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DECEMBER 1970

STATISTICAL ALGORITHMS AND COMPUTER PROGRAMS FOR ANALYSIS OF MULTI-SPECTRAL OBSERVATIONS

FINAL REPORT

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Prepared for:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
Aero-Astrodynamics Laboratory

UNDER CONTRACT NO. NAS8-25182

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STATISTICAL ALGORITHMS AND COMPUTER PROGRAMS FOR ANALYSIS OF MULTI-SPECTRAL OBSERVATIONS

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by

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PREPARED FOR

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FOREWORD

This study was undertaken by Northrop-Huntsville, for the NASA/MSFC Huntsville, Alabama, under Contract No. NAS8-25182. The program was under the direction of MSFC's Flight Data Statistics Office with Dr. F. R. Krause as the project monitor.

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INTRODUCTION

As more sophisticated space vehicles and orbiting space stations are developed, onboard data processing and conditioning becomes an imperative system design consideration. The outputs from hundreds or thousands of various sensors in advanced mission payloads are fast exceeding the capacity of available and near-real-time communication systems. In particular, the airborne sensors for earth resources and advanced surveillance have larger amounts of data output as requirements increase for greater area coverage and resolution.

Remote sensing of the earth's resources and environment from airborne and satellite-borne sensors is becoming one of the most significant and immediate applications of the developed space technology to the whole world. The entire spectrum of remote sensing technology will cover sensor design, ground truth study, atmospheric physics, data handling, and data analysis. This study is concerned with data analysis only.

The purpose of data analysis in remote sensing problems is to assess or identify some desired characteristics of the sensor's targets through analysis of multispectral (or multimage) data collected by the sensors. These characteristics may be surface temperature, humidity of the ground, salinity of the ocean, or classifications among different crops and soils. Different applications mainly require different sensors designed to operate at different ranges of the electromagnetic spectrum, while the methods of data analysis are quite similar in principle. Therefore, it is not necessary to specify any particular applications in order to discuss the data analysis techniques.

Since these techniques are to be used for identifying desired characteristics from some given data measurement, they are really within the region of pattern recognition problems. These problems have a long history of developments especially in the field of experimental psychology, neurophysiology of the visual system, and automatic machine character recognition.

Handling and processing of the vast amount of data, which are usually random processes, will require compression of the data to smaller quantities of more meaningful parameters. These parameters should characterize the physical phenomena recorded by the various sensors and usually include the mean value, first few orders of central moment, correlation functions, spectral density functions, probability density function, and associated error functions with respect to each evaluated parameter. To handle many sensor outputs simultaneously would require multi-channel data processing. Further, to perform the data processing in a continuous and near-real-time basis, on-line sequential techniques are necessary.

Statistical methods for the analysis of aircraft survey data are being developed by the University of Michigan, Purdue University, and the University of Kansas. All these methods require human intervention to select homogeneous training areas on the ground. Spectroscopic reference signatures are then computed for each training set and all other resolution elements are classified by matching them with all the reference signatures. The University of Michigan uses the correlation computation for the match, i.e., by computing the correlation coefficients between the sample spectrum and the various reference spectra (ref. 1). Purdue University uses more complex Bayesian statistical decision methods for classification (ref. 2). The University of Kansas uses even more complex clustering techniques which employ both measurement space and spatial clustering (ref. 3).

Our classification differs from the above techniques in using methods of change analysis for the classification of resolution elements. Human interventions for the selection of training areas and reference spectra are not needed. The strip map of an electromechanical scanner is subdivided into inventory areas whose resolution elements are homogeneous.

Statistical methods for data flow compression and signature enhancement are being developed to improve the utilization of remote earth observations from aircrafts and spacecrafts. The objectives of our present research program are to extend the automatic data flow compression and signature enhancement that has previously been developed for earth based sensors to flight systems.

Section II presents analytical consideration and mathematical algorithms for automatic analysis of multispectral data. Section III describes in detail the computer programs developed based on mathematical algorithms presented above. The application of these computer programs to some actual remote sensing data by the University of Michigan multispectral scanner from a aircraft over some agricultural fields is presented in Section IV. Finally, the summary and conclusions are given in Section V.

Section II

ANALYTICAL CONSIDERATIONS AND ALGORITHMS

2.1 INTRODUCTION

Analytical considerations and the corresponding classification algorithms for multispectral data sequences are presented in this section. In order to have a better understanding of the overall problem involved, a survey of pattern recognition problems will be given first. This will be followed by (a) statistical analysis of feature characteristics, (b) statistical test for inventory boundary, (c) boundary enhancement by area smoothing and differentiation, and (d) similarity criteria between different populations. An overall functional block diagram of the data analysis is shown in Figure 2-1.

2.2 PATTERN RECOGNITION PROBLEMS – A BRIEF SURVEY

Pattern recognition techniques are methods for making decisions based on statistical testing. The purpose is to identify a specified pattern from a set of given input measurement or to classify a given input to one of several prescribed categories. The input measurement is usually composed of a set of N numbers of ordered entries (or components) X_i (i = 1,2, . . ,N), which may be considered as a feature vector $\bar{X}$ in N - dimensional feature space. The pattern recognition technique is to be used to classify $\bar{X}$ to one of M categories C_j, j = 1, 2, . . .M, based on some criterion of similarity between the input feature and the given patterns.

The first important step in any pattern recognition problem is to know the characteristics of the feature vector from a sufficiently large ensemble of presentative samples of every possible category C_i. The necessity of this step is obvious, since, without knowing the characteristic or invariants associated with every pattern category, there is simply no rational basis for identifying them. Some variations in the characteristics of the feature vector always exist and some uncontrollable factors further introduce errors in the measurement of the feature vector. Hence, the logical way to analyze the feature characteristics is by statistical methods. This will require evaluating the

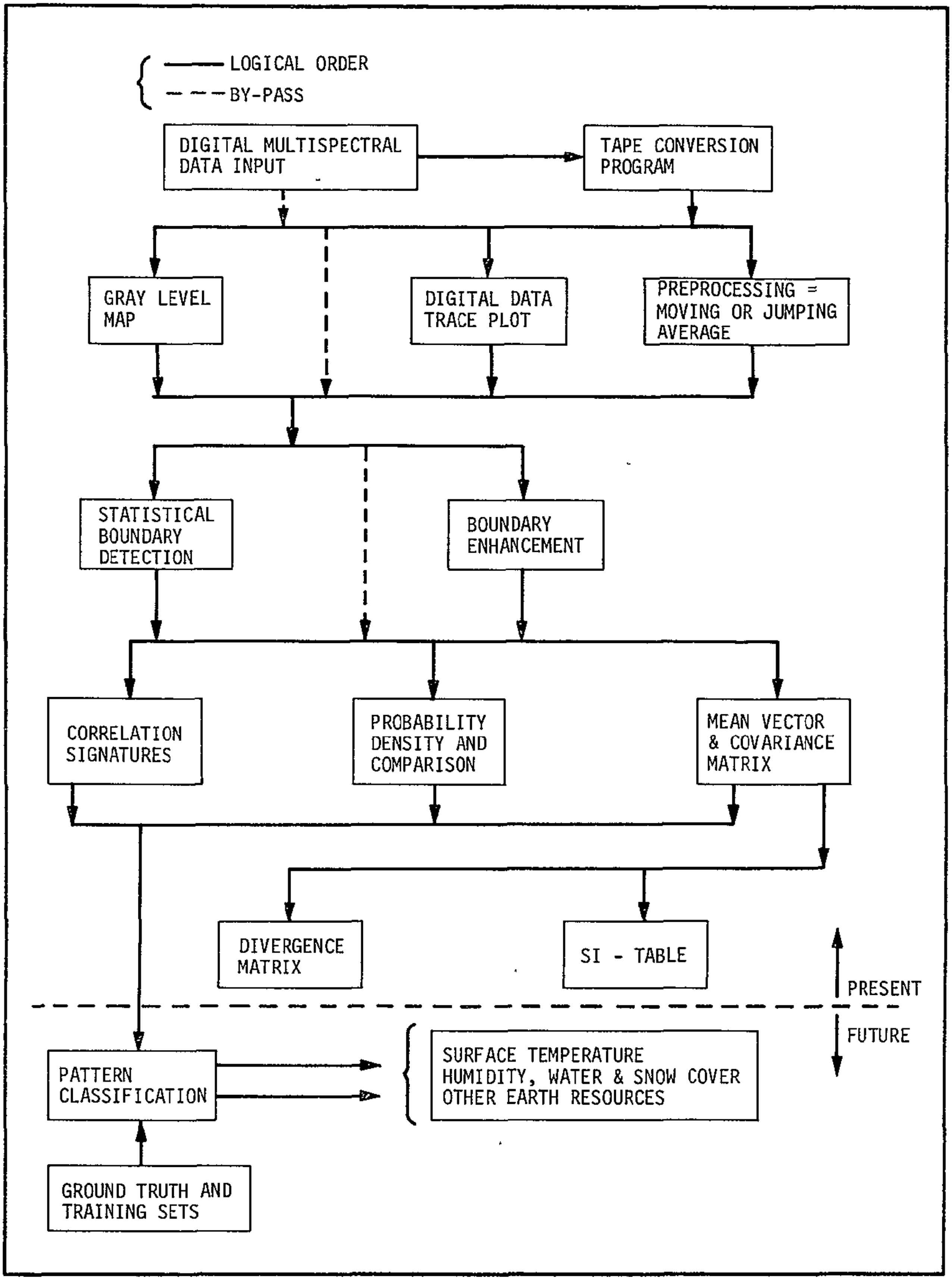

Figure 2-1. BLOCK DIAGRAM OF DATA FLOW

mean, rms, probability density of each component, covariance matrix among any two pair of components, etc., from the set of representative samples (usually, called a training set). From these parameters and quantities evaluated, some statistical models may be formulated. These models, expressed in functional form, may replace those often lengthy and volumous numerical values of the feature characteristics. Some particular statistical models such as Gaussian distribution permit simplification in the latter steps involved in the pattern recognition.

The statistical theory states that if every component of a given feature vector is equally important, then the probability of success for recognizing a certain pattern will increase with the number of the components employed. If every component is not equally important, then the probability of success will depend not only on the number of components employed, but also on their relative importance. Further, a complete statistical description of an ensemble of samples require very large numbers of components to be measured from each sample. It is both impractical and undesirable to do so. This consideration brings out the second important step in pattern recognition, namely, the problem of feature selection. A rationale for feature selection may be stated as follows: "Given the desired accuracy, we want to find the optimum group (or groups) of a predetermined number of components from the feature space so that the probability of error or misrecognition be a minimum." Actually, the optimum feature selection depends on the error criterion chosen, feature characteristics, and algorithms for classification.

Assume one has been given the optimum set of measurement vectors, the next step in pattern recognition is to devise some rule by which to classify any given feature measurement into one of several pattern categories. So this is the classification problem. One of the simplest classification methods is to compare the relative distance between the point (in feature space) to be classified to every representative mean point of available pattern categories. The category with the shortest distance to the point under consideration will be assigned as the recognized pattern. Such a simple classification method is, however, quite limited. For example, there may be a situation where making a wrong classification on some pattern categories is more costly than others.

Under such a situation, we want to weigh differently on different pattern categories according to their relative importance. Many more sophisticated classification methods have been developed based on testing hypotheses in statistical inference theory. One of the most powerful methods is the maximum likelihood ratio test.

In summary, a pattern recognition system consists of three interrelated aspects: feature characteristics analysis, feature selection, and classification algorithms. Each of these aspects will be described in more detail in the following sections including corresponding pertinent bibliographies. A hierarchy of the pattern recognition program is shown in Figure 2-2.

2.2.1 Feature Characteristics Analysis

Because the feature measurement taken in natural situations always involve some influence by the environment, and because some variations also exist in most pattern categories, the logical way to assess the characteristics of the feature vector will be the statistical analysis. More specifically, since the feature vector is of multiple components, a multivariate analysis will be needed. There are many different statistical methods to describe the feature characteristics in the feature space such as joint probability density, correlation function, spectral density, and characteristic function (which is the Fourier transform of the probability density), just to name a few. In general practice and for simplicity, however, it usually takes some combination of these different types of statistical descriptions in their respective lowest order. In other words, one will usually evaluate at least the following quantities from the representative set of available samples:

- Mean vector, which is the ordered mean values of the feature components denoted by $\bar{\mu} = (\mu_1, \mu_2, \ldots \mu_N)$.
- Correlation matrix, which is a matrix of mean products of any two pair of feature components, denoted by R_{ij}.
- Covariance matrix, which is a matrix of mean products of any two pair of feature components subtracted by their respective mean values, denoted by C_{ij}.
- Univariate histogram, which is the probability density of a single feature component.

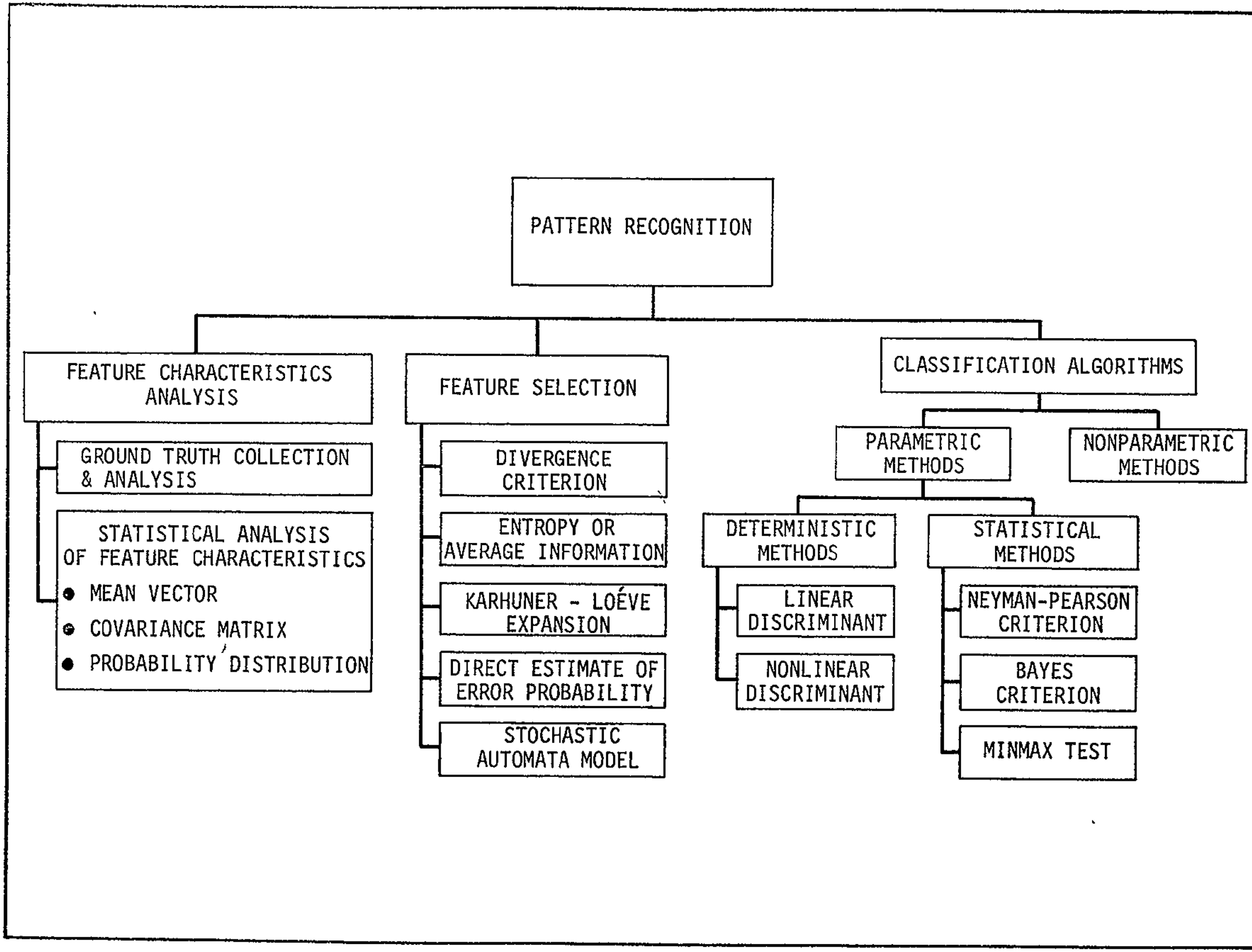

Figure 2-2. A HIERARCHY OF PATTERN RECOGNITION PROBLEM

From the above evaluated parameters and functions some analytical models or approximation of the feature space of the pattern categories may be induced.

When the multivariate Gaussian distribution is made, the ensuing analysis on feature selection and classification algorithms can be greatly simplified. This is also the reason why so many approaches developed for pattern recognition system employ this particular distribution (or model).

2.2.2 Feature Selection

Not every component of the feature vector (or the set of measurement) are equally important for classification. Obviously, those components peculiar to pattern categories are of primary importance. It is also desirable to use as few components as possible to achieve the prefixed accuracy of successful recognition. These two facts suggest the need for an objective study of selecting the feature components. The feature selection is closely related to the performance of pattern classification.

Generally speaking, the more feature components used, the higher the probability of successful recognition. So, the problem of feature selection might be more rigorously stated as follows: out of a given physically accessible or available set of feature components, to select an optimum subset of a prescribed number of feature components such that the probability of successful recognition is maximized. By this definition, the feature selection problem must be analyzed with respect to a particular descision process for pattern recognition. However, this logical approach for feature selection is very complicated. Therefore, several existing methods for the feature selection adopt different approaches based on various measures of effectiveness in the choice of components.

One approach is to employ a measure of distance between any two (arbitrary) probability density of pattern categories (ref. 4). This measure is called "divergence", which is defined as the difference between two expected values of the likelihood ratios. The second approach uses the idea of entropy or average information (ref. 5) as criterion for feature selection. This approach calculates a statistic obtained over a large sample set to yield a measure of goodness for the feature component, which can be considered as the mutual information of the feature and the pattern classes. The third approach employs Karhunen - Loéve expansion which does not require the a priori knowledge of the probability density of the feature vector. The essence of the expansion is to project the original feature vector onto a less-dimensional vector space spanned by a set of deterministic orthonormal coordinate functions. The expansion has the following optimum properties: (1) it minimizes the mean-square error for the truncated series of the expansion and (2) it minimizes the entropy function defined over the variance of the random coefficient in the expansion (ref. 5).

2.2.3 Classification Algorithms

The classification scheme in pattern recognition is to divide the feature space into some prescribed number of subspaces, each of which will be designated for one of the pattern categories. Different classification schemes differ mainly in the criteria used to establish these subspaces. The separating boundaries between these subspaces are called decision surfaces which can be defined by a set of functions. These functions are called "discriminant functions" and are so chosen that one and only one of them will give the larger value compared to the others for all samples in a particular pattern class (i.e., a subspace). That is, for a given feature vector to be classified, a finite number of discriminant functions are to be evaluated with this feature vector. The function which yields the largest value will assign the input feature vector to the pattern category for which this function is designated. This scheme may be expressed as follows: Any given feature vector $\bar{X}$ is classified as a pattern class C_i (i=1, 2...,M), if

$$g_i(\bar{X}) > g_j(\bar{X}) \text{ for all } i \neq j,$$

where g_i (i=1, 2...,M) are the discriminant functions for class C_i.

The classification methods may be divided into two main groups; namely, the parametric method and the nonparametric method. The parametric method is more appropriate for classification when each pattern category can be characterized by a set of parameters obtained from the feature characteristics analysis of the training set. The nonparametric method is more appropriate when no simple realistic assumption can be made on the characteristics of the pattern classes. These two methods are discussed in more detail in the following paragraphs.

The parametric method may be further divided into two distinct groups; deterministic and statistical methods. The discrimination functions in the deterministic methods can be either linear or nonlinear in the input feature vector. The linear discriminant functions separate the feature space by hyperplanes, while the nonlinear discriminant functions divide the feature space into curvilinear hypersurfaces. The simplest linear deterministic method is the so-called correlation method (also called template matching). This method evaluates the scalar product of the input feature vector with a set of reference feature vectors, each of which represents a particular pattern class. The feature vector will then be assigned to the particular pattern class that yields the largest scalar product. Another linear deterministic method is the minimum-distance method which uses the shortest distance between the input feature vector to the set of reference pattern vectors as the criterion.

The three common statistical classification methods are Neyman-Pearson criterion, Bayes criterion, and minimax test. The Neyman-Pearson criterion is the simplest of all and demands the least a priori information. The Bayes criterion is to minimize the average cost of misrecognition, when the priori probability of occurences of pattern classes are known, and when the average cost is a linear function of the absolute error probabilities. The minimax test is a Bayes test except that the former minimizes the maximum of the conditional cost of misrecognition. All three of these tests are optimum under the respective criteria and also use the liklihood ratio of the conditional probability densities of the pattern classes. These methods hold for any arbitrary distribution functions; however, great simplifications may be made if the distribution is Gaussian.

Finally, we shall describe the nonparametric methods for pattern classification. By these methods, no parameter from the training set is evaluated a priori, rather the discriminant function (in the linear case) will assume the form of

$$g_j(\bar{X}) = \bar{W}_j \cdot \bar{X} = \sum_{i=1}^{N} W_{ji} X_i$$

(j=1, 2, ...,M and i=1, 2, ...,N),
where $\bar{W}_j$ (W_{j1}, $W_{1\ 2}$, ...,W_{jN}) are the weighting functions for the j^{th} pattern class. These weighting functions are to be determined by a systematic error-correction scheme from the training set. The error-correction scheme may be written as

$$\bar{W}_j' = \bar{W}_j + c\bar{X}$$

This states that each new weighting function is simply the sum of the old one plus a fixed fraction c of the input feature vector. It has been proven theoretically that within the finite number of error corrections, a suitable weighting function can be obtained, provided that the training set is separable by hyperplanes.

In summary, the advantage of the nonparametric method is that no assumption is needed on the feature space. However, they are applicable to those cases where pattern classes may be separable by hyperplanes, while the parametric method is not restricted by the separability requirement.

2.2.4 Pertinent Bibliography For Pattern Recognition

Some pertinent bibliography on the pattern recognition technique together with remote sensing of the earth's resources and environment will be given in Appendix A. This bibliography is classified into five categories.

- Remote sensing of the earth's resources and environment
- Pattern recognition in general
- Feature characteristics analysis
- Feature selection
- Classification algorithms.

This bibliography is not intended to be extensive, rather it is considered to be more informative for the reader.

2.3 STATISTICAL TEST FOR INVENTORY BOUNDARIES

2.3.1 Introduction

Any statistical evaluation of multispectral observation requires a population of resolution elements that are statistically alike. Such a population occupies a certain area of the strip map, which shall be called an inventory area. In many cases such inventory areas are continuous in space. Typical examples of such continuous inventory areas are clouds, snow fields, agricultural fields, forests, etc. The boundary of the inventory area shall be called inventory boundary which thus separate populations of homogeneous resolution elements. However, all statistical properties will change whenever an inventory boundary is crossed. Conversely, the change of statistical properties along a scan line indicates that an inventory boundary has been crossed.

The above considerations provide a basis for the development of sequential and completely automatic methods for the selection of the inventory boundary. Our previous tests for environmental variations (refs. 6 and 7) recognize the change of statistical parameters with record length. Furthermore, the position of an inventory boundary indicates a change of reflectance or thermal emission which is not tied to any particular application. Statistical methods which utilize inventory areas are thus applicable to crop surveys, yield surveys, and land use investigations. Automatic detection of inventory boundaries could thus support statistical data flow compression and signature enhancement methods that may be sued for many disciplinary applications.

2.3.2 Formulation of the Algorithm

The computer selection of inventory boundaries follows from a direct application of accumulative error curves (refs. 6 and 7). Consider a sequence of resolution areas, i = 1, 2,..., m, along a scan. Each of these resolution areas is assumed to be statistically independent. Any average $\overline{(\ )}_i$ from a single resolution area then represents a statistical experiment. If all resolution areas belong to the same inventory area, then the accumulative average over these areas

$$\overline{\overline{(\ )}}_m = \frac{1}{m} \sum_{i=1}^{m} \overline{(\ )}_i \qquad (2\text{-}1)$$

should become more accurate as m increases. The statistical error of such an accumulative average should thus become smaller with increasing m.

The test for inventory boundaries is now derived by monitoring the decrease of the actual error with accumulative number m, by comparing this actual error curve with the most probable error curve.

The actual (or sampled) error of an accumulative mean, $\Delta\,\overline{\overline{(\ )}}_m$, can be computed from the deviation of the individual experiment $\overline{(\ )}_i$ relative to the accumulative average over all experiments.

$$\Delta\,\overline{\overline{(\ )}}_m^{\,2} = \frac{1}{m(m-1)} \sum_{i=1}^{m} \left[\overline{(\ )}_i - \overline{\overline{(\ )}}_m\right]^2 \tag{2-2}$$

This actual error can also be used to construct a random variable; i,e, Chi-square variable with (m-1) degree of freedom. That is

$$\chi^2\,(m-1) = \frac{m(m-1)\,\Delta^2\,\overline{\overline{(\ )}}_m}{\sigma^2} \tag{2-3}$$

The value of σ^2 is constant as long as the resolution areas, i = 1, 2 ... m, are statistically independent and belong to the same population. Under these considerations, the probability distribution of the variable χ^2 is also known. The most probable χ^2 (m-1) value is given by

$$\chi^2\,(m-1)\Big|_{\text{most prob.}} = m-3 \quad \text{for } m \geq 4 \tag{2-4}$$

This most probable value indicates the existance of a most probable error

$$\delta_m^2 = \frac{\delta^2}{m(m-1)}\;\chi^2\,(m-1)\Big|_{\text{most prob.}} = \frac{m-3}{m(m-1)}\;\sigma^2 \tag{2-5}$$

The value of the unknown variance σ^2 can now be estimated by fitting the shape of the most probable error curve, δ_m, to the actual error curve $\Delta\,\overline{\overline{(\ )}}_m$. This curve fit is chosen such that the relative mean square variation between these two curves become a minimum. Let M denote the last accumulative number. The above curve fit may thus be expressed by

$$\frac{\partial}{\partial\sigma} \sum_{m=4}^{M} \left\{\frac{\Delta\,\overline{\overline{(\ )}}_m - \delta_m}{\delta_m}\right\}^2 = 0 \tag{2-6}$$

Substituting δ_m from the previous equation and differentiating yields

$$\sigma^2 = \frac{\sum_{m=4}^{M} \frac{m(m-1)}{m-3} \Delta \overline{\overline{(\ )}}_m^2}{\sum_{m=4}^{M} \sqrt{\frac{m(m-1)}{m-3}} \Delta \overline{\overline{(\ )}}_m} \tag{2-7}$$

The actual error $\Delta \overline{(\ )}_m$ should oscillate around the most probable error curve. The range of oscillations is given by the confidence factor of the Chi-square χ^2 distribution.

$$\frac{\chi_{1-p}(m-1)}{\sqrt{m-1}} \frac{\sigma}{\sqrt{m}} \leq \Delta \overline{\overline{(\ )}}_m \leq \frac{\chi_p(m-1)}{\sqrt{m-1}} \frac{\sigma}{\sqrt{m}} \tag{2-8}$$

The values of $\chi_p (m-1)/\sqrt{m-1}$ and $\chi_{1-p} (m-1)/\sqrt{m-1}$ are listed in Table 2-1.

The above derivation is only for single channel data. It is natural to extend the test for inventory boundary to a combination of several channels. This extension is achieved by replacing the random variable (defined by equation (2-6)) for a single channel by the generalized random variable of combining L number of channels.

$$\chi^2 (m-1) \Big|_{L} = \frac{m(m-1)}{L} \sum_{\substack{\lambda=1 \\ \text{Selected} \\ \text{Channels}}}^{l} \frac{\Delta^2 \overline{\overline{(\ )}}_{m,\lambda}}{\sigma_\lambda^2} \tag{2-9}$$

Inventory boundaries for a combination of L channels are then derived by testing the following confidence interval.

$$\frac{\chi_{1-p}(m-1)}{\sqrt{m-1}} \leq \left\{ \frac{1}{L} \sum_{\substack{x=1 \\ \text{Selected channels}}}^{L} \frac{\Delta^2 \overline{\overline{(\ )}}_{m,\lambda}}{\sigma_\lambda^2 / m} \right\}^{1/2} \leq \frac{\chi_p(m-1)}{\sqrt{m-1}} \tag{2-10}$$

The derivation of this extended test is exactly analogous to the derivation for the single channel.

Table 2-1. CONFIDENCE FACTORS FOR INVENTORY BOUNDARIES

M	$\chi_p(m-1)/\sqrt{m-1}$					
	p=0.005	p=0.01	p=0.10	p=0.90	p=0.99	p=0.995
3	1.985	1.821	1.17	.01	0.032	0.000
4	1.880	1.752	1.24	.08	0.082	0.058
5	1.789	1.681	1.25	.12	0.170	0.134
6	1.726	1.631	1.25	.46	0.244	0.203
7	1.668	1.586	1.24	.52	0.304	0.262
8	1.626	1.549	1.23	.56	0.353	0.311
9	1.593	1.521	1.22	.60	0.394	0.352
10	1.563	1.494	1.22	.62	0.428	0.386
11	1.536	1.473	1.21	.65	0.457	0.416
13	1.494	1.435	1.20	.68	0.504	0.465
15	1.459	1.407	1.19	.71	0.542	0.505
17	1.432	1.383	1.18	.73	0.572	0.536
19	1.408	1.362	1.17	.75	0.597	0.563
21	1.389	1.345	1.17	.77	0.618	0.585
26	1.351	1.311	1.15	.79	0.660	0.629
31	1.320	1.286	1.13	.81	0.690	0.661
62	1.253	1.214	1.10	.87	0.768	0.755
$m \to \infty$	1	1	1	1	1	1

The above formulation is discussed for a one-dimensional data sequence. Actually, it is applicable equally well for 2-dimensional data sequences such as data from a strip map. The above algorithm may be employed to detect the inventory boundaries in two directions, simultaneously.

2.4 BOUNDARY ENHANCEMENT ALGORITHM

Another method for inventory boundary detection - boundary enhancement method - will now be presented. Basically, the idea of the boundary enhancement is to precondition the two-dimensional array of original data by converting the difference between adjacent samples into the corresponding absolute value or by taking the square of the difference. Since, at the boundary between any two homogeneous regions, one expects larger differences in the data difference, the method of the boundary enhancement will accentuate the existing boundary.

Let the 2-dimensional multispectral data sequence be denoted by x(i,j,k), where i and j represent the scan line and the sample number along a scan line, respectively, while k stands for the channel number for each data sample. Further let

$$i = 1, 2, \ldots, M$$
$$j = 1, 2, \ldots, J$$
$$k = 1, 2, \ldots, K$$

The 2-dimensional moving average, which serves as a smoothing operator, is defined by

$$y(i,j,k) = \frac{1}{(2N+1)^2} \sum_{i'=-N}^{N} \sum_{j'=-N}^{N} x(i+i', j+j', k)$$

where a(2N+1) x (2N+1) array of given data samples have been averaged. This operation is illustrated in Figure 2-3.

Two types of the boundary enhancement have been used. The first type is based on taking the square of the difference of adjacent samples after the 2-dimensional averages. Specifically, it is defined as

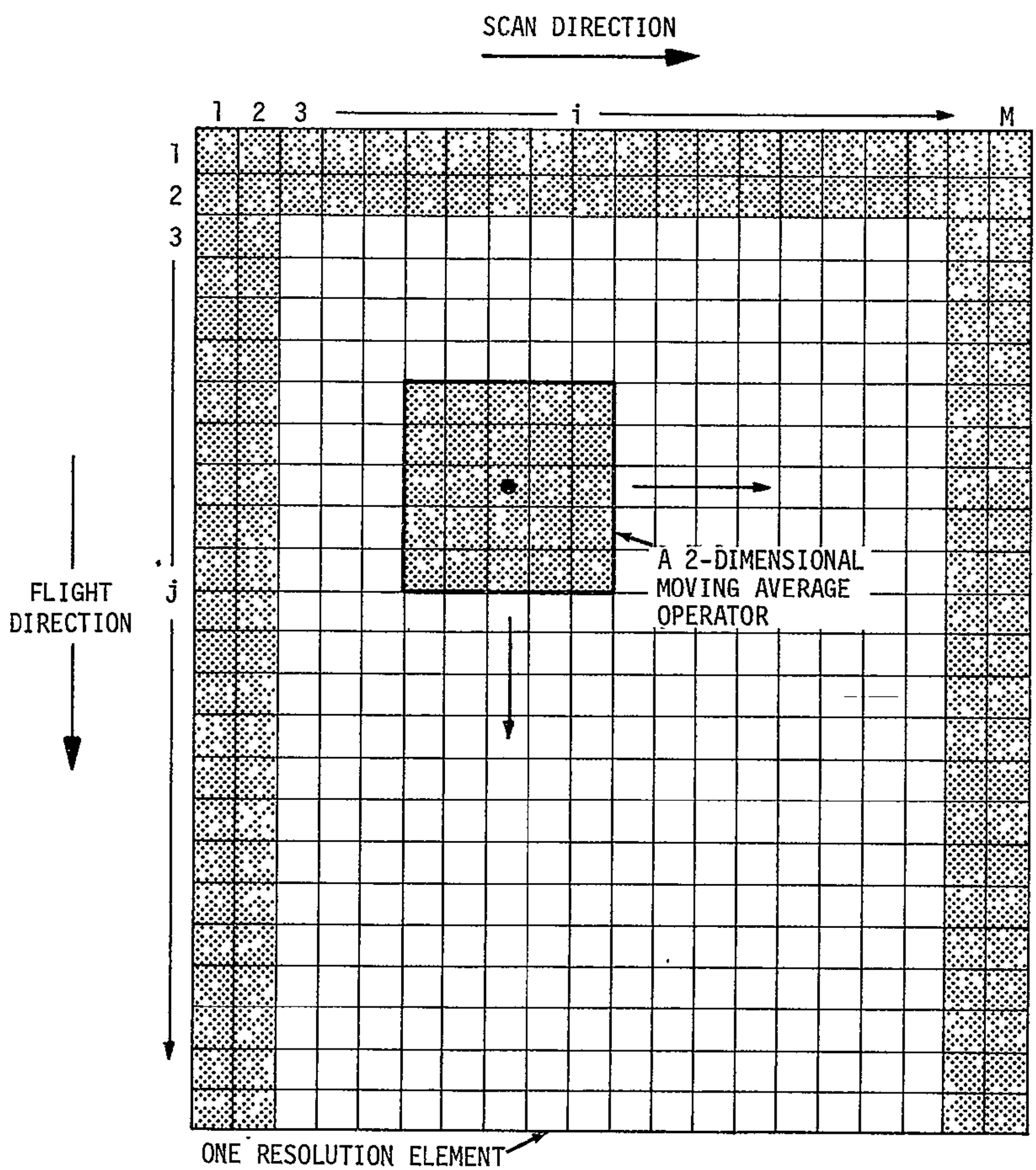

Figure 2-3. ILLUSTRATION OF 2-DIMENSIONAL MOVING AVERAGE OVER TARGET SCENES

$$Z_1(i,j,k) = [y(i,j,k) - y(i,j-d,k)]^2 + [y(i,j,k) - y(i,j+d,k)]^2 + [y(i,j,k) - y(i-d,j,k)]^2 + [y(i,j,k) - y(i+d,j,k)]^2$$

The second type is the same as the first type except replacing the squaring operation by taking the absolute value of difference. That is

$$Z_2(i,j,k) = |y(i,j,k) - y(i,j-d,k)| + |y(i,j,k) - y(i,j+d,k)| + |y(i,j,k) - y(i-d,j,k)| + |y(i,j,k) - y(i+d,j,k)|$$

where d denotes the number of samples skipped in calculating the finite difference and it can be any positive integer. This operation is illustrated in Figure 2-4.

The new sample sequence $Z_1(i,j,k)$ or $Z_2(i,j,k)$ is enhanced data in the sense that their values have been magnified if they happen to locate close to inventory boundaries as illustrated in Figure 2-5.

In order to find a systematic and automatic selection of the inventory boundaries based on these enhanced data, the mean value $\bar{Z}_{1,2}(k)$, mean square value $\bar{Z}^2_{1,2}(k)$, and the standard deviation $\bar{S}_{1,2}(k)$ must be calculated for each channel over the entire 2-dimensional sample sequence as follows.

$$\bar{Z}_{1,2}(k) = \frac{1}{MJ} \sum_{i=1}^{M} \sum_{j=1}^{J} Z_{1,2}(i,j,k)$$

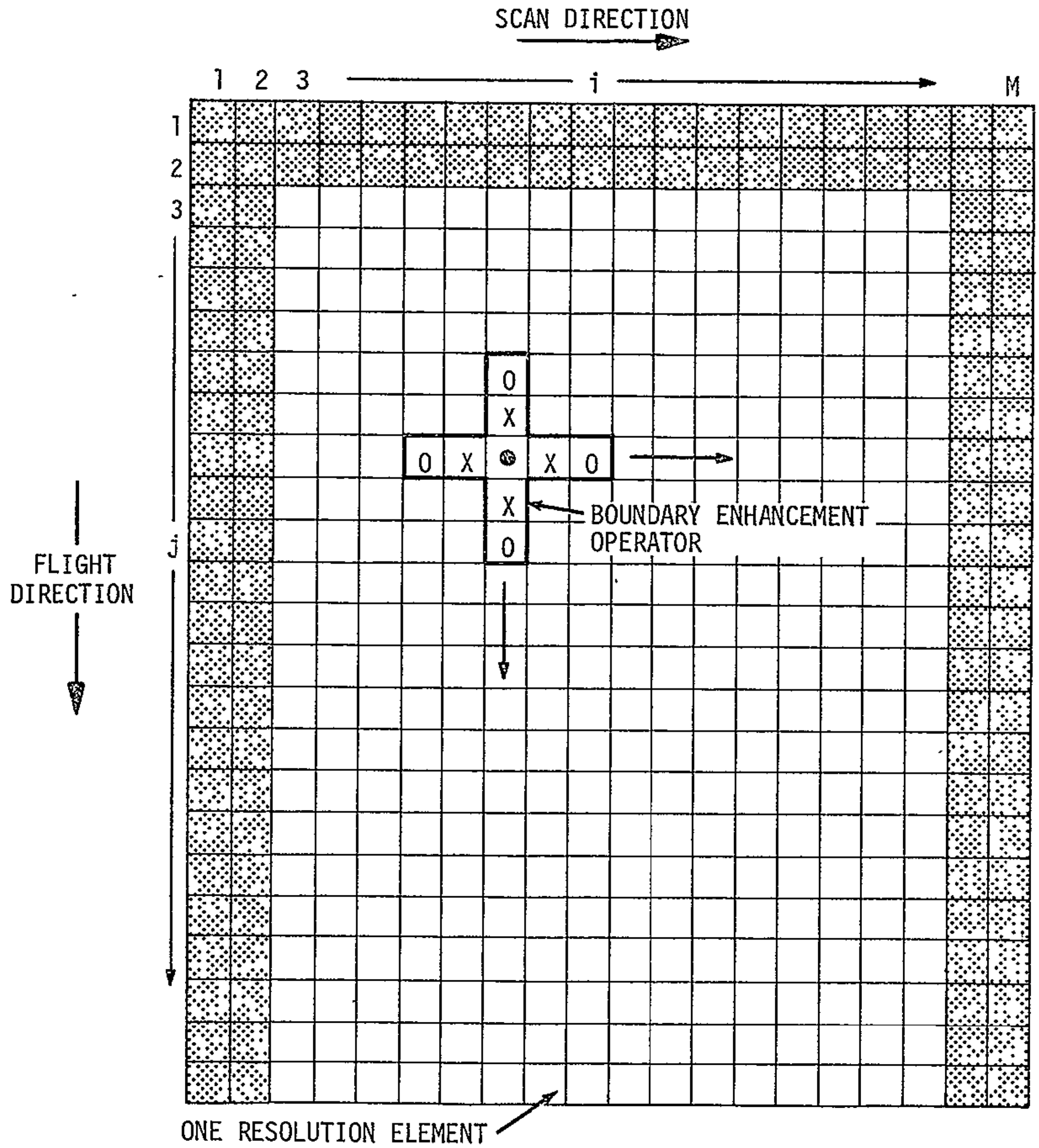

Figure 2-4. ILLUSTRATION OF ENHANCING DATA AROUND INVENTORY BOUNDARIES

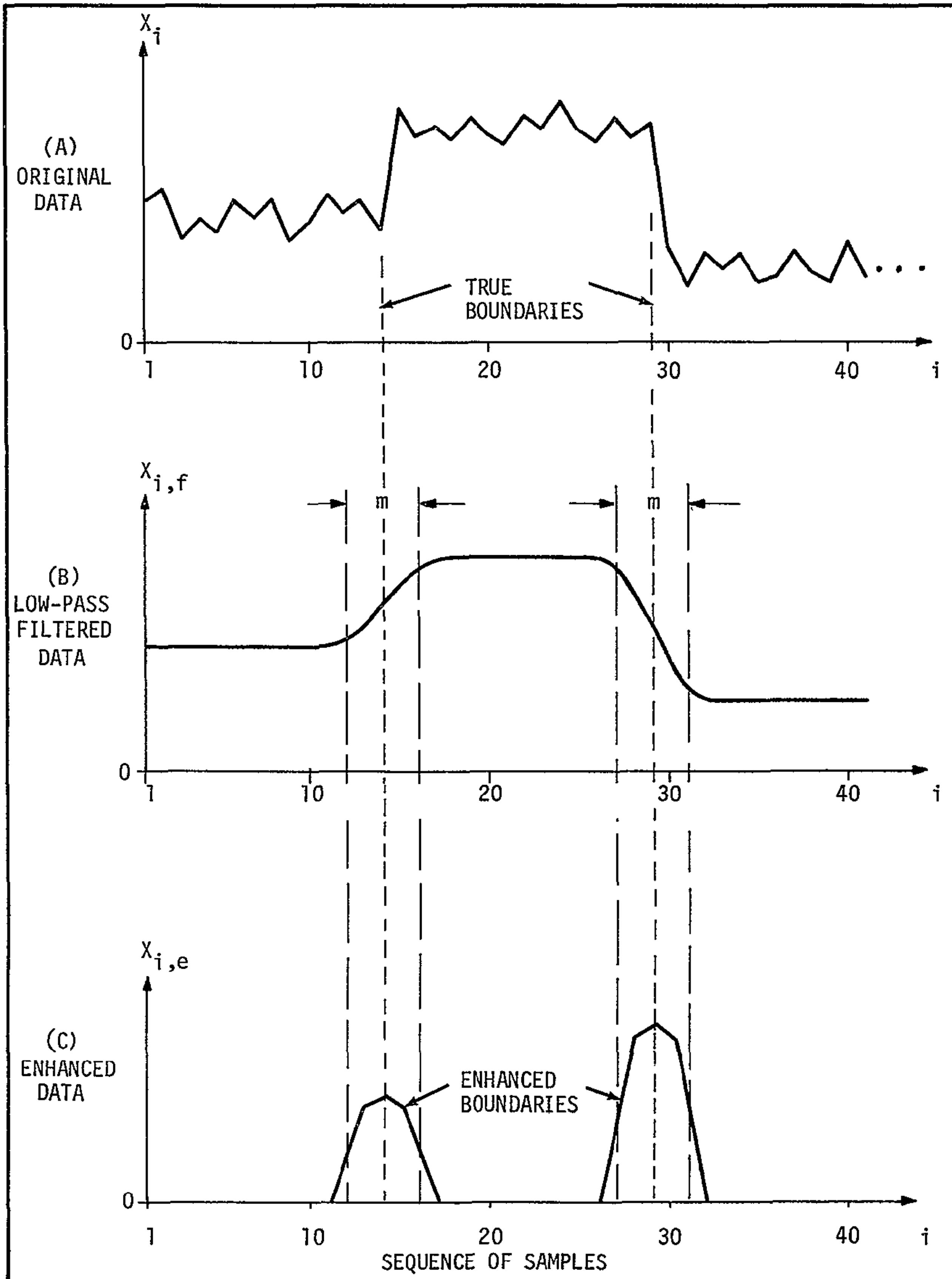

Figure 2-5. ILLUSTRATION OF INVENTORY BOUNDARY ENHANCEMENT

$$\overline{Z}^2_{1,2}(k) = \frac{1}{MJ} \sum_{I=1}^{M} \sum_{j=1}^{J} Z^2_{1,2}(i,j,k)$$

$$\overline{S}^2_{1,2}(k) = \overline{Z}^2_{1,2}(k) - (\overline{Z}_{1,2}(k))^2$$

The threshold value, T, for determining the inventory boundary is then defined by

$$T(k) = \overline{Z}_{1,2}(k) + a\ \overline{S}_{1,2}(k)$$

where a is some arbitrary constant. If the enhanced data sample

$$Z(i,j,k) \geq T\ (k)$$

for at least one channel, then that sample will be considered to locate on or close to the inventory boundary. On the other hand, if $Z(i,j,k) < T(k)$ for all k, then the sample is not considered on the inventory boundary.

In the above discussion, the 2-dimensional moving average and boundary enhancement have been treated as two independent operations. That is, any given data will be processed by the moving average first and then use the output data to be processed by the boundary enhancement. Actually, these two operations may be combined into one. Further, in many applications one needs only to use d=1 or 2. The algorithm to accomplish these required operations simultaneously is given below.

$$Z_1(i,j,k) = W_1^2(i,j,k) + W_2^2(i,j,k) + W_3^2(i,j,k) + W_4^2(i,j,k)$$

and

$$Z_2(i,j,k) = \left|W_1(i,j,k)\right| + \left|W_2(i,j,k)\right| + \left|W_3(i,j,k)\right| + \left|W_4(i,j,k)\right|$$

Here, the expressions in the right hand side of the equations for d=1 and d=2, respectively, are defined as follows.

For d=1:

$$W_{31}(i,j,k) = -\sum_{j'=-N}^{N} x(i-N-1,j+j',k)$$

$$W_{41}(i,j,k) = \sum_{j'=-N}^{N} x(i-N,j+j',k)$$

$$W_{1}(i,j,k) = \sum_{i'=-N}^{N} [-x(i+i',j-N-1, k) + x(i+i',j+N,k)]$$

$$W_{2}(i,j,k) = \sum_{i'=-N}^{N} [x(i+i',j-N,k) - x(i+i',j+N+1,k)]$$

$$W_{32}(i,j,k) = \sum_{j'=-N}^{N} x(i+N,j+j',k)$$

$$W_{42}(i,j,k) = -\sum_{j'=-N}^{N} x(i+N+1,j+j',k)$$

$$W_{3}(i,j,k) = W_{31}(i,j,k) + W_{32}(i,j,k)$$

$$W_{4}(i,j,k) = W_{41}(i,j,k) + W_{42}(i,j,k)$$

For d=2:

$$W_{31}(i,j,k) = -\sum_{j'=-N}^{N} x(i-N-2,j+j',k)$$

$$W_{32}(i,j,k) = -\sum_{j'=-N}^{N} x(i-N-1,j+j',k)$$

$$W_{41}(i,j,k) = \sum_{j'=-N}^{N} x(i-N-1,j+j,k)$$

$$W_{42}(i,j,k) = \sum_{j'=-N}^{N} x(i-N,j+j',k)$$

$$W_1(i,j,k) = \sum_{i'=-N}^{N} [-x(i+i',j-N-2,k) - x(i+i',j-N-1,k) + x(i+i',j+N,k) + x(i+i',j+N+1,k)]$$

$$W_2(i,j,k) = \sum_{i'=-N}^{N} [x(i+i',j-N-1,k) + x(i+i',j-N,k) - x(i+i',j+N+1,k) - x(i+i',j+N+2,k)]$$

$$W_{33}(i,j,k) = \sum_{j'=-N}^{N} x(i+N,j+j',k)$$

$$W_{34}(i,j,k) = \sum_{j'=-N}^{N} x(i+N+1, j+j',k)$$

$$W_{43}(i,j,k) = -\sum_{j'=-N}^{N} x(i+N+1,j+j',k)$$

$$W_{44}(i,j,k) = -\sum_{j'=-N}^{N} x(i+N+2,j+j',k)$$

$$W_3(i,j,k) = W_{31}(i,j,k) + W_{32}(i,j,k) + W_{33}(i,j,k) + W_{34}(i,j,k)$$

$$W_4(i,j,k) = W_{41}(i,j,k) + W_{42}(i,j,k) + W_{43}(i,j,k) + W_{44}(i,j,k)$$

Care has been taken in arranging the above equations such that the input data $x(i,j,k)$ can be read in from magnatic tape in the most sequential manner with respect to data storage in tape for any channel k.

2.5 STATISTICAL CHARACTERISTICS OF AN INVENTORY AREA

Two methods for detecting the inventory boundaries in any given target area have been presented in subsections 2.3 and 2.4. Thus, the area was divided into some inventory areas, each of which represents a homogeneous population. How to describe statistically the properties or characteristics associated with each inventory area will be discussed in the following paragraphs.

In a two-dimensional inventory area, the multispectral data are expressed as x(i,j,k). Here, the scan line i may run from I_s to I_e, and for each particular i, the sample number j may run from $J_s(i)$ to $J_e(i)$, and k represents the channel number (or components) for each sample.

The mean vector for an inventory area is then defined by

$$\bar{M}(k) = \frac{1}{N} \sum_{i=I_s}^{I_e} \sum_{j=J_s(i)}^{J_e(i)} x(i,j,k)$$

where N is the total number of samples within the inventory area.

The correlation matrix of the inventory area is defined by

$$\bar{R}(k_1,k_2) = \frac{1}{N} \sum_{i=I_s}^{I_e} \sum_{j=J_s(i)}^{J_e(i)} x(i,j,k_1)\, x(i,j,k_2)$$

The covariance matrix of the inventory area is defined by

$$\bar{C}(k_1,k_2) = \frac{1}{N} \sum_{i=I_s}^{I_e} \sum_{j=J_s(i)}^{J_e(i)} [x(i,j,k_1) - \bar{M}(k,)]\ [x(i,j,k_2) - \bar{M}(k_2)]$$

$$= \bar{R}(k_1,k_2) - \bar{M}(k_1)\, \bar{M}(k_2)$$

The normalized correlation matrix is defined by

$$\bar{R}_n(k_1,k_2) = \frac{\bar{R}(k_1,k_2)}{\sqrt{\bar{R}(k_1,k_1)\ \bar{R}(k_2,k_2)}}$$

The normalized covariance matrix is defined by

$$\bar{C}_n\ (k_1,k_2) = \frac{\bar{C}(k_1,k_2)}{\sqrt{\bar{C}(k_1,k_1)\ \bar{C}(k_2,k_2)}}$$

Finally, the univariate (first-order) probability density function is defined by

$$p[x_1 \leq x(k) \leq x_2] = \frac{1}{N} \left\{ \begin{array}{l} \text{Number of samples whose value in } k^{th} \\ \text{channel lies between } x_1 \text{ and } x_2 \end{array} \right\}$$

More conveniently, if x_1 and x_2 will be given in exact multiple of prescribed increment Δx, then the above probability density function may be written as

$$p_i(x(k)) = p[(i-\tfrac{1}{2})\Delta x \leq x(k) \leq (i+\tfrac{1}{2})\ \Delta x]$$

$$= \frac{1}{N} \left\{ \begin{array}{l} \text{Number of samples whose value in } k^{th} \text{ channel lies} \\ \text{between } (i-1/2)\ \Delta x \text{ and } (i+1/2)\ \Delta x. \end{array} \right\}$$

Clearly, the above quantities defined for the inventory area are just a few of the simplest and more significant statistical features that one may choose.

In many applications, the multivariate Gaussian distribution is a quite realistic approximation for the multispectral data, as is also predicted by the Central Limit theorem of the probability theory. One of the desirable features of this distribution is because the distribution is completely determined by the mean vector and covariance matrix only. Since this distribution occupies such a central important position in the pattern classification problem, it is given below.

$$p(x(k)) = \frac{1}{(2\pi)^{K/2}|\bar{C}(k_1,k_2)|} \exp \left\{ \frac{-|\bar{C}(k_1,k_2)|}{2} \sum_{k_1=1}^{K} \sum_{k_2=1}^{K} |\bar{C}^*(k_1,k_2)|[x(k_1) - M(k_1)][x(k_2) - M(k_2)] \right\}$$

where $|\bar{C}(k_1,k_2)|$ is the determinant of the matrix $\bar{C}(k_1,k_2)$ while $|\bar{C}^*(k_1,k_2)|$ is the cofactor of $\bar{C}(k_1,k_2)$.

Another form of the expression is

$$p(x(k)) = \frac{1}{(2\pi)^{K/2}|\bar{C}(k_1,k_2)|} \exp \left\{ -\frac{1}{2}\ [x(k) - \bar{M}(k)]'\ \bar{C}^{-1}(k_1,k_2) \cdot [x(k) - \bar{M}(k)] \right\}$$

where the prime represents the transpose and $\bar{C}^{-1}(k_1,k_2)$ is the inverse of $\bar{C}(k_1,k_2)$. Also

$$\bar{C}^{-1}(k_1,k_2) = \frac{(-1)^{k_1+k_2}}{|\bar{C}(k_1,k_2)|} \qquad |\bar{C}^*(k_1,k_2)|$$

2.6 SIMILARITY CRITERIA BETWEEN INVENTORY AREAS

So far, we have formulated methods for determining inventory areas and presented a statistical description for each inventory area. The next question that arises is how to determine the similarity or dissimilarity among those inventory areas that do not have any common inventory boundary. In other words, we want to know whether two inventory areas far apart belong to the same population or not based on their statistical characteristics described in the last subsection.

There are many criteria one can choose to establish the similarity between two inventory areas that are characterized by the given statistical discriptions, such as mean vectors and covariance matrices. One of the most appropriate criteria available is the so-called "divergence" measure, which can be considered to be a dimensionless "distance" between two arbitrary multivariate probability density functions p_i (x(k)) and p_j(x(k)), for i^{th} and j^{th} inventory areas, respectively. Since the mean vector and covariance matrix can be calculated from the probability density function, this "divergence" measure does take into consideration all the information from the inventory areas of interest. This measure is defined as follows (ref. 4)

$$D(i,j) = E\left[\log\left(\frac{p_i(x(k))}{p_j(x(k))} \right) \Big|_i \right]$$

$$-E\left[\log\left(\frac{p_i(x(k))}{p_j(x(k))} \right) \Big|_j \right]$$

Thus, it is the difference between two expected values of the logarithms of the likelihood ratios of a ramdom input sample vector x(k), (k=1,2,...K). In other words, the divergence is a measure of the difficulty for discriminating between the two given probability density functions. The divergence possesses all the properties of "distance" or "norm" as well as several others:

- $D(i,i) = 0$
- $D(i,j) \geq 0$ for $i \neq j$.
- $D(i,j) = D(j,i)$
- If every component of the sample vector is statistically independent, then the divergence is equal to the sum of the divergences for each component, individually, i.e.

  $$D(i,j) = \sum_{k=1}^{K} D_k(i,j)$$

- If one more component is added to the original sample vectors, then the divergence for the (K+1) - dimensional sample space will never decrease, i.e.

  $$D(i,j \mid x(k)) \leq D(i,j \mid x(k),\ x(K+1)).$$

We shall now consider serval special cases of the divergence measure. If the probability density function are Gaussian with the mean vector $\bar{M}_i(k)$ and $\bar{M}_j(k)$, and covariance matrices $\bar{C}_i(k_1,k_2)$ and $\bar{C}_j(k_1,k_2)$, then the divergence becomes

$$\begin{aligned} D(i,j) = \ & \frac{1}{2} \operatorname{tr}\Big\{[\bar{C}_i(k_1,k_2) - \bar{C}_j(k_1,k_2)] \\ & \quad x[\bar{C}_j^{-1}(k_1,k_2) - \bar{C}_i^{-1}(k_1,k_2)]\Big\} \\ & + \frac{1}{2} \operatorname{tr}\Big\{[\bar{C}_i^{-1}(k_1,k_2) + \bar{C}_j^{-1}(k_1,k_2)] \\ & \quad x[\bar{M}_i(k_1) - \bar{M}_j(k_2)]\ [M_i(k_2) - \bar{M}_j(k_2)]'\Big\} \end{aligned} \tag{2-11}$$

where tr denotes the trace, the exponent -1 denotes the inverse, and the prime the transpose.

Further, if the covariance matrices are the same, $\bar{C}_i = \bar{C}_j = \bar{C}\ (k_1,k_2)$, the above expression reduces to

$$D(i,j) = \text{tr}\left\{\bar{C}^{-1}(k_1,k_2)\,[\bar{M}_i(k_1) - \bar{M}_j(k_1)] \times [\bar{M}_i(k_2) - \bar{M}_j(k_2)]'\right\} \tag{2-12}$$

$$= [\bar{M}_i(k_1) - \bar{M}_j(k_2)]'\,\bar{C}^{-1}(k_1,k_2)\,[\bar{M}_i(k_2) - \bar{M}_j(k_2)]$$

If the components are statistically independent, then equation (2-11) can be reduced to

$$D(i,j) = \frac{1}{2}\sum_{k=1}^{K}\left\{[\sigma_i^2(k) - \sigma_j^2(k)]^2 + [\sigma_i^2(k) + \sigma_j^2(k)] \times [\bar{M}_i(k) - \bar{M}_j(k)]^2\right\} / [\sigma_i^2(k)\,\sigma_j^2(k)] \tag{2-13}$$

where $\sigma_i^2(k)$ is the covariance vector which is the diagonal of the original covariance matrix for i^{th} inventory area.

Further, if the covariance vectors are equal, i.e., $\sigma_i^2(k) = \sigma_j^2(k) = \sigma^2(k)$, then the above expression reduces to

$$D(i,j) = \sum_{k=1}^{K}\frac{[\bar{M}_i(k) - \bar{M}_j(k)]^2}{\sigma^2(k)} \tag{2-14}$$

On the other hand, if the mean vectors are equal, then

$$D(i,j) = \frac{1}{2}\sum_{k=1}^{K}\frac{[\sigma_i^2(k) - \sigma_j^2(k)]^2}{\sigma_i^2(k)\,\sigma_j^2(k)} \tag{2-15}$$

Finally, the ordinary Euclidean distance between two vectors is obtained from expression (2-14) by letting $\sigma^2(k) = 1$, or from expression (2-12) by letting $\bar{C}(k_1,k_2)$ equal to the identity matrix.

$$D(i,j) = \sum_{k=1}^{K}[\bar{M}_i(k) - \bar{M}_j(k)]^2$$

From the above various special cases, it can be seen that the divergence measure is to very general criterion for similarity.

Section III

COMPUTER PROGRAMS DESCRIPTION

3.1 INTRODUCTION

Computer programs based on the algorithms discussed in the last section have been developed for processing and analysis of multispectral data. The purposes of these programs, their input and output formats, and the program listing will be presented in this section. A list of these programs is as follows:

- Tape Conversion Program
- Alphanumeric Plot Program
- Statistical Inventory Boundary Program
- Boundary Enhancement Program
- Mean, Correlation, and Covariance Program
- Piecewise Correlation and Covariance Program
- Probability Histogram Program
- Divergence Matrix Program
- Si-Table Program

3.2 TAPE CONVERSION PROGRAM

This program is devised for converting a standard FORTRAN and/or binary tape to the standard format of input data tapes to the following programs:

- Boundary Enhancement Program
- Alphanumeric Plot Program
- Statistical Averages Program
- Piecewise Correlation and Covariance Program
- Statistical Inventory Boundary Programs
- Mean, Correlation,and Covariance Program
- Probability Histogram Program.

The outputs of the program is a FORTRAN binary or BCD tape with a control parameter (fixed-point binary or BCD) and data sets of some specified number of channels (floating point binary or BCD). The data set is a 3-dimensional array, DATA (i,j,k), with i designating the scan line number, j the same number along each scan, and k the channel number. The control number is set to be 1 at the end of each scan line, 2 at the end of each specified field, and 3 at the end of each data set.

It is optional in this program to read a header identification record at the start of each data set and also optional to write this on the output tape in either BCD or FORTRAN binary of some specified length.

Because of the characteristic of most experimental data sets to contain erroneous data samples from some undetermined origin, it becomes desirable to replace these erroneous data samples with some data samples that best characterize the data set. The capability to replace these erroneous data samples is optional in the program.

The control parameters in this program are inputed as NAMELIST parameters. The documentation on the usage of this system package is in IBM Manual C28-6390-2. There are two major sets of NAMELIST calls in this program NAMDAT and NAMFIL. The following is the definition of the input parameters used in NAMDAT and NAMFIL.

NAMDAT

- NFILE - Number of files of data to process from the input tape.
- NWHICH - Number of the selected files to be processed.
- LTN - Logical tape number of the input tape to be reformated.
- LTN1 - Logical tape number of data reformated by the program.
- LTN2 - Logical tape number of output header identification record.
- NSCANS - Number of scan lines to be processed in this field.
- IDWORD - Number of words in the input tapes header identification record.
- LLL - Data sample to start with from input data record in generating the output tape.
- NBEAMS - Number of channels of data.
- IHEAD - Option to read or write a header identification record. IHEAD not equal zero executed.

- IBCDH - Option to read header identification record in BCD. IBCDH ≠ 0 header record read as BCD information. IBCDH = 0 read as Binary.
- IHMRT - Option to write header identification record on output tape. IHMRT ≠ 0, record written.
- ISKBIN - Option to determine if any files are to be skipped on input tape to get to data file. ISKBIN = 0, no files to be skipped.
- IBCDW - Option to write output data tape in BCD. IBCDW ≠ 0, tape written in BCD. IBCDW = 0, tape written in Binary.
- IDROP - Option to replace selected data samples in data set. IDROP ≠ 0, data samples replaced.

NAMFIL

- XMEAN - Variables used to replace erroneous samples in first region of field.
- XMEAN1 - Variables used to replace erroneous samples in second region of field.
- XMEAN2 - Variables used to replace dropouts in third region of field.
- ISAM - Specifies location of regions in the data set to be replaced by means.
- XMIN - Minimum value of each region for a field.
- XMAX - Maximum value of each region for a field.

Figure 3-1 is a flowchart of the program and the following is a listing of the program.

3.3 ALPHANUMERIC PLOT PROGRAM

The program is devised for printing a two-dimensional alphanumeric plot for grey-level display or classification results. The input tape can be BCD or binary. The other input parameters are the upper and lower class limits and desired alphanumeric symbols for each class.

Definition of Input Data:

CARD 1 (A1)

IALPHA - Alpha-numeric characters for printout

LLP - Border designation.

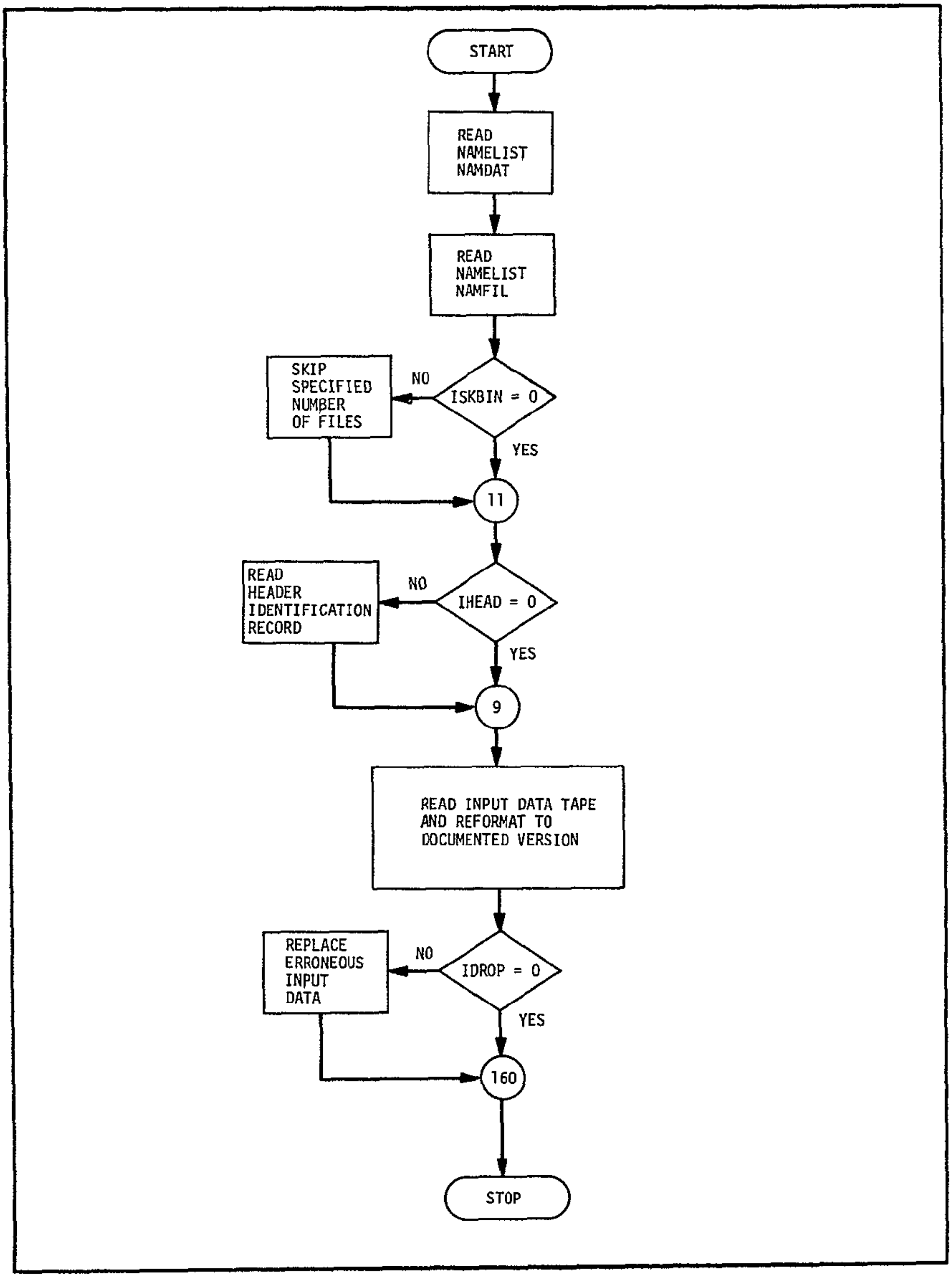

Figure 3-1. FLOWCHART FOR TAPE CONVERSION PROGRAM

```
C       TAPE     CØNVERSIØN     PRØGRAM
      DIMENSIØN  ISAM(6)
      DIMENSIØN  XMEAN(12),XMEAN1(12),XMEAN2(12)
      DIMENSIØN  DATA(12)
      DIMENSIØN DAT(5000),NWHICH(4)
      DIMENSIØN RCDID(20)
      DIMENSIØN DUM(12)
      NAMELIST /NAMDAT/ NFILE,NWHICH,LTN,LTN1,LTN2,NSCANS,IDWØRD,
     1LLL,KKK,NCT,NBEAMS,IHEAD,IBCD,IFLD,ISUB,NA,NAB,NB,IBCDH,
     2IMRD,IMRT,IHMRT,ISKBIN,IBCDR,IBCDW,IDRØP
      NAMELIST /NAMFIL /XMEAN,XMEAN1,XMEAN2,ISAM,XMIN,XMAX
      IZERØ=0
      IØNE=1
      ITWØ=2
      ITHREE=3
      NDUM=0
      DØ 4 J=1,12
 4    DUM=0.0
      READ (5,NAMDAT)
      WRITE(6,NAMDAT)
      REWIND  LTN
      REWIND  LTN1
      DØ 998 IAA=1,NFILE
      READ(5,NAMFIL)
      WRITE(6,NAMFIL)
C       SEARCH     FØR     FILE     TØ     PRØCESS
      IF (ISKBIN.EQ.0)  GØ TØ 11
      REWIND LTN
      IAB=NWHICH(IAA)-1
      IF(IAB)11,11,12
 12   CØNTINUE
      DØ 10 IAC=1,IAB
      CALL SKFBIN(9,1,RD)
   10 CØNTINUE
   11 CØNTINUE
C         READ RECØRD ØNE
C     READ     HEADER     IDENTIFICATIØN     RECØRD
      IF(IHEAD) 14,9,14
 14   CØNTINUE
      IF(IBCDH.NE.0) GØ TØ 5
      READ (LTN)  (RCDID(I),I=1,IDWØRD)
      IF(IFLD.EQ.0)  GØ TØ 6
      NCT=0
      CALL  FLD  (NCT,NA,NAB,NB,RCDID(ISUB))
      GØ TØ 6
 5    CØNTINUE
      READ (LTN,1006)  (RCDID(I),I=1,IDWØRD)
 6    CØNTINUE
      IF(IFLD.NE.0) GØ TØ 21
      RCDID(ISUB)=0.0
      RCDID(ISUB)=NCT
 21   CØNTINUE
      IF (IHMRT) 22,23,22
 22   CØNTINUE
      WRITE(LTN2)      (RCDID(MM),MM=1,IDWØRD)
```

```
 23     CØNTINUE
        WRITE(6,1003)  (RCDID(K),K=1,IDWØRD)
  9     CØNTINUE

C       READ            INPUT           DATA
        NWW=NCT*NBEAMS
        DØ 1 I=1,NSCANS
        IF(IBCDR .NE.0) GØ TØ 8
        CALL REDTPC(LTN,IMRD,IERR,NW,NWW,DAT)
        GØ TØ (50,51,50,50,51),IERR
  51    WRITE(6,1004) I
        GØ TØ 999
 50     CØNTINUE
 8      CØNTINUE
        LL=LLL
        KK=KKK
 13     CØNTINUE
C          REFØRMAT        INPUT            DATA
        DØ 2 J=1,NCT
        IF(IBCDR .EQ.0) GØ TØ 15
        READ (LTN1,1005)  IZ,(DATA(III),III=1,NBEAMS)
        NNN=1
        DØ 31 NN=LL,KK
        DAT(NN)=DATA(NNN)
        NNN=NNN+1
 31     CØNTINUE
 15     CØNTINUE
C          REPLACE      ERRØNEØUS     DATA      SAMPLES
        IF(IDRØP.EQ.0)  GØ TØ 160
        IF (DAT(LL).LT.XMAX.AND.DAT(LL).GT.XMIN) GØ TØ 160
        IF (J.GE.ISAM(1).AND.J.LE.ISAM(2)) GØ TØ 150
        IF (J.GE.ISAM(3).AND.J.LE.ISAM(4)) GØ TØ 152
        IF (J.GE.ISAM(5).AND.J.LE.ISAM(6)) GØ TØ 154
        GØ TØ 160
 150    IZ=LL
        DØ 151 K=1,KKK
        DAT(IZ)=XMEAN(K)
 151    IZ=IZ+1
        GØ TØ 160
 152    IZ=LL
        DØ 153 K=1,KKK
        DAT(IZ)=XMEAN1(K)
 153    IZ=IZ+1
        GØ TØ 160
 154    IZ=LL
        DØ 155 K=1,KKK
        DAT(IZ)=XMEAN2(K)
 155    IZ=IZ+1
 160    CØNTINUE
        IF(IBCDW .EQ.0) GØ TØ 61
        WRITE(LTN2,1000)  IZERØ,(DATA(K),K=LL,KK)
        GØ TØ 64
 61     CØNTINUE
        WRITE  (LTN2)  IZERØ,(DATA(K),K=LL,KK)
```

```
64    CØNTINUE
      LL=KK+1
      KK=LL+NBEAMS-1
   2  CØNTINUE
      IF(I.EQ.NSCANS) GØ TØ 3
      IF(IBCDW.EQ.0) GØ TØ 65
      WRITE(LTN2,1000)   IØNE,(DUMMY(K),K=1,NBEAMS)
      GØ TØ 1
65    CØNTINUE
      WRITE(LTN2)        IØNE,(DUMMY(K),K=1,NBEAMS)
    1 CØNTINUE

3     CØNTINUE
      IF(IBCDW.EQ.0)  GØ TØ 63
      WRITE(LTN2,1000)   ITWØ,(DUMMY(K),K=1,NBEAMS)
      GØ TØ 998
63    CØNTINUE
      WRITE(LTN2)        ITWØ,(DUMMY(K),K=1,NBEAMS)
 998  CØNTINUE
      IF(IBCDW .EQ.0) GØ TØ 67
      WRITE(LTN2,1000) ITHREE,(DUMMY(K),K=1,NBEAMS)
      GØ TØ 999
67    CØNTINUE
      WRITE(LTN2)      ITHREE,(DUMMY(K),K=1,NBEAMS)
 999  CØNTINUE
      END  FILE  LTN2
      REWIND LTN
      REWIND LTN1
      REWIND LTN2
 200  FØRMAT(20I4)
1000  FØRMAT(I1,8X,12F6.3)
1001  FØRMAT(I1)
1002  FØRMAT(1H1//2X,24HINPUT RECØRDS BAD - STØP)
1003  FØRMAT(1X,12A6,I6,5X,2F8.4)
1004  FØRMAT(2X,I4)
1005  FØRMAT(I1,8X,12F5.3)
1006  FØRMAT(20A6)
1007  FØRMAT(I1,8X,12F8.3)
1008  FØRMAT(1X,2I10)
      STØP
      END

$NAMDAT
NFILE=4
NWHICH=2,8,19,12
LTN=9
LTN1=9
ISKBIN=1
IBCDR=0
IBCDW=1
IDRØP=1
LTN2=11
NSCANS=27
IDWØRD=15
```

```
LLL=1
KKK=12
NCT=167
NBEAMS=12
IHEAD=1
IBCD=0
IFLD=0
ISUB=13
NA=19
NAB=17
NB=1
IBCDH=0
IMRD=1
IMRT=1
IHMRT=0
$END
$NAMFIL
XMEAN=1.10358,1.6092,1.13319,1.02380,1.04938,0.99541,0.77604,1.03585,
      0.50232,0.63149,0.81489,0.63113
XMEAN1=0.92628,1.36367,1.00306,0.95745,0.90845,0.76673,0.63609,1.03973,
       0.59239,0.59394,0.39618,0.30986
XMEAN2=1.27359,1.70424,1.14378,1.02141,0.94322,0.82919,0.62134,0.83949,
       0.40804,0.46054,0.58812,0.43592
ISAM=1,63,63,118,118,167
XMIN=0.0
XMAX=3.0
$END
$NAMFIL
XMEAN=1.50995,2.15190,1.52394,1.34540,1.29378,1.15872,0.92575,1.24317,
      0.63664,0.68725,0.76504,0.60184
XMEAN1=0.97784,1.47237,1.08407,1.01881,0.97609,0.84300,0.70877,1.13348,
       0.63643,0.64560,0.44608,0.36001
XMEAN2=1.13874,1.86139,1.27976,1.13856,1.03394,0.86392,0.68685,0.96813,
       0.49192,0.52221,0.49081,0.38598
ISAM=1,42,42,111,111,167
XMIN=0.0
XMAX=3.0
$END
$NAMFIL
XMEAN=1.31144,1.85966,1.28023,1.13480,1.10562,1.C0866,0.76919,1.02518,
      0.49790,0.56153,0.72571,0.54945
XMEAN1=0.98687,1.46594,0.97921,0.85527,0.84487,0.84443,0.60006,0.75333,
       0.33964,0.57555,1.18249,0.89077
XMEAN2=1.29660,1.74870,1.17140,1.05421,0.97544,0.85978,0.64281,0.89028,
       0.42091,0.49407,0.61681,0.46276
ISAM=1,39,39,108,108,167
XMIN=0.0
XMAX=3.0
$END
$NAMFIL
XMEAN=1.00572,1.47489,1.03701,0.96775,0.91567,0.80819,0.63198,0.99724,
      0.53699,0.56149,0.48457,0.36704
XMEAN1=1.16048,1.58077,1.05821,0.94602,0.87191,0.76703,0.54934,0.78006,
      0.37171,0.42442,0.53810,0.39657
ISAM=1,111,111,167,167,167
XMIN=0.0
XMAX=3.0
$END
```

CARD 2 (2F10.0)

XSKSC - Number of scan lines to skip (i.e. every other, 2, 4, etc.)

XSKFL - Number of samples to skip in scan line

CARD 3 (7I4)

ITERM - Set to 1 for new case.

JCNT - Skip numbering across scan line.

NFLSKC - Option to skip data files on input tape.

NFLSFL - Option to skip data sample in scan line.

NFLSKN - Option to skip scan lines.

IAP - = 0 to initialize numbering of data samples across scan line.

IPRNT - = 0 for data from boundary enhancement program.
= 1 for raw data tapes.

CARD 4 (4I4)

N - Number of classes or intervals used.

NPTS - Number of data samples in scan line.

NCH - Number of channels used.

MSTOP - Total data samples used in scan line.

CARD 5 (F6.0)

$XLOW_i$ - Lower limit for each channel. i = 1, NCH

CARD 6 (F6.0)

XUPP - Upper limit for each channel.

CARD 7 - Card NCH (A1)

IWAVE - Wave length in microns for each channel.

CARD NCH+1 (I5)

ICH - Channels used.

CARD NCH+2 - CARD N (F10.0)

XINCR - Increment size/channel for each N(card 4)

The output format is shown in Figure 3-2.

The flowchart is given in Figure 3-3 which is followed by a program listing.

```
                    MULTISPECTRAL  SCANNER  DATA   2 X 2

CHANNEL  1                                         SYMBØL        INTERVAL
WAVE LENGTH (MICRØNS)    0.40 - 0.44                              0.50 -  0.65
                                                     1            0.65 -  0.80
                                                     2            0.80 -  0.95
                                                     3            0.95 -  1.10
                                                     4            1.10 -  1.25
                                                     5            1.25 -  1.40
                                                     6            1.40 -  1.55
                                                     7            1.55 -  1.70
                                                     8            1.70 -  1.85
                                                     9            1.85 -  2.00
                                                     0            2.15 -

CRØPS   C5-17,5-22,5-5,5-8,          ALTITUDE  2000 FT.          DATE RECØRDED  6/30/66

             11111111112222222222333333333344444444445555555555666666666677777777778888
    12345678901234567890123456789012345678901234567890123456789012345678901234567890123
   ***********************************************************************************
  1 *55555555666555555655554555444444444443334433333334333443344455656656656667666677767
  2 *55545555565555565555554455554444333343343433333333333333343456555565566666666666666
  3 *5554455556655545555555545555434344434333333333333334333333345555555555666666666666
  4 *555455556665555545554445554434344333333333333234343333333345556555565566666666666
  5 *555555555555555555545554455534443334434333334343333333333334555555665566566666766
  6 *5554556555555555555555455554444444433334343434343433433343334555656566666666567666
  7 *55545555655445455544554444543343444334333343333333344333333345555565655565666666666
  8 *55555555655545555555544445534444433333333434343343434333333345556555666666666666667
  9 *55555555655556555555444455443444343434334334333334444333443555655555666666676666777
 10 *5555555555544545555455445554444444444333334443333344434334334556655555566666666666
 11 *555555555555454555555454455343344334443333343333333333333334555656656666666666666
 12 *555455555555454444544544444553434444444433333334333334433333333455555565565656666666766
 13 *5554455655555545555445444554444444444443334443333334333333333555554555556666666666
 14 *77888888888888887777778445544544444444444344333343434444457767777777777777766656555
 15 *77887777887778877776784444444434443333344333334443433333456666676767677677776665555
 16 *77787787878888877767784454454444444444443443333433443444456677666667667666766665555
 17 *77787888877777788777784445544444444433444343334344434434346776666766677767676655555
 18 *77778878778777877776784444434444434444344333333433334333466777666766666767666555545
 19 *67777888888887887777779445544444444444444444433334343334434666766676777677776665555555
 20 *77877877777777777777768444444344343444343334333343333343566666666666776766766555545
 21 *77777777777787778767767444444434443444443433333334423333333466666667776676666665555544
 22 *77878778877787887777784445444444433444444333333333333344446666676666666666666666554545
 23 *78888787777777877776774444444444444444443433334334333443446666666767777766666665554
 24 *78888767677777878767667444444444434444443433433343334333334666666666666676666665555555
 25 *77888888877887878777777844454444444344444344343333333443444446666766677676777666666545545
 26 *77778878778778777776774444444344333544433344333334334334455666666667666666656545544
 27 *76677677666666566665665544444444443434344343434443333445655666566666565666766666666
 28 *66676667666566556554564444344433333434444433434434343444556665665555655656666666666566
 29 *66657666666665566666566445444434334444444444433333334344434556656566556566556677665665
 30 *67666777766655557554664444444444444434343343443444454434555665566566666666777666665
 31 *66767766566565666565654444454444444443344434333444434443355666666565665656566665556 6
 32 *66667675666566565665664445334444443444444443444344343435666565656666566565666665655
 33 *66666776566556666665566444444444434344433443333333433434446756656666665665576666665666
 34 *66666776776666665765654444454445433444444333344443444444556666665666666565667666675666
 35 *56777667776656555665554444544444444434334443343434443433555656556666556666676666656
 36 *66655766666666566654664444544444433344434444343333443333334446566555666566666666677677655
 37 *66666766666666565565654444434444433443443334344344444444555666765556565665666667666665
 38 *67656776666666666655665445444444434434344444334444344443345566655566666665666676665655
 39 *66666677665665666665654454444443443343443433433433443444345666666665665566668677676666
 40 *44454444333433333323222233233333332233654555456666666666656666765664565567444344444344
 41 *44455533333333333333232223323223323333554555566556566655666766655565556444444444433
 42 *44445543343333333323233333333333233346445455666666666666666666666555666745434444444
 43 *4444453333332322232322232322332333354445454666556666556677655556555744344443333 3
 44 *4444543433333333232333232223323233333364445455556566656666677666555566566434444444434
 45 *4455554343333333323333323233333333333355445556666566665566666666555566668444444444444
 46 *454555433323233333333323233323223333454445556565665566666776666556665584444444443
 47 *44545554334333333323322222333233333333554555455665566665566666666555656574444444444433
 48 *454555443333333333333333333332333334445545555566666665666665655565668454444444443
 49 *44555544333333433323334223233333333333454554556556566665666676665555666744444444444
 50 *4554555443333333223323233323333333333334545545566555556666556667655556566744444433344 4
 51 *45555644334333333333433333233333333333454555556665566666666666665656656755444444444444
 52 *555556433333333333232343433233333333333355455556655556666556666655555556675454444444443
```

Figure 3-2. MULTISPECTRAL SCANNER DATA 2 X 2

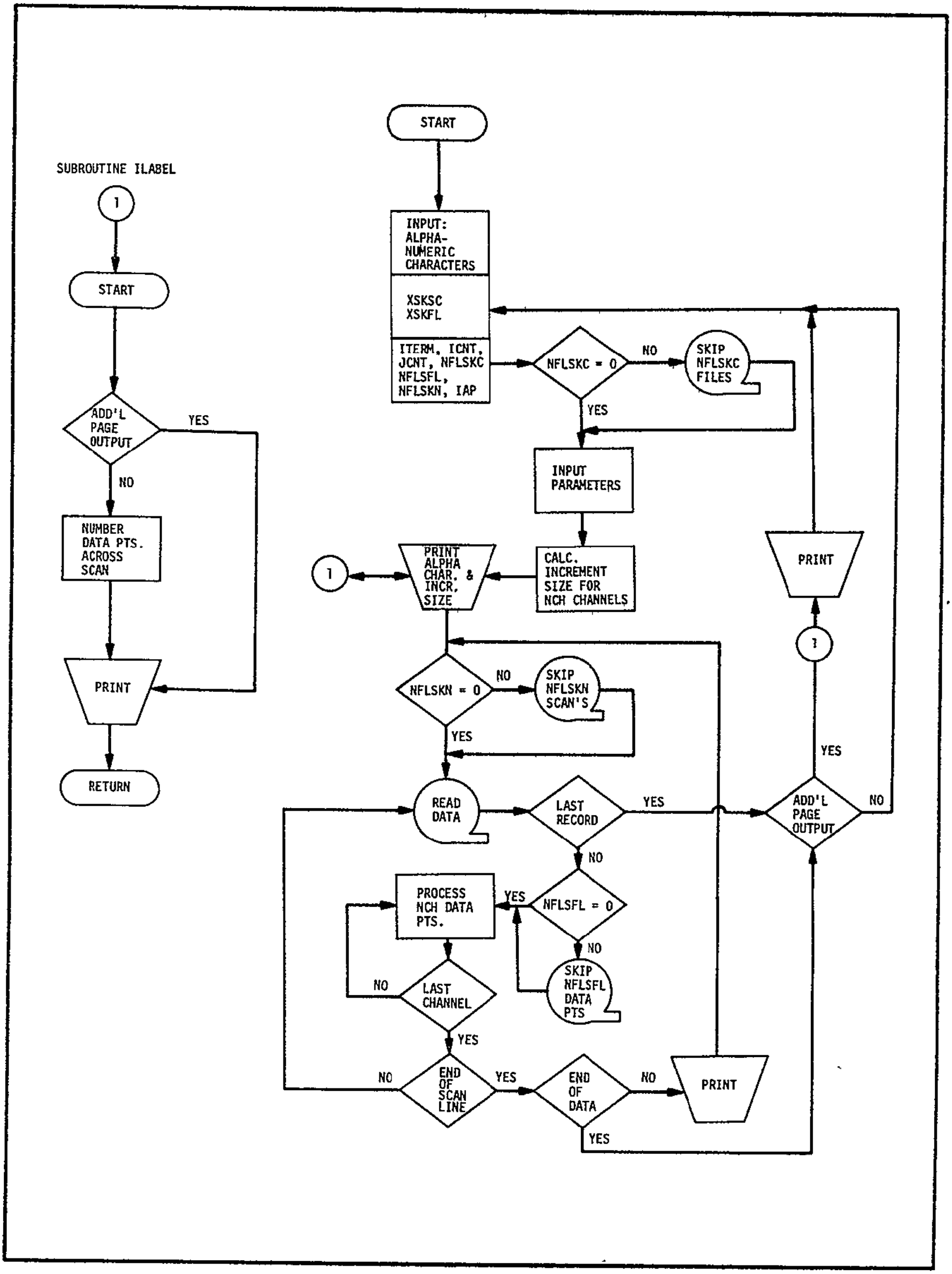

Figure 3-3. FLOWCHART OF ALPHANUMERIC PLOT PROGRAM

```
C
C       ALPHANUMERIC PLOT PROGRAM
C
        DIMENSION IALPHA[13,20],XLOW[13],XUPP[13],XXLOW[13],DATA[170]
        DIMENSION IARAY[170],XDUM[13],IALP[170],JARAY[108,60]
        DIMENSION IDATA[15],XINCR[13,20],ICH[13],XDWN[13],IWAVE[13,13]
        IN=5
        IN1=9
        IOUT=6
        DO 299 L=1,13
        READ[IN,99] [IALPHA[L,I],I=1,20],LLP
  299   CONTINUE
  300   CONTINUE
        READ[IN,114]  XSKSC,XSKFL
        READ[IN,100] ITERM,JCNT,NFLSKC,NFLSFL,NFLSKN,IAP,IPRNT
        IF[NFLSKC.EQ.0]  GO TO 1001
C
C                 NFLSKC  GREATER THAN 0  -  SKIP  FILES
C
        DO 1000 I=1,NFLSKC
        CALL SKFBIN[IN1,1,RD]
 1000   CONTINUE
 1001   CONTINUE
        READ[IN,100] N,NPTS,NCH,MSTOP
        READ[IN,116] [XLOW[I],I=1,NCH]
        READ[IN,116] [XUPP[I],I=1,NCH]
        DO 1002 L=1,NCH
        READ[IN,99] [IWAVE[L,I],I=1,13]
 1002   CONTINUE
        READ[IN,115] [ICH[I],I=1,NCH]
        NUMB=N
        DO 600 L=1,NCH
        READ[IN,114] [XINCR[L,I],I=1,NUMB]
        DO 600 J=1,NUMB
        XINCR[L,J]=XUPP[L]/XINCR[L,J]
        XXLOW[L]=XLOW[L]
  600   CONTINUE
        XN=N
        IFLSKN=0
        ISCAN=0
        L=0
        NCALL=1
        INDEX=0
        NSTART=1
        NSTOP=MSTOP
        JPASS=1
        WRITE[IOUT,110]
        WRITE[IOUT,102]
        WRITE[IOUT,106]
        WRITE[IOUT,111]
        MSKFL=XSKFL
        MPTS=NPTS/MSKFL+2
        DO 1 I=1,MPTS
        IALP[I]=LLP
    1   CONTINUE
```

```
      KK=N+1
C
C                CALCULATE AND PRINT INTERVALS FOR EACH CHANNEL
C
      DO 309 L=1,NCH
      IF[ICH[L].EQ.0] GO TO 309
      WRITE[IOUT,103] ICH[L]
      DO 2 I=1,KK
      IF[I.EQ.1] GO TO 9
      IF[I.EQ.2] GO TO 3
    4 WRITE[IOUT,105] IALPHA[L,I],XDWN[L],XUPP[L]
      GO TO 31
    9 WRITE[IOUT,112] [IWAVE[L,K],K=1,13],IALPHA[L,I],XLOW[L]
      GO TO 32
    3 WRITE[IOUT,105]  IALPHA[L,I],XLOW[L],XUPP[L]
   31 CONTINUE
      XDWN[L]=XLOW[L]+XINCR[L,I-1]
   32 CONTINUE
      XUPP[L]=XLOW[L]+XINCR[L,I]
    2 CONTINUE
      ZUPP=XLOW[L]+XINCR[L,NUMB]
      WRITE[IOUT,105] IALPHA[L,N+2],ZUPP
      WRITE[IOUT,106]
  309 CONTINUE
      IF[IPRNT.GT.0] GO TO 315
      WRITE[IOUT,110]
      WRITE[IOUT,102]
      WRITE[IOUT,111]
      WRITE[IOUT,118]
      DO 310 L=1,NCH
      IF[ICH[L].EQ.0]  GO TO 310
      WRITE[IOUT,119] ICH[L],[IWAVE[L,K],K=1,13]
  310 CONTINUE
      LZ=KK+1
      LL=1
      WRITE[IOUT,106]
      WRITE[IOUT,120] [IALPHA[LL,I],I=1,LZ]
      WRITE[IOUT,106]
  315 CONTINUE
      NSTRT1=1
      NSTOP1=NPTS
      CALL ILABEL[MSTOP,NCALL,NPTS,JCNT,IOUT]
      WRITE[IOUT,106]
      WRITE[IOUT,108] [IALP[I],I=1,MPTS]
C
C               INUM  COUNTS  SCAN  LINES
C
      INUM=0
    5 CONTINUE
C
C                SKIP SCAN LINES
C
  401 IFLSKN=IFLSKN+1
      INUM=INUM+1
      IF[NFLSKN.EQ.0] GO TO 205
```

```
      SS=IFLSKN
      SM=SS/XSKSC
      MS=SS/XSKSC
      SS=MS
      SM=SM-SS
      IF(SM.EQ.0.0) GO TO 205
      DO 400 I=NSTART,NSTOP
      READ(IN1) ICHEK,(DATA(J),J=1,NCH)
      IF(ICHEK.EQ.3) GO TO 210
  400 CONTINUE
      READ(IN1) ICHEK,(DATA(J),J=1,NCH)
      IF(ICHEK.EQ.3) GO TO 210
      GO TO 401
 205  CONTINUE
      KK=NUMB+1
      M=0
C
C                START PROCESSING ONE SCAN LINE
C
      DO 90 I=NSTART,NSTOP
      READ(IN1)  ICHEK,(DATA(J),J=1,NCH)
    7 IF(ICHEK.EQ.3) GO TO 210
      IF(NFLSFL.EQ.0) GO TO 403
      SS=I
      SM=SS/XSKFL
      MS=SS/XSKFL
      SS=MS
      SM=SM-SS
      IF(SM.NE.0.0) GO TO 90
  403 CONTINUE
      M=M+1
      NNX=0
C
C                CLASSIFY DATA SAMPLES
C
      DO 500 J=1,KK
      NNX=NNX+1
      DO 501 L=1,NCH
      IF(ICH(L).EQ.0) GO TO 501
      IF(DATA(L).GT.XXLOW(L)+XINCR(L,NUMB)) GO TO 504
      IF(J.GT.1) GO TO 502
      IF(DATA(L).GT.XXLOW(L)) GO TO 500
      GO TO 505
  502 IF(DATA(L).GT.XXLOW(L)+XINCR(L,J-1)) GO TO 500
  505 IARAY(M)=IALPHA(L,NNX)
  501 IF(L.EQ.NCH) GO TO 90
  500 CONTINUE
      GO TO 90
  504 IARAY(M)=IALPHA(L,NUMB+2)
  90  CONTINUE
      MSKFL=XSKFL
      MPTS=NPTS/MSKFL
C
C                PRINT RESULTS FOR EACH SCAN LINE
C                MAXIMUM OF 110 PTS/LINE
```

```
C
  96  WRITE[IOUT,104] INUM,[IARAY[K],K=1,MPTS],IALP[1]
      READ[IN1]   IDUM,[DATA[J],J=1,NCH]
      IF[IDUM.GE.3] GO TO 211
      IF[NPTS.GE.MSTOP]  GO TO 5
 204  L=0
      INDEX=INDEX+1
      NSTOP2=NPTS+1
      DO 206 KK=NSTOP2,MSTOP
      L=L+1
      JARAY[INDEX,L]=IARAY[KK]
 206  CONTINUE
      GO TO 5
 210  CONTINUE
 211  NCALL=2
      IMMP=MPTS+2
      WRITE[IOUT,108] [IALP[I],I=1,IMMP]
      IF[NPTS.GE.MSTOP] GO TO 216
 212  CONTINUE
      WRITE[IOUT,110]
      CALL ILABEL[MSTOP,NCALL,NPTS,JCNT,IOUT]
      NSTOP1=MSTOP-NPTS
      DO 215 L=1,INDEX
      WRITE[IOUT,113] [JARAY[L,LL],LL=1,NSTOP1]
 215  CONTINUE
 216  REWIND IN1
      IF[ITERM.GT.0]  GO TO 300
  98  WRITE[IOUT,110]
  99  FORMAT[25A1]
 100  FORMAT[16I4]
 101  FORMAT[I1,I4,4X,12F5.3]
 102  FORMAT[14X,46HINVENTORY BOUNDARY MAP BY BOUNDARY ENHANCEMENT//]
 103  FORMAT[2X,8HCHANNEL I2,36X,22HSYMBOL          INTERVAL /]
 104  FORMAT[6X,I3,1X,1H*,112A1]
 105  FORMAT[50X,A1,8X,F7.4,3H - ,F7.4]
 106  FORMAT[1X/]
 108  FORMAT[10X,115A1]
 109  FORMAT[12F10.0,12A1]
 110  FORMAT[1H1/]
 111  FORMAT[2X,83HCROPS   C5-17,5-22,5-5,5-8,         ALTITUDE  2000 FT,
     1          DATE RECORDED  6/30/66 //]
 112  FORMAT[2X,22HWAVE LENGTH [MICRONS] ,13A1,13X,A1,8X,F5.2,
     13H - ,F5.2]
 113  FORMAT[11X,112A1]
 114  FORMAT[8F10.0]
 115  FORMAT[13I5]
 116  FORMAT[13F6.0]
 118  FORMAT[20X,7HCHANNEL,15X,11HWAVE LENGTH/]
 119  FORMAT[22X,I2,14X,13A1]
 120  FORMAT[2X,7HSYMBOLS,5X,A1,18H =  LESS THAN MEAN,5X,A1,16H = MEAN-M
     1EAN+1SD,5X,A1,20H = MEAN+1SD-MEAN+2SD//
     218X,A1,20H = MEAN+2SD-MEAN+3SD,5X,A1,
     325H =  GREATER THAN MEAN+3SD]
      STOP
      END
```

```
      SUBROUTINE ILABEL(N,ICALL,NSTOP,NCNT,KOUT)
C
C                  SUBROUTINE NUMBERS ACROSS SCAN LINE
C                  FOR LABELIND AND IDENTIFICATION
C                  INUM  = HUNDREDS
C                  JNUM  = TENS
C                  KNUM  = UNITS
C
      DIMENSION  INUM(150),JNUM(150),KNUM(150)
      IF(ICALL.GT.1) GO TO 500
      M=NCNT
      K=NCNT
      L=0
      DO 1 I=NCNT,N,NCNT
      L=L+1
      INUM(L)=I/100
      IF(M.EQ.100)  M=0
      IF(M.GT.100) M=M-100
      JNUM(L)=M/10
      M=M+NCNT
      IF(K.EQ.10) K=0
      IF(K.GT.10) K=K-10
      KNUM(L)=K
      K=K+NCNT
    1 CONTINUE
      ISTOP=NSTOP/NCNT
      WRITE(KOUT,110) (INUM(I),I=1,ISTOP)
      WRITE(KOUT,110) (JNUM(I),I=1,ISTOP)
      WRITE(KOUT,110) (KNUM(I),I=1,ISTOP)
  110 FORMAT(11X,120I1)
      GO TO 200
  500 K=NSTOP+1
      K=K/NCNT
      M=N/NCNT
      WRITE(KOUT,110) (INUM(I),I=K,M)
      WRITE(KOUT,110) (JNUM(I),I=K,M)
      WRITE(KOUT,110) (KNUM(I),I=K,M)
  200 RETURN
      END
```

3.4 STATISTICAL INVENTORY BOUNDARY PROGRAM

The inventory boundary program has been developed to automatically construct a map of inventory boundaries for sequential multispectral scanner data. Inventory boundaries are calculated simultaneously in both the scan line (horizontal) and sample number (vertical) directions. The mathematical formulations are given in subsection 2.3.

DEFINITION OF INPUT DATA:

CARD 1

DOT - Symbol used where no boundaries exist. Usually a period (.).

DASH - Symbol used for boundary in the flight line (vertical) direction.

EYE - Symbol used for boundary in the scan line (horizontal) direction.

PLUS - Symbol used where a horizontal and a vertical boundary coincide.

CARD 2

L1 - Lower percentage value (α_L) for first χ^2 table.

U1 - Upper percentage value (α_u) for first χ^2 table.

L2 - Lower percentage value (α_L) for second χ^2 table.

U2 - Upper percentage value (α_u) for second χ^2 table.

IAVG - Number of samples to skip before comparing ERCK to confidence limits.

MACH - Indicates machine and type of input to be used. MACH = 0 indicates card input on the IBM 7044 or IBM 7094. MACH = 32 indicates tape input on unit 3 (logical unit 54) of the CDC 3200. MACH = 44 indicates type input on unit 5 (logical unit 1) of the IBM 7044. MACH = 94 indicates tape input on Unit B-5 (logical unit 9) on the IBM 7094.

CARD 3

XSTOP - Number of values in first χ^2 table.

CARD SET 1

CHIL1(m) - $\frac{\chi_{\alpha_L}}{\sqrt{m}}$ values for first set of tables (13 values per table).

CARD 4

XSTOP - Number of values in second χ^2 table.

CARD SET 2

CHIU1(m) - $\frac{\chi_{\alpha_u}}{\sqrt{m}}$ values for first set of tables (13 values per table).

CARD 5

XSTOP - Number of values in third χ^2 table.

CARD SET 3

CHIL2(m) - $\frac{\chi_{\alpha L}}{\sqrt{m}}$ values for second set of tables (13 values per table).

CARD 6

XSTOP - Number of values in fourth χ^2 table.

CARD SET 4

CHIU2(m) - $\frac{\chi_{\alpha u}}{\sqrt{m}}$ values for second χ^2 table (13 values per table).

CARD 7

SCALE - Scale value for input data.

CARD 8

CONF - Indicates which set of χ^2 tables to use.

CONF1 - Percent of confidence within confidence intervals.

CARD 9

ALPHA1 - ID card (Normally used for field discription).

CARD 10

ALPHA2 - ID card (Normally used for test discription).

CARD 11

CHAN(I) - Channels to be averaged over and number of channels. For each channel N to be used, N must be punched in the n^{th} position on the card. The number "13" must be punched in all other positions except for the thirteenth position which must contain the number of channels used.

DATA 12

NOTE - If data is on cards they can be followed by the "CHAN(I)" card and reloaded for as many channel combinations as required. If data is on tape then the "CHAN(I)" cards can be stacked together for different channel combinations.

OUTPUT:

The program output is given in Figure 3-4 and is self explanatory.

The input card deck is shown in Figure 3-5. The flowchart of the program is given in Figure 3-6, which is followed by a complete listing of the program.

FIELD DESCRIPTION- C5-17 C5-22 C5-5 C5-8
ALTITUDE- 2000 FT. DATE RECORDED- 6/30/66

CHANNEL	WAVE LENGTH(MICRONS)
1	0.40 - 0.44
2	0.44 - 0.46
3	0.46 - 0.48
4	0.48 - 0.50
5	0.50 - 0.52
6	0.52 - 0.55
7	0.55 - 0.58
8	0.58 - 0.62
9	0.62 - 0.66
10	0.66 - 0.72
11	0.72 - 0.80
12	0.80 - 1.00

99 PERCENT CONFIDENCE LIMITS

SYMBOLS= V - VERTICAL BOUNDARY H - HORIZONTAL BOUNDARY
X - BOTH VERTICAL AND HORIZONTAL BOUNDARY

SAMPLE NUMBER

```
             1111111111222222222233333333334444444444555555555566666666667777777777888 8
    123456789*123456789*123456789*123456789*123456789*123456789*123456789*123456789*123456789*123
  1 ................................V.......................................V....................
  2 ...............................V.........................................V...................
  3 ...............................V......................................V......................
  4 ...............................V.....................................V.......................
  5 ...............................V......................................V......................
  6 ...............................V.......................................V.....................
  7 ...............................V....................................V........................
  8 .................................V...................................V.......................
  9 ................................V....................................V.......................
 10 ...............................V......................................V......................
 11 ...............................V........................................V....................
 12 .............................X...........................................V...................
 13 ...HHHHHHHHHHHHH.......HHHHH.V................................HHHHH......V...................
 14 .................H.HHH.V...........................................X.HHHHH....H........V...H.
 15 ...................H...V...........................................V...................V..H..
 16 .......................V................................................V.................H..
 17 ........................V.............................................V................V.....
 18 ........................V........................................V..H..................V.....
 19 ........................V..........................................V...................VH....
 20 ........................V.........................................V...................V.H....
S 21 ........................V..........................................V...................V.....
C 22 ........................V..........................................V...................V.....
A 23 ........................V.........................................V....................V.....
N 24 ........................V........................................V.....................V.....
  24 ........................V........................................V.....................V.....
  25 ........................V.........................................V....................V.....
L 26 ..............H.....H.V.HH.HHHHHHHHHHHHHH...HHHHHHHHHHHHH...............V............H.......
I 27 ............HH..H.........X...H...............HHH..............V.............................
N 28 ........H.H.............V......................................V.............................
E 29 .......................V.......................................V.............................
  30 ........................V......................................V.............................
  31 ........................V......................................V.............................
  32 ........................V......................................V.............................
  33 ........................V.......................................V............................
  34 ........................V......................................V.............................
  35 ........................V.......................................V............................
  36 ........................V.......................................V............................
  37 ........................V......................................V.............................
  38 ........................V.......................................V............................
  39 ...HHHHHHHHHHHH.HHH.HHHHX.HHHHHHHHHHHHHHHHHHH.HHHHHHHHHHHHHHHHH.V................HH.HHH.....H
  40 .............H...H...........................H...........V...............H.....X..H...H......
  41 ................................................................V.........................H..
  42 ..............................................................V..........................H.H.
  43 ..............................................................V..............................
  44 ..............................................................V..............................
  45 ..............................................................V..............................
  46 ...............................................................V.............................
  47 ...............................................................V.............................
  48 ................................................................V............................
  49 ................................................................V............................
  50 ................................................................V............................
  51 ...............................................................V.............................
  52 ................................................................V............................
```

Figure 3-4. MAP OF INVENTORY BOUNDARIES

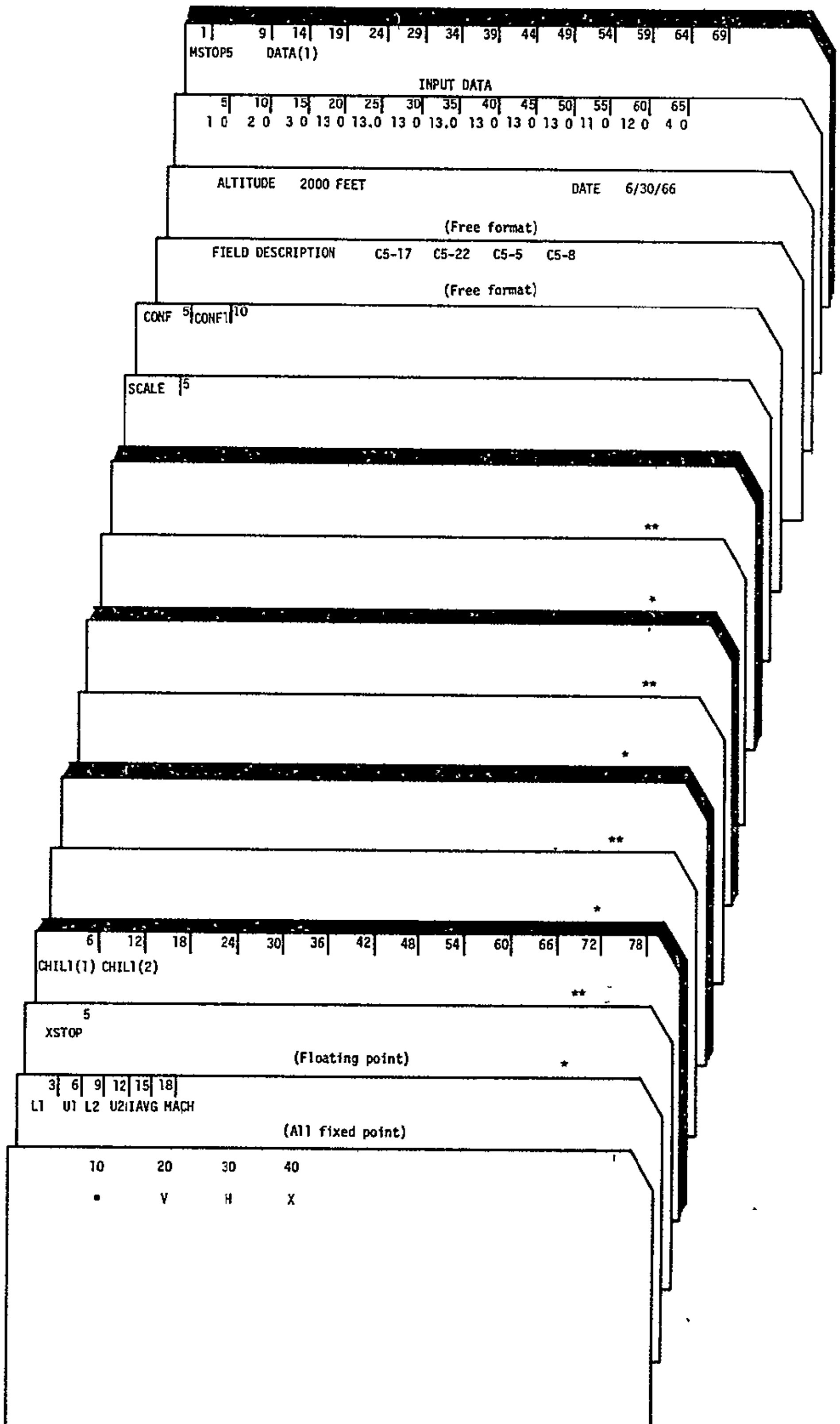

Figure 3-5. INPUT CARDS FOR INVENTORY BOUNDARY PROGRAM

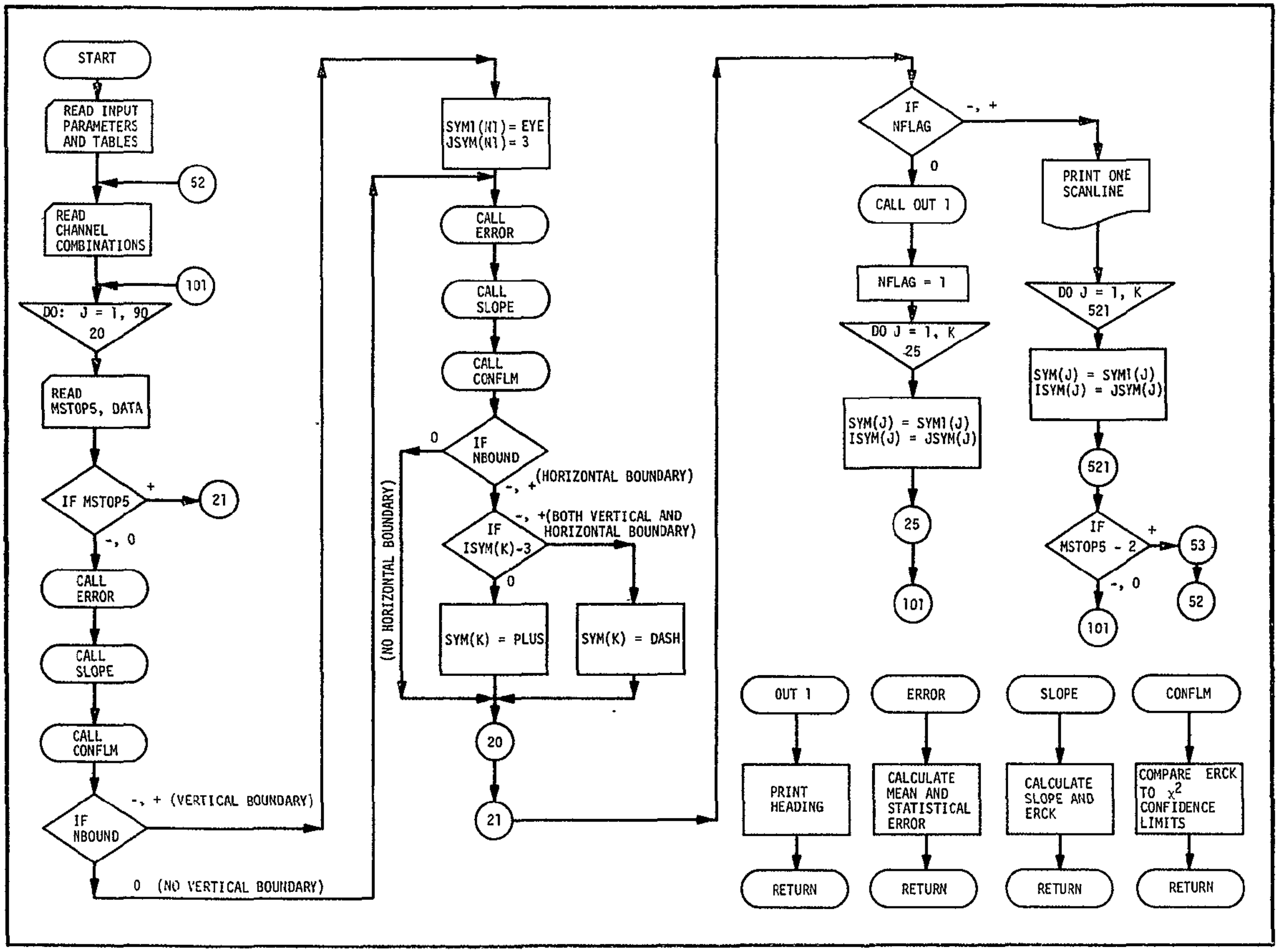

Figure 3-6. FLOWCHART OF INVENTORY BOUNDARY PROGRAM

```
1
      INTEGER U1
      INTEGER U2
      DIMENSION SYM(90),ISYM(90),SYM1(90),JSYM(90)
      DIMENSION CHIL1(175),CHIU1(175),CHIL2(175),CHIU2(175)
      DIMENSION CHAN(13),ICHAN(13),DATA(12),VBAR(12),VBAR1(12),VEACUM(12
     1),XBAR(12,90),XBAR1(12,90),DELX(12,90),X(12),X1(12),XEACUM(12)
      DIMENSION SUM1(90),SUM2(90)
      DIMENSION NV(90)
      DIMENSION ALPHA1(14),ALPHA2(14)
      DIMENSION IDAT(12)
      NRD=5
      NWT=6
      READ (NRD,6000)DOT,DASH,EYE,PLUS,BLANK
C        SET MACH TO 44 FOR IBM 7044
C        SET MACH TO 32 FOR CDC 3200
      READ (NRD,51) L1,U1,L2,U2,IAVG,MACH
      READ (NRD,2003) XSTOP
      MSTOP1=XSTOP
      READ (NRD,201) (CHIL1(NU),NU=1,MSTOP1)
      READ (NRD,2003) XSTOP
      MSTOP2=XSTOP
      READ (NRD,201) (CHIU1(NU),NU=1,MSTOP2)
      READ (NRD,2003) XSTOP
      MSTOP3=XSTOP
      READ (NRD,201) (CHIL2(NU),NU=1,MSTOP3)
      READ (NRD,2003) XSTOP
      MSTOP4=XSTOP
      READ (NRD,201) (CHIU2(NU),NU=1,MSTOP4)
      READ (NRD,2003) SCALE
      READ (NRD,2003) CONF,CONF1
      ICONF=CONF
      ICONF1=CONF1
      WRITE (NWT,1001)
      READ (NRD,2004) (ALPHA1(I),I=1,14)
      READ (NRD,2004) (ALPHA2(I),I=1,14)
 52   CONTINUE
      READ (NRD,2003) (CHAN(I),I=1,13)
      DO 60 I=1,13
      ICHAN(I)=CHAN(I)
 60   CONTINUE
      NCHAN=CHAN(13)
      NFLAG=0
      NSTOP=0
      IPRINT=0
      IF (MACH-32) 62,61,62
 61   NUNIT=54
      REWIND NUNIT
      GO TO 65
```


0

```
62    IF [MACH-44] 64,63,64
63    NUNIT=1
      REWIND NUNIT
      GO TO 65
64    IF [MACH-94] 67,66,67
66    NUNIT=9
      REWIND NUNIT
      GO TO 65
67    NUNIT=5
65    CONTINUE
      DO 6 J=1,90
      SUM1[J]=0.0
      SUM2[J]=0.0
      NV[J]=0
6     CONTINUE
101   CONTINUE
      DO 5000 J=1,90
      JSYM[J]=0
5000  SYM1[J]=DOT
      VSUM1=0.0
      VSUM2=0.0
      K=0
      N=0
      DO 20 J=1,90
      IF [MACH] 68,69,68
69    READ [NUNIT,1000] MSTOP5,[DATA[I],I=1,12]
      GO TO 70
C68   READ [NUNIT] MSTOP5,[DATA[I],I=1,12]
68    READ [NUNIT] MSTOP5,NDUMMY,NDUMMY,[IDAT[I],I=1,12]
      DO 71 I=1,12
71    DATA[I]=IDAT[I]
C     DO 71 I=1,12
C71   DATA[I]=IDAT[I]
70    CONTINUE
      N=N+1
      NV[J]=NV[J]+1
      K=K+1
      N1=J-1
      DO 12 I=1,12
      DATA[I]=DATA[I]/SCALE
      IF [MSTOP5] 9,9,21
9     IF [NV[K]-1] 11,10,11
10    XBAR[I,K]=DATA[I]
      XBAR1[I,K]=DATA[I]
      DELX[I,K]=0.0
11    CONTINUE
12    CONTINUE
      CALL ERROR[VBAR,VBAR1,DATA,VEACUM,ICHAN,N]
```

```
      IF (N-1) 14,14,13
13    CONTINUE
      CALL SLOPE(VEACUM,ICHAN,N ,1,ERCK,VSUM1,VSUM2)
      IF (ERCK) 113,14,113
113   CONTINUE
      CALL CONFLM(CHIL1,CHIU1,CHIL2,CHI U2,MSTOP1,MSTOP2,MSTOP3,MSTOP4,N
     1,IAVG,ERCK,NBOUND,ICONF)
114   IF (NBOUND) 376,14,376
376   SYM1(N1)=EYE
      JSYM(N1)=3
      N=0
      VSUM1=0.0
      VSUM2=0.0
14    CONTINUE
      DO 15 I=1,12
      X(I)=XBAR(I,K)
      X1(I)=XBAR1(I,K)
15    XEACUM(I)=DELX(I,K)
      CALL ERROR(X,X1,DATA,XEACUM,ICHAN,NV(K))
      IF (NV(K)-1) 18,18,16
16    CONTINUE
      CALL SLOPE(XEACUM,ICHAN,NV(K),NV(K),ERCK,SUM1(K),SUM2(K))
      IF (ERCK) 374,18,374
374   CONTINUE
      CALL CONFLM(CHIL1,CHIU1,CHIL2,CHIU2,MSTOP1,MSTOP2,MSTOP3,MSTOP4,
     1NV(K),IAVG,ERCK,NBOUND,ICONF)
      NV1=NV(K)
375   IF(NBOUND) 377,18,377
377   IF (ISYM(K   )-3) 379,378,379
378   SYM (K   )=PLUS
      NV(K)=0
      GO TO 380
379   SYM (K   )=DASH
380   NV(K)=0
      SUM1(K)=0.0
      SUM2(K)=0.0
18    CONTINUE
      DO 17 I=1,12
      XBAR(I,K)=X(I)
      XBAR1(I,K)=X1(I)
      DELX(I,K)=XEACUM(I)
17    CONTINUE
20    CONTINUE
21    K=K-1
      IF (NFLAG) 31,30,31
30    CALL OUT1(ICHAN,ICONF,ICONF1,K,ALPHA1,ALPHA2,DASH,EYE,PLUS)
      K1=K
      NFLAG=1
      DO 25 J=1,K
```

```
      SYM[J]=SYM1[J]
5     ISYM[J]=JSYM[J]
      GO TO 101
1     CONTINUE
      K=K1
      IPRINT=IPRINT+1
      IF [IPRINT-21] 500,501,502
500   WRITE [NWT,6001] IPRINT,[SYM[J],J=1,K]
      GO TO 520
501   WRITE [NWT,6002] IPRINT,[SYM[J],J=1,K]
      GO TO 520
502   IF [IPRINT-23] 503,504,505
503   WRITE [NWT,6003] IPRINT,[SYM[J],J=1,K]
      GO TO 520
504   WRITE [NWT,6004] IPRINT,[SYM[J],J=1,K]
      GO TO 520
505   IF [IPRINT-25] 506,507,508
506   WRITE [NWT,6005] IPRINT,[SYM[J],J=1,K]
      GO TO 520
507   GO TO 500
508   IF [IPRINT-27] 509,510,511
509   WRITE [NWT,6006] IPRINT,[SYM[J],J=1,K]
      GO TO 520
510   WRITE [NWT,6007] IPRINT,[SYM[J],J=1,K]
      GO TO 520
511   IF [IPRINT-29] 512,513,514
512   WRITE [NWT,6008] IPRINT,[SYM[J],J=1,K]
      GO TO 520
513   WRITE [NWT,6009] IPRINT,[SYM[J],J=1,K]
      GO TO 520
514   GO TO 500
520   DO 521 J=1,K
      SYM[J]=SYM1[J]
521   ISYM[J]=JSYM[J]
      K1=K
      IF [MSTOP5-2] 101,101,53
53    WRITE [NWT,1001]
      GO TO 52
1     FORMAT[8I3]
01    FORMAT[13F6.0,2X]
1000  FORMAT[I1,8X,12F5.0]
1001  FORMAT[1H1]
1003  FORMAT[13F5.0]
1004  FORMAT[13A6,A2]
6000  FORMAT[4[9X,A1],5X,A5]
6001  FORMAT[10X,I4,1X,90A1]
6002  FORMAT[9X,1HS,I4,1X,90A1]
6003  FORMAT[9X,1HC,I4,1X,90A1]
6004  FORMAT[9X,1HA,I4,1X,90A1]
6005  FORMAT[9X,1HN,I4,1X,90A1]
```

```
6006 FORMAT(9X,1HL,I4,1X,90A1)
6007 FORMAT(9X,1HI,I4,1X,90A1)
6008 FORMAT(9X,1HN,I4,1X,90A1)
6009 FORMAT(9X,1HE,I4,1X,90A1)
     END
```



```
      SUBROUTINE OUT1(ICHAN,ICONF,ICONF1,N,ALPHA1,ALPHA2,DASH,EYE,PLUS)
      DIMENSION ITEN(90),IONE(90)
      DIMENSION ICHAN(1),ICHAN1(12)
      COMMON/DATA/WLNGTH(13)
      DIMENSION WLNGTH(13)
      DIMENSION ALPHA1(1),ALPHA2(1)
      DATA ((WLNGTH(I),I=1,13)=.40,.44,.46,.48,.50,.52,.55,.58,.62,.66,.
     1  72,.80,1.00)
      DATA WLNGTH/.4,.44,.46,.48,.50,.52,.55,.58,.62,.66,.72,.8,1./
      NWT=6
      DO 9 I=1,12
9     ICHAN1(I)=0
      I1=1
      J1=ICHAN(13)
      DO 12 J=1,J1
      DO 10 I=I1,12
      I2=I
      IF (ICHAN(I)-13) 11,10,11
10    CONTINUE
11    ICHAN1(J)=ICHAN(I2)
      I1=I2+1
12    CONTINUE
      WRITE (NWT,1001)
      WRITE (NWT,1010)
      WRITE (NWT,1007) (ALPHA1(I),I=1,14)
      WRITE (NWT,1007) (ALPHA2(I),I=1,14)
      WRITE (NWT,1010)
      WRITE (NWT,1006)
      DO 13 I=1,J1
      M=ICHAN1(I)
13    WRITE (NWT,1008) M,WLNGTH(M),WLNGTH(M+1)
      WRITE (NWT,1010)
      WRITE (NWT,1005) ICONF1
      WRITE (NWT,1010)
      WRITE (NWT,1009) EYE,DASH,PLUS
      WRITE (NWT,1010)
      WRITE (NWT,1002)
      WRITE (NWT,1010)
      DO 20 I=1,N
      ITEN(I)=I/10
      IONE(I)=I-(I/10)*10
20    CONTINUE
      WRITE (NWT,1003) (ITEN(I),I=10,N)
      WRITE (NWT,1004) (IONE(I),I=1,N)
1001  FORMAT(1H0,28X,27HMAP OF INVENTORY BOUNDARIES/)
```

```
1002 FORMAT(36X,13HSAMPLE NUMBER/)
1003 FORMAT(24X,90I1)
1004 FORMAT(15X,90I1/)
1005 FORMAT(28X,I2,26H PERCENT CONFIDENCE LIMITS/)
1006 FORMAT(26X,32HCHANNEL     WAVE LENGTH(MICRONS)/)
1007 FORMAT(14X13A6,A2/)
1008 FORMAT(28X,I2,12X,F5.2,3H - ,F5.2,/)
1009 FORMAT(14X,8HSYMBOLS=,3X,A1,20H - VERTICAL BOUNDARY,3X,A1,22H - HO
    1RIZONTAL BOUNDARY/22X,A1,40H - BOTH VERTICAL AND HORIZONTAL BOUNDA
    2RY/)
 1010 FORMAT (1H0)
      RETURN
      END

1
      SUBROUTINE ERROR(XMEAN,XMEAN1,XDATA,XEACUM,ICHAN,M)
      DIMENSION XMEAN(12),XMEAN1(12),XEACUM(12),XDATA(12),ICHAN(1)
      XM=M-1
      DO 30 I=1,12
      IF (ICHAN(I)-13) 20,30,30
 20   IF (M-1) 21,21,22
 21   XMEAN(I)=XDATA(I)
      XMEAN1(I)=XMEAN(I)
      XEACUM(I)=0.0
      GO TO 30
 22   CONTINUE
      XMEAN(I)=(XM/(XM+1.0))*XMEAN(I)+(1.0/(XM+1.0))*XDATA(I)
      XEACUM(I)=((XM-1.0)/(XM+1.0))*XEACUM(I)+(1.0/(XM+1.0))*(XMEAN1(I)-
     1XMEAN(I))**2+(1.0/(XM*(XM+1.0)))*(XDATA(I)-XMEAN(I))**2
      XMEAN1(I)=XMEAN(I)
 30   CONTINUE
      RETURN
      END

      SUBROUTINE SLOPE(EACUM,ICHAN,M,MDUM,ERCK,SUM1,SUM2)
      DIMENSION EACUM(1)  ,ICHAN(1)
      CHAN13=ICHAN(13)
      XM=M
      HACUM1=0.0
      DO 20 I=1,12
      IF (ICHAN(I)-13) 10,20,10
 10   HACUM1=HACUM1+EACUM(I)
 20   CONTINUE
      HACUM1=SQRT(HACUM1/CHAN13)
      SUM1      =SUM1      +(XM*HACUM1)**2/(XM-1.0)
      SUM2      =SUM2      +(XM*HACUM1)/SQRT(XM-1.0)
      IF (SUM1) 30,40,30
```

```
30     IF [SUM2] 35,40,35
40     ERCK=0.0
       GO TO 45
35     CONTINUE
       A=SUM1        /SUM2
       ERCK=SQRT[XM]*HACUM1/A
45     CONTINUE
       RETURN
       END

1
       SUBROUTINE CONFLM[CHIL1,CHIU1,CHIL2,CHIU2,MSTOP1,MSTOP2,MSTOP3,
      1MSTOP4,M,IAVG,ERCK,NBOUND,ICONF]
       DIMENSION CHIL1[1],CHIU1[1],CHIL2[1],CHIU2[1]
       IAVG1=IAVG-1
       NBOUND=0
       IF [M-MSTOP3] 342,342,341
342    CHIOL2=CHIL2[M]
       GO TO 343
341    CHIOL2=CHIL2[MSTOP3]
343    IF [M-MSTOP4]345,345,344
345    CHIOU2=CHIU2[M]
       GO TO 346
344    CHIOU2=CHIU2[MSTOP4]
346    CONTINUE
       IF [M-MSTOP2] 31,31,30
30     CHIOU1=CHIU1[MSTOP2]
       GO TO 32
31     CHIOU1=CHIU1[M]
32     IF[ M-MSTOP1] 34,34,33
33     CHIOL1=CHIL1[MSTOP1]
       GO TO 35
34     CHIOL1=CHIL1[M]
35     IF[M-IAVG1] 20,37,37
37     CONTINUE
       IF[ICONF-1] 372,371,372
371    IF    [ERCK-CHIOL1] 376,376,36
36     IF    [ERCK-CHIOU1] 20,376,376
372    IF[ICONF-2] 376,373,376
373    IF    [ERCK-CHIOL2] 376,376,374
374    IF    [ERCK-CHIOU2] 20,376,376
376    NBOUND=1
20     CONTINUE
7000   FORMAT[60X,2F10.5]
       RETURN
       END
```

3.5 BOUNDARY ENHANCEMENT PROGRAM

This program is devised for determination of inventory boundaries through the enhancement of the difference in the multispectral data between homogeneous inventory areas. The mathematical formulation has been given in subsection 2.4.

This program consists of two links. Link 1 performs the moving or jumping averages of the input data. The output is in tape and may be input to Link 2. Link 2 performs the calculation of the finite difference of the averaged data and then calculates the absolute value or square of these differences. The outputs of Link 2 are (a) means and standard deviations for every channel of enhanced data and (b) a digital tape of the enhanced data. These means and standard deviations can be used for setting the class intervals for inputting to the Alphanumeric Plot Program to process the digital tape.

The input data to this program is on tape, while the control parameters for the program are inputed by NAMELIST statements which are documented in IBM FORTRAN IV manual, Form C28-6390-2.

The definitions of the input parameters to each LINK are as follows:

LINKO INPUT PARAMETERS:

LINKNO - Specifies which LINKS to execute. LINKNO equal one LINK1 is executed and LINKNO equal two LINK2 is executed.

LINK1 INPUT PARAMETERS:

- NLOOP - Number of scan lines to be read in.
- NCT - Number of samples per scan line.
- NCHAN - Number of channels of data to be used.
- LTN - Logical tape number of input data tape.
- LTN1 - Logical tape number of output data tape.
- NLOOP1 - Number of scan lines to sort, dependent on the number of scan lines read (NLOOP1 = NLOOP-NSKIPR).
- NSKIPR - Number of scan lines to skip, cannot be greater than the number averaged (NAVGR).
- NAVGC - Number of samples to average in a scan line.
- NSKIPC - Number of samples to skip in a scan line, cannot be greater than the number averaged (NAVGC).

- NAVGR - Number of scan lines to average.
- NFILE - Number of data files to process.
- NBEGIN - Scan line to start processing.

LINK2 INPUT PARAMETERS:

- NLOOP - Number of scan lines to be read in, must be greater than or equal to (2 X NDIFF + 1).
- NCT - Number of samples per scan line.
- NCHAN - Number of channels of data.
- LTN1 - Logical tape number of input data tape.
- LTN2 - Logical tape number of output data tape.
- NLOOP1 - Equals NLOOP minus one.
- NDIFF - Number of adjacent samples to skip in the cross differencing process.
- NFILE - Number of files of data to process.
- IABS - Calculates the sum of the absolute values of the differences about the adjacent data points. If IABS is not equal zero, it is calculated; if it equals zero, it is bypassed.
- ISQ - Calculates the sum of the squared values of the differences about the adjacent data points. If ISQ is not equal zero, it is calculated; if ISQ is equal zero, it is bypassed.
- ISUM - Position in the output array (W(I)) that the sum of the squared or absolute value of the differences from the channels is stored.
- NBEGIN - Scan line to start processing.

An example of the output is shown in Figure 3-7, which is followed by a complete program listing.

3.6 MEAN, CORRELATION, AND COVARIANCE PROGRAM

This program is devised for calculating the mean vector, correlation matrix, covariance matrix, and normalized covariance matrix of a given multispectral data sequence. The format of the input data is specified in the Tape Conversion Program. The mathematical expression for these quantities is given in subsection 2.6.

In addition to the printout, a punched card output for the mean vector and covariance matrix are available. These card outputs form part of the input to the Divergence Matrix Program.

```
         INVENTØRY BØUNDARY MAP BY BØUNDARY ENHANCEMENT

CRØPS    C5-17,5-22,5-5,5-8,        ALTITUDE  200C FT.        DATE RECØRDED  6/30/66

                   CHANNEL              WAVE LENGTH
                     13

SYMBØLS      . =  LESS THAN MEAN      . = MEAN-MEAN+1SD      . = MEAN+1SD-MEAN+2SD

                 2 = MEAN+2SD-MEAN+3SD      3 =  GREATER THAN MEAN+3SD

          00000000000000000000000000000000000000000000000001111111111111111111111111111111
          00001111122222333334444455555666667777788888999990000011111222223333344444555556
          24680246802468024680246802468024680246802468024680246802468024680246802468024680

        **********************************************************************************
      2 *................................................................................*
      4 *................................................................................*
      6 *................................................................................*
      8 *................................................................................*
     10 *................................................................................*
     12 *................................................................................*
     14 *................................................................................*
     16 *................................................................................*
     18 *................................................................................*
     20 *................................................................................*
     22 *..................222.2.........................................................*
     24 *2322...2223332....33332.........................................................*
     26 *2322.....23323....33332................................2........................*
     28 *..................3332..........................................................*
     30 *..................3232..........................................................*
     32 *..................223...........................................................*
     34 *..................223...........................................................*
     36 *...................23...........................................................*
     38 *...................23...........................................................*
     40 *...................23...........................................................*
     42 *...................23...........................................................*
     44 *...................33...........................................................*
     46 *...................23...........................................................*
     48 *...................23...........................................................*
     50 *...................2332333322..2222222......23332322............................*
     52 *....................33223222..223222222....223333322............................*
     54 *....................3................................2..........................*
     56 *....................2...........................................................*
     58 *....................2...........................................................*
     60 *....................2...........................................................*
     62 *................................................................................*
     64 *................................................................................*
     66 *....................2...........................................................*
     68 *....................2...........................................................*
     70 *....................2...........................................................*
     72 *....................2...........................................................*
     74 *....................2...........................................................*
     76 *................2.233................................2..........................*
     78 *22...222......22223333322232223333332.....233322233322...............2.233332...*
     80 *...........2.22.2.2233322222..2333333...22222233333322.............2.3..33332...*
     82 *...................................................................3.3..........*
     84 *...................................................................2.3..........*
     86 *...................................................................2.3..........*
     88 *...................................................................2.3..........*
     90 *...................................................................2.32.........*
     92 *...................................2...............................3.33.........*
     94 *...................................................................3.33.........*
     96 *...................................................................3.33.........*
     98 *...................................................................3.33.........*
    100 *...................................................................3.33.........*
    102 *...................................................................3.33.........*
        **********************************************************************************
```

Figure 3-7. INVENTORY BOUNDARY MAP BY BOUNDARY ENHANCEMENT

```
C          BOUNDARY  ENCHANCEMENT      PROGRAM
      DIMENSION  LINKNO[6]
      NAMELIST/NAMDAT/LINKNO
      READ[5,NAMDAT]
      WRITE[6,NAMDAT]
      IF[LINKNO[1].EQ.0]  GO TO 1
      CALL LINK1
 1    CONTINUE
      IF[LINKNO[2].EQ.0] GO TO 2
      CALL  LINK2
 2    CONTINUE
      STOP
      END
$ORIGIN         ALPHA,REW
$IBFTC TWO      NODECK
      SUBROUTINE  LINK1
C          MOVING  OR  JUMPING  AVERAGE  PROGRAM
      DIMENSION  DUMMY[13]
      DIMENSION  DATA[6,200,12],X[200,12]
      NAMELIST/SIZE/NLOOP,NCT,NCHAN,LTN,LTN1,LTN2,NLOOP1,NSKIPR,NAVGC,
     1NSKIPC,NAVGR,NFILE,NBEGIN
C    NSKIPR  MUST  BE  LESS  THAN   OR  EQUAL  TO  NAVGR
C    NSKIPC  MUST  BE  LESS  THAN   OR  EQUAL  TO  NAVGC
      READ[5,SIZE]
      WRITE[6,SIZE]
      DO 101  IAB=1,NFILE
      IZERO=0
      IONE=1
      ITWO=2
      ITHREE=3
      KS=0
      XNAVGC=NAVGC
      XNAVGR=NAVGR
 100  CONTINUE
      LL=1
      KK=NAVGC
      DO 10 I=NBEGIN,NLOOP
      KS=KS+1
      DO 11 J=1,NCT
      READ[LTN]  ICHEK,IDUM,[DATA[I,J,L],L=1,NCHAN]
C     WRITE  [6,1003]  ICHEK,KS, J ,[DATA[I,J,L],L=1,NCHAN]
      IF[ICHEK-3]  11,7,11
 7    IF[J.NE.NCT]  GO TO 13
 11   CONTINUE
 10   CONTINUE
      DO  12  I=1,NCT
      DO  12 J=1,NCHAN
      X[I,J]=0.0
 12   CONTINUE
      NCT1=NCT-NAVGC
      DO 1 I=1,NCT1
```

```
      DO 3 J=1,NAVGR
      DO 3 K=LL,KK
      DO 4 M=1,NCHAN
      X[I,M]=X[I,M]+DATA[J,K,M]
 4    CONTINUE
 3    CONTINUE
      DO 2 M=1,NCHAN
      X[I,M]=X[I,M]/[XNAVGC*XNAVGR]
 2    CONTINUE
      WRITE[LTN1]  IZERO,[X[I,M],M=1,NCHAN]
C     WRITE[6,1004] IZERO,[X[I,M],M=1,NCHAN]
      LL=LL+NSKIPC
      KK=LL+NAVGC-1
 1    CONTINUE
      IF[ICHEK-3]  9,8,9
 9    WRITE[LTN1]  IONE,[DUMMY[I],I=1,NCHAN]
      IF[NSKIPR.EQ.NLOOP] GO TO 100
      NBEGIN=NLOOP1+1
      DO 5 I=1,NLOOP1
      DO 6 J=1,NCT
      DO 6 L=1,NCHAN
      LZ=I+NSKIPR
      DATA[I,J,L]=DATA[LZ,J,L]
 6    CONTINUE
 5    CONTINUE
      GO TO 100
 13   WRITE [6,1002] KS
 8    WRITE[LTN1]  ITWO,[DUMMY[I],I=1,NCHAN]
 101  CONTINUE
      WRITE[LTN1]  ITHREE,[DUMMY[I],I=1,NCHAN]
      END  FILE LTN1
      REWIND  LTN1
 1000 FORMAT[I1,8X,12F6.3]
 1001 FORMAT[I1,8X,12F6.3]
 1002 FORMAT[1X,11HEND FILE IN,I5,9HSCAN LINE]
 1003 FORMAT[1X,3I5,12F6.3]
 1004 FORMAT[1X,I3,12F6.3]
      RETURN
      END
$ORIGIN          ALPHA,REW
$IBFTC THREE     NODECK
      SUBROUTINE  LINK2
C          CROSS      DIFERENCE      PROGRAM
      DIMENSION  DUMMY[13]
      DIMENSION  DATA[6,200,12],W[15],W1[15]
      DIMENSION  XBAR[15],XMSBAR[15],SIG[15],RMS[15],SIGSQ[15]
      NAMELIST/SIZE/NLOOP,NCT,NCHAN,LTN1,LTN2,NLOOP1,NDIFF,NFILE,
     1IABS,ISQ,ISUM,NBEGIN
      READ[5,SIZE]
      WRITE [6,SIZE]
      NCHAN1=NCHAN+1
      DO 102 IAB=1,NFILE
      IZERO=0
      IONE=1
      ITWO=2
```

```
      ITHREE=3
      MS=0
      KS=0
      DO 18 I=1,NCHAN1
      SIG(I)=0.0
      XBAR(I)=0.0
      XMSBAR(I)=0.0
      RMS(I)=0.0
      SIGSQ(I)=0.0
 18   CONTINUE
 100  IF(KS.GT.0)  NBEGIN=NLOOP
      DO 1 I=NBEGIN,NLOOP
      KS=KS+1
      DO 2 J=1,NCT
      READ(LTN1)  ICHEK,(DATA(I,J,L),L=1,NCHAN)
C     WRITE  (6,1003)  ICHEK,KS, J ,(DATA(I,J,L),L=1,NCHAN)
      IF(ICHEK-3)  2,4,2
 4    IF(J.NE.NCT)  GO TO 7
 2    CONTINUE
 1    CONTINUE
      NCT1=NCT-NDIFF-1
      NDIFF1=NDIFF+1
      NLOOP2=NLOOP-NDIFF
      DO 10 I=NDIFF1,NLOOP2
      DO 11 J=NDIFF1,NCT1
      SM=MS
      MS=MS+1
      W(ISUM)=0.0
      DO  12 K=1,NCHAN
      IZ=I-NDIFF
      JZ=I+NDIFF
      KZ=J+NDIFF
      LZ=J-NDIFF
C          ABSOULTE    VALUE      OF      CROSS      DIFFERENCES
      IF(IABS)  9,8,9
 9    CONTINUE
      AVSUM=ABS(DATA(I,J,K)-DATA(IZ,J,K))+ABS(DATA(I,J,K)-DATA(I,KZ,K))+
     1ABS(DATA(I,J,K)-DATA(JZ,J,K))+ABS(DATA(I,J,K)-DATA(I,LZ,K))
      W(K)=AVSUM
 8    CONTINUE
C          SQUARED     VALUE      OF      CROSS      DIFFERENCES
      IF(ISQ)  14,13,14
 14   CONTINUE
      AVSUM1=(DATA(I,J,K)-DATA(IZ,J,K))**2+(DATA(I,J,K)-DATA(I,KZ,K))**2
     1+(DATA(I,J,K)-DATA(JZ,J,K))**2+(DATA(I,J,K)-DATA(I,LZ,K))**2
      W(K)=AVSUM1
 13   CONTINUE
      W(ISUM)=W(ISUM)+W(K)
 12   CONTINUE
      DO 15 L=1,NCHAN1
      XMSBAR(L)=(SM/(SM+1.0))*XMSBAR(L)+(1.0/(SM+1.0))*W(L)**2
      XBAR(L)=(SM/(SM+1.0))*XBAR(L)+(1.0/(SM+1.0))*W(L)
 15   CONTINUE
      WRITE(LTN2)  IZERO,(W(K),K=1,NCHAN1)
C     WRITE (6,1001)   IZERO,(W(K),K=1,NCHAN)
```

```
C       WRITE [6,1001]    IZERO,[W1[K],K=1,NCHAN]
 11     CONTINUE
        IF[ICHEK-3]  10,3,10
 10     WRITE[LTN2]  IONE,[DUMMY[K],K=1,NCHAN1]
        DO 5 I=1,NLOOP1
        DO 6 J=1,NCT
        DO 6 L=1,NCHAN
        DATA[I,J,L]=DATA[I+1,J,L]
 6      CONTINUE
 5      CONTINUE
        GO TO 100
 7      WRITE[6,1002]  KS
 3      WRITE[LTN2]  ITWO,[DUMMY[I],I=1,NCHAN1]
 101    CONTINUE
        DO 16 I=1,NCHAN1
        SIG[I]=XMSBAR[I]-XBAR[I]**2
        SIGSQ[I]=SQRT[SIG[I]]
        RMS[I]=SQRT[XMSBAR[I]]
 16     CONTINUE
        WRITE [6,1004]
        DO 17 L=1,NCHAN1
        WRITE [6,1005]  L,XBAR[L],XMSBAR[L],SIG[L],SIGSQ[L]
 17     CONTINUE
 102    CONTINUE
        WRITE[LTN2]  ITHREE,[DUMMY[I],I=1,NCHAN1]
        END  FILE  LTN2
        REWIND  LTN2
 1000 FORMAT[I1,8X,12F6.3]
 1001 FORMAT[I1,8X,12F6.3]
 1002 FORMAT[1X,11HEND FILE IN,I5,9HSCAN LINE]
 1003 FORMAT[1X,3I5,12F6.3]
 1004 FORMAT[10X,2HCH,5X,4HMEAN,6X,11HMENN-SQUARE,6X,8HVARIANCE,6X,
     17HSTD-DEV]
 1005 FORMAT[10X,I3,F10.7,5X,F10.7,3X,F10.7,3X,F10.7,3X,F10.7]
        RETURN
        END
$DATA
 $NAMDAT
 LINKNO=0,2,4*0
 $END
 $SIZE
 NLOOP=3
 NCT=164
 NCHAN=12
 LTN1=9
 LTN2=11
 NLOOP1=2
 NDIFF=1
 NFILE=1
 NBEGIN=1
 IABS=0
 ISQ=1
 ISUM=13
 $END
 $SIZE
```

```
NLOOP=5
NCT=168
NCHAN=12
LTN=9
LTN1=10
LTN2=11
NLOOP1=4
NSKIPR=1
NAVGC=5
NSKIPC=1
NBGNC=1
NENDC=5
NAVGR=5
NBEGIN=1
NFILE=1
$END
```

The input card setup is shown in Figure 3-8.

DEFINITIONS OF INPUT PARAMETERS:

CARD 1

- NSCAN - The number of scan lines in a field
- NCHAN - Total number of channels in a field.
- NCOMP - Number of channel cross products calculated to generate the Covariance Matrix.
- NTOTAL - Total number of samples in a scan line.
- NFIELD - Number of fields to process in a data set.
- ISCAN - The number of scan lines to skip before starting calculations in a field.
- NFLD1 - Number of times to process the data set (N X NFIELD)

CARD 2

- An 80 Holerith card used for field identification.

CARD 3

- NBEGIN - Sample number to start with in a specific scan line for a certain field.
- NEND - Sample number to stop on in a specific scan line for a certain field.

CARD 4

- An 80 Holerith card used for field identification.

A listing of the output from this program is given in Figure 3-9. A flowchart of this program is given in Figure 3-10.

The program listing is given below.

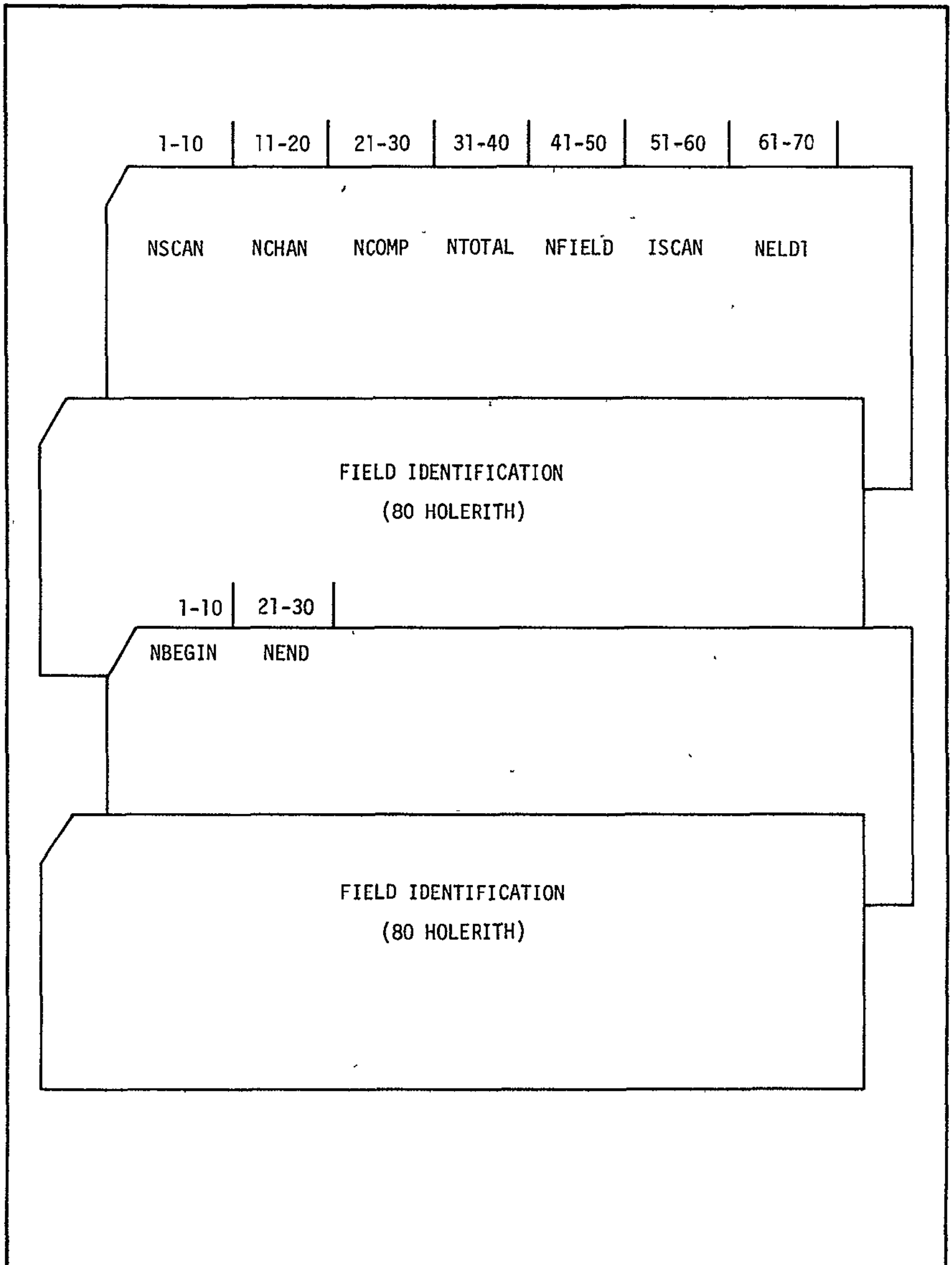

Figure 3-8. INPUT CARD DECK

C(5-17) SECTIØN A

SCAN LINE	START	STØP
1	1	56
2	1	56
3	1	54
4	1	54
5	1	54
6	1	54
7	1	54
8	1	54
9	1	54
10	1	54
11	1	54
12	1	54
13	1	54
14	1	54
15	1	54
16	1	58
17	1	56
18	1	56
19	1	54
20	1	54
21	1	54
22	1	54
23	1	52
24	1	52
25	1	52
26	1	52
27	1	52

Figure 3-9. OUTPUTS OF THE PROGRAM

C(5-17) SECTIØN A 0

MEAN VECTØR

CH	*	1	2	3	4	5	6	7	8	9	10	11	12
1	*	1.13450	1.64770	1.14216	1.02106	1.06431	1.04311	0.80106	1.01016	0.46364	0.63174	0.93581	0.72408

CØRRELATIØN MATRIX

CH	*	1	2	3	4	5	6	7	8	9	10	11	12
1	*	1.29448	1.87150	1.29875	1.16064	1.20975	1.18529	0.91027	1.14810	0.52692	0.71737	1.06134	0.82111
2	*	1.87150	2.72780	1.88613	1.68587	1.75709	1.72116	1.32215	1.66716	0.76575	1.04181	1.54035	1.19234
3	*	1.29875	1.88613	1.31314	1.16979	1.21775	1.19354	0.91642	1.15721	0.53188	0.72268	1.06552	0.82490
4	*	1.16064	1.68587	1.16979	1.04972	1.08874	1.06632	0.81949	1.03485	0.47623	0.64609	0.95135	0.73677
5	*	1.20975	1.75709	1.21775	1.08874	1.14085	1.11169	0.85564	1.07968	0.49579	0.67382	0.99366	0.76941
6	*	1.18529	1.72116	1.19354	1.06632	1.11169	1.09531	0.83689	1.05501	0.48402	0.65967	0.97782	0.75613
7	*	0.91027	1.32215	0.91642	0.81949	0.85564	0.83689	0.64716	0.81229	0.37289	0.50695	0.74945	0.58046
8	*	1.14810	1.66716	1.15721	1.03485	1.07968	1.05501	0.81229	1.03081	0.47294	0.63976	0.93955	0.72739
9	*	0.52692	0.76575	0.53188	0.47623	0.49579	0.48402	0.37289	0.47294	0.22164	0.29306	0.42837	0.33228
10	*	0.71737	1.04181	0.72268	0.64609	0.67382	0.65967	0.50695	0.63976	0.29306	0.40282	0.59004	0.45651
11	*	1.06134	1.54035	1.06552	0.95135	0.99366	0.97782	0.74945	0.93955	0.42837	0.59004	0.89433	0.68781
12	*	0.82111	1.19234	0.82490	0.73677	0.76941	0.75613	0.58046	0.72739	0.33228	0.45651	0.68781	0.53618

CØVARIANCE MATRIX

CH	*	1	2	3	4	5	6	7	8	9	10	11	12
1	*	0.00739	0.00219	0.00297	0.00225	0.00229	0.00188	0.00147	0.00207	0.00092	0.00066	-0.00034	-0.00036
2	*	0.00219	0.01290	0.00420	0.00348	0.00343	0.00243	0.00224	0.00271	0.00180	0.00090	-0.00158	-0.00073
3	*	0.00297	0.00420	0.00861	0.00358	0.00213	0.00214	0.00148	0.00344	0.00233	0.00113	-0.00332	-0.00212
4	*	0.00225	0.00348	0.00358	0.00716	0.00201	0.00125	0.00156	0.00341	0.00282	0.00105	-0.00416	-0.00256
5	*	0.00229	0.00343	0.00213	0.00201	0.00809	0.00149	0.00306	0.00455	0.00233	0.00145	-0.00233	-0.00124
6	*	0.00188	0.00243	0.00214	0.00125	0.00149	0.00723	0.00130	0.00129	0.00039	0.00070	0.00167	0.00083
7	*	0.00147	0.00224	0.00148	0.00156	0.00306	0.00130	0.00546	0.00309	0.00149	0.00089	-0.00018	0.00042
8	*	0.00207	0.00271	0.00344	0.00341	0.00455	0.00129	0.00309	0.01038	0.00459	0.00160	-0.00577	-0.00405
9	*	0.00092	0.00180	0.00233	0.00282	0.00233	0.00039	0.00149	0.00459	0.00668	0.00015	-0.00551	-0.00343
10	*	0.00066	0.00090	0.00113	0.00105	0.00145	0.00070	0.00089	0.00160	0.00015	0.00373	-0.00115	-0.00092
11	*	-0.00034	-0.00158	-0.00332	-0.00416	-0.00233	0.00167	-0.00018	-0.00577	-0.00551	-0.00115	0.01859	0.01020
12	*	-0.00036	-0.00073	-0.00212	-0.00256	-0.00124	0.00083	0.00042	-0.00405	-0.00343	-0.00092	0.01020	0.01188

NØRMALIZED CØVARIANCE MATRIX

CH	*	1	2	3	4	5	6	7	8	9	10	11	12
1	*	1.00000	0.22442	0.37232	0.30954	0.29612	0.25743	0.23174	0.23612	0.13042	0.12555	-0.02887	-0.03883
2	*	0.22442	1.00000	0.39844	0.36209	0.33582	0.25137	0.26733	0.23444	0.19443	0.12931	-0.10191	-0.05864
3	*	0.37232	0.39844	1.00000	0.45614	0.25548	0.27056	0.21556	0.36411	0.30744	0.19968	-0.26247	-0.20957
4	*	0.30954	0.36209	0.45614	1.00000	0.26425	0.17308	0.24922	0.39575	0.40798	0.20245	-0.36068	-0.27787
5	*	0.29612	0.33582	0.25548	0.26425	1.00000	0.19454	0.46018	0.49623	0.31687	0.26472	-0.19027	-0.12606
6	*	0.25743	0.25137	0.27056	0.17308	0.19454	1.00000	0.20639	0.14922	0.05594	0.13470	0.14408	0.08981
7	*	0.23174	0.26733	0.21556	0.24922	0.46018	0.20639	1.00000	0.41050	0.24678	0.19758	-0.01837	0.05237
8	*	0.23612	0.23444	0.36411	0.39575	0.49623	0.14922	0.41050	1.00000	0.55093	0.25650	-0.41557	-0.36464
9	*	0.13042	0.19443	0.30744	0.40798	0.31687	0.05594	0.24678	0.55093	1.00000	0.03099	-0.49461	-0.38526
10	*	0.12555	0.12931	0.19968	0.20245	0.26472	0.13470	0.19758	0.25650	0.03099	1.00000	-0.13767	-0.13817
11	*	-0.02887	-0.10191	-0.26247	-0.36068	-0.19027	0.14408	-0.01837	-0.41557	-0.49461	-0.13767	1.00000	0.68642
12	*	-0.03883	-0.05864	-0.20957	-0.27787	-0.12606	0.08981	0.05237	-0.36464	-0.38526	-0.13817	0.68642	1.00000

Figure 3-9. OUTPUTS OF THE PROGRAM (Concluded)

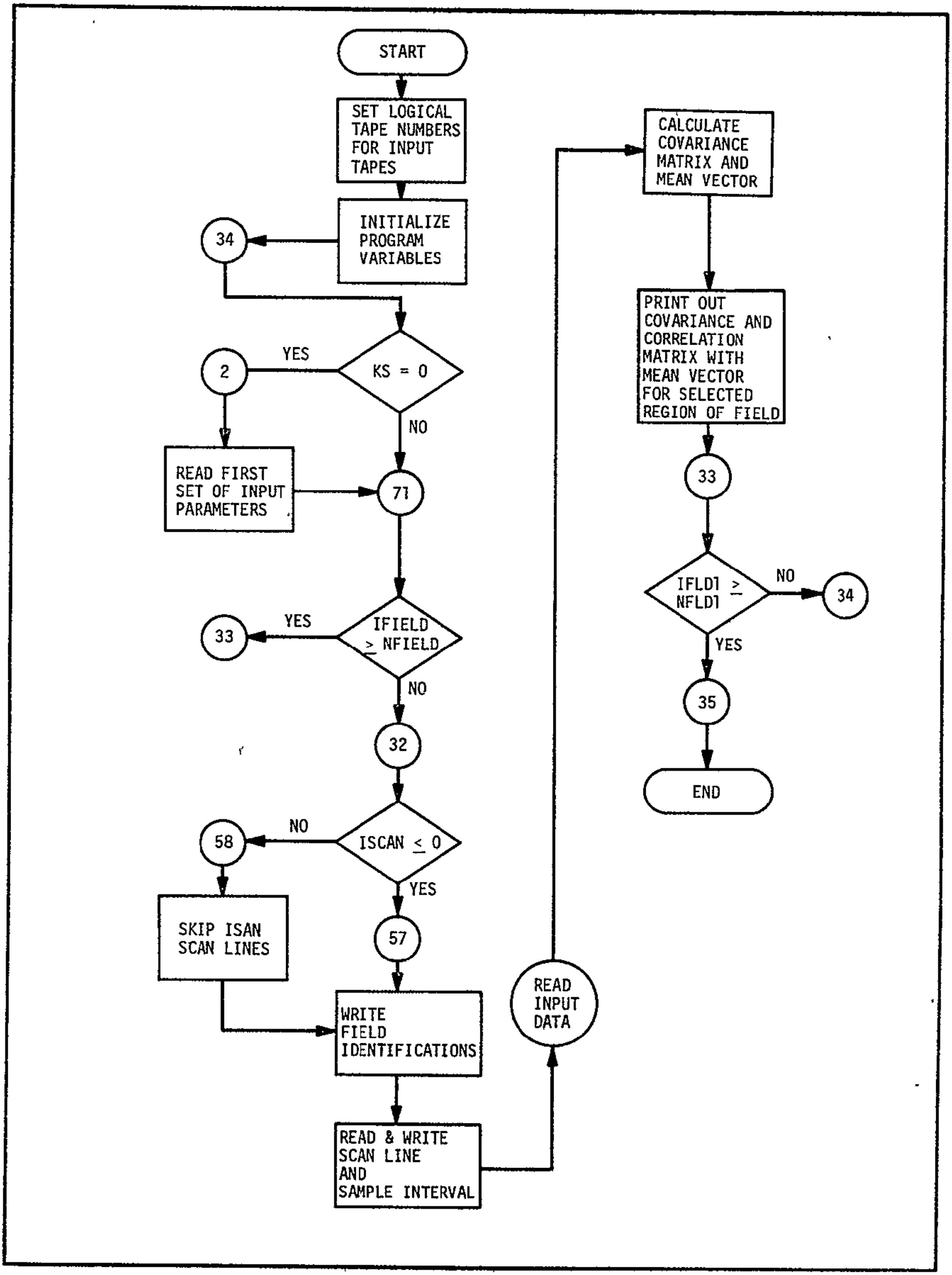

Figure 3-10. CORRELATION AND COVARIANCE MATRIX PROGRAM

```
C     CORRELATION  AND  COVARIANCE  MATRIX  PROGRAM
      DIMENSION XXXXX(12,12)
      DIMENSION  XMEAN(12),DATA(12),CORR(12,12)
      DIMENSION  ACORR(12,12),ACOVR(12,12),XBAR(12)
C     LTN    LOGICAL  TAPE  NUMBER  OF  DATA  TAPE
      LTN=9
C     LTN5  LOGICAL  NUMBER  OF  INPUT  PARAMETERS
      LTN5=5
C     LTN6  LOGICAL   NUMBER  OF  OUTPUT
      LTN6=6
C     LTN7   LOGICAL  NUMBER  OF  PUNCH  OUTPUT
      LTN7=7
C     INPUT  PARAMETERS  INITIALIZED
      KS=0
      SCALE=100.0
      IONE=1
      IFLDI=1
 34   IFIELD=1
      IF (KS)  71,2,71
 2    CONTINUE
      READ (LTN5,100)  NSCAN,NCHAN,NCOMP,NTOTAL,NFIELD,ISCAN,NFLDI
 71   CONTINUE
      IF(IFIELD-NFIELD)32,32,33
 32   CONTINUE
      MS=0
C      OPTION   TO  SKIP  SCAN  LINES
      IF(ISCAN) 57,57,58
 58   CONTINUE
      DO 55 I=1,ISCAN
      DO 55 J=1,NTOTAL
      READ (LTN)       IDUM
 55   CONTINUE
 57   CONTINUE
      ISKIP=ISCAN+1
      WRITE  (LTN6,110)
      WRITE  (LTN6,105)
      READ  (LTN5,106)
      WRITE  (LTN6,106)
      WRITE  (LTN6,105)
      WRITE  (LTN6,105)
      WRITE  (LTN6,103)
      DO 50 IAB=ISKIP,NSCAN
      DO 1 J=1,12
      XMEAN(J)=0.0
      DO 1 I=1,12
      CORR(J,I)=0.0
 1    CONTINUE
      READ  (LTN5,100)  NBEGIN,NEND
      WRITE (LTN6,104)  IAB,NBEGIN,NEND
      WRITE  (LTN6,105)
      NSAMP=NEND-NBEGIN+1
      SAMP= NSAMP
      NSTART=NBEGIN-1
      IF(NSTART)  62,61,62
```

```
 62     CØNTINUE
        DØ 10 II=1,NSTART
 10     READ  (LTN)       IDUM
 61     CCNTINUE
C      INPUT  DAT  READ  FRØM  LTN
        DØ 20 I=NBEGIN,NEND
        READ  (LTN)       ICHEK,IDUM,(DATA(J),J=1,NCHAN)
        DØ 26 L=1,NCØMP
        DØ 21 J=1,NCHAN
        CØRR(L,J)=CØRR(L,J)+DATA(L)*DATA(J)
 21     CØNTINUE
 26     CØNTINUE
C        MEAN   VECTØR    CALCULATED
        DØ 20 K=1,NCHAN
        XMEAN(K)=XMEAN(K)+DATA(K)
 20     CØNTINUE
        NTERM=NEND+1
        DØ 25 I=NTERM,NTØTAL
 25     READ  (LTN)       ICHEK
        SM=MS
        MS=MS+1
        DØ 22 J=1,NCHAN
        XMEAN(J)=XMEAN(J)/(SAMP)
 22     CØNTINUE
C      CØRRELATIØN  AND  CØVARIANCE  MATRIX  CALCULATED
        DØ 23 J=1,NCØMP
        DØ 23 I=1,NCHAN
        CØRR(J,I)=CØRR(J,I)/(SAMP)
 23     CØNTINUE
        DØ 51 J=1,NCØMP
        XBAR(J)  =(SM/(SM+1.0))*XBAR(J)  +(1.0/(SM+1.0))*XMEAN(J)
        DØ 51 I=1,NCHAN
        ACØRR(J,I)=(SM/(SM+1.0))*ACØRR(J,I)+(1.C/(SM+1.0))*CØRR(J,I)
 51     CØNTINUE
 50     CØNTINUE
        WRITE (LTN6,110)
        WRITE (LTN6,105)
        READ (LTN5,106)
        WRITE (LTN6,106)
        WRITE (LTN6,105)
        WRITE (LTN6,107)
        WRITE (LTN6,105)
        WRITE (LTN6,112) (K,K=1,NCHAN)
        WRITE (LTN6,102) IØNE,(XBAR(J),J=1,NCHAN)
        WRITE (LTN7,113)      (XBAR(J),J=1,NCHAN)
        WRITE (LTN6,105)
        WRITE (LTN6,108)
        WRITE (LTN6,105)
        WRITE (LTN6,112) (K,K=1,NCHAN)
        DØ 53 J=1,NCØMP
        WRITE (LTN6,102) J,(ACØRR(J,I),I=1,NCHAN)
   53   CØNTINUE
        DØ 54 J=1,NCØMP
        DØ 54 I=1,NCHAN
        ACØVR(J,I)=ACØRR(J,I)-(XBAR(J)*XBAR(I))
```

```
54    CONTINUE
      WRITE (LTN6,105)
      WRITE (LTN6,109)
      WRITE (LTN6,105)
      WRITE (LTN6,112) (K,K=1,NCHAN)
      DO 56 J=1,NCØMP
      WRITE (LTN6,102) J,(ACØVR(J,I),I=1,NCHAN)
      DO 2004 L=1,12
      XXXXX(J,L)=ACØVR(J,L)*SCALE
2004  CONTINUE
      WRITE (LTN7,113) (XXXXX(J,I),I=1,NCHAN)
56    CONTINUE
      DO 60 J=1,NCØMP
      DO 60 I=1,NCHAN
      ABSCØV=ABS(ACØVR(J,J)*ACØVR(I,I))
      ACØRR(J,I)=ACØVR(J,I)/SQRT(ABSCØV)
60    CONTINUE
      WRITE (LTN6,105)
      WRITE (LTN6,111)
      WRITE (LTN6,105)
      WRITE (LTN6,112) (K,K=1,NCHAN)
      DO 59 J=1,NCØMP
      WRITE (LTN6,102) J,(ACØRR(J,I),I=1,NCHAN)
59    CONTINUE
      IFLD1=IFLD1+1
      IFIELD=IFIELD+1
      IF(ICHEK-2)  24,2,2
24    WRITE(LTN6,115)
      GØ TØ 35
100   FØRMAT(7I10)
101   FØRMAT(I1,8X,12F6.3)
102   FØRMAT(2X,I4,4X,1H*,12F10.5)
103   FØRMAT(20X,11HSCAN    LINE,10X,5HSTART,1CX,4HSTØP)
104   FØRMAT(20X,I5,14X,I5,10X,I5)
105   FØRMAT(1H )
106    FØRMAT(1X,80H
     1                                     )
107   FØRMAT(30X,14HMEAN     VECTØR)
108   FØRMAT(30X,20HCØRRELATIØN    MATRIX)
109   FØRMAT(30X,20HCØVARIANCE     MATRIX)
110   FØRMAT(1H1)
111   FØRMAT(20X,32HNØRMALIZED    CØVARIANCE    MATRIX)
112   FØRMAT(4X,2HCH,4X,1H*,12(I5,5X))
113   FØRMAT(1X,12F6.3)
114   FØRMAT(1X,12F6.4)
115   FØRMAT(1X,40HNØ END ØF FIELD DESIGNATIØN ØN THIS TAPE)
33    CØNTINUE
      KS=KS+1
      WRITE (LTN6,100) KS
      REWIND  LTN
      IF(IFLD1-NFLD1)  34,34,35
35    CØNTINUE
      STØP
      END
```

3.7 PIECEWISE CORRELATION AND COVARIANCE PROGRAM

This program is devised for calculating the piecewise mean, root-mean-square, and cross-correlation of a specified channel with respect to the rest of the channels in the multi-channel data set. The program also calculates the piecewise covariance, the second derivative of the piecewise correlation. The associated statistical errors of the above correlation or covariance are also calculated.

DEFINITION OF INPUT PARAMETERS:

CARD 1

IPIECE - Option for piecewise printout ≠ 0 for printout.

LTERM - TERMINATES JOB
≠ 0 for next case
= 0 to terminate

NTOTAL - Total NR. of samples in scan line.

NARRNG - Rearrange input data for correlations.
≠ 0

CARD 2

NBEGIN - 1st data point to use in each scan line.

NEND - Last data point to use in each scan line.

ICHAN - Reference channel for correlations.

NSAMP - No. of samples/piece, for piecewise calculations cannot be greater than (NEND-NBEGIN).

NORM - ≠ 0 for normalization.

JFIELD - No. of fields to process.

The input deck setup is shown in Figure 3-11.

The flowchart of the program is shown in Figure 3-12 which is followed by a listing of the program.

3.8 PROBABILITY HISTROGRAM PROGRAM

This program is devised for calculating the univariate (first order) probability density functions of the multispectral data set within a specified inventory area. The program can handle up to 12 channels of data simultaneously.

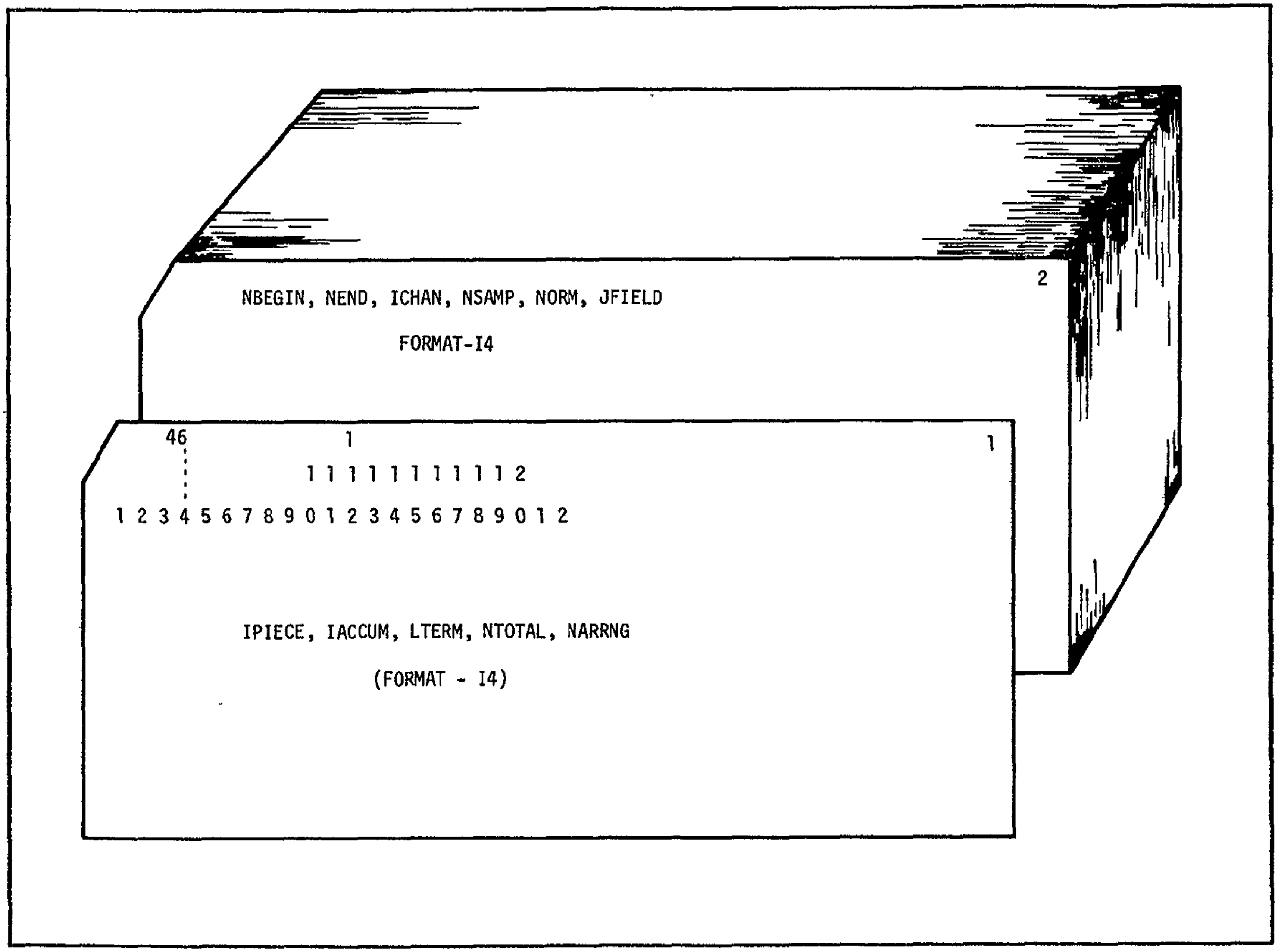

Figure 3-11. INPUT DECK SETUP

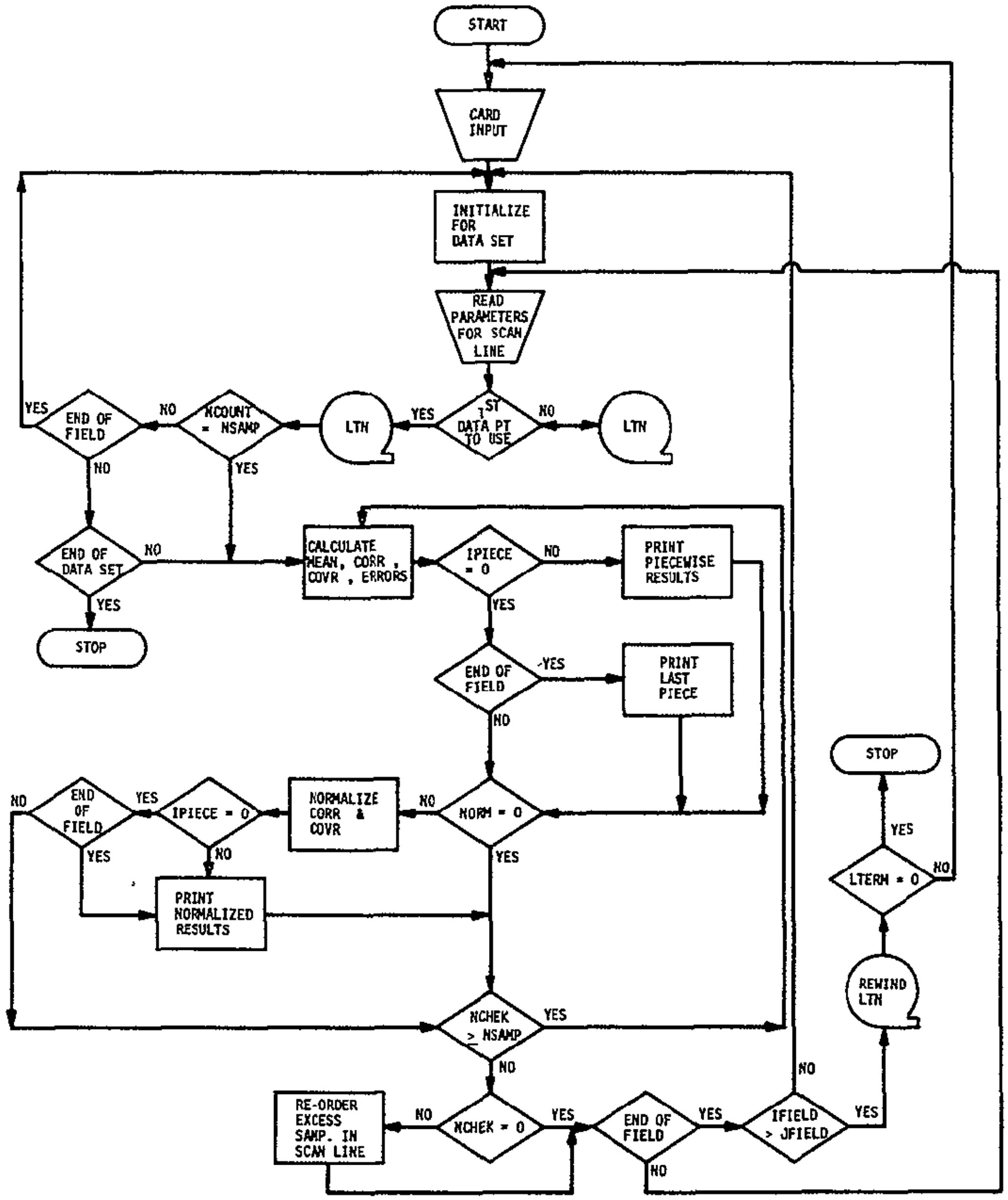

Figure 3-12. FLOWCHART FOR CORRELATION AND COVARIANCE PROGRAM

```
C*************************************************************
C     CORRELATION AND COVARIANCE PROGRAM W/ERRORS
C*************************************************************
      DIMENSION XMEAN(12),COVR(12),ACOVR(12),BCOVR(12),ECOVR(12),
     1FCOVR(12),FRROR(12)
      DIMENSION FCORR(12)
      DIMENSION ARMS1(13)
      DIMENSION DATA(150,12),TEMP(150,12),CORR(12),DAT(150,12)
      DIMENSION ACORR(12),ECORR(12),DUM(12)
      DIMENSION DATS(150,12),ERROR(12),IDAT(12)
      DIMENSION ARMS(13),BRMS(13),BCORR(12),CCORR(13)
      EQUIVALENCE (TEMP,DAT)
      LTN=54
      LTN1=61
      LTN2=60
 2000 CONTINUE
      READ (LTN2,100) IPIECE,IACCUM,LTERM,NTOTAL,NARRNG
      ICHEK=0
      IFIELD=0
      JFIELD=1
      ICHEK=0
  200 CONTINUE
      IFIELD=IFIELD+1
C     PUNCH 116, IFIELD
C
C             JFIELD IS NR. OF CROPS + 1
C             TO  TERMINATE  JOB.
C
      IF(IFIELD-JFIELD) 201,201,113
  201 CONTINUE
      ICHEK1=0
      DO 302 I=1,12
      ACOVR(I)=0.0
      ECOVR(I)=0.0
      BCORR(I)=0.0
      BCOVR(I)=0.0
      FCORR(I)=0.0
      FCOVR(I)=0.0
      ACORR(I)=0.0
      ECORR(I)=0.0
  302 CONTINUE
      MSS=0
      MS=0
      NCOUNT=0
      WRITE (LTN1,108)
    2 CONTINUE
C
C        READ PARAMETERS FOR EACH SCAN LINE
C
      READ (LTN2,100) NBEGIN,NEND,ICHAN,NSAMP,NORM,JFIELD
      NTERM=NEND+1
      NEND=NEND-NBEGIN+1
      MSS=MSS+1
      SAMP=NSAMP
      JEND=NBEGIN-1
      IF (JEND) 501,501,500
  500 CONTINUE
```

```
      DO 10 II=1,JEND
10    READ(LTN,100) IDUM
501   CONTINUE
      DO 20 I=1,NEND
      READ(LTN,101) ICHEK,(DAT(I,J),J=1,12)
20    CONTINUE
      DO 23 I=NTERM,NTOTAL
23    READ(LTN,101) ICHEK
      PRINT  100,ICHEK
      IF(NARRNG) 50,35,50
   50 CONTINUE
      KM=MSS/2
      XM=MSS/2
      BM=KM
      XM=XM-BM
      KM=2.0*XM
      IF(KM-1)35,32,32
   32 JJ=NEND
      KKK=1
      DO 33 II=1,NEND
      DO 28 J=1,12
      DATS(KKK,J)=DAT(JJ,J)
   28 CONTINUE
      KKK=KKK+1
      JJ=JJ-1
   33 CONTINUE
      DO 305 I=1,NEND
      DO 305 J=1,12
      DAT(I,J)=DATS(I,J)
  305 CONTINUE
   35 CONTINUE
      DO 36 II=1,NEND
      NCOUNT=NCOUNT+1
      DO 37 J=1,12
      DATA(NCOUNT,J)=DAT(II,J)
   37 CONTINUE
   36 CONTINUE
      KK=1
      DO 25 I=1,NCOUNT
      LL=I+1
      DO 24 J=1,12
      TEMP(KK,J)=DATA(I,J)-DATA(LL,J)
   24 CONTINUE
      KK=KK+1
   25 CONTINUE
      IF(NCOUNT-NSAMP) 2002,2003,2003
2002  CONTINUE
      PRINT  100,ICHEK
      IF(ICHEK-2)  2004,200,200
2004  CONTINUE
      IF(NCOUNT-NSAMP) 2,2003,2003
2003  CONTINUE
      MCOUNT=0
      ICOUNT=0
   26 CONTINUE
      MS=MS+1
      DO 1 J=1,12
```

```
      COVR(J)=0.0
      ARMS1(J)=0.0
      XMEAN(J)=0.0
      ARMS(J)=0.0
      CORR(J)=0.0
      ERROR(J)=0.0
      FRROR(J)=0.0
    1 CONTINUE
      DO 403 J=1,NSAMP
      MCOUNT=MCOUNT+1
      DO 403 I=1,12
      XMEAN(I)=XMEAN(I)+DATA(MCOUNT,I)/SAMP
 403  CONTINUE
      DO 30 KK=1,NSAMP
      ICOUNT=ICOUNT+1
      DO 29 J=1,12
      COVR(J)=COVR(J)+(DATA(ICOUNT,ICHAN)-XMEAN(ICHAN))
     1 *(DATA(ICOUNT,J)-XMEAN(J))
      CORR(J)=CORR(J)+TEMP(ICOUNT,ICHAN)*TEMP(ICOUNT,J)
      ARMS(J)=ARMS(J)+TEMP(ICOUNT,J)*TEMP( ICOUNT,J)
       ARMS1(J)=ARMS1(J)+DATA(ICOUNT,J)*DATA(ICOUNT,J)
   29 CONTINUE
   30 CONTINUE
      SM=MS-1
      DO 207 J=1,12
      COVR(J)=COVR(J)/SAMP
      ARMS1(J)=SQRT ((ARMS1(J)/SAMP)-XMEAN(J)**2)
      ARMS(J)=SQRT (ARMS(J)/SAMP)
      CORR(J)=CORR(J)/SAMP
      ACORR(J)=(SM/(SM+1.0))*ACORR(J)+(1.0/(SM+1.0))*CORR(J)
      ACOVR(J)=(SM/(SM+1.))*ACOVR(J)+(1.0/(SM+1.0))*COVR(J)
      ECORR(J)=(SM/(SM+1.0))*ECORR(J)+(1.0/(SM+1.0))*(CORR(J)**2)
      ECOVR(J)=(SM/(SM+1.))*ECOVR(J)+(1.0/(SM+1.0))*COVR(J)**2
      IF(ECORR(J)-ACORR(J)**2)  207,207,206
  206 ERROR(J)=SQRT ((1./SM)*(ECORR(J)-ACORR(J)**2))
  207 CONTINUE
      IF(ECOVR(J)-ACOVR(J)**2)  204,204,205
 205  FRROR(J)=SQRT ((1.0/SM)*(ECOVR(J)-ACOVR(J)**2))
 204  CONTINUE
      IF(IPIECE)  3001,3000,3001
 3000 IF(ICHEK-2)  3003,3002,3003
 3002 CONTINUE
 3001 CONTINUE
C
C         PIECEWISE PRINTOUT
C
      WRITE(LTN1,105)
      WRITE(LTN1,106) MS,( CORR(J),J=1,12)
      WRITE(LTN1,600) MS,( COVR(J),J=1,12)
      WRITE(LTN1,110) MS,(ACORR(J),J=1,12)
      WRITE(LTN1,603) MS,(ACOVR(J),J=1,12)
      WRITE(LTN1,112) MS,(ERROR(J),J=1,12)
      WRITE(LTN1,602) MS,(FRROR(J),J=1,12)
C     PUNCH 115, MS,(CORR(J),J=1,12)
C     PUNCH 115, MS,(COVR(J),J=1,12)
      WRITE(LTN1,109)
 3003 CONTINUE
```

```
      IF(NORM) 321,320,321
 321  CONTINUE
C
C             CALCULATE NORMALIZED CORRELATIONS, COVARIANCE
C
      DO 323 J=1,12
      CORR(J)=CORR(J)/(ARMS(J)*ARMS(ICHINA))
       COVR(J)= COVR(J)/(ARMS1(J)*ARMS1(ICHINA))
      BCORR(J)=(SM/(SM+1.0))*BCORR(J)+(1.0/(SM+1.0))*CORR(J)
      BCOVR(J)=(SM/(SM+1.))*BCOVR(J)+(1.0/(SM+1.0))*COVR(J)
      FCORR(J)=(SM/(SM+1.0))*FCORR(J)+(1.0/(SM+1.0))*(CORR(J)**2)
      FCOVR(J)=(SM/(SM+1.))*FCOVR(J)+(1.0/(SM+1.0))*COVR(J)**2
      IF(FCORR(J)-BCORR(J)**2)318,319,319
 319  ERROR(J)=SQRT ((1./SM)*(FCORR(J)-BCORR(J)**2))
      GO TO 322
  318 ERROR(J)=0.0
 322  IF(FCOVR(J)-BCOVR(J)**2)317,316,316
 316  FRROR(J)=SQRT ((1.0/SM)*(FCOVR(J)-BCOVR(J)**2))
      GO TO 323
  317 FRROR(J)=0.0
 323  CONTINUE
      IF(IPIECE) 3004,3005,3004
 3005 IF(ICHEK-2) 320,3004,320
 3004 CONTINUE
      WRITE (LTN1,325)
  325 FORMAT(35X,47H********** NORMALIZED   CORRELATIONS ********
      WRITE(LTN1,105)
      WRITE(LTN1,114)MS,(ARMS(J),J=1,12)
      WRITE(LTN1,106)MS,(CORR(J),J=1,12)
      WRITE(LTN1,600)MS,(COVR(J),J=1,12)
      WRITE(LTN1,110)MS,(BCORR(J),J=1,12)
      WRITE(LTN1,601)MS,(BCOVR(J),J=1,12)
      WRITE(LTN1,112)MS,(ERROR(J),J=1,12)
      WRITE(LTN1,602)MS,(FRROR(J),J=1,12)
      WRITE(LTN1,605)MS,(XMEAN(J),J=1,12)
      WRITE(LTN1,604)MS,(ARMS1(J),J=1,12)
C     PUNCH 115, MS,(CORR(J),J=1,12)
C     PUNCH 115, MS,(COVR(J),J=1,12)
      WRITE(LTN1,109)
 320  CONTINUE
      NCHEK=NCOUNT-ICOUNT
C
C        CHECK FOR SAMPLES LEFT IN SCAN LINE TO SORT AND GROUP
C        WITH BEGINNING OF NEXT SCAN.
C        NCHEK = 0  -  NO SAMPLES LEFT ON PRESENT SCAN LINE
C
      IF(NCHEK-NSAMP)44,26,26
   44 NCOUNT=0
      IF(NCHEK)45,98,45
   45 CONTINUE
      NSTOP=ICOUNT+NCHEK
      DO 40 II=ICOUNT,NSTOP
      NCOUNT=NCOUNT+1
      DO 41 J=1,12
      DATA(NCOUNT,J)=DATA(II,J)
   41 CONTINUE
   40 CONTINUE
```

```
98    IF(ICHEK-2) 2,200,200
 100 FORMAT(6I4)
101   FORMAT(I1,6X,12F6.3)
 105 FORMAT (1X//7X,4HCH 1,5X,4HCH 2,5X,4HCH 3,5X,4HCH 4,5X,4HCH
    15X,4HCH 6,5X,4HCH 7,5X,4HCH 8,5X,4HCH 9,5X,4HCH10,5X,4HCH11,
    24HCH12/)
 106 FORMAT(1X,I3,12F9.6,8H PC CORR/)
 110 FORMAT(1X,I3,12F9.6,8H AC CORR/)
 112 FORMAT(1X,I3,12F9.6,8H ER CORR/)
 114 FORMAT(1X,I3,12F9.6,8H RMS COR/)
115   FORMAT(I3,2X,12F6.4)
 116 FORMAT(20X,14H****** FIELD  I3,8H  ******)
 108 FORMAT(1H1//)
109   FORMAT(1X/)
 600 FORMAT(1X,I3,12F9.6,8H PC COVR/)
 601 FORMAT(1X,I3,12F9.6,8H AC COVR/)
 602 FORMAT(1X,I3,12F9.6,8H ER COVR/)
 603 FORMAT(1X,I3,12F9.6,8H AC COVR/)
 604 FORMAT(1X,I3,12F9.6,8H PC STD /)
 605 FORMAT(1X,I3,12F9.6,8H PC MEAN/)
113   REWIND  LTN
      IF(LTERM) 2000,2001,2000
2001 CONTINUE
      STOP
      END
```

The main outputs are univariate probability histrograms for every channel. In addition, a normal distribution curve is superimposed on the histrograms. The normal curve has the mean equal to the most probable value of the calculated probability density function and the same standard deviation as the calculated one.

It is optional to read a header identification record at the beginning of each data (IHEAD ≠ 0) or to input some header identification via NAMELIST variable IDENT (IHEAD = 0). The one selected can be printed out as a title heading for each data set for the plotted probability density functions and for the printed mean and variance. Bit manipulation on a single variable on the read in header identification may also be done (IFLD ≠ 0).

The program uses as input a tape reformated by the tape conversion program or a standard FORTRAN and/or Binary tape. The program's input control parameters are inputed by NAMELIST and the calling routines are NAMFIL and NAMDAT.

DEFINITION OF INPUT PARAMETER:

NAMFIL

- NFILE1 - Total number of data sets (files) to be processed cannot exceed four.

NAMDAT

- NBEAMS - Total number of channels of data to be processed (cannot exceed 12)
- NWHICH - Specify the numerical value of the files on tape to be processed (not to exceed 4). Does not apply to tapes reformated by the tape conversion program.
- TIMSAM - Specifies the time displacement between samples in the same channel.
- LTN - Logical tape number of the input tape.
- NBLK - Total number of variables for each channel in a data record. For a tape reformated by the Tape Conversion Program, it specifies the number of samples in a scan line.
- NBEGIN - The sample number of the data value in a scan line to start with that will be used in probability density calculation.
- NSTOP - The sample number of the data value in a scan line to stop with that will be used in probability density calculation.

- NTOTAL - The total number of intervals in the range of the values to be considered in the probability density function.
- TINCRE - The increment of data value range considered in the probability density calculation.
- ISKIP - Number of data records to skip at the start of each data set.
- NSCANS - Total number of scan lines in a data set.
- LTABLE - Minimum value of the data range to be considered in the probability calculation.
- IBCD - Option to read header identification record at start of each data set in either Binary (IBCD = 0) or Alpha-Numerically (IBCD ≠ 0).
- IFLD - Option to do bit manipulation on a variable in the header identification record. IFLD ≠ 0 bit manipulation executed.
- NA - Starting bit position in NBLK where bits will be transferred in direction left to right.
- NAB - Number of bit to be transferred.
- NB - Starting bit position in RCDID(ISVB) where bit will be transferred in direction left to right.
- ISVB - Array position in RCDID from which bit will be transferred to NBLK.
- IDWORD - Number of header identification words to be read in.
- IMODE - Mode that system REDTPC is to be read in. REDTPC is documented in 7094 Computer Manual of Marshall Space Flight Center.
- IHEAD - Option to read header identification record. IHEAD ≠ 0 header record read. IHEAD = 0 identification put on with IDENT NAMELIST variable.
- IRDTPC - Option to either read input tape under system REDTPC (IRDTPC ≠ 0) or under format of output from tape conversion program (IRDTPC = 0).
- IDENT - Labeling used in place of header identification record.

Figure 3-13 shows the flowchart of the computer program, which is followed by a complete listing of the program. Some plot outputs are shown in Figures 4-31 through 4-40. The symbol A's designate the actual calculated probability curves, while the symbol B's designated an expected normal distribution curve with its mean equal to the most probable value of the actual curve and with the same standard derivation as the actual curve. Figure 3-14 is a printout result of the program.

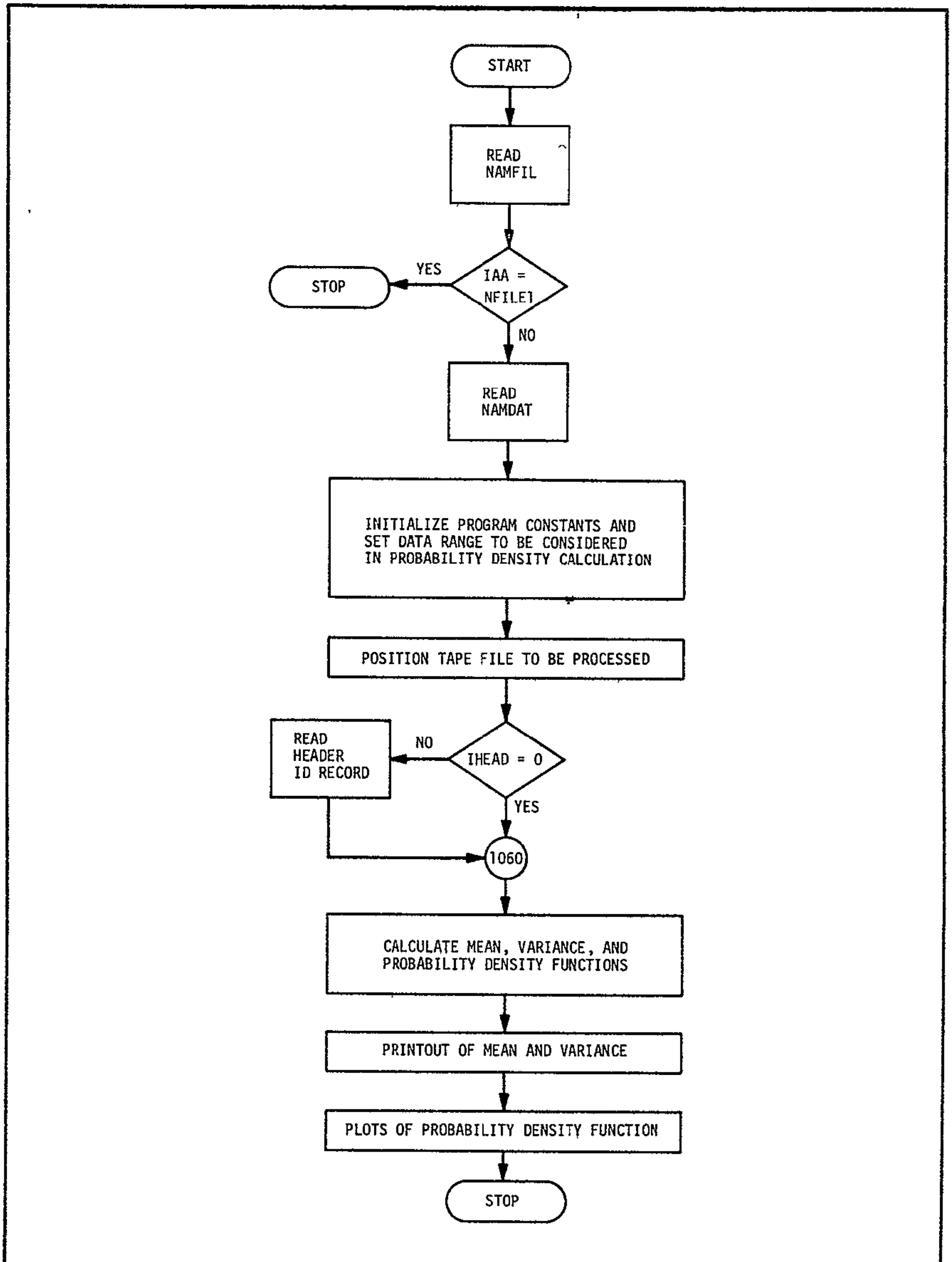

Figure 3-13. FLOWCHART OF MULTI-CHANNEL PROBABILITY DENSITY PROGRAM

EARTH - EFN SØURCE STATEMENT - IFN(S) -

```
C      MULTI-CHANNEL     PRØBAABILITY     DENSITY     PRØGRAM
       DIMENSIØN NBEGIN(27),NSTØP(27)
       DIMENSIØN SAMP(12)
       DIMENSIØN BTABLE(12),GTABLE(12)
       DIMENSIØN AMAX(12),P(201)
       DIMENSIØN RCDID(15),DATA(5000),DAT(5000),TABLE(201),PLAM(201,12)
       DIMENSIØN AVGCL(12),AAVGCL(12),RMS(12),ARMS(12),SIG(12),ASIG(12)
       DIMENSIØN XARRAY(12),XLAM(12),NWHICH(5),IDENT(5)
 1007  FØRMAT(12A6)
       EQUIVALENCE (RCDID(13),NCØUNT)
       CALL CAMRAV(9)
       NAMELIST /NAMDAT/ NBEAMS,NWHICH,TIMSAM,LTN,NBLK,NBEGIN,
      1NSTØP,NTØTAL,TINCRE,ISKIP,NSCANS,LTABLE,IBCD,
      2IFLD,NA,NAB,NB,ISUB,IDWØRD,IMØDE,IHEAD,IRDTPC,IDENT
       READ (5,1007) (XARRAY(I),I = 1,12)
       READ(5,1007) (XLAM(I),I = 1,12)
       NAMELIST /NAMFIL/ NFILEI
       READ(5,NAMFIL)
       DØ 998 IAA=1,NFILEI
C      INPUT NAMELIST DATA
       READ (5,NAMDAT)
       WRITE (6,NAMDAT)
C      INITILIZE CØNSTANTS
       TIME = 0.0
       NCT=NBLK
 1004  FØRMAT(1H 14F8.4)
       DELT = TIMSAM
       DØ 3 I=1,NTØTAL
       P(I) = 0.0
       TABLE (I) = 0.0
 3     CØNTINUE
       DØ 106 I = 1,NBEAMS
       GTABLE(I) = 0.0
       BTABLE(I) = 0.0
       SIG(I) = 0.0
       AMAX(I) = 0.0
       AAVGCL(I) = 0.0
       ARMS(I) = 0.0
  106  CØNTINUE
       DØ 71 II = 1,12
       DØ 71 I = 1,201
   71  PLAM(I,II) = 0.0
C SET  DATA  RANGE  TØ  BE  CØNSIDIERED  IN  PRØBABILITY  DENSITY
       TABLE(1)=LTABLE
       DØ 1011 I = 2,NTØTAL
       TABLE(I) = TABLE (I-1)+TINCRE
 1011  CØNTINUE
C      PØSITIØN TAPE FILES AND NUMBER ØF FILES
       IF(IRDTPC.EQ.0)  GØ TØ 11
       REWIND  LTN
       IAB = NWHICH(IAA)-1
       IF (IAB) 11,11,12
```

```
   12 CØNTINUE
      DØ 10 IAC=1,IAB
      CALL SKFBIN(9,1,RD)
```


EARTH - EFN SØURCE STATEMENT - IFN(S) -

```
   10 CØNTINUE
   11 CØNTINUE
C        READ     HEADER     IDENTIFICATIØN     RECØRD
      IF(IHEAD.EQ.0)  GØ TØ 1060
      IF(IBCD.EQ.0)  GØ TØ 1013
      READ (LTN,1051)  (RCDID(I),I=1,IDWØRD)
 1051 FØRMAT(15A6)
      RCDID(ISUB)=0.0
      RCDID(ISUB)=NBLK
      NCT=NBLK
      GØ TØ 1014
 1013 CØNTINUE
      READ (LTN)  (RCDID(I),I=1,IDWØRD)
      IF(IFLD.EQ.0)  GØ TØ 1014
      NCT=0
      CALL  FLD(NCT,NA,NAB,NB,RCDID(ISUB))
 1014 CØNTINUE
      NCØUNT = NCT
      NBLK = NCT
      WRITE (6,1000) (RCDID(I),I = 1,15)
 1000 FØRMAT(1X,12A6,I6,5X,2F8.4)
 1060 CØNTINUE
      IF(IHEAD.NE.0)  GØ TØ 1070
      WRITE(6,1071)
      WRITE(6,1051)  (IDENT(I),I=1,IDWØRD)
      WRITE(6,1071)
 1071 FØRMAT(1H0)
      DØ 1072 I=1,IDWØPD
      RCDID(I)=IDENT(I)
 1072 CØNTINUE
 1070 CØNTINUE
      WRITE(6,24)
   24 FØRMAT(17X,3HCH1,6X,3HCH2,6X,3HCH3,6X,3HCH4,6X,3HCH5,6X,
     13HCH6,6X,3HCH7,6X,3HCH8,6X,3HCH9,6X,4HCH10,5X,4HCH11,5X,4HCH12)
      NCØUNT=NCT
      NUP = NCØUNT*NBEAMS
      MS = 0
C     ØPTIØN     TØ     SKIP     SCAN     LINES
      NRIN=ISKIP+1
      IF(ISKIP.EQ.0)  GØ TØ 1032
      DØ 1031 J=1,ISKIP
      CALL SKRBIN(9,1,RD)
 1031 CØNTINUE
 1032 CØNTINUE
      DØ 1 IAD=NRIN,NSCANS
      NWDS=(NSTØP(IAD)+1-NBEGIN(IAD))*(NBEAMS+1)
      DØ 104 I = 1,NBEAMS
```

```
      AVGCL(I) = 0.0
      RMS(I) = 0.0
      SAMP(I)=0.0
  104 CONTINUE
      MS = MS+1
      IA = 1
      IF(IRDTPC.NE.0) GØ TØ 1061
      DØ 60 J=1,NUP,NBEAMS
      JZ=J+NBEAMS-1

           EARTH        -  EFN   SØURCE STATEMENT  -  IFN(S)  -

      READ (LTN) ICHEK,(DAT(L),L=J,JZ)
   60 CØNTINUE
      GØ TØ 1062
 1061 CØNTINUE
      CALL REDTPC(LTN,IMØDE,IERR,NW,NUP,DAT)
      GØ TØ (50,51,50,50,51),IERR
   51 GØ TØ 999
   50 CØNTINUE
 1062 CØNTINUE
      NSTART=NBEGIN(IAD)
      NTERM=NSTØP(IAD)
      DØ 80 ICC=NSTART,NTERM
      NFRM=ICC*NBEAMS-NBEAMS+1
      NTØ=NFRM+NBEAMS-1
      J = 0
      DØ 81 I = NFRM,NTØ
      J = J+1
      IF(DAT(I).LT.TABLE(1))  GØ TØ 70
      IF(DAT(I).GT.TABLE(NTØTAL)) GØ TØ 70
      AVGCL(J)=AVGCL(J)+DAT(I)
      RMS(J) = RMS(J)+DAT(I)**2
70    IF(DAT(I).LT.TABLE(1))   SAMP(J)=SAMP(J)+1.0
      IF(DAT(I).GT.TABLE(NTØTAL))  SAMP(J)=SAMP(J)+1.0
   81 CØNTINUE
      DATA(IA)=TIME
      TIME=TIME+DELT
      DØ 83 I = NFRM,NTØ
      IA = IA+1
      DATA(IA)=DAT(I)
   83 CØNTINUE
      IA = IA+1
      IF(IA.GE.NWDS) GØ TØ 100
   80 CØNTINUE
  100 CØNTINUE
      SAMPNØ=NSTØP(IAD)-NBEGIN(IAD)+1
      SM = MS
      DØ 101 I = 1,NBEAMS
      RMS(I)=RMS(I)/(SAMPNØ-SAMP(I))
      AVGCL(I)=AVGCL(I)/(SAMPNØ-SAMP(I))
      ARMS(I) = (((SM-1.)/SM)*ARMS(I) +RMS(I)/SM)
      AAVGCL(I) = (((SM-1.)/SM)*AAVGCL(I)+AVGCL(I)/SM)
      SIG(I)=SQRT(RMS(I)-AVGCL(I)**2)
      RMS(I)=SQRT(RMS(I))
```

```
  101 CONTINUE
      WRITE (6,9000)  ( AVGCL(I)  ,I=1,NBEAMS)
      WRITE (6,9001)  ( RMS(I)    ,I=1,NBEAMS)
      WRITE (6,9002)  ( SIG(I)    ,I=1,NBEAMS)
 9000 FØRMAT(1X,8HPC  MEAN,1X,12F9.4)
 9001 FØRMAT(1X,8HPC  RMS ,1X,12F9.4)
 9002 FØRMAT(1X,8HPC  SD  ,1X,12F9.4)
      DØ 94 I = 1,NBEAMS
      SIG(I)=SQRT(ARMS(I)-AAVGCL(I)**2)
      RMS(I)=SQRT(ARMS(I))
   94 CONTINUE
      WRITE (6,9003)  ( AAVGCL(I),I=1,NBEAMS)
      WRITE (6,9004)  ( RMS(I)    ,I=1,NBEAMS)

         EARTH        -  EFN   SØURCE STATEMENT  -  IFN(S)  -

      WRITE (6,9005)  ( SIG(I)    ,I=1,NBEAMS)
 9003 FØRMAT(1X,8HAC  MEAN,1X,12F9.4)
 9004 FØRMAT(1X,8HAC   RMS,1X,12F9.4)
 9005 FØRMAT(1X,8HAC  SD  ,1X,12F9.4)
      II = 0
      NXYZ=NSTØP(IAD)-NBEGIN(IAD)+1
      DØ 32 I=1,NXYZ
      II = II+1
      DØ 32 III = 1,NBEAMS
      L = 1
      II = II+1
   33 CØNTINUE
      IF(DATA(II).LT.TABLE(1))GØ TØ 30
      IF(DATA(II).GT.TABLE(NTØTAL)) GØ TØ 30
      IF(DATA(II).GT.TABLE(L)) GØ TØ 34
      GØ TØ 30
   34 IF(DATA(II).LT.TABLE(L+1)) GØ TØ 31
      GØ TØ 30
   31 PLAM(L,III) = PLAM(L,III)+1.0
      GØ TØ 32
   30 CØNTINUE
      IF(DATA(II).LT.TABLE(1)) BTABLE(III) = BTABLE(III)+1.
      IF(DATA(II).GT.TABLE(NTØTAL))GTABLE(III)=GTABLE(III)+1.
      IF(DATA(II).LT.TABLE(1))GØ TØ 32
      IF(DATA(II).GT.TABLE(NTØTAL)) GØ TØ 32
      L=L+1
      IF(L.LT.NTØTAL) GØ TØ 33
      GØ TØ 31
   32 CØNTINUE
 1002 FØRMAT(1H 13F9.4)
 1003 FØRMAT(1H 12F9.4)
 1    CØNTINUE
  999 CØNTINUE
      DØ 90 I=1,NBEAMS
      DØ 90 J = 1,NTØTAL
      IF(PLAM(J,I).GT.AMAX(I)) GØ TØ 92
      GØ TØ 90
   92 AMAX(I) = PLAM(J,I)
```

```
   90 CONTINUE
      WRITE(6,9006)
 9006 FØRMAT(35X,37HNUMBER  ØF  VALUES  LESS  THAN  TABLE)
      WRITE (6,1003) (BTABLE(I),I = 1,NBEAMS)
      WRITE(6,9007)
 9007 FØRMAT(35X,40HNUMBER  ØF  VALUES  GREATER  THAN  TABLE)
      WRITE (6,1003) (GTABLE(I),I = 1,NBEAMS)
      WRITE(6,9008)
 9008 FØRMAT(35X,31HMAXIMUM  VALUE  ØF  EACH  TABLE)
      WRITE (6,1003) (AMAX(I),I = 1,NBEAMS)
      NP =  ITØTAL
      DØ 93 I = 1,NBEAMS
      DØ 95 J = 1,NTØTAL
      BASE=(TABLE(J)-AAVGCL(I))**2/(2.*SIG(I)**2)
      IF(BASE.GE.88.) GØ TØ 73
      P(J) = AMAX(I)/EXP(BASE)
      GØ TØ 72
 73   P(J)=0.0

         EARTH      -  EFN   SØURCE STATEMENT  -  IFN(S)  -

 72   CØNTINUE
   95 CØNTINUE
      CALL QUIK3V(-1,1HA,XARRAY,XLAM   ,-NP,TABLE,PLAM(1,I))
      CALL QUIK3V ( 0,1HB,XARRAY,XLAM   ,-NP,TABLE,P)
      CALL PRINTV(90,RCDID,212,1010)
   93 CØNTINUE
  998 CØNTINUE
      CALL CLEAN
      STØP
      END
```

```
$NAMDAT
NBEAMS =          12,
NWHICH =           1,          2,          3,          4,          0,
TIMSAM =   0.10000000E 00,
LTN    =           9,
NBLK   =          56,
NBEGIN =          41,         41,         41,         41,         41,         41,         41,
                  41,         41,          0,          0,          0,          0,          0,
                   0,          0,          0,          0,          0,          0,          0,
                   0,          0,          0,          0,          0,          0,
NSTØP  =          55,         55,         55,         55,         55,         55,         55,
                  55,         55,          0,          0,          0,          0,          0,
                   0,          0,          0,          0,          0,          0,          0,
                   0,          0,          0,          0,          0,          0,
NTØTAL =         101,
TINCRE =   0.30000000E-01,
ISKIP  =           0,
NSCANS =           9,
LTABLE =           0,
IBCD   =           0,
IFLD   =           0,
NA     =          19,
NAB    =          17,
NB     =           1,
ISUB   =          13,
IDWØRD =           5,
IMØDE  =           2,
IHEAD  =           0,
IRDTPC =           0,
IDENT  =      6H      ,  6H     C(,  6H5-17) ,  6H   SEC,  6H-B     ,
$ END
```

C(5-17)   SEC-B

		CH1	CH2	CH3	CH4	CH5	CH6	CH7	CH8	CH9	CH10	CH11	CH12
PC	MEAN	1.2885	1.7115	1.1229	1.0261	0.9514	0.8404	0.6159	0.8537	0.4055	0.4742	0.6076	0.4365
PC	RMS	1.2906	1.7123	1.1234	1.0266	0.9527	0.8411	0.6162	0.8552	0.4068	0.4756	0.6098	0.4383
PC	SD	0.0730	0.0550	0.0344	0.0313	0.0498	0.0353	0.0198	0.0506	0.0332	0.0364	0.0518	0.0392
AC	MEAN	1.2885	1.7115	1.1229	1.0261	0.9514	0.8404	0.6159	0.8537	0.4055	0.4742	0.6076	0.4365
AC	RMS	1.2906	1.7123	1.1234	1.0266	0.9527	0.8411	0.6162	0.8552	0.4068	0.4756	0.6098	0.4383
AC	SD	0.0730	0.0550	0.0344	0.0313	0.0498	0.0353	0.0198	0.0506	0.0332	0.0364	0.0518	0.0392
PC	MEAN	1.2587	1.7091	1.1404	1.0185	0.9428	0.8419	0.6122	0.8455	0.4087	0.4650	0.6051	0.4483
PC	RMS	1.2618	1.7102	1.1420	1.0190	0.9436	0.8423	0.6128	0.8467	0.4094	0.4661	0.6069	0.4507
PC	SD	0.0876	0.0624	0.0610	0.0334	0.0373	0.0268	0.0285	0.0444	0.0234	0.0322	0.0465	0.0468
AC	MEAN	1.2736	1.7103	1.1316	1.0223	0.9471	0.8411	0.6140	0.8496	0.4071	0.4696	0.6063	0.4424
AC	RMS	1.2763	1.7113	1.1327	1.0228	0.9481	0.8417	0.6145	0.8510	0.4081	0.4709	0.6083	0.4445
AC	SD	0.0820	0.0589	0.0503	0.0326	0.0442	0.0313	0.0246	0.0478	0.0288	0.0347	0.0492	0.0436
PC	MEAN	1.2666	1.7047	1.1633	1.0228	0.9542	0.8456	0.6290	0.8504	0.4162	0.4811	0.6068	0.4552
PC	RMS	1.2690	1.7055	1.1644	1.0234	0.9549	0.8466	0.6292	0.8519	0.4177	0.4822	0.6086	0.4572
PC	SD	0.0766	0.0513	0.0516	0.0347	0.0373	0.0409	0.0146	0.0511	0.0346	0.0328	0.0466	0.0419
AC	MEAN	1.2713	1.7084	1.1422	1.0225	0.9495	0.8426	0.6190	0.8499	0.4101	0.4734	0.6065	0.4467
AC	RMS	1.2738	1.7094	1.1434	1.0230	0.9504	0.8433	0.6194	0.8513	0.4113	0.4747	0.6084	0.4488
AC	SD	0.0803	0.0565	0.0529	0.0333	0.0422	0.0349	0.0229	0.0489	0.0312	0.0345	0.0484	0.0435
PC	MEAN	1.2668	1.7223	1.1387	1.0300	0.9540	0.8353	0.6136	0.8652	0.4111	0.4741	0.5944	0.4461
PC	RMS	1.2690	1.7230	1.1395	1.0308	0.9542	0.8356	0.6141	0.8665	0.4128	0.4754	0.5963	0.4481
PC	SD	0.0740	0.0491	0.0431	0.0400	0.0221	0.0227	0.0245	0.0476	0.0371	0.0356	0.0470	0.0423
AC	MEAN	1.2702	1.7119	1.1413	1.0244	0.9506	0.8408	0.6177	0.8537	0.4104	0.4736	0.6035	0.4465
AC	RMS	1.2726	1.7128	1.1424	1.0250	0.9514	0.8414	0.6181	0.8551	0.4117	0.4749	0.6054	0.4486
AC	SD	0.0788	0.0551	0.0506	0.0352	0.0382	0.0324	0.0234	0.0490	0.0328	0.0348	0.0483	0.0432
PC	MEAN	1.2609	1.7084	1.1403	1.0226	0.9274	0.7953	0.6408	0.8438	0.3985	0.4743	0.5915	0.4233

Figure 3-14. PRINT-OUT OF THE PROBABILITY PROGRAM

PC	RMS	1.2632	1.7097	1.1411	1.0234	0.9281	0.7962	0.6413	0.8451	0.4002	0.4758	0.5936	0.4250
PC	SD	0.0767	0.0684	0.0427	0.0392	0.0362	0.0374	0.0260	0.0467	0.0372	0.0380	0.0495	0.0385
AC	MEAN	1.2683	1.7112	1.1411	1.0240	0.9460	0.8317	0.6223	0.8517	0.4080	0.4737	0.6011	0.4419
AC	RMS	1.2708	1.7122	1.1422	1.0246	0.9468	0.8326	0.6228	0.8531	0.4094	0.4751	0.6030	0.4440
AC	SD	0.0785	0.0580	0.0492	0.0361	0.0389	0.0381	0.0257	0.0487	0.0340	0.0354	0.0488	0.0433
PC	MEAN	1.2923	1.7073	1.1605	1.0188	0.9653	0.8386	0.6382	0.8481	0.4304	0.4635	0.6040	0.4619
PC	RMS	1.2952	1.7084	1.1617	1.0194	0.9661	0.8392	0.6388	0.8491	0.4320	0.4643	0.6060	0.4646
PC	SD	0.0867	0.0632	0.0524	0.0340	0.0397	0.0310	0.0270	0.0398	0.0366	0.0271	0.0499	0.0492
AC	MEAN	1.2723	1.7105	1.1444	1.0231	0.9492	0.8329	0.6249	0.8511	0.4117	0.4720	0.6016	0.4452
AC	RMS	1.2749	1.7116	1.1455	1.0238	0.9500	0.8337	0.6255	0.8524	0.4133	0.4733	0.6035	0.4475
AC	SD	0.0804	0.0589	0.0502	0.0358	0.0397	0.0371	0.0266	0.0474	0.0355	0.0344	0.0490	0.0450
PC	MEAN	1.2664	1.7038	1.1331	1.0018	0.9424	0.8237	0.6362	0.8404	0.4151	0.4634	0.5772	0.4202
PC	RMS	1.2687	1.7045	1.1336	1.0026	0.9431	0.8240	0.6366	0.8414	0.4163	0.4643	0.5791	0.4218
PC	SD	0.0773	0.0496	0.0325	0.0402	0.0363	0.0235	0.0236	0.0404	0.0316	0.0288	0.0472	0.0370
AC	MEAN	1.2715	1.7096	1.1428	1.0201	0.9482	0.8315	0.6265	0.8496	0.4122	0.4708	0.5981	0.4417
AC	RMS	1.2740	1.7105	1.1438	1.0208	0.9490	0.8323	0.6271	0.8509	0.4137	0.4720	0.6001	0.4439
AC	SD	0.0800	0.0577	0.0483	0.0372	0.0393	0.0356	0.0265	0.0466	0.0350	0.0338	0.0495	0.0448
PC	MEAN	1.2503	1.6955	1.1446	1.0269	0.9336	0.8437	0.6367	0.8362	0.4121	0.4583	0.6105	0.4400
PC	RMS	1.2524	1.6967	1.1454	1.0277	0.9344	0.8446	0.6371	0.8374	0.4140	0.4591	0.6131	0.4422
PC	SD	0.0725	0.0636	0.0431	0.0381	0.0390	0.0386	0.0206	0.0449	0.0398	0.0269	0.0565	0.0439
AC	MEAN	1.2688	1.7078	1.1430	1.0210	0.9464	0.8331	0.6278	0.8479	0.4122	0.4692	0.5996	0.4414
AC	RMS	1.2713	1.7088	1.1440	1.0216	0.9472	0.8339	0.6284	0.8492	0.4137	0.4704	0.6018	0.4437
AC	SD	0.0794	0.0587	0.0477	0.0374	0.0396	0.0362	0.0260	0.0466	0.0356	0.0333	0.0506	0.0447
PC	MEAN	1.2542	1.7058	1.1229	1.0190	0.9480	0.8424	0.6271	0.8513	0.4219	0.4684	0.5907	0.4499
PC	RMS	1.2573	1.7073	1.1246	1.0197	0.9482	0.8427	0.6277	0.8520	0.4230	0.4697	0.5920	0.4527
PC	SD	0.0876	0.0707	0.0606	0.0386	0.0216	0.0220	0.0255	0.0363	0.0307	0.0357	0.0391	0.0505
AC	MEAN	1.2672	1.7076	1.1408	1.0207	0.9466	0.8341	0.6277	0.8483	0.4133	0.4691	0.5986	0.4424
AC	RMS	1.2698	1.7086	1.1418	1.0214	0.9473	0.8348	0.6283	0.8495	0.4148	0.4703	0.6007	0.4447
AC	SD	0.0805	0.0601	0.0497	0.0375	0.0380	0.0351	0.0260	0.0456	0.0352	0.0336	0.0495	0.0454

NUMBER ØF VALUES LESS THAN TABLE

0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

NUMBER ØF VALUES GREATER THAN TABLE

0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

MAXIMUM VALUE ØF EACH TABLE

21.0000	29.0000	30.0000	35.0000	41.0000	48.0000	59.0000	41.0000	53.0000	55.0000	34.0000	32.0000

Figure 3-14. PRINT-OUT OF THE PROBABILITY PROGRAM (Concluded)

3.9 DIVERGENCE MATRIX PROGRAM

This program is devised for calculating the "divergence" measure which is a similarity criterion between two homogeneous populations whose probability density functions are normally distributed. The mathematical formulation of this divergence criterion is given in subsection 2.6. The program is coded such that up to 12 homogeneous populations can be compared simultaneously. The main input parameters are mean vectors, covariance matrices, and selected channels for all populations. The main output is a square matrix of divergence between all combinations of the given populations. The divergence matrix consists of two terms, which are called Trace 1 and Trace 2 matrix representing the first and second terms of the right hand side of equation (2-11) in Section II.

Four subroutines are used in this program: Matrix Multiplication (MMPY), Matrix Subtraction (MSUB), Matrix Addition (MADD), and Matrix Inversion (MINV).

DEFINITION OF INPUT PARAMETERS:

CARD 1 (7I10) Format

- NSCLE1 - Scale factor for Mean Vectors.
- NSCLE2 - Scale factor for Covariance Matrices.
- NCYCLE - Number of times to cycle through the program comparing the matrices.
- KKK - Maximum row size of Covariance Matrix to be read.
- III - Maximum column size of Covariance Matrix to be read.
- NLOOP - Number of times to cycle through the matrices for different row and column configurations.
- NMEANS - Number of Mean vectors or Covariance Matrices to be used in the calculation.

CARD 2 (3I10) Format

- NLOW - Lower range of field identification to be read.
- NUP - Upper range of field identification to be read.
- NPRINT - Option to print out intermediate calculation of cross products of comparisons of two populations.

CARD 3 (20A4) Format

- Z(L) - Array in which field identifications are stored.

CARD 4 (12I5) Format

- ICH(L) - Specifies which columns of Covariance Matrices to use in calculations. ICH(L) = 0 column not used.

CARD 5 (12I5) Format

- NSC(I) - Specifies which rows of Covariance Matrices to use in calculations. NSC(I) = 0 row not used.

CARD 6 (5I10) Format

- NSCTS - Specifies number of rows actually used in Divergence calculation from NSC(I) selection.
- ICHAN - Specifies number of columns actually used in Divergence calculation from ICH(L) selection.
- ICHAN1 - Used to specify that the mean is a 1 X NCHAN vector. Nominal value is one.
- NCHAN - Maximum row size of covariance Matrix to be read.
- NSCANS - Maximum column size of Covariance Matrix to be read.

CARD 7 (12F6.0) Format

- YBAR(KK,I) - Array that Mean vectors for each population is stored. KK specifies population and I the dimension of the vector.

CARD 8 (12F6.0) Format

- X(KK,J,I) - Array that Covariance Vectors for each population is stored. KK specifies population, I the row dimension, and J the column dimension.

Figure 3-15 shows a flowchart of the divergence matrix program, which is followed by a complete listing of the program. Some sample outputs are shown in Tables 4-1 through 4-5.

3.10 SI-TABLE PROGRAM

This program is devised for calculating the so-called Si-value which represents a measure of similarity between two inventory areas which, in turn, are characterized by the mean vectors and the standard deviations. Let the mean vectors for i^{th} and j^{th} inventory areas be denoted by $M_i(k)$ and $M_j(k)$, and the standard deviations be $\sigma_i(k)$ and $\sigma_j(k)$, where k stands for the channel number, (k=1,2...K). The Si-value between i^{th} and j^{th} inventory areas can be expressed as

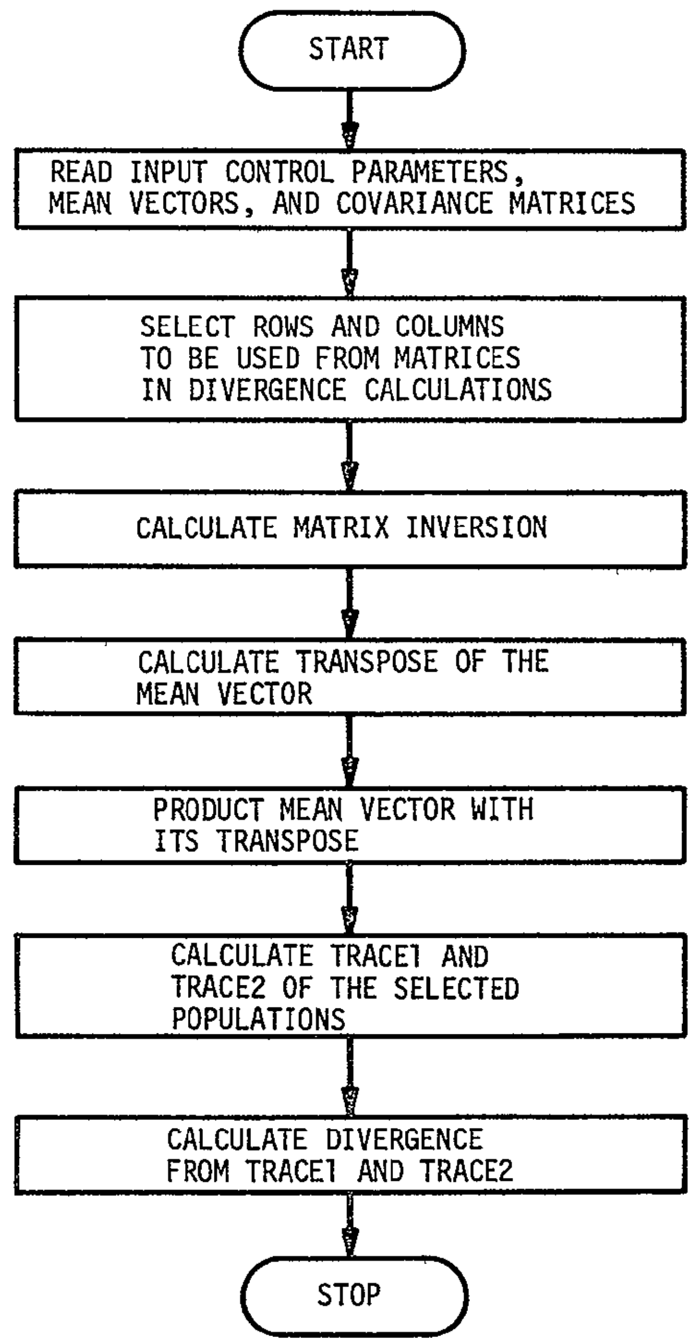

Figure 3-15. FLOWCHART OF DIVERGENCE MATRIX PROGRAM

```
C    PROGRAM  TO  CALCULATE  DIVERGENCE  OF  TWO  MATRICES
      DIMENSION  Z(240)
      DIMENSION  ZBAR(12,12)
      DIMENSION  X1(12,12)
      DIMENSION  DIV(12,12)
      DIMENSION  V(12,12),V1(12,12),VT(12,12),VT1(12,12)
      DIMENSION  VPROD(12,12),VXPROD(12,12),VDIFF(12,12),VTDIFF(12,12),
     AVSUM(12,12),VTSUM(12,12)
      DIMENSION  XBAR(12,12),XTBAR(12,12),XPROD(12,12)
      DIMENSION  X(12,12,12),ICH(12),NSC(12)
      DIMENSION  YBAR(12,12)
      DIMENSION   TRACE(12,12),TRACE1(12,12)
 1000 FORMAT(7I10)
 1001 FORMAT(1X,12F6.0)
 1002 FORMAT(1H0)
 1003 FORMAT(80H
     1                                                  )
 1004 FORMAT(1X,5HDETV=F13.8,6HDETV1=F13.8,6HTRACE=F10.3,7HTRACE1=F10.3)
 1005 FORMAT(2X,I4,4X,1H*,12F10.3)
 1006  FORMAT(1X,80H****************************************************
     1****************************)
 1007 FORMAT(4X,2HCH,4X,1H*,12(I5,5X))
 1008 FORMAT(12I5)
 1009 FORMAT(30X,4HDIV=F10.3)
 1010 FORMAT(1H1)
 1011 FORMAT(2X,I4,4X,1H*,12F10.5)
 1012 FORMAT(30X,20HCOVARIANCE    MATRIX)
 1013 FORMAT(30X,14HMEAN    VECTOR)
 1014 FORMAT(30X,29HINVERSE   COVARIANCE   MATRIX)
 1015 FORMAT(30X,39H(V1(J,I)-V2(J,I)) (INV2(J,I)-INV1(J,I)))
 1016 FORMAT(10X,79H(INV1(J,I)-INV2(J,I)) (XBAR1(J,I)-XBAR2(J,I)) (TRANS
     1POSE(XBAR1(J,I)-XBAR2(J,I)))
 1017 FORMAT(30X,8HFIELD   ,I5)
 1018 FORMAT(30X,34HPRODUCT  OF  MATRIX  WITH  INVERSE)
 1019 FORMAT(30X,20HDIVERGENCE    MATRIX)
 1020 FORMAT(30X,16HTRACE1    MATRIX)
 1021 FORMAT(30X,16HTRACE2    MATRIX)
 1022 FORMAT(30X,36HCHANNELS USED  IN  THIS  CALCULATION)
 1023 FORMAT(20A4)
 1024 FORMAT(1X,5HFIELD,4X,1H*,12(I5,5X))
 1025 FORMAT(10X,5HFIELD,I4,4X,8HCOMPARED,4X,5HFIELD,I4)
      IONE=1
      READ  1000,NSCLE1,NSCLE2,NCYCLE,KKK,III,NLOOP,NMEANS
      NCOVR=NMEANS
      SCALE1=NSCLE1
      SCALE2=NSCLE2
      DO 251 IFF=1,NLOOP
      READ   1000,NLOW,NUP,NPRINT
      PRINT  1010
      PRINT  1006
      NBEGIN=NLOW
      NSTOP=NUP
      DO 205 JJ=1,NMEANS
      IF(IFF-1) 2012,2013,2012
```

```
2013 READ  1023,(Z(L),L=NBEGIN,NSTOP)
2012 PRINT 1023,(Z(L),L=NBEGIN,NSTOP)
     NBEGIN=NBEGIN+NUP
     NSTOP=NUP+NBEGIN-1
205  CONTINUE
     PRINT  1006
     DO 206 J=1,KKK
     DO 206 I=1,III
     DIV(J,I)=0.0
     TRACE(J,I)=0.0
     TRACE1(J,I)=0.0
     ZBAR(J,I)=0.0
     V(J,I)=0.0
206  CONTINUE
     READ  1008,(ICH(I),I=1,KKK)
     READ  1008,(NSC(I),I=1,III)
     READ  1000,NSCTS,ICHAN,ICHAN1,NFILE,NCHAN,NSCANS,NSCALE
     SCALE=NSCALE
     MS=1
     DO 200 IAB=1,NCYCLE
     IF(MS-1)  203,202,203
202  CONTINUE
     IF(IFF-1)  203,2003,203
2003 CONTINUE
     DO 21 KK=1,NCOVR
     PRINT  1010
     PRINT  1002
     READ 1003
     PRINT 1003
       PRINT  1002
     PRINT  1013
     PRINT  1002
     READ  1001,(YBAR(KK,I),I=1,NCHAN)
     DO 201 I=1,NCHAN
     YBAR(KK,I)=YBAR(KK,I)/SCALE1
201  CONTINUE
     PRINT  1007,(K,K=1,NCHAN)
     PRINT  1005,( KK ,(YBAR ( KK ,I),I=1,NCHAN))
     PRINT  1002
     PRINT  1012
     PRINT  1002
     PRINT  1007,(K,K=1,NCHAN)
     DO 21 J=1,NSCANS
     READ  1001,(X(KK,J,I),I=1,NCHAN)
     DO  5 I=1,NCHAN
     X(KK,J,I)=X(KK,J,I)/SCALE
5    CONTINUE
     PRINT  1011,TJ,(X(KK,J,I),I=1,NCHAN))
21   CONTINUE
203  CONTINUE
     DO 402 KK=1,NMEANS
     M=0
     DO  40  I=1,NCHAN
     IF(ICH(I))  42,40,42
42   M=M+1
```

```
      ZBAR(KK,M)=YBAR(KK,I)
40    CONTINUE
402   CONTINUE
      M=0
      DO  22 J=1,NCHAN
      IF(ICH(J))  24,22,24
24    M=M+1
      N=0
      DO 23 I=1,NSCANS
      IF(NSC(I))  25,23,25
25    N=N+1
      V(N,M)=X(MS,I,J)
23    CONTINUE
22    CONTINUE
C        MATRIX      INVERSION     AND     CHECK
      CALL  MINV(V,VT,DET,ICHAN)
      DET1=DET
      CALL  MMPY(ICHAN,NSCTS,ICHAN,V,VT,X1)
      IF (NPRINT) 2007,2006,2007
2007  CONTINUE
      IF (MS-1)  2004,2005,2004
2005  CONTINUE
      PRINT  1010
      PRINT  1002
      PRINT  1002
      PRINT  1002
      PRINT  1002
      PRINT  1006
      PRINT  1002
      PRINT  1022
      PRINT  1002
      PRINT  1008,(ICH(I),I=1,NCHAN)
      PRINT  1002
      PRINT  1006
2004  CONTINUE
      PRINT  1010
      PRINT  1002
      PRINT  1006
      PRINT  1017,IAB
      PRINT  1002
      PRINT  1006
      PRINT  1002
      PRINT  1013
      PRINT  1002
      PRINT  1007,(K,K=1,ICHAN)
      PRINT  1005,(IONE,(ZBAR (IAB ,I),I=1,ICHAN))
      PRINT  1002
      PRINT  1012
      PRINT  1002
      PRINT  1007,(K,K=1,ICHAN)
      DO 501 J=1,NSCTS
      PRINT  1005,(J,(V (J,I),I=1,ICHAN))
501   CONTINUE
      PRINT  1002
      PRINT  1014
```

```
      PRINT  1002
      PRINT  1007,(K,K=1,ICHAN)
      DO 502 J=1,NSCTS
      PRINT  1005,(J,(VT(J,I),I=1,ICHAN))
 502  CONTINUE
      PRINT  1002
      PRINT  1018
      DO 503 J=1,NSCTS
      PRINT  1005,(J,(X1(J,I),I=1,ICHAN))
 503  CONTINUE
 2006 CONTINUE
      NS=MS+1
      DO 20 IAA=NS,NFILE
      DO 10 J=1,NSCTS
      DO 10 I=1,ICHAN
      XBAR(J,I)=0.0
      V1(J,I)=0.0
      VT1(J,I)=0.0
      VPROD(J,I)=0.0
      VXPROD(J,I)=0.0
      VDIFF(J,I)=0.0
      VTDIFF(J,I)=0.0
      VSUM(J,I)=0.0
      VTSUM(J,I)=0.0
      XTBAR(J,I)=0.0
      XPROD(J,I)=0.0
 10   CONTINUE
      M=0
      DO  30 J=1,NCHAN
      IF(ICH(J))  31,30,31
 31   M=M+1
      N=0
      DO 33 I=1,NSCANS
      IF(NSC(I))  32,33,32
 32   N=N+1
      V1(N,M)=X(IAA,I,J)
 33   CONTINUE
 30   CONTINUE
C        MATRIX      INVERSION     AND     CHECK
      CALL  MINV(V1,VT1,DET,ICHAN)
      DET2=DET
      CALL  MMPY(ICHAN,NSCTS,ICHAN,V1,VT1,X1)
      IF(NPRINT) 2009,2008,2009
 2009 CONTINUE
      PRINT  1010
      PRINT  1002
      PRINT  1006
      PRINT  1002
      PRINT  1017,IAA
      PRINT  1002
      PRINT  1006
      PRINT  1002
      PRINT  1013
      PRINT  1007,(K,K=1,ICHAN)
      PRINT  1005,(IONE,(ZBAR (IAA ,I),I=1,ICHAN))
```

```
      PRINT  1002
      PRINT  1012
      PRINT  1002
      PRINT  1007,(K,K=1,ICHAN)
      DO 504 J=1,NSCTS
      PRINT  1005,(J,(V1(J,I),I=1,ICHAN))
504   CONTINUE
      PRINT  1002
      PRINT  1014
      PRINT  1002
      PRINT  1007,(K,K=1,ICHAN)
      DO 505 J=1,NSCTS
      PRINT  1005,(J,(VT1(J,I),I=1,ICHAN))
505   CONTINUE
      PRINT  1002
      PRINT  1018
      PRINT  1002
      PRINT  1007,(K,K=1,ICHAN)
      DO 506 J=1,NSCTS
      PRINT  1005,(J,(X1(J,I),I=1,ICHAN))
506   CONTINUE
2008  CONTINUE
      DO 3 J=1,ICHAN1
      DO 3 I=1,ICHAN
      XBAR(J,I)=ZBAR(IAB,I)-ZBAR(IAA,I)
3     CONTINUE
      DO 8 J=1,ICHAN1
      DO 8 I=1,ICHAN
      XTBAR(I,J)=XBAR(J,I)
8     CONTINUE
      CALL MMPY(ICHAN,ICHAN1,ICHAN,XTBAR,XBAR,XPROD)
      CALL  MSUB(ICHAN,NSCTS,V,V1,VDIFF)
      CALL  MSUB(ICHAN,NSCTS,VT1,VT,VTDIFF)
      CALL  MADD(ICHAN,NSCTS,VT,VT1,VTSUM)
      CALL  MMPY(ICHAN,NSCTS,ICHAN,VDIFF,VTDIFF,VPROD)
      CALL  MMPY(ICHAN,NSCTS,ICHAN,VTSUM,XPROD,VXPROD)
      IF (NPRINT) 2014,2015,2014
2014  CONTINUE
      PRINT  1002
      PRINT  1015
      PRINT  1002
      PRINT  1002
      PRINT  1025,IAB,IAA
      PRINT  1002
      PRINT  1007,(K,K=1,ICHAN)
      DO 507 J=1,NSCTS
      PRINT  1005,(J,(VPROD (J,I),I=1,ICHAN))
507   CONTINUE
      PRINT  1002
      PRINT  1016
      PRINT  1002
      PRINT  1002
      PRINT  1025,IAB,IAA
      PRINT  1002
      PRINT  1007,(K,K=1,ICHAN)
```

```
      DO 508 J=1,NSCTS
      PRINT  1005,(J,(VXPROD(J,I),I=1,ICHAN))
  508 CONTINUE
 2015 CONTINUE
      KK=0
      JJ=0
      DO 4  J=1,NSCTS
      KK=KK+1
      JJ=JJ+1
      TRACE(IAB,IAA)=TRACE(IAB,IAA)+VPROD(KK,JJ)
      TRACE1(IAB,IAA)=TRACE1(IAB,IAA)+VXPROD(KK,JJ)
    4 CONTINUE
      DIV(IAB,IAA)=(TRACE(IAB,IAA)+TRACE1(IAB,IAA))/2.0
C     PRINT  1009,DIV(IAB,IAA)
C     PRINT  1004,DET1,DET2,TRACE(IAB,IAA),TRACE1(IAB,IAA)
   20 CONTINUE
      MS=MS+1
  200 CONTINUE
      PRINT  1010
      PRINT  1002
      PRINT  1002
      NBEGIN=NLOW
      NSTOP=NUP
      DO 2010 JJ=1,NMEANS
      PRINT 1023,(Z(L),L=NBEGIN,NSTOP)
      NBEGIN=NBEGIN+NUP
      NSTOP=NUP+NBEGIN-1
 2010 CONTINUE
      PRINT  1002
      PRINT  1002
      PRINT  1022
      PRINT  1002
      PRINT  1008,(ICH(I),I=1,NCHAN)
      PRINT  1002
      PRINT  1019
      PRINT  1002
      PRINT  1002
      PRINT  1006
      PRINT 1002
      PRINT  1024,(K,K=1,NCOVR)
      DO  2000   IAB=1,NCOVR
      PRINT  1005,(IAB,(DIV(IAB,IAA),IAA=1,NCOVR))
 2000 CONTINUE
      PRINT 1002
      PRINT  1006
      PRINT  1002
      PRINT  1002
      PRINT  1002
      PRINT  1010
      PRINT  1002
      PRINT  1020
      PRINT  1002
      PRINT 1002
      PRINT  1006
      PRINT  1024,(K,K=1,NCOVR)
```

```
      DO  2001   IAB=1,NCOVR
      PRINT  1005,(IAB,(TRACE (IAB,IAA),IAA=1,NCOVR))
 2001 CONTINUE
      PRINT 1002
      PRINT  1006
      PRINT  1002
      PRINT  1021
      PRINT  1002
      PRINT  1002
      PRINT  1006
      PRINT 1002
      PRINT  1024,(K,K=1,NCOVR)
      DO  2002   IAB=1,NCOVR
      PRINT  1005,(IAB,(TRACE1(IAB,IAA),IAA=1,NCOVR))
 2002 CONTINUE
      PRINT 1002
      PRINT  1006
 251  CONTINUE
      STOP
      END

$IBFTC TWO
      SUBROUTINE MMPY(J,K,L,P,Q,R)
      DIMENSION  P(12,12),Q(12,12),R(12,12)
      DO 100 JJ=1,J
      DO 100 LL=1,L
 100  R(JJ,LL)=0.0
      DO 200 LL=1,L
      DO 200 JJ=1,J
      DO 200 KK=1,K
      R(JJ,LL)=R(JJ,LL)+P(JJ,KK)*Q(KK,LL)
 200  CONTINUE
      RETURN
      END

$IBFTC THREE
      SUBROUTINE MADD(M,N,A,B,C)
      DIMENSION  A(12,12),B(12,12),C(12,12)
      DO 2 I=1,M
      DO 2 J=1,N
      C(I,J)=A(I,J)+B(I,J)
    2 CONTINUE
      RETURN
      END

$IBFTC FOUR
      SUBROUTINE MSUB (M,N,A,B,C)
      DIMENSION  A(12,12),B(12,12),C(12,12)
      DO 2 I=1,M
      DO 2 J=1,N
      C(I,J)=A(I,J)-B(I,J)
    2 CONTINUE
      RETURN
      END
```

```
$IBFTC FIVE
      SUBROUTINE MINV(A,AI,DET,M)
      DIMENSION  A(12,12),AI(12,12),IORD(12)
      N=M
      DO 100 I=1,N
      DO 100 J=1,N
  100 AI(I,J)=A(I,J)
      DO 51 I=1,N
 51   IORD(I)=I
      DET=1.
      DO 1 K=1,N
      KP1=K+1
      TEST=ABS(AI(K,K))
      IND=K
      IF(K-N)21,22,21
 21   DO 23 L=KP1,N
      TEST1=ABS(AI(L,K))
      IF(TEST-TEST1)24,23,23
 24   TEST=TEST1
      IND=L
 23   CONTINUE
      IF(IND-K)25,22,25
 25   DO 26 J=1,N
      TEST1=AI(IND,J)
      AI(IND,J)=AI(K,J)
   26 AI(K,J)=TEST1
      DET=-DET
      LL=IORD(K)
      IORD(K)=IORD(IND)
      IORD(IND)=LL
 22   CONTINUE
      IF(AI(K,K))31,32,31
   31 AI(K,K)=1./AI(K,K)
      DO 2 J=1,N
      IF(J-K)3,2,3
    3 QUOT=AI(K,J)*AI(K,K)
      AI(K,J)=QUOT
      IF(QUOT)42,2,42
 42   DO 4 I=1,N
      IF(I-K)5,4,5
    5 TEST=AI(I,J)-AI(I,K)*QUOT
      IF(ABS(TEST)-ABS(AI(I,J))*1.0E-5)70,71,71
   70 AI(I,J)=0.
      GO TO 4
   71 AI(I,J)=TEST
 4    CONTINUE
 2    CONTINUE
      DO 11 I=1,N
      IF(I-K)12,11,12
   12 AI(I,K)=-AI(I,K)*AI(K,K)
 11   CONTINUE
      DET=DET/AI(K,K)
 1    CONTINUE
 55   DO 52 I=1,N
      IND=IORD(I)
```

```
      IF(IND-I)53,52,53
53    LL=IORD(I)
      IORD(I)=IORD(IND)
      IORD(IND)=LL
      DO 54 K=1,N
      TEST=AI(K,IND)
      AI(K,IND)=AI(K,I)
   54 AI(K,I)=TEST
      GO TO 55
52    CONTINUE
33    RETURN
32    DET=0.
      RETURN
      END
```

$$\psi_{ij} = \frac{|M_i(k) - M_j(k)|}{\sqrt{\Delta^2 |M_i(k) - M_j(k)|}}$$

or

$$\psi_{ij} = \frac{\left\{ \sum_{k=1}^{\bar{K}} \boxed{[M_i(k) - M_j(k)]^2} \right\}^{1/2}}{2 \left\{ \sum_{k=1}^{\bar{K}} [M_i(k) - M_j(k)]^2 \; [\sigma_i^2(k) + \sigma_j^2(k)] \right\}^{1/2}}$$

The program is coded such that up to 12 inventory areas can be compared simultaneously, i.e., $\chi_{i,j}$ (i,j = 1, 2, ... 12)

DEFINITION OF INPUT PARAMETERS:

CARD 1

NCHAN = Total number of channels.

NTAU = Number of channels used.

ICHAN = Reference channel used in correlations.

ICHEK = 1 for absolute value calculations of input.

ITERM = 1 for each additional case or data set combination.

CARD 2

ICROP1 = Identification of data set 1.

JIDEN = Output identification of ICROP1.

ICROP2 = Identification of data set 2.

KIDEN = Output identification of ICROP2.

CARD 3

CRN1(I) = Means for data set 1.

CRN2(I) = Standard deviation for data set 1.

WHT1(I) = Means for data set 2.

WHT2(I) = Standard deviation for data set 2.

The input card setup is shown in Figure 3-16. A listing of the program is given below.

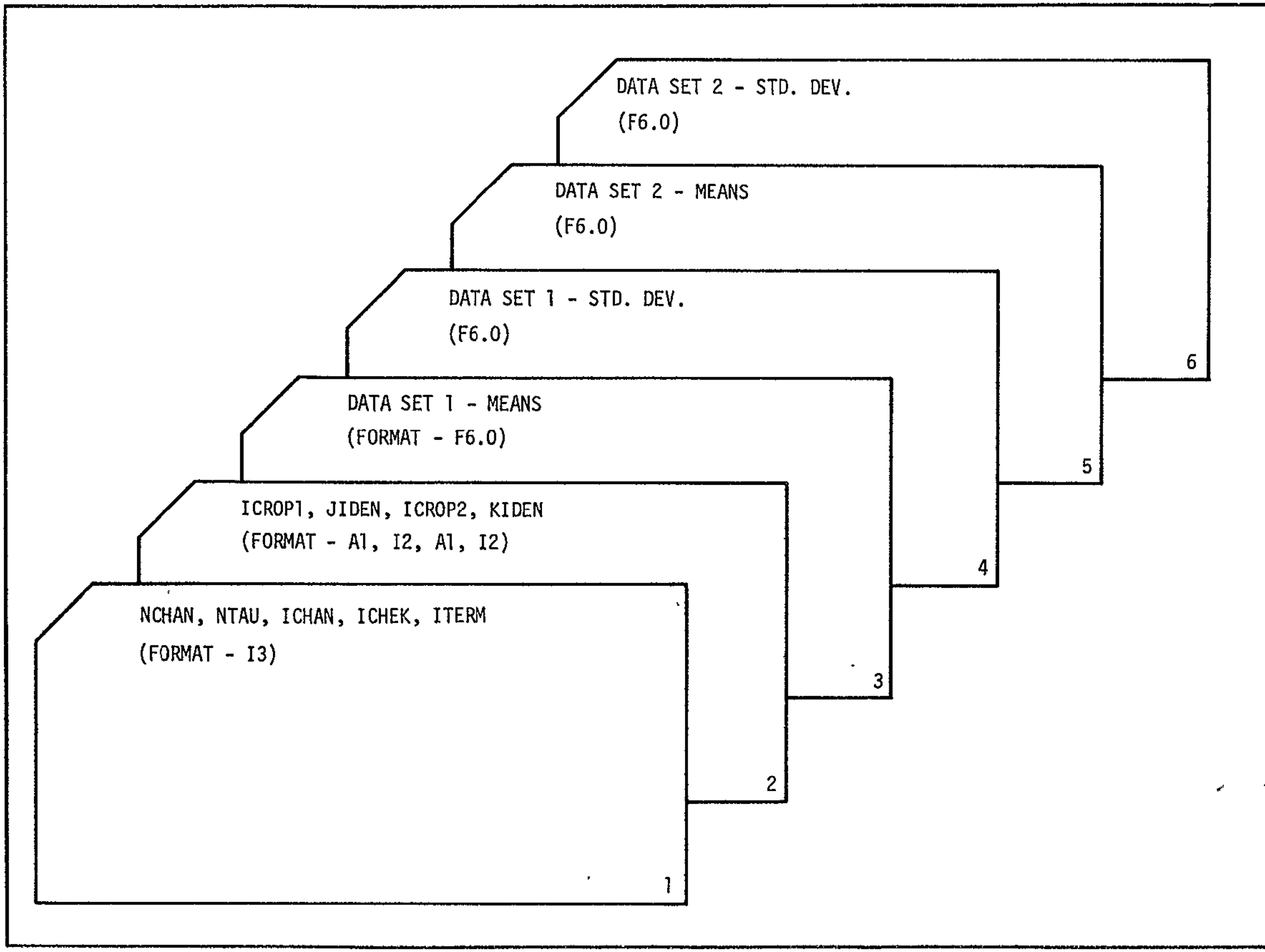

Figure 3-16. INPUT CARD SETUP

```
C                 ****************************************
C                 CALCULATION OF SI VALUES FOR SELECTION OF OPTIMUM
C                 COLOR SPACE PLOTS.
C                 ****************************************
      DIMENSION CRN1[3,12],CRN2[3,12],WHT1[3,12],WHT2[3,12],
     1 DGV[25],XNUM[25],RATIO[25],RZERO[25]
    1 CONTINUE
      READ 80, NCHAN,NTAU,ICHAN,ICHEK,ITERM
      TTAU=NTAU
      XTAU=NTAU
      READ 64, ICROP1,JIDEN,ICROP2,KIDEN
C
C                 NCHAN=NR. OF CHANNEL COMBINATIONS
C                 NTAU=TOTAL NR. OF CHANNELS
C                 ICHAN=REF. CHANNEL USED FOR CORRELATIONS
C
      READ 50, [CRN1[1,J],J=1,NTAU]
      READ 50, [CRN2[1,J],J=1,NTAU]
      READ 50, [WHT1[1,J],J=1,NTAU]
      READ 50,[WHT2[1,J],J=1,NTAU]
C                 ********************************************
      PRINT 62
      PRINT 65
      PRINT 89, ICROP1,JIDEN
      PRINT 95
      PRINT 88, [J,J=1,NTAU]
      PRINT 98
      PRINT 96, [CRN1[1,J],J=1,NTAU]
      PRINT 97, [CRN2[1,J],J=1,NTAU]
      PRINT 61
      PRINT 89, ICROP2,KIDEN
      PRINT 95
      PRINT 88, [J,J=1,NTAU]
      PRINT 98
      PRINT 96, [WHT1[1,J],J=1,NTAU]
      PRINT 97, [WHT2[1,J],J=1,NTAU]
      IF[ICHEK]16,19,16
   16 DO 15 J=1,NTAU
      CRN1[1,J]=ABSF[CRN1[1,J]]
      CRN2[1,J]=ABSF[CRN2[1,J]]
      WHT1[1,J]=ABSF[WHT1[1,J]]
      WHT2[1,J]=ABSF[WHT2[1,J]]
   15 CONTINUE
C
C     CALC. SI FOR EACH CHANNEL COMB.
C
   19 CONTINUE
      NSTOP=NTAU
      K=0
      NSTART=0
      NBEGIN=0
      ICOUNT=0
      PRINT 62
      PRINT 67
      PRINT 90, ICROP1,JIDEN,ICROP2,KIDEN
```

```
   60 FORMAT[3X,2HCH/]
   61 FORMAT[1X//]
   62 FORMAT[1H1//]
  64  FORMAT[A1,I2,A1,2I2]
   67 FORMAT[53X,8HSI TABLE/]
   69 FORMAT[9X,1H*,12F8.4/9X,1H*]
   70 FORMAT[1X,119H*********************************************************
     1*****************************************************************
     1*/9X,1H*,98X,12H*           *]
   71 FORMAT [18X,1H*,12F8.3        /18X,1H*]
   80 FORMAT[6I3]
   82 FORMAT[1X,I4,4X,1H*,12F8.3,
     1 2X,1H*,F8.3,2X,1H*/
     2 9X,1H*,98X,12H*           *]
   83 FORMAT[53X,7HCHANNEL/
     1 9X,1H*,98X,12H*           *]
   84 FORMAT[3X,2HCH,4X,1H*,12[I5,3X],2X,1H*,11H   MEAN   */
     1 9X,1H*,98X,12H*           *]
   85 FORMAT[51X,11HINPUT  DATA//]
   88 FORMAT[9X,1H*,12[I5,3X]/ 9X,1H*]
  89  FORMAT[7X,3HC5-,I2,8X,7HSECTION,5X,A1,10X,15HREF  CHANNEL  6//]
  90  FORMAT[1X,44HDERIVATIVE CORRELATIONS -UN-NORMALIZED - C5-,I2,
     12X,4HSEC A1,1X,3HC5-,I2,2X,4HSEC A1,4X,9H30 SAM/PC//]
   91 FORMAT[1X,119H*********************************************************
     1*****************************************************************
     2*]
   92 FORMAT[1X///10X,13HTRACE MEAN = F8.4//]
   93 FORMAT[10X,13HMATRIX MEAN =F8.4]
   94 FORMAT[2X,12F8.3]
   95 FORMAT[53X,7HCHANNEL/9X,1H*]
   96 FORMAT[1X,8HAC MEAN ,1H*,12F8.4/9X,1H*]
   97 FORMAT[1X,8HSTD DEV ,1H*,12F8.4/9X,1H*]
   98 FORMAT[1X,108H*********************************************************
     1*********************************************************/9X,1H*]
  100 CONTINUE
C           *********************************************
      IF[ITERM-1]200,1,1
  200 CONTINUE
      END
```

```
      PRINT 83
      PRINT 84, [J,J=1,12]
      PRINT 70
      XSUM=0.0
      YSUM=0.0
      DO 40 II=1,NTAU
      K=K+1
      SUM=0.0
      DO 38 J=1,NTAU
      XNUM[J]  = [WHT1[1,K]-CRN1[1,K]]**2+[WHT1[1,J]-CRN1[1,J]]**2
      DGV[J]   =4.0*[[[WHT1[1,K]-CRN1[1,K]]**2 * [WHT2[1,K]**2+CRN2[1,K]
     1**2] +[[[WHT1[1,J]-CRN1[1,J]]**2 * [WHT2[1,J]**2+CRN2[1,J]**2]]]]]
      RATIO[J]= [2.0*XNUM[J]]/SQRTF[DGV[J]]
      IF[RATIO[J]-100.0]30,35,35
   35 RATIO[J]=0.0
      TTAU=TTAU-1.0
      SUM=SUM+RATIO[J]
      YSUM=YSUM+RATIO[J]
      GO TO 38
   30 SUM=SUM+RATIO[J]
      YSUM=YSUM+RATIO[J]
      ICOUNT=ICOUNT+1
   38 CONTINUE
      AVG=SUM/TTAU
      NBEGIN=NSTART+1
      XBEGIN=NBEGIN
      RZERO[NSTART]=0.0
      IF[K-1]39,36,39
   36 CONTINUE
      PRINT 82, K,[RATIO[J],J=1,NTAU],AVG
      NSTART=NSTART+1
      XSUM=XSUM+RATIO[1]
      GO TO 40
   39 CONTINUE
      PRINT 82, K,[RZERO[J],J=1,NSTART],[RATIO[J],J=NBEGIN,NTAU],AVG
      NSTART=NSTART+1
      XBEGIN=NBEGIN
      NSTOP=NSTOP-1
      N=N+12
      IF[RATIO[NBEGIN]-100.0]32,33,33
   33 RATIO[NBEGIN]=0.0
      XTAU=XTAU-1.0
      XSUM=XSUM+RATIO[NBEGIN]
      GO TO 40
   32 XSUM=XSUM+RATIO[NBEGIN]
   40 CONTINUE
      PRINT 91
      YTOT=ICOUNT
      XSUM=XSUM/XTAU
      XTAU=NTAU
      TTAU=NTAU
      YSUM=YSUM/YTOT
      PRINT 92, XSUM
      PRINT 93, YSUM
   50 FORMAT[12F6.0]
```

Section IV

APPLICATIONS TO MULTISPECTRAL REMOTE SENSING DATA OF AGRICULTURAL FIELDS

4.1 INTRODUCTION

In order to test and demonstrate the capability of the algorithms and associated computer programs developed, which have been described in the last two sections, we have employed these computer programs to process and analyze a set of multispectral data records which were made available to us by Dr. R. R. Legault of the University of Michigan. In this section, we shall present the results of the analysis of those actual data.

4.2 MULTISPECTRAL DATA DESCRIPTION

The data to be presented were obtained by the University of Michigan Multispectral Scanner (ref. 11). This particular set of data was obtained over an agricultural area near Lafayette, Indiana, from a flight altitude of 2000 feet at 2:00 p.m., June 30, 1966. In particular, we are dealing with only a small portion of the area designated as field C5-17, C5-22, C5-5, and C5-8, respectively, as shown in Figure 4-1. C5 represents the square area about 1 mile square with 5 marked in the figure. The number following the dash represents a more specific location of each field.

The electromechanical scanner onboard this aircraft used a rotating mirror to scan the ground normal to the flight path. Successive scan lines were separated along the flight path by approximately 6 feet due to the motion of the aircraft. All observations were stored on analog tape. Subsequent analog to digital conversion used a sampling time interval that corresponded to a ground separation of 6 feet along the scan line. The digital data points thus represent the radiation intensity that were received from square resolution elements of 6 feet by 6 feet area.

Spectroscopic observations of each resolution element were conducted by passing the radiation from the rotating mirror through a prism. This prism spectrograph was designed to measure the reflectance between 0.4 and 1.0 μ. The radiation from the ground refers to reflected sunlight. The spectral range was split into 12 different channels which are listed in Table 4-1.

Table 4-1. SPECTRAL BANDS OF MICHIGAN MULTISPECTRAL SCANNER

CHANNEL NO.	SPECTRAL BANDWITH (microns)	CHARACTERISTIC COLOR	
1	0.40 - 0.44	Violet	Visible
2	0.44 - 0.46	Blue	
3	0.46 - 0.48		
4	0.48 - 0.50	Blue-Green	
5	0.50 - 0.52		
6	0.52 - 0.55	Green	
7	0.55 - 0.58		
8	0.58 - 0.62	Yellow	
9	0.62 - 0.66	Red	
10	0.66 - 0.72	Red	
11	0.72 - 0.80	Reflective near infrared	
12	0.80 - 1.00		

Twelve digital time series of the spectral reflectance from the agricultural target were obtained. The channel number, λ, of these time series is directly related to the optical wavelength. The sample number along these time series denotes the position of a resolution element along a scan line. Sample and scan line numbers thus provide a two-dimensional, Cartesian coordinate for the agricultural target.

The data received from each of the four agricultural fields cover only an area of 162 by 1000 feet, i.e. 27 scan lines and 167 samples per scan line. Since we want to test our algorithms for inventory boundary detection and other comparison studies, we have deliberately patched these four fields together as shown in Figure 4-2.

4.3 RAW DATA PLOTS

To have a quick and overall view of the magnitude distribution of the data record, a plotting program was used to plot the raw digital data record in analog form one scan line per agricultural field for selected channels, as shown in Figures 4-3 through 4-8. From these plots, one observes that sections of distinctly different reflectances exist for each agricultural field. These differences are particularly obvious in channels 1, 2, 11, and 12. Although only one scan line per field has been shown, it is representative for each field. This observation tends to imply that each field may consist of three different targets or inventory areas.

It was also found that some resolution elements have negative value (about -1) for all 12 channels, which was obviously caused by human error in data handling prior to our data analysis. Since these negative reflectance cannot be true, we have replaced them when they occur by the mean reflectance of the adjacent resolution elements.

4.4 GREY-LEVEL PLOTS

Figures 4-9 through 4-12 show grey-level plots for the constructed agricultural field for channel 1, 2, 11, and 12, respectively. The grey level plots resemble very crude photographs of the target. In these plots 11 levels of grey as indicated by numerical numbers are used. The original data have been averaged over 4 resolution elements (i.e., a area of 12 feet by 12 feet) first so that the number of scan lines is reduced to 52 and the number of samples per scan is reduced to 83. Human inspection of the plots revealed several areas with difference reflectances. Identifiable boundaries between these areas are indicated by solid lines. Many of these lines coincide with the constructed boundaries that separate the four agricultural fields. This agreement gives a good confidence in the qualitative human judgement for selection of inventory boundaries. It should be noted that the identifiable boundaries for different channels are not exactly the same, as would be expected. Superposition of the inventory boundaries from all the channels is shown in Figure 4-13. The figure indicates that no boundary exists between two middle portions of C5-17 and C5-22, even though they belong to different fields. Some of the inventory boundaries are not so definite from the grey-level plots and they are so designated in the figure by hashed lines. Those boundaries in Figure 4-13 will be regarded as the expected inventory boundaries and will be used for comparison with automatic computer results to be presented in the next two subsections.

4.5 BOUNDARY ENHANCEMENT

Subsection 2.4 discussed the underlying principle for the enhancement of inventory boundaries. To illustrate the principle more vividly, the hypothetical illustrations in Figure 2-10 are now replaced by actual data. Figure 4-14 shows the original raw data for channel 11, of each Scan 13 from the 4 fields. It can be seen that fairly large and frequent fluctuations exist in the samples from each scan line. Figure 4-15 shows the corresponding smoothed data by applying the 2-dimensional moving average over the given raw data. For the results shown, a moving average over 25 resolution elements in the form of 5 x 5 array was used. The curve in Figure 4-15 are not only smoother than the corresponding curves in Figure 4-14, but also reveal more clearly trends of slow variation existing in each scan line. Figure 4-16 shows the resulting enhanced data from the smoothed data using all 12 channels. The peaks in this Figure indicate the location of inventory boundaries in each scan. The larger the peak value, the greater difference exists between any two adjacent inventory areas.

The computer program, which is developed according to the above algorithm has been applied to the multispectral data of the constructed agricultural field containing C5-17, C5-22, C5-5, and C5-8. The computer outputs are shown in Figures 4-17 through 4-21. Figures 4-17 through 4-19 employ the second type of boundary enhancement, while Figures 4-20 and 4-21 employ the first type of boundary enhancement. In Figure 4-17 a 4-level plot is used which prints a dot (.) if the enhanced data lies below the mean plus one σ-value, prints 1 if it lies between the mean plus one σ-value and the mean plus 2 σ-value, and similar definitions for prints 2 and 3. It can be seen that too many boundaries appear in this plot. Figure 4-18 shows a new plot without all those symbol 1's. One can now see very distinct inventory boundaries which correspond very well to those inventory boundaries determined by the human photo-interpretation (Figure 4-13). Figure 4-19 employs only 4 channels instead of all 12 available channels. Close resemblance of this plot to that in Figure 4-18 would imply that these 4 channels may be sufficient to represent all 12 channels. Figures 4-20 and 4-21 are counterparts of Figures 4-18 and 4-19. Very close resemblance between these two sets of plots further indicates that the two types of boundary enhancements, i.e., either taking the absolute value or taking the square of the difference between the 2-dimensional moving averaged data are about the same. For economy of computation time, the second type of boundary enhancement seems to be better. In order to see the effect of the 2-dimensional moving averaging on the enhancement of boundary, we have employed another moving average for 9 resolution elements in the form of a 3 x 3 array. The resulting inventory boundary map is shown in Figure 4-22. Comparing this with Figure 4-18 one can see that the major boundaries are almost the same in the two figures, and that Figure 4-22 shows more isolated boundary spots than Figure 4-18. This implies that using the 5 x 5 array of resolution elements for moving average yields better and more clear-cut boundaries than using the 3 x 3 array. This clearly indicates the importance of the 2-dimensional moving average on the performance of boundary enhancement.

4.6 INVENTORY BOUNDARY DETECTION BY STATISTICAL VARIANCE TECHNIQUE

Figures 4-23 and 4-24 show the inventory boundary map obtained by the statistical variance technique using channel 1 and channel 11, respectively, with 99 percent of confidence limit. The symbol V represents the locations of inventory boundaries as detected in the scanwise direction. The symbol H represents the location of inventory boundaries as detected normal to the scan line. Finally, the symbol X represents the location of inventory boundaries as detected in both directions. Comparing Figure 4-23 with Figure 4-9 (grey-level plot), and Figure 4-24 with Figure 4-11, one can see that the inventory boundaries determined automatically by the statistical variance method compare reasonably well to those selected by the human photo-interpretation.

Figure 4-25 shows the inventory boundary map using channels 1 and 11 together. Comparing this figure with Figures 4-23 and 4-24, one can see that the new inventory boundaries fall roughly in between those indicated by using the individual channels. Two more maps of inventory boundaries using 4 channels (1, 2, 11, and 12) and 12 channels, respectively, are shown in Figures 4-26 and 4-27. Figures 4-25 and 4-26 are quite similar to each other. The only major differences between Figures 4-26 and 4-27 appear in field C5-8. Finally, comparing Figure 4-27 with Figure 4-13, it is seen that good agreement in inventory boundaries are observed for C5-17, C5-22, and C5-5; and that the vertical boundaries in C5-8 are completely different in these two figures. This poor performance detection in C5-8 might be due to the existance of a vertical boundary in C5-8 locating very close to the left end of the field, where the scanwise inventory boundary detection is initiated. It is recalled that at least 4 samples need to be used for the initial estimate of the statistical variations (see subsection 2.5) prior to testing for boundaries. This requirement makes it very difficult to detect the left vertical boundary in C5-8 and further cause misdetection later. In this respect, the boundary enhancement method (Figure 4-22) is more powerful then the statistical variation method for detecting inventory boundaries.

4.7 STATISTICAL FEATURES OF INVENTORY AREAS

Once the inventory boundaries within a given target area (or image) are determined as presented in subsections 4.5 and 4.6, the statistical features of each individual inventory area, which are the areas bounded by the inventory boundaries, may be calculated. For convenience of discussions, we shall designate various inventory areas as indicated in Figure 4-13.

Figure 4-28 is a computer printout of the mean vector, correlation matrix, covariance matrix, and normalized covariance matrix of the inventory area C5-17 Section A. The magnitude of the covariance matrix is about two orders of magnitude less than that of the correlation matrix. This implies that the standard deviation for each channel is about one-tenth of the corresponding mean value. The fact that roughly the average value of the element of the normalized covariance matrix is about 0.50 implies that the 12 channels of the data record are statistically correlated within each inventory area.

Figure 4-29 shows the mean vectors of reflectance for 6 inventory areas in fields C5-17 and C5-22, while Figure 4-30 shows the mean vectors of reflectance for 6 other inventory areas in fields C5-5 and C5-8. It is noted that the mean vectors of C5-17, Section B, and C5-22, Section B, are much closer to each other as compared with other mean vectors. This agrees with the computer results that no inventory boundary is found between these two inventory areas.

We shall next examine the univariate probability density functions of the multispectral agricultural data. It is recalled that among the 12 available channels of data for the four agricultural fields under consideration, we have found that only channels 1, 2, 11, and 12 are almost sufficient for determing inventory boundaries. Thus, the discussion shall be restricted to the univariate probability densities of only these four channels. Figures 4-31 through 4-34 show the univariate probability histograms for field C5-22 for channels 1, 2, 11, and 12, respectively. The curves marked by symbol A are obtained from actual data, while the curves marked by symbol B are gaussianly distributed curves with the same standard deviation and peak value as the actual data. The figures clearly indicate that the reflectance over field C5-22 is definitely not gaussianly distributed, and that the actual distribution are multiple-mode. For channel 1 we can see two distinctly large peaks. For channel 2, there are three main peaks. Figures 4-33 and 4-34 show that the distribution is skew to the low reflectance value. In order to provide one more check to see whether the inventory areas we have established are really composed of statistically homogeneous samples, we have also plotted the probability histograms for C5-22, Section A, B, and C with channel 1 and 11 (Figures 4-35 through 4-40). These figures clearly indicate that the univariate probability histograms are practically Gaussian for all the three inventory areas under consideration. In other words, field C5-22 is composed of three different homogeneous areas, each of which may be approximated by a different gaussian distribution.

Therefore, the division of the field C5-22 into three inventory areas as shown in Figure 4-13 is reasonable.

4.8 DIVERGENCE MATRIX AMONG INVENTORY AREAS

To calculate the divergence matrix among various inventory areas (or populations) and thus to compare the statistical dissimilarity (or separability) among them, we need to input the mean vectors and covariance matrices of all inventory areas into the divergence matrix program. Tables 4-2 and 4-3 show two such inputs for C5-17, Sections A and B. Table 4-4 shows the divergence matrix for the 12 inventory areas as indicated in field designations. (Note that the larger the value of divergence between two inventory areas, the less similar they are.) We have observed in an earlier part of the Section that C5-17, Section A is more similar to C5-22 Section B than any others. The table gives a divergence of 3.303 between these two inventory areas, which happens to be the smallest element of the divergence matrix. Tables 4-5 and 4-6 show two contributing parts, called trace 1 and trace 2 matrices, to the divergence matrix; they represent the first and second term (without the factor 1/2) of the sight-hand side of equation (2-11). If covariance matrices of all inventory areas are identical, then trace 1 matrices will vanish. On the other hand, if the mean vectors of all inventory areas are the same, then trace 2 matrix will vanish. Comparing Tables 4-5 and 4-6 indicate that the elements of trace 1 matrix are much larger than those of trace 2 matrix. This would imply that the dissimilarity among those 12 inventory areas is mainly due to their difference in mean vectors rather than their covariance matrices.

Figure 4-1. AERIAL PHOTOGRAPH OF THE AGRICULTURE FIELD

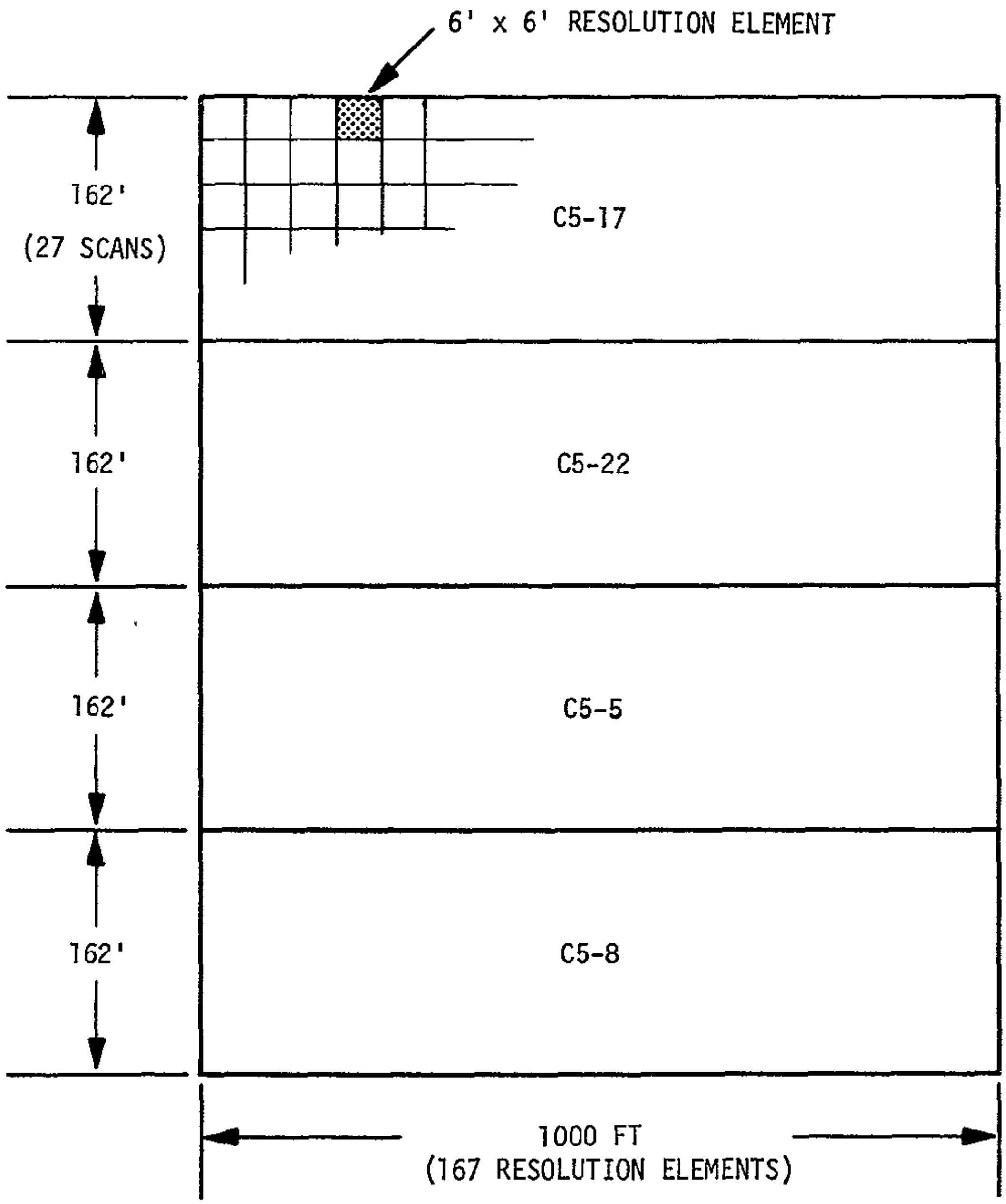

Figure 4-2. A CONSTRUCTED MAP OF FOUR AGRICULTURAL FIELDS

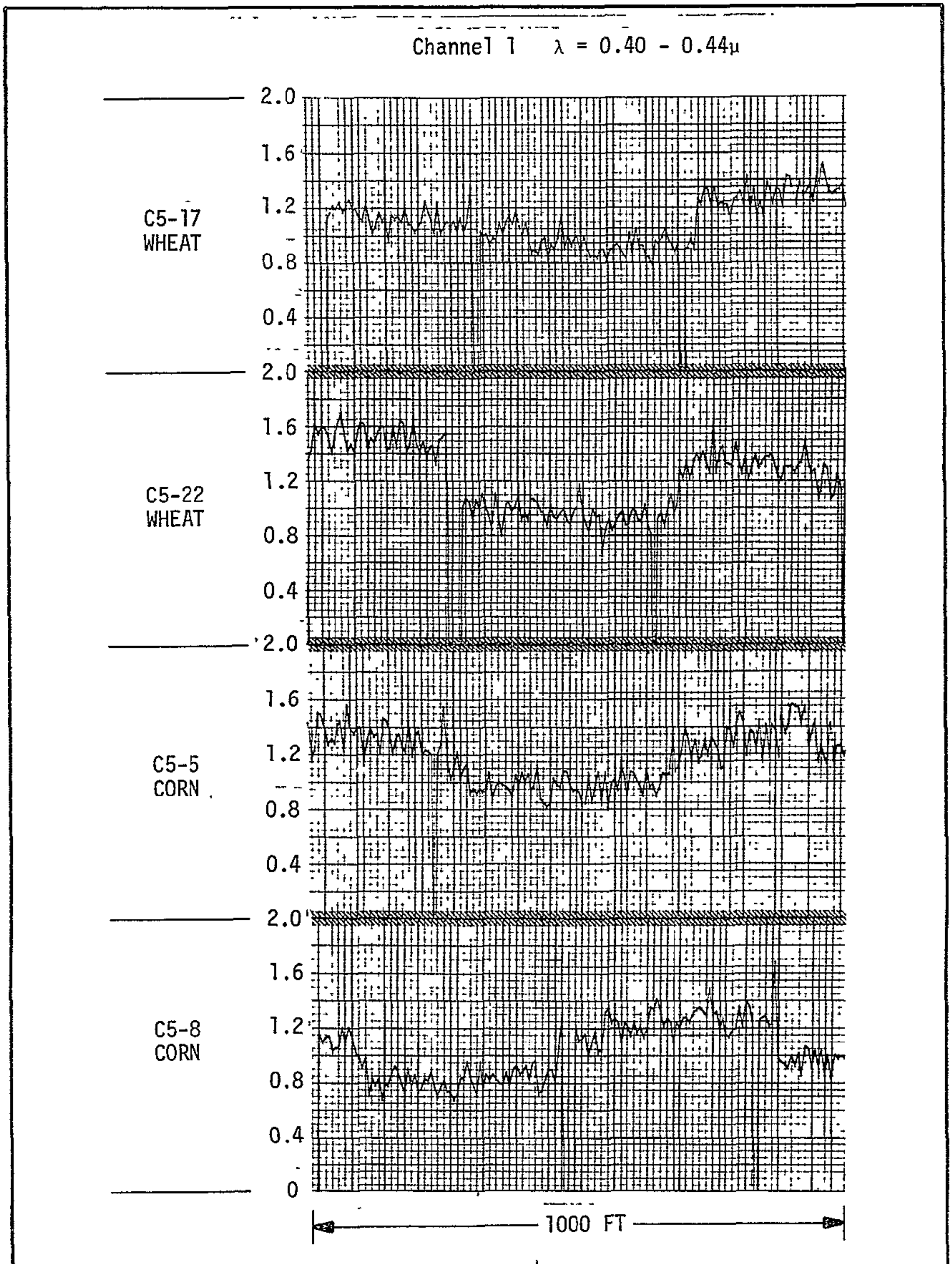

Figure 4-3. RAW DATA PLOT OF CHANNEL 1 FOR ONE SCAN LINE PER FIELD

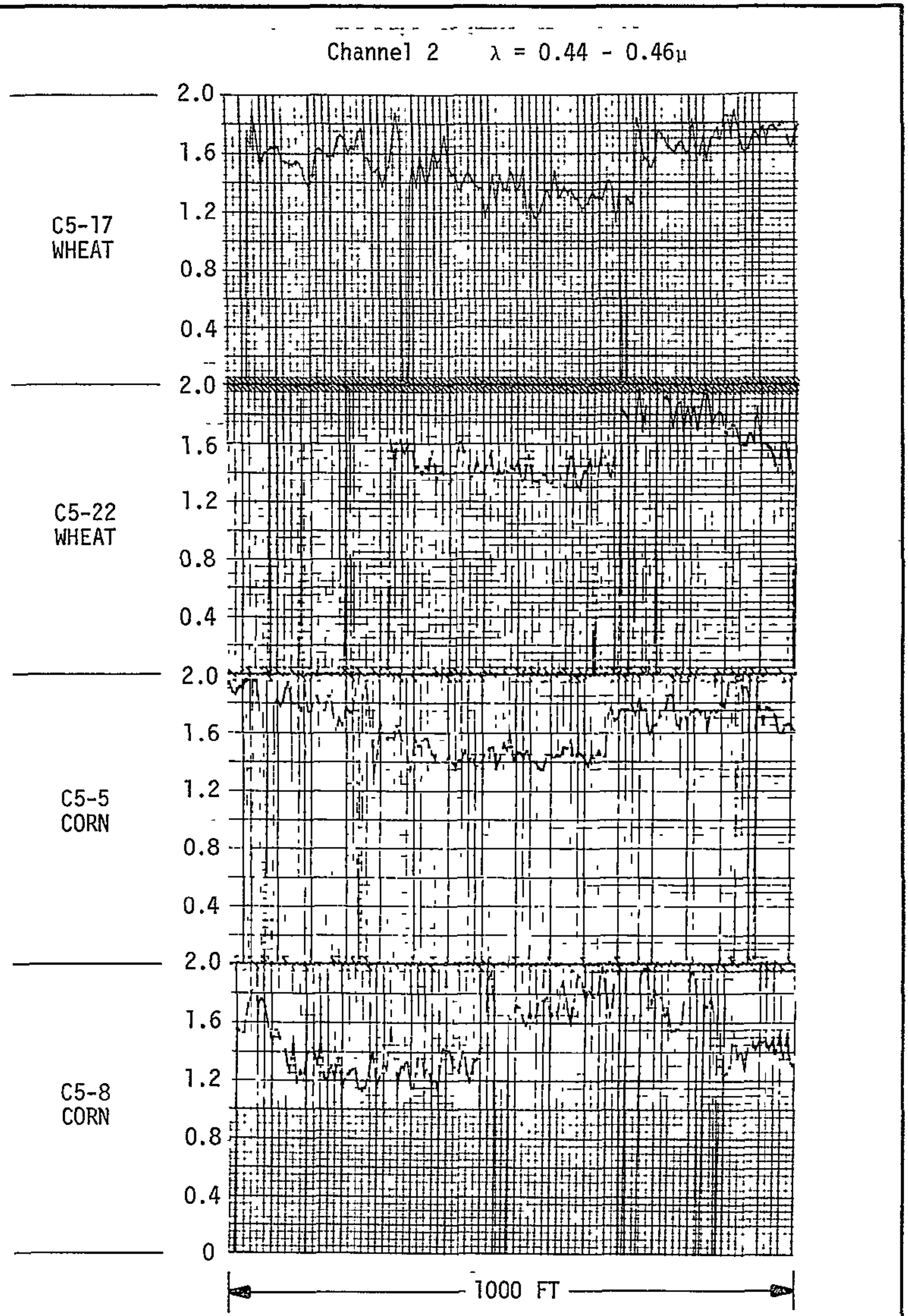

Figure 4-4. RAW DATA PLOT OF CHANNEL 2 FOR ONE SCAN LINE PER FIELD

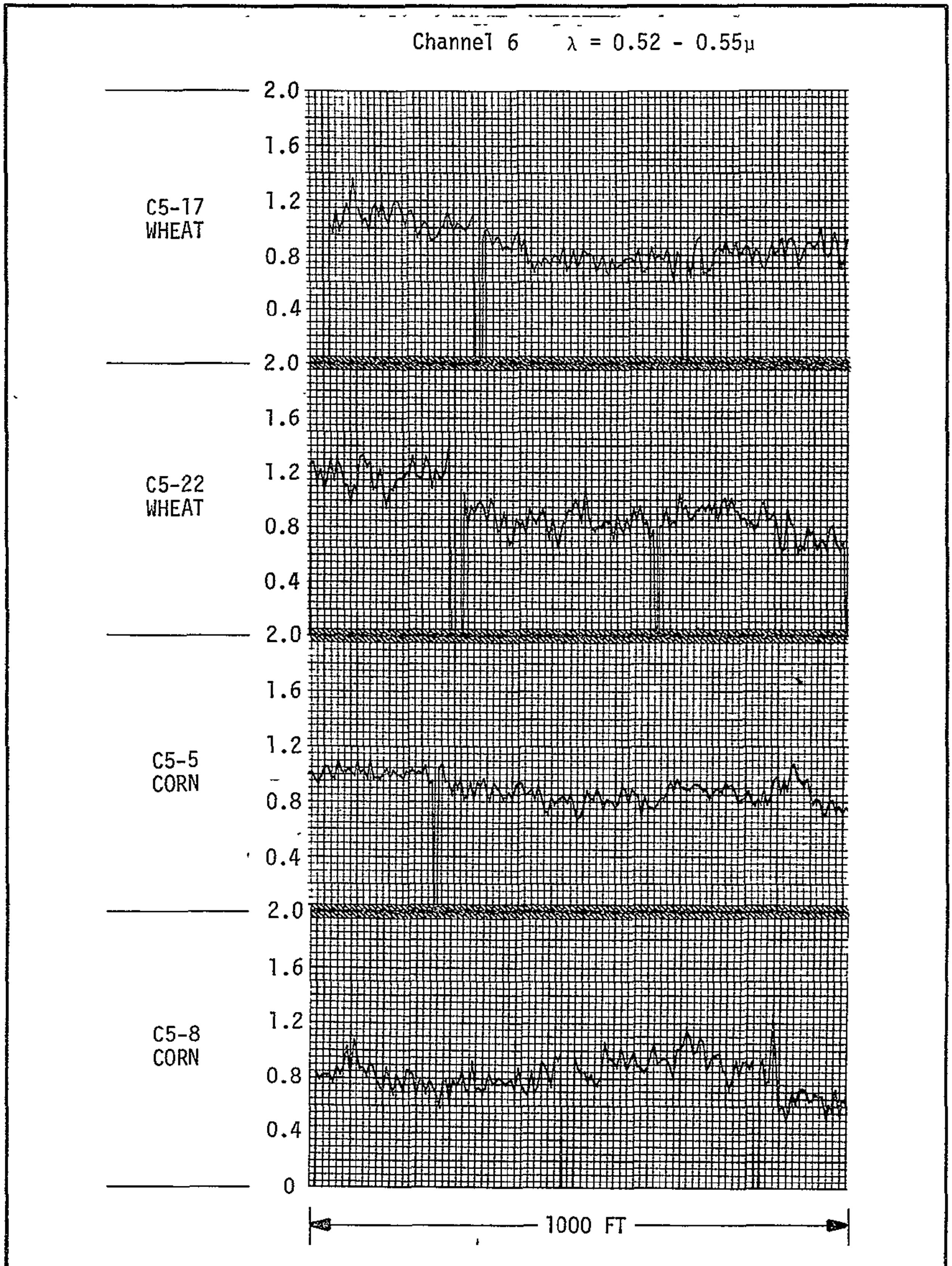

Figure 4-5. RAW DATA PLOT OF CHANNEL 6 FOR ONE SCAN LINE PER FIELD

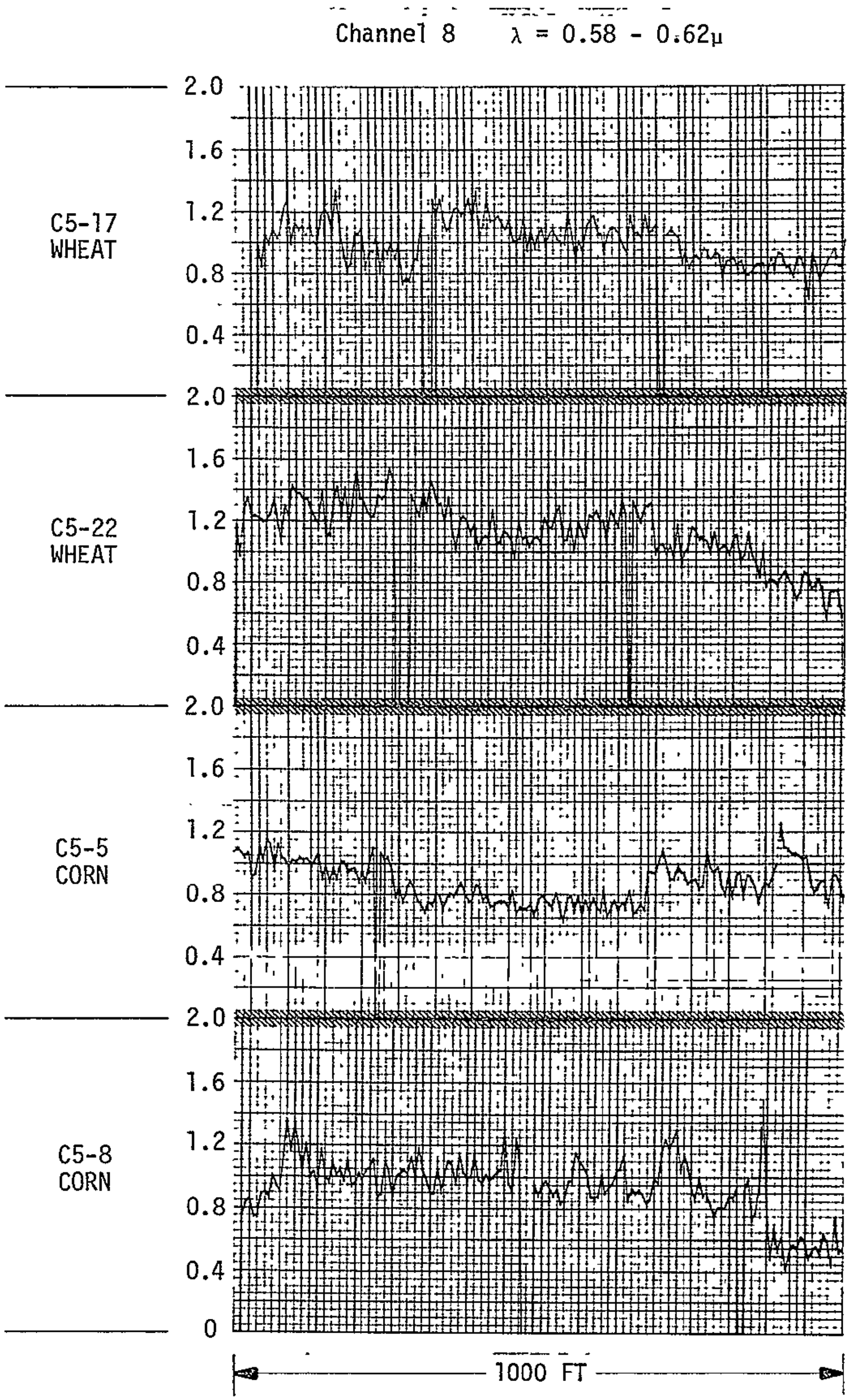

Figure 4-6. RAW DATA PLOT OF CHANNEL 8 FOR ONE SCAN LINE PER FIELD

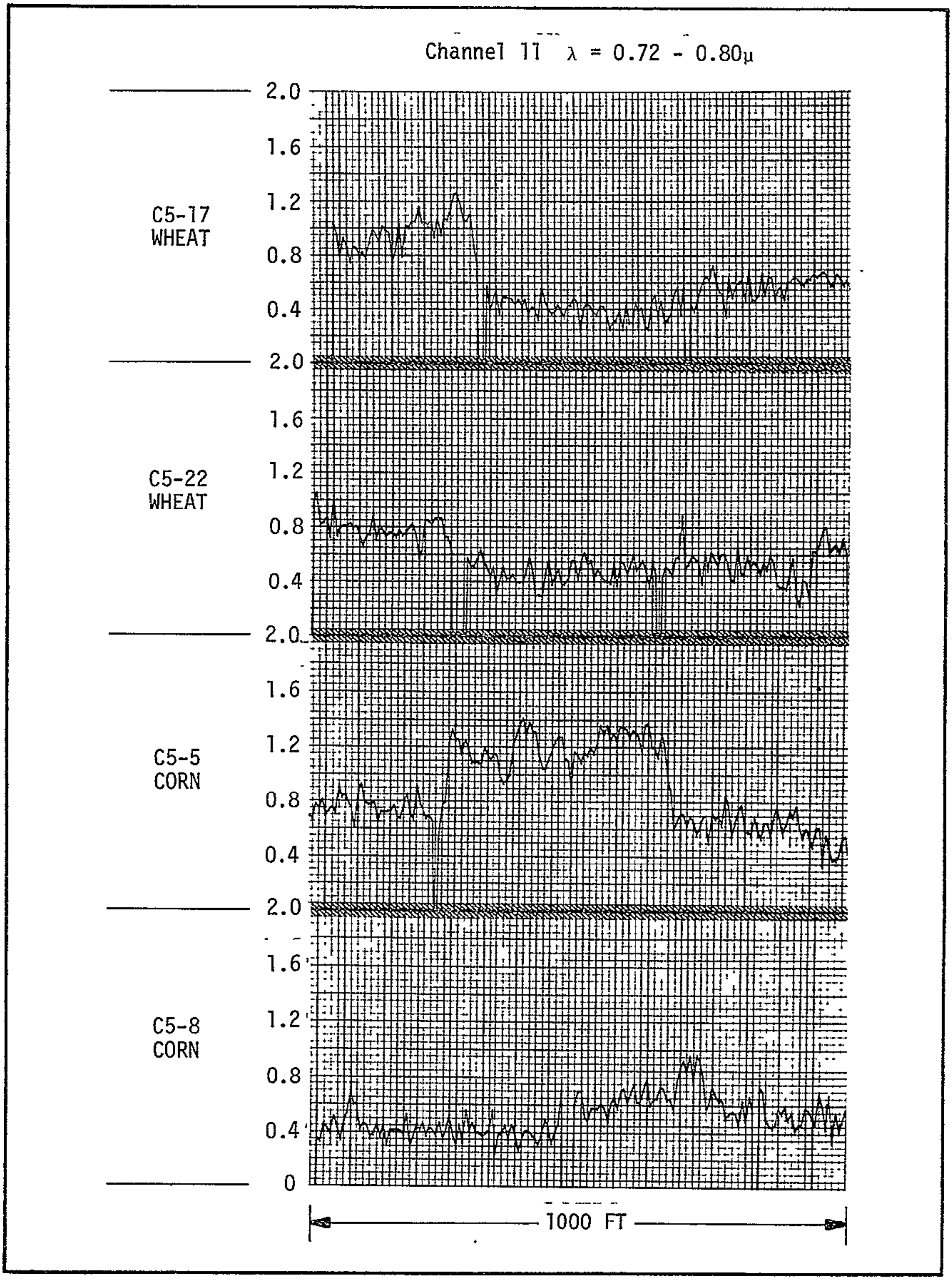

Figure 4-7. RAW DATA PLOT OF CHANNEL 11 FOR ONE SCAN LINE PER FIELD

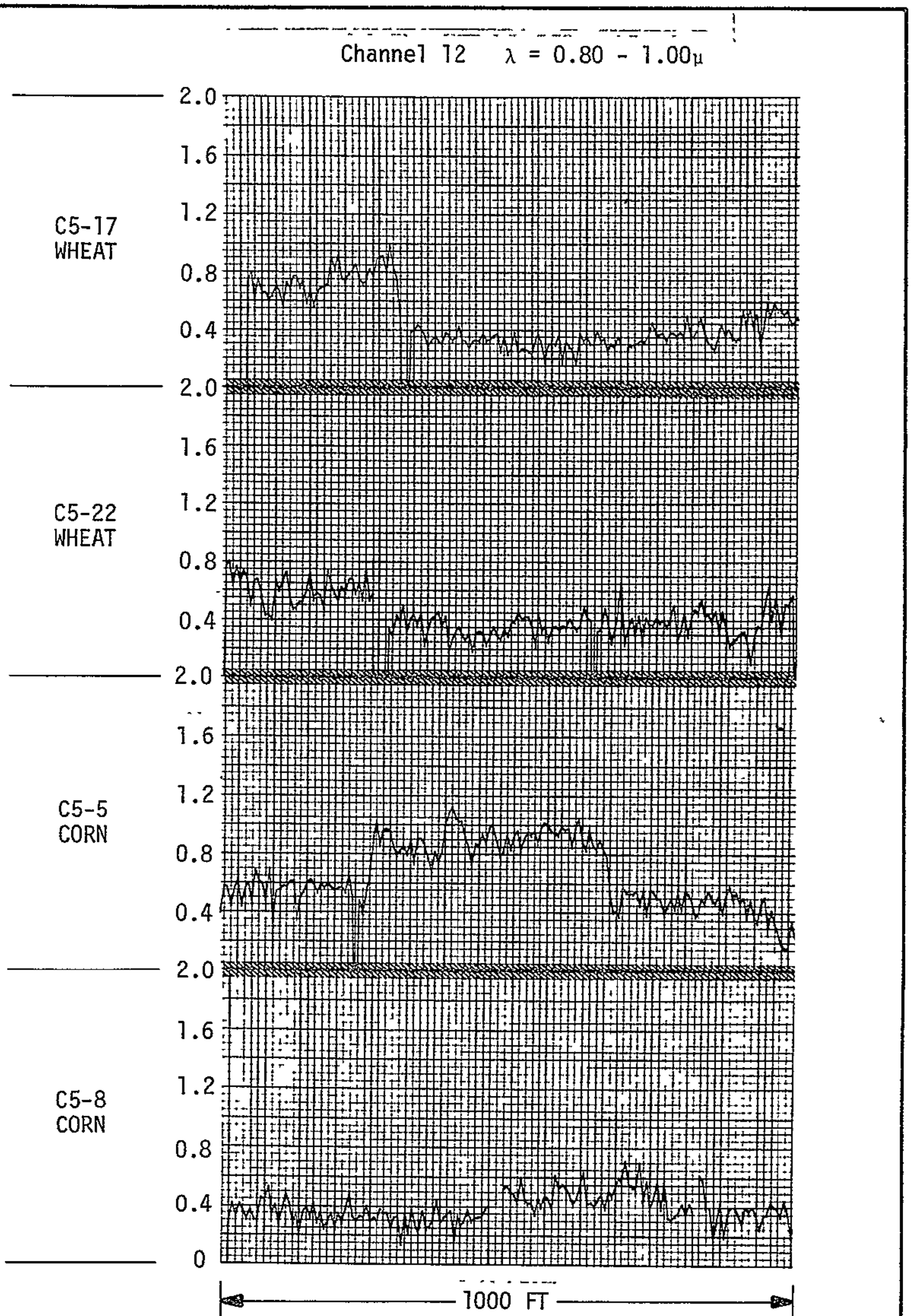

Figure 4-8. RAW DATA PLOT OF CHANNEL 12 FOR ONE SCAN LINE PER FIELD

```
CHANNEL  1                                        SYMBØL          INTERVAL
WAVE LENGTH (MICRØNS)    0.40 - 0.44                              0.50 -  0.65
                                                    1             0.65 -  0.80
                                                    2             0.80 -  0.95
                                                    3             0.95 -  1.10
                                                    4             1.10 -  1.25
                                                    5             1.25 -  1.40
                                                    6             1.40 -  1.55
                                                    7             1.55 -  1.70
                                                    8             1.70 -  1.85
                                                    9             1.85 -  2.00
                                                    0             2.15 -

CRØPS   C5-17,5-22,5-5,5-8,          ALTITUDE  2000 FT.         DATE RECØRDED  6/30/66

                  11111111112222222222333333333344444444445555555555666666666677777777778888
         12345678901234567890123456789012345678901234567890123456789012345678901234567890123
        ************************************************************************************
       1 *55555555666555555655554555544444444444333443333333433334433444556566566566676667776 7
       2 *555455555655555655555445555444433343343433333333333333333434565555655666666666666
       3 *555445555665554555555545555434344434333333333333333343333333345555555556666666666666
       4 *555455556665555554555444555443434433333333333332343433333333345556555655666666666666
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C5-17  7 *55545555655445455544554444543343444334333343333333344333333345555565655565666666666
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C5-22 21 *77777777777787778767767444444434443444443433333344233333346666666777667666666655554 4
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      32 *66667675666566565665664445334444443444444443344434434343566656565666665665656666565 5
C5-5  33 *666666776566556666665664444444444343444334433333343343444675665666665666557666665666
      34 *66666776776666665765654444454445433444444333344443444444556666666566666565667666756 6
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C5-8  46 *45455543332323333333332323332322333345444555656566556666677666655665584444444444443
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      52 *55555643333333333323434332333333333335545555665556666556666665555555667845444444443
```

Figure 4-9. GREY-LEVEL PLOT (Channel 1)

```
CHANNEL  2                                          SYMBØL        INTERVAL
WAVE LENGTH (MICRØNS)  0.44 - 0.46                              1.00 -  1.20
                                                       1        1.20 -  1.40
                                                       2        1.40 -  1.60
                                                       3        1.60 -  1.80
                                                       4        1.80 -  2.00
                                                       5        2.00 -  2.20
                                                       6        2.20 -  2.40
                                                       7        2.40 -  2.60
                                                       8        2.60 -  2.80
                                                       9        2.80 -  3.00
                                                       0        3.20 -

CRØPS    C5-17,5-22,5-5,5-8,        ALTITUDE  2000 FT.        DATE RECØRDED  6/30/66
```

```
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               ***********************************************************************************
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C5-17        7 *4444444454444444444344433344433333332332223332222222223222222234444434434454444444445445
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            19 *666677777777777666566734443443333333333333222323333323234555555555555555554443333335
C5-22       20 *66676766666666666565666733433433332333333322223232333323335555555555555555554443333334
            21 *6666767766766767656667333333333332333333222232323333233355555555555555545544433333334
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            29 *55555555555554455554453333333323323233232223222223332223444544444444444444455443444
            30 *55556565555455455545454343333333333223333323233232333333335455444444444444444555544444
            31 *55566555555554545545454343333333333323333333332223332323354454444454444444455444444444
            32 *565566555544544545545334333333333322333333323322233323333544544444454444444554444444444
C5-5        33 *5555655555545555555545333433333333323333333223322223232333254554444445444444455444444444
            34 *555566555555545555554543343333333333333333323333333223333354564444444444444455544444444
            35 *55555555554455444544533433333333322332333333233333333333545544444454454444455444444444
            36 *555555555555444445554543433333333333233333333332333333333544454444454444444554444444444
            37 *555556655555554444545334333333333333333322333333323332333335445544445444444445554544444
            38 *55555555545554455544464344333333333323333333333233333333335454544444444444444455554444
            39 *665555554444545444545334333333333332333333333332333333333544595444454444444445555544444
            40 *3333432322222222212222122122222222222234334334559444556544565565443445436223222222222
            41 *33334323222222222221222212122212222224533344444455555554455555544444443722323222222221
            42 *33344332222222222222221222222222222335333344445445554445655554433344363233222222222
            43 *33344422222222222222222222222222222335334344455445555444656554543454454223222222222
C5-8        44 *3334433222221221222122212222222222223533433445444455454555555443444436223222222222
            45 *333444232222222122222222222222222222353344345555455554445656554444454455232232322222
            46 *33343433222222222222222222222222222254333344454555444455665544444444445123232222222
            47 *3334433322222222222222222222222222222543334444544544444566554543345444622323232222221
            48 *33344432222222222222222222222222222354344344444555544455665444344444462323322322222
            49 *334444322222222222122222222222222222354333344444445544455665554344444622223332322322
            50 *334444332222222222222222222222222222253344444444444555544566554433454446232223233222
            51 *333444222222222222223222122222222222225334444454444545444555555444344444622222222222
            52 *444444322222222222233322212222222222253344445554445554455655444434444462332233222232
```

Figure 4-10. GREY-LEVEL PLOT (Channel 2)

```
CHANNEL 11                                         SYMBØL       INTERVAL
WAVE LENGTH (MICRØNS)  0.72 - 0.80                             0.00 -  0.20
                                                     1          0.20 -  0.40
                                                     2          0.40 -  0.60
                                                     3          0.60 -  0.80
                                                     4          0.80 -  1.00
                                                     5          1.00 -  1.20
                                                     6          1.20 -  1.40
                                                     7          1.40 -  1.60
                                                     8          1.60 -  1.80
                                                     9          1.80 -  2.00
                                                     0          2.20 -

CRØPS   C5-17,5-22,5-5,5-8,       ALTITUDE  200C FT.       DATE RECØRDED  6/30/66

                         11111111112222222222333333333344444444445555555555666666666677777777778888
                12345678901234567890123456789012345678901234567890123456789012345678901234567890123
               ************************************************************************************
             1 *555566655566654655555665443333233332332233223222322233333334334333334343444444444
             2 *555556555565554555555555453333233223322323223222223222223323333333334343443444444
             3 *555566555566654565555565352333222232232222222222222233332334433333434334344444443
             4 *555566555666655555555666545333222322222232332322322232232333343334344333334444444
             5 *555556555666555555555666545333223322223223223223322322322333333334333343444444444
             6 *555556555665555555555666545333232222222222222233222232223222334433333333434334443344
C5-17        7 *555555555566555555555666645333232222232222222322222233332333333433333334434444343
             8 *555555555666555566655566655333333333233223232222222223332333333434343433344344444444
             9 *555555555665555555555666645333333232222222222222223233332332334433333333344444444444
            10 *555555555666555556555665645333323333222322323323322222232233332433333344344444443
            11 *555555555566556665565667665523333332322322323233222332333332333343443343334344443343
            12 *555565555665555555656677645333333332232222232323333333333233333333433333444444443
            13 *555555554555555565656676645323333333333323223333323232333332333334333334343444444343
            14 *55455555444444454444333333333232233233322233333333333343333334333333333333444443
            15 *455444554444344444543333323332223222222223233333323334333333333333333233244443 3
            16 *45555455554444444454543333333333323223332233333333333343333333333333333332344443
            17 *45555454444444444445443333323323223222222222333333333334333333333333233333233444443
            18 *45554554444444444445443333322332223322222233322333333343333333333333333333334433
            19 *55555545444444444445443332232333223332222323233323333334334333333333333333333334443
C5-22       20 *45455455444444444445443332333233232332222223333233333333433333333333333233333333433
            21 *55555455444444444445443333333333232232322333222333333333433334333333333333333334443
            22 *5555554444444444444443333333232333332322323333333333333433343333333333333322334444 3
            23 *555554445444444444559443333223322233323323233333333233343334333333333333332233 44433
            24 *5444444455444444444544333323323323233222233323333323233343333333333333323322333343
            25 *4455544454444444445544333322333333233323333323323322333433334333333333333223333 44433
            26 *55554444444444444455543333333322223222323333333333333233333333333333333333223343443
            27 *444444444444444444454576667766656666676666555677777766654444434444433433444444 33323
            28 *44444444444444444445457666776665677667766665666777777665544444444444343443344443 3333
            29 *44444444444444444445457767776675677667665566667777676665444444434444444444444443333
            30 *4444444444444444444546766777676667776776555556777777776664444443434443434443443 33323
            31 *444444444444444444454577677777756777677666656677777777665444444344443444443444333232
C5-5        32 *44454444444444454544546667777765677777765666667777777767654444444444443443444443 43333
            33 *444444444444444444454677677777656777777666556677776777664444443444443443444443 43333
            34 *444444444544444444454577667777767877777666666677777776664444433444443334444444 3232
            35 *44445444454444444444546776666776677777776665666777777776764444444444443444444444 33333
            36 *44444444444444454444545776676766678777776676666777777777766444444444444333344444433233
            37 *444454444544444444445467766666666777777776666667777777777664444444444443344444444 3332
            38 *444444444444445444454577666676667777677766666677777677666444444444434333343444343333
            39 *444444444544444444454577766666567877677666666677767766766444444444444343344444 33332
            40 *3222333333333233232323232332222222333344433444444444433344444333333322333333333323
            41 *3222333333323323232322322232222222322334433444344443333344444333333333333333333333
            42 *3232333333333233323333232222333323333233444344444444443344445444333333323333333333323
            43 *3333233333333223333333222333322222333334333344444444334444444333333322333322333322
            44 *3322333333333223232333333223233332333333433334444444443344444444433333333333333333 3
            45 *3322333333333222323332233232323222223333334333344444444433444444433333333333333232333
C5-8        46 *3222334333332223223333333332232223222333433333344444443345444344443334432333332333333
            47 *33223333323332333323233333232233233232333433333444443433445454444333343233333333333
            48 *323233333322222233322323232322223222233344333333344443344454443333344333333 22333233
            49 *333333333333232223232323233232233223333334443343444444434445444343334332333333333333
            50 *3233234333322232332232233223223222222333333333334444444444455454433333343233333333333
            51 *3232334322222333223333222232323222223223344333434344334444455433333333432233333333333
            52 *322333333322232232233333332222222222232334334333343333444444443333333333333333333333
```

Figure 4-11. GREY-LEVEL PLOT (Channel 11)

```
CHANNEL 12                                          SYMBØL       INTERVAL
WAVE LENGTH (MICRØNS)  0.80 - 1.00                               0.00 -  0.15
                                                      1          0.15 -  0.30
                                                      2          0.30 -  0.45
                                                      3          0.45 -  0.60
                                                      4          0.60 -  0.75
                                                      5          0.75 -  0.90
                                                      6          0.90 -  1.05
                                                      7          1.05 -  1.20
                                                      8          1.20 -  1.35
                                                      9          1.35 -  1.50
                                                      C          1.65 -

CRØPS   C5-17,5-22,5-5,5-8,        ALTITUDE  2000 FT.        DATE RECØRDED  6/30/66
```

```
                          1111111111222222222233333333334444444444555555555566666666667777777777788888
                 12345678901234567890123456789C12345678901234567890123456789012345678901234567890123
                 ************************************************************************************
               1 *55556655666654655565655443333322233333322233332223333333343323333333343444444
               2 *55556655665665566555655553232233333223333322333232222332323443333343334334444434 3
               3 *55555655666666556665566655933333233233222322333223322333232334444343333333433444444
               4 *5555666566666554665566665453332333332322332322222232322332333444333433334443443444444
               5 *555556665666655555555566649333332332323333233322333232222333344333333333343434443444
C5-17          6 *55555555566665655566555576593333323222233222322222332222233332333333433334343443444443
               7 *5555555556665655565556665933222232332332222332223232333333233333333333333443344344
               8 *55556565566666556666555676593333322323222223322232233323323233333334333333344444444
               9 *5555655556666556665655567665933333333333323333322332332333332344333433343344444444444
              10 *5555555556665556565566655593333333332222332222232223333233333333333333333343434444
              11 *5555655555566655565665676655933333333322322223222323333323323333333333333333434443
              12 *5555654556565556565656677659233333333332223233332222333333233333333343333434443444444
              13 *55556555555555556666667765933333333333332333323332233332333333433434444443444444444
              14 *5555455554445444445555433333333333322332232333333333334433333333333333333333444443
              15 *555545555444444445554433333333333223333223233333323333343333343333333333233334444 3
              16 *5555554545444444445544333332333333332323323233333723333434333333333333343232334444 3
              17 *5555554554454444444445433333333723332222232333333333333333334333333333334333333334333
              18 *5555545544445445544544333333233333323222232233333333333444334433333333333333334444 3
C5-22         19 *5555555545555445444444533333333333333333323333333333343333433333333333333232334444 3
              20 *555555545555445444454433333332333322332323233333323333334433333434433333323333334443
              21 *5555555554555454444455433333323332223332323333333333333433433333433333333333222344 33
              22 *55565555545444444445544333333333233332333233333333333333333333433333333333333334434 3
              23 *555555555454444444455443333323332323333333333322333333333433334343333333333223343433
              24 *55555444445445454454454433333333323323333333333333333333333433333334333333333322333343
              25 *555555444544444554445543333333323323333333333323333333333334333333333333333323223334 33
              26 *5556554445444445444555333343333223323233333333333333334333343332333333332334434 3
              27 *444444444444444444454577677766666776666656555677777776554434444433444433434433333 3
              28 *4544444444444454444446457676776666677667776656667787777666544544444444434444444433323
              29 *444444444444444444455457767776776577776666556666777767766554344444444443444434444444232
              30 *4444444444444544444554577777777667767777666556777777766654444334444444434444444433 23
              31 *44444444444444444444454567777777666777677666655667777777765444443444444443344434434233
              32 *44444444444444445444454576766777666777677666556677777666665444443334434334344433333 2
C5-5          33 *44554444444444544444545777677775677777766665677777667664444444444444433344444443343 33
              34 *44454444444444444444545776677766677777776566677777777776543444334443443334444443332 3
              35 *44444454444444444444454577667677677777777666656776766766754444434444333344444343333
              36 *44555444444444444445456766766665778777776655667767777777544444344444443334444433232
              37 *44455444444444447457445457766667666788767777666667777777766544444444444433344444433232
              38 *444545444454444444454577766677667777777766666677767776666544444444444443344444443323
              39 *44445444554444444445457776667666777777776666677777776766544444444444443333434433432 3
              40 *22233343333333333333223323333323223322334443344444443333444444433433332233333333332
              41 *3222233333333323233332222233233322323334333344333334323434433333333332223223323 23
              42 *32233343333333333333333333333333333333343333444444444334444333332333233323332 33233
              43 *33323333333333333333233333323222222333334333344444444333444444433233332333333333 22
              44 *3222333333333332233332322332272222333344333334344344333444454433333323333333333 223
              45 *32333343333332323233332322333322223323334333333434444343444444433333333323332 32332333
C5-8          46 *33323344333333233233333333223223233233234433334434444334454544433333332333233333 33
              47 *3233333333332322732235233323222222223333433333344344343444444434923336332333233333 3
              48 *33333333333322323333232333223332332233334333333339444333354454443333333332323232 333222
              49 *3232335433233323322333333322233223222231434434343444334335445634333343333323333223
              50 *3323334333333222233223333222223222223333444333434444333445454333333343223333333 23
              51 *3233334333333323333333323323222223233333444343433434434445543333233343223333333 23
              52 *32333343333333332222234333233333223232323334433333444343344544433333334323333323333332
```

Figure 4-12. GREY-LEVEL PLOT (Channel 12)

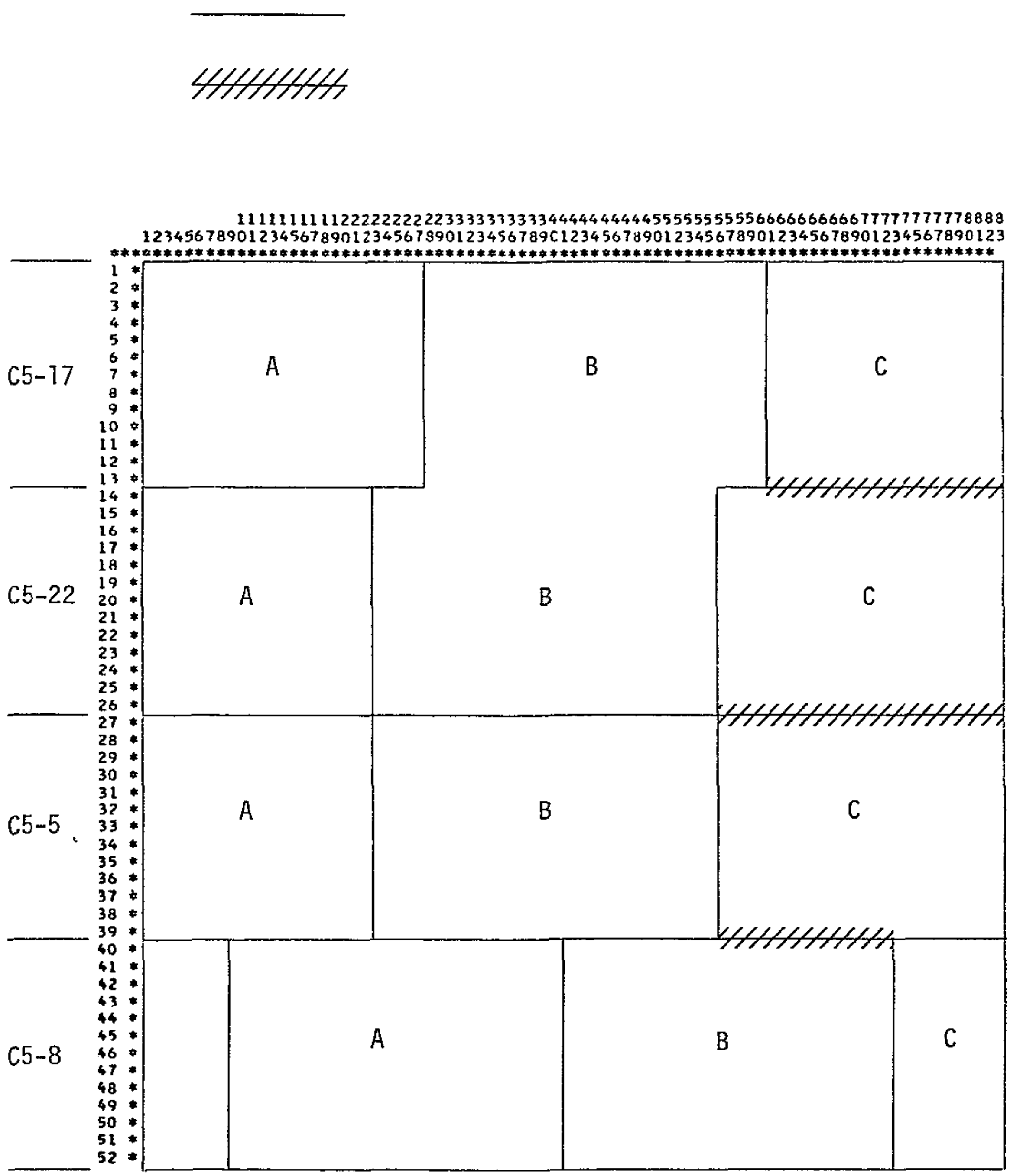

Figure 4-13. INVENTORY BOUNDARIES OBSERVED FROM GREY-LEVEL PLOTS

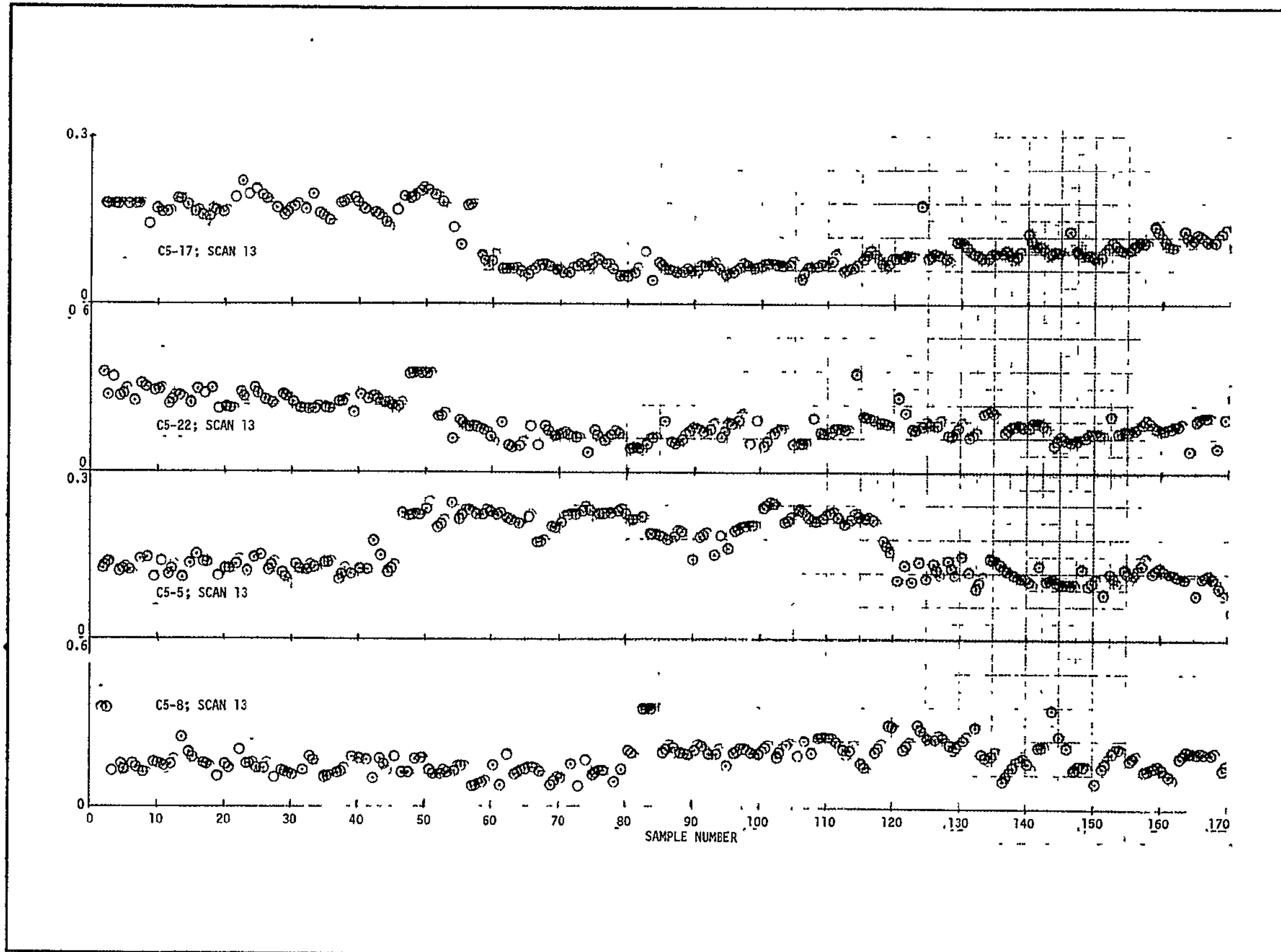

Figure 4-14. ORIGINAL RAW DATA FOR CHANNEL 11 (X = 0.72 - 0.80 μ)

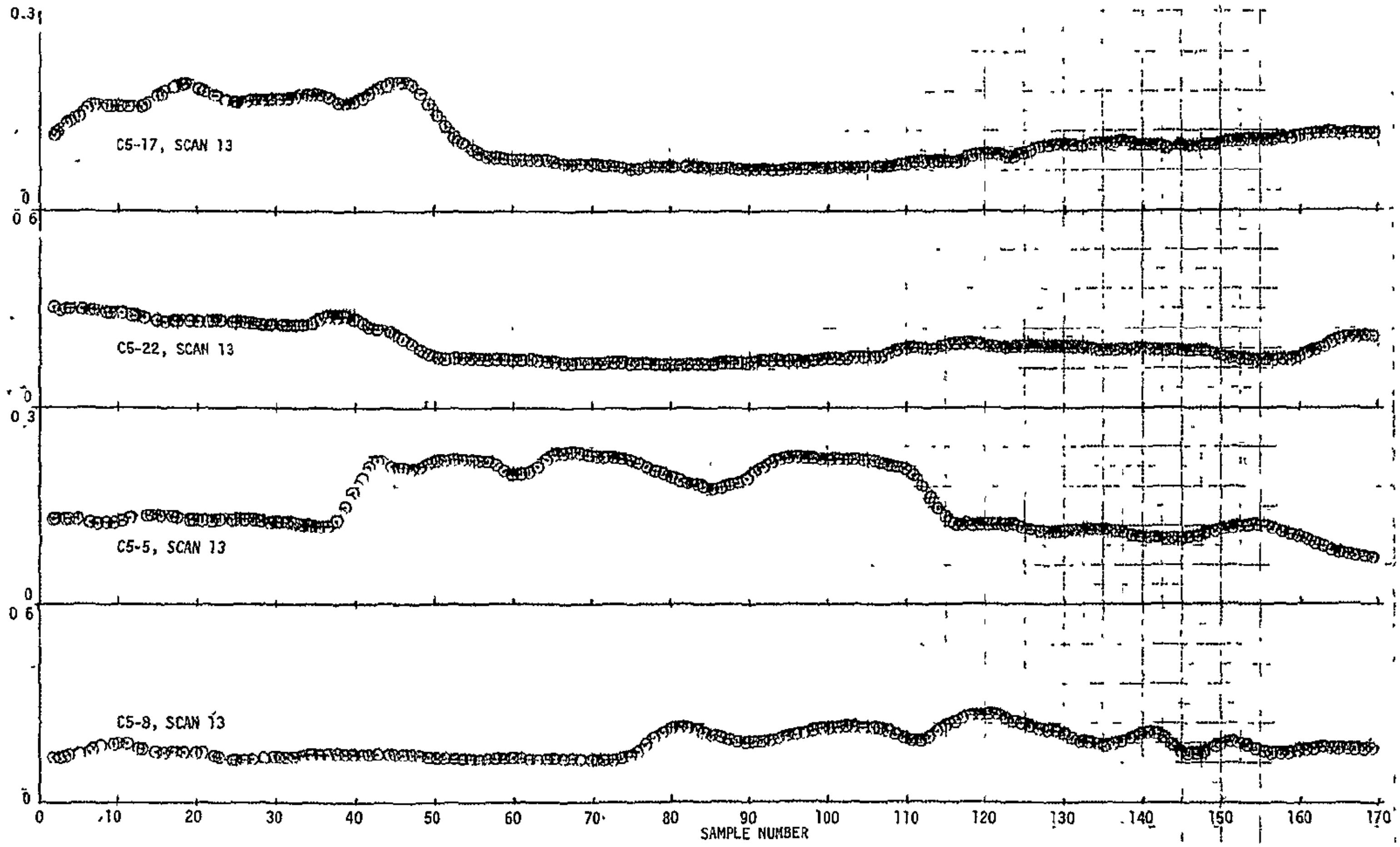

Figure 4-15. SMOOTHED DATA FOR CHANNEL 11 BY AVERAGING OVER 5 x 5 RESOLUTION ELEMENTS

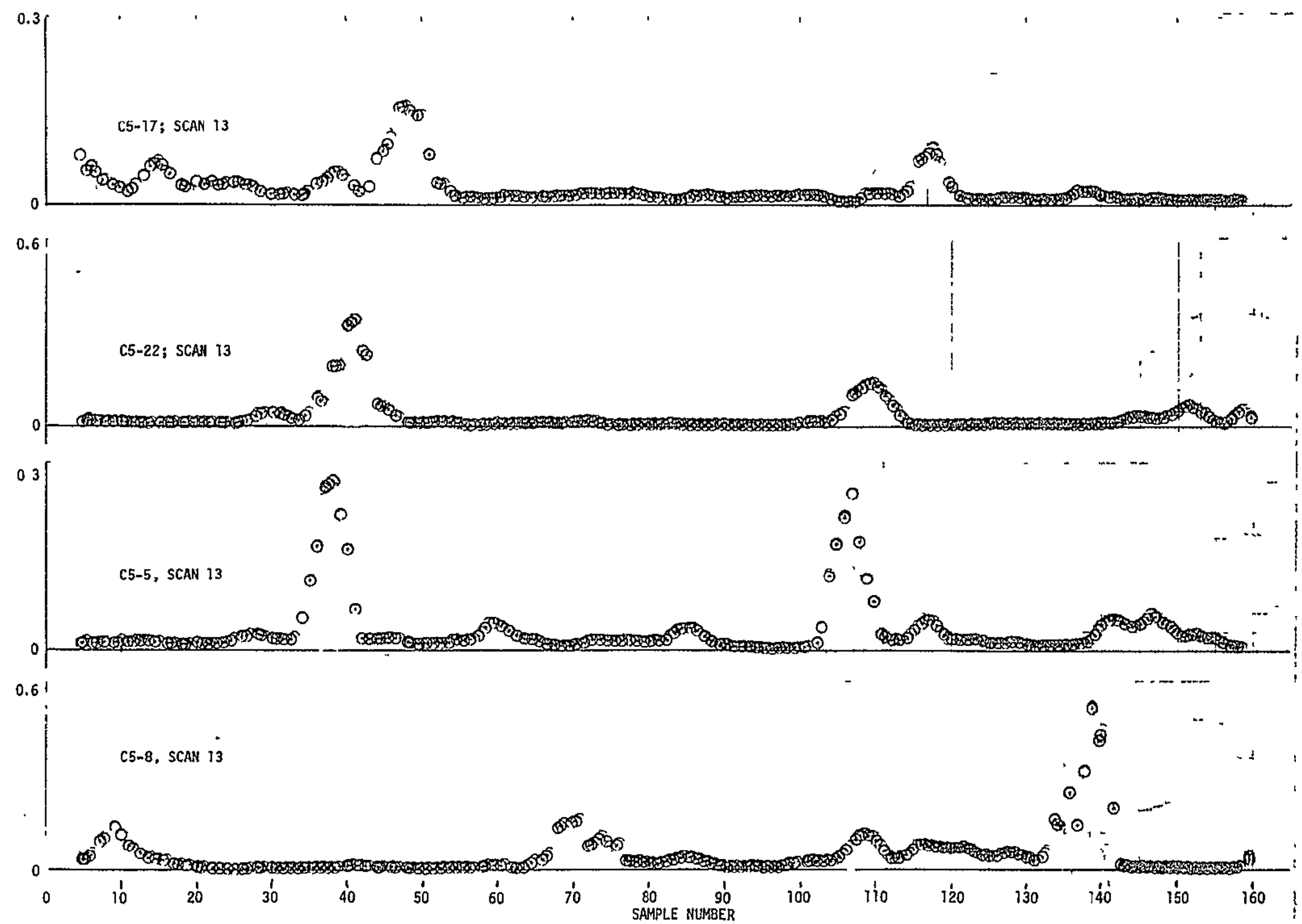

Figure 4-16. ENHANCED DATA USING ALL 12 CHANNELS

```
         INVENTØRY BØUNDARY MAP BY BØUNDARY ENHANCEMENT
CRØPS    C5-17,5-22,5-5,5-8,          ALTITUDF  200C FT.          DATE RECØRDED  6/30/66

                    CHANNEL              WAVE LENGTH
                       1                 0.40 - 0.44
                       2                 0.44 - 0.46
                       3                 0.46 - 0.48
                       4                 0.48 - 0.50
                       5                 0.50 - C.52
                       6                 0.52 - 0.55
                       7                 0.55 - 0.58
                       8                 0.58 - 0.62
                       9                 0.62 - 0.66
                      10                 0.66 - 0.72
                      11                 0.72 - 0.80
                      12                 0.80 - 1.00

SYMBØLS    . =  LESS THAN MEAN      . = MEAN-MEAN+1SD      1 = MEAN+1SD-MEAN+2SD

            2 = MEAN+2SD-MEAN+3SD      3 =  GREATER THAN MEAN+3SD

          00000000000000000000000000000000000000C0000000001111111111111111111111111111111
          00001111122222333334444455555666667777788888999990000011111222223333344444555556
          24680246802468024680246802468024680246802468C246802468024680246802468024680246802468024680

         *********************************************************************************
       2 *...1..................1.11............................133.....................
       4 *.....1.11.........1.....2.11...........................1122....................
       6 *.......1..............2.21.............................1123....................
       8 *...1...1.............1.2121.............1..............1122....................
      10 *..1.12...1............1.21211.........111...1........1......113.................
      12 *.....1.1.............11.1121..1...1.1...1...............122.....................
      14 *....1.11.1..11....1...2121......1................1.........211..............1......
      16 *...1...11.1111.....1..2131..........1.........1...............12?...................
      18 *....1.....1..1.....1..213111.......1........................11...................
      20 *...1........112.1...1..2131.............................22......................
      22 *12222122222322111122323211............................2211233l1.111...11.......1..
      24 *333333333333333323333333321............11......1...1111133333331122121111111....1111
      26 *33333333333333332333333331.1.....111..............1....1233333112221111..1.1111122
      28 *1.......1....1.21..2333312..1..........1....................1233.....1..........11..1..2
      30 *...111.1111..111.13333.2.1............................1...2231................111.11..1
      32 *........1.11111..13333.111.......1....1.................1231...........1....1..1...2
      34 *.....11...111321.13333.21.................................1331...................111...2
      36 *.....1........11.1133211...........................1......123.......1.........11.111.1
      38 *......1........11.13332.2.......11.......................1331..................1..111.1
      40 *..........1.....1...2332....1..1.........................11221....................11..1
      42 *1.........1...11..12331....................................1331..1.1..............1.11.1
      44 *...1.1........21..133321....1.11..........................233.....................11-12
      46 *...............1...233211.1.........111....1............2321.......................1..3
      48 *1......1.....1..1...23321...1.........1.....1.............321...1..1......11.....11..1
      50 *2222112122212232111233333333333333333333332233333333333333321...111.......112222121.1
      52 *21121112232222211212333333333333333333333333333333333331.............1...1133.11.1
      54 *111..11111.111112132322222322222332222111212322222222332...11.1.........2112.1...
      56 *.........1.........1.212....1................................122...1.....1.......11.1.....
      58 *....................1113............1......11.....11.........221..11...............11.111...
      60 *...................1.112...........11.....1....1.11..........122....1..1..........111.1....
      62 *.....1............1.1121...1......1..............................222...1..............1..1.....
      64 *...............1..1.112........1.11......1......11..........223...1................1..1.....
      66 *..................1.112..........11...............1..........2231..2................11.1.....
      68 *..................1.112........1.111..........1..1..........222...2..............1.1.....
      70 *.1................1.113...1......11......1.....1.............222.1.111...............1.11....
      72 *........1............112..........11...........................222...12.1.................
      74 *.1...............11113..........11...........................222...12..............21..1.
      76 *1111121.1..1111222333332121223332322221.1112111111111333....1.111111.11332322211
      78 *33333333322333333333333333333333333333333322233333333333332....11.21111.3333333333
      80 *3333333322333333323333333333333333333333333333333333333211.1.213211231323333333222
      82 *.11333...1.........1...............11311.1..111...1..11..2...111.11..33131.........
      84 *1.13321...11.......................11321......121...1..12.111.1111211..13231.........
      86 *.12331111.....1........11..........11321....111.......11.11..11211....23131.........
      88 *.113311............................1.3111....11.......11.11.11121211..13133.........
      90 *.11231.............................113112...111........1.131.1221211...3233.........1
      92 *..2133.1.......!...................1131.2...111........1.231.122222....3733..1.......
      94 *111332.1..1............1..........1.32.2.1.1.1........1.122.12221.1.1.3233.........
      96 *...3312.1.....................1....1121.2...111.......11.122113111..1..37331........
      98 *11.2311................1...............13711...11........1..122.12111111..3333.........
     100 *...13311...........................1.....121..1.111..1..1..1.121.12211.1..132331........
     102 *.1.1221...............11.................32.2....1.......11.221.1112111...3233.........
```

Figure 4-17. INVENTORY BOUNDARY MAP BY BOUNDARY ENHANCEMENT, CHANNELS 1-12, USING ABSOLUTE VALUE

```
        INVENTØRY BØUNDARY MAP BY BØUNDARY ENHANCEMENT

CRØPS   C5-17,5-22,5-5,5-8,        ALTITUDE  2000 FT.        DATE RECØRDED  6/30/66

                  CHANNEL           WAVE LENGTH
                     1              0.40 - 0.44
                     2              0.44 - 0.46
                     3              0.46 - 0.48
                     4              0.48 - 0.50
                     5              0.50 - 0.52
                     6              0.52 - 0.55
                     7              0.55 - 0.58
                     8              0.58 - 0.62
                     9              0.62 - 0.66
                    10              0.66 - 0.72
                    11              0.72 - 0.80
                    12              0.80 - 1.00

SYMBØLS     . =  LESS THAN MEAN      . = MEAN-MEAN+1SD      . = MEAN+1SD-MEAN+2SD

              2 = MEAN+2SD-MEAN+3SD      3 =  GREATER THAN MEAN+3SD

          00000000000000000000000000000000000000000000000001111111111111111111111111111111
          00001111122222333334444455555666667777788888999990000011111222223333344444555556
          24680246802468024680246802468024680246802468024680246802468024680246802468024680

         **********************************************************************************
       2 *..........................................................33....................*
       4 *......................2...................................22....................*
       6 *......................2.2.................................23....................*
       8 *......................2.2.................................22....................*
      10 *.....2................2.2..................................3....................*
      12 *........................2.................................22....................*
      14 *......................2.2................................2......................*
      16 *......................2.3.................................22....................*
      18 *......................2.3.......................................................*
      20 *.............2........2.3.................................22....................*
      22 *.2222.22222322....2232323.............................22..233...................*
      24 *333333333333333233333333332............................3333333..22.2..............*
      26 *333333333333333233333333.............................233333..222..............22*
      28 *.............2...23333.2.............................233.......................2*
      30 *..................3333.2.............................223........................*
      32 *..................3333................................23.......................2*
      34 *.............32...3333.2..............................33.......................2*
      36 *..................3332................................23........................*
      38 *..................3332.2..............................33........................*
      40 *..................2332................................22........................*
      42 *..................233.................................33........................*
      44 *..............2...3332...............................233.......................2*
      46 *..................2332...............................232.......................3*
      48 *..................2332................................32........................*
      50 *2272..2.22.2232...233333333333333333322333333333333333332...............2222.2...*
      52 *2..2...2232222..2.2333333333333333333333333333333333333..................33.....*
      54 *................2.32322222322227332222...2.2322222222332...............2..2.....*
      56 *..................2.2.................................22........................*
      58 *....................3.................................22........................*
      60 *....................2.................................22........................*
      62 *....................2................................222........................*
      64 *....................2................................223........................*
      66 *....................2................................223...2....................*
      68 *....................2................................222...2....................*
      70 *....................3................................222........................*
      72 *....................2................................222....2...................*
      74 *....................3................................222....2.............2.....*
      76 *.....2.........222333332.2.22333232222.....2.........333...............3323222..*
      78 *33333333223333333333333333333333333332223333333333333332.......2.....33333333333*
      80 *33333332233333323333333333333333333333333333333333333332.....2.32..23.3233333222*
      82 *...333............................3...................2...........33.3..........*
      84 *...332............................32......2........2.........2....323...........*
      86 *..233.............................32.......................2......23.3..........*
      88 *...33.............................3........................2.2....3.33..........*
      90 *...23.............................3..2................3...22.2....3233..........*
      92 *..2.33............................3..2...............23...22222...3233..........*
      94 *...332............................32.2................22..222.....3233..........*
      96 *...33.2...........................2..2................22..3.......3233..........*
      98 *...23.............................32..................22..2.......3333..........*
     100 *....33............................2...................2...22......3233..........*
     102 *....22............................32.2................22....2.....3233..........*
         **********************************************************************************
```

Figure 4-18. INVENTORY BOUNDARY MAP BY BOUNDARY ENHANCEMENT, CHANNELS 1-12, USING ABSOLUTE VALUE

```
        INVENTØRY BØUNDARY MAP BY BØUNDARY ENHANCEMENT

CRØPS   C5-17,5-22,5-5,5-8,        ALTITUDE  2000 FT.        DATE RECØRDED  6/30/66

                  CHANNEL           WAVE LENGTH
                     1              0.40 - 0.44
                     2              0.44 - 0.46
                    11              0.72 - 0.80
                    12              0.80 - 1.00

SYMBØLS    . =  LESS THAN MEAN     . = MEAN-MEAN+1SD     . = MEAN+1SD-MEAN+2SD

              2 = MEAN+2SD-MEAN+3SD     3 =  GREATER THAN MEAN+3SD

      000000000000000000000000000000000000000C000000000111111111111111111111111111111
      00001111122222333334444455555666667777788888999990000011111222223333344444555556
      24680246802468024680246802468024680246802468C2468024680246802468024680246802468024680

     **********************************************************************************
   2 *................................................................................*
   4 *......................2.........................................................*
   6 *......................2.2.......................................................*
   8 *........................2.......................................................*
  10 *......................2.2.......................................................*
  12 *........................2.................................2.....................*
  14 *........................2................................2......................*
  16 *......................2.3.................................2.....................*
  18 *......................2.2.......................................................*
  20 *......................2.2.................................2.....................*
  22 *....2....2232.....22.2323................................233....................*
  24 *3333333333333332323333332............................2333333....................*
  26 *332333333333333223333333.............................233333....................2*
  28 *...................333...............................232........................*
  30 *...................332................................22........................*
  32 *...................332................................22........................*
  34 *...................332................................32........................*
  36 *...................332................................22........................*
  38 *...................332................................32........................*
  40 *...................33.................................22........................*
  42 *...................33.................................33........................*
  44 *...................33................................232........................*
  46 *...................33................................23.........................*
  48 *...................33.................................32........................*
  50 *.............23...23333333333333333333332223333333332.22........................*
  52 *.......22....2..2..33333333333333333333332333333333332..........................*
  54 *..................2232.222322222332222....232..2222232..........................*
  56 *....................2.................................2.........................*
  58 *....................2................................22.........................*
  60 *....................2.................................22........................*
  62 *....................2................................222........................*
  64 *....................2.................................23........................*
  66 *....................2................................223........................*
  68 *....................2................................222........................*
  70 *....................3................................222........................*
  72 *....................2................................222........................*
  74 *....................3................................222........................*
  76 *.....2..........2233332.2.22333232222.....2.........333................22.2.....*
  78 *22223333322332333333333333333333333333322232233333333322..............3233333222*
  80 *.22233332233333232333333333333333333333333333333333333............2..322333222..*
  82 *..................................3................................2.3..........*
  84 *..................................3.................................23..........*
  86 *..................................3...............................2..3..........*
  88 *..................................3................................2.3..........*
  90 *..................................3................................2232.........*
  92 *..................................3................................2233.........*
  94 *..................................32...............................2233.........*
  96 *..................................2................................2233.........*
  98 *..................................32...............................2232.........*
 100 *..................................2................................2232.........*
 102 *..................................32...............................2232.........*
     **********************************************************************************
```

Figure 4-19. INVENTORY BOUNDARY MAP BY BOUNDARY ENHANCEMENT, CHANNELS 1, 2, 11, AND 12, USING ABSOLUTE VALUE

```
INVENTORY BOUNDARY MAP BY BOUNDARY ENHANCEMENT

CROPS    C5-17,5-22,5-5,5-8,        ALTITUDE  2000 FT.       DATE RECORDED  6/30/66

               CHANNEL              WAVE LENGTH
                  1                 0.40 - 0.44
                  2                 0.44 - 0.46
                  3                 0.46 - 0.48
                  4                 0.48 - 0.50
                  5                 0.50 - 0.52
                  6                 0.52 - 0.55
                  7                 0.55 - 0.58
                  8                 0.58 - 0.62
                  9                 0.62 - 0.66
                 10                 0.66 - 0.72
                 11                 0.72 - 0.80
                 12                 0.80 - 1.00

SYMBOLS      . =  LESS THAN MEAN      . = MEAN-MEAN+1SD      . = MEAN+1SD-MEAN+2SD

             2 = MEAN+2SD-MEAN+3SD      3 =  GREATER THAN MEAN+3SD

      00000000000000000000000000000000000000000000000001111111111111111111111111111111
      00001111122222333334444455555666667777788888999990000011111222223333344444555556
      24680246802468024680246802468024680246802468024680246802468024680246802468024680

     **********************************************************************************
  2  *..........................................................33....................*
  4  *..........................................................33....................*
  6  *..........................................................23....................*
  8  *......................2.2.................................23....................*
 10  *........................2..................................3....................*
 12  *......................2.2..................................2....................*
 14  *......................3.3.......................................................*
 16  *......................2.2..................................2....................*
 18  *........................3.......................................................*
 20  *........................3.................................22....................*
 22  *22..2222.2333.....33333.3............................33.2222....................*
 24  *3333333333333332333333333...................'........3233332..2.................*
 26  *3333233333333322333333333............................233333..22.................*
 28  *..................3333.2.............................333........................*
 30  *..................3333.2.............................223........................*
 32  *..................3333................................23........................*
 34  *..............2...3333.2..............................33........................*
 36  *..................3333................................23........................*
 38  *..................2333.2..............................32........................*
 40  *...................33.................................22........................*
 42  *...................33.................................322.......................*
 44  *..................333.................................33.......................2*
 46  *..................2332................................32.......................3*
 48  *...................332................................32........................*
 50  *..22...22...22.....333333333333333333333333333333333333...................2.....*
 52  *.......2332.32.....233333333333333333323333333333333332..................22.....*
 54  *.....22............3232333322.2233222..2222333333333332...................2.....*
 56  *..................2.3...........................................................*
 58  *....................3...........................................................*
 60  *....................2................................2..........................*
 62  *....................2..................................2........................*
 64  *....................2..................................2........................*
 66  *....................2.................................23........................*
 68  *....................2.................................2.........................*
 70  *....................2.................................2.........................*
 72  *....................3...........................................................*
 74  *....................3...........................................................*
 76  *22.......2....222233333222222233332222...............222...............333322...*
 78  *33333333332333333333333333333333333332.22233333333332.........2.....33333333332*
 80  *33233333233333333333333333333333333333333333333333333........32..33.32333333222*
 82  *...333...........................32...............................33.3..........*
 84  *...332...........................22...............................2323..........*
 86  *...33............................32...............................33.3..........*
 88  *...33............................3.........................2.......3.33.........*
 90  *...232...........................3....................3...2..2.....3233.........*
 92  *..2233...........................32.2.................3...2........3233.........*
 94  *...332...........................32...................22..32.......3233.........*
 96  *...33............................3....................33..3........3233.........*
 98  *...332...........................3....................2..2.........3333.........*
100  *....32...........................32...................2............3333.........*
102  *....32...........................32.2.................2..2.........3233.........*
     **********************************************************************************
```


Figure 4-20. INVENTORY BOUNDARY MAP BY BOUNDARY ENHANCEMENT, CHANNELS 1-12, USING SQUARE VALUE

```
        INVENTØRY BØUNDARY MAP BY BØUNDARY ENHANCEMENT

CRØPS   C5-17,5-22,5-5,5-8,          ALTITUDE  200C FT.        DATE RECØRDED  6/30/66

                  CHANNEL                WAVE LENGTH
                     1                   0.40 - 0.44
                     2                   0.44 - 0.46
                    11                   0.72 - 0.80
                    12                   0.80 - 1.00

SYMBØLS      . =  LESS THAN MEAN      . = MEAN-MEAN+1SD      . = MEAN+1SD-MEAN+2SD

                2 = MEAN+2SD-MEAN+3SD      3 =  GREATER THAN MEAN+3SD

          00000000000000000000000000000000000000000000000001111111111111111111111111111111
          00001111122222333334444455555666667777788888999990000011111222223333344444555556
          24680246802468024680246802468024680246802468024680246802468024680246802468024680

         **********************************************************************************
       2 *................................................................................*
       4 *................................................................................*
       6 *................................................................................*
       8 *........................2.......................................................*
      10 *........................2.......................................................*
      12 *........................2.......................................................*
      14 *........................3.......................................................*
      16 *........................2.......................................................*
      18 *........................2.......................................................*
      20 *........................2.......................................................*
      22 *22..222..2323.....22.23.2...............................2222....................*
      24 *333333333333332332333332..............................233332....................*
      26 *3333233333333322.3333332..............................33333.....................*
      28 *...................333................................32........................*
      30 *...................333................................22........................*
      32 *...................333................................22........................*
      34 *...................333................................32........................*
      36 *...................333................................2.........................*
      38 *...................333................................32........................*
      40 *...................33.................................22........................*
      42 *...................33.................................32........................*
      44 *...................33.................................32........................*
      46 *...................332................................3.........................*
      48 *...................332................................3.........................*
      50 *............22.....3333333333333333333332;23333333332...........................*
      52 *.........2.........2333333333333333333222333333333332...........................*
      54 *....................322222222.22333222....23332222222...........................*
      56 *....................2...........................................................*
      58 *....................3...........................................................*
      60 *....................2...........................................................*
      62 *....................2..................................2........................*
      64 *....................2..................................2........................*
      66 *....................2.................................23........................*
      68 *....................2.................................2.........................*
      70 *....................2.................................2.........................*
      72 *....................3...........................................................*
      74 *....................3...........................................................*
      76 *..............222233333222222233332222...............222........................*
      78 *....33333323333333333333333333332.2222333333332................223333332.2*
      80 *....2333233333333333333333333333333333333333333333333.............32.32.33332...*
      82 *..................................3...............................33.3..........*
      84 *..................................2...............................2223..........*
      86 *..................................3...............................23.3..........*
      88 *..................................3...............................2.3...........*
      90 *..................................3...............................2233..........*
      92 *..................................32..............................3233..........*
      94 *..................................32..............................3233..........*
      96 *..................................3...............................3233..........*
      98 *..................................3...............................3233..........*
     100 *..................................32..............................3233..........*
     102 *..................................32..............................3233..........*
         **********************************************************************************
```

Figure 4-21. INVENTORY BOUNDARY MAP BY BOUNDARY ENHANCEMENT, CHANNELS 1, 2, 11, AND 12, USING SQUARE VALUE

```
                    INVENTØRY BØUNDARY MAP BY BØUNDARY ENHANCEMENT

       CRØPS    C5-17,5-22,5-5,5-8,         ALTITUDE  200C FT.        DATE RECØRDED  6/30/66

                         CHANNEL              WAVE LENCTH
                            1               0.40 - C.44
                            2               0.44 - 0.46
                            3               0.46 - 0.48
                            4               0.48 - C.50
                            5               0.50 - C.52
                            6               0.52 - C.55
                            7               0.55 - C.58
                            8               0.58 - C.62
                            9               0.62 - 0.66
                           10               0.66 - 0.72
                           11               0.72 - 0.80
                           12               0.80 - 1.00

       SYMBØLS      . =  LESS THAN MEAN      . = MEAN-MEAN+1SD      . = MEAN+1SD-MEAN+2SD

                      2 = MEAN+2SD-MEAN+3SD     3 =  GREATER THAN MEAN+3SD

                 00000000000000000000000000000000000C000C00000000011111111111111111111111111111111
                 000011111222223333344444555556666677777888889999900C00111112222233333444445555566
                 246802468024680246802468024680246802468C24680246802468024680246802468024680246802

                ***********************************************************************************
              2 *.......................3..2................................2.....................*
              4 *.......................2..2................................2.....................*
              6 *.......................2..................................33.....................*
              8 *..........................................................2......................*
             10 *.......................3...................................2.....................*
             12 *.......2...............3................2..................2.....................*
             14 *....................2.....................................2....2.................*
             16 *..........2............2..................................22.....................*
             18 *.................................................................................*
             20 *......................22..2......................................................*
             22 *.......................3...................................2.....................*
             24 *..22222222222222..233333.2............................2...333.2.......2..........*
             26 *33333333333333333233333333.............2..........2.2223333332..222..2.22......22.*
             28 *..............2.2.333322.........2.....2..............23...................2....2*
             30 *..............2...233333..............................33........................3*
             32 *...............2...3332...............................23.....................2..2*
             34 *2......2.2..2......333................................23.....................2..2*
             36 *............2.....2333.................................3...........2............3*
             38 *...................333................................32........................3*
             40 *...2.......32......3332...............................33......................3.2*
             42 *.....2....2........3322...............................232.......................2*
             44 *.2.2..............2232.2..............................22.....2..............22..3*
             46 *...................333.....................2...........3....2...................2*
             48 *...............2...3322.....................2..........3....2..........2....22..2*
             50 *...................332.................................3..............2.......2.2*
             52 *3..22323333222....2223333333333333333333333333333333333332....3...........33..22.2*
             54 *.2.....2....2....22333223333.2.33333233222333332333322232.................222....*
             56 *...................33.................................2..........................*
             58 *...................332................................2....2.....................*
             60 *...................33.................................22.........................*
             62 *...................33.................................22................2........*
             64 *...................23.................................22.........................*
             66 *...................33.........22......................22..................2......*
             68 *...................33.................................22.................2.......*
             70 *.................2.33.................................23.........................*
             72 *...................33..........2......................23......................2..*
             74 *...................33.................................22.........................*
             76 *...................33..2..............................22.........................*
             78 *2222.222......22223333323333333333333222....2222.2.22233....2..2....2...333332222*
             80 *33333333333323333333333333333333333333333333333333333332......33..23333333333332*
             82 *....32......2......................32..2.............2.............3332..........*
             84 *....32.............................22..............................3333........2.*
             86 *2...22...........................2.22.....2........3.......2.......2332..........*
             88 *..2.23.............................32.................2.......2....2333..........*
             90 *2...2...........2..................322................2......2.....2332..........*
             92 *2....3..........2..................322................2............333...........*
             94 *2.2.23............................2322....3.....................2..333...........*
             96 *...222............................2222...22................2....2..333..2........*
             98 *..2.23............................2.........................2......333...........*
            100 *....332...........................222.......2.....2................333...........*
            102 *2..232.............22.............2222....................2....2...333...........*
            104 *.....3..........2..................322......................2..2...333...........*
                ***********************************************************************************
```

Figure 4-22. INVENTORY BOUNDARY MAP BY BOUNDARY ENHANCEMENT, CHANNELS 1 - 12, USING ABSOLUTE VALUE AND 3 x 3 ELEMENTS FOR MOVING AVERAGE

FIELD DESCRIPTION- C5-17 C5-22 C5-5 C5-8
ALTITUDE- 2000 FT. DATE RECORDED- 6/30/66

CHANNEL	WAVE LENGTH(MICRONS)
1	0.40 - 0.44

99 PERCENT CONFIDENCE LIMITS

SYMBOLS= V - VERTICAL BOUNDARY H - HORIZONTAL BOUNDARY
X - BOTH VERTICAL AND HORIZONTAL BOUNDARY

SAMPLE NUMBER

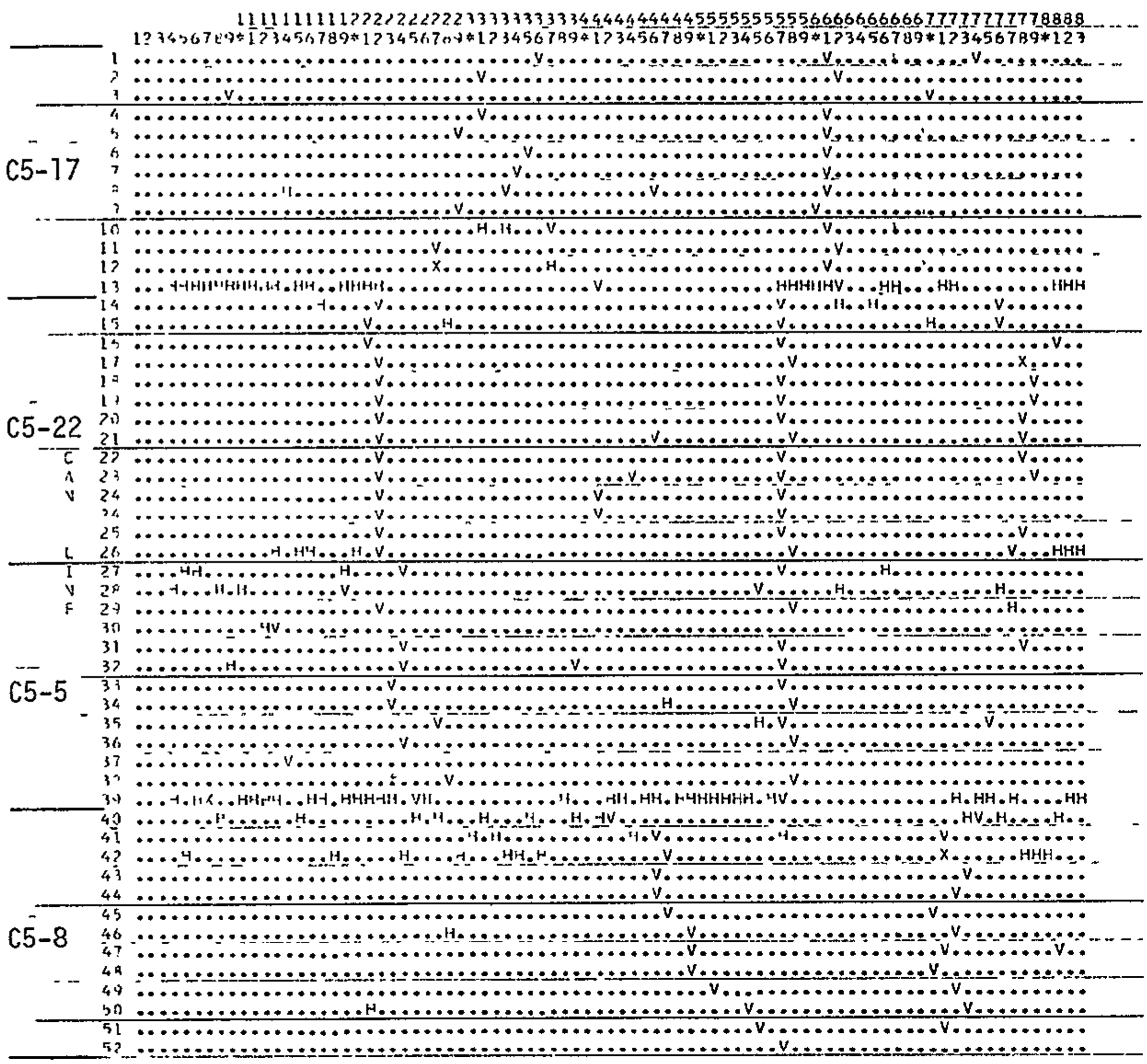

Figure 4-23. MAP OF INVENTORY BOUNDARIES (Channel 1)

```
FIELD DESCRIPTION-    C5-17    C5-22    C5-5    C5-8
ALTITUDE-     2000 FT.     DATE RECORDED-     6/30/66

        CHANNEL        WAVE LENGTH(MICRONS)
          11                 0.72 - 0.80

        99 PERCENT CONFIDENCE LIMITS

SYMBOLS=   V - VERTICAL BOUNDARY   H - HORIZONTAL BOUNDARY
         X - BOTH VERTICAL AND HORIZONTAL BOUNDARY

                      SAMPLE NUMBER
```

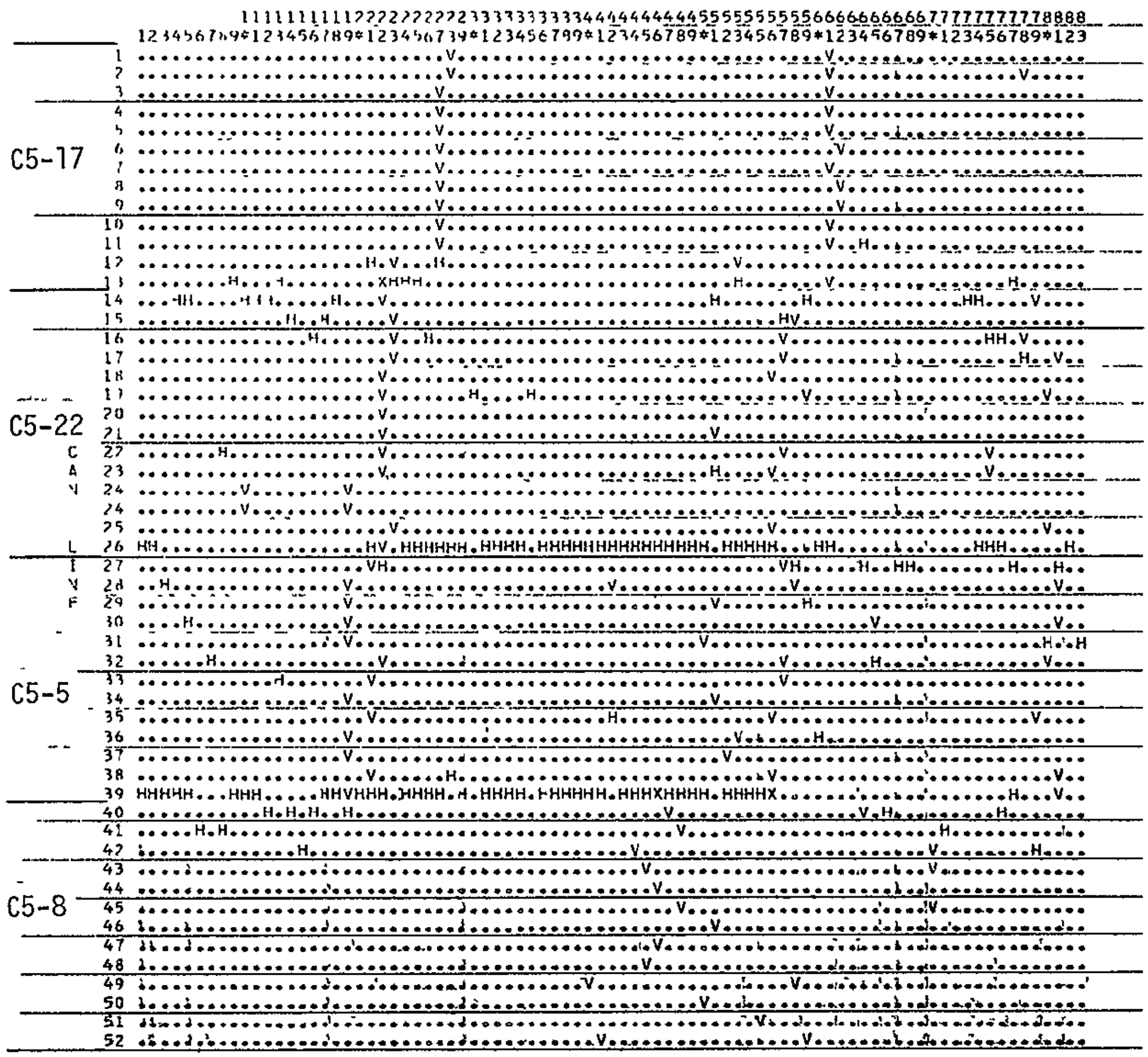

Figure 4-24. MAP OF INVENTORY BOUNDARIES (Channel 11)

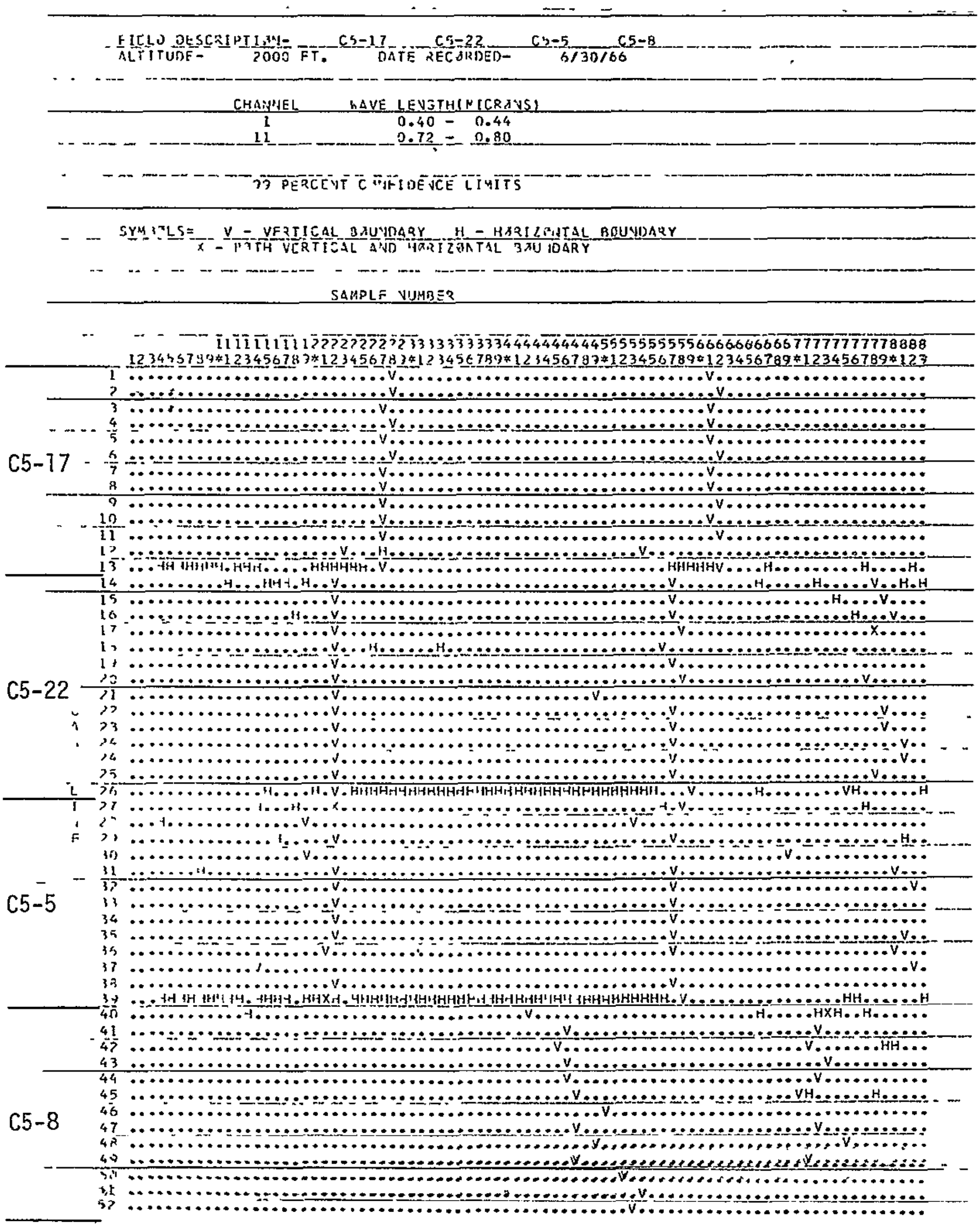

Figure 4-25. MAP OF INVENTORY BOUNDARIES (Channels 1, 11)

FIELD DESCRIPTION- C5-17 C5-22 C5-5 C5-8
ALTITUDE- 2000 FT. DATE RECORDED- 6/30/66

CHANNEL	WAVE LENGTH(MICRONS)
1	0.40 - 0.44
2	0.44 - 0.46
11	0.72 - 0.80
12	0.80 - 1.00

99 PERCENT CONFIDENCE LIMITS

SYMBOLS= V - VERTICAL BOUNDARY H - HORIZONTAL BOUNDARY
X - BOTH VERTICAL AND HORIZONTAL BOUNDARY

SAMPLE NUMBER

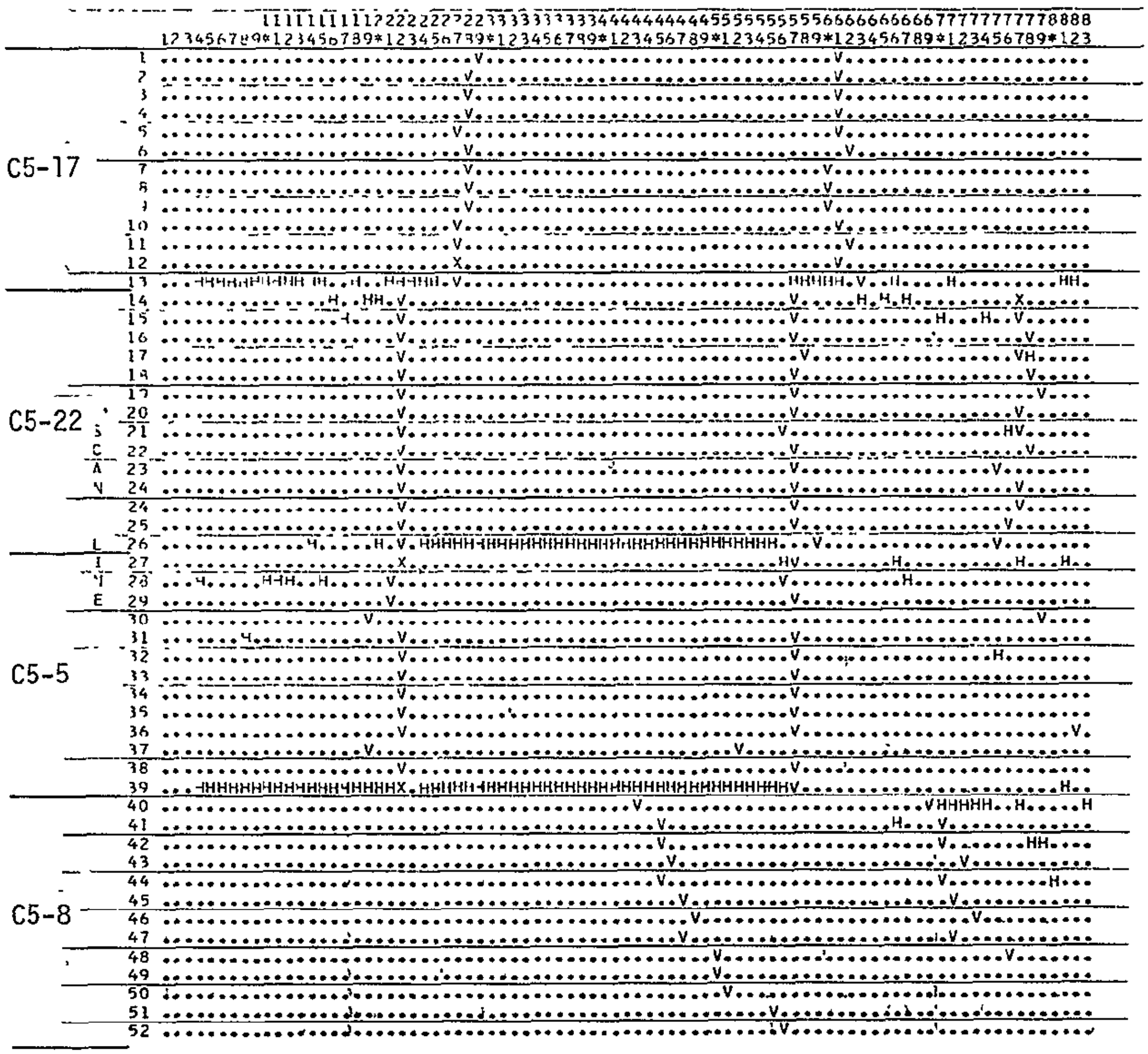

Figure 4-26. MAP OF INVENTORY BOUNDARIES (Channels 1, 2, 11, 12)

```
FIELD DESCRIPTION-   C5-17   C5-22   C5-5   C5-8
ALTITUDE-    2000 FT.     DATE RECORDED-    6/30/66

          CHANNEL      WAVE LENGTH(MICRONS)
             1           0.40 -  0.44
             2           0.44 -  0.46
             3           0.46 -  0.48
             4           0.48 -  0.50
             5           0.50 -  0.52
             6           0.52 -  0.55
             7           0.55 -  0.58
             8           0.58 -  0.62
             9           0.62 -  0.66
            10           0.66 -  0.72
            11           0.72 -  0.80
            12           0.80 -  1.00

          99 PERCENT CONFIDENCE LIMITS

SYMBOLS=   V - VERTICAL BOUNDARY    H - HORIZONTAL BOUNDARY
         X - BOTH VERTICAL AND HORIZONTAL BOUNDARY

                    SAMPLE NUMBER

                   1111111111222222222233333333334444444444555555555566666666667777777777888
          123456789*123456789*123456789*123456789*123456789*123456789*123456789*123456789*123
       1 ............................V...................................V..................
       2 ...........................V....................................V..................
       3 ...........................V..................................V....................
       4 ...........................V.................................V.....................
       5 ...........................V..................................V....................
       6 ...........................V...................................V...................
C5-17  7 ...........................V................................V......................
       8 .............................V................................V....................
       9 ............................V................................V.....................
      10 ...........................V..................................V....................
      11 ...........................V....................................V..................
      12 ..........................X......................................V.................
      13 ...HHHHHHHHHH....HHHHH.V................................HHHHH....V.................
      14 ...............H.HHH.V......................................X.HHHHH...H.......V..H.
      15 ................I...V.......................................V................V..H..
      16 ....................V...........................................V..............H...
      17 ....................V.........................................V..............V.....
      18 .....................V...................................V..H................V.....
      19 .....................V......................................V................VH....
C5-22 20 .....................V......................................V................V.H...
      21 .....................V......................................V................V.....
      22 .....................V......................................V................V.....
      23 .....................V.....................................V................V......
      24 .....................V....................................V..................V.....
      25 .....................V....................................V..................V.....
      26 .....................V......................................V................V.....
      27 ...................H.V.HH.HHHHHHHHHHHHHHH...HHHHHHHHHHHHH......V...........H.......
      28 .........HH.H.........X..H...............HHH............V..........................
      29 .........H.H..........V.................................V..........................
      30 ....................V...................................V..........................
      31 .....................V..................................V..........................
      32 .....................V..................................V..........................
C5-5  33 .....................V...................................V.........................
      34 .....................V..................................V..........................
      35 .....................V...................................V.........................
      36 .....................V...................................V.........................
      37 .....................V..................................V..........................
      38 .....................V...................................V.........................
      39 ...HHHHHHHHH.HHH.HHHHX.HHHHHHHHHHHHHHHHH.HHHHHHHHHHHHHHH.V.............HH.HHH.....H
      40 ............H...H.......................H..........V.............H....X..H...H.....
      41 ........................................................V.......................H..
      42 .......................................................V.......................H.H.
      43 .......................................................V...........................
      44 .......................................................V...........................
      45 .......................................................V...........................
C5-8  46 ........................................................V..........................
      47 ........................................................V..........................
      48 .........................................................V.........................
      49 .........................................................V.........................
      50 .........................................................V.........................
      51 ........................................................V..........................
      52 .........................................................V.........................
```

Figure 4-27. MAP OF INVENTORY BOUNDARIES (Channels 1 through 12)

C(5-17) SECTION A

MEAN VECTOR

CH	*	1	2	3	4	5	6	7	8	9	10	11	12
1	*	1.10358	1.60692	1.13319	1.02380	1.04938	.99541	.77604	1.03585	.50232	.63149	.81489	.63113

CORRELATION MATRIX

CH	*	1	2	3	4	5	6	7	8	9	10	11	12
1	*	1.22478	1.78101	1.25326	1.13077	1.16079	1.10460	.85939	1.14047	.54983	.69671	.91284	.70679
2	*	1.78101	2.59407	1.82522	1.64706	1.69035	1.60726	1.25123	1.66202	.80240	1.01498	1.32523	1.02633
3	*	1.25326	1.82522	1.28773	1.16232	1.19157	1.13040	.88122	1.17583	.56993	.71643	.92444	.71622
4	*	1.13077	1.64706	1.16232	1.05096	1.07608	1.01954	.79545	1.06389	.51696	.64740	.82985	.64310
5	*	1.16079	1.69035	1.19157	1.07608	1.10462	1.04809	.81708	1.08921	.52745	.66371	.85847	.66493
6	*	1.10460	1.60726	1 13040	1.01954	1.04809	.99964	.77696	1.02866	.49478	.62905	.82910	.64182
7	*	.85939	1.25123	.88122	.79545	.81708	.77696	.60572	.80445	.38845	.49078	.64001	.49562
8	*	1.14047	1.66202	1.17583	1.06389	1.08921	1.02866	.80445	1.08283	.52864	.65632	.82785	.64146
9	*	.54983	.80240	.56993	.51696	.52745	.49478	.38845	.52864	.26138	.31867	.38920	.30194
10	*	.69671	1.01498	.71643	.64740	.66371	.62905	.49078	.65632	.31867	.39998	.51273	.39713
11	*	.91284	1.32523	.92444	.82985	.85847	.82910	.64001	.82785	.38920	.51273	.72029	.55612
12	*	.70679	1.02633	.71622	.64310	.66493	.64182	.49562	.64146	.30194	.39713	.55612	.43064

COVARIANCE MATRIX

CH	*	1	2	3	4	5	6	7	8	9	10	11	12
1	*	.00688	.00764	.00269	.00093	.00271	.00608	.00297	-0.00268	-0.00451	-0.00019	.01354	.01028
2	*	.00764	.01187	.00428	.00190	.00408	.00771	.00420	-0.00251	-0.00479	.00022	.01576	.01215
3	*	.00269	.00428	.00361	.00216	.00243	.00241	.00182	.00202	.00071	.00083	.00101	.00103
4	*	.00093	.00190	.00216	.00280	.00173	.00045	.00094	.00339	.00269	.00088	-0.00443	-0.00305
5	*	.00271	.00408	.00243	.00173	.00342	.00353	.00272	.00222	.00033	.00104	.00334	.00263
6	*	.00608	.00771	.00241	.00045	.00353	.00880	.00449	-0.00243	-0.00523	.00046	.01795	.01359
7	*	.00297	.00420	.00182	.00094	.00272	.00449	.00349	.00059	-0.00137	.00072	.00763	.00584
8	*	-0.00268	-0.00251	.00202	.00339	.00222	-0.00243	.00059	.00985	.00831	.00220	-0.01625	-0.01230
9	*	-0.00451	-0.00479	.00071	.00269	.00033	-0.00523	-0.00137	.00831	.00906	.00146	-0.02013	-0.01509
10	*	-0.00019	.00022	.00083	.00088	.00104	.00046	.00072	.00220	.00146	.00121	-0.00187	-0.00142
11	*	.01354	.01576	.00101	-0.00443	.00334	.01795	.00763	-0.01625	-0.02013	-0.00187	.05624	.04182
12	*	.01028	.01215	.00103	-0.00305	.00263	.01359	.00584	-0.01230	-0.01509	-0.00142	.04182	.03231

NORMALIZED COVARIANCE MATRIX

CH	*	1	2	3	4	5	6	7	8	9	10	11	12
1	*	1.00000	.84536	.53920	.21116	.55854	.78158	.60634	-0.32504	-0.57183	-0.06673	.68837	.68978
2	*	.84536	1.00000	.65312	.32905	.63967	.75453	.65303	-0.23192	-0.46187	.05902	.60997	.62060
3	*	.53920	.65312	1.00000	.68002	.69065	.42715	.51383	.33786	.12471	.39806	.07096	.09488
4	*	.21116	.32905	.68002	1.00000	.55795	.09010	.30179	.64602	.53410	.48015	-0.35302	-0.32061
5	*	.55854	.63967	.69065	.55795	1.00000	.64329	.78785	.38161	.05884	.51090	.24111	.25049
6	*	.78158	.75453	.42715	.09010	.64329	1.00000	.80938	-0.26108	-0.58580	.14124	.80655	.80563
7	*	.60634	.65303	.51383	.30179	.78785	.80938	1.00000	.10135	-0.24302	.35027	.54428	.54971
8	*	-0.32504	-0.23192	.33786	.64602	.38161	-0.26108	.10135	1.00000	.87991	.63694	-0.69045	-0.68967
9	*	-0.57183	-0.46187	.12471	.53410	.05884	-0.58580	-0.24302	.87991	1.00000	.44195	-0.89197	-0.88186
10	*	-0.06673	.05902	.39806	.48015	.51090	.14124	.35027	.63694	.44195	1.00000	-0.22646	-0.22794
11	*	.68837	.60997	.07096	-0.35302	.24111	.80655	.54428	-0.69045	-0.89197	-0.22646	1.00000	.98099
12	*	.68978	.62060	.09488	-0.32061	.25049	.80563	.54971	-0.68967	-0.88186	-0.22794	.98099	1.00000

Figure 4-28. MEAN VECTOR CORRELATION MATRIX, COVARIANCE MATRIX, AND NORMALIZED COVARIANCE MATRIX OF C5-17, SECTION A

Table 4-2. MEAN VECTOR AND COVARIANCE MATRIX OF C5-17 SECTION A

C(5-17) SECTION A

MEAN VECTOR

CHANNEL	*	1	2	3	4	5	6	7	8	9	10	11	12
1	*	1.174	1.706	1.177	1.048	1.077	1.062	.806	1.013	.459	.633	.950	.739

COVARIANCE MATRIX

CHANNEL	*	1	2	3	4	5	6	7	8	9	10	11	12
1	*	.00884	.00057	.00294	.00212	.00197	.00291	.00101	.00213	.00001	.00185	.00022	-0.00024
2	*	.00057	.01209	.00287	.00185	.00353	.00202	.00325	.00384	.00198	.00113	-0.00117	-0.00074
3	*	.00294	.00287	.00731	.00242	.00207	.00264	.00157	.00342	.00184	.00150	-0.00111	-0.00024
4	*	.00212	.00185	.00242	.00707	.00096	.00145	.00094	.00234	.00176	.00117	-0.00221	-0.00069
5	*	.00197	.00353	.00207	.00096	.00858	.00115	.00333	.00405	.00168	.00125	-0.00075	-0.00087
6	*	.00291	.00202	.00264	.00145	.00115	.00733	.00071	.00221	.00085	.00157	-0.00067	-0.00028
7	*	.00101	.00325	.00157	.00094	.00333	.00071	.00552	.00300	.00148	.00090	.00027	.00078
8	*	.00213	.00384	.00342	.00234	.00405	.00221	.00300	.00962	.00310	.00141	-0.00144	-0.00049
9	*	.00001	.00198	.00184	.00176	.00168	.00085	.00148	.00310	.00533	-0.00024	-0.00084	-0.00034
10	*	.00165	.00113	.00150	.00117	.00125	.00157	.00090	.00141	-0.00024	.00480	-0.00076	.00002
11	*	.00022	-0.00117	-0.00111	-0.00221	-0.00075	-0.00067	.00027	-0.00144	-0.00084	-0.00076	.00941	.00375
12	*	-0.00024	-0.00074	-0.00024	-0.00069	-0.00087	-0.00028	.00078	-0.00049	-0.00034	.00002	.00375	.00763

Table 4-3. MEAN VECTOR AND COVARIANCE MATRIX OF C5-17 SECTION B

C(5-17) SECTION B

MEAN VECTOR

CHANNEL	*	1	2	3	4	5	6	7	8	9	10	11	12
2	*	.937	1.380	1.031	.977	.934	.791	.648	1.073	.604	.608	.397	.315

COVARIANCE MATRIX

CHANNEL	*	1	2	3	4	5	6	7	8	9	10	11	12
1	*	.00526	.00189	.00133	.00141	.00178	.00111	.00142	.00182	.00161	.00083	-0.00021	.00057
2	*	.00189	.00935	.00556	.00464	.00436	.00327	.00289	.00600	.00333	.00375	.00141	.00033
3	*	.00133	.00556	.00978	.00452	.00447	.00352	.00241	.00571	.00305	.00322	.00059	.00060
4	*	.00141	.00464	.00452	.00774	.00448	.00346	.00207	.00456	.00296	.00323	.00152	.00025
5	*	.00178	.00436	.00447	.00448	.01037	.00598	.00269	.00646	.00352	.00452	.00253	.00063
6	*	.00111	.00327	.00352	.00346	.00598	.00836	.00211	.00514	.00292	.00242	.00205	.00101
7	*	.00142	.00289	.00241	.00207	.00269	.00211	.00671	.00532	.00346	.00199	.00139	.00121
8	*	.00182	.00600	.00571	.00456	.00646	.00514	.00532	.01223	.00547	.00435	.00290	.00146
9	*	.00161	.00333	.00305	.00296	.00352	.00292	.00346	.00547	.00655	.00183	.00124	.00089
10	*	.00083	.00375	.00322	.00323	.00452	.00242	.00199	.00435	.00183	.00615	.00280	-0.00043
11	*	-0.00021	.00141	.00059	.00152	.00253	.00205	.00139	.00290	.00124	.00280	.00615	-0.00005
12	*	.00057	.00033	.00060	.00025	.00063	.00101	.00121	.00146	.00089	-0.00043	-0.00005	.00464

Table 4-4. DIVERGENCE MATRIX USING ALL 12 CHANNELS

FIELD	1	2	3	4	5	6	7	8	9	10	11	12
1	0	130.178	53.767	29.861	90.544	53.447	32.300	34.100	38.590	101.669	30.995	111.866
2	0	0	70.901	148.435	3.303	63.591	133.485	201.396	96.357	5.675	69.853	73.353
3	0	0	0	78.715	51.732	18.335	33.987	86.998	10.939	52.859	14.516	51.710
4	0	0	0	0	80.121	22.347	19.341	138.954	31.482	115.938	11.217	58.848
5	0	0	0	0	0	36.430	93.525	191.596	70.361	9.922	46.503	63.304
6	0	0	0	0	0	0	21.782	125.419	14.521	54.010	5.534	32.697
7	0	0	0	0	0	0	0	109.757	10.551	112.519	9.652	89.001
8	0	0	0	0	0	0	0	0	87.246	178.047	84.181	125.607
9	0	0	0	0	0	0	0	0	0	80.602	7.249	36.028
10	0	0	0	0	0	0	0	0	0	0	57.702	76.894
11	0	0	0	0	0	0	0	0	0	0	0	27.584
12	0	0	0	0	0	0	0	0	0	0	0	0

FIELDS DESIGNATIONS

C(5-17)	SEC-A	IS	FIELD 1
C(5-17)	SEC-B	IS	FIELD 2
C(5-17)	SEC-C	IS	FIELD 3
C(5-22)	SEC-A	IS	FIELD 4
C(5-22)	SEC-B	IS	FIELD 5
C(5-22)	SEC-C	IS	FIELD 6
C(5-5)	SEC-A	IS	FIELD 7
C(5-5)	SEC-B	IS	FIELD 8
C(5-5)	SEC-C	IS	FIELD 9
C(5-8)	SEC-A	IS	FIELD 10
C(5-8)	SEC-B	IS	FIELD 11
C(5-8)	SEC-C	IS	FIELD 12

Table 4-5. CONTRIBUTION TO THE DIVERGENCE MATRIX FROM COVARIANCE MATRICES

TRACE1 MATRIX USING ALL 12 CHANNELS

FIELD	*	1	2	3	4	5	6	7	8	9	10	11	12
1	*	0	7.155	16.371	-8.069	6.356	5.318	7.609	9.006	6.386	6.636	4.549	21.424
2	*	0	0	24.521	-4.290	3.749	6.558	8.958	10.073	7.039	3.562	6.769	27.001
3	*	0	0	0	5.457	21.898	8.483	21.646	23.677	18.420	20.014	15.730	48.868
4	*	0	0	0	0	-7.467	-3.840	-0.763	2.170	-3.113	-5.836	-8.494	-6.049
5	*	0	0	0	0	0	3.751	11.572	16.761	8.320	4.163	4.396	20.624
6	*	0	0	0	0	0	0	7.846	17.761	4.738	2.762	3.176	15.158
7	*	0	0	0	0	0	0	0	9.689	3.449	9.471	7.795	28.289
8	*	0	0	0	0	0	0	0	0	7.728	11.072	13.805	44.448
9	*	0	0	0	0	0	0	0	0	0	6.997	6.082	23.897
10	*	0	0	0	0	0	0	0	0	0	0	5.798	29.554
11	*	0	0	0	0	0	0	0	0	0	0	0	16.269
12	*	0	0	0	0	0	0	0	0	0	0	0	0

Table 4-6. CONTRIBUTION TO THE DIVERGENCE MATRIX FROM MEAN VECTORS

TRACE2 MATRIX USING ALL 12 CHANNELS

FIELD	1	2	3	4	5	6	7	8	9	10	11	12
1		253.201	91.163	67.791	174.732	101.577	56.990	59.194	70.795	196.702	57.441	202.308
2	0	0	117.731	301.160	2.858	120.623	258.033	392.719	185.676	7.787	132.936	119.704
3	0	0	0	151.974	81.506	28.187	46.329	150.318	3.459	85.703	13.302	54.552
4	0	0	0	0	167.710	48.533	39.445	275.737	66.077	237.711	30.928	123.746
5	0	0	0	0	0	69.109	175.479	366.432	132.402	15.680	88.611	185.984
6	0	0	0	0	0	0	35.718	233.077	24.305	105.258	7.892	50.236
7	0	0	0	0	0	0	0	209.825	17.653	215.567	11.508	149.713
8	0	0	0	0	0	0	0	0	166.764	345.021	154.557	206.767
9	0	0	0	0	0	0	0	0	0	154.208	8.417	48.159
10	0	0	0	0	0	0	0	0	0	0	109.605	124.234
11	0	0	0	0	0	0	0	0	0	0	0	38.900
12	0	0	0	0	0	0	0	0	0	0	0	0

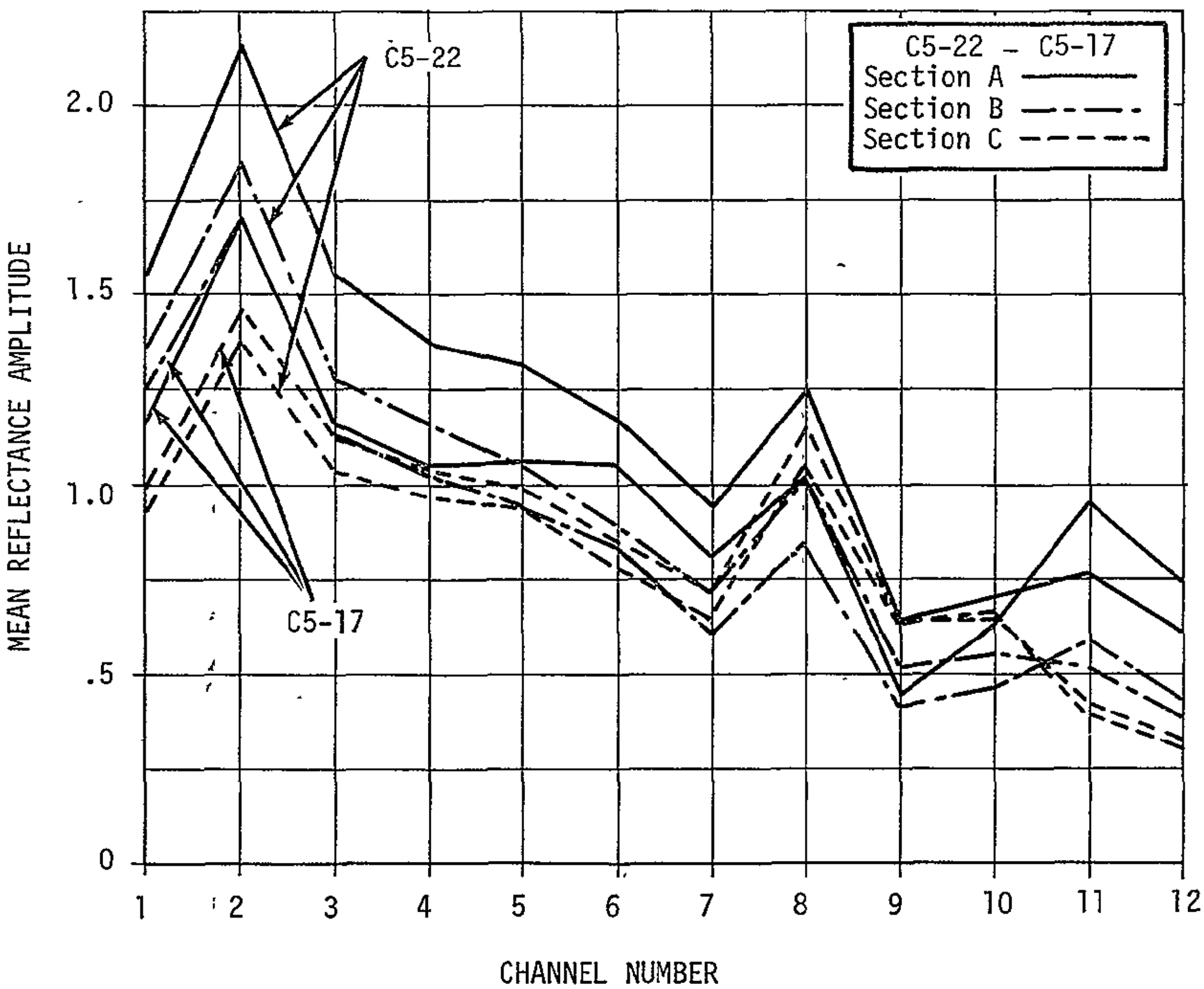

Figure 4-29. MEAN SPECTRAL VECTORS OF THREE HOMOGENEOUS SECTIONS IN FIELDS C5-17 AND C5-22

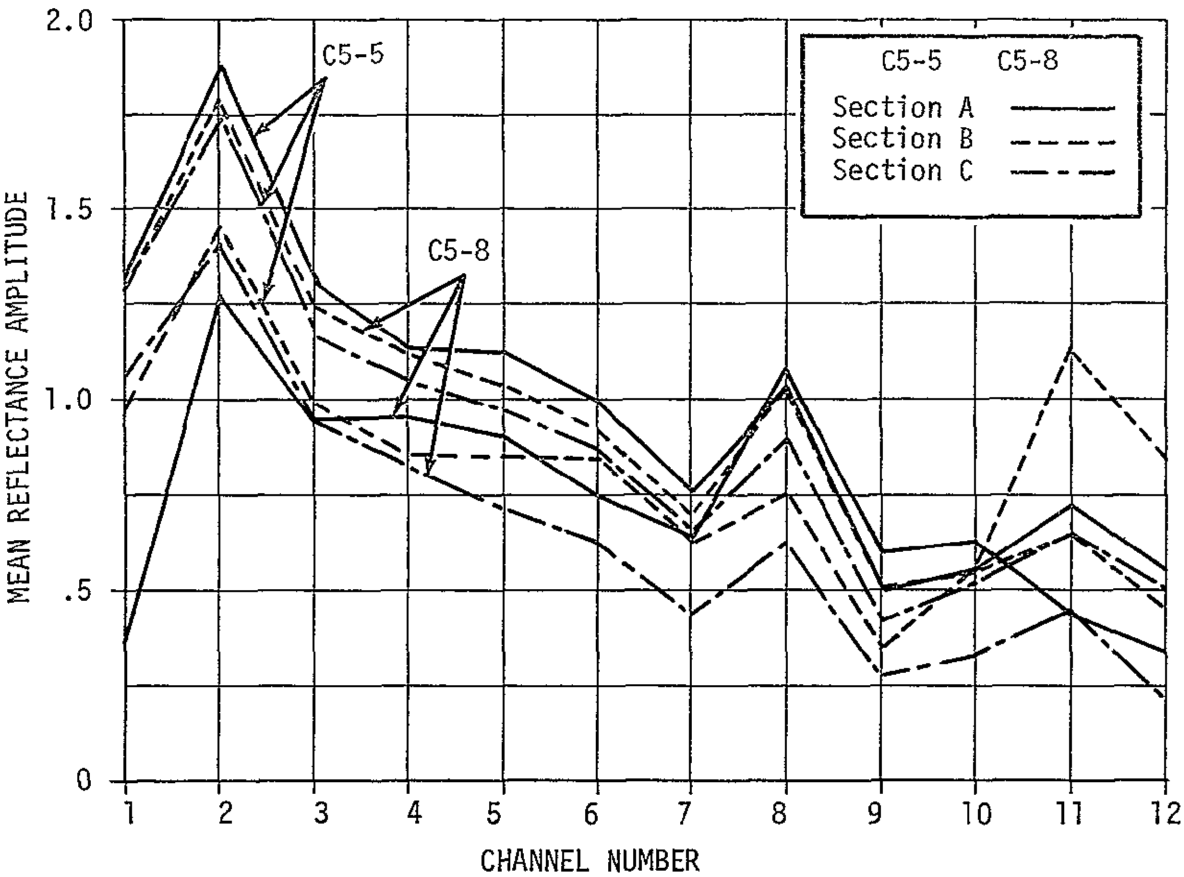

Figure 4-30. MEAN SPECTRAL VECTORS OF THREE HOMOGENEOUS SECTIONS IN FIELDS C5-5 AND C5-8

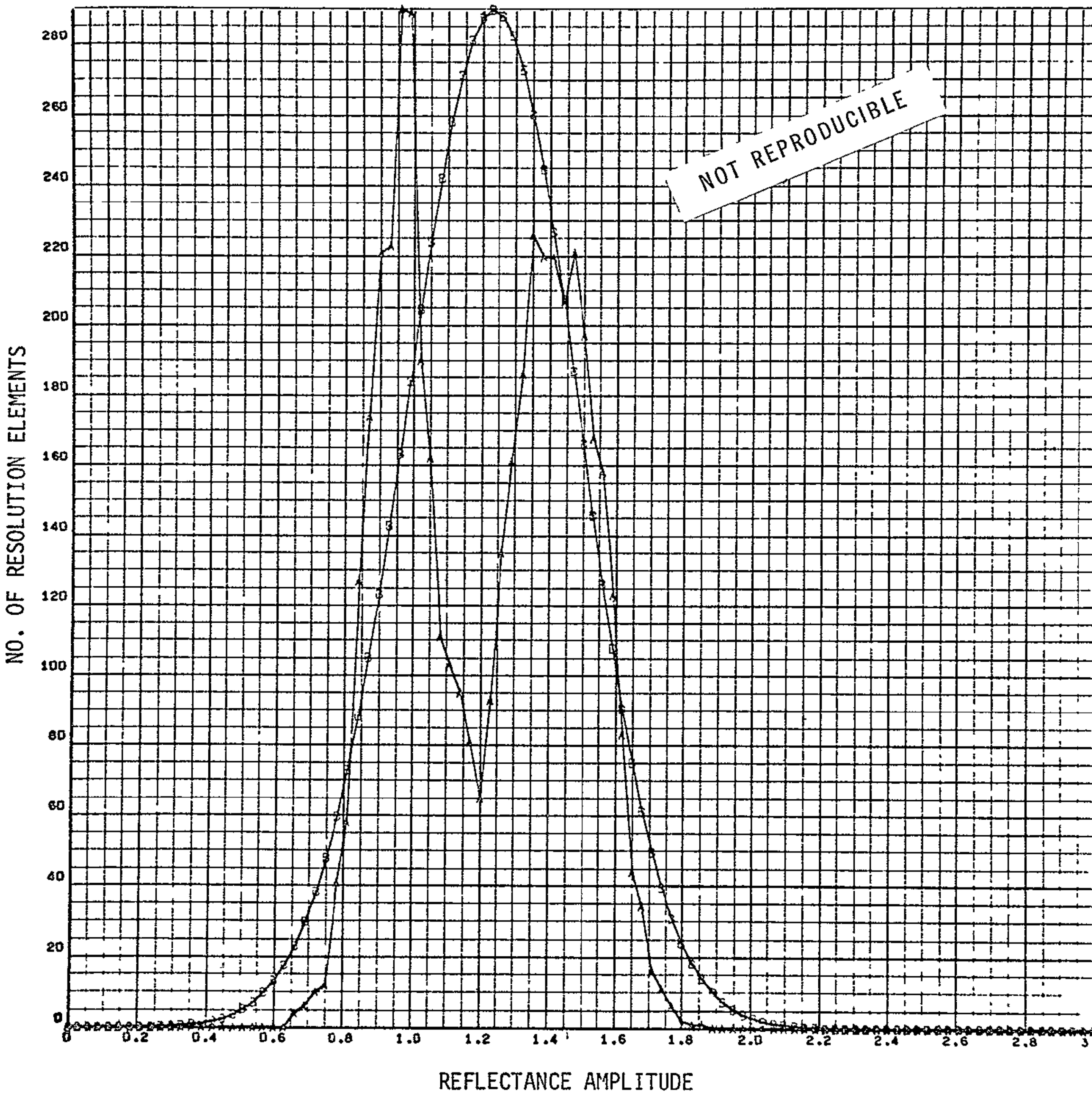

Figure 4-31. UNIVARIATE HISTOGRAM OF CHANNEL 1 OF ENTIRE FIELD C5-22

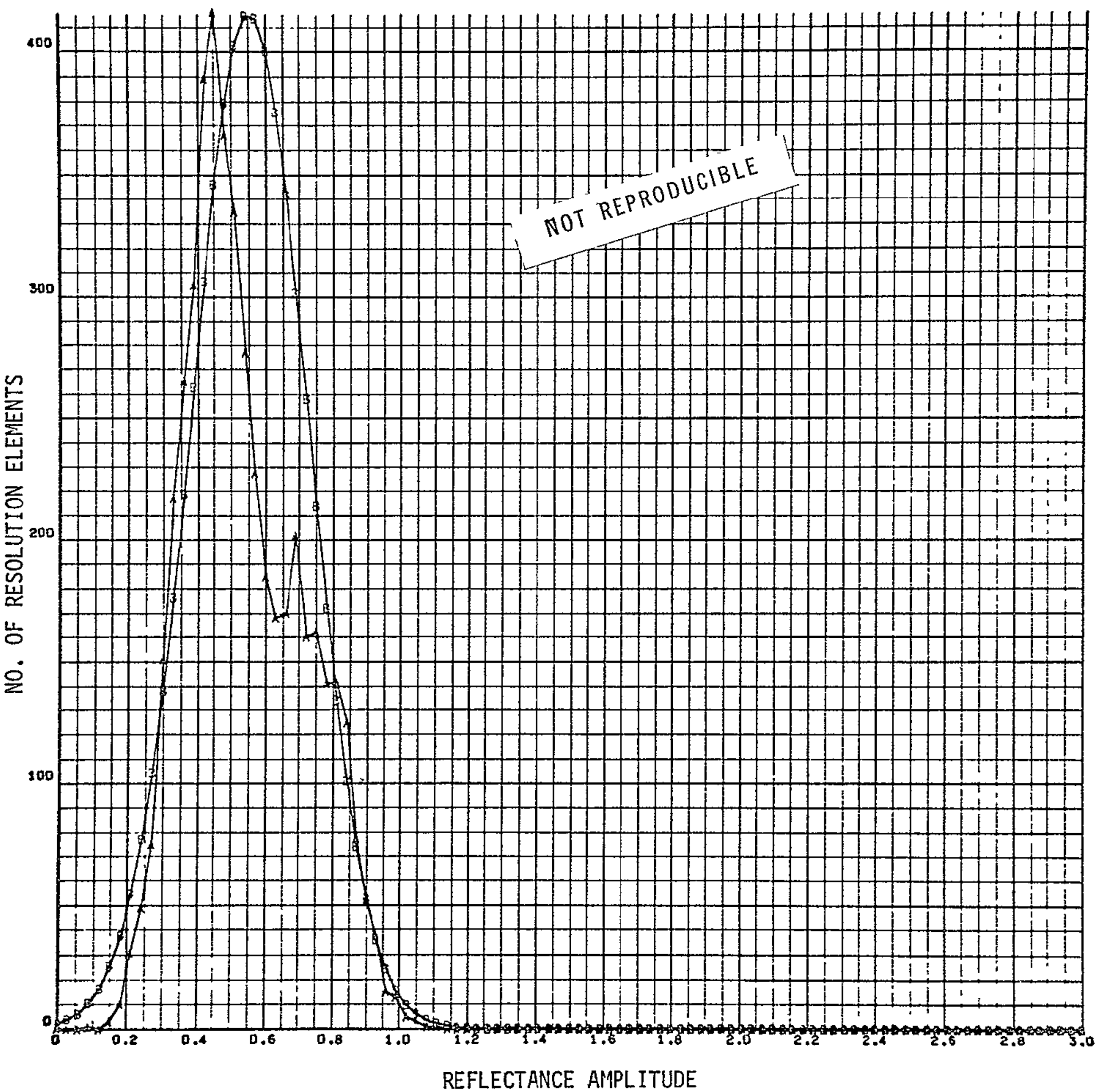

Figure 4-32. UNIVARIATE HISTOGRAM OF CHANNEL 2 OF ENTIRE FIELD C5-22

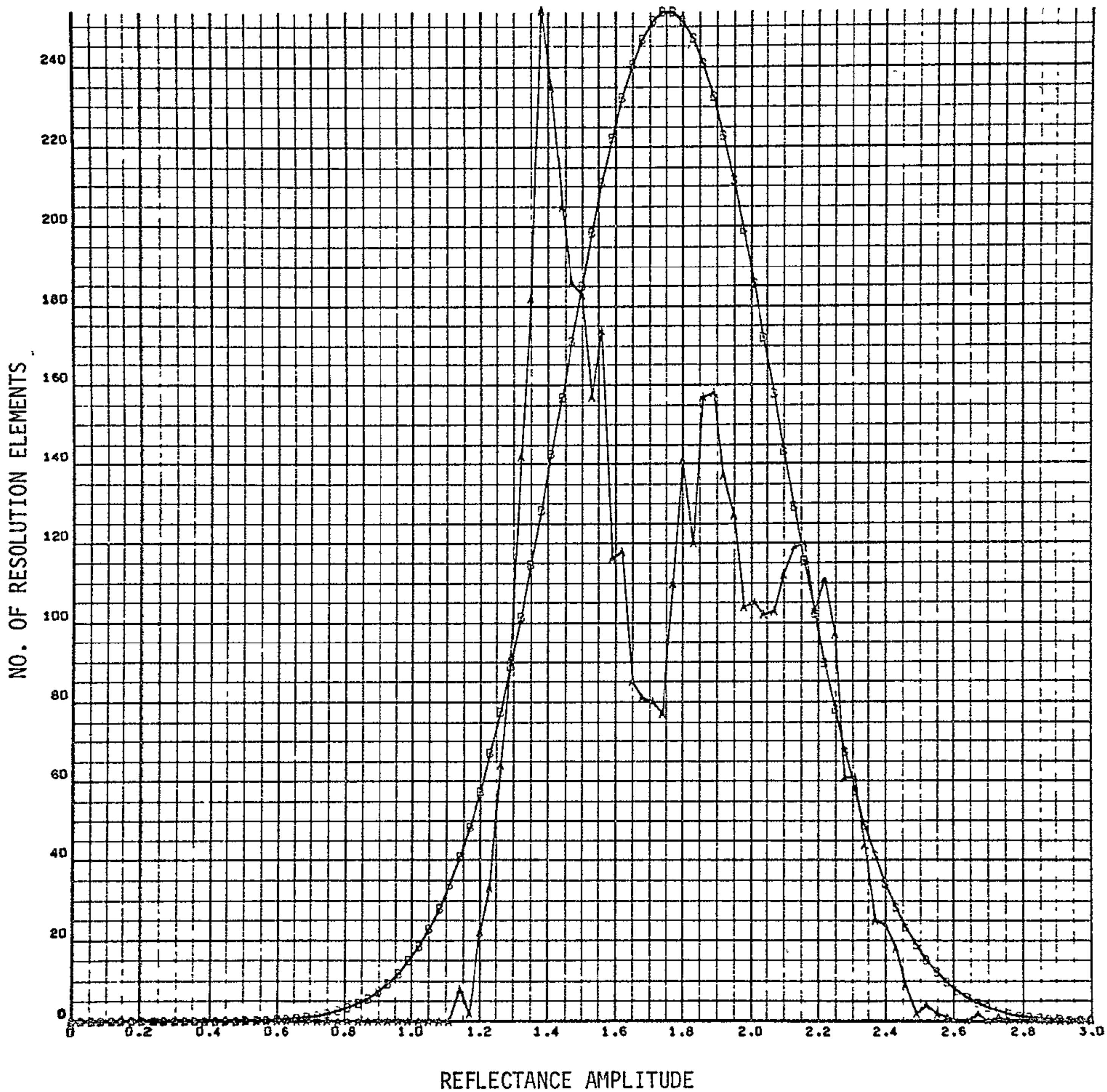

Figure 4-33. UNIVARIATE HISTOGRAM OF CHANNEL 11 OF ENTIRE FIELD C5-22

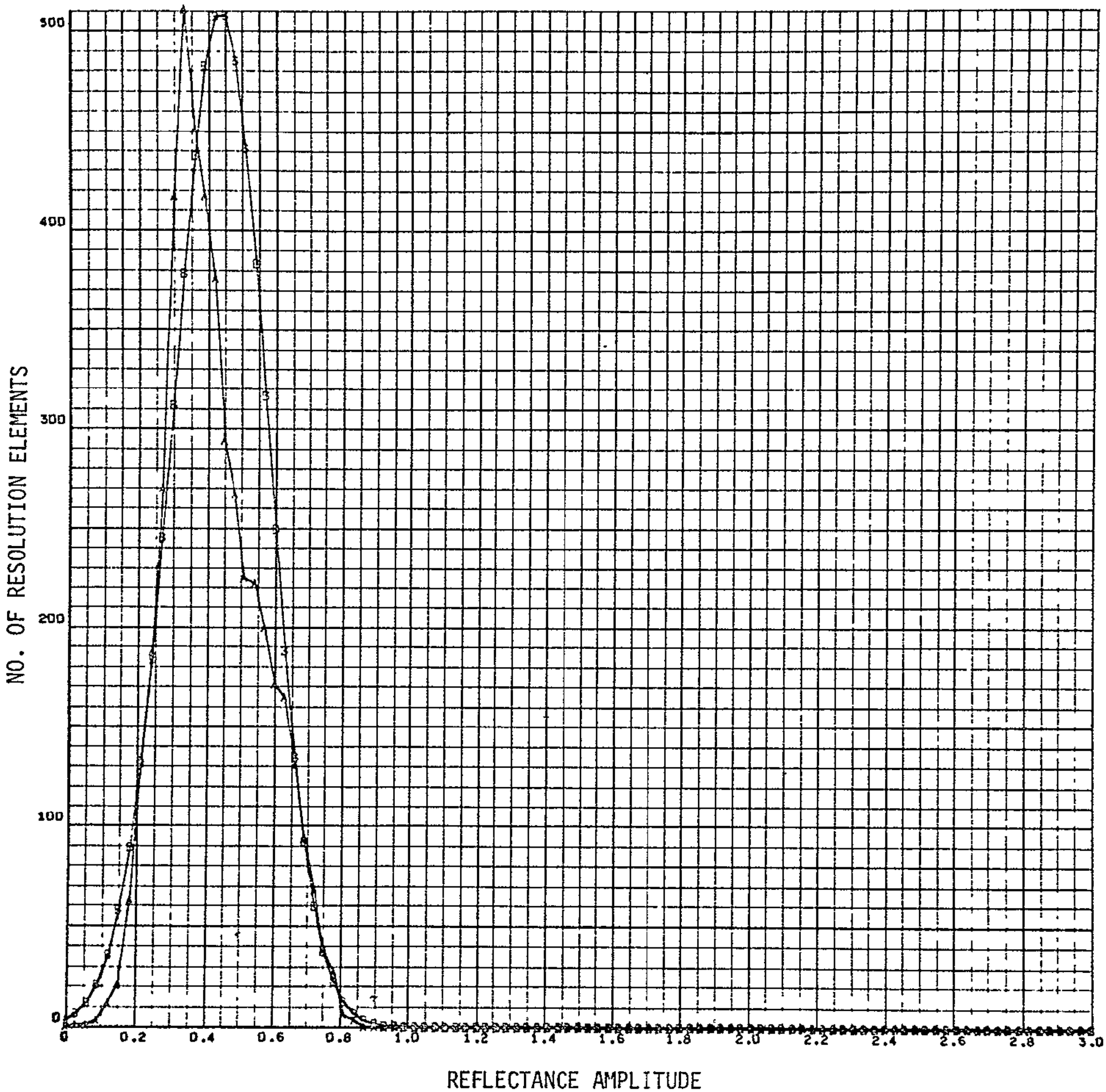

Figure 4-34. UNIVARIATE HISTOGRAM OF CHANNEL 12 OF ENTIRE FIELD C5-22

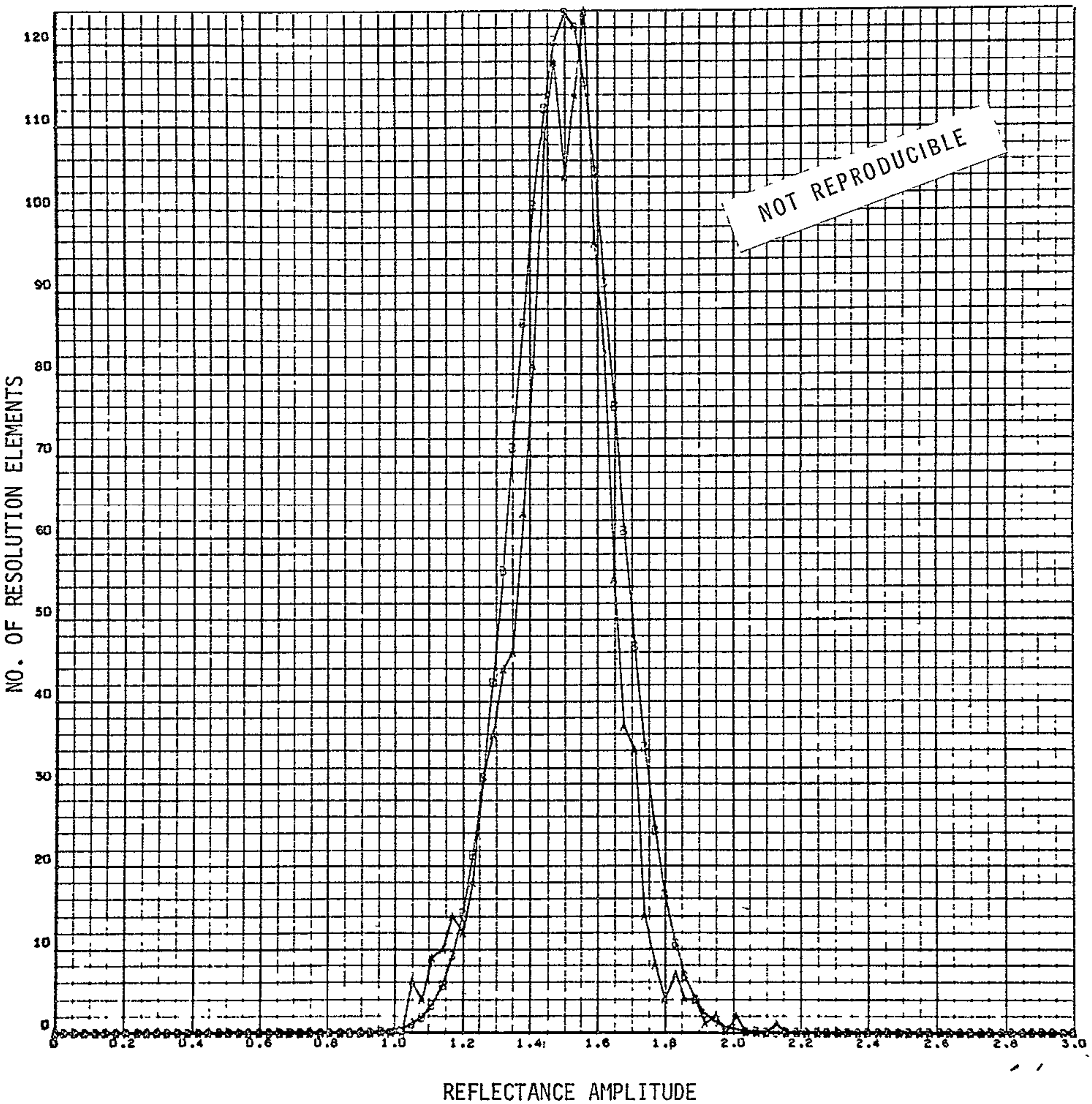

Figure 4-35. UNIVARIATE HISTOGRAM OF CHANNEL 1 OF C5-22, SECTION A

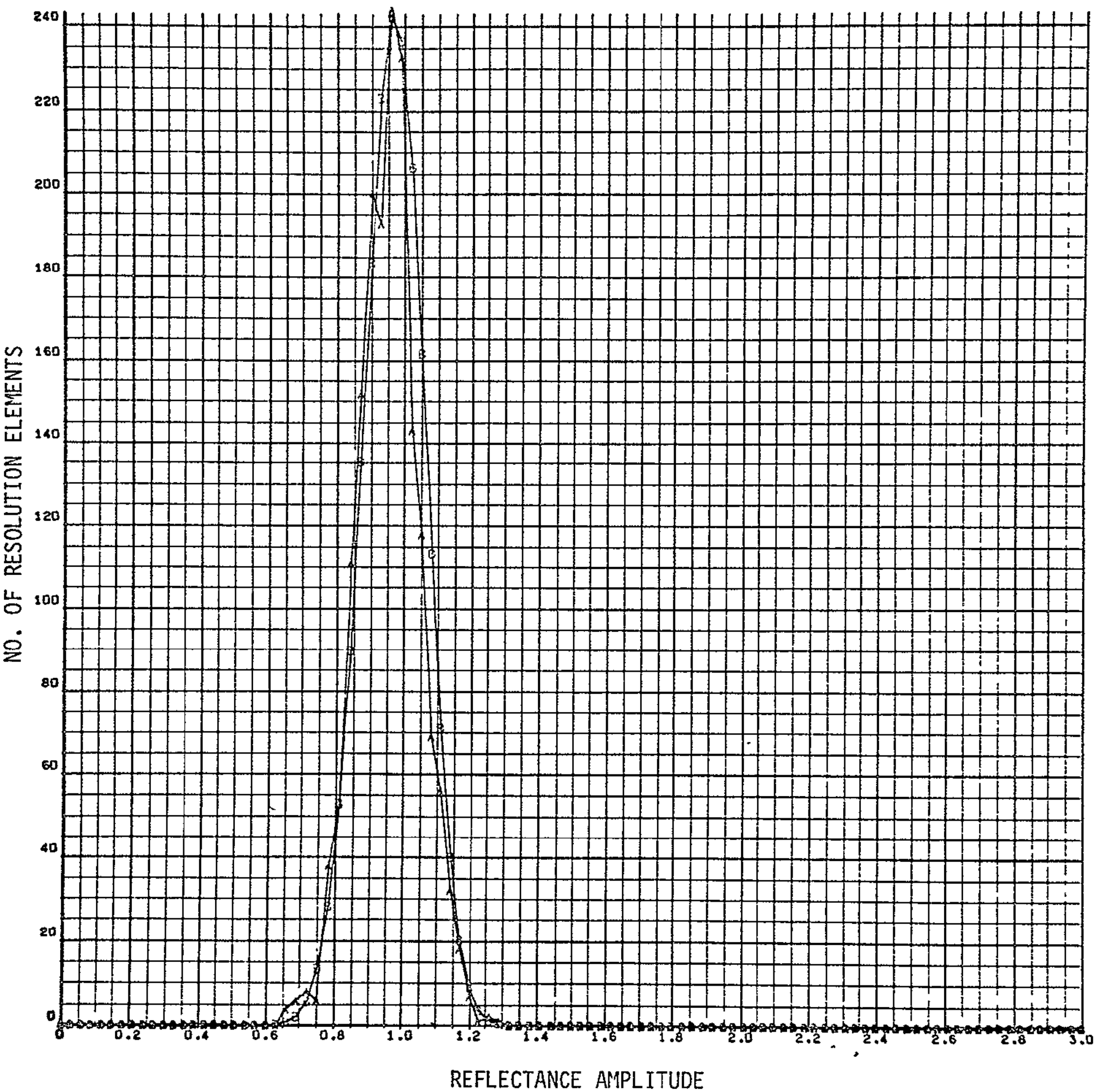

Figure 4-36. UNIVARIATE HISTOGRAM OF CHANNEL 1 OF C5-22, SECTION B

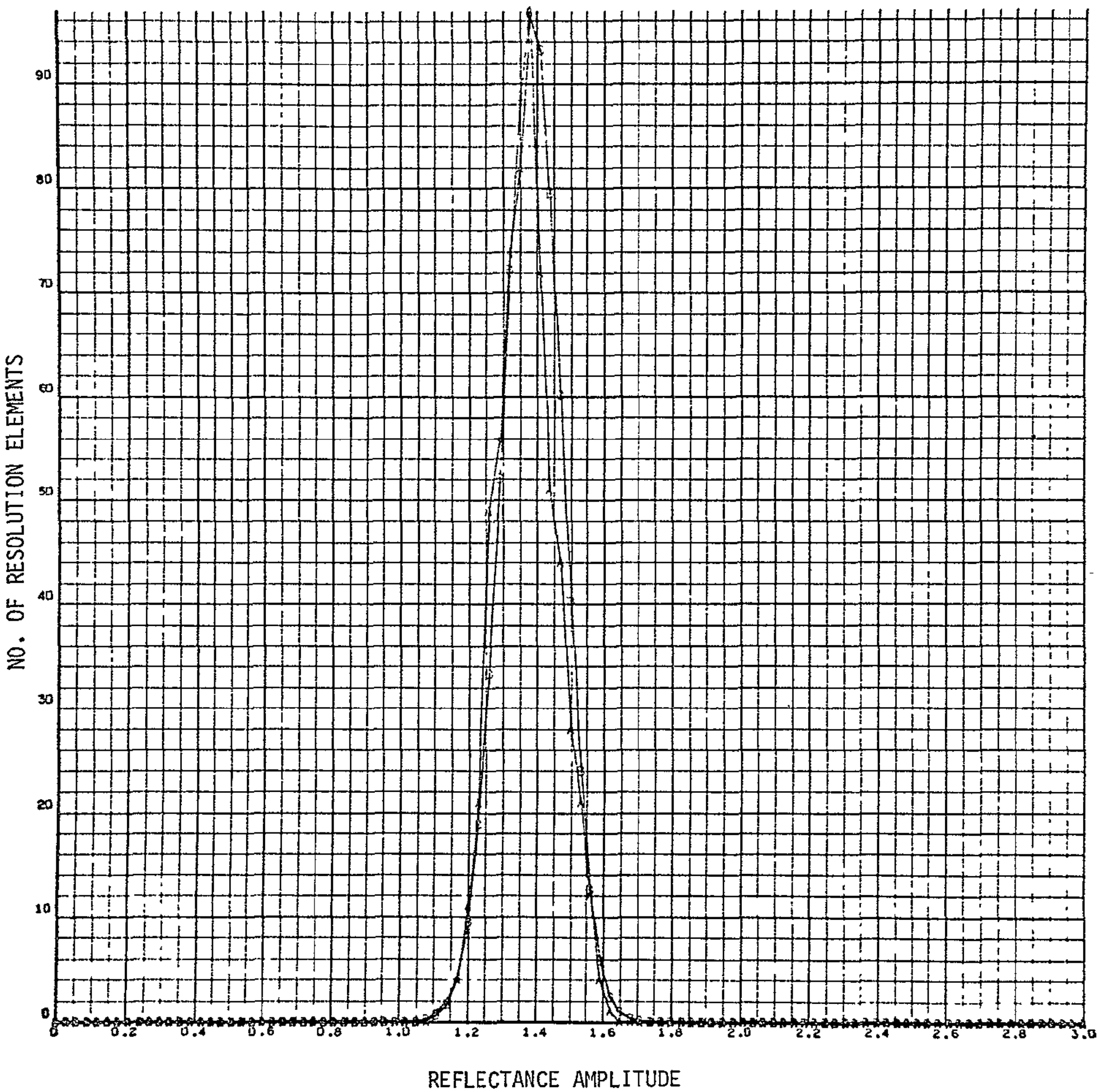

Figure 4-37. UNIVARIATE HISTOGRAM OF CHANNEL 1 OF C5-22, SECTION C

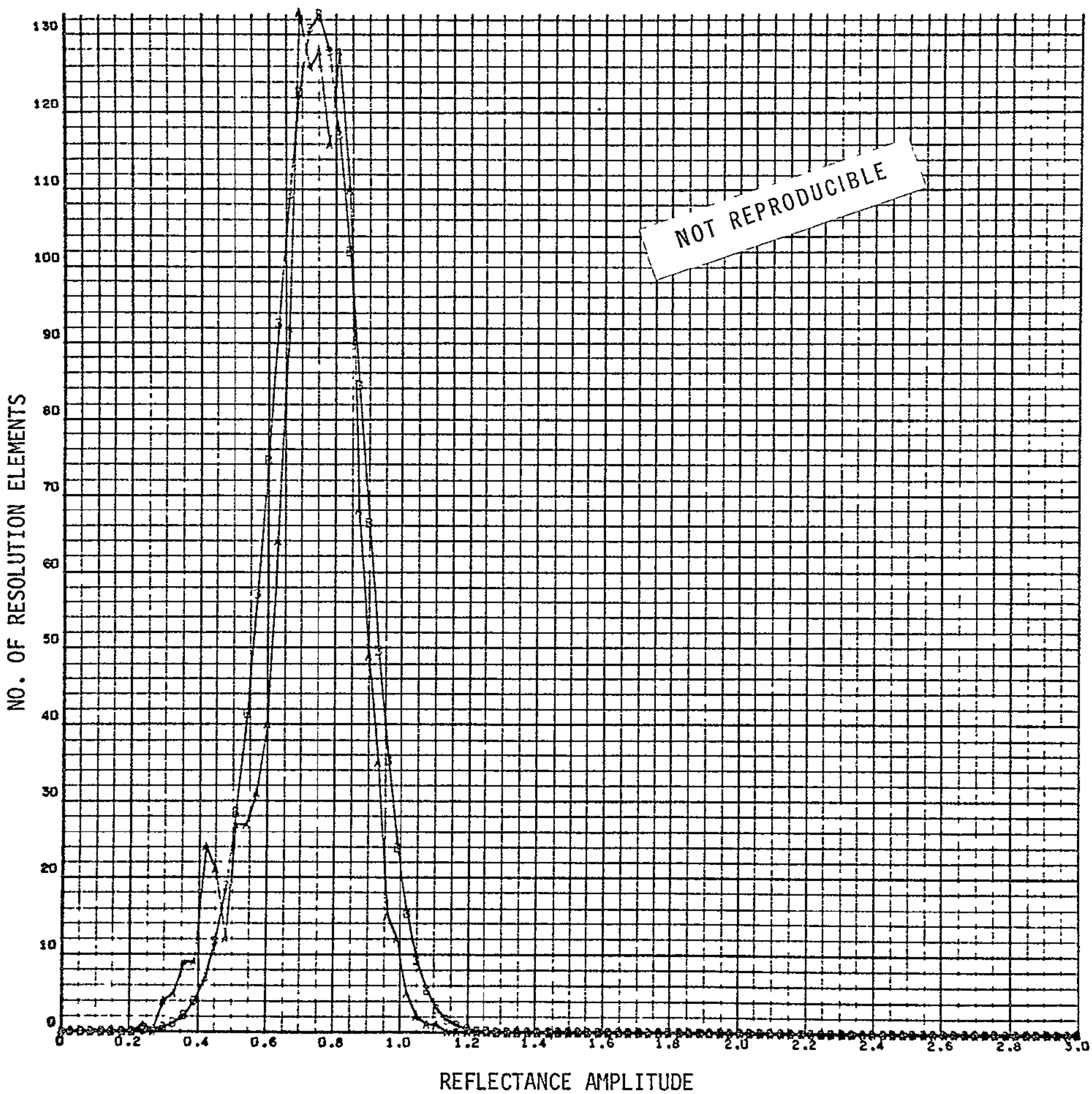

Figure 4-38. UNIVARIATE HISTOGRAM OF CHANNEL 11 OF C5-22, SECTION A

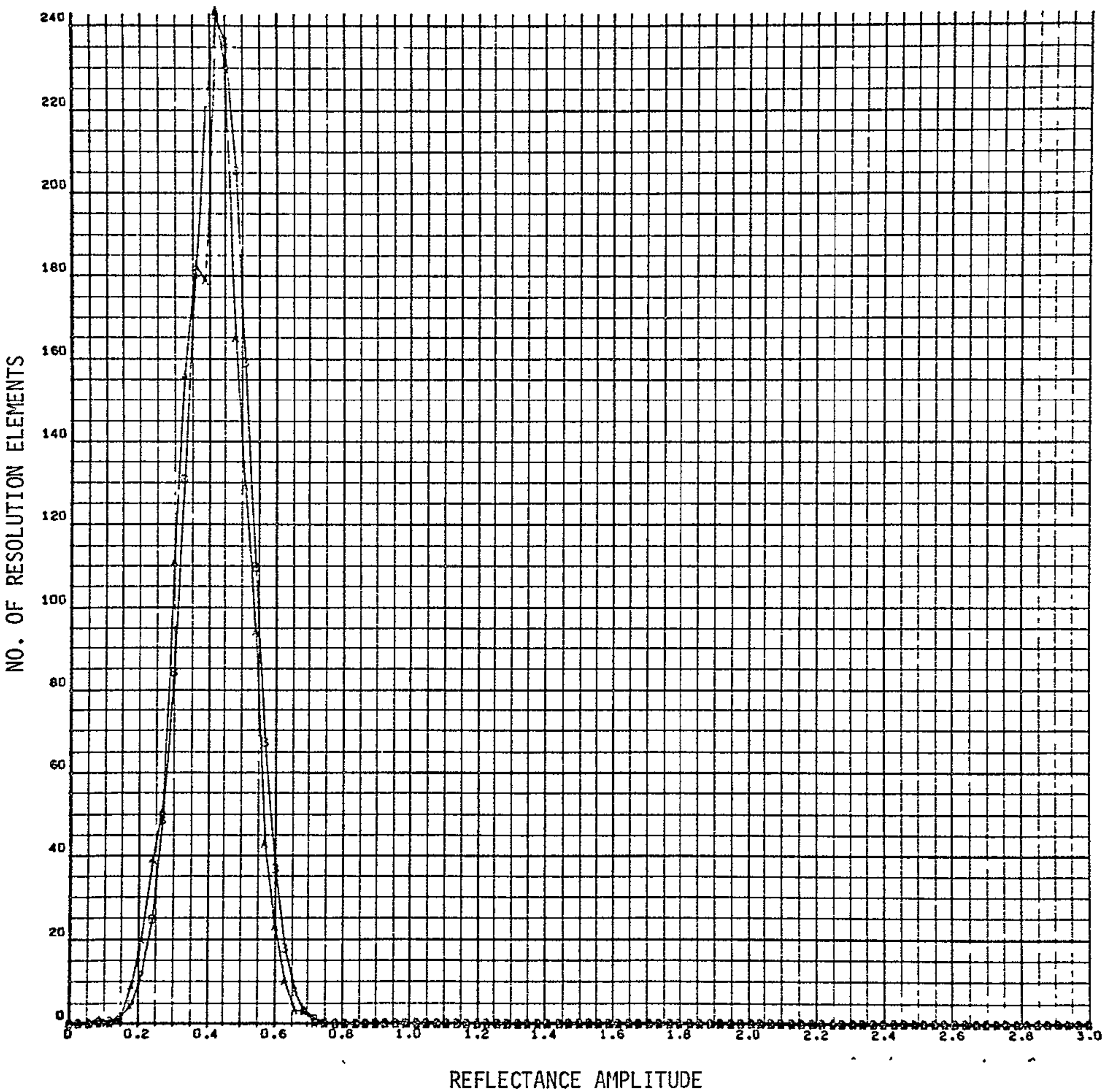

Figure 4-39. UNIVARIATE HISTOGRAM OF CHANNEL 11 OF C5-22, SECTION B

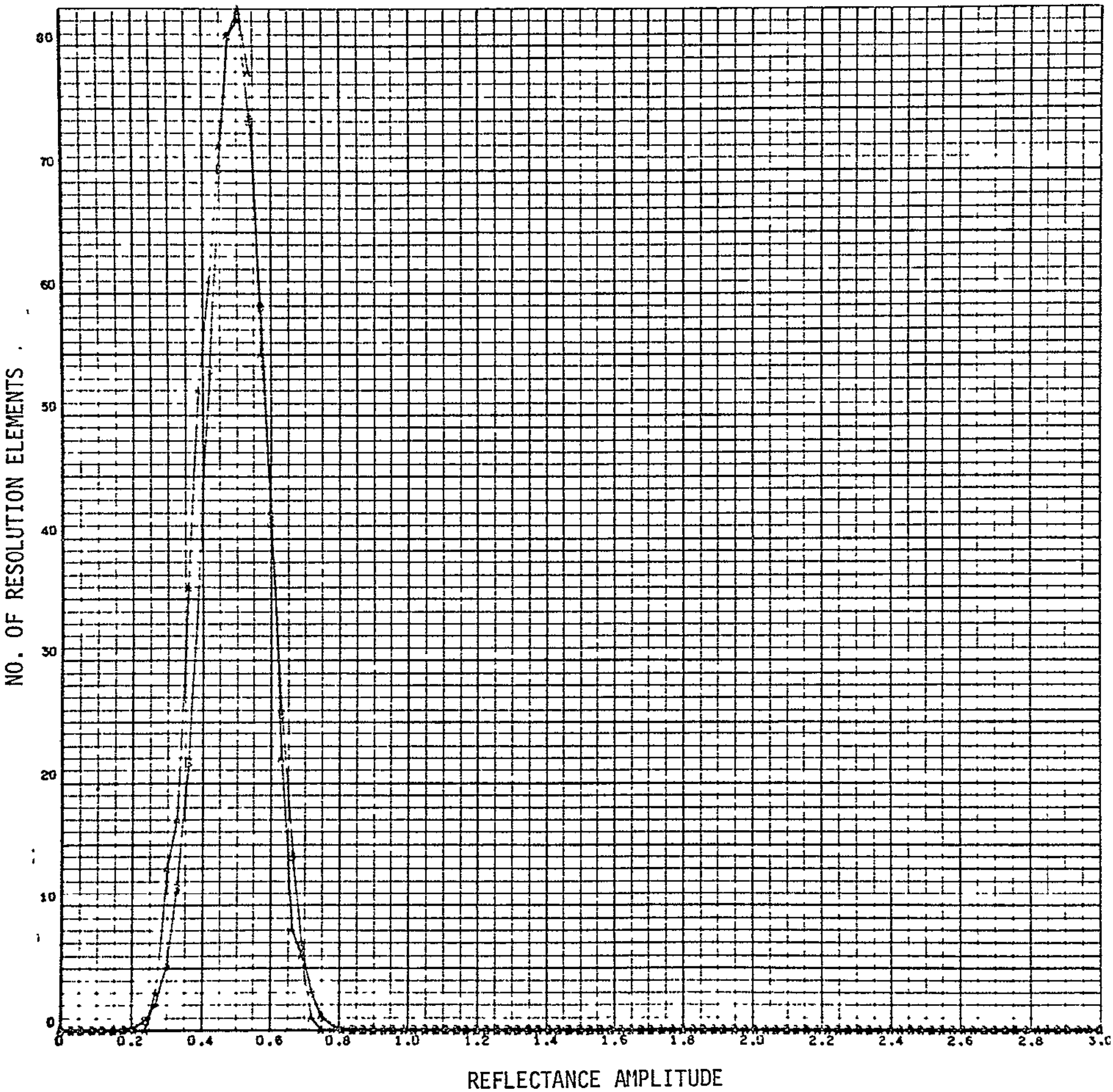

Figure 4-40. UNIVARIATE HISTOGRAM OF CHANNEL 11 OF C5-22, SECTION C

Section V
SUMMARY AND CONCLUSIONS

The most significant results of this study are the development of two statistical algorithms for determination of inventory boundaries within a target area from multispectral remotely sensing data without reference to any ground truth or training data. The samples within each individual area bounded by the inventory boundaries, called an inventory area, constitute a homogeneous population. The first algorithm is based on a principle of boundary enhancement which involves area smoothing and taking absolute value of the 2-directional difference of the smoothed data. The second algorithm is based on the statistical variation of the multispectral data and the confidence limit of the statistical estimation. The two algorithms are thus basically opposite in their underlying principles, since the first relies more heavily on the mean of the data; while the second relies more heavily on the variation of the data about the mean. As such, they really compensate each other. These two algorithms have been implemented into digital computer programs.

In addition, several other computer programs have also been developed for general statistical analysis of multispectral data. Specifically, these programs are for calculating the mean vector, correlation matrix, covariance matrix, and univariate probability density distribution from the inventory area, and for calculating the divergence matrix among various inventory areas. The divergence is a statistical measure for separability or dissimilarity between inventory areas. Also developed is a grey level plotting program for 2-dimensional digital display of a single-channel record which may be either raw data or final classified output data.

The capability of the above computer programs for automatic determination of inventory boundaries has been successfully demonstrated on a set of remotely sensed data obtained by the University of Michigan Multispectral Scanner over some agricultural fields at a flight altitude of 2000 feet.

The most important advantage of the data analysis methods is data compression which is accomplished by replacing voluminous raw data samples by the location of inventory boundaries and associated aerial average over the inventory area. Two to three orders of magnitude of reduction in data flow rate and total computation time may result.

One drawback of the two algorithms for inventory boundary detection is that the boundaries sometimes do not close. To remedy this drawback, a new algorithm for automatic sequential classification of multispectral data into homogeneous populations (without reference to any training set) has been proposed (ref. 13). The performance of the new algorithm will be reported in the future, for it has not yet been implemented.

Section VI

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Appendix A

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