INT. J. REMOTE SENSING, 1987, VOL. 8, NO. 3, 467-483

Remote Sensing in Australia
An overview of capabilities and activities

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(Received 8 September 1986)

Abstract. An account is given of the present state of remote sensing in Australia, covering the facilities and equipment, education and training, software and hardware developments, and research activities in the fields of agriculture, geology, disaster monitoring, surveying and cartography, land management, water conservation, oceanography and meteorology. This article is a shortened version of a publication produced by the Australian Trade Commission and published by the Australian Government Publishing Service (Walker *et al.* 1986).

1. Introduction

Remote sensing plays a prominent and key role in the mapping and management of the Australian continent. Frequently it has been the only practical means to achieve the speed and detail necessary to explore and develop a rugged land covering more than 7 million km, with territorial waters of about the same area, and serve the needs of widely dispersed urban and rural communities.

The first form of remote sensing, aerial photography, was used in mineral exploration in Australia early in the 1930s and for continent-wide soil and geological surveys in the late 1940s.

Australia's remote sensing industry is applications-oriented. It has readily embraced new and improved technologies, making notable contributions in many areas, including the use of data acquired by Earth observation satellites.

An Australian research consortium was accorded principal investigator status for LANDSAT-1 1971 and the Australian mining industry began using LANDSAT regularly in 1973. At this time a few commercial companies became active in the supply and interpretation of LANDSAT images to service the growing interest of the mineral industry. By 1977 it was a vital component of all major mineral exploration programmes.

LANDSAT has been an important contributor to two of the largest mineral discoveries in Australia in the past 10 years. Most major mining companies have extensive image analysis systems as an integral component of their exploration divisions.

The Australian Landsat Station, established in 1979, is run under Government contract by Australian industry. This station has recently been renamed the Australian Centre for Remote Sensing (ACRES). It maintains a high technical standard and has achieved the highest return of operating costs of any LANDSAT station in the worldwide system.

LANDSAT is used routinely by State authorities in mapping and agricultural geocoded data bases. The system has provided cost-effective methods for many tasks, including mapping the Great Barrier Reef, assessing environmental degradation due to excessive grazing and

measuring the effects of wind erosion on agricultural land. Interpretation services and expertise have also been exported to South-East Asia and the Pacific Islands.

Infrared scanners on environmental satellites have been used to great advantage, both on and off shore. They are revolutionizing knowledge of ocean currents around the continent because they alone provide the spatial and temporal detail vital for such studies.

Advanced Australian-developed remote sensing scanners and two sophisticated scanners developed by the U.S. National Aeronautical and Space Administration (NASA) were recently tested in Australia using 58 sites spread the length and breadth of the continent. These studies are directed toward optimising future scanners and developing value-added analysis procedures for use in the 1990s.

Australia is particularly interested in the radar satellites that will come into service early in the 1990s. It has participated in NASA's space shuttle radar projects and part of the European Remote Sensing Satellite, ERS-1, is being built by Australian industry. Design and construction of the reception and processing facilities for ERS-1 will begin in 1986. The Australian remote sensing community is also making a major contribution to PEPS (SPOT evaluation programme). Apart from France, Australia has the largest number of principal investigators supporting this programme.

A recent survey of the Australian remote sensing industry identified 236 professionals wholly engaged in remote sensing and some 1840 other professionals operating as end-users of the products.

Education in remote sensing technology is provided by various tertiary institutions. Postgraduate courses are available in the application of remote sensing to specific topics such as exploration and agriculture.

The success of remote sensing research in Australia and its rapid transfer to the user community is due largely to the structure of Australia's research institutions. The greater proportion of the research and development has been conducted in specialist laboratories that serve specific user communities such as those dealing with minerals, land use, oceanography or agriculture. Consequently, satellite remote sensing has been integrated naturally into existing procedures and accepted rapidly.

Australia has climates that range from tropical to sub-Antarctic and from deserts to dense rain forests, making it an ideal 'laboratory' in which to learn how to apply remote sensing to practical problems. Broad and commercial application of remote sensing technology has made it a continuing leader in the field.

2. Capabilities and services

Australia has the strong technological infrastructure and applications experience necessary to process and analyse remotely-sensed data effectively and to incorporate the results into practical resource management and development operations.

Data are required mainly by the LANDSAT series of satellites and the U.S. National Ocean and Atmospheric Administration (NOAA) polar-orbiting environmental satellites, although research and semi-operational projects have covered the full spectrum of available advanced satellite and airborne data.

Government and private enterprise have invested substantially in processing facilities and in training personnel to use and develop remote sensing technology for projects in Australia and abroad. The Commonwealth Government has many remote sensing activities involving the Australian Landsat Station, the Bureau of Meteorology, the Commonwealth Scientific and Industrial Organisation (CSIRO), the Department of Resources and Energy and other government bodies. Four state governments maintain digital image processing centres. The principal function of these centres is to provide data processing facilities to government users, although some also provide external services.

Private industry in Australia has developed a high degree of expertise in the application of remotely-sensed data. Several oil and mineral exploration companies maintain their own in-house digital image processing systems and have built up extensive tape libraries. A permanent staff of specialists in remote sensing is engaged solely in the interpretation of this information and some also offer their image processing service to outside users.

A vigorous commercial industry in remote sensing services has grown in Australia since 1972. Companies engaged in consultancy activities using remotely-sensed data have proliferated. Service companies supply 'value-added' LANDSAT or other digital data and interpretations. Others are specialists in a particular discipline, such as mineral exploration, agricultural studies or environmental monitoring, and combine satellite data with that collected by other techniques as part of an overall study.

At least two companies offer market research and cost-benefit studies for remote sensing. Several Australian commercial organizations perform airborne multispectral scanner surveys for applications that require data with much greater spectral and spatial resolution than that available from satellites.

Australian remote sensing consultants have carried out many overseas projects for both foreign governments and companies, competing against international consulting organizations. Aid-funded projects in the developing countries and the provision of technical training accounts for part of a successful technology export programme.

Some tertiary education institutions have in-house digital image processing facilities, mainly for teaching and research, and also provide consulting services in research and training. In several cases technical advice has been provided to foreign governments on the operation of image processing facilities in their home countries.

In combination, these diverse concentrations of analytical and applications expertise offer a major source of practical advice and operations assistance to both local and regional resource managers.

The Australian Landsat Station (ALS), now the Australian Centre for Remote Sensing (ACRES), was established in 1979 under the auspices of the Department of Science. When the technology matured from research to operational applications, responsibility for the station was transferred to the Division of National Mapping of the Department of Resources and Energy.

The ALS consists of a commercially operated and maintained data acquisition facility at Alice Springs and a data processing facility in Canberra. The station's digital and photographic

products include pre-processed computer compatible tapes (CCTs) and bulk or precision-processed images at scales ranging from 1 : 1 000 000 to 1 : 50 000. It also offers an 'image writing service' for organizations in need of imagery produced from any type of digital data.

LANDSAT data distribution is performed by the ALS directly and through a network of specially appointed regional distributors. Technical advice on remote sensing is provided by nine accredited Reference Centres throughout the country, chosen for their expertise, to assist prospective users in defining their needs and selecting data.

Australia's remote sensing community is diverse, covering users, consultants, researchers, hardware developers and educators in industry, government and academia. Various committees' co-ordinate the community's broad range of activities. The main remote sensing centre in Australia is the Australian Landsat Station (ALS). The principal advisory body is the Australian Liaison Committee on Remote Sensing by Satellite (ALCORSS), which was constituted by the Federal Government in 1979 to advise on the operation of the ALS.

ALCORSS reviews the implementation and development of remote sensing applications, research and education in Australia and liaises between the various user groups. Its members include representatives from Federal and State governments, industry, the CSIRO, universities and colleges of advanced education. Each State has its own remote sensing committee made up of representatives of the principal user organizations. Various specialist user committees also contribute, such as the Agricultural Remote Sensing Committee, which is a national body reporting to the Agricultural Council.

Private industry established the INDUSAT group in 1977, to co-ordinate industry's views on, and requirements of, remote sensing for presentation to government. INDUSAT also provides a forum of inter-industry co-operation. Other industry groups, such as the Australian Mineral Research Association (AMIRA) also coordinate remote sensing research. Individual interests in remote sensing are served by the Remote Sensing Association of Australia (RSAA).

3. Education

Australian educational institutions provide the opportunity for co-ordinated training and research in this new and rapidly expanding field of technology. More than 45 schools and departments within universities and colleges of advanced education teach remote sensing to undergraduate students. A third of these institutions offer courses at the postgraduate level. Specialized programmes leading to the award of a diploma, master's degree or a Ph. D. in remote sensing are available at the University of New South Wales. These programmes are designed to provide integrated instruction in the principles, applications and digital analysis of remotely-sensed data. Opportunities exist for students to carry out research projects on topics or areas of individual interest. Increasingly, professional people employed in private industry and governmental agencies are returning to university to gain experience and formal qualifications in remote sensing.

Overseas scientists are welcome at Australian universities and research institutions as visiting scholars. Under this scheme visits of a few weeks to 1 or 2 years provide for specialized training and the initiation of collaborative research projects between the visitors' home institutions and the host university or centre.

Short courses and training seminars are available to help managers, technologists, scientists and support staff, assess the relevance of remote sensing to their work and to acquire expertise

in fundamental principles and applications and in new techniques of image processing and analysis. Short courses may range in length from 1 day to several weeks and are designed to cater for the needs of particular interest groups. A 1-day workshop may be used to introduce secondary school teachers to the fundamentals of remote sensing while a short course for geologists might extend over 3 weeks to provide highly specialized training in advanced techniques of image analysis. Workshops dealing with the characteristics of different systems such as LANDSAT, the NOAA meteorological satellites, space shuttle radar missions and airborne photographic and scanner systems are held regularly. Similarly, workshops are held on particular discipline applications such as agriculture, hydrology, engineering and geology. Short courses are available in Australia or can be run for client organizations outside Australia.

4. Research

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) is the main government-funded research and development agency in Australia. Remote sensing applications research and hardware development are undertaken by various CSIRO divisions in liaison with industry groups. Some examples of CSIRO research activities in remote sensing are:

agricultural, hydrological and meteorological research, including crop yield prediction, salinity studies, flood and frost mapping and solar radiation mapping;

the development of techniques to analyse NOAA Advanced Very High Resolution Radiometer (AVHRR) and Japanese GMS data for a variety of applications;

the modelling of regional evapo-transpiration using remotely-sensed data from the Coastal Zone Colour Scanner (CZCS), Heat Capacity Mapping Mission (HCMM) and AVHRR;

long-term vegetation monitoring, assessment of drought status and fire damage and study of wildfire habitats as part of an arid zone management programme;

the employment of thermal infrared aircraft scanner data to investigate and map the development of bush fires;

the mapping of the maintenance/fertilizer needs of improved grazing pastures;

examining the relationship between the nutritional status of grazing cattle and pasture improvement as detected by LANDSAT MSS. These studies are being extended into the dairy industry;

ocean colour and productivity studies to provide information to the fishing industry;

infrared studies of sea surface temperature and other oceanographic studies using, NOAA and GMS data;

evaluation of radar systems including space shuttle imaging (SIR-B) and synthetic aperture;

bathymetric studies of the Great Barrier Reef using LANDSAT MSS imagery;

application studies to help make more effective use of remotely-sensed data for mineral

exploration; these studies have included the development of image processing techniques and the gathering of high-resolution ground-based spectral measurements;

evaluating the exploration potential of the LANDSAT Thematic Mapper by flying surveys, with a commercial Daedalus Aircraft Thematic Mapper Scanner, over gold prospects in Australia; this has led to the development of processing algorithms that can detect mineral alteration haloes in areas with considerable vegetation cover;

investigating terrain stability using LANDSAT-MSS, NOAA-AVHRR and SIR-A data sets; investigations involving ERS-1, LANDSAT TM and the French satellite programme SPOT are planned.

Six CSIRO divisions, the Bureau of Mineral Resources, other government agencies and many private companies participated in the USA–Australia Joint Scanner Project, which involved the NASA C-130 and the CSIRO F-27 research aircraft. This project gathered data for sites throughout Australia for use in salinity mapping, irrigation monitoring, rangeland condition assessment, detection of soil erosion and identification and mapping of potential mineral resources. The C-130 carried three state-of-the-art remote sensing instruments: the Airborne Imaging Spectrometer (AIS), the Thermal Infrared Multispectral Scanner (TIMS) and the NS001 Thematic Mapping Simulator. The AIS and TIMS should provide data for advancing the spectral knowledge of project participants and also for assisting in the development of Australian-designed and manufactured remote sensing equipment.

University research is related to developing suitable hardware and software systems for the integration of remotely-sensed data with other data sets and for the development of routine operational systems for environmental analysis. Interest is centred on contextual classifiers that take into account the spatial information available in pixel neighbourhoods during the classification process. Pattern recognition techniques that allow the incorporation of geographic information into image-based classification systems also are being investigated.

Receiving stations have been established to receive data from geostationary meteorological satellites and the NOAA-TIROS series of polar-orbiting weather satellites, and several groups are involved with NASA (SIR-B program) and SPOT as principal investigators.

Active research programmes include environmental analysis, bushfire mapping, Land-cover change monitoring, agricultural assessment, terrain evaluation, monitoring rural–urban boundary changes, registration and planimetric accuracy of LANDSAT, SPOT and space shuttle radar data and use of airborne scanner data in geological mapping. Research services in remote sensing technology and applications are made available to industry and outside organizations on a contractual basis.

The Australian mineral resources industry has been using LANDSAT almost since the first scenes were available in 1973. The first of a series of Australian Mineral Industry Research Association (AMIRA)-sponsored CSIRO remote sensing research projects began in 1976. Following completion of the first AMIRA project in 1979 six major resource companies installed image processing equipment. All the hardware was imported but two of the companies entered a joint venture with the CSIRO division, CSIRONET, to develop image processing software. Image processing at first was concerned with LANDSAT images. Research led to the use of other satellite data and, in recent times, airborne scanning systems and the processing of geophysical data as images and by the integration of digital data sets.

Many companies and consultants have performed independent research to develop remote sensing methods, software and systems, sometimes collaborating with government and academic institutions. This type of research generally has been aimed at pragmatic solutions to operational problems and applications and has provided a necessary step in the transfer of technology into the practical domain.

5. Software and hardware development

Australian expertise in remote sensing software has been developed by industry, government research institutions and universities. Several CSIRO divisions, collaborating with industry, have developed an advanced suite of software packages to meet the requirements of the user community. One primary software series consists of the programs DISIMP, SLIP and IMAGED. Device-Independent Software for Image Processing (DISIMP) is a FORTRAN sub-routine package for general-purpose image handling. The package contains more than 140 sub-routines for manipulating images and displaying them on system devices.

Software for LANDSAT Image Processing (SLIP) is a collection of interactive image processing utilities designed to process LANDSAT and other satellite imagery. SLIP is supported by DISIMP and may be used also in conjunction with IMAGED. Image-Based Analysis of Geographic Data (IMAGED) is a set of programmes designed to integrate, analyse and display different kinds of geographically-referenced data. IMAGED is part of a large software system being developed by the CSIRO for geographical data processing. The system, called SISDIM (Software for Integrating Spatial Data by Images), formats and manipulates geographic data from various sources.

Special-purpose applications of these primary software programmes have led to other commercially available Australian-developed systems. An example is CSIDA (CSIRO System for Interactive Data Analysis), used for rapid utilization of highvolume-per-day imagery such as that provided by NOAA satellites using AVHRR and by geostationary orbit satellites such as the Japanese GMS series. Receiving systems for such satellites, developed jointly by CSIRO and industry, are marketed by an Australian company.

With these powerful software tools the expanding user community requires relatively inexpensive micro-computer based work stations for image processing and manipulation. Accordingly Australian companies have developed such interactive work stations specifically designed to suit the needs of the remote sensing data user.

Another special-purpose activity relates to coastal zones, and particularly shallow water. Investigations here extend beyond marine science through to mapping. The CSIRO developed the Barrier Reef Image Analysis (BRIAN) software package specifically for this work. Using LANDSAT images, BRIAN enables great savings in cost and time for mapping of the Great Barrier Reef to a scale of 1: 250 000. Designed originally for mini-computers (such as the PDP series), BRIAN was taken up by industry and adapted for use on micro-computers. It is now marketed as Micro-Brian and is suitable for general applications of LANDSAT image processing as well as for its original purpose.

Another approach to shallow water mapping, developed by an Australian Government defence research laboratory collaborating with industry, is known as LADS (Laser Airborne Depth Sounder). The system is carried by aircraft and provides particularly accurate survey data of coastal waters.

The CSIRO has developed its own visible to near-infrared scanner, a high resolution, visible to near-infrared spectrometer and a high resolution short wave infrared spectrometer, all of which are flown on the CSIRO F-27 research aircraft.

An operational airborne spectrometer is being developed for a geophysical contractor to be flown routinely with other geophysical instruments. An Australian university is developing the linear array detector technology needed for this device. A 13-channel, airborne scanner system that operates in the visible and near-infrared, the short wave infrared and the mid-infrared was developed by the CSIRO and an Australian company. This company now offers and operates this Australian-made instrument, which represents a significant advance in airborne remote sensing hardware.

Australian industry and the CSIRO are directly involved in developing and fabricating the Along Track Scanning Radiometer (ATSR) to be flown on the European satellite ERS-1 in 1989. Such collaboration is likely to result in opportunities for Australia to receive data from other ERS-1 instruments, namely its radar scanners, altimeters and scatterometers. Under contract to the Australian Government, Australian industry has conducted a project definition study for reception and processing of data from ERS-1. The study resulted in technical specifications for the appropriate modifications to the Australian Landsat station (ALS) and for image processing computer facilities. The computer hardware has the potential to use a very large scale integrated (VLSI) digital correlator chip developed by the CSIRO and already commercialized. A Fourier transform VLSI chip developed by CSIRO also is potentially applicable.

Image processing of synthetic aperture radar data from space is established at the University of New South Wales where work is under way on software translation under contract to an overseas company. Images have been made from data obtained from the space shuttle imaging radar experiments SIR-A and SIR-B.

The CSIRO is collaborating with the ALS to develop an experimental system to receive and process remotely-sensed data from the LANDSAT Thematic Mapper scanner. These data, though not available in operational quantities, will greatly assist Australian users, allowing the timely development of suitable processing methods and a chance to preview such data before the full upgrade of the ALS.

The CSIRO (through COSSA), the Australian Government's Defence Electronic Research Laboratories and the University of New South Wales have submitted a proposal for the development of an advanced space-borne spectrometer, which would be carried on the Australian reusable scientific satellite, Mirrabooka. The proposal is now the subject of a feasibility study funded by the Australian Government. Mirrabooka will provide valuable experience in the development of space-qualified hardware by Australian industry.

6. Applications of remote sensing in Australia

6.1. *Agriculture*

The original design objective of the LANDSAT programme was vegetation mapping, and it was for this purpose that the band-widths were chosen. Agricultural applications such as crop inventories and yield forecasting were one of the first operational uses of the data. Recent satellite programmes such as SPOT continue to place prominence on agricultural objectives. Australia, with its vast area and fragile arid lands, quickly recognized the value of satellite

data to crop management. State governments in particular have placed a growing emphasis on the use of such data to supplement traditional methods and to achieve management objectives previously considered impracticable. In a recent survey of Australian users of remote sensing, 37 organizations identified substantial improvements in renewable resource management from the use of satellite data.

Although Australia is largely arid, the coastal regions have abundant tropical crops such as sugar, rice, bananas and pineapples and locally developed experience covers a comprehensive range of crop types and conditions. This experience has been transferred with great success to projects in neighbouring countries. The following examples of local and overseas projects are representative.

LANDSAT MSS data has been used for two consecutive seasons to monitor the rice crop area in the Murrumbidgee Irrigation Area in New South Wales, with an accuracy of 98 per cent (± 4 per cent). The method proved to be 57 per cent less expensive than the usual approach of using aerial photographs. Additional benefits accrue from being able to respond within the growing season to changes that affect yield predictions. The approach starts with a geographic information system containing areas that are capable of growing rice. This data base is sequentially updated from MSS data with areas classified as 'could be rice' or 'not rice'. If the 'could be' area is classified on two or more successive images it is coded as definitely rice. This integration of image-based and environmental criteria for updating a total geographic information system is central to the new and effective agricultural assessment methods being developed in New South Wales.

The LANDSAT images have been used in agricultural and land use studies in southern Thailand in which changes in land use, in terms of forest clearing and crop distribution, were contrasted over a decade. Change mapping was accomplished by subtracting the classified themes of a 1973 scene of the project area from those of a 1983 scene. The main limitation of this method is the availability of suitable cloud-free imagery in acceptable date ranges.

Other unwelcome crops, such as weeds or the illegal cannabis crop, are equally well assessed. Satellite data have been of considerable assistance to law enforcement operations in controlling the illicit production of narcotics. LANDSAT MSS data have also been used as evidence in Australian courts for some agricultural disputes, such as illegal cropping and irrigation practices.

Airborne scanner data is used in South Australia to identify stress in crops due to diseases, lack of water and soil variability. A range of subtle variations can be determined from the classified scanner data. These variations are related to areas differing in soil moisture, crop types, transpiration rates and other factors.

6.2. *Geology*

Since the launch of LANDSAT-1, the Australian geological community has accorded a high level of acceptance to remote sensing technology, benefiting from close interaction between research and user organizations. The diverse nature of the Australian continent has required geological remote sensing users to contend with a variety of geomorphic and climatic conditions and gain experience in most types of terrain.

Prior to the launch of LANDSAT-1, Australian geologists were aware of the advantages of using aerial photography for field studies. However, as soon as LANDSAT imagery became

available, they were quick to apply traditional geological aerial photo interpretation techniques to its analysis.

Because of the agricultural bias in the selection of bandpasses for the MSS detectors, LANDSAT data are not optimal for geological spectral studies. However skilled interpreters have used the bias of the MSS sensors to their advantage, detecting, by inference and deduction, geo-botanical associations that have geological significance.

LANDSAT MSS data have also been used as a geographic base for co-registering other forms of exploration data such as aeromagnetics, regional gravity, radiometrics and stream-sediment geochemistry. This integrated approach to geological data analysis is rapidly becoming standard practice among exploration companies, as the search for mineral resources moves from outcropping to 'blind' deposits. Data from the environmental/meteorological satellites have been used in regional faun and in structural studies throughout Australia, for which these images are ideal.

A significant advance in regional structural analysis will result from the availability of stereo-imagery from the French SPOT programme. The assimilation of this new source of data into practical applications should be rapid, considering the high technical capability of the Australian geological remote sensing community.

The availability of airborne spectro-radiometers for research purposes and scanners for both research and operational usage has helped greatly advance geological spectral studies in Australia. An operational airborne spectro-radiometer being developed for an Australian geophysical contractor reflects the level of expertise and commitment in the industry.

Australian geologists have had access to two Daedalus DS1268 TM scanners at a time when there were only four in existence. These devices simulate the bandpasses of the Thematic Mapper (TM) sensors onboard LANDSAT -4 and -5. Data from these scanners have given users experience in how to process and interpret satellite TM data. Alteration haloes associated with gold deposits sometimes can be detected because of anomalous absorption in the 2.2 pm band (indicative of clay).

The Geoscan multispectral airborne scanner is a one-of-a-kind, Australian-developed, geologically-oriented system that illustrates the level to which Australian geological remote sensing has progressed. The Geo scan system acquires data in 13 co-registered channels and provides simultaneous coverage in the VNIR, SWIR and MIR spectral regions. It is equipped with bandpasses that potentially can distinguish between sericite, kaolinite, smectite and carbonates in the 2.0 and 2.5 *pm* region. The system represents the state of the art in commercially available airborne scanners for geological applications.

The level of Australian experience in using radar for geological applications is increasing, primarily through involvement in the space shuttle imaging radar experiments SIR-A and SIR-B. These data highlight topographic features and, geologically, are of most use in structural studies. Significant research has been undertaken using combined SIR-B and LANDSAT data for both structural and lithological studies.

6.3. *Disaster monitoring*

Remote sensing techniques assist not only in assessing the impact of natural disasters, but also in planning suitable strategies to avert or minimize the effects of future occurrences. Droughts

in Australia typically last for extended periods and affect large areas. During the drought of 1982, NOAA data were collected weekly over Australia. The responses of the various land use could be compared and a valuable record of the effects of drought was gained for future use. Such data can assist during a drought in determining a management policy to conserve and utilize existing resources efficiently.

Road transportation routes often are affected by flooding and emergency alternatives can be devised based on the acquired imagery. If images are available for an area with floods of varying intensities, they can be used to predict flood levels and formulate suitable mitigation procedures so as to avoid, if not reduce, possible future damage.

Remote sensing plays a significant role in bushfire control in Australia. Thermal data acquired by aircraft scanners have been used to monitor experimental high intensity fires and develop models of how fires spread (Project Narrik, Project Aquarius). Multiple passes are flown over burning areas, the thermal responses measured being unrestricted by smoke or vegetation canopy, night or day. A consequence of this work has been the routine use of aircraft equipped with thermal scanners to supply support facilities to ground-based fire-fighter crews (Project Firedamp). Primary objectives are to provide timely and accurate imagery of active and incipient fires, and detailed maps of a fire for use in strategic planning of operations. LANDSAT and NOAA data can also be used to monitor the effects of bushfires. Images provide a permanent record, for insurance or compensation purposes, of which properties were affected. As a means of controlling bushfires, authorities in many parts of Australia use LANDSAT images to map probable fuel load conditions then take appropriate action to reduce the threat of a major fire.

Because of a near-tragedy involving a commercial aircraft that had its jet engines extinguished by ingested volcanic ash, a technique has been developed, using NOAA data, to monitor volcanic ash clouds. This has the potential to become a valuable operational tool.

Another use for remotely-sensed data involving volcanic hazards is the monitoring of temperature patterns to assist in the prediction of volcanic eruptions. Airborne thermal scanner data were acquired over Rabaul Harbour, Papua, New Guinea, during a recent volcanic alert.

6.4. *Oceanography*

Australia, like all island nations, depends in many ways on its surrounding oceans. They are a means of transport, they play a significant role in determining climate, and they support a commercially important fishing industry. LANDSAT MSS data have been particularly effective for such studies.

Dynamic oceanographic studies using LANDSAT are limited by the availability of cloud-free images and by a scale that is not small enough. However, some completed studies include the mapping of various water masses and their mixing properties and, at intermediate scales, the demonstration of topographically-trapped eddies on the lee side of headlands, reefs and islands. This last discovery has implications not only in the scientific sphere but also in island management.

A breakthrough in dynamic oceanographic studies has been made using the sensors on the environmental/meteorological satellites, notably the Coastal Zone Colour Scanner (CZCS), the AVHRR and the Japanese GMS (Geostationary Meteorological Satellite) system. These

satellites provide images of sufficiently small scale and with the repetitiveness needed for detailed analysis. Uses of their imagery include:

identification of currents using infrared bands;

identification of upwelling areas of biological significance;

studies of eddy genesis;

studies of Antarctic sea-ice.

A further use of this type of imagery is being made by the West Australian fishing industry. It has been found that bluefin tuna congregate near the boundary of the warm Leeuwin current with the cooler waters. Processed NOAA imagery is sent via a modem to the fishing fleet base, to assist in locating the catch.

Oceanographic Synthetic Aperture Radar (SAR) applications benefit from the cloud-penetration capabilities of these active systems. Australian organizations are involved with the SIR-B experiments in preparation for the time when such data will be routinely available via the planned radar satellites, such as ERS-1.

6.5. *Land management, habitat and vegetation*
Most of Australia's pastoral land has been grazed since the turn of the century. Droughts and poor pastoral management have resulted in declining stock numbers and increasing incidence of degradation since the mid 1930s.

Remote sensing techniques provide an efficient means of assessing and monitoring the condition of the rangelands in Western Australia, a task of enormous proportions if attempted by ground-based surveys. In the West Kimberley region of Western Australia eight pastoral stations have been acquired by the State Government with the aim of restructuring those leases into new and viable holdings. Several levels of information were captured digitally from maps (such as property boundaries, paddocks and land system-types) with areas of severe degradation and erosion being derived from LANDSAT-5 imagery. This data was then interrogated for the most suitable subdivision considering all environmental factors and existing cultural features.

South Australia has developed a rangeland package to map grazing patterns and fodder availability and provides this information to pastoralists and graziers. Remote sensing can also be used in urban and regional planning. With increased spatial resolution becoming available, multispectral scanners, thermal infrared scanners and radar are being used to improve the quality, amount and information content of data available to planners.

Satellite data are being used to provide physical data on land use and land use change, urban morphology, housing density and urban drainage. The data can also act as a surrogate for population, poverty, urban quality and socio-economic statistics and provide accurate maps to allow for data integration into spatial information systems.

Remote sensing data are used to monitor the effects on native vegetation of agricultural activities. They also have been useful for the management of insect pests such as plague locusts. LANDSAT imagery has been used to identify and classify remnants of native

vegetation in agricultural areas. Using colour infrared (CIR) aerial photography at a height of 1500 m university researchers have developed a technique to identify wetland habitats. Because of the large scale, detailed analysis of the study area is possible and the method complements more general satellite surveys. Using ground test classification techniques the researchers have established a relationship between habitat types and the distribution of eggs and larvae of the salt marsh mosquito.

The South Burnett region of Queensland includes important agricultural and recreational areas. A supervised classification was applied to LANDSAT to produce a land use cover image map for the area.

LANDSAT imagery has been used to map vegetation types in the Mount Lofty Ranges east of Adelaide, South Australia, with accuracies of better than 75 per cent.

Shuttle Imaging Radar (SIR-B) data acquired over the Barmah Forest on the Murray River near Echuca in Southern Australia have been registered with LANDSAT in an attempt to improve the accuracy of the classification. The addition of textural information related to tree height and density derived from radar adds another dimension to the surface compositional data of LANDSAT.

6.6. *Water conservation*
State water commissions use LANDSAT to supplement investigations into flood plain management, geological and groundwater studies and increased alkalinity in soils.

Irrigation has brought prosperity to the land around Wakool in south-western New South Wales, but it has also brought about great changes in the district's hydrological balance with increasing amounts of saltation. LANDSAT provides a means to monitor at reasonably frequent intervals the progress of salinity as it spreads or wanes over vast areas of land. This threat to Australia's soil and water resources is of national importance. Two-thirds of all land irrigation in Australia, equivalent to 9000 km', is affected by salinity.

The New South Wales Water Resources Commission flood damage reduction programme requires basic essential data on the inundation of flood plains. Much of this can be obtained inexpensively by remote sensing. LANDSAT imagery and special digital analysis techniques can be used to obtain the delineation of flooded areas and floodways, the effects of levees, road embankments, irrigation channels and diversion works on flow distribution and the performance of flood mitigation works. More expensive oblique aerial photography may be used for situations such as short term flooding on small flood plains and in times of cloud cover when the existing satellite sensors are inadequate. Higher resolution satellites such as imaging radar satellite data may overcome this problem and these are being investigated.

6.7. *Surveying and cartography*
Australian Federal and State Government mapping authorities, and other organizations with special thematic mapping interests, use remote sensing data extensively and routinely evaluate more accurate sources of data as they evolve. Accurate image-based maps are produced from satellite remote sensing data by adjusting the geometry to fit different map projections and spheroids.

LANDSAT data is used by the Division of National Mapping for compiling thematic maps, such as those for the Atlas of Australian Resources, as an aid in the revision of special-

purpose maps such as aeronautical charts and to assist in the planning of aerial photography programmes.

The Australian Survey Office provides a remote sensing service to other government departments. It has been particularly active in shallow water mapping and, with the Australian Federal Police, in detecting illicit crops. Using the Barrier Reef Image Analysis (BRIAN) system, a series of computer enhanced and geometrically rectified image maps of the Great Barrier Reef have been produced at an estimated saving of $21 million on using traditional surveying and mapping techniques.

State mapping authorities have used remote sensing data for mapping soil degradation in marginal farming areas; shallow water image mapping in the Trobriand Islands, Papua New Guinea; environmental impact assessments; land use and vegetation cover mapping; and mosaics of regional areas.

Sources of remote sensing other than LANDSAT, such as gravity measurements and magnetic anomaly data, have been used in special-purpose mapping applications, particularly for geology. The Bureau of Mineral Resources has produced a small-scale digital terrain model of the Australian continent from such data.

6.8. *Meteorology*

Australia's Bureau of Meteorology has amassed considerable experience in using remote sensing for a broad range of applications. Meteorological satellites provide daily data on clouds, temperature, humidity, wind speed and direction, sea surface temperature and ocean currents, atmospheric instability and rainfall. The Bureau also uses remote sensing to acquire data for locating and tracking cyclones, assessing the likelihood of floods and severe storms, monitoring bushfires and in meteorology. The value and impact of satellite imagery have been considerably enhanced by the complementary application of sophisticated computer graphics which allow the user to discriminate and highlight important meteorological events and processes.

Commonwealth Scientific and Industrial Research Organisation investigations into the development and application of remote sensing techniques have contributed much to their usefulness in meteorology, particularly in the reception and use of data acquired from satellites.