PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

The Current Use of Remote-Sensing Data in Peat, Soil, Land-Cover and Crop Inventories in Scotland

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The current use of remote-sensing data in peat, soil, land-cover and crop inventories in Scotland

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The remote-sensing methodology developed, at the Macaulay Institute, for natural resource surveys is introduced and some recent mapping and environmental monitoring projects are reviewed. These include peat resource and peatland vegetation mapping in Lewis and North Harris, crop monitoring in Kincardineshire and land-cover mapping in the Buchan Area of Grampian Region, NE Scotland. The current use of remote-sensing data by the Peat Survey Section and the Soil Survey Department is reviewed for peat, soil and vegetation mapping. The principal current projects, which include the D.A.F.S. Bracken Survey of Scotland, the AGRISPINE Experiment for the U.K. National Remote Sensing Centre at R.A.E. Farnborough and the SAR 580 Experiment for the European Space Agency, are discussed.

1. Introduction

Successful remote-sensing projects completed in recent years at the Macaulay Institute have invariably resulted through the development of an appropriate remote-sensing methodology for natural resource surveys or environmental monitoring operations. Three phases of development resulted in the formulation of a general remote-sensing methodology for application projects:

(1) equipping and certifying an aircraft with a suitable remote-sensing rig for various survey operations;

(2) developing an automated photogrammetric digitizing and plotting facility for handling 'vector' data in mapping;

(3) developing a digital image-processing system linked to (2) for handling 'raster' data, such as Landsat MSS records.

The net result of the above developments at the Macaulay Institute was to create a novel 'hybrid' automated photogrammetric and image processing system, MAPIPS, for processing ground-acquired, aerial-acquired and satellite-acquired data. This system was specially structured for handling data in vector and raster form and to display information in a variety of ways for interpretation and plotting requirements. The general remote-sensing methodology can be summarized as follows:

(A1) acquisition of imagery, e.g. Landsat data, aerial photography (multiband and multilevel products);

(A2) pre-processing optical and digital data, e.g. enhancement of information, restoration and scaling;

(B1) interpretation of film products and correlation with ground truth data;

(B2) photogrammetric plotting and digitizing thematic information;

(C1) analysis of digital image data – enhancements, measurements, correlations, corrections and classifications;

(C2) final feature classifications and storing results;

(D1) data presentation in map or image form, including the compilation and production of reconnaissance maps and detailed maps for reports or publication;

(D2) data presentation in statistical form – final statistics related to feature classifications and areas including significance testing.

2. Peat survey mapping in Lewis and North Harris

The production of a medium-scale map illustrating the peat and terrain categories of Lewis and North Harris was the first major application of this general remote-sensing methodology in Scotland. A multilevel sampling strategy was adopted for this survey, which related small-scale, medium-scale and large-scale aerial photography to multispectral Landsat imagery and ground survey data. The accuracy of the peat categories derived from a supervised classification of Landsat data was assessed by comparing the classified areas against the actual ground areas of the features that were photogrammetrically mapped within selected test blocks. Considering all the categories classified over North Lewis, which included intact peatland, eroded peatland, shallow peat and rock complexes, agricultural land and open water, a final average rank area correlation coefficient, $r_s = 0.905$, was computed (Stove & Hulme 1980). This, together with the fact that r_s ranged only from 0.78 to 0.945, suggests that there is a high degree of correlation and consistency in the order of the areal categories from maximum to minimum rank.

The Lewis study demonstrated that a relatively simple image-processing technique (contrast stretching and density slicing the reflectance range of the infrared band, band 7 of Landsat) produced 80% of the information required to map the peat and terrain categories at the required scale. This map, published in 1981, is primarily a peat resource map that depicts general land-cover types. It also illustrates the present use of peatlands in terms of domestic peat cuttings and land improved for agriculture and forestry. The map is the first of a series of land-cover, peat and other resource maps of Scotland based on Landsat satellite image processing (Stove & Hulme 1980; Macaulay Institute 1981).

3. Land-cover mapping in Grampian Region

The aim of this particular work was to test whether simple image-processing techniques and classification methods based on Landsat data would apply to more complex terrain in the Grampian Region, for the mapping of land-cover types in general. A pilot study was conducted in the Laurencekirk–Cairn o'Mount area in 1977 and, following the successful completion of this project, a collaborative study was undertaken for Grampian Regional Council's Department of Physical Planning in 1979 to produce a land-cover map of the Buchan area in NE Scotland, for physical planning purposes.

(a) *The Laurencekirk pilot study*

This study was based on the analysis of a single Landsat scene, imaged in early August 1977. The results demonstrated that a single Landsat image was inadequate for identifying all land-cover and crop categories required. It was noted that barley and root crops (such as potatoes and turnips) have unique spectral signatures on certain Landsat bands and that band ratios vary during the growing season, in particular from June to August. By using Landsat data, crops were enhanced successfully during the harvest season in August and September.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

(*b*) *The Buchan Study*

The objectives of this study were as follows:

(1) to establish the feasibility of identifying and mapping the following 'land-cover categories', suggested by the planners: (*a*) farmland, (*b*) roughland–moorland, (*c*) hill grazings, (*d*) wetlands–peat, (*e*) forestry, (*f*) vegetated dunes, and (*g*) bare sand (beaches and exposed dune surfaces);

(2) to establish the optimum time during the growing season for differentiating these categories;

(3) to establish the best enhancement and classification techniques for identifying these categories; and

(4) to establish the most cost effective method of mapping the categories and determining their areal extent.

The study area covered 1500 km^2 extending from Troup Head on the north coast and following the coastline east and south to the Ythan Estuary. The experimental programme was carried out between September 1979 and October 1980; the Landsat scenes processed were acquired in July and September 1979, respectively. A wide variety of statistical classification techniques were applied to the Buchan imagery, with the use of automated and interactive procedures. Successive crop classifications based on Landsat imagery were tested and compared with known crops at sample locations. The number of individual picture elements (pixels) successfully classified gave an index of accuracy. Results showed that cereal crops could not be clearly outlined on the July imagery. On the September scene, however, a simple density slice of data on the visible red channel (band 5) provided an accuracy greater than 90% (Stove *et al.* 1980). Analysis of principal components was found to be an efficient interactive enhancement technique for land-cover mapping, particularly where several categories could be highlighted simultaneously.

As a result of this project, a land-cover map of the Buchan area was produced at the same scale as the published soil and land-use capability maps of the area (Stove *et al.* 1981). In addition, by using automated classification techniques, a computer-drawn map illustrating the cereal distribution in September 1979 was produced. In summary, it was demonstrated that all the land-cover categories requested by the planners could be differentiated and mapped entirely from Landsat data. A cost/benefit analysis was made of this work, which showed that the remote-sensing methods employed enabled the work to be done at less than one third the cost of a traditional land use survey by air-photo interpretation and field survey. Furthermore, if repeat surveys were required in subsequent years, this would mean a greater cost saving: with the same techniques, a 1980 map could be produced at one sixth of the cost of the 1979 map.

(*c*) *Multitemporal studies in the Grampian Region*

A joint research programme of work in the Grampian Region has recently been undertaken between the Remote Sensing Units at the Macaulay Institute and R.A.E. Farnborough. The object of this work is to develop an automated land-cover classification procedure for a much larger test block of terrain than Laurencekirk or Buchan. Originally five scenes were selected with a good seasonal range from February to November, covering a 2 year period, but now more scenes are being studied because a number of good images of the Grampian Region were obtained during the AGRISPINE study period in 1982. Change detection is of particular interest in this multitemporal study; in this case scenes are first rectified geometrically to fit the Ordnance Survey grid on regular 50 m × 50 m pixels and then different dates of imagery can be overlaid by the computer. Current investigations include monitoring urban expansion and loss of agricultural land around the city of Aberdeen (Stove 1981).

4. Current use of remote-sensing methods in peat survey

The remote-sensing research programme at Macaulay Institute was initiated in 1975 to assist in the routine mapping and assessment of Scottish peatlands, particularly in remote regions where large-area ground surveys proved costly. The primary aim was to establish a data base of peat and terrain information of value to potential peatland development (Stove & Robertson 1979, 1980; Robertson & Stove 1980).

The initial acquisition of remote-sensing imagery related to this programme included aerial photography (panchromatic, true colour and infrared false colour), multispectral Landsat data (optical and digital products) and airborne thermal line-scan products. Adverse weather conditions in Scotland frequently restrict the use and increase the cost of conventional large-format (230 mm × 230 mm frames) air-photo surveys, but with the development of a suitable camera rig for use in light aircraft (Stove 1981), the small-format photograph (with a 55 mm × 55 mm frame) proved ideal for environmental monitoring and peat survey work.

Although 35 mm Nikon cameras are often used in tandem to acquire simultaneous true-colour and infrared false-colour photography of small areas, the standard 70 mm camera employed for block vertical stereo cover of a small area is the Hasselblad 500 EL/M motor-driven camera, with an automatic diaphragm-controlled lens (Zeiss 80 mm planar) system, ideal for variable light conditions. A special interval meter, designed and constructed at the Institute, is used to set the timing of the exposures according to the required forward overlap along the flightpath. Rating tables for a range of flying heights and ground speeds have been computed, the most common scale required for much of the monitoring tasks being 1 : 10000 scale, as illustrated in table 1. In this example, the flying height is computed to be 800 m above mean ground level, which must be assessed, especially over mountainous terrain. If the ground speed of the aircraft is computed to be 80 knots (148 km h^{-1}) and the required forward overlap of frames is 70 %, then the interval meter is set to 4 s.

The distortion characteristics of the 80 mm Zeiss Planar lens have been computed by using a specially constructed goniometer at University College London's Department of Photogrammetry and Surveying, and a 'best-fit' calibrated focal length of 80.23 mm was obtained. This value, known in photogrammetry as the 'principal distance', is used to set up an accurate scaled orientation of stereo pairs in a photogrammetric plotting machine such as the Wild B8S, for precise topographic heighting and contour plotting. Since this value is now known for the camera and lens system used for survey work, precise topographic rectification and plotting of height information is possible. Consequently, this photogrammetric facility is ideal if detailed topographic maps are required over very boggy peat terrain, saturated with small pools (dubh lochans), which negate the possibility of setting up a theodolite and distomat (infrared distance-ranging equipment) on a firm base for accurate tacheometric ground survey. With this air-survey equipment, specialized vertical stereo and oblique air-photos have been acquired for a variety of peat survey tasks. This year, for example, complete vertical stereo cover was obtained over a peatland drainage scheme in Caithness. For this particular application, infrared false-

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

colour photography, taken with a Wratten 12 filter, proved the most appropriate image product for enhancing the required ground detail.

Table 1. Rating table for the 80 mm lens to give a 1:10000 photo scale

(Focal length, 80 mm; image format, 55 mm × 55 mm; scale required, 1:10000; Flying height, 800 m. Note that flying height is set above mean ground level.)

ground speed		forward overlap (%)			
		60	66.6	70	80
knot	km h^{-1}	time between exposures/s			
60	111	7.2	6.0	5.4	3.6
65	120	6.6	5.5	4.9	3.3
70	130	6.1	5.1	4.6	3.0
75	139	5.7	4.8	4.3	2.8
80	148	5.4	4.5	4.0	2.7
85	158	5.0	4.2	3.8	2.5
90	167	4.8	4.0	3.6	2.4
95	176	4.5	3.7	3.4	2.2
100	185	4.3	3.6	3.2	2.1
105	195	4.1	3.4	3.0	2.0
110	204	3.9	3.2	2.9	1.9
115	213	3.7	3.1	2.8	1.8
120	222	3.6	3.0	2.7	1.8

Peatland surveys over large areas such as the Outer Hebrides or northern islands of Scotland are best planned and carried out initially by using large-format, small-scale aerial photography, if available. If multilevel and multitemporal photography is available (e.g. the Lewis survey) then a multistage and multiphase sampling strategy may be selected. Multistage sampling presumes an interest in a single parameter (e.g. peatland), and an estimate of its total distribution. It is most useful at the primary survey stage when problems are encountered in selecting an initial sampling frame. Multistage sampling is a multilevel method progressively apportioning the universe into smaller units in a nested hierarchy, and is most effectively employed when Landsat data is combined with air-survey data and ground information (Stove & Hulme 1980). Multiphase sampling incorporates the use of auxiliary variables in combination with the parameter of interest, to make estimates of population parameters. For example, in the remote-sensing methodology for peatland survey using Landsat data with air-photography, the reflectance values for eroded peatland were classified in a supervised manner through photogrammetrically plotting the width and spacing of erosion channels. In a similar way, P. D. Hulme has shown that detailed statistical analysis of peatland vegetation samples indicates that the categories identified on medium-scale aerial photographs are reasonably distinctive ground units, reflecting different peatland classes. If such ground units can then be interpreted from aerial photographs in the field, this information may again be used to attempt a controlled or supervised classification of Landsat reflectances to separate, for example, eroded peatland from intact peatland, shallow peat and rock complexes and domestic cuttings (Stove & Hulme 1980).

By using the B8S stereoplotter, tonal and textural features on the magnified stereo model created in this instrument can be greatly enhanced and used to delineate topography, hydrology, erosion, vegetation and other factors that must be considered in peatland classification and evaluation (Robertson & Stove 1980). The automated photogrammetric system developed to improve the speed and accuracy of plotting operations (Stove & Ritchie 1982) assisted in the

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

creation of a data base for peat survey information and paved the way for an interaction of this data in 'vector' form with Landsat multispectral data in 'raster' form (McKay & Stove 1980).

The most significant development in the remote-sensing methodology for peat survey applications came through linking the automated photogrammetric facility with the image-processing system to create a unique hybrid system, MAPIPS (Stove & Ritchie 1982). MAPIPS hardware now consists of two computer systems (the Data General Eclipse and a microcomputer), a Wild B8S stereoplotter fully digitized with a tri-axis locator system, a Ferranti–Cetec System 4 digitizing unit, a Tektronix 4027 colour graphics display and a Wild Aviotab TA flatbed plotting table (Ritchie & Stove 1982). This system can be used not only to display Landsat data and digitized photogrammetric data, but ground survey data can be digitized on the System 4 and, indeed, tacheometric survey data logged from the Wild Distomat system can be manually entered into one of the computers and stored on files. The peat drainage survey area in Caithness was surveyed on the ground with the use of the Wild T1 theodolite with D14 distomat attached; the results were subsequently stored in the peat databank and plotted at the required scale on the Aviotab TA.

It was evident from the close-grid nature of the old peat survey data in map and tabular form that this information would lend itself to geocoding, digitizing and storage in a peat data base. Consequently, a variety of peat bog types throughout Scotland were digitized, the object being to display spatial patterns and relations between topographic and stratigraphic parameters and to correlate the statistical information displayed with Landsat reflectance data.

Ulbster Bog, located on the east coast of Caithness six miles south of Wick, is a typical example of a basin bog that was digitized for this purpose. From the digital topographic data and peat depths, it was possible to compute and display surface and bottom contours, isopachytes, trend surfaces and three-dimensional representations of the surface and basal topography. From the stratigraphic sample records, after peat analysis, surface and bottom moisture contents, ash contents and surface vegetation categories were displayed and cross-correlated. This information was then correlated with Landsat terrain reflectances on all four spectral bands. From the results of this analysis, it was found that the infrared band 6 terrain reflectance categories correlated most closely with the bog vegetation categories, while the infrared band 7 reflectance categories approximated most closely to surface peat moisture variations.

This type of analysis demonstrated the potential of the MAPIPS facility as an interpretation tool to the peat surveyor. It also became clear that access to structured geographical information systems is becoming increasingly important for the Earth scientist and remote-sensing specialist. Furthermore, it was clear that the ability to interpret and fully analyse displays of spatial information (from air, ground and space) statistically should be a prime concern of the remote-sensing data user.

5. Use of remote-sensing methods in soil survey

The main task of the Soil Survey of Scotland is to map and classify systematically the mineral soils of Scotland and to produce land-use capability maps. Through field observations of the soil profile, soil types are identified based on parent materials, pedological drainage and other characteristics. The basic mapping unit is the soil series, defined as a group of soils with similar morphological properties developed on similar geological parent material. Soil series are identifiable with a genetic soil group and drainage class and are grouped into soil associations, which are defined as groups of soil series forming a soil pattern related to parent material and relief. To provide a background to the soil classification, the surveyor has to acquire, from a variety of sources, additional information on the physical environment of the soils. Since the 1950s the main application of remote sensing for soil survey has been through the widespread use of aerial photography for interpretation of terrain and soil characteristics. This additional source of information was initially used in a limited way, but increased availability has led to the adoption of air-photographs as a standard tool for soil mapping. With Landsat satellite imagery now increasingly available on a regular basis for the whole country, current and future image products, in digital form, are being assessed as another additional source of environmental information to the soil surveyor.

Systematic soil survey began in 1947 and until the 1950s work was concentrated in areas of agricultural importance (such as northeast, east, southeast and southwest Scotland). Soil boundaries were drawn in the field on 1:25000 War Edition maps and later edited for publication at 1:63360 scale. In the mid-1950s an attempt was made to evaluate the benefits of aerial photography to soil survey, drawing on experience gained from workers in Holland in particular. Air-photo interpretation methods were subsequently employed in SE Scotland within uncultivated areas. Such techniques were progressively adopted by other soil surveyors who had made extensive use of aerial photography during secondment to Hunting Overseas Surveys. At this time, air-photos were found to be invaluable for the survey of remote hill country, and owing to the inadequacy of the 1:25000 War Edition maps, these photographs were used as base maps as well as interpretative aids. The vertical air-photos were usually borrowed or purchased from the Scottish Development Department's Air Photographs Library. At present, air-photos acquired from Ordnance Survey are used for routine mapping at 1:25000 or 1:50000 scale and for *ad hoc* surveys at 1:10000 scale. Their use to evaluate land with complex terrain and soil patterns in the Western Highlands of Scotland has been assessed (Lawrance *et al.* 1977). All Soil Survey of Scotland work so far has been based on standard panchromatic photography.

Recently the use of Landsat imagery in digital form (in raster-based picture elements or pixels) has been demonstrated to surveyors from all the regional survey teams in Scotland. In addition to MAPIPS, the use of a new high-speed, British-made, interactive image-processing system called GEMS, has been demonstrated for enhancing, interpreting and classifying any remote-sensing data in raster form. The value of the GEMS facility hinges on the GEMSTONE software developed by the U.K. National Remote Sensing Centre at R.A.E. Farnborough for remote-sensing applications. This system, although specially developed for handling Landsat data, can process photography or video data, if raster-digitized, and because of its large number of image stores and overlay planes, is most suitable for superimposing complementary information from ground surveys (as grid data sets), aerial and space imagery. All this information can then be pooled on the GEMS storage planes for correlation and controlled feature classifications. Most of the soil surveyors who examined the potential of Landsat as an additional data source for providing information on the soil environment also had the opportunity to look at the value of Landsat data rectified to the National Grid and resampled at 50 m × 50 m pixels. In this form, ease of location is assured and the zoom and pan facility on GEMS enables rapid training-site identification and assessment.

After a viewing of Landsat scenes acquired at different times of the year on GEMS over the length and breadth of Scotland, some of the conclusions and observations made by the soil surveyors are worth considering. The first general point made was that Landsat imagery at present allows a unique overview of large parts of the country, which can provide added environmental information on surface ground state and crops during the growing season. As a *direct* aid in soil survey, however, Landsat data has limited use because soil survey and classification is concerned with the entire profile, not just the surface horizon. Another observation made was that despite the relatively coarse spatial resolution of Landsat MSS (multispectral scanner) data at present, the superior MSS spectral resolution over broadband panchromatic air-photos means that it can form a valuable complementary source of information, highlighting terrain features that may sometimes not be readily discernible on aerial photographs.

It was also generally stated that Landsat data could provide some positive applications to soil survey as a vegetation indicator to give predictions of soil type. In addition, certain vegetation types could be clearly identified on Landsat data by using GEMS, and the potential of the system as an aid to the subdivision of class 6 land (Land Capability Classification for Agriculture) was suggested. From the results of the Lewis Survey and looking at other scenes of the Western and Central Highlands, it was also accepted that Landsat data could be used successfully to identify peat, shallow peat and rock complexes and rock-dominated land forms. Interdepartmental collaboration is currently being pursued to evaluate the benefit of systems like MAPIPS and GEMS for the production of single-factor maps (Gauld *et al.* 1983). It was concluded that much more emphasis would have to be placed on ground-survey procedures to evaluate fully the applications of Landsat data for soil survey.

6. The D.A.F.S. bracken survey

A pilot study on the use of remote sensing to map bracken in Scotland has just been completed for the Department of Agriculture and Fisheries for Scotland. The major objective of this work was to develop a remote-sensing methodology for mapping bracken and to evaluate the cost-effectiveness of the approach in the light of alternative mapping strategies. The test area selected was in central Perthshire, covering an area of 50 km (east–west) by 44 km (north–south). In the SW quarter of this block, centred on the Menteith Hills (25 km × 22 km), the bracken area classified was about 8% of the total land area, covering some 10% of the upland grass–moorland area. In the NW quarter of the main block, the bracken area was 10% of the total land area, accounting for some 13% of the upland grass–moorland area. Results of this study have shown that bracken does have a unique spectral response at certain times during the growing season and that this signature can best be enhanced by using a ratio of the band 5/b and 7 reflectances. The methodology developed for the pilot study is now being applied to other areas in Scotland; the aim is eventually to complete a bracken inventory of the entire country by remote sensing.

7. The AGRISPINE experiment

R.A.E. Farnborough is an active participant in the Space Informatics Network Experiment (SPINE), which is an international project designed to demonstrate the transfer of bulk digital data at high bit rates by using the Orbital Test Satellite (OTS). In 1982, the AGRISPINE project was conceived as a suitable application of the SPINE facility to allow participants to receive Landsat data in less than 24 h for time-dependent studies.

The principal investigating agencies selected for this project include the Forestry Commission the Ministry of Agriculture, the Macaulay Institute, the National College of Agricultural Engineering and R.A.E. Farnborough. The time-dependent applications currently being studied

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

include monitoring crop growth at agricultural and forestry test sites in the Grampian Region and East Anglia, the calving of icebergs from a glacier in Greenland and sea ice characteristics in the Gulf of Finland. All sites are being monitored from 6 March to 27 November 1982, at the time of Landsat-3 overpass every 18 days. To date (September), every scene of the Jacobshavn Glacier and fjord area in West Greenland has proved satisfactory for detailed analysis. The British sites have been less successful, although the Laurencekirk test area in the Grampian Region has been clear on one third of the passes, sometimes only partly cloud-free, but only one good pass has been acquired of the East Anglian site at Thetford.

Test farms in the Grampian site have been monitored since March at the precise time of Landsat overpass. On each pass date, aerial photography and ground measurements, including ground photography of crop and soil conditions, are made. This year has been the first year in which crop stress conditions have been detected on Landsat imagery in the Grampian area, primarily because of the severe frost conditions in winter, which destroyed large areas of winter wheat and winter barley. The severe drought conditions in May and June also caused stress conditions that were detected on the imagery. However, it is unlikely that such stress conditions would have been detected without acquiring every Landsat scene through the SPINE link in less than 24 h and without the execution of air and ground surveys at the time of satellite overpass.

8. The SAR 580 (Synthetic Aperture Radar) experiment

The main objective of this experiment is to evaluate the potential of Synthetic Aperture Radar (SAR, an active microwave remote-sensing technique) as an all-weather capability for natural resource surveys and agricultural research applications in Scotland. The Macaulay Experiment (21GB), approved by the European Space Agency, comprised a 245 km transect, approximately 6 km wide, extending from a sea area northeast of Rattray Head (north of Aberdeen) southwards along the coastline to Edinburgh, extending as far inland as the Moorfoot Hills. Other investigators currently studying the SAR data from this site include the Forestry Commission, University College London and the Departments of Geography at Aberdeen, Glasgow and Edinburgh.

On 6 June, 1981 a Canadian Convair 580 aircraft acquired X and C band dual-polarization SAR imagery of the experimental block. Ground data collected before, during and after this overpass involved three separate programmes of work related to agricultural applications, aerial photography and hydrographic survey. A report on the ground data collection programme has been submitted to E.S.A. by the site coordinator and this has been published in the ground data collection programme volume. Optical processed film products in X and C bands have been received for the entire test block, but the digital data have been delayed. Six small digital test areas have been selected from the entire coastal strip; once these data have been received and correlated with the ground information, a final assessment of the SAR imagery will be made.

9. Conclusions

The remote-sensing methodology developed for natural-resource surveys has been reviewed through three phases of development. The major applications of this work discussed include peatland surveys in remote areas, land-cover surveys related to agricultural inventories, and environmental monitoring tasks such as bracken mapping. The current use of remote sensing within the Peat Survey is outlined, highlighting in particular the value of MAPIPS (the automated photogrammetric and image-processing system) for various applications. The future potential of remote sensing in the Soil Survey is assessed through the comments of several of the soil surveyors, after conducting Landsat experiments with the high-speed GEMS interactive image-processing system.

After a brief evaluation of the current projects being undertaken by the Remote Sensing Unit, it is interesting to speculate on the future promise of an 'all-weather' monitoring capability with SAR by using the planned European Space Agency's ERS-1 satellite in 1987. Even before then, or indeed the acquisition of higher-resolution multispectral imagery from the latest Landsat-D satellite (with a 30 m × 30 m pixel size) or the planned French SPOT satellite in 1984 (with a 20 m × 20 m multispectral and 10 m × 10 m panchromatic pixel size), a continuation of a timely facility such as the SPINE link to relay Landsat data to the user in less than 24 h is seen as the most important operational development for agricultural remote sensing in Scotland and indeed the U.K. in general. Getting such information on a timely basis and rapidly analysing the data with a GEMS system, for example, would create a very valuable ancillary source of information on land-management practices such as felling, burning, ploughing and harvesting. It is important to realize that the sensor technology is still developing faster than the analytical methods and interpretative skills can be developed to handle the image products (Birnie *et al.* 1982). Much work is still required on the evaluation of radar data compared with MSS data, before an operational 'all-weather' system can be realized and used, in the late 1980s or early 1990s.

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Apart from other staff in the Department of Peat and Forest Soils, who have provided invaluable support during field survey operations, and the other dedicated members of the Remote Sensing Unit, certain key individuals must be mentioned, who through their personal enthusiasm in remote sensing, have often given freely of their time outside working hours to enable aerial photographic sorties to be completed, particularly at times of Landsat overpass during weekend periods. Such enthusiasts include Dr W. H. Ekin, Robert Gordon's Institute of Technology, who finally developed and gained Civil Aviation Authority certification for the present remote-sensing rig on a Cessna 172 aircraft; Mr J. Mitchell, principal photographer, Macaulay Institute, and Mr J. B. G. Campbell, pilot and amateur photographer, Fordoun Flying Club.

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