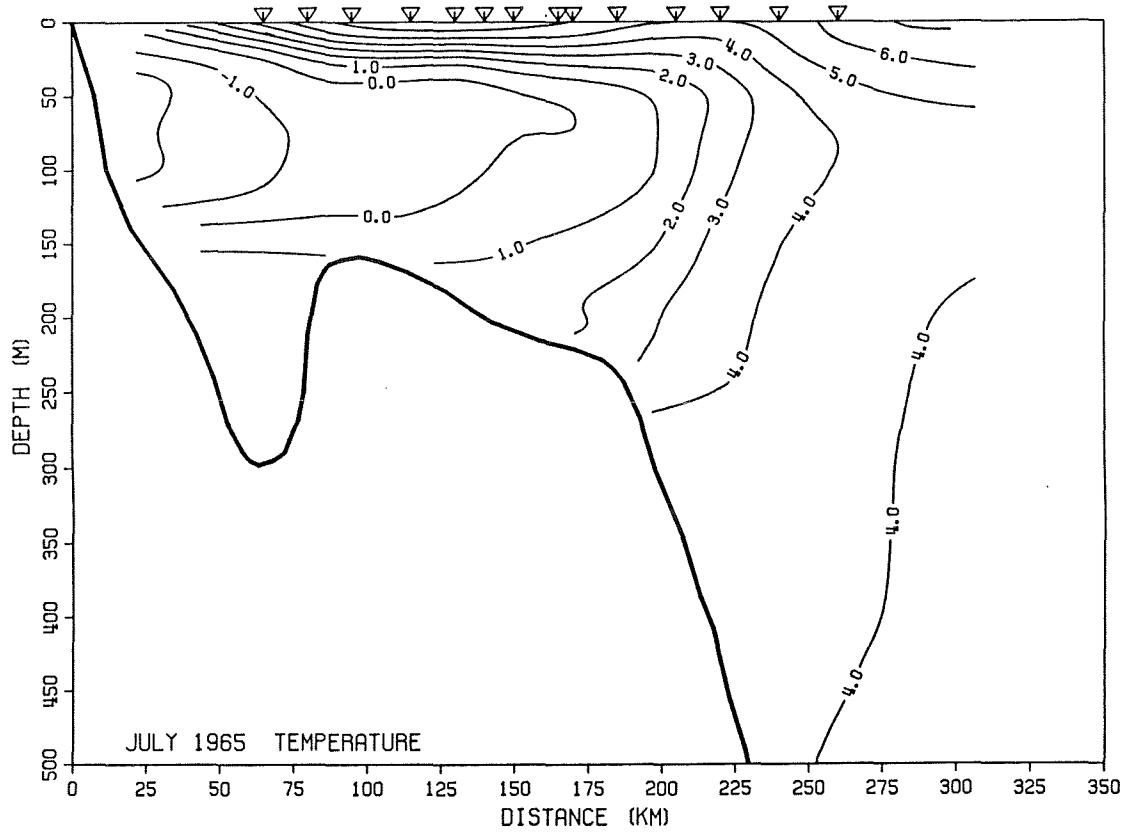
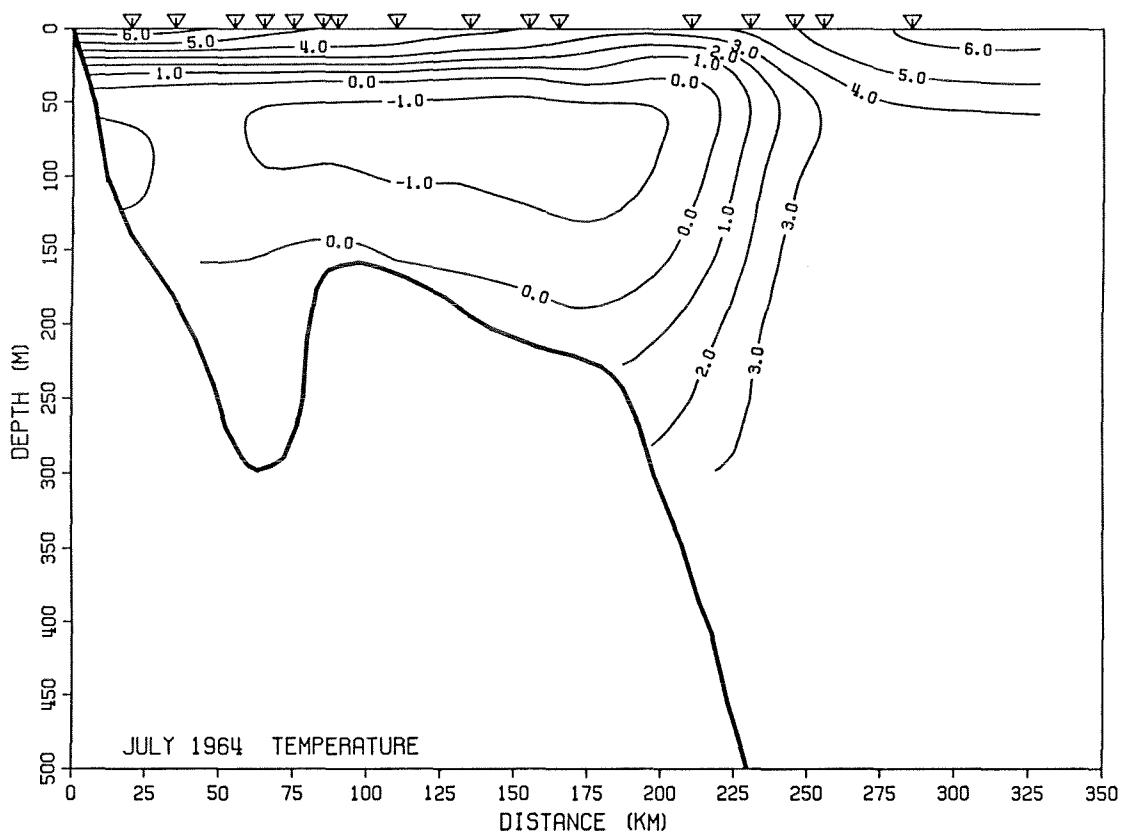


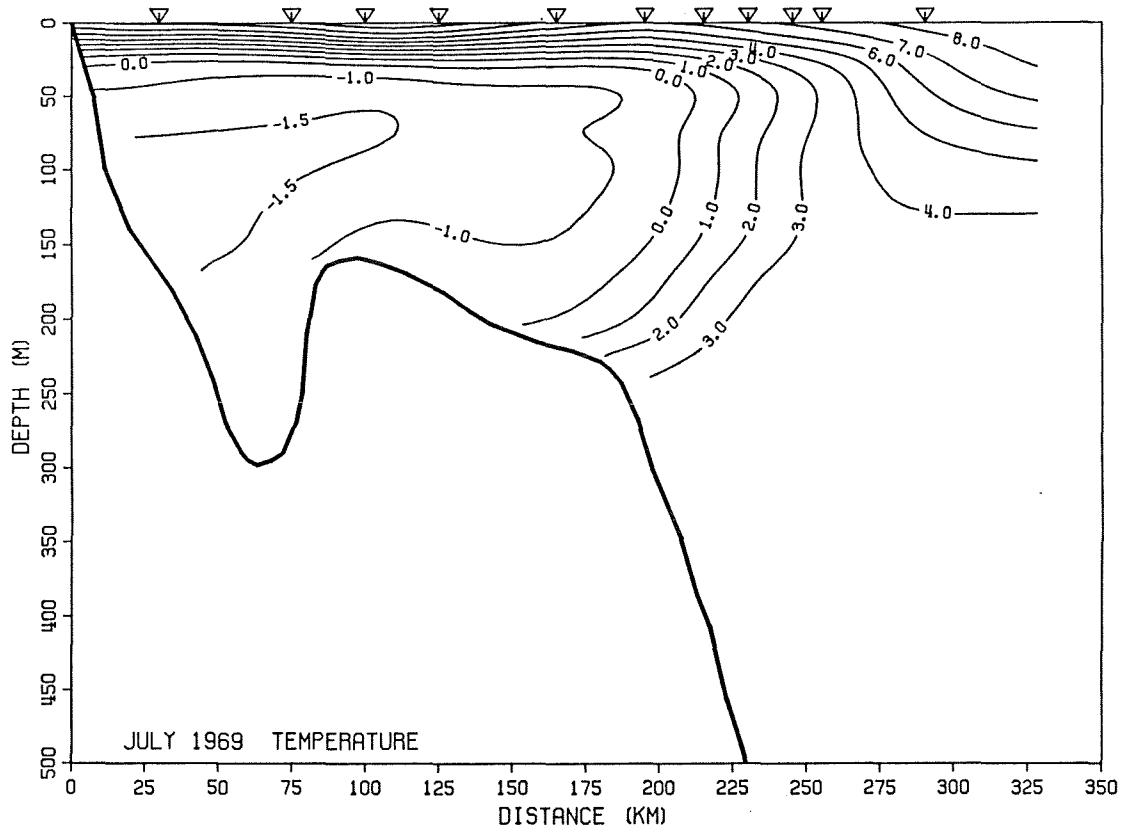
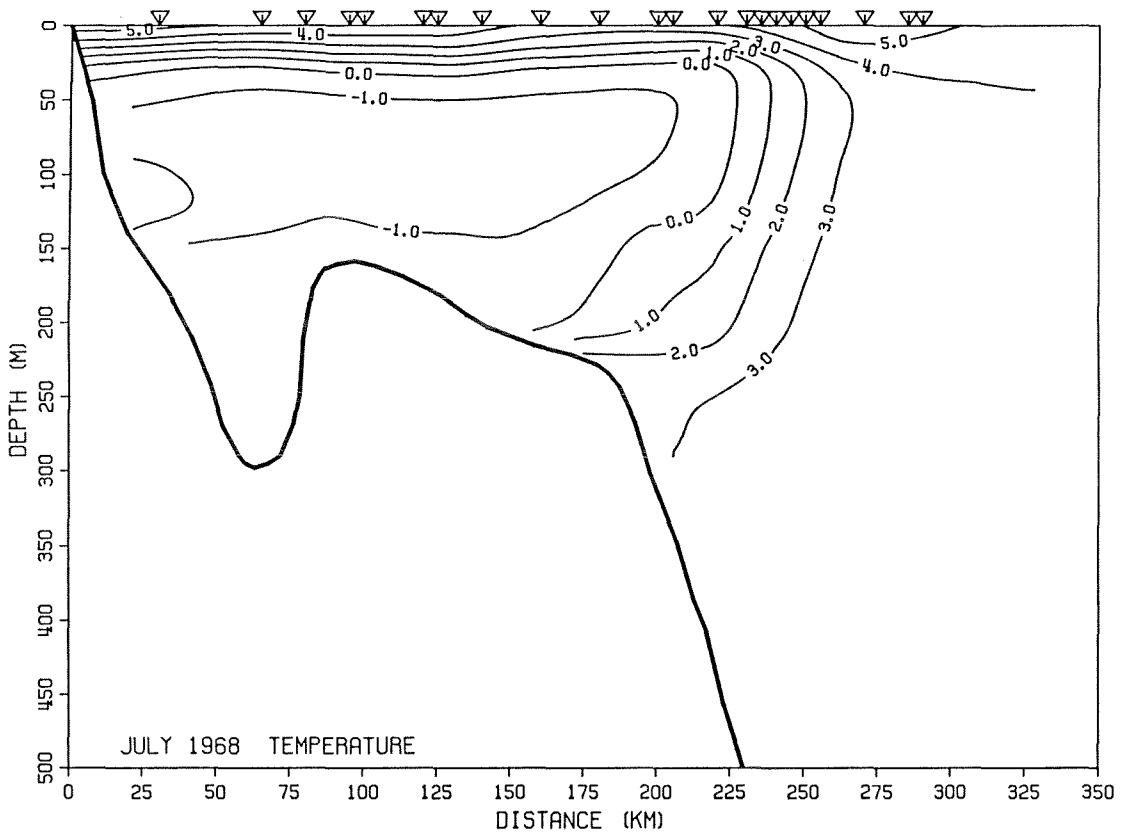


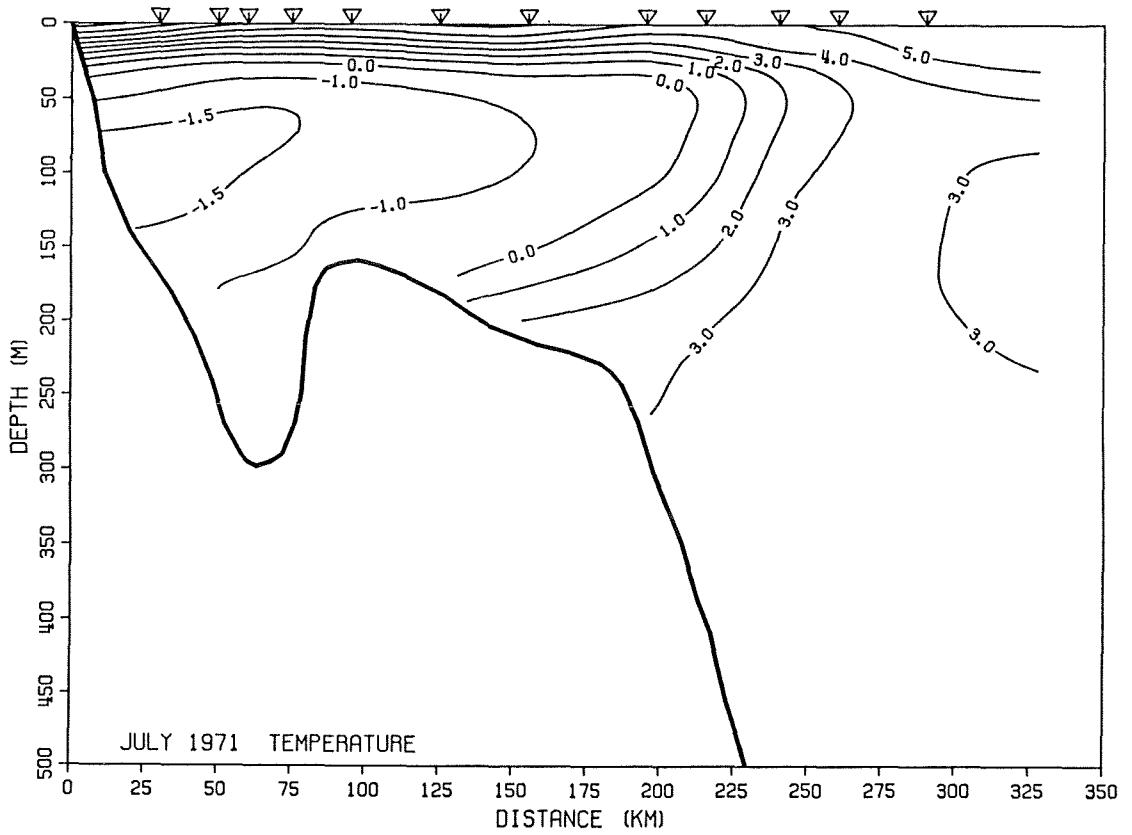
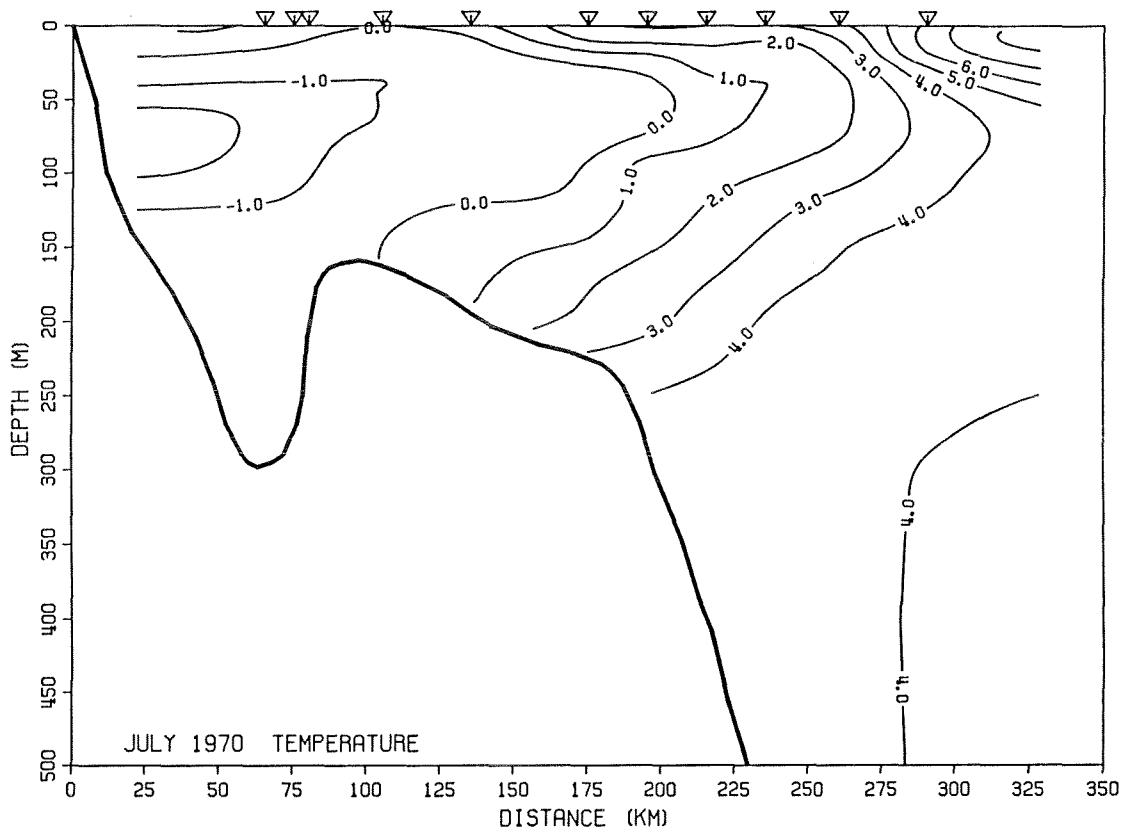


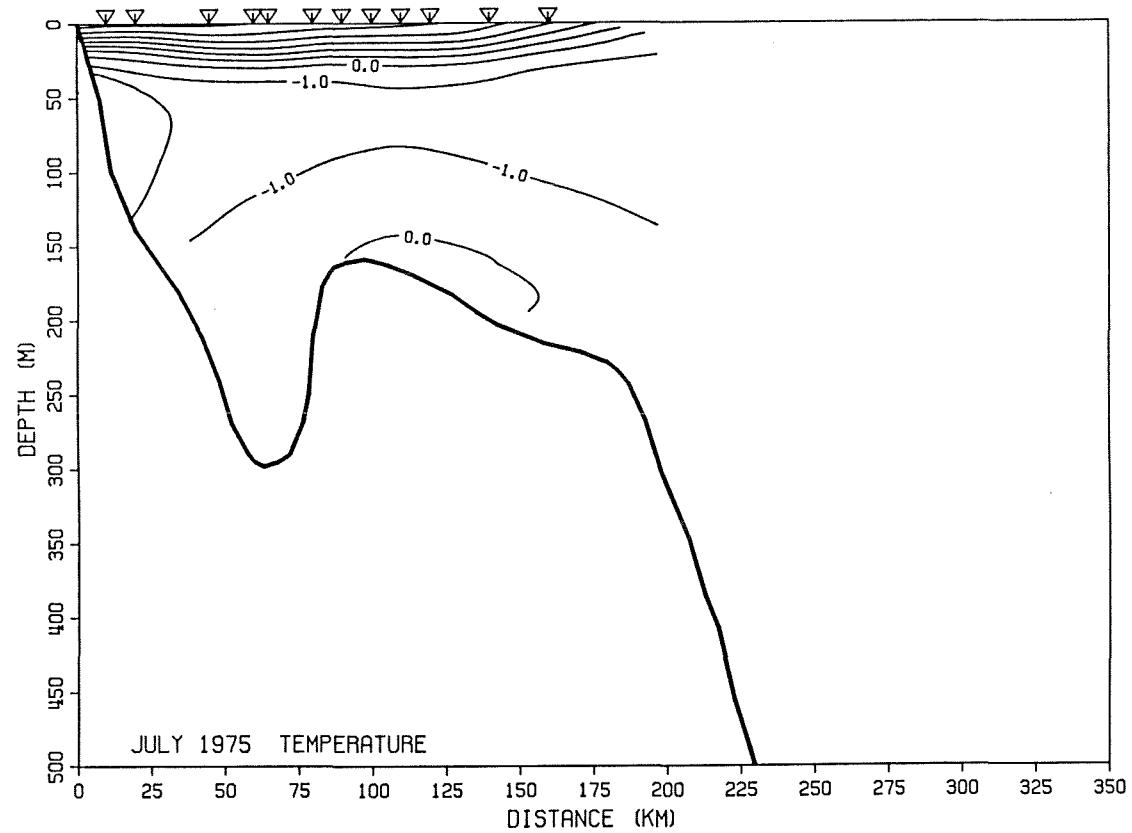
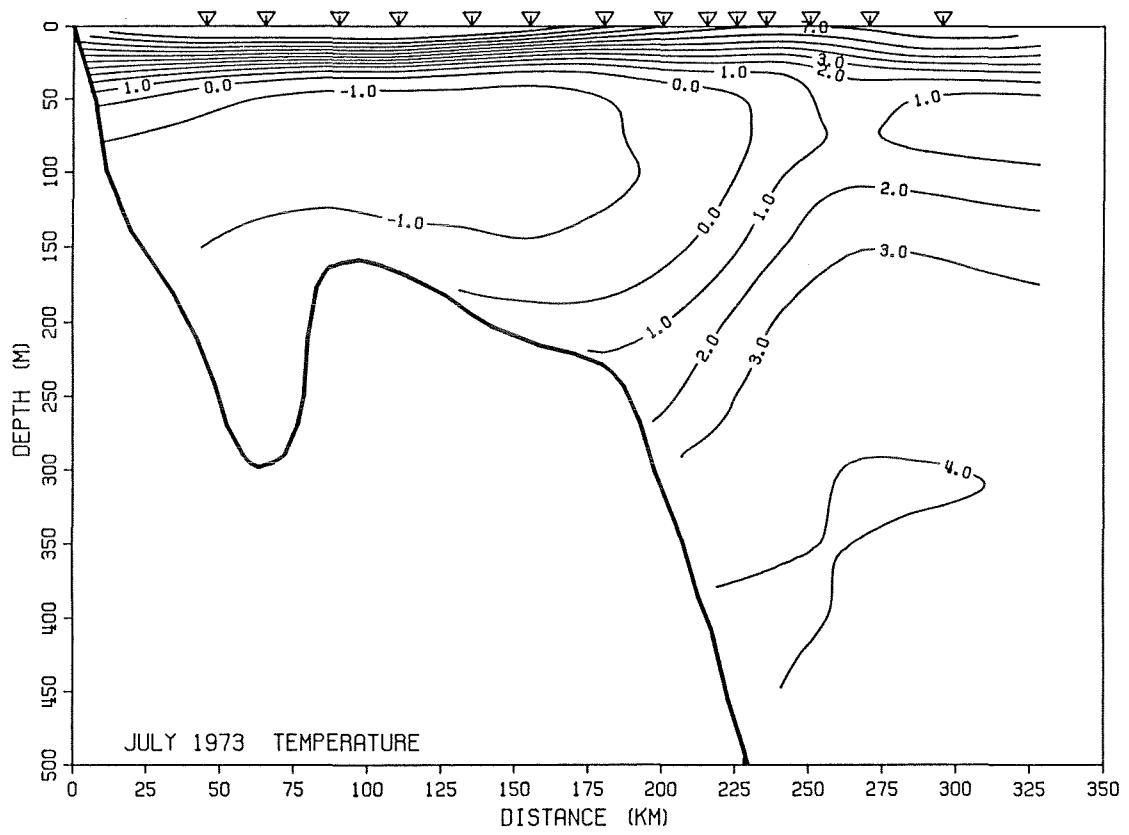




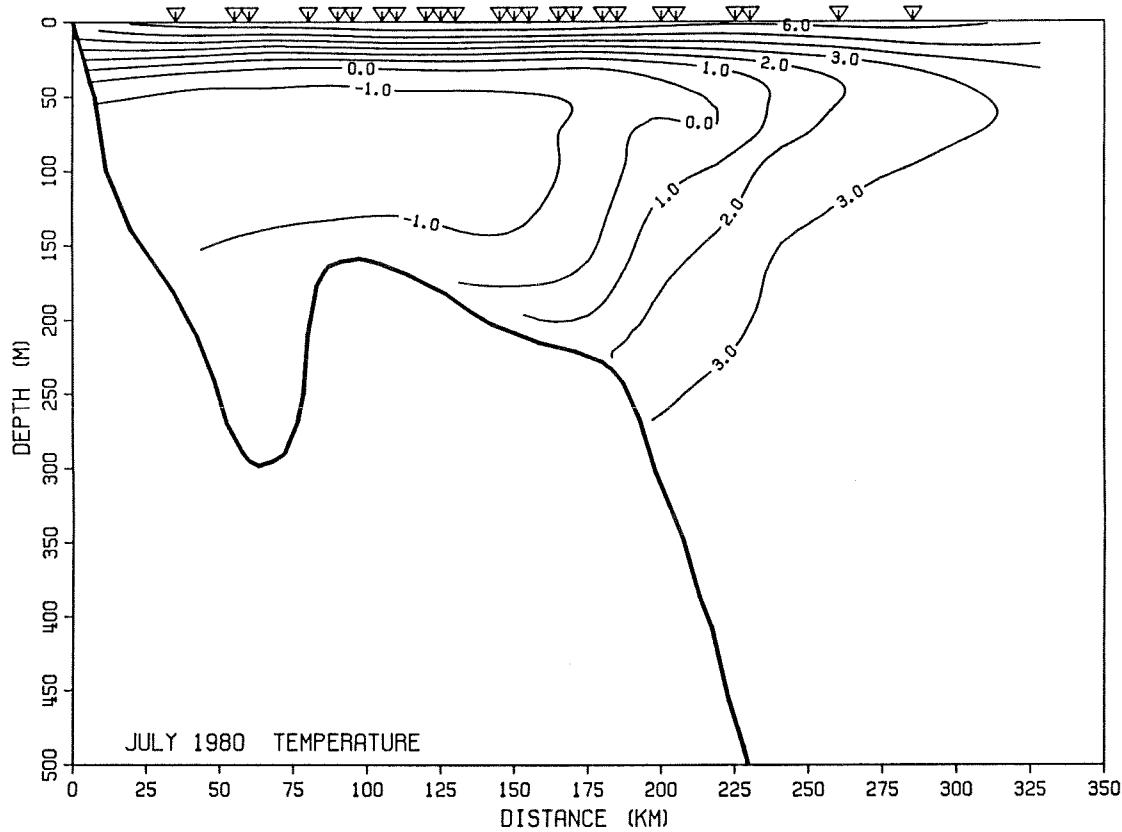
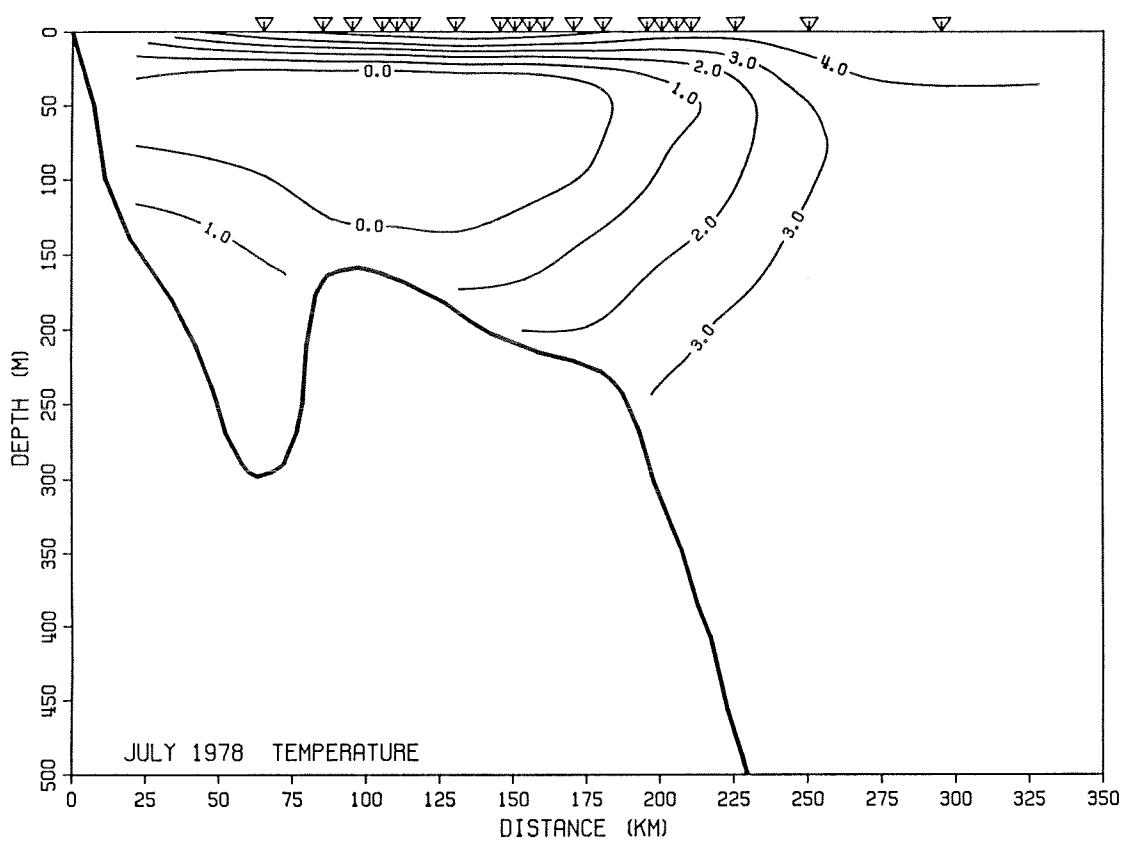


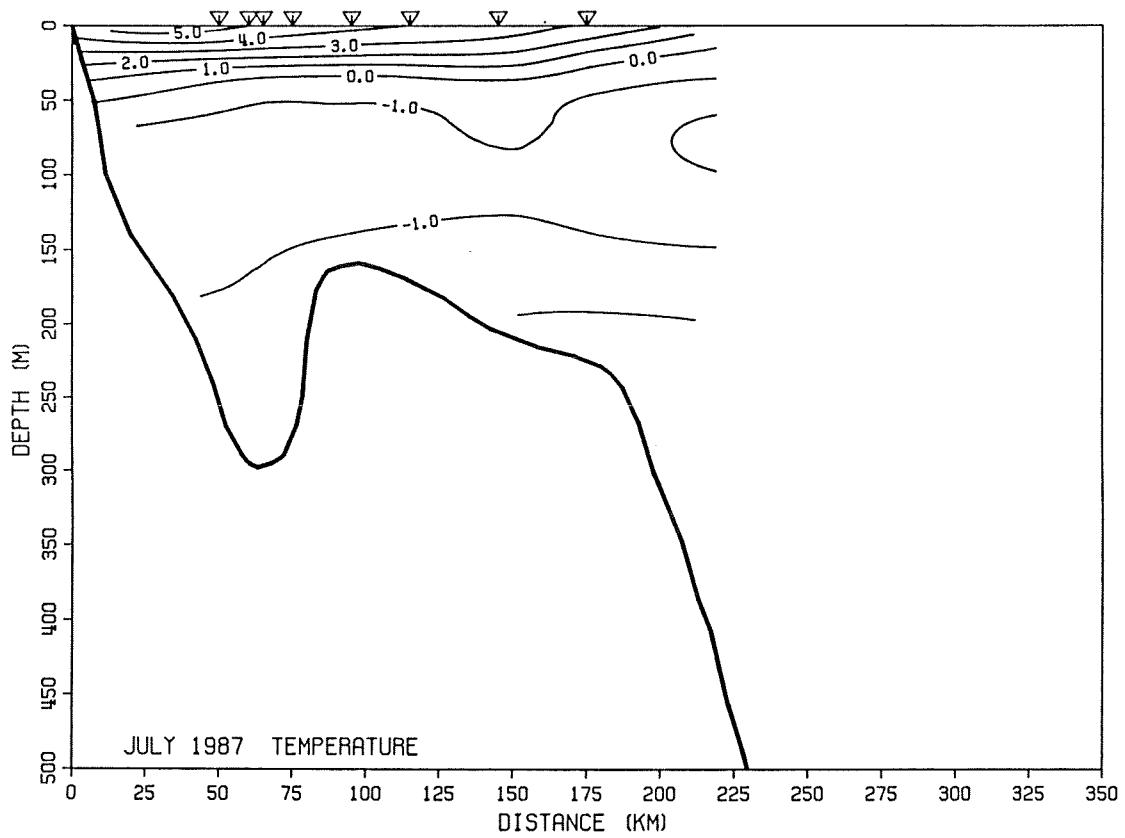
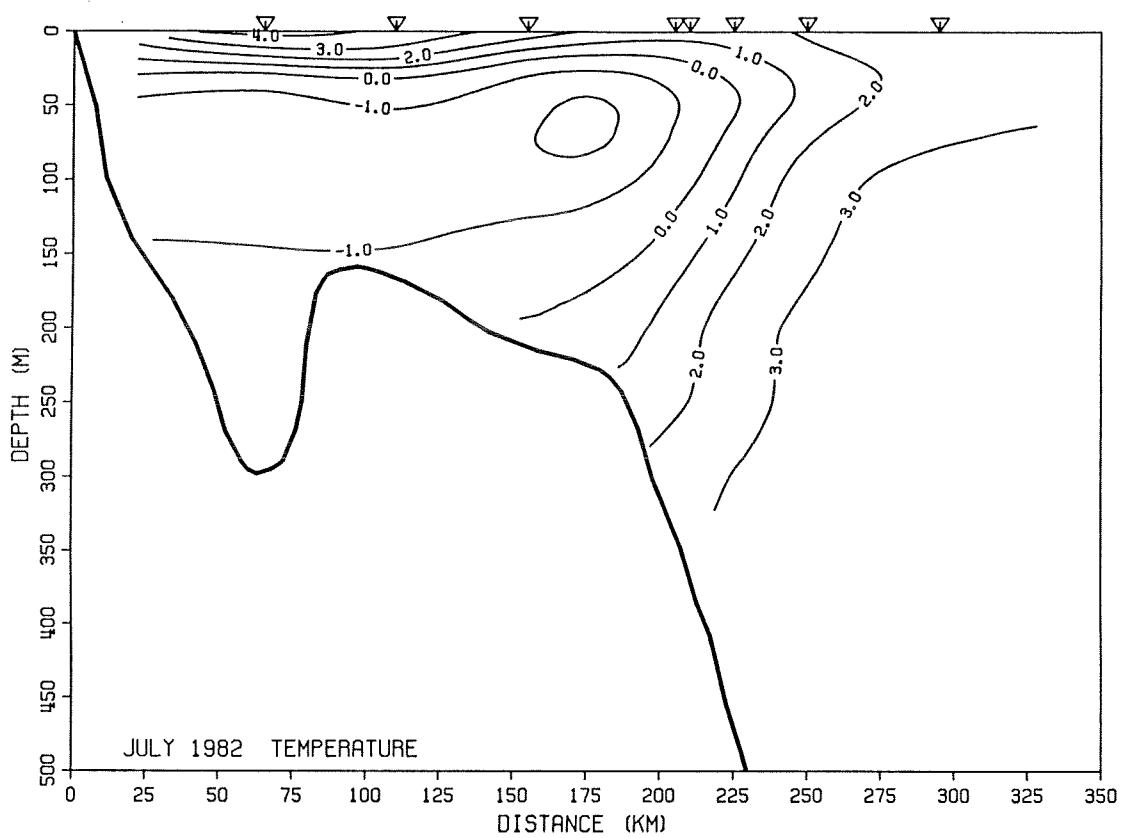


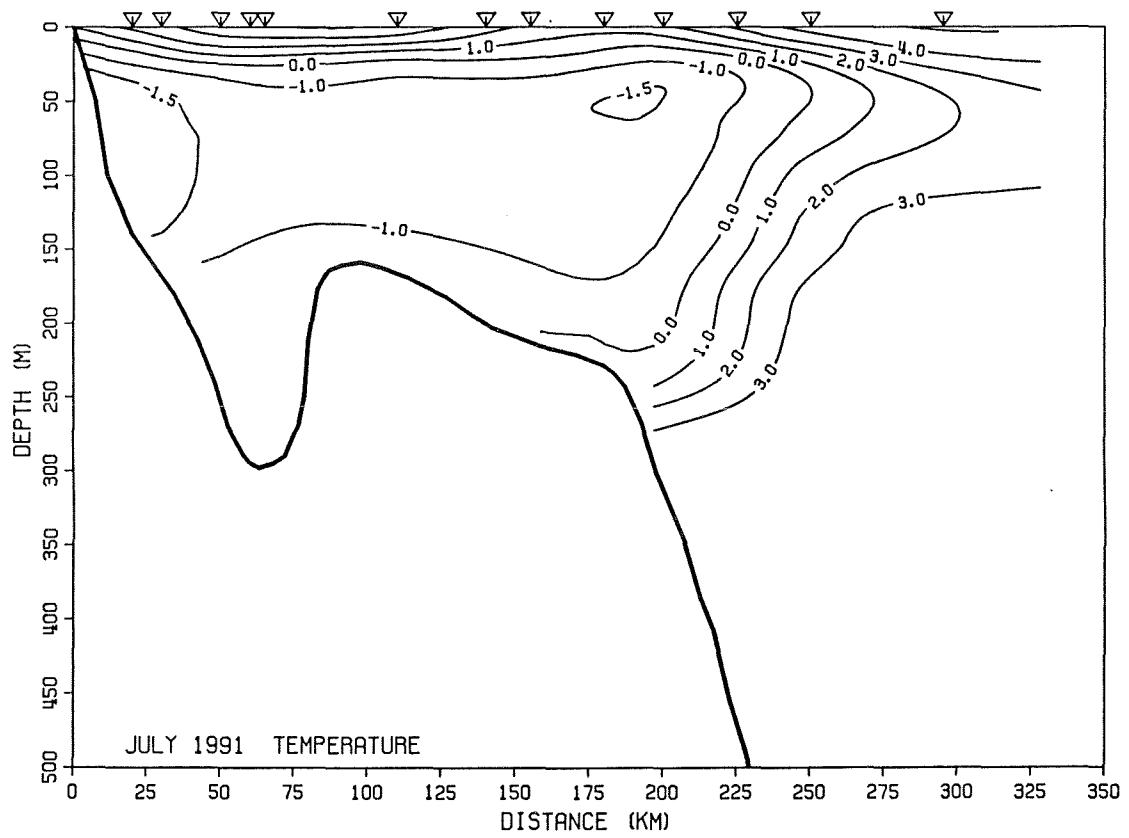
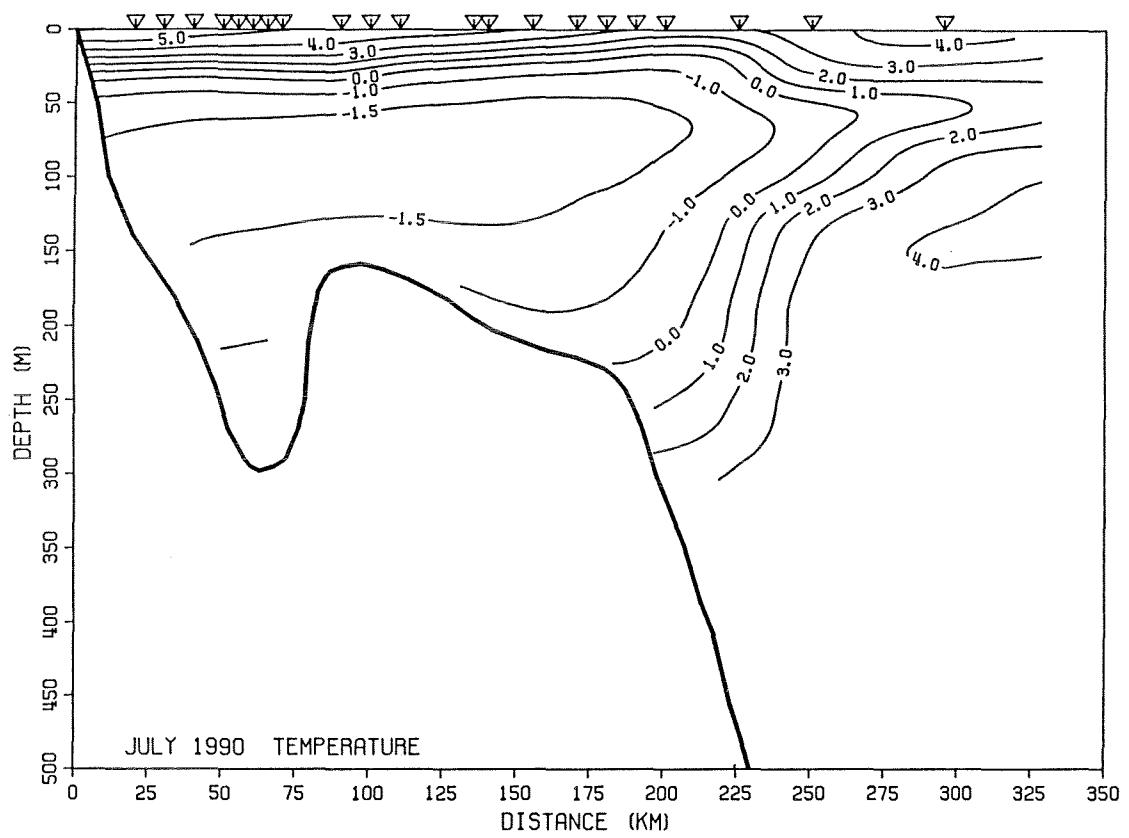




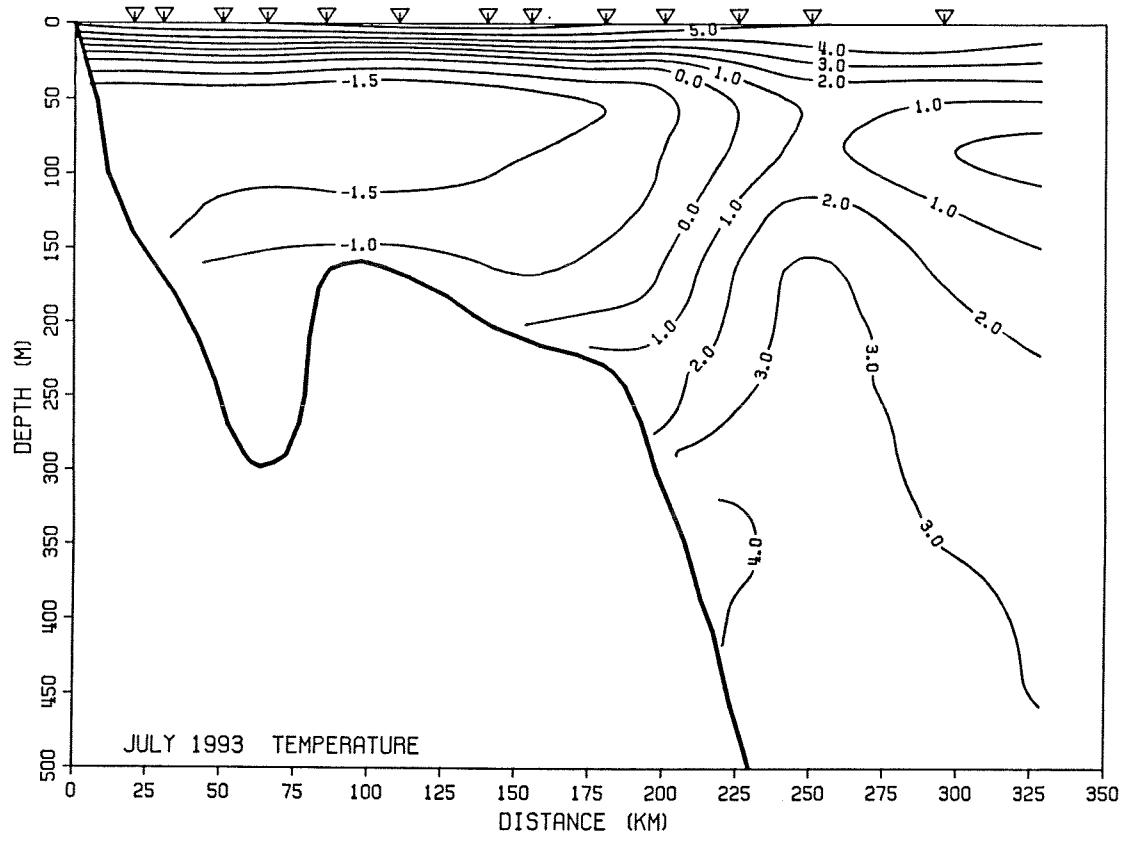
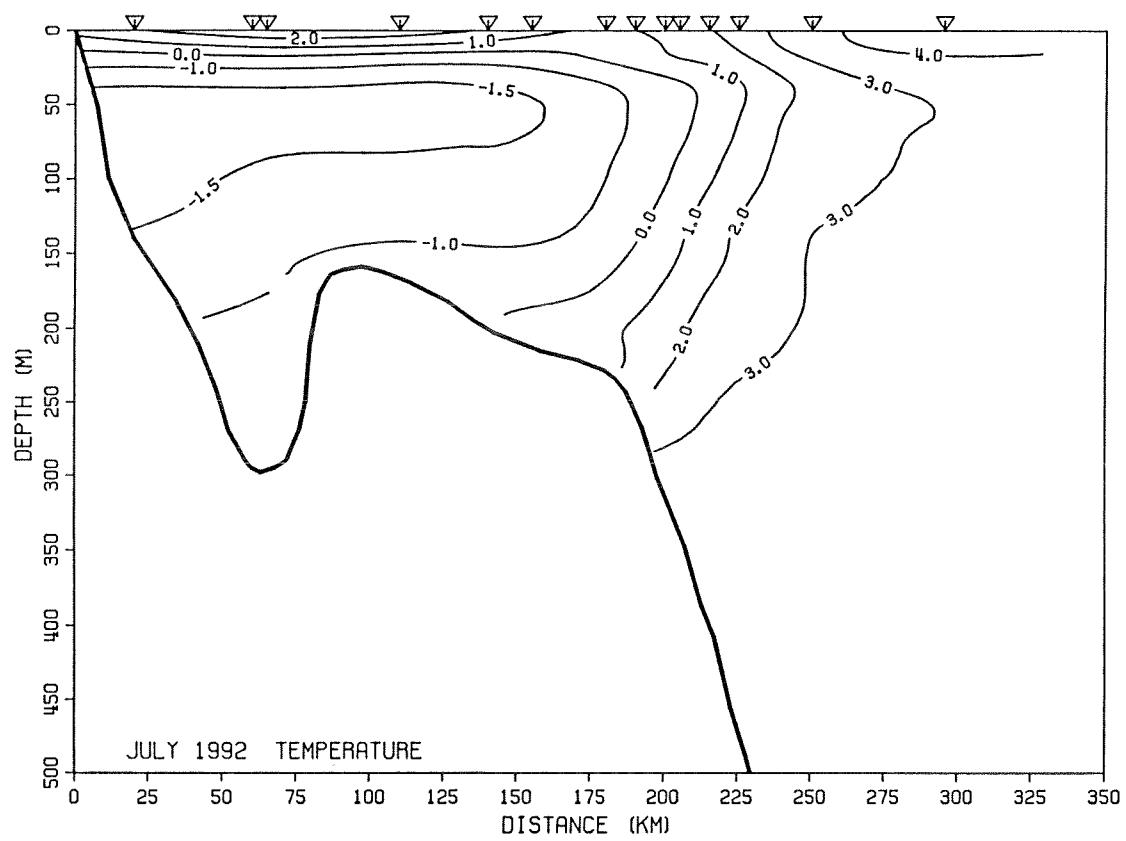
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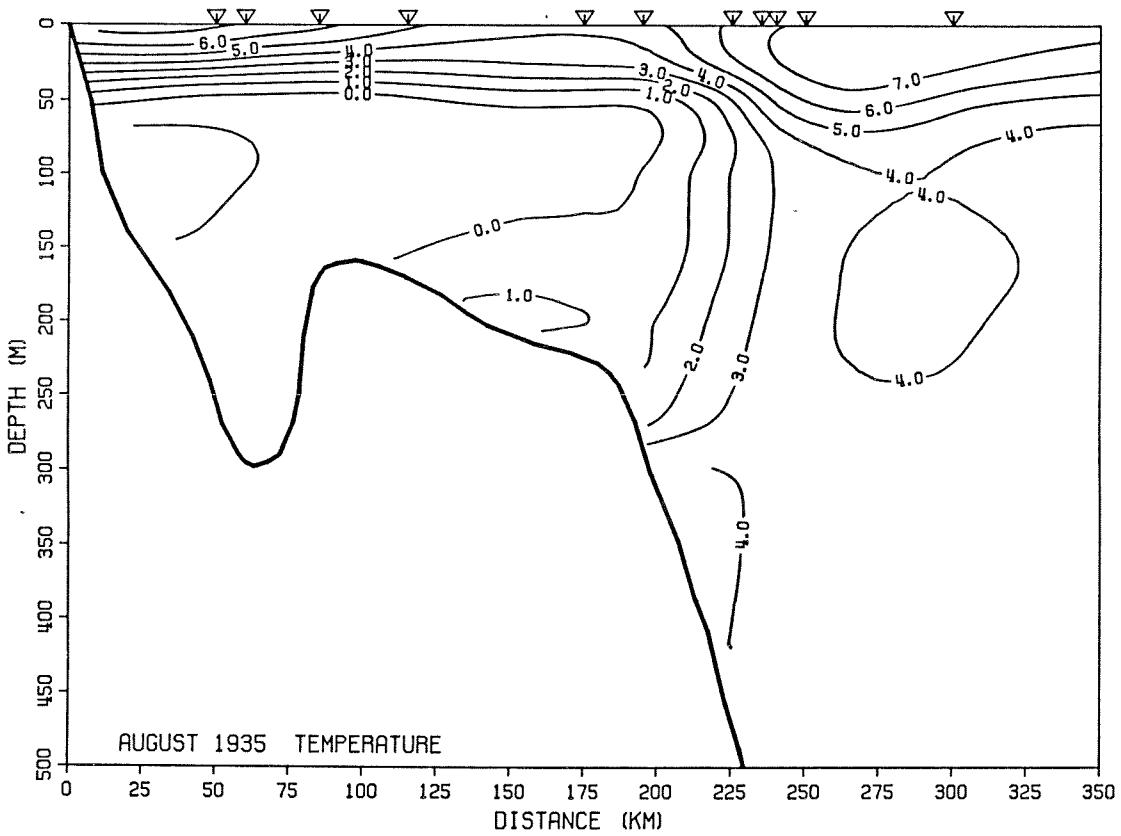
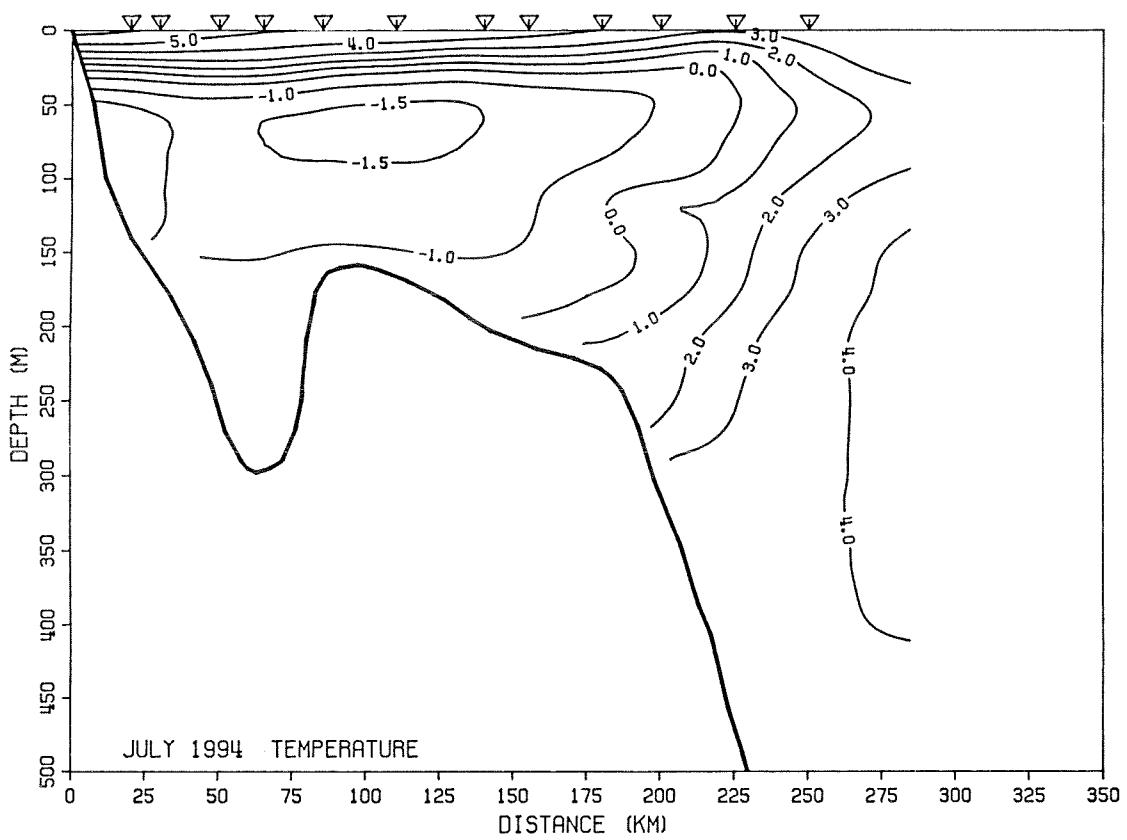


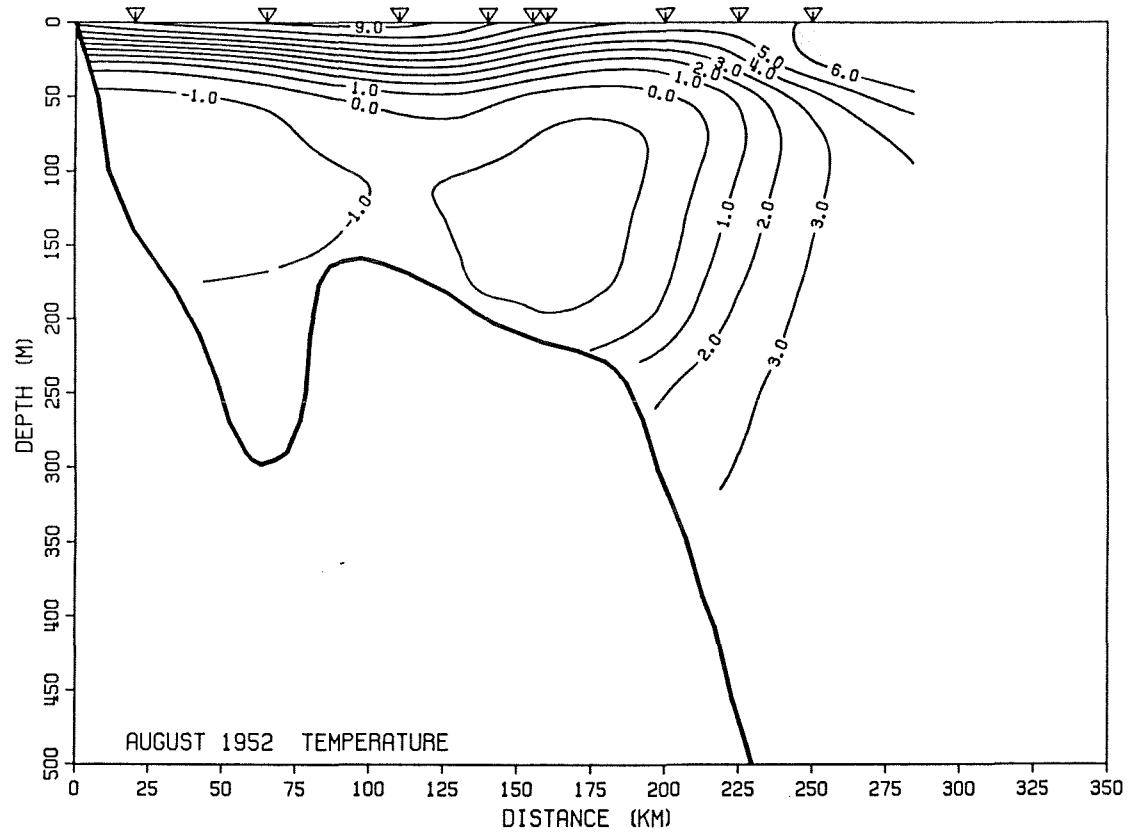
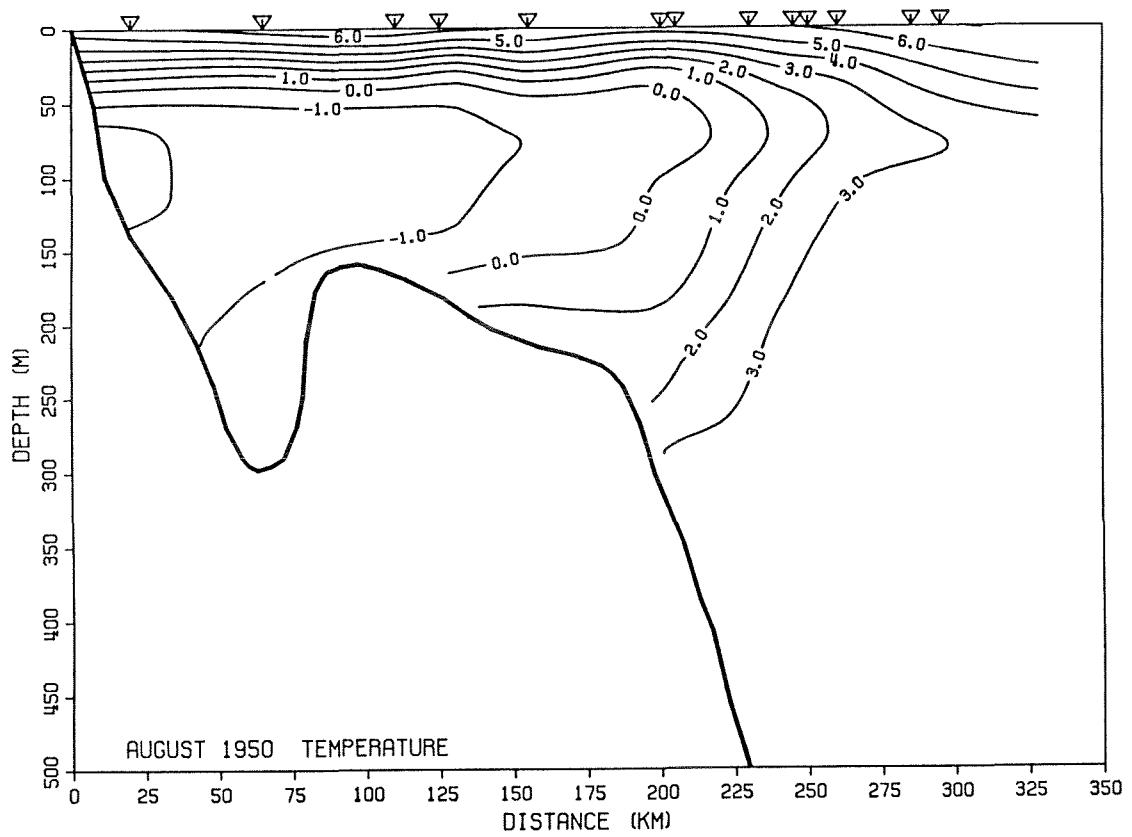


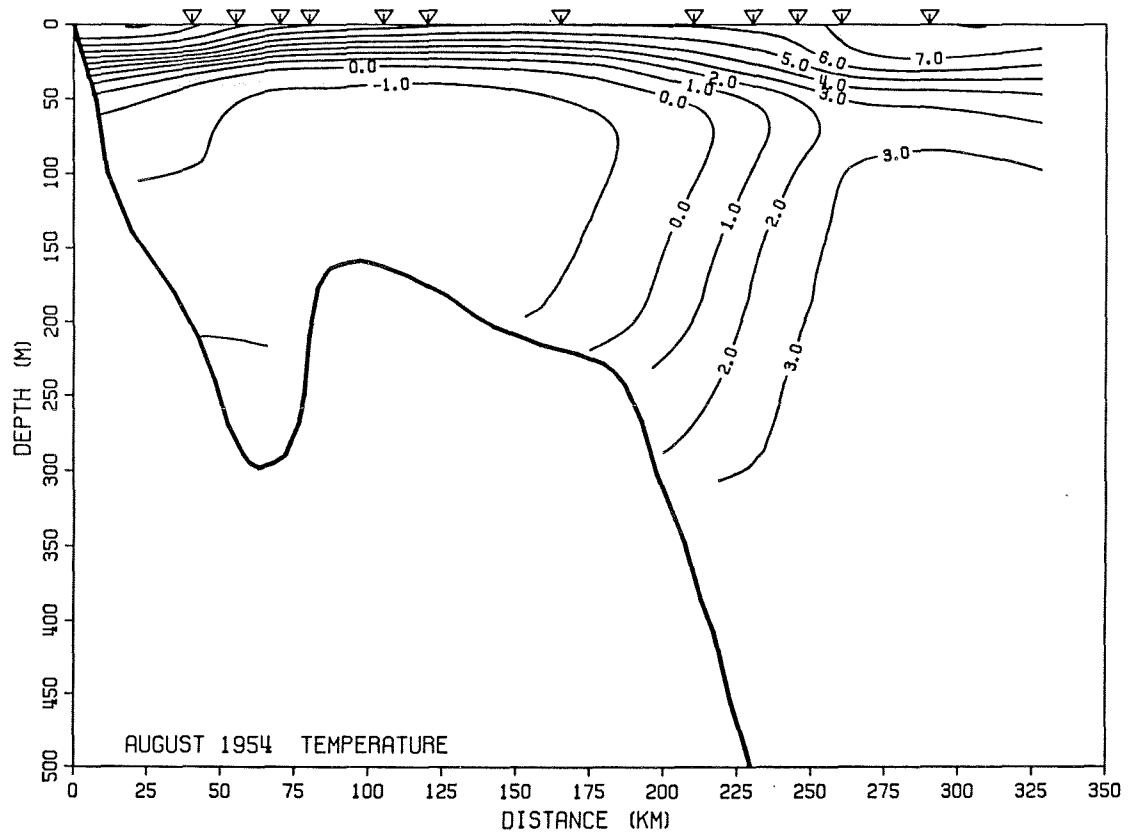
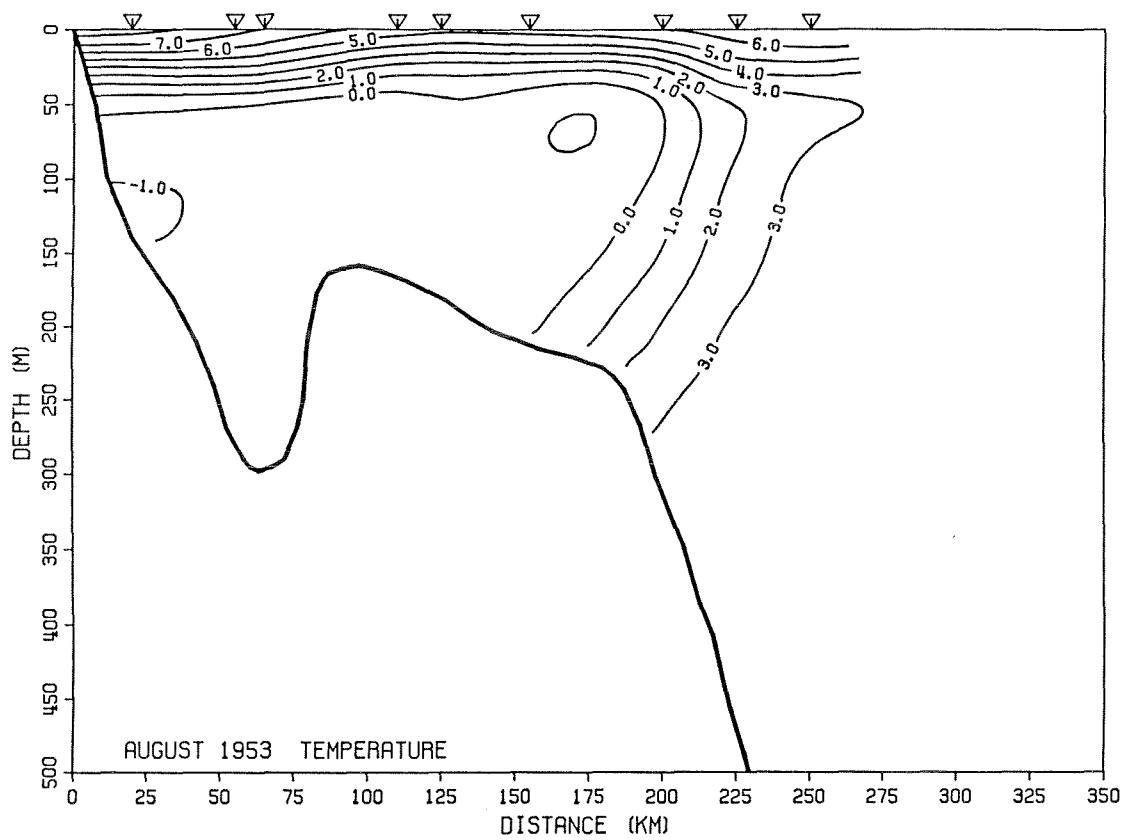


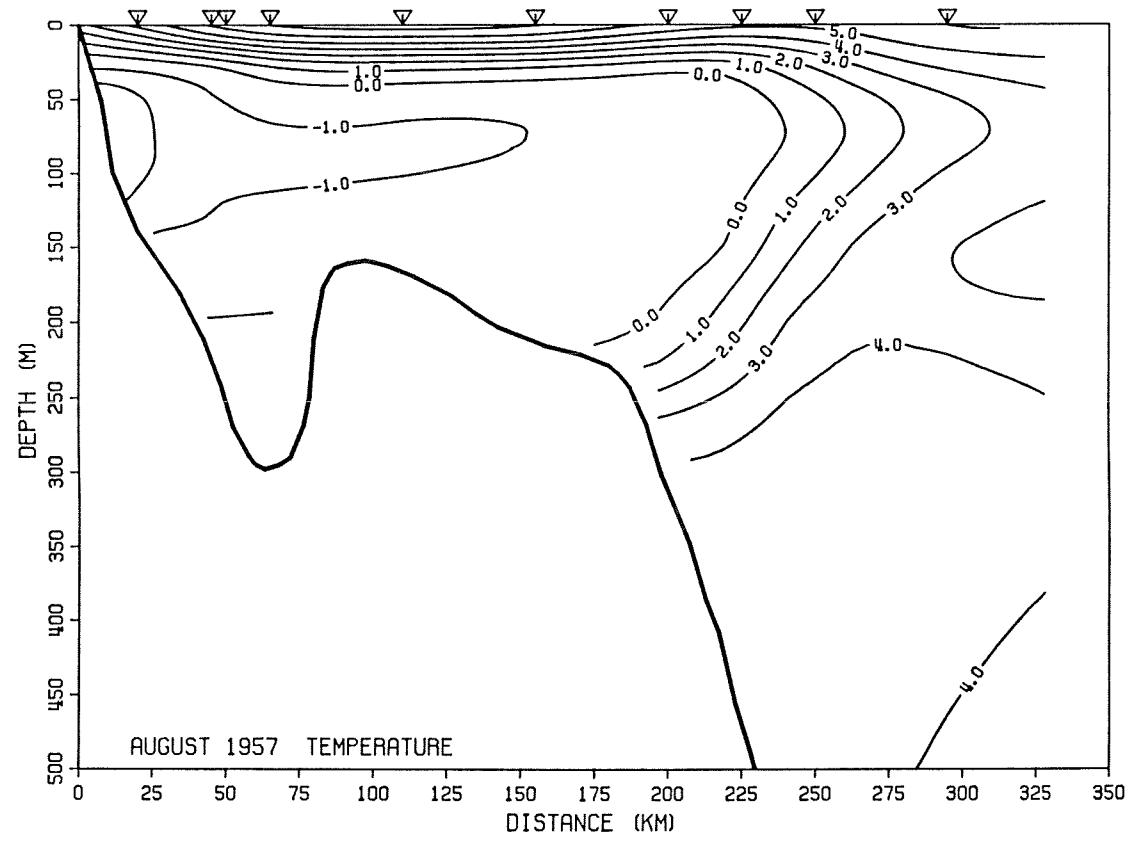
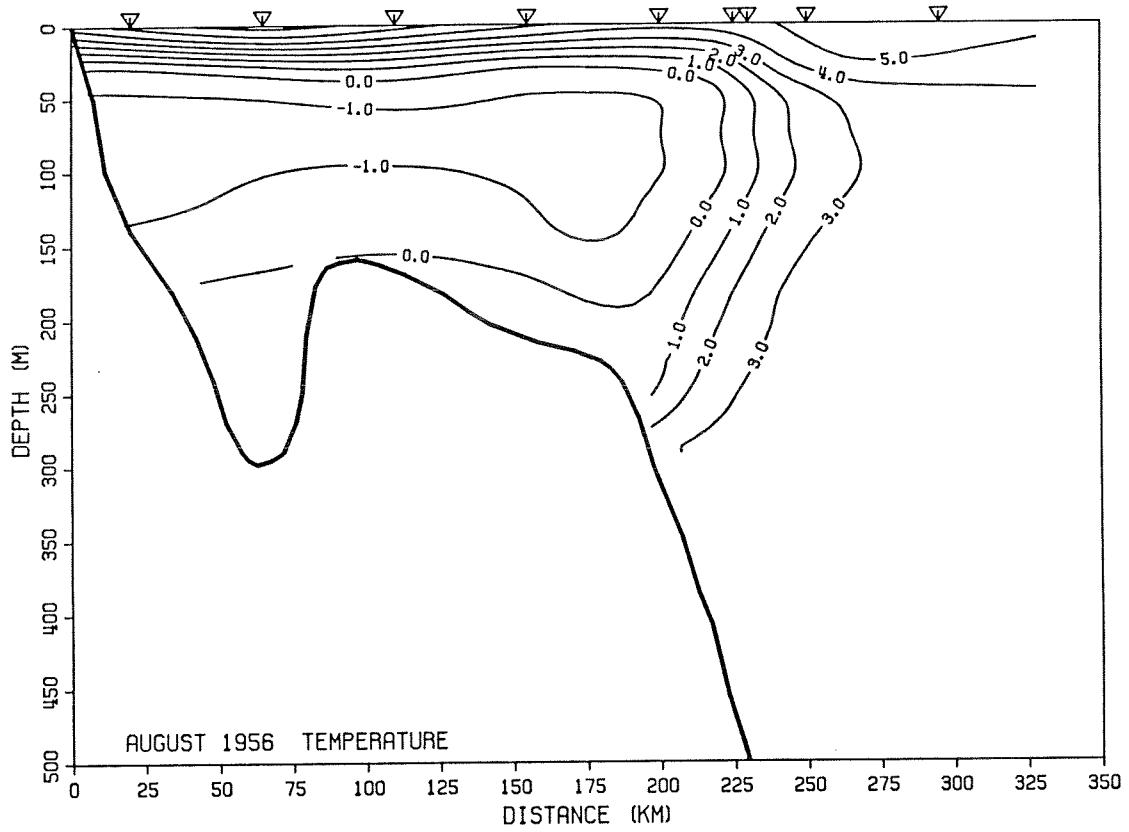
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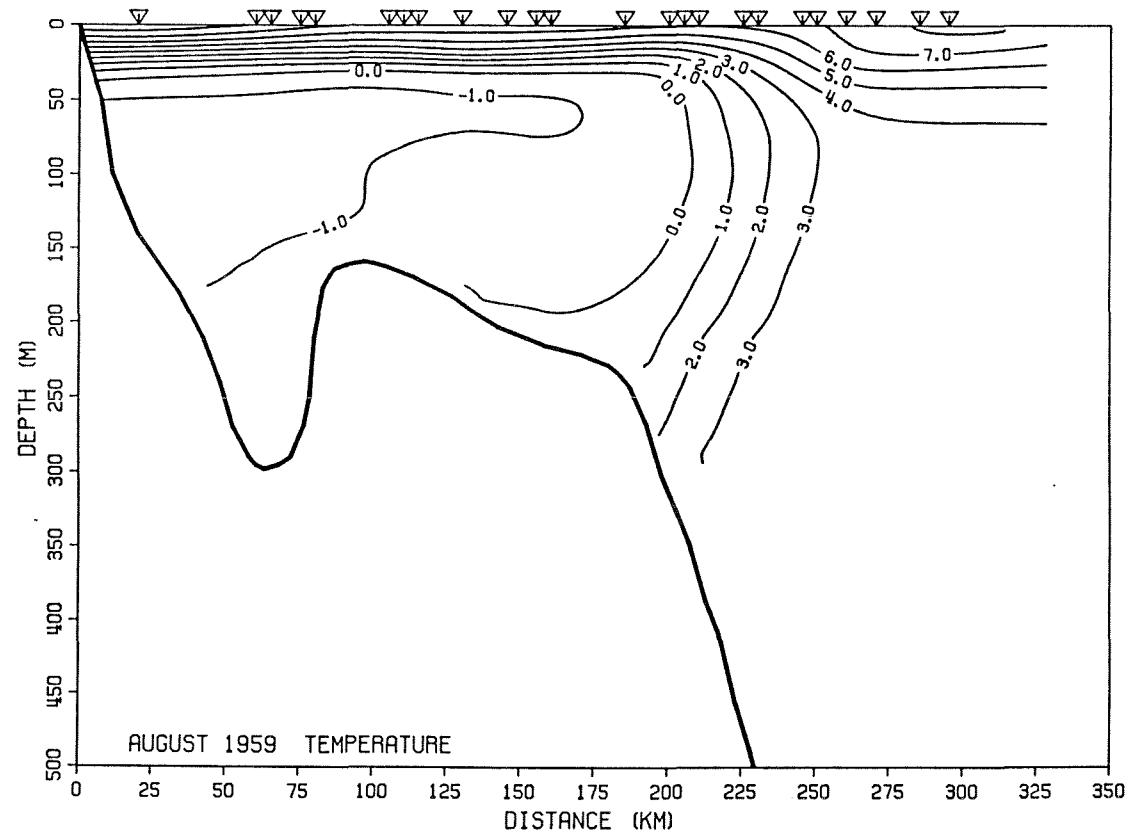
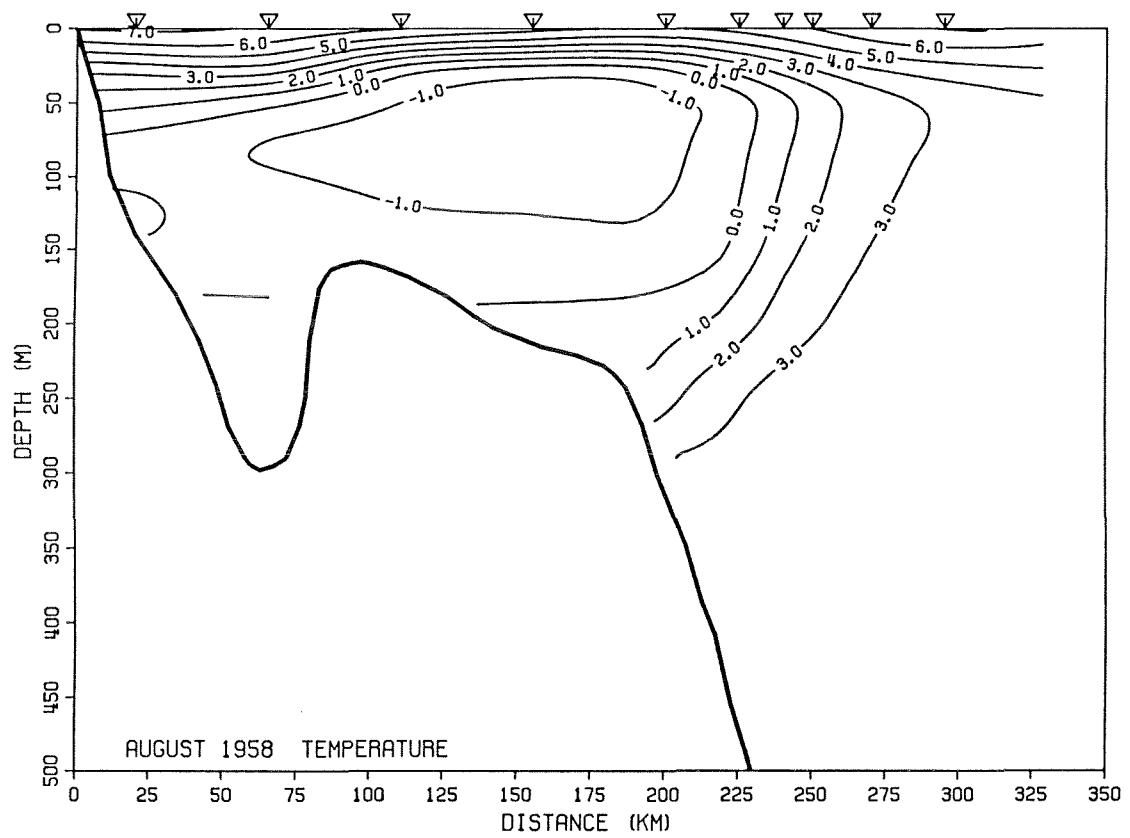




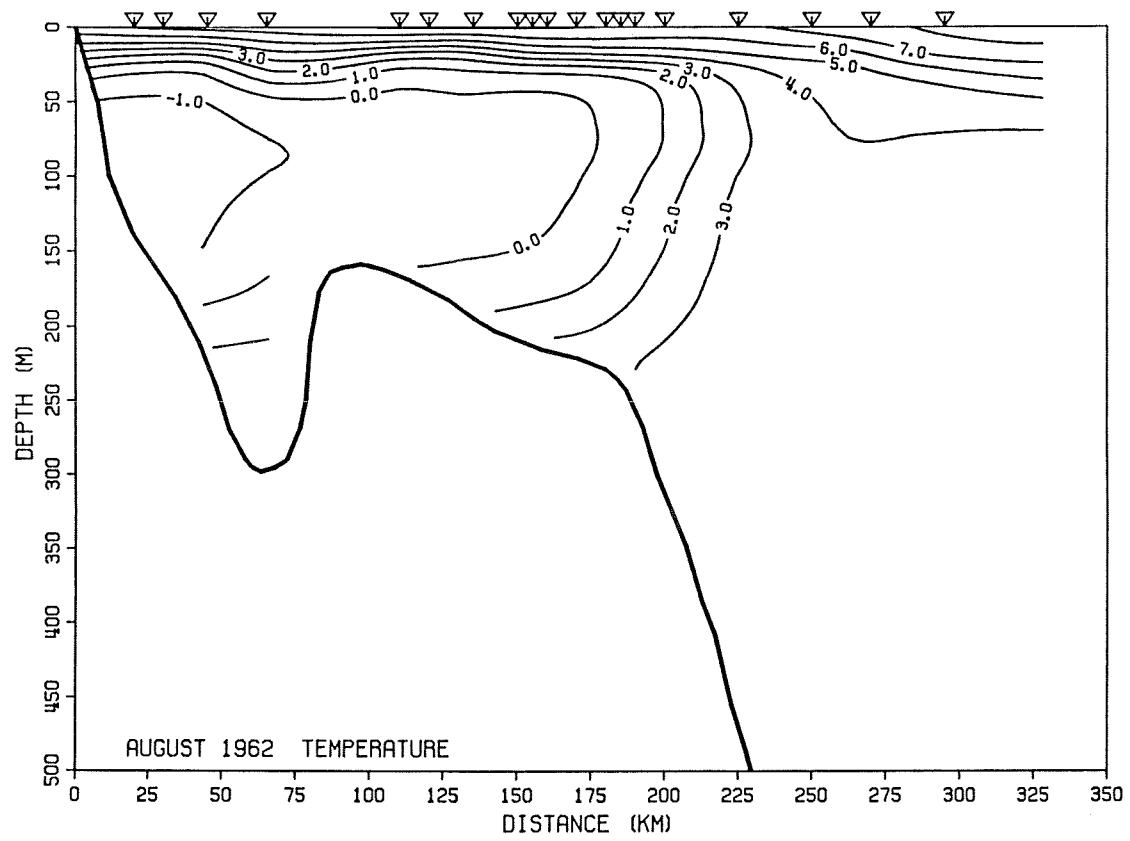
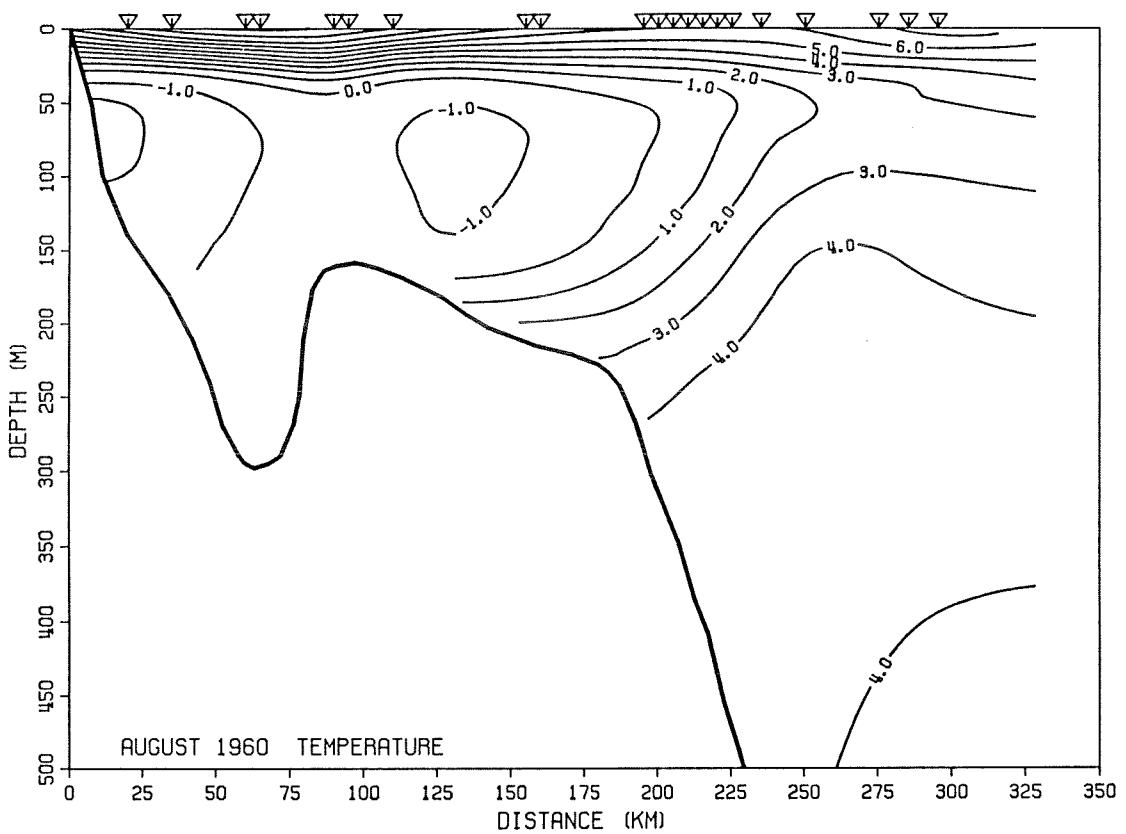




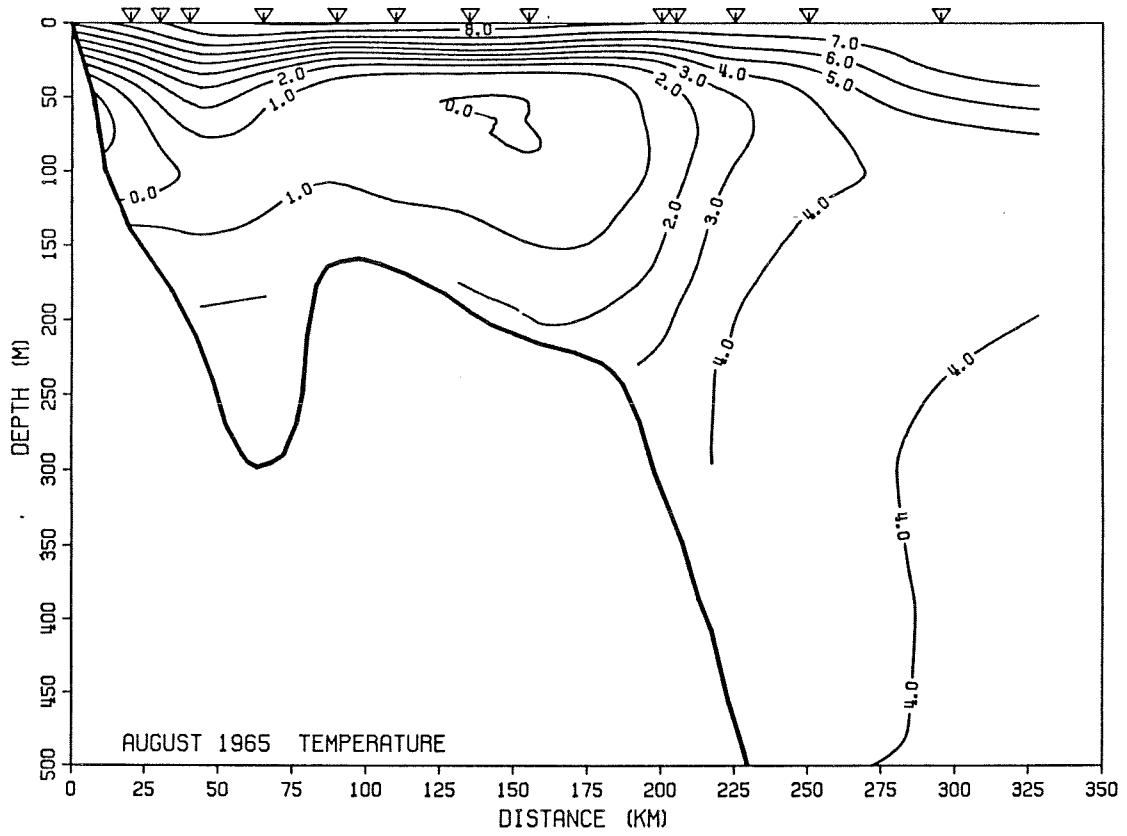
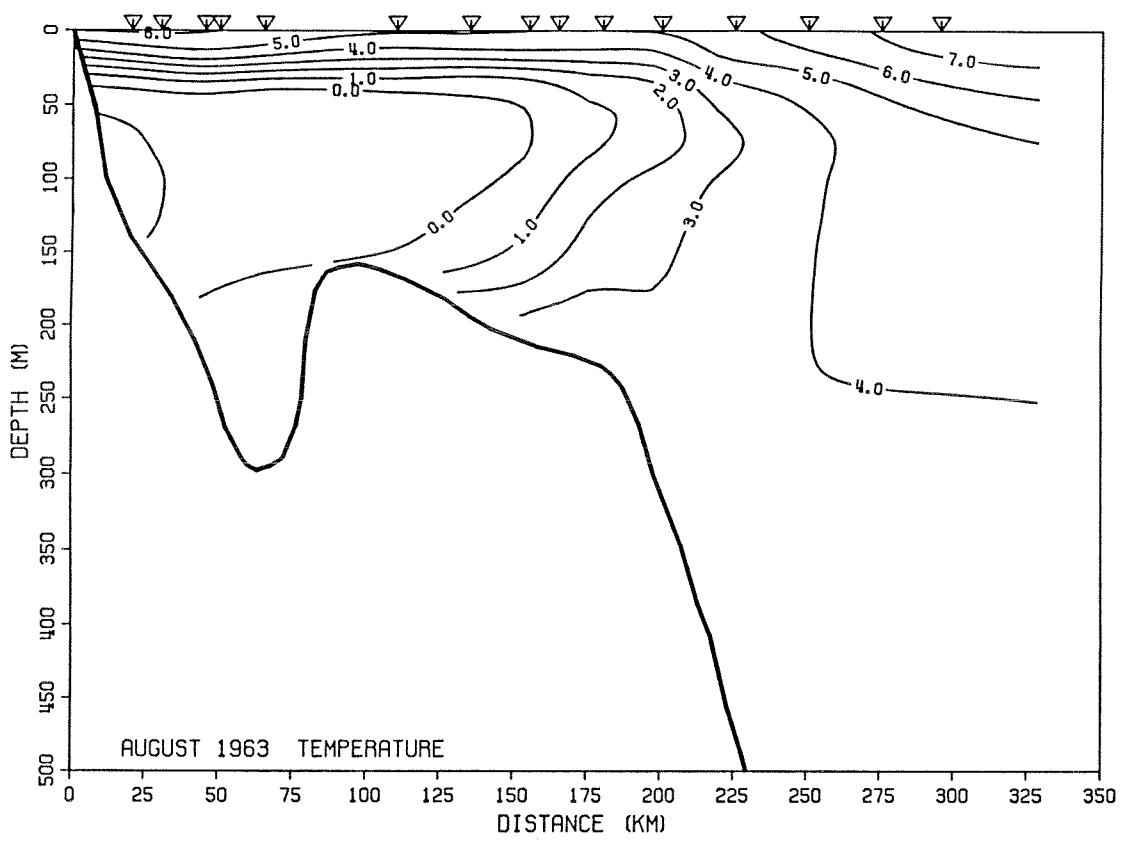




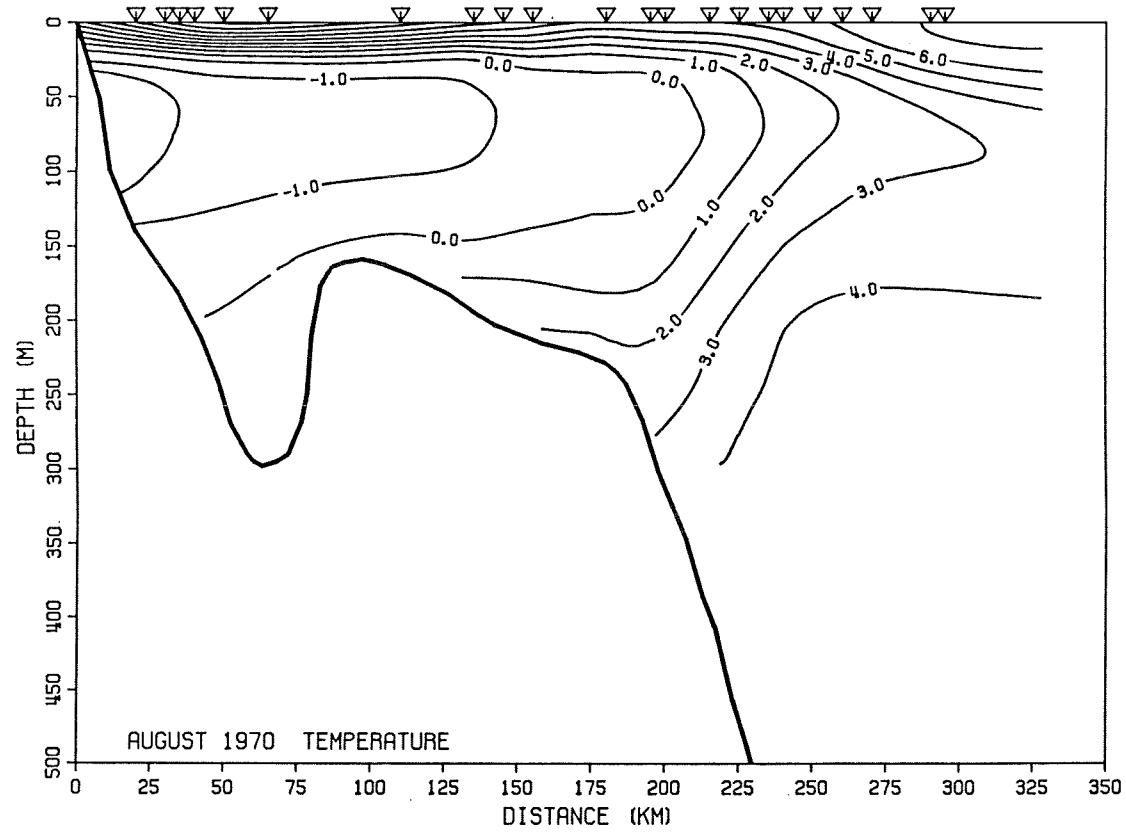
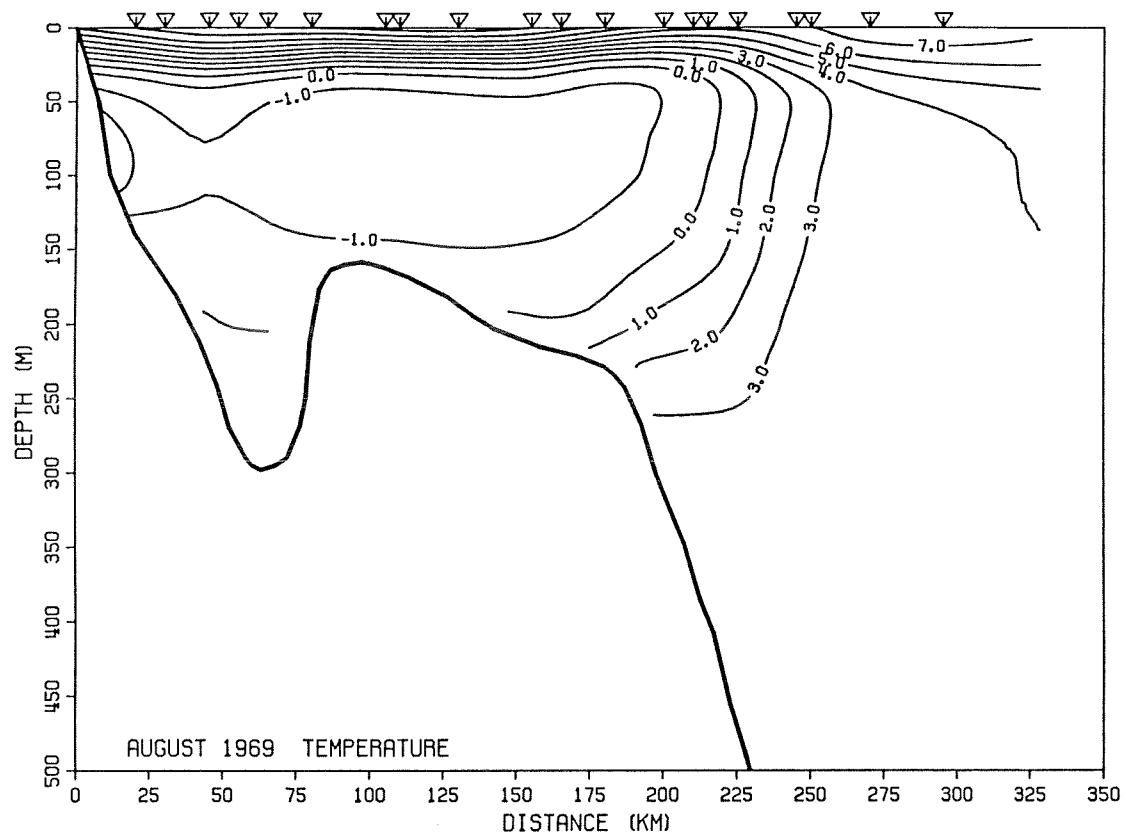
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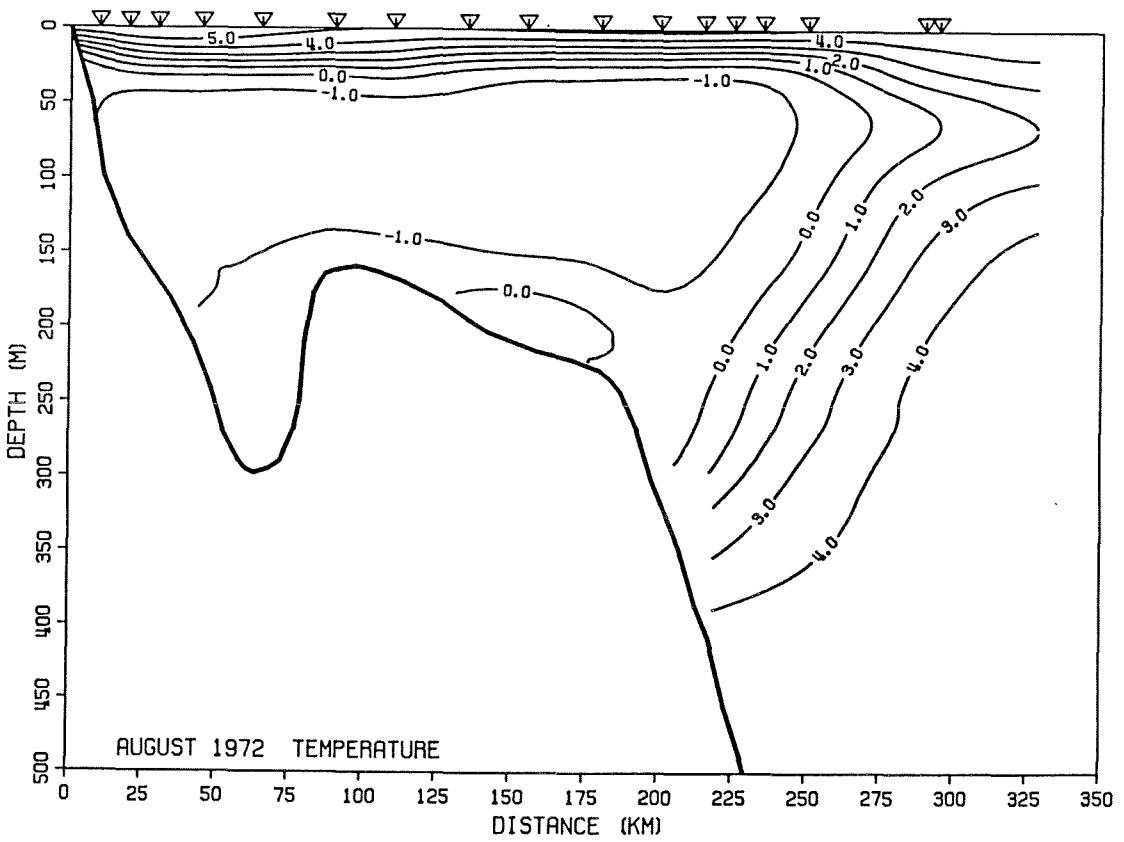
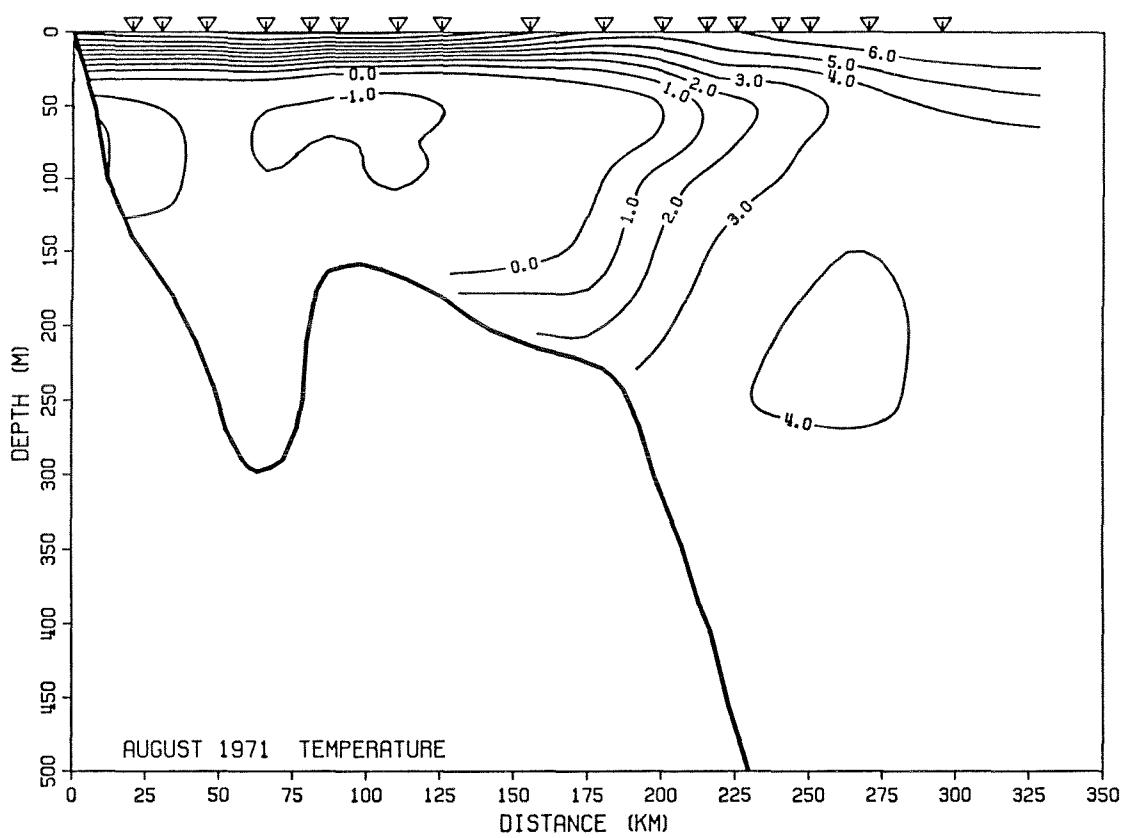
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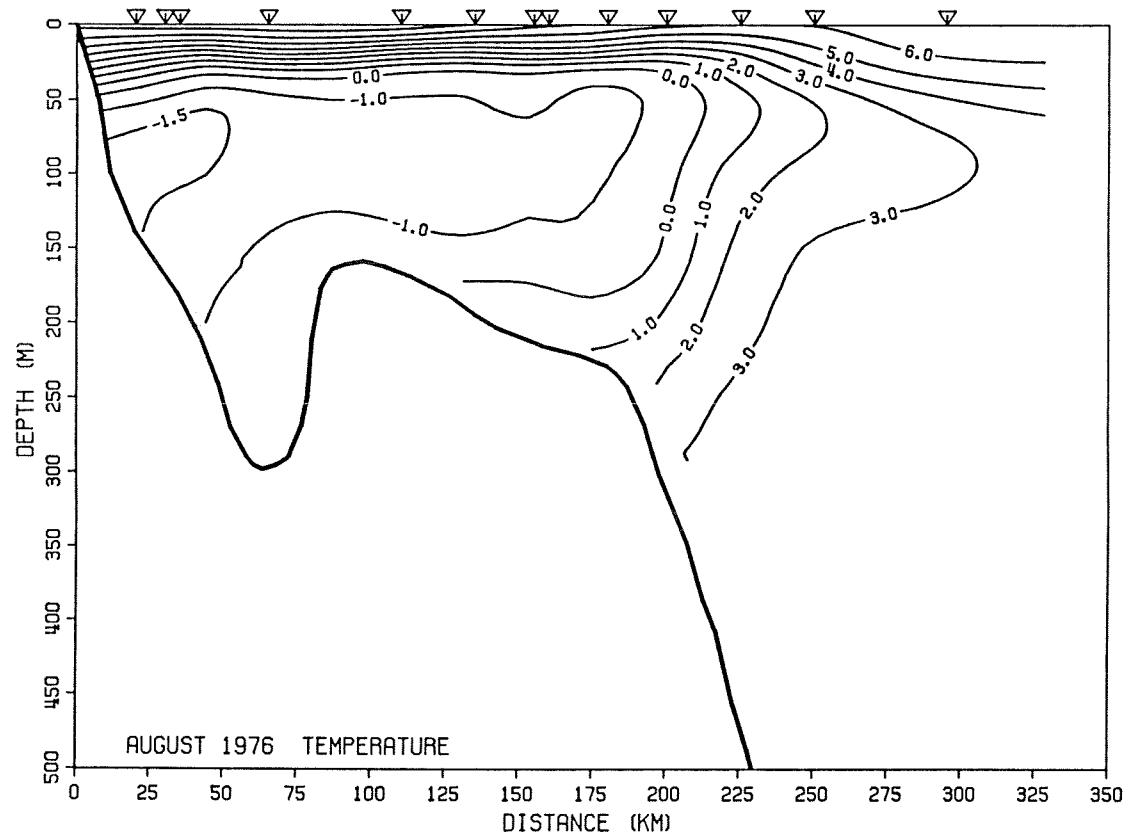
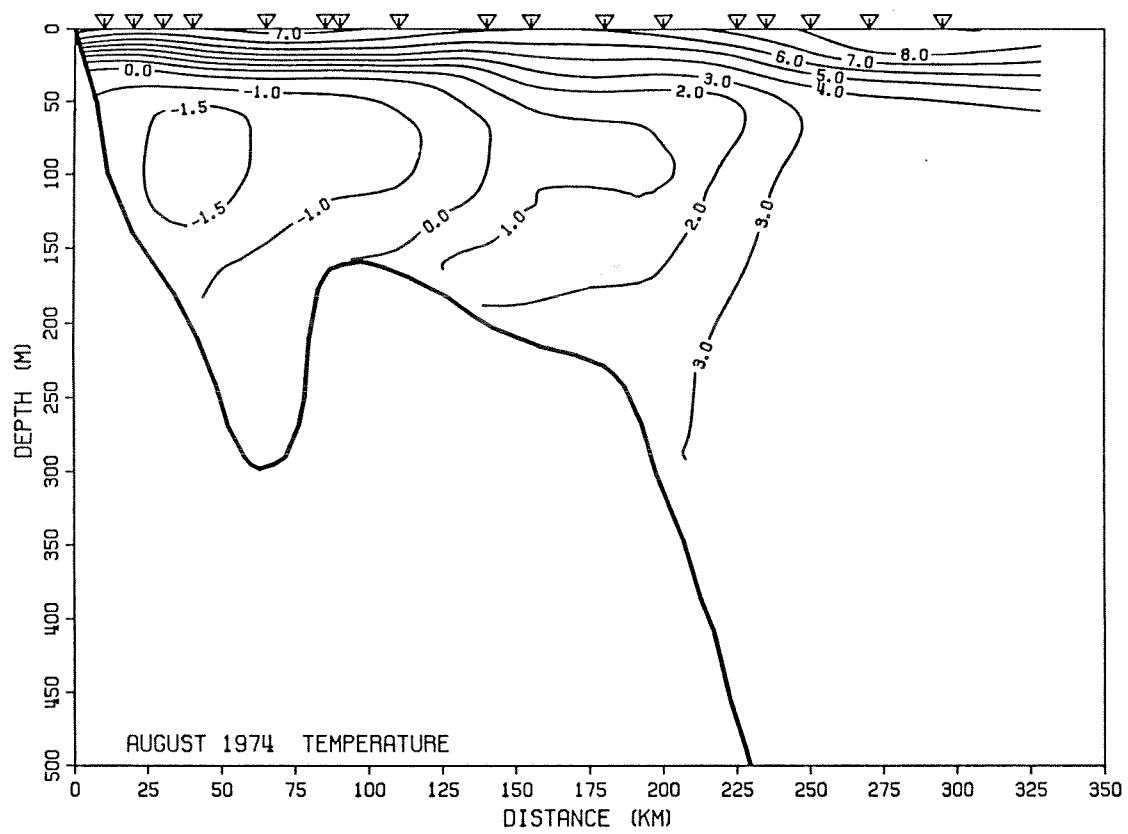


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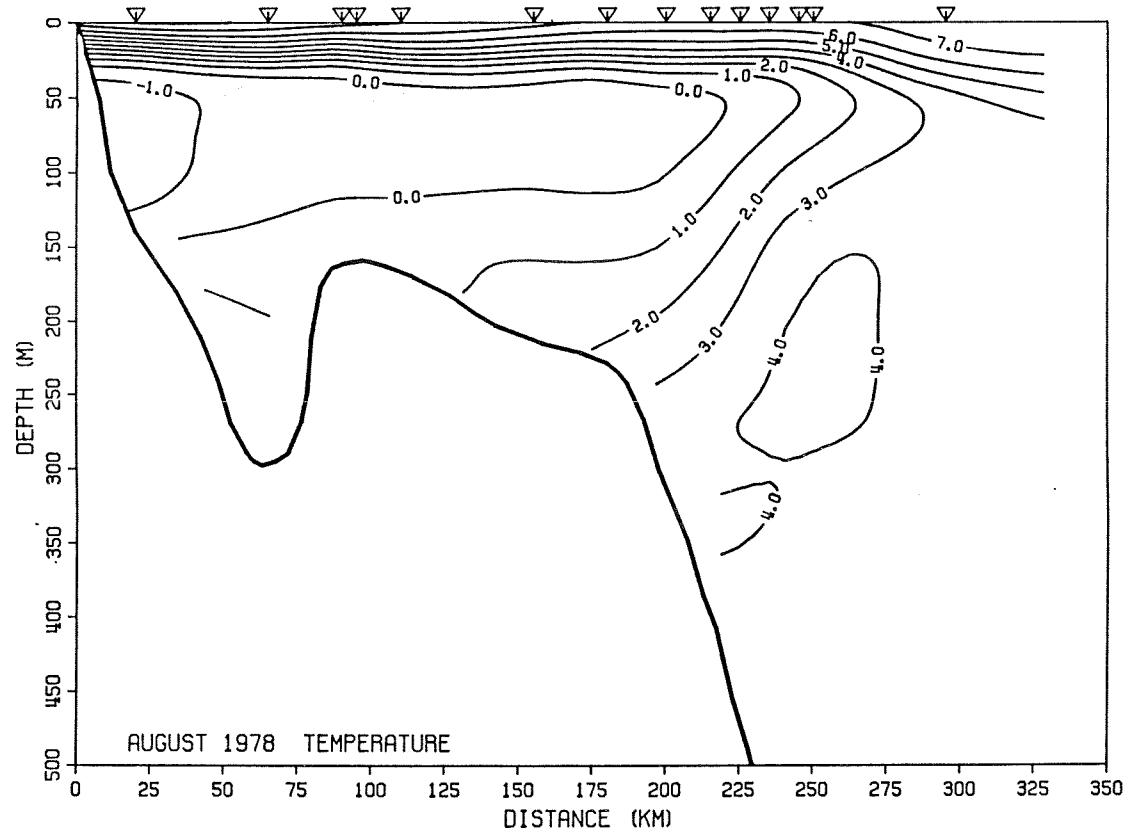
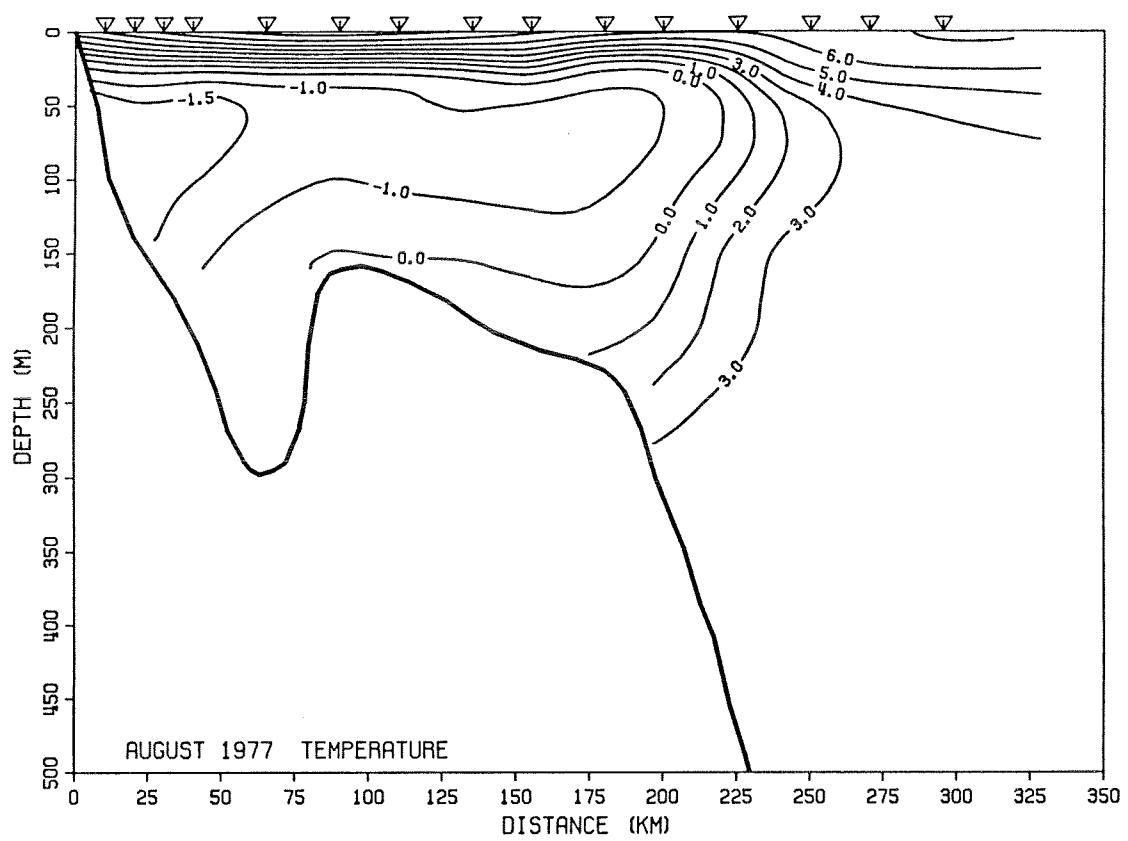


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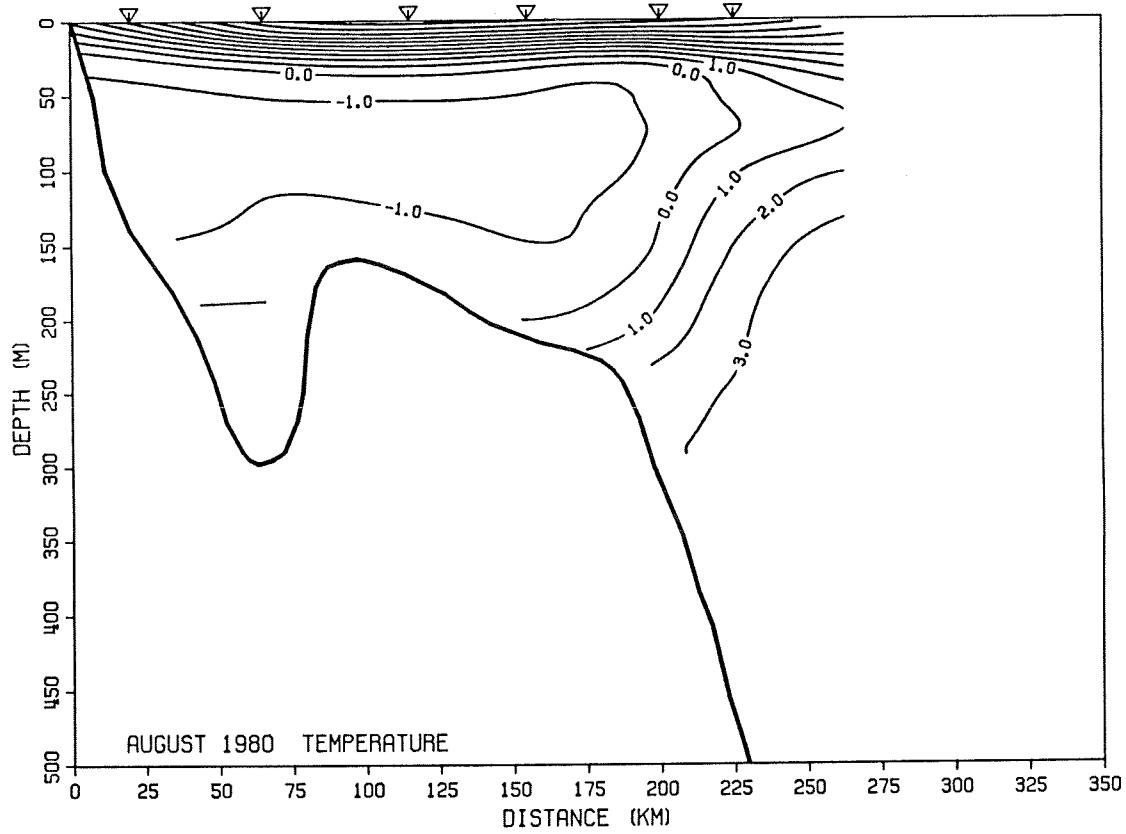
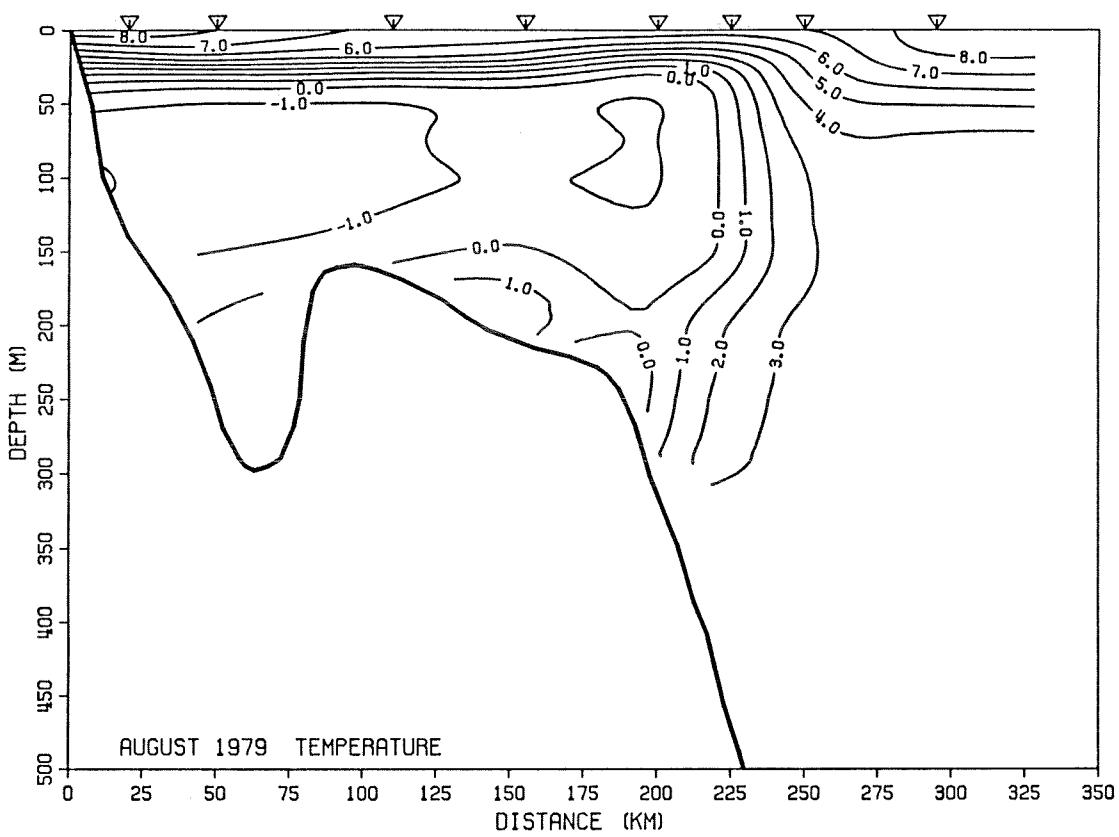


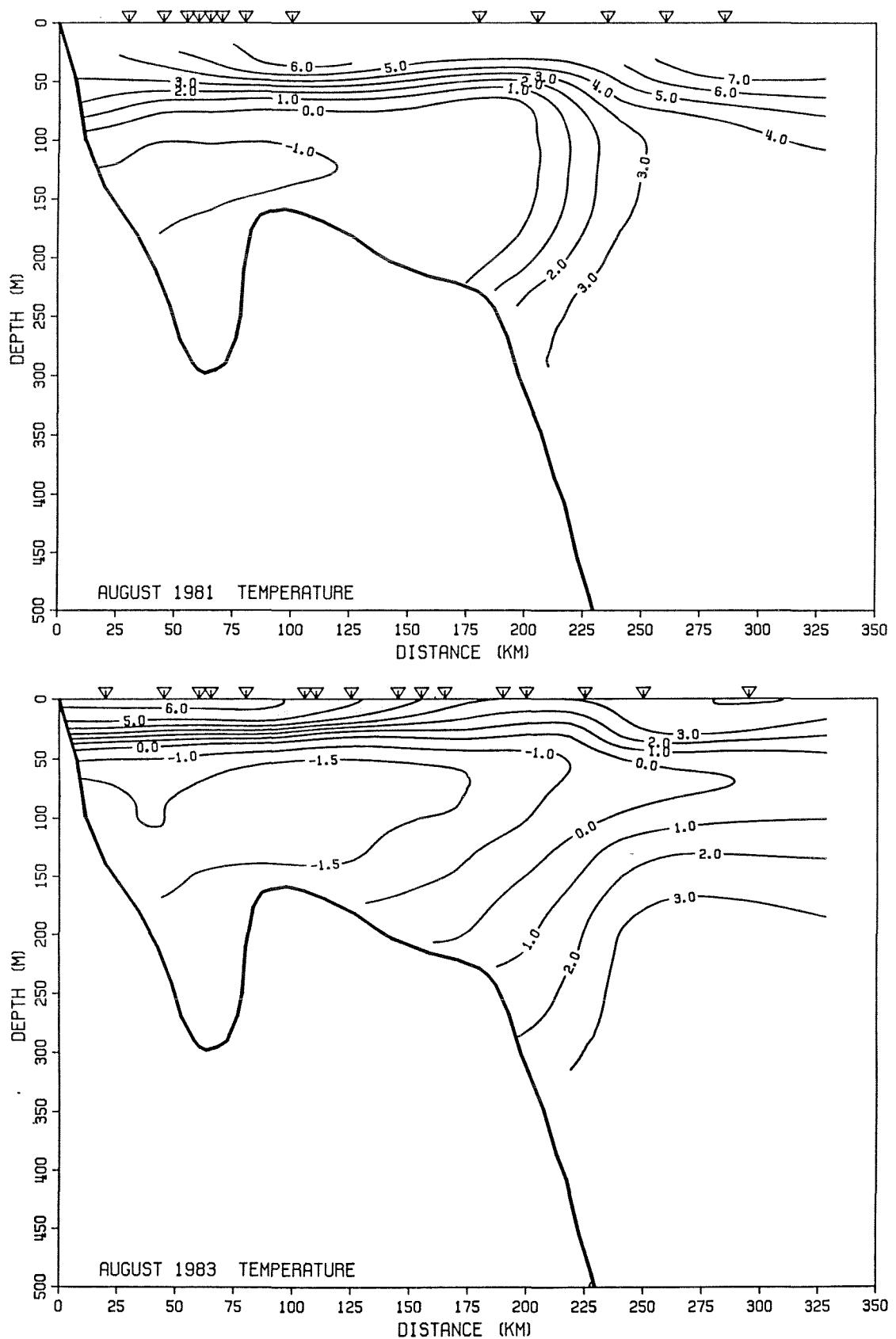


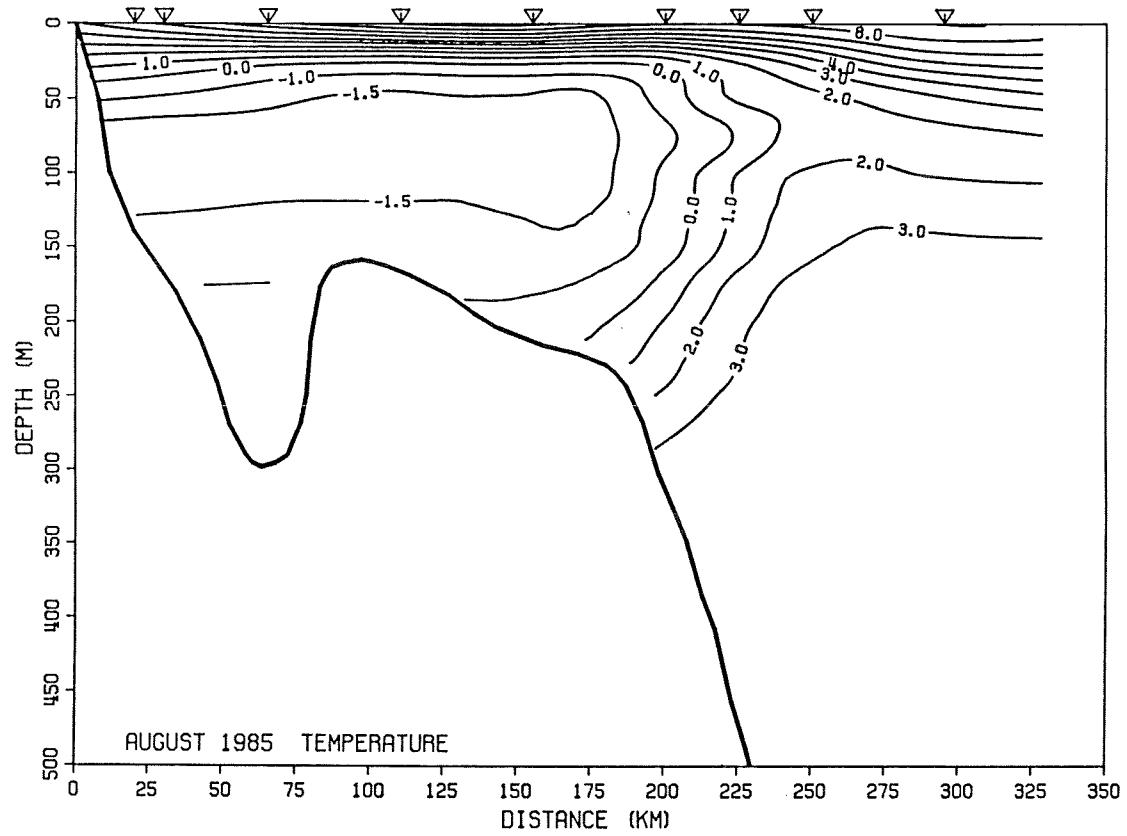
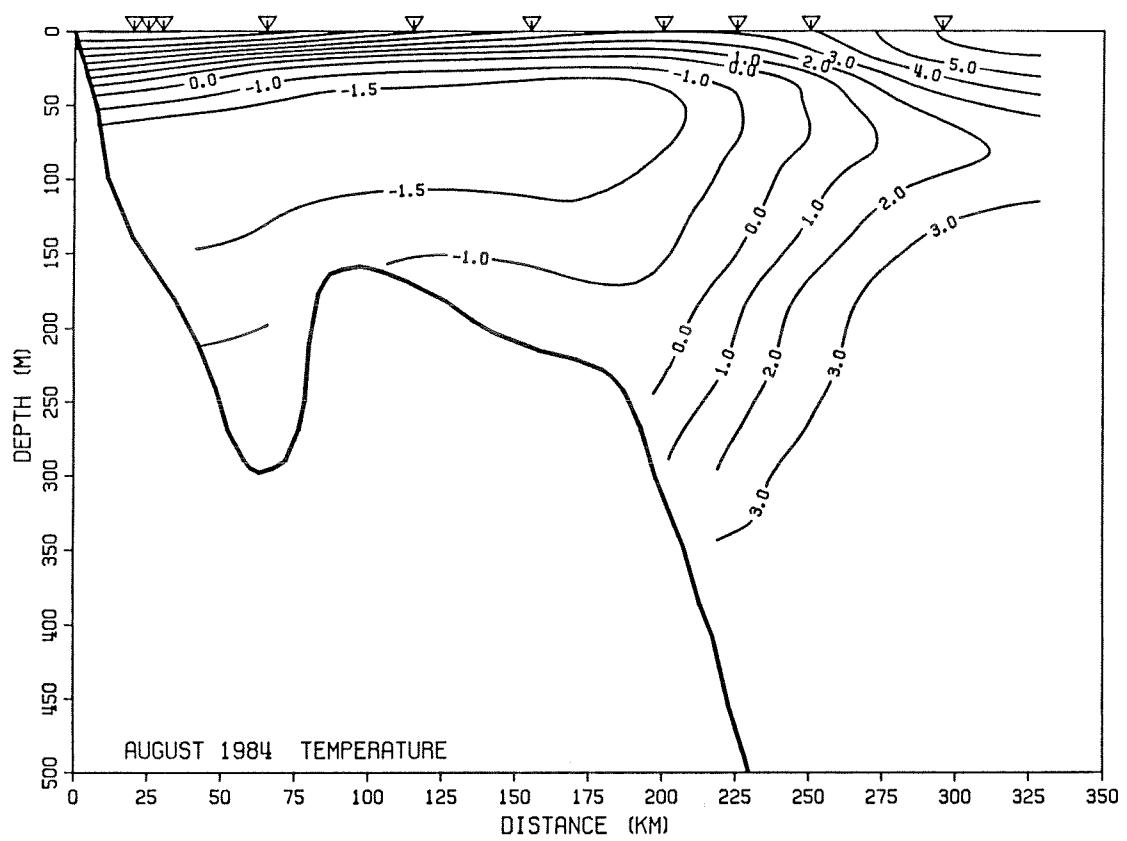
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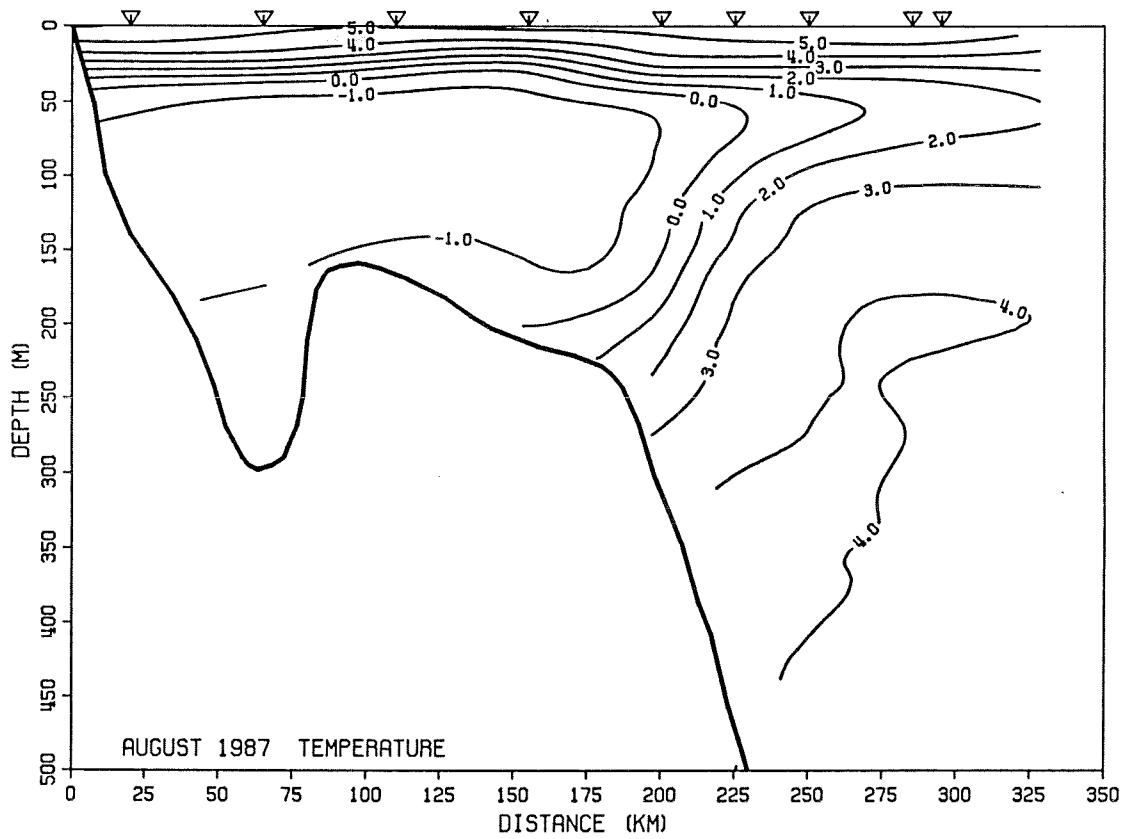
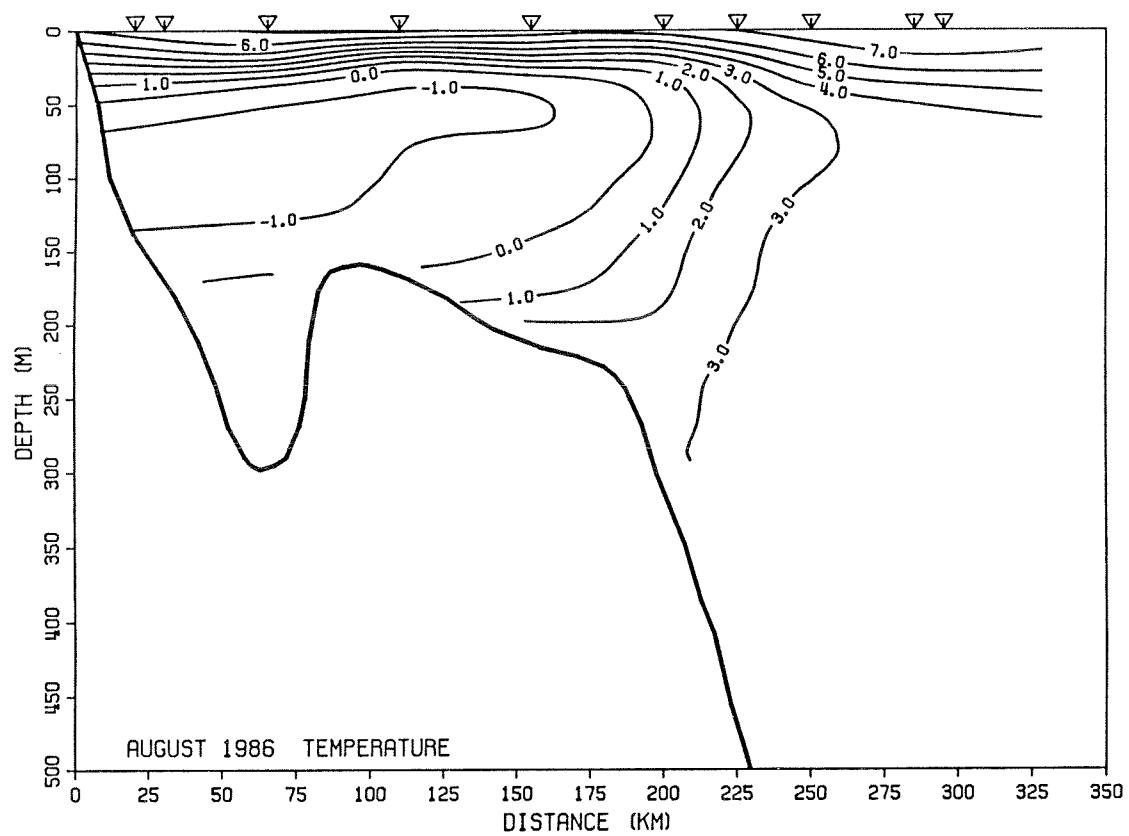


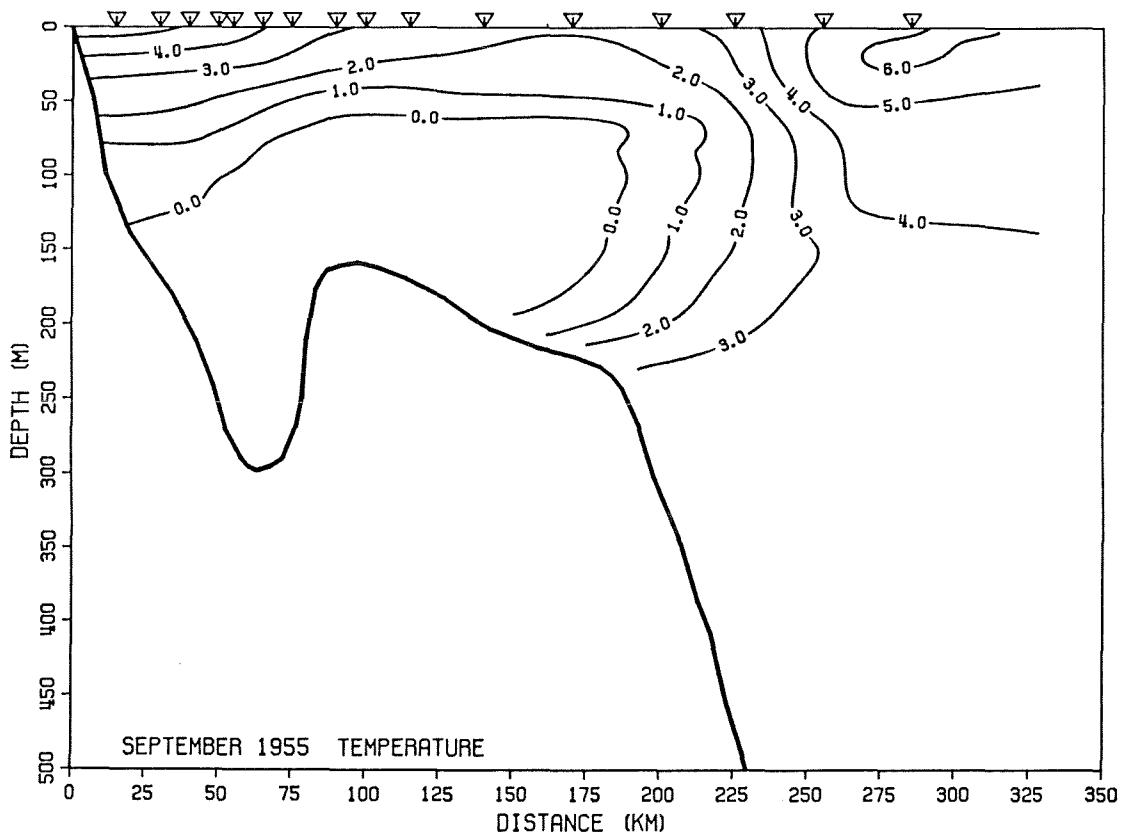
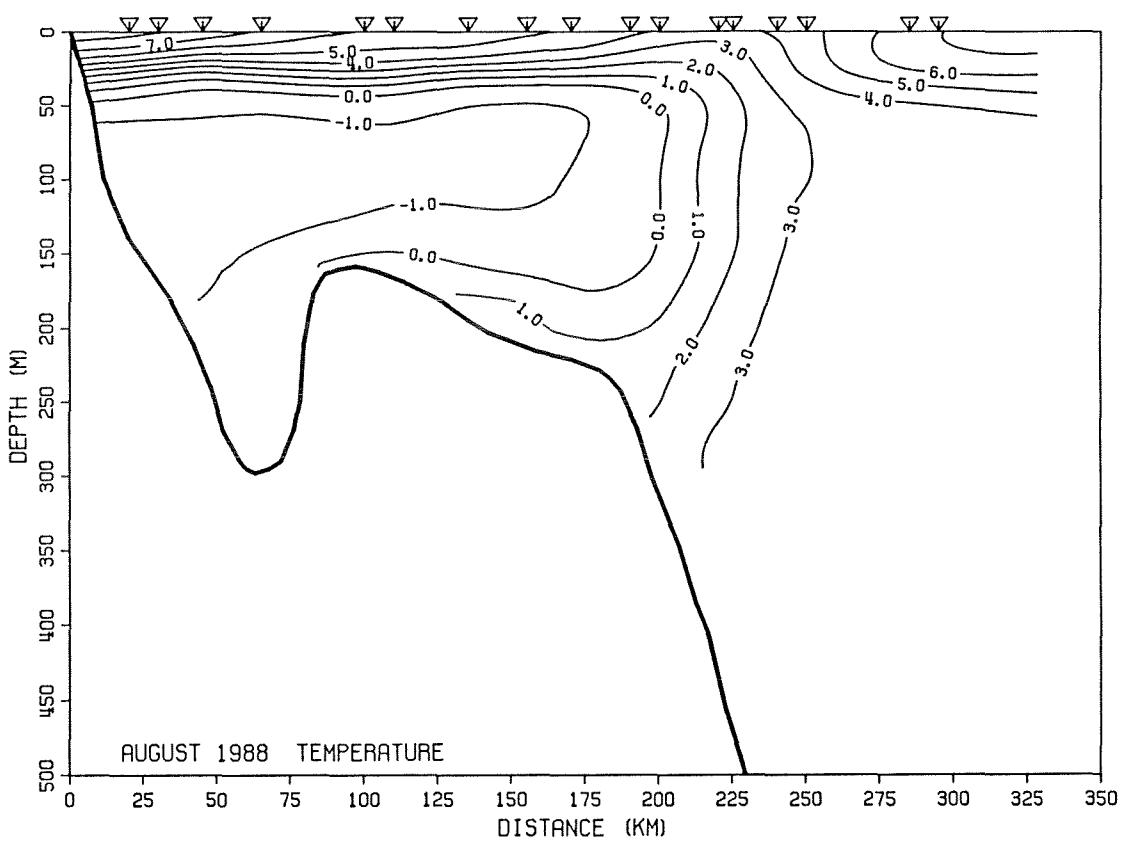
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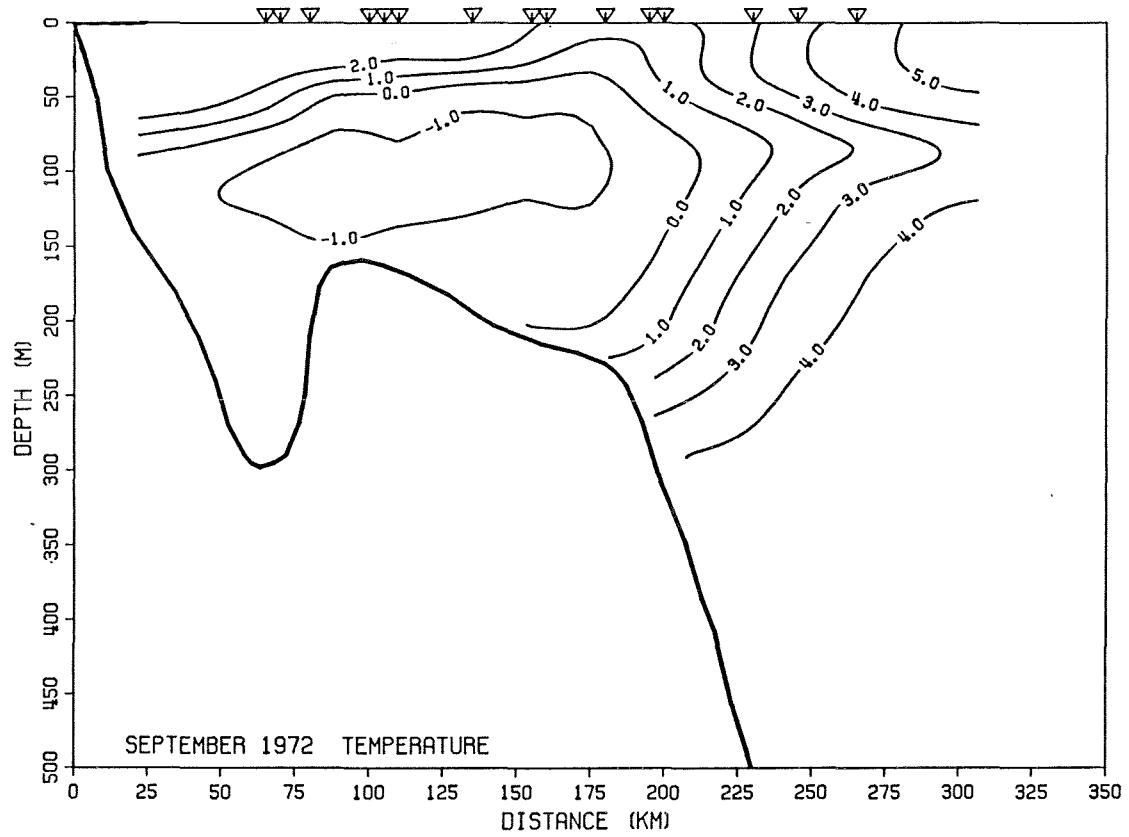
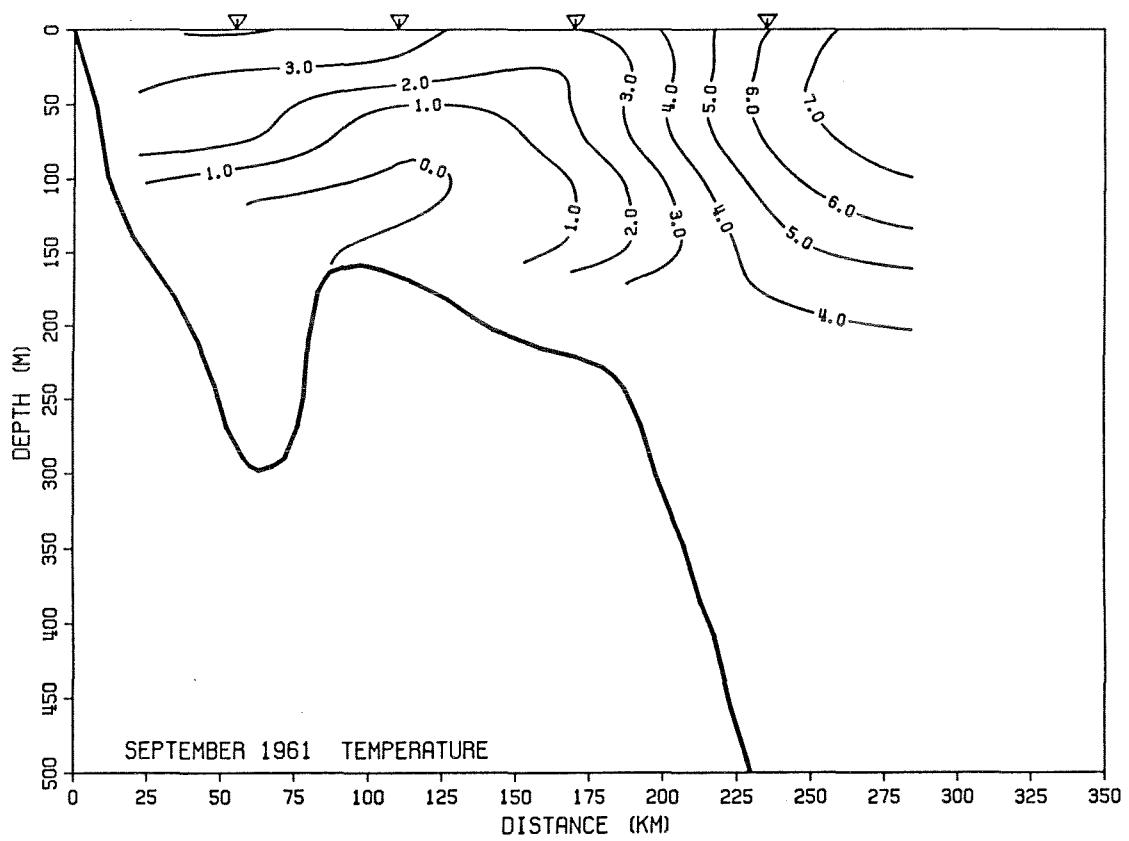


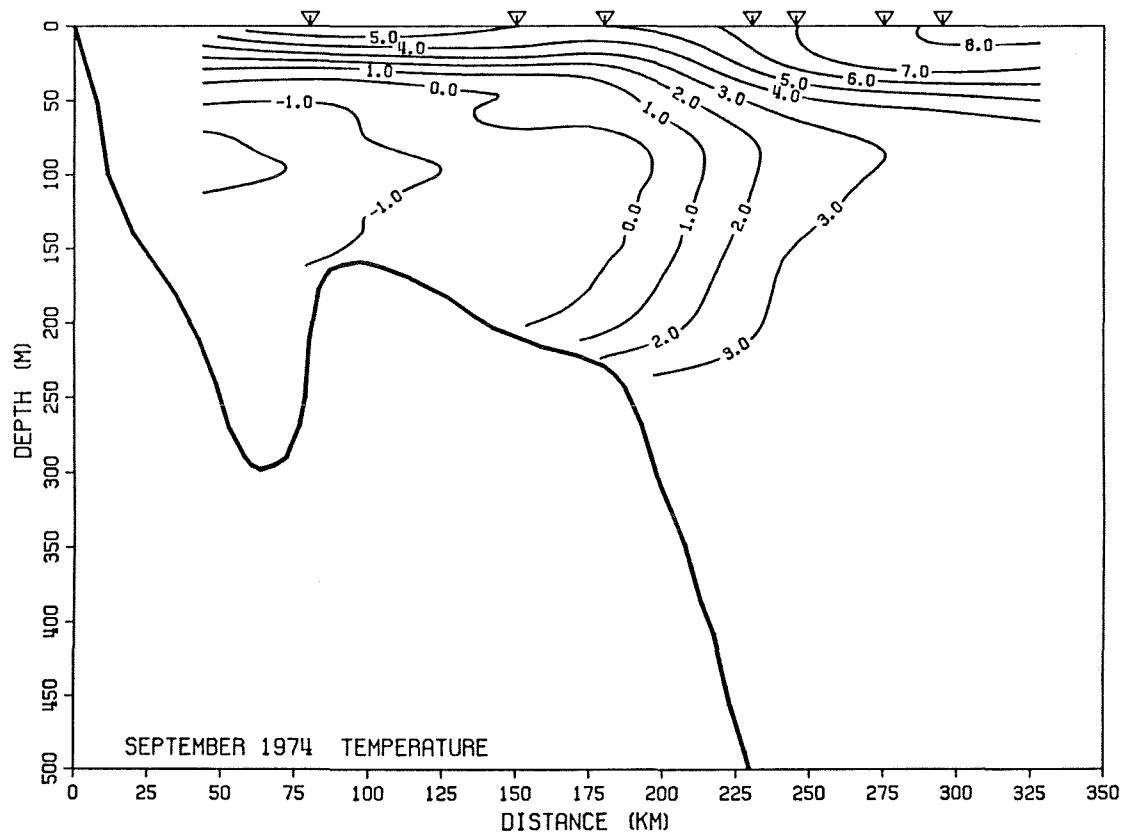
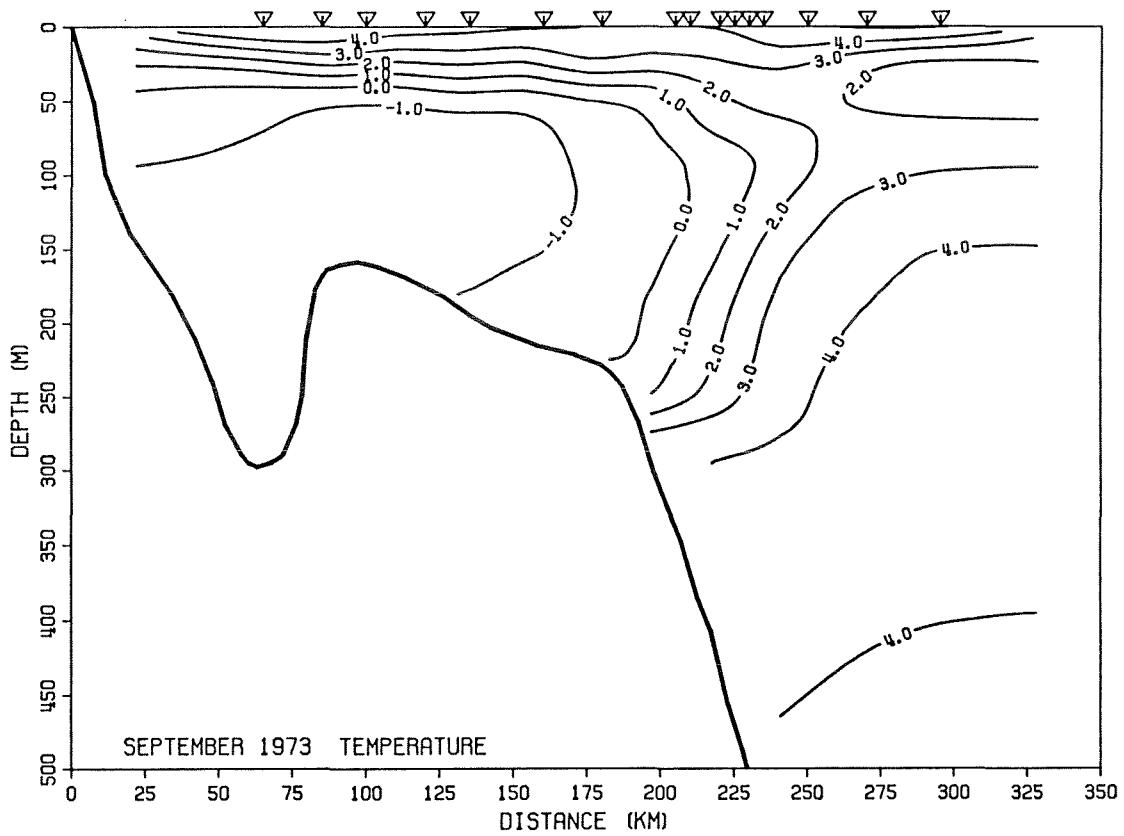


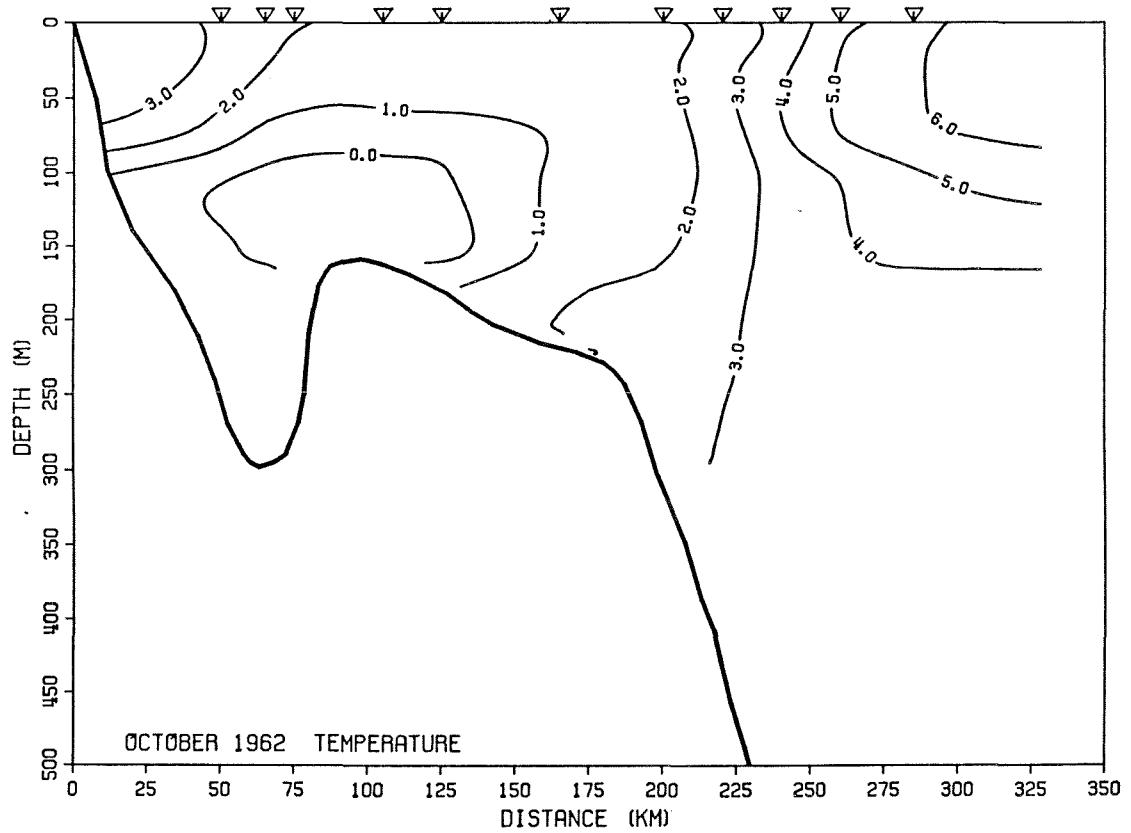
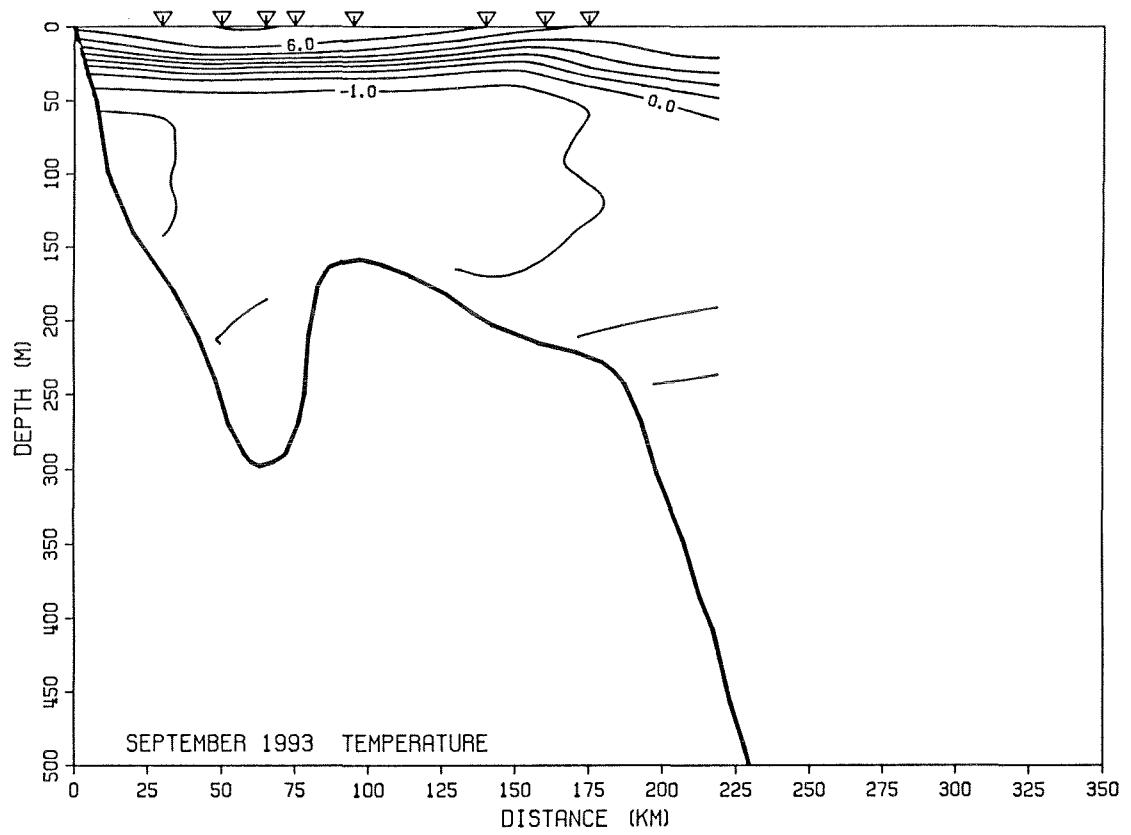


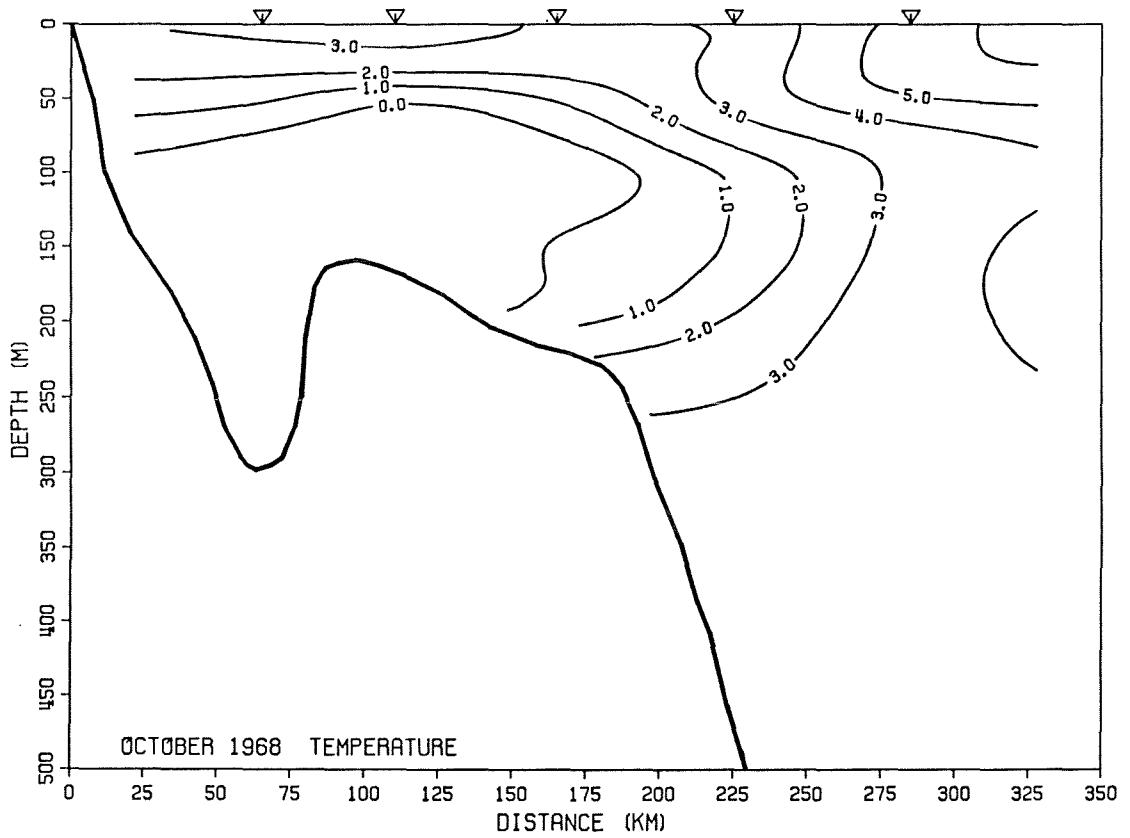
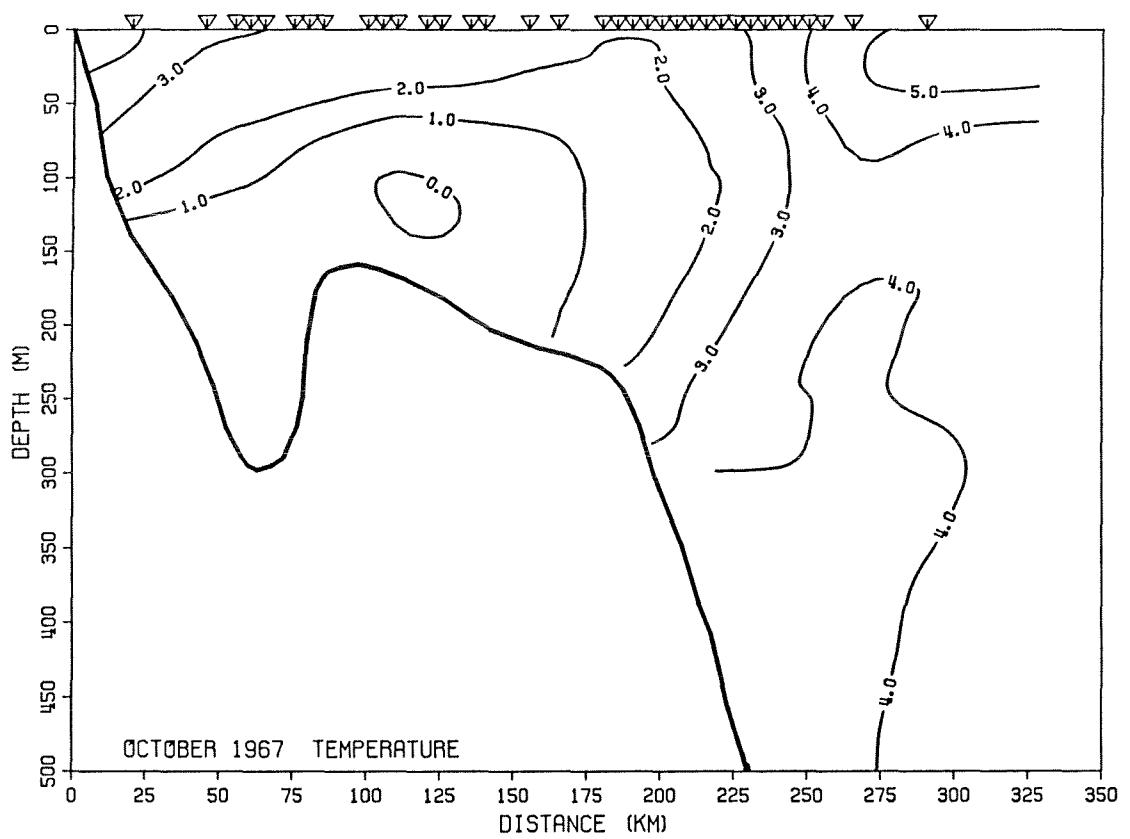


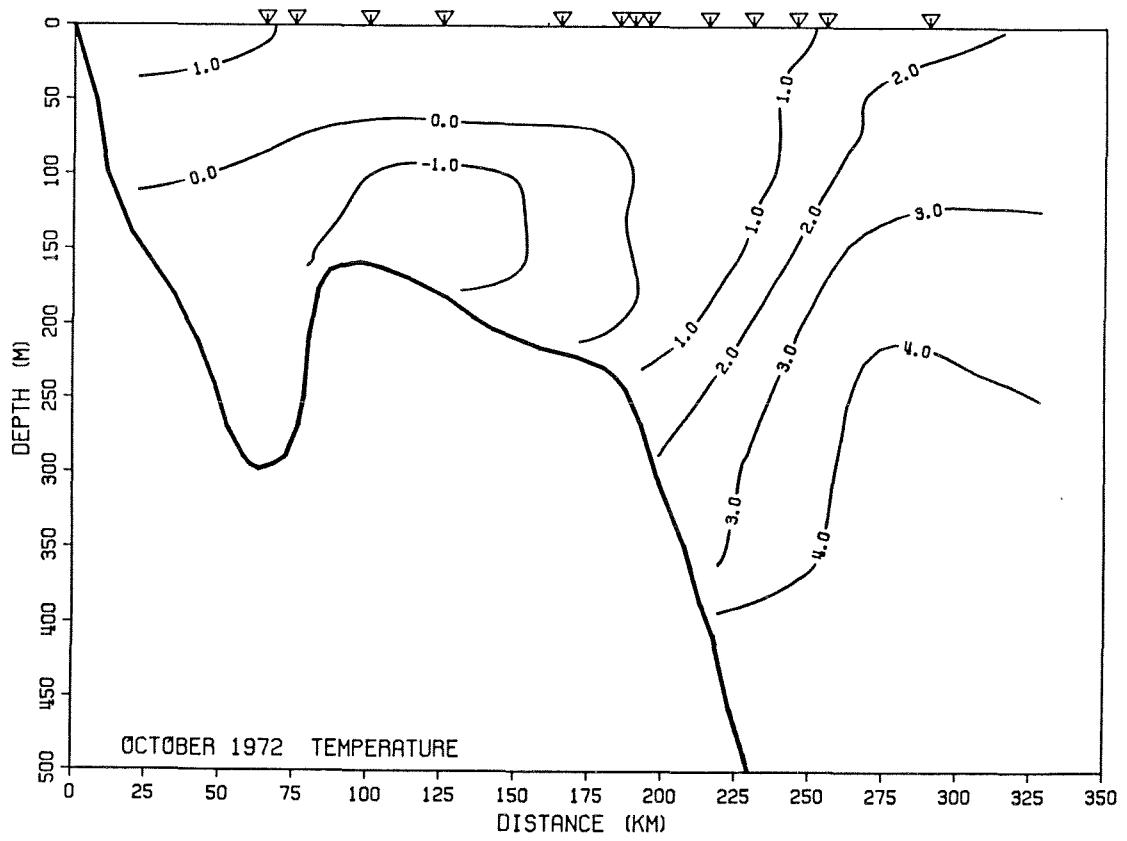
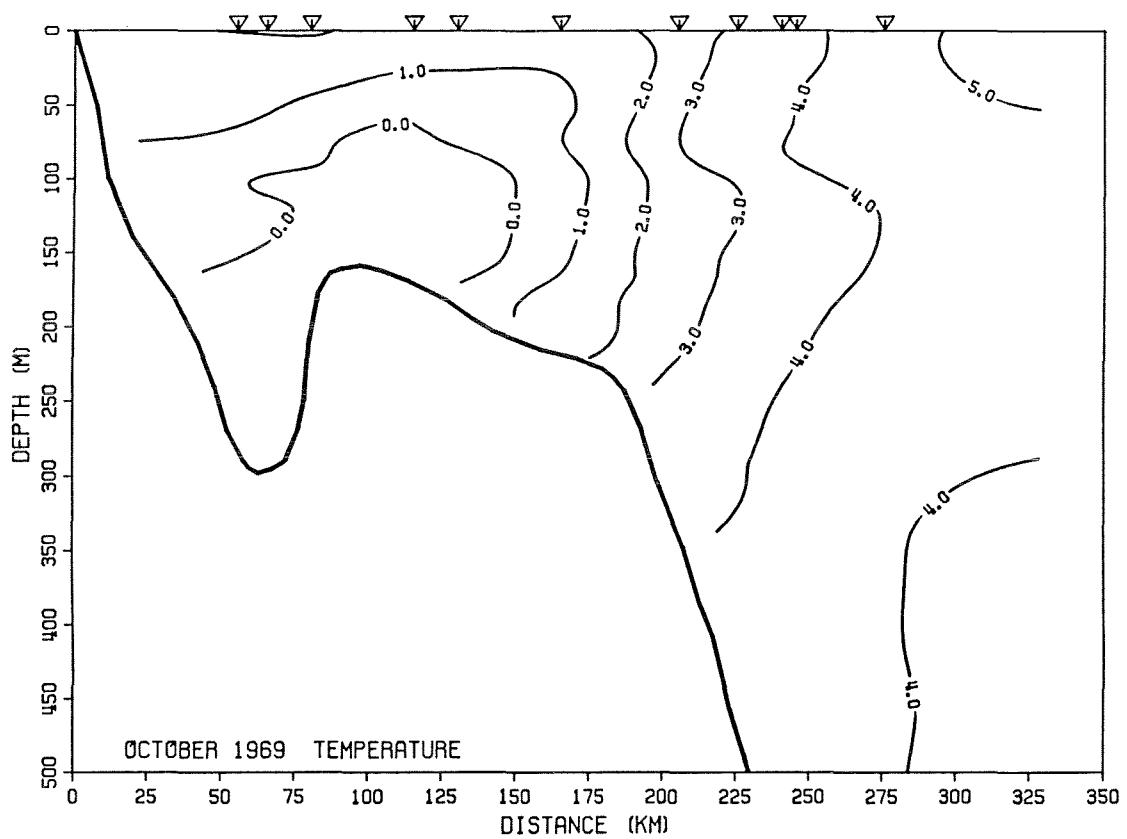
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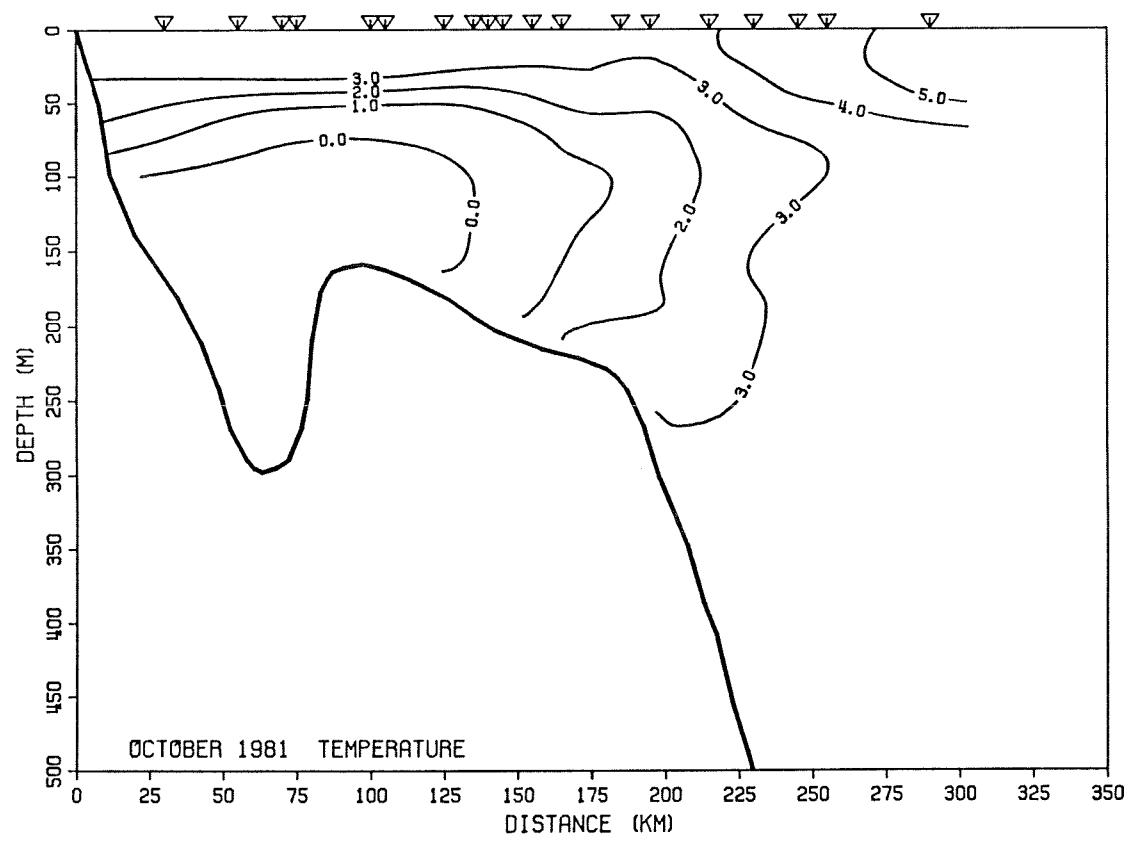
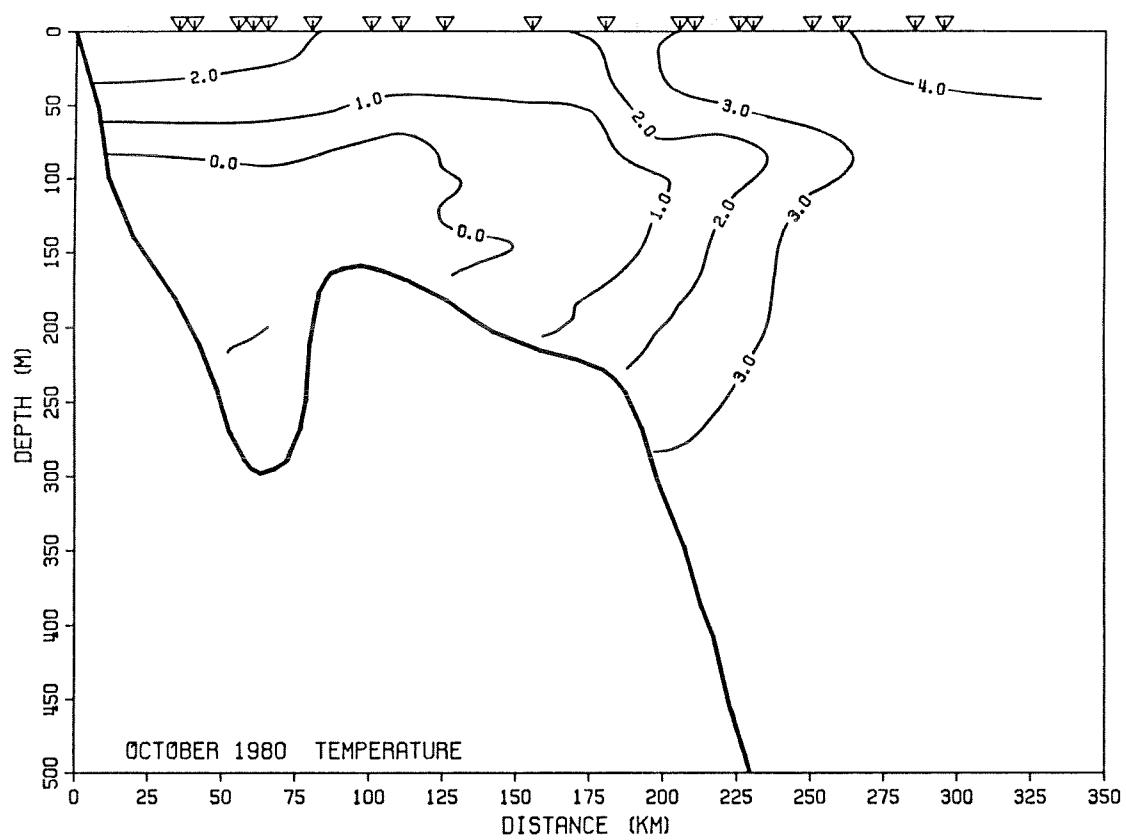


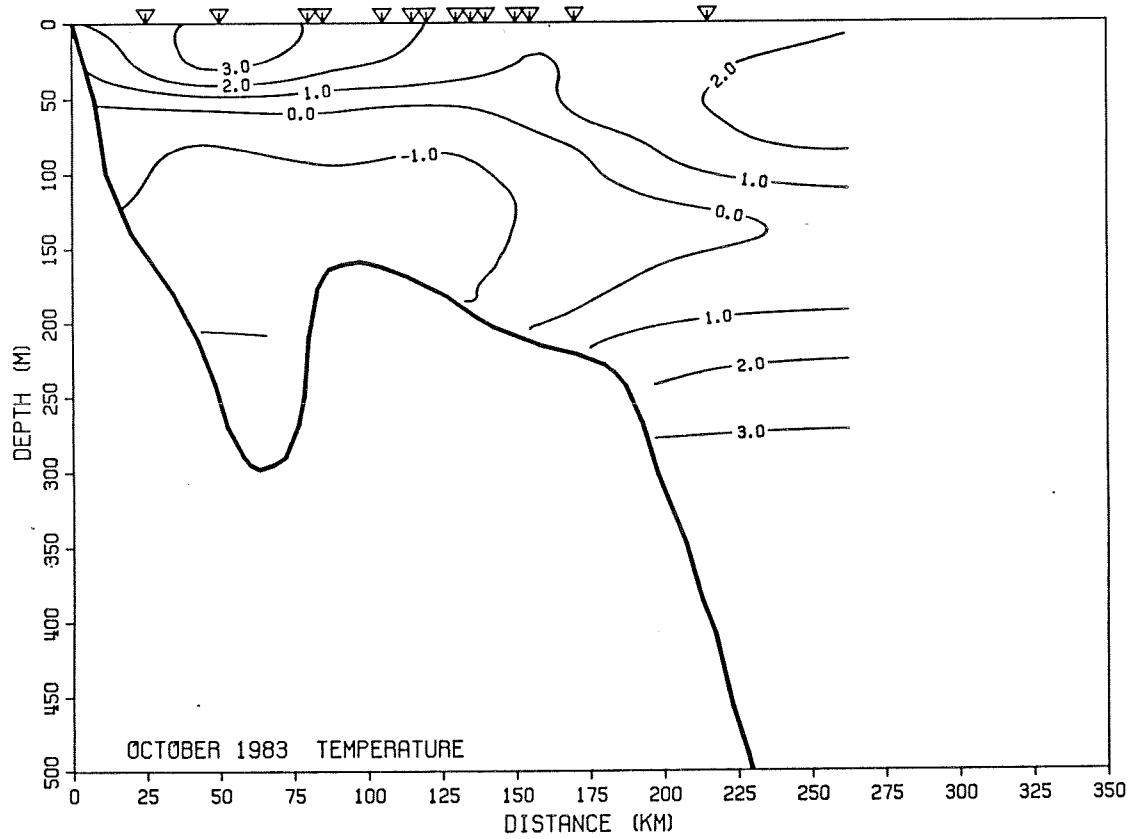
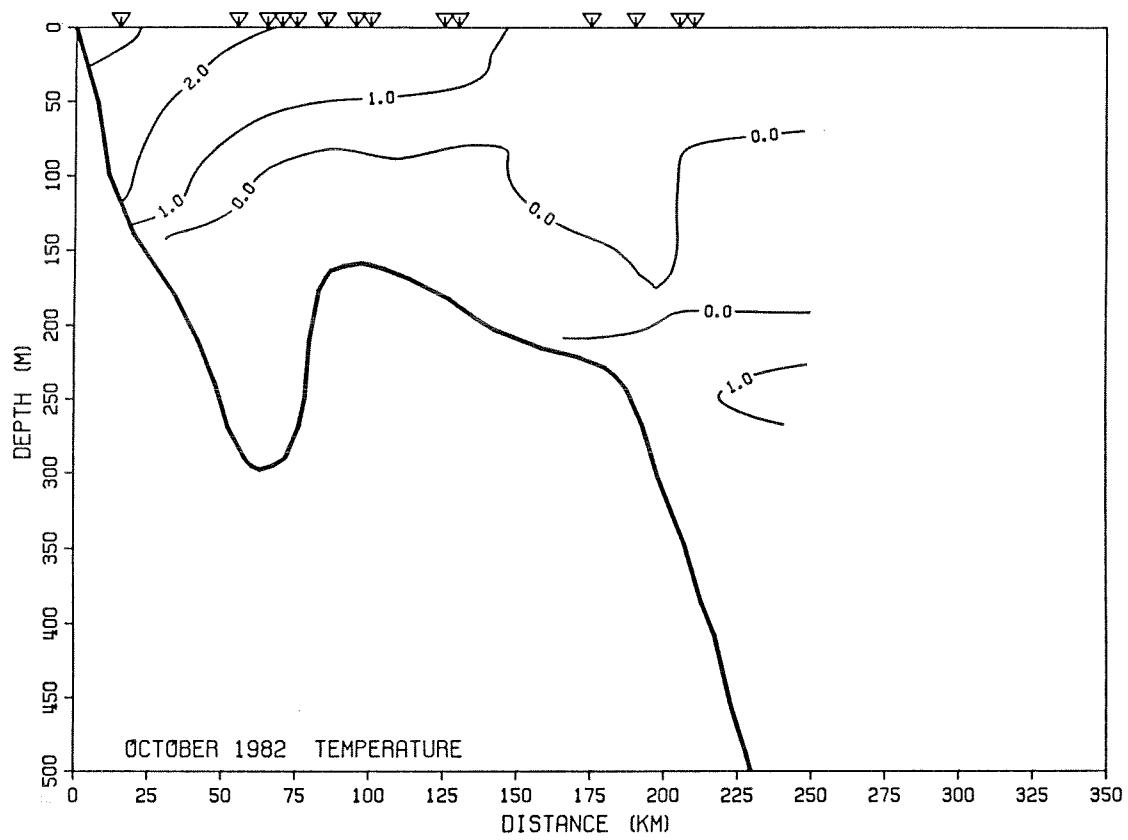


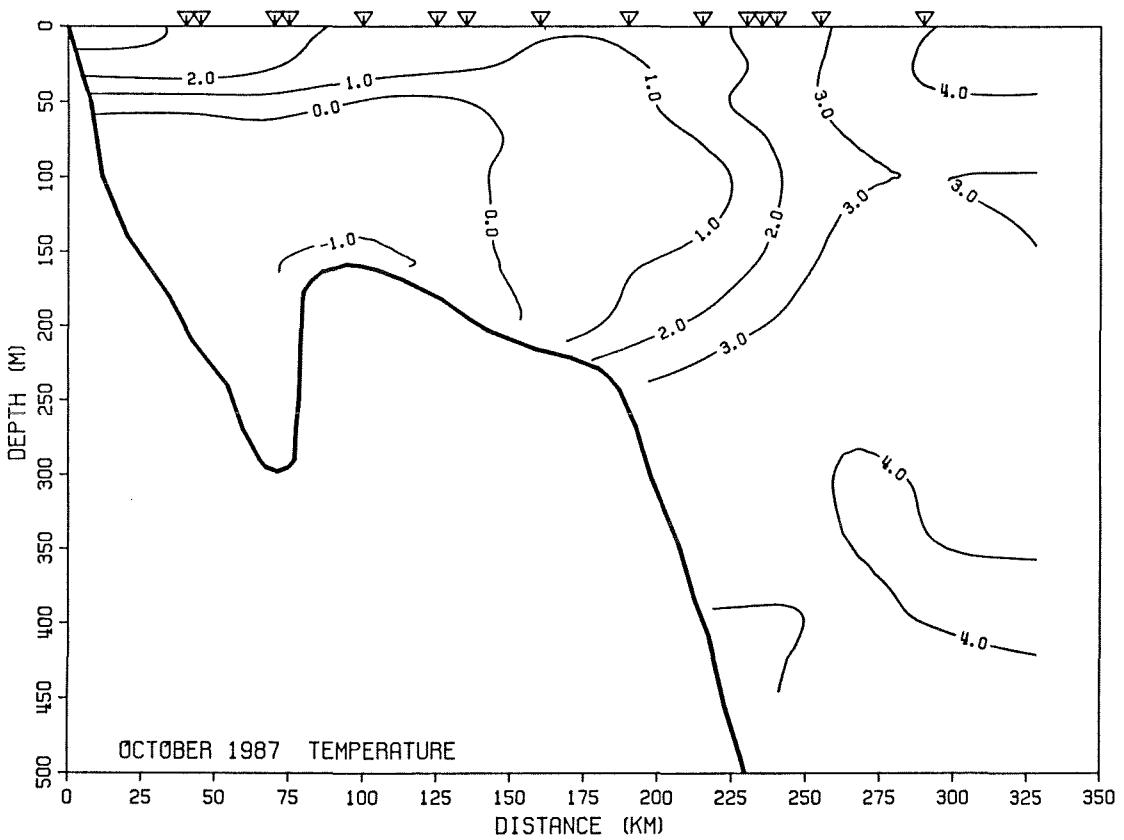
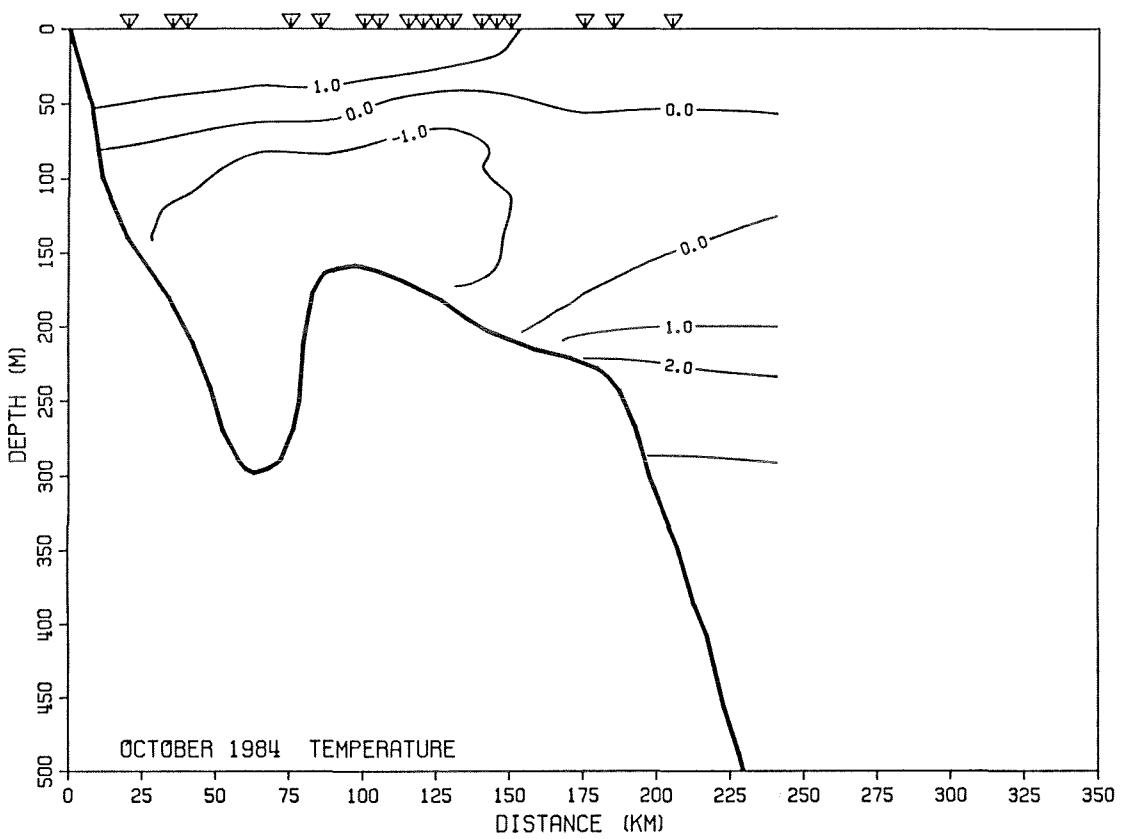


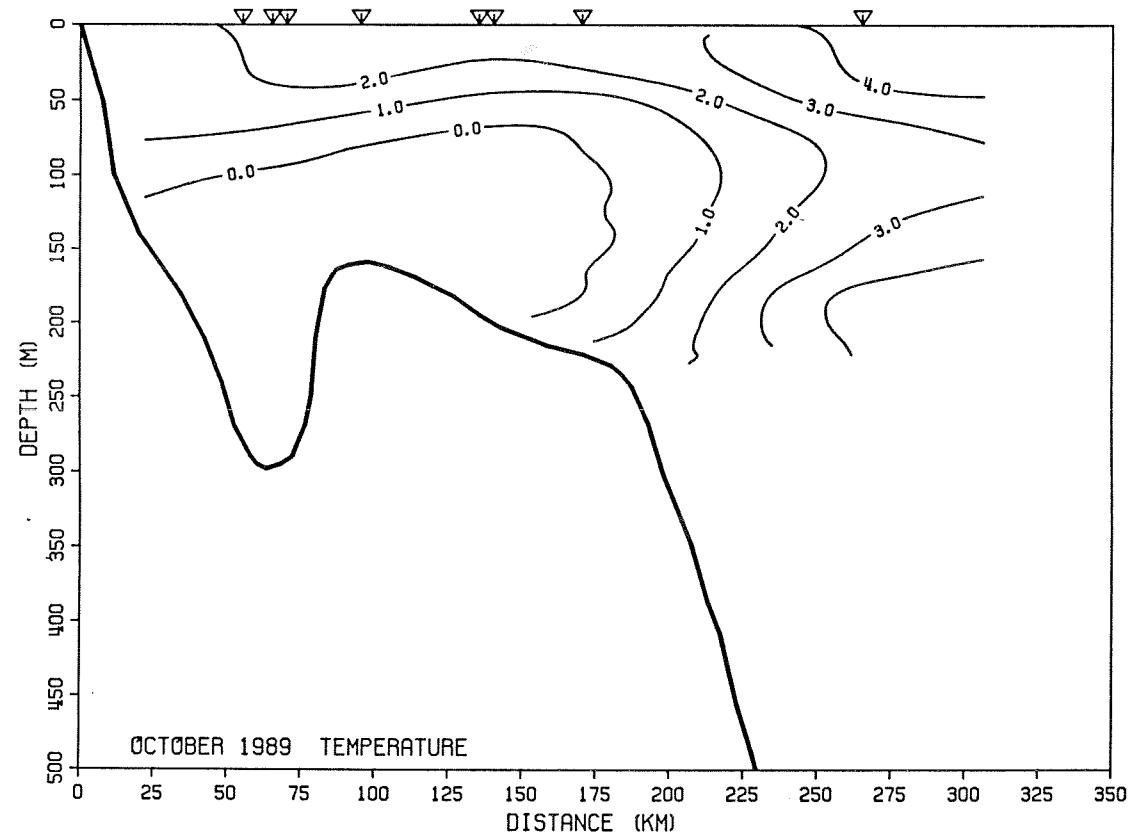
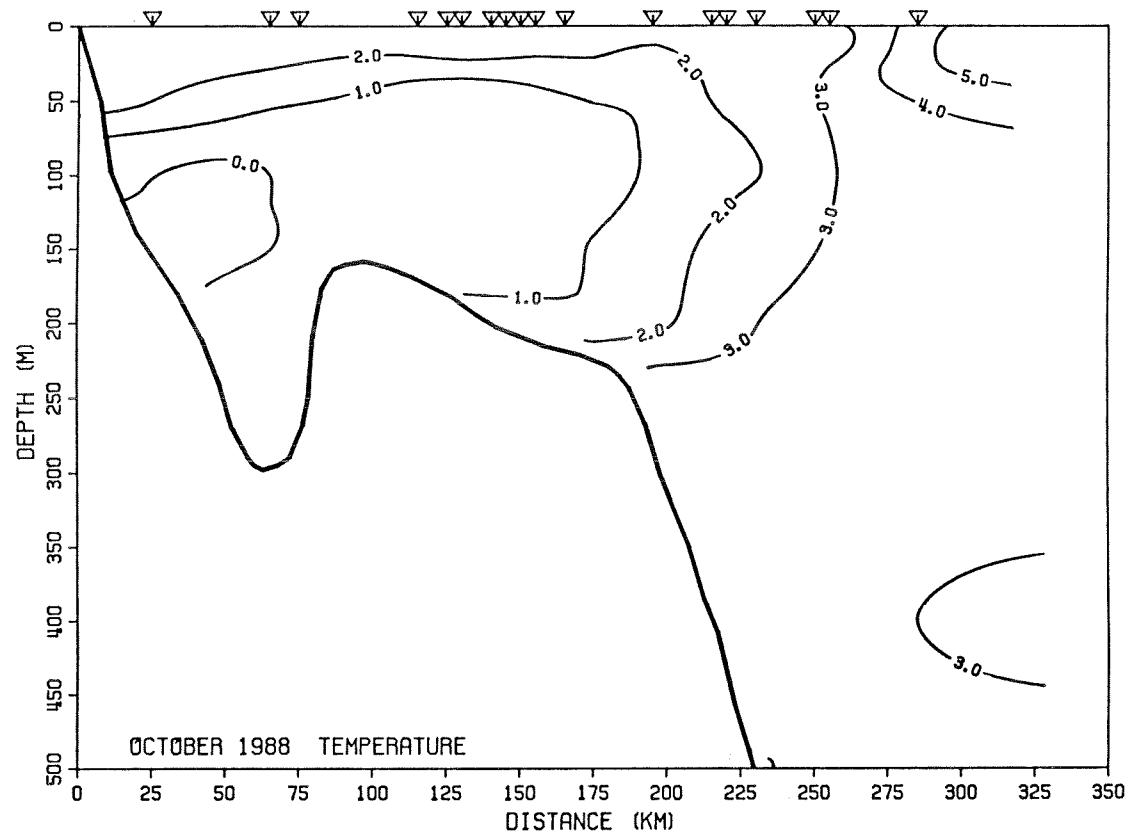


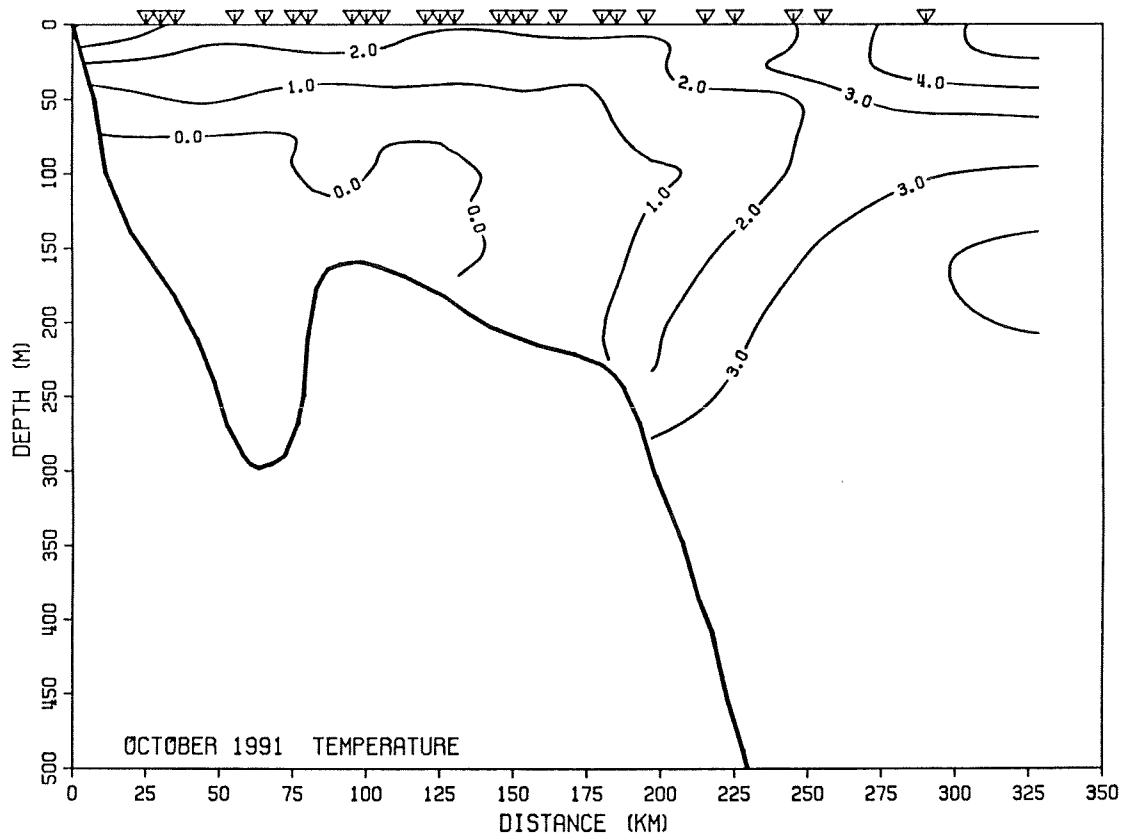
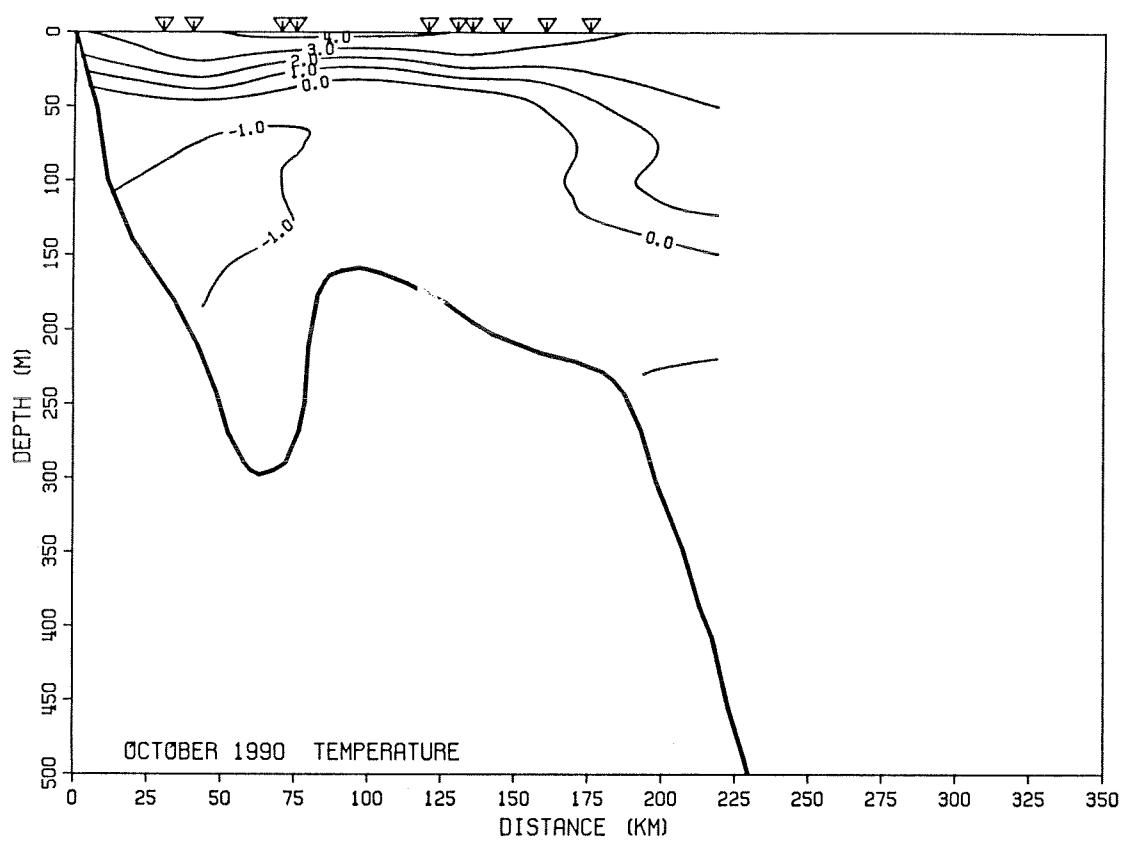




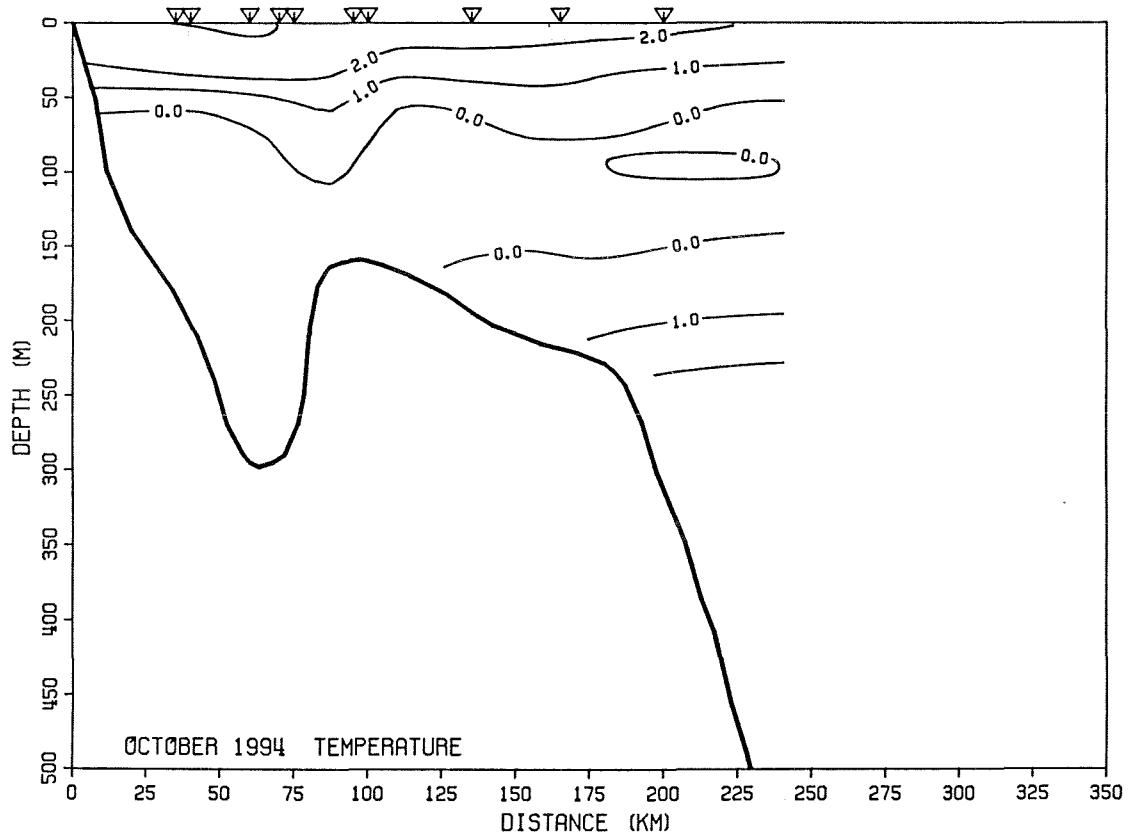
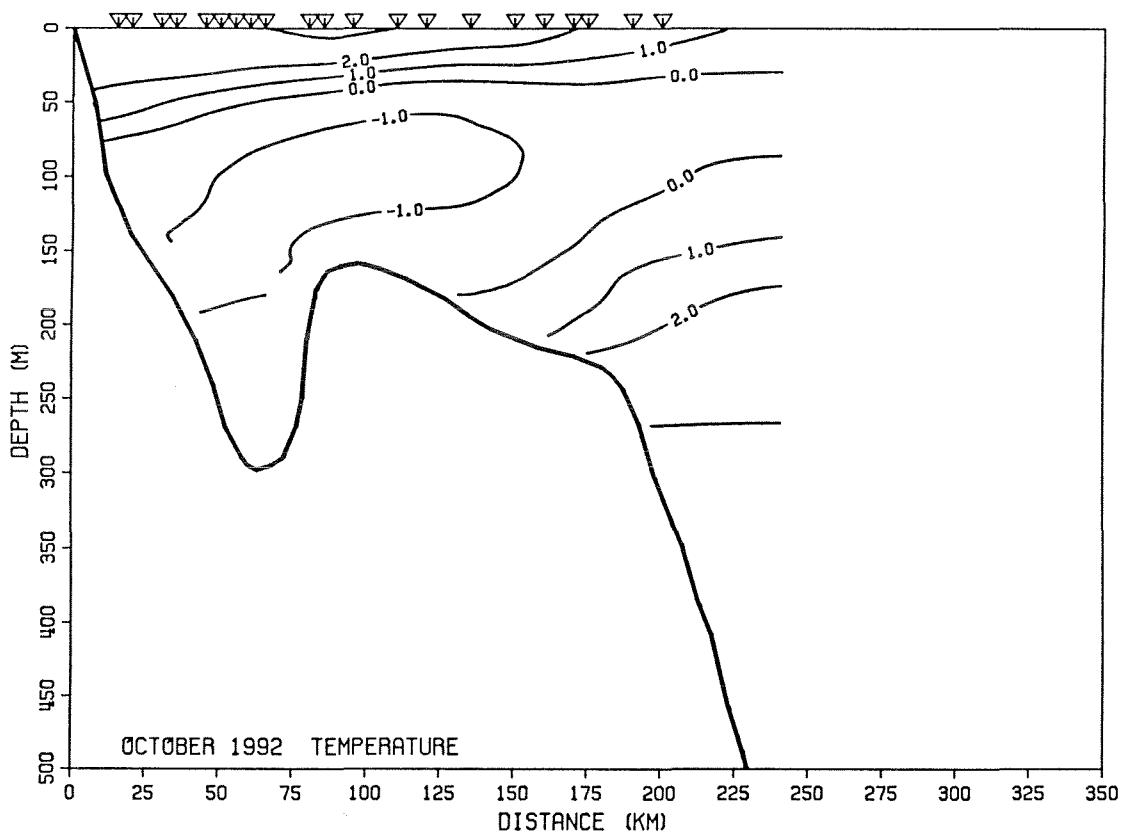


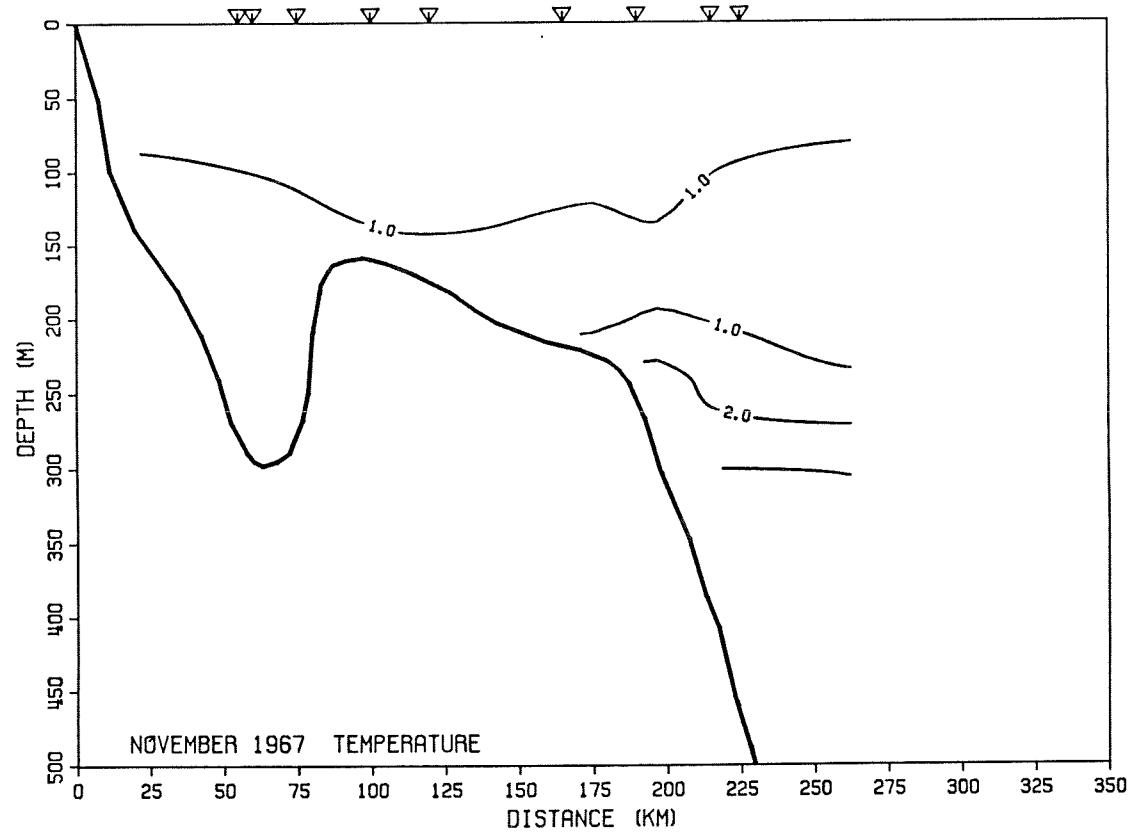
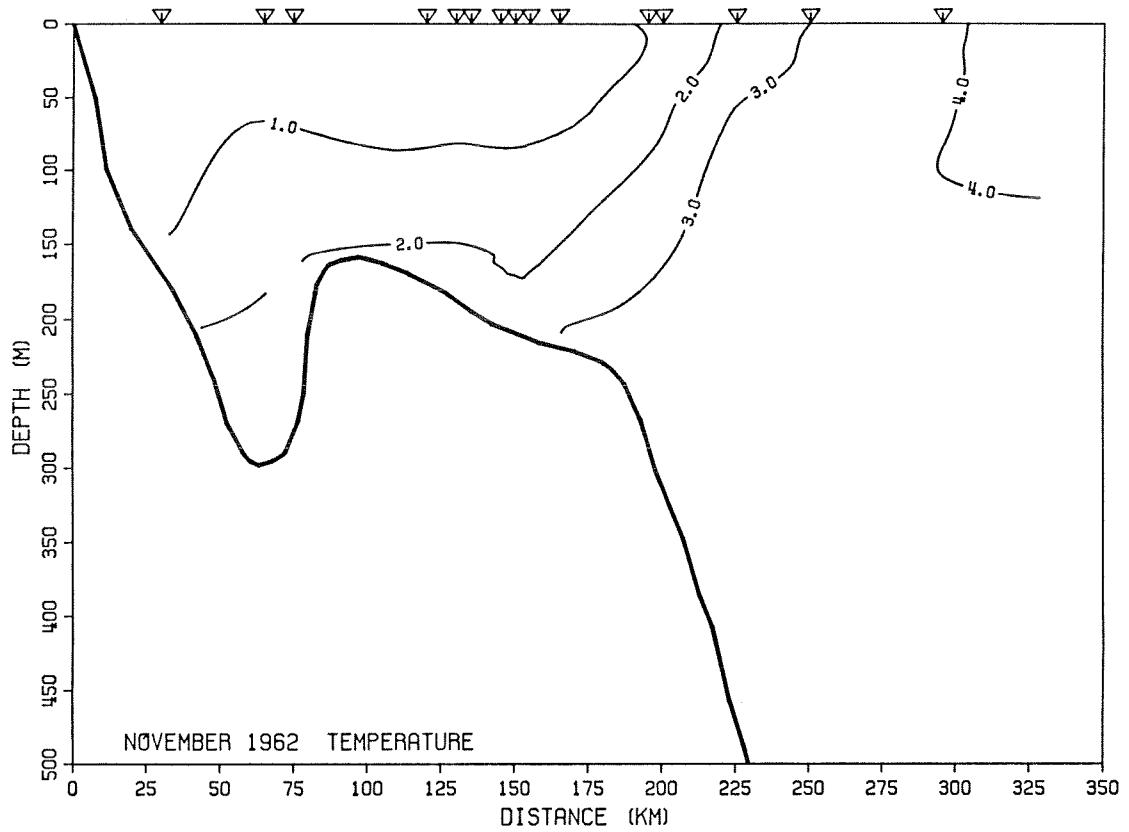


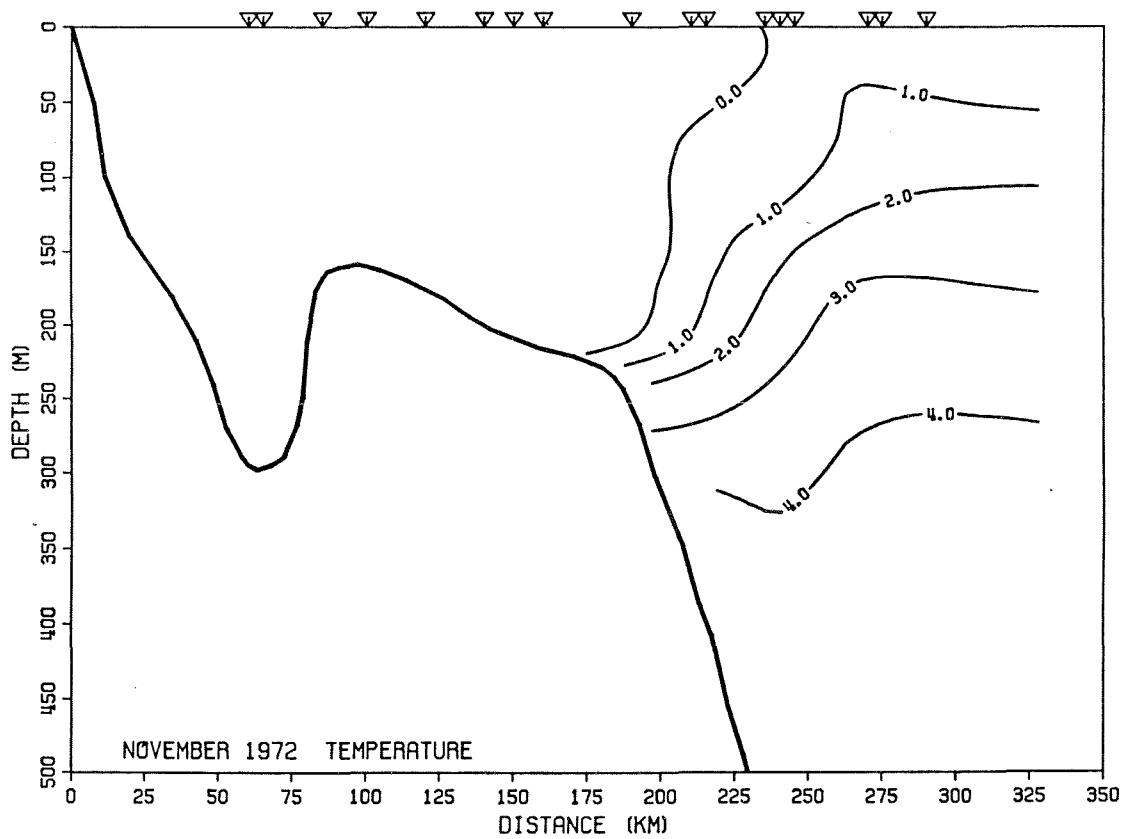
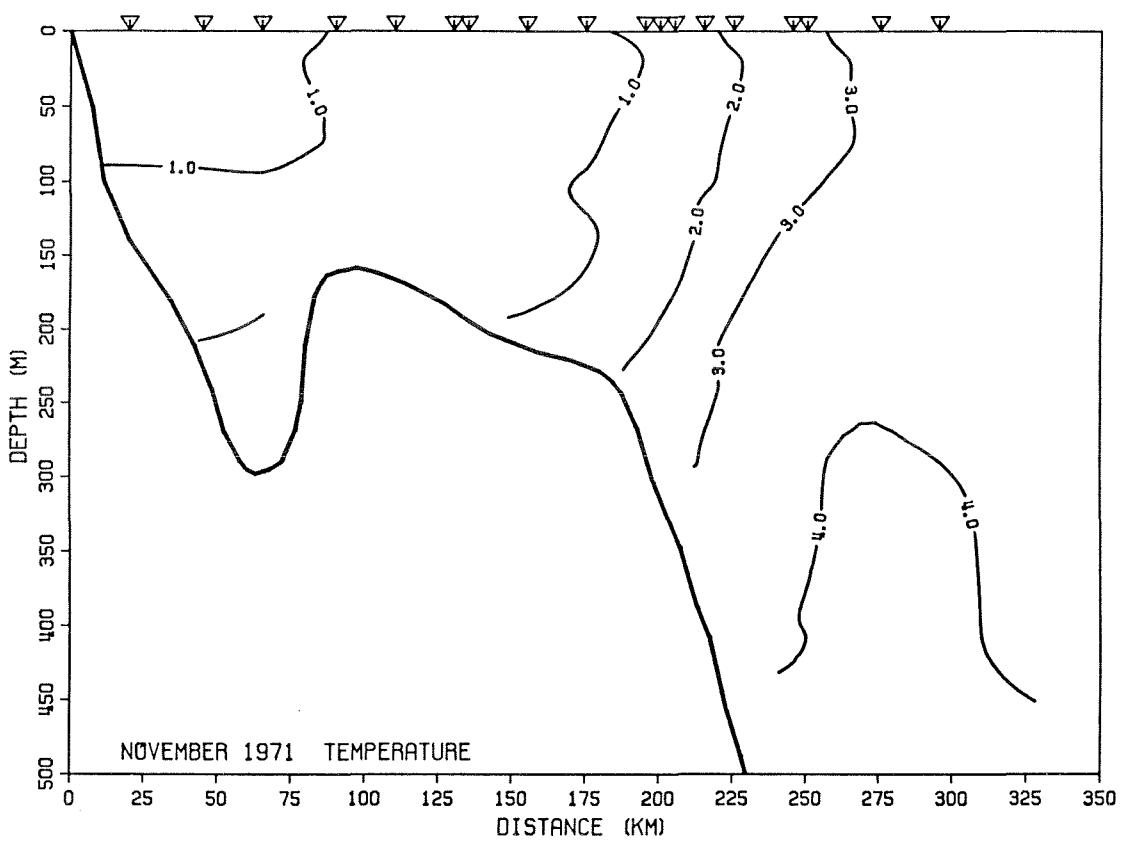


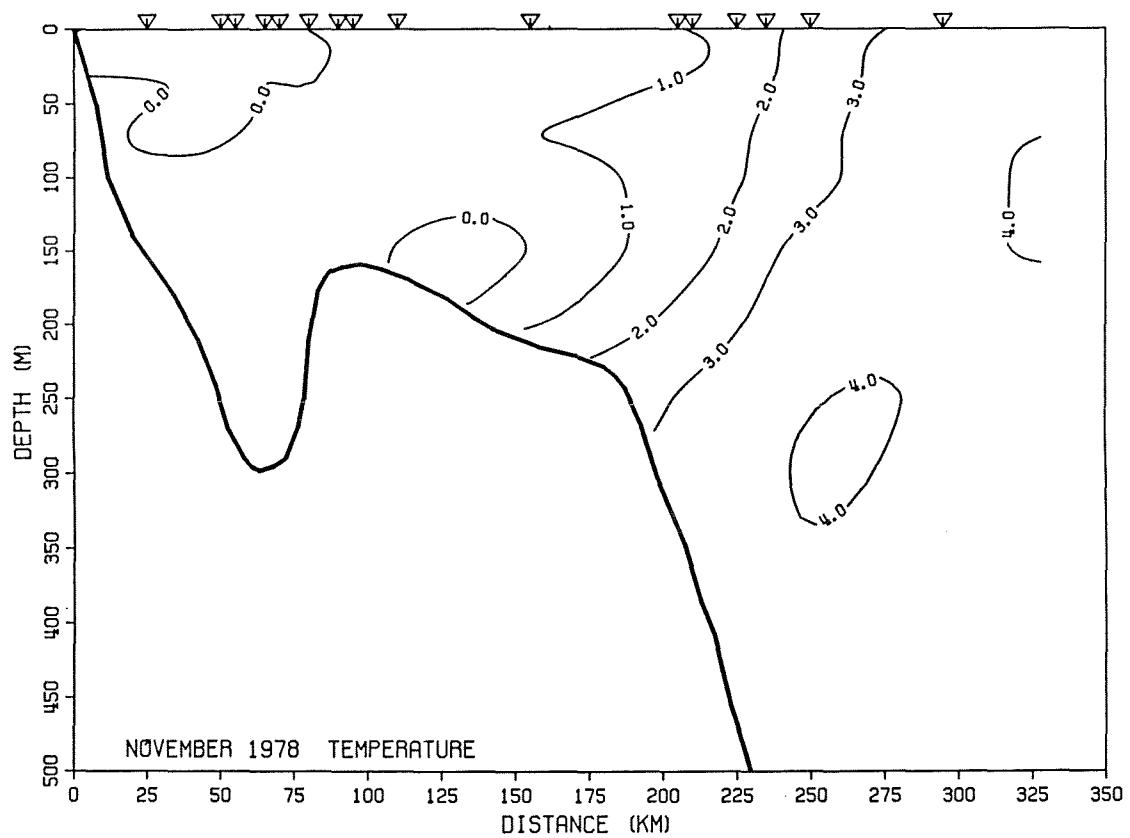
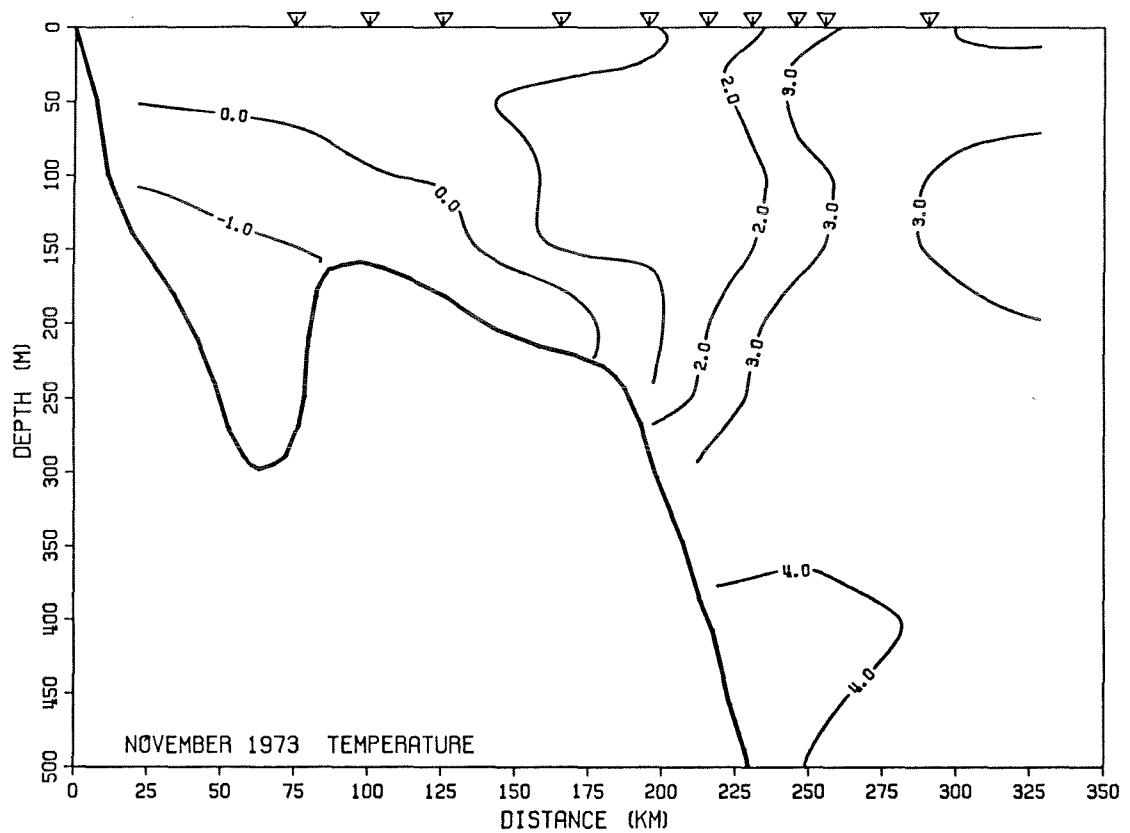


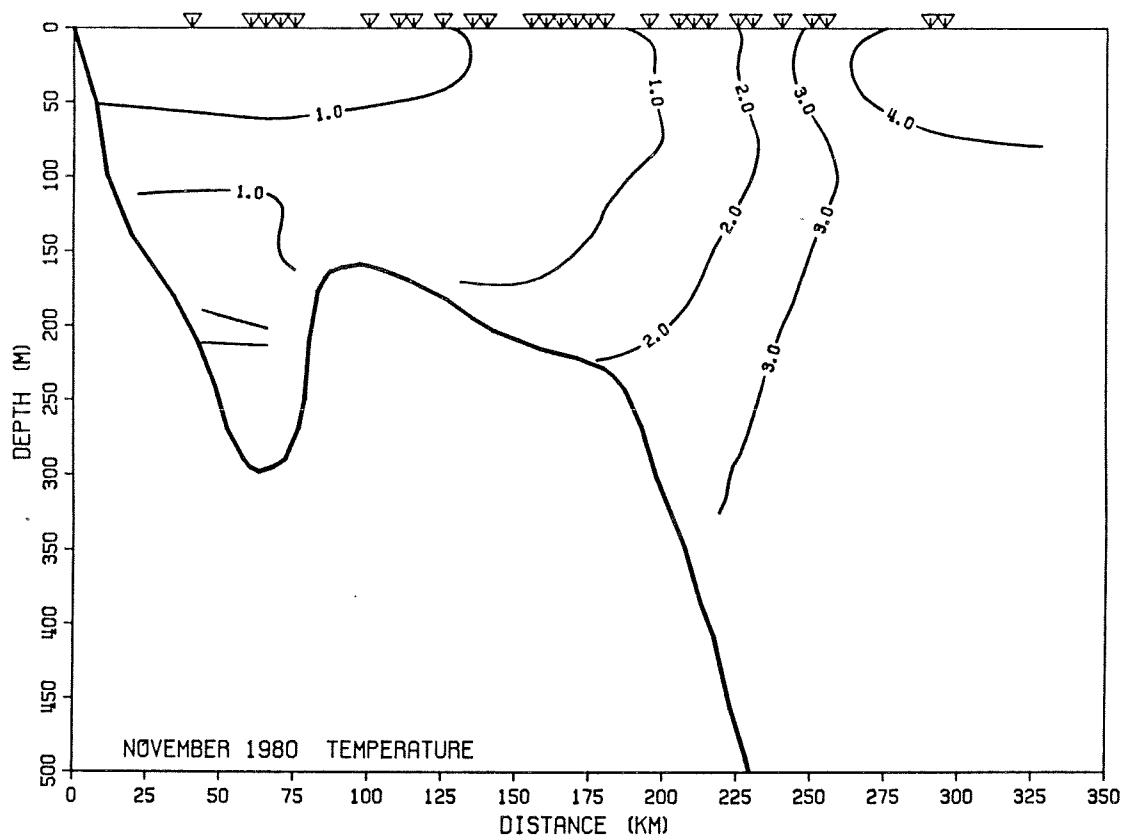
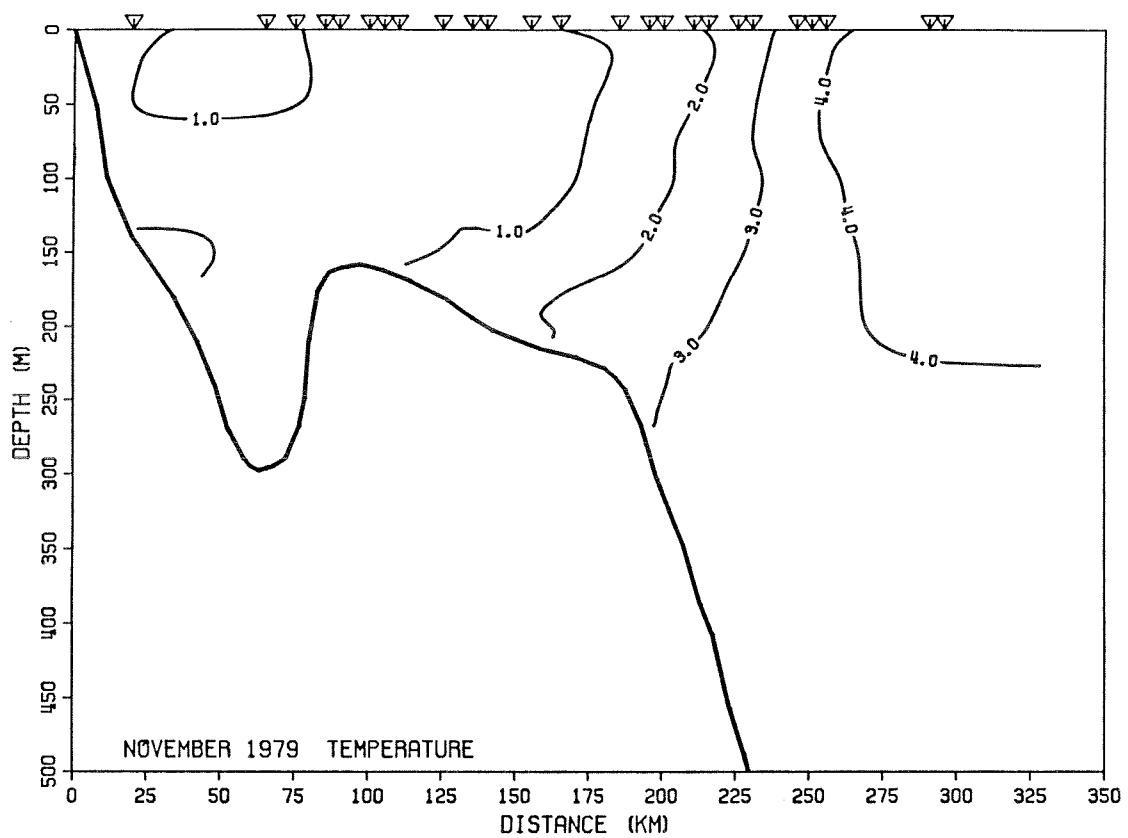
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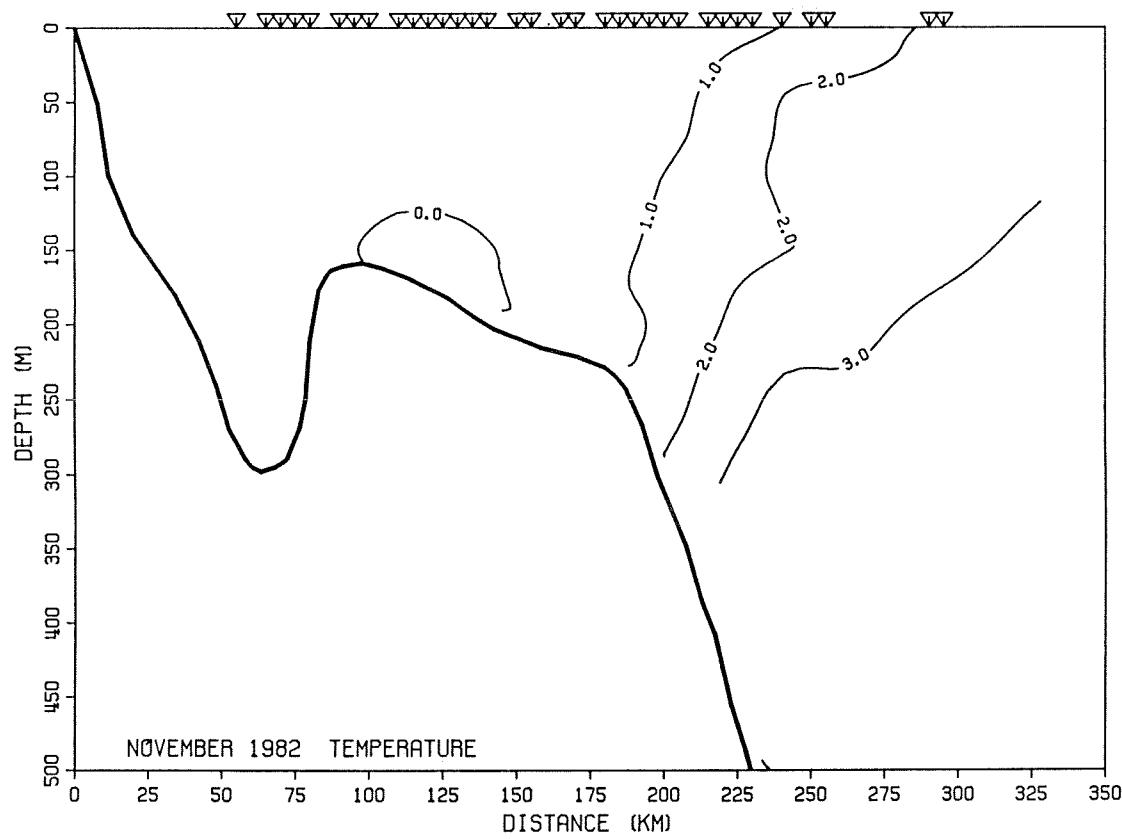
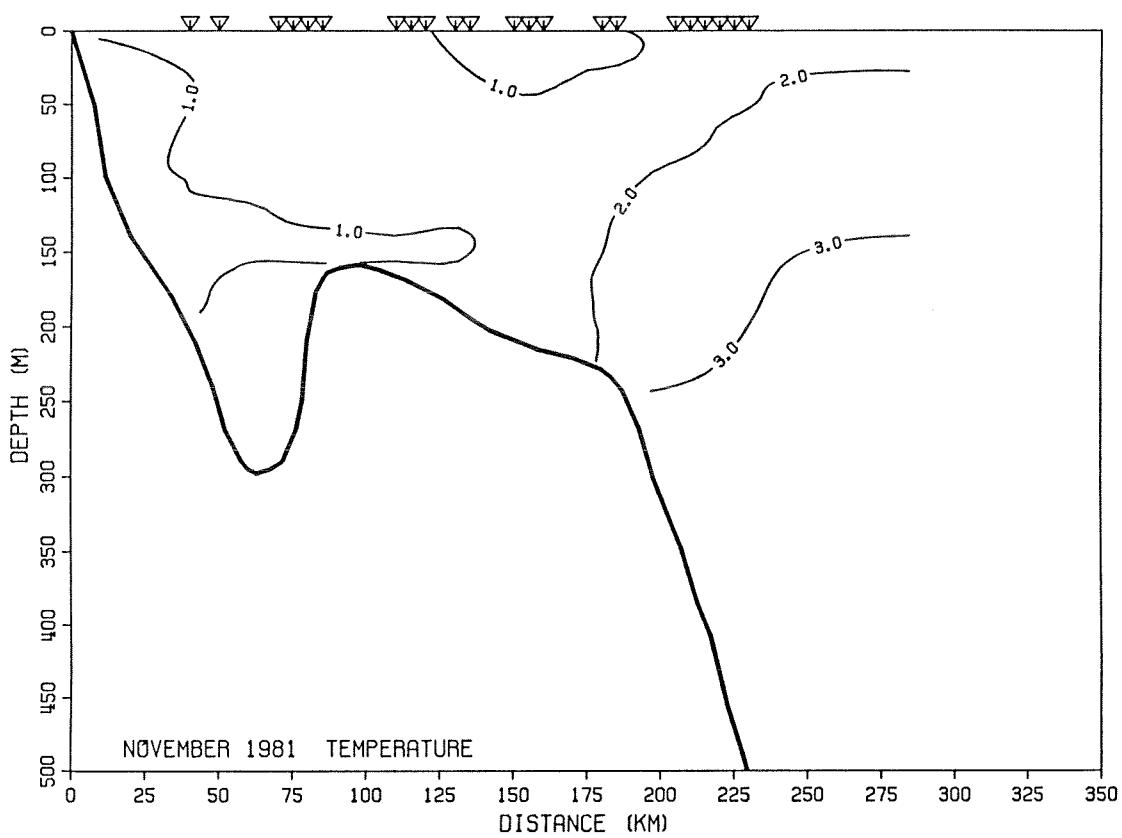


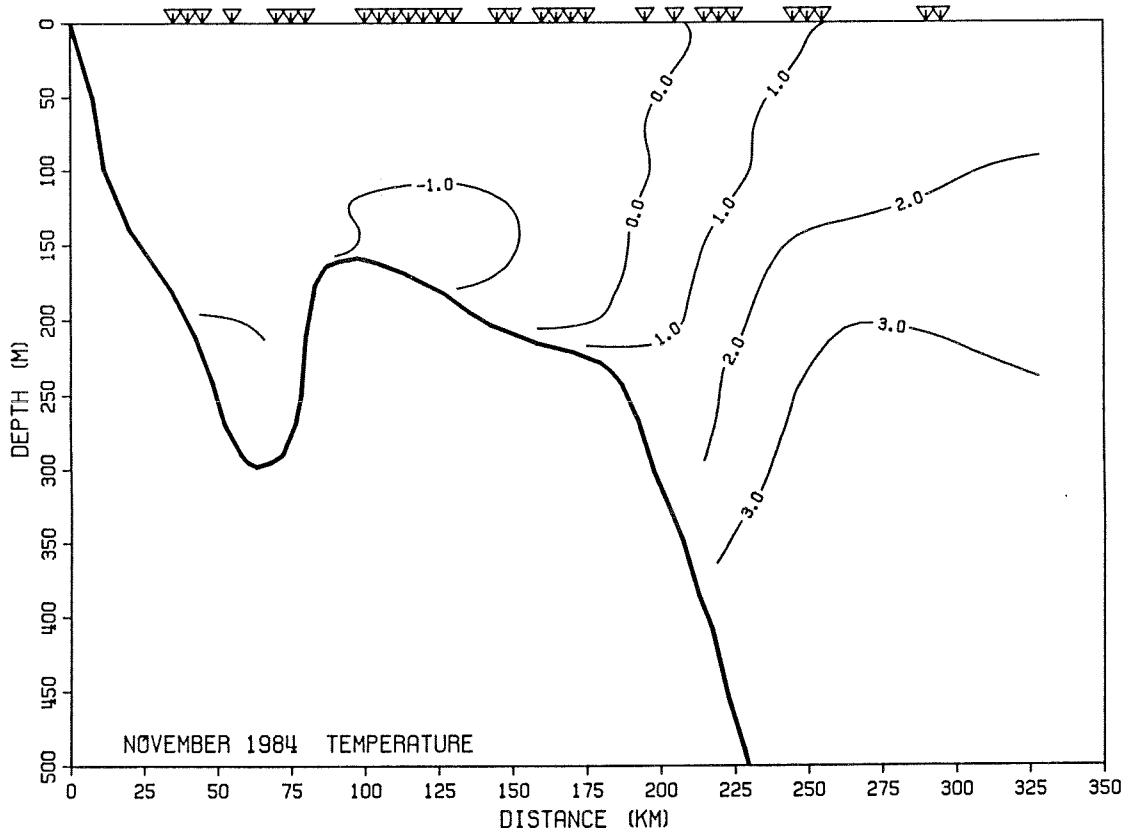
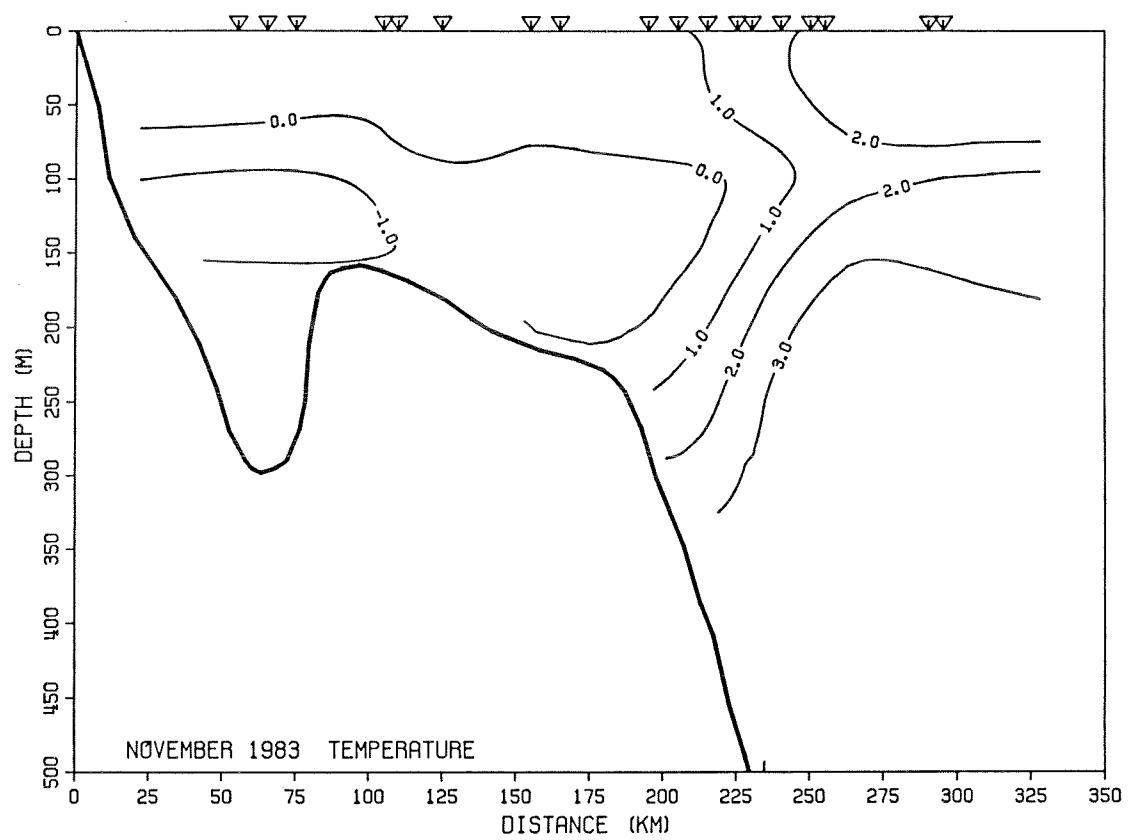


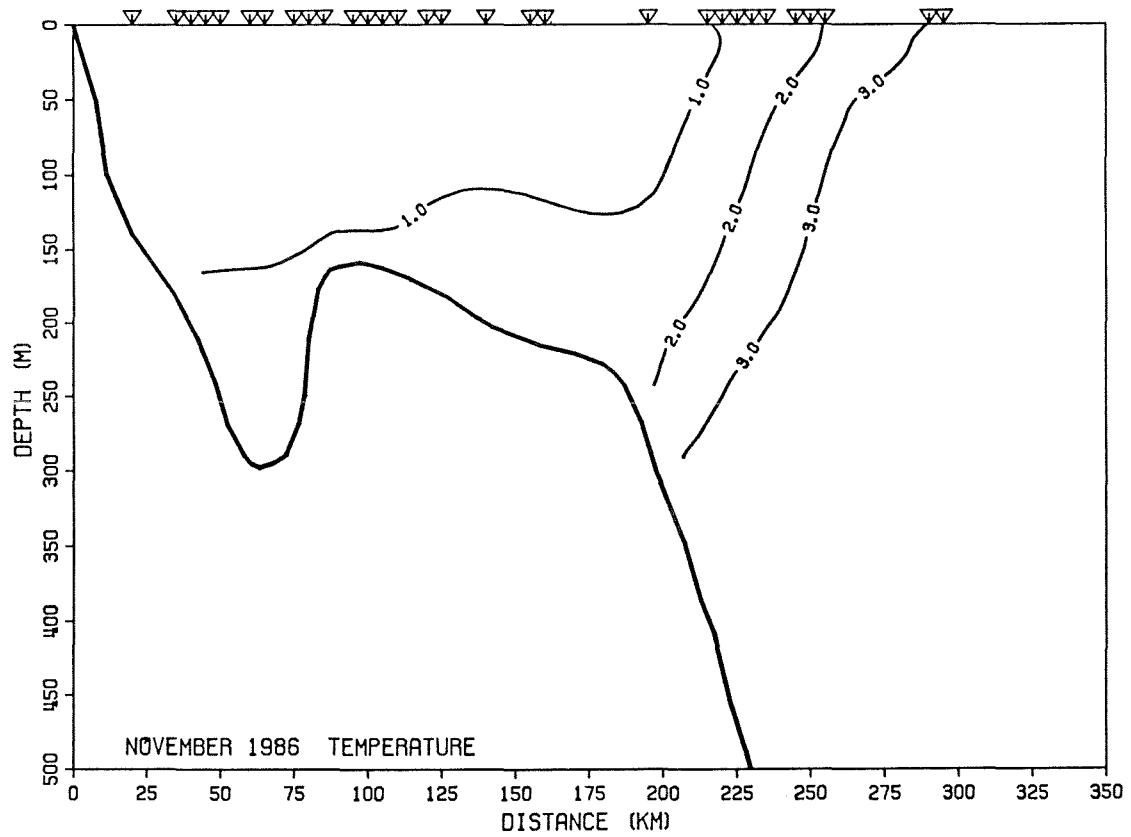
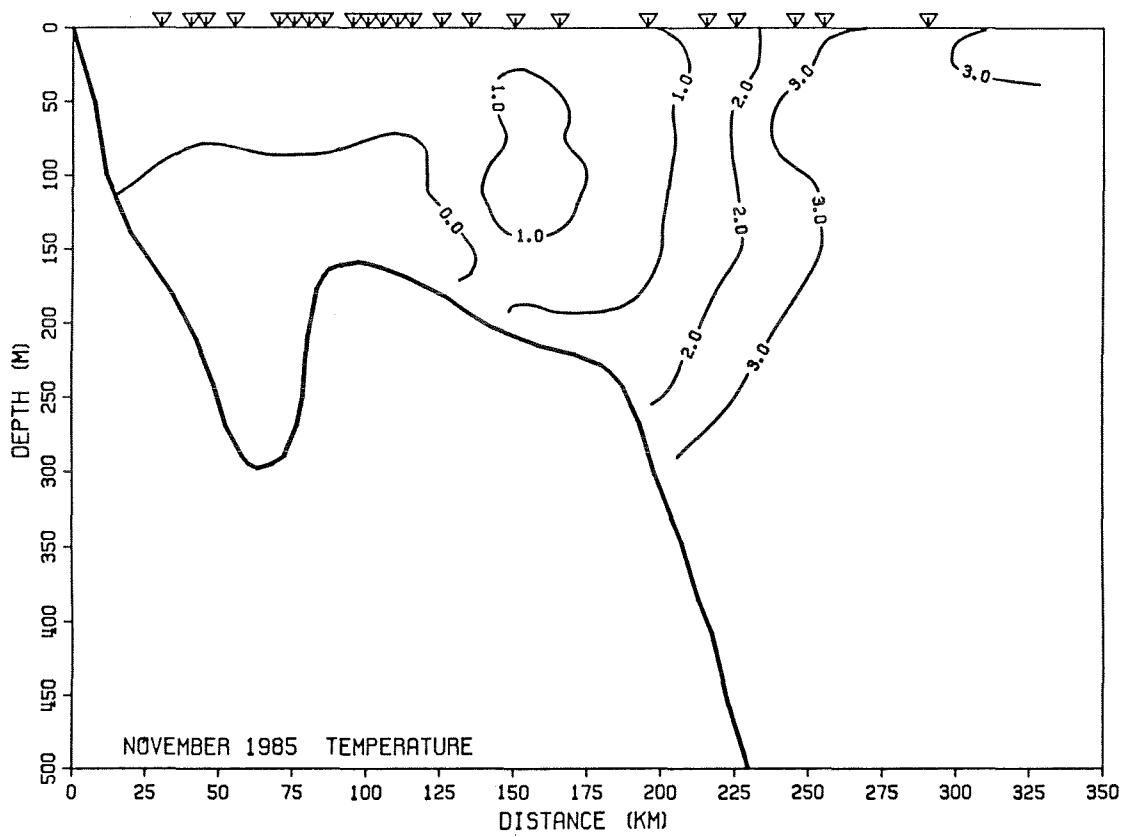


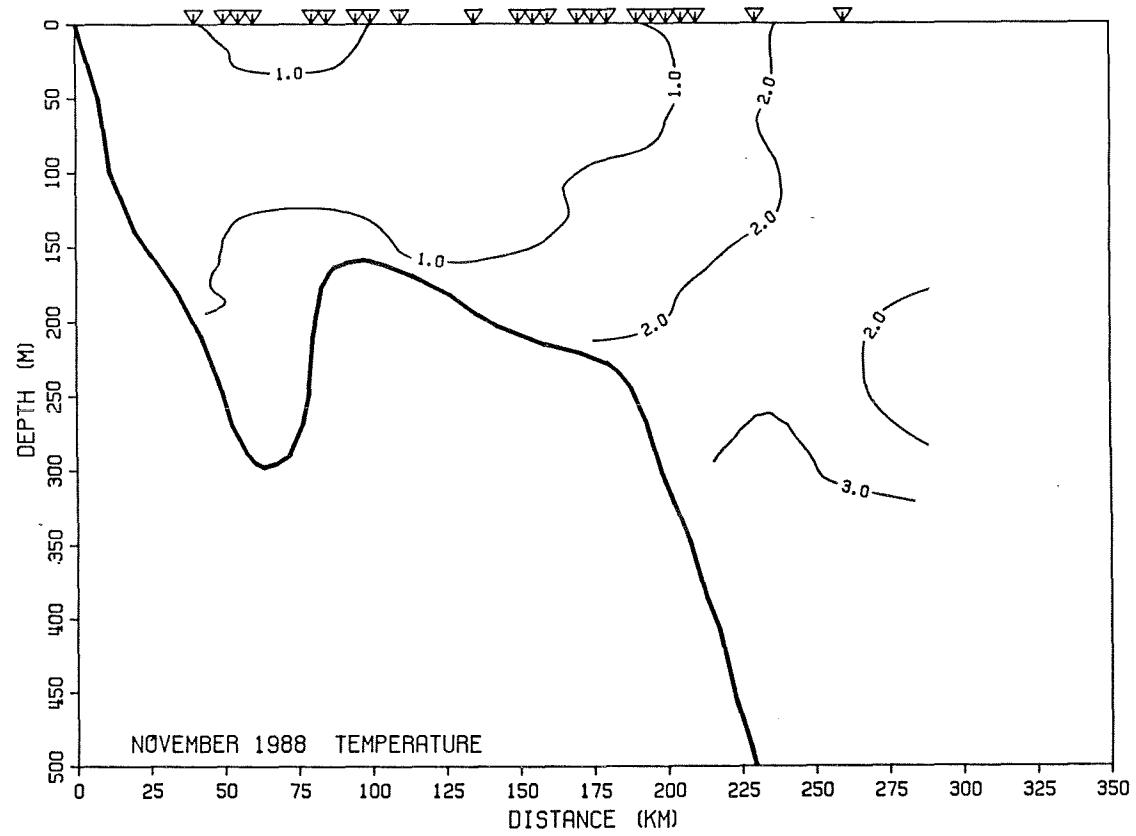
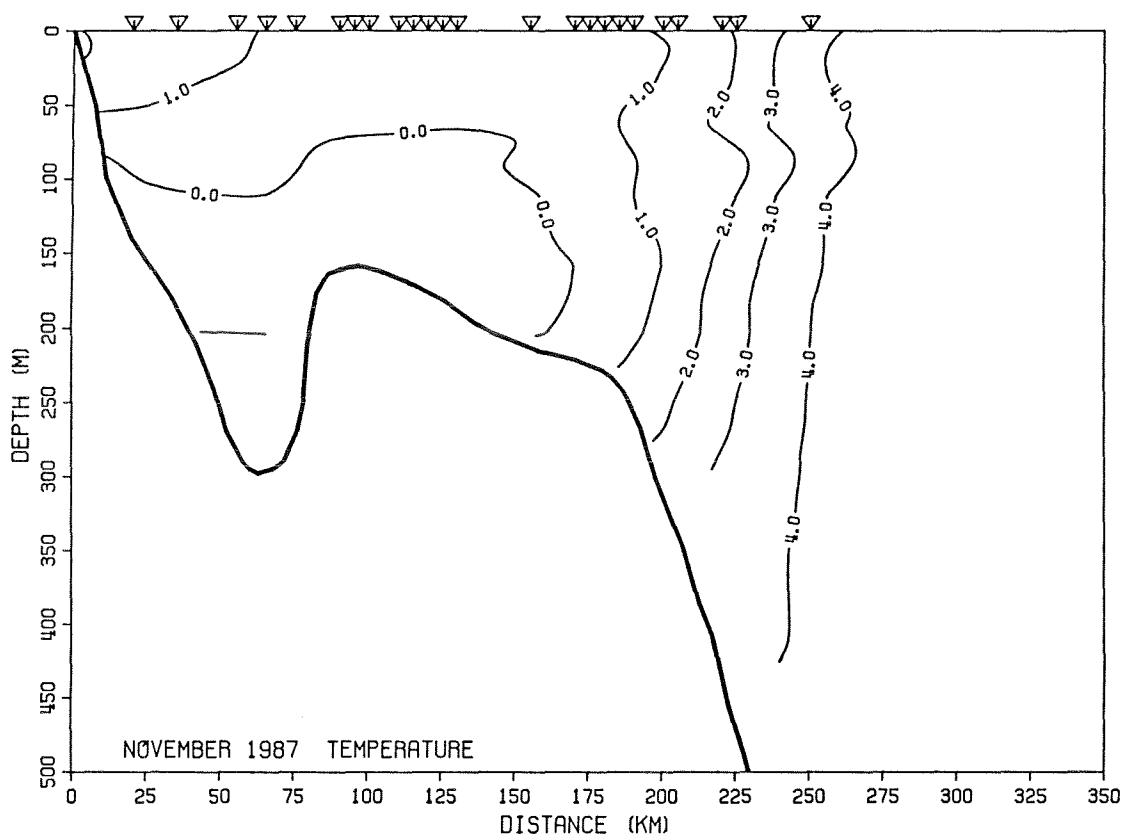


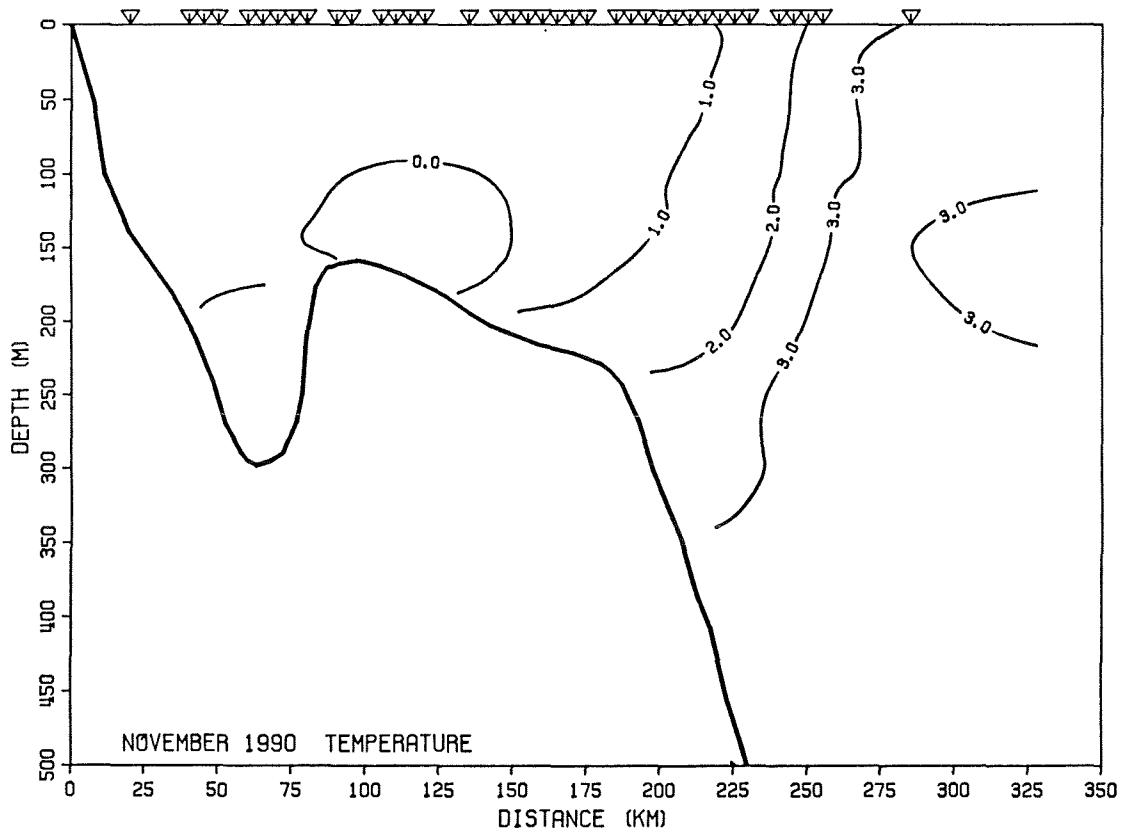
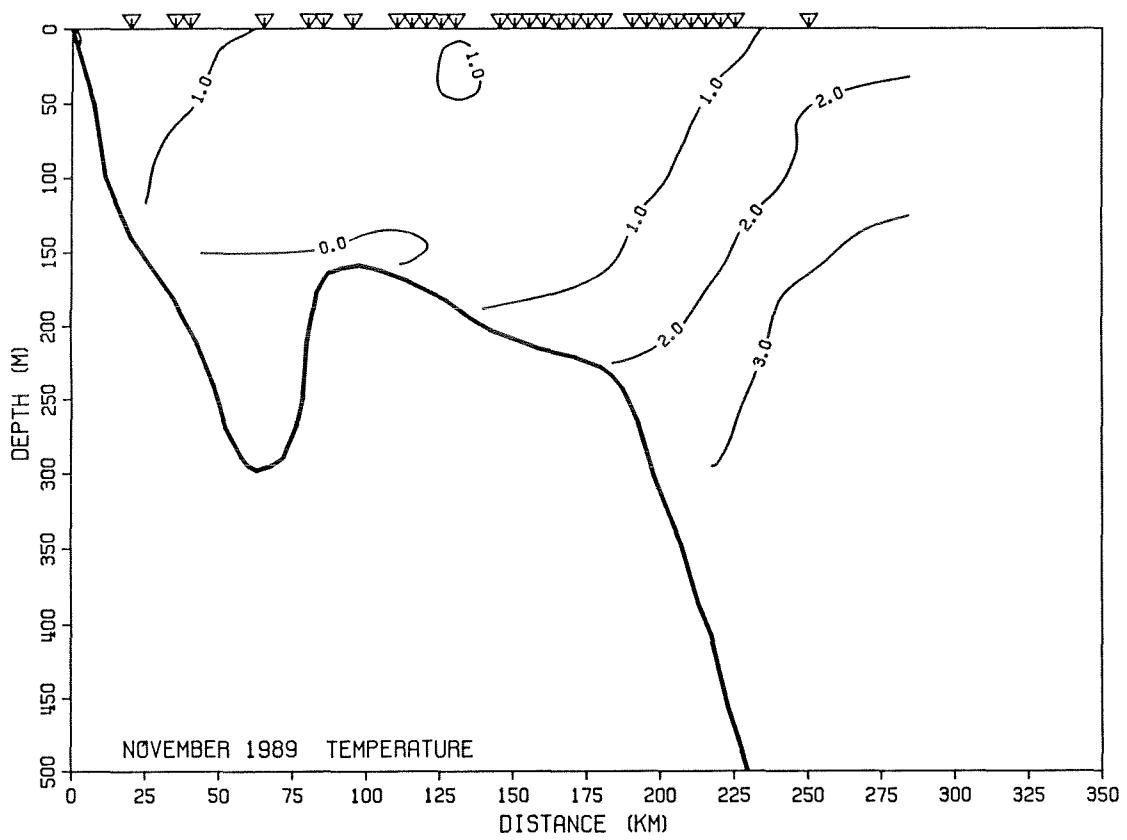
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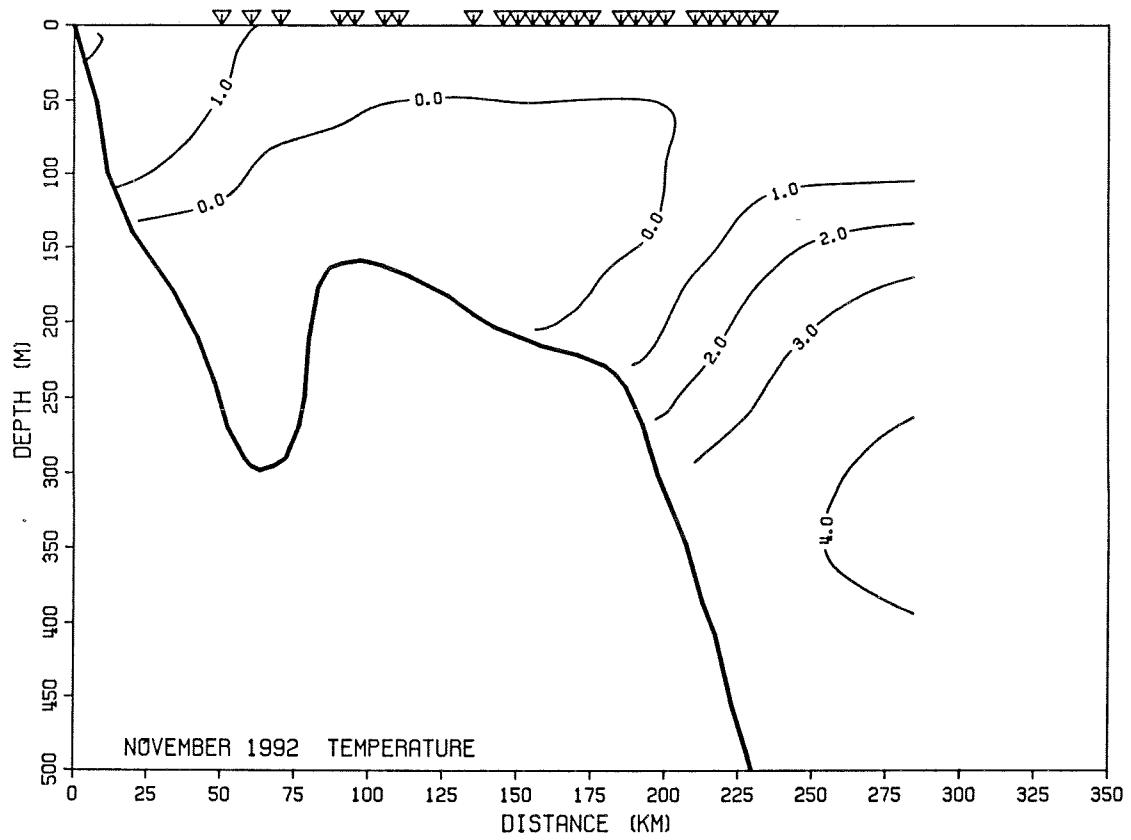
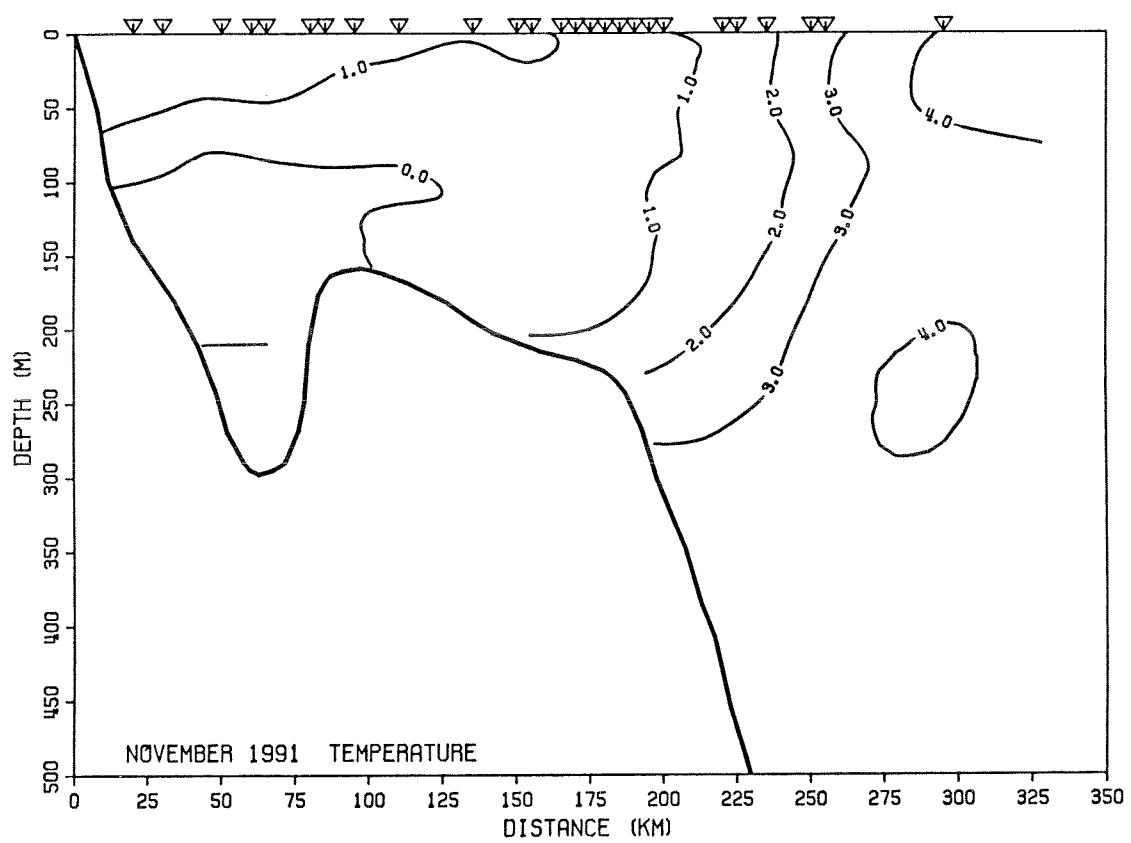


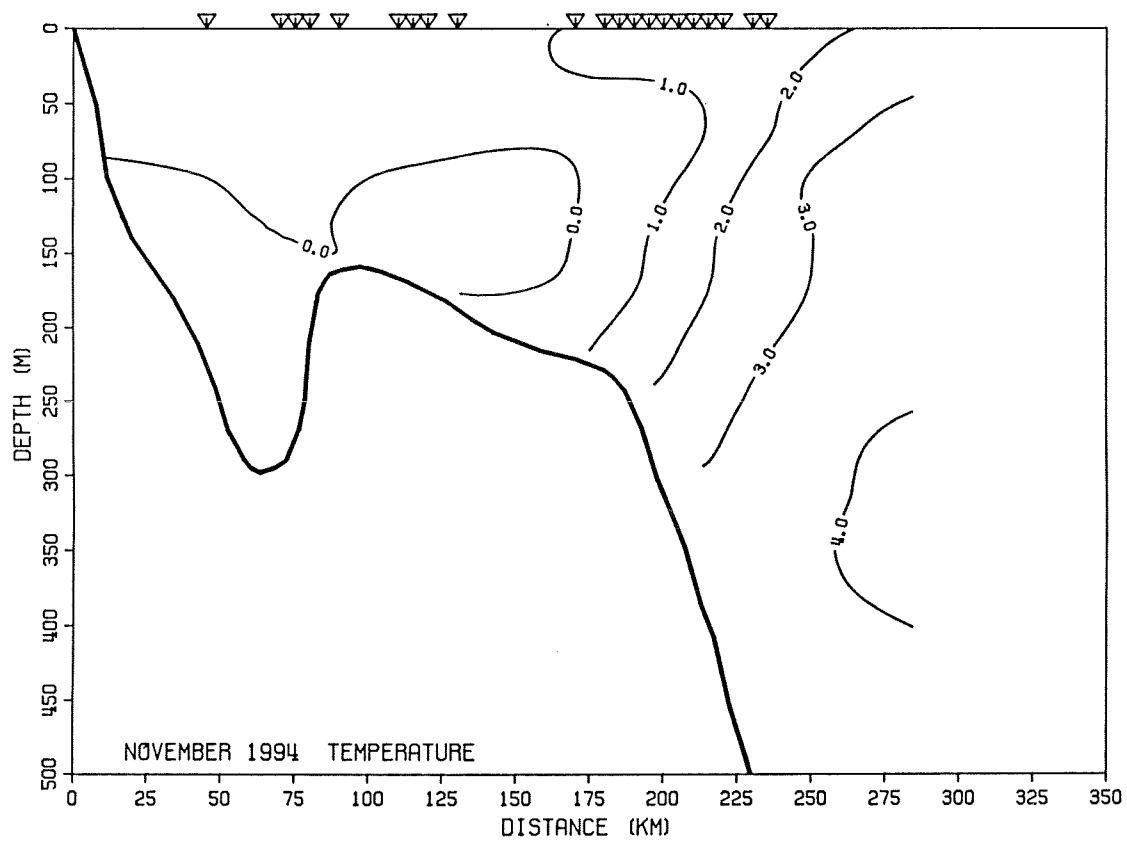
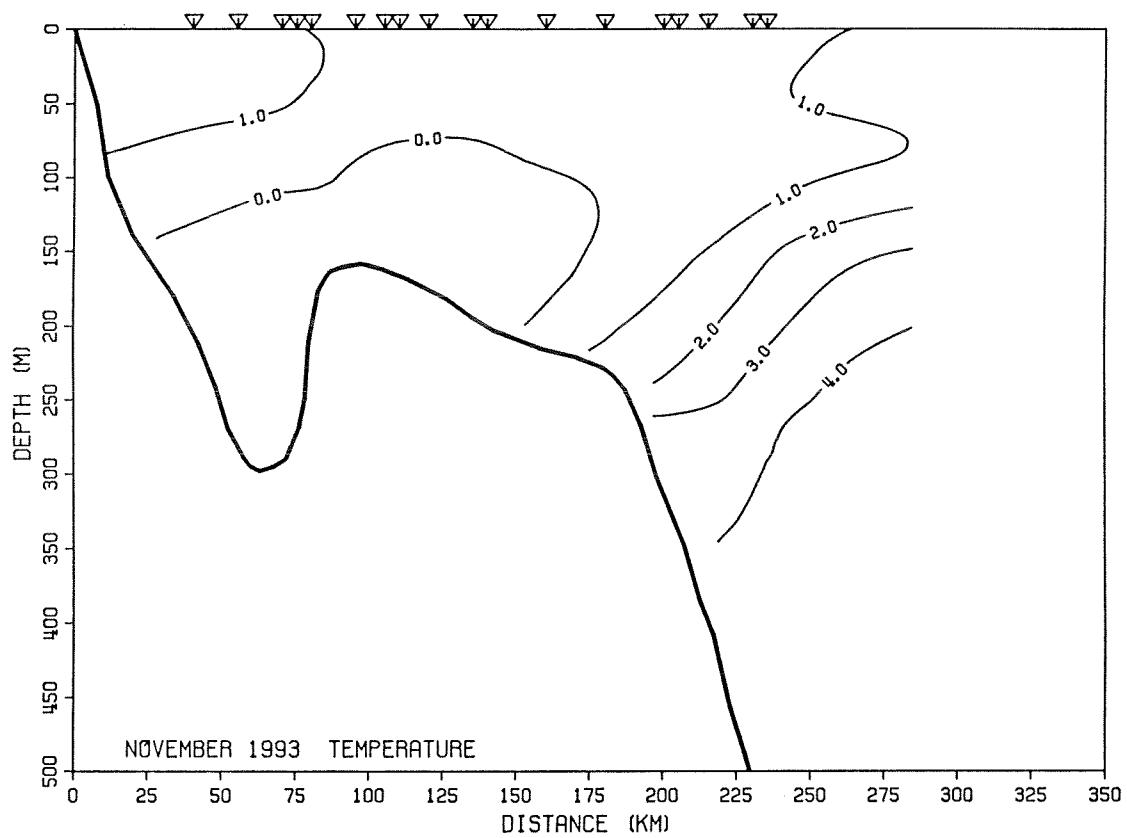


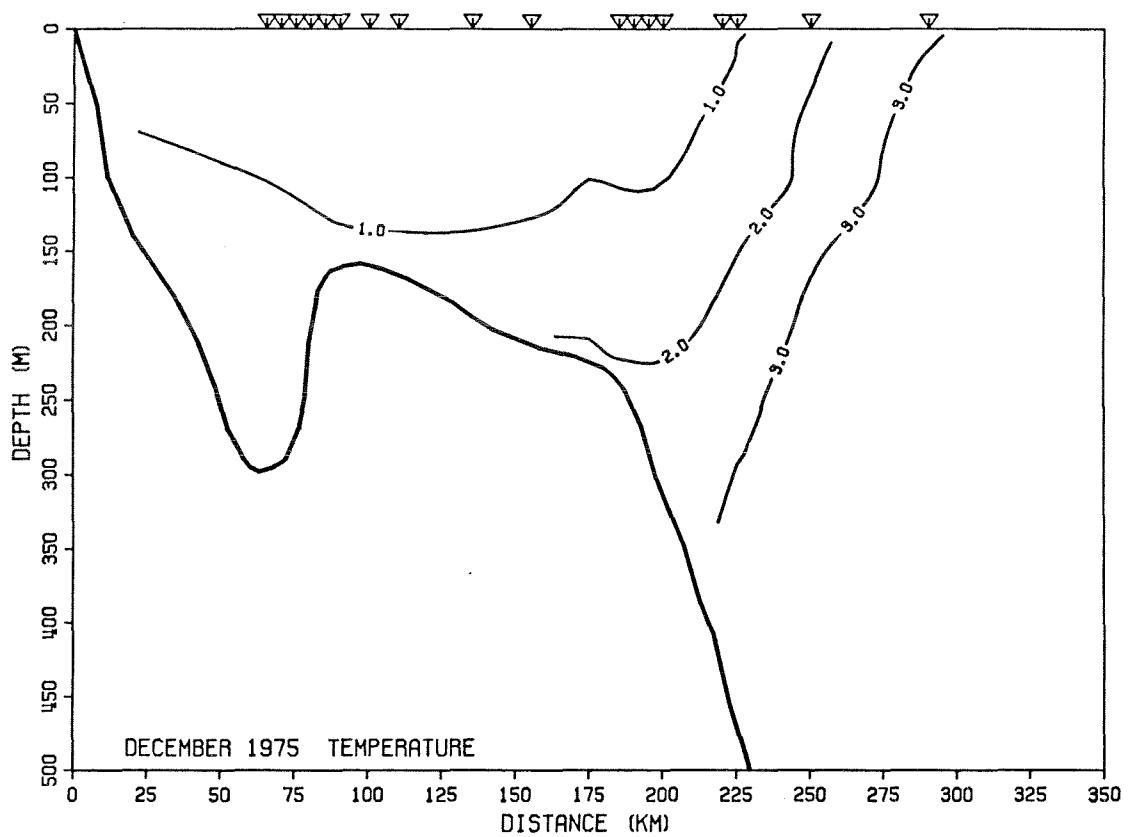




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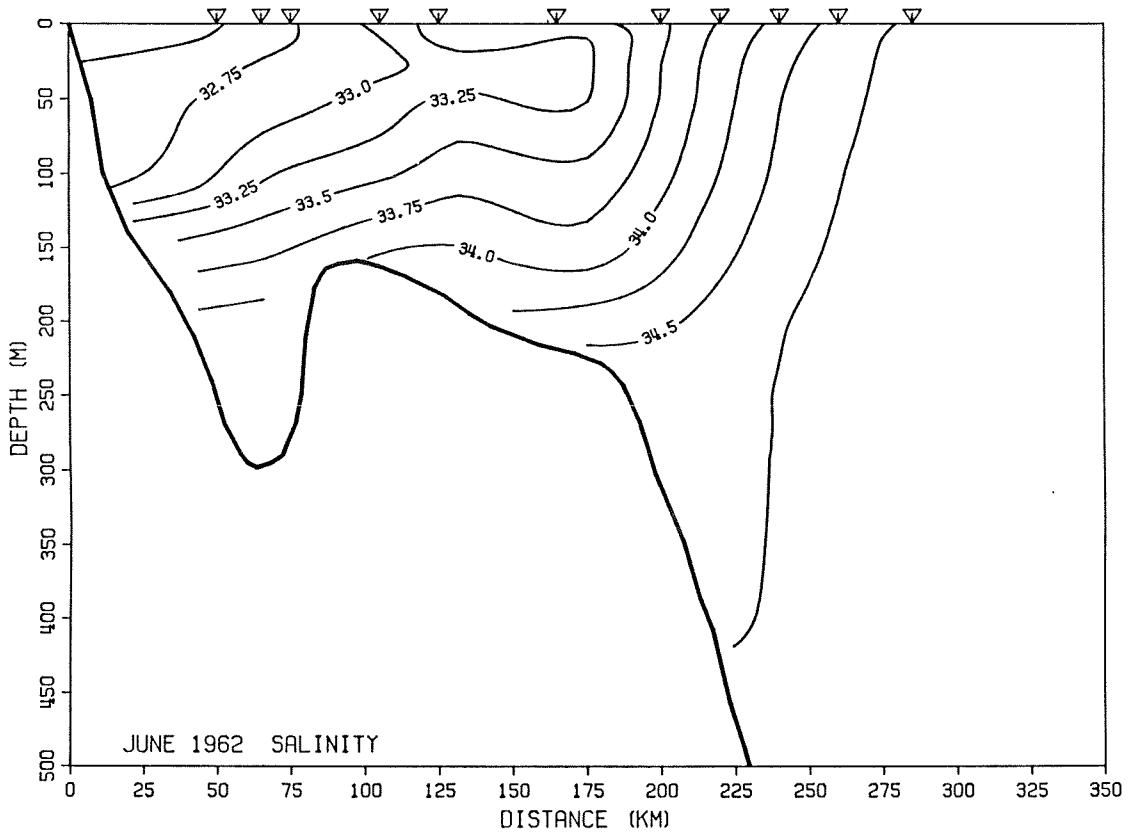
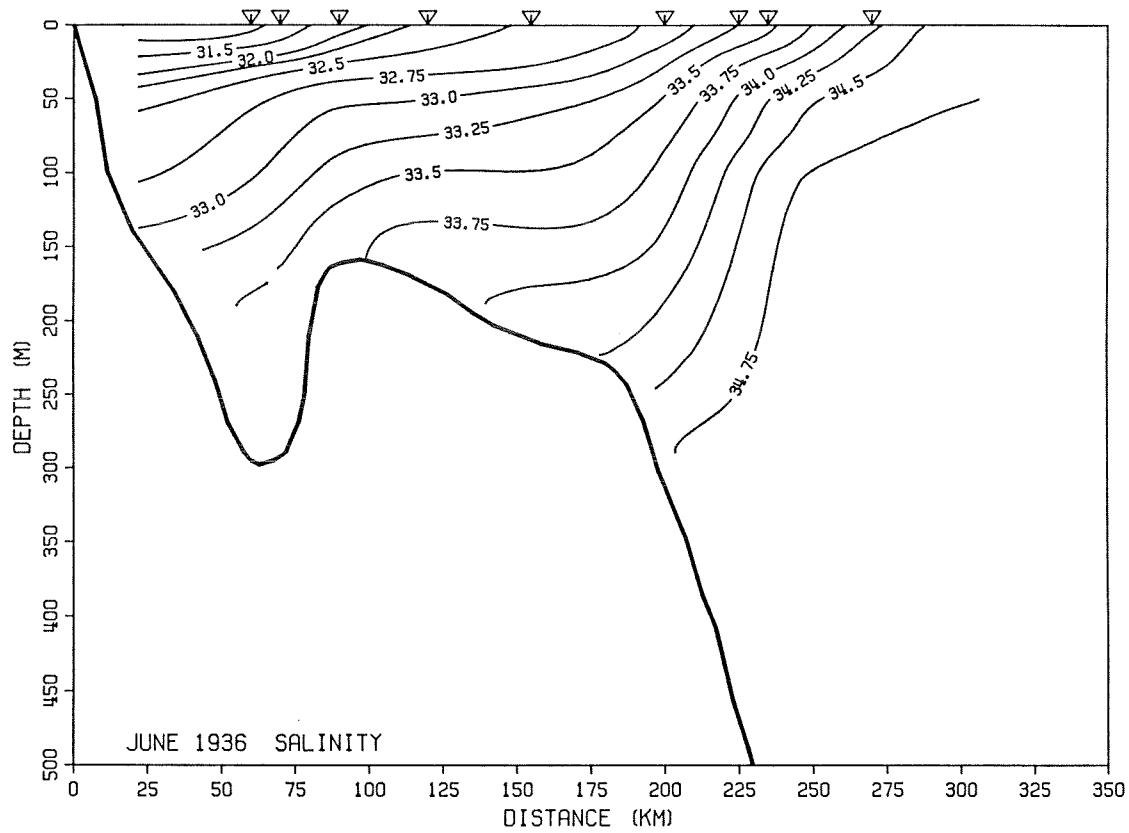


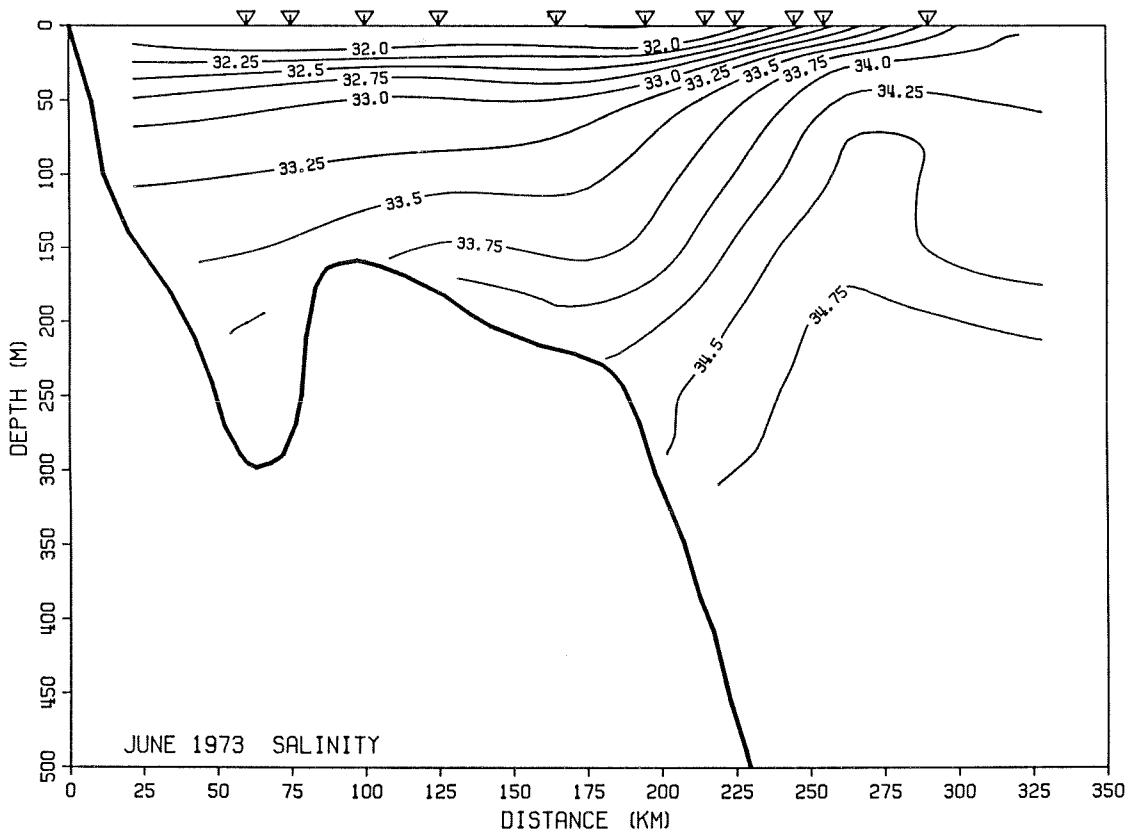
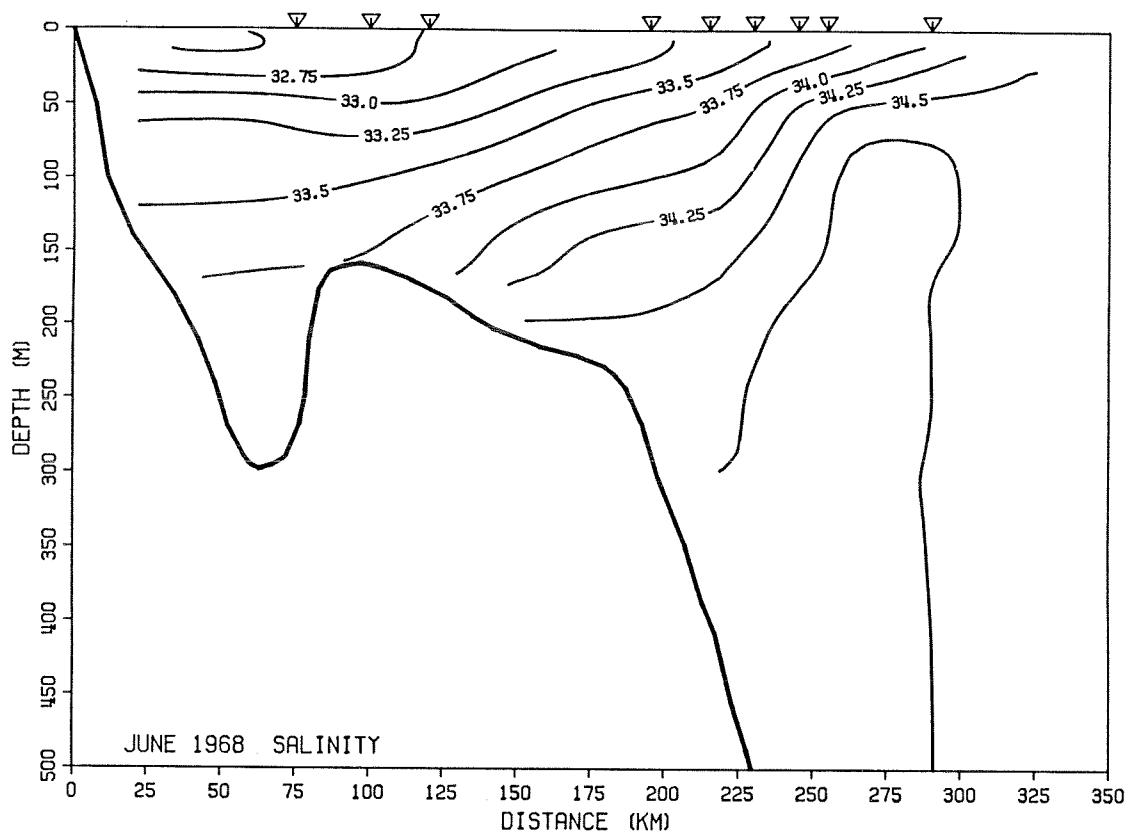


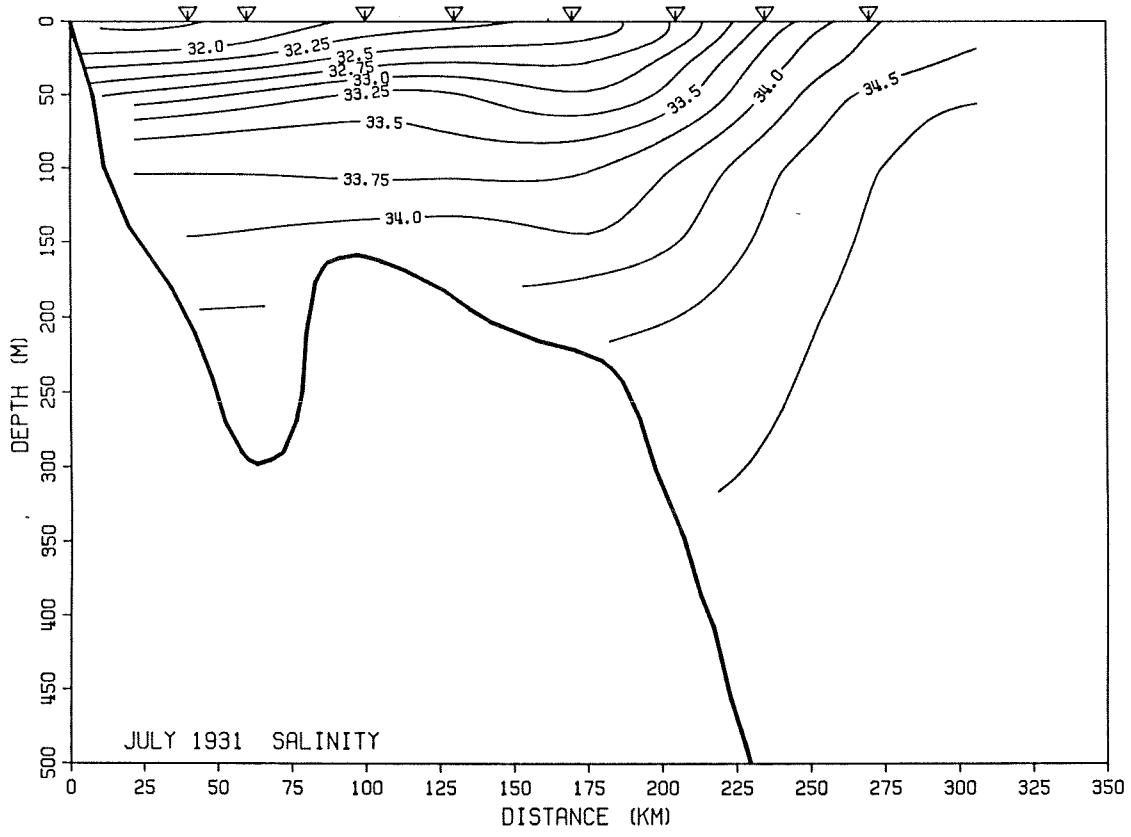
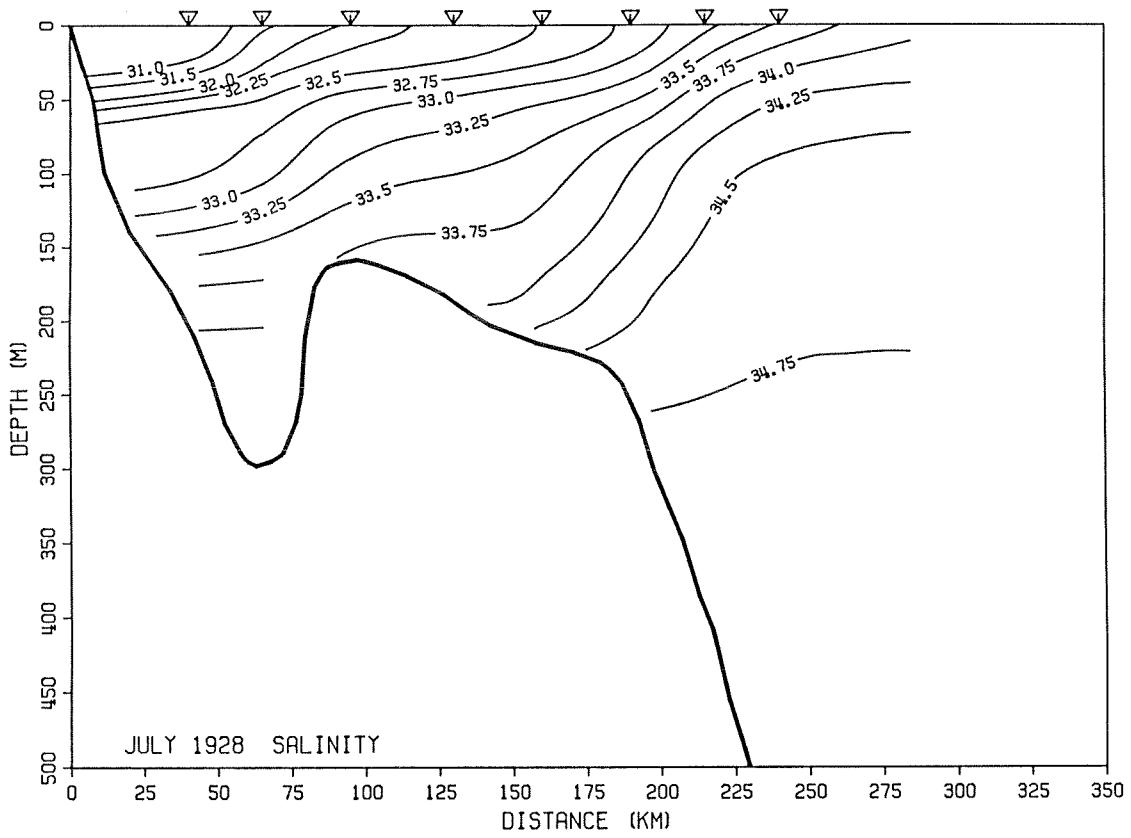


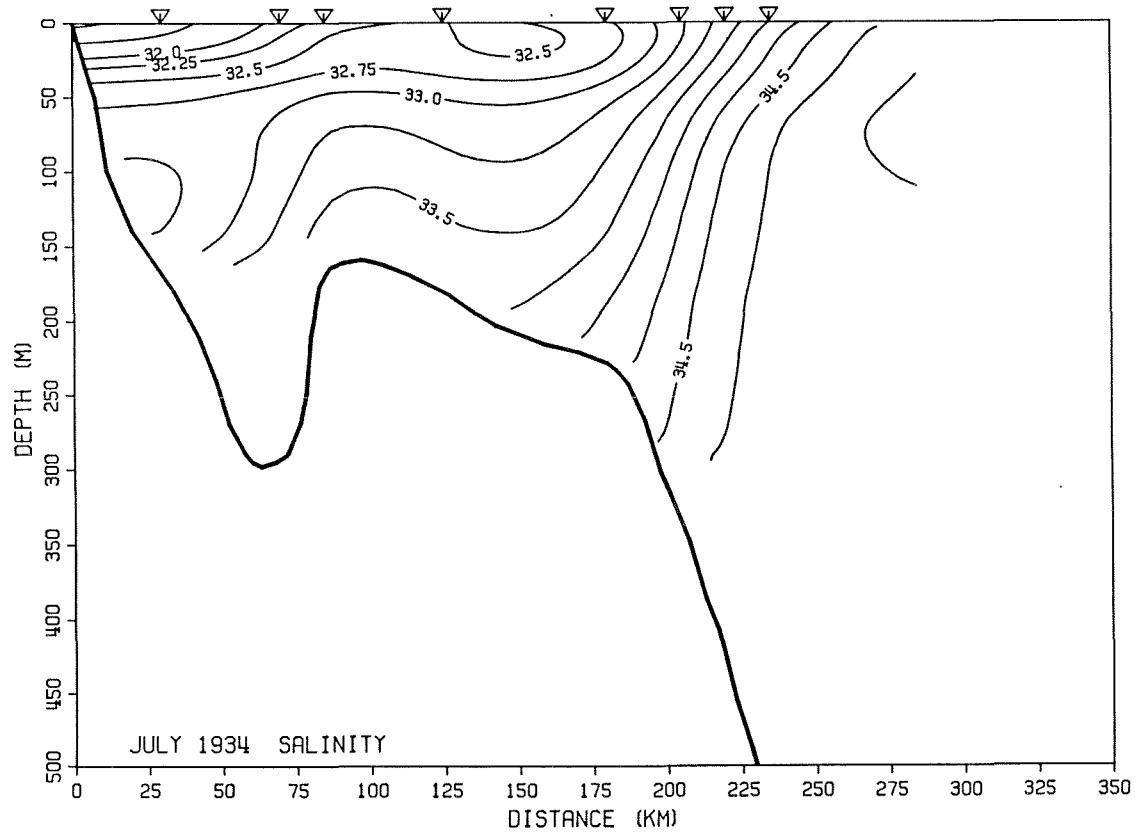
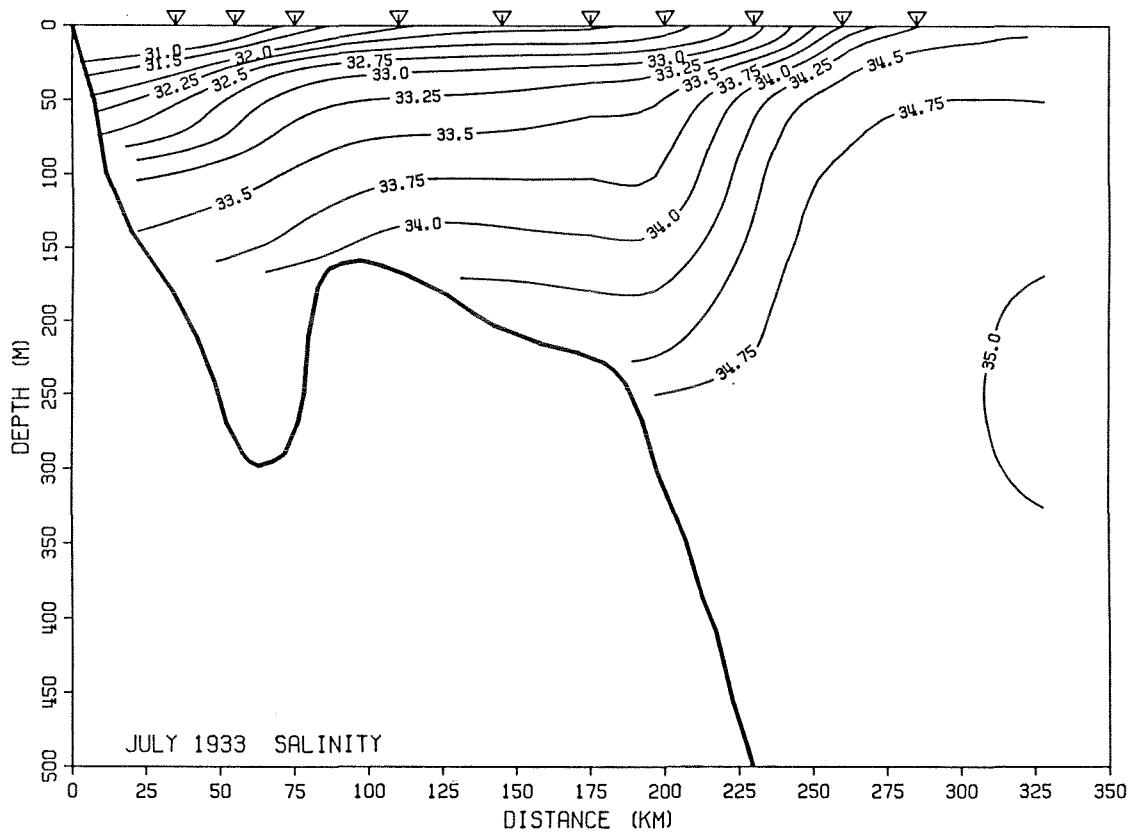
APPENDIX F. Seal Island Annual Salinity Transects

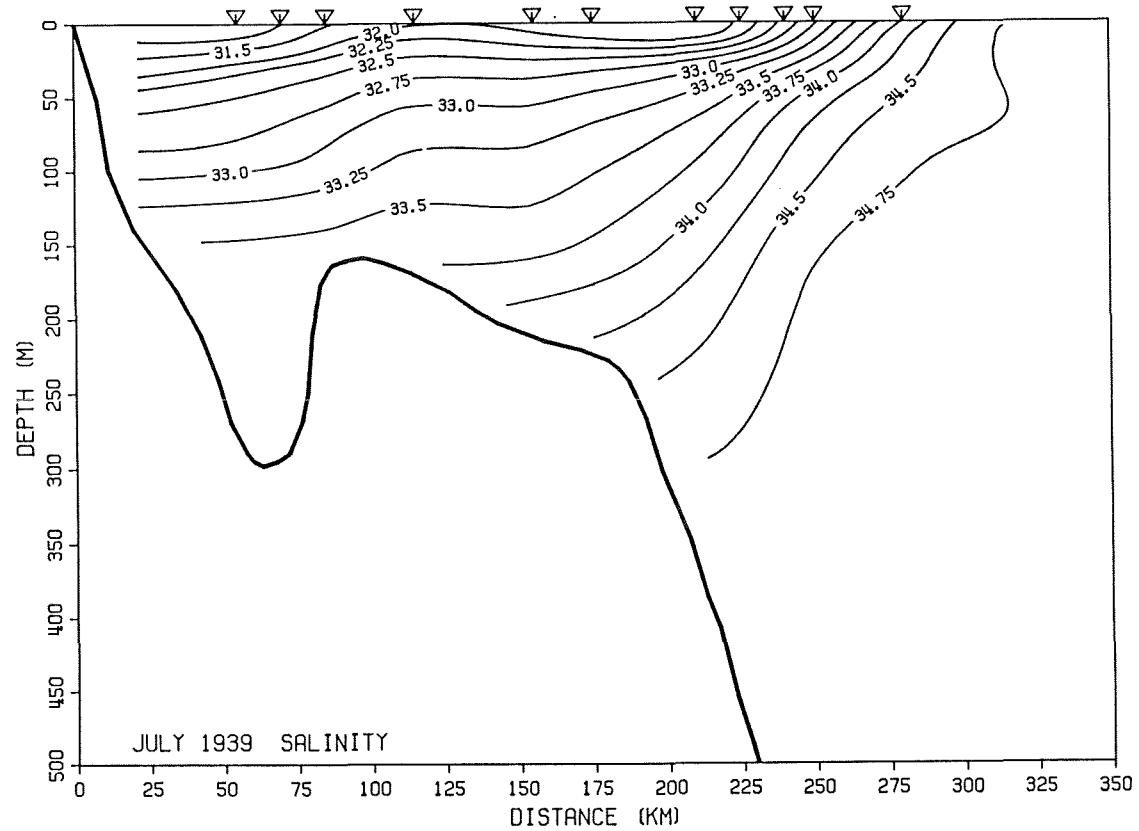
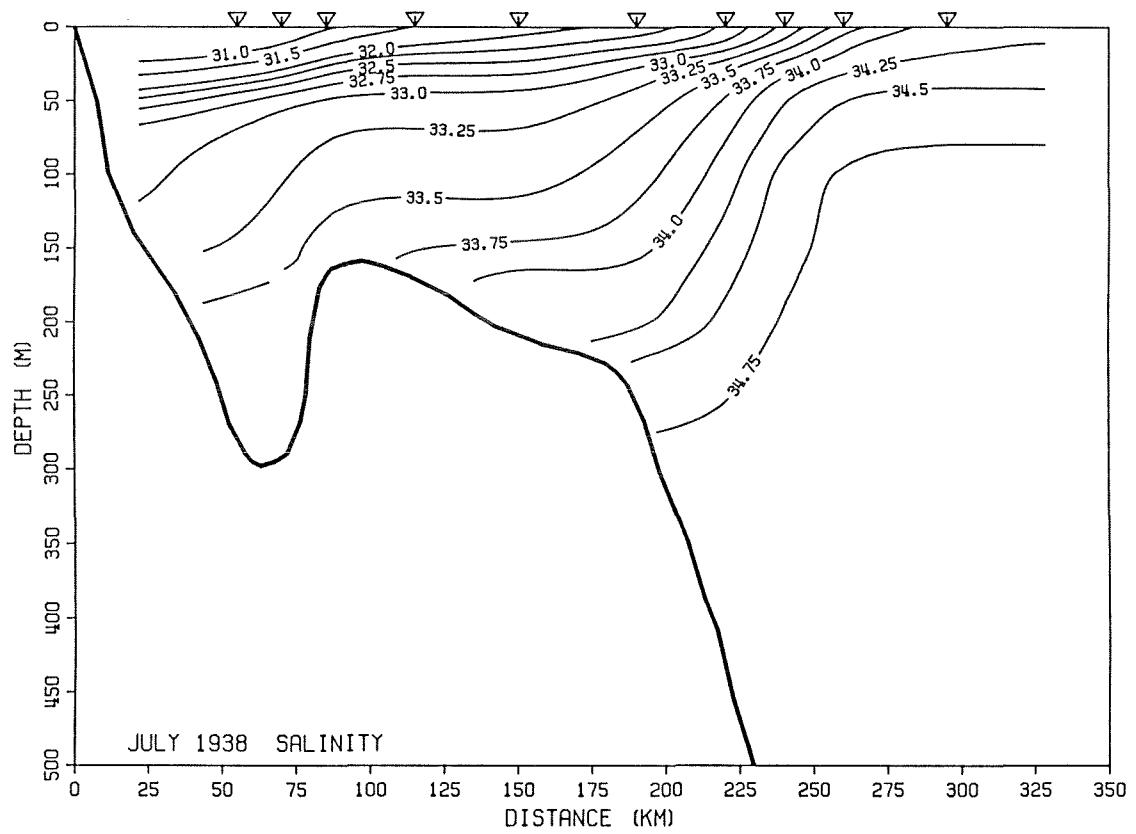
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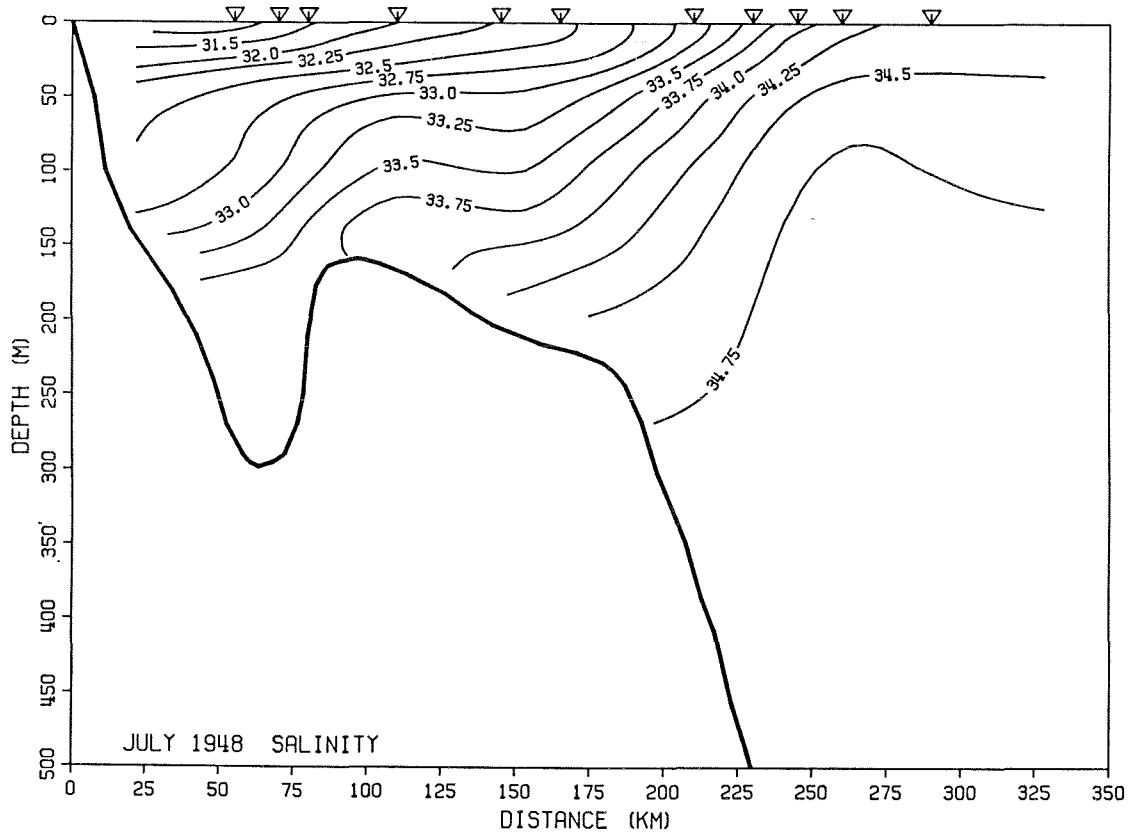
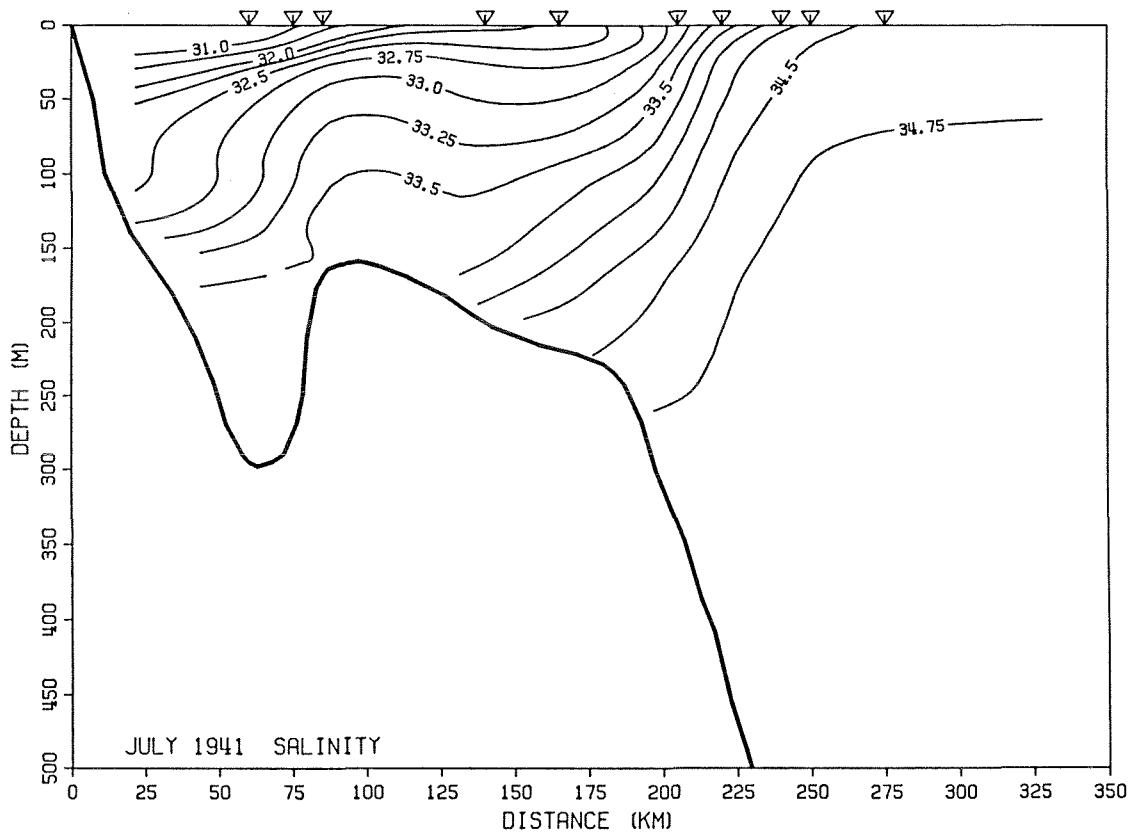


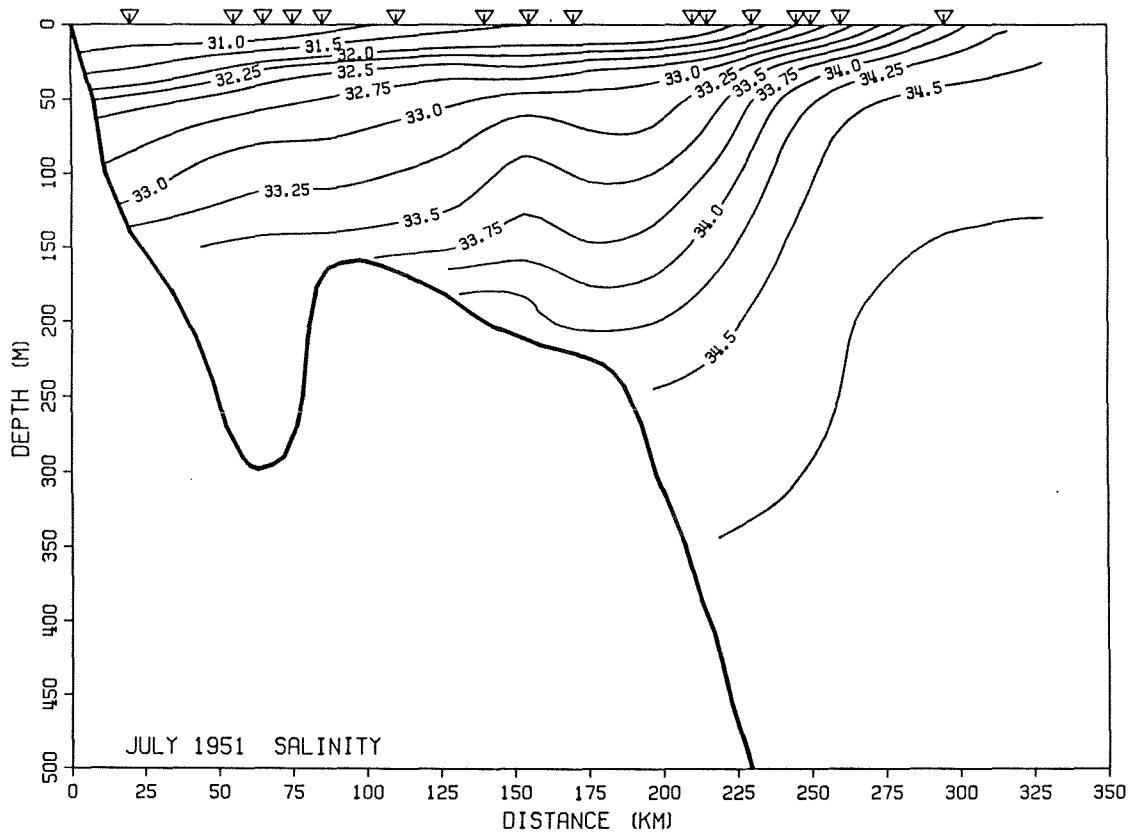
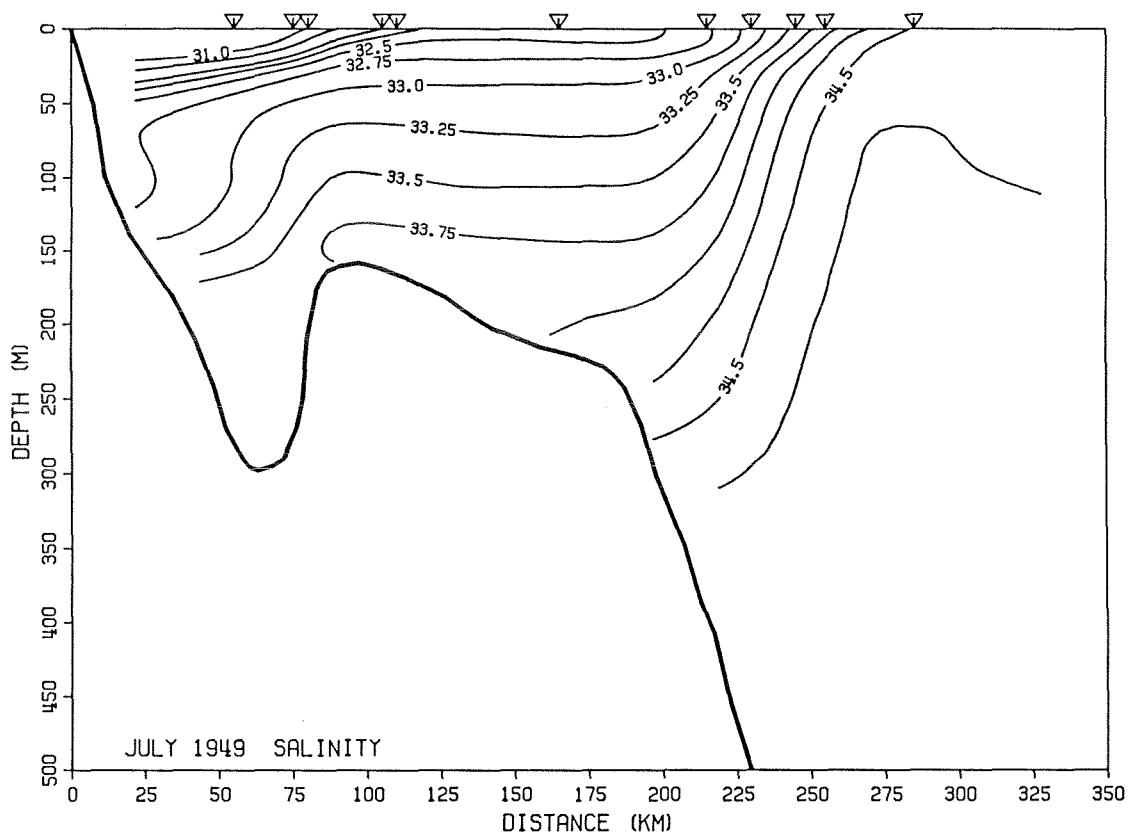




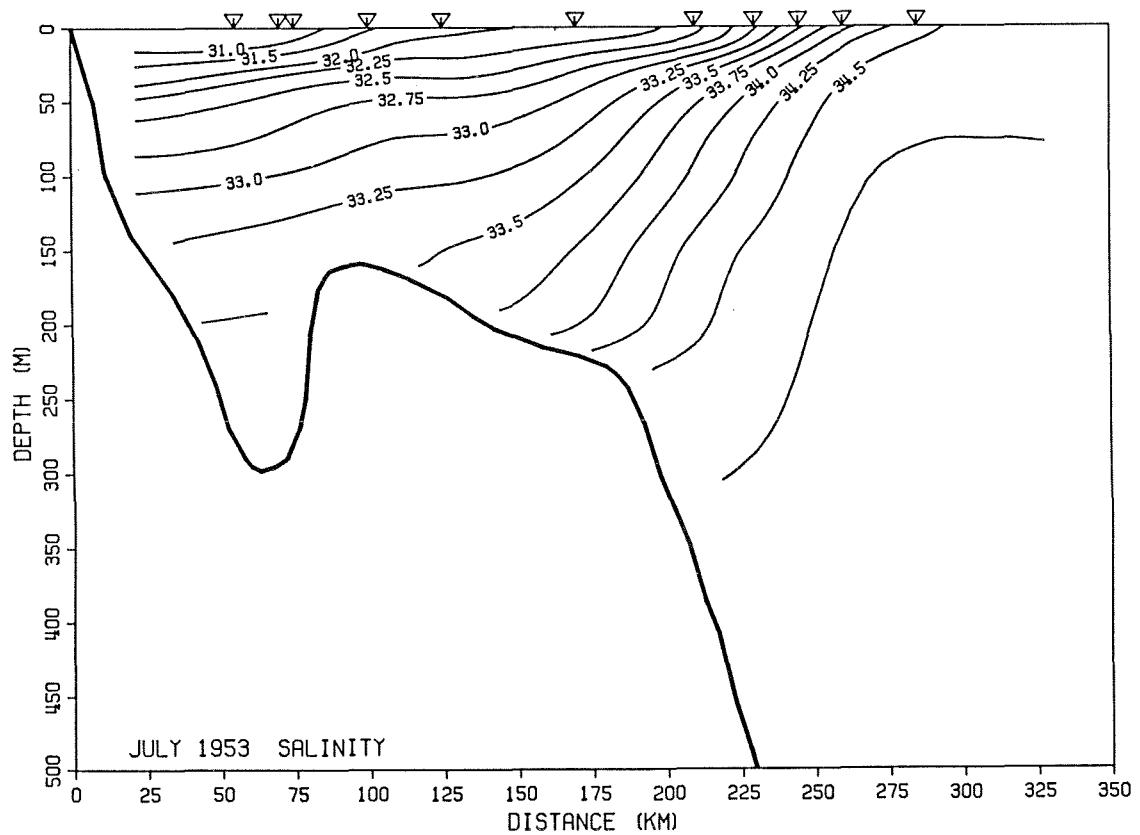
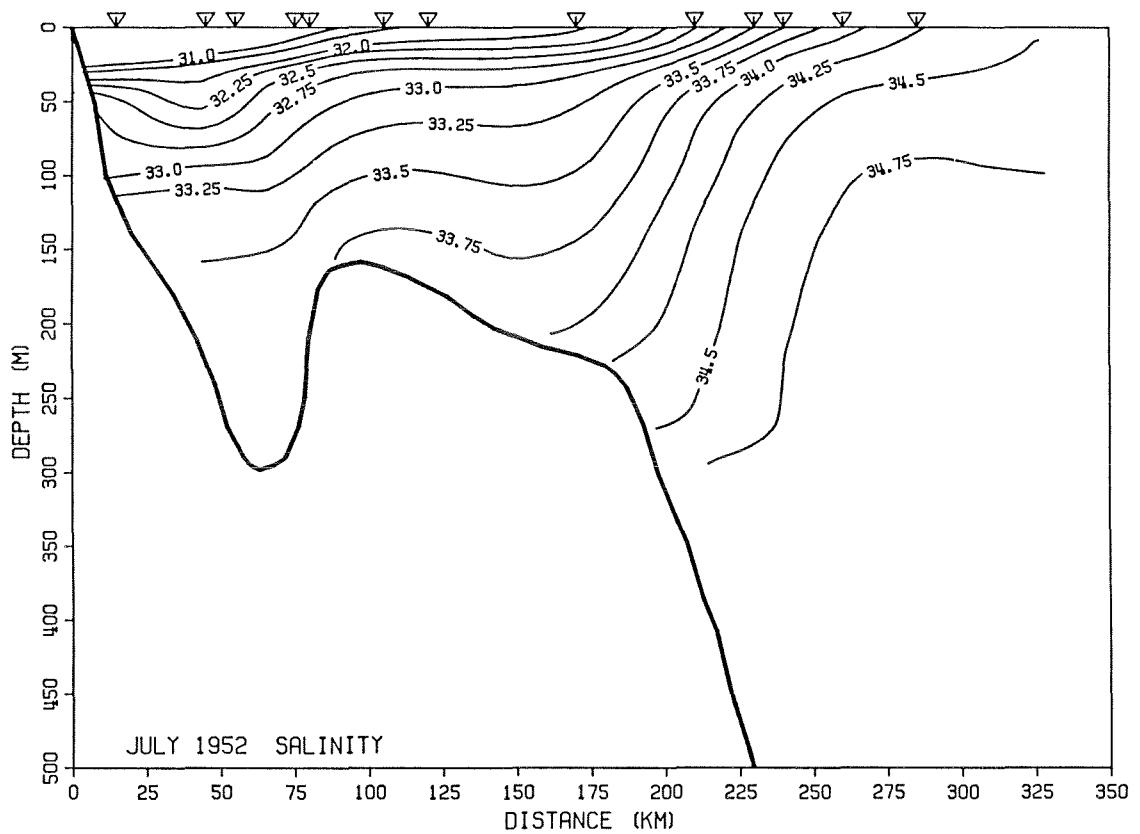


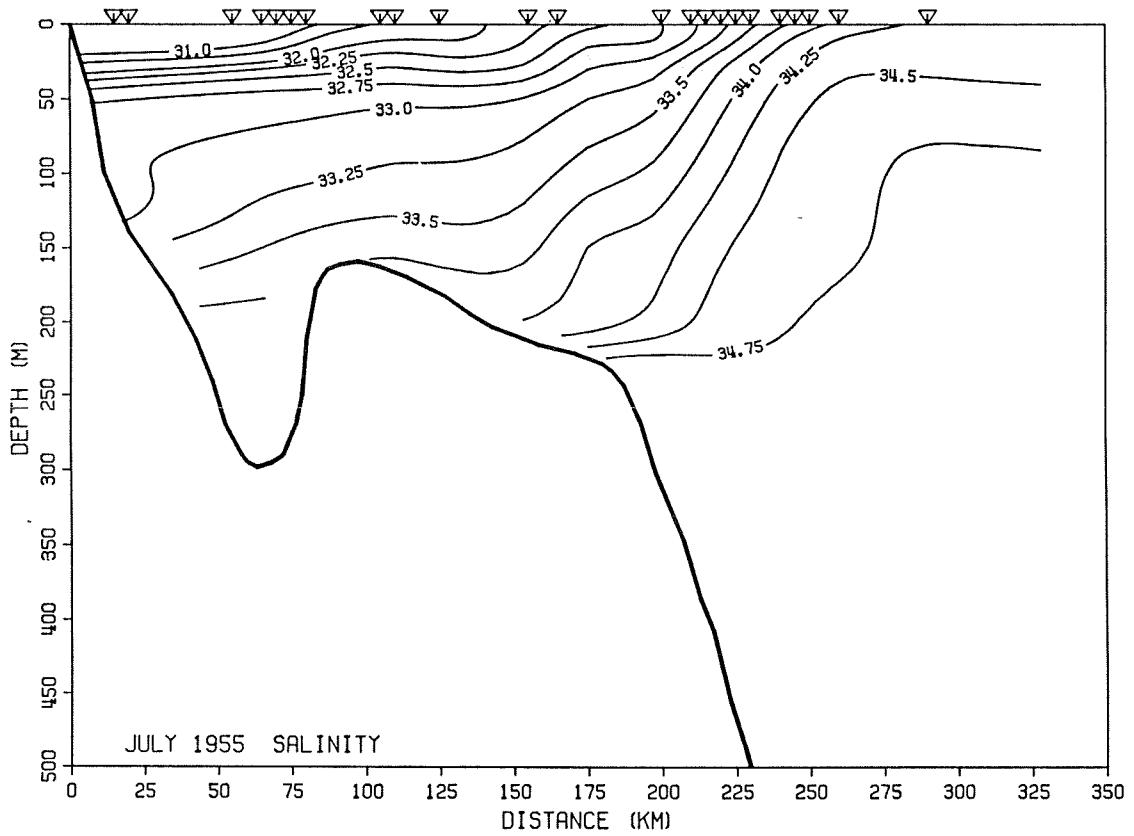
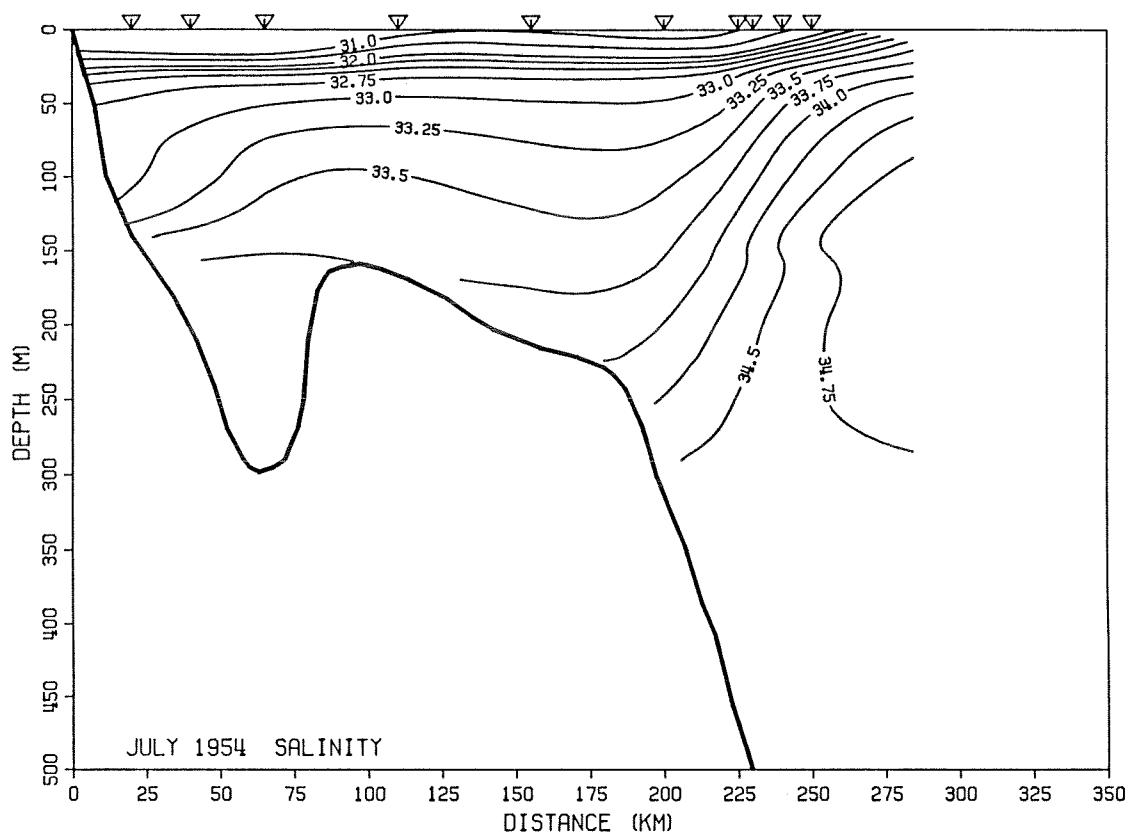
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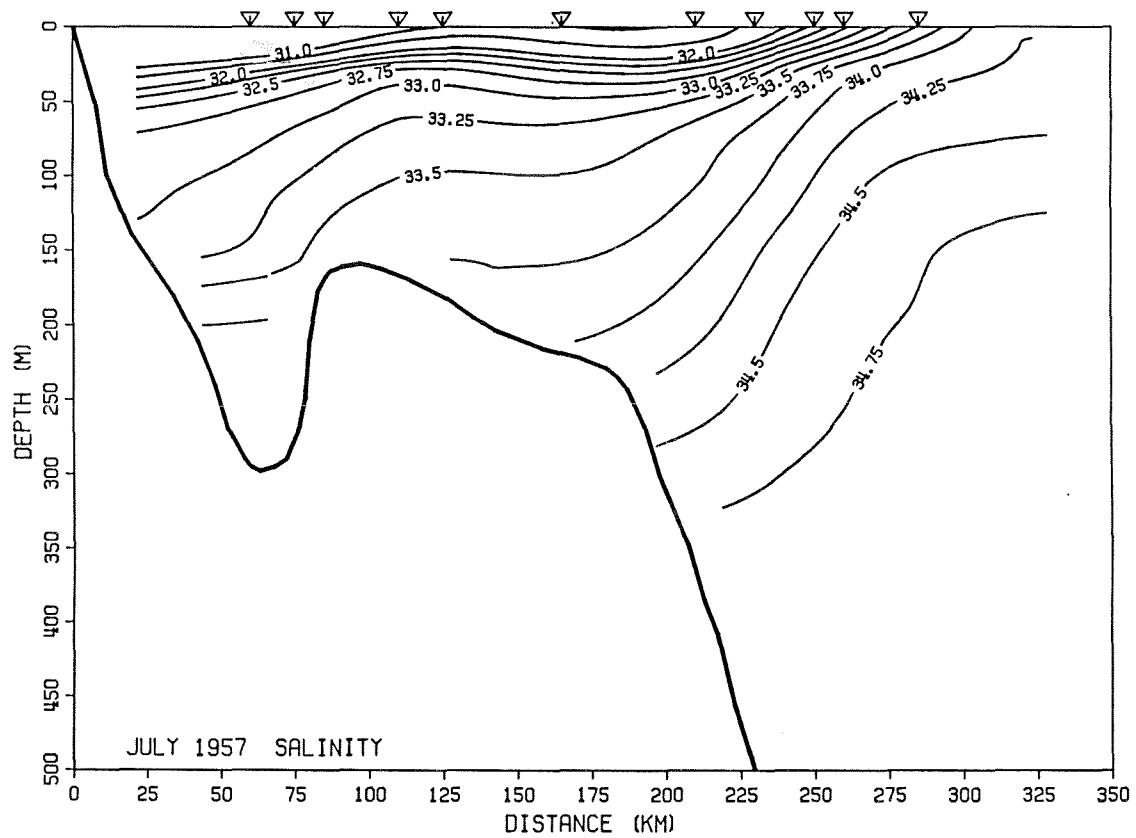
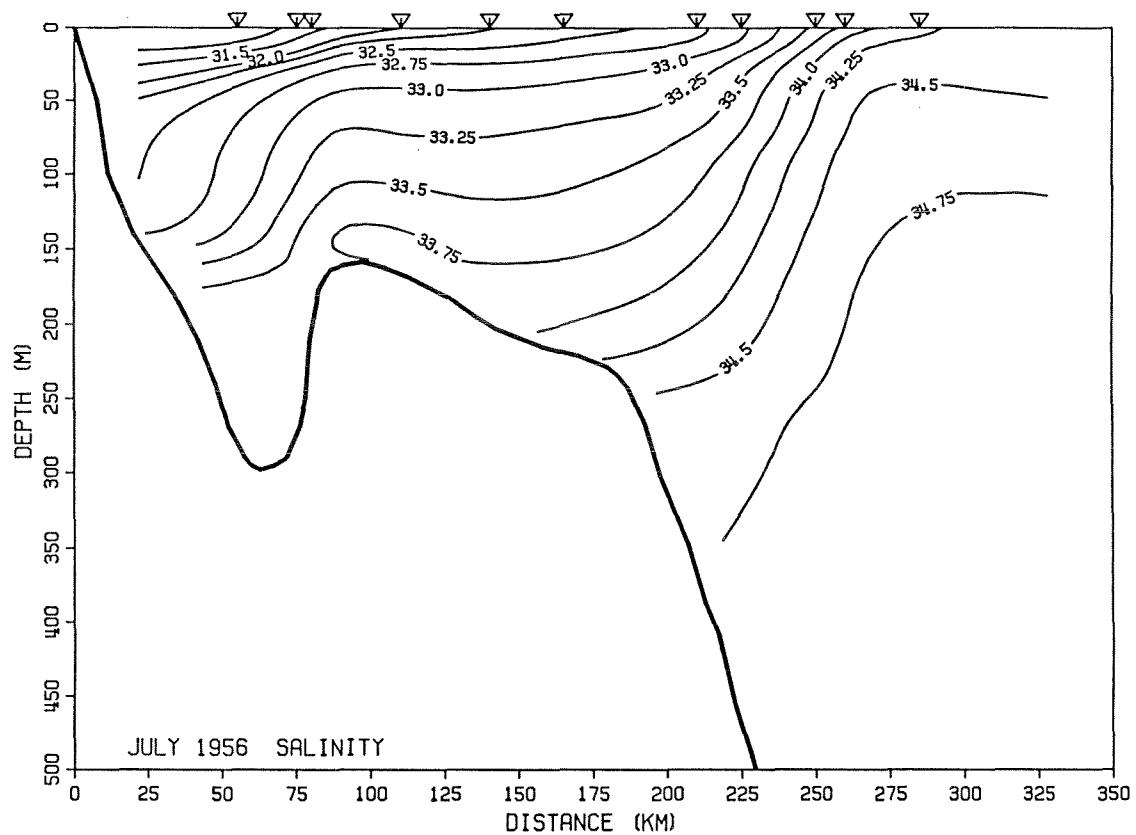


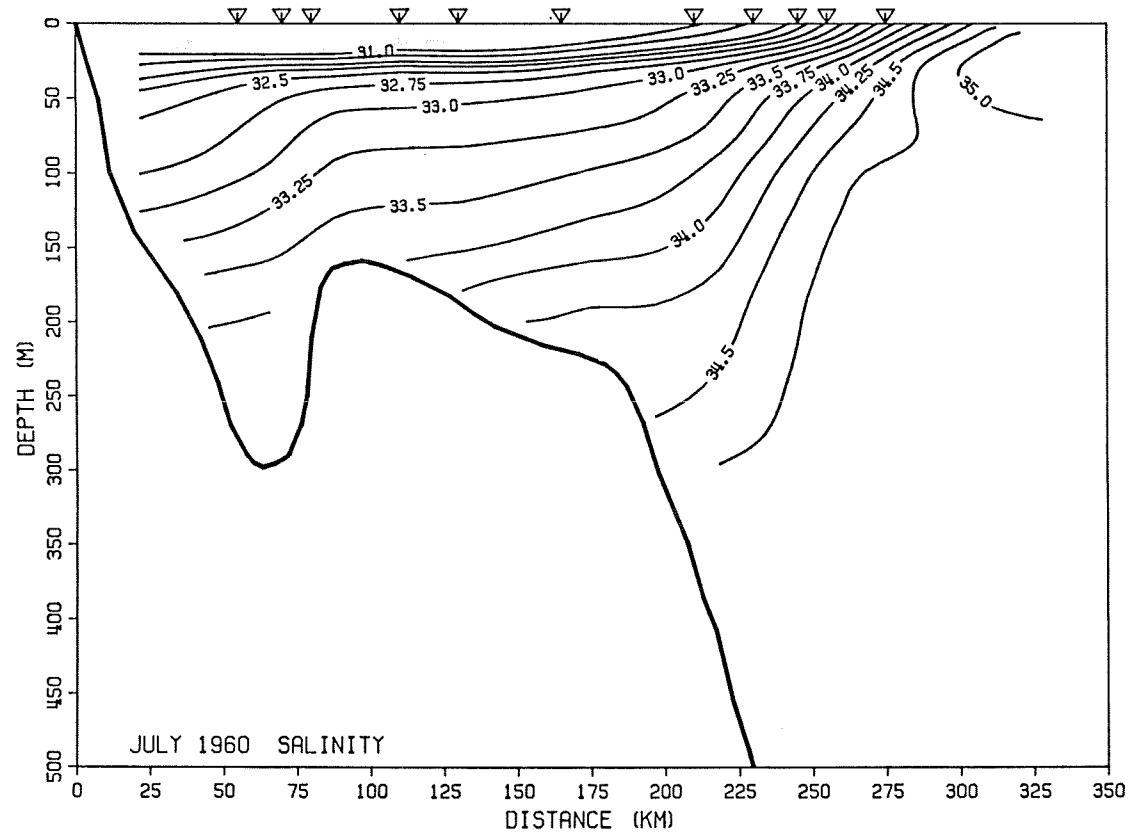
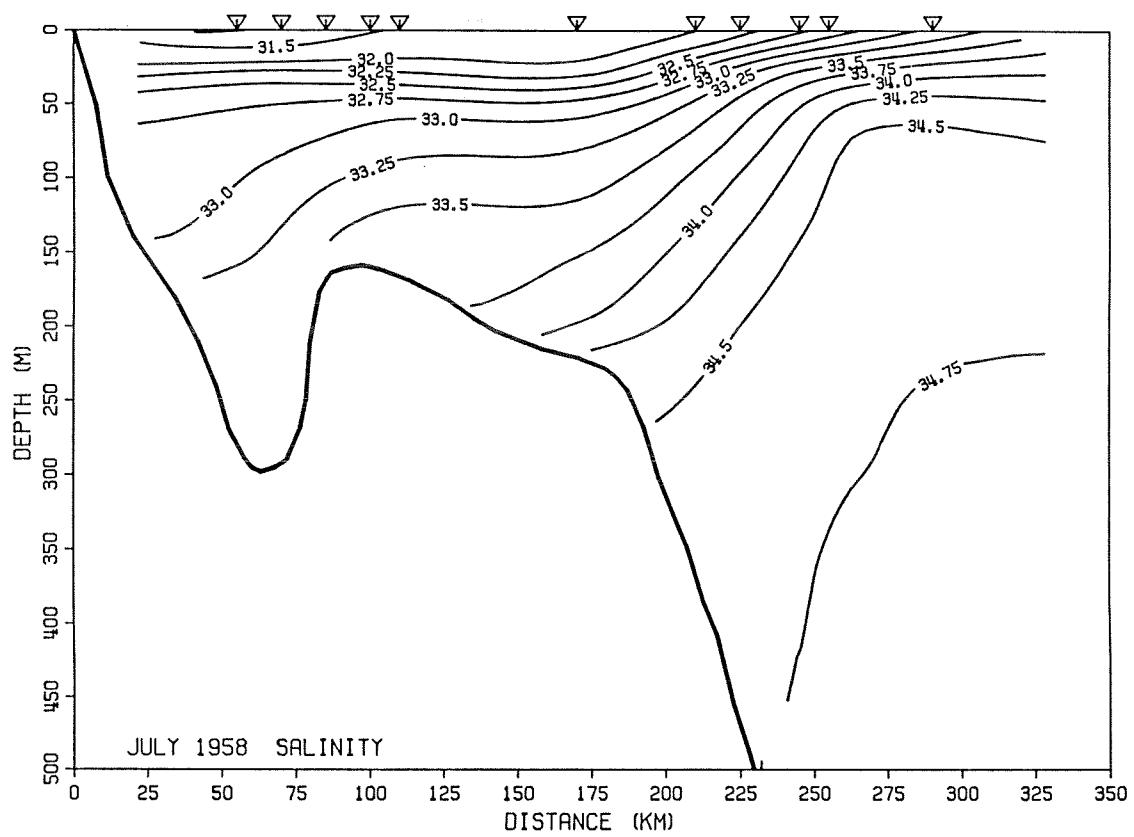


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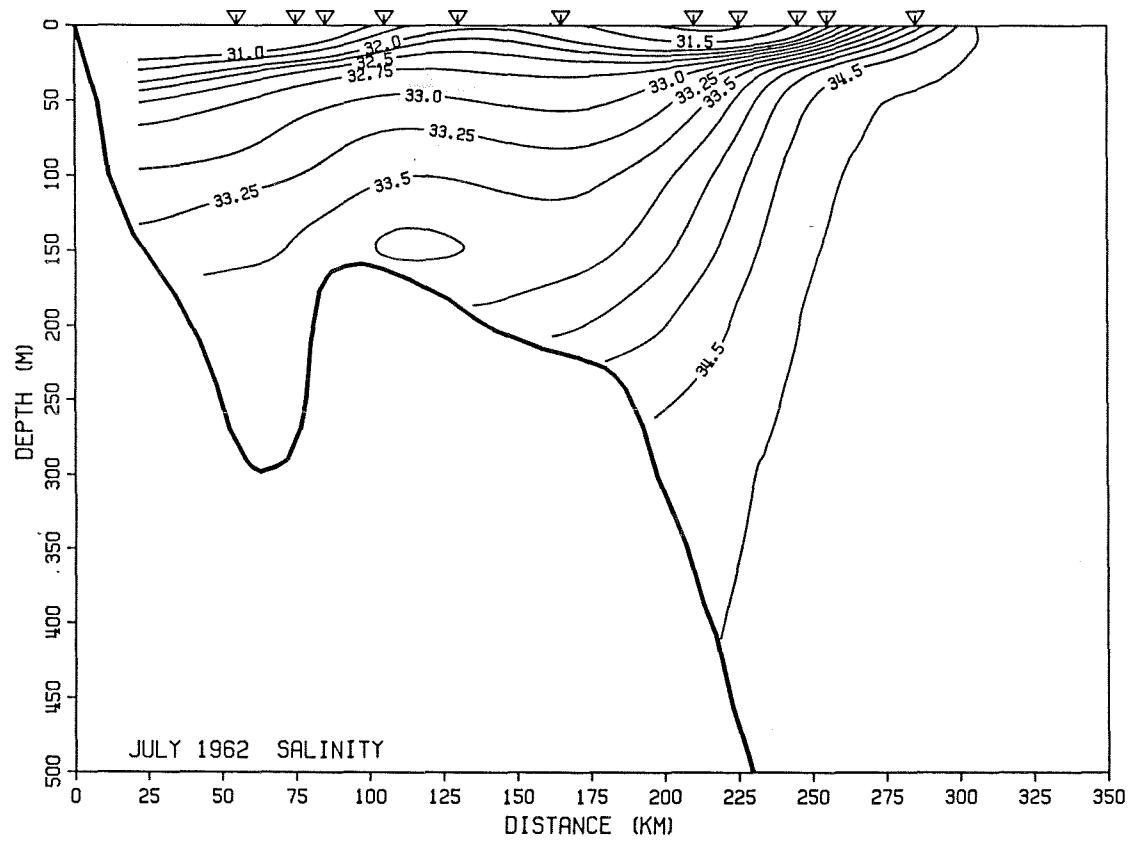
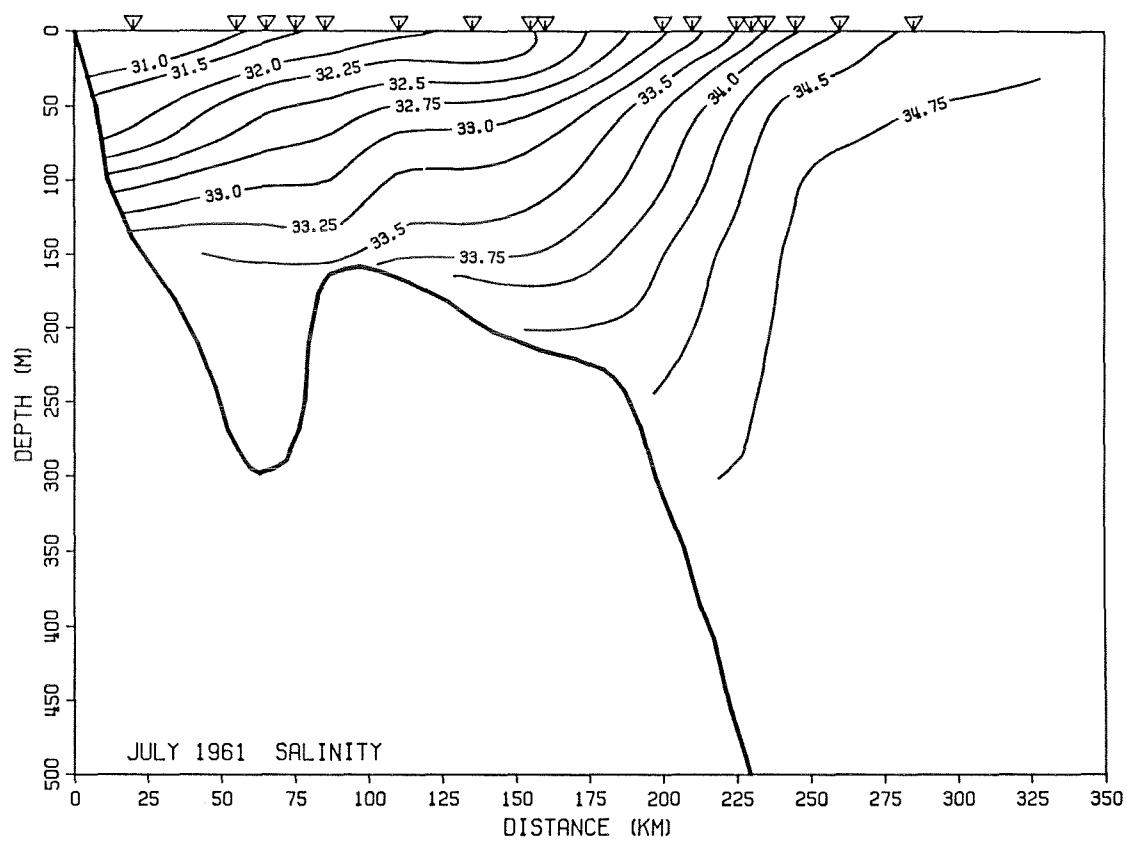


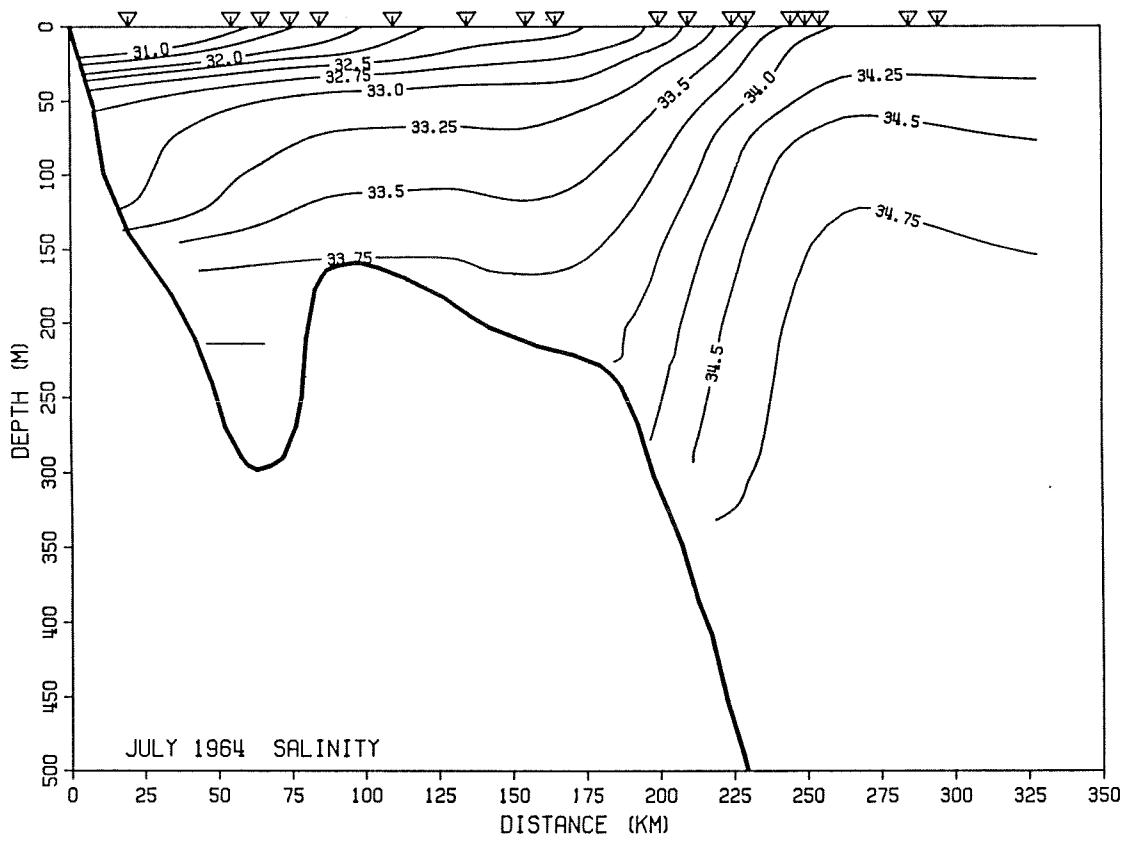
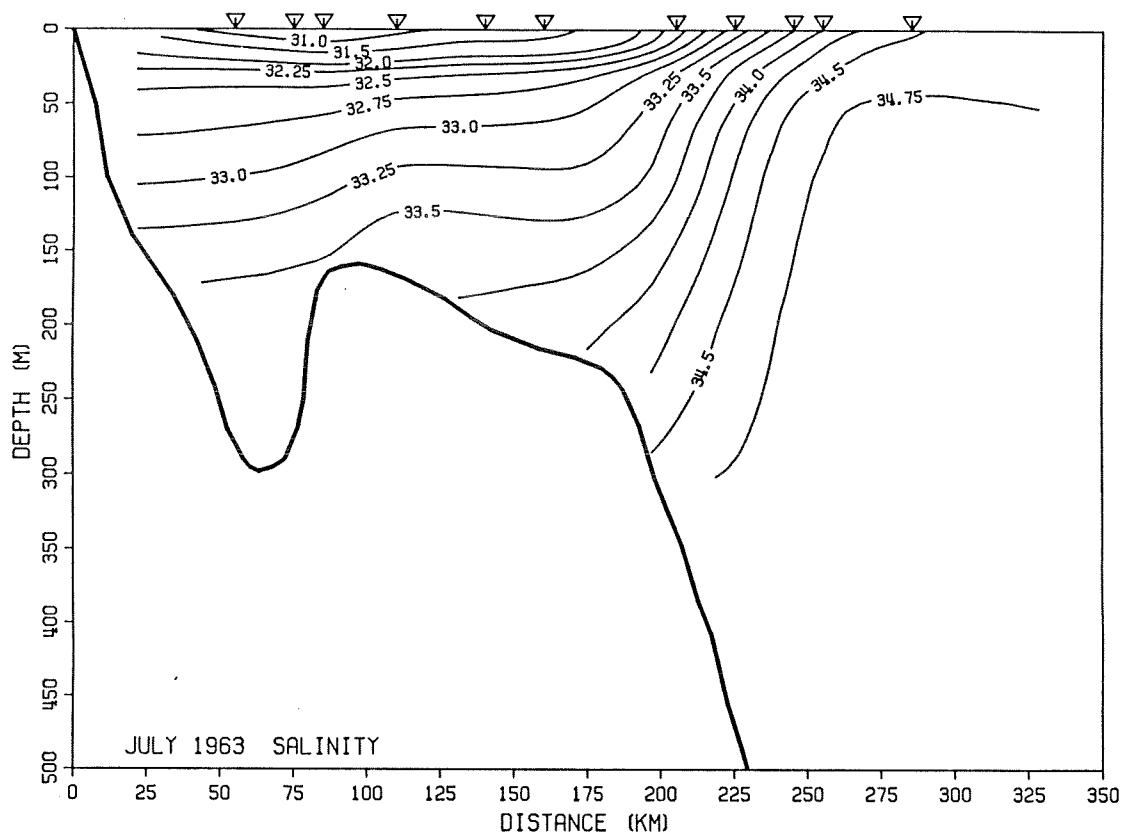


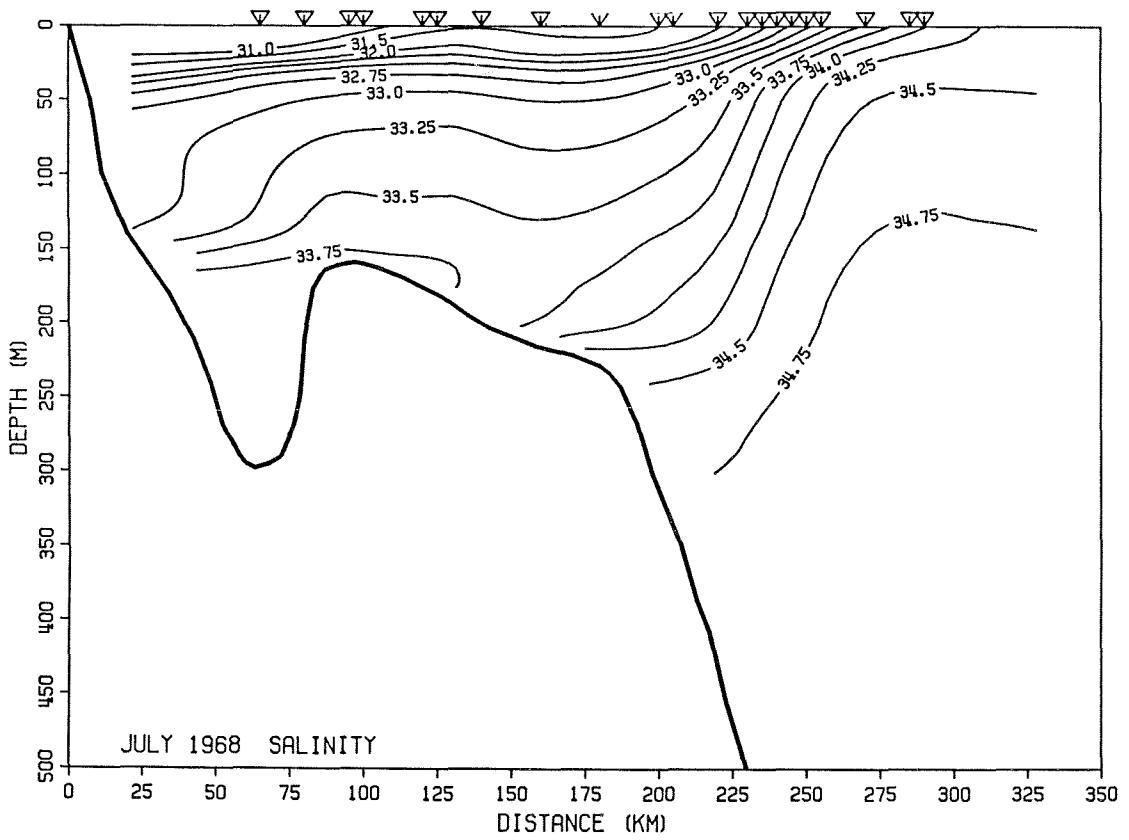
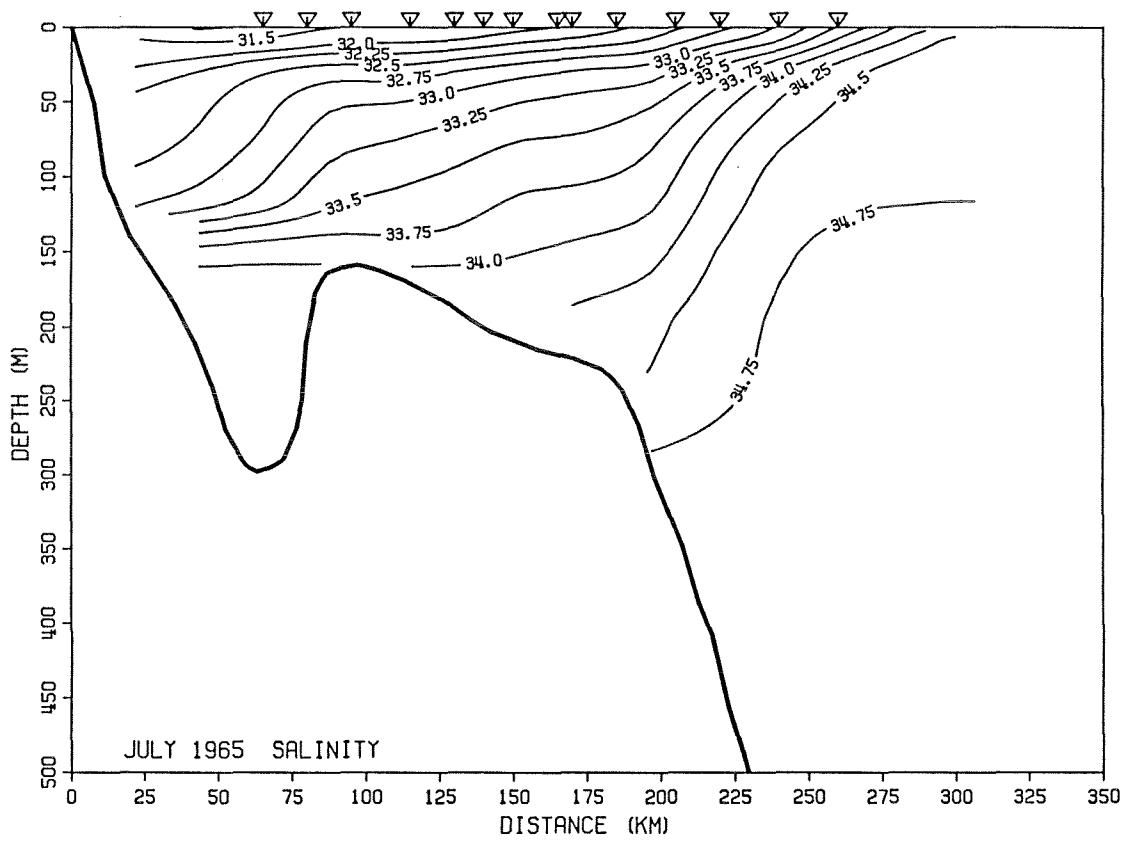




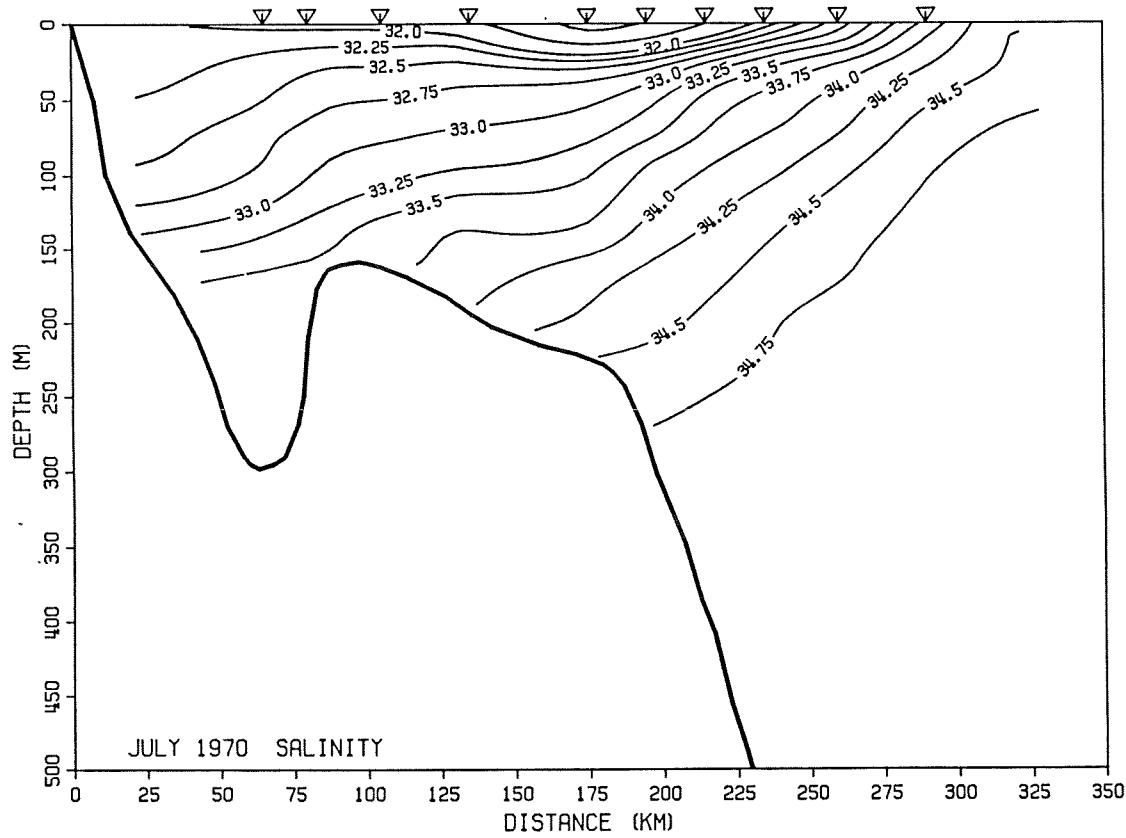
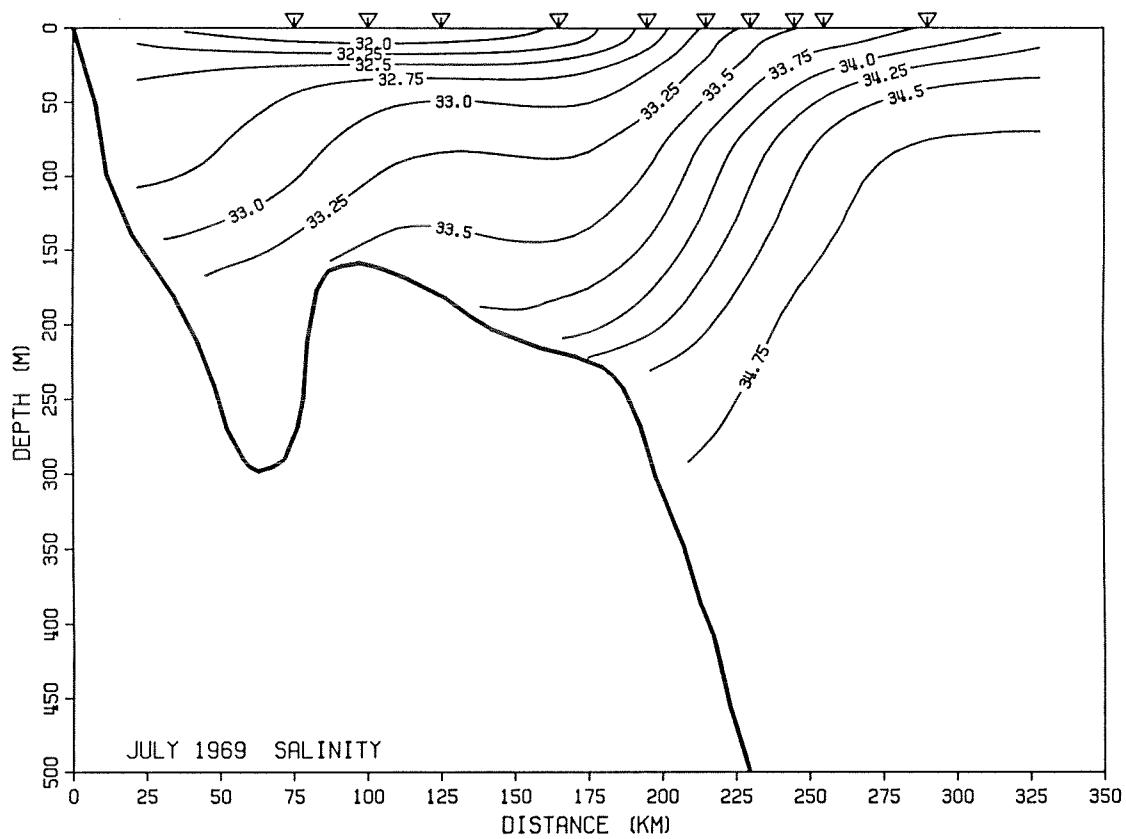
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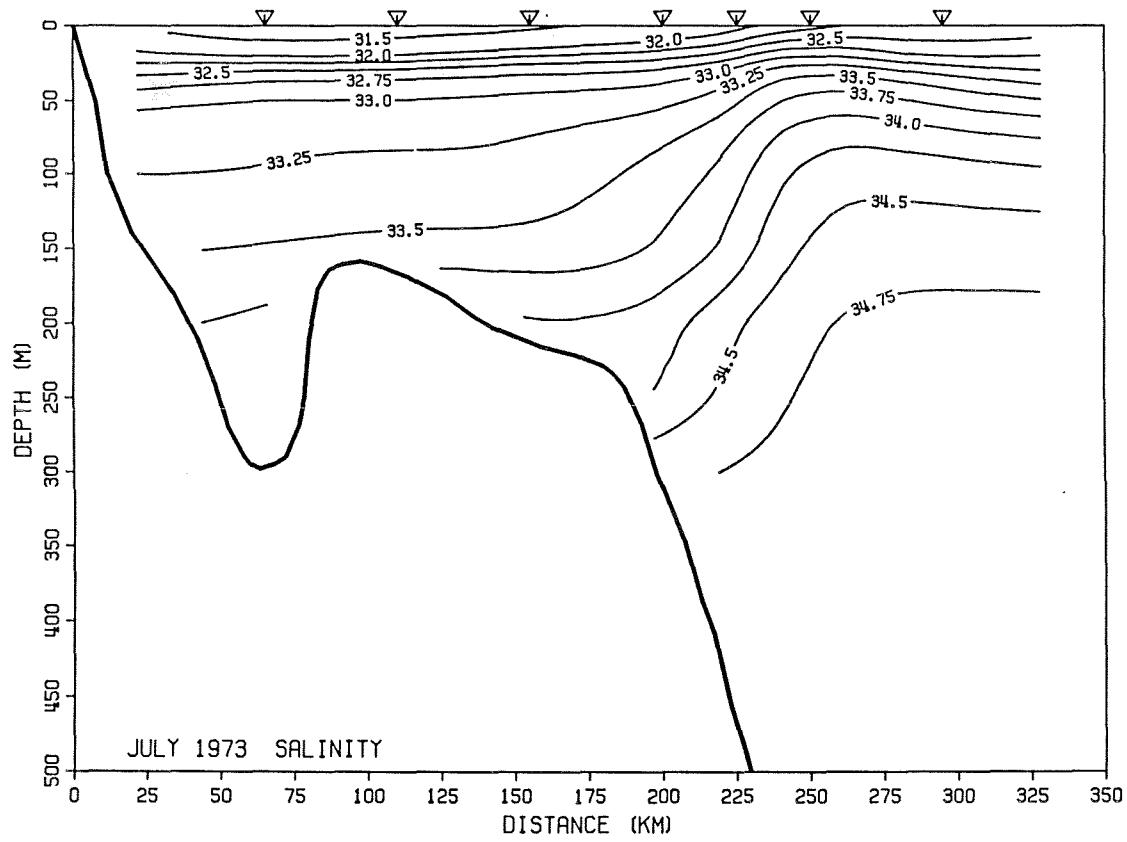
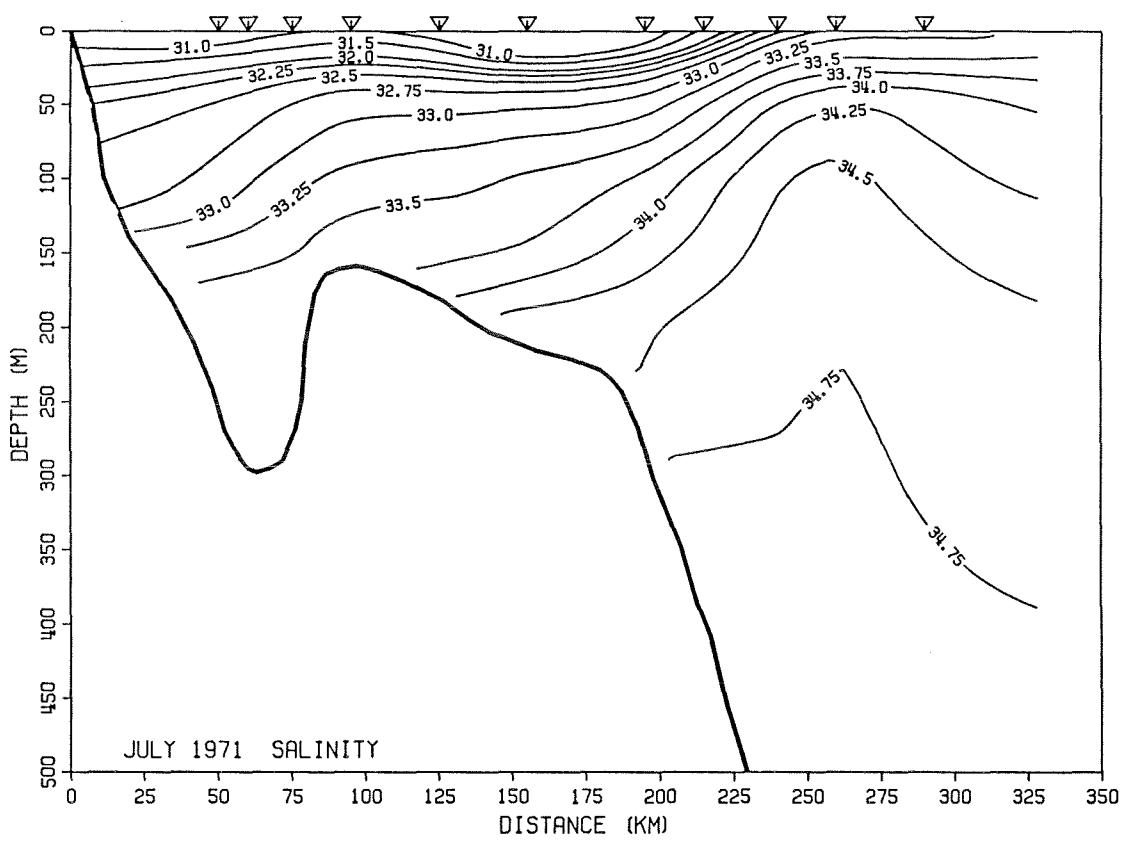


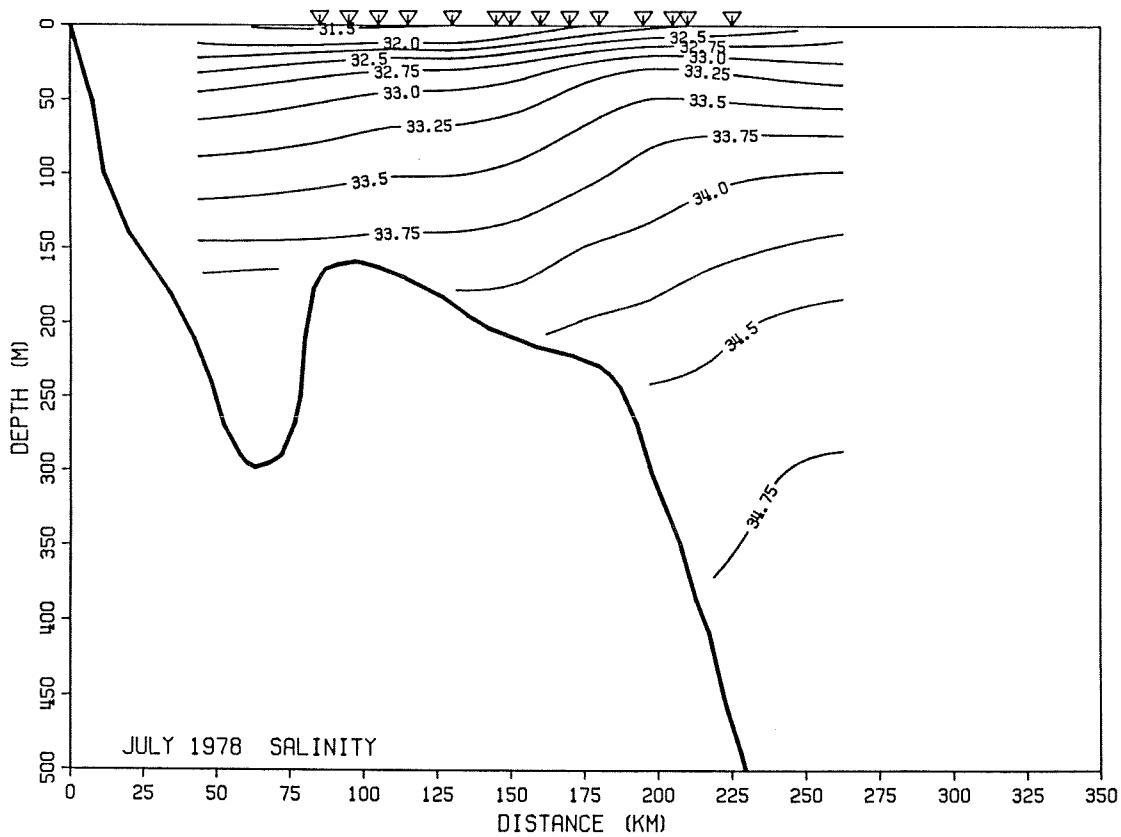
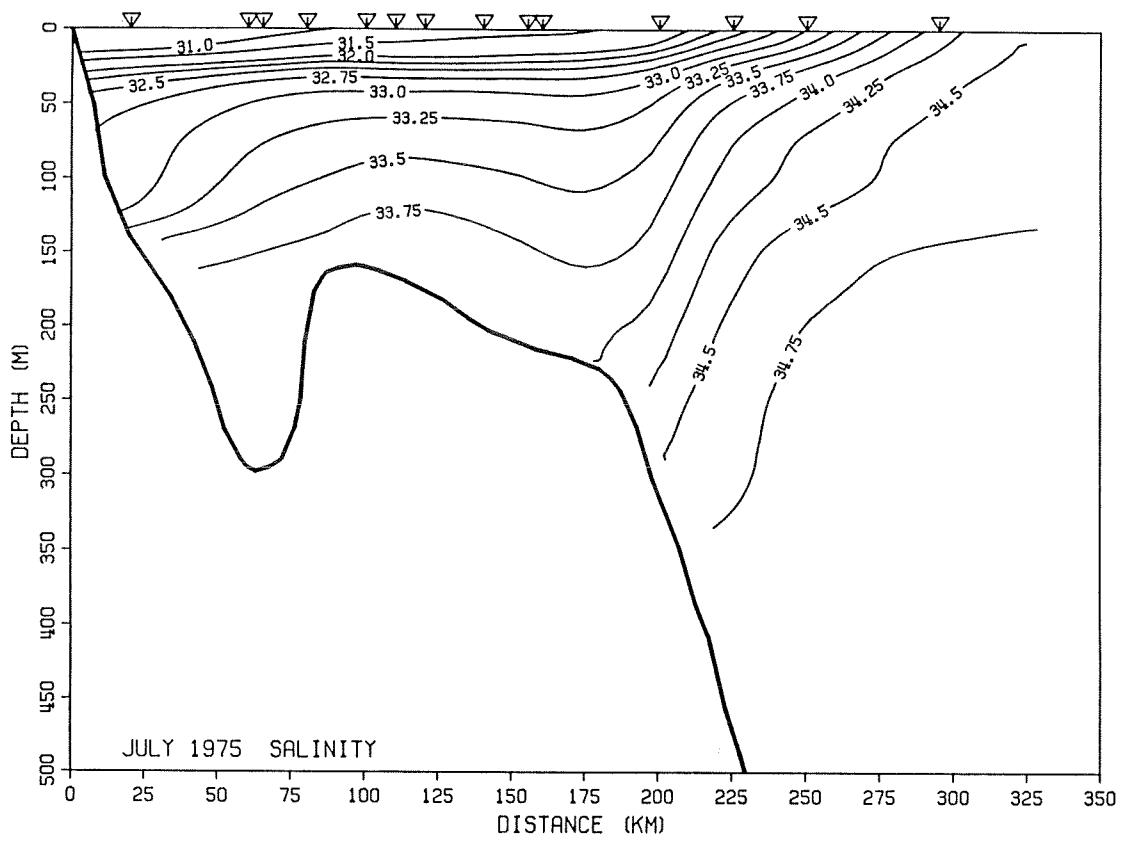


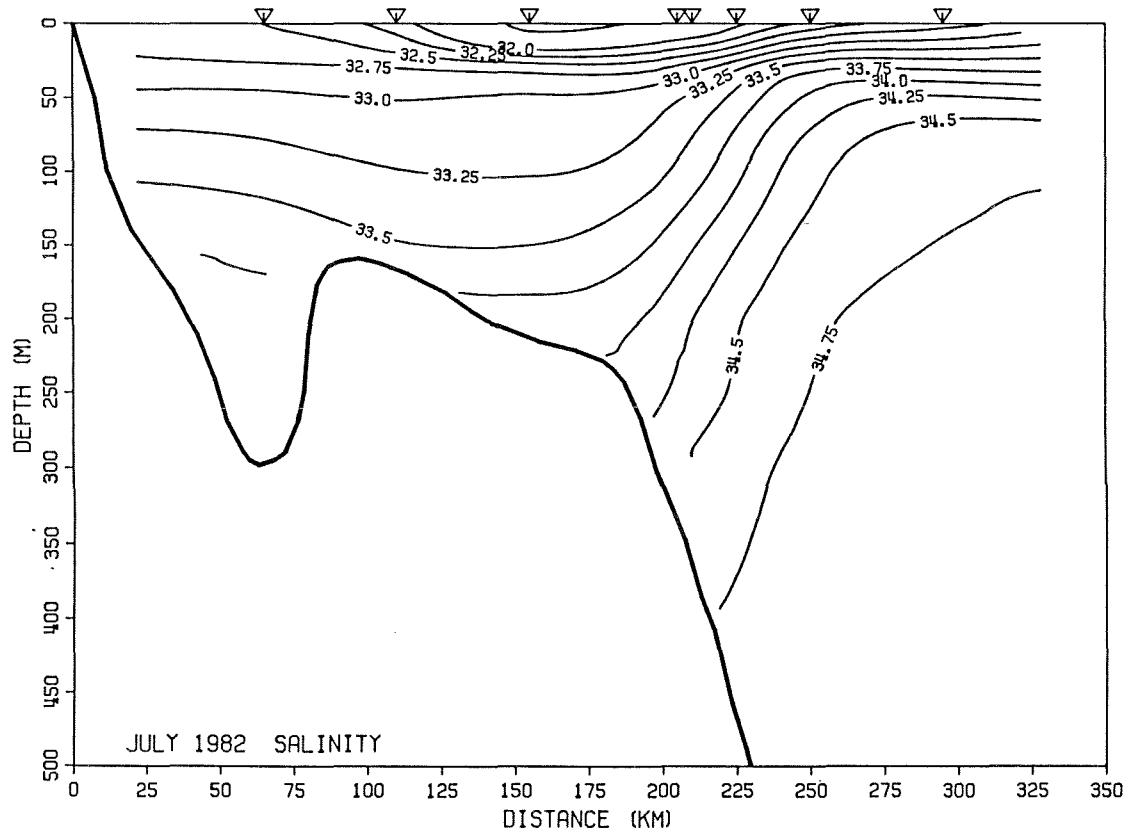
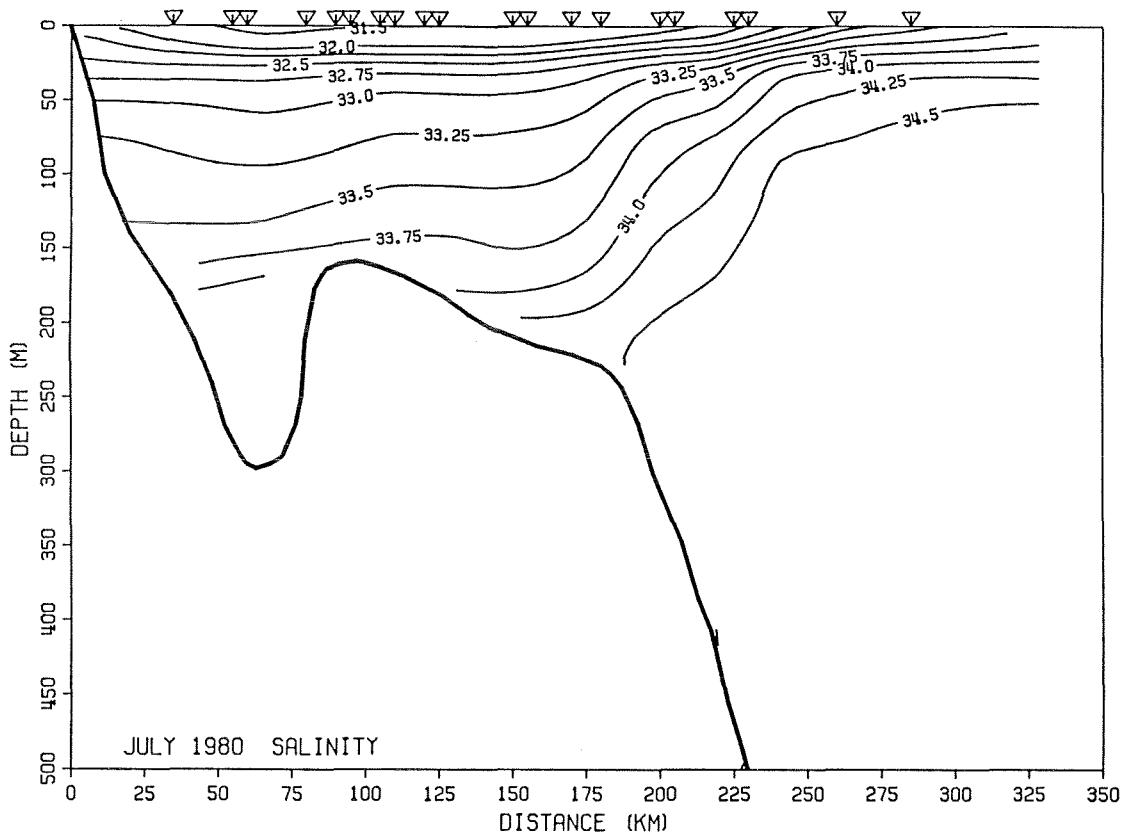
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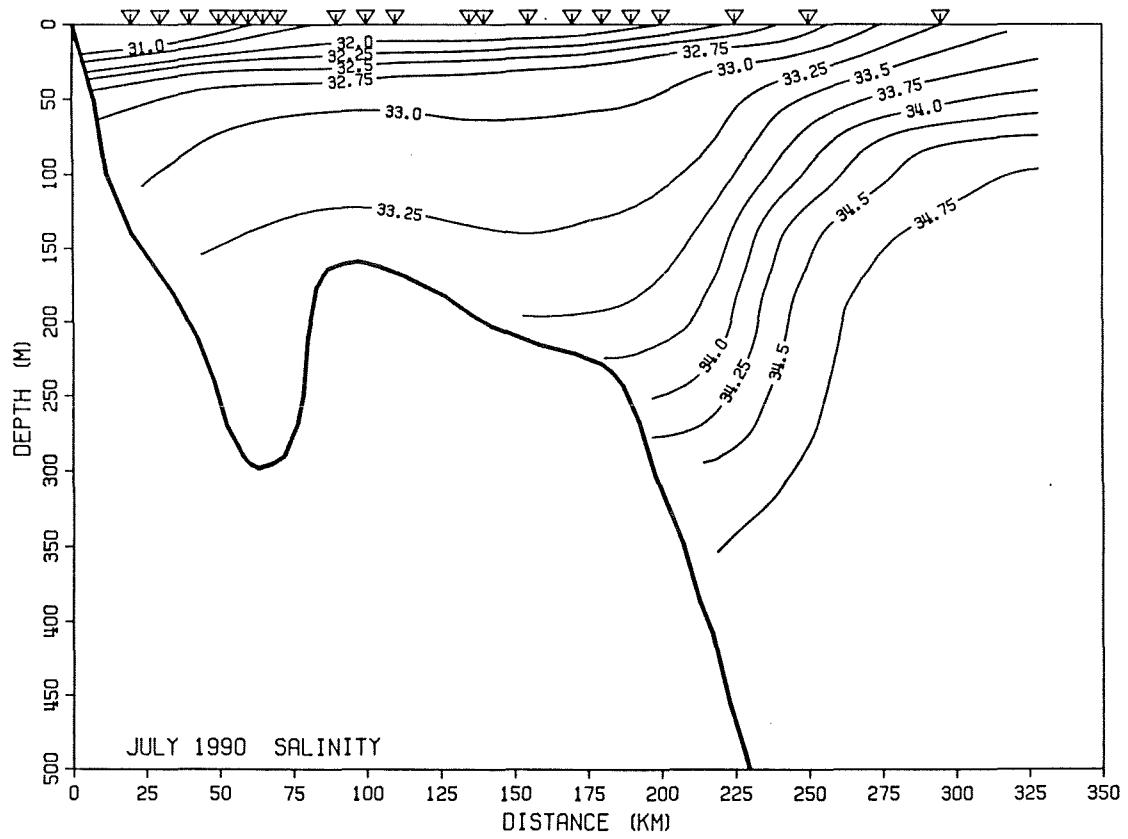
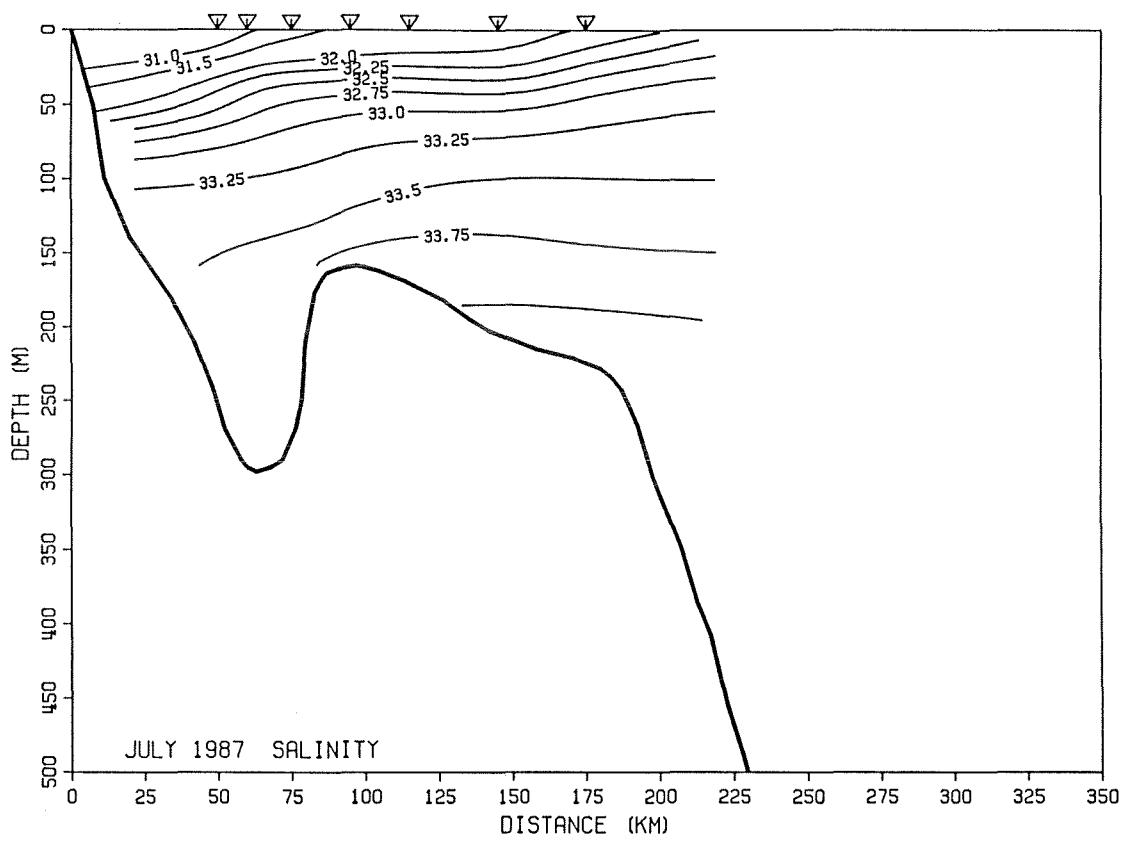


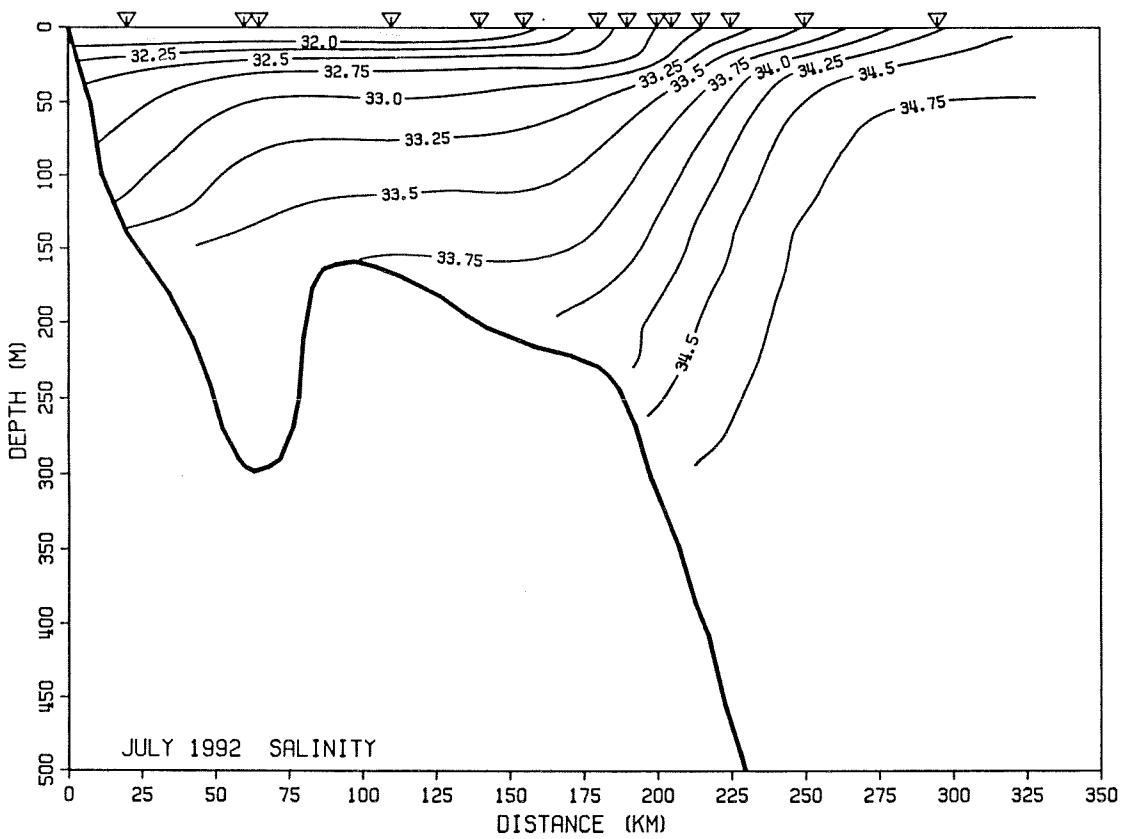
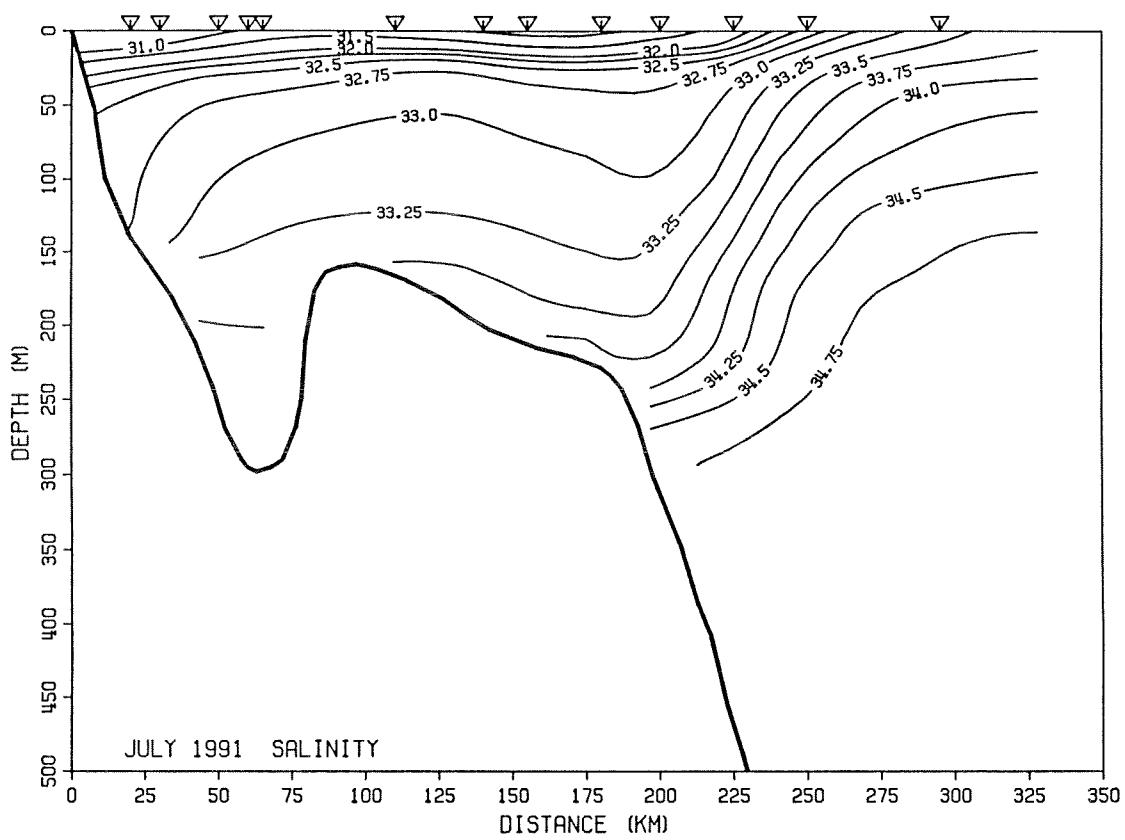
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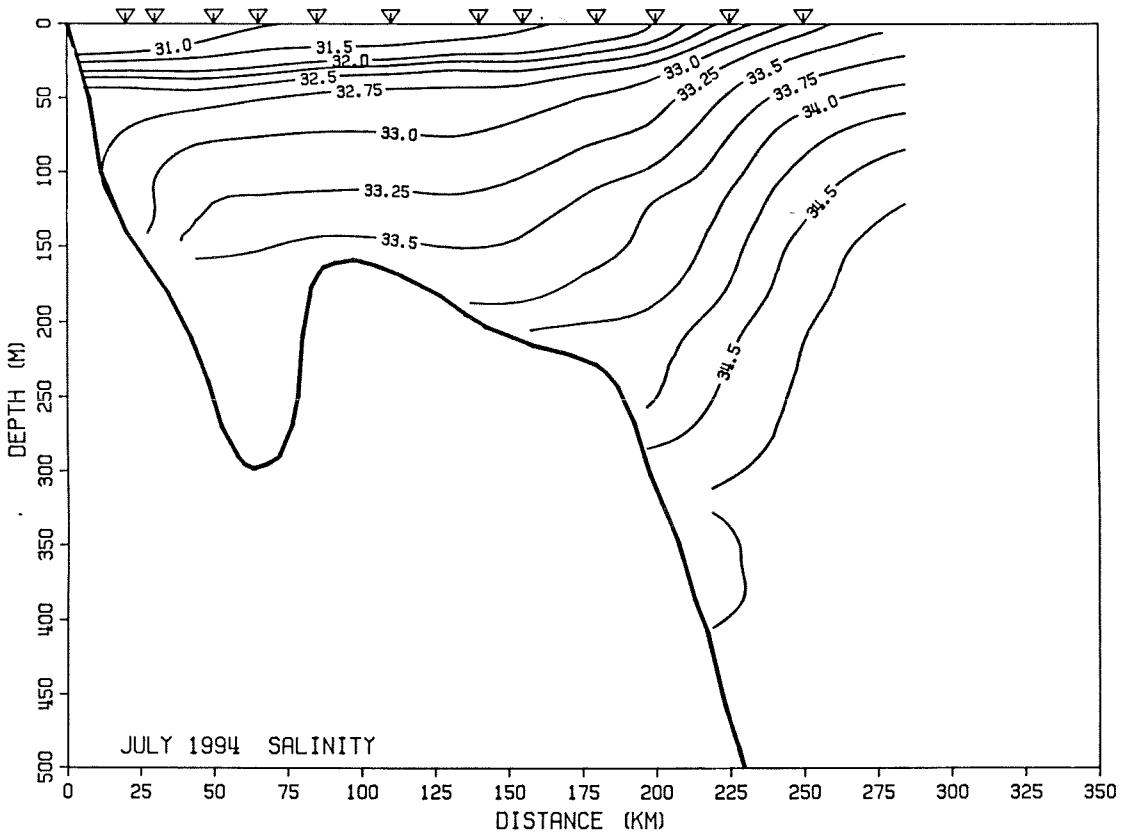
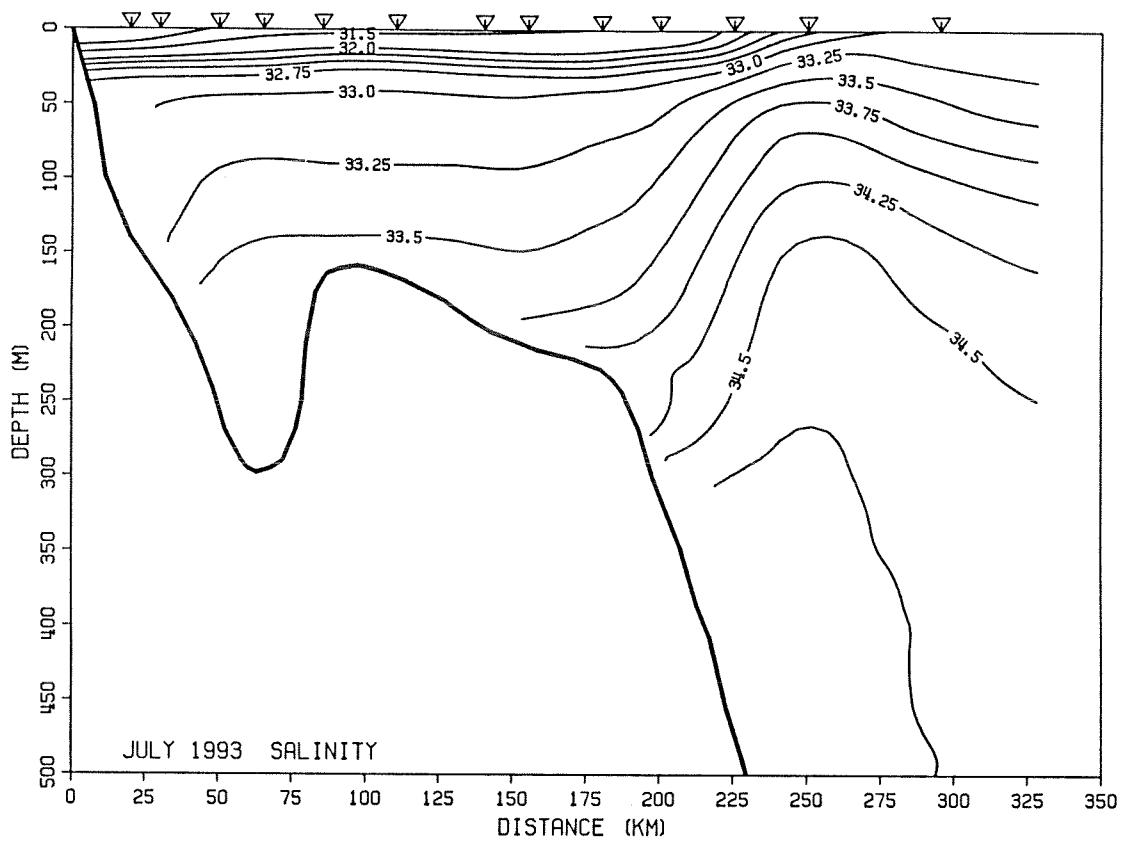


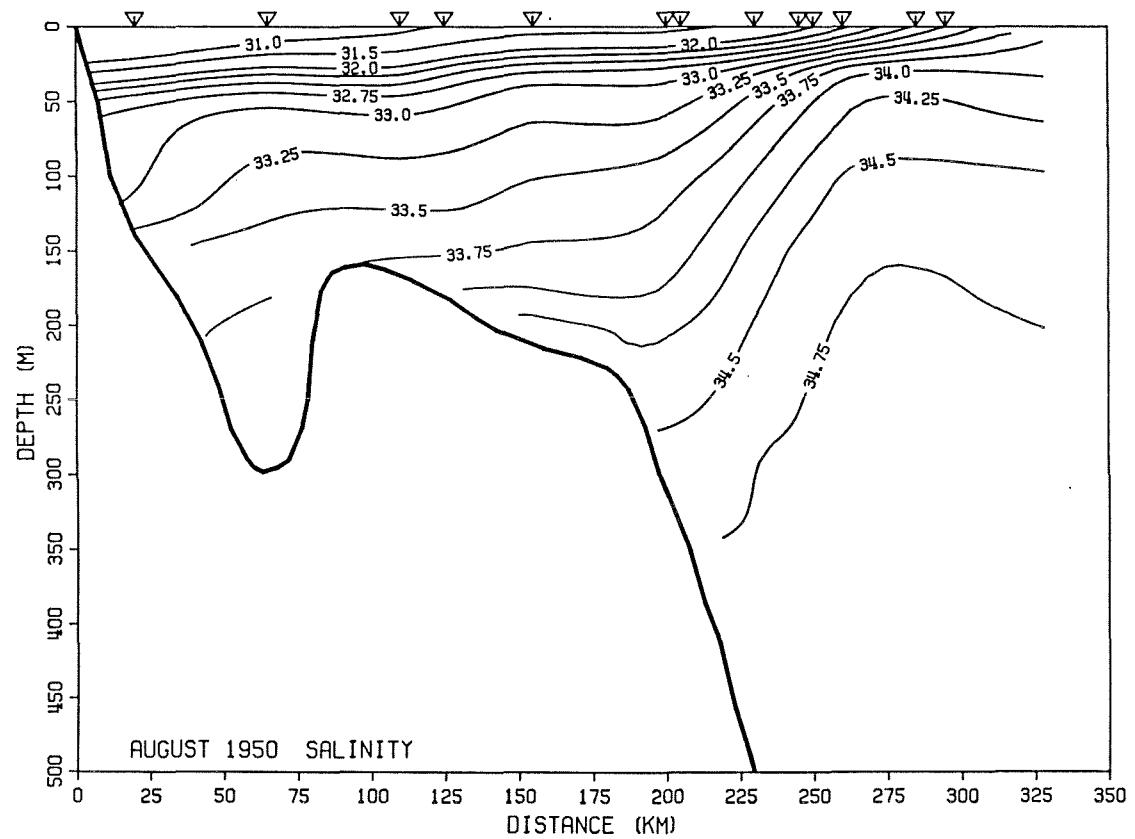
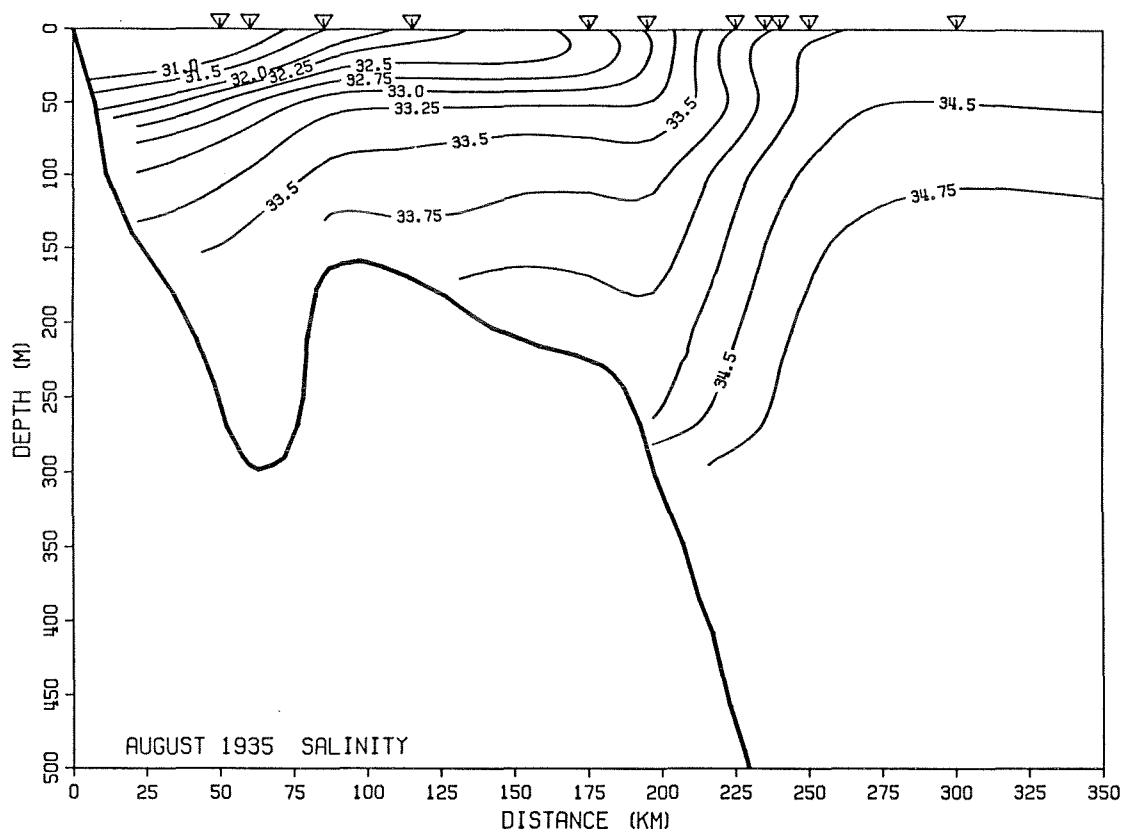


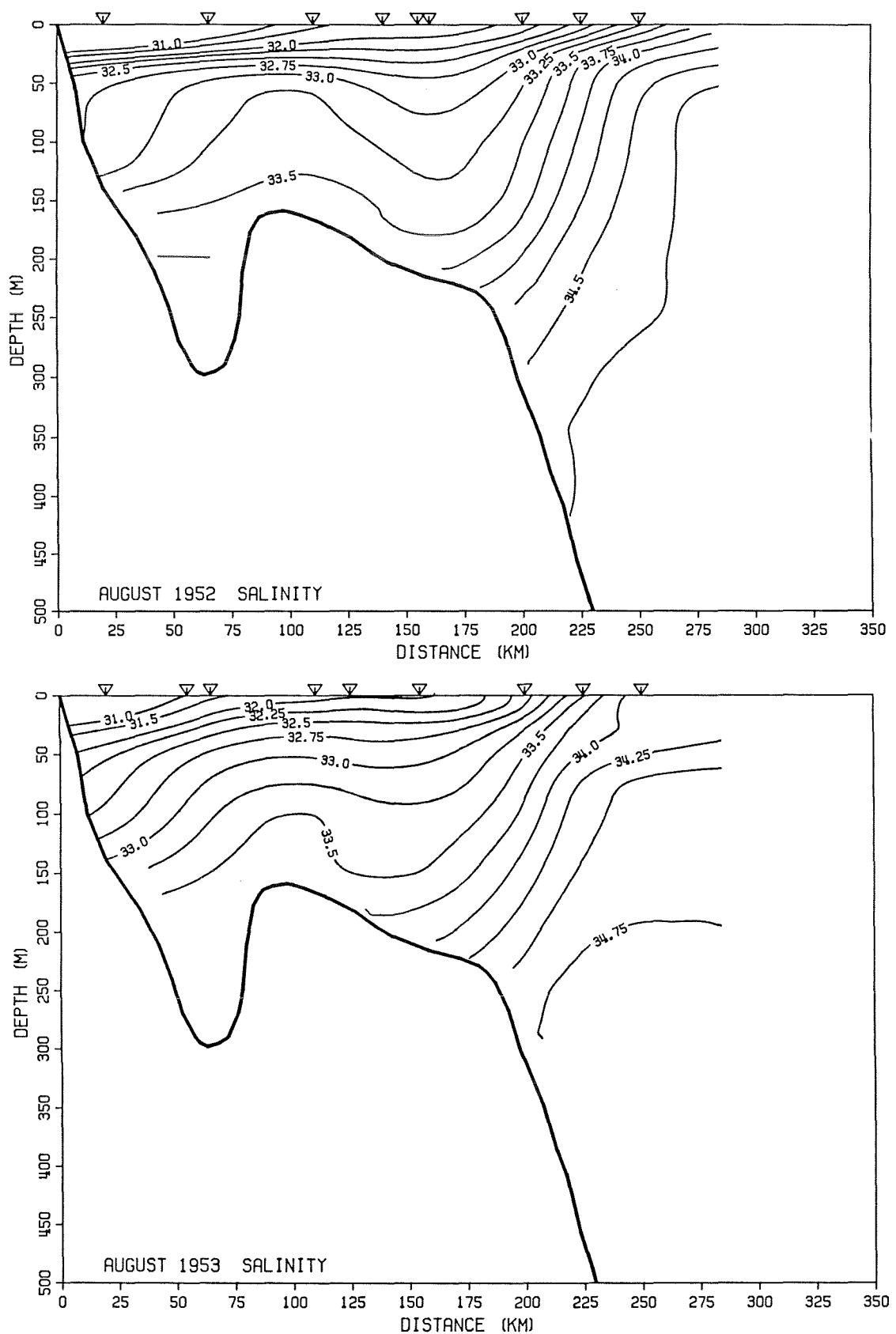


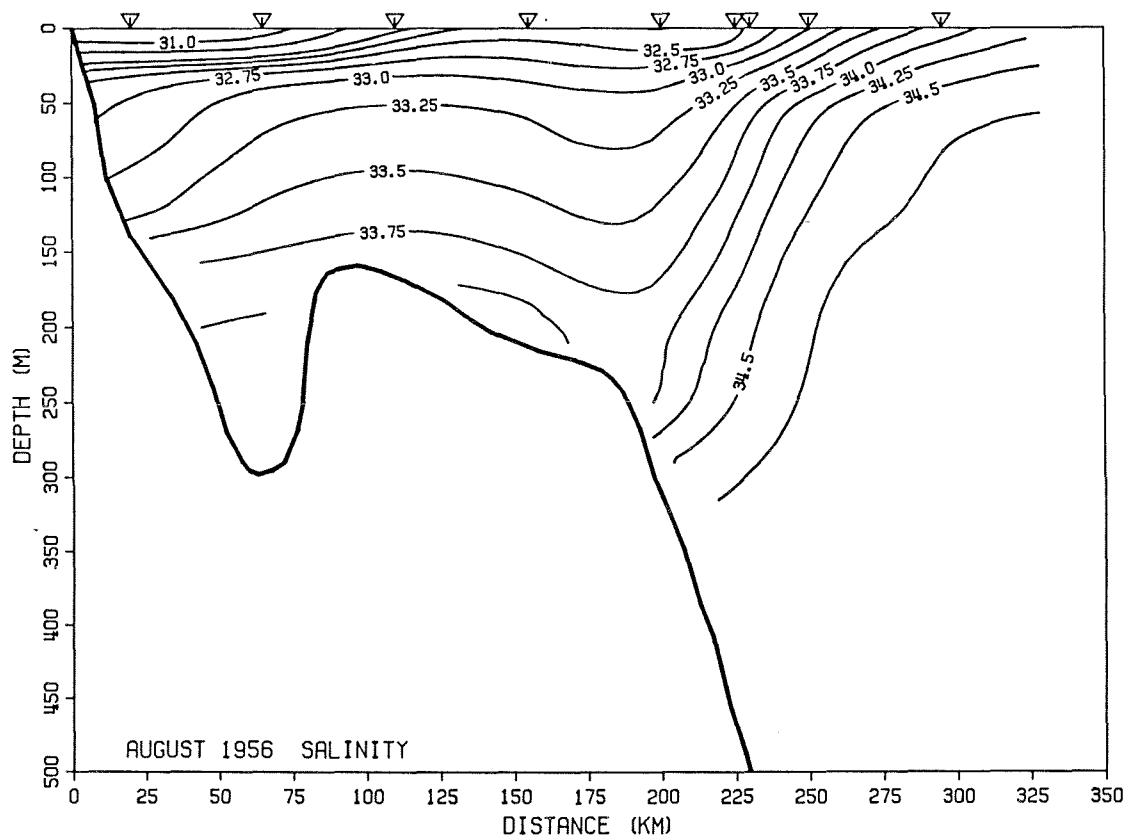
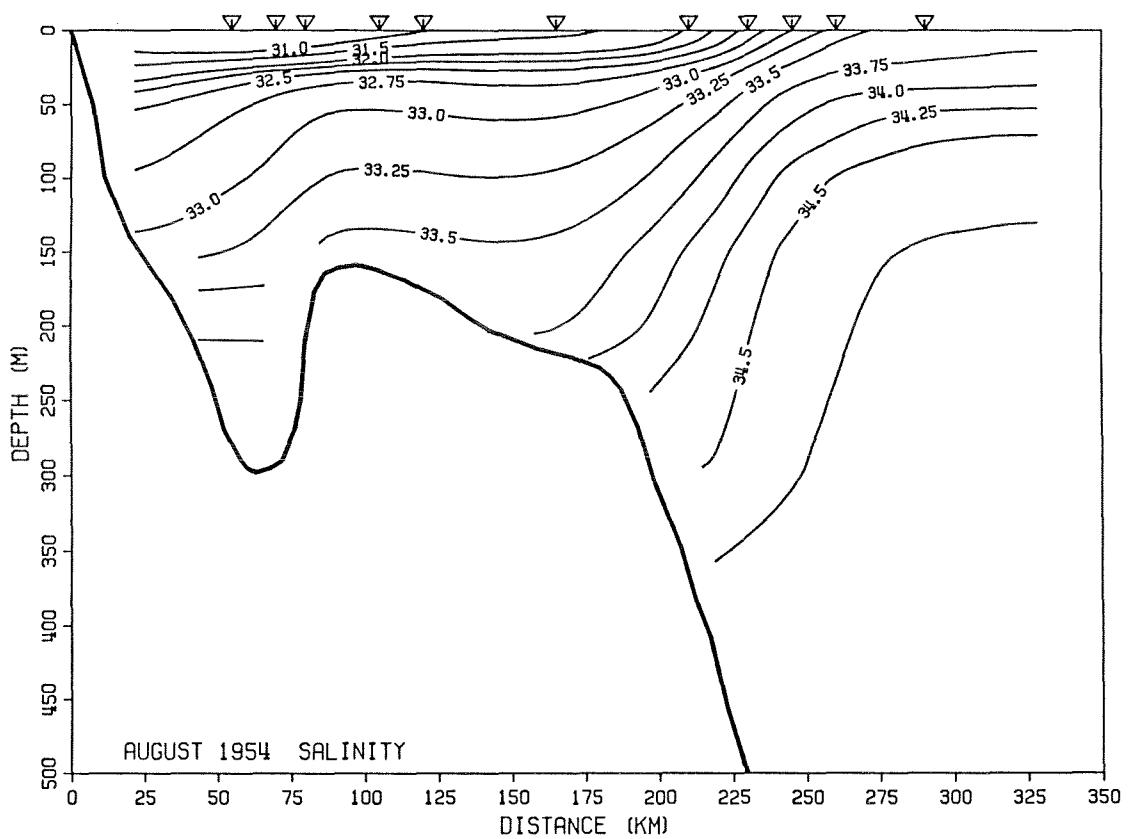


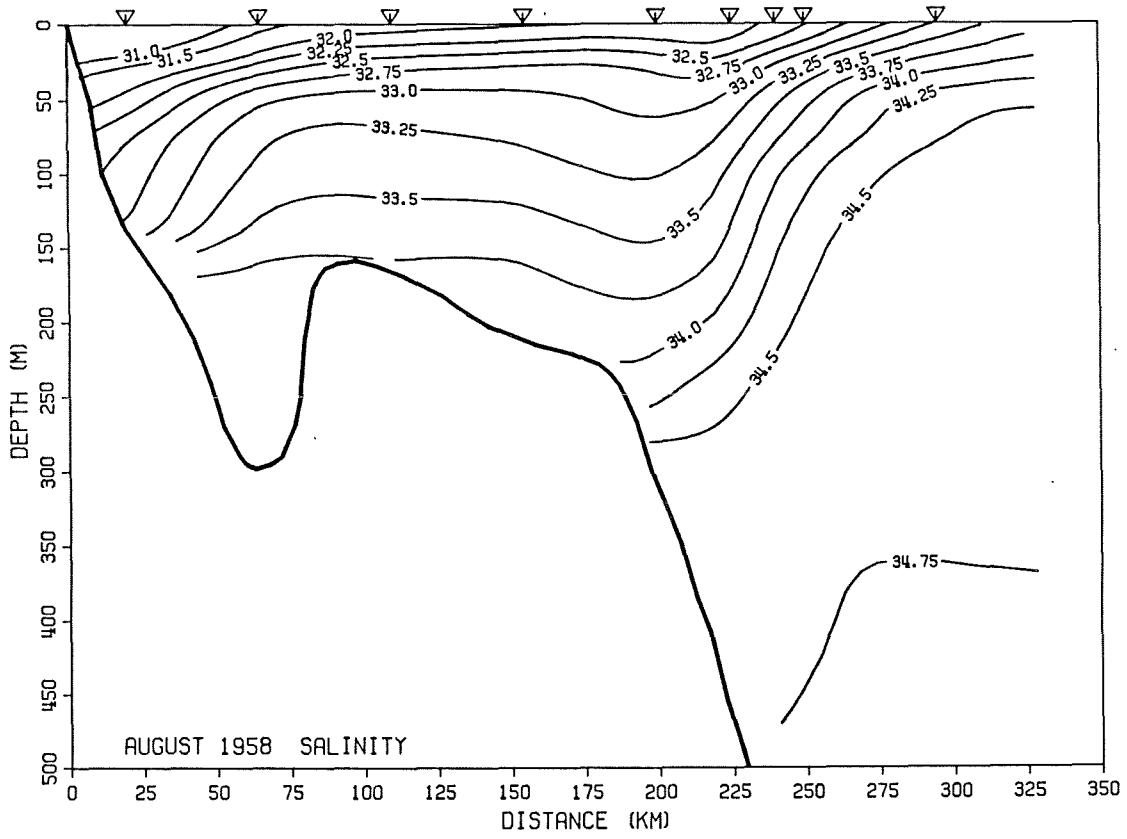
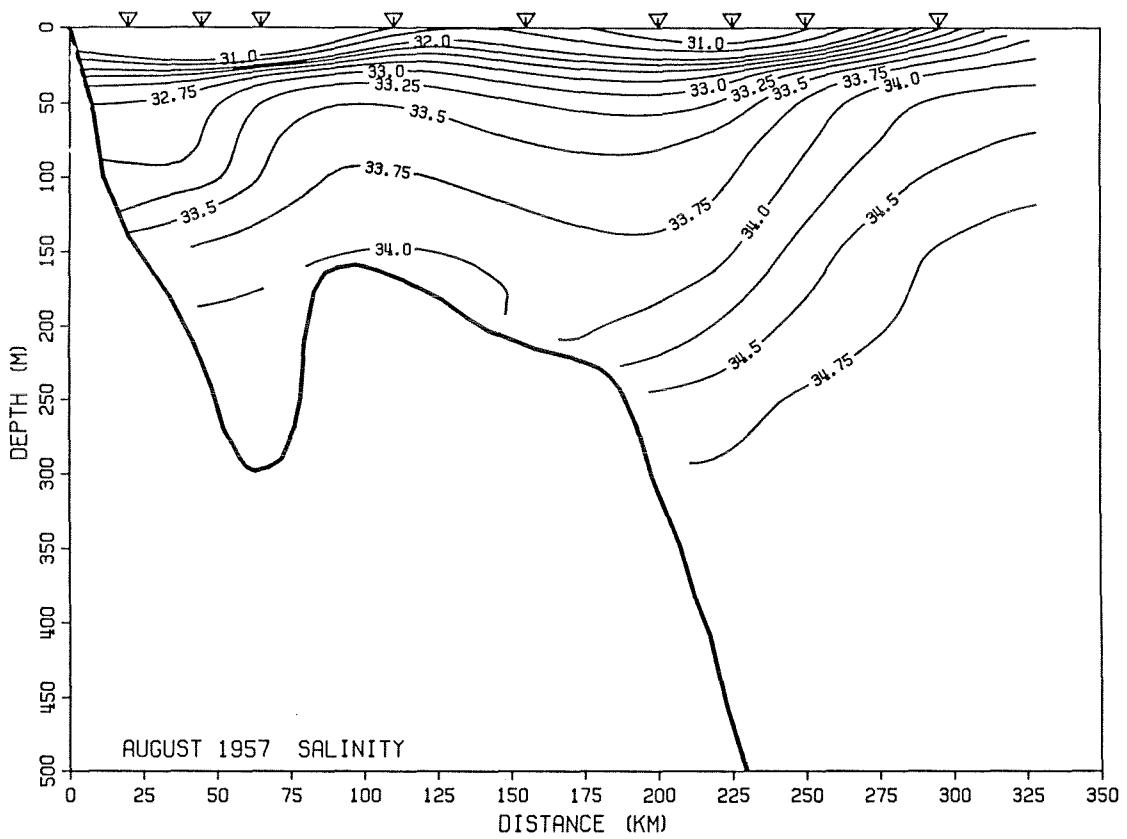
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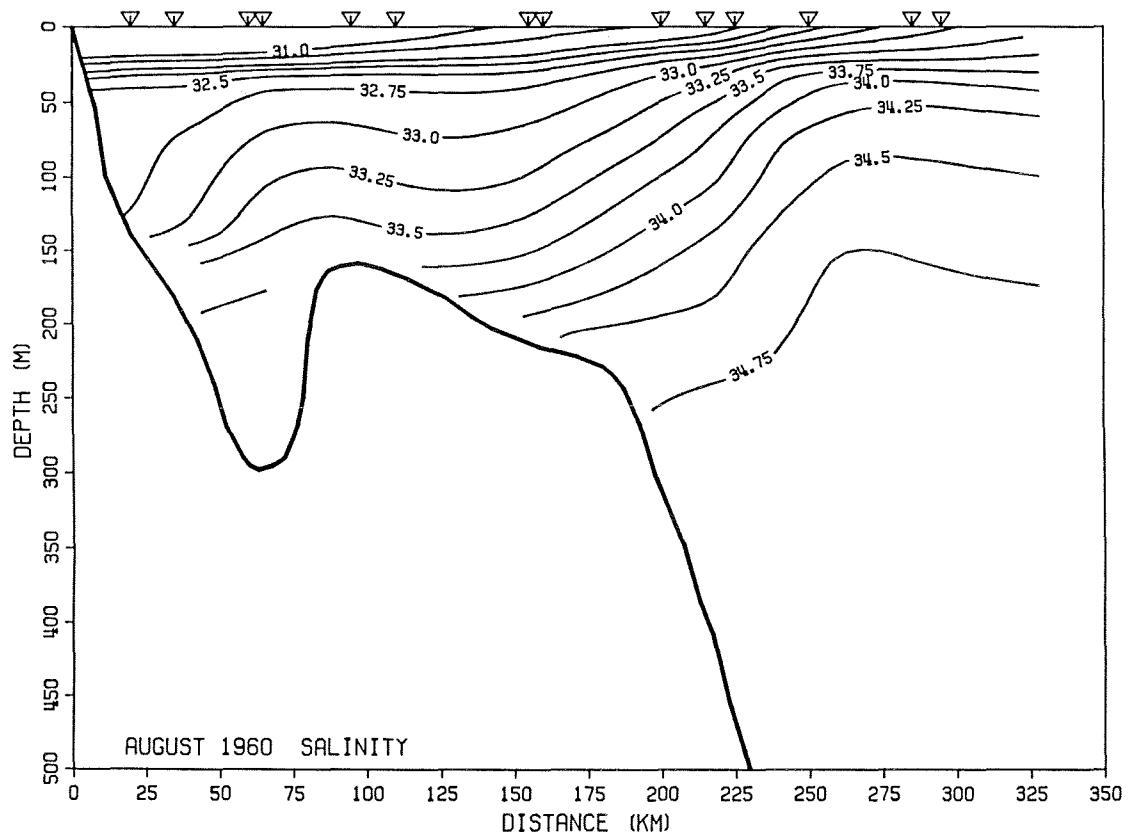
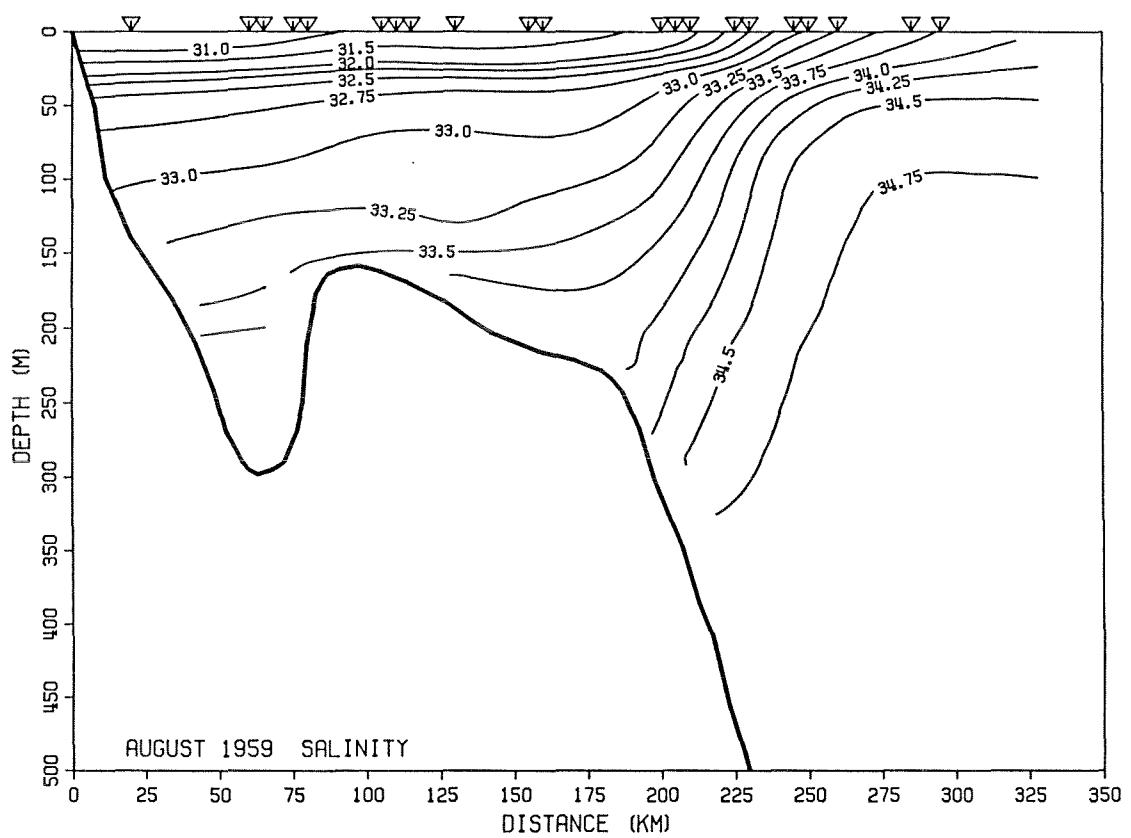




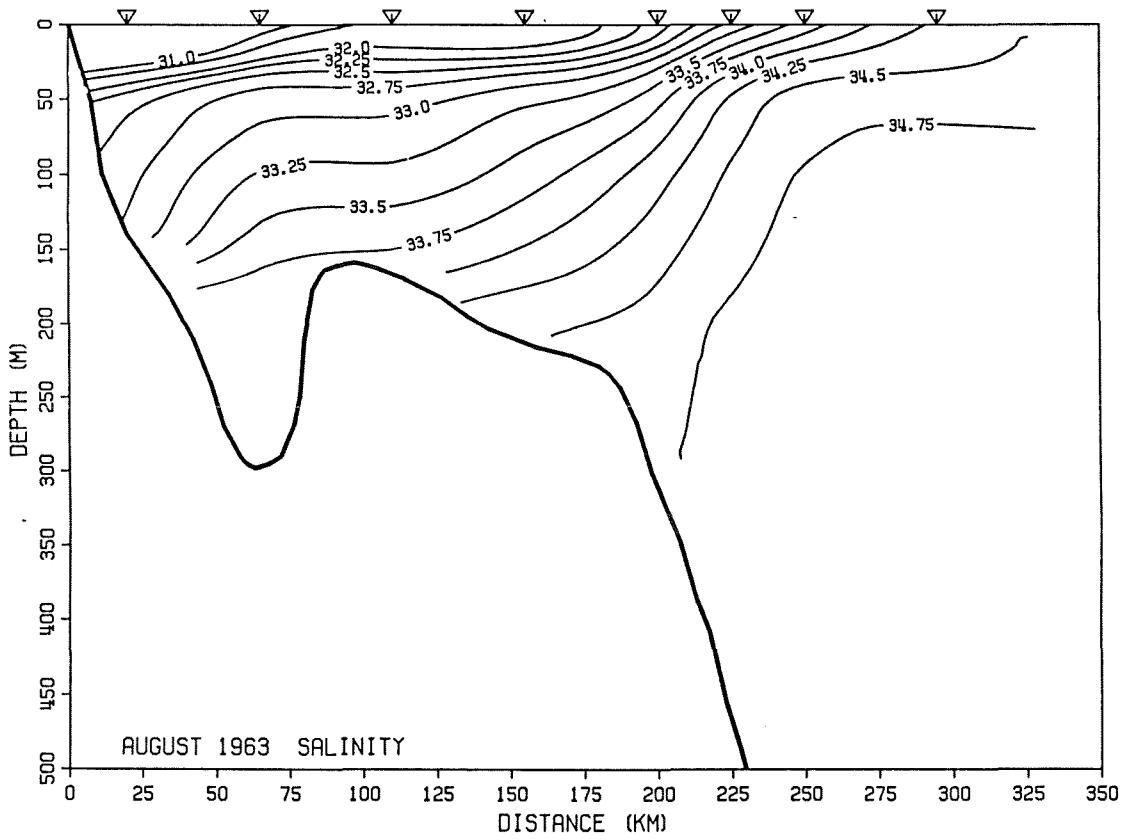
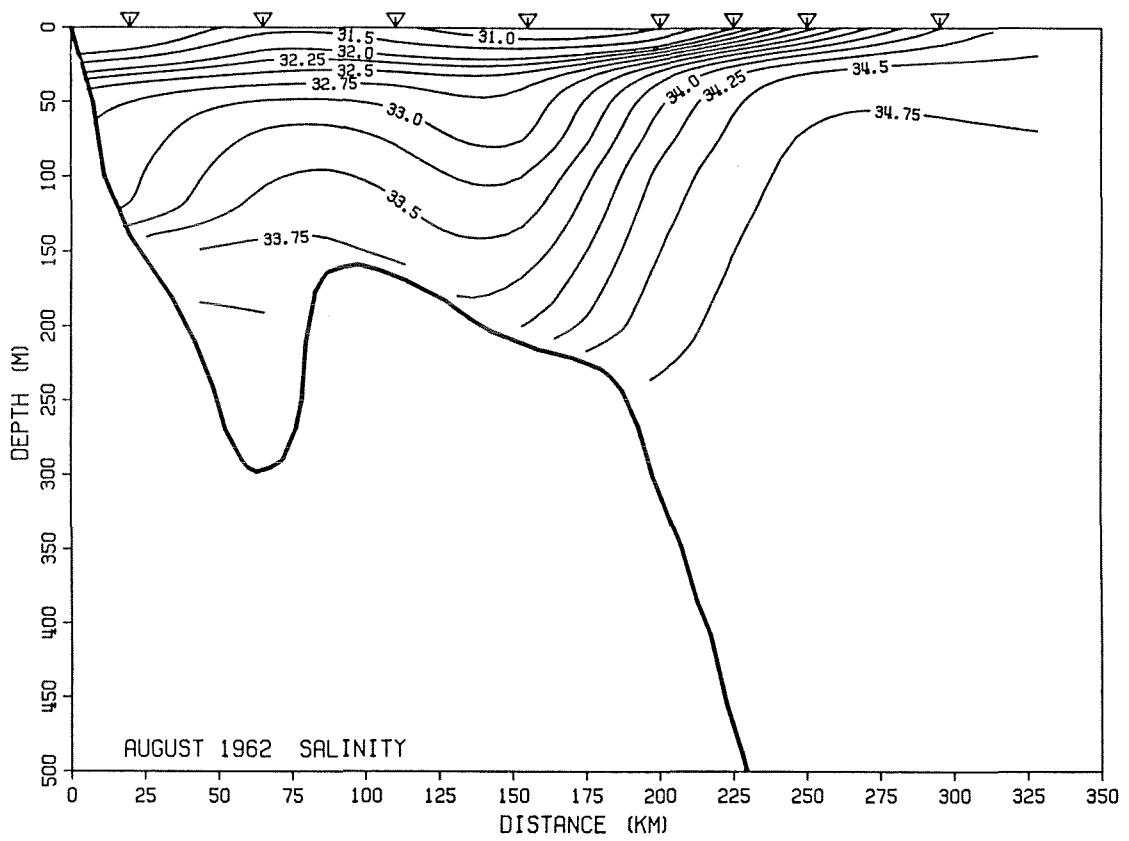


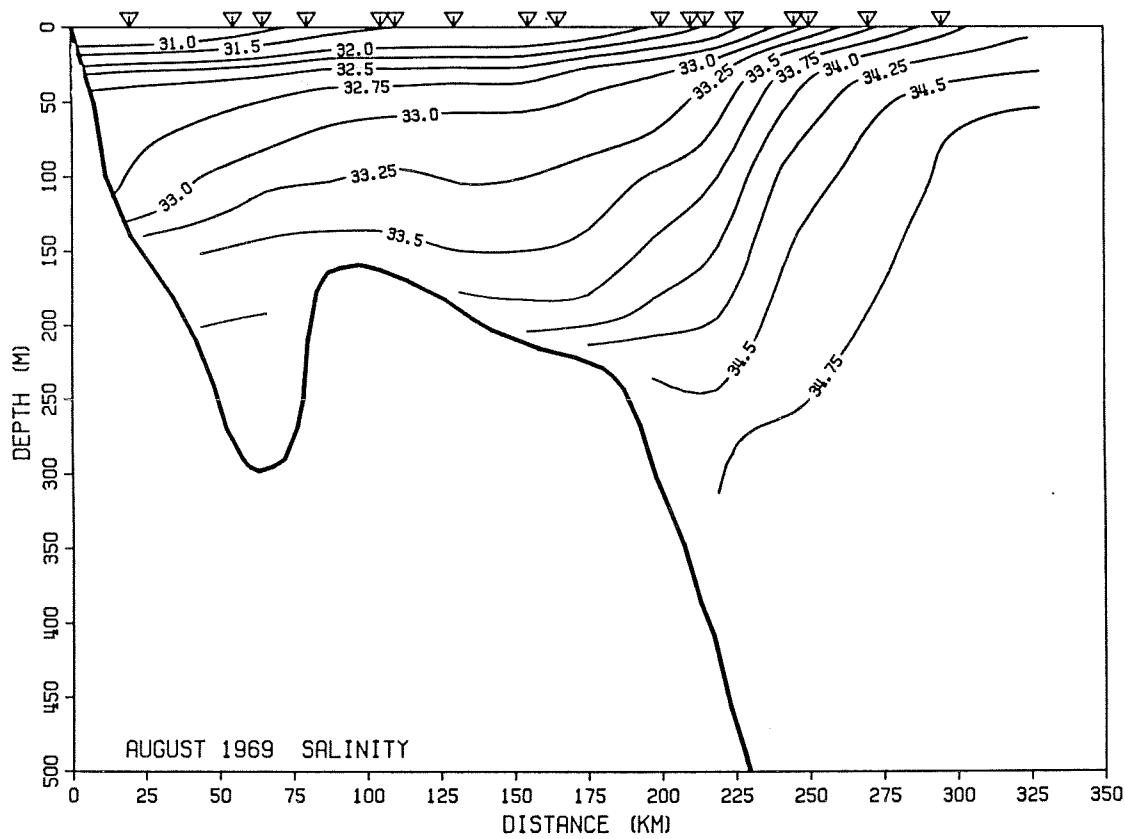
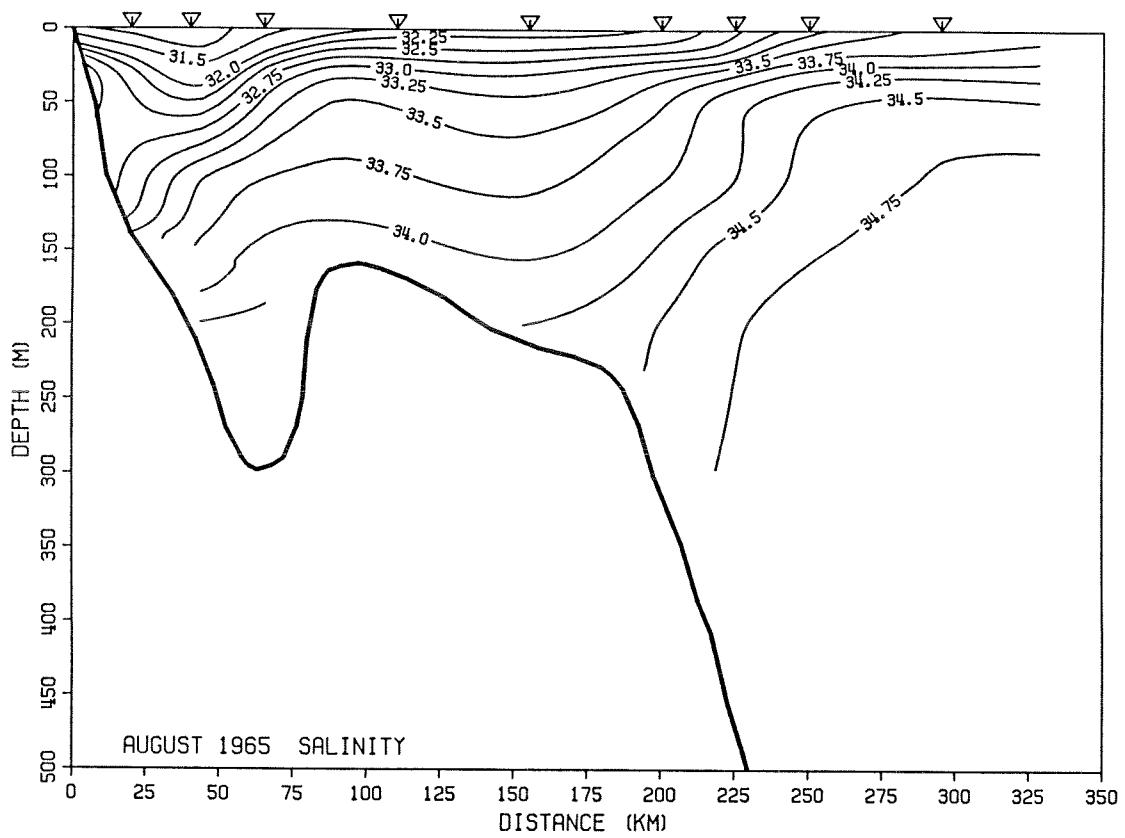


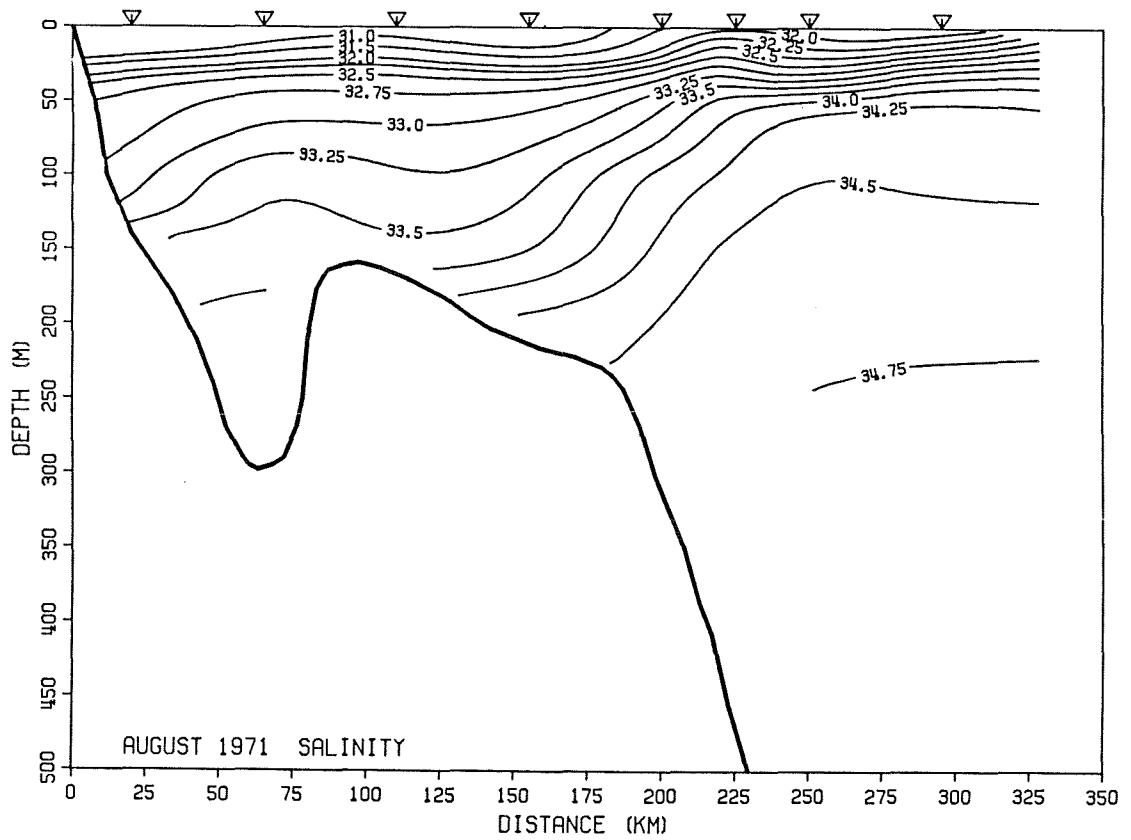
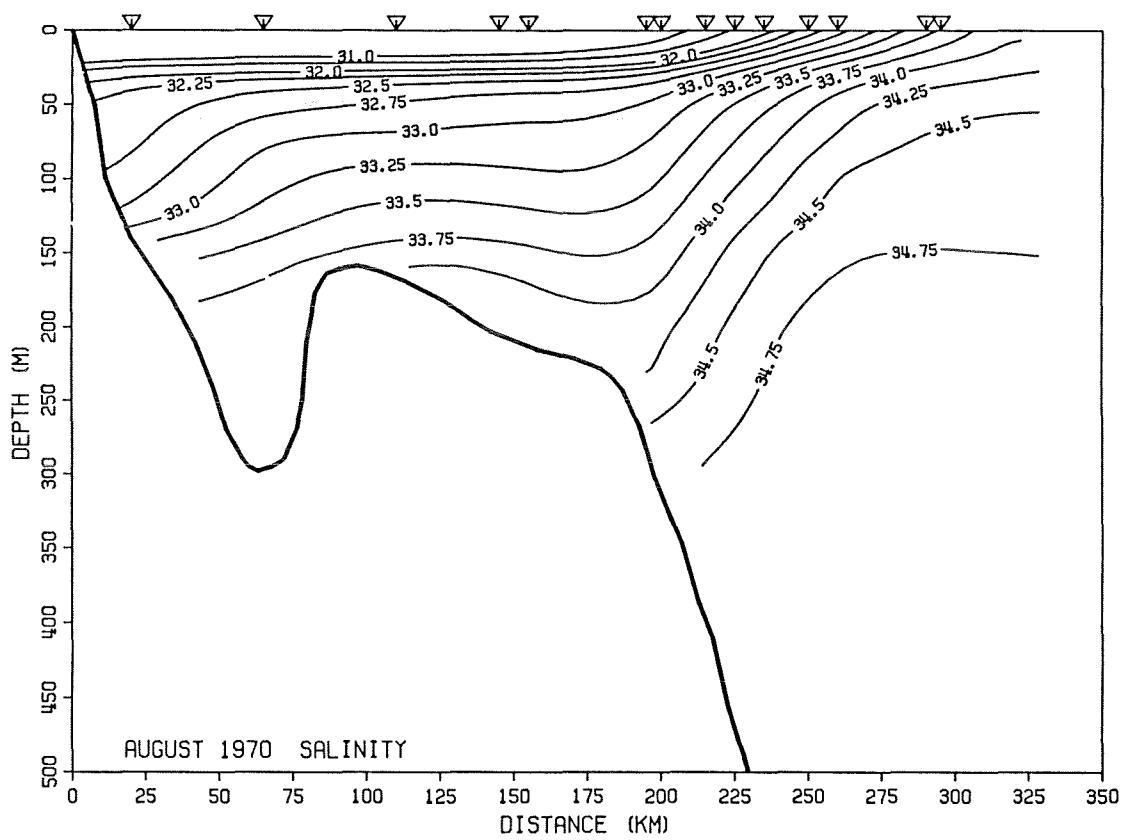
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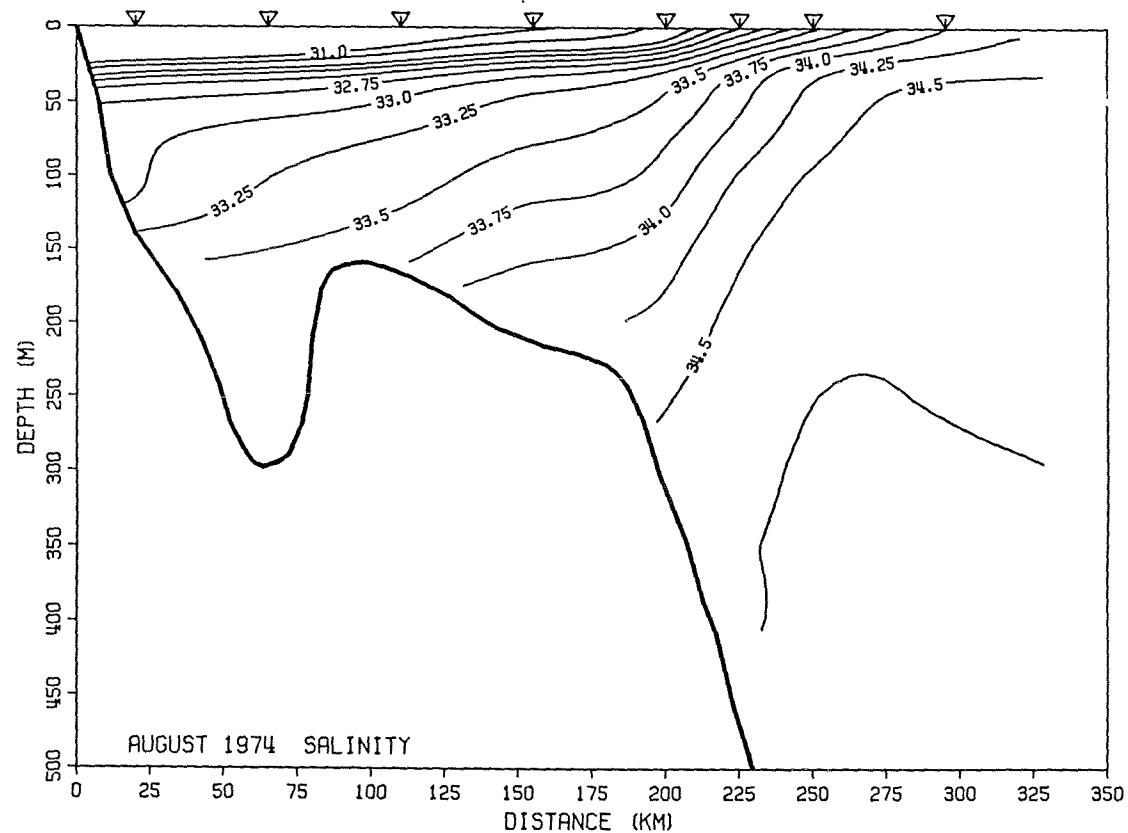
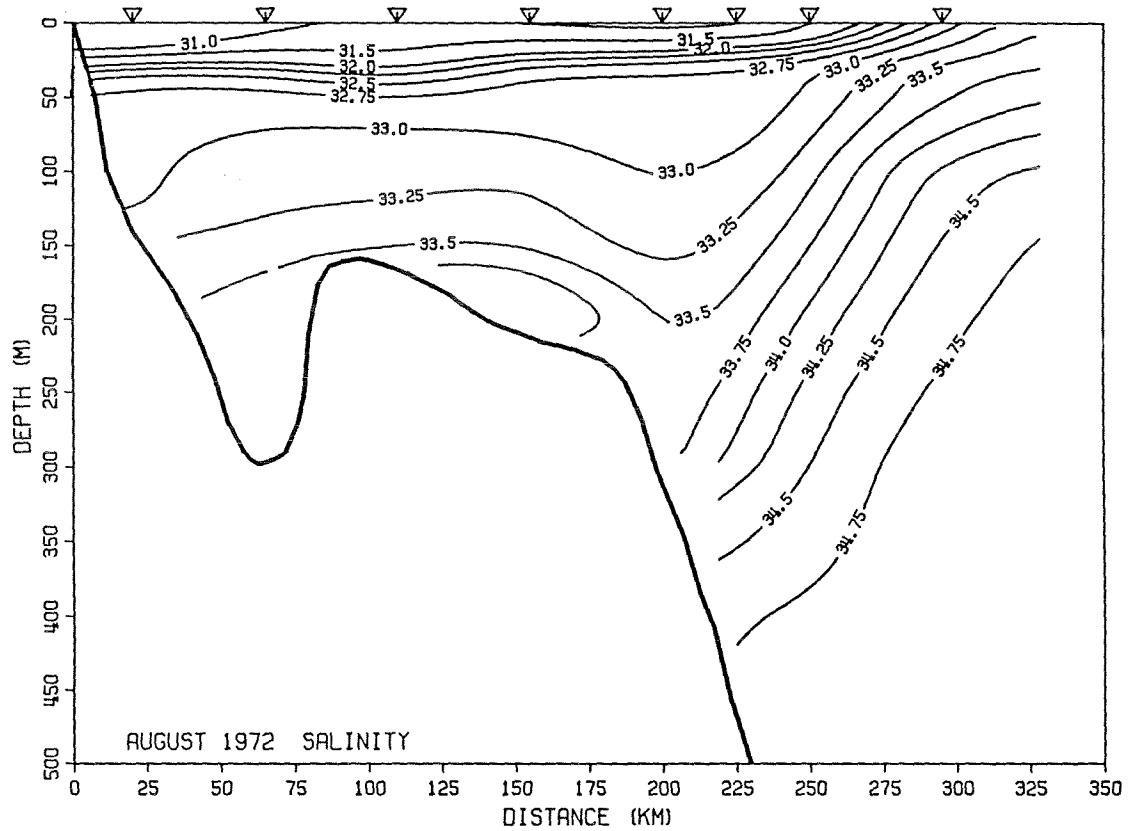


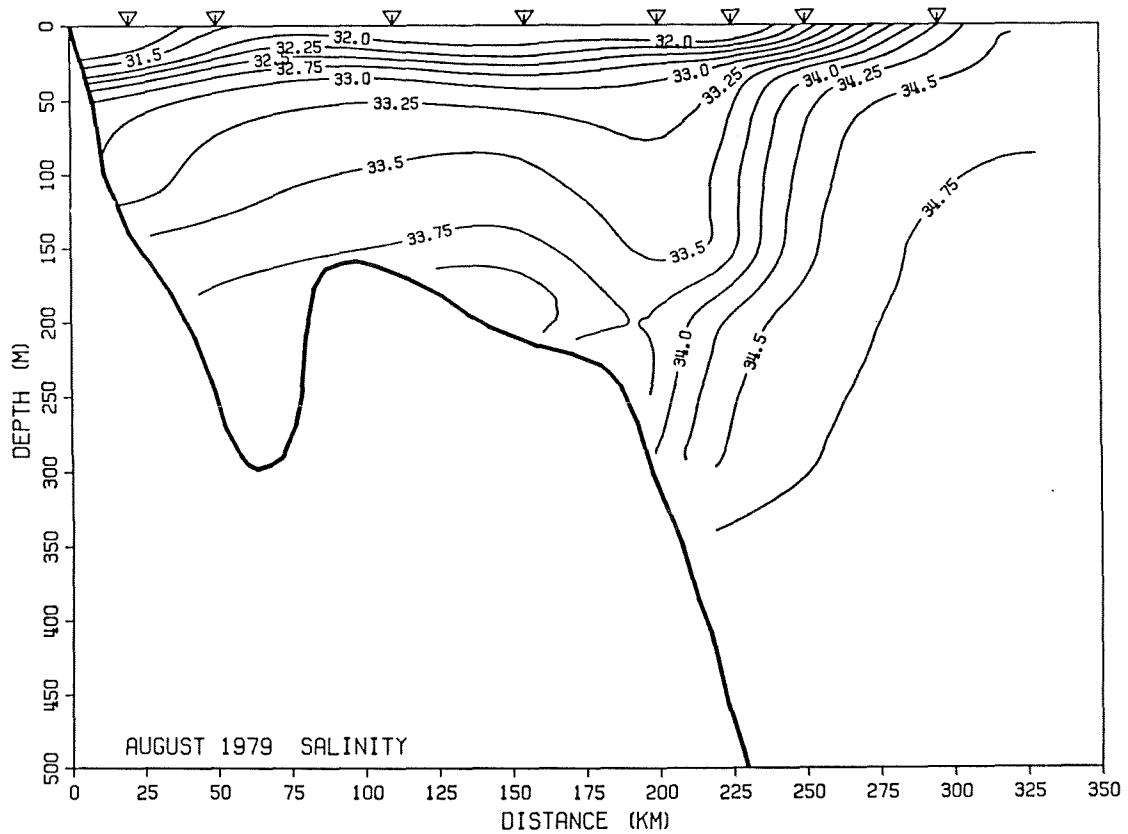
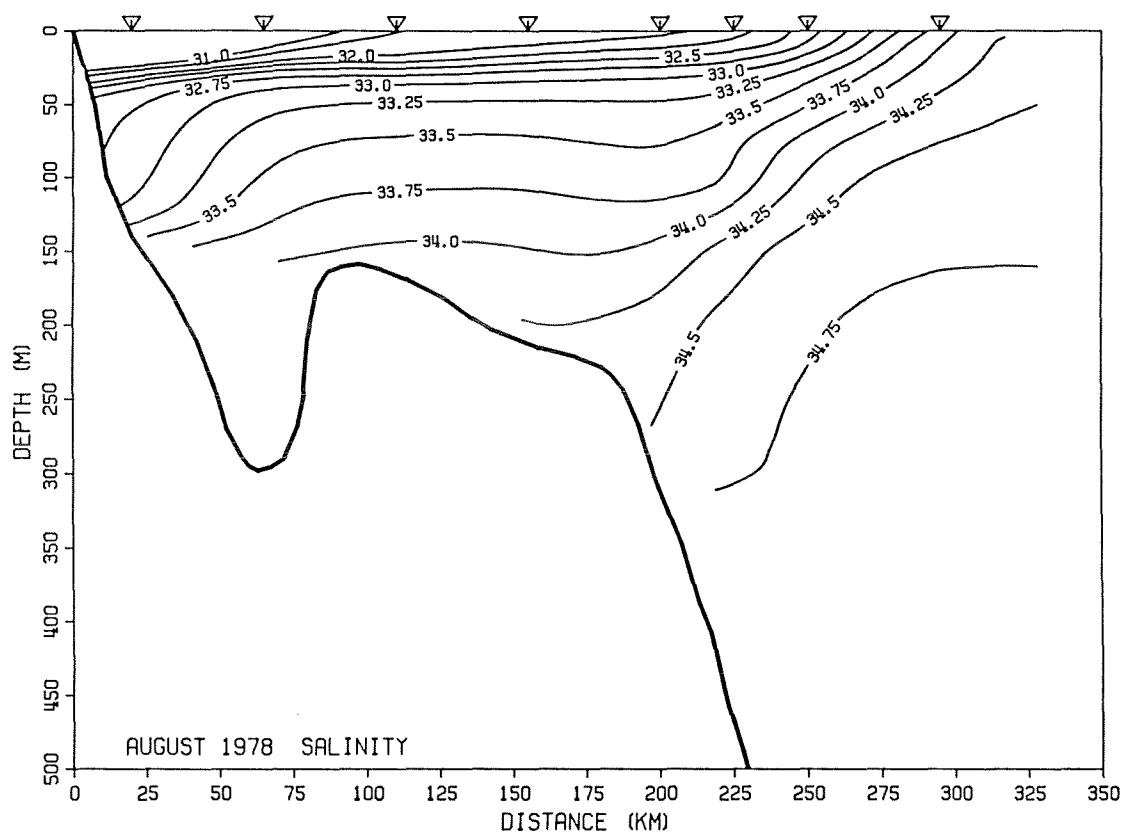
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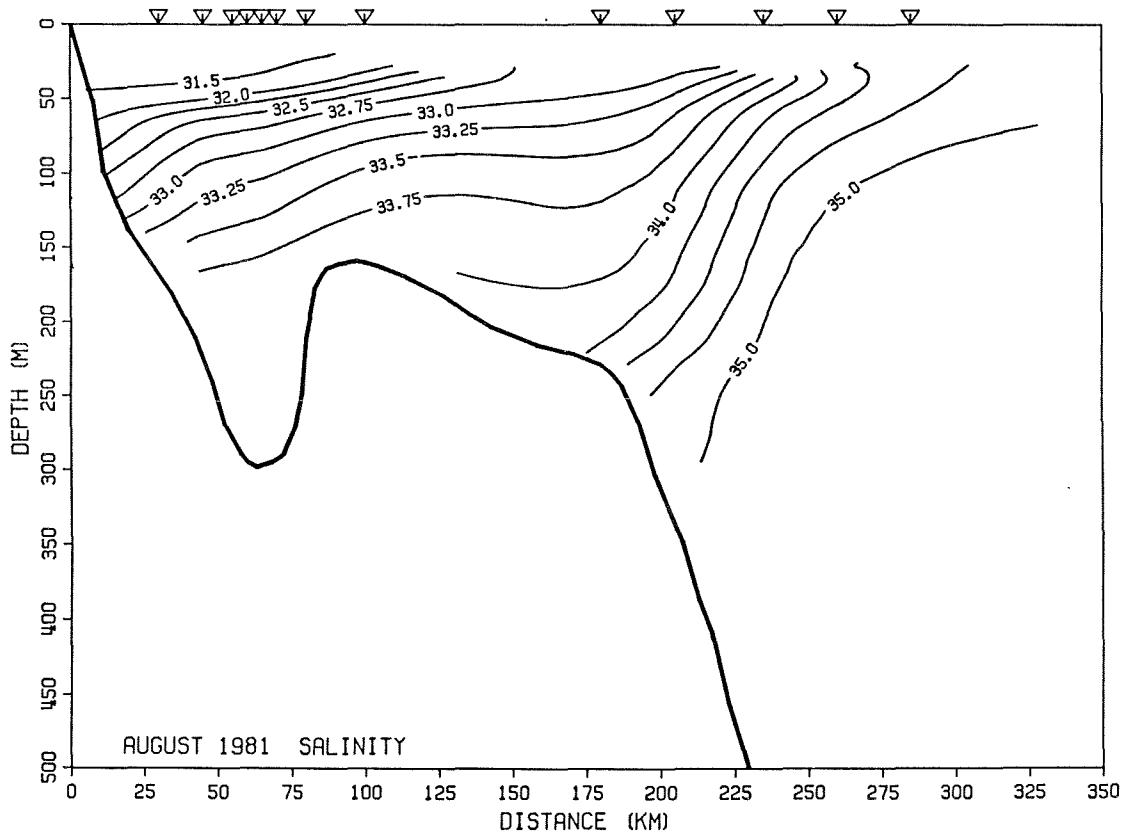
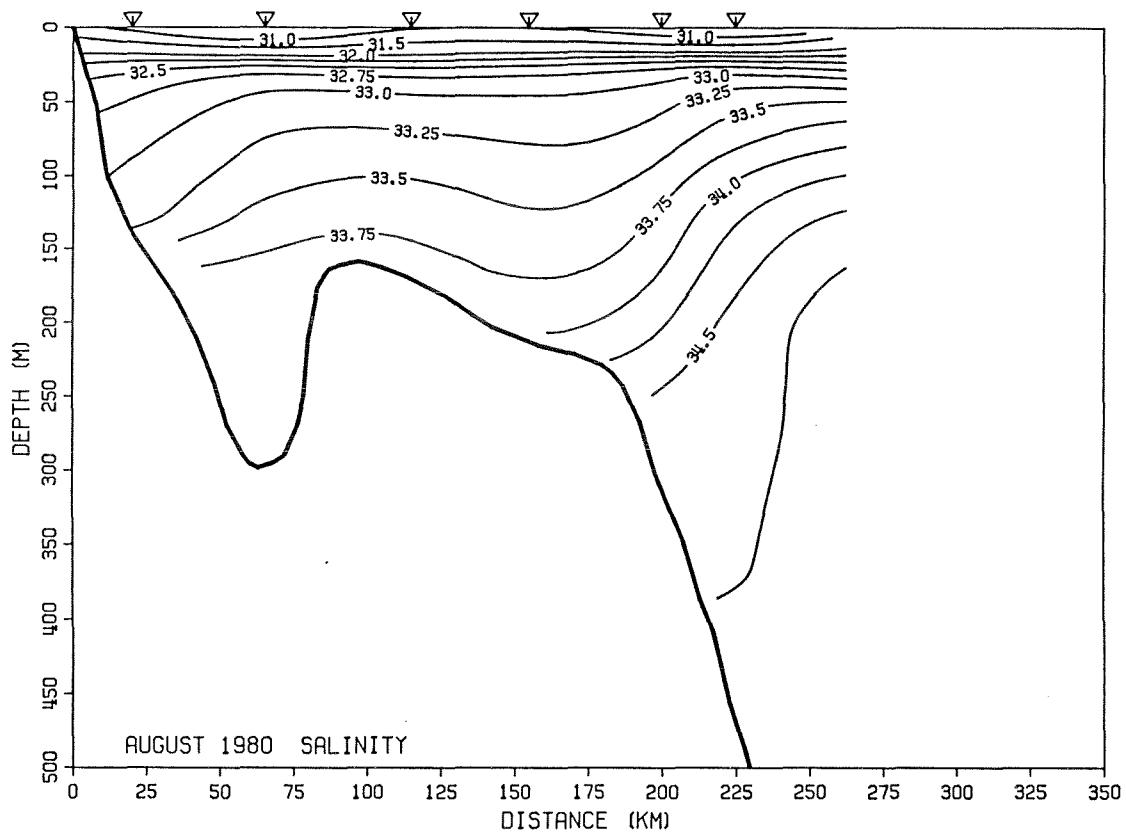


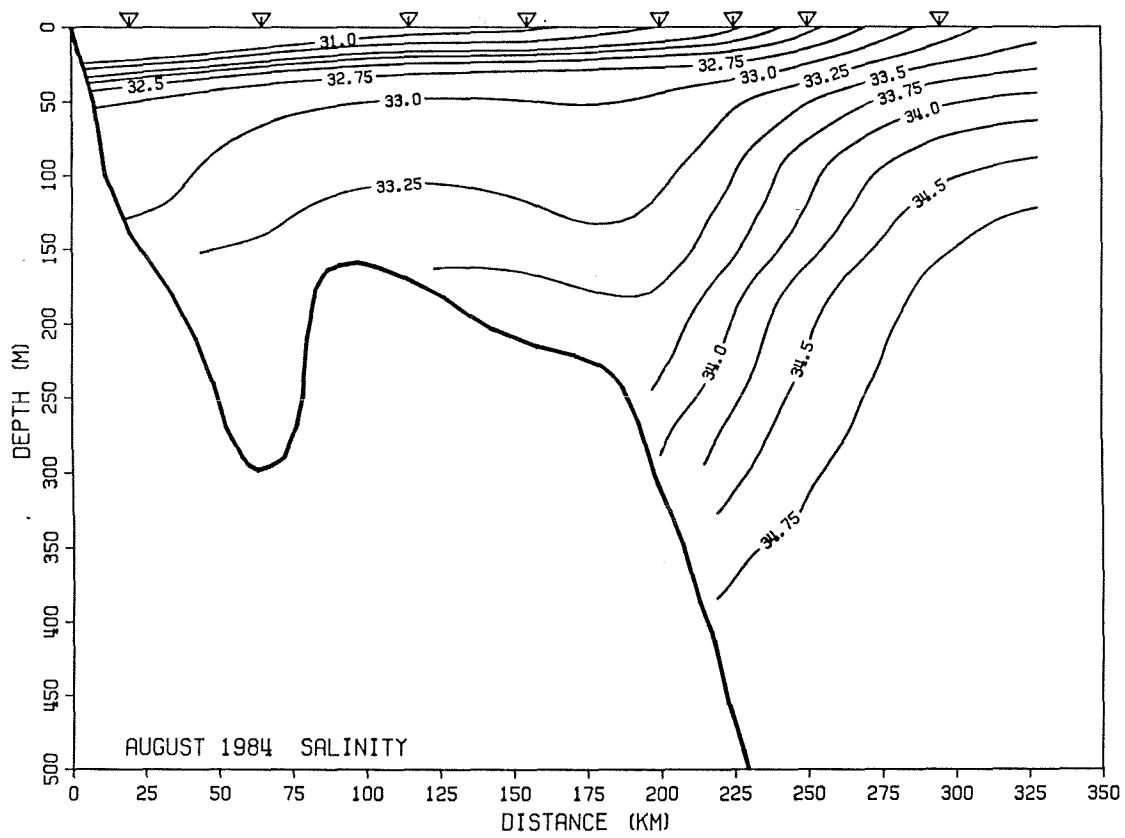
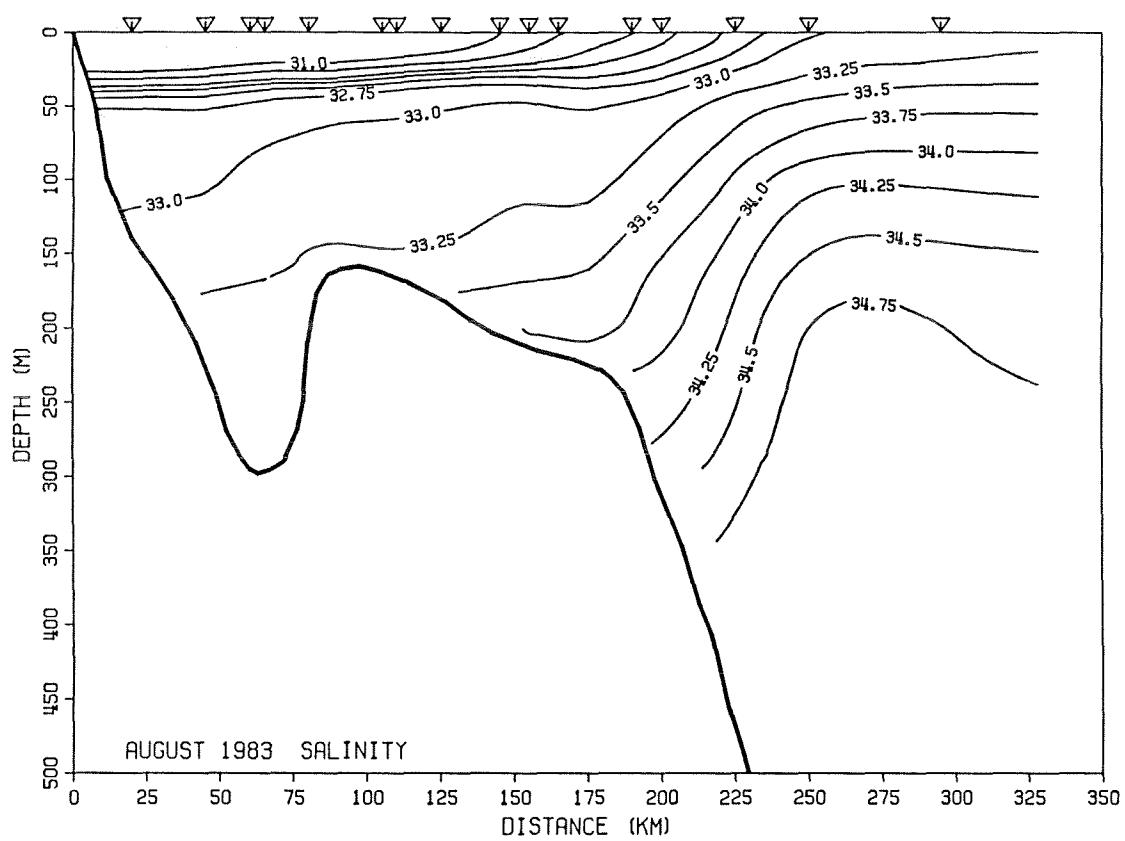


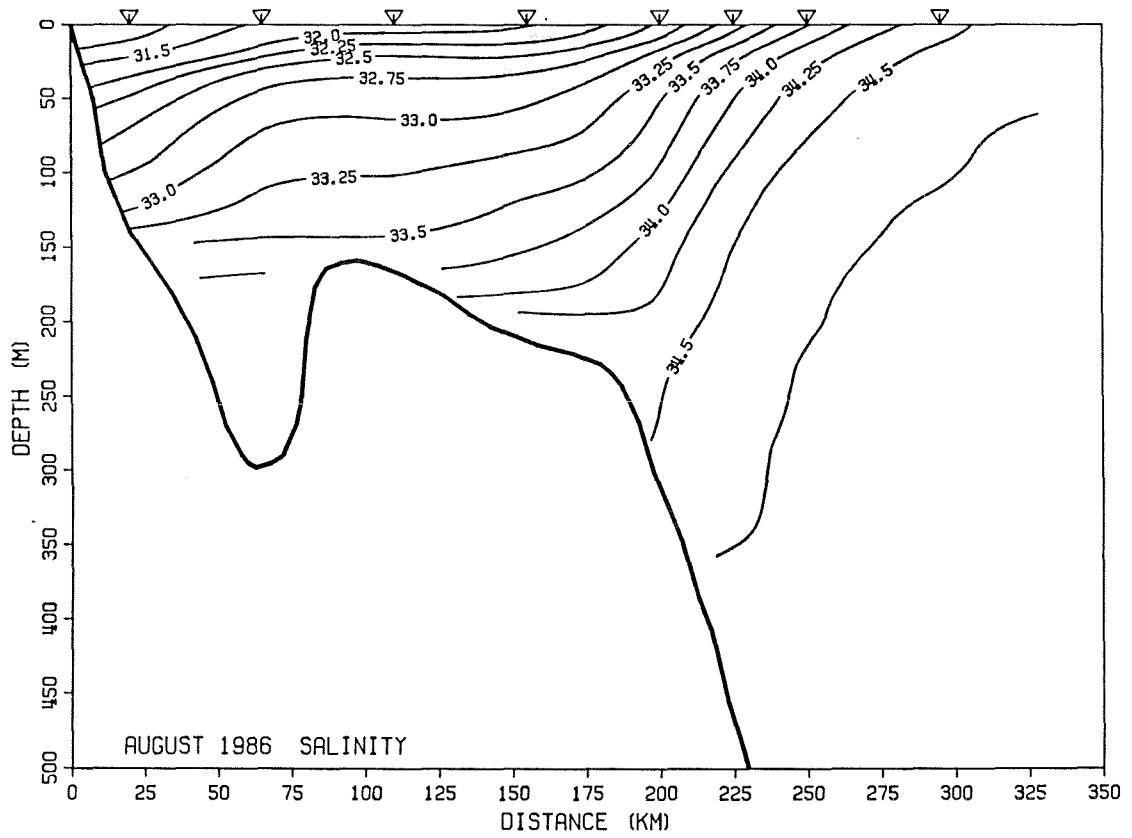
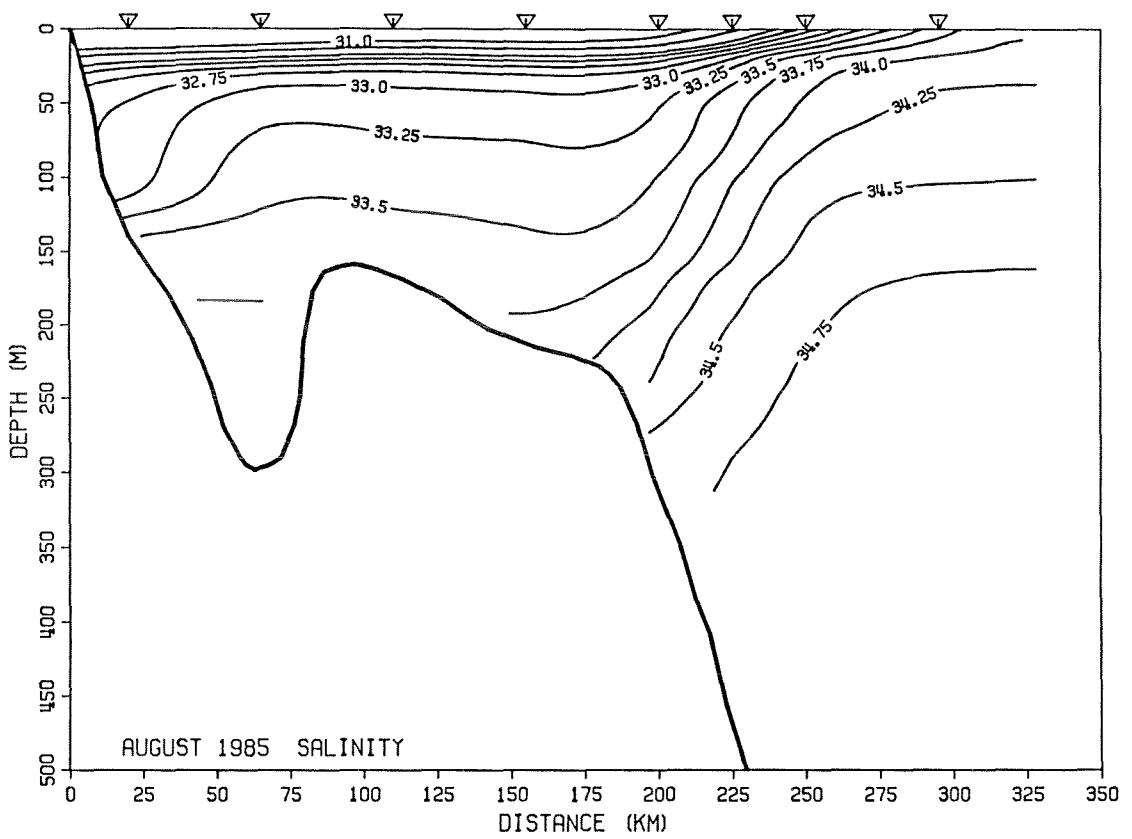


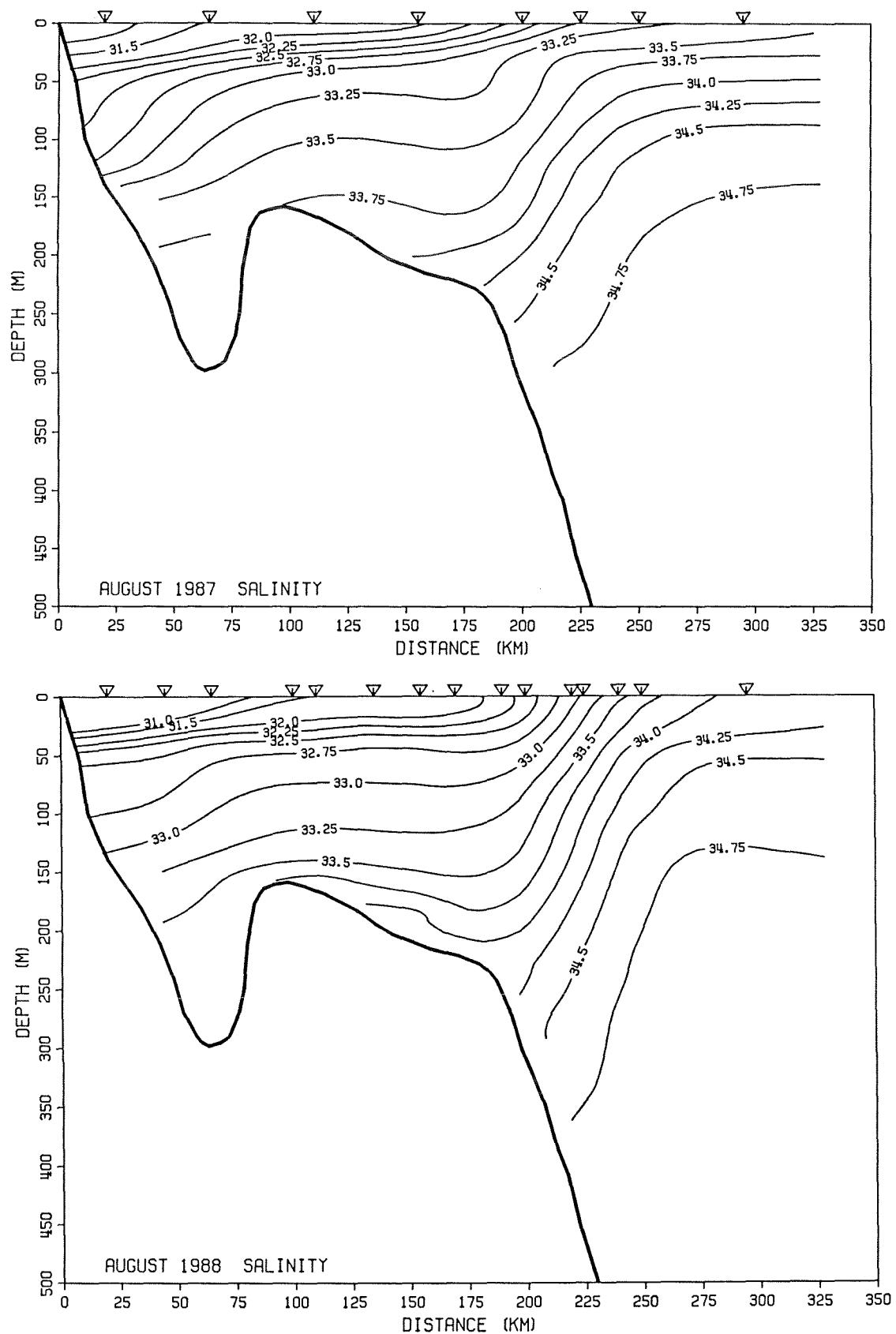


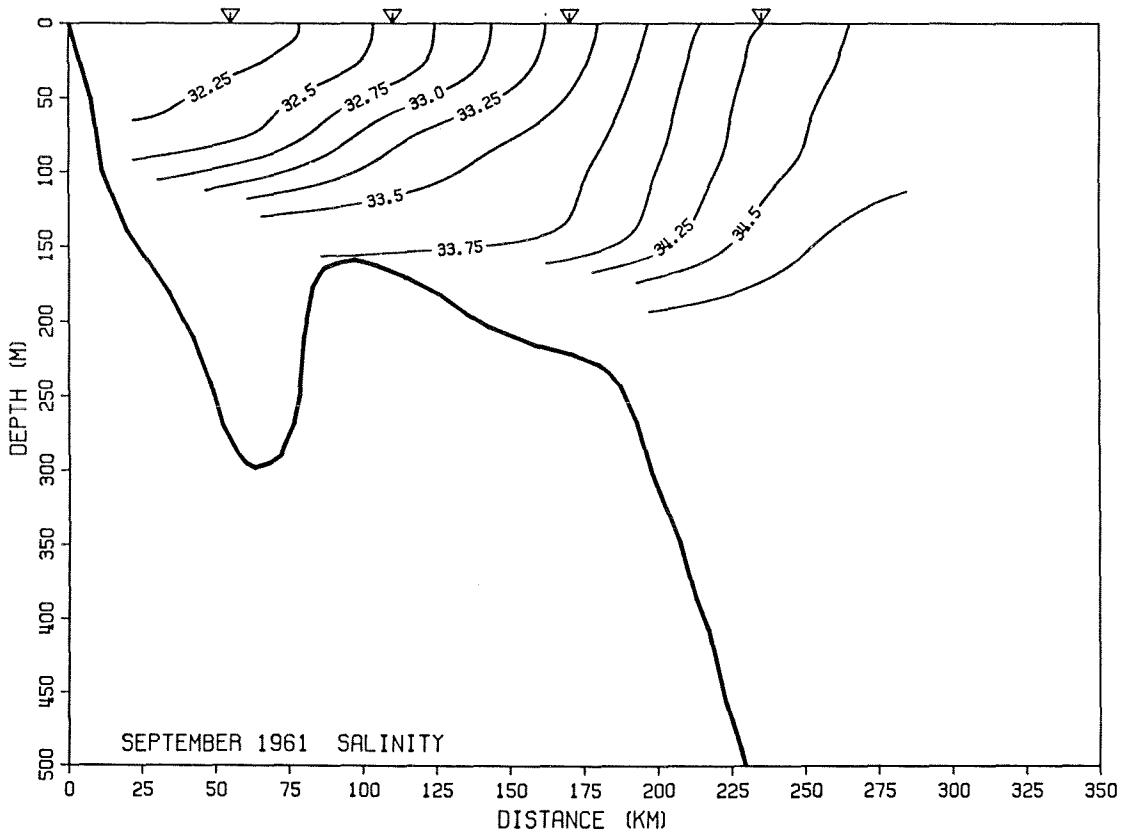
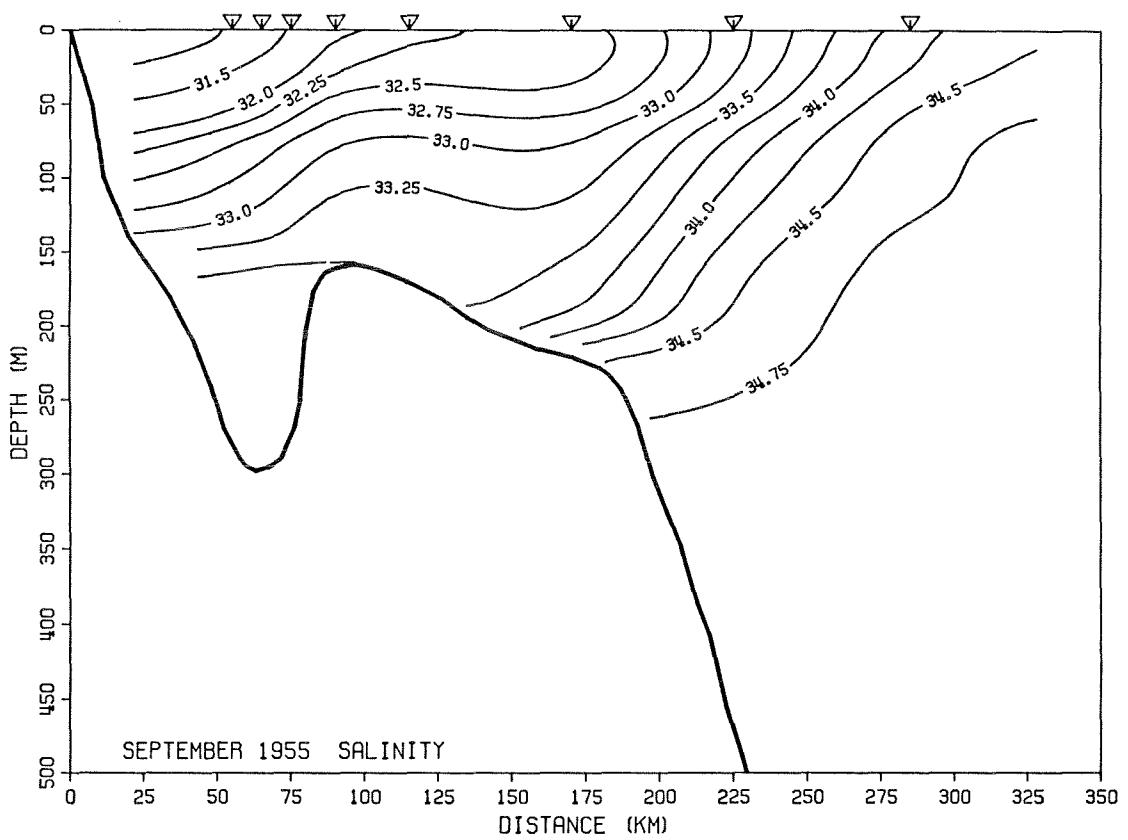




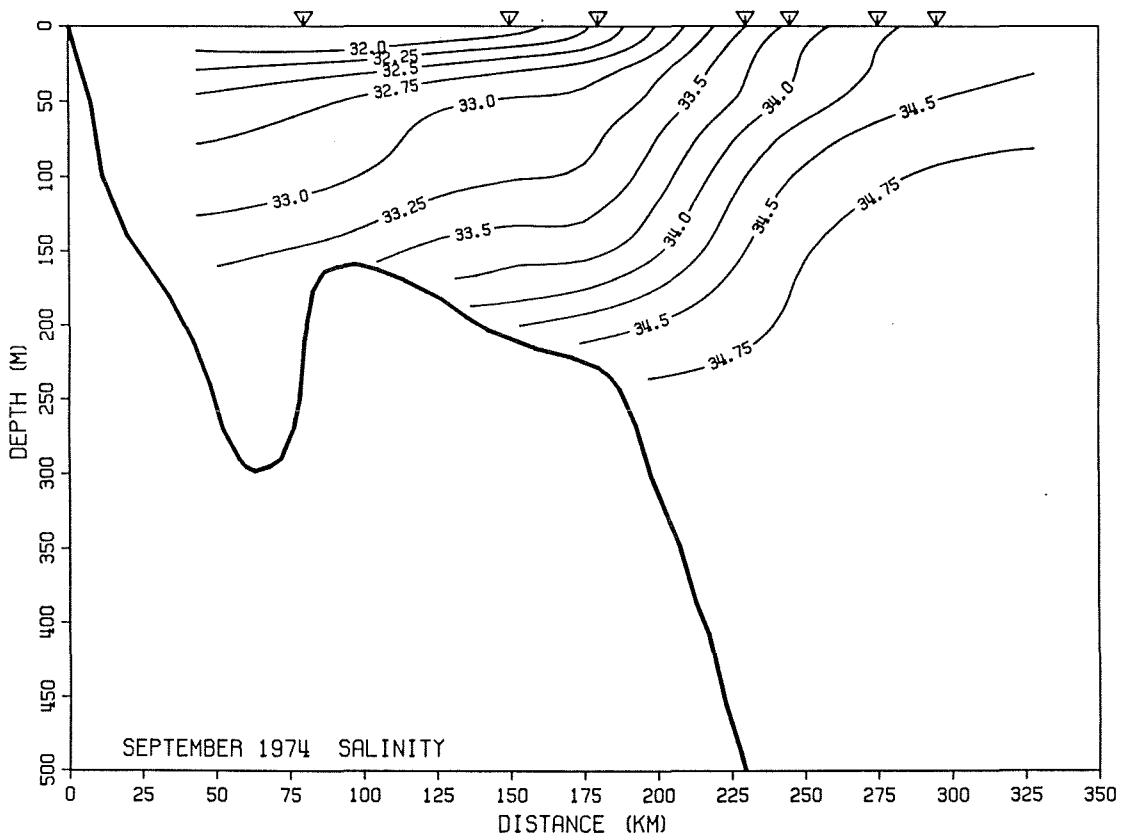
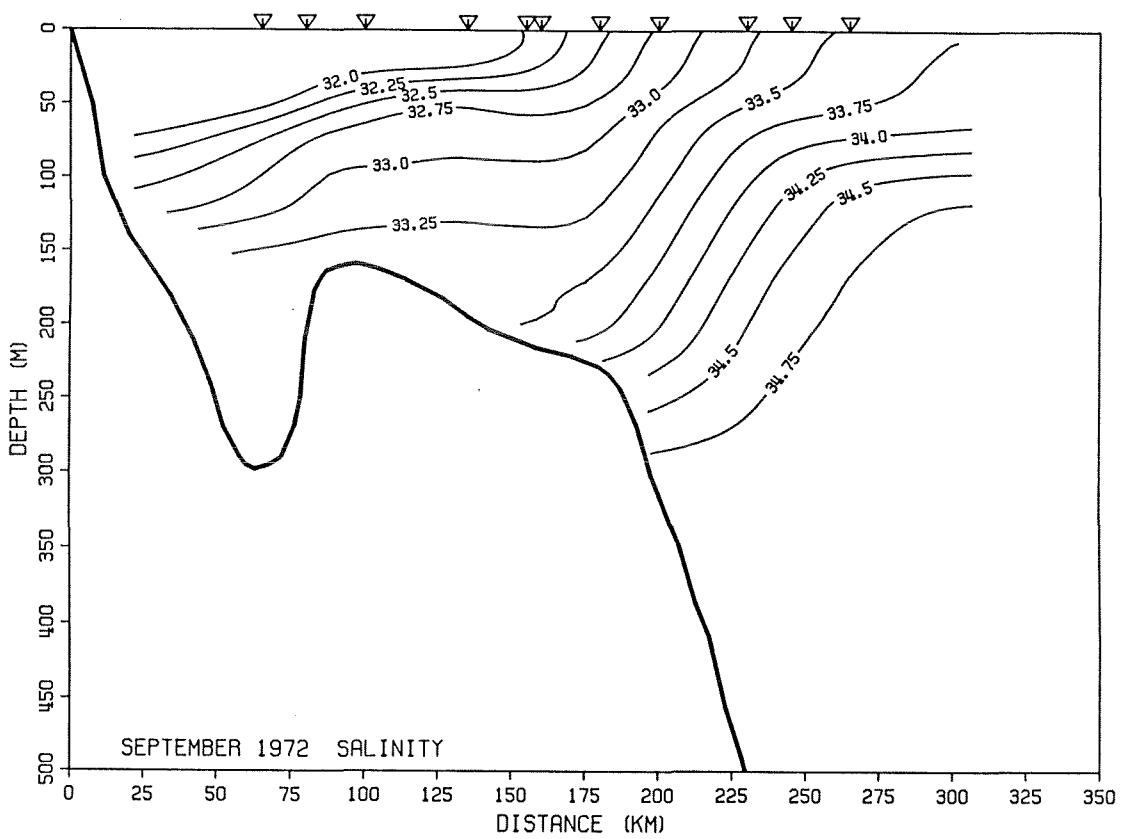


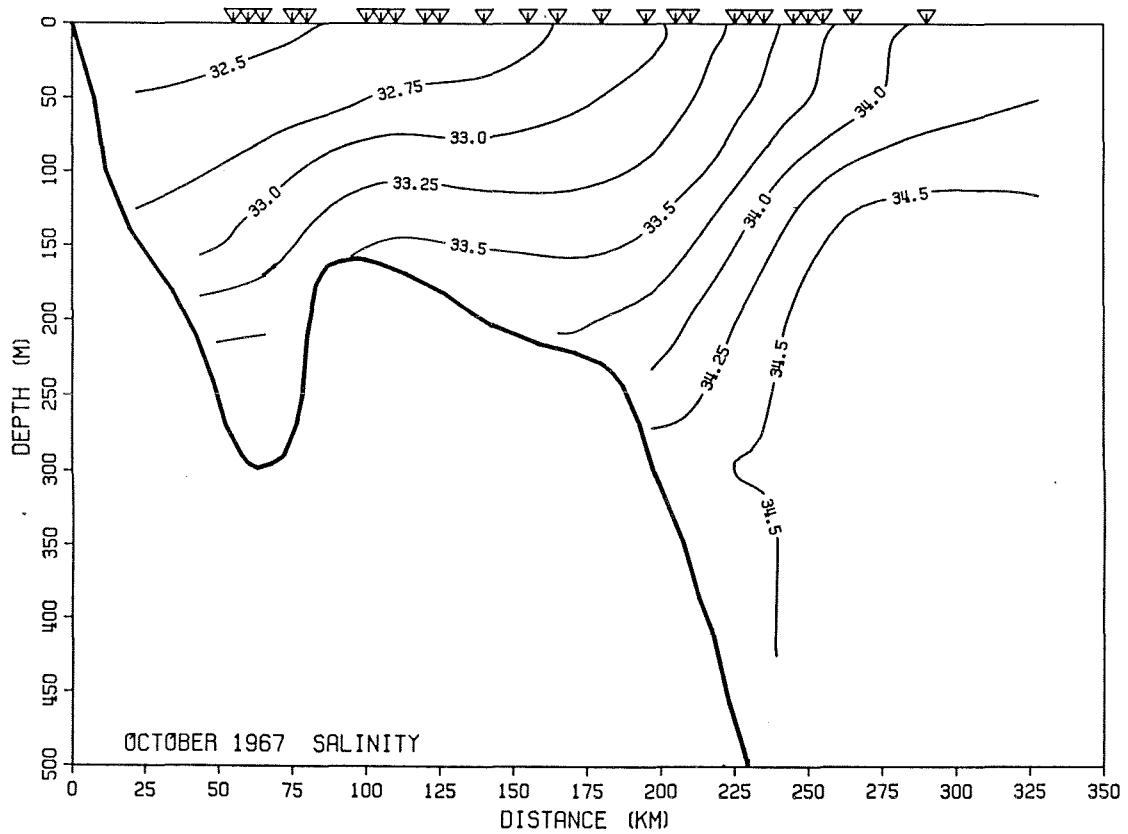
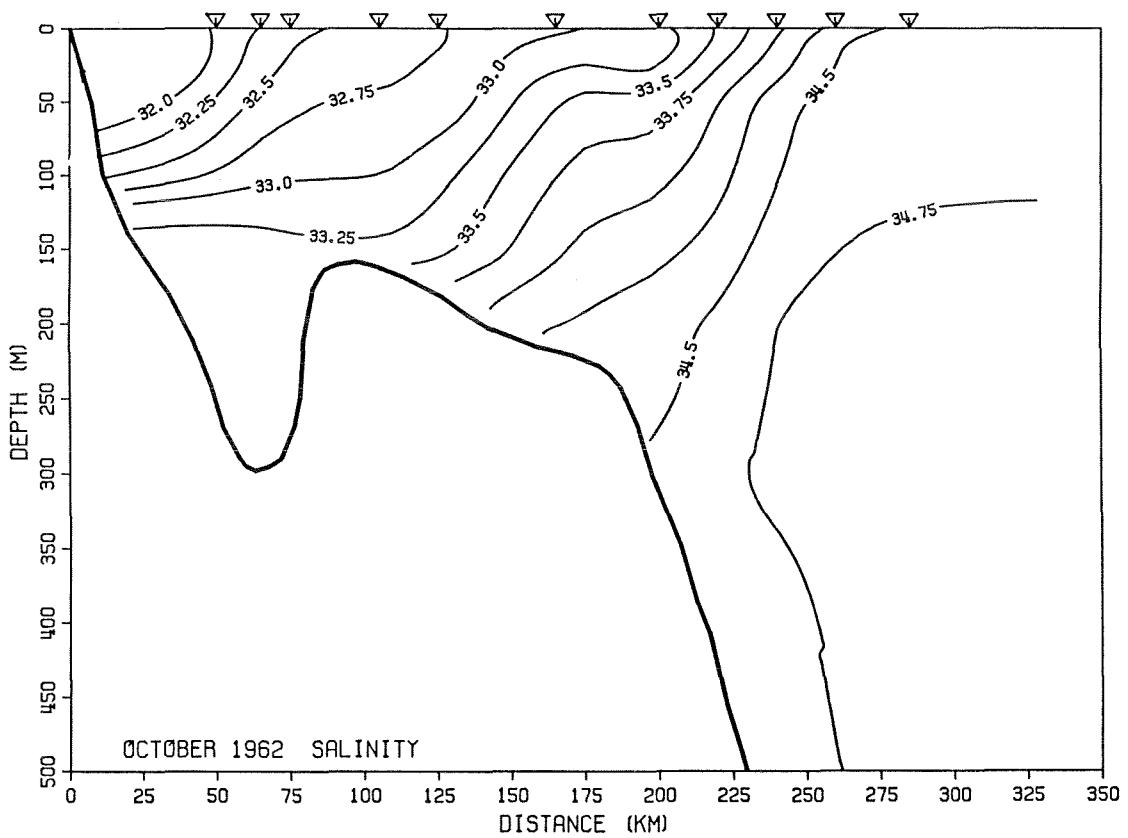


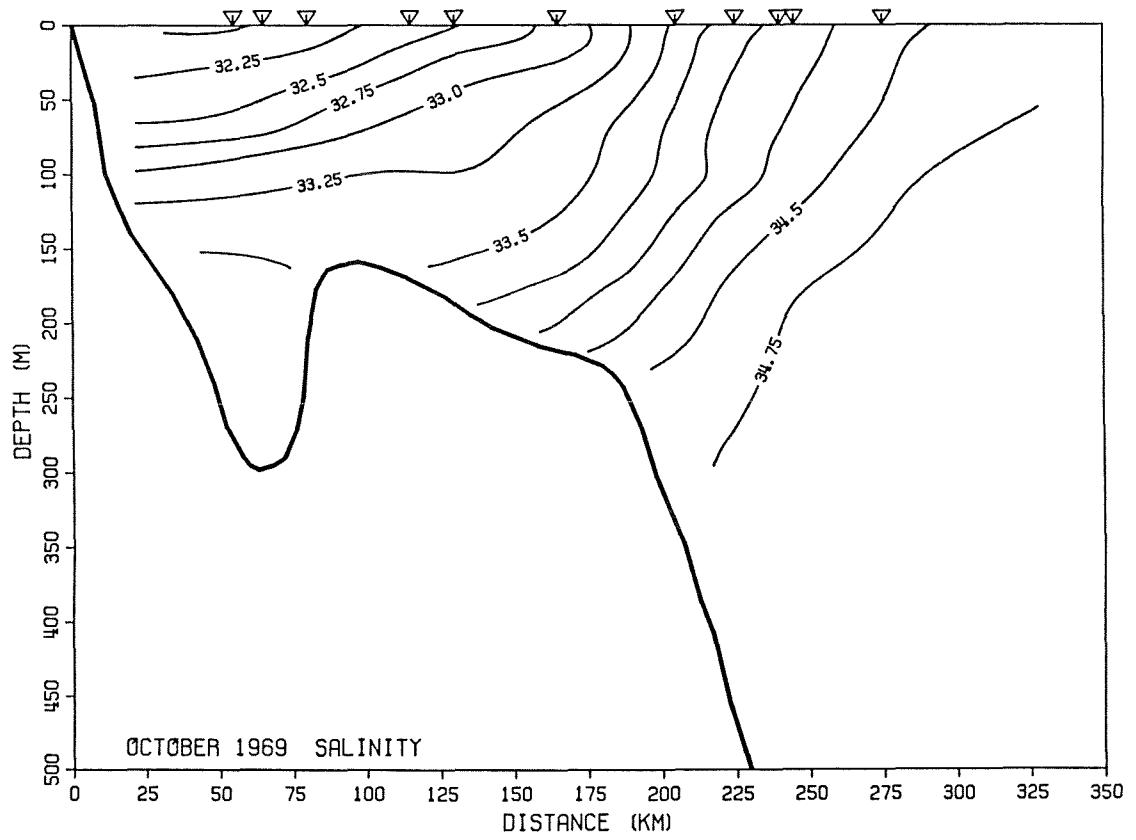
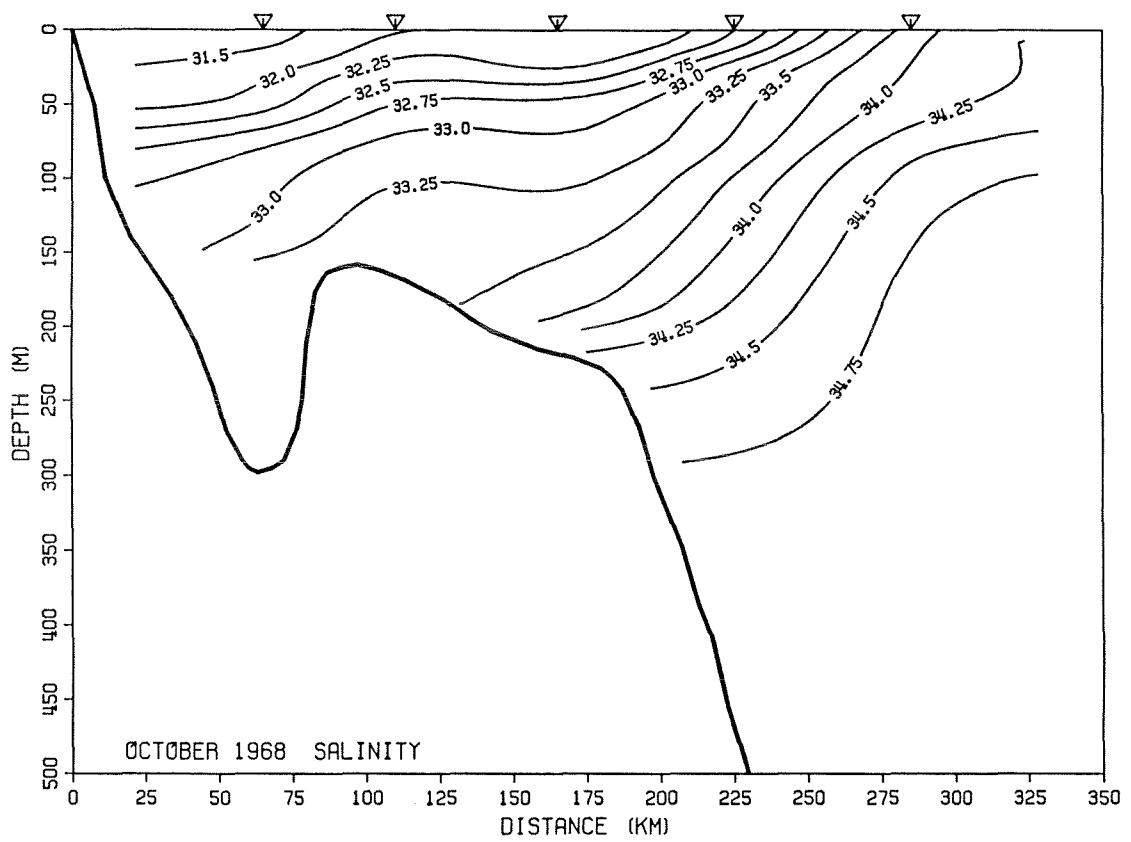


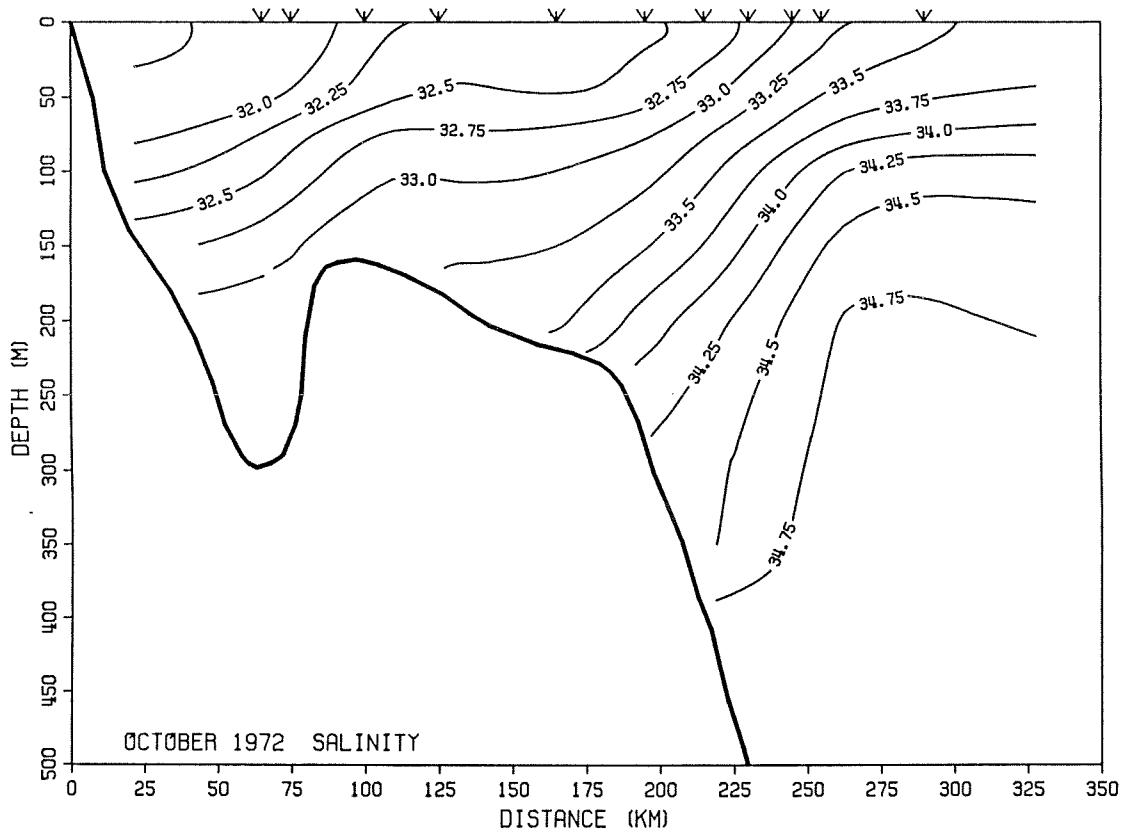
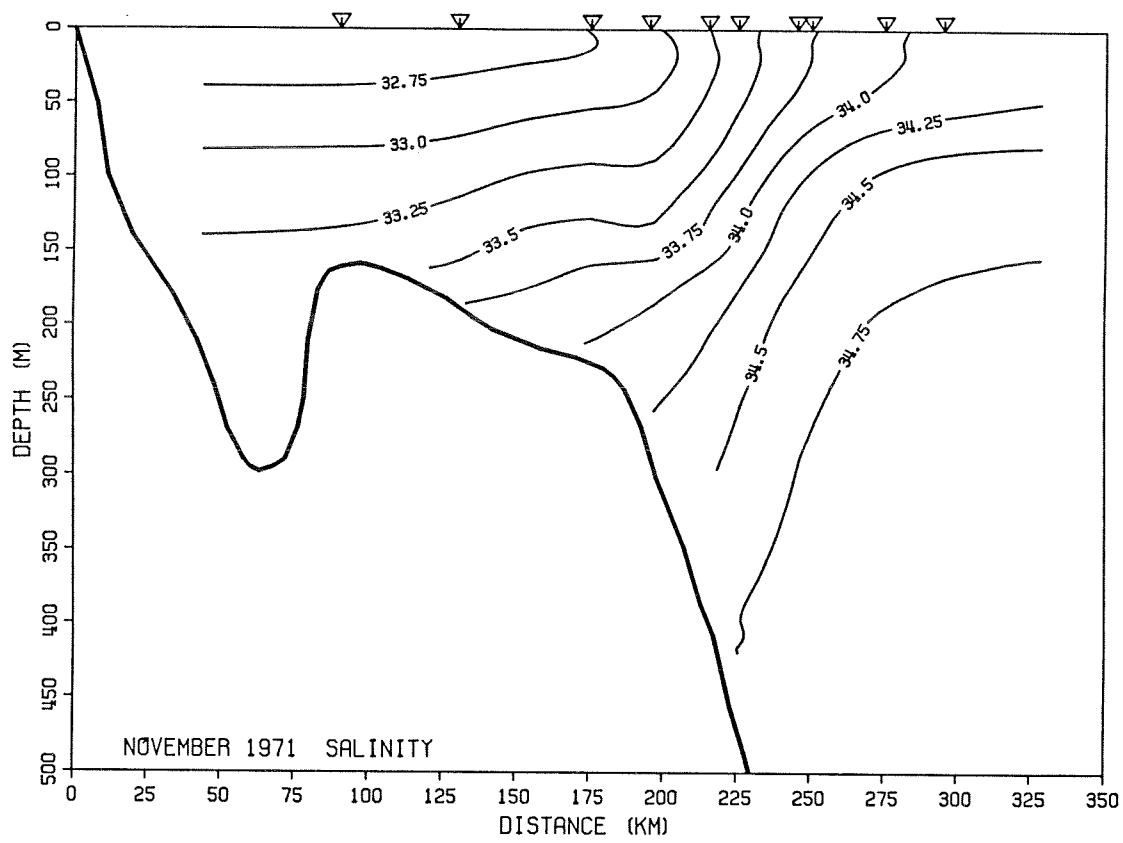


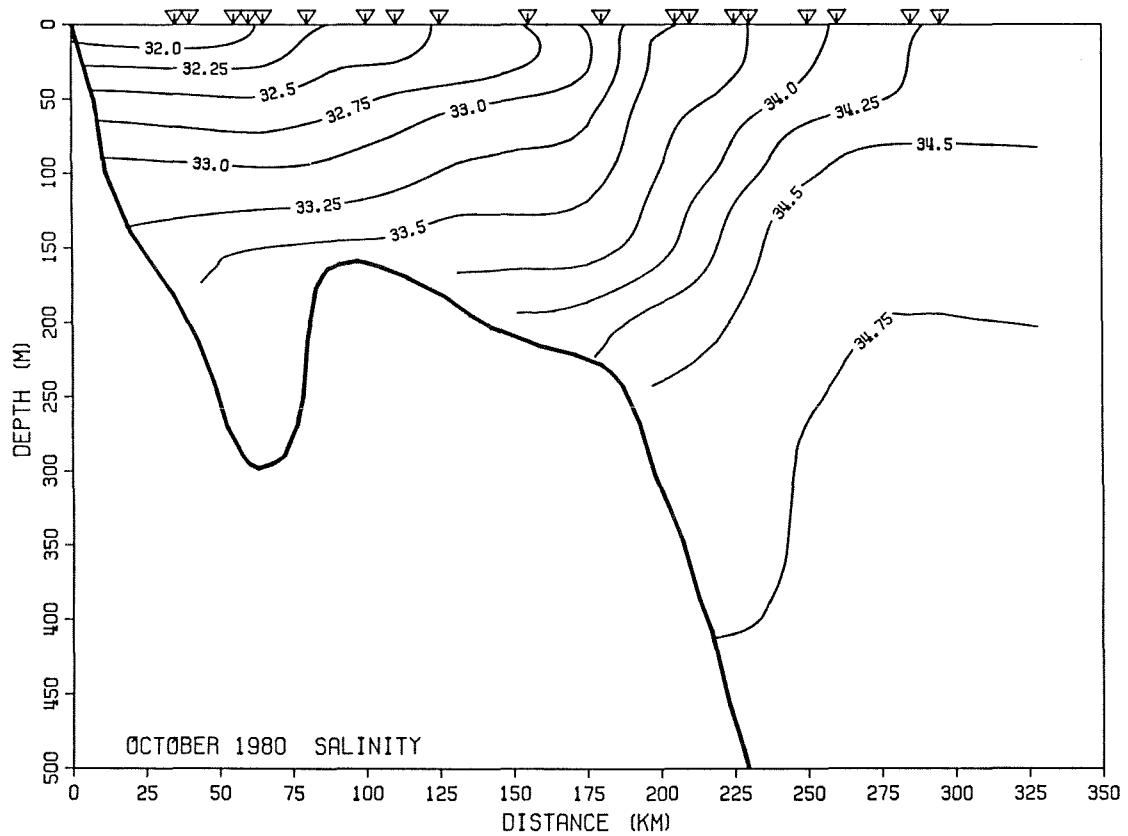
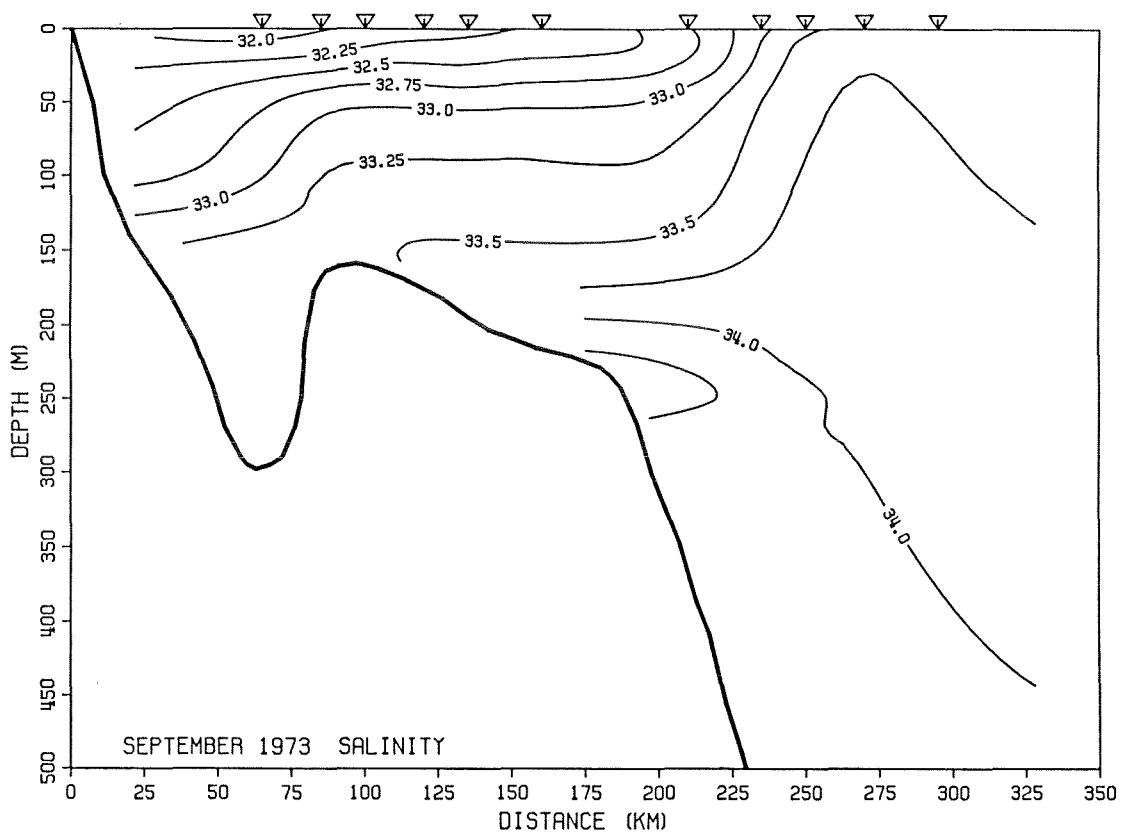
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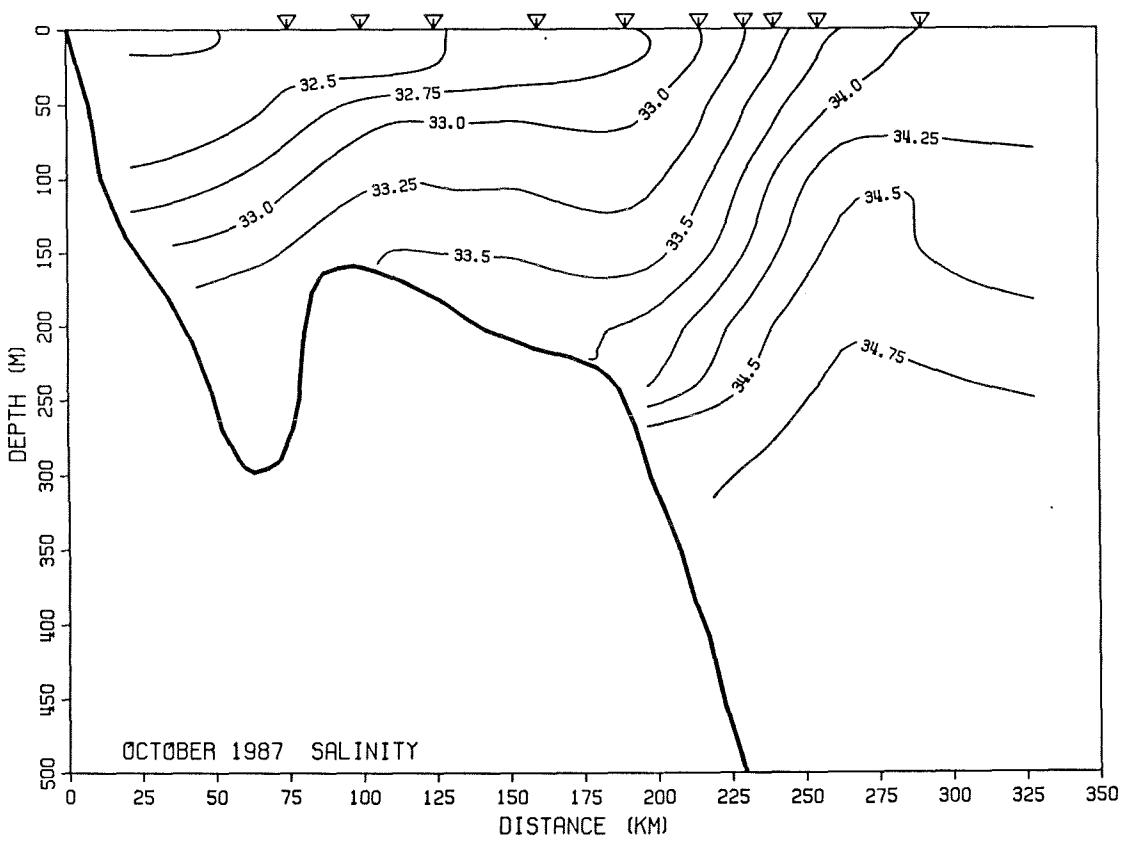
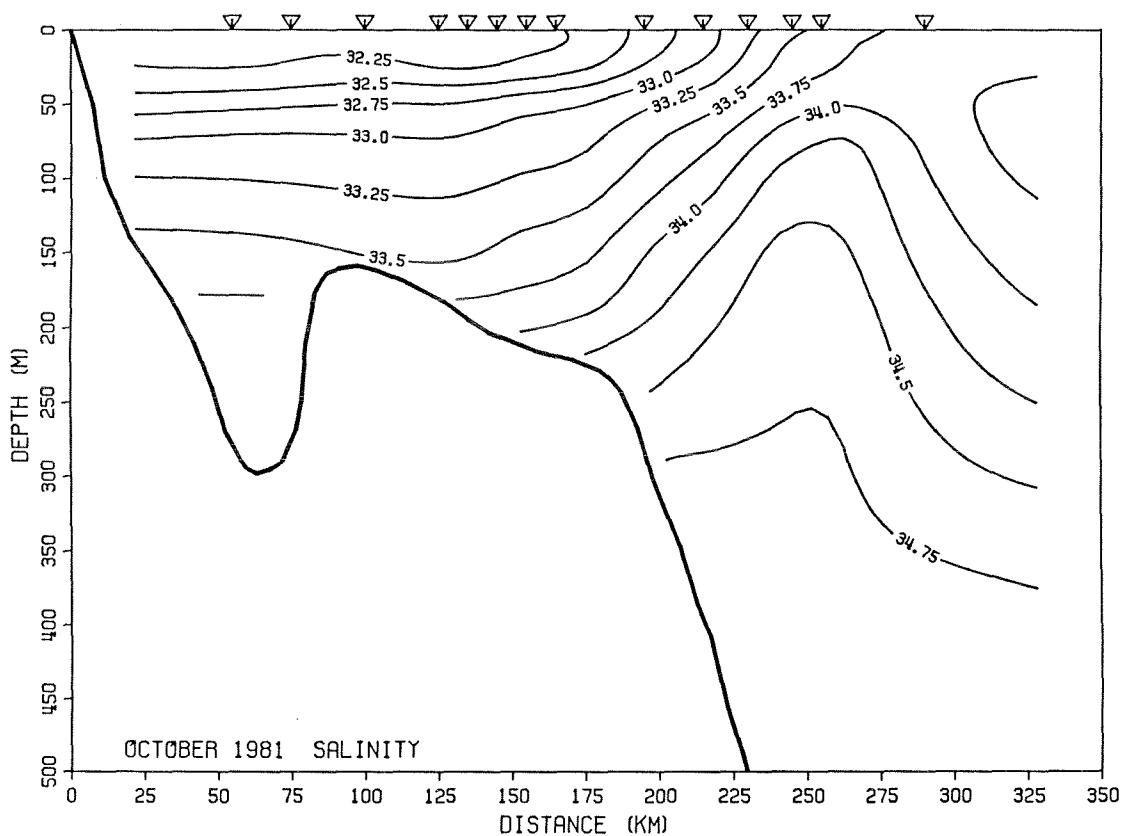


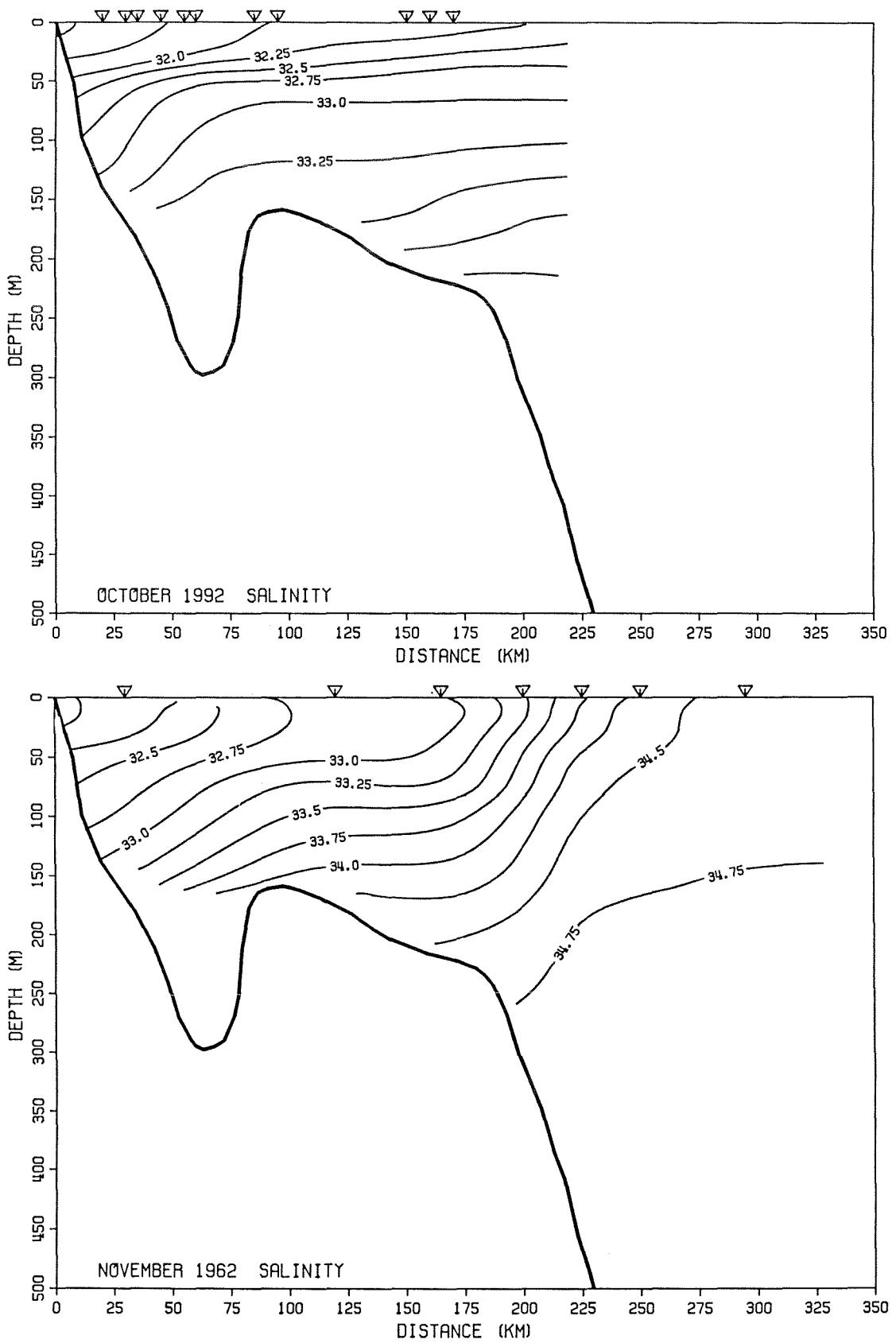


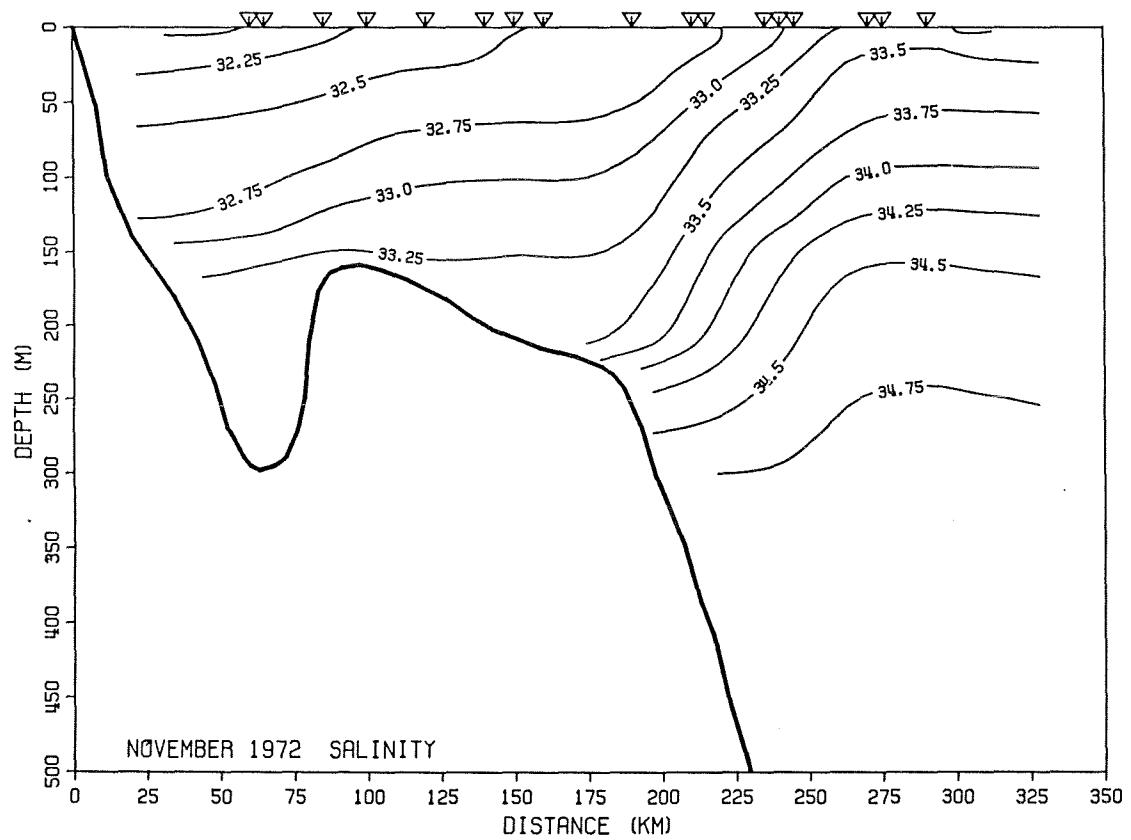
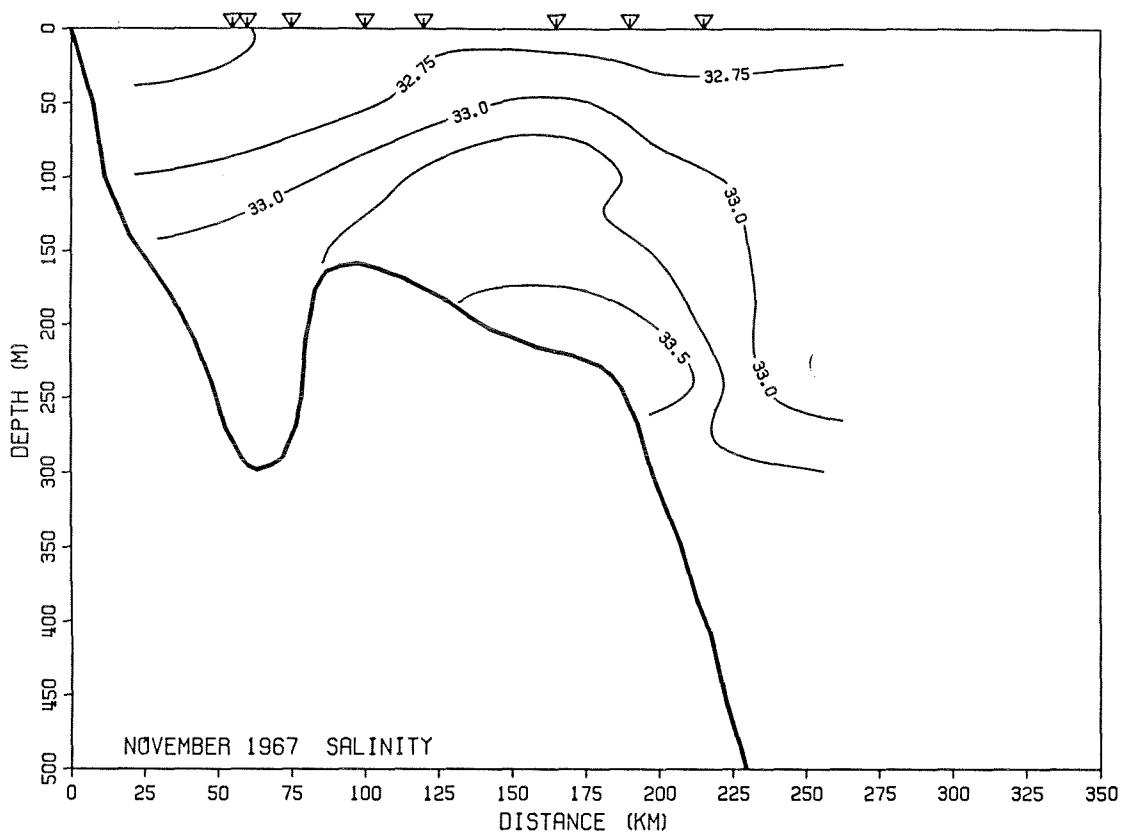


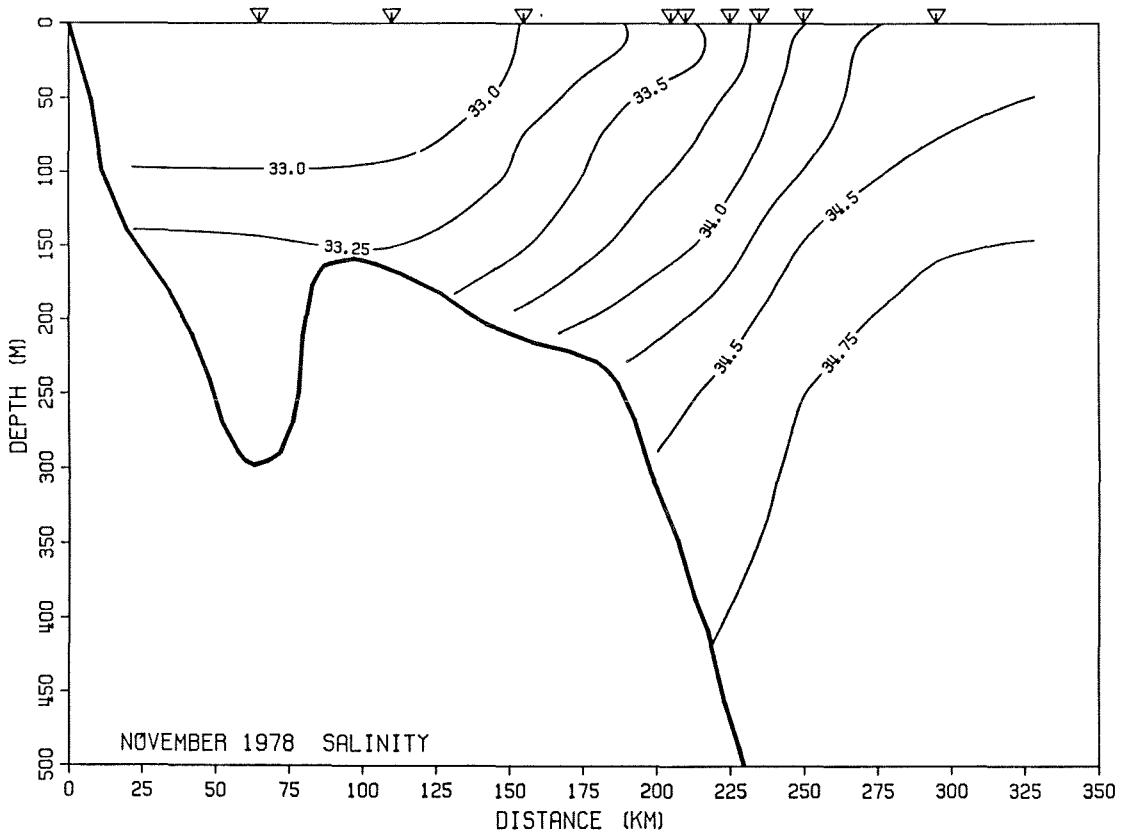
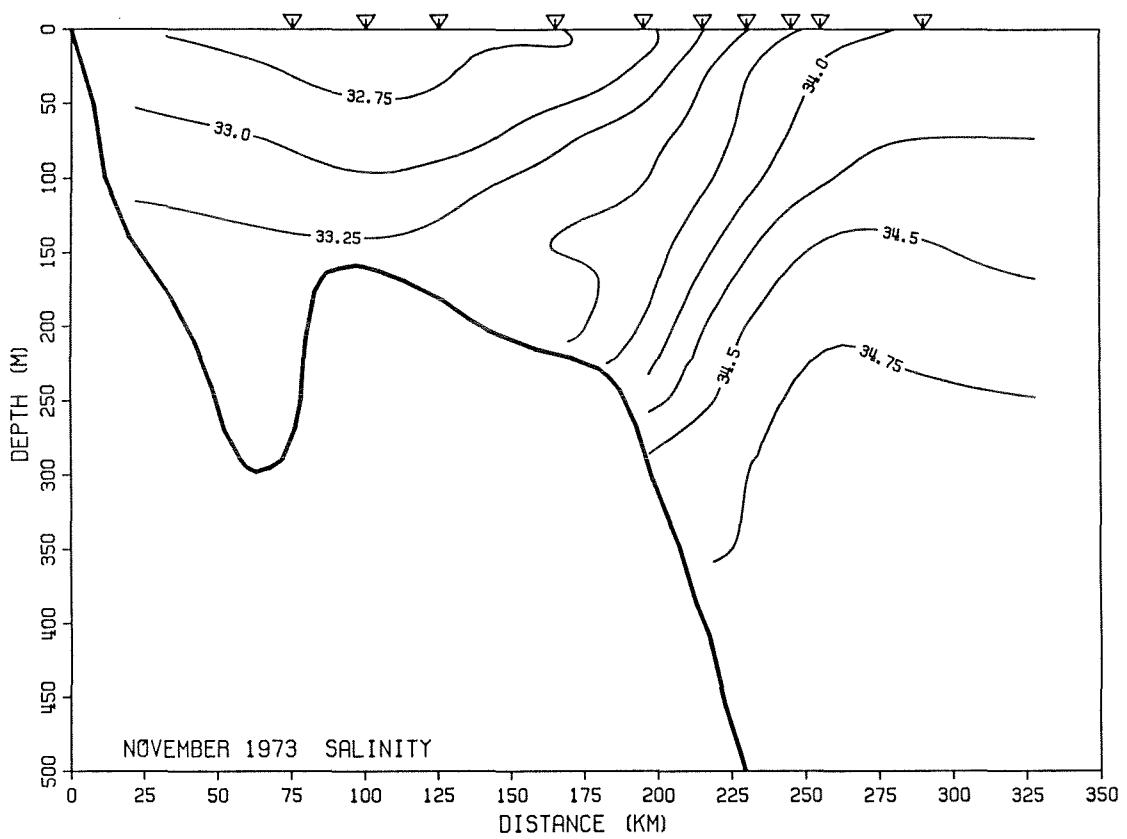




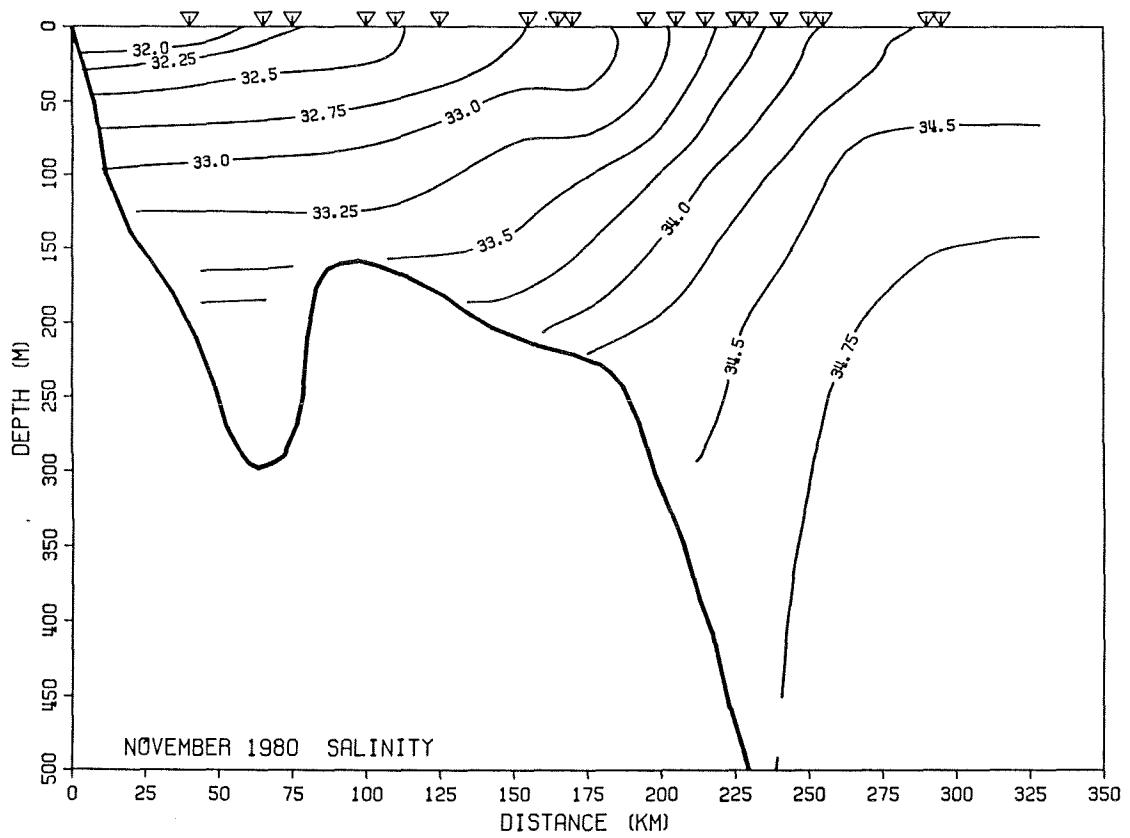
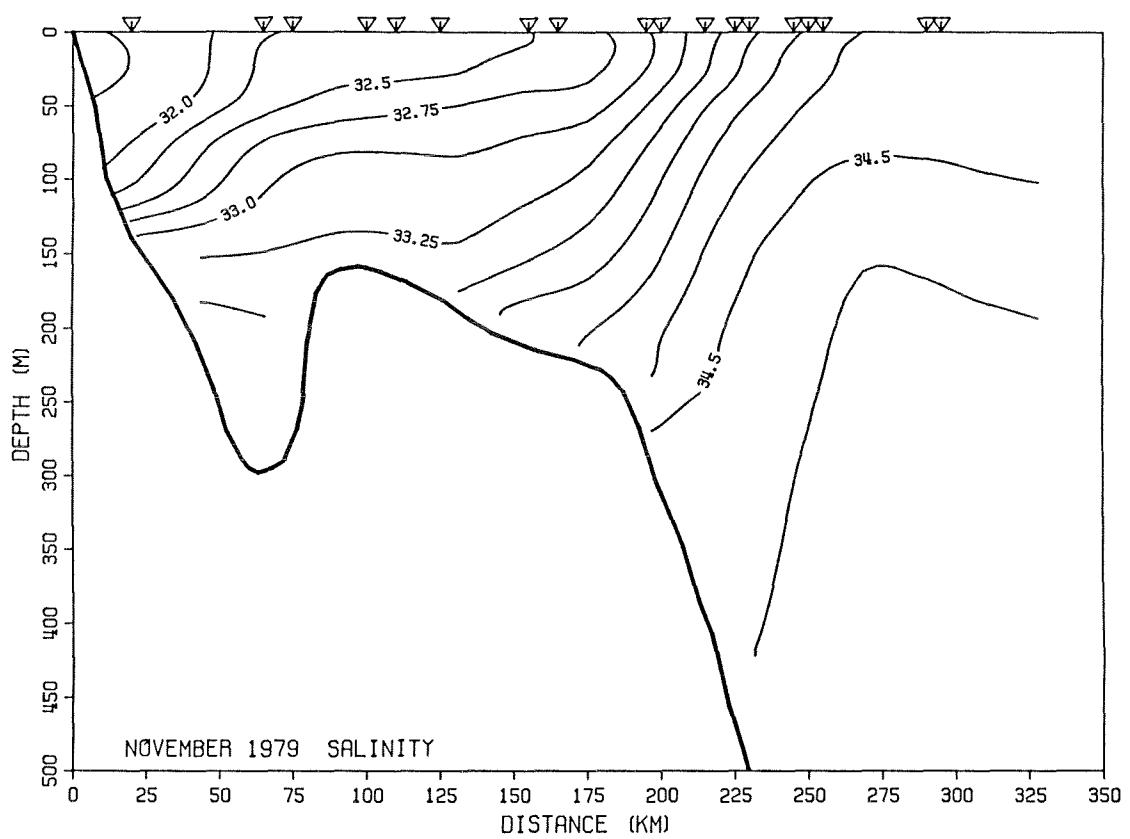


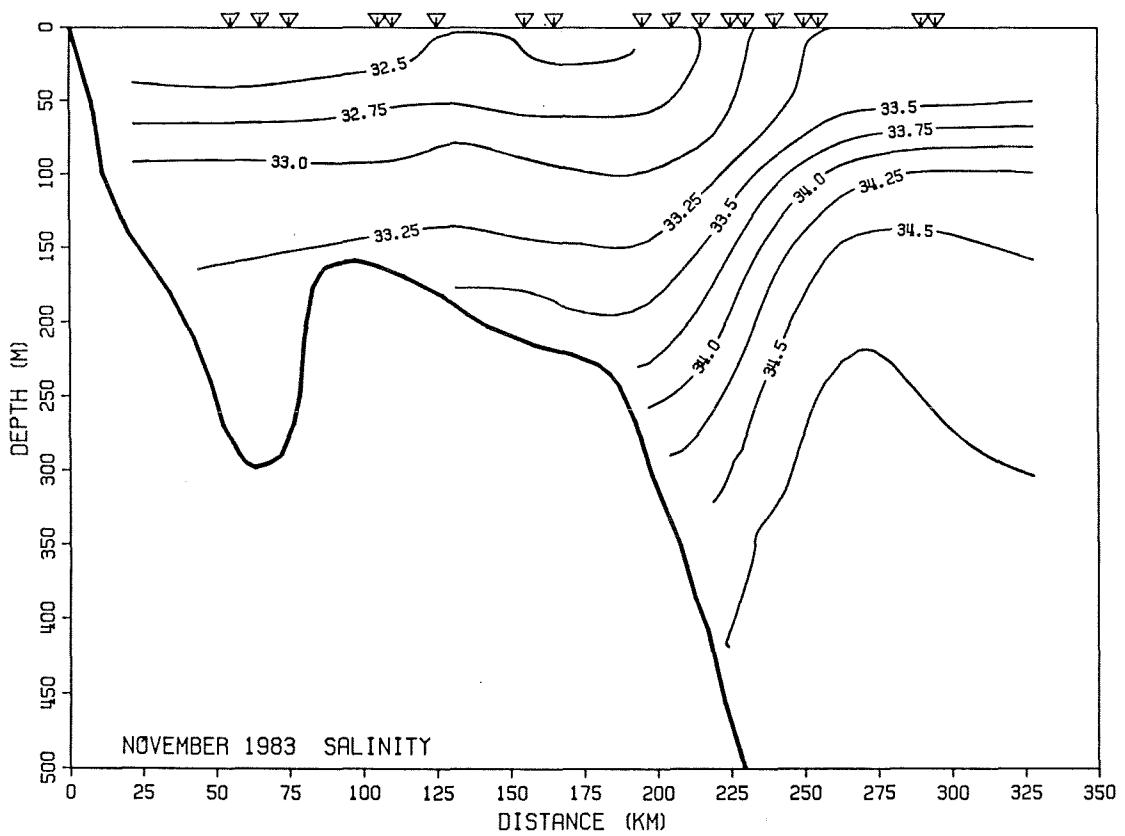
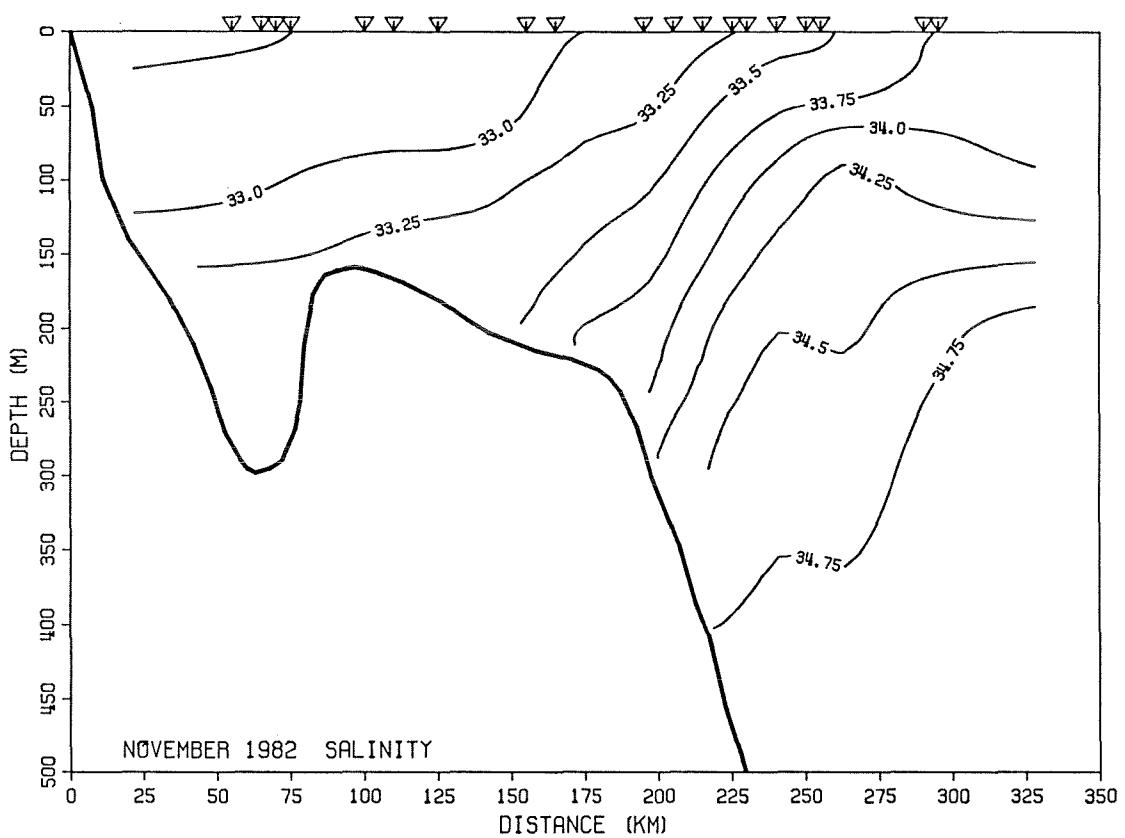


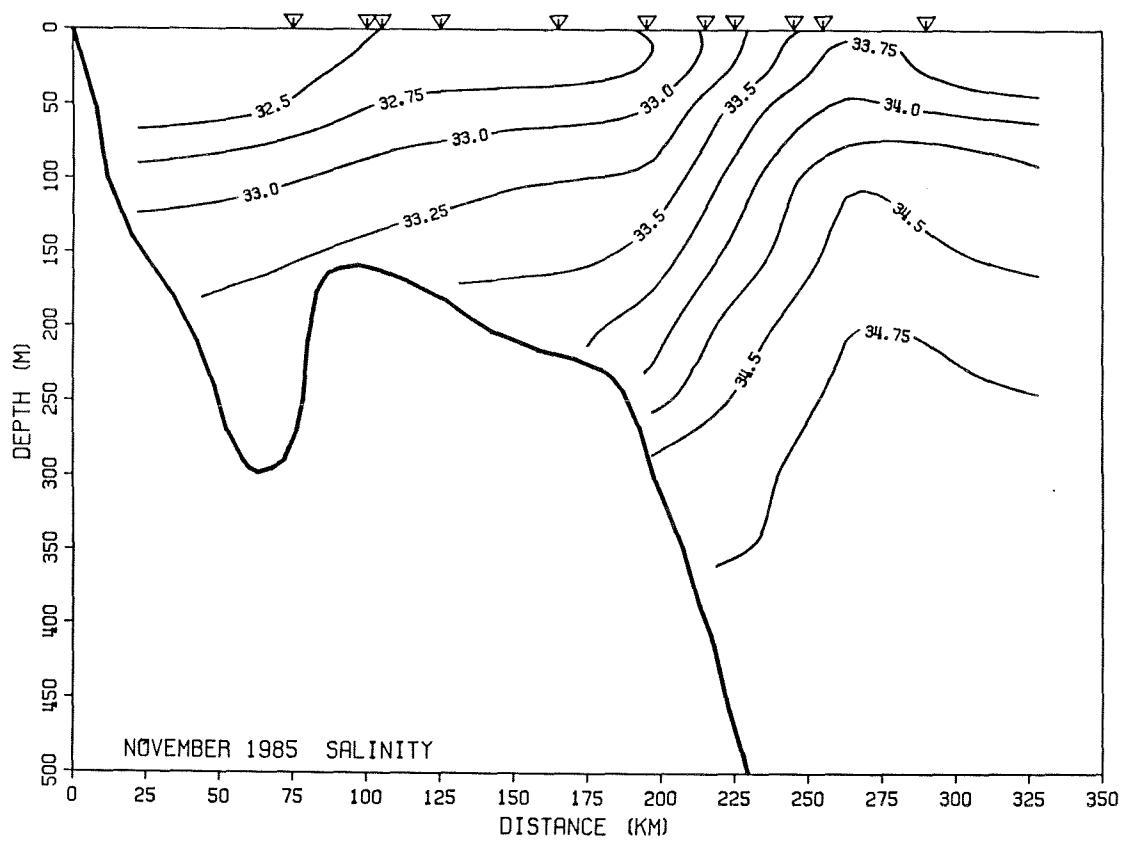
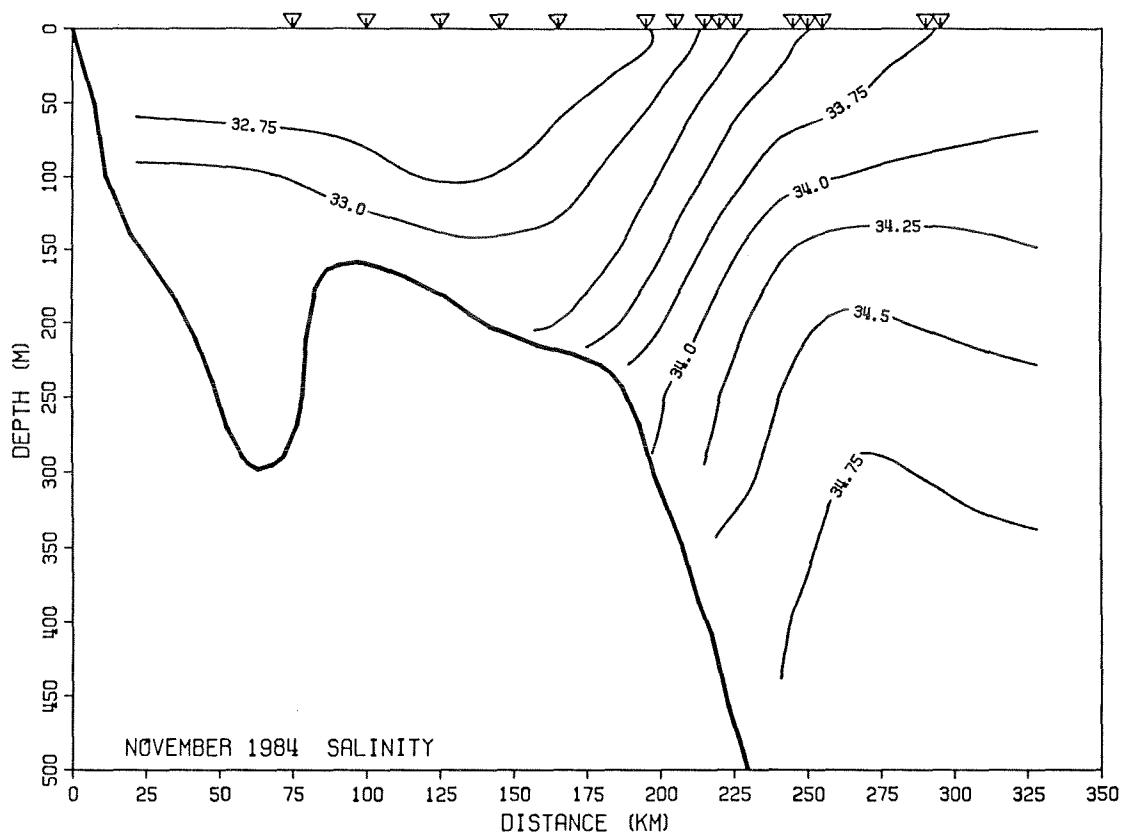


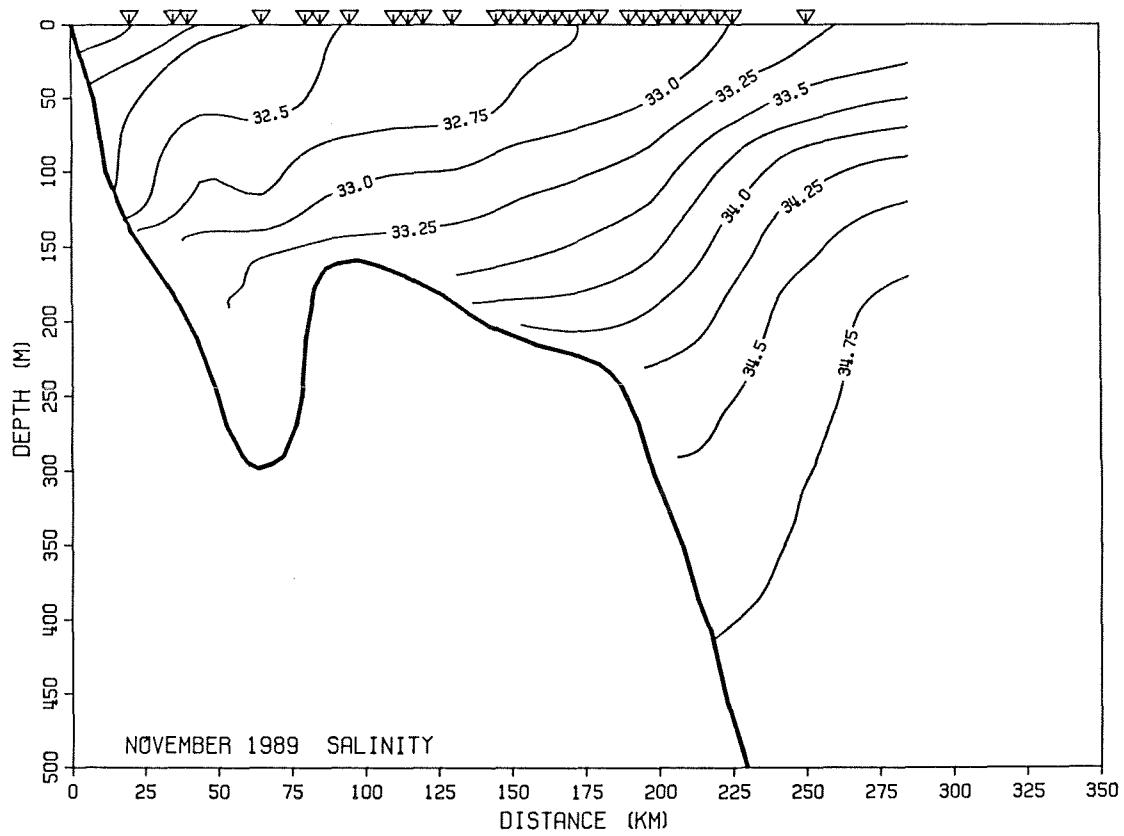
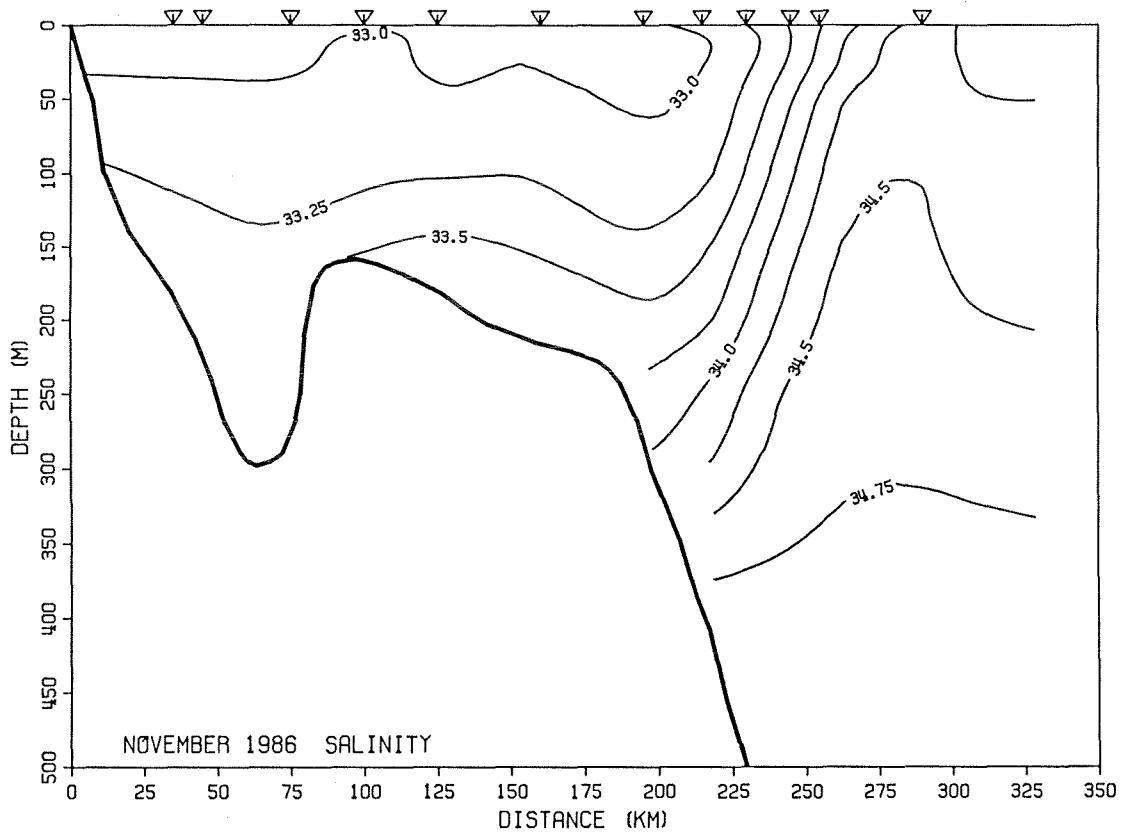


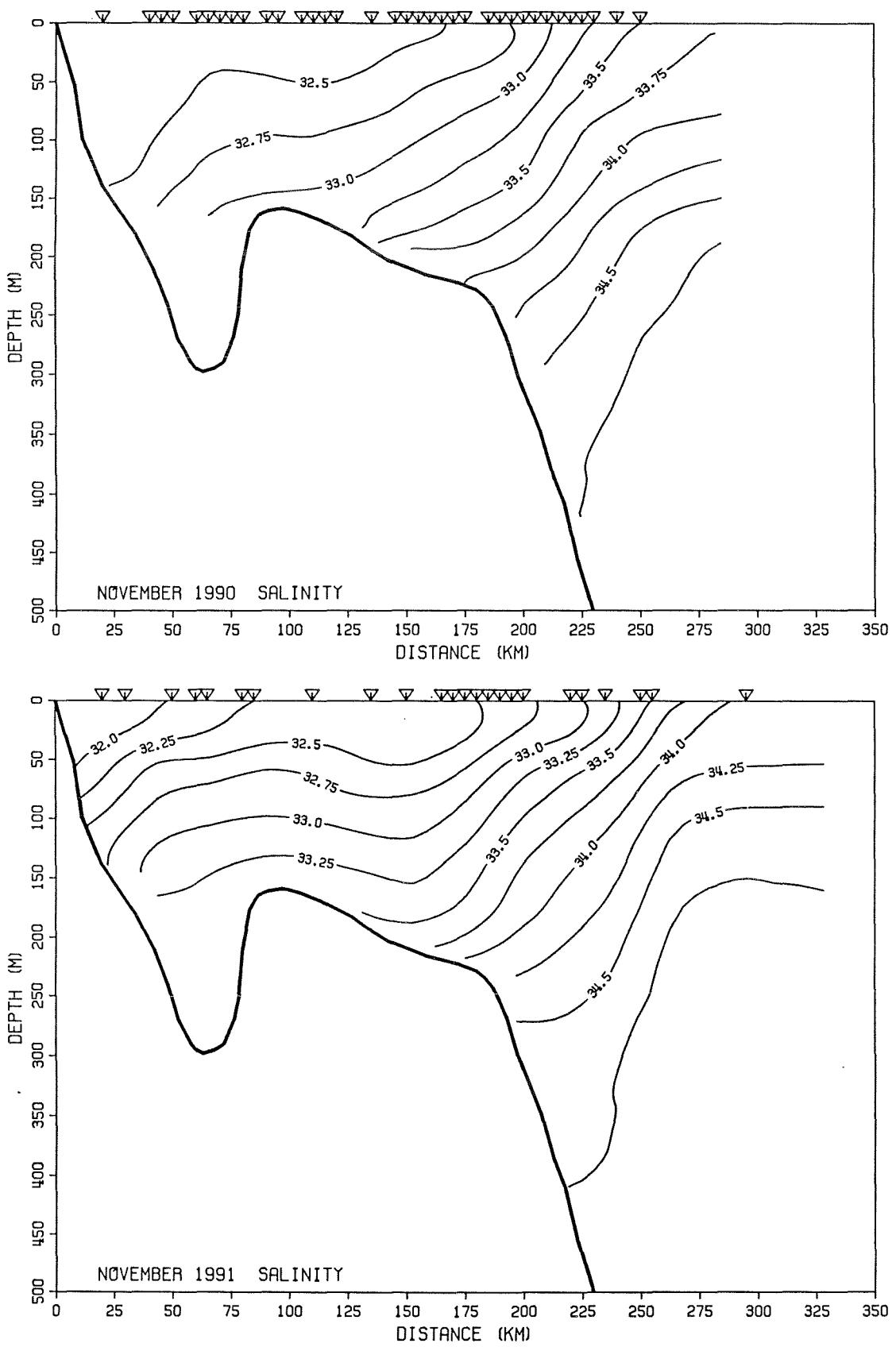
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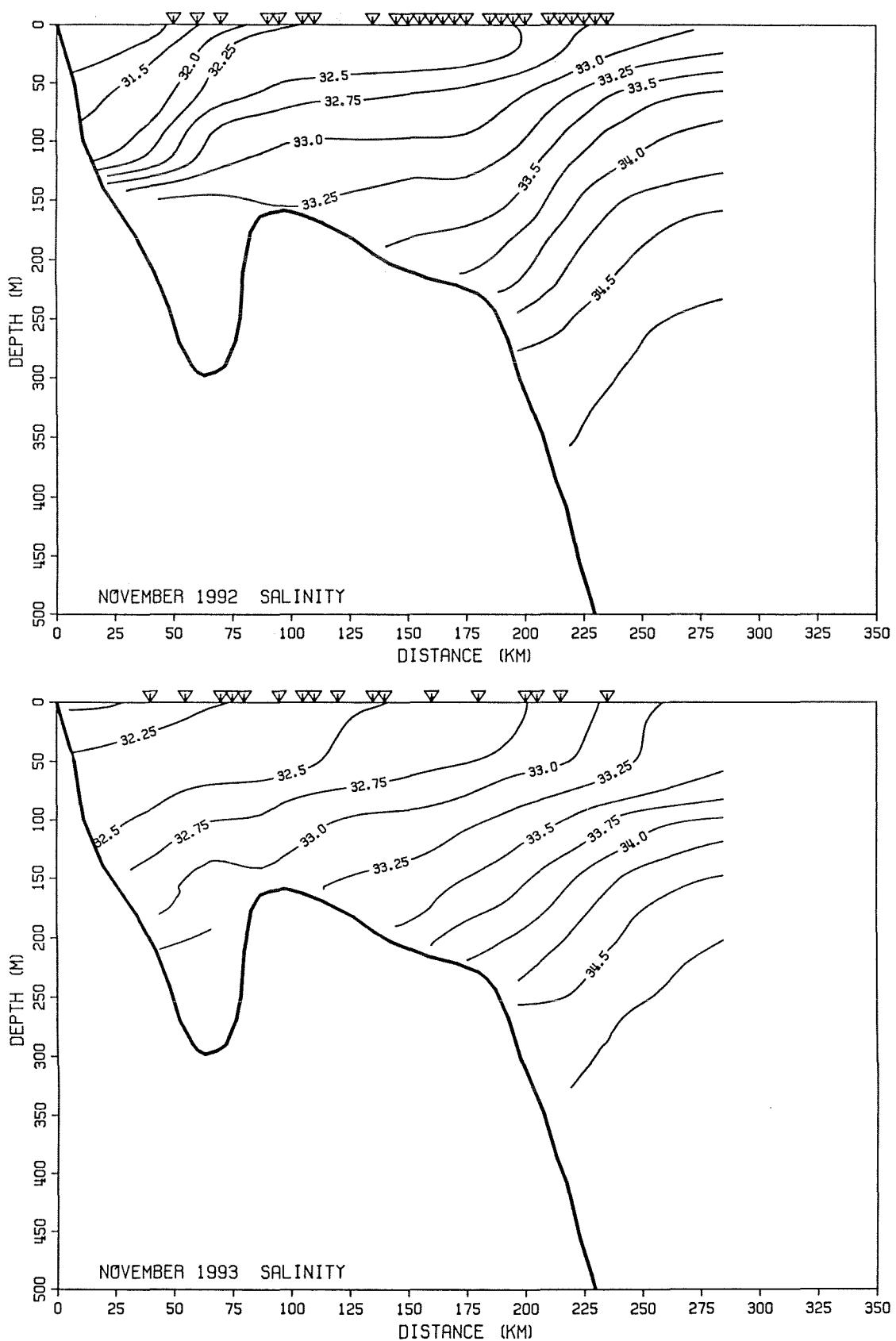


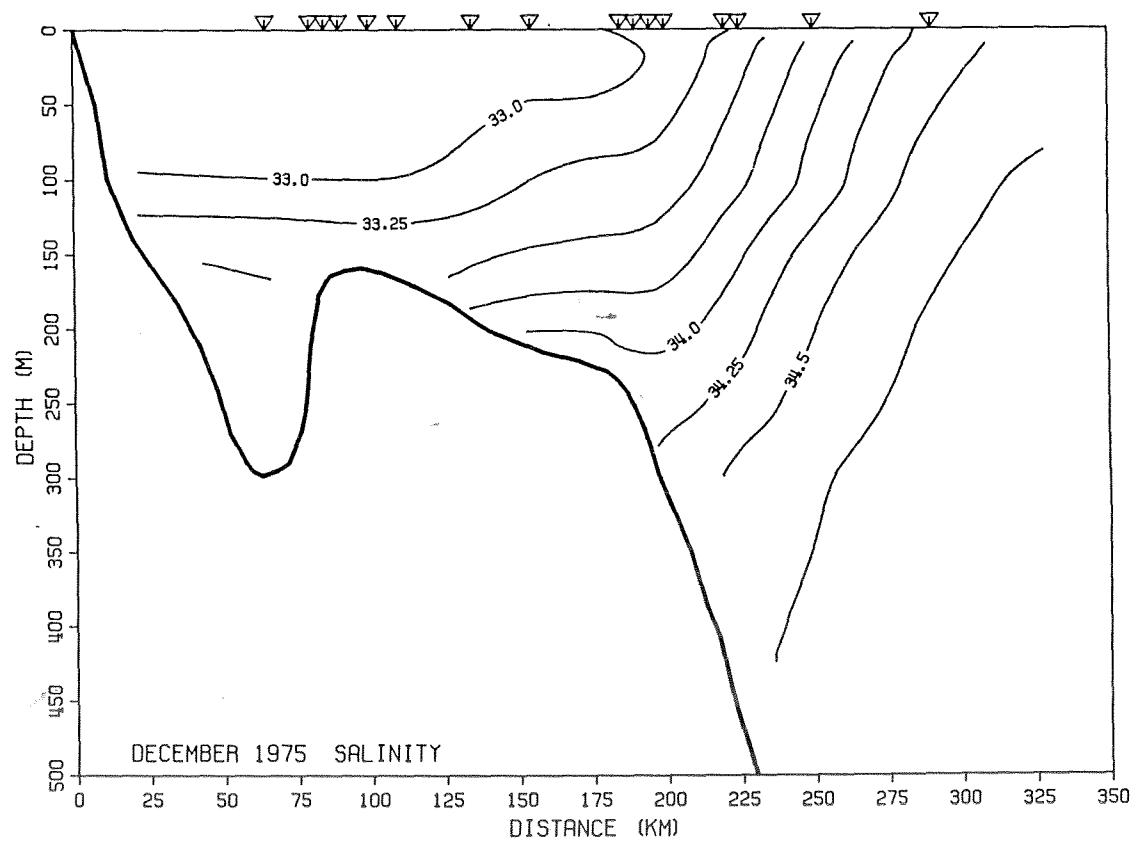
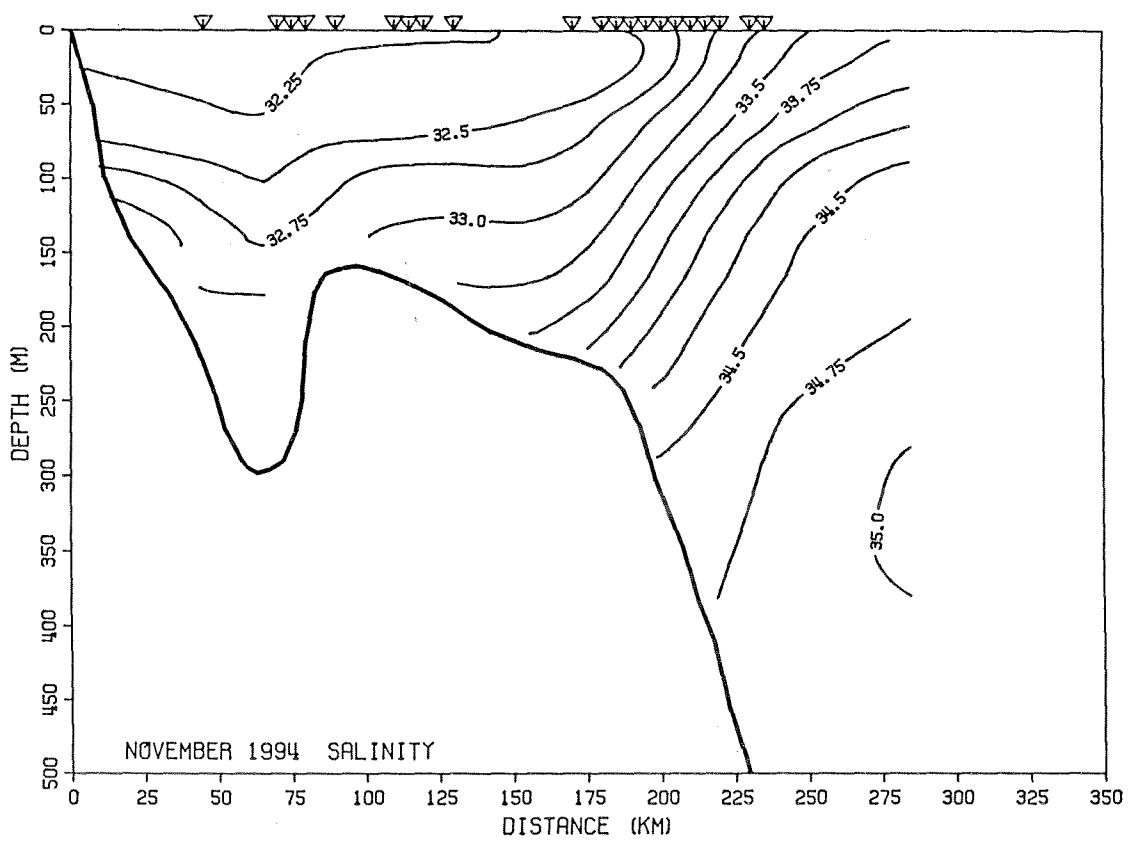




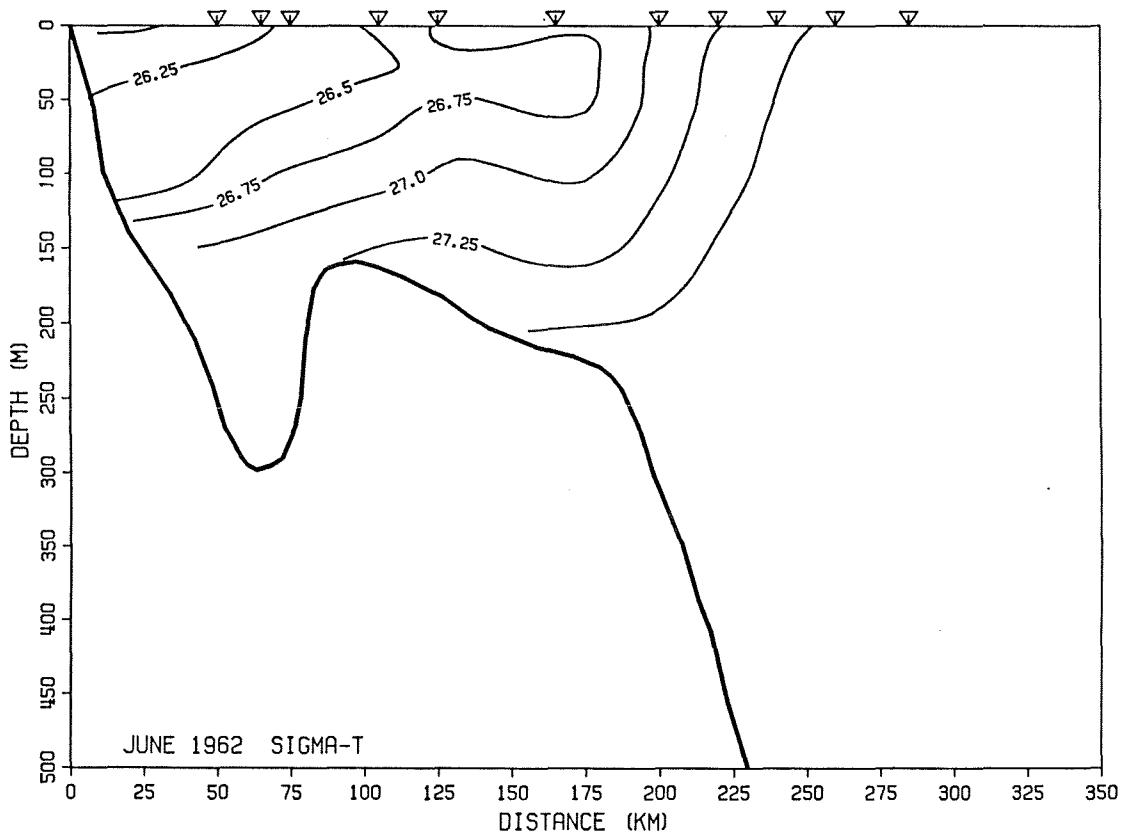
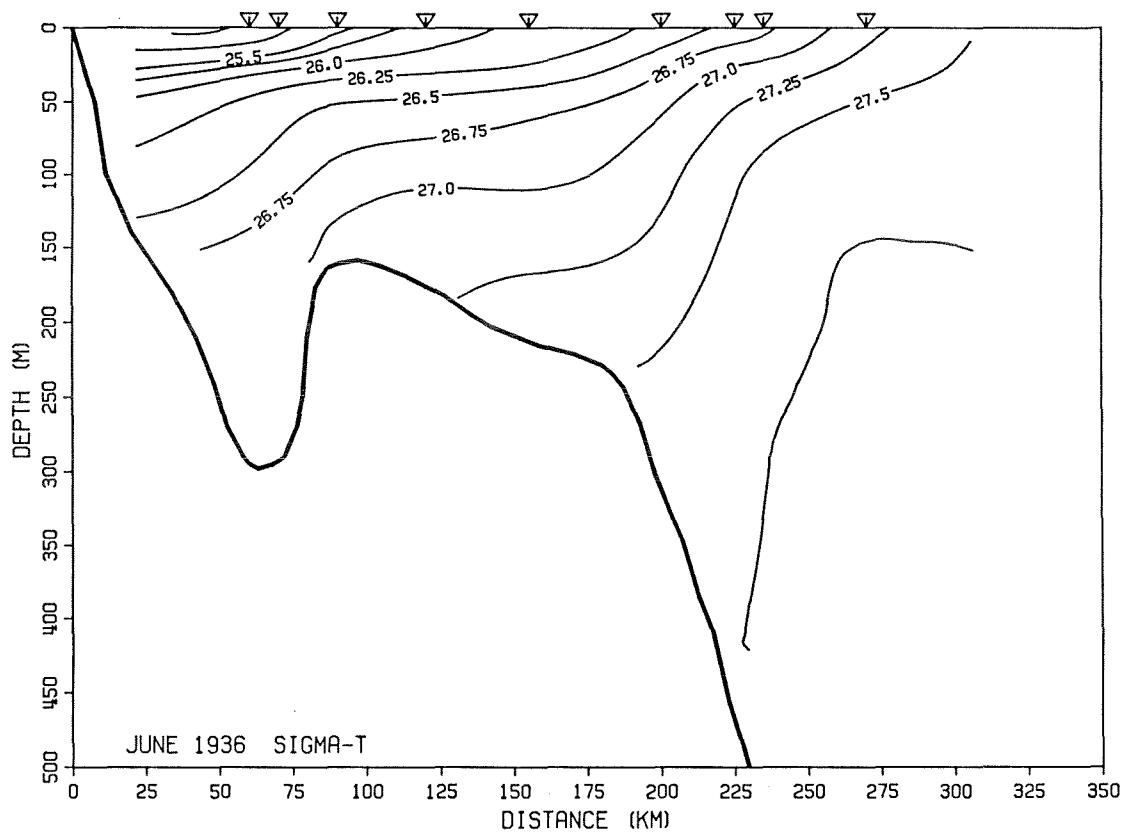


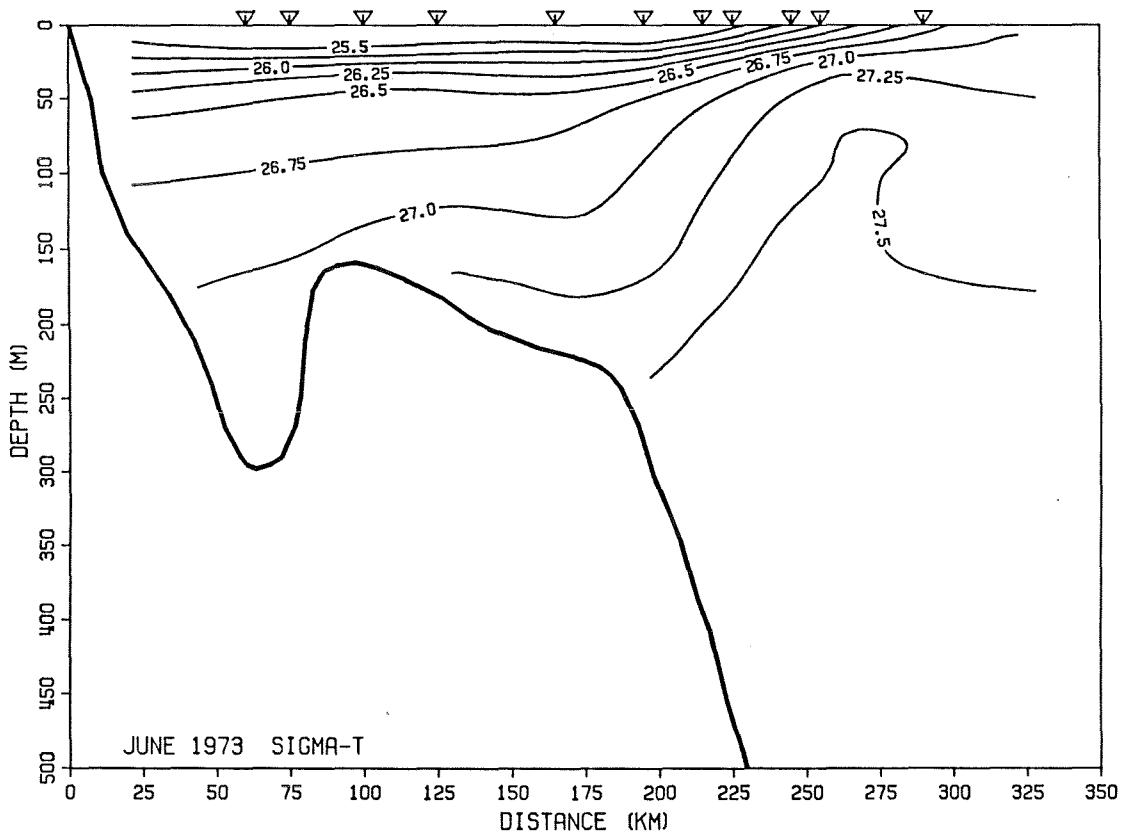
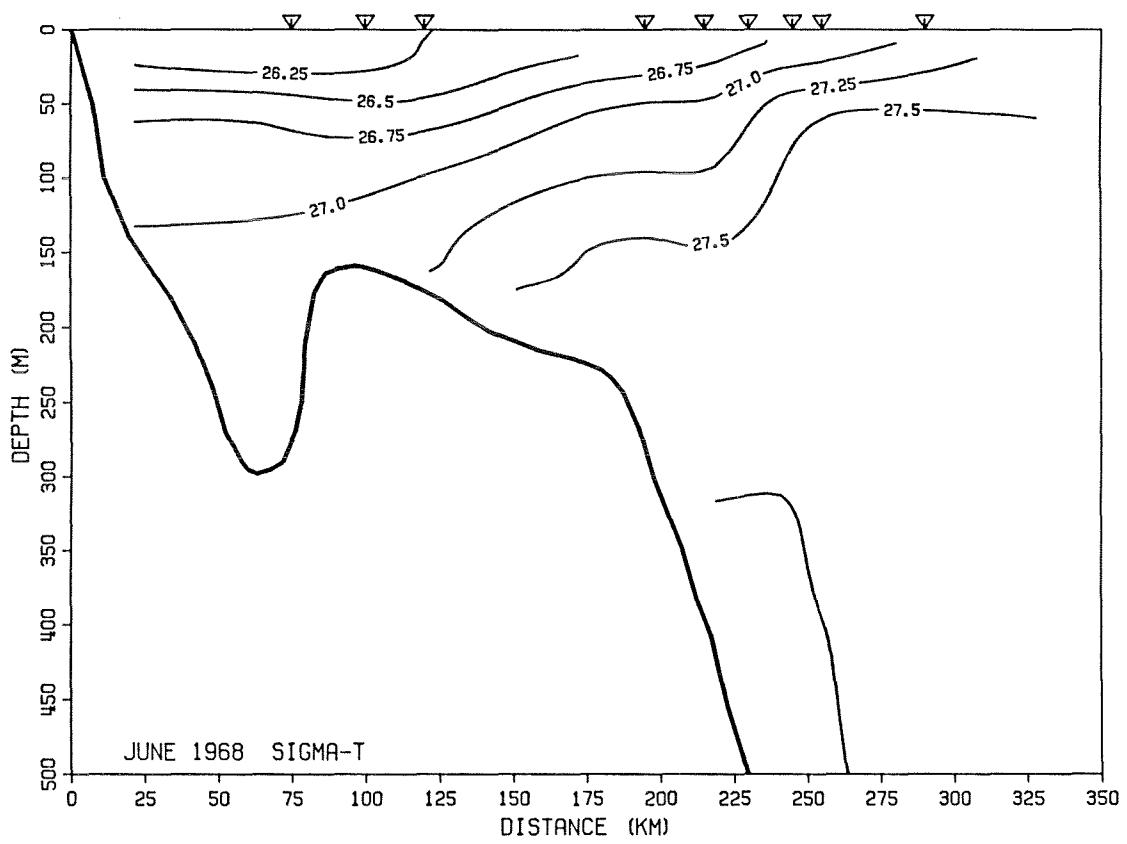


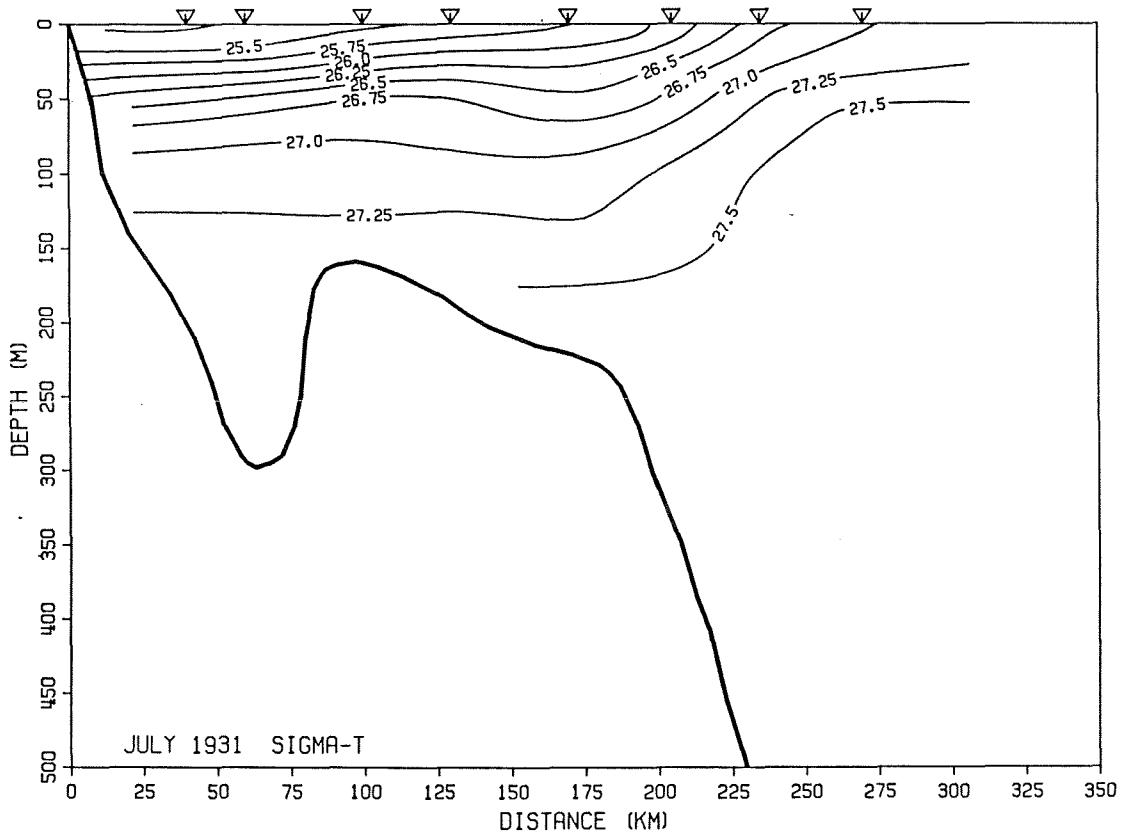
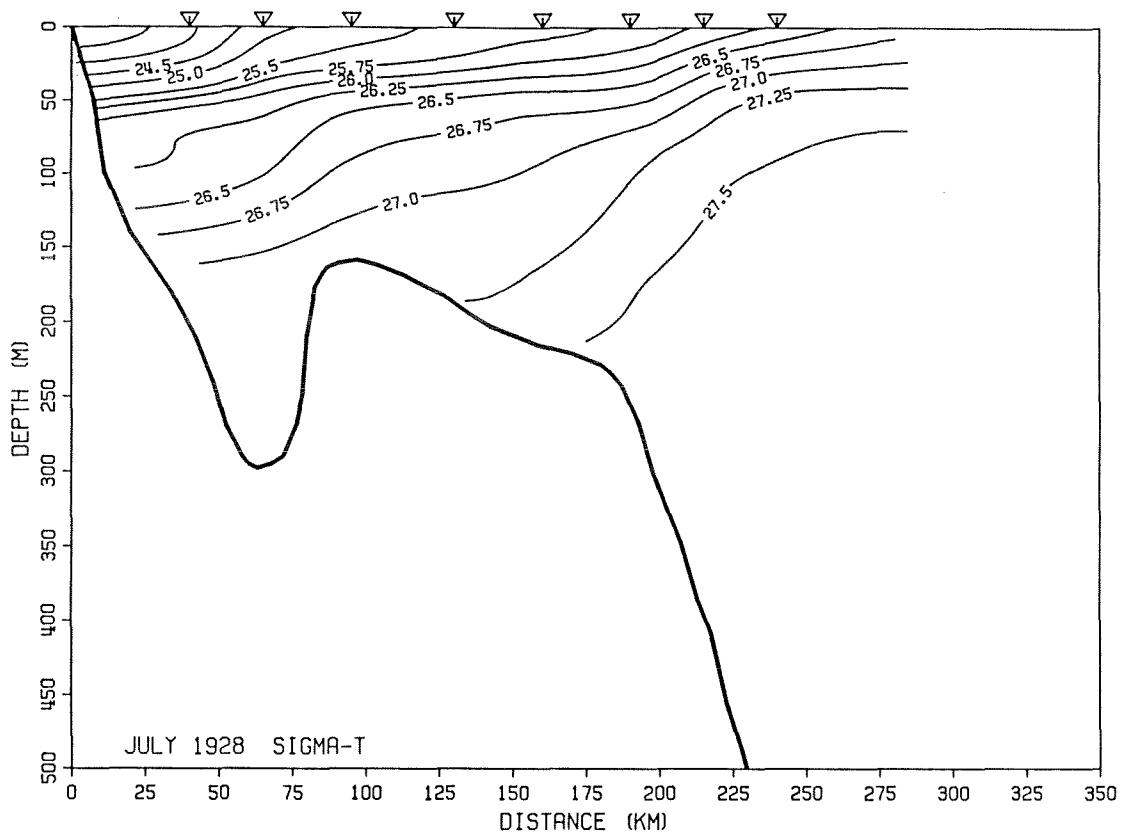




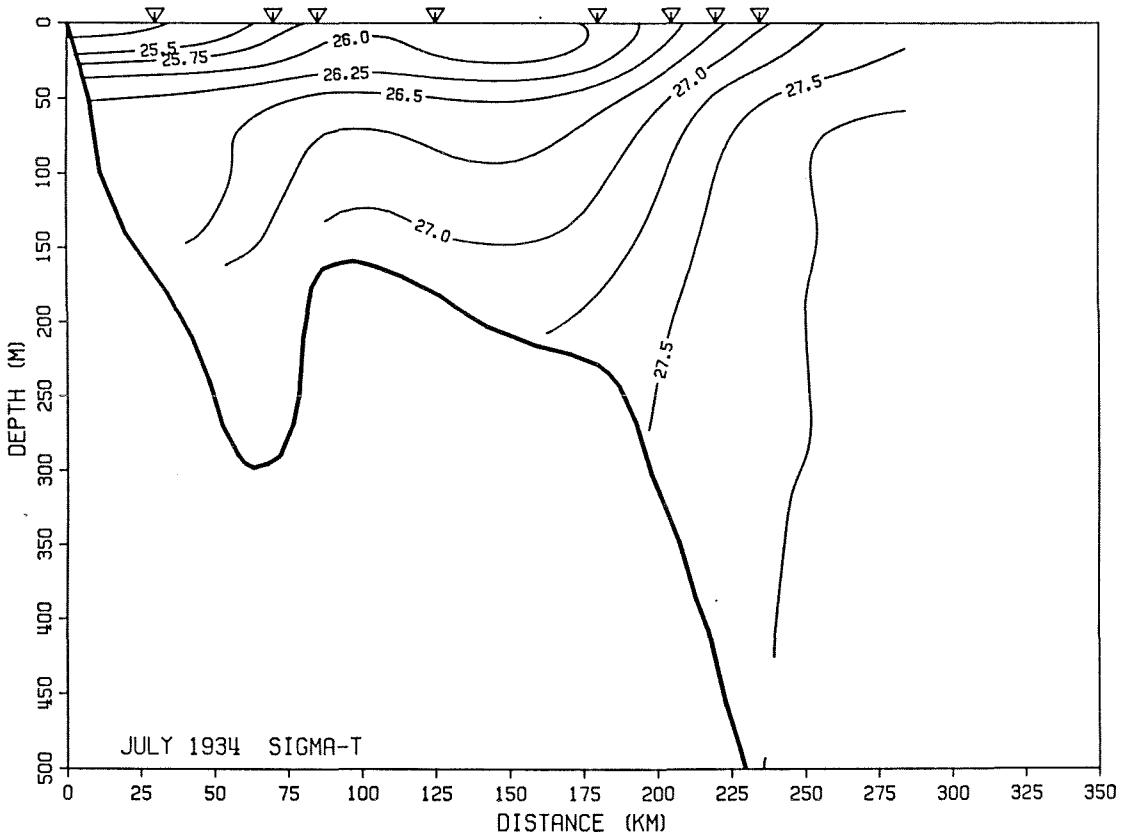
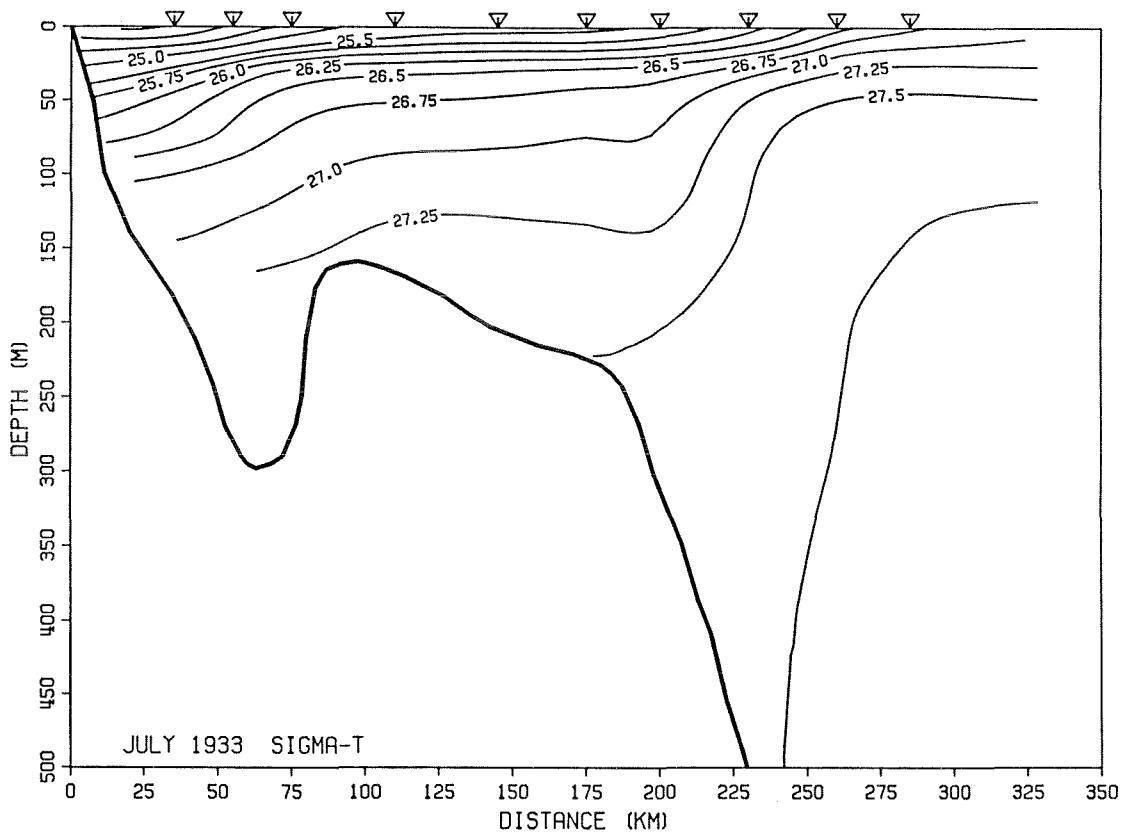
APPENDIX G. Seal Island Annual Sigma-t Transects.

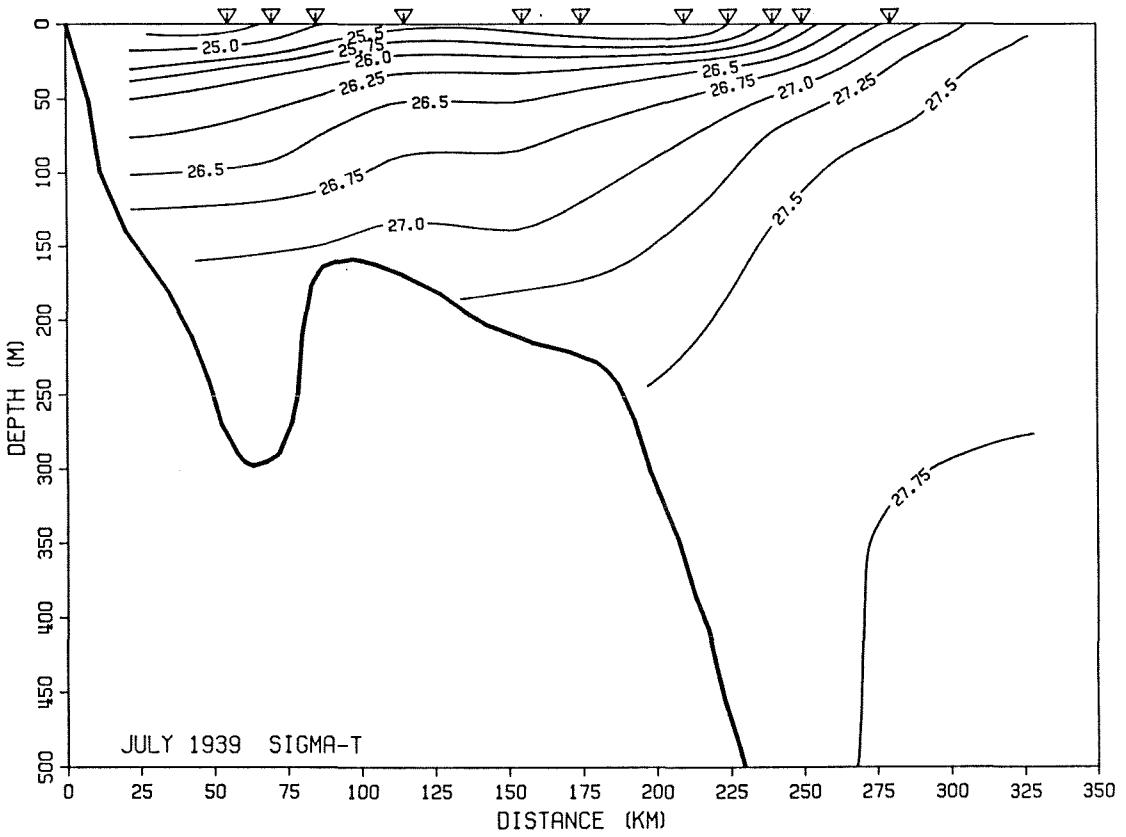
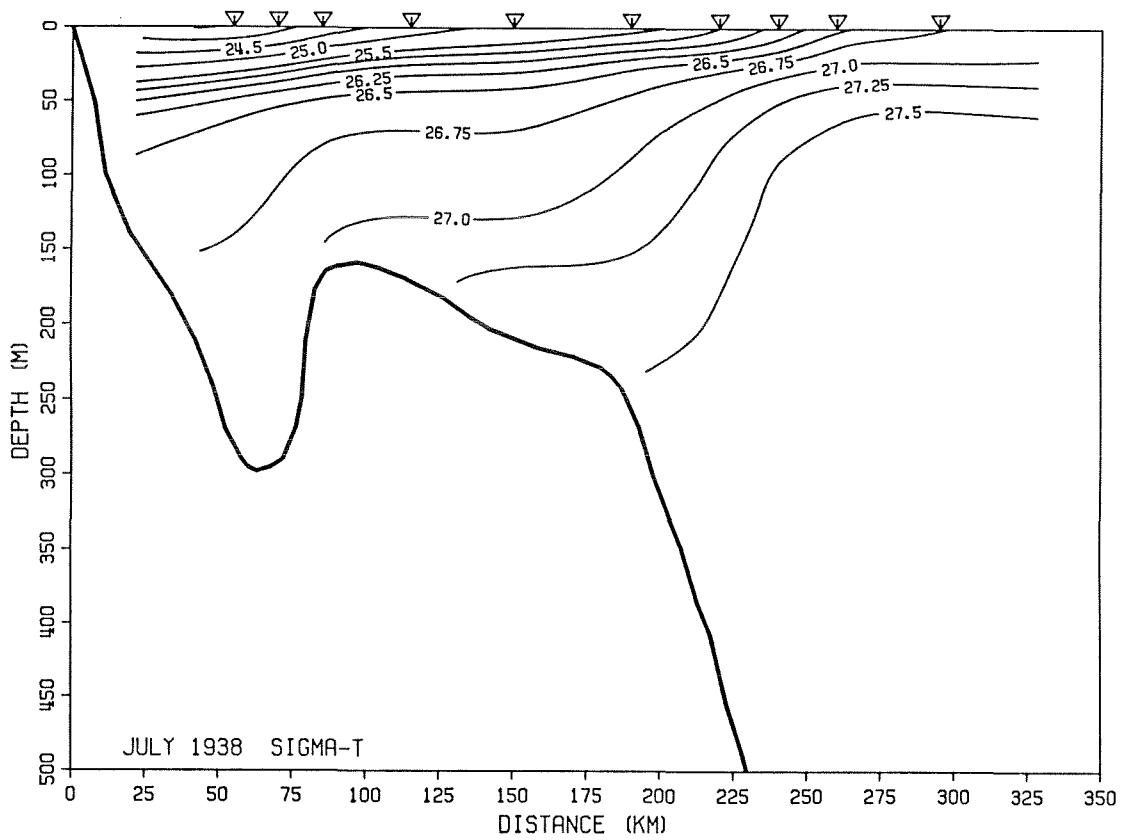




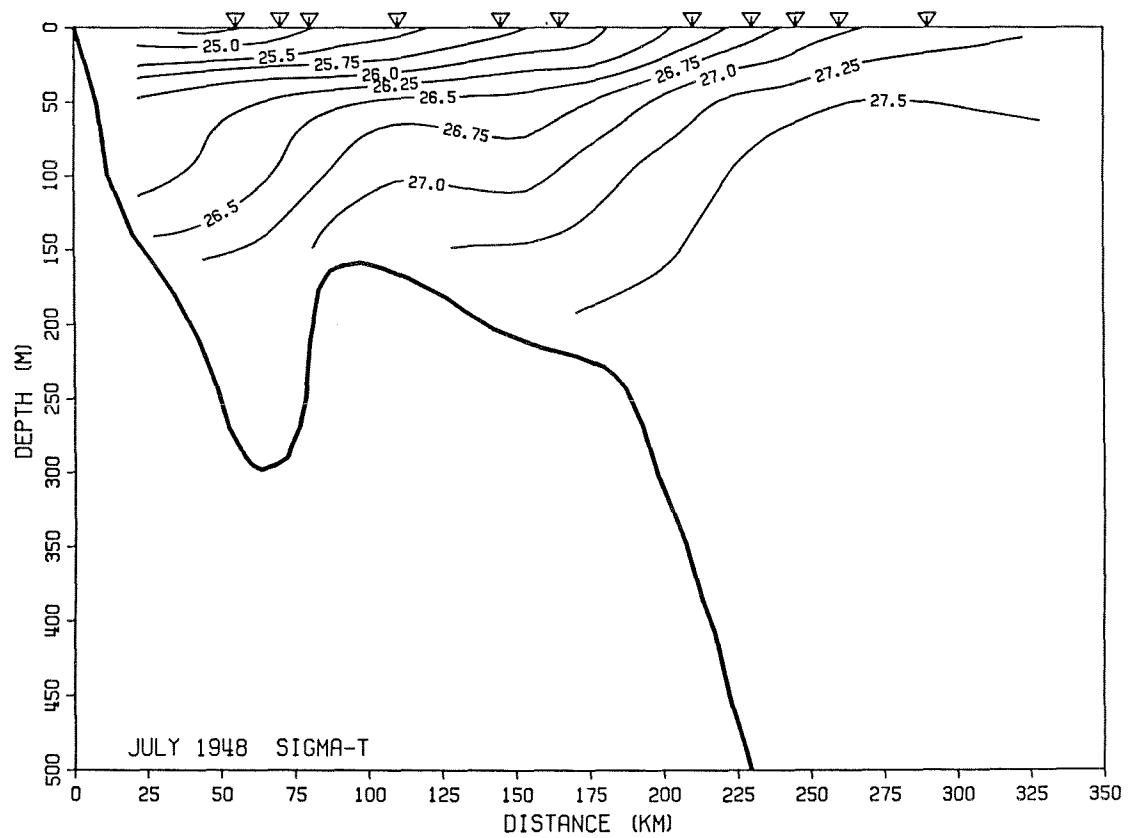
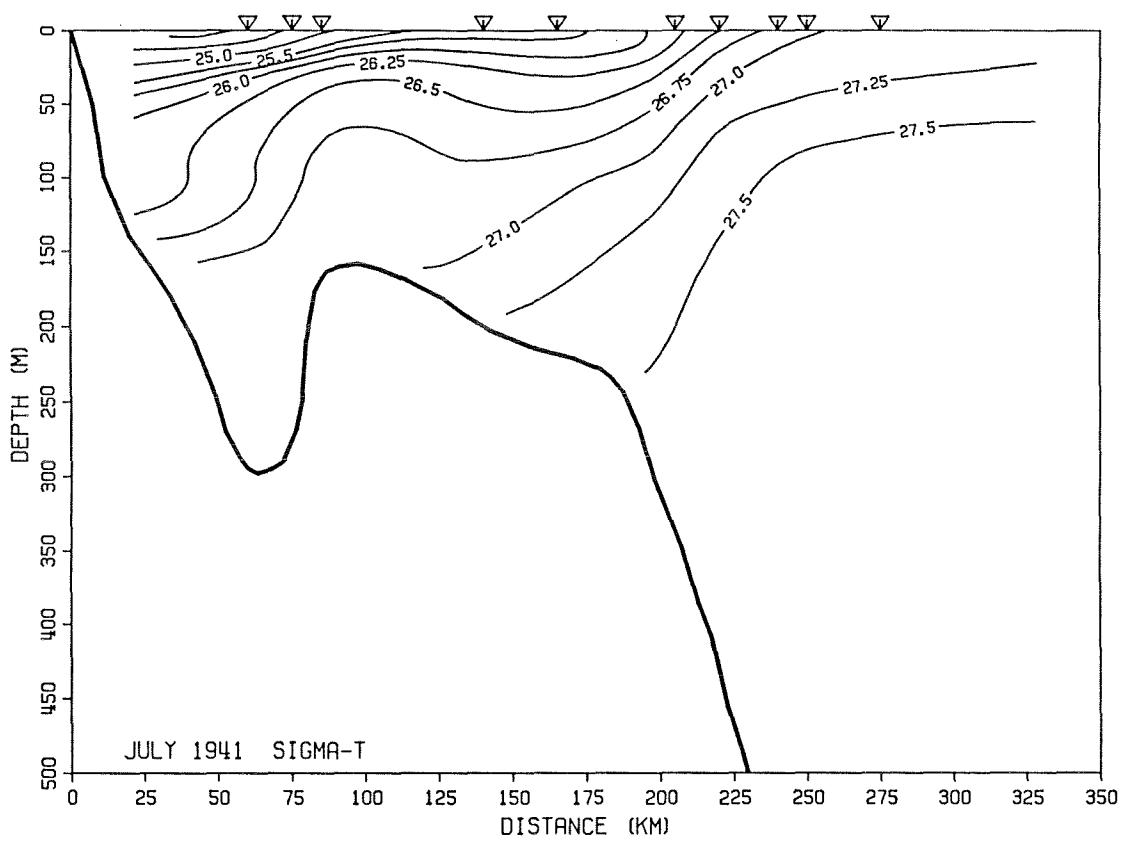


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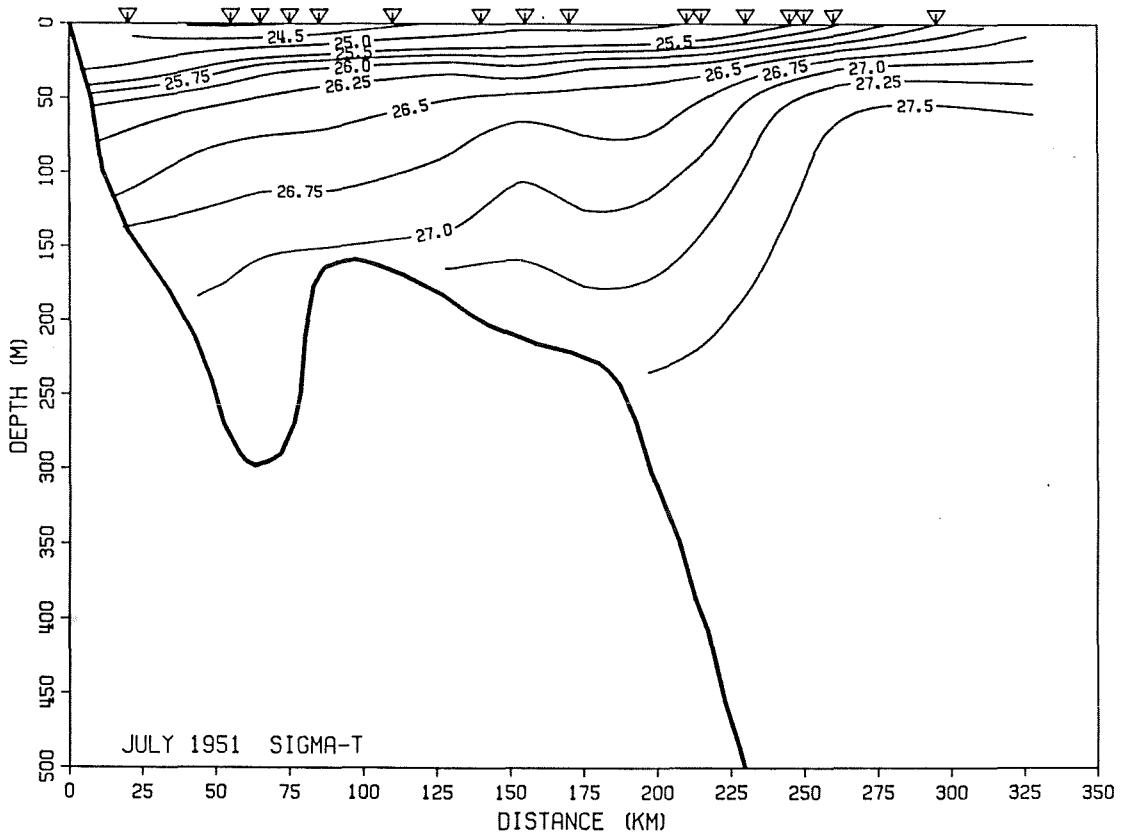
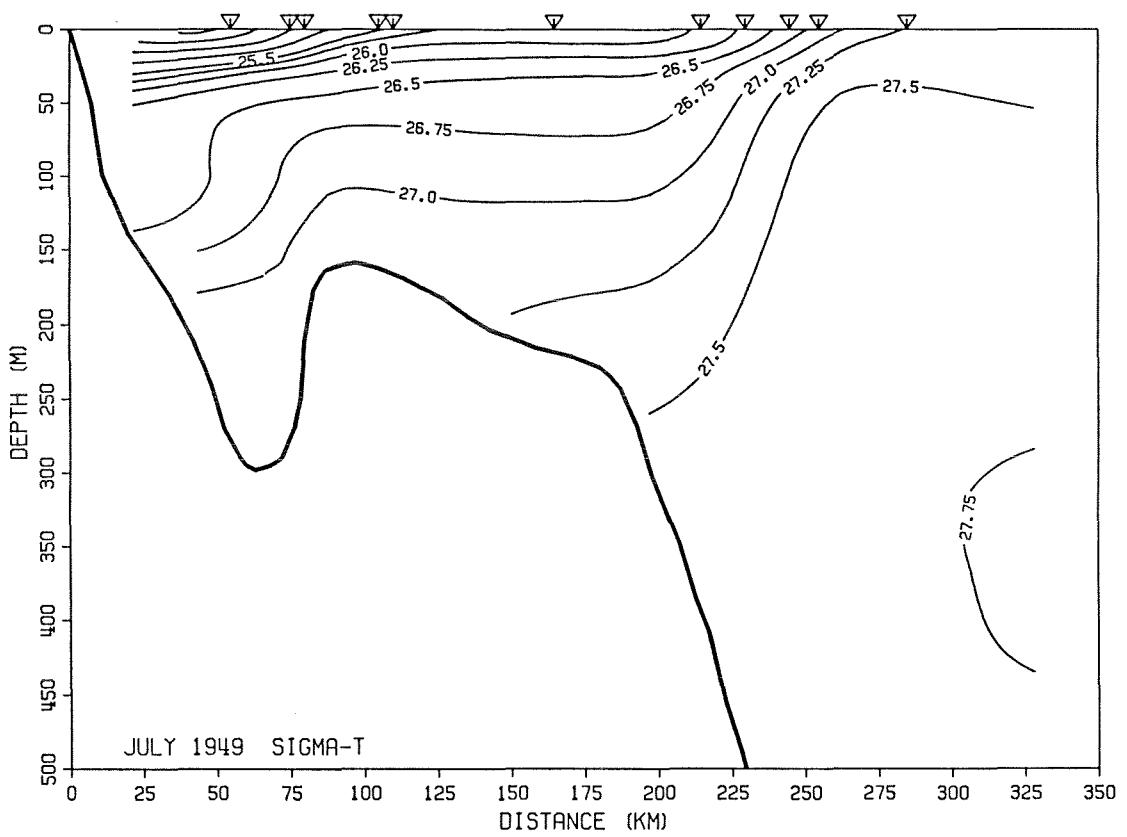




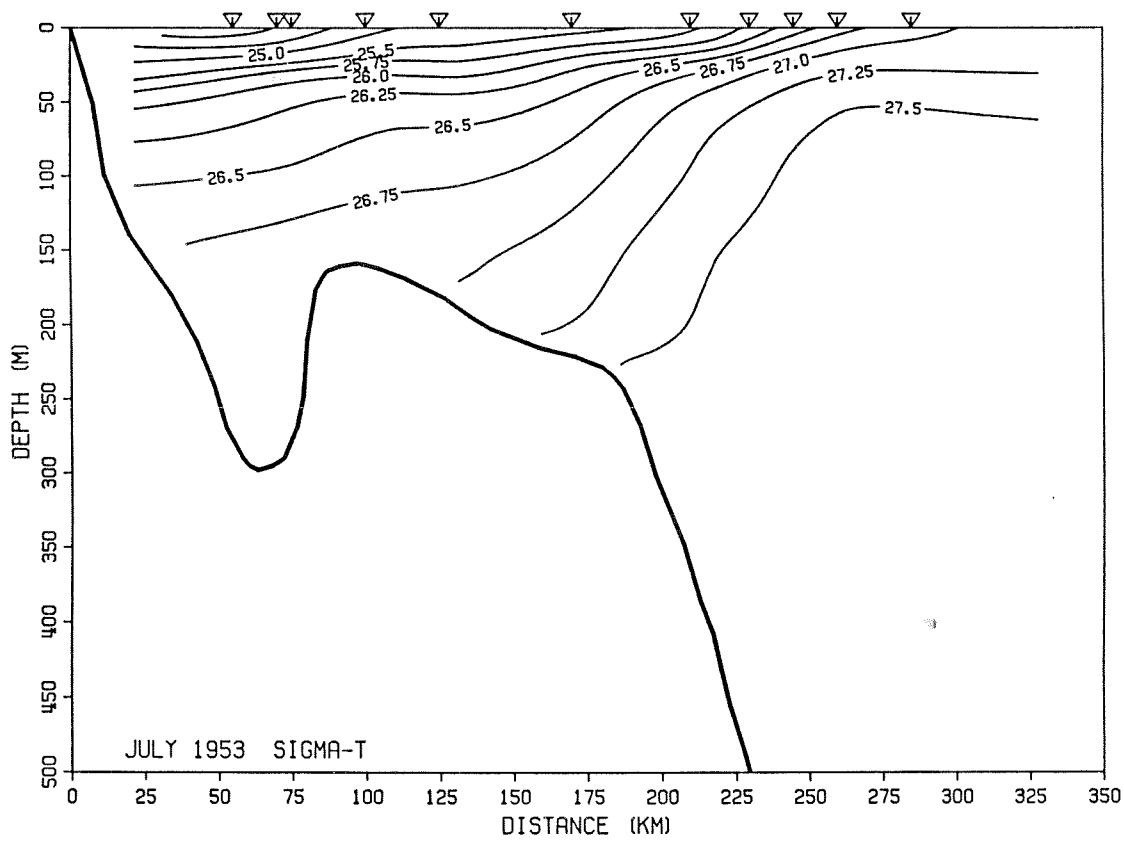
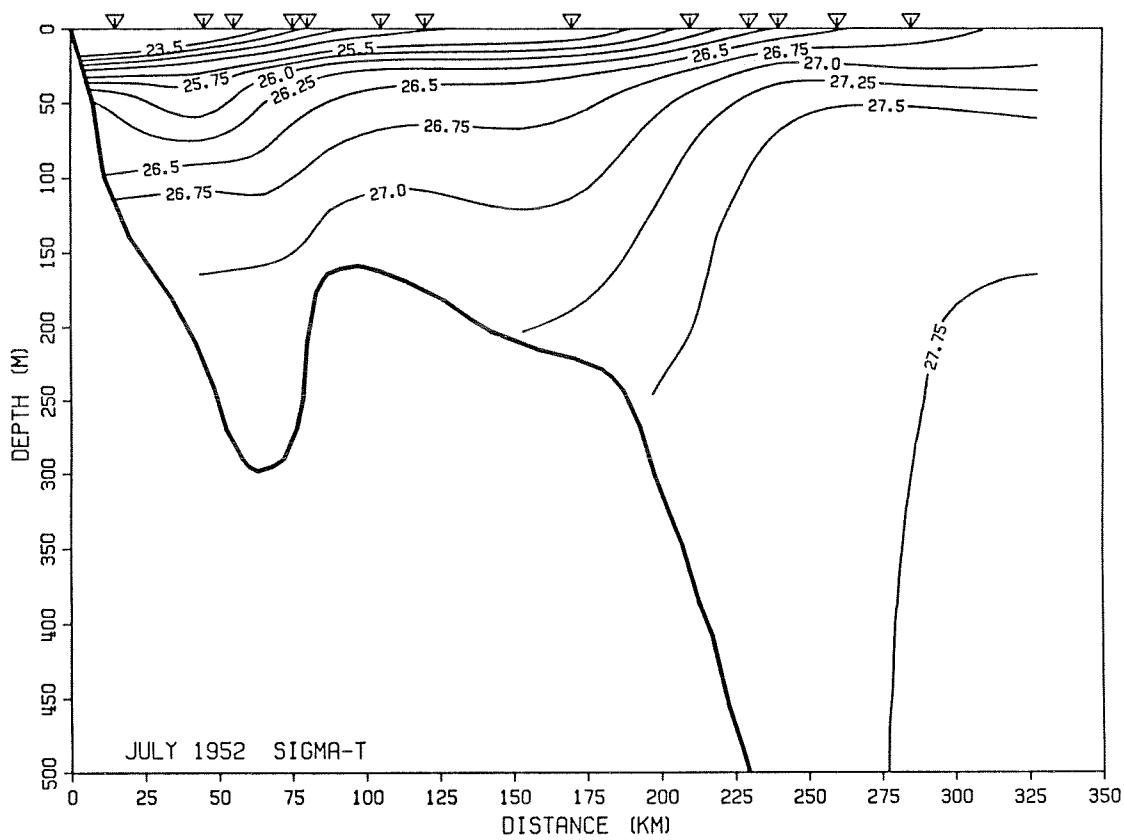
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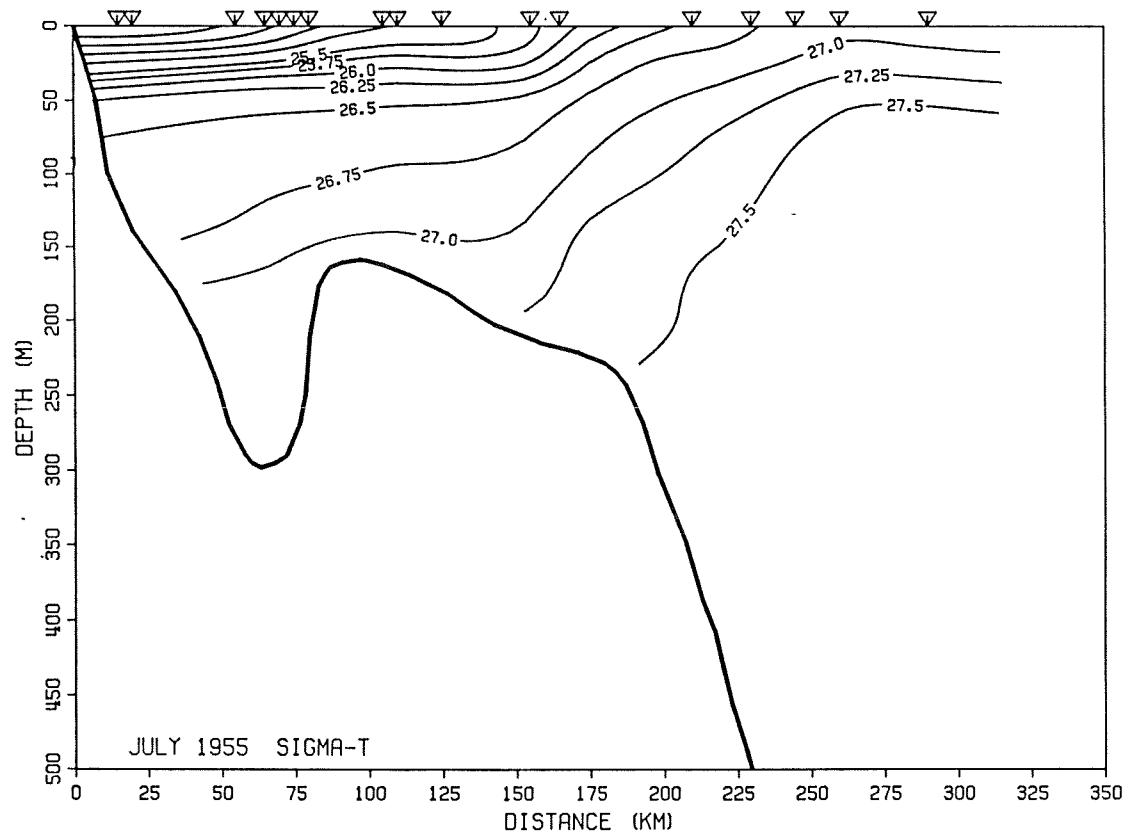
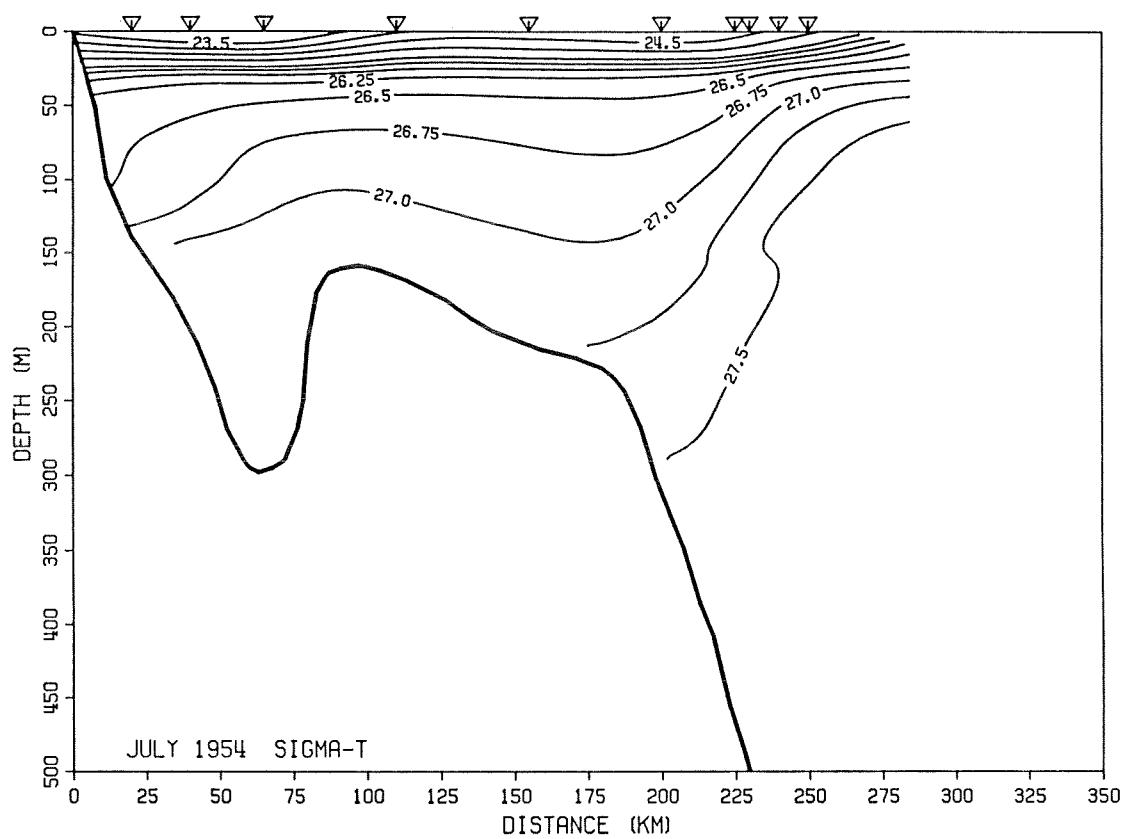


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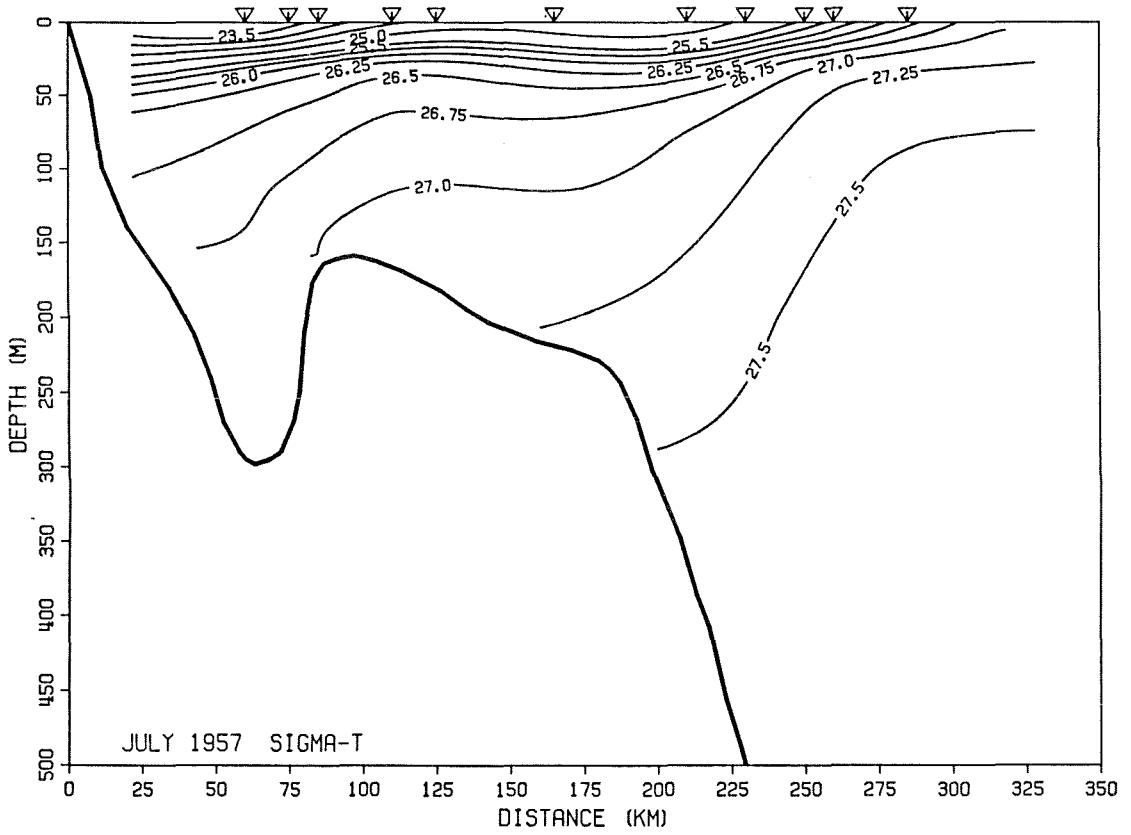
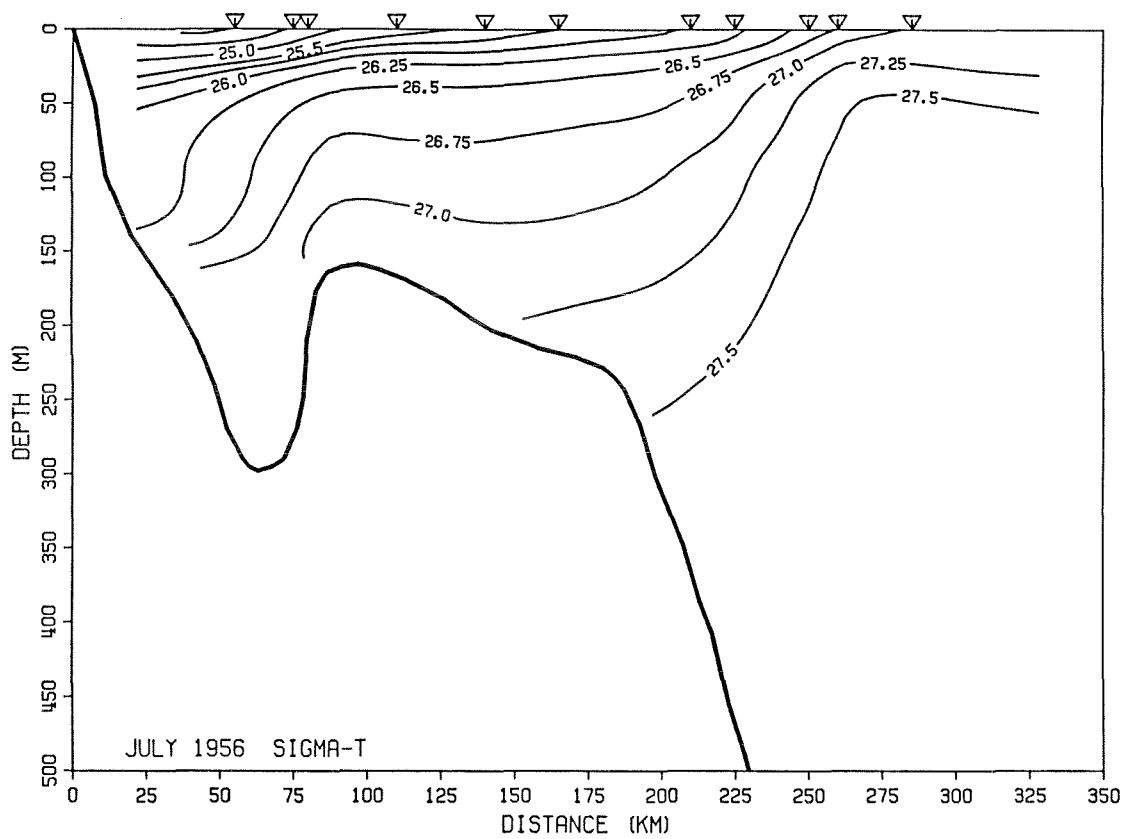


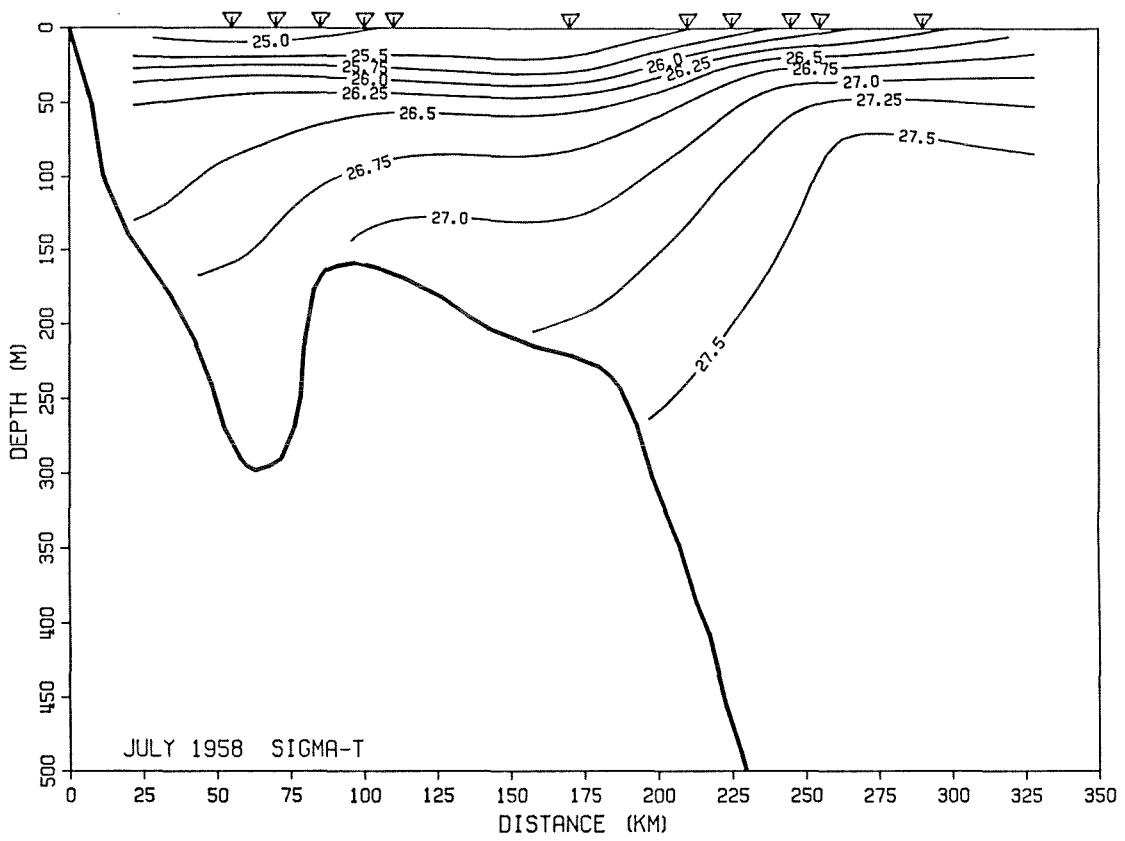
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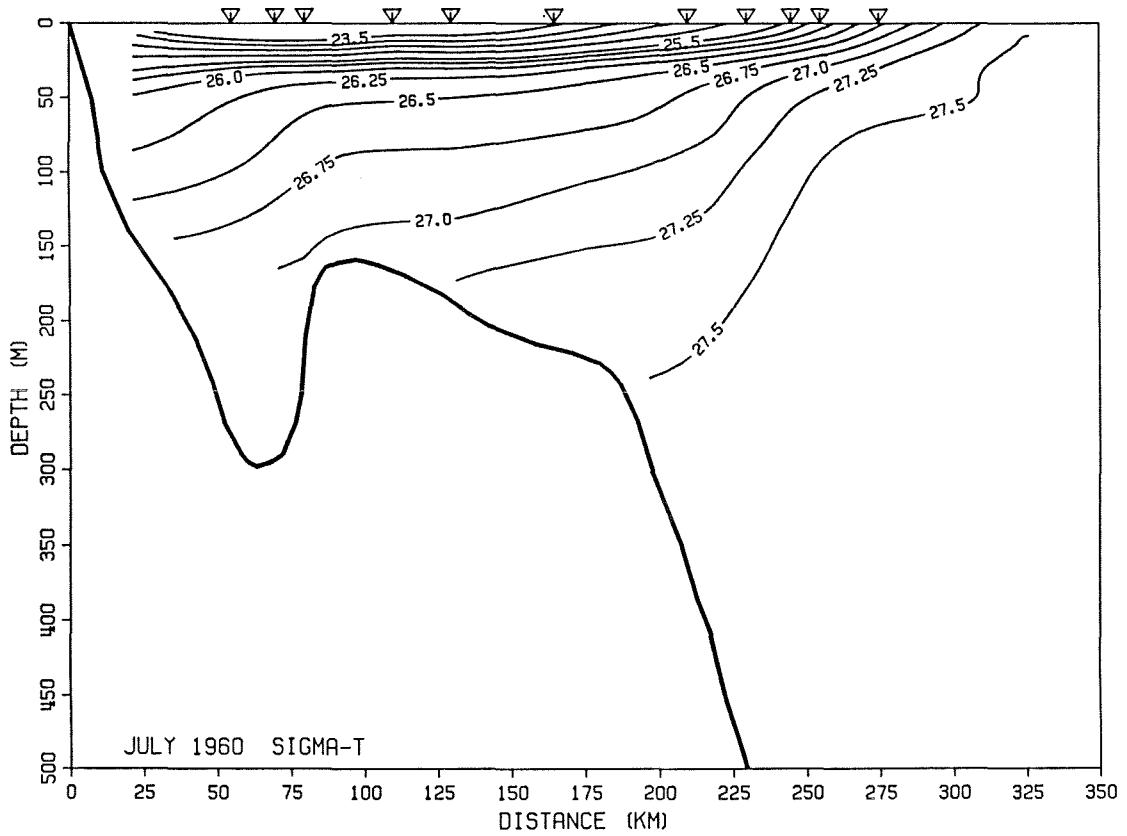


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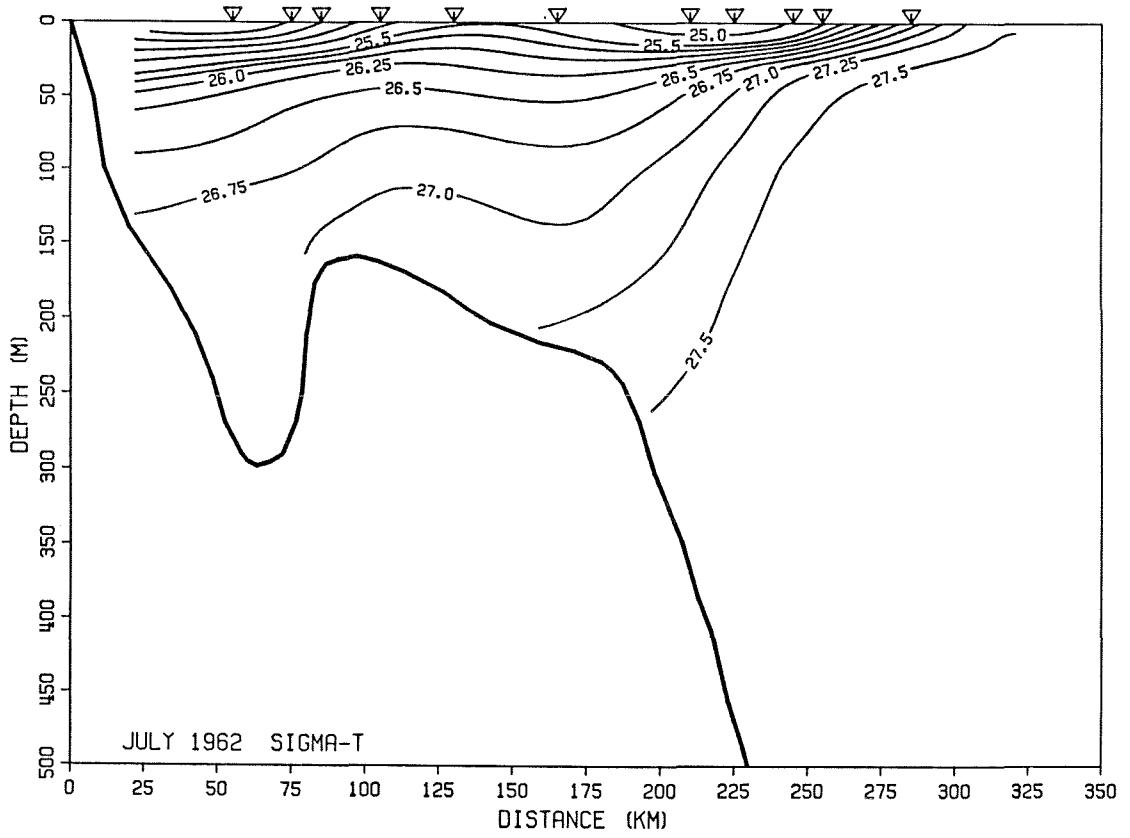
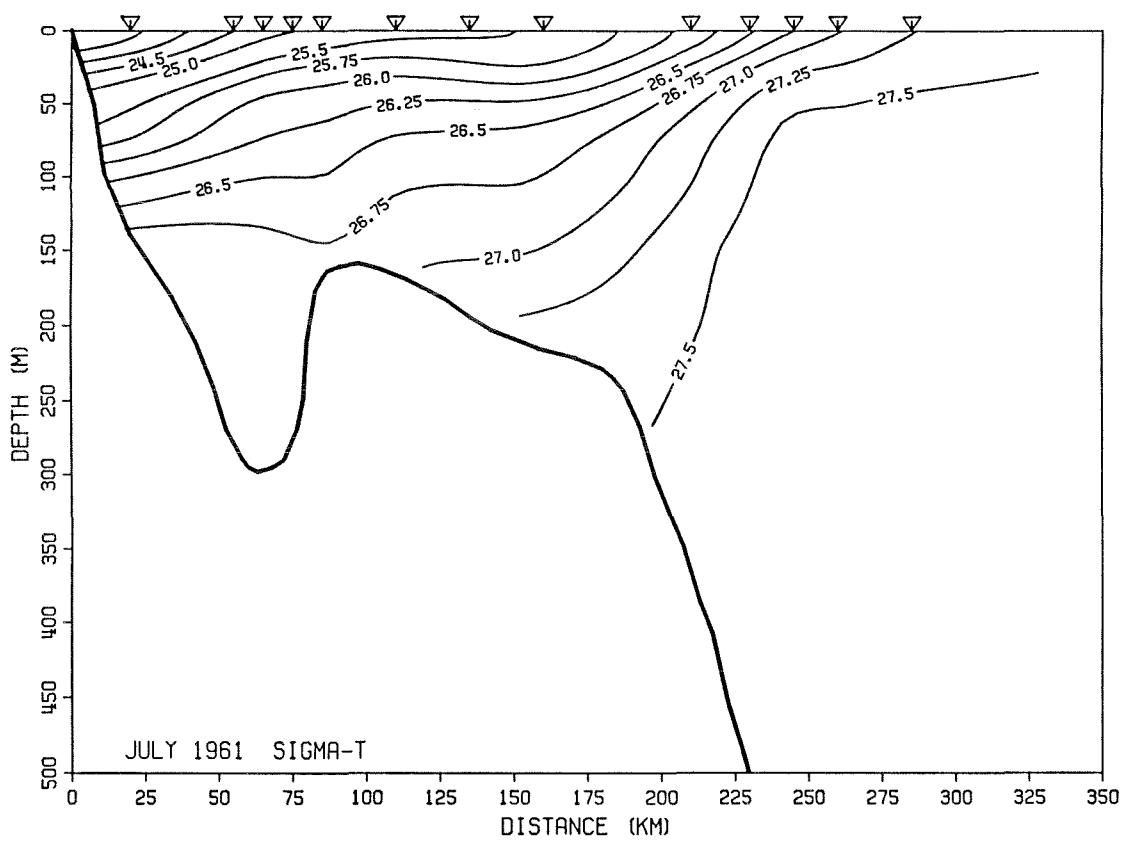


JULY 1958 SIGMA-T

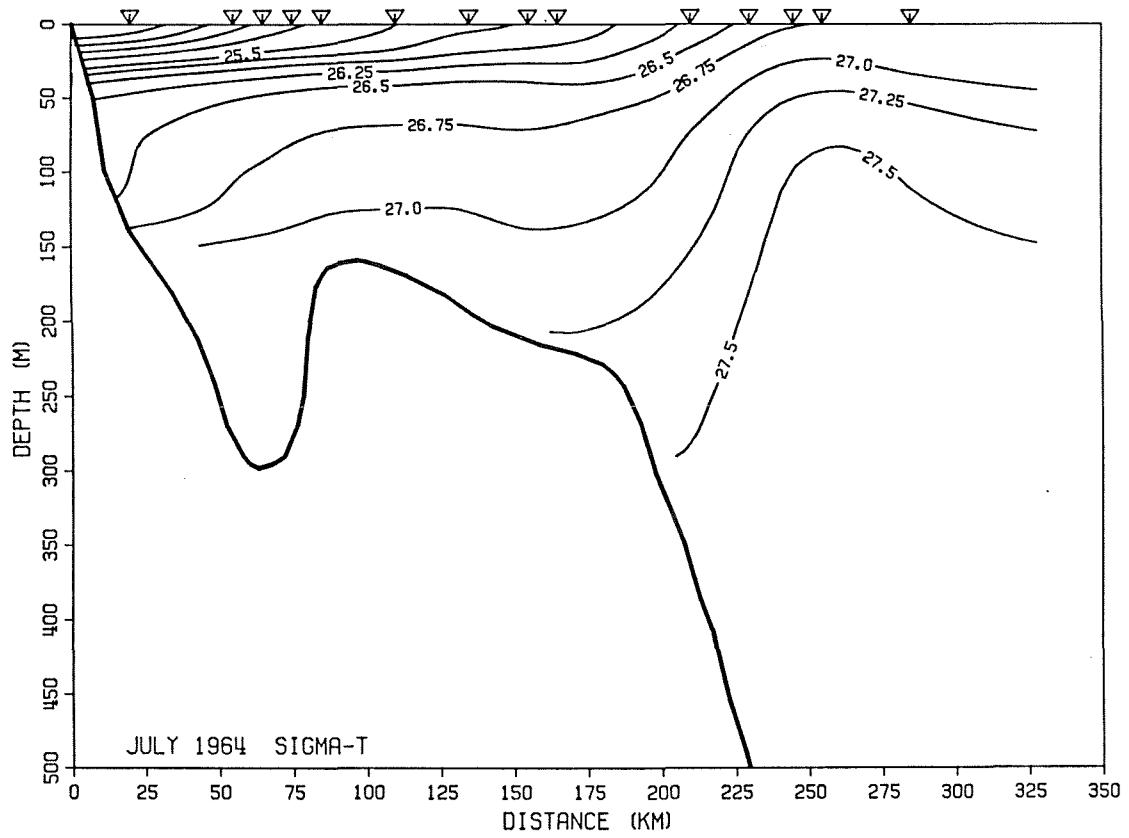
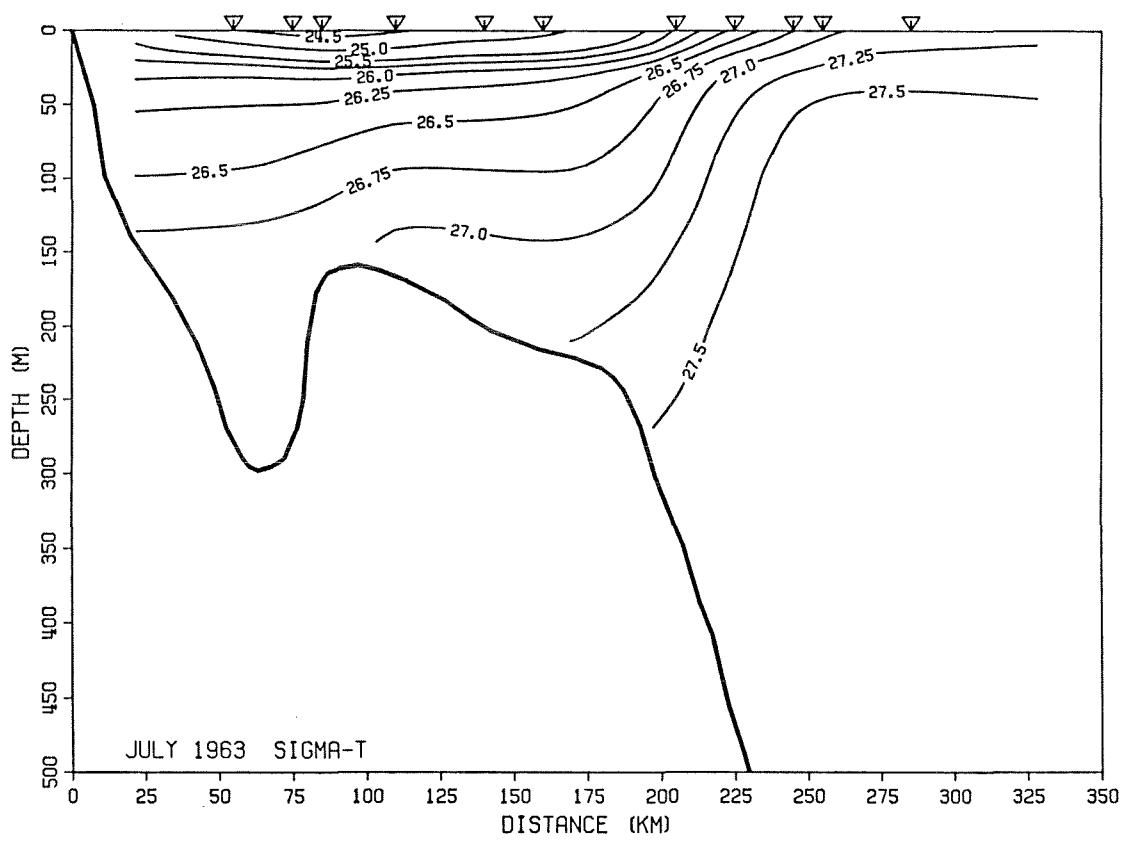


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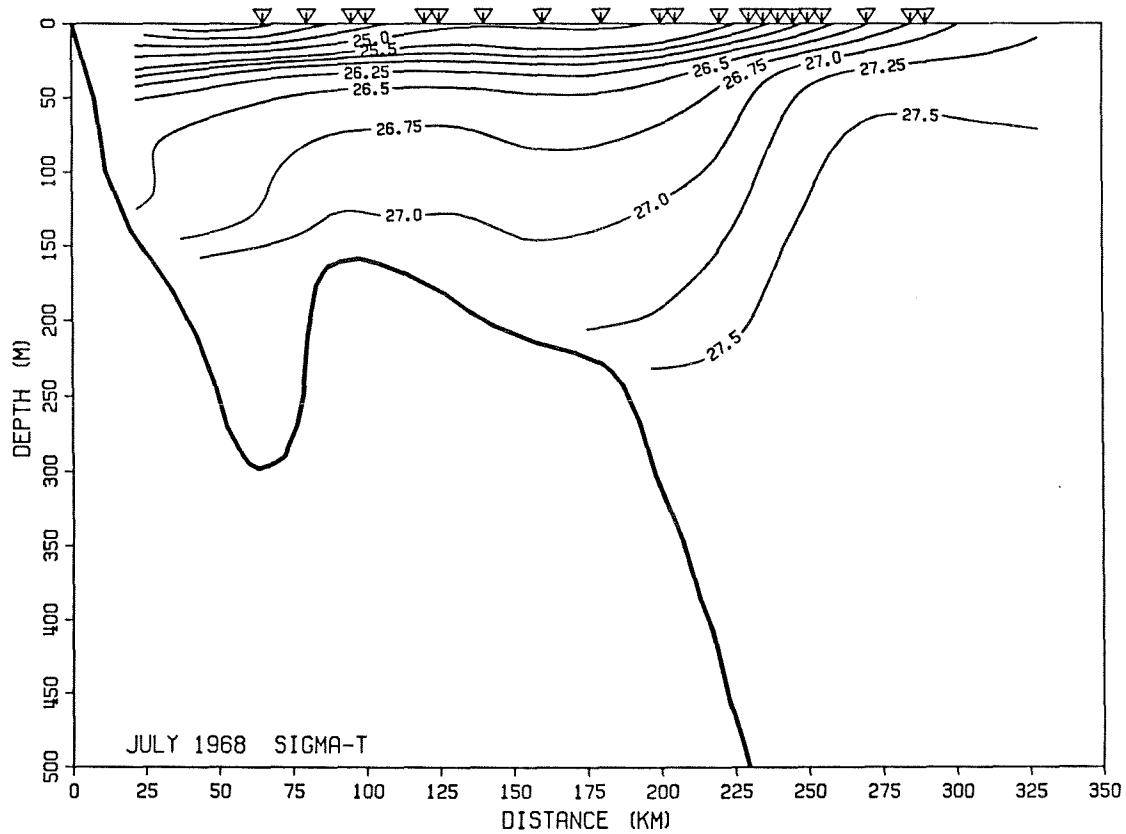
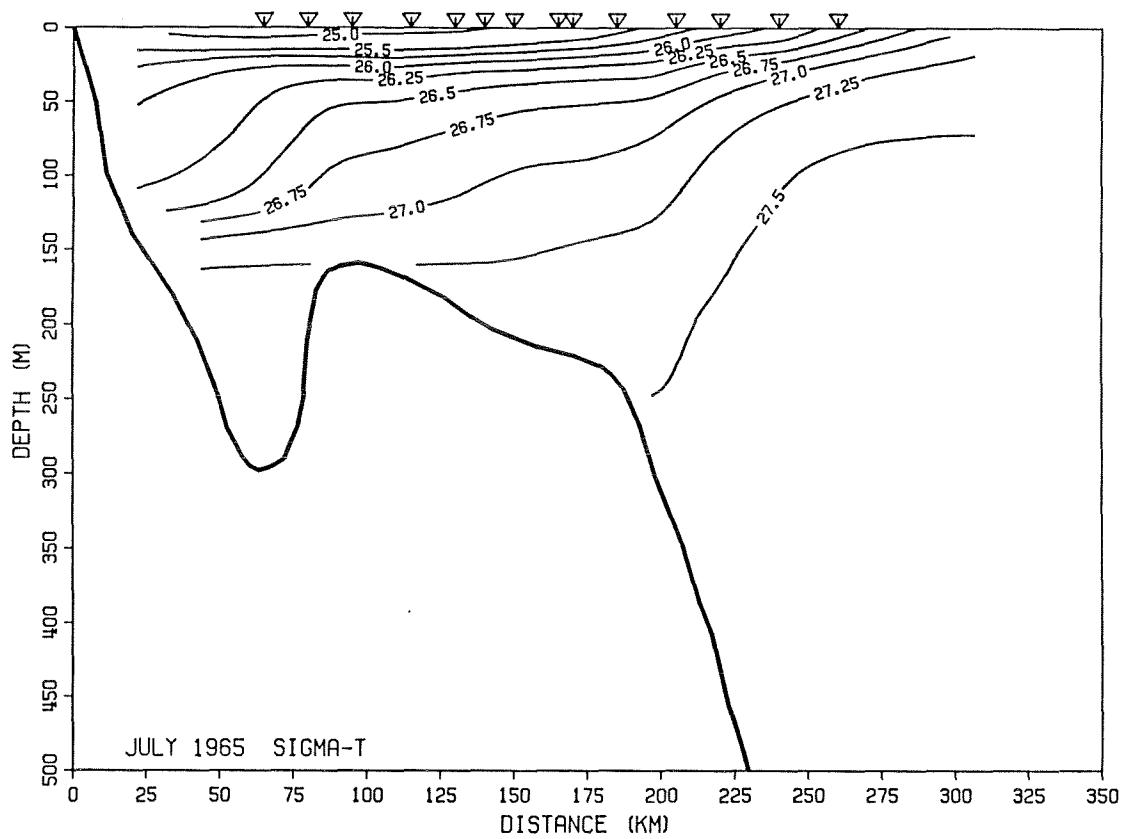
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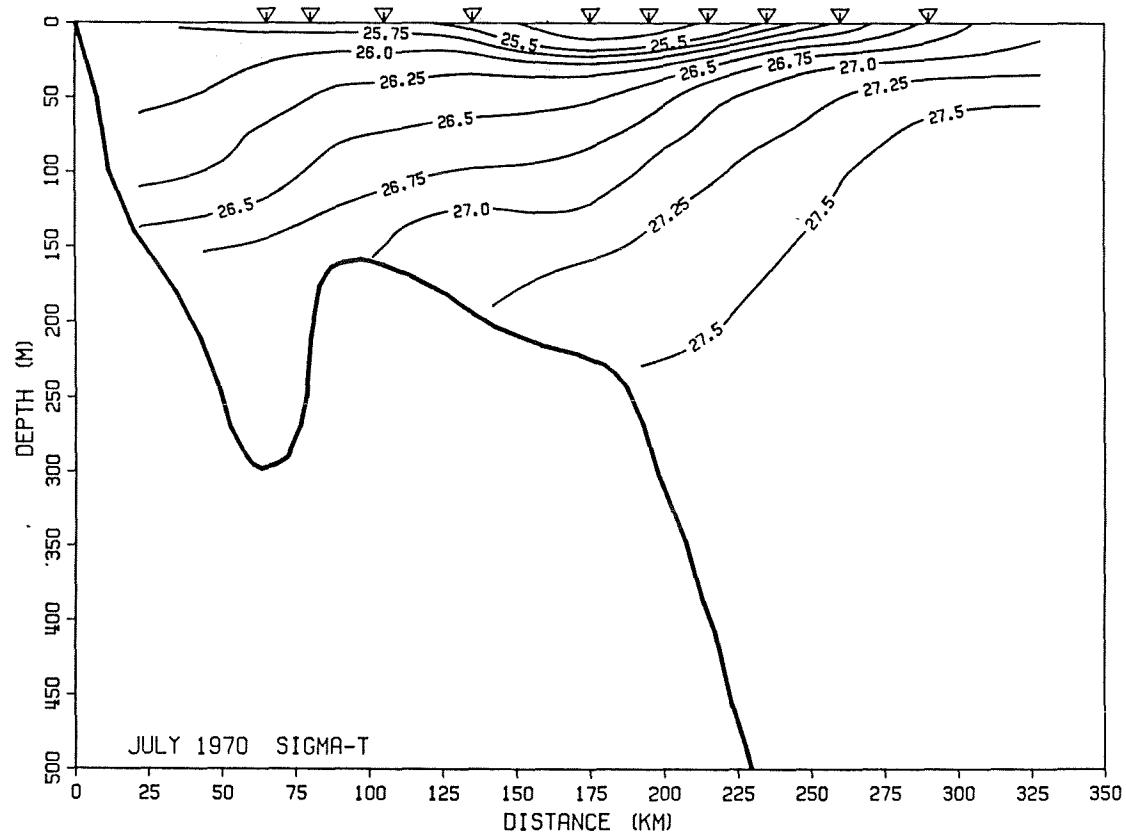
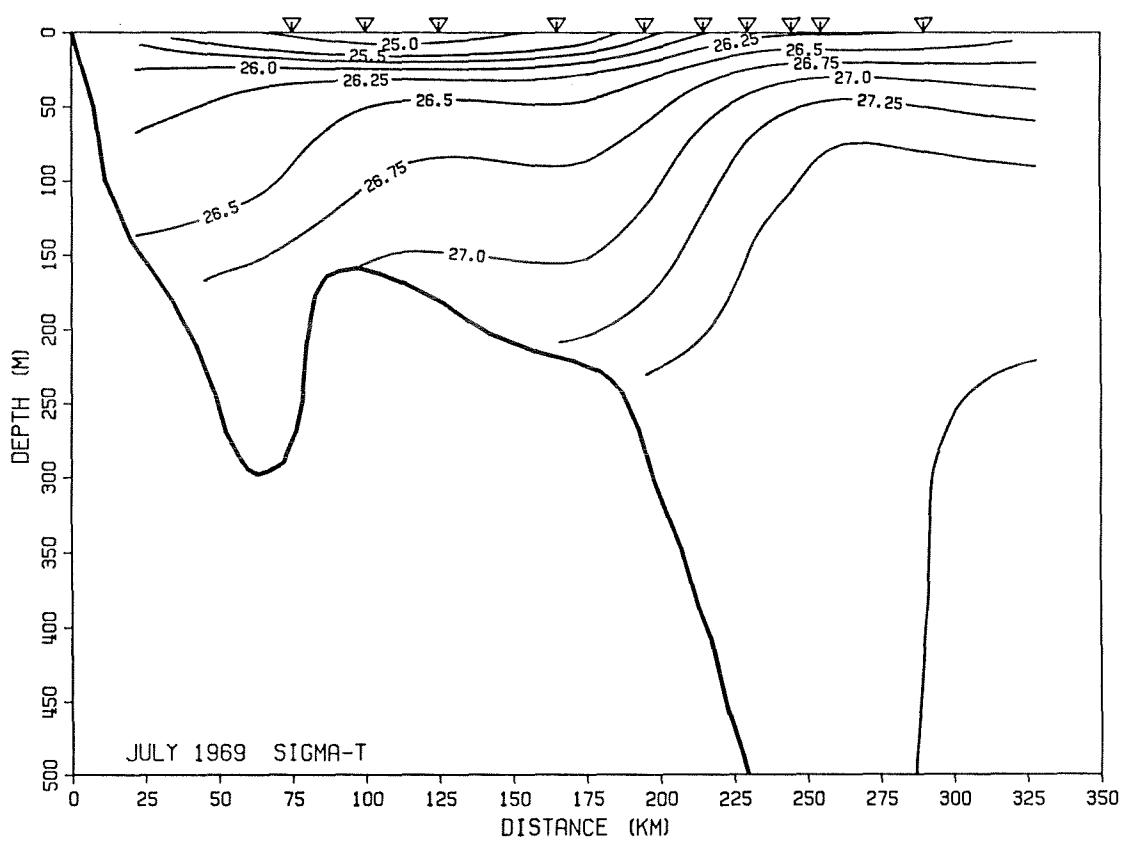
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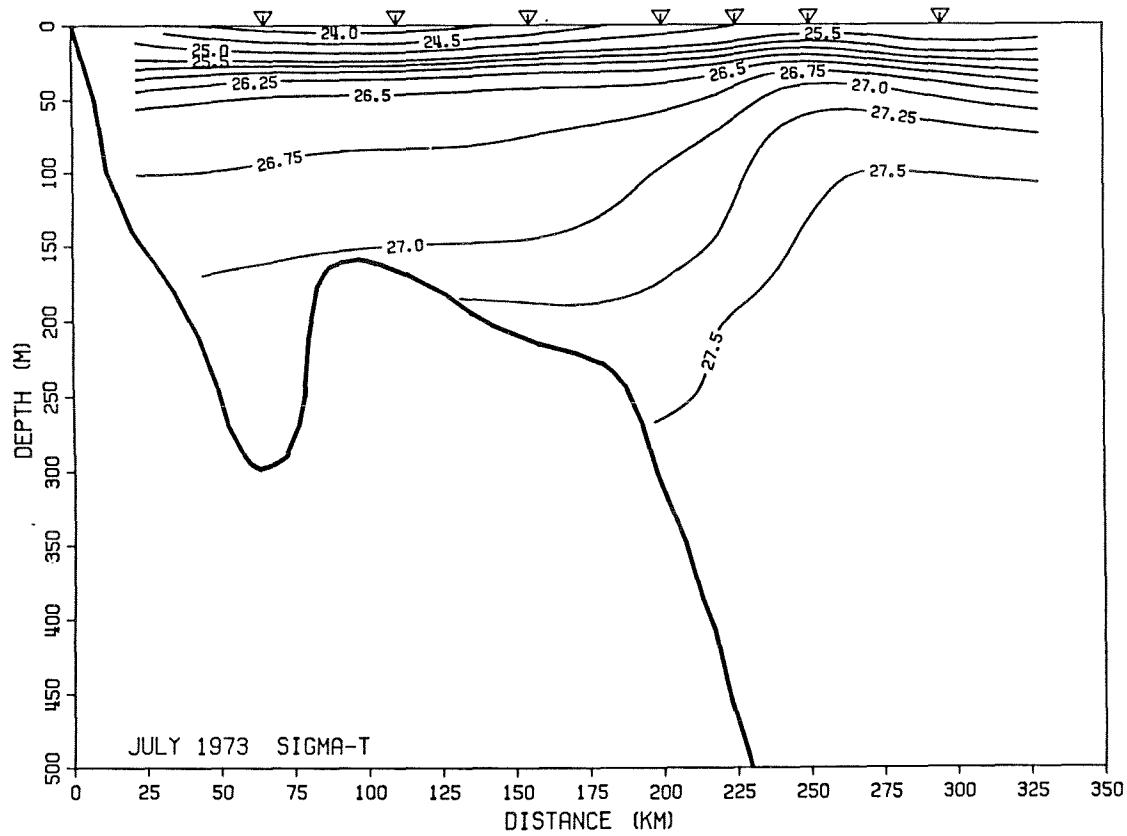
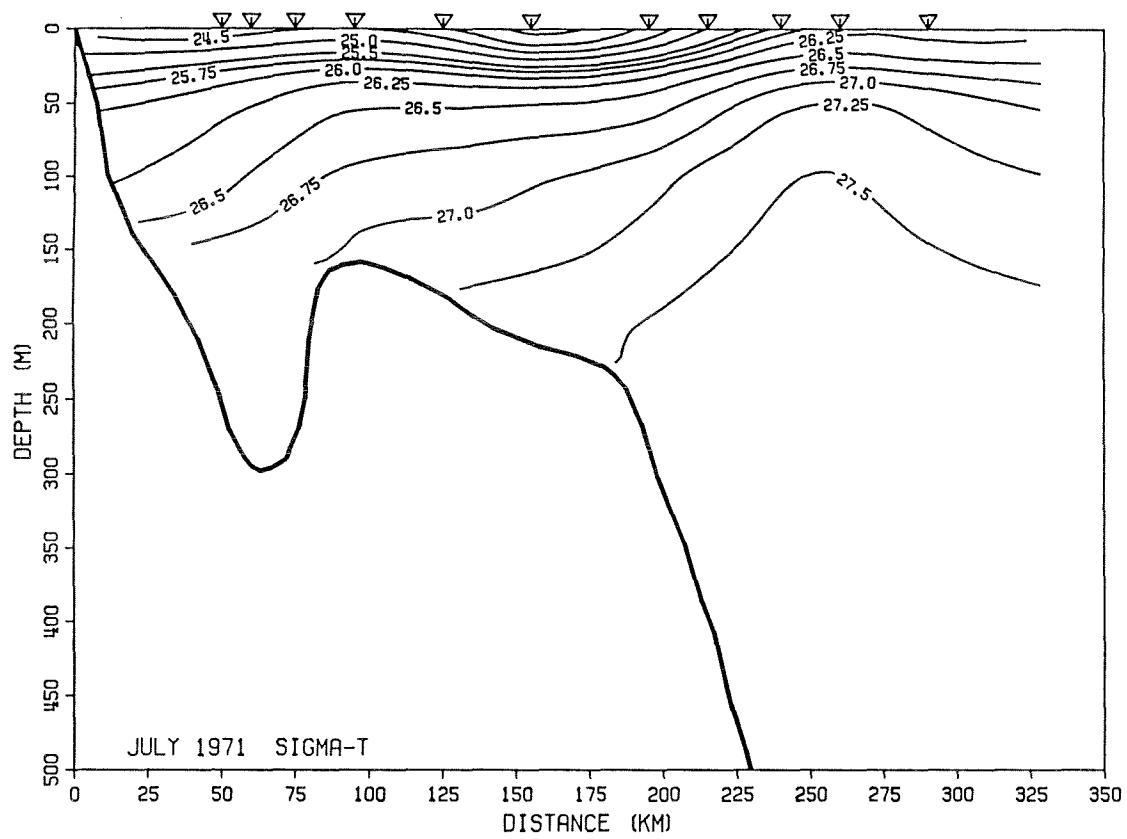
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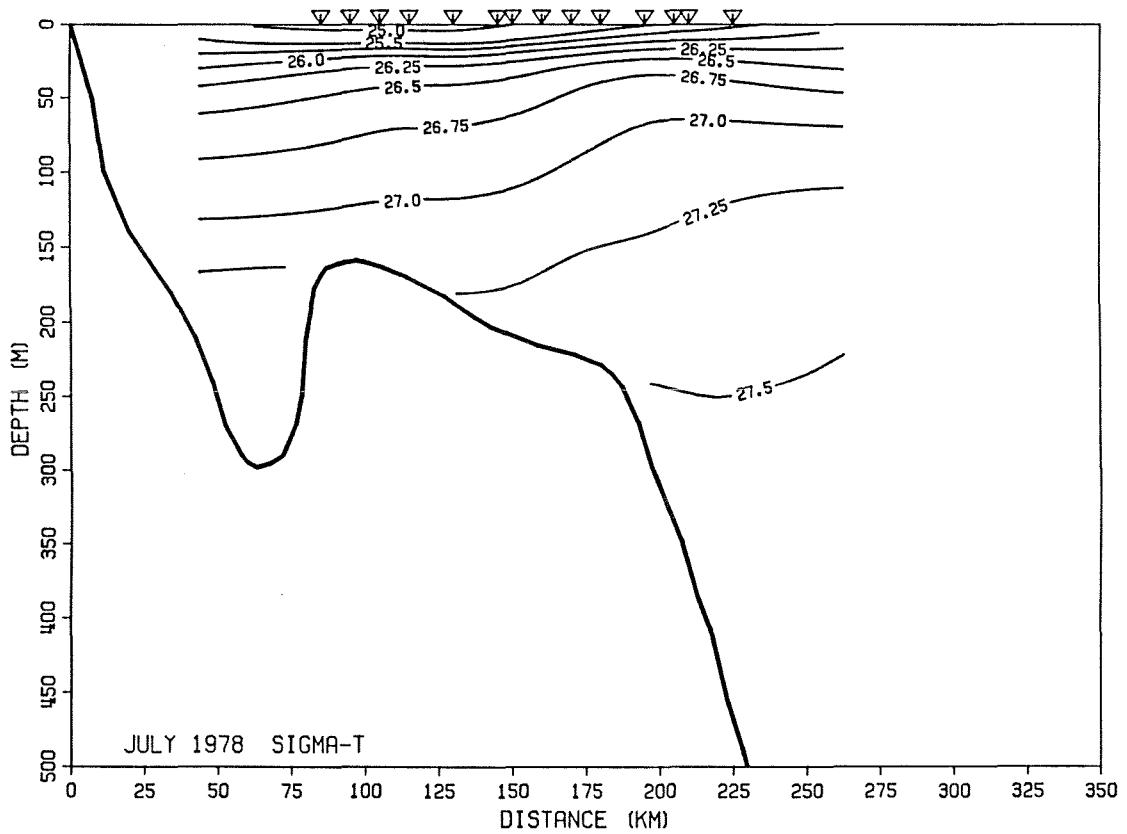
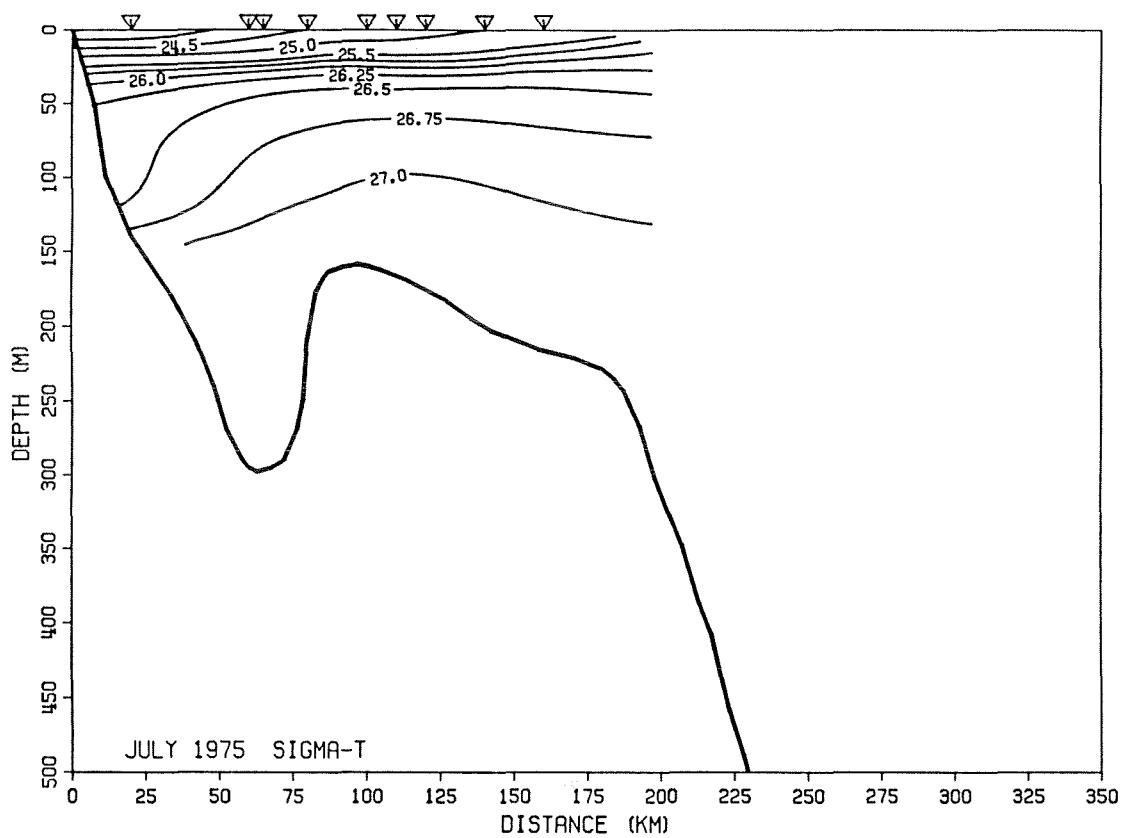
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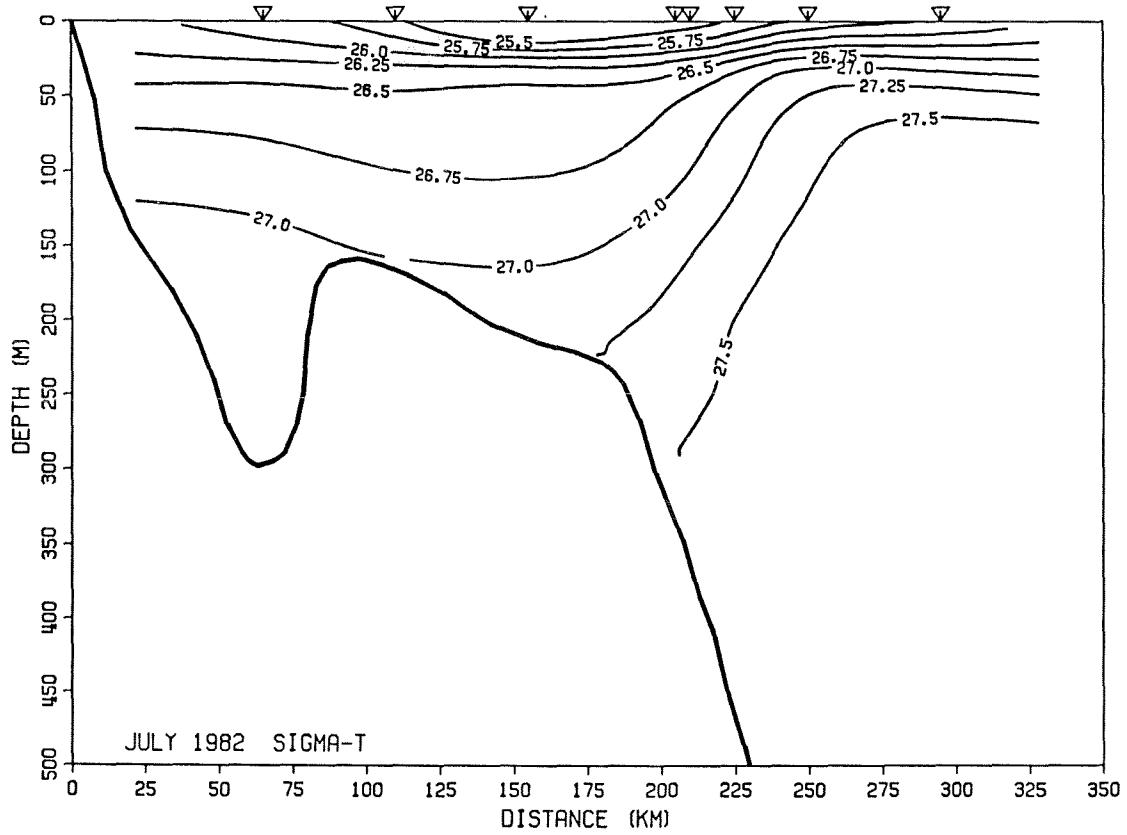
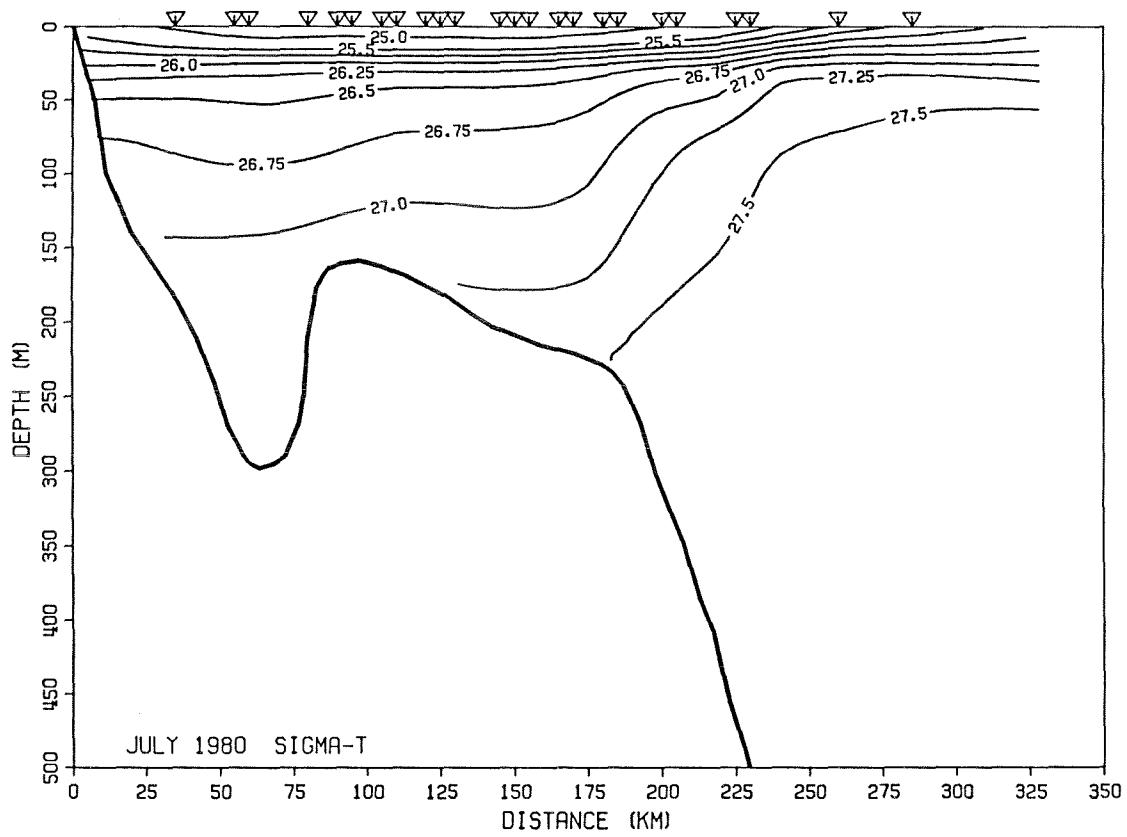
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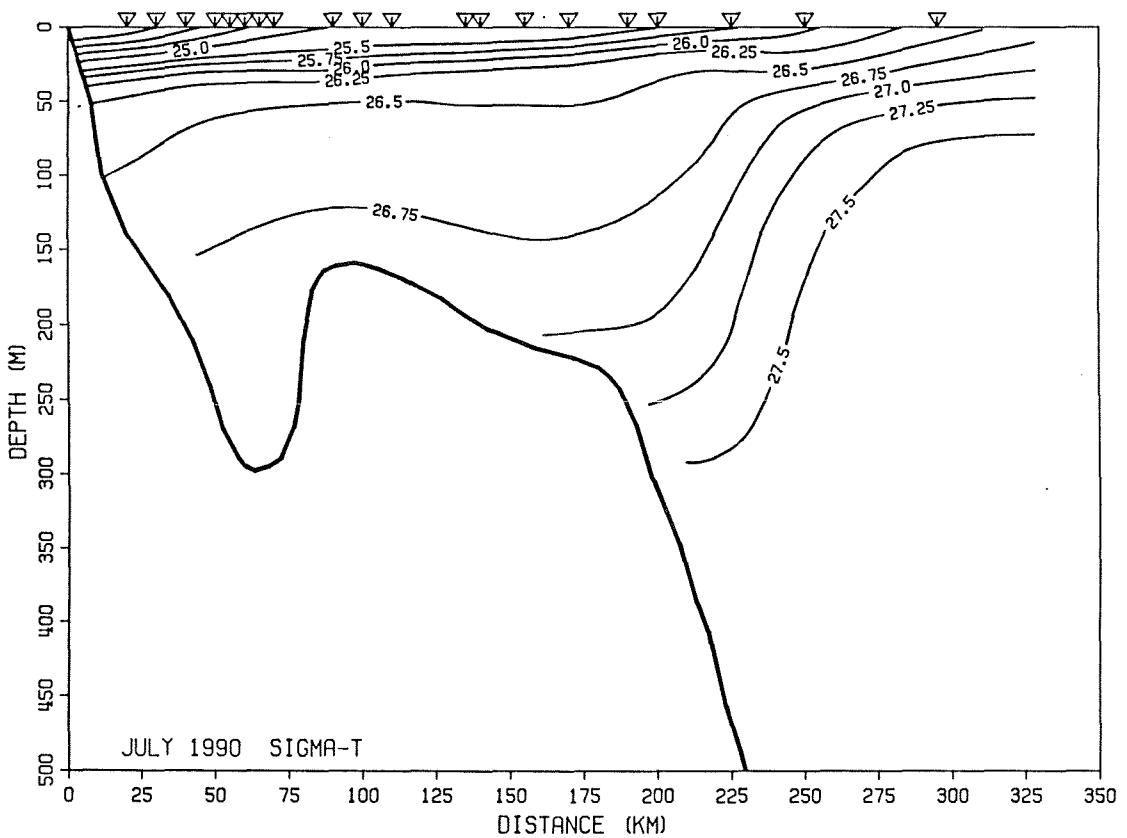
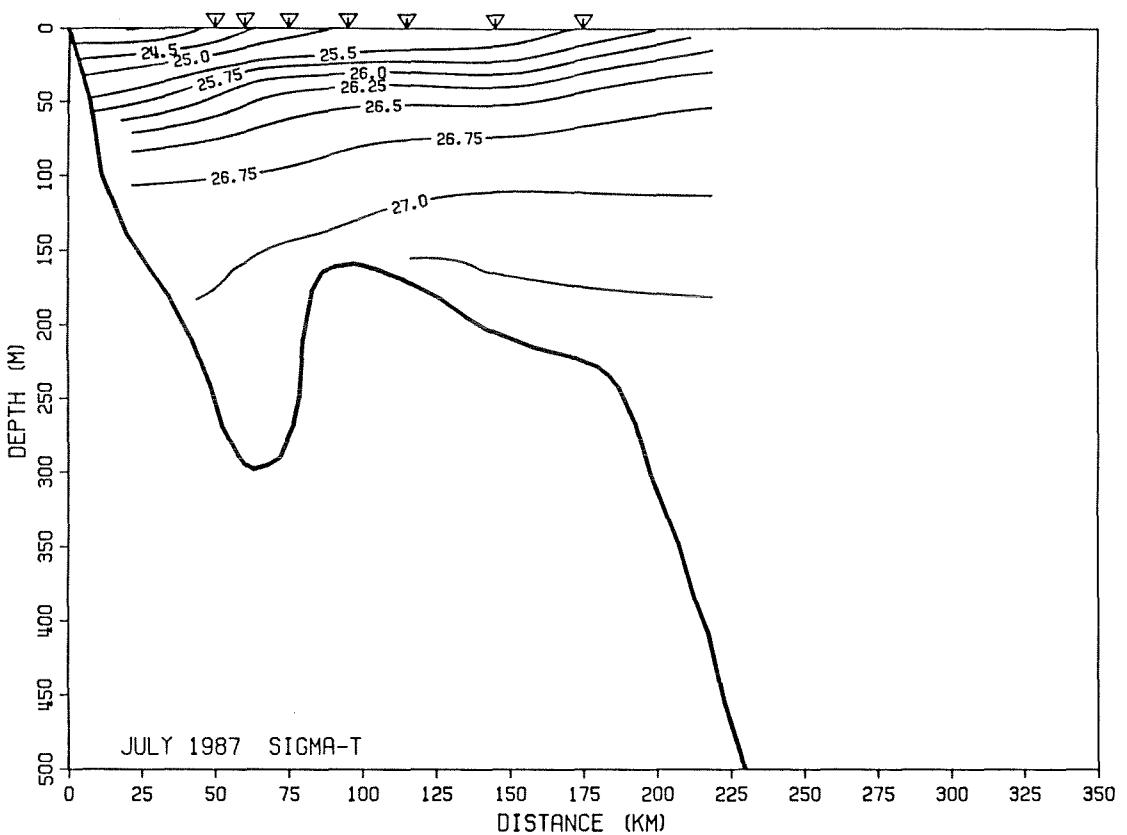


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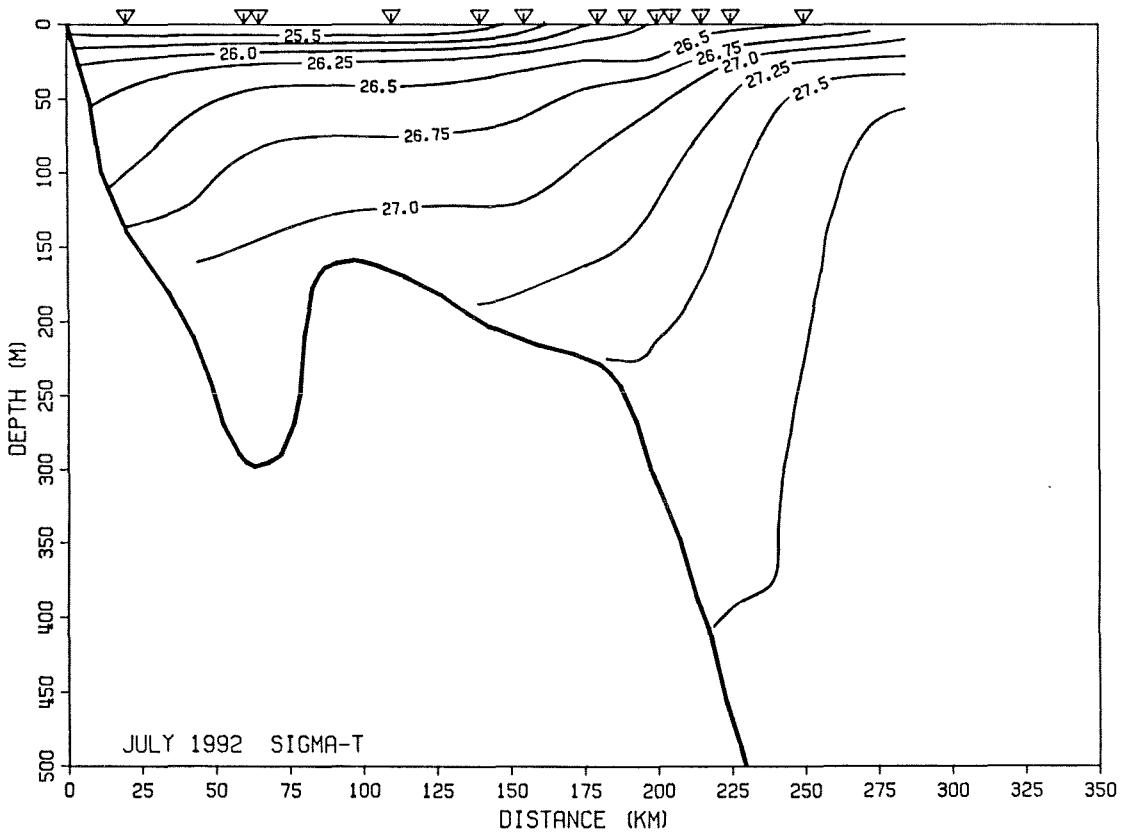
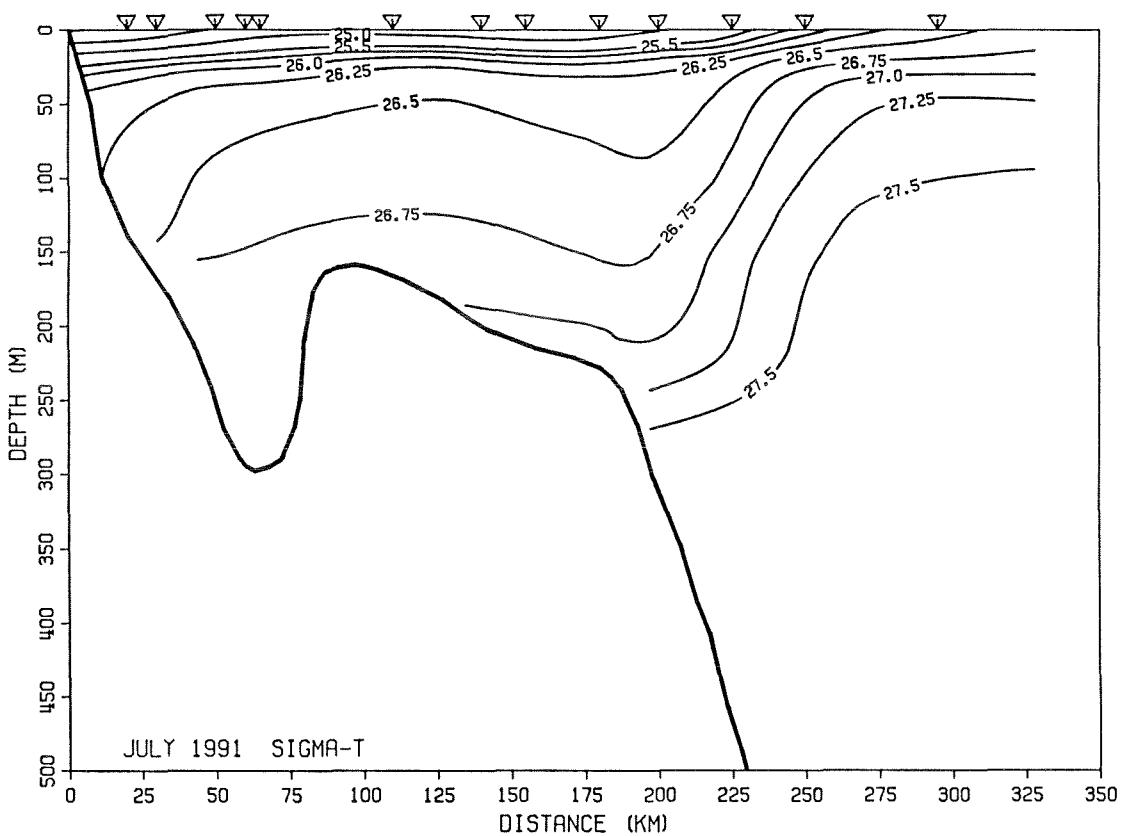


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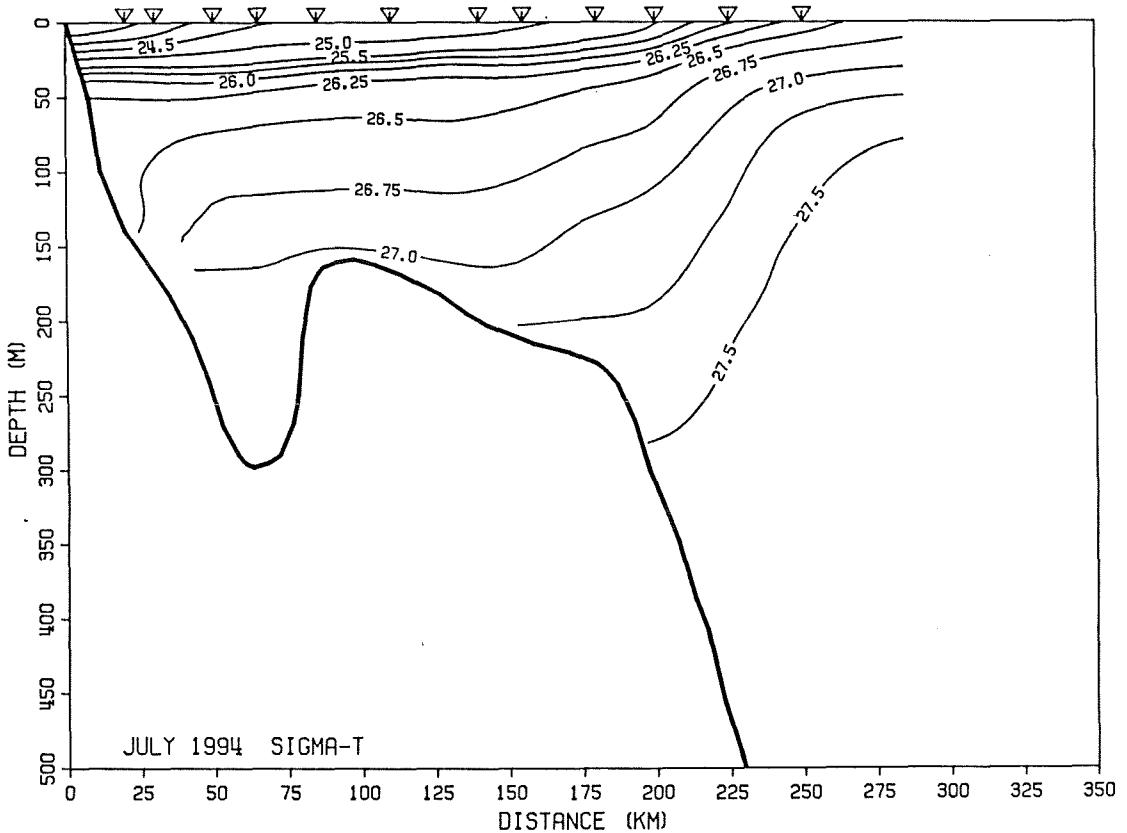
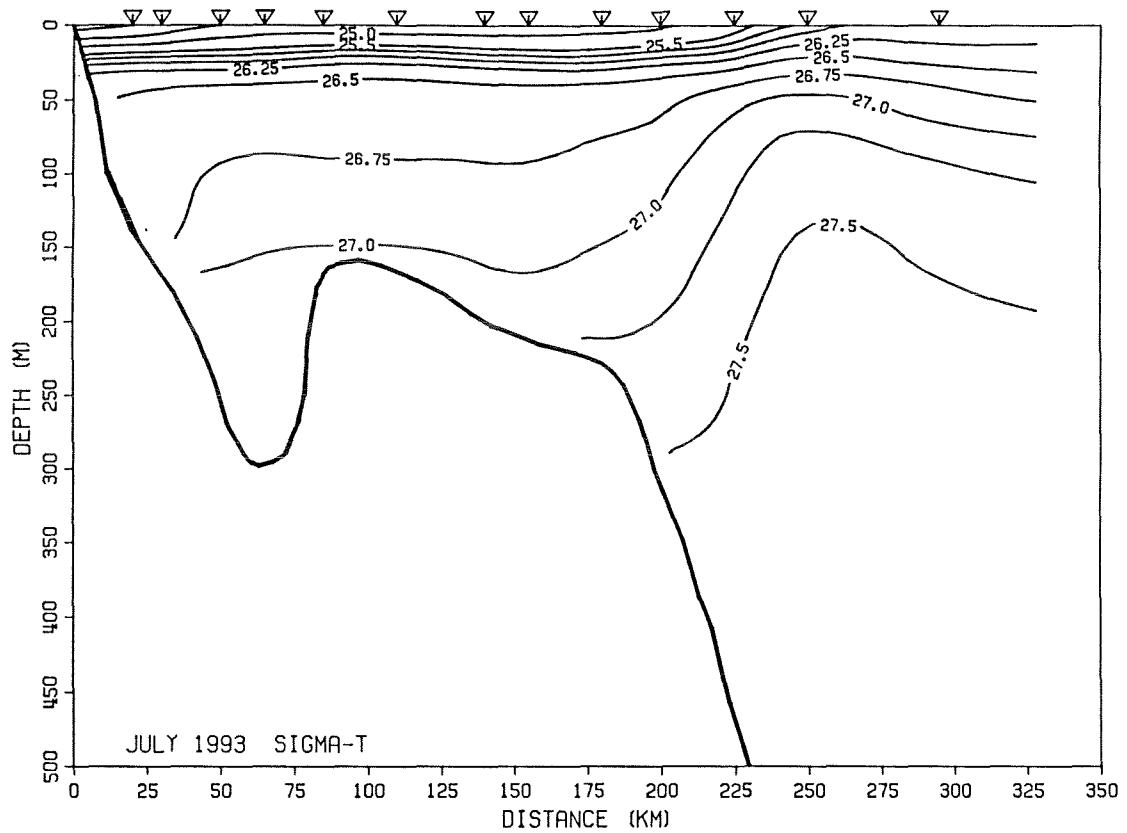




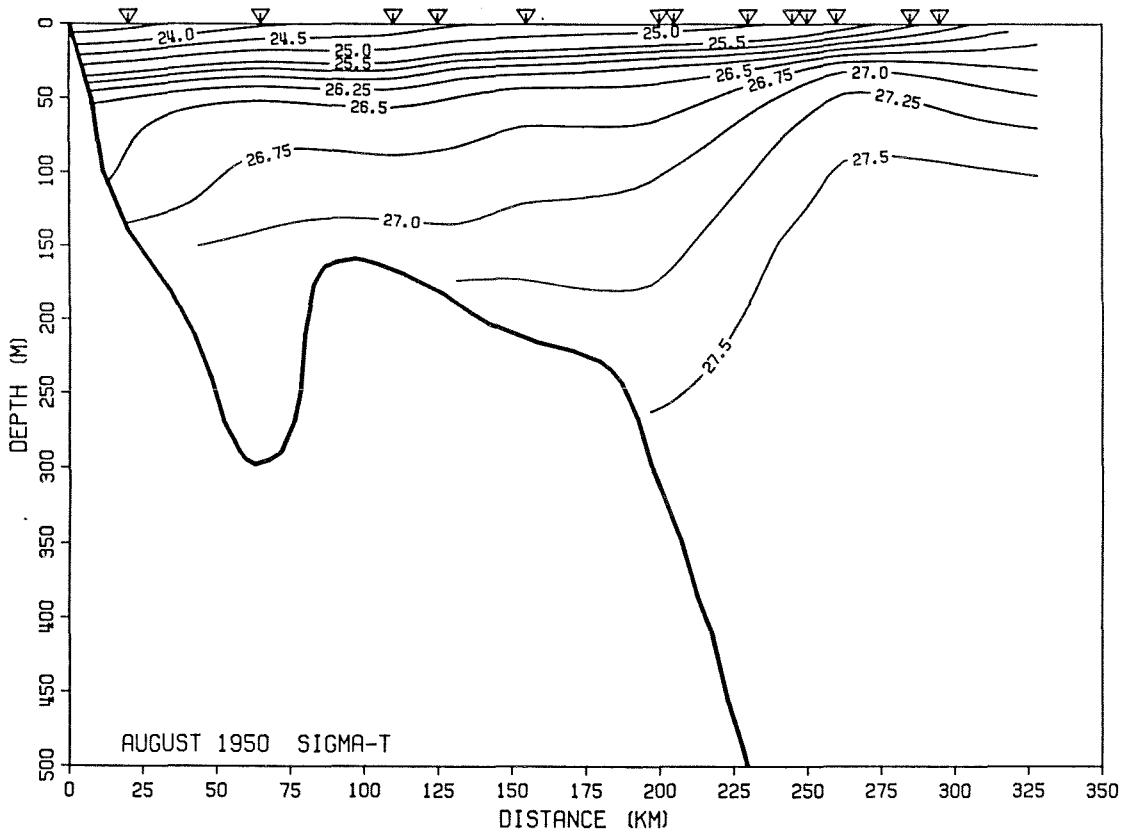
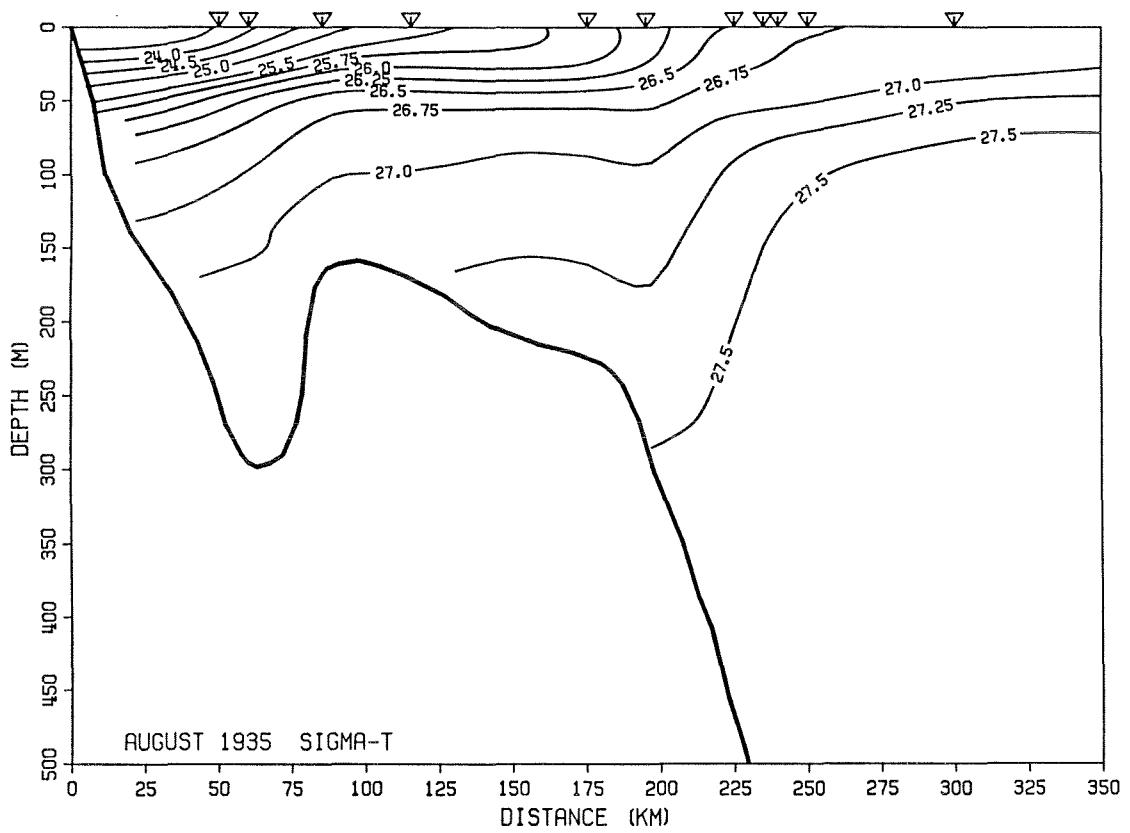
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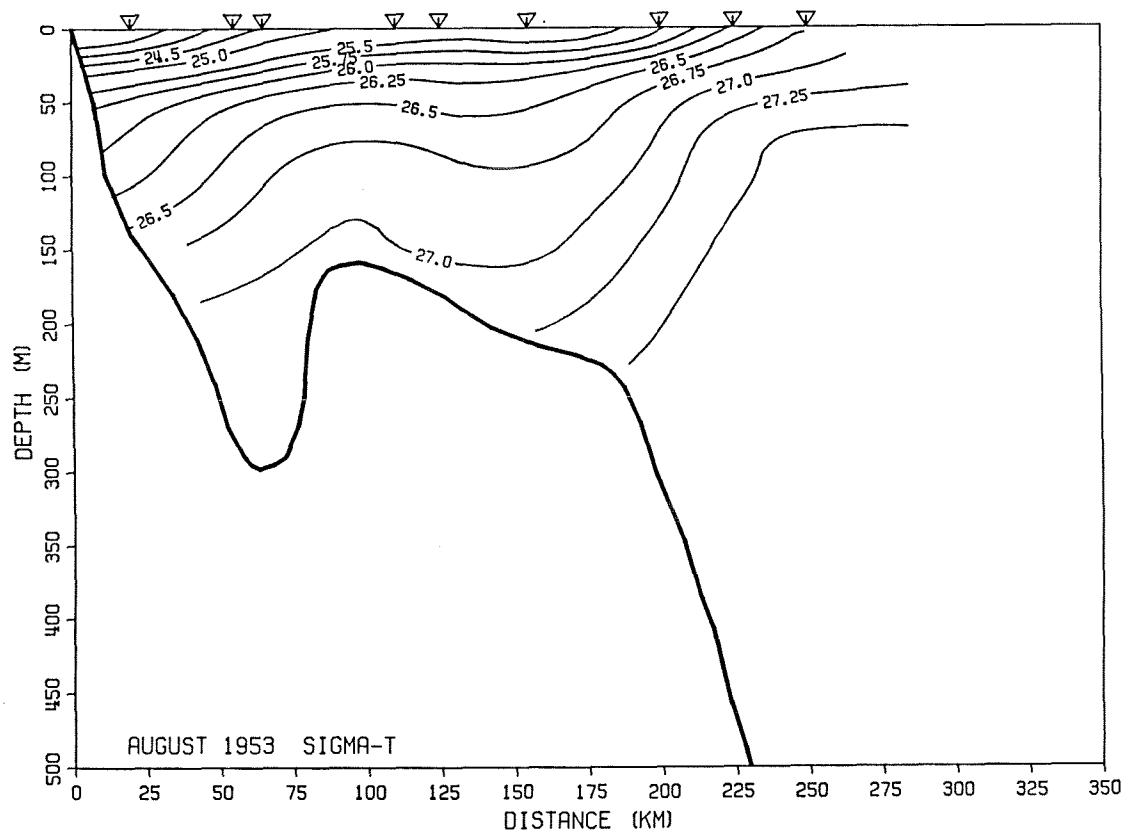
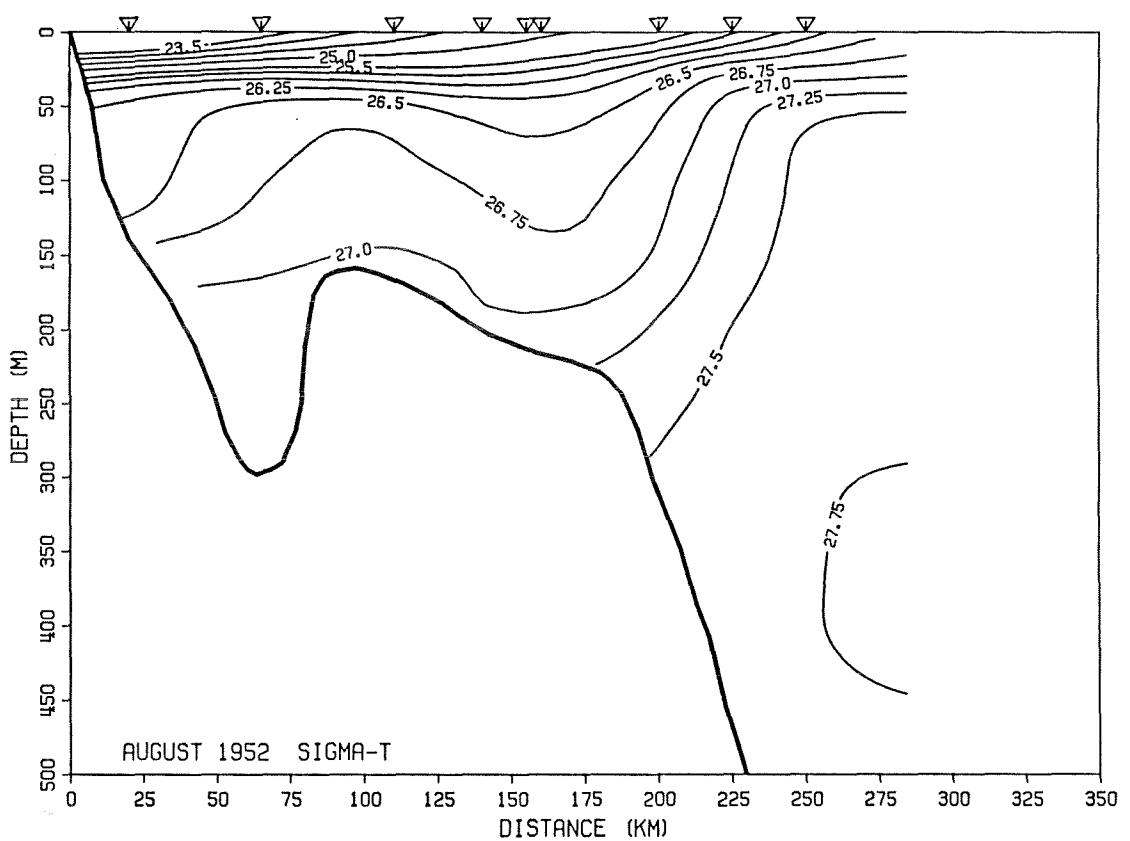


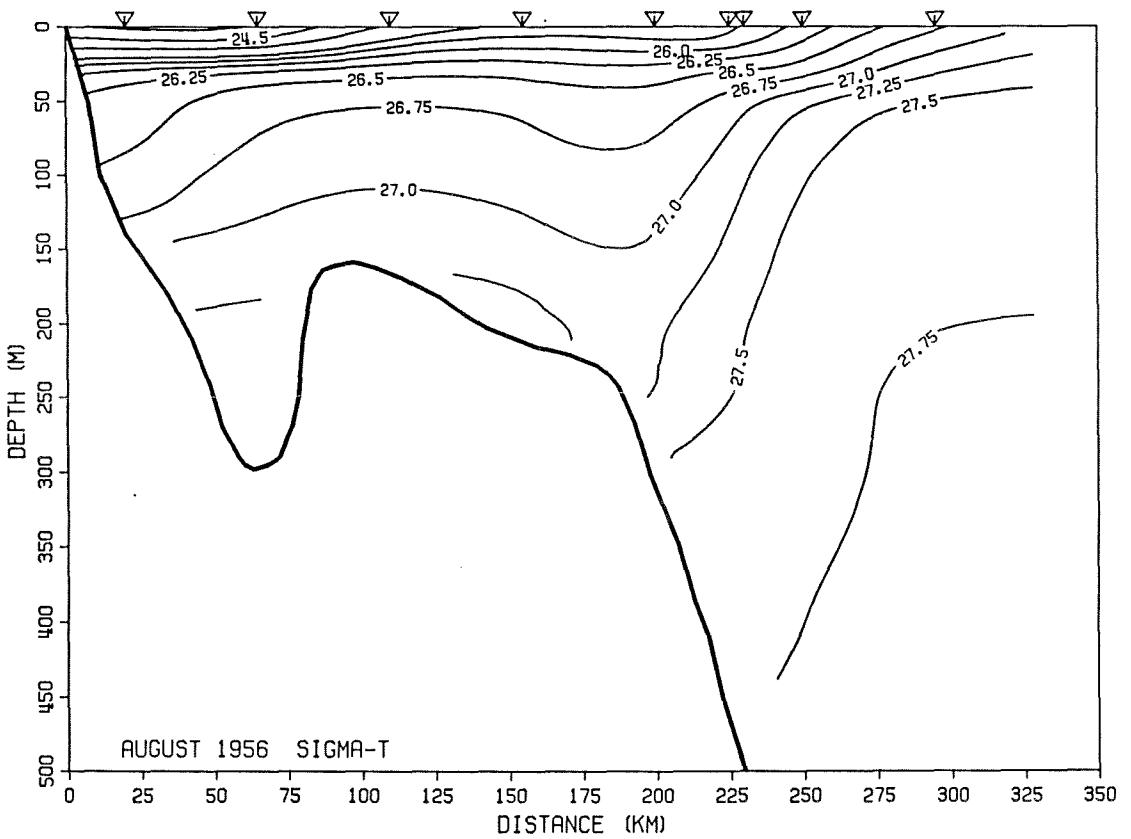
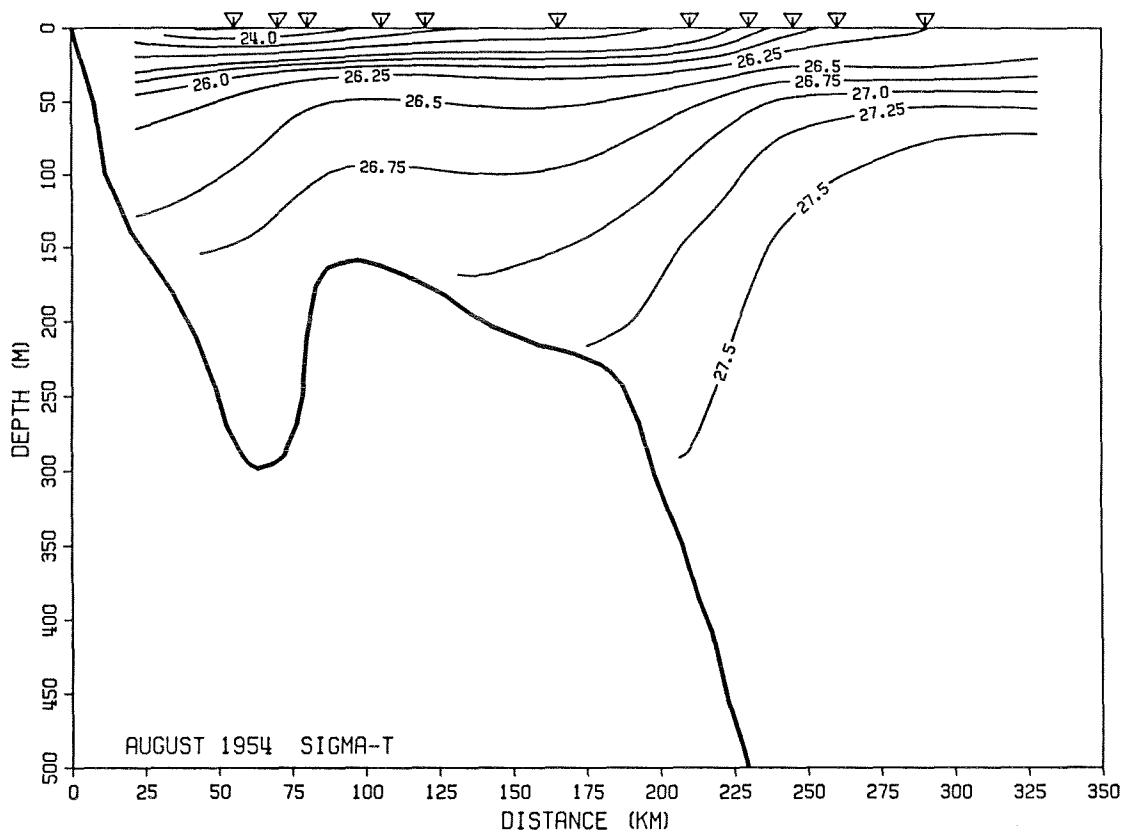
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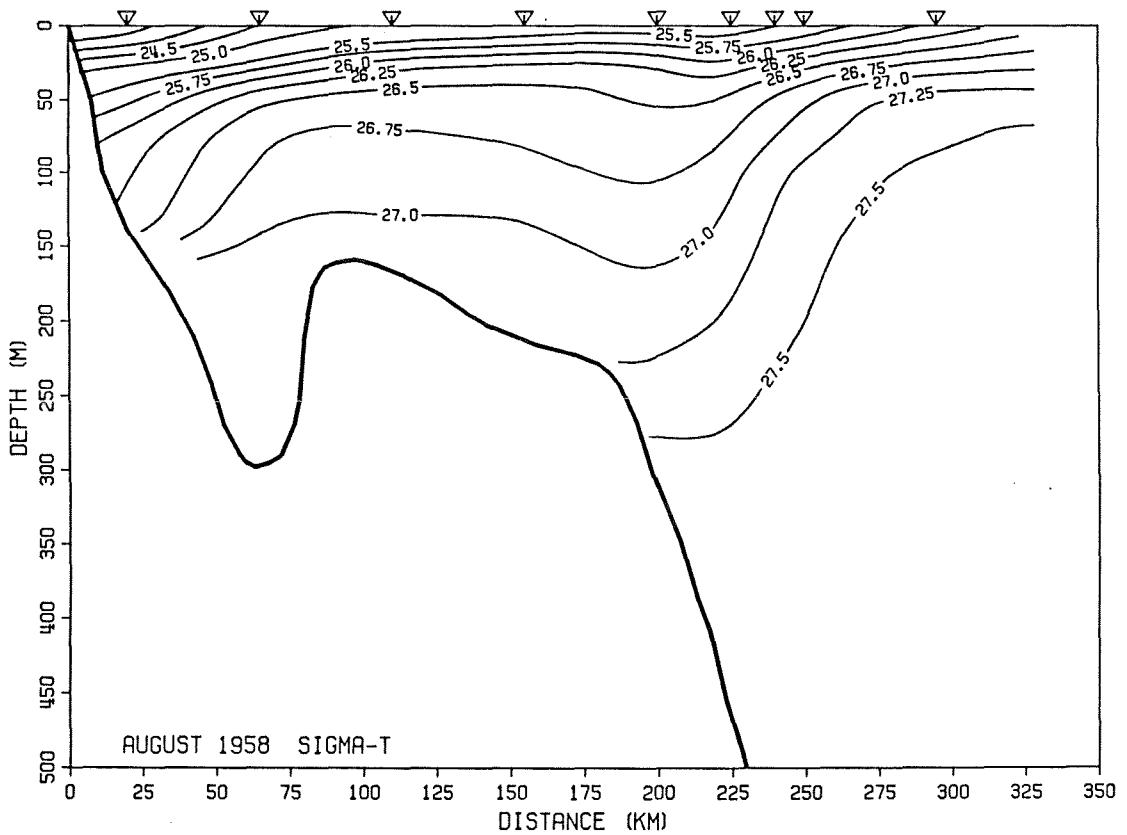
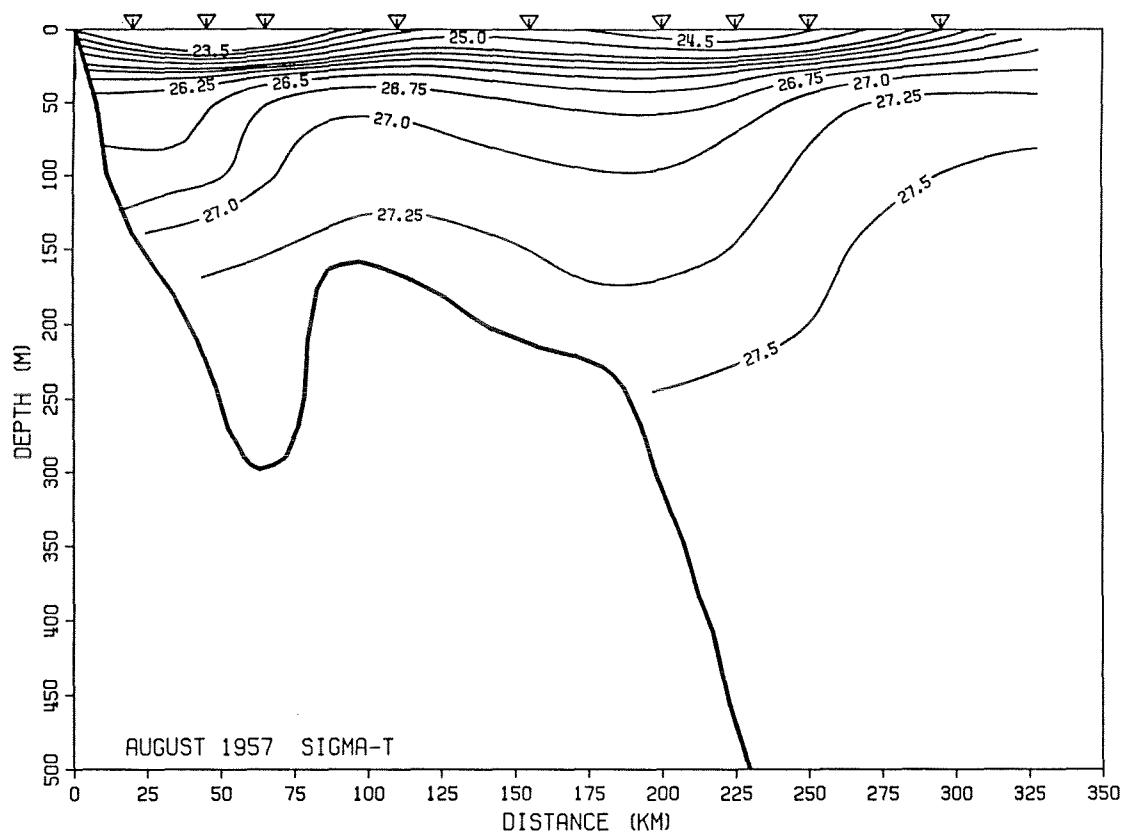


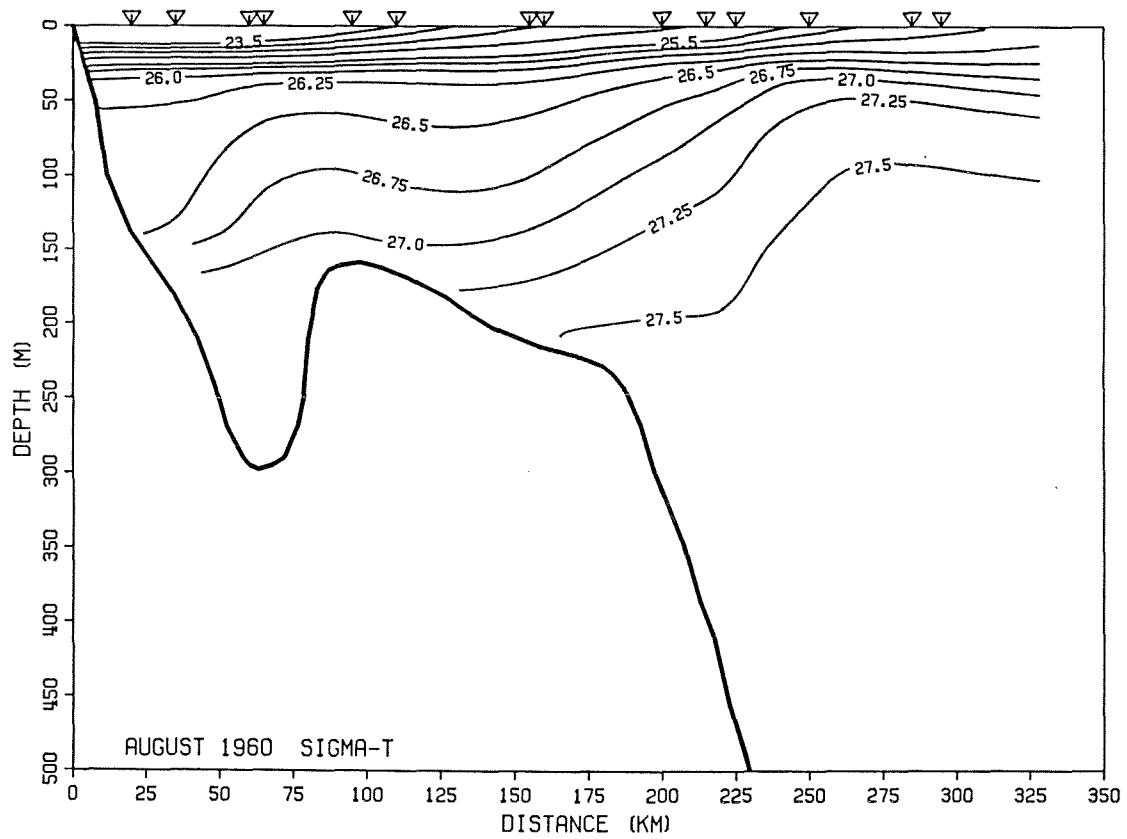
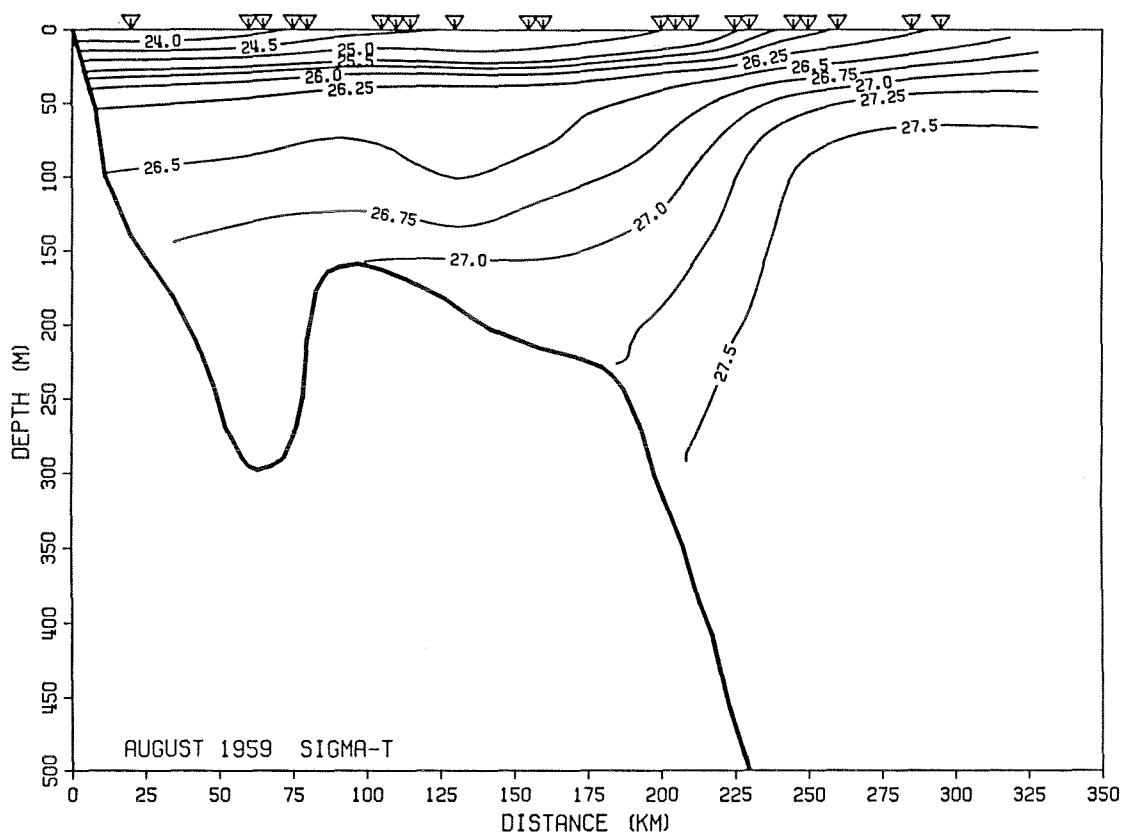
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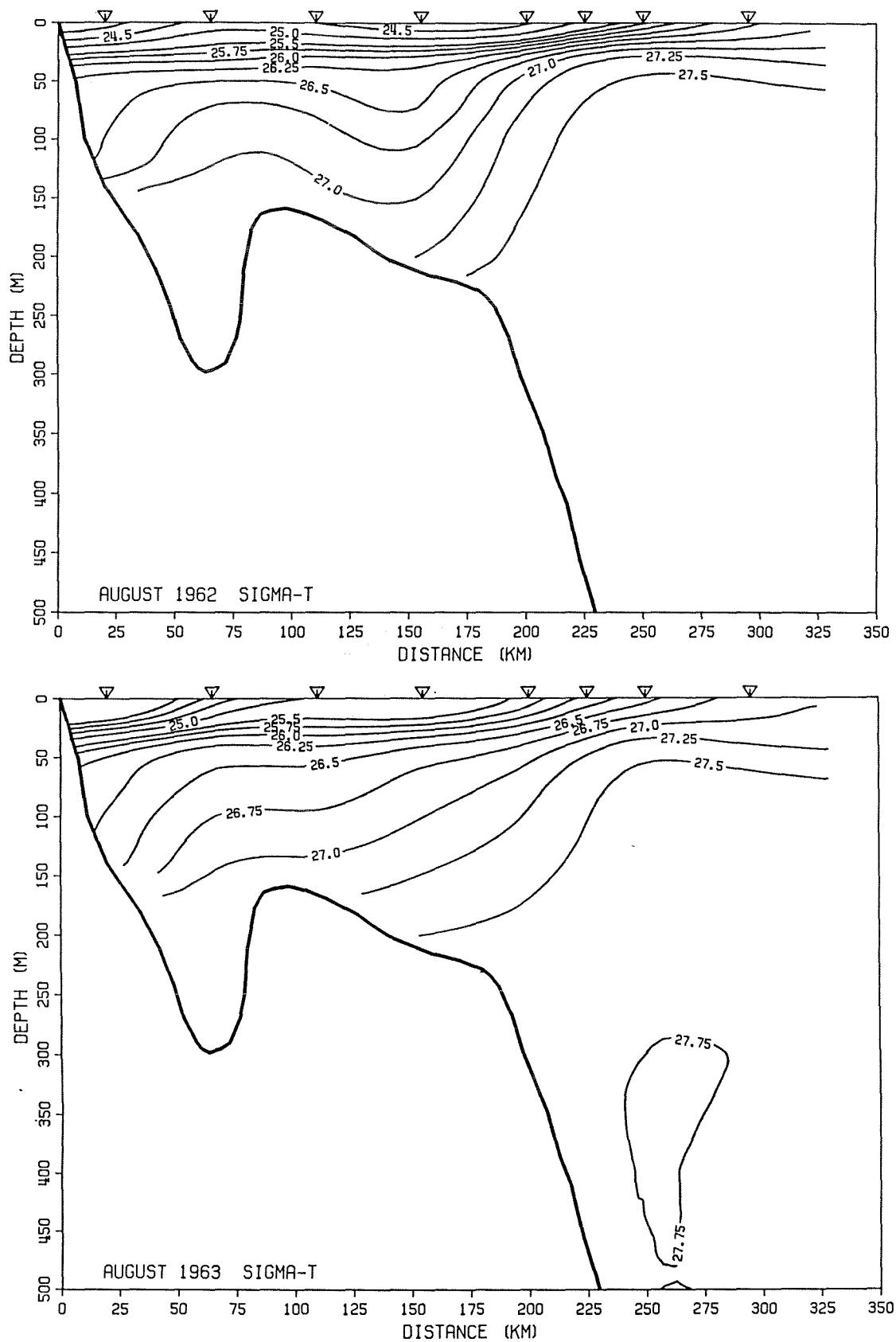


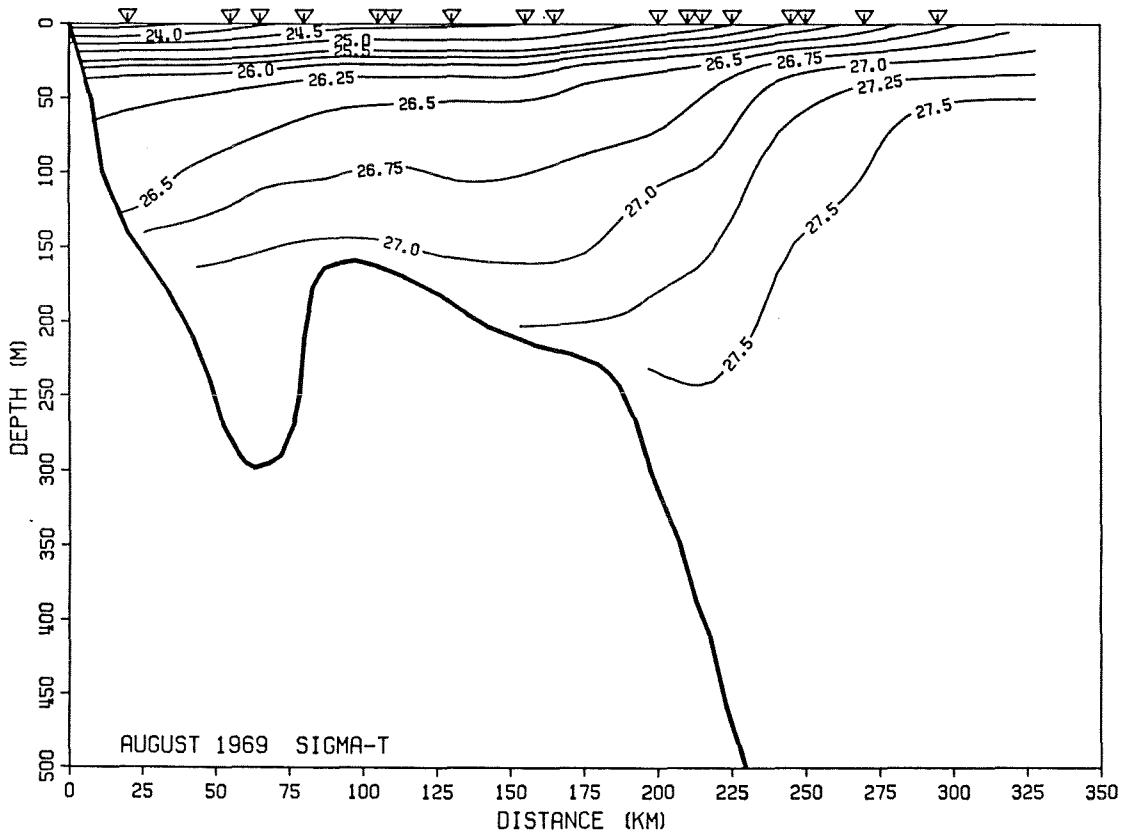
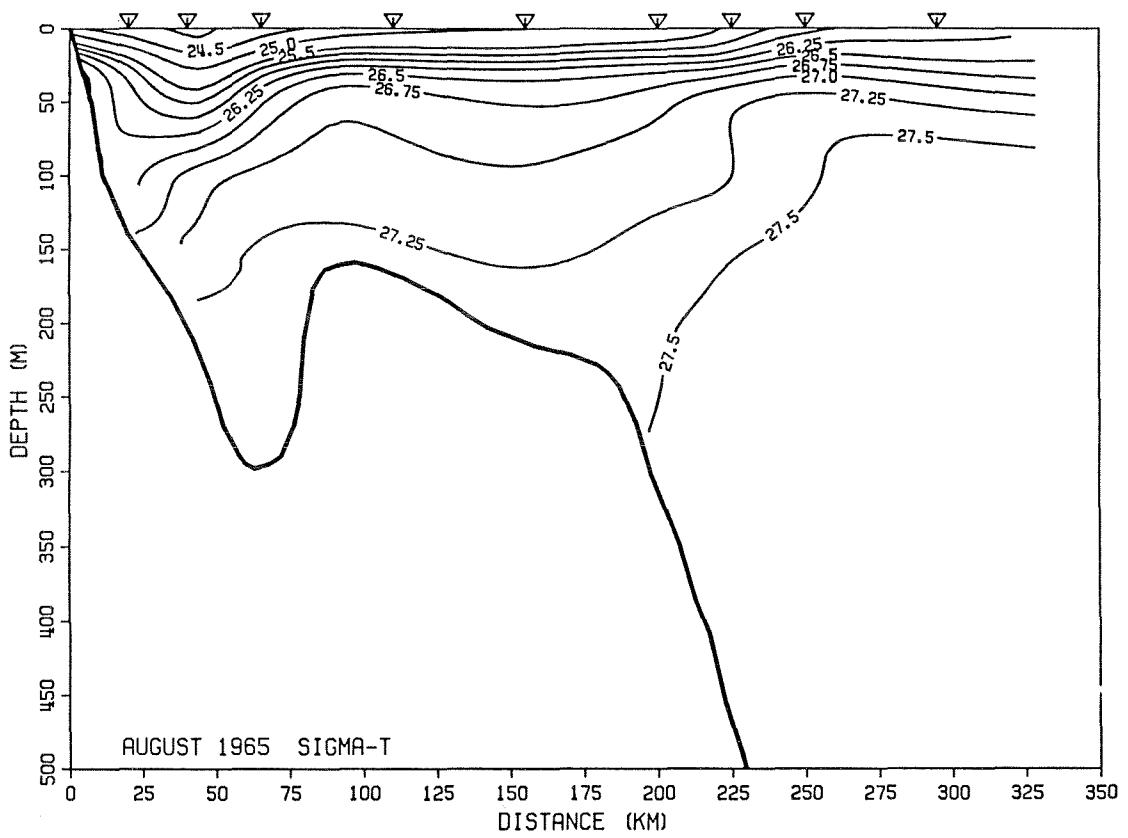


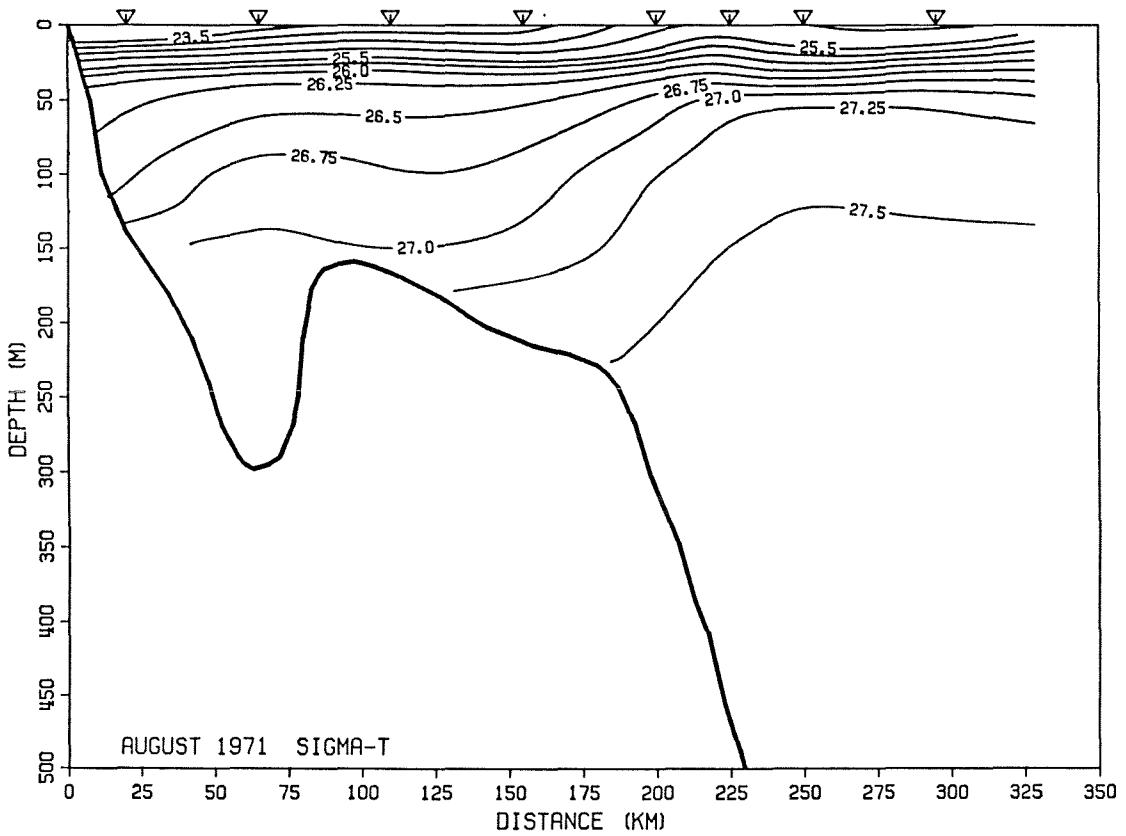
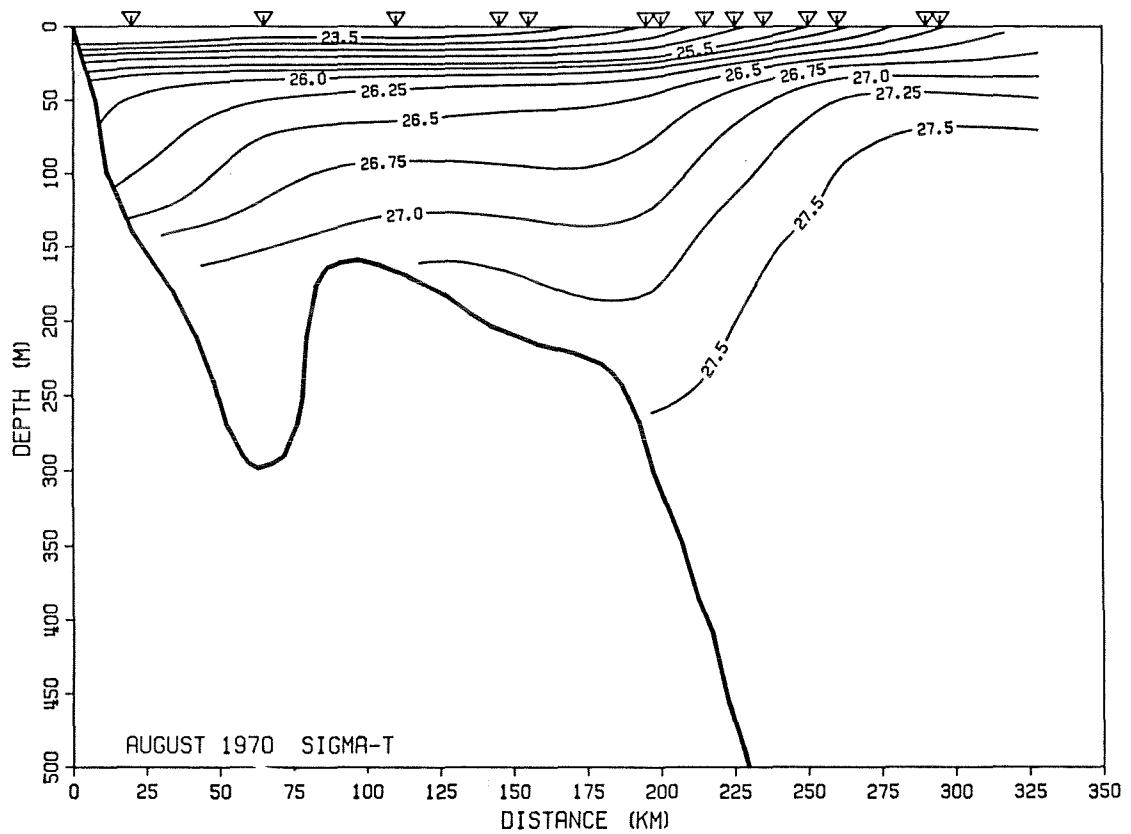


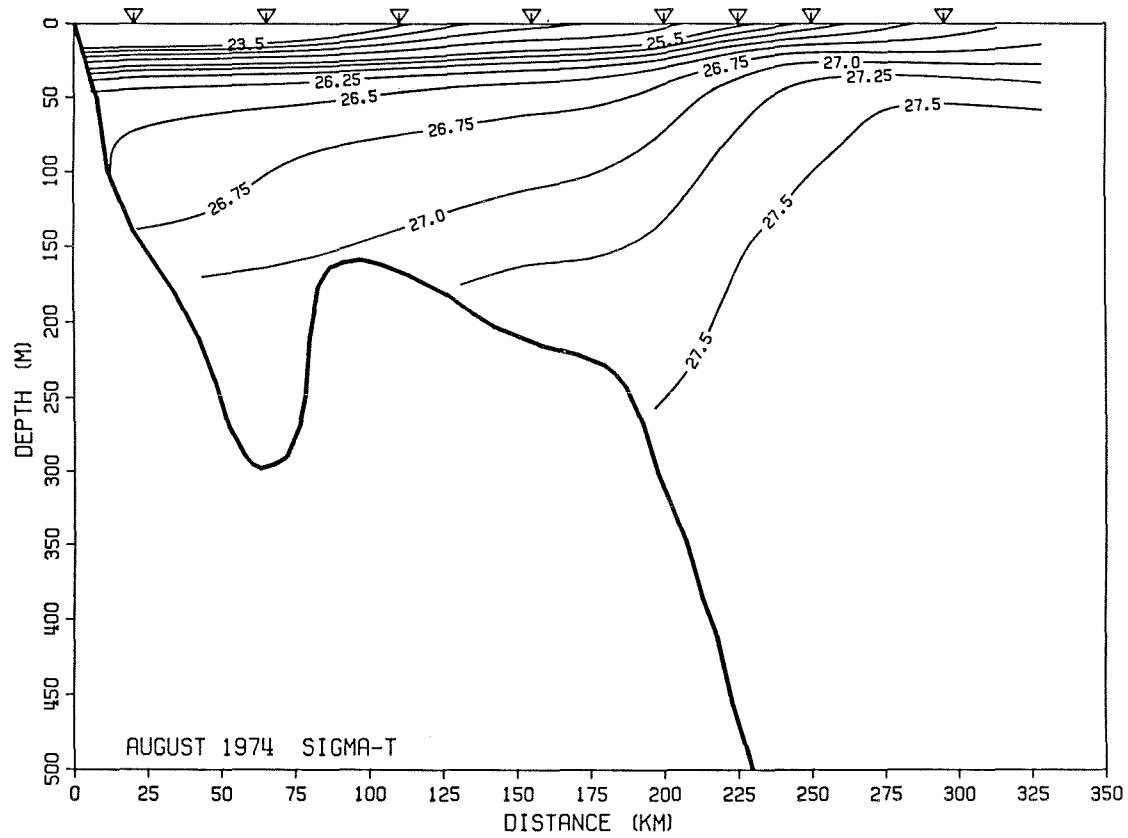
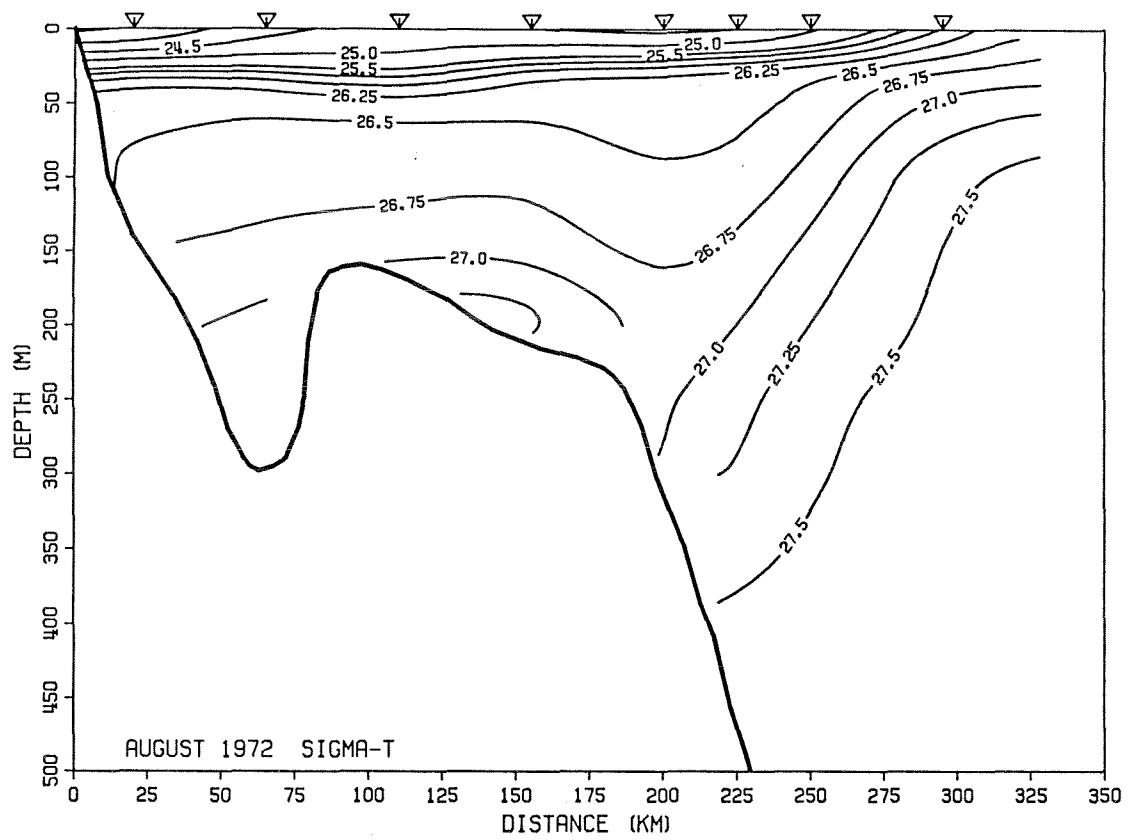




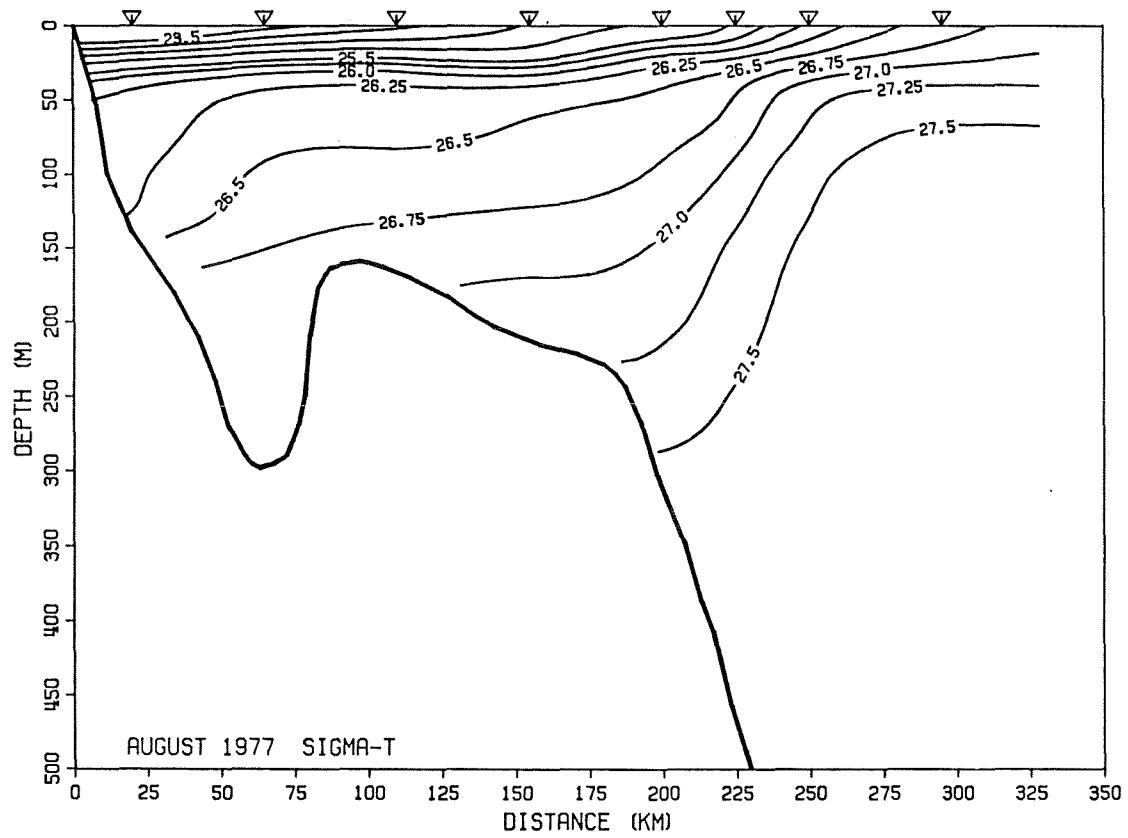
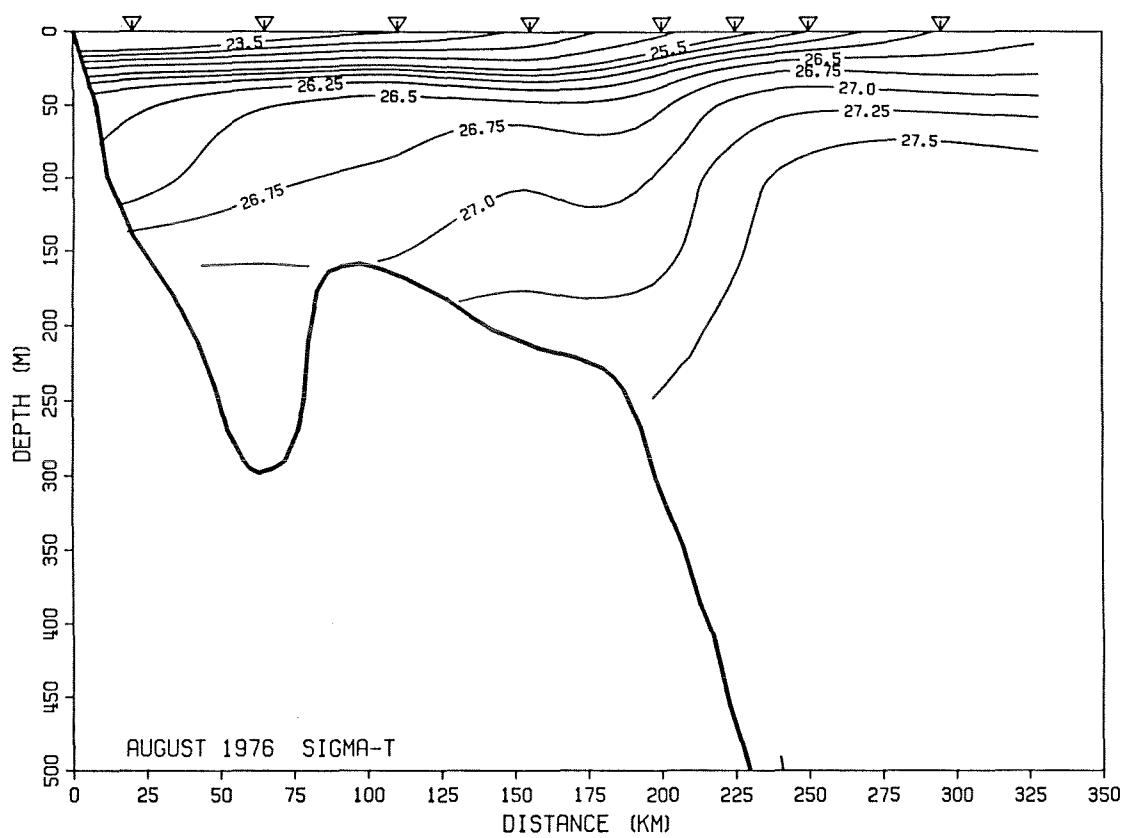




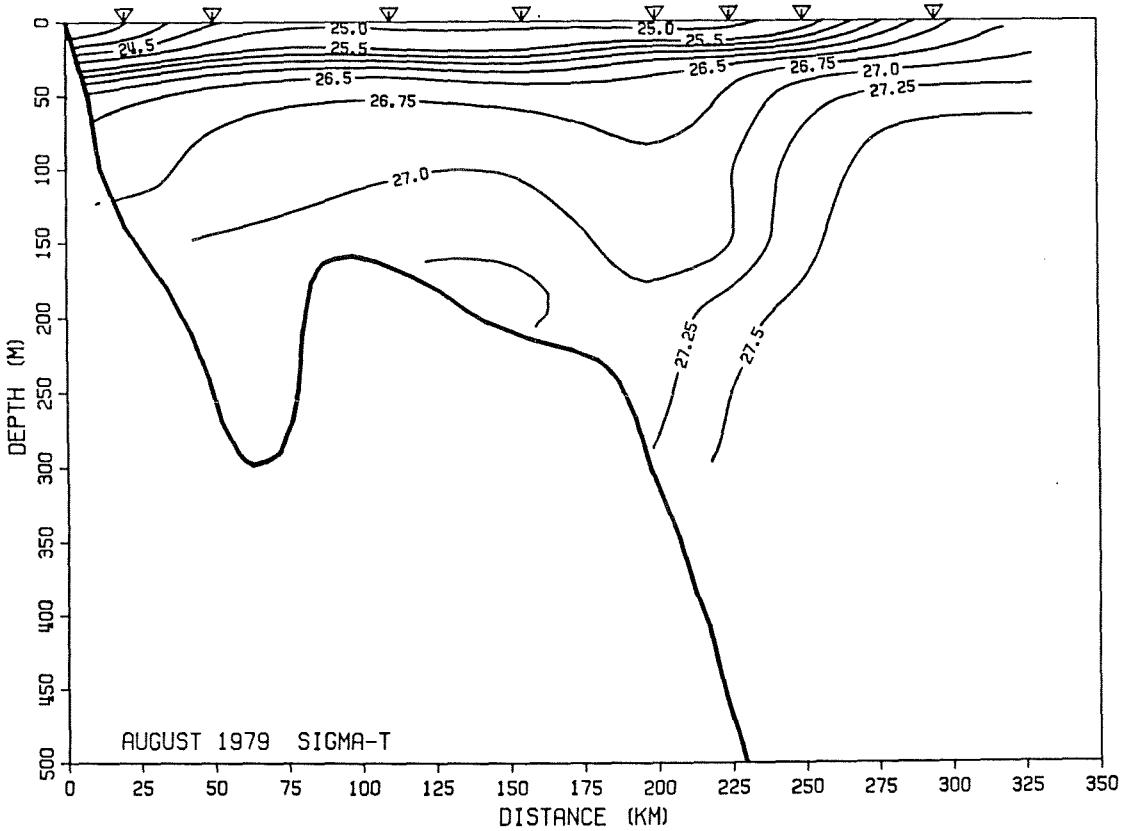
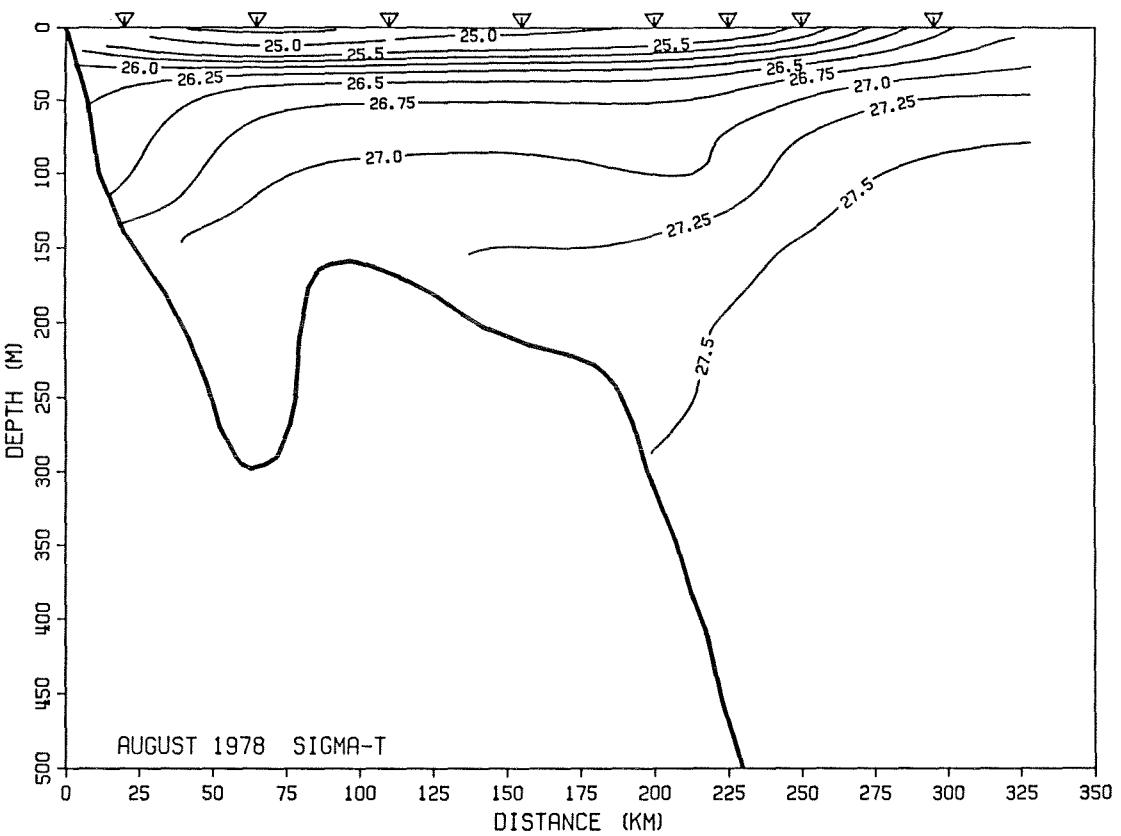


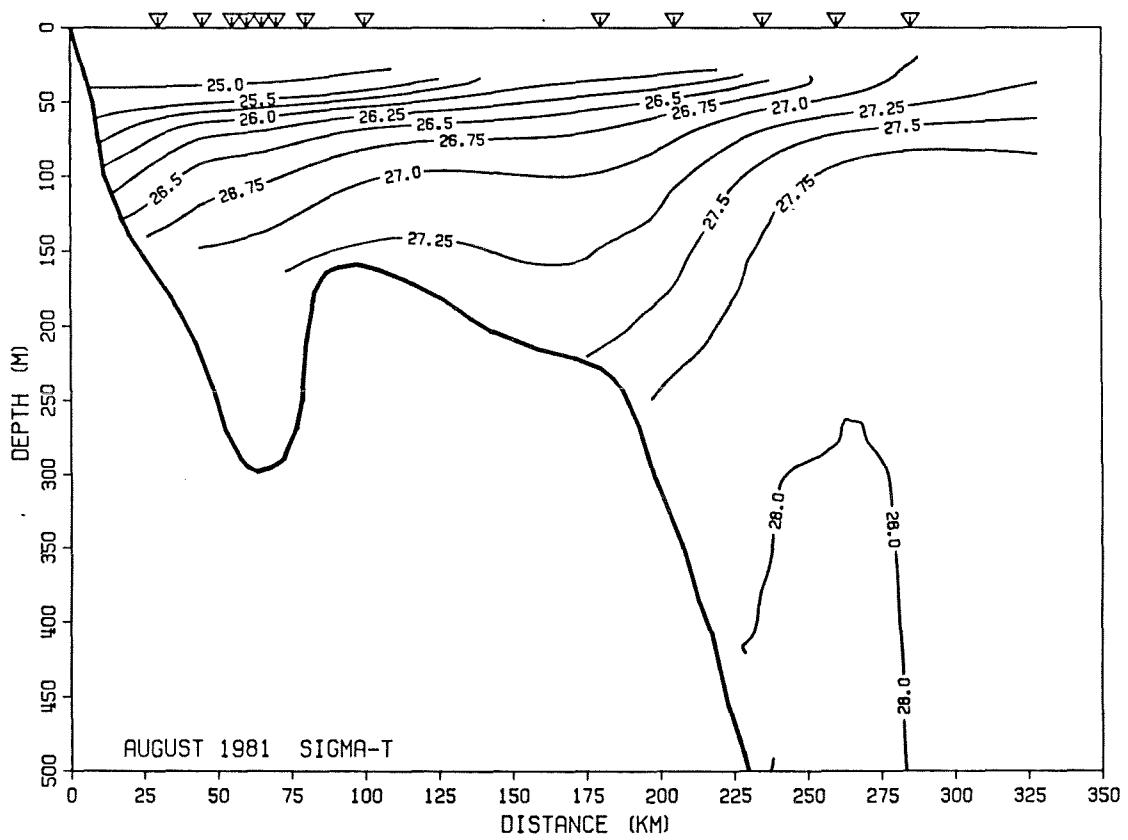
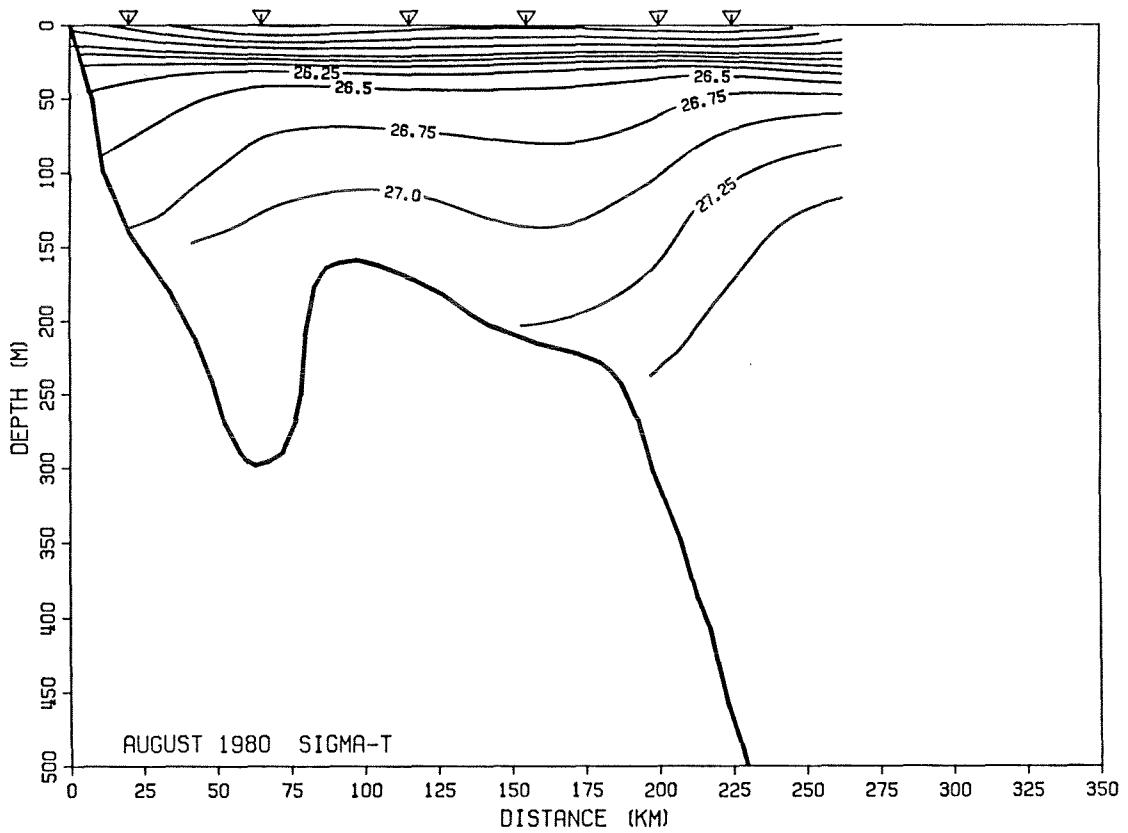


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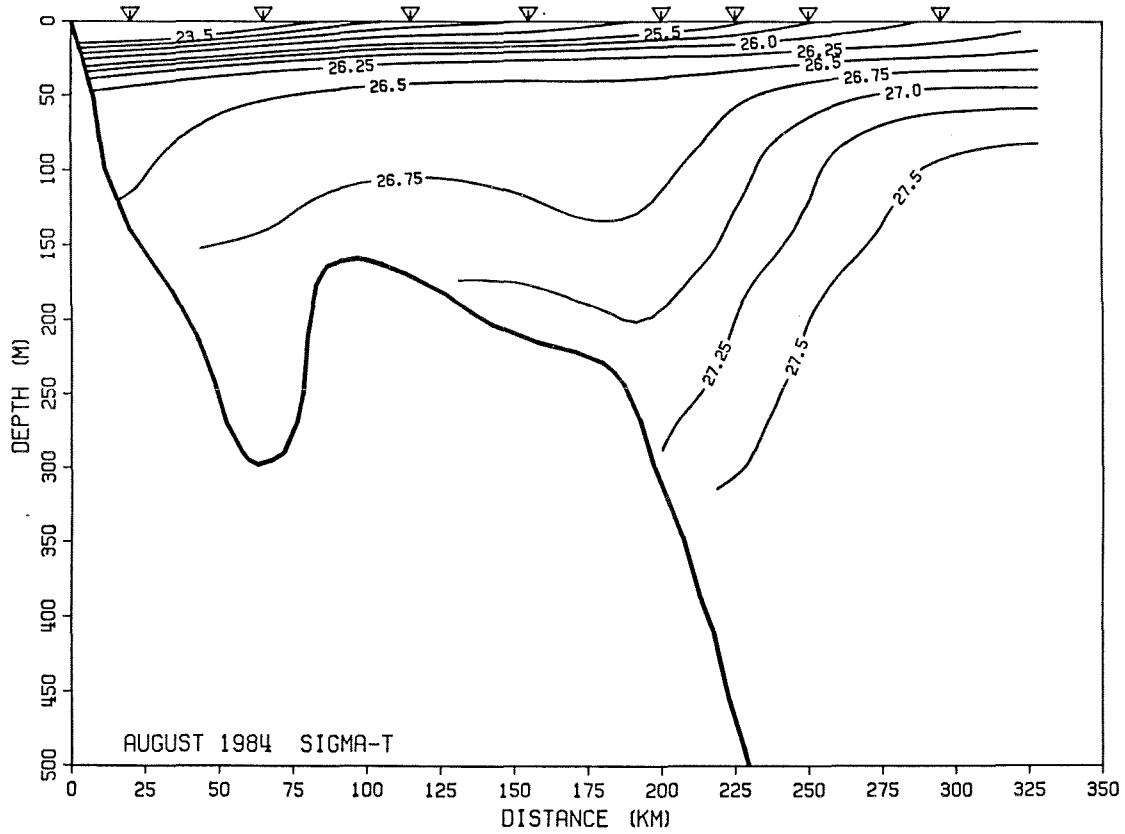
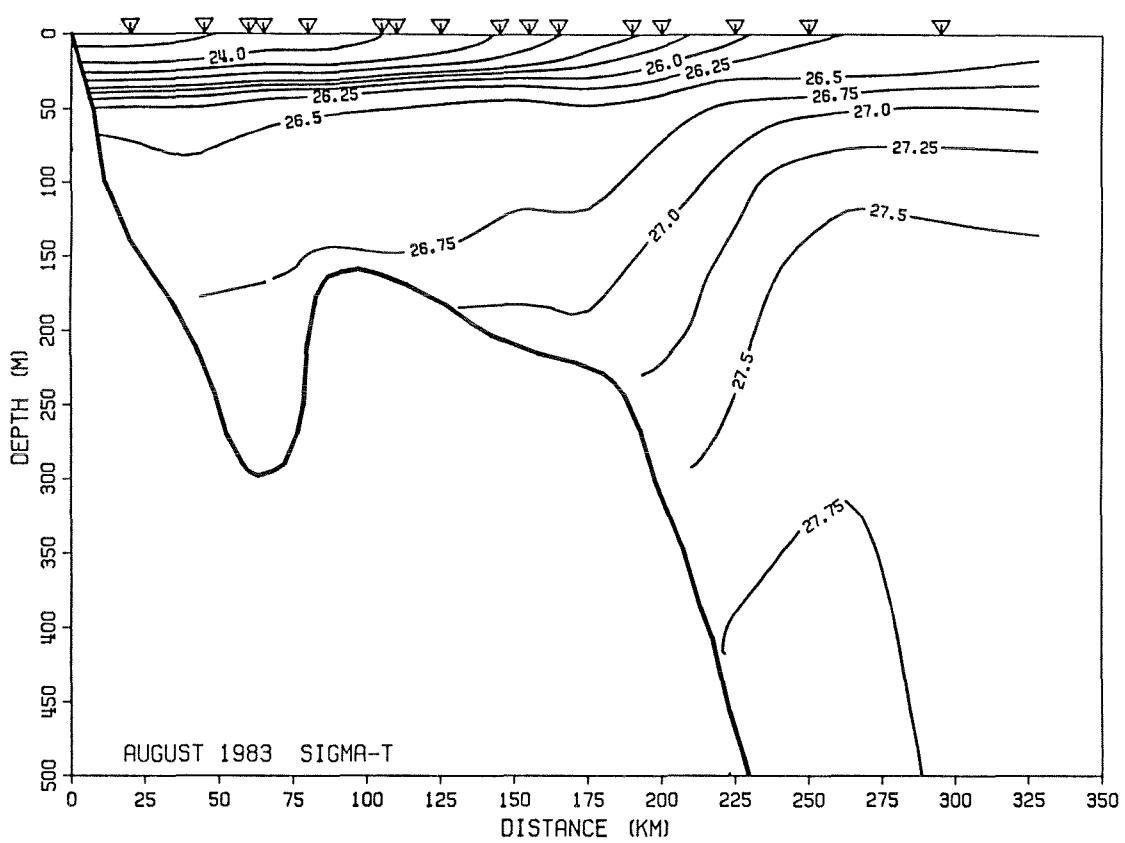


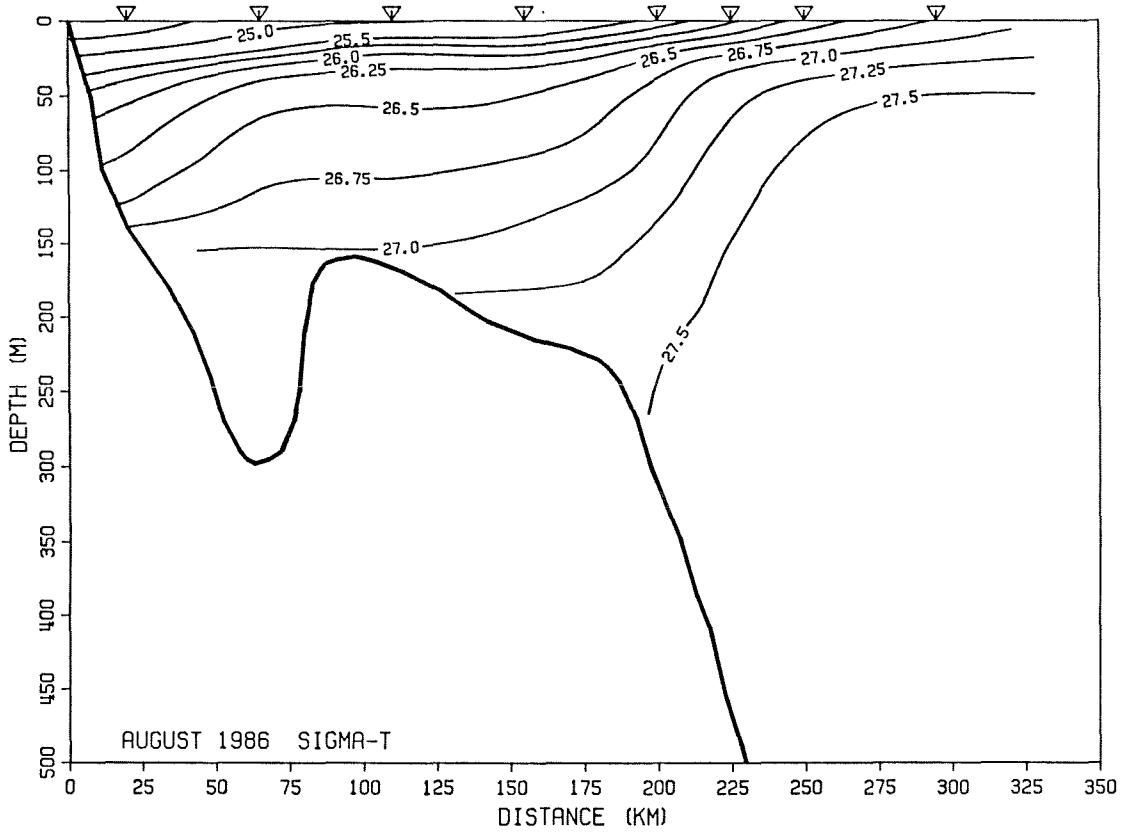
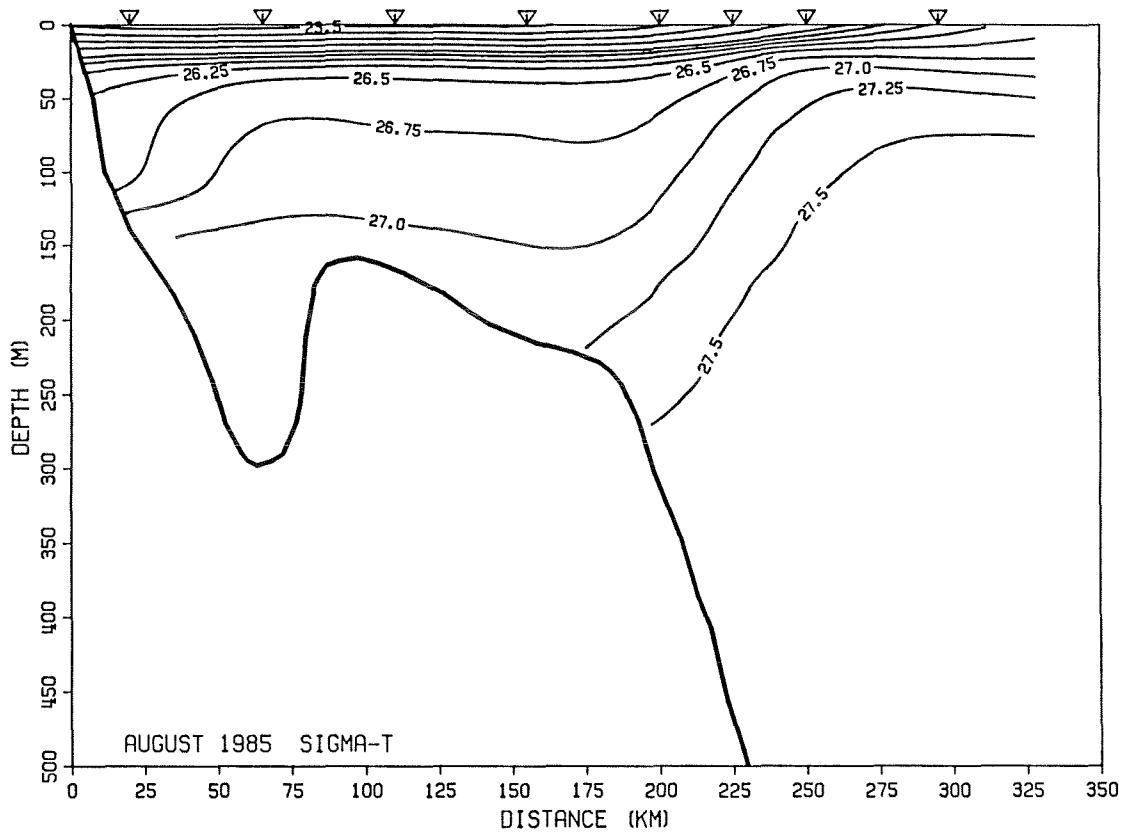
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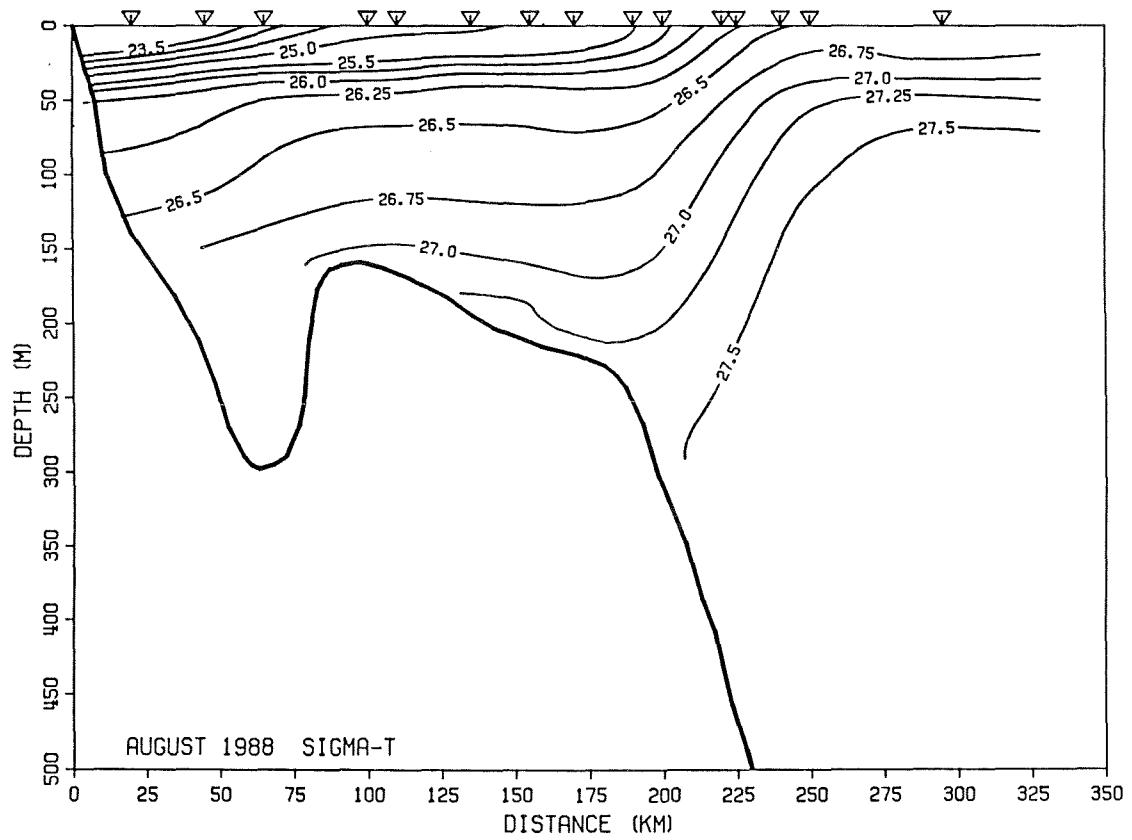
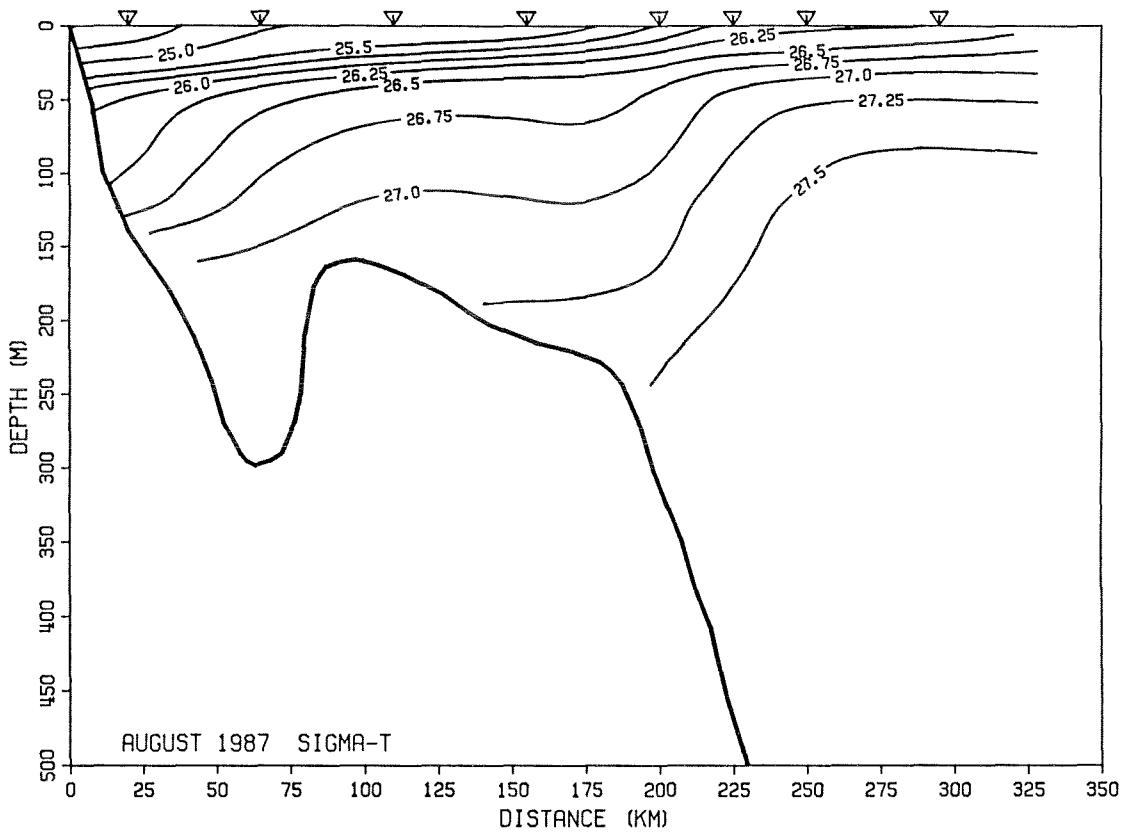


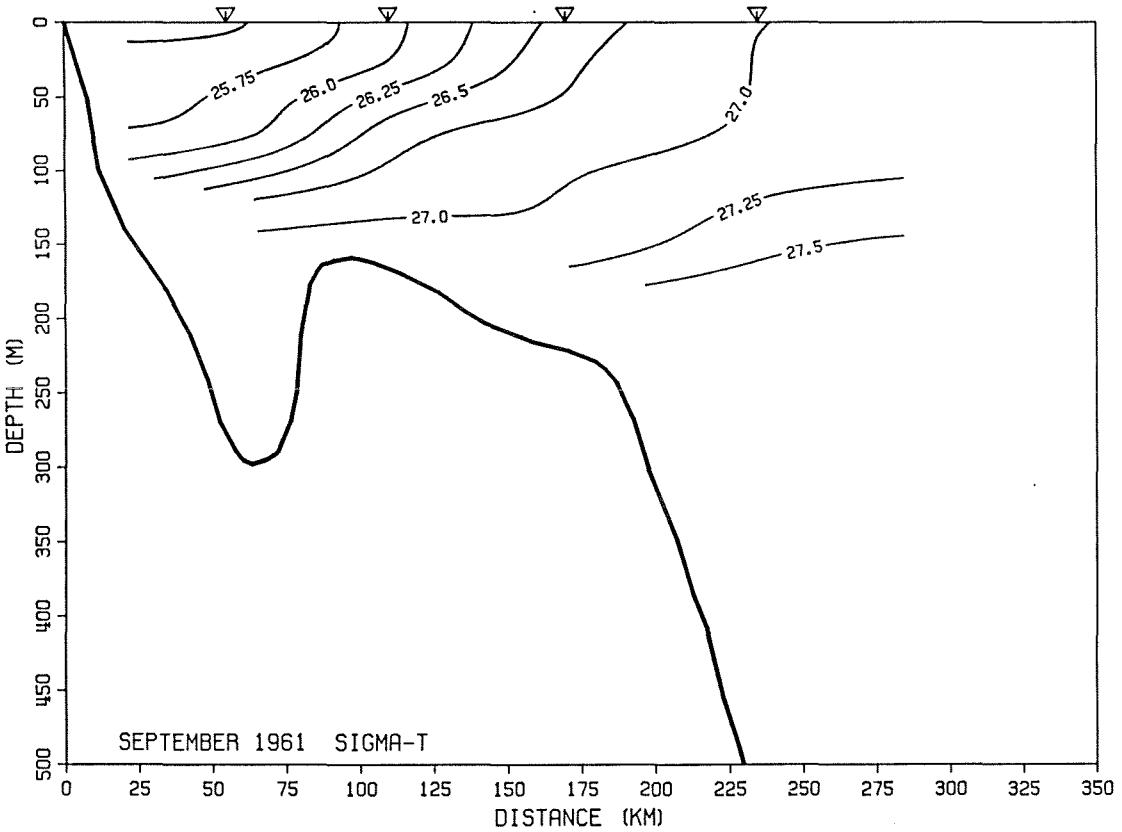
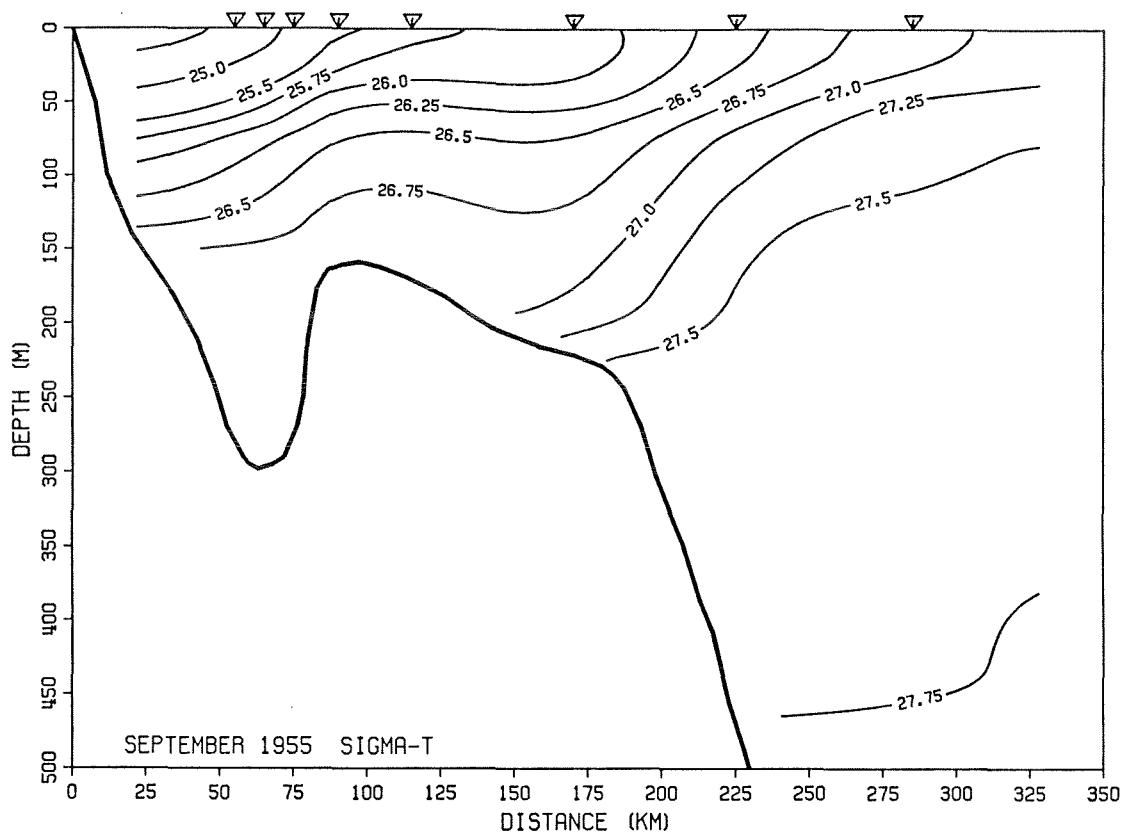
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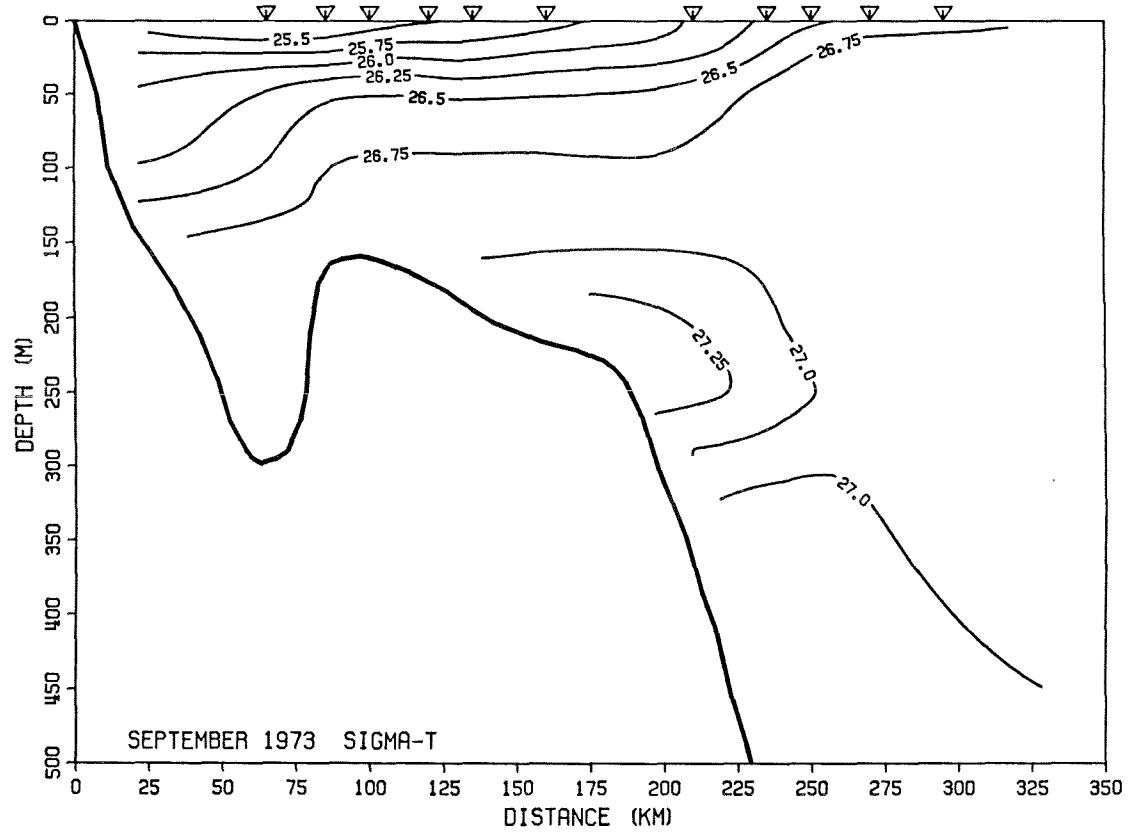
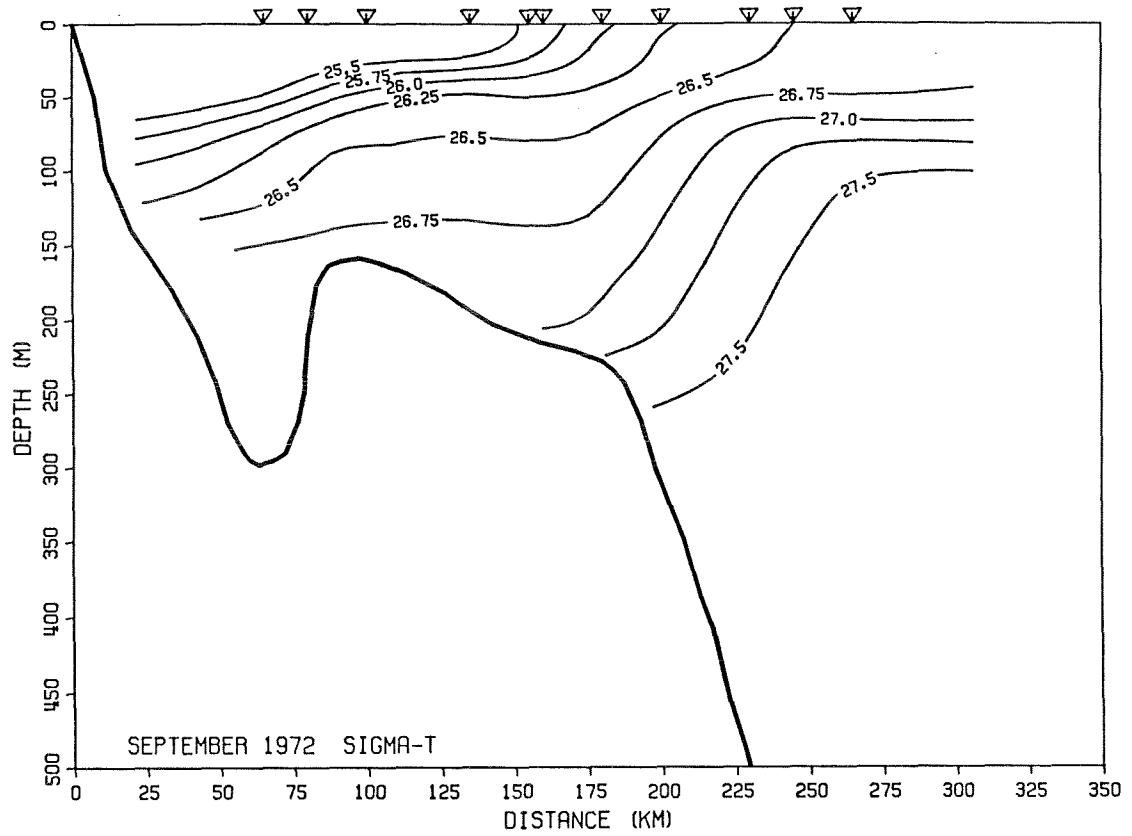


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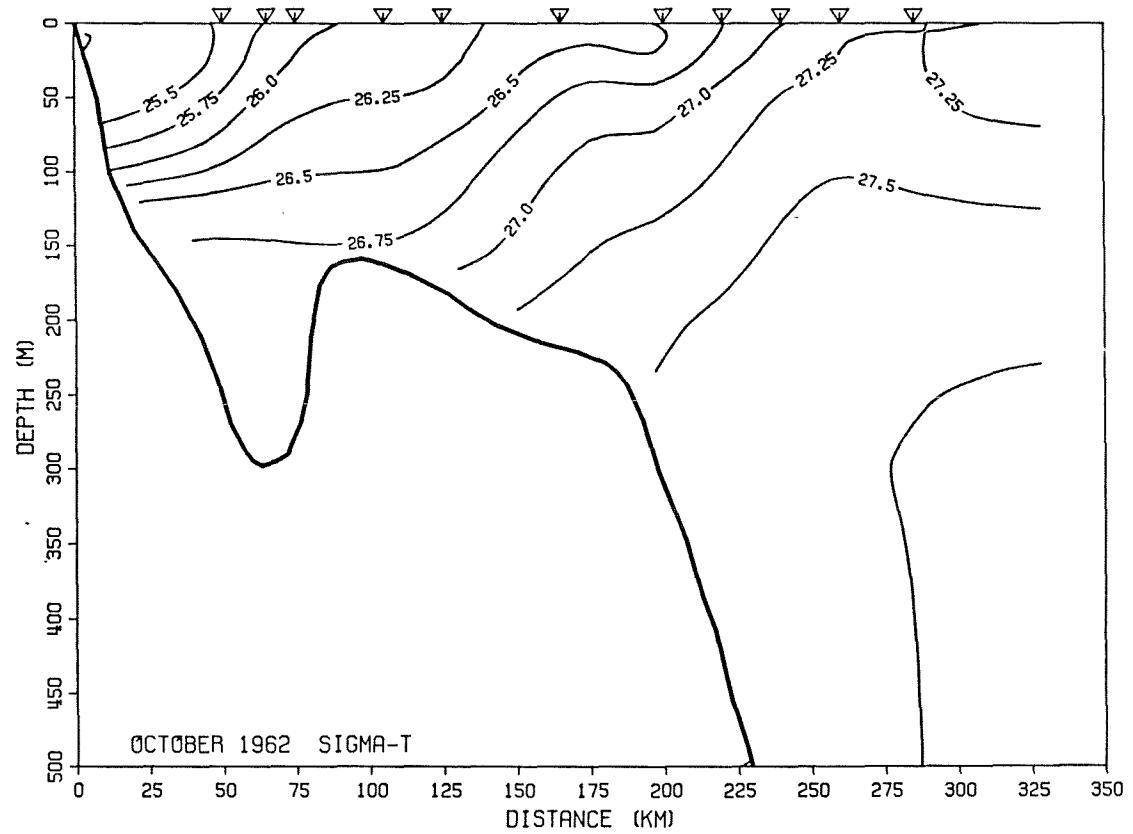
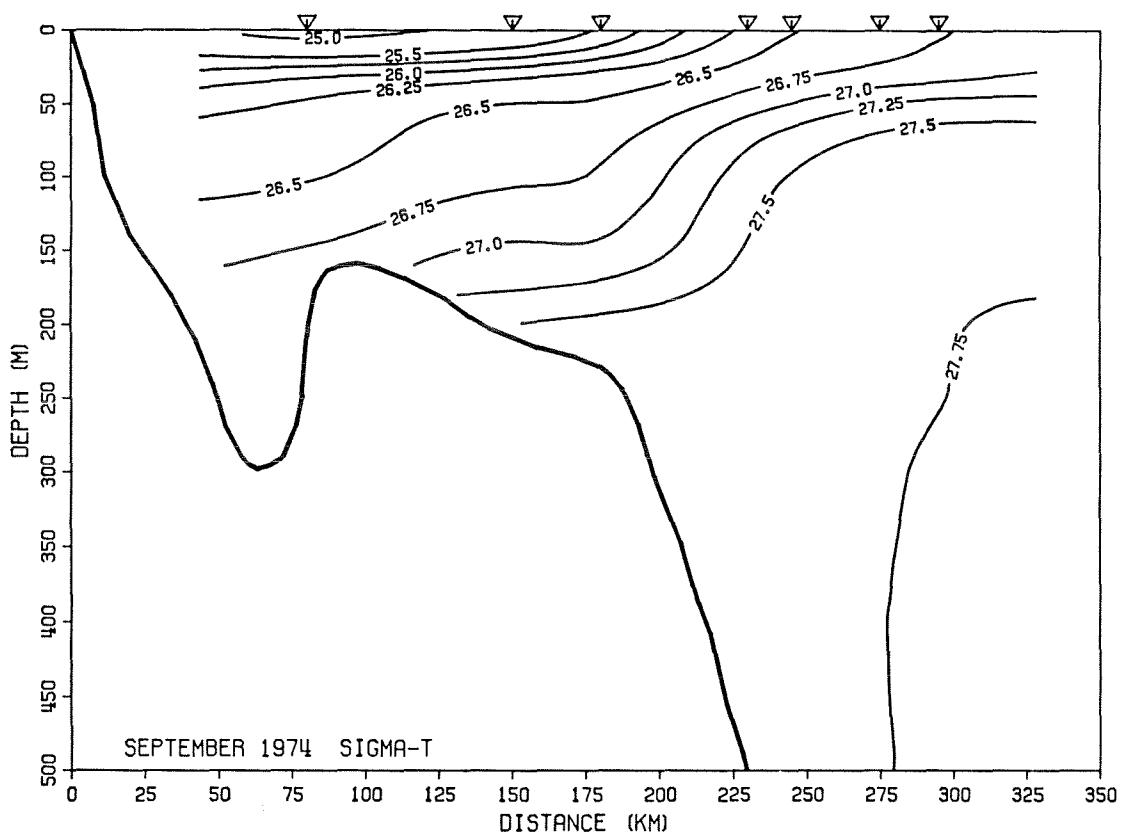


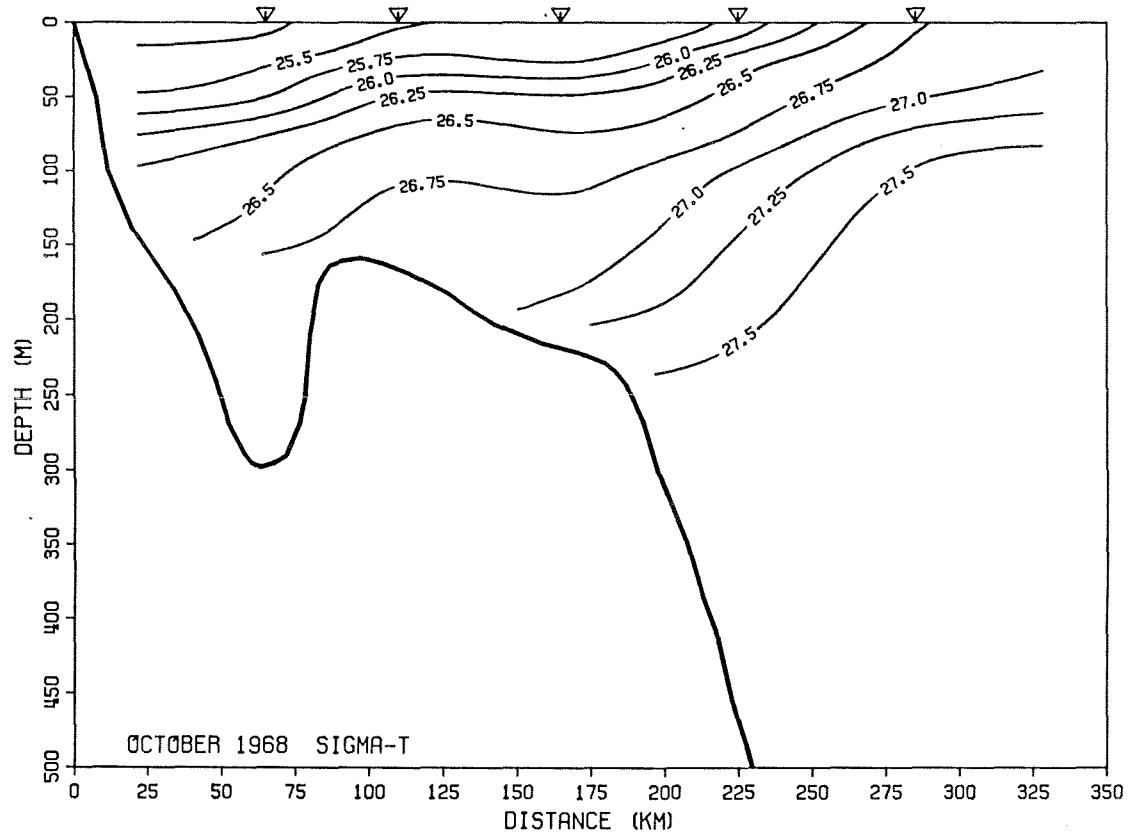
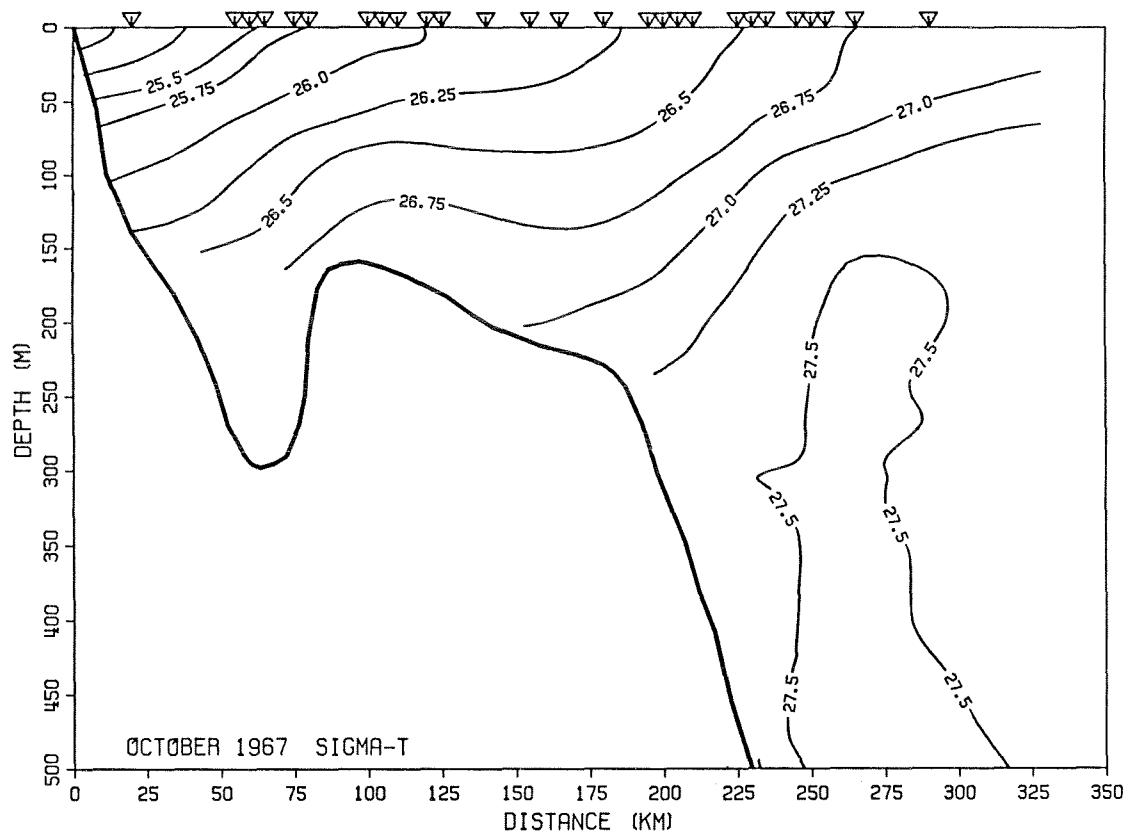


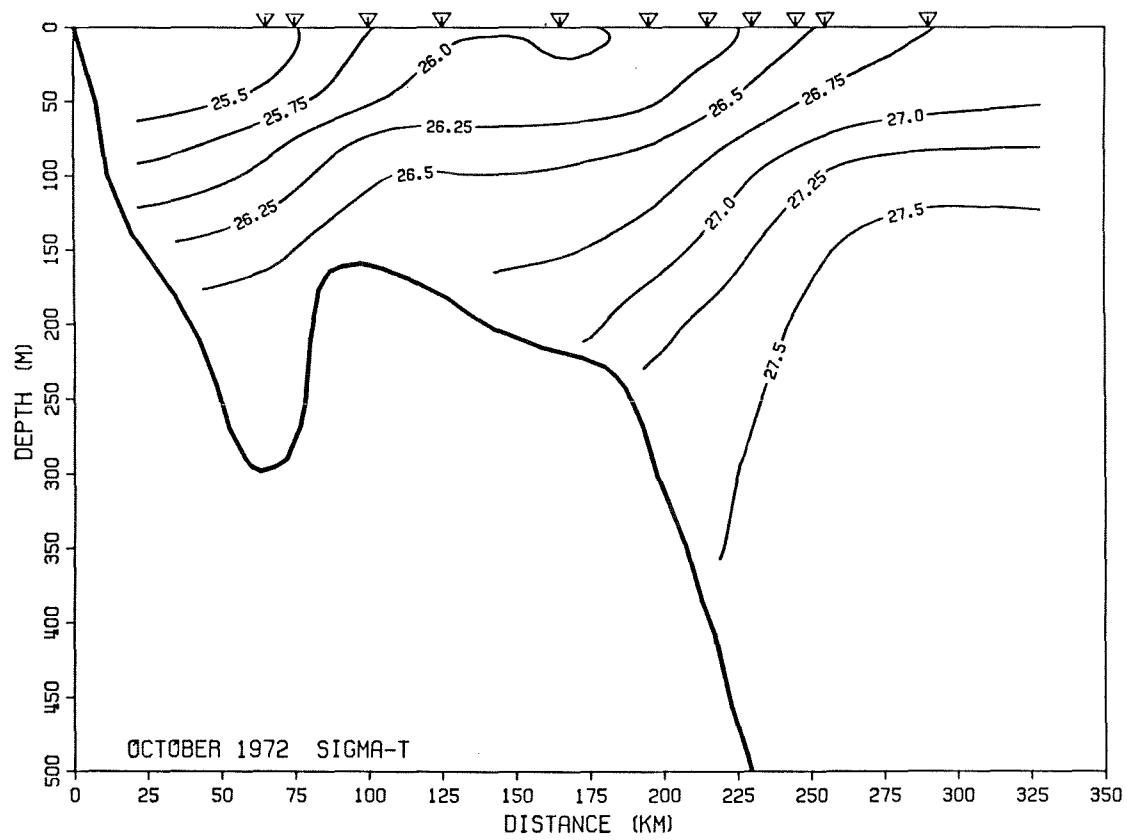
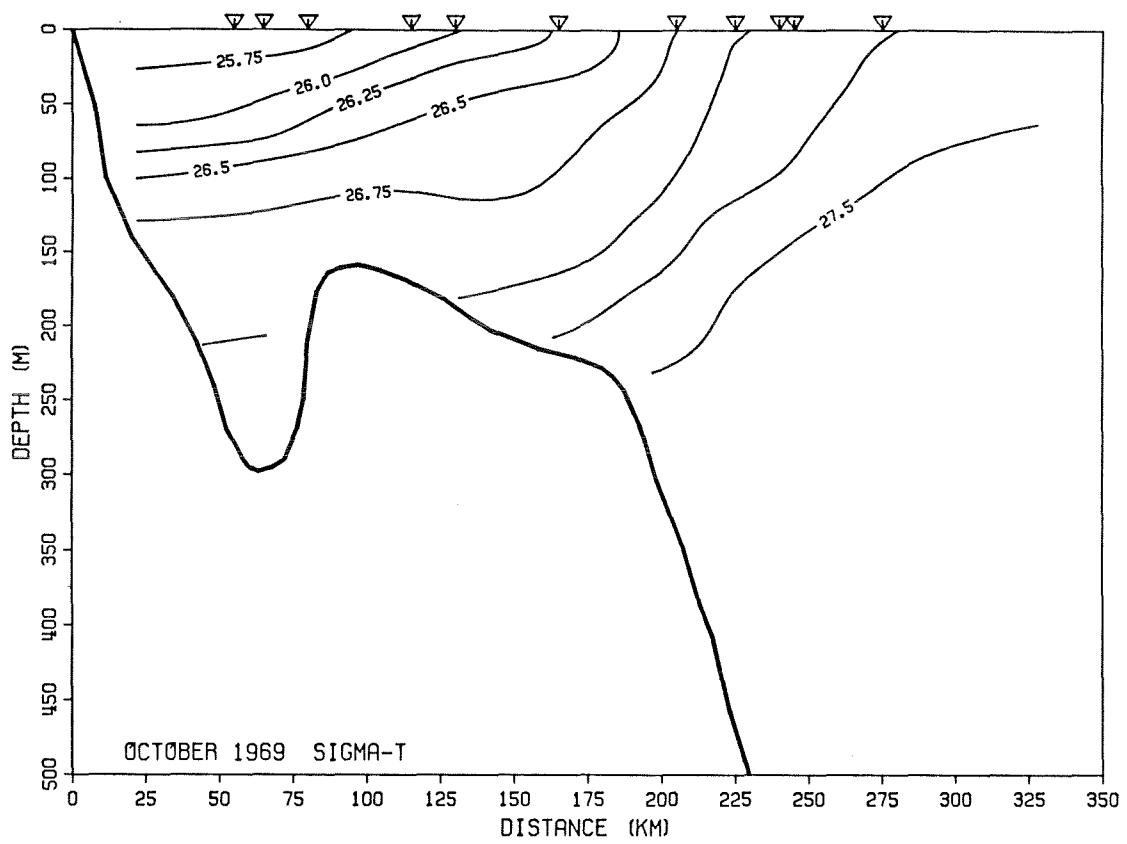
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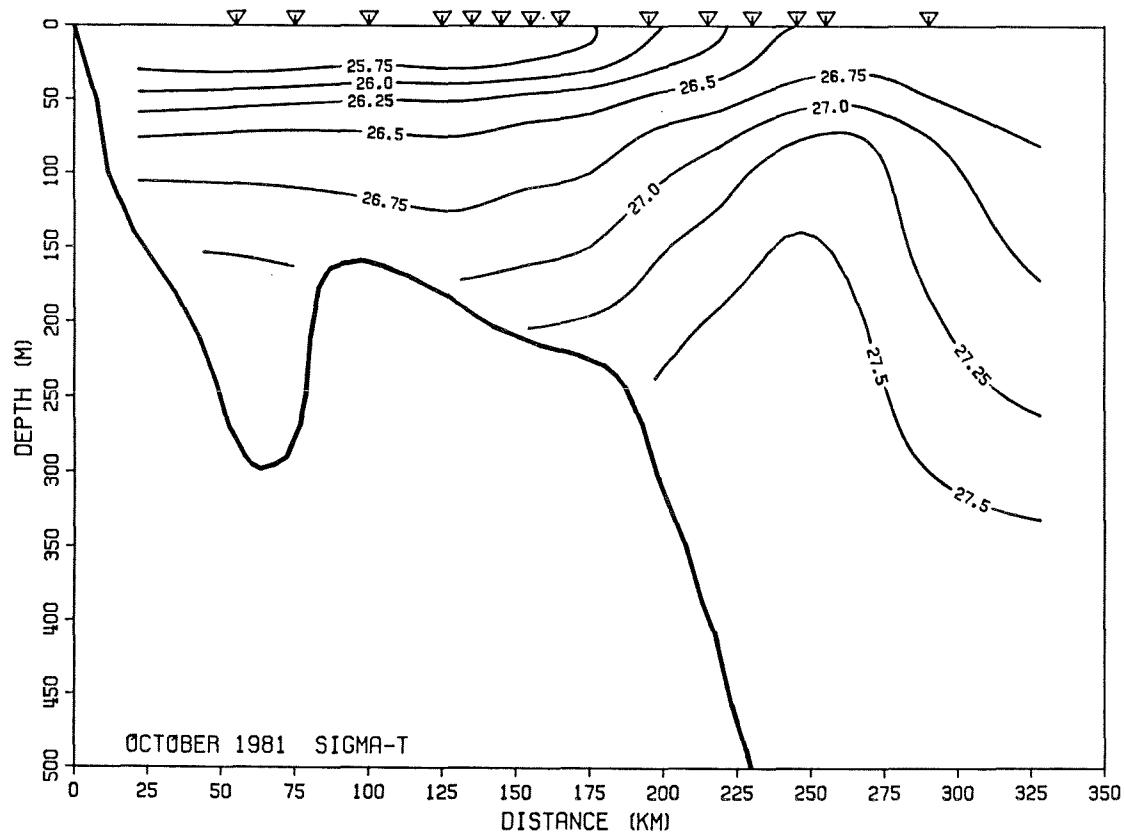
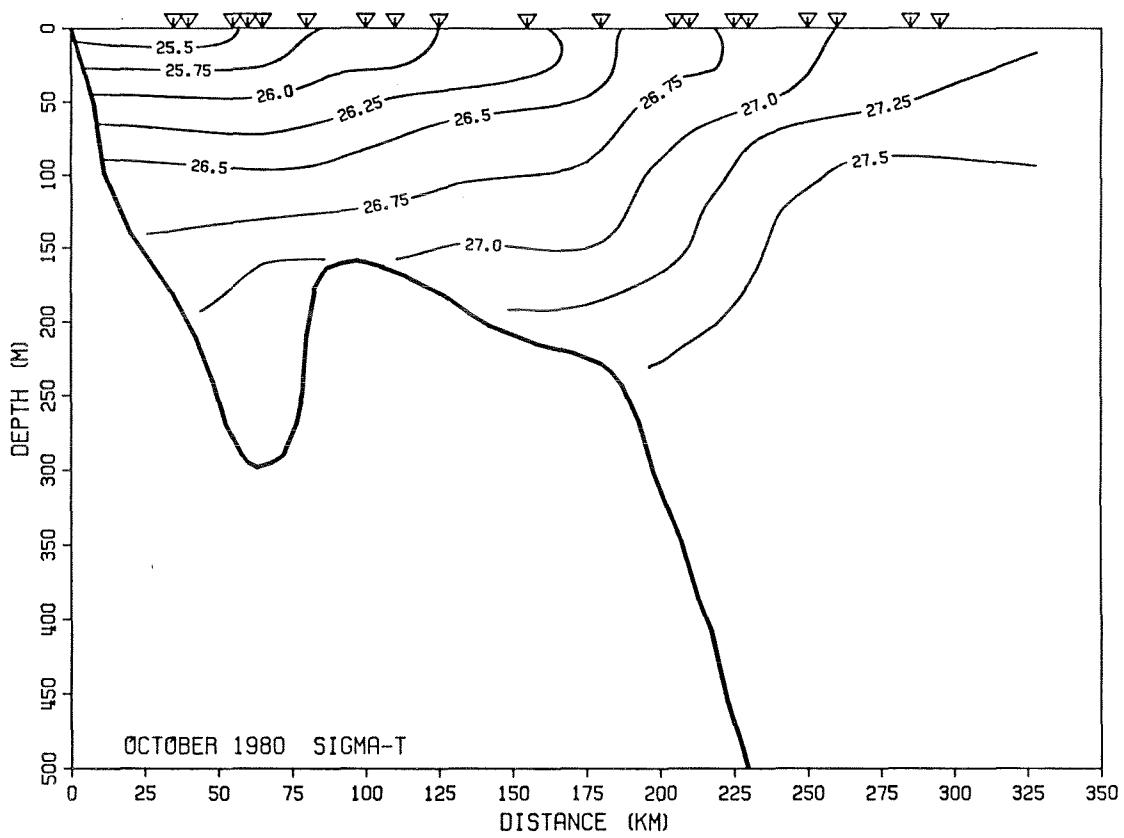
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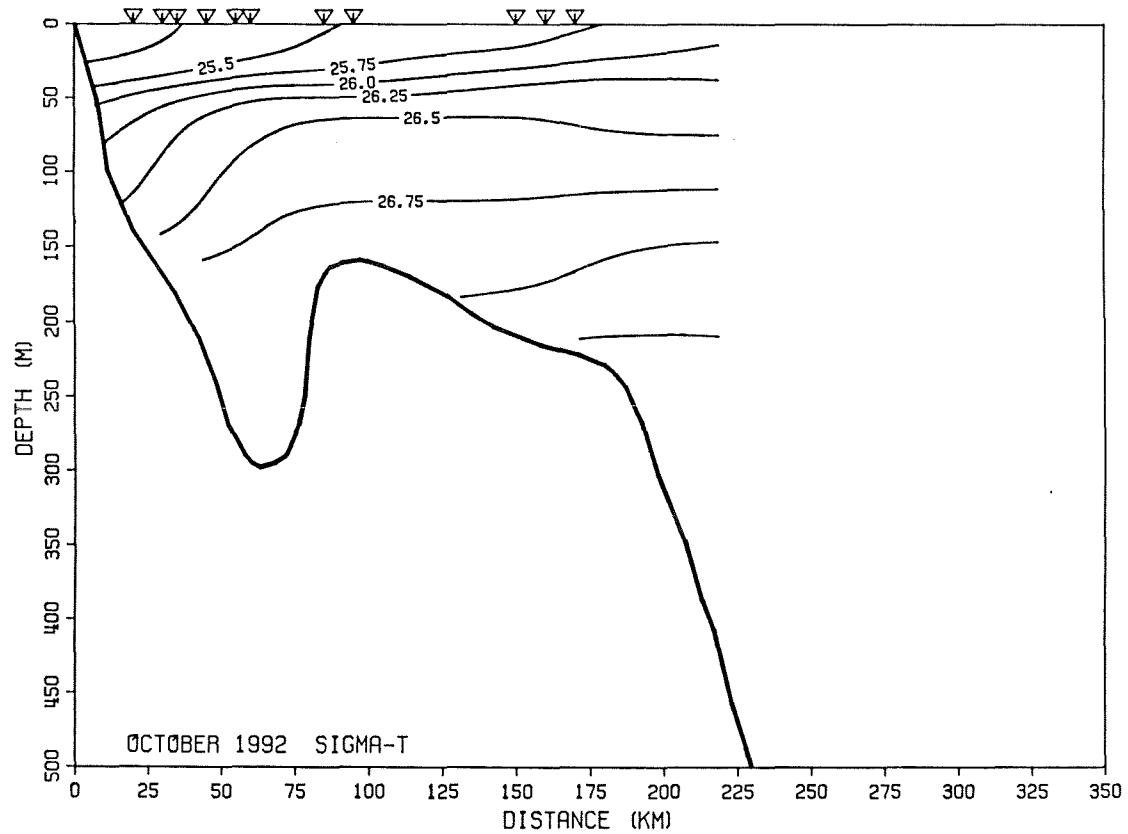
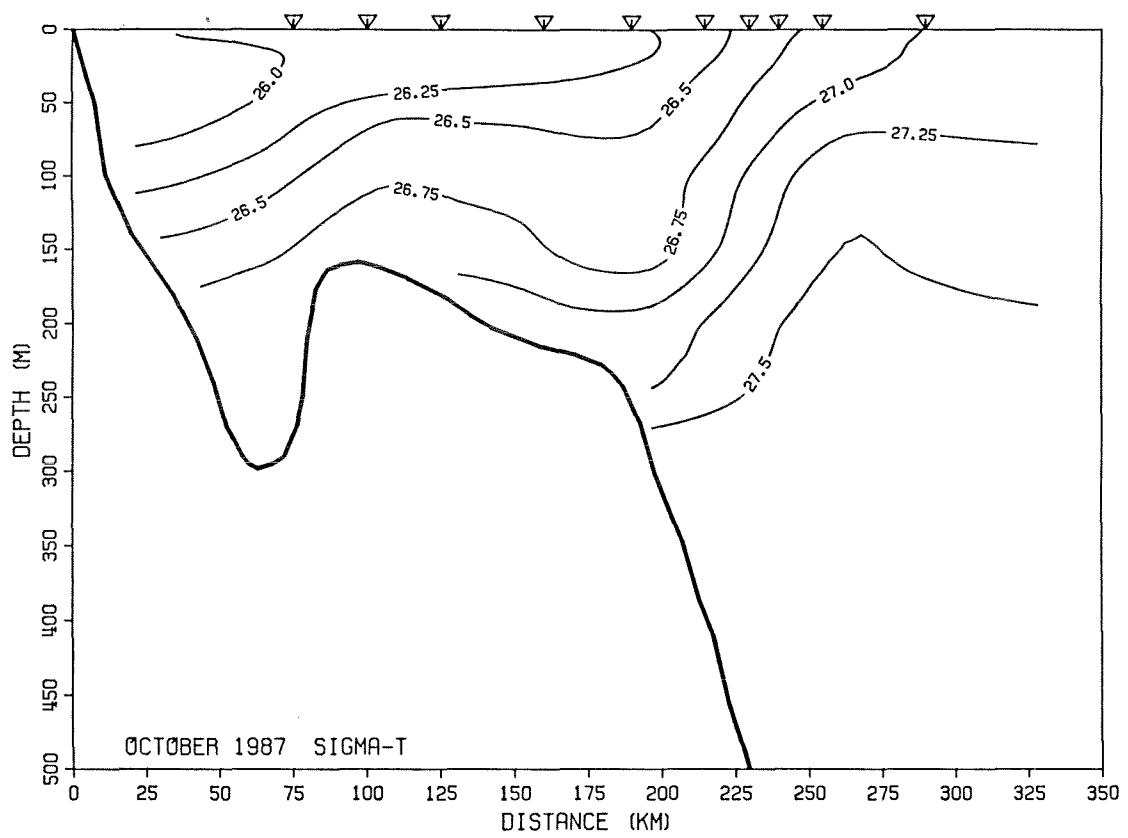


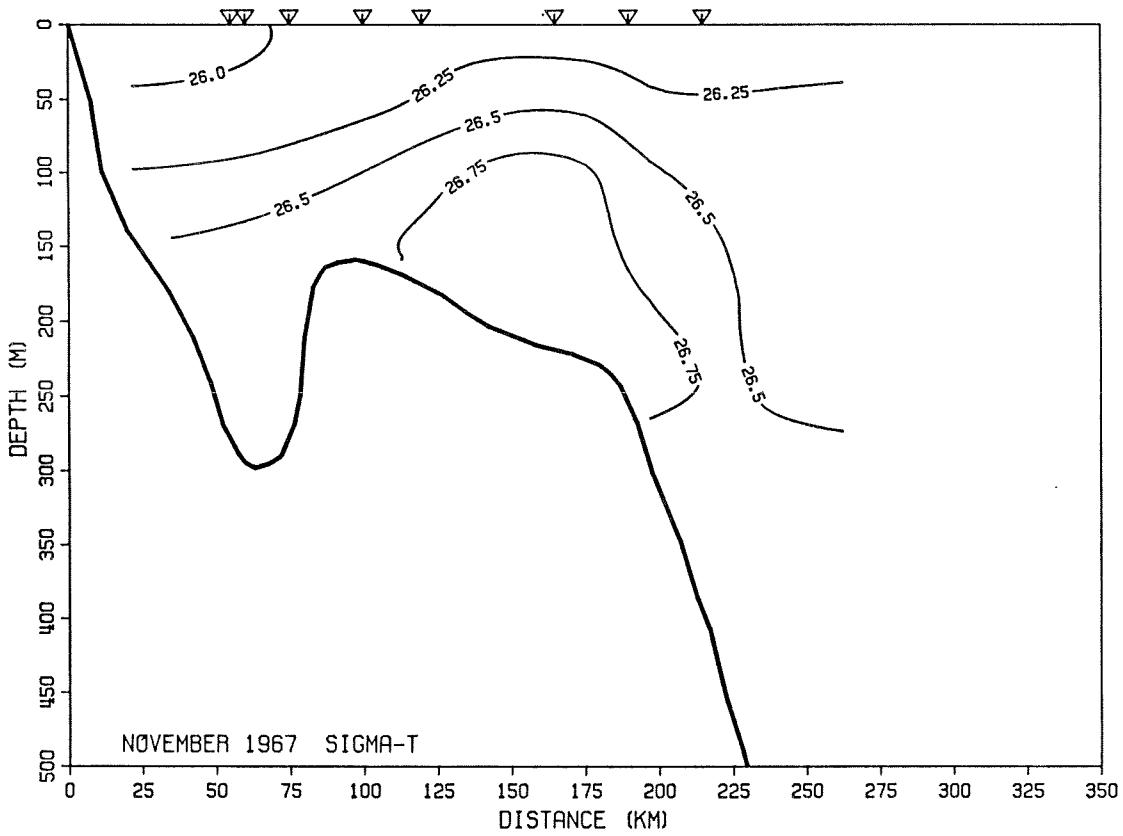
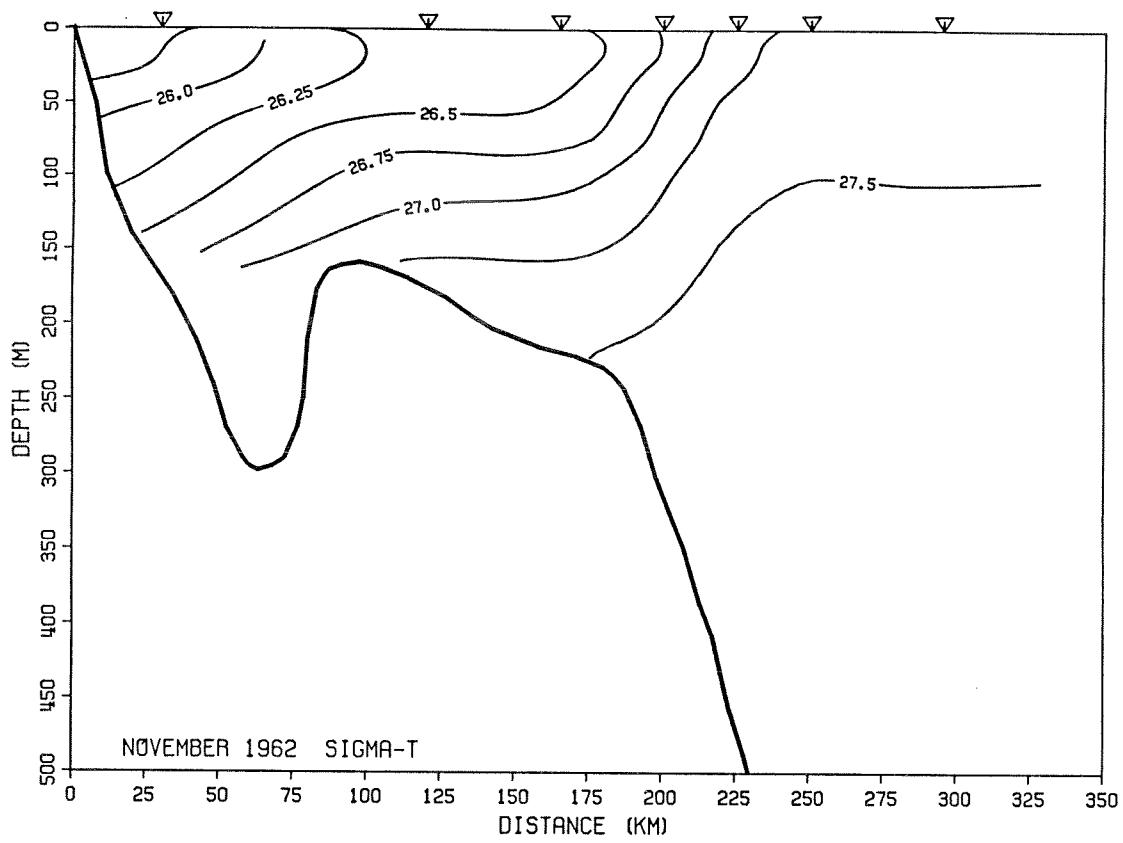


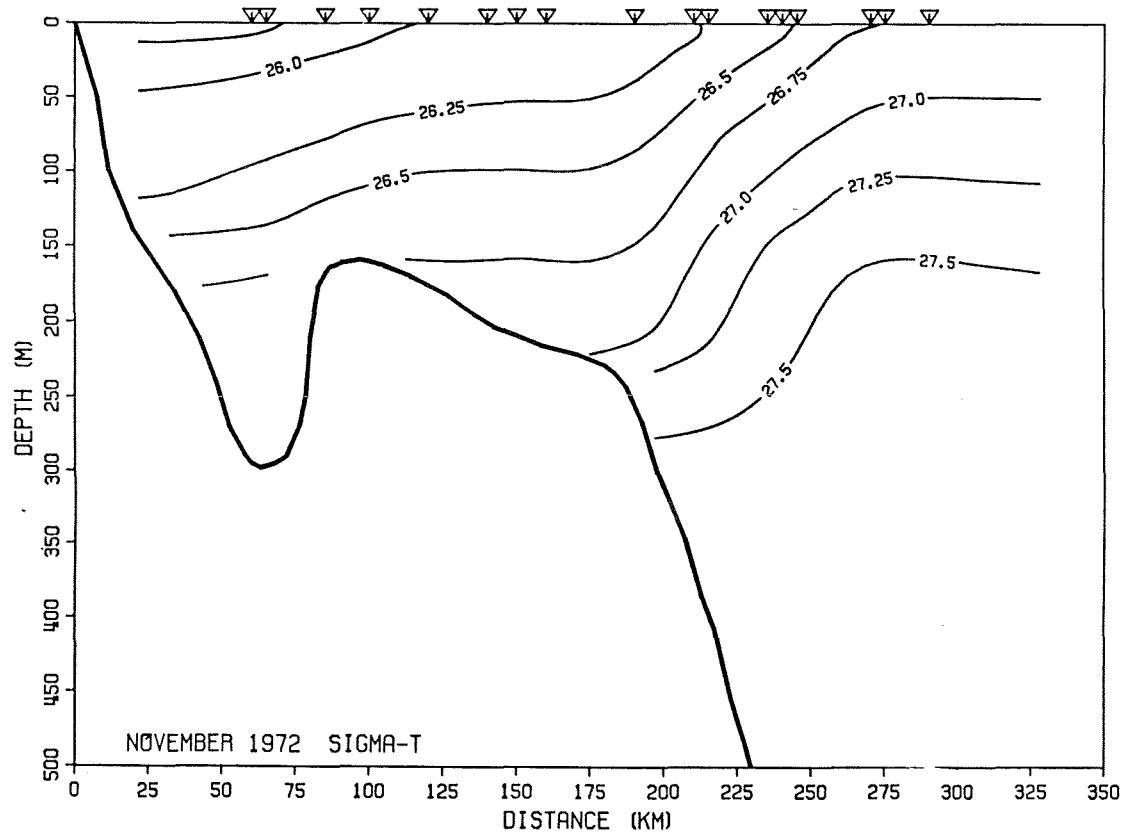
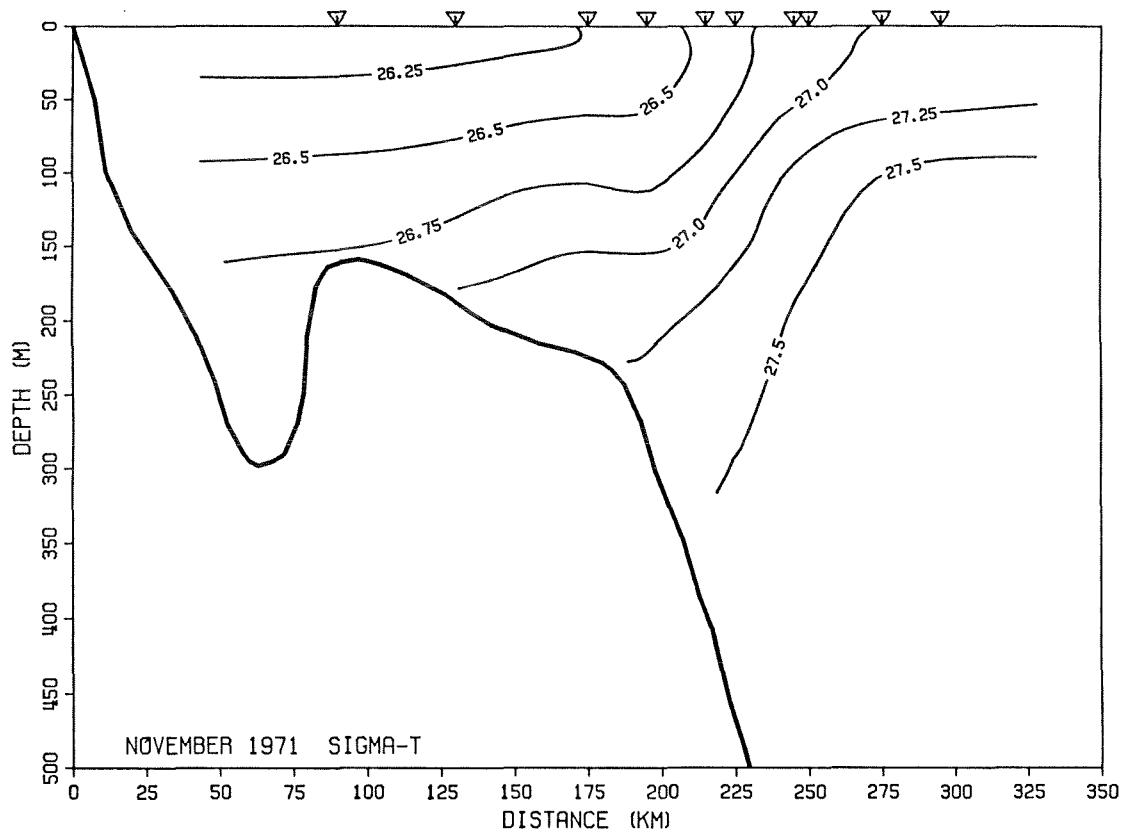


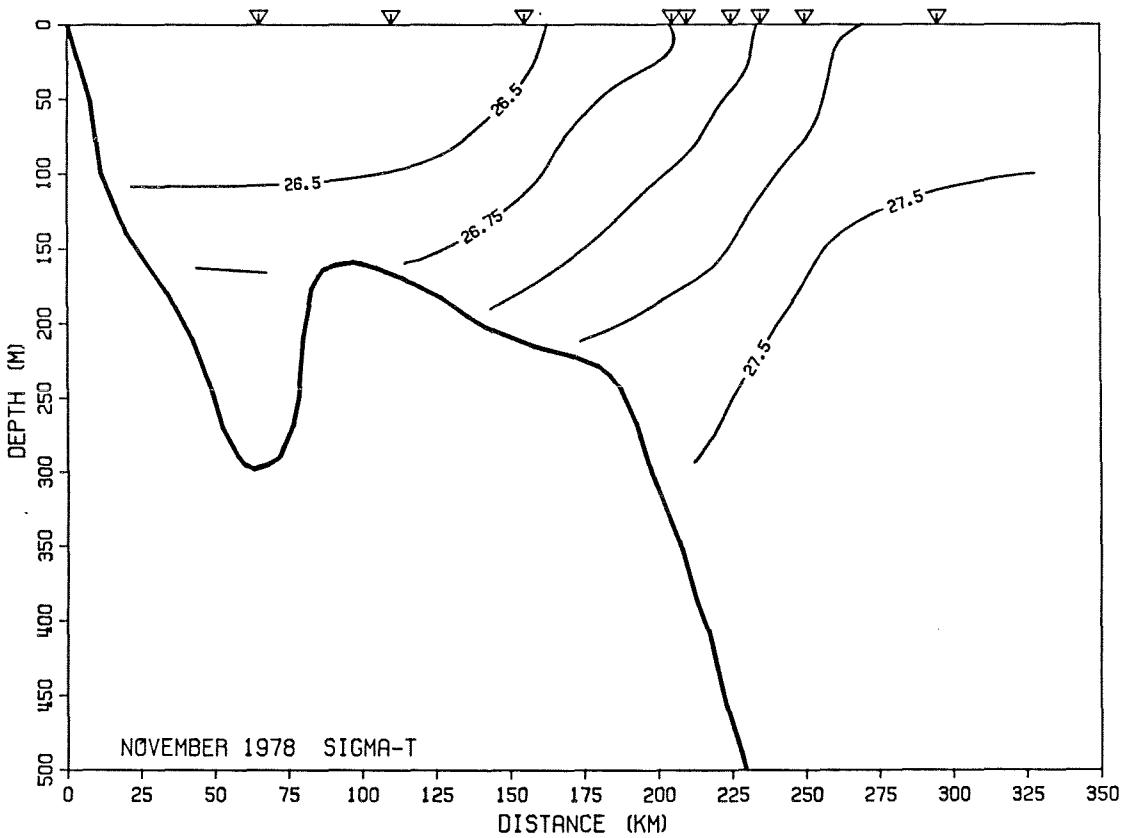
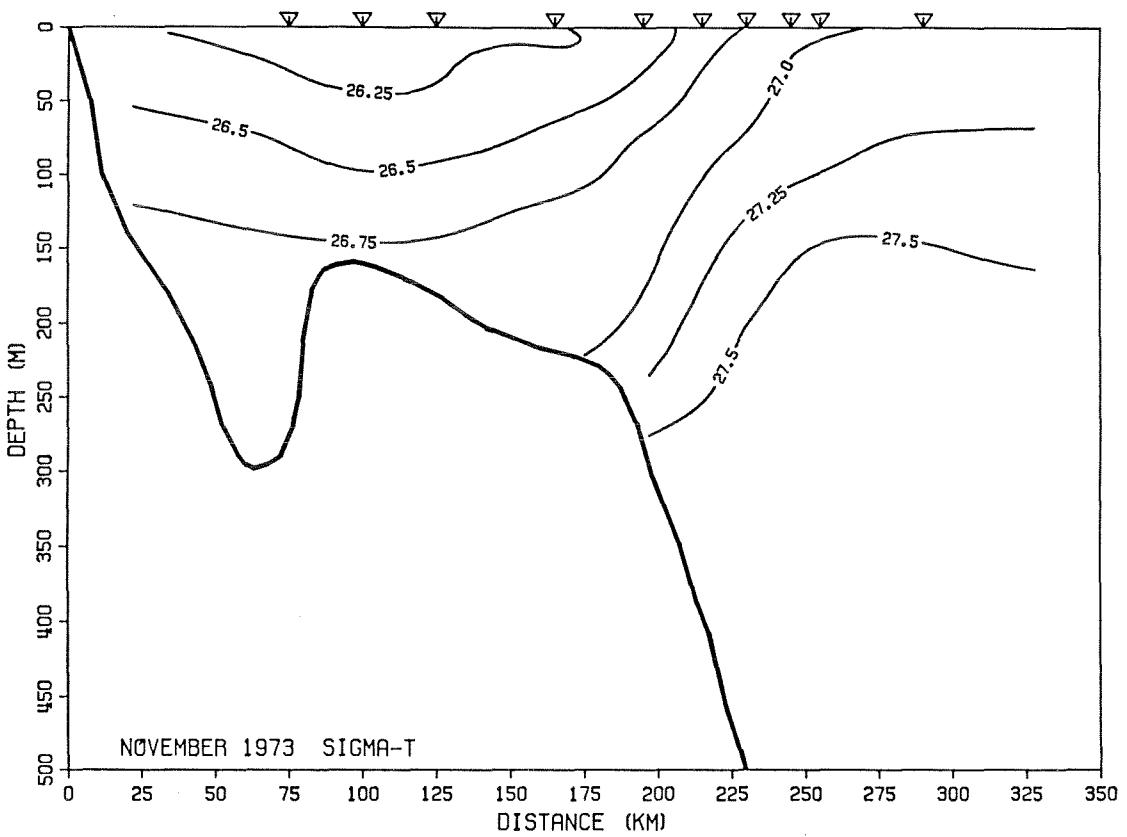
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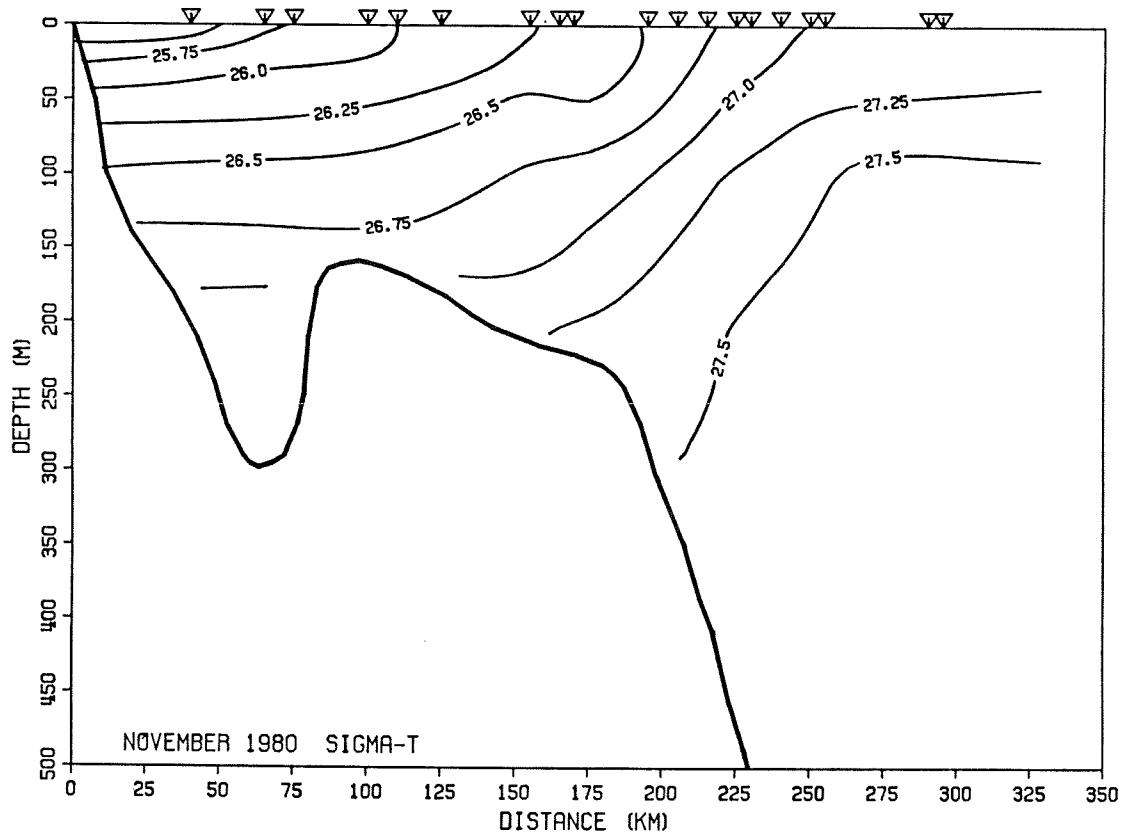
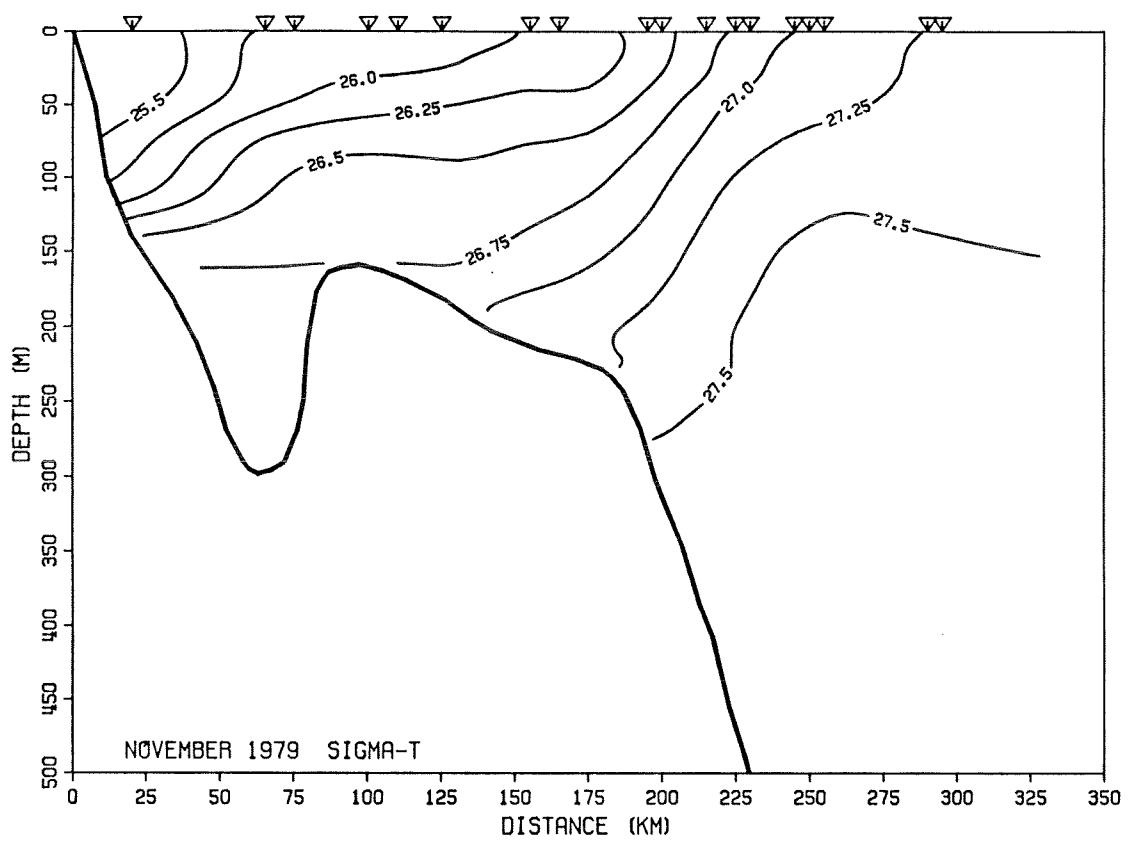


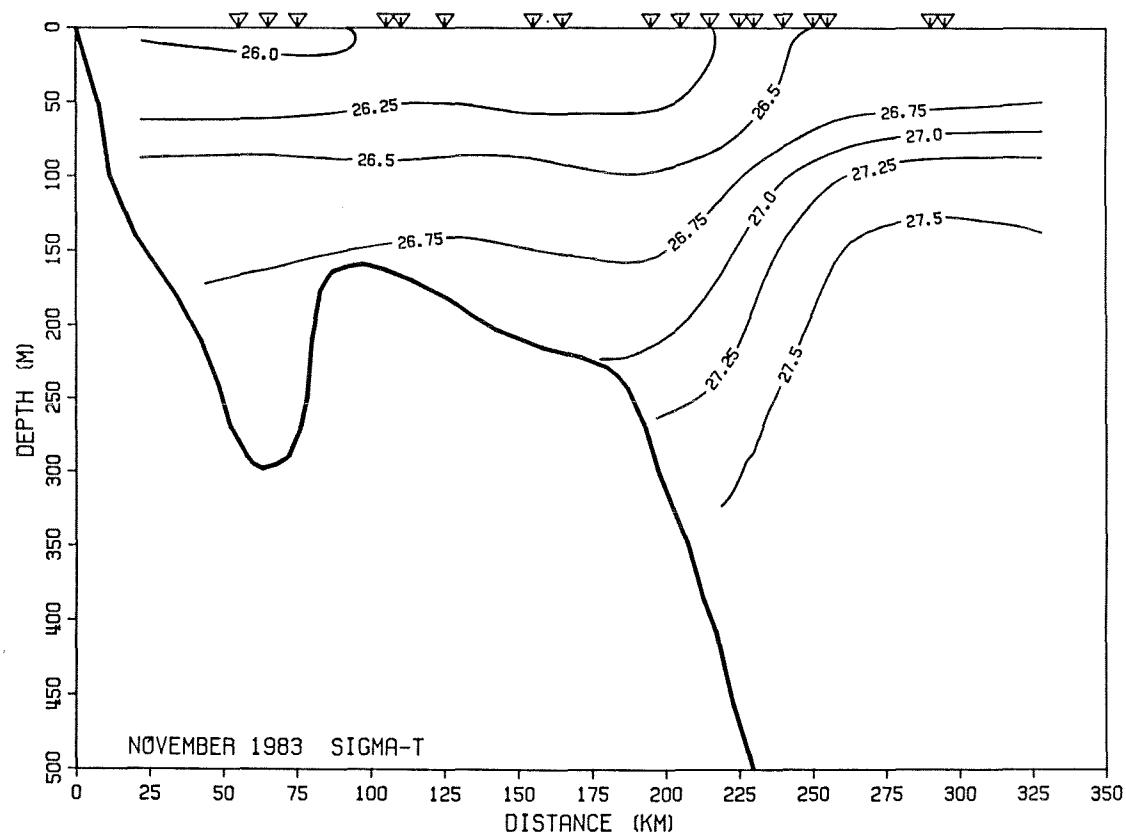
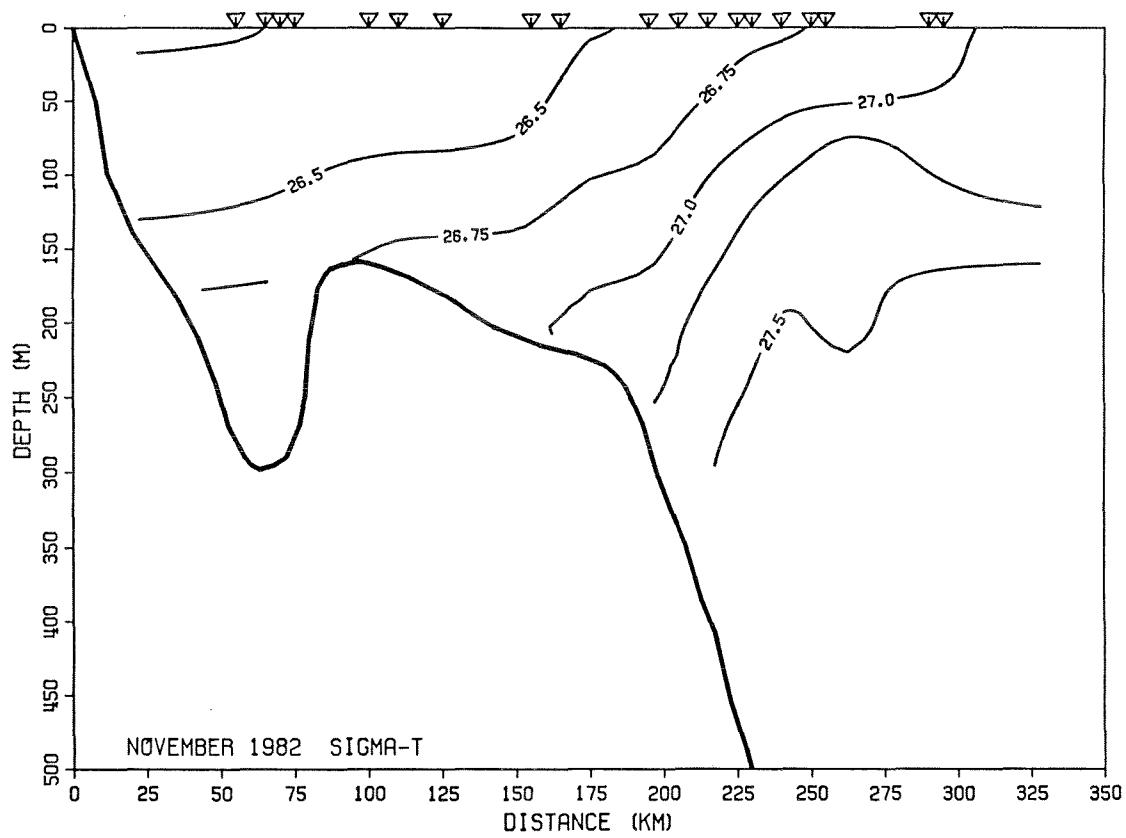


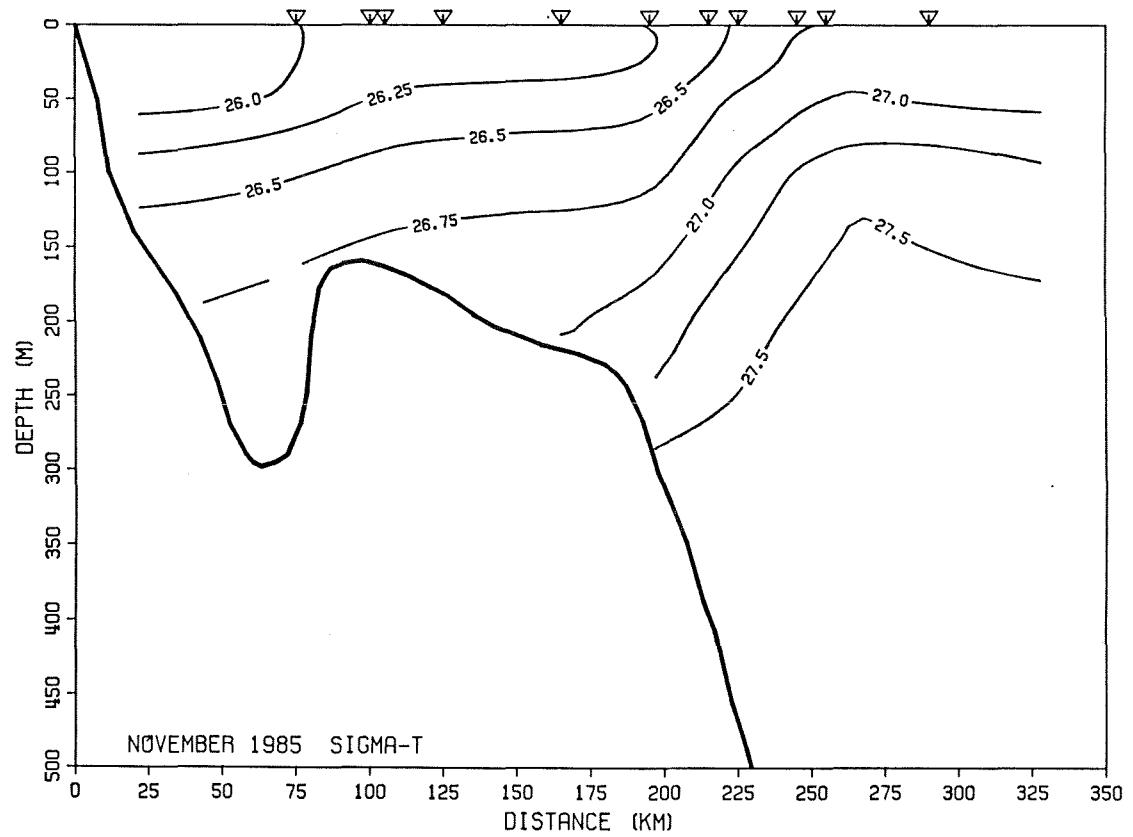
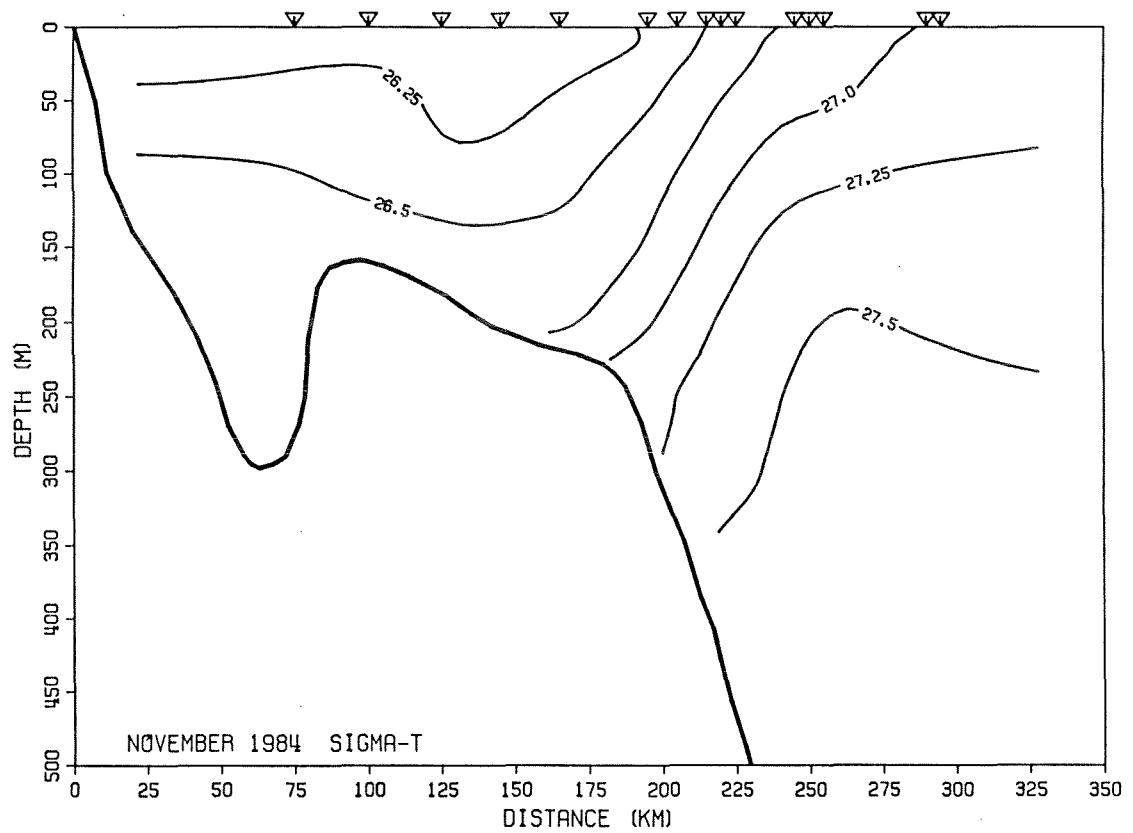


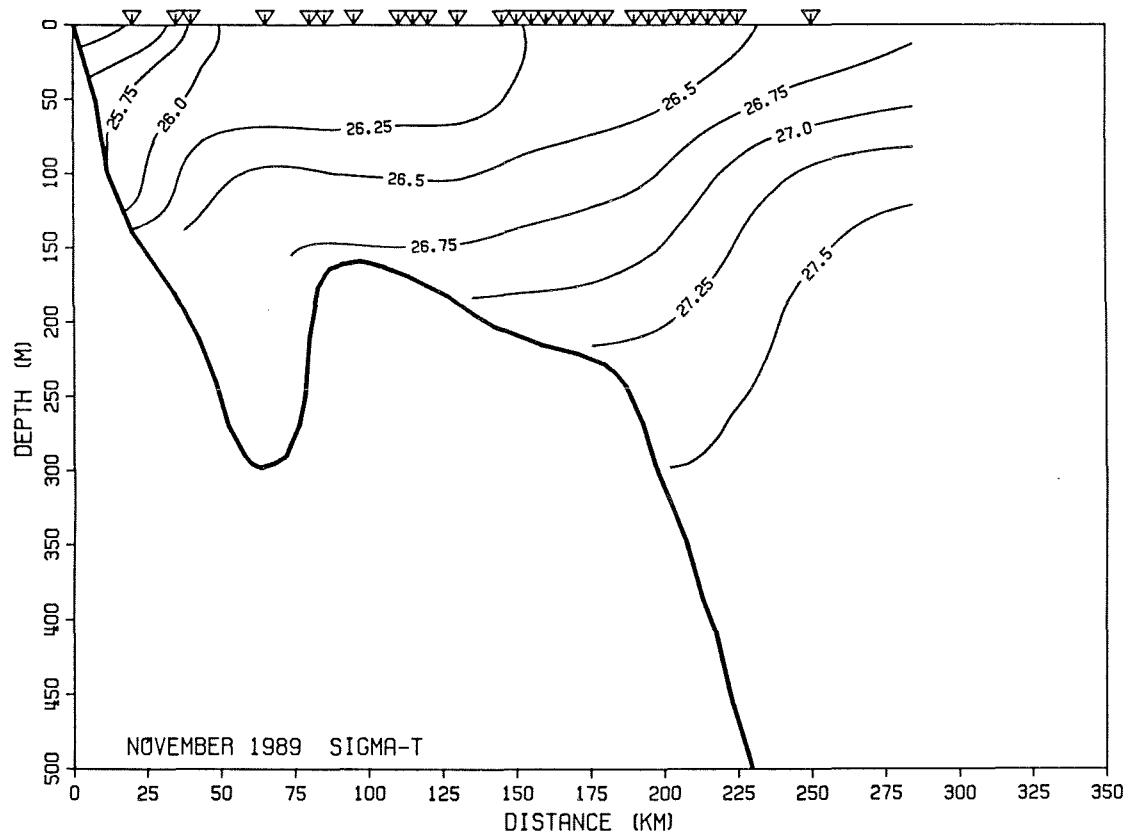
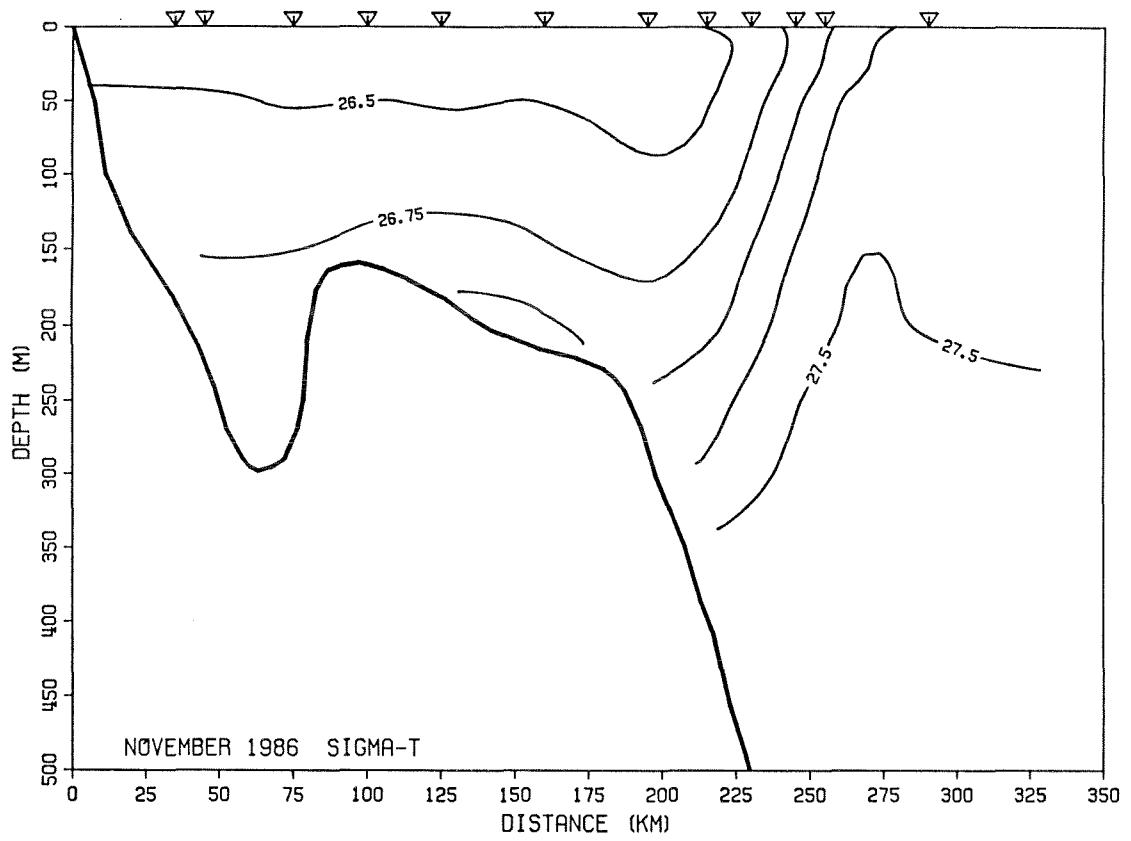


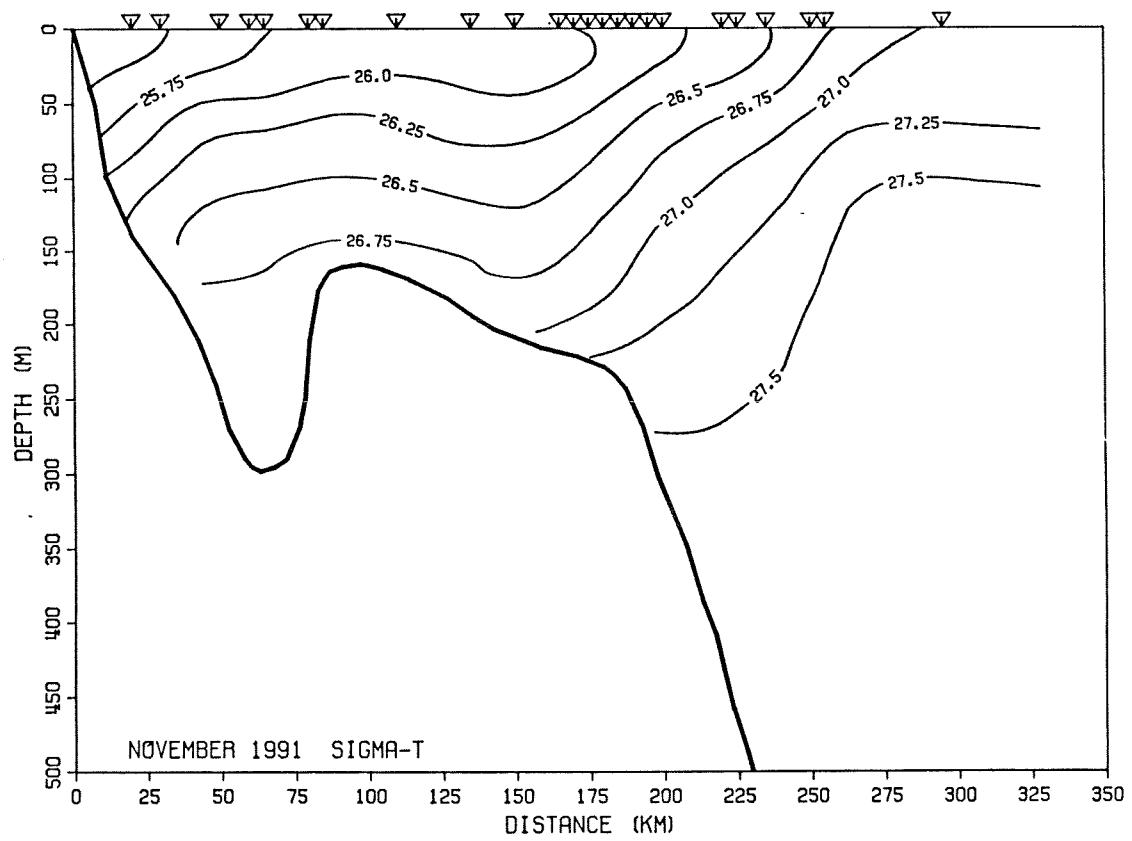
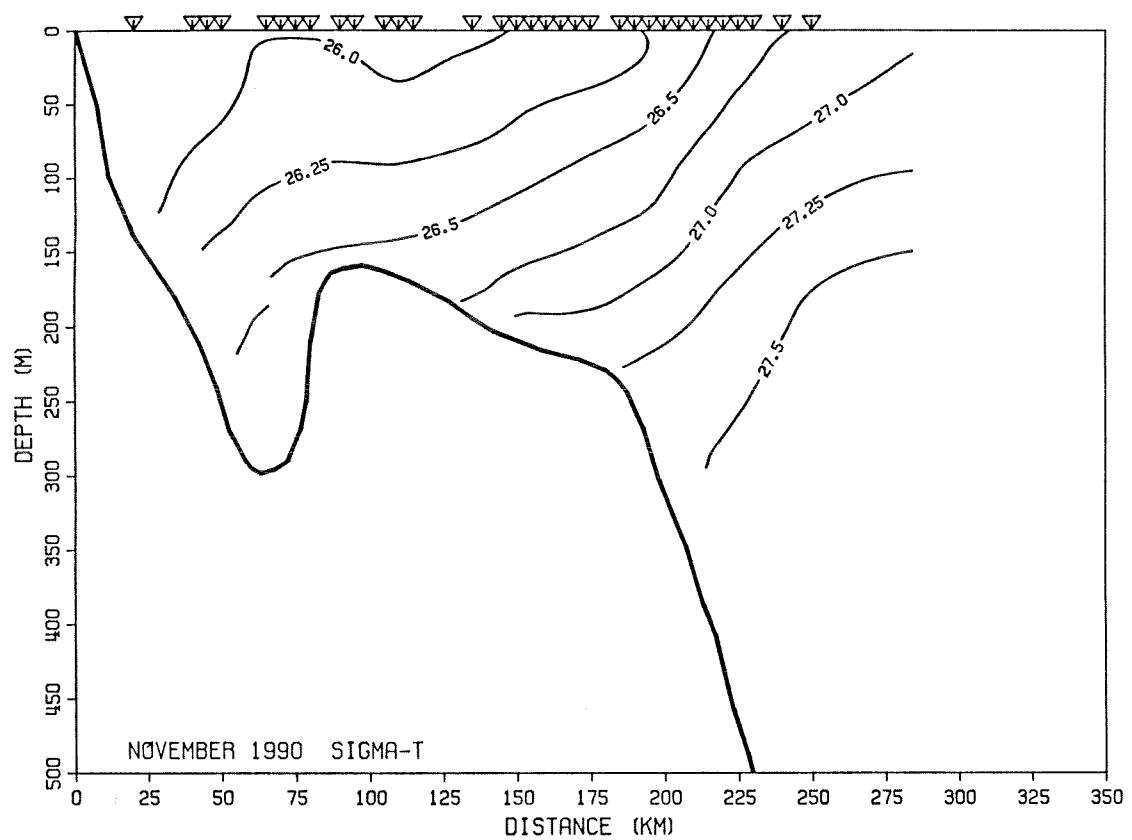
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