GEOLOGICAL SURVEY OF CANADA

OPEN FILE 2367

Computer analysis of thermal data, Norman Wells Pipeline 1989-1990

D.W. Riseborough

1991

FINAL REPORT

COMPUTER ANALYSIS OF THERMAL DATA NORMAN WELLS PIPELINE

1989-90

to the

Terrain Sciences Division
Geological Survey of Canada
Energy Mines and Resources
401 Lebreton Street
Ottawa.

by

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1990

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DSS File Number :23397-9-1287/01-SS

FOREWORD

This report documents work undertaken as part of the federal government's Permafrost and Terrain Research and Monitoring Program along the 868 km Norman Wells to Zama oil pipeline. The 324 mm diameter, shallow burial (1 m) pipeline, traverses the discontinuous permafrost zone of northwestern Canada and began operation in April 1985. A joint monitoring program with Interprovincial Pipe Lines (NW) Ltd. was established following the signing of an environmental agreement between the pipeline company and the Department of Indian and Northern Affairs (INAC) in 1983. INAC coordinates the government's monitoring program in which Energy, Mines and Resources' Geological Survey of Canada, the National Research Council's Institute for Research in Construction, and Agriculture Canada's Land Resource Research Institute participate.

A major component of this research and monitoring program involves the detailed quantification of changes in the ground thermal regime and geomorphic conditions at thirteen instrumented sites along the route. This project was developed in cooperation with the Geological Survey in order to examine and quantify the effects of pipeline construction, operation and maintenance in thaw sensitive terrain. Many components of this research are contracted out.

The work undertaken in this contract report describes but one aspect of these site investigations. Interpretations contained herein are often limited to the specific data base under analysis and may thus not present an integrated or comprehensive analysis of all site observations. The opinions and views expressed by the authors are their own and do not necessarily reflect those of the Geological Survey of Canada or Indian and Northern Affairs.

Funding for the research and analyses reported herein was largely provided by INAC's Northern Affairs Program and the Federal Panel on Energy Research and Development.

Margo Burgess
Scientific Authority
Terrain Sciences Division
Geological Survey of Canada

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Acknowledgements

The long term ground thermal regime monitoring program of the Norman Wells Pipeline permafrost and terrain research and monitoring program has been undertaken by the Terrain Sciences Division of the Geological Survey of Canada, in cooperation with the Department of Indian and Northern Affairs and Interprovincial Pipe Line Ltd. This report is based upon field measurments taken by many people from Energy Mines and Resources and the Department of Indian and Northern Affairs as part of that program. Funding for this contract has come from the Federal Panel on Energy Research and Development and the Department of Indian and Northern Affairs. The work described in this report was assisted and expedited with the help of M. Burgess, J. Naufal and V. Allen of the Terrain Sciences Division and K. MacInnes of Indian and Northern Affairs.

Computer Analysis of
Norman Wells Pipeline Thermal Data

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SECTION 1

Introduction

This report summarizes the results of several analyses performed using the ground temperature data collected along the Norman Wells - Zama pipeline route (Burgess et al. 1985, Burgess and Naufal 1990) to the end of October 1989. Some emphasis is placed upon the analysis of data obtained since the last report (Riseborough 1989), and on extended analyses of the entire record for selected sites.

The work undertaken for this part of the contract comprised the following:

1. Extend calculation of running mean annual air temperatures with monthly Atmospheric Environment Service data from Norman Wells, Fort Simpson, and High Level.
2. Obtain weekly estimates of pipe and ground temperatures by interpolating between approximately monthly temperature measurements, and use the interpolated values to obtain running mean annual temperatures.
3. Compare pipe temperatures to ground temperatures on the adjacent right-of-way and off right-of-way.
4. Compare right-of-way and off right-of-way ground temperature trends with depth for selected sites.
5. Interpret trends in light of available climate data and soil physical and

thermal properties; determine whether response varies according to major soil groupings or site characteristics.

6. Prepare software to facilitate access to and analysis of monitoring program data.

Interpolated temperature curves and running mean annual temperatures were obtained for all sensors: due to the volume of numbers they are not included in this report. A floppy disk copy of all measured, interpolated, and running mean temperatures, for all sensors on all cables has been supplied to the scientific authority.

SECTION 2

Methods of Analysis

The analytical methods used for the present contract are the same as those used previously (Riseborough 1989). Some data handling procedures which previously were done by editing the raw data files or the output files generated by the analytical programs were automated. In the course of developing the software to examine the thermal data, analytical methods were devised which are an improvement over the methods used here, in particular the method of calculating the mean annual ground temperature. These improvements could be incorporated into the data manipulation programs for use in future analyses.

2.1 Interpolation of ground and pipe temperature data.

Smooth temperature curves were created from the original monitoring program data for plotting purposes as well as to permit mean annual temperature estimates. Soil and pipe temperatures were estimated between temperature measurements using cubic spline interpolation, as described in a previous report (Riseborough et al. 1987). As recommended in the addendum to an earlier report (Riseborough 1988), the interpolation program was modified to give estimates at 5 day intervals in order to improve slightly the precision of the mean annual temperatures calculated with the estimates. Pipe temperatures in graphs in Appendix I are the average for the five pipe sensors (with the single exception noted below).

Data files for many cables required some manipulation before satisfactory interpolations were obtained. Sharp transitions from rapid to slower temperature change can produce an interpolation curve which oscillates from datum to datum, rather than forming a smooth curve. Measurements taken close together (relative to the average measurement interval) can cause similar problems. The program was modified to ignore data if measurements were taken less than 9 days apart. If problems with oscillations were still evident, additional "extra" data were removed by editing the data files. This was repeated until a satisfactory interpolated curve was produced. The most common remedy to this problem was the removal of the first few measurements in the data set: This was nessesary at a number of sites which experienced a rapid warming trend at the start of the measurement program (due to snow removal along the right-of-way in the winter of 1984-85).

At the request of the scientific authority pipe temperature data collected in October 1987 for the MacKenzie highway south and Moraine south sites, as well as data collected in August 1989 for the Canyon Creek sites B and C and the Great Bear River sites, were removed from the data sets. Measurements at those times corresponded to a period when oil was not flowing in the pipe, so that temperatures obtained were not representative of normal conditions. Second, average pipe temperatures were determined for only four of the five pipe sensors at the Great Bear River B site. This permits inclusion of the majority of the record, during which the fifth pipe temperature sensor was not functioning.

2.2 Running mean annual temperature estimates

Running mean annual temperatures were calculated from the interpolated temperatures. For each sensor, the first mean annual temperature was obtained as the average of the first 73 five-day values (since 73 x 5 = 365): this mean was assigned to the midpoint of the first year of data. For each subsequent value, the mean annual temperature was re-calculated by dropping the first value and adding the next value to the year. This can be thought of as either a running mean of 73 five day values, or a mean annual temperature updated at five day intervals.

For the data management software, an alternate method of calculating the mean annual temperature was devised: the coefficients of the spline curves are stored, rather than the interpolated values. This permits an exact calculation of the mean annual temperature by:

1) Integration of the spline curves over a one year interval.

2) Dividing the integral by the time period.

This procedure eliminates the need for the storage of large arrays of interpolated values for the calculation of the running mean. It also allows the determination of the interpolation interval for convenience rather than for purposes of precision in the calculation of the mean. While the mean annual temperatures generated are "precise", the values produced are still only as good as the original interpolation curves are at replicating the actual temperature curves.

2.3 Preparation of Geotherm Plots

Geotherms are similar to contour lines on topographic maps, except that they are lines of equal temperature rather than equal elevation. A geotherm plot may be drawn showing a thermal cross section (with depth and distance for y- and x-axes), or showing depth along the y-axis and time on the x-axis. The second type of plot is presented in this report. In a geotherm plot, the spacing between lines indicates the rate of change of temperature over both time and depth. Unfortunately, the distance between sensors on the cables is too coarse to permit accurate plots to be prepared for the monitoring program temperatures, particularly in the upper 2 meters of the ground. Fortunately, however, the rate of change of the mean annual temperature is much more gradual, both over time and with depth, permitting "mean annual geotherms" to be plotted instead. Mean annual geotherms are similar to simple temperature geotherms except that they are lines of equal mean annual temperature.

Geotherm plots were prepared for T1, T2, T3, and T4 for all sites, using the running mean annual temperatures generated from the interpolations. The data were supplied to a three dimensional plotting computer program to generate contour (i.e. geotherm) plots. Vertical dashed lines are included at one year intervals: the program does not allow the placement of the dashed lines at year-end points.

SECTION 3

Surface Climate

Monthly mean air temperatures collected by the Atmospheric Environment Service at Norman Wells, Fort Simpson, and High Level over the period of pipeline operation is shown in Figure 3.1. Figure 3.2 shows the trend in mean annual air temperature for the three stations, based on these values. The cooling which started in 1987-88 has persisted into the next year. The mean remained relativly stable until the winter of 1989-90 was included in the mean, and even this appears to have produced a significant cooling effect on the mean annual temperature for a short term only.

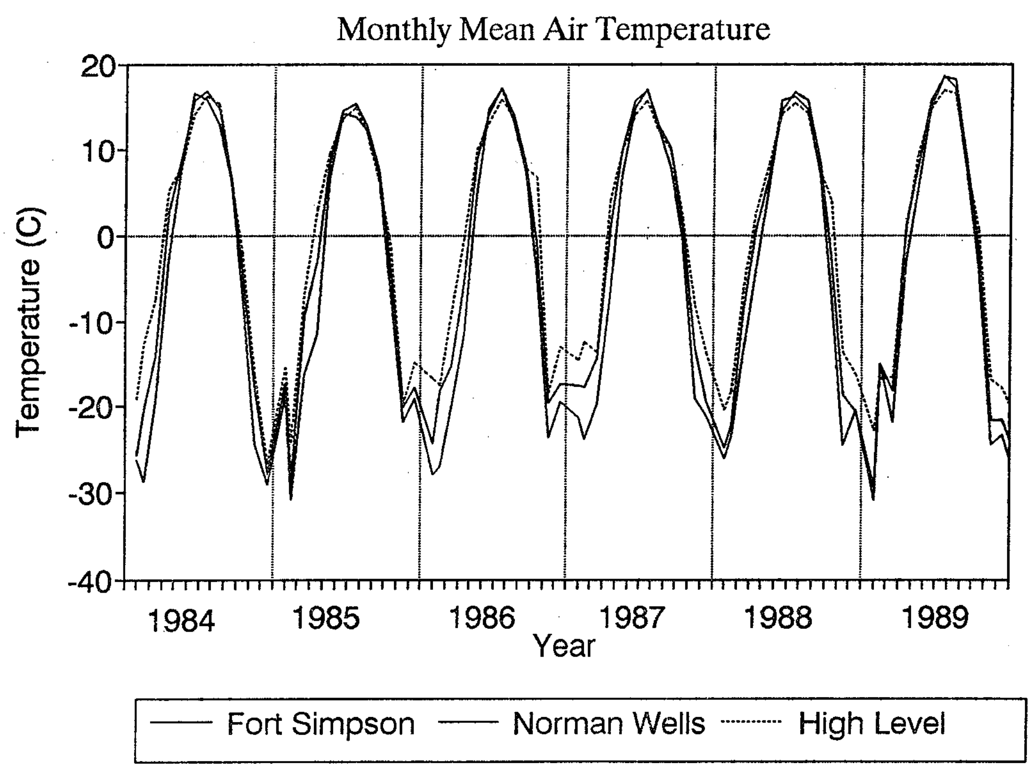


Figure 3.1

Figures 3.3 and 3.4 show the mean temperature of the warmest and coldest six months of the year for the years of pipeline operation. The warm season of 1989 was warmer than for any of the previous five years, while the winter of 1988-89 was colder than the two preceeding winters. (While the winter of 1989-

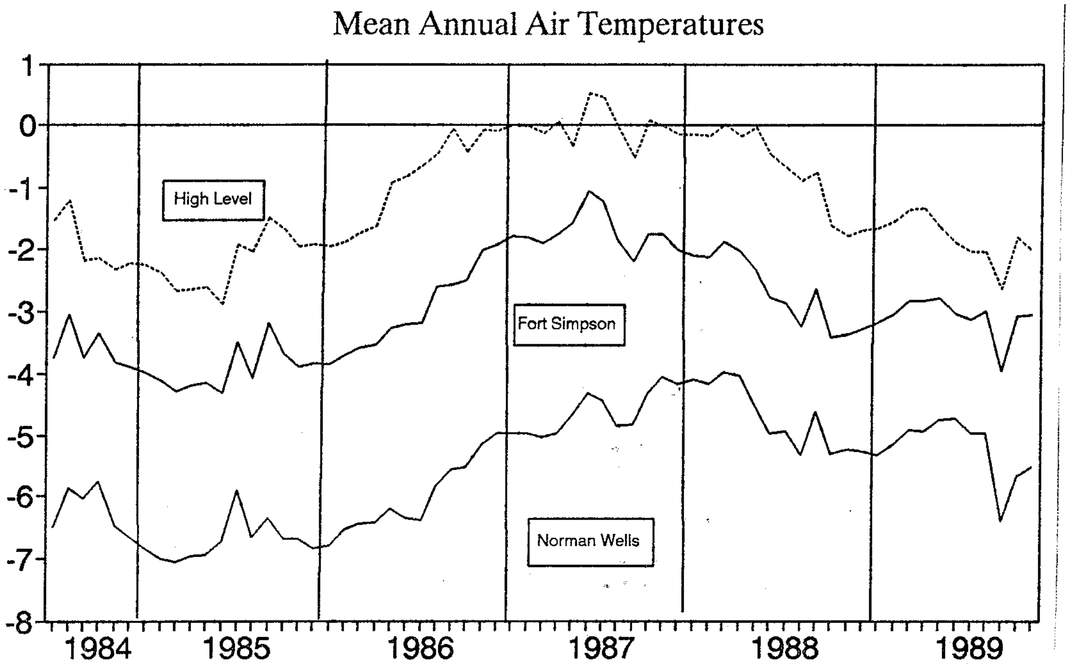


Figure 3.2

90 will probably be determined to be colder than the five previous, it falls after the period under consideration.) This combination resulted in a relatively small fluctuation in the mean annual temperature in the period form March 1988 to March 1989 (remembering that the mean annual temperature centered on March spans from October to October).

As can be seen in Figure 3.1, winter minimum temperatures fluctuate more than summer maximum temperatures from year to year. Figures 3.3 and 3.4 show that this is true for seasonal averages, as well. Mean "winter" temperatures (the mean of the coldest six months of the year) have fluctuated on the on the order of 4 degrees from 1984-89 at each station, while the mean for warmest six months of the year has fluctuated by about 2 degrees over the same period.

While interannual variations in winter temperature are approximately the same at the three stations, interannual variation in summer temperature is different at High Level from the more northerly stations. This can attributed to the summer position of the arctic front. As a result, the difference in

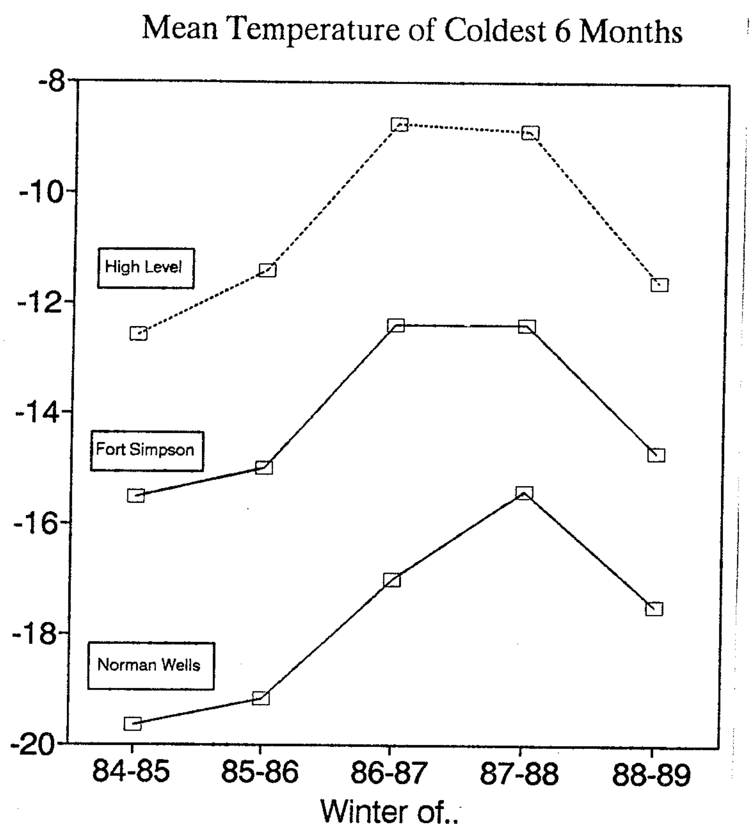


Figure 3.3

mean annual temperatures between the stations has not been uniform over the period of pipeline operation: The mean annual air temperature at Fort Simpson was closer to that of Norman Wells during 1988 than before or since that time.

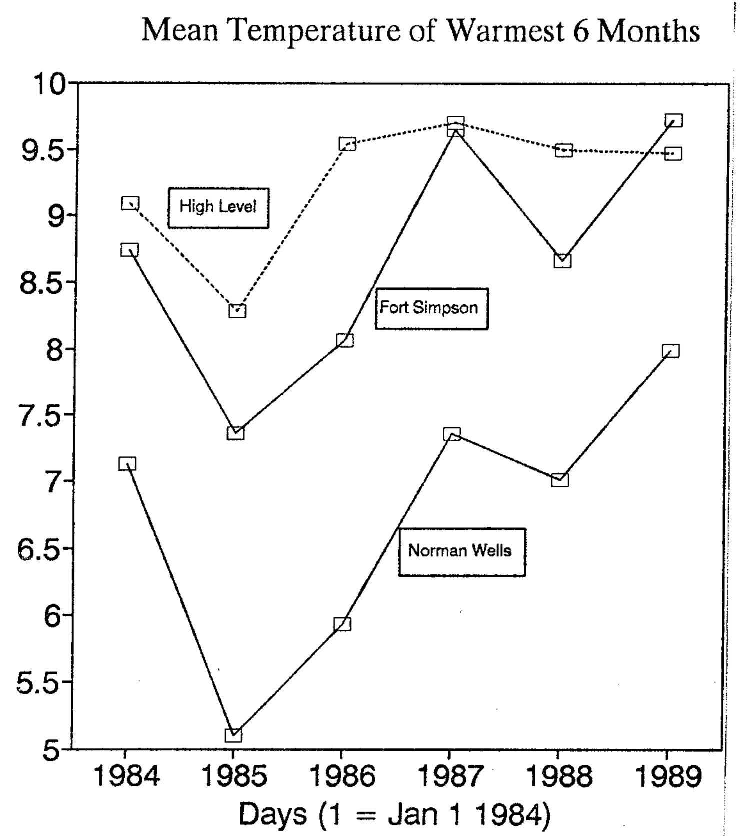

Mean Temperature of Warmest 6 Months
High Level
Fort Simpson
Norman Wells
10
9.5
9
8.5
8
7.5
7
6.5
6
5.5
5
1984
1985
1986
1987
1988
1989
Days (1 = Jan 1 1984)

Figure 3.4

SECTION 4

Change in Mean Annual Temperature, 1988-89.

4.1 Mean annual temperature trends at 1 m depth.

In this section of the report, selected results from the estimates of mean annual temperature are examined in order to understand the pattern of changing temperatures. In general, the changes in mean annual temperature at the 1 m sensor both on and off of the Right of Way were much more variable in the year ending October 1989 than in the previous year (when almost all sites warmed up to some extent). This variability can be attributed to the combined influences of the surface temperature regime and the thermal properties of the ground.

The winter of this period was exceptionally cold, while the summer was exceptionally warm. This combination has lead to different responses at different sites, depending on the relative importance of each season to the annual average ground thermal regime. In addition, the sustained air temperature warming trend from 1984 to 1987 has produced temperature gradients near the top of permafrost which varied according to the thermal properties (principally the strength of latent heat effects) of the soil materials. The cooling trend which has persisted since 1987 has permitted these gradients to weaken or reverse, with those sites exhibiting the strongest gradients producing the most rapid cooling.

Table 4.1 shows mean annual temperatures for the beginning and end of this interval for all of the thermal fence sites. The average rise in the mean annual temperature was the greatest on the pipe (average change: 0.27 ^{o}C), next highest on the Right of Way (0.20 ^{o}C) and least off of the Right of Way (0.08 ^{o}C). Plotting this data in different ways reveals several features of the pattern of mean annual temperature change.

Figures 4.1-4.3 show mean annual temperature for February of 1989 plotted as a function of the mean annual temperature a year earlier, for the pipe and on/off of the ROW. The "1:1" line is the line of zero change from the year before (points above the line indicate an increase in mean annual

Table 4.1 Mean Annual Temperatures - 1 m Depth

			Pipe			On ROW			Off ROW		
site	km	condition	1988	1989	delta	1988	1989	delta	1988	1989	delta
1	0.02	ice rich	-1.48	-1.37	0.10	-0.06	-0.21	-0.15	-1.45	-1.60	-0.15
2a	19	low ice	0.11	0.01	-0.09	-0.87	-0.08	0.79	-0.90	-0.11	0.79
2b	19.3	wood chip	0.13	0.11	-0.02	-0.44	-0.67	-0.24	-2.01	-1.54	0.47
2c	19.6	west	0.19	0.19	0.00	1.86	2.12	0.26	-0.62	0.02	0.63
3a	79.2	ice rich	1.28	1.22	-0.06	-1.17	0.01	1.18	-2.01	-2.73	-0.72
3b	79.4	aeolian	1.26	1.21	-0.05	0.53	0.51	-0.03	-1.91	-1.75	0.16
7a	271.2	ice rich	1.12	1.29	0.17	0.71	0.08	-0.63	-0.34	-0.53	-0.19
7b	272	ice rich	1.09	1.23	0.14	2.39	1.14	-1.25	-0.44	-1.01	-0.57
7c	272.3	ice rich	1.15	1.12	-0.02	-0.56	-0.99	-0.43	-1.29	-1.76	-0.47
4a	478	sat. sand	2.36	2.71	0.35	2.60	2.69	0.09	1.17	1.79	0.61
4b	478.1	dry sand				3.28	3.54	0.26	1.09	0.69	-0.40
8a	557.8	thin peat	2.93	3.42	0.49	0.30	0.17	-0.14	-0.52	-0.66	-0.14
8b	558.2	thick peat	2.89	3.24	0.34	-0.39	-0.59	-0.21	-1.07	-1.50	-0.43
8c	558.3	thin peat	1.68	2.36	0.68	0.01	-0.42	-0.44	-0.20	-0.36	-0.16
9	583.3	granular	3.21	3.65	0.44	4.04	4.50	0.47	2.92	3.57	0.66
10a	588.3	helipad	5.18	5.84	0.66	2.40	2.96	0.56	1.62	2.08	0.46
10b	588.7	thick peat	5.21	5.61	0.40	1.13	2.89	1.76	-0.32	-0.59	-0.27
11	597.4	helipad	4.75	4.68	-0.08	2.39	3.25	0.86	0.92	1.65	0.73
12a	608.6	thin peat	4.66	5.26	0.60	3.49	4.12	0.63	0.69	1.44	0.75
12b	608.7	icy peat	4.60	5.20	0.61	-0.05	-0.02	0.03	-0.65	-0.82	-0.18
5a	783	ice rich	3.24	3.26	0.02	1.63	2.14	0.51	0.62	0.65	0.03
5b	783.3	ice rich	3.06	3.26	0.20	0.00					
6	819.5	icy peat	2.83	3.22	0.39	-0.07	-0.06	0.01	0.06	0.22	0.16
Means:			2.35	2.62	0.24	1.01	1.23	0.18	-0.21	-0.13	0.08

temperature). In general, for sensors both on and off of the ROW, those sites unfrozen in the previous year were more likely to be warmer, while frozen sites were more likely to be cooler than in the previous year.

Comparison of the mean annual temperature changes in Figures 4.1-4.3 shows that the scatter in values (the range as well as standard deviation, of the change in MAT) is least on the pipe, most on ROW. This suggests that the mean annual pipe temperature is less dependent on site specific factors than the ground temperatures on and off of the ROW.

Plotting the change (1988-89) in mean annual temperature as a function

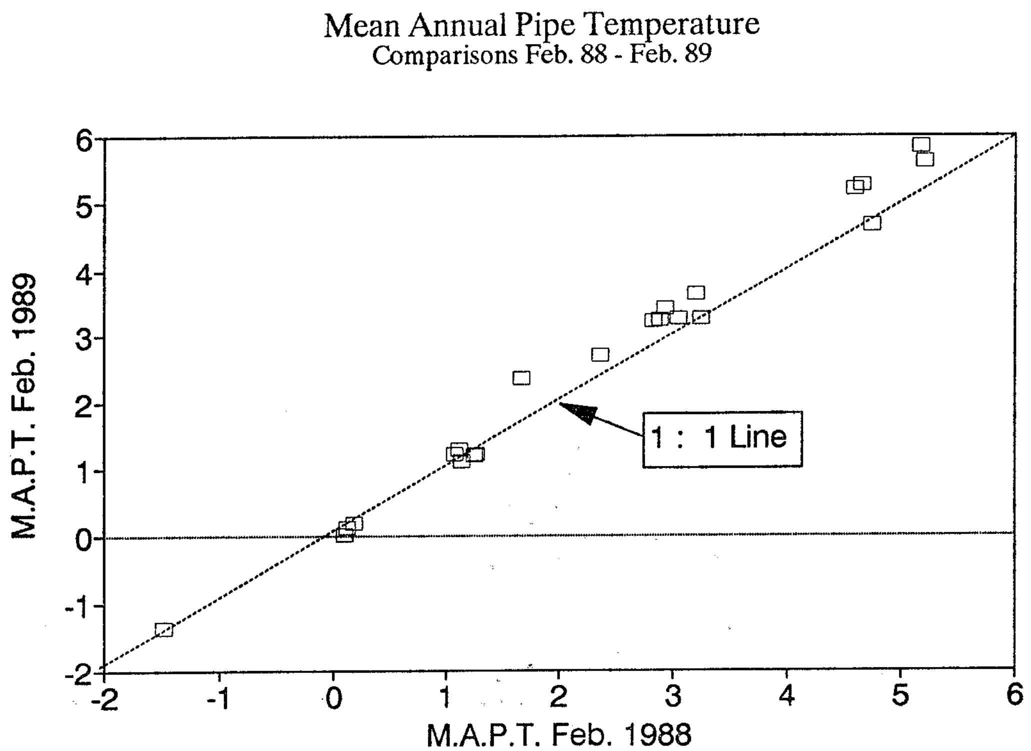


Figure 4.1

of distance along the pipeline (Figures 4.4-4.6) reveals no apparent north-south pattern to the changes.

The consistent relationship between initial ground temperature and temperature rise which was observed in the previous year (Riseborough 1989) is not evident in the behavior observed in the data obtained in the last year: Figures 4.7-4.9 show the rise in mean annual temperature at 1 m depth, for all monitoring sites, beween February 1988 and February 1989, plotted against the

Figure 4.2

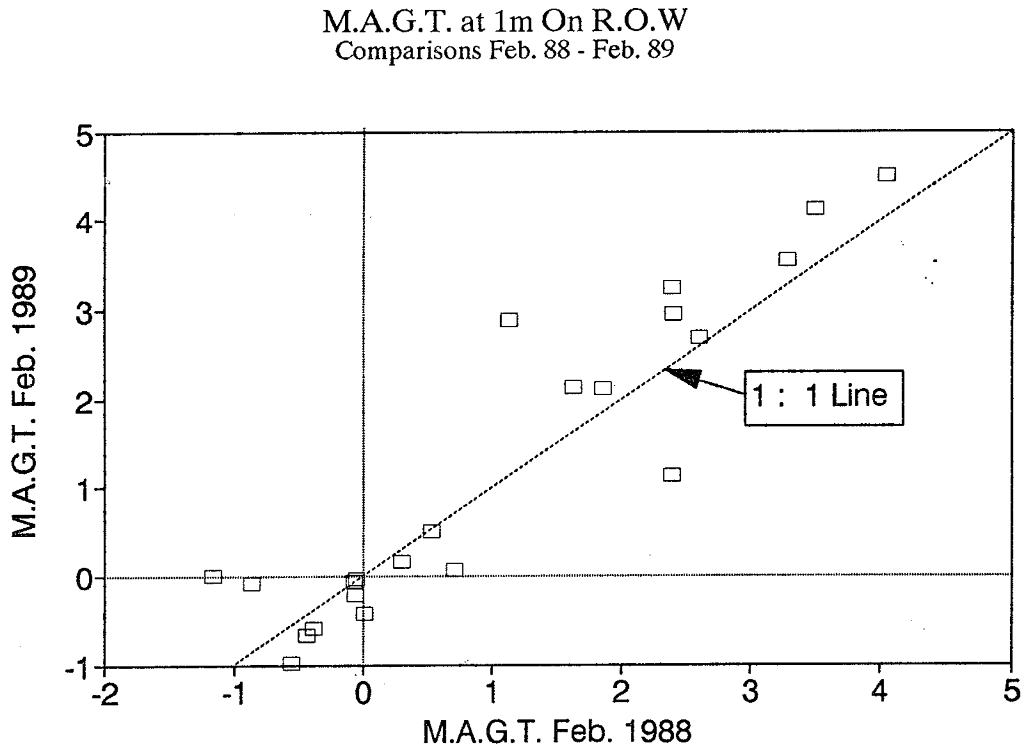


Figure 4.3

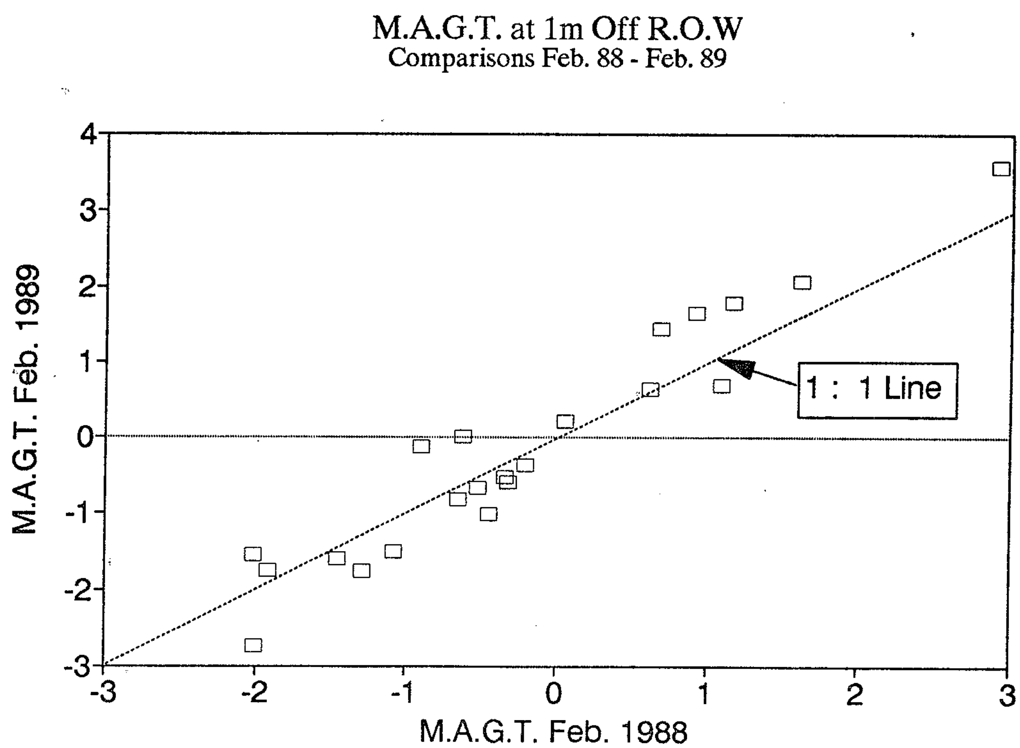


Figure 4.4

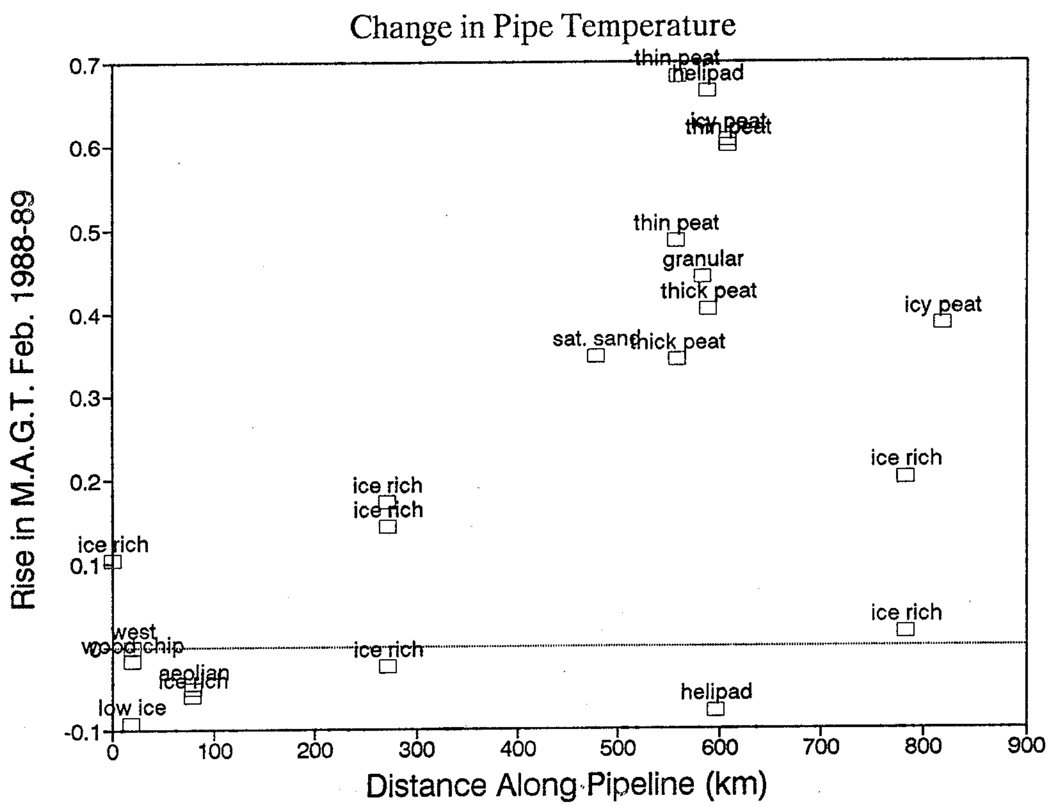
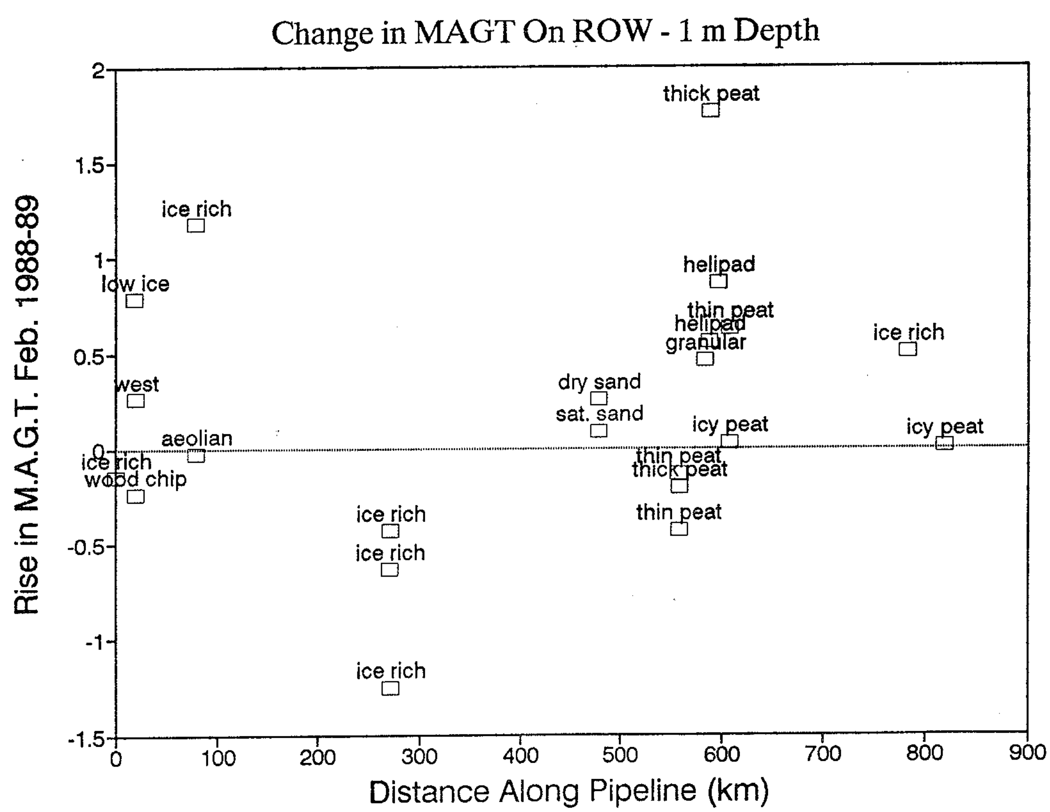


Figure 4.5



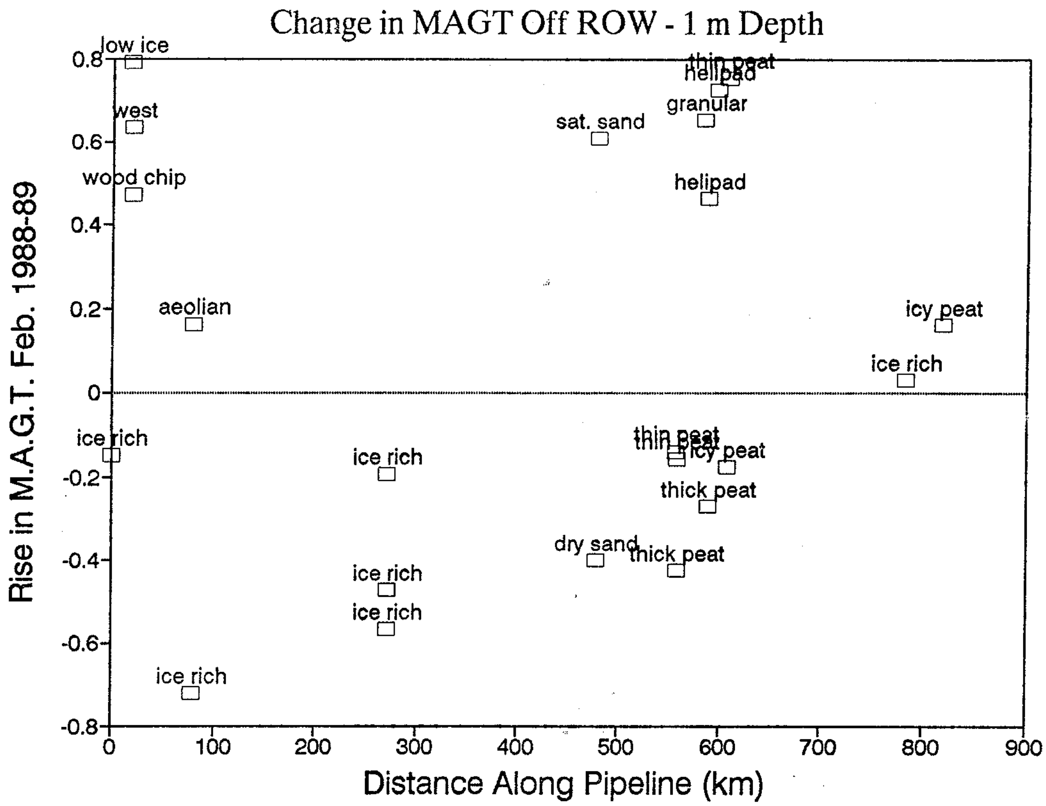


Figure 4.6

mean annual temperature in February 1988. The data are plotted twice: first with points labeled indicating the general site description, then with points labeled indicating the monitoring site. In the previous report a plot of this type produced a strong relationship between initial mean annual temperature and temperature rise, as modelled in Riseborough (1990). Behaviour of that type can only be expected over a period of monotonic temperature change , so that the pattern vanishes when different sites experiencing cooling while others were warming.

Comparison of the thermal behavior of the different sites with the site characteristics reveals that most of the sites which remained frozen and underwent cooling over the past year were classified as ice rich, particularly off of the right of way. Ice rich materials would exhibit a slow temperature rise through the change of phase, and would tend to have a slower penetration

Figure 4.7a

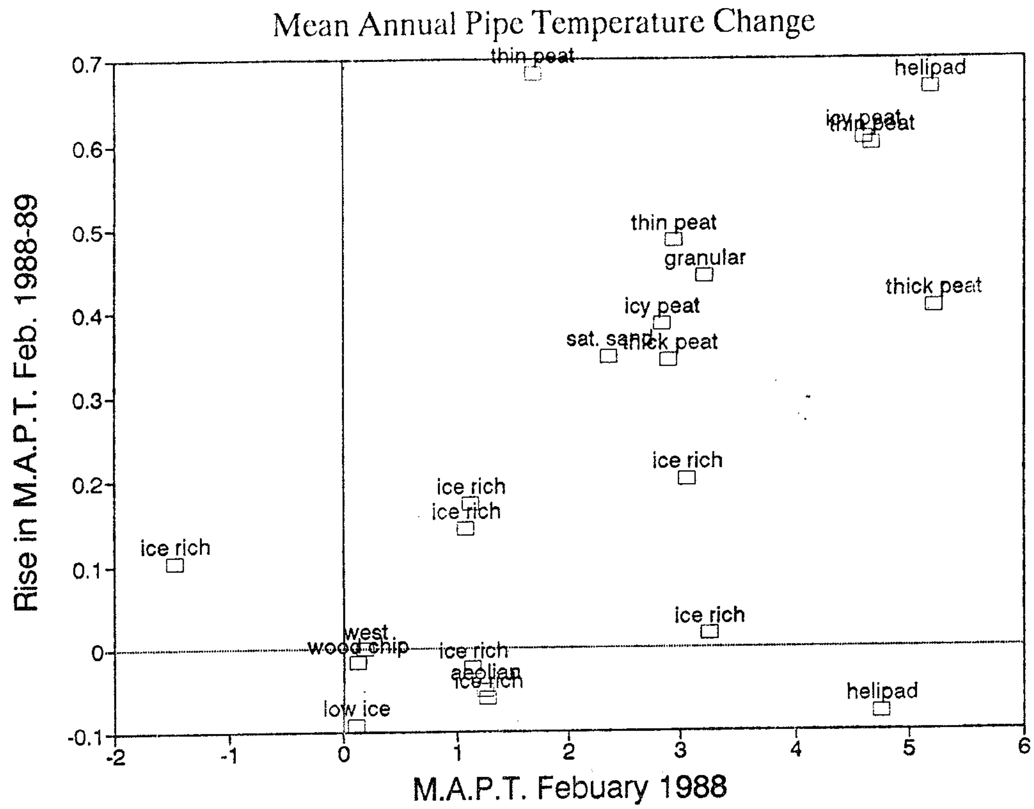


Figure 4.7b

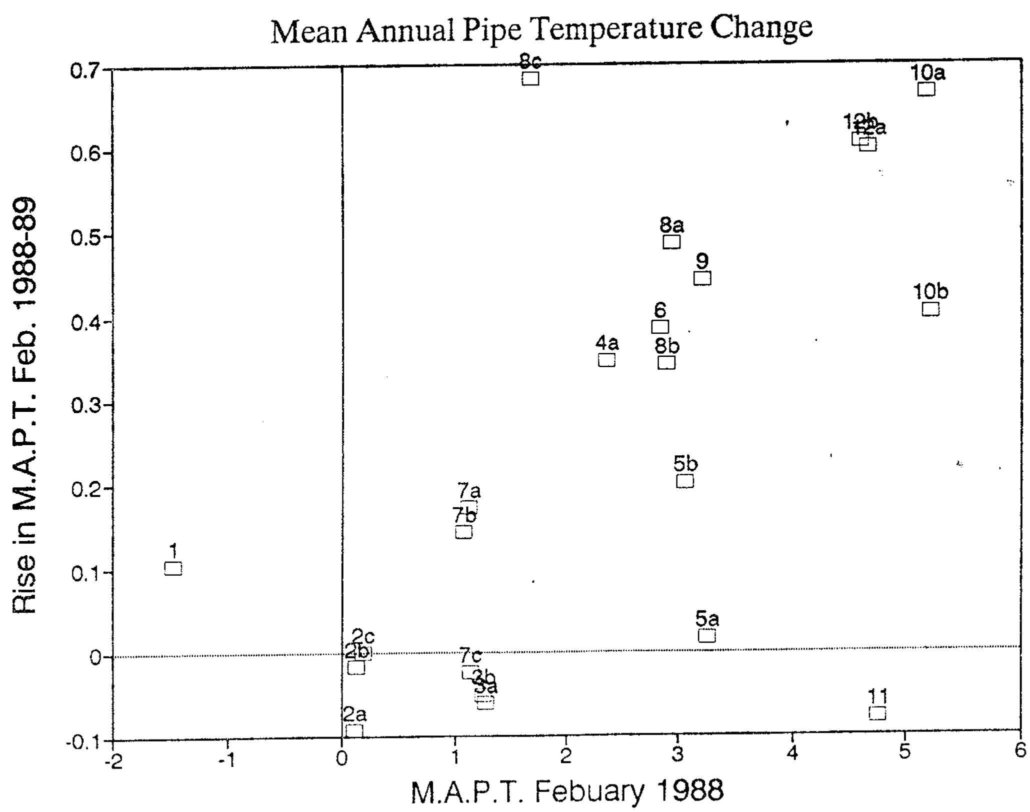


Figure 4.8a

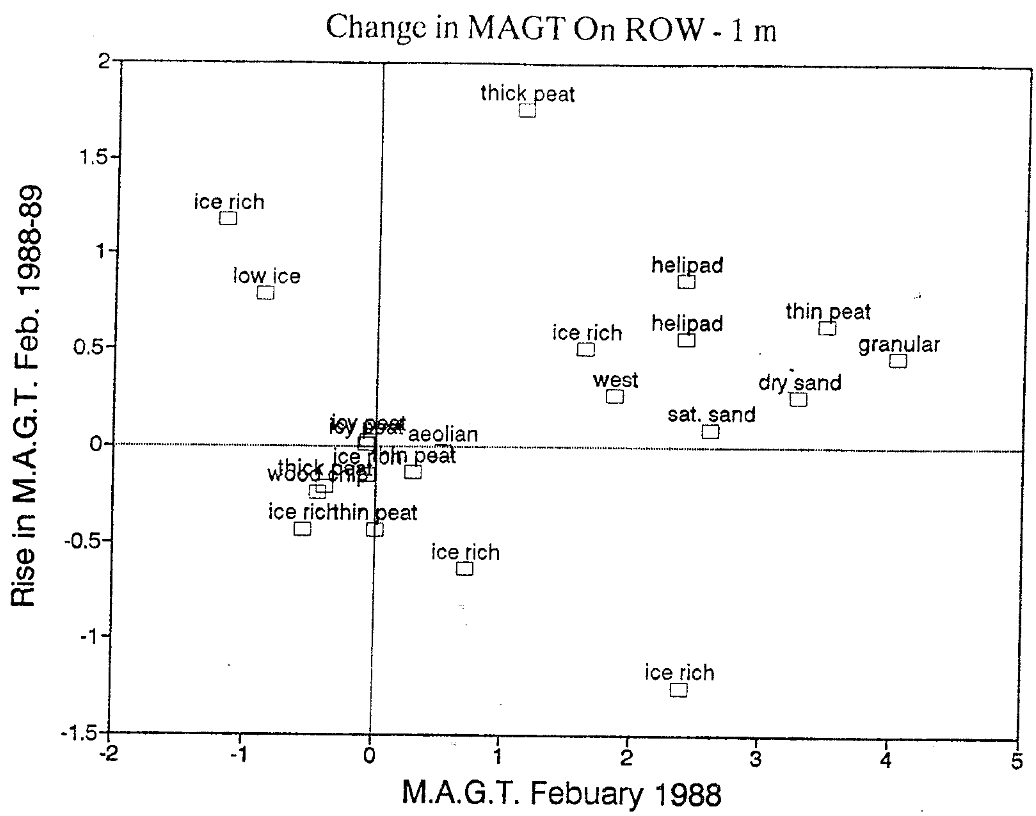


Figure 4.8b

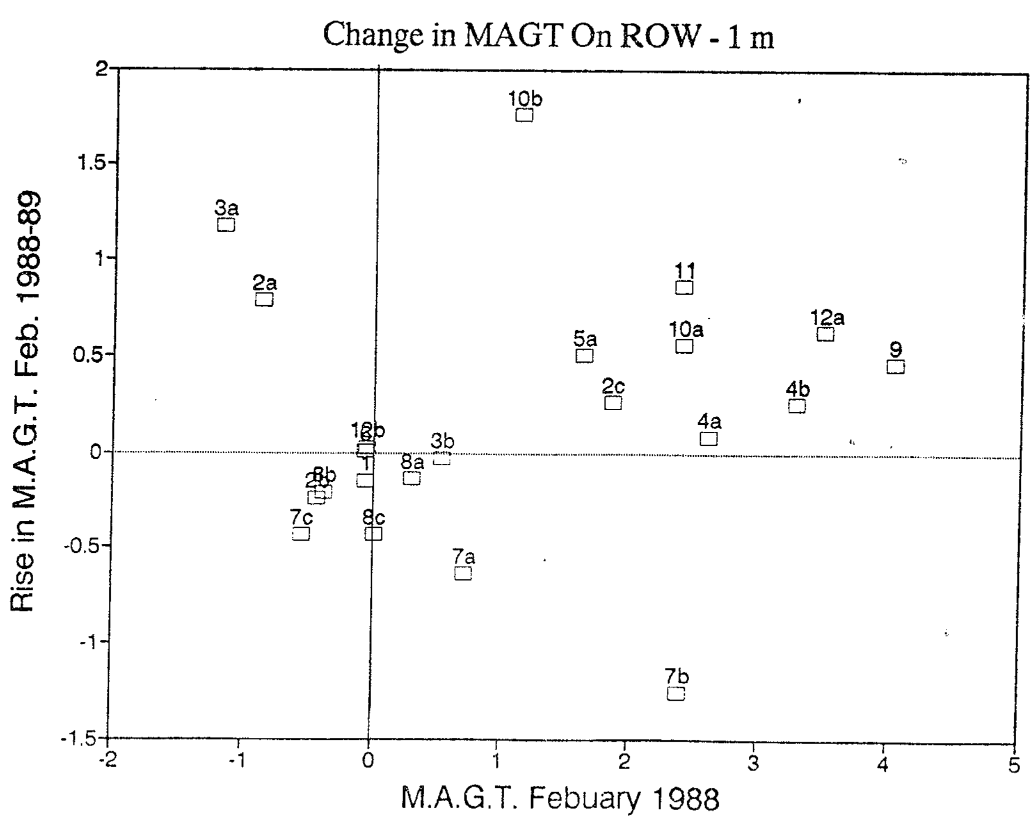


Figure 4.9a

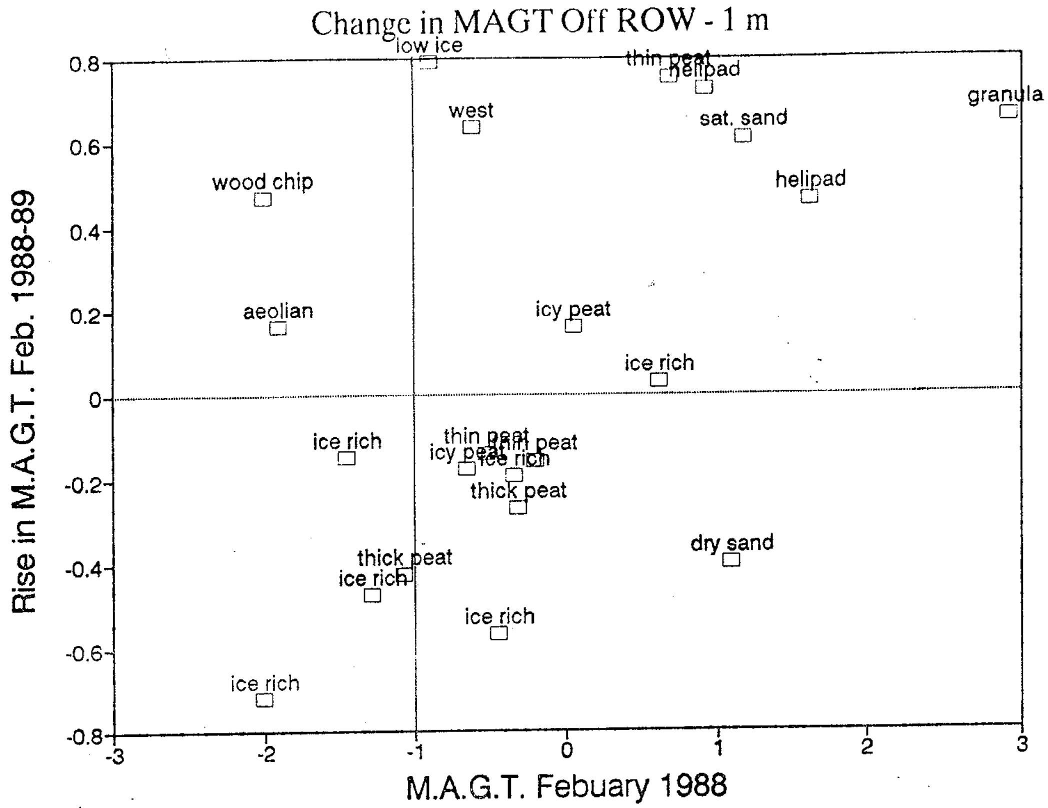
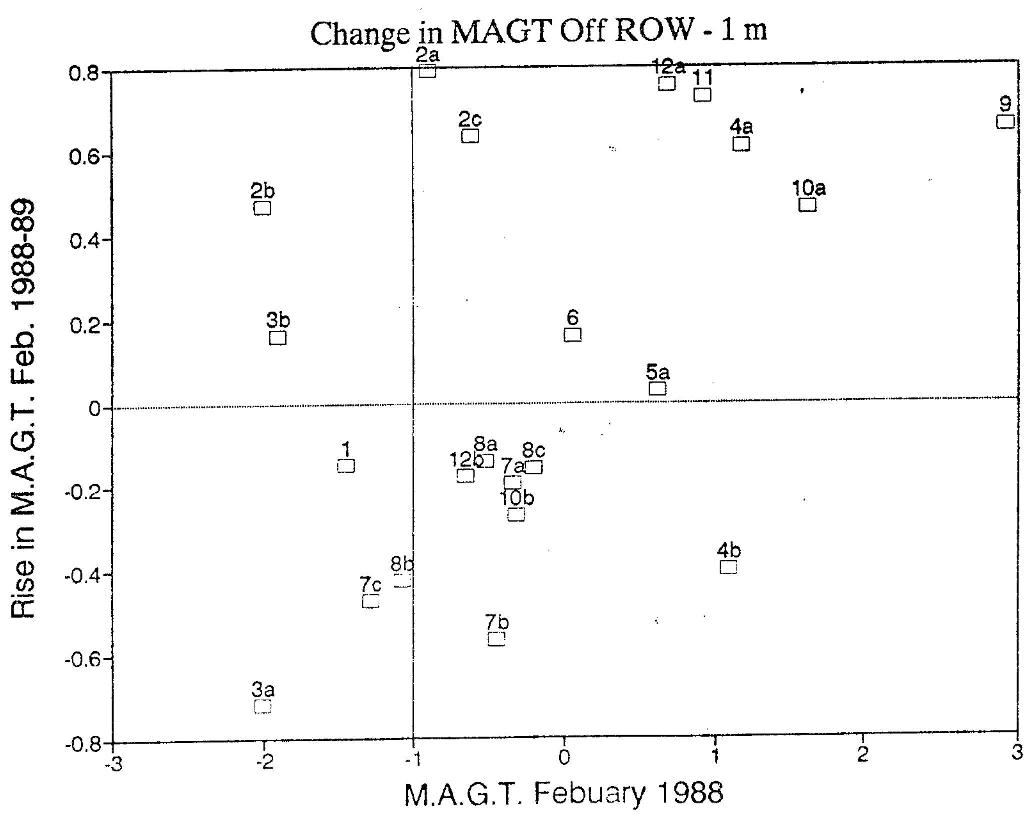


Figure 4.9b



rate for the thaw front as a result of the higher latent heat of fusion. This would produce a relatively steep temperature gradient in the active layer.

On the right of way, the greatest mean annual temperature drop at 1 m depth was at site 7b (classified as ice rich): Significantly, the mean annual temperature at 1 m was well above freezing in 1988, while the profile of mean annual temperatures (Figure 4.10) exhibited a steep gradient toward freezing temperatures in the upper 2 meters. The profile of a year later exhibits a much shallower gradient. The rate of cooling at the ice rich sites may have been accelerated by steep gradients between the surface and a shallow thaw front.

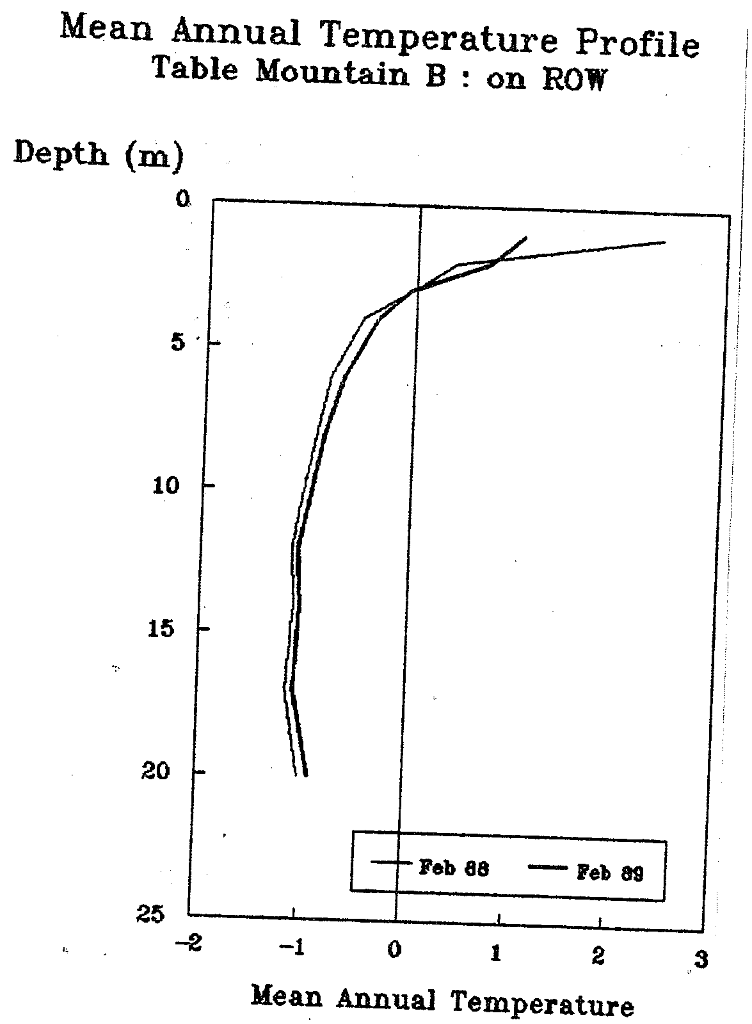


Figure 4.10

Figures 4.11-4.13 show the change in mean annual temperature over the most recent year for the pipe and for the 1 m sensor on and off of the Right of Way. Mean annual pipe temperature increased at almost all sites, while changes to the mean annual 1 m ground temperatures were variable both on and off of the Right of Way. The cooling trends both on and off ROW

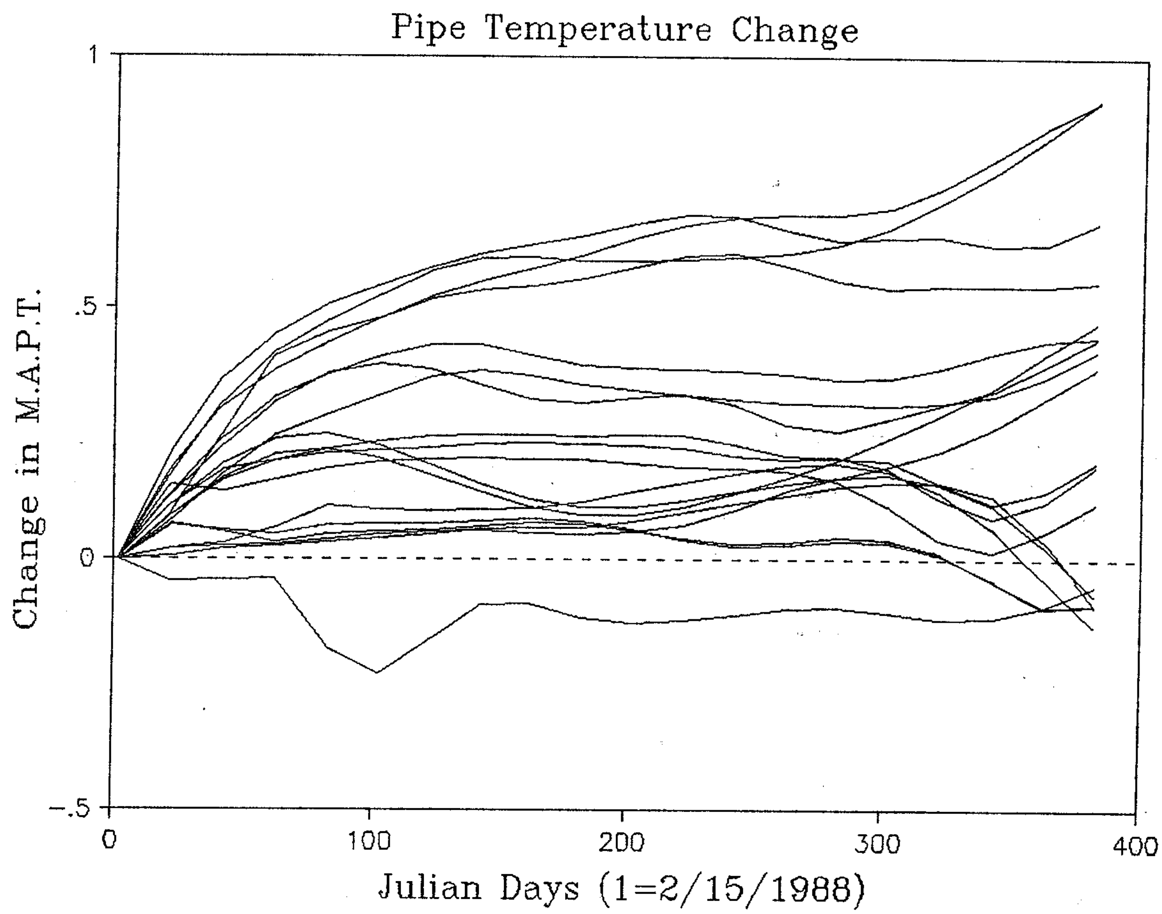


Figure 4.11

begin primarily in summer, indicating that the change in MAT is due primarily to lower temperatures concentrated in winter. This suggests that it was the colder sites which tended to cool while warmer sites tended to warm, as indicated by model experiments in ground temperature behavior (Riseborough 1989, 1990). (compare Figures 4.2 and 4.3)

4.2 Trends at greater depths.

A comparison of the mean annual temperature trends at 1 and 2 m depths for a number of sites showed little significant difference between the trends at the two depths. At a depth of 4 metres (Figure 4.14) however, the short

Figure 4.12

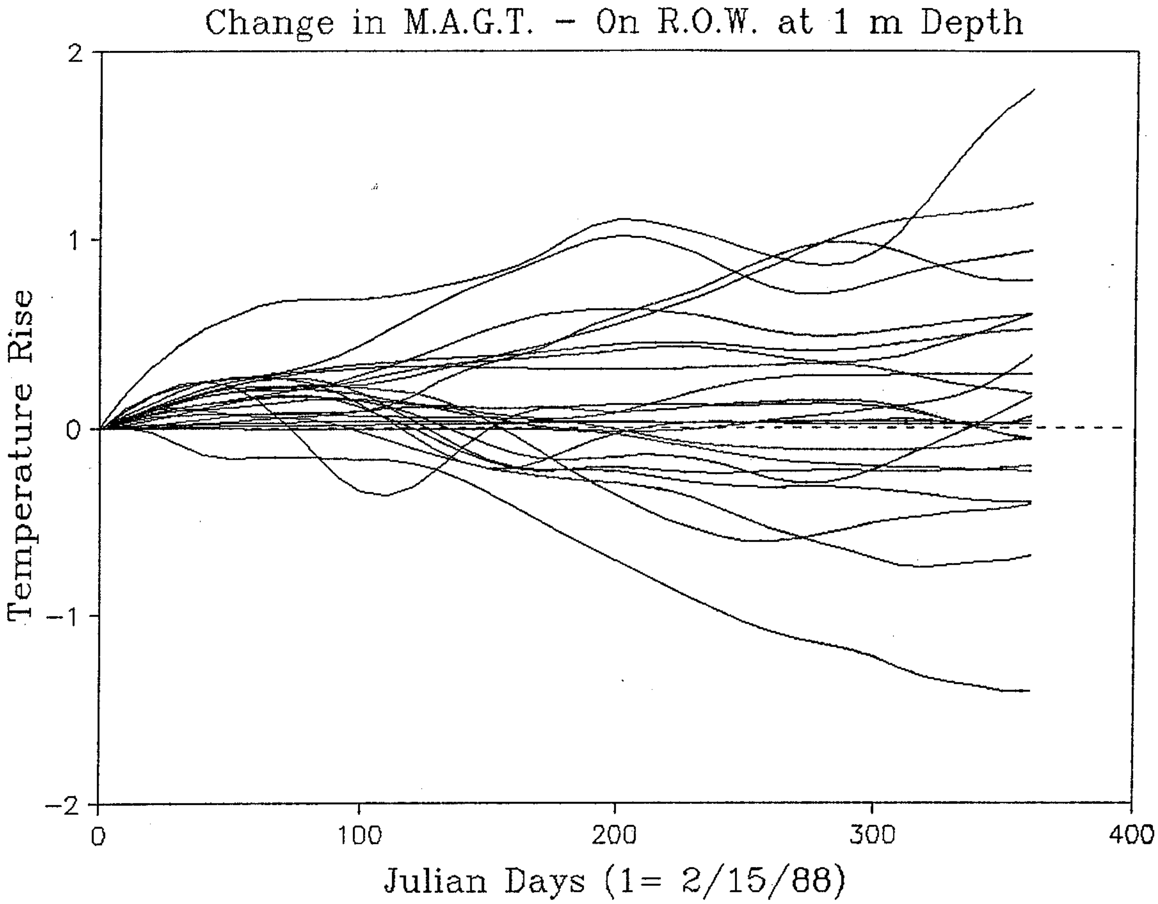
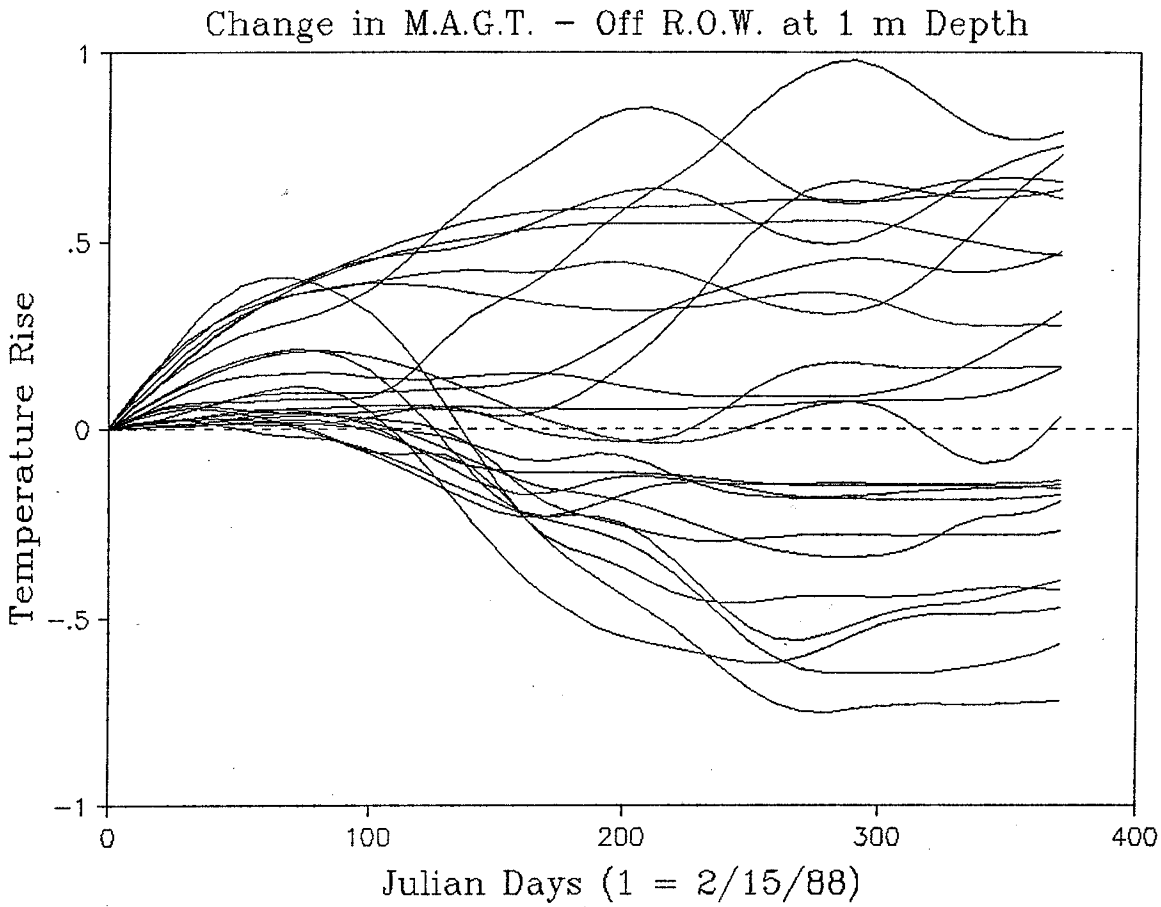
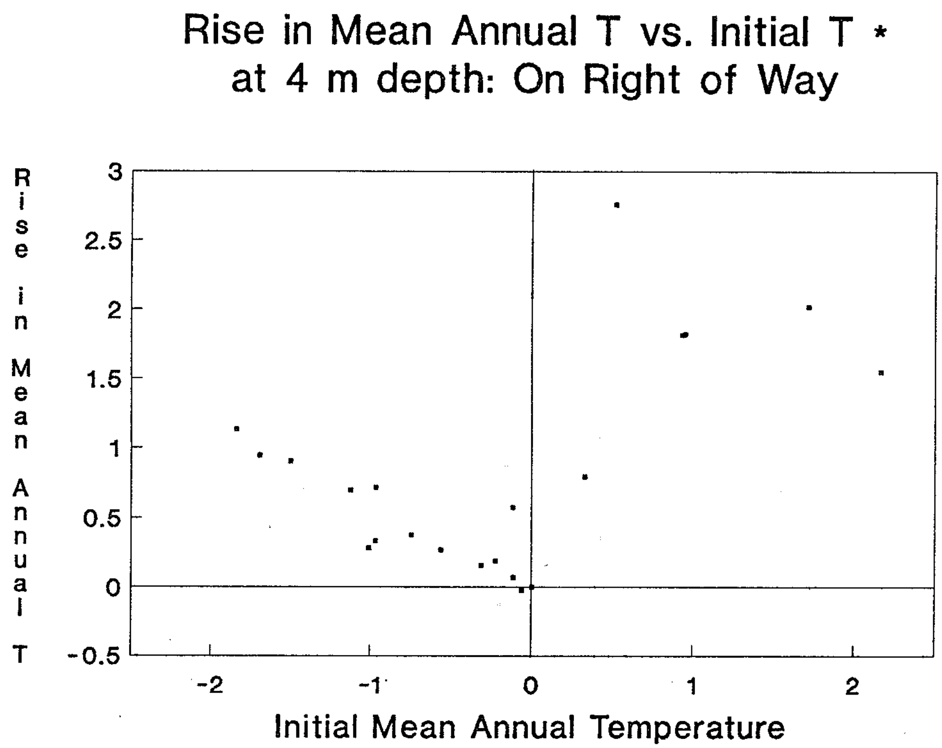

Change in M.A.G.T. - On R.O.W. at 1 m Depth
Temperature Rise
2
1
0
-1
-2
0
100
200
300
400
Julian Days (1= 2/15/88)

Figure 4.13

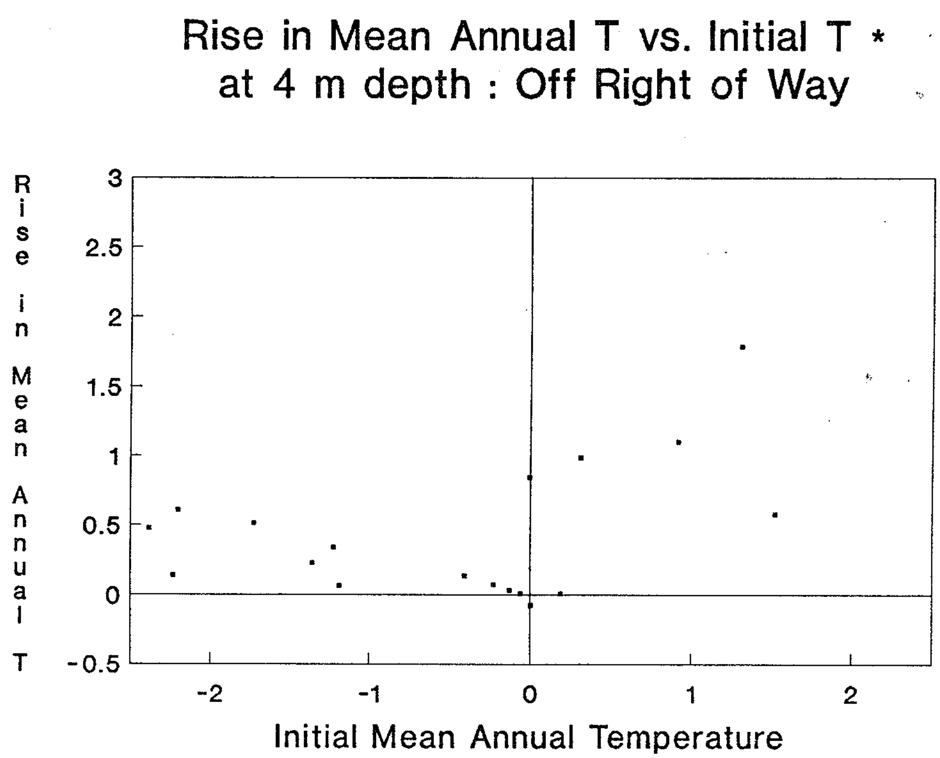


Change in M.A.G.T. - Off R.O.W. at 1 m Depth
Temperature Rise
1
.5
0
-.5
-1
0
100
200
300
400
Julian Days (1 = 2/15/88)

Figure 4.14



* From Nov 85 to Feb 89



* From Nov 85 to Feb 89

term reversal in the mean annual temperature trend (present in the 1 m cables in 1988-89) is not apparent, and the relationship between mean annual temperature change and initial mean annual temperature is again strong. Significantly, the relationship is apparent both on and off of the right of way at this depth, which was not the case at 1 m depth in 1987-88 (Riseborough, 1989). At this depth the shorter term variations in the mean annual temperature are relatively less significant in the range of mean annual temperatures.

Figures 4.15 through 4.17 show mean annual ground temperature trends over a number of depths for three cables with differing thermal regimes: At Trail River A T2 (Figure 4.15), the 1 m ground temperature shows a significant long term warming trend, with significant interannual variability; At Canyon Creek A T3 (Figure 4.16), the warming trend is significant, with almost no interannual variation; At Jean Marie Creek B T4 (Figure 4.17), the 1 m ground temperature does not exhibit a strong trend, but significant interannual variation.

The thermal properites of the ground can be considered as a filter of the temperature signal transmitted from the surface into the ground. The thermal properties of the ground have two effects on the signal: it is delayed in time, and fluctuations are attenuated with depth. The time lag effect is due to the finite thermal diffusivity of soil materials, while the attenuation of the annual surface temperature wave is actually a consequence of the time lag in thermal response of the ground to changes occuring above.

Both the magnitude of the time lag and the attenuation increase with depth. For a theoretical case with no long term temperature trend at the surface and thermal properties constant with depth and time, the magnitude of

Figure 4.15

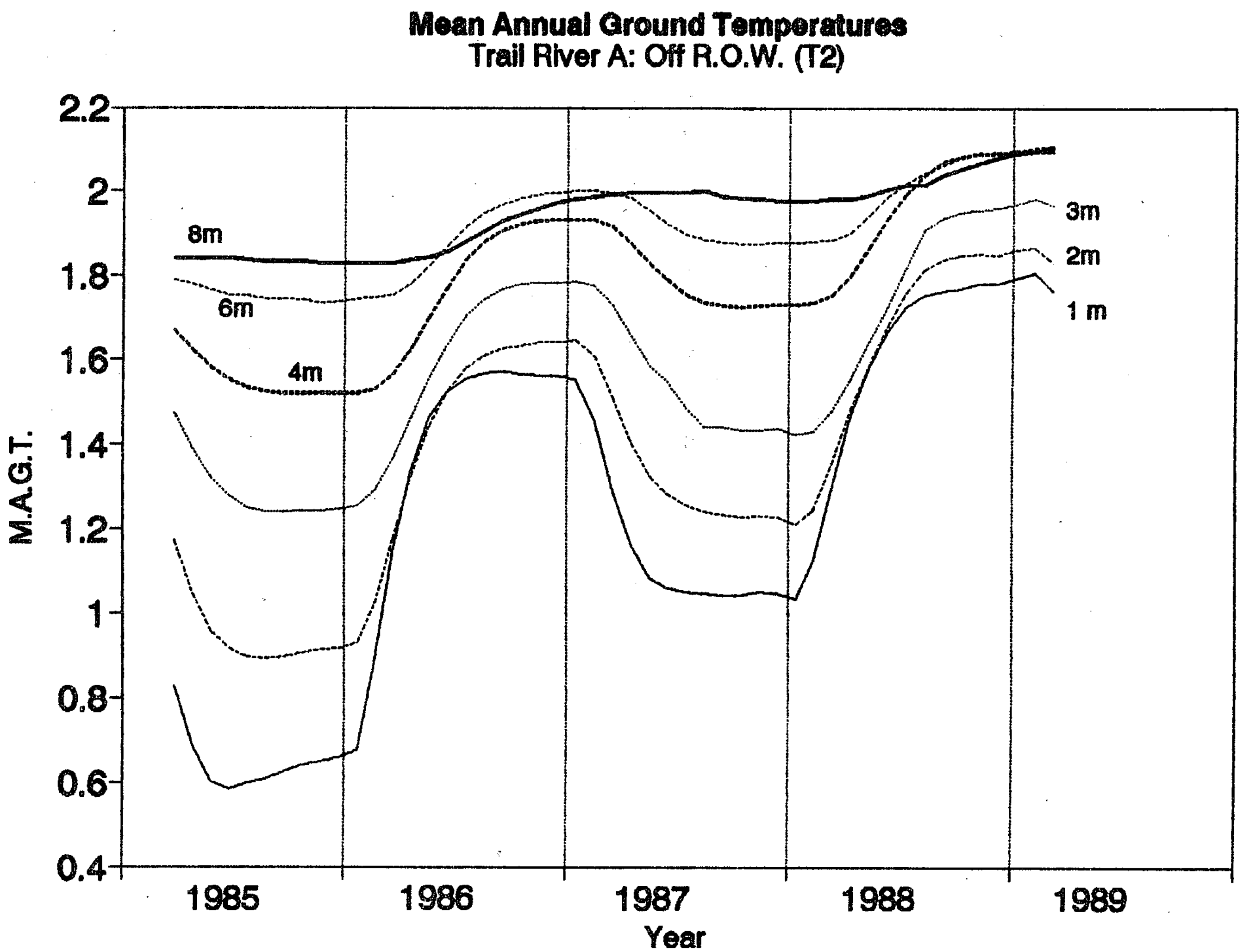

Mean Annual Ground Temperatures
Trail River A: Off R.O.W. (T2)
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
M.A.G.T.
8m
6m
4m
3m
2m
1 m
1985
1986
1987
1988
1989
Year

Figure 4.16

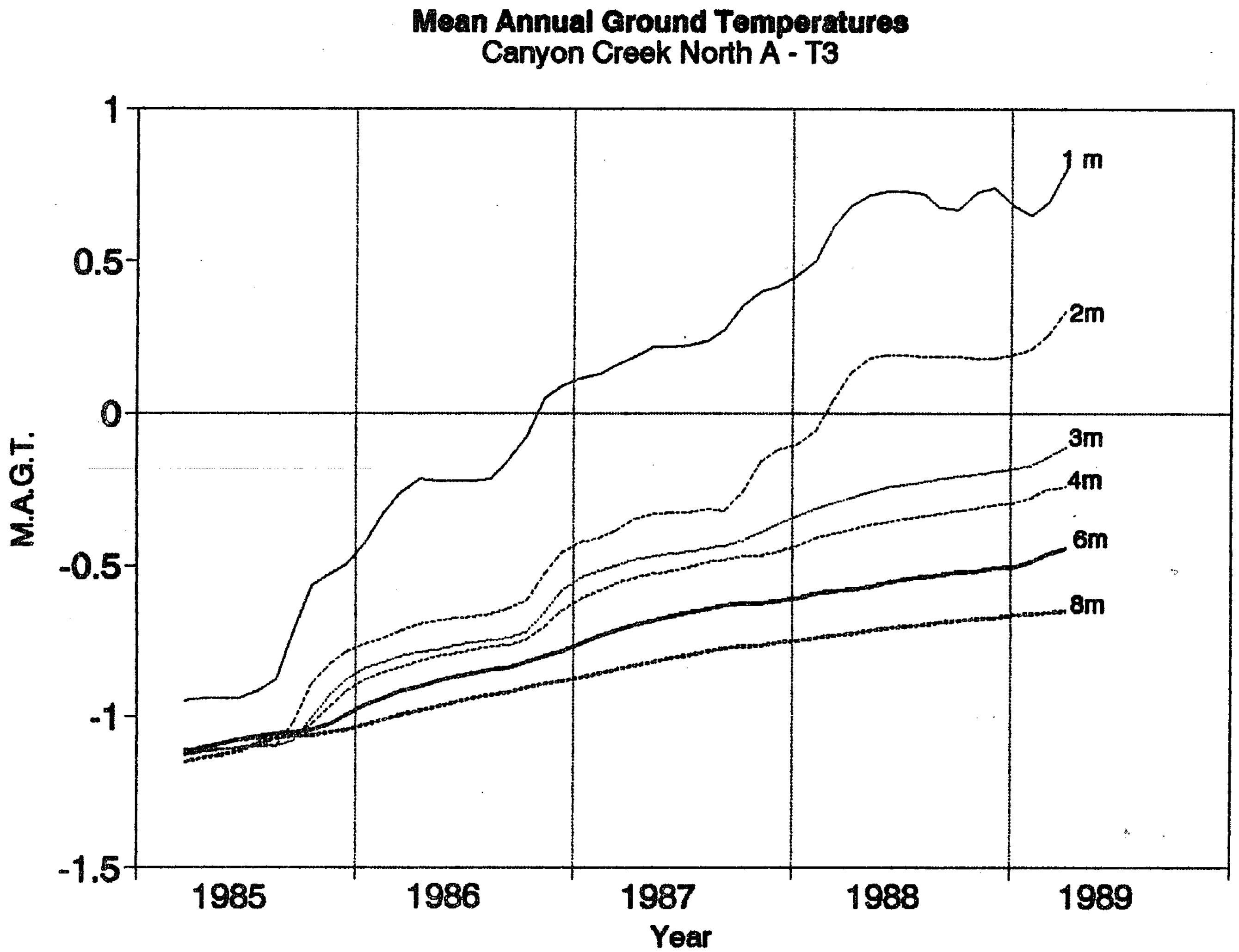
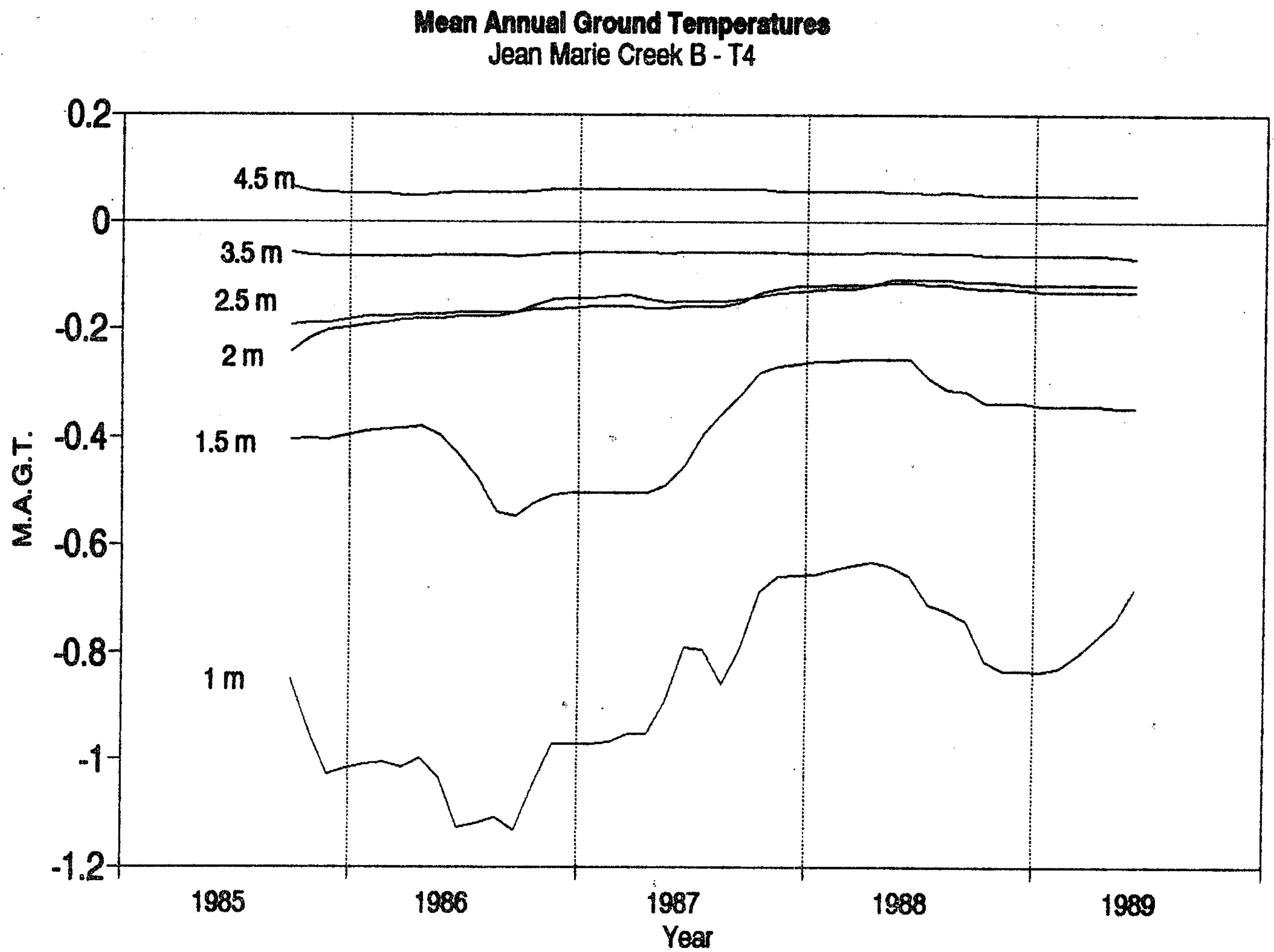

Mean Annual Ground Temperatures
Canyon Creek North A - T3
1
0.5
0
-0.5
-1
-1.5
M.A.G.T.
1 m
2m
3m
4m
6m
8m
1985
1986
1987
1988
1989
Year

Figure 4.17

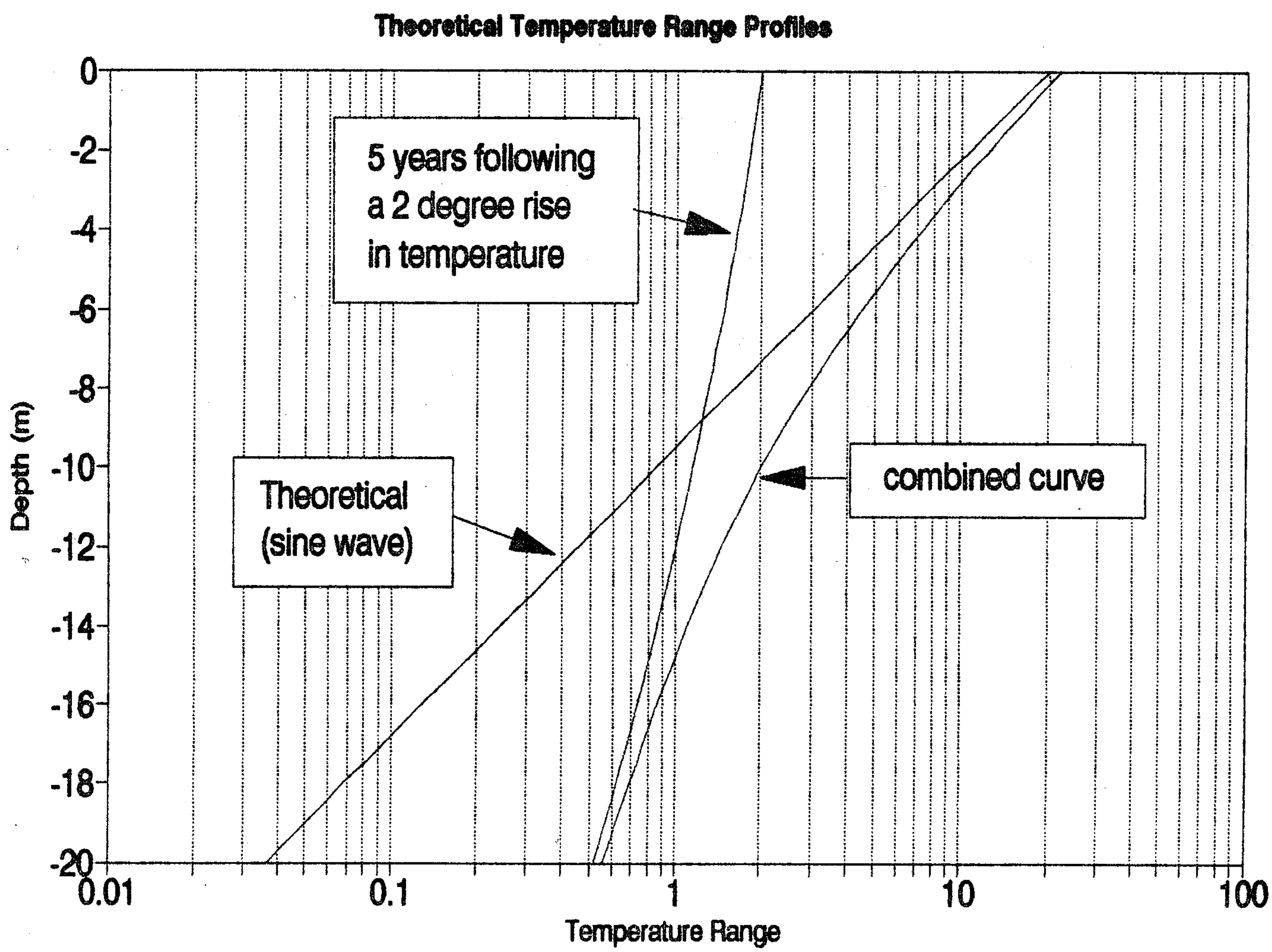


Mean Annual Ground Temperatures
Jean Marie Creek B - T4
M.A.G.T.
Year
4.5 m
3.5 m
2.5 m
2 m
1.5 m
1 m
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
1985
1986
1987
1988
1989

the ground temperature cycle decreases exponentially with depth (Figure 4.18). While the time lag effect produces an approximatly exponential decline profile of temperature change with depth, the figure shows that it not exactly so.

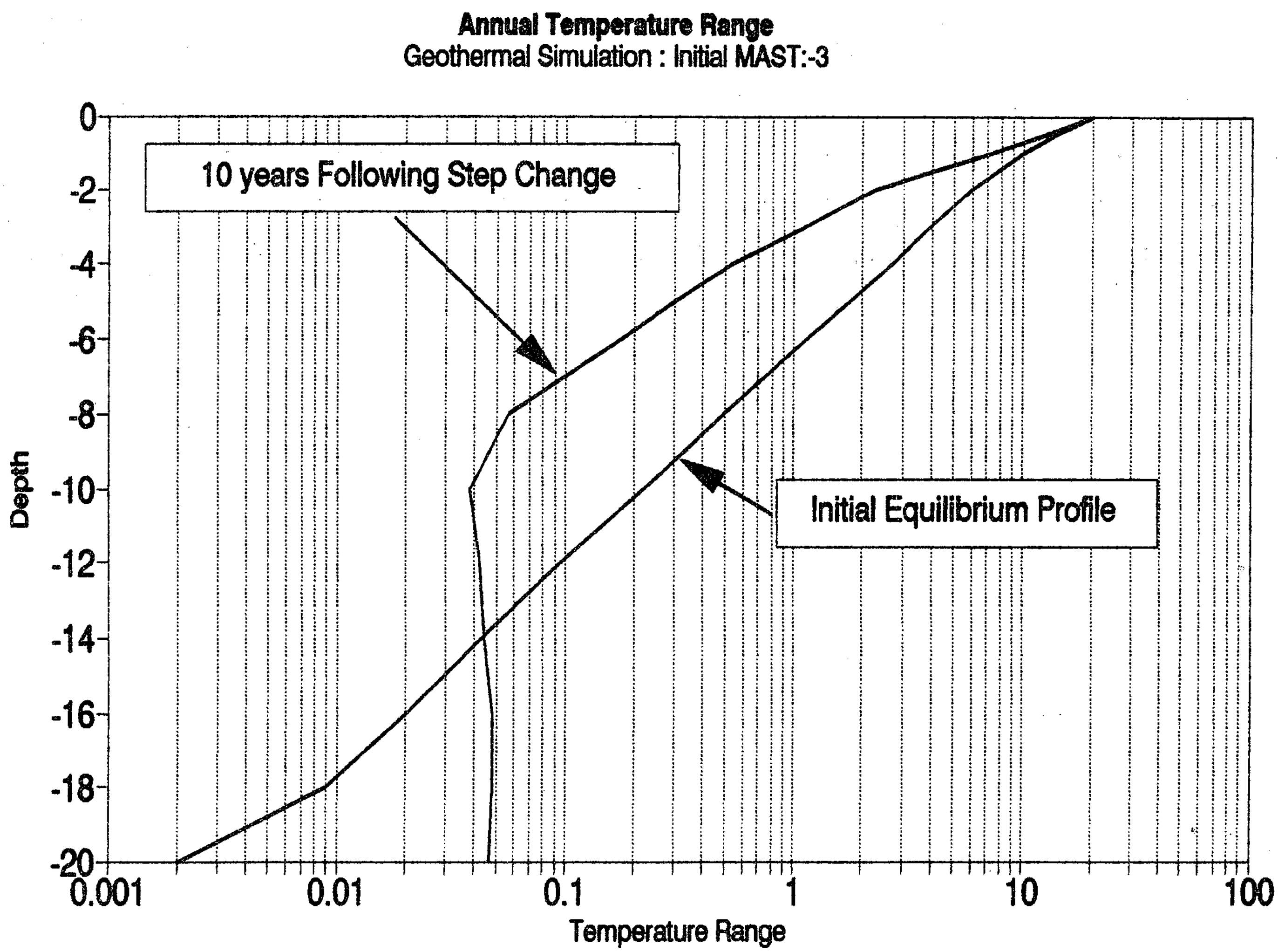
The two profiles may be combined to show the the temperature range profile which results when a cyclical temperature wave is superimposed on a warming trend (analytical results are additive in the absence of latent heat effects). The three profiles in Figure 4.18 represent different profiles which may be expected in examining the ground temperature record: the linear profile represents the range of ground tempreatures experienced at a site where there has been no change in ground temperature; a profile with upward concavity represents a profile of mean annual ground temperature at a site which has experienced a uniform rise in the mean annual temperature; and a profile with downward concavity represents the range of ground temperature experienced at a site which has experienced an increase in mean annual temperature. In examining actual ground temperature records, the curves will normally be truncated at about 0.1 ^{o}C, since this is the limit of recording accuracy. The three distinct profiles suggest that these shapes may indicate particular processes, although inhomogenous and temperature dependent thermal properties preclude their dignosic use. In particular, a change in mean annual temperature which alters the effective annual average of thermal diffusvity of the ground will change the annual temperature range experienced at depth in the soil. This can be seen in Figure 4.19, taken from one case presented in Riseborough (1990). After 10 years under a new regime, the profile is moving toward a new annual regime, with a different slope to the exponential decline in annual range. Below 8 meters in the ground, the annual range is dominated by the transient effect of the step change at the surface, rather than the

Figure 4.18



Thermal Diffusivity : 1e-6 m2s-1

Figure 4.19


Annual Temperature Range
Geothermal Simulation : Initial MAST:-3
10 years Following Step Change
Initial Equilibrium Profile
Depth
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0.001
0.01
0.1
1
10
100
Temperature Range

periodic fluctuation of surface temperature.

Figures 4.20-4.22 show the ground temperature envelops for these sites over the whole period of temperature monitoring. Where there are quasi-cyclic fluctuations in the mean annual temperature at the surface, these will be attenuated in the same manner as the annual cycle. In the mean annual temperatures recorded for Trail River A (Figure 4.15) and Jean Marie Creek (Figure 4.17), fluctuations in the mean annual temperature with a periods of two to three years are lagged and attenuated with depth. Figures 4.23-4.25 show the envelops of mean annual ground temperature for these sites over the period of temperature monitoring, while Figures 4.26-4.28 plot temperature ranges and mean annual temperature ranges for the sites.

At Jean Marie Creek both the range of the temperature envelop and of the mean annual tempeature envelop decrease log-linearly (and in parallel) with depth to a certain depth. (The value for the maximum of the envelop at 5 m depth is a measurement error.) In the case of the temperature envelop, the depth at which the range is equal to the resolution of measurement (0.1°C); For the mean annual temperature this is about one order of magnitude less. The log-linear relationship obtains despite the fact that the envelops exhibit a marked positive gradient. The stability of the gradient, and of the log-linear decline in the temperature range at depth, is attributable to the proximity of the profile to the melting point, and hence the anchoring of the profile at the base of permafrost.

The results at greater depth are consistent with results for the 1 m sensor, and so demonstrate that the measurement program has not been compromised by occasional gaps in measurements. The analyses presented in this section emphasize the value of obtaining data extending over time and space: measurements obtained at one time, depth, or pipeline kilometer-post is much more useful when placed within the context of the rest of the data.

Figure 4.20

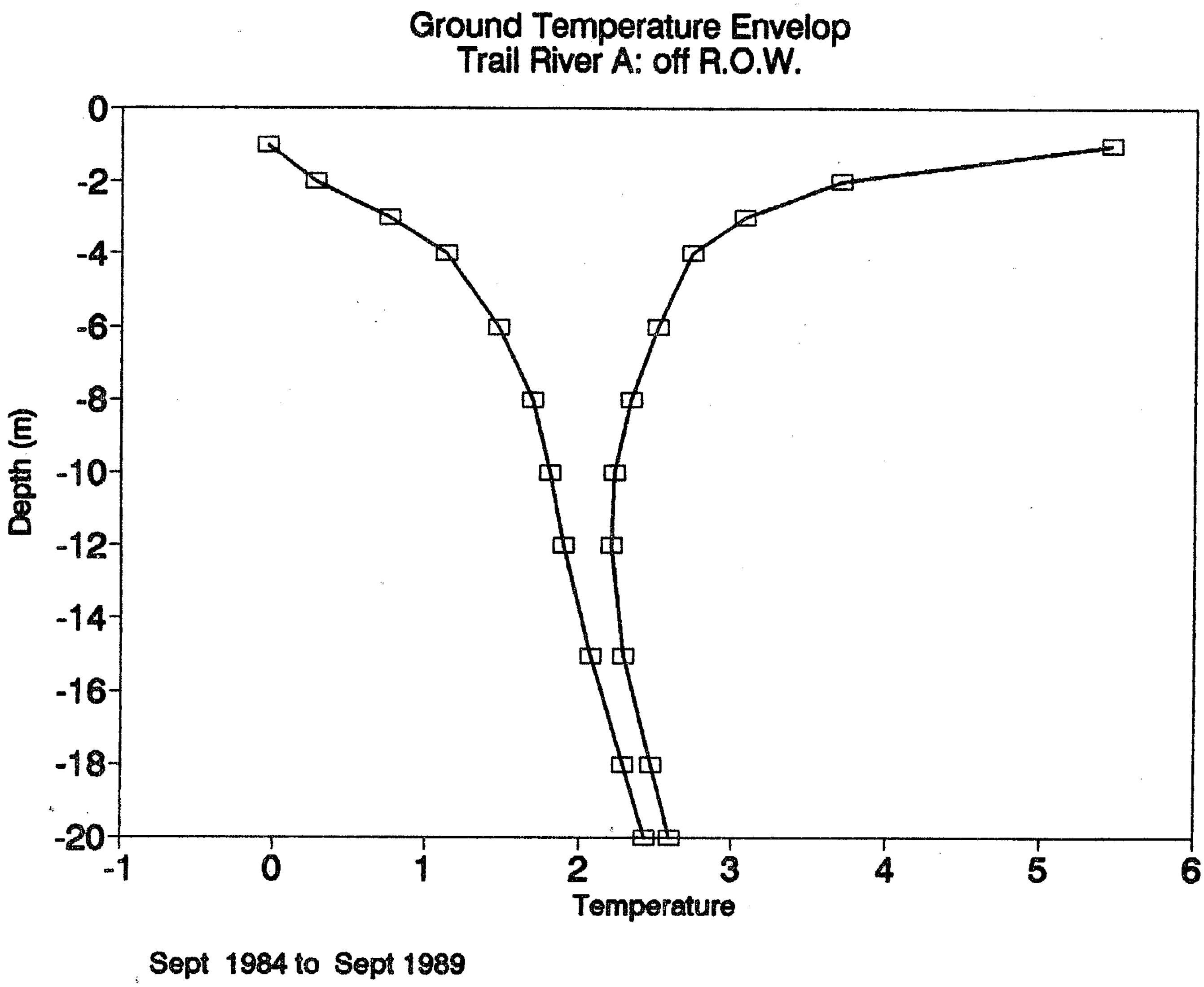

Ground Temperature Envelop
Trail River A: off R.O.W.
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
Depth (m)
-1
0
1
2
3
4
5
6
Temperature
Sept 1984 to Sept 1989

Figure 4.21

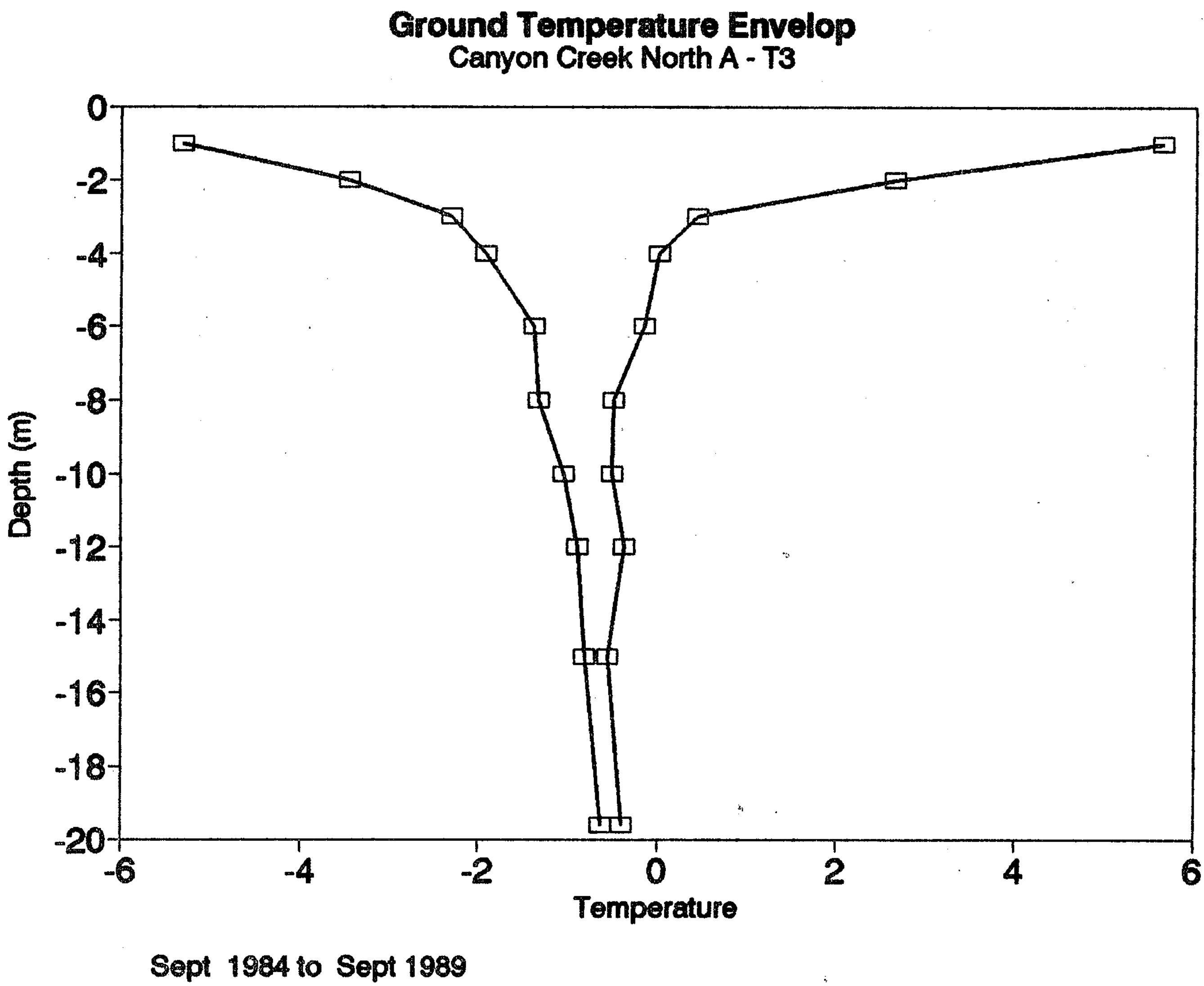
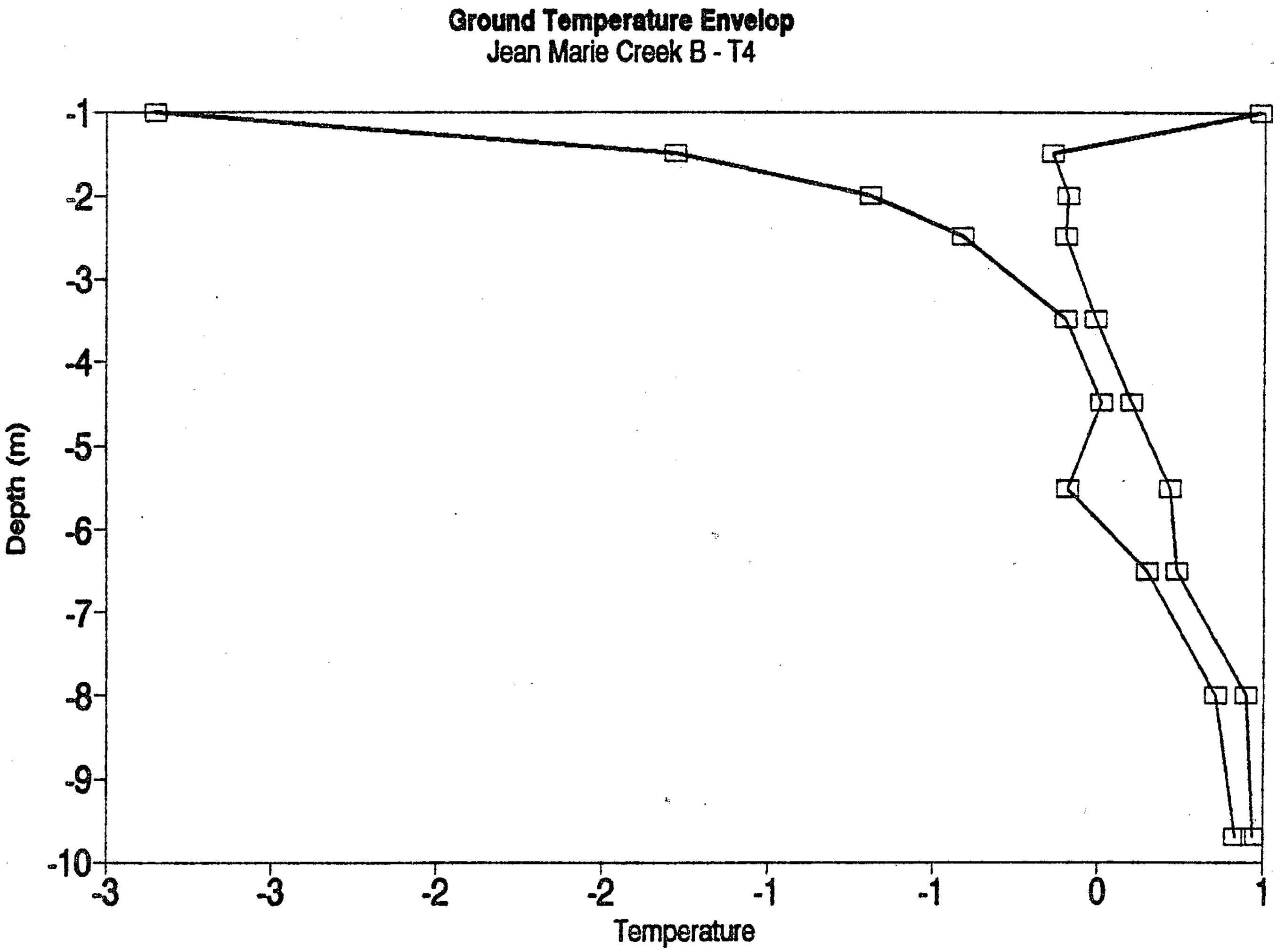
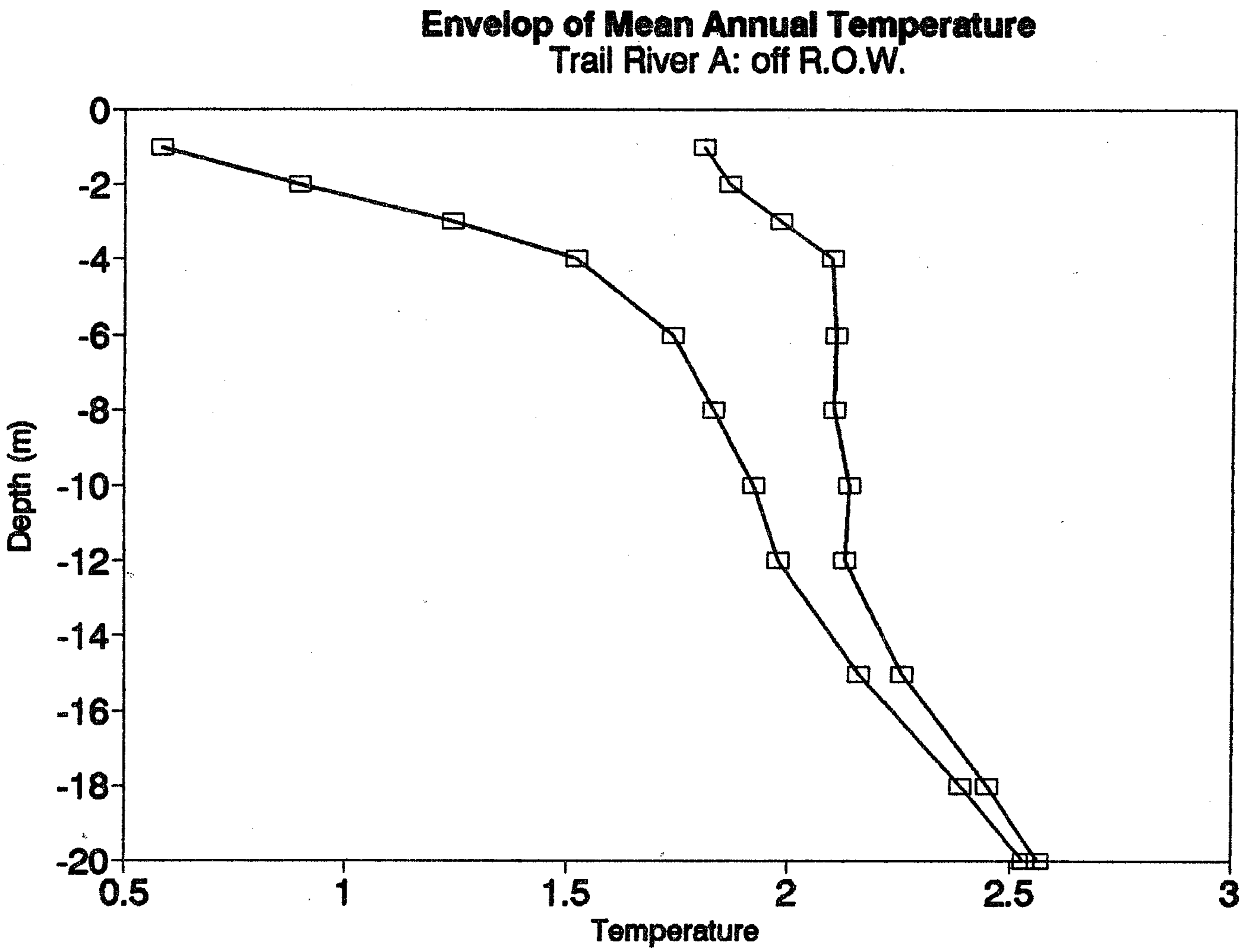

Ground Temperature Envelop
Canyon Creek North A - T3
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
Depth (m)
-6
-4
-2
0
2
4
6
Temperature
Sept 1984 to Sept 1989

Figure 4.22



April 1985 - December 1989

Figure 4.23



Sept 1984 to Sept 1989

Figure 4.24

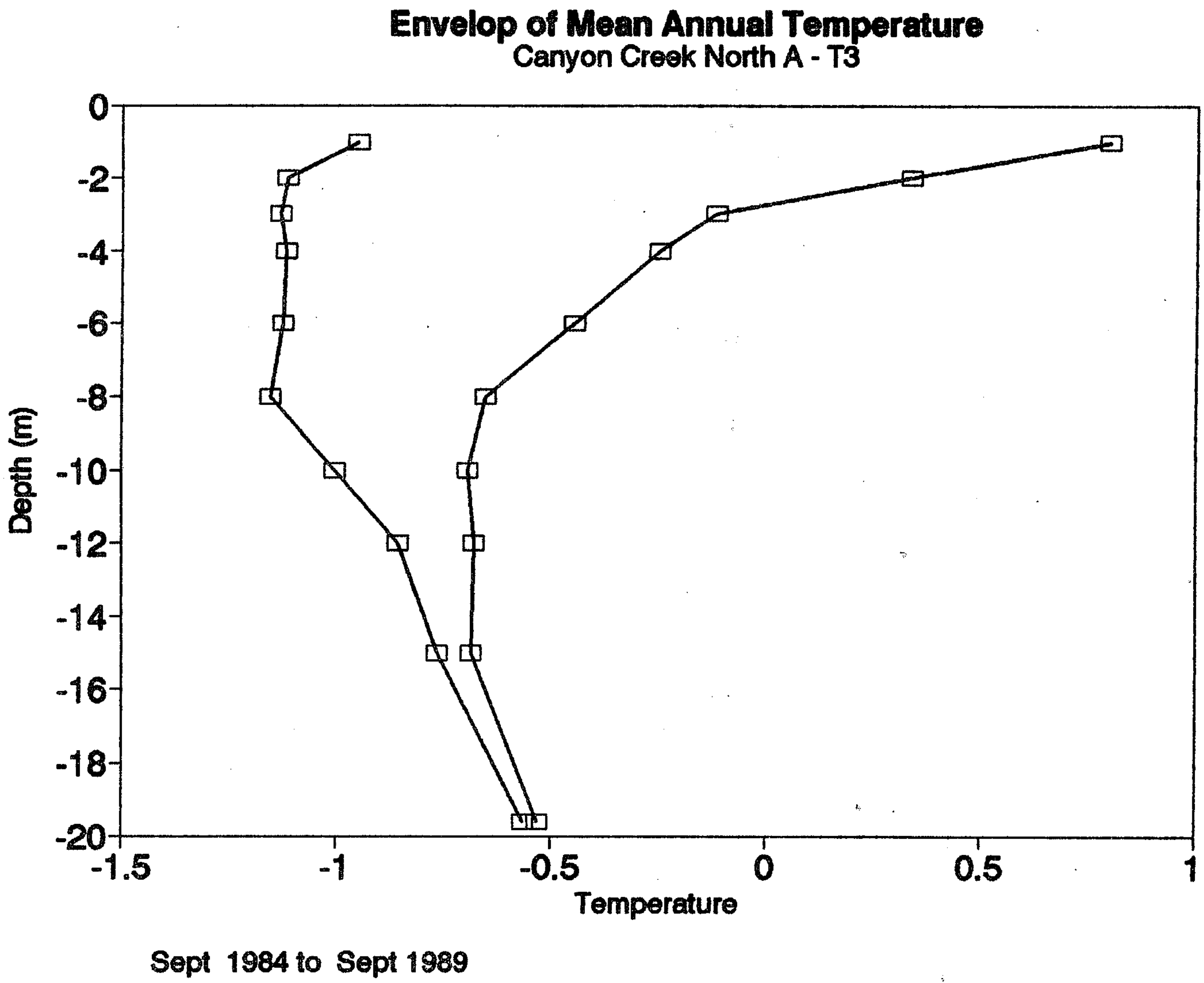
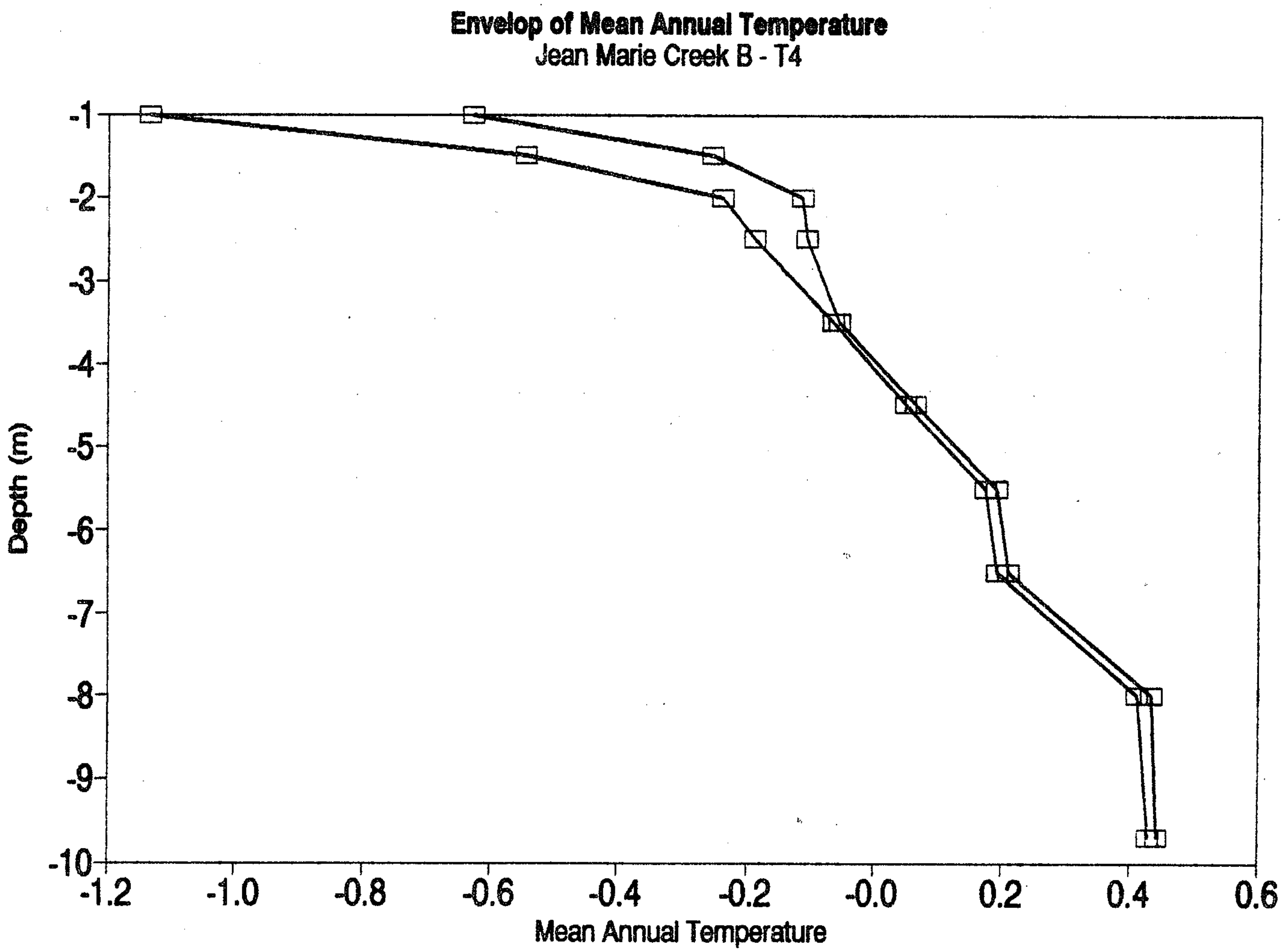
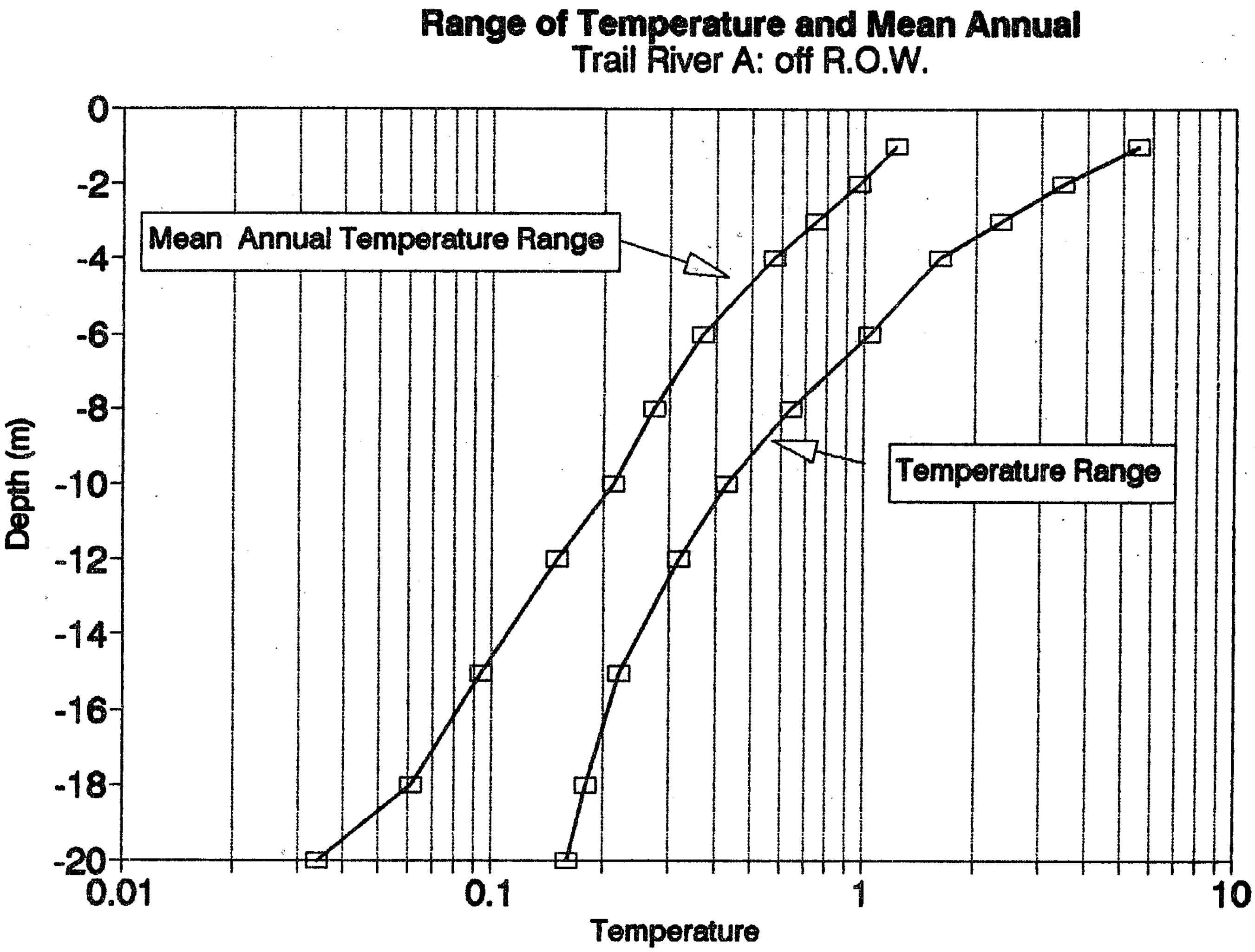

Envelop of Mean Annual Temperature
Canyon Creek North A - T3
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
Depth (m)
-1.5
-1
-0.5
0
0.5
1
Temperature
Sept 1984 to Sept 1989

Figure 4.25



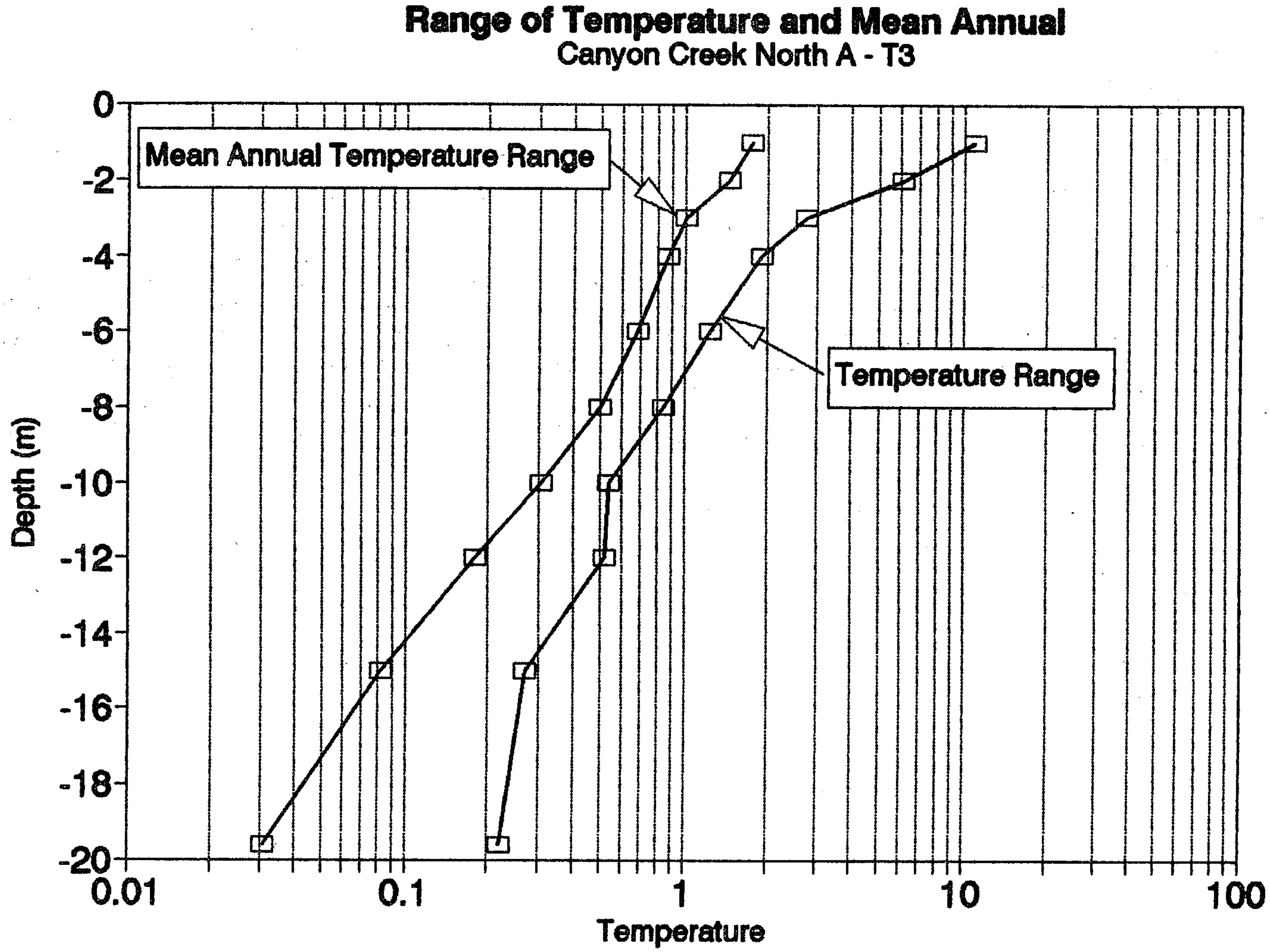
April 1985 - December 1989

Figure 4.26



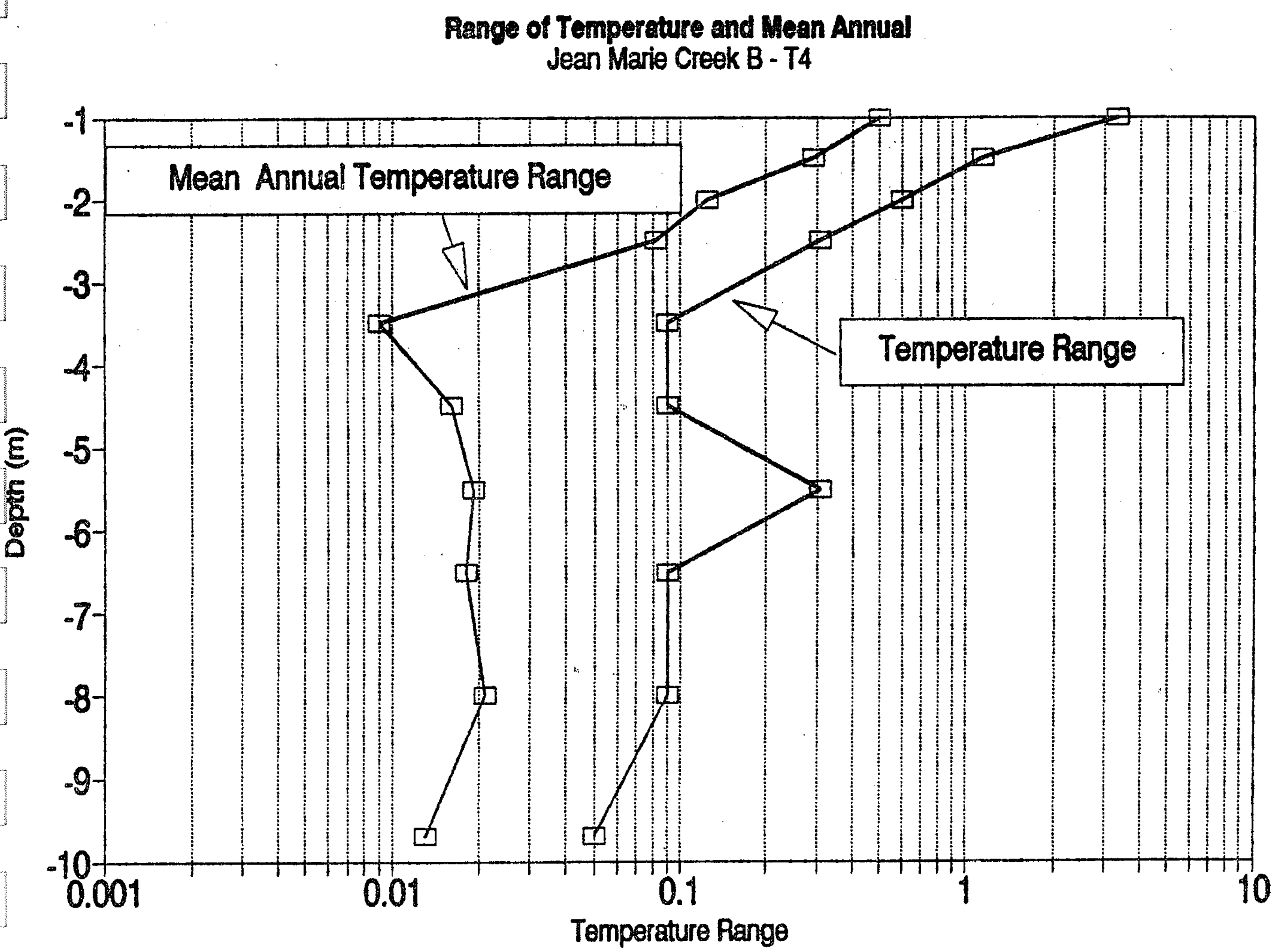
Sept 1984 to Sept 1989

Figure 4.27



Sept 1984 to Sept 1989

Figure 4.28



April 1985 - December 1989

SECTION 5

NW - Data Analysis Utility

The concept of the NW program is to permit access to pipe and ground temperature data for any site, cable, and depth, and graphically display the selected data on screen. Data are initially viewed as individual series (except temperature envelops, which are paired series), which can be added to a file which allows multiple data series (from different sites, cables, or depths) to be shown together graphically. The multiple series data file is initially temporary (as NWZACC.TMP), but may be saved with a permanent file name. The saved file may be imported into spreadsheets or graphics programs which accept comma separated values (CSV) format. The graphic display subprograms are separately compiled programs called by NW, and so can be used as "stand alone" programs.

The data management software consists of several programs:

<u>NW.EXE</u> - the main program, containing data extraction, interpolation, and mean annual temperature routines.

<u>LOGO.EXE</u> - produces the start-up screen when NW is run.

<u>TY.EXE</u> - Shows a single temperature-time plot, and allows editing of the plotted data. Called automatically by NW, but can be run separately.

<u>TTY.EXE</u> - Shows temperature-time plots for up to 6 series, without editing capability. Called automatically by NW, but can be run separately.

<u>TI.EXE</u> - identical to TY.EXE, but without divisions between years (and therefore can be used with other data sets: TY assumes that X data are Julian days with Jan. 1 1984 = day 1)

<u>TTI.EXE</u> - identical to TTY.EXE, but without divisions between years (and therefore can be used with other data sets: TTY assumes that X data are Julian days with Jan. 1 1984 = day 1)

ZT.EXE - Shows a single depth-temperature plot, and allows editing of the plotted data. Called automatically by NW, but can be run separately.

ZTI.EXE - Shows depth-temperature plots for up to 6 series, without editing capability. Called automatically by NW, but can be run separately. Max-Min plots are shown using this program.

In addition to the two temporary data files produced when NW is run (NWZDATA.TMP and NWZACC.TMP), the following supporting files are supplied which must be in the current directory when NW is run.

NWZFILES.LST - contains the list of data files which the program can open, which are displayed after the opening screen. This file must be edited to ensure that the files listed are available in the run-time sub-directory, that all readable files are included in the list. In the NW program, all files in the list are assumed to be in the standard format developed for "NWZ" ground temperature data files, unless they start with the letters "PT" (in which case they are assumed to have the standard format for Pipe temperature data files).

graphics drivers (HERC.DRV, etc.) - needed for screen graphics.

font files (4X6.FON, etc. and TRIP.CHR) - needed for screen graphics.

ERROR.MSG - supplies graphics routine error messages.

ZT, TY, and TI all accept and produce files in CSV format, which can be imported by Supercalc. To run ZT (for example), type command

ZT INDATA OUTDATA

where INDATA is the name of the input data file, while OUTDATA is the name of the file to contain data after editing. They may be the same file name. If file names are missing from the command line, the program prompts for them. Data files for the three programs have the same format:

line 1:   Title for Plot (80 characters max)

line 2:   An integer giving the number of data pairs to follow.

lines 3..n: Data Pairs (one pair per line), separated by spaces or commas.

ZTI, TTY, and TTI accept data files consisting of consecutive sequences of data formatted as above, one for each series. To run ZTI (for example), type command

ZTI INDATA

where INDATA is the name of the input data file. If the file name is missing from the command line, the program prompts for it.

Interpolation

Before interpolation is performed, the data is displayed, and can be edited (this permits culling of data points which are too close together, elimination of data gaps, and editing of erroneous values). The user is asked to supply an interval for output of interpolation results: the interval does not influence the accuracy of subsequent calculation of mean annual temperatures (the same interval is used for the calculation of mean annual temperature values in the output file). After exiting the display, interpolation is performed and the interpolated curve together with the original data are displayed. The data for the interpolated curve can then be further edited, or the interpolation accepted.

Mean annual temperatures are calculated from the interpolated curves by using the coefficients of the spline equations to integrate temperature over a one year interval, and dividing by 365 days. This eliminates problems encountered with the method used in earlier analyses (calculation of interpolated values at closely spaced intervals, storing the results, and calculating the mean annual temperature as a running mean). The new method eliminates the need to calculate values for a large number of points, thereby reducing memory limitations; It also eliminates the error introduced by calculating the mean annual temperature at intervals which are not divisible by 365, as well as the error due to finite sampling of the quasi-continuous interpolated temperature curve.

SECTION 6

Summary

1. The consistent relationship between initial ground temperature and temperature rise which was observed in the previous year (Riseborough 1989) is not evident in the behavior observed in the data obtained in the last year.

2. In general, for sensors both on and off of the ROW, those sites unfrozen in the previous year were more likely to be warmer, while frozen sites were more likely to be cooler than in the previous year.

3. Most of the sites which remained frozen and underwent cooling over the past year were classified as ice rich, particularly off of the right of way.

4. Comparison of the mean annual temperature changes shows that the scatter in values (the range as well as standard deviation, of the change in MAT) is least on the pipe, most on ROW. This suggests that the mean annual pipe temperature is less dependent on site specific factors than the ground temperatures on and off of the ROW.

5. The cooling of the ice rich sites may have been accelerated by steep gradients between the surface and a shallow thaw front.

6. At a depth of 4 metres this short term reversal in the mean annual temperature trend (present in the 1 m cables in 1988-89) is not apparent, and the relationship between mean annual temperature change and initial mean annual temperature is again strong. Significantly, the relationship is apparent both on and off of the right of way at this depth, which was not the case at 1 m depth in 1987-88. Analysis of the data over a range of depths shows that this is to be expected: where there are quasi-cyclic fluctuations in the mean annual temperature at the surface, these will be attenuated in the

same manner as the annual cycle.

7. The results at greater depth are consistent with results for the 1 m sensor, and so demonstrate that the measurement program has not been compromised by occasional gaps in measurements.

References

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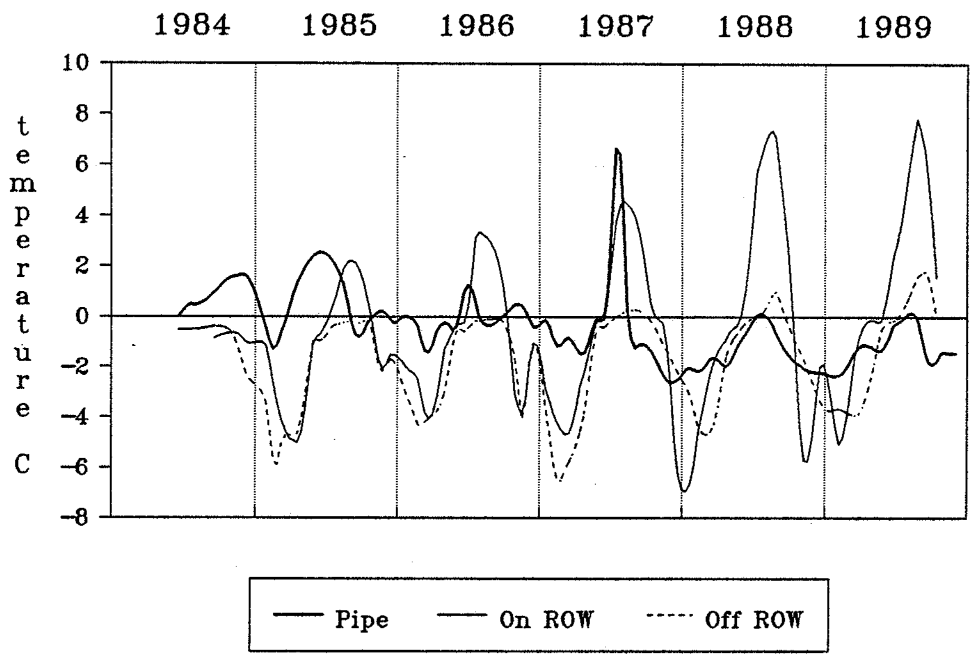
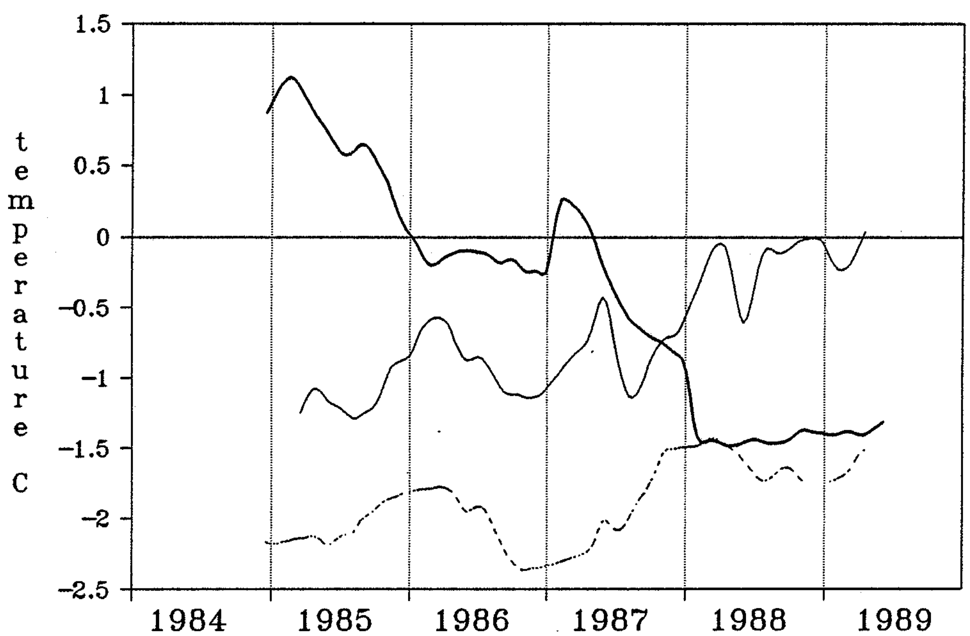
Appendix I
Pipe / 1 m ground temperature graphs
and
mean annual temperature graphs
for all monitoring sites.

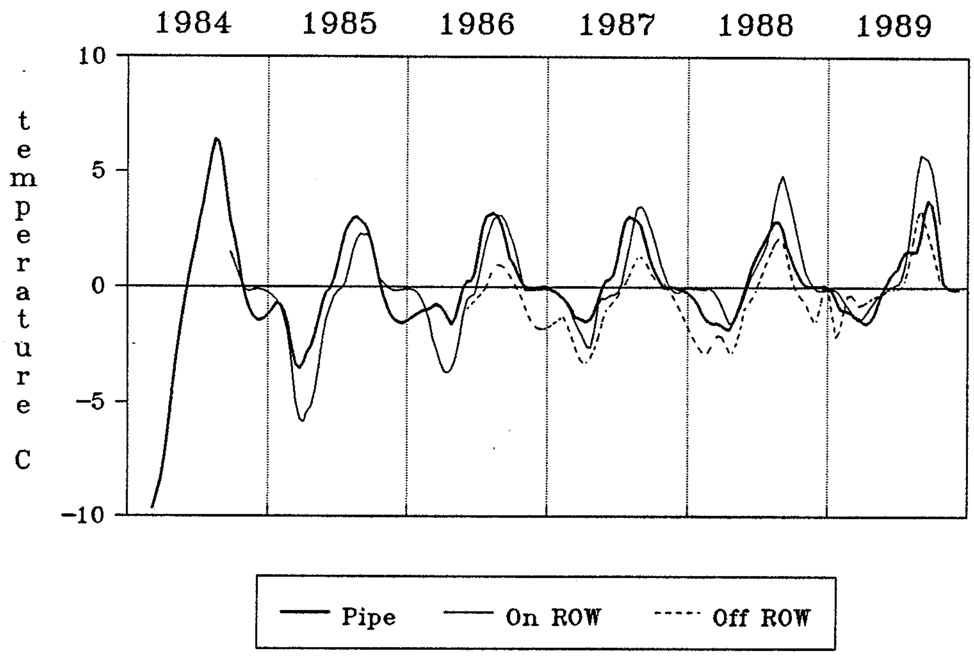
NORMAN WELLS PUMP STATION - PT1-1
Interpolated pipe/1 m ground temperature



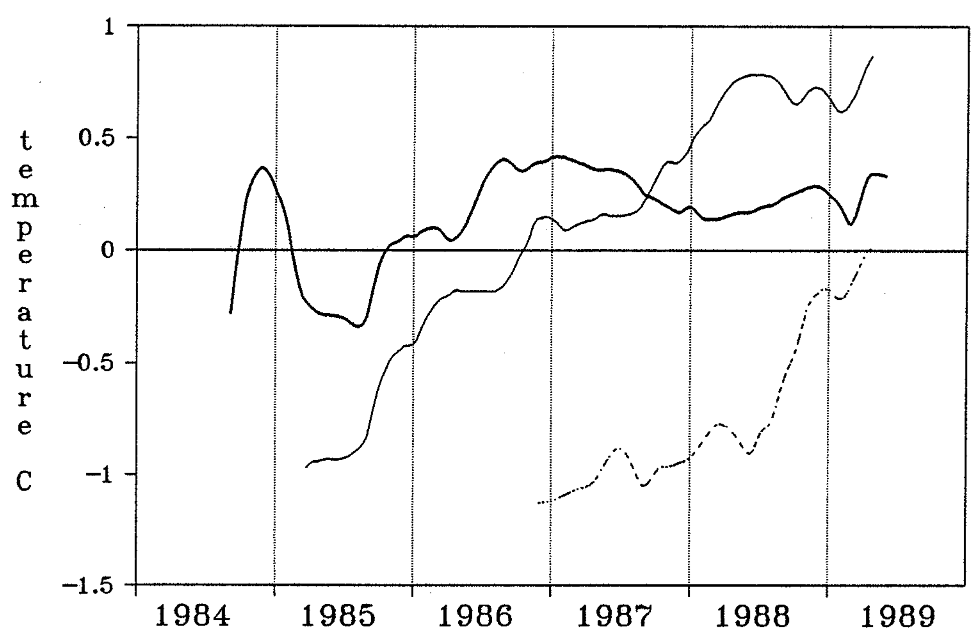
NORMAN WELLS PUMP STATION - PT1-1
Running mean pipe/1 m ground temperature



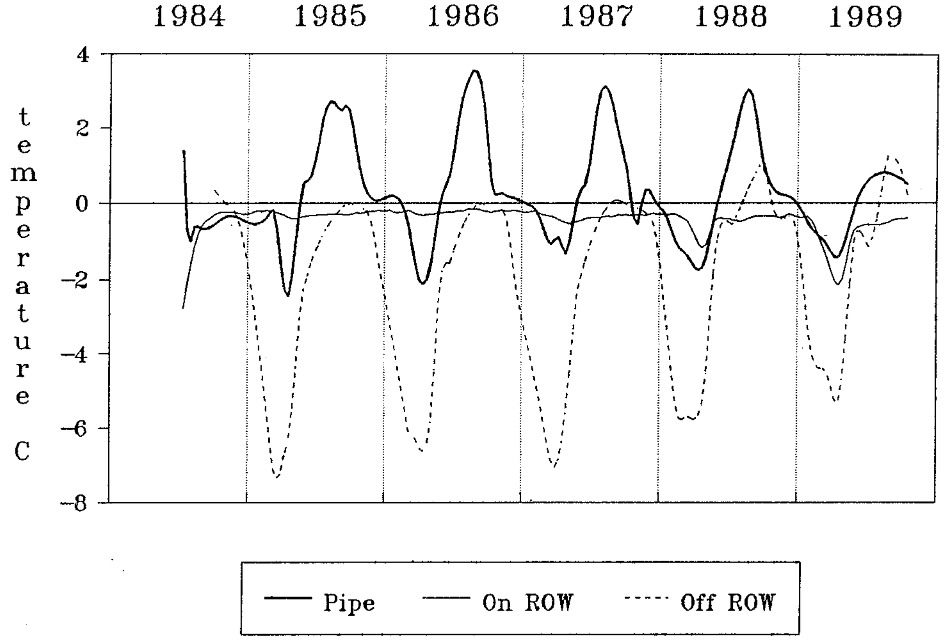
CANYON CREEK NORTH A - PT1-3
Interpolated pipe/1 m ground temperature



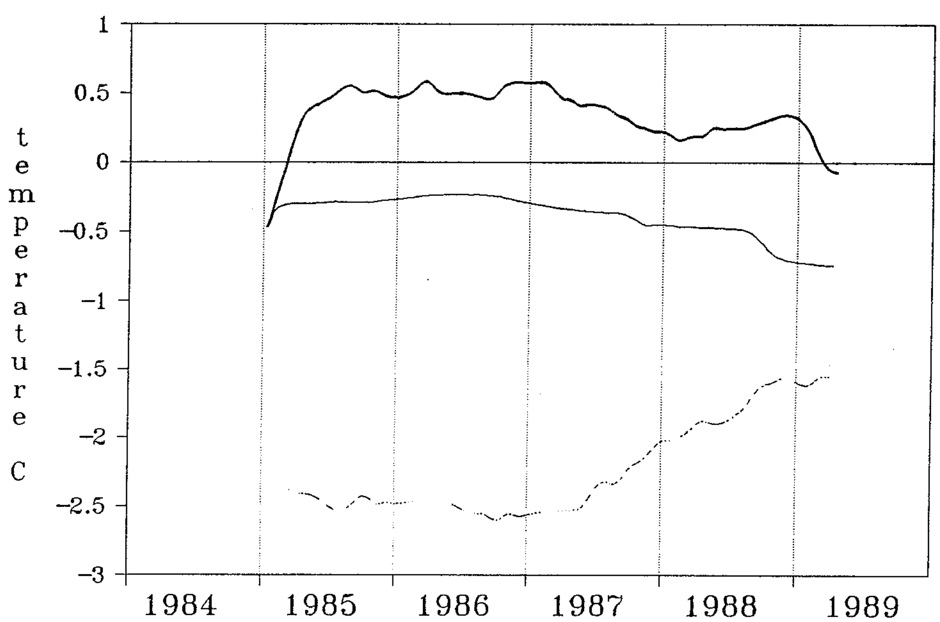
CANYON CREEK NORTH A - PT1-3
Running mean pipe/1 m ground temperature



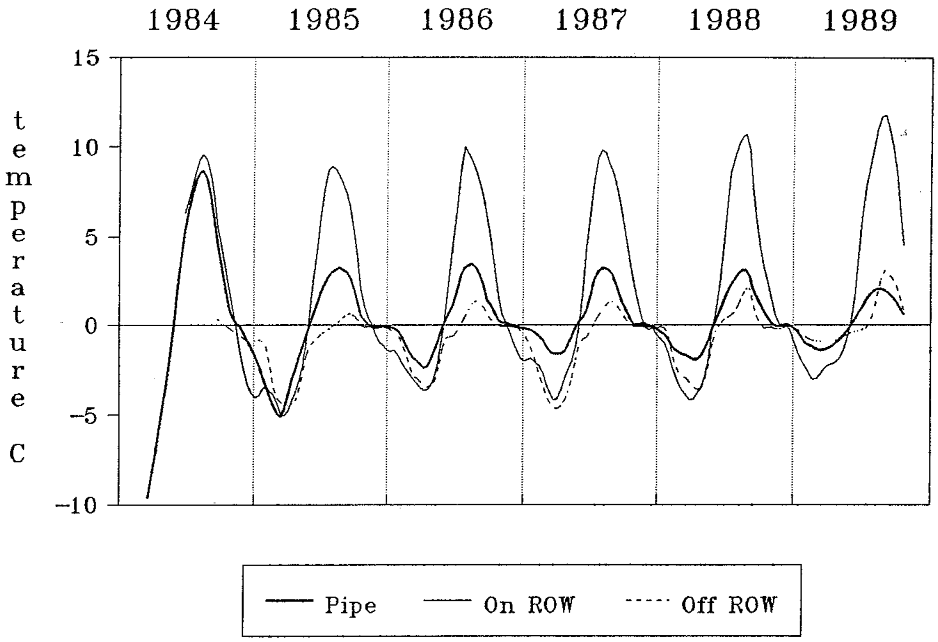
CANYON CREEK NORTH B - PT1-4
Interpolated pipe/1 m ground temperature



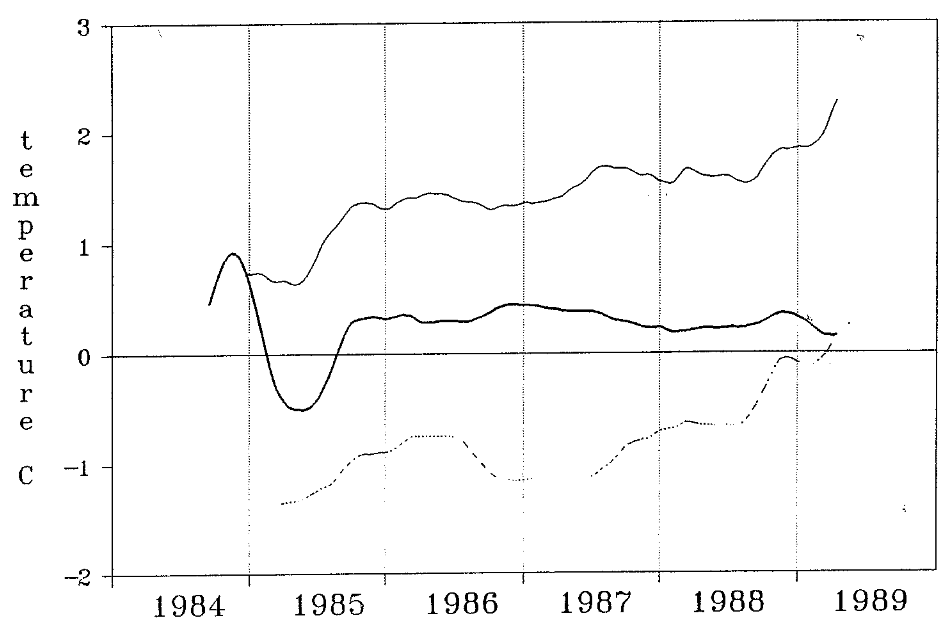
CANYON CREEK NORTH B - PT1-4
Running mean pipe/1 m ground temperature



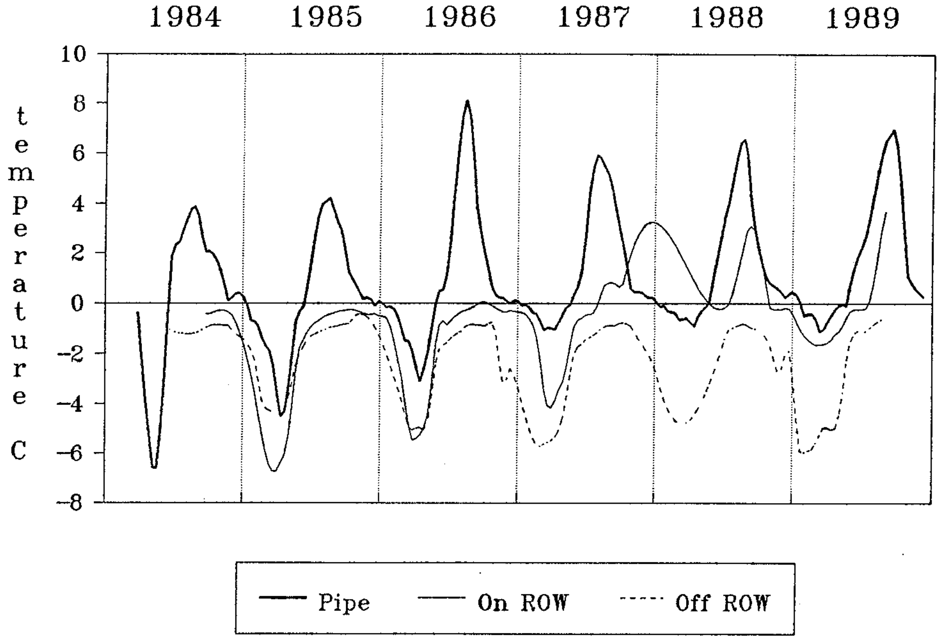
CANYON CREEK SOUTH C - PT1-5
Interpolated pipe/1 m ground temperatur



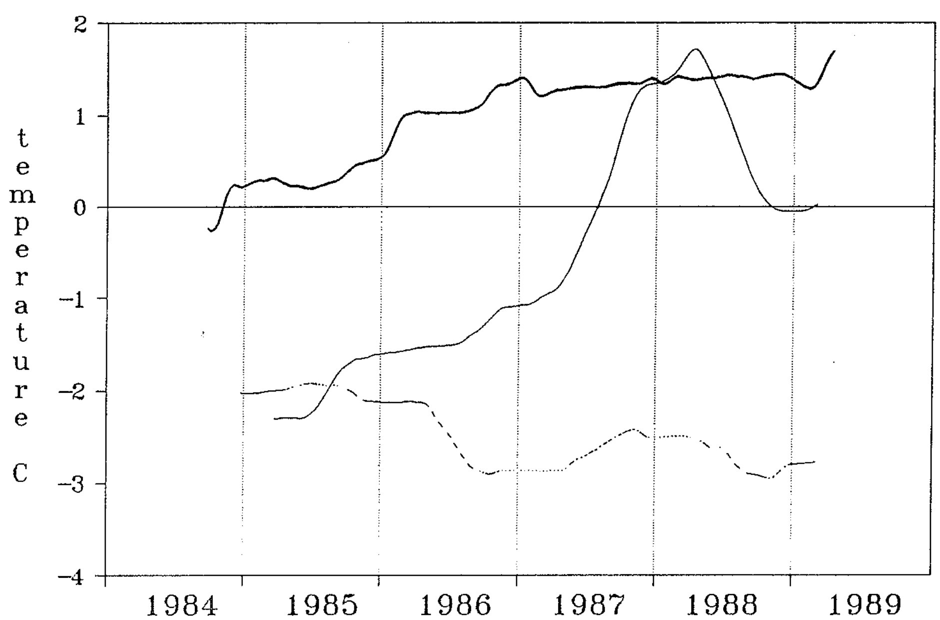
CANYON CREEK SOUTH C - PT1-5
Running mean pipe/1 m ground temperature



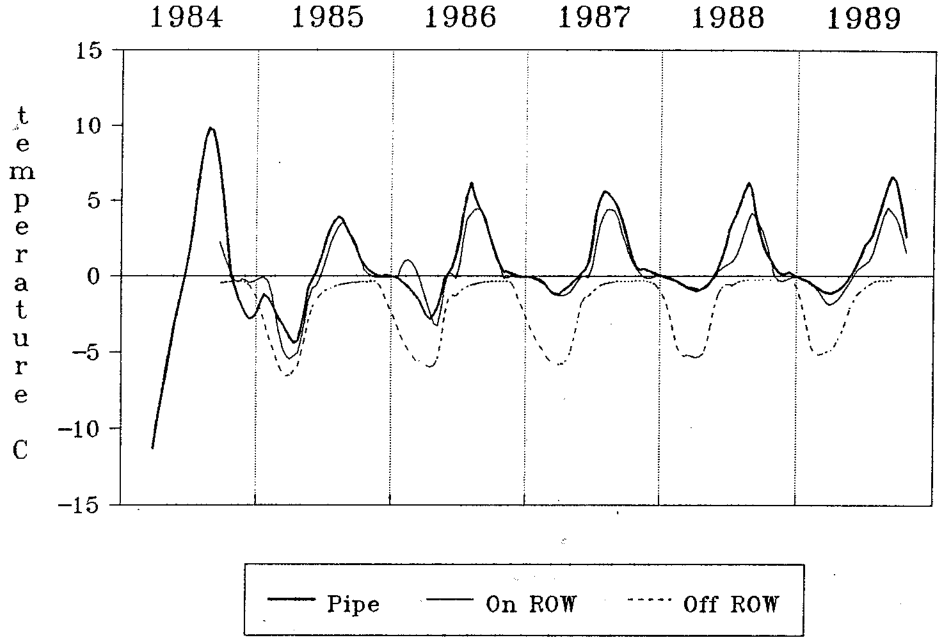
GREAT BEAR RIVER A – EMR11
Interpolated pipe/1 m ground temperature



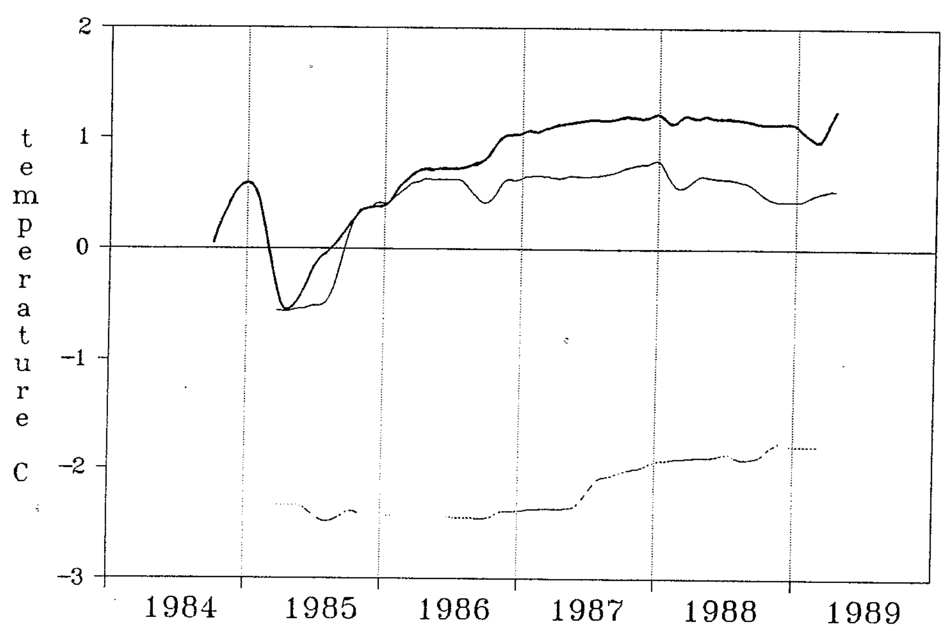
GREAT BEAR RIVER A – EMR11
Running mean pipe/1 m ground temperature



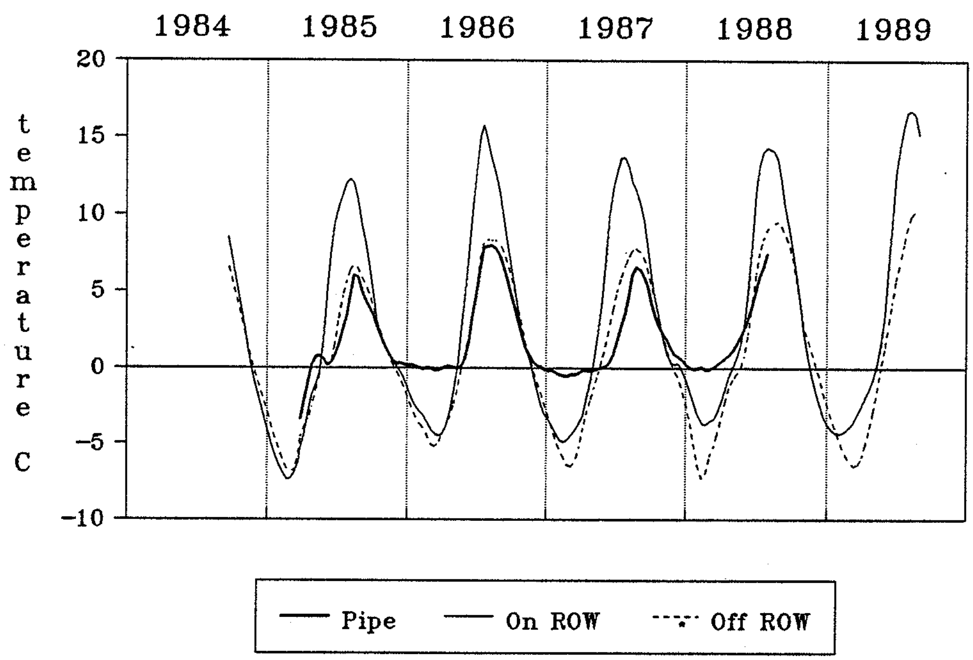
GREAT BEAR RIVER B: PT1-10
Interpolated pipe/1 m ground temperature



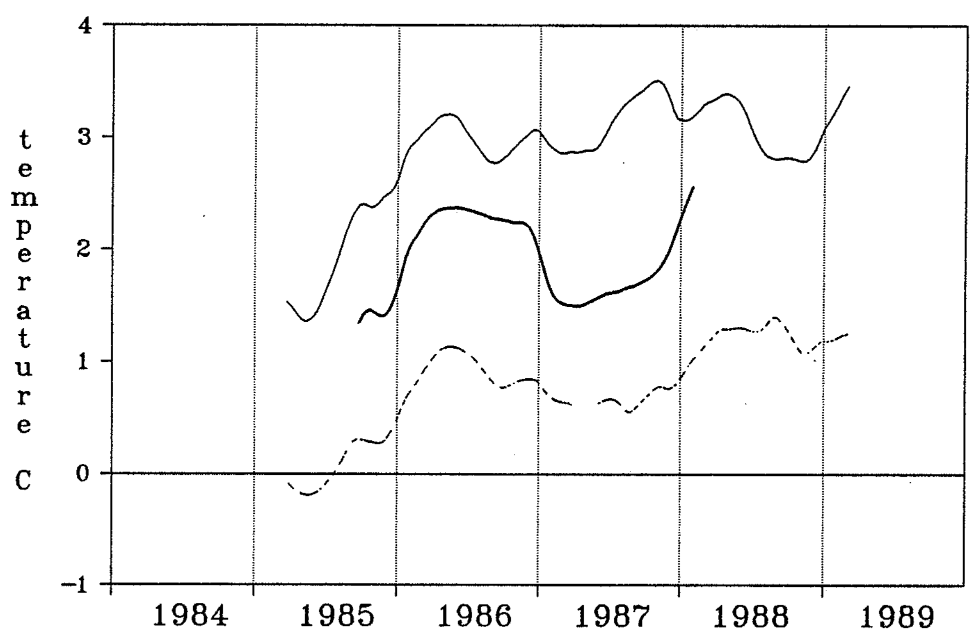
GREAT BEAR RIVER B - PT1-10
Running mean pipe/1 m ground temperature



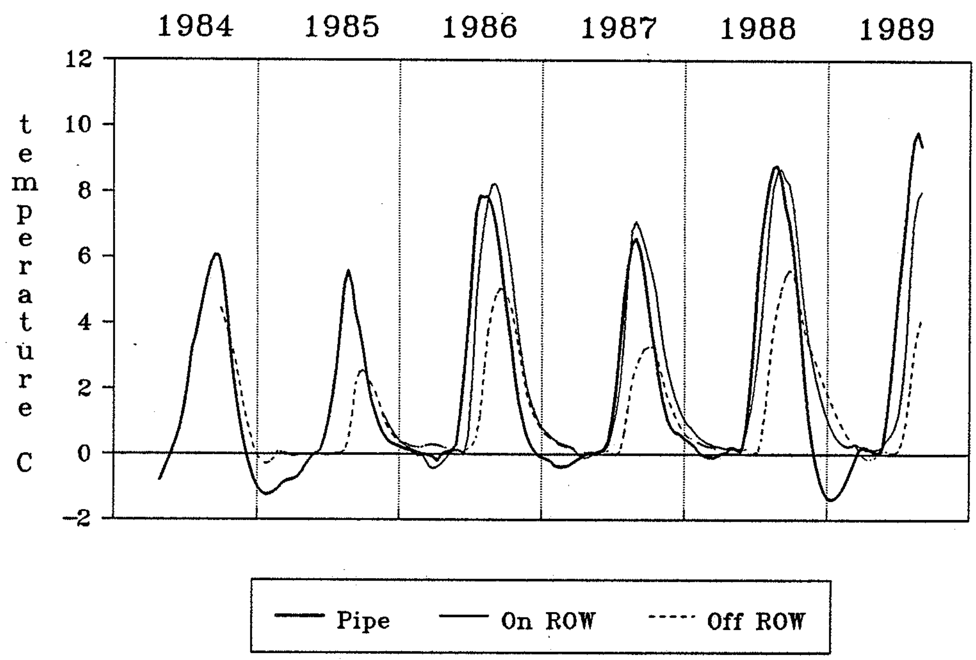
TRAIL RIVER B - PT1-9
Interpolated pipe/1 m ground temperature



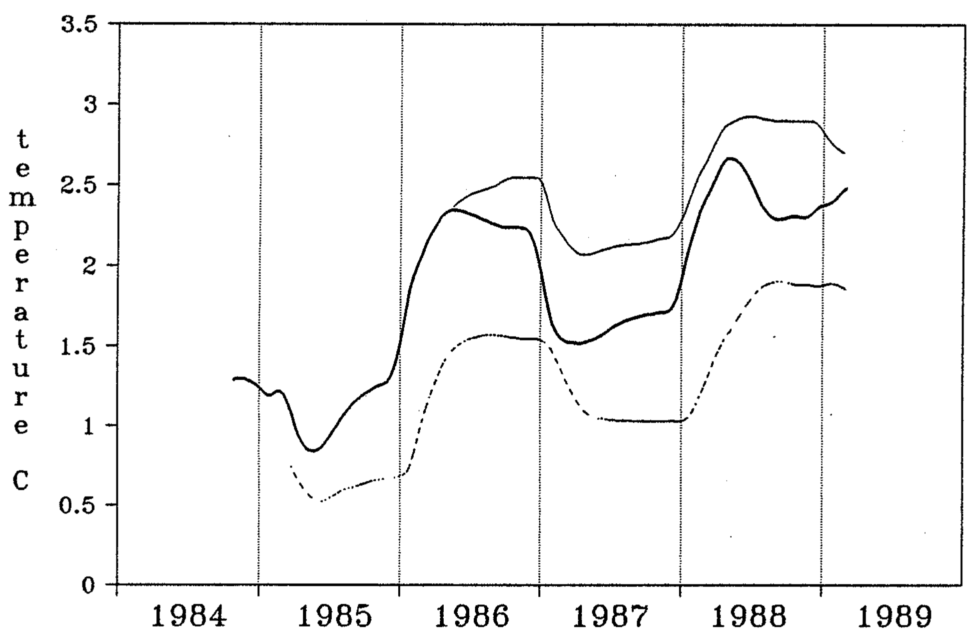
TRAIL RIVER B - PT1-9
Running mean pipe/1 m ground temperature



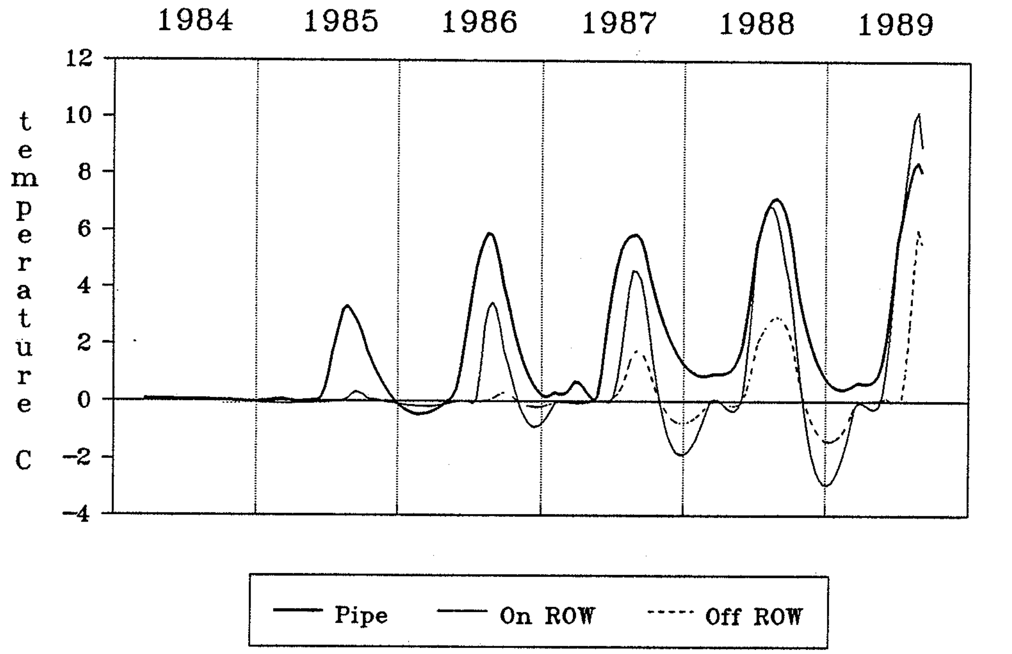
TRAIL RIVER A: EMR1
Interpolated pipe/1 m ground temperature



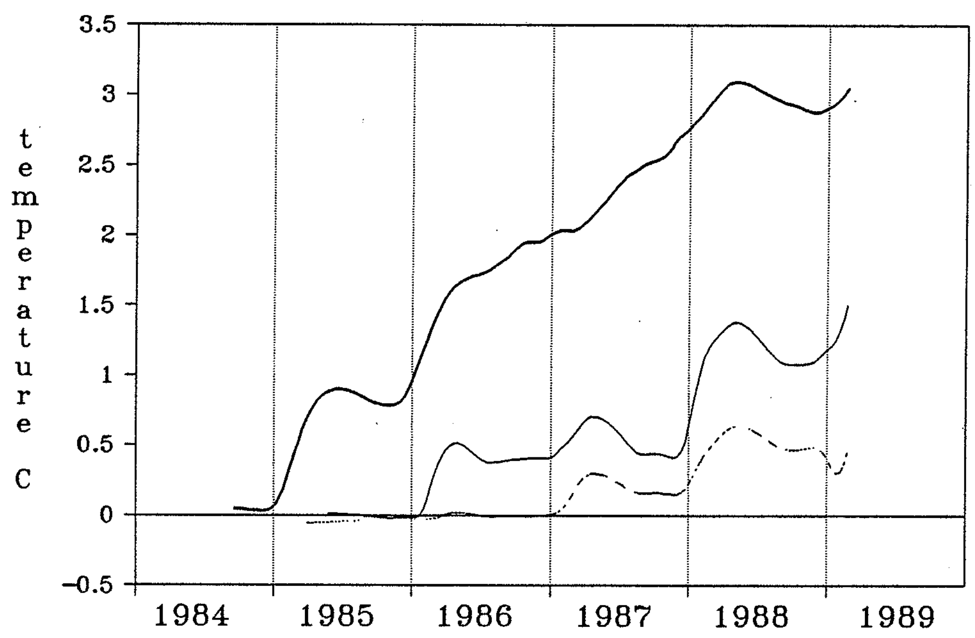
TRAIL RIVER A: EMR1
Running mean pipe/1 m ground temperature



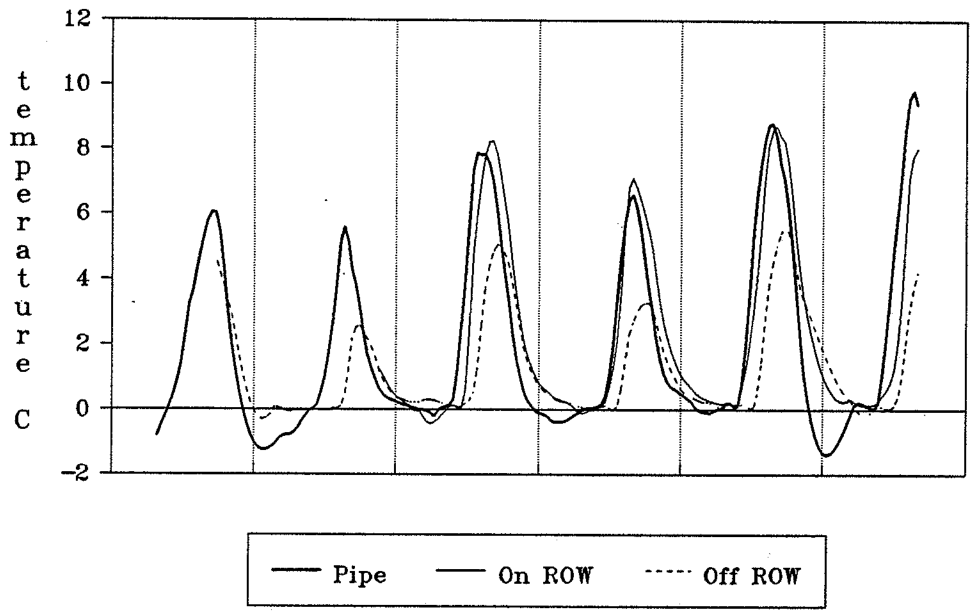
PETITOT RIVER NORTH A: EMR4
Interpolated pipe/1 m ground temperature



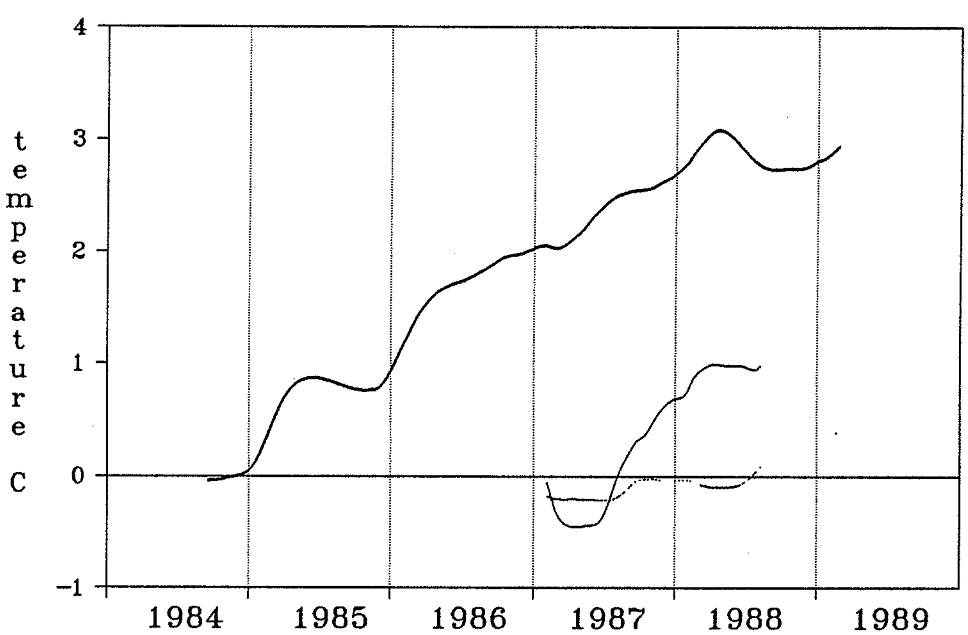
PETITOT RIVER NORTH A: EMR4
Running mean pipe/1 m ground temperature



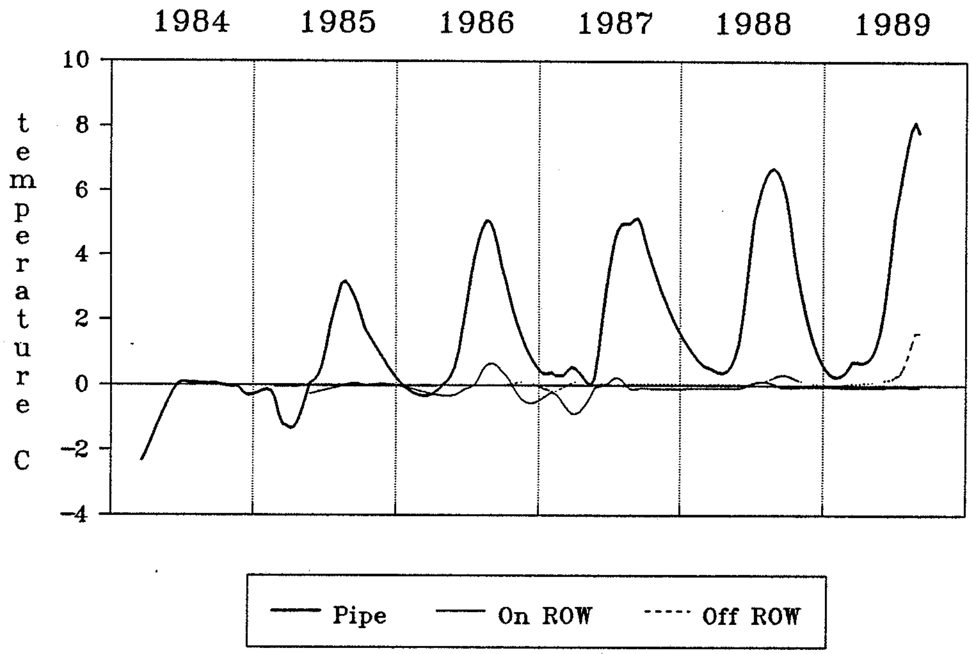
PETITOT RIVER NORTH B – EMR5
Interpolated pipe/1 m ground temperature



PETITOT RIVER NORTH B – EMR5
Running mean pipe/1 m ground temperature



PETITOT RIVER SOUTH - EMR6
Interpolated pipe/1 m ground temperature



PETITOT RIVER SOUTH - EMR6
Running mean pipe/1 m ground temperature

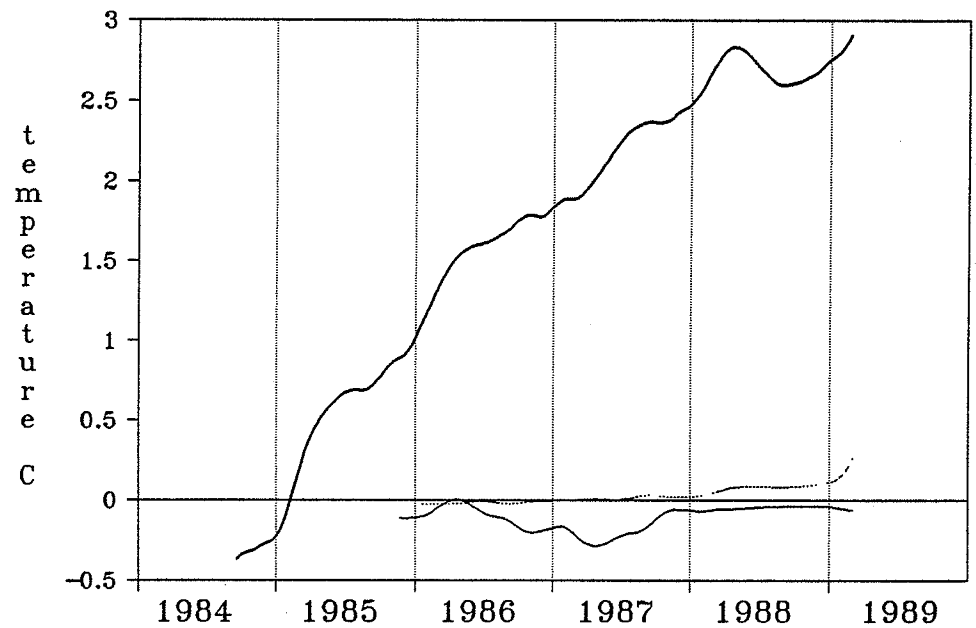


TABLE MOUNTAIN A – 85–EPT 1
Interpolated pipe/1 m ground temperature

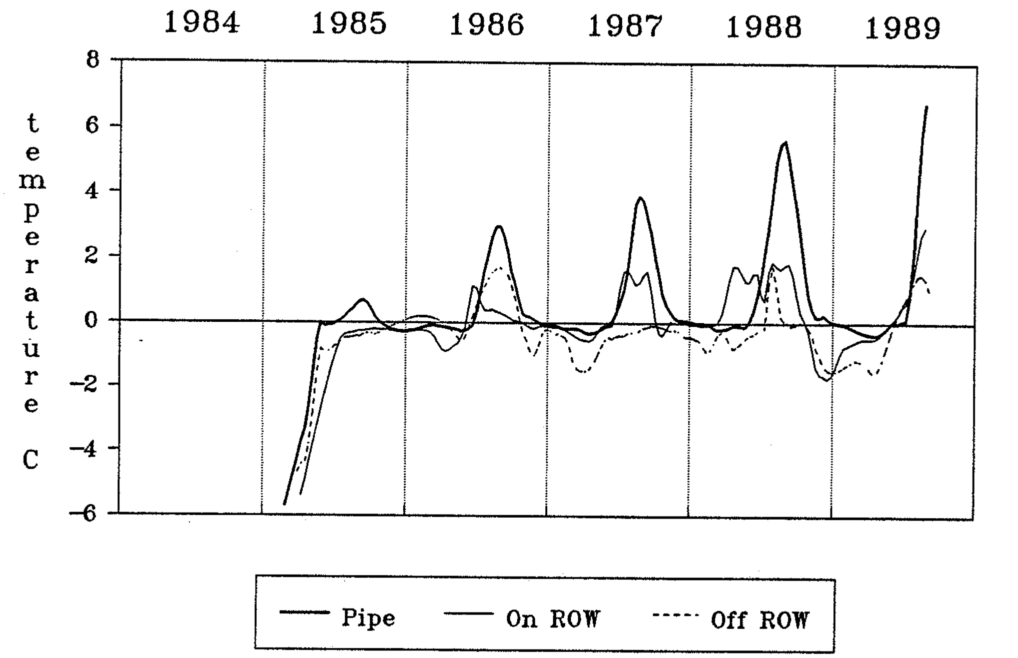


TABLE MOUNTAIN A – 85–EPT 1
Running mean pipe/1 m ground temperature

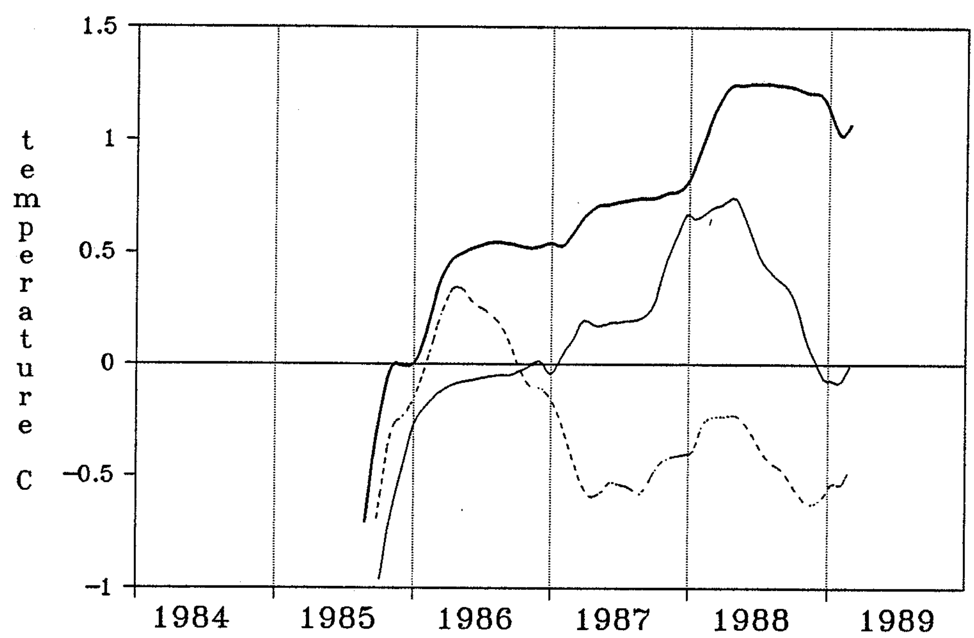


TABLE MOUNTAIN B – 85–EPT 3
Interpolated pipe/1 m ground temperature

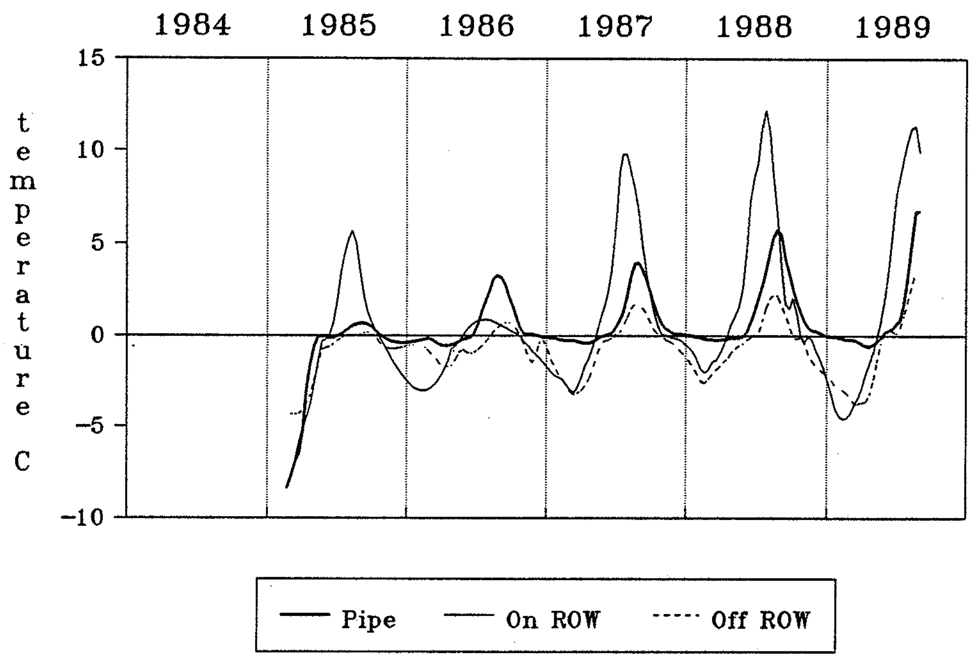


TABLE MOUNTAIN B – 85–EPT 3
Running mean pipe/1 m ground temperature

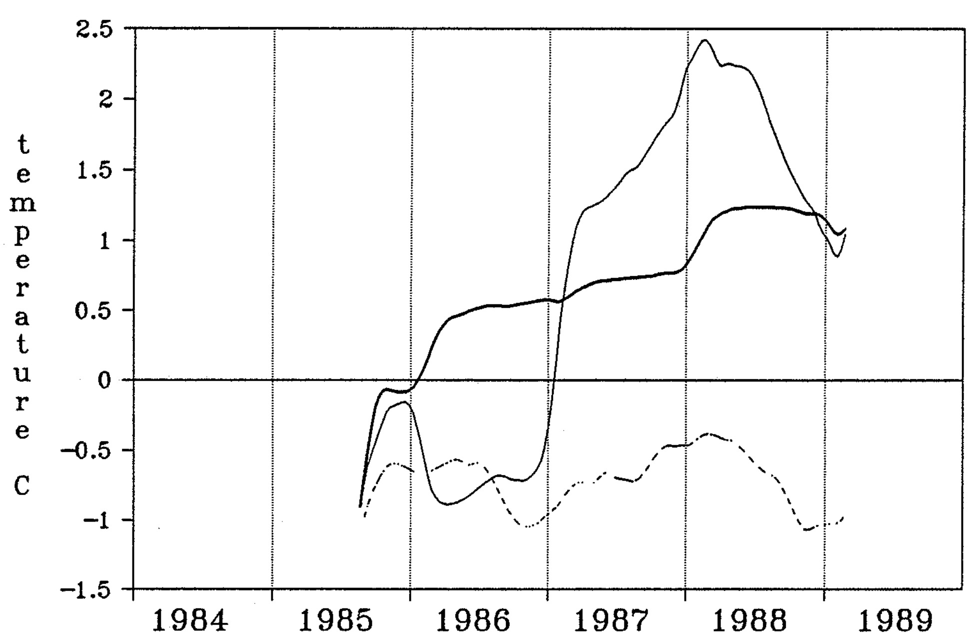


TABLE MOUNTAIN C - 85-EPT 2
Interpolated pipe/1 m ground temperature

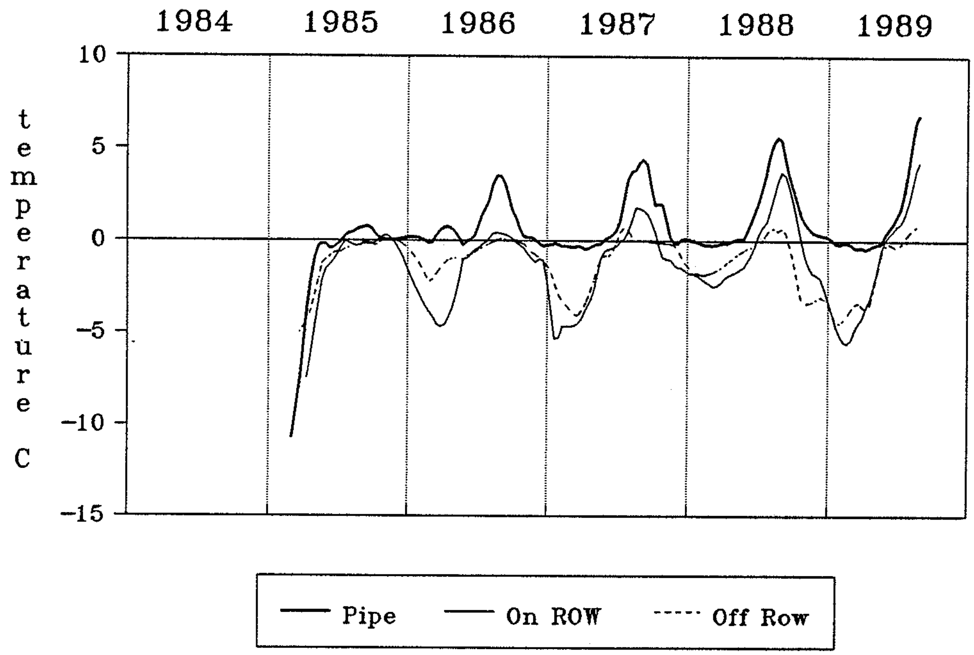
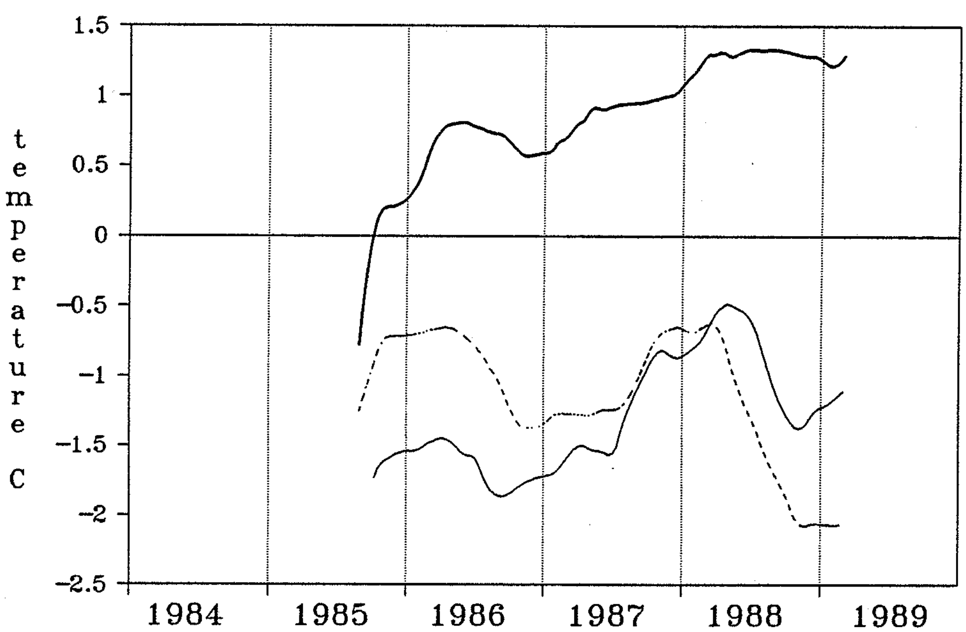
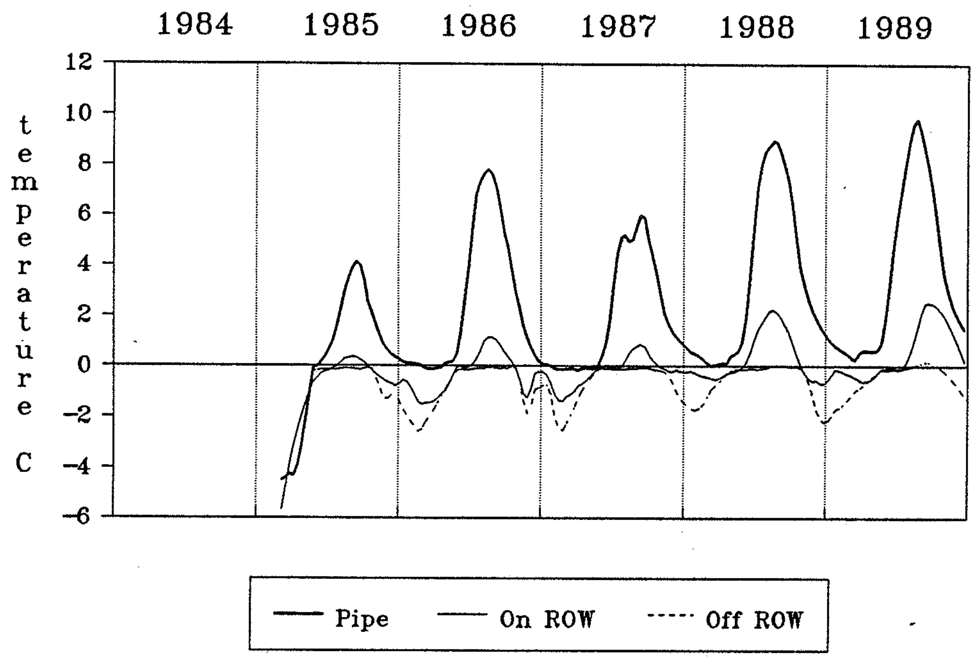


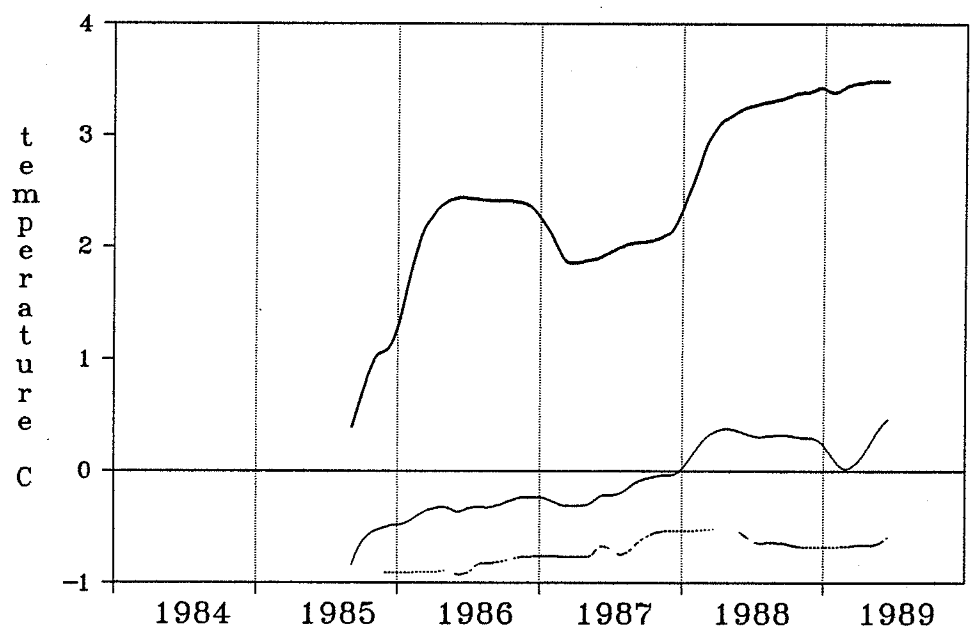
TABLE MOUNTAIN C - 85-EPT 2
Running mean pipe/1 m ground temperature



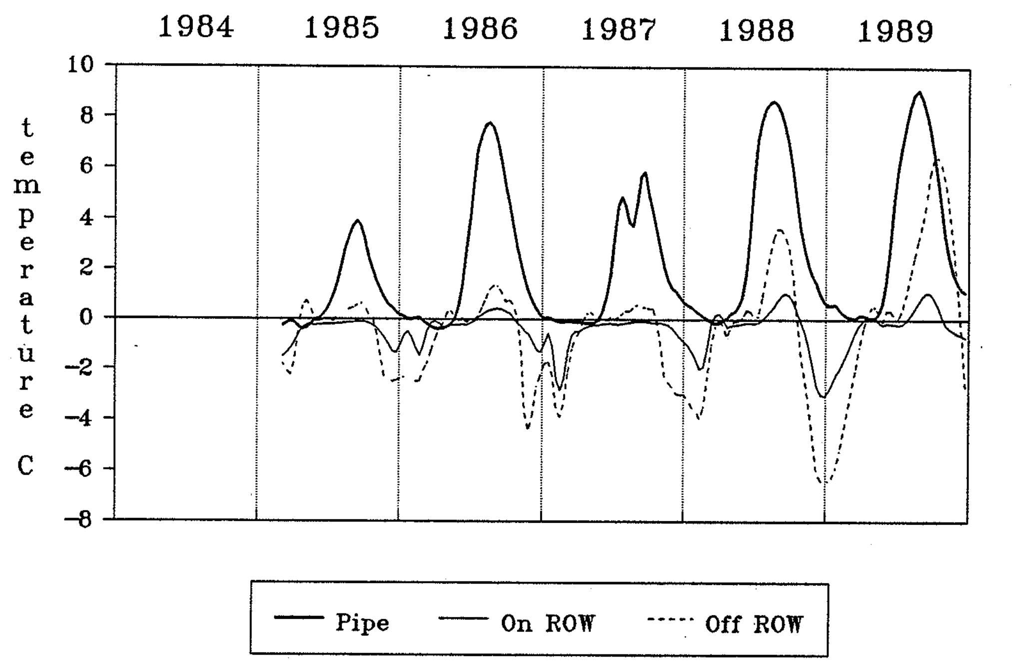
MANNERS CREEK A - 85 EPT8
Interpolated pipe/1 m ground temperature



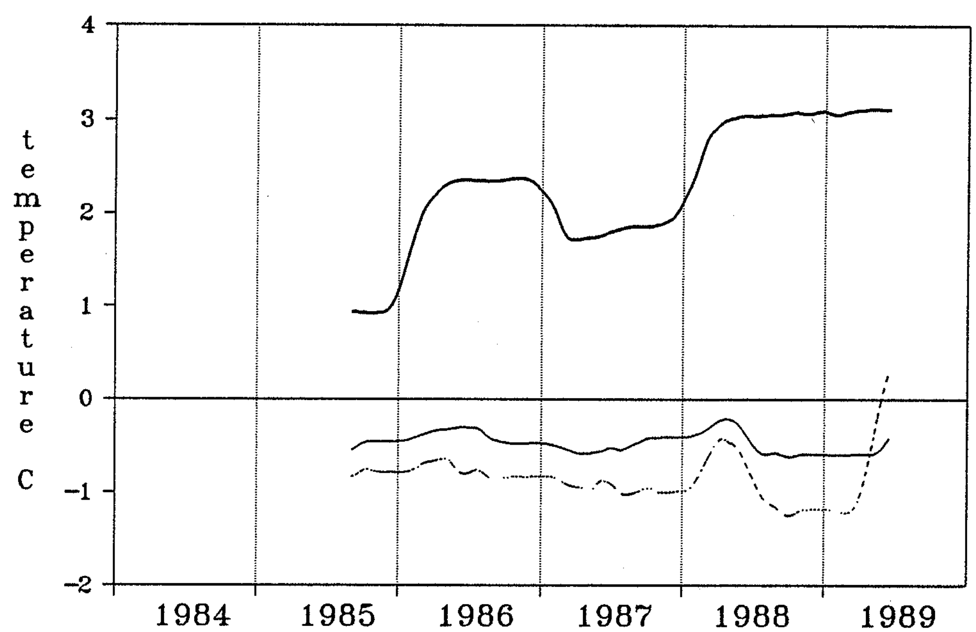
MANNERS CREEK A - 85 EPT8
Running mean pipe/1 m ground temperature

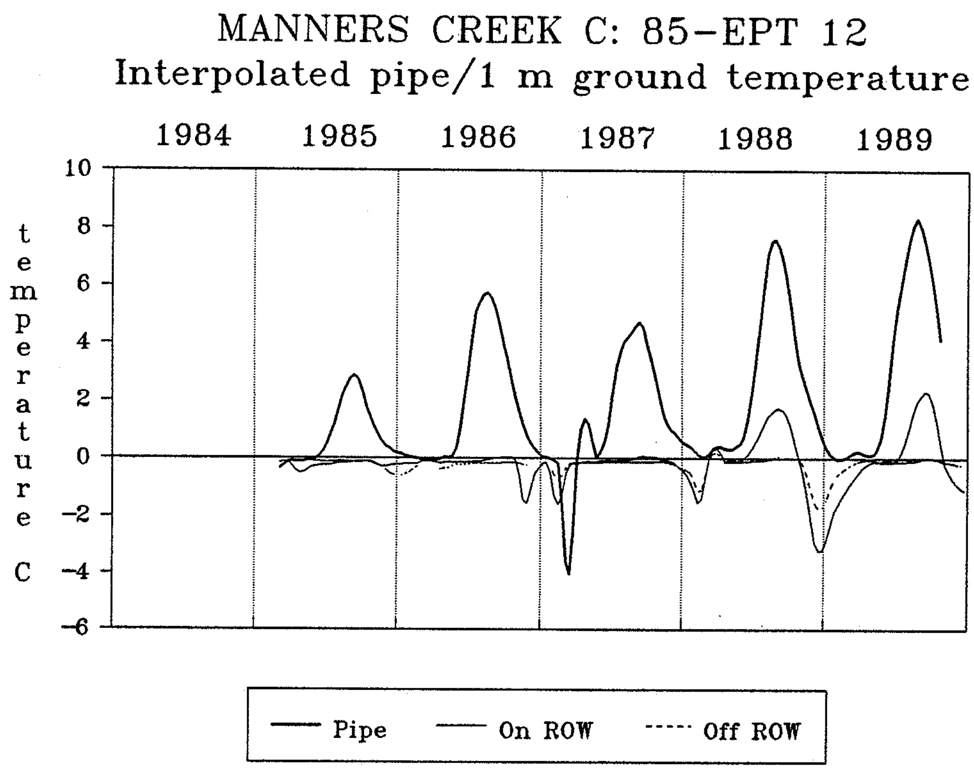


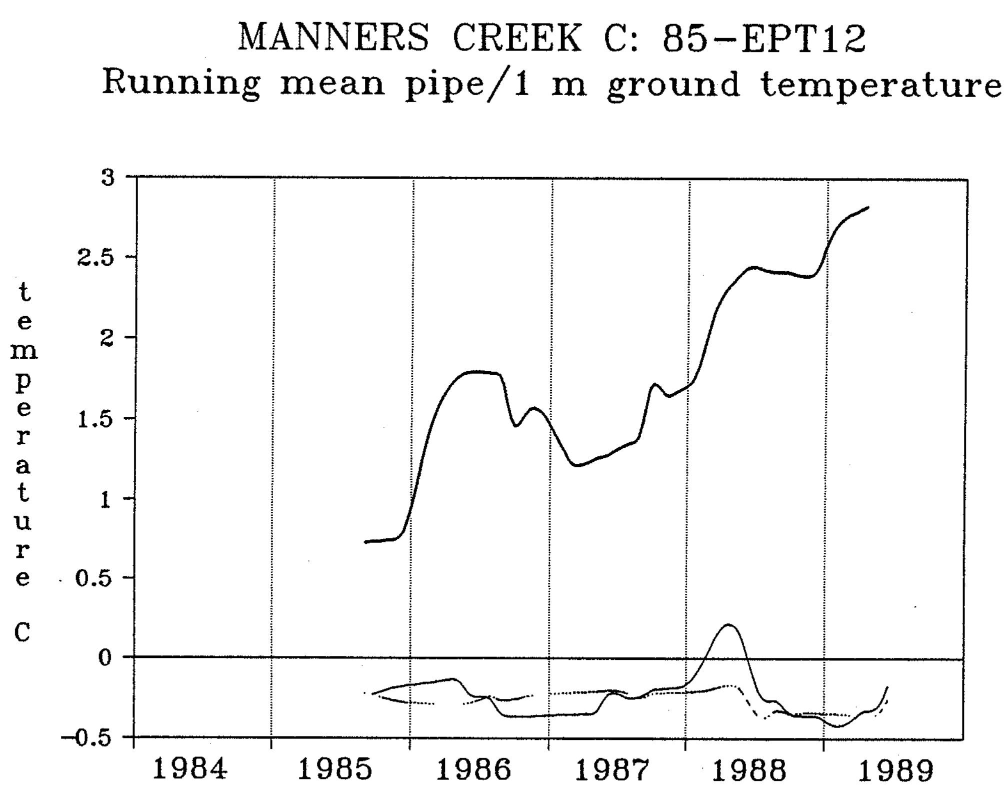
MANNERS CREEK B – 85 EPT7
Interpolated pipe/1 m ground temperature



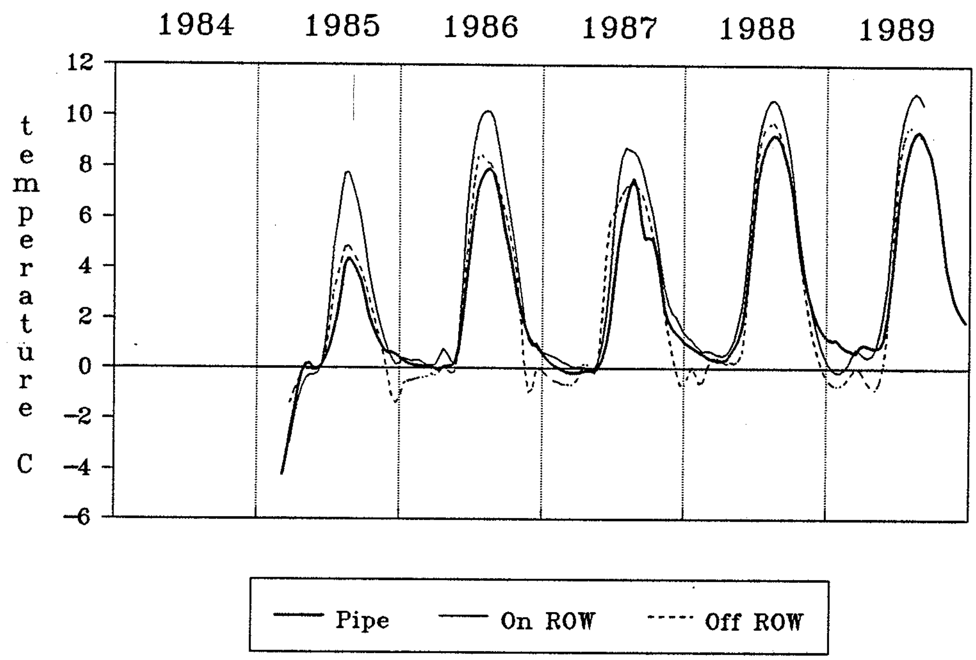
MANNERS CREEK B – 85 EPT7
Running mean pipe/1 m ground temperature



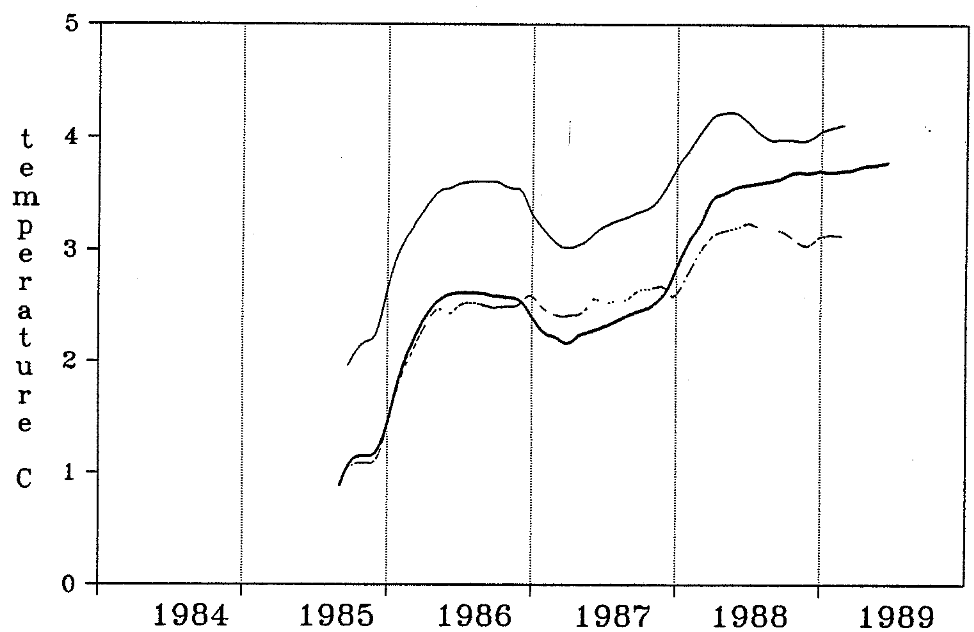

MANNERS CREEK C: 85-EPT 12
Interpolated pipe/1 m ground temperature
1984
1985
1986
1987
1988
1989
temperature C
10
8
6
4
2
0
-2
-4
-6
Pipe
On ROW
Off ROW


MANNERS CREEK C: 85-EPT12
Running mean pipe/1 m ground temperature
temperature C
3
2.5
2
1.5
1
0.5
0
-0.5
1984
1985
1986
1987
1988
1989

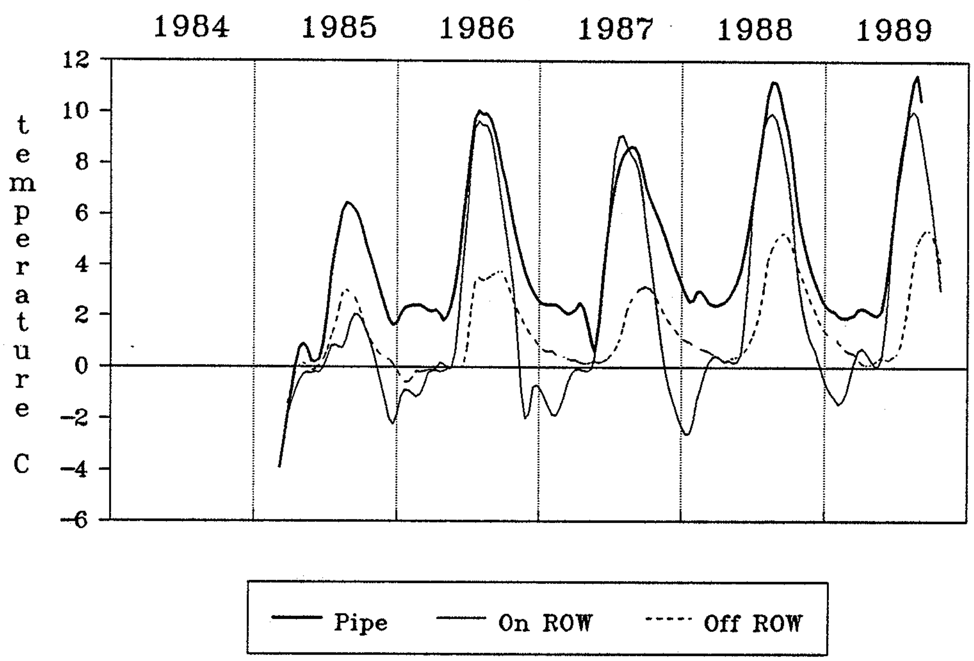
PUMP STATION 3 - 85 EPT9
Interpolated pipe/1 m ground temperature



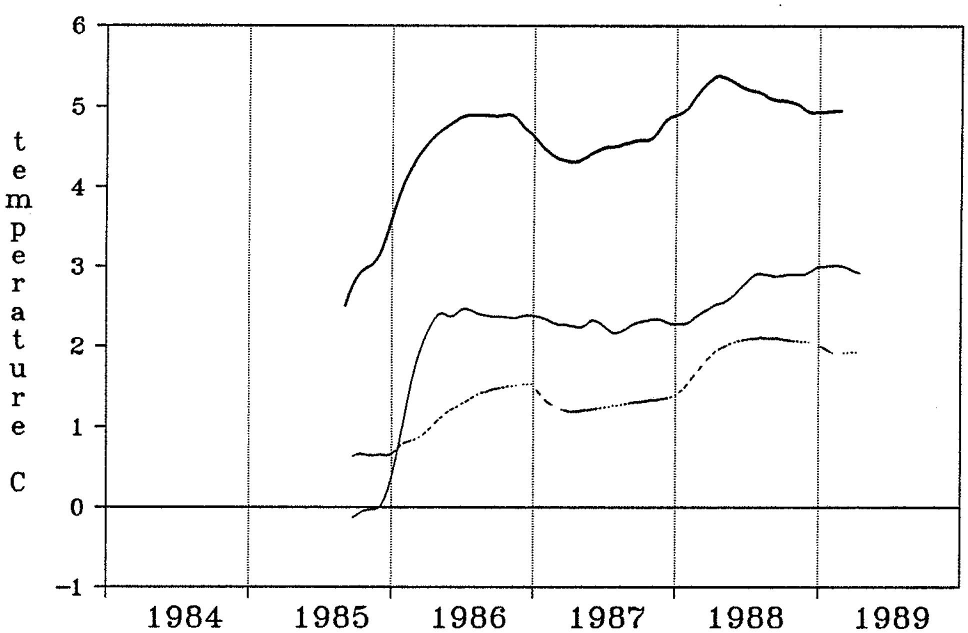
PUMP STATION 3 - 85 EPT9
Running mean pipe/1 m ground temperature



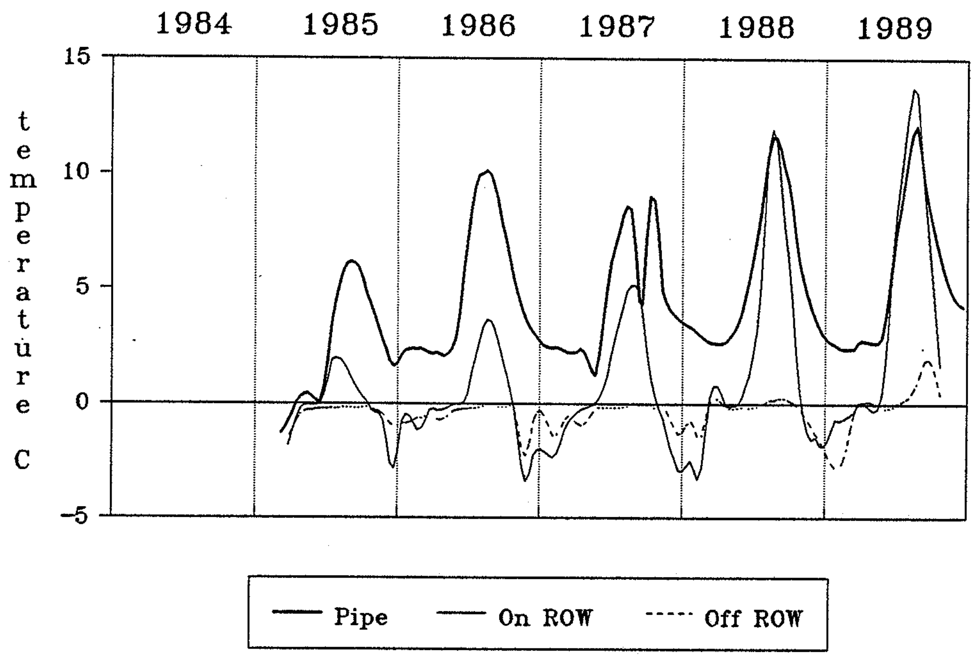
MACKENZIE HIGHWAY SOUTH A: 85-EPT4
Interpolated pipe/1 m ground temperature



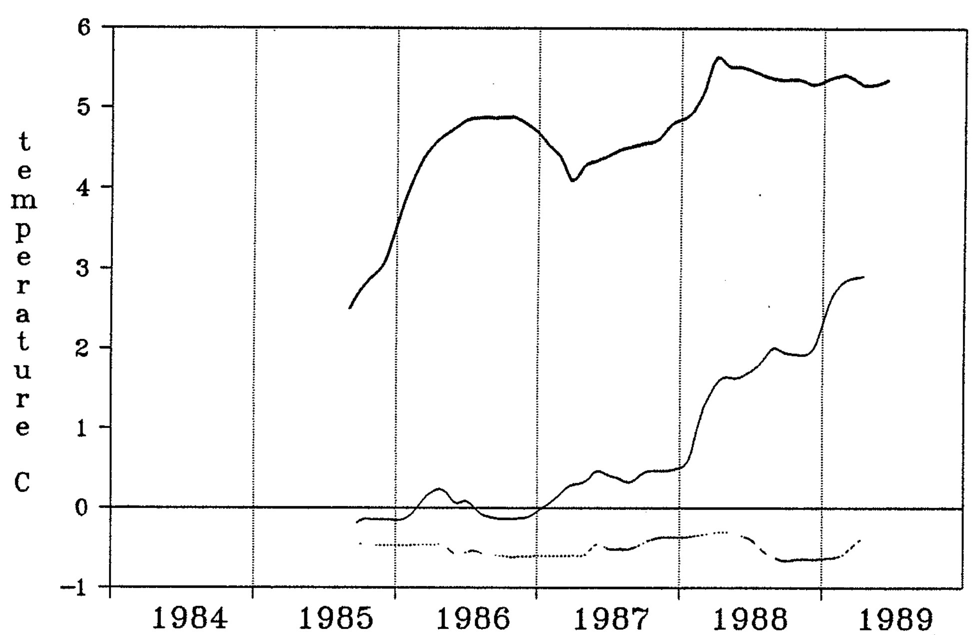
MACKENZIE HIGHWAY SOUTH A: 85-EPT4
Running mean pipe/1 m ground temperature



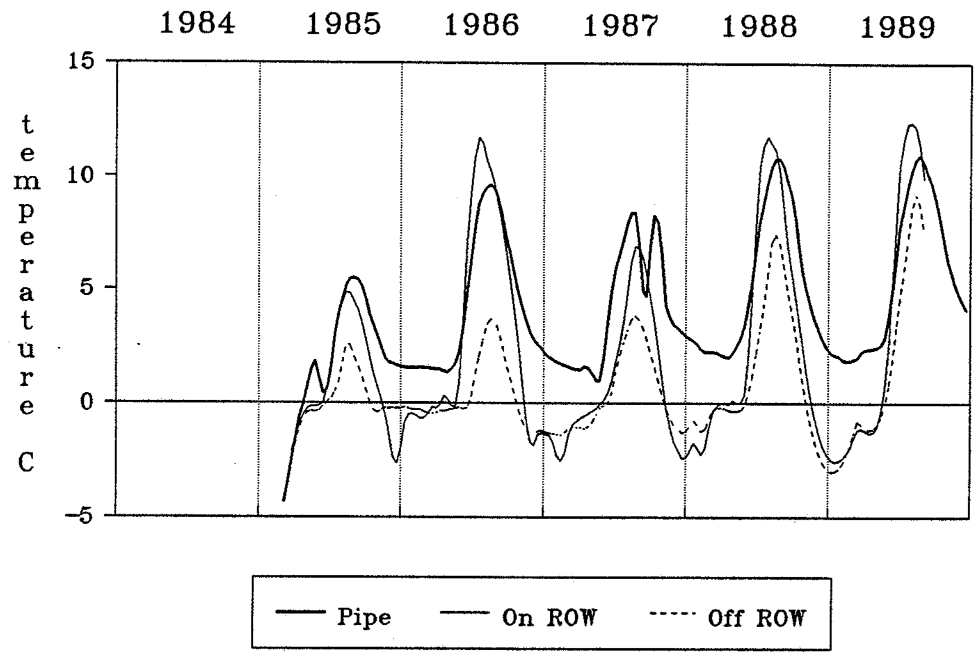
MACKENZIE HIGHWAY SOUTH B - 85 EPT5
Interpolated pipe/1 m ground temperature



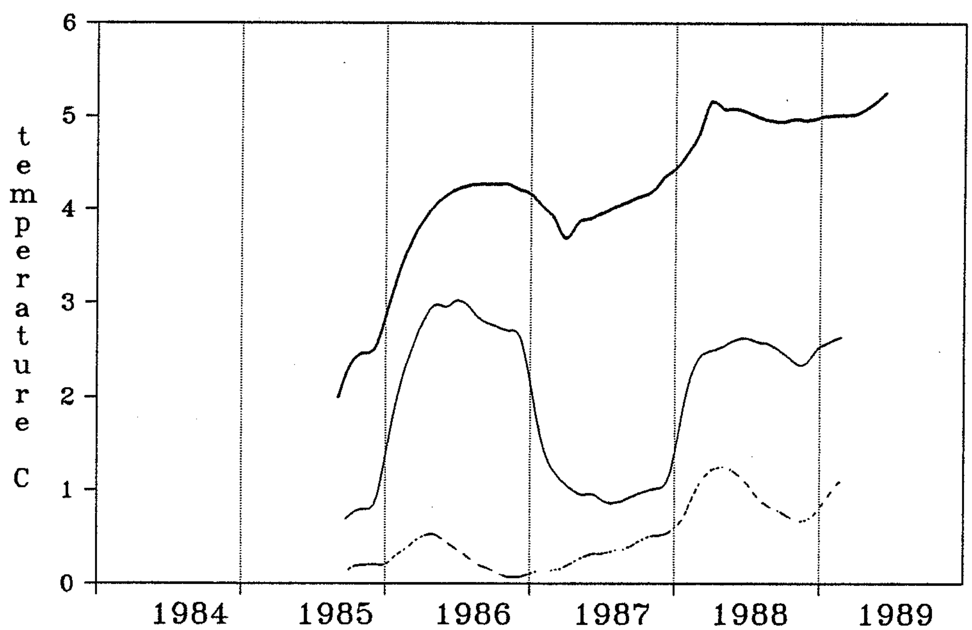
MACKENZIE HIGHWAY SOUTH B - 85 EPT5
Running mean pipe/1 m ground temperature



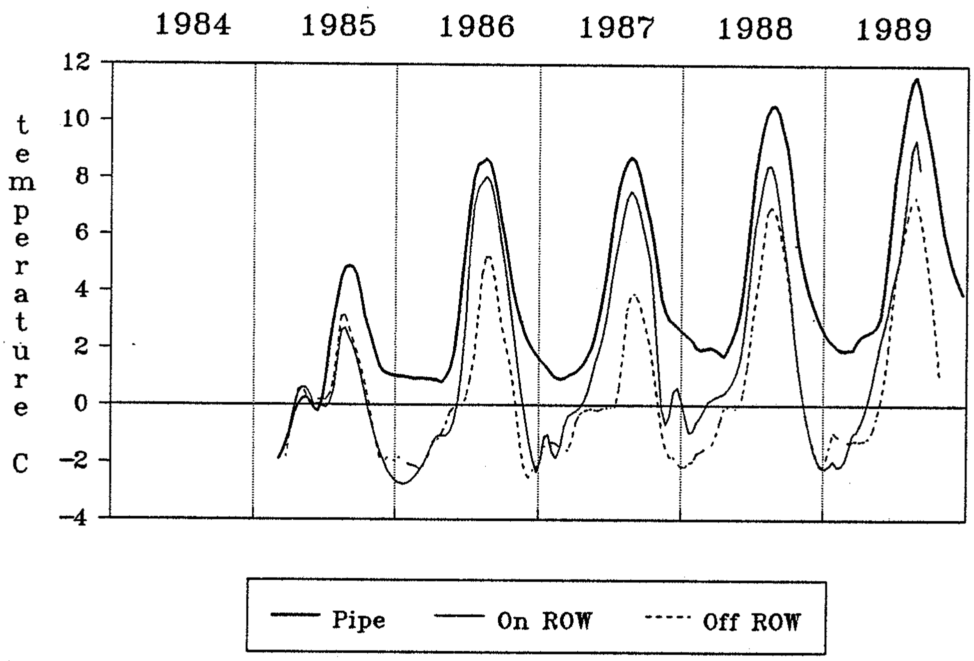
MORAINE SOUTH - 85 EPT11
Interpolated pipe/1 m ground temperature



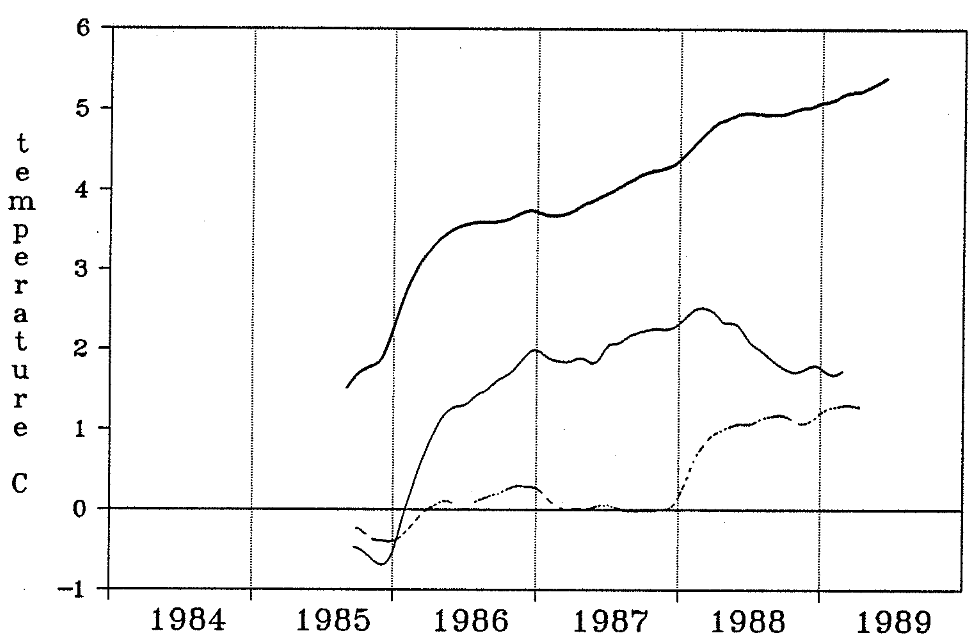
MORAINE SOUTH - 85 EPT11
Running mean pipe/1 m ground temperature



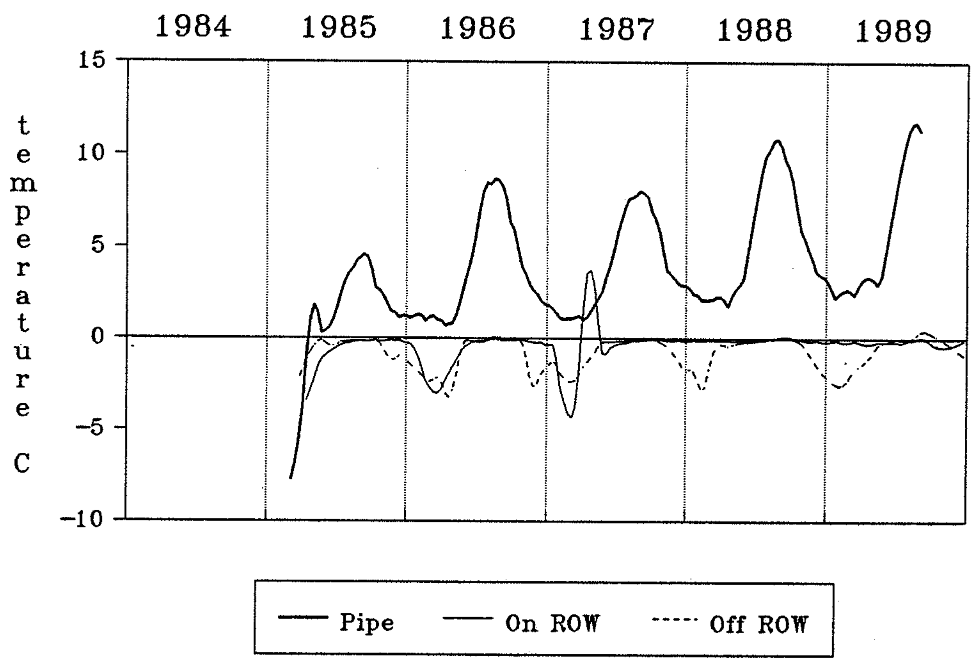
JEAN MARIE CREEK A - 85 EPT6
Interpolated pipe/1 m ground temperature



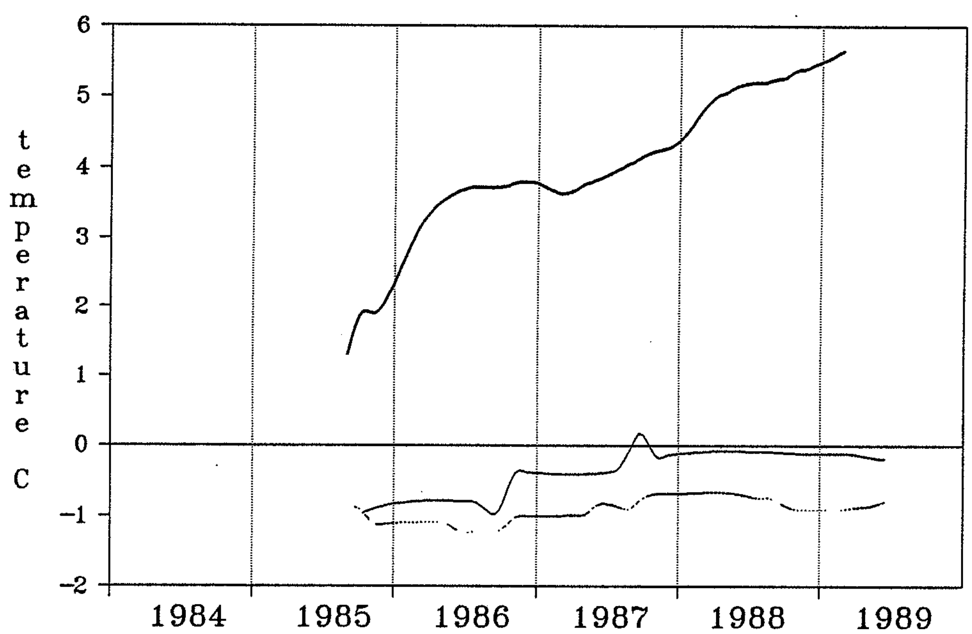
JEAN MARIE CREEK A - 85 EPT6
Running mean pipe/1 m ground temperature



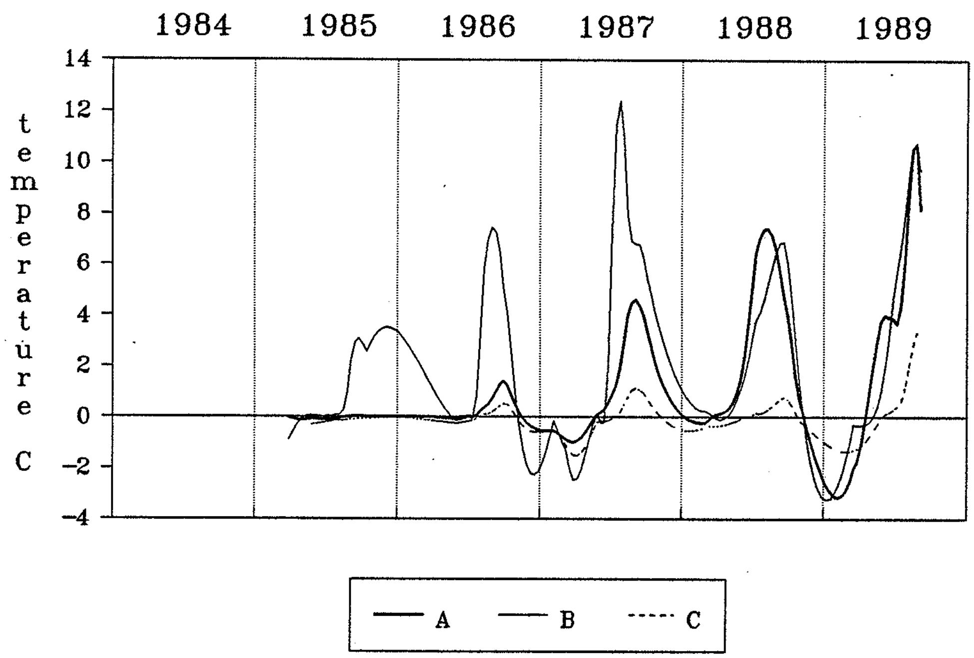
JEAN MARIE CREEK B - 85 EPT10
Interpolated pipe/1 m ground temperature



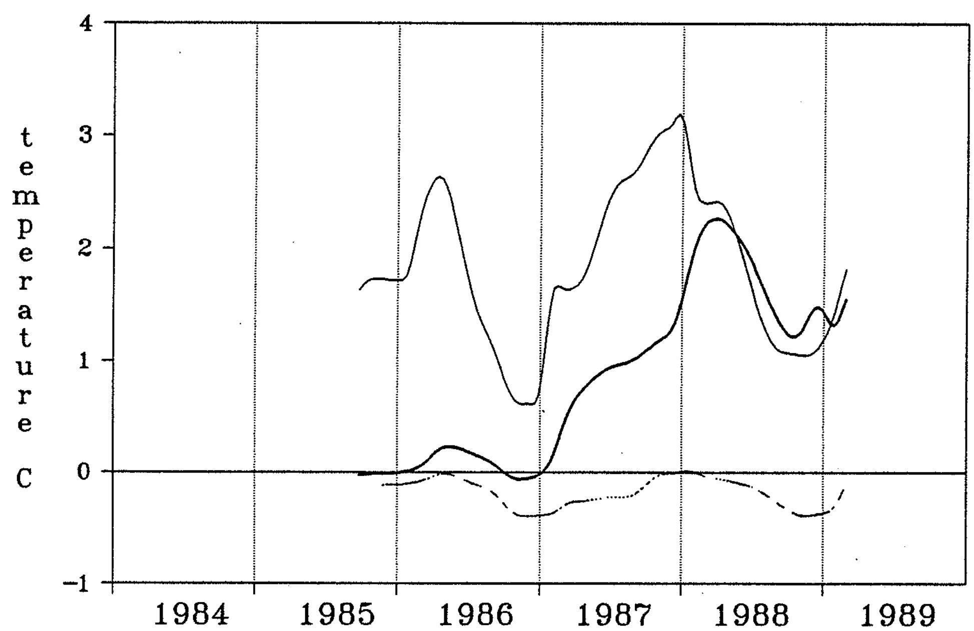
JEAN MARIE CREEK B - 85 EPT10
Running mean pipe/1 m ground temperature



SITE 85-13: REDKNIFE HILLS
Interpolated 1 m ground temperature

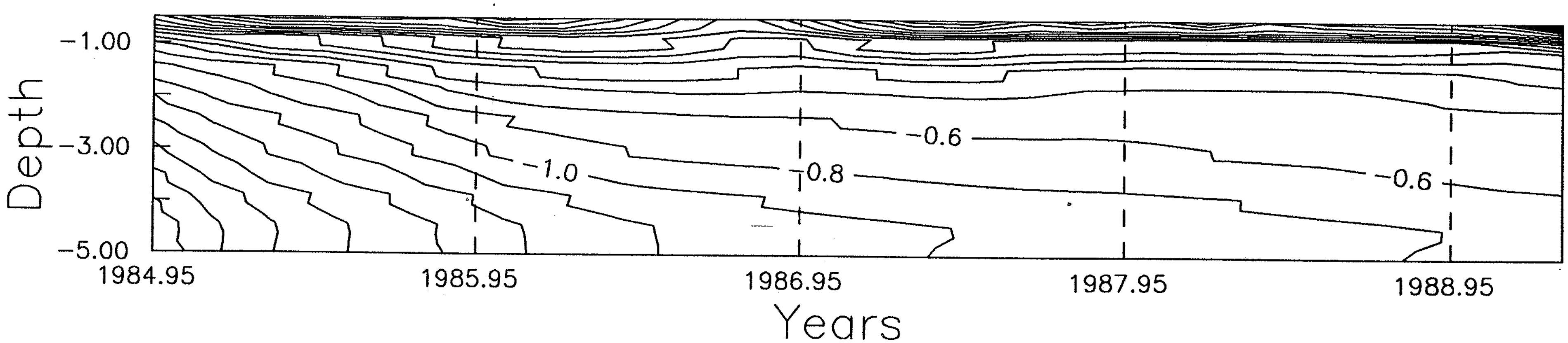


SITE 85-13: REDKNIFE HILLS
Running mean pipe/1 m ground temperature



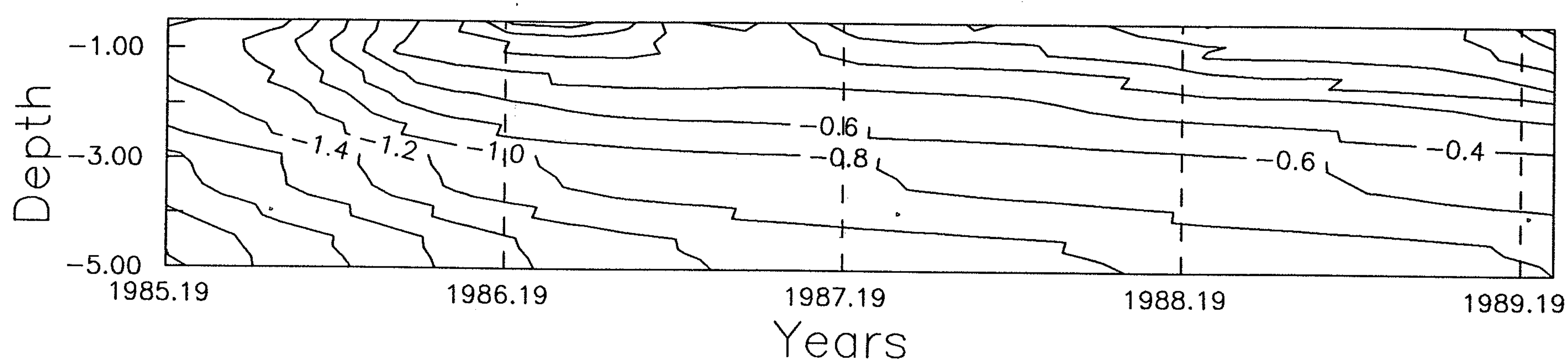
Appendix II
Geotherm plots
for all monitoring sites

NWZ1 – T1



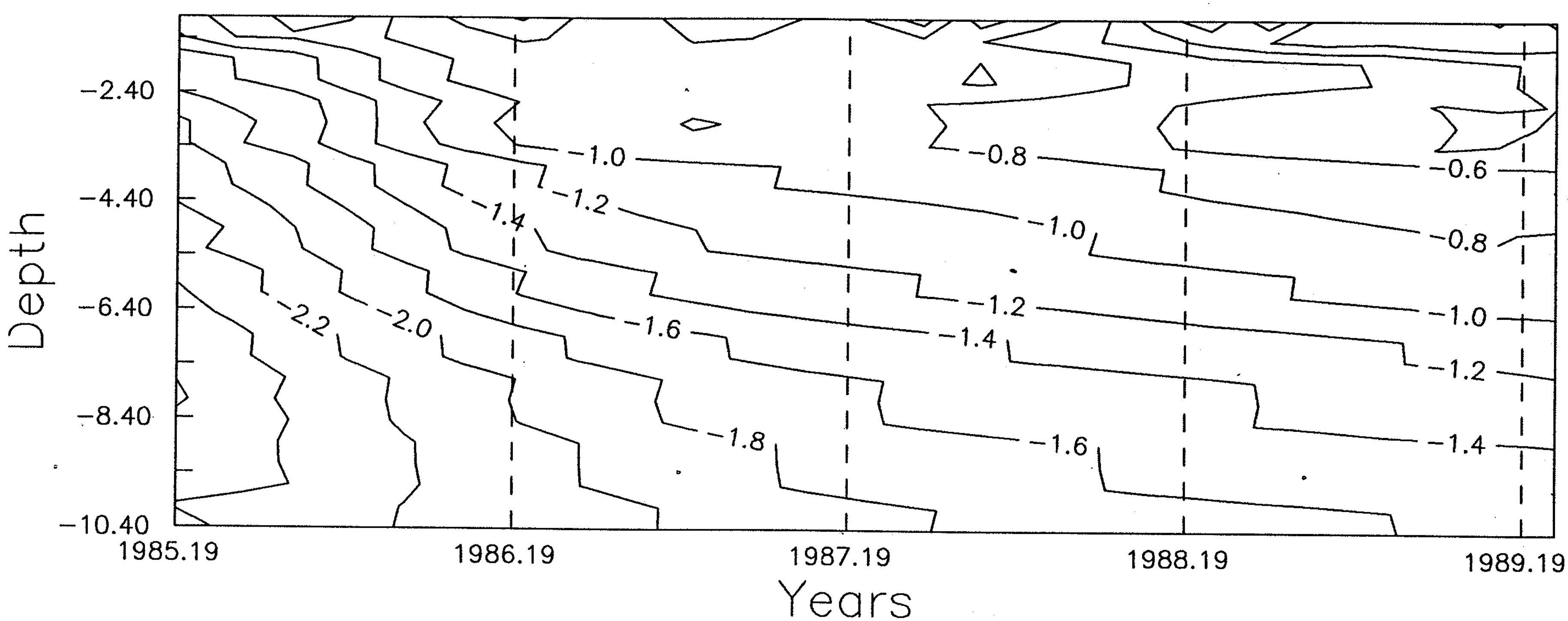
Depth
−1.00
−3.00
−5.00
1984.95
1985.95
1986.95
1987.95
1988.95
Years
−0.6
−1.0
−0.8
−0.6

NWZ1 - T2



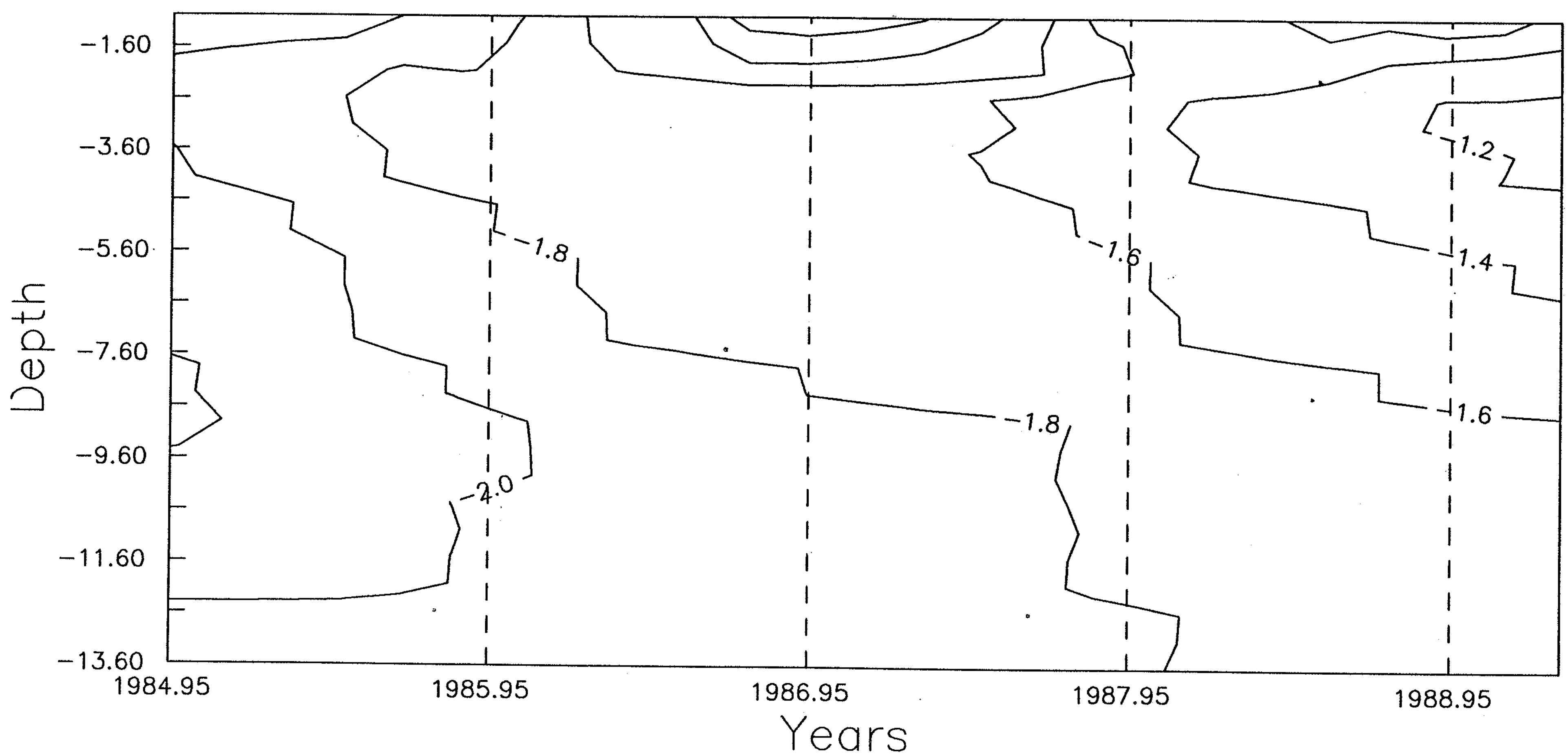
Depth
-1.00
-3.00
-5.00
1985.19
1986.19
1987.19
1988.19
1989.19
Years
-1.4
-1.2
-1.0
-0.16
-0.8
-0.6
-0.4

NWZ1 – T3



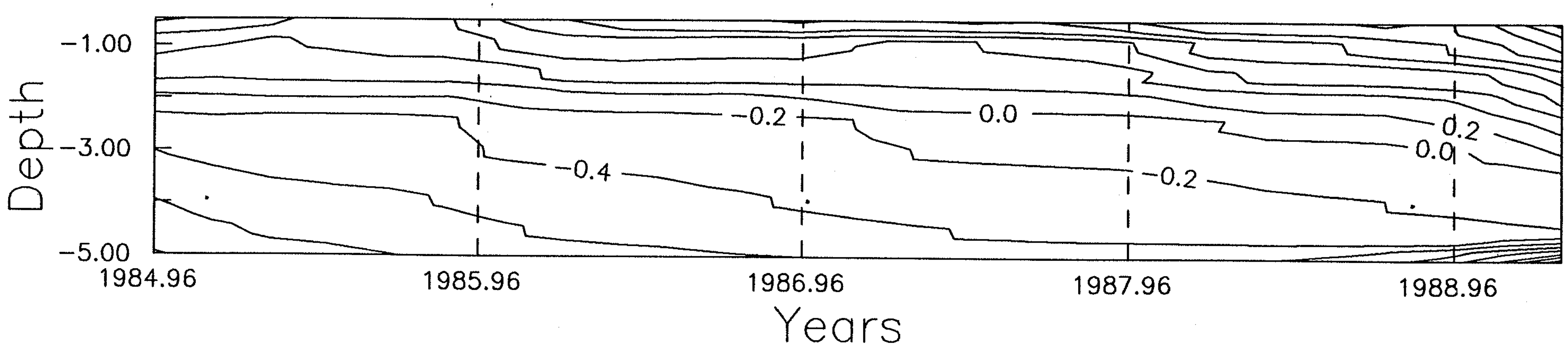
-2.40
-4.40
-6.40
-8.40
-10.40
Depth
1985.19
1986.19
1987.19
1988.19
1989.19
Years
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
-2.0
-2.2

NWZ1 — T4



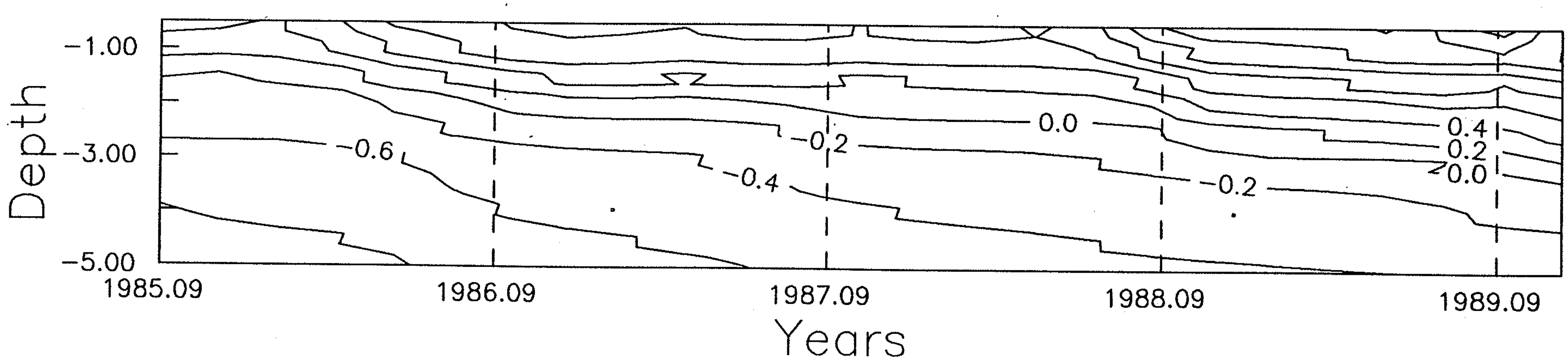
-1.60
-3.60
-5.60
-7.60
-9.60
-11.60
-13.60
Depth
1984.95
1985.95
1986.95
1987.95
1988.95
Years
1.2
1.4
1.6
1.8
2.0

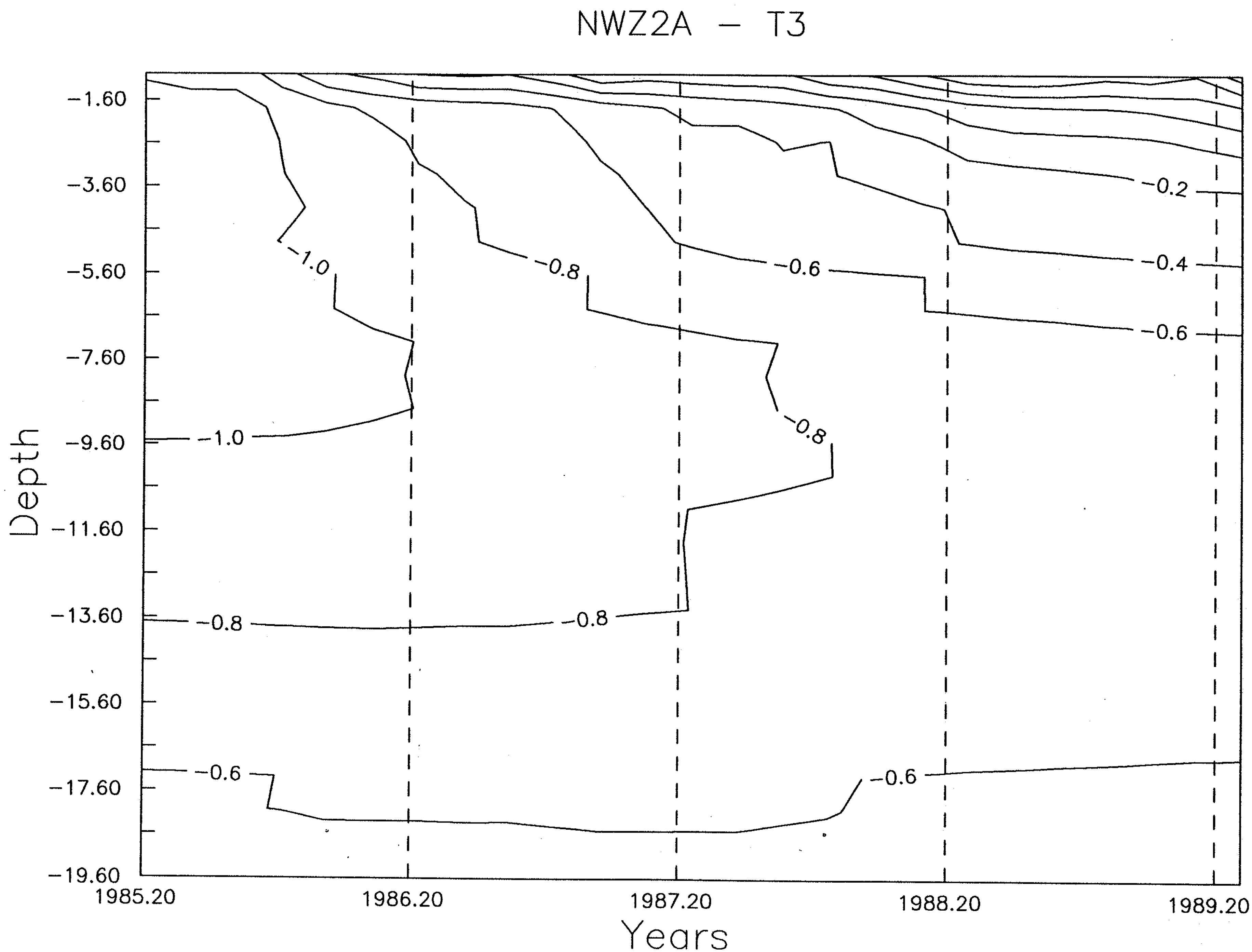
NWZ2A — T1

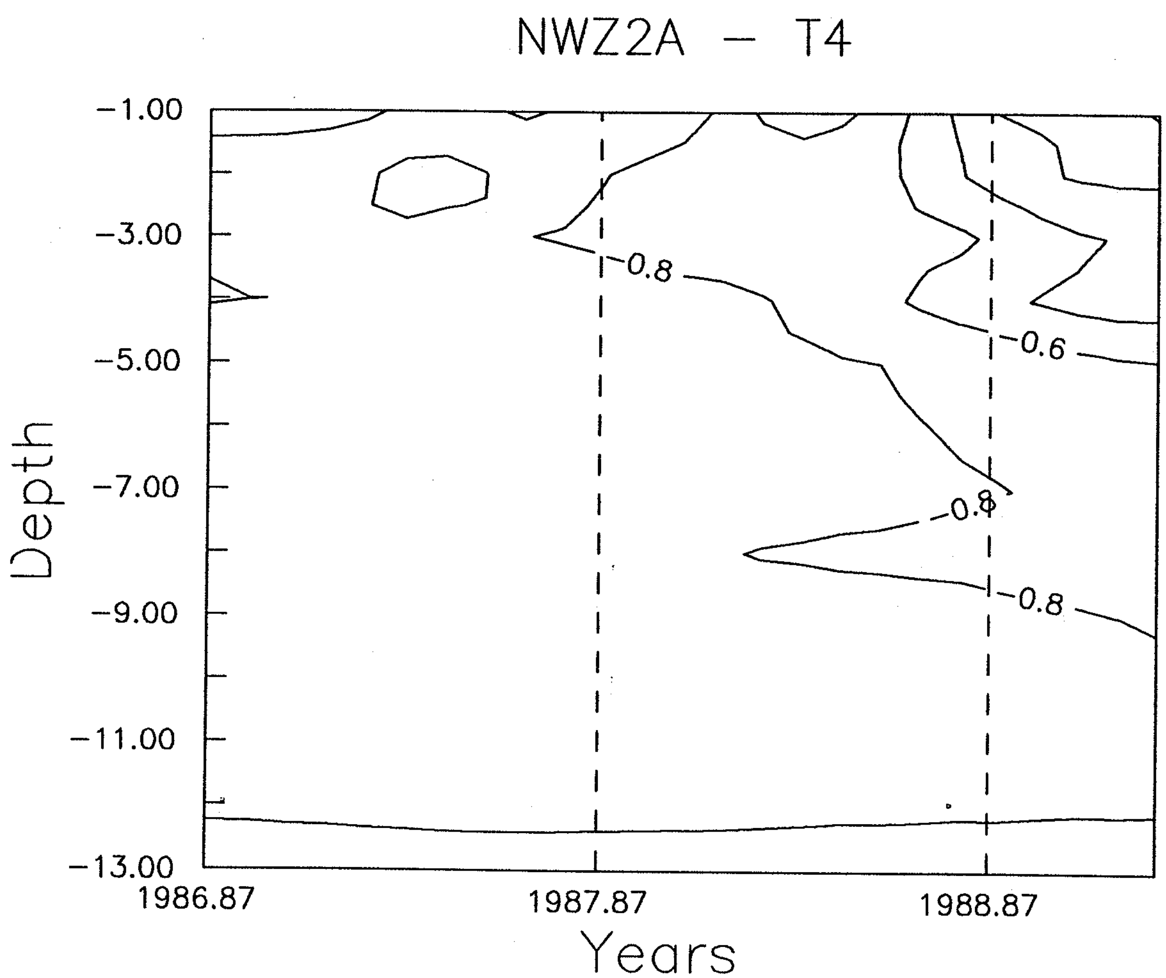


Depth
-1.00
-3.00
-5.00
1984.96
1985.96
1986.96
1987.96
1988.96
Years
-0.4
-0.2
0.0
-0.2
0.2
0.0

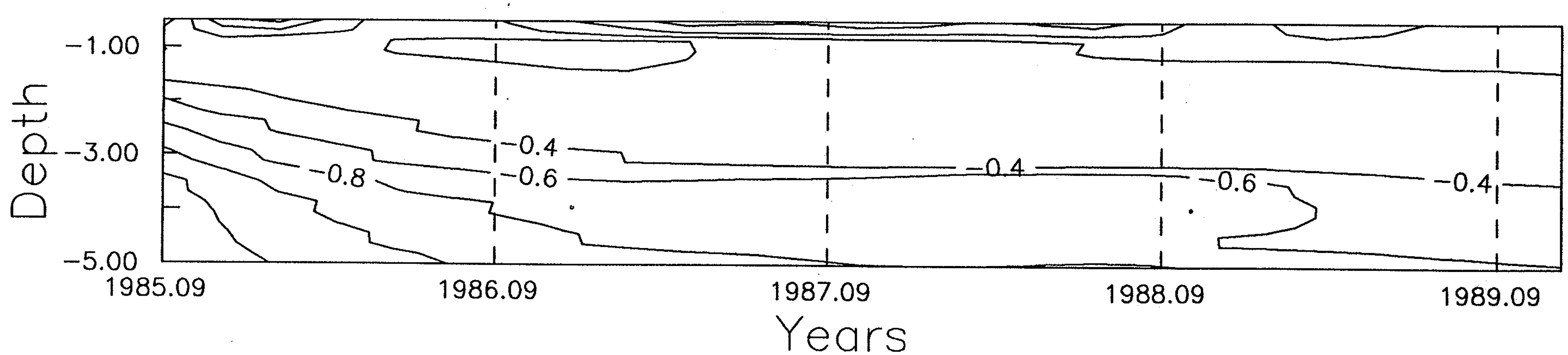
NWZ2A - T2


-1.00
-3.00
-5.00
Depth
-0.6
-0.4
-0.2
0.0
-0.2
0.4
0.2
0.0
1985.09
1986.09
1987.09
1988.09
1989.09
Years


NWZ2A - T3
Depth
-1.60
-3.60
-5.60
-7.60
-9.60
-11.60
-13.60
-15.60
-17.60
-19.60
Years
1985.20
1986.20
1987.20
1988.20
1989.20
-1.0
-0.8
-0.6
-0.4
-0.2

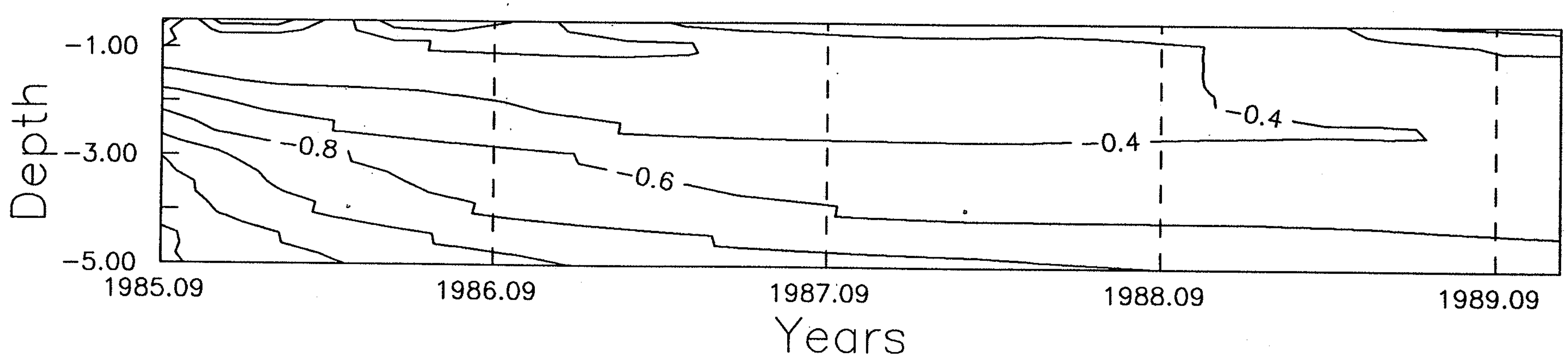

NWZ2A - T4
-1.00
-3.00
-5.00
-7.00
-9.00
-11.00
-13.00
Depth
1986.87
1987.87
1988.87
Years
0.8
0.6
0.8
0.8

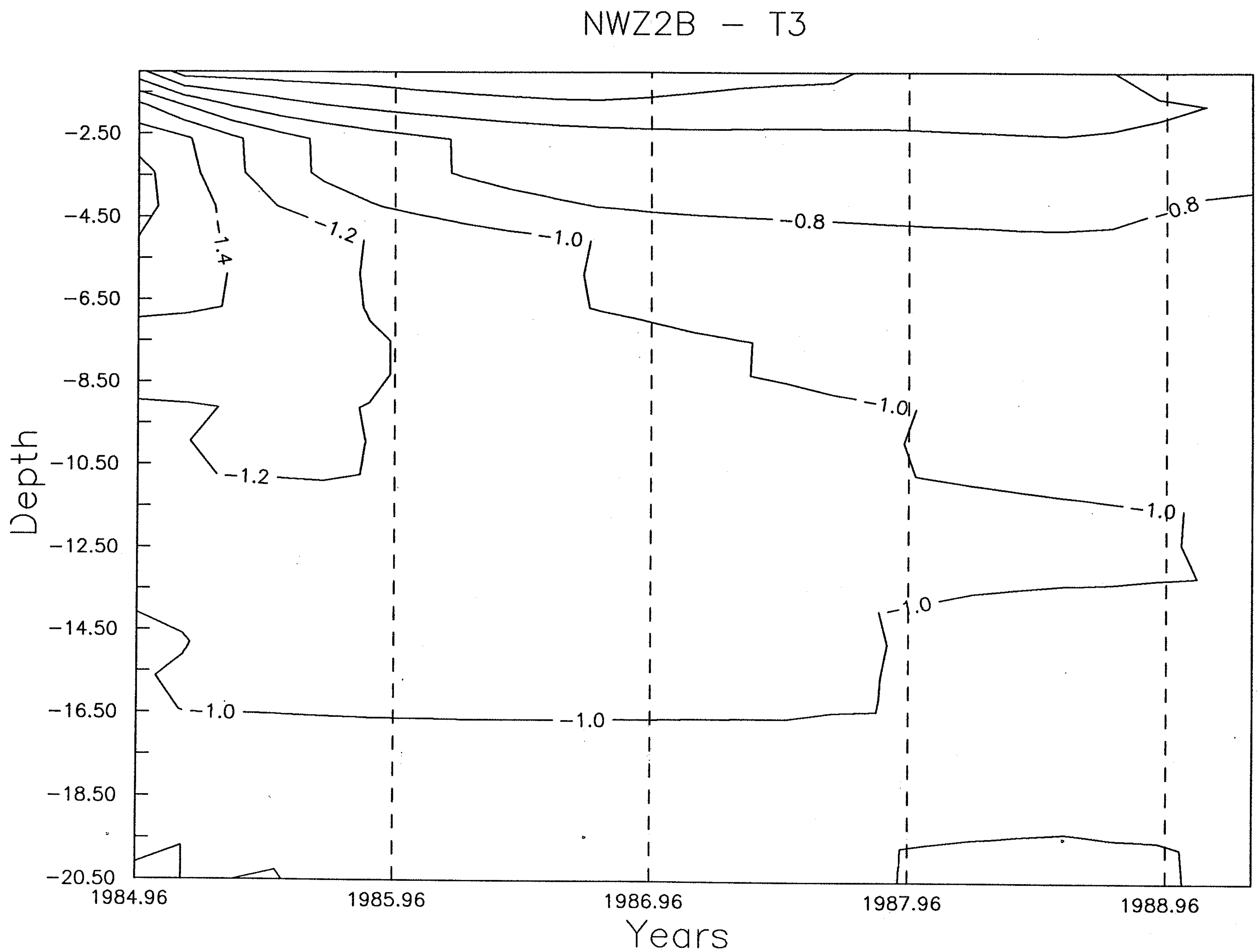
NWZ2B – T1



Depth
-1.00
-3.00
-5.00
-0.4
-0.6
-0.8
-0.4
-0.6
-0.4
1985.09
1986.09
1987.09
1988.09
1989.09
Years

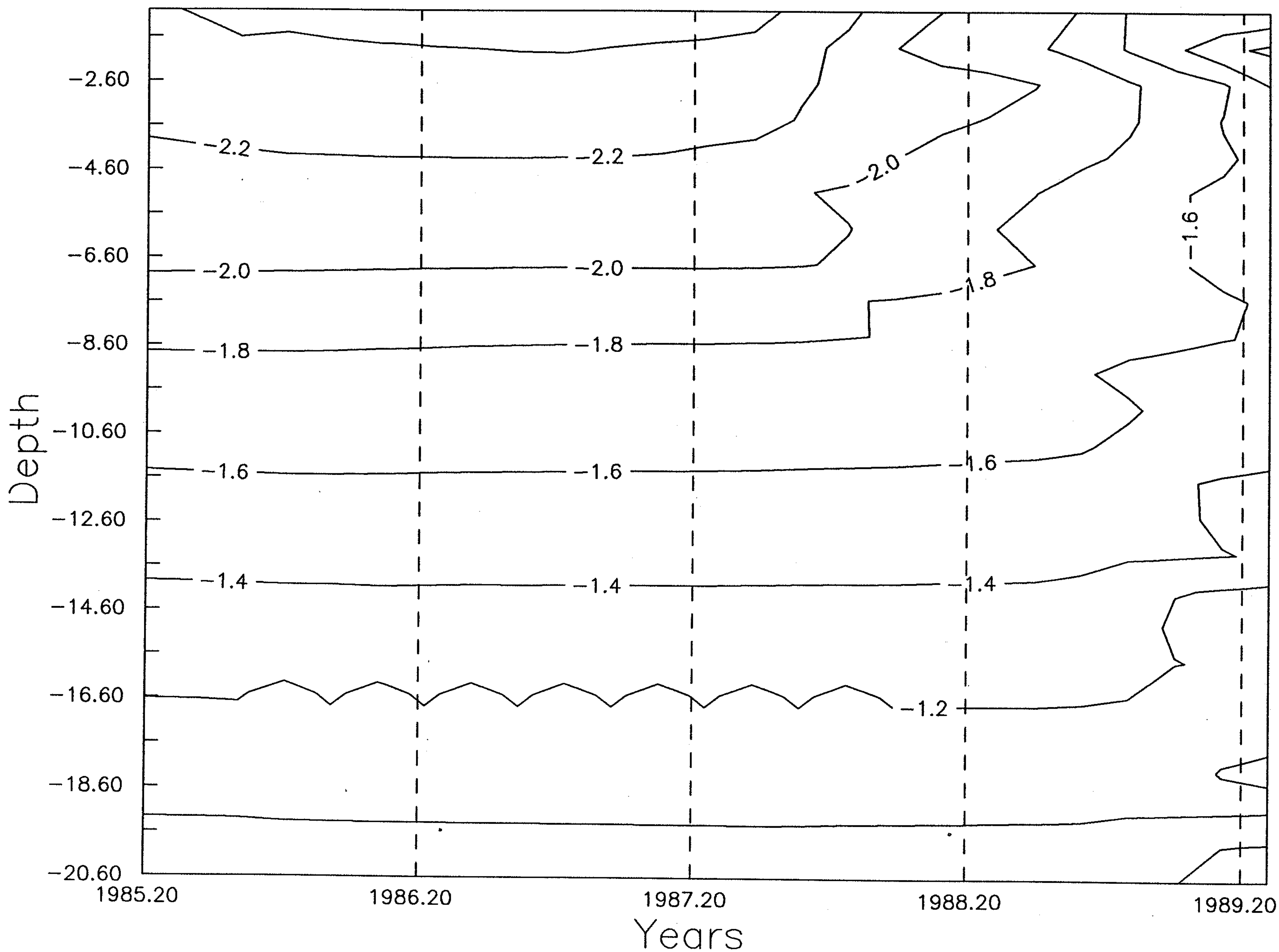
NWZ2B - T2


-1.00
-3.00
-5.00
Depth
-0.8
-0.6
-0.4
-0.4
1985.09
1986.09
1987.09
1988.09
1989.09
Years



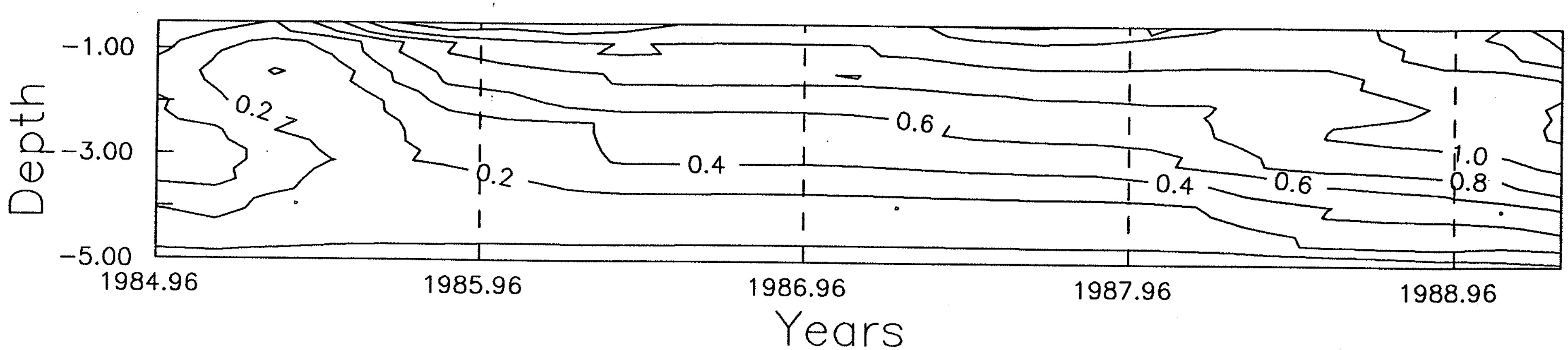
NWZ2B - T3
Depth
-2.50
-4.50
-6.50
-8.50
-10.50
-12.50
-14.50
-16.50
-18.50
-20.50
1984.96
1985.96
1986.96
1987.96
1988.96
Years
-0.8
-1.0
-1.2
-1.4

NWZ2B – T4



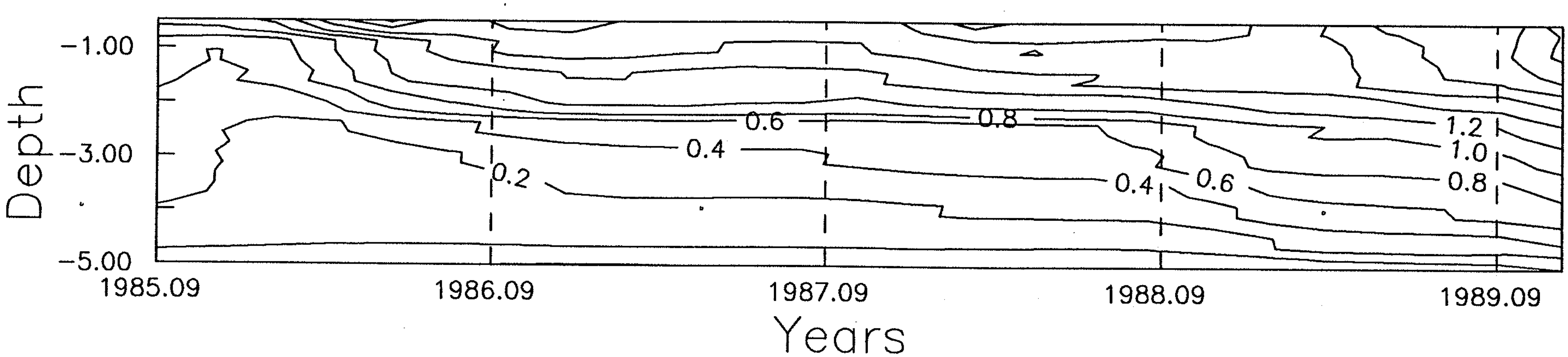
Depth
-2.60
-4.60
-6.60
-8.60
-10.60
-12.60
-14.60
-16.60
-18.60
-20.60
1985.20
1986.20
1987.20
1988.20
1989.20
Years
-2.2
-2.0
-1.8
-1.6
-1.4
-1.2

NWZ2C – T1



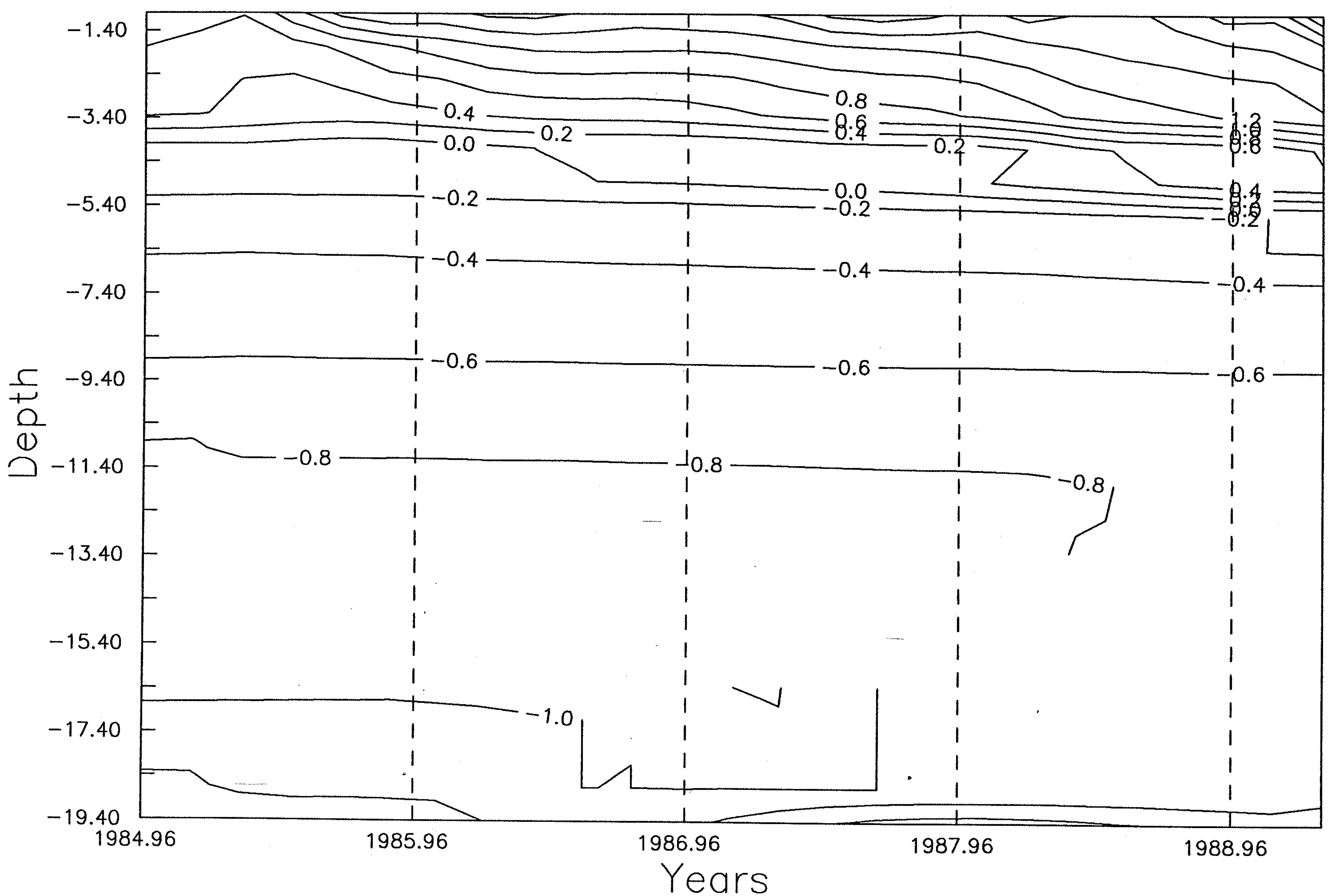
-1.00
-3.00
-5.00
Depth
0.2
0.2
0.4
0.6
0.4
0.6
1.0
0.8
1984.96
1985.96
1986.96
1987.96
1988.96
Years

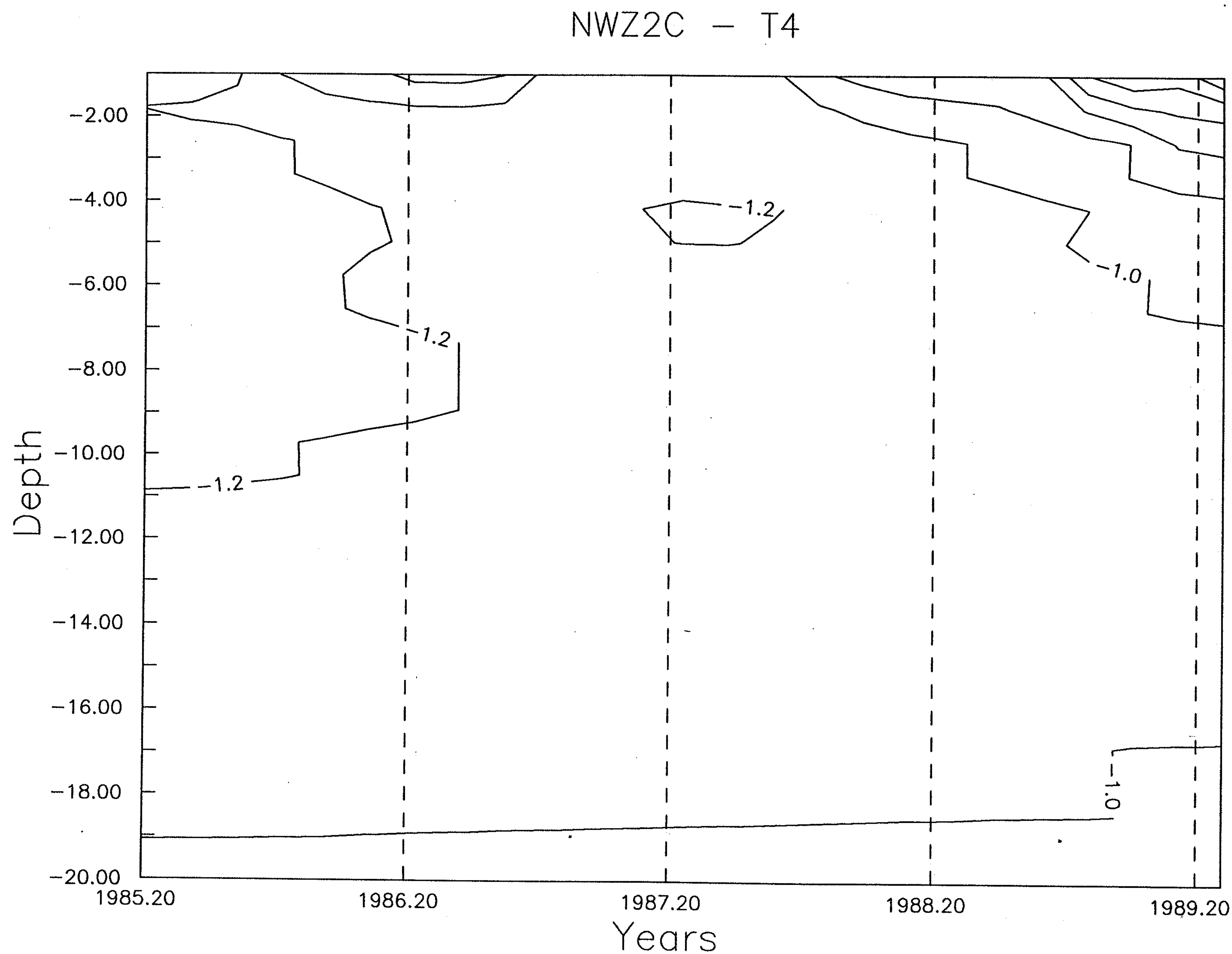
NWZ2C - T2

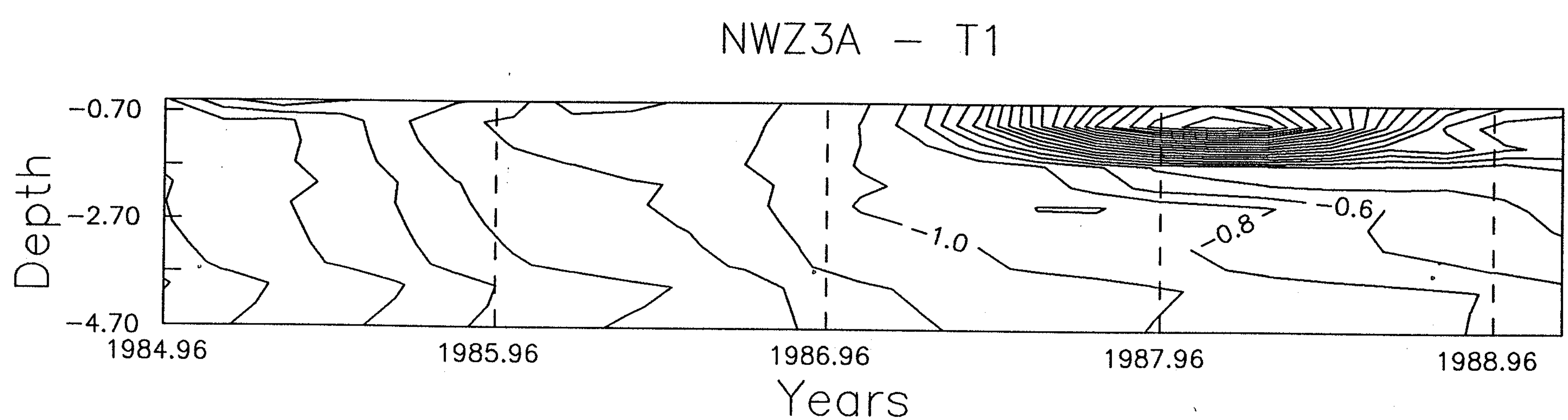


Depth
-1.00
-3.00
-5.00
0.2
0.4
0.6
0.8
0.4
0.6
0.8
1.0
1.2
1985.09
1986.09
1987.09
1988.09
1989.09
Years

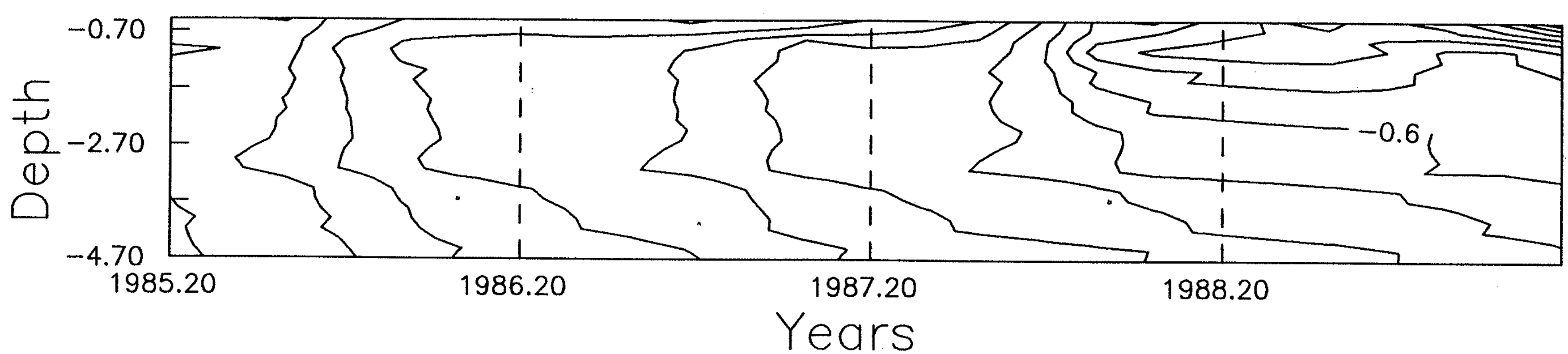
NWZ2C - T3


Depth
-1.40
-3.40
-5.40
-7.40
-9.40
-11.40
-13.40
-15.40
-17.40
-19.40
1984.96
1985.96
1986.96
1987.96
1988.96
Years
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
1.2

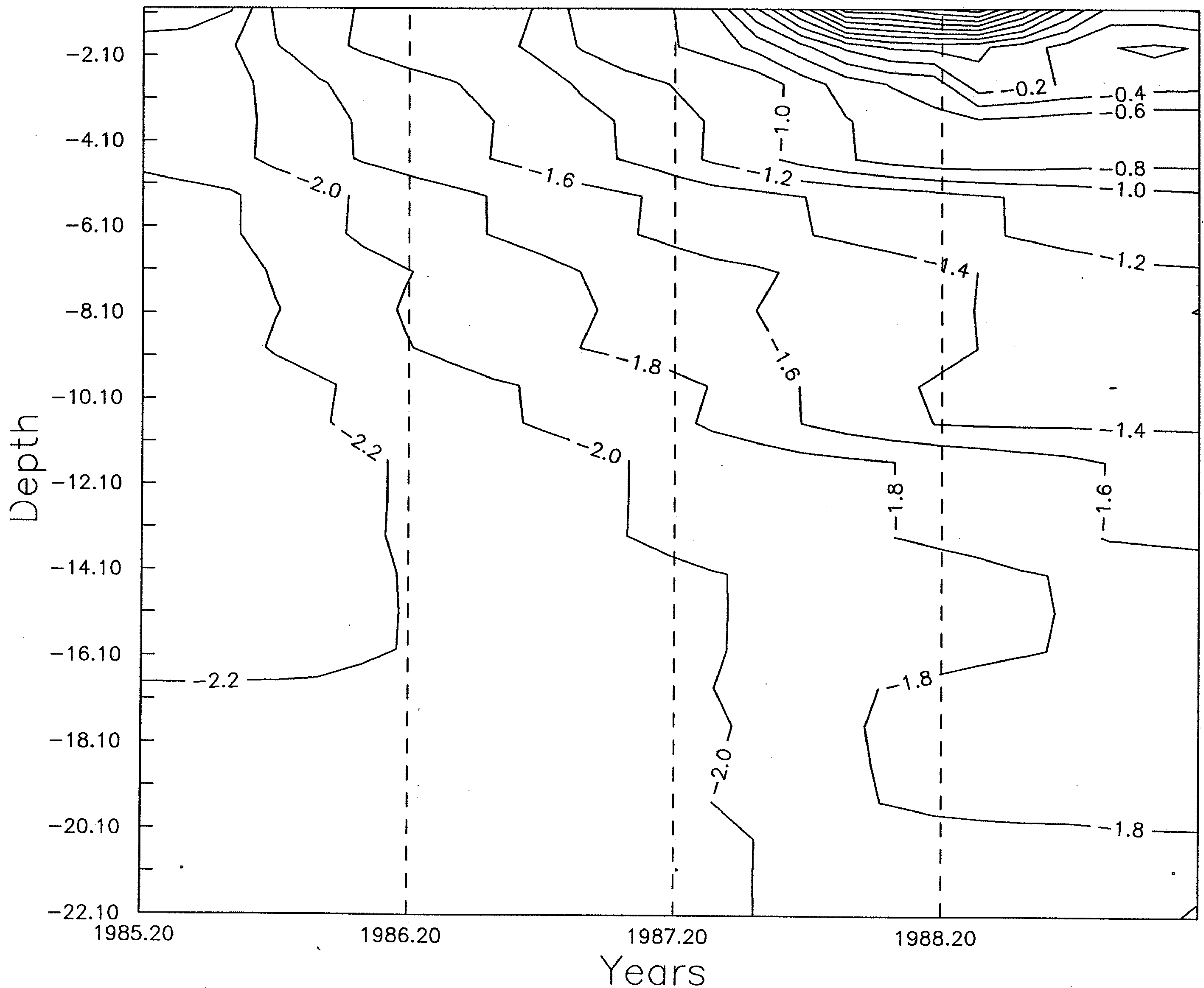

NWZ2C - T4
Depth
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
-14.00
-16.00
-18.00
-20.00
1985.20
1986.20
1987.20
1988.20
1989.20
Years
-1.2
-1.2
-1.2
-1.0
-1.0


NWZ3A – T1
Depth
−0.70
−2.70
−4.70
−1.0
−0.8
−0.6
1984.96
1985.96
1986.96
1987.96
1988.96
Years

NWZ3A – T2

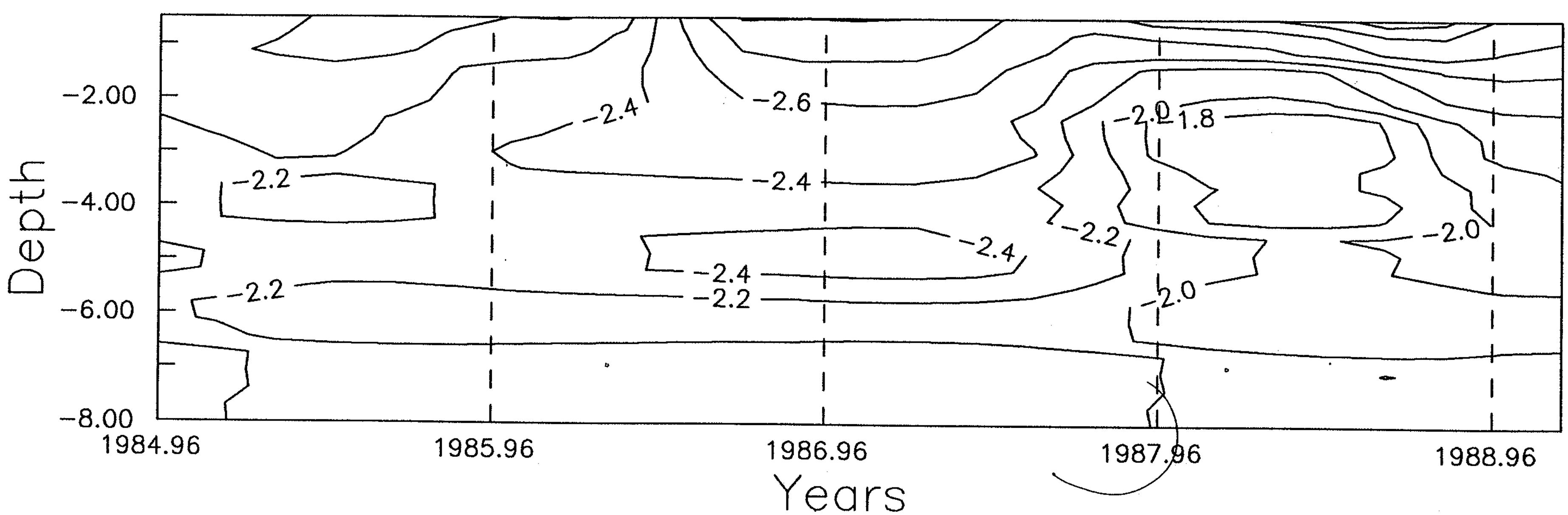


NWZ5A — T3



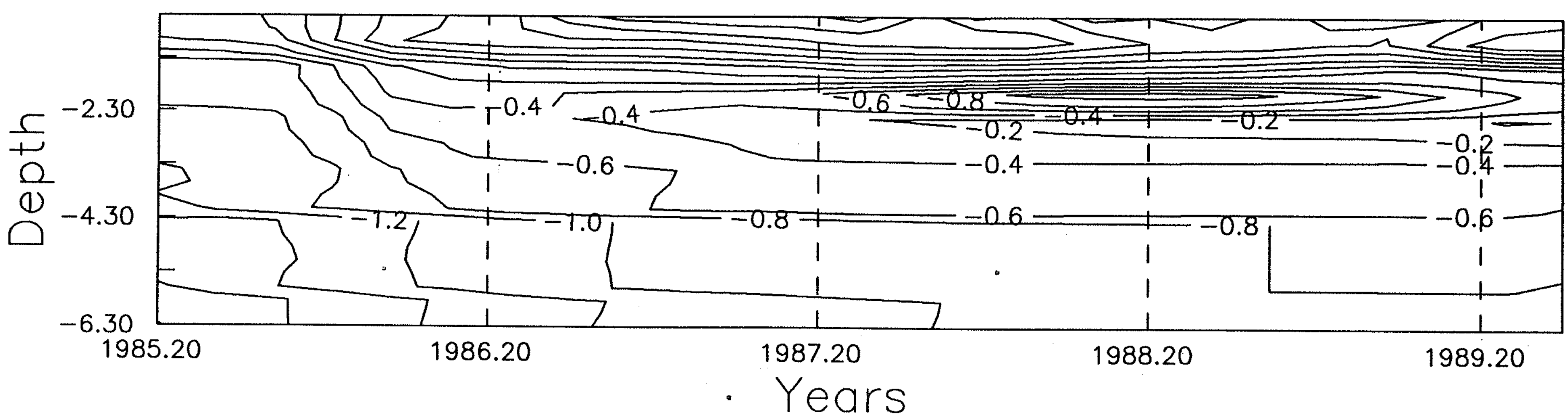
Depth
-2.10
-4.10
-6.10
-8.10
-10.10
-12.10
-14.10
-16.10
-18.10
-20.10
-22.10
1985.20
1986.20
1987.20
1988.20
Years
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
-2.0
-2.2

NWZ3A - T4



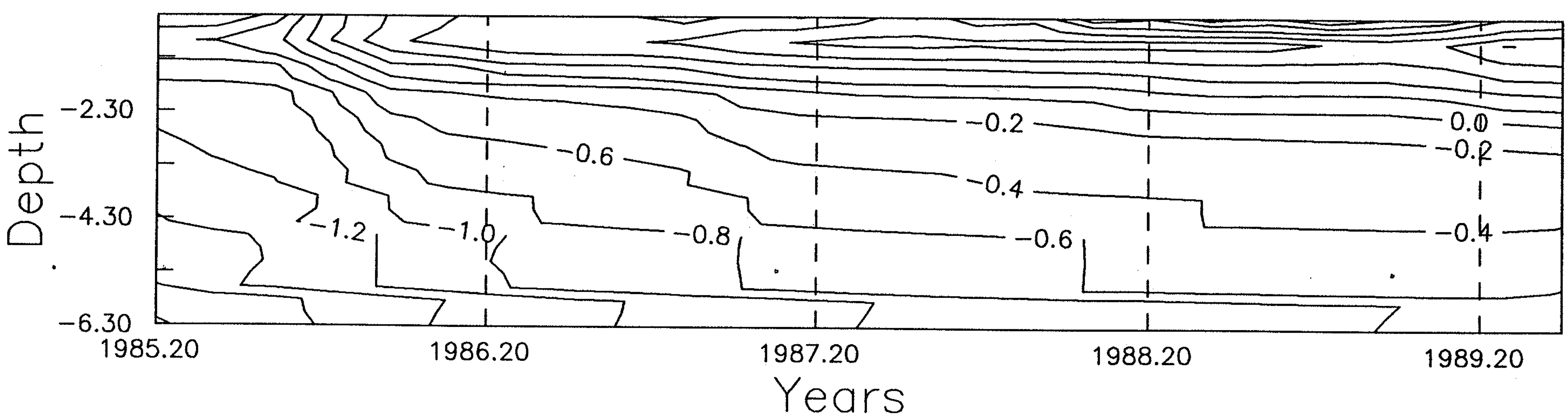
Depth
-2.00
-4.00
-6.00
-8.00
1984.96
1985.96
1986.96
1987.96
1988.96
Years
-2.2
-2.4
-2.6
-2.4
-2.2
-2.4
-2.2
-2.4
-2.2
-2.0
-1.8
-2.0
-2.0

NWZ3B – T1



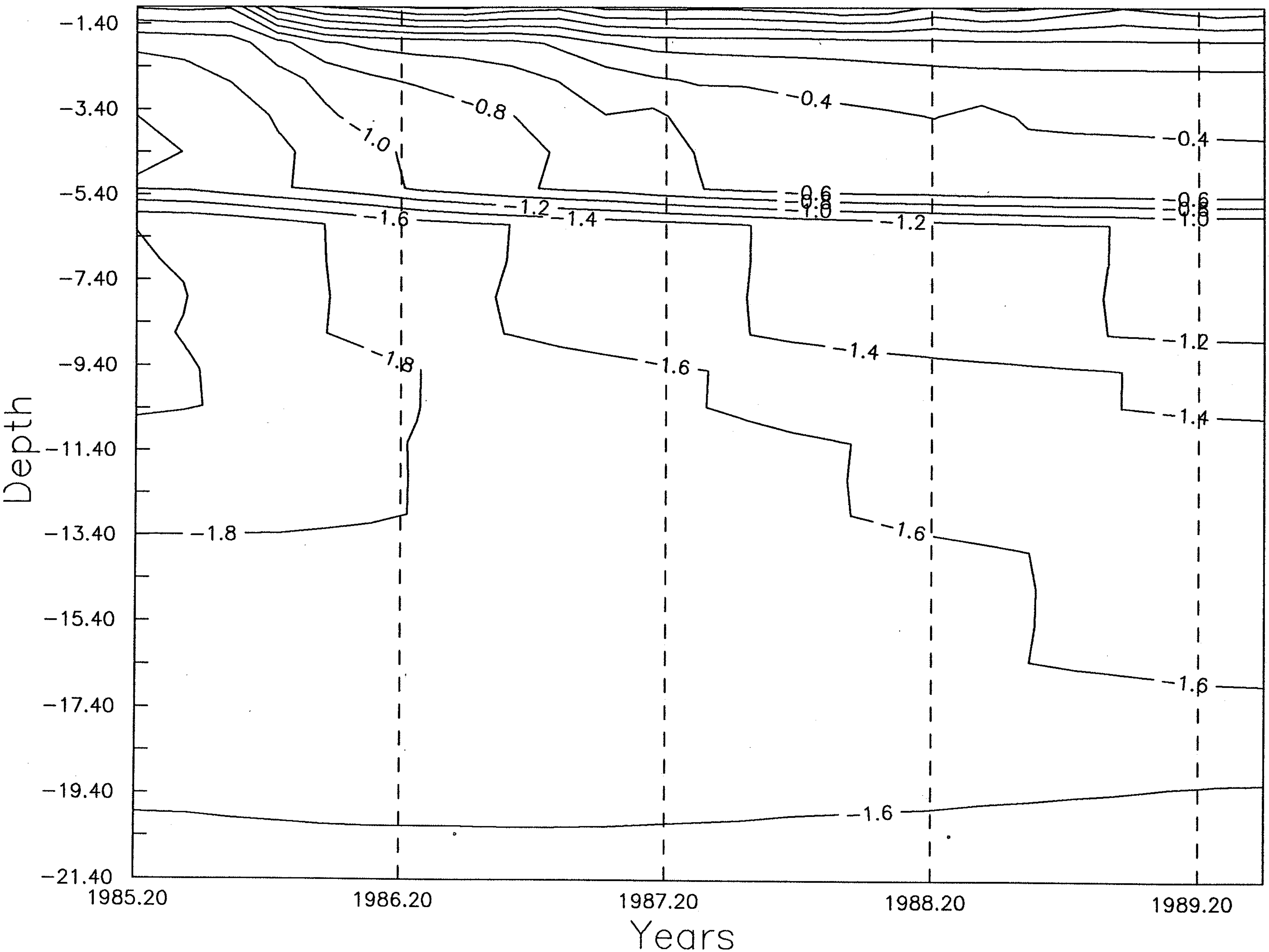
Depth
-2.30
-4.30
-6.30
1985.20
1986.20
1987.20
1988.20
1989.20
Years
-0.4
-0.6
-0.8
-1.0
-1.2
-0.2

NWZ3B – T2



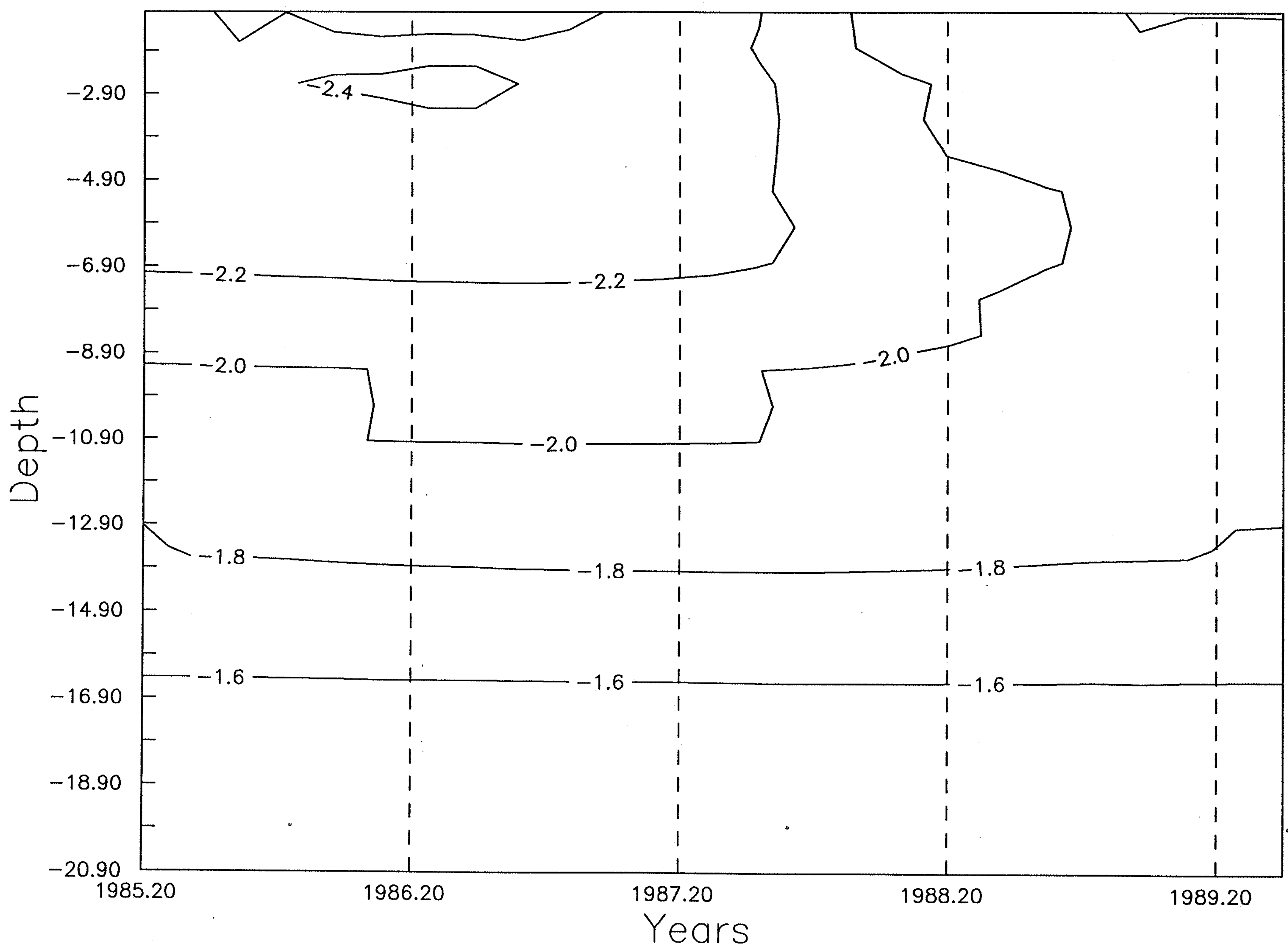
Depth
-2.30
-4.30
-6.30
1985.20
1986.20
1987.20
1988.20
1989.20
Years
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2

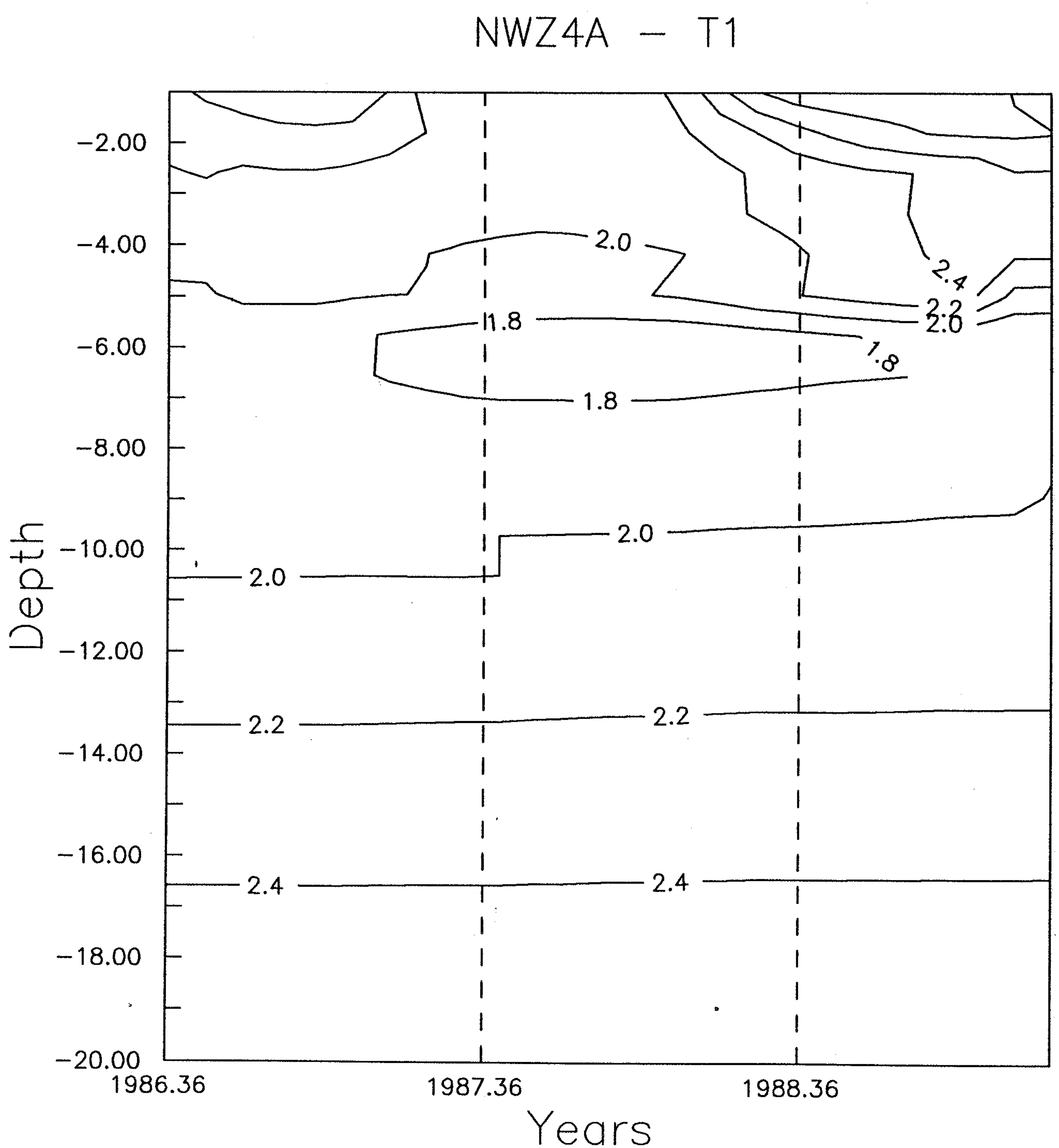
NWZ3B - T3



-1.40
-3.40
-5.40
-7.40
-9.40
-11.40
-13.40
-15.40
-17.40
-19.40
-21.40
Depth
1985.20
1986.20
1987.20
1988.20
1989.20
Years
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8

NWZ3B - T4


-2.4
-2.2
-2.2
-2.0
-2.0
-2.0
-1.8
-1.8
-1.8
-1.6
-1.6
-1.6
-2.90
-4.90
-6.90
-8.90
-10.90
-12.90
-14.90
-16.90
-18.90
-20.90
Depth
1985.20
1986.20
1987.20
1988.20
1989.20
Years


NWZ4A — T1
Depth
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
-14.00
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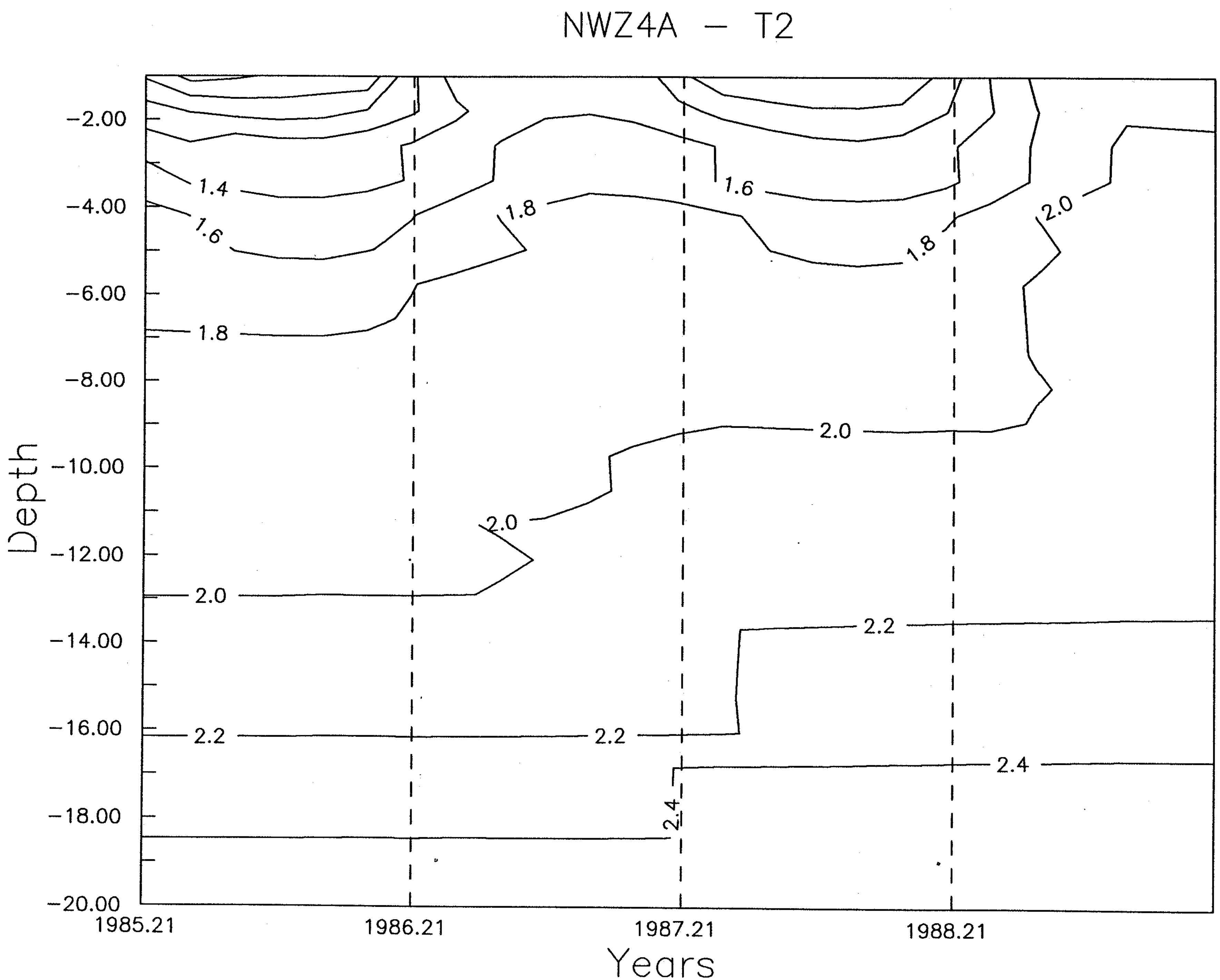
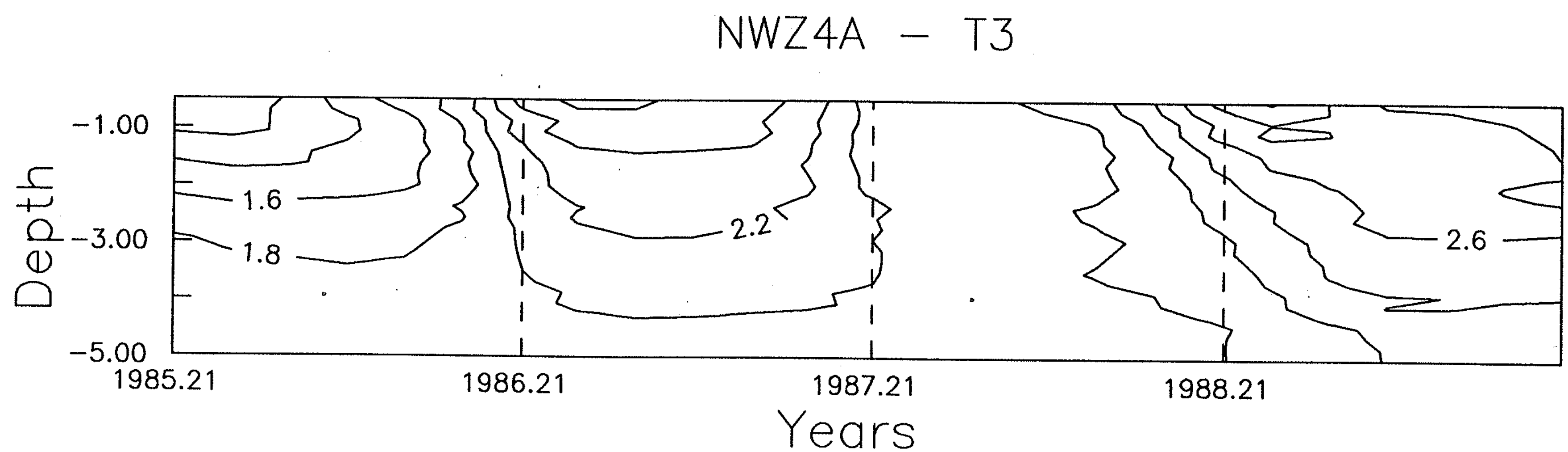
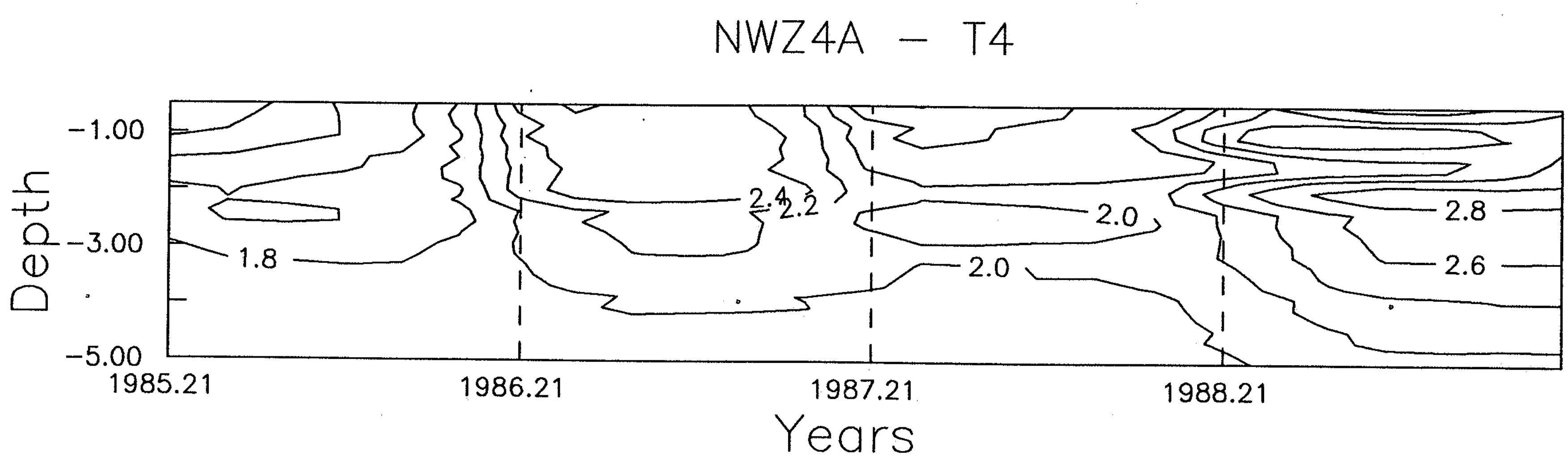
-18.00
-20.00
1986.36
1987.36
1988.36
Years
2.4
2.2
2.0
1.8

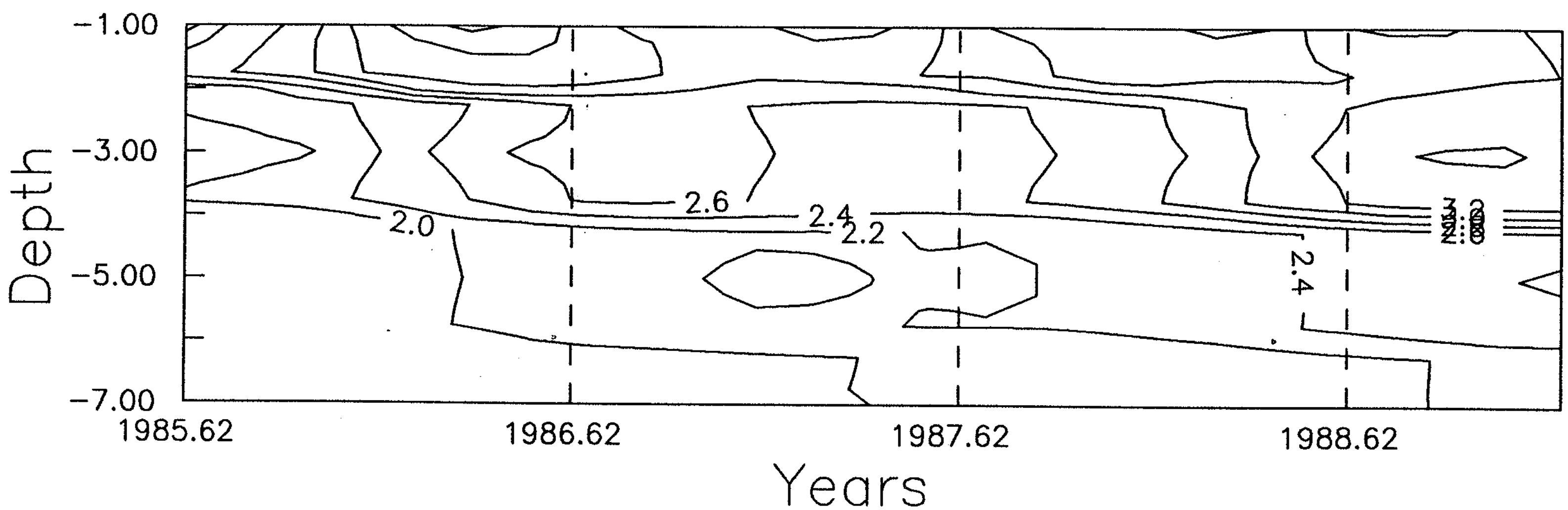

NWZ4A - T2
Depth
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
-14.00
-16.00
-18.00
-20.00
1985.21
1986.21
1987.21
1988.21
Years
1.4
1.6
1.8
2.0
2.2
2.4



NWZ4A – T3
Depth
-1.00
-3.00
-5.00
1985.21
1986.21
1987.21
1988.21
Years
1.6
1.8
2.2
2.6

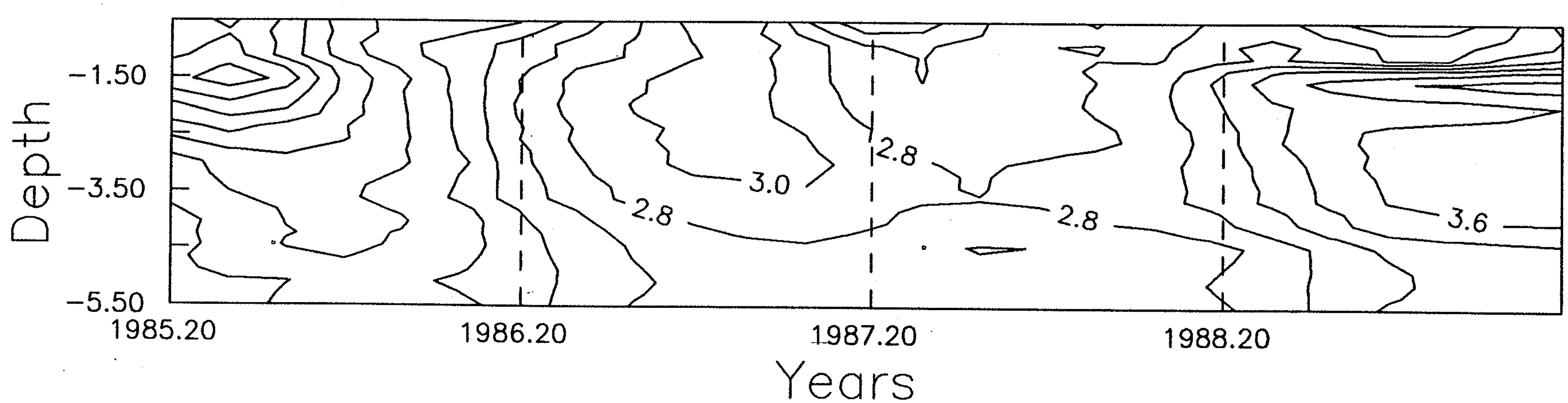

NWZ4A – T4
Depth
-1.00
-3.00
-5.00
1985.21
1986.21
1987.21
1988.21
Years
1.8
2.4
2.2
2.0
2.0
2.8
2.6

NWZ4B – T1



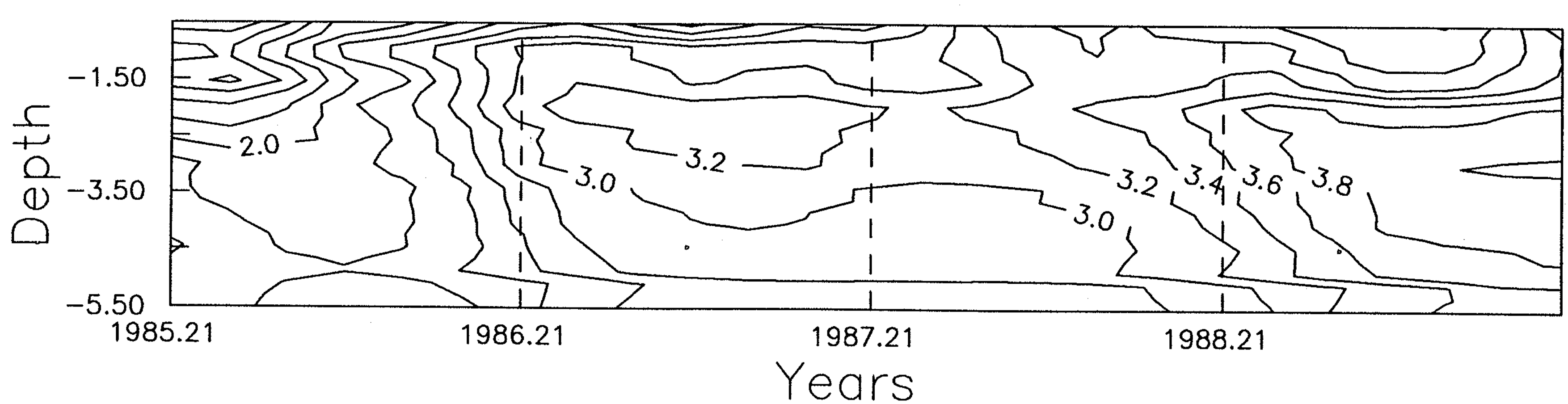
Depth
−1.00
−3.00
−5.00
−7.00
1985.62
1986.62
1987.62
1988.62
Years
2.0
2.2
2.4
2.6
2.4

NWZ4B – T2



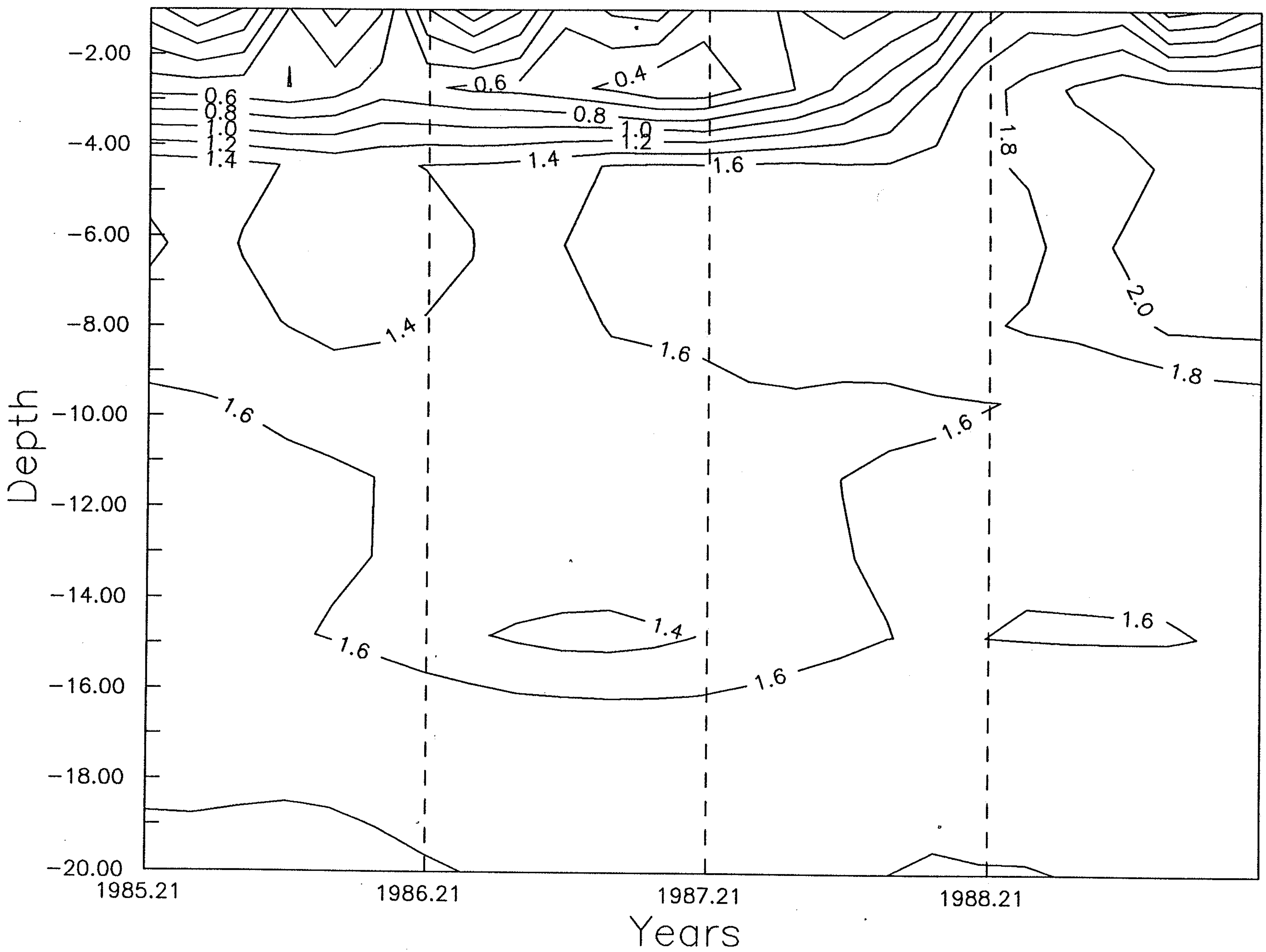
Depth
-1.50
-3.50
-5.50
1985.20
1986.20
1987.20
1988.20
Years
3.0
2.8
2.8
2.8
3.6

NWZ4B – T3

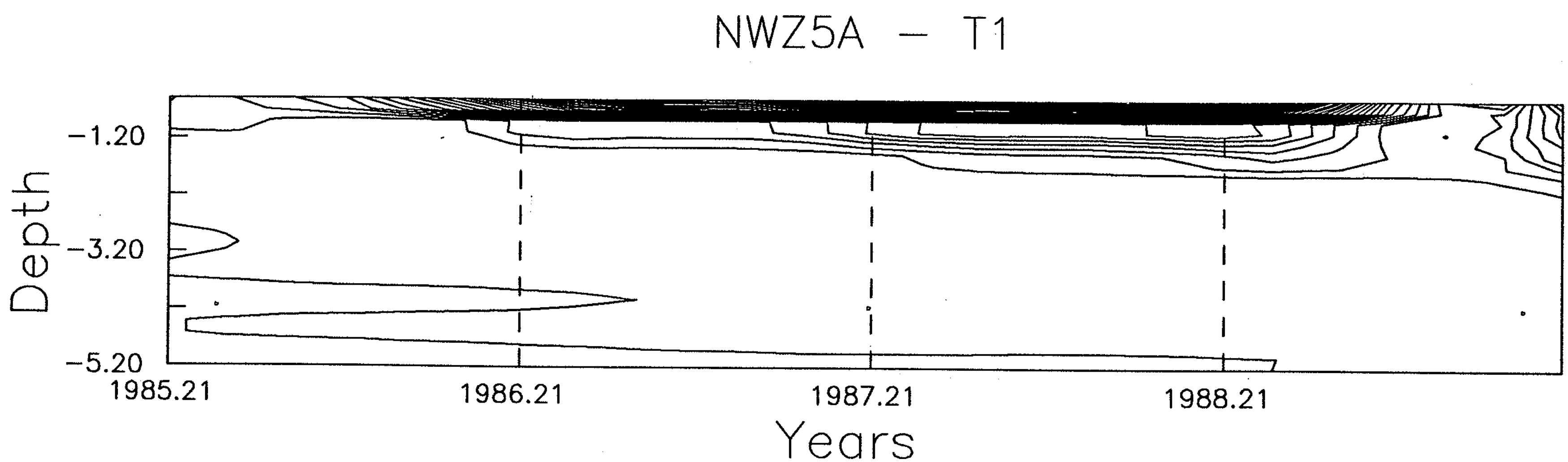


Depth
-1.50
-3.50
-5.50
1985.21
1986.21
1987.21
1988.21
Years
2.0
3.0
3.2
3.2
3.0
3.4
3.6
3.8

NWZ4B – T4



-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
-14.00
-16.00
-18.00
-20.00
Depth
1985.21
1986.21
1987.21
1988.21
Years
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0


NWZ5A – T1
Depth
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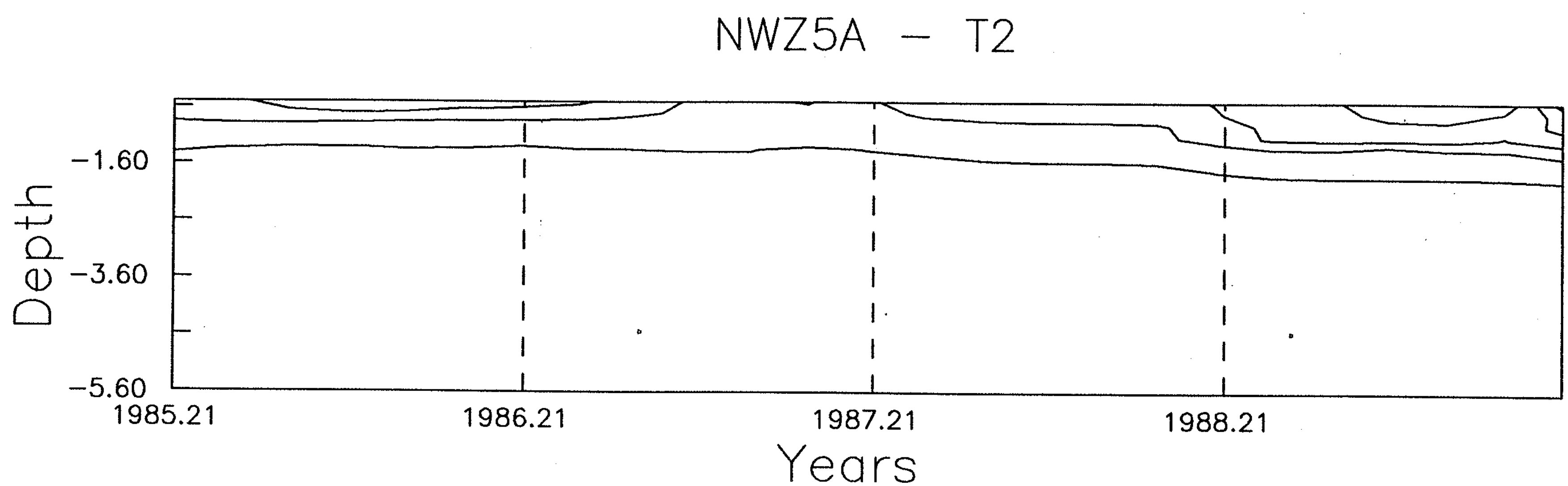
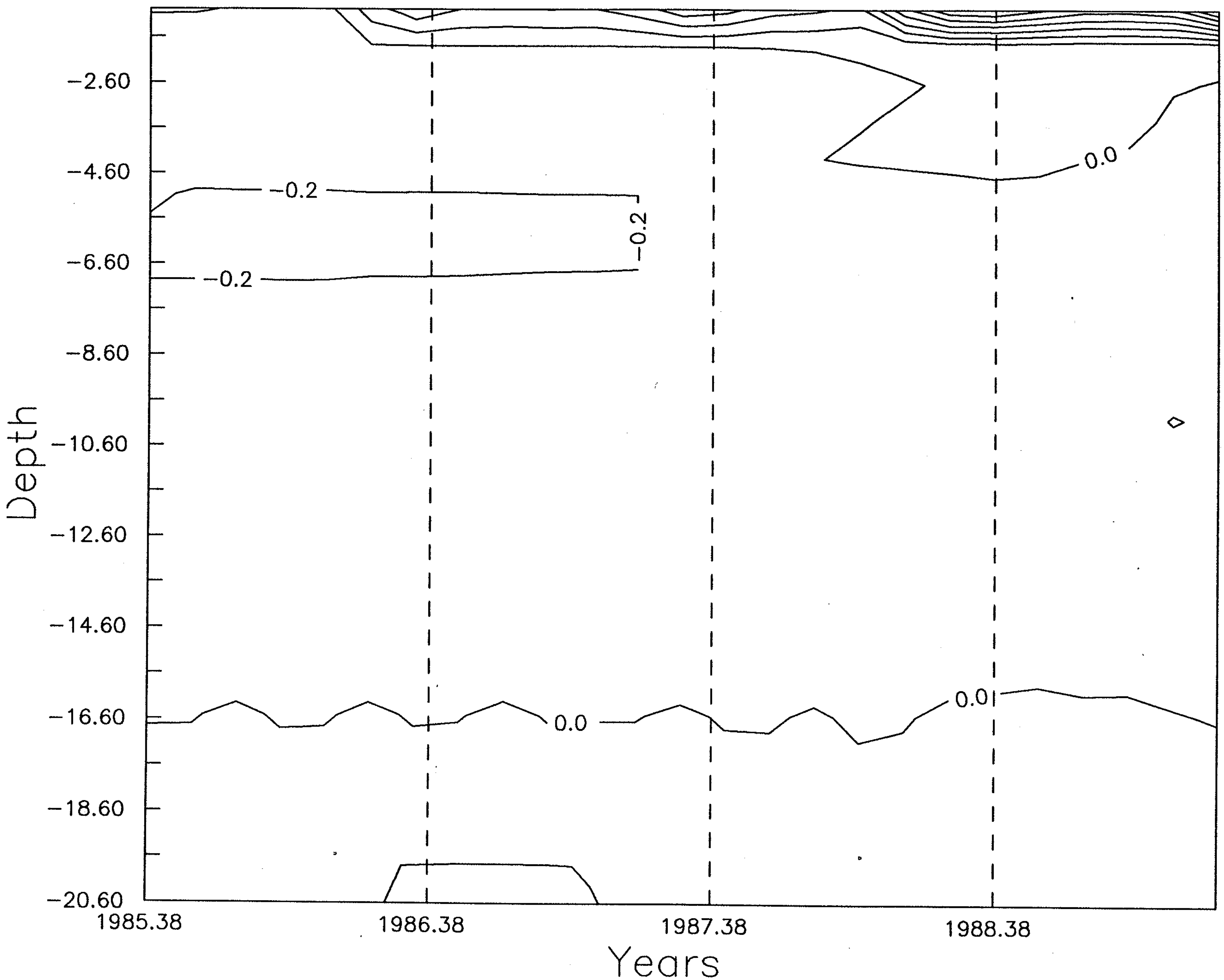
-3.20
-5.20
1985.21
1986.21
1987.21
1988.21
Years

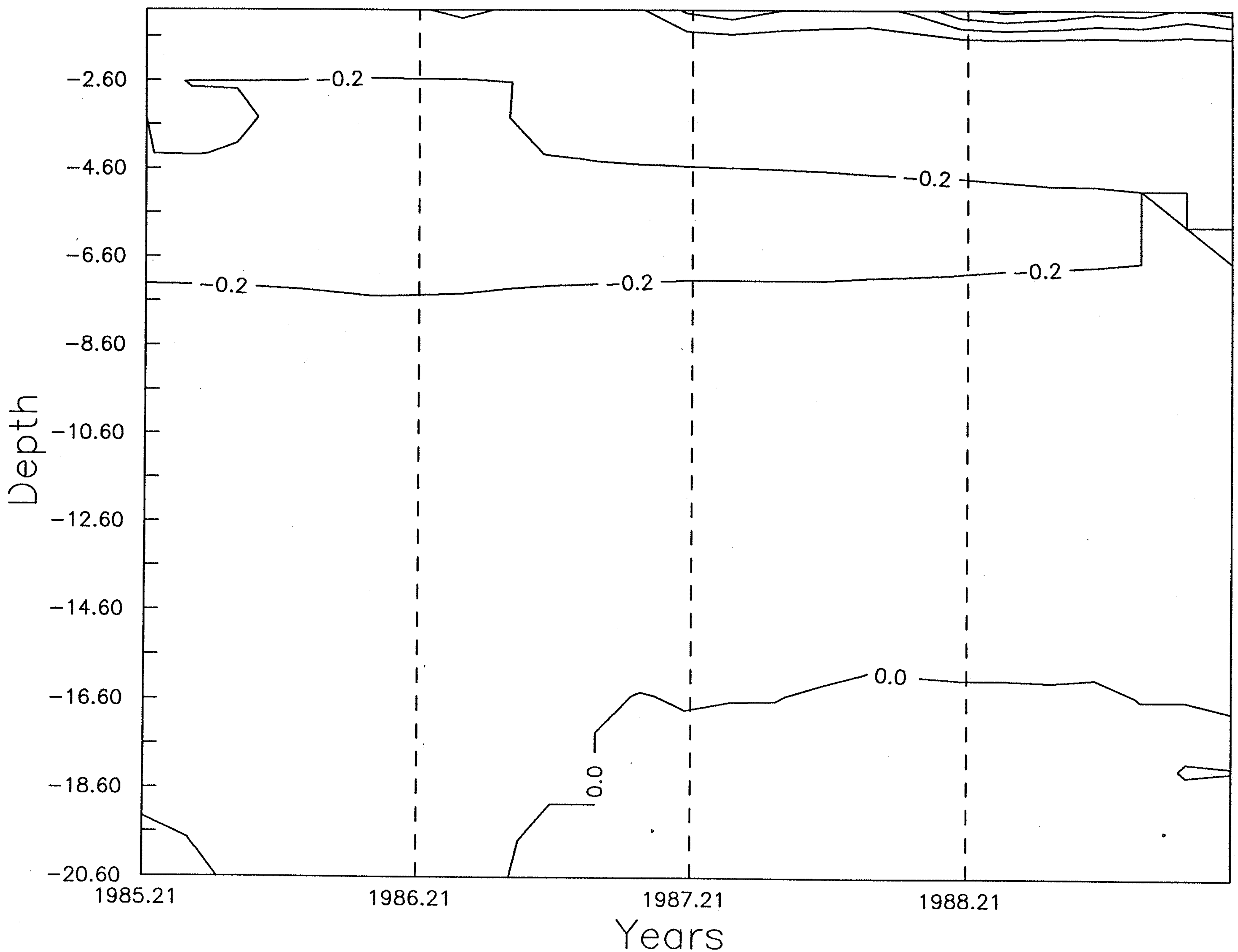

NWZ5A – T2
Depth
−1.60
−3.60
−5.60
1985.21
1986.21
1987.21
1988.21
Years

NWZ5A – T3



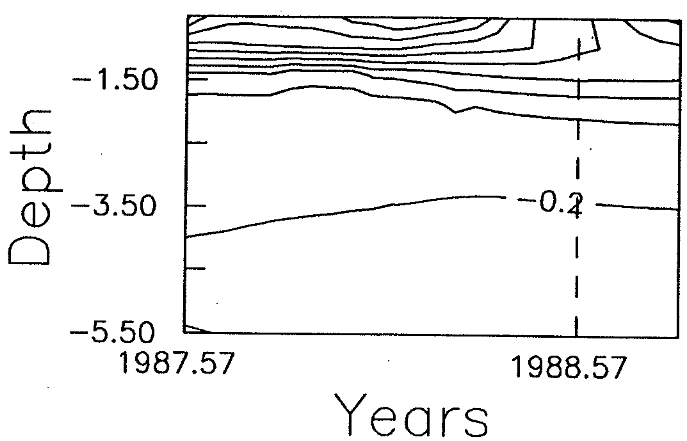
Depth
-2.60
-4.60
-6.60
-8.60
-10.60
-12.60
-14.60
-16.60
-18.60
-20.60
1985.38
1986.38
1987.38
1988.38
Years
-0.2
-0.2
-0.2
0.0
0.0
0.0

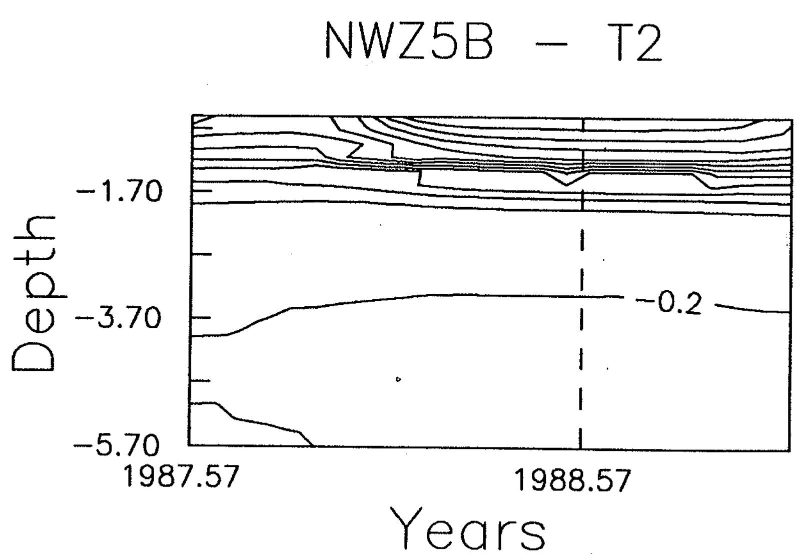
NWZ5A – T4

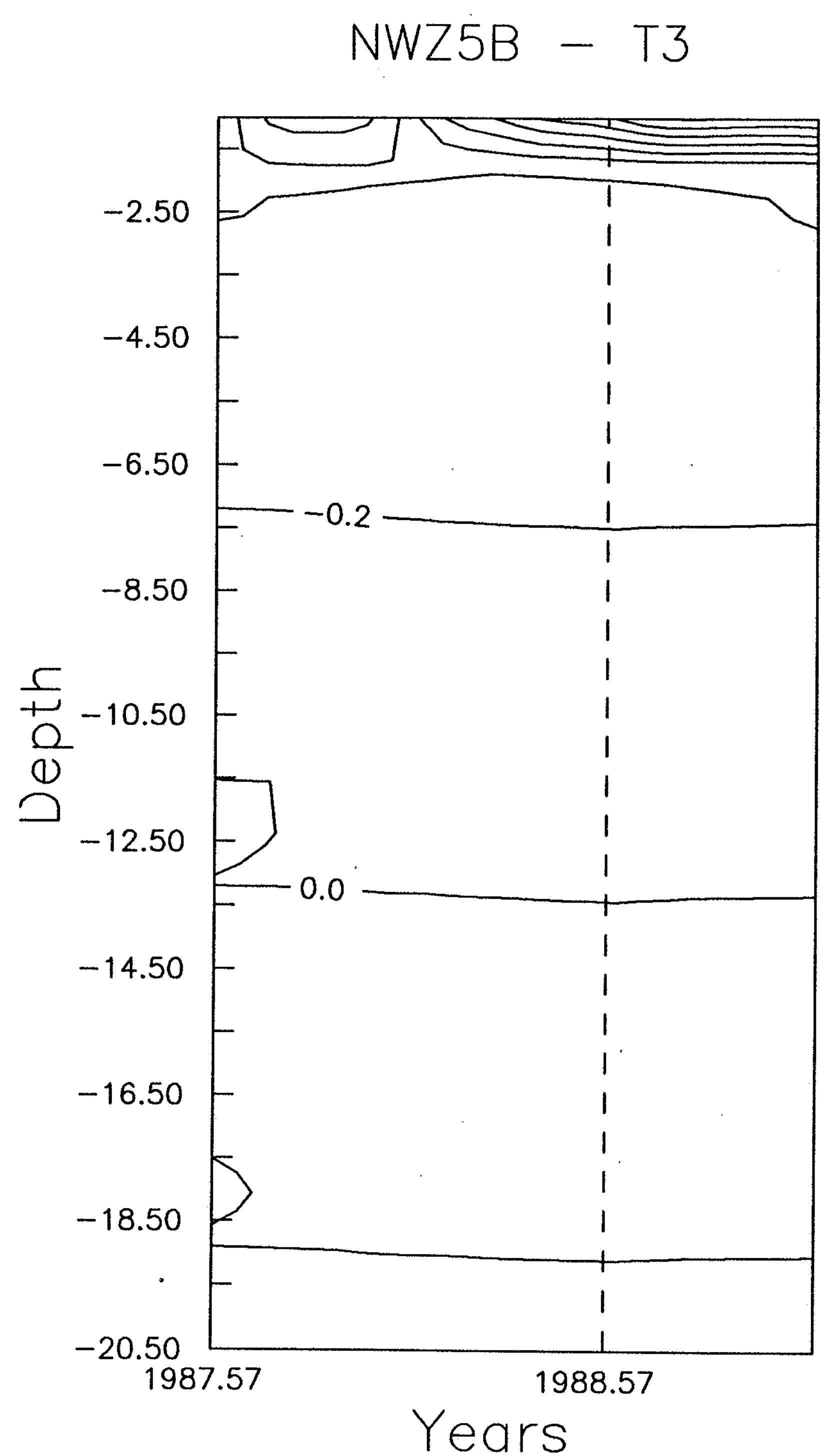


-0.2
-0.2
-0.2
-0.2
-0.2
0.0
0.0
-2.60
-4.60
-6.60
-8.60
-10.60
-12.60
-14.60
-16.60
-18.60
-20.60
Depth
1985.21
1986.21
1987.21
1988.21
Years

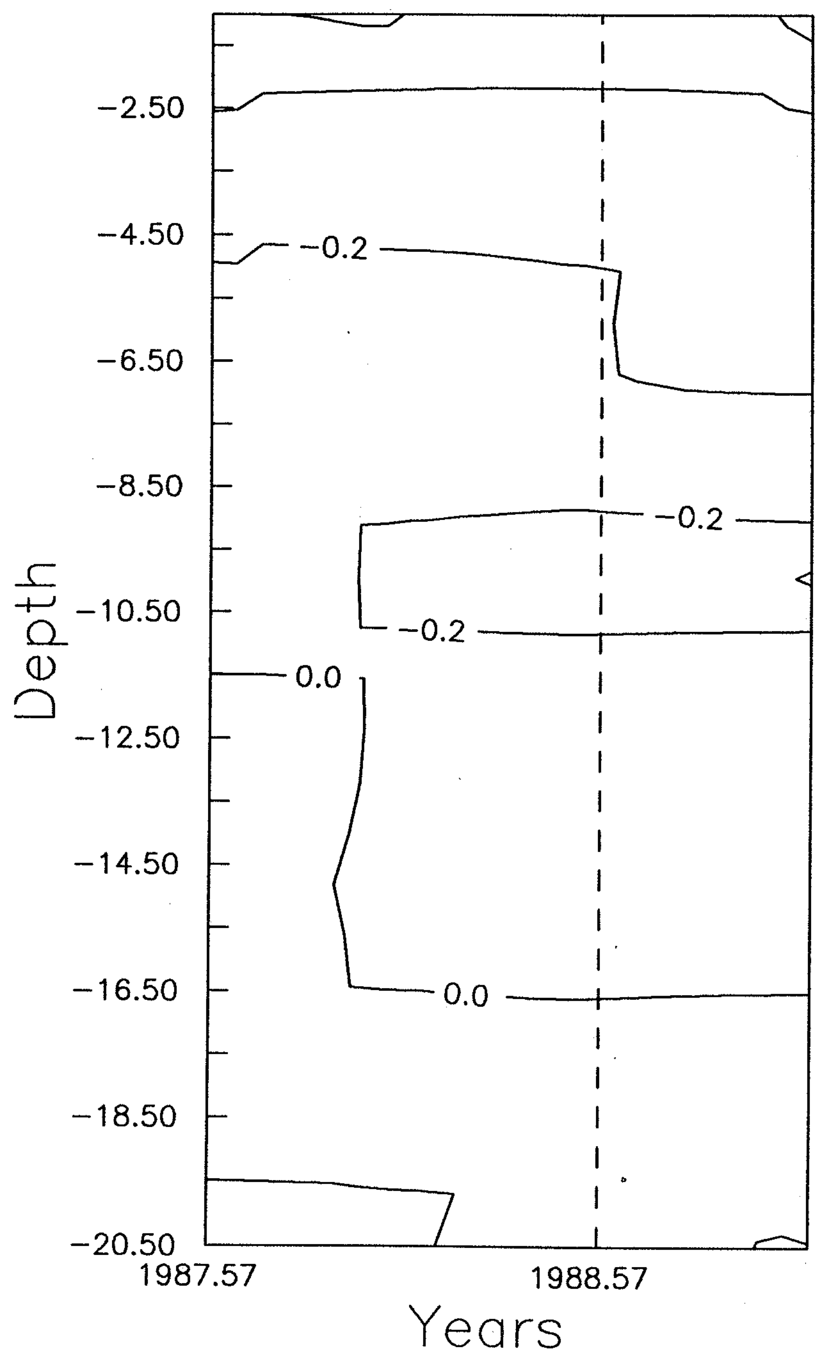
NWZ5B — T1




NWZ5B - T2
Depth
-1.70
-3.70
-5.70
-0.2
1987.57
1988.57
Years

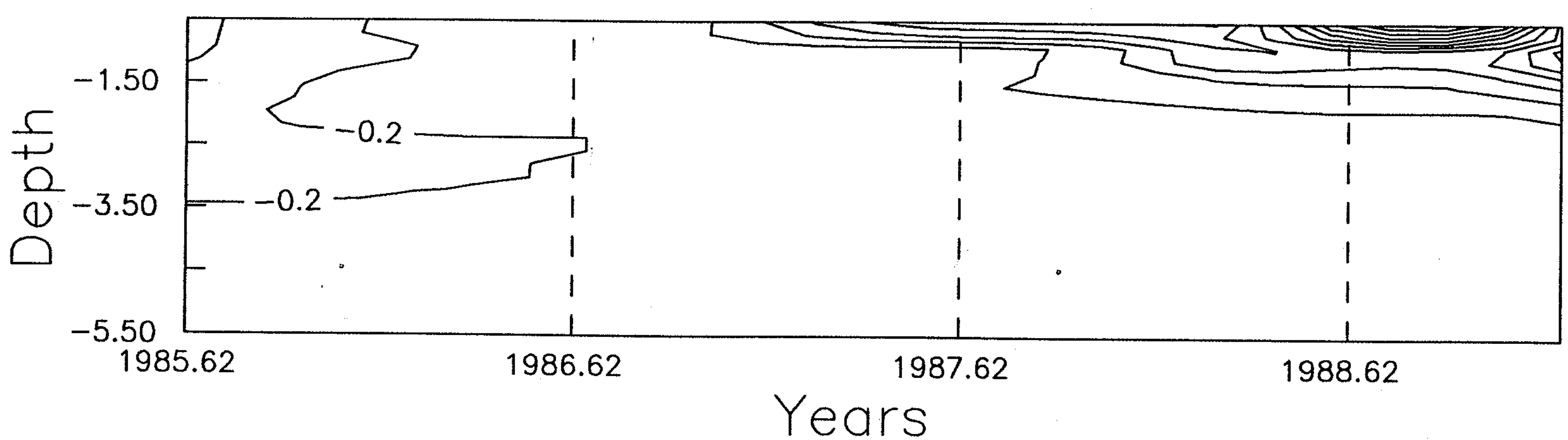

NWZ5B — T3
Depth
-2.50
-4.50
-6.50
-8.50
-10.50
-12.50
-14.50
-16.50
-18.50
-20.50
-0.2
0.0
1987.57
1988.57
Years

NWZ5B – T4

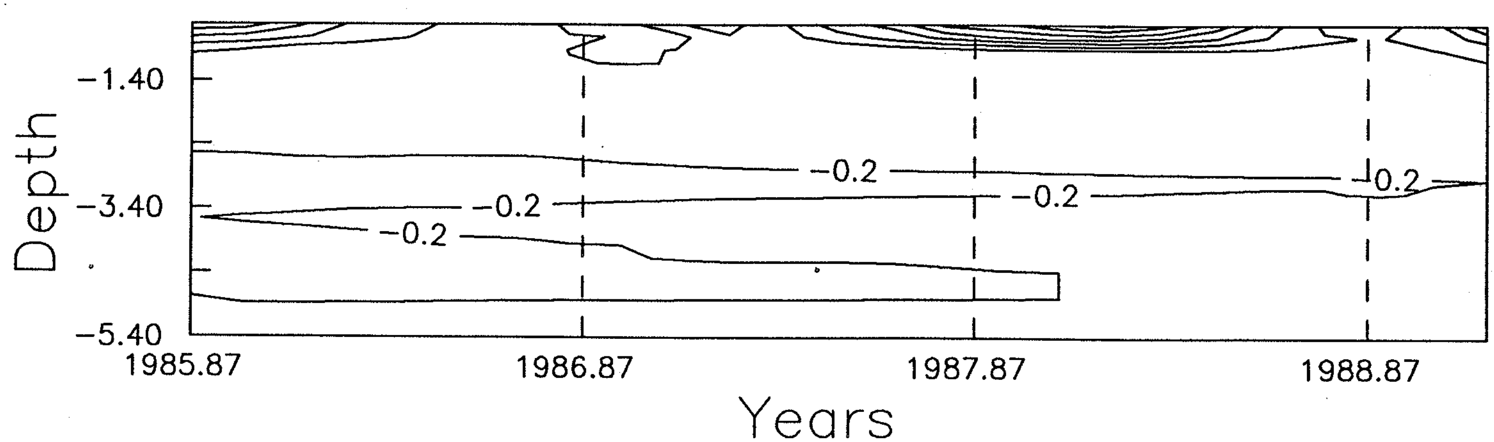


Depth
-2.50
-4.50
-6.50
-8.50
-10.50
-12.50
-14.50
-16.50
-18.50
-20.50
-0.2
-0.2
-0.2
0.0
0.0
1987.57
1988.57
Years

NWZ6 – T1

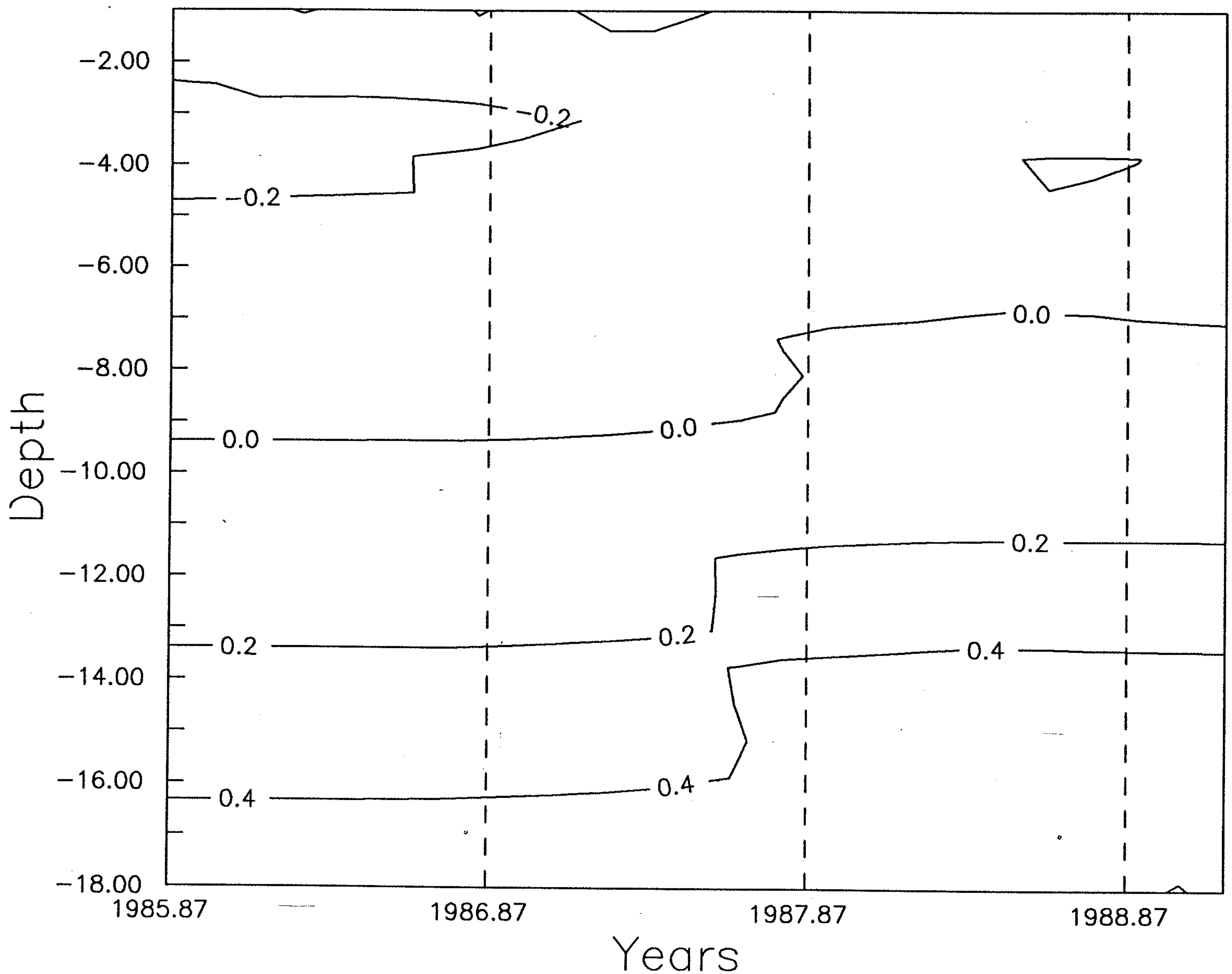


NWZ6 – T2



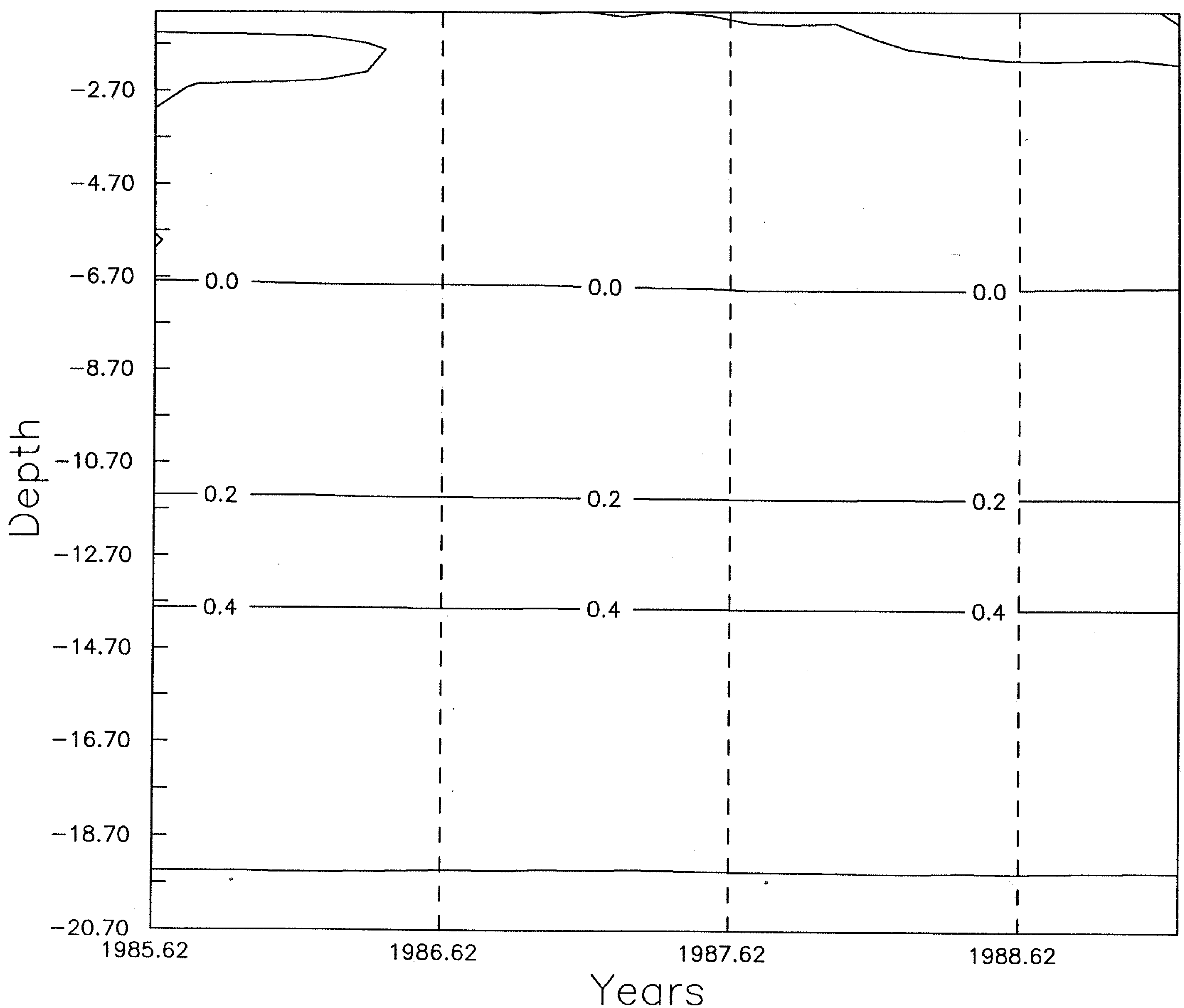
Depth
−1.40
−3.40
−5.40
1985.87
1986.87
1987.87
1988.87
Years
−0.2
−0.2
−0.2
−0.2
−0.2
−0.2

NWZ6 – T3



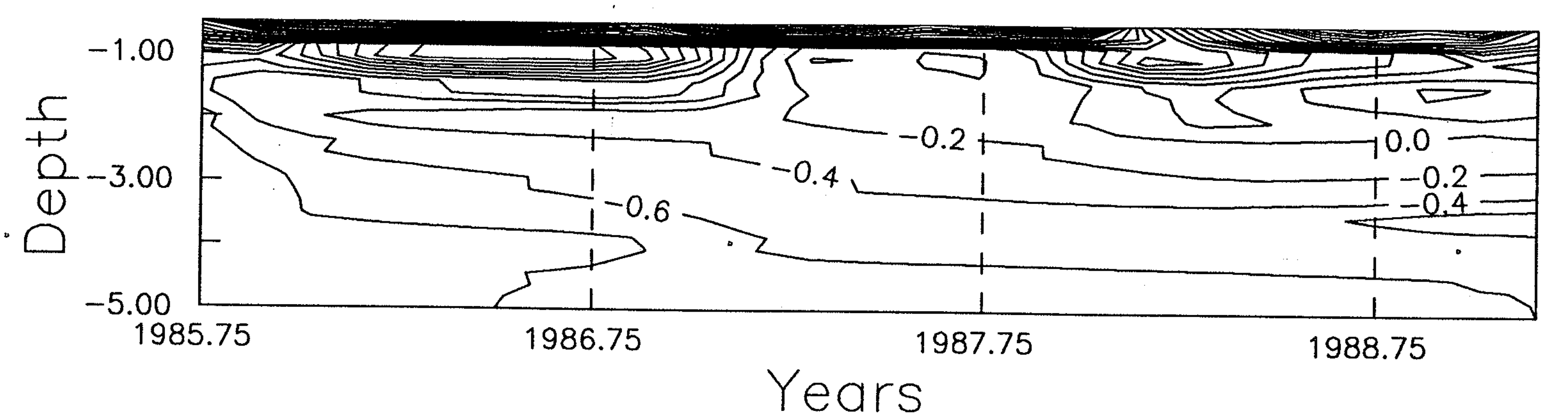
−2.00
−4.00
−6.00
−8.00
−10.00
−12.00
−14.00
−16.00
−18.00
Depth
1985.87
1986.87
1987.87
1988.87
Years
−0.2
−0.2
0.0
0.0
0.0
0.2
0.2
0.2
0.4
0.4
0.4

NWZ6 — T4

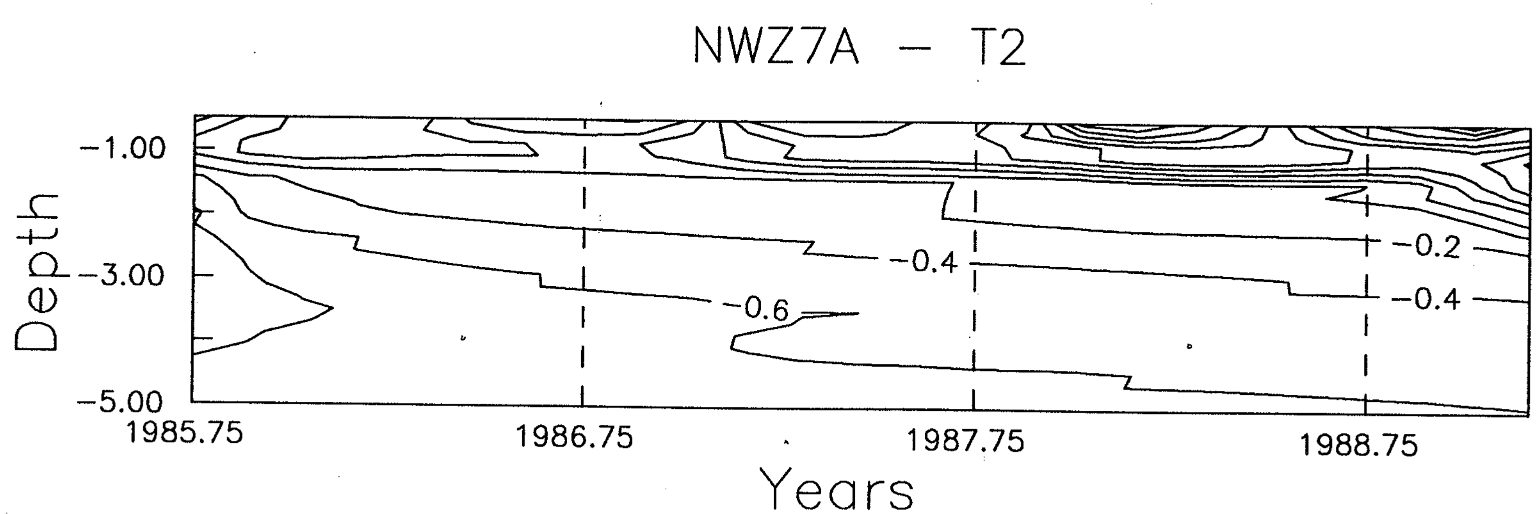


Depth
-2.70
-4.70
-6.70
-8.70
-10.70
-12.70
-14.70
-16.70
-18.70
-20.70
0.0
0.2
0.4
1985.62
1986.62
1987.62
1988.62
Years

NWZ7A – T1



Depth
-1.00
-3.00
-5.00
1985.75
1986.75
1987.75
1988.75
Years
-0.2
-0.4
-0.6
0.0
-0.2
-0.4


NWZ7A - T2
-1.00
-3.00
-5.00
Depth
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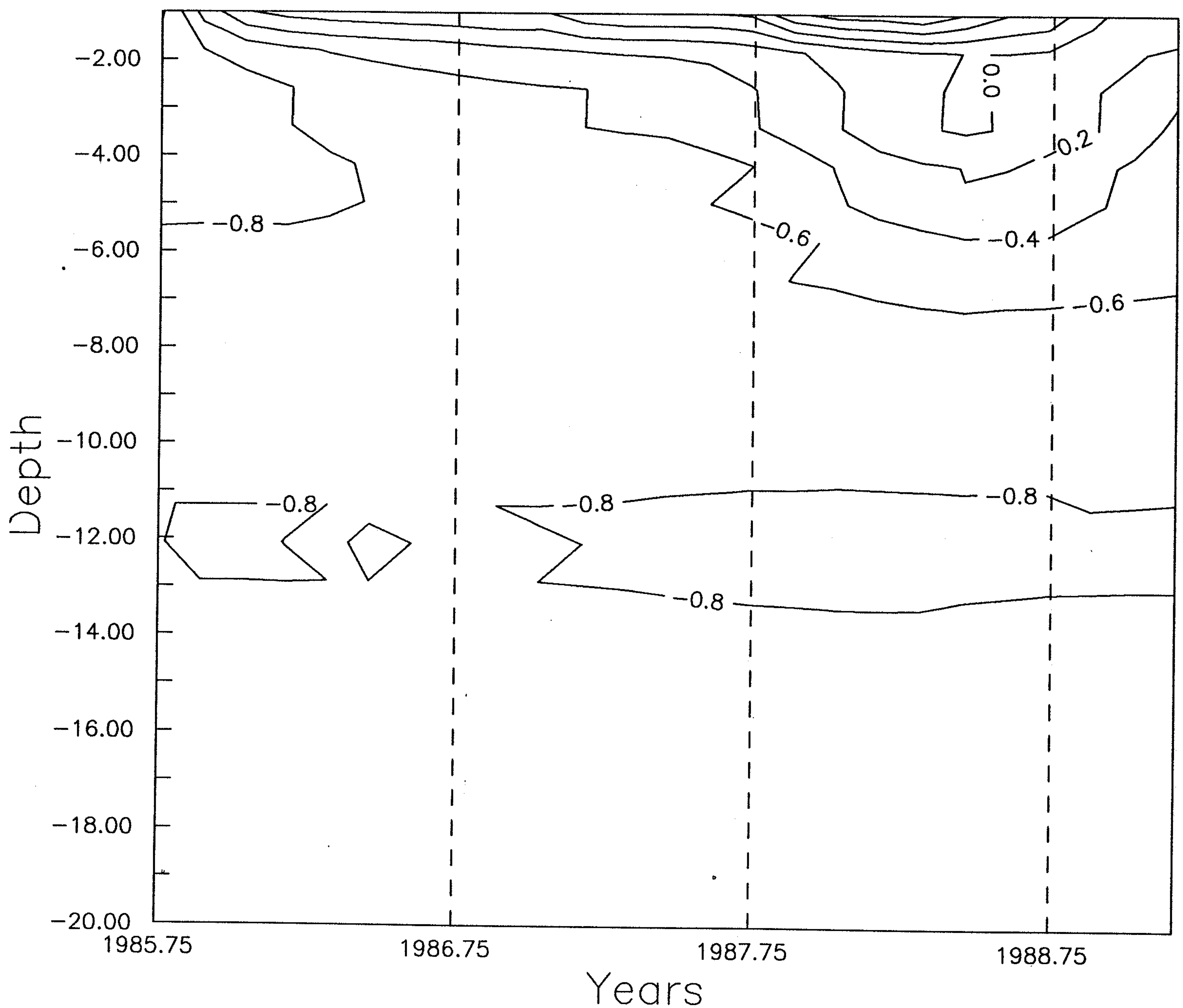
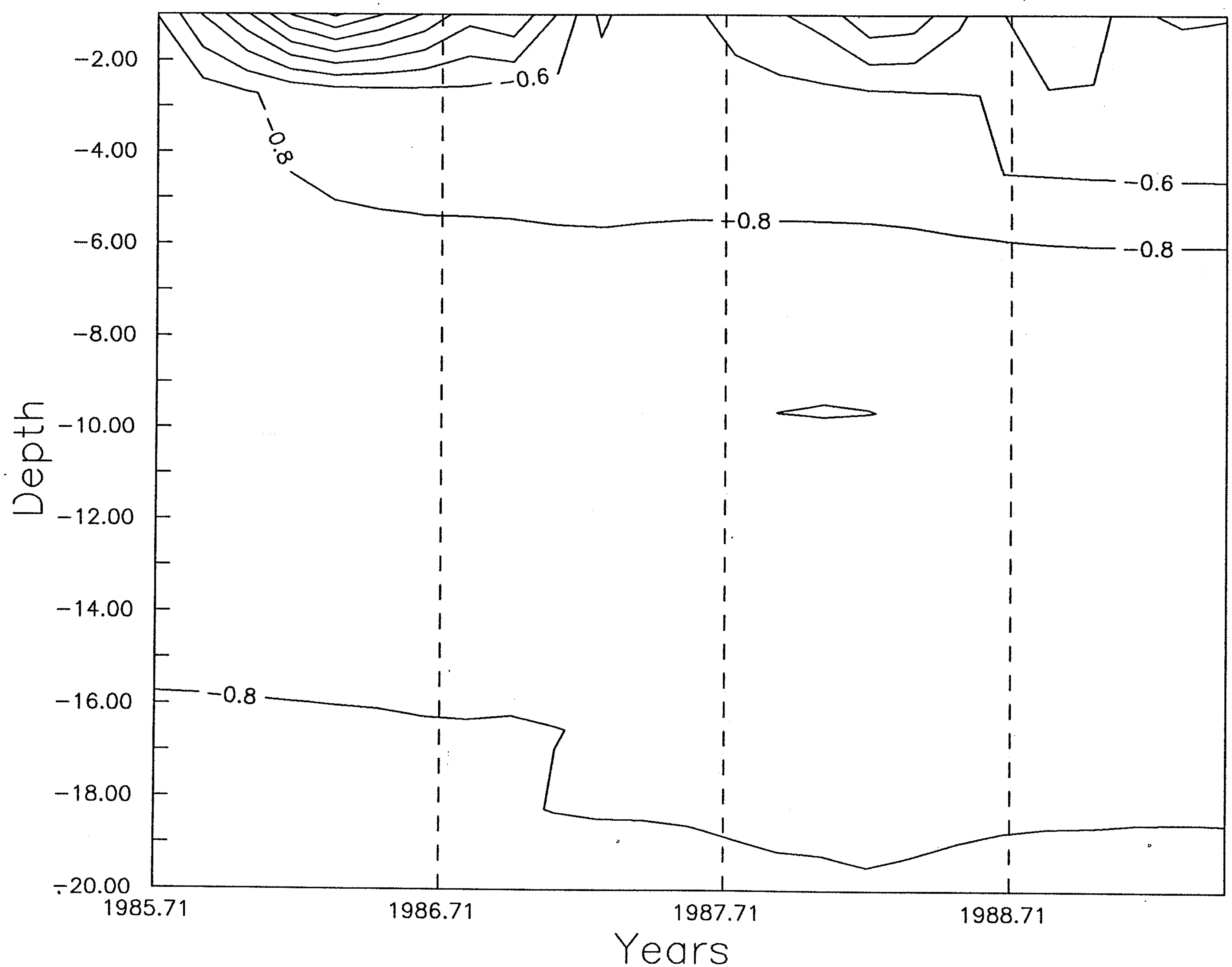
-0.4
-0.4
-0.6
1985.75
1986.75
1987.75
1988.75
Years

NWZ7A – T3

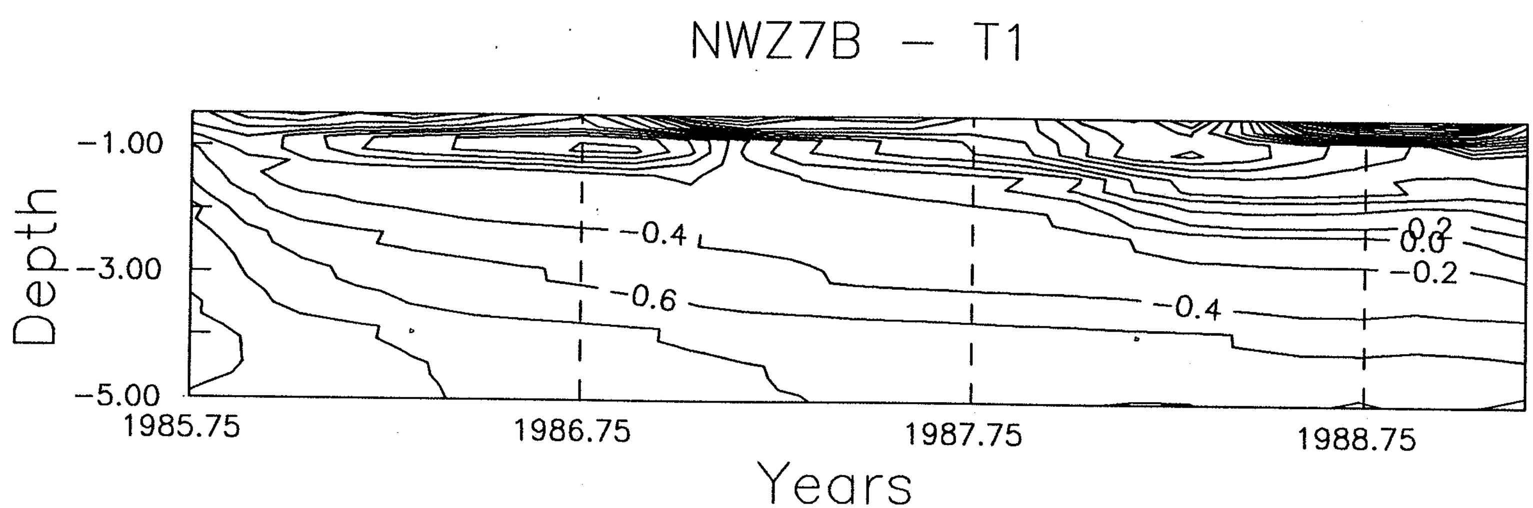


Depth
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
-14.00
-16.00
-18.00
-20.00
1985.75
1986.75
1987.75
1988.75
Years
0.0
-0.2
-0.4
-0.6
-0.6
-0.8
-0.8
-0.8
-0.8
-0.8

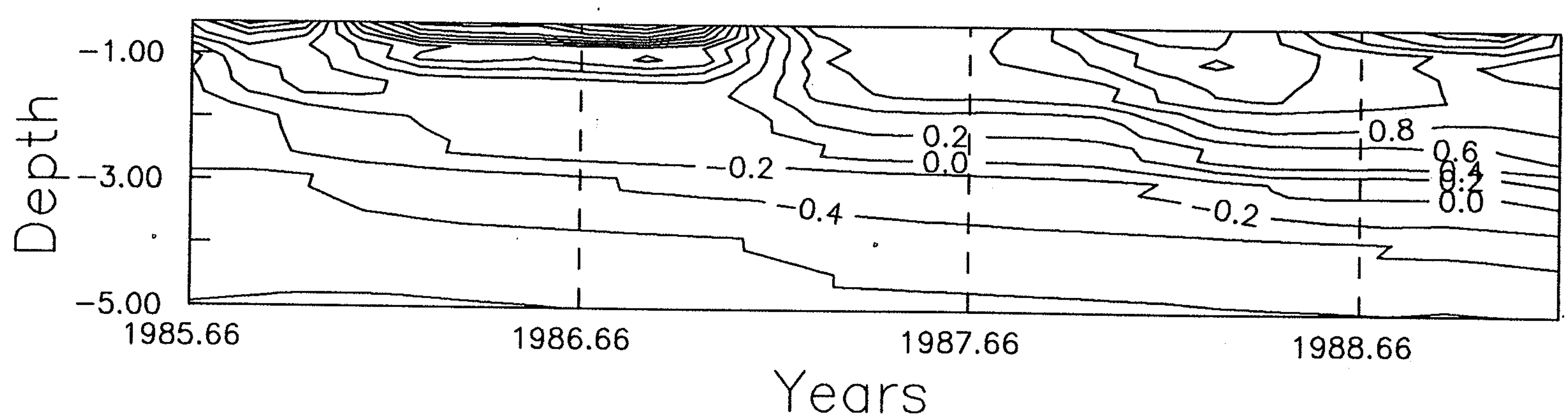
NWZ7A – T4



-0.6
-0.8
-0.6
-0.8
-0.8
-0.8
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
-14.00
-16.00
-18.00
-20.00
Depth
1985.71
1986.71
1987.71
1988.71
Years

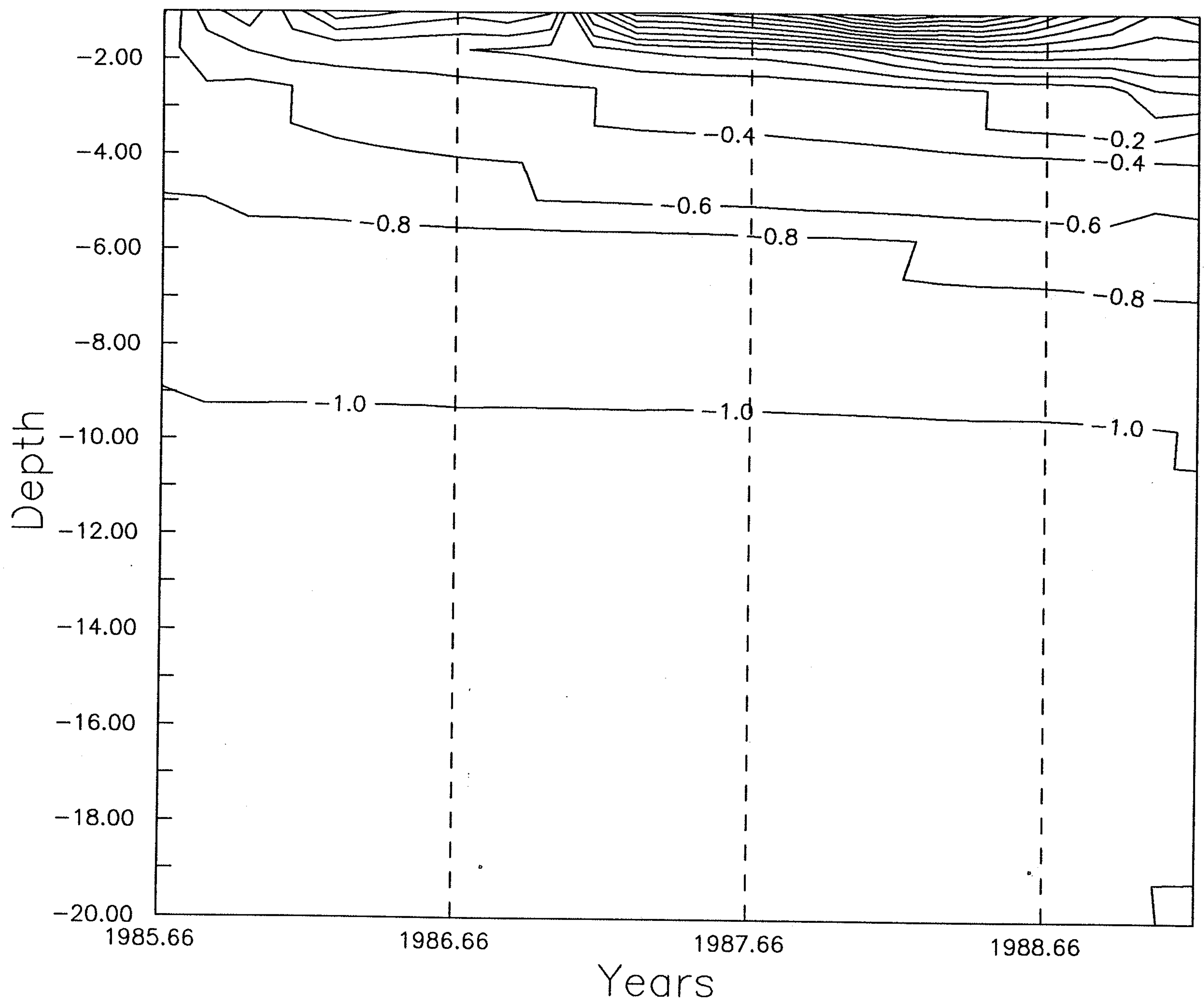

NWZ7B — T1
Depth
-1.00
-3.00
-5.00
1985.75
1986.75
1987.75
1988.75
Years
-0.4
-0.6
-0.4
0.2
0.0
-0.2

NWZ7B – T2

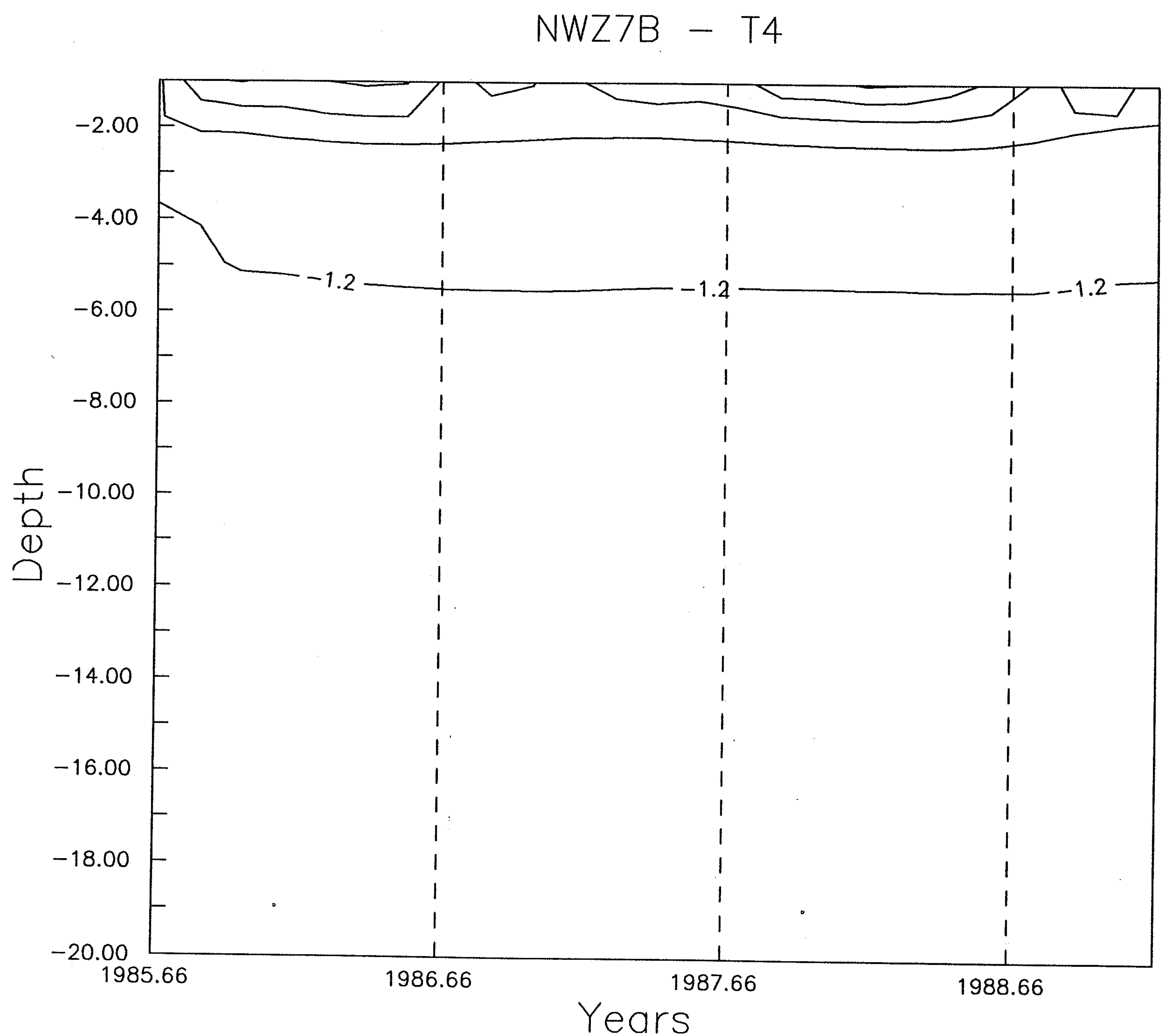


0.8
0.6
0.4
0.2
0.0
0.2
0.0
-0.2
-0.4
-0.2
-1.00
-3.00
-5.00
Depth
1985.66
1986.66
1987.66
1988.66
Years

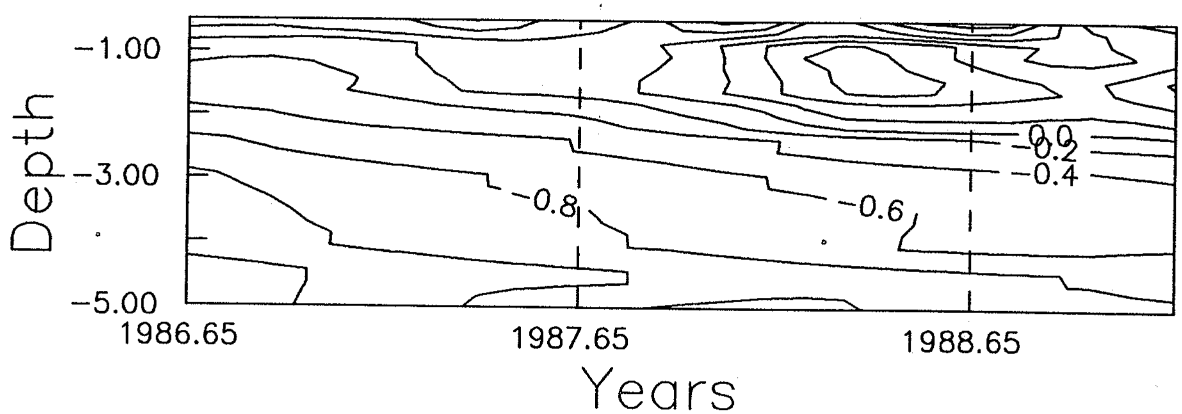
NWZ7B — T3



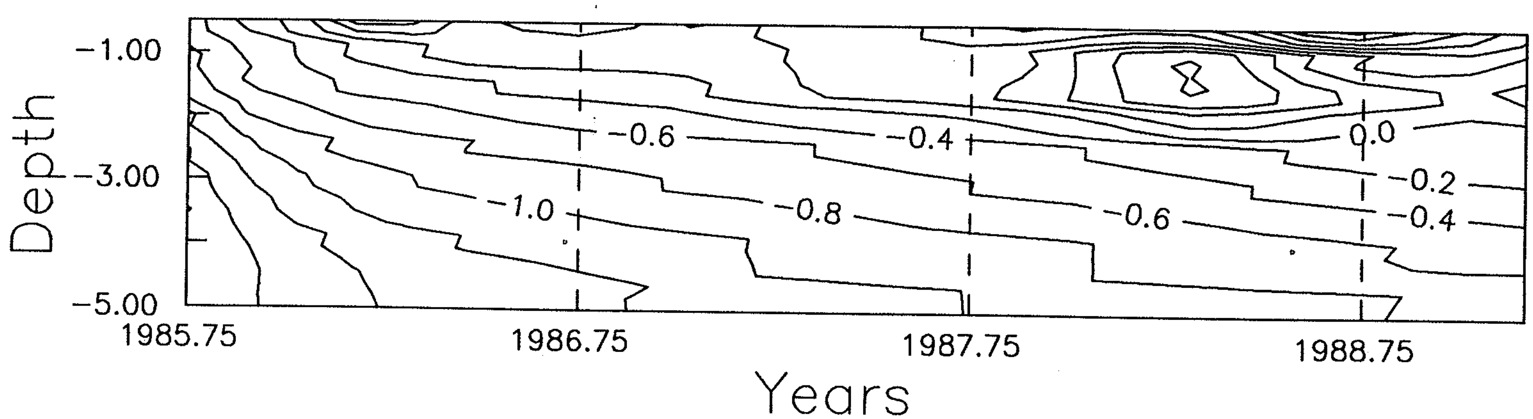
Depth
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
-14.00
-16.00
-18.00
-20.00
1985.66
1986.66
1987.66
1988.66
Years
-0.2
-0.4
-0.6
-0.8
-1.0


NWZ7B - T4
-1.2
-1.2
-1.2
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
-14.00
-16.00
-18.00
-20.00
Depth
1985.66
1986.66
1987.66
1988.66
Years

NWZ7C – T1

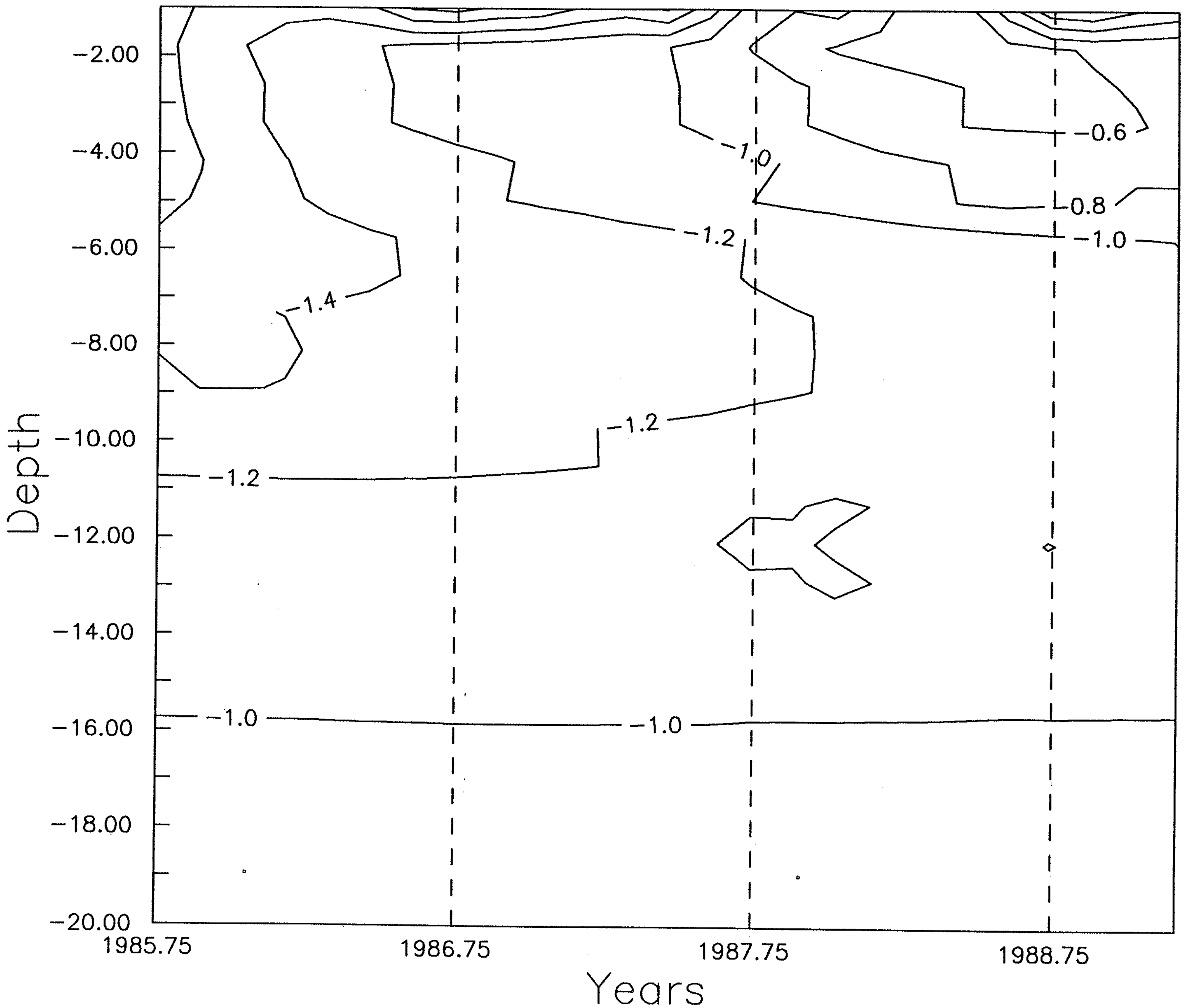


NWZ7C – T2

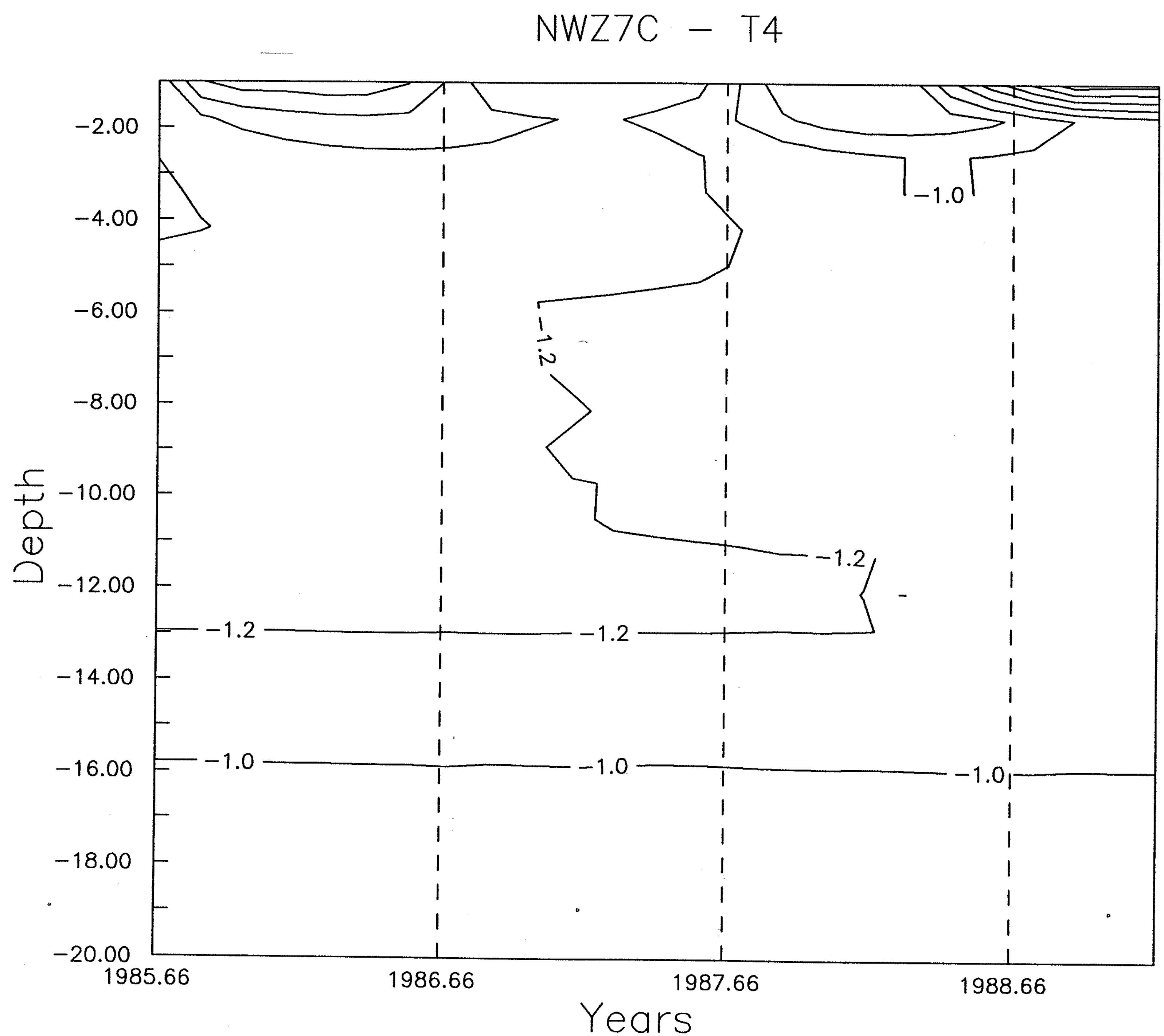


-1.00
-3.00
-5.00
Depth
1985.75
1986.75
1987.75
1988.75
Years
-0.6
-0.4
0.0
-0.2
-1.0
-0.8
-0.6
-0.4

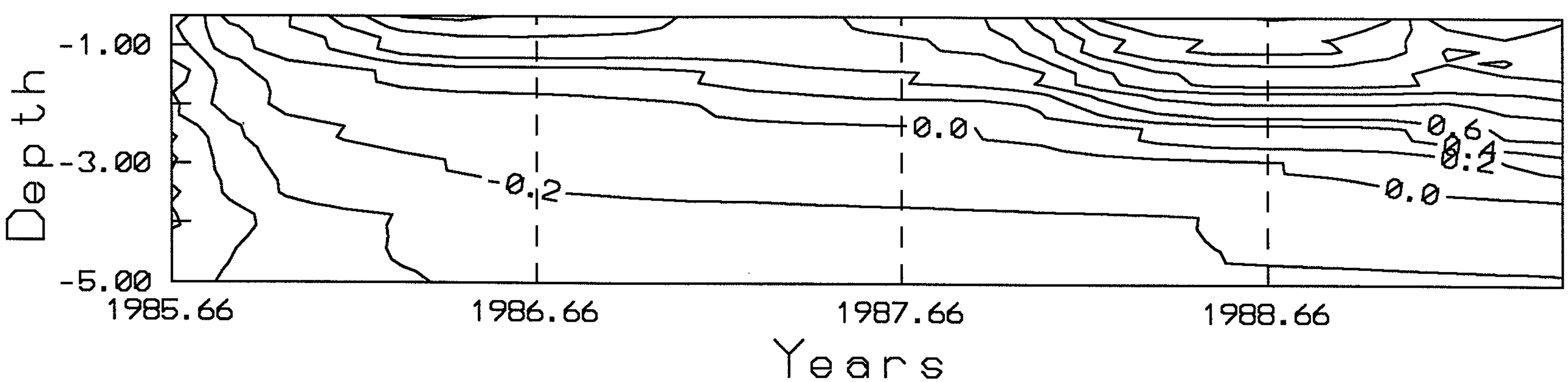
NWZ7C — T3



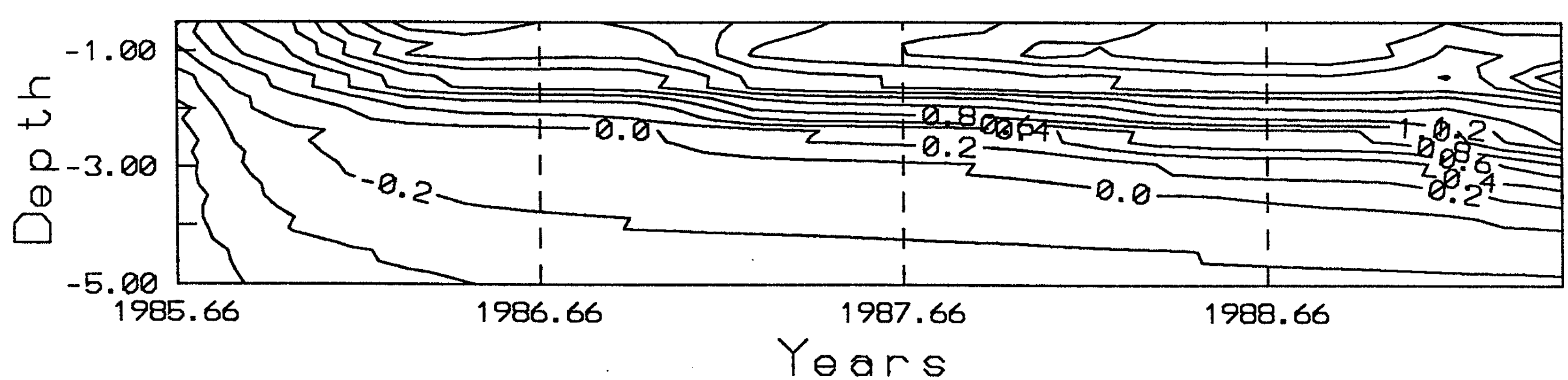
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
-14.00
-16.00
-18.00
-20.00
Depth
1985.75
1986.75
1987.75
1988.75
Years
-0.6
-0.8
-1.0
-1.2
-1.4
-1.2
-1.2
-1.0
-1.0
-1.0

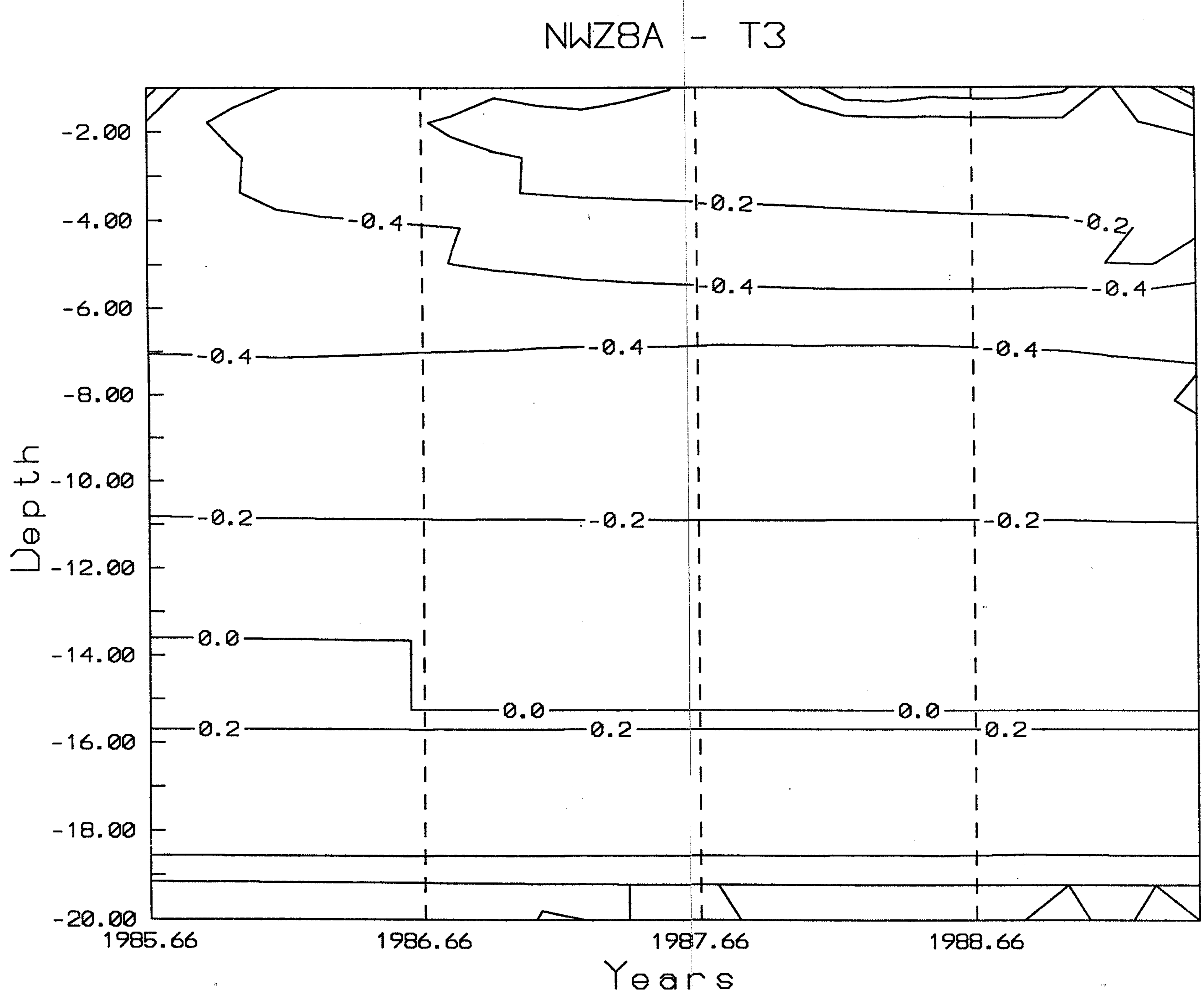

NWZ7C - T4
-1.0
-1.2
-1.2
-1.2
-1.2
-1.0
-1.0
-1.0
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
-14.00
-16.00
-18.00
-20.00
Depth
1985.66
1986.66
1987.66
1988.66
Years

NWZ8A - T1


Depth
-1.00
-3.00
-5.00
1985.66
1986.66
1987.66
1988.66
Years
-0.2
0.0
0.6
0.4
0.2
0.0

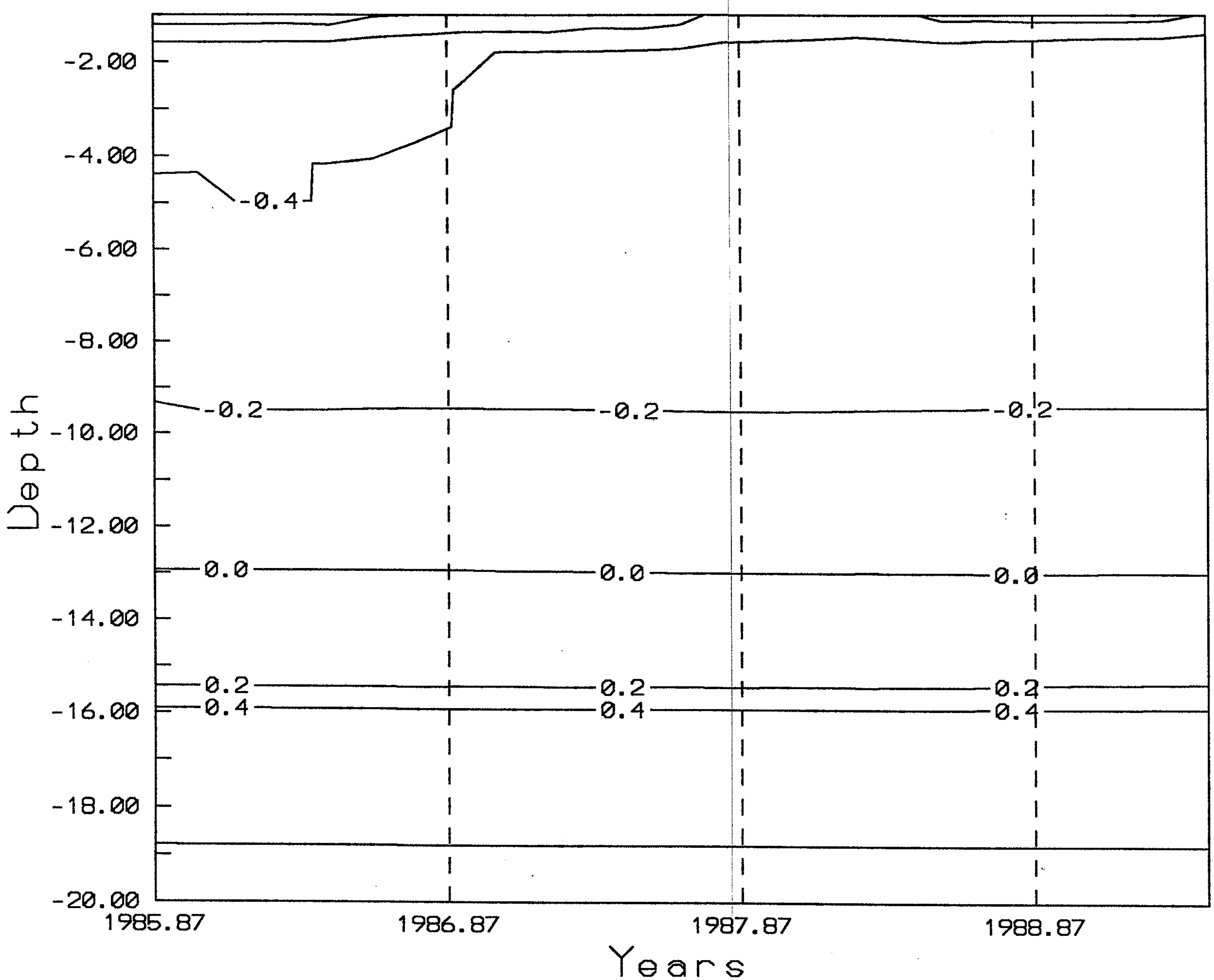
NWZ8A - T2





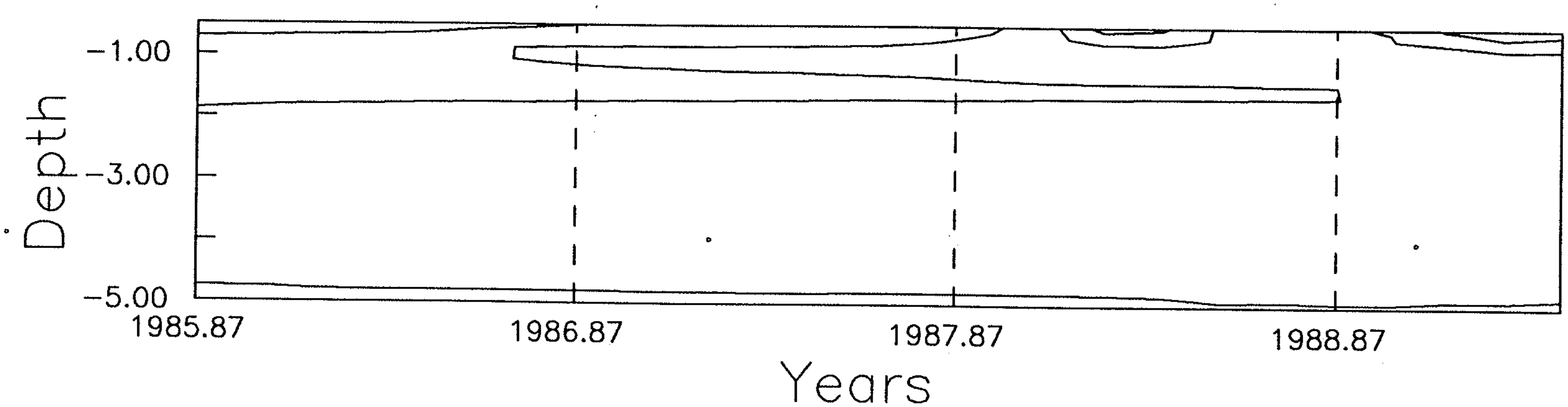
NWZ8A - T3
Depth
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
-14.00
-16.00
-18.00
-20.00
1985.66
1986.66
1987.66
1988.66
Years
-0.4
-0.2
0.0
0.2

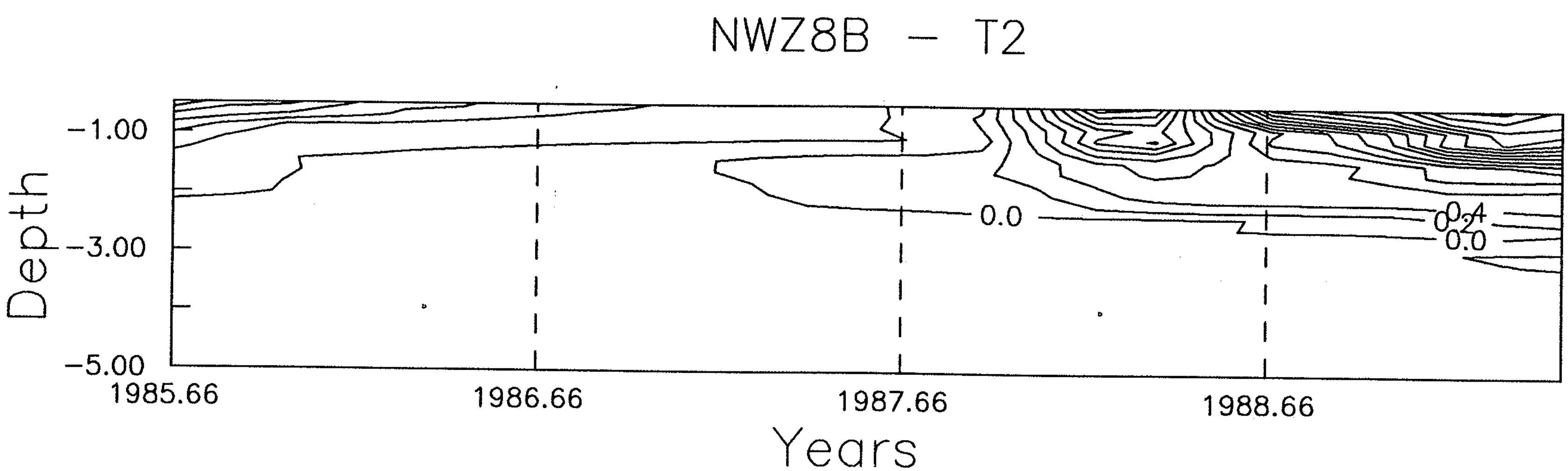
NWZ8A - T4



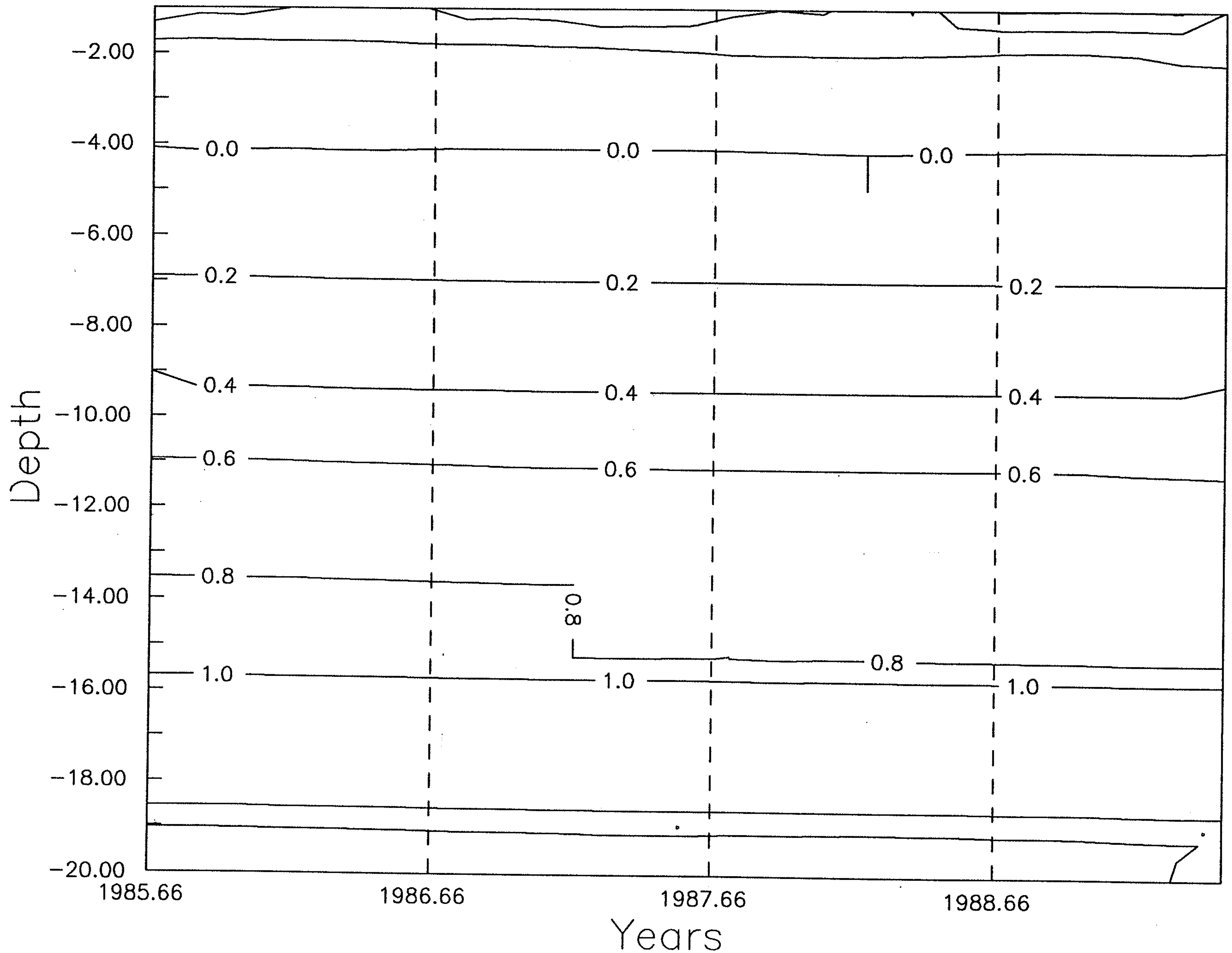
Depth
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
-14.00
-16.00
-18.00
-20.00
-0.4
-0.2
0.0
0.2
0.4
1985.87
1986.87
1987.87
1988.87
Years

NWZ8B - T1




NWZ8B - T2
Depth
-1.00
-3.00
-5.00
1985.66
1986.66
1987.66
1988.66
Years
0.0
0.4
0.2
0.0

NWZ8B – T3



Depth
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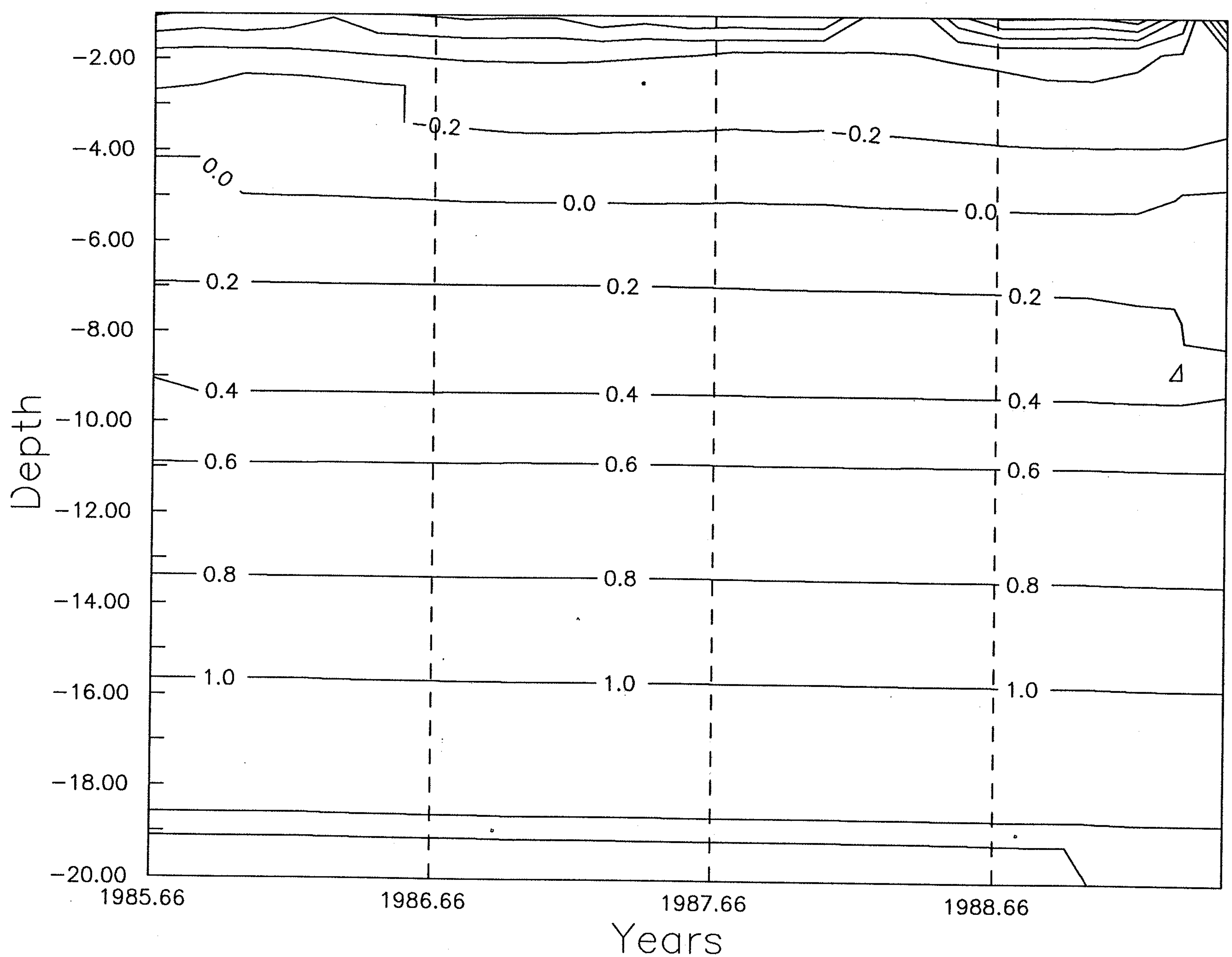
0.2
0.4
0.6
0.8
1.0
1985.66
1986.66
1987.66
1988.66
Years

NWZ8B – T4



-2.00
-4.00
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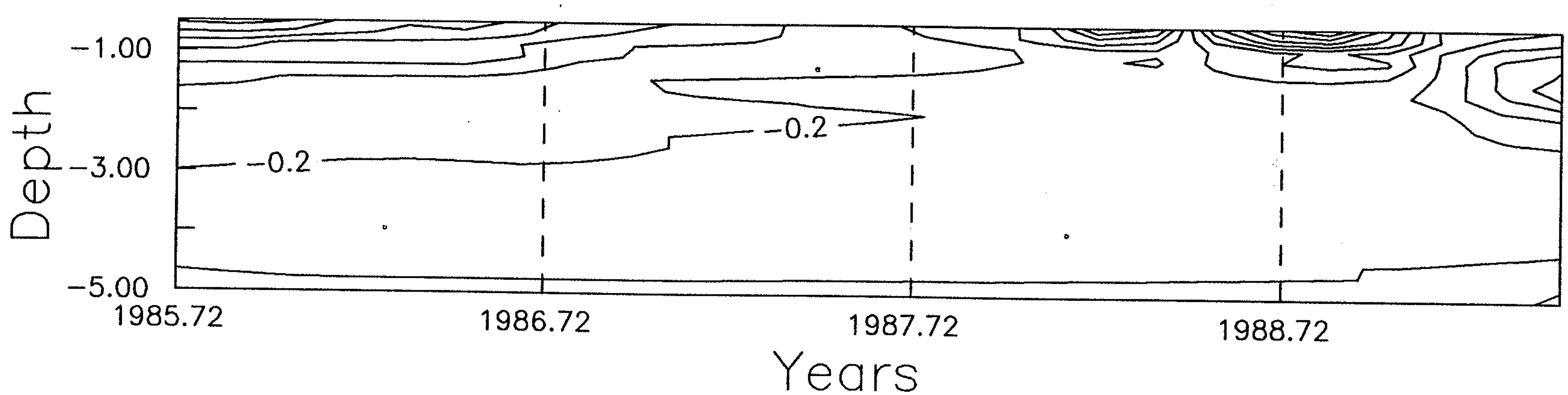
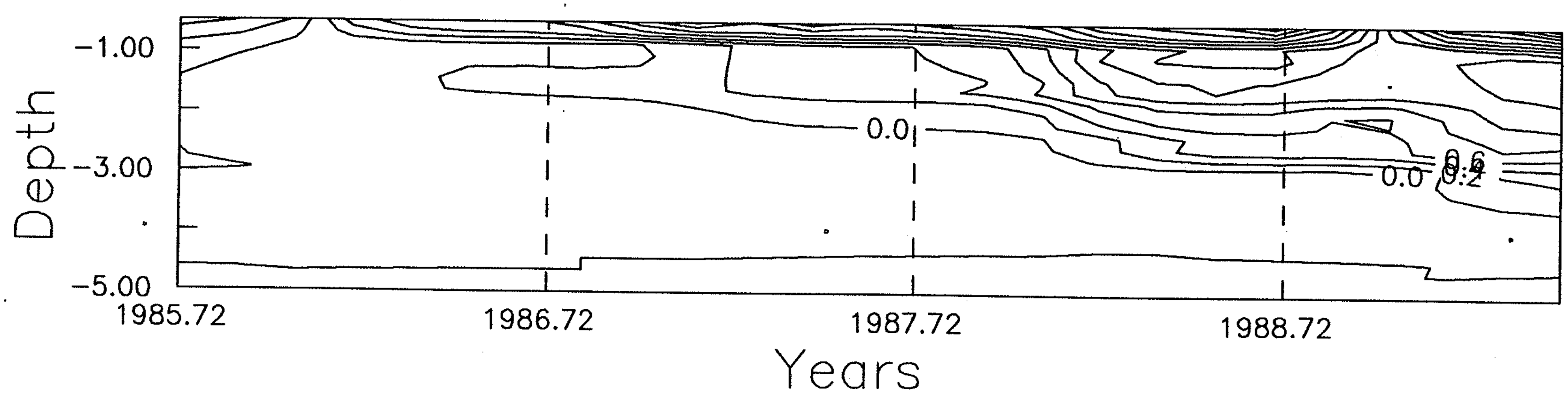
Depth
1985.66
1986.66
1987.66
1988.66
Years
-0.2
0.0
0.2
0.4
0.6
0.8
1.0

NWZ8C – T1



NWZ8C – T2



Depth
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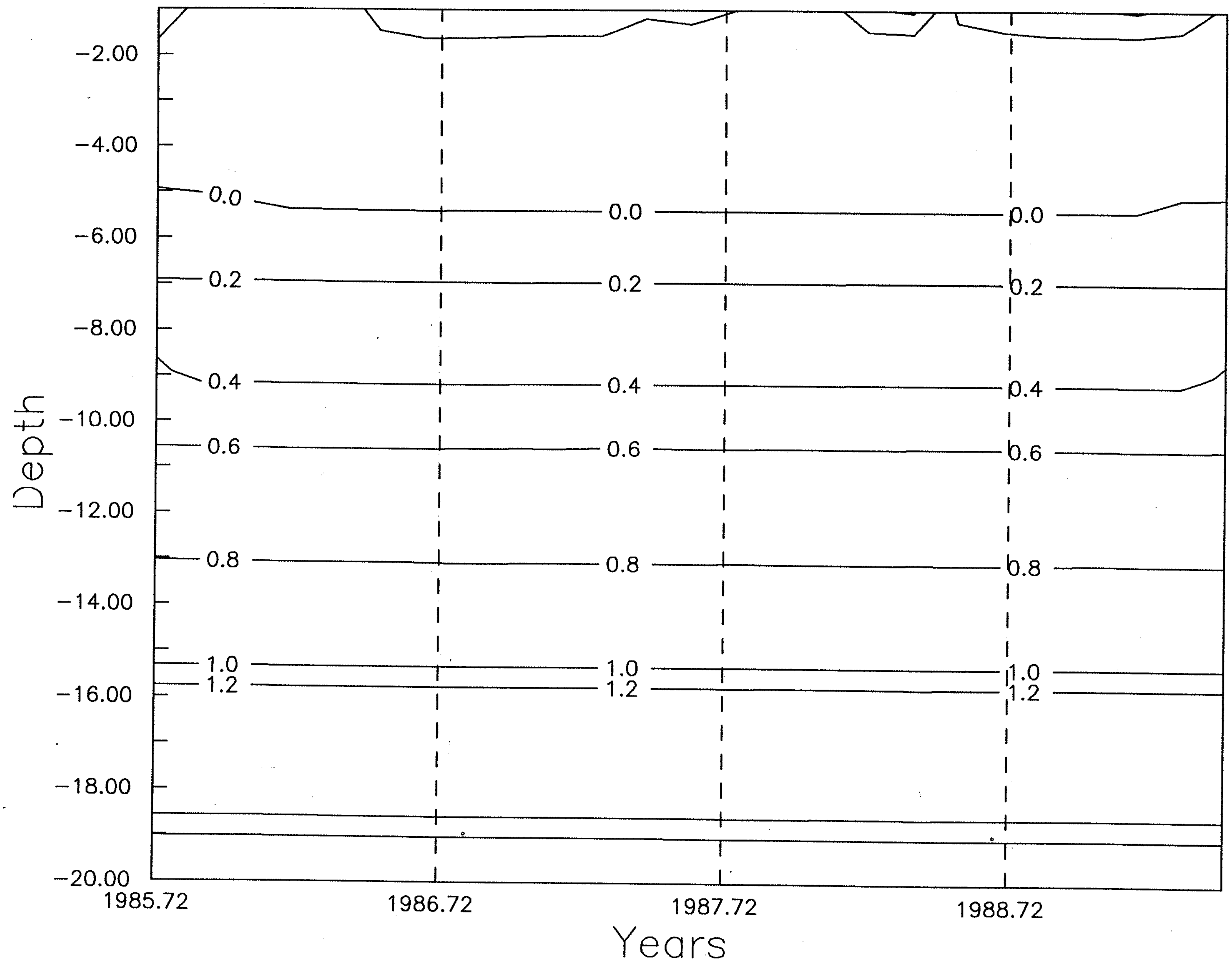
0.4
0.6
1985.72
1986.72
1987.72
1988.72
Years

NWZ8C - T3



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0.0
0.2
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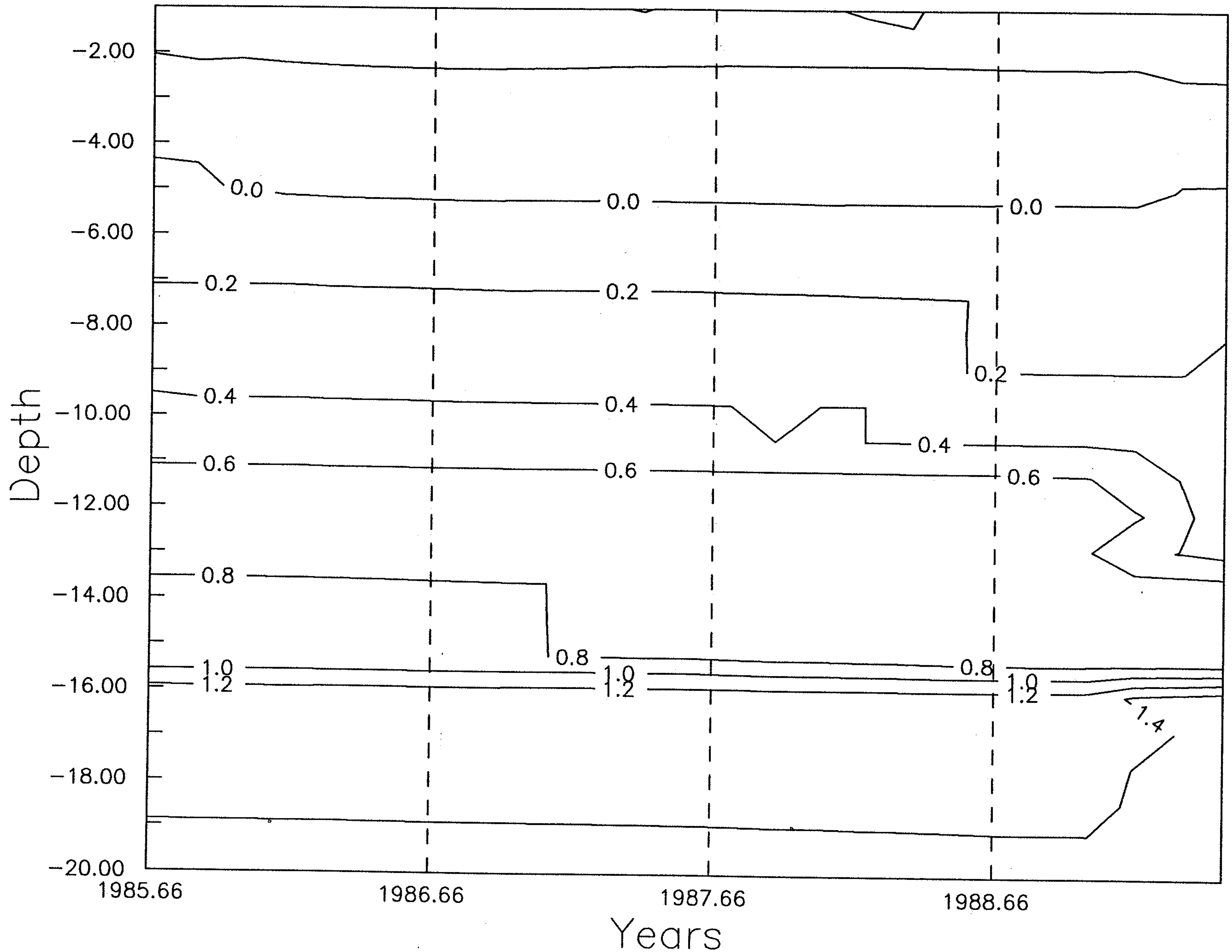
0.8
1.0
1.2
1985.72
1986.72
1987.72
1988.72
Years

NWZ8C – T4



Depth
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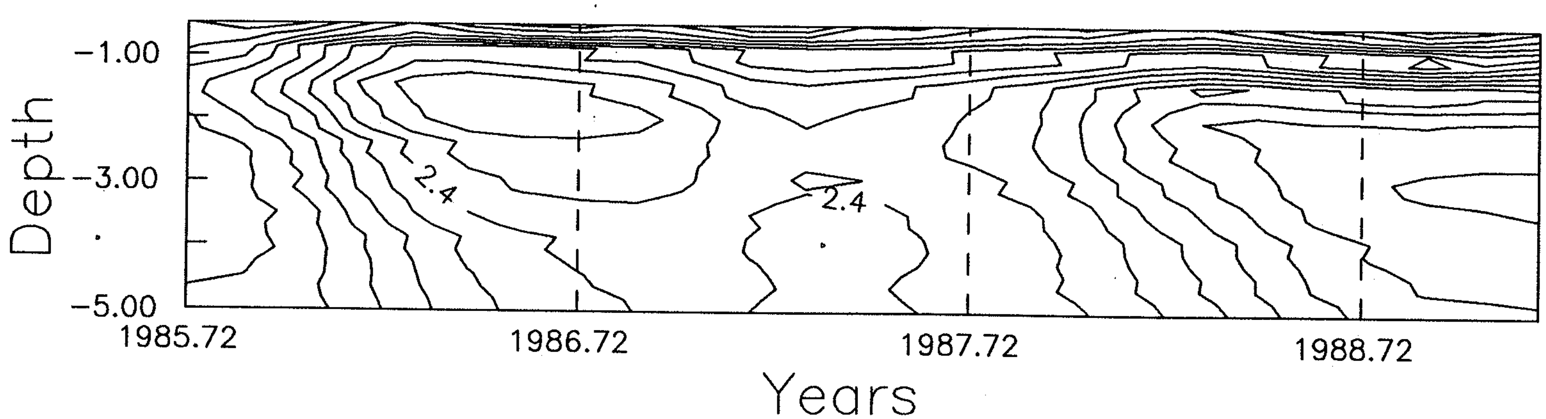
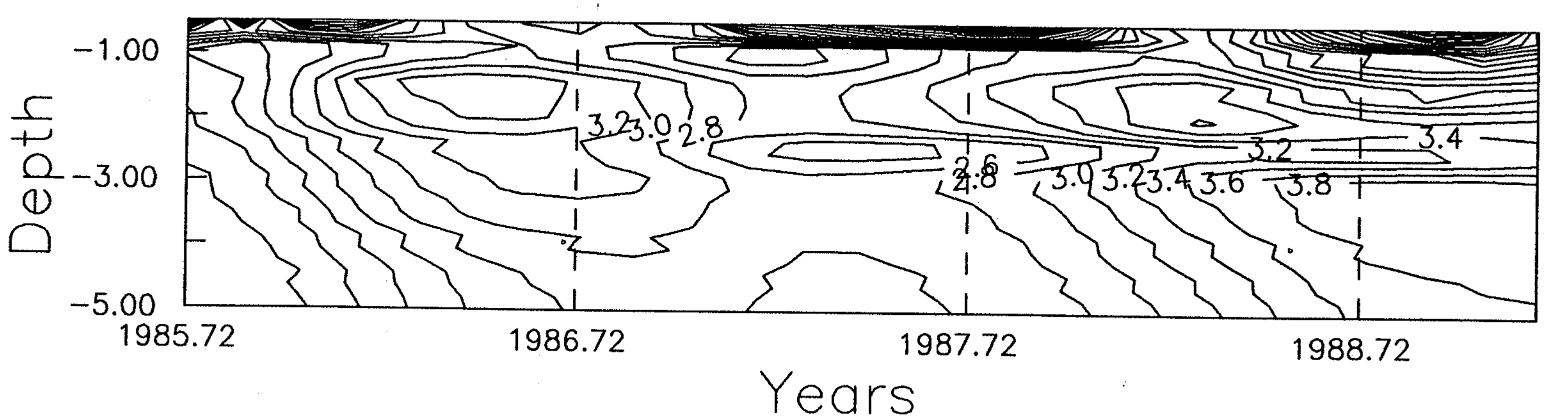
Years
1985.66
1986.66
1987.66
1988.66
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4

NWZ9 — T1



NWZ9 – T2



Depth
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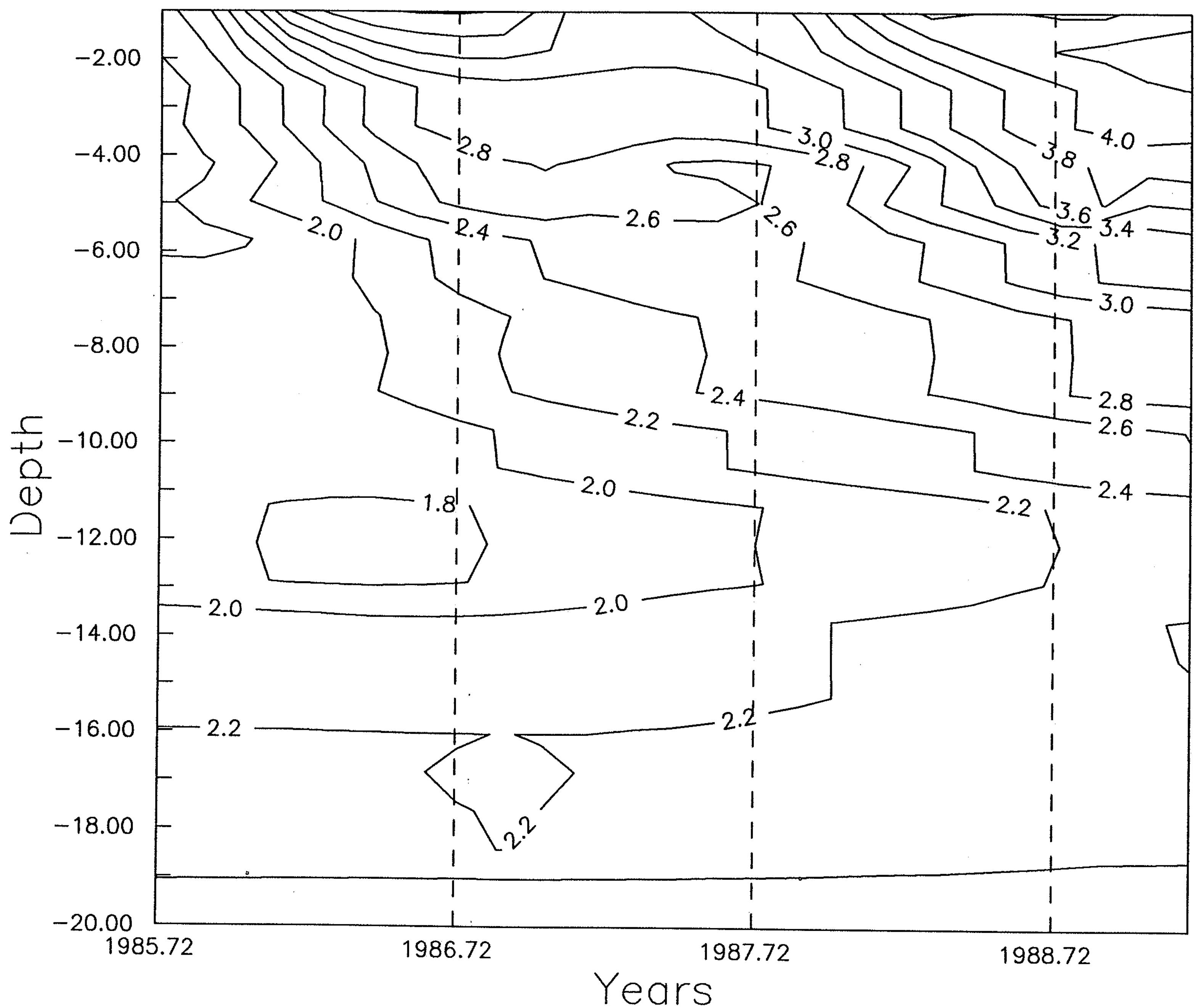
-5.00
1985.72
1986.72
1987.72
1988.72
Years
3.2
3.0
2.8
2.6
2.8
3.0
3.2
3.4
3.6
3.8
3.2
3.4

NWZ9 – T3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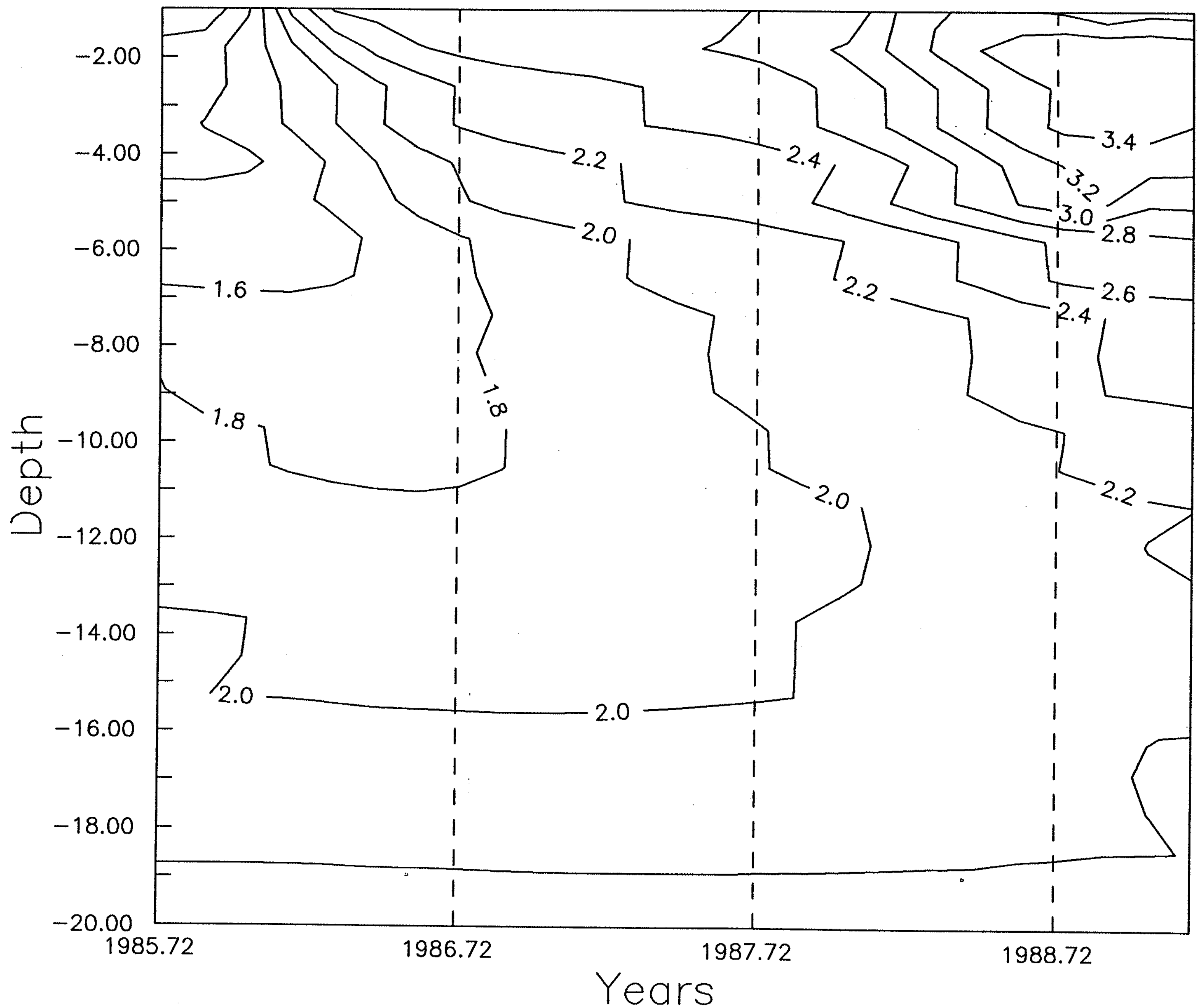
-18.00
-20.00
1985.72
1986.72
1987.72
1988.72
Years
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8

NWZ9 – T4



Depth
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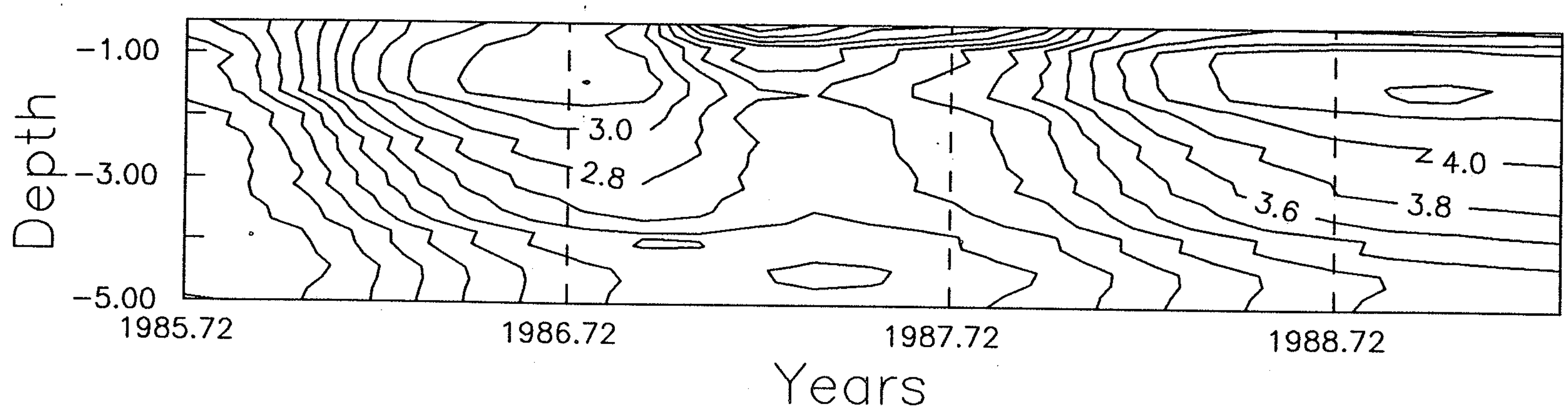
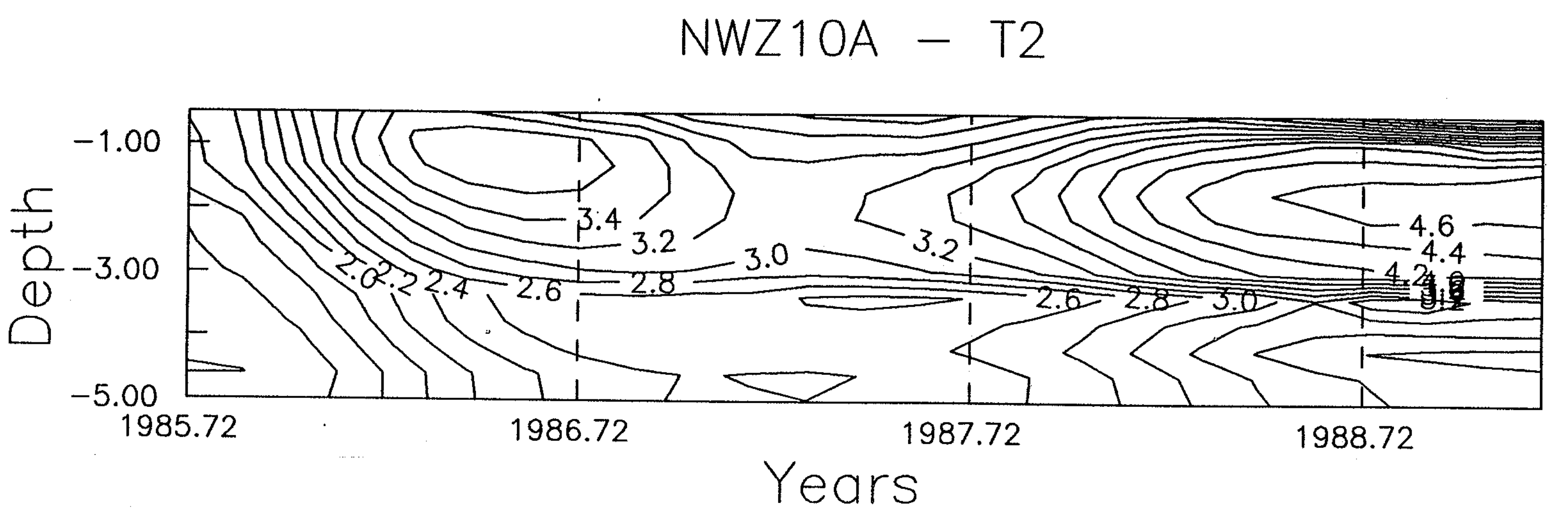
-18.00
-20.00
1985.72
1986.72
1987.72
1988.72
Years
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4

NWZ10A — T1



3.0
2.8
4.0
3.8
3.6
Depth
-1.00
-3.00
-5.00
1985.72
1986.72
1987.72
1988.72
Years


NWZ10A – T2
Depth
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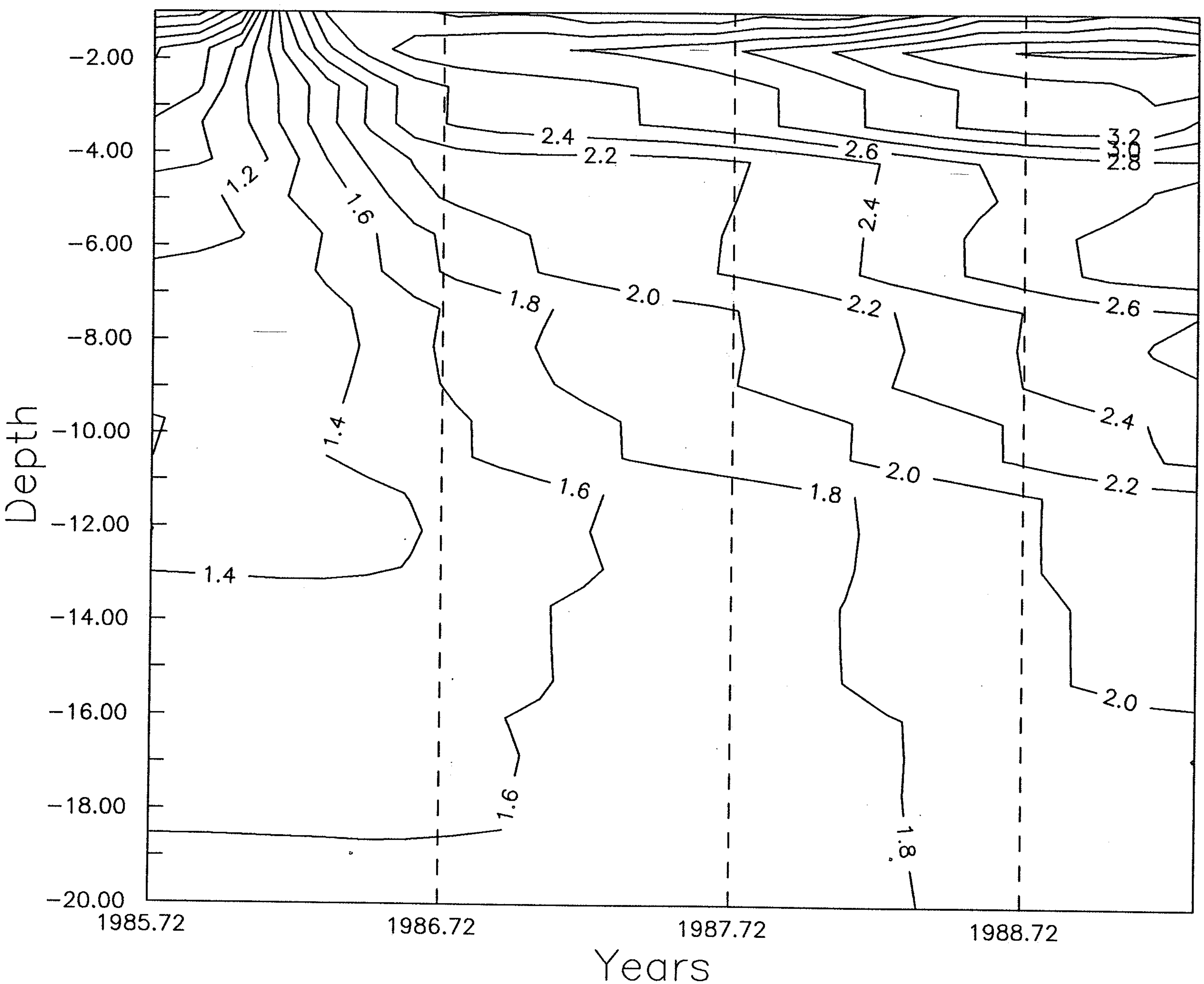
−5.00
1985.72
1986.72
1987.72
1988.72
Years
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.2
2.6
2.8
3.0
4.2
4.4
4.6

NWZ10A — T3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-10.00
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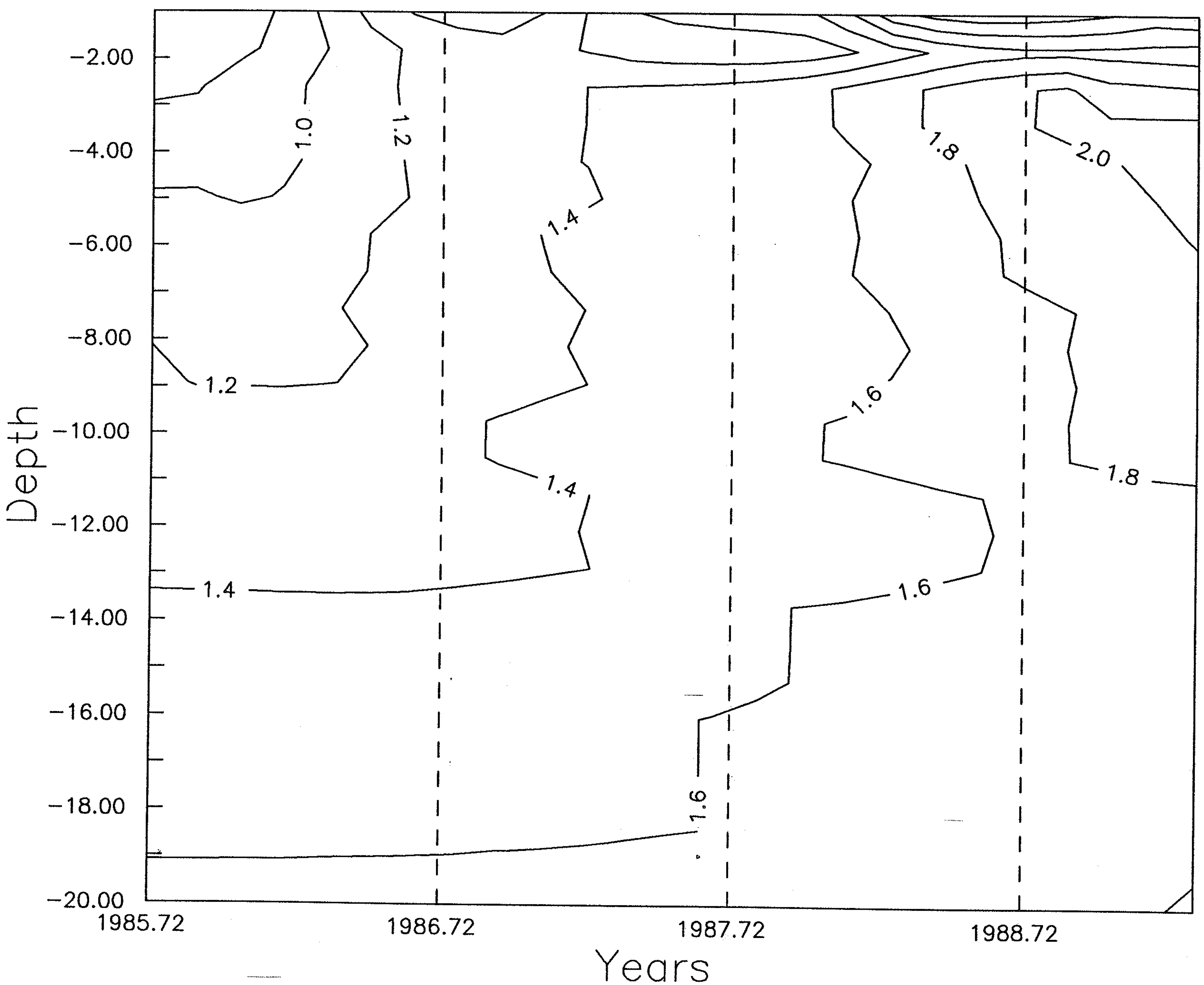
-14.00
-16.00
-18.00
-20.00
1985.72
1986.72
1987.72
1988.72
Years
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2

NWZ10A – T4



Depth
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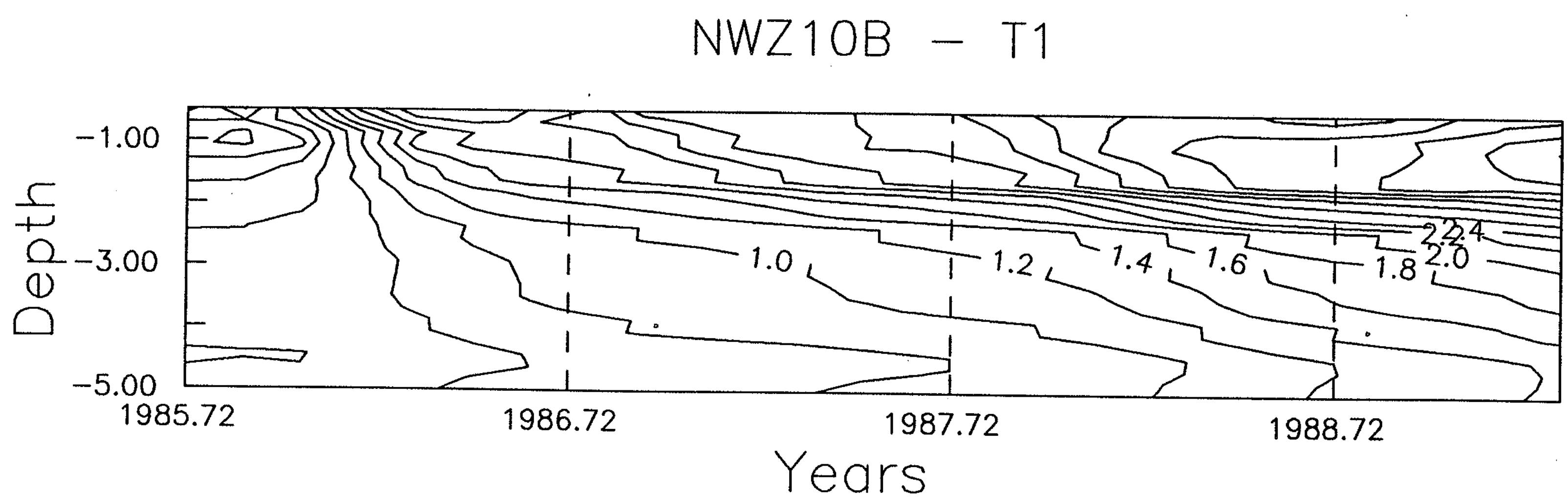
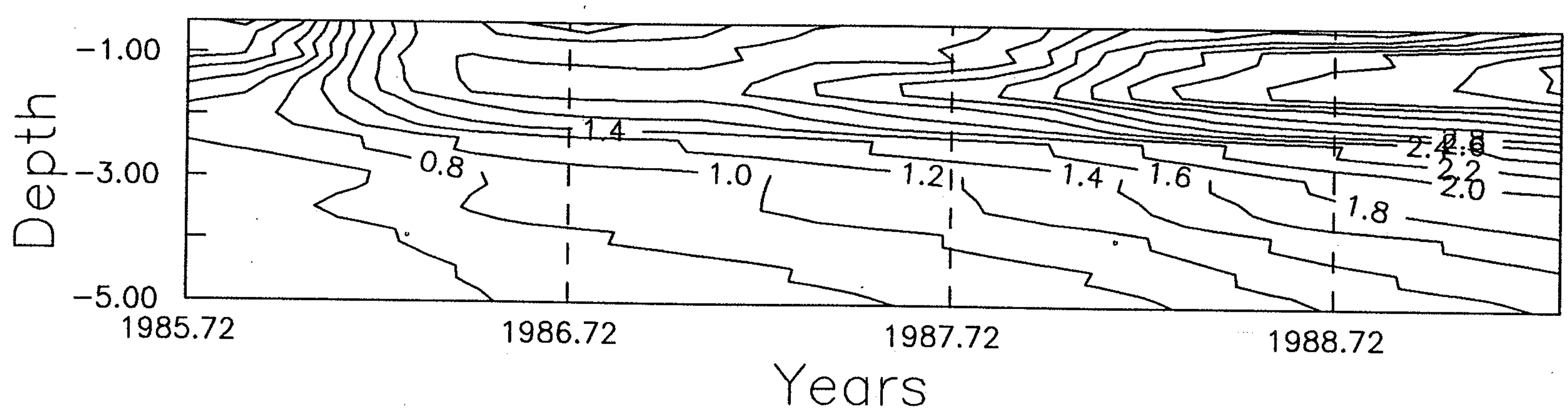
-12.00
-14.00
-16.00
-18.00
-20.00
1985.72
1986.72
1987.72
1988.72
Years
1.0
1.2
1.2
1.4
1.4
1.4
1.4
1.6
1.6
1.6
1.8
1.8
2.0

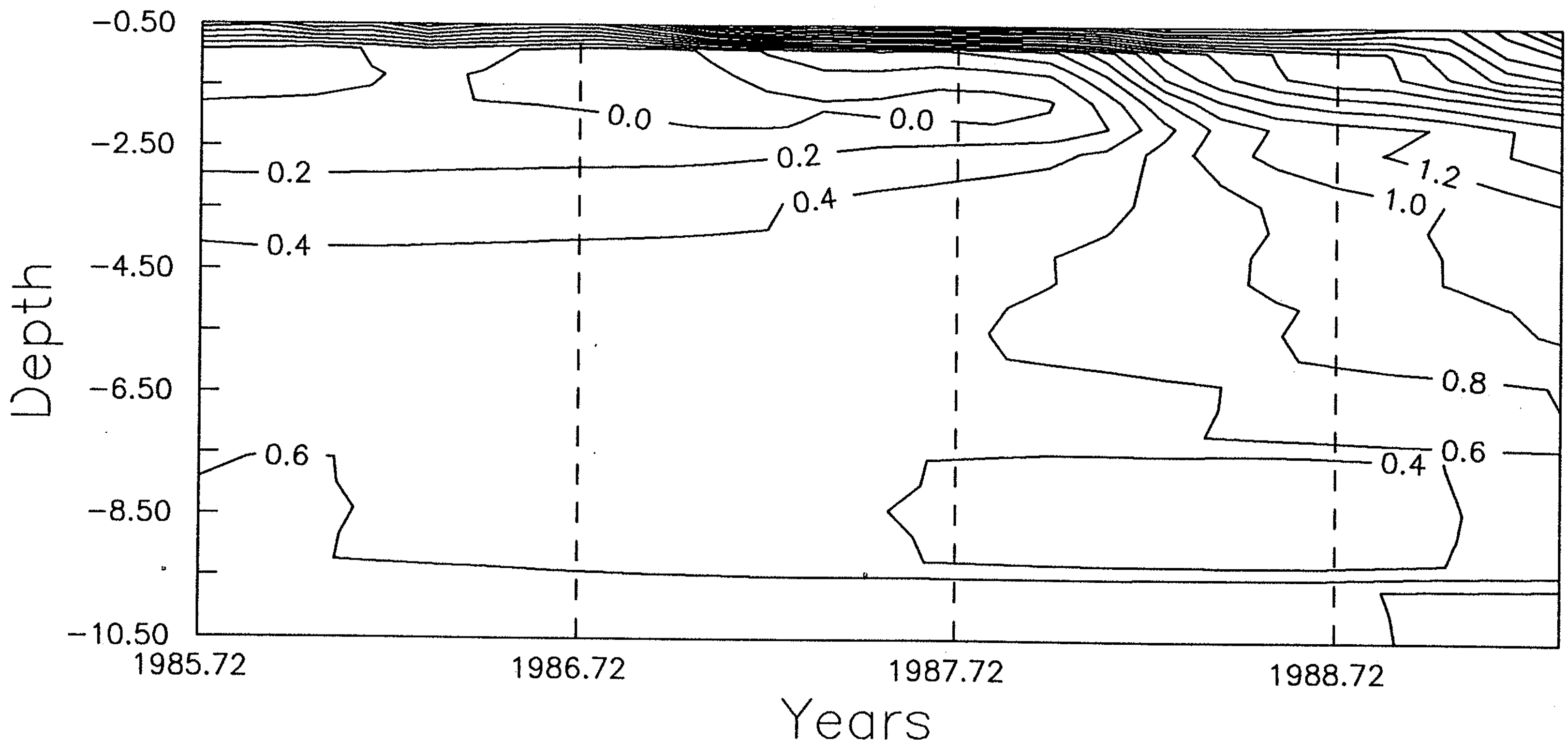

NWZ10B – T1
Depth
−1.00
−3.00
−5.00
1985.72
1986.72
1987.72
1988.72
Years
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4

NWZ10B – T2



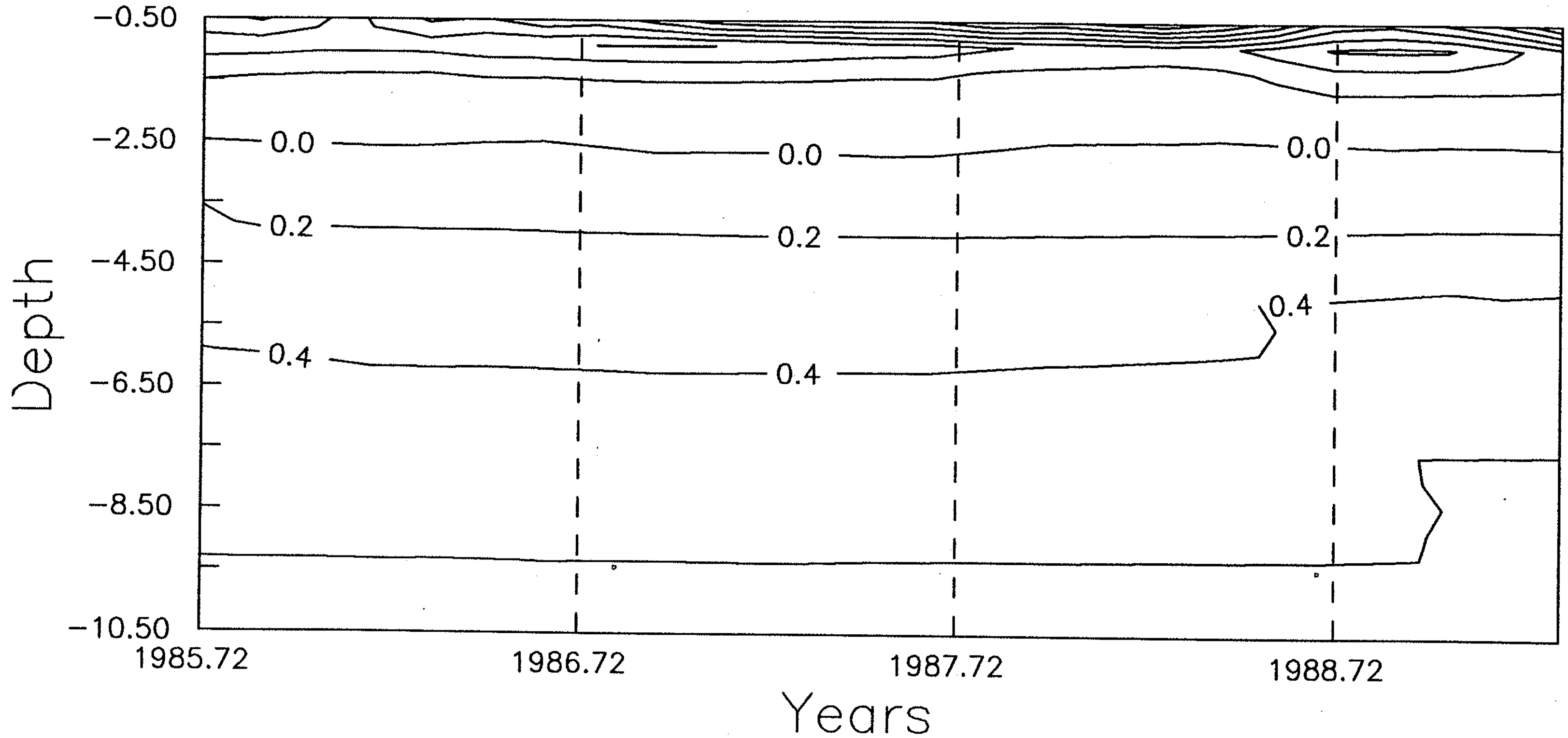
-1.00
-3.00
-5.00
Depth
1.4
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
1985.72
1986.72
1987.72
1988.72
Years

NWZ10B – T3



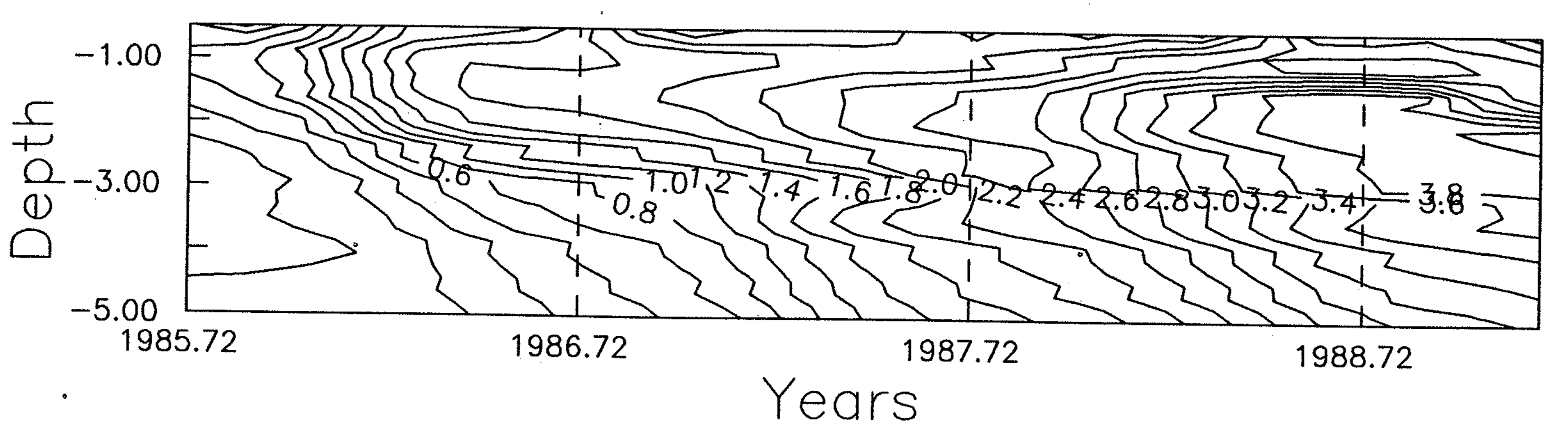
-0.50
-2.50
-4.50
-6.50
-8.50
-10.50
Depth
1985.72
1986.72
1987.72
1988.72
Years
0.0
0.0
0.2
0.2
0.4
0.4
0.6
0.6
0.4
0.8
1.0
1.2

NWZ10B – T4



−0.50
−2.50
−4.50
−6.50
−8.50
−10.50
Depth
0.0
0.2
0.4
1985.72
1986.72
1987.72
1988.72
Years

NWZ11 – T1



Depth
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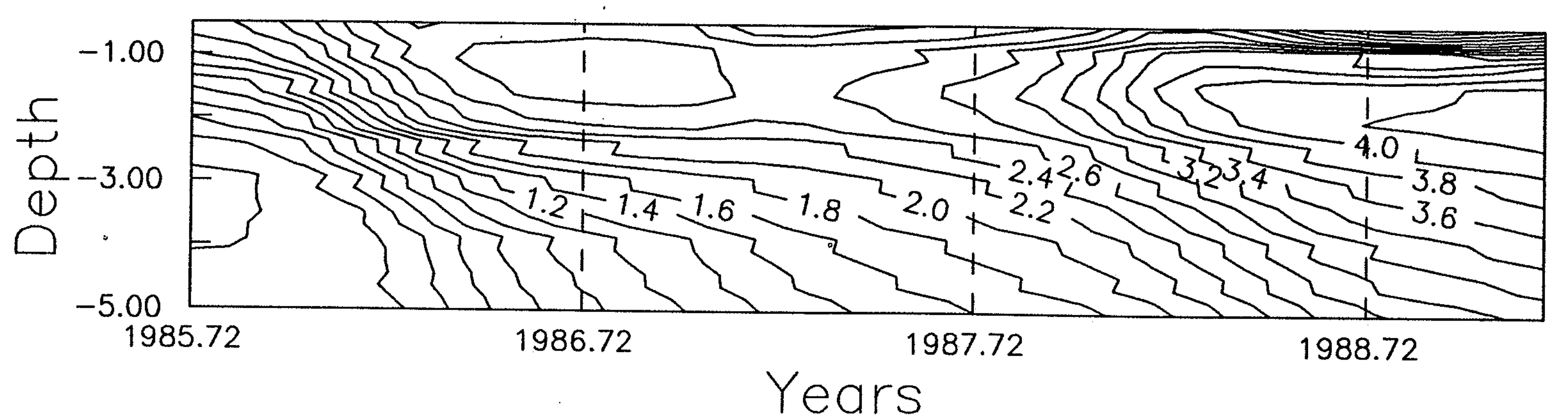
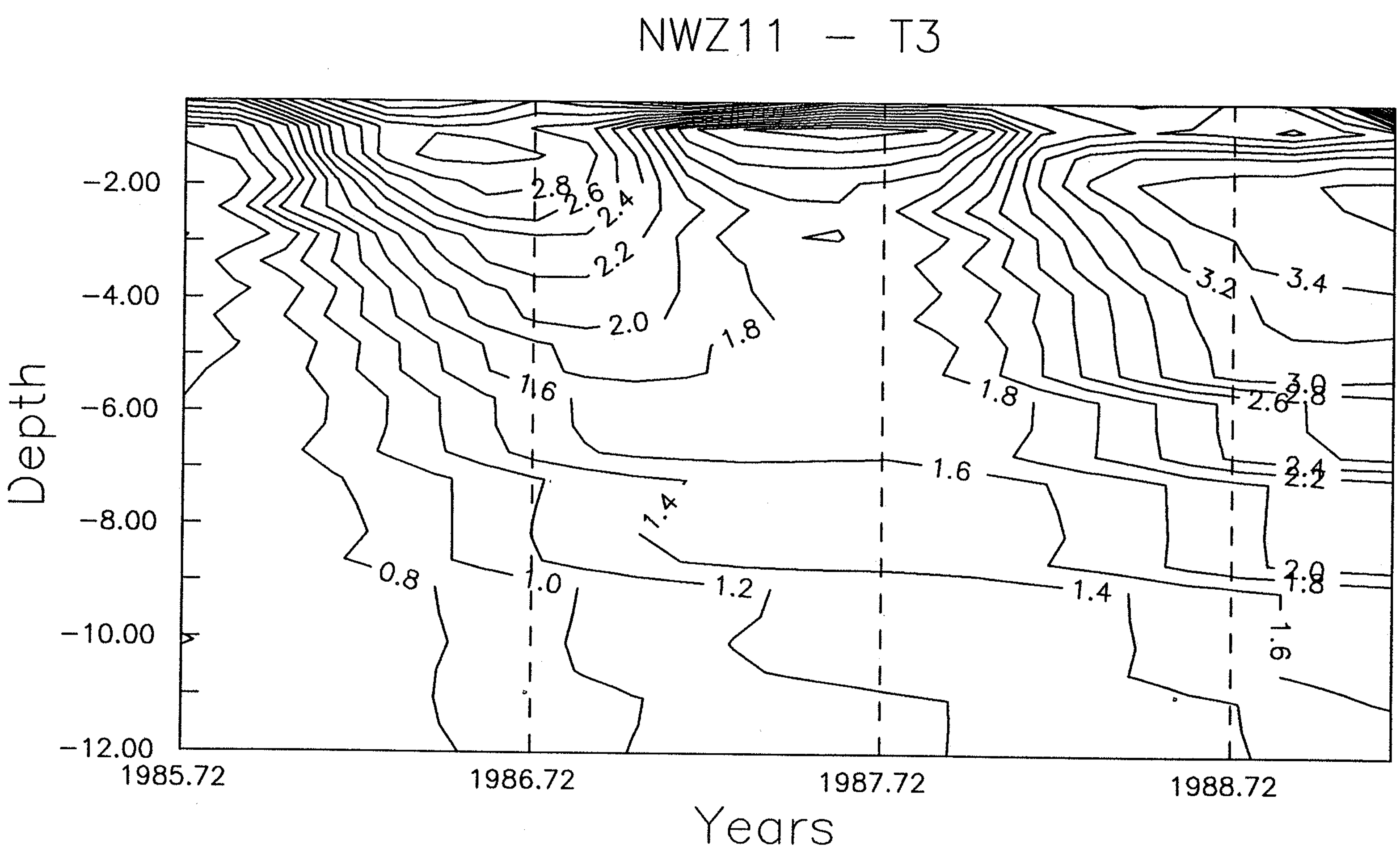
-3.00
-5.00
1985.72
1986.72
1987.72
1988.72
Years
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.8

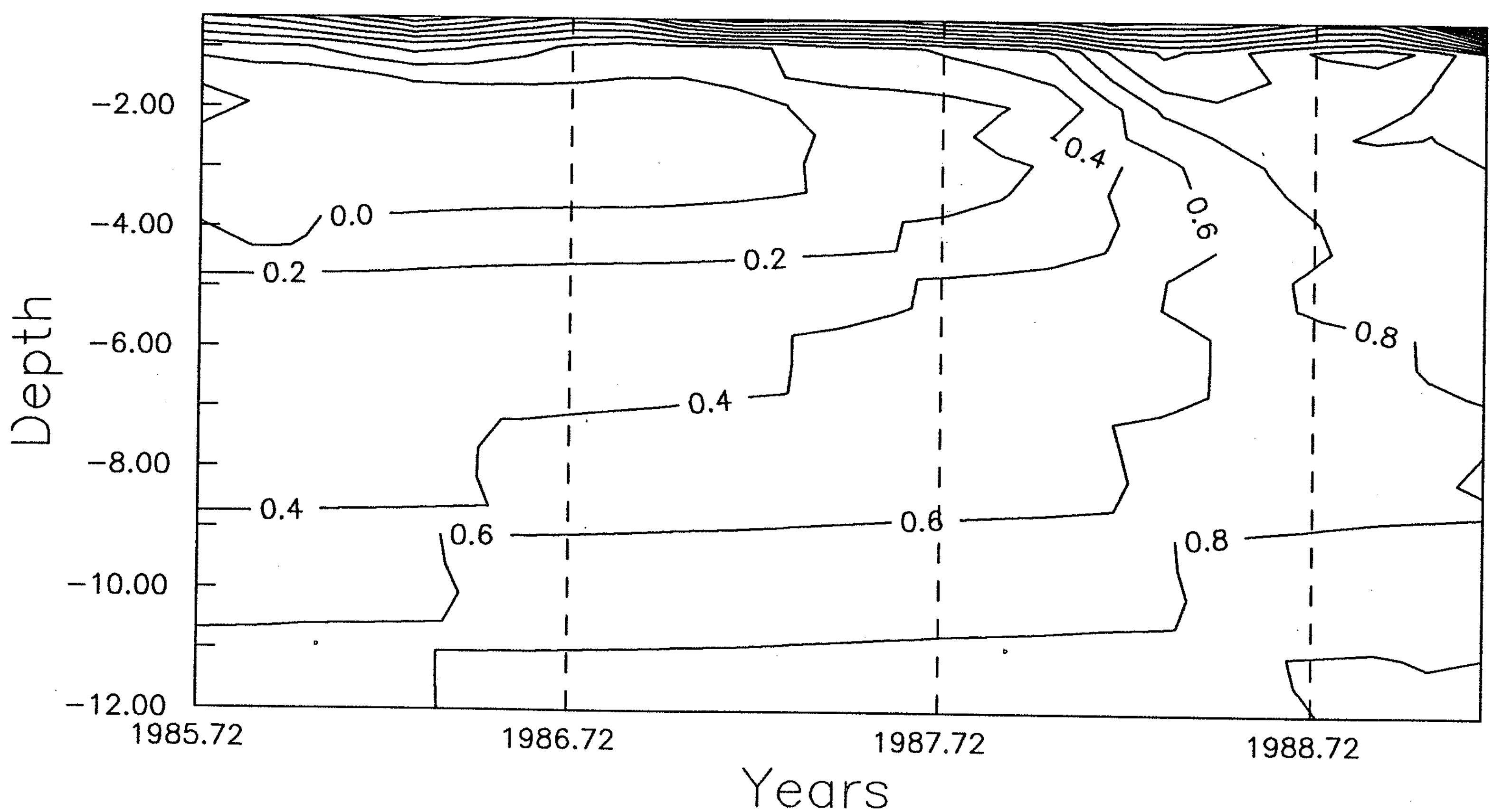
NWZ11 – T2



Depth
-1.00
-3.00
-5.00
1985.72
1986.72
1987.72
1988.72
Years
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
3.2
3.4
3.6
3.8
4.0

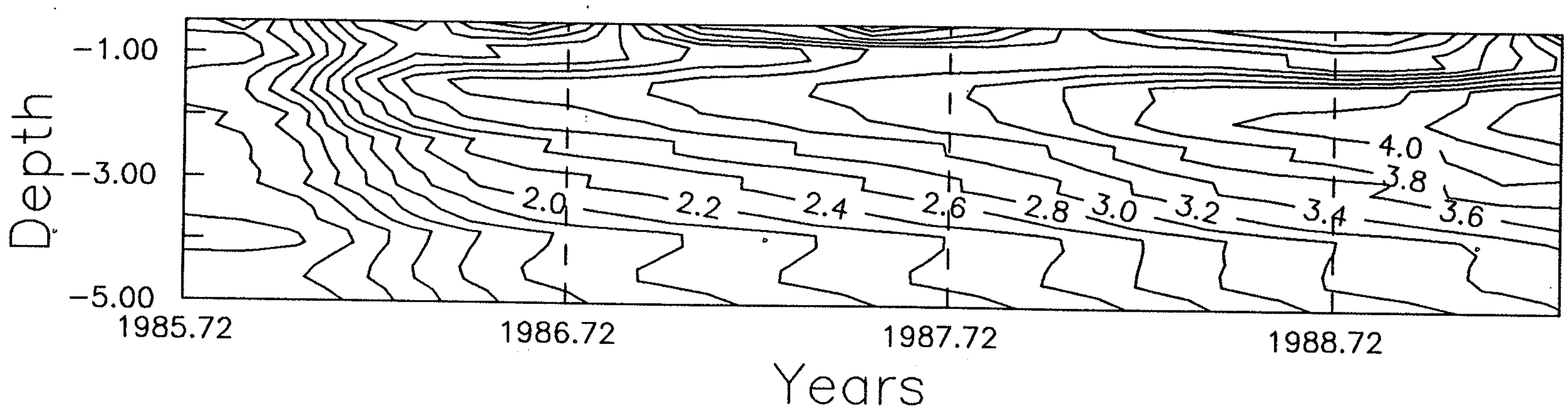

NWZ11 – T3
Depth
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
1985.72
1986.72
1987.72
1988.72
Years
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4

NWZ11 — T4



Depth
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
1985.72
1986.72
1987.72
1988.72
Years
0.0
0.2
0.2
0.4
0.4
0.4
0.6
0.6
0.6
0.8
0.8

NWZ12A - T1



Depth
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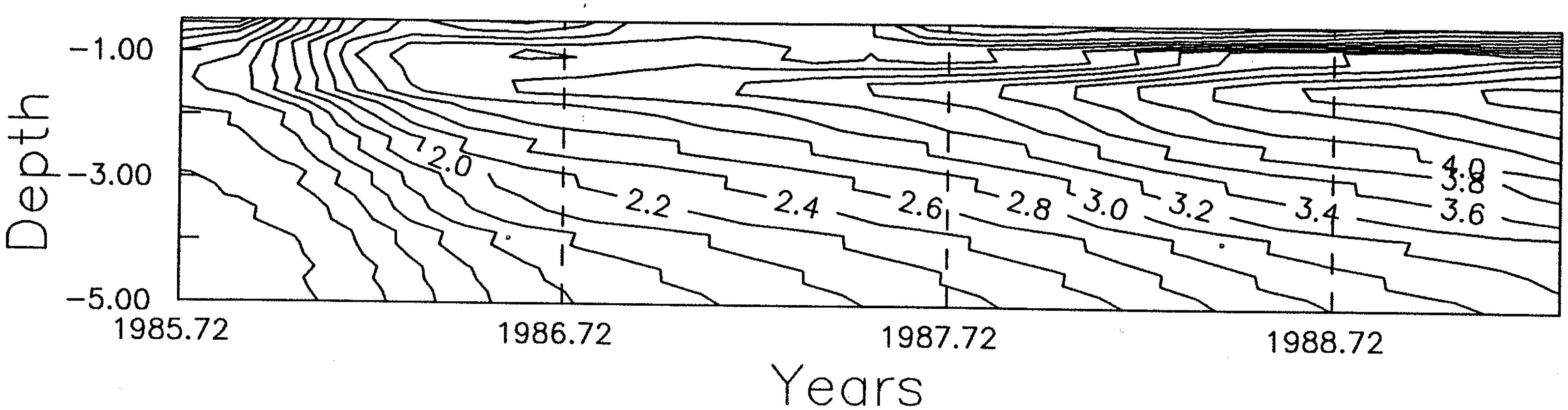
-5.00
1985.72
1986.72
1987.72
1988.72
Years
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0

NWZ12A – T2



Depth
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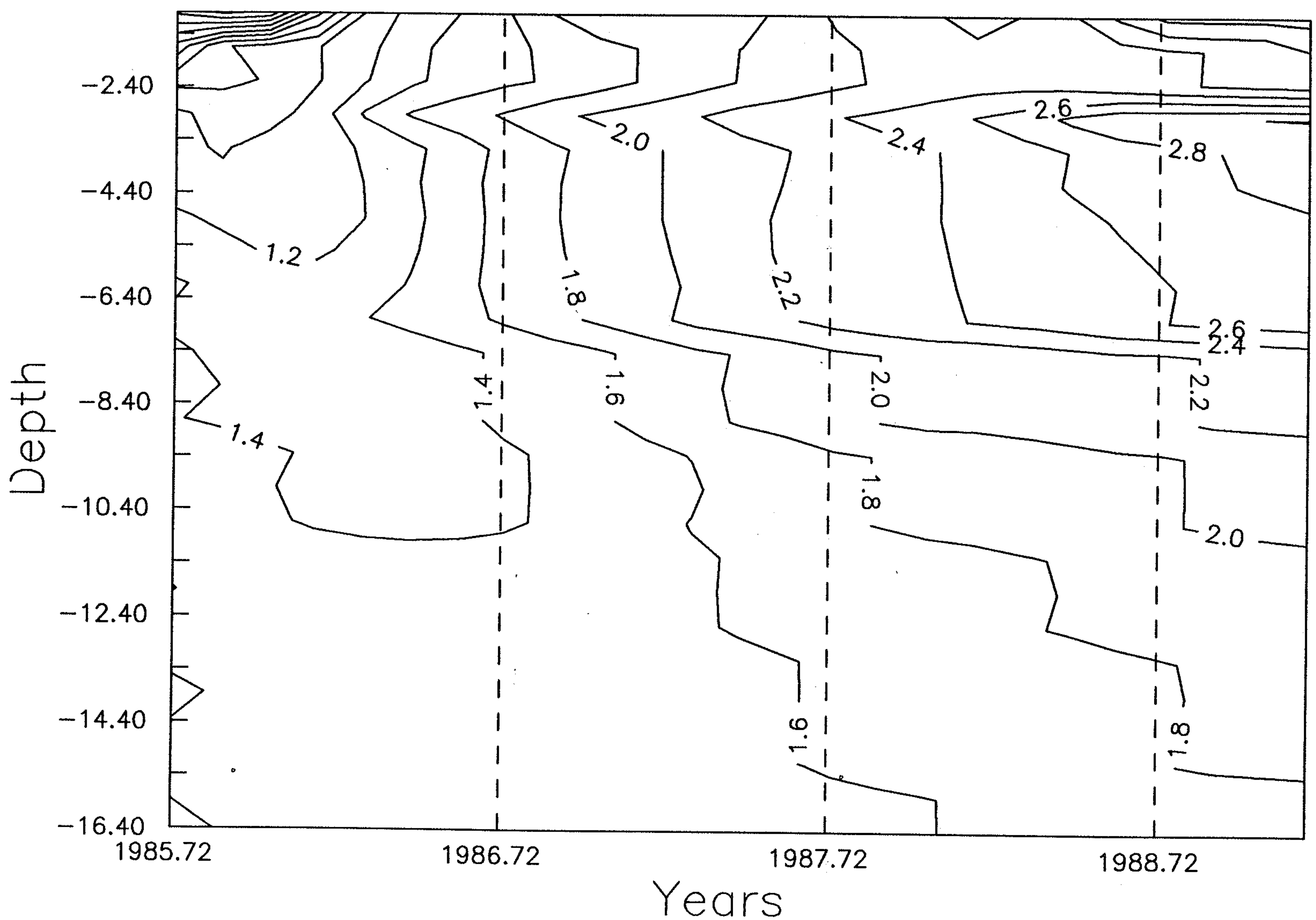
-3.00
-5.00
1985.72
1986.72
1987.72
1988.72
Years
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0

NWZ12A - T3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1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
Depth
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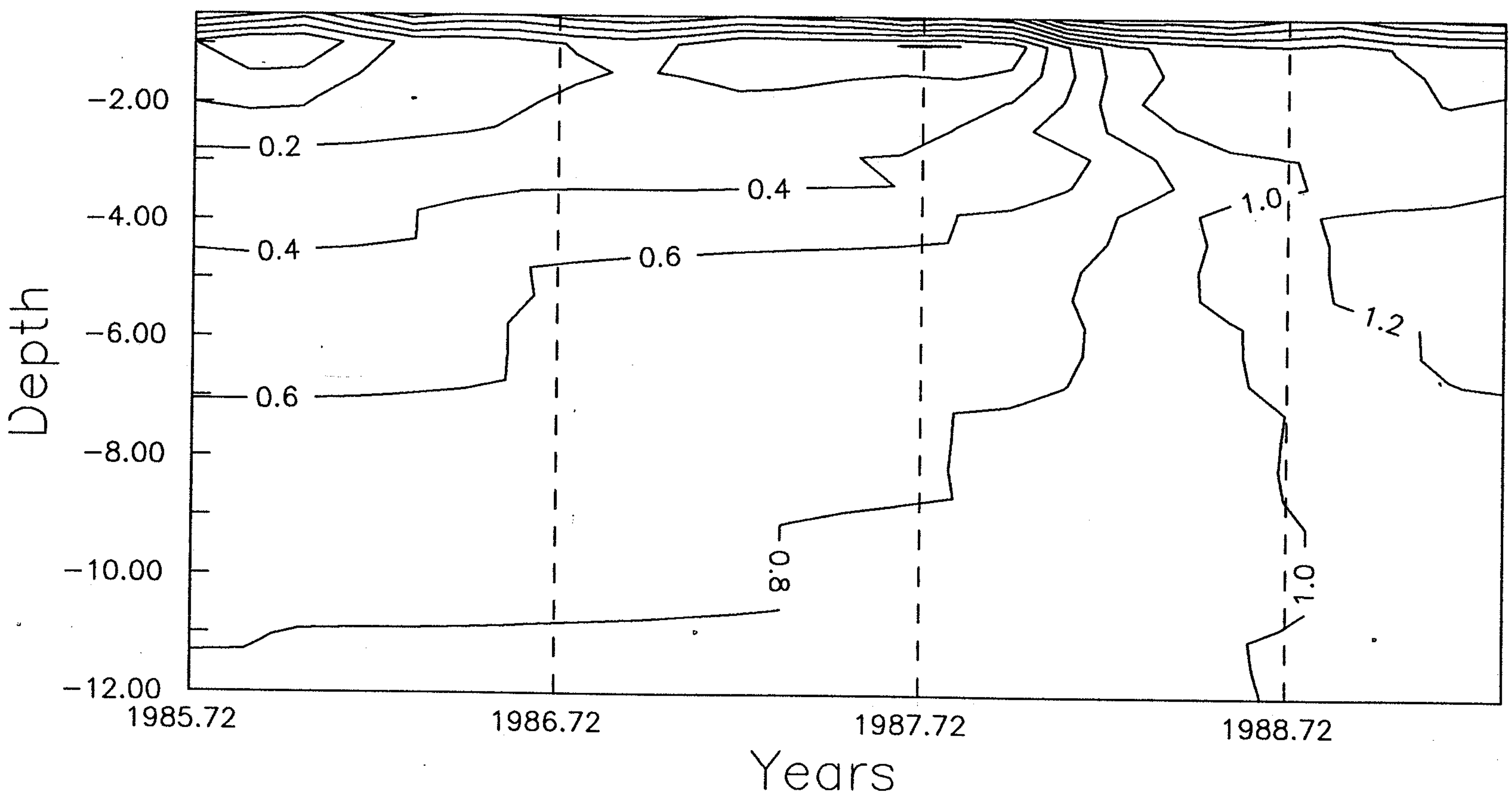
-4.40
-6.40
-8.40
-10.40
-12.40
-14.40
-16.40
1985.72
1986.72
1987.72
1988.72
Years

NWZ12A — T4


Depth
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-10.00
-12.00
1985.72
1986.72
1987.72
1988.72
Years
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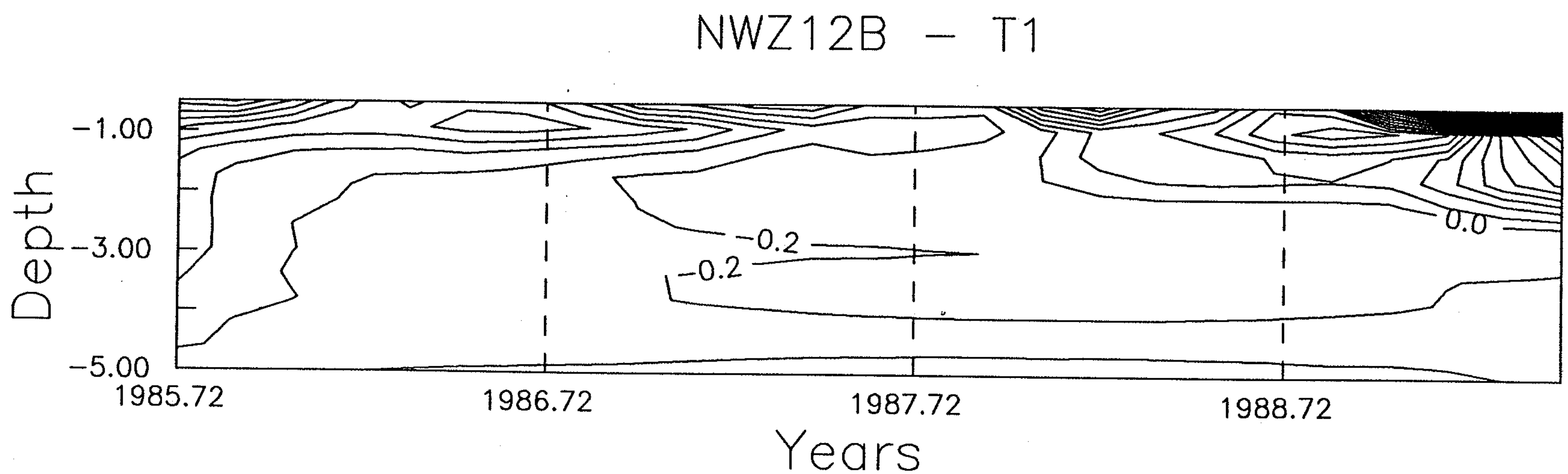
0.4
0.4
0.6
0.6
0.8
1.0
1.0
1.2


NWZ12B – T1
Depth
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1986.72
1987.72
1988.72
Years
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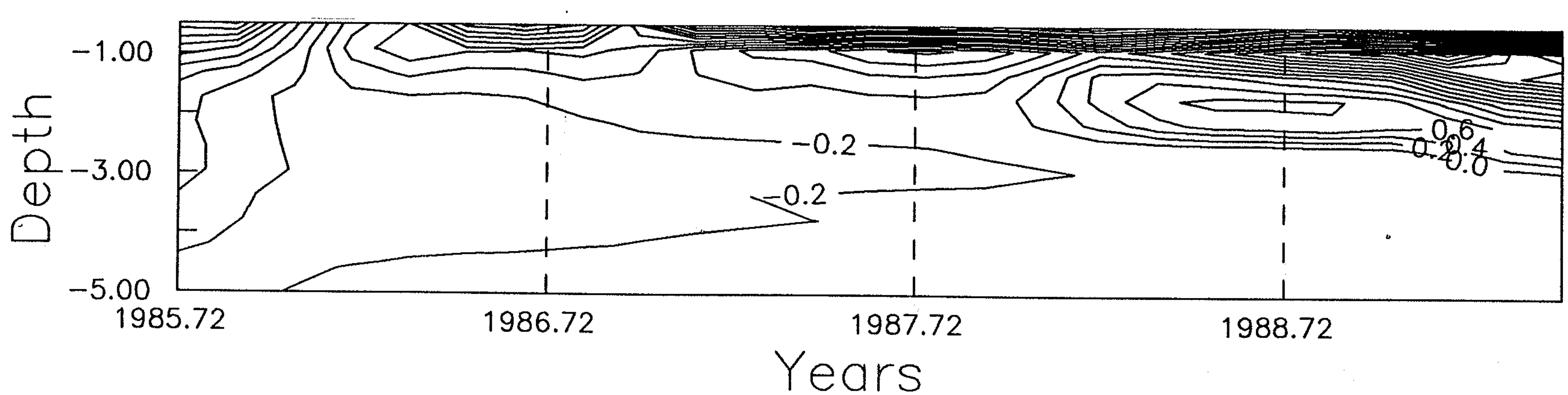
−0.2
0.0

NWZ12B – T2



Depth
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-3.00
-5.00
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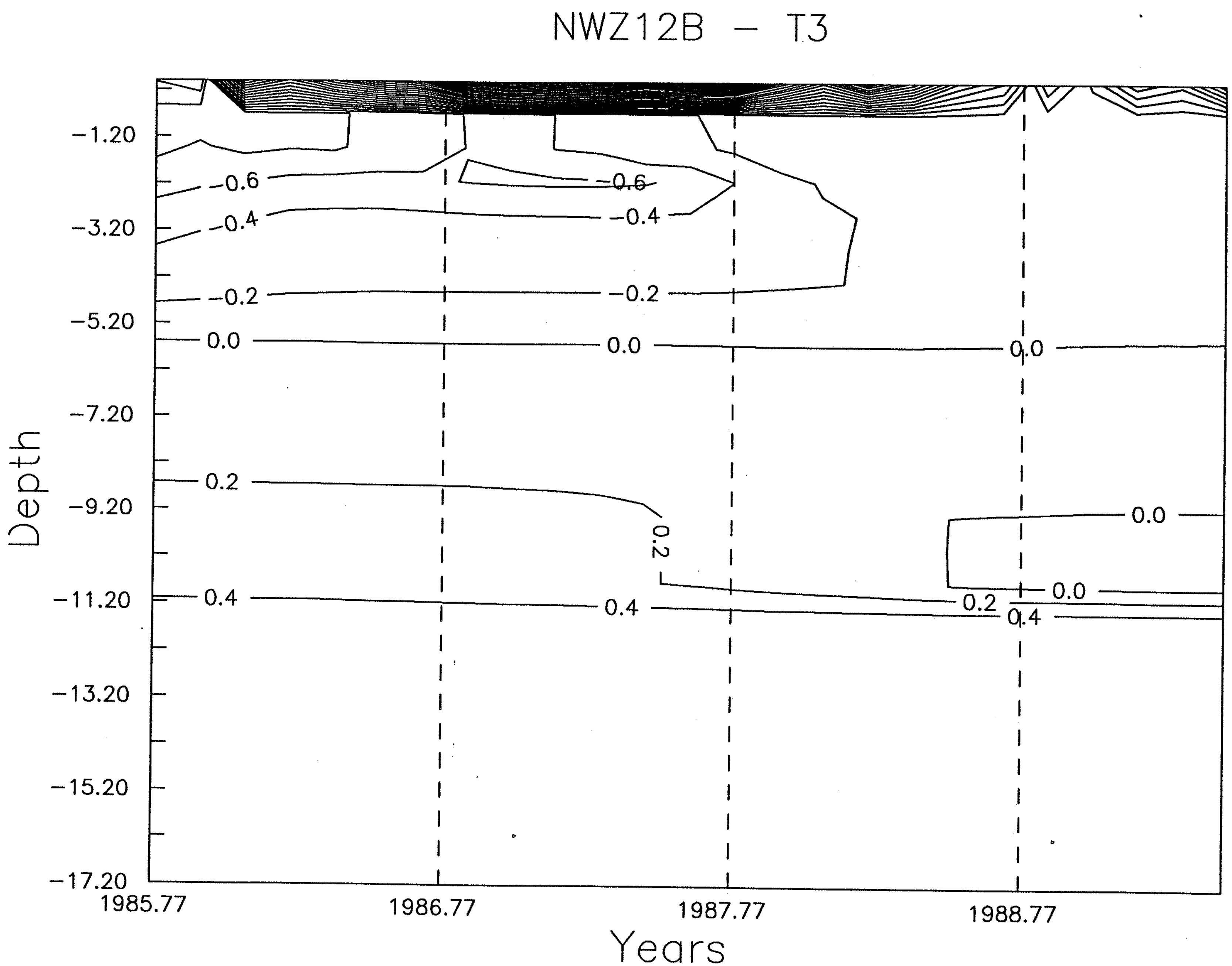
1986.72
1987.72
1988.72
Years
-0.2
-0.2
0.6
0.4
0.2
0.0


NWZ12B – T3
Depth
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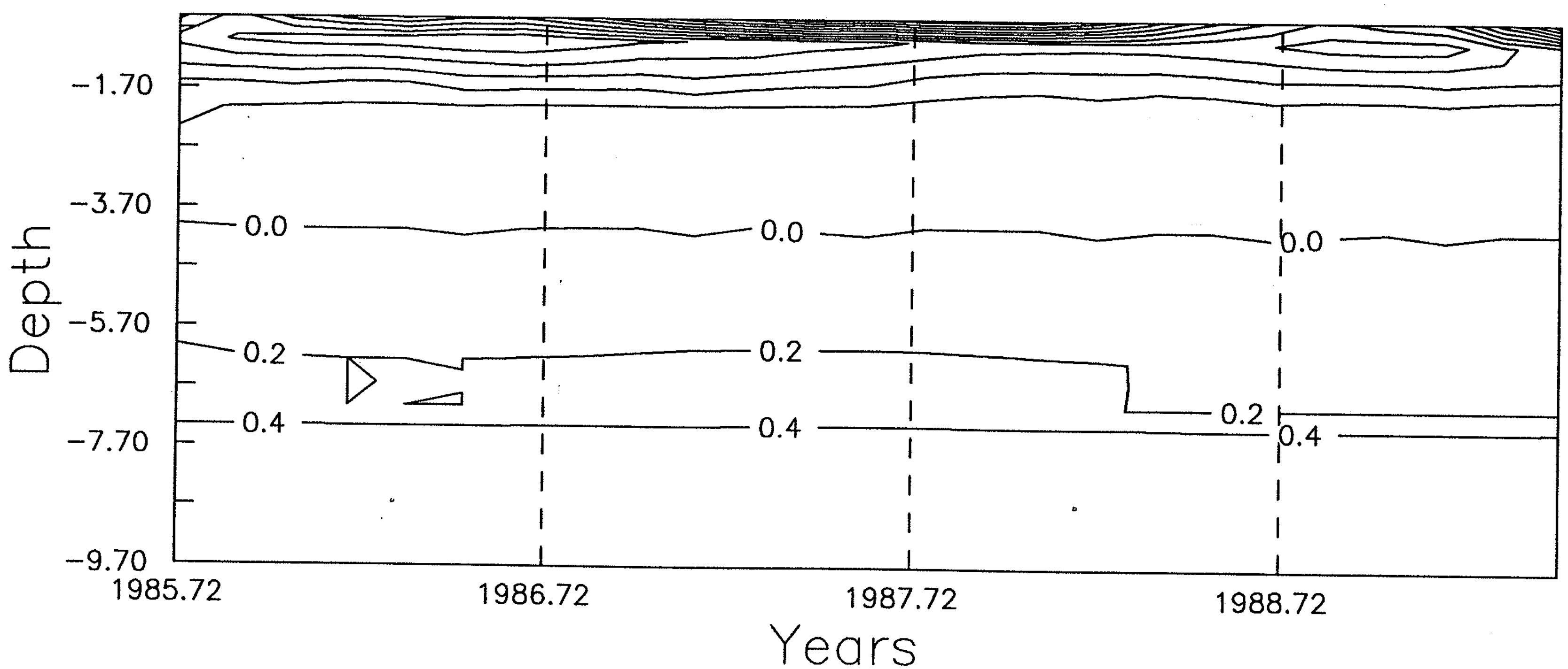
−5.20
−7.20
−9.20
−11.20
−13.20
−15.20
−17.20
1985.77
1986.77
1987.77
1988.77
Years
−0.6
−0.4
−0.2
0.0
0.2
0.4

NWZ12B – T4


Depth
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1985.72
1986.72
1987.72
1988.72
Years
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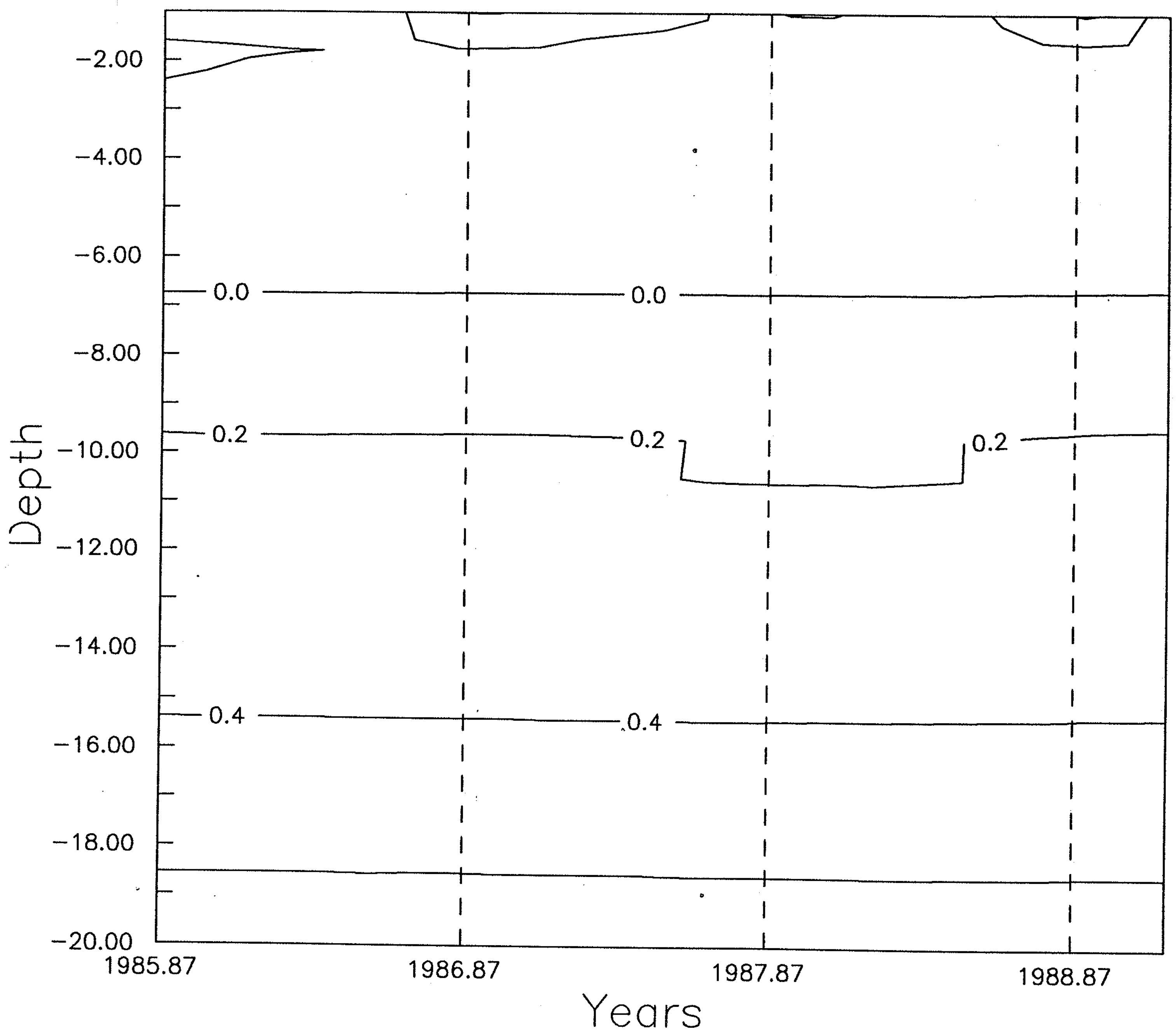
0.2
0.4

NWZ13 - T1



Depth
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-10.00
-12.00
-14.00
-16.00
-18.00
-20.00
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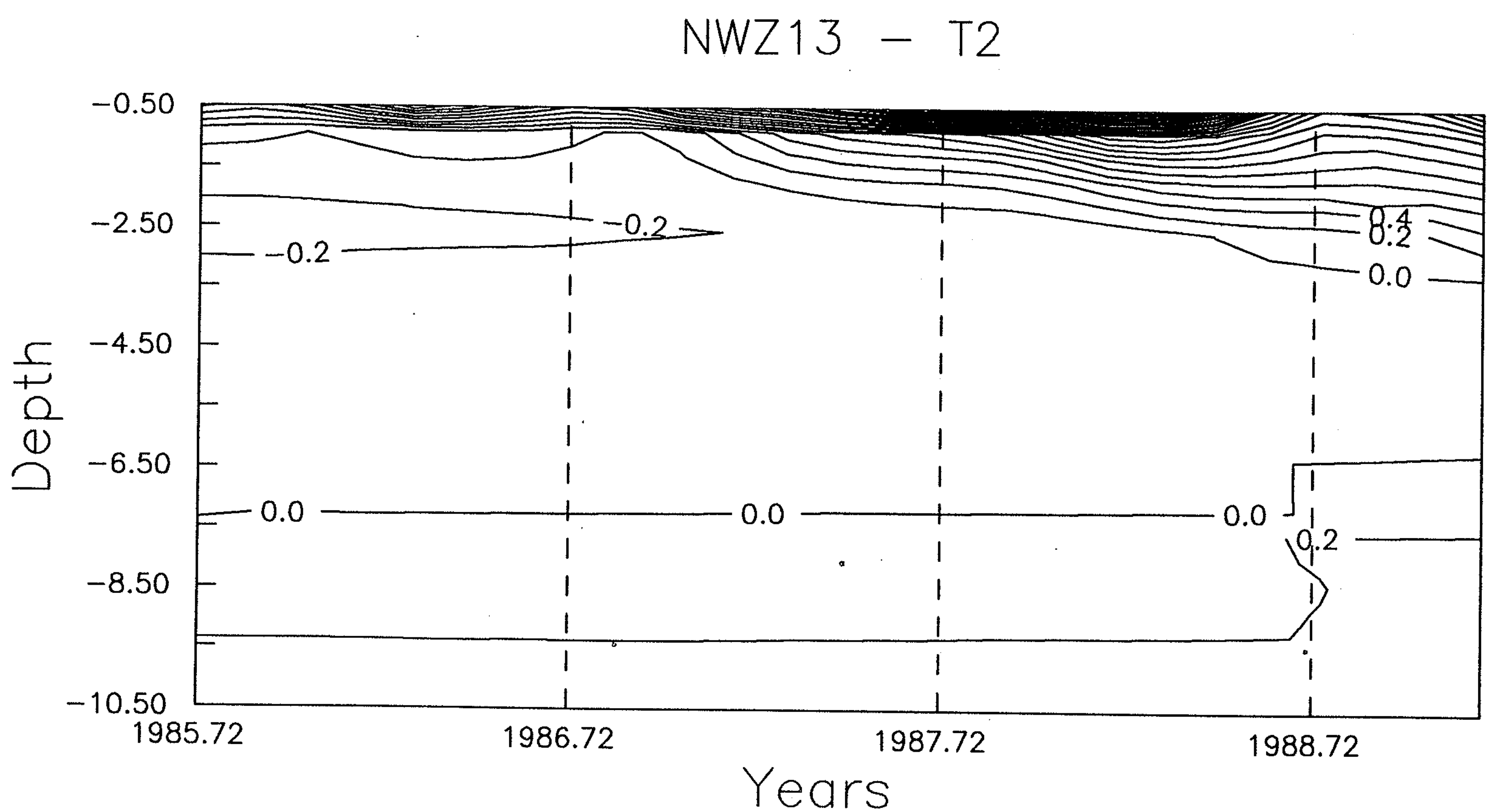
0.2
0.2
0.2
0.4
0.4
1985.87
1986.87
1987.87
1988.87
Years


NWZ13 - T2
Depth
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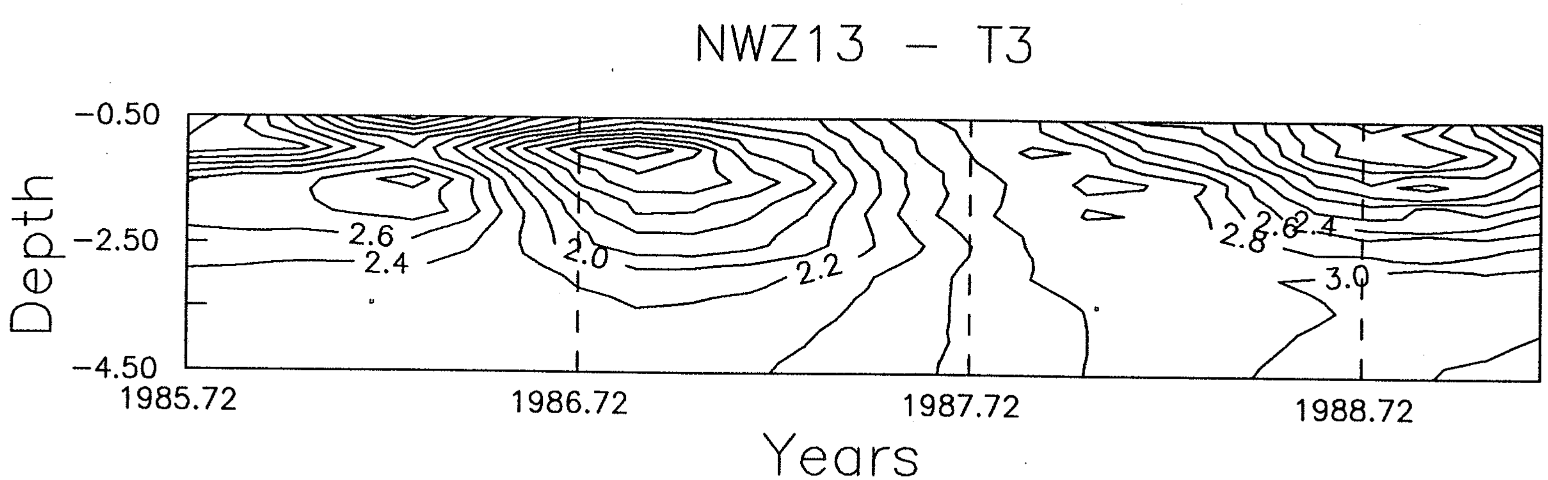
-8.50
-10.50
1985.72
1986.72
1987.72
1988.72
Years
-0.2
-0.2
0.4
0.2
0.0
0.0
0.0
0.0
0.2


NWZ13 – T3
Depth
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−2.50
−4.50
1985.72
1986.72
1987.72
1988.72
Years
2.6
2.4
2.0
2.2
2.8
2.6
2.4
3.0