

WHY NOT USE A GRADIOMETER?: ON THE USE OF MAGNETIC PROSPECTION
DATA OBTAINED AT TWO SENSOR HEIGHTS ON ARCHAEOLOGICAL SITES

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ABSTRACT

Magnetic surveys on archaeological sites are sometimes conducted using a gradiometer consisting of a vertical pair of magnetometer sensors. This configuration eliminates diurnal changes and long range trends. However, if the data from the two sensors are separately used, additional information is available. Possibly significant longer range patterning can be seen and estimates of anomaly source depth can be made. In addition, the gradiometer results can be approximated by filtering single-sensor data. These points will be discussed using model calculations and two sets of magnetic data from a prehistoric Mississippian site in Missouri, USA, the primary features of which are storage pits and hearths. The magnetic results will be compared with excavation data obtained from the site after the survey.

INTRODUCTION

The usual manner of conducting a magnetic survey on an archaeological site is to use the difference mode with two, total-field (proton) magnetometers. One is used as a fixed reference, the other is moved over a closely spaced grid of points over the site. Both are fired at the same time and the reference values are subtracted from the grid point values. This mode not only corrects for the diurnal variation but also completely removes the high frequency ambient fluctuations of the total field. Of course the data corrected in this manner still contain all of the long range trends which are frequently geological in origin in which case not of archaeological interest.

Another approach is to use the gradiometer mode, the usual configuration being two sensors, one above the other. One form is to use two proton magnetometer sensors, another form uses two fluxgate sensors aligned accurately parallel. In this latter case the output can be continuous. Using a gradiometer removes diurnal and high frequency fluctuations as well as long range trends. However, it may very well be that the long range patterns are of archaeological significance, for instance the distribution of a midden or an earthen house outline. Also, in principle, it should be possible to obtain depth-of-source information using a gradiometer.

This paper will discuss the advantages and disadvantages of the the use of a gradiometer and alternate approaches using a filter. These concepts will be applied to a set of survey and excavation data obtained from a prehistoric Native American site in the U. S. A.

THEORY

It is first desirable to review the pertinent theory of a gradiometer. For simplicity we will first assume an isolated source of induced magnetization with the total field measurement taken with a single sensor above the source along the axis of magnetization. The anomalous field T is then given by

$$T = \text{CONST}/Z^n$$

where Z is the source-sensor distance ($n=2$ for monopole, $n=3$ for dipole, etc.). The vertical gradient is then given by

$$dT/dZ = -n(\text{CONST})/Z^{n+1} = -nT/Z.$$

The $n+1$ drop-off results in suppressing deeper, longer wavelength trends in favor of accenting near-surface, shorter wavelength features. In addition, the time varying field contributions are removed if dT is measured by the two sensors at the same time.

Also, in principle, the source depth can be obtained from

$$Z = -nT/(dT/dZ).$$

However, in the case of archaeological applications, the sources of interest may be weak, near surface features such as storage pits or small hearths. It is not practical to obtain Z from the data for the following reasons: 1) the features can have dimensions of the order of a meter and it is time consuming to use a grid interval smaller than a meter, 2) there will be uncertainty in the n th power of the source, 3) there is uncertainty in determining the background field in order to estimate the anomalous field T , 4) there can be appreciable uncertainty in dT because of the small values of T .

Another approach to the removal of long range trends and accenting near surface sources is to apply a high-frequency band pass filter to data obtained at one sensor height.

MODEL CALCULATIONS

It is of interest to get a feeling for these concepts as applied to sources typical of archaeological sites by doing some model calculations.

Single and Double Sensor Measurements

In the following figures, calculations were done to simulate the magnetic field that would be measured by a magnetometer above the surface for a single dipole buried below the surface, with the dipole magnetized in the direction of the earth's field.

In Figure 1 the dipole is 4 m deep and the sensor is 30 cm high (top figure) or 60 cm high (bottom figure). Comparison shows that in the case of a deep source there is not much difference. Figure 2 is for a dipole 0.5 m deep and the sensors again 30 cm or 60 cm high. This time there is quite a bit of difference in the measured values. Figure 3 is the difference (30 cm data minus 60 cm data) or gradiometer values for the 4 m deep dipole. the resulting values are very small with only a trace of the anomaly remaining, thus illustrating the removal of deep-source contributions. Figure 4 is the gradiometer results for the 0.5 m deep dipole. In this case the anomaly is still quite strong, since the gradient is larger closer to the source.

Filtered Data

The gradiometer mode is not, however, the only way to remove the effect of deep sources. Another approach is to mathematically filter single-sensor data in such a way as to remove the longer wavelength features.

What we have utilized here is a convolution filter. Each grid point value is replaced by a weighted average of it and neighboring values out to a preset number of neighbors - usually two to four in each direction. The weighting function is a sum of a narrow positive Gaussian function and a broad negative Gaussian. The effect of this is to remove the local trend at each point, which is equivalent to removing the longer wavelength features and leaving the shorter wavelength features. Thus by filtering one set of data essentially the same results are obtained as from gradiometer data.

Again we use model calculations, this time to compare gradiometer and filtered data. Figure 5 is the result of combining the 4 m deep dipole source with the 0.5 m deep dipole source. The top map is of the gradiometer or difference values, the bottom map is of the 30 cm data set filtered. There are slight differences which depend on the particular parameters used in the filter, but in general there are very similar. In both cases the deeper-source anomaly has been removed.

APPLICATION TO AN ARCHAEOLOGICAL SITE

As part of a program of an archaeological inventory of the Ozark National Scenic Riverways in southeast Missouri, the Midwest Archeological Center, National Park Service, collected sets of magnetic surveying data on three archaeological sites. I then analyzed the data at the University of Nebraska. At one one of these sites two surveys were conducted at two different sensor heights, the analysis provided a valuable opportunity to compare the two sets of data, to compare them with gradiometer data and also with filtered data, and to compare predictions with excavation results.

The site under discussion is Shawnee Creek, 23SH11, in southeast Missouri. It lies on a flat terrace of the Jacks Fork River and had been known for some time by collectors who had found material from the late archaic period through the proto-historic period. Test excavations were first carried out on the site in June 1985 which revealed the location of a burned Mississippian house. The approximate extent of the structure is marked by dotted lines on Figure 6.

The Magnetic Surveys

Two magnetic surveys were carried out on this site, the first in 1985 and the second in 1986. Both surveys were done with two Geometric G856 Memory Magnetometers having a sensitivity of 0.1 gamma and used in the difference mode with one stationary or reference magnetometer and one magnetometer positioned on the grid points, both being fired at the same time for each reading. In all cases the grid unit was one meter.

The excavations in 1985 were done before the first magnetic survey. The excavations by the Midwest Center were done after the second magnetic survey. The hearth of the excavated house produced a strong anomaly pattern in both of the surveys.

The 1985 survey

Three 20 m by 20 m blocks were surveyed in November 1985 with the sensor of the moving magnetometer kept at 60cm above the surface. The layout of the survey is shown in Figure 6. However, since the later survey only covered Blocks A and B, the maps will only cover these two blocks. The results of the 1985 survey are shown in Figures 7, which is a grey-scale, SYMAP rendition of the results. This type of map is limited to only 10 levels, so non-linear level intervals have been used with the mid-level interval in this case being 1 nT. It can be seen that there is a strong high trend crossing over the site. The north-east part is generally low while the southern part is high. The house-hearth anomaly is obvious in Block A. This anomaly is distorted by the fact that the hearth region was excavated before the survey. There are numerous smaller anomalies, some of which are lost in the strong trend. There are two ways to remove the trend. One is to take another set of readings at a different sensor height and simulate the gradiometer mode, the other is to mathematically filter the data.

The 1986 survey

The second survey was done in June 1986 with the sensor of the moving magnetometer kept at 30 cm above the surface. This survey only covered Blocks A and B. Figure 8 is a SYMAP map of the survey. In comparing the results with those obtained with the earlier survey, many of the anomalies are repeated in the same position, thus showing that the relocation of the grid had little error. A gradiometer survey was simulated by subtracting one set of data from the other and also the data were filtered.

Analysis of the Shawnee Creek data

All of the above analysis has been used to interpret the isolated anomalies in Blocks A and B. Figure 9 shows line contour maps of Blocks A and B for the two sets of data: 60 cm high sensor and 30 cm high sensor. Figure 10 show the difference or gradiometer data and the 30 cm high data filtered.

Although the excavations carried out by The Midwest Center were done soon after the 30 cm survey, I did not examine the results of the excavations until after I had made my "predictions" based on the analysis of the data. I identified at least 14 anomalies of possible significance. On the basis of the 1985 magnetic survey results, The Midwest Center positioned 5 excavation units over anomalies. The excavations units are marked on Figure 10. Four of these occurred in the Blocks A and B. I have listed below my "predictions" and the excavation results in table I. It should be kept in mind that depth estimates are very rough, partly because a 1 m grid unit is too coarse for features that are less than 1 m in size.

The results of No. 4 were quite satisfactory. The prediction on No. 6 overestimated the depth. The prediction on No. 8 was correct in suggesting a weak source and because it was weak the depth estimate was incorrect. The gradiometer values of No. 10 were weaker than the filtered values, possibly a result of the fact that the two surveys were not done at the same time which may have introduced a positioning error. The filtered results agreed with the fact that the hearth was not deep. All of these anomalies, some of which were on top of a strong geological trend, correctly predicted archaeological features.

TABLE I
 Shawnee Creek, 23SH11
 Magnetic Anomalies, Predictive Interpretations and
 Excavation Results
 (PZ = plow zone, FCR = fire cracked rock)

No.	Predictive Interpretation	Excavation Results
4	Normal dipole, strong on 30 cm. 60 cm and gradiometer about same. 40 cm to 60 cm deep, significant.	Pit, 1.1 m diam. to 75 cm deep. Burned earth, FCR, chipped stone, ceramics, bone, charcoal.
6	Monopole, weaker on 60 cm than gradiometer, 30 cm and filtered. Moderate depth.	Pit 61 cm by 20 cm to 36 cm deep. Ceramics, flakes, charcoal.
8	Weak on all data sets, particularly 60 cm and gradiometer. Source not strong magnetically, possibly 80 cm deep.	Some chipped stone and FCR in PZ, no evidence of subsurface feature. Excavation terminated at 17 cm.
10	Stronger on 30 cm than 60 cm. Filtered strong but gradiometer not so strong so depth interpretations ambiguous. Filtered suggests not deep.	FCR and burned soil in PZ, at 33 cm lens of burned soil 10 cm by 30 cm to 45 cm deep. Archaeomagnetic sample taken.
11	On edge of Block C, not enough information.	Pit 2.1 cm diam. to 68 cm deep. Ceramics, chipped stone, FCR, charcoal.

CONCLUSIONS

If possible, it is desirable to get two sets of magnetic survey data at two different sensor heights. This will provide more information on the nature of the anomaly sources. However, taking two sets of data is time consuming and costly. Thus, the next best thing is to examine filtered data as well as the original data set. Such a process is easier and cheaper. There exists on the market, gradiometers that give the difference values directly (two coupled sensors in a vertical configuration). If such an instrument is used without having each sensor reading recorded separately with reference corrections, then valuable information is thrown away. Such an instrument is useful for quick, preliminary surveys or in a situation where only near-surface sources are of interest. But more extended patterns and information on deeper sources will be lost.

FIGURE CAPTIONS

1. Grey-scale map and data matrix for model calculation of anomalous field of dipole 4 m deep measured on a 1 m grid with sensor 30 cm (top figure) or 60 cm (bottom figure).
2. Grey-scale map and data matrix for model calculation of anomalous field of dipole 0.5 m deep measured on a 1 m grid with sensor 30 cm (top figure) or 60 cm (bottom figure).
3. Grey-scale map and data matrix for model calculation of anomalous field of dipole 4 m deep measured on a 1 m grid with gradiometer (30 cm high minus 60 cm high).
4. Grey-scale map and data matrix for model calculation of anomalous field of dipole 0.5 m deep measured on a 1 m grid with gradiometer (30 cm high minus 60 cm high).
5. Grey-scale map and data matrix for model calculation of anomalous field of two dipoles, one 0.5 deep the other 4 m deep, measured on a 1 m grid with a gradiometer (top figure) or sensor 30 cm high and high frequency band pass filtered (bottom figure).
6. Layout of survey blocks with locations of anomalies and excavation units.
7. Grey-scale (SYMAP) magnetic map of 23SH11, Blocks A and B, sensor 60 cm high, contour interval 1.0 nT in mid-intervals.
8. Grey-scale (SYMAP) magnetic map of 23SH11, Blocks A and B, sensor 30 cm high, contour interval 1.0 nT in mid-intervals.
9. Line contour magnetic map of 23SH11, Blocks A and B, sensor 30 cm high (left figure) and 60 cm high (right figure), contour interval 1.0 nT.
10. Line contour magnetic map of 23SH11, Blocks A and B, gradiometer with excavated anomalies marked (left figure) and sensor 30 cm high and high frequency band pass filtered (right figure).

LEVMAP OF SITE: DIPOLE 4m 50cm

INTERVAL BOUNDARIES		-24	-12	-6	-3	0	3	6	12	24			
		x	o	::	+	+	+	+	+	+			
21		-1	-1	-1	-1	-2	-2	-2	-2	-2	-1	-1	-1
18		-1	-1	-1	-2	-2	-2	-2	-2	-2	-2	-1	-1
15		-1	-1	-1	-2	-2	-2	-2	-2	-2	-2	-1	-1
12		-1	-1	-1	-1	-1	0	0	0	-1	-1	-1	-1
9		-1	-1	-1	-1	0	2	4	5	4	2	0	-1
6		0	0	0	1	3	7	11	13	11	7	3	1
3		0	0	0	1	3	7	13	20	23	20	13	7
1	10	0	0	0	1	3	6	11	16	19	16	11	6
	19	0	0	0	1	3	5	8	11	12	11	8	5
		0	0	0	1	2	4	5	7	8	7	5	4
		0	0	0	1	1	2	3	4	4	3	2	1
		0	0	0	1	1	1	2	2	3	2	2	1
		0	0	0	1	1	1	1	2	1	1	1	0

LEVMAP OF SITE: DIPOLE 4m 60cm

INTERVAL BOUNDARIES		-24	-12	-6	-3	0	3	6	12	24			
		x	o	::	+	+	+	+	+	+			
21		-1	-1	-1	-1	-1	-2	-2	-2	-2	-1	-1	-1
18		-1	-1	-1	-1	-2	-2	-2	-2	-2	-2	-1	-1
15		-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
12		-1	-1	-1	-1	-1	0	0	0	0	-1	-1	-1
9		-1	0	0	1	3	6	9	11	9	6	3	1
6		0	0	0	1	2	5	10	15	17	15	10	5
3		0	0	0	1	3	6	11	16	19	16	11	6
1	10	0	0	0	1	3	6	10	14	16	14	10	6
	19	0	1	1	3	5	8	10	11	10	8	5	3
		0	1	1	2	4	5	7	7	7	5	4	2
		0	0	0	1	2	2	3	4	4	3	2	2
		0	0	0	1	1	2	2	2	3	2	2	1
		0	0	0	1	1	1	2	2	2	1	1	0

Figure 1

LEVMAP OF SITE: GRADIOMETER 4m

INTERVAL BOUNDARIES -24 -12 -6 -3 0 3 6 12 24

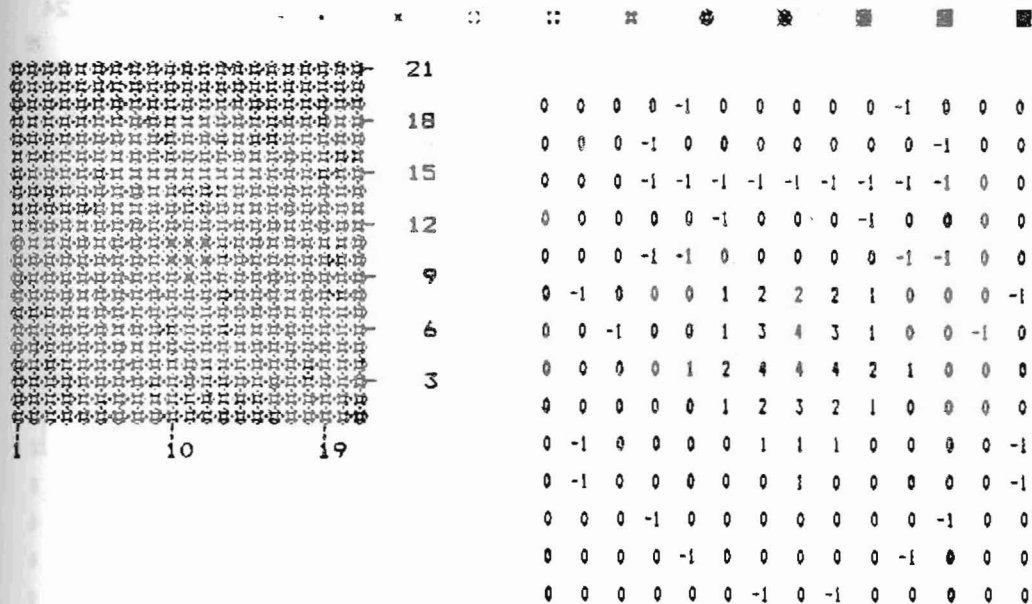


Figure 3

SITE 23SH11, SHAWNEE CREEK

Magnetic Survey Blocks

Anomaly Locations and Excavation Units

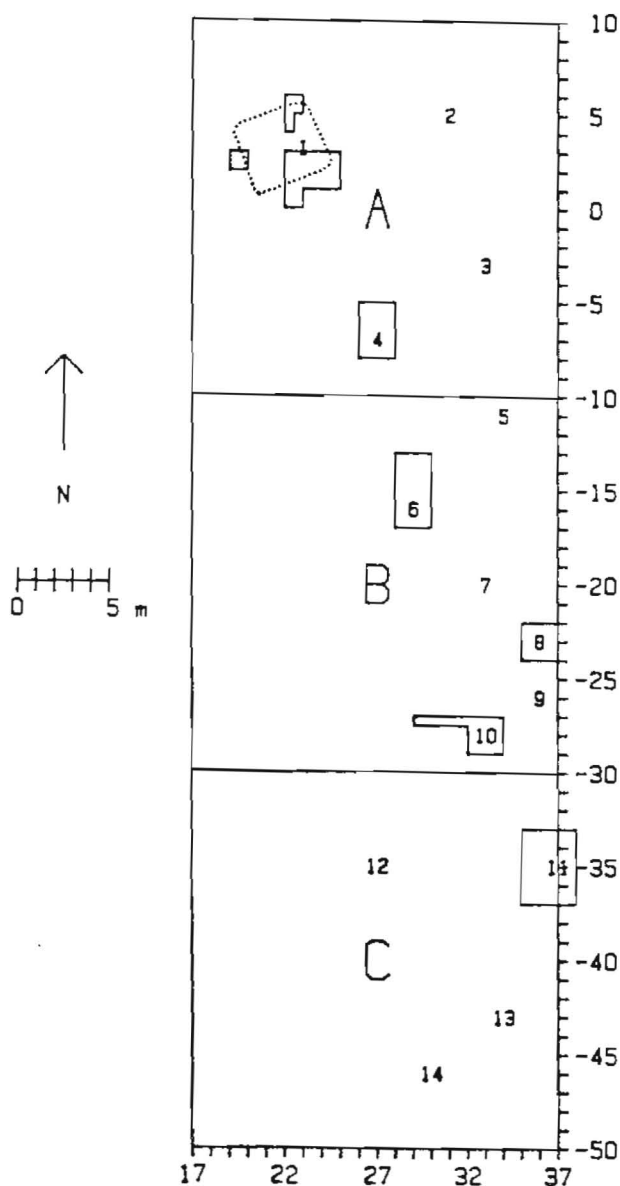
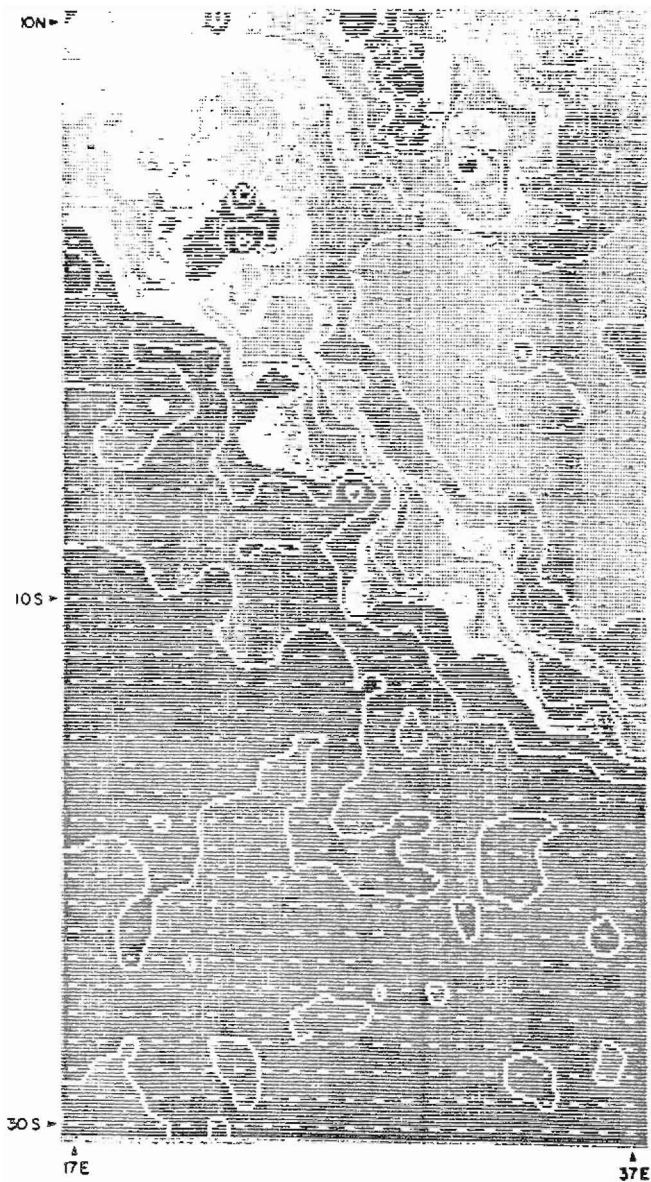
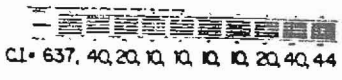


Figure 6



23SH11
 SHAWNEE CREEK
 Sensor 60 cm high

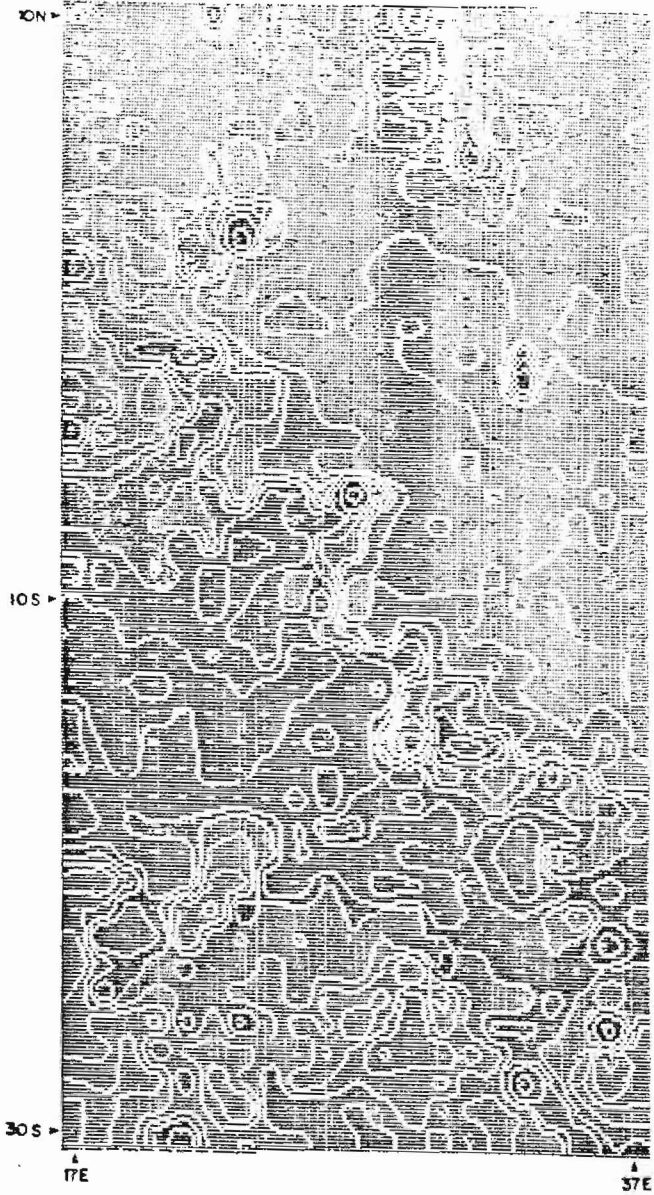


In Q1nT units

NEBCAR 1988



Figure 7



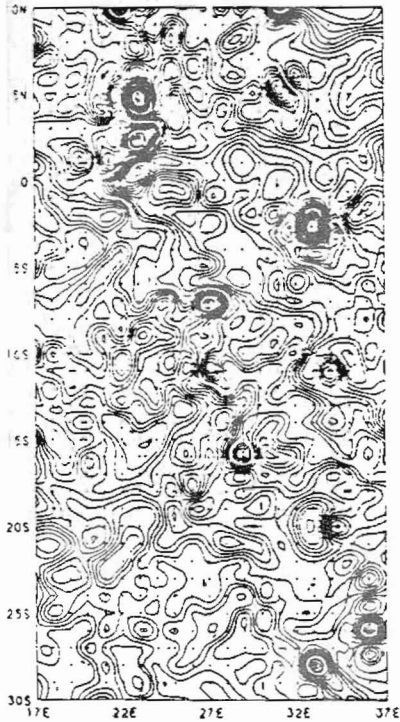
23SH11
 SHAWNEE CREEK
 Sensor 30 cm high

CI = 156, 48, 24, 12, 12, 12, 24, 48, 24
 in Q1nT units

NEBCAR 1988

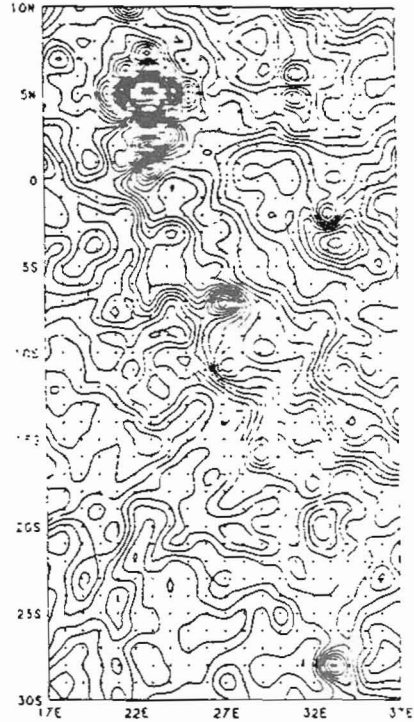


Figure 8



30 cm.

23SH11
SHAWNEE CREEK



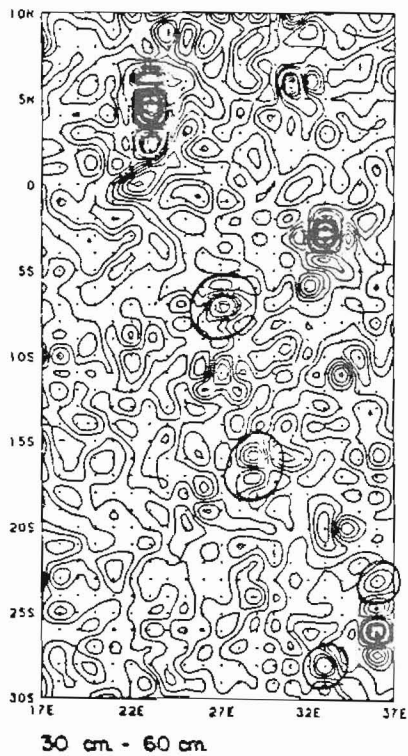
60 cm.

C.L. = 1mT

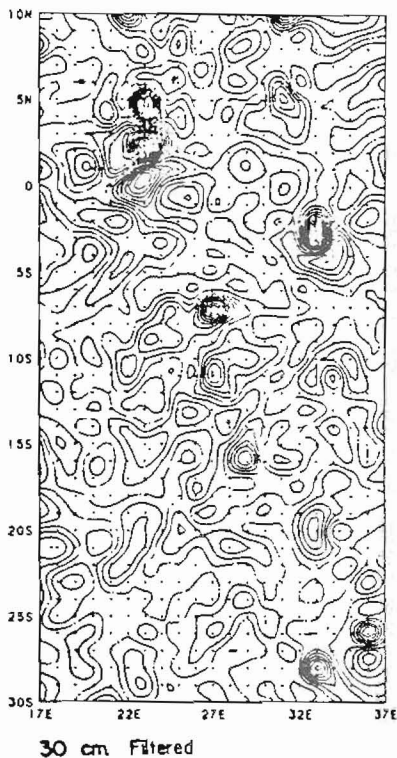


Nebcar 1988

Figure 9



4
6
8
10



CL = 1mT



Nebcor 1988

Figure 10