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TEMPERATURE, SALINITY AND DENSITY AT STATION 27 FROM 1978 TO 1993

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1994

**Canadian Technical Report of
Hydrography and Ocean Sciences
No. 159**



Fisheries
and Oceans

Pêches
et Océans

Canada

Canadian Technical Report of Hydrography and Ocean Sciences

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Canadian Data Report of Hydrography
and Ocean Sciences No. 159

April 1994

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From 1978 to 1993

by

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Cat. No. FS97-18/0000E ISSN 0711-6764

Correct citation for this publication:

Colbourne, E. B. and C. Fitzpatrick. 1994. Temperature, salinity
and density at Station 27 from 1978 to 1993. Can. Tech. Rep.
Hydrogr. Ocean Sci. No. 159: v + 117 p.

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ABSTRACT

Colbourne, E. B. and C. Fitzpatrick. 1994. Temperature, salinity and density at Station 27 from 1978 to 1993. Can. Tech. Rep. Hydrogr. Ocean Sci. No. 159: v + 117 p.

A review of the temporal distribution of the Station 27 (Latitude 47° 32.8' N, 52° 35.2' W) data set is presented. The seasonal cycles of temperature, salinity and density are presented based on a least squares harmonic regression of all available data. The 1978 to 1993 yearly mean temperature, salinity and density (σ_t) are presented at standard depths, as well as the mean annual temperature, salinity and density (as depth versus time contours) based on all available data from 1946 to 1993. The yearly time-series of temperature, salinity and density and their respective anomalies are also presented as depth versus time contours for 1978 to 1993. Finally, time-series of temperature, salinity and density anomalies are presented at standard depths from 1978 to 1993.

RÉSUMÉ

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On donne ici une vue d'ensemble de la distribution temporelle de la série de données provenant de la station 27 (47°32,8' de latitude nord et 52°35,2' de longitude ouest). Les cycles saisonniers de température, de salinité et de densité présentés sont fondés sur une régression harmonique des moindres carrés de toutes les données existantes. On fournit aussi les moyennes annuelles de température, de salinité et de densité (σ_t) aux profondeurs de référence de 1978 à 1993, ainsi que la moyenne annuelle de température, de salinité et de densité (sous forme de courbes profondeur-temps) fondée sur toutes les données dont on dispose pour la période 1946-1993. Les séries chronologiques annuelles de température, de salinité et de densité, et leurs anomalies respectives, sont également présentées sous forme de courbes profondeur-temps pour 1978-1993. De plus, le document comprend les séries chronologiques d'anomalies de température, de salinité et de densité aux profondeurs de référence de 1978 à 1993.

1. INTRODUCTION

Station 27 is the first hydrographic monitoring station in the standard St. John's to Flemish Cap transect established in 1946. It is located about 8 km off St. John's harbour Newfoundland (Fig. 1), in a water depth of 176 m. The position of this station is such that cold water ($< 0.0^{\circ}\text{C}$) that forms the cold intermediate layer (CIL) on the continental shelf is present year around in water depths from about 100 m to the bottom at 175 m. In recent years the station has been occupied on a regular basis mainly by oceanographic and fisheries research vessels at a frequency of about 2-4 times per month on average. Hence data from this location is invaluable in monitoring the seasonal and interannual variability in the core of the CIL as well as the upper water column.

Previous reviews of the Station 27 data set include a study by Huyer and Verney (1975) in which temperature, salinity and density data from 1950 to 1959 were presented. Keeley (1981a) extended the review from 1946 to 1977. Additional studies using the Station 27 data base have included extensive analysis of temperature and salinity variability along the east and northeast Newfoundland shelves (Bailey, 1961, Petrie et al. 1988, Petrie et al., 1991, Petrie et al. 1992, 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 Senciali (1993) have presented an analysis of the historical Bonavista transect data set and Keeley (1981b) has presented an analysis of the historical Flemish Cap data set from 1910 to 1980. The International Ice Patrol of the U.S. Coast Guard has 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).

This review of the physical oceanographic data at Station 27 complements and up-dates the earlier studies by Huyer and Verney (1975), Petrie et al. (1991,1992) and Keeley (1981a) by extending the review from 1978 to 1993. The results presented here concentrate mainly on data collected at Station 27 from 1978 to 1993, however the anomalies are referenced to the 1946 to 1993 average. The report includes a brief summary of the data sources, the temporal distribution of the data, analysis, and a brief discussion of some of the data products presented.

2. DATA

The data contained in this report were obtained from the Marine Environmental Data Service (MEDS) in Ottawa, Canada and the Northwest Atlantic Fisheries Center (NAFC) in St. John's Newfoundland, Canada. Most of the data were collected at standard oceanographic depths (0, 10, 20, 30, 50, 75, 100, 125, 150, and 175 m) using water sampling bottles fitted with reversing thermometers. Since the 1960s and up to the present a considerable amount of data were also collected using mechanical and electronic bathythermographs and since the late 1970s conductivity-temperature-depth (CTD) recorders have been used extensively. The expected accuracies of these data range from ± 0.2 °C in temperature for bathythermographs to ± 0.02 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. Densities are reported as sigma-t values calculated using the UNESCO equation of state for seawater (Millero, et al. 1980).

The distribution of temperature data collected among years is shown in Fig. 2a. The average number of profiles collected from 1946 to 1980 remained nearly constant at about 19. This accounts for about 50 % of the data set. Since 1980 and particularly during the last 3 years there has been a large increase in data collection with an average of 46 profiles per year or about 50 % of the data set. The largest number of temperature profiles collected in any one year occurred in 1992 when 79 profiles were collected.

The seasonal distribution of the historical data set shows a weak bias towards a maximum in spring and early summer to a minimum in the winter months but otherwise reasonably well sampled (Fig 2b). The number of profiles range from a minimum of 65 in January to a maximum of 161 in May with an average of 107 profiles per month over all years. About 19 % of the data were collected in the winter (December, January and February), 27 % in the spring (March, April and May), 28 % in the summer (June, July and August) and 26 % in the fall (September, October and November).

The distribution of salinity data shows similar patterns as temperature (Fig. 3), however the number of salinity profiles collected from 1980 to 1993 have not increased in parallel with temperature indicating an increase in the usage of expendable bathythermographs particularly during the 1980s.

3. ANALYSIS

The Station 27 data set were quality controlled for obvious spikes and range restricted. The profiles were not extrapolated beyond their depth range. Data for each day of the month were obtained by linear interpolation between actual observations during the month. For months in which no data were available either at the beginning or the end of the month, data from the preceding or following month were used in the interpolation. Monthly mean temperature, salinity and sigma-t values were then computed by summing all data over each month.

Some temporal biasing in the calculation of monthly averages are likely given the 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 possible temporal biasing arising from the sample distribution.

The data for all years were then sorted by Julian day to determine the seasonal cycle. Following the general methods of Akenhead (1987) and Myers et al. (1990) the seasonal cycles in temperature, salinity and density fields at selected water depths were determined by fitting a least-squares regression to the data. The fitted values were the mean and 4 sines and cosines pairs representing 4 harmonics (1, 1/2, 1/3 and 1/4 years). The amplitude of the seasonal cycle is then plotted by summing the mean and the 4 sine and cosine terms of the form $c_i \cos(\omega t)$ and $s_i \sin(\omega t)$, where ω is the frequency ($2\pi/T$), T in this equation is the period of the i^{th} harmonic, t is the day of the year and c_i and s_i are the least-squares fitted coefficients. The amplitude and phase of each harmonic are given by $(c_i^2 + s_i^2)^{1/2}$ and $\tan^{-1}(s_i/c_i)$ respectively.

Tables 1 to 6 list the regression coefficients, the mean and the amplitude and phase for each harmonic based on all data from 1946 to 1993 at standard oceanographic depths. Appendix A contains plots of the seasonal cycles of temperature, salinity and sigma-t at the selected depths. To show the degree of scatter about the fitted seasonal cycles, the historical data is also plotted for each depth.

Time series of temperature, salinity and sigma-t anomalies were then formed by taking each observation and subtracting the amplitude of the least squares fitted value of the seasonal cycle for the same day of the year. The time series of anomalies were then low pass filtered to highlight interannual variations and to suppress the high frequency variations shorter than a season.

4. DATA PRODUCTS

Appendix B contains yearly averages of temperature, salinity and sigma-t at standard oceanographic depths as bar graphs. The mean annual time series of temperature, salinity and density versus depth are shown in Appendix C contoured from all available data from 1946 to 1993. These plots show the seasonal variations in the temperature, salinity and density fields in the inshore branch of the Labrador current along the Canadian Atlantic coast.

The whole water column is below 0.0 °C from January until mid April in the upper 30 m of the water column and throughout the year at depths below approximately 100 m. The seasonal warming in the upper layer commences by early May and continues to warm at a rate of about 0.1 °C per day until late August to early September when it reaches its maximum of about 12.0 °C at the surface. The thickness of the seasonally warmed upper layer reaches a maximum of about 50 to 60 m by early November by which time the surface layer is already cooling down.

The salinities in the inshore areas range from 32.0 psu in the upper water column to 33.3 psu near the bottom from January to June after which the upper layers experience a gradual freshening with salinities reaching a minimum of 31.2 psu by late September. In the deeper water (below 150 m) the salinities remain above 33.0 psu over the entire year. At cold water temperatures the density field is mainly determined by salinity and so the isopycnals generally follow isohalines.

Presented in Appendices D though F are the yearly time series from 1978 to 1993 of the vertical distributions of temperature, salinity and density and anomalies versus time from all available data for each year. The anomalies are referenced to the annual cycles determined from the 1946 to 1993 data time series at standard depths. Appendices G to I contain the 1978 to 1993 time series of temperature, salinity and density anomalies at standard oceanographic depths.

The time series of temperature anomalies at Station 27 at various standard depths are characterized by major cold periods: early to mid 1980s and the early 1990s. The time series exhibit lower frequency variations in the anomalies in deeper water compared to the shallower depths consistent with the slower response of the deeper water to atmospheric forcing. During 1984 in the top 50 m of the water column and early 1983 in the deeper water, intense negative temperature anomalies occurred with peak amplitudes reaching -3.0 °C at 30 m depth by late 1984. This cold period lasted until mid 1986 over most depths. By late 1986 near the bottom, by 1990 at mid depths and by early 1991 in the

surface layers the temperature again fell below normal. In the upper layers the negative temperature anomalies that began in late 1990 and reached a peak of -4.0 °C in mid 1991 have continued into summer of 1993; for example at 20.0 m depth temperature anomalies were about -2.0 °C in early June, indicating a delayed warming of the surface water. In general deep water temperature anomalies have persisted at Station 27 since 1983 with a few periods of positive anomalies during the mid to late 1980s.

The corresponding salinity anomalies during these same cold periods show fresher than normal conditions with anomalies ranging from -0.25 to -0.80 psu over the upper water column. From 1986 to 1989 the anomalies range from about normal in 1986 to generally positive (saltier than normal) in other years. In 1990 the salinity anomalies remained positive in the upper layer but had reversed to slightly fresher in deeper water and by 1991 the freshening extended over the entire water column, a trend continuing to mid 1993. Again the most intense anomalies are restricted to the upper layer where the influence of ice melt is the largest.

Acknowledgements

This work has been supported through the Government of Canada's Atlantic Fisheries Adjustment Program (Northern Cod Science Program). We thank Drs G. Mertz and S. Narayanan for their helpful reviews and comments. We would also like to thank the many scientists and technicians who have contributed to the station 27 data base over the years.

REFERENCES

- Akenhead, S. 1987. Temperature and Salinity off Newfoundland: Station 27 annual cycle and residuals. NAFO SCR Doc. 87/66, 20 p.
- Bailey, W. B. 1961. Annual variations of the temperature and salinity in the Grand Banks region. Fish. Res. Board Canada, Manuscript Rep. Ser. No. 74: 30 pp.
- Colbourne, E. and D. R. Senciall. 1993. Temperature, salinity and density along the standard Bonavista transect. Can. Tech. Rep. Hydrogr. Ocean Sci. 150: v + 311 p.

- Drinkwater, K. F., and R. W. Trites. 1986. Monthly means of temperature and salinity in the Grand Banks region. Can. Tech. Rep. Fish. Aquat. Sci. 1450:iv + 111 p.
- Huyer, A., and A. Verney. 1975. Temperature, salinity and sigma-t at Station 27, 1950-1959. Mar. Environ. Data Serv. Tech. Rep. No. 3: 45 pp
- Keeley, J. R. 1981a. Temperature, salinity and sigma-t at Station 27. An analysis of historical data. Mar. Environ. Data Serv. Tech. Rep. No. 8: 56 pp.
- Keeley, J. R. 1981b. Mean conditions of potential temperature and salinity along the Flemish Cap section. Mar. Environ. Data Serv. Tech. Rep. No. 9: 148 pp.
- Kollmeyer, R. C., R. M. O'Hagan, R. M. Morse, D. A. McGill, and N. Corwin. 1965. Oceanography of the Grand Banks region and the Labrador Sea in 1964. U. S. Coast Guard Oceanography Rep. No. 10, CG 373-10: 285 pp.
- Millero, F.J., Chen, C.T., Bradshaw, A. and Schleicher, K. A High Pressure Equation of State for Seawater, Deep Sea Res., 27A 255-265, 1980.
- Myers, R. A., S. A. Akenhead, and K. Drinkwater. 1990. The Influence of Hudson Bay Runoff and Ice-Melt on the Salinity of the Inner Newfoundland Shelf. Atmos.- Ocean 28, No 2: pp. 120-157.
- Petrie, B., S. Akenhead, J. Lazier and J. Loder. 1988. The Cold Intermediate Layer on the Labrador and Northeast Newfoundland Shelves, 1978-1986. NAFO Sci. Coun. Stu. 12: 57-69.
- Petrie, B., J. Loder, S. Akenhead. and J. Lazier. 1991. Temperature and salinity variability on the eastern Newfoundland shelf: the annual harmonic. Atmos.- Ocean 29: 14-36.
- Petrie, B., J. Loder, J. Lazier and S. Akenhead. 1992. Temperature and salinity variability on the eastern Newfoundland shelf: the residual field. Atmos.- Ocean 30: 120-157.
- Templeman, W. 1975. Comparison of temperatures in July-August hydrographic sections of the eastern Newfoundland areas in 1972 and 1973 with those from 1951 to 1971, ICNAF Spec. Publ., 10:17-39.

DEPTH	C1	S1	C2	S2	C3	S3	C4	S4	MEAN
0	-3.5392	-5.9076	-0.3296	1.2442	0.15701	-0.30632	-0.11784	0.06015	4.6163
10	-3.1981	-5.8953	-0.4262	1.1327	0.18915	-0.18934	-0.04392	0.01969	4.3353
20	-1.8686	-5.2059	-0.9360	0.2943	0.16620	0.43220	0.26388	-0.26020	3.4396
30	-0.4556	-4.0319	-1.0425	-0.6120	-0.20337	0.62417	0.46674	-0.04366	2.3030
50	0.8110	-2.2071	-0.4956	-1.1710	-0.40103	0.12504	0.03238	0.14749	0.5906
75	0.9295	-0.9223	0.2037	-0.7405	-0.02827	-0.29196	-0.07681	-0.10333	-0.4046
100	0.7618	-0.3396	0.3767	-0.3042	0.20848	-0.18618	0.07516	-0.13412	-0.8646
125	0.5327	-0.0599	0.3167	-0.0651	0.21024	-0.04173	0.11259	-0.04630	-1.1075
150	0.3181	0.1054	0.1506	0.0618	0.07568	0.05075	0.05478	0.01351	-1.0881
175	0.1665	0.1503	0.0287	0.0812	-0.01329	0.05276	0.02756	0.02543	-0.9616

Table 1. Harmonic regression coefficients by standard depths for annual cycle of temperature at station 27.

DEPTH	C1	S1	C2	S2	C3	S3	C4	S4	MEAN
0	0.0301	0.6562	0.0702	0.0147	-0.00509	-0.03558	-0.00044	0.00449	31.7359
10	-0.0086	0.6737	0.0800	0.0233	0.00102	-0.05175	-0.01256	0.02311	31.7549
20	-0.1089	0.6195	0.1112	0.0800	0.01079	-0.08716	-0.03594	0.02880	31.8581
30	-0.2268	0.5037	0.1243	0.1376	0.04025	-0.09574	-0.03892	0.00895	32.0012
50	-0.3558	0.2776	0.0537	0.1747	0.05231	-0.02697	-0.01603	-0.01146	32.2714
75	-0.3258	0.0476	-0.0514	0.0871	-0.01126	0.03378	-0.00303	0.02596	32.5292
100	-0.2398	-0.0379	-0.0515	0.0146	-0.03671	0.01513	-0.01611	0.02945	32.7146
125	-0.1577	-0.0644	-0.0406	-0.0091	-0.03338	0.00373	-0.02276	0.01473	32.8632
150	-0.0705	-0.0746	-0.0025	-0.0227	-0.01148	0.00561	0.00100	0.01685	33.0230
175	-0.0260	-0.0920	-0.0003	-0.0239	-0.00944	0.00234	-0.00216	0.01695	33.1683

Table 2. Harmonic regression coefficients by standard depths for annual cycle of salinity at station 27.

DEPTH	C1	S1	C2	S2	C3	S3	C4	S4	MEAN
0	0.4296	1.1603	0.1424	-0.2483	-0.06398	0.02167	0.03358	-0.00624	24.9980
10	0.3496	1.1547	0.1684	-0.2152	-0.06088	-0.01202	0.01255	0.01732	25.0451
20	0.0915	0.9954	0.2490	-0.0316	-0.03458	-0.13515	-0.06241	0.05886	25.2456
30	-0.1495	0.7464	0.2424	0.1383	0.05127	-0.15972	-0.08866	0.00753	25.4906
50	-0.3412	0.3674	0.0961	0.2212	0.08801	-0.03869	-0.01302	-0.03139	25.8583
75	-0.3081	0.0821	-0.0501	0.1115	-0.00251	0.04579	0.00696	0.02633	26.1327
100	-0.2238	-0.0177	-0.0579	0.0266	-0.03870	0.02198	-0.01482	0.03064	26.3056
125	-0.1456	-0.0496	-0.0452	-0.0040	-0.03585	0.00530	-0.02218	0.01397	26.4334
150	-0.0673	-0.0642	-0.0074	-0.0194	-0.01241	0.00247	-0.00062	0.01266	26.5661
175	-0.0271	-0.0801	-0.0026	-0.0216	-0.00904	-0.00028	-0.00343	0.01253	26.6794

Table 3. Harmonic regression coefficients by standard depths for annual cycle of density at station 27.

Depth(m)	A_1	ϕ_1	A_2	ϕ_2	A_3	ϕ_3	A_4	ϕ_4	A_0
0	6.89	243	1.29	53	0.34	100	0.13	39	4.62
10	6.71	245	1.21	56	0.27	107	0.05	40	4.34
20	5.53	254	0.98	82	0.46	143	0.37	80	3.44
30	4.06	267	1.21	107	0.66	157	0.47	90	2.30
50	2.35	294	1.27	125	0.42	175	0.15	110	0.59
75	1.31	320	0.77	145	0.29	209	0.13	149	.40
100	0.83	341	0.48	163	0.28	228	0.15	166	-.86
125	0.54	359	0.32	177	0.21	238	0.12	176	-1.11
150	0.34	19	0.16	191	0.09	251	0.06	184	-1.09
175	0.22	43	0.09	216	0.05	275	0.04	191	-.96

Table 4. The mean (A_0 °C) and the amplitude (in °C) and phase (days) of the annual (A_1) and 3 harmonics of temperature by standard depths at Station 27.

Depth(m)	A_1	ϕ_1	A_2	ϕ_2	A_3	ϕ_3	A_4	ϕ_4	A_0
0	0.66	89	0.07	6	0.04	89	0.00	24	31.74
10	0.67	92	0.08	8	0.05	92	0.03	30	31.75
20	0.63	101	0.14	18	0.09	94	0.05	36	31.86
30	0.55	116	0.19	24	0.10	99	0.04	42	32.00
50	0.45	144	0.18	37	0.06	113	0.02	55	32.27
75	0.33	174	0.10	61	0.04	157	0.03	25	32.53
100	0.24	192	0.05	83	0.04	173	0.03	30	32.71
125	0.17	205	0.04	98	0.03	179	0.03	37	32.86
150	0.10	230	0.02	134	0.01	172	0.02	22	33.02
175	0.10	258	0.02	137	0.01	176	0.02	25	33.17

Table 5. The mean (A_0) and the amplitude and phase of the annual (A_1) and 3 harmonics of salinity by standard depths at Station 27.

Depth(m)	A_1	ϕ_1	A_2	ϕ_2	A_3	ϕ_3	A_4	ϕ_4	A_0
0	1.24	71	0.29	152	0.07	55	0.03	89	25.00
10	1.21	74	0.27	156	0.06	65	0.02	104	25.05
20	1.00	86	0.25	179	0.14	86	0.09	125	25.25
30	0.76	103	0.28	195	0.17	97	0.09	134	25.49
50	0.50	135	0.24	214	0.10	114	0.03	153	25.86
75	0.32	167	0.12	238	0.05	151	0.03	199	26.13
100	0.22	187	0.06	259	0.04	171	0.03	209	26.31
125	0.15	202	0.05	274	0.04	178	0.03	217	26.43
150	0.09	227	0.02	306	0.01	177	0.01	204	26.57
175	0.08	255	0.02	313	0.01	181	0.01	207	26.68

Table 6. The mean (A_0) and the amplitude and phase of the annual (A_1) and 3 harmonics of density by standard depths at Station 27.

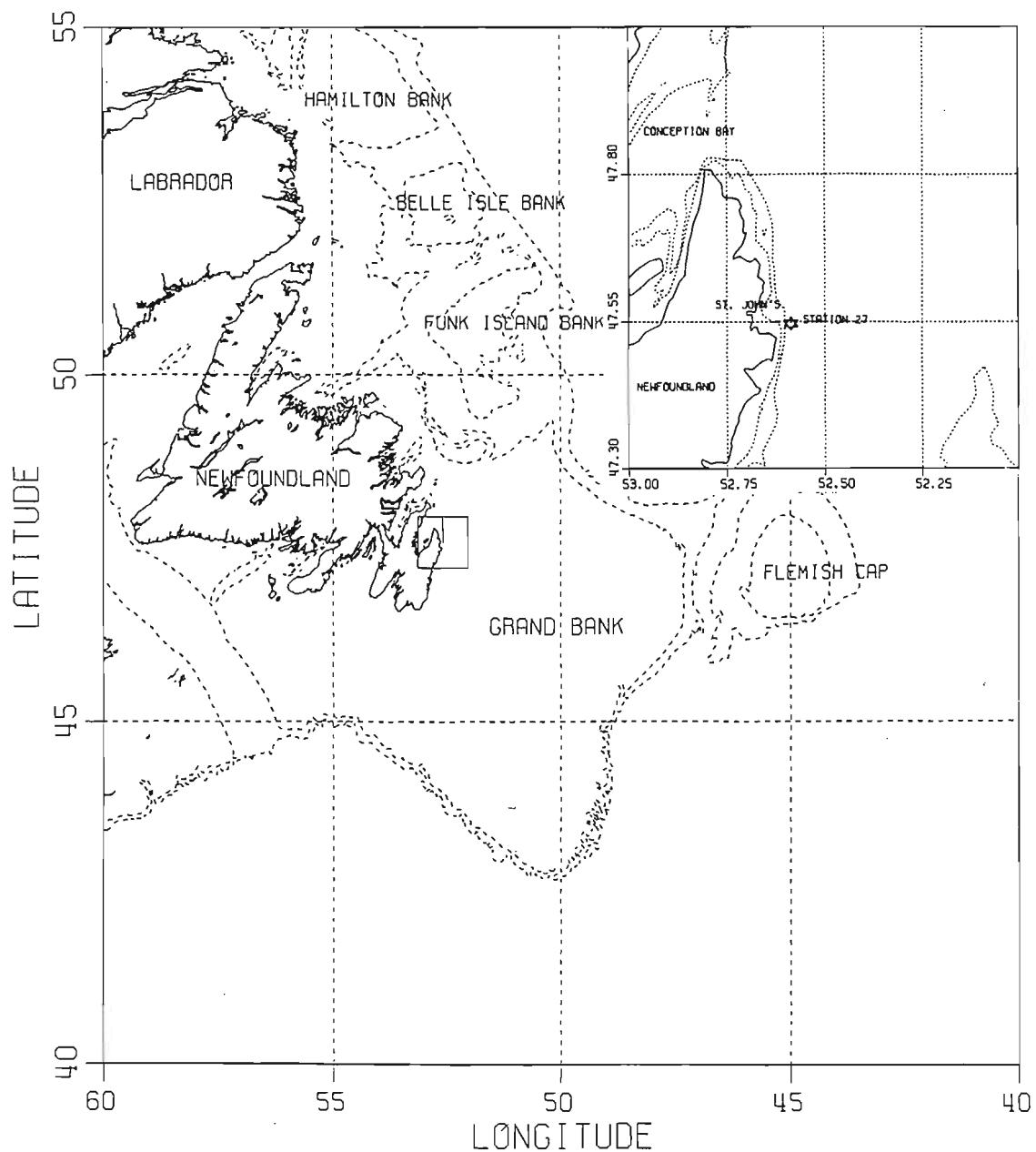


Fig. 1. Location map of the general area and the position of Station 27 (inset). The bathymetry lines are 300 and 1000 m (100 and 150 m inset).

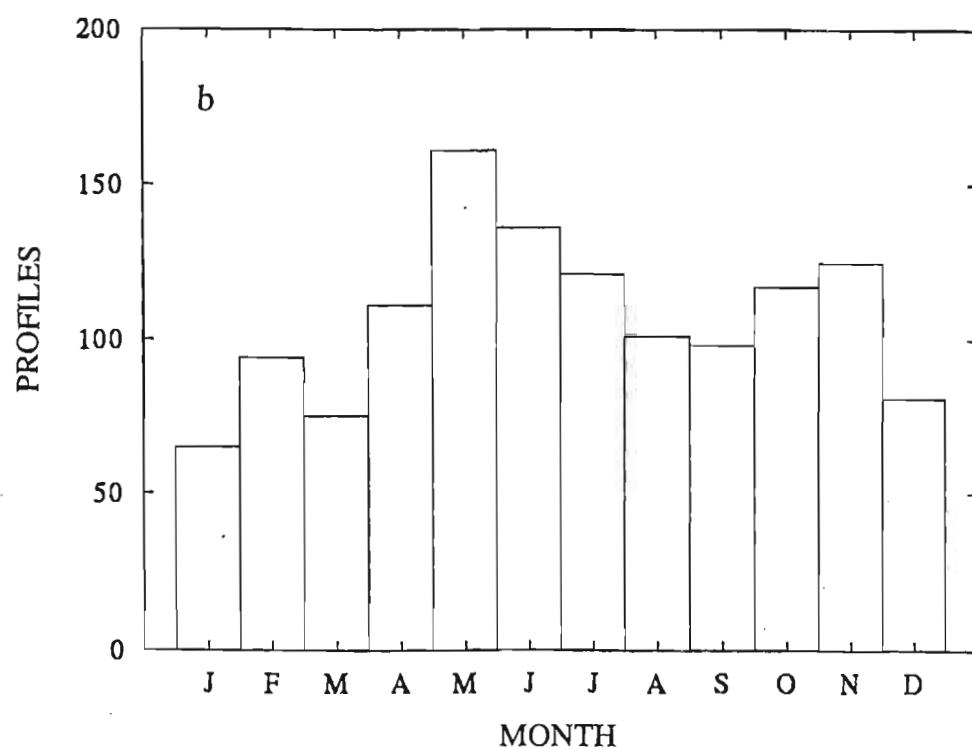
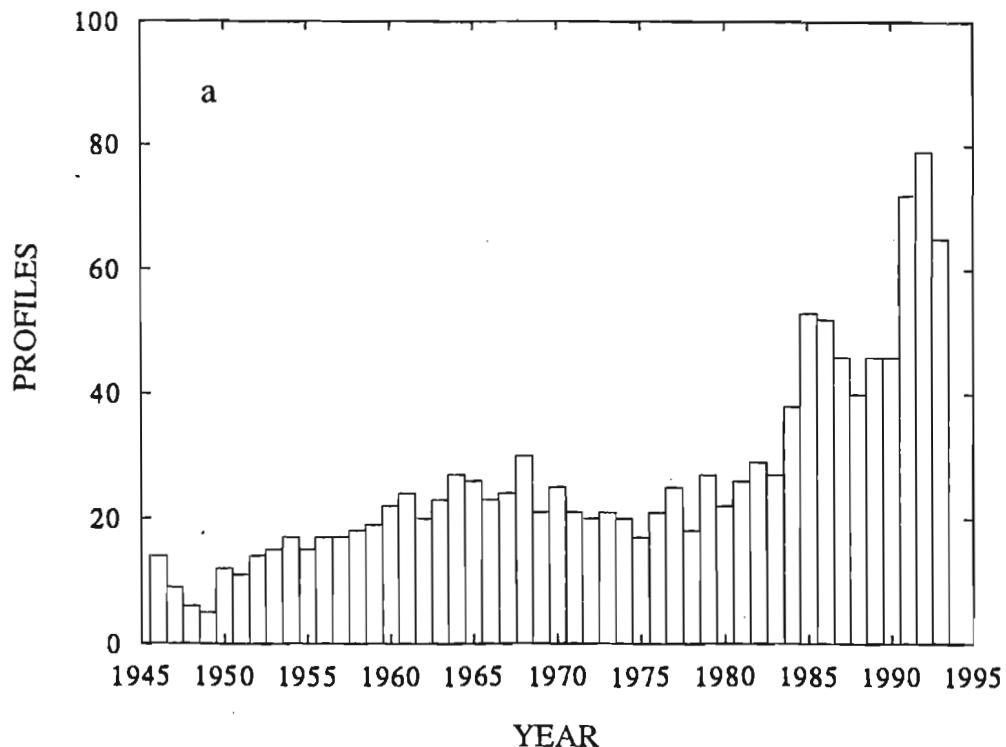


Fig. 2. The total number of Station 27 temperature profiles by (a) year and (b) by month from 1946 to 1993.

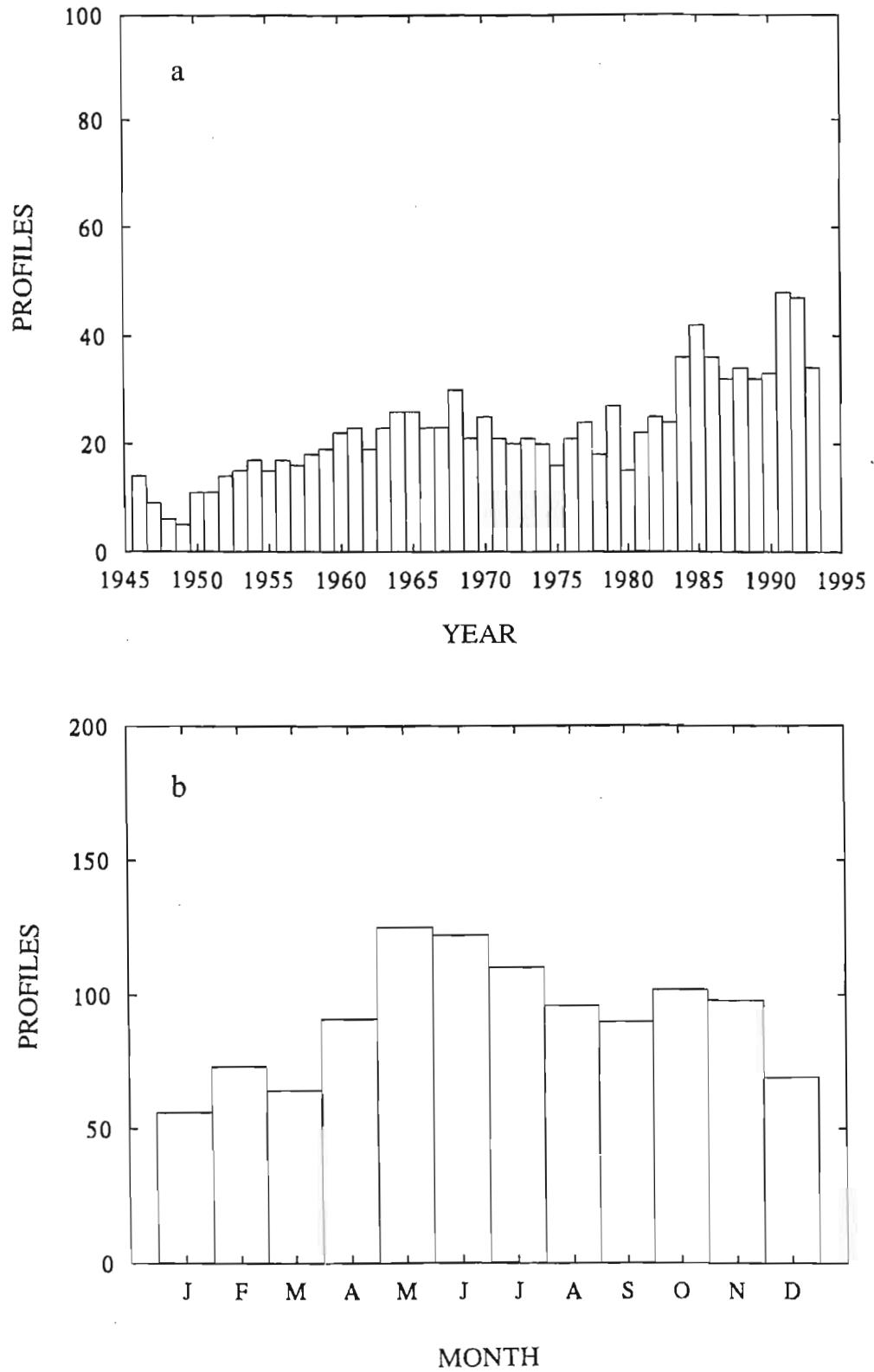
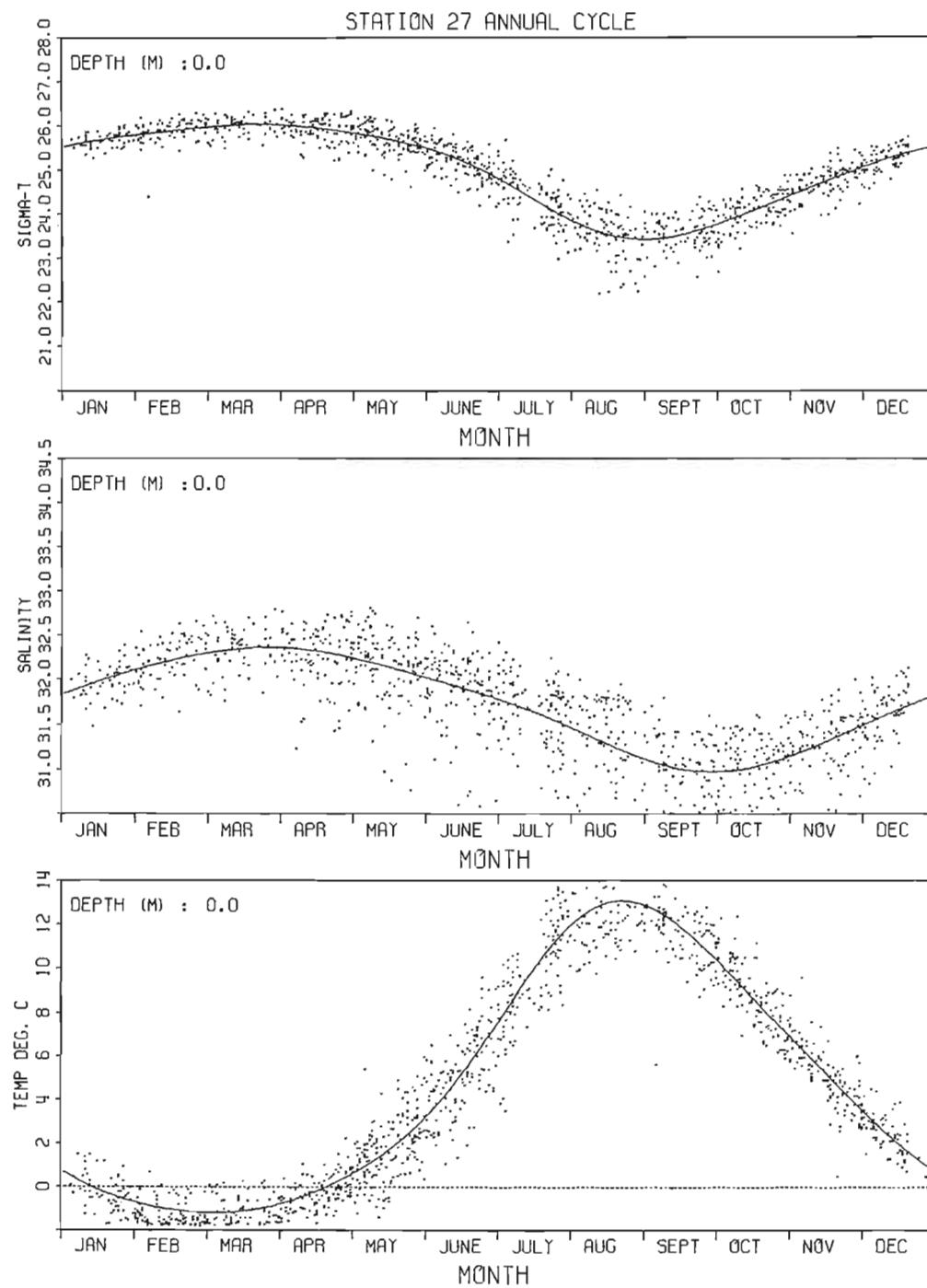
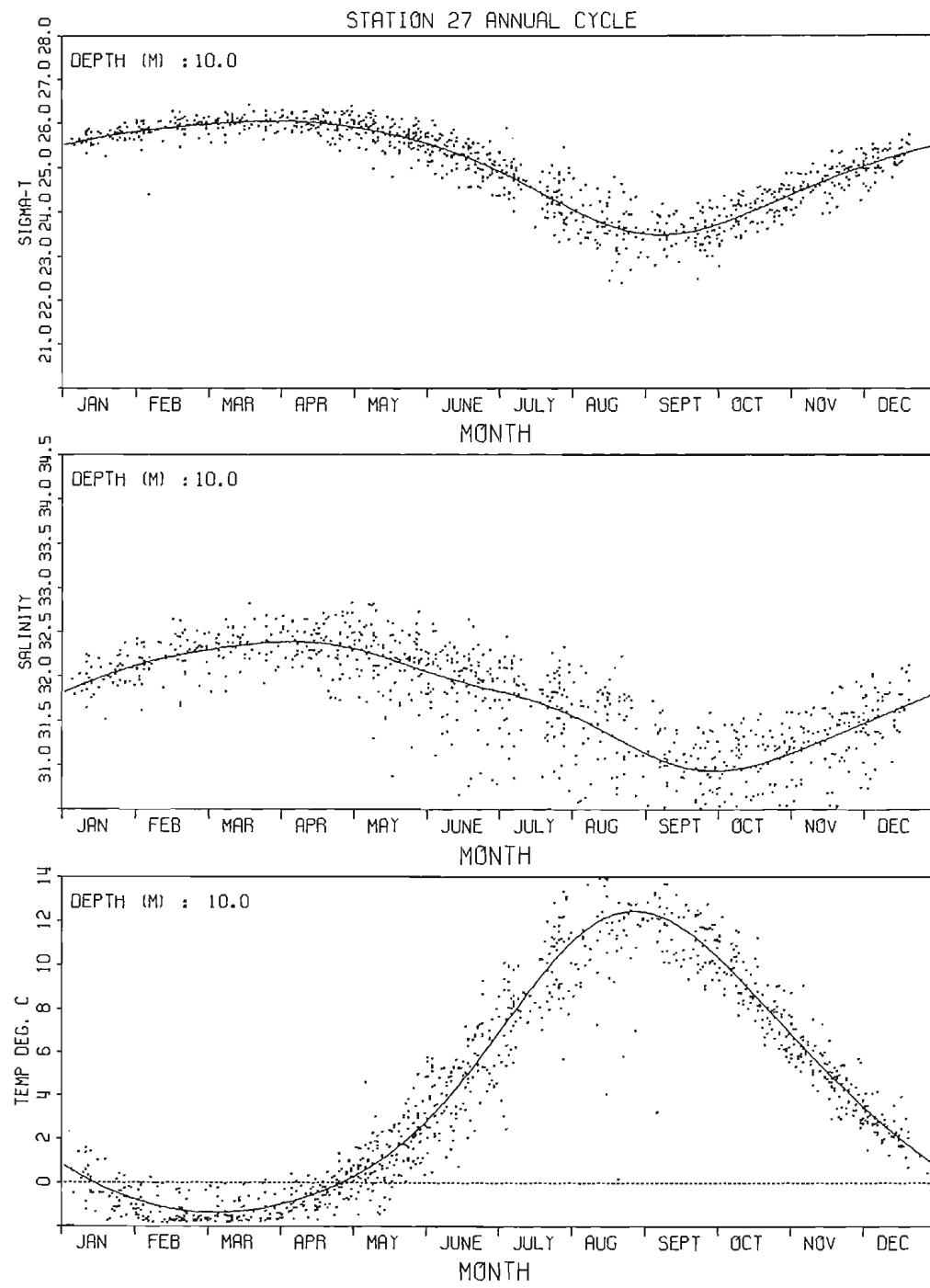
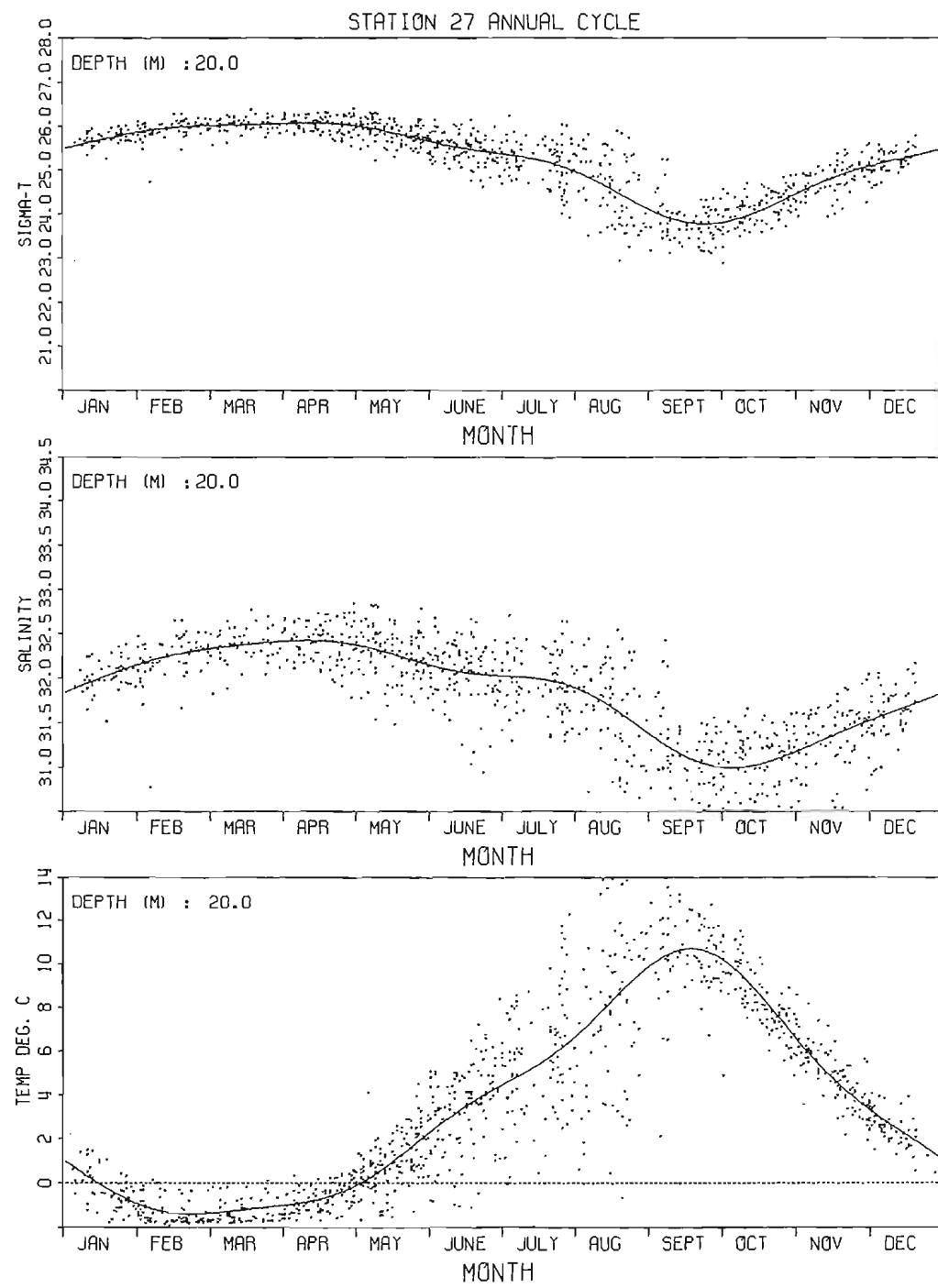


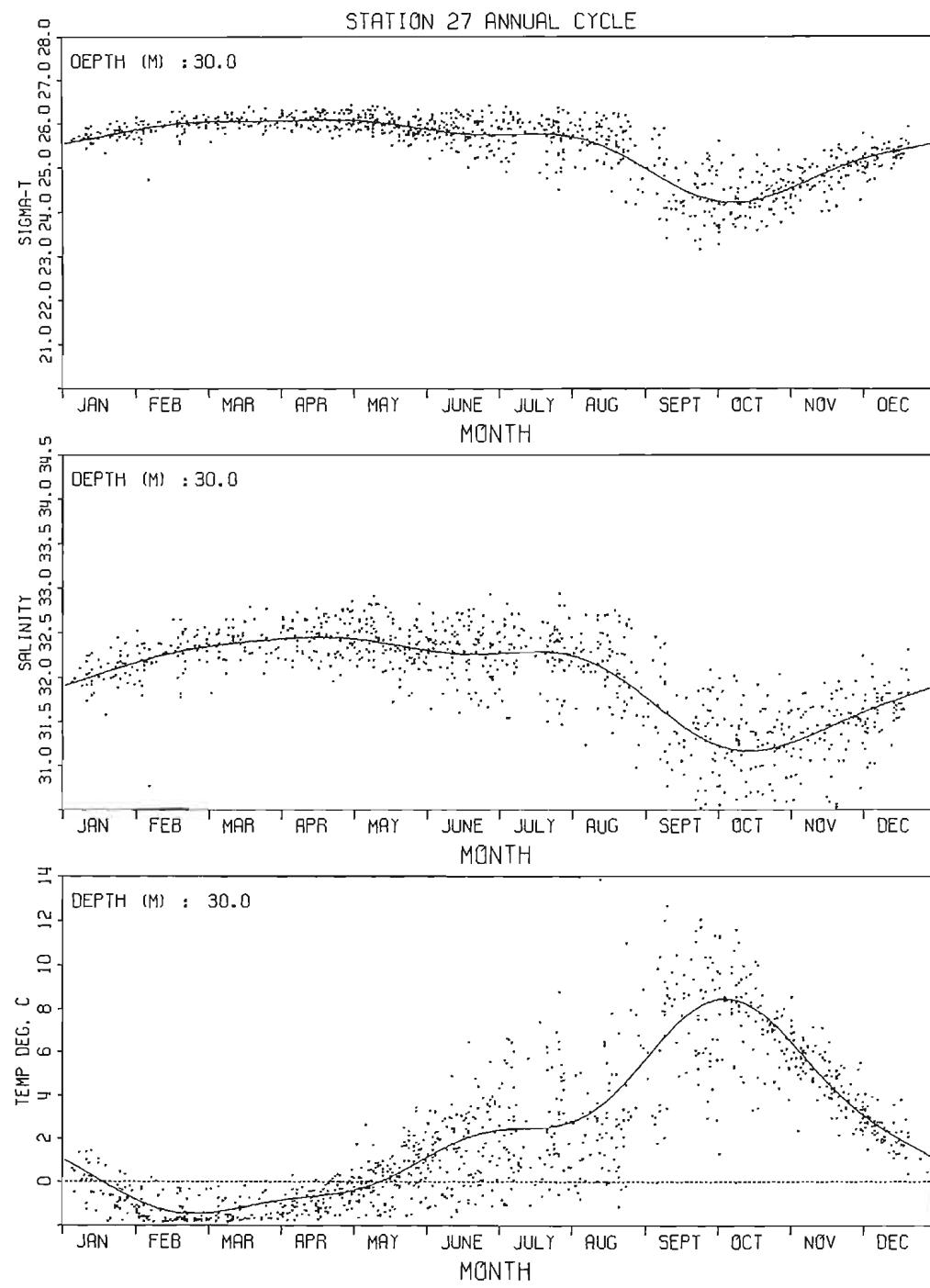
Fig. 3. The total number of Station 27 salinity profiles by (a) year and (b) by month from 1946 to 1993.

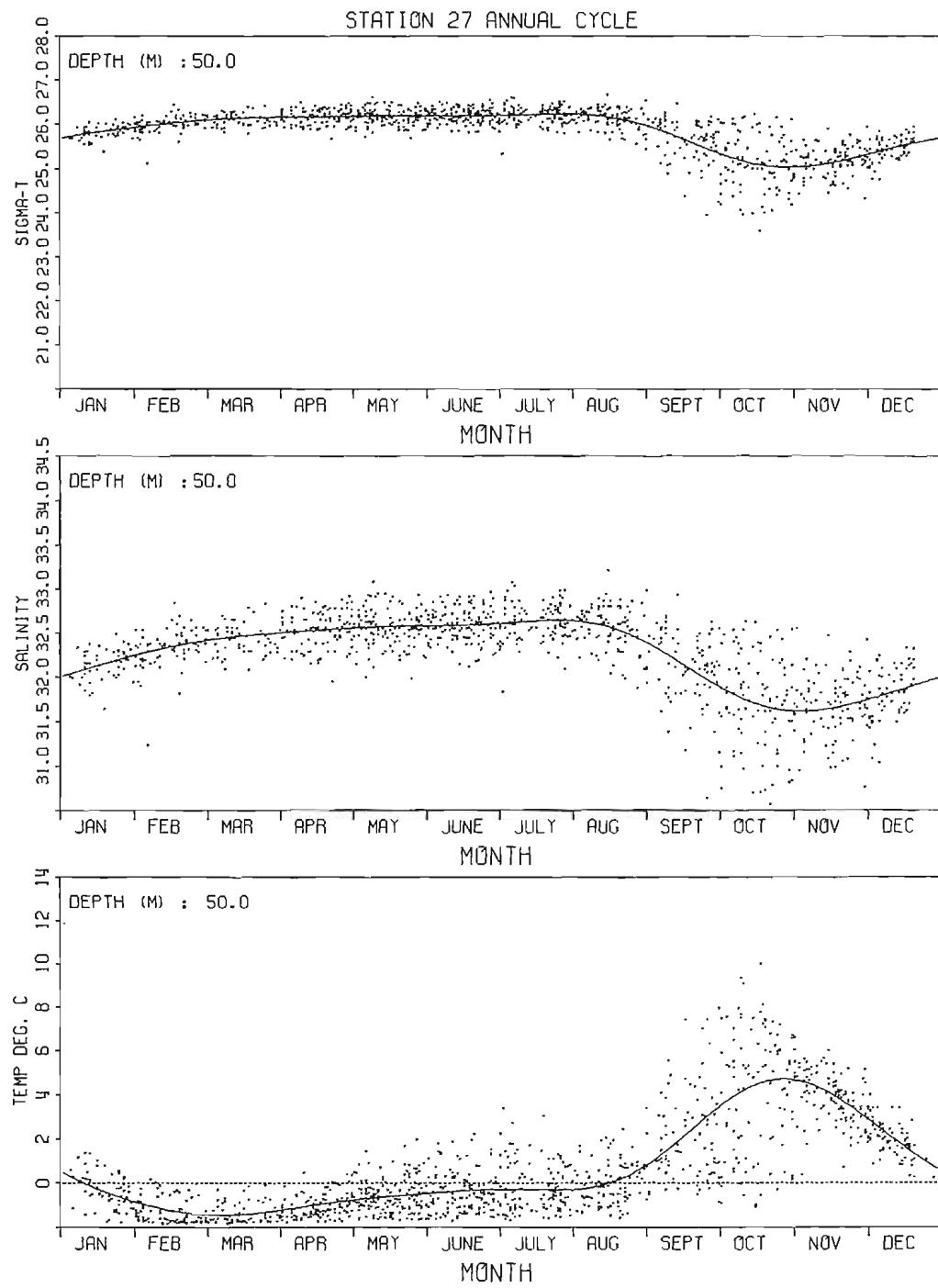
APPENDIX A. The seasonal cycles of temperature, salinity
and sigma-t at Station 27 from an harmonic
regression of all data from 1946 to 1993.

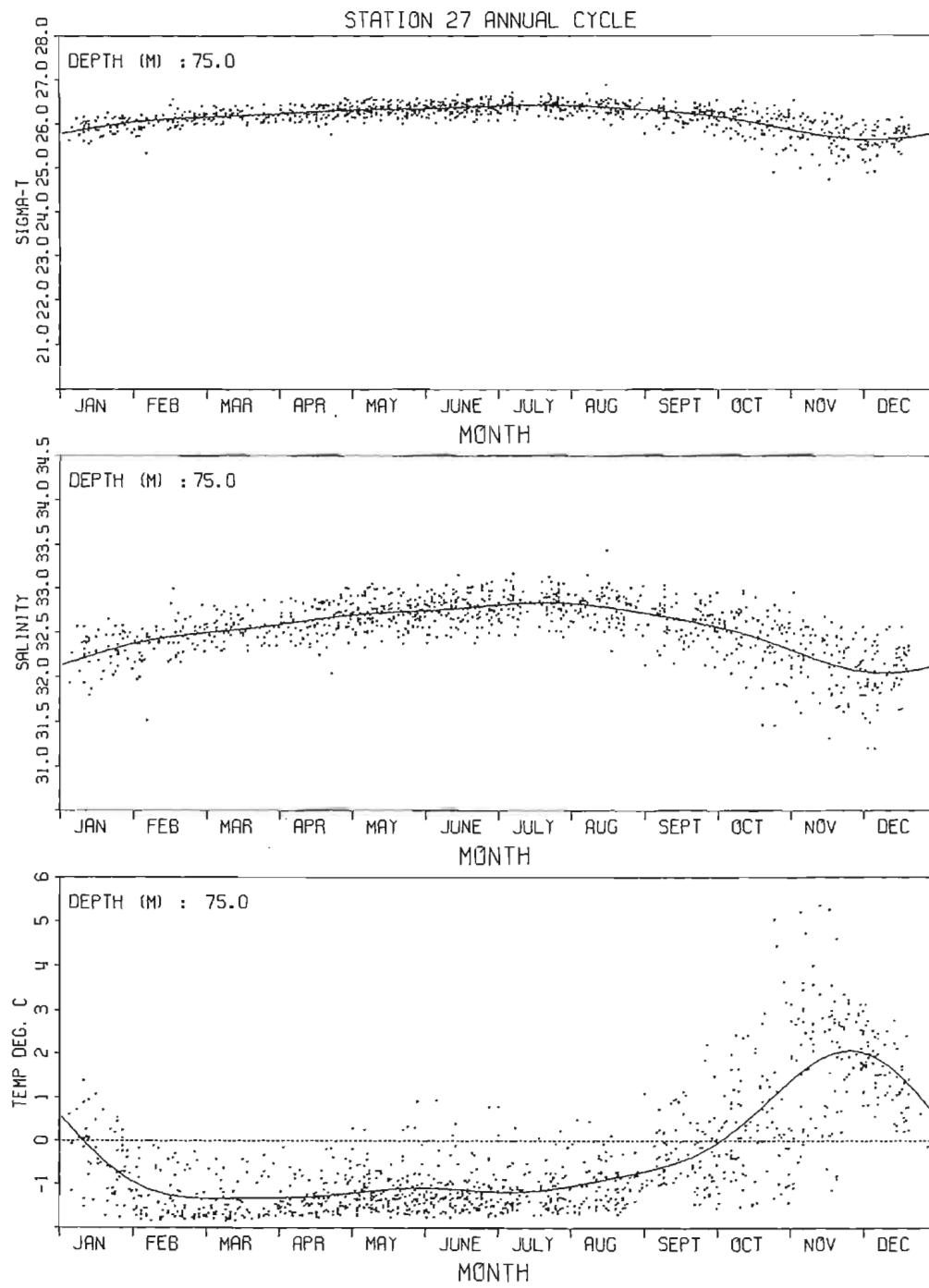


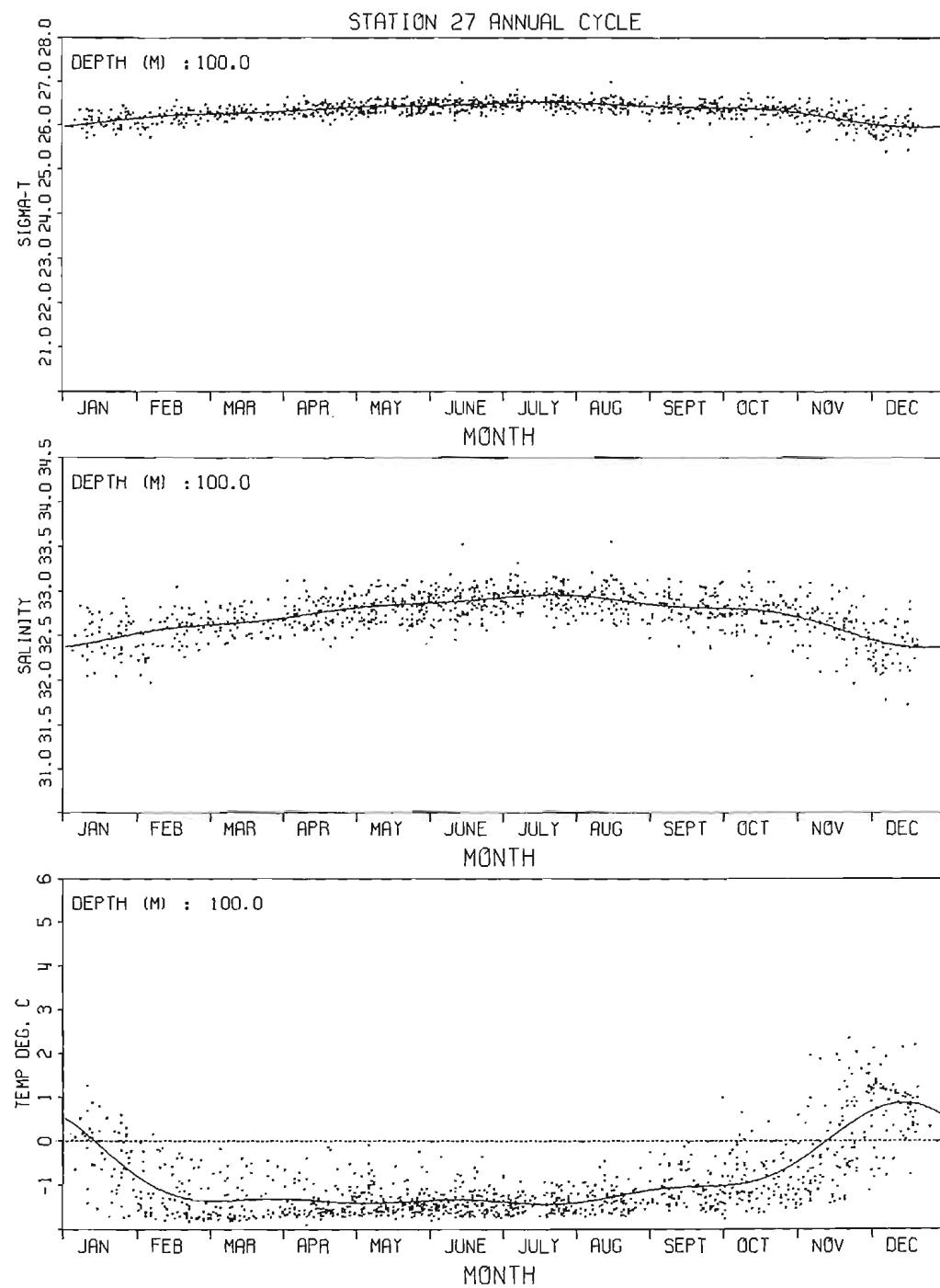


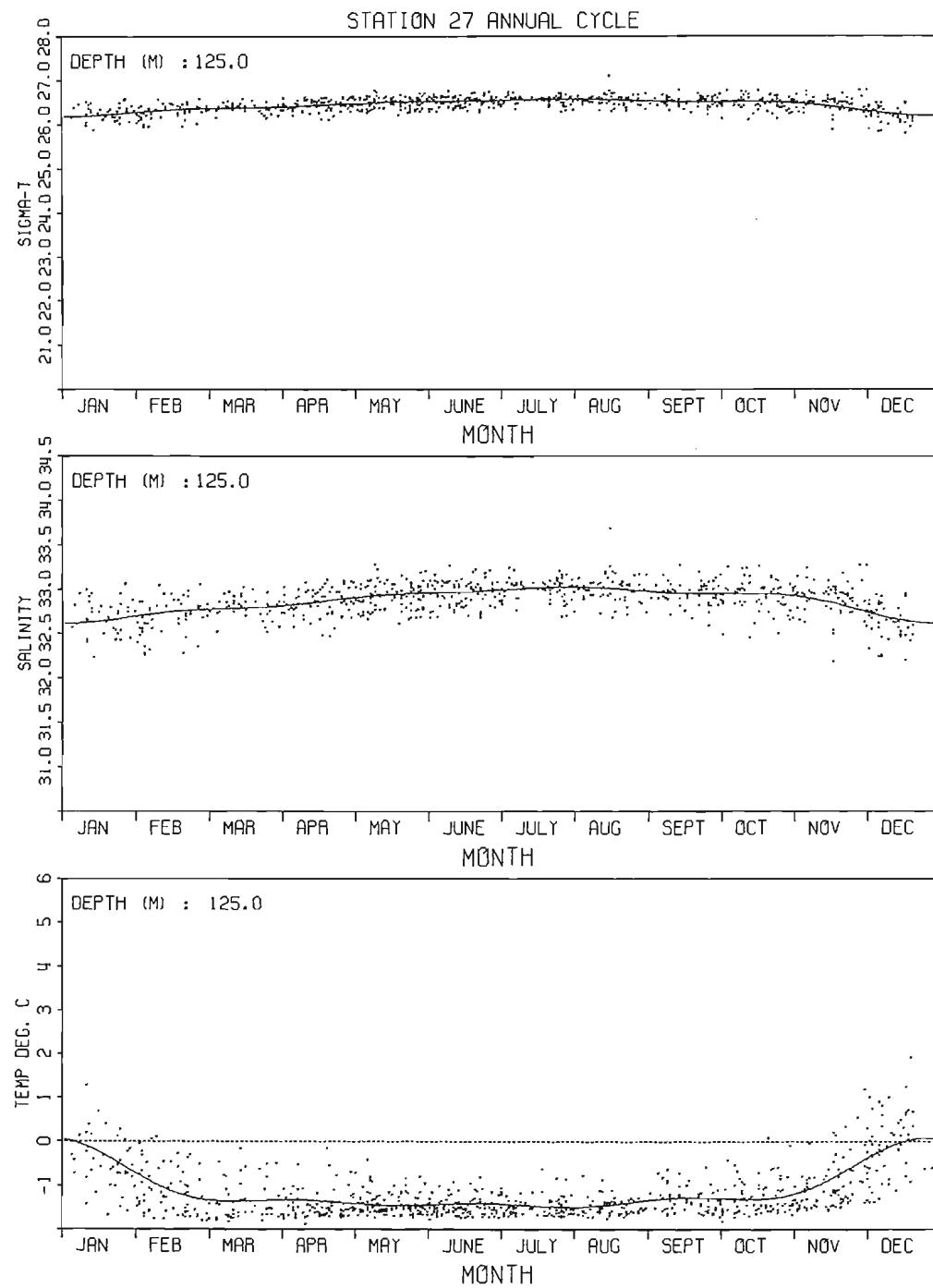


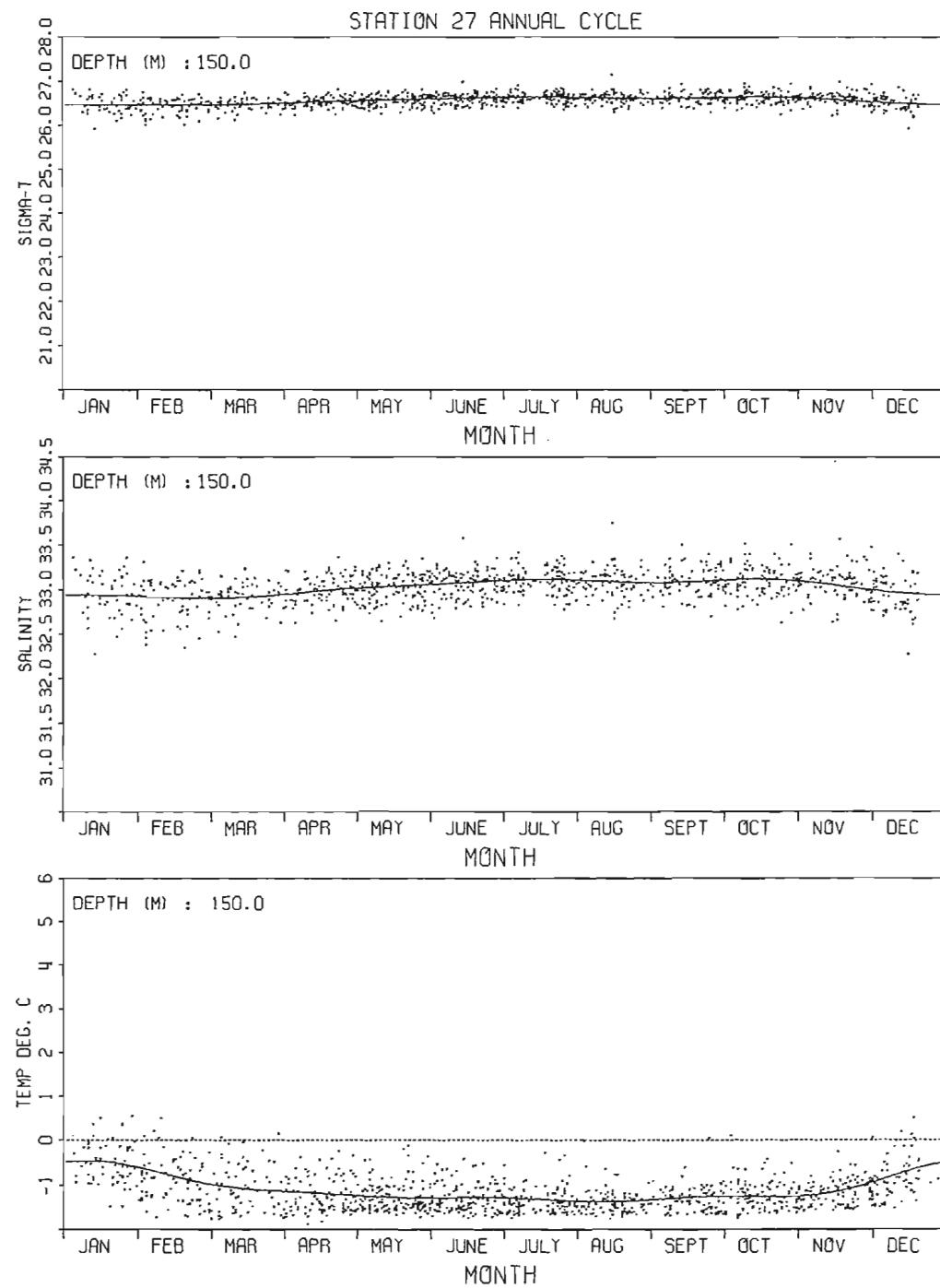


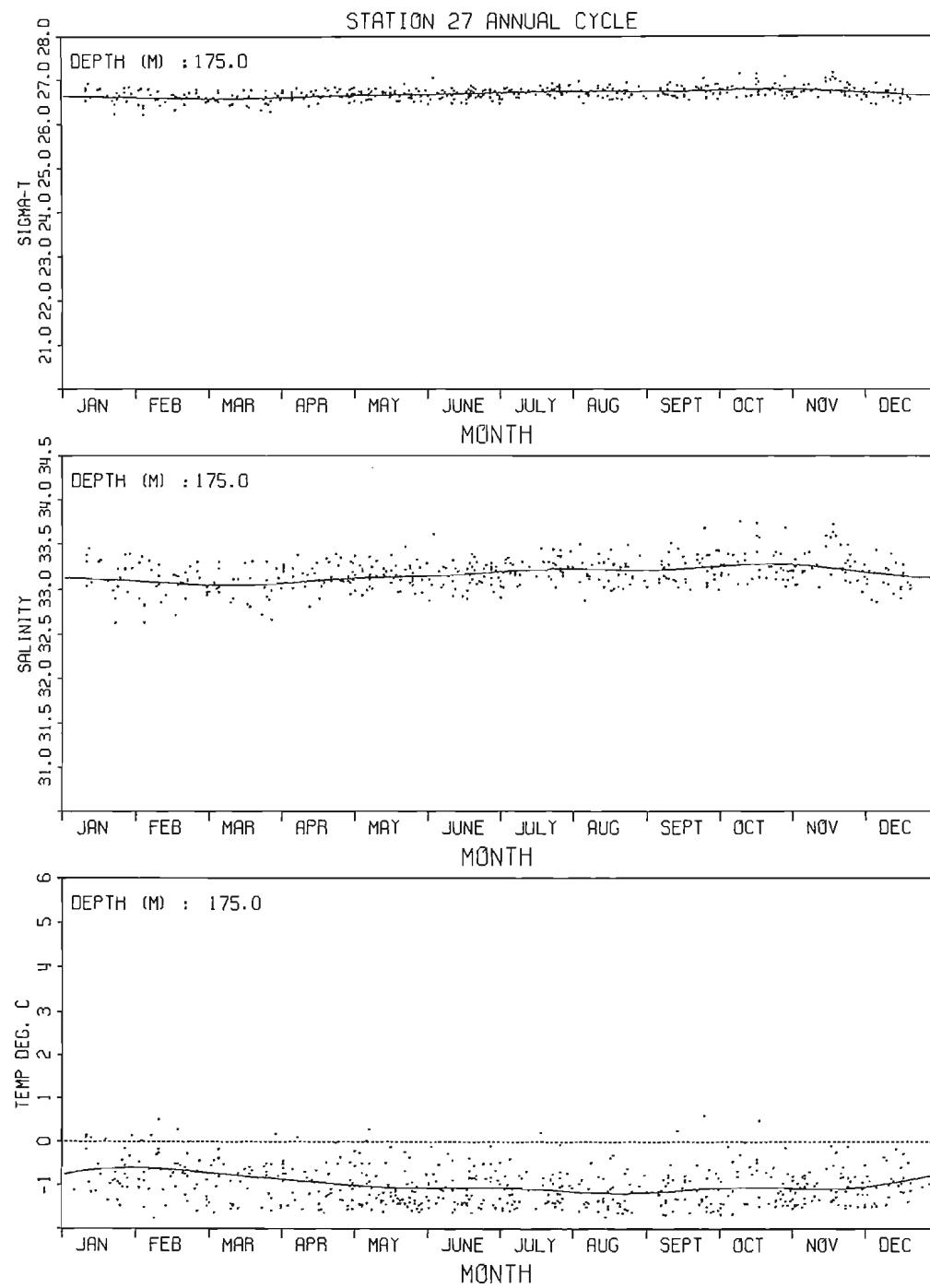




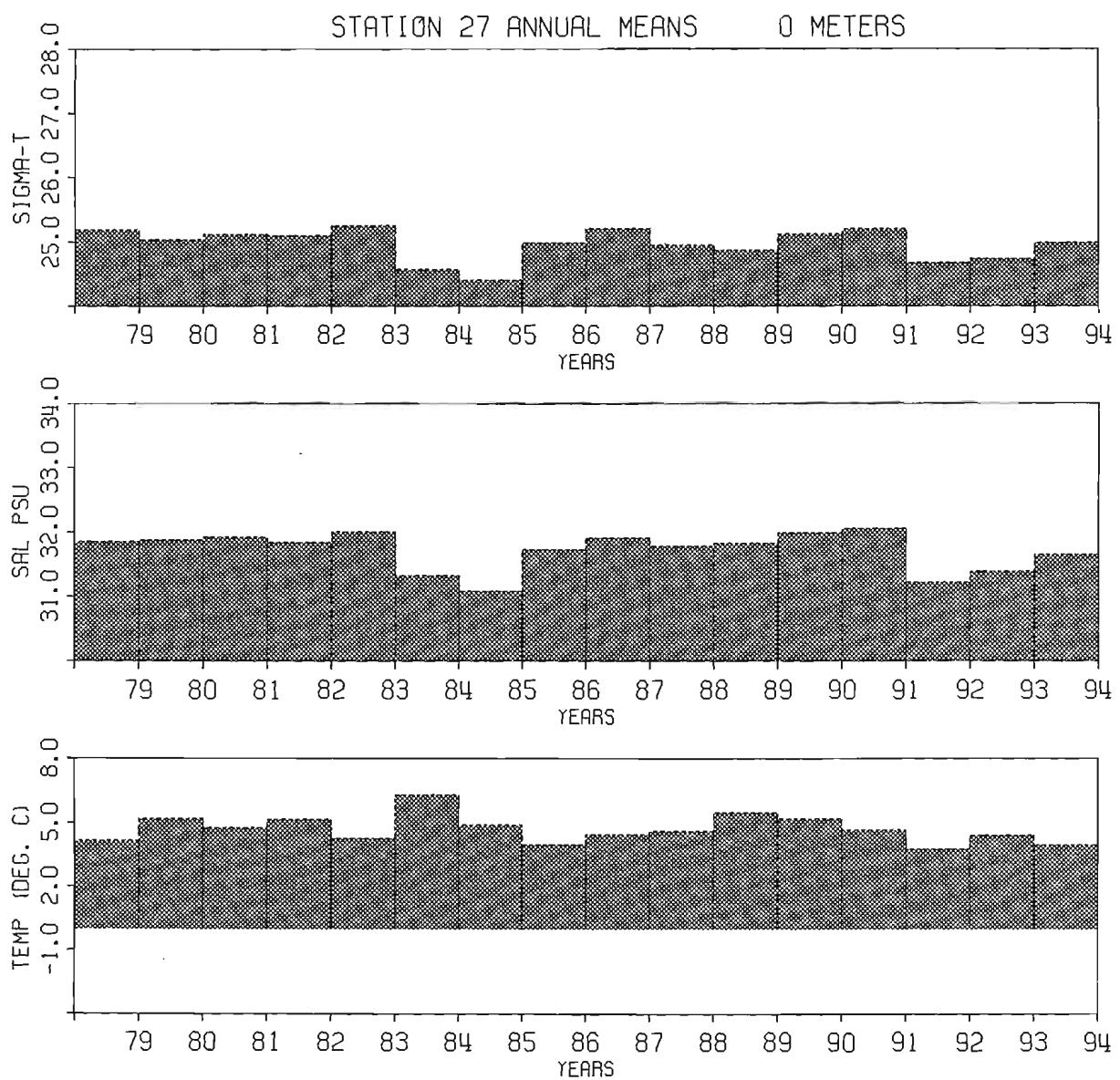


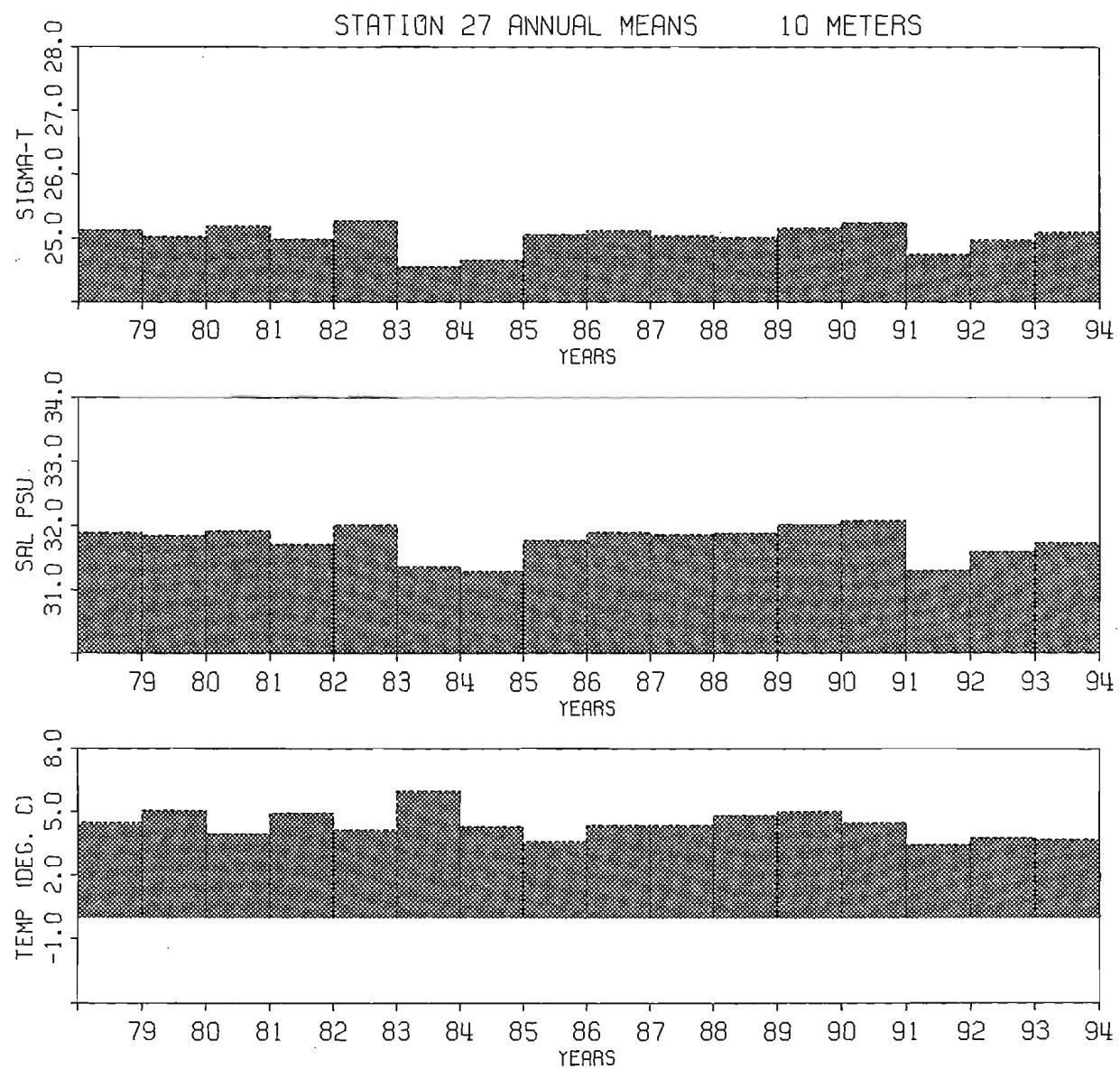


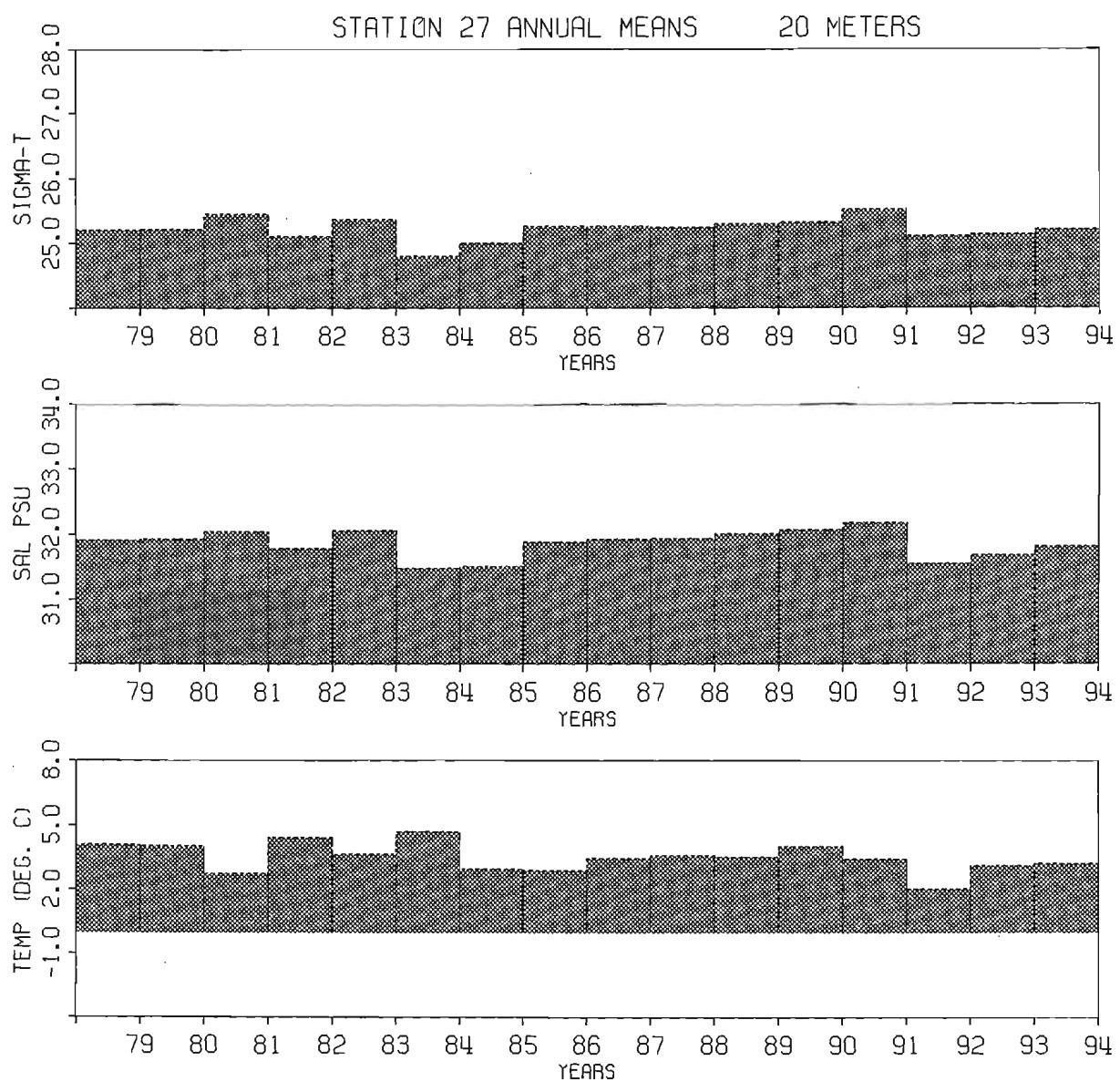


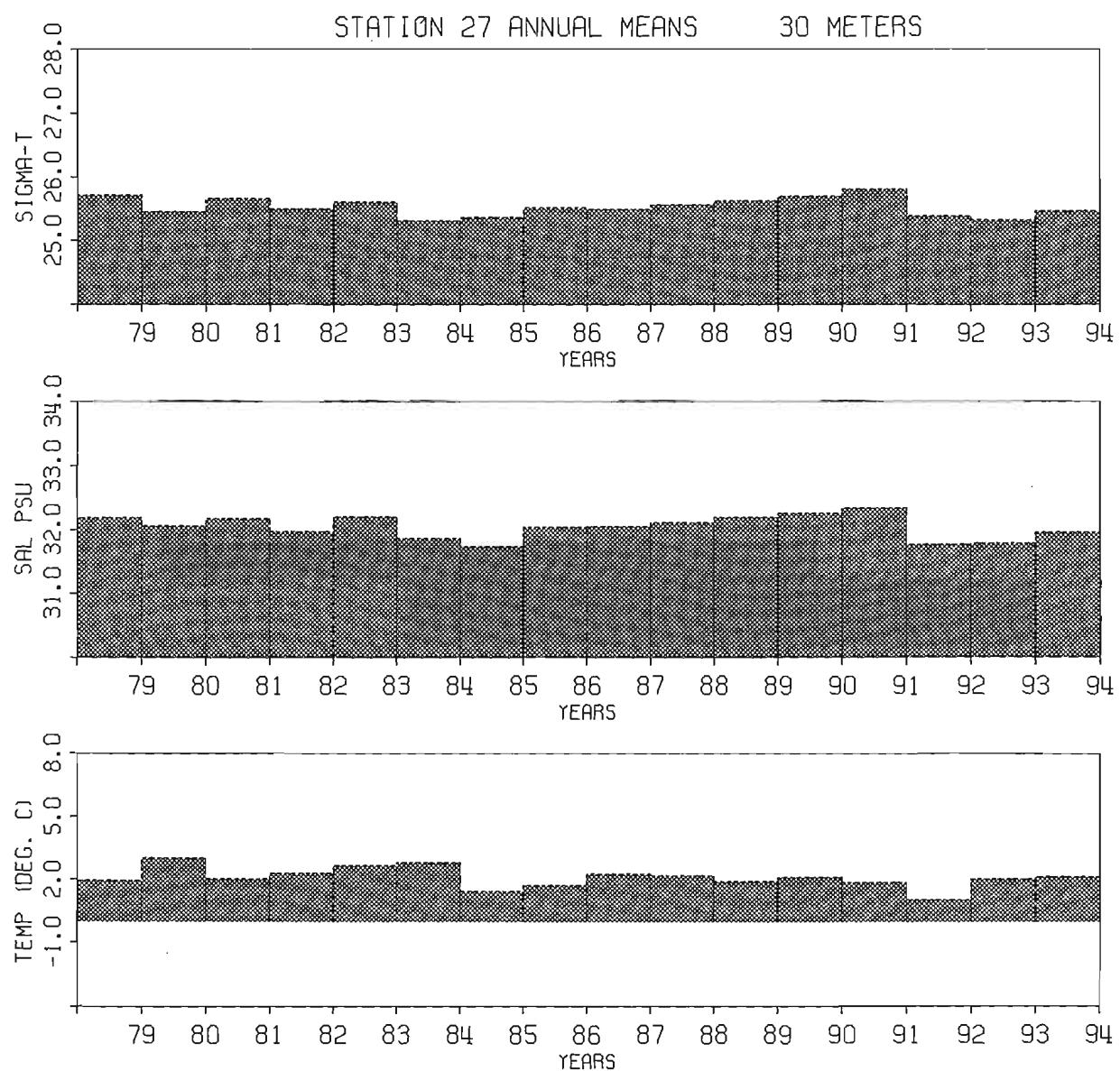


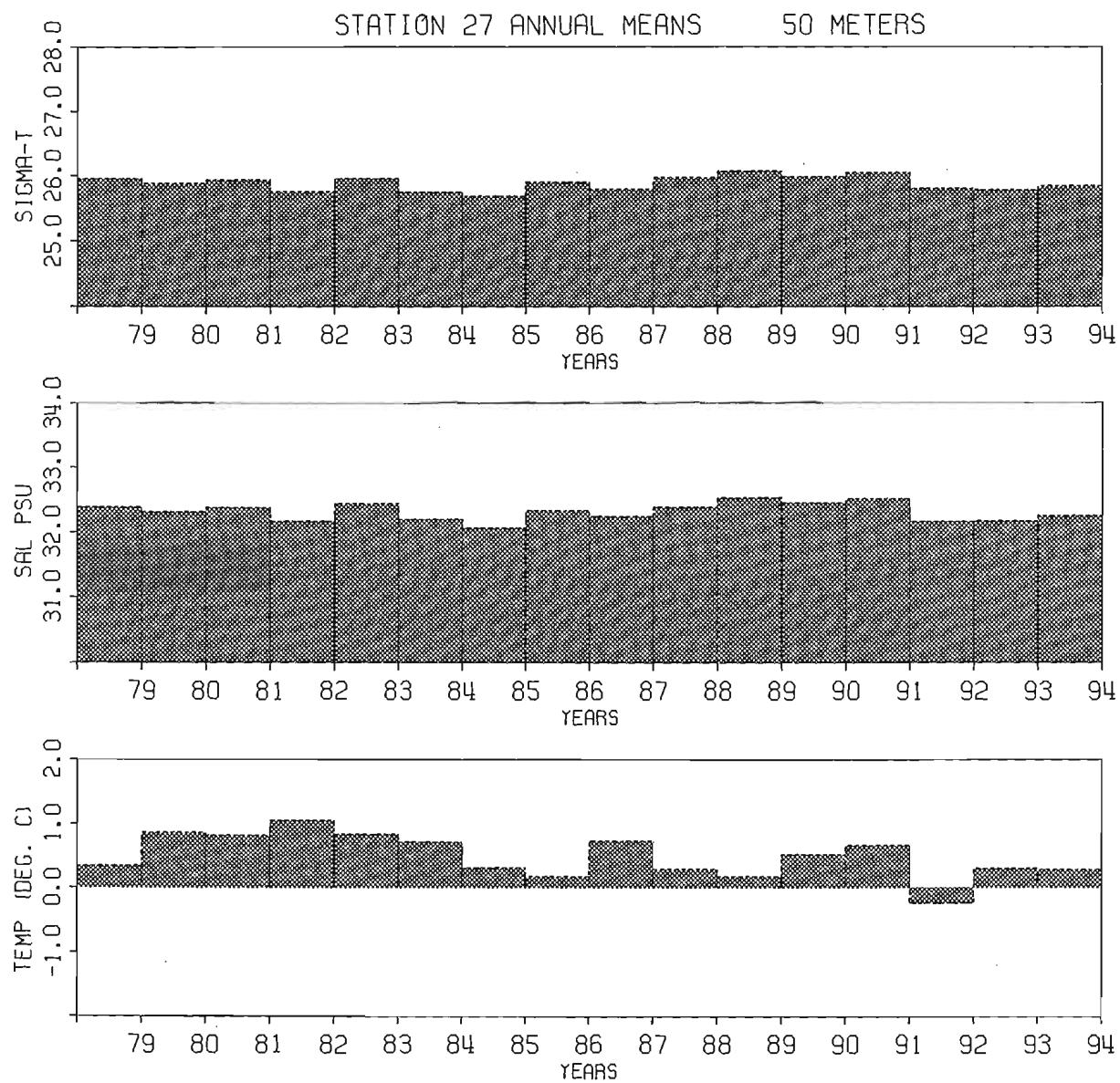
APPENDIX B. The yearly averages of temperature, salinity and sigma-t at Station 27 at standard oceanographic depths.

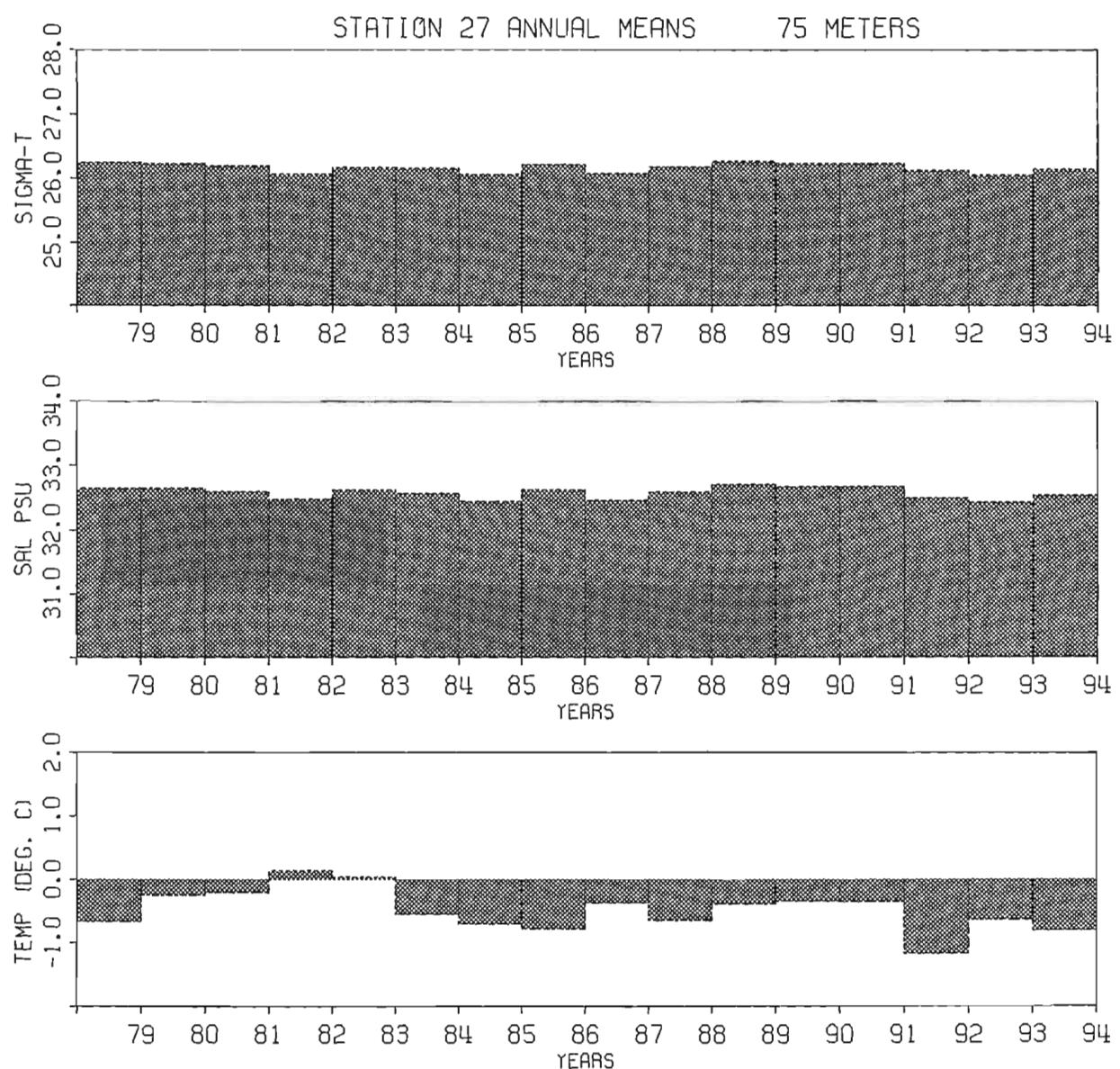


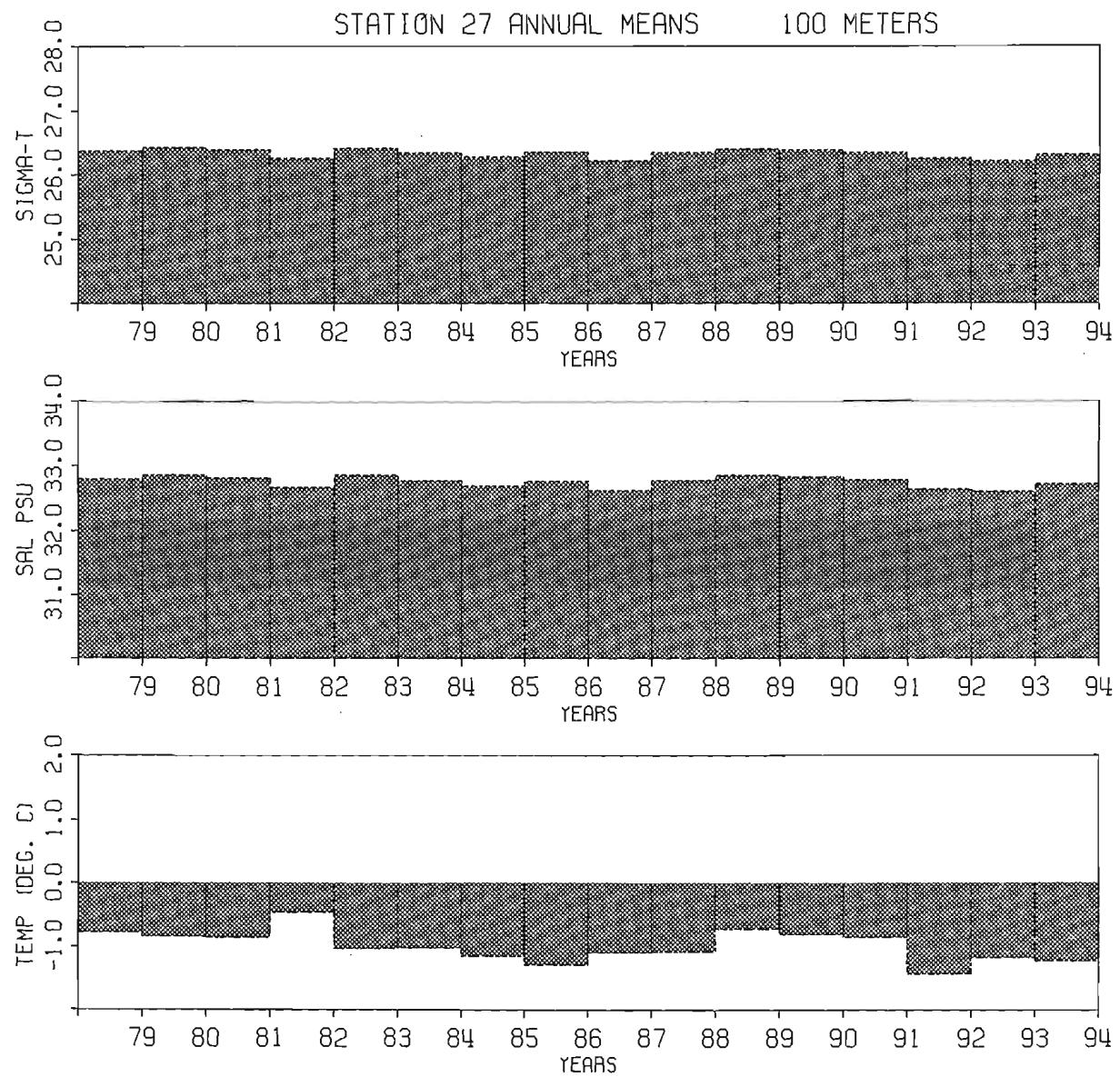


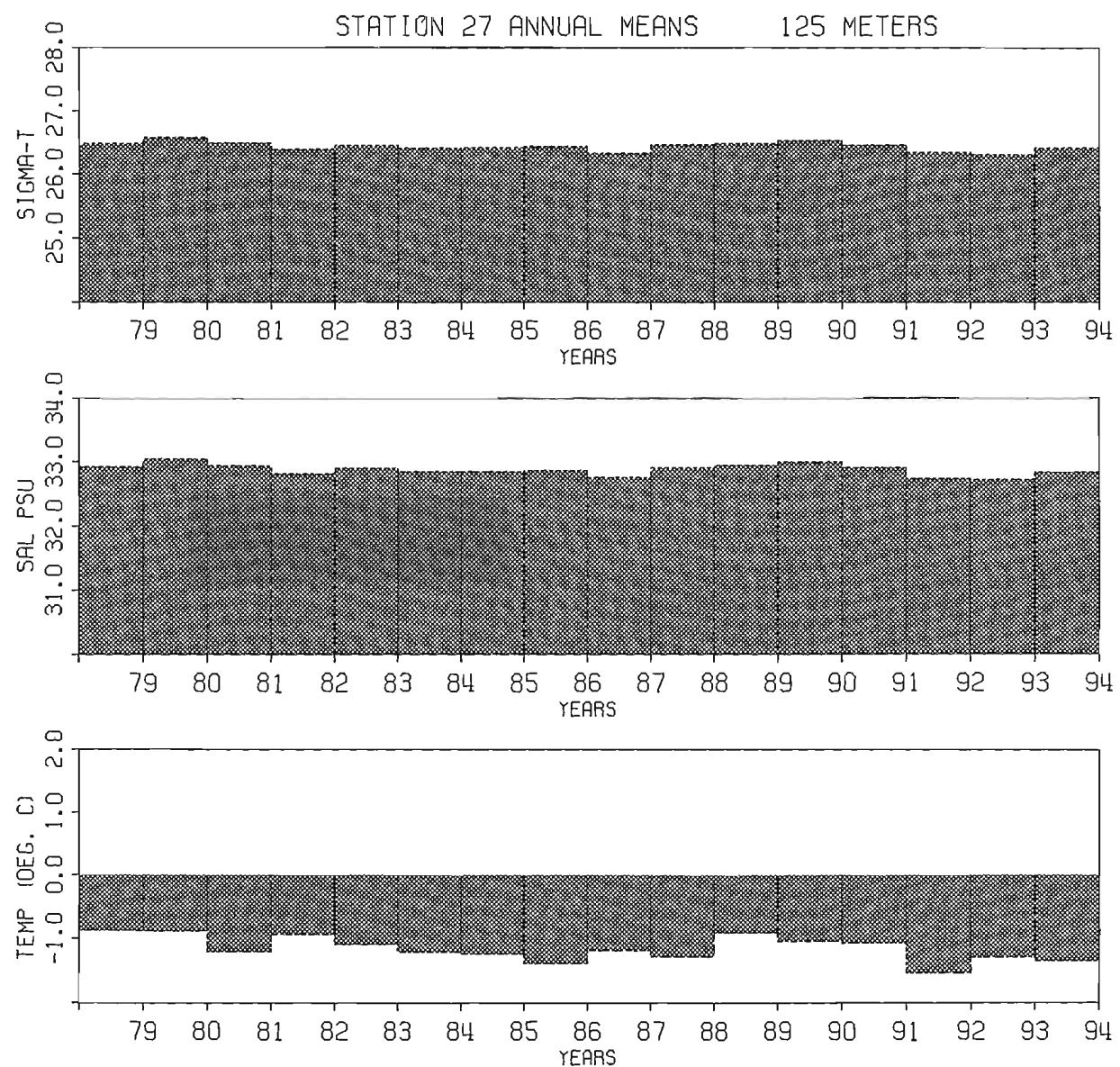


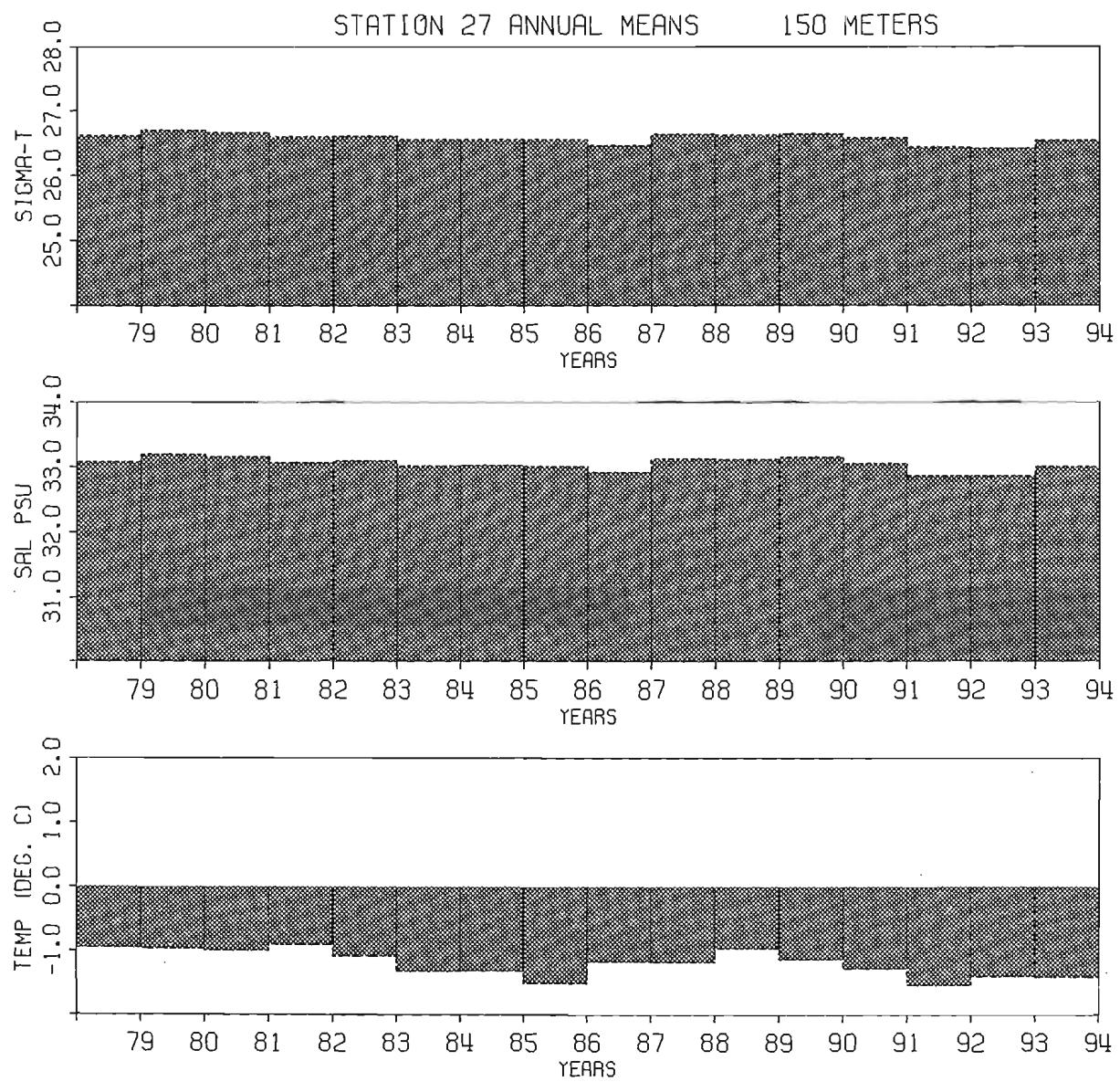


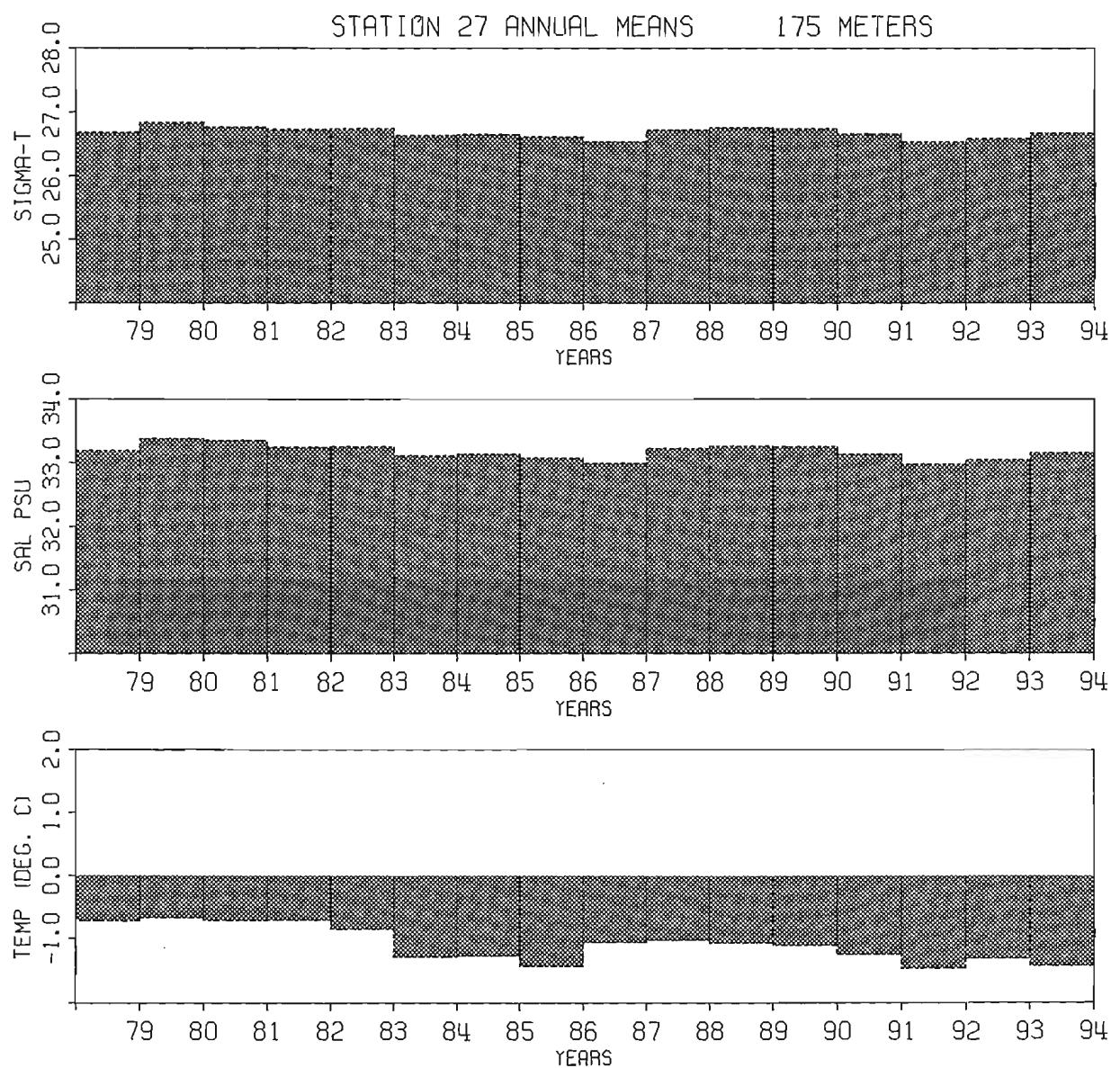




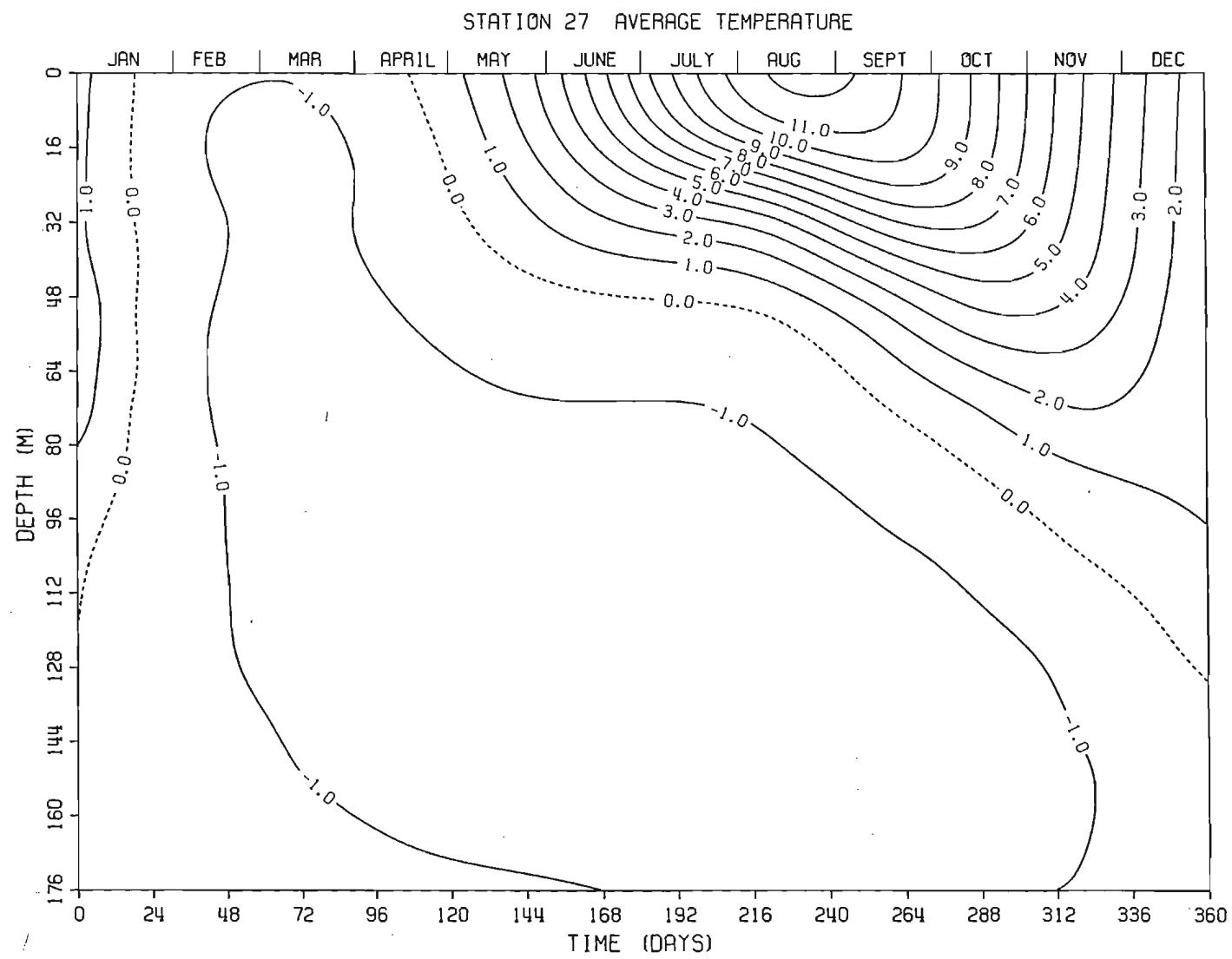


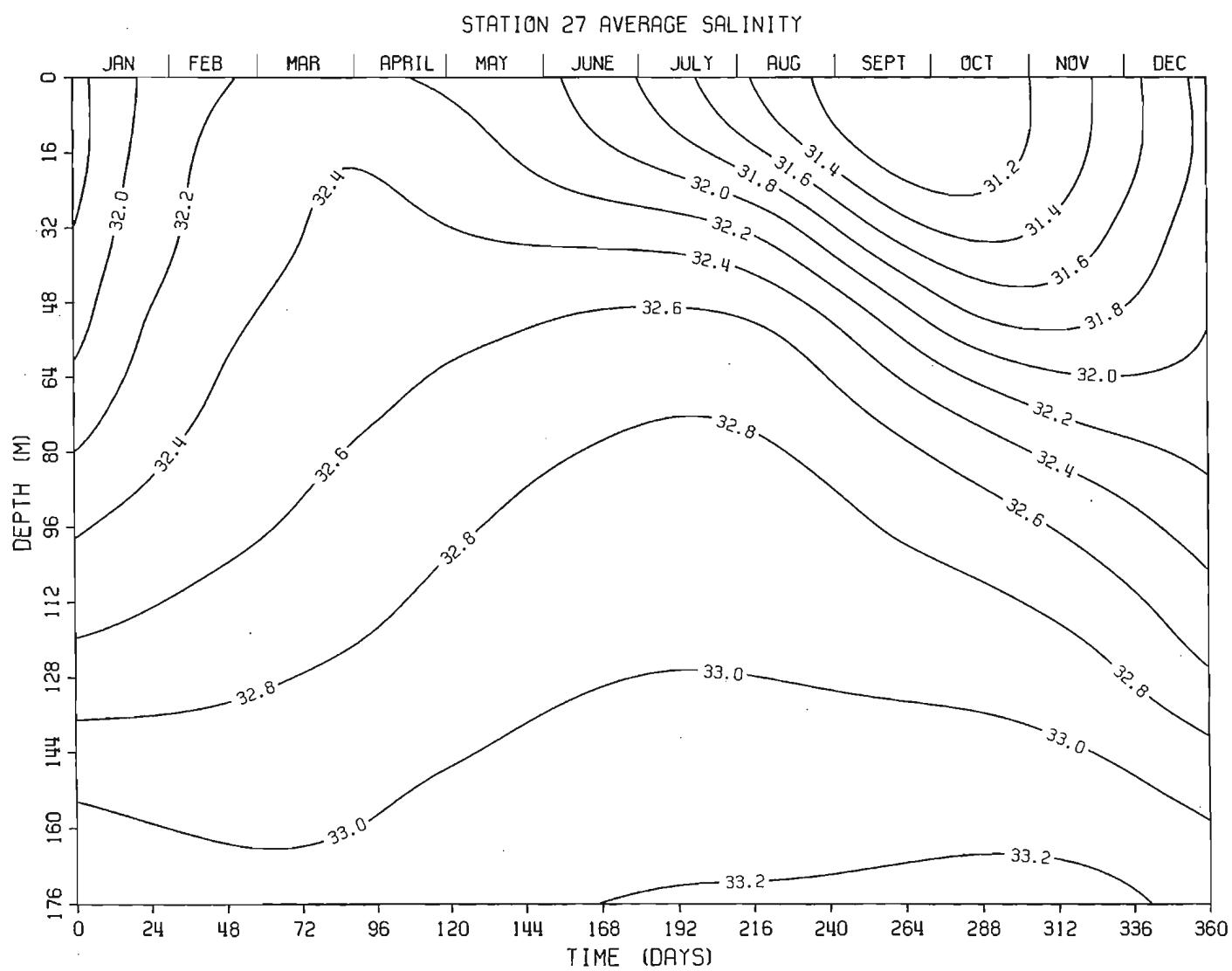


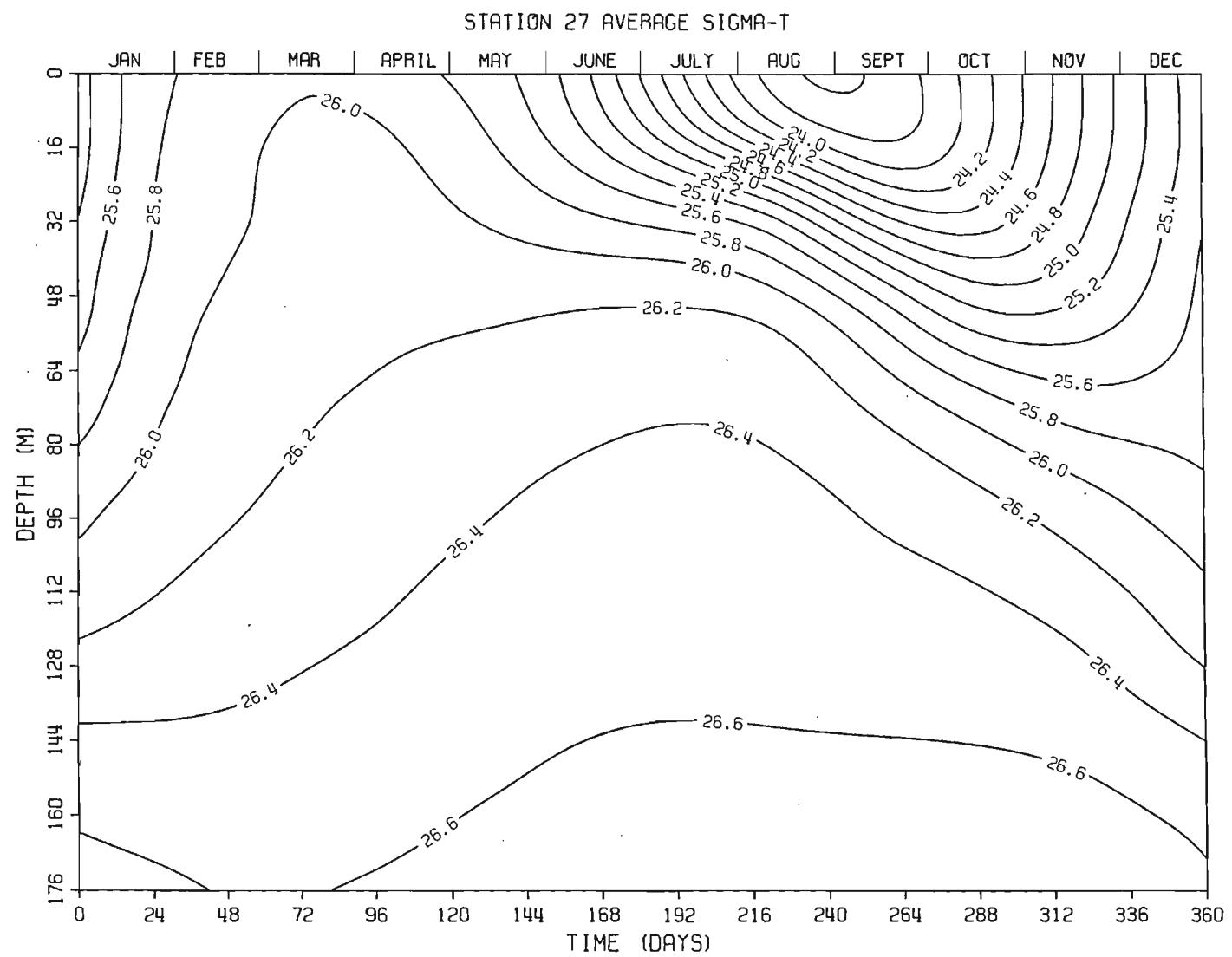




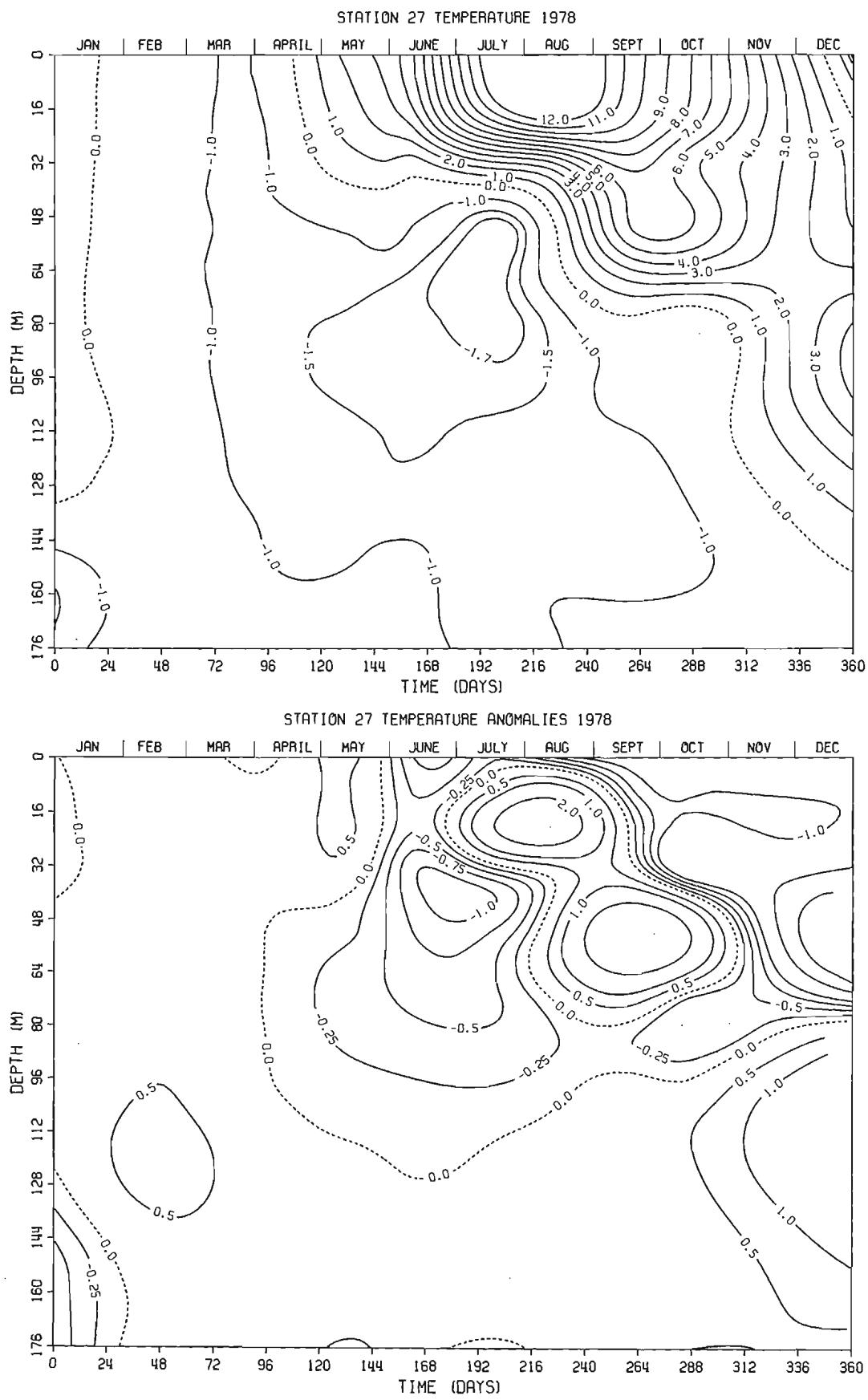
APPENDIX C. Depth versus time contours of the average annual temperature, salinity and sigma-t at Station 27 based on all available data from 1946 to 1993.

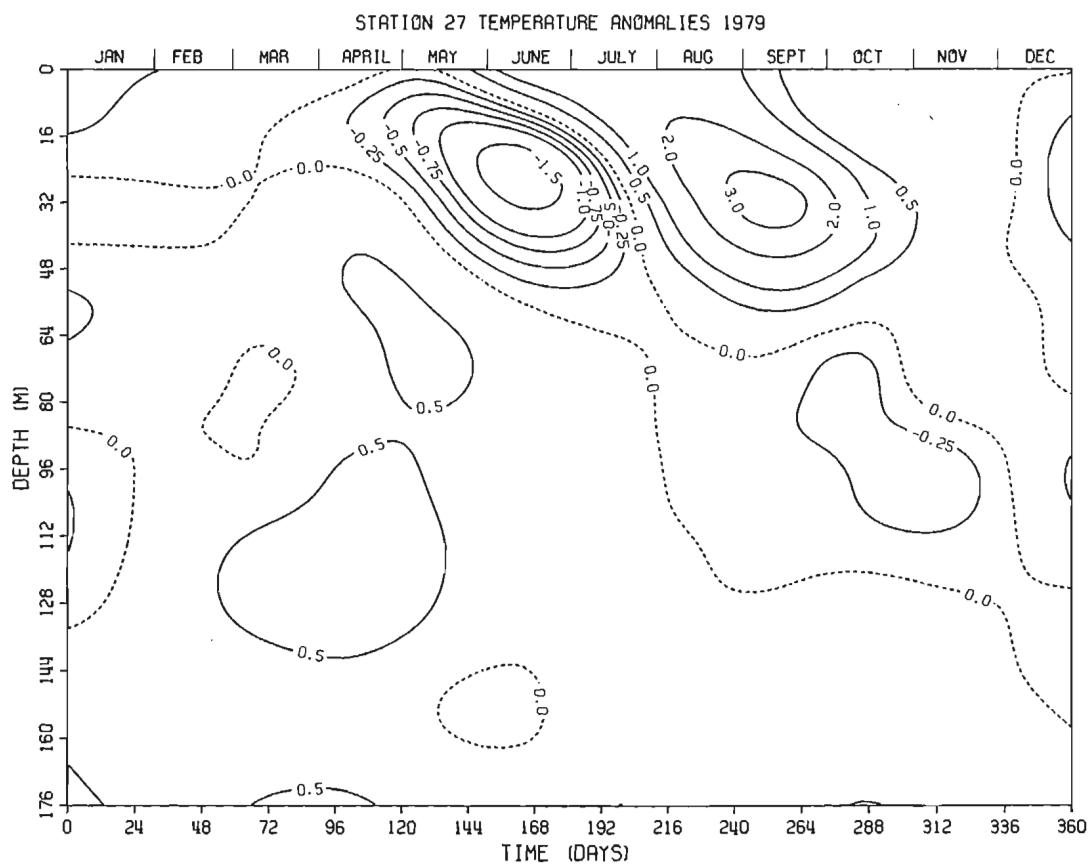
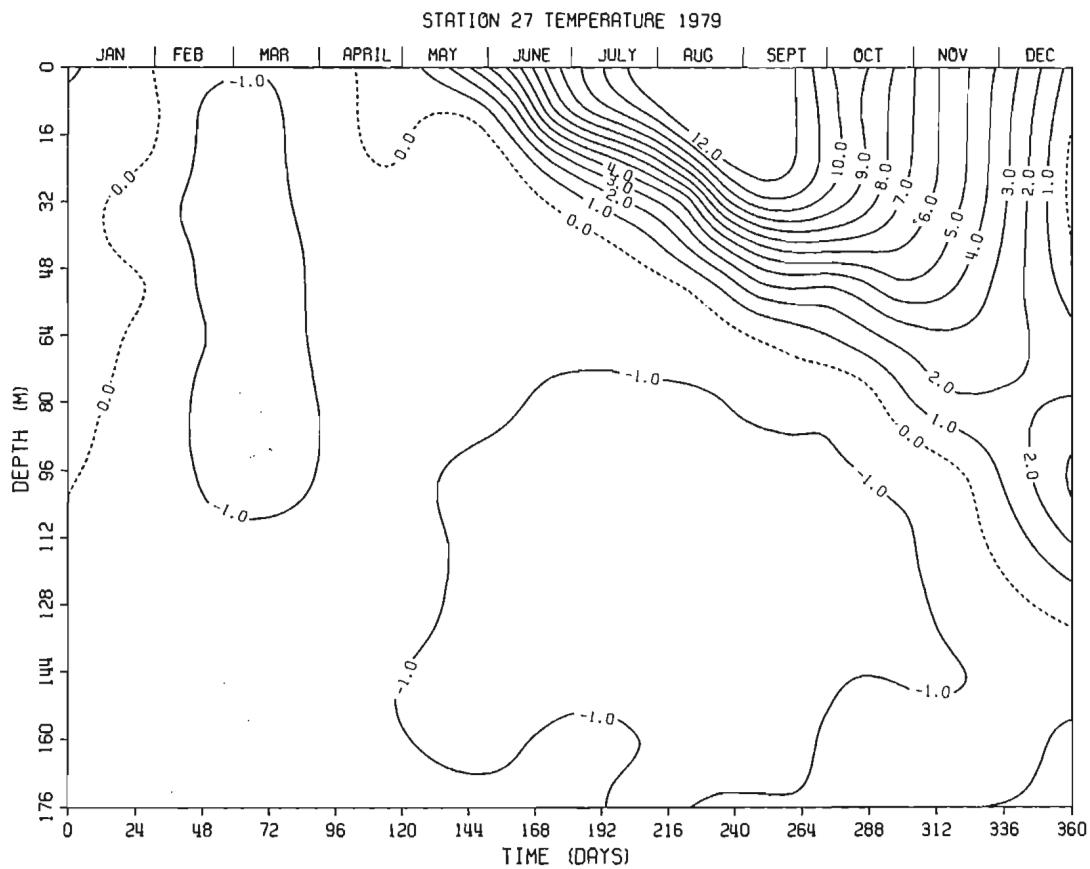


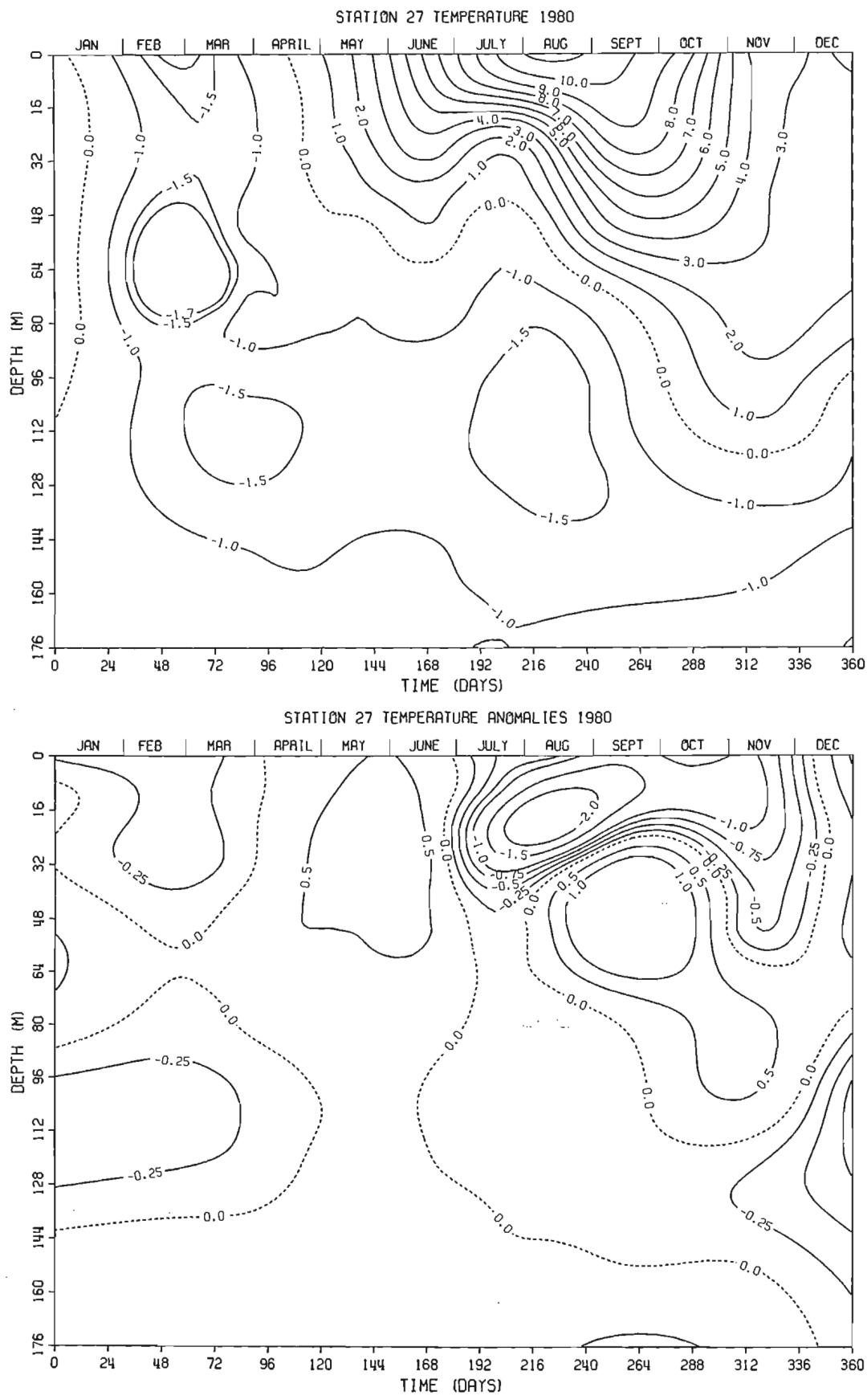


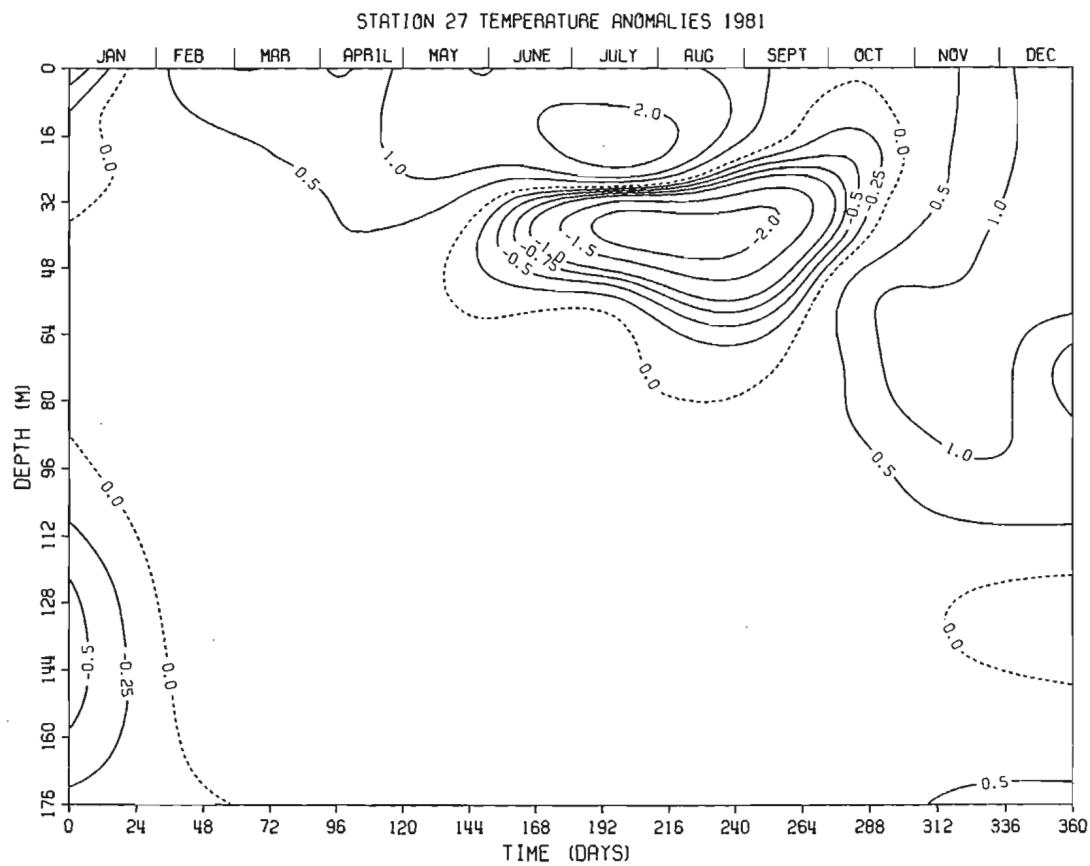
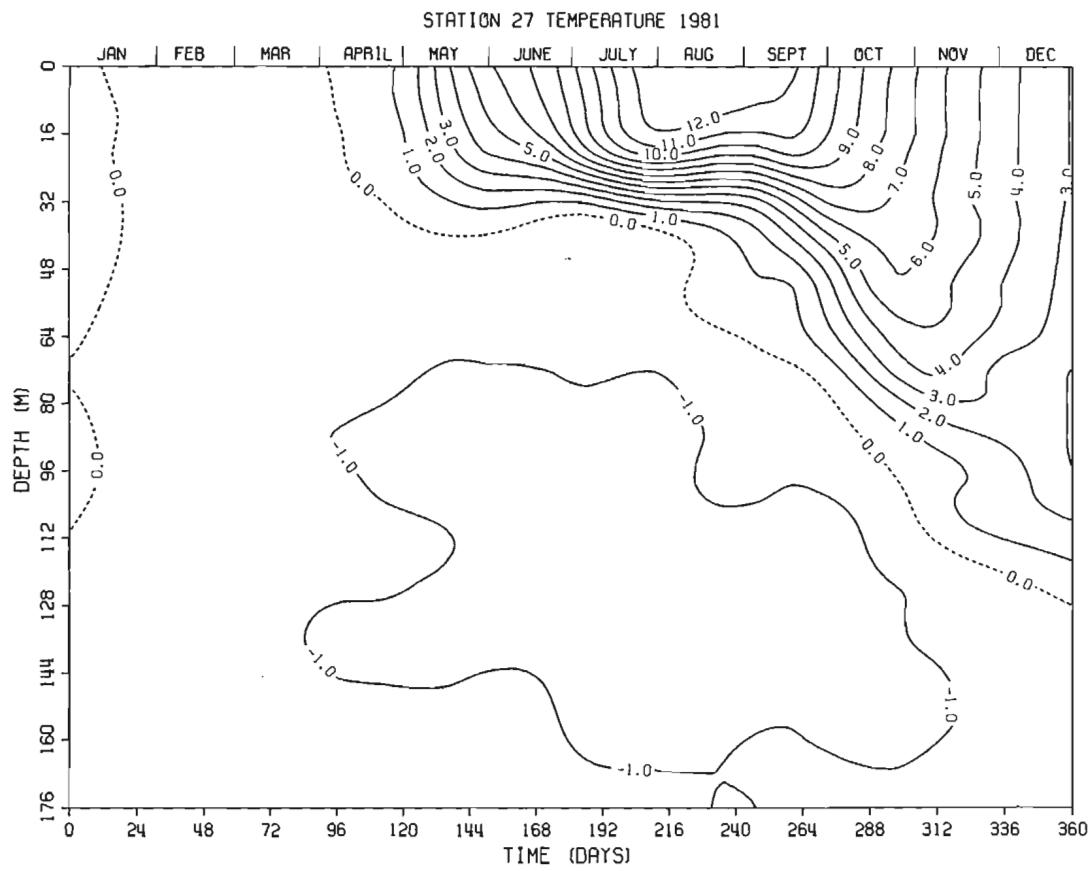


APPENDIX D. Depth versus time contours of the yearly temperature and temperature anomalies at Station 27 from 1978 to 1993.

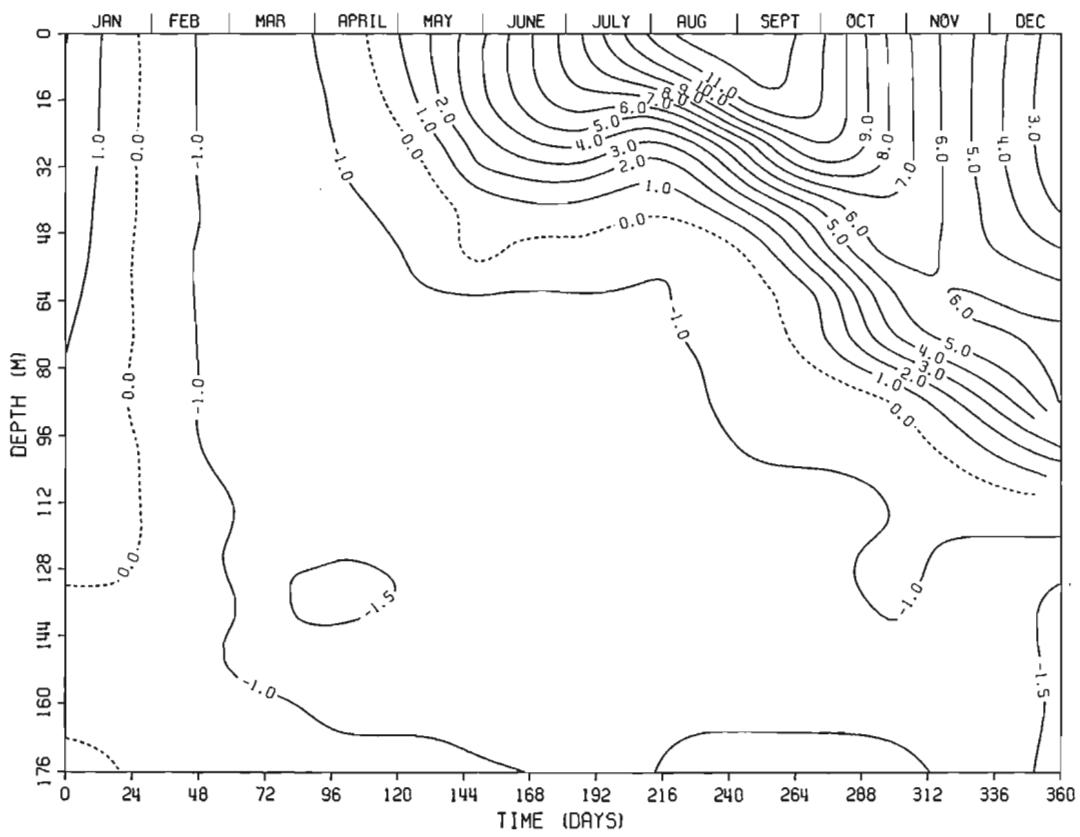




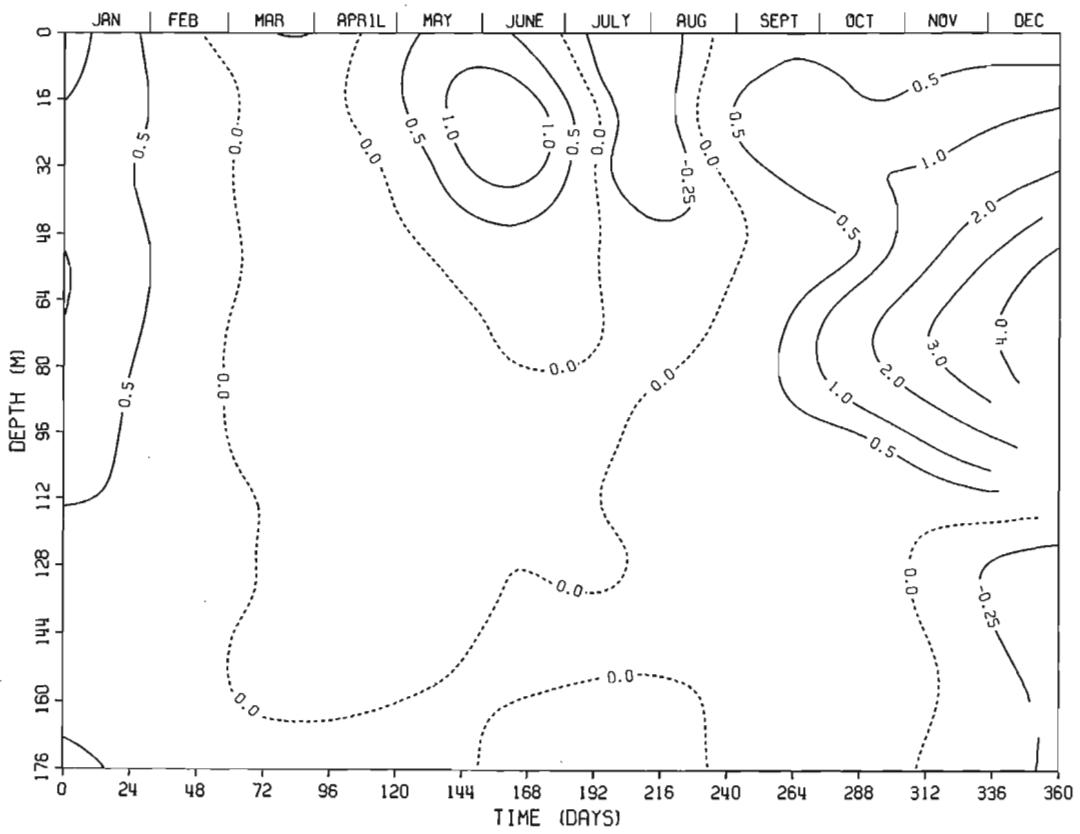


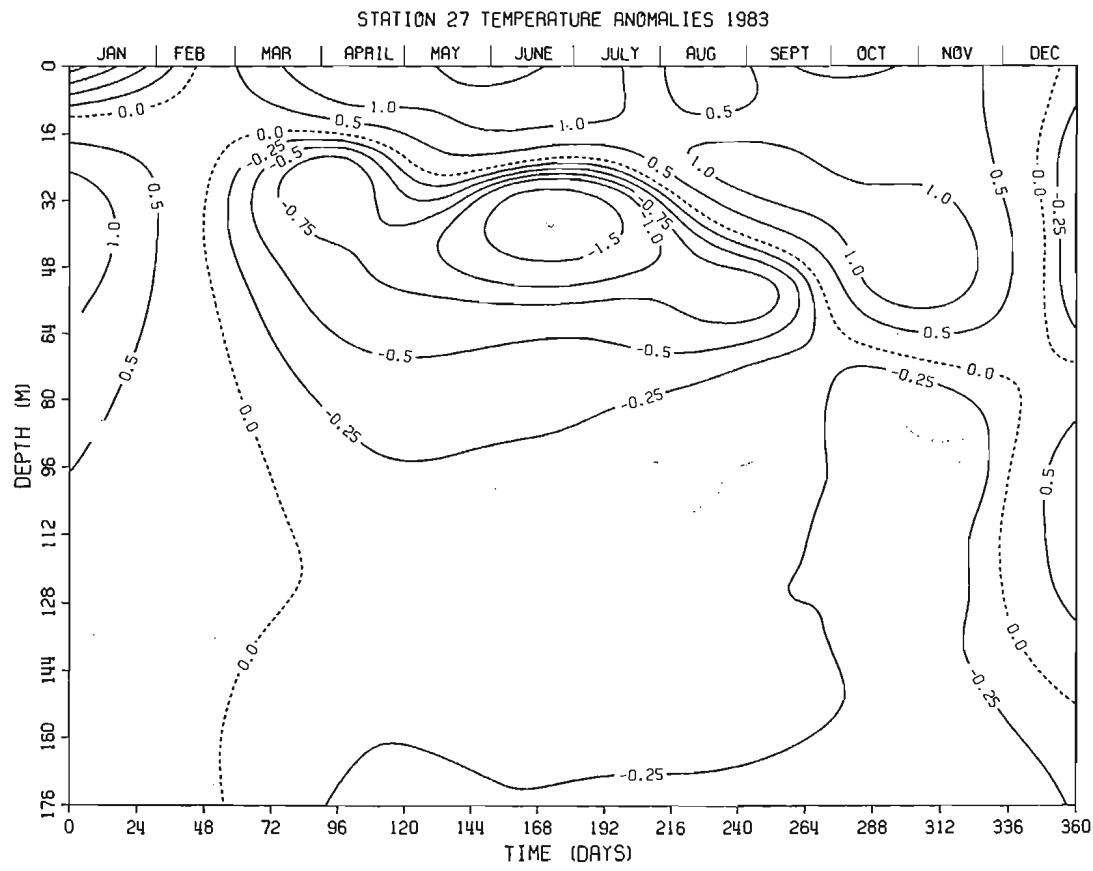
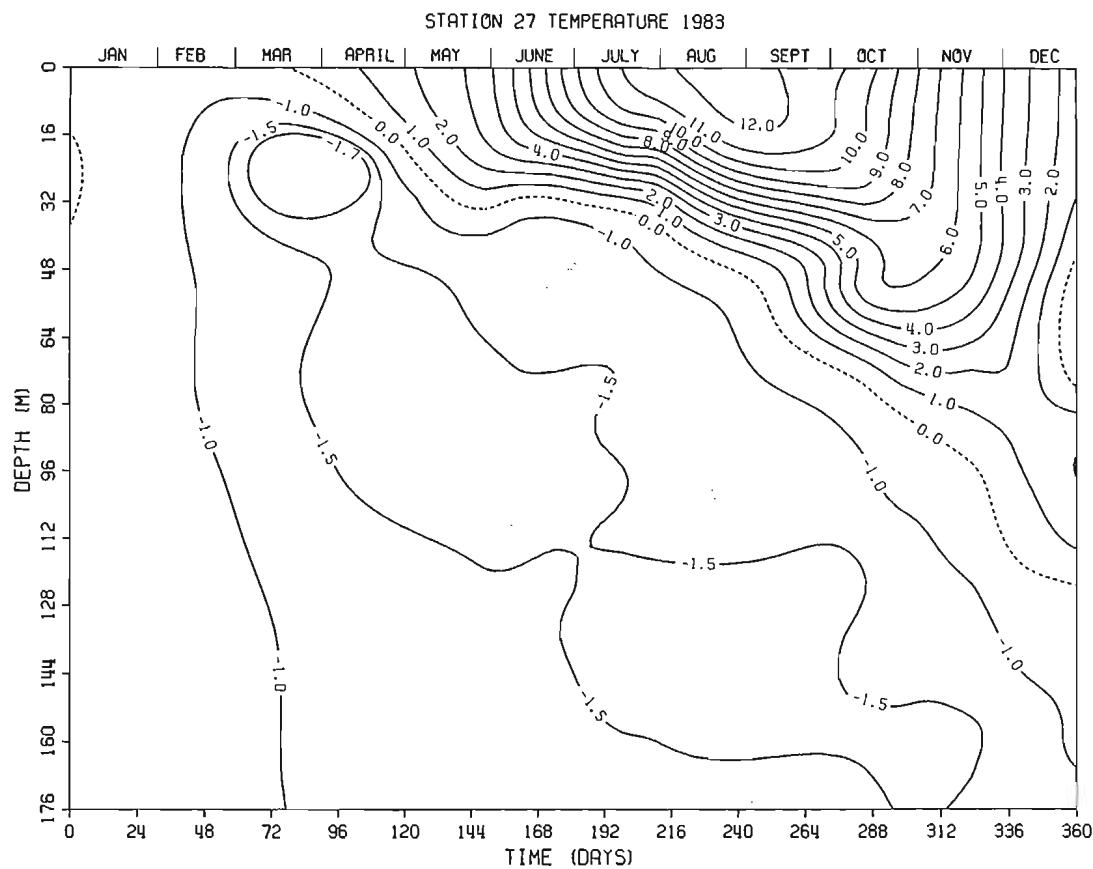


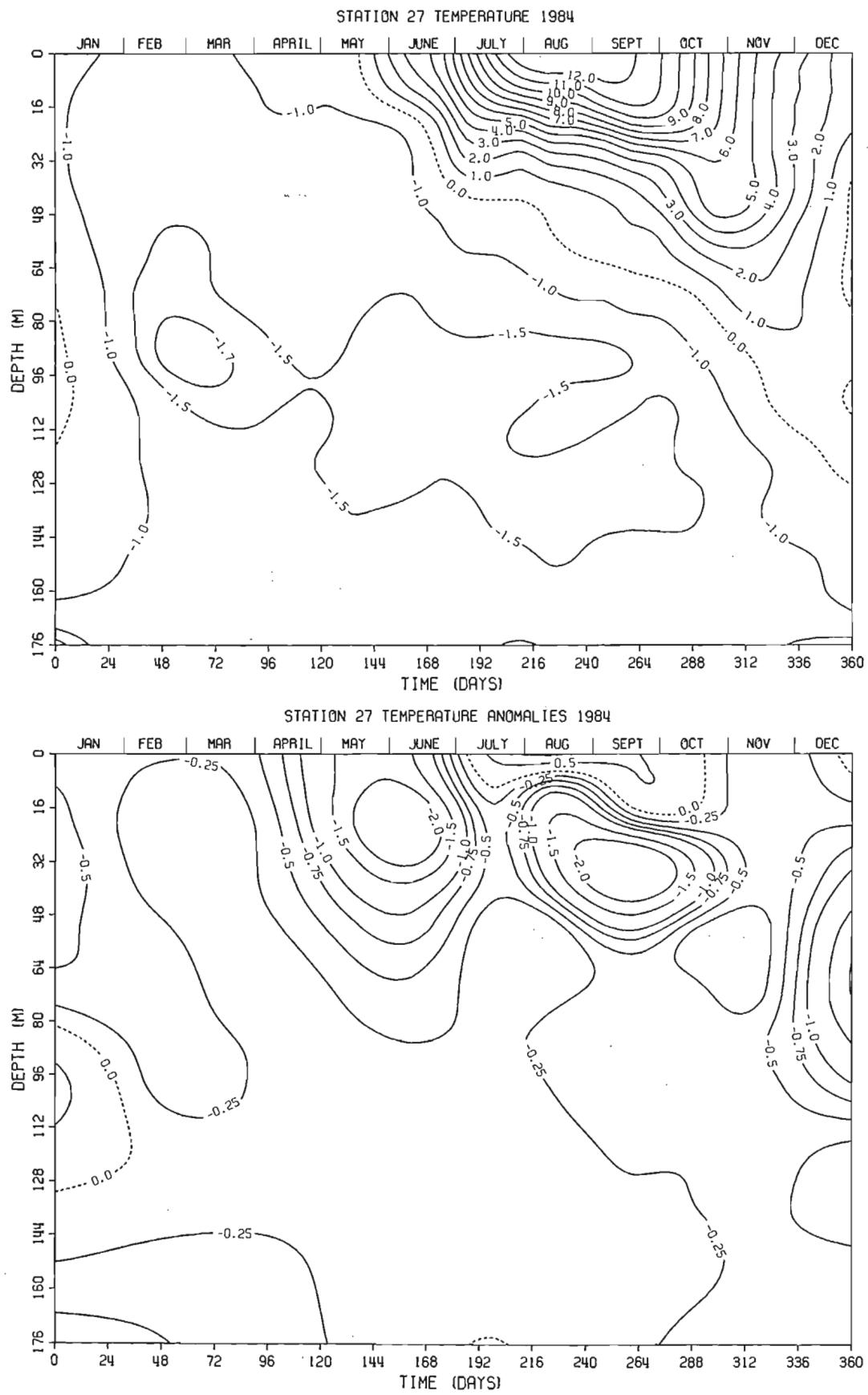
STATION 27 TEMPERATURE 1982



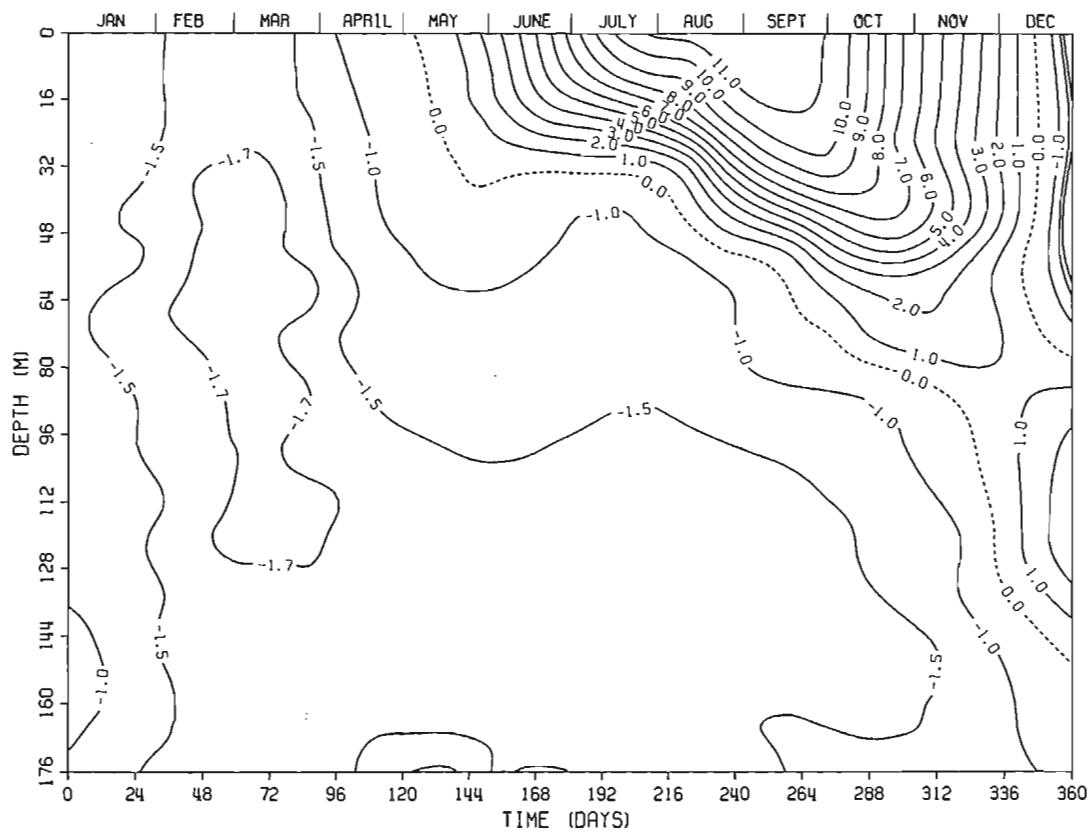
STATION 27 TEMPERATURE ANOMALIES 1982



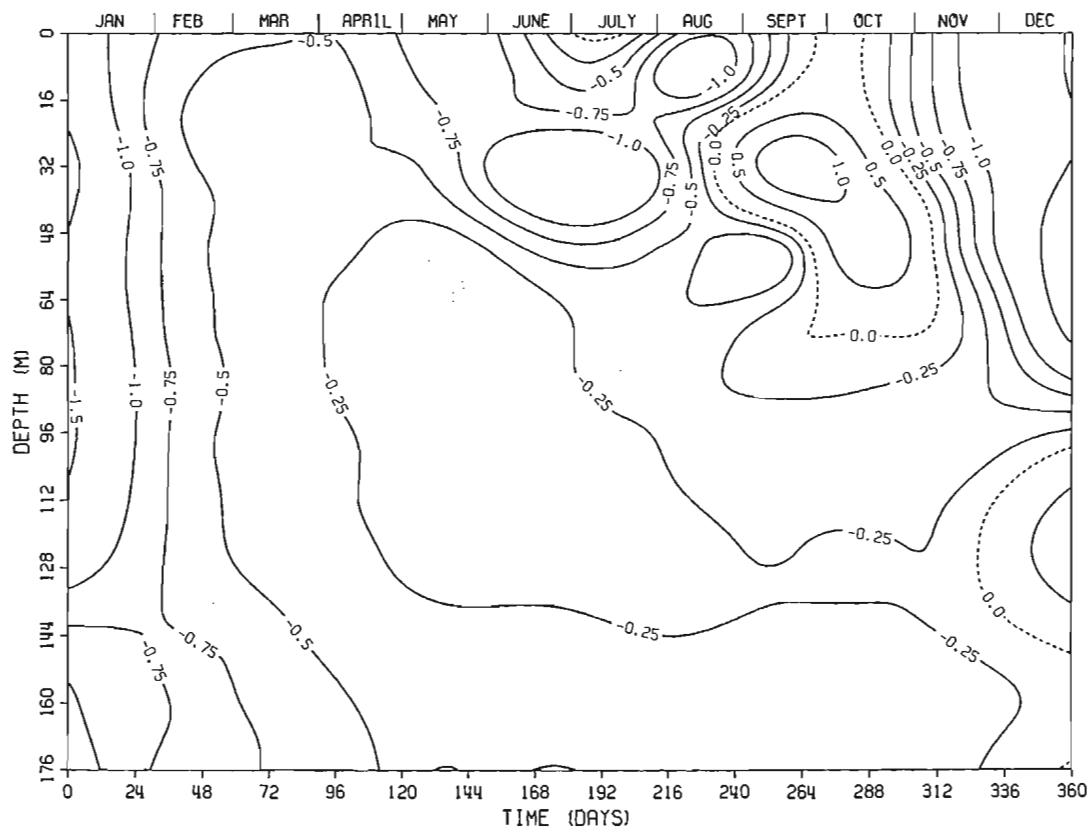


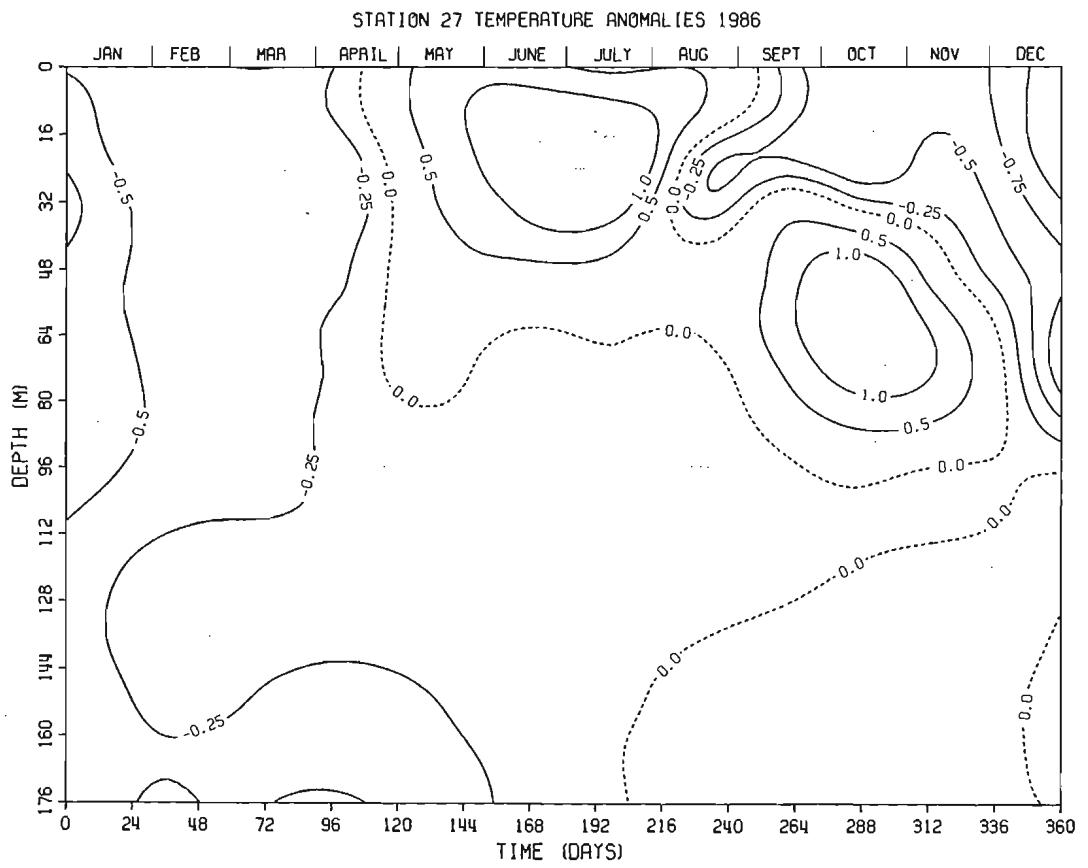
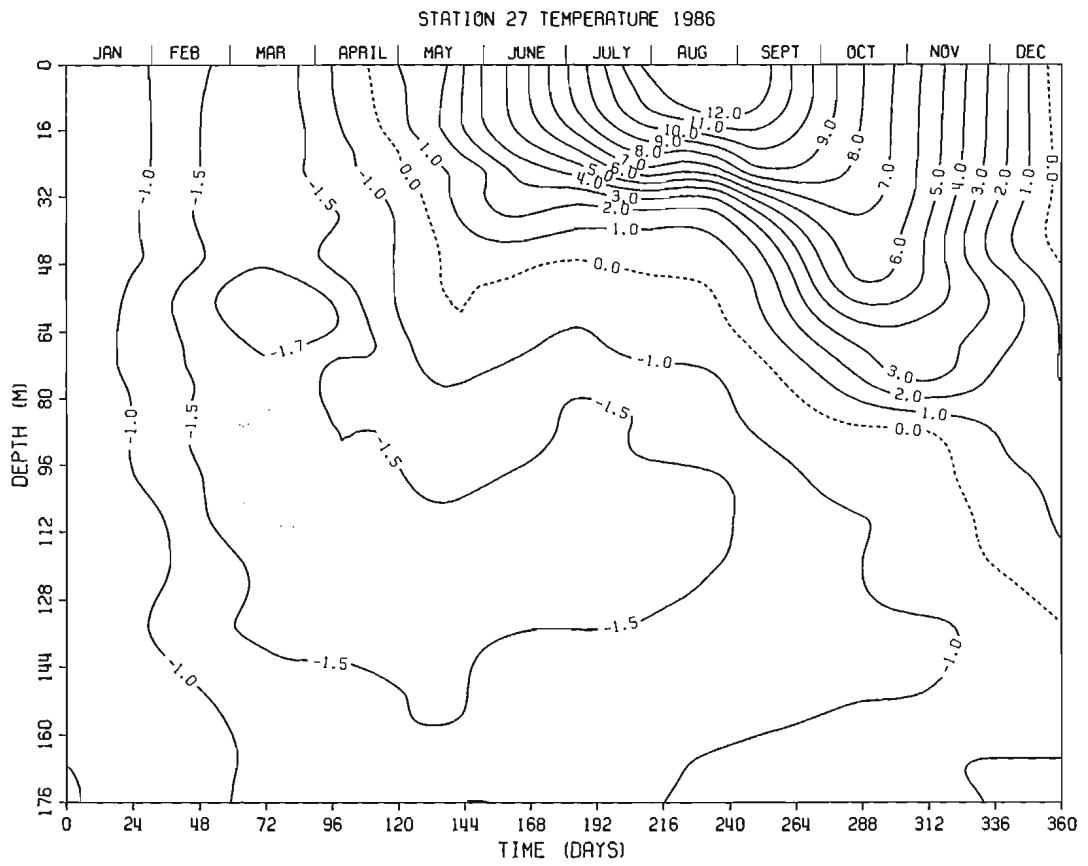


STATION 27 TEMPERATURE 1985

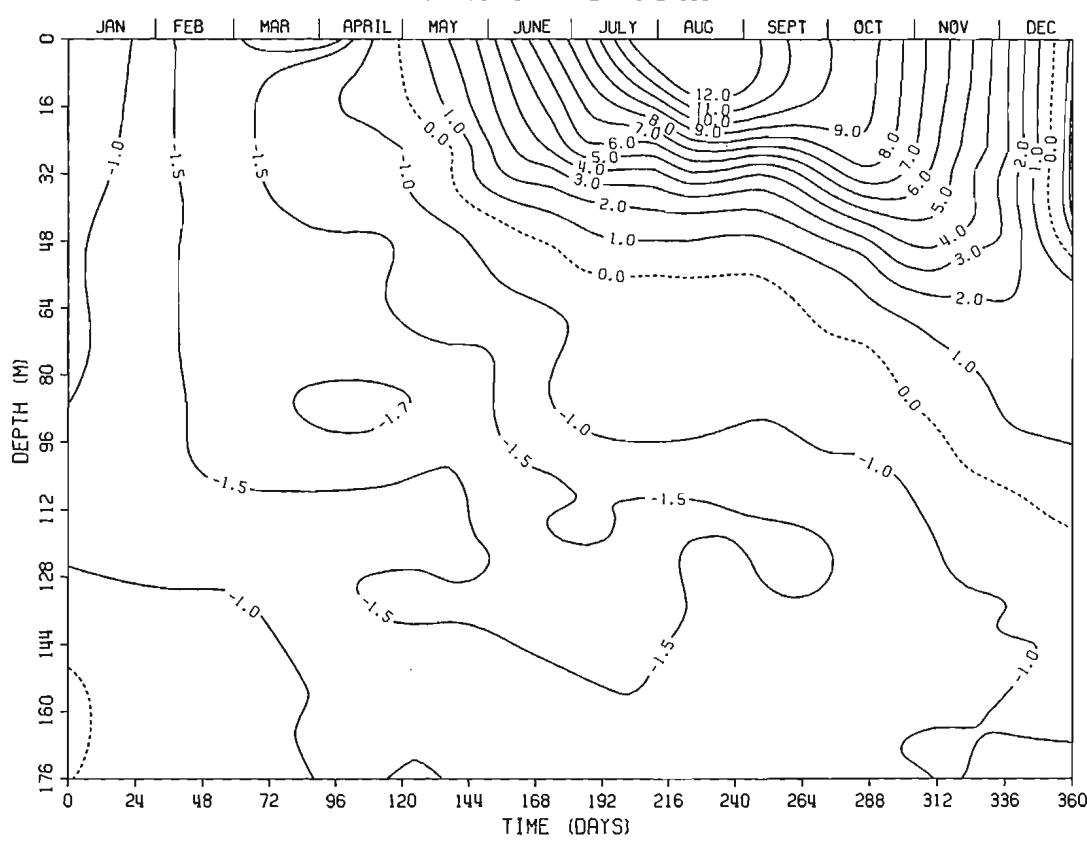


STATION 27 TEMPERATURE ANOMALIES 1985

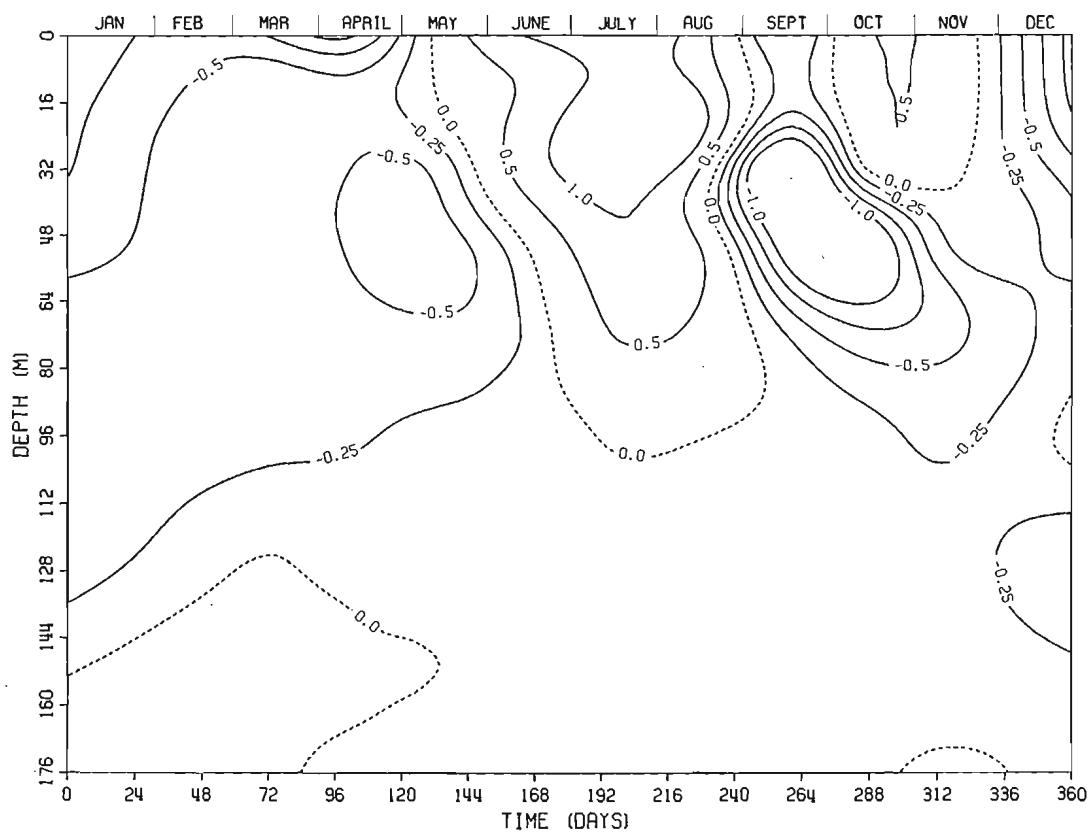


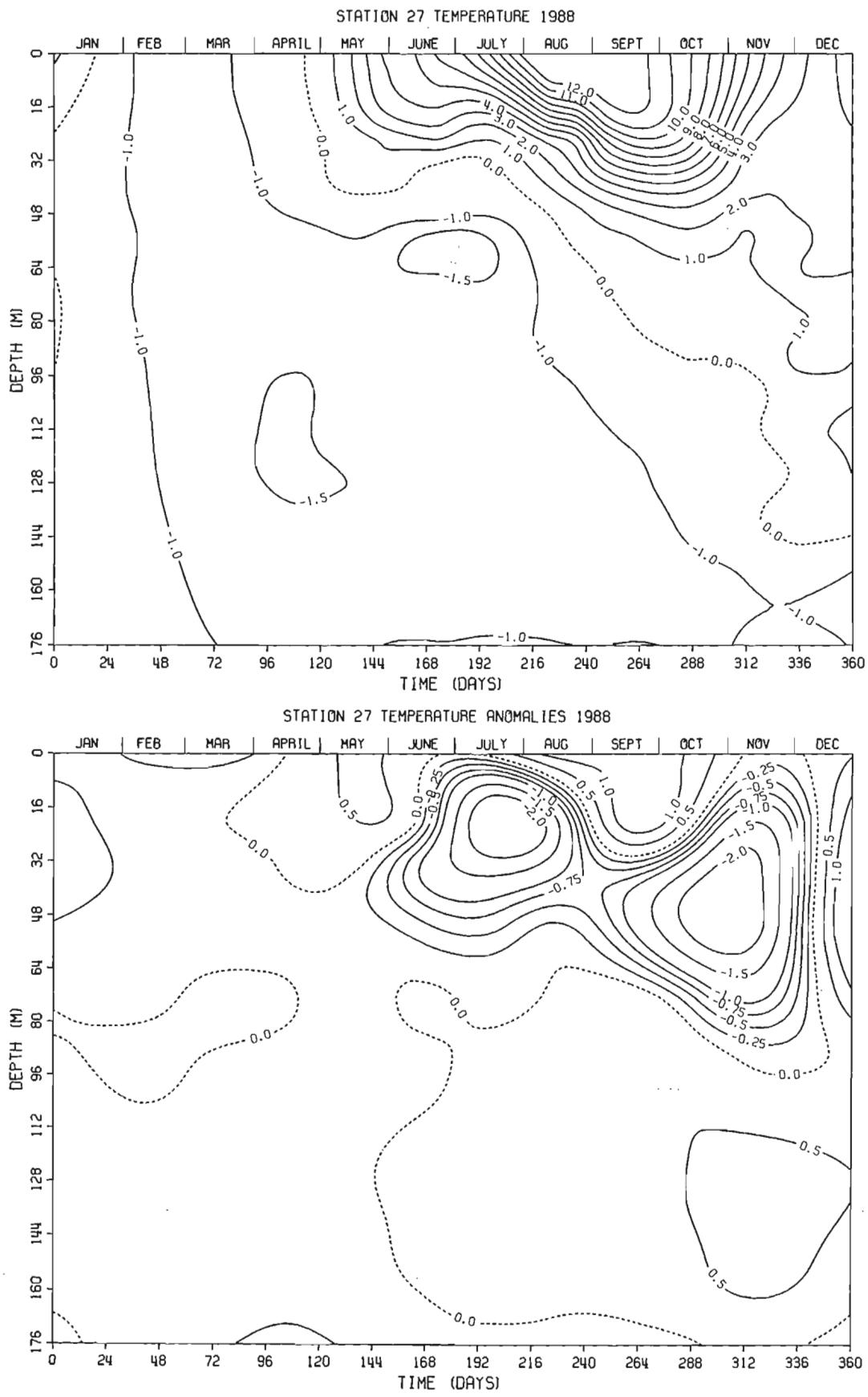


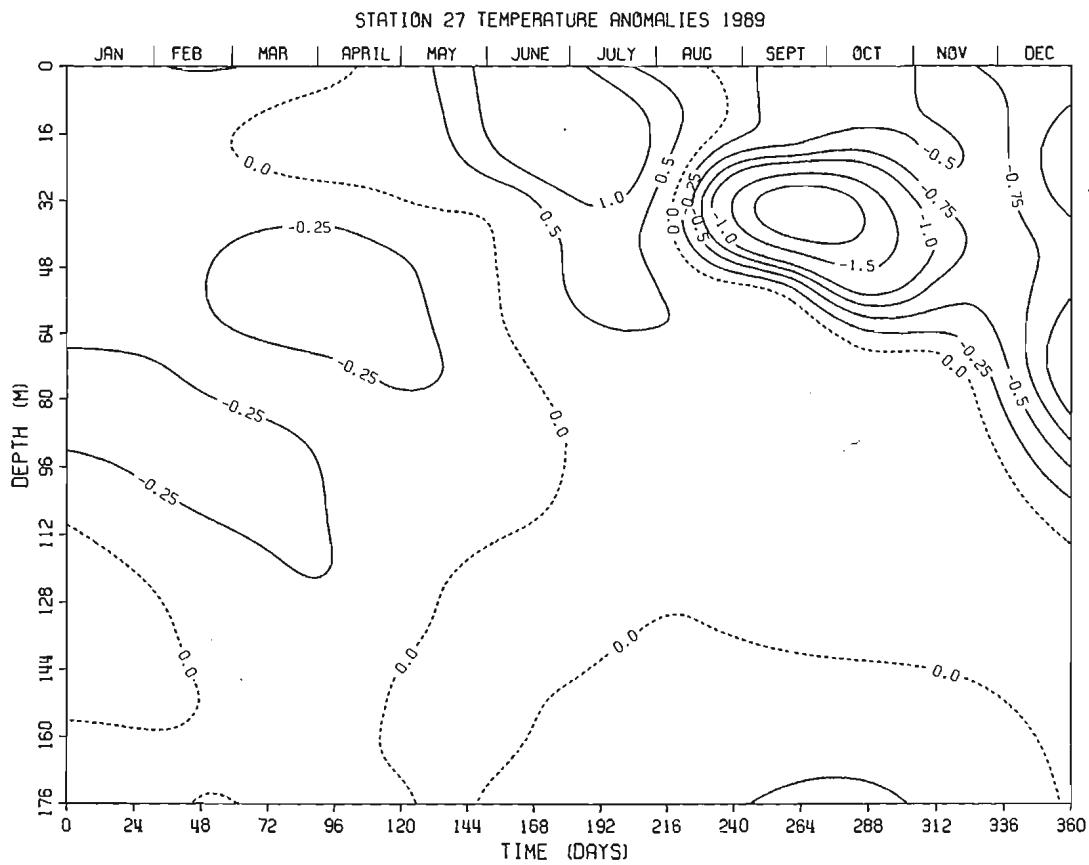
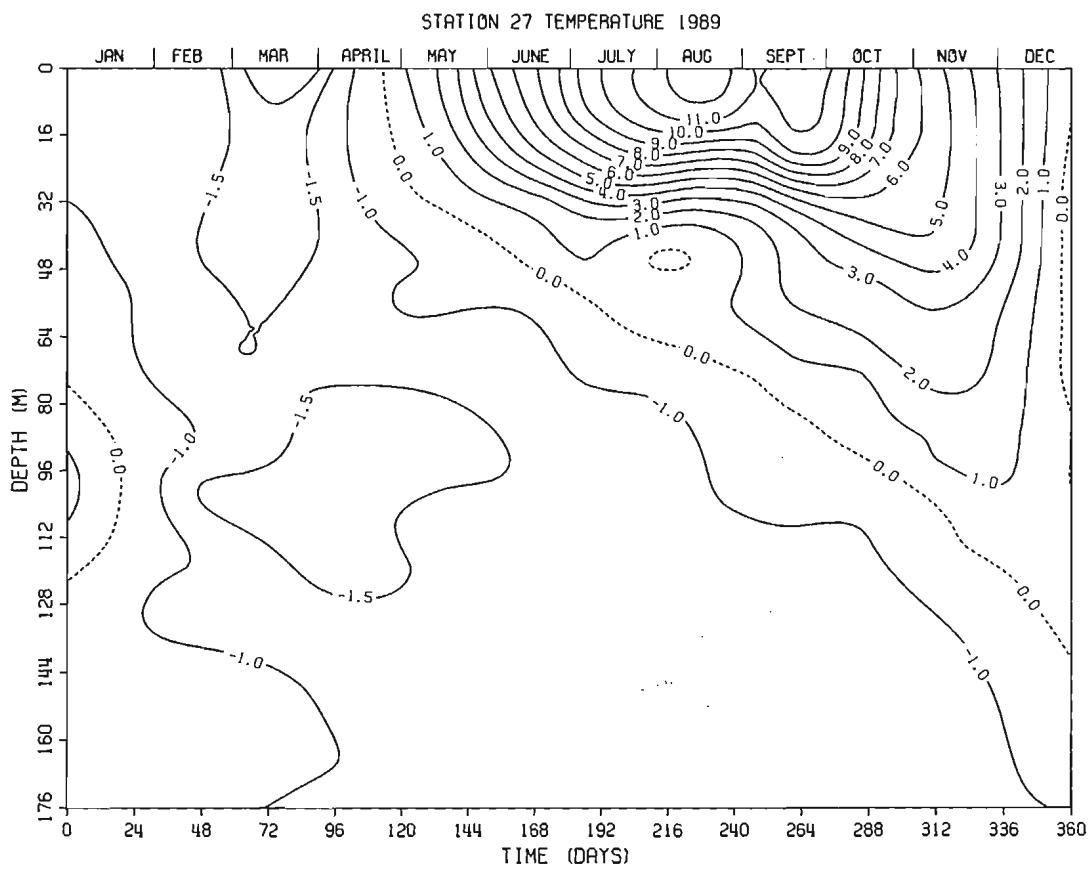
STATION 27 TEMPERATURE 1987

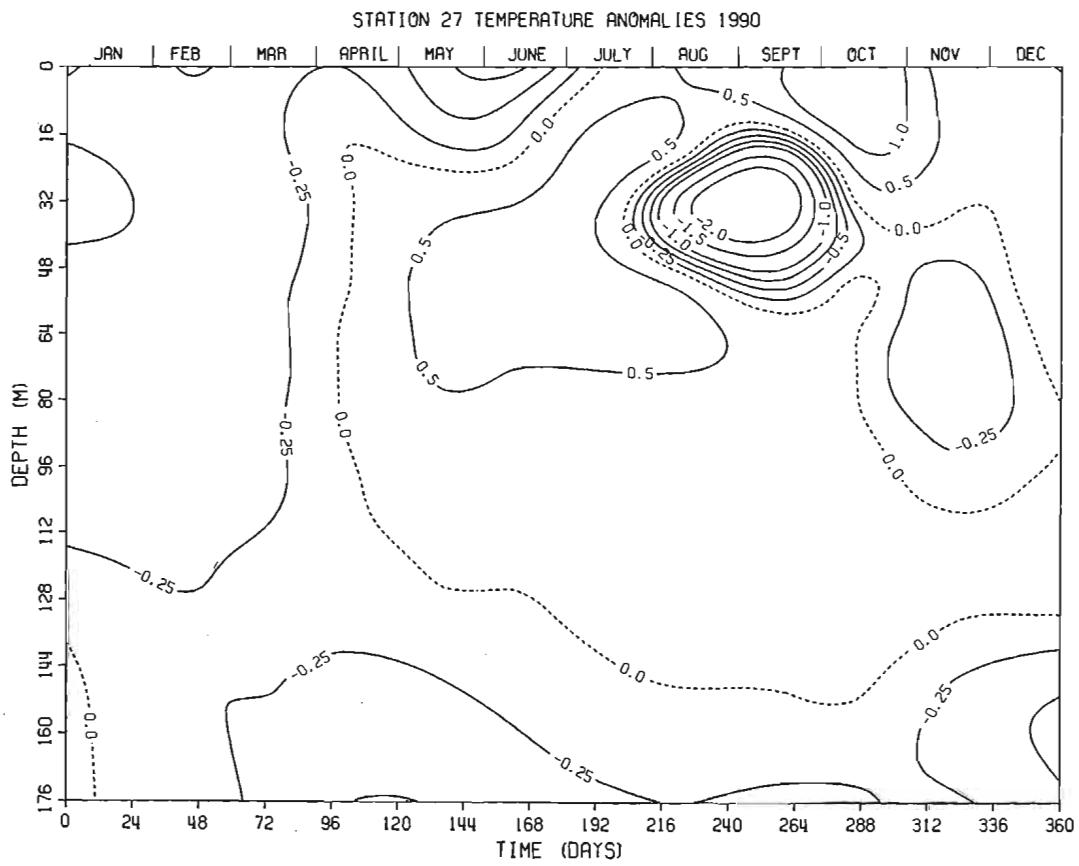
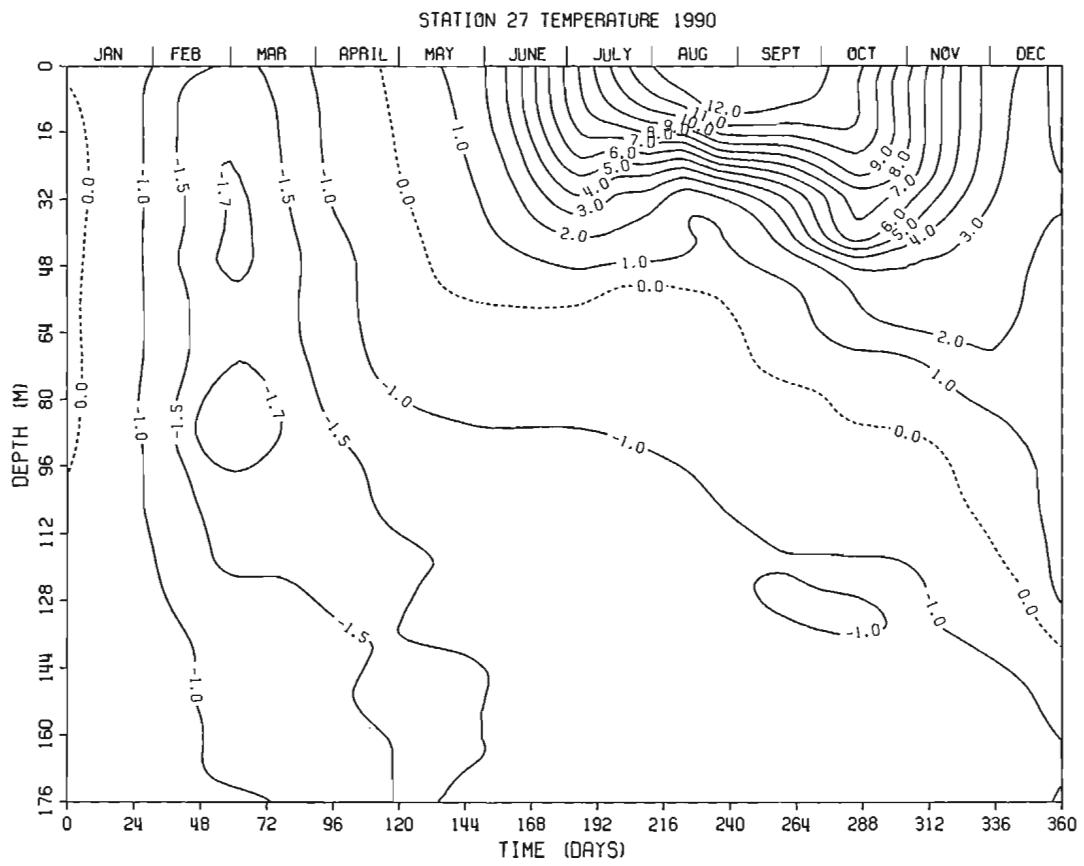


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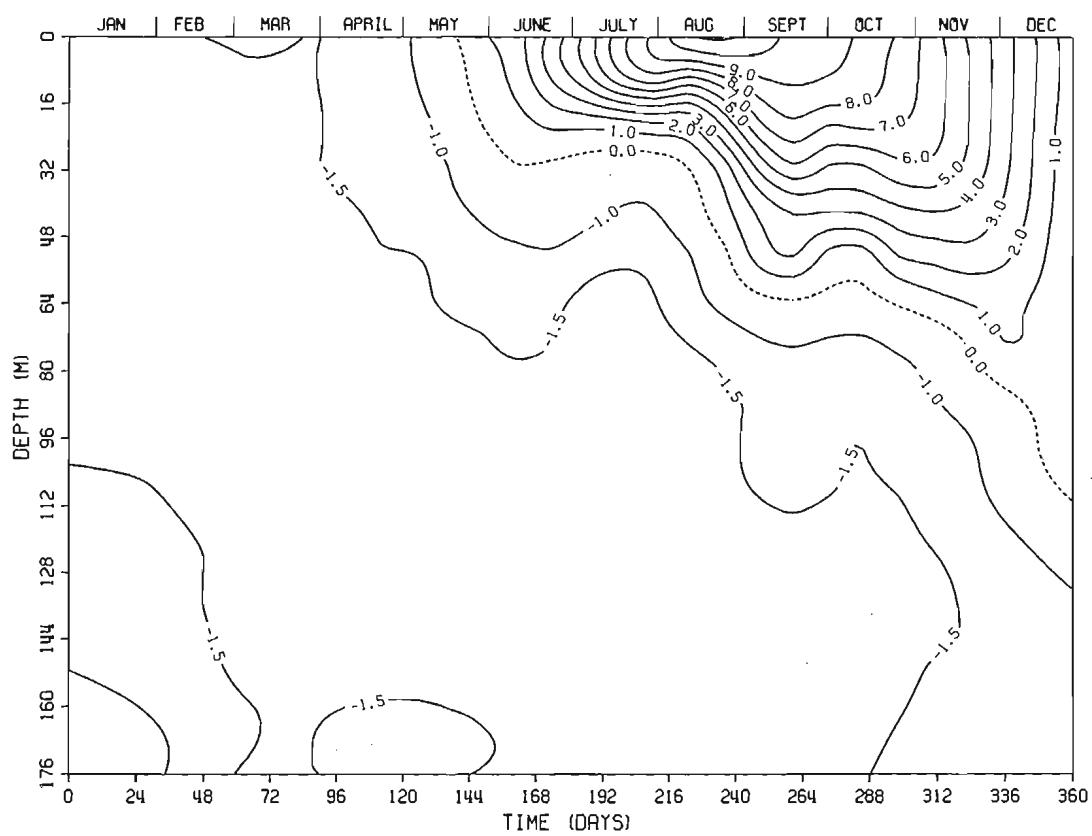




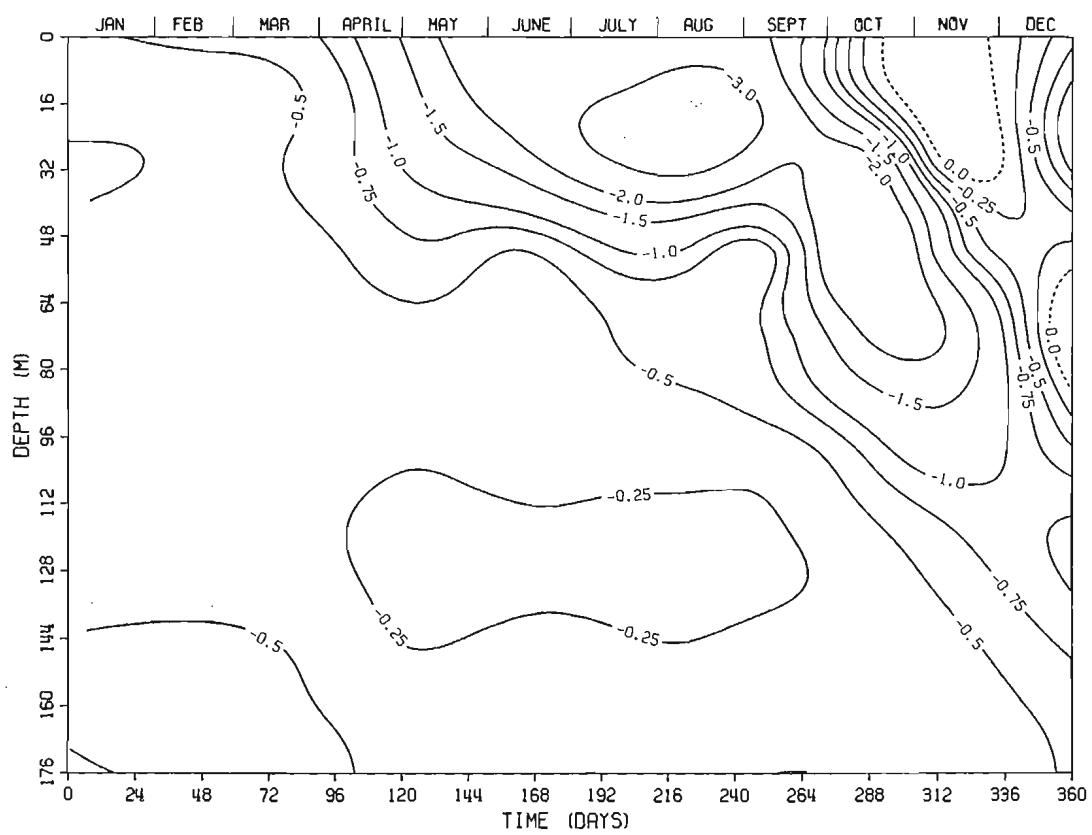


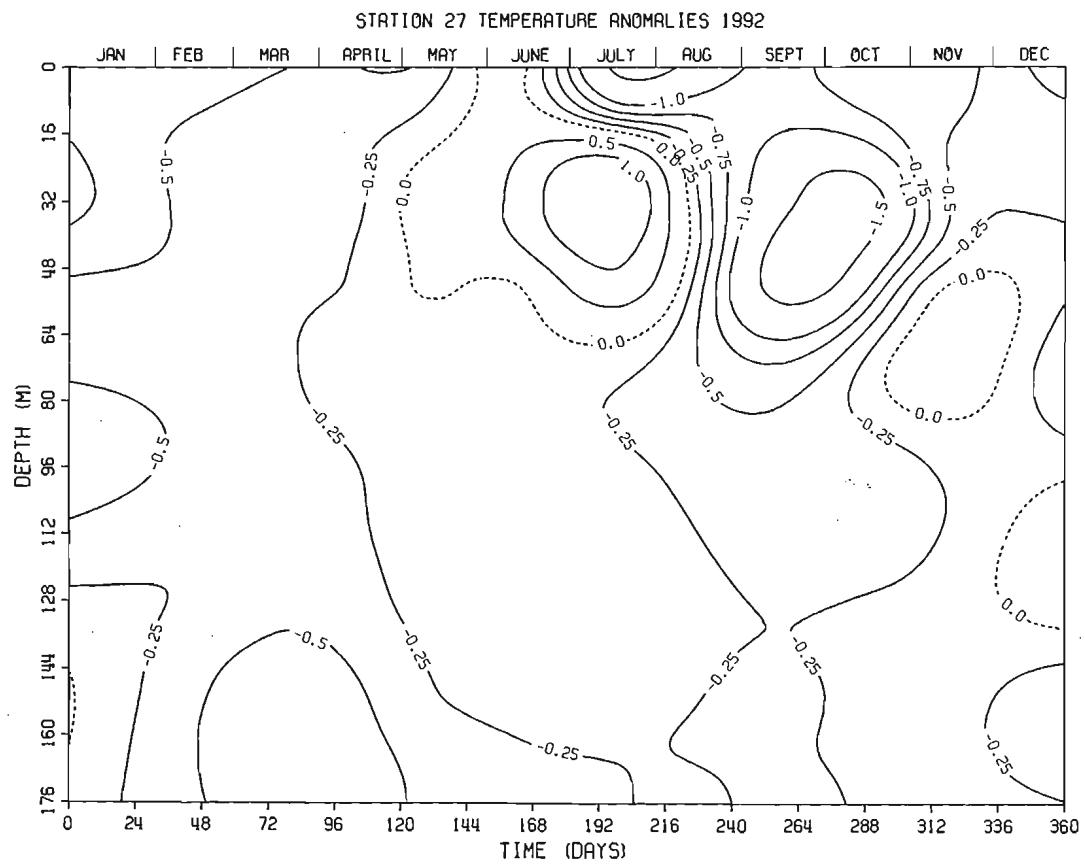
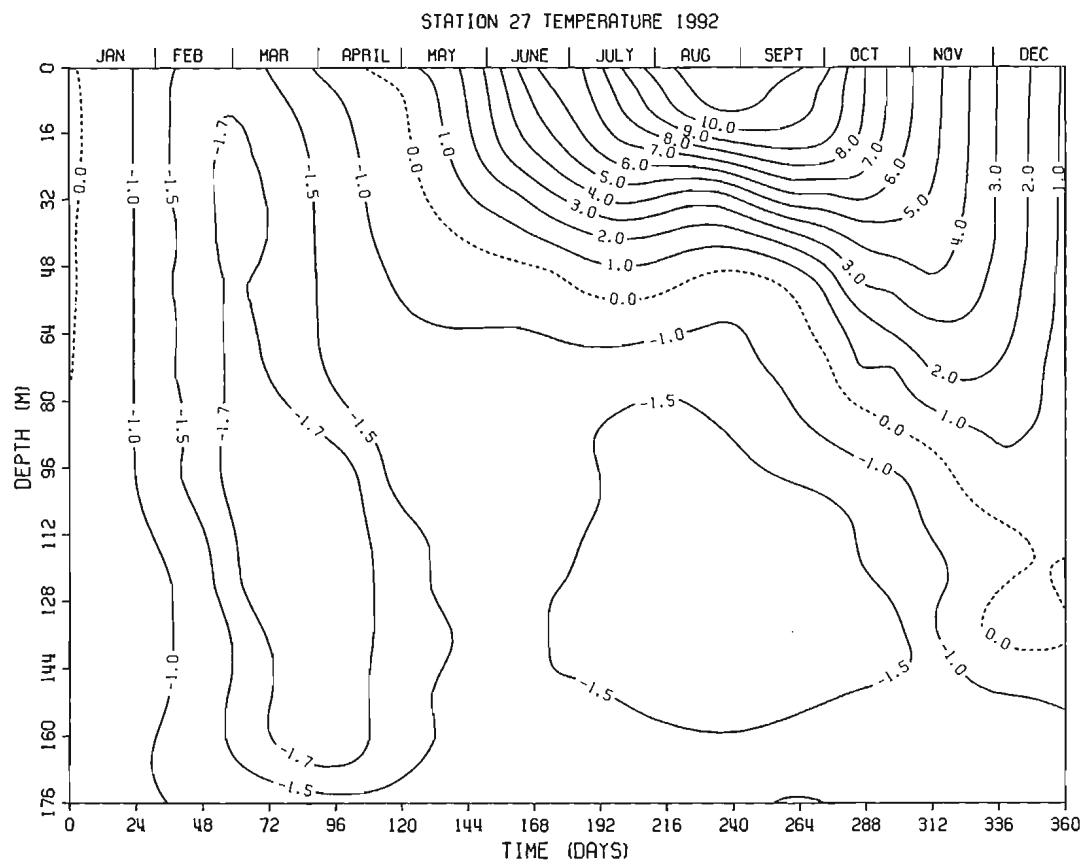


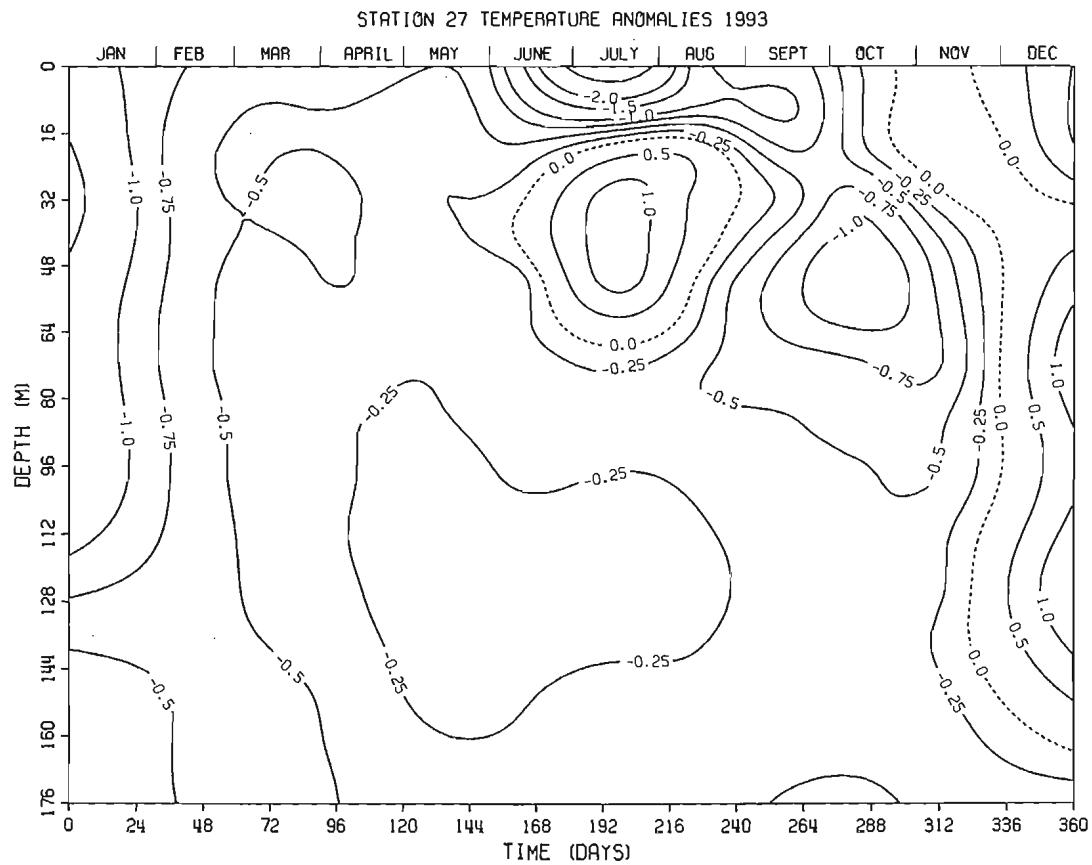
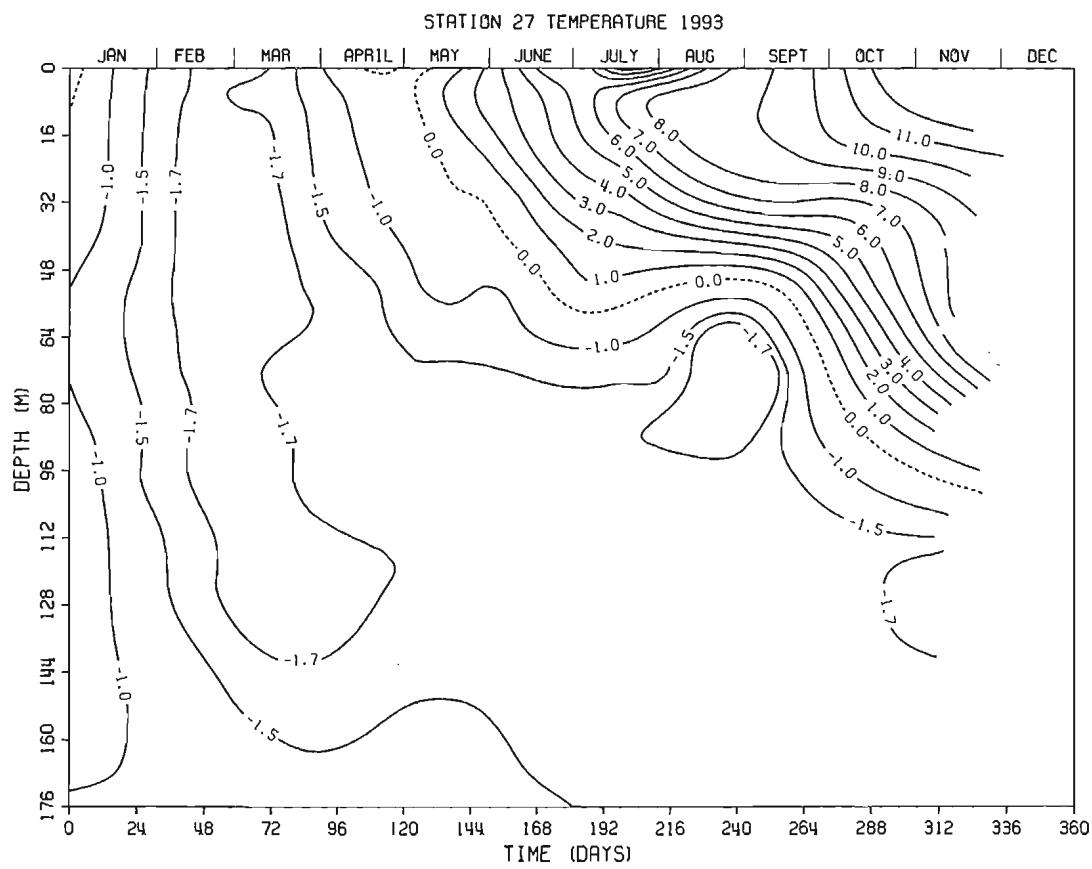
STATION 27 TEMPERATURE 1991



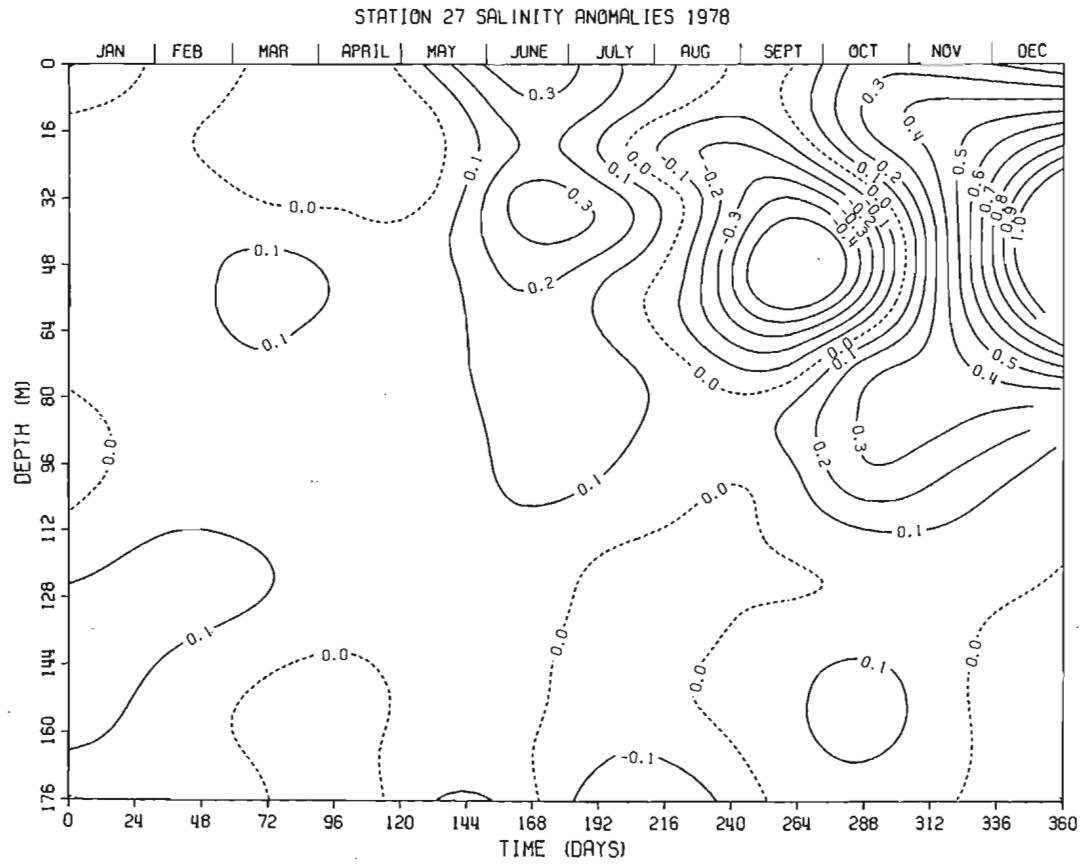
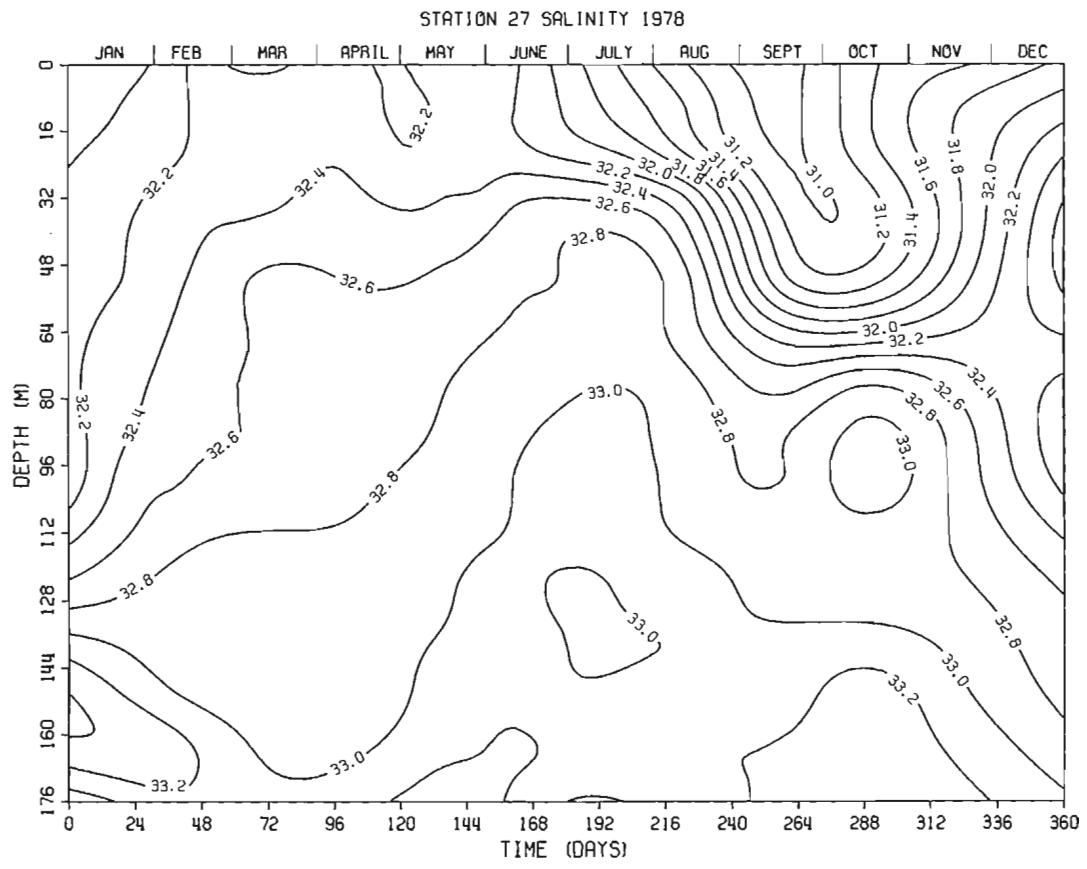
STATION 27 TEMPERATURE ANOMALIES 1991

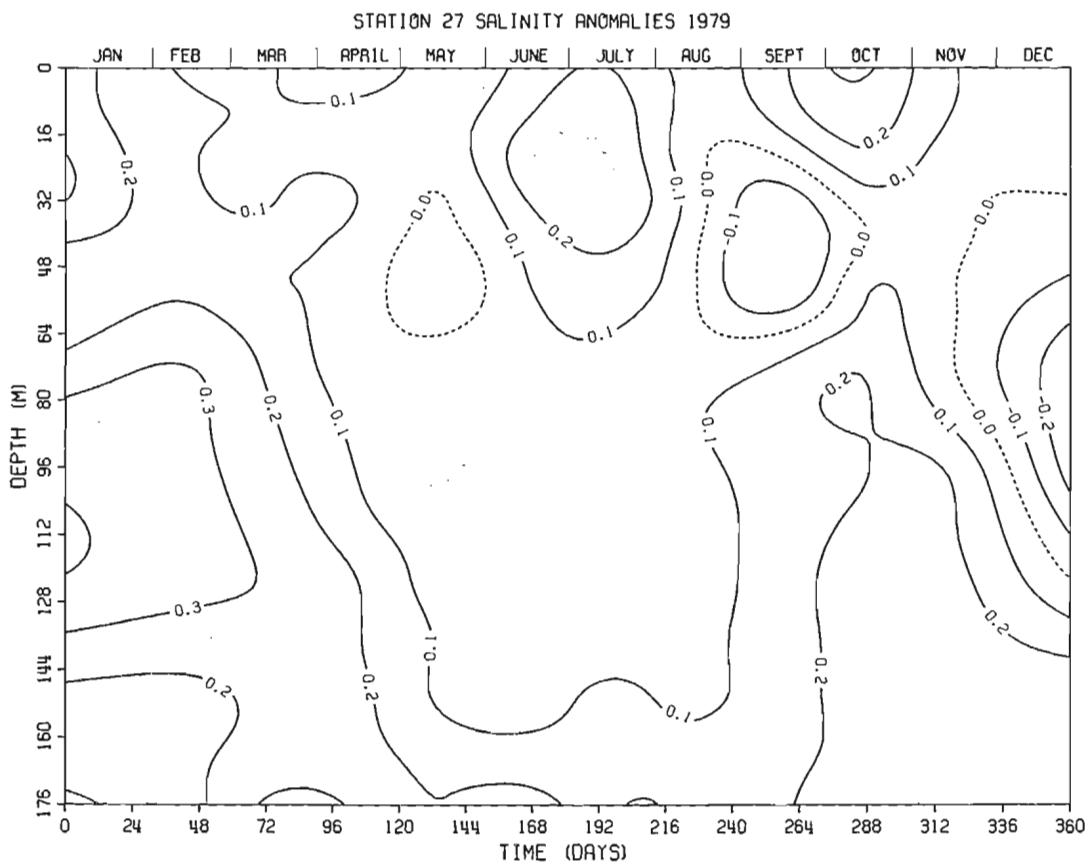
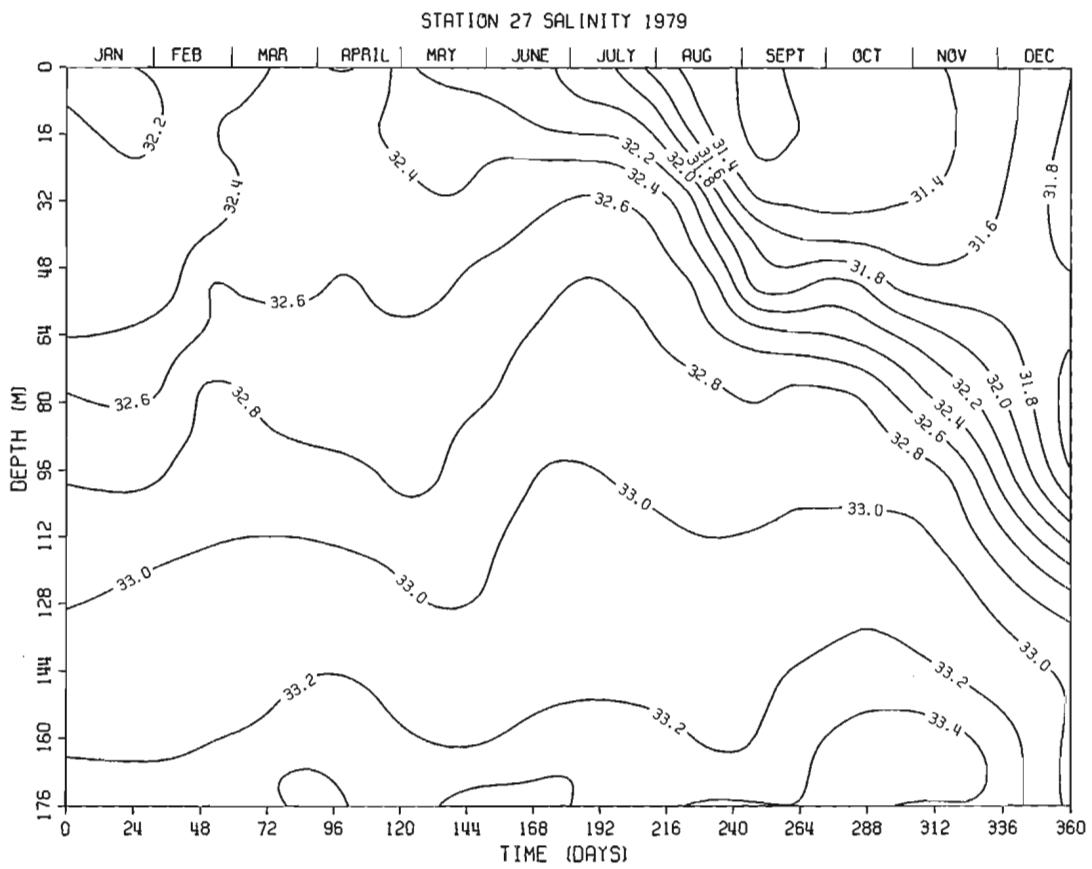


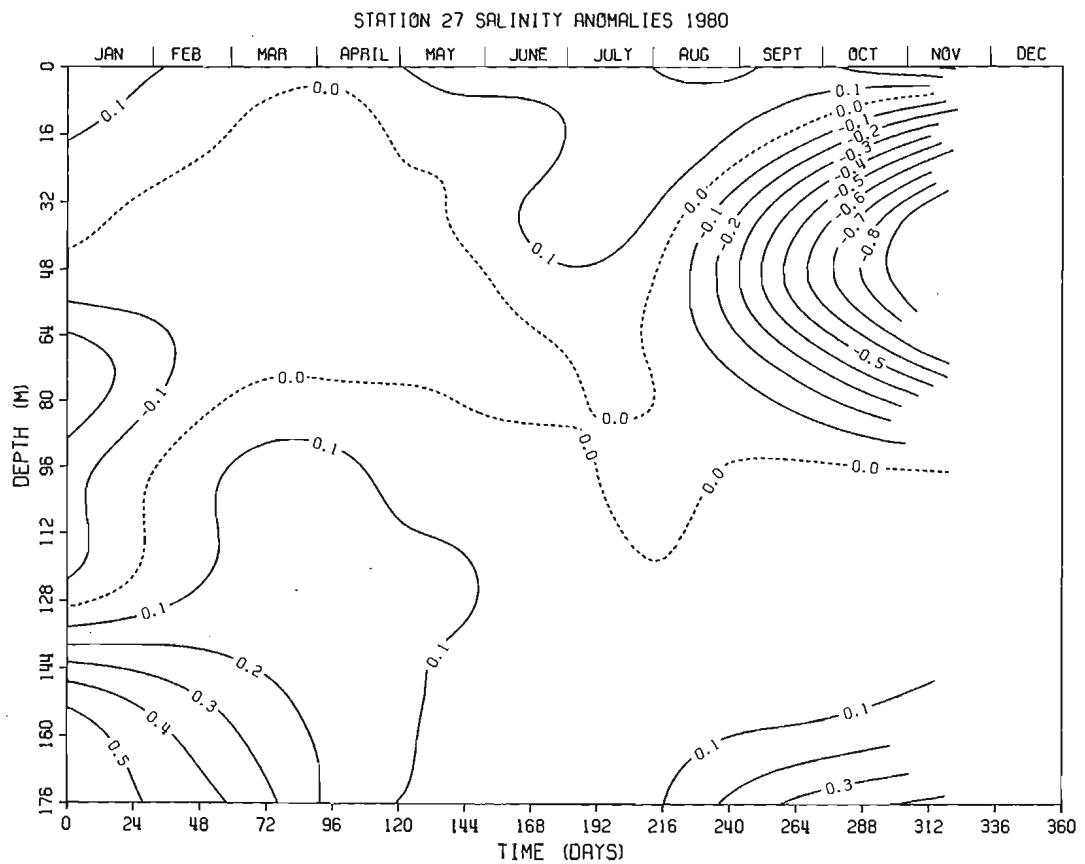
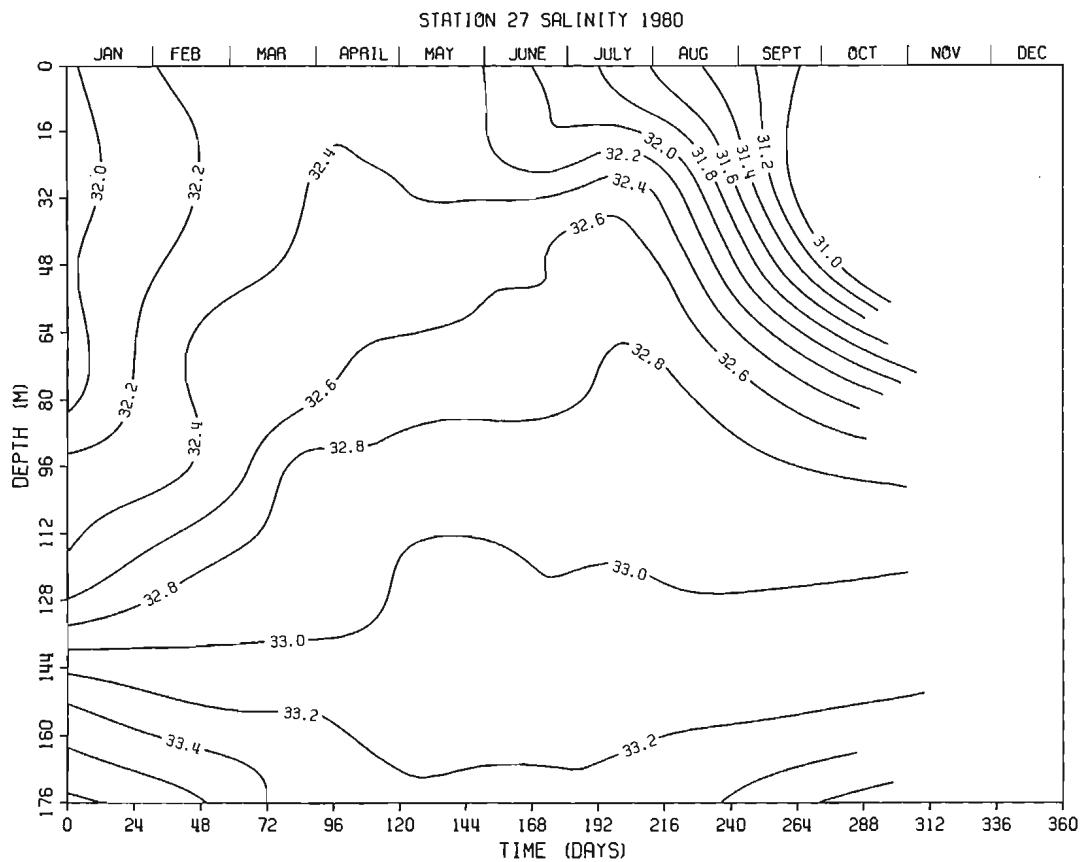




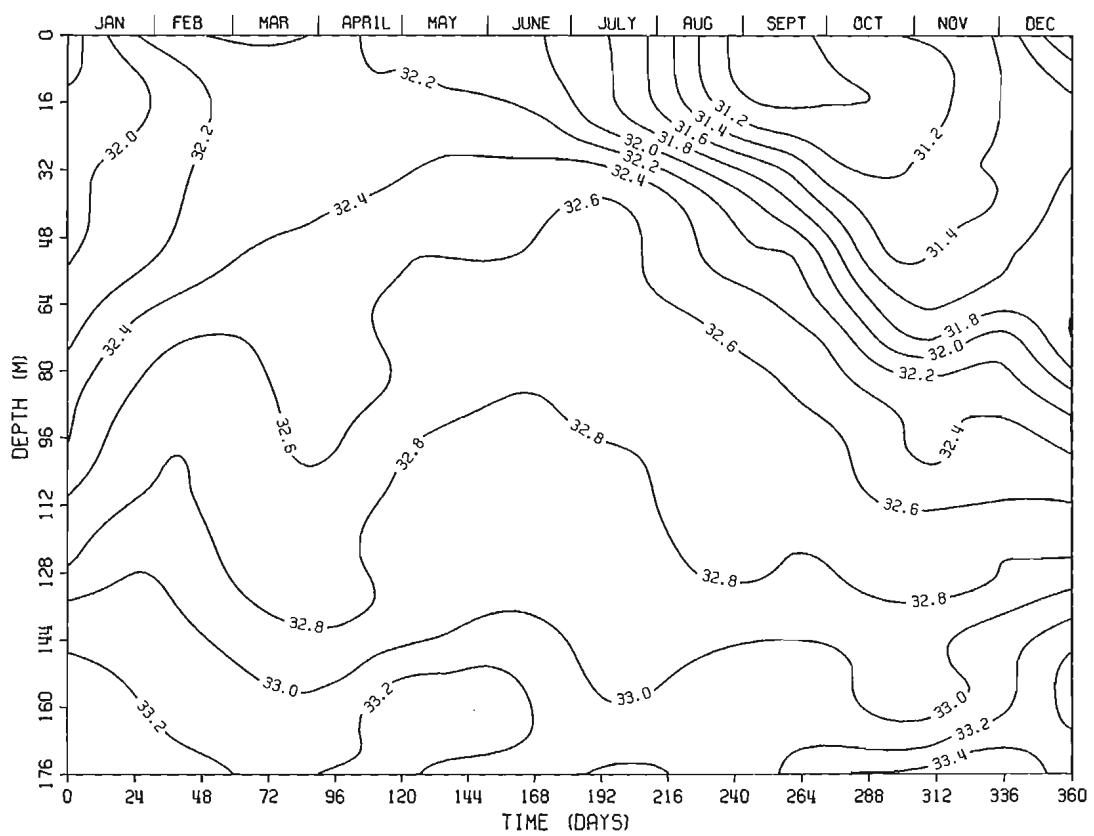
APPENDIX E. Depth versus time contours of the yearly salinity and salinity anomalies at Station 27 from 1978 to 1993.



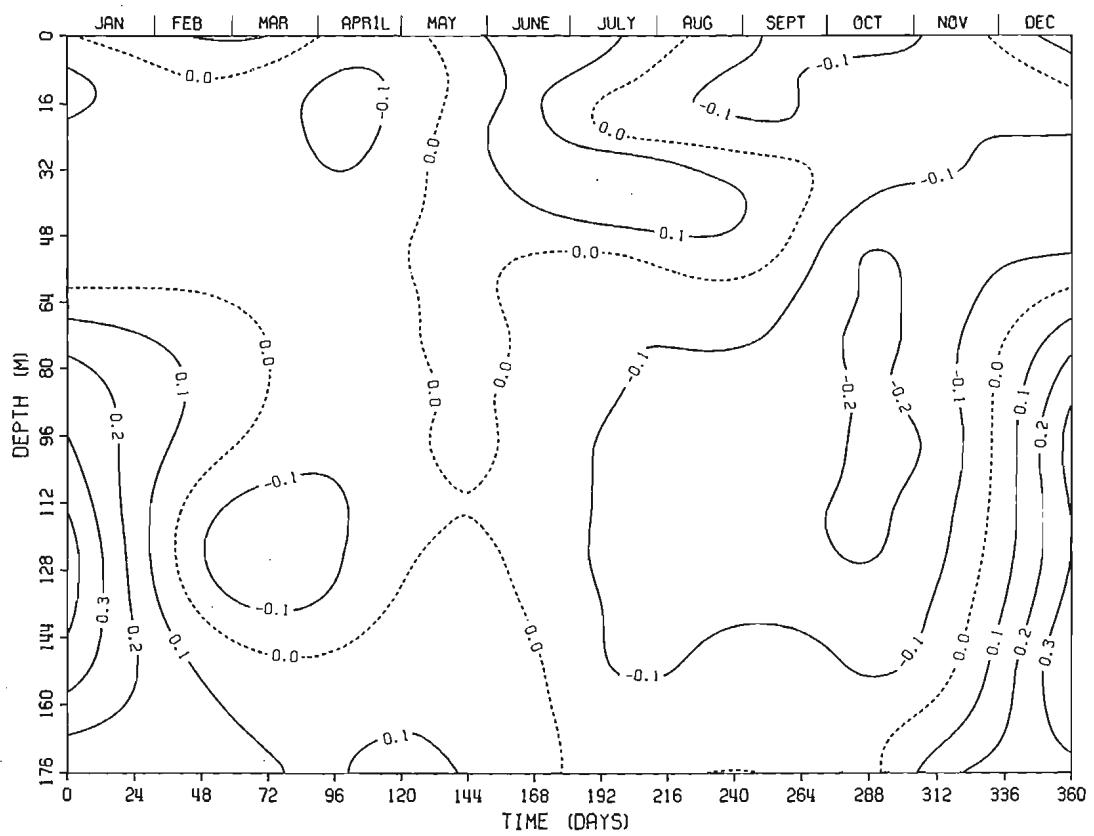


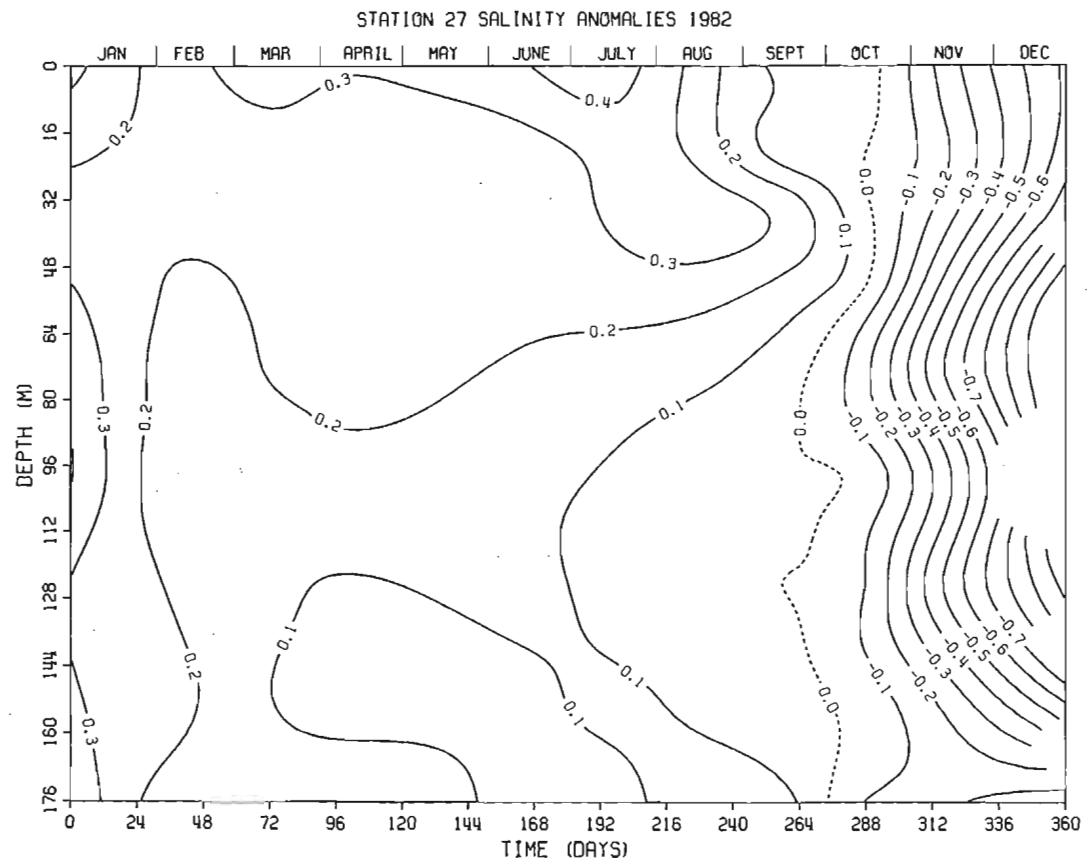
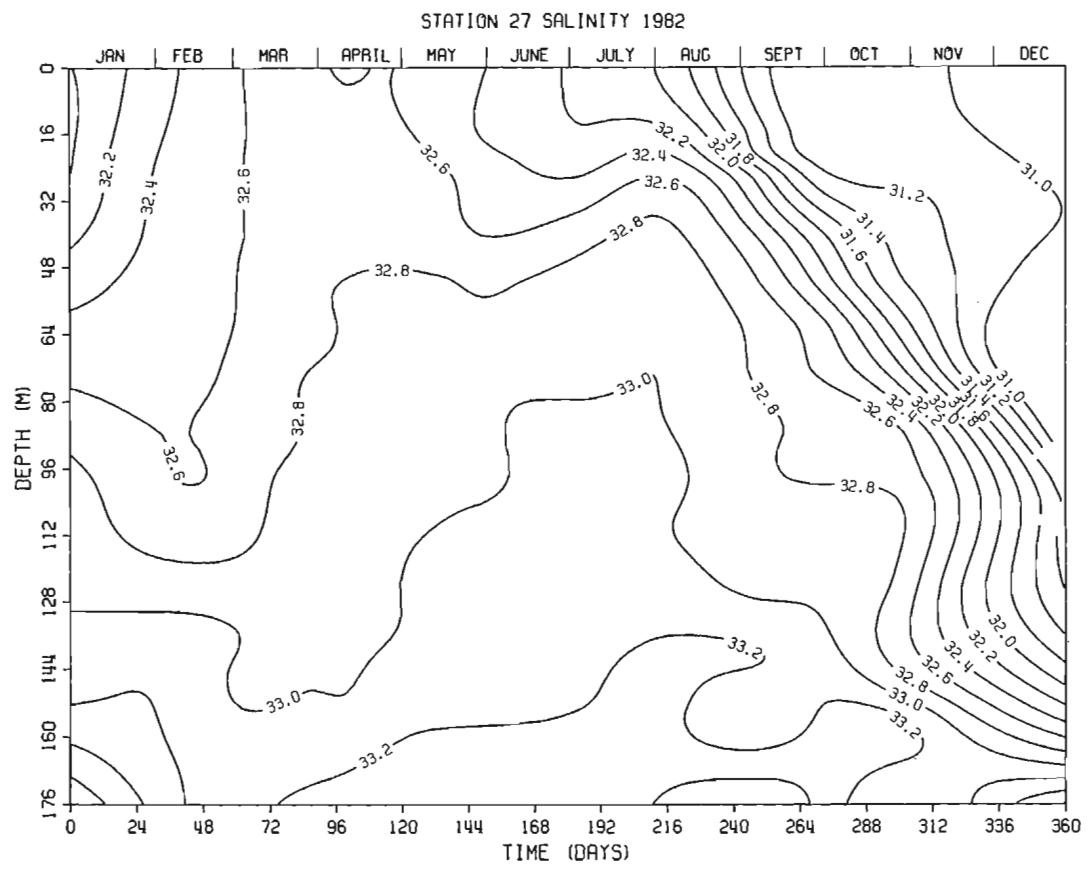


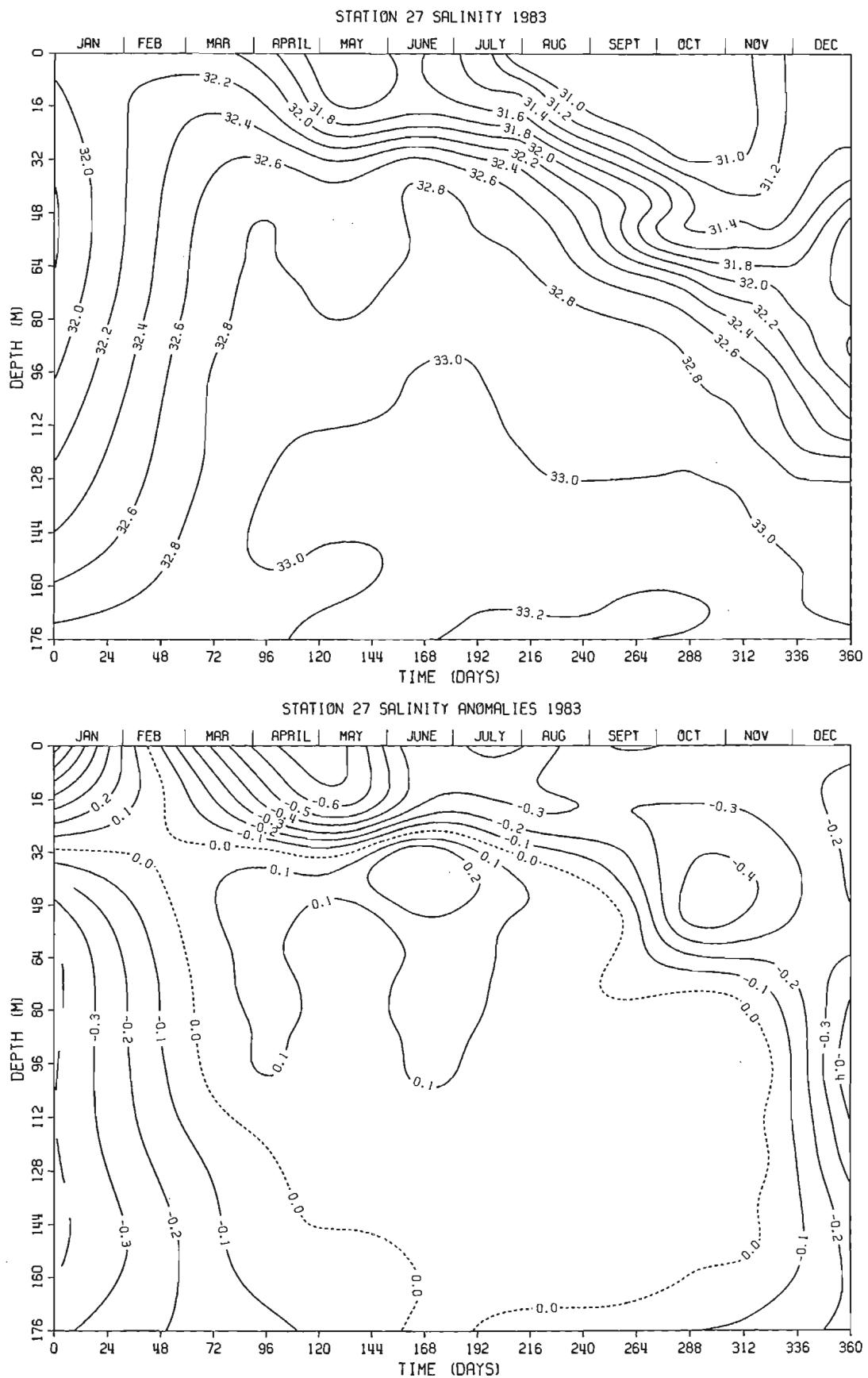
STATION 27 SALINITY 1981

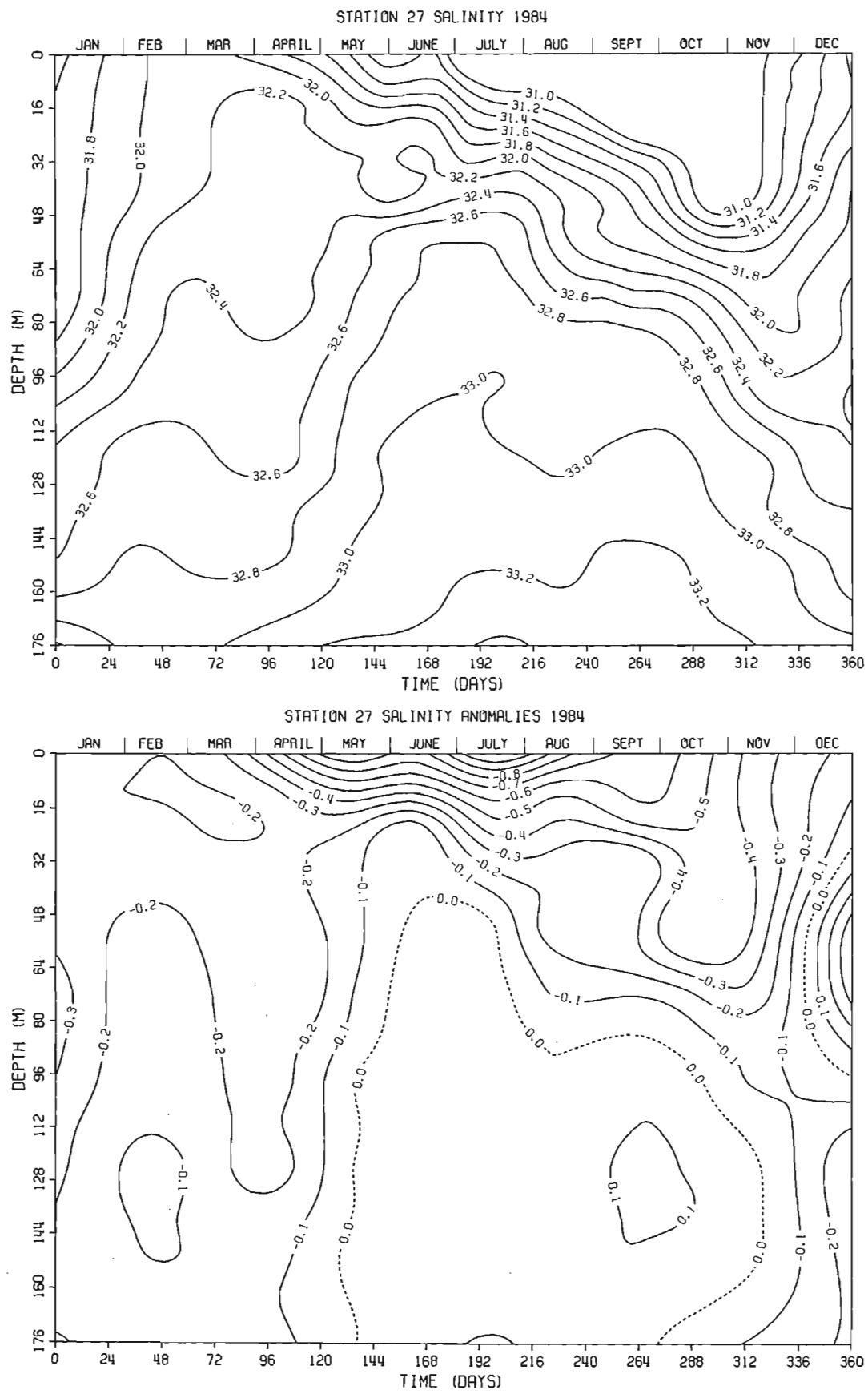


STATION 27 SALINITY ANOMALIES 1981

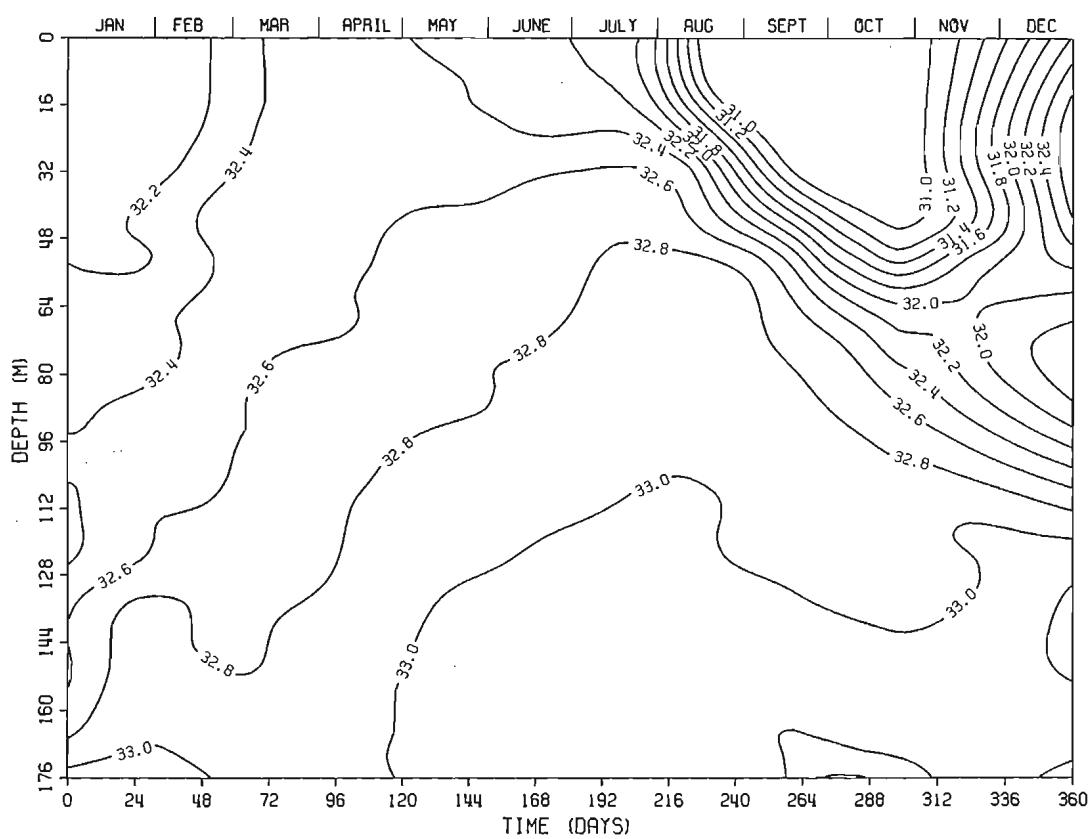




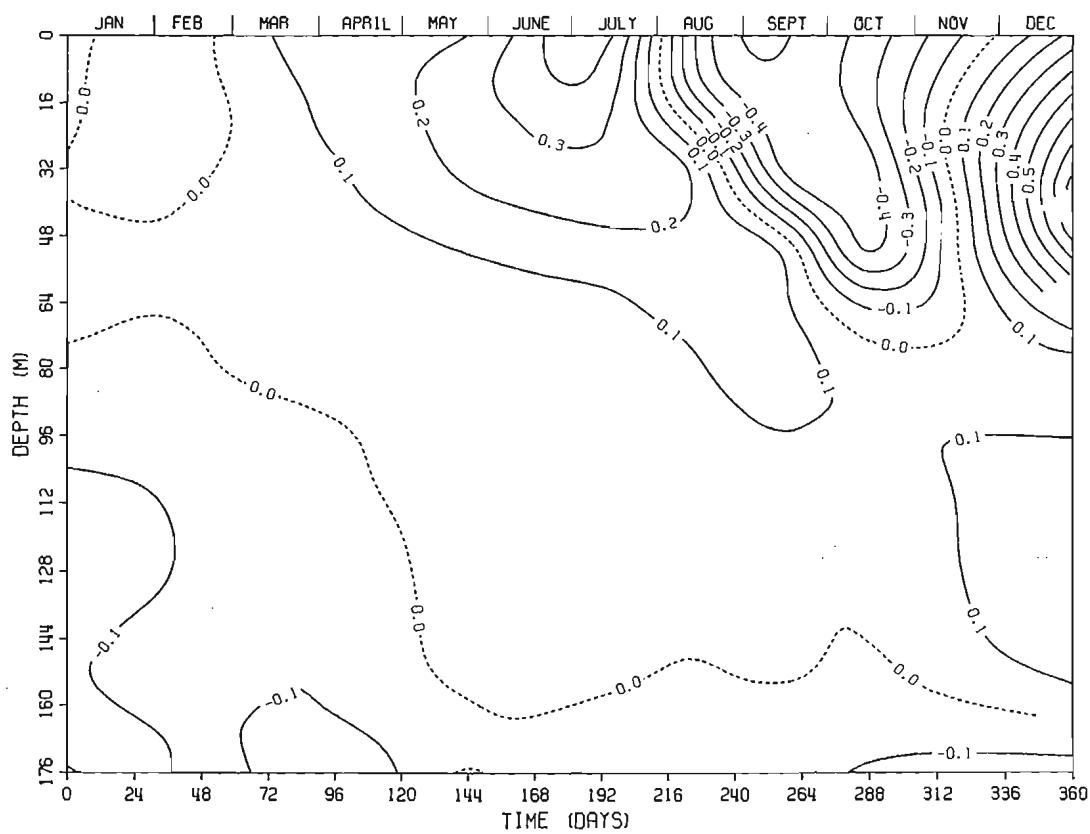


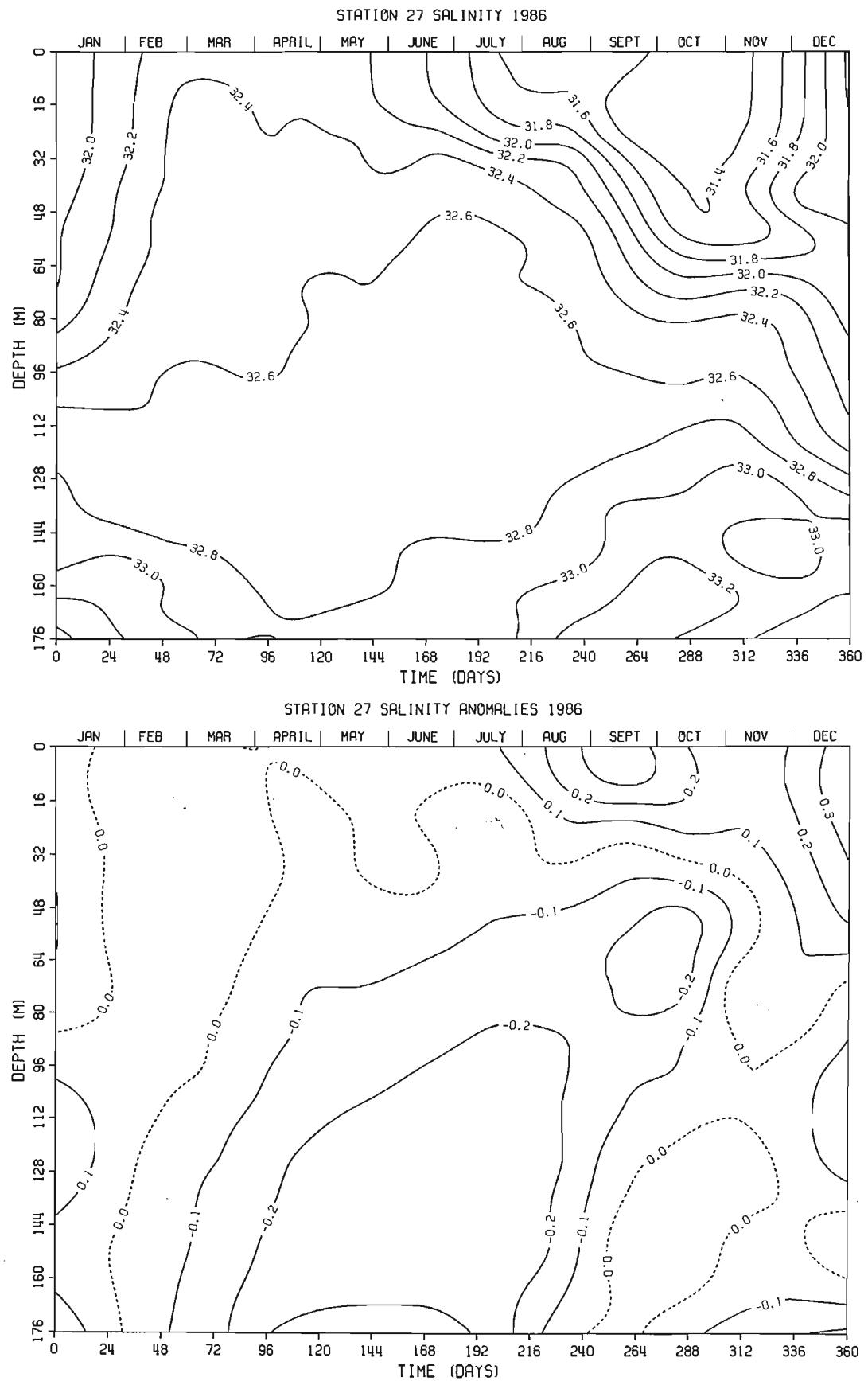


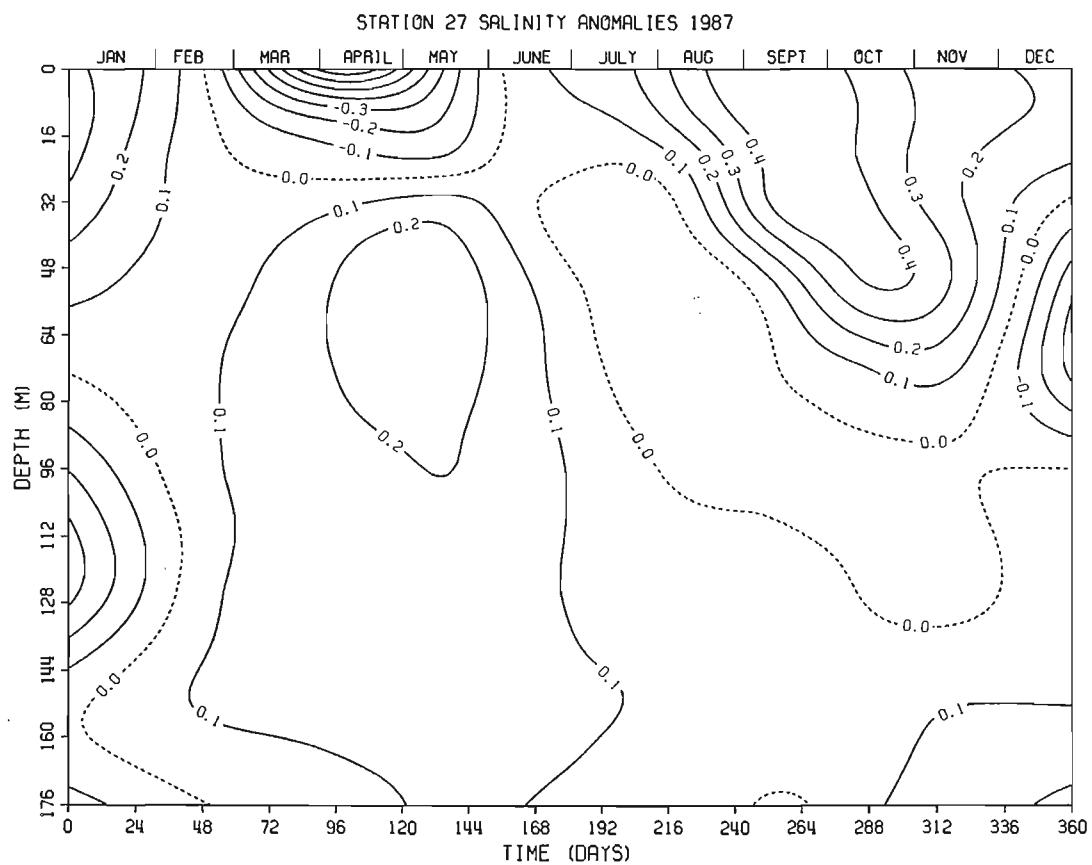
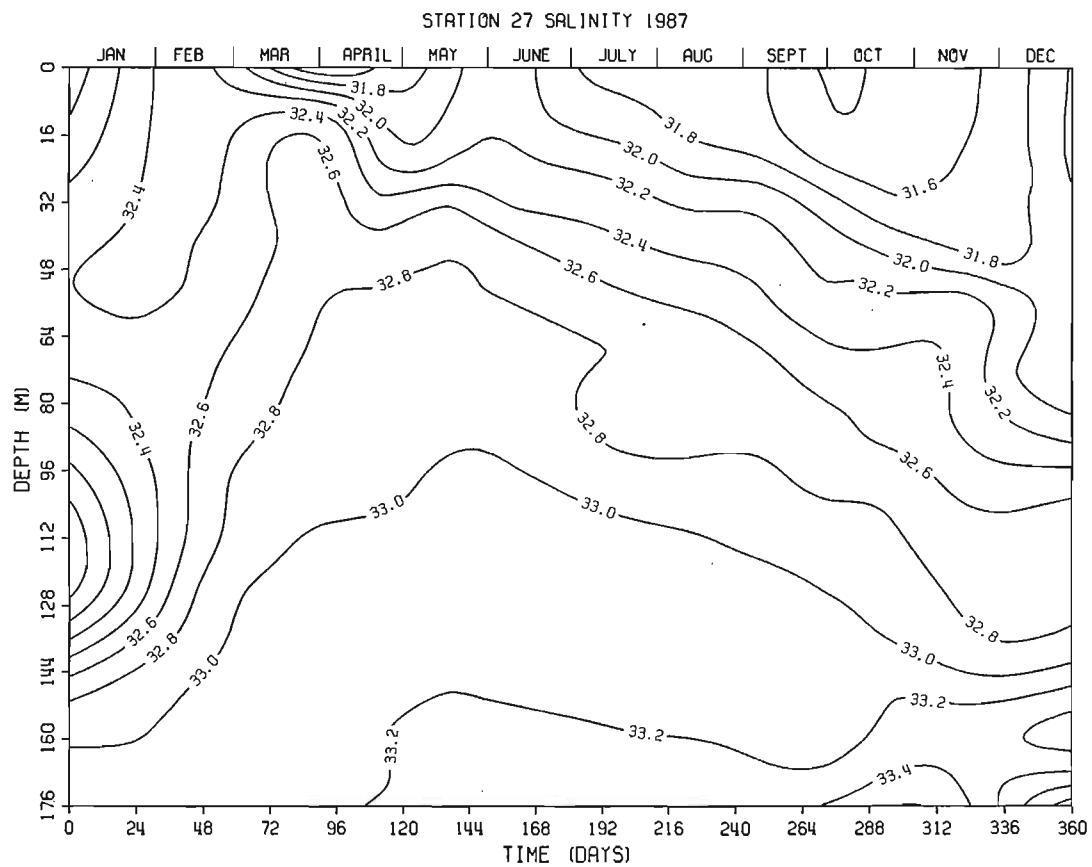
STATION 27 SALINITY 1985

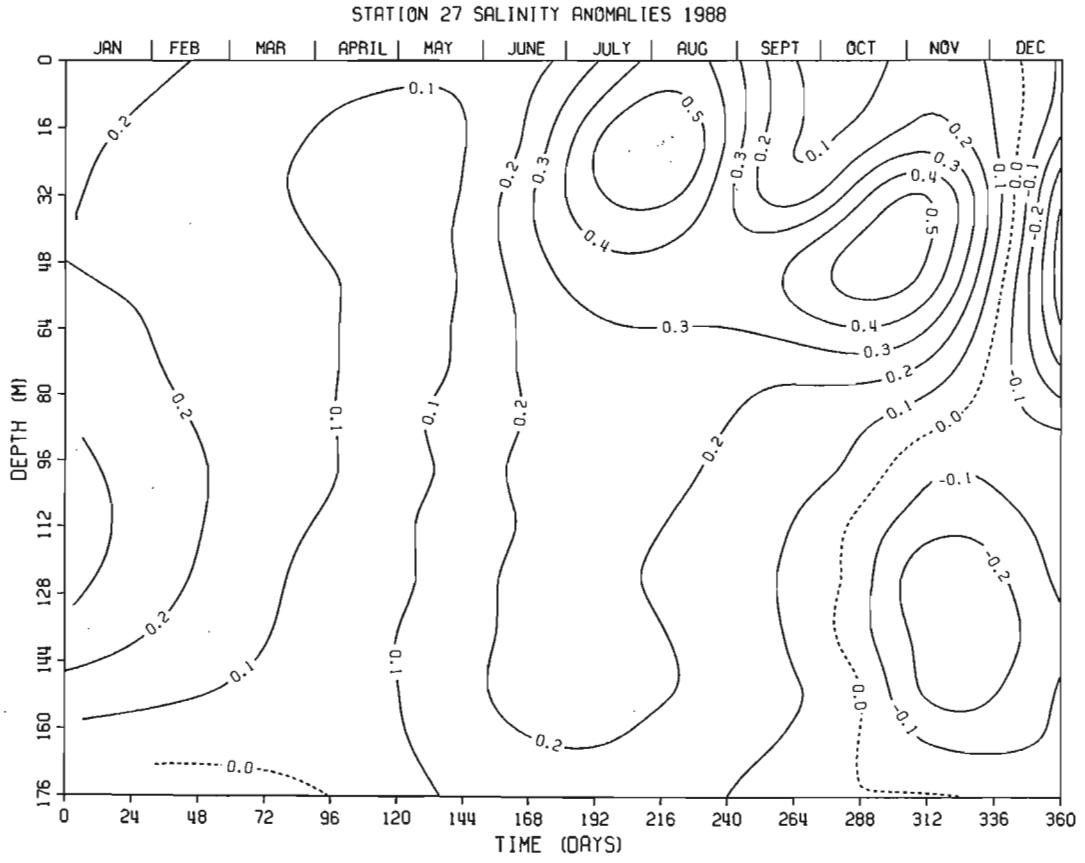
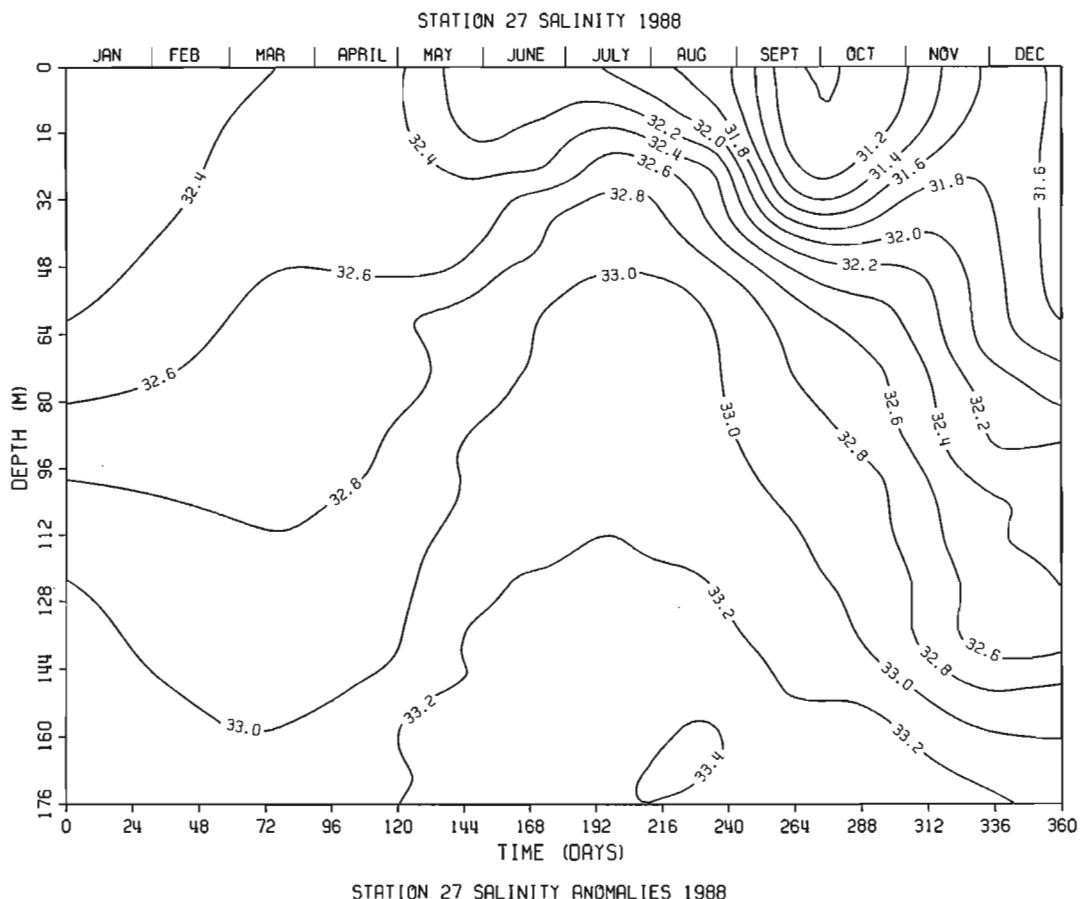


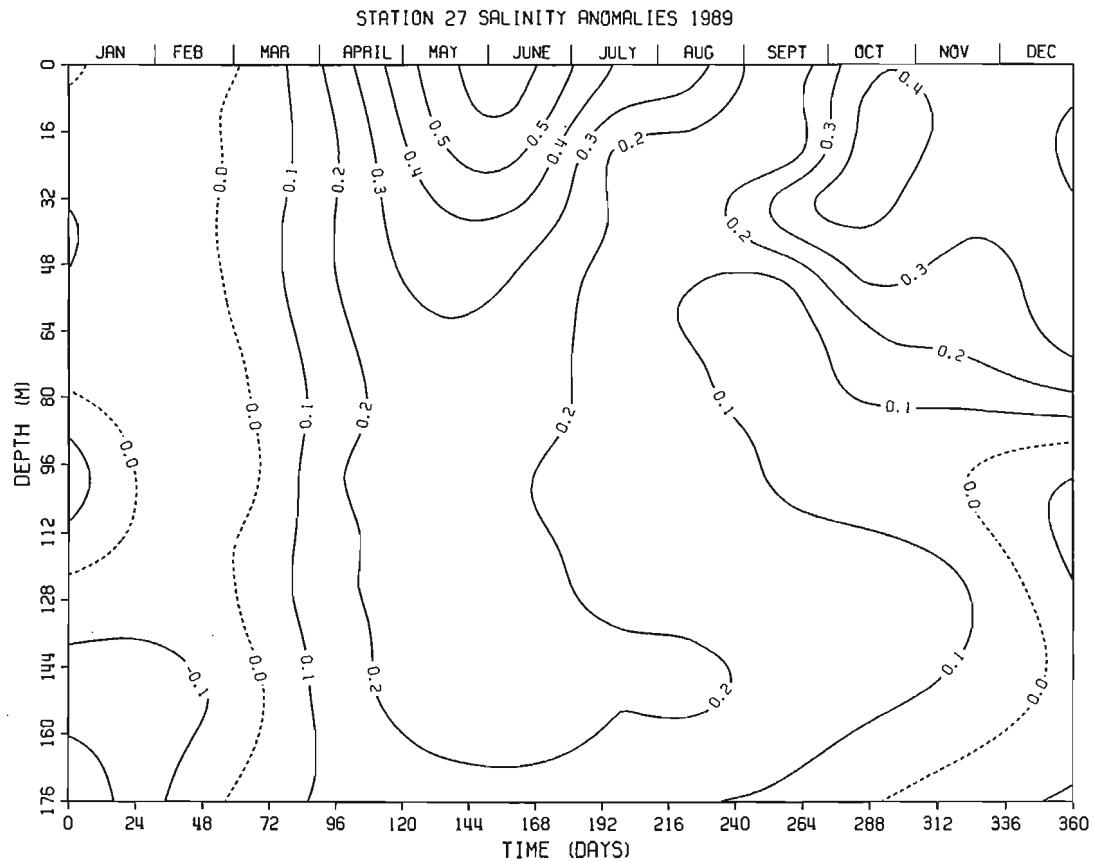
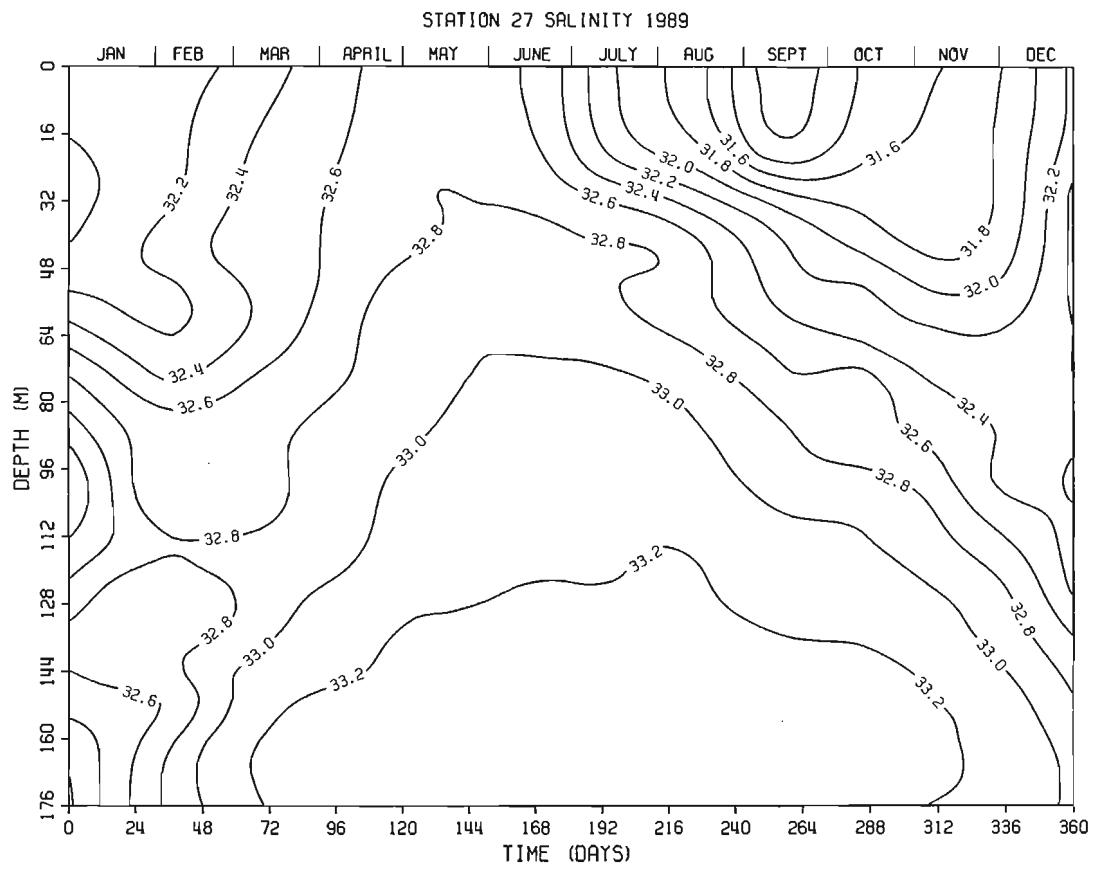
STATION 27 SALINITY ANOMALIES 1985

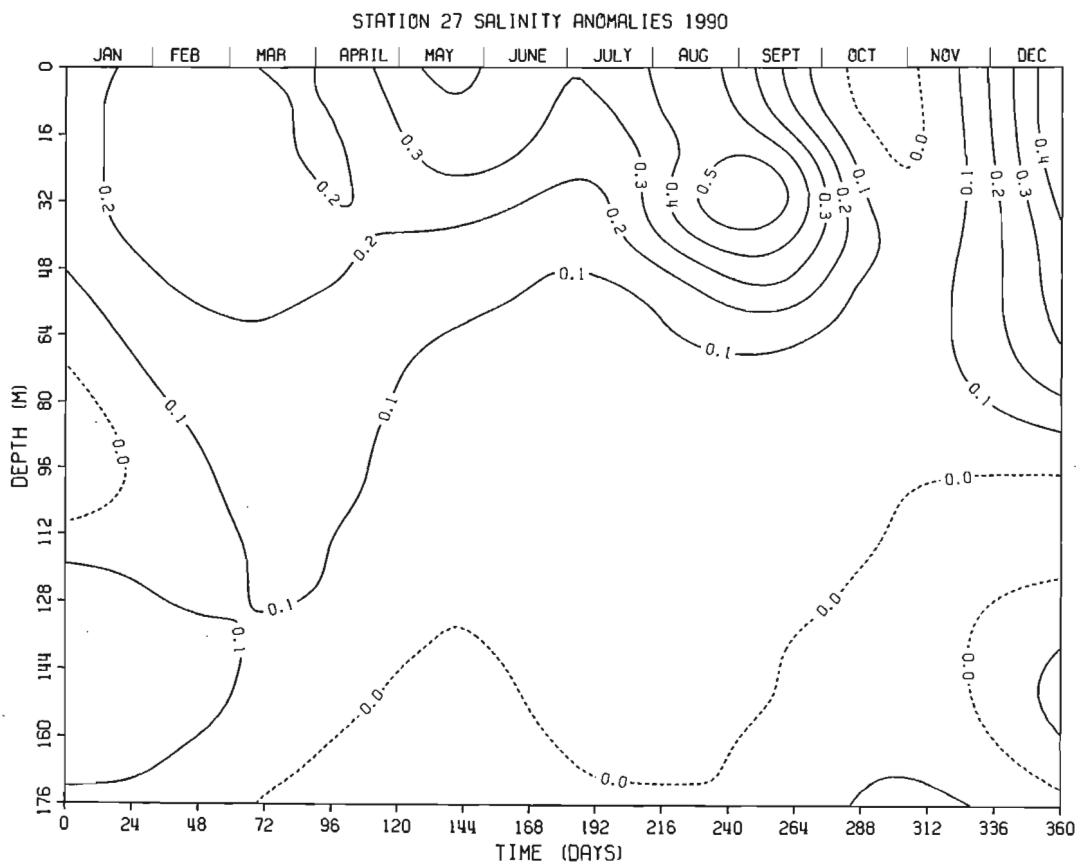
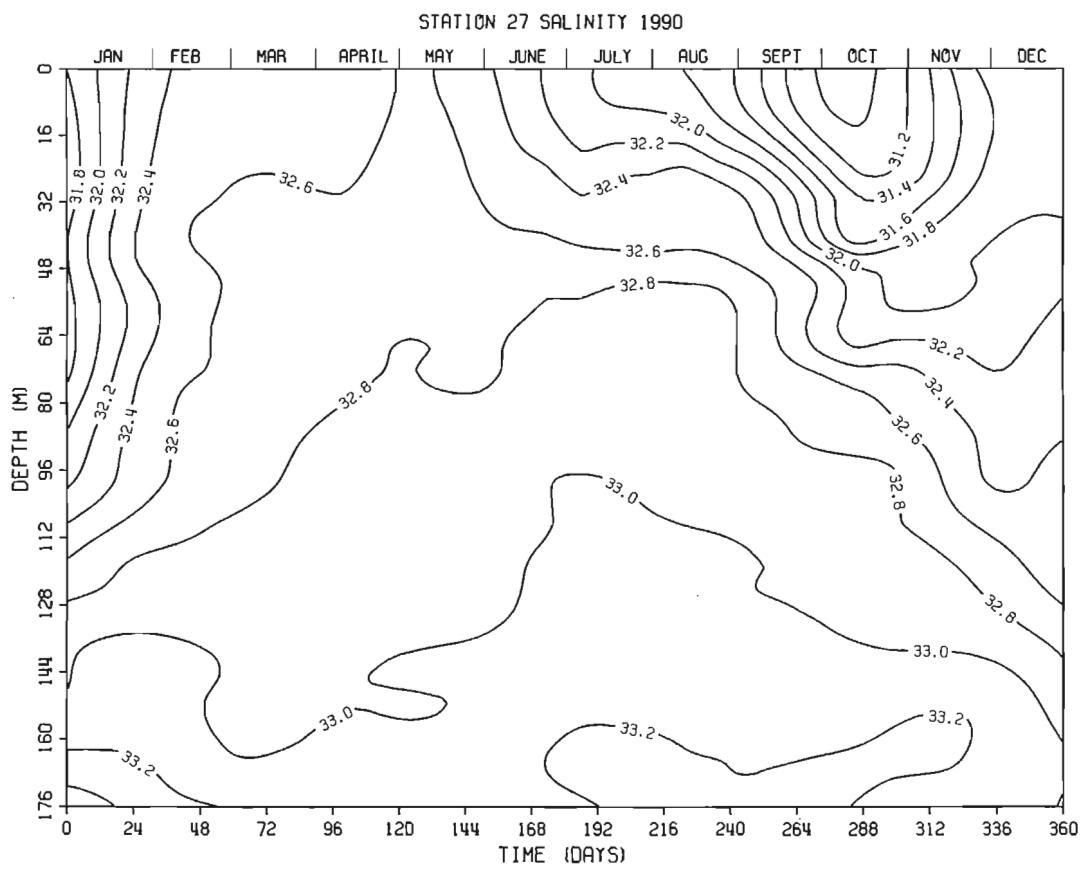


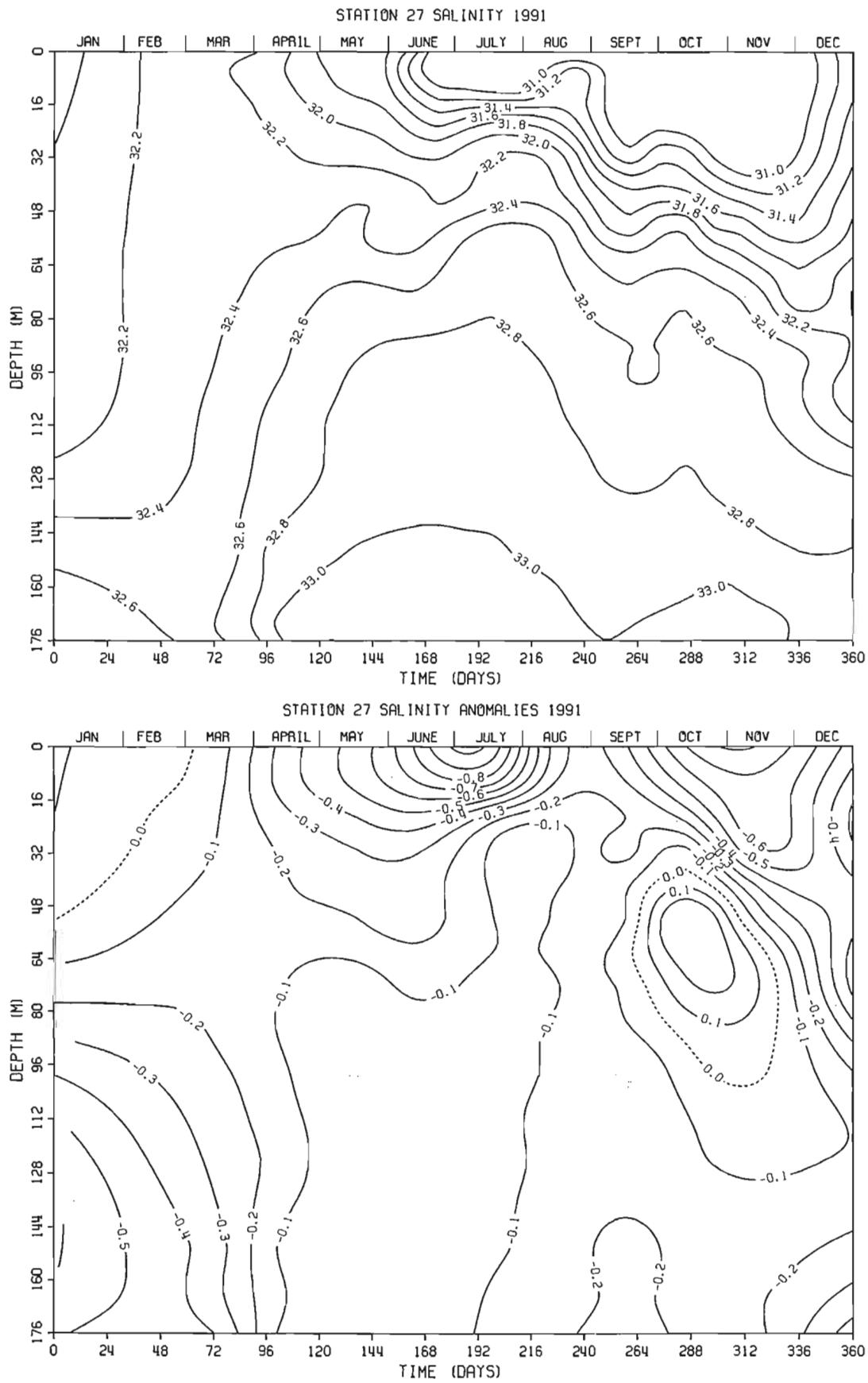


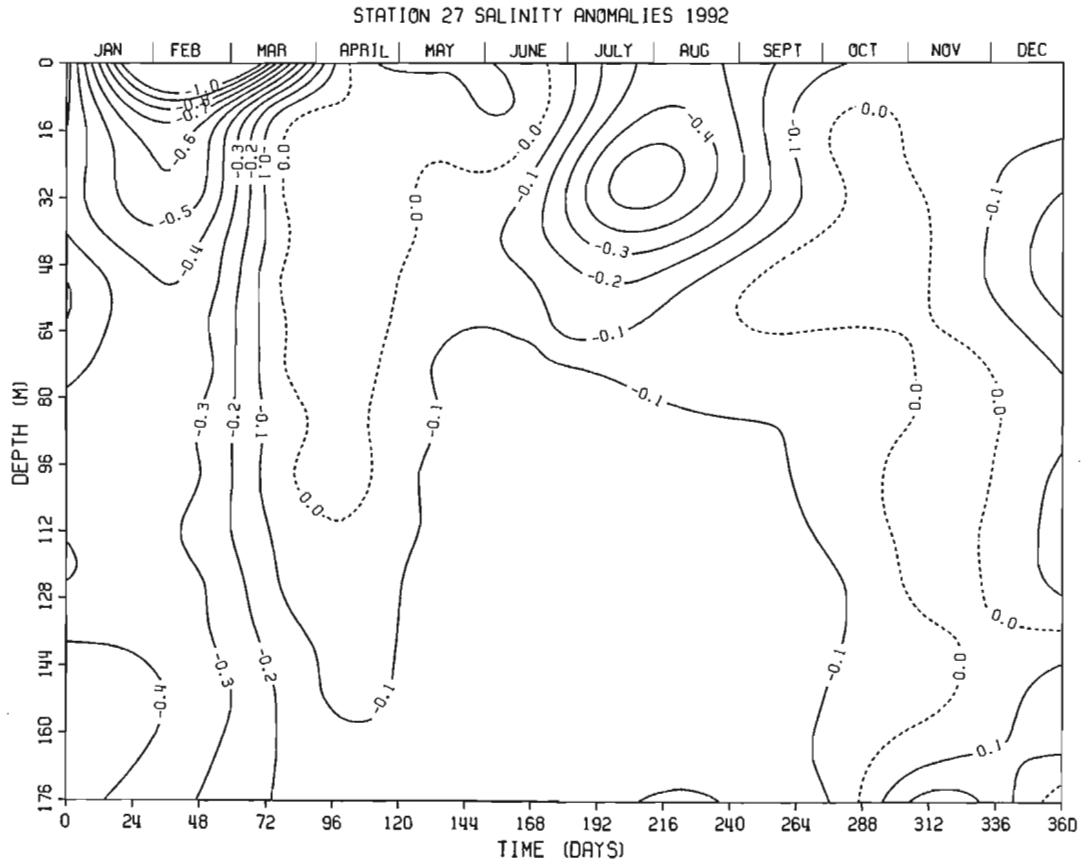
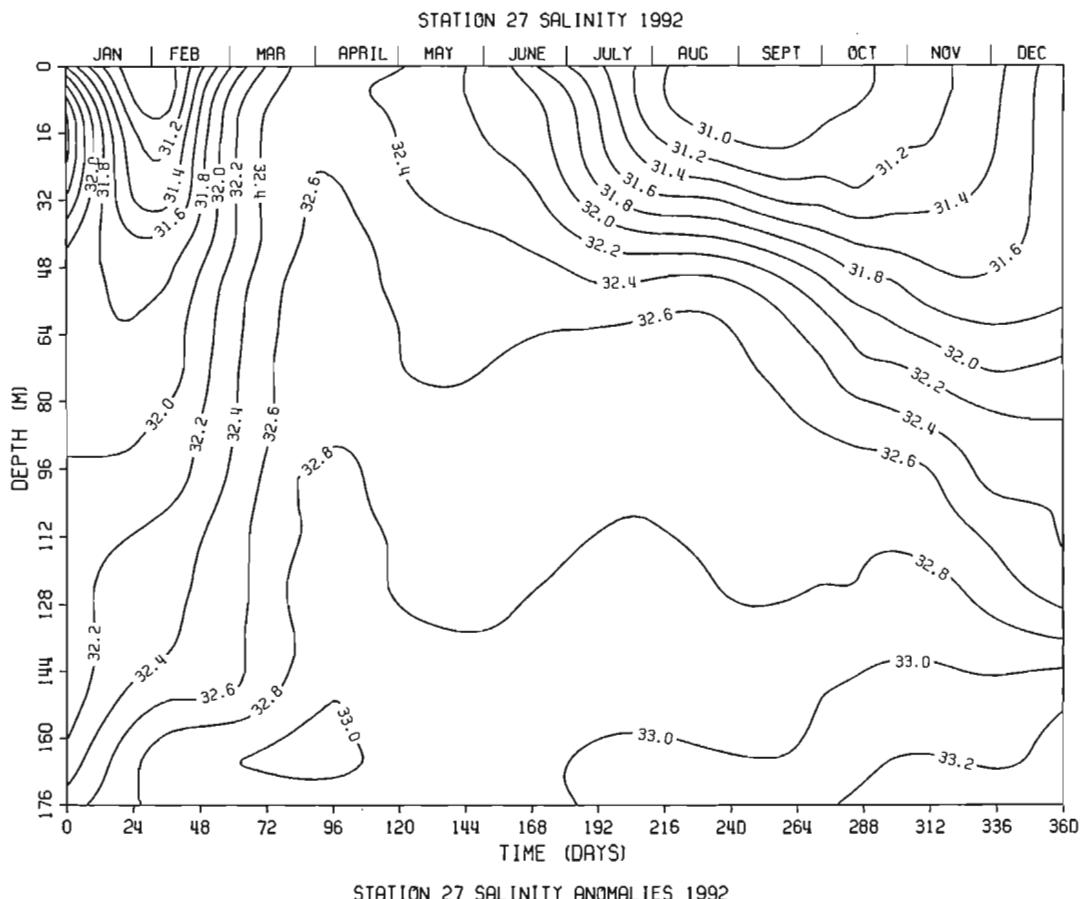


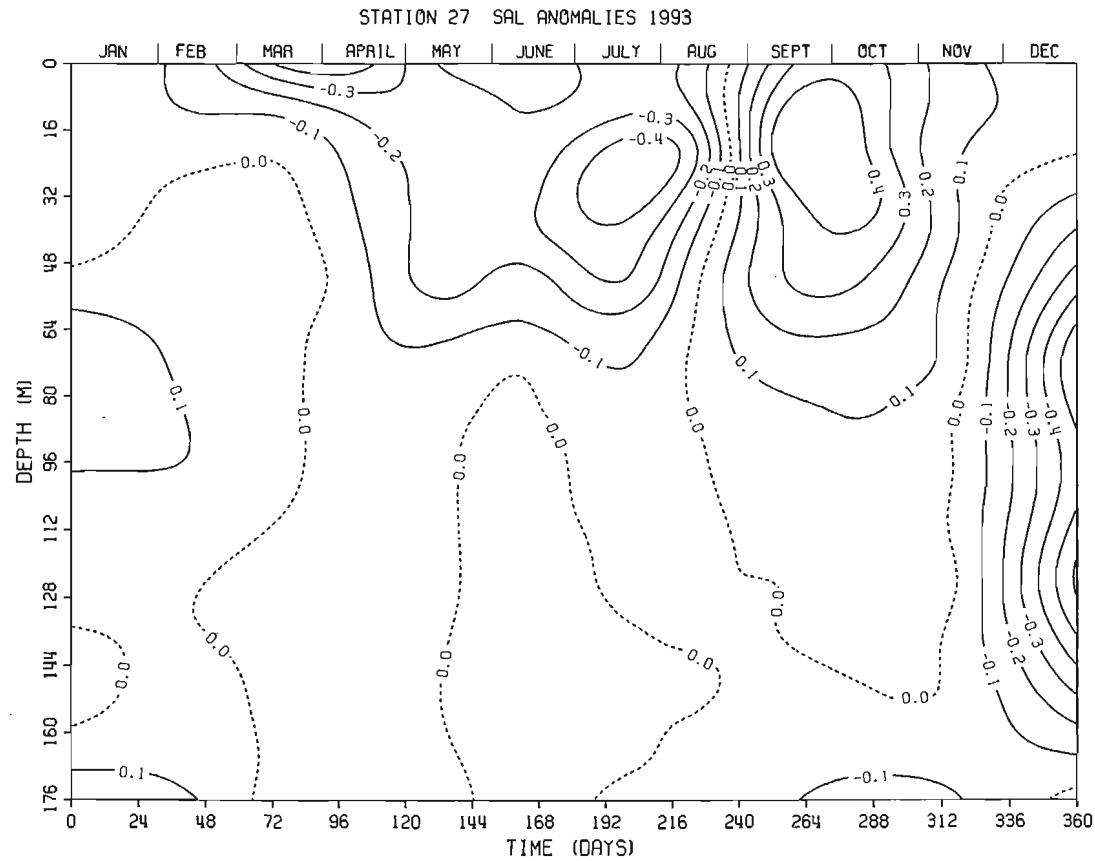
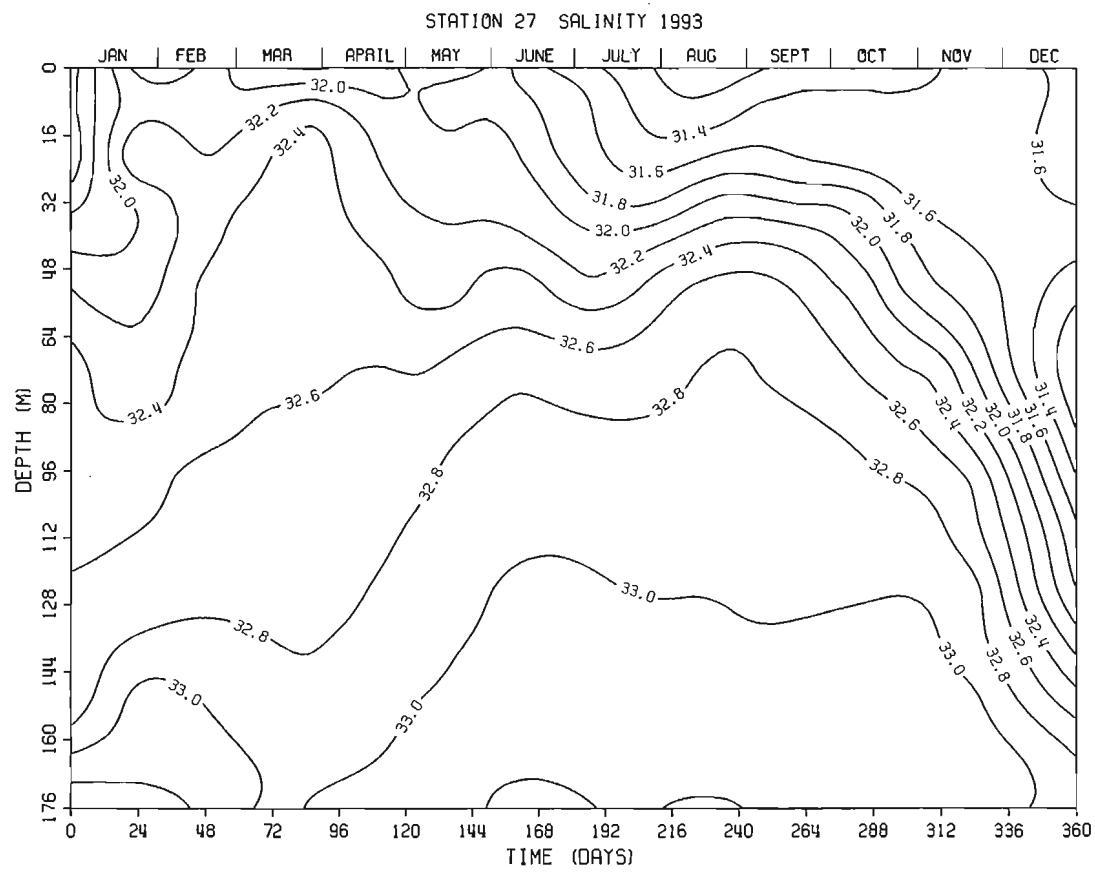




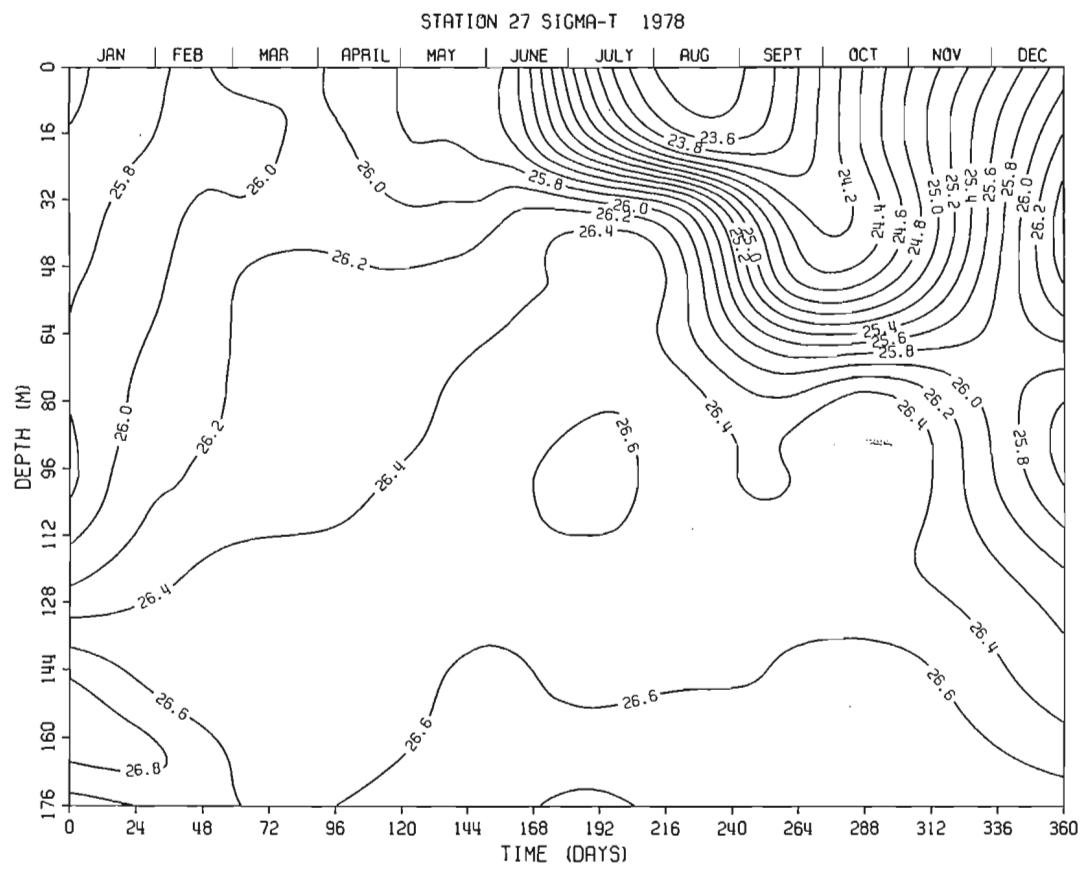


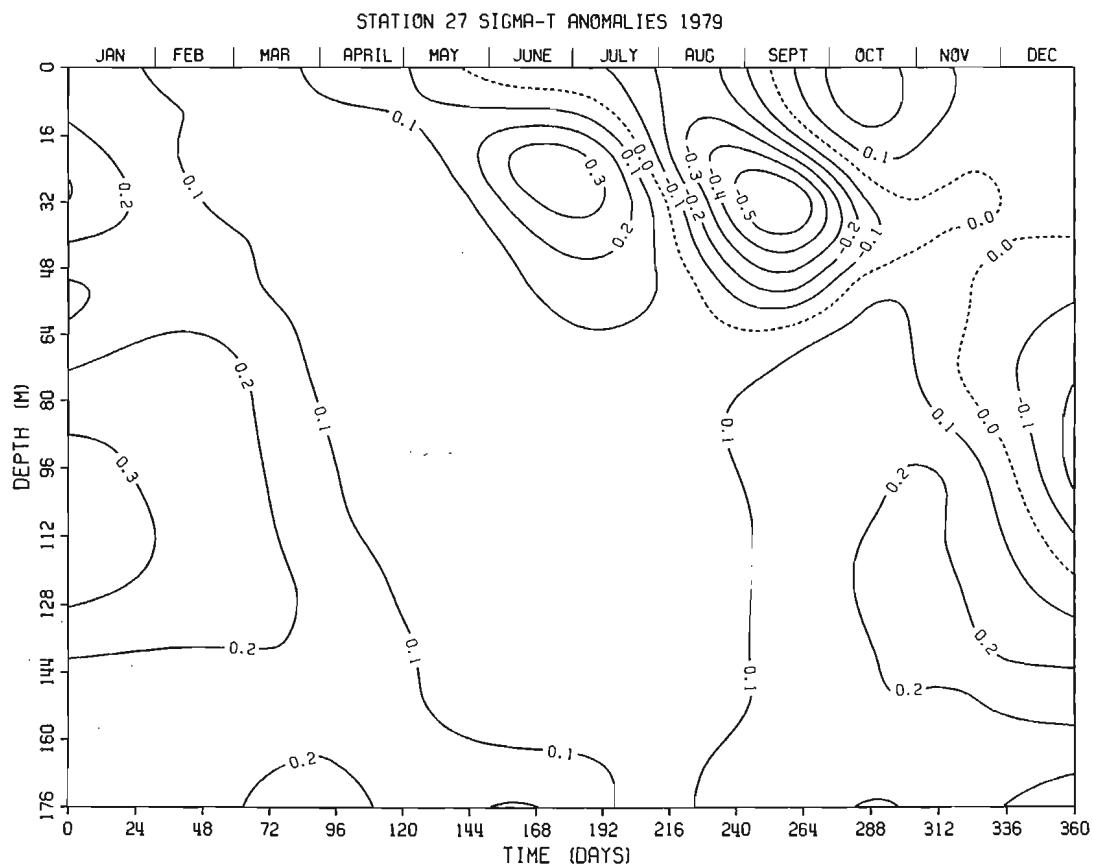
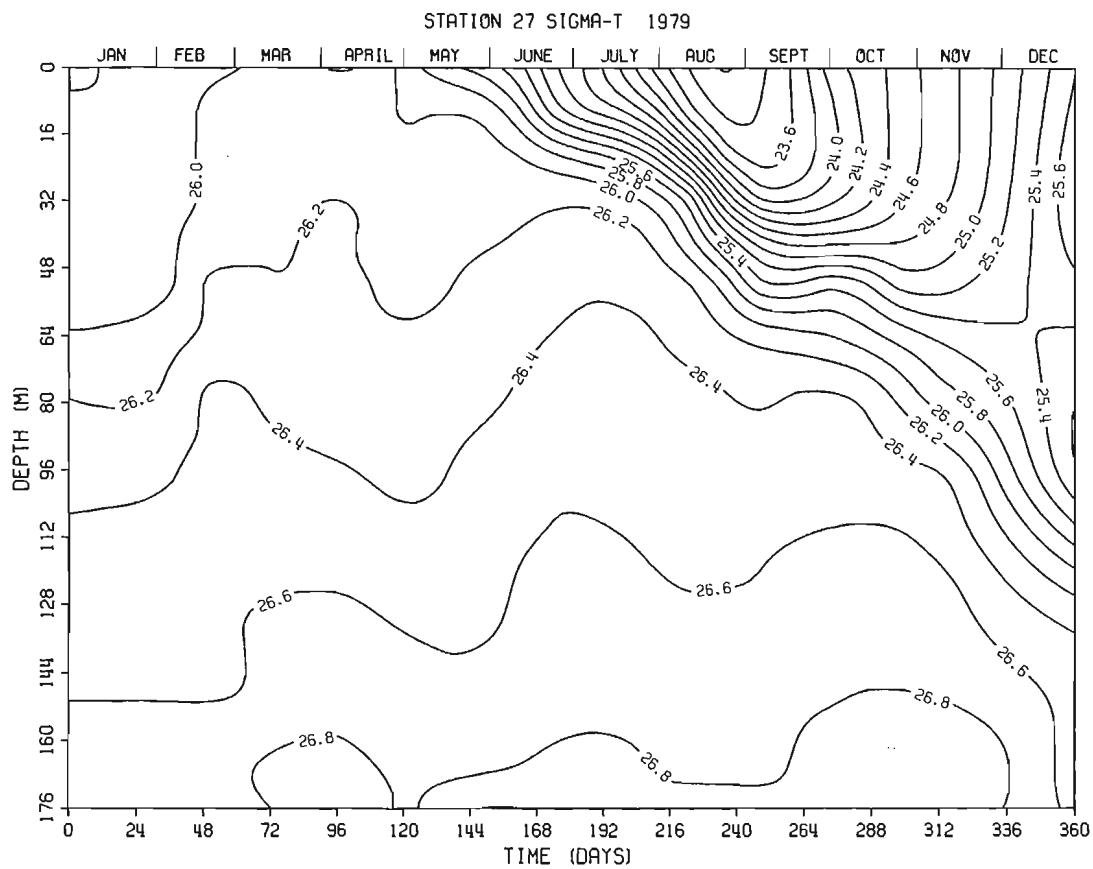


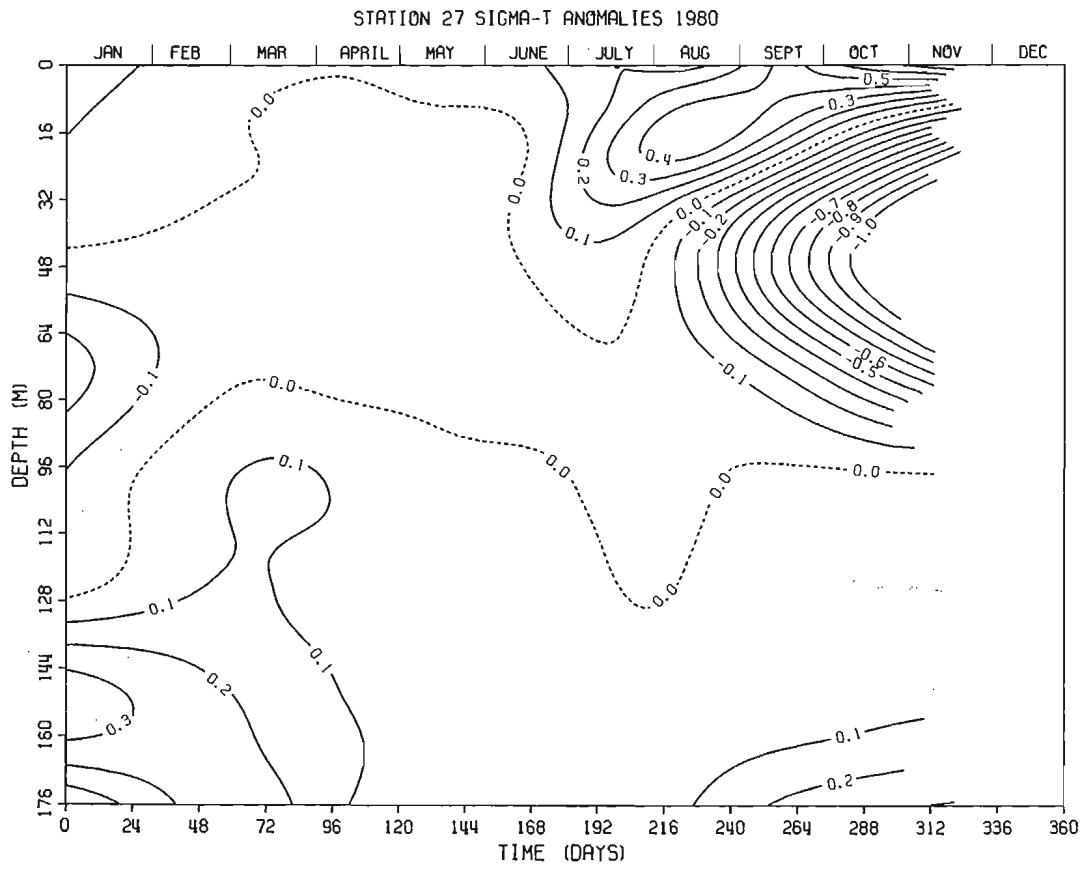
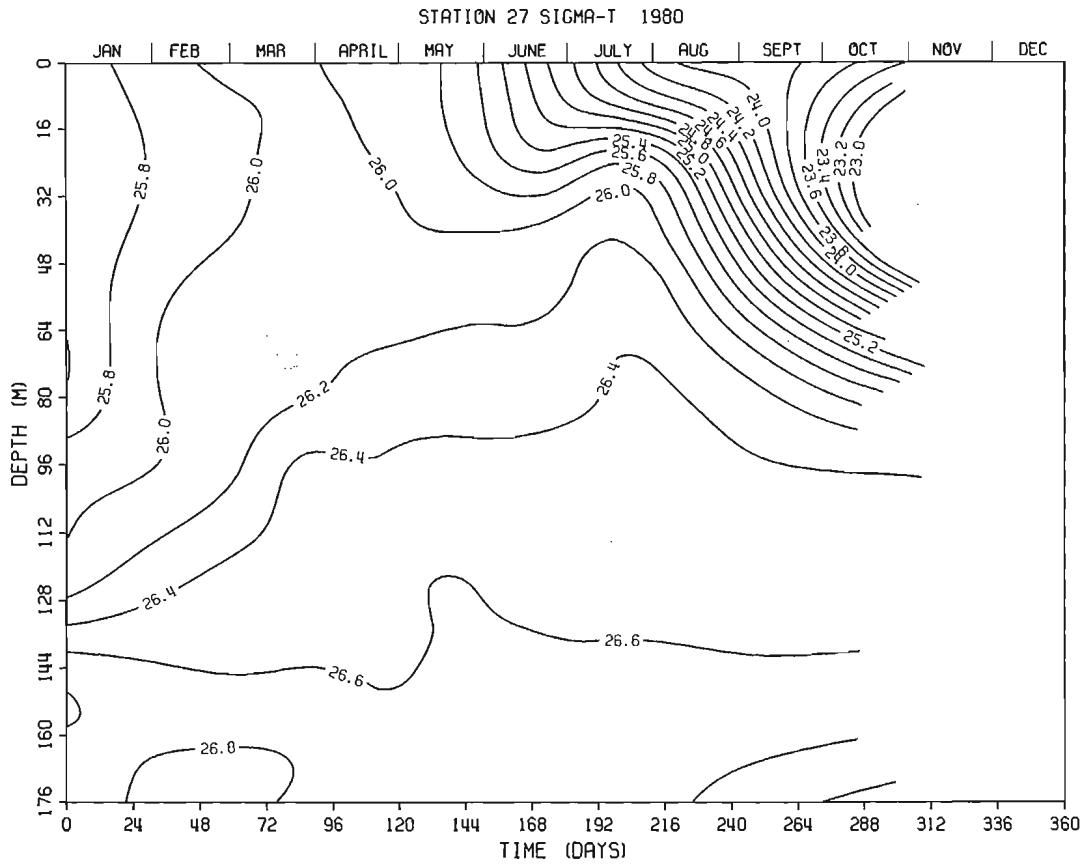


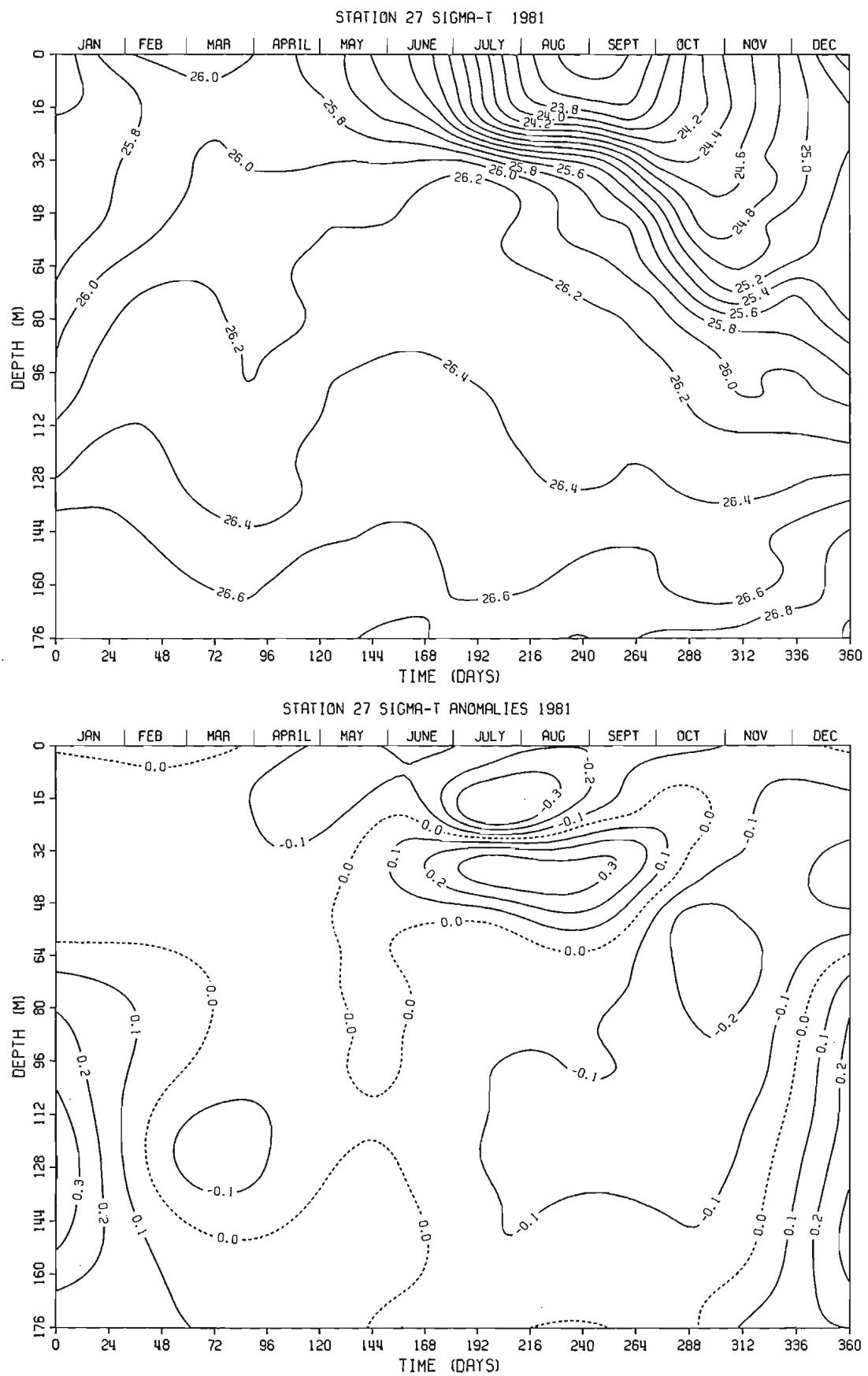


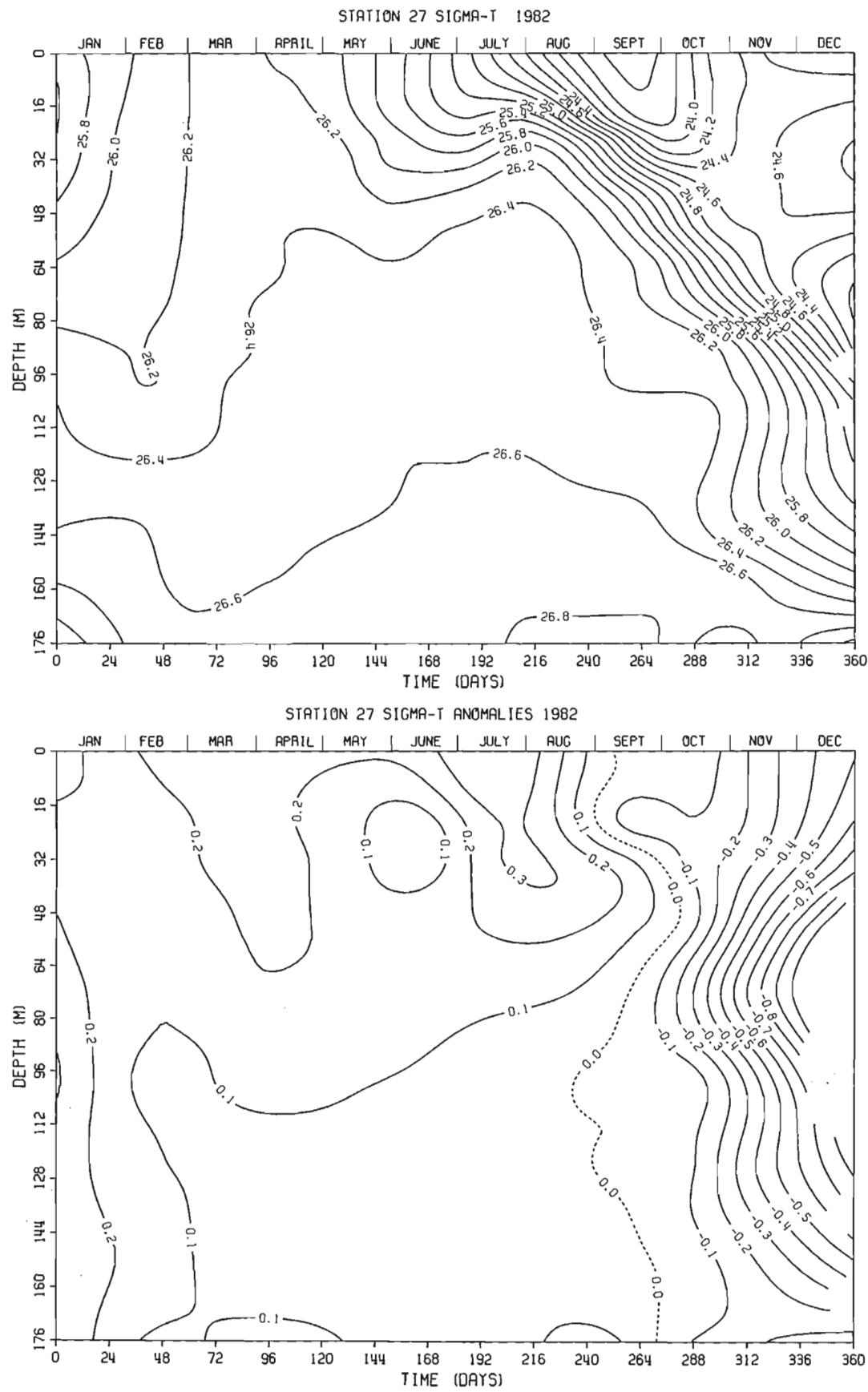
APPENDIX F. Depth versus time contours of the yearly density (σ_t) and density anomalies at Station 27 from 1978 to 1993.

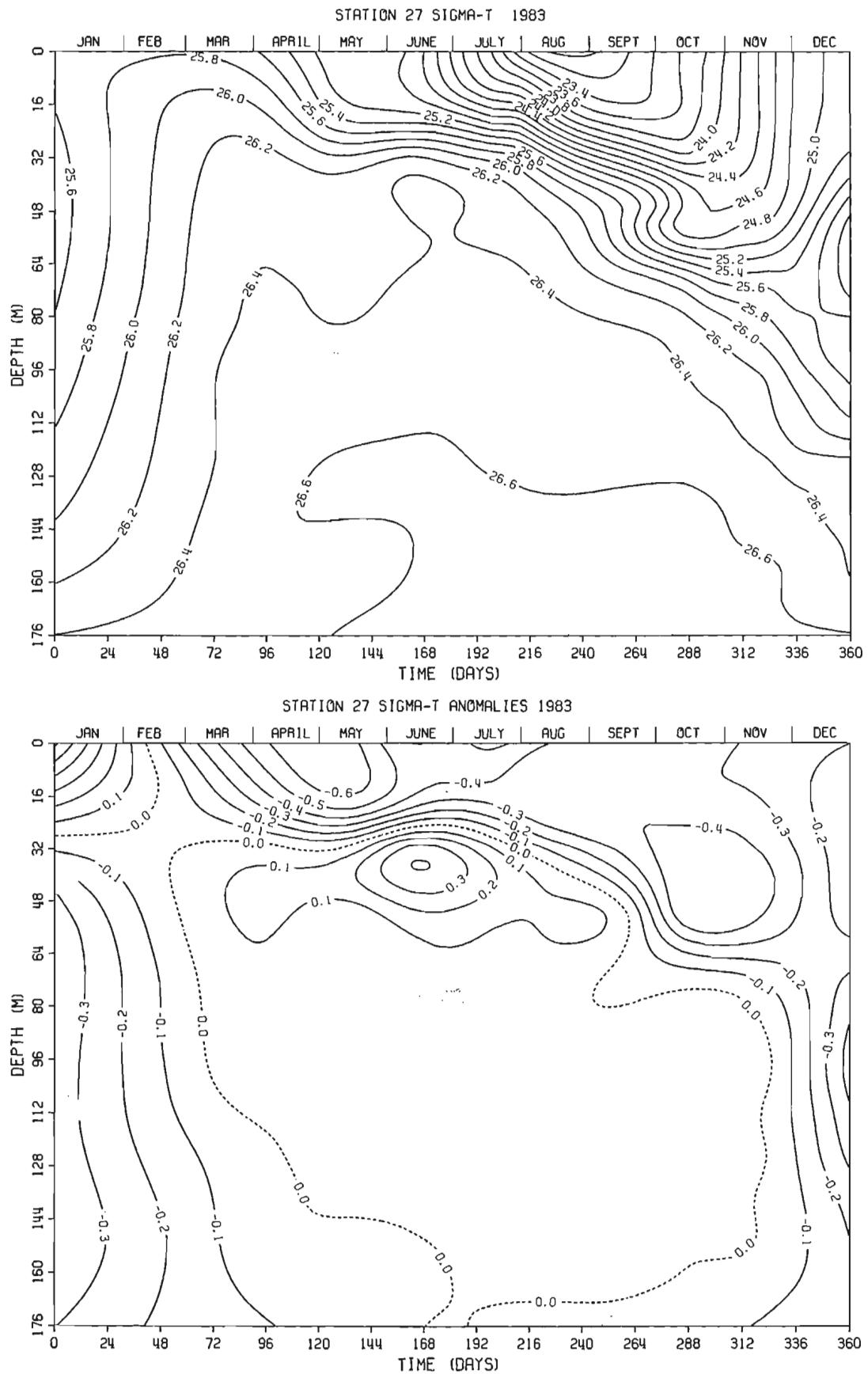


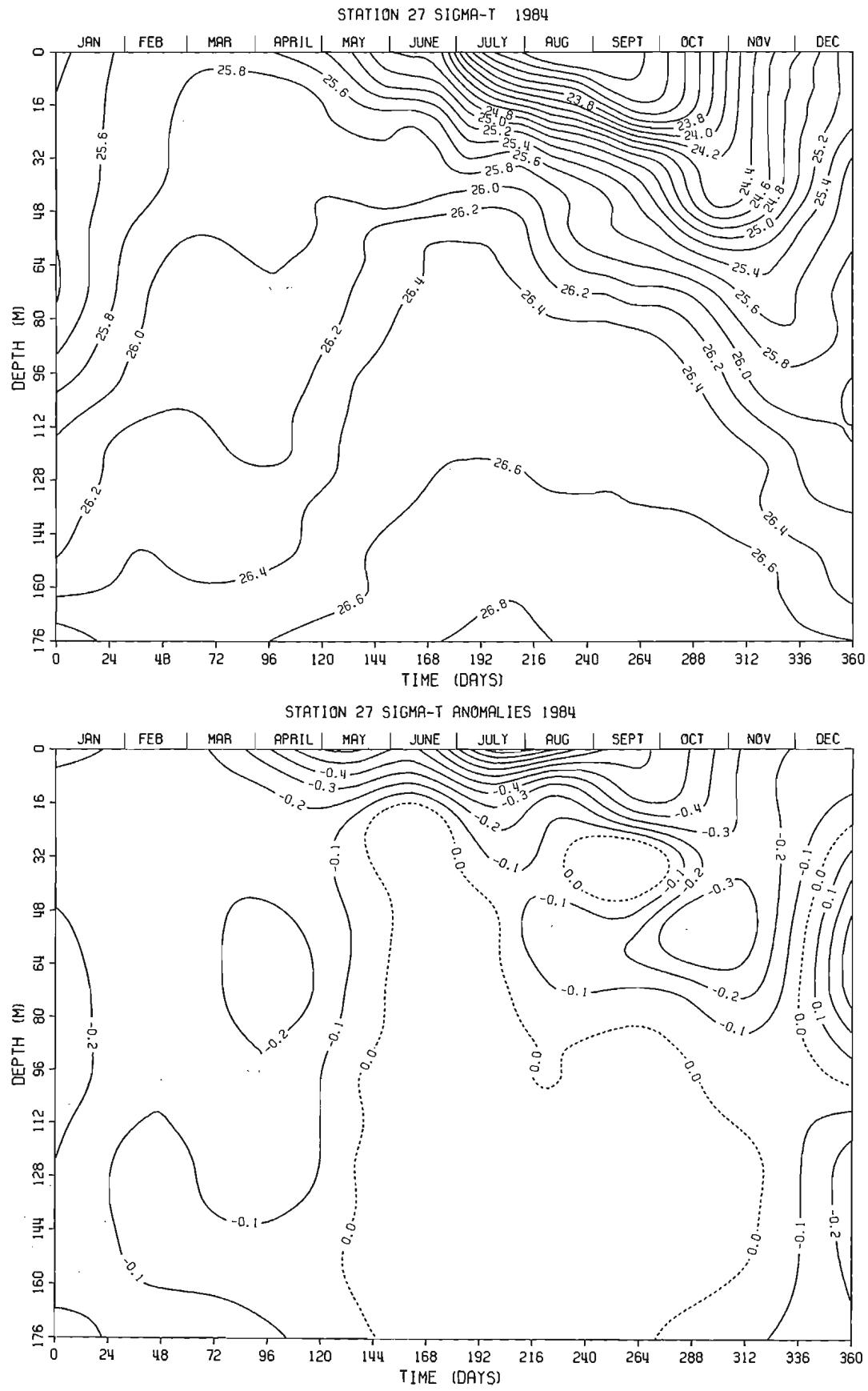


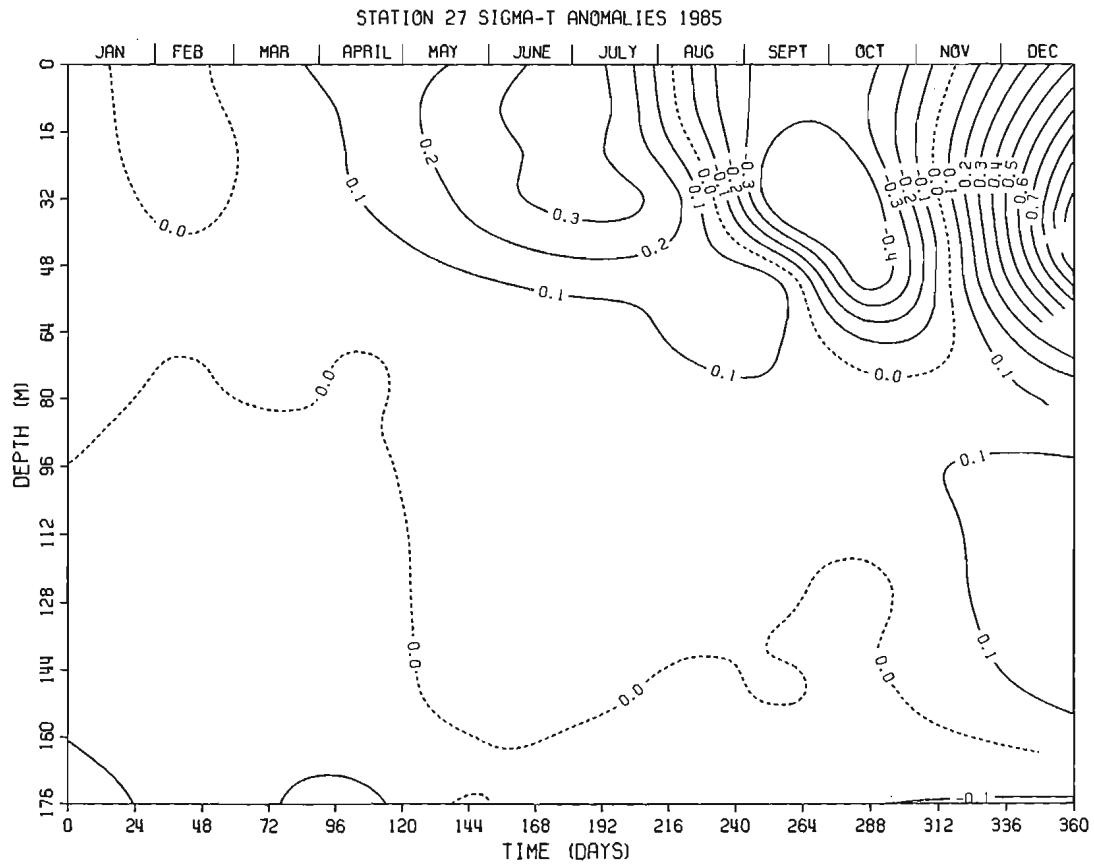
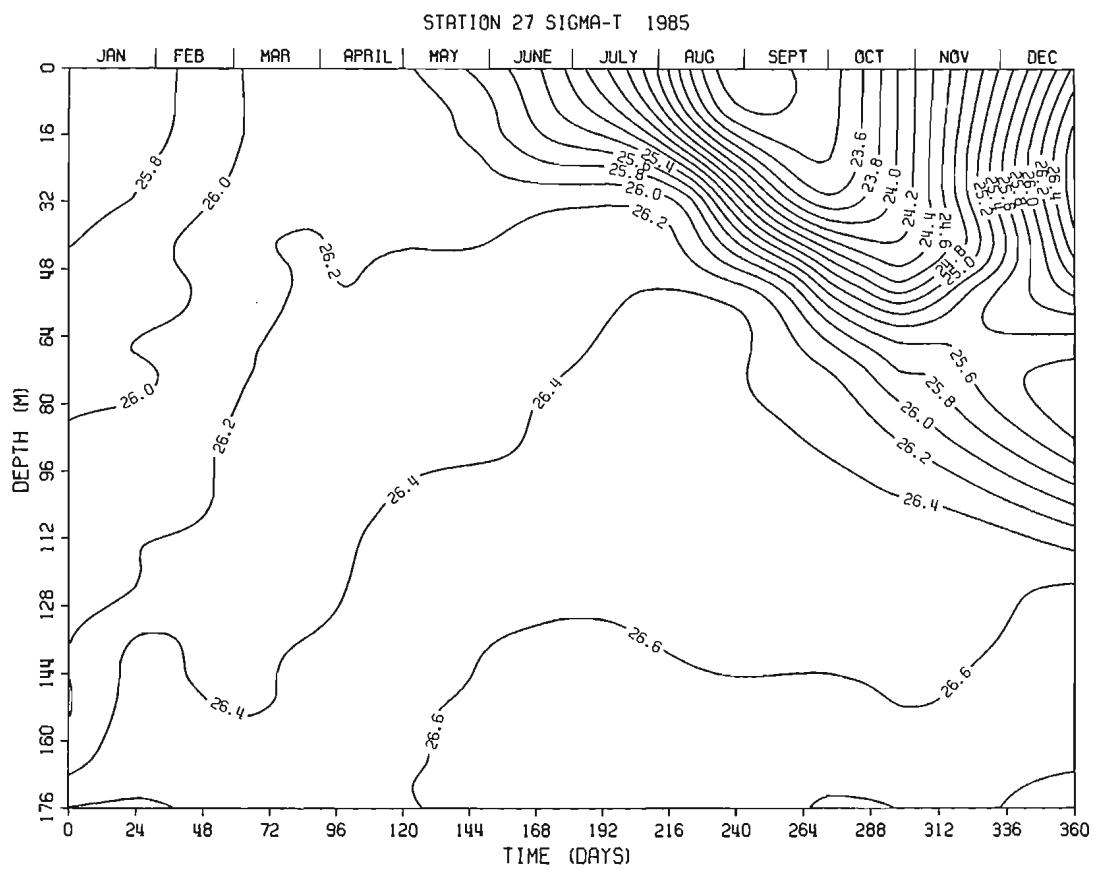


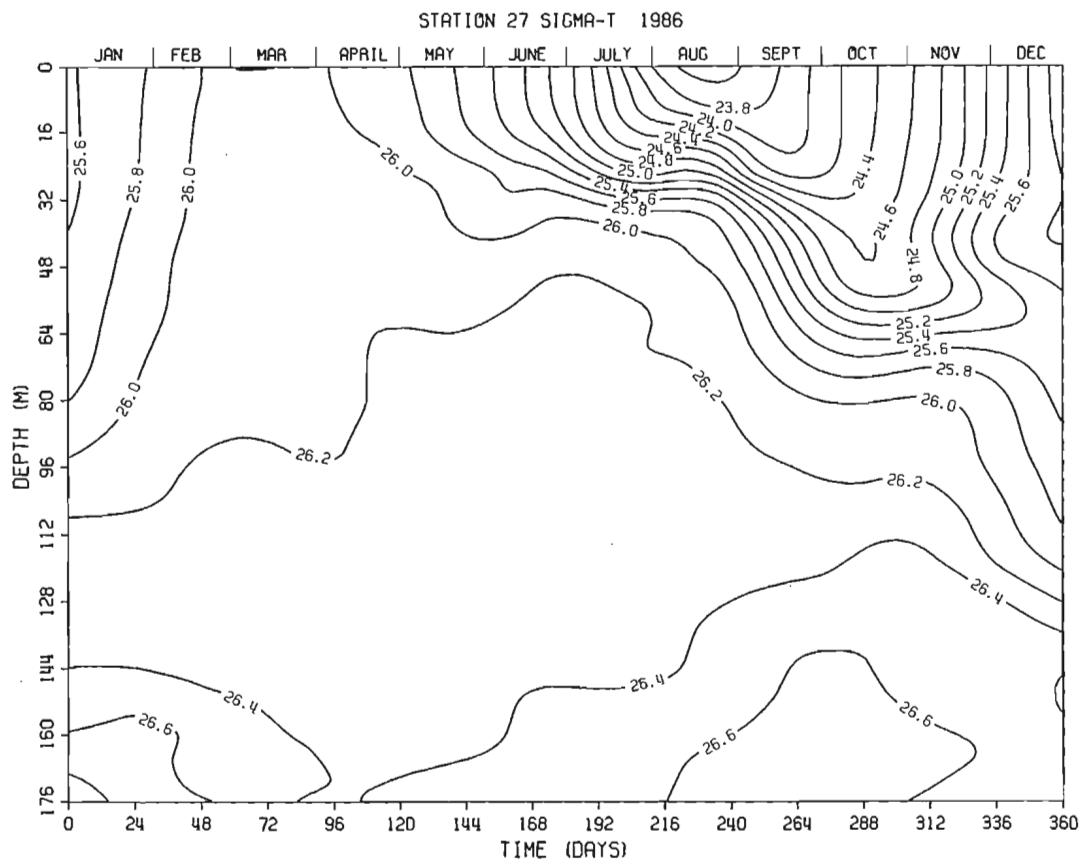


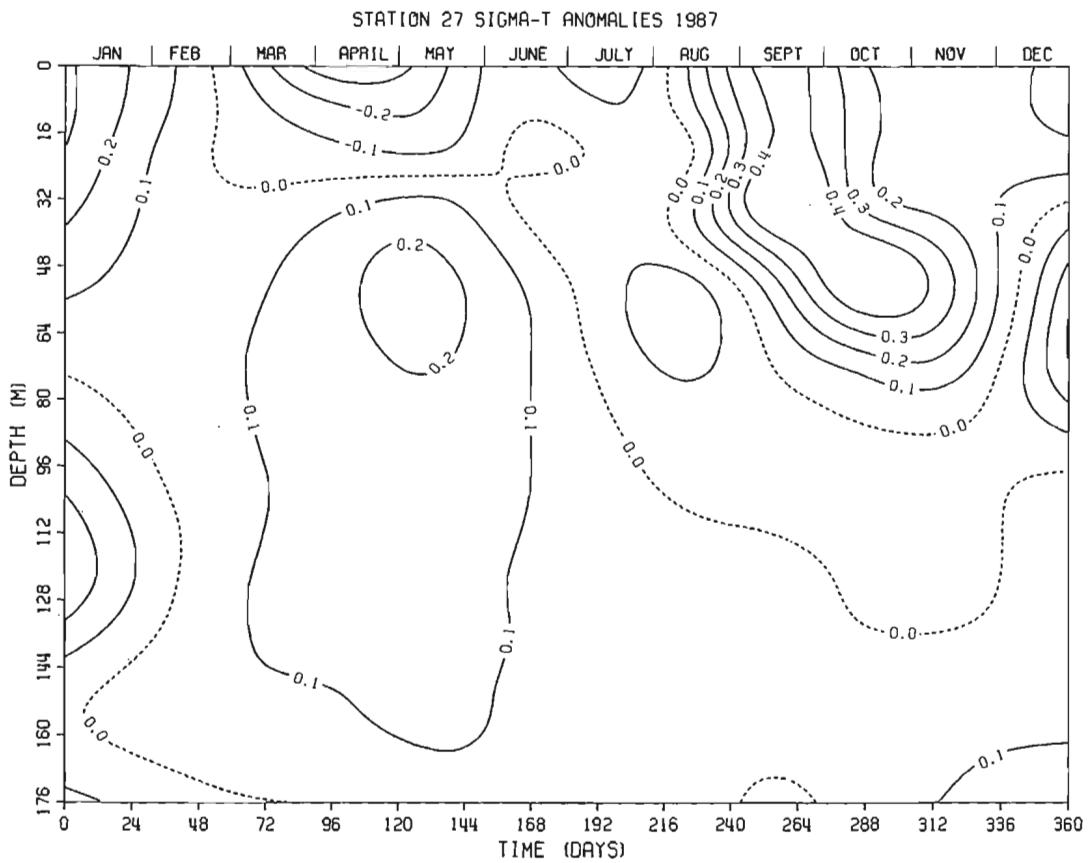
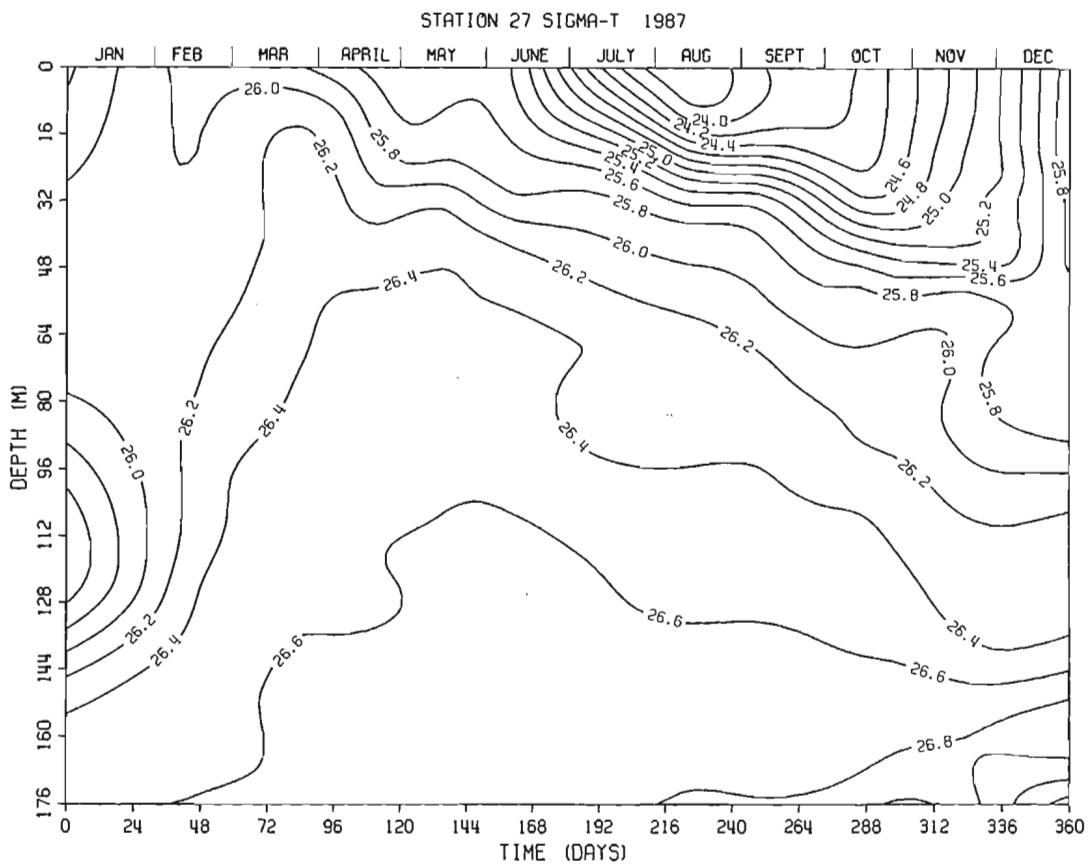


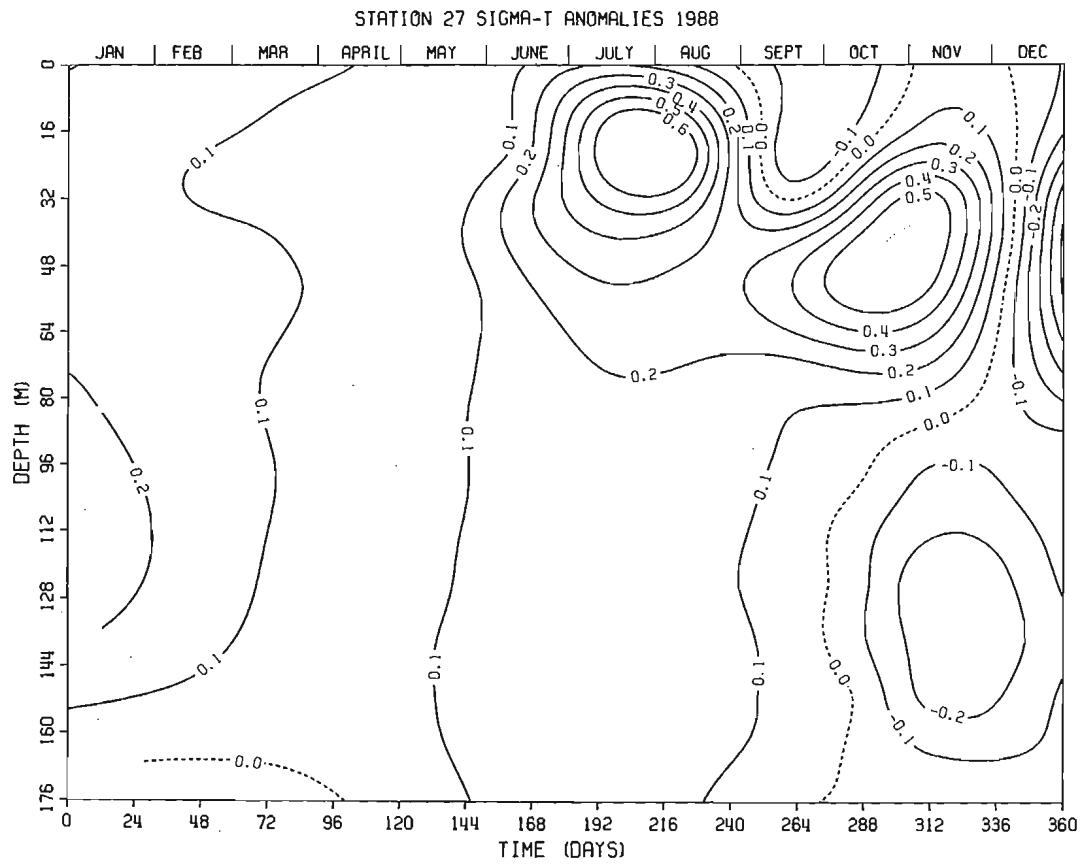
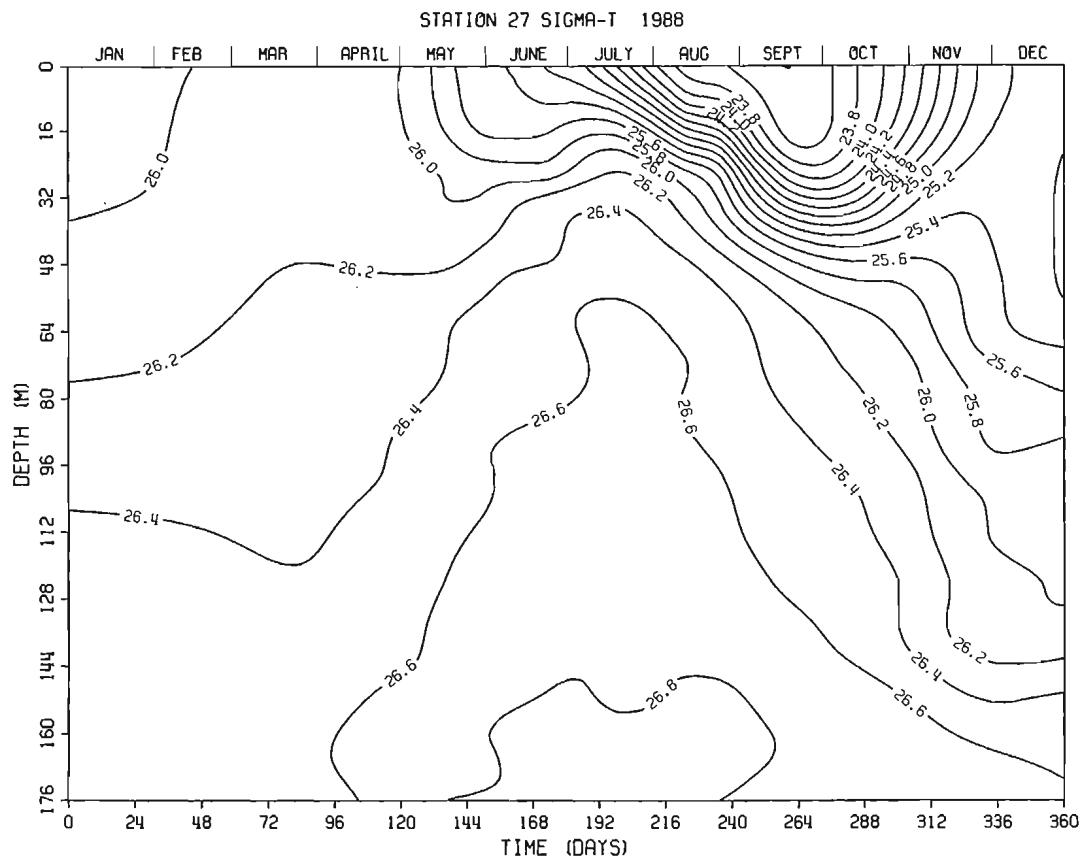


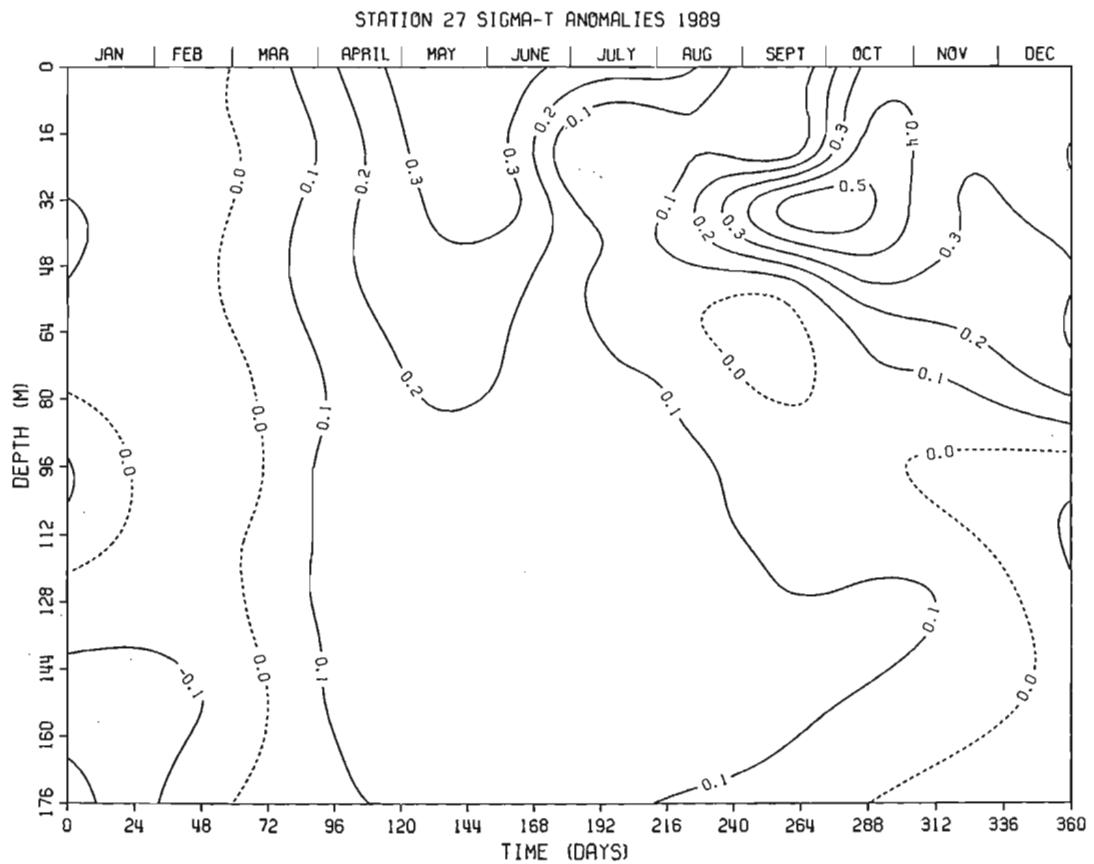
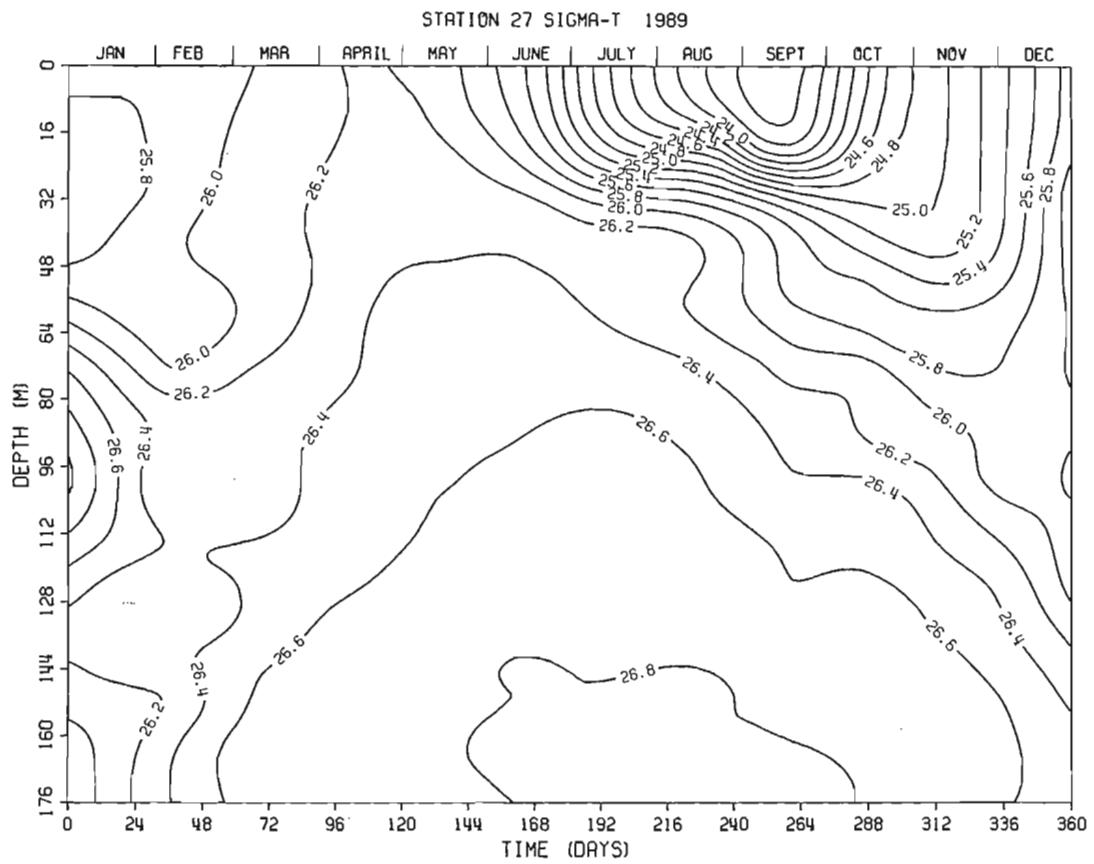


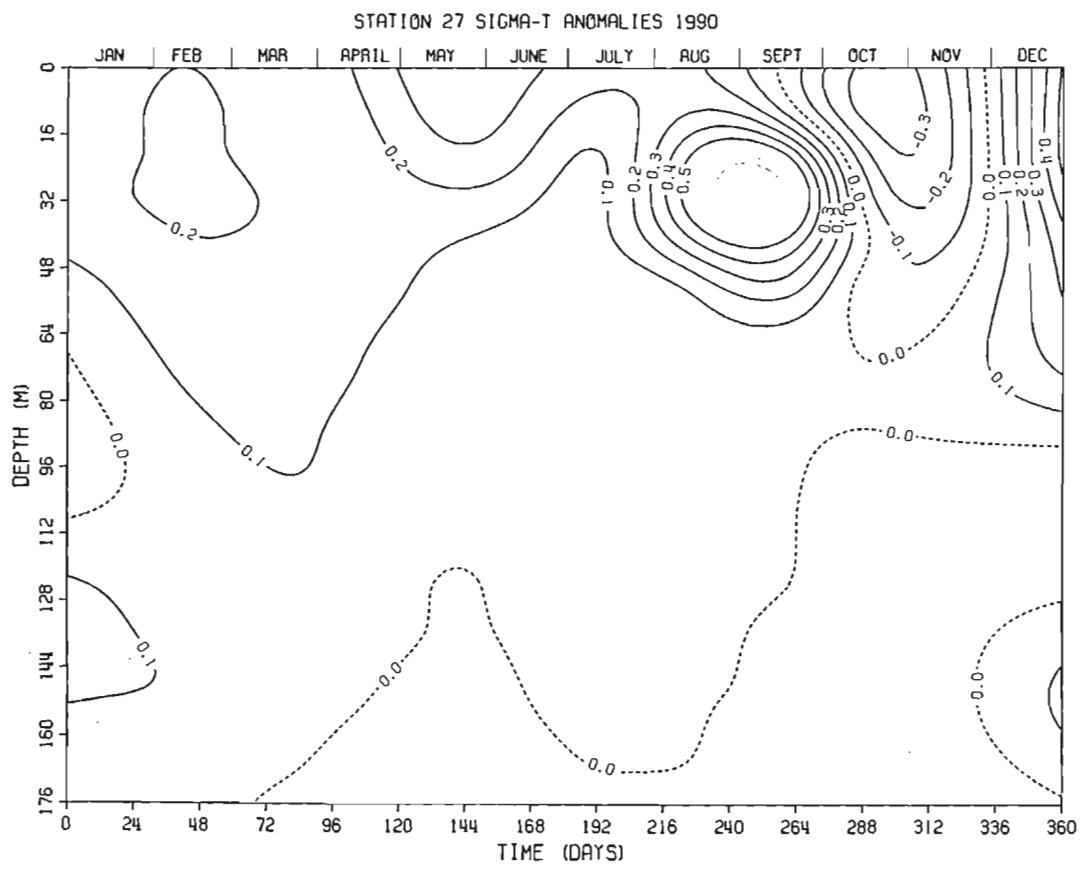
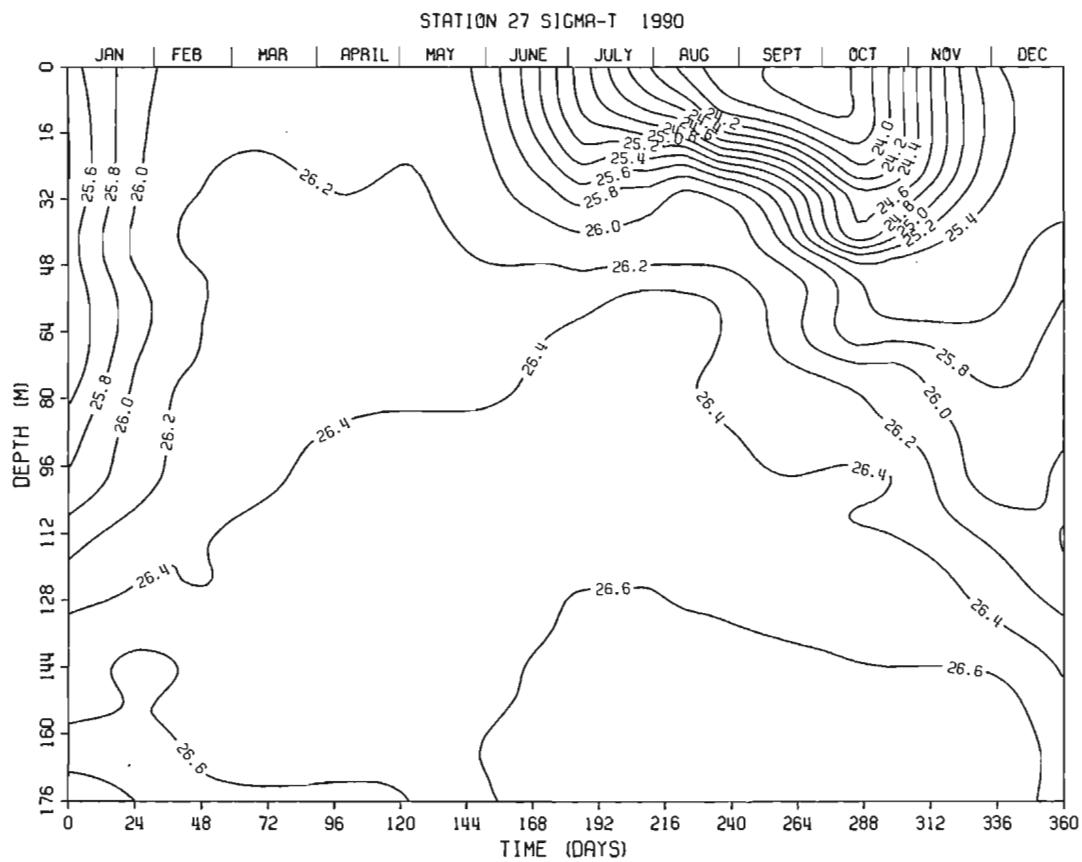


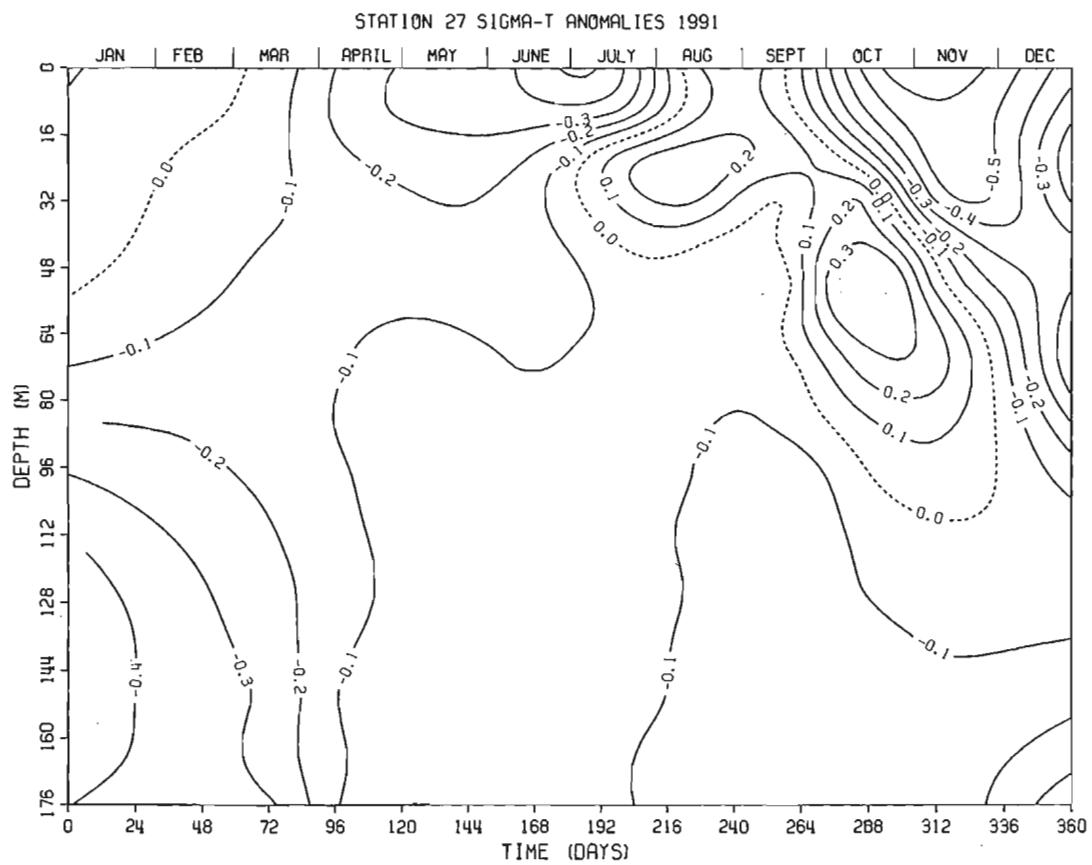
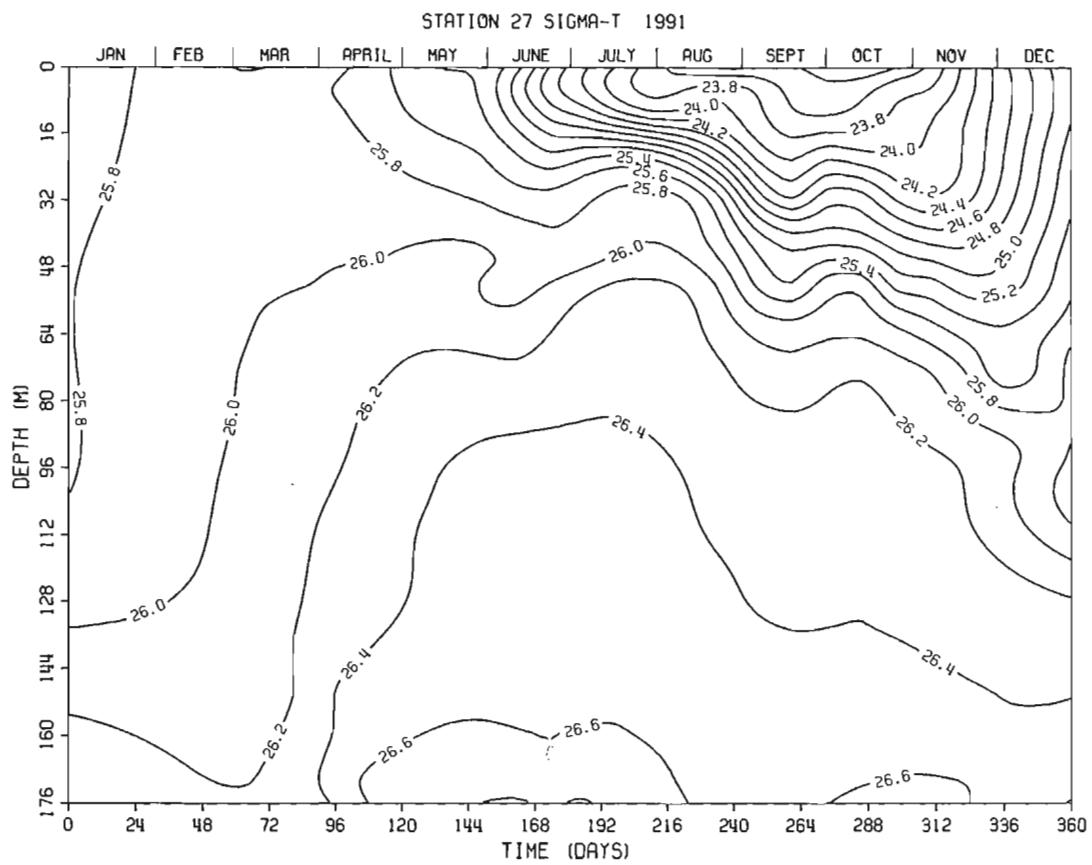


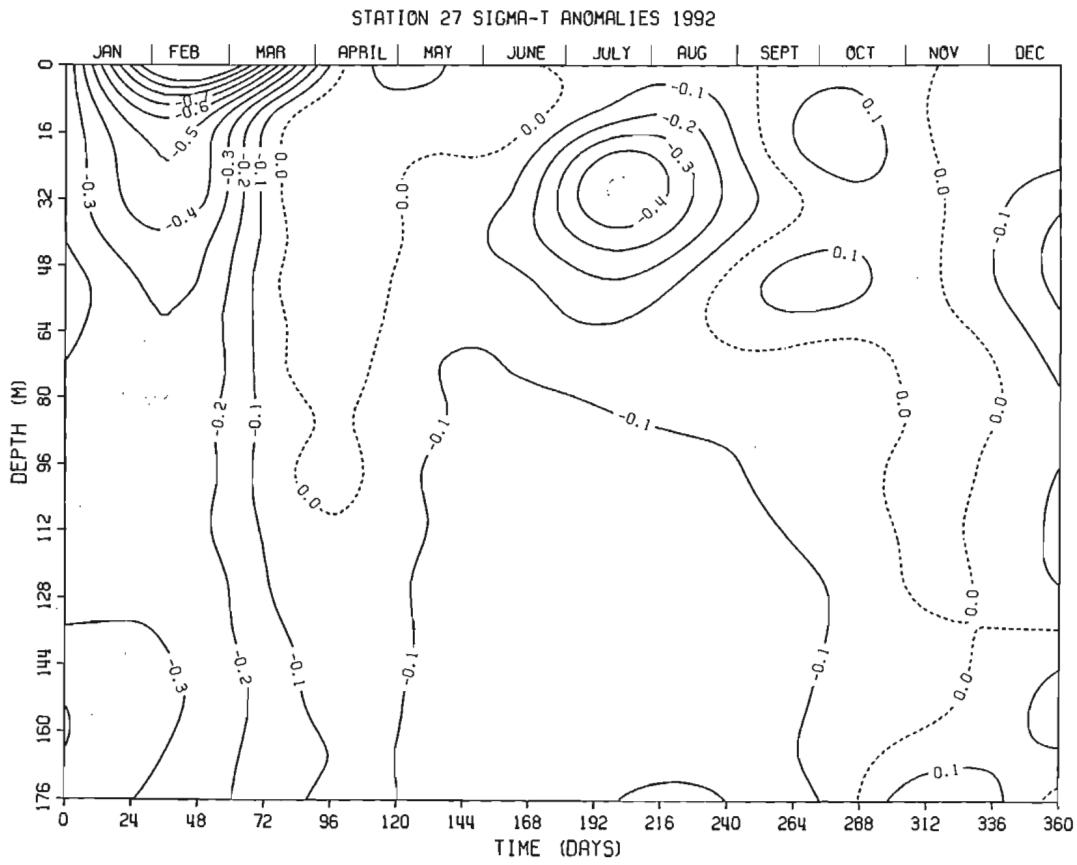
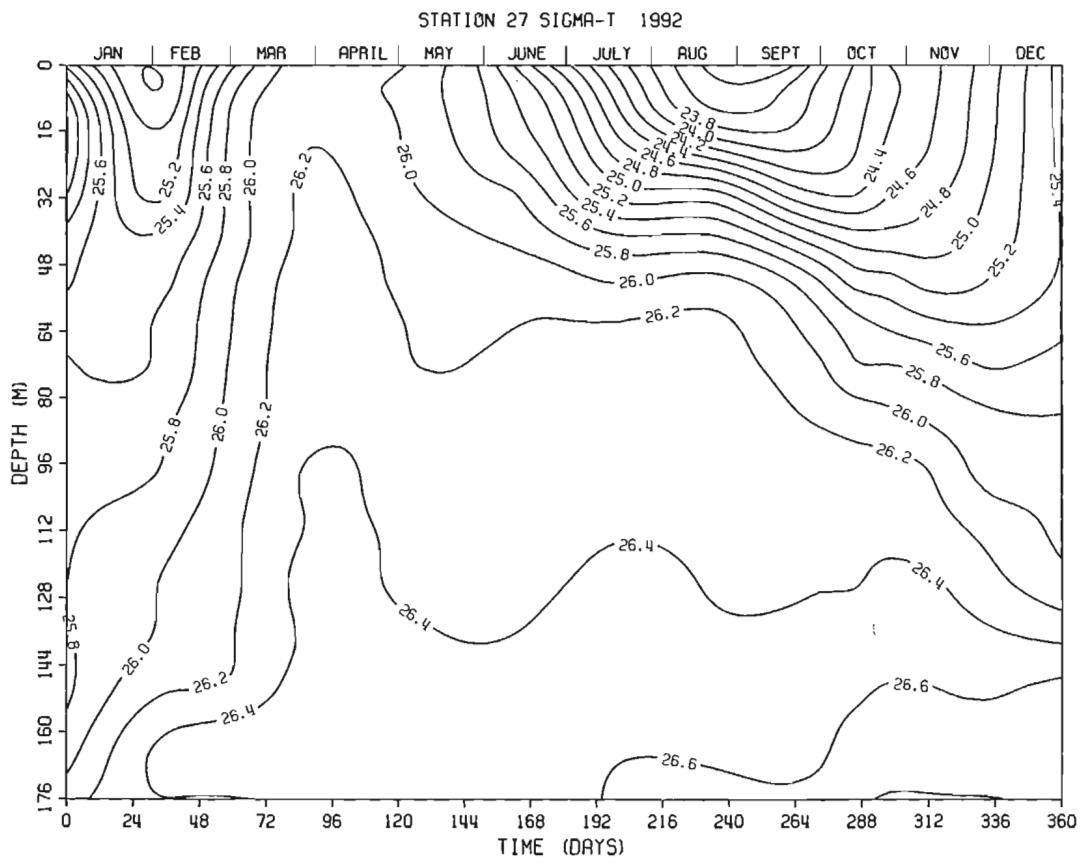




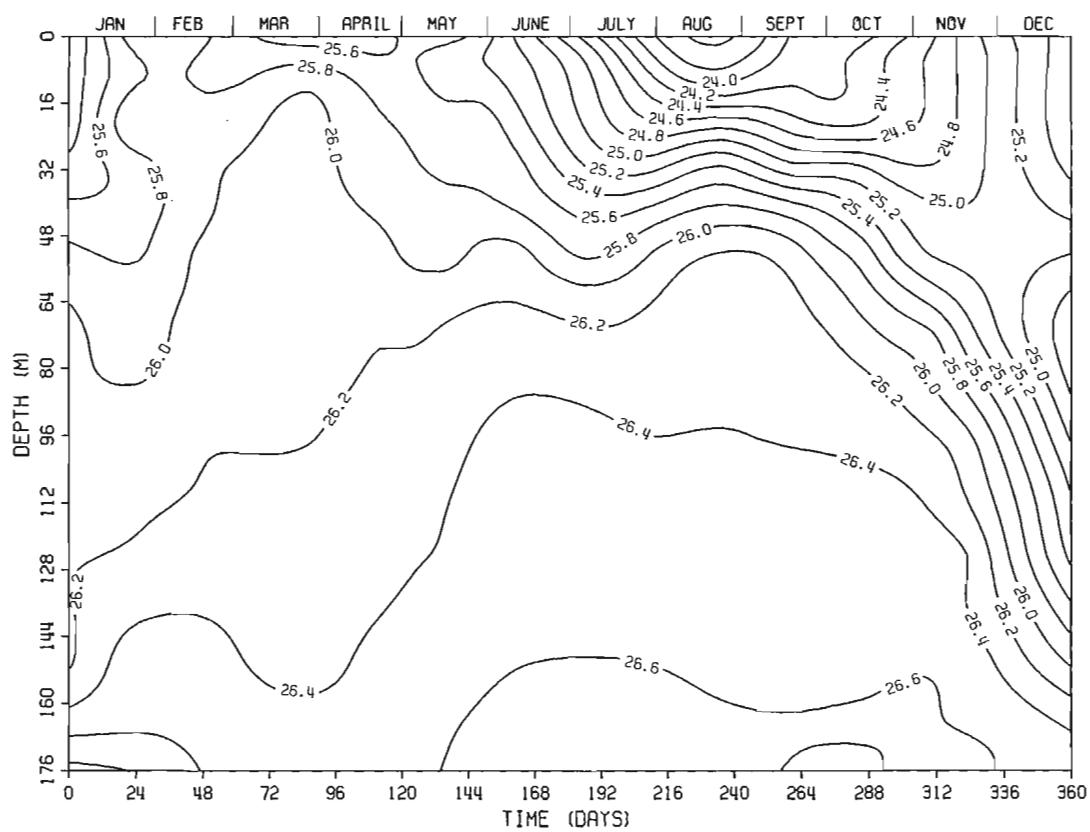




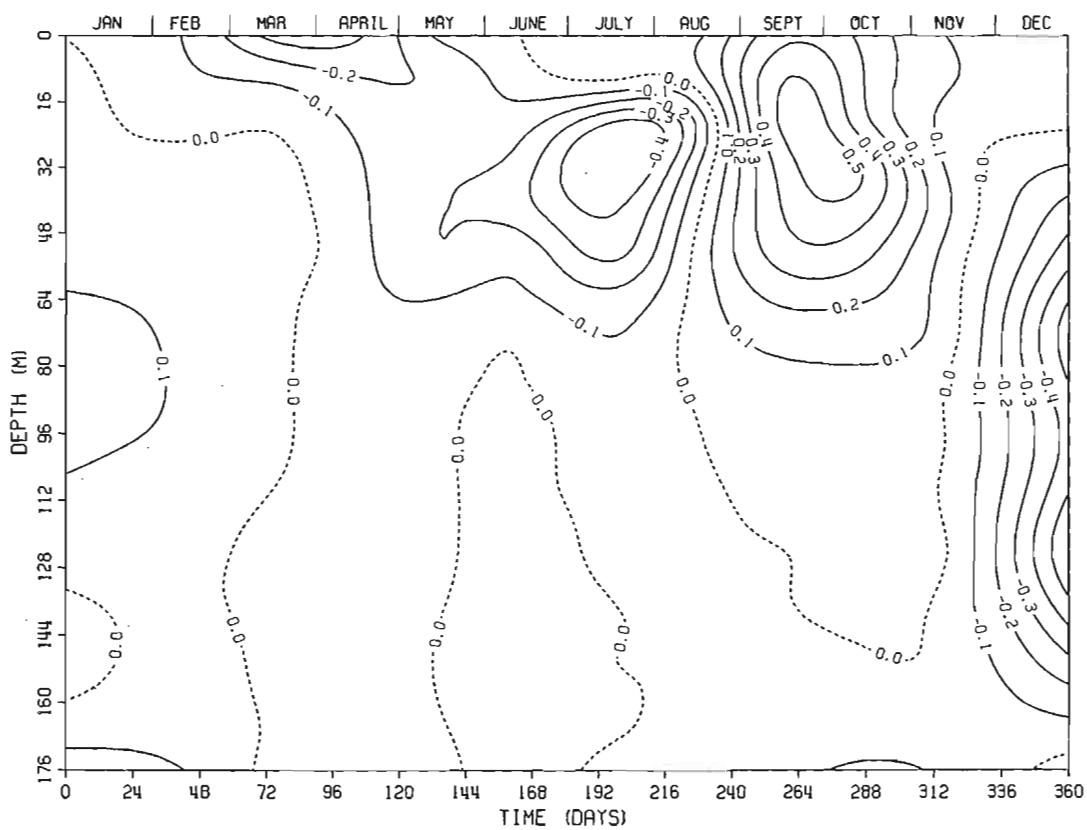




STATION 27 SIGMA-T 1993

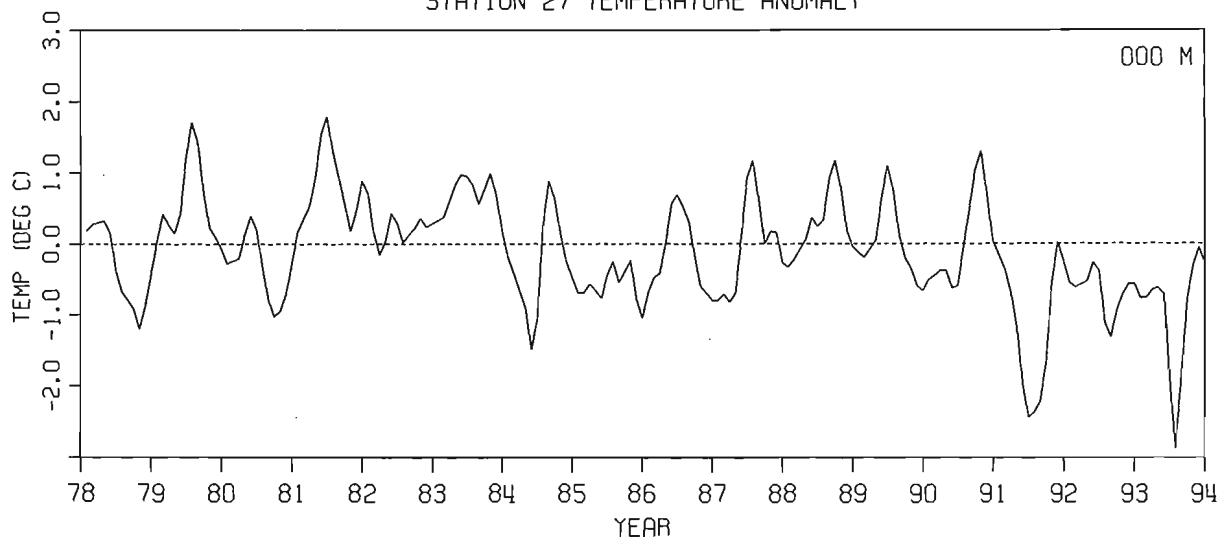


STATION 27 SIGMA-T ANOMALIES 1993

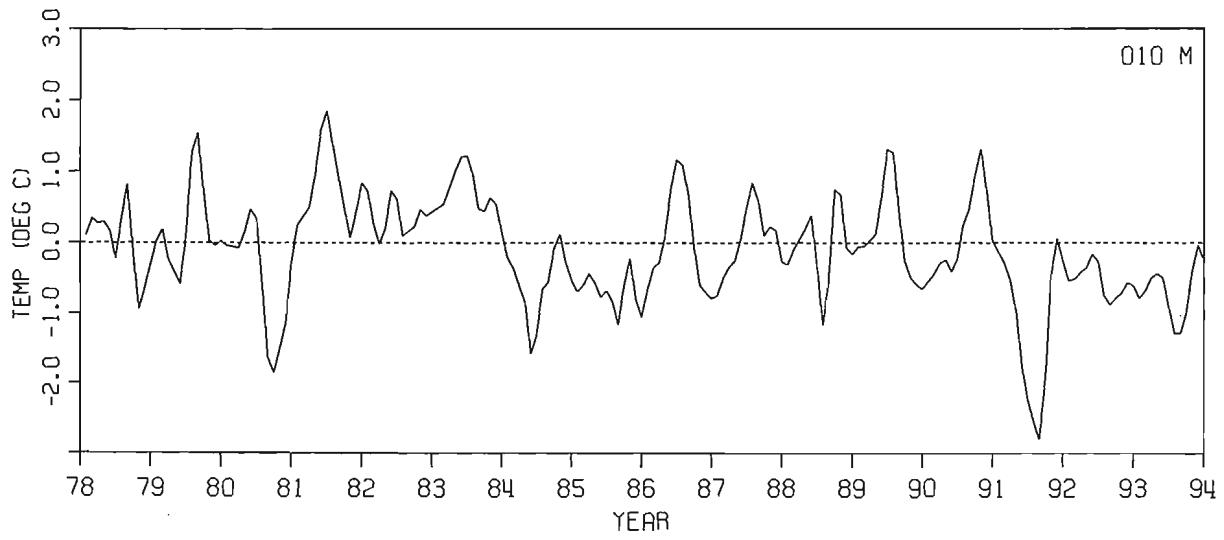


APPENDIX G. Time series of temperature anomalies from 1978 to 1993 at standard oceanographic depths.

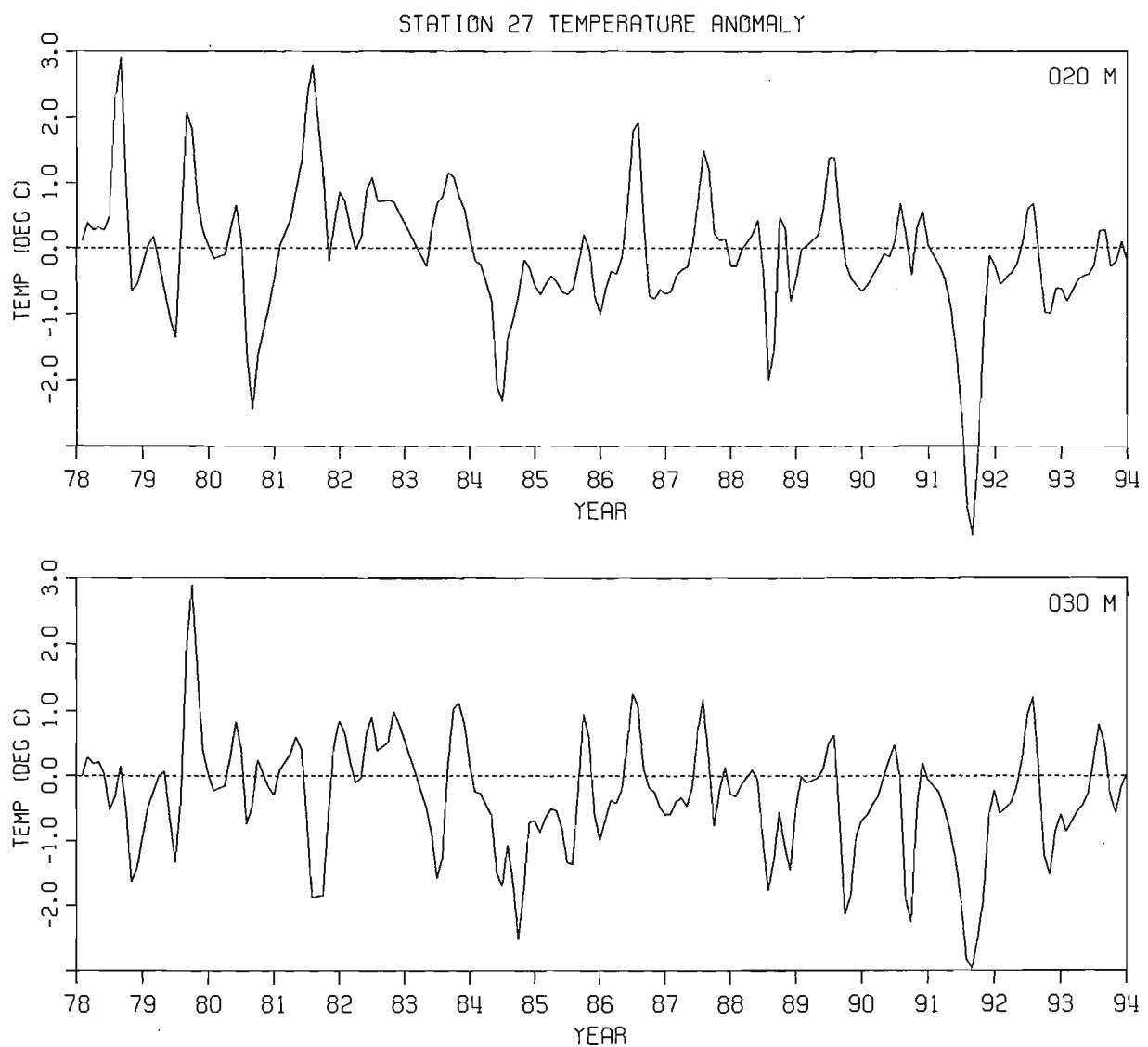
STATION 27 TEMPERATURE ANOMALY



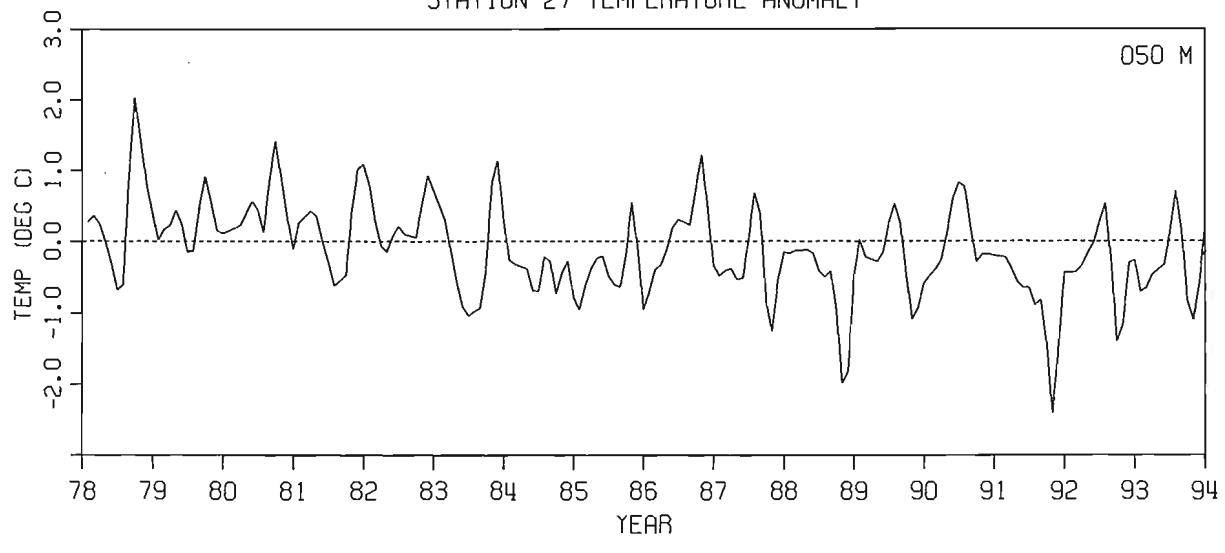
000 M



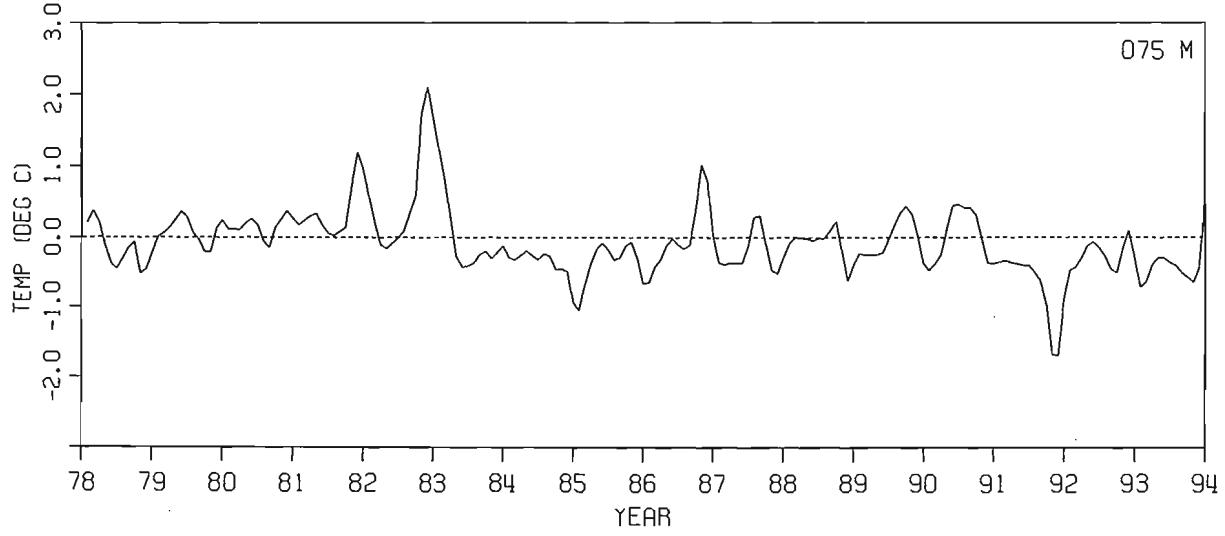
010 M



STATION 27 TEMPERATURE ANOMALY

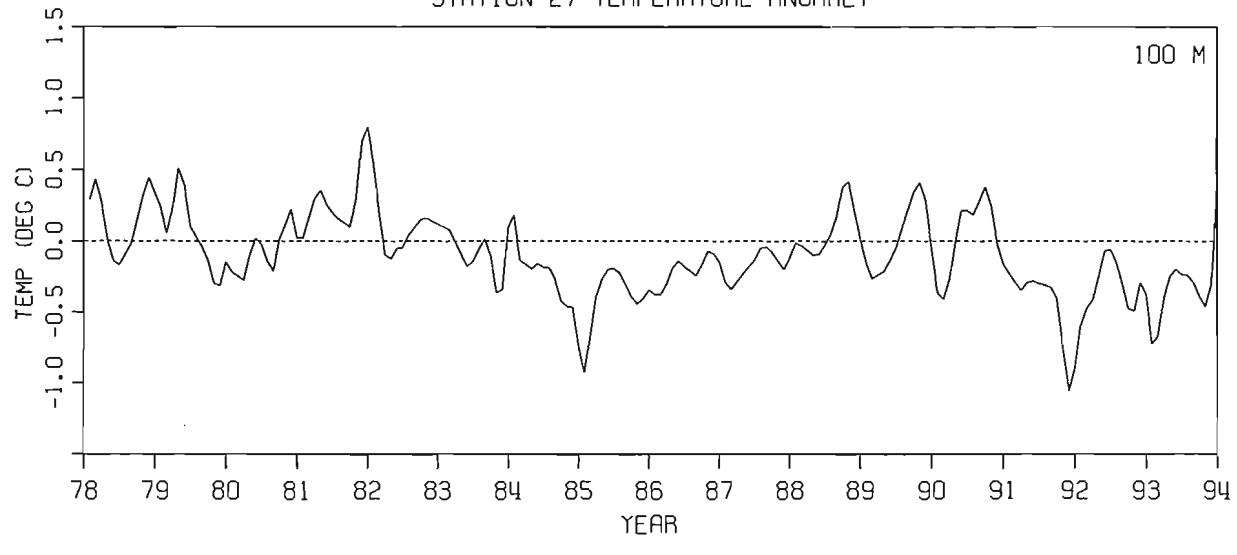


050 M

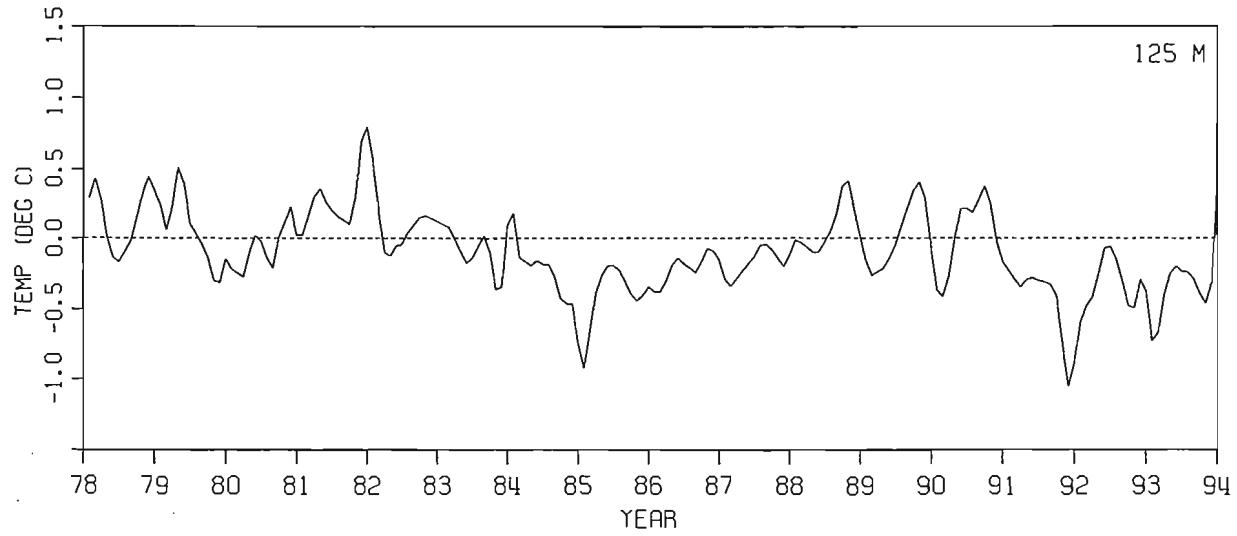


075 M

STATION 27 TEMPERATURE ANOMALY

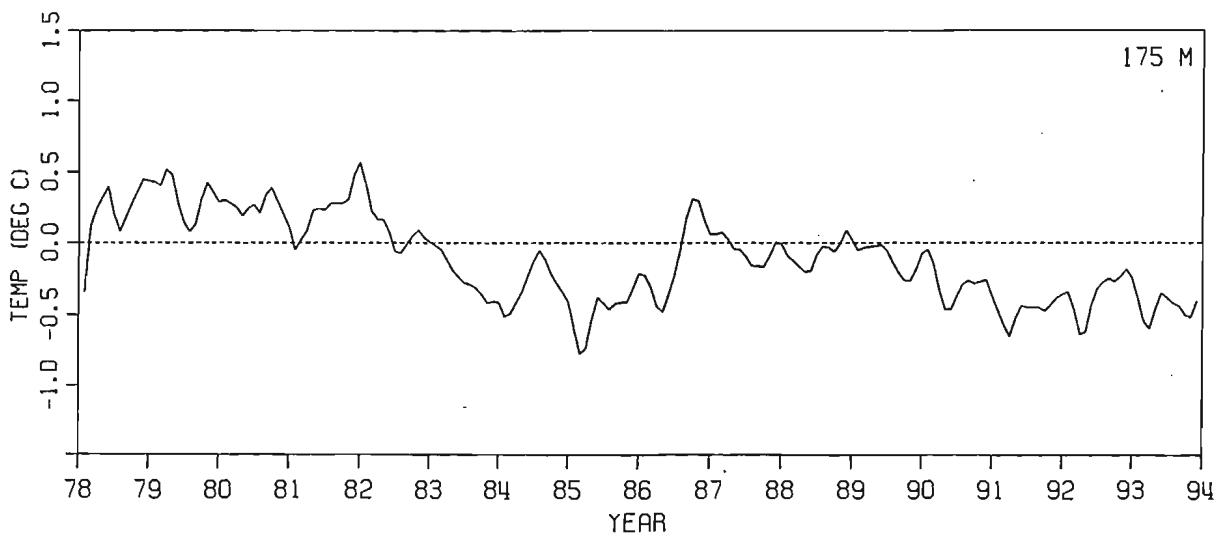
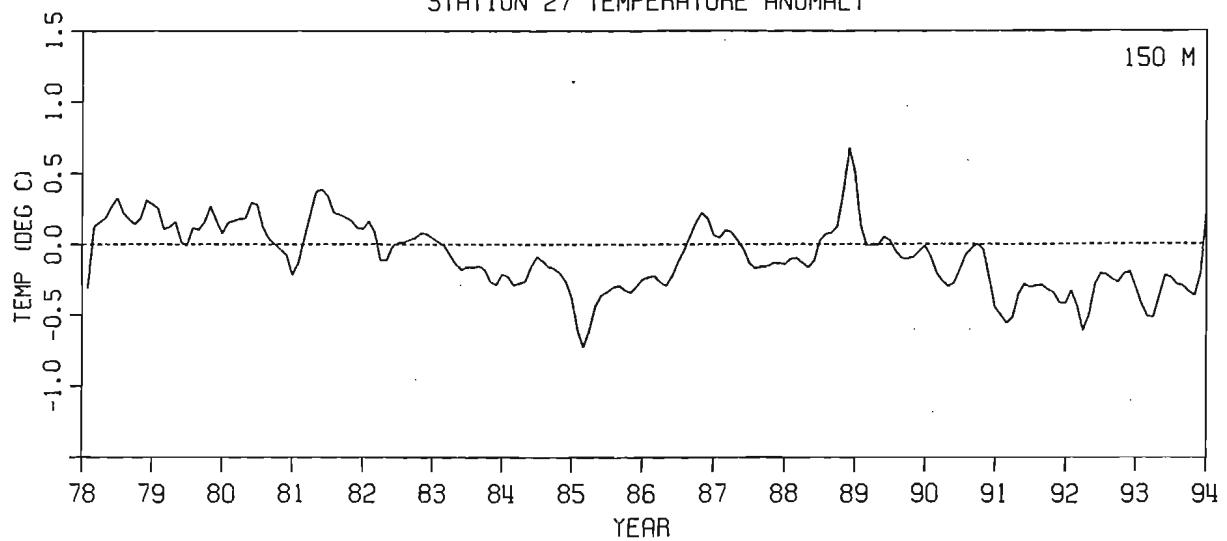


100 M

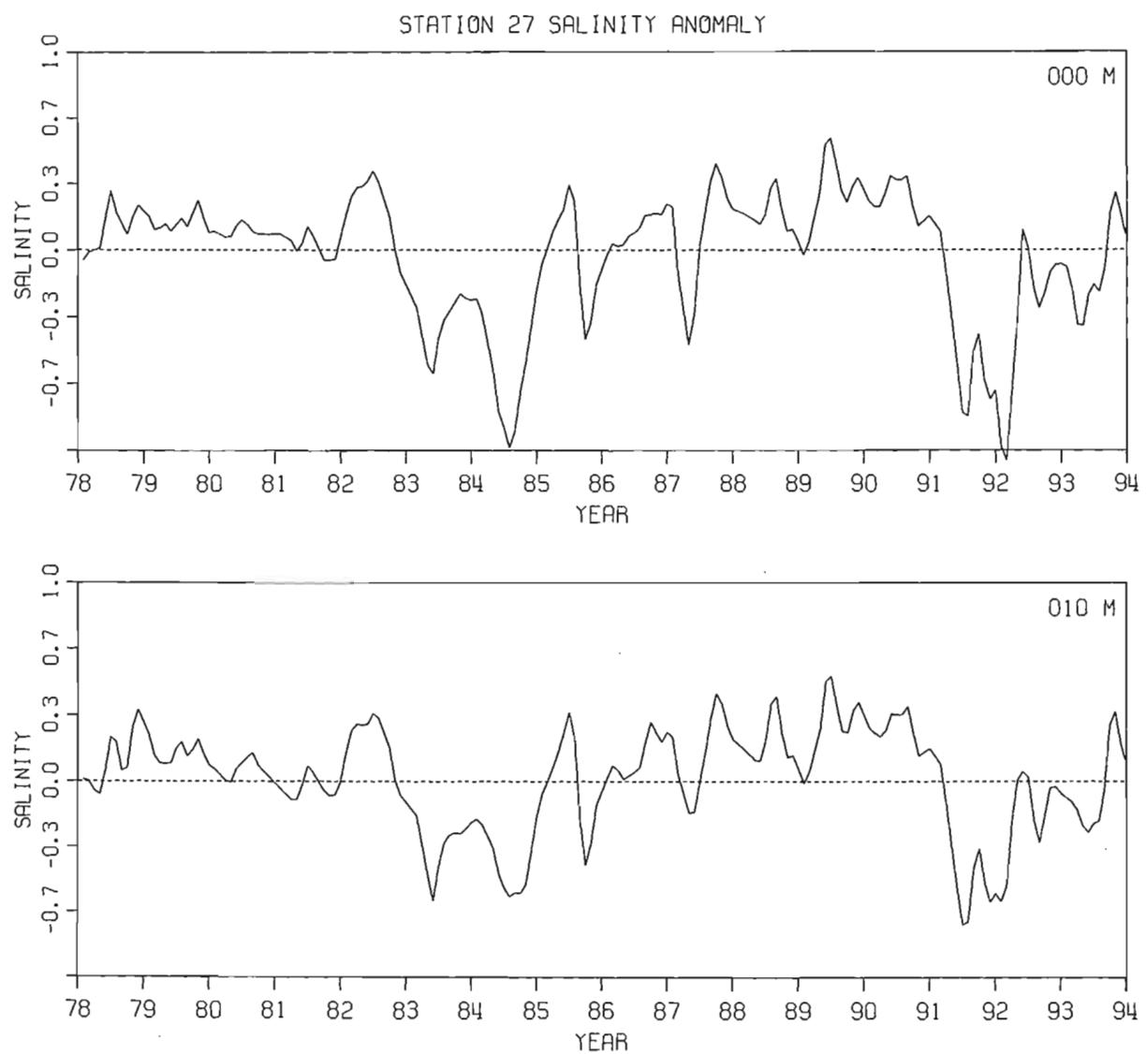


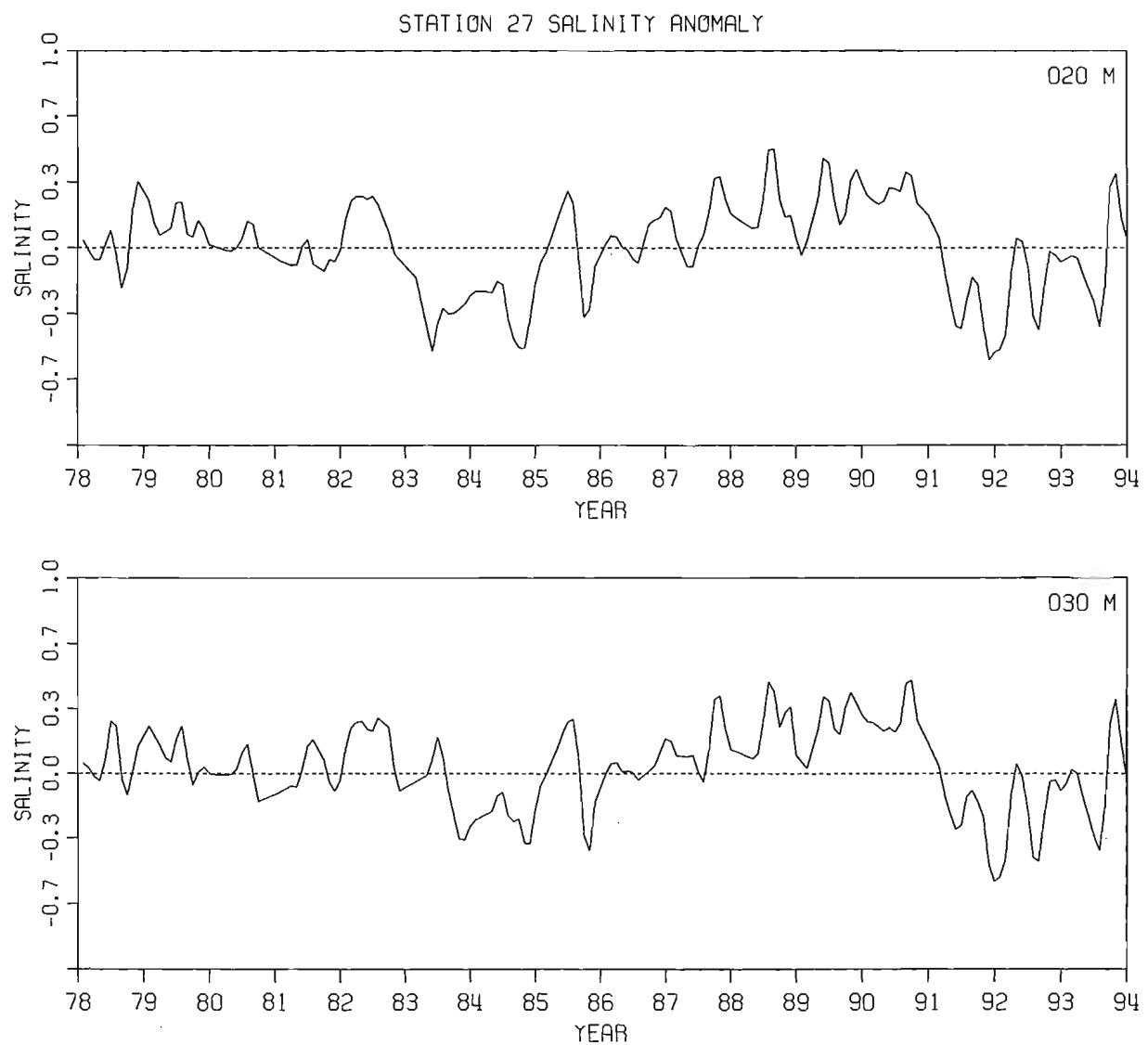
125 M

STATION 27 TEMPERATURE ANOMALY

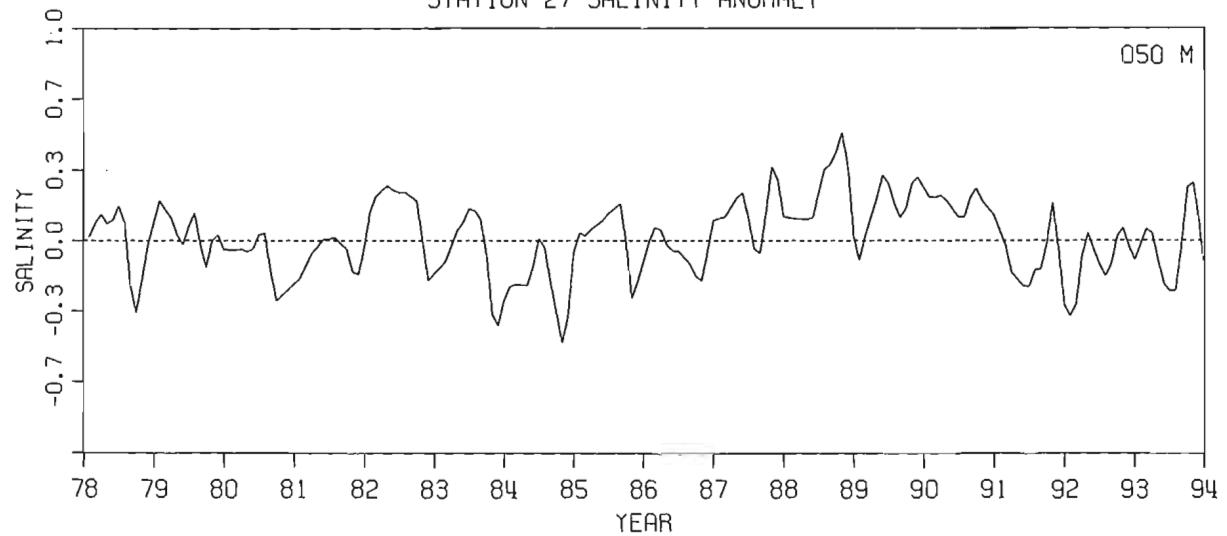


APPENDIX H. Time series of salinity anomalies from 1978
to 1993 at standard oceanographic depths.

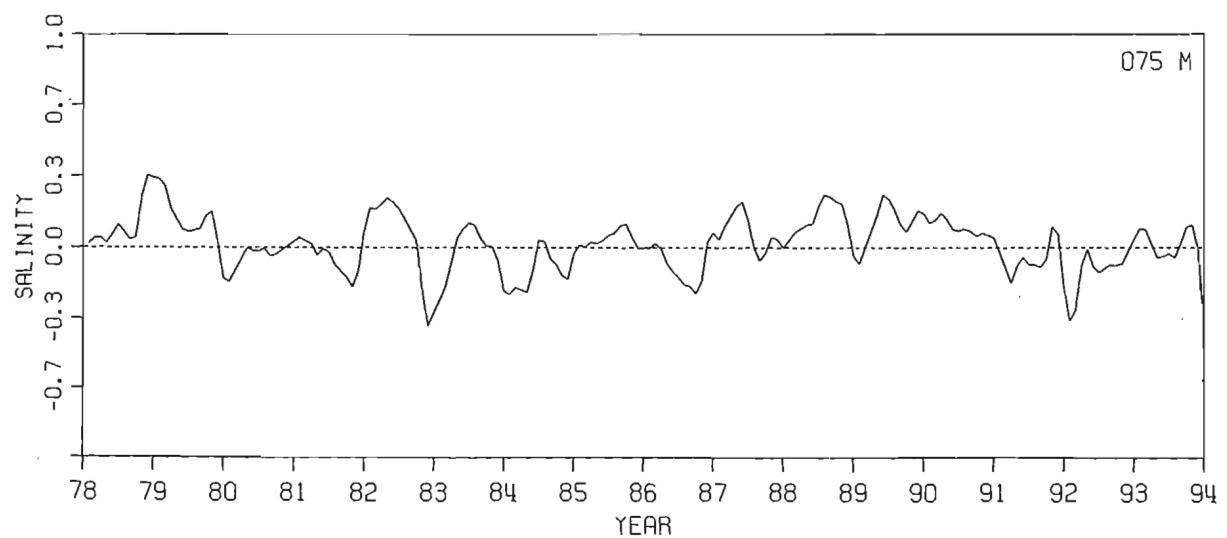




STATION 27 SALINITY ANOMALY

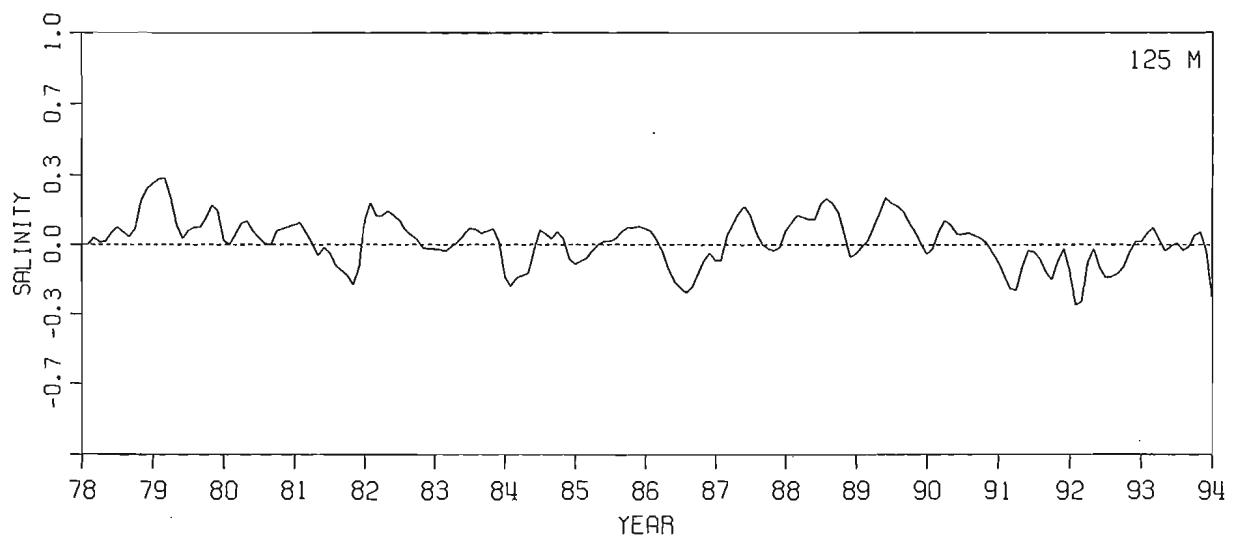
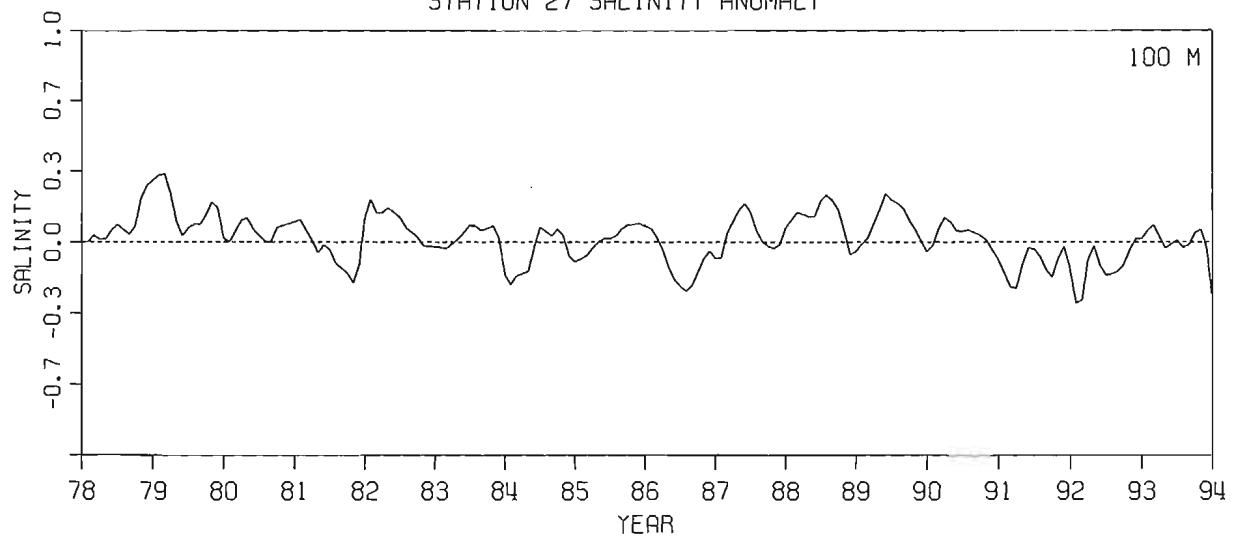


050 M

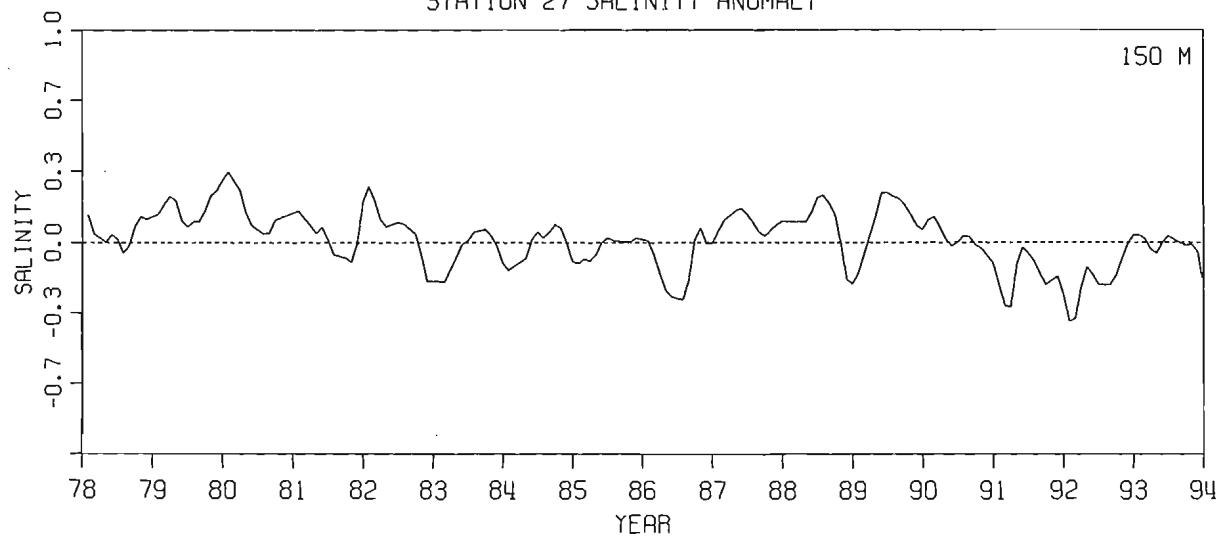


075 M

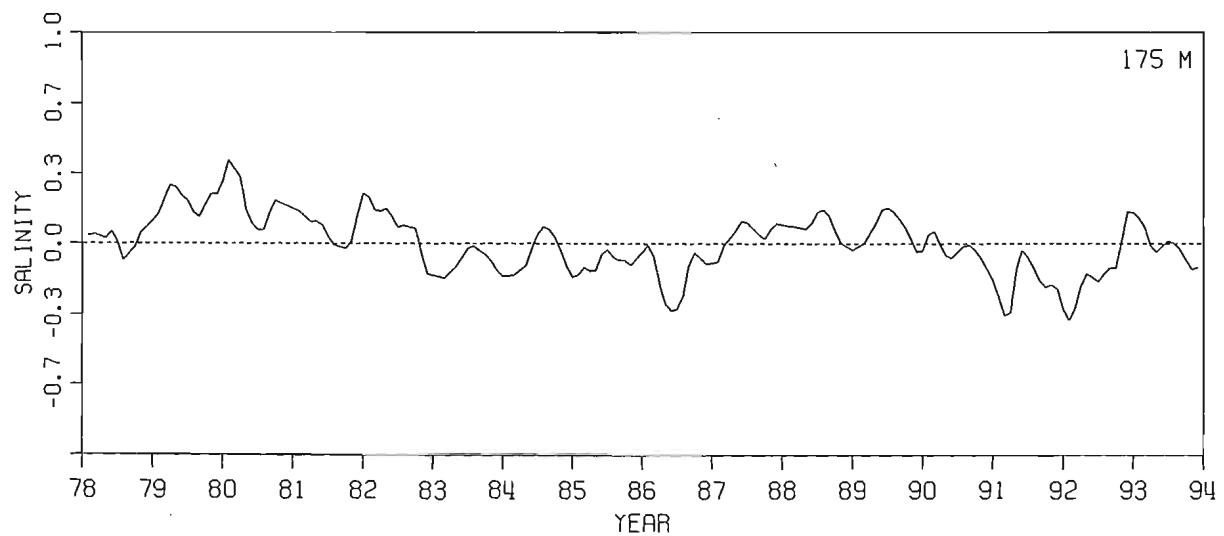
STATION 27 SALINITY ANOMALY



STATION 27 SALINITY ANOMALY

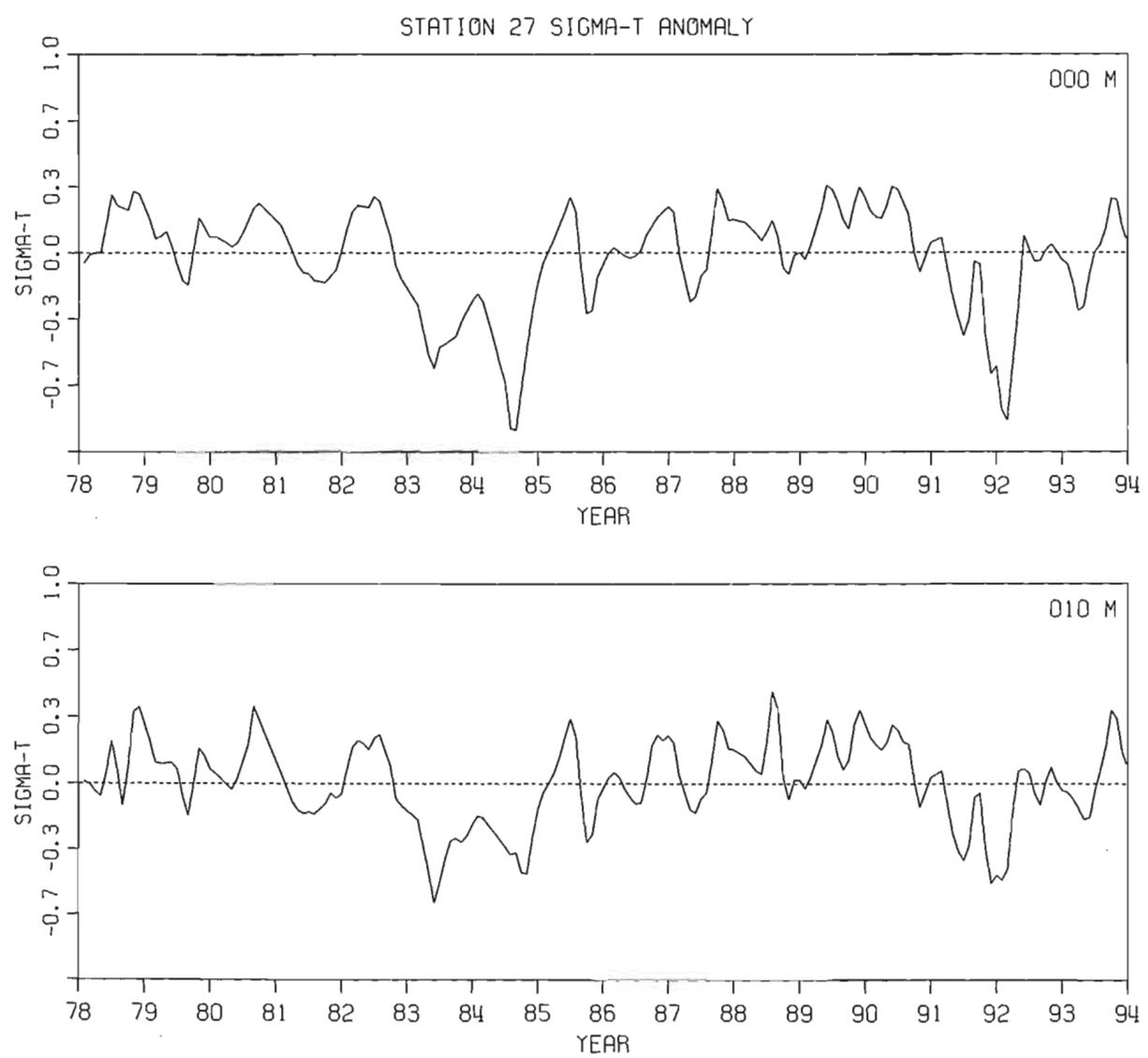


150 M

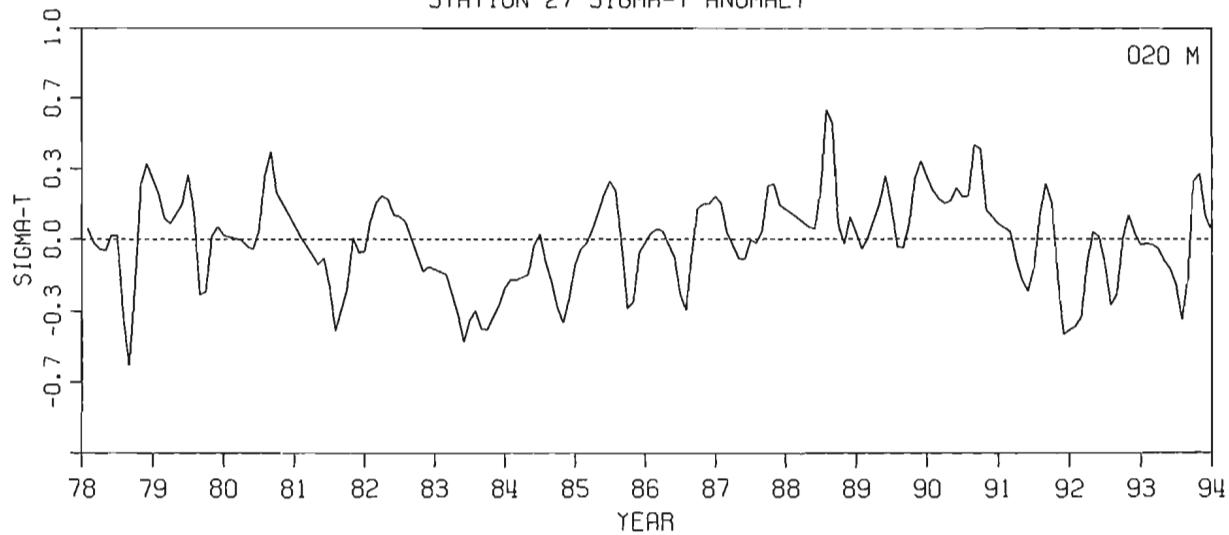


175 M

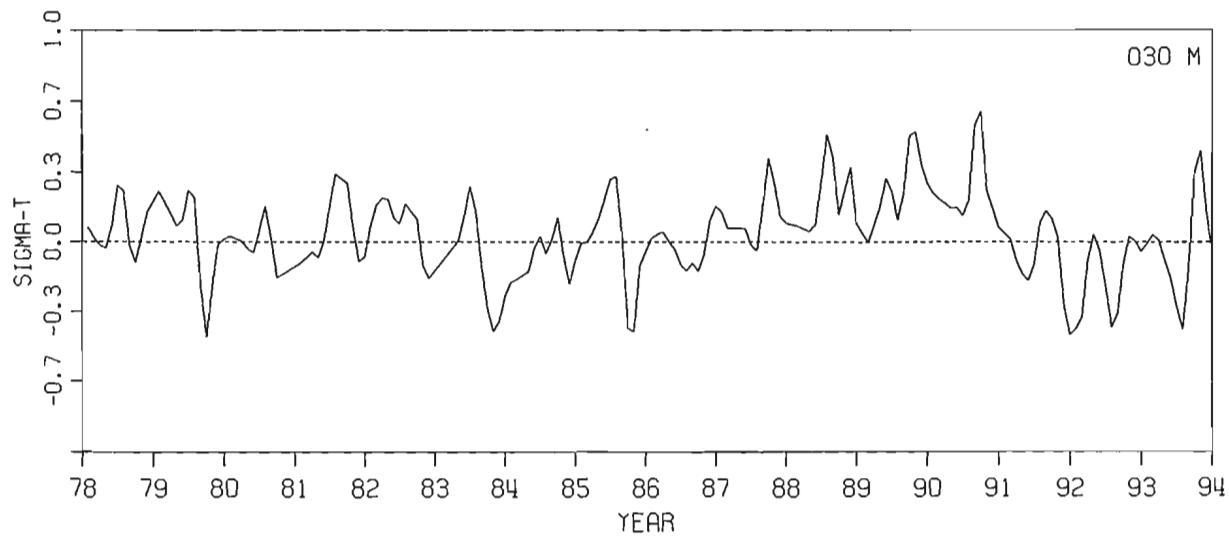
APPENDIX I. Time series of density (σ_t) anomalies
from 1978 to 1993 at standard oceanographic
depths.



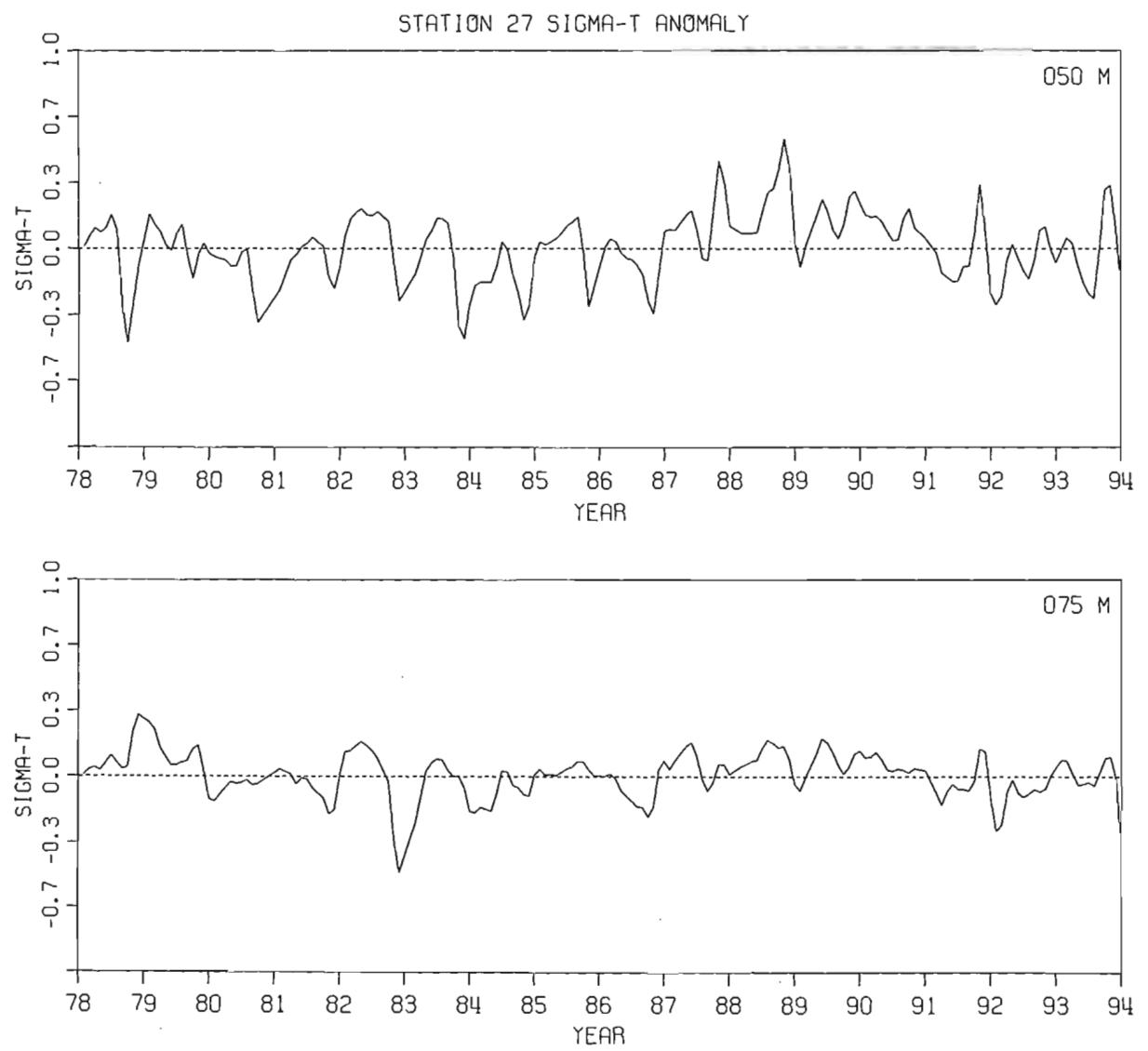
STATION 27 SIGMA-T ANOMALY



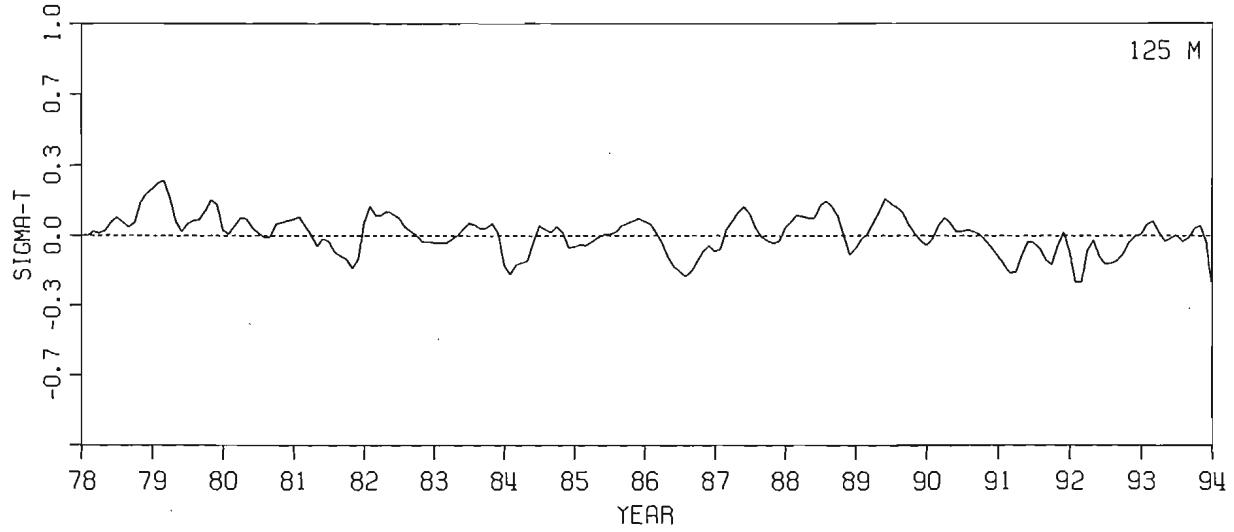
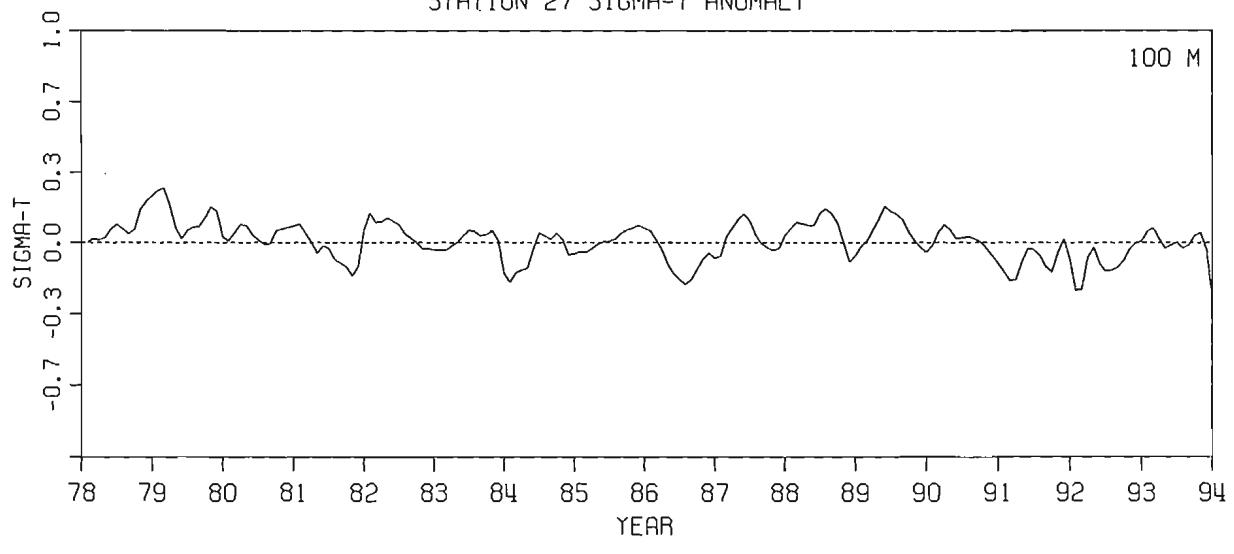
020 M



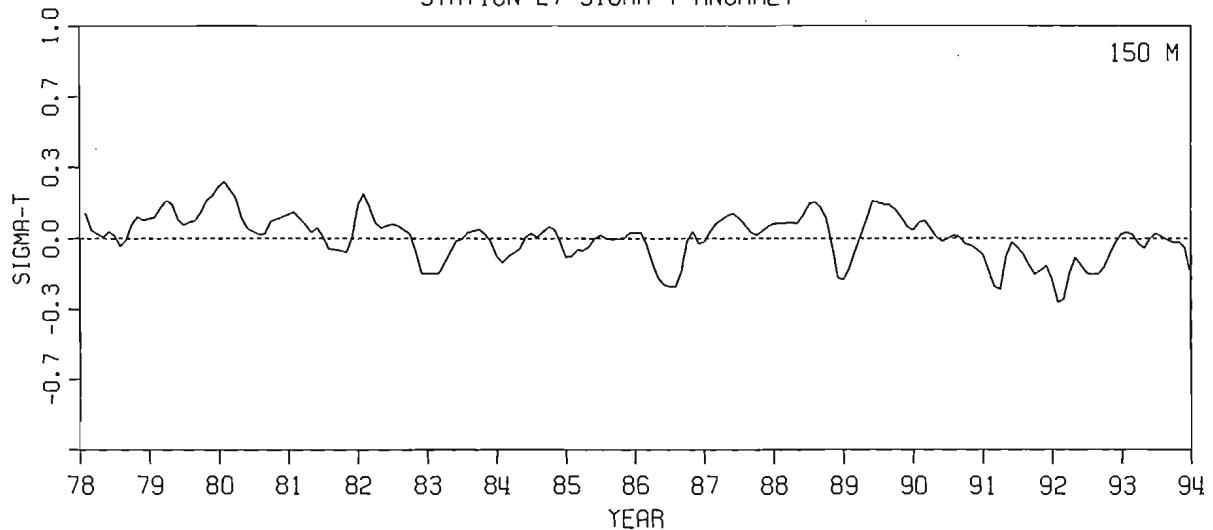
030 M



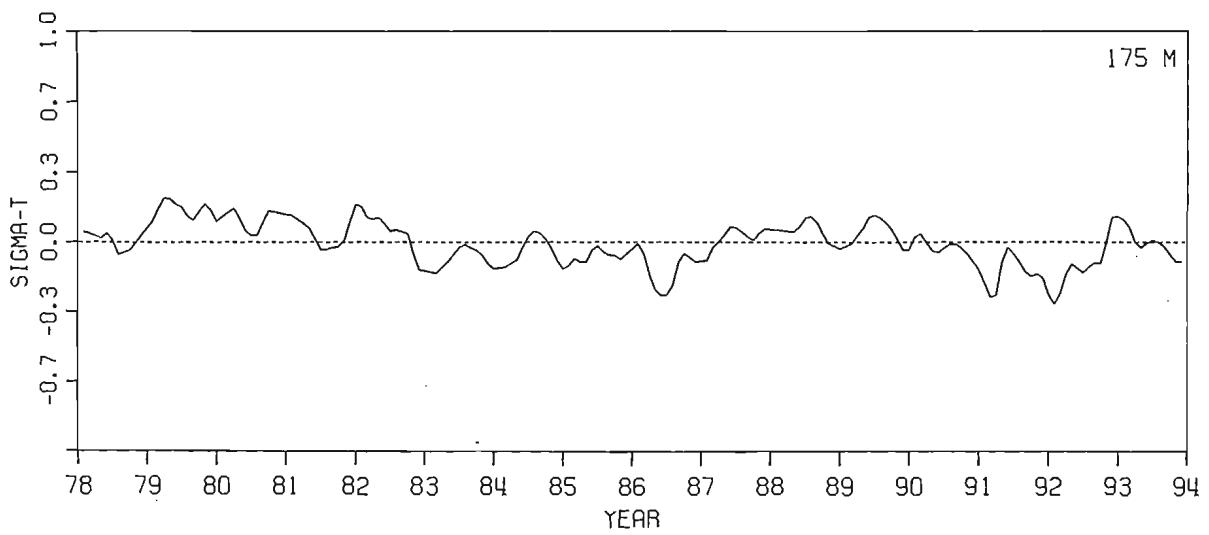
STATION 27 SIGMA-T ANOMALY



STATION 27 SIGMA-T ANOMALY



150 M



175 M