LARS REPORT 091977

DIGITAL MAPPING OF THE SANTA CRUZ INTEGRATED SUBREGION USING LANDSAT MULTISPECTRAL SCANNER DATA

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PURDUE UNIVERSITY, WEST LAFAYETTE, INDIANA

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ABSTRACT

Quantitative, detailed, and comprehensive information about the existing natural resources in the Santa Cruz Integrated Subregion of Bolivia is needed by the various government planning agencies.

This study was primarily concerned with the assessment of computer-aided techniques to analyze Landsat Satellite multispectral data for applications to regional mapping of natural resources in the Santa Cruz Integrated Subregion.

The LARSYS computer-aided processing and analysis software was utilized to produce cover type maps and tabulated areal extent information for six provinces in the Santa Cruz Integrated subregion. The analysis was performed on a province by province basis and the final multispectral classification maps (at scales of 1:25,000 and 1:50,000) and tabular results were previously made available to the Bolivian ERTS Program Office.

After the processing and analysis was completed at LARS, a team of Bolivian and LARS Scientists conducted a field evaluation of the computer-generated cover type maps. The results of this evaluation indicated that in general, the multispectral classification maps represented accurately most of the ground cover types present in the test site. Specially, the three major types of forest cover in the region were correctly identified and mapped. However, the identification of the agricultural crops was very difficult because at the time the Landsat data were gathered, (September 16, 1975) most of the agricultural crops had been harvested, and in the few instances in which there was sugar cane in the fields, they were spectrally confused with tall natural grasses which are very similar to the sugar cane plant.

Therefore, it is recommended that for an effective agricultural inventory, the Landsat data should be collected at a (several) time(s) of the year coincident with the growing season(s) of the various agricultural crops. Also it is recommended that additional verification field work be done by the Bolivian scientists to relate the spectral classes obtianed from the Landsat data to the informational classes present in the various provinces.

DIGITAL MAPPING OF THE SANTA CRUZ INTEGRATED SUBREGION USING LANDSAT MULTISPECTRAL SCANNER DATA

INTRODUCTION

This report describes the approach, procedures, and results of a cooperative research project between the ERTS Bolivian Program Office and the Laboratory for Applications of Remote Sensing (LARS) of Purdue University. The Project was conducted under the sponsorship of the Agency for International Development (A.I.D.) of the United States.

The project involves the use of data collected by the Landsat satellite over a large region of east-central Bolivia near the city of Santa Cruz. The satellite data is obtained in digital format, such that analysis of the data using computer processing techniques is possible. The basis of these techniques involves "pattern recognition" theory, whereby the computer is "trained" by experienced data analysts to recognize different "spectral response patterns". In essence, these spectral response patterns could be thought of as quantitative measurements of color, but involve wavelength bands in the infrared[1] as well as the visible portion of the electromagnetic spectrum. Since the Landsat satellite was designed to measure energy reflected from the ground in the green, red, and two infrared wavelength bands, the computer can be trained to recognize rather subtle differences in these reflectance measurements.

The pattern recognition approach to the analysis of such satellite data is based upon the theory that different objects on the surface of the earth reflect different amounts of energy in different wavelength bands. Therefore, vegetation is usually green, soil ranges in color from grey to black to yellow to red, water appears blue to brown to black, etc. If all features or cover types on the surface of the earth were absolutely constant and unvaried in their color (or spectral response), and if every cover type had a somewhat different spectral response from all other cover types, one could define a "unique" spectral signature that would correspond to each cover type. However, it is obvious that natural objects do not possess unique, unchanging spectral reflectance patterns. Vegetation often has significant variations in reflectance from one season of the year to the next; the same body of water is sometimes clear and sometimes turbid; agricultural lands sometimes are covered with

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[1] Strictly speaking, spectral response patterns can involve data from any portion of the electromagnetic spectrum, not just the visible and near infrared regions to which the Landsat detectors are sensitive.

green vegetation, at other times of the year are stubble or simply bare soil, etc. The key to these variations in spectral response is to determine which earth surface features or cover types can be accurately identified on the basis of their spectral response patterns, and at which time of the year such identification can be achieved most reliably. Experience over the past decade in working with remotely sensed spectral data and computer analysis techniques has shown that many cover types can be accurately and reliably identified using this type of data and analysis technique (Bauer, 1975; Hoffer, 1975).

The advantages of such computer-aided analysis of satellite data are that cover type maps and acreage estimates for large geographic areas can be obtained rapidly and more economically than by conventional photo interpretation techniques. Since Bolivia is a large country, and many portions of Bolivia have not been mapped in detail, the potential for utilizing Landsat satellite data and computer-aided analysis techniques appeared very promising to Dr. Carlos Brockmann, Director of the Bolivian ERTS Program. Initially, he worked with Landsat and Skylab satellite data in image format, and was outstandingly successful in utilizing this small scale satellite imagery for mapping geologic features, land use patterns, forest cover and hydrological features for the entire country of Bolivia. In addition, many areas and features of special interest have been successfully interpreted and analyzed by Dr. Brockmann and his staff, resulting in cost savings of millions of dollars in several cases. However, this imagery can only be effectively utilized in scales of 1:1,000,000 to 1:250,000 when interpreting the data manually. Computer-aided analysis techniques involve procedures whereby the computer classifies the cover type for each individual acre on the ground, and more detailed maps having scales of 1:50,000 or even 1:25,000 can be obtained. Furthermore, once the computer has identified the various cover types over a particular region of interest, it is a simple matter to have the computer tabulate the number of individual data points that were classified into each cover type, and an estimate of the acreage of each cover type for the entire area can thereby be obtained in a matter of a few seconds.

Recognizing the potential value of such computer-aided analysis techniques for meeting the information needs of Bolivia, Dr. Brockmann approached A.I.D. concerning the possibility of evaluating the feasibility for such computer-aided analysis techniques in Bolivia. He also contracted LARS at Purdue University about the possibility of such an endeavor, since LARS was the originator of this type of digital data processing and is well recognized nationally and internationally for their efforts in this area of research.

Following a series of discussions between Dr. Brockmann, A.I.D. officials and LARS scientists, a project was developed involving the computer-aided analysis of Landsat data for an area of critical importance near Santa Cruz, Bolivia, and also to train several Bolivian scientists at Purdue University.

The results of this cooperative project are the subject of this report.

OBJECTIVES

During the past few years, the agricultural production in the Santa Cruz area has been experiencing a rapid growth. Based on the increasing demand for agricultural goods to meet the national needs and export quotas, and considering the extensive colonization programs, it is anticipated that the agricultural production in the Santa Cruz Integrated Subregion will continue to increase. Therefore, quantitative, detailed, and comprehensive information about the extent and type of existing agricultural land use, and data concerning areas for future agricultural development is needed by Bolivian planning agencies.

Manual interpretation of Landsat imagery has clearly shown the advantages and benefits of this type of data and analysis procedure. However, previous studies at LARS and elsewhere have established the advantages of computer-aided analysis of Landsat MSS data for obtaining more detailed and quantitative cover type maps and acreage tables for various features of interest and over broad geographic areas. Therefore, this project was established to investigate the feasibility of applying computer-aided analysis techniques to Landsat data obtained over the Santa Cruz Integrated Subregion, in order to obtain quantitative and detailed cover type maps and acreage tables for each of the provinces in this area.

More specifically, the objectives of this project are to:

(1) Apply modern computer-aided analysis techniques to Landsat MSS data of the Santa Cruz Integrated Subregion in order to obtain geometrically correct cover type classification maps at scales of 1:25,000 and 1:50,000, and also to obtain a quantitative determination (in hectares) of the various cover types present, on a province-by-province basis. The analysis should attempt to classify such major cover types as agricultural lands, forested areas, rangelands, barren lands, water, wetlands, and cultural features. Each of these major cover types would also be classified into as many spectrally separable and meaningful subclasses as possible.

(2) Assist, advise and train two Bolivian scientists in the detailed procedures followed in the above analysis of Landsat MSS data and in the implementation of selected LARSYS Version 3.1 processors in a Bolivian computer system.

BACKGROUND

Computer-Aided Analysis of Remotely Sensed Data

In the mid 1960's, research efforts were initiated in the United States to investigate the potential of utilizing data obtained by multispectral scanner instrument systems for identifying and mapping various agricultural features of interest, (especially conditions indicating disease or insect infestations). At that time, multispectral scanner systems were just evolving, (and were flown from air-craft at altitudes from 500 to 10,000 ft.). Such instruments consist of a complex system of mirrors, lenses, prisms, and electronics such that reflected and/or emitted energy from a relatively small area on the ground (e.g. 10 ft. x 10 ft. from an altitude of 5,000 ft.) is measured and recorded simultaneously in each of several wavelength bands. These reflectance values from the different wavelength bands therefore define the spectral response pattern for the particular spot on the ground. The scanner mirrors are designed to rotate very rapidly in a manner such that reflectance data from a series of these small areas on the ground (called resolution elements) is recorded in sequence along a line (called a scan line). These scan lines are similar to the scan lines one sees on a T.V. screen. In the case of multispectral scanners, the scan lines are oriented prependicular to the direction of flight. Therefore, as the airplane moves forward, the scanner records the reflectance values for a new scan line, and another, and another, until eventually the reflectance measurements for an entire strip of the earth's surface below the airplane have been recorded on magnetic tape.

Early research with such multispectral scanner data indicated that a potential did exist for identifying various agricultural features of interest through the use of such data, but also showed that some type of computer processing technique would be essential to effectively analyze the type and quantity of data that such instrument systems produce (Hoffer, 1966).

As a result of the potentials that were indicated by this preliminary work, in 1966 the Laboratory for Agricultural Remote Sensing (later renamed the Laboratory for Application of Remote Sensing) was founded at Purdue University, with an overall goal of applying computer technology to the quantitative analysis of multispectral earth resources data. In 1967, the first results were obtained which proved that pattern recognition theory could be applied to multispectral scanner data for purposes of identifying and mapping selected agricultural cover types or species (Landgrebe, 1967).

Although it was still fairly early in the space program being developed by NASA (the National Aeronautics and Space Administration), a number of scientists involved in the development of this remote sensing technology recognized the potentials for utilizing multispectral scanner systems aboard earth-orbiting satellites to gather earth resources data. It was also recognized that the rate of acquisition and volume of data that could be collected by such satellite systems would be staggering. The application of computer processing techniques involving pattern recognition theory appeared to be appropriate for handling such data, since the data are gathered in a quantitative format, and since the data analysis techniques involved are also quantitative in nature. For these reasons, much of the early research work at LARS was designed to develop the techniques and procedures that would be suitable for analyzing the multispectral scanner data that eventually was to come from the Landsat satellite system.

Because LARS is part of a University whose main functions are education, research and service, there were, and are still, a number of key elements that influence the thinking and the approach taken by the remote sensing scientists at LARS, and which are important in assessing the utility of computer-aided techniques as applied to multispectral scanner data of earth resources. One of these is that for the forseeable future, man is an important and indispensable part of the overall analysis process, which should therefore be described as "computer-assisted" rather than "automatic" data analysis. Also, it is recognized that multispectral scanner systems have several inherent advantages as compared to photographic systems, but they also have some disadvantages. The quantitative characteristics of the data obtained by multispectral scanners make computer-aided analysis techniques particularly appropriate for analyzing this type of data, whereas photographic data can generally be analyzed by conventional photo-interpretation techniques. Therefore, effective utilization of remote sensing techniques should not necessarily involve either multispectral scanner systems or photographic systems, but rather should attempt to utilize an optimum combination of both systems in a manner that emphasizes the advantages of each system. Another key element of the approach development by LARS was that of technology transfer. As various data processing and analysis procedures were developed, it was believed to be important that other scientists throughout the U.S. and the world should have access to these capabilities. For these reasons, much of the LARS software was documented in a software package called LARSYS Version 3.1, which is now available to anyone anywhere in the world, simply for the cost of reproduction (through COSMIC). In addition, a series of remote terminals were established at NASA and USGS centers, universities, and even state government offices throughout the country, so that these people might have access to the same analysis capabilities as the LARS scientists. Other technology transfer activities involved the development of a series of mini-courses (slide-tape units with a study guide) which provide tutorial material on a wide range of remote sensing subjects; the development of a one-week long short course on quantitative remote sensing, which is offered the first week of every month; and of particular interest of this project is the visiting scientists program, whereby scientists from throughout the world come to LARS to spend anywhere from three months to two years studying remote sensing technology with various members of the LARS staff.

Thus, in summary, one could say that the overall approach followed at LARS is to conduct research, primarily in the area of computer-aided analysis techniques as applied to multispectral scanner data, in order to optimize the effective interaction of man and computer, using the complementary capabilities of each, to produce rapidly and efficiently the quantitative and accurate information needed in a wide range of earth resource applications; and secondly, to transfer the results of this work to the rest of the remote sensing and earth resource community. As indicated earlier, much of the early work was directed at developing the understanding and the techniques necessary to effectively utilize multispectral scanner data from satellite altitudes, and since the launch of Landsat-1, the emphazis has been on developing more effective techniques to utilize this type of data for various earth resource applications.

The Landsat Satellites

In July 1972, the National Aeronautics and Space Administration (NASA) launched the first Earth Resources Technology Satellite, originally called ERTS-1. The purpose of this satellite was to obtain data about the surface of the earth for various earth resource applications. Although it was designed to have a one year life expectancy, the system has functioned so well that in 1977 it is still producing useable data in three of the four wavelength bands. Because ERTS-1 functioned so well, it was not until February 1975 that the second satellite (identical to the first) was launched to continue the data collection task. At about the same time (1975) the satellites were renamed Landsat.

In order to collect data over as much of the earth's surface as possible, the Landsat satellites were placed in a near-polar orbit at a nominal altitude of 900 km (570 miles). The satellites circle the earth 14 times per day, with each pass being located approximately 1800 miles west of the previous pass. In this way, since the earth has rotated approximately 1800 miles in the 103 minutes between Landsat passes, the satellite always passes overhead at about the same local time for all portions of the earth's surface (nominally at 10:30 AM at the equator). This orbit also enables data to be obtained over the entire earth's surface every 18 days. Therefore, if it collects data today where you are located it will collect data tomorrow along a path about 160 km (100 miles) to the west, and 18 days from today, it will again pass over your location.

The primary instrument of interest on Landsats 1 and 2 is a 4-band multispectral scanner system. (There is also a Return Beam Vidicon RBV and a Data Collection Plat form DCP relay system, but since these systems were not involved in the present study, they will not be described here). The multispectral scanner (MSS) system on the Landsat satellites collect data in the 0.5 - 0.6 μm (green), 0.6 - 0.7 μm (red), 0.7 - 0.8 μm (reflective infrared), and 0.8 - 1.1 μm (reflective infrared) wavelength bands. The swath width of the scanner is 185 km (115 miles), so that as the satellite passes overhead, it collects data continuously from an area 185 km wide. For ease of handling, the MSS data is divided into frames having dimensions of 185 x 185 km which corresponds to the frame size of the RBV data. It takes the satellite only 25 seconds to collect a frame of data which covers an area of 3,422,500 hectares (or 8,556,250 acres).

As is the case for all scanner systems, the data is collected in a series of scan lines which can be numbered, and the individual resolution elements along each scan line can also be numbered. This allows an X-Y coordinate system to be developed for any particular frame of Landsat data, such that any resolution element or data point in the frame can be addressed by the computer in the analysis process using the appropriate X-Y coordinates (line and column numbers). Each resolution element of Landsat data covers an area on the ground of approximately 79 x 56 meters. Therefore, on the geometrically corrected computer line-printer output which has a 1:25,000 scale, each resolution element represents an area of approximately 0.48 hectares or 1.1 acres. Because of the size of the resolution elements, it is easily seen that very small objects (i.e. individual trees, houses, small road, etc.) cannot be discerned on Landsat data. However, when one considers that data can be gathered at relatively frequent intervals throughout the year (cloud cover permitting), and for essentially every individual acre of the earth's surface, the potentials for such a system appear tremendous. This is particularly true when it is remembered that a data tape containing a full frame of MSS data can be obtained for any location on the earth's surface for only U.S. $200, which amount to approximately 171 hectares (428 acres) of data for 1 cent U.S. However, when one also considers the fact that each frame of Landsat MSS data contains data from over 7.5 million resolution elements in each of four wavelength bands, with each band measuring up to 128 levels of reflectance, the need for some type of computer processing to handle this tremendous amount of data becomes obvious, if a quantitative approach to the analysis of the data is to be pursued.

METHODS AND MATERIALS

Data Utilized

The Landsat data utilized in this project involves one frame (scene ID: 2237-13340) gathered over Santa Cruz, Bolivia on September 16, 1975. The center coordinates for this frame are Latitude $17^{\circ}13'$ South and Longitude $63^{\circ}44'$ West. This frame covers the western portion of the Santa Cruz Integrated Subregion. Figure 1 shows the Landsat coverage of Bolivia in which the shaded area indicates the location of the "Buena Vista" frame used in this study. This study was focused upon the digital analysis of a computer-compatible tape of this frame of Landsat MSS data. Black and white, as well as a color IR prints of this frame of Landsat data at a scale of 1:250,000 were also utilized to supplement the aerial photos in locating and selecting training data blocks. In addition to the Landsat data tape and imagery, aerial photos (B&W 1:30,000 scale) which had been obtained in June 1976 were available for portions of the study area. These photos were utilized to select representative training areas and to evaluate the effectiveness of the training statistics just prior to the final classification of each province.

Province boundaries were delineated on 1:250,000 scale Landsat image and supplied to LARS for digitizing and separating the Landsat data into the individual provinces. These boundary locations were obtained from existing cartographic maps of Bolivia, and were transcribed from these maps to the 1:250,000 Landsat image by the staff of the Bolivia ERTS Program office. Another type of data utilized in this study involved field data concerning the various cover types and their condition at the time of year the Landsat data had been collected. Reference data of this type was in the form of representative color photographs of the various cover types and personal knowledge of the area by the Bolivian scientists working on the project (particularly Ing. Ruben Zerain).

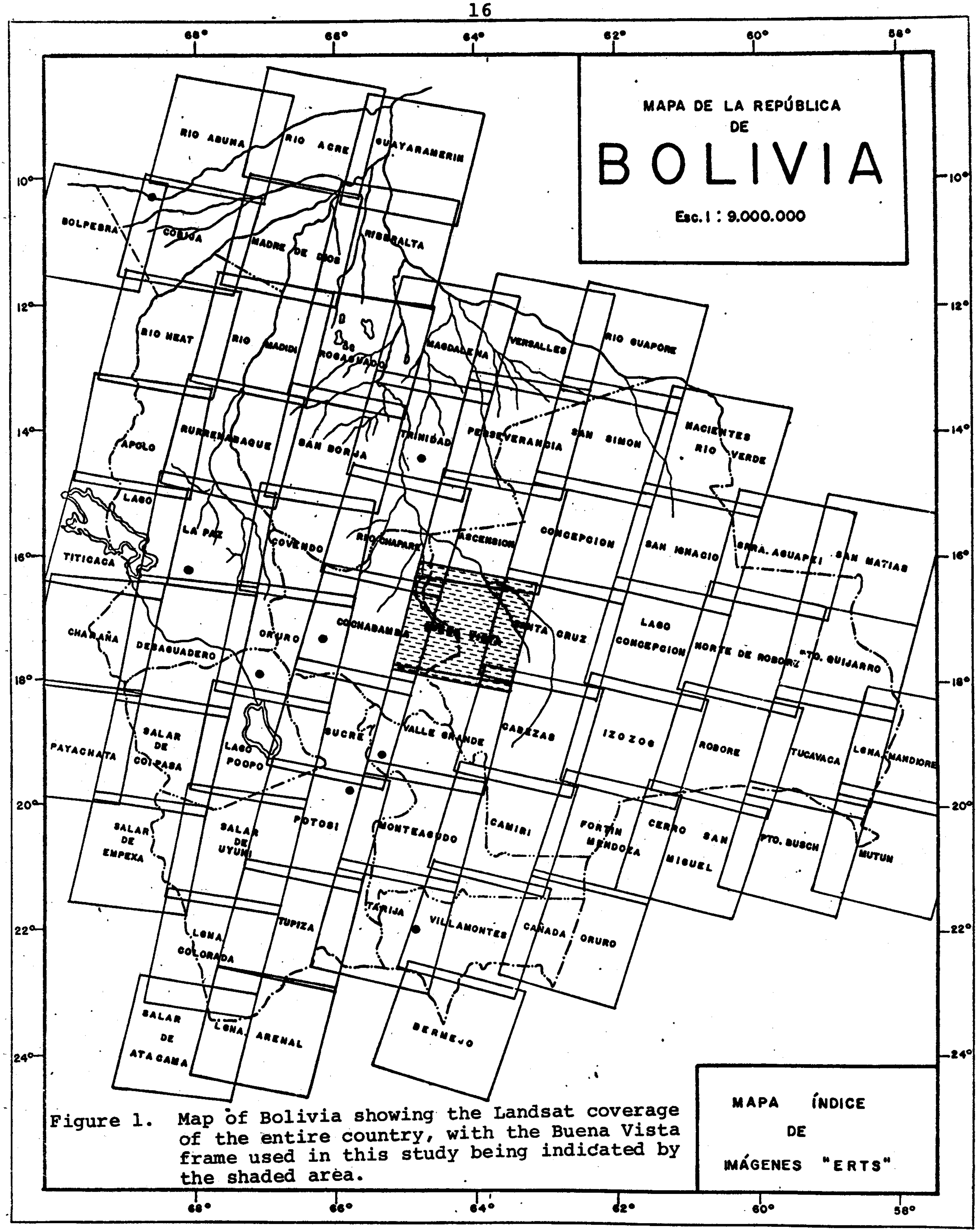

Figure 1. Map of Bolivia showing the Landsat coverage of the entire country, with the Buena Vista frame used in this study being indicated by the shaded area.

Test Site Description

The area analysed in this project covers part of the Santa Cruz Integrated Subregion which contains extensive forest reserves (including the Choré and Guarayos reserves), agricultural fields, wet lands, and pasture lands.

The forest type in the area ranges from deciduous trees in the southern part to evergreens (not coniferous species) in the northwestern part of the Buena Vista frame. Between the northern and southern portions of the test site, there is an extensive and complex transition zone in which the predominant forest type is a mixture of deciduous and evergreen trees.

The major agricultural production in this area involves fields of sugar cane, cotton, pasture, grasses, rice (dry land rice), soy beans, corn, winter wheat, and citrous plantations. Most of the agricultural fields in this area area small irregularly shaped fields.

A large portion of the northeastern part of the Buena Vista frame is covered by wet lands (primarily grasses) located along the Rio Grande river. During the dry season, these wet lands are used for cattle grazing in addition to the pasture lands which are found throughout the entire Buena Vista frame.

Most of the region covered by the Buena Vista frame is physiographically classified as a plain (llanura Chaco-Beniana) having a mean elevation of approximately 400 meters above sea level. However, there is some rolling terrain, peidmont topography, aeolian deposits (sand dunes distributed along a NW-SE direction which indicate the predominant NW wind direction), and mountains corresponding to the Bolivian Sub-Andean (Subandino) morpho-structural belt.

The climate in this region ranges from dry subtropical in the southeastern part to humid tropical climate in the northwestern part of the area covered by the Buena Vista frame.

The hydrographic network in this region is composed of the several tributaries of the Amazon river, that is, the Rio Grande, Rio Piraí, Rio Yapacaní, and Rio Ichilo. Numerous shallow and turbid lakes are also found in the northern part of the test site.

The mean annual precipitation in this area ranges from approximately 1,300 mm (50 inches) in the southern part to over 2,000 mm (80 inches) in the northern part, with an annual mean temperature of 24°C (75°F).

Although from an ecological point of view, the area covered by the Buena Vista frame is extremely complex, the major cover types can be classified as follows:

1) Water bodies. All of these are natural water bodies which include rivers, streams, lakes, and lagoons or ponds. Most of the rivers and lakes are turbid (high concentration of suspended organic and inorganic solids), and the lagoons and ponds are shallow and usually covered by aquatic vegetation. Some of these lakes and most of the lagoons and ponds are temporal

water bodies, i.e. they are dry during the dry season.

2) Soils. The soils in this area are young in age and have been originally formed from aeolian (wind) and fluvial deposits. These are generally classified as sandy soils. Some silty soils are also found in this area.

3) Deciduous Forest. This type of forest is composed mainly of xerophytic species. One of the "chaparral" classes which was composed of short xerophytic species, frequently having a dense canopy, was included as part of this forest type in the analysis. The predominant species of the deciduous type of forest are:

Choroqui (Ruperchtia triflora)
Algarrobo (Prosopis juliflora)
Ajunado (Andina inermis)
Palo Blanco (Calycophyllum multiflorum)
Tajibo (Tabebuia sp.)
Charahuata (Bromelia sp.)
Toborochi (Chorisis ventricosa).

The deciduous forest is found primarily in the Chaco plains (llanura Chaqueña) and the gentle slopes of the subandean (subandino) belt. That is, in the southern part of the area studied in this project.

4) Semi-evergreen forest. This type of forest is composed of a mixture of deciduous and evergreen trees and is found in the transition areas between the

deciduous forest in the south and the evergreen forest in the north and northwest. The semi-evergreen forest ranges from tall to medium height trees with the deciduous species losing their foliage during the dry season (approximately from May to November). The predominant species of this forest type are:

Algarrobo (Prosopis juliflora)
Alcornoque (Tecoma sp.)
Almendro (Magonia glubrata)
Bibosi (Verschiedene arten)
Cuchi (Astronium urumdeuva)
Curupaú (Piptadenia macrocarpa)
Mapajo (Bombax sp.)
Mara (Swietenia macrophilla)
Morado (Platymiscium floribumdum)
Ochoó (Hura crepitana)
Palo Santo (Triplaris caracacena)
Tajibo (Tabebuia sp.)
Motacú -palm (Attalea princeps)
Totaý-palm (Acrocomia totay)

This semi-evergreen forest is primarily found in the forest reserves of Guarayos and Choré.

5) <u>Evergreen Forest</u>. This type of forest is composed mainly of broad-leaf tropical trees which never lose their foliage, except some species lose some of their leaves during their flowering stage. The annual mean precipitation in the areas where the evergreen forest is found, is greater than 2,000 mm (80 inches) and the

mean temperature in approximately 25^{0}C (77^{0}F). The typical characteristics of the evergreen trees in the study area are: a) tall, straight, and smooth trunks, and (b) narrow crowns. These trees form an extremely dense forest cover with heights of over 30 metres (100 ft), and constitute the most economicaly valuable sources of timber. Also typical of this forest type is the presence of aerial plants (such as orchids) and "Bejucos" (rope-like features that hang from the tall trees). The most important species of evergreen trees found in the area covered by the Buena Vista frame are:

Guitarrero (Didymopanax morototoni)
Palomaria (Calophyllum brasiliensis)
Canelón (Anibo puchuryminor)
Ochoó (Hura crepitana)
Verdolago-Negro (Terminalia sp.)
Mara (Swietenia macrophilla)
Sangre de toro (Virola sebifera)

The evergreen forest is primarily found in the western and northwestern part of the area covered by the Buena Vista frame.

6) Range Land (Pastizales). This vegetative cover type is primarily composed of natural pastures which range from short grasses to very tall grasses that resemble sugar cane plantations. The most important species of grasses found in the area covered by the Buena Vista frame are:

(Paspalum sp.)

(Aristida sp.)

(Hyparrhenia bracteata)

(Elyonurus adustus)

Most of the range lands are found in the eastern and central parts of the Buena Vista frame. Certain species of these pastures commonly grow along the low lands adjacent to the Rio Grande river.

7) Wet Lands. These are extremely humid areas that are temporarily covered by water (flooded). These wet lands are covered by certain types of hydrophilous grasses and shrubs, and by a bamboo-like plant commonly known in the region as "chuchio" (Gynerium). During the dry season, the wet land areas are generally used for cattle grazing.

8) Agriculture. A large partion of the area covered by the Buena Vista frame is used for agricultural purposes. Most of the agricultural fields in this area are relatively small (from 5 to 10 hectares in size). The major agricultural crops grown in this area are:

Sugar cane

Cotton

Grazing pastures

Rice (dry land rice)

Wheat (winter wheat)

Citrous Plantations

During the time when the Buena Vista frame was collected (September 16, 1975) most of the crops in the area had already been harvested. Only a few small sugar cane fields had not been harvested yet.

9) Barren lands. This type of lands are those mainly composed of sand flats and sand dunes that are not covered by any type of vegetation. Most of the sand dunes are found on the western side and southern part of the city of Santa Cruz. The sand flats are also found along the rivers of the region.

Figure 2 shows some examples fo the various cover types present in this region.

Data Pre-processing

Before the Landsat MSS data tapes are ready for processing and analysis, they have to undergo a series of pre-processing steps. These pre-processing steps include 1) reformatting, 2) geometric correction, and 3) boundary delineation.

Reformatting. - Landsat data reformatting is the pre-processing step through which the original NASA computer compatible tapes (CCT's) that contain the digital Landsat data are converted to a format compatible with the LARSYS processing and analysis software. The LARSYS format is a highly efficient format for inputing multispectral data to the LARS multispectral processing system.

Geometric Correction. - The Landsat multispectral scanner (MSS) data received by the satellite ground stations is calibrated and line-length adjusted by NASA, but no geometric corrections are applied to the digital data tape. Thus, the digital form of the Landsat MSS data contains several serious geometric distortions. To rectify and compensate for these

Evergreen forest
(slide)

(slide)
Mixed Forest

A

B

Deciduous

Brush Land

C

D

A. Evergreen Forest.

B. Mixed forest, containing both deciduous and evergreen species.

C. Deciduous Forest.

D. Brush Land. Areas such as this are common and are quite variable in their characteristics and spectral response. Such areas were referred to as "chaparral", in the analysis.

Chaparral

E

E. Another example of the type of area referred to as "chaparral", having scattered brush and trees with a grass background.

Figure 2. Photographs illustrating some of the characteristics of the various cover types in the test site.

Sand Dunes
(slide)

Tall Grass
(man in foreground)
(print)

F

G

Wetlands

Pasture
(with cows)
(print)

H

I

Agricultural
fields (slide)

J

F. Sand dunes, with mixed brush and grass (referred to as "chaparral") in surrounding area. Some agricultural fields in background.

G. Tall grass. When green, this tall grass looks very much like sugar cane from the air.

H. Wetlands area. Some vegetation is often standing in water.

I. Pasture. In areas as heavily grazed as this, the reflectance essentially represents a bare soil.

J. Agricultural fields. Note that most fields are very narrow, having approximately the same width as the size of a Landsat resolution element.

Figure 2. (continued)

Sugar Cane at 2 stages of growth (print)

Sugar Cane being harvested (slide)

K

L

Dark Soil (print)

Light Soil (print)

M

N

Houses in Santa Cruz (slide)

O

K. Sugar cane at two stages of growth.

L. Sugar cane being harvested. Note that a considerable amount of residue remains on the ground.

M. Agricultural soil. Sugar cane had been grown here, but the residue had been burned, thereby adding to the dark tone of the soil.

N. Light colored sandy agricultural soil. This type of soil is typical of this area.

O. House rooftops in Santa Cruz city. This typical conditions helps to explain why Santa Cruz had a spectral response similar to one of the agricultural soil catagory.

Figure 2. (continued)

geometric distortions, LARS scientists have developed and implemented a set of computer programs that can produce a geometrically correct Landsat image when displayed on either a video digital display device, or a computer line printer.

The LARS standard geometric correction function consists of a series of linear transformations which act on a specified block of Landsat MSS digital data. The output of these transformations is a Landsat data tape containing an image which has been corrected for 1) sampling aspect ratio differences in the vertical and horizontal directions, 2) off-north orientation of the image due to the non-polar orbital track of the spacecraft, 3) skew effects caused by the earth rotation, and 4) scale differences of the output products.

For this project, after the digital data were reformatted, the Buena Vista Landsat MSS frame was geometrically corrected and the output scale was set to 1:25,000 when displayed on a standard computer line printer format.

<u>Boundary Delineation.</u> - Because one of the objectives of this project called for the multispectral classification and cover type mapping of the Santa Cruz Integrated Subregion on an individual province by province basis, the entire Buena Vista Landsat (geometrically corrected) frame was digitally subdivided into nine individual provinces. It should be noted however, that the Buena Vista frame did not completely cover any one of the nine provinces. Figure 3 shows a Landsat photomosaic of Bolivia in which state boundaries are delineated, and for the state of Santa Cruz, all the province boundaries are delineated. The Buena Vista frame coverage

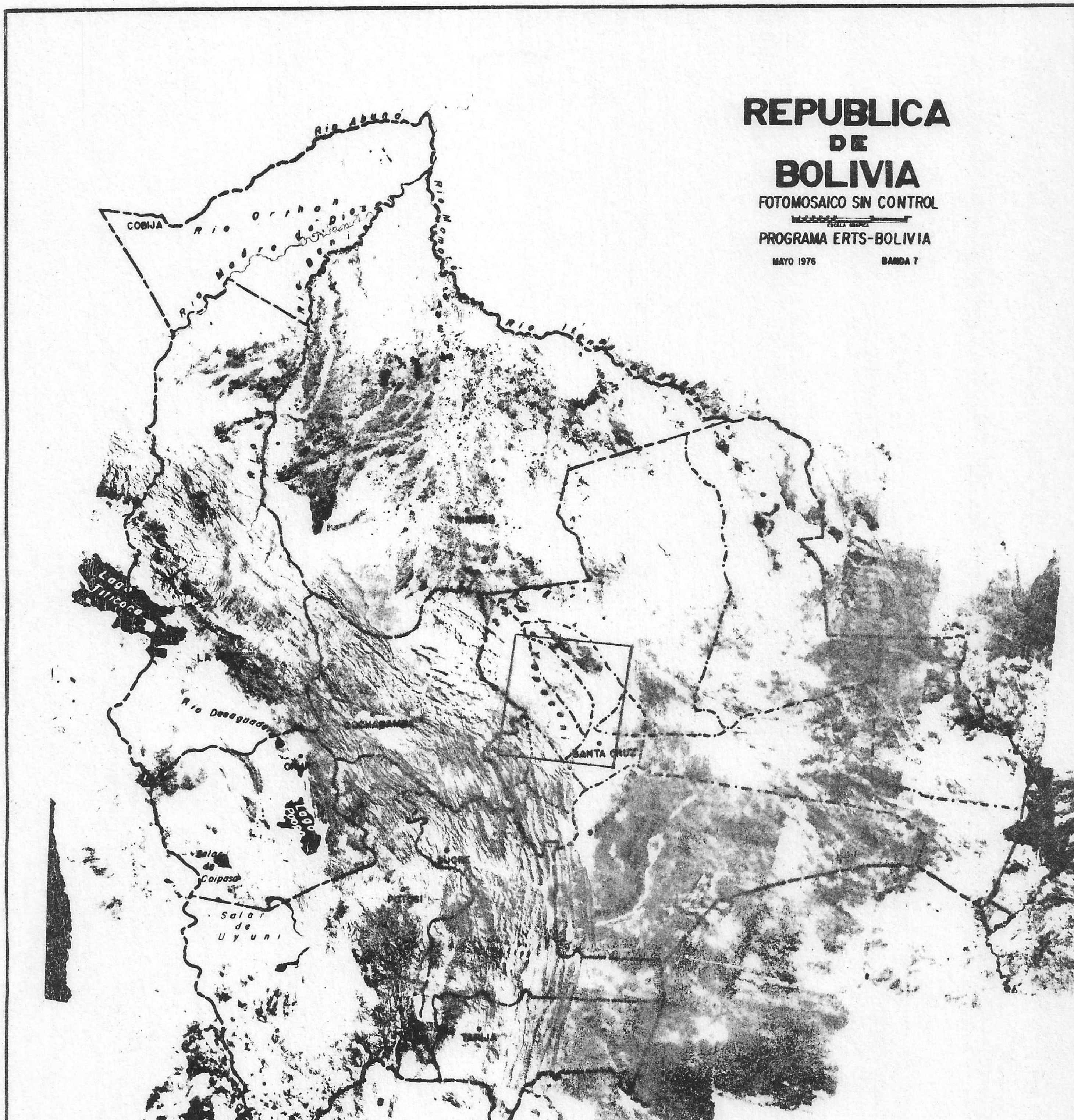

Figure 3. Landsat photomosaic of Bolivia. See Figure Captions

is also defined. Figure 4 shows the Buena Vista frame and the boundaries of the provinces covered by the Landsat data used in this study. To delineate the province boundaries on the Buena Vista digital data, the Bolivian ERTS Program provided LARS with a Landsat photographic product of the Buena Vista frame (at a scale of 1:250,000) which contained the boundaries of the nine provinces. The boundaries were digitized at LARS and the resulting X-Y boundary coordinates were digitally registered (overlaid) onto the geometrically corrected Landsat data. The result of this pre-processing step was a tape containing nine separate data files which corresponded to the nine provinces. Table 1 shows the name of the provinces or portions of provinces contained on the Buena Vista frame, their respective LARS identification number (run number), their tape and file location information, and their political location in Bolivia.

In the separate file format, the Landsat multispectral scanner data of the Buena Vista region was ready to be processed on an individual province by province basis. It should be noted that since the province boundaries were initially delineated on a 1:250,000 scale image and the final outputs from the digital data were 1:25,000 maps, any variations from the true province boundary locations on the 1:250,000 image were amplified by a factor of ten on the resulting 1:25,000 digital maps

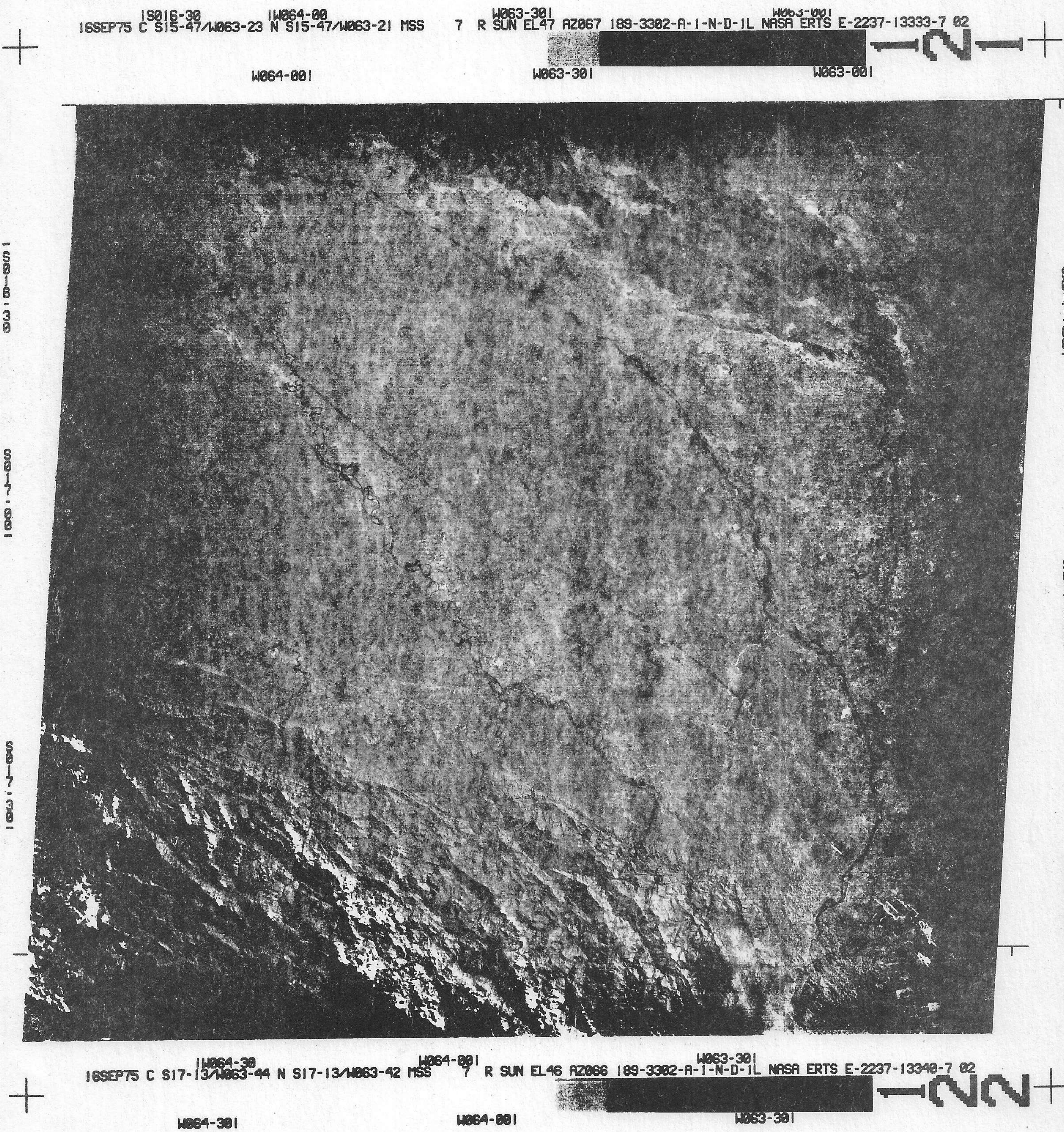

Figure 4. Buena Vista Landsat Frame (band 7) showing the boundaries of the provinces analyzed in this study.

TABLE 1. Identification Information for each Province Covered by the Buena Vista Landsat Frame.

Province	LARS Run #	Tape #	File #	Location
Andres Ibañez	75016110	3492	1	Santa Cruz
Warnes	75016112	3494	1	Santa Cruz
Ñuflo de Chavez	75016111	3494	3	Santa Cruz
Santiesteban	75016109	3494	4	Santa Cruz
Gutierrez	75016107	3493	3	Santa Cruz
Ichilo	75016104	3492	2	Santa Cruz
Florida*	75016108	3493	1	Santa Cruz
Caballero*	75016106	3494	2	Santa Cruz
Carrasco*	75016105	3493	2	Cochabamba

Data Processing and Analysis Procedures

As indicated in the previous section, the entire Buena Vista frame was subdivided into nine individual provinces. This allowed the processing of the data on an individual province by province basis.

The first step in the processing sequence involved the production of grey-scale maps (*PICTUREPRINTS) for each province at a scale of 1:25,000. These maps were used in conjunction with the color infrared composite image and the available aerial photography to select an appropriate number of training areas on the grey-scale maps (ranging from 4 to 7 areas depending on the size and complexity of the province).

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*These three provinces were not processed because they are not part of the Santa Cruz Integrated Subregion and also because of cloud cover problems.

Each training area consisted of a data block of approximately 100 lines x 100 columns and containing several different cover types. These training areas were selected as being representative samples of the whole provinces by Ing. Rubén Zerain who was familiar with the region, and they were used as input to the LARSYS non-supervised classifier or clustering algorithm (*CLUSTER).

The resulting spectral class statistics from all the training areas within a province were merged into one statistics file. Then, the pairwise spectral separability for all possible combinations of classes was measured using the *SEPARABILITY processor. At this point, a bi-spectral plot showing the relative position (in two-dimensional spectral space) of the classes defined by the clustering algorithm was also produced for each province. (examples of these bi-spectral plots are shown in the Results section of this report). Using both the separability information and the relative spectral location on the bi-spectral plot, the total number of spectral classes was reduced by pooling and/or deleting those classes that were spectrally non-separable. The separabilities of the reduced statistics file were again measured, and if all pairwise combinationsof spectral classes were separable, then this reduced statistics file was used as an input to the LARSYS maximum likelihood classifier (*CLASSIFY-POINTS) for the classification of those same training areas that were selected for clustering. Also, in each province two or three additional areas (test areas) were classified using this training statistics file in order to further assess the performance of the training statistics. These results were evaluated by comparing the computer classification maps of the satellite data (obtained from the *PRINTRESULTS processors) with the aerial photography. It was at this stage of the processing and analysis sequence that the spectral classes originally defined by the clustering processor and further refined by the analyst were identified and labeled as informational classes.

If the classifications of these small areas (100 lines x 100 columns) were satisfactory, then these statistics were used for the classification of the entire province. However, if the test classifications of the small areas were not satisfactory, then the statistics were revised and the test areas were reclassified so that the analyst could be confident that an effective set of training statistics had been defined. The test and final classifications were carried out using all four Landsat bands.

It should be noted that the average separability between all possible spectral class pairs for all of the six provinces that were analyzed was in each case higher than 1950. Figure 5 shows the relationship between the separability measure (in saturated transform divergence units ranging from zero to 2000) and the expected percent correct classification (Swain and King, 1973). As this figure illustrates, a separability measure of over 1500 would indicate that an average classification accuracy of approximately 90% should be achieved. Therefore, since the average separability for all class pairs

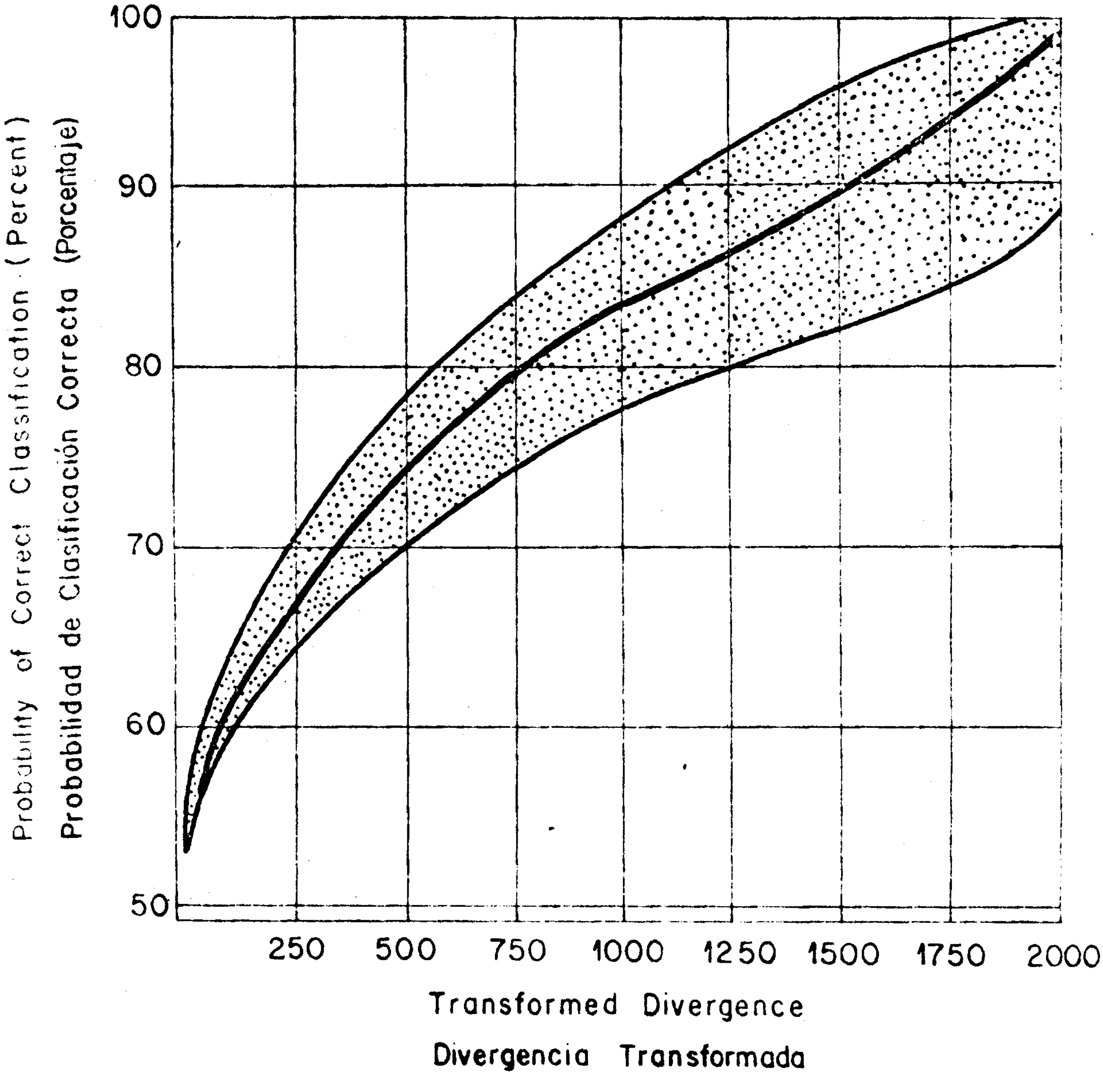


Figure 5. Relationship between transformed divergence and probability (in percent) of correct classification.

in each province analyzed in this study was 1950 or better, we were confident that if the training statistics were truly representative of the spectral characteristics of the various cover types throughout the province, an accurate classification would be achieved.

The spectral separability for all possible class pair combinations for each one of the six provinces of the Santa Cruz Integrated Subregion are given in a series of tables in the Results section of this report.

The final classification of each province was stored on different files of magnetic LARS results tapes. The LARS results tape and file numbers in which the final multispectral classifications of each province were stored is given in Table 2.

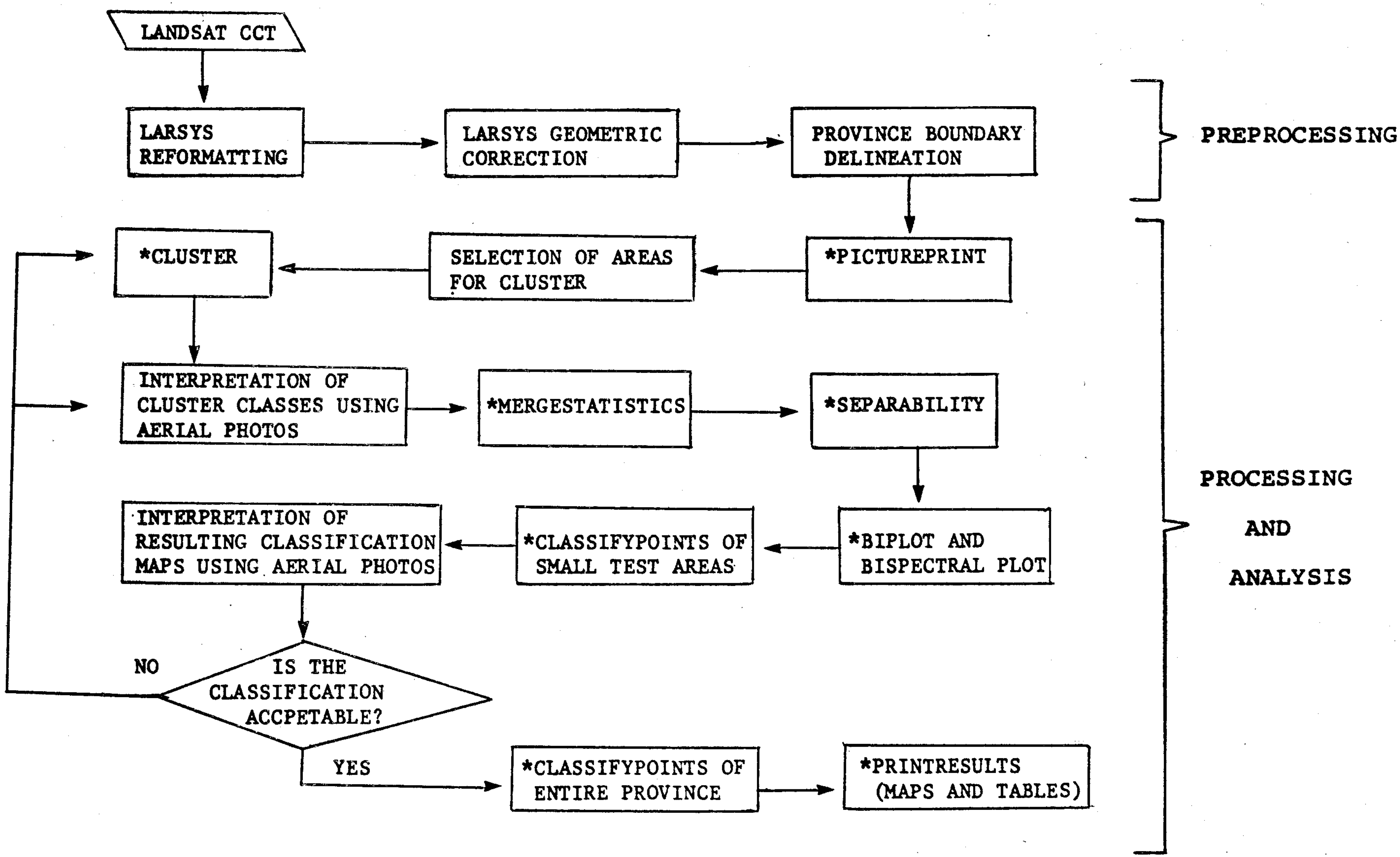
TABLE 2. Results Tape and File Number of The Final Calssifications

Province	Results Tape #	File #
Andres Ibañez	637	1
Warnes	637	2
Ñuflo de Chavez	637	3
Gutierrez (Sara)	750	1
Santiesteban	750	2
Ichilo	745	1

In order to obtain the output products requested by the Bolivian ERTS Program, the final classifications were displayed on a standard computer line printer using different symbols (alphanumeric characters) to represent each of the different spectral classes. The scale of these computer-generated classification maps was 1:25,000, and every individual pixel or resolution element represented approximately 0.5 hectares on the ground. But since the requested final product had to be at a scale of 1:50,000 in order to match the standard Bolivian topographic maps, the computer generated 1:25,000 scale maps were reduced by a factor of two using a Photo-Mechanical-Transfer process (P.M.T.) in blocks of 180 lines by 180 columns. The resulting 1:50,000 scale classification maps were then sent to Bolivia together with two copies of the computer output of each intermediate processing step. A detailed list and description of the products sent to the Bolivian ERTS Program office is given in the Results section of this report.

Since the Bolivian ERTS Program now has the capability of displaying LARSYS classification results using the *PRINTRESULTS processor implemented in the CENACO (National Center for Computation) DEC System 10 computer in La Paz, Bolivia, LARS will provide them with copies of the results tapes containing the classifications of the six Santa Cruz Integrated Subregion provinces. This will allow the Bolivian ERTS Program to change symbols, pool classes together, or display only selected cover types as desired. Figure 6 summarizes the entire processing and analysis sequence of this investigation in a graphical form.

Figure 6. Flow diagram showing the pre-processing, processing, and analysis sequence used in this study.



RESULTS AND DISCUSSION

The results of the computer-aided analysis of the six provinces of interest within the Buena Vista Landsat frame involved several different computer-generated materials. Of particular importance were the final classification maps at different scales along with tabulated information on the areal extent of the different cover types. Also included were the spectral separability tables and two-dimentional spectral plots for each one of the provinces. Two copies of these result products were sent to the Bolivian ERTS Project office for their use and evaluation. Specifically, these materials included the following items:

*PRINTRESULTS at a scale of 1:25,000 for the final classifications of (1) Santa Cruz City, (2) prov. Andres Ivañez, (3) prov. Warnes, (4) prov. Ñuflo de Chavez, (5) prov. Gutierrez, (6) prov. Santiesteban, and (7) prov. Ichilo, using different symbols for every spectral class.

*PRINTRESULTS at a scale of 1:50,000 (every other line and every other column) for the final classifications of (1) prov. Andres Ibañez,(2) prov. Warnes, (3) prov. Ñulflo de Chavez, (4) prov. Santiesteban, (5) prov. Gutierrez, (6) prov. Ichilo, using different symbols for every spectral class.

*PRINTRESULTS at a scale of 1:50,000 (every other line and every other column) for the final classification of (1) prov. Andres Ibañez, (2) prov. Warnes, (3) prov. Ñuflo de Chavez, (4) prov. Santiesteban, (5) prov. Gutierrez, and (6) prov. Ichilo, using symbols only for the "forest (s)" and "water" classes.

*SEPARABILITY (Combinations 4,3,2, and 1) for the final spectral statistics used in the classifications of the entire provinces. Also, the separabilities for three problem classes (turbid and shallow water, one urban, and a type of soil) were included.

*BIPLOTS for (1) Santa Cruz city, (2) problem classes, (3) prov. Andres Ibañez, (4) prov. Warnes, (5) prov. Ñuflo de Chavez, (6) prov. Santiesteban, (7) prov. Gutierrez, and (8) prov. Ichilo.

*BI-SPECTRAL PLOTS for Santa Cruz city, problem classes, and all of the six provinces of interest.

In addition to the above materials, LARS provided the Bolivian ERTS Program office with a series of color-coded 35 mm slides of the final classifications of province Andres Ibañez and Santa Cruz City. Since at the present time the Bolivian ERTS Program office has the capability of producing multispectral classification results maps using the LARSYS Ver. 3.1 *PRINTRESULTS processor (recently implemented in the CENACO DEC System 10 computer located in La Paz), LARS has also provided the computer compatible results tapes which contain all the multispectral classification files. These tapes will allow the Bolivian ERTS Program to generate thematic maps of selected cover types and to obtain areal extent information (in hectares) for individual regions or geographic units of interest.

The most important final products made available to the Bolivian ERTS Program office were a set of multispectral classification maps at a scale of 1:50,000 which contain every data point (pixel), i.e. every line and column present in the original Landsat data tapes. These maps were obtained by a Photo-Mechanical-Transfer (P.M.T.) process which reduced the 1:25,000 scale maps by a factor of two. An example of the 1:50,000 line printer output showing every line and column is shown in Figure 7A. Figure 7B is a photo-mosaic showing the same area (an area West of the Santa Cruz City in province Andres Ibañez). The aerial photos were obtained on June 9, 1975, whereas the Landsat data was obtained on Sept. 16, 1975. Therefore, the spectral characteristics on the Landsat data are not always accurately indicated by the aerial photography. A key feature

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seen in the printout is the Piraý River in the lower right. Note that the river area has both · and / symbols. The · represents water and the / was designated as wet sand or soil areas by the analyst. Several pasture areas can be seen on the photo above and to the left of the Piray River, and on the printout these pastures have generally been designated with the letter I, which is the symbol the analyst used to define the spectral class tentatively identified as pasture. Brushland areas have been grouped with forest.

In the lower left, the sand dune has been correctly identified by the computer on the Landsat data, and is indicated by the symbol ' . The Surrounding area is a mixture of - and ε symbols which were spectral classes 2 and 10, respectively, which the analyst had tentatively designated as soils and chaparral-2, respectively. The area in the upper left is a mixture of symbols for the classes which the analyst had tentatively identified as pasture, chaparral-2, soils, and forest. The complexity of these areas, and the need to clearly describe the characteristics of the cover types represented by each of these spectral classes is clearly indicated by this figure.

To evaluate the performance of the training statistics and to aid in the interpretation of the spectral classes defined by the clustering algorithm and by the analyst, Tables 3 through 7 give the pairwise spectral class separability for each one of the six provinces and for the spectral classes within the city of Santa Cruz. Also, Figures 8 through 14 illustrate the distribution and relative location of these spectral class means in a two-dimentional bi-spectral plot.

The most important information that can be obtained from Tables 3 through 9 is the fact that the average spectral separability for all possible pariwise combinations of spectral classes is over 1950 for each province, which indicates (see Figure 5) that the average expected percent correct classification for each province should be over 95%, provided the training statistics are representative of the entire test site. Tables 10 through 16 show the relationship between the symbols used to designate the different spectral classes in (1) the separability tables (2) bi-spectral plots, and (3) final classification line-printer output maps.

The bi-spectral plots (Figures 8 through 14) are very helpful in the interpretation of the spectral classes defined by the clustering algorithm from a strictly spectral view point. For example, in the bi-spectral plot corresponding to the Gutierrez province (Figure 12), one can easily identify the class denoted by the letter "I" as being water because it has the lowest relative spectral response in the near infrared portions of the spectrum, i.e. in the horizontal axis labeled "average mean for infrared bands (chan. 3 & 4)", which in fact corresponds to the informational class "water" as shown in the legend on the top right hand

TABLE 3. Spectral Separability for All Possible Pairwise Combinations of Classes in Province Andres Ibañez.

BATSHORT   LABORATORY FOR APPLICATIONS OF REMOTE SENSING   DEC 29,1976
G.A.MCGREW   PURDUE UNIVERSITY   11 19 56 PM
LARSYS VERSION 3

SEPARABILITY PARA ANDRES IBANEZ

RETENTION LEVEL .. 1 MAXIMUM 30000
MINIMUM 0   DIVERGENCE **WITH** SATURATING TRANSFORM

WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	CHANNELS	DIJ(MIN)	D(AVE)	. (10)	- (10)	O (10)	/ (10)	) (10)	* (10)	& (10)	X (10)	= (10)	((10)	Z (10)	.- (10)
1.	1 2 3 4	1670.	1985.	1936	2000	2000	1974	2000	2000	2000	2000	2000	2000	2000	2000

CONTINUED...

WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	.O (10)	./ (10)	.) (10)	.* (10)	.& (10)	.X (10)	.= (10)	.((10)	.Z (10)	-O (10)	-/ (10)	-) (10)	-* (10)	-& (10)	-X (10)	-= (10)	-((10)	-Z (10)
1.	2000	1994	1957	2000	2000	1955	1980	2000	2000	2000	2000	2000	2000	2000	2000	2000	1999	2000

CONTINUED...

WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	O/ (10)	O) (10)	O* (10)	O& (10)	OX (10)	O= (10)	O((10)	OZ (10)	/) (10)	/* (10)	/& (10)	/X (10)	/= (10)	/((10)	/Z (10)	)* (10)	)& (10)	)X (10)
1.	2000	1924	2000	1989	1995	1996	1670	2000	2000	1958	2000	2000	2000	2000	2000	2000	2000	1988

CONTINUED...

WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	)= (10)	)((10)	)Z (10)	*& (10)	*X (10)	*= (10)	*((10)	*Z (10)	&X (10)	&= (10)	&((10)	&Z (10)	X= (10)	X((10)	XZ (10)	=((10)	=Z (10)	(Z (10)
1.	2000	2000	2000	2000	2000	2000	2000	2000	2000	1876	1994	2000	1854	2000	2000	2000	2000	2000

TABLE 4. Spectral Separability for All Possible Pairwise Combinations of Classes in Province Warnes.

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LABCRATORY FOR APPLICATIONS OF REMOTE SENSING
PURDUE UNIVERSITY

DEC 29,1976
11 20 10 PM
LARSYS VERSION 3

SEPARABILITY PARA WARNES

RETENTION LEVEL .. 1 MAXIMUM 30000
MINIMUM 0

DIVERGENCE **WITH** SATURATING TRANSFORM

	CHANNELS	DIJ(MIN)	D(AVE)	. (10)	- (10)	0 (10)	/ (10)	) (10)	* (10)	& (10)	X (10)	= (10)	T (10)	((10)	Z (10)
1.	1 2 3 4	1526.	1965.	1914	1950	1792	1991	2000	1860	2000	2000	2000	2000	2000	2000

CONTINUED... WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	.- (10)	.0 (10)	./ (10)	.) (10)	.* (10)	.& (10)	.X (10)	.= (10)	.T (10)	.((10)	.Z (10)	-0 (10)	-/ (10)	-) (10)	-* (10)	-& (10)	-X (10)	-= (10)
1.	1992	2000	1921	2000	1880	1982	2000	2000	2000	1999	2000	1960	1526	1829	2000	2000	1998	2000

CONTINUED... WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	-T (10)	-((10)	-Z (10)	0/ (10)	0) (10)	0* (10)	0& (10)	0X (10)	0= (10)	0T (10)	0((10)	0Z (10)	/) (10)	/* (10)	/& (10)	/X (10)	/= (10)	/T (10)
1.	1997	1995	2000	2000	1999	2000	2000	1859	2000	2000	2000	2000	1920	1997	1973	2000	1999	1798

CONTINUED... WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	/((10)	/Z (10)	)* (10)	)& (10)	)X (10)	)= (10)	)T (10)	)((10)	)Z (10)	*& (10)	*X (10)	*= (10)	*T (10)	*((10)	*Z (10)	&X (10)	&= (10)	&T (10)
1.	1799	2000	2000	2000	1889	1944	1994	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000

CONTINUED... WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	&((10)	&Z (10)	X= (10)	XT (10)	X((10)	XZ (10)	=T (10)	=((10)	=Z (10)	T((10)	TZ (10)	(Z (10)
1.	1946	2000	1760	2000	2000	2000	1932	2000	2000	1892	2000	2000

TABLE 5. Spectral Separability for All Possible Pairwise Combinations of Classes in Province Ñuflo de Chavez.

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SEPARABILITY PARA NUFLO DE CHAVEZ

RETENTION LEVEL .. 1 MAXIMUM 30000
MINIMUM 0

DIVERGENCE **WITH** SATURATING TRANSFORM

	CHANNELS	DIJ(MIN)	D(AVE)	WEIGHTED INTERCLASS DIVERGENCE (DIJ)											
				. (10)	- (10)	O (10)	/ (10)	) (10)	* (10)	& (10)	X (10)	= (10)	((10)	Z (10)	.- (10)
1.	1 2 3 4	1788.	1978.	1996	2000	2000	2000	2000	1996	1999	2000	2000	1985	2000	2000

CONTINUED...

	WEIGHTED INTERCLASS DIVERGENCE (DIJ)																	
	.O (10)	./ (10)	.) (10)	.* (10)	.& (10)	.X (10)	.= (10)	.((10)	.Z (10)	-O (10)	-/ (10)	-) (10)	-* (10)	-& (10)	-X (10)	-= (10)	-((10)	-Z (10)
1.	2000	1803	2000	1788	2000	2000	1805	1892	2000	1961	1998	2000	2000	2000	1965	2000	2000	2000

CONTINUED...

	WEIGHTED INTERCLASS DIVERGENCE (DIJ)																	
	O/ (10)	O) (10)	O* (10)	O& (10)	OX (10)	O= (10)	O((10)	OZ (10)	/) (10)	/* (10)	/& (10)	/X (10)	/= (10)	/((10)	/Z (10)	)* (10)	)& (10)	)X (10)
1.	1876	1930	1950	2000	1993	2000	2000	2000	2000	1977	2000	1926	1870	1999	2000	1895	2000	2000

CONTINUED...

	WEIGHTED INTERCLASS DIVERGENCE (DIJ)																	
	)= (10)	)((10)	)Z (10)	*& (10)	*X (10)	*= (10)	*((10)	*Z (10)	&X (10)	&= (10)	&((10)	&Z (10)	X= (10)	X((10)	XZ (10)	=((10)	=Z (10)	(Z (10)
1.	2000	2000	2000	2000	2000	2000	1999	2000	2000	2000	1993	2000	1984	2000	2000	1981	2000	2000

TABLE 6. Spectral Separability for All Possible Pairwise Combinations of Classes in Province Gutierrez.

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SEPARABILITY FOR GUTIERREZ

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08 11 28 PM
LARSYS VERSION 3

RETENTION LEVEL .. 1 MAXIMUM 30000
MINIMUM 0

DIVERGENCE **WITH** SATURATING TRANSFORM

	CHANNELS	DIJ(MIN)	D(AVE)	-. (10)	-$ (10)	-T (10)	-B (10)	-Z (10)	-L (10)	-I (10)	-W (10)	-R (10)	-S (10)	-H (10)	-+ (10)
1.	1 2 3 4	1586.	1963.	1627	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000

WEIGHTED INTERCLASS DIVERGENCE (DIJ)

CONTINUED...

WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	- (10)	.$ (10)	.T (10)	.B (10)	.Z (10)	.L (10)	.I (10)	.W (10)	.R (10)	.S (10)	.H (10)	.+ (10)	. (10)	$T (10)	$B (10)	$Z (10)	$L (10)	$I (10)
1.	2000	2000	2000	2000	2000	2000	1989	2000	2000	2000	2000	2000	2000	1991	1697	1998	1996	2000

CONTINUED...

WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	$W (10)	$R (10)	$S (10)	$H (10)	$+ (10)	$ (10)	TB (10)	TZ (10)	TL (10)	TI (10)	TW (10)	TR (10)	TS (10)	TH (10)	T+ (10)	T (10)	BZ (10)	BL (10)
1.	2000	1999	200C	1987	1997	2000	1586	1987	1807	1739	2000	1955	2000	1995	2000	2000	1997	1922

CONTINUED...

WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	BI (10)	BW (10)	BR (10)	BS (10)	BH (10)	B+ (10)	B (10)	ZL (10)	ZI (10)	ZW (10)	ZR (10)	ZS (10)	ZH (10)	Z+ (10)	Z (10)	LI (10)	LW (10)	LR (10)
1.	1982	200C	1855	2000	1971	2000	2000	1998	1904	2000	1864	2000	2000	2000	2000	1952	2000	1999

CONTINUED...

WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	LS (10)	LH (10)	L+ (10)	L (10)	IW (10)	IR (10)	IS (10)	IH (10)	I+ (10)	I (10)	WR (10)	WS (10)	WH (10)	W+ (10)	W (10)	RS (10)	RH (10)	R+ (10)
1.	1986	1647	1804	2000	2000	1995	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000

CONTINUED...

WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	R (10)	SH (10)	S+ (10)	S (10)	H+ (10)	H (10)	+ (10)
1.	2000	200C	1597	2000	1787	2000	2000

TABLE 7. Spectral Separability for All Possible Pairwise Combinations of Classes in Province Santiesteban.

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MAR 4,1977
08 12 31 PM
LARSYS VERSION 3

SEPARABILITY FOR SANTIESTEBAN

RETENTION LEVEL .. 1 MAXIMUM 30000
MINIMUM 0

DIVERGENCE **WITH** SATURATING TRANSFORM

WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	CHANNELS	DIJ(MIN)	D(AVE)	AB (10)	AC (10)	AD (10)	AE (10)	AF (10)	AG (10)	AH (10)	AI (10)	AJ (10)	AK (10)	AL (10)	AM (10)
1.	1 2 3 4	1452.	1955.	2000	1923	2000	1784	2000	1612	2000	1999	2000	1908	2000	2000

CONTINUED...

WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	BC (10)	BD (10)	BE (10)	BF (10)	BG (10)	BH (10)	BI (10)	BJ (10)	BK (10)	BL (10)	BM (10)	CD (10)	CE (10)	CF (10)	CG (10)	CH (10)	CI (10)	CJ (10)
1.	2000	2000	2000	2000	2000	2000	2000	2000	1999	2000	2000	2000	1816	1844	2000	2000	2000	2000

CONTINUED...

WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	CK (10)	CL (10)	CM (10)	DE (10)	DF (10)	DG (10)	DH (10)	DI (10)	DJ (10)	DK (10)	DL (10)	DM (10)	EF (10)	EG (10)	EH (10)	EI (10)	EJ (10)	EK (10)
1.	2000	2000	2000	1999	2000	2000	1979	1998	2000	2000	1615	2000	2000	1956	2000	1999	2000	1999

CONTINUED...

WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	EL (10)	EM (10)	FG (10)	FH (10)	FI (10)	FJ (10)	FK (10)	FL (10)	FM (10)	GH (10)	GI (10)	GJ (10)	GK (10)	GL (10)	GM (10)	HI (10)	HJ (10)	HK (10)
1.	1935	200C	200C	2000	2000	2000	2000	2000	2000	1998	1872	1997	1515	1997	2000	1536	1931	1990

CONTINUED...

WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	HL (10)	HM (10)	IJ (10)	IK (10)	IL (10)	IM (10)	JK (10)	JL (10)	JM (10)	KL (10)	KM (10)	LM (10)
1.	1993	2000	1955	1934	1987	2000	1452	2000	2000	2000	2000	2000

TABLE 8. Spectral Separability for All Possible Pairwise Combinations of Classes in Province Ichilo.

```
BATSHORT                        LABORATORY FOR APPLICATIONS OF REMOTE SENSING         DEC  30,1976
G.A.MCGREW                      SERVICIO GEOLOGICO DE BOLIVIA (PROGRAMA ERTS)         12 56 08 AM
                                                                                      LARSYS VERSION 3
SEPARABILITY PARA ICHILO

RETENTION LEVEL ..    1  MAXIMUM ..........30000       DIVERGENCE **WITH** SATURATING TRANSFORM
                         MINIMUM ..........    0
```

WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	CHANNELS	DIJ(MIN)	D(AVE)	* (10)	- (10)	/ (10)	Q (10)	W (10)	E (10)	R (10)	T (10)	Y (10)	U (10)	I (10)	O (10)
1.	1 2 3 4	1744.	1988.	2000	2000	2000	1998	2000	2000	2000	2000	2000	2000	1965	1995

CONTINUED... WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	P (10)	A (10)	S (10)	D (10)	F (10)	G (10)	H (10)	J (10)	M (10)	*- (10)	*/ (10)	*Q (10)	*W (10)	*E (10)	*R (10)	*T (10)	*Y (10)	*U (10)
1.	1996	2000	2000	2000	2000	2000	2000	2000	2000	1869	2000	2000	2000	1999	2000	2000	2000	2000

CONTINUED... WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	*I (10)	*O (10)	*P (10)	*A (10)	*S (10)	*D (10)	*F (10)	*G (10)	*H (10)	*J (10)	*M (10)	-/ (10)	-Q (10)	-W (10)	-E (10)	-R (10)	-T (10)	-Y (10)
1.	2000	2000	1999	2000	2000	2000	2000	1998	2000	2000	2000	1768	2000	2000	2000	2000	2000	2000

CONTINUED... WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	-U (10)	-I (10)	-O (10)	-P (10)	-A (10)	-S (10)	-D (10)	-F (10)	-G (10)	-H (10)	-J (10)	-M (10)	/Q (10)	/W (10)	/E (10)	/R (10)	/T (10)	/Y (10)
1.	2000	2000	2000	1945	2000	2000	2000	2000	2000	2000	2000	2000	1879	2000	2000	2000	2000	2000

CONTINUED... WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	/U (10)	/I (10)	/O (10)	/P (10)	/A (10)	/S (10)	/D (10)	/F (10)	/G (10)	/H (10)	/J (10)	/M (10)	QW (10)	QE (10)	QR (10)	QT (10)	QY (10)	QU (10)
1.	2000	2000	2000	1874	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000

TABLE 8. (continued)

BATSHORT
G.A.MCGREW

LABORATORY FOR APPLICATIONS OF REMOTE SENSING
SERVICIO GEOLOGICO DE BOLIVIA (PROGRAMA ERTS)

DEC 30,1976
12 56 08 AM
LARSYS VERSION 3

SEPARABILITY PARA ICHILO

RETENTION LEVEL .. 1 MAXIMUM 30000
MINIMUM 0

DIVERGENCE **WITH** SATURATING TRANSFORM

CONTINUED...

WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	QI (10)	QO (10)	QP (10)	QA (10)	QS (10)	QD (10)	QF (10)	QG (10)	QH (10)	QJ (10)	QM (10)	WE (10)	WR (10)	WT (10)	WY (10)	WU (10)	WI (10)	WO (10)
1.	2000	2000	1806	2000	2000	2000	2000	2000	1999	2000	2000	1963	2000	2000	1920	1998	1981	2000

CONTINUED...

WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	WP (10)	WA (10)	WS (10)	WD (10)	WF (10)	WG (10)	WH (10)	WJ (10)	WM (10)	ER (10)	ET (10)	EY (10)	EU (10)	EI (10)	EO (10)	EP (10)	EA (10)	ES (10)
1.	2000	2000	2000	1872	2000	2000	2000	2000	2000	1984	2000	1871	1857	1990	2000	1935	1999	2000

CONTINUED...

WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	ED (10)	EF (10)	EG (10)	EH (10)	EJ (10)	EM (10)	RT (10)	RY (10)	RU (10)	RI (10)	RO (10)	RP (10)	RA (10)	RS (10)	RD (10)	RF (10)	RG (10)	RH (10)
1.	2000	2000	2000	2000	2000	2000	2000	2000	1959	2000	2000	2000	1873	2000	1998	1978	2000	1998

CONTINUED...

WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	RJ (10)	RM (10)	TY (10)	TU (10)	TI (10)	TO (10)	TP (10)	TA (10)	TS (10)	TD (10)	TF (10)	TG (10)	TH (10)	TJ (10)	TM (10)	YU (10)	YI (10)	YO (10)
1.	1958	2000	2000	2000	2000	2000	2000	2000	2000	2000	1879	2000	2000	2000	2000	2000	1995	1985

CONTINUED...

WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	YP (10)	YA (10)	YS (10)	YD (10)	YF (10)	YG (10)	YH (10)	YJ (10)	YM (10)	UI (10)	UO (10)	UP (10)	UA (10)	US (10)	UD (10)	UF (10)	UG (10)	UH (10)
1.	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	1998	1998	2000	2000	2000	2000	1954

TABLE 8. (continued)

BATSHORT
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SEPARABILITY PARA ICHILO

LABORATORY FOR APPLICATIONS OF REMOTE SENSING
SERVICIO GEOLOGICO DE BOLIVIA (PROGRAMA ERTS)

DEC 30,1976
12 56 08 AM
LARSYS VERSION 3

RETENTION LEVEL .. 1 MAXIMUM 30000
MINIMUM 0

DIVERGENCE **WITH** SATURATING TRANSFORM

CONTINUED... WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	UJ (10)	UM (10)	IO (10)	IP (10)	IA (10)	IS (10)	ID (10)	IF (10)	IG (10)	IH (10)	IJ (10)	IM (10)	OP (10)	OA (10)	OS (10)	OD (10)	OF (10)	OG (10)
1.	2000	2000	1987	1934	2000	2000	1924	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000

CONTINUED... WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	OH (10)	OJ (10)	OM (10)	PA (10)	PS (10)	PD (10)	PF (10)	PG (10)	PH (10)	PJ (10)	PM (10)	AS (10)	AD (10)	AF (10)	AG (10)	AH (10)	AJ (10)	AM (10)
1.	2000	2000	2000	2000	2000	1984	2000	1952	1961	2000	2000	2000	1835	2000	2000	2000	1744	2000

CONTINUED... WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	SD (10)	SF (10)	SG (10)	SH (10)	SJ (10)	SM (10)	DF (10)	DG (10)	DH (10)	DJ (10)	DM (10)	FG (10)	FH (10)	FJ (10)	FM (10)	GH (10)	GJ (10)	GM (10)
1.	2000	2000	2000	2000	1991	2000	2000	2000	2000	2000	2000	2000	1999	2000	2000	2000	2000	2000

CONTINUED... WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	HJ (10)	HM (10)	JM (10)
1.	2000	2000	2000

TABLE 9. Spectral Separability for All Possible Pairwise Combinations of Classes in the City of Santa Cruz.

BATSHORT
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LABORATORY FOR APPLICATIONS OF REMOTE SENSING
SERVICIO GEOLOGICO DE BOLIVIA (PROGRAMA ERTS)

DEC 30,1976
12 37 18 PM
LARSYS VERSION 3

SEPARABILITY PARA SANTA CRUZ

RETENTION LEVEL .. 1 MAXIMUM 30000
MINIMUM 0

DIVERGENCE **WITH** SATURATING TRANSFORM

CHANNELS	DIJ(MIN)	D(AVE)	) (10)	- (10)	O (10)	) (10)	* (10)	$ (10)	X (10)	M (10)	)- (10)	)O (10)	)) (10)	)* (10)
1. 1 2 3 4	1126.	1832.	1997	1885	2000	2000	2000	2000	2000	2000	1479	1674	1489	1996

WEIGHTED INTERCLASS DIVERGENCE (DIJ)

CONTINUED...

WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	)$ (10)	)X (10)	)M (10)	-O (10)	-) (10)	-* (10)	-$ (10)	-X (10)	-M (10)	O) (10)	O* (10)	O$ (10)	OX (10)	OM (10)	)* (10)	)$ (10)	)X (10)	)M (10)
1.	1967	2000	2000	1743	1942	1999	1746	2000	2000	1619	1661	1484	1994	1996	1844	1976	2000	1993

CONTINUED...

WEIGHTED INTERCLASS DIVERGENCE (DIJ)

	*$ (10)	*X (10)	*M (10)	$X (10)	$M (10)	XM (10)
1.	1525	1665	1570	1614	1950	1126

BOLIVIA
GLORIA MCGREW

LABORATORY FOR APPLICATIONS OF REMOTE SENSING
SERVICIO GEOLOGICO DE BOLIVIA (PROGRAMA ERTS)

DEC 29,1976
10 33 44 PM
LARSYS VERSION 3

GRAFICO BI-SPECTRAL PLOT DE LAS AREAS EN LA PROV. ANDRES IBANEZ

COINCIDENT BI-SPECTRAL PLOT (MEAN) FOR CLASS(ES)

LEGEND
A = CLASS 1 AGUATURB
B = CLASS 2 SOILS
C = CLASS 3 SOMBTOPO
D = CLASS 4 BOSQUE-1
E = CLASS 5 ARENAHUM
F = CLASS 6 PASTC
G = CLASS 7 DUNA
H = CLASS 8 CHAPAR-1
I = CLASS 9 SUELO
J = CLASS 10 CHAPAR-2
K = CLASS 11 BOSQUE-2
L = CLASS 12 NULA

AVERAGE MEAN FOR INFRARED BANDS (CHAN. 3 & 4)

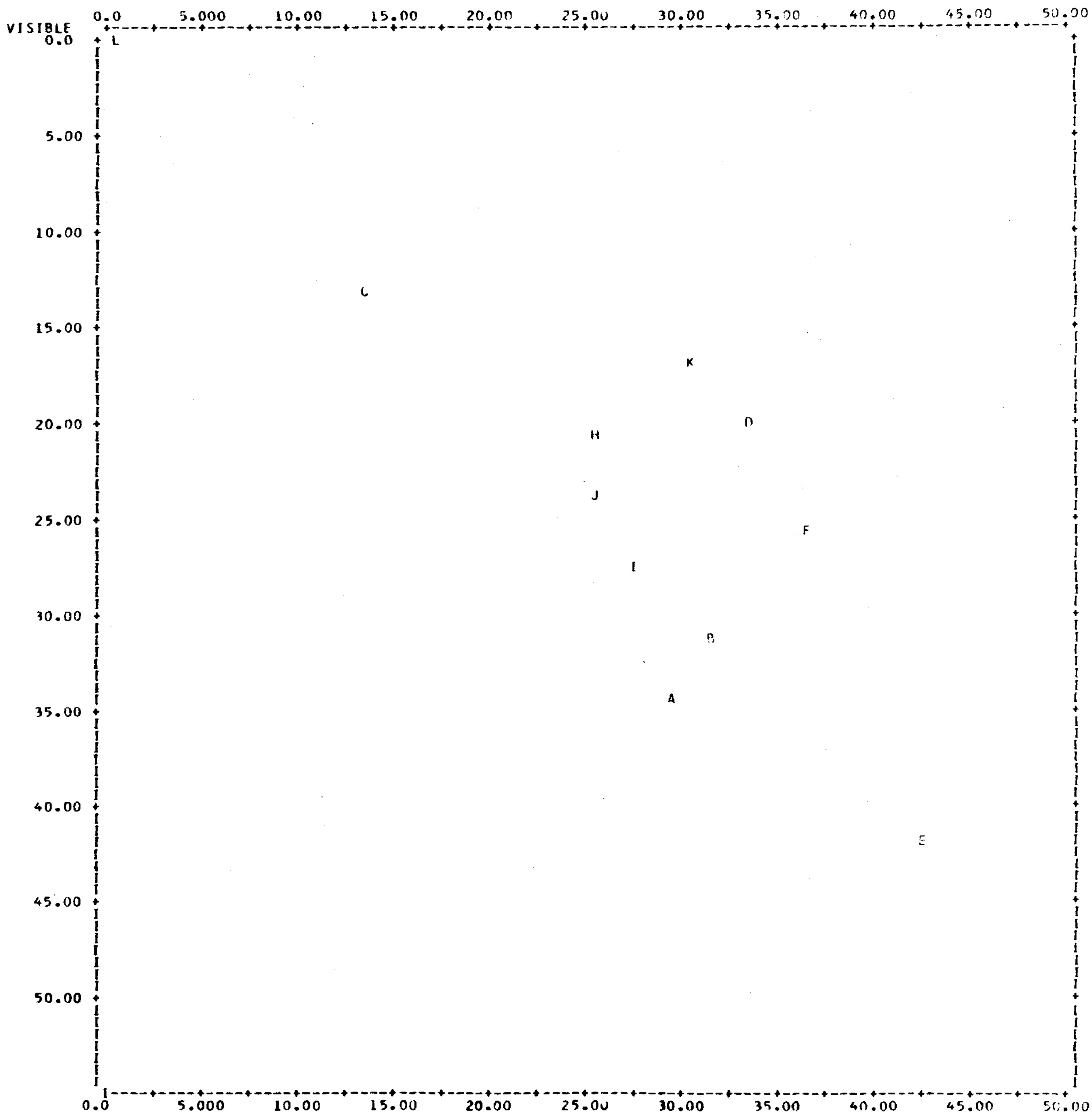

Figure 8. Bi-spectral plot for Province Andres Ibañez.

BOLIVIA
GLORIA MCGREW

LABORATORY FOR APPLICATIONS OF REMOTE SENSING
SERVICIO GEOLOGICO DE BOLIVIA (PROGRAMA ERTS)

DEC 29,1976
10 36 02 PM
LARSYS VERSION 3

GRAFICO BI-SPECTRAL PLOT DE LAS AREAS EN LA PROV. WARNES

COINCIDENT BI-SPECTRAL PLOT (MEAN) FOR CLASS(ES)

LEGEND
A = CLASS 1 SUELO
B = CLASS 2 SUE-AGUA
C = CLASS 3 SUE/VEG
D = CLASS 4 CULTIVO
E = CLASS 5 V.S.CHU
F = CLASS 6 VEG.SECO
G = CLASS 7 ARENA
H = CLASS 8 AGUA/S.H
I = CLASS 9 BOSQUE-1
J = CLASS 10 BOSQUE-2
K = CLASS 11 PASTO
L = CLASS 12 V.S.CH,O
M = CLASS 13 NULA

AVERAGE MEAN FOR INFRARED BANDS (CHAN. 3 & 4)

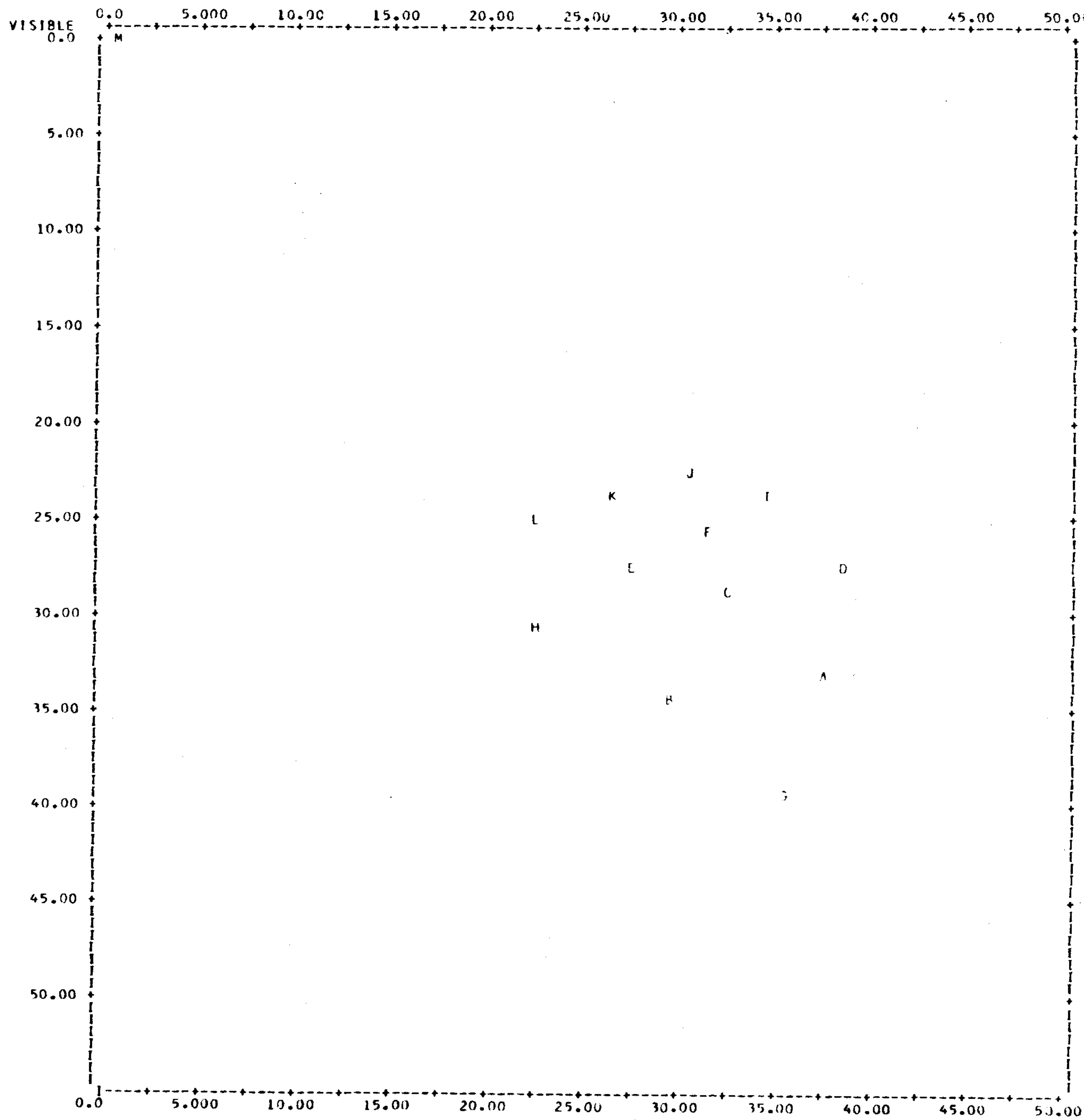

Figure 9. Bi-spectral plot for Province Warnes.

BOLIVIA
GLORIA MCGREW

LABORATORY FOR APPLICATIONS OF REMOTE SENSING
SERVICIO GEOLOGICO DE BOLIVIA (PROGRAMA ERTS)

DEC 29,1976
10 39 28 PM
LARSYS VERSION 3

GRAFICO BI-ESPECTRAL PLOT DE LAS AREAS EN LA PROV. NUFLO DE CHA

COINCIDENT BI-SPECTRAL PLOT (MEAN) FOR CLASS(ES)

LEGEND
A = CLASS 1 AGUA
B = CLASS 2 VEG.HERB
C = CLASS 3 BOSQUE-1
D = CLASS 4 VSEC,BUS
E = CLASS 5 B2,CH,CU
F = CLASS 6 SUEL/VEG
G = CLASS 7 PAST,VSE
H = CLASS 8 CHUCHI01
I = CLASS 9 BOSQUE-3
J = CLASS 10 VS,CH,CU
K = CLASS 11 CHUCHI02
L = CLASS 12 NJLA

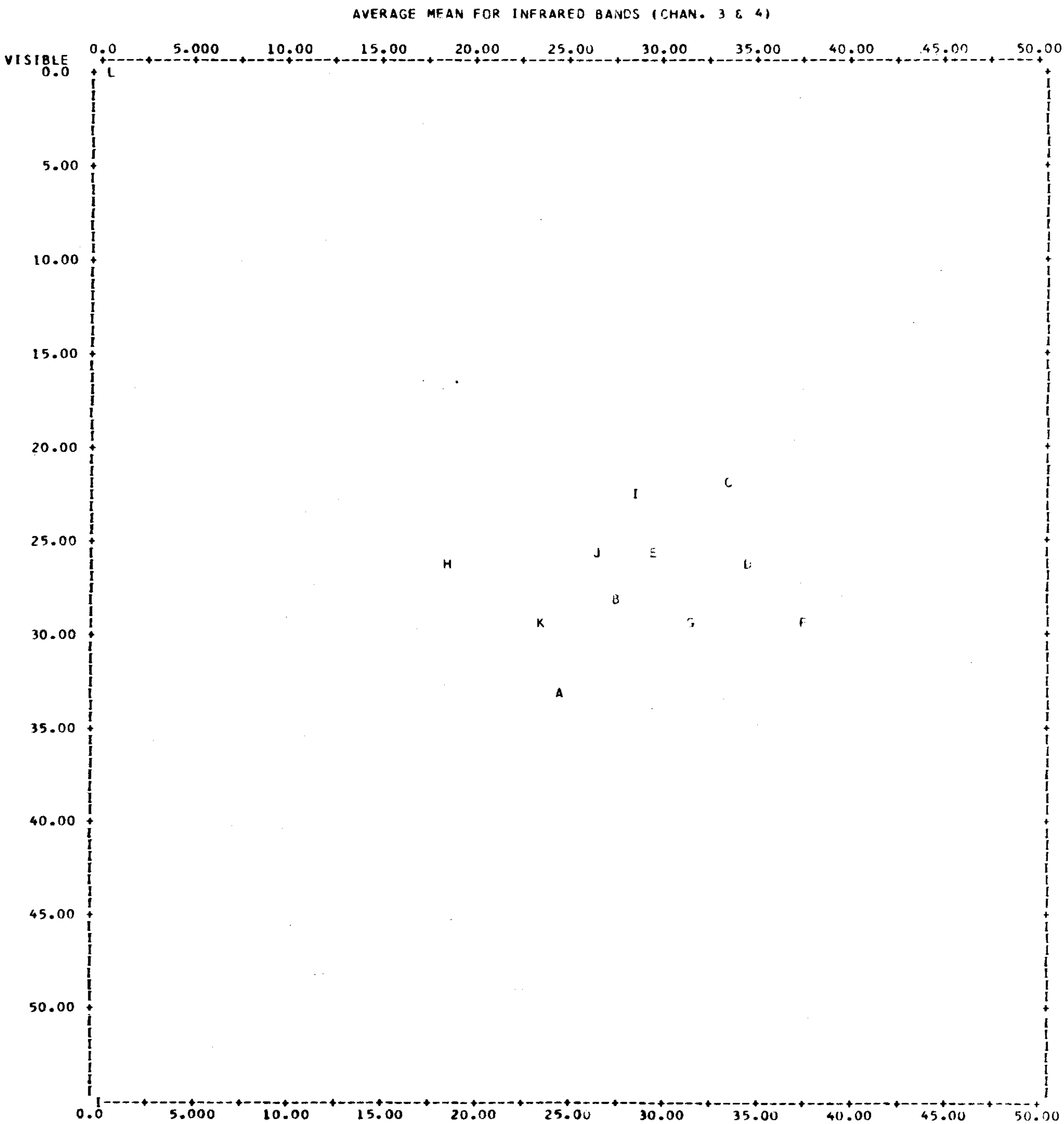

Figure 10. Bi-spectral plot for Province Ñuflo de Chavez.

BOLIVIA
G.A.MCGREW

LABORATORY FOR APPLICATIONS OF REMOTE SENSING
PURDUE UNIVERSITY

MAR 4,1977
05 35 41 PM
LARSYS VERSION 3

BI-SPECTRAL FOR SANTIESTEBAN

COINCIDENT BI-SPECTRAL PLOT (MEAN) FOR CLASS(ES)

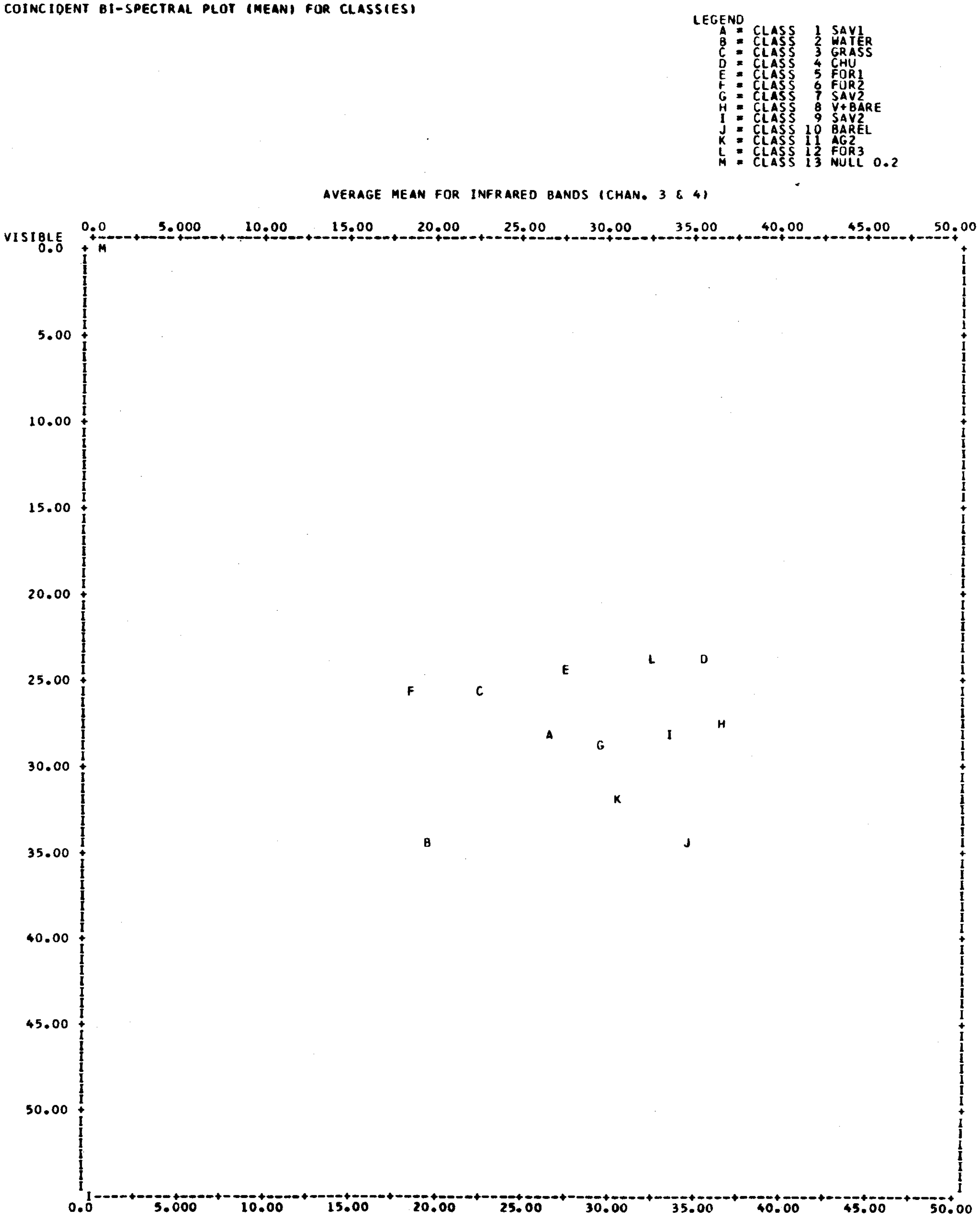

Figure 11. Bi-spectral plot for Province Santiesteban.

BOLIVIA
G.A.MCGREW

LABORATORY FOR APPLICATIONS OF REMOTE SENSING
PURDUE UNIVERSITY

MAR 4,1977
05 25 37 PM
LARSYS VERSION 3

BI-SPECTRAL FOR GUTIERREZ

COINCIDENT BI-SPECTRAL PLOT (MEAN) FOR CLASS(ES)

LEGEND
A = CLASS 1 RIVER
B = CLASS 2 BAREL1
C = CLASS 3 FOR1
D = CLASS 4 GRASS2
E = CLASS 5 FOR2
F = CLASS 6 AGV1
G = CLASS 7 SAV1
H = CLASS 8 GRASS1
I = CLASS 9 WATER
J = CLASS 10 DFOR
K = CLASS 11 SAV2
L = CLASS 12 BFOR3
M = CLASS 13 AGV2
N = CLASS 14 NULA

AVERAGE MEAN FOR INFRARED BANDS (CHAN. 3 & 4)

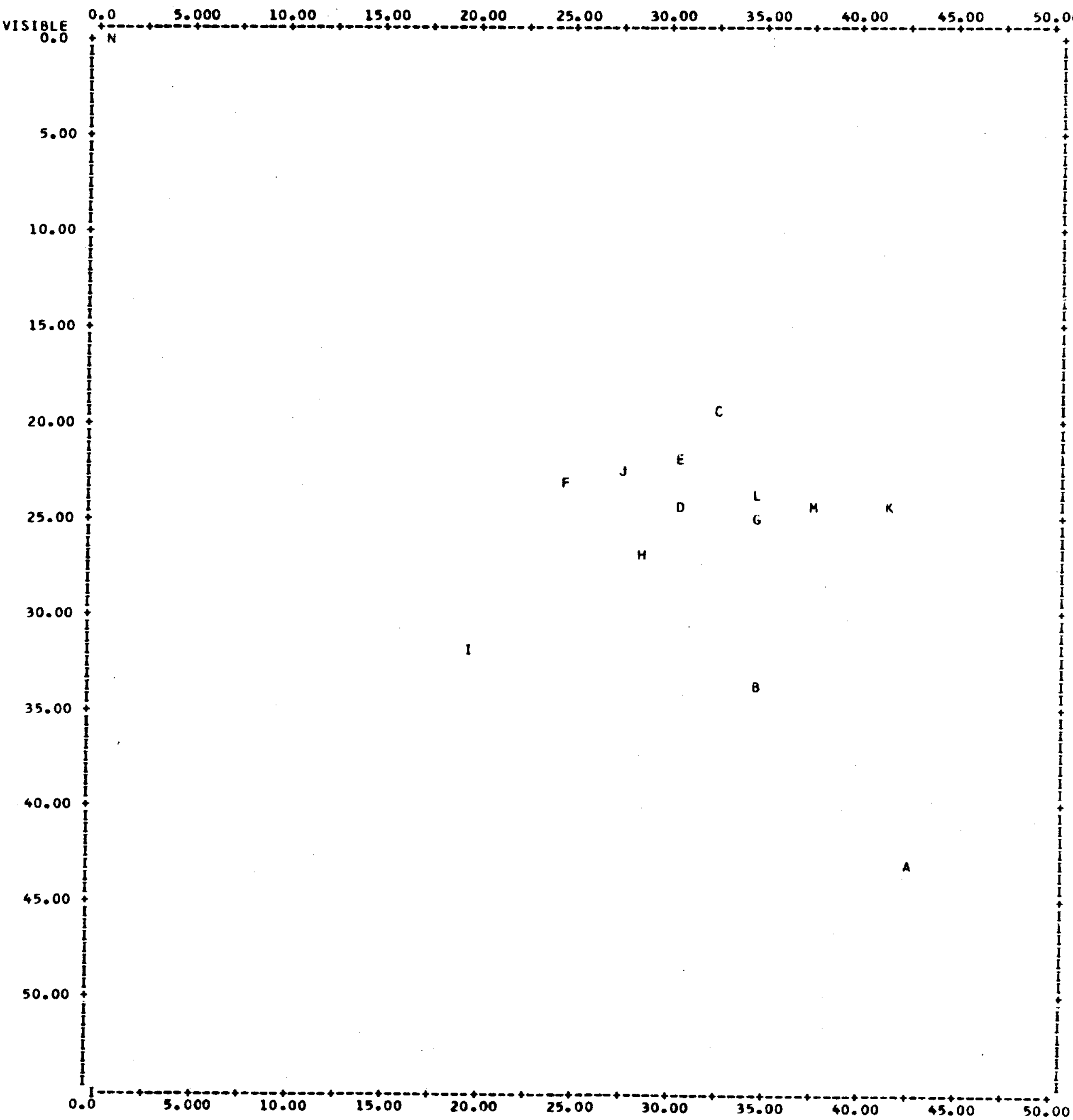

Figure 12. Bi-spectral plot for Province Gutierrez.

BOLIVIA
GLORIA MCGREW

LABORATORY FOR APPLICATIONS OF REMOTE SENSING
SERVICIO GEOLOGICO DE BOLIVIA (PROGRAMA ERTS)

DEC 29,1976
10 41 56 PM
LARSYS VERSION 3

GRAFICO BI-SPECTRAL PLOT DE LAS AREAS EN LA PROV. ICHILO

COINCIDENT BI-SPECTRAL PLOT (MEAN) FOR CLASS(ES)

LEGEND
A = CLASS 1 BOSQUE-1
B = CLASS 2 BOSQUE-2
C = CLASS 3 BOSQUE-3
D = CLASS 4 BOSQUE-4
E = CLASS 5 SOMBTOPO
F = CLASS 6 RA,PA,CU
G = CLASS 7 RA,B,BDE
H = CLASS 8 AGT,SHUM
I = CLASS 9 AGUAVEFL
J = CLASS 10 PA,RA,BS
K = CLASS 11 PAS,SHUM
L = CLASS 12 BOSQBAJO
M = CLASS 13 BOS,BOSF
N = CLASS 14 BO,VEARB
O = CLASS 15 CU,SU,PA
P = CLASS 16 ARENA
Q = CLASS 17 CULTSOYA
R = CLASS 18 AGUACLAR
S = CLASS 19 BODE,BSE
T = CLASS 20 AGTU,SHU
U = CLASS 21 ARHU,SHU
V = CLASS 22 NULA

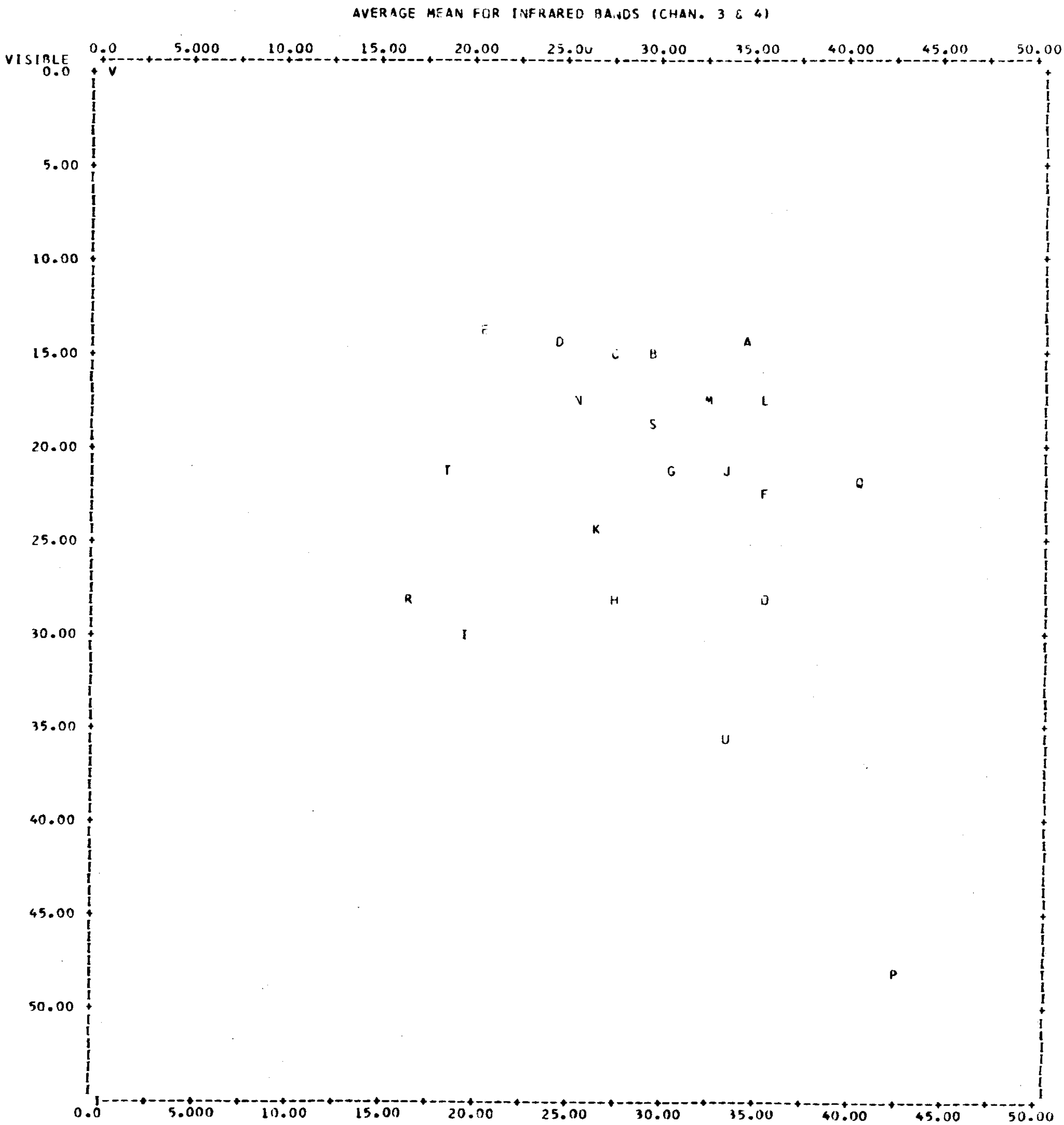

Figure 13. Bi-spectral plot for Province Ichilo.

BOLIVIA
GLORIA MCGREW

LABORATORY FOR APPLICATIONS OF REMOTE SENSING
SERVICIO GEOLOGICO DE BOLIVIA (PROGRAMA ERTS)

DEC 30,1976
12 49 07 PM
LARSYS VERSION 3

BI-SPECTRAL PARA SANTA CRUZ

COINCIDENT BI-SPECTRAL PLOT (MEAN) FOR CLASS(ES)

LEGEND
A = CLASS 1 NS- 1/
B = CLASS 2 NS- 2/
C = CLASS 3 NS- 3/
D = CLASS 4 NS- 4/
E = CLASS 5 NS- 5/
F = CLASS 6 NS- 6/
G = CLASS 7 NS- 7/
H = CLASS 8 NS- 8/
I = CLASS 9 NS- 9/

AVERAGE MEAN FOR INFRARED BANDS (CHAN. 3 & 4)

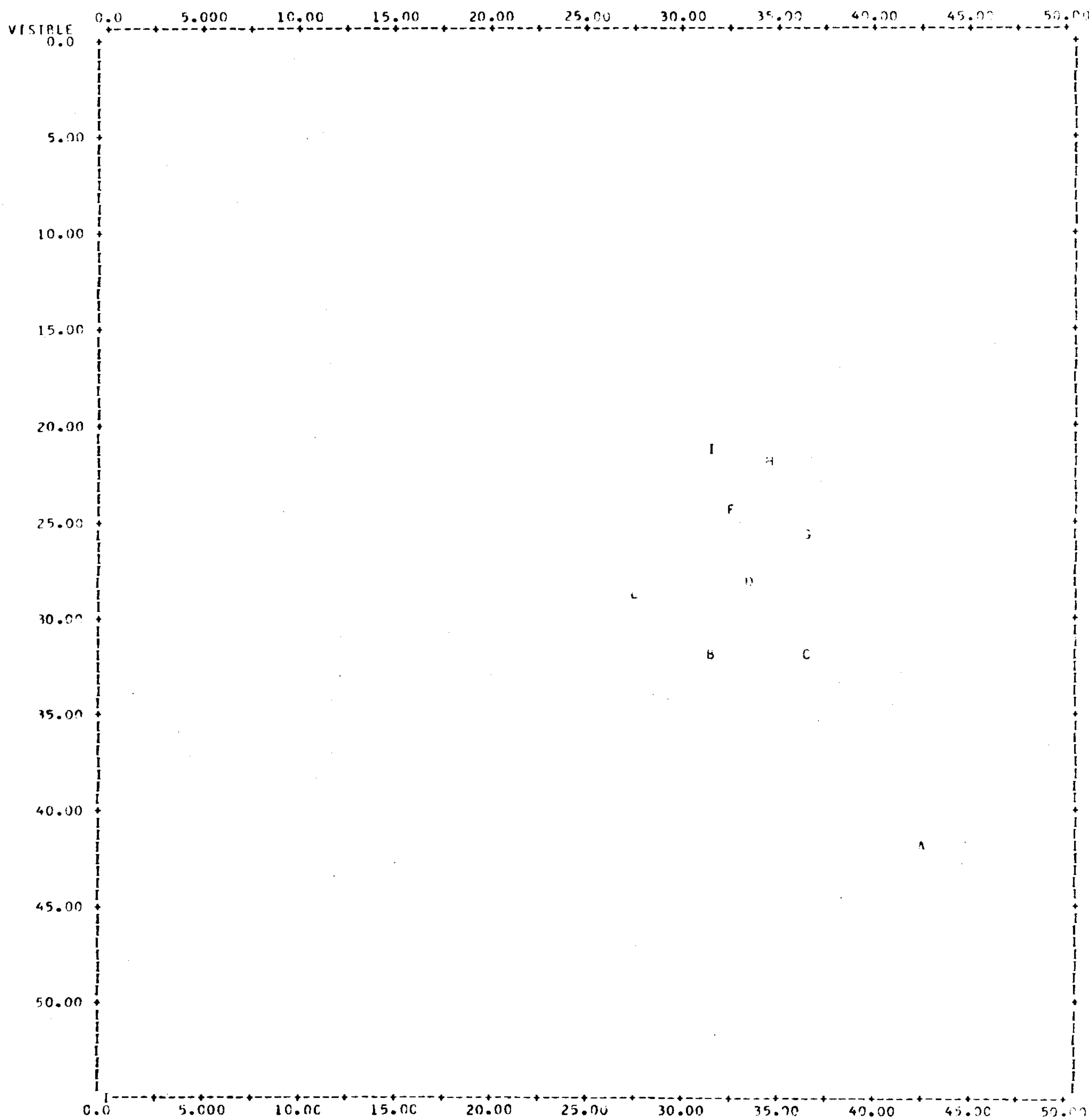

Figure 14. Bi-spectral plot for the ciry of Santa Cruz.

TABLE 10. Symbols used for Each Spectral Class in the Various Processors for Province Andres Ibañez.

Spectral Class	Separability	Bi-Spectral Plots	Classifications Printouts	Tentative Cover Type Designation
1	b̸	A	.	Agua Turbia
2	.	B	-	Soils
3	-	C	$	Somtopo
4	0	D	M	Bosque-1
5	1	E	/	Arena Hum
6	)	F	I	Pasto
7	*	G	1	Duna
8	ε	H	+	Chapar-1
9	X	I	=	Suelo
10	=	√	ε	Chapar-2
11	(	K	B	Bosque-2
12	Z	L	b̸	Nula

TABLE 11. Symbols used for Each Spectral Class in the Various Processors for Province Warnes.

Spectral Class	Separability	Bi-Spectral Plots	Classifications Printouts	Tentative Cover Type Designation
1	b̸	A	-	Sueld
2	.	B	=	Sue-Agua
3	-	C	T	Sue/Veg
4	O	D	+	Culyiuo
5	/	E	S	V.S. Chu
6	)	F	B	Veg. Secu
7	*	G	/	Arena
8	ε	H	.	Agua/S.H.
9	X	I	$	Bosque-1
10	=	J	M	Bosque-2
11	T	K	I	Pasto
12	(	L	X	V.S. Ch.2
13	Z	M	b̸	Nula

TABLE 12. Symbols used for Each Spectral Class in the Various Processors for Province Ñuflo de Chavez.

Spectral Class	Separability	Bi-Spectral Plots	Classifications Printouts	Tentative Cover Type Designation
1	ƀ	A	.	Agua
2	.	B	l	Veg. Herb.
3	-	C	M	Basque-1
4	O	D	T	Vsec. Bos
5	/	E	X	B2, Ch, Cu
6	)	F	+	Suel/Veg.
7	*	G	I	Past, Vse
8	ε	H	=	Chuchio-1
9	X	I	$	Bosque-3
10	=	J	S	Vsich, Cu
11	(	K	-	Chuchio-2
12	Z	L	ƀ	Nula

TABLE 13. Symbols used for Each Spectral Class in the Various Processors for Province Santiesteban.

Spectral Class	Separability	Bi-Spectral Plots	Classifications Printouts	Tentative Cover Type Designation
1	A	A	ε	Sav 1
2	B	B	.	Water
3	C	C	+	Grass
4	D	D	U	Chu
5	E	E	X	For 1
6	F	F	$	For 2
7	G	G	I	Sav 2
8	H	H	=	V+Bare
9	I	I	s	Sav 2
10	J	J	-	Barel
11	K	K	/	Ag 2
12	L	L	M	For 3

TABLE 14. Symbols used for Each Spectral Class in the Various Processors for Province Gutierrez.

Spectral Class	Separability	Bi-Spectral Plots	Classifications Printouts	Tentative Cover Type Designation
1	-	A	-	River
2	.	B	.	Barel 1
3	$	C	$	For 1
4	T	D	T	Grass 2
5	B	E	B	For 2
6	Z	F	Z	Agv 1
7	L	G	L	Sav 1
8	I	H	I	Grass 1
9	W	I	W	Water
10	R	J	R	o for
11	S	K	S	Sav 2
12	H	L	H	8 for 3
13	+	M	+	Agv 2
14	ƀ	N	ƀ	Nula

TABLE 15. Symbols used for Each Spectral Class in the Various Processors for Province Ichilo.

Spectral Class	Separability	Bi-Spectral Plots	Classifications Printouts	Tentative Cover Type Designation
1	b̸	A	M	Bosque-1
2	*	B	O	Bosque-2
3	-	C	-	Bosque-3
4	1	D	X	Bosque-4
5	Q	E	/	Comb Topo
6	W	F	=	Ra, Pa, Cu
7	E	G	C	Ra, B, Bde
8	R	H	V	Ast, Shum
9	T	I	J	Aguavefl
10	Y	J	H	Ra, Ra, Bs
11	U	K	W	Ras, shum
12	I	L	E	Bosq Bay o
13	O	M	S	Bos, Bose
14	P	N	L	Bo Verb
15	A	)	*	Cu, Su, Pa
16	S	P	&	Arena
17	D	Q	+	Cuitsoya
18	F	R	.	Aguaclar
19	G	S1	T	Bode, Bse
20	H	T	B	Agtu, Shu
21	J	U	I	Arhlu Shu
22	M	V	b̸	Nula

TABLE 16. Symbols used for Each Spectral Class in the Various Processors for the City of Santa Cruz.

Spectral Class	Separability	Bi-Spectral Plots	Classifications Printouts	Tentative Cover Type Designation
1	b̸	A	b̸	Arena
2	)	B	.	Aqua tuobia
3	-	C	-	Urbano 1
4	O	D	=	Urbano 2
5	)	E	/	Casco Viejo
6	*	F	*	Suelo 1
7	$	G	O	Silo 2
8	X	H	S	Bisque 1
9	M	I	M	Bosque 2

side of the bi-spectral plot. Similarly, the class denoted by the letter "A" which has the highest spectral response both in the visible as well as in the near IR corresponds to the highly reflective sand flats of the dry river beds. The class denoted by the letter "C", which has a relatively high spectral response in the near IR but a relatively low spectral response in the visible bands, should correspond spectrally to a vegetation class; in fact, this class "C" corresponds to a forest class (and is indicated as such in the legend of the bi-spectral plot).

Therefore, the use of the separability information, relative position of the classes in a two-dimentional spectral space (bi-spectral plots), and the knowledge of the basic spectral characteristics of the different materials found on the earth surface, can be very useful as an aid to the conventional photointerpretation during the analysis phases in which the non-supervised spectral classes are labeled as informational classes.

In addition to the multispectral classification result maps sent to the Bolivian ERTS Program office, tabulated information on the areal extent (in hectares) and the percent area covered by the different spectral classes for each individual province have also been provided to the Bolivian ERTS Program office. Tables 17 through 22 give, on a province by province basis, (1) the spectral class number, (2) the symbols used in the final classification maps, (3) the tentative informational class designations, (4) the number of resolution elements (pixels) classified into each spectral class, (5) the number of hectares of each spectral class, and (6) the percent area covered by each class. The spectral class labeled "null" or "nula" was defined by the analyst to represent those areas of a Landsat data set which do not contain actual spectral data since they are outside the boundary of the Landsat frame or are outside of the boundaries of that particular province.

It should also be noted that in these tables, the area estimates apply only to the portion of the province that was actually covered by the Landsat data. In no case was an entire province covered by Landsat, so these figures do not represent the amount of the various cover types present for the entire province.

The evaluation of the multispectral classification results conducted by both the Bolivian and LARS scientists has shown that most of the major cover types in the area (primarily the forested areas) covered by the Buena Vista frame were classified with a high degree of accuracy. However, certain specific cover types which were different informational classes, were not correctly discriminated on the basis of their spectral response. This problem was found when sugar cane fields (Figure 3) were misclassified as pasture (Figure 3). Comparison of Figures 3 and clearly show that the tall pasture plants are extremely similar to the sugar cane plants.

TABLE 17. Areal Extent of Different Spectral Classes for Province Andres Ibañez.

Spectral Class	Classification Symbol	Class Designation	No. Pixels	Hectares	Percentage
1	.	Aguturb	3,079	1,478	0.46
2	-	Soils	25,498	12,239	3.85
3	$	Sombtopo	15,904	7,634	2.40
4	M	Bosque-1	207,031	99,375	31.30
5	1	Arenahum	13,761	6,605	2.08
6	I	Rasto	78,516	37,688	11.87
7	1	Duna	1,618	777	0.24
8	+	Chapar-1	54,793	26,301	8.28
9	=	Suelo	37,615	18,055	5.68
10	ε	Chapar-2	30,112	14,454	4.55
11	B	Bosque-2	193,429	92,846	29.24
12	ƀ	Nula	343,208		
		Total Pixels	1,004,564	317,452	100%
		- Null Data	343,208		
		Totals	661,356		

TABLE 18. Areal Extent of Different Spectral Classes for Province Warnes.

Spectral Class	Classification Symbol	Class Designation	No. Pixels	Hectares	Percentage
1	-	Suelo	12,957	6,219	3.74
2	=	Sue-Agua	20,757	9,963	5.99
3	T	Sue/Veg	54,530	26,174	15.74
4	+	Cultivo	25,819	12,393	7.45
5	S	V.S., Chu	40,858	19,612	11.79
6	B	Veg. Secu	70,656	33,915	20.39
7	l	Arena	2,646	1,270	0.76
8	.	Agua/S.H.	3,821	1,834	1.10
9	$	Bosque-1	42,220	20,266	12.18
10	M	Bosque-2	55,496	26,638	16.02
11	I	Pasto	10,647	5,111	3.07
12	X	V.S.,Ch,Q	5,942	2,852	1.71
13	b̸	Nula	310,006		
		Total Pixels	656,355		
		- Null Data	310,006		
		Totals	346,349		

TABLE 19. Areal Extent of Different Spectral Classes for Province Ñuflo de Chavez.

Spectral Class	Classification Symbol	Class Designation	No. Pixels	Hectares	Percentage
1	.	Agua	2,055	986	0.32
2	l	Veg. Herb	10,479	5,030	1.64
3	M	Basque-1	98,439	47,251	15.46
4	T	V Sec, Bos	42,879	20,582	6.73
5	X	B2, Ch, Cu	146,358	70,252	23.0
6	+	Suel/Veg	1,007	483	0.15
7	I	Past, USE	2,635	1,265	0.41
8	=	Chuchiol	20,511	9,845	3.22
9	$	Bosque-3	251,602	120,769	39.53
10	s	VS, Ch, Cu	52,282	25,095	8.21
11	-	ChuchioZ	8,073	3,875	1.26
12	b̸	Nula	731,431		
		Total Pixels	1,367,751		
		- Null Data	731,431		
		Totals	636,320		

TABLE 20. Areal Extent of Different Spectral Classes for Province Gutierrez.

Spectral Class	Classification Symbol	Class Designation	No. Pixels	Hectares	Percentage
1	.	River	3,145	1,510	0.35
2	-	Barel 1	18,195	8,734	2.08
3	$	For 1	177,706	85,299	20.31
4	T	Grass 2	54,968	26,385	6.28
5	B	For 2	339,549	162,983	38.82
6	Z	Ag Vl	32,108	15,412	3.67
7	L	Sav 1	49,030	23,534	5.60
8	I	Grass 1	50,720	24,346	5.79
9	W	Water	1,557	747	0.17
10	R	D for	90,235	43,313	10.31
11	S	Sav 2	782	375	0.08
12	H	8 For 3	51,001	24,481	5.83
13	+	Agv 2	5,605	2,690	0.64
14	b̸	Nula	623,471		
		Total Pixels	1,498,072		
		- Null Data	623,471		
		Totals	874,601		

TABLE 21. Areal Extent of Different Spectral Classes for Province Sautiesteban.

Spectral Class	Classification Symbol	Class Designation	No. Pixels	Hectares	Percentage
1	ε	Sav 1	56,555	27,146	6.18
2	.	Water	1,863	894	0.20
3	+	Grass	133,446	64,054	14.59
4	u	Chu	58,623	28,139	6.41
5	X	For 1	134,848	64,727	14.75
6	$	For 2	15,542	7,460	1.70
7	I	Sav 2	101,246	48,598	11.07
8	=	VtBare	61,877	29,701	6.76
9	S	Sav 2	106,446	51,094	11.64
10	-	Barel	8,195	3,934	0.89
11	l	Ag 2	11,719	5,625	1.28
12	M	For 3	233,774	107,412	24.41
13	ƀ	Null 02	613,112		
		Total Pixels	1,527,246		
		- Null Data	613,112		
		Totals	914,134		

TABLE 22. Areal Extent of Different Spectral Classes for Province Ichilo.

Spectral Class	Classification Symbol	Class Designation	No. Pixels	Hectares	Percentage
1	M	Bosque-1			
2	0	Bosque-2			
3	-	Bosque-3			
4	X	Bosque-4			
5	1	Samb topo			
6	=	RA,PA,CU			
7	C	RA,B,BDE			
8	V	Agt, Shum			
9	J	Agna Ve Fl			
10	H	PA,RA,BS			
11	W	Pas, Shum			
12	E	BosqBajo			
13	S	Bos, Bose			
14	L	Bo, Vearb			
15	*	Cu, Su, Pa			
16	&	Arena			
17	+	Cult Soya			
18	.	Agua Clar			
19	T	Bode, Bse			
20	B	Agtu, Shu			
21	I	Arhu, Shu			
22	ƀ	Nula			

Spectrally, these two different cover types (tall pastures and sugar cane) were not separable. Therefore, more basic research on the spectral characteristics of sugar cane and pasture should be conducted in order to determine whether there is a particular portion of the spectrum (perhaps outside the spectral range of the current Landsat detectors) in which these two different cover types have different and distinct spectral responses.

Another problem involved the confusion between an urban class with a partially vegetated soil class. Figure 3 shows a photograph of the center and older part of the Santa Cruz City. Note in this photograph that the roof tops are covered by vegetation.

Because the area covered by the Buena Vista frame is a region of ecological transition, a major problem of cover type definition was encountered both during the analysis sequence and during the evaluation process. For example, extensive areas of a mixture of grassland, brush, and trees are common in this region. This complex type of vegetation cover is sometimes categorized by the Bolivian ecologists and land use specialists as grassland, chaparral, and sometimes even as forest. Therefore, this complex mixture of vegetation cover should be more precisely identified and classified in the field before the spectral class(es) representing this type of vegetation can be correctly labeled.

Since the Landsat data used in this study were collected on September 16, 1975, which is the end of the winter season, very little agricultural corps were present in the area. Only a few fields of sugar cane were still not harvested. The rest of the agricultural fields were covered by weeds or stubble, which were frequently missclassified as pasture land. Also, mostof the agricultural fields in this region are relatively small with respect to the spatial resolution of the Landsat MSS system. Therefore, in order to improve the accuracy of the agricultural classification of the Santa Cruz Integrated Subregion, it is necessary to learn more about the agricultural calendar and practices of this area, so that an optimum date(s) during the growing season can be selected for the gathering of the Landsat data.

CONCLUSIONS AND RECOMMENDATIONS

Since each province was classified separately, and because the characteristics of the various cover types were quite different among the different provinces, the resultant classifications have different numbers of spectral classes. For example, in the Ichilo Province, 22 significant spectral classes were defined, whereas in most of the other provinces only 12-14 significant spectral classes were defined. Thus, a particular spectral class could be present in one province but not in another. The field work by both the Bolivian and LARS scientists indicated that the spectral classes utilized were very effective in distinguishing the various cover types present. Therefore, the classification results are basically considered to be very good. However, it was also noted that in some cases, a single informational class was represented by several spectral classes, thereby resulting in the printouts (classification results) having more information and detail than was really necessary or even desired. In other cases, more than one informational class was represented by a single spectral class. Both situations require that the Bolivia ERTS Program office clearly describe the characteristics of each of the spectral classes, then define the informational classes that are desired for each province and for the region as a whole, and then define which spectral classes belong to which informational class. For example, should the spectral classes tentatively defined as "chaparral" be placed in a "forest" or "pasture" informational class? The field work by the LARS scientists tended to indicate that in the Andres Ibañez Province, one of the chaparral spectral classes probably should be placed in the "forest" category, (deciduous forest sub-class) whereas the other should be placed in the "pasture" information category. However, these types of decisions should be made by the Bolivian scientists in relation to the informational classes that are to be defined and utilized. It is therefore recommended that the following course of action be pursued by the Bolivia ERTS Program office as a matter of high priority:

(1) Clearly describe the characteristics of the various cover types indicated by each spectral class defined in the analysis, and then attach a meaningful name to that spectral class.

(2) Based upon the experience that has been developed in computer classification techniques and the results of the field work, define and describe the meaningful information classes and sub-classes that can be achieved for each province and for the entire Santa Cruz Integrated Subregion.

(3) Determine which spectral classes belong to which of the various informational classes defined in step 2 above.

(4) Develop a set of computer symbols that are the same for all provinces and which can be utilized to display the various informational classes and sub-classes in a meaningful, easy-to-locate manner.

(5) Utilizing the newly developed capability to print computer classification results (*PRINTRESULTS) on the CENACO computer in La Paz, display the classification results in a 1:25,000 scale format and obtain the data for tabulating the number of hectares of the

various informational classes and sub-classes on a province by province basis.

(6) Test the validity of the informational class maps and tables by sufficient field work (much of which could be done by plane) so that an indication of the accuracy and reliability of the maps and tables can be given on a province by province and a class by class basis.

The recommended procedure for doing this verification field work would be to randomly locate a large number of areas on the classification maps that can be easily and confidently recognized from the air or on the ground, and number these areas for reference purposes. Then, fly over or go to these areas and determine whether the cover type on the ground is accurately described by the previously developed description for that class or sub-class. If a number of areas on the ground do not adequately match the description, then the descriptions would need to be modified so that they truly reflect the actual characteristics of the cover type existing on the ground, or, secondly, exceptions to the class description are duly noted.

The thrust of this entire endeavor should be a meaningful set of descriptions of the various classes and sub-classes such that there is a reasonable certainty that if a person uses the classification results and goes on the ground to the location of a particular class or sub-class, the cover type actually present on the ground will generally match the description given to that particular class or sub-class of cover. There are likely to be exceptions for some of the classes and sub-classes, and these need to be known and documented on a province by province basis.

Another recommendation is that a VARIAN plotter be purchased and connected to the Bolivian computer system for purposes of obtaining output results. The reasons for this recommendation are that (1) the VARIAN plotter can produce output maps at various scales, thereby enabling a 1:50,000 scale format to be achieved directly from the classification results tape, and (2) that a variety of symbols having greater contrast and being more representative of the various informational classes can be utilized, thereby enabling the output maps to be more readily integrated and utilized.

One of the problems that we faced in this analysis of the Santa Cruz Integrated Subregion was the fact that the data that was available was obtained at a time of year (September 16, 1975), that was not good for agricultural cover type mapping (i.e. the crops had mostly been harvested already). Therefore, one of the questions that has come up involves crop calendar information and the corresponding cloud cover information (e.g. at what stage of development are the different crops at various times of the year, what time of the year would be best for spectrally identifying and mapping the different crops of importance, and what is the probability of obtaining cloud-free Landsat data during those key time periods). These are questions that the appropriate people having a familiarity with agricultural practices in the various regions of Bolivia could help answer. There is a need, however, to relate the agricultural crop calandar information to the spectral characteristics of the scene. In other words, "think spectral"! The agronomist can define the crop calendar information, but he can't effectively define the best time of the year to obtain the spectral data via Landsat. For that part of the question, a well qualified scientist trained in interpreting the spectral characteristics of earth surfaces features must be involved.

Added evaluation of the classification results indicated that the various classes of forest cover had been delineated and mapped with a surprising degree of detail and accuracy. This was particularly true in relation to the varying amounts of deciduous and evergreen trees present in a forest area. Thus, it would appear that the mid-September data is very good for mapping forest cover conditions. The main difficulty noted in the forest cover mapping was the fact that some of the brush-land areas that had been recently cleared and are now comming back into forest were classified as forest cover rather than as brush-land, even though they are not yet of economic importance as forest lands. Periodic analysis of satellite data of this area would be one way of eliminating this type of interaction among informational categories.

In looking to the future, another question that could be addressed involves the potential for multi-temporal data analysis. Considerable research in this area is needed to define the times (more than one date) that may be required for effective mapping of certain cover types. There are many questions that could be investigated concerning the value and applicability of thermal IR data that will soon be available from Landsat-C, and what type of reference data (ground truth) is necessary for effective interpretation of such satellite data.

There are also many potentials for utilizing radar data, particularly in these tropical regions where cloud cover is perhaps a major problem at critical times of the year. There may soon be an opportunity to assess the value of Seasat active microwave data.

With developing capability for computer analysis of satellite MSS data here in Bolivia, the ERTS Program office will be in a rather unique position among the countries in this portion of the world, from two interrelated standpoints. First they will have a capability to process Landsat MSS data, and secondly, they will have some of the equipment capabilities and experience which could serve as a basis for developing a training center to serve all of the other Latin American countries in the interpretation and analysis of satellite data for various earth resource applications. Either or both of these potential capabilities offer many possibilities, but will require detailed planning, appropriate equipment, and appropriate staffing if they are to be fully realized.

Because of the large number of potentials and opportunities that the future holds, it is critical to define the long term goals that the Bolivian ERTS Program should pursue. With limited resources, only a limited number of projects can be pursued. It is very important that the projects to be pursued are within an overall well-defined program having clearly defined objectives.

REFERENCES

Bauer, M.E. 1975. "The Role of Remote Sensing in Determining the Yield and Distribution of Crops." Advances in Agronomy, Vol. 27. Also LARS Information Note 122075, 34 pp.

Hoffer, R.M. and Staff. 1975. "Computer-Aided Analysis of Skylab Multispectral Scanner Data in Mountainous Terrain for Land Use, Forestry, Water Resource, and Geologic Applications." LARS Information Note 121275, 397 pp.

Landgrebe, D.A. 1967. "Automatic Identification and Classification of Wheat by Remote Sensing." Research Progress Report 279, Agricultural Experiment Station, Purdue University. 7 pp.

Swain, P.H. and R.C. King. "Two Effective Feature Selection Criteria for Multispectral Remote Sensing. LARS Information Note 042673, 5 pp.