REMOTE SENSING DATA FROM SPACECRAFT AND AIRCRAFT : THEIR PROCESSING AND APPLICATIONS

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Abstract

Some aspects of the New Zealand remote sensing programme involving the US spacecraft "Landsat II" are discussed. An agricultural project is used as an illustration of the many ways in which "multispectral" data can be processed to yield the desired information. Finally, some of the possible futures for an "operational" remote sensing programme from spacecraft are considered.

INTRODUCTION

ONE of the fastest developing branches of science in the 1970s has been the remote sensing of our environment from space. These developments have been largely due to a series of satellites first called ERTS (Earth Resources Technology Satellite) and now called Landsat. Two Landsat satellites have been launched into orbit up to the present. The spectrally filtered pictures taken by the Landsat Multi-Spectral Scanner (MSS) have been used in numerous applications ranging from the production of land-use and vegetation maps to the detection of minerals and oil resources. In the U.S.A. utilization of Landsat data is moving from the public into the private sector with at least one company exceeding $3 million in turnover, mainly through mineral analysis and verification of crop production estimates.

In New Zealand, a two-year co-operative programme with the U.S. National Aeronautics and Space Administration (NASA) has just beeen concluded, in which many applications of Landsat data have been investigated (Probine *et al.*, 1977). These investigations cover regional land-use and vegetation studies, cartographical applications, analysis of snow cover, coastal sediment and other hydrological variables, geological studies, forest mapping, crop inventory and the detection of crop stress. The investigations have been based on data from Landsat 11 but some data from Landsat I have also been used. Many of these projects are continuing and will utilize data from Landsat "C" after its launch in 1978.

Pictures taken from earth resources satellites differ from more conventional photography derived, for instance, from aircraft., The relatively great height of the spacecraft gives a "synoptic" view covering a large area, even for a sensor with a narrow angular field of view. The result in the case of Landsat is a scene covering 34 000 km' with very little inherent distortion and requiring few further corrections to fit existing map projections (Fig. 1). Except in certain military satellites which use photographic recovery techniques, the scene below the satellite is scanned with an electronic sensor, and the data can be stored on the satellite tape recorder for later transmission to a ground station. At this stage the data consist of a series of numbers which describe the brightness (radiance) of each target. On the ground,

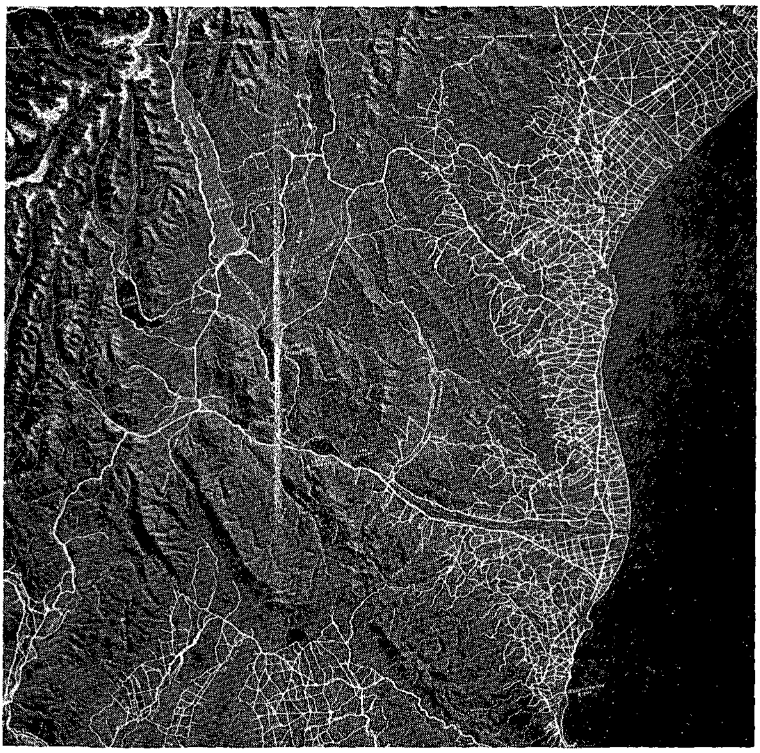

FIG. 1: *Topographic compilation data at 1: 1 000 000 scale combined with Landsat scene of North Otago, South Island. Combination demonstrates the low distortion of system-corrected (unrectified) Landsat imagery. Picture produced jointly by Department of Lands and Survey and PEL.*

the numbers are reconstituted as pictures on a photographic. base, and these products are usually the first to be seen by the user.

Much of the early work in satellite remote sensing was centred around these "standard" photographic products derived from the numerical data. Subsequently, interest switched to interpretation using the numerical data directly, without the intervening photographic stage. Even more recently, improvements in computing techniques have led to the development of digitally enhanced pictures, in which the end product is a colour picture with increased contrast and spatial resolution, optimized for the interpreter's application. In many cases it is now recognized that the most effective way to analyse satellite data is to allow the human interpreter to control the computer processing interactively, using a CRT display which presents the results of his analysis in "real-time". In the days before numerical techniques were widely employed, potential users of Landsat data often failed to realize the true information content of the pictures and were led to believe that satellite imagery was of limited use in their discipline.

This paper gives a brief outline of some of the characteristics of Landsat and the satellite data, and considers some of the ways in which the data can be used for specific applications. The effect of different methods of data processing is illustrated with a description of an agricultural project, using selected areas in the Canterbury Plains as test sites. The final objectives of this project are to find the extent to which satellites may be used in the future to monitor our crops repetitively throughout the growing season, to observe the regional patterns of crop stress, and to conduct timely yield estimates of major crops such as cereals.

THE LANDSAT SATELLITES AND THEIR DATA

Landsat 1 was launched in July 1972 and Landsat II in January 1975. Both of these satellites are in circular orbits at a height of 920 km above ground level. Each satellite completes fourteen orbits per day with the orbital plane inclined to the equator at an angle of 81°. This near-polar inclination is used to maintain a sun-synchronous orbit in which the satellite passes over a region at the same local time throughout the year. Landsats I and II pass over New Zealand at about 0900 to 0930 h NZST. Successive orbits are displaced by about 2 100 km in a westerly direction over New Zealand, and each orbit is of 103 min duration. On successive days, each spacecraft track is displaced westward by about 120 km from the equivalent track of the previous day. Thus the gaps between orbits are filled in over a period of 18 days. Over New Zealand the spacecraft passes in a NNE-SSW direction, starting with the north-east coast and taking seven passes (at one pass per day) to cover the whole country.

Two sensors, the Multi-Spectral Scanner (MSS) and the Return Beam Vidicon (RBV) are aboard Landsat I and Landsat II. Early failure of RBV on both satellites has meant that no RBV pictures of New Zealand have been obtained, and this instrument will not be considered further here.

The MSS has been described by Lansing and Cline (1975). It uses an oscillating mirror to scan at right-angles to the line of flight of the spacecraft, and thus it builds up a line-by-line image of the ground below. The width of the image strip is 185 km and the strip is divided into scenes which are 185 km in length. The MSS ground resolution element or "pixel" size is approximately GO x 80 m, and this sets the minimum detectable size of ground targets. The present MSS sensors split the incoming radiation into four spectral bands, MSS 4 covering the green spectrum (500-600 nm) , MSS 5 covering the red spectrum (600-700 nm), MSS 6 in the infrared (700-800 nm) , and MSS 7 also in the infrared (BOO-1 100 nm) . Thus four pictures are produced simultaneously, and it is the combination of radiances from each band that characterizes a ground target and is referred to as its spectral signature. The stored information for one Landsat scene exceeds 240 million bits.

Although the first product released to the user is a set of four transparencies or prints reconstituted from the numerical data, it is also possible to obtain the actual numerical data on a Computer Compatible Magnetic Tape (CCT), and this of course has not suffered degradation due, for instance, to the photographic process.

Landsat photographic products and CCTs are made available to world users by the EROS Data Center in the USA; which has been the source of all data obtained in New Zealand so far. The inevitable delays in receipt of New Zealand scenes (up to 12 weeks for a CCT) mean that Landsat cannot be regarded as an "operational" system at present, since it is the timely analysis of changing parameters which will have the greatest significance in the future.

LANDSAT DATA PROCESSING AND INTERPRETATION

PHOTOGRAPHIC PROCESSING

A convenient way to interpret data from up to three MSS bands is to colour combine them to make a "false colour composite". The majority of false colour composites until recently have been made to a "standard" system in which the blue sensitive layer has been exposed to MSS 4 (green), the green layer to MSS 5 (red), and the red layer to MSS 7 (infrared). In this combination, vegetation with a high chlorophyll content appears as bright red owing to its high infrared reflectance. Rock, bare soil and features devoid of vegetation are usually blue in colour, and intermediate targets vary between these two extremes. A land-use classification system for use with remote sensor data has been proposed by Anderson et *al.* (1972) in which targets arc divided into 9 major categories (level I) and 32 sub-classifications (level 11). Experience in the U.S.A. with Landsat I colour composites has shown that the level I categories can usually be mapped with accuracy, and that the possibility of differentiating level 11 categories varies according to the type of target and its background. In New Zealand, the Landsat II investigations have shown that the following major categories can be identified from colour composites produced at the Physics and Engineering Laboratory, DSIR: Urban areas, indigenous forest, exotic forest, scrub, pasture, crops, bare soil, tussock grassland, bare rock, water and snow. Subdivision of some of these categories, for instance of crop types, can be achieved with imagery acquired at the right time of year (Thomas et *al.,* 1977) .

It is also possible to enhance photographic products by, for instance, producing "contrast stretched" copies of monochrome transparencies and using these to make colour composites. This has the effect of increasing the range of colours and enables subtle differences between similar targets to be more clearly seen. In some cases, combinations of two positive transparencies with a negative transparency will result in an unconventional colour composite with the property of highlighting a certain desired feature. Suggate and Lensen (1976) have found that a positive-negative combination can be used to distinguish the crush zones of major active faults in New Zealand.

Finally, single MSS band prints and enlargements have proved to be valuable in certain applications such as geology, where linear features have been mapped from MSS 7 imagery (Oliver, 1977). In coastal studies, the differential water penetration properties of the MSS bands can be used to estimate sediment flow (Thomas, 1977) and sediment distribution can also be mapped from MSS band 4 (Male and Cochrane, 1977; Male, 1977; Campbell and Cochrane, 1977).

Monochrome prints and enlargements of Landsat scenes of New Zealand can be obtained from the Photo Library, Department of Lands and Survey, Wellington.

ELECTRONIC PROCESSING

Single band transparencies can be "density sliced" by scanning them with a monochrome TV camera, splitting the output signal electronically into a series of discrete levels ranging from low to high image density, and displaying each level as a unique colour on a CRT display. Thus a target whose image density is different from its background can be detected by its contrasting colour. Moreover, the area of one or more density levels can be measured as a fraction of the total screen area. This technique is useful only when the desired target can be uniquely identified on one of the MSS spectral bands, as is the case with snow, whose projected area has been mapped from Landsat scenes of the South Island.

The disadvantage is that, since only one band is used, the multispectral properties of Landsat imagery are lost, and the classification accuracy can rarely approach that of multiband analysis. The applications of television scanning to remote sensing are described by Schlosser (1972).

USE OF THE COMPUTER TO PROCESS OR INTERPRET DATA

The numerical data which constitute a Landsat scene and are stored on a magnetic tape can be displayed directly by means of the lineprinter. Typically two forms of output have proved to be useful. The Grst is a coded output in which each radiance level in one MSS band is represented by an alphanumeric character and the printed sheet constitutes a "map" of a small region within a Landsat scene. Since each "pixel" is individually recorded, the spatial resolution achieved represents the best available resolution from the sensor. Four images, one for each MSS band, together give all the information for the subscene derived by the sensor, and detailed analyses of small areas can be carried out directly from these products.

The second form of output is a "density coded" one in which the density of the printed character is related to the radiance level of the target. This gives a pictorial display which aids the geographical location of ground features. Computer programs to produce these two forms of output are described by McDonnell (1976).

For larger areas, "hardcopy" output products can be made with a "photowrite" machine in which the numerical data are "written" as a series of grey levels on to unexposed film, thus producing a photographic image to any desired scale. At sufficiently large scales, the individual pixels are clearly distinguishable; for Landsat this means that targets such as roads longer than about 300 m and paddocks larger than 2 ha can be seen. A recent innovation has been the "colorwrite" machine in which the data from three MSS bands can be made to produce a colour composite directly. This avoids the photographic colour compositing process with its attendant image registration problems.

The production of hardcopy products implies that it is the human interpreter who makes the final analysis. The computer can be used to enhance the numerical data before their conversion into a picture. As with photographic processing, images can be "stretched" to enhance colour differences, and positive-negative combinations of MSS bands can be made,

The technique of band ratioing is used in a variety of applications. Typically the pixel radiances of three MSS bands are individually ratioed against the pixel radiance of a fourth band or against a mean value derived from two or more bands. In agriculture, Kanemasu *et al.* (1974) have related the ratios MSS 4/MSS 5 and MSS 5/MSS 6 to the growth of wheat, and wheat yield and disease severity with MSS 4/MSS 6 and MSS 4/MSS 7. In geology, band-ratioed images have been used to detect iron compounds (Vincent, 1973) and soil types and mineral deposits (Vincent and Pillars, 1974). Other more recent enhancement methods include principal component or Eigen image methods (Billingsley, 1975) and canonical analysis (Eppler, 1976) which can maximize colour differences to a degree not possible with band ratioing, and which tend to reduce the amount of redundant information to be analysed.

Principal component methods and canonical analysis are among the techniques used in the automatic classification of target types by computer. Automatic classification usually involves "cluster analysis" in which targets are partitioned according to their spectral signature. "Unsupervised" clustering implies that the number and distribution of classifications are determined by the computer in accordance with inbuilt decision rules in the program. In "supervised" clustering the partitioning is determined by the interpreter who may use a "training set" of known targets to define the spectral signatures and their ranges. Automatic classification methods are reviewed by Fu (1976) and Steiner (1972).

The expected large increases in data volume from future earth resources satellites, together with the need for timely interpretation of data, have led to the development of interactive systems in which the computer is linked to a "real time" display such as a colour CRT. The interpreter is then able to "call up" a Landsat scene, or part of a scene, process the information with one of a number of enhancement or classification programs, and display the result on the screen. Only when a satisfactory result is obtained will a hardcopy product be produced, for instance, on a colorwrite machine. Apart from being able to iterate towards an optimum colour combination for a particular purpose, the interpreter can classify an area and display each category in a distinctive colour. The result is a "thematic" map of the area. Computer generated thematic maps are used in land-use and vegetation mapping, utilizing the synoptic Landsat view to classify large areas from the one scene. Thematic maps of more limited areas can also be produced as a character-coded lineprinter product.

LANDSAT DATA ANALYSIS IN NEW ZEALAND

During the course of the Landsat investigations in this country, the Remote Sensing Section at PEL, DSIR, has been developing techniques to process and interpret Landsat data, and to provide complementary data in the form of 4-band "MSS type" multispectral photography from aircraft.

The photographic laboratory is able to produce colour composite prints in the combinations described above. These have been used by more than ten New Zealand "user" groups in a variety of projects. Density slicing and area measurement from single band images are also possible using an electronic density slicer of the type described under Electronic Processing above.

Numerical data from CCTs have been extensively used during these investigations, mostly for the analysis of small areas using lineprinter products such as radiance or density coded copy, or as thematic maps. One approach to the numerical analysis has been to develop classification and other programs for a national computer network based on a large computer (IBM

370/168). Users with terminals to this system' are now able to access the programs and perform their own analyses of Landsat scenes. More sophisticated programs have been developed using a smaller "in-house" computer, and these include, for instance, a package of image rectification programs which geometrically correct an image to any desired map projection. Photographic products derived from some numerically processed scenes have been generated on machines of the photowrite type, in Australia and the U.S.A.

Aircraft data are obtained from a four Hasselblad camera system developed at PEL, which uses MSS type filters so that the pictures can be directly compared with the satellite products. Details of the PEL program arc given in Probine *et al.* (1977).

Recently: a colorwrite machine has been installed and photographic products derived from CCT data should, shortly be available in this country.

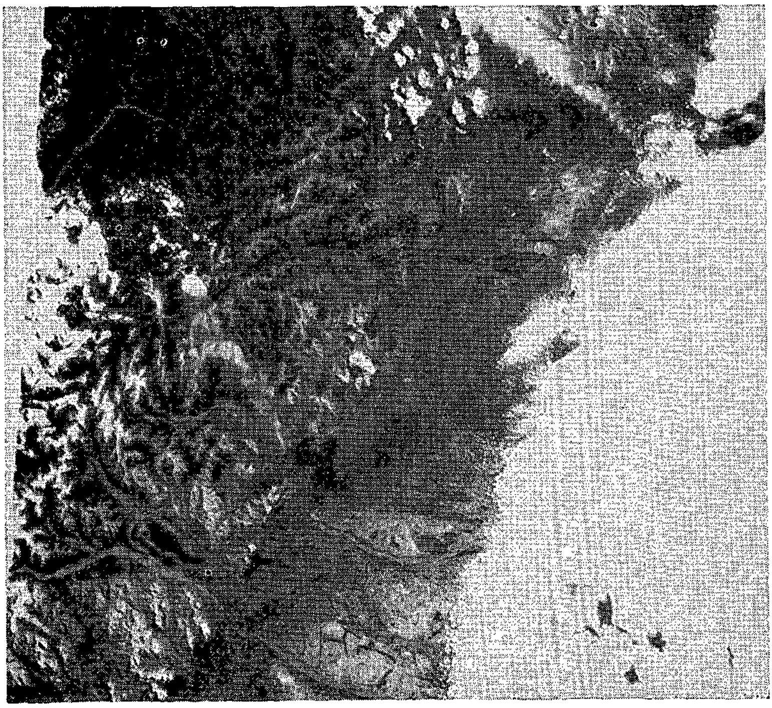

FIG. 2: Full scene (Landsat 1, summer, 1973) of north/central Canterbury (MMS band 5). Darfield test area lies to the south of the Waimakariri River (centre-bottom). (The area to the east is covered by cloud.)

MID-CANTERBURY CROP ANALYSIS FROM LANDSAT

The agricultural test sites established at Darfield, Leeston and Southbridge were chosen because of the variety of crops and soil types, and the clearly defined paddocks when viewed from Landsats I and II. Figure 2 shows MSS band 5 of the first scene of the region taken by Landsat I in summer 1973-4. At this time of the year, regional patterns of crop stress can be seen on the "standard" colour composite as variations in the red content of adjacent areas. Monochrome enlargements, produced from "first generation" CCT data on a photowrite machine at CSIRO, Aus-

FIG. 3: *MSS band 5 enlargement of mid-Canterbcrry region around the Waimakariri River. Note the pine shelterbelts (dark bands) near Darfield and south of the Selwyn Kiver. Roads and river channels can he clearly seen on this photowrite enhanced product derived from numerical (CCT) data. Part of the scene shown in Fig. 2.*

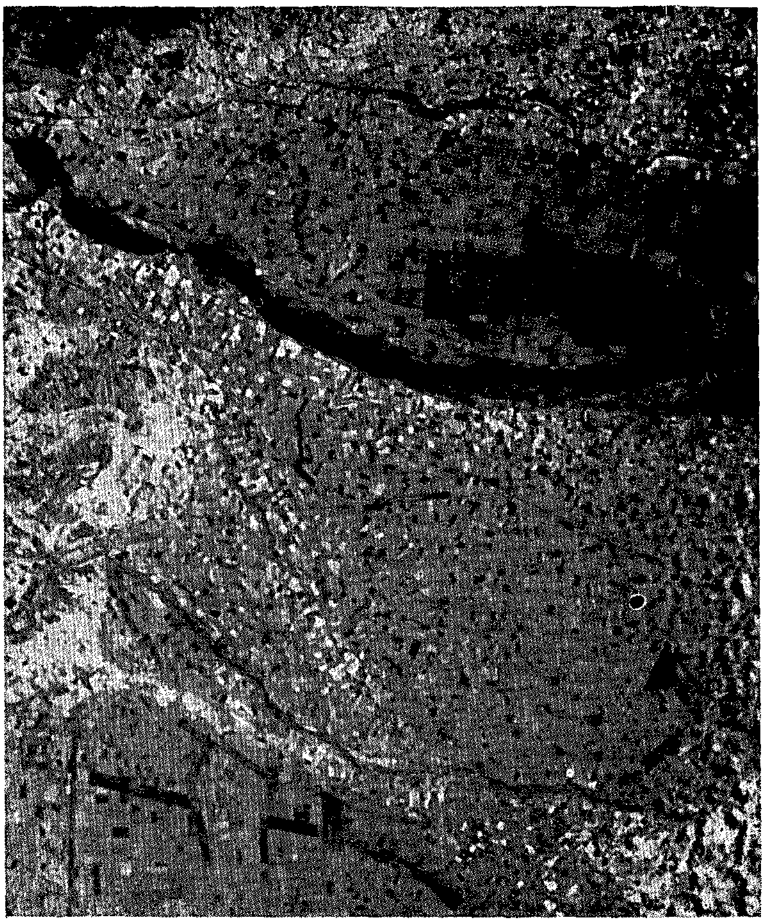

FIG. 4: *MSS band 7 photowrite enlargement corresponding to Fig. 3. High infrared reflectivity of crops shows up us bright bands along the south bank of the Waimakariri River and following the Hawkins River.*

tralia, are shown in Fig. 3 (MSS 5) and Fig. 4 (MSS 7). In Fig. 3 the areas of more vigorous growth appear to be darker than their surroundings, along the south bank of the Waimakariri River and following the course of the Hawkins and Selwyn rivers. The photowrite products illustrate the extent to which Landsat scenes can be usefully enlarged, and the degree of difference which can occur between the visible and infrared bands. A simple illustration of thematic mapping is given in Fig. 5, in

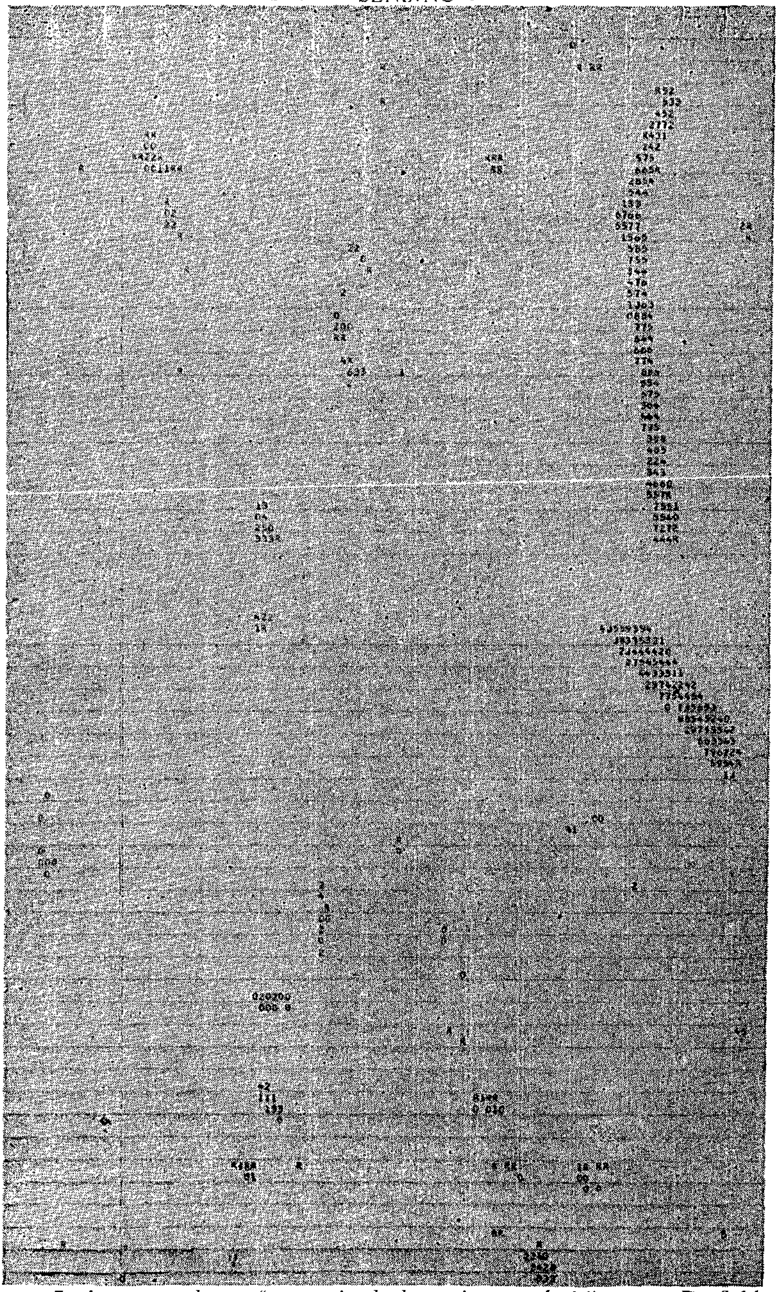

FIG. 5: *An example of "supervised clustering analysis" of the Darfield subscene, in which the computer has been "trained" to print out picture elements (pixels) corresponding to exotic forests. This picture shows the shelterbelts to the north-west of Darfield.*

which the computer has been trained to print out only the forest areas in a portion of the scene to the north-west of Darfield.

Extensive cloud cover during the investigation period has limited the total number of Landsat II scenes received to 51, of which only one, taken in Ocotber 1975, covered the test sites at a time when the crops had grown significantly. This has severely limited the conclusions that can be drawn at present concerning the possibility of obtaining routine area inventories of major crops such as wheat.

This scene has been analysed at PEL, and at the EROS Data Center, U.S.A., using their "Image 100" interactive data analyser. With the lmage 100, it was possible to manipulate the numerical data by, for instance, "stretching" the radiance levels to enhance the colour differences on the composite. Using a human interpreter and a number of different colour combinations, the following general results were obtained:

(1) Within a limited "homogeneous" region in which soil and soil moisture conditions did not vary too greatly, the autumn-sown wheat (Kopara, Hilgendorf, Arawa, Aotea) could be quite easily distinguished in both satellite and aircraft multispectral imagery taken at approximately the same time.

(2) It has not yet been possible to extrapolate these results into the other test areas (Leeston/Southbridge) for which "ground truth" was obtained. It is believed that imagery acquired rather later in the growing season would increase the chance of more accurate classification.

(3) The wheat paddocks could be most clearly seen on a "normal" colour composite (MSS bands 4, 5 and 7). Other combinations produced quite different results.

(4) lnverting the colours, that is. producing a "negative" colour composite, highlighted details in the forest areas (normally very dark). Colour variations within the shelterbelts at Darfield were found to correspond to the windthrown areas caused by the severe storm of August 1975. Subsequent work with the N.Z. Forest Service has shown that windthrown areas in State forests could be mapped from Landsat imagery (Lean, 1977).

(5) Combining a "positive" (MSS 7) with two "negatives" (MSS 4 and 5) gives a composite in which certain other features are easily seen. Recently mowed paddocks (lucerne or clover) appeared as bright red against a generally "quiet", background.

A report on this project and its progress up to September 1977 is given by Thomas et *al.* (1977), including a description of the subsequent computer analysis of the scene at PEL. This project is continuing into the 1977-S season. and it is hoped that repetitive satellite cover will be acquired. Ground truth surveys have already obtained information about 400 or more paddocks in the test areas.

CONCLUSIONS AND FUTURE PROSPECTS

This paper has illustrated some of the many ways in which remote sensing satellite data can be processed to yield the desired information. The agricultural project used as an example has pointed to the possibility of routine monitoring of crop stress and potential yield, if this type of data becomes operationally available. The Landsat II investigations in New Zeaiand have included projects in many other disciplines besides agriculture. In most cases, it is in the timely detection of change that these satellites may show the greatest benefits.

In February 1978, Landsat C is scheduled for launch. In addition to having the existing MSS spectral bands, a fifth "thermal" band, capable of sensing heat emission from ground targets, will be included. For the first time, therefore, it may be possible to obtain regular "synoptic" maps of New Zealand's geothermal areas. Ground resolution will improve with future satellites. Landsat C will fly a Return Ream Vidicon sensor with a resolution of 40 metres, and Landsat D, due for launch in 1981, will fly a Thematic Mapper with six spectral bands and a resolution of 30 metres square.

The advent of the space shuttle seems to have spurred plans for a variety of new spacecraft or series of spacecraft. Of these, the series of most immediate interest could be Seasat, the marine equivalent of Landsat. Seasat will be equipped with microwave instruments capable of detecting ocean surface features, including wave height, wind speed, potential fishing areas and surface transport. The Synthetic Aperture Radar (SAR) , with. its 25 metre ground resolution, also has potential applications over land.

The overall picture is one of continued improvement in data quality and quantity. However, the increasing flood of spacecraft data has generated several problems. Transmitted data rates will increase considerably as the ground resolution improves, and this has reduced the feasibility of on-board recording. It is therefore likely that future "operational" users of spacecraft imagery will need to receive it in "real time" via a local receiving station, as the spacecraft passes over the country. Local stations for Landsat already exist in Canada, Brazil and Italy, as well as in the U.S.A., and stations are planned for Iran, Argentina, Norway and Australia, and possibly India, Zaire and Indonesia. It is hoped that in the near future a careful assessment of the potential benefits will determine whether similar action should be taken in New Zealand.

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