GEOLOGICAL SURVEY OF CANADA

OPEN FILE 2433

Paleoclimatic and geotechnical analysis of ground temperature data at Alert, N.W.T.

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1991

Energy, Mines and Resources Canada

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Canada

UNIVERSITY OF WATERLOO
Faculty of Engineering

PALEOCLIMATIC AND GEOTECHNICAL ANALYSIS OF GROUND TEMPERATURE DATA AT ALERT N.W.T.

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9 May 1991

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SUMMARY

In an effort to understand the processes that have created the Arctic landscape this study undertakes some exploratory analysis in terms of climate-induced change and ground thermal properties.

Ground temperature data have been collected for the past 12 years at Alert N.W.T.. A description of the process used to prepare the data for analysis is provided. The results of calculations and observations are shown, conclusions drawn and recommendations made.

It was concluded that the seasonal variation in surface temperature from summer to winter is sending a signal through the ground. This signal is both decreased in amplitude and shifted in time with depth. It was found that cross-correlation, in an attempt to determine the phase lag between various depths, was restricted to the upper 25 m. Inconsistency in apparent thermal diffusivity calculations were observed and may partly be attributed to errors, however, other factors like fracturing and non-homogeneous material may have had a much larger impact.

It is recommended that ground-weather temperature correlations be undertaken upon the arrival of the weather data and that similar studies be undertaken using data from the other four sites.

CONCLUSIONS

The seasonal periodic variation in surface temperature from summer to winter appears as a sinusoidal like signal in the ground. This annual wave diminishes in amphlitude with depth where it is overtaken by noise at about 25 m; the phase also shifts in time. A correlation exists between weather and ground temperatures.

Two dimensional splining was successful only with the first subset of data, spanning from October 19, 1978 to May 15, 1981, when temperature measurements were taken every two or three weeks. Statistical cross-correlation techniques were found to be an ideal method to determine objectively the phase shift of the periodic variation with depth. Reasonable correlations were recovered to a depth of 25 m while correlating adjacent depths. Correlation of the first depth with greater depths was successful only to a depth of about 15 m.

Inaccurate measurements primarily in phase lag, and also in thermistor spacing account for some of the variability observed in apparent thermal diffusivity calculations. Greater variation than can be accounted for in the sensitivity analysis is apparent and can perhaps be attributed to rock fracturing and non-homogeneous material reported especially in the upper few metres.

RECOMMENDATIONS

The data should be measured at more frequent intervals to make it more consistent with the requirements of statistical and time series analysis.

Alert weather temperatures should be acquired to cross-correlate with ground temperatures at various depths for site #1.

Similar studies need to be conducted for sites 2 - 5 Particular emphasis should be placed on sites 4 - 5 where the data is more detailed in depth.

INTRODUCTION

Recently, Canada's north has been subject to a number of intensive permafrost studies in an effort to increase our understanding of the natural processes that have created it's landscape.

Scientists such as Brown (1973) have analyzed shallow subsurface temperatures and the effect of vegetation, at various locations throughout northern Canada. Similar studies were also undertaken by Judge (1973), in the Mackenzie Valley, and Harris (1982), in the Rocky Mountains.

In 1978, a subsurface permafrost and terrain analysis study was established at the Canadian Forces Station Alert N.W.T., 82°30'N, 62°26'W, the most northern community on the North American continent. The station lies in the continuous permafrost zone. Five holes were drilled to depths up to 60m and equipped with cables instrumented with 10 - 12 thermistors. For the past 12 years temperature measurements have been taken at various intervals ranging from two weeks to three months. The program and initial data are reported in Taylor et al., 1982 (see Figure 1.1).

Alert experiences approximately four frost free days per year and therefore has a very shallow active layer generally less then one half metre. Combined with a mean annual rainfall of 1.9cm and snowfall of 145cm (Environment Canada, 1975), this 'Arctic Desert' is ideally suited for detailed geothermal/geomorphological study.

This report presents data recovered since the initial results presented in Taylor et al., 1982 and undertakes some exploratory analysis in terms of climate-induced change and ground thermal properties. Five major sections are noted which describe:

1) The geology and surficial deposits in the region of the five test sites.

2) The results of a paleoclimatic study using data from borehole #1.

3) The cross-correlation process essential in determining phase lag and thus apparent thermal diffusivity.

4) The calculations of Apparent Thermal Diffusivity from the time series of ground temperatures of borehole #1.

See Appendix A and B for the process of converting raw temperature data into formats suitable for plotting and for further analysis as well as for the methods used in screening the data for errors.

1.0 **GEOLOGY**

Alert is located within the Imina Formation near the northern limit of the Franklinian Geosyncline. The Formation itself, named after a Greenland Eskimo, outcrops widely across the northern coast of Ellesmere island and is estimated to range between 250 to over 3000m in thickness in spite of the fact that it is tightly folded and shows many changes in plunge (Trettin, 1971). The formation is upper Middle Ordavician to Lower Devonian in age and primarily consists of calcareous siltstone, shale and greywacke deposited in a deep sea environment. In fact "Imina Group" was originally named by Christie to describe a "uniform series of subgreywacke, greywacke, and argillaceous greywacke beds" (Christie, 1957; quoted from Trettin, 1971).

Two major rock types were discovered in drilling the five boreholes: a varved argillite, a fine-grained rock derived from mudstone or shale, and calcareous greywacke, a course-grained sandstone believed to be deposited by submarine turbidity currents. Also noted was the fact that the upper 2 to 3 metres was highly fractured rock, held together by ice up to 3 cm in thickness. Similar discoveries of frost fractured rock were also reported at Resolute (Cook, 1955). The different borehole geologies are described in Table 1.1 (Taylor et al, 1982).

TABLE 1.1. Drill core descriptions[1]

Site	Depth interval (m)	Rock
1	0 - 3.8	Overburden and shattered rock, poor sample recovery
	3.8 - 61.0	Argillite
2	0 - 3.0	Overburden and shattered rock, infilled with ice
	3.0 - 61.0	Argillite; fine fractures between 30 and 48 m cemented with ice
3	0 - 2.4	Overburden and shattered rock, infilled with ice up to 2 cm thick
	2.4 - 12.8	Argillite
	12.8 - 60.0	Greywacke; some ice up to 2 cm around 18 and 38 m
4	0 - 3.0	Overburden and shattered rock
	3.0 - 7.9	Greywacke
	7.9 - 15.2	Argillite
5	0 - 2.4	Overburden and shattered rock, infilled with ice up to 3 cm thick
	2.4 - 15.2	Argillite

[1]logged in field; lithologic identification by Gratton-Bellew (Brown et al. 1979)

It is suspected that the Innuition Ice sheet covered the Alert area during the Quaternary, although its extent and thickness are not known. It has been suggested that deglaciation of northern Ellesmere island took place as recently as 7500 to 8100 years B.P.

An emergence curve of the Alert area, based on driftwood dates, has been established since that time. (*see* Figure 1.2). At 6000 years B.P. the curve shows an emergence of 30m, and at 8000 years B.P. an emergence of about 75m. (England, 1976). These dates and elevations have been used to depict shoreline positions at these dates and the considerable amount of land mass that was submerged (*see* Figure 1.1). This map reveals that site #3, at present elevation of about 170m ASL, lies beyond the maximum marine limit of 135m, while site #1 at 4.6m ASL and 50m from the coastline was submerged after the ice retreat until emergence about 2000 years ago. According to England's emergent curve site #4 emerged about 7000 years ago. This demonstrates the diversity of each site in both its glacial and post-glacial history.

Permafrost is expected to be continuous and very thick in the Alert area. Using the equation $Q = k\nabla T$ where: Q = Terestrial Heat flow, k = Thermal Conductivity, and ∇T = Temperature Gradient, it is possible to estimate a range of equilibrium ground permafrost thickness. Approximating Q = 0.060 W/m^2 and taking a lab measured k = 2.5 -3.5 W/mK, the temperature gradient was determined to range from 24 - 17 °C/km respectively. Therefore, the equilibrium permafrost thickness, using an average ground temperature of -18°C, ranges from 750 - 1059m. This is only an approximation and is greatly dependent on the deeper geology and environment of the area. For instance at site #1, located only 50m from the ocean, permafrost may be much shallower, perhaps only 300 - 400m, due to the warming affects of the ocean and its recent emergence (Lachenbruch, 1957; Taylor, 1991).

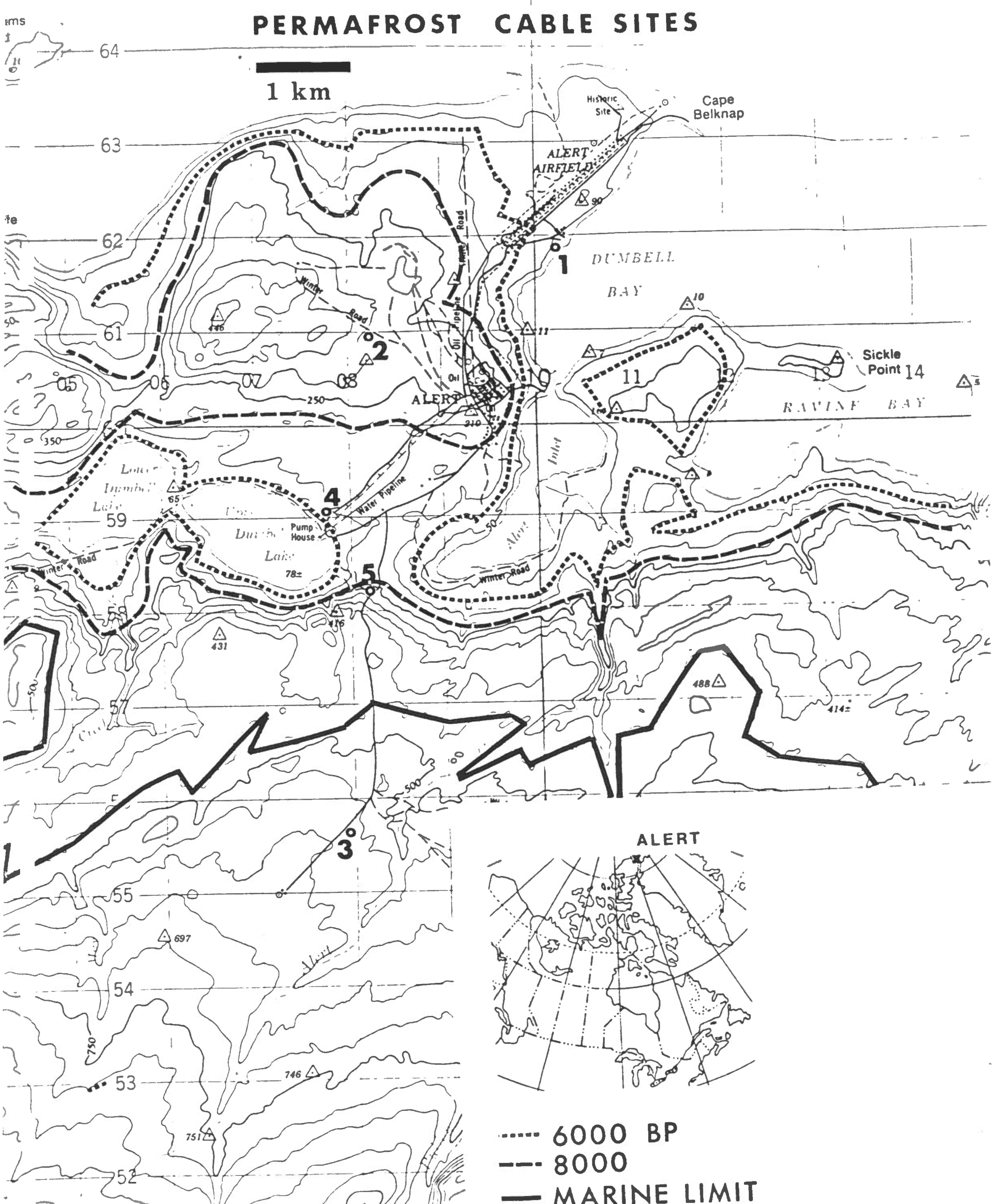

Figure 1.1. Map showing Alert and the five drilling sites. Contour interval:1…

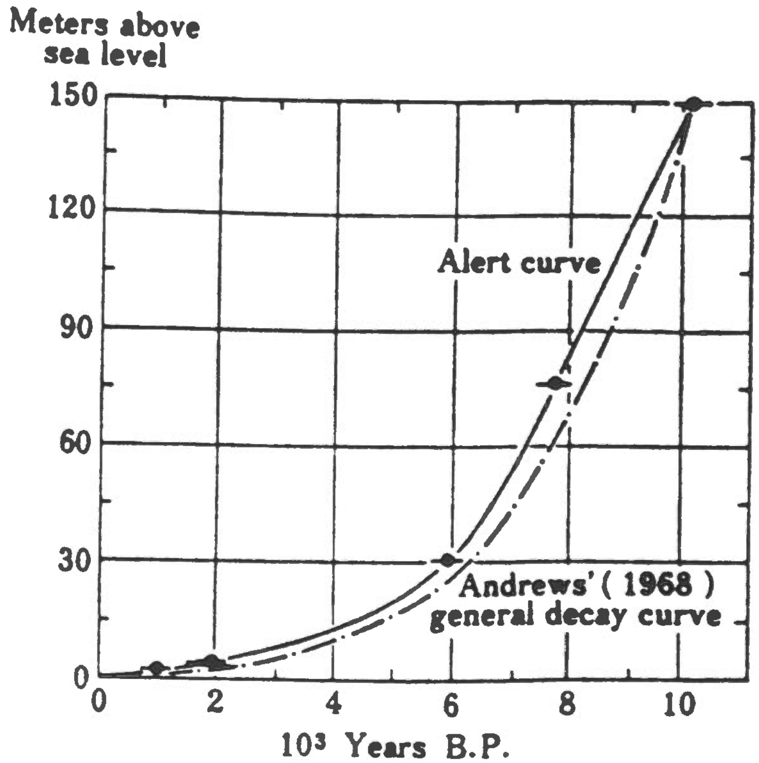

Figure 1.2. Emergence curve of the Alert area. (England, 1976)

2.0 PALEOCLIMATIC STUDY

It is evident that the seasonal periodic variation in surface temperature from summer to winter is sending a signal through the ground (see Appendix C, for annual wave patterns at various depths). Therefore, in taking temperature measurements at various depths for a long period of time, a correlation should exist with some equally long weather pattern in the past. The phase shift depends on the ground thermal diffusivity and the depth that the temperatures are measured. Although no actual ground - weather correlations were undertaken a basis for this argument was established.

It is apparent upon graphing temperature versus time, at various depths, that the signal of the annual wave diminishes with depth to the point where it is eventually overtaken by noise at approximately 25 m (see Appendix E1). However, upon performing regressions on the deeper data it is evident that a trend still exists (see Appendix H1).

Also apparent, particularly in the multiplicative regressions, is the thermal disturbance of the well drilling, seen on approximately the first year of data. A cooling effect occurred at the shallower depths down to about 27 m while a warming effect occurred from that point to 60 m (Compare Figures H2.1-H2.2, Appendix H2). In analyzing these deeper depths, the well drilling effect should be removed since a shift in temperature of several tenths of a degree is very large compared to the seasonal variation at these depths. Near the surface this effect is negligible. Alternatively, the first year of the deeper data might be ignored.

Figure 2.1 (Maxwell, 1980) reveals that for the period of time between 1950 and 1976 Alert has been experiencing a cooling trend. Linear regressions were performed on the data at all depths to determine any long-term trend (see Appendix H1). Above 30 m, the regressions suggest a trend to increasing ground temperatures in time. This can be compared to the weather record (monthly means) of the last 12 years (see Figure 2.2). Note the appearance of randomness in the data is due to the annual wave pattern and not error in temperature measurements). The regression also suggests a cooling trend for the ground temperatures below 30 m. This probably reflects the earlier cooling of the weather record as previously noted (see Figure 2.1). Further analysis perhaps using equations other than that describing a periodic temperature variation, is required to relate the trend in deeper temperatures to the weather record.

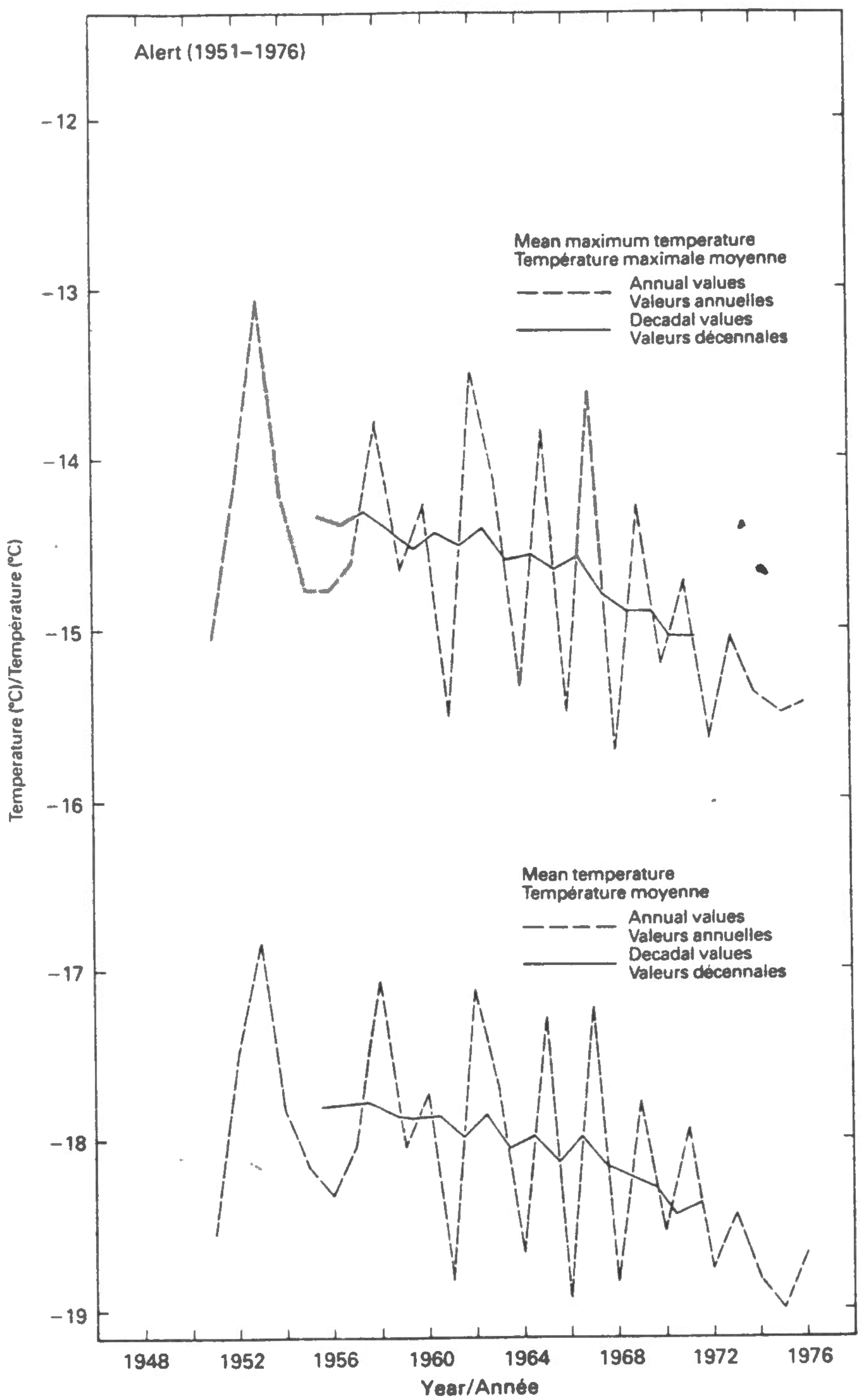

Figure 2.1. Year to year annual mean and mean maximum temperatures and corresponding ten-year running means. (Maxwell, 1980)

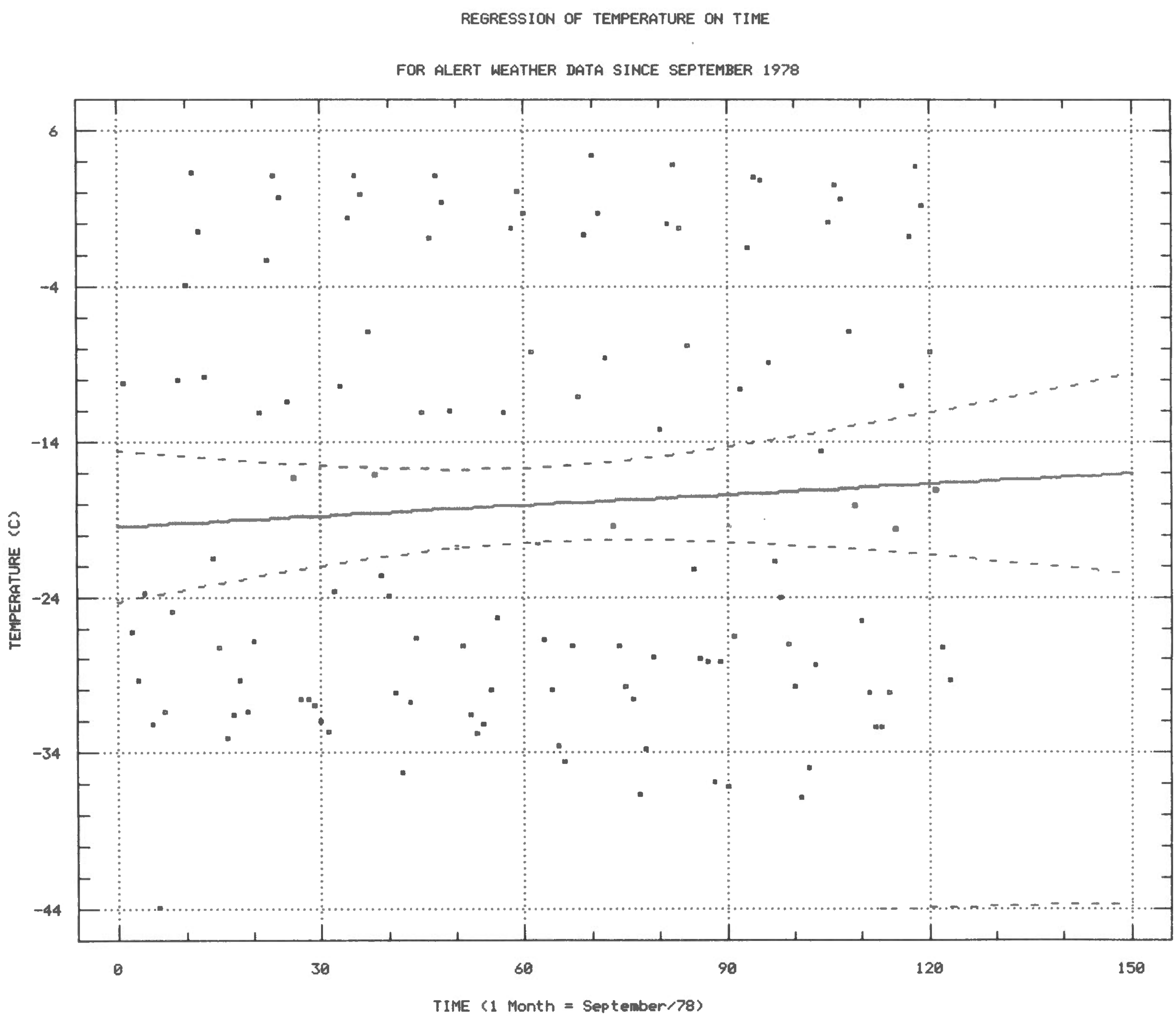

Figure 2.2. Regression of monthly mean temperatures for past 12 years.

3.0 CROSS-CORRELATION

3.1 Data Splining

Over the years the data have not been obtained at equally spaced time intervals (see Appendix E1 and assorted graphs). For approximately the first three years the Department of National Defence (DND) personal measured temperatures every two or three weeks. However, since 1986 EMR and DND have agreed to extend this interval to every three months on boreholes 1 - 3 and every month on boreholes 4 - 5. This took place over the course of approximately two years where fewer measurements were taken. There are also times when natural occurrences cause breaks in the data record; for instance in May of 1981 a rabbit chewed the temperature cable in two places at site #1. In this case it was seventeen months before readings resumed on October 26, 1982.

Because two periods exist where there is little recorded data, it was necessary to make three subsets from the readings recorded at site #1, the first spanning from October 19, 1978 to May 15, 1981, the second from October 26, 1982 to February 5, 1985 and the third from April 24, 1987 to the present.

In order to undertake analysis of this time series data, and in particular use cross-correlation techniques, the vectors themselves must be of equally spaced time intervals. Hence, it was necessary to spline the data using a graphing package, by Trimetrix, called Axum. Cross-correlation was undertaken using the package "Statsgraphics," which was further restricted to vectors of equal length. A program for cross-correlating data was later developed by the author for vectors of unequal length.(<u>see</u> Appendix D).

The spline interval was chosen at fifteen days for the first data subset which yielded a reasonably accurate representation of the raw data.(see Appendix E1). However, at depths greater than 25 m it was found that the signal of the annual wave had basically disappeared and so splining for the purpose of cross-correlation was perhaps less meaningful.(Compare Figures E1.12-E1.13, Appendix E1). Regression was used, as explained earlier, to detect the general trend of the deeper data towards warming or cooling.

For the later two subsets, where the frequency of measurement was decreased to three months, it was apparent that the data interval was insufficient to define the nature of the seasonal variation. It was difficult to obtain a reasonable representation of the annual wave when splining the raw data. First an interval of 50 days was chosen in which case the spline represented the raw data very little.(<u>see</u> Figures E2.5-E2.6, Appendix E2). Secondly a smaller increment of 15 days was used which appeared to cross most of the raw data points but as the graphs suggest, too much is added that is not supported by the original data.(<u>see</u> Figures E2.1-E2.4, Appendix E2).

3.2 <u>Cross-Correlation</u>

It is necessary to cross-correlate the temperature vectors at various depths in order to obtain the phase lag in the annual wave. Phase lag in this case simply refers to how much one temperature vector lags another temperature vector in time, and is used to calculate the Apparent Thermal Diffusivity of the soil.

Two approaches were taken in the cross-correlation process. The first was simply to cross-correlate the temperature vector at one depth with the temperature vector at the adjacent depth. The second was to correlate the temperature vectors at various depths to that of the first depth. In the first case, the incremental variation of thermal diffusivity may be calculated; in the second case a bulk average of thermal diffusivity between the surface and the deeper depth may be obtained. In doing so, we are able to trace how long a thermal disturbance at the surface takes to reach various depths in the ground.

Statsgraphics, a statistical package produced by A Plus*Ware Product, was used to correlate these temperature vectors at different depths. It was found that the correlation between adjacent depths was successful to a depth of approximately 25 m (<u>see</u> Appendix F1). Correlation of the first depth with greater depths was successful only to a depth of about 15 m (<u>see</u> Appendix F2).

This may be explained in that any signal produced at the surface as a result of a thermal disturbance is greatly reduced in magnitude at deeper depths and is ultimately drowned out by noise. At best one can only detect the general trend of the data at these depths as mentioned.

A cross-correlation program called 'Croscr', was developed by the author from Davis (1978), for the purpose of correlating two vectors of unequal length.(<u>see</u> Appendix D). This will in future prove useful for comparing the weather record, at the surface, over the past 40 years at Alert to the ground temperature data recorded at various depths. The program calculates the phase lag and was used to correlate the same vectors as Statsgraphics for the purpose of verification. It was found that either method yielded the same results (Appendix G1 (compare to app. F1) Appendix G2 (compare to app. F2).

4.0 APPARENT THERMAL DIFFUSIVITY (ATD) ANALYSIS

4.1 Calculation of ATD

The apparent thermal diffusivity was calculated from the time series of ground temperatures at site #1, using the following formula (Horton et al. 1983).

$$\alpha = \frac{1}{2\omega}\left(\frac{\Delta z}{\Delta t}\right)^2$$

where, α =Apparent Thermal Diffusivity (m^2/s)

ω $= \dfrac{2\pi}{p}$ where p = period of annual wave (sec)

Δz =change in depth (m)
Δt =phase lag (sec)

Only the first data subset measured frequently at every two or three weeks, and which could be splined properly, was considered in the calculation process. Of this it was found that good correlation occurred, between adjacent temperature vectors to a depth of about 25m, and between 1.52 m and succeeding deeper temperatures to about 15 m. Only for these correlations where phase lag can be determined with some precision, was it possible to calculate the apparent thermal diffusivity using Horton's equation.

The results are as follows:

Table 4.1 Apparent Thermal Diffusivity Results

UPPER DEPTH (m)	LOWER DEPTH (m)	AVERAGE DEPTH (m)	PHASE SHIFT (Years)	APPARENT THERMAL DIFFUSIVITY (x 10^{-6} m^2/s)
-1.524	-3.048	-2.286	0.12	0.41
-3.048	-6.096	-4.572	0.21	0.53
-6.096	-12.192	-9.144	0.25	1.50
-12.192	-18.288	-15.24	0.33	0.86
-18.288	-24.384	-21.336	0.29	1.12
-1.524	-6.096	-3.81	0.25	0.84
-1.524	-12.192	-6.858	0.49	1.20

4.1a Discussion of ATD Results

However, upon graphing depth versus phase shift (*see* Figures 4.1 and 4.2) for adjacent depths as well as for those depths compared to depth 1.52m, it becomes apparent that some error exists. For instance we would expect to find identical phase shift results for exactly the same section of rock whether measured as one body, as is the case of graph 4.2, or in segments as in graph 4.1. The following table demonstrates that this is not the case.

Table 4.2 Results of Phase Shift Comparision using adjacent depths

Lower Depth (m)	Upper Depth (m)	Phase Shift (units)	
-1.524	-3.048	0.12	
-3.048	-6.096	0.21	
			0.33[A]
-6.096	-12.192	0.25	
			0.58[B]

Using depth 1.5 m and succeeding greater depths

Upper Depth (m)	Lower Depth (m)	Phase Shift (years)	
-1.5	-6.1	0.25	(compare result A, above)
-1.5	-12.2	0.49	(compare result B, above)

These values should be identical.

The error must lie in the phase shift measurement itself. The program "croscr" measured the phase lag using vectors interpolated from the spline at 15 day intervals. This leads to the observation that an error of ±7.5 days is inherent in this method, since a correlation beyond this would cause the measurement to be taken at the next 15 day interval.

Further if the ground material at site #1 were homogeneous and no error was made in depth or phase shift measurement, then one could expect, at adjacent depths of equal depth interval, the phase shift to be precisely the same. However, Figure 4.1 reveals that at the 3 lower measurements, where the depth increment is nominally the same, the phase shift appears to be staggered. There may be several explanations for this: the phase lag is measured perhaps more inaccurately as explained above; the thermistors were measured, in spacing, to an accuracy of ±0.1m thus each segment of depth may not be the same; or the geology of the ground at these depths is not homogeneous. It is quite likely that the staggered appearance can be attributed to all three of these reasons.

This causes one to wonder just how these different variables affect the overall apparent thermal diffusivity calculations. A plot of depth versus apparent thermal diffusivity reveals a wide range of results (*see* Figure 4.4). How much is due to measurement errors and how much can be attributed to different ground geology at various depths? This question is answered by the following sensitivity analysis.

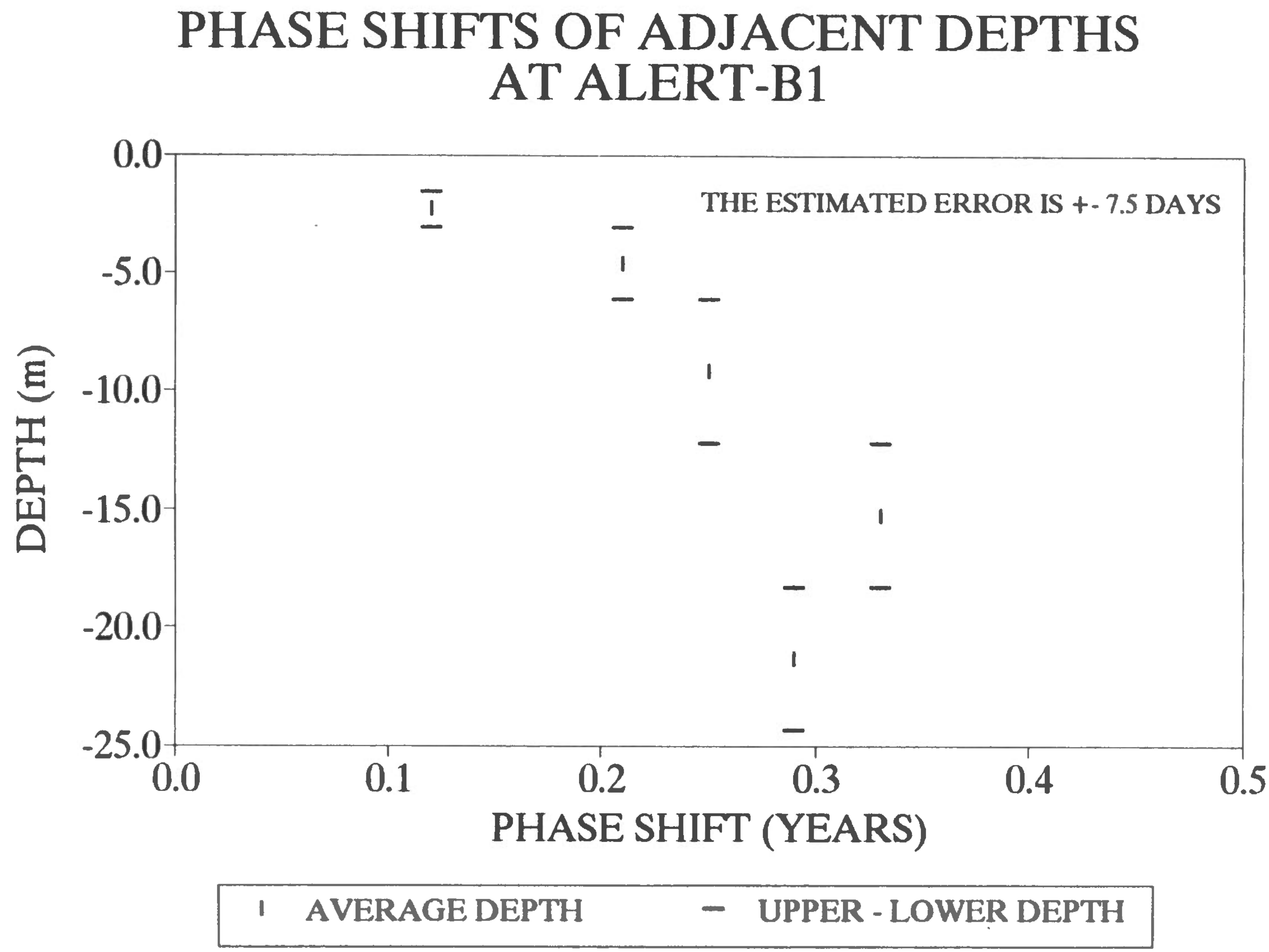

Figure 4.1. Phase shift of adjacent depths.

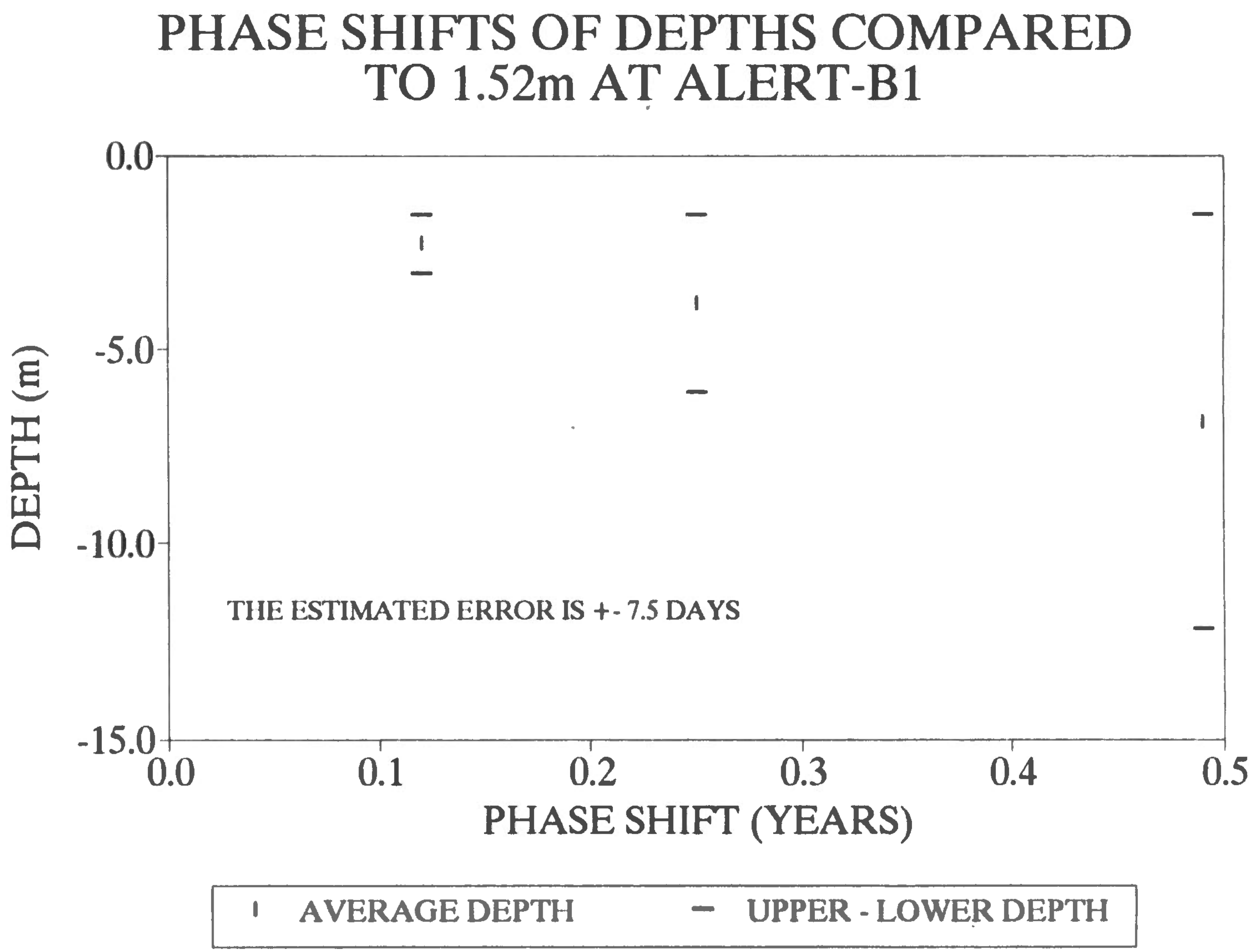

Figure 4.2. Phase shifts of depths compared to 1.52 m.

4.2 Sensitivity analysis

4.2a Sources of Error

1) The position of each thermistor on the cable was measured to the accuracy of ± 0.1m.

2) The phase lag was calculated to an accuracy of $\pm$ 7.5 days.

Either of these errors could lead to an inaccurate Apparent Thermal Diffusivity calculation.

4.2b Calculated Error

Using the method of partial derivatives, the error due to these inaccuracies will be evaluated (Young, 1962).

The Apparent Thermal Diffusivity, using the Phase Equation, is defined as follows (Horton et al. 1983).

$$\alpha = \frac{1}{2\omega}\left(\frac{\Delta z}{\Delta t}\right)^2$$

Therefore,

$$d\alpha = \frac{\delta\alpha}{\delta(\Delta z)}d(\Delta z) + \frac{\delta\alpha}{\delta(\Delta t)}d(\Delta t)$$

$$\frac{\delta\alpha}{\delta(\Delta z)} = \frac{1}{\omega}\left(\frac{\Delta z}{(\Delta t)^2}\right)$$

$$\frac{\delta\alpha}{\delta(\Delta t)} = \frac{-1}{\omega}\left(\frac{(\Delta z)^2}{(\Delta t)^3}\right)$$

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es of Error

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Th mal Diffusivity, using the Phase Equation, is defined as follows 98.

$$\alpha = \frac{1}{2\omega}\left(\frac{\Delta z}{\Delta t}\right)^2$$

$$d\alpha = \frac{\delta\alpha}{\delta(\Delta z)} d(\Delta z) + \frac{\delta\alpha}{\delta(\Delta t)} d(\Delta t)$$

$$\frac{\delta\alpha}{\delta(\Delta z)} = \frac{1}{\omega}\left(\frac{\Delta z}{(\Delta t)^2}\right)$$

$$\frac{\delta\alpha}{\delta(\Delta t)} = \frac{-1}{\omega}\left(\frac{(\Delta z)^2}{(\Delta t)^3}\right)$$

ase lag)

x 10^{-7}

.48x10^5

itude greater than

tional to dα so that

In this case,

$$\frac{d\alpha}{\alpha}=\frac{1.98x10^{-7}}{1.5x10^{-6}}x100=13.2\%$$

Similar Analysis reveals:

Table 4.3 Sensitivity Analysis Results

Depth (m)	Depth Interval (m)	Error	Nominal Error
1.524 - 3.048	1.524	8.61 x 10^{-8}	21.1%
3.048 - 6.096	3.048	6.92 x 10^{-8}	13.0%
1.524 - 6.096	4.572	10.2 x 10^{-8}	12.1%
6.096 - 12.192	6.096	19.8 x 10^{-8}	13.2%
12.192 - 18.288	6.096	7.91 x 10^{-8}	9.2%
18.288 - 24.348	6.096	12.2 x 10^{-8}	10.9%
1.524 - 12.192	10.668	7.8 x 10^{-8}	6.5%

4.2c Sensitivity Results Discussed

It is evident that the greatest error occurs when the smallest depth interval of soil is considered and conversely the smallest error occurs when the interval is greatest (*see* Figure 4.3). Therefore when computing Apparent Thermal Diffusivity, using the phase equation, for a column of uniform material the largest possible soil section should be used.

It should also be noted that error in phase shift measurement itself can have the greatest impact on the calculated error of apparent thermal diffusivity. For instance if the measured error were twice as much, at ±15 days, then this would more than double the error of the apparent thermal diffusivity calculation. However, the time series vectors used in the previous calculations correlated very high with one another with the coefficients of correlation dropping off rapidly on either side (*see* appendix G1-G2). This indicates that the signal of the annual wave is very strong at these depths and that the index of correlation is not likely to be in error by more then 7.5 days.

In drilling the five sites 2-3m of highly fractured rock, bonded by up to 3 cm of ice, was encountered at the surface (*see* geology section #1). Because the rock is no longer uniform due to fracturing, this could account for the low thermal diffusivity values calculated near the surface. It is reported that some fracturing was observed to a depth of 48m.

It has been established that the randomness in Apparent Thermal Diffusivity, shown in Figure 4.4, is partly due to errors in phase shift and depth measurements. However, it is obvious that other variables such as fracturing and nonhomogeneous material (*see* Table 1.1 in Geology Section #1) can have a much larger impact on final calculations.

Apparent thermal diffusivity can also be calculated from measurements of k, c, p using the formula

$$\alpha = \frac{k}{c\rho}$$

where

α	=	Apparent Thermal Diffusivity (m^2/s)
k	=	Thermal Conductivity ($Wm^{-1}k^{-1}$)
ρ	=	density (kgm^{-3})
c	=	850 $Jkg^{-1}k^{-1}$ (assumed)

The porosity, density and thermal conductivity were measured in the lab from core samples taken from the site. The following results were obtained

Table 4.4. Laboratory measurements on core samples (1)

site	number of samples and lithology	k thermal conductivity ($Wm^{-1}K^{-1}$)	α density ($kg\ m^{-3}$)	porosity (percent)	calculated diffusivity(2) (mm^2s^{-1}
1	6, argillite	2.82-3.52	2670-2837	0.7-5.2	1.25-1.53
2	6, argillite	2.47-3.47	-	3.2-5.1	-
3	3, argillite	2.59-3.73	2608-2689	0.9-3.9	1.19-1.68
	8, greywacke	2.90-3.92	2628-2738	0.5-3.4	1.27-1.71
4	2, greywacke	3.52, 3.69	2740, 2776	0.6, 0.8	1.53, 1.59
	1, argillite	2.76	2734	1.4	1.21
5	3, argillite	3.07-3.62	-	0.4-1.8	1.4-1.6 est.

(1) by Prof. M. King, University of Saskatchewan
(2) from thermal conductivity, density and an assumed specific heat of $c = 850 Jkg^{-1}K^{-1}$

The above thermal diffusivity result is very comparable to that of the most accurate results using the phase shift equation. Compare these results on Figure 4.4.

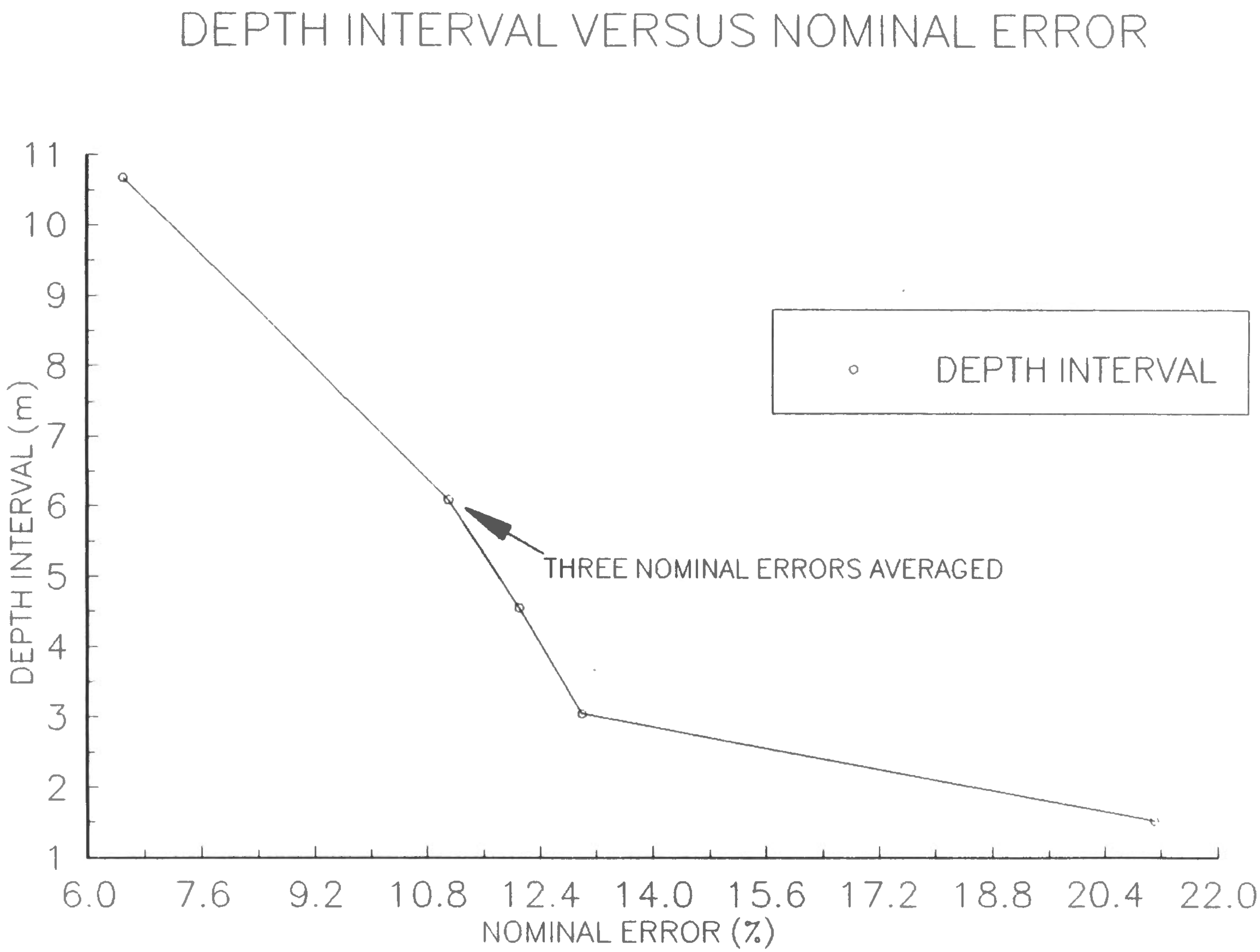

Figure 4.3. Demonstration that error increases when the depth interval decreases.

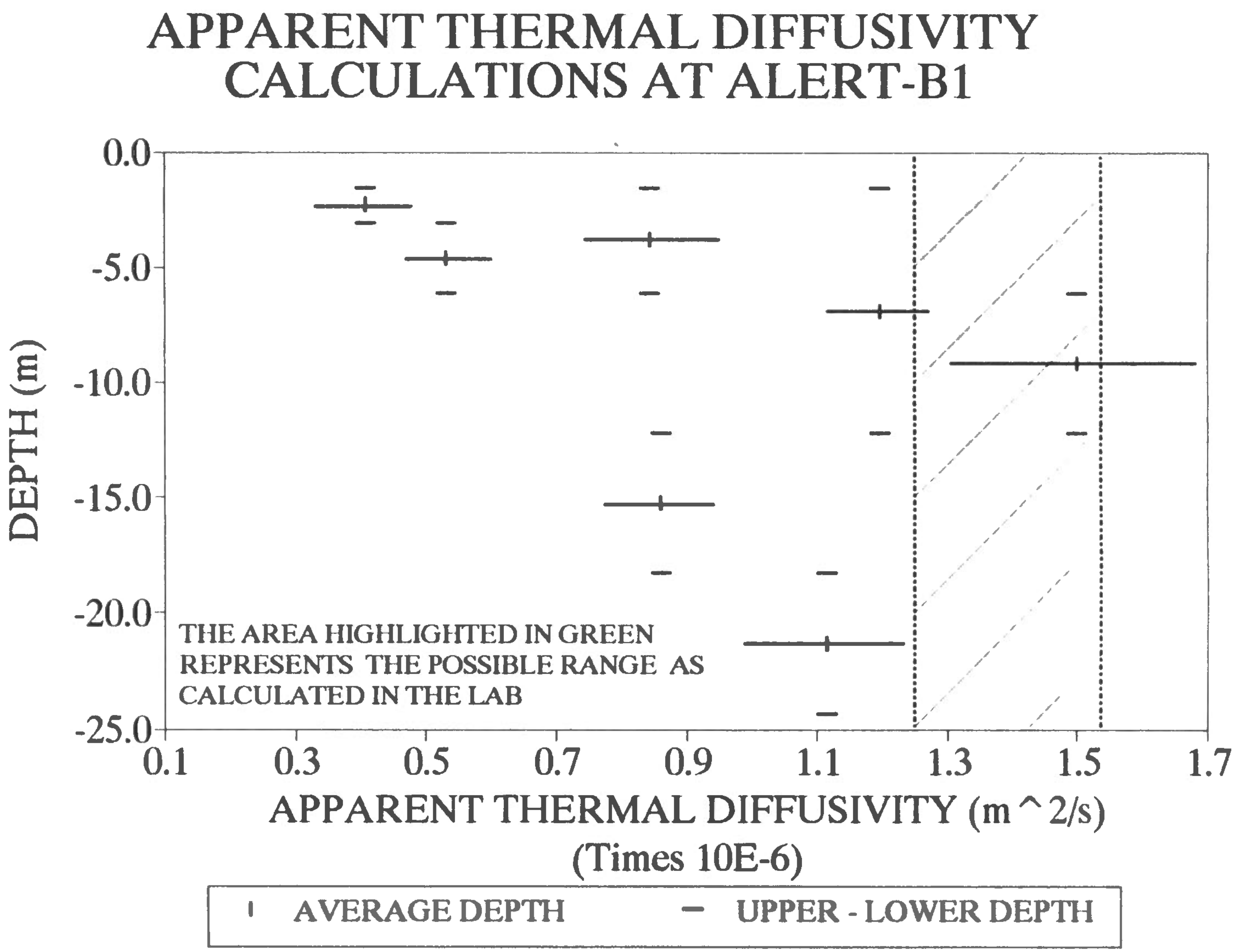

Figure 4.4. Range of apparent thermal diffusivity calculations.

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APPENDIX A

A description of the process of converting raw temperature data into formats suitable for plotting and further analysis.

Table A.1. Typical mainframe data output.

Table A.2. Typical P.C. spreadsheet.

DATA MANIPULATION

Since the thermistor readings at each site are measured and recorded by hand it is necessary to convert these data into a spreadsheet where they can be further analyzed by computer routines. Originally this was achieved by coding the data on punch cards for use on a mainframe system. The resulting data files could then be analyzed using a specific program (<u>see</u> Table A.1 for example of typical output). This method of analyzing data is cumbersome by the standard of today and has been outdated by the modern PC. This section outlines the procedure of converting the mainframe data files to a spreadsheet that is useful in analyzing data using modern techniques and commercial software.

The data files initially were imported into Norton Editor where any headers or special coding were deleted. The file was scanned at this point in order to remove any duplicate data. Norton Editor is advantageous in that the file remains as an ASCII file thus allowing for problem free importing to other programs.

After dividing the data into five files, each file representing 1 site, the sections were imported into Quattro Pro, a spreadsheet package produced by Borland, and analyzed separately. Using various functions, the dates of recorded measurements were decoded and converted into days, starting with Sept 1/78 = day 1. Upon transforming columns to rows, formulas were again used to convert depth from feet to metres. Any supplementary data in the form of resistances, not previously contained in this record, was converted to degrees celsius and then added to make the record as complete as possible. See Tables A.1-A.2 for an example of the old format for mainframe data files and the PC spreadsheet.

TABLE A.1

```
 1
 2     1   0
 230  ALERT -1                                                                21
(8(F5.0,F5.3))
DND-NRC-EMR ALERT PERMAFROST EXPT                           82 30.6   62 17.4    5
031078 041078 99         1   61  2
230-1...LOCATION UTM N9161900  E0510200.  ELEVATION APPROX. 4.6M ASL,
   SITE IS ABOUT 50M FROM MEAN SHORELINE.
4612
 305061078 279 1
   -5 6472   -10 8204  -2012201  -4013164  -6012317  -8011798 -10011350 -12010870
 -14010600 -16010298 -18010020 -200 9797
 230191078 292 1
   -510379   -10 8943  -2012017  -4013300  -6012551  -8012036 -10011555 -12011078
 -14010797 -16010451 -18010123 -200 9819
 305021178 306 1
   -513034   -1010327  -2011784  -4013201  -6012575  -8012063 -10011577 -12011095
 -14010805 -16010460 -18010130 -200 9819
 305181178 322 1
   -515573   -1011953  -2011755  -4013092  -6012588  -8012091 -10011593 -12011114
 -14010825 -16010473 -18010138 -200 9833
 230051278 339 1
   -516079   -1013382  -2011987  -4012962  -6012569  -8012106 -10011609 -12011120
 -14010831 -16010486 -18010144 -200 9843
 230281278 362 1
   -515803   -1014126  -2012447  -4012801  -6012556  -8012114 -10011609 -12011123
 -14010823 -16010474 -18010132 -200 9831
 230180179  18 1
   -516566   -1014432  -2012801  -4012717  -6012526  -8012124 -10011611 -12011120
 -14010828 -16010477 -18010132 -200 9831
 230120279  43 1
   -517994   -1015221  -2013148  -4012724  -6012521  -8012163 -10011651 -12011164
 -14010862 -16010506 -18010176 -200 9873
 230140379  73 1
   -520458   -1017048  -2013766  -4012725  -6012458  -8012145 -10011649 -12011145
 -14010857 -16010500 -18010159 -200 9855
 230030479  93 1
   -520332   -1017604  -2014280  -4012779  -6012436  -8012151 -10011662 -12011152
 -14010864 -16010516 -18010175 -200 9864
 230170479 107 1
   -520092   -1017835  -2014572  -4012820  -6012413  -8012134 -10011657 -12011150
 -14010853 -16010496 -18010155 -200 9851
 230040579 124 1
   -519566   -1017792  -2014699  -4012885  -6012373  -8012130 -10011656 -12011145
 -14010850 -16010476 -18010160 -200 9851
 230180579 138 1
   -518505   -1017593  -2014916  -4012962  -6012397  -8012126 -10011654 -12011143
 -14010853 -16010494 -18010155 -200 9848
 230270579 147 1
   -517225   -1017087  -2015096  -4013040  -6012396  -8012123 -10011658 -12011152
 -14010855 -16010496 -18010163 -200 9848
 230120679 163 1
   -515294   -1016353  -2015116  -4013145  -6012394  -8012124 -10011662 -12011153
 -14010856 -16010497 -18010164 -200 9852
 230290679 180 1
   -511382   -1014760  -2015000  -4013201  -6012386  -8012124 -10011638 -12011139
```

```
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230160779 197 1
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-14010850 -16010376 -18010138 -200 9786
230310779 212 1
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-14010831 -16010456 -18010158 -200 9783
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-14010850 -16010448 -18010164 -200 9848
230310879 243 1
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-14010850 -16010476 -18010164 -200 9843
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230281279 362 1
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```

```
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```

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-14010917 -16010536 -18015740 -20013372
```

TABLE A.2

DATA FOR SITE 1 AT ALERT

Z(M)	36	49	63	79	96	119	140	165	195	215	229
1.524	-6.472	-10.379	-13.034	-15.573	-16.079	-15.803	-16.566	-17.994	-20.458	-20.332	-20.092
3.048	-8.204	-8.943	-10.327	-11.953	-13.382	-14.126	-14.432	-15.221	-17.048	-17.604	-17.835
6.096	-12.201	-12.017	-11.784	-11.755	-11.987	-12.447	-12.801	-13.148	-13.766	-14.28	-14.572
12.192	-13.3	-13.3	-13.201	-13.092	-12.962	-12.801	-12.717	-12.724	-12.725	-12.779	-12.82
18.288	-12.551	-12.551	-12.575	-12.588	-12.569	-12.556	-12.526	-12.521	-12.458	-12.436	-12.413
24.384	-12.036	-12.036	-12.063	-12.091	-12.106	-12.114	-12.124	-12.163	-12.145	-12.151	-12.134
30.48	-11.555	-11.555	-11.577	-11.593	-11.609	-11.609	-11.611	-11.651	-11.649	-11.662	-11.657
36.576	-11.078	-11.078	-11.095	-11.114	-11.12	-11.123	-11.12	-11.164	-11.145	-11.152	-11.15
42.672	-10.797	-10.797	-10.805	-10.825	-10.831	-10.823	-10.828	-10.862	-10.857	-10.864	-10.853
48.768	-10.451	-10.451	-10.46	-10.473	-10.486	-10.474	-10.477	-10.506	-10.5	-10.516	-10.496
54.864	-10.123	-10.123	-10.13	-10.138	-10.144	-10.132	-10.132	-10.176	-10.159	-10.175	-10.155
60.96	-9.797	-9.819	-9.819	-9.833	-9.843	-9.831	-9.831	-9.873	-9.855	-9.864	-9.851

DATA FOR SITE 1 AT ALERT

609	625	638	655	669	686	699	715	729	746	761	776
-21.977	-20.19	-18.187	-14.359	-10.8	-7.699	-6.5	-5.556	-5.115	-5.08	-6.504	-7.69
-19.649	-19.248	-18.513	-17.112	-15.363	-13.001	-11.67	-10.462	-9.663	-8.993	-8.734	-8.97
-15.756	-16.055	-16.149	-16.049	-15.984	-15.538	-15.017	-14.337	-13.77	-13.181	-12.679	-12.26
-12.947	-13.077	-13.191	-13.384	-13.486	-13.6	-13.676	-13.711	-13.69	-13.68	-13.584	-13.48
	-12.319	-12.319	-12.355	-12.363	-12.401	-12.437	-12.447	-12.5	-12.588	-12.603	-12.61
	-12.095	-12.085	-12.101	-12.093	-12.09	-12.088	-12.077	-12.088	-12.134	-12.124	-12.14
	-11.672	-11.675	-11.683	-11.675	-11.675	-11.667	-11.651	-11.648	-11.694	-11.675	-11.68
-11.172	-11.183	-11.191	-11.199	-11.191	-11.191	-11.194	-11.172	-11.172	-11.224	-11.205	-11.21
-10.867	-10.878	-10.878	-10.895	-10.884	-10.887	-10.878	-10.867	-10.864	-10.917	-10.903	-10.90
-10.488	-10.502	-10.505	-10.522	-10.519	-10.519	-10.519	-10.491	-10.502	-10.551	-10.528	-10.54
-10.176	-10.182	-10.184	-10.199	-10.193	-10.187	-10.196	-10.176	-10.182	-10.237	-10.205	-10.22
-9.863	-9.866	-9.869	-9.881	-9.875	-9.875	-9.872	-9.86	-9.851	-9.908	-9.89	-9.89

DATA FOR SITE 1 AT ALERT

791	806	820	837	851	868	881	900	911	928	942	958
-9.13	-9.85	-13.19	-15.36	-16.51							
-9.35	-9.97	-10.84	-12.38	-13.43							
-12.00	-11.80	-11.69	-11.74	-11.95	-12.30		-13.07	-13.39	-13.79		-14.74
-13.35	-13.23	-13.08	-12.97	-12.88	-12.78		-12.68	-12.69	-12.72	-12.76	-12.84
-12.63	-12.64	-12.59	-12.61	-12.62							
-12.14	-12.15	-12.12	-12.18	-12.18	-12.19		-12.20	-12.19	-12.18	-12.19	-12.19
-11.68	-11.68	-11.65	-11.68	-11.68	-11.69	-11.68	-11.69	-11.70	-11.70	-11.70	-11.70
-11.20	-11.20	-11.17	-11.20	-11.21	-11.20	-11.20	-11.20	-11.19	-11.20	-11.19	-11.20
-10.91	-10.90	-10.86	-10.90	-10.90	-10.90	-10.91	-10.91	-10.89	-10.89	-10.90	-10.89
-10.53	-10.53	-10.49	-10.52	-10.53	-10.53	-10.52	-10.54	-10.53	-10.53	-10.52	-10.52
-10.21	-10.20	-10.17	-10.20	-10.21	-10.20	-10.21	-10.20	-10.20	-10.20	-10.20	
-9.89	-9.89	-9.89	-9.89	-9.89	-9.89	-9.89	-9.88	-9.88	-9.88		

DATA FOR SITE 1 AT ALERT

974	1436	1517	1628	1638	1737	1832	1923	1993	2064	2099	2188
			-22.79	-17.38	-13.69	-4.27	-16.21	-22.789	-23.05	-18.70	-4.91
	-10.28	-8.42	-17.79	-14.82	-15.99	-8.28	-12.42	-17.794	-20.18	-18.83	-9.58
-14.03	-13.64	-11.27	-13.06	-12.31	-14.32	-12.23	-10.97	-13.065	-15.59	-16.34	-13.79
-12.80	-13.05	-12.80	-12.02	-12.16	-12.50	-12.81	-12.28	-12.017	-12.44	-12.88	-13.60
	-12.34	-12.43	-12.07	-12.26	-12.15	-12.22	-12.23	-12.072	-11.99	-12.06	-12.41
	-12.13	-12.13	-11.96	-12.13	-12.06	-12.02	-12.01	-11.96	-11.94		-12.06
	-11.73	-11.72	-11.61	-11.72	-11.71	-11.70	-11.66	-11.611	-11.59	-11.65	
	-11.24	-11.19	-11.16	-11.23	-11.22	-11.23	-11.20	-11.156	-11.15	-11.20	
	-10.94	-10.94	-10.89	-10.93	-10.94	-10.95	-10.93	-10.887	-10.87	-10.93	
	-10.54	-10.54	-10.48	-10.53	-10.54	-10.55	-10.53	-10.482	-10.48	-10.54	
	-10.22		-10.19	-10.21	-10.22	-10.22	-10.22	-10.19	-10.17	-10.22	
	-9.90	-9.89	-9.87	-9.91	-9.91	-9.92	-9.91	-9.866	-9.86	-9.92	

DATA FOR SITE 1 AT ALERT

2350	2645	2756	3158	3256	3285	3382	3501	3562	3682	3753	3798
-15.74	-17.55		-6.39	-5.93	-4.72	-16.20	-20.69	-9.60	-6.05	-13.82	-17.19
-13.38	-11.66	-18.04	-16.39	-11.14	-9.32	-12.36	-17.97	-13.59	-8.11	-11.30	-13.96
-11.93	-11.08	-14.00	-13.59	-14.59	-13.43	-11.56	-14.51	-15.12	-12.13	-11.27	-11.92
-12.48	-12.42	-12.27	-12.45	-13.40	-13.45	-12.83	-12.62	-13.20	-13.22	-12.71	-12.41
-12.40			-12.27	-12.36	-12.43	-12.48	-12.30	-12.34	-12.47	-12.49	-12.38
-12.10			-12.10	-12.05	-12.06	-12.07	-12.07	-12.06	-12.13	-12.12	-12.09
-11.64	-11.66	-11.66	-11.67	-11.64	-11.64	-11.61	-11.62	-11.64	-11.63	-11.65	-11.62
-11.19	-11.20	-11.21	-11.19		-11.19	-11.15	-11.15	-11.15	-11.16	-11.17	-11.14
-10.92	-10.91	-10.91	-10.92	-10.89	-10.89	-10.85	-10.84	-10.85	-10.85	-10.85	-10.82
-10.54	-10.54	-10.54	-10.55	-10.53	-10.54	-10.49	-10.47	-10.47	-10.49	-10.52	-10.46
	-10.24	-10.23	-10.22	-10.22	-10.22	-10.17	-10.16	-10.17	-10.16	-10.17	-10.14
	-9.94	-9.94	-9.94	-9.94	-9.94	-9.91	-9.90	-9.90	-9.90	-9.92	-9.88

DATA FOR SITE 1 AT ALERT

3835	3925	4018	4110	4207	4297	4383	4474
	-17.43		-13.12	-18.55	-15.47	-4.28	-15.61
-16.09	-16.94	-8.67	-10.79	-15.76	-15.84	-8.36	-11.64
-12.96	-14.88	-12.74	-10.95	-12.80	-14.55	-12.42	-10.92
-12.41	-12.76	-13.14	-12.59	-12.20	-12.60	-12.90	-12.38
-12.38	-12.28	-12.38	-12.42	-12.24	-12.17	-12.26	-12.28
-12.17	-12.13	-12.11		-12.10	-12.06	-12.17	-12.04
-11.70	-11.71	-11.70	-11.70	-11.69	-11.68	-11.68	-11.67
-11.21	-11.22	-11.23	-11.23	-11.22	-11.24	-11.24	-11.24
-10.90	-10.90	-10.91	-10.84	-10.89	-10.90	-10.92	-10.92
-10.52	-10.53	-10.54	-10.54	-10.54	-10.54	-10.54	-10.55
-10.21	-10.22	-10.21	-10.22	-10.22	-10.23	-10.23	-10.25
-9.95	-9.95	-9.96	-9.96	-9.96	-9.93	-9.96	

APPENDIX B

A description of the process used to screen the data for errors.

Figures B.1-B.2. Typical plots that aid in the error screening process. The portions circled in black represent suspected error.

ERROR SCREENING

For approximately the past 12 years DND personal have been measuring temperatures at the sites; generally, they have been resolving changes in thermistor readings to better than ±0.01 K, a credit to the care with which the measurements have been taken. However, it is inevitable that errors will occur using a hand method to obtain thermistor readings. An automatic data logger has recently replaced this method at site #4 in an effort to collect data consistently and at regular intervals, the results of which are now being tested. This section describes the methods used in screening the data for errors.

There are many approaches to this problem depending on the type of data that has been collected. For instance in this case, where a definite annual wave pattern exists, one could choose either a statistical approach, in which one requires advanced statistical procedures, or a much simpler method, deleting those points which do not follow any dominant pattern, for which one requires considerable experience in thermal dynamics. (see Appendix C for, annual wave patterns of the past 12 years at each site. Note particularly sites 4 and 5 where the maximum depth is about 15 m). From previous experience it has been established that the latter of these is sufficient.

From Appendix C it is apparent that the annual wave is both lagged in time and decreased in amplitude at increasing depths, until the signal is eventually overtaken by noise at a depth of about 25 m. These two observations form the basis of a very crude but effective error screening process.

For instance, an error in measurement may be observed at several depth intervals (<u>see</u> Figures B.1-B.2). The circled portion on these plots were diagnosed as error for either of the following two reasons: 1) The point is not lagged at successive depths. 2) The magnitude at the deeper depths does not diminish and therefore is probably not real. This same kind of reasoning was used to analyze each of the 5 data sets.

Any further screening beyond this point could jeapordize the credibility of the data set. Although slight errors may still exist, they are difficult to distinguish from the annual wave and shorter term events and will have little impact on future analysis.

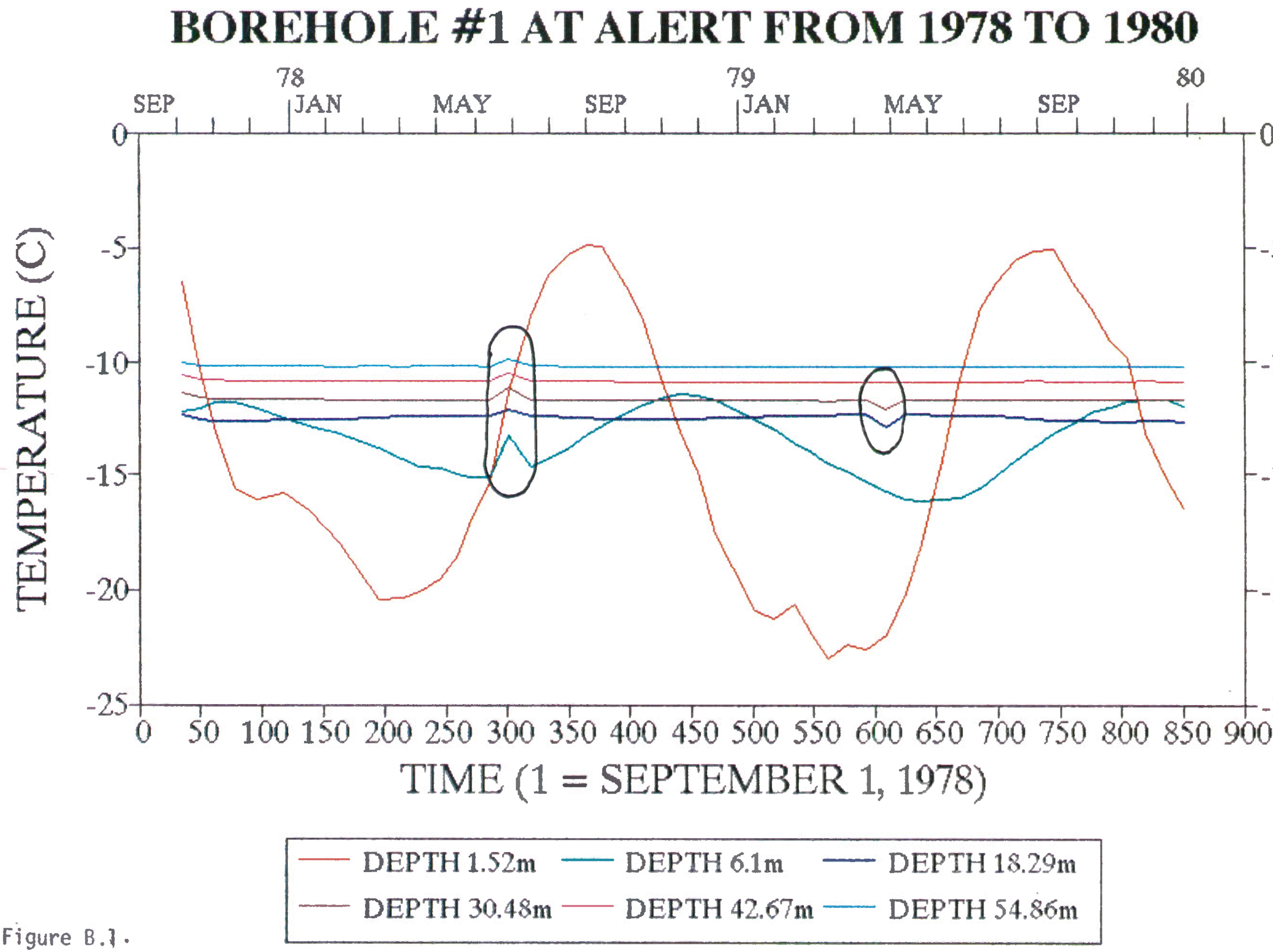

BOREHOLE #1 AT ALERT FROM 1978 TO 1980
78
79
80
SEP
JAN
MAY
SEP
JAN
MAY
SEP
0
-5
-10
-15
-20
-25
TEMPERATURE (C)
0 50 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800 850 900
TIME (1 = SEPTEMBER 1, 1978)
DEPTH 1.52m
DEPTH 6.1m
DEPTH 18.29m
DEPTH 30.48m
DEPTH 42.67m
DEPTH 54.86m

Figure B.1.

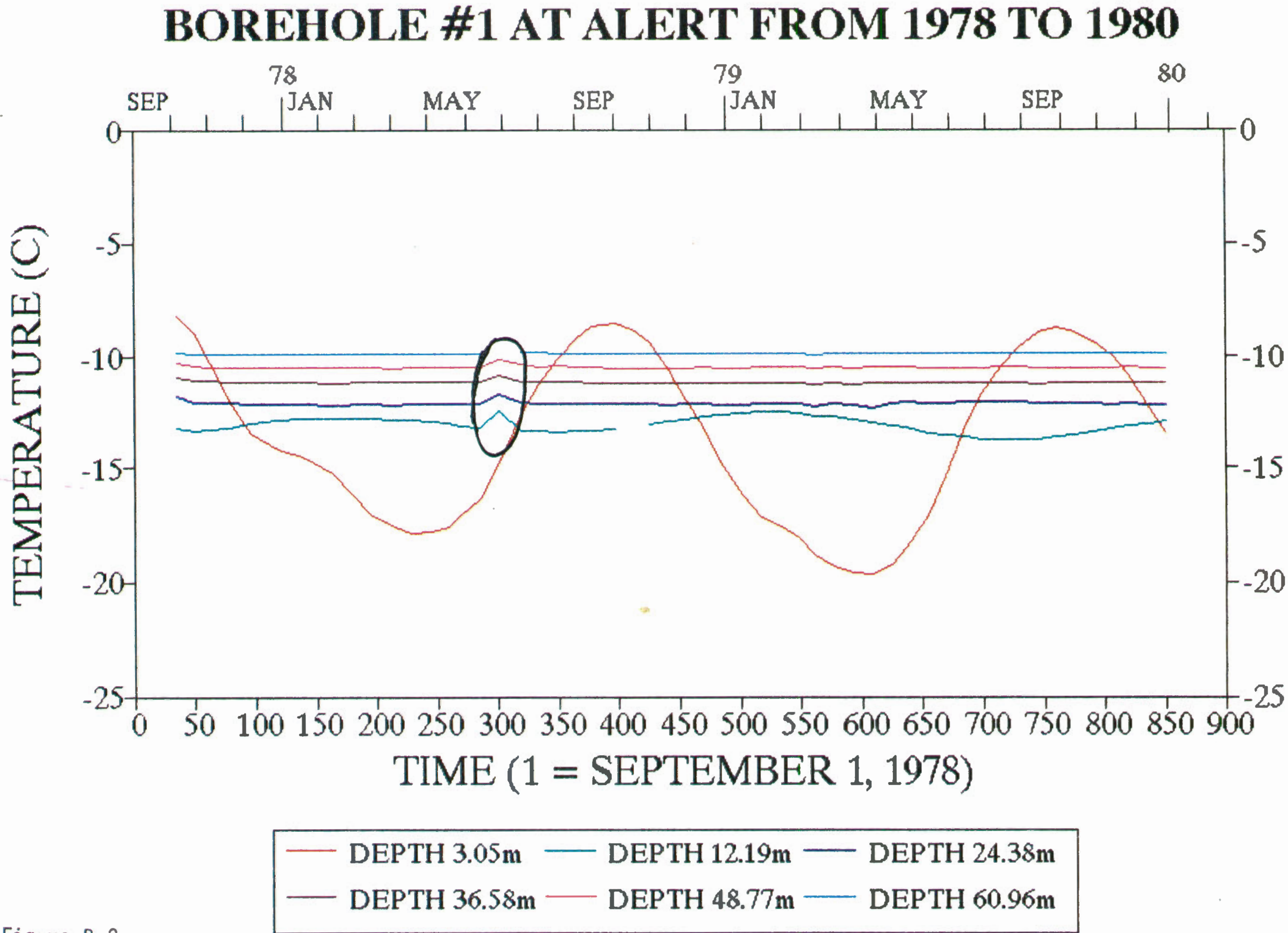

BOREHOLE #1 AT ALERT FROM 1978 TO 1980
78
79
80
SEP
JAN
MAY
SEP
JAN
MAY
SEP
0
-5
-10
-15
-20
-25
TEMPERATURE (C)
0 50 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800 850 900
TIME (1 = SEPTEMBER 1, 1978)
DEPTH 3.05m
DEPTH 12.19m
DEPTH 24.38m
DEPTH 36.58m
DEPTH 48.77m
DEPTH 60.96m

Figure B.2.

APPENDIX C

Figures C.1-C.10. The annual wave pattern for each of the five sites. Each site represents two plots, one of even depths and the other of odd depths.

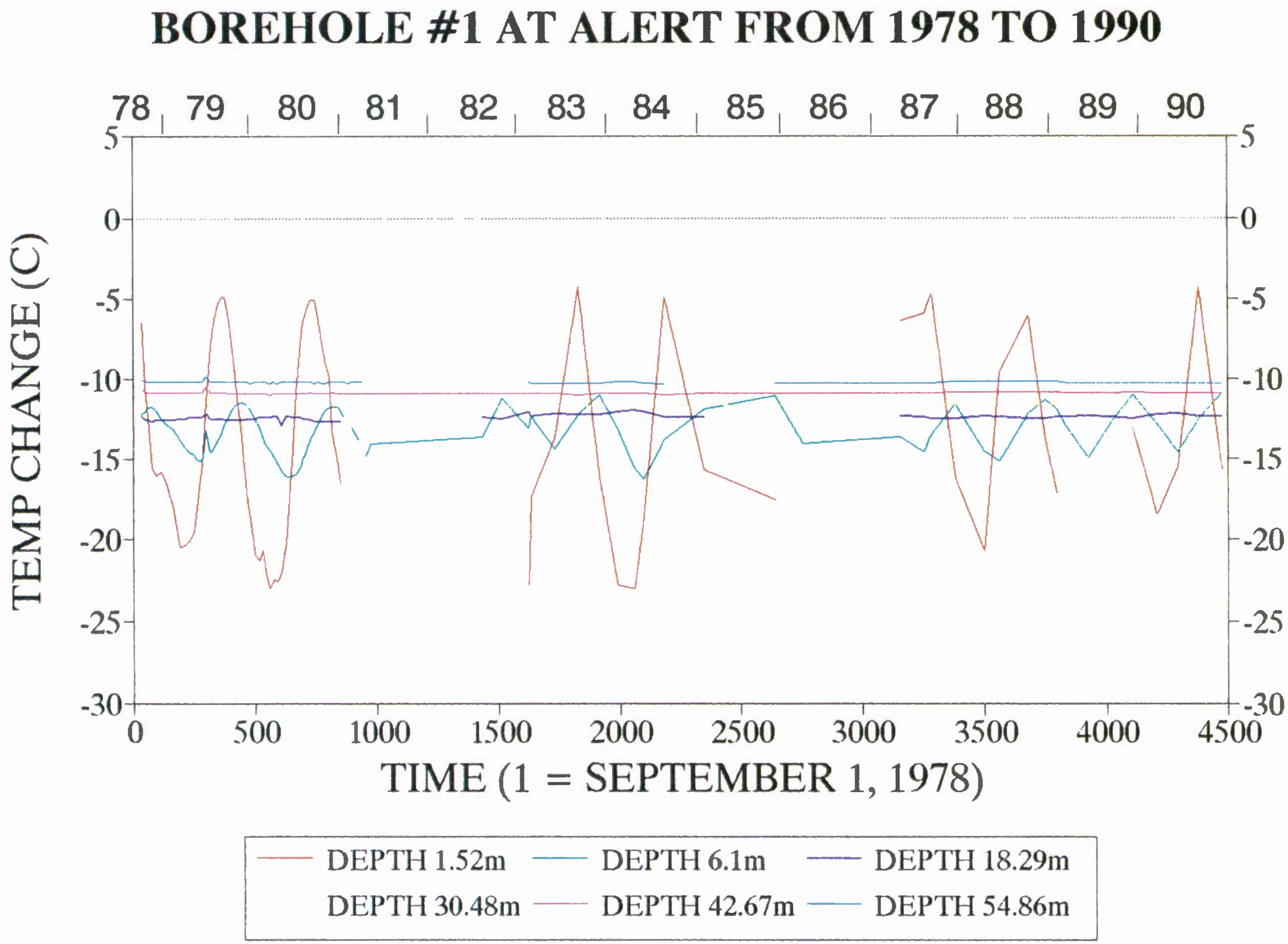
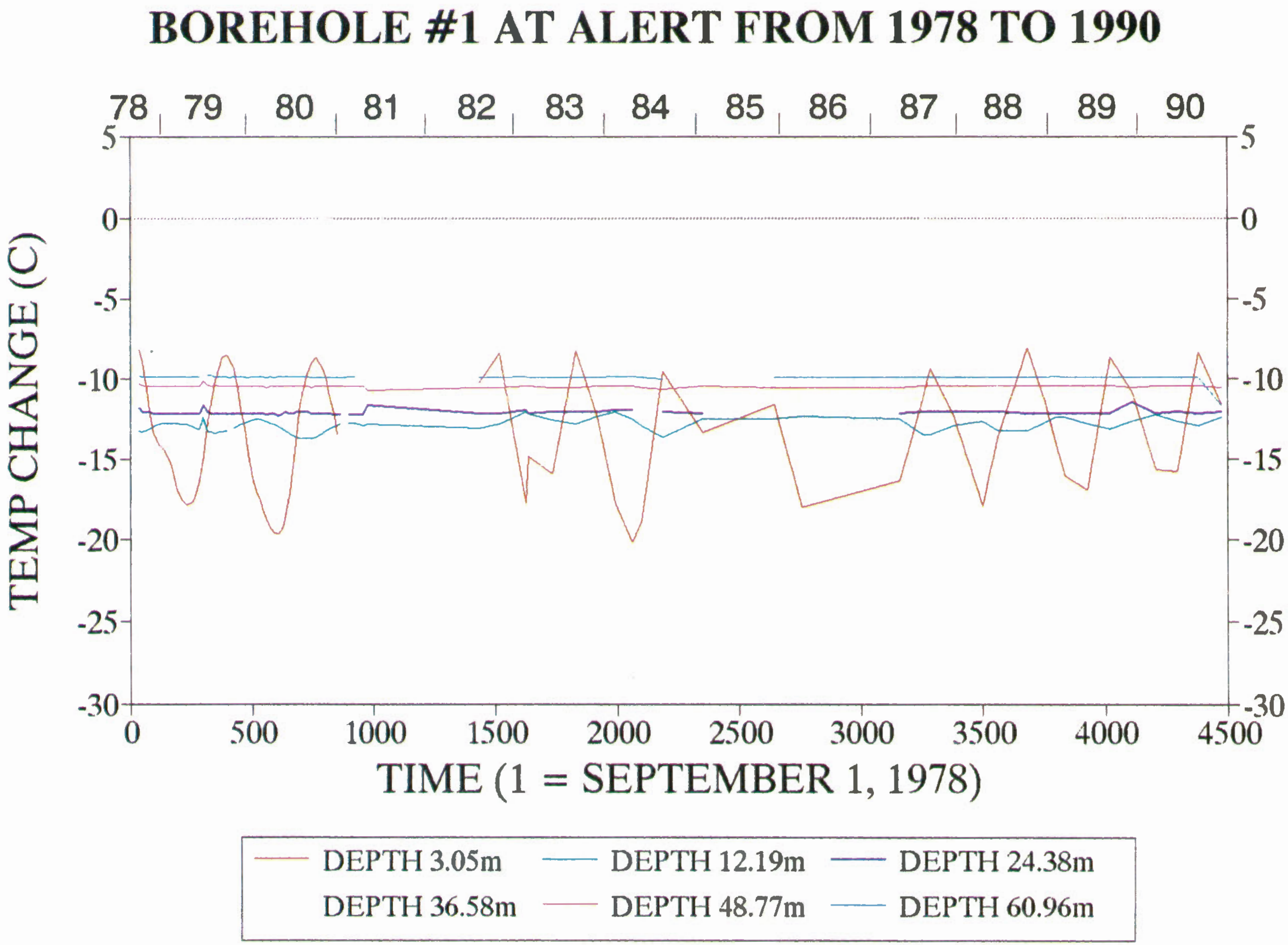

BOREHOLE #1 AT ALERT FROM 1978 TO 1990
78
79
80
81
82
83
84
85
86
87
88
89
90
TEMP CHANGE (C)
5
0
-5
-10
-15
-20
-25
-30
0
500
1000
1500
2000
2500
3000
3500
4000
4500
TIME (1 = SEPTEMBER 1, 1978)
DEPTH 1.52m
DEPTH 6.1m
DEPTH 18.29m
DEPTH 30.48m
DEPTH 42.67m
DEPTH 54.86m

Figure C.1.



BOREHOLE #1 AT ALERT FROM 1978 TO 1990
78
79
80
81
82
83
84
85
86
87
88
89
90
TEMP CHANGE (C)
5
0
-5
-10
-15
-20
-25
-30
0
500
1000
1500
2000
2500
3000
3500
4000
4500
TIME (1 = SEPTEMBER 1, 1978)
DEPTH 3.05m
DEPTH 12.19m
DEPTH 24.38m
DEPTH 36.58m
DEPTH 48.77m
DEPTH 60.96m

Figure C.2.

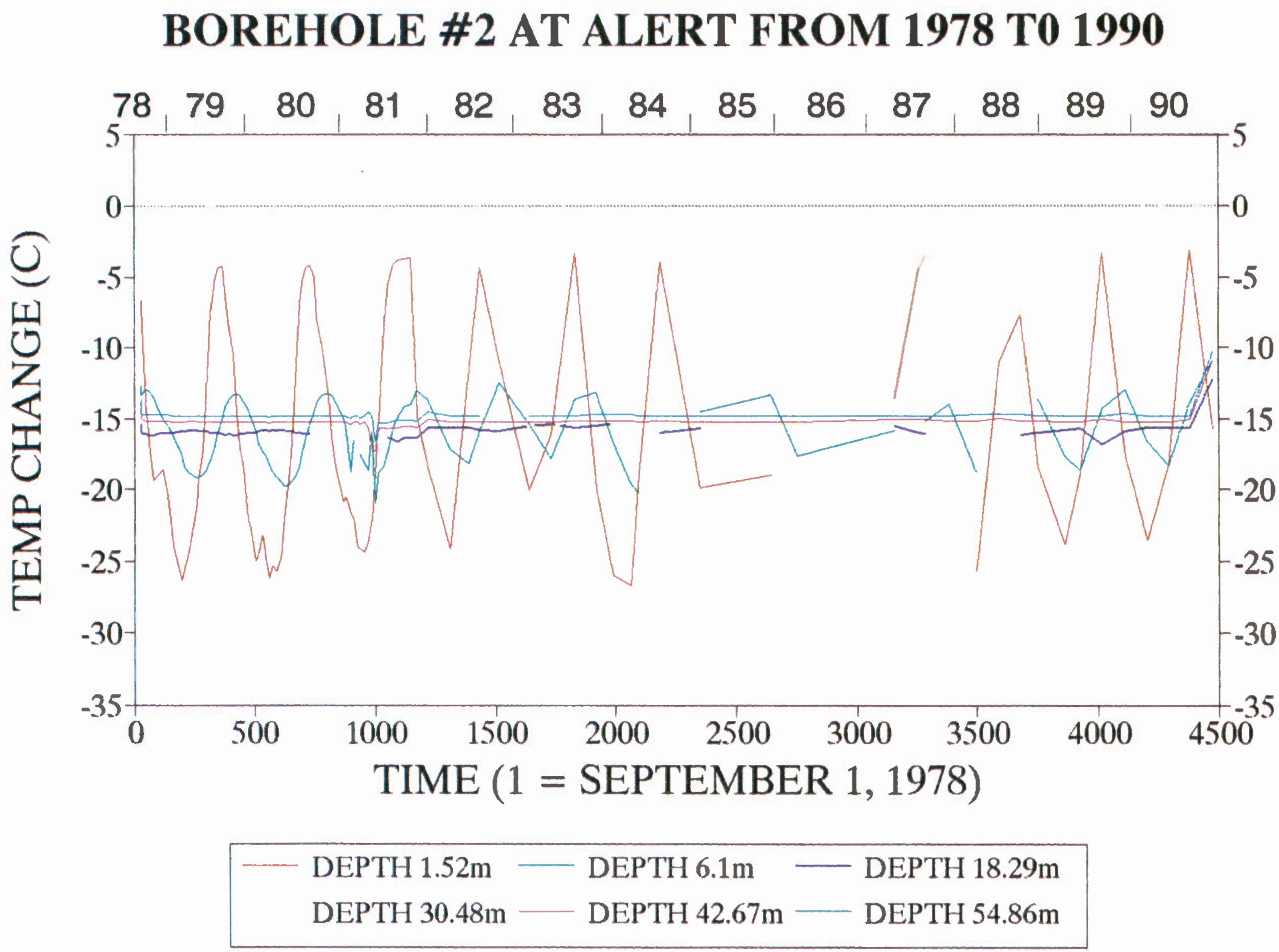

BOREHOLE #2 AT ALERT FROM 1978 T0 1990
78
79
80
81
82
83
84
85
86
87
88
89
90
TEMP CHANGE (C)
5
0
-5
-10
-15
-20
-25
-30
-35
0
500
1000
1500
2000
2500
3000
3500
4000
4500
TIME (1 = SEPTEMBER 1, 1978)
DEPTH 1.52m
DEPTH 6.1m
DEPTH 18.29m
DEPTH 30.48m
DEPTH 42.67m
DEPTH 54.86m

Figure C.3.

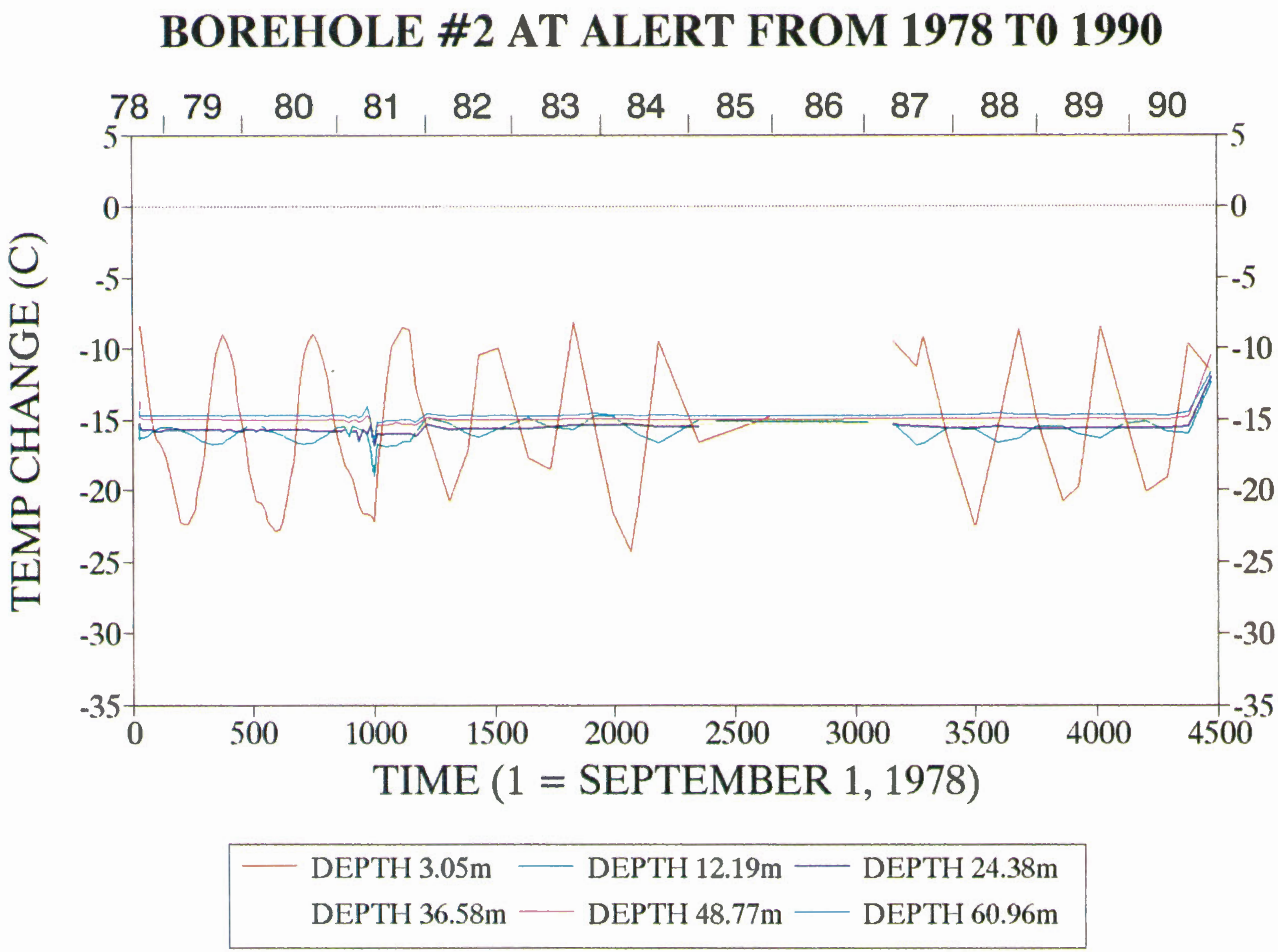
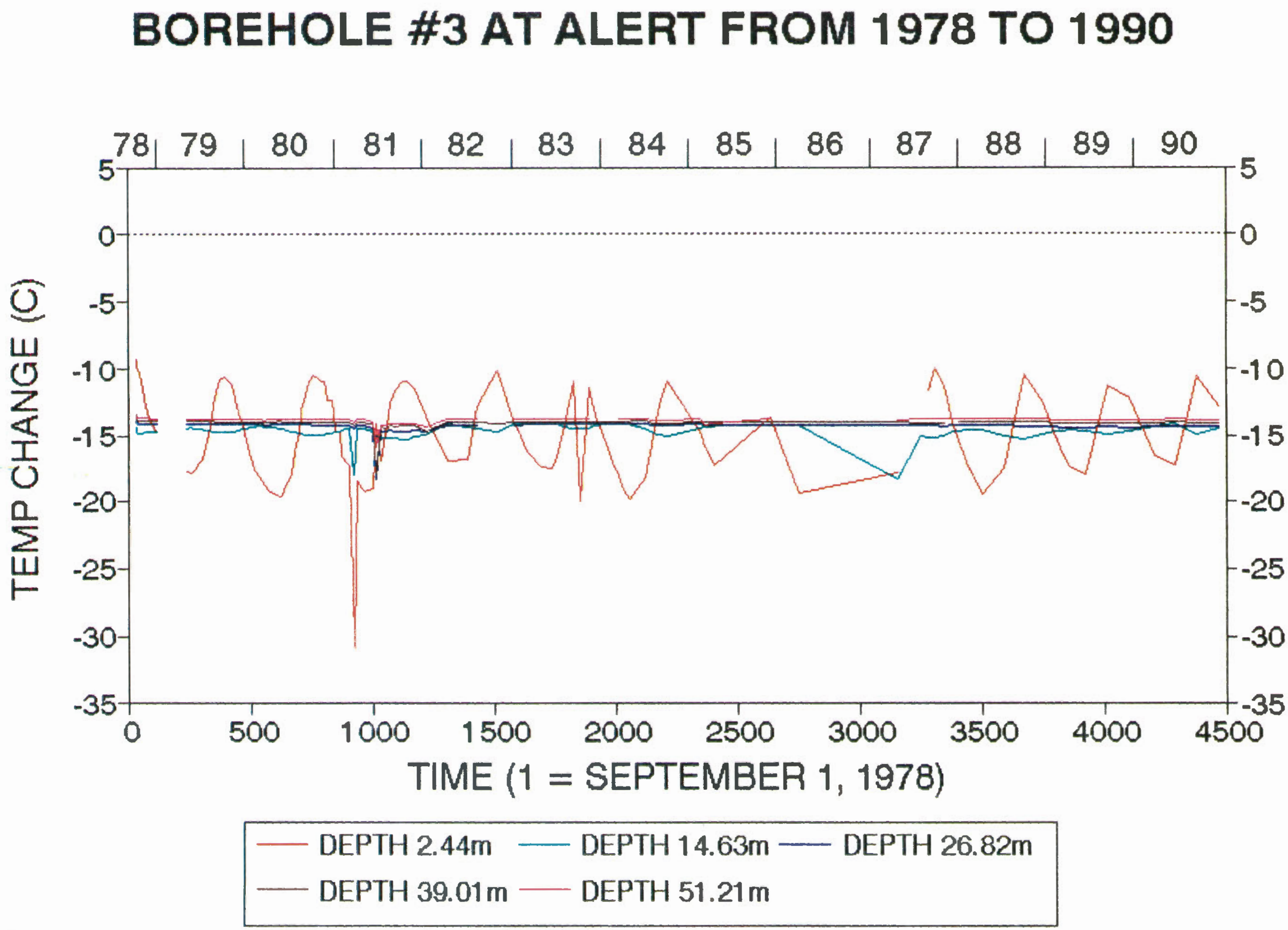

BOREHOLE #2 AT ALERT FROM 1978 T0 1990
78
79
80
81
82
83
84
85
86
87
88
89
90
TEMP CHANGE (C)
5
0
-5
-10
-15
-20
-25
-30
-35
0
500
1000
1500
2000
2500
3000
3500
4000
4500
TIME (1 = SEPTEMBER 1, 1978)
DEPTH 3.05m
DEPTH 12.19m
DEPTH 24.38m
DEPTH 36.58m
DEPTH 48.77m
DEPTH 60.96m

Figure C.4.



BOREHOLE #3 AT ALERT FROM 1978 TO 1990
78
79
80
81
82
83
84
85
86
87
88
89
90
5
0
-5
-10
-15
-20
-25
-30
-35
TEMP CHANGE (C)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
TIME (1 = SEPTEMBER 1, 1978)
DEPTH 2.44m
DEPTH 14.63m
DEPTH 26.82m
DEPTH 39.01m
DEPTH 51.21m

Figure C.5.

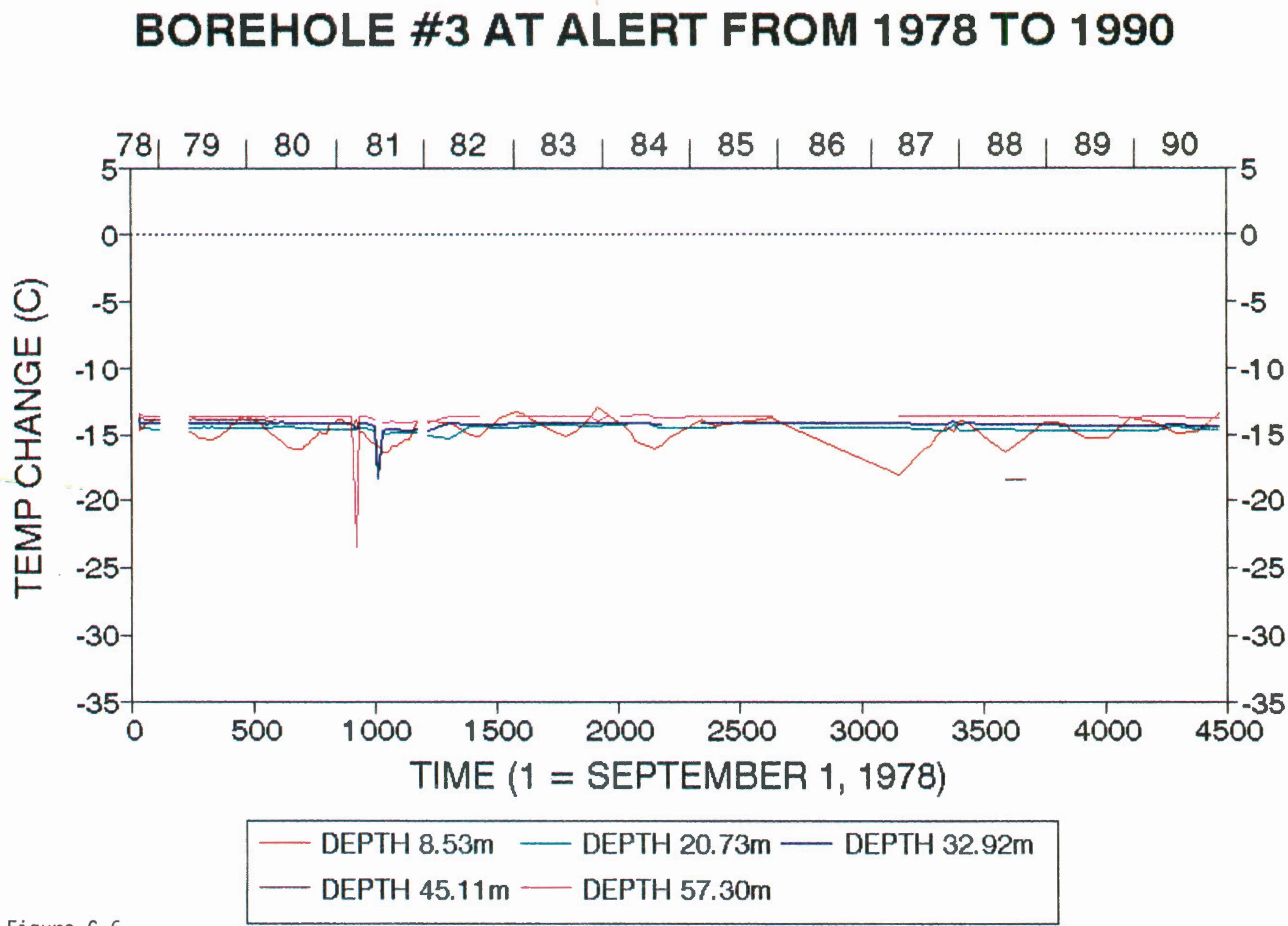

BOREHOLE #3 AT ALERT FROM 1978 TO 1990
78
79
80
81
82
83
84
85
86
87
88
89
90
5
0
-5
-10
-15
-20
-25
-30
-35
TEMP CHANGE (C)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
TIME (1 = SEPTEMBER 1, 1978)
DEPTH 8.53m
DEPTH 20.73m
DEPTH 32.92m
DEPTH 45.11m
DEPTH 57.30m

Figure C.6.

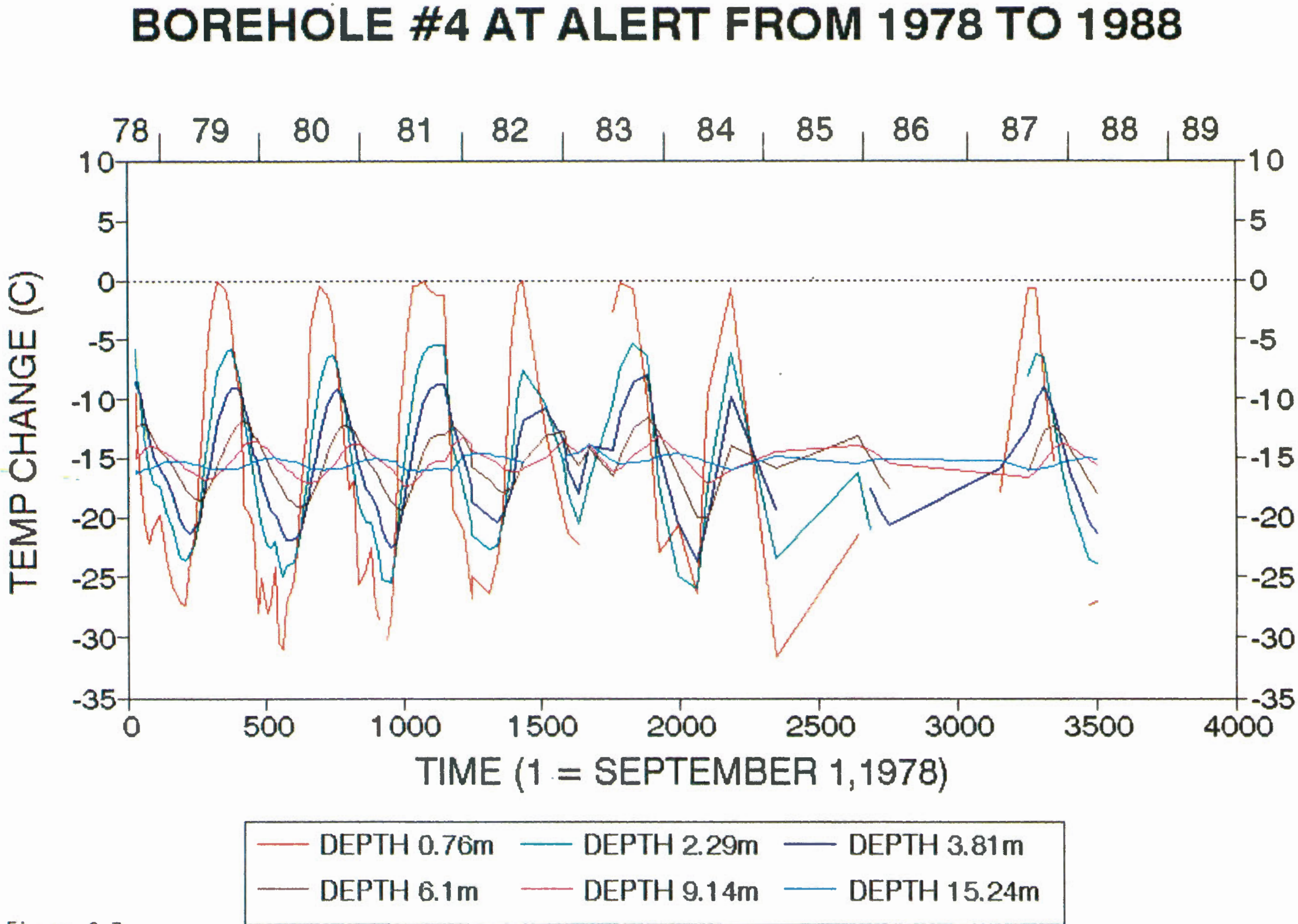

BOREHOLE #4 AT ALERT FROM 1978 TO 1988
78
79
80
81
82
83
84
85
86
87
88
89
10
5
0
-5
-10
-15
-20
-25
-30
-35
TEMP CHANGE (C)
0
500
1000
1500
2000
2500
3000
3500
4000
TIME (1 = SEPTEMBER 1,1978)
DEPTH 0.76m
DEPTH 2.29m
DEPTH 3.81m
DEPTH 6.1m
DEPTH 9.14m
DEPTH 15.24m

Figure C.7.

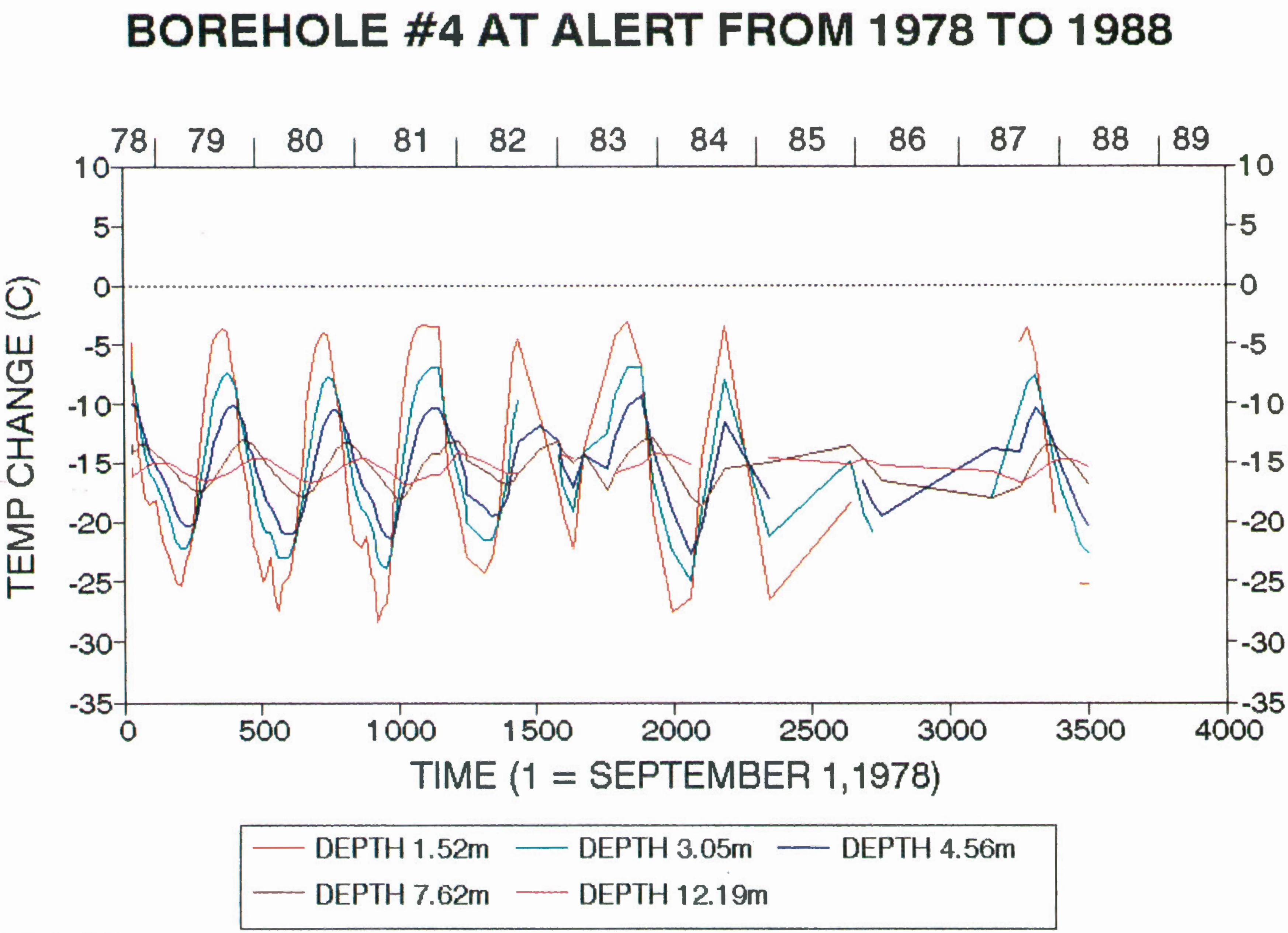
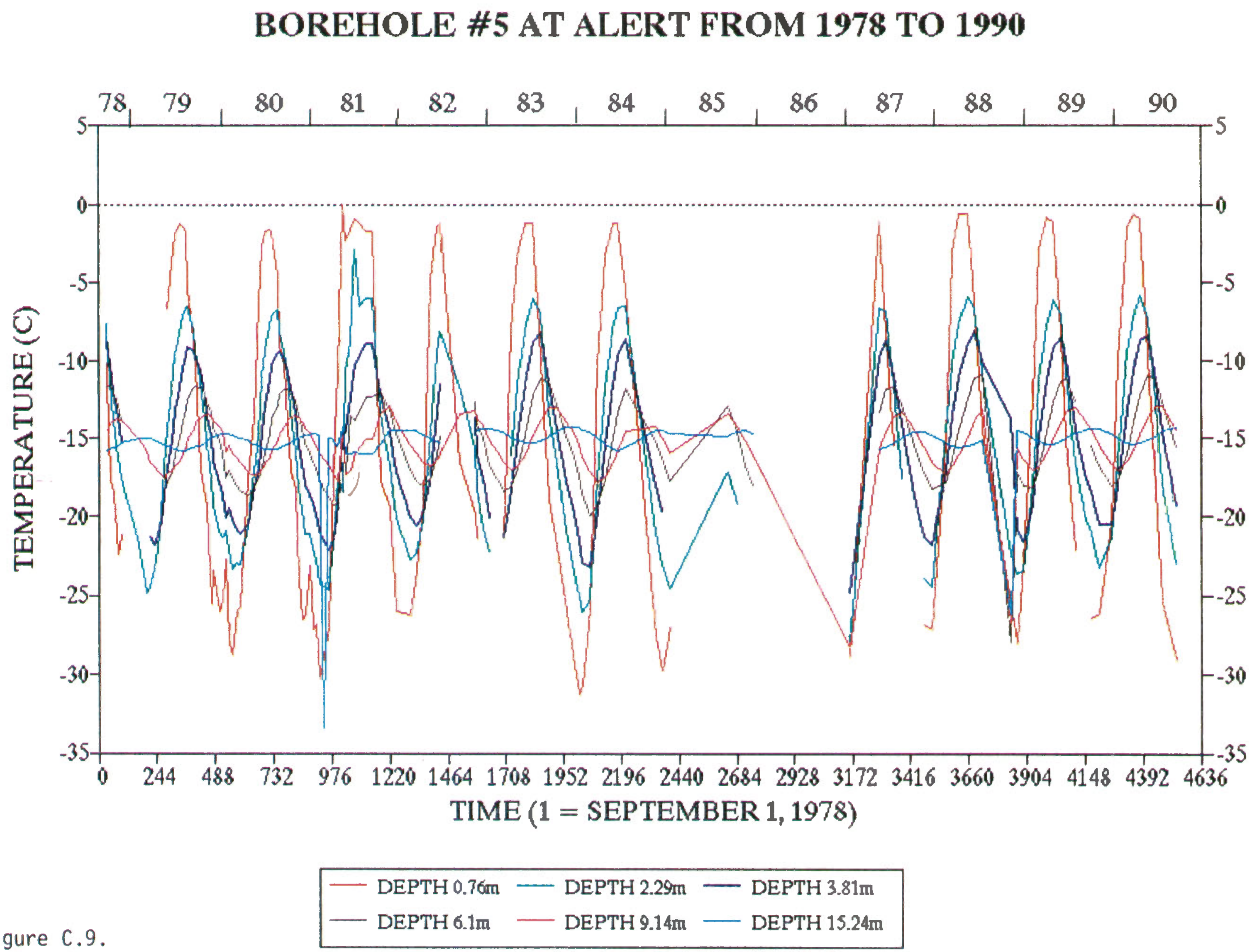

BOREHOLE #4 AT ALERT FROM 1978 TO 1988
78
79
80
81
82
83
84
85
86
87
88
89
10
5
0
-5
-10
-15
-20
-25
-30
-35
TEMP CHANGE (C)
0
500
1000
1500
2000
2500
3000
3500
4000
TIME (1 = SEPTEMBER 1,1978)
DEPTH 1.52m
DEPTH 3.05m
DEPTH 4.56m
DEPTH 7.62m
DEPTH 12.19m

Figure C.8.



BOREHOLE #5 AT ALERT FROM 1978 TO 1990
78
79
80
81
82
83
84
85
86
87
88
89
90
5
0
-5
-10
-15
-20
-25
-30
-35
TEMPERATURE (C)
0
244
488
732
976
1220
1464
1708
1952
2196
2440
2684
2928
3172
3416
3660
3904
4148
4392
4636
TIME (1 = SEPTEMBER 1, 1978)
DEPTH 0.76m
DEPTH 2.29m
DEPTH 3.81m
DEPTH 6.1m
DEPTH 9.14m
DEPTH 15.24m

Figure C.9.

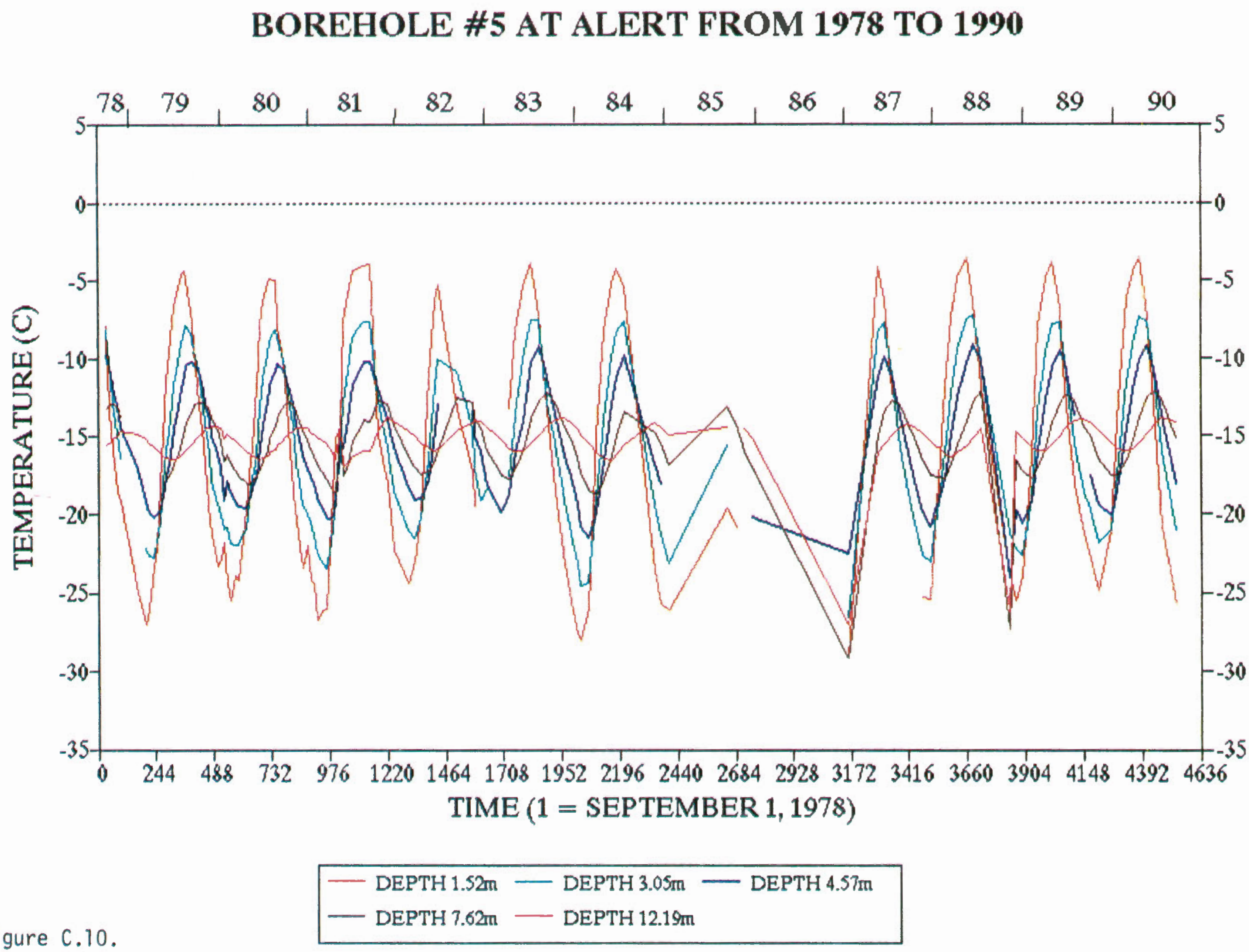

BOREHOLE #5 AT ALERT FROM 1978 TO 1990
78
79
80
81
82
83
84
85
86
87
88
89
90
TEMPERATURE (C)
5
0
-5
-10
-15
-20
-25
-30
-35
0
244
488
732
976
1220
1464
1708
1952
2196
2440
2684
2928
3172
3416
3660
3904
4148
4392
4636
TIME (1 = SEPTEMBER 1, 1978)
DEPTH 1.52m
DEPTH 3.05m
DEPTH 4.57m
DEPTH 7.62m
DEPTH 12.19m

Figure C.10.

APPENDIX D

The program "Croscr" developed by the author for the purpose of correlating two vectors of unequal or equal length (Davis, 1973).

```
C       PROGRAM TO DETERMINE THE BEST CORRELATION BETWEEN WEATHER AND
C       DEPTH DATA.

        INTEGER  DUNIT, WUNIT, OUTUNIT, LY, LX, AN, LEN1, LEN2,I,
     +           REA,L,DEP,REA1,REA2,COUNT
        REAL SX,SY,SXY,SXX,SYY,R,T,IB1,IE1,IB2,IE2,PHASE,DD,DEND,
     +       DBEG,DDATE,YRCORR,WDATE,TSHIFT,INEDAY
        REAL*4 DEPTH(300), WEATH(300), XOUT(300), MXOUT(300)
        CHARACTER*30 DINFILE, WINFILE, OUTFILE

        DUNIT = 1000
        WUNIT = 1100
        OUTUNIT = 1200

C       PROMPTS AND READS INPUT AND OUTPUT FILES

        WRITE (*, 1500)
 1500   FORMAT (' PLEASE ENTER THE WEATHER FILE NAME,'$)
        READ (*, '(A12)') WINFILE

        WRITE (*, 150)
 150    FORMAT (' PLEASE ENTER THE DEPTH FILE NAME,'$)
        READ (*, '(A12)') DINFILE

        WRITE (*, 200)
 200    FORMAT (' PLEASE ENTER THE OUTPUT FILE NAME,'$)
        READ (*, '(A12)') OUTFILE

        WRITE (*,900)
 900    FORMAT ('   PLEASE ENTER THE BEGINNING YEAR OF THE WEATHER DATE
     +IN DECIMAL FORM,'$)
        READ(*, '(F7.2)') WDATE

        WRITE (*,910)
 910    FORMAT ('  PLEASE ENTER THE BEGINNING YEAR OF THE DEPTH DATE IN
     +DECIMAL FORM,'$)
        READ(*, '(F7.2)') DBEG

        WRITE (*,920)
 920    FORMAT ('     PLEASE ENTER THE ENDING YEAR OF THE DEPTH DATE IN
     +DECIMAL FORM,'$)
        READ (*, '(F7.2)') DEND

C       OPEN FILES

       OPEN (UNIT=DUNIT, FILE=DINFILE, FORM='FORMATTED',
     +       STATUS='OLD')
       OPEN (UNIT=WUNIT, FILE=WINFILE, FORM='FORMATTED',
     +       STATUS='OLD')
       OPEN (UNIT=OUTUNIT, FILE=OUTFILE, FORM='FORMATTED',
     +       STATUS='NEW')

C       DETERMINES THE LENGTH OF INPUT FILES AND CROSS CORRELATION
```

```
      READ (DUNIT,'(I12)') LX
      READ (WUNIT,'(I12)') LY

C     READS DATA FROM TWO INPUT FILES INTO TWO ARRAYS

      READ (DUNIT,'(F12.2)') (DEPTH(I), I = 1, LX)
      READ (WUNIT,'(F12.2)') (WEATH(I), I = 1, LY)

      NOT = LY + LX -5
      IB1 = 1
      IE1 = 3
      IB2 = LX - 2
      IE2 = LX
      LEN1 = 3
      WRITE(OUTUNIT,215)
      DO 100 I=1, NOT
          SX = 0.0
          SY = 0.0
          SXY = 0.0
          SXX = 0.0
          SYY = 0.0
          DO 101 J=1, LEN1
               J1 = IB1 + J - 1
               J2 = IB2 + J - 1
               SX = SX + WEATH(J1)
               SY = SY + DEPTH(J2)
               SXY = SXY + WEATH(J1) * DEPTH(J2)
               SXX = SXX + WEATH(J1)**2
               SYY = SYY + DEPTH(J2)**2
C               IF (IB1 .EQ. 65) THEN
C                  WRITE(OUTUNIT,*) J1, J2, SX, SY, SXY, SXX, SYY
C               ENDIF
101        CONTINUE
          AN = LEN1
          R = (AN*SXY-SX*SY)/SQRT(ABS(AN*SXX-SX*SX)*ABS(AN*SYY-SY*SY))
          IF (R .NE. 1.) THEN
          T = R*SQRT(ABS(AN-2.0)/ABS(1.0-R*R))
          ELSE
          T = 1000
          ENDIF
          XOUT(I) = R
      WRITE(OUTUNIT,210) I, IB1, IE1, IB2, IE2, LEN1, R, T
          IE1 = IE1+1
          IF (IE1-LY) 2,2,1
   1      IB1 = IB1+1
          IE1 = LY
   2      IB2 = IB2-1
          IF (IB2) 3,3,4
   3      IB2 = 1
          IE2 = IE2-1
   4      LEN1 = IE1-IB1+1
          LEN2 = IE2-IB2+1
          IF (LEN1-LEN2) 5,100,6
   5      IB1 = 1
          IE2 = IE2-1
```

```
            GO TO 4
   6        IB1 = IB1+1
            IE2 = LX
            GO TO 4
 100    CONTINUE
        REA = LX-2
        DO I=REA, NOT
            MXOUT(I-REA+1)=XOUT(I)
C            WRITE(OUTUNIT,*) MXOUT(I-REA+1)
        ENDDO

         L = NOT-REA+1
C        WRITE(OUTUNIT,*) L, NOT, REA, LX, LY

        CALL MAXSN(L,MXOUT,XMAX,INDEX,COUNT)
        INEDAY=(INDEX-1)*15.
        TSHIFT=(INDEX*15.)/365.
        YRCORR=WDATE + TSHIFT + ((LX*15.)/(2.*365.))
        DD=(DEND - DBEG)/2.
        DDATE=DBEG + DD
        PHASE= ABS(DDATE - YRCORR)
C        WRITE(OUTUNIT,*) INDEX, XMAX, COUNT
C        WRITE(OUTUNIT,*) TSHIFT,YRCORR,WDATE,DD,DEND,DBEG,DDATE,PHASE
        REA2 = REA - 1
        REA1 = INDEX - REA2
        DEP = REA1 + LX
C        WRITE(OUTUNIT,*) REA1, DEP, LX, INDEX ,REA
        WRITE(OUTUNIT,400)
         DO I=1, LY+REA2
            IF (I .LT. INDEX) THEN
                 WRITE(OUTUNIT,450) I, XOUT(I+REA2), WEATH(I)
            ELSEIF (I .GE. INDEX .AND. I .LT. INDEX+LX) THEN
      WRITE(OUTUNIT,650) I,XOUT(I+REA2),WEATH(I),
     + DEPTH(I-INDEX+1)
            ELSEIF (I .GE. INDEX+LX .AND. I .LE. COUNT) THEN
                 WRITE(OUTUNIT,450) I, XOUT(I+REA2), WEATH(I)
             ELSEIF (I .GT. COUNT .AND. I .LE. LY) THEN
                 WRITE(OUTUNIT,700) I, WEATH(I)
            ENDIF
        ENDDO
        WRITE(OUTUNIT,600) INDEX
        WRITE(OUTUNIT,500) YRCORR
        WRITE(OUTUNIT,550) PHASE
        CALL CORRPL(DEPTH, WEATH,MXOUT, LX, LY, L,INEDAY)
 400   FORMAT(//,2X,'CORRELATION INDEX',5X,'CORRELATION',5X,
     +        'WEATHER DATA',5X,'DEPTH DATA',/)
  450   FORMAT(7X,I4,16X,F7.4,8X,F7.2)
  500   FORMAT(2X,'THE DATE OF BEST CORRELATION IS',5X,F7.2,1X,'YEARS')
  550   FORMAT(2X,'THE PHASE SHIFT IS',5X,F7.2,1X,'YEARS')
  600   FORMAT(//,2X,'THE INDEX OF CORRELATION IS',5X,I4)
  650   FORMAT(7X,I4,16X,F7.4,8X,F7.2,12X,F7.2)
  700   FORMAT(7X,I4,31X,F7.2)

  210   FORMAT(2X,I4,3X,F7.2,3X,F7.2,3X,F7.2,3X,F7.2,3X,
     +        I4,3X,F7.4,3X,F8.2)
```

```
  215   FORMAT(5X,'I',7X,'IB1',7X,'IE1',6X,'IB2',6X,'IE2',6X,
     +          'LEN1',7X,'R',8X,'T',//)
        STOP
        END


C       SUBROUTINE MAXSN

        SUBROUTINE MAXSN(LX, X, XMAX, INDEX,COUNT)
        INTEGER LX, COUNT
        REAL XMAX
        REAL*4 X(LX)
        INDEX = 1
        COUNT = 0
        DO 1 I=1, LX
             IF (X(INDEX) .LT. X(I)) INDEX=I
             COUNT=COUNT + 1
  1     CONTINUE
        XMAX=X(INDEX)
        RETURN
        END

       SUBROUTINE CORRPL(V1, V2, V3, N1, N2, N3,INEDAY)
       CHARACTER LEGEND*35,XLABEL*11,YLABEL*5,LEGEND2*25,LEGEND3*25
       REAL FACT,XLEG,YLEG,TIM1,TIM2,TIM3,TIME1(1000),
      + TIME2(1000),TIME3(1000),INEDAY,X1LEG,Y1LEG,X2LEG,
      + Y2LEG,X3LEG,Y3LEG
       INTEGER IOPORT,MODEL,N1,N2,N3,TIMINC
       REAL*4 V1(N1), V2(N2), V3(N3)
* Initialize PLOT 88
          IOPORT = 1
          MODEL = 67
          FACT = .6
          FNAME='~~~~~~~~~.~~~'
C       CALL DEVICE(IOPORT,MODEL,FACT,FNAME)
       CALL PLOTS(0,IOPORT,MODEL)
       CALL FACTOR(FACT)
       CALL PLOT(1.3,1.5,-3)
*  Pen width 2 for axes and labelling; width 1 for profiles
       CALL NEWPEN(2)
*  Define TRIPIX symbol font to be used by SYMBOL
       CALL TRIPLX

*  Read file names for two vectors and R vector
*       WRITE(*,'(A\)')'...Enter file name for vector 1...'
C       READ(*,'(A)')FILE1
C       OPEN(UNIT=1,FILE=FILE1,STATUS='OLD')
C       WRITE(*,'(A\)')'...Enter file name for vector 2...'
C       READ(*,'(A)')FILE2
C       OPEN(UNIT=2,FILE=FILE2,STATUS='OLD')
C       WRITE(*,'(A\)')'...Enter file name for r-vector 3...'
C       READ(*,'(A)')FILE3
C       OPEN(UNIT=3,FILE=FILE3,STATUS='OLD')
C*  Read vector data
```

```
C      READ(1,'(I5,2F5.0/15F8.3)')N1, TIM1, TIMINC, (V1(I),I=1,N1)
C      READ(2,'(I5,2F5.0/15F8.3)')N2, TIM2, TIMINC, (V2(I),I=1,N2)
C      READ(3,'(I5,2F5.0/15F8.3)')N3, TIM3, TIMINC, (V3(I),I=1,N3)
C      WRITE(*,'(I5,2F5.0/15F8.3)')N1, TIM1, TIMINC, (V1(I),I=1,N1)
C      WRITE(*,'(I5,2F5.0/15F8.3)')N2, TIM2, TIMINC, (V2(I),I=1,N2)
C      WRITE(*,'(I5,2F5.0/15F8.3)')N3, TIM3, TIMINC, (V3(I),I=1,N3)
*  Create the time vector for each temperature vector, in days
      TIMINC=15
      TIM1=0.
      TIM2=0.
      TIM3=0.
      DO 1 I=1, N1
 1    TIME1(I)=TIM1+(I-1)*TIMINC+INEDAY
      DO 2 I=1,N2
 2    TIME2(I)=TIM2+(I-1)*TIMINC
      DO 3 I=1,N3
 3    TIME3(I)=TIM3+(I-1)*TIMINC
      WRITE(*,'(3I5,6F10.0)')N1,N2,N3,(TIME1(I),I=1,6)
*  Scale the time arrays based on V3 (correlation) being longest
      CALL SCALE(TIME3,15.,N3,1)
      TIME1(N1+1)=TIM1
      TIME1(N1+2)=TIME3(N3+2)
      TIME2(N2+1)=TIM3
      TIME2(N2+2)=TIME3(N3+2)
*  Scale the temperature arrays
      CALL SCALE(V1,3.,N1,1)
      CALL SCALE(V2,3.,N2,1)
*  Scale of correlation array R, from -1 to +1
      V3(N3+1)=-1.
      V3(N3+2)=1.
*  Draw the time axis as the x-axis
      XLABEL='Time (days)'
      CALL STAXIS(.15,.3,.08,.111,-1)
      CALL AXIS(0.,0.,XLABEL,-11,-15.,0.,TIME3(N3+1),TIME3(N3+2))
*  Draw a temperature axis for each vector as the y-axis
*   and plot the vector
      YLABEL='T (C)'
*   Correlation axis and V3
      CALL STAXIS(.15,.3,.1,.111,-1)
      CALL AXIS(0.,0.,'R',1,-2.,90.,V3(N3+1),V3(N3+2))
      CALL LINE(TIME3,V3,N3,1,0,15)
*   Temperature axis and V2
      CALL PLOT(0.,3.,-3)
      CALL STAXIS(.15,.3,.1,.111,1)
      CALL AXIS(0.,0.,YLABEL,5,-3.,90.,V2(N2+1),V2(N2+2))
      CALL LINE(TIME2,V2,N2,1,0,15)
*   Temperature axis and V1
      CALL PLOT(0.,4.,-3)
      CALL STAXIS(.15,.3,.1,.111,1)
      CALL AXIS(0.,0.,YLABEL,5,-3.,90.,V1(N1+1),V1(N1+2))
      CALL LINE(TIME1,V1,N1,1,0,15)
*  Reinitialize Origin to (0,0)
      CALL PLOT(0.,-7.,-3)
*  Put in legend at top right corner
      WRITE(*,'(A\)')'...Enter text for legend...'
```

```
      READ(*,'(A)')LEGEND
      XLEG=4.
      YLEG=10.
      CALL SYMBOL(XLEG,YLEG,.35,LEGEND,0.,35)
*   Put in Subtitles for each Graph
      X1LEG=11.5
      Y1LEG=.2
      X2LEG=11.5
      Y2LEG=2.8
      X3LEG=11.5
      Y3LEG=6.8
      WRITE(*,'(A\)')'...Enter text for deeper depth...'
      READ(*,'(A)')LEGEND2
      WRITE(*,'(A\)')'...Enter text for shallower depth...'
      READ(*,'(A)')LEGEND3
      CALL SYMBOL(X1LEG,Y1LEG,.15,'Correlation Coefficients',0.,24)
      CALL SYMBOL(X2LEG,Y2LEG,.15,LEGEND2,0.,25)
      CALL SYMBOL(X3LEG,Y3LEG,.15,LEGEND3,0.,25)
*   End of plot
      CALL PLOT(0.,0.,999)
      RETURN
      END
```

APPENDIX E1

Figures E1.1-E1.24. Ground temperatures versus time at each depth measurement, 1.52 m to 60.96 m. At each depth graphs of measured field data and of spline data (15 day intervals) are presented one above the other, and then followed by a separate graph overlaying the two.

APPENDIX E2

Figures E2.1-E2.6. Layout similar to above. A demonstration of insufficient splining at various intervals for the later two subsets.

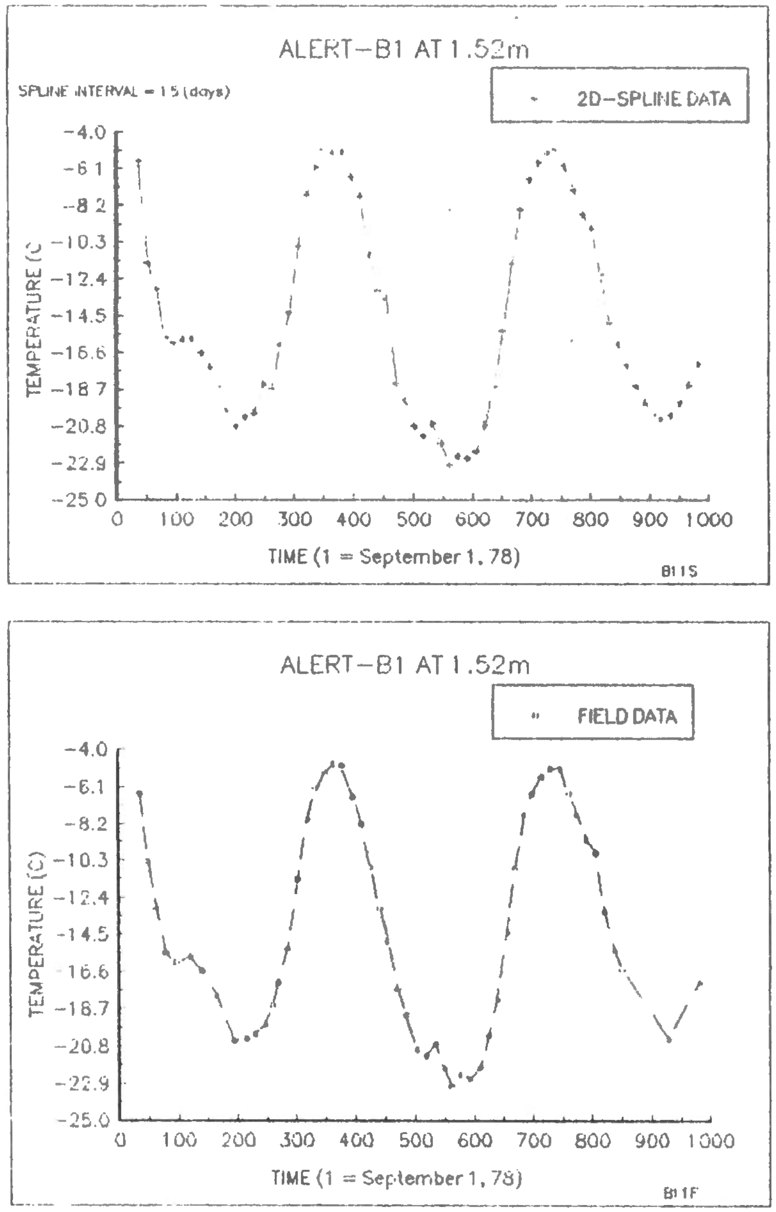


Figure E1.1.

B112F

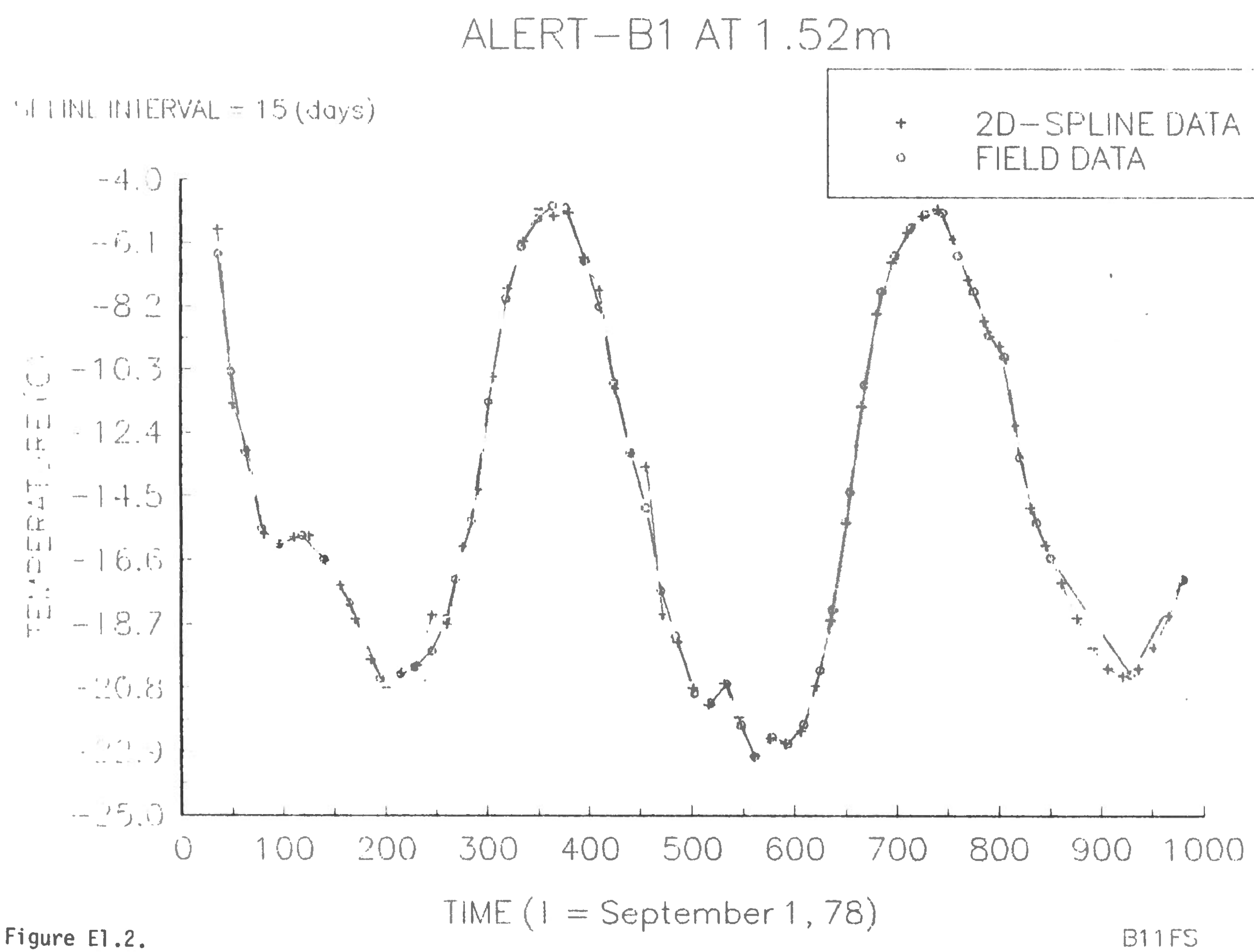

ALERT−B1 AT 1.52m
INTERVAL = 15 (days)
+ 2D−SPLINE DATA
o FIELD DATA
-4.0
-6.1
-8.2
-10.3
-12.4
-14.5
-16.6
-18.7
-20.8
-25.0
0
100
200
300
400
500
600
700
800
900
1000
TIME (1 = September 1, 78)
B11FS

Figure E1.2.

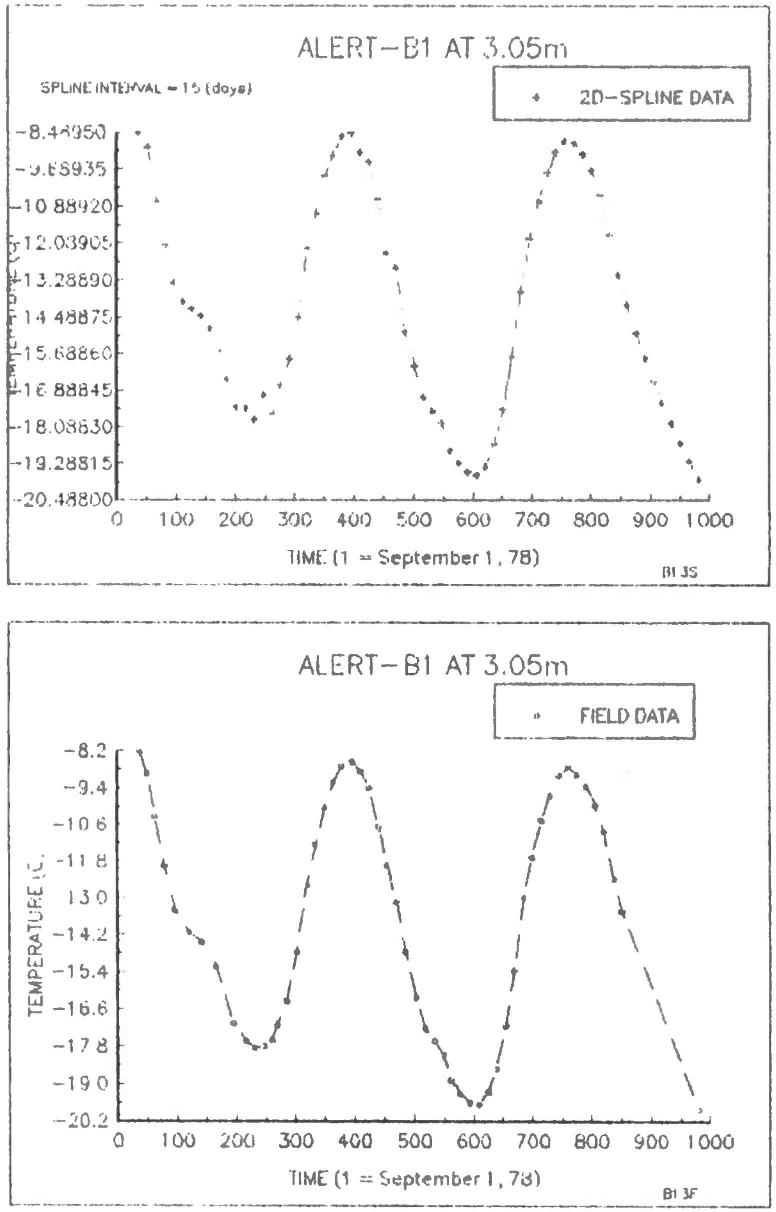


Figure E1.3.

B1 32FS

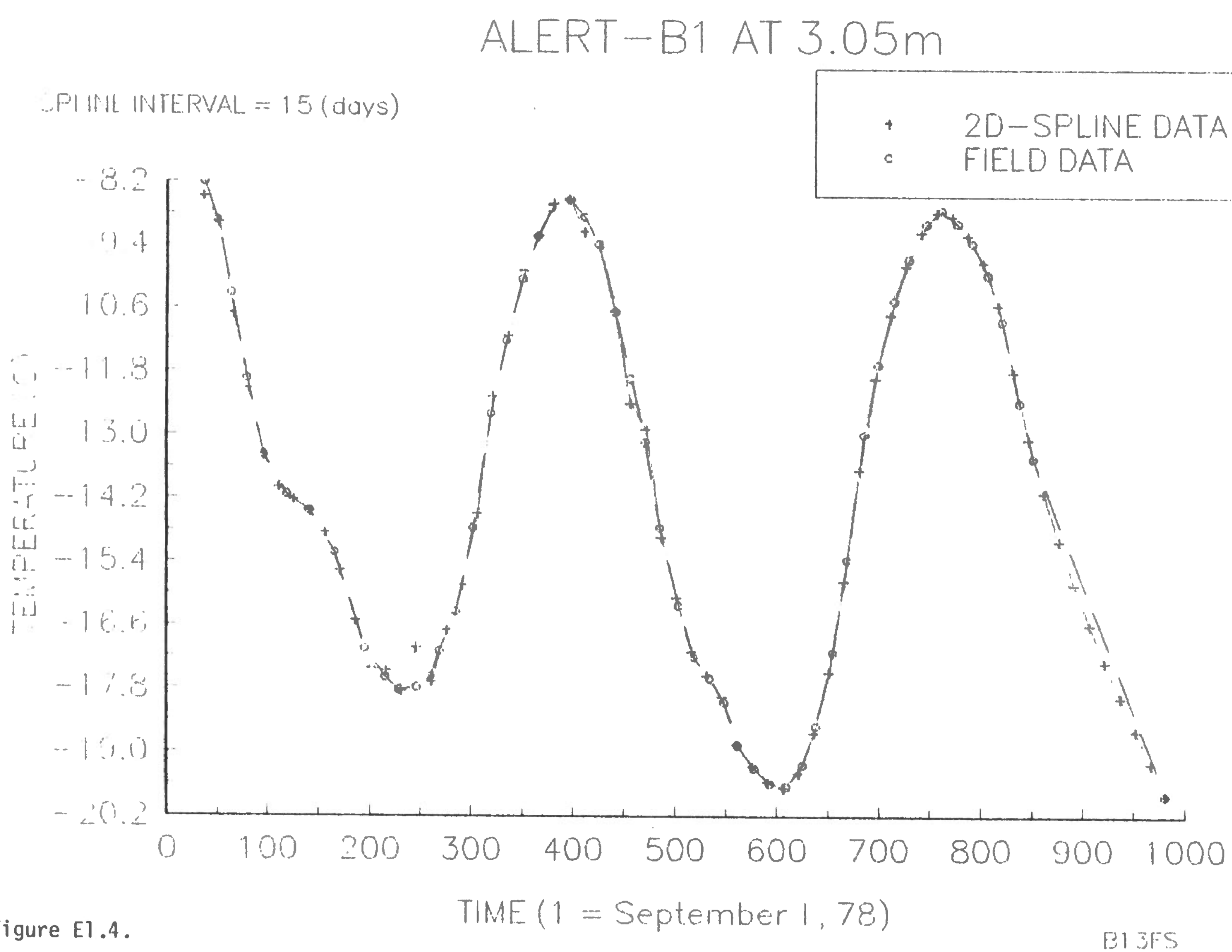

ALERT–B1 AT 3.05m
SPLINE INTERVAL = 15 (days)
2D–SPLINE DATA
FIELD DATA
TEMPERATURE (C)
TIME (1 = September 1, 78)
B13FS

Figure E1.4.

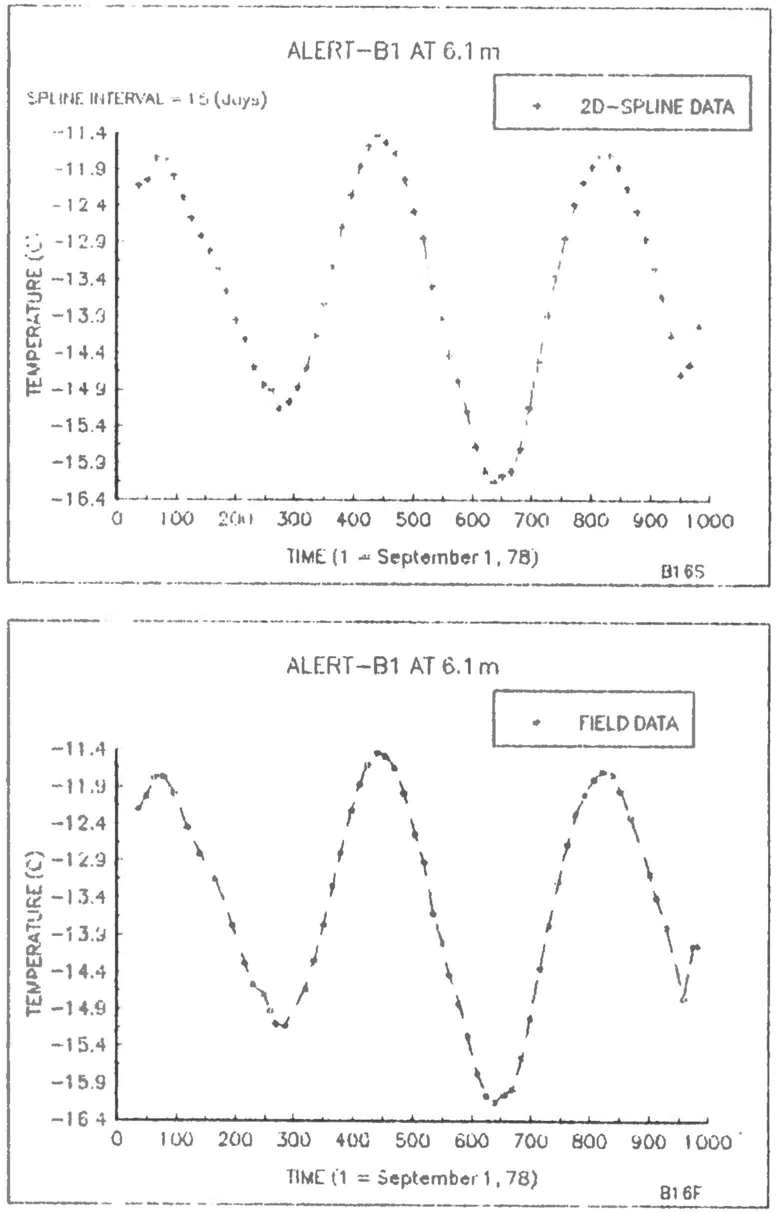
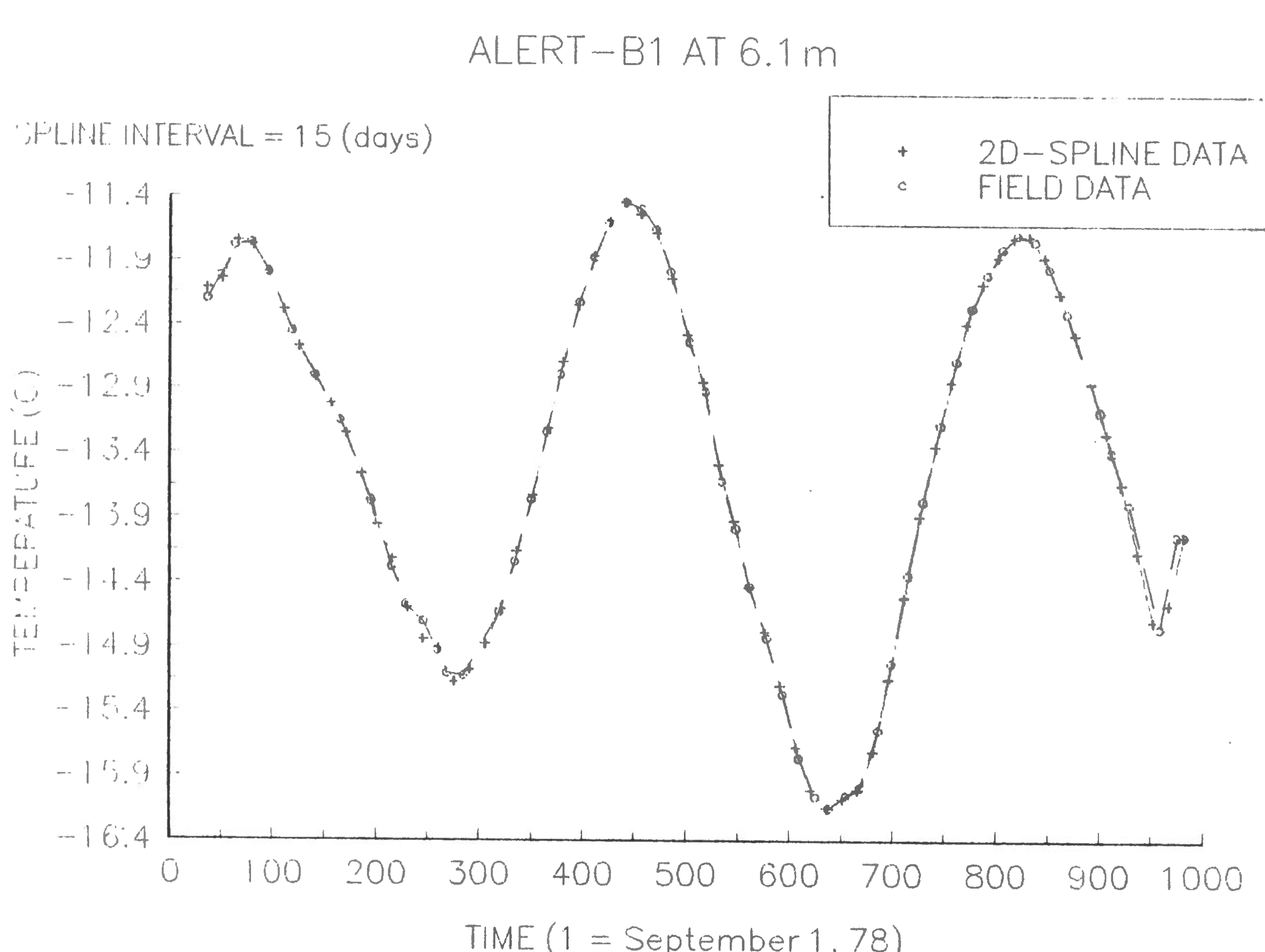


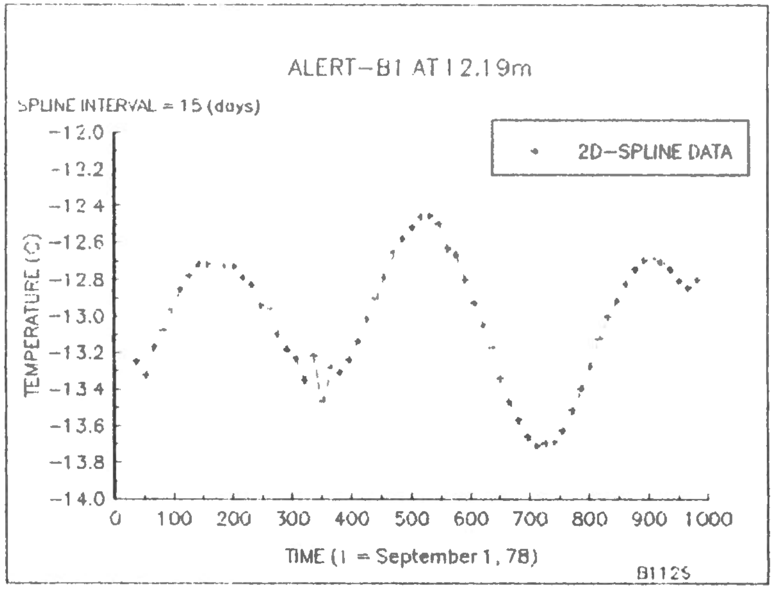
Figure E1.5.

B162FS



ALERT-B1 AT 6.1 m
SPLINE INTERVAL = 15 (days)
+ 2D-SPLINE DATA
○ FIELD DATA
TEMPERATURE (C)
-11.4
-11.9
-12.4
-12.9
-13.4
-13.9
-14.4
-14.9
-15.4
-15.9
-16.4
0
100
200
300
400
500
600
700
800
900
1000
TIME (1 = September 1, 78)
B16FS

Figure E1.6.



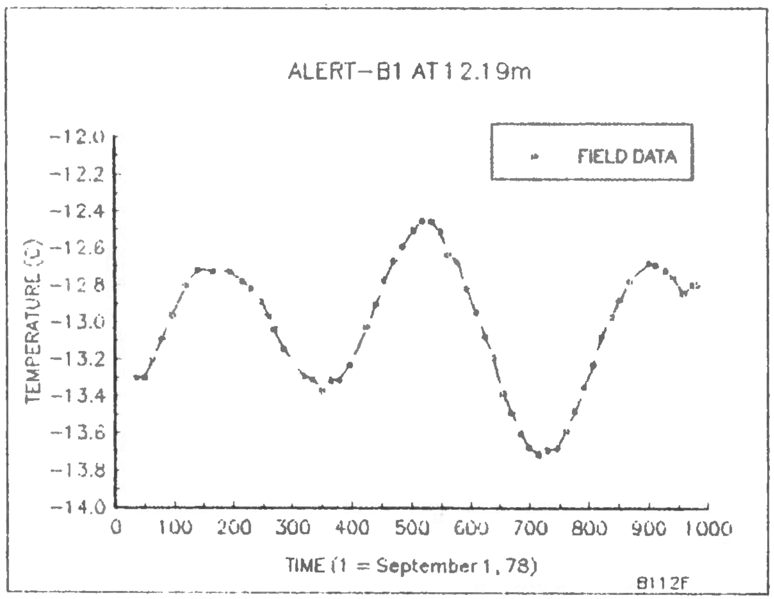


Figure E1.7.

B1122F

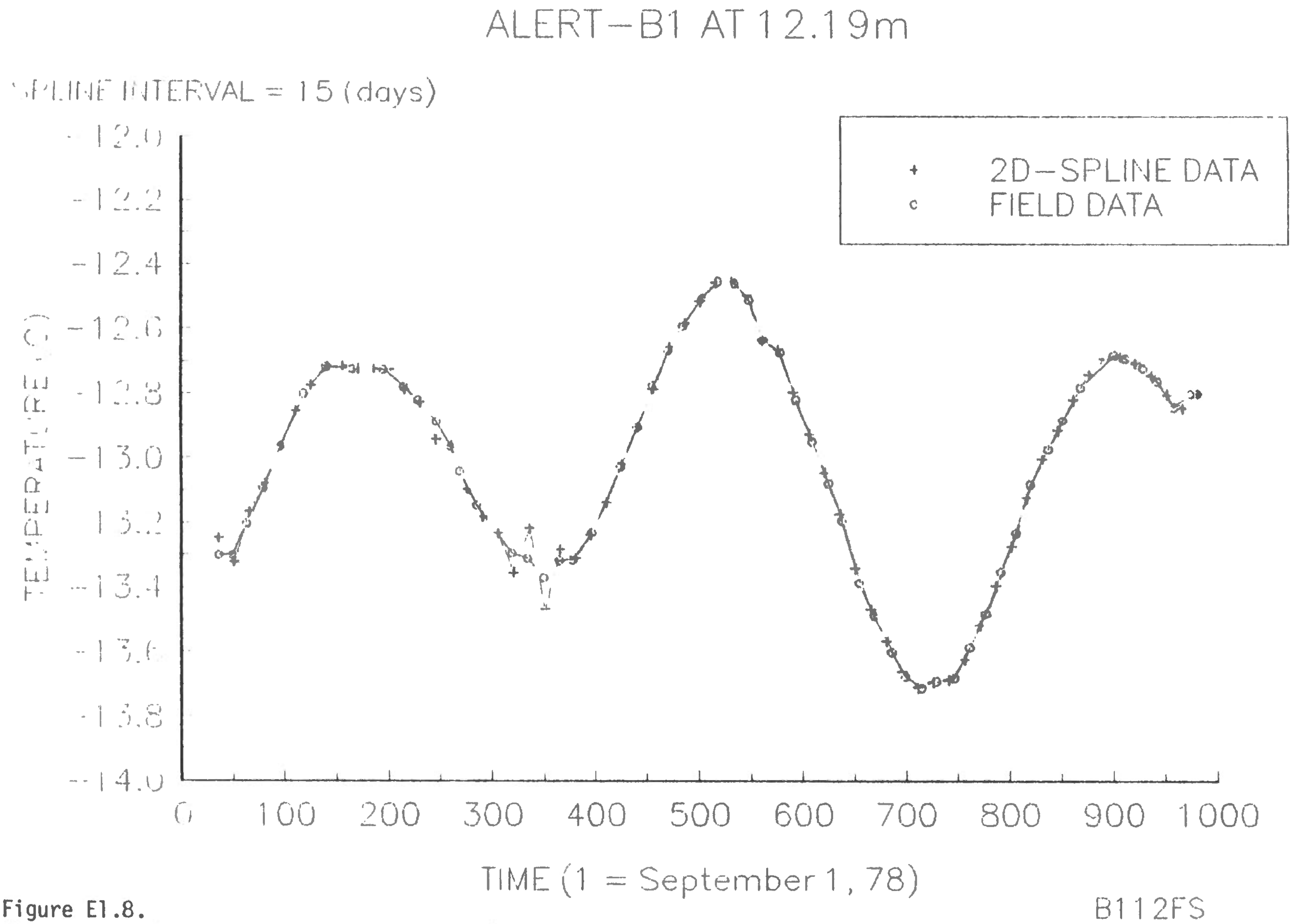

ALERT-B1 AT 12.19m
SPLINE INTERVAL = 15 (days)
+ 2D-SPLINE DATA
c FIELD DATA
TEMPERATURE (C)
-12.0
-12.2
-12.4
-12.6
-12.8
-13.0
-13.2
-13.4
-13.6
-13.8
-14.0
0
100
200
300
400
500
600
700
800
900
1000
TIME (1 = September 1, 78)
B112FS

Figure E1.8.

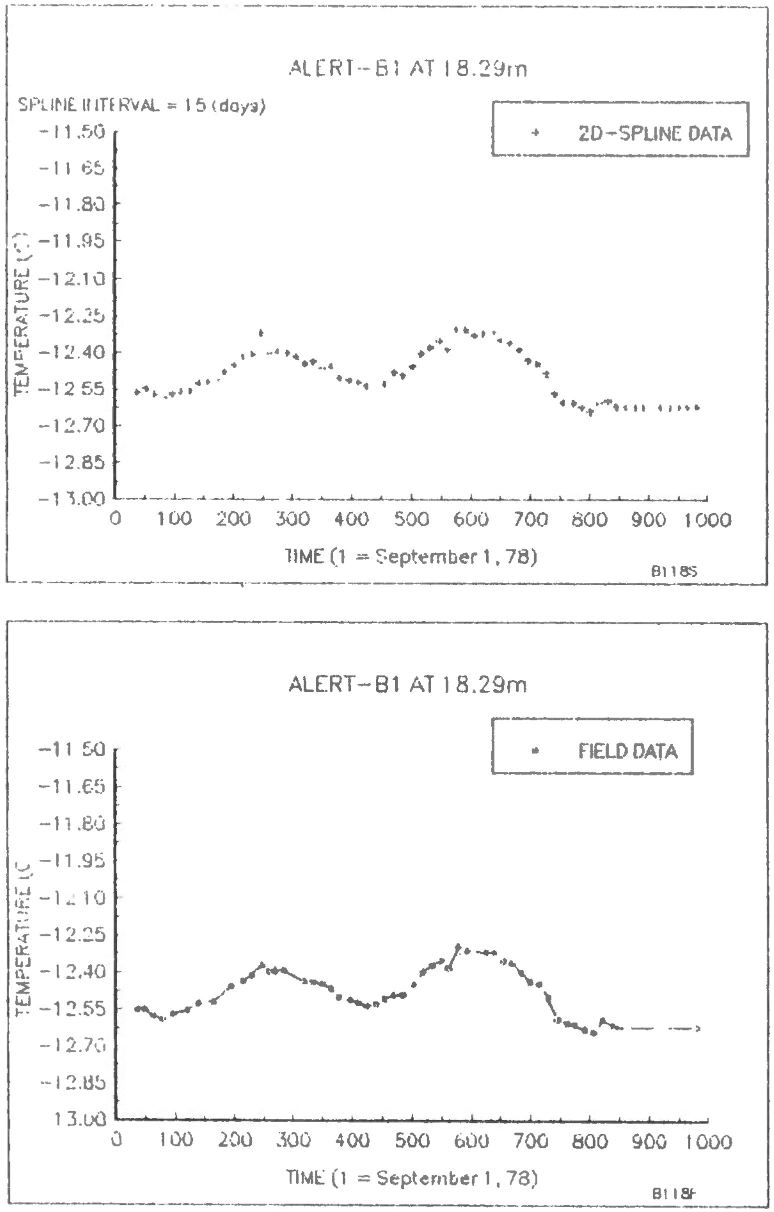


Figure E1.9.

B1182F

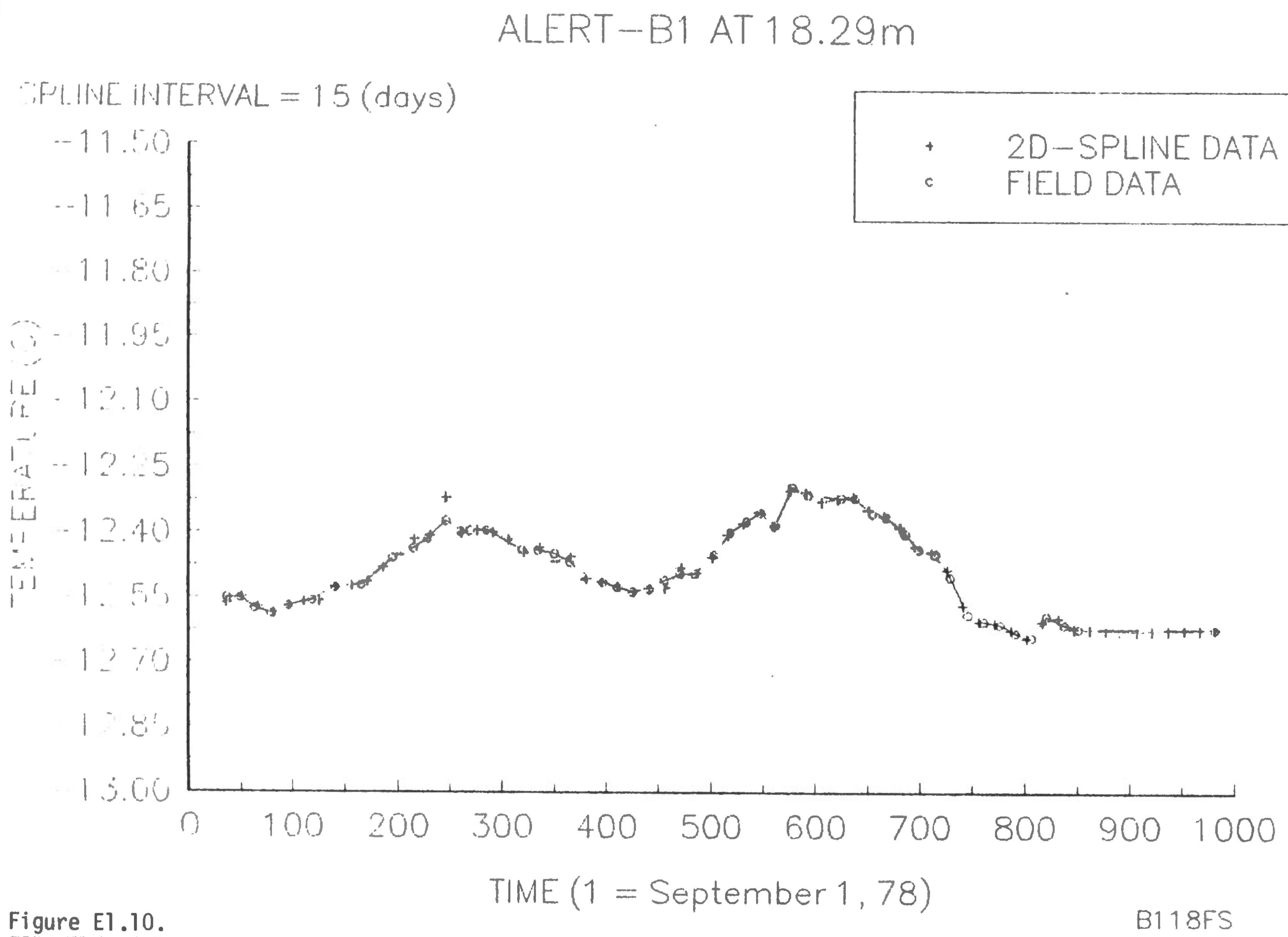
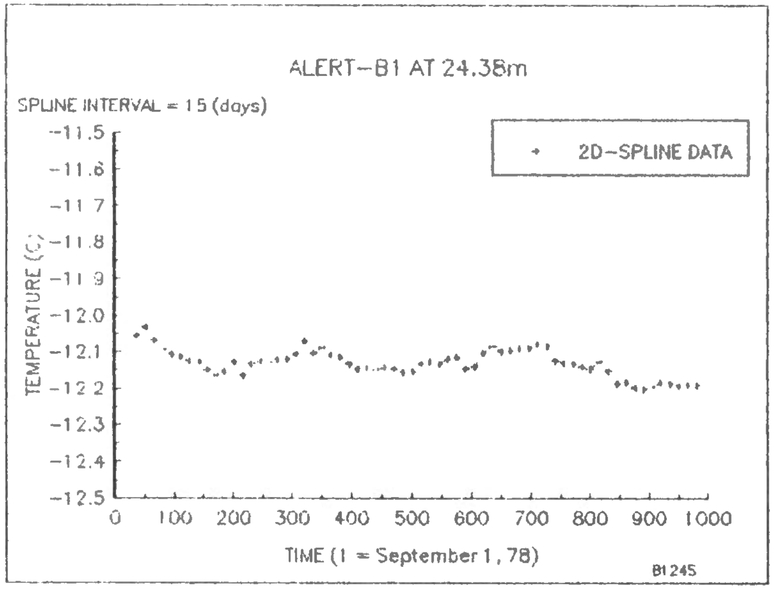

ALERT—B1 AT 18.29m
SPLINE INTERVAL = 15 (days)
2D—SPLINE DATA
FIELD DATA
TEMPERATURE (C)
-11.50
-11.65
-11.80
-11.95
-12.10
-12.25
-12.40
-12.55
-12.70
-12.85
-13.00
0
100
200
300
400
500
600
700
800
900
1000
TIME (1 = September 1, 78)
B118FS

Figure E1.10.



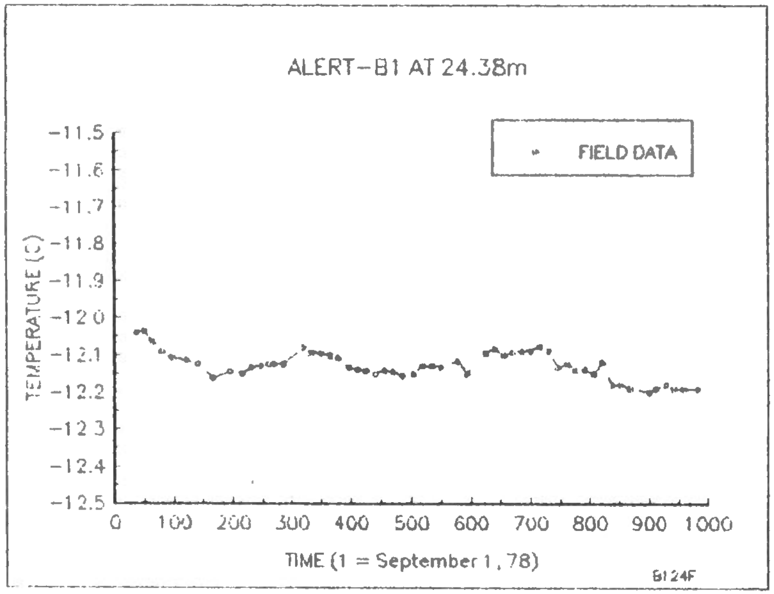


Figure E1.11.

B1242F

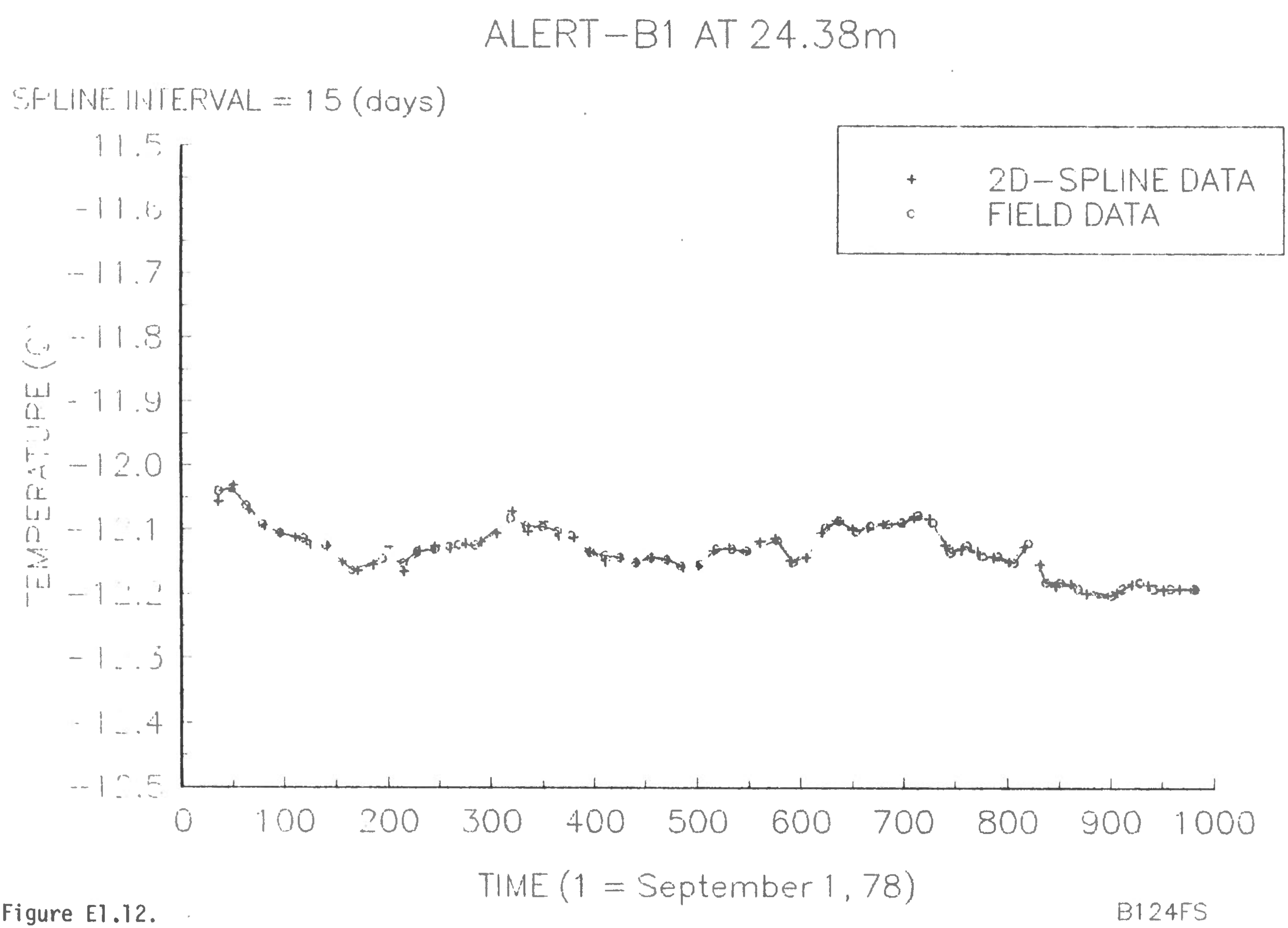
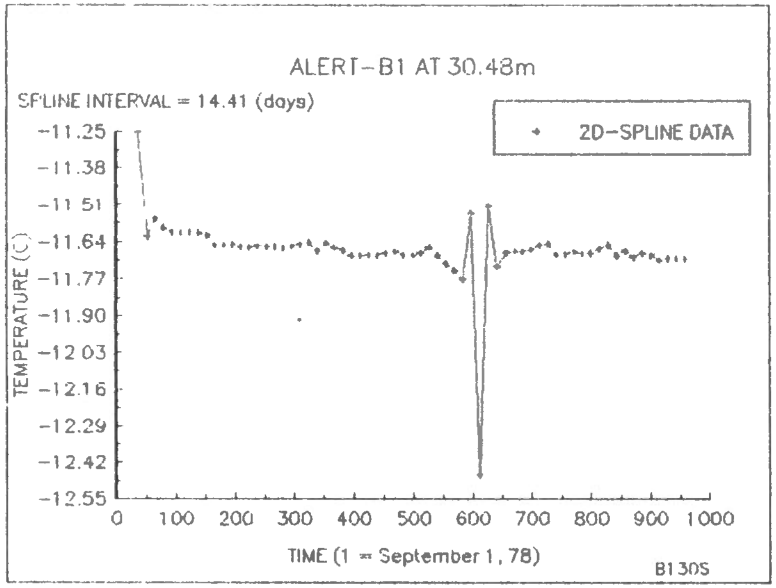

ALERT–B1 AT 24.38m
SPLINE INTERVAL = 15 (days)
+ 2D–SPLINE DATA
c FIELD DATA
TEMPERATURE (C)
-11.5
-11.6
-11.7
-11.8
-11.9
-12.0
-12.1
-12.2
-12.3
-12.4
-12.5
0
100
200
300
400
500
600
700
800
900
1000
TIME (1 = September 1, 78)
B124FS

Figure E1.12.



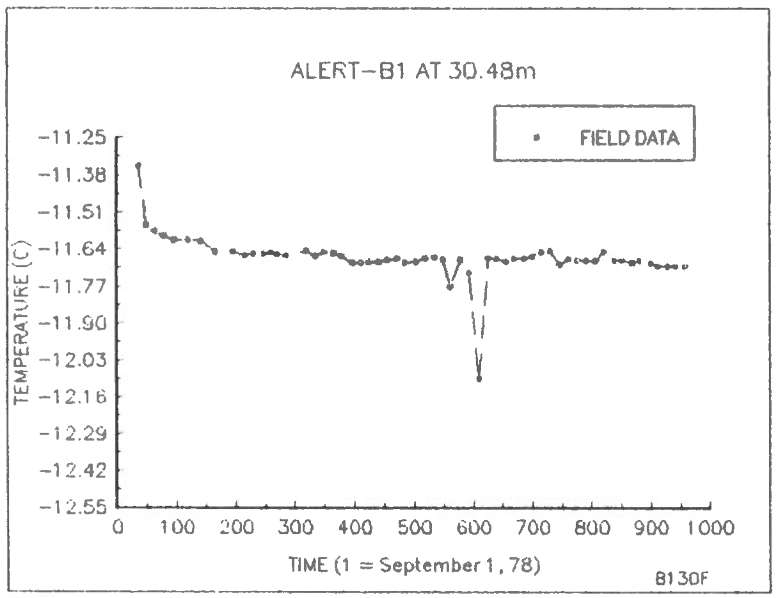


Figure E1.13.

B1302F

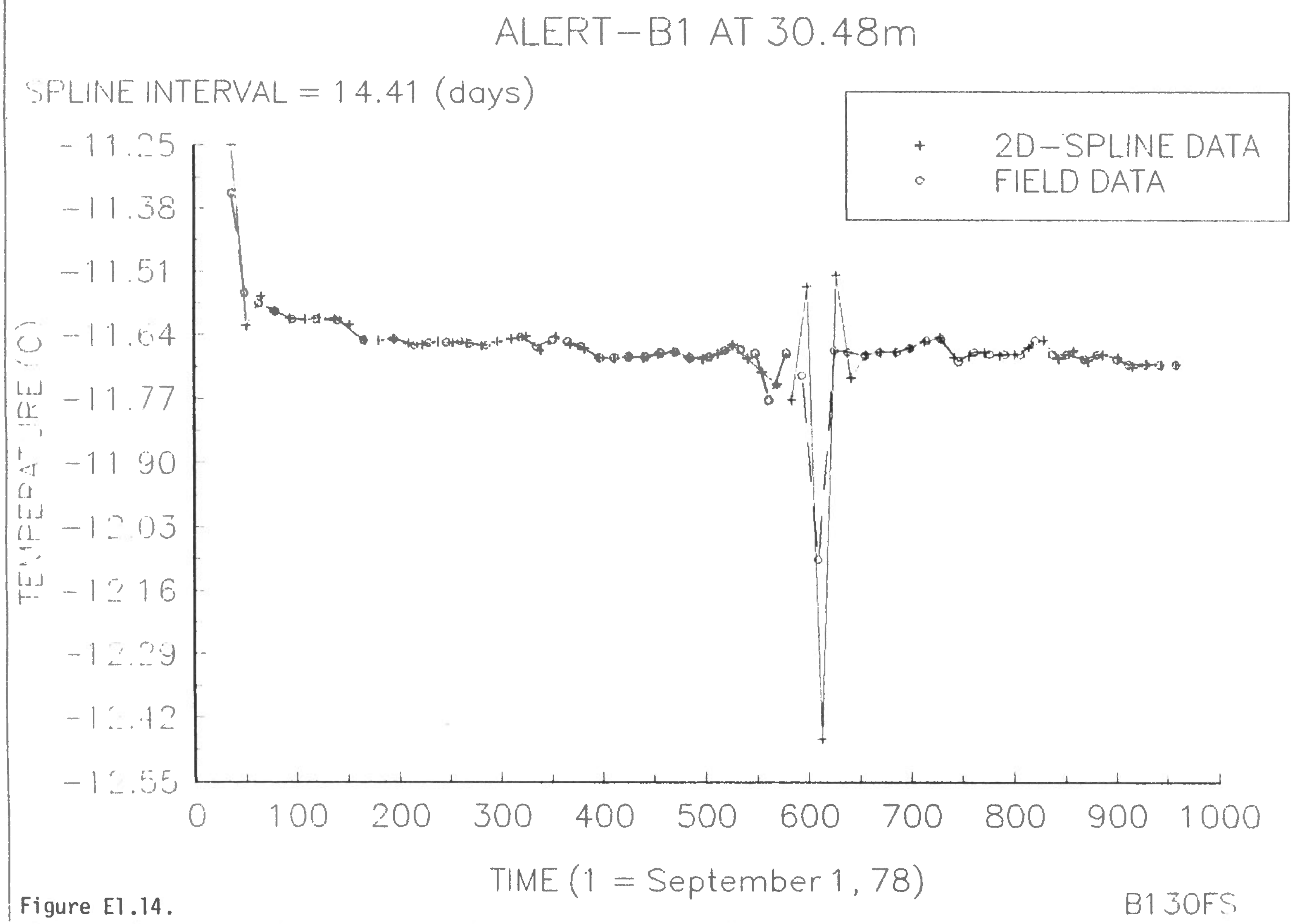
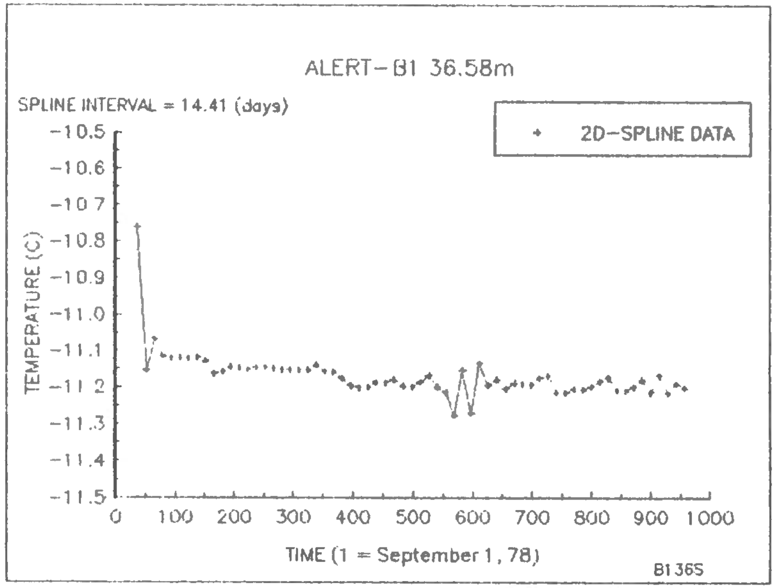

ALERT-B1 AT 30.48m
SPLINE INTERVAL = 14.41 (days)
+ 2D-SPLINE DATA
○ FIELD DATA
TEMPERATURE (C)
-11.25
-11.38
-11.51
-11.64
-11.77
-11.90
-12.03
-12.16
-12.29
-12.42
-12.55
0
100
200
300
400
500
600
700
800
900
1000
TIME (1 = September 1, 78)
B130FS

Figure E1.14.



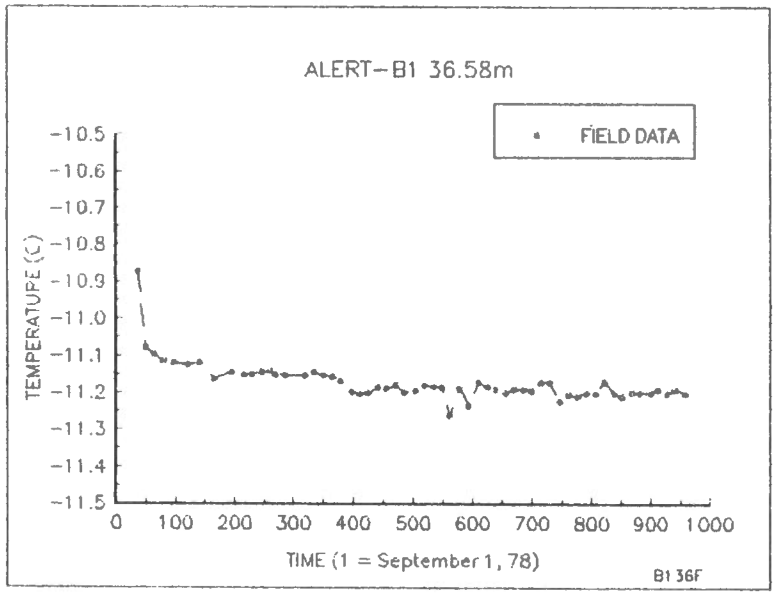


Figure E1.15.

B1 362F

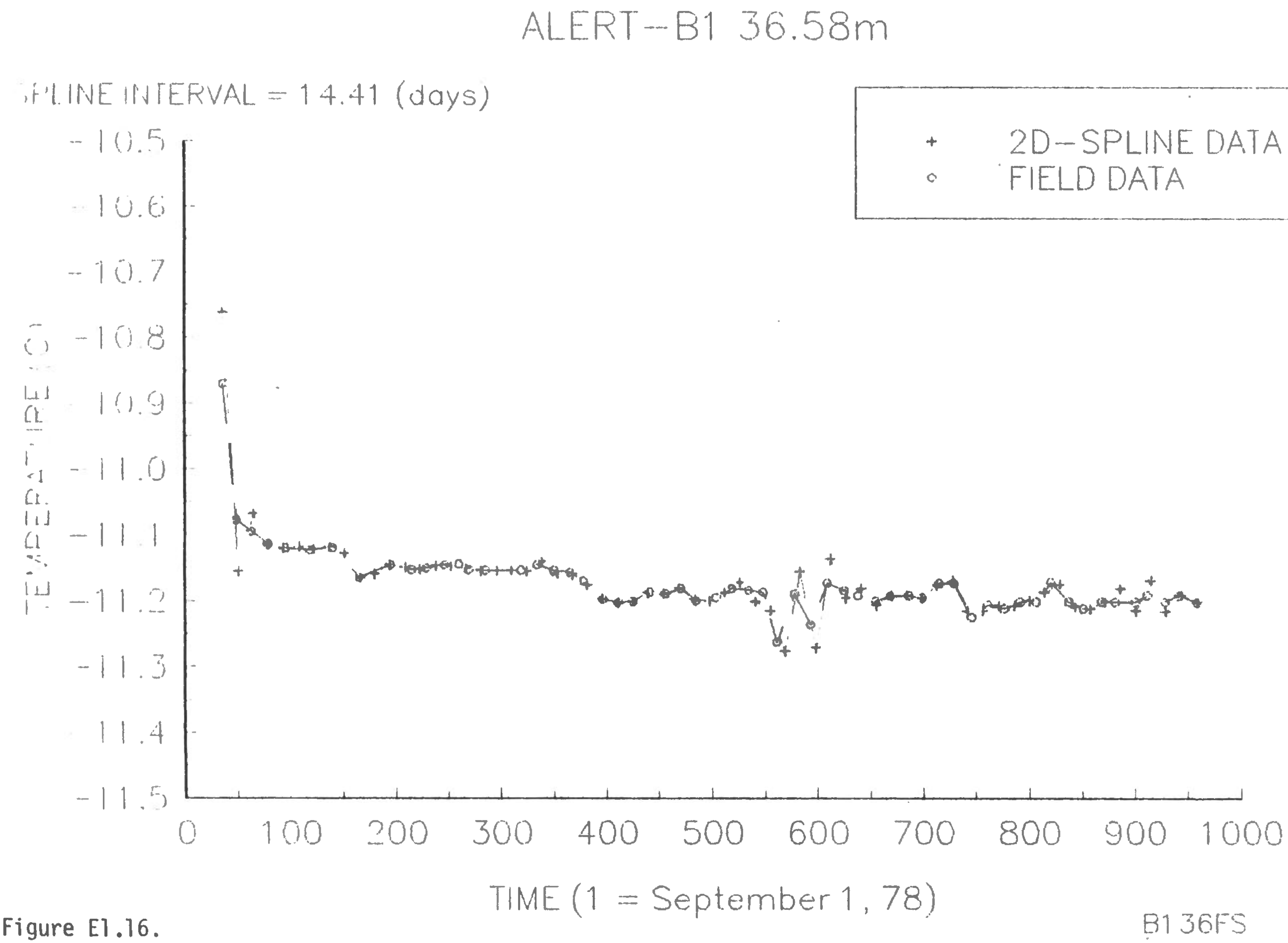
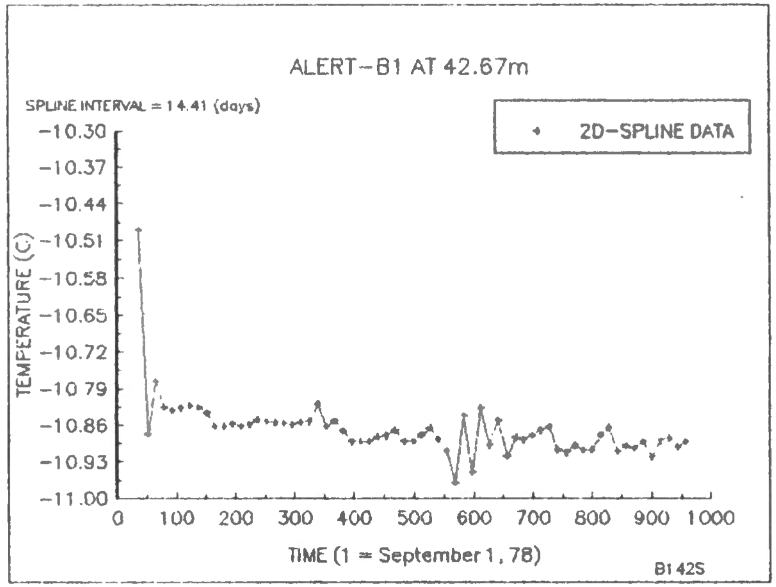

ALERT--B1 36.58m
SPLINE INTERVAL = 14.41 (days)
+ 2D--SPLINE DATA
○ FIELD DATA
TEMPERATURE (C)
-10.5
-10.6
-10.7
-10.8
-10.9
-11.0
-11.1
-11.2
-11.3
-11.4
-11.5
0
100
200
300
400
500
600
700
800
900
1000
TIME (1 = September 1, 78)
B136FS

Figure E1.16.



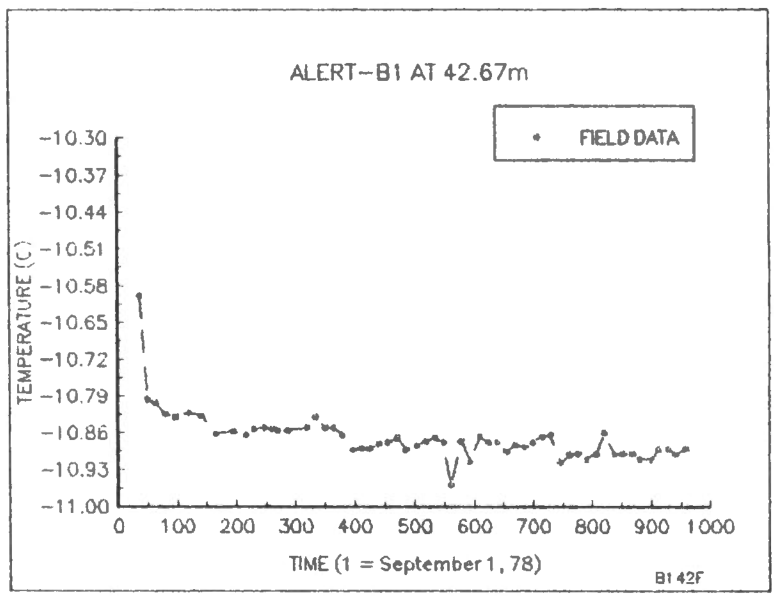
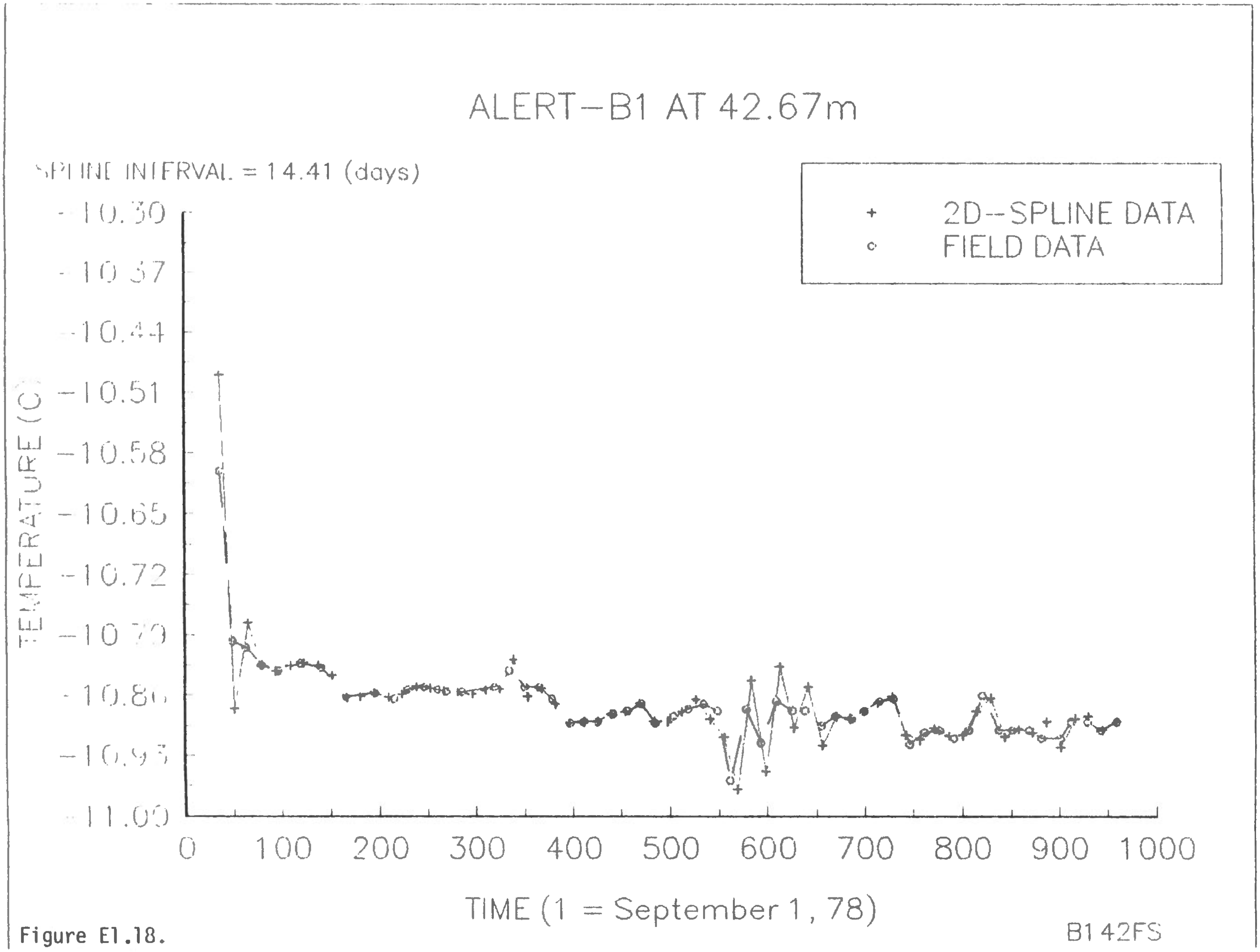


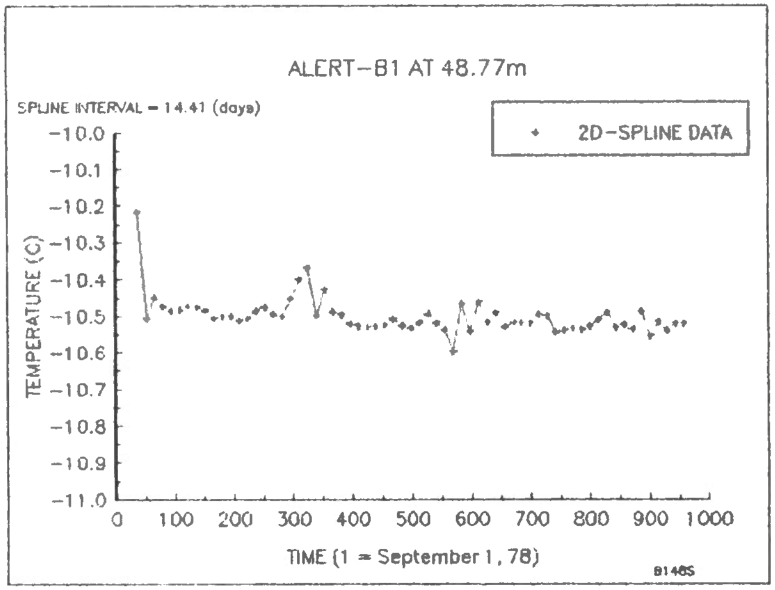
Figure E1.17.

B1 422F



ALERT–B1 AT 42.67m
SPLINE INTERVAL = 14.41 (days)
+ 2D--SPLINE DATA
○ FIELD DATA
TEMPERATURE (C)
-10.30
-10.37
-10.44
-10.51
-10.58
-10.65
-10.72
-10.86
-11.00
0
100
200
300
400
500
600
700
800
900
1000
TIME (1 = September 1, 78)
B1 42FS

Figure E1.18.



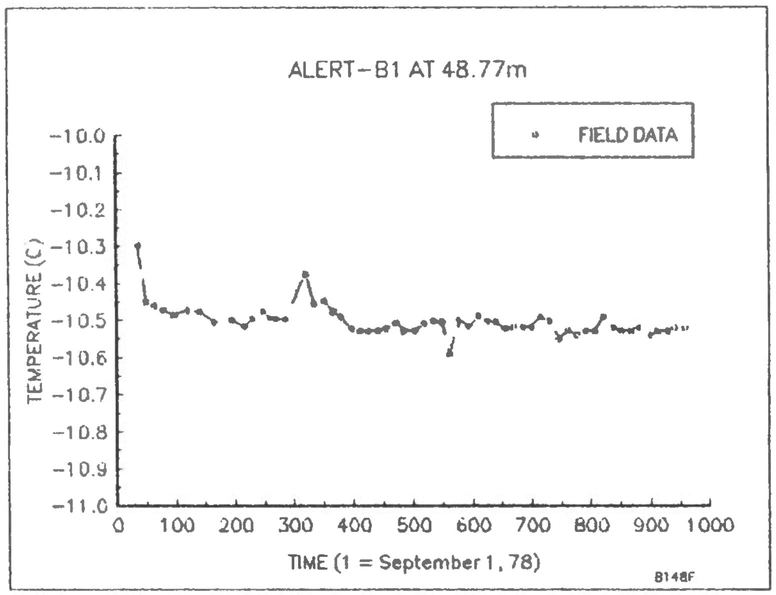
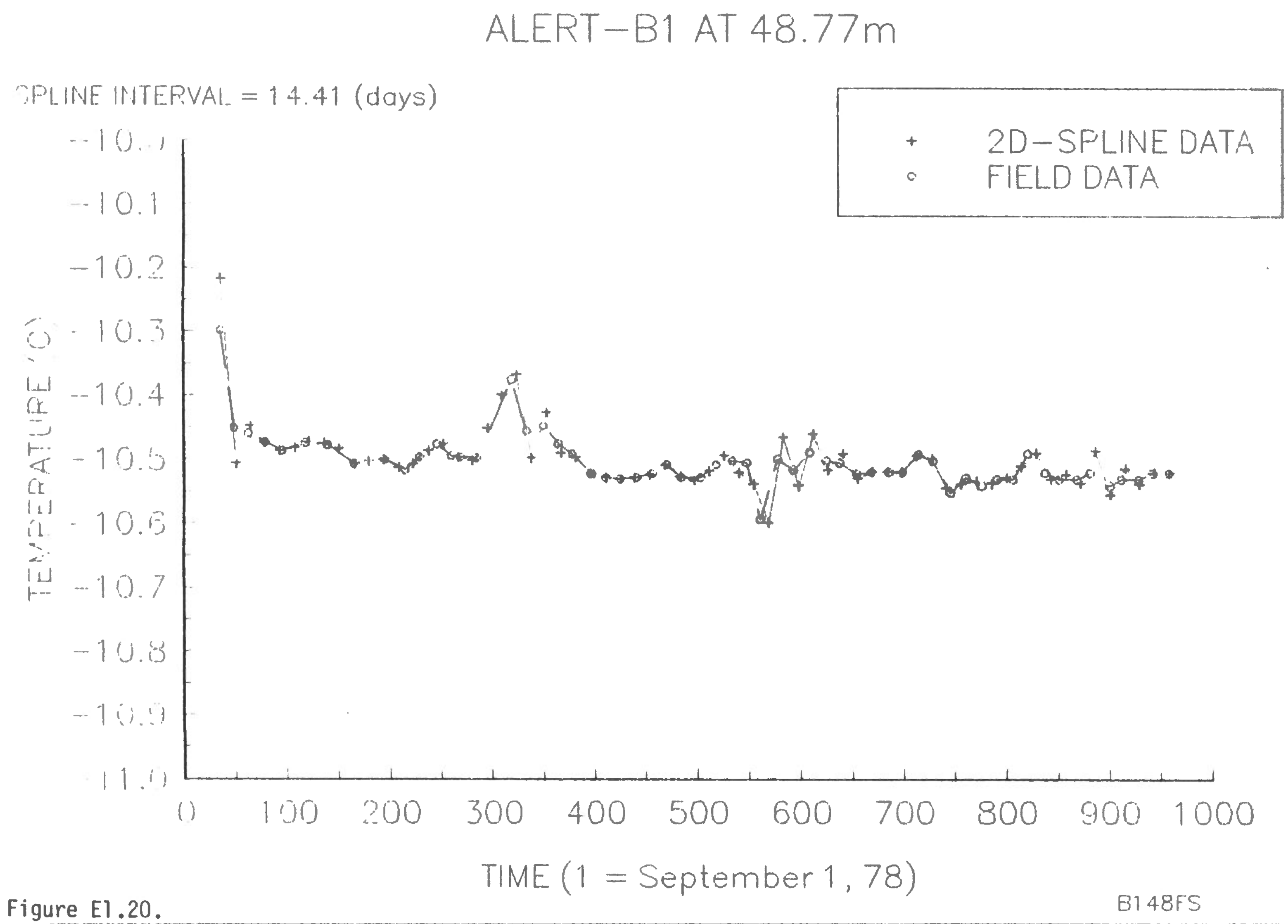
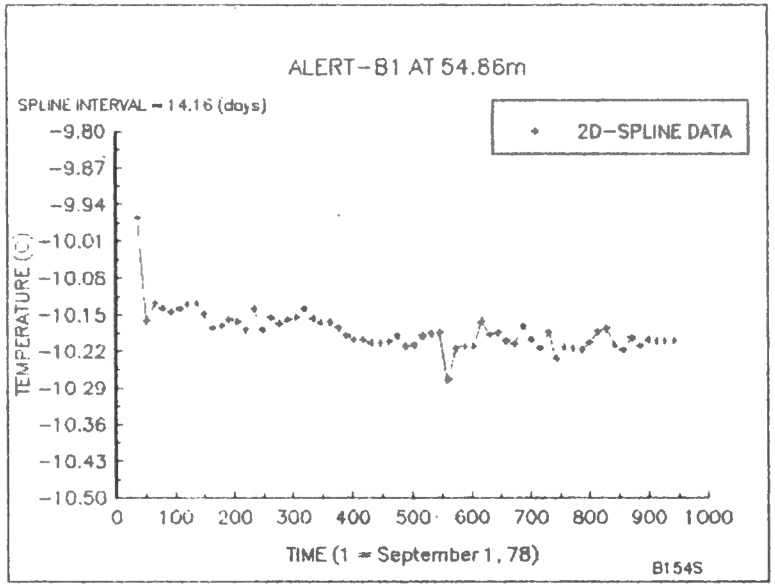


Figure E1.19.

B1482F


ALERT–B1 AT 48.77m
SPLINE INTERVAL = 14.41 (days)
+ 2D–SPLINE DATA
○ FIELD DATA
TEMPERATURE (C)
-10.1
-10.2
-10.3
-10.4
-10.5
-10.6
-10.7
-10.8
0
100
200
300
400
500
600
700
800
900
1000
TIME (1 = September 1, 78)
B148FS
Figure E1.20.



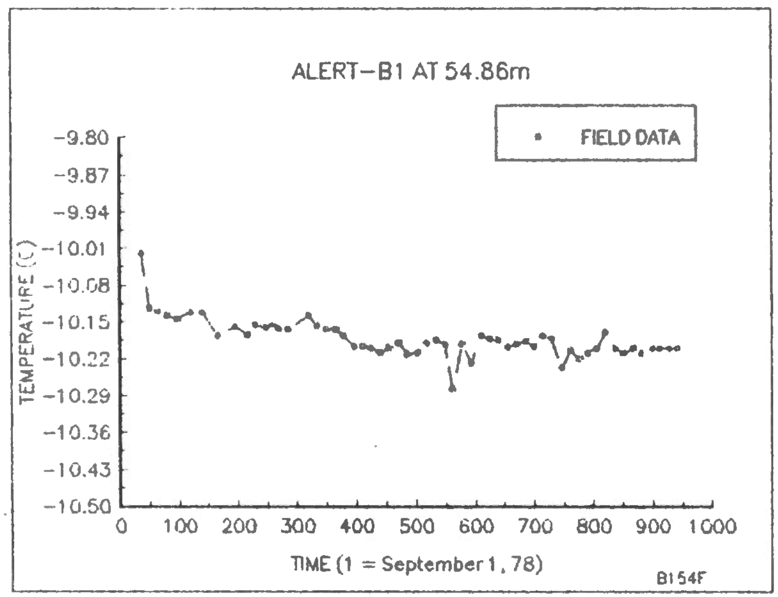


Figure E1.21.

B1542F

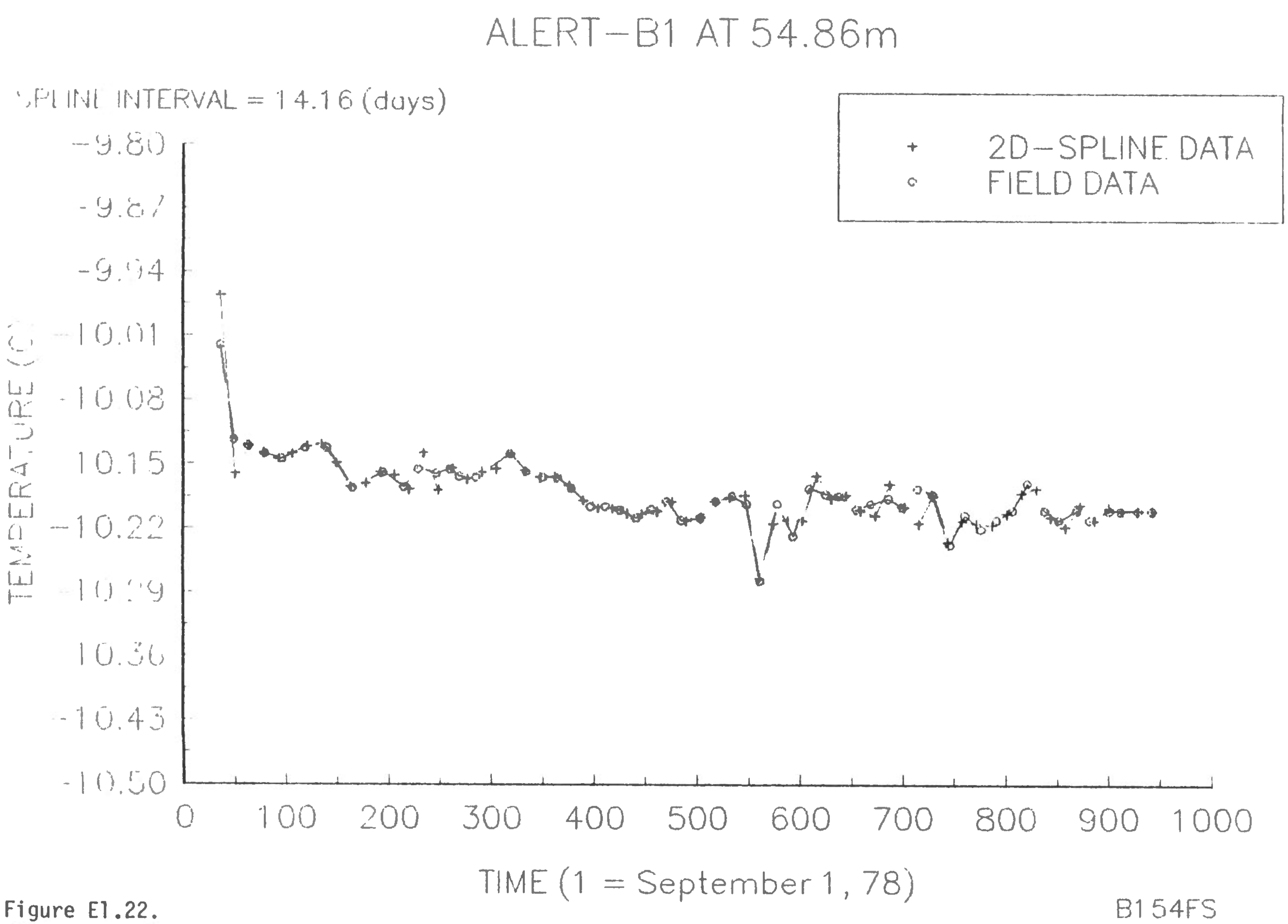
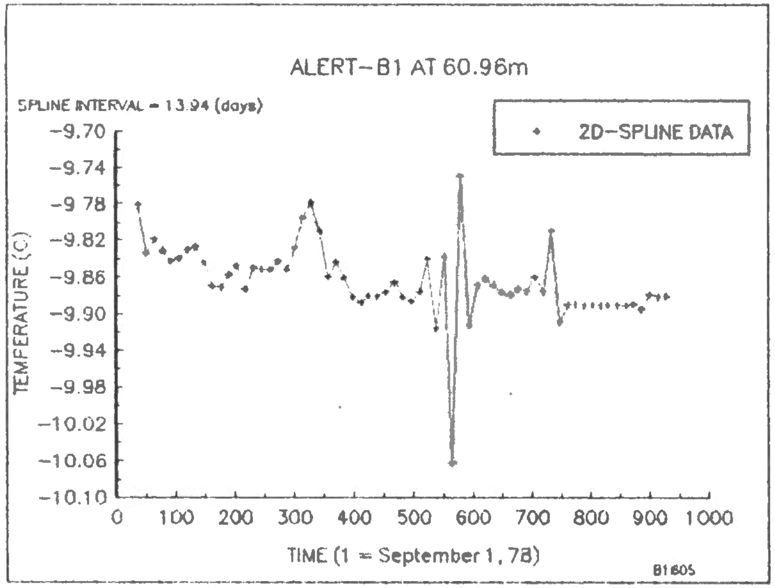

ALERT–B1 AT 54.86m
SPLINE INTERVAL = 14.16 (days)
+ 2D–SPLINE DATA
○ FIELD DATA
TEMPERATURE (C)
-9.80
-9.87
-9.94
-10.01
-10.08
-10.15
-10.22
-10.29
-10.36
-10.43
-10.50
0
100
200
300
400
500
600
700
800
900
1000
TIME (1 = September 1, 78)
B154FS

Figure E1.22.



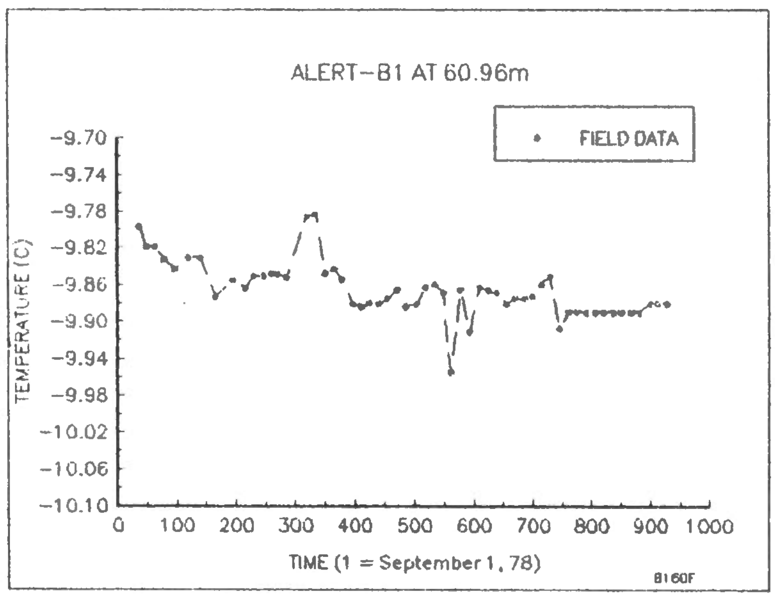


Figure E1.23.

B1 602F

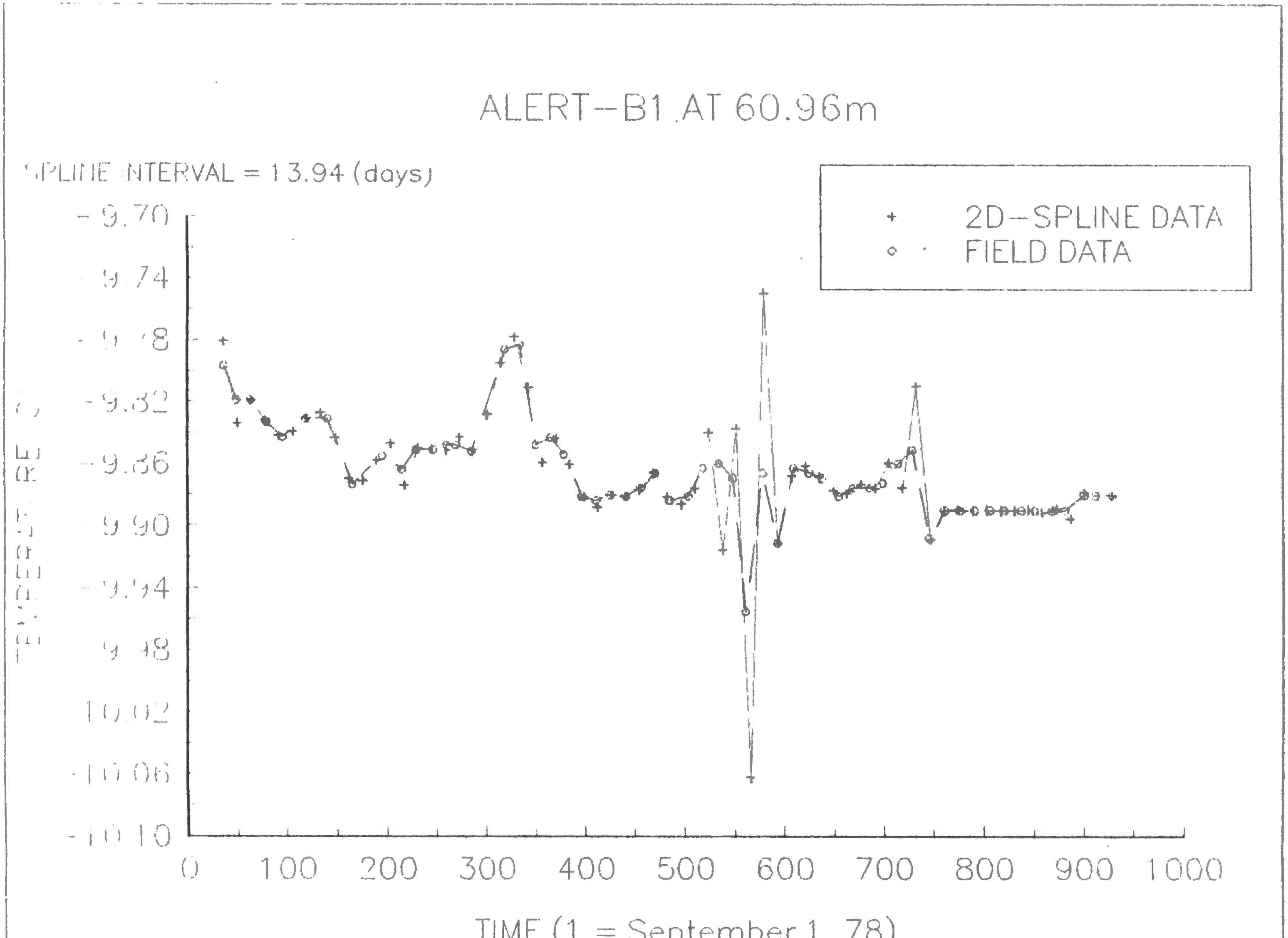
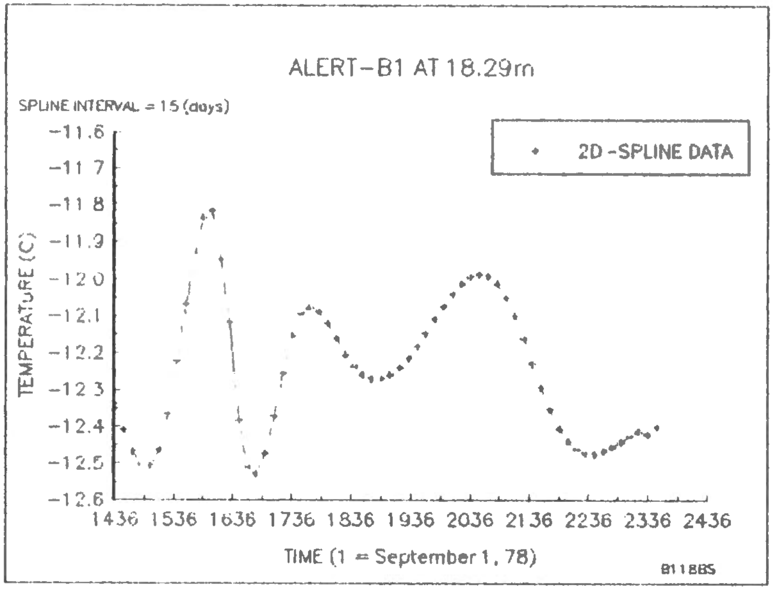

ALERT-B1 AT 60.96m
SPLINE INTERVAL = 13.94 (days)
2D-SPLINE DATA
FIELD DATA
-9.70
-9.74
-9.78
-9.82
-9.86
-9.90
-9.94
-9.98
-10.02
-10.06
-10.10
0
100
200
300
400
500
600
700
800
900
1000
TIME (1 = September 1, 78)
B160FS

Figure E1.24.

APPENDIX E2



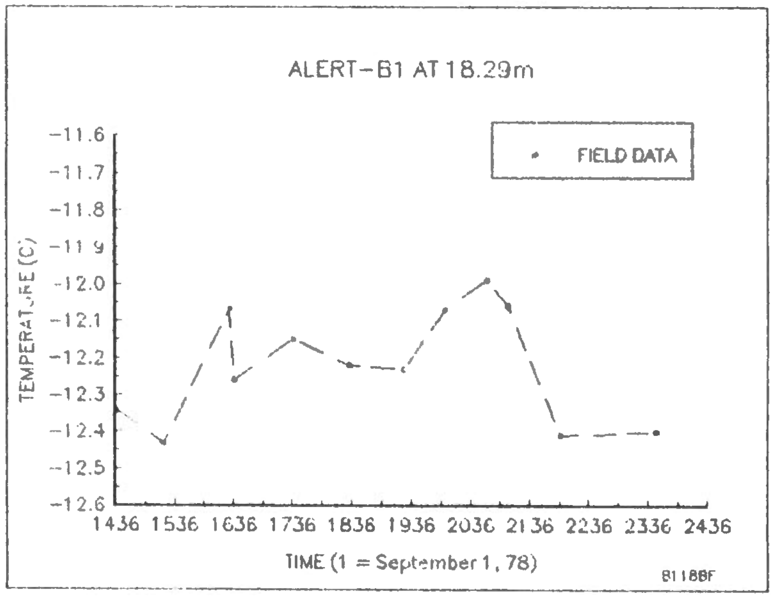


Figure E2.1.

B118B?F

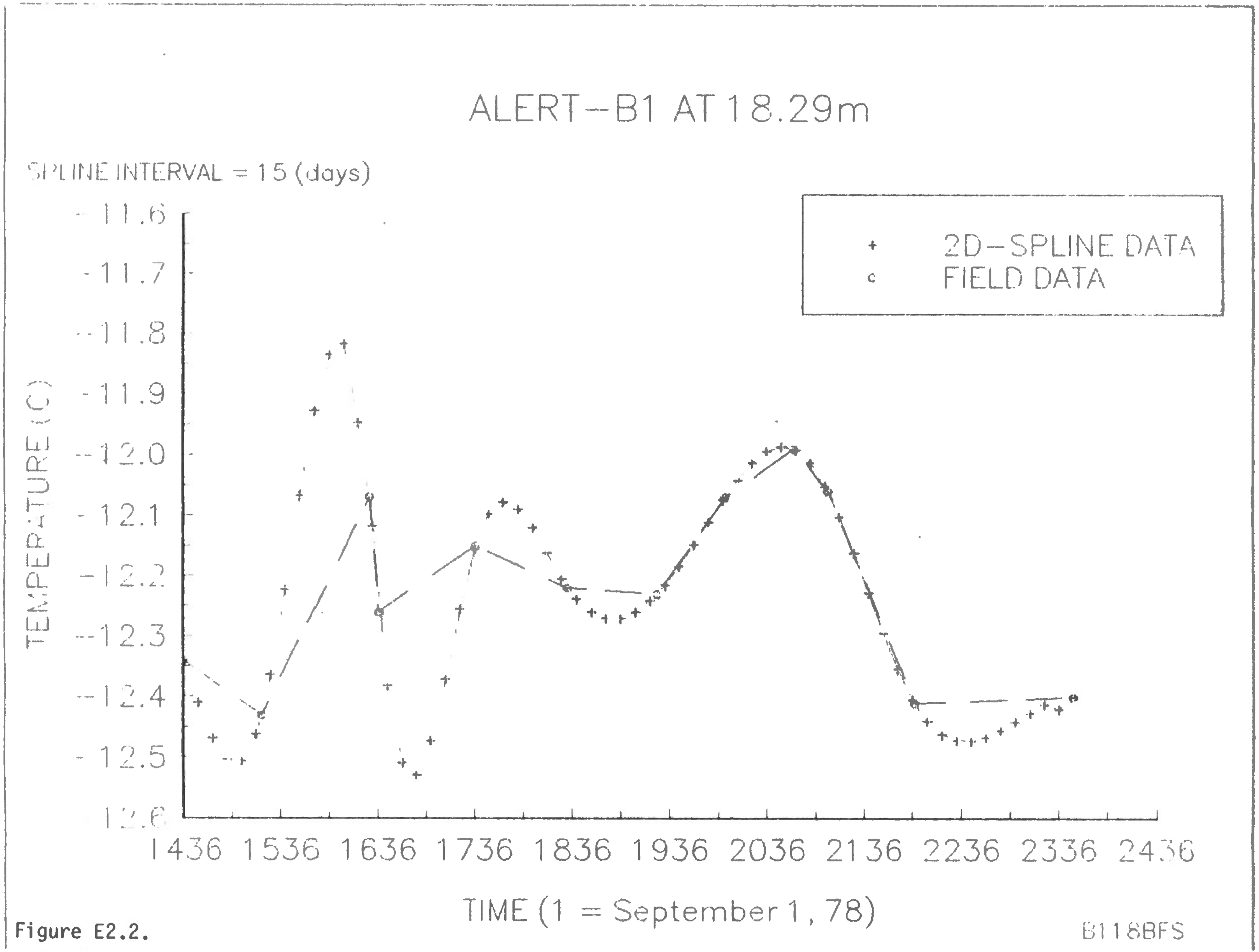

ALERT-B1 AT 18.29m
SPLINE INTERVAL = 15 (days)
2D-SPLINE DATA
FIELD DATA
TEMPERATURE (C)
-11.6
-11.7
-11.8
-11.9
-12.0
-12.1
-12.2
-12.3
-12.4
-12.5
-12.6
1436
1536
1636
1736
1836
1936
2036
2136
2236
2336
2436
TIME (1 = September 1, 78)
B118BFS

Figure E2.2.

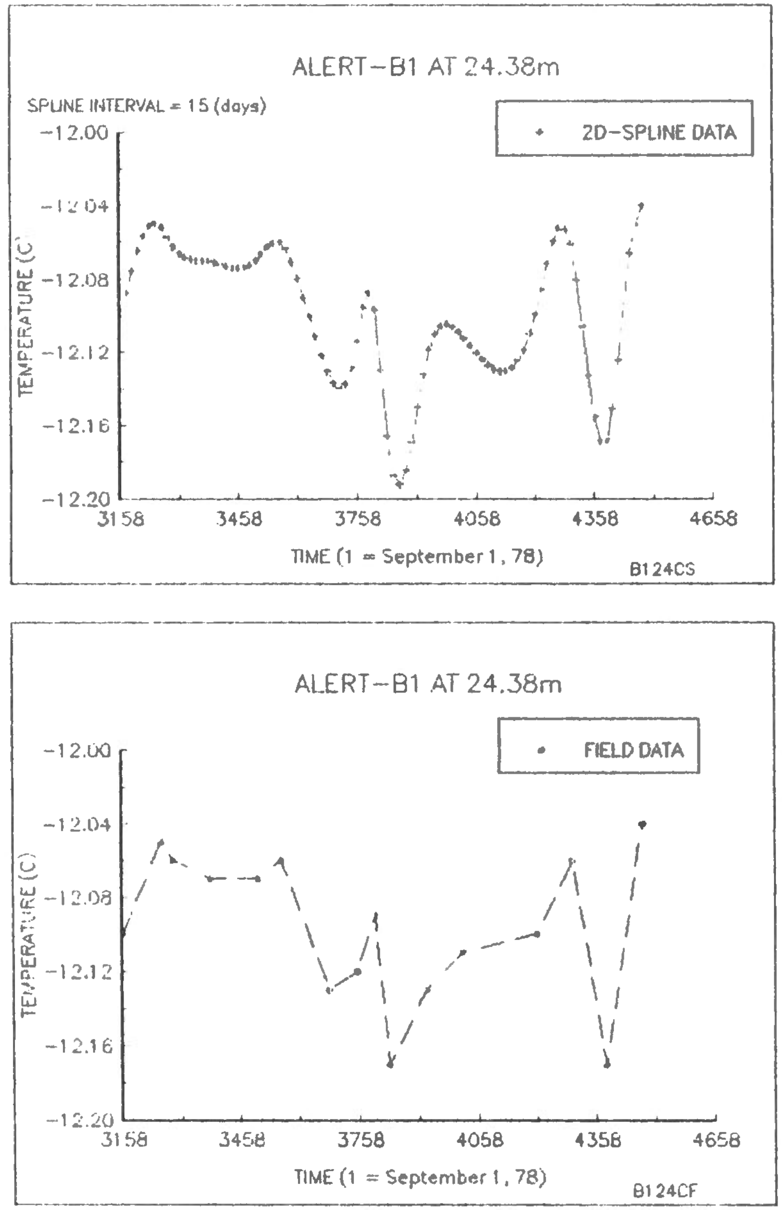


Figure E2.3.

B124C2F

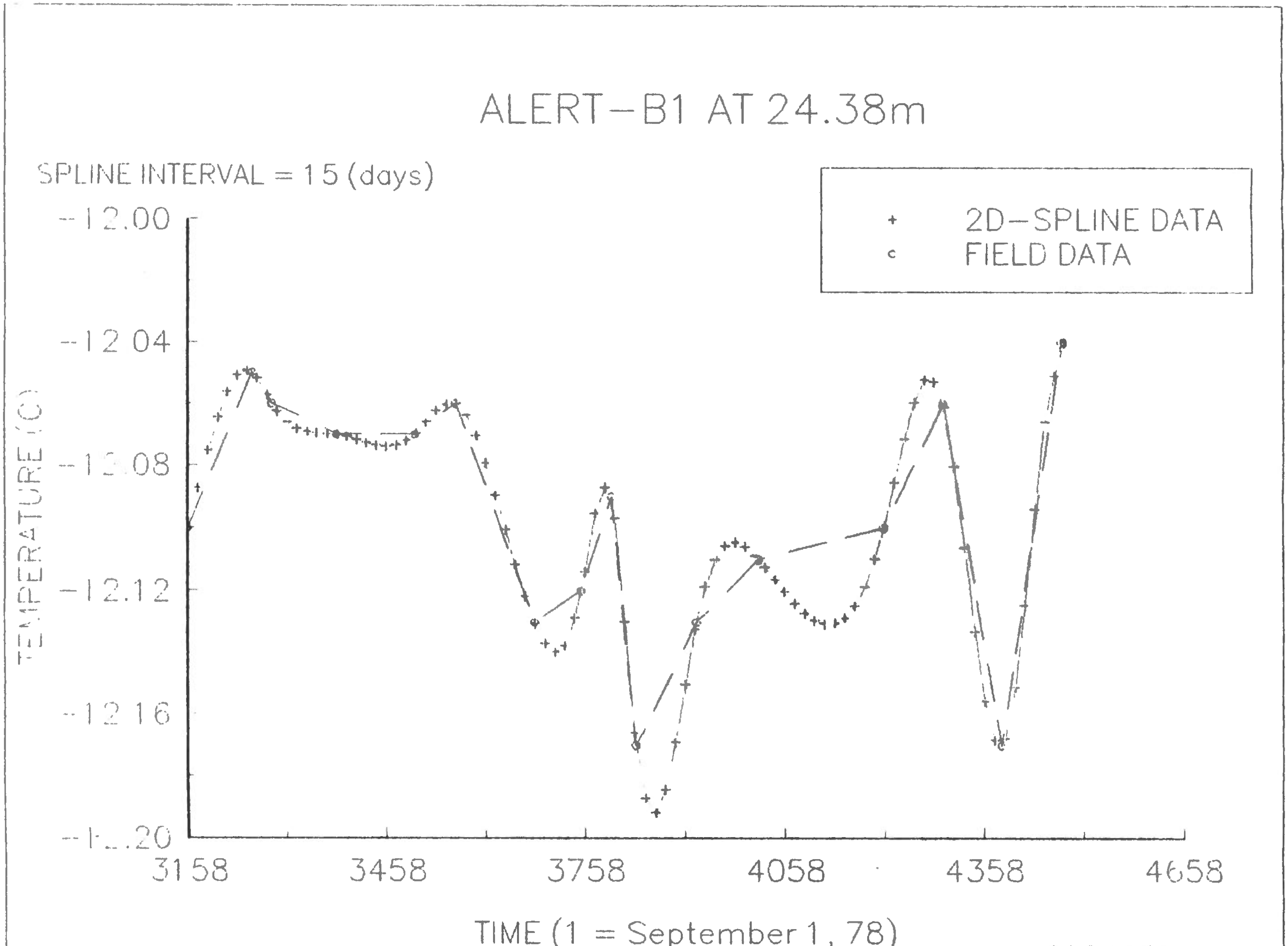
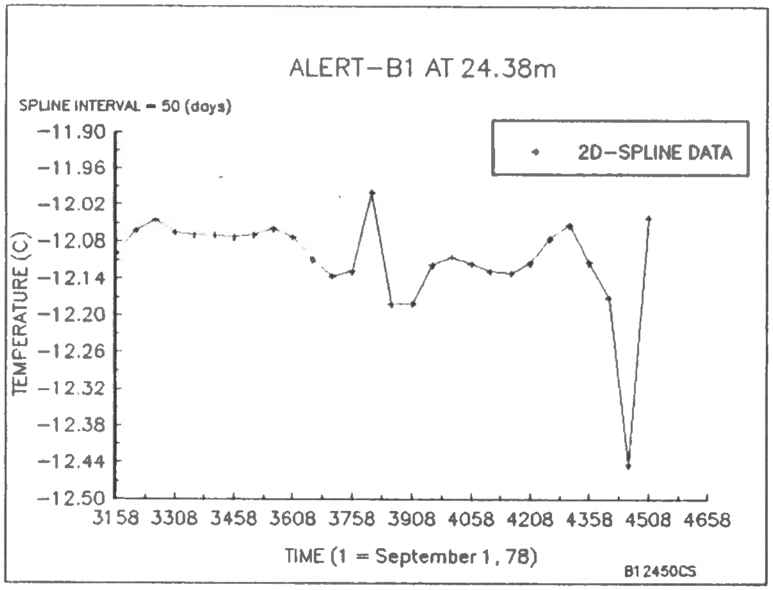

ALERT-B1 AT 24.38m
SPLINE INTERVAL = 15 (days)
+ 2D-SPLINE DATA
c FIELD DATA
-12.00
-12.04
-12.08
-12.12
-12.16
-12.20
TEMPERATURE (C)
3158
3458
3758
4058
4358
4658
TIME (1 = September 1, 78)
B124CFS

Figure E2.4.



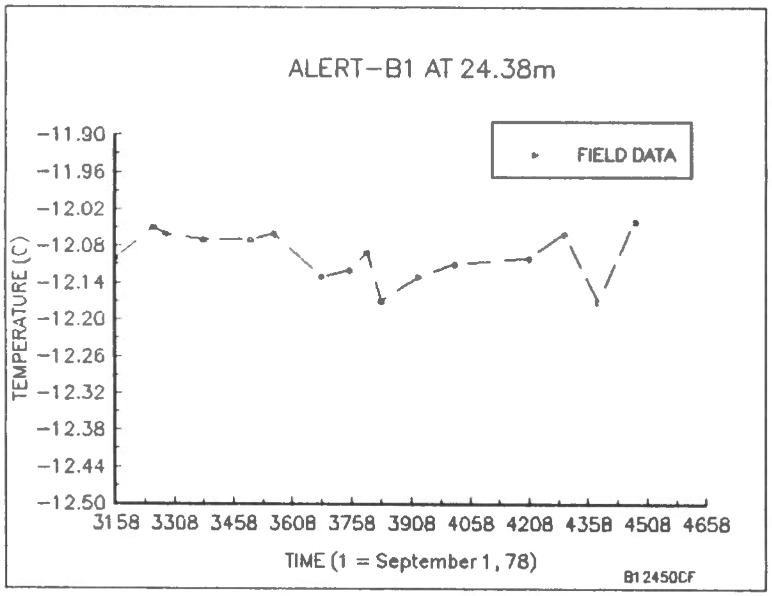
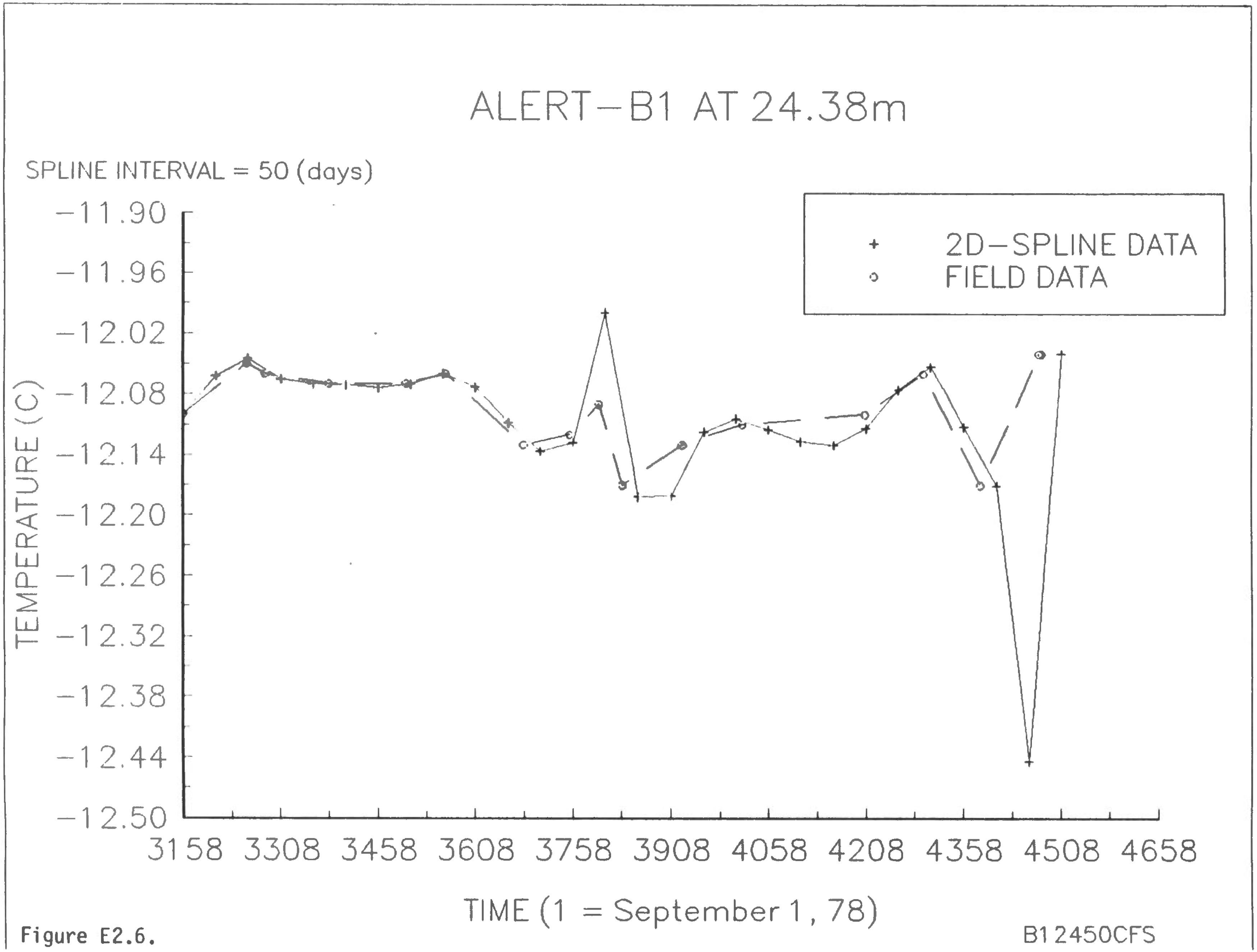


Figure E2.5.

B124C502F



ALERT−B1 AT 24.38m
SPLINE INTERVAL = 50 (days)
+ 2D−SPLINE DATA
○ FIELD DATA
−11.90
−11.96
−12.02
−12.08
−12.14
−12.20
−12.26
−12.32
−12.38
−12.44
−12.50
TEMPERATURE (C)
3158
3308
3458
3608
3758
3908
4058
4208
4358
4508
4658
TIME (1 = September 1, 78)
B12450CFS

Figure E2.6.

APPENDIX F1

Figures F1.1-F1.11. Cross-correlation of adjacent depths using a package produced by A Plus*Ware Product called Statsgraphics. A sample data table is provided with Figure F1.1 only.

APPENDIX F2

Figures F2.1-F2.6. Layout similar to above. Cross-correlation of depth 1.52m to successive depths.

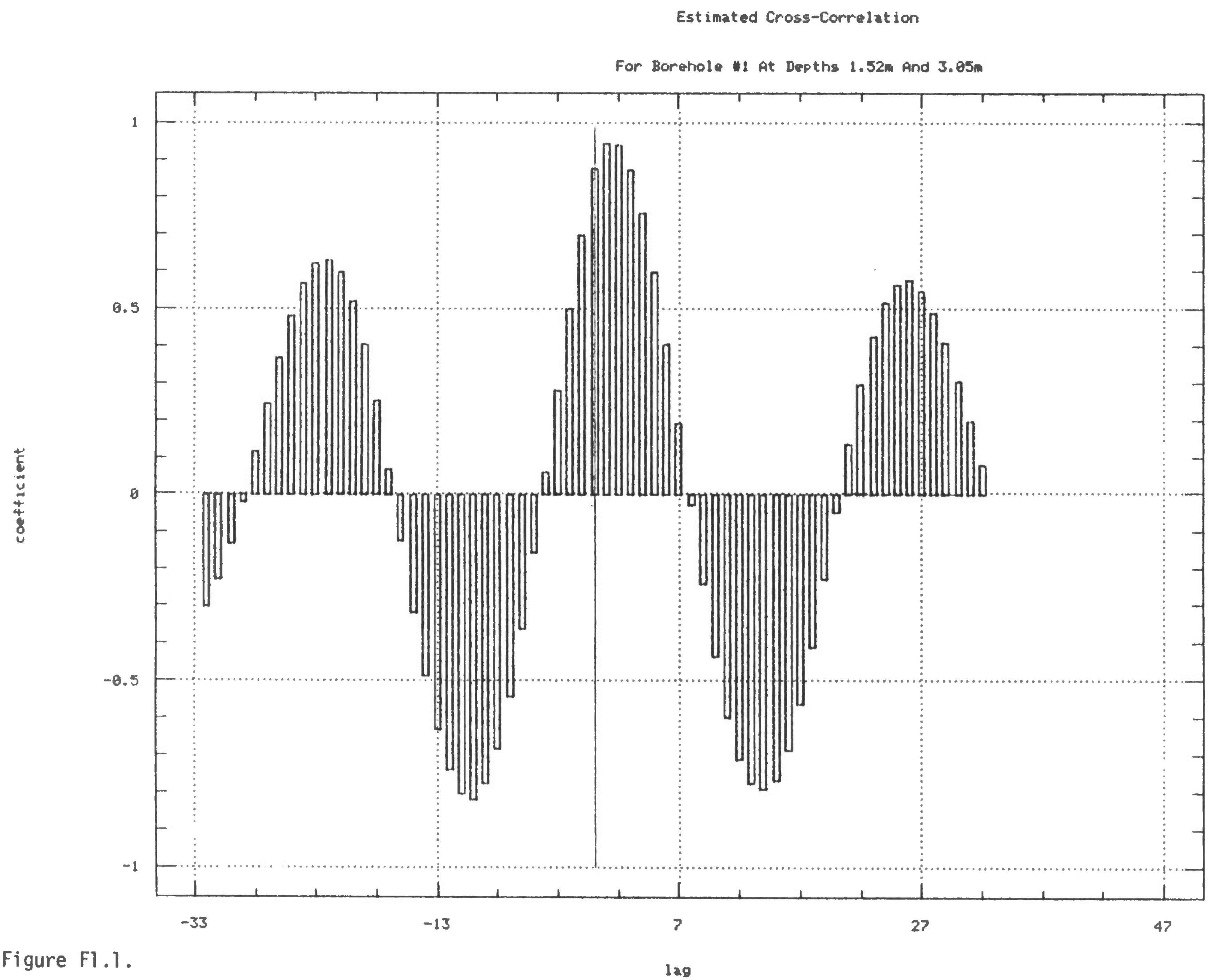

Estimated Cross-Correlation
For Borehole #1 At Depths 1.52m And 3.05m
1
0.5
0
-0.5
-1
coefficient
-33
-13
7
27
47
lag

Figure F1.1.

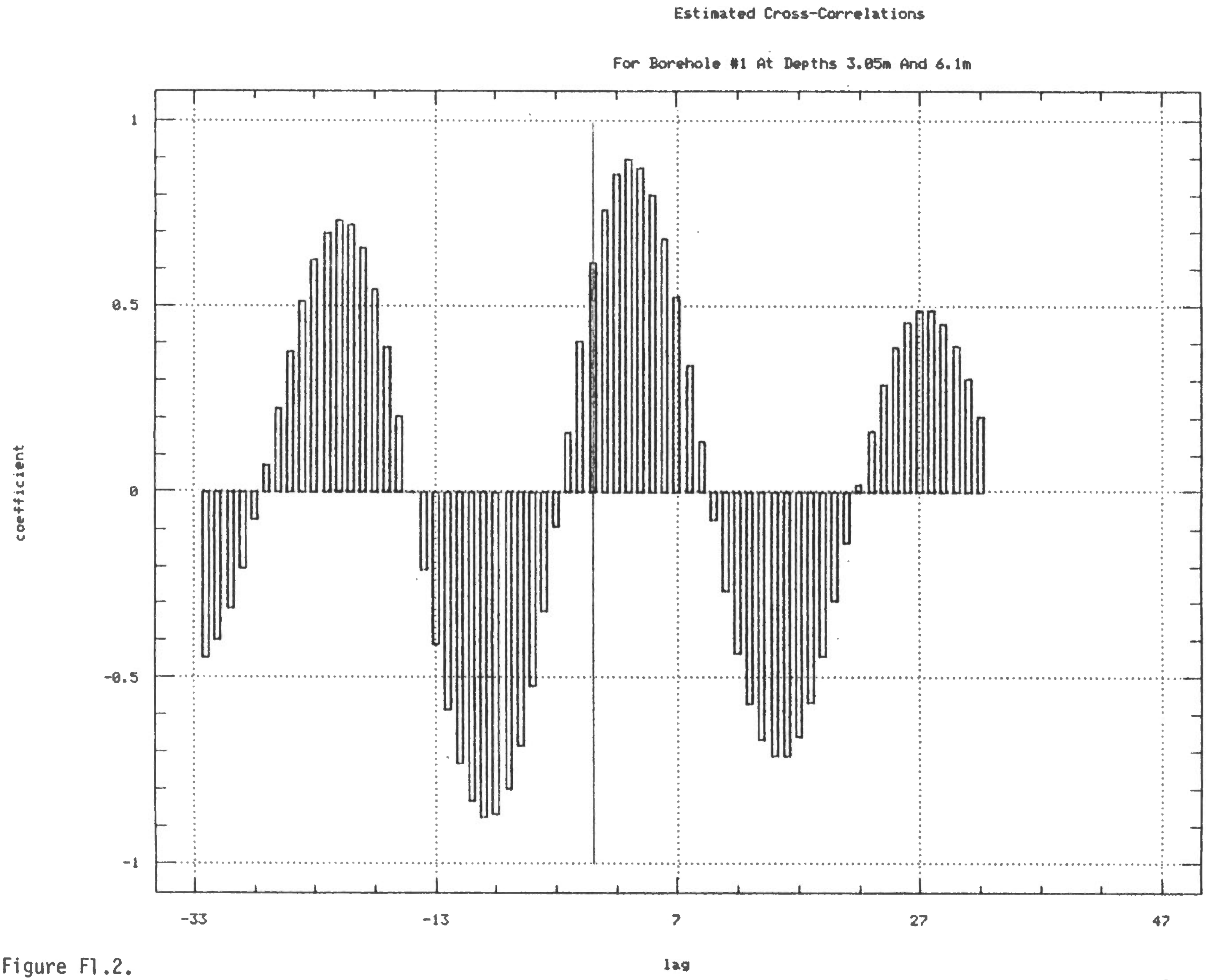


Figure F1.2.

CC36

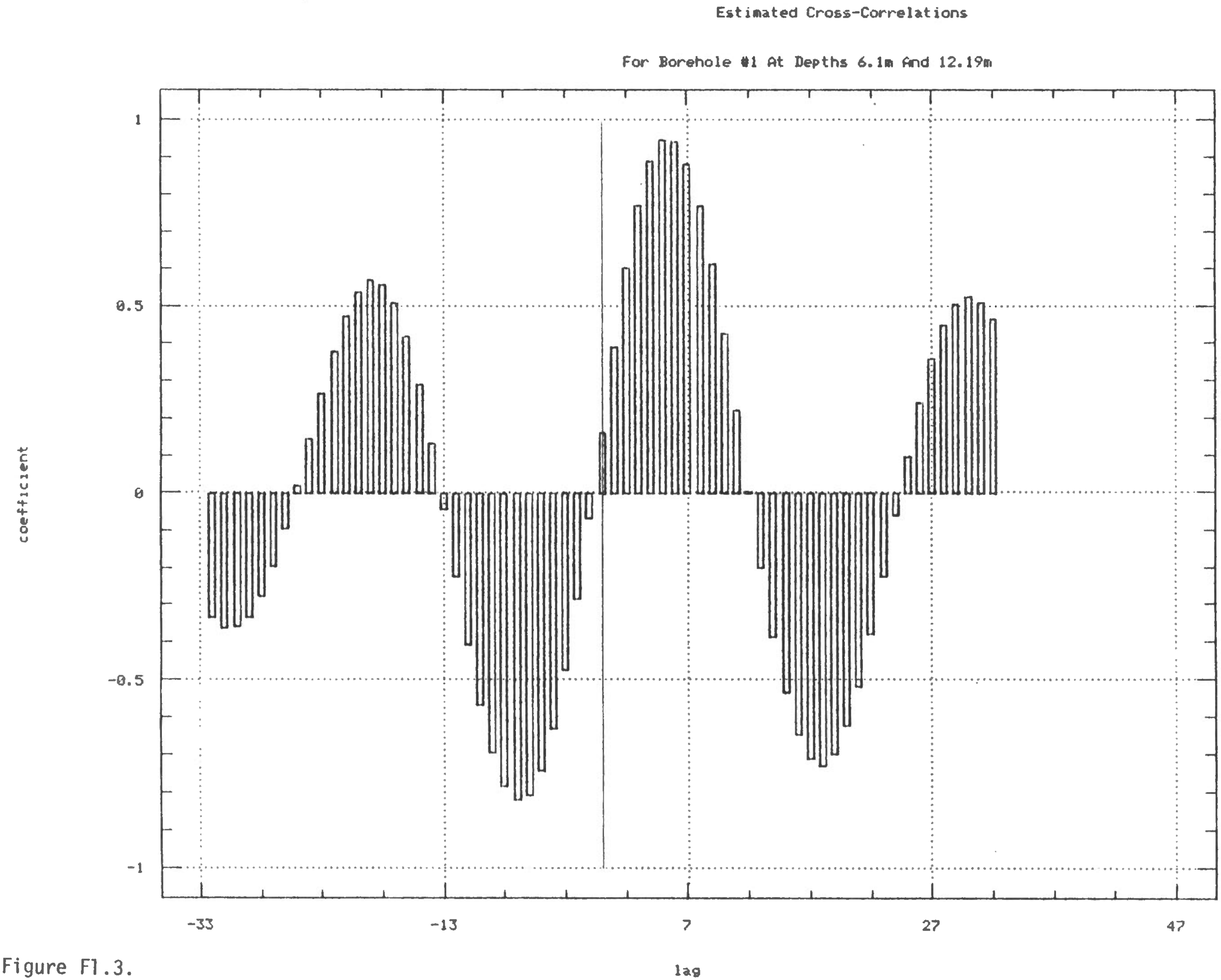

Estimated Cross-Correlations
For Borehole #1 At Depths 6.1m And 12.19m
1
0.5
0
-0.5
-1
coefficient
-33
-13
7
27
47
lag

Figure F1.3.

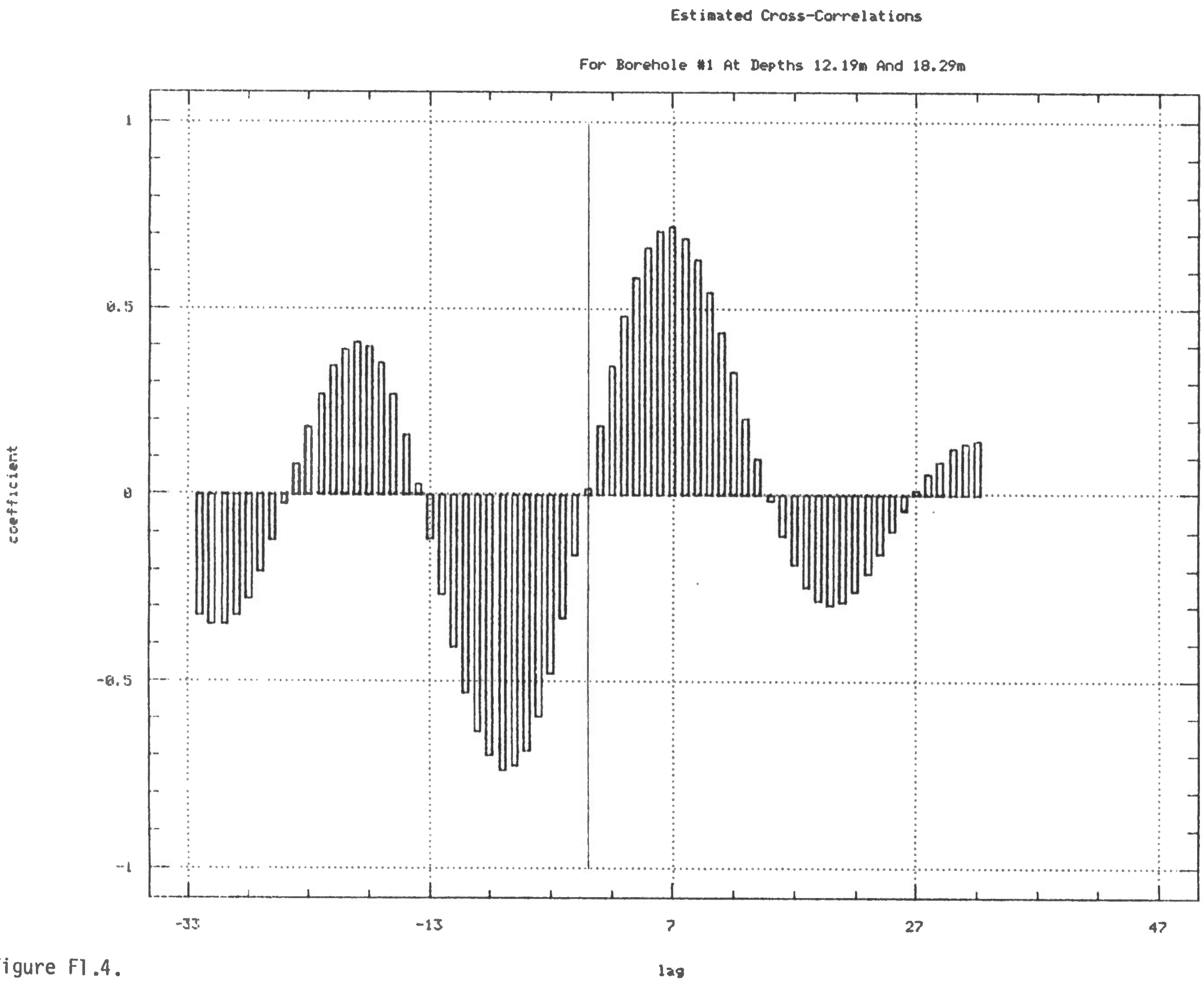

Estimated Cross-Correlations
For Borehole #1 At Depths 12.19m And 18.29m
1
0.5
0
-0.5
-1
coefficient
-33
-13
7
27
47
lag

Figure F1.4.

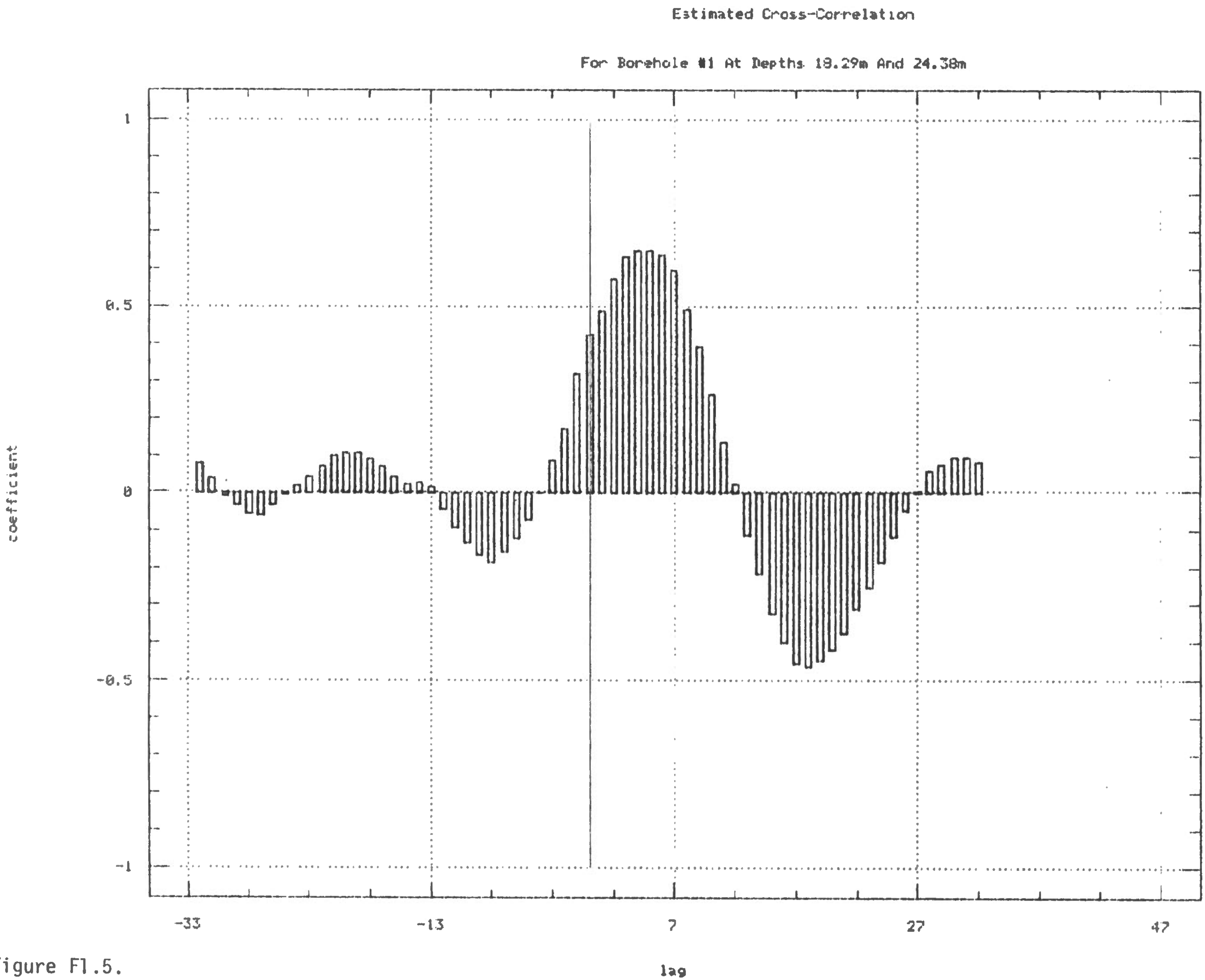

Estimated Cross-Correlation
For Borehole #1 At Depths 18.29m And 24.38m
1
0.5
0
-0.5
-1
coefficient
-33
-13
7
27
47
lag

Figure F1.5.

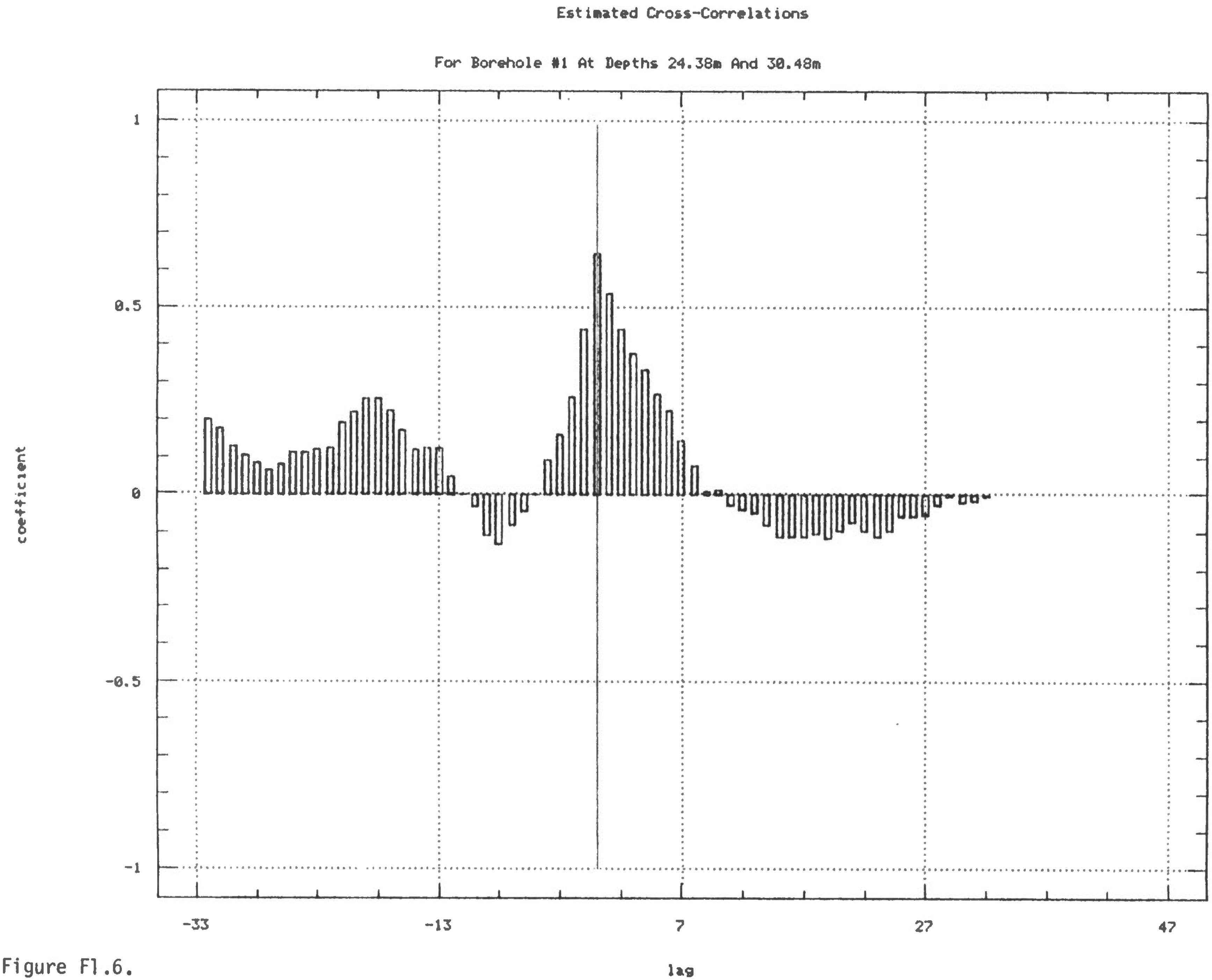


Figure F1.6.

CC2430

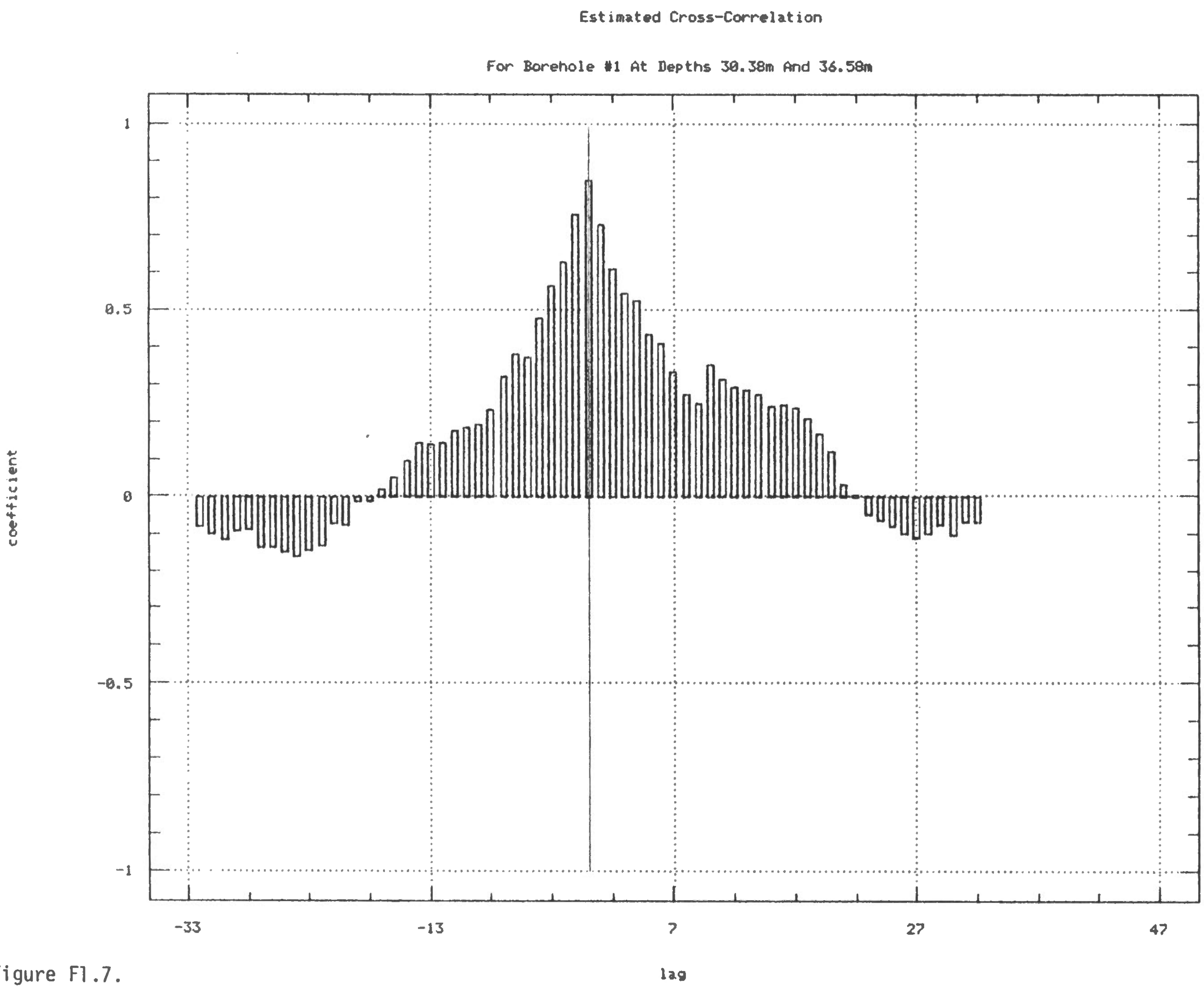


Figure F1.7.

CC303

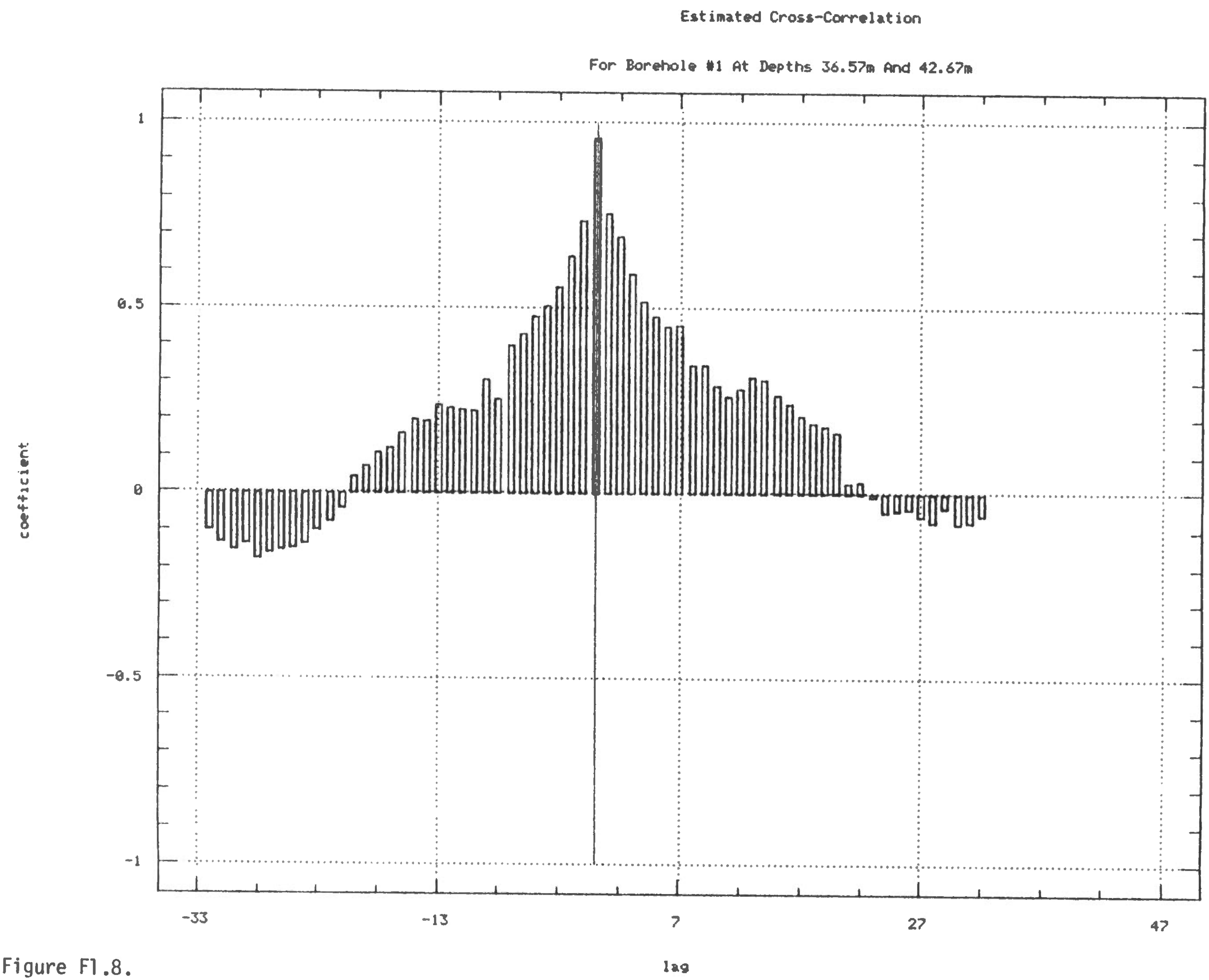


Figure F1.8.

CC364

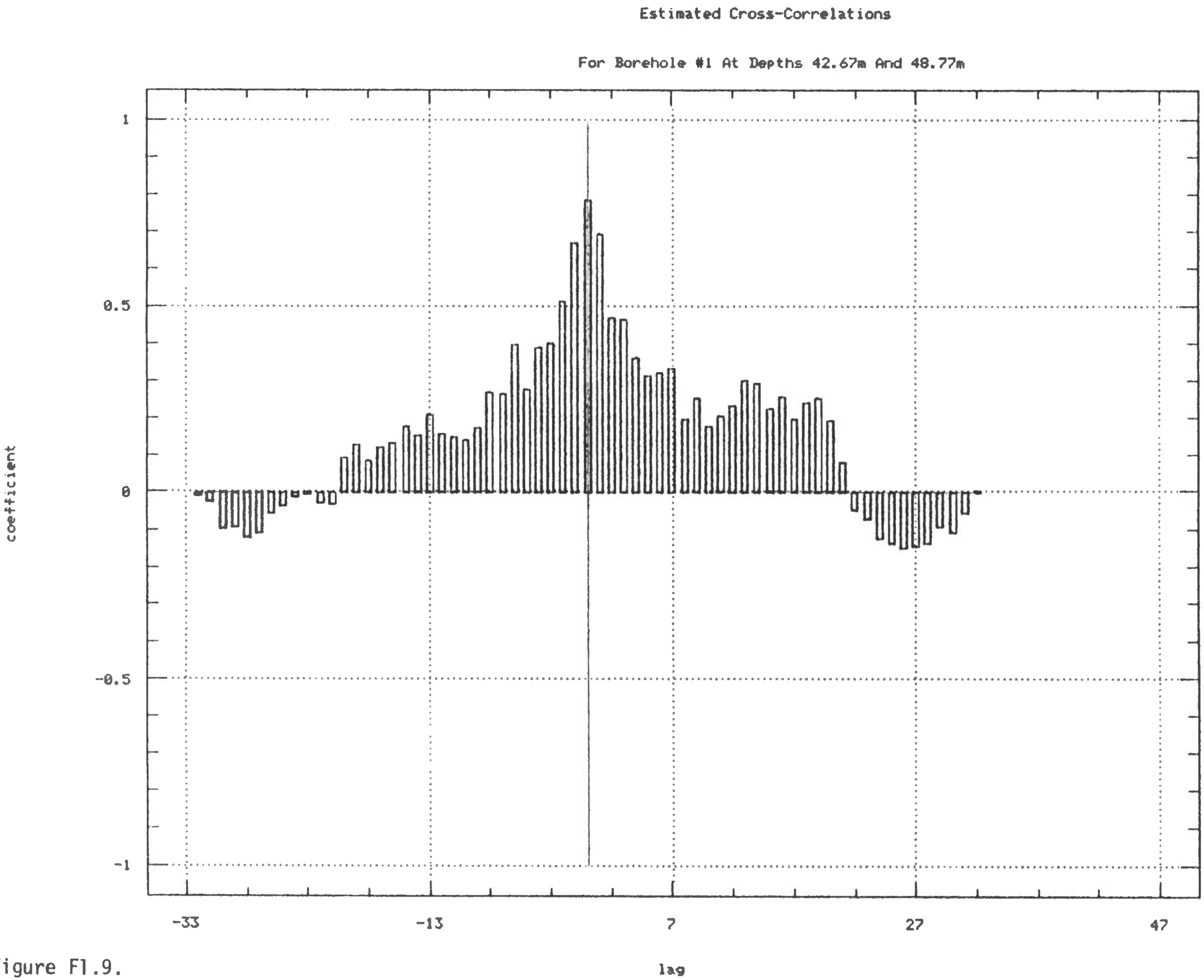


Figure F1.9.

CC424

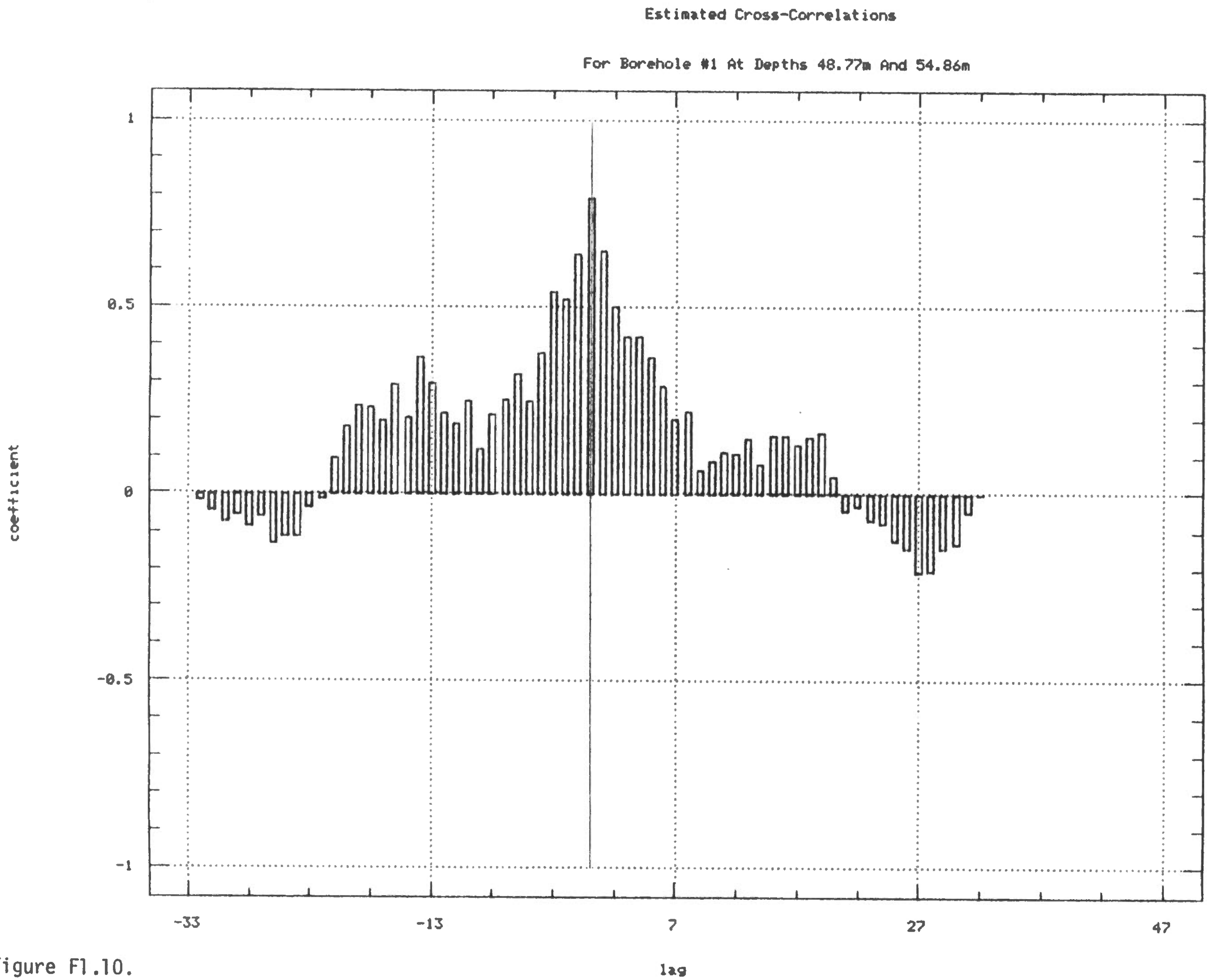


Figure F1.10.

CC485

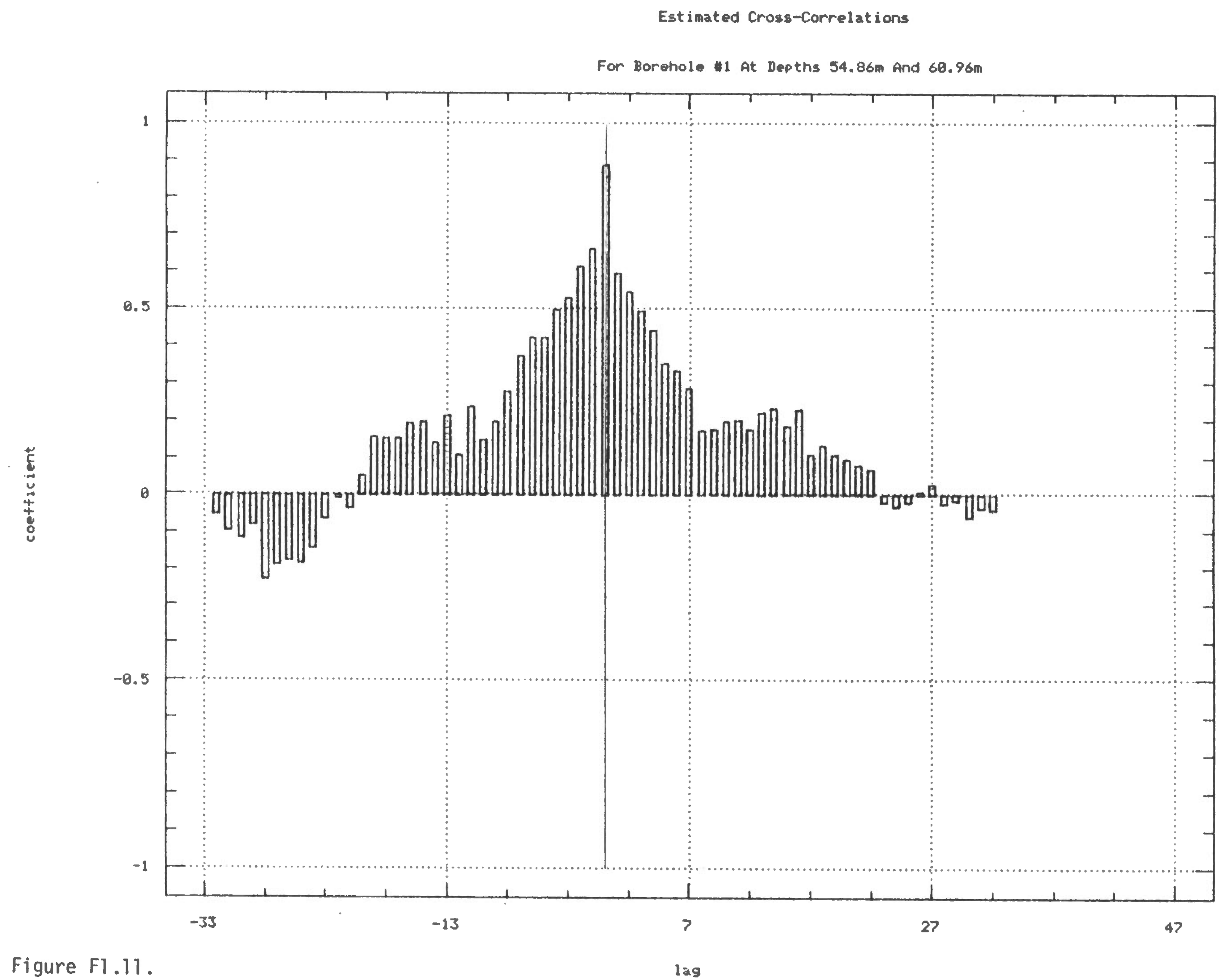
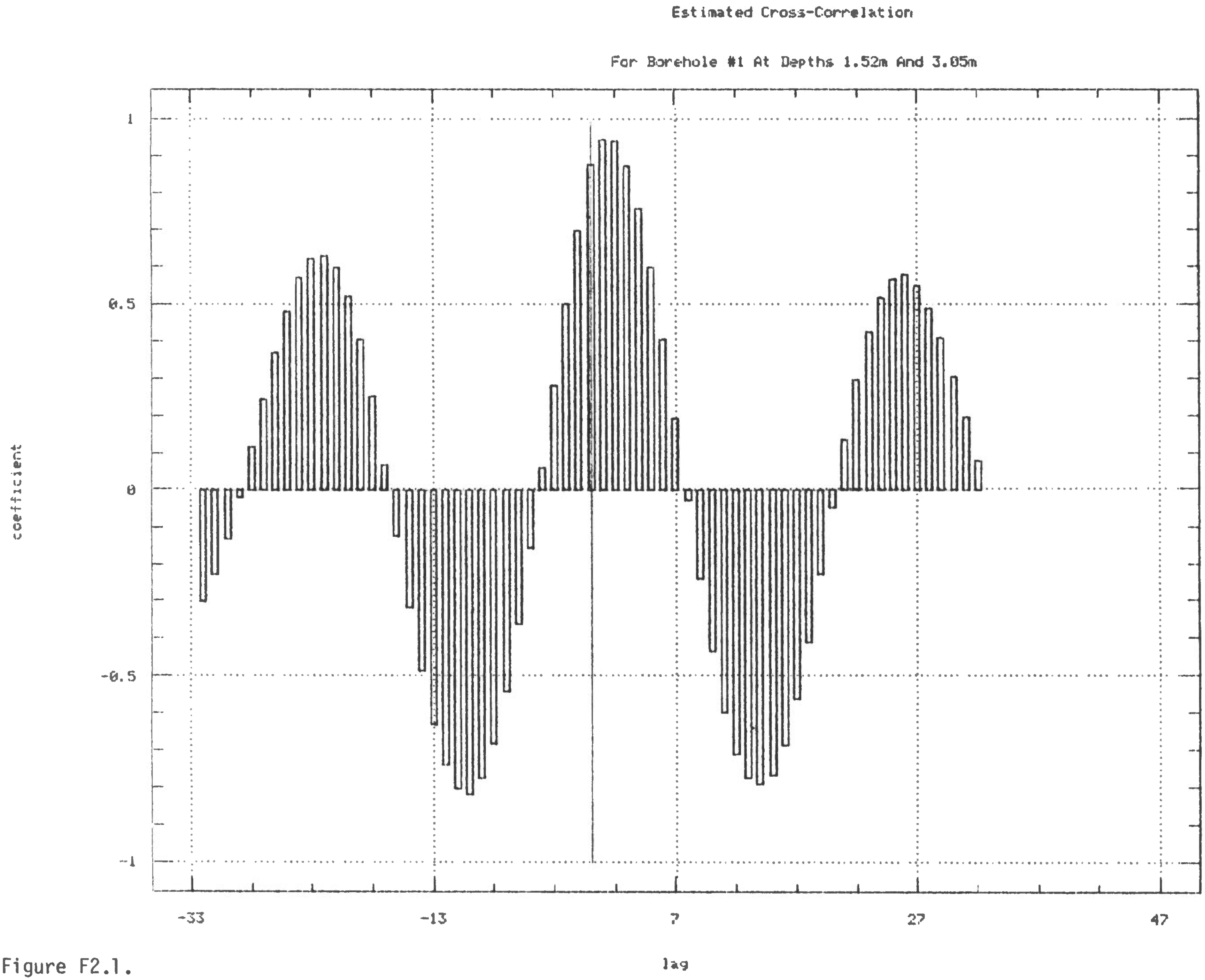


Figure F1.11.

Cr 0

APPENDIX F2



Estimated Cross-Correlation
For Borehole #1 At Depths 1.52m And 3.05m
1
0.5
0
-0.5
-1
coefficient
-33
-13
7
27
47
lag

Figure F2.1.

C

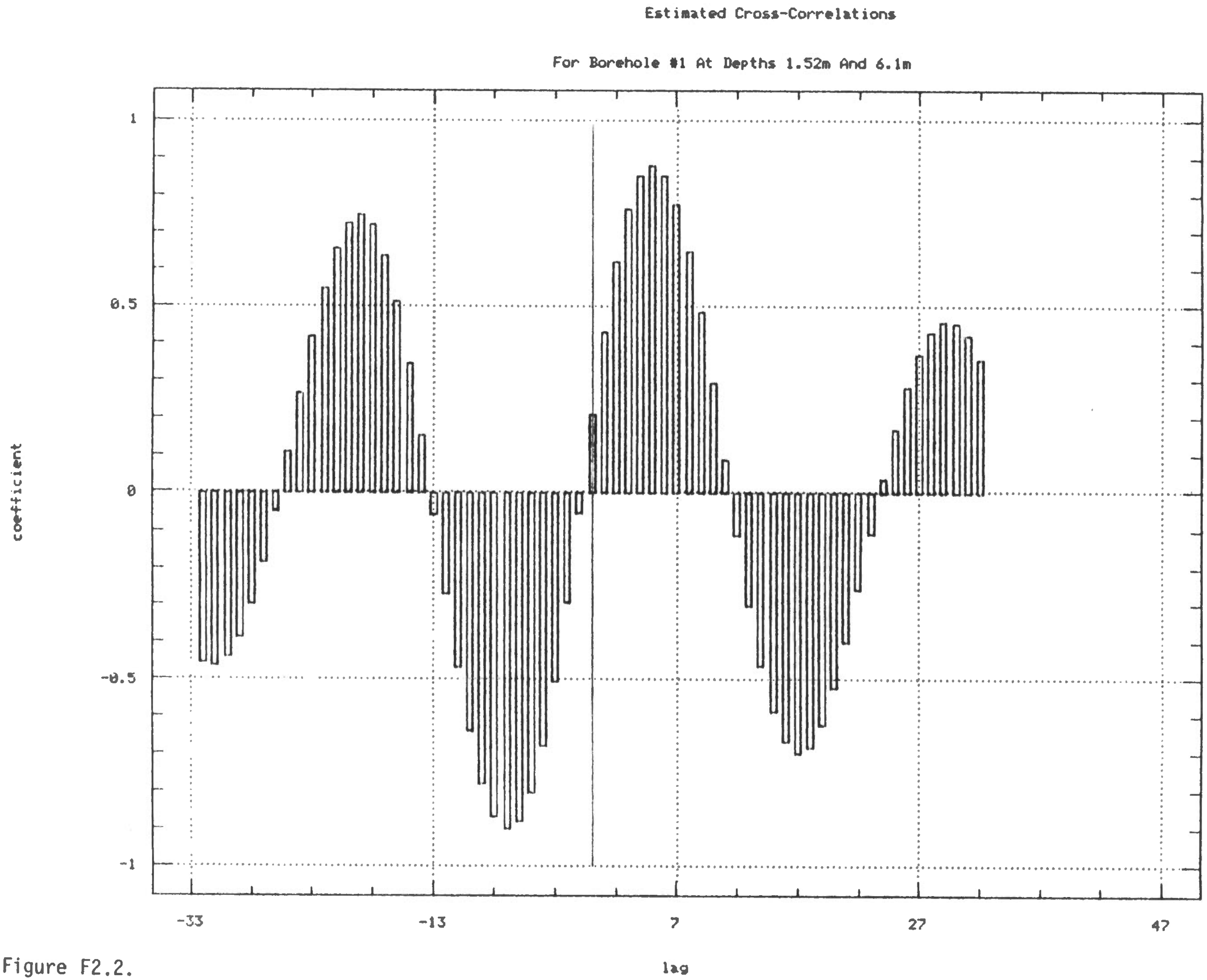


Figure F2.2.

CC16

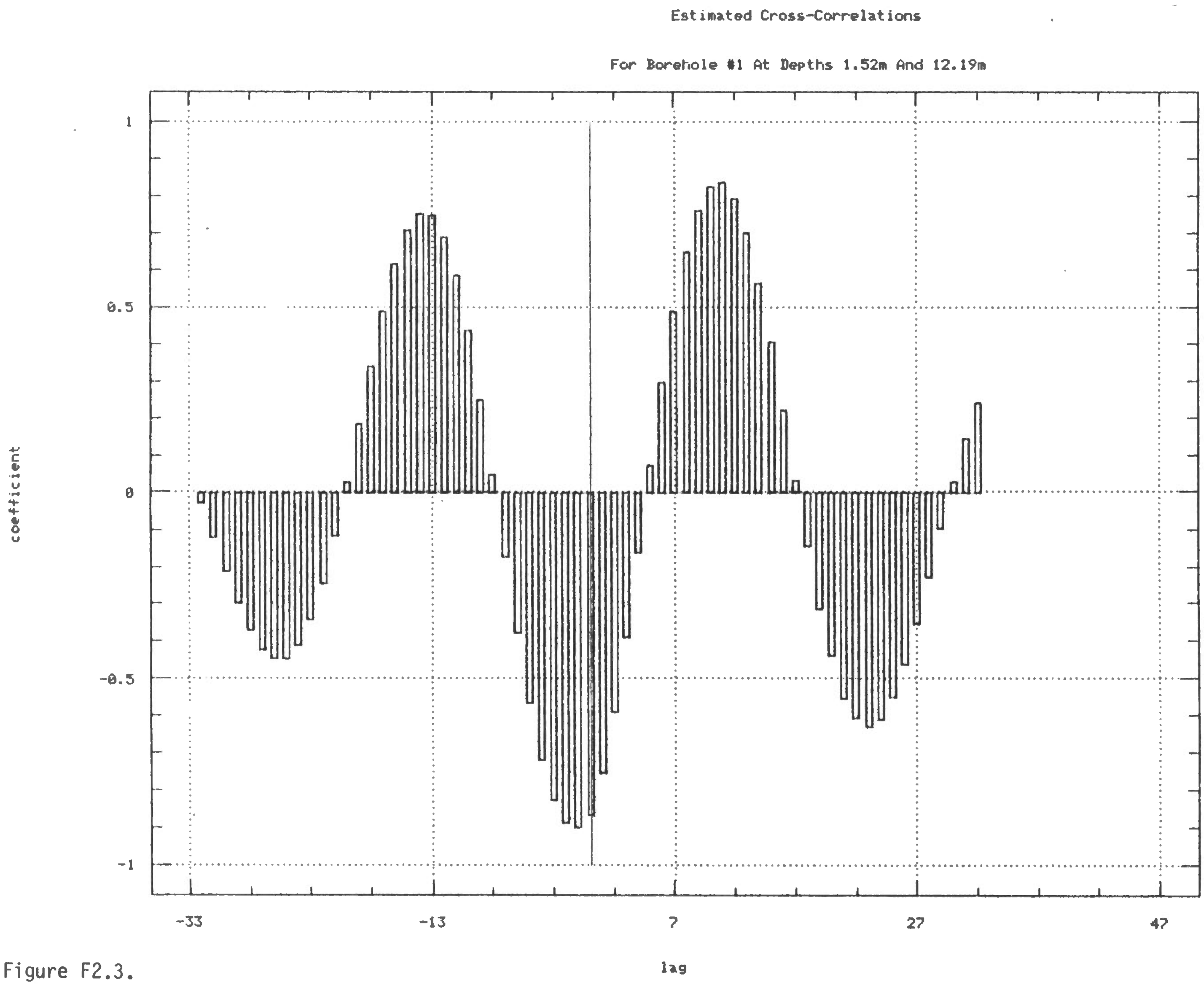


Figure F2.3.

CC

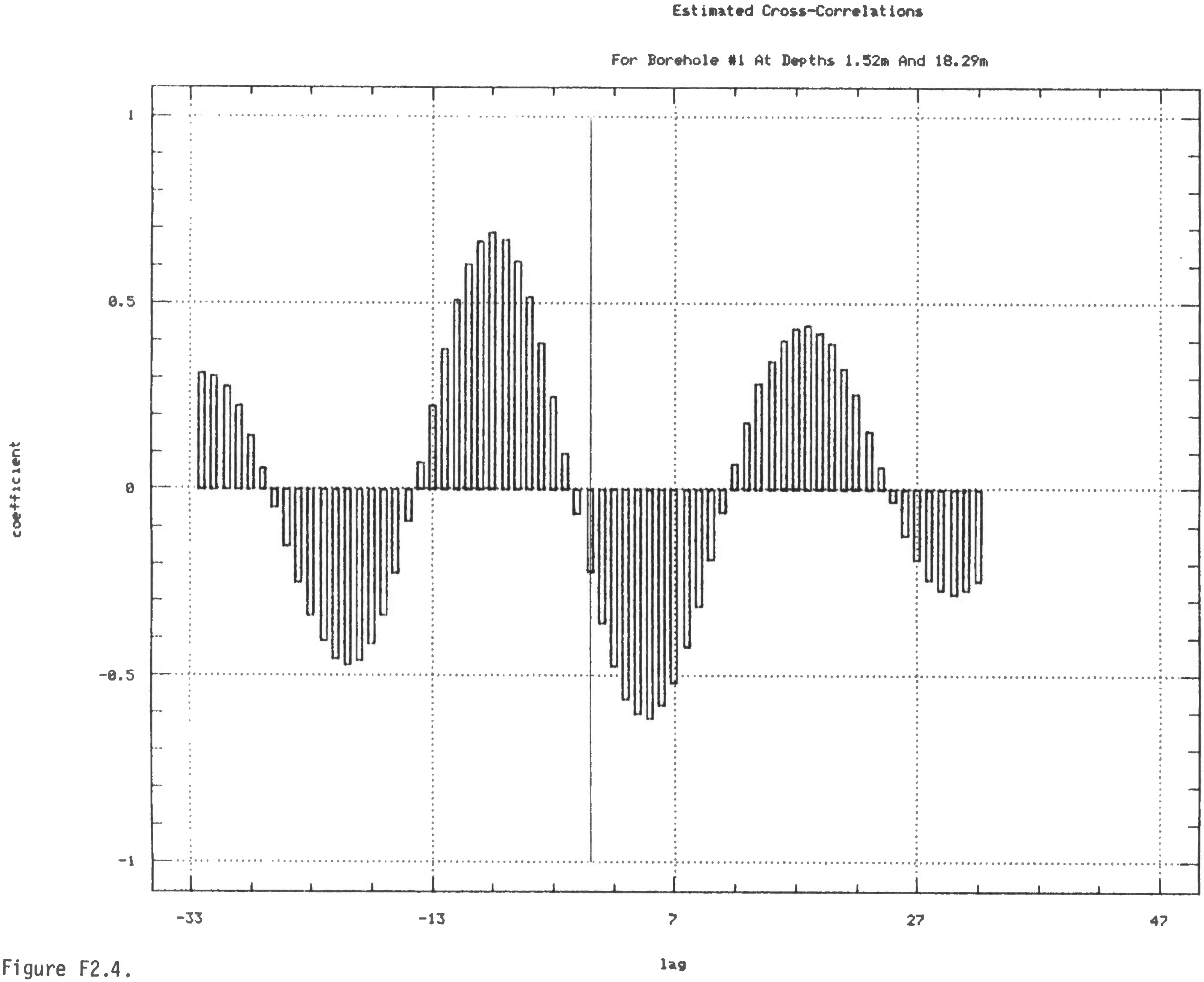


Figure F2.4.

CC

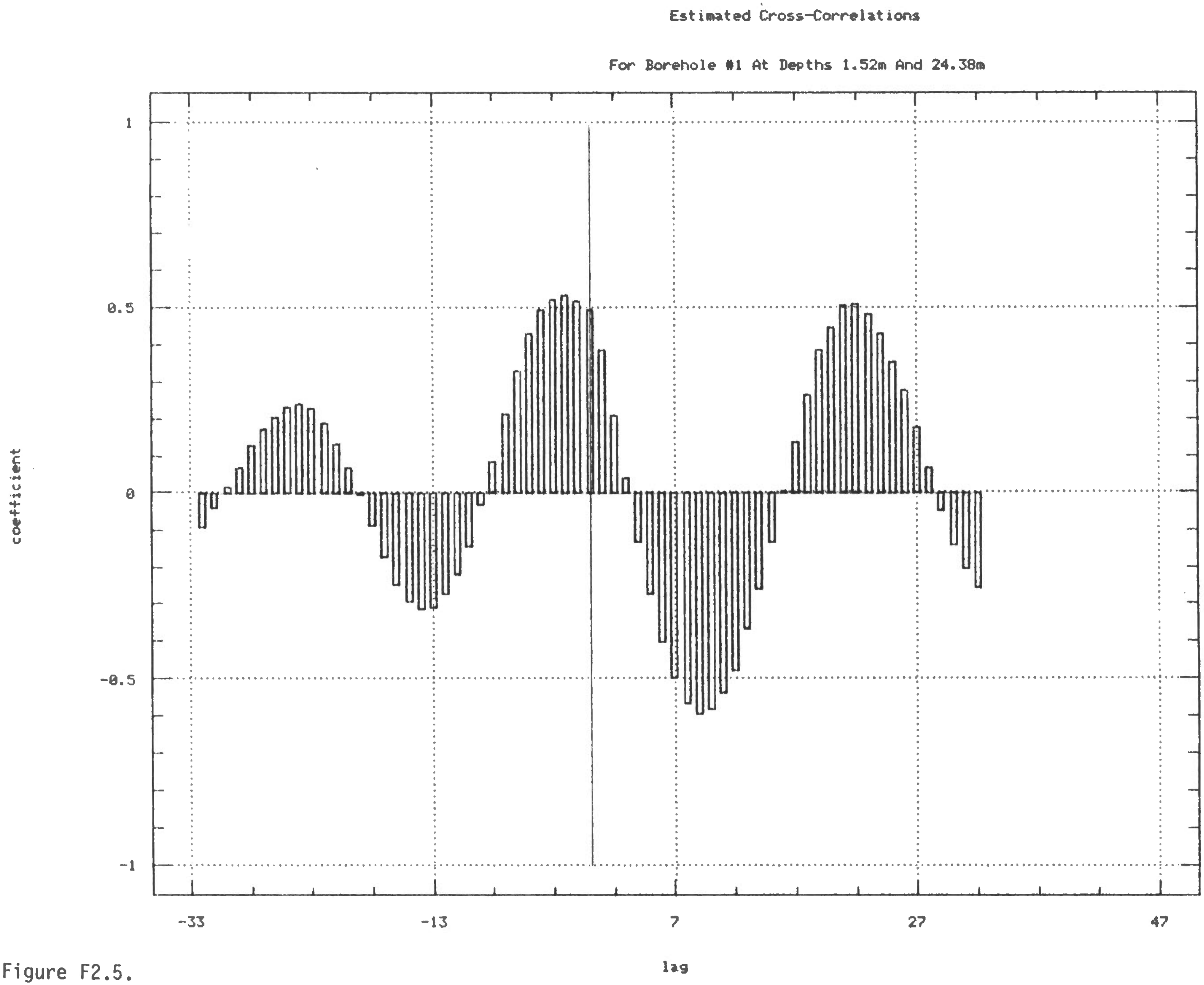


Figure F2.5.

CC

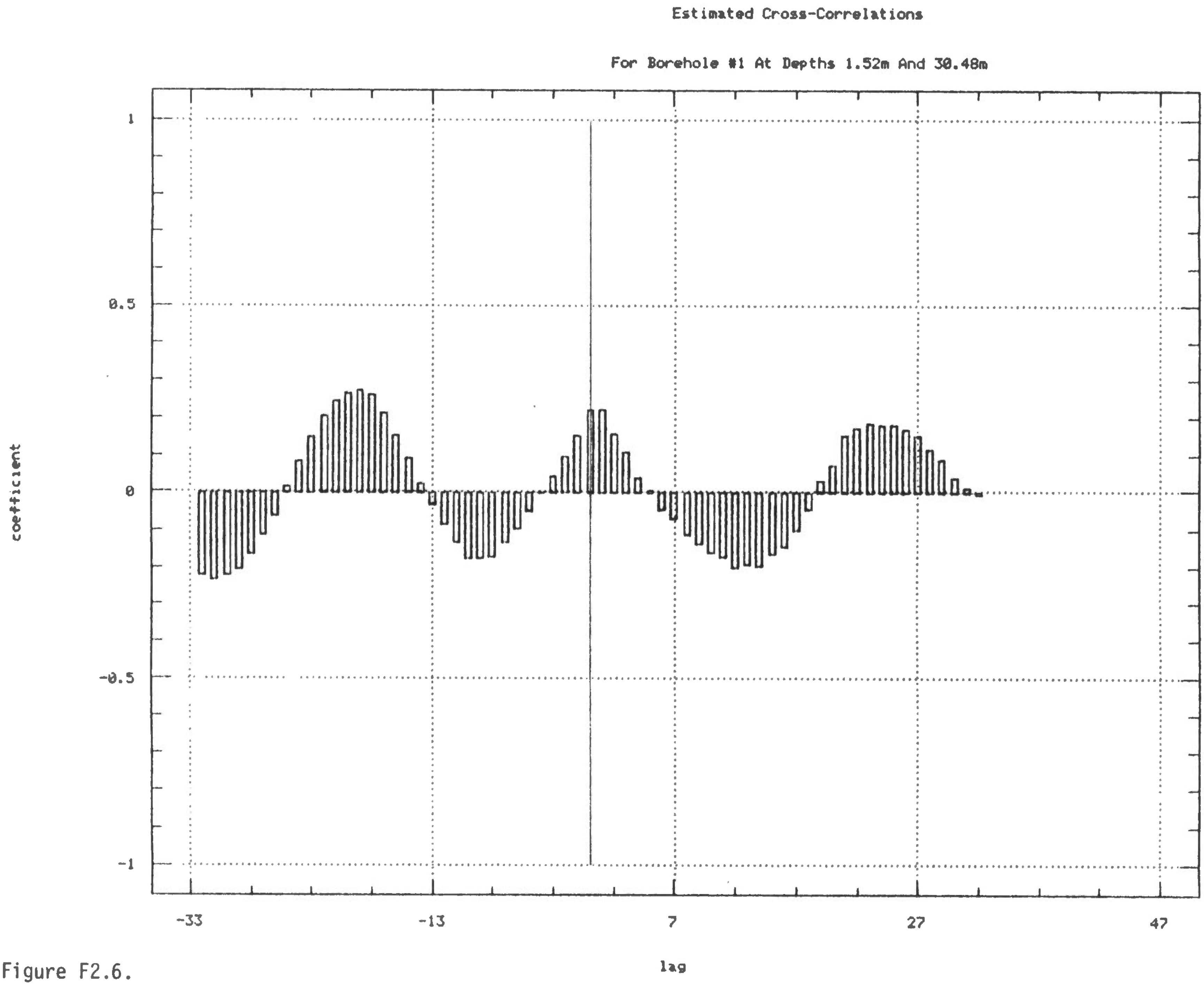


Figure F2.6.

CC

APPENDIX G1

Figures G1.1-G1.7. Cross-correlation, using the program "croscr", of adjacent depths. A sample table is provided with Figure G1.1 only.

APPENDIX G2

Figures G2.1-G2.3. Similar layout to above. Cross-correlation of depth 1.52 m to successive depths.

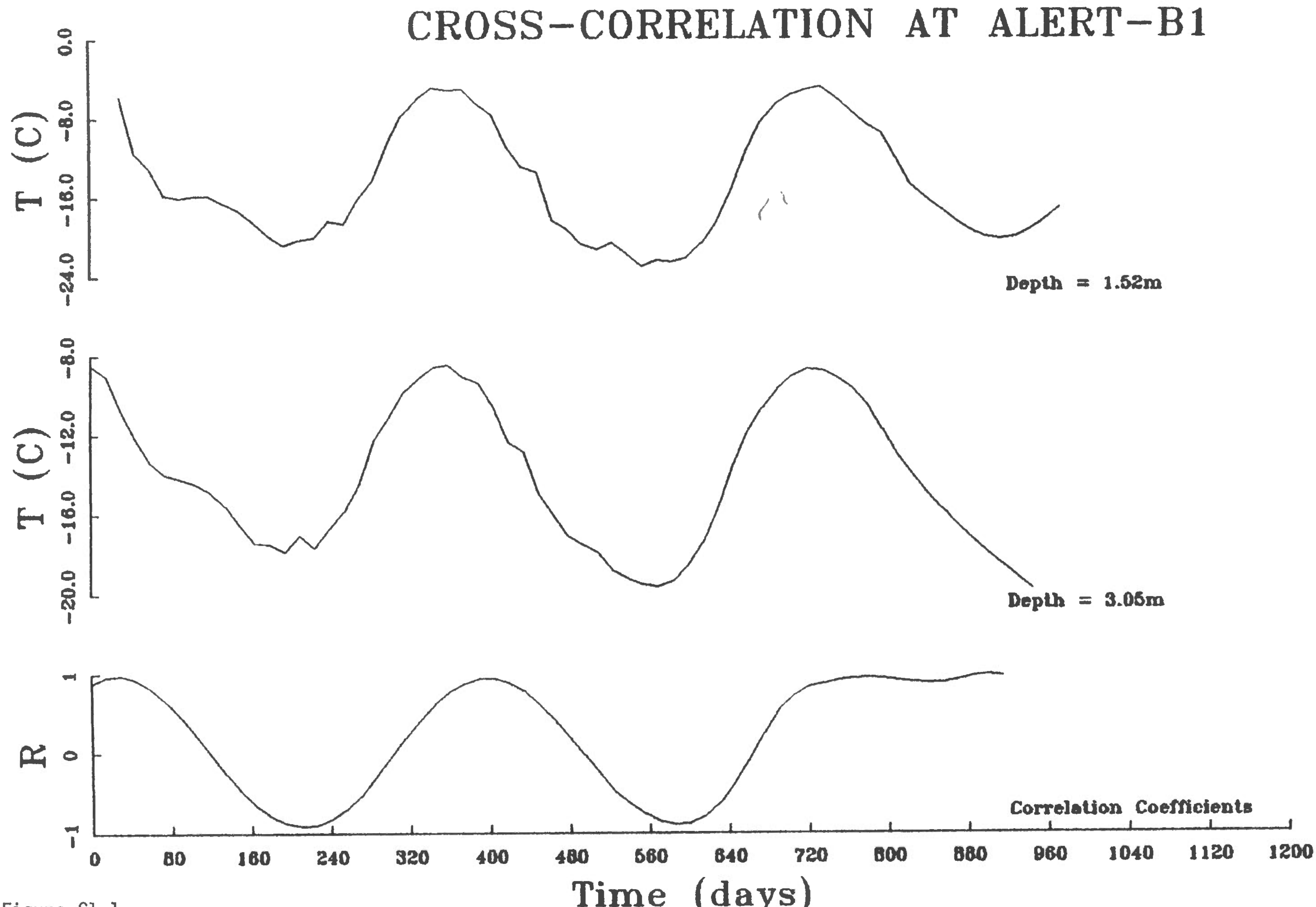

CROSS-CORRELATION AT ALERT-B1
T (C)
0.0
-8.0
-16.0
-24.0
Depth = 1.52m
T (C)
-8.0
-12.0
-16.0
-20.0
Depth = 3.05m
R
1
0
-1
Correlation Coefficients
0
80
160
240
320
400
480
560
640
720
800
880
960
1040
1120
1200
Time (days)

Figure Gl.1.

ROSS-CORREALATION OF ALERT-B1 AT DEPTHS 1.52 AND 3.05m

CORRELATION INDEX	CORRELATION	DEPTH 3.05	DEPTH 1.52
1	.8741	-8.49	
2	.9646	-8.98	
3	.9797	-10.73	-5.67
4	.9256	-12.14	-11.46
5	.8108	-13.38	-12.99
6	.6479	-13.99	-15.75
7	.4473	-14.22	-16.08
8	.2184	-14.45	-15.85
9	-.0219	-14.86	-15.80
10	-.2587	-15.57	-16.62
11	-.4746	-16.52	-17.42
12	-.6592	-17.43	-18.53
13	-.7924	-17.48	-19.85
14	-.8778	-17.85	-20.81
15	-.9125	-17.04	-20.27
16	-.9003	-17.68	-20.05
17	-.8313	-16.70	-18.39
18	-.7061	-15.84	-18.67
19	-.5278	-14.49	-16.15
20	-.3033	-12.27	-14.28
21	-.0616	-11.13	-10.56
22	.1887	-9.90	-7.62
23	.4178	-9.23	-6.03
24	.6106	-8.61	-4.97
25	.7620	-8.53	-5.19
26	.8688	-9.15	-5.11
27	.9297	-9.45	-6.58
28	.9364	-10.68	-7.66
29	.8795	-12.41	-10.92
30	.7725	-12.90	-13.04
31	.6039	-14.95	-13.52
32	.4126	-16.09	-18.37
33	.1952	-17.11	-19.26
34	-.0333	-17.56	-20.79
35	-.2593	-17.96	-21.35
36	-.4812	-18.86	-20.64
37	-.6363	-19.28	-21.76
38	-.7664	-19.57	-23.04
39	-.8551	-19.67	-22.46
40	-.8927	-19.40	-22.60
41	-.8795	-18.64	-22.21
42	-.7970	-17.50	-20.71
43	-.6332	-15.77	-18.55
44	-.3864	-13.66	-15.36
45	-.0880	-11.94	-11.53
46	.2399	-10.73	-8.43
47	.5310	-9.81	-6.72
48	.7060	-9.15	-5.75
49	.8174	-8.77	-5.20
50	.8621	-8.85	-4.96
51	.9088	-9.21	-5.95

Table G1.1.

52	.9282	-9.73	-7.31
53	.9357	-10.55	-8.68
54	.9212	-11.81	-9.50
55	.8942	-13.09	-12.15
56	.8753	-14.09	-14.88
57	.8666	-15.00	-16.10
58	.8721	-15.83	-17.33
59	.9085	-16.59	-18.48
60	.9472	-17.30	-19.44
61	.9668	-17.97	-20.11
62	.9493	-18.60	-20.37
63	.0000	-19.21	-20.14
64	.0000	-19.81	-19.42
65	.0000	.00	-18.40
66	.0000	.00	-17.21

THE INDEX OF CORRELATION IS 3
THE DATE OF BEST CORRELATION IS 1980.10 YEARS
THE PHASE SHIFT IS .12 YEARS

Table G1.1. (con't)

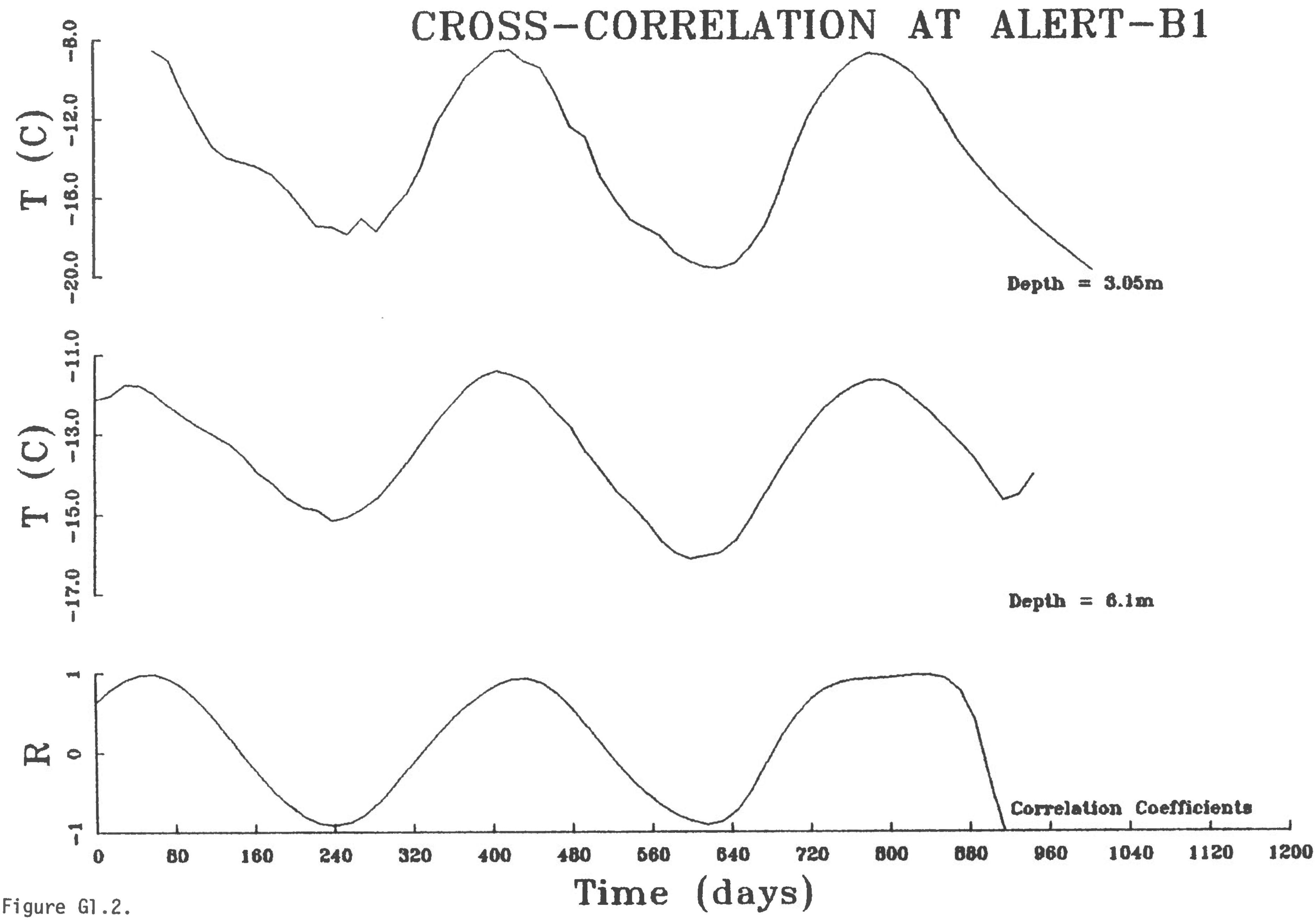

CROSS-CORRELATION AT ALERT-B1
T (C)
-8.0
-12.0
-16.0
-20.0
Depth = 3.05m
T (C)
-11.0
-13.0
-15.0
-17.0
Depth = 6.1m
R
1
0
-1
Correlation Coefficients
0
80
160
240
320
400
480
560
640
720
800
880
960
1040
1120
1200
Time (days)

Figure G1.2.

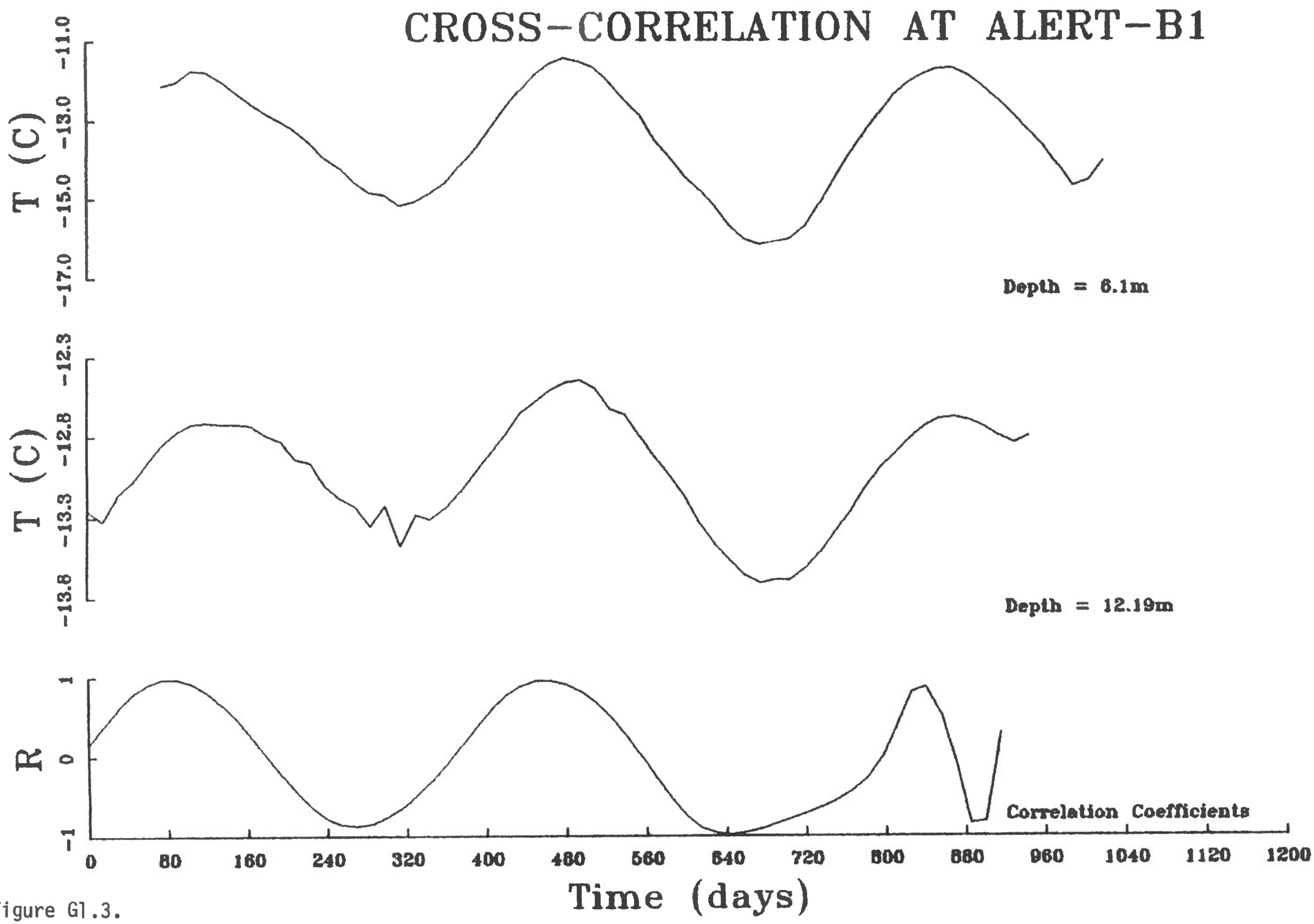
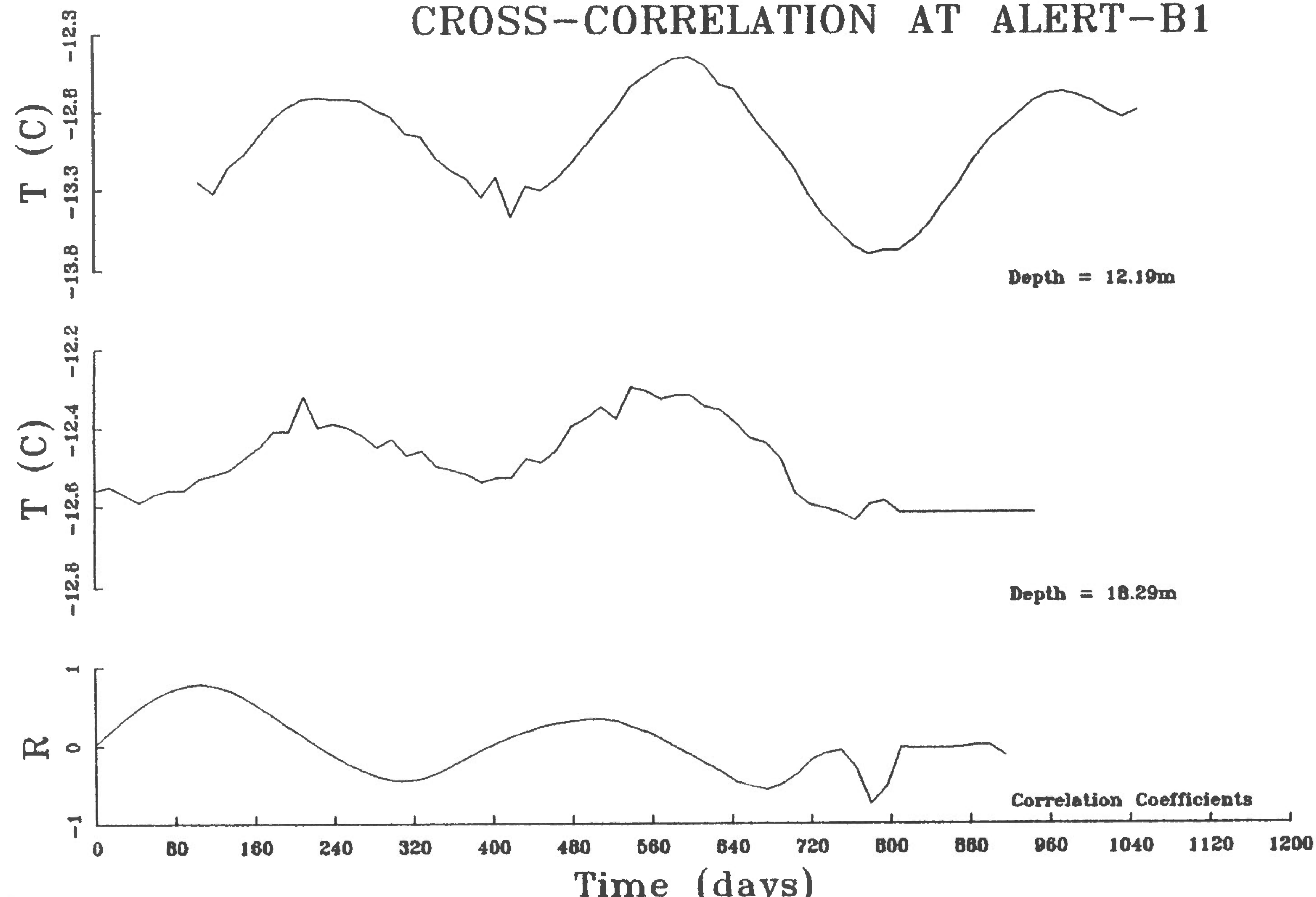
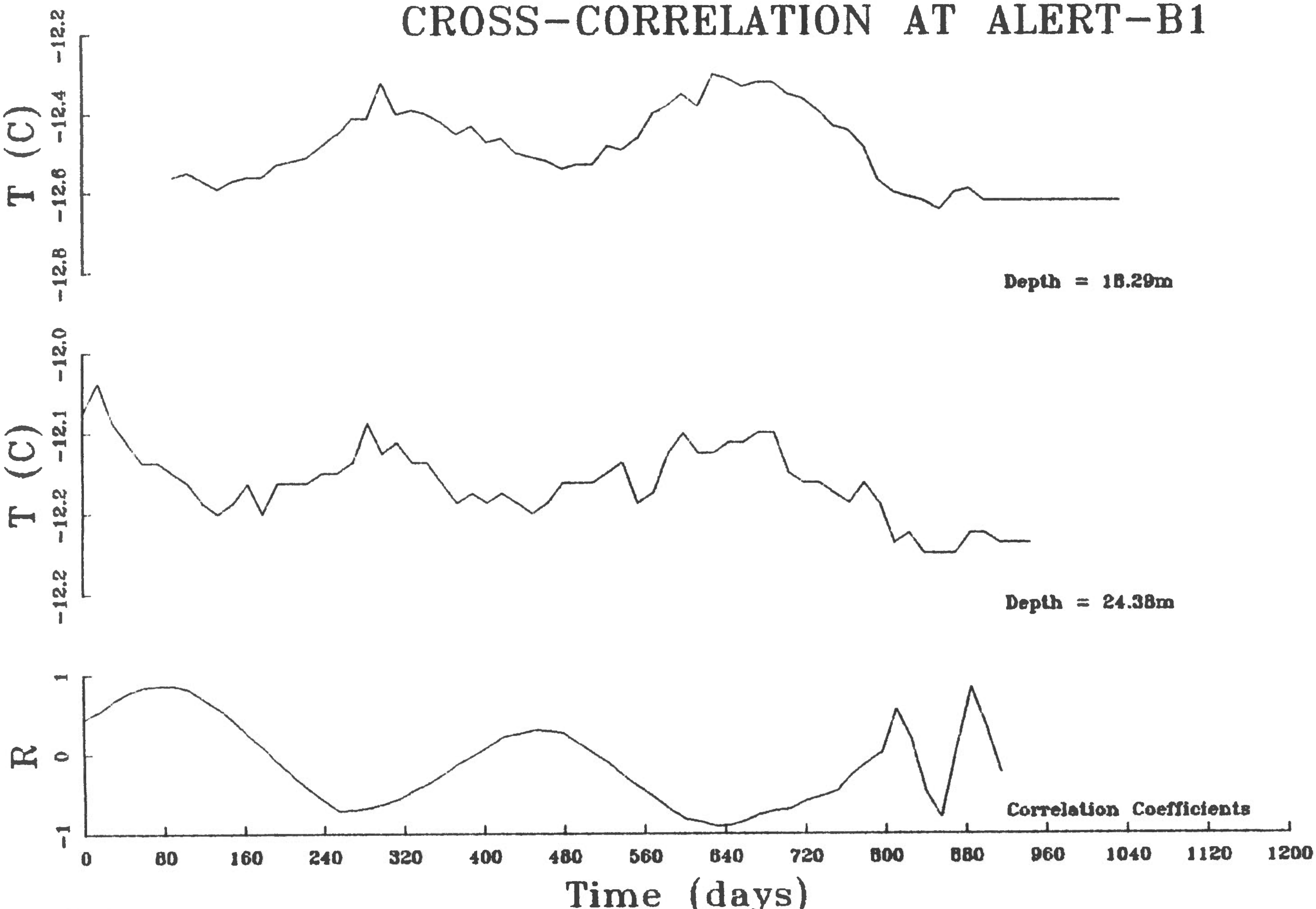

CROSS-CORRELATION AT ALERT-B1
T (C)
-11.0
-13.0
-15.0
-17.0
Depth = 6.1m
T (C)
-12.3
-12.8
-13.3
-13.8
Depth = 12.19m
R
1
0
-1
Correlation Coefficients
0
80
160
240
320
400
480
560
640
720
800
880
960
1040
1120
1200
Time (days)

Figure G1.3.



CROSS-CORRELATION AT ALERT-B1
T (C)
-12.3
-12.8
-13.3
-13.8
Depth = 12.19m
T (C)
-12.2
-12.4
-12.6
-12.8
Depth = 18.29m
R
1
0
-1
Correlation Coefficients
0
80
160
240
320
400
480
560
640
720
800
880
960
1040
1120
1200
Time (days)

Figure Gl.4.



CROSS-CORRELATION AT ALERT-B1
T (C)
-12.2
-12.4
-12.6
-12.8
Depth = 18.29m
T (C)
-12.0
-12.1
-12.2
-12.2
Depth = 24.38m
R
1
0
-1
Correlation Coefficients
0
80
160
240
320
400
480
560
640
720
800
880
960
1040
1120
1200
Time (days)

Figure G1.5.

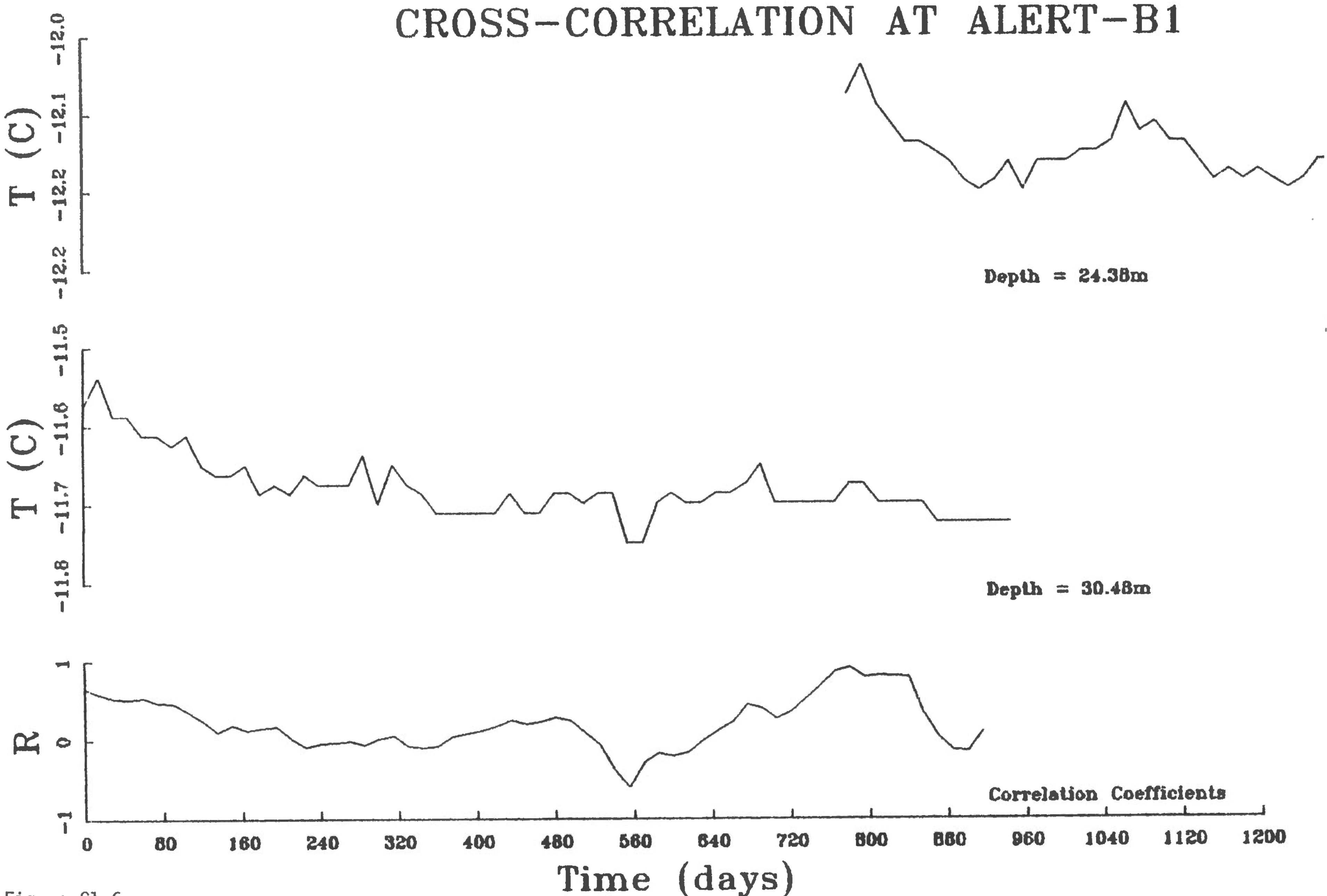
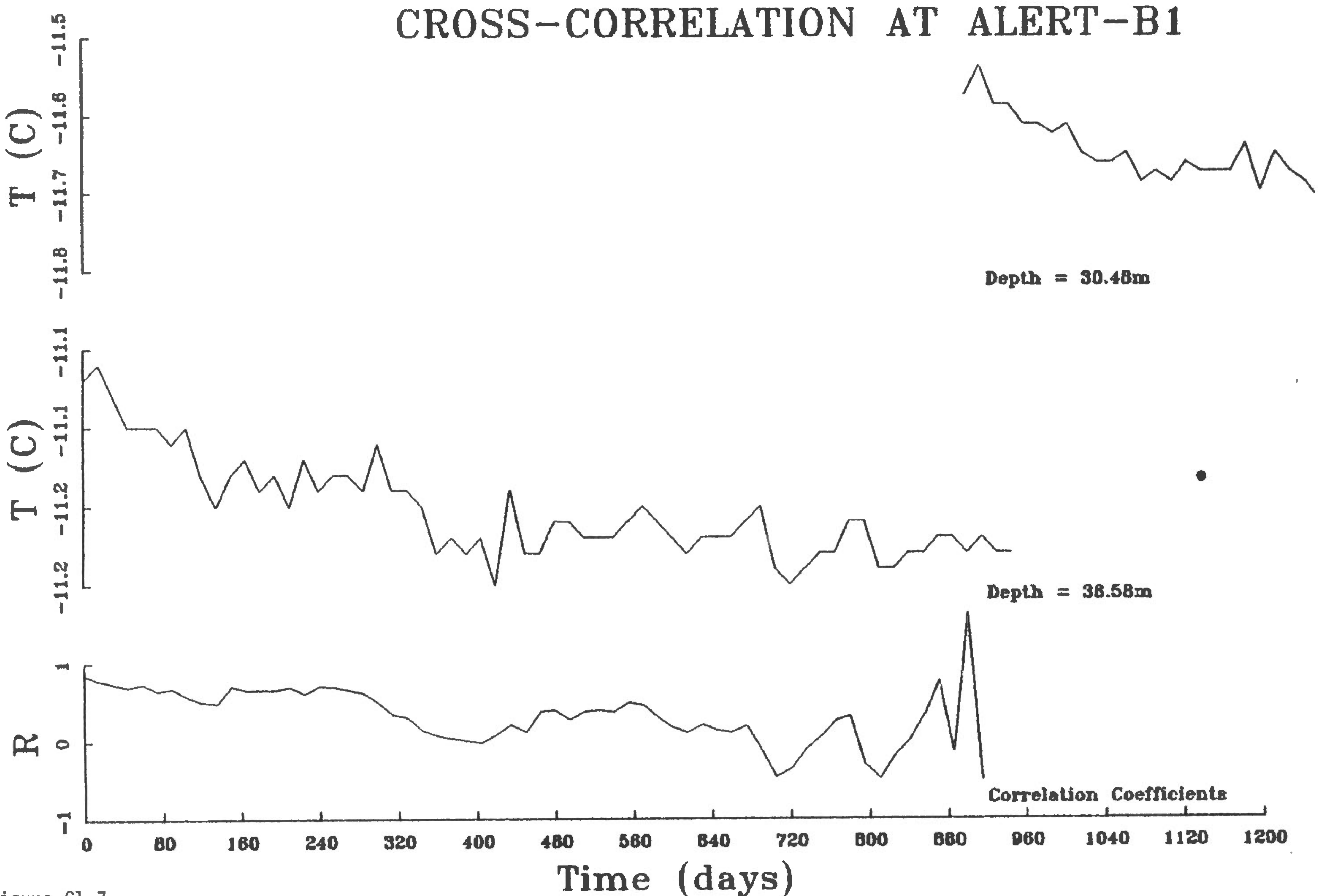

CROSS-CORRELATION AT ALERT-B1
T (C)
-12.0
-12.1
-12.2
-12.2
Depth = 24.38m
T (C)
-11.5
-11.6
-11.7
-11.8
Depth = 30.48m
R
1
0
-1
Correlation Coefficients
0
80
160
240
320
400
480
560
640
720
800
880
960
1040
1120
1200
Time (days)

Figure G1.6.



CROSS-CORRELATION AT ALERT-B1
T (C)
-11.5
-11.6
-11.7
-11.8
Depth = 30.48m
T (C)
-11.1
-11.1
-11.2
-11.2
Depth = 38.58m
R
1
0
-1
Correlation Coefficients
0
80
160
240
320
400
480
560
640
720
800
880
960
1040
1120
1200
Time (days)

Figure G1.7.

APPENDIX G2

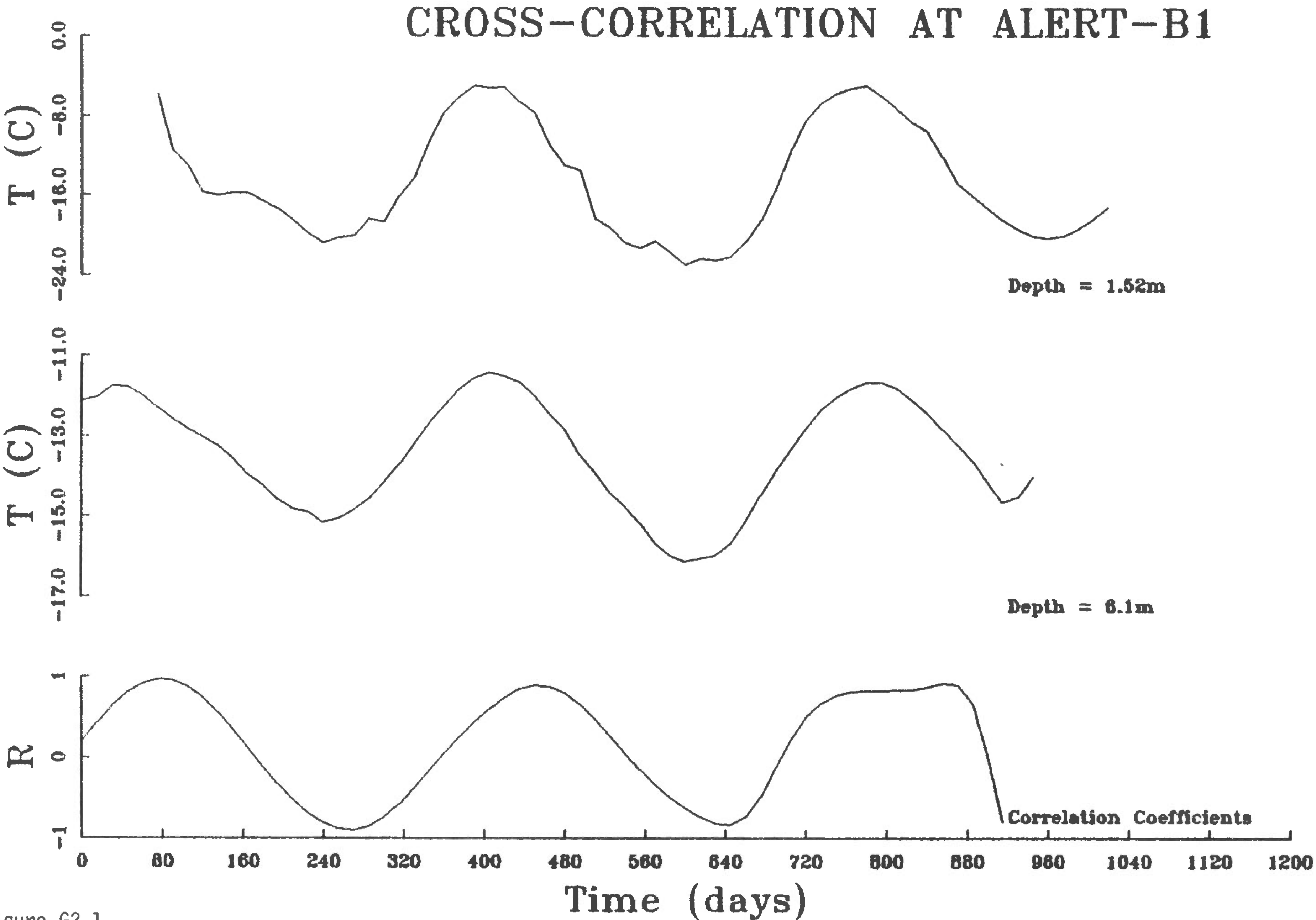

CROSS-CORRELATION AT ALERT-B1
T (C)
0.0
-8.0
-16.0
-24.0
Depth = 1.52m
T (C)
-11.0
-13.0
-15.0
-17.0
Depth = 6.1m
R
1
0
-1
Correlation Coefficients
0
80
160
240
320
400
480
560
640
720
800
880
960
1040
1120
1200
Time (days)

Figure G2.1.

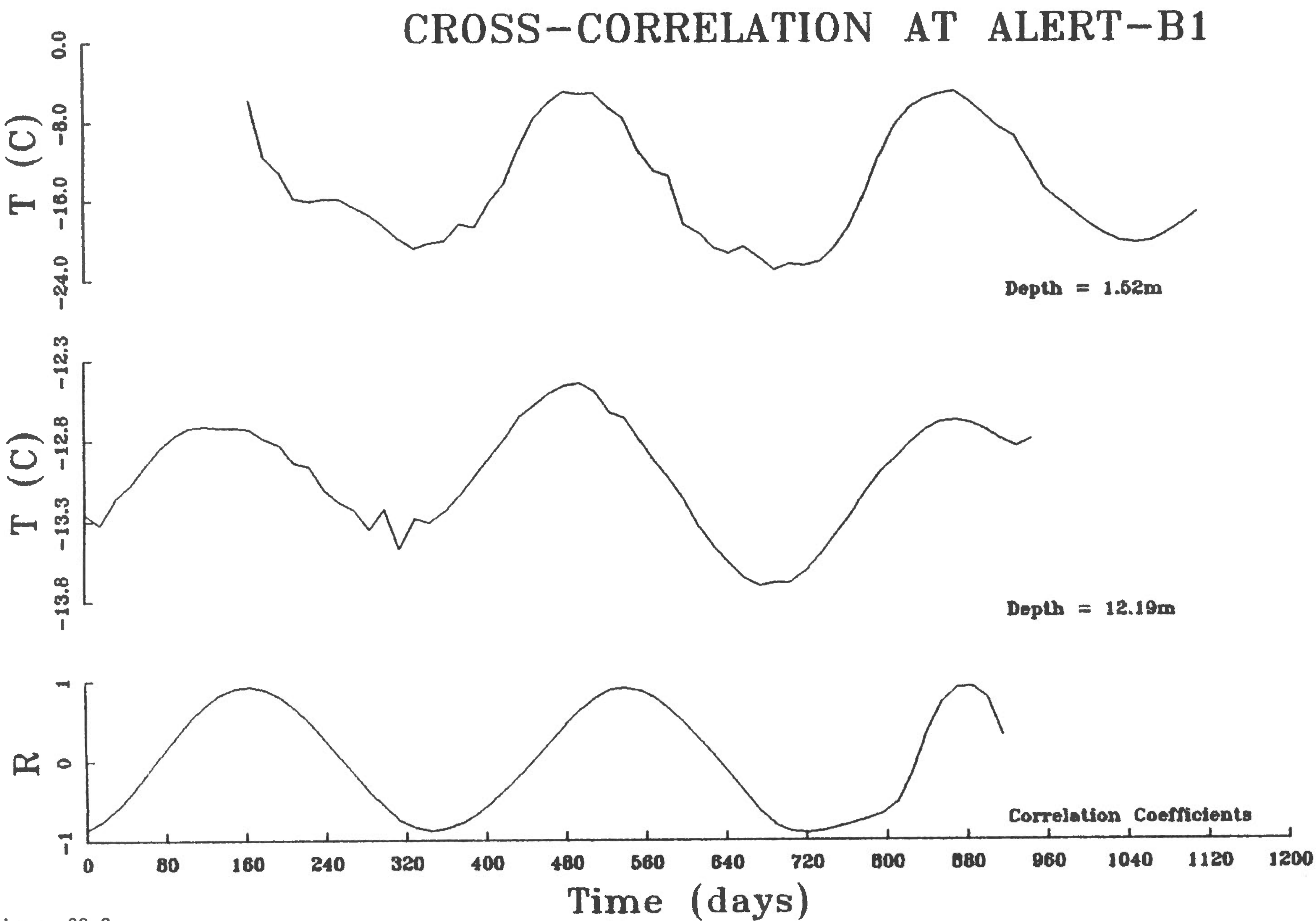
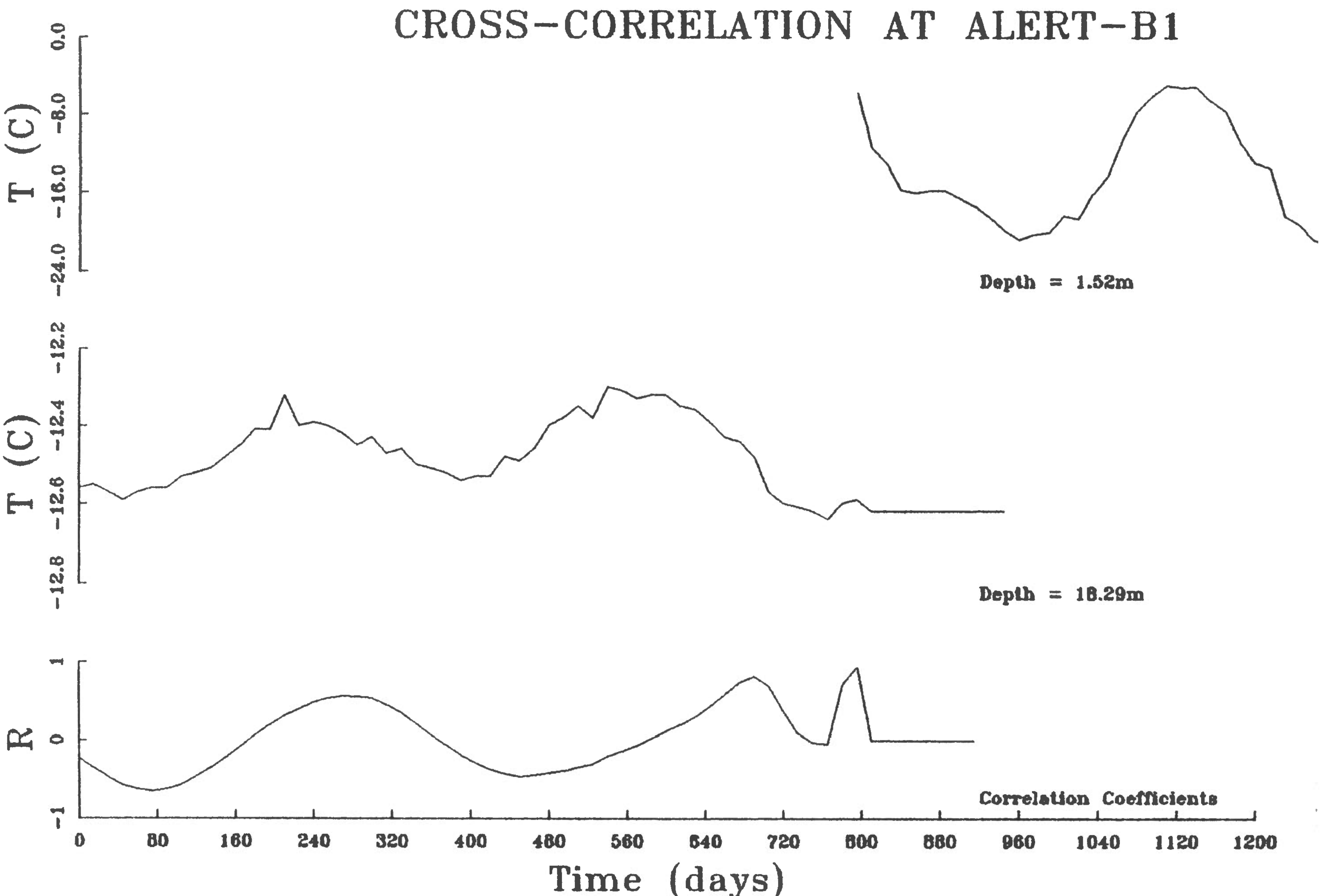

CROSS-CORRELATION AT ALERT-B1
T (C)
0.0
-8.0
-16.0
-24.0
Depth = 1.52m
T (C)
-12.3
-12.8
-13.3
-13.8
Depth = 12.19m
R
1
0
-1
Correlation Coefficients
0
80
160
240
320
400
480
560
640
720
800
880
960
1040
1120
1200
Time (days)

Figure G2.2.



CROSS-CORRELATION AT ALERT-B1
T (C)
0.0
-8.0
-16.0
-24.0
Depth = 1.52m
T (C)
-12.2
-12.4
-12.6
-12.8
Depth = 18.29m
R
1
0
-1
Correlation Coefficients
0
80
160
240
320
400
480
560
640
720
800
880
960
1040
1120
1200
Time (days)

Figure G2.3.

APPENDIX H1

Figures H1.1-H1.12. Linear regressions revealing the warming and cooling trends at various depths for site #1.

APPENDIX H2

Figures H2.1-H2.2. Multiplicative regressions demonstrating the thermal disturbance of the well drilling.

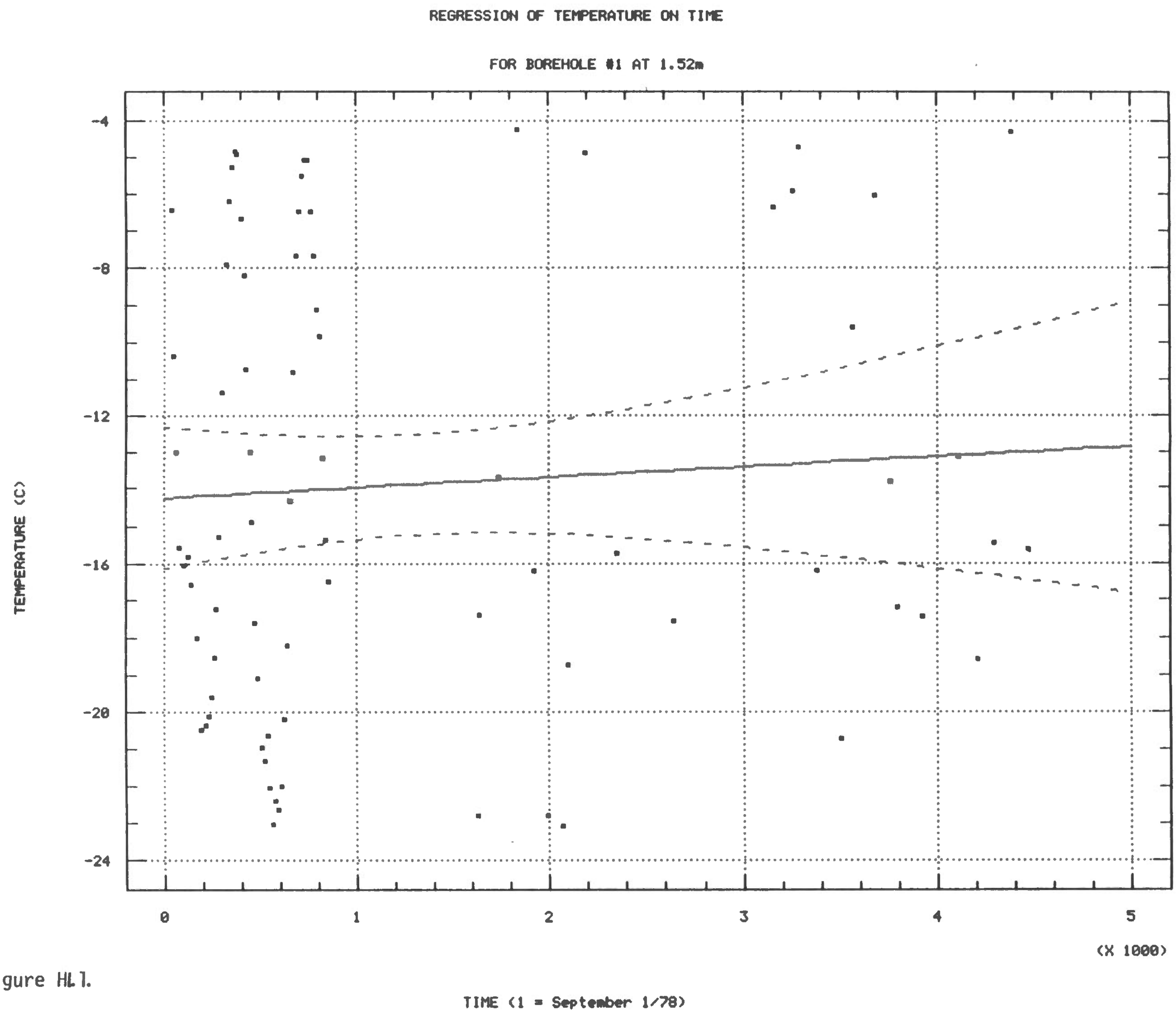

REGRESSION OF TEMPERATURE ON TIME
FOR BOREHOLE #1 AT 1.52m
TEMPERATURE (C)
-4
-8
-12
-16
-20
-24
0
1
2
3
4
5
(X 1000)
TIME (1 = September 1/78)

Figure HL1.

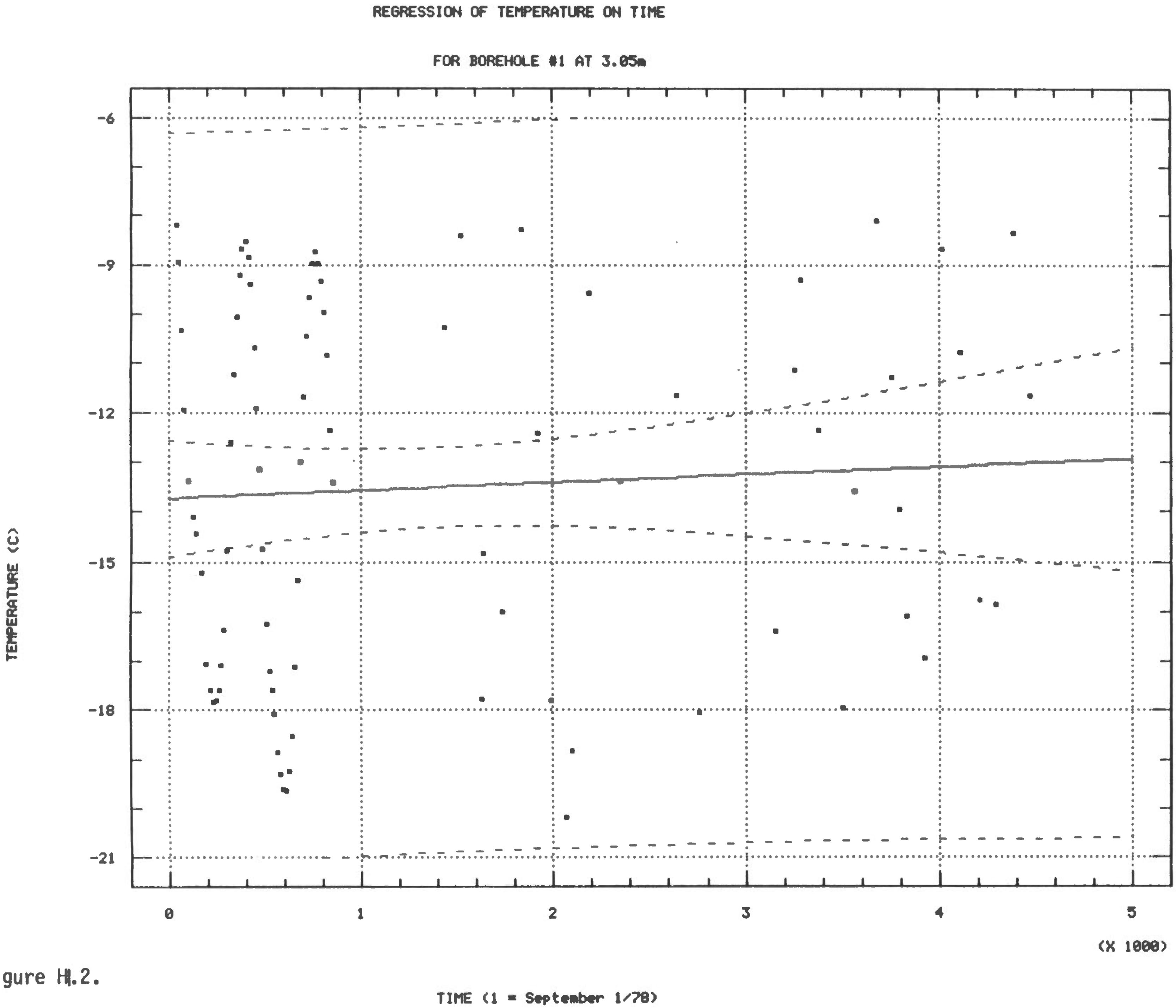

REGRESSION OF TEMPERATURE ON TIME
FOR BOREHOLE #1 AT 3.05m
TEMPERATURE (C)
-6
-9
-12
-15
-18
-21
0
1
2
3
4
5
(X 1000)
TIME (1 = September 1/78)

Figure H.2.

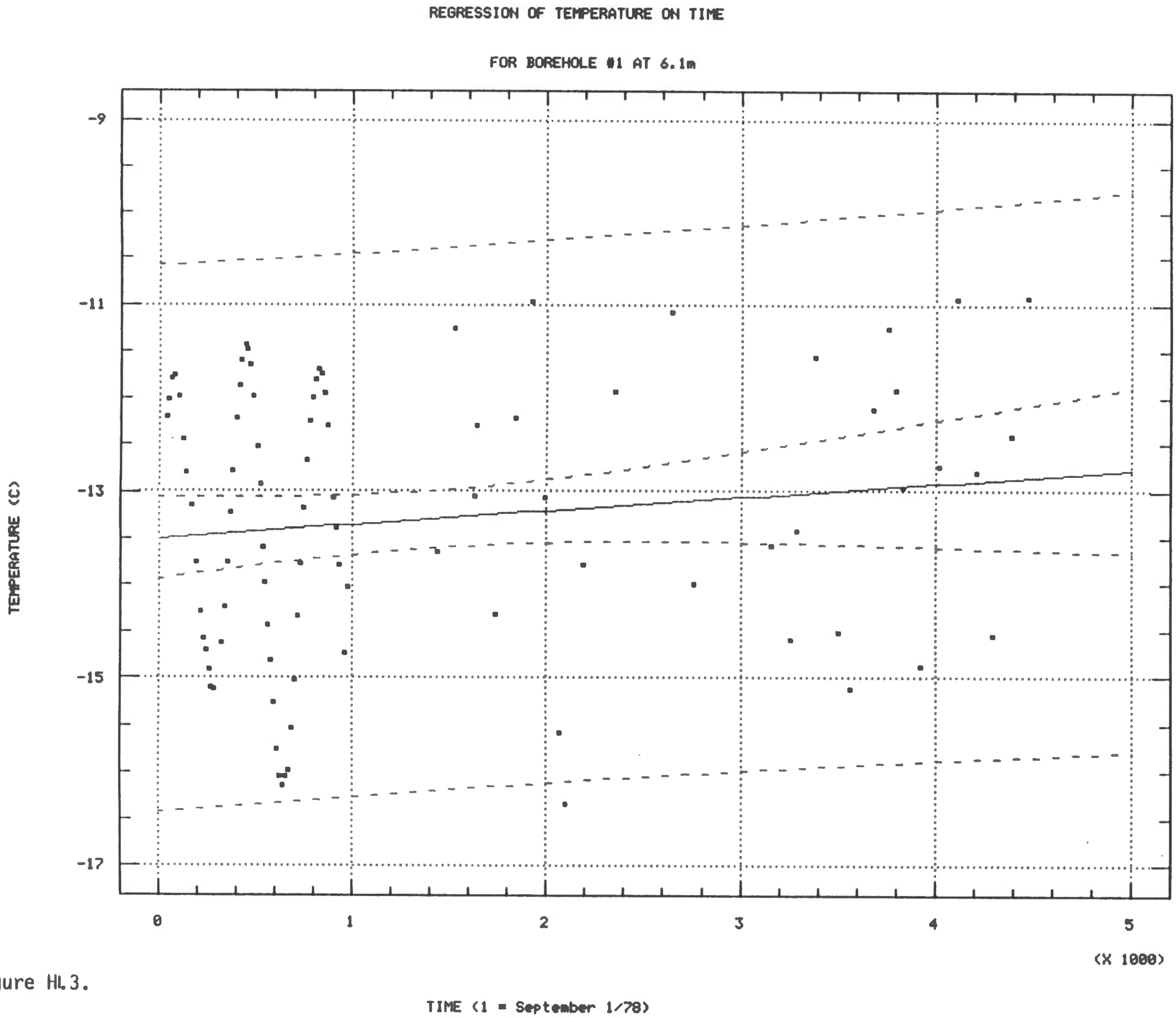

REGRESSION OF TEMPERATURE ON TIME
FOR BOREHOLE #1 AT 6.1m
TEMPERATURE (C)
-9
-11
-13
-15
-17
0
1
2
3
4
5
(X 1000)
TIME (1 = September 1/78)

Figure HL3.

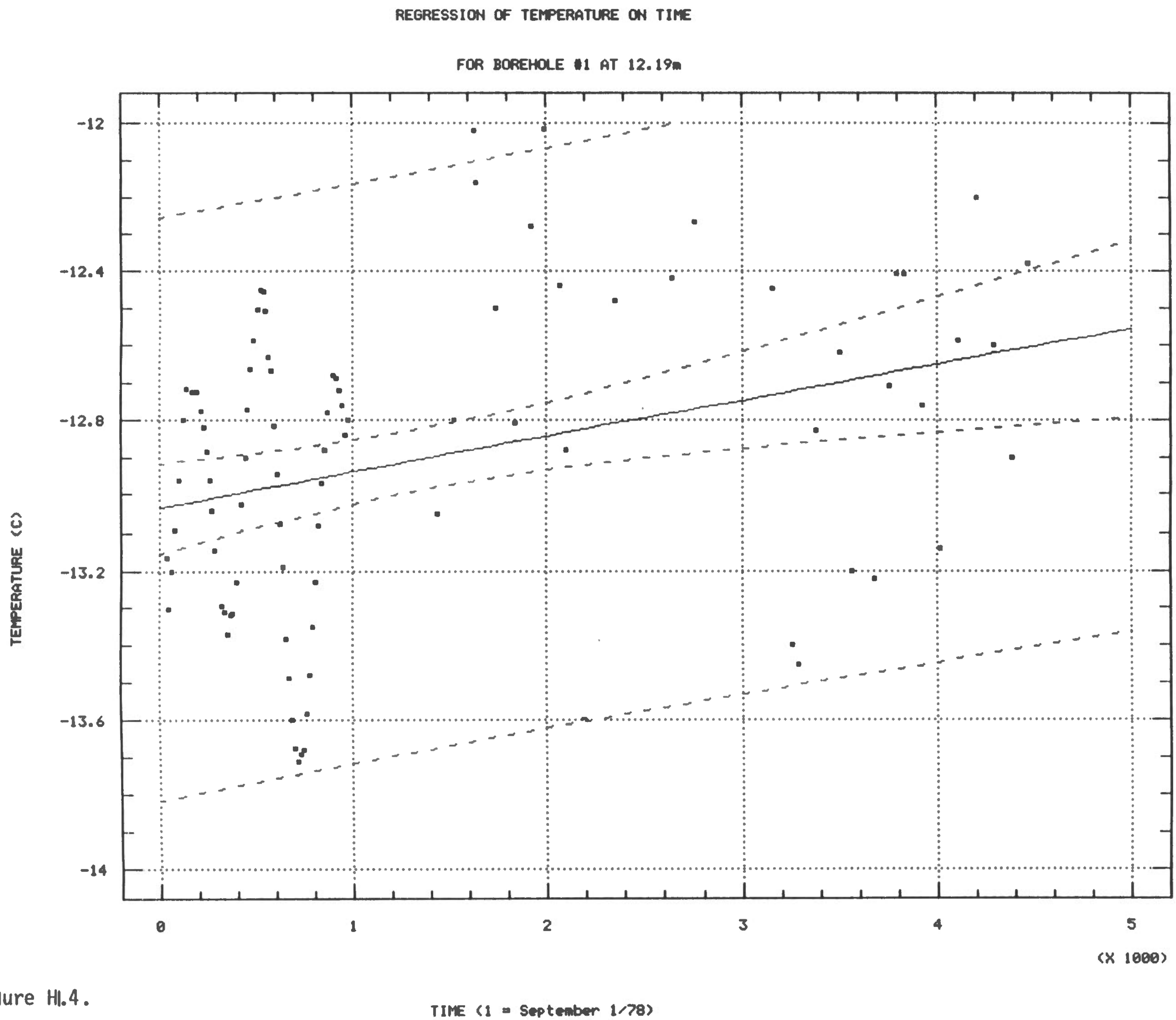

REGRESSION OF TEMPERATURE ON TIME
FOR BOREHOLE #1 AT 12.19m
-12
-12.4
-12.8
-13.2
-13.6
-14
TEMPERATURE (C)
0
1
2
3
4
5
(X 1000)
TIME (1 = September 1/78)

Figure HI.4.

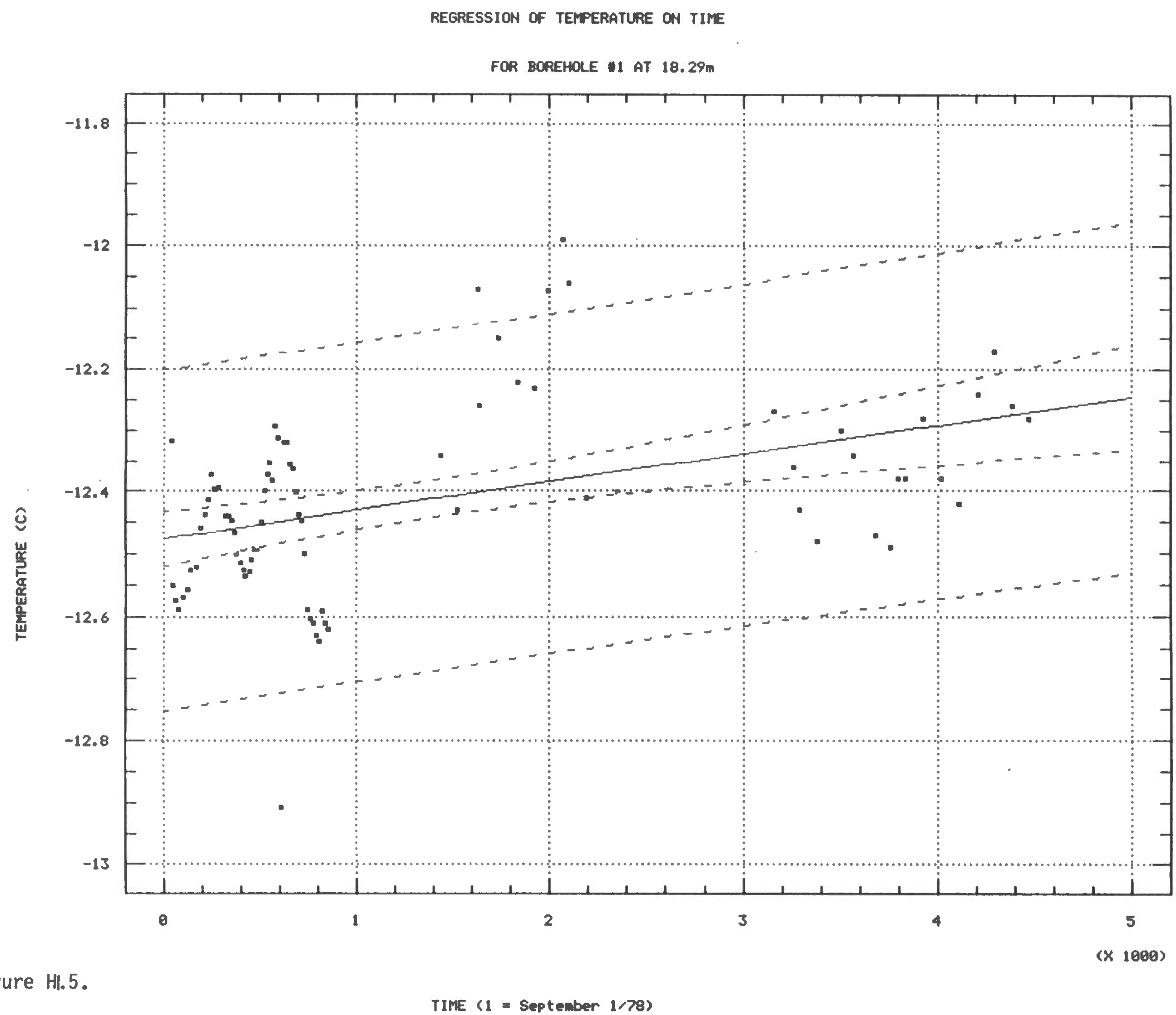

REGRESSION OF TEMPERATURE ON TIME
FOR BOREHOLE #1 AT 18.29m
-11.8
-12
-12.2
-12.4
-12.6
-12.8
-13
TEMPERATURE (C)
0
1
2
3
4
5
(X 1000)
TIME (1 = September 1/78)

Figure HI.5.

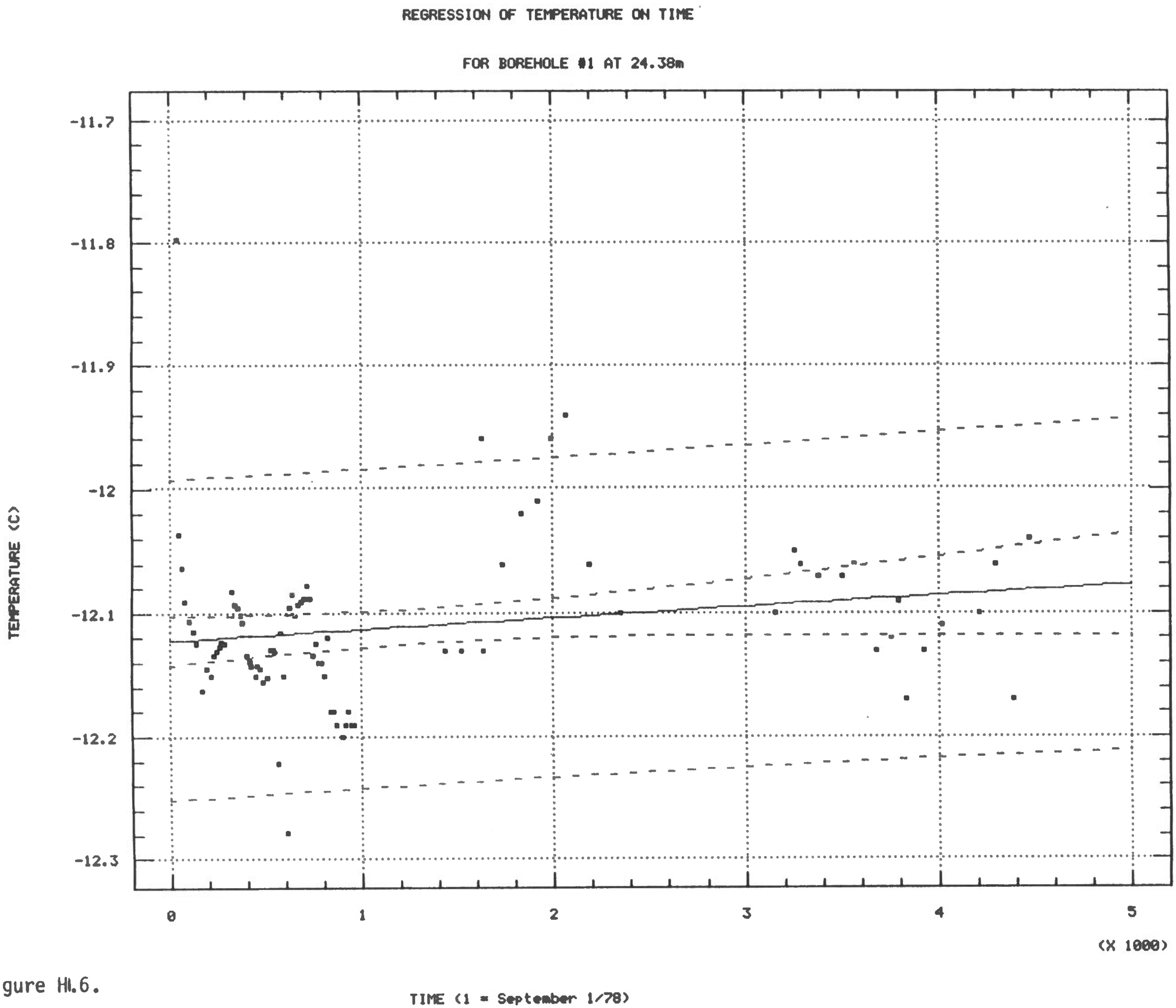

REGRESSION OF TEMPERATURE ON TIME
FOR BOREHOLE #1 AT 24.38m
-11.7
-11.8
-11.9
-12
-12.1
-12.2
-12.3
TEMPERATURE (C)
0
1
2
3
4
5
(X 1000)
TIME (1 = September 1/78)

Figure H1.6.

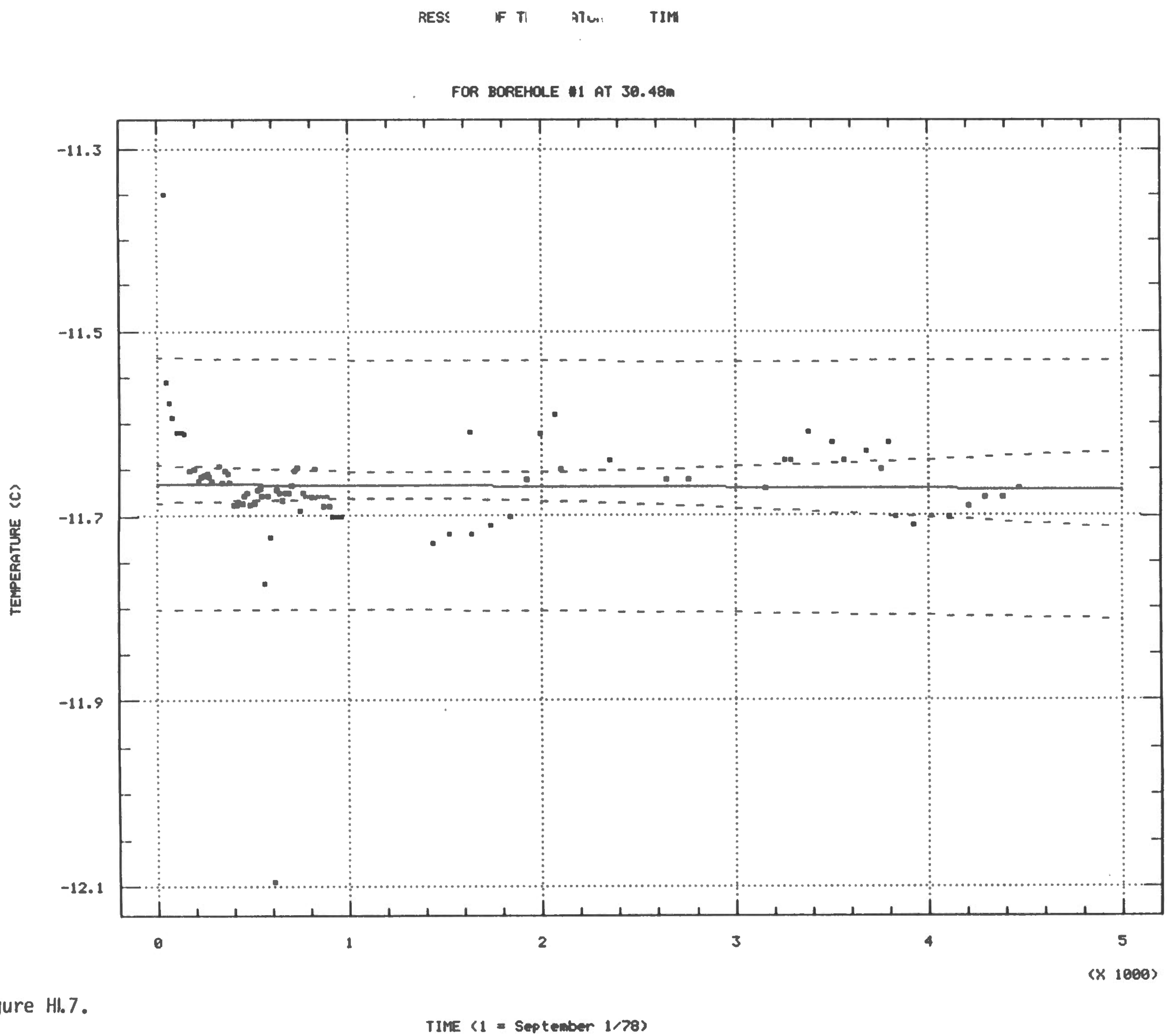

RESS F T TIM
FOR BOREHOLE #1 AT 30.48m
TEMPERATURE (C)
-11.3
-11.5
-11.7
-11.9
-12.1
0
1
2
3
4
5
(X 1000)
TIME (1 = September 1/78)

Figure H1.7.

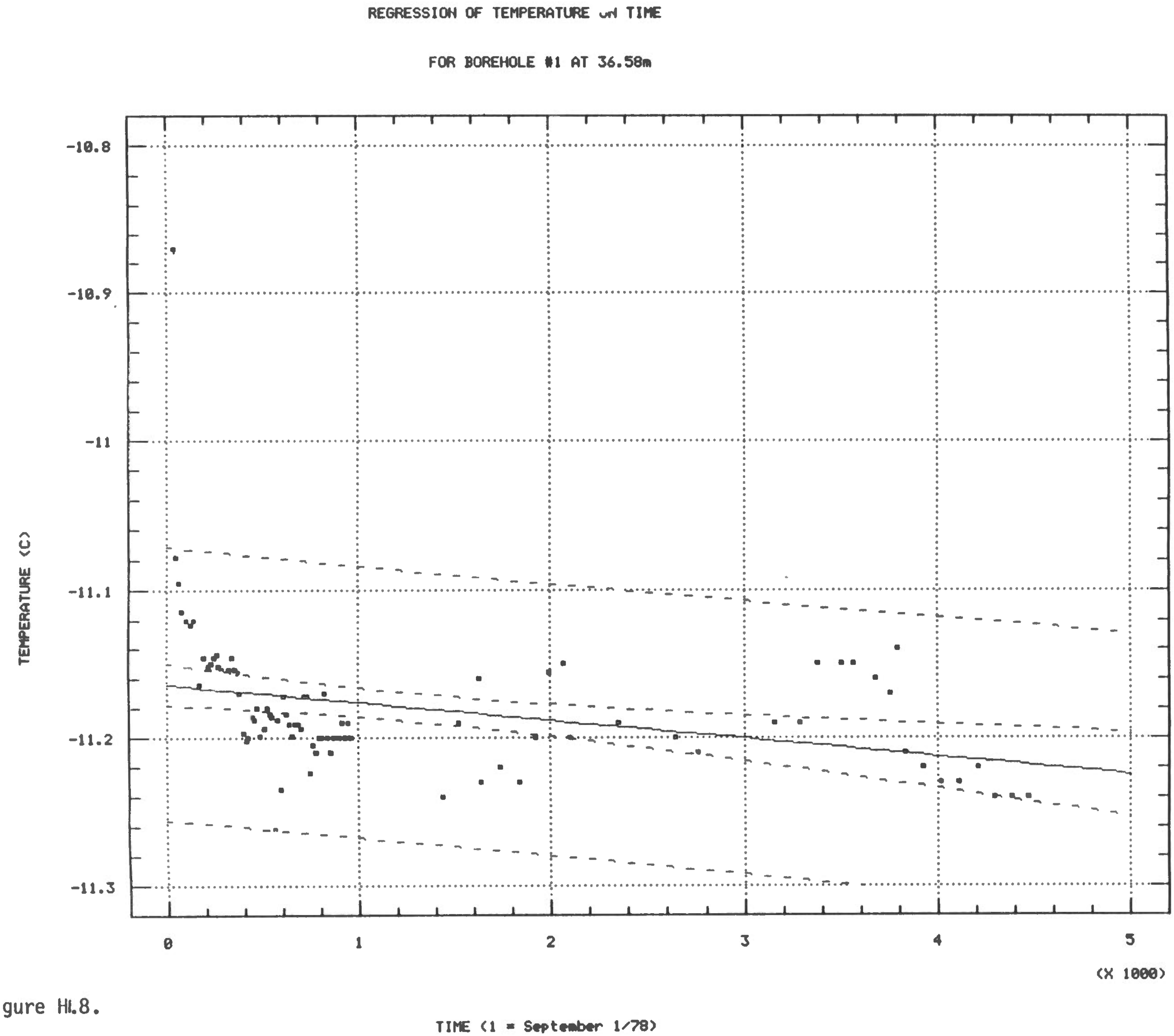

REGRESSION OF TEMPERATURE ON TIME
FOR BOREHOLE #1 AT 36.58m
TEMPERATURE (C)
-10.8
-10.9
-11
-11.1
-11.2
-11.3
0
1
2
3
4
5
(X 1000)
TIME (1 = September 1/78)

Figure H1.8.

GRES OF RAT. I TI

FOR BOREHOLE #1 AT 42.67m

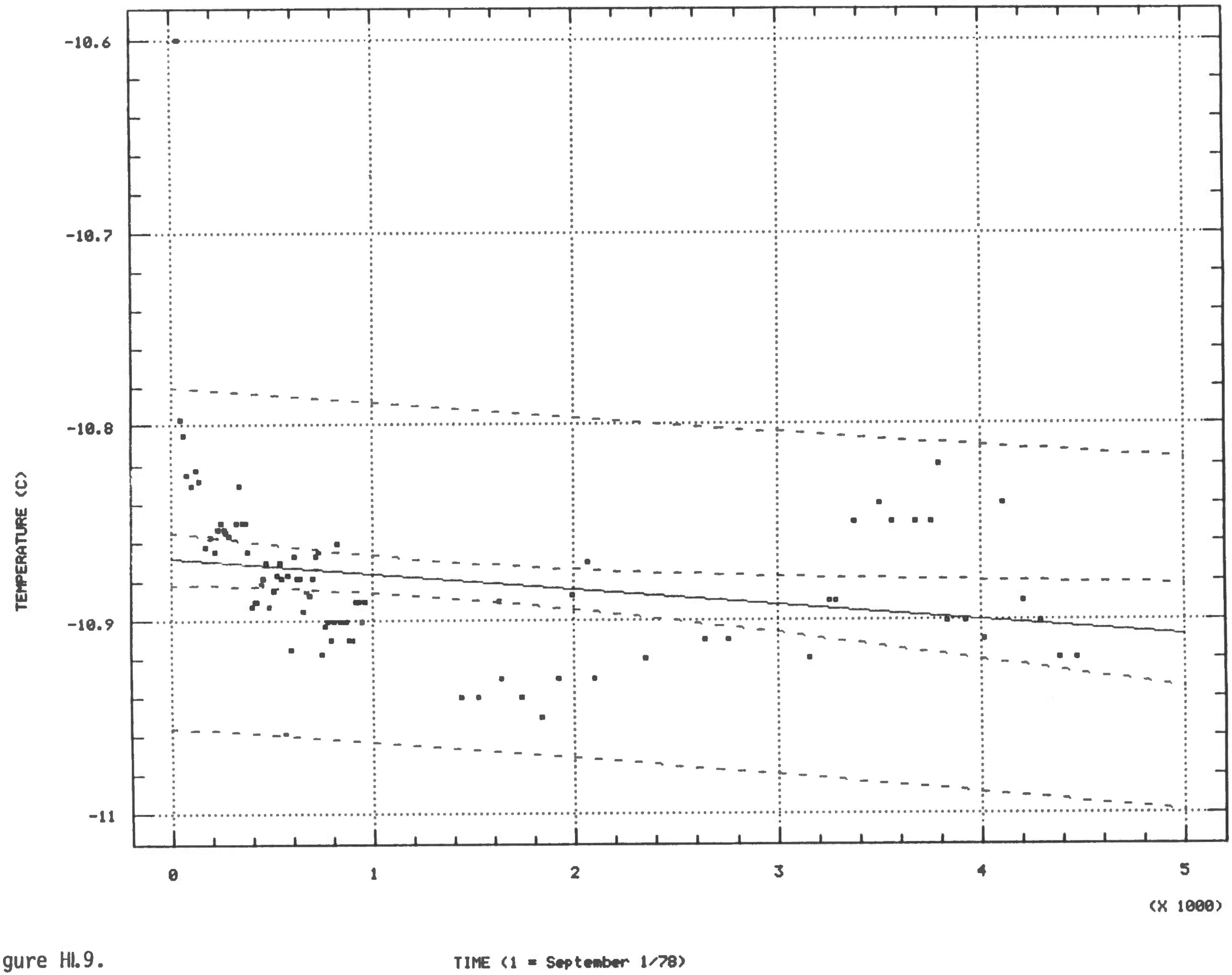


Figure HI.9.

REGRESSION OF TEMPERATURE ON TIME

FOR BOREHOLE #1 AT 48.76m

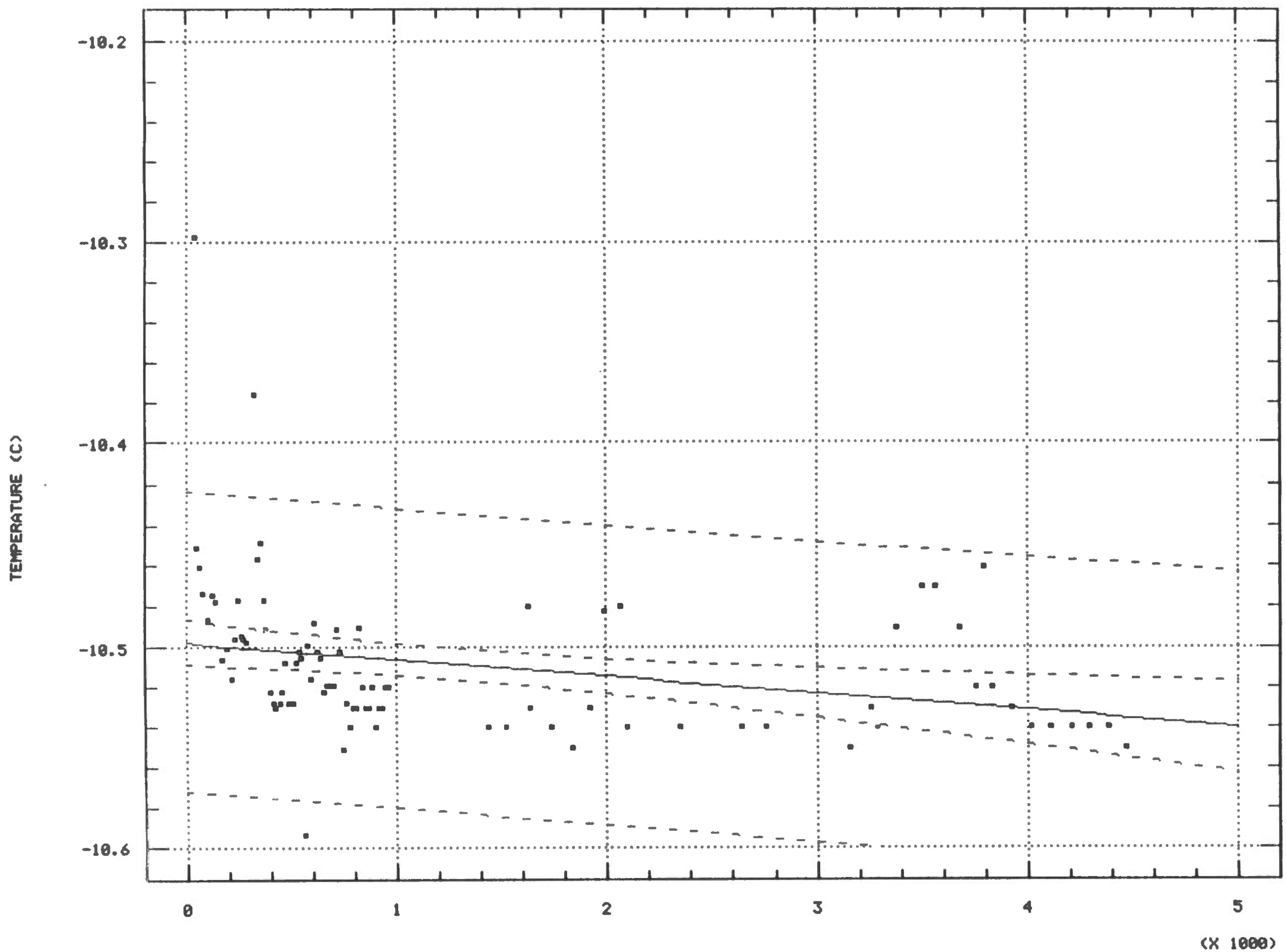


Figure HL10.

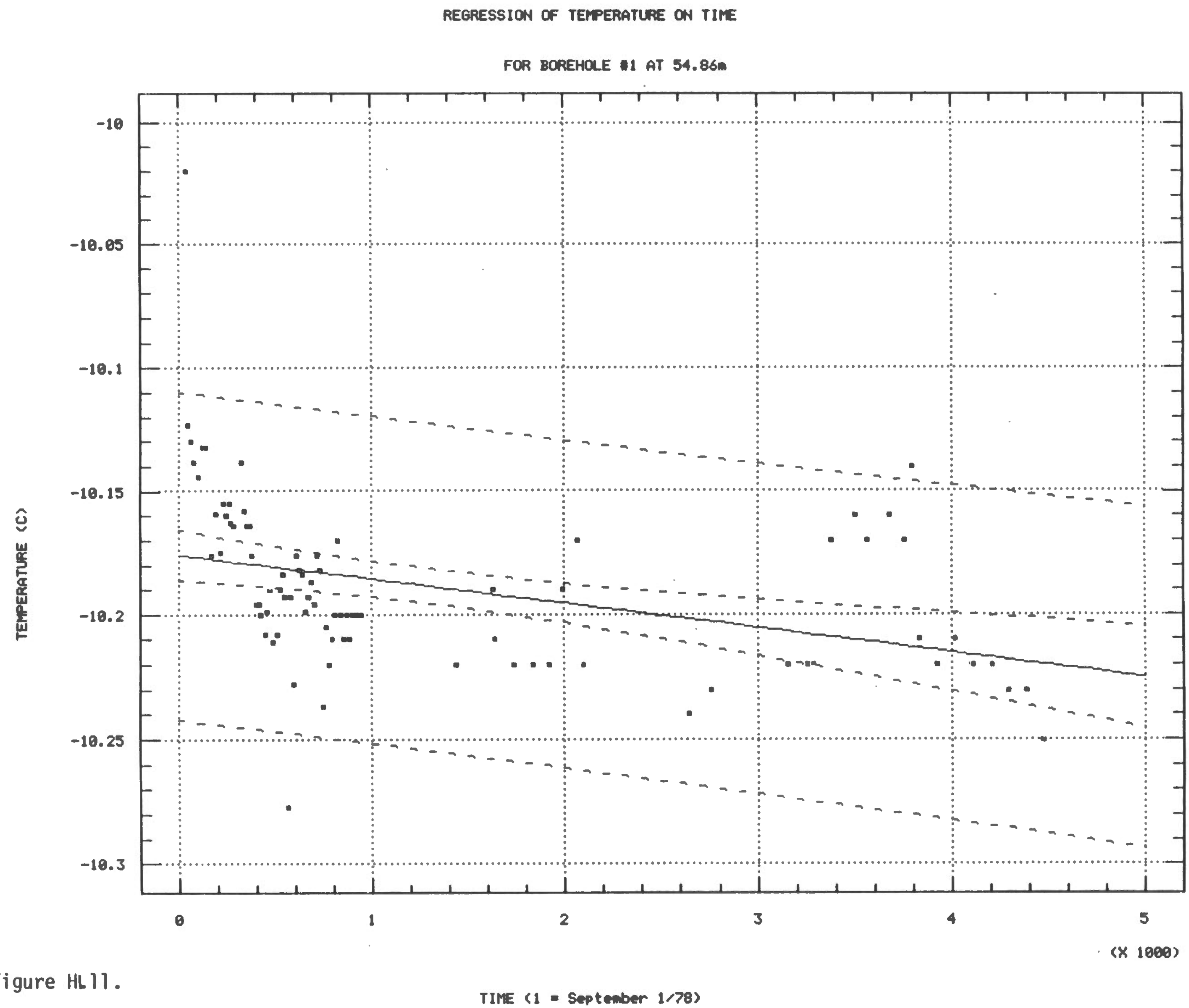
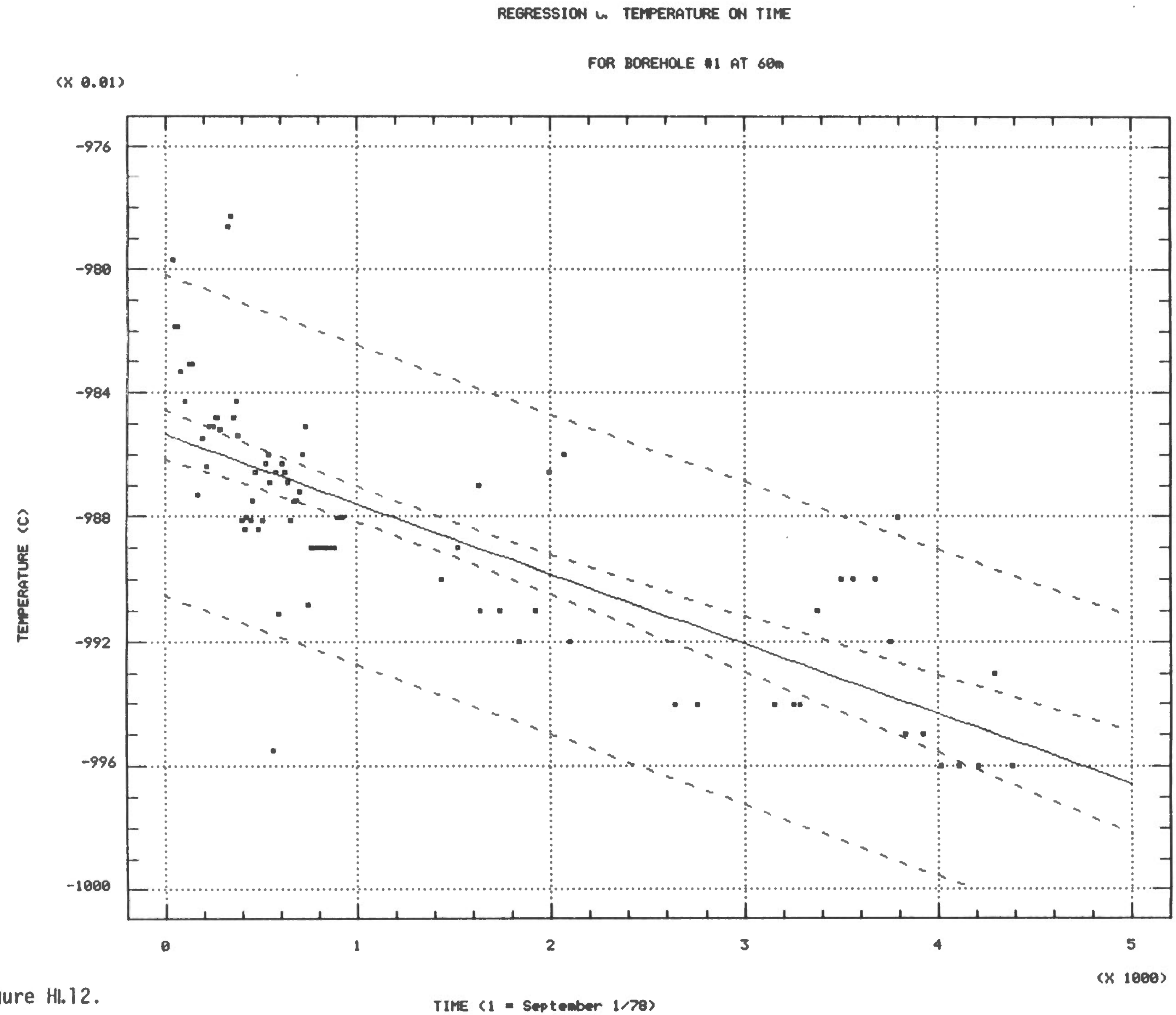

REGRESSION OF TEMPERATURE ON TIME
FOR BOREHOLE #1 AT 54.86m
TEMPERATURE (C)
-10
-10.05
-10.1
-10.15
-10.2
-10.25
-10.3
0
1
2
3
4
5
(X 1000)
TIME (1 = September 1/78)

Figure HL11.



REGRESSION ω. TEMPERATURE ON TIME
FOR BOREHOLE #1 AT 60m
(X 0.01)
-976
-980
-984
-988
-992
-996
-1000
TEMPERATURE (C)
0
1
2
3
4
5
(X 1000)
TIME (1 = September 1/78)

Figure H1.12.

APPENDIX H2

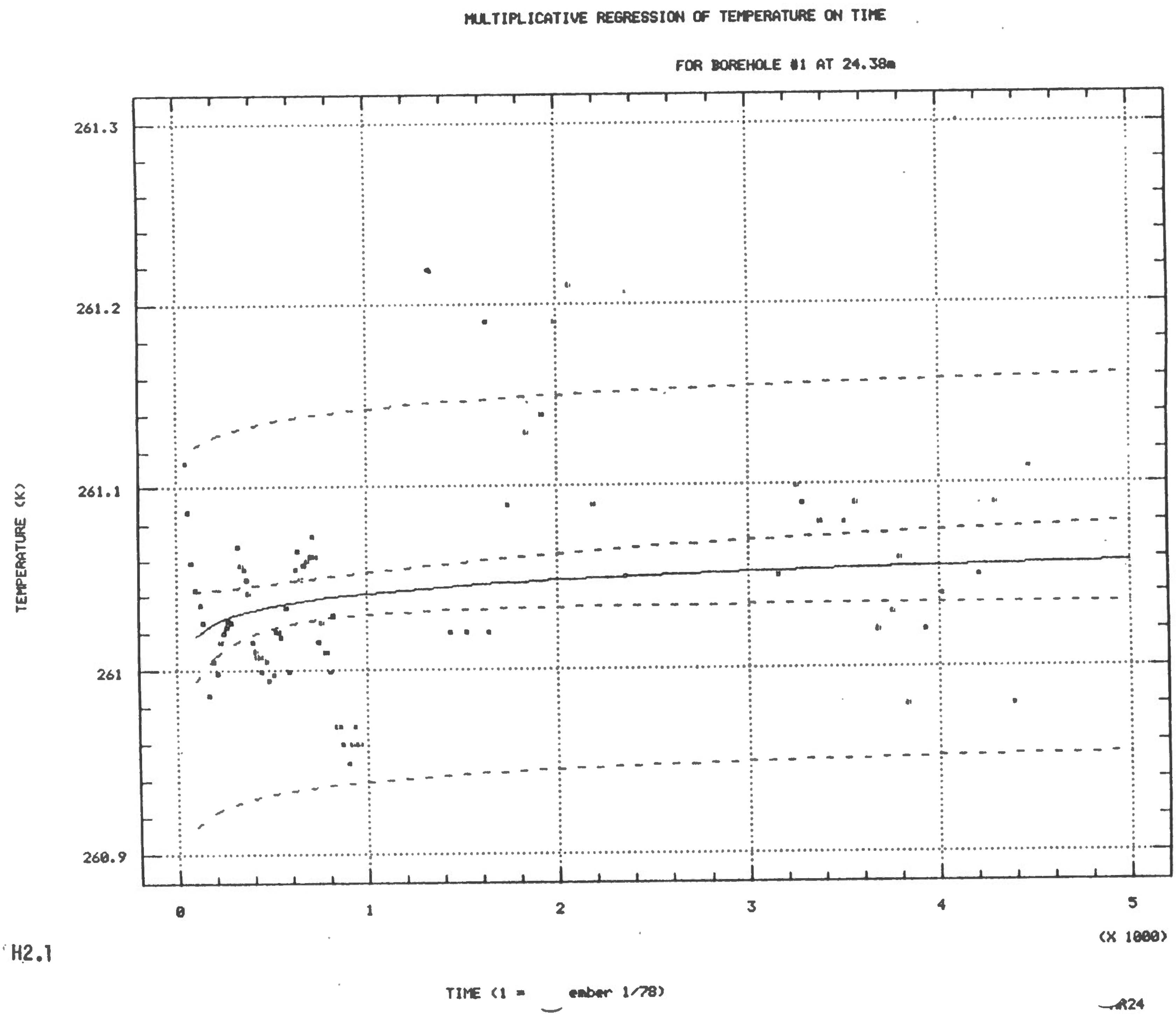

MULTIPLICATIVE REGRESSION OF TEMPERATURE ON TIME
FOR BOREHOLE #1 AT 24.38m
261.3
261.2
261.1
261
260.9
TEMPERATURE (K)
0
1
2
3
4
5
(X 1000)
TIME (1 = ember 1/78)
R24

Figure H2.1

MULTIPLICATIVE REGRESSION OF TEMPERATURE ON TIME

FOR BOREHOLE #1 AT 24.38m

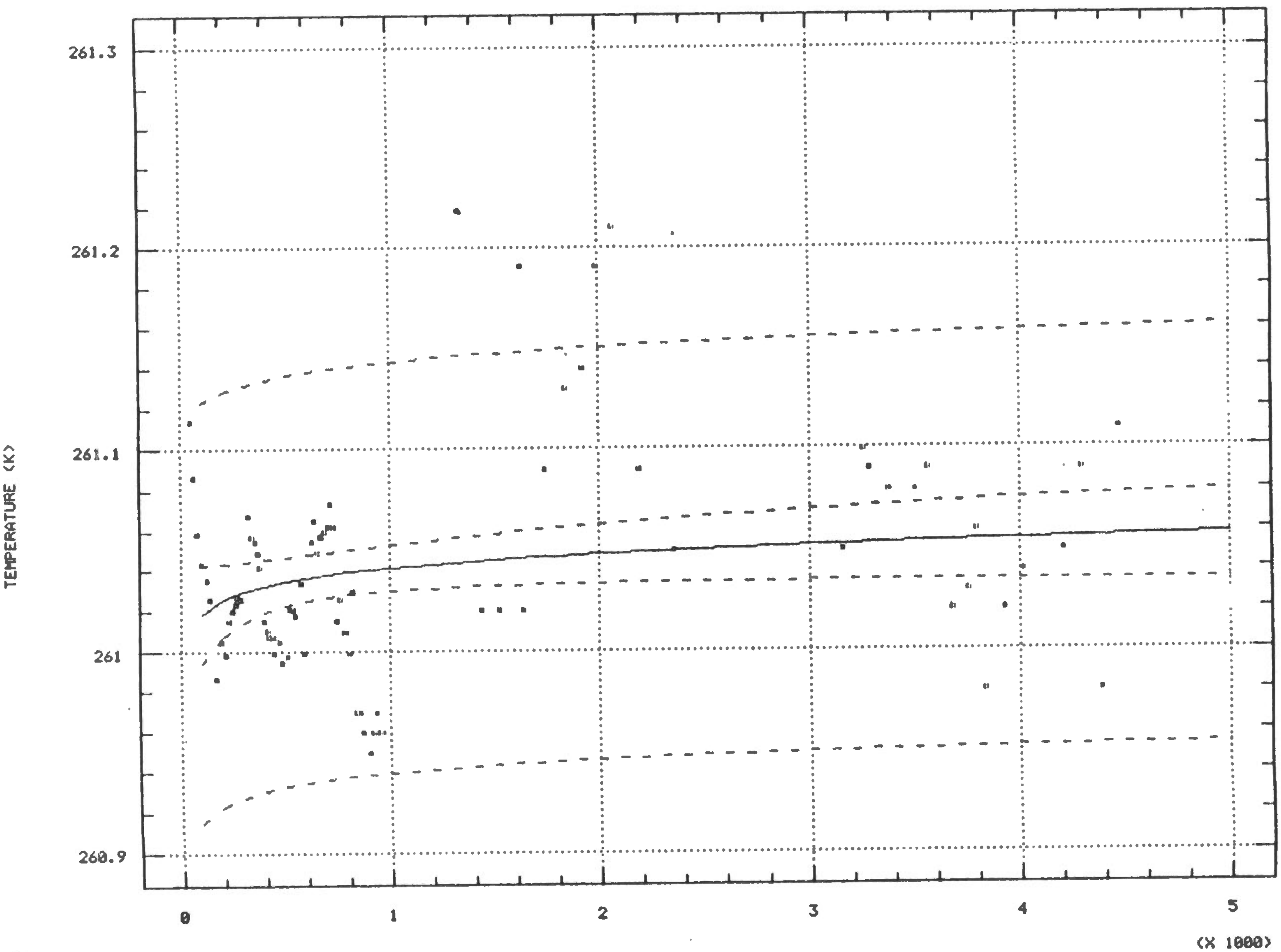


Figure H2.1