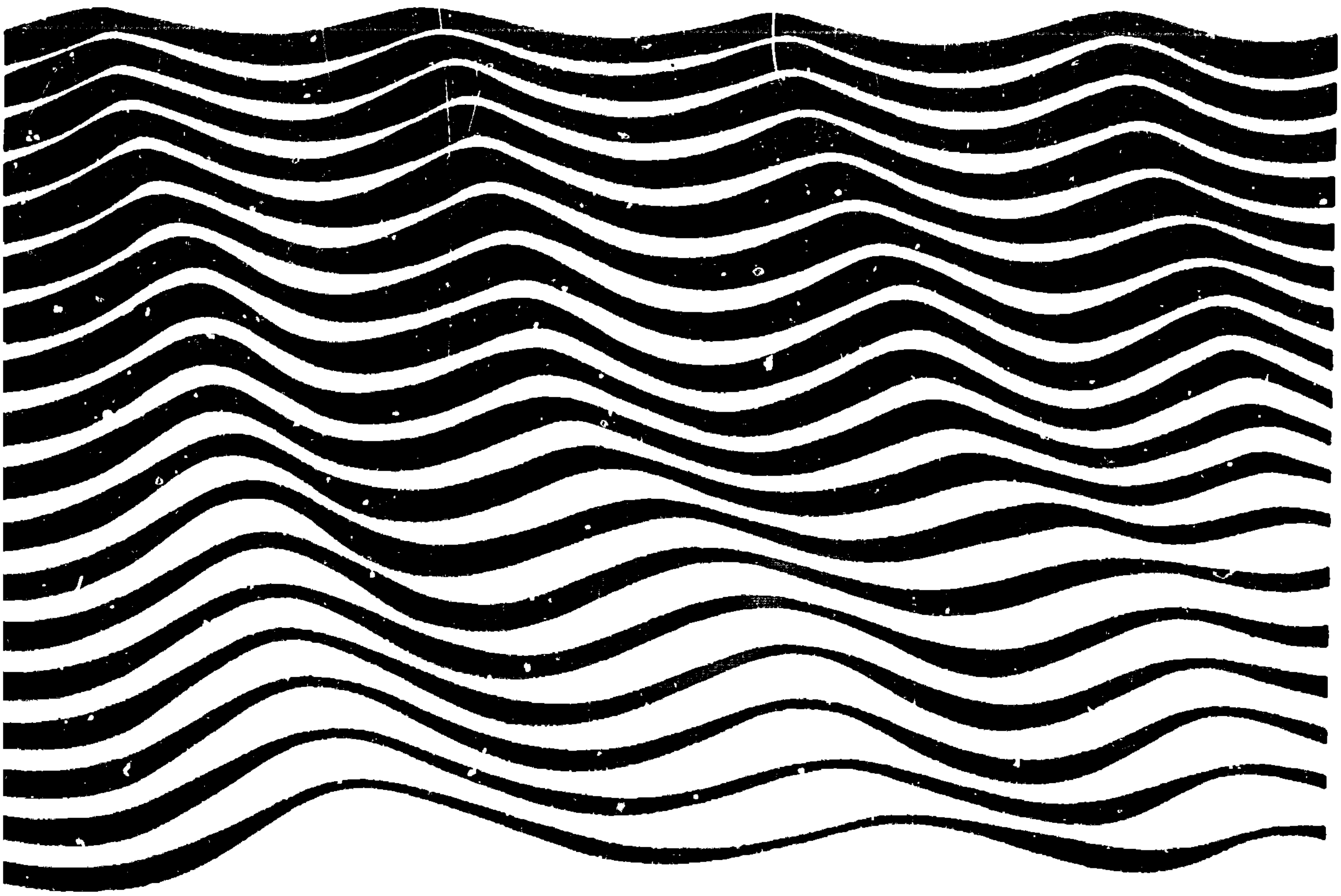
Unesco reports in marine science 42

The application of digital remote sensing techniques in coral reef, oceanographic and estuarine studies

Report on a regional Unesco/COMAR/GBRMPA Workshop

Townsville, Australia
August 1985



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UNESCO REPORTS IN MARINE SCIENCE

No.		Year
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21	Comparing coral reef survey methods A regional Unesco/UNEP workshop, Phuket Marine Biological Centre, Thailand, December 1982 English only	1983
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27	Productivity and processes in island marine ecosystems. Recommendations and scientific papers from the Unesco/IOC sessions on marine science co-operation in the Pacific, at the XVth Pacific Science Congress, Dunedin, New Zealand, February 1983 English only	1984
28	Oceanographic modelling of the Kuwait Action Plan (KAP) Region. Report of simposium/workshop; University of Petroleum and Minerals, Dhahran, Kingdom of Saudi Arabia 15-18 October 1983 English only	1984
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32	L'estuaire et la mangrove du Sine Saloum Résultats d'un Atelier régional Unesco-COMAR tenu à Dakar (Sénégal) du 28 février au 5 mars 1983 French only	1985
33	Coral taxonomy Results and recommendations of a regional Unesco (COMAR)/UNEP Workshop with advanced training Phuket Marine Biological Centre Thailand, 10-26 February 1984 English only	1985
34	Bibliography on costal lagoons and salt marshes along the Southern Mediterranean coast (Algeria, Egypt, Libya, Morocco, Tunisia) Available in Arabic, English and French	1985
35	Physical oceanography of the Eastern Mediterranean (POEM): A Research Programme. Reports of the Organizing Committee Meeting, Paris, August 1984, and the Scientific Workshop, Lucerne, October 1984 English only	1985
36	Méthodologie d'étude des lagunes côtières. Résultats d'un atelier régional réuni à Abidjan du 6 au 11 mai 1985 French only	1986
37	Principles of Geological Mapping of Marine Sediments (with special reference to the African continental margin) Available in English and Russian	1986
38	Marine Sciences in CMEA countries Programme and results of co-operation Available in English and Russian	1986
39	Development of marine sciences in Arab Universities Meeting of Experts held at the Marine Science Station Aqaba, Jordan 1-5 December 1985 Available in Arabic, English, French	1986

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PREFACE

Unesco Reports in Marine Science are designed to serve specific programme needs and to report on developments in projects conducted by the Unesco Division of Marine Sciences, including those involving collaboration between the Division and the Intergovernmental Oceanographic Commission.

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75700 Paris
France

ABSTRACT

This report is the result of the Unesco/COMAR remote sensing workshop held in Townsville, Australia (19-26 August 1985), to introduce resource specialists, marine researchers and coastal zone, shallow sea managers to digital image processing of remotely sensed data and its applications in coral reef, oceanographic and estuarine studies. It contains an assessment of the workshop proceedings together with 14 papers dealing with project planning, the basic physics of marine remote sensing and remote sensing applications in coastal marine studies. Topics covered include project planning for remote sensing, biophysical considerations in marine remote sensing, remote sensing applications for coral reef, oceanographic and shallow water benthic studies and mapping, output product types and uses, digital and analogue data sources for the ASEAN South-West Pacific Regions, a micro-computer based image analysis system, a summary of the exercise project, and a review of potential applications in coastal marine remote sensing.

RESUME

Ce rapport est le fruit de l'atelier Unesco/COMAR sur la télédétection, organisé à Townsville (Australie), du 19 au 26 août 1985, en vue d'initier les spécialistes des ressources, les chercheurs en sciences de la mer et les responsables de l'exploitation des zones littorales et des eaux peu profondes au traitement numérique des images obtenues par télédétection et à ses applications dans les études sur les récifs coralliens, les problèmes d'océanographie et les estuaires. On y trouve une évaluation des travaux de l'atelier et 14 communications traitant de la planification des projets, des notions de physique sur lesquelles repose la télédétection marine et de l'application de la télédétection aux études sur les zones marines côtières. Les points abordés sont notamment les suivants : planification des projets de télédétection, considérations biophysiques dans le domaine de la télédétection marine, application de la télédétection aux activités d'étude et de cartographie concernant les récifs coralliens, les problèmes d'océanographie et les communautés benthiques des eaux peu profondes, types de produits et leurs utilisations, sources de données numériques et analogiques pour les régions de l'ANASE et du Pacifique Sud-Ouest, système d'analyse des images fondé sur l'emploi de micro-ordinateurs, exercice d'application proposé aux participants (compte rendu succinct) et inventaire du potentiel de la télédétection dans les zones côtières.

RESUMEN

Este informe es el resultado del seminario Unesco/COMAR sobre teledetección celebrado en Townsville, Australia, del 19 al 26 de agosto de 1985, para presentar a los especialistás, los investigadores del mar y los administradores de zonas costeras y zonas marinas poco profundas, el procesamiento de visualización digital de los datos teledetectados y sus aplicaciones en los estudios sobre los arrecifes de coral, el océano y los estuarios. Contiene una evaluación de las actas del seminario y 14 documentos que tratan sobre la planificación del proyecto, la física básica de la teledetección marina y las aplicaciones de la teledetección en los estudios de las costas del mar. Entre los temas tratados figuran la planificación de proyectos de teledetección, consideraciones biofísicas de la teledetección marina, las aplicaciones de la teledetección en los estudios y cartografías bentónicas de los arrecifes de coral, el océano y las aguas marinas poco profundas, los tipos y utilizaciones de los productos, las fuentes de datos digitales y análogos para las regiones del Pacífico Sudoccidental de la ASEAN, un sistema de análisis de imágenes por medio de microcomputadoras, un resumen del proyecto de ejercicio y un análisis de las aplicaciones posibles en la teledetección marina costera.

РЕЗЮМЕ

Этот доклад является результатом учебно-практического семинара ЮНЕСКО/КОМАР по дистанционному зондированию, состоявшегося в Таунсвилле, Австралия (19-26 августа 1985 г.), для ознакомления квалифицированных специалистов, исследователей в области морских наук и руководителей прибрежных зон и мелководных районов с цифровой обработкой изображений данных дистанционного зондирования и их применением в исследованиях коралловых рифов, океанографических исследований и исследований эстуариев. Он содержит оценку работы учебно-практического семинара, а также 14 документов, касающихся планирования проектов, физических основ морского дистанционного зондирования и применения дистанционного зондирования в прибрежных морских исследованиях. Охваченные темы включают планирование проектов дистанционного зондирования, биофизические аспекты в морском дистанционном зондировании, применение дистанционного зондирования в изучении коралловых рифов, океанографические и мелководные придонные исследования и картирование, виды и использование конечного продукта, цифровые и аналоговые источники данных для юго-западных регионов Тихого океана АСЕАН, систему анализа изображений на основе микро-ЭВМ, краткое содержание осуществляемого проекта, а также обзор возможных видов использования дистанционного зондирования в прибрежной зоне.

خلاصة

هذا التقرير هو نتيجة حلقة العمل التى عقدتها اليونسكو / كومار بشأن الاستشعار عن بعد ، فى تاونزفيل ، أستراليا (١٩ - ٢٦ أغسطس / آب ١٩٨٥) ، بقصد تعريف أخصائيى الموارد، وباحثى علوم البحار والمناطق الساحلية ، ومنظمى شؤون البحار الضحلة بطرائق معالجة الصورة الرقمية للبيانات المستمدة من الاستشعار عن بعد وتطبيقاتها فى الدراسات المنصبة على الشعب المرجانية والمحيطات والمصبات الخليجية • ويتضمن هذا التقرير تقييما لمداولات حلقة العمل الى جانب ١٤ بحثا تعالج تخطيط المشروعات ، والفيزياء الأساسية للاستشعار عن بعد فى البحار، وتطبيقات الاستشعار عن بعد فى دراسات المناطق البحرية الساحلية • ومن بين الموضوعات المعالجة تخطيط مشروعات الاستشعار عن بعد، وبعض الاعتبارات البيوفيزيائية بشأن الاستشعار عن بعد فى البحار، وتطبيقات الاستشعار عن بعد فى الدراسات المنصبة على الشعب المرجانية والمحيطات وقيعان المياه الضحلة ووضع الخرائط لها، وأنماط المنتجات المستخرجة وأوجه استخدامها، والمصادر الرقمية والبيانات القياسية المتعلقة بمناطق جنوبى غربى المحيط الهادى والمناطق الآسيوية ، ونظام لتحليل الصور يعتمد على الحاسب الالكترونى الدقيق ، وملخص عن المشروع التطبيقى ، واستعراض للتطبيقات الممكنة فى مجال الاستشعار عن بعد المنصب على المناطق البحرية الساحلية •

摘　　要

这一报告是在澳大利亚汤斯维尔举办的教科文组织／沿海生态系统综合治理研究与培训地区重大项目遥感讲习班（１９８５年8月１９—２６日）的成果，举办该讲习班的目的是向资源专家、海洋研究人员及沿海地区和浅海治理人员介绍遥感资料的数字图象处理及其在珊瑚礁、海洋及港湾研究方面的应用。本报告包括对讲习班工作的评价及１４篇论述项目规划、海洋遥感的基本物理性质及遥感在近海海洋研究中的应用等方面的论文。涉及的题目包括：遥感项目规划，海洋遥感方面需要从生物物理学角度考虑的问题，遥感在珊瑚礁、海洋及浅水的底栖研究和制图方面的应用，产出成果的种类和利用，东盟西南太平洋地区的数字与模拟数据来源，微计算机图象分析系统，实施项目总结和近海海洋遥感未来应用问题评述。

CONTENTS

NOTES

The workshop was sponsored by the Unesco Regional Office for Science and Technology for South East Asia under the Unesco/COMAR program. The workshop was organised by the Great Barrier Reef Marine Park Authority of Australia. Important contributions to the organisation and proceedings were made by the Remote Sensing Group of the Division of Water and Land Resources of the Commonwealth Scientific and Industrial Research Organisation of Australia, the Australian Survey Office, and the ASEAN-AIMS-ADAB Living Resources in Coastal Areas Program based at the Australian Institute of Marine Science.

Digital image processing of satellite data is an increasingly important source of information useful to the development of planning and management data bases. The utility of the Landsat and Coastal Zone Color Scanner data in marine applications has become increasingly evident. Much of the recent work and proven application has seen refinement in the Great Barrier Reef Region of north eastern Australia. As the area lies substantially in the tropics, contains many coral reefs and important shallow sea water mixing patterns, the techniques have wide application throughout the East Asian and Pacific seas regions.

The authors and participants are responsible for the choice and presentation of the facts contained in this report and for the opinions expressed therein, which are not necessarily those of Unesco and does not commit the organisation in any way.

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SUMMARY

A workshop organised by Unesco and the Great Barrier Reef Marine Park Authority was held at the Australian Institute of Marine Science, Townville, Australia, in order to transfer digital remote sensing techniques to marine resource specialists from South East Asia, the South West Pacific and Australasia. The overall aim of the workshop was to introduce resource planners, researchers and managers to digital image processing of remotely sensed data and its applications in coral reef, oceanographic and estuarine studies.

An intensive review of the theory and practice behind remote sensing applications in the area of shallow sea analysis was presented to the participants over the first two days of the workshop. From the general review the presentations narrowed to focus on a specific approach and the analysis system to be used in the workshop exercises. The workshop exercise was designed to simulate a typical project process culminating in the provision of planning related information which could provide input to a resource data base.

THE UNESCO/COMAR WORKSHOP ON THE APPLICATION OF DIGITAL REMOTE SENSING TECHNIQUES IN CORAL REEF, OCEANOGRAPHIC AND ESTUARINE STUDIES

INTRODUCTION

BACKGROUND

The UNESCO/COMAR Training Workshop on the Application of Digital Remote Sensing Techniques in Coral Reef, Oceanographic and Estuarine Studies was held from 19-26 August 1985 in Townsville, Queensland, Australia. The workshop was sponsored by the Unesco Regional Office for Science and Technology for South East Asia under the UNESCO/COMAR program. Mr. Graeme Kelleher, Chairman of the Great Barrier Reef Marine Park Authority, opened the workshop on behalf of UNESCO.

Digital image processing of remotely sensed data is becoming an important source of timely and action oriented information useful to the development of coastal area planning and management data bases. The utility of satellite scanner data in marine applications has become increasingly evident. Much of the recent work and proven application has seen refinement in the Great Barrier Reef Region of north eastern Australia. As this area lies substantially in the tropics and contains many coral reefs and important shallow sea phenomena the techniques were seen to be widely applicable in the area of marine resource management in the ASEAN and South West Pacific nations. It was considered timely to arrange for a vehicle to transfer the technology to some of the marine resource specialists, researchers and managers of these countries.

PARTICIPATING INSTITUTIONS

The workshop was organised for UNESCO by the Great Barrier Reef Marine Park Authority of Australia. Important contributions to the organization and proceedings were made by practising remote sensing and resource specialists from the Remote Sensing Group of the CSIRO Division of Water and Land Resources, the Australian Survey Office, the Philippines Natural Resources Management Centre, the ASEAN-AIMS-ADAB Living Resources in Coastal Areas Program based at the Australian Institute of Marine Science, the Australian Institute of Marine Science, the Australian National University and the James Cook University of North Queensland, as well as the Great Barrier Reef Marine Park Authority.

PARTICIPANTS

Nineteen marine resource specialists, researchers and managers from the five ASEAN nations, Australia, Korea, New Zealand and Papua New Guinea attended the workshop. Nine members of the group were already in Townsville as part of the ASEAN-AIMS-ADAB Living Resources in Coastal Areas Program, eight were sponsored by Unesco, and there were four from local Australian institutions. There were eight invited speakers. A full list of the speakers and participants is given in Annex I to this report.

PUBLICATION OF REPORT

All participants recommended the publication of an edited report of the proceedings to serve as both a general introduction to marine remote sensing and a general record of the event. Edited versions of presentations made at the workshop incorporating suggestions made in critiques submitted by participants are included. Additional material, which participants felt would be useful and necessary to introduce new users to the field of remote sensing has also been incorporated.

This report now covers such topics as project planning for remote sensing, biophysical considerations in marine remote sensing, remote sensing applications for coral reef, oceanographic and shallow water studies, output product specifications, handling supplementary data, digital and analogue data sources for the South East Asia-South West Pacific Region, description of a suitable micro computer based hardware and software system, a summary of the workshop exercise, and a review of potential applications in marine remote sensing.

2. PLANNING THE INCORPORATION OF REMOTE SENSING DATA IN MARINE PROJECTS.

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2. PLANNING THE INCORPORATION OF REMOTE SENSING IN MARINE PROJECTS

Daniel van R. Claasen & Deborah Kuchler

INTRODUCTION

Sound marine resource planning and management, and large area marine research, needs up to date information. Such information should, ideally, be no more than two years old (McQuillan 1975). Achieving this level of map data collection or revision is difficult in isolated coastal sea and coral reef areas. Satellite remote sensing can meet this need. In recent years remote sensing techniques have become increasingly sophisticated, reliable and useful tools for the marine resource specialist.

The following guidelines have been collated in order to assist resource specialists new to remote sensing to choose the technique(s) which will realize the potential benefits of speed and relative low cost of digital image analysis, when applied to a given project. These guidelines owe much to the experience of many practitioners as well as, in particular, articles on planning for digital image analysis by the Canada Centre for Remote Sensing (CCRS, 1981), Lindenlaub & Davis (1978), and Rohde (1978).

Remote sensing is only one of a number of sources of information. It cannot provide all the information likely to be needed or wanted. It is rarely possible and never desirable to carry out resource investigations using remote sensing as the sole source of information. A successful survey must integrate as many different types and sources of data as are relevant, useful and available.

The guidelines described below assume a stratified multistage approach to data gathering and integration. The multistage concept is based on the acquisition of progressively more detailed information from progressively smaller sub-samples of the project area. The term is used in the same sense as statistical stratified multistage sampling (Colwell, 1978). The approach demands a good, hierarchical classification model.

The satellite sensor effectively records synoptic, integrated information over a wide area. At the other end of the scale the field sample provides a detailed record of the integral elements of a surface feature within the area. Medium and small scale aerial photography, in turn, gives the intermediate picture, integrating the information from detailed sample sites into broader classes which are themselves elements of the larger features visible in the satellite imagery. Each level of analysis complements the other and provides a way to verify or resolve any accuracies or inconsistencies in the hierarchical, nested classification model.

A stratified, multistage approach can reduce the amount of field sampling required while greatly improving the information value of each sample. It is of particular benefit in remote areas where logistic problems and short field survey opportunities are prevalent.

PROJECT INFORMATION PLANNING

The first and most important task in planning any area survey is to clearly define the project information needs and objectives. Project staff must know the resource parameters they want to survey and the amount of work involved in getting the information. The project terms of reference must therefore be clear, definitive and must include a statement on the study objectives, area boundaries and time frame.

The "pre-field" phase of the project is critical to the success of the survey. The quality of the available data must be evaluated so that an effective survey program can be organised, with the objective of filling in gaps in the data base rather than carrying out a new inventory,. The pre-field assessment phase will also allow staff and/or management to determine whether remote sensing data analysis is an appropriate and optimum tool.

The questions posed below are derived from the work by Lindenlaub & Davis (1978) and the CCRS (1981).

STEPS IN THE PLANNING PROCESS

Step 1 - Defining the Information Need

Two points must be stressed :

- the entire project is built on this foundation
- the remote sensing specialist should be working very closely with the project and resource specialist(s)

Four basic questions will need to be answered to an appropriately detailed level :-

(1) What data? (its nature, cost and accuracy)

(2) For what purpose?

(3) Where?

(4) When?

(1) WHAT DATA ?

Specify :

(1) the surface features or cover types of interest

(2) the size of the area involved

(2) FOR WHAT PURPOSE?

Specify :

(1) What the resource specialist wants to know about these earth surface features?

It is essential to identify the precise nature of the resource specialists information needs:

Example :

The user may want only a partial reef feature map for a specific purpose, such as a map of shoal and slope areas for potential recreational fishing sites, rather than a total reef cover map.

(2) The format for the results

line maps, tables, thematic maps, images, combined formats, computer compatible geographic data base information inputs.

It is necessary to consider how the resource data are normally presented and used, whether this is how they are required in this instance, and whether all of the stipulated data is really needed.

Example :

Is a map essential or is it simply an intermediate step between the data source and statistical, tabular data normally required? Are finished, high cartographic standard, rectified maps needed or are unrectified theme maps sufficient?

(3) The required accuracy of the output results

The quality of information is always constrained by the available resources of money, manpower and time. At the beginning of the project accuracy levels should be clearly stated so that trade-offs between cost and accuracy can be identified and used to advantage.

The question of trade-offs is a key to effective and efficient use of remote sensing. There are trade-offs between the high spatial and geometric fidelity of vertical photography from either air or space craft and the lower spatial and geometric resolution from line scanning devices such as the Landsat multispectral scanner (MSS).

Example :

The use of high resolution aerial photography to map reefs on a regional base for planning. It will take several months to obtain photo coverage for a large area. It will take a year or two to interpret the photos and produce a final cartographic quality. The maps will be highly accurate and detailed, however, the planners may not require such detail over the whole region but will need synoptic cover in map form quickly. In such a situation it may be better to use the coarser resolution satellite data to gain a regional view of an area and then select target areas for closer study where high spatial detail is needed.

The trade-off between quality of data and the cost of obtaining the data is an important consideration. For any data gathering system selected there is a residual level of error within the data beyond which it is uneconomic to attempt further improvement. The relative cost-effectiveness of each approach must always be considered.

All project staff must be aware of the accuracy required and understand the terminology defining it. Accuracy refers to the closeness of an estimated value or interpreted class to the "true" value or class. The use of the word "true" usually implies that the values or classes have been checked "less remotely" (e.g. by surface measurements) and are therefore more likely to be correct than an estimate or interpretation made from the more "remote" data source.

In specifying the required accuracy of the final product actual or potential associated costs must also be considered :

Example :

when mapping reefs and shoals in or near a shipping channel one will not want to miss any potential item of interest - in other other cases such as the location of shallow, clear water reefs for tourist development, one may want to include only those items which are of general interest -.

---

(3) WHERE?

Specify :

(1) Whether complete coverage of the area is required,

or

whether a suitable sample of the area is sufficient to provide the necessary information?

As the amount of information needed is constrained by available resources of time, people and money project budget limits should be specified at the project's beginning. This will allow consideration of alternatives before project resources are committed.

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(4) WHEN?

Specify :

(1) Any special temporal considerations affecting the resource targets; time of day or season of the year.

The reason for considering the season or time of day, is to maximize contrast between surface features of interest and the background. To make the best decision one must consider the phenology and related spectral characteristics of the target, as well as the surrounding, features.

A thorough knowledge of how the features of interest are juxtaposed with other temporal features is also needed. In the case of reefs for example, one must at least consider tide height and turbidity levels. Hence, remote sensing specialists should always work very closely with the resource experts.

CHECK LIST FOR DATA NEED DEFINITION

The information needs of a project are summarized in Table 2.1. It will make sure that the data needs definition is complete to the satisfaction of the project team.

PLANNING AND IMPLEMENTATION

Once the nature of the data required has been confirmed the feasibility of using remote sensing in a project can be assessed.

Two questions need to be answered :

(1) Can the information be obtained through analysis of remotely sensed data?

If the answer is Yes, then -

(2) What is the best combination of type of remote sensing data which will provide maximum information

As to what constitutes the "best" combination will depend on the final purpose. In most instances "best" equates with "least cost". In some cases however savings in costs will be unimportant because fast results are wanted.

The decision whether or not the use of remote sensing in a given project is feasible, as determined by the answers to the above questions, can occur at any of several stages in the process:

(1) After the data need has been defined.

The first decision may, of course, be made after defining the information needs. If the data needs can not be met using remotely sensed data then any further assessment is unnecessary. For example, if the intention is to map groups of coral at the species level with Landsat imagery then the obvious decision is not to use satellite remote sensing, as it cannot be done.

It may be, however, that there is insufficient information to hand to know whether satellite data could provide the necessary information needs. If this is the case it may be necessary to defer the decision until a later stage.

TABLE 2.1 DATA NEEDS ASSESSMENT CRITERIA
(Source CIAS Workshop Lecture Notes 1981)

- Determine information requirements and accuracy levels
- Determine the earth surface features of interest and the type of information required (type, individuals, groups, boundaries, patterns)
- Resource parameters to be located and mapped or identified and measured (e.g. relative location, extent, condition, frequency of measurement)
- Temporal considerations (phenological aspects of features of interest, particular times of year)
- Area involved (size, location, boundaries)
- Form of output products, purpose and relative cost
- type of units (biophysical, political, administrative)
- Output type
  - Maps (end use, scale, minimum unit, accuracy, base data, format, reproduction method and frequency)
  - Graphs (end use, parameters, format)
  - Tables (end use, parameters)
- Accuracy (measure of accuracy, acceptable accuracy levels
- Coverage (area coverage, full area or sample, stratification method e.g. random, stratified or probability)

(2) After a literature review and/or consultation with experienced remote sensing/resource specialists.

If the decision cannot be made after (1) information about a remote sensing application for a specific case may be available in the literature and the experience of people working in the field. Libraries, specialist agencies, remote sensing journals, etc., can be consulted. The Manual of Remote Sensing (ASP 1983) is a good starting point. Specialists should be consulted. The review may provide enough information to make a decision to proceed, not to proceed or to try a test project.

A note of caution. Costs and accuracies of reported results should only be applied to a new project with due care. The methods used to derive these items can vary significantly. It is better to extract the survey or project task components and prepare the project budget as a separate costing exercise based on local costs and conditions.

(3) After considering potential problem areas and available resources.

Once technical feasibility is confirmed planning can proceed commencing with an assessment of available resources and potential problem areas. Depending on the outcome of the assessment there are four possible decisions :

(a) The project is not feasible with existing resources and/or logistic, technical or financial problems.

(b) The project is not feasible, do not proceed.

(c) The project is feasible, proceed.

(d) Outcome is uncertain but worthy of investigation, proceed with a pilot or test project.

The following points will have to be considered :

(a) project flexibility and capacity to absorb equipment breakdown or inaccessibility;

(b) adequacy of sensor for proposed task(s) and accessibility of data;

(c) ground data collection methods and logistics;

(d) the range of possible analysis methods;

(e) hidden costs if experimentation with data is needed;

(f) dependency on other agencies, consultants, contractors - are they reliable, competent, available?

(g) human resource availability;

(h) cost effectiveness and funds availability;

(i) resources necessary to complete project - if different from (h) and (i) delay project until support is adequate or change the specifications - do not proceed if under-funded or understaffed.

(4) **After evaluating the range of methods, including non-remote sensing techniques, of data collection.**

The feasibility analysis should describe all realistic alternative methods which could be used and list them in terms of priority on the basis of cost, accuracy, timeliness and feasibility, taking into account local conditions. All integral personnel should be consulted in this assessment so that all relevant data collection methods are represented and evaluated. The analysis must include the integration of remote sensing and non remote sensing techniques where possible.

On completing this part of the evaluation the decision comes down to a choice between the different methods or combinations of methods in the light of local conditions. The second choice is between two decisions, to proceed or not to proceed. Either the project is feasible with available money, time and personnel resources or it is not. In any case, the best method or combination of methods should be planned for implementation.

(5) **On completion of a pilot project designed to test the feasibility of using remote sensing.**

As a final component in the feasibility assessment a trial project may be considered. The trial or pilot project should be restricted to conditions similar to the environment applicable to the primary project - e.g. for a reef mapping inventory the appropriate trial may be the analysis of reefs with comparable tidal and water quality conditions.

The trial must be realistic and meet the following objectives:

(a) it must establish accuracies and precise costs for the methods used;

(b) it must evaluate whether or not remote sensing will supply the required data;

(c) it must allow refinement of the methodology;

(d) it must serve as a believable demonstration to the client, resource agency or management agency that the methods work.

ASSESSING THE RESULTS

Whether the results being assessed are those of the trial or the entire project it is essential that some measure of success is made available to the end user. For the end product to be useful it must have the confidence of the user.

To assess the accuracy of the remote sensing classification it is necessary to select an area that is representative of the total project area. It should include both the area used to develop the classification as well as an extended area outside the training area. The map containing the interpreted or chosen classes derived from the remote sensing analysis can be tested for accuracy by comparing it with a map of known or "true" classes developed from available ground observations. Overlaying the two maps is a useful exercise. Classes which are incorrect or inconsistent can be identified and a means devised to map them correctly.

The following parameters can be used to determine accuracies:

(a) percentage of total correctly identified;

(b) percentage accuracy of area estimates by class;

(c) percentage accuracy of area estimates for the total test area;

(d) confusion between classes;

(e) percentage of parcels correctly identified by class and area (a measure of correct vs incorrect decisions);

(f) deterioration of accuracy away from the training area;

Although it might be stating the obvious, it must be stressed that the locations and relevant environmental characteristics of the test and training areas must be adequately defined in terms relevant to the remotely sensed data.

The remaining papers of this report will help to answer some of the questions posed in this section and direct users to more comprehensive texts, handbooks or references.

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3. BIOPHYSICAL CONSIDERATIONS

INTRODUCING SOME REMOTE SENSING BASICS

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THE PHYSICAL BASIS FOR REMOTE SENSING OF COASTAL WATERS BY LANDSAT

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INTRODUCING SOME REMOTE SENSING BASICS

Daniel van R. Claasen

INTRODUCTION

Remote sensing is a process of identifying, measuring and recording the presence of, and information about, objects from a distance. This paper is a brief introduction to some remote sensing basics. It is intended only to serve as a bridge for those persons who have had little remote sensing experience to the more technical aspects presented in other material later in this volume

REMOTELY SENSED DATA

In order to review the components of the remote sensing process it is necessary to understand the nature of the data being collected.

The usual end result of a remote sensing process are photographs, photographic copies of electronically scanned images, or processed data stored in digital, computer compatible format. The family photograph is a simple example of how such an image is formed. The principles operating to form that picture are generally true for all images.

To obtain an image, three things are necessary :

(1) a source of electro-magnetic radiation (the sun, a camera flash);

(2) a target (object) to modify the radiation in a particular and characteristic way (water, rocks, people);

(3) a device to measure and record the reflected energy (a camera and film, a scanning sensor).

When the camera "sees" and forms the family photograph it does so by directing reflected rays of light through a lens, thereby exposing the film and recording the data in the form of an image.

To the human eye reflected light is the visible portion of the electromagnetic radiation range or spectrum. Electromagnetic radiation is a form of energy which moves at the speed of light and is characterized by wavelengths or frequencies. The whole spectrum (figure 3.1) extends from the very short (micro), gamma and x ray, to the long, radio wavelengths.

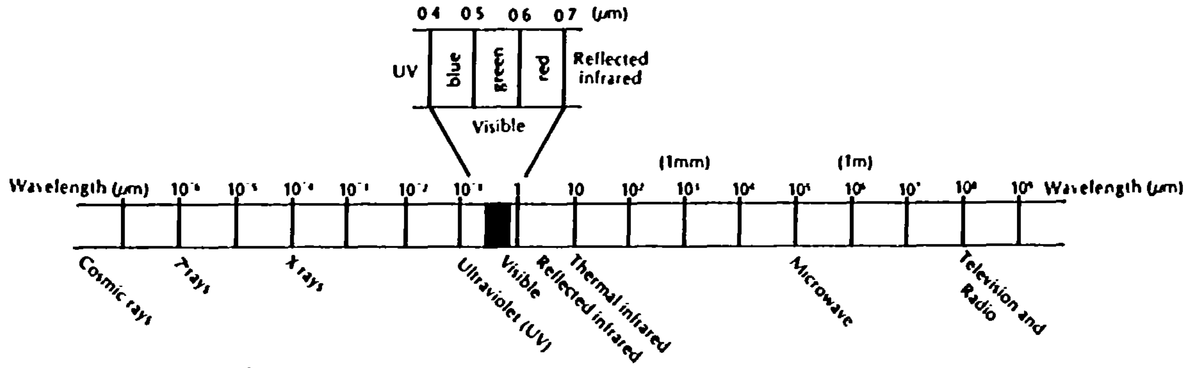


Figure 3.1 <u>The Electromagnetic Spectrum</u>

The visible spectrum forms only a small part of the whole. Visible spectrum wavelengths are interpreted by the human brain as colours. These visible light wavelengths range from 400 to 750 nanometres (nm). (A nanometre is, for the record, 1/1,000,000,000th of a metre).

Photographic films can be designed to record radiation from the visible region, and from the ultraviolet and near infra-red regions on either side of it. Multi spectral scanners are instruments designed to sample various parts of the spectrum, some outside the visible range, known to contain useful, interpretable, data.

The sensor, whether it be the eye, camera or scanner, records the spectral response of, or the intensity of the wavelengths of the reflected energy from, the object. In theory, every object has a characteristic spectral response pattern which is a function of both the electromagnetic energy falling on, and the structure and component materials of, the object. This response pattern can be so characteristic of a feature's surface geometry and content as to provide a spectral and/or spatial "signature" for that object. It is a code which, if it can be deciphered, can produce information about the feature or object.

In practice, the response pattern is damped and otherwise complicated by a variety of object, atmospheric, sensor and analysis system induced effects, or "noise", which obscure the significant, information bearing responses or "signal". It is part of the process of interpretation to distinguish the difference.

The major influences on spectral response patterns of objects, and therefore important in analysis and interpretation, are :

- the absorption and scattering of energy by various atmospheric components such as dust, haze, water vapour, etc., which reduce the spectral intensities of the signal;

- scene illumination alterations due to differences in sun elevation and topography; and,

- biophysical effects of the earth surface targets such as vegetation morphology and phenology, response to climatic patterns, etc. (see also Table 3.2)

Each of these can so modify the spectral response that different objects may result in similar spectral responses or the same feature may be represented by a range of different spectral responses depending on location, time of year or day, etc.

Photographs or images, then, are formed when the electromagnetic energy is radiated from a source, usually the sun, falls on, and interacts with, an earth surface object and is reflected or re-radiated to be recorded by a sensor.

DATA ACQUISITION

Remotely sensed information can be recorded by the human eye, cameras and passive and active radiation measuring devices. An "active" remote sensing device is one which transmits a signal on a particular wavelength and records it when it is reflected from an object. Radar and laser transmitters are examples of active devices. In this introduction the focus is on passive systems.

Cameras are passive systems of a specific nature. They use lenses to focus the visible or near visible radiation onto specially sensitized photographic film. The film, once processed, forms a image which can then be immediately interpreted.

Aerial photographs continue to be an important component in remote sensing for resource surveys, particularly when high spatial resolution is required. They are of particular value when studying small areas in great detail. The role of conventional photography in resource analysis is well known (Colwell - 1983, 1975).

Electronic or non-photographic scanners scan a swath or path of the area below the air or space craft. As the craft moves forward the radiation detectors sweep across the path line by line and record the spectral responses from the area below the craft. The equipment converts the measured radiation into electrical signals representing the spectral reflectance and stores them, after preliminary processing, on magnetic tapes. When required the signals can be used to produce images of the features that were scanned. This digital form of remotely sensed data usually requires further processing before it can be analyzed and interpreted. Useful explanations of the digital analysis of remotely sensed data is given by Swain & Davis (1978).

Optical-electronic scanners are spectrally more sensitive than photographic sensors but do not have the same spatial accuracy. Multispectral scanners can collect data in specific wavelength "windows" simultaneously on several channels or bands. Airborne scanners have been designed to record data on, for example, 127 channels. Spacecraft scanners have, until recently, been limited to fewer channels. Table 3.1 summarizes the more important instruments available at present and their proven applications.

The most readily available satellite data for resource planners is that provided by the Landsat program. The Landsat satellites were designed to carry a multispectral scanner (MSS) which measured the electromagnetic radiance in four wavelength "bands" of the spectrum (Table 3.2). Landsat 1, 2, and 3, and now Landsat 4 and 5 MSS images provide continuity of data in these same bands from 1973. Only Landsats 4 and 5 are still operating at present. Landsat 5 also carries an operational Thematic Mapper (TM) scanner. This has a spatial resolution of 30 metres and a greatly improved, seven band, spectral resolution. TM data is not yet readily available in the ASEAN and S.W. Pacific Region. To date however, the Landsat program has resulted in a substantial body of data which can be used to great effect for basic inventory, mapping and other studies.

A standard Landsat MSS scene covers an area of 185 km x 185 km or 34,225 square kilometres of the earth's surface. It consists of four images, one for each of the bands. The smallest resolution element, which represents the intensity of electromagnetic radiation from an 80 x 80 metre, 0.44 hectare, portion of the earth surface, is termed a "pixel" or picture element. Each single band image can be viewed separately or combined into a colour composite product. The digital data, stored on computer compatible tapes (CCT), can be manipulated with the aid of computers to produce enlarged and/or enhanced products for improved interpretation and permit the development of thematic products.

For greater detail about the Landsat systems readers are referred to Thomas (1977). Other useful references are Colwell (1983), Slater (1980) and Guerin and Bina (this volume).

INTERPRETATION

There is a deliberate distinction between the words "data" and "information". It focusses attention on the need to interpret the data obtained in the remote sensing process before it becomes useful to an end user.

In simple applications, such as when taking the family photograph, identification is almost immediate because the objects and the medium are familiar. The interpreter knows what he or she should be seeing. This highlights an important factor in photo or image interpretation - the interpreter must have a good knowledge of both the target characteristics, and those characteristics of the imaging system important to the recognition of the target characteristics.

In more complex situations, because the data is acquired by a more complex means, such as a multispectral scanner, and is

Table 3.1 Remote Sensing Instruments and Applications

Instrument	Description	Applications
Ocean Colour Instrument (OCI)	Selected visible and thermal bands or chlorophyll mapping	Primary production shelf processes, chlorophyll and suspended sediments.
Multispectral Scanner (MSS)	Wide set of bands for general applications, flexible spectral extent	Coastal zone (inc. wetlands) mapping and shallow water applications
Imaging Spectrometer (ISS)	Like MSS but using solid state technology	As for MSS but with better rectification
Camera System (AC, MSC, LFC)	Film based, possibly multispectral (MSC) or large format (LFC), recording, low sensitivity	Similar to MSS better rectification cheaper data
Infra-red Radiometer (IR)	Thermal emission from sea surface	Sea surface temperature, upwellings, fronts, water masses
Laser Fluorosensor (FLIR)	Single wavelength laser to induce fluorescence, emission measured over many bands	Chlorophyll "a" and pigments, light attenuation, oil type
Laser Depth Sounder (LIDAR)	Multi-wavelength laser profiler to measure time delay between sea floor and sea surface	Bathymetry, turbidity
Microwave Radiometer (MR)	Microwave emission from sea surface	Sea surface temperature, salinity, thickness of oil slicks
Altimeter (ALT)	Very precise nadir radar sensing height of satellite	Surface current velocities, shear convergence and divergence
Scatterometer (SCAT)	Off nadir back scattered radar	Wind driven zones of convergence and divergence

..cont.

Table 3.1 (continued)

Instrument	Description	Applications
Synthetic Aperture Radar (SAR)	Off nadir radar with high (processed) resolution	Sea surface effects (e.g. swell, internal waves), bathymetry and surveillance

Source : Jupp, (in press).

Table 3.2 Landsat MSS Spectral Bands

Band	Spectral Interval & Range		Utility
4	500-600nm	green visible light	Cultural features, vegetation classes, geology, water turbidity, depth.
5	600-700nm	red visible light	Vegetation, cultural features, water depth
6	700-800nm	photographic infra-red	Water property determination, vegetation differences
7	800-1100nm	near infra-red	Shoreline determination, wet soils, wetlands, plant vigour.

stored in digital format, the interpretation process is more difficult. The interpreter must have an awareness of the biophysical and sensor system characteristics affecting spectral responses, or object "signatures", in order to provide the optimum interpretation and minimize misclassifications.

In interpreting the remotely sensed data the interpreter has to identify features of interest and organize and classify them in terms meaningful to himself and to the USER of the information. In approaching the interpretation of an image it is therefore necessary to be organised and follow a logical method.

For photographic images, whether of direct (film) or scanner (digital) origin, standard photo interpretation techniques can be used. The interpreter systematically considers such photo or image elements as feature size, shape, shadows, tone and colour, texture (rough or smooth, or as a pattern of homogeneous or recurring heterogeneous variations of tone/colour units), spatial organisation or distribution of units, and association of the units within the image. Most interpreters use interpretation keys of one sort or another to aid and organize the process (Colwell, 1975). The keys are a set of references which guide the use of the photo or image elements to aid the systematic and accurate identification of features in the scene. Table 3.3 lists some additional factors of which the interpreter needs to be aware.

Digital data can be manipulated, using a computer, in three ways. The first is to acquire a standard, colour composite photographic image product, perhaps with a transparent base map overlay at the same scale, and interpret the image visually using the standard techniques mentioned above.

The second approach is to acquire a computer compatible tape of the scene, process it with a computer image processing system and develop photographic products which have been enhanced so as to improve their visual interpretability. The interpreter can then interpret the image. The computer can be used to apply contrast stretches to the data, to ratio two or more bands, or to use simple enlargement to improve interpretation.

The third approach is to carry out a full digital analysis of the data. It consists of displaying the data on the computer colour video monitor and carrying out the necessary enhancement techniques to select training areas (i.e. areas which can be used to identify the spectral characteristics of known features to the computer for subsequent quantitative analysis and manipulation), and apply various algorithms designed for multispectral classification applications, to produce thematic maps of land and water features.

There are principally two forms of computer classification which can be used with digital, multispectral data. In applying the supervised classification approach the interpreter selects relatively homogeneous areas in the image and defines and describes them on the basis of their, usually known, ground characteristics. The features are also analyzed and defined in terms of the spectral response characteristics in each spectral band. The resulting selected feature data are called "training sets" and are used to develop statistical decision rules or algorithms which will determine the group or "class" to which any new pixel will belong. When the interpreter has decided that a feature has been optimally defined the computer can be instructed to search the image for any pixels similar to the training sets and assign them to the same spectral class.

The unsupervised classification approach limits the amount of interaction as the computer is instructed to develop classes using algorithms based on spectral similarity between classes rather than on the basis of the identified ground characteristics of each class. The result is a map of spectral classes, each of which has yet to be transformed into land cover unit descriptions. The approach is of use when attempting to analyse images of areas about which little is known.

A good summary of the different approaches to digital classification techniques is found in Dubes & Jain (1976).

OUTPUT

There are a number of forms in which the final output of remotely sensed data can be produced. The final choice or choices will depend on the use to which the product will be put. These uses can range from simple illustration or display to detailed thematic, cartographic standard, resource mapping.

In basic applications standard image or aerial photographic data are visually interpreted and transferred to base maps. Two products are thus produced in the process, the image(s) or photograph(s), and the derived map.

Where digital processing is used to enhance the images for visual interpretation, several products can be produced - photographic slides or prints of the video monitor, high quality photo-images, and derived unrectified or rectified maps.

Full digital analysis will provide opportunities to produce photos of the video monitor image(s), photographically produced image maps, alphanumeric thematic maps, colour thematic maps, histograms, theme area summaries, and other numeric summaries and graphs. Derived rectified and unrectified maps can also be produced.

In most instances where remote sensing is used the final output will be in the form of a map or will have a map as a supporting document. The problem of rectification or fitting the remotely sensed images to a standard map projection is common to all of the data discussed above.

CONCLUSION

This introduction is, necessarily, brief. The papers to follow will expand on many of the concepts, principles and processes touched on above.

Table 3.3 Biophysical Factors Affecting Spectral Response

Factor	Type
Surface cover differences	effects of disturbance, cultural practices, spatial distibution of natural cover due environmental conditions (temperature, soil type, moisture, stress, disease, micro-climate effects, etc.);
Variations in vegetation maturity	due to phenological or micro-climatic factors;
Geometric configuration	vegetation stand density, tree size, age;
	topographic variables, slope, aspect;
Surface conditions	texture - rough or smooth; moisture - wet to dry;
Environmental variables	atmospheric - wind - solar illumination - solar angle physical - precipitation - substrate materials time

THE PHYSICAL BASIS FOR REMOTE SENSING OF COASTAL WATERS BY LANDSAT

David L.B. Jupp & Kevin K. Mayo

INTRODUCTION

Remote sensing by the Landsat multispectral scanner (MSS) lies on the divide between direct visual sensing of the environment, as typified by conventional photography, and observation of the environment by instruments which produce data requiring interpretation within the strict framework of the physical laws governing the transfer of radiation through materials and space.

The spectral content of the light reaching the Landsat scanner is separated and recorded into four broad bands. The contribution of this separation to a resultant image is similar to to the addition of colour to a photograph. The distinct recording of each band however adds a dimension to subsequent interpretation which can only be achieved from photography with some difficulty.

The key to the ultimate utility of spectral data however, is the existence of a particular relationship between the spectral character of the recorded signal and the nature of the earth surface target. In effect, spectroscopy is added to the spatial pattern of the land or surface cover target as a factor in the interpretation process.

The spectral character of the signals recorded by the satellite is a function of both the physics of radiative transfer and the earth target's physical environment. In this paper some of the processes which make up these aspects are described as a background to the interpretation of spectral data.

It should be recorded that much of the following applies to any remote sensing in the visible and near infrared (NIR) regions of the spectrum, (but not to the thermal infrared), and therefore applies to data collected by many multispectral scanning devices. However, the emphasis is on the readily available Landsat MSS data and its specific parameters of spatial, temporal and spectral resolution.

SPATIAL, TEMPORAL AND SPECTRAL FRAMEWORK

The 79 x 59 metre (0.45 ha.) pixel size, the 18 day (Landsat 1, 2 and 3) and 16 day (Landsat 4 and 5) repeat cycle, and the broad width of the spectral bands define the absolute limits of resolution for Landsat data. A description of the Landsat system characteristics is beyond the scope of this paper and, if required, can be obtained by referring to published materials (see Bibliography).

In coral and benthic mapping, as for land, applications, the pixel size creates problems on boundaries between benthic features in shallow waters, natural reef cover zones and on the narrow, linear zones of coral reef rims. This is especially relevant to monitoring applications where the same site has to be relocated each time. It is also a problem when attempting to locate field sample sites on the image. In a very real sense the spatial resolution of a remote sensor depends as much on the ability to locate a pixel on the earth's surface as on the pixel size.

It is expected that the improved resolution data from the Thematic Mapper on Landsat 5 (30 metre pixel) and the proposed French SPOT satellite (20 metre pixel) will provide a solution to these limitations. The higher resolution data will attract a much higher cost for comparable areas than Landsat data. At this time (1985) however, these products are not yet readily available in the ASEAN and S.W. Pacific regions.

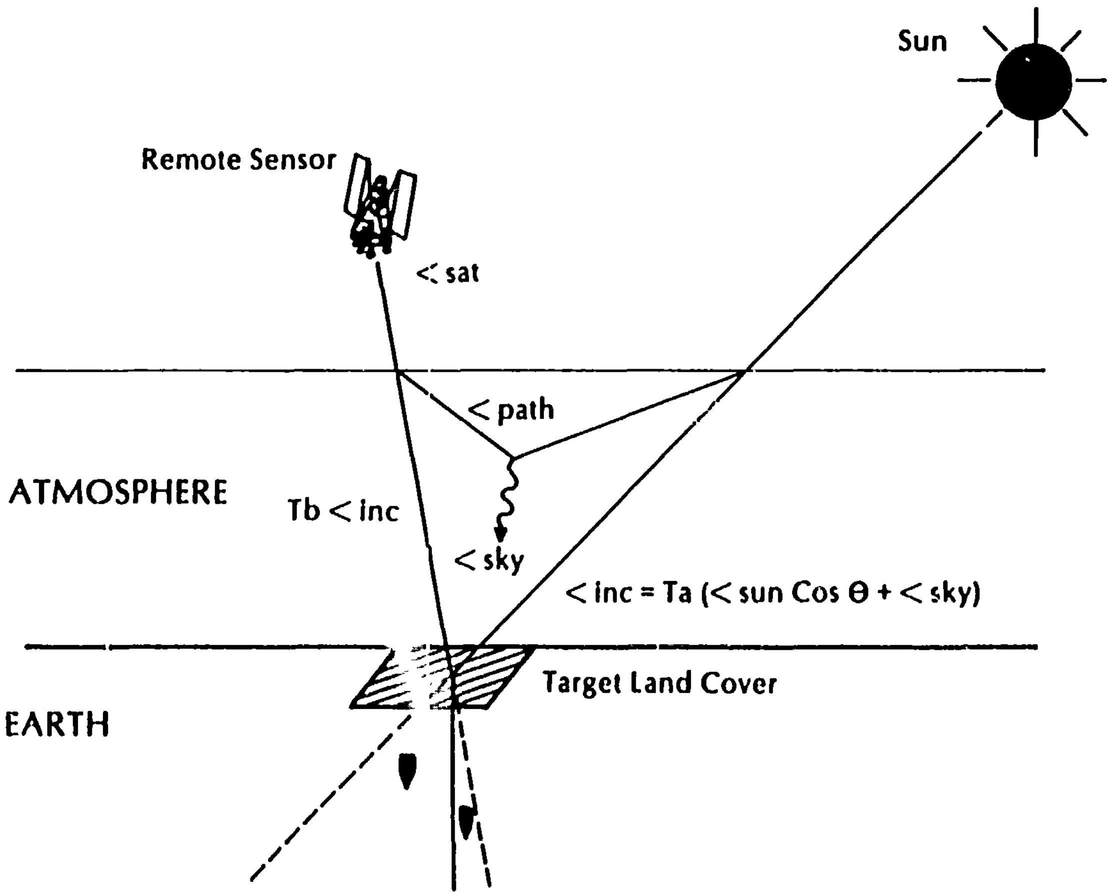
The Landsat MSS spectral bands are quite broad and therefore have a relatively coarse spectral resolution. The choice of bands on both the Thematic Mapper carried by Landsat 5, and on some of the meteorological satellites provide a much more significant spectral separation than is currently achieved from Landsat data. The Landsat bands were not designed for water mapping or reef work but rather for crop state and geological mapping. In this regard it should be pointed out that the SPOT satellite will have the same kind of spectral resolution as the Landsat MSS.

For those problems which are outside the scope of the current and planned satellite sensors there is the possibility of using airborne scanners. However, as with the acquisition of aerial photography, the expense and logistical problems in isolated regions restricts their use to those occasions where the remote sensing capabilities of the satellite sensors are clearly inadequate.

ATMOSPHERIC EFFECTS

Many submerged features of interest (such as coral patches) are only out of the water at very low tides. In most Landsat scenes therefore these features are being sensed through a combination of two media - the atmosphere and the covering layer of water.

The effect of the atmosphere on the signal from a target land cover type being recorded by a scanner is well documented (see Colwell, 1983, Chapter 5) and is summarized in Figure 3.2. The effects are mathematically represented by the equation :



COMPONENTS OF THE RADIANCE OF THE RECORDED SIGNAL

Figure 3.2 Atmospheric/Path Radiance Effects

Lsat = r*Ta*Tb*Linc + Lpath

where -

Lsat is the radiance measured by the satellite,

r is the reflectance of the earth' surface,

Ta is the transmission factor for radiation through the atmosphere to the earth's surface,

Ta = exp[-tau*sec(theta)]

theta is the sun zenith angle

Tb is the transmission factor for reflected radiation through the atmosphere to the satellite,

Tb = exp[-tau*sec(theta0)]

theta0 is the look angle from the satellite

tau is the atmospheric transmission coefficient;

Linc is the incident radiation on the earth's surface;

Linc = Ta cos(theta) Lsun + Lsky;

Lsun is the sun's radiance incident on the atmosphere;

Lsky is the diffuse (or sky) light incident on the earth's surface; and

Lpath is the radiance due to back scattered light which never reached the earth.

The many parameters in this expression are closely inter-related, so that, for example, if the water vapour and aerosol content of the atmosphere increase then the atmospheric transmission coefficient (tau) increases which decreases the transmission factors for radiation (Ta) and reflected radiation (Tb) through the atmosphere to the earth's surface and the satellite respectively, and increases both the diffuse light falling on the earth's surface (Lsky) and the radiance caused by back scattered light which never reached the earth (Lpath). As the sun gets higher in the sky (theta decreases), Linc generally increases with Ta and cos(theta), although the diffuse component of Linc (Lsky) decreases.

Since the objective of remote sensing is to measure the reflectance (r), the best conditions occur when "r*ta*Tb*Linc" is large relative to Lpath, which would ensure that the contrast between neighbouring pixels is as high as possible. Assuming that the look angle of the satellite is vertical (theta0 = zero) and that specular effects (e.g. sun glitter patterns) can be neglected, then the best conditions for remote sensing any part of the earth's surface occur when :

1. Lsun is greatest - for the southern hemisphere as near to January as possible;

2. The sun is high (theta is small, so that cos(theta), Ta and Tb are increased towards 1.0 and Lsky and Lpath are reduced); and

3. The sky is clear (tau is small, so that Ta and Tb are increased and Lsky and Lpath are reduced).

For remote sensing of tropical waters (2) is especially important since when the sun is high much less light is specularly reflected from the surface of the water and depth penetration is increased. Also, when the sky is clear the atmospheric point spread function, which reduces the contrast between a pixel and its background, is minimum.

With airborne sensors, unlike satellites, the time of the flight may be chosen to optimize these conditions and the specular effects controlled during the acquisition.

THE REFLECTANCE OF SHALLOW WATER AREAS

When water covers the surface the reflectance, "r", is a function of (see Jerlov, 1976, and Duntley, 1963) :

(i) the state of the air/water interface (sea state, waves, etc.);

(ii) the optical properties (colour and turbidity) of the water;

(iii) the water depth; and

(iv) the reflectance properties of the floor (e.g. sea bottom) and associated, submerged scattering components (e.g. rough ground, coral blocks, micro atolls).

When reef tops, for instance, are being mapped in terms of the reflectance properties of the floor and structural components (see iv above) both the atmospheric effects described in section 4.3 and in (i), (ii) and (iii) above, disturb the analysis of the data.

If the light distribution below the water surface is not important it is possible to use a simple exponential decay to model the general behaviour of the surface reflectance.

In this model (cf Doak et al, 1981) the radiance above the water in band "i" ("i" = 4, 5, 6, 7 for Landsat), which corresponds to the term "r*Ta*Linc" in section 3.3, is written :

$$Li = Lwi + L0i * \exp(-Ki*z)$$

where,

Lwi is the deep water signal (which depends on sea colour);

Ki is the water attenuation coefficient (factor "ii" above);

z is the water depth (factor "iii" above); and

L0i is the increase in radiance over the deep water signal due to the (wet) bottom reflectance (factor "iv" above).

Taking logarithms (see Lyzenga, 1981), leads to the expression :

$$Xi = \mathrm{Log}(Li-Lwi) + \mathrm{Log}(L0i) - Ki*z$$

This linear relation between radiance and water depth forms the basis for most bathymetric applications of Landsat data (Warne, 1978, Doak et al, 1980). It is possible, by using multiple scenes and existing bathymetric data, to extend the latter to shallow areas around unsurveyed reefs. While the accuracy of this procedure may not be sufficient for navigation it can satisfy many needs for shallow area bathymetric information in isolated areas which, because of cost and isolation, may otherwise not be mapped at all.

ATTENUATION OF LIGHT BY WATER

The attenuation of light by water is also a strong function of wavelength (Moore, 1980). The implication for Landsat remote sensing can be summarized as follows :

- Band 4 has maximum water penetration, although, for the clear waters around many tropical coral reefs, a band falling into the blue region of the electromagnetic spectrum would have much greater penetration. (Such a band is included on the Thematic Mapper carried on Landsat 5). Band 4 however, is also most affected by atmospheric scattering.

- Band 5 is rapidly attenuated by water. Most of band 5 is lost in the upper 5 metres. When water is less than 3 metres deep however band 5 becomes a highly significant indicator of bottom cover type.

- Band 6 of the Landsat MSS contains part of the visible red portion of the spectrum although most of its response is in the near infra red (NIR). In clear, deep water most NIR is absorbed within 20 cm of the surface. In shallow water (20-30 cm) the combination of fine differential depth information with band 5, and a sensitivity to chlorophyll, makes band 6 very significant for shallow intertidal and immediate subtidal vegetation, and for reef top, mapping.

When all, or part, of a reef top or tidal flat is exposed, the four bands operate much as they do on land. In particular, the chlorophyll associated with algae, which is prevalent in many areas of reef tops, affects the NIR sensors in a similar way to green vegetation. At Heron Island Reef in the Australian Great Barrier Reef Region, members of the CSIRO conducted experiments with infra red film (roughly analogous to band 6) to determine the precise cut-offs and disturbing effects involved in the sensing of chlorophyll associated with macro algae and corals. This work is to be reported elsewhere but supports the usefulness of the NIR region of the spectrum in benthic studies claimed by Hopley (1978).

TURBIDITY AND WATER COLOUR

The optical properties of the sea have received a great deal of attention (see Jerlov, 1976, for a definitive treatment). In general the major contribution to the blue colour of clear deep water is selective absorption by the water, although molecular scattering, the sea state, and the type of incident radiation all play a part.

The colour of turbid, other oceanic waters and coastal waters arises from the combined effects of the selective absorption of the light by the water, of substances carried in the water, and by scattering of the light by particles, air bubbles, etc. Often the term "colour" is used to denote the colour due to absorption and the term "turbidity" to denote colour due to scattering of light by suspended particles.

The Landsat signature is a form of "colour", even though not all the visible bands of the spectrum are covered and the bands 6 and 7 are out of the visible range. The properties of deep water (where no component of the signal is due to any bottom reflectance) can therefore be studied using Landsat data. These signals are, of course, affected by the state of the sea (wind, waves, etc., - see 3.3 and 3.4 above) and the disturbing effects of the atmosphere such as weather fronts and spatial variation in atmospheric parameters. In spite of these surface disturbances mapping spatial patterns and signature variations is a highly significant use of Landsat data (Thomson & Carpenter, 1981).

The spatial pattern of turbidity and wave colour can map the currents that mix various water masses. This is well demonstrated, for instance, in the Great Barrier Reef Lagoon. The mixing is especially significant along the coastal strip where large amounts of fresh water flow into the sea during and after the wet season, and where wind driven currents transport large amounts of sediment during the time that the winds blow from the South East (Wolanski et al, 1981). A great deal of work has been done to relate variations in the Landsat signature to actual physical measurements of the sediment load (Munday & Alfoldi, 1979; Amos & Alfoldi, 1979) with considerable success.

While the delineation of water turbidity and colour patterns is of significance for current studies, the patterns also disturb both water depth and reef top mapping. Hence, in most cases, it is desirable to analyse a number of scenes simultaneously to separate cloud, haze, colour and turbidity from depth variations and changes in bottom reflectance.

CLOUD COVER AND TIDES

To summarize, the physics of remote sensing of the reefs and waters of an environment like the Great Barrier Reef imply that it is most effective when the sun is high (i.e. during the summer months), when the sky is clear, when the wind speed is low (i.e when the sea surface is calm), and most important - when the water covering is at a minimum. That is, when there is a conjunction of low tide and low cloud cover.

The likelihood of such an occurence is a function of the physical environment of the target region. Any complete study of the usefulness of remote sensing for either mapping or monitoring will have to define the physical limits imposed by the environment.

The general spatial structure of tides in the ASEAN and South West Pacific regions are not well known. This is also true for the Great Barrier Reef Region of Australia where they have been the subject of considerable research (Pickard et al, 1977; Easton, 1970). Despite this, it is possible to study the time variation at specific locations in the Region (Australian National Tide Tables).

As an example, the tide heights at Heron Island in the Great Barrier Reef Region at 0915 over the past five years coinciding with actual Landsat overpasses, for instance, were computed by Dr. J. Church of the CSIRO Division of Fisheries and Oceanography, and matched with weather records taken at 0900 by the Heron Island Research Station for the Australian Bureau of Meteorology.

The weather records on the Reef are also sparse, although the analysis of the records available from the existing stations

Table 3.4 Percent Occurrence of Tide Height/Octas

(a) December to May

Tide Height (Metres)

OCTAS	0 - 1.5	1.5 - 2.5	over 2.5	
6 - 8	10.98	20.73	23.15	54.86
3 - 6	7.32	12.20	4.88	24.40
0 - 3	4.88	10.98	4.88	20.74
	23.18	43.91	32.91	100.00

(b) June to November

Tide Height (Metres)

OCTAS				
6 - 8	7.22	13.25	27.22	27.69
3 - 6	3.61	12.05	2.41	18.07
0 - 3	18.07	24.10	12.07	54.24
	23.18	49.40	21.70	100.00

provide some idea of its main features (see Pickard et al, 1977, or Davies et al, 1976). Similar analyses can probably be carried out elsewhere. In the Great Barrier Reef area the monsoons bring considerable cloud cover and rain during the summer, which leads to extensive turbidity along the coast near river mouths. Images recorded at these times are of great value in the investigation of the pattern of coastal fronts, significant agents in the dispersion of pollutants (Klemas, 1980). During the period from February to August the South Easterly winds prevail. In this period wind action creates turbid conditions along the coast and makes field work difficult. Between September and November however, the region is, on average, most calm and cloud free. This time also coincides with the lowest tides for the year and therefore should provide the most useful scenes for mapping normally submerged features such as reef tops or aquatic vegetation.

Table 3.4 shows a cross tabulation between cloud cover in octas and tide height in metres for satellite overpasses in the months December to May at Heron Island. The average monthly data show this to be the cloudy and wet six months of the year. Roughly 5% of overpasses fall into a "desirable" region of less than three octas (eighths) cloud cover and less than 1.5 metres tide above the nearest harbour datum (Gladstone). Given that there are 10 overpasses by one satellite in the summer months therefore, it would take over four summers before there is a 90% probability of getting at least one overpass in the desirable range.

The situation for late winter, Table 3.4(b), is much better with about a 90% chance of obtaining one good scene every year. This period of the year is expected to supply most of the good images for computer classification and change monitoring.

For many studies involving Landsat data, such as water depth, colour and turbidity studies, and often also for cartographic purposes, the low tide condition may be relaxed. This would potentially make many more images available over the year. Again, referring to Table 3.4, the expected number of overpasses with only low cloud cover is 2 in December/May and 5 in June/November. That is, seven scenes will, on average, be available over the year - although only two will have a low enough tide for effective reef top mapping.

The situation could be improved technologically by having more than one satellite operating or having a satellite with a shorter cycle. Landsat 4 and 5 have, in fact, 16 day cycles as against 18 for the Landsat 1, 2 and 3 satellites. The French SPOT satellite will have the capacity to point the sensor to take advantage of cloud free areas, and to enable the same point to be imaged daily for a number of days. This will be of considerable interest for remote sensing of reefal waters.

The only other way to increase the data flow is to develop methods which maximize the usefulness of scenes where higher tides prevail. Some of the work carried out by the CSIRO Division of Water and Land Resources and described in the BRIAN Handbook (Jupp et al, 1985) describe various correction, enhancement and multiple scene registration techniques which could be used to effect for this purpose.

CONCLUSIONS

By far the greatest limitation on the use of Landsat data for mapping and monitoring tropical and sub-tropical coastal seas is the physical environment. Despite 20 overpasses by the Landsat satellites each year over the Great Barrier Reef Region of Australia, which covers approximately 340,000 square kilometres in area, only a few will be useable for analysis. If reef top mapping requires a low tide then this data only reliably provides the possibility of a yearly monitoring service. However, the advantage is that this facility is available over a vast geographical area.

The combination of the physics of remote sensing as it relates to the Landsat MSS bands, and the physical environment of the Great Barrier Reef leads to the interesting conclusion that the three months September to November are, in a sense, the optimum for remote sensing of this area. It appears that this conclusion holds for nearly all remote sensing, including photography and airborne scanners, since the combination of generally lower tides, cloud cover, wind speeds, and high sun angles is beneficial in each case.

Considerable care must be taken to separate the various effects of haze (atmospheric effects), turbidity, water depth and actual sea bottom or floor reflectance changes between scenes. This implies that a number of scenes are needed to separate the transient phenomena, which could mean that the monitoring time scale of the Landsat data may be lengthened to more than a year. Although the question still requires complete resolution it appears that transient effects and land cover changes may be separated by combining scenes with less optimal haze and tide conditions with the better scenes, thereby providing a yearly monitoring framework.

Despite the many difficulties outlined above, the Great Barrier Reef has been, and is an ideal environment for testing satellite remote sensing and its general application. The various problems encountered there affect all problems of remote sensing. The logistical problems and expense of ground or aerial surveys are similar to those faced by many island and maritime nations of the South East Asian - South West Pacific regions and satellite remote sensing provides a relatively cost effective means of dealing with such vast areas. Unlike ground or aerial based surveys, satellite data are only purchased when an overpass results in a successful image, and a repetitive sampling scheme such as that provided by Landsat, is possibly the best given the highly variable nature of the coastal seas environment. The Landsat MSS and other higher resolution satellites have the potential to survey vast areas of coastal seas in a way which is logistically and financially impossible using ground and aerial survey techniques.

4. APPLICATIONS

REVIEW OF CURRENT APPLICATIONS*

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* Adapted from Jupp, D.L.B. The application and potential of Remote Sensing in the Great Barrier Reef Region. Research Report, Great Barrier Reef Marine Park Authority, Townsville. (in press).

REVIEW OF APPLICATIONS

David L.B. Jupp

INTRODUCTION

Existing remote sensing devices provide an opportunity to gather valuable data on static and dynamic physical and biological systems in continental shelf and reef waters. Remote sensing by Landsat has proven to be an effective tool for the establishment of a basic reef data base for the Australian Great Barrier Reef Region (Jupp et al., 1985a) which is effective for current inventory and planning needs. While the discussion presented here will refer principally to applications developed in the Great Barrier Reef waters it is considered that they can be effectively used in any area with similar biophysical conditions.

ESTABLISHED REMOTE SENSING OF THE GREAT BARRIER REEF

Until recently, remote sensing of the Great Barrier Reef has been restricted to traditional aerial photography and photo interpretation, and to Landsat satellite data which became routinely available in Australia in late 1979.

Aerial photography, both historical and recent, provides the most detailed image data available for the Great Barrier Reef system. However, much of the historical photography is taken at high altitude, is panchromatic, taken at a non-optimum time of day and tide and is uncontrolled.

The Australian Survey Office (ASO) and the Queensland Department of Mapping and Surveying (Q.DMS) are gradually replacing this photography with low level colour aerial photography and are extending cartographic control over much of the reef (Lamond, 1982). However, the process is time consuming and expensive, and up until recently much work in marine park planning has had to proceed with unsatisfactory photo and map bases.

LANDSAT IMAGERY

Landsat imagery, spanning more than ten years, from the highly successful experimental series of satellites (Landsats 1, 2, 3, 4 and now 5) are providing and will continue to provide effective map bases for the Great Barrier Reef until the progressing schedule of accurate survey work is complete.

The optical scanner system carried by the Landsat satellites records data in four bands - one in the green, one in the red and two in the near infra-red. The green band (band 4) covers the region of maximum penetration of light into coastal waters (Jerlov, 1976). Blue is not recorded and there is therefore no information available on the blue to green ratio (or colour index) which is the basis for optical classification of oceanic water types. Landsat data do, however, provide a large area, synoptic coverage of systems like the Great Barrier Reef of great value.

The CSIRO Division of Water and Land Resources, Great Barrier Reef Marine Park Authority (GBRMPA) and the Australian Survey Office (ASO) co-operated on studies investigating the value and application of Landsat data for large area planning and management of coastal waters.

Methods and the computer programs to realize them were developed (Jupp et al., 1985a) to interpret reef cover types based on the physical and biological zonations of reef tops (Jupp et al., 1985b). These interpretations provide a standard set of thematic images which have been used as a base for the initial planning of the Great Barrier Reef Marine Park.

The difficulties encountered in establishing ground control on reefs led to the development of image rectification methods which maximized the value of each control point (Jupp et al., 1982). The ASO is integrating this analysis with traditional survey methods to maximize the benefits of field survey. Reefs are now being chosen for survey in order to maximally improve the overall rectification of the Great Barrier Reef Landsat image set. Based on this work, a complete cover of rectified standard images and thematic interpretations at 1:250,000 and 1:100,000 map scales for the entire 348,000 square kilometres of the Barrier Reef Region will be completed shortly.

Landsat data were also transformed and developed to provide shallow bathymetric and reef morphological information. Although the accuracy of depth measurements from single images was low, it was improved by using several images taken at different times and choosing images which occurred with the best combinations of environmental conditions (Jupp and Mayo, 1982).

REMOTE SENSING OPPORTUNITIES

Within the scope of useful and feasible types of remote sensed data applicable to coastal marine system research and management needs there exists a significant base of largely unexploited data. Table 3.1 (Claasen, this report) summarizes some of the available instrumentation and their applications.

Aerial photography and sunglint

Existing aerial photography of reefs contains interesting information on micro-flows of water around and over reefs. Where sunglint occurs within the frame, extensive slick and shear patterns can also be seen (cf Stilwell, 1969). Cox and Munk (1954, 1956) have also used the glint area to infer wind speeds and spectra near the sea surface. At spacecraft altitudes, the areas of extensive calm within the sunglint can be mapped and related to frontal areas in the wind and current systems (McClain and Strong, 1969). Even simple hand-held panchromatic photography could be gleaned for important wave information, such as dominant wavelength, wave direction and refraction around shallow reef areas. However, the lack of quantitative multispectral information in a photograph generally limits the use of this type of opportunity.

Landsat data

Landsat combines good spatial resolution with a large area mapping capability (80 metre resolution element or pixel, and a 180 km swath width). This enables it to detect broad scale ocean and shelf circulation and suspended sediment flow patterns throughout the, for example, the Great Barrier Reef system on an opportunistic basis dependent on the 18 or 16 day repeat cycle and the degree of cloud cover. Such data have been successfully used (Thomson and Carpenter, 1981; Wolanski et al., 1984a, 1984b) in oceanographic applications to investigate the large area context of current mixing and island wakes and thereby to optimize the data from extensive ship based surveys.

Oceanic and near coast fronts occur between water masses with quite different dynamics (such as tidal currents) or properties (such as river outflows). The fronts are the areas where material or energy exchanges are occurring and represent highly significant features in Great Barrier Reef studies. Klemas (1980) has shown how frontal systems, which can be delineated in Landsat imagery, are highly significant in pollution dynamics as oil and even fish eggs are entrapped by the fronts. Such oceanic fronts are some of the most dynamic areas of the ocean and growth of phytoplankton is often associated with them (Pingree et al., 1979). The Landsat image provides one means of locating and investigating persistent frontal systems.

Landsat images sense different water masses and associated fronts since the different masses hold different amounts of suspended particles. This difference is also associated with different temperatures, salinities and chlorophyll contents (Mueller and LaViolette, 1981).

Alfoldi has applied several algorithms developed in Canada (Alfoldi and Munday, 1978; Amos and Alfoldi, 1979; Munday et al., 1979; Alfoldi, 1982) to map suspended sediment concentration for selected rivers of the Queensland, Australia, coast. The technique, called the "Chromaticity" method, uses colour ratios of Landsat bands and a method for standardizing between different dates to obtain quantitative estimates of suspended solids concentrations. With more ground data for calibration the method could be applied to a complete historical set of available images and help research the dynamics of the plumes of terrigenous sediment which move along the coast (cf Lindell, 1983, for applications in Sweden). The chromaticity technique has also been applied to mapping, on an opportunistic basis, oil slicks which it is able to separate from sediment plumes.

Landsat does not, however, have sufficient spectral resolution to separate inorganic and organic suspended solids and also lacks the time resolution (a repeat time, assuming no cloud, of 18 or 16 days) to investigate shelf circulation, suspended sediment plumes and pollutants on any more than an opportunistic basis (Klemas and Philpot, 1981). It is, for example, feasible that, due to the effective time resolution of the Landsat MSS, that if an oil spill occurred it may never be imaged, even if cloud free scenes were available, since the oil could be spilled and dispersed between overpasses.

Coastal Zone Color Scanner (CZCS)

An instrument with much better spectral and time properties - but having low spatial resolution - is the CZCS which has been imaging the oceans from the NIMBUS-7 satellite platform since 1978 (Hovis et al., 1980).

The CZCS has a range of sensors for spectral bands in the blue (443 nanometres (nm)), the green (520 nm and 550 nm) and the red regions of the spectrum as well as one on the boundary between the red and near infra-red (700 to 800 nm) and one in the thermal infra-red region (10.5 to 12.5 microns). These sensors were designed with high sensitivity and optimized for water property mapping. The CZCS bands are about 60 times as sensitive as the corresponding Landsat bands. It is a large area mapping tool with a pixel size of 800 metres and a swath width of some 1000 km. CZCS has a 6 day repeat coverage of any area - assuming cloud free days - with consecutive day overlap to improve the chance of attaining its basic period.

CZCS is designed to assess marine biomass (Hovis et al., 1980; Gordon et al., 1980) by detecting variations in concentrations of phytoplankton pigments. It has been shown that optical measurements using well placed spectral bands in the blue (high chlorophyll absorption) and green (low chlorophyll absorption) regions can give quantitative estimates of chlorophyll and related pigments concentration in ocean regions where organic suspensions dominate (Gordon and Clark, 1980; Smith and Baker, 1982; Gordon et al., 1983).

The CZCS thermal channel senses sea surface temperature (SST) to the same spatial resolution and is co-registered with the optical bands.

Considerable data of opportunity exist over oceanic and coastal regions in the CZCS archive. These data represent a prime source for opportunistic mapping of marine biological dynamics - including general communications between reefs and estuaries (cf Smith and Eppley, 1982).

Advanced Very High Resolution Radiometer (AVHRR)

The energy distribution in the sea which is displayed by thermal gradients comes from absorption of the sun's energy and through the tidal forces of the sun and moon. The turbulent mixing in the ocean expresses the interaction of these physical forces through the energy balance and can be sensed as temperature differences in the upper layers of the ocean.

To the extent that the temperature of the sea surface (SST) mirrors temperature of the upper layers, the AVHRR instrument carried on the NOAA 6 and 7 satellites represents another large area data opportunity for detecting frontal systems in oceanic and coastal shelf waters.

The AVHRR has five spectral bands (one visible, one near infra-red, and three thermal bands). The most important bands for the SST studies are two thermal infra-red bands in the 8 to 14 micron atmospheric window. The use of this pair allows measurement of absolute SST to within 1.0 degrees Celsius. With two satellites in operation up to four images may be obtained in a day (one in the morning, on afternoon, two at night) giving this instrument excellent time resolution.

The sensor transmits data in two modes, a high resolution mode (HRPT or High Resolution Picture Transmission) and a lower resolution mode (APT or Automatic Picture Transmission). HRPT data has a pixel size of about 1.1 km. APT data pixel size is about 4 km. APT data for the whole earth can be collected by NOAA but the HRPT data, because of the volume of the data generated, has only been collected for specific areas by NOAA or by local receiving stations.

Unfortunately for research in the Great Barrier Reef Region there are few high resolution images for that area and existing data are limited to low resolution SST data (based on AVHRR-APT data). As the AVHRR-HRPT becomes routinely recorded in East Australia by local receiving stations (Carroll, 1982; Nilsson, 1982) these data will be significant for very large area research in the region. It is worth investigating the establishment of a local receiving station for this purpose as such a station could provide valuable region wide information useful to oceanographers and other marine researchers. Of particular value is the application of these data in fisheries research and applications (cf Borstad et al., 1982) where the rapid availability of data will enable many of the large area factors in fish population dynamics to be investigated.

Depth of Penetration

While optical and thermal sensors provide significant data from the ocean and coastal regions, it must be borne in mind that the information contained in the data concerns the uppermost layers of the water.

The depth of penetration by optical sensors such as the first four CZCS bands is maximum in the blue for clear water at about 20 to 40 metres with the peak of penetration shifting to the green and red accompanied by rapidly decreasing depth as suspended particle concentrations increase. There is no water penetration in the thermal band and the AVHRR only measures the temperature of the surface skin of the water mass. The relationship between this surface temperature and the optical depth penetration is also complex as the optical depth defines the extent to which the sun's radiation reaches different depths.

This has two implications. The first is that different bands provide information on different sections of the water column and should be used in conjunction to assess the homogeneity of the column. Mixing, for example may, may be visible in in one band and not in others. It is especially important also, when using sea surface temperature, to assess the homogeneity of the water mass beneath the surface. The blue and green bands can do this.

The second implication is that supplementary data, taken at the sea surface and from the water column, are necessary to interpret and fully utilize remotely sensed data. A balanced integration of ship, aircraft and satellite borne measurements is therefore necessary to fully study the water mass.

CONCLUSIONS

Remote sensing provides an ideal frame in which to embed traditional survey data and conversely, the ground truth provided by traditional survey and a variety of measuring tools is essential to obtain full value from remotely sensed data. However, existing (historical) data lacks the ability to integrate with other data in this way and the greatest benefits from future remote sensing will come when the remotely sensed and field based data types are combined in a well planned design.

VERIFICATION OF LANDSAT MSS DATA ON HERON REEF

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VERIFICATION OF LANDSAT MSS DATA ON HERON REEF

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INTRODUCTION

This paper briefly outlines the procedure used to ground verify Landsat MSS image data on Heron Island Reef, Great Barrier Reef, Australia. A full account of the procedure is given in Kuchler, 1985a. The BRIAN (Barrier Reef Image Analysis) software (Jupp et al, 1985a) was used in the project.

A CLASSIFICATION SYSTEM

In comparing two or more data sets, standard nomenclature and classification systems have to prevail. Such systems did not exist for coral reef covers in general or for reef covers on the Great Barrier Reef in particular. Consequently, standard nomenclature and classification systems were specifically developed as tools for the formal identification and codification of remotely sensed and ground observed coral reef features. The systems are documented in Kuchler 1985b, 1985c.

DATA SETS

In the verification exercise, four different types of data were used. These were:

(1) A Landsat MSS image
(2) Colour aerial photographs at 1:12065 scale
(3) A rectified aerial photomap at 1:5000 scale
(4) Ground survey data

SELECT AND PREPROCESS LANDSAT IMAGE

The 'best' Landsat scene in terms of the Heron Island research was selected. The scene was recorded on 27th November, 1980. The 'best' scene for reef work is recorded in the summer months when the sun is high, the sky clear, the sea surface calm because of low wind speeds and most importantly when a low tide occurs, resulting in either shallow water covering the reef or an exposed reef surface.

Heron Island reef, located at the centre of the selected Landsat scene, was submitted to form a separate image, now referred to as the Heron image. The Heron image was prepared for pre-processing by digitizing out the open deep water and the coral cay, since the very low and very high radiance values for these features distort the histogram for the Heron reef surface data. The image was pre-processed by contrast stretching where subtle grey-scale differences in the image were made more obvious for interpretation.

IMAGE CLASSIFICATION

In classifying the image, the first step was to locate training samples. A training sample is a pixel or a collection of pixels known to be specific ground/features or known to be spectrally similar. The values/s of the training pixels are used as 'seeds' in the classification process to classify all pixels in the image into spectral classes to which they are most statistically similar.

As a result of the classification, two images were produced; a mean image and a residual image. In the mean image each pixel value of the spectral class is replaced by the mean value of the spectral class into which it is classified. In the residual image, each pixel value and its spectral class mean values. Both these images were used in an iterative classification process until the total spectral variation with the Heron image had been considered. The image was finally classified into 85 spectral classes.

SAMPLE SITES

The verification of the Landsat image data was conducted using a set of sample sites. The density and distribution of samples sites resulted from a stratified image data. A total of 341 sample sites were generated. A sample site was equal to the area of one pixel, a dimension which remained standard for aerial photographic interpretation of the sites and for ground survey.

TRANSFER OF SAMPLE SITE LOCATIONS

The locations of sample sites were transferred from the Landsat image onto the rectified photomap, aerial photographs and the ground in that sequence. An appropriate coordinate reference system geometry which could be superimposed both on the Landsat image and the aerial photographs was employed to present the remote sensor data in a standard cartographic form. Australian Map Grid coordinates were printed on the 1:5000 scale rectified enlarged photomap, so these provided a cartographic map base for interfacing the different types of remotely sensed data. Thus, the Australian Map Grid coordinates of the photomap and the Landsat Transverse Mercator coordinates of the Landsat image were used in a rectification between two images. Both the Landsat image and the photomap in one instance, and the photomap and the aerial photograph images in another instance were registered and sample site locations were marked.

INTERPRETATION OF SAMPLE SITES

Sample sites on the Landsat image were interpreted with the aid of aerial photographs and methods which analyze, enhance or summarize the data acording to user requirements. Such methods included histogram equalization, color enhancement, spatial filtering, theme mapping, extension mapping, image enlargement, feature space plots and depth of penetration mapping. These methods will only be mentioned here, since they are described in Kuchler, 1985a; Jupp et al., 1985a and any standard remote sensing text. Interpretations of the sample sites were coded and classified according to the nomenclature and classification systems mentioned earlier.

GROUND DATA

Both the colour aerial photographs (1:12,065) and the photomap (1:500) on which the sample sites were marked, were used to locate the sample sites on the ground. The photo pattern information on the 1:12,065 scale photos was first used to generally locate a sample site, while the more detailed information on the photomap was used for accurate positioning. Reef cover at the pixel size sample site was surveyed, coded and classified.

LANDSAT AND GROUND DATA CROSS-COMPARED

The sample site data which had been stored on two separate files, namely, one file containing the interpreted Landsat sites and one file containing the reef covers of the ground sites were cross-compared. An additional file containing the Landsat spectral classes was also cross-compared with the ground data.

Resource matrices, a concept available within the BRIAN package (Jupp et al., 1985) was the method used for cross-comparison. The number of sample sites in which interpreted reef cover types cross-compare in a one to one association and the number of sample sites in which the interpreted reef cover types are different are confused for the two data sets are given in a resource matrix.

ACCURACY ASSESSMENT

The results of the verification exercise are given in the resource matrices in Figures 4.1 and 4.2. Overall, the interpreted sample sites on the Landsat image cross-compared 74.7% with the ground data (Figure 4.1). Since the Landsat spectral classes cross-compared 81.6% with the ground data (Figure 4.2), the results given in Figure 4.1 are probably indicative of how well an interpreter can map reef covers on a Landsat image.

There are a number of factors influencing the cross-comparison results. Among these factors are water depth, data contrast and uniqueness of reef cover type. However, three factors which operate together to influence the cross-comparison results are spatial resolution, class adjacency and transient boundaries pertaining to any particular reef cover type. A lengthy discussion of these factors is given in Kuchler, 1985a.

LEVEL 1 - 6 CLASSES

Labelled Ground Data Classes (columns); Labelled Interpreted Landsat Image Classes (rows)

	RF	L	RR	O	RS	C	Total
RF	78 58.2%	19 14.1%		35 26.1%	1 0.7%	1 0.7%	134
L	11 8.6%	113 88.9%		2 1.5%	1 0.7%		127
RR	1 5%	1 5%	16 80%		2 10%		20
O	2 5%	4 10%		26 65%	8 20%		40
RS					17 100%		17
C						3 100%	3
Total	92	137	16	63	29	4	341 74.7%

RF Reef Flat **RR** Reef Rim **RS** Reef Slope

L Lagoon **O** Ocean **C** Cay

Fig. 4.1. Resource matrix used to compare the classification and labelling of resources as interpreted on Landsat image with those identified on the ground (Level I separation).

LEVEL 1 - 6 CLASSES

Labelled Ground Data Classes

Landsat Spectral Classes	RF	L	RR	O	RS	C	Total
RF	5650 90%	475 7.5%	3 1%	23 0.3%	127 2.0%	2 0.03%	6277
L	267 26%	698 68.1%	59 5.7%				1024
RR	69 7.5%	4 0.4%	468 51.2%	117 12.8%	255 27.9%		913
O	175 5.1%	38 1.1%	3 0.08%	2873 83.9%	333 9.7%		3422
RS	110 8%	19 1.3%	129 9.3%	184 13.4%	925 67.6%		1367
C						4 100%	4
Total	6271	1234	66	3194	1640	6	13007 81.6%

RF Reef Flat **RR** Reef Rim **RS** Reef Slope

L Lagoon **O** Ocean **C** Cay

Fig. 4.2 Resource matrix used to compare the classification and labelling of resources as identified on the ground with classification of Landsat MSS data into spectral classes (Level I separation).

REMOTE SENSING IN OCEANOGRAPHY : APPLICATIONS IN MARINE SCIENCE

MARINE REMOTE SENSING

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SUMMARY : PHYSICAL OCEANOGRAPHY OF TURBID COASTAL WATERS USING SATELLITE IMAGES

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SUMMARY : CHROMATICITY TECHNIQUE FOR MEASUREMENT OF SUSPENDED SOLIDS USING LANDSAT

MARINE REMOTE SENSING

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INTRODUCTION

Remote sensing offers the possibility of regularly collecting data from otherwise inaccessible areas. In marine science this has great attraction since ships, the traditional data collection systems, are expensive to run, collect data irregularly from rather restricted areas over time periods which are often of the same order as the duration of the ocean processes it is desired to study.

The unique viewpoint of the satellite and the subsequent synoptic coverage it provides yields data that essentially complement the more detailed and precise data collected by ships. Unfortunately only certain physical processes can be sensed remotely and there are severe technological limitations which further restrict the possibilities. There are however a number of available techniques which are discussed below.

Satellite remote sensing provides four available techniques at present:

- radiometric sensing of temperature
- radiometric sensing of colour
- radar measurement of height (altimetry)
- radar measurement of surface roughness (imaging radar)

Other techniques using, for example, radar to measure salinity, or lasers to measure fluorescence, depth or even temperature profiles are feasible but will not be available for some time yet.

The first two of the above methods area passive, i.e. using an external energy, the sun, and its interaction with the target, the ocean. Both methods use multispectral scanning radiometers and rely on digital image processing to produce maximally useful final results.

The second two techniques are active, i.e. they transmit a signal that is later re recorded, and require considerable power supplies on the satellite. Although experimental systems have been flown (GOES-3, SEASAT) there are no current operational systems.

In marine applications multispectral scanning radiometers can be used to sense ocean colour remotely by measuring the reflected sunlight from the ocean. The sensors in this case are sensitive to visible light in the range 400 nm (blue) to 700 nm (red). The surface temperature of the ocean may also be remotely sensed by radiometers sensitive to radiated thermal energy in the infrared region, 10 um to 14 um. In both cases corrections must be made to the data to compensate the effects of the atmosphere.

Although ocean colour and surface temperature constitute a restricted set of oceanographic parameters they are particularly useful, giving insight into biological activity, water depth, water movement and circulation.

OCEAN COLOUR

Ocean colour is sensed by measuring the upwelling irradiance emerging from the surface of the ocean. This irradiance is the volume of reflected daylight from the near surface illuminated layer, the euphotic zone, in which the majority of biological activity occurs. The spectral composition of this irradiance is determined by the water itself and the various dissolved and suspended materials. The accurate measurement of ocean colour can provide information on the constituents in the euphotic zone.

It has been shown that ocean colour measured at the sea surface can be reliably related to levels of near surface planktonic pigment and is a useful indicator of oceanic water type. The penetration of daylight into the ocean varies strongly with wavelength of the light and the concentrations of absorbing and scattering material. The colour of the resulting backscattered light depends on the total integrated effects experienced by the light throughout the layer on the way down and on the return path. On leaving the ocean surface the upwelling radiance is transmitted through the atmosphere where further changes occur due to atmospheric absorption and scattering. These effects are very strong in the important blue region of the spectrum. The removal of these effects allows remote sensing to of ocean colour to provide quantitative estimates for oceanic pigments.

SEA SURFACE TEMPERATURE

The remote sensing of sea-surface temperature can be accomplished using a single radiometer although the potential precision is then limited by a lack of knowledge of the effect of the atmosphere. The use of more than one channel allows some correction to be made for the air-mass and allows the calculation of absolute values. The measurement is based on the thermal energy radiated by the sea surface and is restricted to only the top few millimetres of water. This can be a cause of concern since this thin layer may be affected by local heating or cooling or even transport, and so not reflect accurately the temperature of the bulk of the water below it. In general however the ocean features displayed in thermal imagery are of such a scale and duration that it is clear that they do represent real circulation patterns.

RADAR

Radar altimeters are active remote sensing systems used to measure the height of the platform (satellite) above the ground. The highly accurate systems flown on GOES-3 and SEASAT could measure altitude to a precision of 10-20 cm. The measurements have been used to derive oceanic dynamic height profiles along the sub-satellite orbital track to yield information on frontal systems, currents and eddies. Unfortunately there are no currently operating systems although plans are in hand for new systems later this decade.

Imaging radar from satellites is a very ambitious proposal since the system requires considerable power and the volume of data produced is enormous. The most successful such system operated so far was that on SEASAT which had a short lifetime (even so, the data are still being analysed years later). Surprising detail of ocean surface , and to some extent sub-surface, features has been extracted and there is continuing pressure and planning for follow on systems (SAR-A and -B, ERS-1, RADARSAT).

COASTAL ZONE COLOR SCANNER

The Coastal Zone Colour Scanner (CZCS) is a six channel multispectral scanning radiometer carried on the NIMBUS-7 satellite. This satellite was launched on October 21, 1978 and was operational until quite recently. It is hoped that a follow on CZCS will be carried on a future NOAA series satellite. The NIMBUS-7 is at 954 km altitude, the northbound equatorial crossing is within ten minutes of local noon and the orbital path repeats every six days or 83 orbits. The scanner has a nadir (sub-satellite) pixel size of 825 m and a swath width of 1636 km. The data are encoded with eight bit precision, giving 256 grey levels. Three gain settings may be selected to ensure the range is appropriate.

The CZCS was developed to allow the quantitative estimation of near surface oceanic planktonic pigment concentrations. The term "coastal"has proven to be something of a misnomer since it has been found that suspended material and "green-stuff" in near shore waters reduce the accuracy of the estimates and the best performance has been achieved with data from the open ocean. Although there is no way to distinguish between the effects of chlorophyll and the pheopigments from such datat, the usually low levels of the latter (typically less than

10% of the chlorophyll levels) mean that the quantity estimated is usually referred to as chlorophyll.

The applications of the CZCS data in coastal and reefal waters would appear to include not only the obvious one of estimation of planktonic chlorophyll in the ocean, but also estimation of water depth with considerable accuracy to perhaps 50 metres given the effective penetration of the water by channels 1, 2 and 3. The large pixel size may reduce the precision of such estimates, as would the potentially arduous task of geometric rectification of the data given the complex projection of the scanlines on to the sea surface when large mirror tilt angles are employed. The sensitivity of the CZCS to turbidity should allow tidal flow patterns to be observed with ease and could be a valuable adjunct to ground based studies.

Any applications to reef areas will have to take note of the relatively poor spatial resolution in this context and not expect that the fine detail of small reef structures to be resolved. Other restrictions also apply, the local noon timing of the overpass may mean that cloud cover will prevent thecollection of useful data on many orbits, an insoluble problem with a passive, satellite based system.

The last and by no means least problem with the coastal zone colour scanner is that of data supply. The satellite was expensive on power consumption and could only be operated for a maximum of two hours per orbit. A set of target areas were defined pre-launch in conjunction with overseas collaborators and it is possible that the area of interest has not been imaged. Such data as is available is obtainable from the NOAA-NESS organisation responsible for the processing and dissemination of CZCS data. There were great problems encountered in setting up and making operational the correction algorithms so that routine production of data products did not begin until 1981. The whole CZCS project has been subject to severe budget restrictions and there is an enormous backlog of data awaiting processing to the level of computer compatible tapes. Only data specifically requested is processed. Some catalogues are available but generally it is hard to determine what data is available and whether it is sufficiently cloud free to be useful. The situation will probably remain unchanged. The satellite system has now degenerated to the degree that it can no longer be classed as operational.

SUMMARY : PHYSICAL OCEANOGRAPHY OF TURBID COASTAL WATERS USING SATELLITE IMAGES

Eric Wolanski

SUMMARY

Understanding of the water circulation in shallow turbid coastal areas can be greatly improved by the use of satellite images. While attention has been focussed on satellite images for a long time there have been comparatively few studies where satellite images have played an integral part in the planning of the field work together with the interpretation of the results. A description of the most succesfully integrated satellite/field work studies of water circulation in coastal waters was briefly presented. The use of satellite images for the planning of oceanographic studies on the Great Barrier Reef were also discussed. The details of such studies have been presented elsewhere (see bibliography).

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THE CHROMATICITY TECHNIQUE FOR THE MEASUREMENT OF SUSPENDED SOLIDS USING LANDSAT

A Summary of the paper Measurement of Suspended Solids Using the Landsat - Chromaticity Technique by Thomas T. Alfoldi as presented to the Workshop on Remote Sensing of the Great Barrier Reef Region (Australia), held in Townsville in May 1982.

SUMMARY

The chromaticity technique for suspended solids concentration (SSC) estimation from Landsat imagery was developed initially with Landsat photographic images (Munday, 1974a, 1974b) progressing subsequently to digital analysis of computer compatible tapes (CCTs) (Alfoldi and Munday, 1977, 1978). The methods were developed and configured into an interactive suite of programs at the Canada Centre for Remote Sensing, Ottawa (Munday, Alfoldi and Amos, 1979).

The technique provides a (semi) automatic means of SSC determination with a measurable degree of accuracy. It has the special feature of only requiring in situ verification data for one image. No subsequent sampling is required for further images of the same area.

The usefulness of remote sensing by satellite is due to its repetitive and synoptic coverage of the earth's surface and its ability to provide quantitative data. Whereas many applications demand visual interpretation of the shape, size, texture, location, etc., of image features it is those methods which remove the heavy burden of expensive and extensive manpower from image analysis which can be most cost-efficient. The estimation of suspended solids concentration from satellite borne multispectral scanner data depends entirely on spectral/radiometric instead of spatial information and thus, in theory, may be automated.

The technique is simple and practical with significant potential economic benefits in reducing field expenses. It complements in situ examinations. It is subject to sensor and data constraints (spatial, radiometric and temporal resolution). There is a problem of ambiguity between turbidity and bathymetry. In shallower waters multi-temporal techniques must be used to eliminate bottom reflection effects in order to measure SSC, just as turbidity effects must be removed to measure bathymetry.

The technique permits correction for atmospheric variability over time in order to quantitatively measure SSC. Chlorophyll concentration may be measured, though in a coarser fashion than SSC due to the darker target provided by algae and other chlorophyll-bearing agents, if constant atmospheric conditions are accepted. Bathymetric applications are also possible. It can be applied to oil slick identification by

permitting separation of marine oil slicks from typical false oil targets of inorganic sediment plumes and cloud features.

A full description of the technique and its background theory is contained in Munday, Alfoldi and Amos (1979), and Munday and Alfoldi (1975, 1979).

PRELIMINARY MAPPING OF BENTHIC VEGETATION AND WATER COLOUR WITH SATELLITE DATA

Daniel van R. Claasen, Len D. Zell, David L.B. Jupp, and J. Bolton

INTRODUCTION

In 1983 a pilot study conducted by D. van R. Claasen and L.D. Zell* of the Great Barrier Reef Marine Park Authority and D.L.B. Jupp and J. Bolton of the CSIRO Division of Water and Land Resources attempted to define the extent to which Coastal Zone Color Scanner (CZCS) and Landsat MSS data could be used to map near shore sea bottom benthos and water colour features of the northern Great Barrier Reef Region of Australia. The results were presented to 10th International Symposium for Machine Processing of Remotely Sensed Data, June 12-14, 1984, at Purdue University, Indiana, USA (Claasen et al., 1984).

Data Sources

Satellite Imagery

- 2 x Landsat Multispectral Scanner (MSS) scenes
- 1 x Coastal Zone Color Scanner (CZCS) scene.

Other data

- hydrographic charts and maps (bathymetry and shoal conditions at selected sites)
- reconnaisance air surveys
- 35mm photographs of the coast line taken from aircraft with handheld cameras
- site inspections and rapid, manta tow survey data.

The CZCS scene showed apparent high chlorophyll absorption features at certain points along the coast.

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*now with the Queensland National Parks Service, Brisbane

There was some correlation with areas known to support large accumulations of seagrasses and/or river/mangrove area outflows. Landsat scenes were used to focus on two of these areas.

Target Characteristics

Seagrass meadows occur from the intertidal to subtidal levels. Distribution is determined by local topography, substrate type and stability, exposure and water clarity. Seasonal fluctuation in density is common.

Tidal conditions at the selected study sites at the time of satellite overpasses was noted. Variations in water depth and tidal flow affect analysis. Deeper water, expanding turbid areas spread by outflowing tide and/or inflow of less turbid water masses on incoming tides affects light penetration and interpretation.

ANALYSIS

Image Preprocessing

Relevant sub-sets of the CZCS and Landsat images were selected for computer aided analysis. Features of little or no interest (land, clouds, etc.) were masked out of each subset image. Preliminary processing included the application of alinear contrast stretch, to enhance water feature detail, and destriping and filtering of the data.

Digital Enhancement - CZCS Image

The CZCS blue band (channel 1 centred on 450nm) is a chlorophyll absorption band and is used as a basis for chlorophyll mapping algorithms. The ratio of blue to green bands (450nm/520nm) is an index of water type and has been used to quantify chlorophyll concentration (Gordon et al., 1983).

It was observed that certain areas along the coast appeared to indicate chlorophyll absorption. Some preliminary data available appeared to show a correlation of these areas with large seagrass beds and/or outflows from mangrove inhabited estuaries. This was confirmed by subsequent fieldwork.

Interpretation of nearshore features was difficult because of the complex relationships between the many physical components in the scene.

It is apparent that the main water masses act as a basic stratification for further interpretation of water features. The nature of pixels in the same basic spectral class will almost certainly change between the water masses. This can be a problem in extending signatures for features in Landsat data. The CZCS data was used to delineate the different zones to assist later interpretation of other data.

The water masses were mapped using a three band "Inflection Ratio" (Grew and Mayo, 1983). This algorithm uses the measure -

G124 = [channel 1*channel 4)/(channel 2**2)]

(where the channels have been first order atmospherically corrected) to estimate chlorophyll in the deep ocean by sensing the blue to green shift. In fact, since bathymetry and turbidity also cause a blue to green and, eventually, a green to red shift in the peak of water penetration, this statistic covers the range of ocean to coastal variation.

The transformation resulted in the delineation of a clear and homogeneous set of water areas ranging from the deep ocean to the near shore. As the shore was approached the index value generally decreased with increasing suspended solids concentration, increasing chlorophyll and decreasing depth. Without verification it would seem that this manipulation of the CZCS image separated the following water masses -

1. Oceanic water,
2. Shelf breakwater,
3. Barrier Reef Lagoon water,
4. Inner shelf water, and
5. Nearshore water.

Digital Enhancement - Landsat

Multiple enhancement techniques were applied to the Landsat images in order to enhance the detection of near-shore anomalies which, in suitable habitat, could reasonably be expected to represent submerged vegetation, possibly seagrass.

A band 5/Band 4 ratio enhanced the wet reflectance of sea floor features. On the video display monitor the effect is to cast a red hue to low reflectance areas. This hue is also present in deep water areas. Separation between the deep water and other features is possible on the basis of known or inferred water depth. Nearshore, low reflectance features cannot be deep water responses if the known depth is between 2 and 5 metres above datum.

By comparing responses in each individual band it was apparent that radiance from shallow, dark, nearshore features was reduced by absorption in the green and the red portion of the spectrum. As the sea floor was known to be sand it was concluded that the decrease was caused by submerged vegetation. This was subsequently confirmed during a site visit.

CLASSIFICATION OF NEARSHORE FEATURES

Coastal Zone Color Scanner

The nearshore areas were classified and the themes labelled. Available data and limited field visits confirmed that unclassified, nearshore dark tones were associated with seagrass covers and/or the high organic content outflow of rivers. The large pixel size (800m) proved a distinct disadvantage in mapping the spatially variable and, relatively, small extent of these features. The boundaries between submerged vegetation (seagrass) beds and water masses could not be delineated with confidence. It is possible that the technique is mapping waters associated with seagrass meadows, as being distinct from surrounding water masses (King, 1981) rather than the seagrass.

Landsat Classification

Landsat spectral themes were interpreted and given a surface cover description or label on the basis of two surface sites. There was considerable variation between the sites. In the first, Shelburne Bay, 67 computer generated classes were aggregated into 10 surface cover classes. Three of these were associated with seagrass, algae and/or living coral cover.

The second, Bathurst Bay, classification proved more complex. The computer generated 125 themes. Of these, about twenty were related to signatures attributable to onshore lakes and marshes adjacent to the coast containing brackish or fresh water. From limited field work it appeared that only 4 groups of themes represented biological features. Further definition was not possible.

CONCLUSION

The method used in the study was a multi stage approach to classification. The CZCS image was used to delineate the basic water masses and to highlight apparently significant areas of productive (chlorophyll rich) water nearshore. Landsat data was used, conditional on this primary stratification and the hypothesis based on water colour, to attempt to map boundaries and extent at a finer scale. Finally air survey and field visits were used to verify the remote sensing mapping results.

The multiple source image process appears to indicate a useful approach to locating and mapping productive, sub-tidal coastal areas. The spatial definition of seagrass areas from the CZCS is not feasible, given the pixel resolution, and it is difficult to consistently map seagrass using Landsat. The two data sets together, however, seem to form a useful, complementary mapping system.

SHALLOW WATER MAPPING

SUMMARY OF A PILOT PROJECT TO EVALUATE SHALLOW WATER MAPPING OF THE TROBRIAND ISLANDS AREA - PAPUA NEW GUINEA

Information Memorandum issued by
Queensland Department of Mapping and Surveying
P.O. Box 234, North Quay, Q. 4000
Australia

BACKGROUND

The purpose of the pilot project was to establish that geometrically rectified and classified Landsat Satellite data could be merged with other data sources such as aerial photography, topographic maps and hydrographic charts to produce more complete coverage of shallow water areas with respect to water depth, reef location and bottom type.

The object was to provide various graphics which would provide more information on shallow water areas than any individual source in order to assist the fishing and related industries, identifying areas of fishing potential and navigation for trial catches.

A map was produced by the University of Queensland, the Queensland Department of Mapping and Surveying and the Australian Survey Office with the sponsorship of the Australian Development Assistance Bureau (ADAB).

THE AREA

The pilot area was chosen for its diversity of features such as islands, shallow water, reef formations and deep water channels. Existence of information such as topographic maps, hydrographic charts and aerial photography was necessary so that details could be partially verified against published information.

AVAILABLE DATA

Data available consisted of reference material such as mapping reports, aero triangulation reports, pilot information, tidal calculations, weather reports, lists of available satellite imagery, aerial photography and photo mosaics.

Working data included original repromat materials for the 1:100,000 topographic maps and hydrographic charts. Data was obtained from the National Mapping Bureau of PNG, Australian Survey Office, Australian Survey Corps, Royal Australian Air

Force, University of Queensland, The Hydrographer - Royal Australian Navy, Department of Mapping and Surveying Queensland, National Library Canberra and Harbours and Marine, Queensland.

PROCEDURES

Rectified and classified Landsat satellite imagery were obtained from the Australian Survey Office in the form of inkjet plots. Clear film overlays of selected information from both the topographic and hydrographic map were prepared over the pilot area and registered to the satellite imagery. The ink jet plots were then scanned to produce colour separation suitable for printing.

Individual printing negatives were produced to form the line and type sheets for both the topographic and hydrographic information. All negatives were then registered prior to printing.

The resultant map has demonstrated that the combination of the various forms of data can be relatively simply accomplished. The map permits the extension of survey data to unsurveyed areas with some degree of confidence because the satellite data provides the additional, thematic information. Copies of the map were distributed to the workshop participants. Any further enquiries can be addressed to :

The Surveyor General Of Australia,
Australian Survey Office,
P.O. Box 2, Belconnen, A.C.T. 2616 Aust.

or,

Department of Mapping and Surveying, Queensland
P.O. Box 234, North Quay, Q. 4000, Australia

5. DATA SOURCES, ANALYSIS AND OUTPUT PRODUCTS

OUTPUT PRODUCT SPECIFICATIONS

David L.B. Jupp
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Peter Guerin
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OUTPUT PRODUCT SPECIFICATIONS

David L.B. Jupp and Peter Guerin

INTRODUCTION

The hard copy products used and described at this workshop were produced by the Australian Survey Office and the CSIRO Division of Water and Land Resources using the BRIAN (Barrier Reef Image ANalysis) system developed at the Division. The BRIAN system was developed during the course of a program aimed at determining the applicability of digital image analysis of Landsat data for Great Barrier Reef region planning and management (Jupp et al, 1985a).

All digital data acquired from current satellite or airborne remote sensing platforms require corrections. As the data are acquired there are a number of induced image error sources, most of which can be corrected. These error sources are both geometric (caused by platform, sensor and scene movements and characteristics) and radiometric (caused by sensor, scene and atmospheric factors). A summary of potential error sources is given in table 5.1. Some of these can be carried out on request or as part of the bulk processing of data at the receiving station. Others will be necessary before or after carrying out enhancements or analysis processes. The processes which concern us here are the rectification of images to map projections and the technical specifications for the standard thematic products such as the depth of penetration (indicative bathymetry) and exposure (indicative reef topography based on exposure to the prevailing wind direction) images.

IMAGE RECTIFICATION

A prime necessity for all standard or enhanced Landsat imagery produced for the planning and management process is the rectification or geometric correction and registration of the image to a geographical co-ordinate system. In the case of the material produced for the Great Barrier Reef Marine Park Authority and presented at the workshop, the projection used is that of the Australian Mapping Grid (AMG) or Universal Transverse Mercator (UTM) projection.

The accuracy of the rectification of an image to any map projection depends on the number and distribution of accurate ground control points available. The rectification of Landsat satellite imagery and registration to cartographic bases has been the subject of considerable interest and a number of sophisticated image rectification systems have been developed (Van Wie and Stein, 1976, Strome et al, 1978, Orth et al, 1978, and Grebowsky, 1979).

Table 5.1 LANDSAT IMAGE ERROR SOURCES

A. GEOMETRIC

1. Platform Effects

Altitude
Attitude (Yaw, pitch, roll)
Velocity

2. Sensor Effects

Mirror scan linearity
Detector band sample
Band to band mis-registration
Perspective geometry
Panoramic distortion
Aspect ratio

3. Scene Effects

Earth rotation
Earth curvature
Earth elevation *

B. RADIOMETRIC

1. Sensor

Absolute detector difference
Relative detector difference

2. Scene

Solar angle

3. Atmospheric

Absorption
Scattering

From the work done in the Barrier Reef area it has been demonstrated that Landsat imagery can be geometrically rectified to satisfy the stringent Australian National Map Accuracy Standard for 1:250,000 scale maps (Jupp et al, 1982). This requires that 90% of all accurate, independently chosen ground control points must fall within 0.5mm of their known grid reference position on the rectified image. For Landsat data this means an RMS (residual root mean square) error of about 64 metres.

With a sufficient number of such points RMS errors of about 50 metres have been consistently achieved. It should be noted however that the accuracy quoted here refers to the error between grid co-ordinates predicted by a model for a given pixel and the grid co-ordinates of the corresponding point on a good base map. This is not the same as the accuracy of a photographic or inkjet plotter product, which may have added distortions due to the method of production.

Nominally rectified images are those in which the principal orbit and sensor effects and distortions have been corrected (Thomas, 1975). This is sufficient if spectral information is of primary interest and absolute spatial accuracy not essential. If accurate registration is required, the remaining distortions due to instantaneous satellite orbit and attitude variations have to be removed using surveyed ground control.

The process used in the BRIAN rectification package can be summarised as follows:

1. Co-ordinates of points digitized from existing topographic or photo maps are converted to a local co-ordinate system which uses the centre of the scene as the origin, and the longitude of the nominal scene centre as the meridian for a transverse mercator projection. This ensures minimum convergence of meridians and enables easy conversion between Landsat and standard geographical co-ordinate systems.

2. Assuming an affine relationship between satellite and ground co-ordinate systems, any misidentified or incorrectly scaled ground control points are identified and corrected or deleted from a points file.

3. A general image to map transformation based on the satellite model which, due to significant attitude variation in the satellite orbit, may be a higher order than affine, is then computed and the original image resampled at the plotting stage to fit the map projection.

The registration process emphasis is placed on removing or not fitting terms in the models which cannot be supported by the data. Although satellite orbital and attitude parameters may vary over a scene, results have shown that unless that variation is significant relative to both the random error in the ground control points and their spatial distribution, a lower order model should be used. Affine and bilinear models appear to provide the most stable extrapolations.

A measure of sufficiency of control in a given area is available as a by-product of the rectification process in the form of a predictive error image. The predictive error based on a quadratic model can be added as a channel to the image and plotted as a theme overlay. This allows the eventual user to see the varying accuracy of the product and can be used to determine where further control could be most effectively located.

See also Jupp et al, 1982, for a more detailed explanation of the rectification process.

ENHANCEMENTS

The computer can be used to digitally enhance images in order to improve the interpretability of the data. The aim is to separate water features so that they can be distinguished from each other either visually or spectrally. In shallow water mapping work three types of enhancement have been commonly used (Jupp et al, 1985a).

- Colour Enhancement

For coastal marine work the standard colour display on the video colour monitor uses the radiance in any three bands as the intensity of colour on the blue, green and red guns of the display. The colours mix additively to produce a colour image of the scene. For water and reefal areas band 4 is displayed through the blue, band 5 through the green, and band 6 through the red gun. The manipulation of colour, by interchanging colours between, and by using positives and negatives of, bands can enhance features of interest.

It must be stressed that the colours used do not normally represent visual colours of the features and such images are usually termed "false colour" enhancements.

- Linear Stretch

Colour enhancements can be further modified by changing the relative intensities of the displayed bands. The linear stretch technique enhances the contrast between colour intensities in the scene and improves it for subsequent interpretation.

The data in each spectral band occupy a range of radiance values along a grey scale with 255 levels. Each level of the scale represents a particular radiance value or colour intensity. The linear stretch method works by expanding the original range of radiance values over the full grey scale range of 255 levels. If this is done in each band the overall colour balance and intensity of the scene will be modified. The technique requires the interpreter to decide the number of percentage levels which are to be used in modifying the data.

- **Non-linear Stretch**

Non-linear stretches aim at redistributing the data so that the histogram matches as nearly as possible some reference histogram (Jupp et al., 1985a). This can enhance features of interest markedly as it alters the relative intensity of colours among pixels in a more complex manner than the linear stretch.

CLASSIFIED DATA PRODUCTS

Depth of Penetration

The Landsat data depth of penetration products are classified images indicating approximate bathymetry. Remote sensing of depth involves the measurement of light reflected from the sea floor substrate. For a constant water colour, turbidity and bottom type the individual band radiances vary directly with the depth of water down to the limit of depth penetration for each band. The four Landsat bands penetrate water to different degrees. In clear, oceanic waters with little atmospheric haze the depths of penetration for each band are approximately 15 to 20 metres (m) for band 4, 4 to 5 m for band 5, and 50 cm for band 6. Band 7 is fully absorbed but provides a useful measure of drying reef areas.

The depth of penetration of a given band is that depth beyond which returning signals cannot be distinguished above physical and sensor noise. Given sun angle, atmospheric effects, tidal variation, natural variations in turbidity and refractive properties of sea water and the different reflective properties arising from the nature of the wet substrate and associated biological communities, there are significant obstacles to overcome in precise depth measurement.

The procedure (Jupp et al., 1984) used to produce these images is summarised as follows :

- Image is displayed. A training set is taken over deep water (no resolvable signal in any band).

- The one percent and 99% levels of the deep water histogram are used to define lower and upper limits so that all pixels with values between the limits are effectively deep water.

- The bounds are used to divide water covered areas of a prepared image into depth zones -

  - Band 4 zone - bands 5, 6, 7 within deep water limits but band 4 above, indicating a depth signal

  - Band 5 zone -- bands 6, 7 within deep water limits but band 5 above

  - Band 6 zone - band 7 within the deep water limits, band 6 above; difficult zone to map on reefs as variations in substrate influence the signal

- Band 7 is used in all cases to ensure the depth zones are in fact water covered.

Considerable preprocessing is required to ensure satisfactory results. This will include destriping, despiking, spectral digitizing and double average smoothing. Interpolation of depth zones is also possible to give intermediate contours.

It must be remembered that these images only indicate the amount of water over the seafloor at the time of acquisition with only general corrections for tidal depth. The advantage is that this product can be developed rapidly without need for additional information.

Exposure Image

The exposure or indicative reef topography product is produced by spatially filtering Band 4 to remove pixel to pixel noise and small variations due to substrate. The remaining signal is dominated by water depth variations in clear water. The variations in substrate are significant but not as great as the effect of depth. The image enhances topographic features on reefs and can be used to delineate approximately the exposure to weather (aspect facing the prevailing winds) of parts of reefs, a useful indicator for ecological survey and mapping.

The Landsat band 4 signal is directly related to depth and can be regarded as a model for topography down to about 15 metres. The relationship is represented by the equation (Doak et al., 1980) -

$$Li = Lwi + (Lbi - Lwi) * Exp(-2K*Z)$$

where,

Li is (band 4) radiance above water depth
Z is the water depth
Lwi is the deep water signal (which depends on sea colour
Lbi is the (wet) radiance of the substrate with no water cover

K is the water attenuation coefficient

Slope and aspect of the topographic model is computed and used to calculate exposure defined as -

$$E = -\left(p \frac{L4}{x} + q \frac{L4}{y}\right)$$

Reef Cover Classification

Different patterns of reflectivity can be observed within each Landsat depth of penetration zones. Bina (1982) has shown that it is possible to produce a broad classification of Phillipines reefs and reef zones from Landsat imagery. This approach was further developed for Great Barrier Reef applications by applying a computer algorithm to a preprocessed image to identify sets of pixels with similar spectral values as spectral classes. A reduced set of these classes, usually 80 to 150, may then be interpreted and described by a reef resource specialist. Classification products are difficult to specify as a standard product because of the need for skilled interpretation and the relative complexity of the computer based classification. Jupp et al. (1985b, p.39) describes how an interim, specifiable product could be produced and used as a basis for later interpretation by resource interpreters. The process is summarized below :

- Define the deep water and Band 4 zones (see depth of penetration process above). Subdivide the Band 4 zone by interpolation and combine the product (either by computer or manual overlay) with the exposure image to provide useful geomorphological and implicit biological classifications of deep water areas.

- Map compositional zones in Band 5 and Band 6 Zones. In the Band 5 zone band 5 responds principally to variations in depth and band 4 to variations in substrate. In this Zone therefore depth may be consistently interpolated using band 5 and band 4 to separate substrate. As coral is dark and sand is bright in band 4 the interpolated depth classes may be separated into two sub zones based on high and low band 4 values corresponding to "sand" and "coral".

- A similar procedure is used to produce the thematic image in the Band 6 Zone.

The procedure provides an initial indication of general zones on reefs based on current information for future interpretation as the ancillary information base and experience of resource specialists increases.

OUTPUT DEVICE

For practical results the final products of image interpretation and enhancement need to be produced quickly, cheaply and accurately, retaining as much of the resolution achieved during the machine processing. An effective device has been the inkjet plotter. Much of the work produced at the CSIRO Division of Water and Land Resources, and the Australian Survey Office, has been on an Applicon device (Cook, 1982). This consists of nozzles which direct jets of ink, primary colours magenta, cyan and yellow, on to a rotating drum. Images are plotted as the nozzles move from one end of the drum to the other.

The raster basis for the plotter facilitates the incorporation of the rectification process into the image writing program and can avoid costly computer based image resampling. Images can be readily produced at various scales. Inkjet images have lower resolution than alternative means of producing images such as high precision photographic processes, but have cost and convenience advantages when presenting or using the hard copy data. Best results are obtained at 1:50,000 to 1:250,000 scales where plotter pixels closely represent data pixels. For smaller scales photographic products are more suitable.

CONCLUSIONS

Rectified and partially rectified images have been used to effect in the Great Barrier Reef area to improve accuracies in mapping the location and orientation of some reefs. The depth of penetration (indicative bathymetry) and exposure (indicative topography) products can be readily combined with ancillary data to provide a basis for reef cover classification and extending the information over wide areas. The resultant thematic products provide information about reef and shallow benthic conditions of considerable benefit to planning which could not be obtained by other means without a heavy commitment of human and other resources.

6. REMOTE SENSING DATA TYPES AND SOURCES IN THE ASEAN AND SOUTH-WEST PACIFIC REGIONS

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6. REMOTE SENSING DATA TYPES AND SOURCES IN THE ASEAN AND SOUTH-WEST PACIFIC REGION

Ricardo Bina and Peter Guerin

INTRODUCTION

One of the main difficulties facing prospective users of digital remote sensing data analysis is that of locating and ordering the right type of data for their particular purpose. A second problem is that of finding people with suitable expertise to seek advice. This section provides a summary of places and facilities in the ASEAN and Australasian regions where data and expertise may be found.

THE LANDSAT PROGRAM

The focus of this review is the Landsat program as it provides the most accessible data and most applications have been tried and tested somewhere in the world. The objective of the Landsat program is the provision of high resolution synoptic data of the earth's surface on a repetitive basis for the efficient management of earth's resources. In general it has met this objective very well. In this review therefore we address briefly the type of products generally available to users, the receiving stations and services generally provided in each country, and the analysis and research facilities available to prospective users in the region.

The emphasis on Landsat data does not imply that other data sources are inferior. Aerial photography is a long established source of resource data and most resource specialists will have used, and will be aware of how to obtain, aerial photographs. Other digital data from specialist satellites such as the Coastal Zone Color Scanner (CZCS) are not readily available and special procedures are required to obtain such data.

STANDARD LANDSAT DATA PRODUCTS

Standard Landsat products are available in three forms. Not all of those listed below are available from all the listed data sources. Details of standard services available from each facility will have to be obtained from them. The listing demonstrates what could be generally available.

A. **Black and White Prints and Transparencies**

1. 70mm - 4 band film strips either positive or negative

2. 185mm paper positive prints - 1:1,000,000 scale

3. 185mm film transparencies either positive or negative - 1:1,000,000 scale

4. 371mm positive paper enlargements - 1:500,000 scale

5. 371mm positive film enlargements - 1:500,000 scale

6. 742mm positive paper enlargements - 1:250,000 scale

B. **Colour Prints and Transparencies**

1. 185mm paper positive prints - 1:1,000,000 scale

2. 185mm film positive transparencies - 1:1,000,000 scale

3. 371mm paper positive enlargements - 1:500,000 scale

4. 742mm paper positive enlargements - 1:250,000 scale

C. **Landsat Data in Digital Form on Computer Compatible Tape (CCT) - One Scene per Single CCT**

Normally CCT's are framed according to the World-Wide Reference System (see Figures 6.1 and 6.2), however users can sometimes request non-standard framing by providing the latitude for the format centre or the area of overlap.

A more detailed listing of remote sensing data products and sources available in the ASEAN Region is provided in Appendix 11.3.

LANDSAT GROUND RECEIVING STATIONS COVERING THE ASEAN AND AUSTRALASIAN REGIONS

There are five operating ground receiving stations in the South East Asian-South West Pacific region, Australia, India, Indonesia, Japan, and Thailand. The ground receiving station in Iran which was established in 1977 is partially operational. Two more stations are under construction and will become operational shortly, one in Bangladesh, the other in China. In addition to these two more are planned, one in Pakistan and the other in New Zealand.

Figure 6.1 Worldwide Reference System - ASEAN Coverage

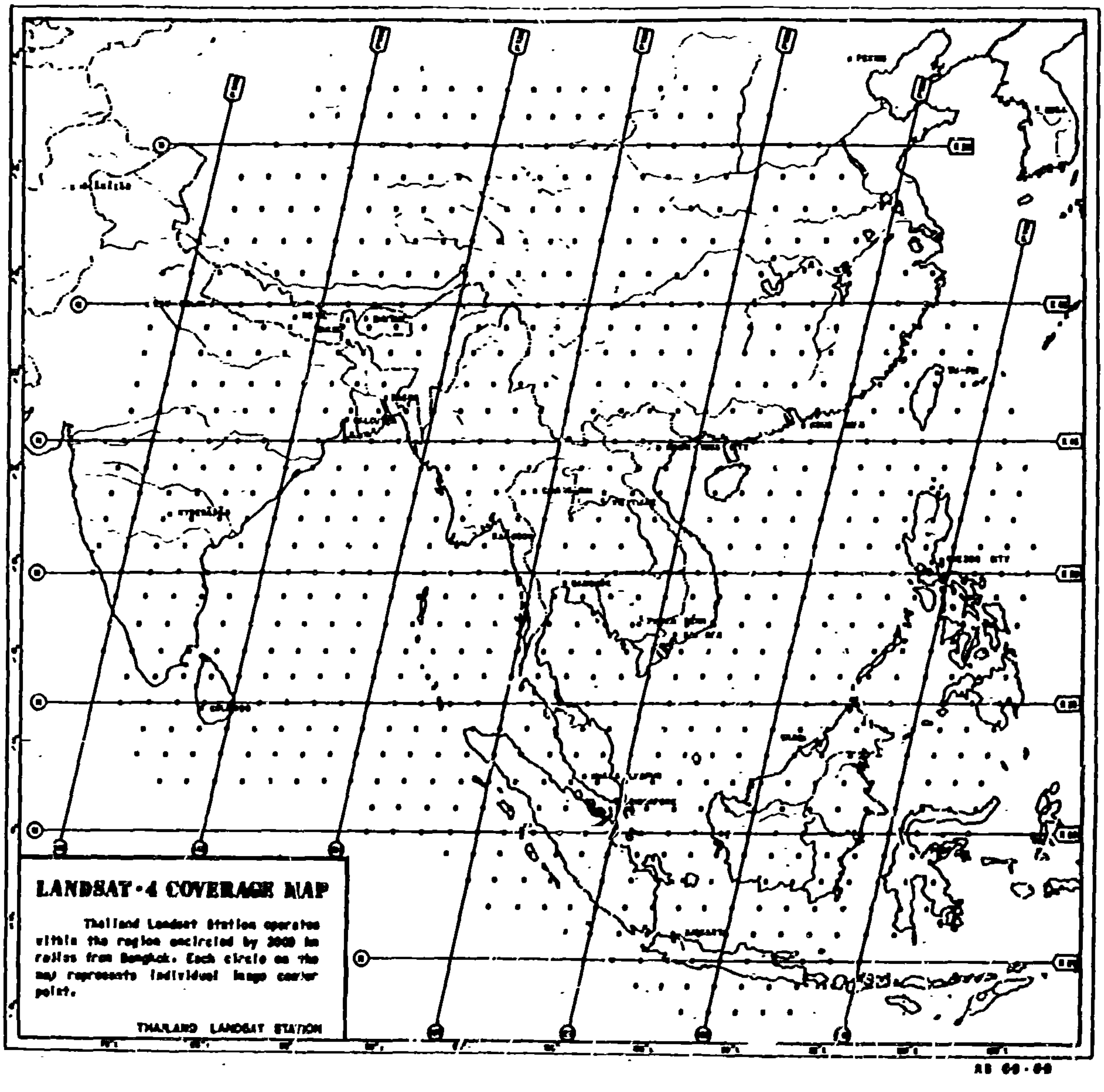
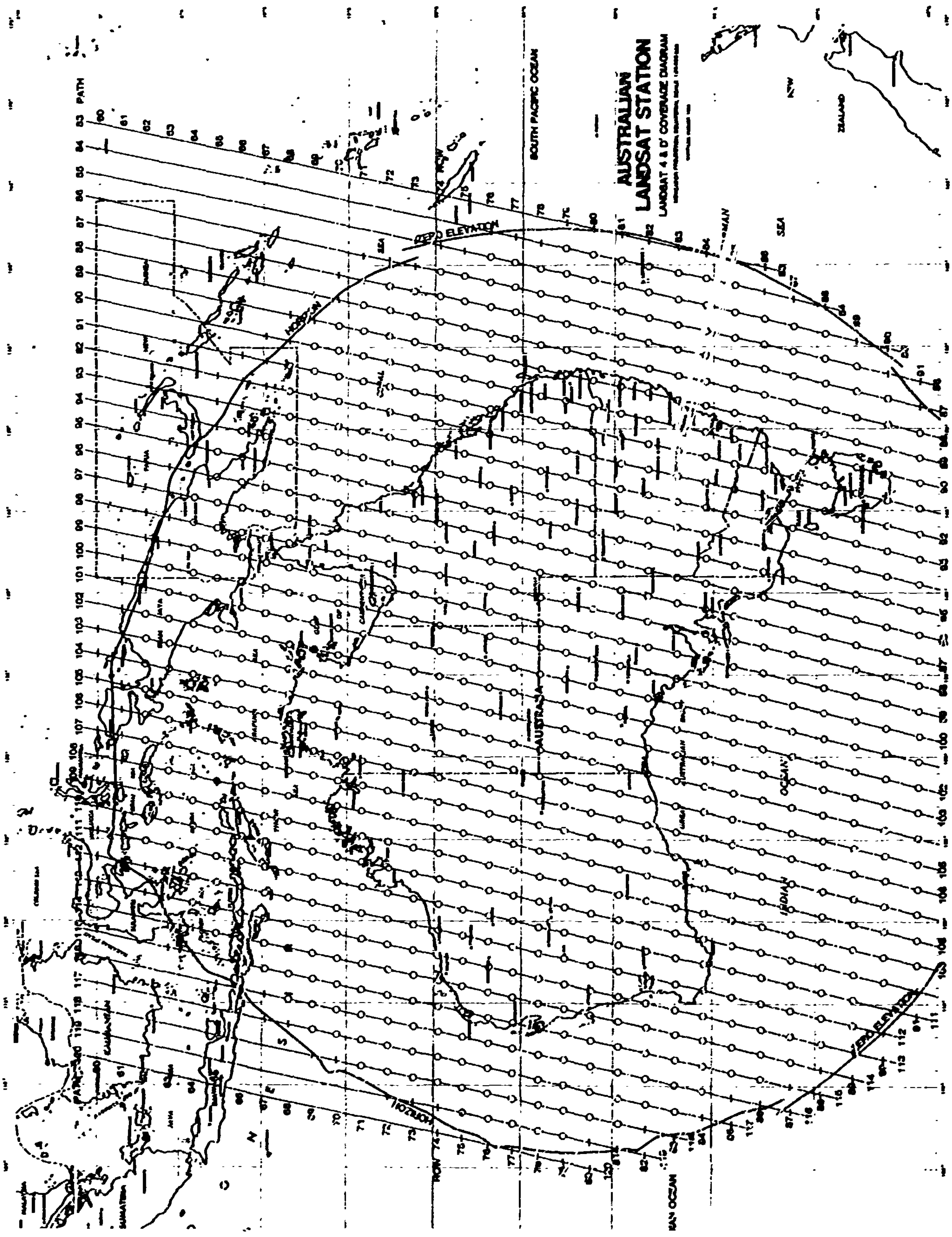


Figure 6.2 Worldwide Reference System - Australasian Coverage



Some information on other stations relevant to the region is also presented.

Australian Landsat Station

The Australian Landsat Station (ALS) consists of a data acquisition facility at Alice Springs in central Australia and a data processing facility in Canberra. The coverage circle includes all of the Australian land mass, most of Papua New Guinea and a substantial part of Indonesia. Currently the station can only receive the Landsat MSS data on S-band. A submission is being prepared for Government consideration for upgrading to Landsat Thematice Mapper (TM), SPOT and Advanced Very High Resolution Radiometer (AVHRR) capability. A decision on the upgrade is expected early in 1986.

Thailand Landsat Station

Receives Landsat MSS data only. Landsat MSS data that are recorded are processed into CCT (Computer Compatible Tape) or photographic images via a bulk processing system. These data are further reproduced and distributed to users both domestic and foreign. The Thai Government is considering upgrading the Thailand Landsat Station so that it can also receive and process SPOT data. The Thai Ground Receiving Station (GRS) covers 60% of Indonesia, 80% of the Philippines, the whole of Malaysia including Sabah, Kampuchea, Burma, Vietnam, Laos, Bangladesh, the eastern portion of India and the southern portion of China.

Indonesian Landsat Station

The Indonesian Earth Resources Satellite Ground Station in Pekayon, Jakarta, was officially inaugurated in November, 1984. The Station has the capability for direct reception of Landsat 4 and 5 MSS data with coverage of the major part of the Indonesian territory, Malaysia, and southern portions of Thailand and Vietnam. At present the upgrading of the system to receive TM (Thematic Mapper) is underway. SPOT data reception is also planned for. The processing facility of the ground station has the capability for bulk as well as precision processing to produce photographic data and CCTs. The technical status of the station is still in the trial stage of operation, hence no regular user services have been established at this time (December 1985).

Indian Landsat Station

The Indian Landsat Station in Hyderabad, India, is operated by the Indian National Remote Sensing Agency (NRSA). It receives both Landsat MSS and TM data which are processed to produce CCTs and other data products such as positive and negative transparencies as well as paper photo products. Aside from the whole of India, it coves the entire Bay of Bengal, Bangladesh, Burma, 50% of Thailand, 50% of the Malaysian Peninsula and the northern tip of Sumatra.

Bangladesh Landsat Station

Bangladesh has already set up a Landsat TM/SPOT ground station at Savar 30 miles from Dhaka. It has a 9 meter parabolic tracking antenna. The station is capable of receiving MSS and TM data from Landsat in HDDT (High Density Digital Tape) format. As the installation of the image processing system has not yet been completed, it is not possible at present to receive CCTs from the Bangladesh station. This processing system is expected to be installed by the end of 1985 and the station will be ready to receive TM data and SPOT data as soon as SPOT is launched. The ASEAN coverage possible from the Bangladesh station will cover the whole of Thailand, 75% of Peninsular Malaysia and 30% of Sumatra.

Japan

The Japanese station is operated by the Earth Observation Centre (EOC) which was established by the National Space Development Agency in 1979. The station can receive both Landsat 5 MSS and TM data. The EOC will be the responsible agency for the reception and processing of Marine Observation Satellite (MOS-1) data. The facilities for MOS-1 are now under development and will be installed at the EOC by March 1986.

New Zealand

New Zealand is working towards the installation of an earth resources satellite receiving station. The concept has been approved in principle by the Government, however final financial approval has not yet, October 1985, been given. The intention is that the station would receive data from a range of current and future satellite systems including SPOT, Landsat MSS, TM and ERS-1.

China

It is expected that the Chinese Landsat station will be completed in October 1985. The station is located in Beijing and will receive, process, archive and disseminate Landsat MSS and TM data and will be upgraded to receive SPOT data. With the present configuration the station will be able to process four TM scenes or two TM scenes and twenty MSS scenes per day.

This receiving facility will cover about 70% of the country. In order to cover all of China three ground stations would be required.

Pakistan

Pakistan's ground receiving station for satellite remote sensing data is being established near Islamabad. The station will be able to acquire and process Landsat MSS and TM, SPOT HRV and NOAA AVHRR data. The zone of coverage for Landsat 5 and SPOT will be a circle of approximately 2700 km radius. The station is expected to be commissioned before the end of 1986.

REMOTE SENSING FACILITIES

We have used the term "region" in a very broad sense in that we have included information on countries such as Pakistan and China. Within the whole West Pacific - ASEAN region there has been a great deal of development and generally a high degree of awareness of the applications of satellite data for a wide range of purposes.

China

In China there are about 180 organisations involved in research in the field of remote sensing. This represents about 300 researchers throughout the country. The National Remote Sensing Centre of China co-ordinates all remote sensing activities in China. The activities include both basic research and technological developments in many areas including ground spectrometers, multi band metric cameras, charged couple devices, microwave radiometers and airborne synthetic aperture radar (SAR). Several image processing systems have also been developed

Vietnam

The National Committee of Space Research and Applications has been established to co-ordinate all the remote sensing scientific applications in Vietnam. The remote sensing activities are carried out by many applications including the National Centre for Scientific Research (NCRS), Ministry of Geology, Forest Inventory and the Planning Institute. In NCRS emphasis is placed on basic research for technical and applied problems. The Institute of Physics in Hanoi and the Centre for Remote Sensing Techniques in Ho Chi Minh City are conducting research in the development and implementation of digital image processing systems. The majority of applications work is executed by the Centre for Studies of Natural Rescurces, Institute of Earth Science and the Institute of Marine Science.

New Zealand

There are several small groups in New Zealand that are directly involved in remote sensing. These include the Department of Geology at the University of Auckland, the Ministry of Works and Development Group at Palmerston North, the Department of Electrical and Electronic Engineering at the University of Canterbury, the Department of Lands and Survey, the Oceanographic Institute of the Department of Scientific and Industrial Research (DSIR) and the Division of Information Technology of DSIR.

The image processing group of the Division of Information Technology has developed a general purpose image processing system - EPIC, which is being marketed internationally. The primary use of EPIC is in resource mapping from multispectral satellite and aircraft data. It also has direct application in a diversity of other areas such as map production, image analysis, reproduction of electronic masks for printed circuit or silicon chip manufacture and forensic investigation. EPIC is installed on eight computer systems (all VAX or LSI) in New Zealand.

Papua New Guinea

The Department of Surveying and Land Studies at the Papua New Guinea University of Technology in Lae has a software package for the analysis of Landsat MSS data. This is installed on a Dec PDP 11/34. A software package for the analysis of digital data is also being developed on a BBC model B microcomputer.

Korea

The Remote Sensing Laboratory of the Korean Advanced Institute of Science and Technology is one of the principal centres for remote sensing in the Republic of Korea. The laboratory is equipped with KIPS (KAIST Image Processing System) which operates on an IBM 3032 and Cyber 170. There are also a number of other software packages running on IBM and Perkin Elmer minicomputers.

Japan

Full scale remote sensing activities by the National Space Development Agency of Japan (NASDA) began in January 1979 with the reception and processing of Landsat data at the Earth Observation Centre. Data from the centre is distributed to a wide variety of users including national and public research institutes of the Ministry of Agriculture, Forestry, Fisheries and Transport as well as universities, local government authorities and commercial organisations. A number of Japanese remote sensing systems have been developed including the LODIA (Low Cost Data Image Analyser) system by NEC Aeospace Systems.

Australia

In Australia a deliberate policy of not providing centralised analysis facilities has been pursued on the premise that they can and should be developed or implemented by those organisations responsible for resources management and utilisation. This policy has been largely successful.

There are now over 40 digital analysis systems in operation throughout the country. Some organisations have attached intelligent terminals and appropriate peripherals to existing mainframes. Some IBM PC based systems exist or are under development.

Information on the Australian Landsat Station and a summary of the Australian remote sensing capability is provided in Appendix 11.3.

IMAGE PROCESSING AND ANALYSIS SYSTEMS AVAILABLE IN THE ASEAN REGION

This section summarizes ASEAN facilities and institutions involved in remote sensing throughout the region. In addition to systems research, a wide range of project applications using remotely sensed data have been investigated and incorporated into the planning and management process. These include :

- Regional Land Use Assessment
- Land Use Changes (trends, rates)
- Detailed Land Use Inventory
- Land Suitability Assessment
- Forest Inventory
- Reforestation Planning and Monitoring
- Watershed Monitoring
- Crop Monitoring
- Water Resources Studies/Monitoring
- Coastal Zone Mapping Studies
- Water Pollution/Sedimentation Monitoring
- Marine Habitat/Communities Studies
- Estuarine Studies
- Geological Studies
- Volcanology
- Disaster Assessment
- Urban Studies

The following national agencies within each of the ASEAN countries have overall remote sensing applications programs.

Indonesia

- National Aeronautics and Space Research Institute (LAPAN)

- National Co-ordination Agency for Surveys & Mapping

Indonesia has a number of remote sensing data analysis facilities within various public and academic institutions. These include:

LAPAN
- COMTAL Processing System on 32-bit Perkin Elmer 3220 Mini Computer

.BAKOSURTANAL
- DIPIX Aries II System
- Bakosurtanal Image Analysis System (BIAS) on a DEC PDP 11/32 computer

GADJAH MADA UNIVERSITY - Center for Remote Sensing
- DIPIX LCT-11 Digital Analysis System on PDP 11

DEPARMENT OF PUBLIC WORKS
- IBM 3403 Digital Remote Sensing System

Malaysia

- Directorate of National Mapping

- National Remote Sensing Committee, Economic Planning Unit, Office of the Prime Minister

Data analysis facilities are currently being established in Malaysia. Details are not yet to hand.

Philippines

- Natural Resources Management Center

The Natural Resources Management Center has a G.E. IMAGE 100 Multispectral Analyzer system on a PDP 11/35 computer. The Bureau of Mines and Geosciences possesses a multispectral viewer/projector (I^2S)

Singapore

No information to hand at time of workshop as to which agency will have responsibility for the oversight of a national remote sensing program. The National University of Singapore Department of Physics has locally developed image processing software which runs on a 32-bit mainframe computer. It is understood that they are currently developing micro-based image processing software.

Thailand

- Thailand Remote Sensing Center (NRC)

The Thailand NRC Remote Sensing Center also co-ordinates remote sensing within the country. It operates the Thailand Landsat Station and has a COMTAL Image Processing System on a Perkin Elmer 3220 Mini Computer as well as a DIPIX Aries II system on a DEC PDP 11/34 Mini Computer.

The following agencies also possess remote sensing data analysis equipment:

- Royal Thai Air Force
  - Multispectral viewer/projector (I^2S)
- Land Development Department
  - Multispectral viewer/projector (I^2S)
- Asian Regional Remote Sensing Training Center
  - DIMAPS (Digital Image Manipulation and Processing System) on an IBM 3083 computer
  - DELTA DATA SYSTEMS ATLAS (Image processing and Geographic Information on a mainframe computer
  - ERDAS Image Processing and Geographic Information System on an IBM-XT micro computer
- Royal Survey Department
  - Density Slicer Image Analysis System ISI 130

Further information on the data products types and sources available in the ASEAN Region, together with a listing of Institutions currently conducting research into remote sensing data analysis, is presented in Appendix 12.3.

DIGITAL DATA ACQUISITION

The three stations of immediate importance to prospective users of digital remote sensing data in the ASEAN-Australasian Regions are the Australian Landsat Station, the Indonesian Landsat Station and the Thailand Landsat Station. At the time of writing no regular user services had been established at the Indonesian station. The ordering procedures described below therefore relate specifically to the Australian and Thailand facilities. The general procedure however should not differ greatly from any of the stations - principally, users will have to locate the image of interest and specify the type of corrections, enhancements and type of data (digital tape, transparency or positive photographic images).

When ordering Landsat imagery the user should outline :

A. the area of interest on a map, describing the latitudinal and longitudinal boundaries in degrees and minutes, or by specifying the path(s) and row(s) picture (or frame) centre(s) covering the area on the Landsat Worldwide Reference System Index Map [see Figures 6.1 (Thailand Station Coverage) and 6.2(Australian Station Coverage)];

B. the seasonal coverage and year of coverage required;

C. the maximum acceptable cloud cover; and,

D. the format and band required.

The best quality image available will then be selected and processed for sale. Alternatively it is possible to review the micro-fiche images recorded and select one on the basis of its apparent usefulness.

Figure 6.3 Sample Order Form - Landsat Standard Products Thailand Landsat Station

ORDER FORM

LANDSAT STANDARD PRODUCTS

REMOTE SENSING DIVISION

NATIONAL RESEARCH COUNCIL OF THAILAND

196 Phahonyothin Rd., Bangkhen, Bangkok 10900, Thailand

Tel 5790116, 5791370-9 Ext 401, Telex No. 82213

NAME.. DATE........................

ADDRESS... PHONE.......................

.... TELEX NO....................

COMPANY... YOUR REF. NO.................

SHIP TO...

PLEASE TYPE OR PRINT PLAINLY

Page...1...of.1....

PATH - ROW	DATE	PRODUCT CODE	PHOTOGRAPHY ONLY					CCT ONLY	QTY	UNIT PRICE	TOTAL PRICE
			MSS BANDS				NO. OF EACH				
			4	5	6	7					
125-48	080383	41							1	70.-	70.-
125-47	130382	41							1	70.-	70 -
125-48	130382	41							1	70.-	70 -
125-49	130382	41							1	70.-	70 -

TOTAL ABOVE	A 280.-
TOTAL FROM PREVIOUS SHEETS	B
TOTAL COST	C 280.-

STANDARD PRODUCTS TABLE

BLACK AND WHITE PRODUCTS		
FORMAT	SCALE	CODE
9in. Positive Film	1:1,000,000	11
9in. Negative Film	1:1,000,000	21
9in. Paper	1:1,000,000	31
20in. Paper	1:500,000	32
36in. Paper	1:250,000	33

COMPUTER COMPATIBLE TAPES (CCT)

MSS 4,5,6,7 BANDS in one tape ~~with ... print 1 set ...~~

TRACKS	b.p.i.	FORMAT	CODE
9	1600	BIL*	184-A

*CCRS or Telespazio Format

FALSE COLOR COMPOSITE PRODUCTS		
FORMAT	SCALE	CODE
9in. Positive Film	1:1,000,000	41
9in. Paper	1:1,000,000	61

Received
....../....../......

PAYMENT MUST ACCOMPANY ORDER

GOV ACCOUNT ☐

CASH ☐

CHEQUE, DRAFT, BILL OF EXCHANGE ☐

COMMENTS:...

....

FORM 1/1982 (May 1982)

Table 6.2 Ordering Instructions - Thailand Landsat Station

HOW TO ORDER STANDARD LANDSAT DATA

This form is used to order all standard Landsat data. Necessary order information can normally be extracted from a computer listing of available data or the LANDSAT DATA CATALOG issued by NRCT, THAILAND.

Please provide the following information in the indicated areas on the order form:

A. List your complete NAME, ADDRESS, and name of your COMPANY if applicable
B. If you desire to have the products mailed to an address other than yourself please complete the "SHIP TO" address.
C. List a PHONE NUMBER and TELEX NUMBER where you can be contacted during business hours.
D. Enter the complete PATH-ROW, DATE. This number can be transcribed directly from the COMPUTER LISTING or the LANDSAT DATA CATALOG.
E. Review the STANDARD PRODUCTS table on the front of the ORDER FORM and determine the type of product desired.
F. Enter the PRODUCT CODE of the type product being ordered from the STANDARD PRODUCTS table.
G. For ordering MSS photographs, check columns for bands you desire and also indicate the copies of each band in the NUMBER OF EACH column. Check the CCT box only if a digital tape is being ordered. In selecting the tape format make sure that you consider your equipment and usage. Please complete the QUANTITY column. Count the number of MSS bands checked multiply by the figure in the NUMBER OF EACH column and enter the result in the QUANTITY column.
H. Enter the UNIT PRICE of the type of product as refelected in the PRICE LIST LANDSAT STANDARD PRODUCTS.
I. Multiply the figure in the QUANTITY column by the UNIT PRICE and enter the result in the TOTAL PRICE column.
J. Repeat steps D through I for each product ordered.
K. TOTAL the costs of all the products ordered on this order form and enter the net result in BLOCK A (TOTAL ABOVE).
L. For a single order form, enter the Figure in BLOCK A in BLOCK C (TOTAL COST). If more than one order is required, on the last order form, enter the sum of the figures in BLOCK A in BLOCK B and then total BLOCK A and BLOCK B in BLOCK C (TOTAL COST).
M. Include type of payment (CHEQUE, DRAFT or GOV ACCOUNT) authorized by a banker having a local branch in Bangkok. Make all drafts, etc. payable to REMOTE SENSING DIVISION (NRCT). DO NOT SEND CASH in mail.
N. Mail ORDER FORM(S) and PRE-PAYMENT to REMOTE SENSING DIVISION, NATIONAL RESEARCH COUNCIL OF THAILAND (NRCT).

14-16 Oatley Court, Belconnen, A.C.T. 2617
P.O. Box 28,
Belconnen, A.C.T. 2616
Telephone: 51 5411, 52 4411
Telex: 61510 (LANSAT)

BULK PRODUCT ORDER FORM

Customer's Ref. Date

Consign to:

NAME:
COMPANY:
ADDRESS:

STATE: POSTCODE:
PHONE (BUS)
CONSIGN BY:

Invoice to:

Acct No.

NAME:
COMPANY:
ADDRESS:

STATE: POSTCODE:

PRODUCTION CONTROL						SPACE CRAFT	LOCATION			DATE D/M/Y	BAND(S)				CORRECTIONS	PROD CODE	PRTY	QTY	UNIT COST	LINE TOTAL COST
NO.	MASTER NO.	FORMAT	D	P	INVOICE		WRS PATH	WRS ROW	SUB-SCENE		B/W	COLOUR B	G	R						
1																				
2																				
3																				
4																				
5																				
6																				
7																				
8																				
9																				
10																				

Orders for Australian Landsat Station products are accepted subject to the Conditions of Sale printed on the reverse of this form.

SUB-TOTAL
FREIGHT
TOTAL

REMARKS

USAGE:

- ☐ Hydrology/Water Resources
- ☐ Land Use/Mapping
- ☐ Oceanography/Marine Resources
- ☐ Other
- ☐ Agriculture
- ☐ Environment
- ☐ Forestry ☐ Geography ☐ Education
- ☐ Geology/Exploration

DISTRIBUTION:
1. White—ALS Control
2. Yellow—ALS Digital
3. Pink—ALS Photo
4. Green—Customer

FOR OFFICE USE ONLY	TYPE ACCOUNT	ORDER NO
INVOICE/D.A.	CASH/DEPOSIT/CREDIT	
NO	REC NO	ACCEPTED
DATE		

MARCH 1984

Figure 6.4 Order Form - Australian Landsat Station

Table 6.3 Ordering Instructions Australian Landsat Station

AUSTRALIAN LANDSAT STATION

14-16 Oatley Court, Belconnen, A.C.T. 2617
P.O. Box 28, Belconnen, A.C.T. 2616
Telephone: 52 4411, 51 5411
Telex: 61510 (LANSAT)

PRODUCT AND PRICE LIST
AS AT 1 JANUARY 1984

A Master Generation Charge is applicable where ordered images have not previously been generated at the time of ordering, i.e. for which new Masters have to be created. The Microdata Catalogue which is published monthly, includes a listing of all scenes for which Masters exist. The published Catalogue is the reference which determines if a Master Generation Charge applies. The Master Generation Charge is not applicable to CCT's, QLP's and Chips.

Most ALS products will be dispatched by the normal mail or parcel post services provided by Australia Post. Large sub-scenes however will be dispatched by road freight. Customers requiring dispatch by **Air-mail** will be charged a percentage of the Priority 3 price as follows:

(a) Australia, Papua New Guinea and New Zealand—5%
(b) All other destinations—10%

Customers may, however, nominate any other method of dispatch, the cost of which will be added to the invoiced cost of the products.

Priority pricing provides for the processing of a Customer order, in sequence, before any orders of a lesser priority. Nominal dispatch times from acceptance of the order by ALS are:

Priority 1 . . . 2 working days at treble normal prices
Priority 2 . . . 5 working days at double normal prices

However, actual turnaround times should be discussed with ALS when placing the order.

CONDITIONS OF SALE

1. The Australian Landsat Station products are sold for the use of the purchaser and shall not be loaned, leased or copied without the express permission of, and only in accordance with terms and conditions if any agreed with, the Department of Resources and Energy.
2. No conditions or warranties, either express or implied, are given or offered for products sold by the Australian Landsat Station except as provided by law.
3. Prices are subject to variation without notice.
4. The ALS does not warrant the suitability for any purpose of Landsat data and will not be liable for any damage or injury brought about by the customer's use of the Landsat system.

7. IMAGE PROCESSING SYSTEM DESCRIPTION

MICRO-BRIAN: AN APPLICATIONS ORIENTED MICRO-COMPUTER BASED IMAGE PROCESSING SYSTEM

Kevin K. Mayo

CSIRO Division of Water and Land Resources
Canberra, A.C.T. Australia

MICRO-BRIAN: AN APPLICATIONS ORIENTED MICRO-COMPUTER BASED IMAGE PROCESSING SYSTEM

Kevin K. Mayo

INTRODUCTION

Micro-BRIAN is the image processing system used in the workshop exercise project. It is an inexpensive yet powerful and expandable implementation of the BRIAN (Barrier Reef Image ANalysis) system based on an IBM-PC XT, or AT or appropriately compatible microcomputer and the Vectrix Corporation Midas graphics board set.

Micro-BRIAN contains the features of a general mini-computer based image processing system developed at the CSIRO Division of Water and Land Resources, Canberra, Australia. This system has a history of proven applications in image processing including:

- . remote sensing based shallow water mapping,
- . coastal zone inventory,
- . water colour mapping,
- . mangrove mapping and sediment load analysis,
- . baseline inventory of large wilderness areas,
- . monitoring successional change and fire effects,
- . forest inventory using DEM data,
- . continental scale mapping using environmental satellite data,
- . crop yield monitoring, and
- . land erosion mapping.

Micro-BRIAN provides access to such applications in a microcomputer environment.

In the applications area of shallow water and reef mapping more than $21 million and 10 years of effort have been saved in mapping the Great Barrier Reef of Australia using Landsat data and the BRIAN system. This was achieved during a collaborative project between CSIRO, the Great Barrier Reef Marine Park Authority and the Australian Survey Office. The BRIAN and micro-BRIAN software systems are the only systems incorporating all of the algorithms developed for this project. BRIAN therefore provides a system with direct applicability to shallow water mapping and reef survey in many parts of the world.

Micro-BRIAN has also been been specifically developed to enable general users who may not intend to specialise in image processing to undertake analysis of remotely sensed or other raster coded data - with an emphasis on applications in shallow water, reef and land cover mapping. Its software is menu based, fully internally documented and user friendly and it is accompanied by a set of applications based external documentation. It represents a significant move to distribute image processing away from large centralized computer systems into the offices of the end users through its use either as an intelligent workstation or a stand alone system.

Micro-BRIAN's hardware configuration has been chosen to allow the user to take advantage of the full range of general software that are offered by the current "standards" of IBM-PC XT and AT and PC DOS. The system in no way limits access to word processing, data base management, communications, general statistical or financial arrangement packages. In addition, its power as an image processing system arises from the combination of this technology with the many features of the Vectrix Corporation Midas board. The PC/Vectrix combination also offers the user a wide range of commercial graphics software including solid modelling and computer aided design (CAD).

THE BRIAN SYSTEM

The BRIAN (Barrier Reef Image ANalysis) system is an approach to image interpretation established as mini and micro computer based interactive programs by the CSIRO Division of Water and Land Resources. The methodology was developed in response to a specific need for very large area mapping by an operational planning and management agency. The project was entitled "Remote Sensing by Landsat as an aid to Management of the Great Barrier Reef". It was a collaborative project between the CSIRO, the Australian Survey Office (ASO), and the Great Barrier Reef Marine Park Authority (GBRMPA), and was financially supported by the Australian Marine Sciences and Technologies Advisory Council (AMSTAC) and GBRMPA.

The success of the shallow water mapping applications of BRIAN is well recognised in Australia and internationally. The ASO has used the BRIAN software to operationally map the whole of the Great Barrier Reef of Australia and have demonstrated its wider applicability during a successful pilot project in Papua New Guinea. Interest in the methods and the system have been shown by government authorities in Indonesia, the Philippines, Malaysia, Thailand, the Maldives, Fiji and the Solomon Islands. The micro-BRIAN system has been specifically developed to enable transfer of this technology to a wide range of users.

The BRIAN system has, however, also had extensive applications in other areas of remote sensing and processing of raster coded data. Within BRIAN are sufficient algorithms and image processing capability to solve a range of applications problems in areas of land cover mapping and large area inventory and monitoring, crop yield and condition mapping and, in cooperation with the CSIRO Division of Wildlife and Rangelands Research, erosion mapping and prediction. The extensive scientific literature arising from BRIAN applications is readily available and reference lists and copies may be obtained from the CSIRO.

The methods have not only been applied to Landsat data. Data from two of the large area environmental satellites NOAA 7 and 8 (AVHRR scanning radiometer) and NIMBUS 7 (the CZCS scanning radiometer) have been used for oceanographic and very large (continental scale) area mapping exercises. Geometric rectification of a variety of satellites is available for this purpose. Data from airborne scanners and digitized photography may be processed in a similar way and in an increasing number of projects digital elevation data and thematic data (such as soil types, processed GIS data in gridded or polygonal format and management or cadastral zones) have been integrated with remotely sensed data as raster channels.

To a new user, the micro-BRIAN system which implements these opportunities is interactive and menu-driven. The modules listed below however, are also accessible as direct command calls for the experienced user. The base level utilities will be made accessible in the near future as a programmer's toolkit. The micro-BRIAN system has extensive documentation and a HELP facility. Through the development of this system, its internal documentation and the BRIAN Handbook and Recipe Book series, the BRIAN methodology is made accessible to a wide range of CSIRO, Australian and international users.

micro-BRIAN OPTIONS

A number of hardware and software options are planned for the micro-BRIAN system by co-operative arrangement between CSIRO and Microprocessor Applications (MPA). It is intended that the system will be officially released within Australia and in the Indo-Pacific and South-East Asian Regions with three configuration options.

There are three hardware configuration options proposed for end-users of the micro-BRIAN system. The hardware would be marketed with effective product quality control, after sales assistance and a complete repair service.

Underlying all three options are a Wavemate 286 motherboard and the Vectrix Corporation Midas board set. The Wavemate 286 board with the optional 80287 floating point co-processor provides greater power for the XT than would be obtained by purchase of an AT and will provide up to seven times improvement in image processing speed.

The Midas board set is a powerful graphics system with full DMA transfer and extensive hardware graphics options. This inexpensive but powerful board has provided the means for generating the micro-BRIAN system in a way which serves user needs for distributed image processing without sacrificing the advantages of interactive image processing.

The three configurations proposed are:

The micro-BRIAN software and manuals (including the BRIAN Handbook and the BRIAN Recipe Books), serial port communications software, plus -

1. A Vectrix VX/PC board set, an RGB colour monitor, inkjet plotter, and a Wavemate 286 board for use with existing IBM-PC XT's or without the Wavemate board for the IBM-PC AT; or,

2. A standard IBM-PC XT with printer and inkjet plotter fitted with the Wavemate 286 board, a Vectrix VX/PC board set and RGB monitor and appropriate commercial communications software or an IBM-PC AT without the 286 board; or,

3. An MPA manufactured computer based on the Wavemate 286 board and including the Vectrix VX/PC board set, a 20 Mbyte hard disk, printer, inkjet plotter and an RGB color monitor. This configuration would have an expansion capability for options such as extra hard disc units, a cartridge tape drive, SKY array processor (based on the TI320 signal processing chip), optical disk, joystick and full communications interface.

The configuration options are shown in figure 7.1. Option 3 would provide the best overall performance.

Final costs are not fixed but will be about $A20-25,000 for option 1 and 2, and around $A33,000 for option 3 as at December 1985. The software is fully compatible with all the options except for some of the expansions mentioned for option 3. These will be upwardly compatible however and be available as software upgrades rather than a new software system.

The option of accepting the reduced performance of an existing standard IBM-PC XT to save on the cost of the high performance Wavemate 286 board will also be provided. The question of IBM-PC clones and compatibles will also be addressed by the marketing company.

The possibility to acquire the micro-BRIAN software by itself as source code for user implementation on hardware other than the Vectrix exists. In this case the marketing company would provide only minimal support and it is not anticipated that CSIRO would provide support for user software problems unless it has direct value to its research goals or involves a bug in the primary source code.

Data input to the system is currently via floppy disks or serial line. Considerable quantities of data have been transferred to floppy disk recently and there are currently international moves to standardize this form of data distribution among the Landsat receiving stations. The Australian Landsat Station, in particular, has indicated that it will be releasing Landsat data on floppy disk in 1986.

Communications software will be supplied with micro-BRIAN to communicate subsets between a mainframe or other PC's and the micro-BRIAN PC by serial line. This will enable, in particular, subsets of data to be transferred to floppy disk from the main frame via the PC. However, faster and more direct communications with selected main-frames (VAX, HP) are being developed which will create a complete workstation environment for the micro-BRIAN system. Options for the direct input of vector and raster data through digitizing and video scanning are being planned.

Micro-Brian is to be accompanied by a set of applications based manuals or "Recipe Books" which present the means for carrying out all the applications listed below and include a set of demonstration images on floppy disks matching the examples used in the "recipe book" series. These will include:

. basic image processing
. shallow water mapping
. land cover mapping
. land cover monitoring
. image rectification and data integration
. crop condition mapping
. land erosion mapping.

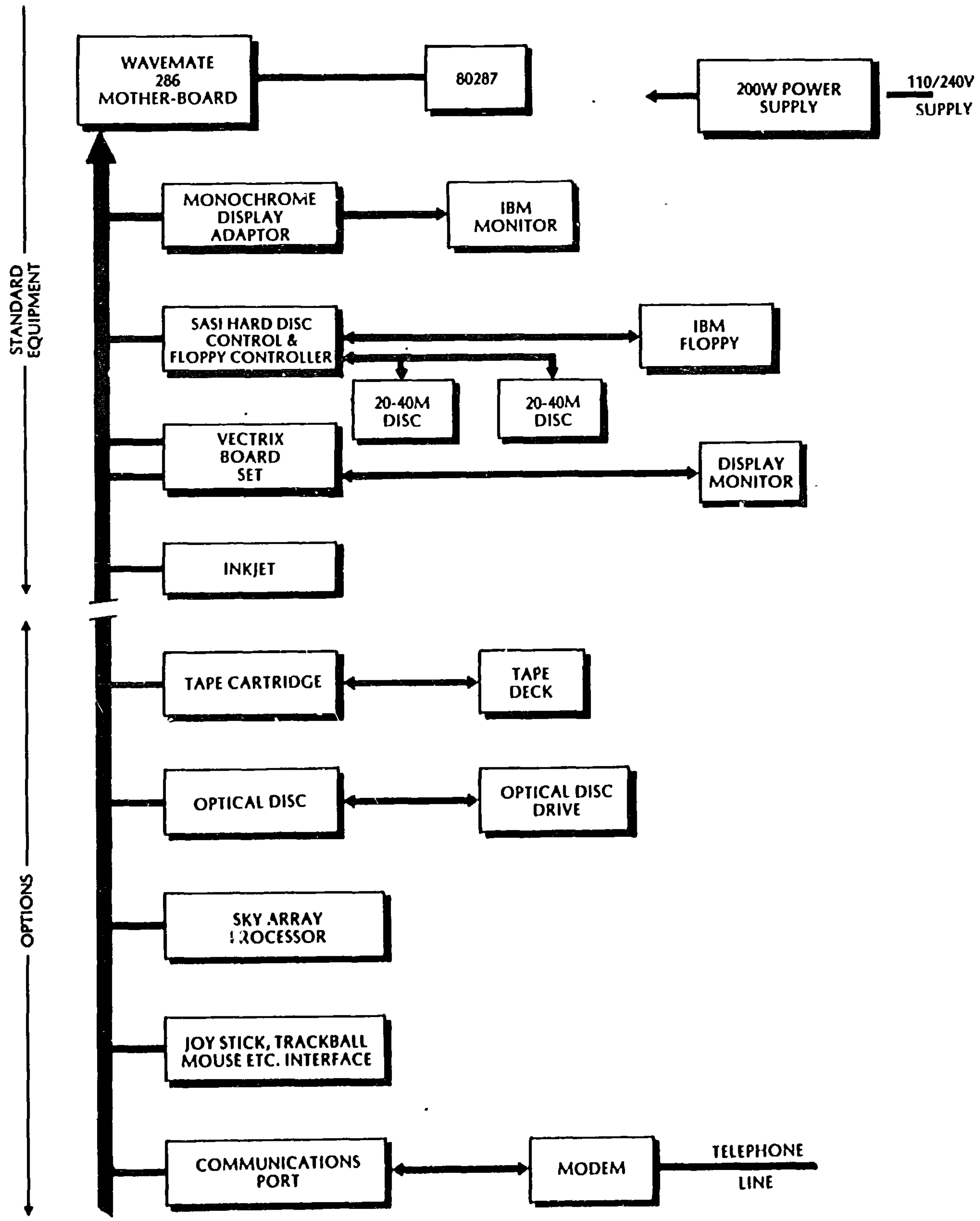


Figure 7.1 micro-BRIAN Configuration Options

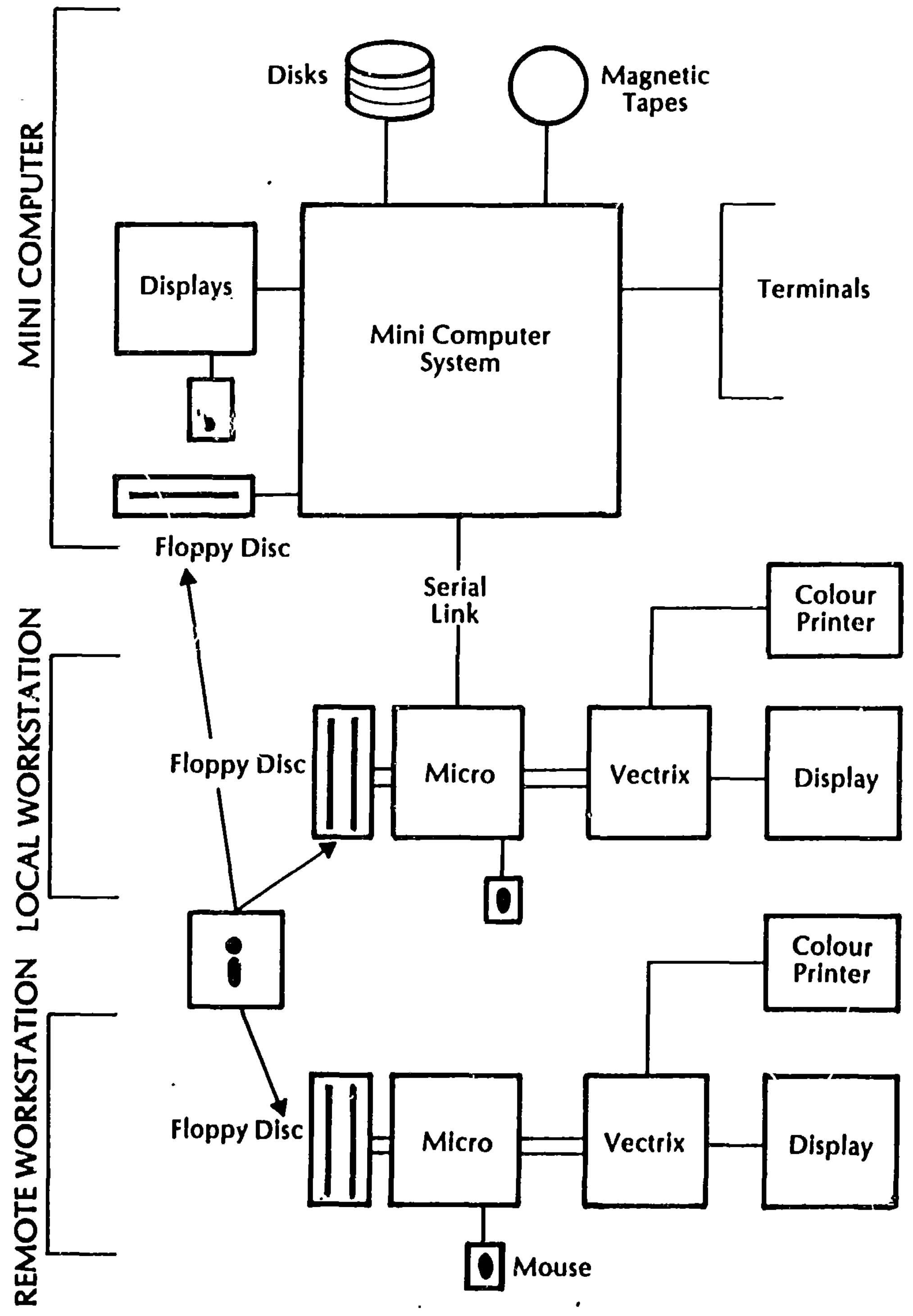


Figure 7.2 Conceptual Operation - Micro-computer Workstations

ANNEX 7.1 - ENQUIRIES

Enquiries about the micro-BRIAN system may be made to:

Hal Schuster
Microprocessor Applications Pty Ltd
Melbourne Office
48 Rutland Road
Box Hill, Victoria, 3128
Australia.

Phone - National (03) 890 0277
International + 61 3 890 0277

TELEX AA 31187

or to -

Mario Vecchio
Microprocessor Applications Pty Ltd
Sydney Office
Suite 2
156 Military Road
Nuetral Bay, NSW, 2089
Australia.

Phone - National (02) 908 3666
International + 61 2 908 3666

TELEX - AA 31187

or to -

Dr. David L. B. Jupp
CSIRO (Australia)
Division of Water and Land Resources
P.O. Box 1666,
Canberra, A.C.T., 2601
Australia.

Phone - National (062) 46 5477
International + 61 62 46 5477

TELEX AA 62377

ANNEX 7.2 - micro-BRIAN SOFTWARE OVERVIEW

Micro-BRIAN is organized into four levels, accessed througha structured series of menus. The top two levels of menu are organizational and contain considerable documentation and user helps.

The levels are -

- the access menu (mBRIAN)
- the work areas
- the program set, and
- the utility libraries.

The main menu is accessed on entry to micro-BRIAN (by running mBRIAN) and lists a set of 15 work areas which collect together the following types of image processing tasks:

1. mBRSUB - manage image files
2. mBREDT - edit image menu files, Ground Control Point (GCP) files and transformation files
3. mBROUT - output image files to Vectrix display or Tektronix ink jet plotter
4. mBRTRN - perform selected transformations on images stored on hard disk
5. mBRDIG - image spectral and spatial digitizing routines
6. mBARRY - image rectifications and registration modelling routines
7. mBRRES - image resampling and blocking routines
8. mBRCLS - image feature classification statistical analysis and labelling routines
9. mBRAD - analyse image labelling by sampling and cross tabulation
10. mBRMIA - multiple (eg multidate) image analysis routines
11. mBRWAT - analyse water depth, water colour and chromaticity (suspended sediment)
12. mBRSTS - compute spatial statistics for images
13. mALICE - analyse eroded surfaces using spatial modelling
14. mBRUTE - operating system interface to allow directory list, delete, reformatting and restore of image and ancillary files
15. mUSER - user interface to micro-BRIAN system

Each of these work areas has a menu of options comprising choices from the main level of micro-BRIAN programs. Help is available for each option at this level and communication of current image processing parameters is maintained through a standard file called SAM.TXT.

The mUSER option and the SAM.TXT communication file provide a user with the means to link his and other software packages with the micro-BRIAN system without rebuilding.

A brief description of the options available at the second level of menu is as follows:

1. mBRSUB Program Options

   - mSBSET - subset an image from image disk file
   - mSEW - join subsets into a large image
   - mBLOCK - block pixels to form small scale image

2. mBREDT Program Options

   - mMENGN - generate and edit image menu files
   - mGCPGN - generate and edit GCP files
   - mTRNGN - generate and edit transformation files

3. mBROUT Program Options

   - mJLAT - display images on Vectrix as colour or gray scale images and interface with Vectrix hardware features (zoom and colour lookup table)
   - mIJET - write ink jet plot file from an image file containing either raw, enhanced or theme overlayed data

4. mBRTRN Program Options

   - mSMOOO - smooth or despike selected channels of an image using mean or median filters - thresholding and user supplied filters optional
   - mTEXT - compute and write a texture (or local data variation) channel into an image
   - mEXPOS - compute and write an exposure channel into an image using weather direction parameters and an estimate of shallow water topographic aspect (usually done after pre-filtering for water depth mapping
   - mFRITE - rewrite image using user specified linear stretch and gamma stretch
   - mIMERR - compute and write predictive error channel into image
   - mRATIO - compute and write selected ratio channels into image
   - mSSCTR - write suspended sediment concentration channel into image
   - mGRNTR - compute greeness index as defined by Kauth and Thomas
   - mAFFTR - compute linear (affine) transformation
   - mBLOCK - combine pixels to form blocked pixel in new image
   - mFILLA - fill digitized pixels using local

neighborhood data - useful for eroding or dilating data sets

mPCA - compute transformed or rotated back Principal Component transformed image

5. mBRDIG Program Options

- mSPDIG - separate an image into one or two images on the basis of spectral themes
- mPASTE - join two images together after spectral digitizing with flexible choice of data
- mDIGIT - manually digitize area(s) on screen image for inclusion or exclusion in image analyses
- mPREDG - convert digitizer image coordinates to continuous string of image coordinates and edit
- mDIGLN - merge digitized string (polygon) data with images
- mDIGVL - digitize single channel of image and assign set value to digitized area

6. mBARRY Program Options

- mCNTRL - determine image coordinates of cursor defined GCP's
- mNOMNL - transform GCP file into nominal satellite or map coordinates
- mSIEVE - detect outlier GCP's from among control point set
- mMODEL - fit polynomial registration model (using affine, bilinear or quadratic fit) to (transformed) GCP's
- mGCPGN - generate and edit GCP files
- mTRNGN - generate and edit TRN files
- mCNVRT - apply nomminal and polynomial transformations to GCP's
- mIMERR - compute and write predictive error channel in image

7. mBRRES Program Options

- mRESMP - resample an image to match another image or map using nearest neigbour or bilinear interpolation
- mBLOCK - combine pixels to form blocked pixel in new image
- mLNRES - produce image which is resampled along scan lines to remove main satellite induced distortions

8. mBRCLS Program Options

- mTRAIN - locate and analyse training sets on image using Vectrix cursor
- mCPLOT - pairwise crossplots of bands
- mOVRLY - paint themes or classes for spectral /spatial editing and final map

production

- mTHEME - generate statistics for a set of themes (used for auto-seeding)
- mCLASS - classify an image into feature classes and generate mean and residual images
- mSPTRN - transfer feature classes from one image to another using classified image (used for migration of means)
- mCANVA - canonical variates analysis based on within and between group variance from mCLASS
- mPLMN - crossplot spectral class means (developed in mTRAIN as seeds or mCLASS as class means) and additional transformed channels as required
- mTAXON - group spectral classes into larger groups using standard numerical taxonomic measures
- mSUPER - create labelled classification channels for images

9. mBRAD Program Options

- mSAMPL - randomly sample a classification (produced by mCLASS) and output samples file
- mLABEL - interactively label sample (produced by mSAMPL) and output labels file
- mCTAB - cross tabulate labels (produced by mLABEL) with the spectral classes to form a resource matrix
- mEXTAB - cross tabulate two label files produced for the same sample file by different interpreters
- mMTAB - general resource matrix manipulation
- mESV - analyse resource matrix for row/column association
- mGEOPR - locate set of geographic coordinates in image and get local statistics

10. mBRMIA Program Options

- mRESMP - resample an image to match another image or map using nearest neighbour or bilinear interpolation
- mSPTRN - transfer feature classes from one image to another using classified image (may be modified image or resampled image)
- mDIFIM - compute difference image from two (registered) images
- mSEW - join two images together
- mMULTI - combine channels from different images to form a new image
- mPASTE - join two images together after spectral digitizing with flexible choice of data

11. mBRWAT Program Options

- mWDPTH - write water depth data into band 7 of image based on digital data tapes from Australian Survey Office

- . mRATIO - write Landsat water colour index (ratio of bands 5 and 4) into image
- . mEXPFT - fit exponential model to data
- . mCROMA - chromaticity analysis (Alfoldi method)
- . mSSCTR - write suspended sediment concentration channel into image

12. mBRSTS Program Options

- . mVARGM - compute along line image variograms and covariograms
- . mSPSTA - compute spatial statistics (local variance) used in combination with mBLOCK
- . mBLOCK - combine pixels to form blocked pixel in new image
- . mTHEME - generate statistics for a set of themes
- . mCPLOT - pair wise crossplots of bands

13. mALICE Program Options

- . mAUTOS - spatial auto correlation using fast fourier transform
- . mESTPH - estimation of parameters in simultaneous autoregressive image models
- . mERGEN - soil erosion transform (parallelogram data space)
- . mDRGEN - soil erosion forecasting using texture generation and inverse filtering algorithms
- . mLTXT - texture analysis using local pattern masking

At the fourth and lowest level are the Library routines which are not usually directly accessible to the user from the micro-BRIAN system. However, documentation for a programmers utility which will enable users to develop micro-BRIAN programs based on the lowest level utilities is to be developed.

The basic program toolkit libraries are organized as follows :

LIBRARIES

- . mFILLB - general file and image utilities
- . mGENLB - general IO routines
- . mMTHLB - maths routines
- . mGRFLB - graphics/plotting routines
- . mSRTLB - sorting min/max routines
- . mLUTLB - Lookup Table routines
- . mMATLB - matrix manipulation routines
- . mCLSLB - classification routines
- . mSMDLB - satellite model routines
- . mGEOLB - geographical routines

- mGCPLB - GCP file and TRN file routines
- mNLSLB - linear and non-linear least squares modelling routines
- mVECLB - Midas board utilities
- mBLKLB - COMMON BLOCK directory

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8. THE WORKSHOP EXERCISE

8. THE WORKSHOP EXERCISE - IMAGE ANALYSIS OF JOHN BREWER REEF, GREAT BARRIER REEF, AUSTRALIA

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8. THE WORKSHOP EXERCISE : IMAGE ANALYSIS OF JOHN BREWER REEF, GREAT BARRIER REEF, AUSTRALIA

Richard A. Kenchington

INTRODUCTION

The objective of the mini project was to give participants a brief exposure to the use of Landsat imagery in relation to a local reef for which it was possible to gain ground truth experience.

The workshop participants were divided into smaller groups. Each team was asked to simulate a reef interpretation exercise using digital remote sensing data. The nominal objective of the exercise was the generation of resource information in a form suitable for inclusion in a planning data base.

The reef selected was John Brewer Reef which is close to Townsville and which is the site of a regular tourist operation providing access on a high speed catamaran vessel. John Brewer reef has been a study site for the Australian Institute of Marine Science and James Cook University for a number of years and has, in particular, been studied in the context of the impact of Crown of Thorns starfish (Acanthaster planci) and the development of coral communities following predation by the starfish. Further, John Brewer has been the subject of detailed physical survey by the Australian Survey Office with the consequent availability of detailed bathymetric ground truth data.

PROJECT OUTLINE

The workshop exercise was conducted in accordance with the following outline :

1. Briefing on the project target.

    - a briefing on the biophysical conditions at the reef by persons familiar with the area.

2. Analysis of Project Information Needs -

    - the objective of the exercise was to provide planning related information about the reef in a form suitable for inclusion in a planning data base. Each team was directed to follow the "key steps in project planning" outline to assist in defining their respective data needs.

3. Field Trip to John Brewer Reef.

4. Field Trip Review - a round table session with participants and the briefing team to discuss results and anomalies.

5. Image Analysis Sessions on MicroBRIAN.

   - Each team had sessions scheduled on the micro-BRIAN units to become familiar with enhancement, depth-of-penetration, labelling and final classification routines.

RESOURCE PERSONS

Presentors of materials to the workshop were enlisted as resource persons to assist the teams throughout the analysis sessions. Both the technical as well as the procedural aspects of image analysis were provided for.

BRIEFING

John Brewer Reef

The initial phase of the exercise commenced with a general briefing on the physical structure and biological community zonation of John Brewer Reef. The briefing was conducted by showing a series of colour slides to illustrate conditions at a number of locations ranging from the steepest face of the reef exposed to the prevailing wind, to the most protected locations in the back reef areas.

Remote Sensing Data

Participants received an introductory briefing on the micro-BRIAN package and a preliminary "hands-on" session on the computer system for familiarization. The detailed description of the system is presented elsewhere (Mayo, this report). Participants were then able to work with the package to develop preliminary classifications of a, previously prepared, image subset which contained John Brewer Reef. It was suggested that participants concentrate on areas of the western lagoon.

In addition to the digital data provided on "floppy" discs and used on the computer, participants received prepared hardcopy versions of idealized final products - the raw data rectified image, depth of penetration, indicative topography and exposure, and a basic classification. The latter consisted of two versions, one a desk labelled preliminary classification of features visible in the various band zones (4 classes in the Band 4 Zone - 5 to 15 m; 9 classes in the Band 5 Zone - 0.5 to 5 m; 4 classes in the Band 4 Zone - 0 to 0.5 m), the other an un-labelled product for use by participants in the field if desired. The preliminary classification was developed without any ground truth or other data input.

Participants also received a photo-copied package of computer print-out material. The package contained statistical information and other data needed for preliminary data analysis prior to the computer labelling and reef interpretation exercise. The use of the material was explained during the course of the exercise.

FIELD VISIT

For the field phase of the exercise participants travelled to the reef on the high speed catamaran "Reeflink". A 40 minute session in the coral viewing vessel "Yellow Submarine", provided a view of back reef lagoonal "bommies" or coral head patch reeflets, and sand. Although it did not prove possible, in the available time, to relate the communities observed to precise geographic locations it was particularly valuable to be able to discuss and describe the communities and their differing reflective properties.

Participants also had the opportunity to visit the back reef "bommie" field to the south west corner of the reef. This provided an opportunity to see a wider range of reef community types and to take spectographic measurements at a number of sites with a reasonable, but not precise correlation of field location and position on the Landsat image.

Finally participants had the opportunity to snorkel around a reef patch close to the tourist pontoon.

A consequence of using available tourist transport for the field exercise was that the time at the reef site was limited to four hours. Operations were further hampered by the failure of an outboard motor although this was compensated by the loan of an aluminium boat by the tourist operator. Whilst it was not possible in the time to carry out precise ground truth correlation the field trip was seen by participants to provide important background to the interpretation of the image of John Brewer Reef.

ANALYSIS PROCEDURE

Each team was asked to ensure they became familiar with the two important facets of digital image analysis:

- The interactive processes on the computer in selecting training samples, using the values of the training sets as seeds in the classification process to classify the image into spectral classes and to label the resulting classes into a final product.

- Use of the statistical material, minimum spanning trees and/or dendograms of the computer generated spectral classes, as a means to identify the similarities and differences in the classes prior to interpretation and labelling;

Participants were also taken through the processes used to generate the depth of penetration and exposure products

RESULTS

As might have been expected the final results of each group's work bore little resemblance to each of the others. Some elected to go for simple, very broad classes. Others attempted a fine detailed classification. In any event, the final result was unimportant - the objective being to give participants an appreciation of the various facets and assumptions that go into the processing, analysis and interpretation of digital data and to give them a degree of confidence in the process and the potential of the end products.

A number of improvements could be incorporated in any future workshop exercises. These include :

- provision of detailed transect data of ground surveys of the workshop project target area

- consideration of the provision of a larger, more diverse transect as the exercise project target area covering, for instance, a reef to shallow water through to a mangrove system to represent all the targets of interest

- specialisation of exercises to suit participants' specific interests rather than being restricted to only one of a number of coastal shelf system components

  this would have the advantage of giving all participants the opportunity to learn and appreciate the use, the advantages and the difficulties of digital remote sensing data in a variety of environmental systems.

9. FUTURE APPLICATIONS *

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* Adapted from Jupp, D.L.B. The application and potential of Remote Sensing in the Great Barrier Reef Region. Research Report, Great Barrier Reef Marine Park Authority, Townsville. (in press).

9. FUTURE APPLICATIONS

David L.B. Jupp

INTRODUCTION

Immediate future developments in remote sensing should enhance the current capability for acquiring marine and coastal data. The most immediate improvements are likely to be in the area of the spatial and spectral resolution of optical scanning devices. The further development of active, laser and radar, scanning devices will improve the study of the finer scale dynamic phenomena of coastal and continental shelf systems. It is also true that much can yet be extracted from existing data sources, including the humble aerial photograph. Here we briefly review the prospects for the immediate future.

DATA ACQUISITION POTENTIAL

In the future, the flow of data from satellites and aircraft scanners and sensors mounted on ships and buoys will increase dramatically.

Meteorological Satellites

The fundamental role of the ocean temperature and the ocean climate in weather prediction and monitoring means that global coverage by meteorological satellites will continue and grow. This provides an opportunity for continental shelf and coral reef seas studies as satellites such as the NOAA series with the AVHRR sensors provide extremely valuable oceanographic data.

Future plans indicate that an AVHRR with a smaller pixel size (possible as low as 100 metres or less than 400 metres) may be developed which would provide data of great value for research into dynamic inter-reef flows.

High Resolution Satellite Data

Satellites carrying higher resolution instruments like Landsat-5 with the TM (Thematic Mapper) instrument (which has a 30 metre spatial resolution and 7 bands) and the French SPOT satellite (20 metre spatial resolution for 3 bands and 10 metre for the single panchromatic band) offer the prospect of significant data opportunities to help map and survey coastal seas and reefs. However, their spectral and time resolutions and extents are generally not ideal for fine scale dynamic water property mapping.

It is expected that within 10 years there will be a large number of high resolution optical scanning satellites in orbit, including the commercial successor to the NASA Landsat experiment. These satellites will almost certainly address the needs of the oceanic marketplace. For a discussion of future plans in this area see ALCORSS (1982).

Multispectral Scanners

Multispectral scanners and imaging spectrometers on aircraft platforms sensing natural radiation provide a new dimension in flexible assessment of the properties of coastal waters in and around reefs. Although they are not new in remote sensing of water properties (Clarke et al., 1970; Arvesen et al., 1973; Hovis and Lueng, 1977), instrumentation and recording technology have developed considerably in recent years. (cf Hoge and Swift, 1981a; Edel et al., 982).

It is important to note that despite advances in data analysis such as the development of algorithms for chlorophyll and suspended sediment mapping from passive multispectral data (Zwick et al., 1981), the actual limits and abilities of multispectal data to resolve significant water parameters are not fully established. Any actual data collection by multispectral instruments over Great Barrier Reef (GBR) waters, for instance, needs to be made initially in a research framework, be based on careful planning and utilize in-water measurements (cf Anderson, 1976; Smith et al., 1979).

Scanner data is becoming more common as an (expensive) option offered by commercial groups. As sensors and data logging systems develop and more companies provide scanners these costs can only decrease.

Active Scanners

Active scanners carried on aircraft platforms can map at spatial scales relevant to reef lagoon and estuary dynamics and local variations in phytoplankton populations. The laser fluorosensor (Campbell and Thomas, 1981) is among the most discriminating of the instruments available for deployment and such instruments are becoming available for research or commercial applications in the USA and Canada (EPA, 1981).

As with any aircraft flown instruments, the time resolution is poor and they lack the ability to make routine biological measurements with depth. Therefore, collateral data from moored buoys or ships are needed to fully utilize the remotely sensed data. The use of fluorescence to construct a biological analogue of the current meter, and provide such collateral data, is described by Whitledge and Wirick (1982).

Camera Systems

The presence of camera systems as opportunities should not be neglected. Camera systems lead to film products which have good rectification and which are easily accommodated within existing survey systems.

A camera system is a basic complement to any aircraft based remote sensing system. It provides a record of the flight and data collection and may range from a hand held 35mm camera to a battery of fixed and free cameras with a variety of formats, films and filters.

Modern filters and films can provide narrow band data and multispectral cameras may be used to separate the bands during flight. Even at spacecraft altitudes, the high resolution, large format metric camera deployed on a space shuttle by NOAA-NOS provides a data opportunity of great value for marine mapping and inventory.

The main limitation to film is that the data is not radiometric, cannot be directly analysed by computer and its dynamic range (maximum measurable contrast) is poor. In water this problem is significant although film digitizing, in which the photography is converted into digital form, with subsequent computer enhancement may improve matters (Munday and Zubkoff, 1981). The effectiveness of film digitizing and computer enhancement in this context should be researched as a significant means of providing future remotely sensed data for coastal waters and marine areas.

Radars

In the next 10 years there will be a dramatic increase in the number of radars flown by satellites. Following the (brief) success of SEASAT, radars (mainly Synthetic Aperture Radar or SAR) will be flown on the Japanese Marine Observation Satellite (MOS-1), the Canadian RADARSAT and the European Space Agency's Earth Resources Satellite (ERS-1).

The USA plans to launch a satellite with an accurate altimeter called TOPEX and this, as well as those listed above, will provide data of great value for oceanographic and reef current studies.

The main impetus for operational radar sensors on satellite platforms has been the benefits of their use for mapping and monitoring sea ice. Oceanography generally, however, will benefit from their data.

DISCUSSION

The types of instruments available for deployment are listed and described in Table 3.1 (this report). These instruments currently have the capability of mapping water and sediment movements, primary productivity and even bioluminescence. In addition to providing a basic research complement this set of instruments provides possibly the most realistic set of tools for monitoring and mapping pollutants - such as oil-spills.

Within tropical continental shelf and reef systems the question is to assess how the planned combinations of remote sensing platforms and sensors apply for research, planning and management. Where significant gaps exist the task is to assess how the needs of coastal management might promote research into specific combinations of platforms and sensors.

Table 9.1 lists the available data platforms and sensors together with potential sensors by scale of application. The abbreviations used for the sensors are from Table 3.1.

At scales covering entire regions such as the Great Barrier Reef Region, the Papua New Guinea coastal shelf or an archipelago of islands such as the Maldives which may be found in similar waters, the NIMBUS-7 CZCS, the NOAA AVHRR and Landsat MSS data provide a significant data set for general definition of biological productivity and the movement of water masses. Taken together, the variations in the pattern of suspended sediment, phytoplankton and sea surface temperature over space and time provide indirect measurements of ocean structure and movement as well as being significant direct parameters in themselves (Gower et al., 1980).

One problem is that CZCS is an experimental instrument. Data continuity will depend on an OCI (Ocean Color Instrument, see Stewart, 1981) being flown in the mid 1980's on board the NOAA series of satellites, or on the availability of data from the Japanese Marine Observation (MOS-1) satellite or the European Space Agency's ERS-1, each of which may carry a set of ocean mapping instruments including an optical scanner.

At regional scales, there is scope for using high resolution satellite data in conjunction with the existing satellite data. Further radar missions on the Space Shuttle (such as SIR-B), the Canadian RADARSAT and the MOS-1 and ERS-1 satellites referred to previously could provide significant wave and current data at this scale.

At reef-to-reef, within-reef and specific coastal and estuarine site scales the remote sensing tools must be flown from high resolution satellites, from aircraft or deployed from boats and buoys. It is at this, and the point events level that the major deficiencies in data availability exist at this time.

One example of a point event is an oil spill. To assess and model oil-spills it is necessary to combine rapidly collected data about a detected oil slick (oil type and quantity) with environmental data such as surface winds and currents. Oil thickness information is also important for planning cleanup and contaminant activities. Microwave radiometers, SLAR and Laser fluorosensors mounted on aircraft platforms provide the most practical instrument systems for detecting, monitoring and assessing the fate of oil slicks (Klemas, 1982; O'neil et al., 1980; Hoge and Swift, 1983). They also may be used at other times for more general remote sensing purposes. However, aircraft equipped in this way are not always readily available.

Table 9.1 Data Platforms and Sensors by Scale of Application

Scale	Platform(s)	Existing* Systems	Potential* Sensors
Oceanic |1,000	Satellite	NIMBUS-7 OCI, MR, NOAA-6, MSS, IR	ALT, SCAT, SAR
Whole Reef |500 km	Satellite	NIMBUS-7 OCI, MR, NOAA-7, MSS, IR LANDSAT-5 MSS	ALT, SCAT, SAR
Regional reefs |100 km	Satellite	NIMBUS-7 OCI, MR, NOAA 6 & 7, MSS, IR, LANDSAT-5 MSS, LANDSAT-5 TM	ALT, SCAT, LFC, MSC, SAR, ISS
reef-to-reef |10 km	Satellite Aircraft Ship	LANDSAT-5 TM AC -	MSS, MR, IR MSC, LIDAR, ISS, SAR
Within-reefs |1 km	Aircraft Ship	AC -	MSS, MR, IR, MSC, LIDAR, ISS, SAR
Point Events 1 km	Aircraft Ship	AC -	MSS, MR, IR MSC, LIDAR, ISS, SAR

Source : Jupp (in press). * Abbreviations from Table 3.1 (p.30, this report).

The full value of the available tools and future space and aircraft platforms for GBR research, planning and management will only come when adequate research and development has been done. A series of research and development projects which will assess and modify the existing opportunities must therefore be of prime importance.

CONCLUSIONS

Remotely sensed data from satellite and aircraft platforms are providing, and can continue to provide, operational information about tropical coastal marine systems structure and dynamics of value to coastal zone management.

In the context of whole regions a design for research and applications using remote sensing is feasible by using existing and planned satellite data which would improve the overall information base on fronts, water circulation and general biological productivity. At the finer, and possibly more important, scale of coast-reef, inter-reef or island or within-reef, bay or estuary communication and flows there is a range of tools available or at present under development which, with effective research, could prove to be immensely valuable for coastal waters research, planning and management. These tools could map and monitor suspended sediment and biological dynamics within the space and time scales occupied by these phenomena. they would also be to hand in the event of spillage of oil or other pollutants for monitoring and assessment.

To accomplish this there is a need to identify the essential limits to spectral resolution of tropical, continental shelf phenomena and events and to develop an operational system encompassing broad scale satellite data, aircraft based data as well as instruments deployed on ships and buoys. This system could be similar to (but with greater emphasis on fine scale data from aircraft platforms) the OCS Working Group's (1982) MAREX sampling strategy.

In the initial stages such research would use existing satellite data and an airborne multispectral camera or spectroradiometer in company with in-water measurements. The most useful piece of equipment for such a project would be an airborne MSS with adjustable band widths and locations. Such aircraft based systems could be used in a number of ways. The pilot projects could, in fact, also investigate an optimum deployment of such an aircraft based monitoring system.

On the basis of such research, a designed, rather than ad hoc, approach to fine scale remote sensing may be developed and applied to fill data needs for coastal and marine area management.

To summarize :

(i) Remote sensing technology exists to address many of the information acquisition problems faced by planners and managers working in tropical, continental shelf marine and estuarine environments,

(ii) there is a range of currently available satellite data (AVHRR, CZCS and Landsat) which should be incorporated into the current marine data bases,

(iii) future satellite data, and even more especially, airborne scanner data from a variety of instruments, have a significant ability to address the data needs if developed carefully through applied research,

(iv) in order to take maximum advantage of the data provided by remote sensing they need to be integrated with data from other instruments and from ground survey, and

(v) among the remote sensing tools of greatest future potential are the active Lidars and Radars which are under development in a number of research centres internationally.

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10. WORKSHOP ASSESSMENT

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WORKSHOP ASSESSMENT

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INTRODUCTION

The primary objective of the workshop was to introduce marine oriented planners, managers and scientists to the various applications of digital remote sensing data in coral reef, oceanographic and coastal studies. In the main the workshop achieved this objective.

This portion of the report discusses the value of the workshop as perceived by the participants and comes to some conclusions about the value of courses and workshops of this nature. It also considers the possible future directions remote sensing training could take to disseminate and apply the principles and practices of remote sensing to research and management studies in the ASEAN and South West Pacific area.

QUESTIONNAIRE

Participants were asked to comment on the proceedings both as a group and individually on a distributed questionnaire (Table 1). The Participants divided naturally into two groups. Group one was the ASEAN-AIMS-ADAB Project Group consisting of representatives from the ASEAN nations to the ASEAN-AIMS-ADAB Living Resources In Coastal Areas Program. The second group consisted of those sponsored by UNESCO to attend the workshop, together with representatives of Australian agencies involved in the workshop program.

The group reports were presented to the workshop at a specially scheduled session.

APPLICATIONS OF REMOTE SENSING TO THE ASEAN-AIMS-ADAB PROJECT : GROUP 1 ASSESSMENT

This group generally agreed that the use of environmental satellite data would be of tremendous use in the implementation of various studies proposed under the ASEAN-AIMS-ADAB coastal living resources program.

Landsat and other satellite data such as those derived from the AVHRR (Advanced Very High Resolution) scanner, Coastal Zone Color Scanner (CZCS), Landsat, etc., are being used to map, monitor and assess coral reefs, mangrove systems, seagrass beds, mud-flat, nearshore sediment patterns, planktonic primary productivity, clear shallow water bathymetry, surface water temperature and circulation patterns. Such capabilities and their inherent advantage in offering synoptic and multi temporal views of the earth's surface would be extremely useful in the following areas of the Coastal Living Resources Program :

- General identification of coastal communities (e.g. mangrove, mudflat, coral reef, etc) for site selection purposes.
- Selection and determination of the number of sampling stations within the study sites.
- Integration and correlation of various environmental phenomena which influence study sites.
- Monitoring of dynamic phenomena over time periods.
- Mapping of general morphology of coral reefs and zonation pattern of mangrove areas.
- Determination of primary productivity of mangrove areas.
- Spatial projection of ground data.
- Fieldwork planning and implementation.
- Preparation of project reports.

The group felt that the use of satellite remote sensing technology should be adopted as one of the tools to be used for the various studies to be undertaken in the program. There was a strong interest in encouraging the program sponsors to facilitate the purchase of satellite data available at the various regional ground receiving stations.

The potential of the low cost, micro computer hardware and software image analysis package used during the workshop exercise was considered to be high. Provided the cost could be maintained within the proposed price range, the group could see extensive demand for such a configuration for each individual participating nation in the Coastal Living Resources Program.

It was recognised that the full potential of satellite data in terms of providing environmental information cannot be realised without the aid of computer processing and analysis. This requires appropriate digital image analysis software and hardware systems. Sophisticated image analysis systems are available at the remote sensing centres located in Indonesia,

TABLE 1 WORKSHOP EVALUATION QUESTIONNAIRE

WORKSHOP EVALUATION

If you wish to make any comments on the workshop would you please keep in mind the following areas :

1. Did you think the workshop content was provided at the appropriate level for -

   - your specific requirements
   - marine scientists/resource managers generally
   - interesting but not useful
   - inappropriate
   - other.

2. Were the topics covered sufficient to inform you about the usefulness of the techniques for marine and coastal studies?

3. Would you have preferred more topics at the same level; fewer topics but more extensively covered; more information at a more basic level?

4. Was the timing of the workshop appropriate for you given your other activities and demands?

5. Were you satisfied with the documentation provided? Was it appropriate, good, poor? Do you have any other comment?

6. Do you have any other specific criticisms not mentioned above?

7. What did you consider to be the best aspects of the course?

8. If the workshop was to be repeated what recommendations would you make for improvement?

9. What is your area of expertise and/or responsibility?

10. Did you have any experience with remote sensing prior to this workshop?

11. As a result of the workshop do you feel that digital image processing of remotely sensed data could be useful to you to a great degree; will provide some help; only a little?

12. Any other comments

Thailand and the Philippines. However, these are not readily available to public users because such systems require special training and their use for long term, repetitive analysis is expensive. For the purpose of the ASEAN-ADAB project, satellite data users require long term, personal interaction with an image processing machine - a condition not possible with the large, existing remote sensing facilities in the region.

The micro-computer system used at the workshop was considered a good example of an inexpensive image processing software system specifically designed by CSIRO of Australia (see Mayo, this volume) for coastal resources studies. It can be operated on IBM PC-XT microcomputers which are readily available in the region. The system is designed for users with little background in remote sensing and computers and could be effectively used by ASEAN-ADAB project scientists.

EFFECTIVENESS OF THE COURSE : GROUP 2 ASSESSMENT

In considering the course as a whole, the Group 2 participants agreed that they had enjoyed and learnt from the workshop. This observation was qualified by observing that the the value placed on various aspects of the course varied with their individual background and area of expertise of participants. The following points were offered as constructive comments to improve subsequent courses.

The members of this group were quite diverse in academic background and knowledge of remote sensing techniques, uses and especially jargon. It was felt that a presentation on the basics of the technology at the beginning of the program would have been invaluable. Another, perhaps even more effective, method could have been the distribution of a set of background papers to participants before the workshop. This would have had the effect of giving them an idea of remote sensing basics. Those participants who had expressed a need for such introductory material acknowledged however, that the extra assistance given to them during the course made up for this. Unfortunately the assistance invariably came after the presentations on these topics.

A brief resume of the different space craft and associated sensors would have proved useful.

Some of the more difficult concepts such as rectification, atmospheric corrections etc., could have been easier to explain and understand with some 'before' and 'after' slides.

A common critique was that the course concentrated on reef mapping at the expense of other coastal response areas (mangroves, seagrass for example). It was felt that there would have been time for presentations on these topics.

With respect to the 'hands-on' image analysis exercises the group felt that an overall demonstration of the program to begin with, including a step-by-step printout of the process the sequences for reference, would have made the experience easier to follow and study. As one participant put it "trial by example rather than trial and error".

The group felt that one way to ensure that each participant literally obtained hands on experience was to split the groups into pairs and allow computer time under a tightly controlled system bookings schedule.

A major difficulty found by many was the transition from the quantitively derived spectral maps to the more subjective classification product. More time could have been spent on this.

ANALYSIS OF INDIVIDUAL RESPONSES

The Respondents

A questionnaire was distributed to all participants. These included 6 UNESCO/COMAR sponsored participants, 8 ASEAN-ADAB Coastal Living Resources Program representatives, and four others. Of the 18, thirteen responded to the mini-survey. Of these respondents 7 had no previous remote sensing experience, one had 'only a little' and four had used remote sensing data in their work. Eight participants indicated that the workshop would be useful to a great degree and five stated it would be of some help in their work.

Of the thirteen respondents, 10 were active in research and management in a Marine and/or coastal environment. Of the remainder, one had experience in geological work, one was a terrestrial wildlife biologist/habitat analyst and one was a resource planner.

Appropriateness of Workshop Material

Most of the respondents agreed that the level of information presented was appropriate to the Marine Studies objective of the workshops. Only one stated the material was "of interest but not particulary useful".

Adequacy of Material

Eight respondents stated the material on the topic(s) as presented was adequate but all had qualifications. A consistent complaint was the overemphasis on coral reef applications, even though in the presentations on applications only one session was dedicated to reefs with two sessions allocated to oceanography. However, many examples used in the technical presentations, and indeed in the workshop exercise, were of coral reef studies and this would have emphasized the "reef" focus.

Future programs could avoid this by ensuring the inclusion of specific sessions on estuaries, mangroves, coastal land use studies, etc., rather than by relying on mentioning these in the context of presentations on a strictly marine aspect.

Range of Topics

Only four respondents expressed complete satisfaction with the number of topics at the level of detail presented in the workshop. They did qualify this by suggesting the sequence of presentations could be improved. Two respondents, both with remote sensing backgrounds, would have preferred fewer topics (by implication in their own area of interest) at a more intensive and detailed level. The remaining seven all suggested a preference for more information on the basics of remote sensing. This reflects the fact that 8 of the respondents had no previous remote sensing experience.

Timing

Generally the timing (August/September) appeared appropriate to most of the respondents. Two indicated a May/June timing would have been an improvement as it would have fitted better with their project planning schedules.

Documentation

Documentation was considered appropriate by 8 respondents, adequate by 4, with one stating it was unsatisfactory. All qualified their statements. A number complained about the timing of the hand-outs, feeling that a distribution of all the basic information prior to the workshops would have been beneficial. Specific mention was made about the information on the software/hardware system in this respect.

Part of this problem originated in the relatively short pre-workshop time available to distribute the material. Details on the UNESCO participants were not to hand until a week before the workshops leaving no time to mail information to these participants. Introductory material had been issued to the ASEAN-AIMS-ADAB people.

Critiques

The following specific criticisms were raised by the respondents:

. it was claimed that as this was an introductory course to marine remote sensing it should have been properly described. In fact it was agreed that the workshop/course objective - to introduce marine specialists to remote sensing - had been achieved.

- Too much emphasis on coral reef applications rather than on the range of coastal environments (mangroves, estuary, benthic vegetation).

- More time needed to allow for questioning the workshop faculty after presentations.

Best Aspect of the Course

The "hands-on" micro computer analysis sessions were considered the best aspect of the course. It was felt that this experience could have been improved if the groups had been divided into pairs rather than groups of 4.

The opportunity to meet with practising remote sensing specialists and /or resource specialists using remote sensing in the marine services was frequently mentioned as a positive benefit.

Much attention was given to the micro computer system (micro BRIAN) and all participants indicated they would be interested in having access to a final version.

Suggestions for Incorporation in Future Workshops

A number of suggestions were made for inclusion in future courses/workshops ranging from curriculum changes to requests for follow-up workshops of both introductory and specialist applications focus. These suggestions are summarized in Table 2.

EVALUATION

The workshop was very much an introductory workshop to transfer a tool (remote sensing) to a user community (marine resource specialists). In general this objective was achieved. It was apparent during the course of the workshop however, that greater attention to the basics of remote sensing theory and practice would have been of considerable benefit. The shortcoming was overcome to a degree by including special tutorial sessions on various occasions during the program, and a paper introducing some remote sensing basics has been included in this report. Summary reports to redress the perceived lack of coverage on water colour analysis, benthic vegetation mapping, shallow water analysis and other applications, have also been included.

TABLE 2. FUTURE WORKSHOP INCLUSIONS

- Clear statement of objectives (workshop, training course?)
- More emphasis on basics (if at same level)
- More attention on selection of participants with regard to levels of expertise, experience, area of interest; a more homogeneous grouping by interest/experience.
- A longer, more detailed and improved field exercise
- Greater hands-on computer time with more tutorial assistance
- More coverage of other applications (oceanic, coastal shelf, coral reefs, estuaries, mangroves, land use, benthic vegetation)
- Clearer identification of the need for integration of remote sensing and ancilliary data
- Tailor material to participants.
- Encourage greater participation of countries of the region in co-ordinated approach to remote sensing training and applications
- More frequent courses - follow up course(s) as soon as possible.

In any future introductory workshops it may be of value to stress the training aspect by labelling the project as a 'course' rather than a workshop. It is to be hoped however that the spread of the technology will lead to genuine participatory workshops in the future.

It is clear, both from the analysis of participants responses as well as from observation, that the wide disparity of remote sensing backgrounds was causing both presentors and participants some problems. Organisors were constrained to a degree in that the final composition of the Unesco sponsored group was not known until a few days before the course commenced. Not only did a number of participants not have any remote sensing background but a few were not familiar with computers generally. When this became apparent an attempt was made to correct the imbalance by additional tutorial sessions, hand-outs, etc., but it was not an ideal progression.

In general the workshop proved a definite success. The information was well presented and all participants, despite some concerns, found the material to be "useful to a great degree" or, at least, "of some help". The hands on nature of the exercises clearly showed the group the potential viability and utility of image analysis and an inexpensive hardware and software image analysis system for educational and decentralised, applied agency work. Nevertheless - should the course be repeated the following topics need to be specifically and definitively addressed:

1. Introduction to remote sensing (the biophysical basis of remote sensing - terrestrial and marine).

2. Overview of applications - terrestrial and marine.

3. Introduction to planning for the incorporation of remote sensing in coastal study projects.

4. Remote Sensing Data Sources - satellite systems, scanners and receiving facilities.

5. Data Integration - the importance of integrating ancillary and remote sensing data sources for best results.

6. Applications
   - Coral Reef Analysis
   - Coastal Shelf Features (bathymetry, water features, water mixing)
   - Oceanography (system dynamics, water colour, productivity)
   - Estuarine Studies (chromaticity, sediments dispersion)
   - Submerged Vegetation/Benthic cover mapping
   - Mangroves, coastal forests, coastal Land use Studies

7. Output Products Services - product types, specifications

8. Hands on Exercise - group participants by specialty and/or technical expertise. Hands on computer exercises to be done in pairs with tutorial assistance.

CONCLUSIONS

The demand for remote sensing training throughout the ASEAN/Australasian region is evident in the recent activity in the area.

Following on from this workshop, the ASEAN-ADAB Coastal Living Resources Program groups C and D (those attending this workshop were group A) requested and received similar training at a more specific level. In addition, a number of agencies are continuing to carry out applications and training workshops in the South West Pacific (ESCAP, ADAB, Q.DMS, UNESCO). It would be particularly useful if all agencies co-ordinated these activities in order to avoid duplication and to provide an integrated, sequential upgrading of training opportunities. It would be beneficial to design a series of workshop modules ranging from introductory to intermediate and advanced, specialised applications sessions. Certainly the participants at this workshop would support and commend such an approach. If the agencies interested in remote sensing in the South East Asian and South West Pacific region were to adopt a co-ordinated approach, the sequence of training could lead to a significant improvement in the application of remote sensing in marine and terrestrial resource management.

Properly applied remote sensing can extend the scarce expertise of a few resource specialists over wider areas. This eventuality would result in substantial and increasing cost-effectiveness that would be of benefit to South East Asia and the S.W. Pacific. A three tier training system would include:

1. - introductory courses

2. - specific applications courses/workshops
   - coral reefs, shallow water mapping
   -water colour, productivity, sediment mixing
   -mangroves, forestry, coastal land use
   -marine specialisations - fisheries

3. - Workshops for Regional Interaction of trained specialists applying the tools in their area of speciality.

Finally, it is apparent that this report contains a wide range of background and introductory material which can provide pre-session reading for subsequent workshops or training sessions.

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TECHNICAL INFORMATION

THE AUSTRALIAN LANDSAT STATION

This information is included to give some idea of the functions of a typical ground receiving station and the activities and services provided. The description is condensed from the paper The Australian Landsat Station and Use of Satellite Remote Sensing Data in Australia by Mr. D.J. Gray (MIREE), Station Director and issued by the Australian Landsat Station.

General

The Australian Landsat Station (ALS) was established under the auspices of the Department of Science and Technology in 1977. The station is equipped to receive, record and process data from the low resolution MSS and telemetry transmissions at S-Band from all Landsat satellites. It is not equipped to handle the high resolution TM data at X-Band from Landsats 4 and 5.

Regular recording and archiving of data from the Landsat 2 and 3 satellites began in December 1979. Processing and distribution of customer products began in October 1980. Current operating costs are about A$2.0m per year with a current revenue of about A$0.5m per year.

Organisation

International

The station operates in accordance with a Memorandum of Understanding between the Division of Resources and Energy and the US National Oceanic and Atmospheric Administration (NOAA) under the umbrella of the US/Australia Agreement Relating to Scientific and Technical Co-operation.

In return for payment of a satellite access fee (US $600,000 per year) and a distribution fee (US $5 per image, $65 per tape) Australia obtains direct access to Landsat satellite transmissions which occur within the viewing range of the receiving facility. All data acquired must be made freely available for sale or distribution on a public non-discriminatory basis.

Australia

The station is under management of the Division of National Mapping of the Department of Resources and Energy.

Distribution of materials is effected directly from the ALS (60%) and through distributors in each State capital city.

Two advisory committees provide user community advice to the department.

Functional Description

The Australian Landsat Station consists of two facilities:

- Data Acquisition Facility (DAF) - Alice Springs
- Data Processing Facility (DPF) - Canberra

Data Acquisition Facility (DAF - Alice Springs)

The DAF is equipped with a a 9.14 metre steerable parabolic dish antenna and electronic equipment for the reception and storage of Landsat Multi Spectral Scanner (MSS) and housekeeping telemetry data. The area over which the satellite passes while in view of the antenna comprises a circle of about 3000 kilometres radius centred on Alice Springs. Routine coverage is confined to the Australian landmass and surrounding waters to about 320 kilometres, Papua New Guinea and parts of Indonesia.

The two data streams are recorded on high density digital magnetic tapes which are airshipped daily to the DPF in Canberra for subsequent processing and archiving.

Data Processing Facility (DPF - Canberra)

The DPF is located in Belconnen in the Australian Capital Territory and is the headquarters of the ALS providing management, engineering and administrative support as well as performing the following functions :

- cataloguing and archiving all acquired data
- generation of products to fulfill customer orders
- conduct of business activities
- support of distributors with catalogues, sample products and documentation
- liaison with the user community
- development of new and/or improved products and services

There are three operational elements within the DPF:

- the Digital Processing Section
- the Photographic Laboratory
- the User Services Section

The Digital Processing Section produces master catalogues, generates master negatives and digital products in the form of computer compatible tapes (CCT).

Four levels of processing are provided, the first three by the Bulk Processing System (BPS), the fourth by the Precision Processing System (PPS).

- Reduced Resolution Imagery for Cataloguing

  produces colour negatives in the standard x24 micro-fiche format of a complete set of micro-images of all scenes acquired over a satellite coverage cycle

- Quick-look Imagery

  production of black and white 70mm master negatives at 1:4,000,000 scale of a single band of data at full resolution but with minimal correction and enhancement of data in response to customer orders

- Bulk Processing

  Bulk processing frames the data into scenes according to the World Reference System (WRS) and enables a wide range of corrections and enhancements as listed below to be performed on the data.

  Geometric Corrections

  - earth rotation correction
  - earth curvature correction
  - panoramic distortion correction
  - mirror scan velocity non linearity correction
  - sensor off-set correction
  - sensor communication correction
  - line length correction

  Radiometric Corrections and Enhancements

  - contrast stretch or sun angle correction (mutually exclusive)
  - sensor mis-match correction (destriping)
  - film characteristics corrections (film output only)

All of the foregoing corrections and enhancements are generally performed on master negatives but are optional for CCTs.

Other options available for both CCTs and negatives are:

non-standard framing (i.e. scene centre moved in the along track direction to a location other than as specified by the WRS)

digital enlargements at x2 and x4 enlargement which result in quarter and sixteenth scenes respectively

Master negatives are generated on 240mm film stock in either black and white (single band) or colour (3 band composites) at 1:1000,000 (full scene), 1:500,000 (quarter scene) or 1:250,000 (sixteenth scene). CCTs are generated in either band sequential (BSQ) or band inter-leaved-by-line (BIL) format at packing densities of either 800 or 1600 bits per inch.

Precision Processing

The main function of the PPS is to provide precision rectification images. Rectification is the pocess of fitting an image to a standard map projection. The PPS uses surveyed ground control points to calculate corrections to warp the image to the required map projection.

In addition to precision rectification and the corrections and enhancements listed above the PPS can also provide the following enhancements:

- data drop-out repair (cosmetic)
- haze removal
- edge enhancement of linear features
- custom contrast stretching and manipulation to suit particular applications
- full geographic gridding or tick marks
- full UTM gridding or tick marks
- variable format text annotations

PPS output is in the form of master negatives on 240mm film stock. Scales are infinitely variable in the range 1:1,000,000 to 1:50,000.

User Services Section

The user services section attends to customer enquiries, assists in the selection and ordering of products, co-ordinates the processing of orders, maintains business records of all transactions, collects moneys owing and pays the proceeds of sales into consolidated revenue, it also supports distributors with catalogues, sample products and documentation.

Any requests for information should be forwarded to :

The Australian Landsat Station
PO Box 28, BELCONNEN, ACT. 2616.
Australia.

AUSTRALIAN REMOTE SENSING CAPABILITY

INTRODUCTION

Information on Australia's Remote Sensing Capability was provided by the Australian Landsat Station. The following is a summary of a document issued by the station in June 1985.

Australia's remote sensing capability exists in :

- Universities and colleges conducting remote sensing courses, and carrying out original remote sensing projects in reception, data processing and interpretation.
- Federal Government Organizations.
- State Government Organizations.
- Australian Industry.

The areas of capability include applications in Geology, Rangelands Assessment, Agriculture, National Mapping, Topographic Mapping, Shallow-water Hydrographic Mapping, and Engineering. Details of these applications can be obtained by writing to the Australian Landsat Station, PO Box 28, Belconnen, A.C.T. 2616, Australia.

Tertiary Colleges and Universities

Many of Australia's 19 Universities and 110 Colleges of Advanced Education, Agricultural Colleges and Institutes of Technology are actively involved with teaching and research in many aspects of remote sensing. A recent survey has shown that about 60 departments at tertiary level incorporate a degree of remote sensing into traditional teaching programs in earth sciences, engineering and surveying.

Four Universities and Colleges offer formal postgraduate qualifications in remote sensing. The University of New South Wales offers a Graduate Diploma in Remote Sensing along with a Master's degree program. The South Australian Institute of Technology also has a Graduate Diploma in remote sensing. The University of New England offers Master's programs in environmental studies with majors in remote sensing. The Canberra College of Advanced Education offers a remote sensing component under its graduate program in Surveying.

The University of New South Wales offers the only regular professional training in remote sensing by way of short courses. Between four and six courses are offered each year. The Centre for Remote Sensing co-ordinates and administers all of the teaching, training and research activities at the University and acts as a focus for post-graduate training in a research environment.

Conclusions

Research, development and many applications programs being undertaken in the Universities, Colleges, Industry and Federal and State Agencies cover a broad range of topics. In many cases the expertise existing in those areas could perhaps be exploited in a suitable program of co-operative development.

THE AUSTRALIAN SURVEY OFFICE

Remote Sensing Activities in the Australian Survey Office (ASO)

The Australian Survey Office (ASO) is the Commonwealth of Australia's central surveying authority responsible for land, engineering and topographic surveys for Commonwealth purposes.

As part of the service to Commonwealth departments and authorities the ASO provides digital image processing facilities to assist clients with planning, monitoring and management of natural resources. The services include :

- a bureau service whereby clients have access to ASO image processing equipment and assistance from personnel;
- support for client's in-house remote sensing systems, including preprocessing of data and plotting of imagery;
- transfer of technology to other Commonwealth organisations, the Australian surveying and mapping industry and, where consistent with foreign policy, to developing countries particularly in the ASEAN and South Pacific Regions;
- facilities and resources for general image analysis and processing for a diverse range of applications.

The ASO has two digital image processing systems. The first, established in 1982, uses the BRIAN (Barrier Reef Image ANalysis) software on a Prime computer and a Ramtek high resolution display. The principal application has been to use Landsat MSS data for shallow water mapping. Projects include mapping the Great Barrier Reef Region at 1:100,000 and 1:250,000 scales, as well as isolated areas in the Timor and Coral Seas, Shark Bay in Western Australia, and selected sites in Milne Bay, Papua New Guinea. Several projects to map and classify vegetative land cover over large areas in Australia have also been completed.

In 1985 the ASO acquired a Dipix Aries III system, including an LSI 11/73 host computer and peripherals, a high rsolution video digitiser and a small format ink-jet plotter. The Dipix will be used as a general purpose image processing system. The digital camera will enable maps, charts and aerial photography to be scanned and integrated with satellite and airborne scanner imagery. Commonwealth departments and authorities will be encouraged to use the system on a bureau basis to carry out their own work.

Both systems are supported by peripheral equipment including an XY digitising table and Applicon large format plotter.

The ASO has long been involved in the Pacific and ASEAN region with major projects (including the Fiji Land Survey, Thailand Land Titling) and other aid funded projects in Indonesia, Papua New Guinea and Samoa. The ASO has co-operated with the Q. Department of Mapping and Surveying and Queensland University in completing a shallow water mapping pilot project in Milne Bay, Papua New Guinea.

The project was designed to provide information for Fisheries and Transport. For fisheries, considerable fish catch statistical work for reef areas near Port Moresby has been done. Investigations will be carried out to determine whether there is a correlation between the fish catch and reef substrate. Satellite imagery can cost effectively classify reef substrate over large areas. If correlation can be shown it may then be possible to use enhanced satellite imagery showing reef cover type to predict areas of high potential fish yield and improve fish resources management on a national basis. For many countries, particularly in the Pacific region, this is important.

For Transport, the rectified images enhanced to show reef areas are often the best available information for shallo water area navigation. While it is not suggested that rectified Landsatimagery could replace hydrographic charts the can show areas of "no-go" and "possible go". They can be used as a planning tool to direct hydrographic vessels to areas where there are potental navigatable routes thereby greatly reducing the time and cost associated with traditional hydrographic surveys.

In addition to the PNG pilot project, expressoions of interest and some requests have been received for similar projects in Indonesia, Malaysia, Thailand and Fiji. Most of these projects will be externally funded.

There are a number of organisations who will consider funding projects. These include the Australian Development Assistance Bureau (ADAB), Asian Development Bank, World Bank, and the United Nations (UNEP, FAO, ESCAP). Provided funds are available within approved budgets of departments collaborative projects with organisations within Australia could be instigated by an approach through the appropriate Australian High Commission.

For further information regarding the services provided by the Australian Survey Office please write to :

The Surveyor-General
Australian Survey Office
PO Box 2, BELCONNEN ACT 2616
Australia.

ASEAN INSTITUTIONS CONDUCTING RESEARCH ON REMOTE SENSING

INDONESIA

Bakosurtanal
Lapan
Gadjah Mada University - Faculty of Geography
Faculty of Biology
IPB - Agricultural University Soil Science Department
LGPN - Institute for Geophysics and Mineral Exploration, LIPI
Institute of Ecology, Padjadjanan
Biotrop-Seamo Center for Biological Studies
Geological Directorate
Asian Regional Remote Sensing Training Center

MALAYSIA

Malaysian Agricultural Research and Development Institute (MARDI)

PHILIPPINES

Natural Resources Management Center

SINGAPORE

National University of Singapore, Dept. of Physics

THAILAND

National Research Council, Remote Sensing Division
Kasetsart University
Royal Forestry Department

11.3.3 SOURCES OF REMOTE SENSING DATA IN THE ASEAN REGION

INDONESIA

Bakosurtanal -
- panchromatic aerial photography
- 1:30,000 false color infrared photography
- SLAR imagery

Lapan -
- Multispectral aerial photography (b & w, false color composites)
- Infrared and thermal infrared imagery
- Metsat, NOAA AVHRR and TIROS imagery
- Landsat MSS CCTs (no paper products yet)

MALAYSIA

Directorate of National Mapping -

panchromatic aerial photography at 1:10,000, 1:25,000, 1:40,000, 1:60,000 and 1:90,000 scales

PHILIPPINES

Bureau of Geodetic Surveys -
panchromatic aerial photography (1:15,000, 1:60,000
Bureau of Forestry Development -
b & w infrared photography (1:15,000)
Natural Resources Management Center -
Landsat 2, 3, 4 and 5 MSS CCTs
Landsat False Color Transparencies (1:1,000,000 or larger)
Landsat FCC paper products (any scale)
Pagasa -
GMS Facsimile
US Air Force Base -
panchromatic aerial photography (1:60,000)
NOAA AVHRR primary imagery and analog tapes
GMS primary imagery and analog tapes
Possibly other airborne sensor products

SINGAPORE

Aerial photograpy
NOAA AVHRR imagery

THAILAND

Thailand Remote Sensing Centre, NRC -
Landsat MSS CCTs
Landsat b & w film products [positive film (1:1000,000; negative film (1:1000,000); paper (1:1000,000, 1:500,000, 1:250,000)]
Landsat MSS FCC [positive film (1:1000,000), paper products (1:1000,000, 1:500,000)]
NOAA AVHRR, TIROS and GMS imagery and digital tapes

Royal Thai Air Force -
panchromatic and color aerial photography (1:15000); color infrared photography (1:15000); multispectral photography (b & w, fcc)
Airborne MSS, infrared imagery

REMOTE SENSING DATA ACQUISITION EQUIPMENT AND FACILITIES IN THE ASEAN REGION

INDONESIA

Bakosurtanal
Gadjah Mada University, Faculty of Geography Centre for Remote Sensing (PUSPICS), Jogjakarta
Bandung Institute of Technology
Bogor Agricultural University
Padjadjaran University
University of Indonesia

MALAYSIA

University of Malaya Engineering Department
Malayan Pertanian University

PHILPPINES

Training Centre for Applied Photogrammetry and Geodesy, College of Engineering, University of the Philippines
Natural Resources Management Centre, Ministry of Natural Resources

SINGAPORE

University of Singapore, Department of Physics

THAILAND

Asian Regional Remote Sensing Training Centre, Asian Institute of Technology
National Research Council through the National Remote Sensing Coordinating Committee
Kasetsart University

UNESCO REPORTS IN MARINE SCIENCE

No.		Year
40	Human induced damage to coral reefs Results of a regional Unesco (COMAR) workshop with advanced training Diponegoro University, Jepara and National Institute of Oceanology Jakarta, Indonesia May 1985 English only	1986
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