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Machine Processing Methods for Earth Observational Data

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ABSTRACT

A brief review of the development over the last decade of earth resource informations systems is presented. Machine data preprocessing and analysis methods are surveyed and illustrated. These include preprocessing steps intended to modify geometric and radiometric aspects of earth observational image data to enhance the ability of either human interpreters or machine algorithms to extract information from data. Illustrations of processed and analyzed images from spaceborne sensors including the Earth Resources Technology Satellite are discussed.

INTRODUCTION

It has been within only the last decade and one-half that an intensive research effort has been underway to learn how to operate satellite systems in earth orbit. For about the same period intensive research programs have been directed at the question of machine processing of data in image form. Given the need to better manage the earth's resources, based on both humanitarian and economic motivations, it was only natural that these two technologies should come together. In the short time since this has occurred, very significant progress has been made. It is the purpose of this paper to briefly discuss and show illustrations indicating the current state of this technology.

For orientation purposes, Figure 1 shows the major elements necessary in an earth resources information system.[1] A study of the current state-of-the-remote sensing-science, however would show that there exists a duality of system types, since the present science springs from two different stems. The names used here for these are "image oriented" and "numerically oriented" systems.[2] The differences between them may, at first, appear to be quite subtle, but they are quite far-reaching in their effect.

One impact of these differences is shown in Figure 2. The ground processing portion of the system here has two branches. The upper one is needed for image oriented systems and the lower one for numerically oriented ones. One obvious difference is in the location of the "form image" block. In the upper (image oriented) branch it is in line with the data stream. Thus, an important intermediate step in the processing of data in this fashion is the formation of a high-quality image. In the lower branch, the numerically oriented one, the "form image" block is at the side of the data stream and is used only for monitoring the processing progress.

It is apparent from viewing this figure that all data processing for either branch falls into one of three catagorical types, preprocessing, analysis, and display (form image). The analysis step is a pivital one and so a further remark about it is in order.

Generally speaking, analysis in the image oriented situation is accomplished by a human observer. Machine analysis methods of images are not well advanced, and the human, with his superior intelligence, is well suited to this type of analysis procedure. Computing machines, on the other hand, are ordinarily used for the analysis activities of the numerically oriented system. This tends to be the distinguishing feature between the two types of systems at the present state of development.

The general method of analyzing data in an image oriented system is reasonably well known across the scientific community. The fields of photointerpretation and photogrammetry are older sciences and have been well developed in other contexts. Numerical methods of analysis in earth observation systems are less widely known since they are newer and have so far been less widely applied. For this reason we shall briefly consider one approach to numerically analyzing data. This method is referred to as the multispectral approach.

In this case, data in the form of the energy spectrum from a single resolution element is used. (See Figure 3 at top). By sampling the spectrum at n wavelengths and using a computer to view the data in the resulting n-dimensional space (the lower portion of the figure illustrates the $n = 2$ case) one can achieve a truly multivariant analysis method especially suited to machine computation.

Given that this approach is significantly different than that used in an image oriented system, it follows that (a) it is an optimum choice for different information need situations than the image oriented approach is and (b) the preprocessing needs may also be different in the two cases.

The remainder of this paper will be used for examining the state-of-the-science of preprocessing, analysis and data display by machine processing methods.

EXAMPLES OF DATA PREPROCESSING

Data compression is an important type of preprocessing since the volume of data involved in earth observations systems is typically large. Much progress has been made in devising suitable data compression schemes. Figure 4 shows the results of utilizing the redundancy present spatially, as well as spectrally, in order to compress the data for transmission or storage and then to reexpand it at a point where data in the original form is needed. The method utilized in this example [3,4] has been found, generally, quite compatible with both image oriented and numerically oriented systems in that the type of distortion introduced in the compression and reexpansion steps apparently occurs in such a way as to have little effect on the performance of analysis methods in either case.

The left image shows a reproduction of the original data, and on the right is the result of the same data having been compressed by eight times then reexpanded and redisplayed for comparison.

Another major type of preprocessing is image registration. This type can be used for two purposes: (1) associating data from two different data gathering missions, and (2) adjusting the geometric qualities of the data to cartographic quality. In the case of the former, increased identifiability of materials can result by having available to the analysis algorithm temporal variations of the scene.

The image registration step itself (Figure 5) amounts to aligning data from different channels so that points from the same ground location are precisely aligned with one another. The different channels can be from different parts of the spectrum or from different data gathering missions at different times, as indicated before. Generally, it is important not only to align the images in a global sense, but also to do so in a local sense by adjusting local distortions in one channel to conform to those of another channel.[5,6,7]

Figure 6 shows the value of using temporal variations in the analysis process. A data set over an agricultural area was collected at four different times through the season. The bar-graphs marked 43M, 44M, 45M, and 46M are the results of analyzing by multispectral numerical means the data into the classes corn and other. One sees that the accuracy possible varies during the growing season.

Each of these analyses were carried out using four spectral bands. By combining the four spectral bands from the four missions through an image registration step into a 16 spectral band data set, one sees the apparent improvement in the performance. Further, by attempting to choose a subset of four of the 16 channels, one finds a decrease in accuracy indicating that the intrinsic dimensionality of the data has, indeed, been increased through the multitemporal data registration step.

Figure 7 shows an example of using a registration method to adjust geometric qualities of an image to cartographic standards by digital computer methods. In this case, the skew and rotation present in an ERTS-1 image due to the rotation of the earth during the data collection and due to the inclination of the orbit from a true north-south orientation has been removed and the data has been rescaled so that the vertical and horizontal scales are the same. Using this approach, ERTS data has been converted to high quality cartographic standards down to a scale of 1/24,000.

The methods involved in preprocessing by these means are such as to be compatible with both image and numerically oriented systems. The next preprocessing example is one especially suited for image oriented analysis methods. It is an image enhancement technique achieved by displaying ratios of spectral bands rather than the intensity of the spectral bands themselves. Figure 8 (left image) gives a reference ERTS-1 image. This presentation is very similar to the simulated color IR image produced by the ERTS ground station as a standard product.

The enhancement of this image is shown on the right of Figure 8. In this case each scene element in the enhanced image is the result of the ratio of the data values from two ERTS spectral bands. Channel 4 divided by Channel 7 is displayed in green, Channel 4 divided by Channel 5 is displayed in blue, and Channel 6 divided by Channel 7 is displayed in red. Notice that the layout of the streets of the city of Tucson, Arizona, which is in the lower center of both images, is considerably enhanced in the later case. Actually, this enhancement was produced to make more obvious the erosion patterns present on the mountain slopes. Note in particular the enhancement achieved on the slopes that are southeast and northwest of the city of Tucson. It is apparent that the interpretability of these erosion patterns has been significantly enhanced.

There are many other types of data preprocessing algorithms which have been studied. Others have been omitted only because of space limitations and not because of any decreased significance.

ANALYSIS EXAMPLES

The first example to be presented here is one in which the multispectral approach has been utilized with a maximum likelihood Gaussian classification algorithm in order to achieve an agricultural crop classification of ERTS-1 data. Figure 9 shows a display of the classification results, in which each point classified into the class corn is displayed in red; points classified into the soybean class are displayed as green, and points classified into all other categories are displayed as white.[6]

The data involved is from ERTS Frame 1017-16093, collected August 9, 1972 over the northern portion of the State of Illinois in the U.S. Corn Belt. It is apparent from a qualitative review of Figure 9 that points in individual fields are, indeed, being associated with single classes; however, a more quantitative evaluation of classifier performance for this task was 83 percent. This performance has been judged to be clearly high enough for operational purposes. It is interesting to observe that this accuracy is similar to that obtained by classifying the same type of data gathered from a low altitude aerial scanner system.

The next example is one intended to show how the image oriented and numerical approaches can be combined into a single analysis procedure taking optimal advantage of both system types.[9] The left portion of Figure 10 shows a standard color composite of the data used. This color composite was generated from ERTS-1 MSS data utilizing channels 4, 5, and 7, from data gathered over San Joaquin County, California on July 26, 1972.

The techniques involved in this analysis procedure is to stratify the analysis process by first delineating by photointerpretive means, areas which fall into such more general categories as wild land, urban, and agriculture.

The boundaries of this first stratum are then digitized, including a description of the individual stratum. As a result, the various subareas are then related directly to the ERTS imagery and the data is turned over to a machine classification scheme such as described above. However, since the preliminary manual classification into gross classes has been carried out, the machine classification is simplified since only a small number of subclasses must be associated with each of the gross classes identified by the photointerpreter.

The advantages of such an approach are that potentially higher identification accuracy is possible and less computer time is involved. The right portion of Figure 10 shows the final result. In this case, since only agricultural information was desired, a detailed classification of only the agricultural areas of the scene was carried out. The classes were asparagus, sugar beets, alfalfa, tomatoes, urban, water, and harvested.

ON THE TECHNIQUES OF DATA DISPLAY

The question of data display in the field of earth observations is a most significant one. Displaying data in image form, of course, is the most efficient way to present the data or the results to a human observer. However, advancing technology in other areas has called for new techniques and optimization in the data display process. New sensors having greater radiometric range, for example, result in data whose dynamic range exceeds that possible with photographic film. Questions such as displaying with proper resolution so that images are provided with neither too little, nor too much detail, and displaying analysis results in map form have all found need of attention in the last few years.

It was, of course, necessary to use display techniques in providing the previous examples of preprocessing and analysis techniques; these tend to illustrate the current state-of-the-art. We will, therefore, conclude with only one final illustration of display technology. Figure 11 shows a black and white reproduction of one spectral band of ERTS-1 multispectral scanner data. This scene shows the Chicago, Illinois area and the southern portion of Lake Michigan. An ERTS image with its more than 7,000,000 resolution elements represents a tremendous amount of information and the question of mating that information quantity with the amount perceivable by human is an important one in achieving overall system optimization. The figures which follow are intended to illustrate an efficient means by which the large volume of data actually represented by such an image can be efficiently displayed. Figure 12 shows a redisplay of the same area using bands 4, 5, and 7 of the scanner data, but adjusting the contrast range of the photographic exposure to precisely match the actual range of the data in that channel.

Assume now that special interests exists in the region at the southern-most tip of Lake Michigan. Figures 13, 14, 15, and 16 (in order) show examples of presenting increasing amounts of detail for that particular region. Viewing Figure 16, relative to the original display of the data, provides a most graphic illustration of the amount of data which this one ERTS frame represents.

SUMMARY

In summary, it has been suggested that two types of significantly different system technologies are being used to derive information from earth observational data. They were referred to here as image or numerically oriented systems. For each of these, the types of processing necessary can be broken into three types: preprocessing, analysis, and display; in many cases the algorithms needed for each differs depending on the system type. A sampling of examples illustrating the state-of-the-science of each was presented.

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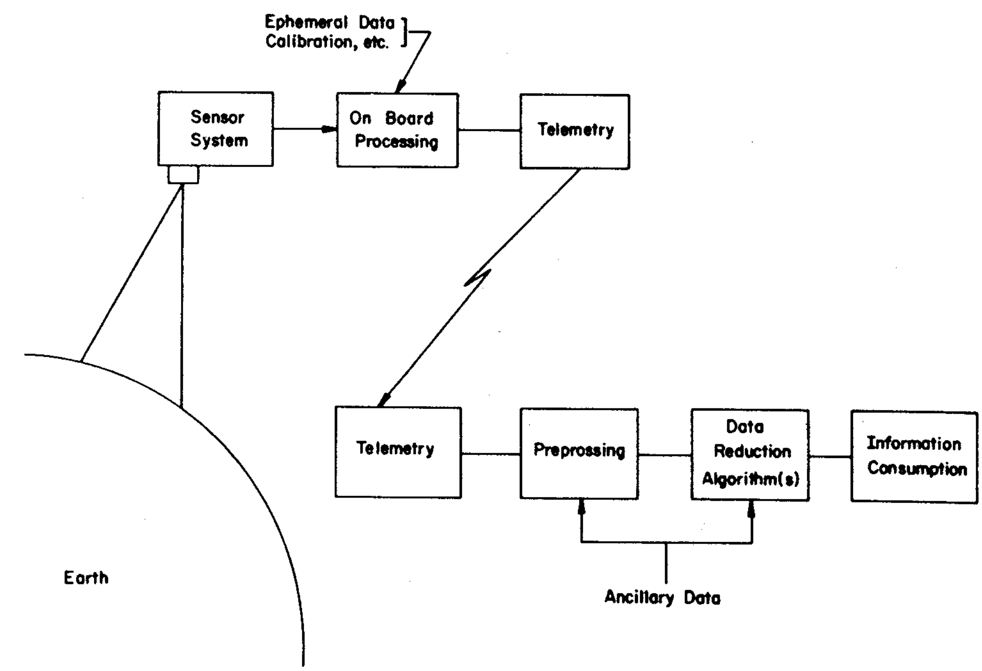


Figure 1. Major elements of an earth resources information system.

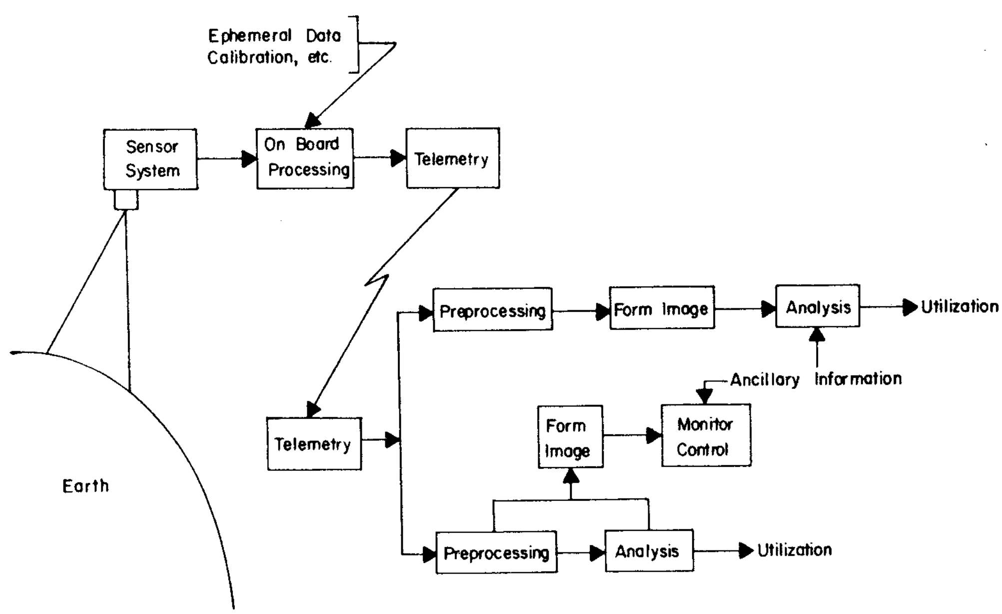


Figure 2. System organization for both image oriented and numerically oriented systems. The upper branch of the ground portion relates to image oriented systems; the lower branch is intended for numerically oriented ones.

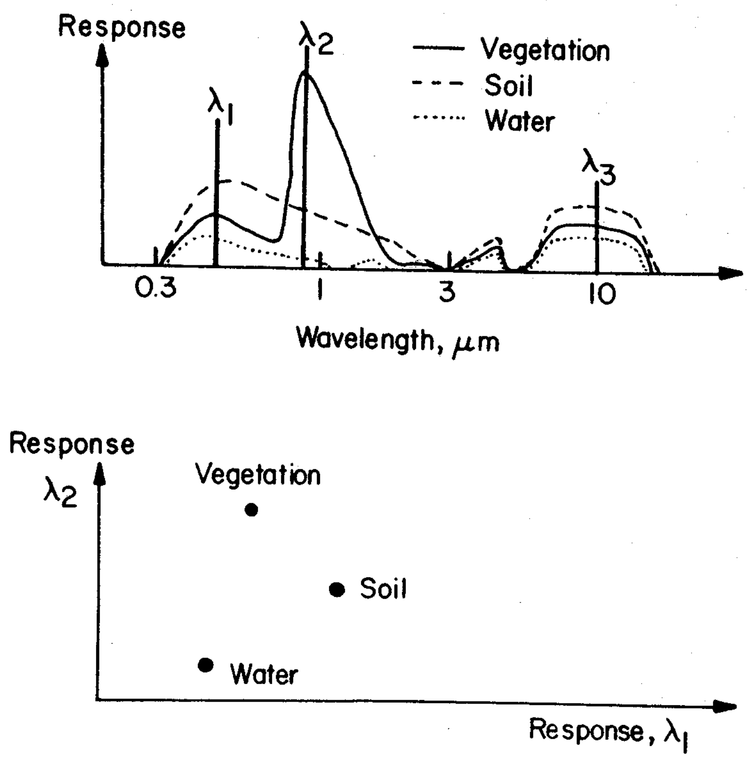
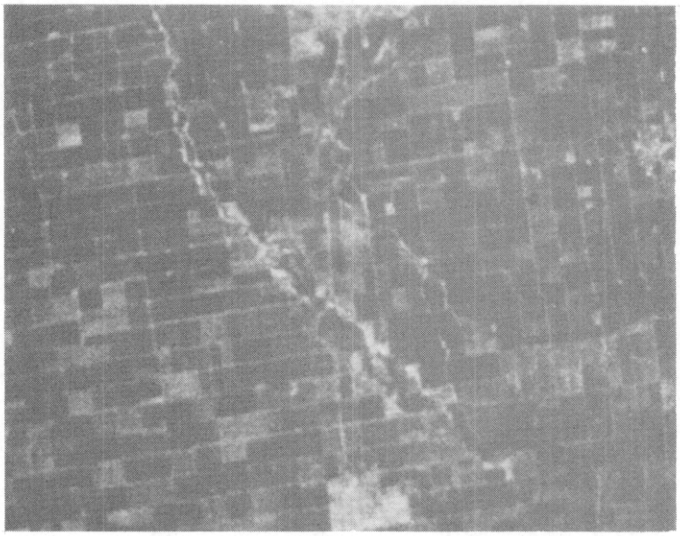
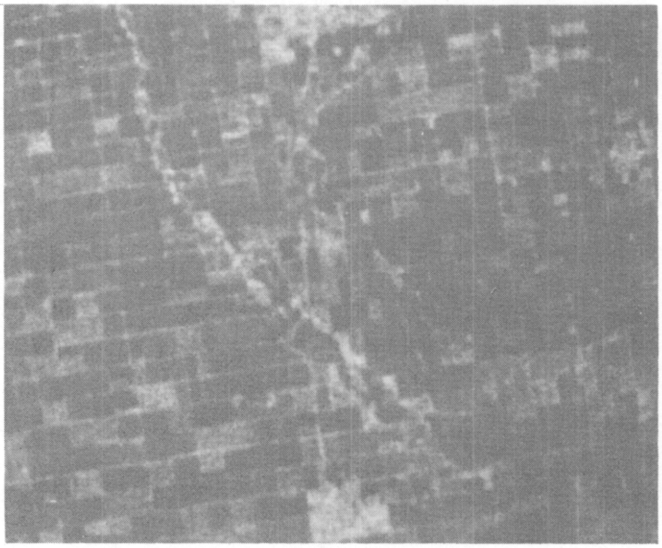


Figure 3. Spectral data and two dimensional feature space.



Original



8 x Compression

Figure 4. An example of data in image form before and after data compression, (Apollo 9, Frame No. 3698A).

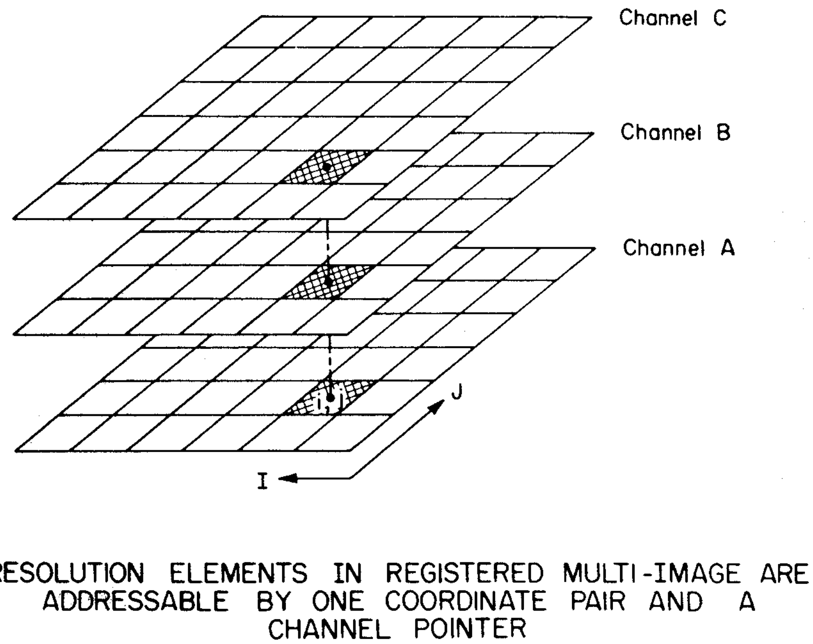


Figure 5. Multi-image data formed by image registration. The various channels are of the same scene but may be from different parts of the spectrum and gathered at different times.

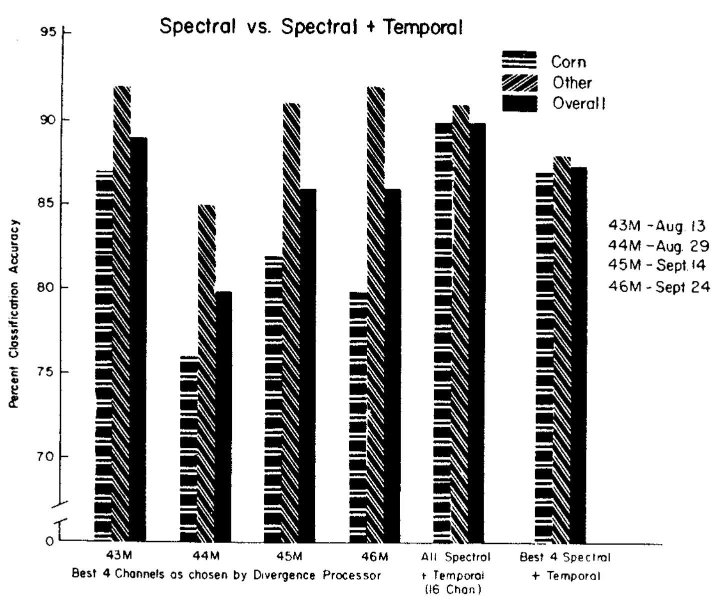
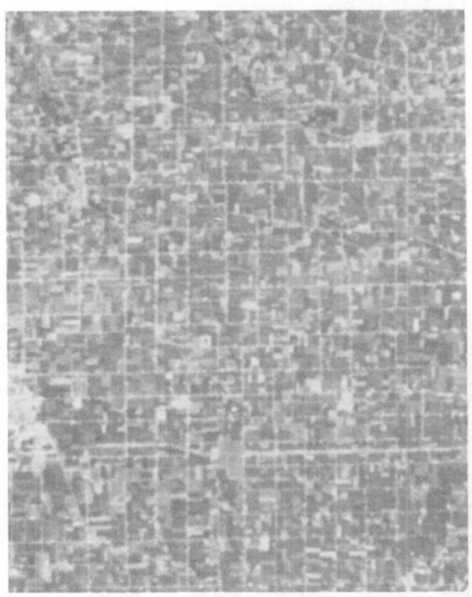


Figure 6. These bar graphs show the effect of temporal changes and the effect of these changes upon class discriminability.

Original Data



Deskewed, Rotated & Rescaled Data

Figure 7. Geometric correction of ERTS-1 data.

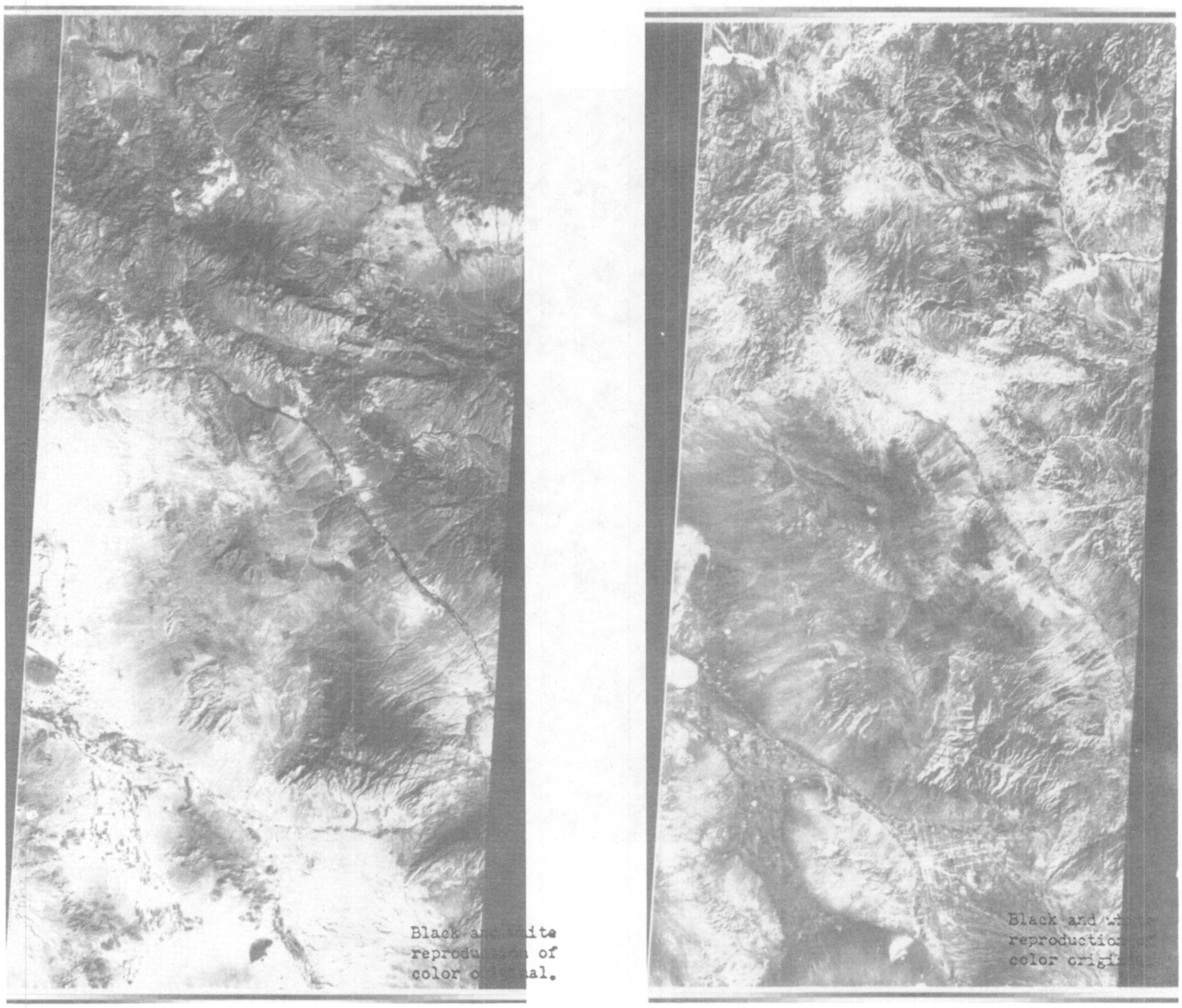


Figure 8. ERTS-1 data in simulated color IR (left) and color enhanced (right) form.

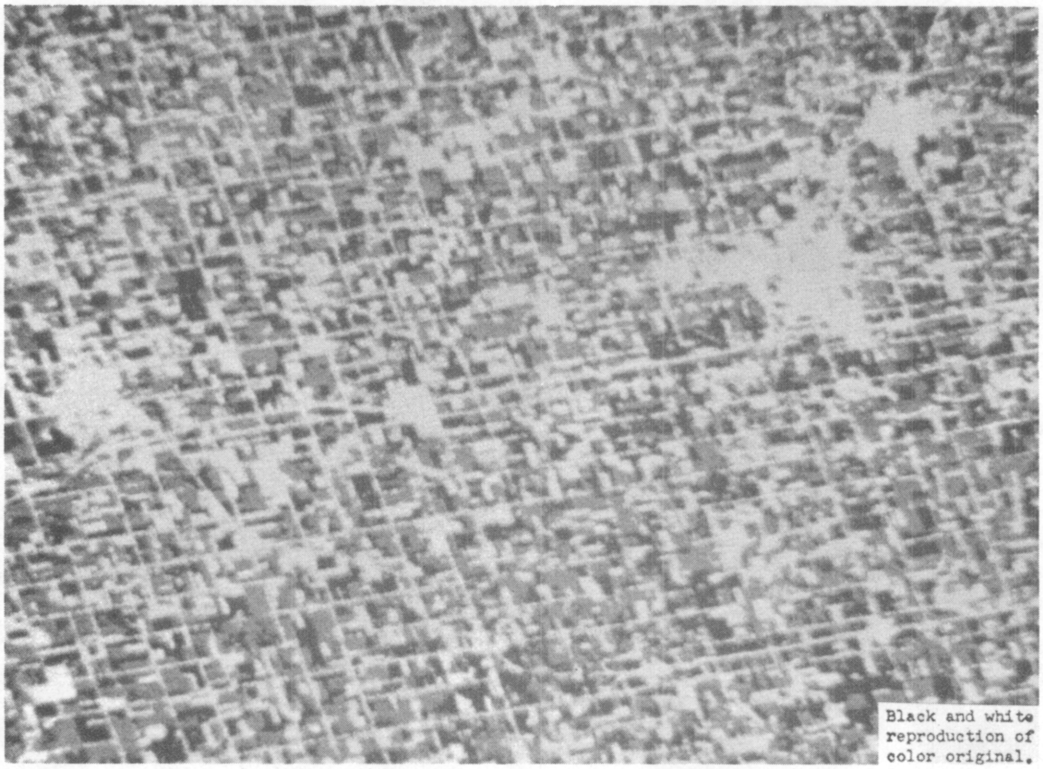


Figure 9. A map of a portion of northern Illinois showing areas in corn (red) soybeans (green) and other (white and yellow) classes. The map was generated by directly classifying ERTS-1 data.

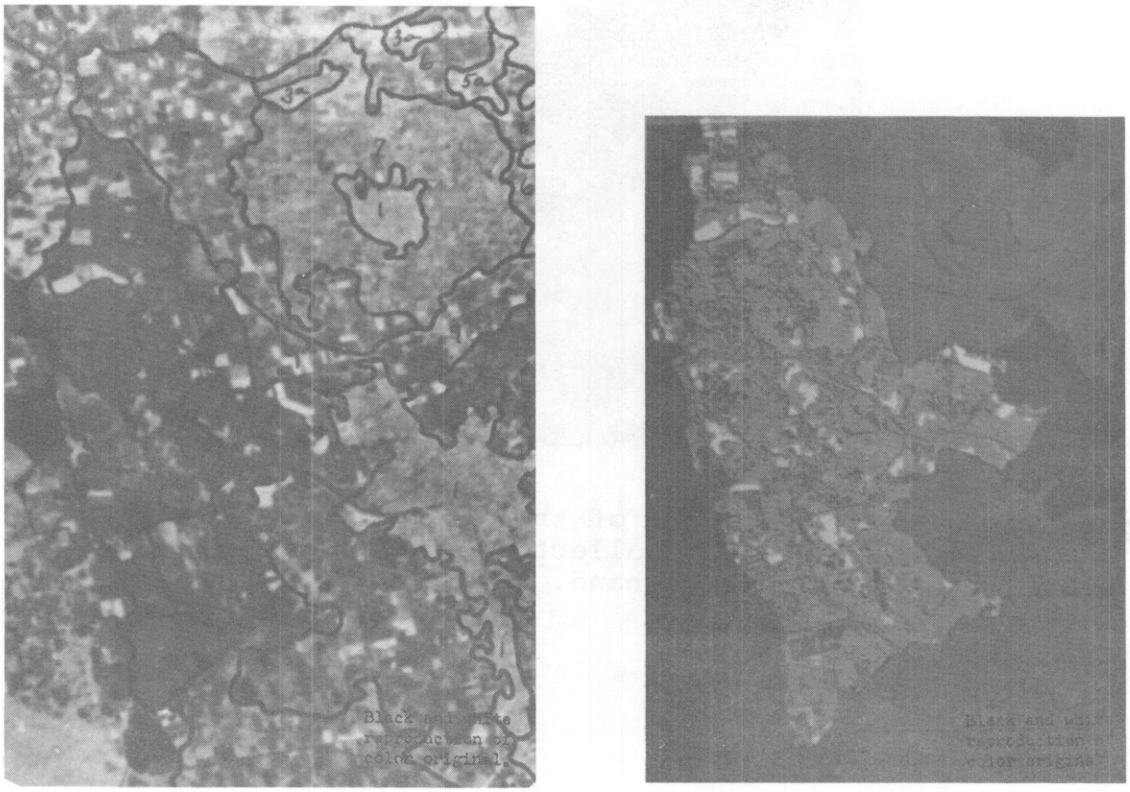


Figure 10. Analysis results obtained by a combination of image and numerically oriented methods. The left image shows the original data with boundaries for simple classes manually added. The right image shows the result in color coded map form of classifying the simple classes into more detailed ones by numerical means. The color code is: green, asparagus; red, sugar beets; pink, alfalfa; pale blue, tomatoes; black, water; and white, harvested.

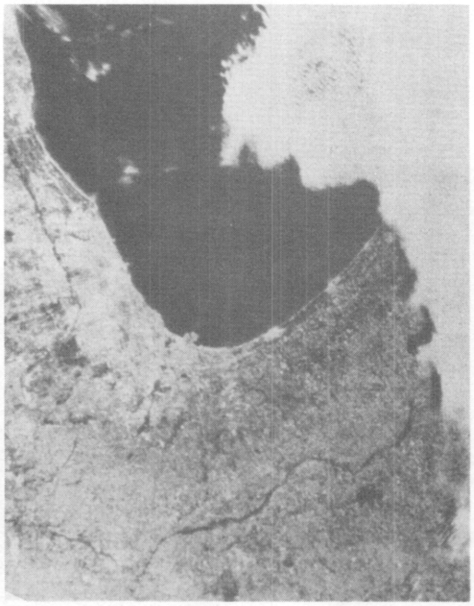


Figure 11. An ERTS-1 image of the Southern Lake Michigan. This data was collected October 1, 1972 in the 0.6-0.7μ meter band.

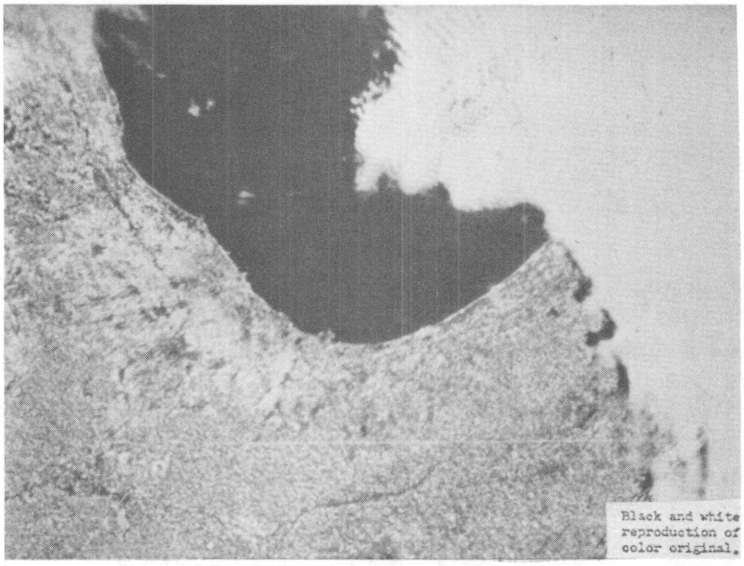


Figure 12. Digital data from the same ERTS-1 frame as Figure 11 but displayed in a contrast enhanced simulated color IR form.

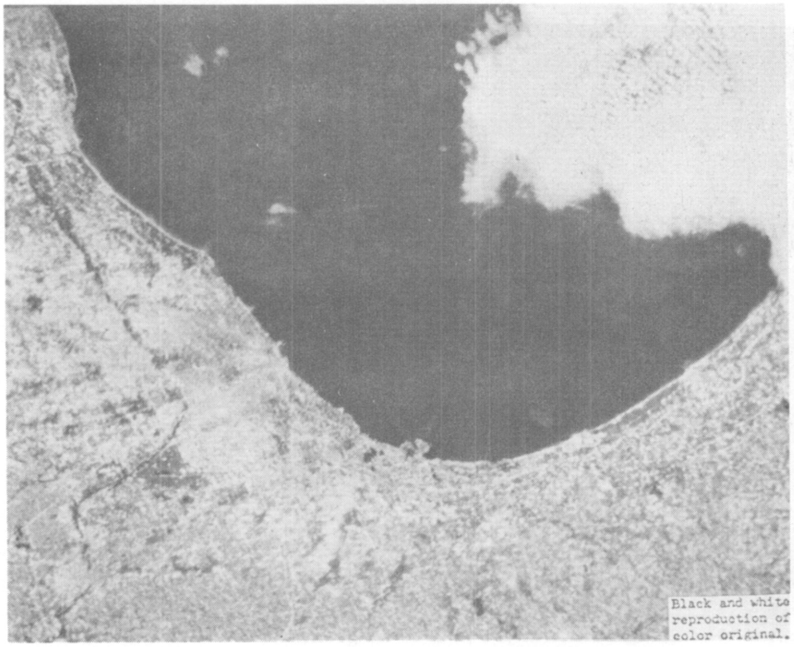


Figure 13. The digital data of Figure 12 displayed with increased detail.

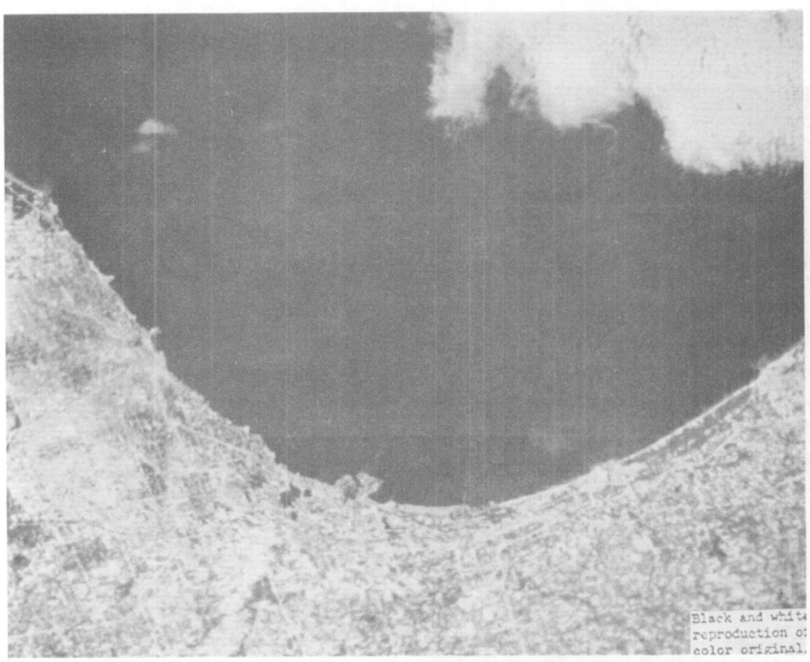


Figure 14. The digital data of Figure 13 displayed with further detail.

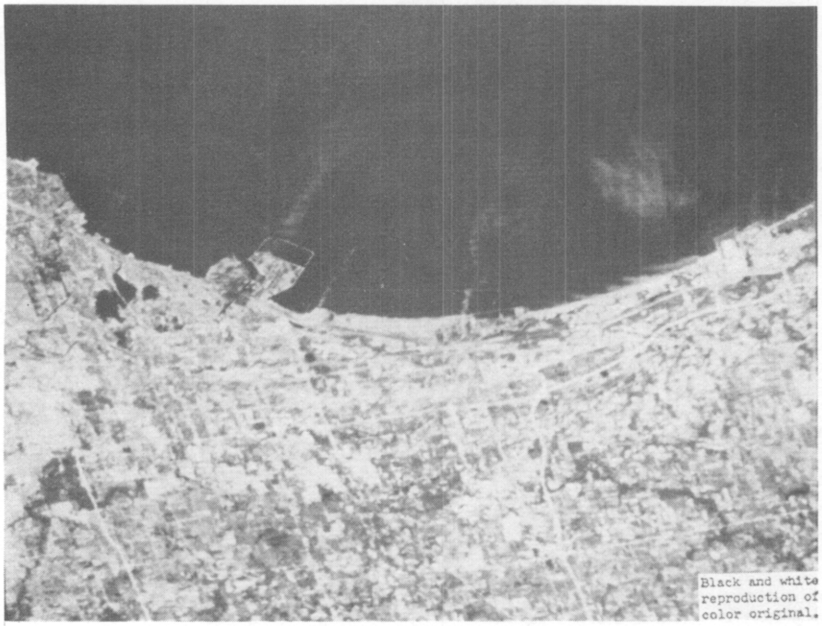


Figure 15. The digital data of Figure 14 displayed with still further detail.

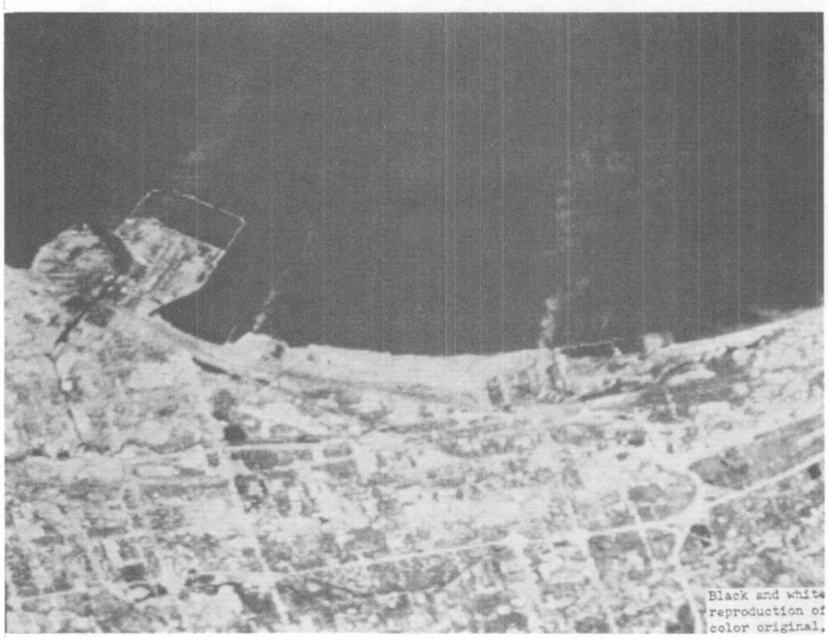


Figure 16. The digital data of Figure 15 displayed with full detail.